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Science *Can* Predict Earthquakes

- Lynn Margulis: Pioneering Biologist
- South Africa in Space
- Evidence-Based Medicine Kills

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Features

An almost-completed astrolabe, constructed using a PC. *See p. 38.*

Departments

ON THE COVER: A two-stage suborbital sounding rocket launched by NASA into a brilliant aurora display above northern Alaska on Feb. 18, 2012, from the Poker Flat Research Range near Fairbanks. The Black Brant IX rocket carried an experiment from Cornell University to study space weather. Photo by Lee Wingfield/NASA; cover design by Alan Yue

News

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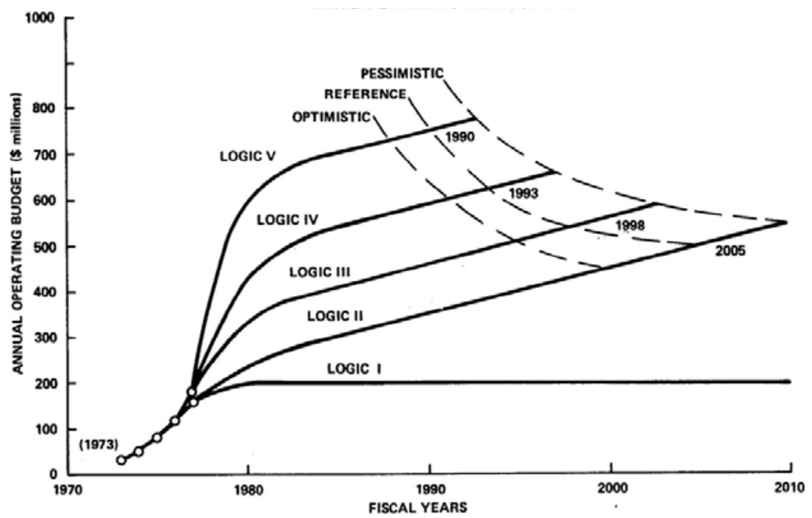
Fusion and Foreknowledge

If the vicious cuts demanded in the Obama Administration's proposed FY 2013 budget are not reversed, the U.S. fusion energy program will join the growing list of crucial science projects sabotaged by President Barack Obama's fawning servility before the principle of oligarchy and that nasty British royal family which is its present embodiment. Harsh words, not the sort to be uttered in respectable precincts, especially where funding is at issue. But true, nonetheless.

Fusion energy, this present beacon of hope for all mankind, promising a final end to human want and deprivation on this Earth and the spread of our unique species beyond its bounds, is on the chopping block.

And yet, it is no exceptional case. The guiding policy, so frankly enunciated by Britain's Prince Philip, is to reduce world population by 5 to 6 billion souls. The justification for this act of premeditated mass murder, is the argument that there are simply too many of us to "sustain" ourselves. All means and instruments of human innovation which demonstrate the fraud of this assertion, must thus be destroyed. Consider some of the other recent milestones, in this evil and premeditated drive: The September 2011 shutdown of the Tevatron accelerator at Fermilab, the U.S.A.'s only significant capability for antimatter production; the



WHAT IT TAKES TO REACH FUSION—ERDA'S LOGIC IN 1976

In 1976, the Energy Research and Development Administration (ERDA) published this chart showing the required fusion operating budgets to reach a working magnetic fusion reactor. Each option was called a "Logic," and each had three variations from optimistic to pessimistic. With $600 to $750 million a year, as shown in Logic V, the program would have been able to operate a demonstration reactor by 1990. Logic I, which represents the actual fusion budgets from 1976 to the present, produces "fusion never," as shown.

Source: ERDA, 1976

virtual end of the U.S. manned space program; the 2005 shutdown of the Fast Flux Test Facility at Hanford, Washington; the 23-year pogrom against cold fusion . . . and the list goes on.

If passed, the FY 2013 fusion budget will shut down or severely cripple the last three remaining tokamak reactors in the United States: The Alcator C-Mod at MIT would shut down. The ongoing upgrade at Princeton's National Spherical Torus Experiment would be extended by six additional months, delaying restart of this reactor until 2015. That would leave the General Atomics DIII-D in San Diego as the only operating major fusion experiment for the coming three years. But an axing of one out of six staffers, and other cuts, would reduce its running time to just 10 weeks out of the year.

A Downward Trend Since JFK

It did not all start with our current President Obama's servile allegiance to the British monarchy's stated commitment to a mass murder that makes Hitler's seem mild. Indeed, the trend line for science, and humanity's future, has been a downward one since the 1963 assassination of President John F. Kennedy.

Begin with the collapse in morality produced in America's leaders by the pragmatic acceptance of the Warren Commission's cover-up—while a new President governed in fear of the assassin's bullet. The long war in Vietnam, which JFK had resisted, taking wise counsel of General Douglas MacArthur, followed close on, and with it, a destruction of the national will from which we have never yet recovered.

The riot of irrationality which accompanied the 1960s birth of the rock-drug-sex counterculture, that joint venture of Cambridge Apostles Aldous Huxley and Bertrand Russell, two of the last century's most evil men, opened the way to the successful attack on science and the American principle of progress.

The insertion of the virus of environmentalism into the cell culture of the Baby Boomer generation then became the means by which all could be destroyed. A population embracing a disease which destroys itself—nature's ultimate recipe for self-destruction.

Prometheus depicted on a Greek vase, bound to a stake while an eagle pecks at his heart.

The Promethean Principle

Our problem is that science does not presently contain within itself the means for its own perpetuation. The principle of science does so, for in that lies the secret of human creativity, the Promethean principle. But that is a subject no longer taught, nor tolerated. To succeed in the game as played now, one sacrifices one's commitment to that principle at an early stage. One accepts the doctrine of reductionism, of building up from below, when all truth, the very notion that there exists a universal law, proceeds in the opposite direction.

The principle represented in classical culture by the name of Prometheus, which means foreknowledge, is the method of actual scientific discovery. That, not any form of deductive method, is what has led to every true discovery of fundamental importance.

Mankind, unique among all presently known species, possesses the ability to foresee, as a mental construct, truths consistent with those of the natural law, and to act upon those visions in ways which transform nature to his own ends. In such acts of true discovery which appear, not out of any pre-existing understanding, but as if from the future, we act in harmony with the creative principle of universal self-development.

Creativity, whether of the human or the universal variety, is the action of the future upon the present. It can never be derived by deductive modes of thinking from past knowledge. It is *foreknowledge* in the sense that classical thought identified with the name of Prometheus, who was chained to a rock by Zeus for bringing the gift of fire to mortal men. Such is science, and such also is the principle of classical composition in music, art, and poetry. Free it, like Prometheus from his iron bonds, that mankind may again have hope and joy and love.

—Laurence Hecht

Fusion Breakthrough at NIF

The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory is to be congratulated for its recent world historic achievement in laser fusion, a milestone on the path to achieving an energy-dense source of power for mankind's future.

In a record-breaking shot made on March 15, NIF's 192 lasers fired in perfect unison, delivering a record 1.875 million joules of ultraviolet laser light to the facility's target chamber center. This historic laser shot involved a shaped pulse of energy 23 billionths of a second long that generated 411 trillion watts of peak power (1,000 times more than the United States uses at any instant in time).

This achievement shows that despite the vicious cuts in the U.S. fusion budget since about 1980—and the still worse cuts proposed in President Obamas FY 2013 budget—we can achieve workable thermonuclear fusion by a variety of means. Fusion provides the highest energy flux density of any presently known power source. It is the key to future economic development, and an absolute requirement for powering man's next step into space.

Laser, magnetic, and inertial electrodynamic methods of thermonuclear fusion, as well as cold fusion research, must be fully funded on a crash program basis to assure the future of our nation and the world.

OUT OF THE SHADOWS

The Emerging Science of Earthquake Prediction

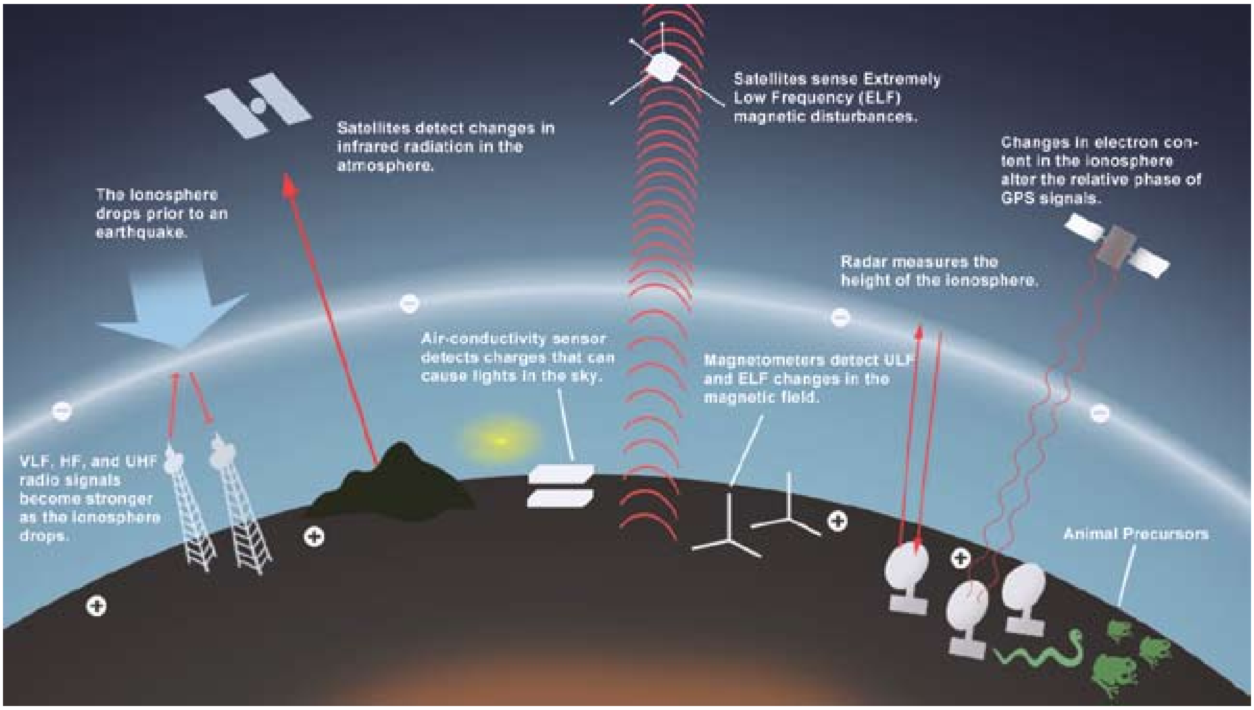
by Oyang Teng

Aerial photo of the San Andreas Fault in the Carrizo Plain, northwest of Los Angeles.

Earthquakes are in some ways the most unsettling of natural disasters. On the one hand, the furies unleashed by tornadoes, hurricanes, and even volcanoes, appear to develop somewhat logically from the action of clouds, winds, and smoking calderas in plain sight. The rumblings of the Earth, on the other hand, seem a betrayal of an almost ingrained trust in the solidity of the ground beneath our feet—and worse, they seem to strike with no warning.

Or do they?

Eyewitness reports going back millennia testify to the existence of aberrations preceding large earthquakes: spooked animals, foggy air, fouled well water. In recent decades, observations with a variety of satellite and ground-based instruments, have expanded the list to include a multitude of transient phenomena outside the range of our normal perception: changes in the electrical conductivity of the air, pulsations in the geomagnetic field, variations in the electron density of the ionosphere, and spikes in electrical ground currents near epicentral zones, among others. These non-seismic signals have been observed on numerous occasions anywhere from weeks to days and hours leading up to an earthquake, speaking to the complexity of the much larger process of physical preparation surrounding the actual rupture of a fault.



EARTHQUAKE PRECURSORS AND THEIR SENSING MECHANISMS

A multi-parameter sensor web can provide the means for earthquake prediction, through the integration of ground and satellite-based measurements of precursor phenomena in the ground, atmosphere, and ionosphere.

In one sense, it should come as no surprise that earthquakes are often preceded by a number of seemingly unrelated, precursory phenomena—not unlike a patient presenting with a range of symptoms, says Chapman University geophysicist Dimitar Ouzounov, a leading scientist in the field of earthquake precursors. Only, in this case, the patient's insides are built from massive blocks of rock tens of kilometers thick, comprised of a variety of minerals under immense pressure, some of which are capable of carrying electric charge, and containing microscopic pores and fracture channels pulsing with high pressure, high-temperature aqueous fluids and gases such as hydrocarbons, carbon dioxide, and radon.

It would be strange if the physical potentials built into such a system under accumulating stress and strain, bringing into play a complex of mechanical, electromagnetic, and geochemical phenomena, *were not* discharged in some detectable form leading up to the final rupture of a fault zone. The bigger the earthquake, the greater the precursor "symptoms."

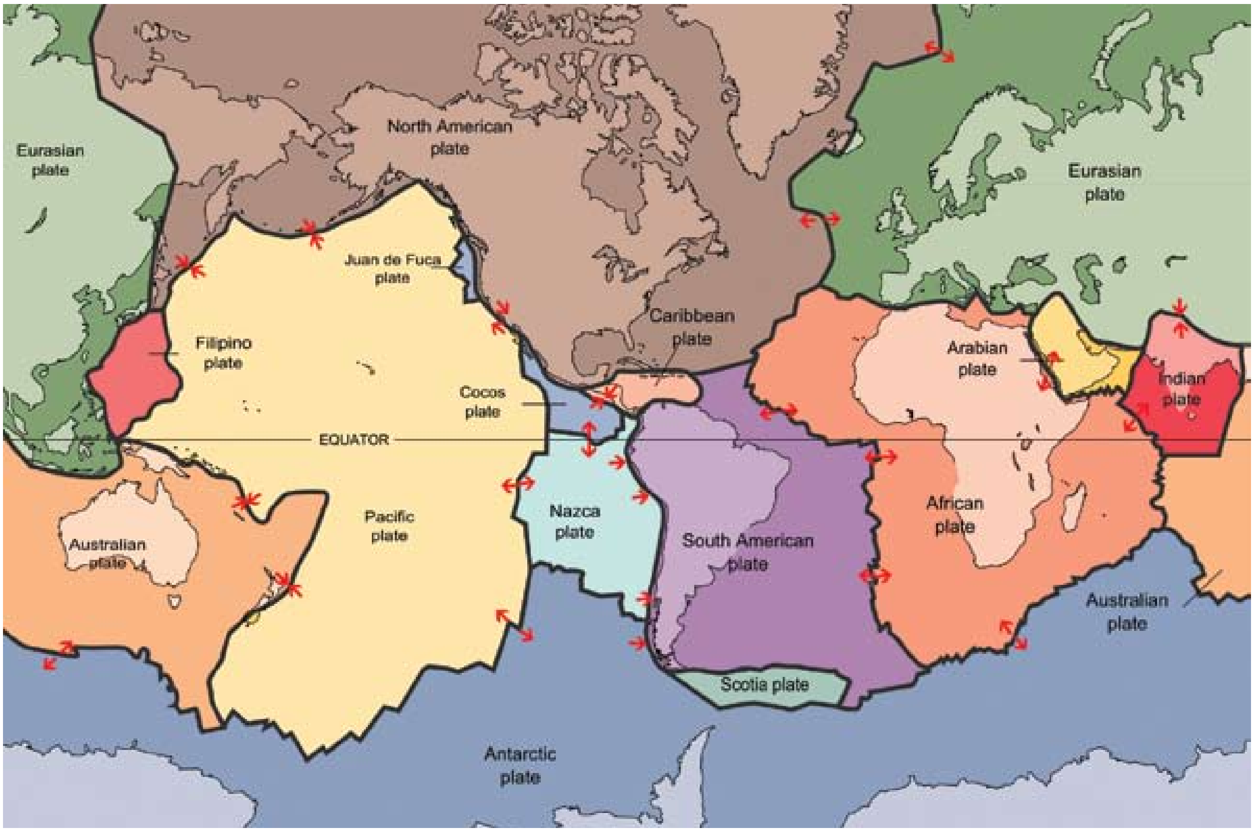
However, the process just described, visualizable in the imagination, is largely a mystery. Earthquake epicenters are located miles below the surface, where we have no direct observations. Our deepest drill holes generally penetrate no more than about 5 kilometers beneath the surface (the record is 10 km) at a very few select spots on the planet; yet, earthquakes classed as "shallow" can extend down to 70 km, with the deepest recorded epicenter at roughly 700 km. Our knowledge of the detailed composition and dynamics of the deep crust, let alone the mantle beneath it, is still conjectural.

The encompassing armature for the geosciences, including seismology, has been provided by the theory of plate tectonics. It gained widespread acceptance beginning in the 1960s as a way to account for matching fossils and landforms on separate continents, seafloor spreading along the mid-Ocean ridges, and—most important for seismologists—the observation that most earthquakes are concentrated within thin geographical bands that are now known to demarcate plate boundaries.

(Intraplate earthquakes, occurring far from any known plate boundaries and, therefore, without any conventional explanation for their cause, have proved to be a particularly deadly exception to this rule. A study published in 2011 showed that, not counting deaths from tsunamis, these intraplate quakes have killed more people in the last 120 years than the more common quakes along plate boundaries).

Because the strongest empirical evidence for plate tectonics pertains to processes occurring on the geological timescales needed for continents to move, it is far too blunt a tool to be applied to earthquake prediction, which must be able to identify both the magnitude and location of a coming quake on a timescale of hours or days.

But despite the fact that we cannot yet directly observe the subsurface crust, its secrets are not so easily contained. As biogeochemist Vladimir Vernadsky was the first to describe, the concentric geospheres of the Earth are closely integrated. Therefore, the 300-km thick shell extending down beneath our feet, containing the majority of earthquake epicenters, can be probed indirectly by examining the transient electromagnetic



15 OF THE LARGEST TECTONIC PLATES

Most earthquakes take place within the narrow geographical bands that demarcate plate boundaries.

Source: USGS

"shadows" projected on the 300-km thick curtain of atmosphere which rises upward from the surface.

Critics argue that these shadows are too elusive to be reliable. The very diversity and seeming inconsistency of precursor phenomena has been used to argue against their validity; according to traditional seismology, they must be flukes, or artifacts in the data. Moreover, critics argue, there doesn't seem to be any overarching mechanism, like plate tectonics, to tie them all together. Yet, the lack of agreement on a particular theory or mechanism hasn't stopped the continued accumulation of evidence for systemic earthquake precursors by researchers across the world.

The Case of Japan

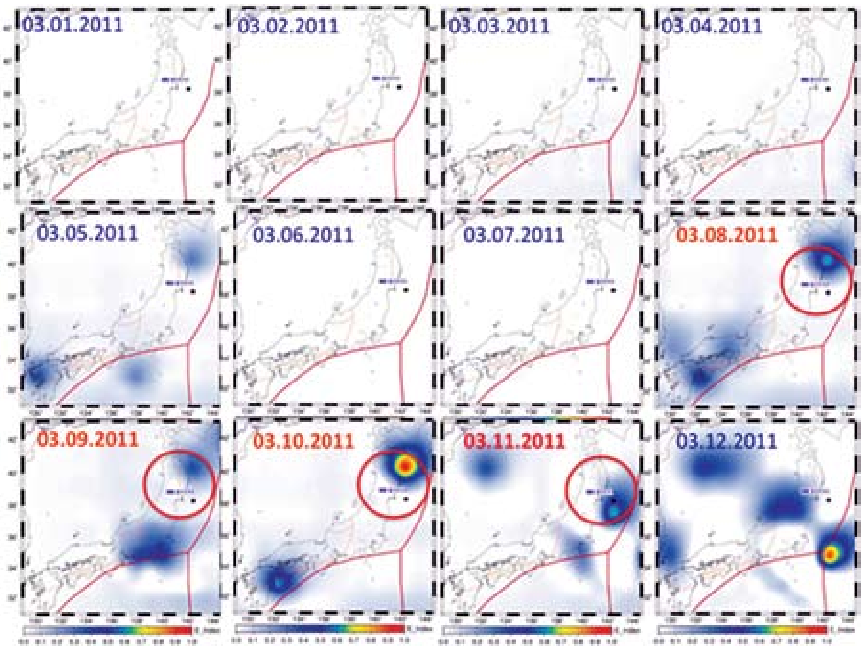
The urgency surrounding earthquake prediction was put sharply in focus by last year's March 11 magnitude 9.0 Tohoku earthquake and tsunami which killed over 15,000 people in Japan, the world's most disaster-prepared nation. Nine months later, at the Dec. 5-9 Fall conference of the American Geophysical Union (AGU) in San Francisco—the world's largest geophysics gathering—an international group of scientists demonstrated that strong precursor warning signs had, in fact, preceded the megaquake.

Lance Cpl. Garry Welch/U.S. Marine Corps

The March 11, 2011 mega-earthquake in Japan, which killed nearly 20,000 people and left scenes of destruction, as shown here, did have precursor warning signs.

Transmission of Very Low Frequency (VLF) and Low Frequency (LF) electromagnetic waves to receivers by way of reflection off the lower layers of the ionosphere (about 60-90 km high), allow scientists to measure changes in the ionosphere by analyzing changes in the signal propagation. Using a worldwide network of such VLF/LF transmitters and receivers, Masahi Hayakawa and Yasuhide Hobara, from the University of Electro-Communications near Tokyo, measured an anomalous drop in the height of the ionosphere in the region above the future epicenter about five days before the main shock.

Hayakawa believes that this precursory phenomenon, which has been measured in other earthquakes they have studied, results from pre-earthquake fractures which send vibrations, called atmospheric gravity waves, up through the air and into the ionosphere. Hobara presented the results of their work in a session devoted to "Monitoring of Mega Earthquake Disasters by Integrating Multi-parameter and Multi-sensors Observations from Ground and Space."



THERMAL ANOMALIES BEFORE THE TOHOKU EARTHQUAKE

Anomalous Outgoing Longwave Radiation (OLR) measured by satellite in the general region above the epicenter (the black star) in the days leading up to the March 11, 2011 Tohoku earthquake in Japan. The infrared thermal anomalies, indicated within the red circle, were determined by comparing outgoing long wavelength measurements on a given day against a reference background field of OLR data for the same day for the seven years between 2004-2011.

Source: D. Ouzounov, S. Pulinets, et. al., "Atmosphere-Ionosphere Response to the M9 Tohoku Earthquake Revealed by Joined Satellite and Ground Observations, Preliminary Results.

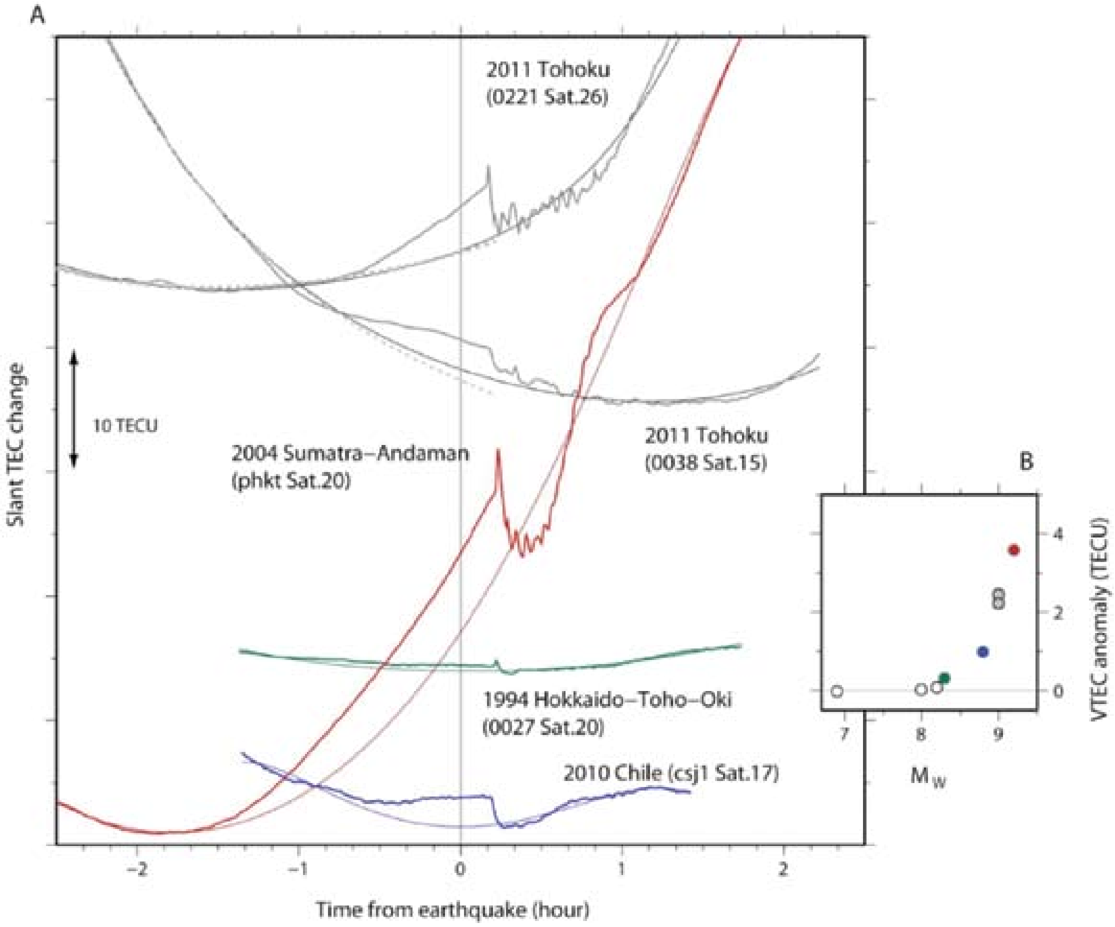
Dimitar Ouzounov, who chaired the session, has found that atmospheric and ionospheric anomalies consistently appear roughly 1 to 5 days before major earthquakes. Among these are satellite-detected long wavelength infrared emissions (in the range of thermal imaging), appearing within the troposphere up to 12 km above the surface. Ouzounov, along with Sergey Pulinets of the Moscow-based Institute of Applied Geophysics, and others, measured such thermal anomalies localized in the general region above the future epicenter in the days before the Tohoku quake, by analyzing deviations from a reference background of satellite-derived atmospheric infrared radiation from the previous seven years.

A rapid increase in emitted infrared emission began on March 8, three days before the main shock. According to the LAIC (Lithosphere-Atmosphere-Ionosphere-Coupling) model developed by Ouzounov and Pulinets, the anomalies are connected to the release of radioactive radon gas within the area of earthquake preparation. Radon ionizes the atmosphere, producing ion clusters which serve as condensation nuclei for atmospheric water vapor, and as the vapor condenses, it releases latent heat in the form of infrared radiation.

They found that this also coincided with anomalous precursory spikes of the total electron content (TEC) of the ionosphere above the epicentral zone, measured by three independent techniques: through GPS satellites transmitting to ground-based receivers; radio tomography, involving radio transmissions from low-orbiting satellites to ground-based receivers; and soundings from four Japanese ionosondes, ground-based radar installations which bounce varying high-frequency signals off different layers of the ionosphere and analyze the time delay of the resulting echoes.

In each case, the measured electron concentration grew to a maximum on March 8, returning to normal within several days following the earthquake. As explained by the Lithospere-Atmosphere-Ionosphere-Coupling model, these ionospheric anomalies are the result of the ionosphere's sensitivity to changes in the conductivity of the lower atmosphere, caused by radon-induced ionization.

Ionospheric anomalies were also detectable within one hour of the earthquake. Delivering the AGU Bowie lecture on "GPS Array as a Sensor of Lithosphere, Troposphere and Ionosphere," Kosuke Heki of Hokkaido University in Japan showed how the total electron content of the ionosphere above the future epicenter markedly increased, beginning about 50 minutes before quake began, and gradually subsided to normal within an hour or so. The measurements were obtained by analyzing phase differences in dual signals sent from GPS satellites to ground stations, utilizing both the dense network of



TOTAL ELECTRON COUNT CHANGES IN SELECTED EARTHQUAKES

Shown are the total electron count (TEC) changes and their models in the 2011 Tohoku earthquake, the 2004 Sumatra-Andaman earthquake, the 1994 Hokkaido-Toho-Oki earthquake, and the 2010 Chile (Maule) earthquake. The horizontal axis shows the time from the earthquakes. Dashed curves in gray for the top two time series show the models derived with data prior to the possible onset of the precursor.

The inset at right shows the vertical TEC anomalies immediately before the earthquakes as a function of their moment magnitudes. Colors correspond to those in the larger figure, and data from three smaller earthquakes (white circles) are included.

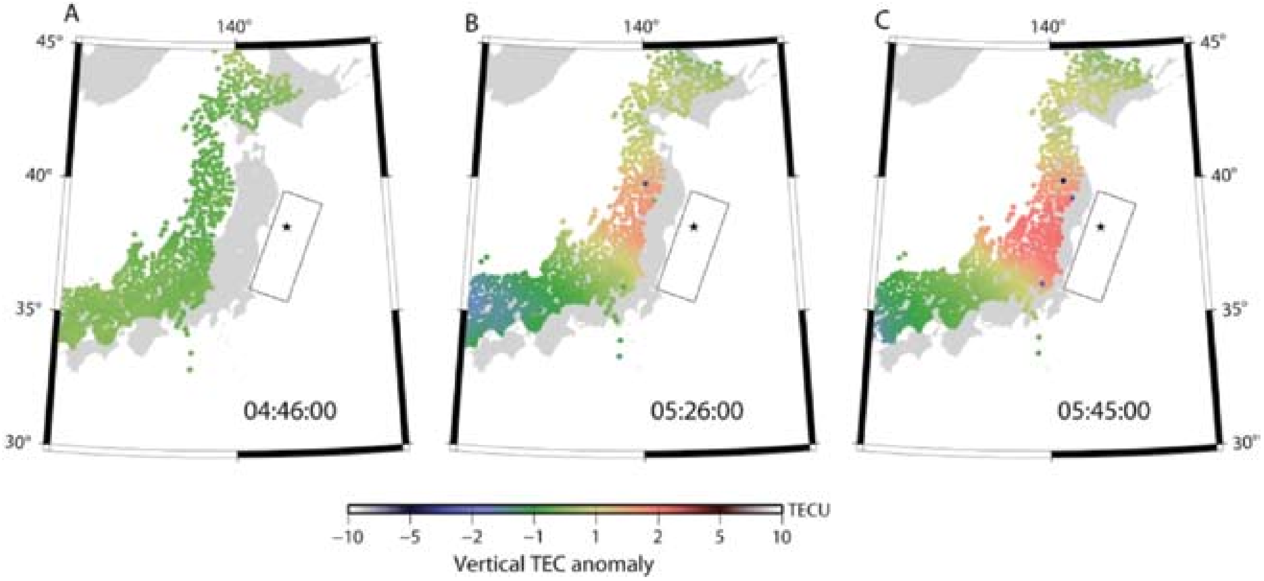
Source: K. Heki, 2011. "Ionospheric Electron Enhancement Preceding the 2011 Tohoku-Oki Earthquake," in *Geophys. Res. Lett.*, Vol.38, No. L17312, doi:10.1029/2011GL047908.

about 1,000 GPS receivers installed within Japan, as well as a global network of 100+ receivers that are used to construct global ionospheric maps.

Heki, whose analysis was published in the Sept. 15, 2011 issue of *Geophysical Research Letters,* also found the same pattern of localized GPS-total electron content increases beginning roughly 50 minutes before the main shock for the two other largest earthquakes of the past decade: the magnitude 9.2 Sumatra-Andaman quake in 2004 and the magnitude 8.8 Chile quake of 2010, as well as the smaller magnitude 8.3 Hokkaido-Toho-Oki quake of 1994. In each case, there was a clear dependence of the size of the anomaly on the magnitude of the earthquake.

While stating that "no conclusive models" have been put forth, Heki points to two possible explanations for the electron count enhancement preceding these large quakes. The first is that proposed by Ouzounov and Pulinets, by which alpha decay of radon changes the resistivity of the lower atmosphere, disturbing the global electric circuit—the diffuse flow of current that flows between the negatively charged ionosphere and the positively charged surface of the planet—and redistributing ionospheric electrons.

The other is a mechanism proposed by NASA physicist Friedemann Freund, involving the production of electric ground currents induced by seismic stress. In this scenario, subatomic alterations in the crystal lattice of igneous or high-grade metamorphic rocks propagate toward the surface as positive charge carriers, leading to the ionization of the near-surface atmo-



INCREASE IN TOTAL ELECTRON CONTENT BEFORE TOHOKU EARTHQUAKE

The total electron content (TEC) in the ionosphere above the epicenter of the Tohoku earthquake increased, beginning about 50 minutes before the quake began. The vertical anomalies in total electron content of the ionosphere are shown at three time periods, (a) 1 hour, (b) 20 minutes, and (c) 1 minute before the 2011 Tohoku earthquake, as observed at Japanese-based GPS stations with GPS satellites in Earth orbit. Positive anomalies (red color) are seen to grow near the focal region.

Source: K. Heki, K. (2011), "Ionospheric Electron Enhancement Preceding the 2011 Tohoku-Oki Earthquake," *Geophys. Res. Lett.*, Vol. 38, No. L17312, doi:10.1029/2011GL047908.

sphere. According to Freund, this not only perturbs the ionosphere by altering the vertical electric gradient, but leads to the thermal infrared anomalies seen by Earth observation satellites, as expanding bubbles of positive ions well up into higher levels of the atmosphere and catalyze water vapor condensation.

A Multi-Parameter Approach

Although particular kinds of precursor measurements have yielded positive results in many of the earthquakes studied, there is no one parameter that has proven consistent across all of them. For this reason, many precursor scientists emphasize that real-time prediction will depend on the integration of a number of different measurements of precursor signals simultaneously.

As Ouzounov pointed out in a presentation on "Utilizing New Methodologies to study Major Earthquakes: Multi-Parameter Observation of Pre-earthquake Signals from Ground and Space," this requires an integrated sensor web of new satellites and ground instruments deployed across the globe, enabling, minimally, constant coverage of the earthquake hotspots around the Pacific Rim and the inland zone stretching from Turkey to Iran, and through to India and China.

In addition to the Tohoku earthquake, multi-parameter hindcasts have been performed for dozens of large earthquakes, including Sumatra-Andaman 2004 (magnitude 9.2), Wenchuan, China 2008 (M 7.9), Haiti 2010 (M 7.0), and Chile 2010 (M 8.8). Precursors were also found for relatively smaller earthquakes such as L'Aquila, Italy 2009 (M 5.8) and the Mineral, Virginia, quake (M 5.8) that took the eastern seaboard of the United States by surprise on Aug. 23, 2011.

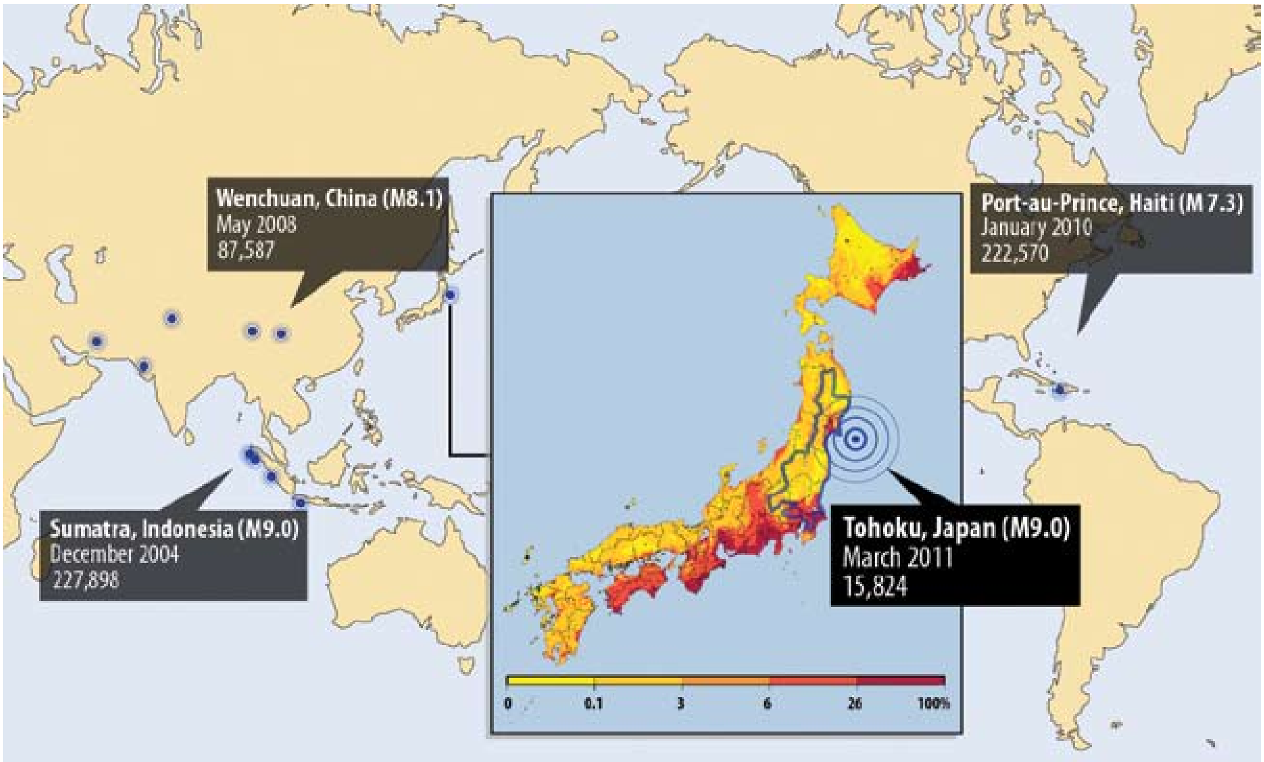
Scientists like Ouzounov are confident that such hindcasts, presented by participants from Russia, Europe, Japan, China, and the United States during the poster and oral sessions in San Francisco, have validated the general program of precursor research as the basis for short-term earthquake prediction.

But such research has been viewed with skepticism, even hostility, by mainstream seismology.

"We are in the absolute minority globally," said geophysicist Seyia Uyeda, a professor emeritus at Tokyo University, during a joint presentation with Greek physicist Panyiotis Varotsos on a panel on "Predicting Extreme Events." "Although I have deep respect for seismologists, seismologists don't like us," Uyeda said.

And because seismologists generally control appropriations for earthquake research, scientists studying non-seismic precursors have operated almost entirely without government support. Despite the heightened interest in earthquake prediction after the Japan disaster, a corresponding level of funding has not been forthcoming. In the United States, the austerity is typified by the Obama Administration's decision in late February 2011 to cancel the planned DESDynI natural hazard monitoring satellite, which would have performed high-fidelity observations in the radar and optical range, and to make cuts to other remote sensing satellite programs on which precursor monitoring depends.

One notable exception to the lack of government sponsorship has been China. Xuemen Zhang of the Beijing-based Institute of Earthquake Science, outlined the Chinese government's



SEISMIC HAZARD MAP

The 12 deadliest earthquakes between 2000-2011 (11 are represented as blue dots) claimed some 700,000 lives. In every case, the actual seismic intensity of the earthquake exceeded the maximum predicted by the Global Seismic Hazard Assessment Program (GSHAP) map published in 1999, which is used as a standard government reference for building codes and emergency response.

On Japan's seismic hazard map (at center), published by the government in 2009, the colored bars indicate the government's predictions of the probability of a high hazard or very high hazard (according the GSHAP seismic intensity criteria) earthquake occurring within 30 years. As can be seen from the blue lines on the map, the region which actually experienced this level of seismic intensity from the March 2011 earthquake was generally assessed as a relatively low-hazard region.

Sources: Vladimir Kossobokov, International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences; Japan Meteorological Agency.

ambitious expansion of the country's precursor monitoring capabilities, with the launch of three dedicated earthquake monitoring satellites planned between 2014-2017, as well as the construction of 50 new ionosondes (up from the current 20 in operation) in the next five years as part of an expanded seismo-ionospheric ground-based monitoring network.

"They're doing this because they realize the technology is affordable, and the science is ready, and needs to be applied," said Ouzounov.

"Why China? Because they have the economic potential to put about $100 million into this project. But also because they're not afraid to test new ideas, new methodologies."

Hazardous Assessments

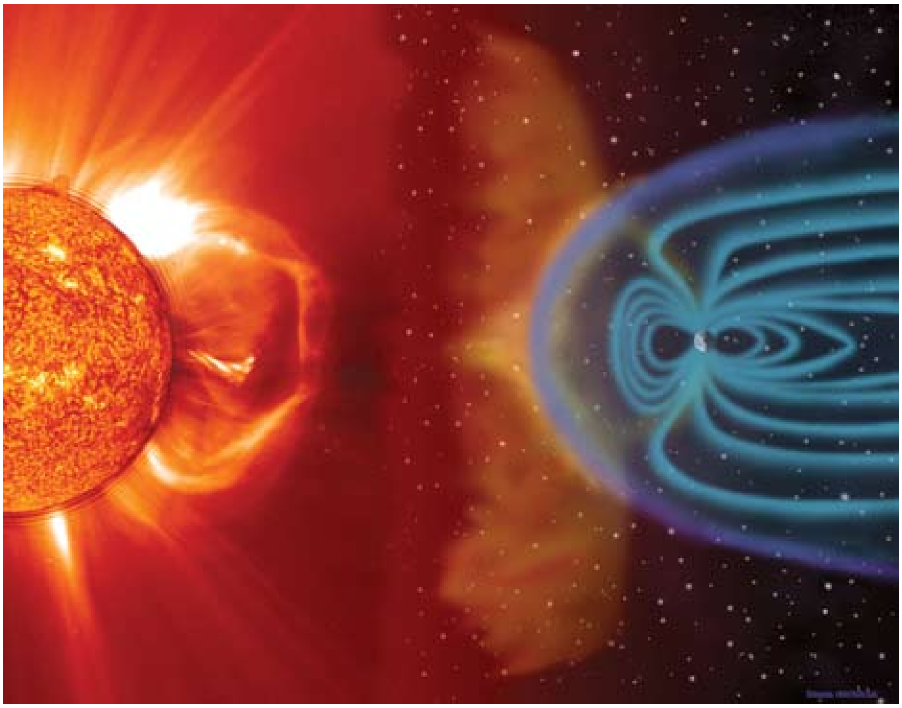
In its starkest terms, the field of earthquake prediction—or lack thereof—is about human lives lost to sudden catastrophe, a point driven home by Vladimir Kossobokov of the Russian Academy of Sciences' International Institute of Earthquake Prediction Theory and Mathematical Geophysics. In a talk with the deceptively dry title "Statistical Validation of Earthquake Related Observations," Kossobokov presented a withering indictment of the status quo in assessing, and therefore preparing for, earthquake hazards.

In its retreat from earthquake prediction, which was once considered the holy grail of the field, seismology has settled on broad forecasts of the probability that certain areas will experience a certain magnitude of seismic risk within a 30- to 50-year timeframe. While short-term prediction relies on precursors, long-term forecasts rely on past events to model risk, based on statistical extrapolations and certain assumptions about the way fault systems build up strain over time.

This has been codified, for example, in the Global Seismic Hazard Assessment Program (GSHAP) map published in 1999, which is used as a standard reference for governments in determining such regulations as building codes. But as a measure of risk for the worst events, it has proven a remarkably consistent failure.

Some 700,000 people have been killed globally in the 12 deadliest earthquakes (and related tsunamis) between 2000-2011. In every case, the actual magnitude of the event was greater than the maximum forecast of the GSHAP map—the Tohoku quake occurred in a region generally assessed as low-hazard, for example—allowing Kossobokov to quantify a surprise factor for each earthquake. The failure, says Kossobokov, is one of methodology, of abstract models of seismic processes accepted without proper validation, and given the stamp of official government sanction.

"Very often people would suggest the seismic hazard assessment maps as an alternative to prediction, as a reliable instrument to reduce disasters," said Kossobokov. But it happened that it's not so. It happened that those maps create disasters, by introducing the wrong estimate of hazards."



NASA

This illustration (not to scale) shows a coronal mass ejection blasting off the Sun's surface toward the Earth (the white dot inside the blue lines on the right). Two to four days later, the CME cloud is shown striking and beginning to be deflected around the Earth's magnetosphere. The blue lines represent magnetic field lines.

One of the most vocal critics of earthquake prediction, University of Tokyo seismologist Robert Geller, also takes issue with the use of hazard maps for risk assessment, but for a different reason. In a commentary in the April 28, 2011 issue of *Nature* magazine, titled "Shake Up Time for Japanese Seismology," Geller argued that the maps should be scrapped, not in favor of greater efforts at prediction, but instead, acceptance that earthquakes are inherently unpredictable on any time scale: We should instead tell the government and the public to "prepare for the unexpected."

But, according to Seyia Uyeda, seismologists simply aren't equipped for earthquake prediction, by the very nature of their current job description.

"Seismology is a science of earthquakes based on seismic records recorded by seismograms. And seismograms only record earthquakes, not precursors," Uyeda said. "Therefore, seismologists never say they can predict short-term. They are honest in that respect. But they think they are the only people who understand earthquakes. That's the trouble with the whole thing, in my view."

A New Geophysics

With earthquake science now swelling with ranks drawn from such fields as atmospheric, ionospheric, and solid-state physics, this institutional prejudice is bound to change, and, Ouzounov hopes, will soon lead to a hybrid system of research between seismologists and precursor scientists working in collaboration.

The strongly interdisciplinary nature of such work also suggests implications that go beyond practical earthquake prediction, but point to the possibility of a new kind of geophysics. For example, the close electrodynamic coupling of the lithosphere, atmosphere, and ionosphere may provide a new framework for studies that have shown strong correlations between solar activity and seismicity, perhaps revealing previously unknown pathways for seismic triggering. This line of investigation overlaps recent decades' developments in climate science, in which solar activity has been found to play a significant role in processes such as cloud formation, through its influence over the electrodynamics of the atmosphere.

The evidence for cosmic influences over the Earth extends even further, into galactic-scale processes whose effects can be read, among other things, in the geological record of long-period cycles of seismic and volcanic activity.

These larger questions, concedes Ouzounov, should not be ignored. But for the moment, he says that he and his colleagues are focussed on validating their methodologies through an actual proof-of-concept prediction, which they hope will bolster their case with the skeptics. If the proper resources were available today, he estimates that real-time monitoring of the United States, for example, could be a reality within a year.

In the meantime, the urgency for such a program is not likely to diminish. Large earthquakes have proven to be more destructive as population densities have increased, and the frequency of megaquakes, such as the Tohoku disaster, appear to have increased in the last decade. The point at which natural disasters become man-made ones, will depend on the choices we make in the coming period.

Oyang Teng is a member of the LaRouche "basement" research group. He can be reached at oyangt@gmail.com

Earthquake Precursors: 'The Science Is Ready, and Needs to Be Applied'

Geophysicist Dimitar Ouzounov works as an associate professor at Chapman University in California and a staff scientist at NASA's Goddard Space Flight Center in Maryland. Since conducting an accidental precursor study in 2000, while he was analyzing thermal image data from NASA's MODIS (Moderate Resolution Imaging Spectroradiometer) satellite, Ouzounov has emerged as a leading figure in the field of non-seismic earthquake precursor research.

Dr. Ouzounov was interviewed by Oyang Teng on Dec. 8, 2011, at the American Geophysical Union Fall conference in San Francisco.

Dimitar Ouzounov at the AGU meeting.

21st Century: What is your overview of the current state of precursor research?

Ouzounov: Precursor research is based on the science of studying the signals associated with the appearance of major earthquakes, and historically it was developed in the last 20 years. At the current status of earthquake prediction today, it's not possible to give you the same information as a weather forecast about a possible earthquake.

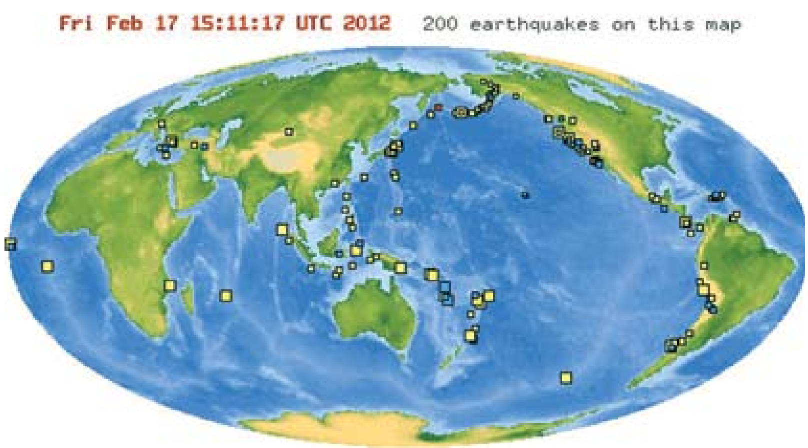
So, a lot of research has been proposed, mostly about any physical phenomena associated with earthquakes. The idea has been research dedicated to any physical connection between different signals with earthquake preparation processes. The idea is that there is something ongoing related to earthquakes, and that these kind of mega-events could be detected in advance. And 2011 also became very important because of the Japanese earthquake.

What's different today? Twenty years ago we had no satellite measurements. Today we have lots of data from satellites, and many scientists are trying to use satellites for this kind of research. What is new in earthquake science in 2011, is that many scientists are applying methodology using satellite data.

The second new technology is that GPS (global positioning systems), became very affordable and very convenient. Now Japan, California, Europe, Asia, South America, have so many GPS receivers, that people are trying to use GPS, not only for ground deformation studies, but also to study ionospheric science. So the new technology provides a new opportunity for scientists to study and to analyze new data.

Today, we have seen during this meeting new methods proposed for using satellite data, using GPS, but this methodology is still far from validation; it needs time to be studied. In other words, we need more statistics, more earthquakes, in order to decisively confirm that any methods, any new ideas, have systematic value for earthquake prediction.

21st Century: I was struck by how



EARTHQUAKES WORLDWIDE (REAL TIME)

There is good data about earthquakes when they happen, as this real time map shows. The challenge is to predict major earthquakes before *they happen to warn the affected populations. Ouzounov and other scientists at the AGU conference are collaborating on this task.*

Source: USGS

NASA

There are 24 satellites, orbiting 20,000 km above the Earth in 12-hour circular orbits. The satellites are divided into six groups of four, each with a different path, creating six orbital planes which completely surround the Earth.

Boeing

Artist's illustration of a GPS satellite.

quickly China seems to be moving in this direction, as far as policy. Where is the most active area of research internationally?

Ouzounov: Yes, China became a very important player in this field. Historically, it's been the case for many years, but we didn't pay it any attention, for the simple reason that we had no globalization in science. Now we do have, which means it's much easier to integrate our ideas over the Internet, to interact with people in China.

And now, Chinese scientists can speak English; before, it was a problem! China opened the opportunity, and I'm very delighted to have visited China this year, for two reasons. I was part of a review team for their satellite system. They're planning a very ambitious satellite system to study earthquakes. But not only with satellites: they're trying to build satellite and ground data measurements. And they've put in lots of money, but they realize they don't have enough knowledge. So they invited experts from different parts of the world to China, and are trying to learn.

We gave several presentations over the last few years, and this year was very important because China's government funded the next five years of its system. One satellite is going to be launched in 2014, and there will be two more in 2017 and 2018. And the question is, "Why are they doing that?"

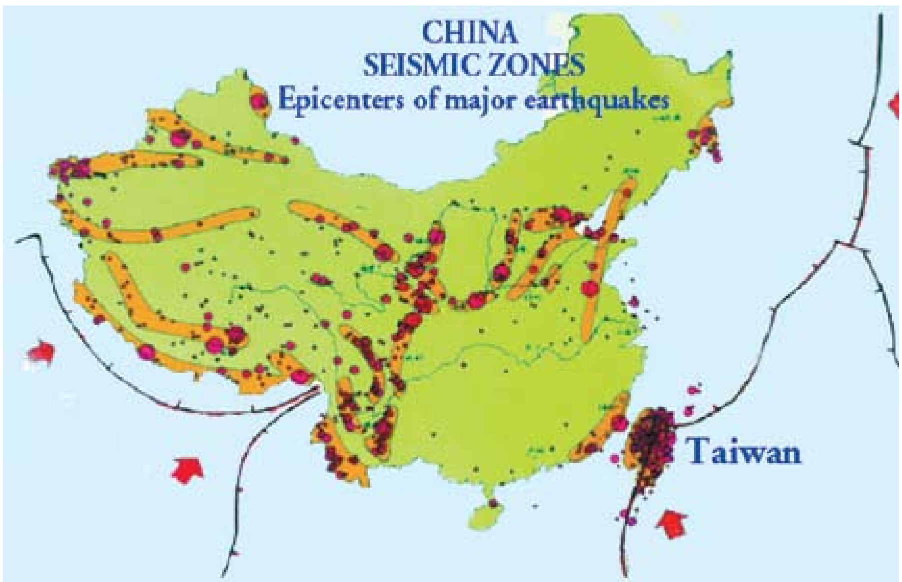
They're doing this because they realize that the technology today is affordable, and the science is ready, and needs to be applied. Why China? Because they have the economic potential to put about $100 million into this project. But also because they're not afraid to test new ideas, new methodologies.

I didn't know that until I visited China and found that they've been doing this for 20 years. I saw animals, I saw birds, I saw very old design techniques and hardware, working for 15 years on this. But because we had no connection with the Chinese, we didn't know about that. And now they said, "We're interested, we'd like to cooperate."

What's going to happen in China means very much to us, because with the end of the French mission DEMETER [an earthquake precursor monitoring satellite, decommissioned in December 2010—ed.], their satellite system will be mostly the only one we can work with for the next five years. And they are very open for that.

21st Century: They'll be the only country with a dedicated earthquake monitoring satellite?

Ouzounov: The Russians are also doing it, actually. But the Chinese will be doing it much more openly, and the scale will be different. The Russians now have many satellites, and they integrate these measurements over their areas of inter-



SEISMIC ZONES IN CHINA

China has a large-scale program to monitor earthquakes and precursor phenomena.

Damage to the Agriculture Development Bank of China branch in Bei Chuan after the devastating earthquake, May 12, 2008. The U.S. Geological Survey reported that there were "at least 69,195 people killed, 374,177 injured and 18,392 missing and presumed dead in the Chengdu-Lixian-Guangyuan area. More than 45.5 million people in 10 provinces and regions were affected. At least 15 million people were evacuated from their homes and more than 5 million were left homeless. An estimated 5.36 million buildings collapsed and more than 21 million buildings were damaged.... The total economic loss was estimated at $86 billion."

est, as in Kamchatka in Eastern Russia where they have so many earthquakes, and try to understand how different satellites and ground data work together. Russia has the experience of doing this for many years.

But China provides the large scale, much more than satellites. They are building a ground data center which is pretty big. And they have a simple reason to do that: economics. They have two areas of major concern. One is central China, and the second is western China, which is high elevated mountains. And there is no other way to study it; it's very difficult to investigate on the ground, and satellite technology is pretty cheap today. So they can do that.

It's much cheaper to do it from space, and they can cover a large territory, and then they can bring in international scientists, because these satellites are not only for China, they can study other places, like Europe, and the United States, so it's a double win for China.

21st Century: On the actual precursor parameters that are studied—and the field is as broad as animal behavior, to actual seismic foreshocks, to the electrodynamics of the atmosphere, to thermal emissions—are these different precursor parameters telling us something new about the geophysical processes involved? In other words, do they give us new insight into the actual nature of the physical preparation, not just of earthquakes, but maybe the way the planet as a whole is organized?

Ouzounov: Yes, this is giving new insight about the Earth. You name it exactly correctly: it's preparation. We're talking about for mega-earthquakes, we're talking about preparation for large-scale events. Usually large-scale events need much more time for preparation, and many more parameters are sensitive to this preparation. So this means we've seen multi-parameter changes, not because we're looking in specific fields, but because nature provides this opportunity. So that means we have to have a better physics to understand nature.

So let's suppose, "Is this only earthquakes?"

No, precursory science is the same as medical science; just the language is different. When you go to the doctor, he looks for symptoms. Symptoms is just another name for precursor, right? And when you go to the doctor, you're sick, but you don't know what's wrong with you. And usually what they do is a CT scan, temperature, other analysis—exactly what we do.

We check different wavelengths, we check different medicine, we check dif-

Logan Abassi/U.N. Photo

The magnitude 7 earthquake in Haiti on Jan. 12, 2010, qualifies as a mega-quake because of the tremendous destruction of people and buildings. Here, a poor neighborhood in Port au Prince, flattened by the earthquake.

ferent symptoms, different precursors, different physics. So the approach is the same.

I learned a lot about earthquake prediction from my doctor, because I had some problems with my health, and several times I had to do four or five different checks. And then he said, "Okay, we have some problem, but I don't trust that; we need to double check." In our language, he said *the anomaly is not statistically significant.*

So now, we're trying to take the anomaly, but we need to check with the normal. And my doctor did the same tests three times, because he said, "Maybe it's the wrong instrument, maybe you had much more coffee in the morning, maybe the lab did it in the wrong way." And on the fourth time, he said, "Yes, you're okay, it was error."

NASA

A video grab of aurora borealis over Northern North America and Canada taken by the crew of Expedition 30 on board the International Space Station. The sequence of shots was taken Jan. 29, 2012, on a pass from the North Pacific Ocean, approximately 1,000 miles west of western Quebec. The video can be seen here.

That's why we're following the same analysis in our work. We're trying to integrate different physical measurements—but to integrate, we need to validate. How significant are they to the normal?—in which normal means no major event.

Major earthquakes are relatively rare cases, if you compare with the everyday events, so you should be able to distinguish what is the normal, for example, if you check background seismicity over a certain area. That's easy to say, but more complicated to do. But we do it the same way as my doctor checking my blood pressure or blood test; we're trying to take long periods of data, define what is the normal status of these parameters, and then see if we see abnormal behavior, and if this abnormal behavior has anything to do with earthquake processes.

We found that some events happen without earthquakes, which means that some parameters are influenced by weather, by the general geodynamic activity, and we learn this when we do statistical analysis. So, in other words, better physics provides better science, but also proves that seismic waves are not the only waves that can give information about earthquakes. And that's why we're exploring electromagnetics, that's why we're exploring atmospheric physics, ionospheric physics. Because we found that the Earth interacts between mega-events like volcanoes, earthquakes, so we're looking for this coupling between physics environments.

21st Century: On the issue of mega-earthquakes, there seems to have been an apparent rise in the incidence of both large earthquakes and large volcanoes in roughly the last 10 years. Earlier this week, there was a poster session at the conference, where somebody disputed the claim that there has been an increase in large earthquakes, based on a statistical analysis, but also motivated by a skepticism that any kind of global process could be at work, that the mega-earthquakes in different parts of the globe could be related to a unified process.

Could you speak to the difference, at least on the mega-quake scale, between something that's acting only regionally, and the possibility that you're dealing with a global phenomenon?

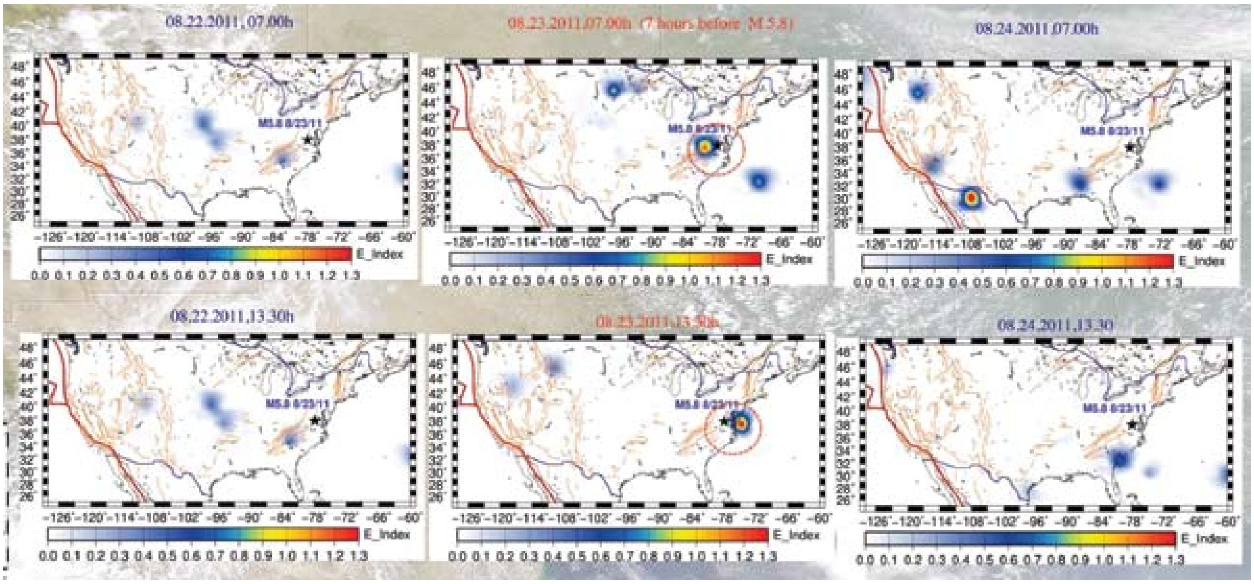
Ouzounov: This is exactly the same question as global change: In other words, whether we see global warming, or not. It depends on what your time scale of analysis is. We see global warming, but is it global, or is it natural or is it artificial? We have a perception of something going very high in terms of earthquakes or volcanoes, but when you scale up to the 100 years or 50 years, we can see there is just a fraction of change.

I'll say it this way: that we consider mega-earthquakes not only by the size, but also by their location. If you have a 9.0 earthquake in the middle of nowhere, in the Pacific Ocean, with zero population, we don't consider this a mega-earthquake. We consider a mega-earthquake to be one which has an extremely vast impact on society.

So if we consider the mega-impact of an earthquake, probably the earthquake in Haiti qualifies, even though the magnitude is not so high. We consider the mega-impact of the Wenchuan earthquake in China, where so many people died. So magnitude matters, but it also matters where the earthquake is located. This is what we've been discussing with Prof. Seyia Uyeda: The increasing density of population brings warning that as we move to big cities, the risk of having more casualties is much higher.

Because there is a global change of area of population, it becomes a much higher concern to have an alert system for a mega-earthquake. Because a mega-city like Istanbul, Cairo in Egypt, Tehran, or the two biggest cities in Pakistan, which are very close to thrust faults—that becomes a problem, because of the constant growth of population density, and concern that even magnitude 6, 7 will play a huge role. So this is one of the trends of statistics.

Another trend of statistics is that of course, we have been very busy with earthquakes for the last few years, and one of the possible explanations for this



THERMAL ANOMALIES BEFORE THE VIRGINIA EARTHQUAKE

Satellite data show a rapid change in the anomalous flux rate of infrared radiation above the epicentral area, in Mineral, Virginia, seven hours before the Aug. 23, 2011 M 5.8 earthquake. This was determined by comparison with a reference field of infrared observations for the month of August between 2004 to 2011.

Source: "Satellite Thermal and GPS/TEC Observations of Atmospheric Process during the time of M5.8 Mineral, Virginia Earthquake of Aug. 23, 2011. Preliminary Results," poster presentation at AGU conference, Dec. 6, 2011.

by people working with space science, is that there is increasing solar activity. Many scientists consider the link between Sun and Earth as a possible interaction and activity on the global scale. But this is a connection that's been in science for many, many years.

Now this connection is more fresh, keeping in mind climate change, because, as you see at this meeting, one of the very interesting topics in many sessions, is the solar-Earth connection to climate change: Maybe we see an increasing in temperature because of increasing solar activity.

There are many questions we cannot answer now, but that doesn't mean we stop looking for solutions. We're looking for solutions, and science today is better than yesterday, but next year will be better than this year.

21st Century: You brought up the solar-Earth connection. Again, we don't have answers, but I'd like your view on two related points: First, is it possible that a lot of the precursor activity that's measured, including especially things like ground current and other electrodynamic effects in the atmosphere, aren't simply an end result of seismic activity, but may play some role in actually causing seismic activity, or triggering seismic activity?

Second, one of the most obvious areas where this might be mediated is through the Sun-Earth relationship, because, as you mentioned, we're still now finding out a lot more about how closely you have this coupling to this larger system. Larger than just the Earth itself, larger than just indigenous processes within the deep Earth. How far should we expand our scope in terms of looking at—minimally—the solar environment?

Ouzounov: That's a very good question. Even if you gave me a few hours, I could not actually finish this, because it's endless, there are so many opportunities!

Now, we have good interaction with the Sun, and for many things that happen here we can claim the Sun is guilty, but we need to have evidence that it's actually really happening. We can talk about different subjects about this interaction; it goes to different layers, among climate, with the environment, with the food, temperature, earthquakes, all these natural disasters.

Well, let us say there are two major components: one component is connected to earthquakes. There are two different categories which most of the mainstream seismologists don't agree with: that there are precursors, and that there is triggering of earthquakes. In other words, that there is something deterministic in the way that earthquakes happen, and that could be blamed on the Sun, or on solar-planet interactions, and things like that.

And by the way, there is a lot of work, published at some conferences, and some work shows that planetary position, and solar activity, could play a role. The Moon, of course, could play a role in the triggering of earthquakes. And somebody says: "OK, c'mon guys, this probably contradicts your precursor studies. If you have a precursor, how does the trigger actually work? Precursor means that there is a physical environment preceding the earthquake, leading to the release of the event. And then you say also there is triggering, which comes from outer space, or from the Sun or the Moon. How does this work together? Is there not a contradiction?”

No there’s not!

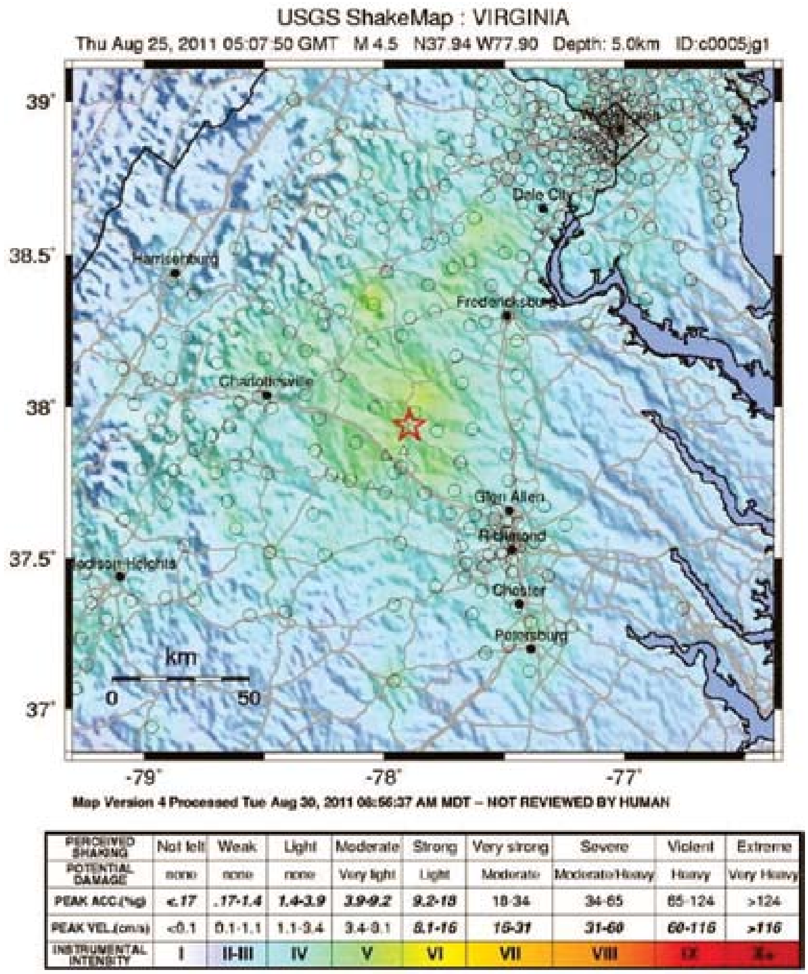
Basically when you see interference between the Sun or other planets, there is definitely interference with Earth, with tidal waves, gravitational waves, electromagnetic coronal mass ejections (CMEs) from the Sun and other activities—they play a role because the Earth is one electromagnetic system, and many scientists are trying to do statistics between solar activity, tidal activity, and Earth, and they found interesting results.

One of the results shows that in most of the cases, we have a magnetic storm during the time of earthquake or before the earthquake, and that’s a manifestation that there’s an interaction between solar activity and Earth, on some level. It’s not clear yet if this is something to do with preparation of an earthquake, with triggering of an earthquake; all this is, is there is some interaction.

And the second question is, “How to use this information?” Sometimes science works with a very high level of uncertainty. You know that the Sun or Moon or other planets can play a role, but you don’t know what kind of role, or how to quantify it. So in our research, we don’t have pure evidence that solar activity and planetary position has a role, but that doesn’t mean we don’t use this information.

In our analysis of multiple precursors, we use Moon phase, tidal waves, and solar cycle as potential additional sources influencing the precursor activity and the triggering of earthquakes. That doesn’t mean I’m 100 percent in favor of that, but I have a few cases in our work which shows a real connection, but also cases in which I see no connection.

There is a very famous way of making a decision, called “Occam’s razor.” When you have two hypotheses, you have to choose one of them. You take the hypothesis that is much simpler, less entropy. So in this case I try to work within what I know, but I also consider from time to time to check what I don’t know. Basically we’re checking the solar activity, and the Moon, and I think this is very helpful information.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

‘SHAKEUP’ MAP OF VIRGINIA FOR AUG. 25, 2011 EARTHQUAKE

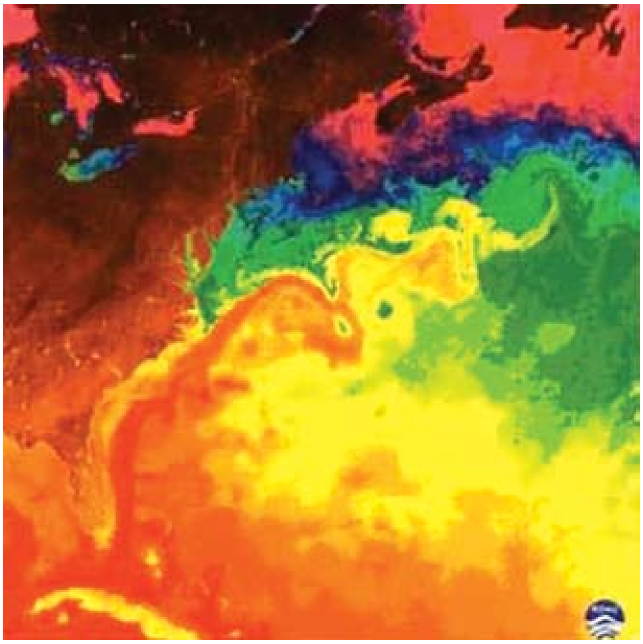
The star marks the epicenter of the magnitude 5.8 earthquake, which surprised seismologists, because it is in an intraplate region. Now, Ouzounov said, this area and others like it will be monitored for precursor anomalies.

Source: USGS

21st Century: The poster that you presented earlier in the week was on the precursor hindcasting of the Mineral, Virginia earthquake. That’s interesting because that was a pretty anomalous earthquake. Like the New Madrid Seismic Zone, it’s an intraplate region. So it seemed like an anomalous earthquake to begin with, and you have a study showing that there are validatable precursors for that. Could you briefly describe what you found, and say whether there’s any distinction of precursors for intraplate earthquakes versus those that occur on plate boundaries?

Ouzounov: Yes, this is an interesting study, for the same reason. I was in Virginia when this earthquake happened, so I have real experience! It was interesting, because I was well trained for that, I was out of my house in 8 seconds. I was first on my street and all my neighbors came and they said, “What was it?” and I said it was a 5.8 earthquake in Virginia. And they asked, “How do you know that?” And I said, “Well, that’s what I do.”

But going back to the real scientific question: It was a real surprise for us, because we don’t expect strong earthquakes in Virginia. First, it’s an intraplate region, like the earthquake we are probably going to expect in the New Madrid zone—and some geologists say, maybe soon. These are very dangerous because usually these regions are not prepared. Their houses and business buildings are not built like those in California, according


Source: GSFC/NASA

THERMAL VARIATIONS ON EAST COAST, AS SEEN FROM SATELLITE

Many meteorological satellites, including most geostationary satellites, have at least one thermal channel. This is a map of thermal variations off the U.S. East Coast, based on meteorological data. When an earthquake is happening, Ouzounov says, some very strong thermal signals will be seen in places where they usually are not, because the atmosphere is artificially heated.

to seismic engineering models, because they're very expensive. And then people are totally unprepared.

We saw what happened in Washington, D.C., when this earthquake happened—panic, traffic jams, and all kind of things. What we have found is that we are able to detect, to hindcast thermal anomalies a few hours and days before the earthquake. In other words, if we had the chance to monitor the area, we should be able to get a signal in advance which is going to tell us that in a few hours an earthquake will happen.

We presumed Virginia was not active. But now we're seriously considering to study Virginia, Maryland, and Pennsylvania as well, in our analysis in the United States. And what we have found is a thermal signal with a significant anomaly near the epicenter, and it was the biggest signal over the entire United States, which normally is not the case. This anomaly shows exactly the reason we do this analysis.

When we study the thermal field and we get lots of different anomalies, that's normal. It's very good to have different anomalies in different places, that are not connected to earthquakes. But when an earthquake is happening, because the atmosphere is artificially heated, we see some very strong signals in places where usually they should not be.

21st Century: So you correct for effects that might be weather induced?

Ouzounov: Yes, we take the weather out. We've been criticized at this meeting that we're not doing very well, but we're doing this. We're taking the weather out by averaging the thermal field. What's happening is that these kind of signals, these kind of anomalies, build very rapidly. If someone is doing this kind of research for different purposes, he's going to filter out these data, this anomaly, as an error, because there's no explanation for why it's happening.

We take this not as error, because we understand the physics. It's happening because we have an increase in gas release during the final stage of preparation. Gas is coming out on a regular basis. Especially in Virginia, where they have so many uranium-type of rocks, radon gas is very high.

But, what is different is that gas is coming out very rapidly, and the concentration is very high, and that makes a big difference. So when you have more gas concentrated, that immediately changes the atmospheric chemistry of the region, and latent heat is released very quickly. We saw this a few hours in advance.

The good news is, why do you see this signal as very strong? Because we don't have too much background seismicity in this region, so the background is clear. If you had the same event in California, it would be very difficult to distinguish, because in California we have earthquakes almost every week, of about 3-magnitude.

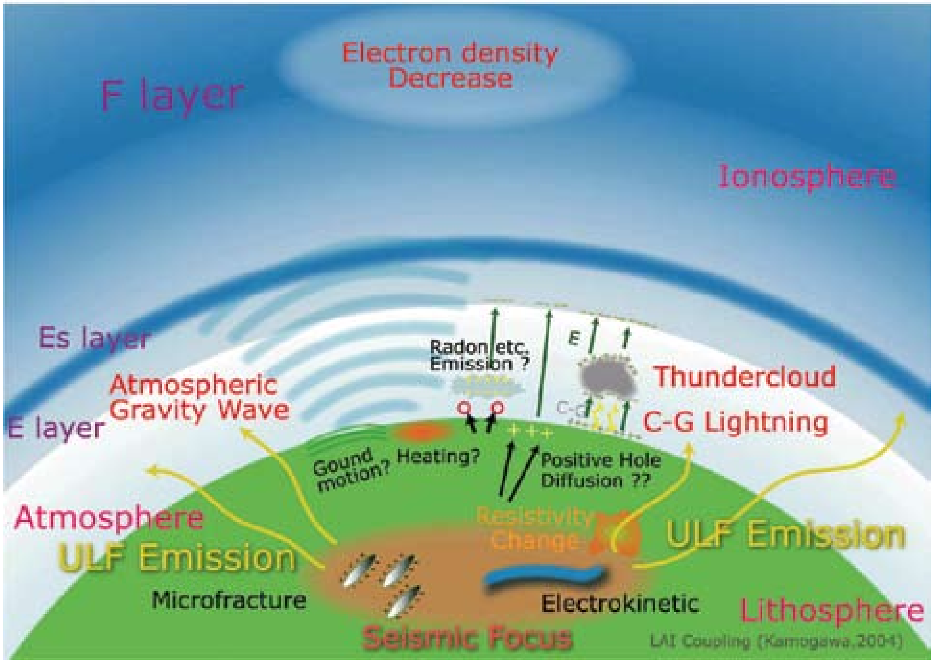
In Virginia, that's not the case, so we have a very clear background and it's very easy to distinguish what is normal vs. abnormal. So, this is the first good finding.

The second was, it's an intraplate earthquake. We don't have much experience with intraplate earthquakes. Usually we do earthquakes in California or other places where we have collision between different platforms on a regular basis, and we expect them, we know the earthquake might happen. That's not the case in Virginia.

There are similar earthquakes in the New Madrid zone, also in India, in Pakistan, far away from major plate tectonic boundaries, and these earthquakes are dangerous; they're strong, and scientists still don't know too much about this. So that's why we presented this work, which shows that we still can see thermal signals before intraplate earthquakes. That's the lesson learned from this presentation.

21st Century: In terms of this field of precursor research, in order to make it full fledged for real-time forecasting, but also in terms of the fundamental science involved, do you think the most important work to be done now is in improved statistical methods to analyze the data, or in coming up with better models of the physical processes involved? What's needed to go forward?

Ouzounov: Everything is important. There are two points, I can have two opinions about this question. What do we think needs to be done in the short-term? What do we do next?



LITHOSPHERE, ATMOSPHERE, IONOSPHERE COUPLING MODEL

Illustration of various phenomena related to earthquake prediction.

Source: "Electromagnetic Phenomena Related to Earthquake Prediction," eds. M. Hayakawa and Y. Fujinawa (Tokyo: TERRA Scientific Publishing Company).

I think in terms of the model, from our perspective, we completed our work. There are a few things we need to justify in terms of tuning the physics of some processes, but most likely, from our perspective, the data we analyze are pretty connected with the concept we have [the Lithosphere-Atmosphere-Ionosphere Coupling, or LAIC model, see accompanying article—ed.].

Another question is, what do other people think about this model? Do they agree with that or not? I'm just giving our inside opinion on that.

The second point: we need to demonstrate that this really works *before* the earthquake. I don't agree with many other kinds of criticism, but I do agree with this kind of criticism: that all of our work is hindcasting. So we need to specifically focus on pre-event analysis.

What are we trying to do right now? We're able to get consent with other scientists in the field, that we need to do joint validation in the field before the earthquake, to get a knowledge, to understand our science before the event, and to verify if our physical understanding is really relevant to the ongoing processes. And then, when the event has already happened, to step back and say, "Okay, what was wrong?"

That's number one right now. Number two is to open this kind of work to the seismologists, because we don't see this as a silver bullet. I think this study can play a very important role as a complementary study to seismology. Our vision of this work in its practical meaning is like a hybrid system. When you have seismological measurements which are definitely everywhere and you are trying to set up a system or analysis of a different kind of precursor which is not seismic, or any pre-earthquake precursor in the area of interest, it will basically benefit the seismic measurements and also give a chance to seismologists to explore also different physics.

Now we're expanding our knowledge to our colleagues in seismology, to try to work with them, to try to have them understand that the signals we are working on are part of earthquake processes, and that they measure data which are pretty relevant to what we do from space. So basically these are the two major goals we're focussed on right now.

21st Century: Are there certain types of crucial experiments that you think could be done and either aren't being done for lack of funding, or for some other reason, that get at the physics of the process? One that comes to mind that some people have done in materials science is rock compression studies.

Ouzounov: A lot of their measurements are very important in terms of clarifying the general physics. But the real work is more complicated than laboratory measurements. We're very interested to do the real measurements, active measurements in the real environment. So what we're trying to set up now in Japan, are measurements that are going to verify the LAIC model. Along with Dr. Pulinets, we had a very good reception in Japan for the last year, especially after the Tohoku earthquake. What's happening now is that our Japanese friends from Hokkaido University and Chiba University, are setting up the types of measurements we recommended. And these measurements will give a long base of verification of the LAIC model. So that's the way to go.

I mean, that in the lab you can see many things, but because of the scale, you're probably not able to see other things. So, our Japanese friends are now setting up measurements, ion measurements on the ground, at the same time they are studying GPS-TEC (total electron content), and ionospheric variability over southern areas.

Of course, we cannot put instruments everywhere, but they know the seismicity in Japan very well, so they chose two areas. And there will be continuous measurements over these two areas probably for one year, five or six independent measurements, and they're going to provide

Oyang Teng

Some of the participants in the American Geophysical Union's 2011 Fall conference sessions on earthquake precursors, which included scientists from the United States, Russia, China, Japan, Greece, and France. One of the goals of the participants was to strengthen international collaboration for real-time analysis of impending earthquake threats in order to validate methods that have been proven in hindcasts for various medium- and large-scale earthquakes.

the results for us.

The idea is, whether they are going to see independently what we have projected to see: in terms of different kinds of precursors, the time observation, how these signals are related to the earthquake process; if they see, without earthquakes, what is the significance of the signals related to the magnitude, and what is the significance of the signals related to overall seismicity.

We can do that in Japan because of the high rate of seismicity in Japan, and because after the Tohoku earthquake they started to look for other options, not only seismic measurements and seafloor measurements; they're looking for any other measurements that are credible, they're open to verify some new methodologies. So that's what we plan to do as an experiment.

21st Century: What agency in the U.S. or internationally should be primarily responsible for earthquake forecasting? Is there some new agency that needs to be created?

Ouzounov: That's the million-dollar question, for the simple reason that the world operates differently than the United States.

Here's the example: in Japan, earthquakes are under the weather bureau, and that's a very right way to do that, in my personal opinion. The weather bureau in Japan actually collects all seismic information, all weather information, all ocean data information, because they are built as an organization responsible for monitoring the data, any kind of data.

In European Geological Surveys, EGS, we have separate agencies, and each agency has—as you know very well, they want to survive—special responsibilities, and sometimes we have a war of agencies. So there are different interests, there's no consensus, they're very powerful, and they're well-funded.

Now in Europe, they show a very good example. They have a financial problem now, but they've built a system for natural hazard monitoring. After the Iceland volcano they found that each country has its own disaster management team, but they cannot talk to each other. So they start to integrate over different boundaries, over different countries the same umbrella, and earthquakes became part of that, also fires, all natural hazards. This means that if there's something happening, or research needed for these kinds of hazards, they respond for all European Union members.

In the United States, this kind of research related to earthquakes is under the umbrella of the U.S. Geological Survey. They have funding, they have priority, and they have expertise doing that. So everything which is going to be developed by us and other teams on some level needs to be presented, and approved by the USGS. We're not successful yet at doing that.

Basically, the practical application, the outcome of this kind of research, needs to be presented to USGS and be approved. We like to talk about global-scale problems, but it's very complicated to coordinate this kind of research on a global scale. Because we have a global problem, but we have not global funding.

We failed to propose something to Japan because the Japanese people have a problem getting funding for this kind of research. And we proposed joint projects several times this year, but they didn't go through.

Because we don't have the same system of funding, we also have a problem working together. Basically, we're not working together. We're exchanging papers, exchanging data, but we don't have a joint team which is actually solving the problems because we always have a problem in the funding, and that could be done by an international organization.

The United Nations, World Bank, UNESCO, or the Global Disaster Reduction Fund—they have the capacity to invest all over the world in different kinds of disasters, but the question is: We're talking about prevention, we're not talking about after the event.

They're very good after the event. We're talking *in advance,* and that's very difficult, because you have to convince international organizations that something is going to happen, so they need to react prior to the earthquake. And that's not been very successful, because people are usually skeptical of this kind of work, and we have not demonstrated, at least once, that our alert made a difference.

If we had a chance to do that, it would be much easier. So we're working on this one alert, one event, for which we can actually provide information in advance and bring more credibility on a global scale.

Approaching the Critical Point in Earthquake Prediction

Seyia Uyeda and Panyiotis Varotsos at the AGU conference.

Professors Seyia Uyeda and Paniyotis Varotsos have been collaborating on earthquake prediction for three decades. Their joint presentation at the American Geophysical Union (AGU) Fall conference in San Francisco on Dec. 6, 2011 was titled, "Earthquake Prediction in Japan and Natural Time Analysis of Seismicity."

Dr. Uyeda, a professor emeritus at the University of Tokyo, is recognized as one of the founders of the theory of plate tectonics in the 1960s. In 2001, he became the first President of the Inter-Association Working Group for Electromagnetic Studies of Earthquakes and Volcanoes (EMSEV), within the International Union of Geodesy and Geophysics.

Dr. Varotsos is a physics professor at the University of Athens, and one of the founders of the VAN method of earthquake prediction, based on the recording of Seismic Electric Signals from the ground, and the utilization of natural time analysis. The latter is the subject of a recently published book, Natural Time Analysis: The New View of Time *(Springer, 2011).*

Drs. Uyeda and Varotsos were interviewed jointly by Oyang Teng and Alexandra Peribikovsky on Dec. 7, 2011 at the AGU conference.

21st Century: Please introduce yourself, and tell us how you came to the field of earthquake prediction.

Uyeda: I come from Tokyo, and I have long been a professor at Tokyo University. My main job when I was young was developing plate tectonics and these types of theories. Towards the end of my active duty, I switched over to the problem of short-term earthquake prediction, by chance. By chance, I mean that I came across the work of Professor Varotsos at that time, the 1980s.

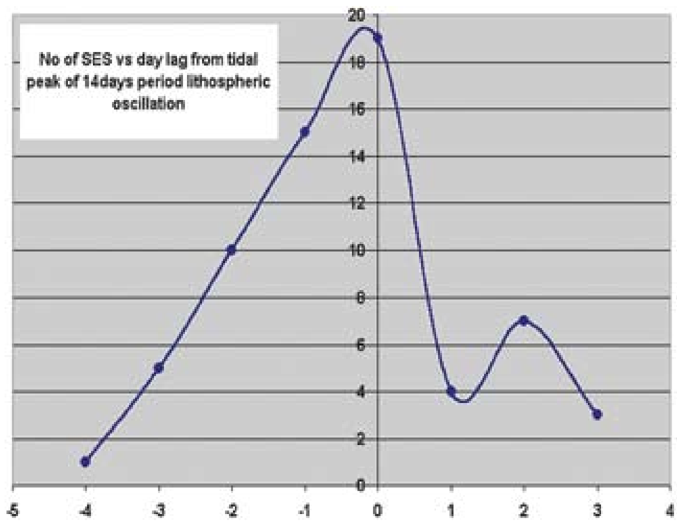
His group had been developing its own method of short-term prediction by monitoring telluric currents in Greece. And I was so much impressed by that, and the method was very unpopular—earthquake prediction is always unpopular—so I switched over to this interesting subject, and I became unpopular too!

Varotsos: I come from the University of Athens. I'm a solid-state physicist, I'm not a seismologist. And in the 1970s, my expertise was thermodynamics for defects in solids, in solid-state physics. And at that time, we concluded that when you increase the stress on a solid, say, a rock, before the rupture, when you reach a critical stress, there is an emission of a precursor electrical signal, which we term a Seismic Electric Signal. And this is emitted a few days, to a few months before an earthquake.

From '81 until today, we have continuously worked on this matter in Greece. We have various stations in Greece, at 10 sites, and we continuously measure the electric field of the Earth. We collect the data, we analyze the data, and when we see that there is an important earthquake, that means, of magnitude 6 or larger, we publicize it well in advance.

In particular, to the ArXiv, to the well known scientific website of Cornell University [www.arxiv.org—ed.]. For instance, the two very strong earthquakes in 2008 that occurred in Greece were both publicized on the Cornell University website, well in advance. The population of course knew about it after this publication.

21st Century: Let me ask you both: What do you think is the essential difference in outlook between those who believe that earthquakes are forecastable



SEISMIC ELECTRIC SIGNAL

A precursor electrical signal is emitted before an earthquake, caused by increased stress on rocks before a rupture. Here a graph compiled by the Varotsos group from one of their seismic measuring stations, showing the seismic electric signal variation with tidal changes.

or predictable, and the majority of seismologists who seem to categorically deny that possibility?

Uyeda: It is rather obvious to everybody, or it should be, that what we are interested in is short-term prediction; then you need a precursor, right? Without a precursor, you can tell nothing—except if you are a fortune teller or something, you could do that, but it's not scientific. So you need a precursor.

By definition, a precursor takes place *before* the earthquake, you see? And seismologists—seismology is a science of earthquakes based on seismic records recorded by seismograms. And seismograms only record earthquakes, *not* precursors. So this is obvious to start with.

Therefore, seismologists never say they can predict short-term. They are honest in that respect. But they think they are the only people who understand earthquakes. That's the trouble with the whole thing, in my view.

This is very true all through the Japanese program of earthquake prediction. The name of the program is "earthquake prediction," but they think prediction is not possible. And yet the government provides lots of budgeting and everything, because they can't say, "We stop studying earthquake prediction." Then the government itself will be very unpopular.

So the seismologists take advantage of this situation, and they say we will do that sometime, sometime, maybe sometime. That has been the case for over 50 years. This situation is true in Japan, but more or less true for many other countries, including the U.S. too, I think, and Greece.

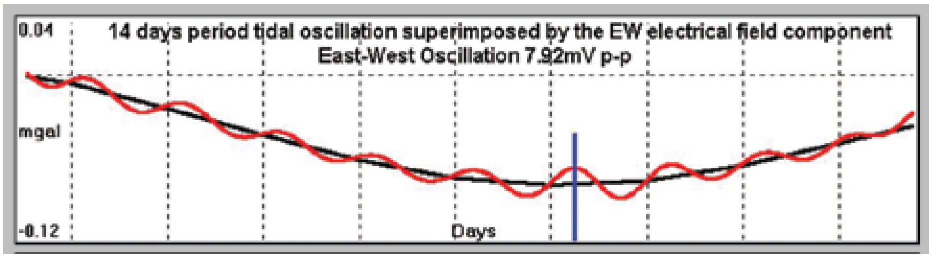
21st Century: Let me ask you, Professor Varotsos, with your background as a solid state physicist, is there an issue in terms of seismologists being biased against people who aren't in the field of seismology? Is there a methodological issue in terms of what areas of physical processes are actually being studied?

Varotsos: From a purely scientific point of view, how the solid is fractured is a matter of solid-state physics. Purely scientific. From a purely scientific point of view, it's not a matter for a seismologist. This is my scientific response to your question. But irrespective of that, I would say the following: in order to understand, "What is an earthquake?" which, practically, is a phase change, that we approach a critical point, this requires the knowledge of modern physics. And what I mean is new ideas on statistical physics.

For instance, the analysis we use now, which you know is in the recent book about natural time analysis [*Natural Time*

EARTHQUAKE MAP FOR GREECE

A videograb of a real time map of earthquakes in Greece. The colors of the dots indicate the time in a 24-hour period. The size of the dots indicates the size of the earthquake.



ELECTRICAL SIGNALS MEASURED AT ATHENS STATIONS

This is a sample of electric signals measured Feb. 7, 2012, from the Athens station, one of 10 sites where the Earth's electrical field is continuously measured. The changes in the field are analyzed, so that warnings of earthquakes can be given in advance.

Analysis: The New View of Time, Springer 2011—ed.], it allows us to count the events event-by-event, and you will understand when the system, which is a complex system, like the case of the Earth, approaches a critical point. This requires knowledge of statistical physics.

21st Century: Can you elaborate on what you mean for a process to reach a critical point and say a little bit about what you mean by natural time? What kind of analysis is needed for that?

Varotsos: Maybe Professor Uyeda has a more simple way to describe it. We suggested it in the beginning of this decade, but Professor Uyeda has the ability to say it in simpler words.

Uyeda: Well, the whole idea of natural time, is that time proceeds when something happens. If nothing happens, nobody knows time is going on. So time is specific to the process, you see? So, in the case of earthquakes, when the earthquake takes place, time proceeds. During the inter-earthquake period, nothing happens, there is no time increase. So we disregard the interval of time, and just put them in order: this happens, this happens, this happens.

21st Century: What type of events do you order? Earthquakes?

Uyeda: Earthquakes. Small earthquakes, for instance. And this can be compared to the way people can remember what happened by order in their life. I was born some time, then I became a boy, and went to school, and so forth, and got married , and had children.

But you don't exactly remember the dates, of course, unless you take notes or something. You can remember what happened by what order; so the importance of the event and the order are important factors.

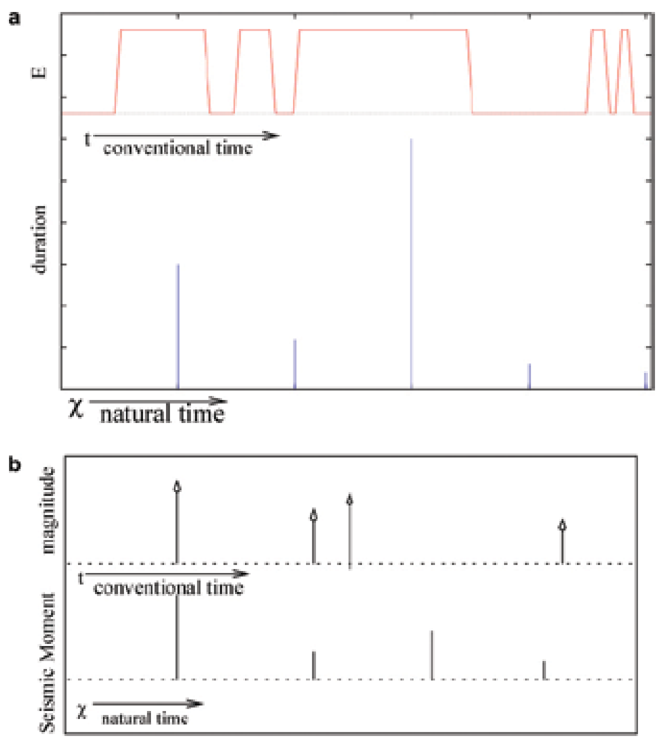
That is the basic thought behind the natural time concept. And for some reason, not very easy to explain, by doing this, one can specify some parameters that describe the approach to criticality. That is what Varotsos calls kappa 1. Its value converges as natural time goes on; it converges toward 0.07. That is the time when the system approaches the critical point. That is the backbone, so to speak, of his natural time analysis.

21st Century: What are the physical processes that characterize this specific critical process in terms of the Earth currents? To the best of your understanding, how does this actually function?

Varotsos: You are asking about the generation of the electric signals?

21st Century: Right.

Varotsos: You see, it is absolutely sure that when you have a rock there are electric dipoles inside the rock. No question about it. But the electric dipoles, need



EARTHQUAKES AND NATURAL TIME

Varotsos models the properties of earthquakes in what he calls natural time, where the seismic moment and energy emitted, for example, are graphed together in a time evolution. Or, shown here, the electrical pulses during an earthquake are graphed in conventional time (red in the upper panel) and then in natural time (blue, in the lower panel). The duration in natural time is indicated on the vertical axis. E = the electrical field. By using the natural time concept, Varotsos et al. can describe when various earthquake precursor parameters approach a critical point.

Source: P. Varotsos, "Is Time Continuous?," in http://arxiv.org/pdf/cond-mat/0605456v1.pdf time to change their orientation. This is called relaxation time. When you apply a stress, and this stress gradually increases as time goes on, the relaxation time of the dipole may decrease. And when this relaxation time becomes very short, all the dipoles, all together, can change the orientation. They cooperate, let me say, and they achieve the same orientation.

Therefore, when you have a cooperative orientation from a random orientation, this change in physics means the emission of an electric current. This is the electric current that we measure before an earthquake. And we know very well that this is a fact, because it has been repeatedly observed in lab experiments. There are many scientists in the world, who have measured it: There are electric signals before the rupture of a solid. There is no question about it.

21st Century: How easy is it to see those electrical signals, or to find them?

Varotsos: It's not such an easy job. I'll tell you why. The most difficult thing is to find the proper sites on the surface of the Earth at which we can record electric signals. It's not an easy job, because the Earth is inhomogeneous, and only specific sites are sensitive to the recording of electric signals. And you need experience.

For instance, in Greece, we tried 10 sites, we installed 10 stations; we waited for a period of time, say one or two years, and after accumulating enough experience, we find which of them is the sensitive point. And then we change.

21st Century: Is there something that's common to the sensitive sites, which characterizes them?

Varotsos: Yes. Now we understand why. And the understanding is quite simple. Because it happens that the earthquakes happen in faults. And nowadays we know that the faults are conductive corridors; it's a conductive channel, as we say. Therefore, when the current starts from the focus, it follows this corridor and it arrives at some point on the surface of the Earth. You must measure very close to the outcrop of these channels.

21st Century: Is it basically where the current leaks out to the surface?

Varotsos: Exactly. Nowadays we understand why there are sensitive points and insensitive points on the surface of the Earth. This is why you need very careful experimentation to find these sites.

Uyeda: Actually, their field work involves a tremendous amount of work. And nobody else has followed that way. We tried to do that in Japan, starting in 1996, when for two or three years, we put many stations in Japan; and some of them were found to be sensitive. But generally the island of Japan is full of electric trains, which is a source of noise, and to deal with this is a big fight, and very difficult on the mainland.

So the only place of success was on faraway islands, and the islands are sensitive sometimes, which is very good, but very few people live there, so practically that doesn't help people too much. But physically, we found the same thing happens in Japan also, and that is important for us.

21st Century: Where the signal leaks out, is that where the epicenter of the earthquake is?

Uyeda: Close to the epicenter, not always very close, but usually rather close, of course. But sometimes if the channel goes through in a strange way, it can go 100 km, for instance.

Varotsos: But the method allows you to determine the epicenter and the magnitude.

21st Century: How do you get the magnitude?

Varotsos: From the amplitude of the signal. If the signal has a larger amplitude, you can calibrate your station and you estimate the magnitude. This is the way.

21st Century: There are a whole range of precursory signals that different groups are studying, everything from low frequency electromagnetic radiation, to the thermal anomalies that some are connecting to radon gas emission, to others that are only now being looked at. Are these other precursors that are being measured related directly to this ground current? What's the best approach in terms of all these different parameters, for precursor analysis?

Varotsos: The current we are measuring, as I said before, may be recorded two months before, for instance. And after the emission of the current, as the time goes on, and you approach the critical point, that means a few days or one week before the main event, how do we understand it? We understand it from natural time analysis.

We have the way to understand when we approach the time [of criticality]. But at that time when you approach the critical point, maybe other phenomena, as you said before, may also occur. Near the critical point, there is a phrase in physics, when we say that long-range correlations always appear. And therefore maybe lights may appear, or radon gas, for instance.

21st Century: How long is this critical point usually? Does it vary depending on the magnitude of the earthquake?

Varotsos: No, empirically we have observed, that from the time we see a condition as Professor Uyeda said to be valid, the main shock occurs within a few days up to one week. This is the accuracy we now have for the prediction of the time.

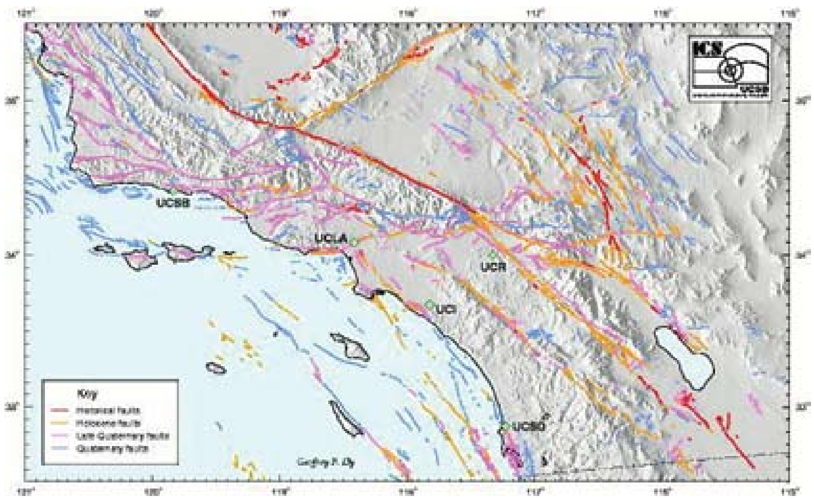
Uyeda: That is for his method, of course. You're also asking about other methods, right? All other frequency problems, they have their own specific mechanism, slightly different. So their lead time before the main shock may differ. But sometimes they are common. So it varies, of course. And technically, the observations of electromagnetic waves for instance, are much easier than the VAN method. The VAN method, as Varotsos explained, is a very difficult operation. Lots of work is needed, tremendous work, really.

21st Century: Is most of the difficulty in getting the measurements?

Uyeda: Yes. And finding the sensitive sites. But for the radio measurements, all you need are antennas, and you can put them anywhere. It's much easier, so everybody jumps on that; that's why it's very popular now.

As to your question of mechanism: these mechanisms are not very well known, I must say. . . . People like Pulinets, they all have their own hypotheses, gathering all the kinds of data, and some more or less reasonable-looking theory, yes. So they may be right, but it's not completely sure. But the phenomena are without doubt, I think. They do exist.

21st Century: What seems clear is that very few people understand what does actually occur when you look at an earthquake. You're not just looking at an event in itself. It seems a lot of the work of what the precursors are based on, is



FOREESHOCKS AND AFTERSHOCKS IN TOHOKU EARTHQUAKE, 2011

The foreshocks are shown in green, and the main shock and aftershocks are in red. Uyeda and Varotsos note that there was an obvious increase in small shocks before the Tohoku earthquake.

Source: USGS

that you're looking at something that is occurring over several months, and it's not just about fault lines rupturing, but you have various other gases, ionosphere changes, perhaps even solar changes that are occurring at the same time: you have a whole entire system. So the real question is, what is this process? What is the entire process that to our senses simply appears as an earthquake?

Varotsos: No question, the whole process is very complex. And you know, let me explain that in physics during the last two decades, we have a new branch in physics: the physics of complex systems. It is in order to understand these complex phenomena. And the physics of complex systems, brings into light a lot of new laws which were unknown previously.

That means you need tedious study to see a few months before an earthquake what is going on. But in order to understand it, you need to follow carefully which physical laws you should apply. This is not an easy job.

For instance, you should see if the earthquakes, the small shocks that occur, are correlated or not. This is a very modern part of statistical physics. And what we presented yesterday in our joint paper [Earthquake Prediction in Japan and Natural Time Analysis of Seismicity—ed.], we have seen that before the Tohoku catastrophic earthquake. Our result was, from a random orientation, exactly this point: to see how the small events before the Tohoku earthquake gave an obvious increase a few weeks before the main event.

But this needs a careful physical study between all the correlations between the small shocks. It's not so easy. This is not a seismological study. This is a study within the frame of modern physics. It's not a work for seismologists.

Uyeda: Seismic waves are very useful for sounding the internal structure and internal process, of the Earth. It's very useful. But as far as the seismogenic process is concerned, they only study how stress is applied or exerted, and what process causes plate pushing. This is a matter of plate tectonics, more or less.

Anyway, after the big earthquake, most of the Japanese seismologists were very depressed. They could not even think of this kind of thing. But it's not their job. Nobody is expecting them to be able to predict that a magnitude 9 will take place, because in Japanese history it has never happened, according to the seismological records. So they don't have to be so depressed. They're okay. But it's not their job.

The other thing is, precursors do not necessarily cause the earthquake. The only thing is that they occur before the earthquake; nobody actually thinks that telluric currents cause earthquakes, so that's why seismologists are not interested—it has nothing to do with the stress accumulation with which they're interested. It's just current flows.

And that is one aspect why seismologists are not interested in us. It's very natural: it's out of their field. They are interested in how stress accumulates to become high, and so forth. Many of the precursors have nothing to do with this. Maybe it's a by-product of the same process—earthquakes and precursors, the whole process.

21st Century: In terms of international policy, it seems like this type of work needs international collaboration. Earthquakes don't respect national boundaries. Where do you think we need to go in terms of collaboration in advancing this work, as a matter of international policy, national security, and also basic science?

Uyeda: As far as earthquakes are concerned, and geophysics is concerned, there is an international organization called IUGG, International Union of Geodesy and Geophysics; it's the largest science group organization. We now have a working group called EMSEV, Electromagnetic Studies of Earthquakes and Volcanism, and this was established 10 years ago. I was one of the founders.

This is essentially an international, interdisciplinary working group. Because those who are active in this type of work are generally not seismologists. They can be atmospheric physicists, purely solid-state physicists, and so forth, and their language is different, they cannot talk to each other. Something that is very common sense to one discipline, is entirely unknown in the others.

But the common point is, we are interested in precursors so we needed this type of organization, and this organization has been very active, very, very active. So that is one thing.

Varotsos: International collaboration is very important. And from our point of view, we have a very close collaboration with the group of Professor Uyeda in Japan. We have an exchange of data, of information, and so on, every day. And we said today in this meeting, we have this collaboration on a daily basis. This is of key importance for such a matter. We all must be united. We must intensify our efforts.

LYNN MARGULIS (1938-2011)

Pioneering American Biologist and Geoscientist

by Mark A.S. McMenamin

University of Massachusetts

Best known for what is now called endosymbiosis or endosymbiotic theory, American geoscientist and biologist Lynn Margulis played a critical role in convincing Western science that the chloroplasts of eukaryotic cells were descended from once free-living photosynthetic bacteria, and that mitochondria were descended from free-roaming parasitoid bacteria. Margulis was not the first to propose what would become her trademark theory, but from now on, the history of endosymbiosis theory will be divided into a pre-Margulis phase, a Margulis phase, and a post-Margulis phase.

Margulis served as midwife to a much broader concept, a concept that the Russian biologist Konstantin S. Merezhkovsky (1855-1921) called *symbiogenesis*. Symbiogenesis is defined as the origination of new organisms through the symbiotic association and unification of two or more species.

The Western reception of symbiogenesis had a long gestation and a difficult birth. It was Lynn Margulis who finally convinced us that endosymbiosis was required to understand the constitution of the eukaryotic cell. Margulis strived to uncover the full implications of symbiogenesis theory, doing so with an iconoclastic fervor.

Shortly after she arrived at the University of Massachusetts, Amherst in 1988, she and I began to work closely on subjects of shared interest, such as the Ediacaran fossil record and early Russian re-

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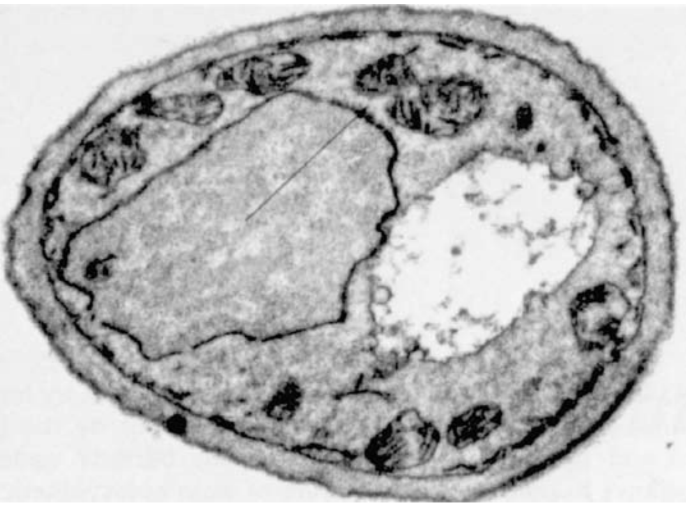
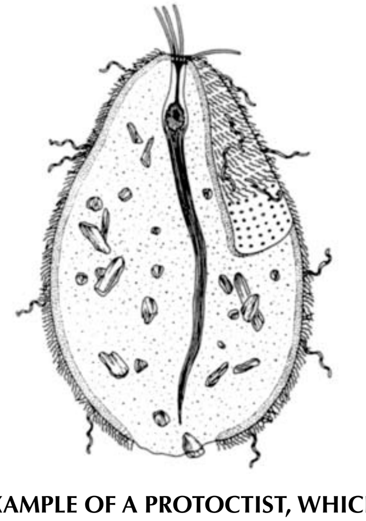
Mark McMenamin is a professor of geology at Mount Holyoke College in the Department of Geology and Geography. His research is primarily focussed on paleontology, particularly the Ediacaran *biota.*



MITOCHONDRIA IN YEAST CELL

Margulis viewed mitochondria, which generate the energy for cell metabolism, as descended from free-roaming parasitoid bacteria. Here, an electron micrograph of a yeast cell, showing mitochondria (small black bodies). The arrow points to a mitochondrion that is apparently dividing.

Source: A.W. Linnane, Monash University, Australia, in Lynn Margulis, *Early Life* (Boston: Jones and Bartlett Publishers, Inc., 1984), p. 76



EXAMPLE OF A PROTOCTIST, WHICH EVOLVED FROM BACTERIAL SYMBIOSIS

The protoctist Mixotricha paradoxa. *Protoctists evolved from bacterial symbiosis, and are neither plant nor animal, Margulis said. This is an example of an individual composed of at least five kinds of organisms.*

Source: Lynn Margulis, *Symbiotic Planet: A New View of Evolution* (New York: Basic Books, 1998), p. 63.

University of Massachusetts

Margulis looking at Spirochaeta perfilievia*, a sulfide-requiring round body-forming spirochete bacteria, provided by her Russian colleague, Galina Dubinina, who studied the organism for 40 years.*

search. In one of our first discussion sessions at the university, we discovered a mutual interest in the work of the great Russian biogeochemist Vladimir I. Vernadsky (1863-1945).

Vernadsky was virtually unknown among our Western colleagues at the time. We developed this interest together for over 20 years, collaborating on the first full English translation of Vernadsky's great work *The Biosphere*.[1] The work continues to this day, and in my final project with Lynn, only a few months before her death, I uncovered in the Vernadsky archives at Columbia University, an exchange of letters between Vernadsky's son George Vernadsky and George Evelyn Hutchinson (1903-1991), discussing the preparation of Vladimir Vernadsky's research for a wider audience. Margulis expressed delight with this find in one of my last communications with her.

Neo-Darwinism Is Dead

One day while walking together across the Amherst College campus, Margulis turned to me and announced that Neo-Darwinism was dead and that, as a result, we needed an entirely new evolutionary paradigm. At the time, I was unaware of any credible challenge to the prevailing evolutionary model. Lynn proceeded to explain how the stepwise natural selection required by the Neo-Darwinian Modern Synthesis had never actually been demonstrated in the vast majority of cases.

The concept that most major evolutionary changes occurred by slow accumulation of mutations, lacked decisive scientific support. Rather, all known cases of what might be called speciation in the laboratory involved sudden reproductive isolation via genital infections, rendering the infected individuals able to interbreed only with conspecifics that had already contracted the same venereal disease.

For Margulis, this was compelling evidence that symbiogenesis was not only responsible for the makeup of the eukaryotic cell, but that it was also responsible for virtually all speciation events in animals, plants, fungi, and protists. In other words, symbiosis equates to evolutionary transformation at both the macroevolutionary (new major cell types) and microevolutionary (new species) levels.

University of Massachusetts

Margulis answers questions from students on a field trip to Harvard Forest, in Petersham, Mass., during a course on Environmental Evolution.

The great Russian symbiogeneticist Andrey S. Famintsyn (1835-1918) had arrived at a similar conclusion a century before, noting that the major steps in evolution are not in the least elucidated by Darwin, and remain, as before, an unresolved question. Margulis framed this as an astonishing scientific insight, and I have since come to realize that once again she was on the trail of something important, a major advance in science that would be fully revealed only after much argument and debate, finally leading to acceptance by the scientific community.

By 1989, Margulis was in full swing with this aspect of her research, spearheading conferences and sponsoring book projects with the aim of showing that virtually all evolutionary innovation was the result of symbiogenesis. We might even say that it was Lynn Margulis, not Charles Darwin, who actually explained the mechanics of the origin of species.

A Contagious Enthusiasm

Margulis's enthusiasm for moving science forward was contagious, and inspired by endosymbiosis theory, groundbreaking Russian research, and the Lovelock-Margulis articulation of the Gaia hypothesis, my wife, Dianna, and I proceeded to consider the biosphere as a whole from a symbiogenesis perspective. Our primary goal was to enhance Mount Holyoke College's introductory geology course, *History of Life* (Geology 102).

I wanted, at long last, to provide my students with an adequate explanation for how and why vascular land plants transformed dry land surface into undulating forest. Our solution, the idea that cooperation among fungi, vascular plants, and other organisms in a vast symbiotic network—a geophysiological entity we called Hypersea, with the ability to induce upward nutrient flow (hypermarine upwelling)—was published by Columbia University Press in 1994 as *Hypersea: Life on Land*.

1. *The Biosphere*, Vladimir Vernadsky (New York: Copernicus, 1998) English translation ed. Mark A.S. McMenamin.

In her foreword to the book (she also took the splendid cover photomicrograph), Margulis announced that *Hypersea* blended Vernadskian biospheric thinking and Lovelockian Gaian spatial "connectedness" to allow us to "look wide-eyed upon a land surface whose history we thought we understood. Returning to where we stood before, enlightened by a century of biological and paleontological insight, we now see this place for the first time."

Her foreword encapsulates the classic Lynn Margulis approach to appreciating the full symbiogenetic glory of the natural world.

Due at least in part to her difficulties with the Neo-Darwinian synthesis, Margulis astonished many of her colleagues by changing her departmental affiliation from biology to geosciences. This made good sense, for Margulis had come to admire how the geosciences superintend a rich temporal data set that biologists tend to neglect.

For example, the great American geologist Preston Cloud determined that the Cambrian Explosion must represent a truly massive case of punctuated evolution. Cloud argued that the filter feeding apparatus (*lophophore*) of a brachiopod couldn't function properly as a brachiopod filtering loop without a completely bivalve shell.

The first brachiopods in the fossil record are fully formed bivalve filter feeders. This does not mean that there were no intermediate stages. However, there is no evidence that early brachiopods developed by the countless generations of gradual, incremental change demanded by conventional Neo-Darwinian theory.

Margulis took Cloud's insight a step further, urging me to consider the possibility that the relatively sudden appearance at the Cambrian boundary of numerous different types of skeletons, composed of different types of biominerals, might very well represent yet another case of symbiogenesis. I was initially skeptical, but sure enough, the shell structure of an Early Cambrian stem group (mickwitziid brachiopods) proved to be packed with spherules of hydroxyapatite. These tiny spherules might best be interpreted as the permineralized fossil remains of coccoid symbiotic microbes.

BU Photography

Margulis at Boston University in 1982.

The importance of symbiosis in the acquisition of early animal shells remains an unsettled question, but here again, Lynn Margulis may be on the right track.

The Oxygen Revolution

Preston Cloud is also known for his discovery of the Oxygen Revolution, announcing the discovery at the same time that Margulis was about to publish her endosymbiosis research. The Oxygen Revolution occurred approximately 2 billion years ago, when diatomic oxygen gas released by photosynthesis (Photosystem II) overwhelmed Earth's reservoirs of native and ferrous iron, thereby allowing oxygen to accumulate in the oceans and atmosphere and thus completely altering the geochemistry of the planet.

Russian scientists are chagrined at the fact that Cloud, apparently unfamiliar with Vernadsky's work, was able to link the Proterozoic banded iron formations to the concept of an anoxic early Earth atmosphere.

Discovery of the Oxygen Revolution by all rights should have gone to the

Courtesy of Mark McMenamin

A 1975 photo of visiting and resident scientists at the Clean Lab (now Cloud Lab), at the University of California at Santa Barbara. Lynn Margulis is third from right in the front row. Preston Cloud is first from left; Stanley Awramik is first from right; and, in the rear row, Elso Barghoorn is third from right.

Russians, but in this particular case, the honors went to an American. This discovery, along with the plate tectonic revolution and symbiogenesis theory, constituted one of the great American geoscience contributions of the 20th Century. Margulis was very much front and center among the giants in this amazingly fruitful episode of American geoscience achievement.

In a 1975 photograph from the Clean Lab (now Cloud Lab), at the University of California, Santa Barbara, Lynn Margulis appears in the middle, beaming like a school girl, with Preston Cloud to her far right and Stanley Awramik (my graduate advisor) to her far left. Behind Margulis in the photograph stands Elso Barghoorn, the Amherst College/Harvard University professor of whom Margulis always spoke with great admiration.


University of Massachusetts

Margulis exporing microbialites at the Moroccan field site studied by one of her graduate students.

Barghoorn was graduate advisor and mentor to many of the scientists (and their students) who conducted most of the best and most original research on early life on Earth, in what we may now refer to as the Golden Age of American Geoscience (ca. 1965-2000).

In this golden era of field and laboratory research, Americans collected lunar rock samples (the Clean/Cloud Lab was originally designed to receive the Apollo mission Moon rocks), confirmed plate tectonic theory, discovered the oldest fossils known, named the supercontinent Rodinia (using the Russian language root word for *homeland* to honor the Russian geoscience contributions), linked the decline of stromatolites to the emergence of animals, discovered the oldest fossils of complex life, confirmed endosymbiotic theory, and identified the Oxygen Revolution, among many other groundbreaking scientific advances.

It may be some time before the world witnesses a comparable series of discoveries in the Earth sciences. The heady excitement of discovery after discovery was a wonder to behold. I will never forget the excitement, in pre-digital graduate school as Stan Awramik's research assistant, of developing the first photographic images of what may very well be the world's oldest microfossils, watching their images slowly emerge (*de profundus*) on the glossy print photo paper in the faint red safe light of the darkroom.

Nor will I ever forget the excitement of flipping over a slab of siltstone on a mountainside slope in Sonora, Mexico, and discovering the earliest evidence for complex life on the Earth.

Champion of the Unorthodox

Probably due to the long list of rejections she accumulated while trying to promote endosymbiosis theory early in her career, Lynn Margulis was always ready to champion an intriguing new concept or a potentially fruitful (if unorthodox) new approach. This inevitably led her to advocate ideas that many of her less adventuresome colleagues would consider fringe science or worse, such as her endorsement of AIDS "denialism" (Margulis held a microbial-consortial view of the etiology of AIDS).

Such aberrations must be seen in the context of the classic Lynn Margulis approach to research, an approach always ready to challenge the scientific establishment, always ready to consider a new direction, and always ready to advance the science.

I attribute this tendency to her acute sense that science is an eternally unfinished project, with the next big advance just around the corner. She combined this with an intense desire to communicate a sense of possibility and discovery to her students.

As part of scrutiny of yet another unorthodox idea, Margulis set up a transatlantic Skype interview with the great German paleontologist Adolf "Dolf" Seilacher, asking him to discuss with students his ideas about the non-animal nature of the Ediacaran fossils. This interview, delivered in Seilacher's rich Teutonic baritone, was only one of a marvelous series of recorded interviews that Margulis collected from her vast network of colleagues.

Seilacher's Skype interview has become a mainstay of my popular first year seminar course *Geology 115: Emergence of Animals*. Margulis was a favorite guest lecturer in my classes, and she will be greatly missed.

Evidence-Based Medicine: Treating by Chance

by Cathy M. Helgason, M.D.

Evidence-based medicine is the basis for clinical guidelines and algorithms that is now considered a standard ruling for medical practice. The "evidence" refers to the results of large, double-blind, randomized clinical trials. That which is evidenced is the causal effect predicted for any action taken by the physician, and the algorithms reflect this: If the physician does this, then he/she causes that. From the probablities, the claim is that of numeric certainty of prediction.

This evidence is in the form of probabilities calculated for the findings of clinical trials, and the evidence claims scientific and numeric certainty in the probabilities. Because the numeric certainty applies to the group of patients studied, it is removed from the individual patient's case.

The current popular understanding of science is that it defines causation. Probability theory is the reigning theory of causation, and thus method of causal problem-solving, and medicine has adopted this method for clinical practice. The question asked is, "What is the probability that the patient has this or that, and what is probability of a given result of physician action?"

Why did medicine adopt probabilities as its guide for diagnosis and treatment? Why did a scientific theory overtake, or gain a place near-equal to the Hippocratic Oath as the guide for clinical decision?

Underlying this method of solution by probabilities is something more fundamental. Science in this form provides a dispassionate numeric, unbiased authority to any decision. The unbiased nature of the probability as an authority satisfies the view that truth for any action cannot be known perfectly. That is, the belief that the physician cannot ever know how to solve any problem without using probabilities. This is because the context for truth is a universe of Chance.

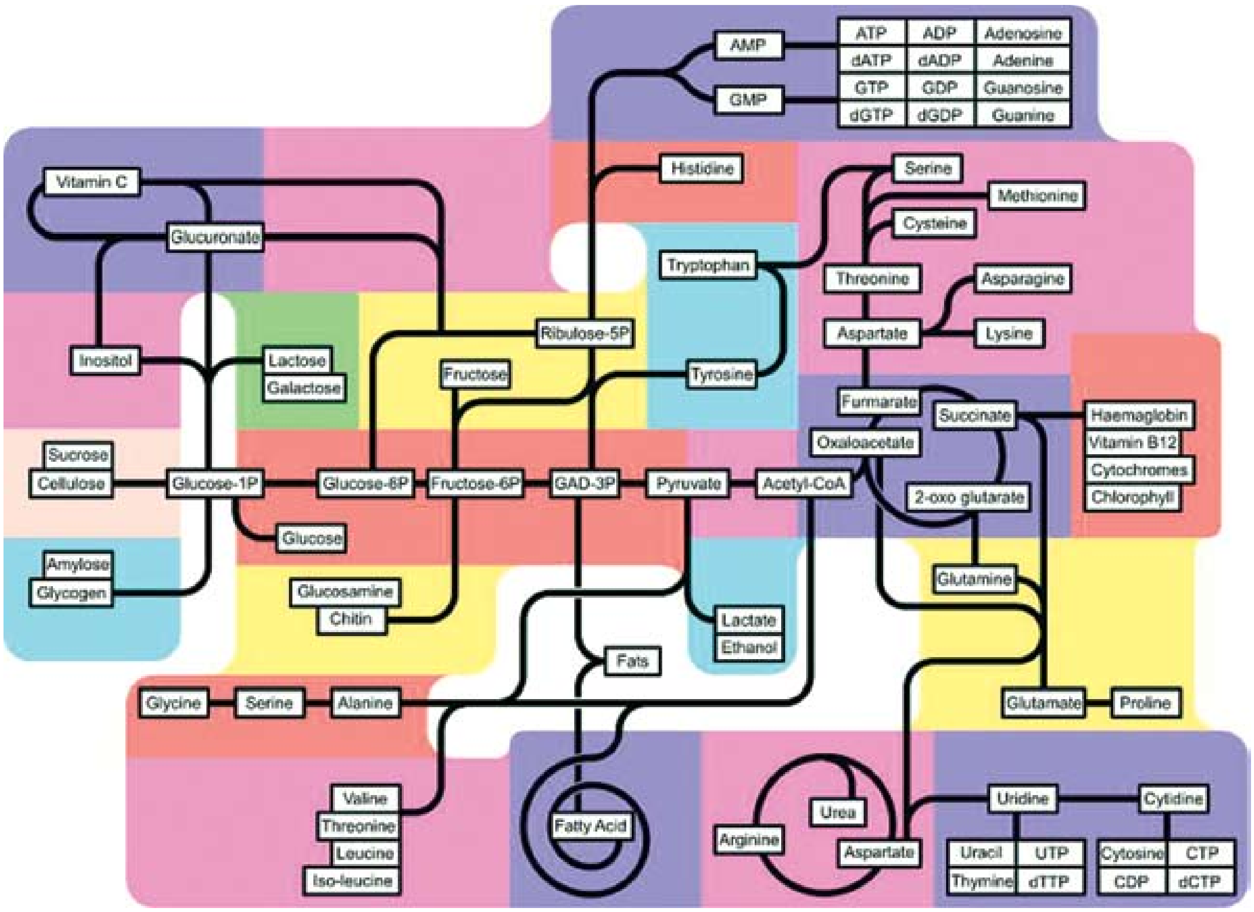
Thus, said in a different way, probability is a theory limited to the uncertainty of causation in a field of Chance. So, therefore, the fundamental underlying motive of evidence-based medicine is to satisfy the belief that no physician knows what he/she is doing, unless acting through probabilities of numeric certainty. If acting within a high probability, a failure to cure divests the physician of responsibility for the outcome, which then is due to chance—something outside the probability.

If acting within the probability, the in-

Measure	Definitions	How to calculate
Relative Risk (RR)	RR is how many times more likely it is that an event will occur in the intervention group relevant to the control group RR=1 means there is no difference between the two groups RR>1 means the intervention increased the risk of the outcome RR<1 means the intervention decreased the risk of the outcome	EER/CER
Relative Risk Reduction (RRR)	RRR is the reduction in rate of the outcome in the intervention group relative to the control group	(CER-EER)/CER
Absolute Risk Reduction (ARR)	ARR is the absolute difference in the rates of events between the two groups and gives an indication of the baseline risk and intervention effect	CER-EER
Number Needed to Treat (NNT)	NNT tells us the number of patients we need to treat to prevent one bad outcome	1/ARR or when the ARR is expressed as a decimal or 100/ARR when the ARR is a percentage

THE STATISTICAL METHOD OF TREATMENT

A sample table from the Centre for Evidence-Based Medicine at Oxford University, instructing physicians on using relevant information from randomized controlled trials. The acronyms in the "How to Calculate" column are CER for Control Event Rate, EER for the Experimental Event Rate, and ARR for absolute risk reduction. Here, statistics, not creativity, rules.



METABOLIC PATHWAYS: WHY STATISTICAL MODELING FAILS

Depicted here are the distinct metabolic pathways used by cells to transfer energy. This, not chance, is the interactive and dynamic physiology comparing the clinical context of medical expectation and forecast.

surance company or other interested parties potentially predict the outcome of millions of patients.

Clothed in a dispassionate but numerically certain and scientific approach to the patient, evidence-based decision now competes with the Hippocratic Oath. Medical ethicists claim that "to do no harm" means to follow the guidelines of evidence-based medicine. These physician or non-physician ethicists have not given up the Hippocratic Oath per se, but have folded evidence-based medicine into its territory.

Serving the Medical Oligarchy

This author was witness to the history of how this came to be. Evidence-based medicine came about so that a type of medical elite within academia—elite because they also claim the title of scientist—adopted the theory or method of determining causation for the purpose of prediction. Prediction carries the awe of the crystal ball for the patient, the certainty of an outcome of a gamble for the insurance company, and the authority of numeracy.

Because all physicians do not belong to the group of physician-scientists, the latter has become a type of oligarchy, which uses evidence-based medicine to control and judge the practice, certification, and continued licensing of all physicians. Those guidelines and algorithms written by the cadre of elite scientist-physicians make certain that the influence of the individual physician is minimized, by restricting his/her activity or decisions to those options provided by the probabilities of outcome determined from the large, double-blind, randomized trials.

These are physicians with a certain outlook on human ingenuity and creativity. Not only do they believe that creativity has no place in medicine, but they carry hatred and disdain for it, because in their limited view, it is not "scientific."

Killing for Chance?

But what drives the so-passionate push for evidence-based medicine? Passion suggests a purpose. What drives the physician who would deny a cancer patient or otherwise terminally ill patient a treatment which *might* work but has a low *probability* of working, and does so although the patient is requesting that therapy? Who is willing to kill for Chance?

In a Universe of constantly changing states of increased energy flux density,

Doctors take the Hippocratic Oath, with its message that physicians should "do no harm." The statisticians of the large double-blind randomized clinical trials have not taken the Hippocratic Oath.

the physician must constantly improve the quality of diagnosis and treatment in order to improve the patient context within which disease occurs. This requires an understanding that it is within the context of living physiology, rather than Chance, that the principles and laws of life determine the results of any chosen action.

To improve the quality of medicine, creativity is necessary on the part of the physician. Creativity always involves the introduction of a new idea, a new intervention to the process. That intervention may be a new way of putting together the facts, other than that framework provided by probabilities, or a new thought object—for example, a new drug, new diagnostic technique, new diagnosis, or a treatment used in an innovative and expectedly successful way. A new method of problem solving.

This requires that the physician understand how his/her action will change the condition of the patient. This understanding is an expectation, and expectations lead to forecast. Neither expectation nor forecast carry numeric certainty. Nonetheless, progress at the bedside demands an analysis of expectation and product of forecast on the part of the physician

Creativity Is Not Allowed

But evidence-based medicine is concerned with prediction. Predictions are probabilities, and are calculated by the method of probability-based statistics. No additional factors other than those laid out for the purpose of the calculation of a probability against the empty background of Chance are allowed to enter the equation. No additional variables are ever allowed to enter the final calculation of the probability. Thus, creativity is not allowed to enter the diagnostic or treatment algorithm.

Instead of working within the context of Chance, the physician understands that the patient's condition, while measured by discrete observations, is really that of a continuum of changing physiological state. That state casts its shadow in the form of measured variables. The principles of this changing physiology must be tackled and mastered in order to forecast the effect of an intervention.

Because the physiologic state is constantly changing, new interventions are always required to gain a desired effect. Without creativity on the part of the physician, this cannot be achieved. Evidence-based medicine outlaws this creativity. As a scientific model for medicine, it guarantees a closed system of no progress.

The author's article "The Evil Intention of Evidence-Based Medicine" can be found here.

Detail from "The Doctor," an 1891 painting by Samuel Luke Fildes (1843-1927). Evidence-based medicine intends to eliminate the thinking process depicted here.

INTERVIEW: DR. AKIRA TOKUHIRO

Fukushima, Science, and Radiation

Dr. Akira Tokuhiro is a professor of mechanical and nuclear engineering at the University of Idaho. He was interviewed at the American Nuclear Society, Washington, D.C. meeting, Nov. 21, 2011, by Marjorie Mazel Hecht.

Tokuhiro, along with Wade Allison, a professor emeritus of physics at Oxford University, visited Japan in September 2011, to hold public forums and meetings on radiation and reason, as opposed to the scare stories. They were joined by David Wagner, a Tokyo-based risk communication specialist. Tokuhiro and Allison visited Fukushima to learn, and to discuss post-accident contamination with local residents.

The three are pursuing the question of changing the international standards of radiation protection, which are now arbitrarily low, based on the false Linear No-Threshold (LNT) thesis that all radiation is dangerous.

21st Century: What inspired you to go to Japan, to promote "radiation and reason"?

Tokuhiro: Being Tokyo-born and in the nuclear profession, I wanted to contribute to the recovery effort and crisis management effort. I just felt that I needed to do something to help.

Originally I had an idea in mind—sounds a little bit negative—but I wanted to have an international conference in Fukushima called "the plight conference." That was to really bring attention to the victims and the evacuees. Not the nuclear accident, because that just got too big.

It's been hard to organize that, but maybe next year.

That's how it started, through discussions on nuclear safety, questions of what's the most recent news, keeping track of the technical side.

21st Century: That was a big job.

Tokuhiro: Yes, that was my "hook." So we realized at some point that putting on a conference is not so easy. The novel thing about the conference is that we were going to get about 500 journalists to come to Japan, and invite only evacuees and victims to the conference to bring out the human side of the story. We didn't want any anti-nuclear people, we didn't want nuclear vendors, we didn't want utilities. But we had to whittle it down to just "radiation and reason."

Radiation and Reason is the title of Wade Allison's book. He wrote that well before Fukushima, and it happened to be translated into Japanese. There was a very motivated woman who convinced a publisher in Japan to translate it.

So that came out in Japanese, and the timing was just right.

21st Century: Just after Fukushima?

Tokuhiro: Yes, in the July-August timeframe.

It was Wade Allison's first time in Japan. We met for the first time at Narita Airport. And we went right to Fukushima. And through his contacts there were a couple of high school teachers, some hospital doctors and administrators who were our hosts. One of them picked us up and took us around.

We went to Minami-Soma, one of the hospitals. They said they were operating at about 40 percent capacity. Some of the doctors had left because of the scare over radiation, and some of the patients were evacuated and had not come back.

21st Century: That's terrible—the patients would probably have been helped by a little low-level background radiation.

Photos courtesy of Akira Tokuhiro

From right: Akira Tokuhiro and Prof. Wade Allison with two Minami-Soma Hospital hosts, on a coastal road bridge near Namie village, about 3-4 km north of the Fukushima Dai-ichi plant, Oct. 1, 2010. The ocean is about 1 km on the left. Note the mound of debris in the background at right.

Three dosimeter readings at the coastal road bridge, showing 0.58, 0.40, and 0.529 millisieverts/hour.

Tokuhiro: Yes—this thing about the linear no threshold theory, LNT: There's no scientific basis for damage at low levels. So, for the cleanup, the number of becquerels per kilogram of soil that is their clean-up goal, makes a critical difference in how much they'll have to spend on the cleanup, trying to get it to a low level, say, 500 becquerels per kilogram of soil. There's a Health Ministry report that says they want to reduce the final kilobecquerels of radiation per gram of beef down to 100. It's just unbelievable.

21st Century: It doesn't make sense. But people are so brainwashed. That's the word you have to use, because they just don't understand what it is.

Tokuhiro: Wade Allison had a specific message on this. He really would like to encourage the ICRP—International Commission on Radiation Protection—to reconsider the prescriptive levels that they have.

21st Century: How does Dr. Allison intend to go about changing the ICRP?

Tokuhiro: Right now, I think he's just bringing up the discussion, a first step. And if you look at his book, he shows that in 1951, the ICRP's original prescriptive levels were much higher, and the ICRP kept just lowering and lowering them.

21st Century: Based on fear, really, not any change in the science.

Tokuhiro: I guess my analogy is—I'm much more of a big picture person. It's really Wade Allison's expertise—if you make the safety argument, say for highways, then we need to have the speed limit go down to zero for automobiles, because it's safer.

So I would say that risk is a spectrum. And when you talk about risk, you can't just talk about radiation. You have to talk about all kinds of risks, including external or internal exposure, chemicals, smoke, hormones, and so forth

If you're eating sushi, for instance, you know that the tuna has mercury content. It's mercury laden, so there's risk in that. In Japan, you eat the puffer fish for the delicacy of the poison. And there are *E. coli* outbreaks all over the world.

The other thing I want to stress is that there's a concept called resiliency, and that's what I said in the presentations I made in Japan. The body has an ability to accommodate to toxins that are ingested.

21st Century: It may even strengthen the body's immune system functioning.

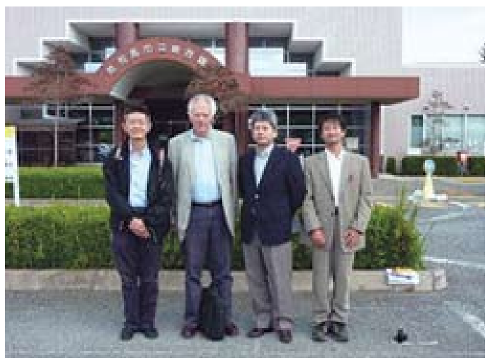
Tokuhiro: Exactly. So there is a human resiliency in terms of ingesting radioactive particulates—cesium-137 or others. And I can tell you what science doesn't know today: Science does know that resiliency is different in every individual human being, **but** cannot predict the resiliency in each individual. We don't have enough scientific knowledge to predict the resiliency of the human body against ingesting toxins.

21st Century: You know, Dr. Edward Calabrese looked at thousands of studies on all kinds of toxins, including radiation, and he finds the same spectrum of results, a "J" curve, so that on all of them there is a beneficial effect up to a certain dose level. Above that, there isn't.

And it doesn't matter what the substance is, he says. He's found that the curve in different kinds of things is the same. He says it's very clear; there are so many experiments that show it that it's really unassailable. Exactly what the mechanism is, is another question.

Tokuhiro: That's why I'm trying to use

Tokuhiro and Allison at Minami-Soma Hospital, talking with senior doctors who monitored the radiation exposure of evacuees.



Tokuhiro and Allison posing with a hospital host and a Soma High School science teacher host, in front of Minami-Soma Hospital, which is 25 km north of the Fukushima nuclear plant.

Professors Tokuhiro (left) and Allison addressing a Tokyo meeting, sponsored by the American Chamber of Commerce in Japan, on food safety, Oct. 3, 2010. An outline of the presentations can be found here. Videos of the meeting are here.

a little bit of street sense. When you have these international entities and there's a consensus, that consensus view sometimes is a social activity. People agree because they're part of the party. There's a sense of membership and they don't want to go against the legacy of their organization.

21st Century: That's very apparent with the Linear No-Threshold.

Tokuhiro: It becomes detached from the science. They are not willing to look at the science, because everybody in this membership has agreed to maintain the *status quo*.

21st Century: And new people coming in to the profession, learn that "this is how it's done." So it never changes.

Tokuhiro: Right. So there's a threshold level, and there is no scientific basis for saying there is not. And we are abandoning our principles as scientists not to say we really need to look at this again. And we need to look at it in the broader context of toxins that we ingest and that we're exposed to.

21st Century: How would you get the American Nuclear Society, for example, to begin to look at this?

Tokuhiro: Well, I'll take that up at a talk this week, that we need to look at that, that we need to reconsider.

21st Century: I didn't find a single negative response from anybody I've talked to at the conference today on the LNT question. Most people knew about it. They didn't know that Herman Muller, the Nobelist was a eugenicist, or some of the other nasty background....

I was really surprised. Muller was a protégé of Huxley, who was a vicious green and eugenicist of the hard-line Nazi type. As far as I can tell, Muller was not that, but Huxley invited him to come to his institute in the early 1900s, so they must have shared some kind of ideology.

Then Muller went to Germany to study, and he left in the 1930s because of the Nazis and went to the Soviet Union. He wrote a book on eugenics in 1935, and when Stalin read the book in Russian translation, he told Muller to get out of the Soviet Union.

I think there's a big story there—I don't know what it is yet. So then he went to England and later returned to the United States.

But people change over their lifetime.... Muller was very active with Bertrand Russell in the "Ban the Bomb" movement, and Russell was a big genocidalist. He wanted to kill off millions of people periodically, and he said how to do it. He made no bones about that. I couldn't quite believe this in the 1970s when I first heard it, but the quotes from him are there, in black and white.

Russell said, we don't want to go out and just kill people, but disease, wars, famine, and sometimes other methods would be necessary. He was targetting people of color in particular, but also people in general. Russell was not a nice, happy person.

Dr. Calabrese thinks that Muller just wanted to protect the human genome from radiation. I'm not sure; I think that there might be more to it.... He's gone into the archives at the Atomic Energy Commission and others looking for correspondence and reading some of the papers. Muller wrote a lot.... I think it's important to look at the history of this.

Tokuhiro: It has the makings of a movie. It's really pretty fascinating. It brings a dark history of humankind into view.

21st Century: And the continuation of it, the people who are still defending the LNT, on what basis are they doing it?

Tokuhiro: That's why it's a social activity, not so much a science activity.

21st Century: Well, it's one of the bad social activities that have to be turned around! Do you have specific proposals

Debris alongside a coastal road near Namie village. Their hosts took Tokuhiro and Allison on a tour of the area via ambulance.

More scenes of tsunami destruction near the same coastal road. "It's a beautiful area—hills, mountains, and a lot of trees. Very different from Tokyo," Tokuhiro said.

that you want the ICRP to discuss.

Tokuhiro: I agree with Allison, that we have to get away from the idea of "as low as reasonably achievable"—ALARA. He proposed "as low as safety allows."

Allison's view, and I agree, is to set an upper limit, and that would be *half* the actual radiation threshold beyond which you would actually start to see evidence of harm.

21st Century: So he wouldn't go to the actual threshold, but halfway?

Tokuhiro: Yes, he was saying, if the current standard is 20 millisieverts per year, and the threshold is actually 200 millisieverts per year, let's make it 100 millisieverts per year. Beyond that higher level, you may start to see some documented medical evidence that there is a health effect.

But even then—I was discussing with a health physics professor today, asking what is really the definition of health effects? What if, because of ingesting cesium-137, for example, what if it disturbs your sleep pattern? Is that a health effect? You get into gray areas in terms of what is a health effect that you can attribute to radiation.

21st Century: Does cesium-137 actually disturb sleep patterns?

Tokuhiro: I was just using it as an example. With some toxins, that can be. But if you have indigestion, that can disturb your sleep pattern as well. I'm not trying to be humorous, but that's actually from ingesting rich food, or too much food, which can be an health effect; there is a gray area. So, as a scientist, we would say that we need to look at this scientifically.

21st Century: But you also have to look at the enormous benefits that we are missing out on. The Japanese studies, for example, that gave whole-body, low-level radiation to people with lymphoma; those patients are still alive today, as opposed to the patients who didn't get that low dose, before they had the targetted high-dose radiation. So, why wouldn't we be doing that for everybody? If people understood that radiation is good for you at that low level, we would be.

Tokuhiro: Professor Allison has said that because of a set of circumstances—the Cold War, the fear of nuclear warfare, fallout, nuclear winter—all of these things created a generation of people, and now we're sustaining that fear of radiation.

21st Century: I would add the genocidal factor. Population control.

Tokuhiro: That's kind of a coincidental thing. The headlines are that we've now reached 7 billion population.

21st Century: That doesn't worry me, because you look at human beings in terms of their minds, and what they're capable of doing. So the more you have of them, and the more educated they are, the more innovation you have, and the more you can move society forward. . . .

I wish the ANS would begin to promote nuclear really fully. I don't think it does now, because—this morning's session, for example, they were talking about cost-benefit on the lowest possible level. And really, you can't do that with nuclear, because the benefit you get from the high energy flux density, is not measured in cost-benefit.

Tokuhiro: I know. I thought of some different things. A couple of the speakers today talked about nuclear energy and energy as a national security issue, quite a few times. When you talk about national security, and when you, for example, talk about going to Afghanistan or Iraq, you don't do that. We're not talking about cost-benefit there. So, if energy security is a national security issue, then you cannot bring cost-benefit analysis or dollar arguments into it.

21st Century: Yes, it's stupid. It's stupid with health care also. If you have a healthy population, then you get more brain power, more ideas, you can move forward. In this country, you probably have lived here long enough to know the

difference that has occurred, that we've been going backwards not forward in so many ways.

Tokuhiro: I was telling a friend who was sitting next to me, when your child is ill, and in the hospital, you don't do a cost-benefit analysis, you think about that later, about managing how to pay for that surgery.

21st Century: So many things are like that. You have to have a top-down view, look at the overall picture from the world perspective, where resources go, and what they should be used for.

I think a lot of this was to stop civilian nuclear power, because you can show that with nuclear power, you can support an increased population at a better living standard. We proved that years ago, with a study that showed, without any dispute, that the economic benefits to the whole society would be great. China knows that, India knows that. That's why they are going nuclear.

Tokuhiro: We started that, actually. President Eisenhower gave that Atoms for Peace speech in 1953, and many say, set the civilian nuclear energy in motion.

21st Century: And for a good reason! I think a certain faction has always been opposed to that idea. With many others, it's the social factor. They grew up with this, they're continuing to perpetuate it. But behind it is the ideological battle. There has been terrific opposition to giving the developing sector civilian nuclear power.

Tokuhiro: Right, so at this point, we're saying let's put this on the table, let's discuss it again.

21st Century: That's great.

Tokuhiro: So, along with this, what really is a "health effect" of radiation, and what is not a health effect? I think you have to agree on some of these things—positive benefits and negative effects.

21st Century: Edward Calabrese has written many articles on this… on the history, and the medical profession.

Tokuhiro: This is great. I have to look at that. I'm thankful that you brought it up. These are interesting topics. I'd love to read those kinds of papers.

21st Century: And you have students who could do some research.

Tokuhiro: Yes, these are some of the more interesting things. As an engineering professor, I mostly deal with the more nuts-and-bolts stuff. And I have the luxury of most of the time staying away from these issues that are "softer." We call them softer as engineers—but this is actually the biggest challenge when people get entrenched in a position, and it's hard to change that, when it doesn't have the proper scientific basis.

It's an issue that we face with many, many things. Climate change for example. You have science people making science.

21st Century: One of the issues I have with Professor Allison in his book, is that he premised the nuclear issue on global warming. And I think that's silly, because that's research that I've done myself, in terms of how global warming got started. In 1975, there was a meeting with Margaret Mead, a conference. All of the major global warmers were there, and they discussed on the basis of population control, how can we scare people into cutting back on their living standard.

They had tried global cooling, and it didn't catch on, and so they discussed this, and you can read some of the speeches, which were published, where Mead was actually coming out for inventing, just jimmying things so that you could scare people. And that's what happened. The people at this conference included Stephen Schneider, some of the other bigwigs.

Some of them are rabid—They were quoting Paul Ehrlich, who had written *The Population Bomb* a few years earlier. They were quoting Ehrlich, saying yes, we have to figure out ways to curb population. Americans are too consumerist, we have to cut back. This is 1975, and it took off from there. And like the LNT, they surround it with "science," but is it true? I don't think so.

Tokuhiro: Well, it's the reality of humanity that even science is a human activity, and people who have the ability—not necessarily to see the future—but they are smart enough to make a change that will have an impact on the future. So you see that in radiation, and as you said, you see it in climate change.

How to Construct an Astrolabe, Using Your PC

by Christine Craig

But considere wel, that I ne usurpe nat to have founde this werk of my labour or of myn engin. I nam but a lewd compilatour of the labour of olde Astrologiens, and have hit translated in myn English only for thy doctrine; & with this swerd shal I sleen envye.

—Chaucer,
Treatise on the Astrolabe ca. 1391

Figure 1
PTOLEMY WITH AN ARMILLARY SPHERE
This painting of Ptolemy with a armillary sphere model is by Joos van Ghent and Pedro Berruguete, ca. 1476.

Introduction to the Astrolabe

There is a tale, both apocryphal and scatological, that Claudius Ptolemy, the Alexandrian astronomer (ca. 90 A.D.-168 A.D.) whose ideas dominated astronomical thought for well over a millennium (Figure 1), got the idea for the planispheric astrolabe while riding a donkey. The armillary sphere he was carrying fell and was flattened by the donkey's hoof into a pile of fresh donkey dung. Upon inspecting the resulting impression, a candle ignited in his mind, leading to the creation of an astronomical instrument so useful, that it outlasted Ptolemaic astronomy itself.

Because the first preserved astrolabes are made of brass and dated since the time of Muhammad, and the first known treatise on the astrolabe was written well before Muhammad, it is unknown when and where the astrolabe was born—surely not full-grown and fully adorned, like Athena from the head of Zeus. Early astrolabes probably long predated the technology for accurately rendering the requisite lines and arcs onto brass. Paper, cloth, and wood were more likely the media for the first astrolabes.

The Muslims attribute the astrolabe to the Greeks, and certainly Greek geometry informed its development. As Greeks moved East, conquering and occupying areas such as Bactria, and areas in India during and after the reign of Alexander the Great, they took Greek culture and technology with them, and they maintained contact with the Mediterranean Greeks.

However, when the Romans conquered the Greeks during the Third Punic War, it seems as if a semi-permeable membrane were applied between the Eastern Greek areas such as Bactria, and the Roman strongholds to the West. Much Greek science, especially new developments, could not penetrate back into that area, but flowed freely into parts of India and much of Asia Minor and North Africa.

These new developments, as well as older knowledge destroyed in the West, became the heritage of the people who would fall under the influence of the Muslims. Whether because of Roman indifference or Greek reluctance, such discoveries as the planispheric astrolabe never penetrated back into the Roman Empire in the West, but had to await the Muslim conquest of Spain a thousand years later to be re-introduced into Europe.

Figure 2
PLANISPHERIC ASTROLABE
A planispheric astrolabe of Persian origin, ca. 1590, on display at the Putnam Gallery in the Harvard University Science Center.

During that millennium, the astrolabe and countless other treasures of Greek culture exclusively enriched the East. It was there that the planispheric astrolabe reached its maturity as an astronomical instrument (Figure 2).

An Analog Computer

The planispheric astrolabe is a two-dimensional analog computer for solving problems related to celestial movements: time, the seasons, and star positions. It is also an observing instrument; the back of the astrolabe is set up, among other things, to measure altitudes of stars and planets, including the daytime Sun. The astrolabe packs a lot of information into a very small space—even more than an adventurer's

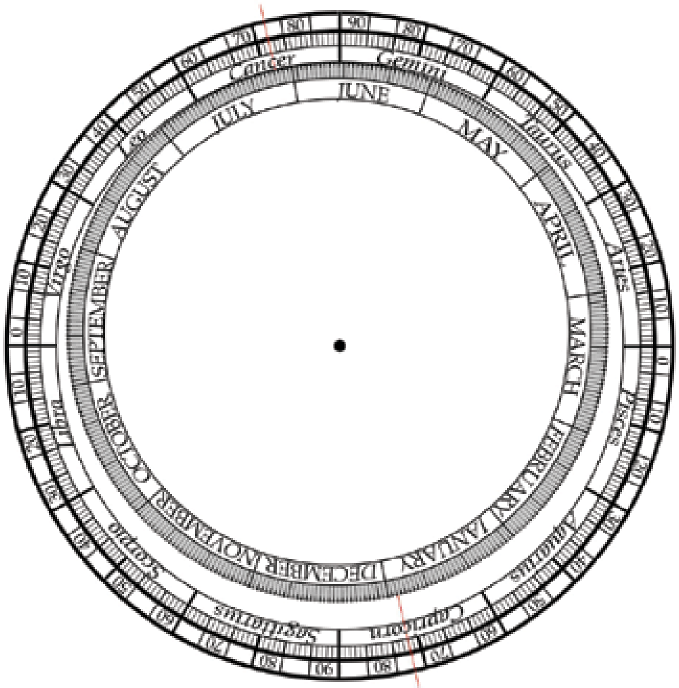


Figure 3
ASTROLABE MATER (BACK)

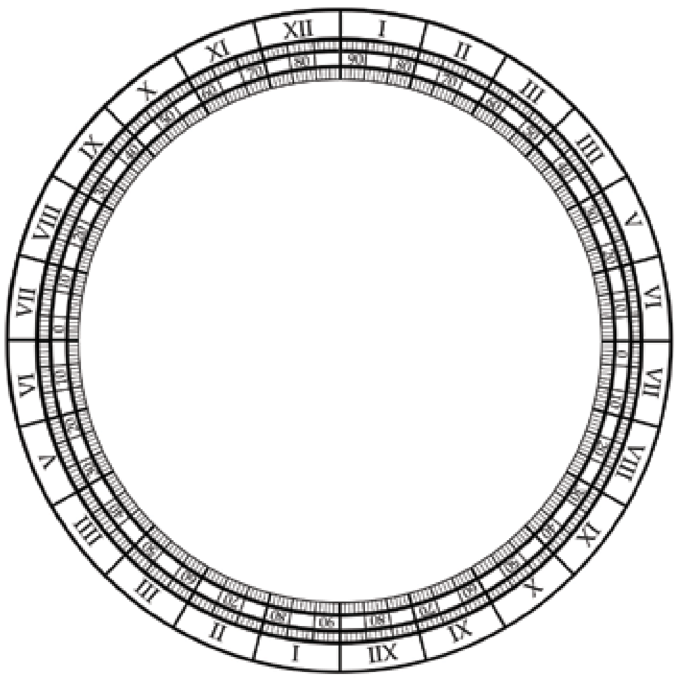


Figure 4
ASTROLABE MATER (FRONT)

wristwatch (although at least one manufacturer—Ulysse-Nardin—made a wristwatch in the 1980s that was a functional, automated astrolabe. You can buy one for only $27,500 online).

The planispheric astrolabe is really just a stereographic projection of all objects of interest on the Celestial Sphere (one like Ptolemy's armillary sphere, complete with ecliptic and useful stars) to a plane coincident with the Equator of the Celestial Sphere. (However, a glance at the work on the astrolabe of the 9th Century Persian astronomer al Farghani shows his plane tangent to the North Pole of the Celestial Sphere). The Equator of the Earth is understood to be coincident with that plane as well. The origin point for the projection is the South Pole of the Celestial Sphere, a convention convenient for those residing north of the Equator on Earth.

The stereographic projection was discovered by the ancient Greeks, and is usually attributed to Hipparchus (ca. 190 B.C.-120 B.C.), although Apollonius of Perga (ca. 262 B.C.-190 B.C.) could well have developed it. It is a useful way to map the heavens onto a flat surface while preserving both circles and angles between objects, as measured on the three-dimensional sphere.

The astrolabe is made up of several moving parts securely attached to the *mater,* which holds and protects the other parts, and also contains essential degree and time or other scales on the outer race or limb of both the front and back.

The back of the astrolabe mater contains degree, calendar, and zodiacal scales (Figure 3). Astrolabe makers often added many useful tables for solving astronomical, time, and trigonometric problems. The back also contains a movable pointer, the *alidade,* attached to the center, with sights for observing a celestial object to find its altitude.

To do this, one would hang the astrolabe on the thumb with the arm held above the eye. Ancient astrolabes contained rings attached to a top piece called the throne for hanging the device on the thumb. The altitude of the object in view could then be read from a scale along the limb of the back.

The front of the astrolabe mater (Figure 4) contains the limb with scales in degrees and hours, and a central circular cavity capable of holding several climate plates, overlain with a movable *rete* (pro-

Figure 5
AN ASTROLABE DISASSEMBLED
An 18th Century astrolabe from North Africa, showing its various parts. The axle and linchpin device are in the foreground.

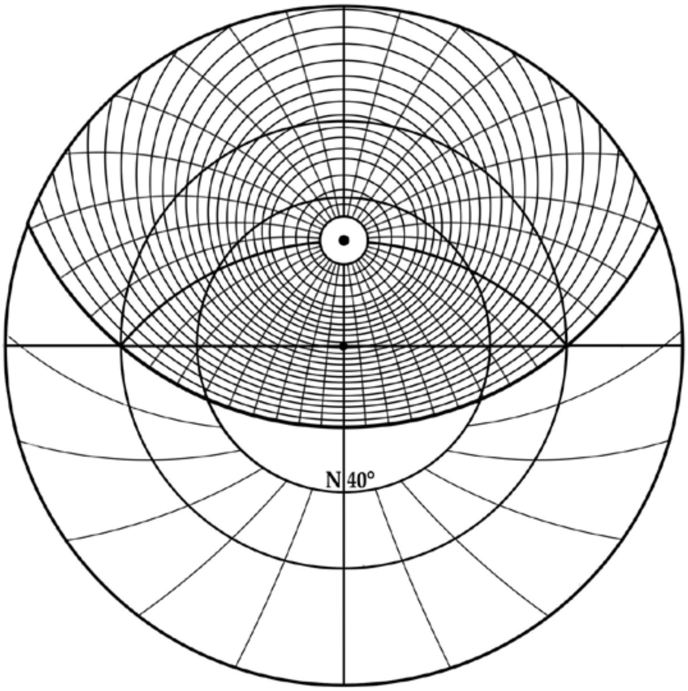


Figure 6
CLIMATE PLATE

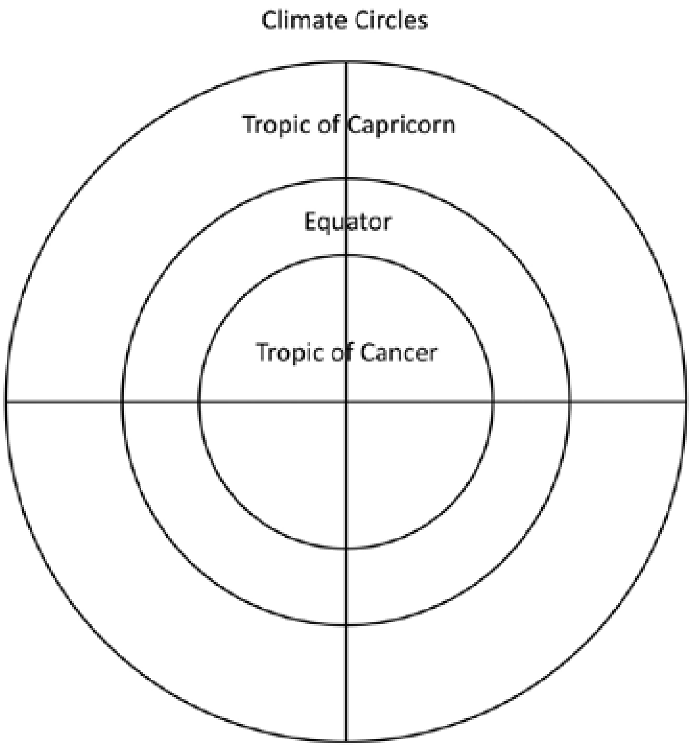


Figure 7
CLIMATE CIRCLES

nounced reetee), the ecliptic circle with useful stars located on it. Finally, there is a movable graduated pointer called a *rule,* for reading off declinations from the plate, or degrees or hours from the limb.

The whole device is held together with an axle and linchpin device (Figure 5).

Existing ancient astrolabes were made from durable engraved brass, but it stands to reason that most astrolabes were drawn on paper, wood, or similar materials, which were cheaper and more readily available. Unfortunately, those instruments did not survive the ravages of time and human events.

Your instrument will suffer the same fate, unless you plan to engrave or etch your astrolabe markings into brass. But luckily for you, you can preserve the templates for your astrolabe on your computer to be reprinted onto cardstock in the future, in case of the tragic demise of your present astrolabe.

Why Build an Astrolabe?

Almost everyone seems to have a PC these days, with Microsoft Office on it. Mostly it is used for e-mail and simple document production, and the expensive software just goes to waste. Constructing our astrolabe will push the limits of one of the applications of Microsoft Office that few people take seriously: PowerPoint. PowerPoint might just be the perfect vehicle to introduce people to the power and beauty of an ancient astronomical instrument with relevance even today: the planispheric astrolabe.

Using PowerPoint to construct an astrolabe is as close to constructing the astrolabe with straightedge, compass, and protractor as you can get on a computer. If you can do it with PowerPoint, you can do it on cardstock.

But PowerPoint has many advantages over pencil and paper in adjustability, erasability, and transferability of lines and circles. Further, the whole process, from beginning to end, can be saved on slides to illustrate your progress for posterity.

My aim is to convince people to learn more about astronomy and its history by constructing an astronomical instrument so useful that it may have predated, and certainly outlasted, the Ptolemaic astronomical system. Because the subject is a large one, this article will focus mainly on the construction of one important part of the astrolabe: the *climate plate*.

Elements of the Climate Plate

The heart of the mater is the climate, or latitude plate, which, as its names imply, is different for different latitudes of the Earth (Figure 6). The climate plate is a latitude-specific circular slide rule for calculating solutions to problems dealing with time, season, the Sun, the fixed stars, and even the planets and the Moon, given an ephemeris to locate the planets upon the plate for the time and date of interest.

The other parts of the astrolabe can be used anywhere, but the climate plate must be constructed specifically for the latitude of the observer. In the time of Claudius Ptolemy, the Earth was divided into Climates based on maximum hours of sunlight/darkness, with the Equator being XII, and the North Pole being XXIV. Six or seven climate plates would serve for the known Northern World of Ptolemy.

Nowadays, we measure Earth's latitude by degrees, with the Equator being 0 degrees, and the North Pole being 90 degrees. A reasonable compromise between accuracy and expediency would be a latitude plate for each 5 degrees of latitude where one expected to use the plate.

The climate plate is made up of several types of circles and arcs, which are necessary for its functionality as a measuring instrument. The three main types are the *climate circles,* the *almucantars,* and the *azimuth arcs*.

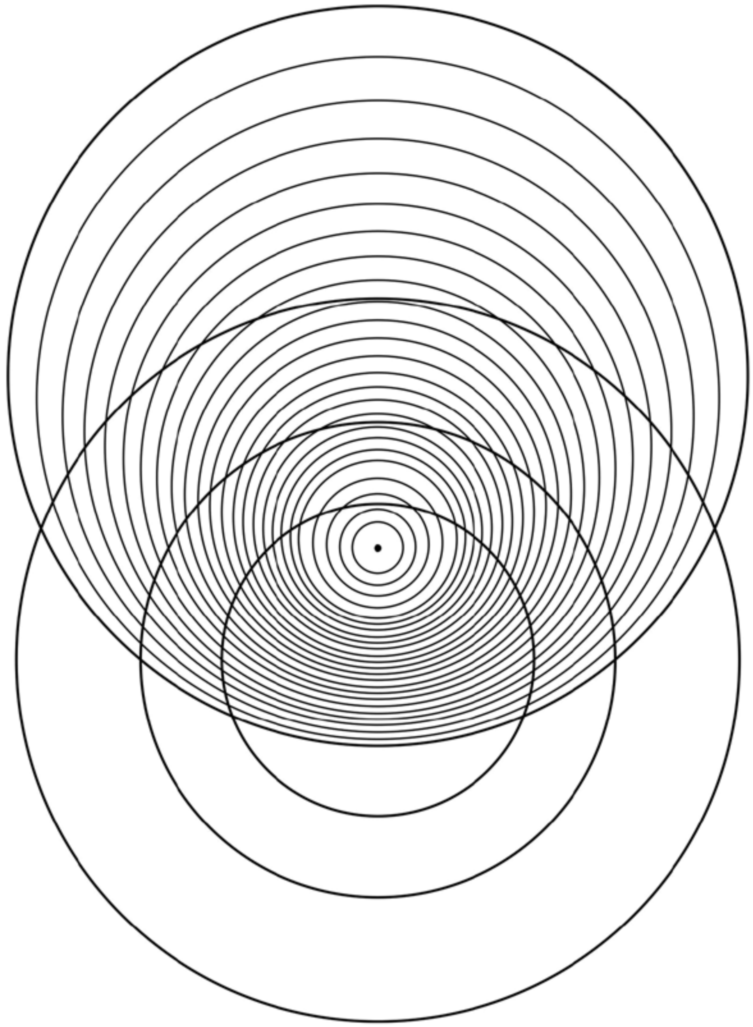


Figure 8
ALMUCANTARS

The climate circles (Figure 7) are circles representing the Tropic of Capricorn, the Equator, and the Tropic of Cancer, as viewed by stereographic projection from the South Celestial Pole. The Tropic of Capricorn is the largest circle, while the Tropic of Cancer is the smallest one. The North Pole would be represented by a point in the center of the three concentric circles.

The almucantars (Figure 8) are a series of nested but non-concentric circles radiating outward from the Zenith (a point at 90 degrees from the Horizon). They represent the altitude, in degrees, of objects of interest above the Horizon, which is the largest circle, at 0 degrees. The larger almucantar circles are cut off by the outer edge of the climate plate—the Tropic of Capricorn circle.

The North Pole is a hole at the center of the plate where the climate plate is attached to the mater, and would correspond to the latitude of your location on Earth.

The third major curves on the climate plate are called azimuth circles (Figure 9), although they are truncated into arcs by the edge of the plate. These arcs, intersecting at the Zenith, represent divisions of the climate plate into degree-segments from East through South through West, and back to East, with East and West designated as 0 degrees, and South and North designated as 90 degrees (this varied among astrolabe makers).

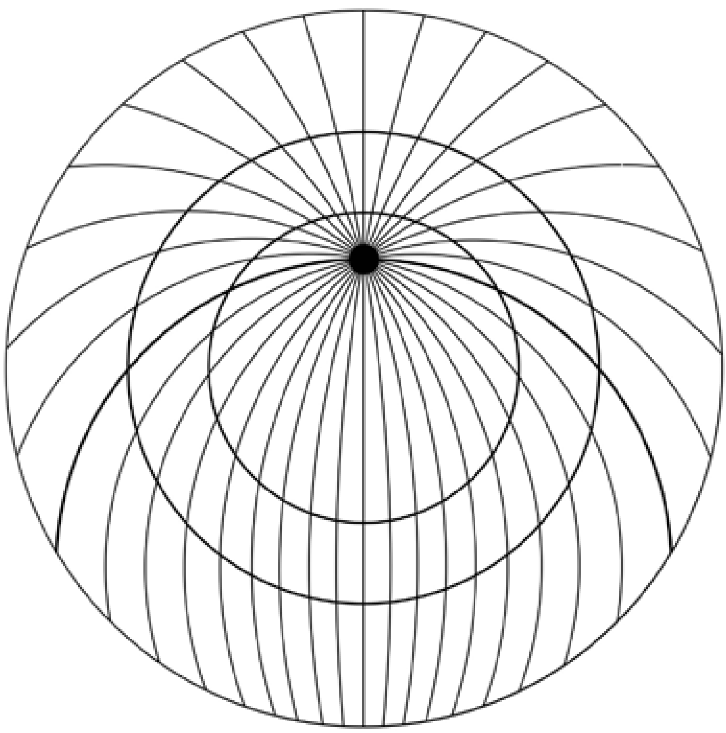


Figure 9
AZIMUTHS

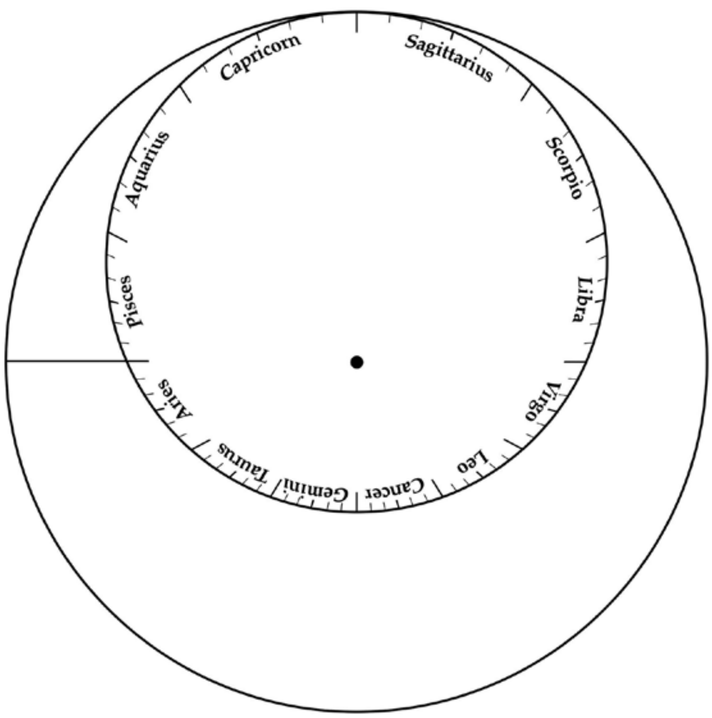


Figure 10
RETE

Building the Climate Plate

We shall now focus on constructing such a plate for 40 degrees North Latitude. Such a plate would be usable throughout a wide swath of the United States, including many of the largest cities, from San Francisco to the Oregon border, St. Louis up to Detroit, and Washington, D.C., up to Boston.

The first step in constructing the climate plate is to determine the size of the Equator circle, for that will determine the overall size of the plate. The radius of this circle will be used in calculating the sizes of the Tropic of Cancer radius and the Tropic of Capricorn radius. The limb of the mater, with its markings, must lie outside the Tropic of Capricorn circle. The Ecliptic circle of the rete will cycle eccentrically between the Tropics of Cancer and Capricorn circles in its diurnal and seasonal motions (Figure 10).

We will choose the radius of the Equator to be 2 inches for our purposes, giving us an overall dimension for the astrolabe of less than 7.5 inches.

Next we must draw this circle on a blank PowerPoint slide by selecting the **circle object,** clicking it onto the slide, and right-clicking on it to bring up the menu to **Format Shape.** Choose size as 4 (diameter), after checking the **Lock** aspect ratio box. Choose the **Fill** as clear. **No Shadow. Line color** and **thickness** of your choice. **Center** the circle in the center of the slide. Select a **line object** from the **Object Palette.** Click it onto the slide at the center of the circle, and draw it out to the edges of the slide horizontally, bisecting the circle.

You may do the same with a **vertical line.** You now have a cross section of the Celestial Sphere, with the North/South axis and the Equatorial axis displayed. If you wish, you may color the two lines to differentiate them from new lines you will draw on your working slide.

Now duplicate that slide using the **Insert menu/Duplicate Slide.** I note here that it is important to continually duplicate slides to preserve parts of your work while you are constructing your climate plate. Select a **line object** from the **Object Palette.** Click it onto the first slide at the center of the circle, and draw it out to the circumference on the right-hand horizontal radius of the circle.

Next, copy and paste that line onto the same slide to give you a second line to

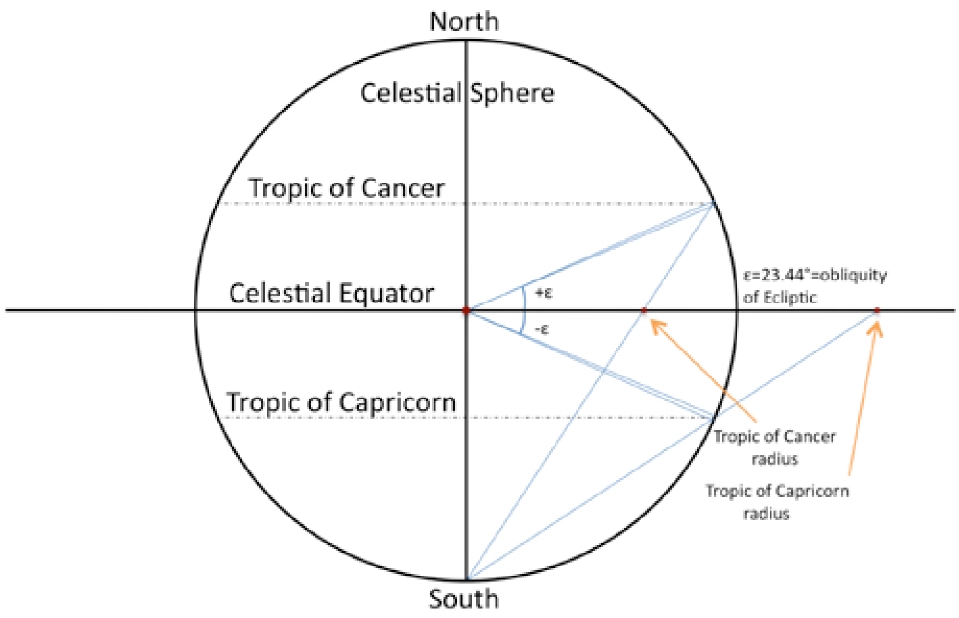


Figure 11
CLIMATE CIRCLE PROJECTION

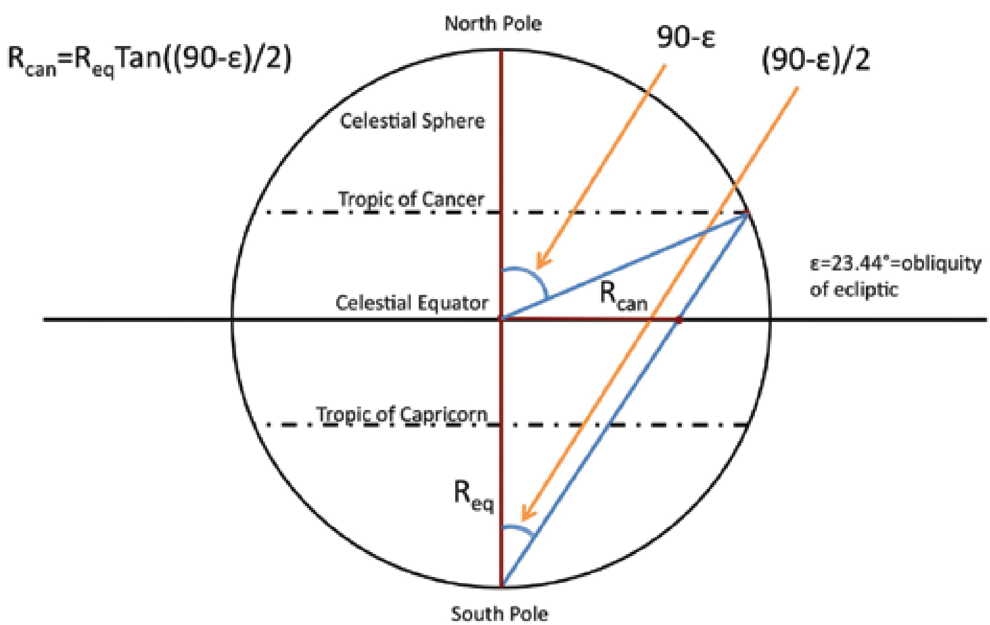


Figure 12
CONSTRUCTING THE CANCER CIRCLE

work with. Now right-click that second line to bring up **Format Shape,** and go to the **Size** submenu. Add the present angle for the obliquity of the Ecliptic to the existing angle in the **Angle** field, and move it so it extends from the center to the circumference.

Then, using the first horizontal line, again copy and paste the line, and next subtract the angle of the obliquity of the Ecliptic from whatever angle is in the Angle field. Move that line so it extends from the center to the circumference.

Because the present angle of the obliquity is about 23.44 degrees, and PowerPoint accepts only integer angles, you are left with the contrivance of producing thin lines at 23 degrees, 24 degrees, and minus 23 and 24 degrees, then splitting the difference at high Zoom in the next operation. Once you have the angles of the obliquity marked on the circumference above and below the Equator, select a **new line,** click it onto the South Pole point, and draw it up to the Tropic of Cancer point.

Take another line and draw it from the South Pole, through the Tropic of Capricorn point, and onto the Equator line. Where each of these lines intersects the Equator line, marks the length of the radius of each circle from the center. To find the length of those radii, you can extend a line to each point from the center, and find the length in the **Size** field. Multiply by 2 to get the diameter of each circle.

Now **select and format** circles of those sizes from the **Object Palette,** and center them concentric with the Equator circle on your duplicate slide (Figure 11). Alternatively, you can figure out the two tropic circles more precisely using trigonometric ratios: Rcan=ReqTan((90– ϵ)/2) (Figure 12) and Rcap=ReqTan((90+ ϵ)/2) (Figure 13). Multiply by 2 to get the diameters and place them around the equator circle in the duplicated slide.

Construction of the Almucantar Circles

The next step is to draw the almucantar (altitude) circles. All of this can be done on the same slide, but it would get in-

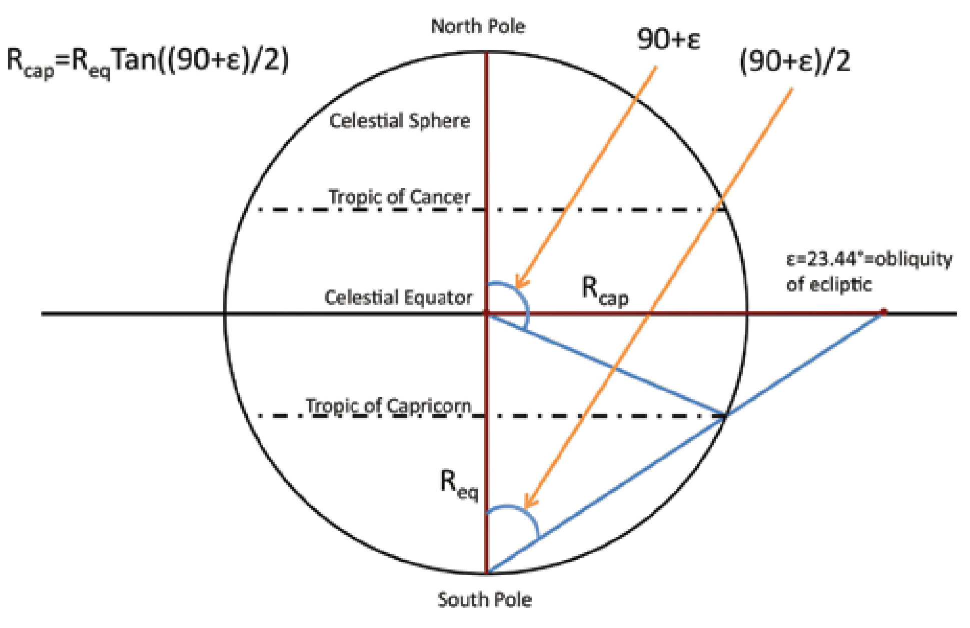


Figure 13
CONSTRUCTING THE CAPRICORN CIRCLE

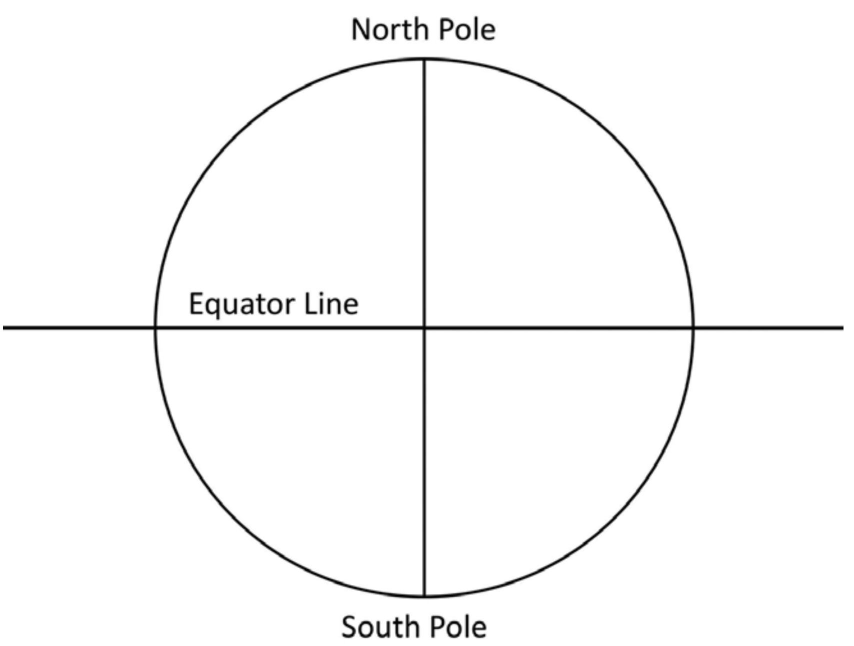


Figure 14
NORTH-SOUTH-EQUATOR CROSSHAIRS

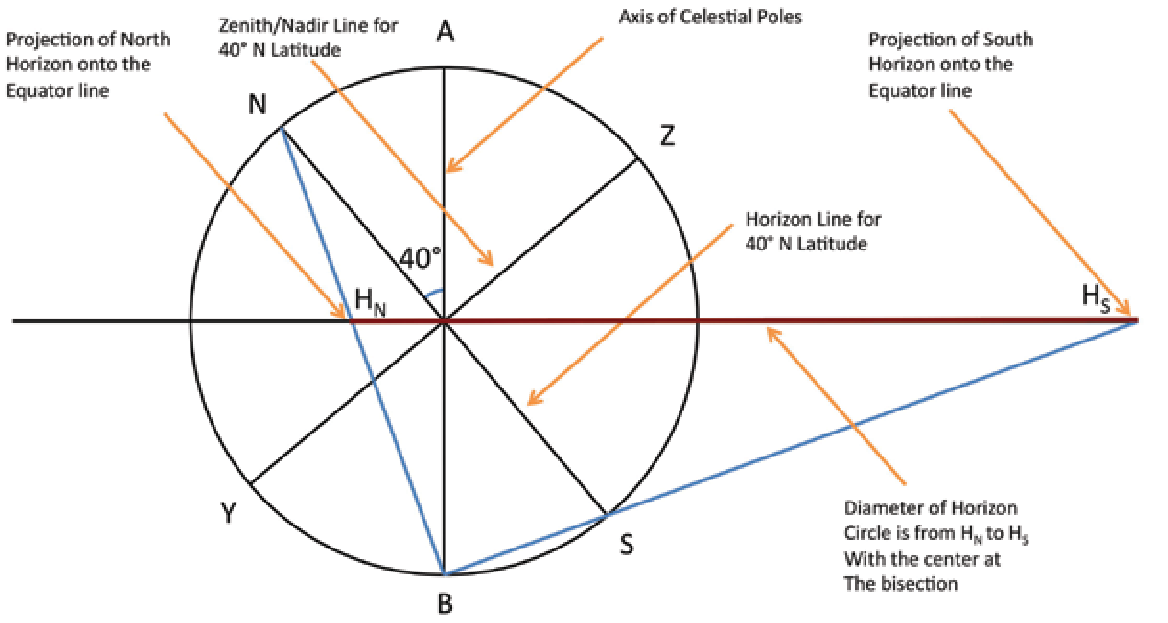


Figure 15
CONSTRUCTING THE HORIZON CIRCLE

credibly cluttered and hard to place the lines. Also, some of the almucantar circles, especially the Horizon circle, are very large, so it is best to create a new slide using the same-size circle as the Equator circle, but moving it to the left of center by 2.5 inches.

Divide the circle vertically and horizontally by selecting line objects and clicking them into place (as in Figure 14). The vertical diameter represents the North/South Poles of the Celestial Sphere. The horizontal line should be extended to the limits of the slide. It is a cross section of the plane of projection at the Equator of the Celestial Sphere. It also represents the Meridian of the astrolabe under construction, with South to the right and North on the projection point of the Celestial North Pole (at the circle's origin). Create a duplicate slide at this point.

Now **paste** a new line from the origin of the circle to the top, on top of the vertical diameter line. **Copy and paste** that line onto the slide so you have two working lines to use next. Right click the newly pasted vertical line and go to the **Size** window. Whatever the angle says for the vertical line, add 40 degrees to it and enter that in the rotation field.

Move your line to the origin so that it is a radius pointing 40 degrees to the left of vertical, and extend it to the circle circumference in both directions, making sure it passes through the center. This line is your Horizon line for a latitude of 40 degrees. The Celestial North Pole is 40 degrees clockwise from the North Horizon.

Now **copy and paste** your original vertical line again, this time subtracting 50 degrees from it. Put it at the origin, and extend it to the circle circumference in both directions, making sure it passes through the center. This line is the Zenith/Nadir line. It is 90 degrees from the North Horizon.

Select a new line from the **Object Palette** and click it onto the South Pole of the Celestial Sphere. Extend it to the North Horizon point on the circle circumference. Where this line meets the Equator line is the projection of the North Horizon point onto the astrolabe plate.

Repeat, by extending lines to the South Horizon point, the Zenith point, and the North Pole point (projected to the origin of the circle). **Mark** the projection points for the Zenith and North Pole with tiny colored circles. The distance from the North Horizon projection point to the South Horizon projection point (Figure 15) gives the diameter and location of the Horizon circle to be created on the climate plate.

Create a circle of this diameter just like the earlier circles, and position it so that the North and South Horizon projection points are on the circumference of the circle—if you were using compass and straightedge, you would bisect the line between the projection points, and use the compass to draw the circle (Figure 16). Now, **select** that circle and **copy and paste** it onto your duplicate slide.

You may alternatively figure out your Horizon circle diameter using trigonometric ratios (Figure 17).

The rest of the almucantar circles can be constructed the same way (see Figure 18), by finding the angles for each altitude up to 90 degrees (the Zenith), projecting from the South Celestial Pole to get the north and south diameter points for the necessary circle, and placing the circle on the slide. The construction, moved to the climate circles, and including the Horizon circle and the almucantar circle for 50 degrees, is shown in Figure 19.

Note that while the 50-degree circle will be a circle in the final plate, the Ho-

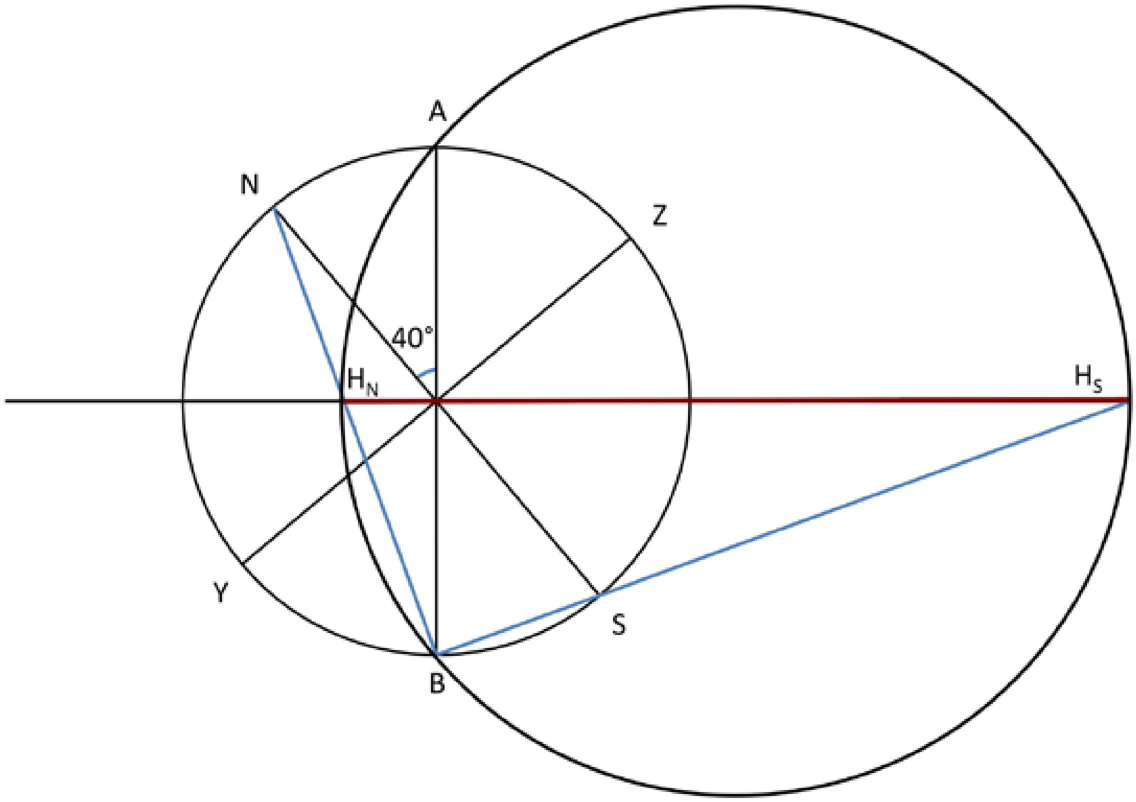


Figure 16
THE CONSTRUCTED HORIZON CIRCLE

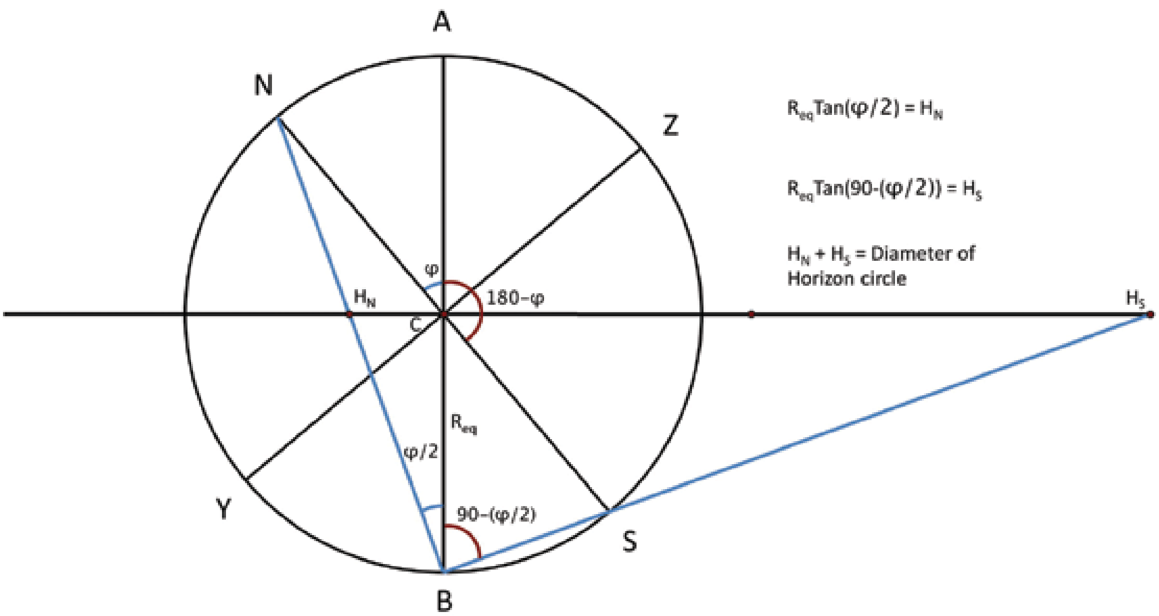


Figure 17
THE TRIGONOMETRY OF THE HORIZON CIRCLE

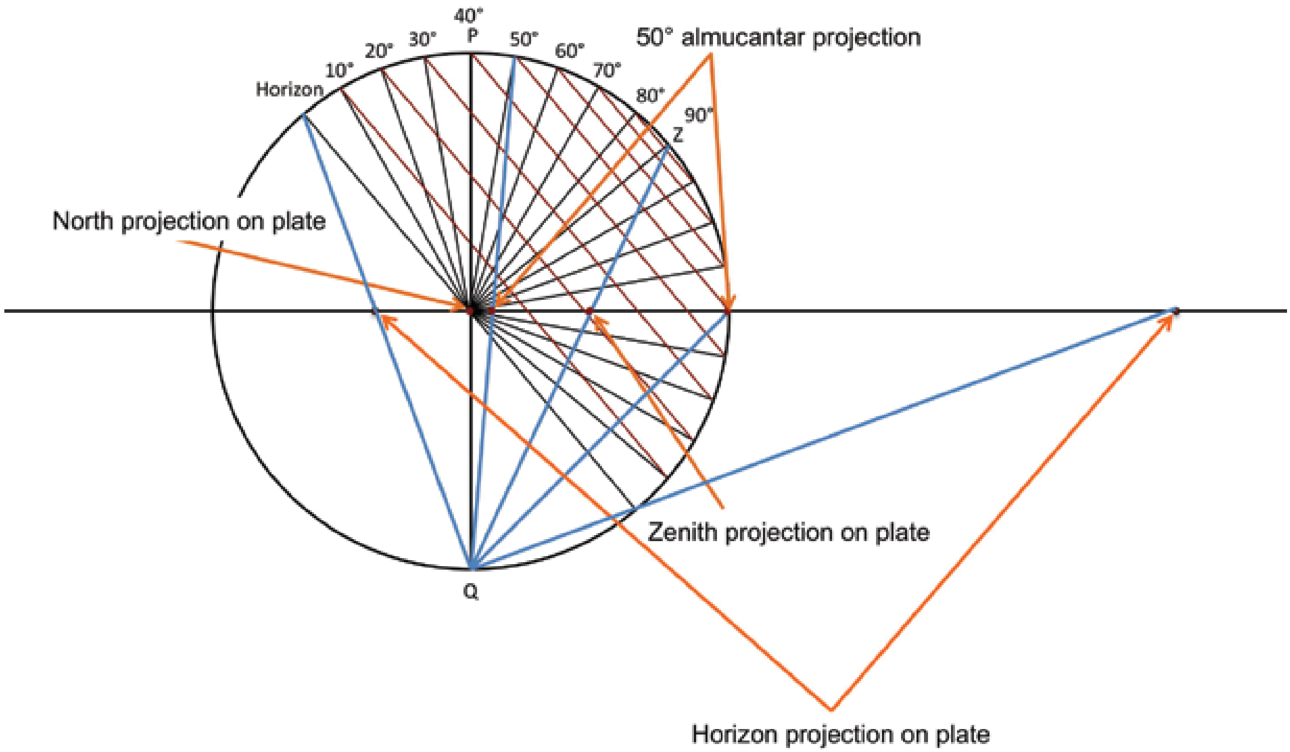


Figure 18
ALMUCANTAR PROJECTIONS

rizon circle will be an arc cut off by the Tropic of Capricorn circle. Figure 20 shows all of the almucantar circles in 3-degree intervals from 0 degrees to 60 degrees, and in 5-degree intervals from 60 degrees to 80 degrees.

The 50-degree circle from the previous slide is superimposed in red to illustrate where it falls on the plate. You will find it valuable to **Zoom** in and out during the construction of the almucantar circles.

Constructing the Azimuth Circles

After constructing the almucantar circles, the next phase is to construct the azimuth circles. If the almucantar circles are viewed as dividing the heavens up into equal altitude zones from the Horizon to the Zenith, the azimuth circles divide the heavens from Zenith to Nadir into equal angle zones from East through South to West to North, then back to the East, like the segments of an orange. When projected onto the climate plate, each azimuth circle has both the Zenith and the Nadir as points on its circumference, but each has a different origin ranged out on a line which is the perpendicular bisector of the line connecting the projection points of the Zenith and Nadir.

If you create a circle connecting the Zenith and Nadir projection points as a diameter, the perpendicular diameter of that circle would be the line of circle centers for the azimuth circle projections (Figure 21). That circle symmetric about the Meridian line is called Prime Vertical (Figure 22).

To find the other azimuth circles, we must find their center points along the line of centers. A line drawn from each center to the Zenith or Nadir projection point will define that circles radius. Doubling that radius will give us the diameters for the circles we need. To find the centers of the circles, we must measure angles from the Zenith to the line of centers equal to the angles of the azimuths we wish to draw.

If we wish to have azimuth circles for each 10 degrees, then lines with these angles must intersect the line of centers on both sides of the Meridian for each 10 degrees. The intersections define the azimuth circle centers, and the lines define the azimuth radii. Prime Vertical is the special case of a 0-degree angle. The other special case is the 90-degree angle, which is an infinitely large circle indistinguishable from the Meridian itself.

Because the azimuth circles become very large along the line of centers, we will align that line of centers left to right on the slide upon a copy of the three climate circles centered on the slide. Don't forget to **Zoom** liberally. As with the almucantar circles, we start with a centered circle of diameter 4. **Select** a line with the qualities desired, **copy and paste** that line to have a working copy, and use that line to create the angles we need.

Figure 23 gives the Prime Vertical circle and the two 40-degree azimuth circles. The slide had to be reduced to 75 percent to fit the 40-degree circles into

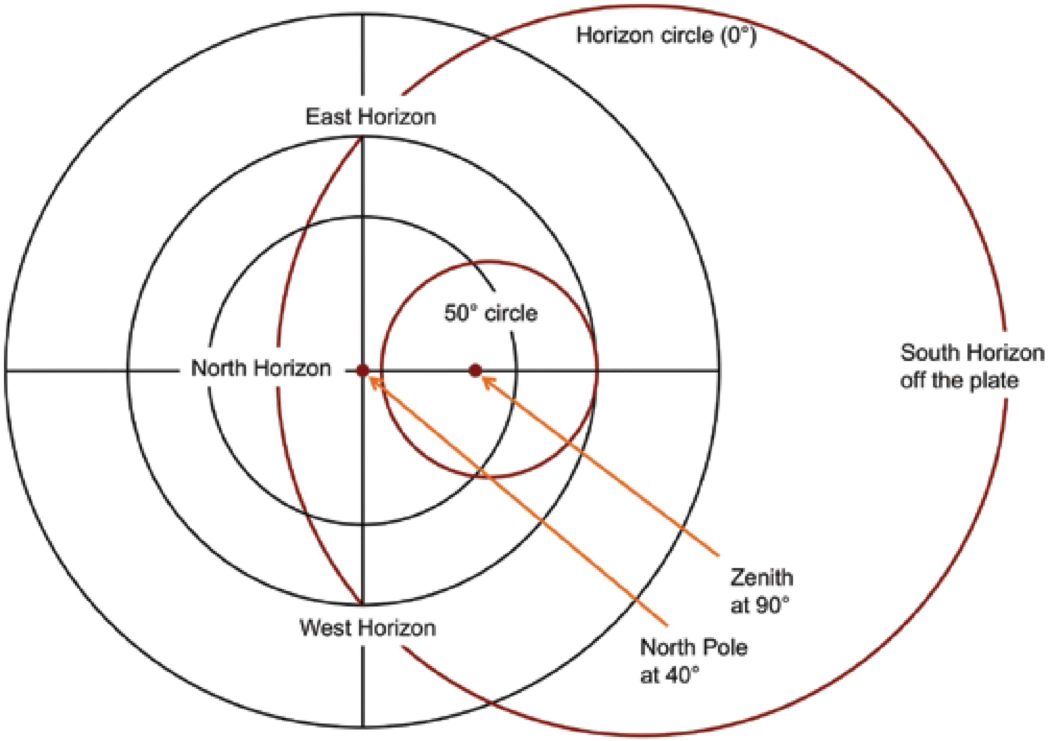


Figure 19
ALMUCANTAR RELATIONSHIPS

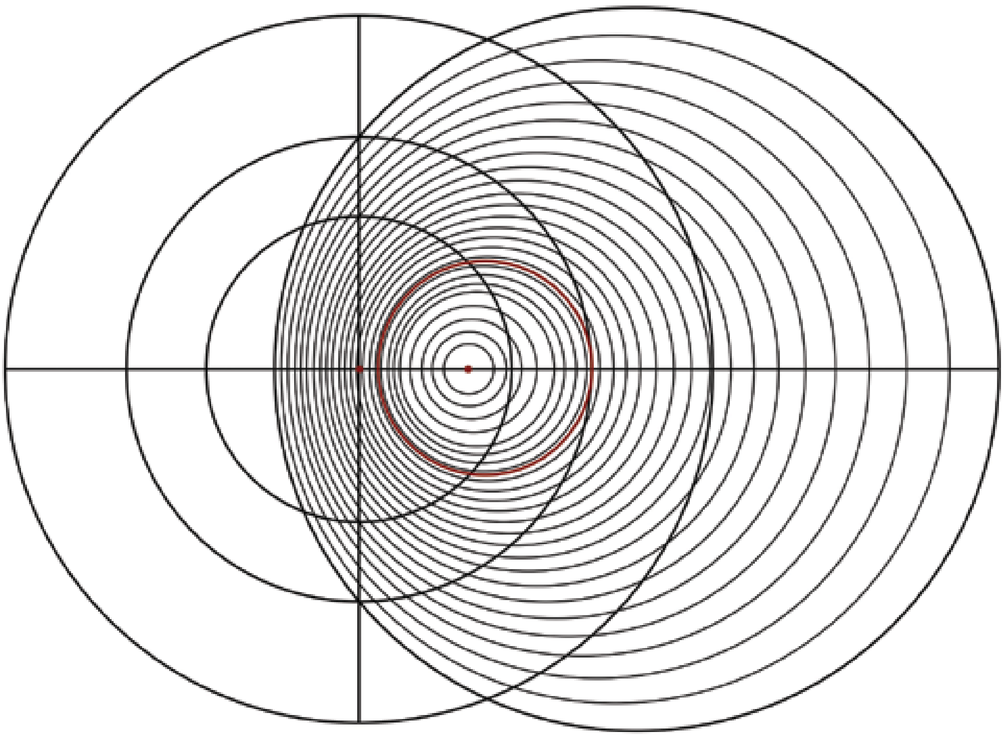


Figure 20
ALL ALMUCANTARS

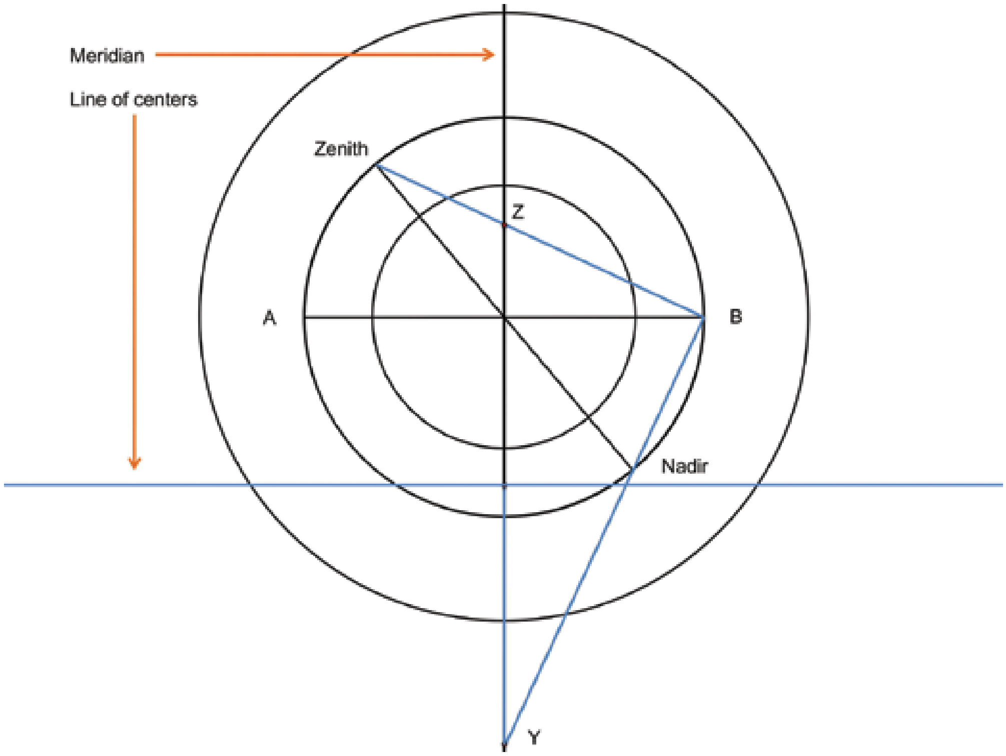


Figure 21
AZIMUTH LINE OF CENTERS

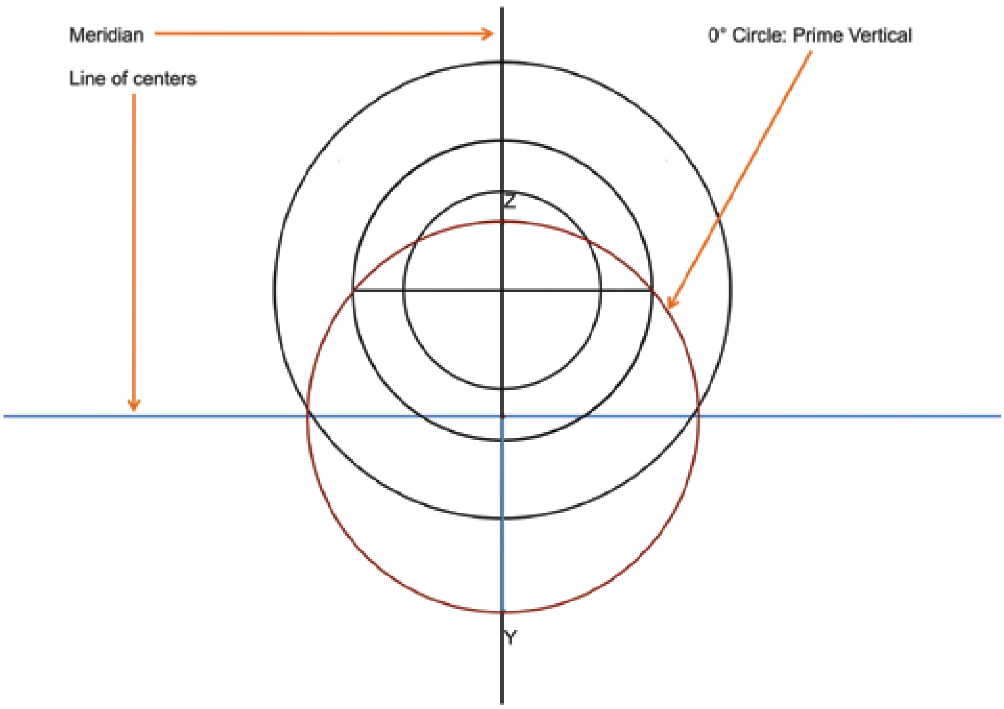


Figure 22
AZIMUTH PRIME VERTICAL

the figure. Figure 24 shows all the circles in place, and Figure 25 shows them highly reduced to fit on the slide.

The azimuth circles as seen on the final astrolabe climate plate are only arcs, since they are only expressed above the Horizon circle and are bounded, as are the almucantar circles, by the Tropic of Capricorn. As with the almucantar circles, a **ring object** will be later be used to block out those parts of the circles outside the desired bounds.

Assembling the Parts

Now that we have created the climate circles, the almucantars, and the azimuth circles, we have all the major elements necessary for the climate plate. The next step is to assemble them together. If you built your almucantars upon your climate circle slide, they are already assembled.

If you used a new circle of diameter 4 inches, you must add the Tropic of Cancer and Tropic of Capricorn circles to your almucantar slide, concentric with your Equator circle. These circles, and their horizontal and vertical diameter lines, must be right-clicked after selecting, to bring up the menu. Then choose **Arrange,** and **Bring to Front** for each of them.

Once you have your almucantars on your climate circles, you need to group all of the elements, then rotate the group 90 degrees counter-clockwise. To finish off the construction, you must put an opaque **white ring** around the Horizon circle to remove the azimuth lines from the area below it, since they are needed only above the horizon.

Select **Donut** from the **objects** and size it so the inside ring just fits around the Horizon circle. The ring fill should be opaque white to match the background (Figure 26). This group will now be copied and pasted onto your azimuth circle slide, making sure that the 4-diameter circles coincide.

Now, go to the **Object Palette** and select the **Donut** object. Click it onto your slide, **format** it to

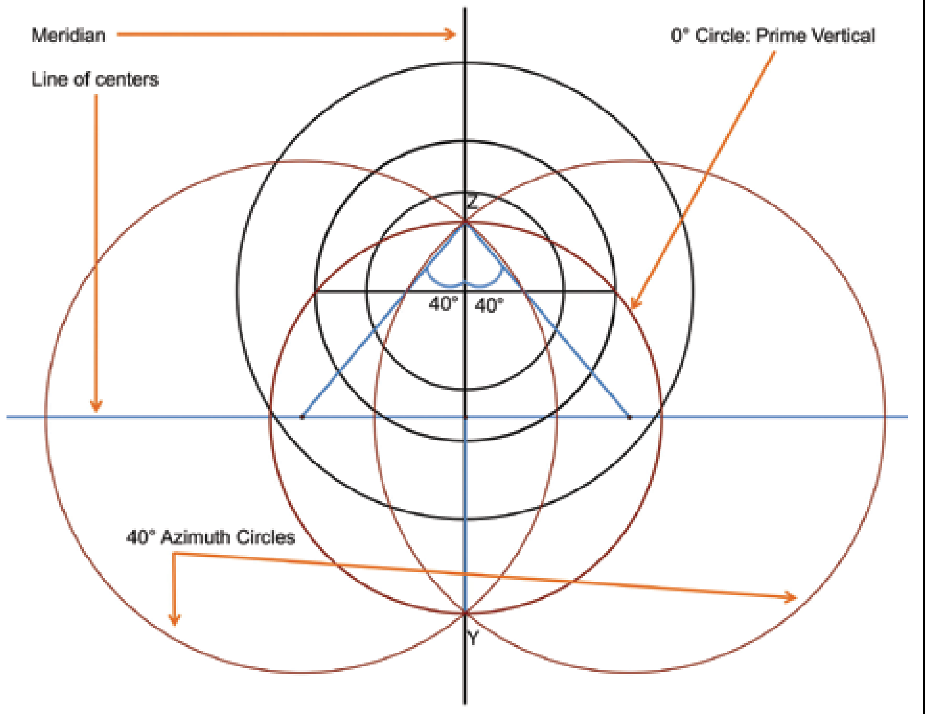


Figure 23
AZIMUTH 40-DEGREE CIRCLES

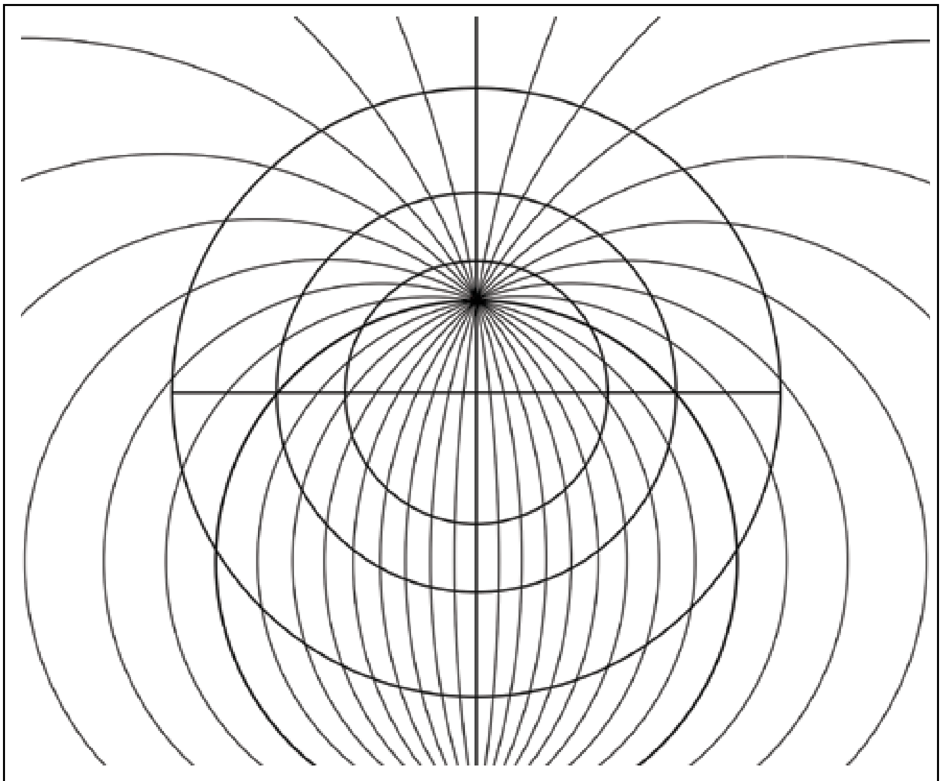


Figure 24
ALL AZIMUTHS

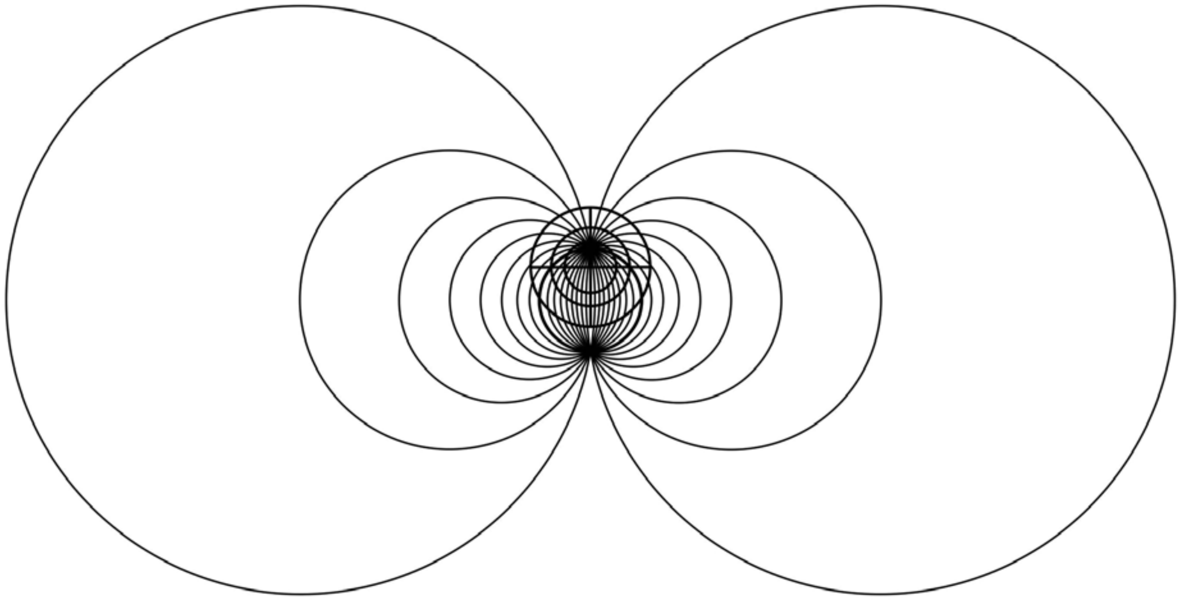


Figure 25
AZIMUTHS VIEWED IN THE SMALL

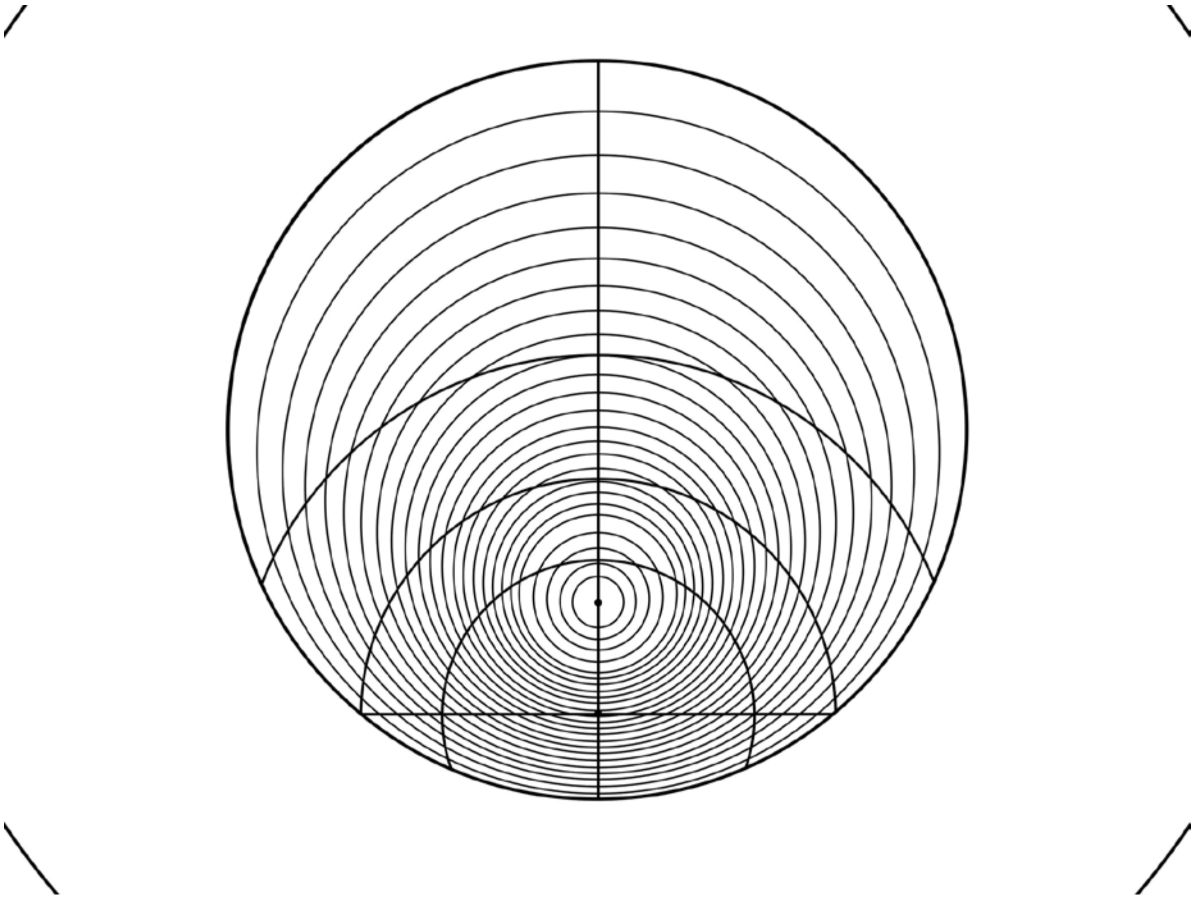


Figure 26
AZIMUTHS WITH RING FILL

white, no shadow, with lines to match your other lines, and set the diameter to 12. Center it on your circles. Next, click the **yellow box,** and drag it so the inner edge of the ring coincides with the Tropic of Capricorn circle. Small position adjustments can be made using the **keyboard arrows** to nudge the shape.

All lines outside of the Tropic of Capricorn circle have now been covered by your ring fill .

Because the three climate circles with their vertical diameters do need to be seen below the Horizon circle, they must be selected and brought to the front by right-clicking each circle, clicking **Arrange,** and then clicking **Bring to Front.** The horizontal diameter may be included or left off the plate. One more, a **tiny ring** will be used to fill the space between the 80-degree almucantar circle and the Zenith point at 90 degrees (Figure 27).

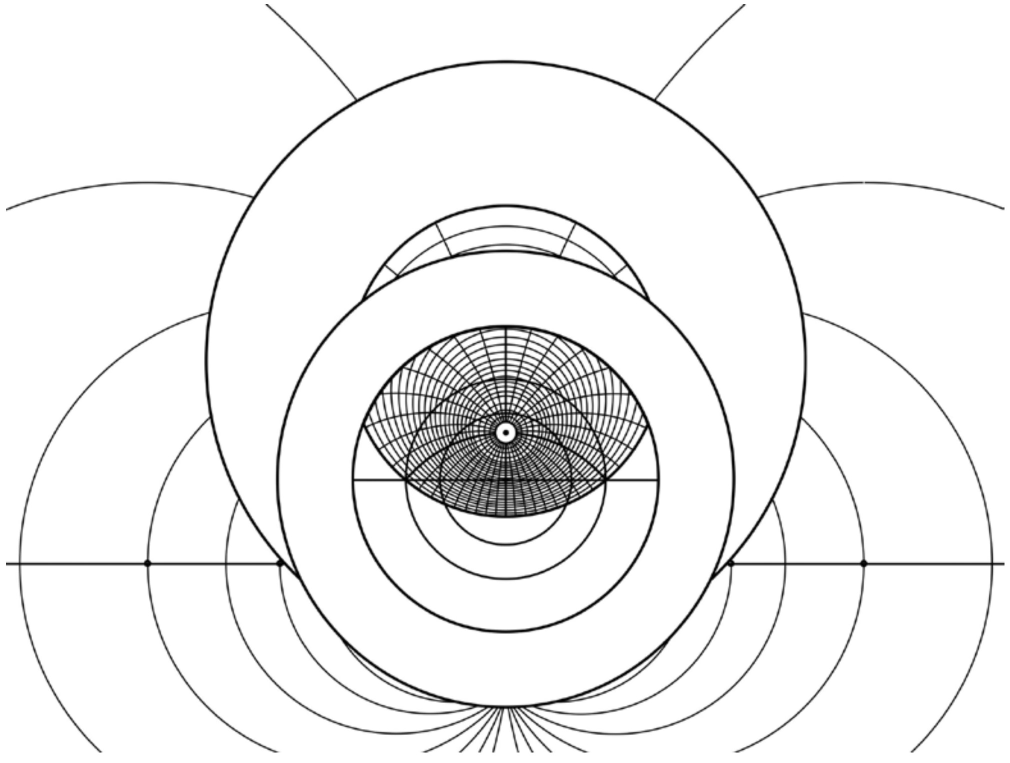


Figure 27
ANOTHER RING FILL ADDED

Figure 28 shows the cropped climate plate, ready to be labeled.

Labeling the Climate Plate

How you label your climate plate is to a large degree a matter of choice. Too much labeling gets cluttered, while too little can lead to extra work while using the astrolabe. The almucantar circles are labeled from 0 degrees at the Horizon circle, to 80 degrees near the Zenith. The plate used as an example, has almucantars every 3 degrees to 60 degrees, then every 5 degrees to 80 degrees. In that case, labeling every 12 degrees to 60 degrees, and every 10 degrees to 80 degrees would work.

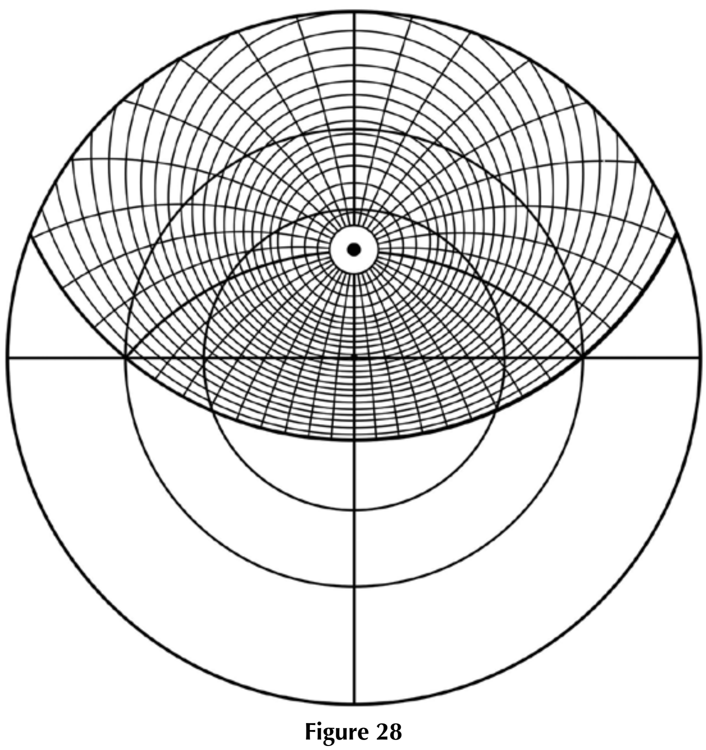


Figure 28
CROPPED CLIMATE PLATE BEFORE LABELING

The azimuths are labeled 0 degrees west where the Horizon circle meets the Equator circle on the right of your climate plate. On the left, it is labeled 0 degrees east. Where the Horizon circle meets the vertical line passing through the center of the plate, is labeled 90 degrees north.

South, of course, is off the top of the

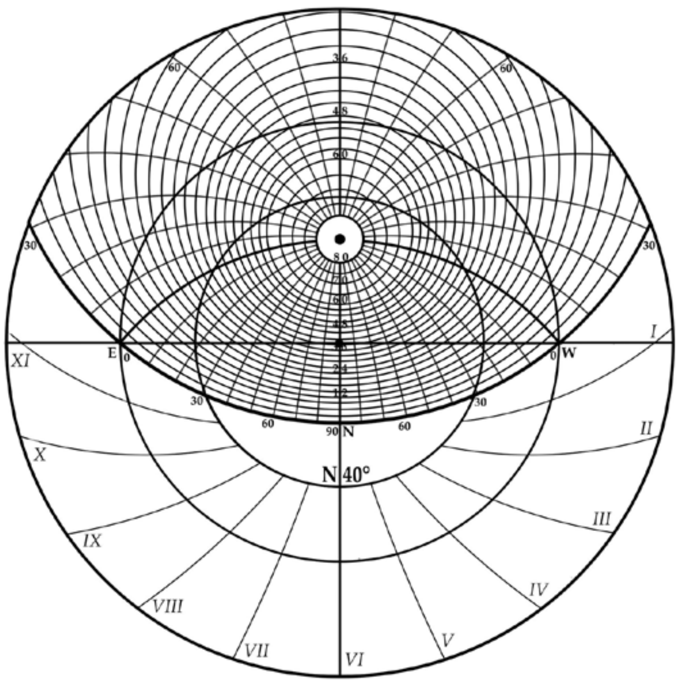


Figure 29
CLIMATE PLATE LABELED

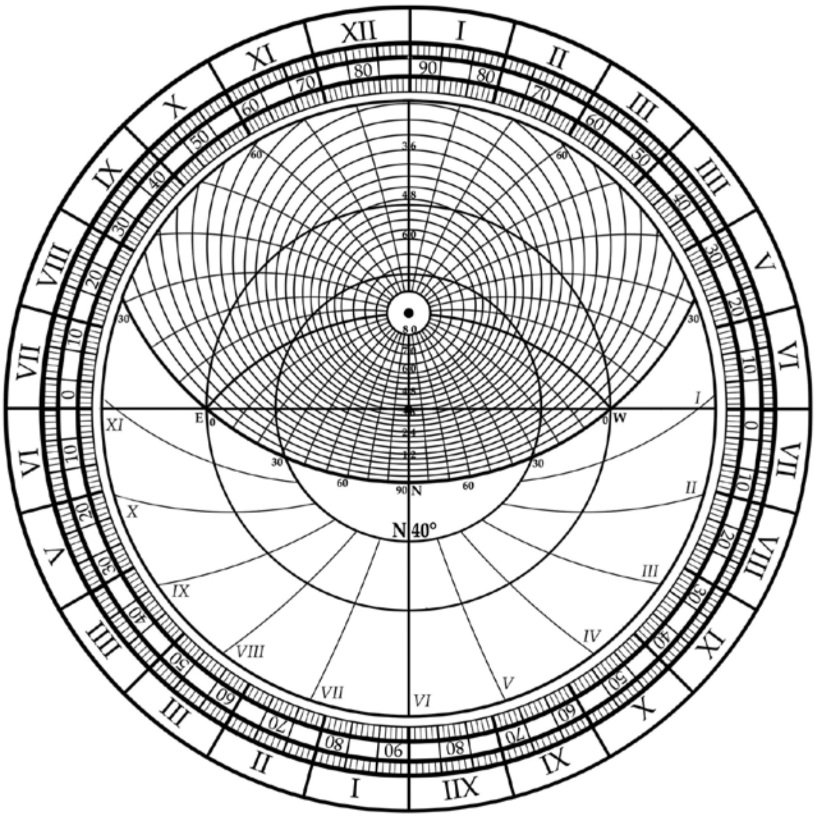


Figure 30
MATER AND CLIMATE PLATE COMBINED

plate, but the top of the plate is 90 degrees in the south direction. Figure 29 shows the climate plate labeled. Since I have seasonal hours on my plate, I labeled them clockwise from I to XI (see below). Figure 30 shows the climate plate placed onto the front of the mater I created in PowerPoint.

Seasonal Hours

Ancient climate plates had other arcs on them as well. Often they had seasonal hour arcs filling the mostly empty area under the Horizon circle. These divided the day or night into 12 equal parts, whose hour-lengths depended on the season. Rather than have more hours of daylight in the Summer, there were just 12 longer hours of daylight.

Conversely, the 12 hours of night would each be shorter by a proportional amount. These lines are often called unequal hour lines, but a better name might be proportional hours, since each hour occupies a proportional 12th of the day or night. Ancient astrolabes also often had inscribed on them arcs representing the 12 houses of heaven useful to astrologers.

Figure 29 shows an astrolabe climate plate with the seasonal hours marked in. If you were to take a series of circles representing latitudes between the Tropics of Cancer and Capricorn, all cut off by the sweep of the arc of the Horizon circle, and divide each of those many circles into 12 equal parts below the Horizon circle (the Equator would be 180 degrees divided by 12, which is 15 degrees each), a set of smooth arcs connecting the divisions from the Tropic of Capricorn to the Tropic of Cancer would represent the 12 seasonal hours.

In practice, this can be accomplished very closely by just dividing the three climate circles of the astrolabe plate into their 12 equal segments, then finding circles that contain each set of 3 points on the circumferences. That works fine for compass and straightedge (and a good eraser), but for PowerPoint, it leaves a set of arcs above the climate circle, which cannot be removed by the ring maneuver used earlier.

One can, however, use the curve line to trace over the arcs of the seasonal hour circles from the tropic of Capricorn to the Tropic of Cancer. You do this by **selecting** the **curve line** and clicking it at the Tropic of Capricorn.

Move a little smoothly along the hour

Figure 31
THE ALMOST-COMPLETED ASTROLABE
The photos illustrate a simple astrolabe in the finishing stages of construction. The mater front with climate plate, and the mater back, were printed onto cardstock and glued to a sturdy cardboard circle. The rete (as yet without stars and constellations), was printed onto acetate. The front rule (as yet without declination hatches), and the back alidade were cut from container plastic; cardstock was glued on top. Holes were carefully made in all the parts to receive the bolt and nut.

At the top of the instrument, another hole was made to receive a bolt from which to hang a lanyard. A thumb can be inserted therein so the astrolabe can be held at arms length to sight stars and planets. Once the front rule has been marked with declination hatches, it can be used in conjunction with the astrolabe and an ephemeris to mark prominent stars/constellations onto the rete, if desired.

line and click. Repeat that action until you reach the tropic of Cancer. Then **double click** to **release** the line. A smooth curve should appear. Format the curve to your specifications and move on to the next arc. After you have created your seasonal hours, you can simply erase the circles you used as templates.

You've Made Your Climate Plate. Now What?

Now that you have created your climate plate for the astrolabe, you will no doubt wish to use it. That, of course, requires creating the mater front limb scales, the rete (with useful stars), as well as at least a simplified mater back with scales. You will also need to make a rule for the front and an alidade for the back.

These things can all be created on the computer, and almost all can be created using PowerPoint, using techniques similar to those you have already used to design the climate plate.

You are also most likely itching to know how to use this device to solve medieval problems related to time, season, the Sun, and the fixed stars. Luck is with you. There are several good websites focussing on the astrolabe, but the best I have found is "The Astrolabe." This is a very useful site, where there is a wealth of resources related to the astrolabe.

One very fun part of the site presents the Electric Astrolabe (one running on computer code of the DOS variety). This is a very instructional program for people running Windows XP or below. For other operating systems, a DOS emulator, called DOSBox must be used. With the Electric Astrolabe, you can easily find out where the planets will be at chosen times in the past or future, just by entering your date and location. It is a wonderful tool for learning how the astrolabe works. I highly recommend that you try out this program.

The person who created this site, James E. Morrison (Janus), has recently published a book about the astrolabe, which is well worth the money. This book, *The Astrolabe* (Classical Science Press), is very complete, giving the history, the astronomy, the trigonometry, how to use it, and even how to construct one.

Another resource I have found very valuable is the book, *The History & Practice of Ancient Astronomy,* by James Evans (Oxford University Press). Although only a small portion of the book deals with the astrolabe, per se, you can learn a lot about the ancient astronomy that informed the development of the astrolabe. The first astrolabe I built was from instructions and templates in his book.

Finally, if you really wish to know how the astrolabe was used in medieval times, treat yourself to reading Chaucer's *Treatise on the Astrolabe,* written around 1391 to his sone Lowis, a 10-year-old.

EVIDENCE FOR A TRIASSIC KRAKEN

Unusual Arrangement of Bones at Ichthyosaur State Park in Nevada

by Mark A. S. McMenamin

Did a giant kraken drag nine huge ichthyosaurs back to its lair in the Triassic era, where their fossil remains are found today? The author of this hypothesis tells why he thinks so.

Courtesy of Mark McMenamin

Shonisaurus *ichthyosaur vertebral disks at the Berlin-Ichthyosaur State Park in Nevada, arranged in curious linear patterns with almost geometric regularity. The arranged vertebrae in this Specimen-U resemble the pattern of sucker discs on a cephalopod tentacle, with each vertebra strongly resembling a coleoid sucker.*

The Triassic Kraken hypothesis, presented to the Geological Society of America at its October annual meeting in Minneapolis (McMenamin and McMenamin 2011), generated an enormous amount of attention on Internet media, immediately after the Society's press release announcing the discovery.

Nine gigantic ichthyosaurs are preserved in a rock layer belonging to the Shaly Limestone Member of the Luning Formation at the Ichthyosaur State Park in Nevada. Geological analysis of this fossil site had shown it to be a deep water deposit (Holger 1992), thus invalidating Camp's (1980) original hypothesis that the fossil bed represented an ichthyosaur mass-stranding event. Holger's (1992) study left unexplained, however, how it came to be that nine giant *Shonisaurus* ichthyosaurs sequentially accumulated at virtually the same spot on the Triassic sea floor.

This paleontological conundrum was crying out for an unconventional new approach to attempt to solve the problem. McMenamin and McMenamin (2011) hypothesized that the nine gigantic ichthyosaur fossils were captured and transported by a gigantic cephalopod ("a Triassic kraken"), that killed the marine reptiles and then dragged their carcasses back to its lair. The giant cephalopod then proceeded to arrange the bones of its victims into almost geometric patterns, some of which resemble the sucker arrays on cephalopod tentacles.

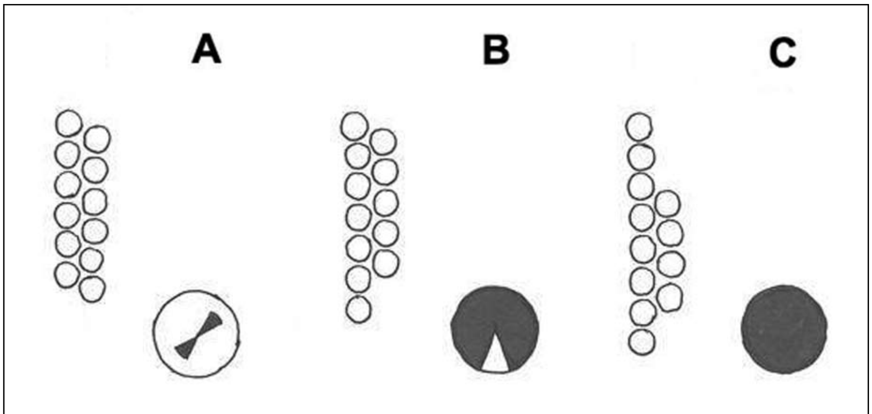
A YouTube video from the Seattle Aquarium, showing a Pacific Octopus attacking and killing a shark, lent widespread credence to the hypothesis. To date, nearly 250 news and analysis articles on the subject have appeared online.

The Triassic Kraken hypothesis is in fact an extension of the great Seilacherian research program (named for the renowned German paleontologist Adolf "Dolf" Seilacher) that sees trace fossils as fossilized behavior. Once alerted to the new hypothesis, Seilacher seemed intrigued by the Triassic kraken and noted that the bone arrangement has indeed "never been observed at other localities."

Seilacher remarked that Jurassic ichthyosaur skeletons in Germany, which may provide analogous examples, occur in stagnant basin strata devoid of sea floor animals. Such sites received most of their sediment via muddy turbidity currents. (A turbidity current is a dilute underwater mudslide that forms a deposit called a turbidite.) Ammonite fossils at these sites are, on occasion, current-aligned in an otherwise quiet water setting in a body of stagnant water.

Seilacher wonders, first, are there fossils of seafloor animals associated with the Nevadan ichthyosaur bones? Second, even an entirely soft-bodied cephalopod

The kraken, a colossal octopus, in an 1801 Century drawing by Pierre Dénys de Montfort, based on descriptions by French sailors.



ROSE DIAGRAM SHOWING POSSIBLE CURRENTS AND RESULTING VERTEBRAL ARRAYS

would still need a horny jaw, and assuming that it was not destroyed by bacteria, might it still be possible to find a fossil of its beak? Third, why did the bones near the critical Specimen-U bi-serial vertebral array remain undisturbed, and could the arrangement possibly be due to compaction?

Possible Comparisons

The strata of the *Shonisaurus*-bearing Shaly Limestone Member of the Luning Formation in Nevada might very well be compared to the famous Jurrasic fossil beds near Holzmaden, Germany, but they might also be compared to the muddy strata appearing as parallel-bedded lime mudstones of Lefkara, southern Cyprus. Stow (2006) interprets the Cypriot strata as alternating between distal turbidites and open-water sedimentation (pelagites) in a deep-water slope to basinal setting.

Referring to the Cypriot strata, Stow (2006, p. 179) notes that "the distinction between turbidite and pelagite is often very difficult to make … as is the case here."

Similar considerations would apply to the Shaly Limestone Member of the Luning Formation. In any case, the sedimentology of the Shaly Limestone Member is in close accord with a deeper-water setting. Essentially the same depositional setting is inferred for *Shonisaurus* specimens of Hound Island, southeastern Alaska (called the deep-water Facies 2 by Adams [2009]). Sediment analysis at the Nevada park indicates that the site was deep, and that local marine depth had been increasing right up to the time that the bones were buried (Silberling 1959).

We can now confidently rule out a shallow water environment for the Berlin Ichthyosaur fossil site. Turbidite flows can undoubtedly align ammonite remains, as seen in Germany and elsewhere, but whether or not such deep water flows could arrange large, dense ichthyosaur bones into bi-serial accumulations seems highly unlikely.

Furthermore, the bi-serial vertebral array in Specimen-U is in a hydrodynamically unstable arrangement, *regardless* of inferred current direction.

A simple geometrical proof demonstrates the hydrodynamic instability of the bi-serial array at Berlin Ichthyosaur State Park with regard to currents fast enough to displace ichthyosaur vertebrae. Case A is the most hydrodynamically stable. For the sake of discussion, we will consider north to be at the top of the image. Only currents from the northeast and the southwest, of sufficient force to displace ichthyosaur vertebral centra (a relatively dense bone type, shaped like a hockey puck), have much chance of displacing the bones, and only the ones on the ends of the array are in much danger of thus being displaced.

The rose diagram shows a narrow band of competent currents, with the center of the diagram representing the strongest currents and the perimeter of the diagram representing the weakest currents that could move a vertebral centra.

Case B has a dangling vertebral centra on its bottom end, hence it is safe from displacement only from a relatively narrow wedge of current directions that come from north of the array and would flow around the array like currents moving along the streamlined body of a fish. In this case the dangling vertebra is roughly streamlined like the tail of the fish.

Case C is the array actually seen at Berlin Ichthyosaur as Specimen-U. With dangling vertebrae at both ends, any competent current (be it from turbidity current influx, shelf-edge contour currents, etc.), from any direction, is going to displace one or more of the bones; hence the entire rose diagram is filled in.

Hence, it is virtually impossible that currents arranged the bi-serial array seen in Specimen-U. This demonstration considers currents that are linear in terms of their trajectory. Non-linear currents, such as swirling currents or gyres, would be even less likely to form the bi-serial array seen in case C (Specimen-U).

Probability of Displacement

This demonstration can also be given in terms of probabilities. The probability of displacement (PD), or tendency to displacement, by currents in a random set of directions, in Case A, is approximately PD = 60/360 = 1/6 = 0.167 = 17 percent. The probability of displacement in Case B is PD = 320/360 = 8/9 = 0.889 = 89 percent. The probability in Case C, the actual case, is PD = 1.0 = 100 percent.

Once again, the probability that currents assembled the Nevada array is vir-

An exhibit at the Berlin-Ichthyosaur State Park where visitors can view an exposed bone bed surface.

tually zero. Even in the unlikely event of two spiral current bores, of the type known to be responsible for forming elongate grooves, called flute casts, on the sea floor, that happened to converge along a center line to push material to the boundary between the spiraling currents (analogous to the converging circulation cells in the Sargasso Sea), Case C would still be impossible because we would expect the dangling vertebrae on both ends of the pattern to align along a boundary line (or line of symmetry along the long axis), and what we see instead is that they are displaced to the left side.

Thus, there is virtually no possibility that currents formed Case C. The triangular neck vertebra on one end of the Specimen-U array is in a particularly precarious position, with only one point of contact with an adjacent centra and two corners of the triangle exposed to torque by current flow. The likelihood of the neck vertebra being displaced by current is particularly high, especially considering its position on one end of the Specimen-U array.

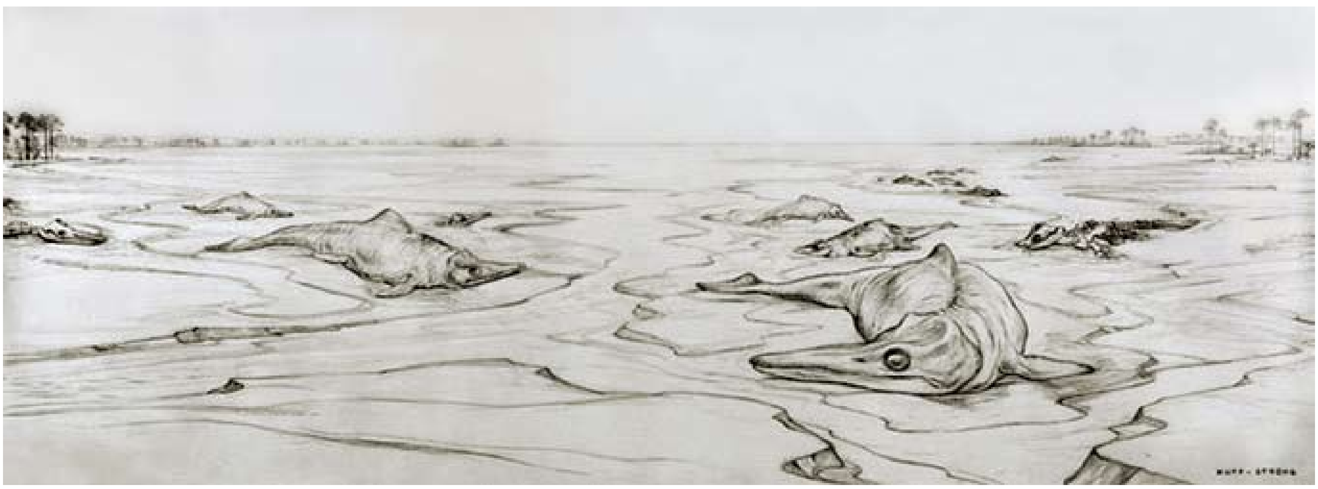
Each individual disc in the array is embedded into the matrix, and there are no associated external casts of nearby discs, therefore no discs were removed from the array subsequent to fossilization.

Seafloor Animal Fossils

The question of *in situ* seafloor animal fossils in association with the Nevadan bones is an important one. Sea floor animal fossils are rare at the site, although some brachiopods and/or halobiid bivalves have been reported from this horizon in the Luning Formation. No trace fossil burrows are known from the Fossil House Quarry, but in the absence of sandy turbidite layers to cast the underlying traces, these would not be expected to fossilize.

The depositional setting may have been one that experienced reduced oxygen levels, as some organic matter is visible in the rock thin sections. The environment, however, was evidently not greatly anoxic, because the mudstones and micrites are light in color. Modern vampire squids (*Vampyroteuthis*) are able to thrive at dissolved oxygen levels as low as 3 percent.

Giant Cretaceous squids (such as *Tusoteuthis*), reaching lengths of up to 11 meters, are assigned to the vampire squids because of similarities in the shape of their pen (gladius) to that of *Vampyroteuthis*. Thus, somewhat reduced oxygen levels would not necessarily have posed a significant challenge for the hypothesized Triassic Kraken, although we do not know exactly what



Drawing of ichthyosaurs by William Huff, depicting Charles Camp's 1980 hypothesis that they were stranded at the site in low tide. A later study showed, however, that this was a deep water site, invalidating the Camp hypothesis.

The Berlin-Ichthyosaur State Park in Nevada is also home to a 19th Century ghost town and an abandoned mine.

type of cephalopod this creature represented. Interestingly, the question of anoxic versus aerobic conditions and the Holzmaden, Germany strata are still a topic of debate.

The kraken would have indeed required hard jaws, and plans are under way to search the Luning Formation for such remains. There is a possibility for success in this effort, as a calcareous nodule from Wakkaweenbetsu Creek, Hokkaido, Japan has already produced an enormous Cretaceous cephalopod upper jaw assigned to the species *Yezoteuthis giganteus* by Tanabe et al. (2006).

With a search image now in hand, the chances of finding a giant cephalopod beak in the Luning Formation are dramatically enhanced. Modern octopi will kill sharks and use their beaks to pluck the flesh off of the shark's remains, leaving behind a cartilaginous vertebral column that rather resembles the long, relatively intact ichthyosaur vertebral columns seen at Berlin Ichthyosaur State Park.

Regarding the question of sediment compaction, the process can certainly lead to "bed parallel alignment and more close-spaced packing" (Stow 2006, p. 102) of the particles of fine sediment. Compaction processes would tend to flatten the orientation of vertebral discs, especially if they rested on a relatively resistant, hard, smooth surface. However, compaction processes do not appear to be capable of causing discs to move laterally to form an organized bi-serial array.

In conclusion, the Triassic Kraken hypothesis has survived all tests to date, including the current displacement probability test performed here, and is thus the leading explanation for the otherwise unexplained arrangement of ichthyosaur bones at Berlin Ichthyosaur State Park in Nevada.

The author is Professor of Geology at Mount Holyoke College in the Department of Geology and Geography. His research is primarily focussed on paleontology, particularly the Ediacaran *biota.*

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Looking to the Heavens To Develop Africa

by Marsha Freeman

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Three of South Africa's Karoo Array Telescopes, or MeerKAT, a mid-frequency 'pathfinder' or demonstrator radio telescope. Inset is the Congress banner.

For the first time in 62 years, the annual Congress of the International Astronautical Federation was held on the continent of Africa. More than 2,000 scientists, engineers, and students, including hundreds from half of Africa's nations, travelled to Cape Town, South Africa, Oct. 3-7, 2011, to discuss the latest developments in space science, technology, and applications. There is no continent, many speakers emphasized, facing greater challenges than Africa. And no continent where space technology could make a more dramatic positive difference to the future.

Although South Africa is the most economically developed and scientifically advanced nation in Africa, all of the speakers from the host country stressed that the Congress was being held for the benefit of, and by invitation of, all of Africa. At the opening ceremony of the Congress, Dr. Sandile Malinga, head of the South African National Space Agency (SANSA), extended his welcome "from the heads of the space agencies of Africa."

Although South Africa itself has had space science and astronomy efforts going back decades, and more than a decade of space technology development, SANSA itself is only six months old. South Africa is in the process of gaining approval of a multi-year plan.

At present, a number of African nations are using data from space-based Earth-orbiting satellites to bring a scientific dimension to decision-making for building transportation infrastructure, monitoring agriculture, assessing water resources, recovering from natural disasters, tracking disease, and other applications. A handful—principally, South Africa and Nigeria—are working towards building their own satellites, to develop an independent and more affordable alternative to hardware and software from abroad, and to be able to tailor satellite technology to their specific needs. Multination science projects are under way and are being planned to develop Africa's scientific and technical manpower, and to contribute to global scientific achievements.

An Earth-Observing Constellation

Africa, the second-largest continent in area, has a population of about 1 billion people, the majority of whom live without the most basic economic infrastructure, including electricity, transportation, clean water, and adequate education and health care. National leaders are looking toward the use of data from Earth-orbiting resource-monitoring satellites and space-based communications capabilities for problem-solving. All of the speakers stressed that this can only be done effectively through a continent-wide effort.

The week before the International Astronautical Congress (IAC) meeting, Kenya hosted the 4th African Leadership Conference on Space Science and Technology for Sustainable Development in Mombasa. The timing was not coincidental; the theme of that conference was "Building a Shared Vision for Space in Africa," and was preparatory to the discussions the following week in Cape Town. The government leaders at Mombasa declared their commitment to extend and broaden Africa's participation in, and utilization of, space science and technology.

In 2009, Algeria, Nigeria, Kenya, and South Africa established the Africa Resource Monitoring Constellation (ARMC), to consist of four micro-satellites tasked with Earth observation, from which data would be freely shared among the members. At the IAC meeting, representatives from the ARMC nations explained why, with the dozens of Earth-observing satellites already in orbit, an African constellation is necessary. From the practical

William Jones/EIRNS

At the first space Congress to be held on the continent of Africa, leaders of five African space agencies described the space programs and the aspirations of their nations. Second from left: Seidu Oneilo Mohammed, Nigeria; Sandile Malinga, South Africa; Harry Kaane, Kenya; and Tahor Iftene, Algeria. At the microphone, is Mustapha Masmoudi, Tunisia.

standpoint, the head of SANSA, Dr. Malinga, explained, it takes nine days for one satellite to cover the entire continent. This is grossly inadequate to monitor changes in real time, such as disasters, the spread of crop disease, changing water resources, and many other factors. With a constellation of four satellites, optimized for African coverage, he said, 1,000 images a day can be taken.

During the last session of the week-long Congress, Konrad Wessels, principal researcher at the Council for Scientific and Industrial Research of South Africa, cited the importance of data becoming more affordable to Africa's decision-makers, farmers, and citizens. "It would cost $40,000 to buy three images" of Africa from foreign commercial companies, he said. With an African system, the data will be free.

Dr. Seidu Oneilo Mohammed, head of the National Space Research and Development Agency of Nigeria, expressed the problem as "more than $100 billion of 'capital flight' to buy services" abroad, in order to have access to and utilize space data. Nigeria's goal, he said, is to reduce that by 50 percent in the next 10 years, by creating its own capabilities, which will "create jobs and social stability." Nigeria's 5-year roadmap is to work with partners in satellite building and systems, then increase the local input for the satellites, and later, build satellites themselves.

So far, Algeria, Nigeria, Angola, and Egypt have operating Earth-observation satellites. The week before the Cape Town Congress, Malinga announced that the South African space agency will ask the government to fund the design and construction of a South African satellite, to join the constellation. He cited the need to reduce the country's "high-technology trade deficit," stressing that the project would also excite South African youth. The new satellite is estimated to cost in the range of 400 million rand (more than $55 million), which is more than 10 times the cost, and capability, of their previous Sumbandila prototype Earth-observation satellite.

So far, South Africa has taken the lead in developing the skills to design and build its own satellites, which requires creating an entirely new space industry. "No leader in the world has succeeded in developing [his or her country] without improving [its] manufacturing capacity," observed Prof. Henry Kaane, Secretary of Higher Education, Science, and Technology in Kenya. He cited India, China, and Korea as examples. As is true in every space-faring nation, the exacting demands of space technology raise the skill, technology level, and productivity throughout the economy.

With this initiative, Africa will be able to develop the capabilities *in Africa* to collect data from satellites, interpret data to create useful information, learn to design, build, and operate satellites indigenously, and, in the future, launch them from African soil. Each step of this progression requires the acquisition of increasingly complex and advanced science, engineering, and manufacturing skills.

South Africa: Challenges and Progress

South Africa is a country of dramatic contrasts. It is host to the most advanced radio telescope in the Southern Hemisphere, but is struggling to overcome 400 years of subjugation of the great majority of its people by two European empires, and nearly 35 years of the forced segregation of the races under apartheid. It is the only nation in Africa to operate a nuclear power plant, but at the same time, 55 percent of its rural population, and more than 12.5 million people in total, have *no* access to electricity. It is the leading nation in the world in producing radioactive isotopes, critical for advanced medical diagnosis and treatment, while millions of non-white South Africans live in hovels made of scrap metal, in "informal settlements," with no electricity or running water.

National unemployment is about a quarter of the 50 million population, with black youth unemployment double that figure. The Afrikaner government's apartheid policy of the second half of the 20th Century left the nation with a 5:1 differential in spending for whites versus blacks in education. Although the government spends about 18 percent of its total budget on education, it will likely take a generation or more to eliminate that inequality.

In 1994, the first democratically elected government faced almost insurmountable challenges, while thousands of the well-educated whites, who could have contributed critical help in rebuilding the country, left. Nelson Mandela's policy that there be reconciliation, not retaliation, as the apartheid government left of-

NASA/JPL/NIMA

Cape Town and the Cape of Good Hope, South Africa, are in the foreground of this perspective view, which was generated from a Landsat satellite image and elevation data from the Shuttle Radar Topography Mission. The city center is located at Table Bay (lower left), adjacent to the 3,563-foot Table Mountain. Inset is the Sumbandila satellite in its testing phase.

fice, likely saved South Africa from a civil war.

The government of South Africa is committed to uplifting the 80 percent of the population that had been held in virtual slavery since colonial rule. It has pledged to increase literacy from the current level of 82 percent; to continue to bulldoze the "informal settlements" as they are replaced with decent housing and basic infrastructure; to create 5 million new jobs, by 2020.

But even with its great riches in minerals and raw materials, South Africa cannot escape the international financial blowout which is now bringing world trade, along with South Africa's exports, to a halt. Last year, South Africa lost 53,000 manufacturing jobs, and the projected economic growth rate for this year is down to about 3 percent. In order to create the jobs required, it is estimated that at least a 7 percent annual real growth rate is needed.

And South Africa, with all of its own challenges, lives in a neighborhood where people suffering from drought, famine, and civil war are flocking to the "greener pastures" of that nation, thanks to its open-door policy. As quickly as the

William Jones/EIRNS

William Jones/EIRNS

Groups of attentive schoolchildren crowded around the Congress exhibits on the day it was open to the public.

William Jones/EIRNS

The South African government is building new housing to replace the "informal" settlements. Here, new homes surround old shantytown housing.

government is building housing for the poorest of its population, new arrivals to the "informal settlements" make it more difficult to attain the rate of progress it has planned.

But democratic South Africa also inherited a scientific and technological legacy which has been deployed to uplift that nation, and Africa more broadly.

Scientific Orientation

While it is focussed on investment in housing, education, transportation, energy, health care, and other basic economic infrastructure, the government of South Africa intends to use all of the available resources it has to accelerate progress. In this, its emphasis on, and deployment of resources into scientific advancement, education, and development is extraordinary.

Prior to 1994, leading-edge space and rocket technology and nuclear programs were under development as military projects. The African National Congress-led government abandoned these programs after 1994. More recently, and with an impetus from the scientific community, universities, and industry, the government has placed a new emphasis on leveraging its human capital and base of high technology skills to initiate national science and technology programs as a driver and enabler for leapfrogging into the future.

In 1999, South Africa became the first country to send a microsatellite, weighing 64 kilograms (about 140 pounds), into Earth orbit. SunSat was designed, assembled, and operated by faculty and students in the electrical engineering department at the University of Stellenbosch, and was launched by the United States.

Using data from foreign satellites, South Africa developed the capacity to interpret and make use of Earth-observation imagery. In one example, five years ago, the Satellite Applications Centre, now SANSA (South African National Space Agency) Earth Observation, began using satellite data to create a multi-year data base to document the state of "informal settlements," for the Department of Human Settlements in the North West Province. By comparing new housing delivery rates with settlement growth, the government is able to more accurately identify and track the housing gap.

Building on the country's experience and skill, and recognizing the value of an African-designed and -owned Earth remote-sensing satellite, the government commissioned SunSpace—a company spun off from the University—to build a larger, prototype Earth observing satellite, Sumbandila, which means "lead the way." The R26 million ($3.7 million) Sumbandila satellite was launched in 2009, and collected images of the Earth for two years.

The next step, as outlined in late September by Dr. Sandile Malinga, the head of the new South African National Space Agency, is Sumbandila-2, an operational Earth observing satellite, projected to cost approximately R400 million ($52 million), and operate as part of the African Resource Management Constellation (ARMC).

The government of South Africa is also considering resurrecting the rocket test-and-launch facilities at the Overberg Test Range, which had been developed in the 1980s, to launch an Earth-observing/reconnaissance satellite for the military. That program also created satellite integration and test facilities, and some industrial capabilities, which are now deployed for the civilian space program. A rocket launch facility at the Overberg site would be the first one on the African continent.

Overcoming Afro-Pessimism

One of the most important reasons that the government of South Africa has placed such a prominent emphasis on promoting advancements and contributions to space science was expressed by Dr. Malinga at the Cape Town international space conference (see accompanying interview). The practical applications of space technology in agriculture, communications, long-distance learning, weather forecasting, health, disaster management, infrastructure planning, and all the rest, will allow South Africa to compress its timeline of economic development.

But it is science, which Dr. Malinga described as "imagination and wonder," which justifies his government's expendi-

Stellenbosch University

South Africa's first satellite, SUNSAT, was launched by the United States in 1999 and operated for two years. It was designed and run by the University of Stellenbosch as a research and development program. Now South Africa is considering development of an indigenous launch capability.

SKA Africa

SKA Africa

An artist's depiction of the Karoo Array Telescope, or MeerKAT, an array of 64 radio astronomy dishes, to be completed in 2016-2017. When operational, MeerKAT will be the most sensitive radio telescope in the Southern Hemisphere. Inset: Dr. Bernie Fanaroff, MeerKAT project director.

tures on projects such as the Square Kilometer Array.

In her interview (see below), Minister of Science and Technology Niladi Pandor expressed the need to move forward, and overcome "Afro-pessimism." That is the *intention* of the South African government. But the accelerating global financial crisis and collapse of, most profoundly, the European and American economies, will make that impossible. When America returns to being "the country that inspires us," as Pandor recalled, South Africa will be positioned to contribute to, and benefit greatly from, a new alliance among nations based upon great global economic projects. South Africa also will play a critical role in the development of all of sub-Saharan Africa.

South Africa's World-Class Telescopes

South Africa has more than a 70-year history in world-class space science projects. Its telescopes are the prime facilities for looking into space from the Southern Hemisphere. These include the Hermanus Magnetic Observatory, which takes advantage, through continent-wide collaboration, of the fact that the Earth's magnetic equator passes through the middle of Africa. The magnetically quiet environment of the observatory is protected, as the scientists measure minute changes in the magnetic field of the Earth, and the effect of solar activity on our space weather.

Dr. Lee-Anne McKinnell, of SANSA Space Science and director of the Observatory, explained at the Congress, that through her program, students from throughout Africa are being trained, with exchange visits among students from Kenya, Nigeria, and Zambia. The Hermanus Observatory has been leading the effort to collect geophysical data in Africa, the science of which was largely unknown on the continent until recently. The South African Astronomical Observatory and the Hartebeethoek Radio Astronomy Observatory are operated by the National Research Foundation of South Africa.

South Africa has recently undertaken a very ambitious project to build 64 radio astronomy dishes in an array, to be completed between 2016-17. The first telescope dishes of the Karoo Array Telescope, or MeerKAT, are now being tested to be commissioned. When complete, MeerKAT will be the most sensitive radio telescope in the Southern Hemisphere, and the second in the world.

The project has required new, cutting-edge technology. For this reason, although scientific observations will not begin until 2016, some 500 astronomers worldwide have already applied for time on the telescopes. Even South African postgraduates currently in the United States plan to come back to do advanced research, Dr. Bernie Fanaroff said at the Congress.

But MeerKAT is seen as a "dress rehearsal" for a truly gigantic project the scientists hope will rewrite what we know about the cosmos. At the Congress, Dr. Fanaroff announced that on Sept. 15, 2011, the final proposal was submitted by South Africa and eight other African nations to the international astronomy community, to build the Square Kilometer Array (SKA) radio astronomy project in South Africa. To demonstrate its support for this enormous and highly ambitious project, the South African government created a special cabinet position for SKA. Fanaroff is the project manager.

South Africa is well situated as the site for the project, Fanaroff explained, as it created a "radio astronomy reserve," through the North Cape Province Astronomy Geographic Advantage Act, which prohibits any activity that would interfere with radio astronomy. Internet connections are only fiber optic, for example. And no cell phones.

The SKA will consist of up to 3,000 radio astronomy dishes which could be spread all over Africa, over thousands of kilometers. The farther apart they are, the higher the precision of the observations. The partners with South Africa in the bid for the SKA project are Namibia, Ghana, Kenya, Madagascar, Mauritius, Mozambique, and Zambia, and it is hoped that each would host stations, with the South Africa site at the core.

The SKA is designed to be 50 times more sensitive and 10,000 times faster in data processing than the best radio telescope today. It is estimated that it will cost about $2 billion to build, funded by a U.K.-based consortium which could be made up of about 16 nations. The SKA should be in operation by 2024.

In order to develop the leading-edge technologies that will be required to build, operate, and coordinate the Square Kilometer Array's 3,000 radio antennas (with a total surface area of the dishes of 1 km) which will be spread over 1,000-km distances, the government embarked on a precursor radio astronomy program, which is now coming to fruition.

The African nations preparing the proposal for the SKA have worked on it since 2003, with about 100 young scientists and engineers working on the proposal in the Cape Town office. Fanaroff is especially proud that 300 grants for studies and five university research chairs have been created in South Africa through this proposal preparation process. There have been 25 Ph.D.'s and 52 Masters degrees granted, on the basis of research done on the project. And astronomy is now being taught in Botswana, Ghana, Kenya, Mozambique, Madagascar, Mauritius, and Zambia.

Most important, Fanaroff believes, is that the project has "raised the science and technology profile" in South Africa, and also in Europe and other countries," which now see "that Africa can do cutting edge science and technology."

Africa's only competitors for hosting the SKA project are Australia and New Zealand. The decision on which site will be chosen will come early next year. Fanaroff was asked in a Congress session, what if Africa is not chosen for the SKA? And how could he justify the amount of money that will have to be spent?

We will complete MeerKAT, he replied, and "do world-class science for 50 years" using that facility. "We will do remarkable science" by also expanding the use of other telescopes in Africa, and "we will play a leading role in SKA, no matter where it is built."

"There are short-term problems" in Africa, he responded, "but we can't limit ourselves" to those. Astronomy is "inherently a very exciting subject. We are creating the cadre who are transforming the way Africa sees itself, and is seen around the world."

INTERVIEW: NALEDI PANDOR

South Africa in Space: Ending 'Afro-Pessimism'

South African Minister of Science and Technology, Naledi Pandor, is a passionate supporter of scientific and technological progress for her country. She is the former Minister of Education of South Africa, and a Member of the National Executive Committee of the African National Congress. Since 1994, she has been a Member of Parliament. Minister Pandor received degrees, and furthered her education, at the University of Botswana and Swaziland, the University of London, Bryn Mawr, the Kennedy School of Government, and the University of Stellenbosch. She is responsible for a sweeping array of scientific programs, for which she is an ardent proponent.

In order to educate the Parliament, which must approve federal program budgets, the Ministry prepared a pamphlet, explaining the importance of South Africa's radio astronomy projects, and why it is bidding to host the Square Kilometer Array (SKA).

With scientific advancement as a leading edge, the Minister is dedicated to the education of both citizens and policymakers, and expresses the optimism that South Africa will continue to lead the continent into the space age.

Pandor, who addressed the Congress of the International Astronautical Federation, in Cape Town Oct. 3-7, 2011, was interviewed by Marsha Freeman and William Jones. Here are excerpts.

21st Century: It was very clear from your statements at the Congress, that the government of South Africa has made a very serious commitment for space technology and development, and, of course, you have a country that faces many challenges, such as in education and employment. Could you tell us why you think that the space program is important for South Africa?

Pandor: Well, we need to go back a little bit. When South Africa achieved democracy in 1994, I think the country had to reflect on what it needed to do. And at the time, the new government was aware that we had a fairly strong scientific base. But I think it believed that it must focus on the socio-economic development issues, and therefore tended primarily to highlight education, health, issues of equity. Those were paramount, I think, in the mind of the South African populace at that time.

And so while we were really fortunate that Mr. [Nelson] Mandela's government established a Department of Science and Technology in 1994, the problem was somewhat that it was merged with another department. So we had something called Arts, Science, and Technology, then. And given the socio-economic concerns, arts and culture tended to dominate the discourse of that department.

But our scientists, I think, were very strong, in that they worked to formulate a strategy for the country. They did a foresight study like the decadal review by the National Academy of Sciences that you have in the United States, and set out a research and development strategy which was adopted by government in 1996, and continues to influence a great deal of the work we even do up to now. So I think that phase assisted the African National Congress to continue to have an interest and an objective of investing in science and technology.

Between the period between 1996, up to 2004, we continued with that conjoined department; but as matters developed, it became clear that science was of such importance that it needed its own department, it needed its own budget, and it needed a much more definitive strategy which would highlight what had been done in 1996, lift it out, and really begin to tie into new developments that had emerged in that period of eight or so years.

A Department of Science and Technology

So in 2004, after the elections, the ANC decided to establish a stand-alone Department of Science and Technology. So we're a new department as a stand-alone, although it existed since '96. That new department was charged with determining a new innovation policy for South Africa. Building on the research and development strategy but drawing on what had been learnt since democracy.

In 2007, they put before the Government a 10-year innovation plan with five key focus areas identified. Now in the plan, they indicated that we've been clearly all right, as to investing in fundamental scientific research and development activity. So our scientists have been receiving grants, and while not enough, monies have been flowing; our science councils have been productive. On the basic science level, we're all right.

But we had problems with respect to human capital, and we're really not doing as well as we should with respect to innovation. We're producing basic scientific outcomes, but were not converting them into a product that can be commercialized. We didn't have the institutional base for that, and we're not investing. The private sector is traditionally not venture-capital-oriented in this country, so the Government decided we had to do something. Hence, a 10-year innovation plan for science and technology, which identified five key focus areas which you hear us all talking about.

The first is space science and astronomy: very, very important, because they realized there are opportunities there, but also, we have capabilities in South Africa. The second is biotechnology, and that linked into our whole problem of the disease burden in South Africa and in Africa, and a very productive health sciences academic contingent in South Africa.

As you know, the first heart transplant was carried out here, so our human and health sciences faculties tend to be quite, quite productive. So biotechnology is the second area.

The third area was energy, because the Government was concerned that we were not doing enough for renewables, that we're too reliant on fossil-based energy sources, and thus, we're contributing to all the horrible gases in the atmosphere, and needed to change the way we resource energy.

William Jones/EIRNS

William Jones/EIRNS

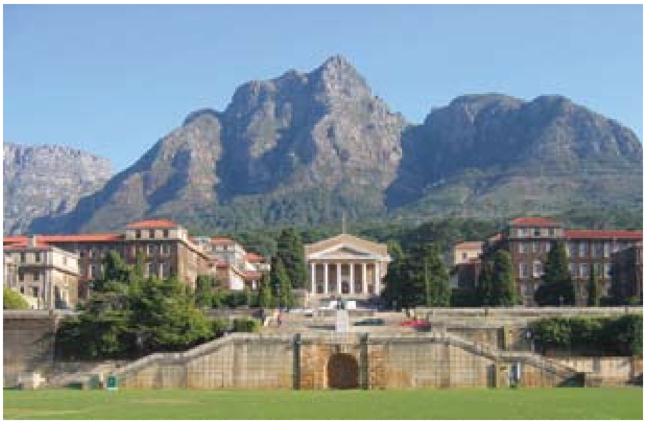
South Africa is fostering science and technology capabilities at the same time that it is trying to push forward socio-economic development. Khayalitsha (shown here), is a Cape Town informal settlement with more than 1.5 million residents. While hundreds of thousands of new homes, with electricity and water, are being built each year, the influx of refugees from neighboring countries has made eliminating these squatter villages more difficult. Below: new Khayalitsha housing.

The fourth area was climate change. And there, they call it actually global change, but the primary focus is climate change, to look at what technologies should we develop in order to understand what is happening to the world better, from a Southern, rather than a global perspective. And then the global view would be linking into other sciences, and really developing our geo-spatial understanding of the world and our ability to monitor climate change and learn from other systems. And then also to improve the search with respect to the southern oceans and understanding the southern currents much better than we do up to this point. So global change is a fourth dimension.

The fifth one, which, I must admit I am one of the people who added, was the human and social dynamics. Because in discussing the plan, some of us became concerned that there was potential to neglect the humanities and the social sciences, and given a society in transition, it was absolutely imperative that we understand what is happening with society, and are able to support a change in society and communities to grapple and cope with change. Plus, you want poetry, literature, and so on. So human and social dynamics is the fifth area.

Now embedded in those finally, is really ensuring sufficient resources for those areas without neglecting the other areas scientists want to pursue. But these would be kind of where we want to see focussed, ensured resources. Two, making sure we have the human capital, because without the people, you're not going to do the science you want to do, so your Masters degrees and Ph.D.'s are very important to us, post-graduate study. And third, making sure we have the institutional structures to give us these areas that we want to focus on. So the universities must have appropriate facilities, the science councils must have infrastructure.

So we're looking within these five areas: How do you ensure, how do we position ourselves in a way that allows us to continue to do basic science, produce the right human capital, be innovative, and actually build alliances with the private sector that support innovation. And



University of Cape Town

Tshwane University

UNESCO

South Africa has 23 universities with 820,000 students enrolled, 50,000 of them from other African countries. Here, the University of Cape Town, founded in 1829; Tshwane University of Technology, founded in 2003; and a group of students at Tshwane University.

that essentially in a very brief outline, is the agenda of the Government at this time.

South Africa's Role in the Continent

21st Century: You also have a very broad view in terms, I think, of what South Africa's role is for the whole continent.

Pandor: Absolutely! Africa is central for us, because, you know, we believe that you cannot have an island of development in a sea of underdevelopmental poverty. And so we've worked very hard to ensure as we initiate our programs that we do so with the African continent. We have 23 universities in South Africa. At the moment, we have around 820,000 young people registered, so we are almost bursting at the seams. And what's intriguing is that of that number, around 50,000 are from other African countries. So we've become a resource for the continent.

I think it is tough for us. We are worried about success rates in higher education, but we have some universities that are pretty good quality, and about 7 out of the 23 are research-intensive. We want to build much more capacity, but we have a committed Government, and fortunately, we are getting support, never enough money, but we are always fighting for more. This week, I was having big fights with my colleague in Finance, but I think we do get resources and we're able to deploy them.

21st Century: One of the most remarkable projects that you are now in a tough fight with Australia for, is the Square Kilometer Array. It's a very impressive project itself, but also the fact that you made it a joint project with a number of other countries on the continent is very impressive. How do you see that as kind of a driver? What impact do you see it having if you get the program?

Pandor: You know, one of the things that we wanted to do is to change the way the world sees Africa. We tend to view the continent as a place of awful problems—famine, disease, war—and not as a knowledge region of the world. Now we're trying to change our character into one where we are associated with an iconic research facility that draws researchers into Africa to carry out high-level research work. That, we believe, would fundamentally alter the way that the world sees us.

Because they will come to countries on the continent for a very different purpose. So we regard the Square Kilometer Array and the fact of the African partnership as part of this alteration of the perception of Afro-pessimism that we have in Africa. But also it would mean a massive boost to human capital development because it involves so many areas of technological and scientific activity.

Just two weeks ago, I was in Washington, and I was speaking to all the top corporations in the information-communications-technology (ICT) domain—your Ciscos, your IBM, Honeywell—briefing them on the opportunities offered by SKA, and it was incredible. Here's an African minister talking to the top executives of the major world ICT companies, saying please come to South Africa and see what opportunities you could derive from the Square Kilometer Array, and assist us in ensuring that we have the best programming, the best systems analysis, the best data management facility for this important project. And we told them that, even if—the Lord forbid—we don't get the SKA, we are committed to the demonstrated telescope MeerKAT, which in itself will be a significant research facility.

And it was great! They were all excited. They all wanted to be part of it. We have agreements with IBM already. We have agreements with Nokia, with Intel—so there's a lot of excitement. And this excitement: It begins with South Africa, but then it must look at Mozambique; it must look at Zambia, Namibia, Ghana, Botswana. All the partners to this

© SKA South Africa

The first few dishes of the Karoo Array Telescope, or MeerKAT, is a symbol of what Minister Pandor called "the alteration of the perception of Afro-pessimism that we have in Africa." It will mean a "massive boost to human capital development," she said.

new development are all the various sides of our program.

I've found a bit of money in my budget to start helping Mozambique to build a radio astronomy observatory. And we hope we'll do the same with Zambia; we're doing so with Ghana as well.

Inspired by Eleanor Roosevelt

21st Century: When Nigeria launched its two satellites a week or so ago, one of the ways that the press covered it was to say that Nigeria is now winning the "African space race." But all of the South African speakers at the Cape Town Congress have stressed international cooperation.

One project under development is the African Resources Monitoring Constellation. Dr. Malinga, who had a press conference in Johannesburg before the IAC conference started, said that the next South African satellite, Sumbandila-2, which will be South Africa's contribution to the Constellation, would be developed. Has that been approved?

Pandor: Not yet. No, they're still working on it, but we've agreed that that's the direction we're going. And we'll look at what they've produced, their plan, and I hope by the end of this year we will have an indication what the needs are, what the timelines are, and what resources are required.

21st Century: I have to say that an inspiring thing about South Africa is the leading role of women here.

Pandor: We all draw on the U.S. We all talk about Eleanor Roosevelt and the contributions she made to the empowerment of women. We never forget that we wouldn't have the Universal Charter of Human Rights were it not for her. A great woman. So we draw inspiration. And that's what we would like America to go back to—to be the country that inspires us.

INTERVIEW: DR. SANDILE MALINGA

Space in South Africa: A Change in Paradigm

Dr. Sandile Malinga is the first chief executive officer of the recently established South African National Space Agency (SANSA). He is a space physicist, who earned a doctorate from Rhodes University. In 2002, he joined the University of Natal and later became the Dean's Assistant at the University KwaZulu-Natal, responsible for student academic support programs.

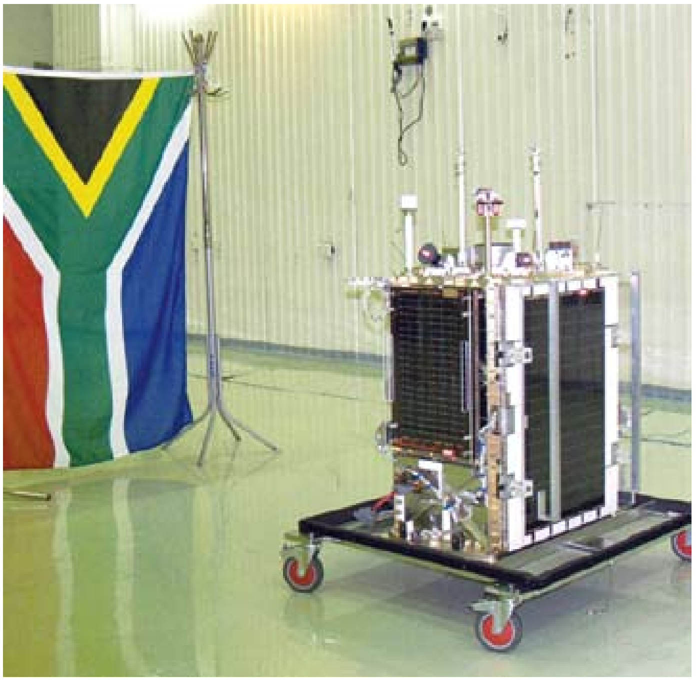
In 2007, Dr. Malinga joined the leadership of the Hermanus Magnetic Observatory, now SANSA Space Science. He is a member of the South African Council for Space Affairs, and serves on numerous scientific committees. Dr. Malinga is dedicated to bringing young people into science and technology, a commitment which he says is inspired by his three young children; and he sees his responsibility not only to his nation, but to all of Africa.

Dr. Malinga was interviewed by Marsha Freeman on, Oct. 6, during the International Astronautical Congress, in Cape Town.

21st Century: You gave a briefing for the press in Johannesburg about a week ago, prior to the Congress, in which you mentioned that you hoped to start a project next year to build an operational Earth-observation satellite; that Sumbandila was a prototype, not designed to be operational. Why have you put this forward? People would ask, wouldn't it be cheaper and faster to just go to a foreign commercial company and buy a satellite?

Malinga: The reason we think we should build our own satellite, goes beyond what the satellite can do. We hope that through this, we will come up with new technologies. We have a very bad shortage in terms of highly skilled people in the country. So this would be one vehicle that one can use to train people in high technologies.

Further, as a country, we have challenges. We import quite a lot of high technologies from other countries. We currently have a trade deficit, in terms of high technologies, in excess of 70 billion rand (about $9 billion) a year. And this has gone up. In the past, I think around 2005, the trade deficit in terms of high technology was around R43 billion a year, and it's gone up to 70-something. So there is something going wrong, in terms of competence in high technology; it is probably slipping.



www.sunspace.co.za

South Africa's Sumbandila micro-satellite before its launch in September 2009, from the Baikonur Cosmodrome. Sumbandila means "lead the way" in the Venda language. Dr. Malinga stressed the importance of South Africa's building its own satellite to meet the nation's needs.

We also see that in terms of our patent share. Around 2005 or so, it was around 0.1-0.2 percent of the global share. In 2009, it has gone down about 80 percent to .02-something. We're slowly slipping as a country, globally. So we believe that by doing this, it will contribute to addressing those challenges, which the country is trying to address. In addition, we will create the skills that are required. And the biggest thing is that the skills that are created in terms of space could help people find jobs elsewhere in other industries, car manufacturing, or mining areas, and also other industries. They could work just about anywhere. Those are related benefits that we hope to derive out of this.

Besides that, we believe that we should build our own satellite, so that we design it to meet our needs. When you build a satellite, you build it for your own needs. If we use the French satellite, which we use at the moment, it's not designed for what we want. We have our savannas here. France is in Europe. You know, they have different vegetation from what we have. We need to customize our satellites, to meet our requirements, and achieve what we want. So those are the reasons why we think we should build our own satellite.

And there's the issue of national pride, as well. We can't underestimate that. That is what has propelled other nations globally to be where they are: National pride. It's as simple as that. "We got it; it's been done here." It has an immense motivational affect on your people, your young people, who will see this satellite that they have developed. It drives you on to other things. The sense of belief that we can do just about anything, and that's an advantage.

We Must All Prosper Together

21st Century: You said at various times throughout this week that your country has many challenges, and not every problem can be solved quickly. But for people to think that their children's lives will be better than theirs, that is the hope.

There was an article recently, when Nigeria had two satellites launched, that Nigeria is winning the "African space race." But you have stressed the cooperative space projects that are under way, such as the African Resource Management Constellation (ARMC). How important is it to have a regional view and not just use your satellite to look at South Africa?

Malinga: That's very important, that we take a regional view. Especially for us, in terms of where we are in the SADC (Southern African Development Community) region. If you look at our neighboring countries, we're far ahead, in terms of space. And so it's not in our interest to just benefit ourselves. The SADC countries will prosper, or none of us will be prosperous. Then, no one would have to be monitoring borders, because people want to remain where they were born, largely, unless there is something else that pushes them to seek greener pastures.

So by stimulating the region as a whole, that creates markets for SADC, as well. If there is someone who can buy a product and can afford it, then you can sell more. So we have to look at it that way. That it's in our interest to develop the region as a whole, and when we collect satellite data, we would love to distribute it to our neighbors.

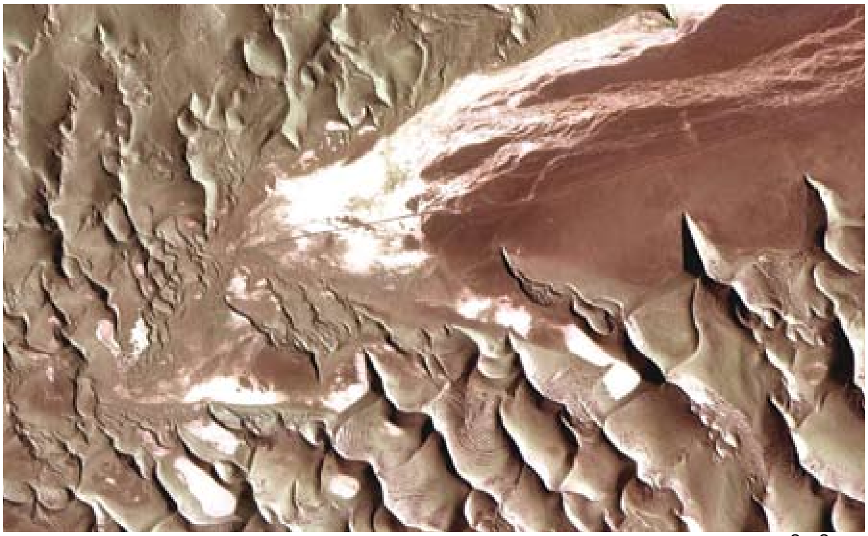
There are programs, for instance, CBERS, the China/Brazil Earth Resources Satellite.

21st Century: You had mentioned that. I had no idea South Africa was involved in that project.

Malinga: We *are* involved in that. We are downloading the data; it's just that right now, the satellite is not working. But we're downloading the data, and the license for it was crafted under the so-called "data democracy framework," where data are freely available. So the mandate that was given is that the data are to be distributed to neighbors for free. That's the commitment that we made.

Now we have signed another contract for CBERS 3, which will be launched next year. That is still under that framework—that we'll download the data and distribute it freely to our region. We're committed to do that, and we think it's important.

Similarly, with our satellite as well: The data should be shared. When you look at it, there is South Africa in the southern region; there's Nigeria in the West; there's Kenya in the East; and there's Algeria up north. If we were to think about this very carefully, and sort of, each be a space powerhouse in those regions, we could do more. We could cover the whole of Africa in a very meaningful way (with a satellite constellation by these four nations.)



SunSpace

SunSpace

Sumbandila images of Sossusvlei in Namibia (above) and Cape Town, both taken in February 2010.

Issues of collaboration in Africa are very interesting, and tricky, in the best of times. That's another issue.

You know, it's coincidental, but we are more or less covering all of the main regions of Africa, almost all of them through the proposed ARMC constellation. We could cover Africa very easily through our regional cooperation; South Africa would be responsible for the SADC, and assist our region as much as possible. Even then, we don't want them depending on us. We assist them to get on their feet and fly on their own. That's the intention.

Raising the Bar

21st Century: And you had said that if other countries can't fly their own satellites, they could participate in the program, and build and operate a ground station.

One of the other things that has been mentioned, is the possibility of a launch facility. Every continent has a rocket launch facility, except Africa. And you have infrastructure at the former Overberg Test Range that existed in previous times. Is there much there at the site, or has it all been dismantled?

Malinga: It's still there. The site is still there—the bunker, and other things; the tall hangars. Everything is still there. The infrastructure is there.

21st Century: So it could be developed to launch satellites?

Malinga: Everything is still there; the telemetry systems.

21st Century: It is our view that the path to economic development is through great projects. You talked about how having a vision is important, and that nothing that is done in space can be done in a few months, but takes a long-term commitment. How do you see what you are doing in space as having an impact on the long term, such as in education? We saw the impact of the Apollo Program in the U.S.

Malinga: Do you mean, why not use this money for education, as an example? I think the point that you are raising is, where you raise the bar, you stretch people. Instead of doing the mundane, the things that they are able to do, you set a higher bar whereby they have to stretch themselves and think of things differently. That is the way to change and have that paradigm-shift, that now we're taking a jump.

You know, to some extent, our program's not of that nature. We haven't taken on a very ambitious program. I mean, building a satellite—we've done it before. The first one we built, Sumbandila, is not necessarily an operational satellite, but I don't think putting up an operational satellite is necessarily a huge jump, as in making a paradigm-shift.

By what we're doing—are we really going to change things? Probably not. But I think if we were to take even more ambitious goals and objectives, and say, "This is what we're going to do," that would probably propel us further, even faster in our development.

I think this is a good start. We can start by completely building our own satellites. And we look at this as a way

SANSA

We need to raise the bar, to "stretch people," Dr. Malinga said, as a way of bringing about change through education. Here, an outreach program of the South African National Space Agency, which aims to create the next generation of space pioneers.

of working with African countries. It's a challenge in the sense that I'm talking about, more on the patriotic and African kind of vision. But when people talk—the company that builds our satellites—they're more concerned about the money. Me, I'll be saying to them: "Let's impart the knowledge to the African countries. They'll build their own."

Because the way I look at it, we can't build five, ten satellites in the country, alone. So can you imagine, if each and every African country was doing so, and we use all of those—?

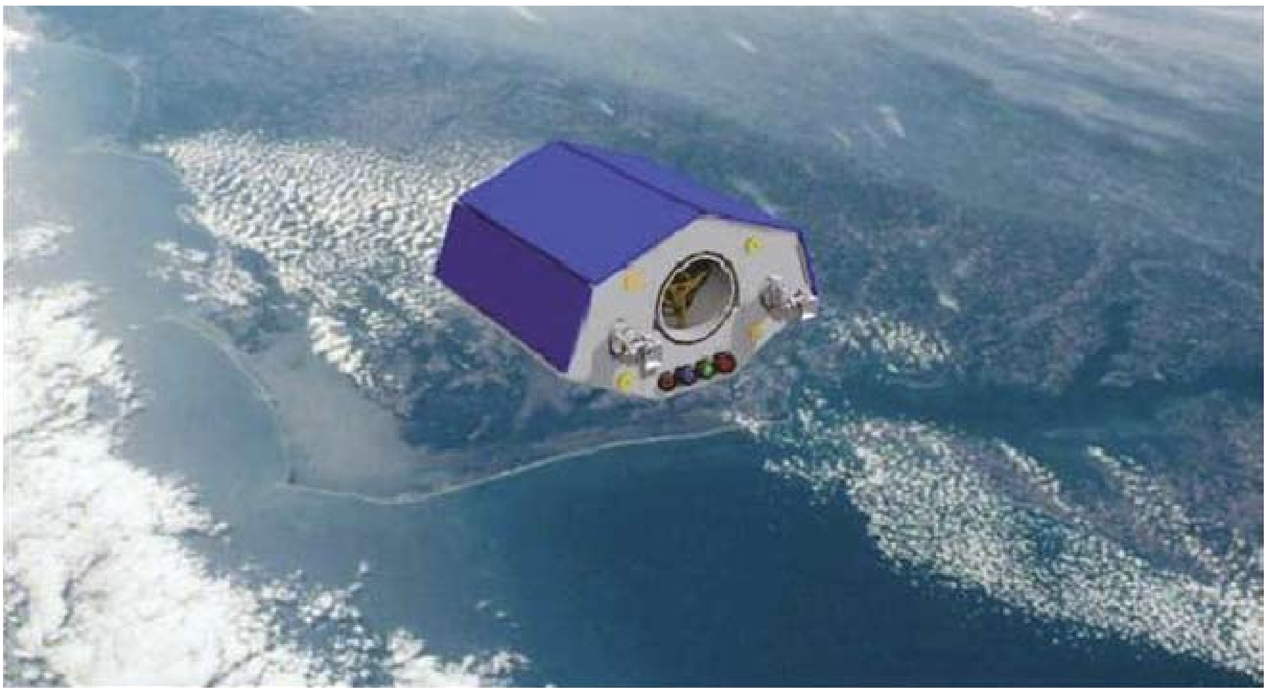
For me, I'll say the skills should be created elsewhere, so there are more people who can do this, so we can have more satellites. So as a country, yes. But for a businessman, probably not!

21st Century: That's why it was important for the government to create a South African National Space Agency.

Malinga: Yes. That's the intention. I'll try to have more social activism, and say, "Create these capabilities elsewhere, and we'll have more satellites, and we'll put them up there together, so as a country, we don't have to spend more money creating our own constellation." The thing about one satellite is that it doesn't assist you much; it does a good job, but it is limited. If there's a disaster, coverage is small, and the revisit time is long. You can't, when there's a disaster, be coming back in a couple of months to the same spot. So those are the things that are helped by a multi-satellite constellation. My model will be: Build the capacity, and people will build their own.

Inspiring Young People

21st Century: You mentioned, in terms of political stability and economic growth, it is never a benefit to any coun-



SSTL

Dr. Malinga stressed the need for collaborative space projects and a regional view of space development and resources. One of the partners is Nigeria. Here, an artist's depiction of the NigeriaSat-2 spacecraft in orbit, and Nigerian engineers in training.

try to have poor neighbors.

Malinga: You close borders, and do other things, and spend so much money. We have a center where we keep people who come in to the country, and then deport them. We are paying a lot of money doing that. Whereas, if their economies were okay, they would stay. Home is home. Everyone wants to get home, as long as the conditions are okay. Having said that, it's a challenge, but it's very important.

21st Century: Do you think this Astronautical Congress will have an impact, especially on young people, and education?

Malinga: I think it has done a great job. We had more of our students who otherwise would not have been exposed to this. They came, they attended. Our professionals, also. But, I have a feeling we could have done better, on attendance. I'd expected it to be more.

initiative.wordpress.com/category/satellites/

Government representatives signing a memorandum of understanding, during the Third African Leadership Conference on Space Science and Technology for Sustainable Development, in Algiers, in December 2009. The African Resource Management Constellation involves an initial collaboration of Nigeria, South Africa, Kenya, and Algeria.

I think the impact will be immense, going forward. People will look back. Can you imagine the kind of impact that is made on young people? NASA Administrator Charles Bolden spoke to school kids. It's amazing what that does for a child. I go to places in schools and say, "Just remember this day." Probably this is where your space career started; when someone came and spoke to you about space.

21st Century: That's what many of the astronauts on their Congress panel said had inspired them.[1]

Malinga: So it has an amazing impact, to see someone like you saying to us, "I can actually do this myself."

1. See *EIR*, Oct. 7, 2011, for the Apollo astronauts' testimony before Congress.

INTERVIEW: DR. PETER MARTINEZ

We See an African 'Astronaissance'

South African scientist Peter Martinez headed the Local Organizing Committee for the International Astronautical Congress (IAC). Dr. Martinez is the chairman of the South African Council for Space Affairs, which oversees space activities in South Africa, and he is division head for Space Science and Technology at the South African Astronomical Observatory. Dr. Martinez has made important contributions to the development of South Africa's national space policies. He holds a doctorate in astrophysics from the University of Cape Town, and contributes to international policymaking in space affairs.

At the final count, 345 African delegates, from 13 African nations, attended the Congress. A special Developing Countries Support Programme (DCSP) had been organized by the International Astronautical Federation to support the participation of delegates. Twenty of the 30 participants supported by the DCSP program were from Africa.

Dr. Martinez was interviewed by Marsha Freeman on Oct. 3, 2011 in Cape Town.

21st Century: As the head of the local committee that organized this first-ever Congress of the International Astronautical Federation in Africa, you must be very pleased by the turnout.

Martinez: We've got about 2,800 delegates registered. We're very excited about that. I think it shows the interest by the global space community in finding out about that's happening in the African space arena, and the potentials that it holds, not only for space in Africa, but the potential for cooperation and commercial applications of space technology in Africa and the markets associated with that.

21st Century: How many African countries sent delegates to the Congress?

Martinez: There are 53 countries in Africa, and I would be surprised if all 53 are represented here; it will probably be fewer than half. But still, in terms of space development in Africa, that would be a significantly higher number than you might have attracted, had this Congress been held, say, 10 years ago. We're seeing a birth of a number of space programs in Africa, hence the theme of the conference, "An African Astronaissance."

21st Century: All of the speakers at the opening session of the Congress today made it very clear that they were welcoming the delegates from all over the world, on behalf of *all* of Africa.

Martinez: We were very conscious that this was the first IAC for the continent, and when we bid to host it, we submitted our bid as an African bid. Our perspective has always been that it's a Congress *for* Africa, and we've taken a great deal of care to involve our African colleagues in the planning leading up to this Congress, and to ensure that this Congress responds not only to our interests and needs, but the interests and needs of Africa, in general.

www.sunspace.co.za

The SumbandilaSat (upper right) being integrated on Fregat for launch at Baikonur. Dr. Martinez pointed to the inspirational role of South Africa in space for the rest of the continent.

An All-African Space Agency?

21st Century: Last year, at a conference of African leaders, there was discussion of forming an African Space Agency, similar to the European Space Agency. At that time, you were quoted saying that such an organization would be premature. What are your thoughts on that?

Martinez: This exact question was discussed at the African Leadership Conference on Space Science and Technology, held in Mombasa last week. And I am pleased to say that the heads of the other African space agencies who were on the panel discussing this very subject, all expressed views very much in line with my own personal opinion, which is that it would be premature at this stage for Africa to develop a continental space agency.

I think where we are now is, that we're seeing the birth of coordinated space activities at a national level. Countries need to develop their space activities, and experience, and operational programs first, and then develop experience in cooperating with each other in executing space activities jointly.

There are many, many challenges and issues to overcome in conducting joint space projects. In the fullness of time, I think we will see whether we need a continental space agency, or if some other modality of cooperation would suffice. It's not clear to me that one needs to establish a new institution. Perhaps just very good coordination and networking among a series of strong African space agencies would achieve the same results, but in a more efficient manner.

The poster for the African Leadership Conference on Space Science and Technology in Mombasa, where heads of the African space agencies discussed collaboration.

21st Century: How have the development and achievements in South Africa in space science and technology radiated to other African nations?

Martinez: I think the most significant role, perhaps, is an inspirational one, of being a kind of role model for the African continent, demonstrating that such things *can* be done in Africa, by Africans. An example of that is the Sumbandila satellite, which was developed in South Africa, and designed, built, and operated in this country, with, really, a very small percentage of components that were imported from elsewhere.

Other projects, such as the Southern African Large Telescope, which is currently the largest single telescope in the Southern Hemisphere, and projects like the MeerKAT radio telescope—all of those demonstrate technological and scientific capability here, on the continent, and, I think, serve to inspire other African nations. And, incidentally, I should say that all of these projects are being pursued in a manner that is quite open to collaboration with other African countries.

In terms of the MeerKAT and Square Kilometer Array (SKA) projects—the SKA is very much an African bid to host this very large instrument, simply because of the continental dimensions of the array, once it's built. So we have stations as far north as Ghana, which are projected; and interestingly, Nigeria is another country in the region that has strong capability in radio astronomy. It's very exciting to be working with these countries on SKA.

Also, in the domain of satellite technology, there is an African Resource Monitoring Constellation. This is a project whereby each country contributes one satellite to the constellation, but has access to the data from the other satellites. At the moment, the ARMC project is being led by Algeria, Kenya, Nigeria, and South Africa, but it is, in principle, open to other countries to join at the level appropriate to their development and needs.

The South African Astronomical Observatory (SAAO) is the national center for optical and infrared astronomy in South Africa, and home to the largest single telescope in the Southern Hemisphere. The larger view, with SALT in the foreground, shows the older and smaller telescopes seen at the other end of the plateau. Inset is a close-up of the South African Large Telescope (or SALT).

SAAO

INTERVIEW: DR. LEE-ANNE MCKINNELL

What Is the Weather in Space?

Dr. Lee-Anne McKinnell is the managing director of space science at the South African National Space Agency (SANSA), and former acting managing director at the Hermanus Magnetic Observatory. Her area of research is in the development of an ionospheric model for application to communication in the ionosphere.

In addition to her scientific research, she plays a leading role in developing a new generation of young scientists from the nations of Africa.

She was interviewed by Marsha Freeman on Oct. 6, 2011, during the International Astronautical Congress in Cape Town.

SANSA

21st Century: Can you give us a bit of the history of the Hermanus Magnetic Observatory, and why it was built in South Africa?

McKinnell: It was started in 1937 at the University of Cape Town, for measuring the Earth's magnetic field, which was needed at that time. But by 1940, they realized that when you measure the Earth's magnetic field, you want to do it as accurately as possible, in an area where there are not outside influences.

In Cape Town, where the University was based, there was an electric railway line, and the system was causing inaccuracies in the measurements they were trying to make. So they decided to move the observatory to a place which is what we call "magnetically clean," where there are no serious external influences on the Earth's magnetic field. They looked for a town that didn't have a railway line. And Hermanus, which is 120 kilometers from Cape Town, off the coast, had no electric railway in those days—and still doesn't today, thankfully, so the Observatory was placed there.

At Hermanus, we have 16 hectares of land, and in the middle, we have a magnetically clean area, which is where we take the measurements of the Earth's magnetic field. All of the buildings use non-magnetic material and are built with non-magnetic material, and we restrict activities in that area. We don't allow people to dig and put up structures that have magnetic components. We preserve the pristine nature of that.

21st Century: I believe there have been changes over time in the strength of the Earth's magnetic field. Have you seen this in your measurements?

McKinnell: You are absolutely right. The reason why we want to measure the Earth's magnetic field in different places is because it's changing, and it's different in different places. SANSA, at the moment, operates four permanent field observatories, where we have accurate instrumentation to take measurements, in South Africa and in Namibia. Hermanus is one of them; and then we have one in Hartebeesthoek, which is north of Pretoria, and then there are two in Namibia, at Tsumeb and Keetmanshoop.

All four these have INTERMAGNET (International Real-Time Magnetic Observatory Network) status, which is an in-

SANSA

The management team of the South African National Space Agency (SANSA) poses with the Congress 2011 flag at their offices in Pretoria.

ternational organization that dictates the standards for measurements. It's a bit like having a standard measure for the kilometer, or the meter.

21st Century: Where are the data collected?

McKinnell: There is a global database of magnetic field measurements, called the INTERMAGNET Data Base, and all of the data from these four observatories, plus many other observatories around the world, contribute to that. There are a number of magnetic observatories which do very similar things to what we do, all around the world. A number of them, including the one in Hermanus, had been chosen to use their data to calculate what we call the DST index, the Disturbance Storm Time index. It is a global index for magnetic field measurements, and if you have that index, you can correlate with any other space environment data and see the effects the magnetic field is having on the rest of the space environment.

The Earth's magnetic field is a very important parameter in space measurements. And we're very proud of the fact that Hermanus is of such a standard that it can be used for that calculation.

In terms of the change in the magnetic field, we have people on our staff whose specialty is geomagnetic data, and every magnetic observatory should have somebody like that. But we go one step further—we have people on the staff who simulate the Earth's magnetic field. They will have a look at how it's changing with time, and try to predict how it is going to change in the future, and then will update it with new measurements, as they become available.

What they have noticed is that the Earth's magnetic field is changing, and that in Hermanus, it has changed by up to 20 percent over the last 75 years. Apparently, this is something that they've seen in geologic ages; around 100,000 years ago, the Earth's magnetic field actually switched and that it will switch from time to time, in geological time-spaces, and that we're due for a change—a switch of the Earth's magnetic field, again. When it's going to happen, they're not so sure, but they say we're about 200,000 years overdue, and that it might happen in the next 100,000 years. So I don't think we have to lose any sleep over it tonight, but it is going to happen.

What will happen when the Earth's magnetic field switches, is a question we get asked, and of course, we have no scientific evidence. None of us were around the last time; we didn't have the measurements we have today. All they know from geological records is that the last switch of the Earth's magnetic field did not coincide with the extinction of any life form. They feel we're probably going to be safe. It's not life-threatening.

The Earth's magnetic field has a purpose—it keeps the atmosphere to the Earth, and the atmosphere protects us from the Sun's rays. So we're probably

HMO

Hermanus Magnetic Observatory

The Hermanus Magnetic Observatory is in a "magnetically clean" area where it takes measurements of the Earth's magnetic field. Above is the observatory in 1932, and at right, the observatory today, with its logo. It is one of four field observatories operated by SANSA.

After the International Polar Year of 1932-1933 a magnetic observatory was established at the University of Cape Town, and later moved to Hermanus, where it operates today. It recently inaugurated the Space Weather Operations Centre, to develop the tools to issue warnings of magnetic storms.

going to get stronger rays coming through the atmosphere, more extreme ultraviolet light coming through as the magnetic field weakens. But probably not for a very long period of time.

The Earth's Space Environment

21st Century: The Observatory is also part of an international network of regional warning centers for space weather. How does that function?

McKinnell: Space weather is the term we give to changing conditions in the Earth's space environment. It is a very hostile environment, and conditions that happen in that environment can affect our technology on Earth.

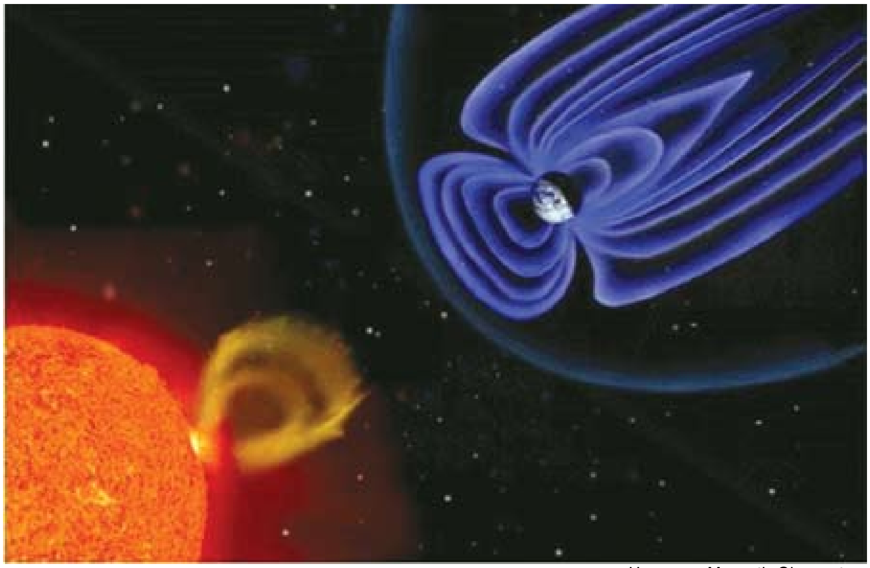
It starts with the Sun as the driver, propagates through interplanetary space, and affects the atmosphere. The atmosphere maybe receives an increased number of particles. We're putting satellites into the atmosphere that we're dependent on for communications, the Global Positioning System, the Internet, etc. We have long pipelines on Earth, and they are susceptible to currents.

Space weather has been around for a long time, of course, but we recently coined the term. It's become a hot topic, because of the effects it's having on technology, and our dependence is growing. So, therefore, we really need to know and understand the effects it has on technology.

In order to coordinate global activities—because really every country is, or should be, interested in space weather—there is an international body, called the International Space Environment Service, ISES, and they have set up regional warning centers around the globe. They try to go for at least one on every continent, whose job it is to coordinate space-related data for each continent. You call it the applied side of research.

They take the models the researchers have developed, and they take the data that are coming in from the instrumentation that we deployed, and turn it into information. We call it the operational and forecasting and predicting side of space weather.

In Hermanus, in 2007, ISES approached us because they didn't have a regional warning center in Africa, and Africa is a continent a lot of people are interested in, because it's very sparsely populated with geophysical instrumentation, and the data are still a little bit scarce. We are playing a major role in putting infrastructure in Africa.



Hermanus Magnetic Observatory

Artist's composite of space weather, showing the Sun's interaction with the magnetic field of the Earth. Centuries ago, explorers observed the southern sky, as they rounded the Cape of Good Hope, hoping to find a sea route to the East, and before 1600, they made measurements of the Earth's magnetic field to aid navigation. This region was also of particular interest, because of the South Atlantic anomaly, a region of weakening of the Earth's magnetic field.

Cosmic Radiation

21st Century: People have been looking at how galactic cosmic radiation affects Earth's climate, and geophysical phenomena, and have noted changes in the ionosphere, for example, preceding earthquakes. Have you looked into that?

McKinnell: We've not really concentrated on precursors to earthquakes or the effects of cosmic rays. But there are people globally who are studying just that, particularly precursors to earthquakes—the huge disasters that have happened in Argentina and Japan, for example. We do run networks of ionospheric equipment that tell us about changes in the ionosphere. But we're interested in the ionosphere for another reason, in South Africa.

We're interested for our ability to communicate through the ionosphere, with radio waves. In Africa, that's very important. Because not all African countries can afford satellite communications, a lot of them are still using high-frequency (hf) radio-wave propagation through the atmosphere. In South Africa, we still use hf radio-wave propagation quite a bit. So our space weather center, until now, has concentrated on being able to predict communication via the ionosphere; being able to predict frequency changes. And then also just looking at warnings, in relation to space weather.

For example, we monitor the Sun. We don't have any solar satellites ourselves. We use the data from U.S. and European satellites.

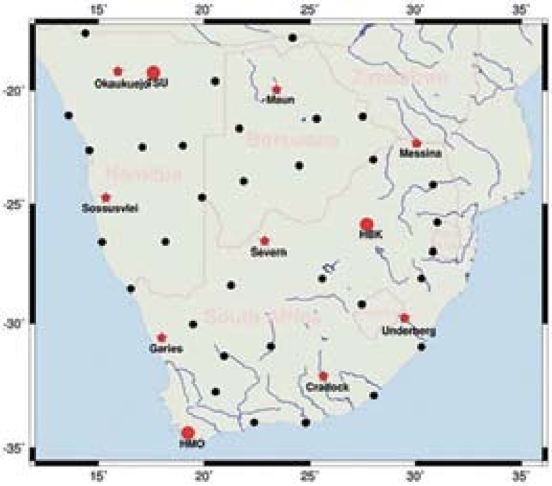
Space weather starts with the Sun. So no matter what your interest is, you're always going to start by looking at the Sun. We do have requests to notify people when there is a coronal mass ejection from the Sun. We are trying to give some indication of how long it will be before it hits the Earth. We've concentrated on the communications side. Anybody who wants to know, can find out from our website or from contact with us, or from subscription services we offer: "This thing has left the Sun, and is heading towards Earth."

Then there is a whole range of things that come after that. What happens when it hits the Earth. If you're using GPS, is it going to be affected? If you have a long pipeline, and you're piping something from here to North Africa, should you stop it for a few days? We provide the information up to a point. The customer, the client, the person on the other side, will decide how serious it is, and what to do.

Then, on top of that, we are also running an investigation where we gather data from different people who are affected by these things, and look at ways in which we can tell you, "Okay, a coronal mass ejection has left the Sun. It's going to hit the Earth. Now it has hit the Earth. This is the effect it had on the ionosphere, and because of those effects, this is the likelihood that something will happen to your equipment." We're not quite there yet, but we're working on that.

We hope to be at a point where we can say to you: "This afternoon at 2:00, there was a coronal mass ejection; we saw it, we know it's there. It is likely to hit the Earth's atmosphere four days later," and give you a probability: "These are the effects that are likely to happen," be it to satellites, to power lines, to whatever it is that you're operating.

We also, at SANSA, will be looking at satellite programs for South Africa. Every country that has a satellite program, has a direct link to the space-weather center. You're not going to spend a lot of money on your satellite, and then put it into an environment that is currently unstable. You want your satellite launch window to happen at a stable period of the Sun's activity. So you will keep in constant contact with your space-weather center.



The map shows the magnetic measuring stations in southern Africa. where measurements were recorded in 2004-2005 The large dots are the three stations with continuous-recording magnetic observations—Hermanus (HMO), Hartebeesthoek (HBK), and Tsumeb (TSU).

Extreme Weather Events

21st Century: Changes in the Earth's magnetic field have an impact on the amount of cosmic radiation that reaches the Earth's atmosphere, which appears to have an effect on the process of nucleation to create clouds, for example.

McKinnell: There are three things in your question. The first, is that currently there's been no scientific evidence that relates space weather to terrestrial weather. The weather all around us we now phrase as "terrestrial weather," to distinguish it from space weather. But that's not to mean that there isn't a correlation; and there is a group of people who are trying to correlate terrestrial weather data and space weather data.

For example, we do do some science that involves lightning strikes, and waves in the atmosphere. There is a group in South Africa that is studying what we call the heliosphere, the Sun's atmosphere. A portion of that group was looking at cosmic rays, solar cosmic rays, and the effect on the Earth's magnetosphere, and trying to model the effects.

There are two spacecraft that have recently gone into the edge of this heliosphere—Voyager 1 and Voyager 2. Those spacecraft have released a whole lot of new data that these scientists are very excited about, and probably will show us much more than what we've seen before. At least that will validate the models, anyway.

Our atmosphere protects us from the solar cosmic rays. We have done no studies to see whether those cosmic rays are penetrating further down in the atmosphere than we believe they are. However, the reason we believe they are not penetrating down very far, is because of the ionosphere, which are the dense layers that protect us.

So, at the moment, what I can tell you is that the extent of the cosmic ray effects on people on Earth is very small. The Earth's atmosphere is doing a good job of protecting us.

The effects of any kind of particles that the Sun ejects are first felt in the magnetosphere, usually in the form of a magnetic storm. The study of magnetic storms is something we do know a lot about, and have done a lot of work on, because that's the first time you feel the effects of space weather. A magnetic storm compresses and expands the Earth's magnetosphere, and that has an effect on the ionosphere; and that, in turn, has an effect on radio communications and other things. We can measure it, we can see the Earth's magnetic field, and that is part of what the space-weather center does. It will look at raw magnetic data. It turns it into what we call an index, and the level of that index tells us the severity of the event—whether it's a minor, or moderate, or severe magnetic storm.

There have been a lot of studies of coronal mass ejections coming off the Sun, which is particles being thrown at the Earth's magnetic field, geomagnetic storms or events, and the ionosphere. That link is fairly well known. There are lots and lots of scientific papers published on that link. What we're trying to do now—

The Hermanus Observatory is one of 12 regional facilities of the International Space Environment Service's Regional Warning Center Network. The centers are responsible for issuing warnings of geomagnetic storms that can affect radio communications, long-distance pipelines, and electric-power grids on Earth.

and we have got some scientists working on it in SANSA—is looking at the lower atmosphere, which is still above terrestrial weather, looking at that effect and whether what we see is different when we have a geomagnetic storm.

And we've recently installed a piece of equipment in Hermanus called a Doppler radar, which will basically sound the atmosphere at a very low frequency, continuously at certain times, but only at that one single frequency, and bring us back spectrograms that will allow us to see disturbances and irregularities in the ionosphere, mostly in the lower ionosphere. We're hoping to see a correlation between those, and the geomagnetic storms, which happen much higher up. So we haven't gotten down to terrestrial weather yet, but we're coming down in our science!

Particularly in this kind of science, we specialize in two ways: in the area in which you have expertise, so if we have scientists who are interested in certain aspects of the space environment, we tend to build a specialty around them; and then, in terms of the needs of that particular country. That's why our space-weather center has done so much hf propagation work, because that happens to be a need in this particular area.

Hermanus Magnetic Observatory

Hermanus has graduate students from all over Africa, and conducts outreach programs for younger students (shown here).

The 'Extended Solar Minimum'

21st Century: There was a lot of concern about the lateness of the onset of this current solar cycle. Is that an area that you also can measure and confirm, looking at the changes in the Earth's magnetic field?

McKinnell: We monitored that. It's been termed "the extended solar minimum of 2007." I think 2007 was when we thought the end of it would come, but it was a much longer solar minimum than the previous one, which was 11 years before. The concern was that the last time such a long solar minimum had been seen was what we called the Maunder Minimum, beginning in 1645, which was the mini-ice age.

Another concern was that after a solar minimum, the next thing you worry about is the solar maximum. The question was: What is this going to do to our solar maximum? Does this mean we get an enlarged solar maximum or that the solar maximum will be delayed, because the whole cycle has now been shifted by the extended solar minimum?

As far as measurements are concerned, of course we were measuring throughout that period and we monitored the Sun. Space-weather enthusiasts and operators don't get very excited during that time, because nothing is happening on the Sun, so everything else is quiet. During that time, everybody was complaining that there was no activity on the Sun. "What's happening?" was a question we got asked a lot.

We have a period of solar data which we didn't collect ourselves, which we have access to, and the whole array of geomagnetic data which we did collect ourselves. So now, there is a whole research study into whether it's possible to model the effects during the solar minimum. What effects did it have on ionospheric propagation? You don't assume that nothing is going on. Let's have a look at the data, and see.

And also, what are the effects now? I think it's going to open up a whole interesting area of study now, going into the next solar maximum, because I've seen quite a few scientific papers coming through, where they refer to the extended solar minimum and its effect on the magnetosphere and on the ionosphere. They're looking at the correlation between data during that period; but we're also looking at what happens immediately after that period.

21st Century: The Sun doesn't often make front-page news, but this extended solar minimum was very heavily publicized.

McKinnell: Yes. And the Sun is going to be making more front-page news in the coming years, as we go towards the solar maximum. Because now the Sun is getting more and more active, and the solar maximum is predicted for the end of 2012, beginning of 2013. There is a six-month uncertainty on the prediction, because of how these things work. And that prediction has been shifted up because of the extended solar minimum. All indications are that the solar maximum will be at the same level of the previous one. The majority of predictions have shown that, but, of course, we don't know.

The difference between now and 11 years ago, is that now we are really dependent on technology that could be disrupted by solar events. Now we do need to be aware. Eleven years ago, we were doing research on it, of course, but it wasn't making front-page news, and we weren't concentrating on the forecasts and predictions. Eleven years ago, you used a normal phone, or waited until you got home to make a call. Now there is a good chance that you don't have a phone at home, because you're dependent on your cell phone. So our technological dependence has grown remarkably in the last 11 years.

That's why we need to be up-to-date with space weather. That's why we need regional warning centers. That's why we need people who are trained to forecast and predict. You know, a researcher—he knows his data—but most researchers cannot look at the Sun and tell you exactly what it's going to do to technology in four days' time. A good forecaster can. And that's why we are trying to develop good forecasters here to work alongside the researchers and interpret.

21st Century: I'd bet that your goal is to do better than the weather forecasters, who are about 50 percent accurate!

McKinnell: . . .The thing that we don't fully understand yet, and we are still grappling with, is the history of data, keeping the history of what's happened before. The Sun is very predictable, except for the lower solar minimum, I guess. But every 11 years, it will do something. We have all of that solar data, going back to the 1600s. There's a very good reason why it's been kept, and we should be keeping ours, and we are, by the way, keeping our data as well as delivering real-time data.

Archiving the data is just as fundamentally important. The really good models take the physics into account, but they use the history and data, of what came before, to help us decide what's going to come in the future. And that's also going to really, really help us.

21st Century: It is quite remarkable that this data, from the 1600s, has been preserved.

McKinnell: The curiosity and the need for scientific knowledge have always been there. One of the first things scientists were sensitive to was the presence of the Sun. And I think it's great that they had the presence of mind to keep it. And I think it was scientific curiosity that drove that, rather than the thought that "400 years from now, they're going to want this data."

Typically, we don't use the data from 400 years ago; we only use the data from three or four solar cycles. But the sunspot number data base is the longest archived data base, ever. Ionospheric data, we only started archiving in the '50s. Geomagnetic data, I don't think even goes back as long as that. There is also the whole thing of how you keep and record the data, and technology has helped us with that.

SANAP

SANAP

Hermanus runs an active program in Antarctica. Here, Antarctica SANAE IV: South Africa's base station. Inset is a GPS station at the base.

21st Century: At the Hermanus Observatory, how many people are involved? Do you have people from other countries?

McKinnell: Absolutely. We have a number of international collaborations. It's very important for space science. In fact, next week, we are hosting an international workshop of 65 delegates, 60 of whom come from other countries. So this weekend we are going to have a huge influx of visitors to the facility and to Hermanus.

Our permanent staff is South African, but we have students that come from the rest of Africa. One of the ways in which we work with the rest of Africa is through training and helping them to build capacity in their countries, and the exchange of expertise. We are going to have at least 25-30 African scientists joining us next week for the international workshop, all of whom are contributing in their own right. In our student exchange, we have a number of students from other African countries, who are getting Ph.D.s and Masters degrees in space science, and want to go back to their countries and work in the space-science programs. In any given month, we have a good flow of people travelling and people coming in, and I think that's what keeps the science alive.

The Southern Hemisphere

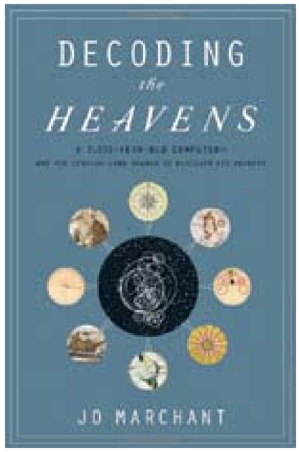
21st Century: The International Astronautical Congress here in Cape Town was organized for all of Africa, so there is a large role for South Africa to play on the continent. You have a special geographic position globally, but there are other countries, such as in Latin America, that are also relatively close to the South Pole. Are there other, sister, observatories in the Southern Hemisphere?

McKinnell: Argentina, Brazil, and Australia have very vibrant space science programs, and we work very closely with them. Two years ago, when I needed to send a young person to learn about space weather operations, I sent her to Australia, because they have quite a fantastic space weather center there, and they know about space weather forecasting in the Southern Hemisphere, and I wanted her to get a Southern Hemisphere perspective. They were very happy to help.

We run a very active program in Antarctica. We have a suite of equipment down at the South African National Antarctic Expedition Base, and one of those is in high frequency radar which is used to observe irregularities at the poles. It is part of the International Super DARN (Dual Auroral Radar Network). We run one of the Southern Hemisphere radars. The other one is the Halley Research Station run by the U.K. And the two of them have overlapping beam patterns, which allows you to see a certain kind of irregularities, which is the way that Super DARN works. It's an international network of polar high frequency radars. We send people down there every year, to look after the equipment and to maintain it. It's very much a part of what we do.

An Encrusted Mystery: The Saga Of the Antikythera Mechanism

by W. Leonard Taylor, M.D.



Decoding the Heavens: A 2,000-Year-Old Computer—and the Century-Long Search to Discover Its Secrets
Jo Marchant
New York: Da Capo Press, 2009
Hardcover, 328 pp., $25.00

To anyone who has even a tangential interest in the Antikythera mechanism, I highly recommend Jo Marchant's book *Decoding the Heavens*. My interest dates back to 1959, when Derek J. de Solla Price published an article in *Scientific American* entitled "An Ancient Greek Computer." I was amazed that such a complex mechanism of antiquity was not better known. Unfortunately, it still remains obscure.

Through the years, the published papers on the mechanism have increased asymptotically. Jo Marchant has done a great service to the present generation, by condensing and presenting it in an interesting way. I fervently hope this book will finally cause the teaching of history to no longer omit the most significant discovery of antiquity, and allow it to be given the emphasis it deserves.

Here, I summarize the story, as told in *Decoding the Heavens* and selected other sources listed in the Bibliography.

The saga of the Antikythera is about an incredibly miraculous chain of events. The ending is still in progress, but it has revolutionized our understanding of the genius of antiquity. This report, for the most part, is not about mechanical detail, but rather about the people who strived to make the incomprehensible comprehensible—and how their lives were forever changed, as they unraveled a creation historians could not believe and still have trouble accepting.

Never before has there been a discovery so long enshrouded in mystery, which, on being unraveled, resulted in such an unparalleled shift in traditional historical thought regarding the genius of deep antiquity. Without this information, the world would have been left with a fateful historical blunder.

How It Began

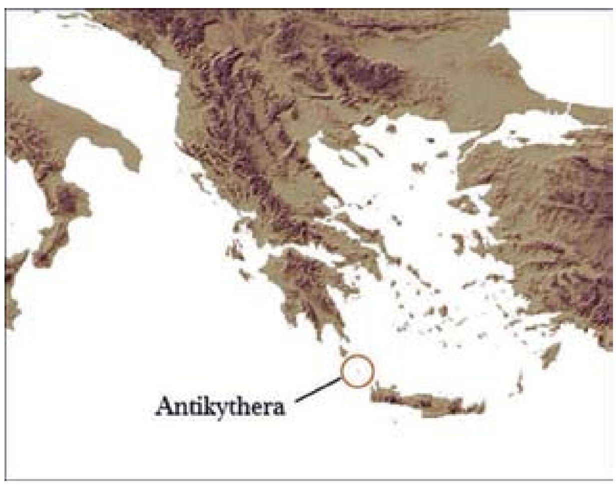
My interest in this saga began in June 1959, upon reading that article in *Scientific American* entitled, "An Ancient Greek Computer." By contrast to men who literally gave their lives in the study of the mechanism, mine was limited in trying to keep up with the literature, and a trip to Athens to see the instrument in person. Articles were few and far between for about three decades, gradually leading to a trickle of information.

Then, about 15 years ago, it became a torrent. So much so, you would think that everyone in the world knew about the Antikythera mechanism. But even to this day, as monumental as this object is, one finds that most individuals have never heard of it.

A 300-ton ship, laden with magnificent marble and bronze Greek artifacts set sail from Pergamon in about 60 B.C., headed for Rome. This was a period of transition in which the Roman Empire was in ascendancy. The wealthy were decorating their villas with coveted works of Greek art, and this ship was filled with objects to satisfy the demand.

On this journey, the first of a long series of unanticipated events occurred. First, a great storm arose causing the

The harbor at the island of Antikythera, where sponge divers in 1900 found the ancient wreck from ca. 60 B.C., with its load of Greek artifacts, including the torquetum device.



A view of the Antikythera mechanism found in the ancient ship.

overloaded ship to take on water. The ship and all its artifacts began to sink. But instead of going to the bottom, the ship came to rest on a narrow ledge, 130 feet below the surface, on the side of a tiny island, where it lay avoiding detection for more than 2,000 years, while Empires were formed, grew, and crumbled.

Historians pontificated: It was universally agreed that the Greeks could never have made the mysterious object, which was subsequently found on board that ship. Therein lies the crux of this tale. The historians now have been proven wrong, and the genius of the Greek civilization has been firmly established. The impact this has had on understanding the scientific knowledge of the Iron Age is beyond monumental, as author Jo Marchant shows.

During the 2,000 years it lay hidden in the sea, it escaped destruction, along with many other creations of the demonized Greek civilization. So its watery 2,000-year sequestration constitutes another link in the chain of fortunate coincidences.

The discovery was made by a group of very hard working sailors, who made their living harvesting sponges. Their profession resulted in high mortality and morbidity, because of a danger they had no way of understanding. They knew, of course, the agonizing afflictions and frequent death of their fellow divers, but the high demand for sponges made for high incomes of those that survived.

This affliction we now know to be caused by bubbles from nitrogen dissolved in the blood under the pressure of the deep water. The nitrogen in the dissolved state is actually not the main cause of the problem. It is rather due to a phenomenon the modern world observes every day as they open a can of carbonated beverage. There is an instantaneous formation of bubbles.

The bubbles that form as the can is snapped open are caused by the dissolved carbon dioxide gas that was forced into the liquid under pressure during manufacture. In the situation of the sponge divers, it is dissolved nitrogen, the main constituent of the air we breathe, which is forced into the blood stream under the pressure of the deep water. The release of this pressure, like snapping the lid of a pop bottle, happens if the diver surfaces too rapidly, producing bubbles in the blood stream.

The tiny bubbles aggregate, causing blockage of flow of blood through the small blood vessels. These small blood vessels are precisely where oxygen is transferred to the tissues, to keep the tissues alive. The tissues then become necrotic, resulting in agonizing pain and death. This condition is known clinically as the bends.

Sponge-diving had been a constant source of income from before the time of Homer, about 1000 B.C. The divers could descend to 90 feet below the surface. The duration of their dives was limited by their lung capacity, so, of necessity, was of short duration. This prevented the divers from developing the bends. Short-duration dives are not a risk, because it takes time for the nitrogen to go into solution.

This all changed in 1837, when a prolific German inventor by the name of Augustus Siebe invented a diving helmet attached to a watertight suit. Air was pumped down by a compressor. Now the divers could go down to 220 feet and remain there. By about 1865, the suits were brought to Symi, the home of most of the sponge divers.

Fortunes were made. Of course, it was all too good to be true. No one there knew at that time about the bends, although it had been described in the 1840s in miners, and in people working on the footing of bridges. The name "bends" came from the tortured body position, some of which simulated a popular pose known as the Gratian Bend.

Between 1886 and 1920, about 10,000 divers died and 20,000 were paralyzed. One can imagine the adverse impact this had on the families and lives of the sponge divers. Subsequently, most of the helmets and the suits were abandoned throughout the Mediterranean Sea.

The Discovery

A group of sponge divers, returning from Tunisia in the Summer of 1900, risked death by continued use of the helmet. They travelled in small boats, carrying 15 divers who would share one battered helmet. When they reached the passage between Cape Malea and Crete, they encountered a great gale. Captain Kontos, sought shelter off a small island.

Three days later the shrieking wind in the rigging began to abate and calmness returned to the surface. So there they were, next to this small island, in a region noted for its lack of sponges. They were tired, with a boat full of sponges gathered in Tunisia, and eager to go home. Then the last thing one would have expected happened.

Elias Stadiatis, one of the divers, had an unusual thought. We will never know exactly why, but he decided to dive.

This dive forever changed the world! To the amazement of those on deck he surfaced in just 5 minutes in a very agitated state. He was convinced that a ship had recently sunk depositing a heap of naked women. Captain Kontos immediately went down and discovered a 150-foot-long deposit of bronze and marble statues, corroded and encrusted with marine sediment.

Kontos resurfaced, carrying of all things, a bronze arm. The finding of a bronze arm from a statue generated tremendous excitement in Athens and throughout Greece. The bronze arm dated the wreckage to be at least 2,000 years old.

An 1873 newspaper illustration of the Siebe diving invention, which made it possible for sponge divers to descend 200 or more feet.

Within days, a Greek navy transport, bearing Kontos, his divers, and an archaeologist, arrived at the site. It was November 24, 1900. As the artifacts were transported to the National Archaeological museum, crowds came from long distances to see the treasures, corroded as they were. Every day, newspapers carried the unfolding drama, in scintillating detail. It was the largest find of ancient Greek bronzes ever found.

Then problems arose. The divers were having problems finding more artifacts, partly because so many had been taken out, and partly because large boulders obscured the objects. The archaeologist determined that the huge boulders had been dislodged by an earthquake and fallen from the cliffs above the water.

A scheme was devised to pull several of these monstrous boulders over the subterranean ledge into the abyss below, which extended down to 11,600 feet. Fortunately, another archaeologist, Spyridon Staïs, came aboard. He had another idea. Could those boulders be colossal statues so overgrown that the divers could not recognize them. And that is exactly what they were!

For the next 40 years, the experts argued the age of the artifacts, and wound up with a very wide range, spanning the 2nd Century B.C. to the 3rd Century A.D. There was great interest in knowing the date, because taken out with the statues was an encrusted bronze mystery, the likes of which had never before been seen.

The Antikythera Emerges

The object would take more than a century to unravel. It became known as the Antikythera Mechanism because the small island's name, where Captain Kontos had sought shelter, was Antikythera. The name comes from the island's close physical distance to a larger, nearby island by the name of Kythera.

Then came another calamity. Bronze, which is 90 percent copper and 10 percent tin, is relatively safe so long as it remains in seawater. Had it been constructed of iron, it would have soon become an amorphous lump of sludge.

But by a fortunate coincidence of inorganic chemistry, seawater reacts with the copper in the bronze, forming copper chloride. Tin in seawater forms tin oxide. The two compounds form a thin protective film of copper chloride and tin oxide on the surface of the bronze, protecting it from damage. So it would seem that all was well.

However, removing the bronze from the sea results in a series of chemical reactions in which the oxygen from the air, along with moisture, reacts with copper chloride, forming hydrochloric acid. This acid attacks the underlying bronze to form more copper chloride, which again reacts with the oxygen in the air to form more hydrochloric acid. This will go on forever destroying the bronze and whatever object it is made into.

This fate nearly became a reality as this object remained in a crate in the open courtyard of the National Archaeology Museum. It could have remained unnoticed and would have self destructed, except by a chance coincidence of a museum worker eight months later, who picked up the decaying lump and carried it to the museum director, Valorios Staïs.

The outer layers of the artifact had been completely destroyed. The slightest touch caused the powdery material to crumble beyond recognition. Staïs was an ambitious well-trained individual who had studied medicine and archaeology, and became director of the prestigious Archaeological Museum at the age of 30. Since 1889, he had been working on arranging and displaying the artifacts that found their way to Athens.

This object was completely different. He had never seen anything like it. Recognizable gear wheels were present. Author Marchant comments, "The overall effect was eerie and otherworldly, like finding a steam engine on the ancient pitted surface of the Moon."

The cogs and gears had small carefully crafted teeth that required a magnifying glass to count. Staïs was overwhelmed. This mechanism had to be 2,000 years old. But it couldn't be. Nothing like it had ever before been discovered in antiquity. Besides, the Greeks were not supposed to have this degree of sophistication. Clock works didn't show up in Europe for another 1,000 years.

Staïs knew he was in over his head. He made contact with two expert consultants: John Svoronos, director of the National Numismatic Museum of Athens, and one of the most serious archeologists in Greece; and Adolf Wilhelm, a brilliant young Austrian expert in inscriptions, who was in Athens at the time.

Wilhelm determined the device to be dated between the 2nd Century B.C. and the 2nd Century A.D., while Svoronas dated it to the first half of the 3rd Century A.D. Svoronas worked with Pericles Rediadis, a professor of geodesy and hydrography, who provided the first technical account of what he called "this completely strange instrument."

Svoronas noted that the instrument was carried in a wooden box, and decided it was not a piece of cargo, but rather a navigational instrument. He put great weight on a very unusual technical Greek word referring to a graduated scale. This launched speculation that this object was some sort of astrolabe, an instrument dating back into antiquity, which could find the time and position of the Sun and stars. Astrolabes were not used aboard ships to any great extent, as they could not give longitude or latitude.

Not an Astrolabe

During the next few years, scholars at various archaeological institutes became involved in trying to understand what this device was. The battle heated up as to whether this was or was not a modification of the Astrolabe. Then, Albert Rehm, an investigator from the University of Munich, discovered a previously hidden Greek word, "Pynchon." Derived from an ancient Egyptian Calendar, Pynchon means month.

Astrolabes had nothing to do with months; therefore, the mechanism had nothing to do with Astrolabe technology, as Marchant discusses.

The work on the object was completely stalled by the First World War. Then, John Theophanidis, an admiral in the Greek Navy, became interested, and found what he thought was a zodiac scale. He became convinced that the Antikythera was a navigational instrument. He spent many years studying and analyzing the inscriptions, and constructing a model of the gear work. His work became so passionate that he sold his real estate in the center of Athens to finance his research. But, unfortunately, he didn't publish, and his years of work lay hidden in piles of papers after his death.

Many other individuals subsequently made contributions, but their story must regrettably be omitted from this review. In the meantime, Albert Rehm, who had found the word "Pynchon," had become a rector at the University of Munich. His increasing recognition came during the rise of Hitler, and he eventually lost his position because of his hostility to Hitler.

After the war, Rehm was reinstated, only to lose his position again in 1946, after a disagreement with the new authorities regarding the importance of classical studies in German education. Despite his academic dissonance, for the rest of his life, Rehm constantly studied and analyzed the geared mechanism. But its mystery eluded him; the keystone paper was never published, and he died in 1949.

During the Second World War, this priceless mechanism was in great peril as the Nazi invasion of Greece put everything in the museum at risk. The museum staff hid objects in caves and in bank vaults, buried them in underground deposits, or hid them under the floors of the museum and covered them with sand. After the war, it took 20 years to get the museum back together. In the confusion, many of the artifacts had been lost. But, by another miracle, the Antikythera mechanism survived.

The previous excitement was gone, however, and the device was largely forgotten, languishing in the bottom of a storeroom box.

More Discoveries

During the 20 years that the museum was reorganizing, important things were happening. Jacques Cousteau and Frederic Dumas visited the underwater ledge with their improved diving equipment, once in 1953 and again in 1976. They found additional objects, but their main contribution was a chance finding of two stacks of coins, one silver and the other bronze. These finds resolved the questions of previous efforts to date the sinking of the ship, and to determine where it had been before it departed on its ill-fated voyage.

Inscriptions on the coins tell who issued them. This information, along with the fact that the coins do not stay in circulation for very long, helps to determine date, better than anything else. The silver coins were from the city of Pergamon and had the initials of a ruler who ruled in Pergamon from 85 to 76 B.C. The bronze coins were from Ephesus, 100 miles south of Pergamon, and were dated from 70 to 60 B.C.

During this period, an American archaeologist, Peter Throckmorton, was working at the museum in Athens, and one of his goals was to get a fragment of wood from the boat tested by radiocarbon dating. He had an impatient personality that did not always follow accepted protocols, and was frustrated that the museum staff refused to let him take away some of the wood from Athens.

However, he managed to spirit away a tiny fragment to the laboratory of Elizabeth Ralph, in America, one of a very few scientists who knew the technique of radiocarbon dating. The radiocarbon dating of the boat gave an age of 260 B.C to 180 B.C. Keeping in mind that the boat was made of wood older than the boat itself, and that the boat had likely been sailing for some time before it sank, there is excellent correlation of the radiocarbon and coin dates.

Of interest is the construction of the boat. It was similar to techniques that had lasted for 3,000 years. In contrast to the modern, less expensive techniques, in which the frames are built before the planking, in this boat, the hull was built first and then the frame. Furthermore, the hull was built with the labor-intensive mortise and tenon construction used in fine furniture, which made for a very strong sturdy ship.

Another captivated individual was Derek J. de Solla Price whose article had caught my attention in 1959. He was born in 1922 in England, and obtained a Ph.D. degree in experimental physics at age 24. He went on to obtain a second Ph.D. degree in the history of science. Then he came to the United States as a consultant to the Smithsonian Institution, and a fellow of the Institute of Advanced Studies in Princeton, spending the remainder of his life at Yale University.

Price took interest in the Antikythera Mechanism in 1951. His great contribution, in addition to understanding this instrument, was to popularize it. Despite his work in other areas of science, the Antikythera mechanism was always on his mind. He spent inordinate amounts of time counting the teeth in the gears and attempting to make sense of their interrelation. Price said: "Nothing like the

Michael Wright, a curator at the London Science Museum, who became fascinated with the Antikythera mechanism, and spent years piecing together the puzzle of how it worked, and what its purpose was. The photo is from his presentation, "The Greek Planetarium: A New Reconstruction of the Antikythera Mechanism," an American Institute of Archaeology Lecture Program, at the Adler Planetarium in Chicago, October 2006.

instrument is preserved elsewhere. On the contrary, for all that we know of science and technology, it could not exist."

Price did not win friends by telling those who had carefully studied a subject all their lives that they were wrong. But he knew that his own conclusions had a high chance of error because of his limited information. When he read a technical report from the Oak Ridge National Laboratory on how gamma rays could be used to study archeological objects without destroying them, he wrote to the lab director, Alvin Weinberg. Weinberg put Price in contact with a radiography lab in Athens.

As so often happens in science, such networking leads to a major discovery. Deep within the encrusted object were even more gear trains than had been expected. Getting the newly discovered gears to make sense in terms of the periods of the Sun and Moon led Price to only one conclusion: He was convinced that he was looking at a differential gear train!

Enter Michael Wright

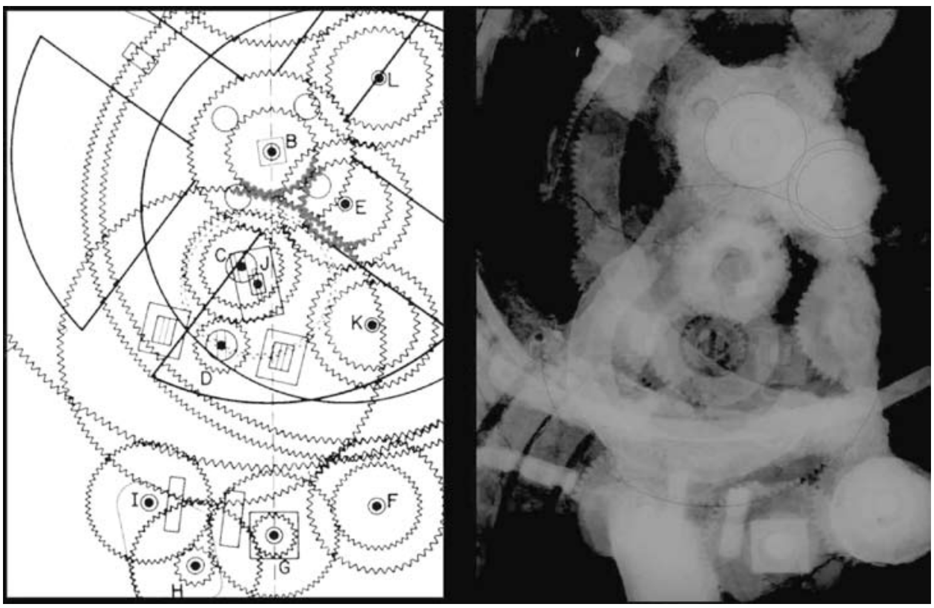
Without Price's enthusiasm and drive, it may have taken decades longer to piece everything together. Price's last paper, "Gears from the Greeks," sparked another life-long obsession with the Antikythera Mechanism. This time, the torch was passed to Michael Wright, a 26-year-old assistant curator at London's Science Museum. Price moved on to computer technology and artificial intelligence, while Wright scrutinized every detail of Price's publications.

Questions arose about the differential gears supposedly used to calculate the phases of the Moon. The emphasis Price had given in his earlier *Scientific American* article to the motion of the planets, was hardly mentioned. In 1983, Wright wanted to discuss things with Price on his next visit to the Science Museum, but unfortunately, just at that time, Price died.

As Wright studied Price's work, more and more details worried him. In particular, he found that Price had discounted and altered many of the tooth counts. Wright had studied carefully the ancient clocks in the Science Museum and understood gear trains well. Price's conclusions didn't make any sense.

Price had argued that a particular dial exhibited a 4-year cycle, but Wright noted that the mechanism had 7 gears and a dial of 7 concentric rings. Why, Wright wondered, did someone go to all the trouble? Price had a lot of insights, but Wright could see that he had barely scratched the surface. As Wright dreamed of going to Athens, he studied ancient astronomy and brushed up on his Greek.

Then, an energetic astrophysicist from the University of Sydney, Allan G. Bromley, came into Wright's life. His expertise was interstellar gas, which required high-power computing, and so he studied the history of computation. In the course of this work, he became aware of Charles Babbage, who had worked with the famous astronomer John Herschel in the early 1800s.



An X-ray image of the Antikythera gears with one of Wright's gear diagrams.

Through Herschel, Babbage saw the tremendous need for precise astronomical tables. So Babbage, then a 29-year-old mathematician, began a project to do just that. He filled numerous notebooks with notes and drawings of his ideas, and the British government paid a fortune to Babbage to produce this machine.

Although none of these machines was completed, the London Science Museum held the largest collection of Babbage's work, and Bromley would spend his Summer vacations there in London. By the mid-1980s, he understood enough of Babbage's notes to start construction, but he had questions about how the parts would have to be made and assembled.

Wright, a highly intelligent curator and a master craftsman, knowing clocks inside and out, was assigned to work with Bromley on assembling one of Babbage's calculating machines. With Wright's insights, a most ambitious scientific reconstruction began, costing a quarter of a million British pounds. By November 1991, their computer turned out its first calculation, one month before the bicentennial celebration of Babbage's death. During Bromley's many visits to the London Museum of Science he and Wright became friends, and Wright introduced the Antikythera Mechanism to Bromley.

At the same time, Wright talked of his dream to go to Athens and study the mechanism firsthand. Price's paper was discussed and Wright indicated the areas where Price had gone wrong. Immediately, like many before him, Bromley became totally captivated. His mind began to form a new plan of action. He would be the first man to solve its mystery.

Bromley returned to Sydney and put together a working alternative sequencing of the gears. Wright, by contrast, was even more rapidly losing faith in Price's reconstructions. Just before Christmas 1989, Bromley suddenly burst into Wright's office announcing he had just returned from Athens where he had obtained permission to work on the Antikythera mechanism!

This was more than Wright could bear. How could this man from Australia, his friend and confidant, steal his ideas? There was a written code of Greek antiquities that no researcher could begin work on an artifact until the person already working on it had finished. But then the nature of Wright's character and dedication broke though, overrode his depression. He went to Bromley and asked if he could go to Athens—as his assistant.

Bromley agreed, and for the next 30 days they photographed and measured everything in detail. It became clear that Price was wrong in many important details, and his model had to be discarded. Additionally, a new fragment was discovered, not known to Price. Standard X-rays were taken of every fragment. But for unexplained reasons, the images were fogged and discolored. The team ran out of time and left disappointed.

Later in England, Bromley gave a lecture to the Antiquarian Horology Society, and referred to the project as if it were entirely his. Despite this belittling of Wright, Bromley's lecture had a positive outcome. In the audience was a retired physician who had a real interest in Price's work and had attempted a reconstruction, Dr. Alan Partridge.

Partridge suggested they use a technique called linear tomography that he had used to locate bullets and shrapnel. With it, the X-rays could be reconstructed to see deeply into the interior of a human at sequential levels. Wright then studied tomography and built an improved linear tomograph suitable for metal. It worked beautifully, resulting in separating the layers to less than a tenth of a millimeter.

Wright's handsome working model of the Antikythera mechanism.

The next year, Bromley and Wright were back in Athens with Wright's tomography machine. Their first task was to find out why the X-ray images were fogged. The culprit was an incredibly careless technician using extremely old chemicals. Wright took over the darkroom work while Bromley took the photographs. They repeated this routine every Winter, and after three years, they had taken and processed 700 exposures. Wright knew that the films would provide the answer.

But then Bromley dropped a bombshell: He was taking the tomographic X-rays back to Sydney, leaving in February 1994. After five years of hard work, Wright was horrified and totally depressed. The years went by, and correspondence from Bromley had trickled to a stop, when an unexpected letter came from Bromley's wife. "If you want to see him, you have to come soon." After an invitation arrived from Bromley himself, Wright left for Australia in November 2000, with great misgivings.

It was nearly 10 years since they had begun their work together and six years since he had seen Bromley. His on again/off again friend was dying of Hodgkin's lymphoma, but even then Bromley tenaciously refused to release the films. Mercifully, Bromley's wife intervened, allowing Wright to bring the majority of the films back to England. Bromley died in September 2002.

Back in England, Wright was working nights and weekends publishing significant discoveries. By now, Wright's son was at Oxford University where he had the equipment to scan the radiographs at high resolution. At the end of 2003, things were really starting to move. Wright discovered what is known as a pin and slot component in the mechanism, which predated by 1,500 years anything like it in

Europe.

Then, another Antikythera-obsessed scientist came on the scene, an English mathematician and filmmaker, Tony Freeth. With the urging of Mike Edmonds, chief of astronomy at Cardiff University, Freeth was trying to get access to the fragments, but according to protocol, this was not possible while Wright's work was ongoing. Freeth had read Price's publications, and, like Wright, saw that the details didn't add up.

Mathematician and filmmaker Tony Freeth, who also took up the challenge of solving the Antikythera mystery. He raised the funds to provide the new technology of micro X-ray imaging to scan the Antikythera fragments, providing images with resolution down to a few thousandths of a millimeter.

Soon Freeth was beyond obsessed; not only was he going to make a film about it, but also, like Bromley, he was determined to be the man to solve the mystery. As he researched the project he became aware of Wright's publications, and mistakenly considered the technique too crude to be useful. But this led him into discovering the usefulness of micro X-ray imaging, and Roger Hadland's X-Tec Company that made micro X-ray equipment.

Freeth also read about the incredible technique developed at Hewlett-Packard by Tom Malzbender, which made it possible to read unreadable ancient clay tablets from the 4th Millennium B.C. Malzbender was working in computer graphics in Southern California. So, Freeth had two state-of-the-art companies to work on the Antikythera mechanism—but he had no money, and no permission to study the mechanism!

Freeth intensively lobbied the science community, and amassed a team of scientists, including Greece's most eminent astronomer and astrophysicist at the University of Athens, and the director of the Center for History and Paleontology. By 2005, the team had persuaded the soon-to-be-founder of Unilever to fund the project.

To gain access to the mechanism, the astrophysicist ceaselessly lobbied the Greek Ministry of Culture, and through his persistence, in June, the Ministry finally permitted Freeth to have access to the fragments for the month of September. This brought the high drama of the Antikythera mechanism to a head. It was 2006, and Wright, after a lifetime of work, was very close to solving the mystery.

Meanwhile, Freeth had to convince Roger Hadland at the X-Tec Company to make a suitable X-ray machine for investigating the fragments. This would have to be two times more powerful than anything in the world, and ordinarily would take two to three years to build. Hadland accepted the challenge. He shut down the other work of his company and put all his research and development staff on the new project.

Freeth was in a state of panic as September approached. Would Hadland be able to produce the equipment necessary to do the job? Freeth's anxiety was increasing as Wright's papers systematically were taking the wraps off the great archeological secret, and Freeth worried that there wouldn't be anything else to discover by the time they could bring all his team's expertise together.

Then in the process of improving the museum catalogs, another three large fragments and many small fragments of the mechanism were found, for a total of 82! If these fragments had been available to Wright, he probably would have by that time, solved the mystery. It was now September 2006, and the X-ray machine lay in pieces all over Hadland's research floor in England. Malzbender was already in Athens, and in seven days he had taken 4,000 photographs.

Hadland's team was working night and day, with only one week left. But the meters on his machine were registering only one tenth the voltage needed. When he yanked a cable from the generator, there was a terrific explosion. Fortunately, no one was hurt. The near-lethal explosion told Hadland that the generator was working just fine, and the fault must be in the recording instruments.

In what seems to be a miracle, within two days the apparatus was fixed and packaged for shipment—all 12 tons of it. After truck transport across Europe, the 20-meter long rig made it to Athens, where it required a police escort to clear the narrow streets of traffic. With the aid of three forklifts, all the equipment was finally packed into the research room. In one hour, Hadland collected 3,000 images, and then scanned all the fragments.

The pictures were spectacular, with resolution down to a few thousandths of a millimeter. Freeth's team had increased the number of legible characters to approximately 3,000. It is estimated there were originally 15,000. They found that operating instructions were written directly on the instrument!

Freeth's major contribution came in realizing that the apparatus had the capability of predicting eclipses. And six months later, he realized that also built into its gears, with the pin and slot, was the measurement of a nine-year lunar cycle, tracking its elliptical orbit around the Earth. Wright had predicted it, and Freeth had proved it.

Freeth set up a conference in Athens to announce his findings on Nov. 29, 2006, and he invited Wright to speak. Wright had completed his working model of the Antikythera mechanism, to present at the conference. More than 500 people were in attendance, and they gave Freeth a standing ovation.

Wright then gave a half-hour presentation: "…I have conducted [my research] on my own time and my own cost in the face of professional and personal difficulties: intrigue, betrayal, bullying, injury and illness, loss of years of my data, the long illness and death of my collaborator, and more…." Then Wright paused, and said, "Even so, I am still here."

Wright challenged Freeth on several points, which although contested at the time, were later found to be true. At dinner that night, Wright, Freeth, Hadland, Malzbender and others were sitting at the same table. The encrusted mystery had finally given up "most" of its secrets, and history was rewritten.

I use the word "most," because there is at least one more consideration. This is related to a proposal by *21st Century Science & Technology* Associate Editor Rick Sanders that the device had the potential to determine longitude aboard ship. I

Fragments of the Antikythera mechanism on display at the National Archaeological Museum of Athens. A short film of the mechanism can be found here and here. A virtual reconstruction of the mechanism by Wright and Mogi Vincentini can be found here.

have been in personal contact with Sanders regarding this proposal because of my interest in celestial navigation. He has studied how the ancients used the Moon in the determination of longitude.

The story, as told in *21st Century* magazine, is that around 232 B.C., Captain Rata and Navigator Maui set out from Egypt to circumnavigate the Earth. Maui's expedition was under the guidance of Eratosthenes, who had, by other means, determined the Earth to be a sphere with a circumference of 24,500 miles. Maui had with him an ancient navigational instrument that he called a Tanawa, later called a Torquetum, and he would have used tables brought from Alexandria drawn up by Eratosthenes.

If a known star is in a given position on the celestial sphere (measured by azimuth and right ascension), a table can be drawn up at a given location for each night, showing how distant the Moon appears to be from the star. And from this, a longitude can be determined. We know that Maui and Rata travelled as far as Irian Jaya, in Western New Guinea. Here, there is a cave, on the walls of which are drawings, left by Maui, of his Tanawa. Also on the walls was written out a proof of Eratosthenes' experiment to measure the Earth's circumference.

Farther east, in Chile, more evidence of Maui's trip is reported. Discoveries were made on Pitcairn Island, with evidence that they were there to observe an eclipse predicted by Eratosthenes.

The Antikythera mechanism, as we know, was constructed with the motion of the Moon integrated in amazing detail, including its elliptical orbit and oscillations. From the work of Wright and Freeth, we know the instrument was capable of depicting the positions of the stars, the planets, the Sun, and the Moon, and in predicting the eclipses of the Sun and Moon, as well as giving the dates of the Olympic games. But why, as Sanders asks, was so much attention given to the intricate detail of the Moon's celestial mechanics. What would justify the creation of a "Mount Palomar" instrument, to be carried on a ship?

Was it there as cargo, or more importantly, was it an aid to navigation? From a navigational standpoint it has two significant capabilities: one is to predict eclipses and the other to forecast lunar distances among the stars and planets, both of which are critical for determination of longitude. As noted earlier, one must have tables as a point of reference to reduce the sights. The advantage of a geared mechanism is that it provides a portable almanac, which would make tables unnecessary.

In modern times, we know that in 1802, Nathaniel Bowditch published a comprehensible method by which the Moon could be used to determine longitude. This revolutionized the spice trade and provided a great economic advantage for the newly formed United States.

It wasn't until accurate, affordable mechanical clocks capable of maritime use were introduced in 1850, that the Moon was no longer used for longitude determination. Sanders's work with the Torquetum, using the Moon in the determination of longitude, should refocus discussion on longitude as the real reason for the Antikythera mechanism.

Dr. Taylor has been a Pathologist at Redlands Community Hospital for 46 years. For the majority of this time he has been the Chief of Pathology and Medical Director of the Department of Pathology.

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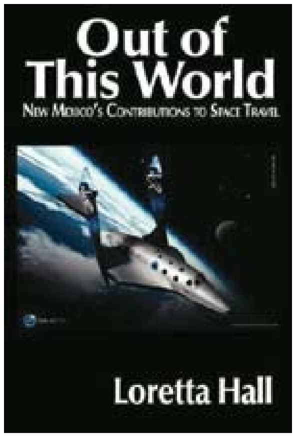
New Mexico's Role in Space

by Glenn Mesaros

Out of This World: New Mexico's Contributions to Space Travel
by Loretta Hall
Los Ranchos, N.M.: Rio Grande Books, 2011
Paperback, 175 pp., $19.95
www.LPDPress.com

When the Massachusetts State Fire Marshal banned Robert Goddard from launching any more rockets in that state in 1929, little did he know that he would set into motion a multi-billion-dollar space and defense industry in New Mexico. One of Goddard's rockets had set fire to some grass near the city of Worcester, Mass., on July 17 that year, after it rose a mere 90 feet before landing 170 feet from the "launch" site, an old windmill.

After securing funding from Daniel Guggenheim, via Charles Lindbergh, Jr., Goddard moved one train-carload of equipment to a desolate southeastern section of New Mexico, near Roswell. In the next 10 years, Goddard perfected his rocketry to the point where his last rocket, in 1937, reached 9,000 feet altitude in 7 seconds. By 1935, his rockets had broken the sound barrier.



This book tells the story of New Mexico's role in space, from the beginning to the present. It has some excellent pictures of these early rockets, which featured liquid fuels, gyroscopes, and advanced engineering, all designed in Goddard's own machine shop.

As World War II interrupted Goddard's research and development of rocketry, another scientist, Robert Oppenheimer, organized the Manhattan Project in Los Alamos to construct the atom bomb. The test bomb was detonated in July 1945, in this same desolate New Mexico desert, called the "White Sands Missile Range."

After the end of the war in Europe, in August 1945, 300 train-carloads of German V-2 rocket components arrived at the White Sands Proving Grounds in

The Alamogordo Space History Museum overlooking White Sands Missile Range.

The remains of a V2 rocket on display at the Museum (left) and an F1 rocket engine.

southern New Mexico, followed soon by several hundred German rocket scientists, led by Werner Von Braun.

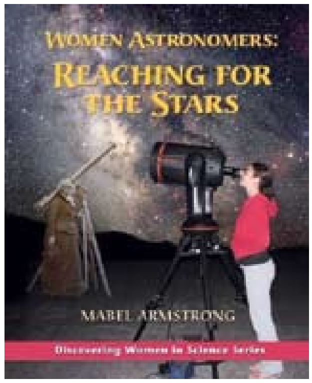
The newly assembled U.S. rocket program launched 67 V-2 rockets there between 1946 and 1951, some reaching 132 miles altitude. One of the charred V-2 rocket remains is now featured as an exhibit in front of the Alamogordo Space History museum.

Scientists used these launches for the first-ever space age experiments of the upper atmosphere, and its effects on everything from fruit flies to corn seed.

When Werner Von Braun moved his team to Huntsville, Alabama in 1951, NASA utilized the New Mexico area and R&D facilities for certain aspects of the Mercury program. The U.S. government built two huge science labs at Los Alamos and Sandia, which continue today.

Women at the Forefront of Astronomy

by Steve Carr



Women Astronomers: Reaching for the Stars
by Mabel Armstrong
Marcola, Ore.: Stone Pine Press, Inc., 2008
Paperback, 288 pp., $16.95

Mabel Armstrong has written a refreshing and inspiring tale of triumph for teenage readers about pioneering female astronomers who made great contributions in science, and who dared to challenge many assumptions of the day.

This is not a feel-good book, however, and in fact is a bit alarming, since over and over again these most promising women found that their biggest adversaries were often the prestigious universities and ivory tower research institutions which used blatant, heavy-handed tactics to discriminate against women and protect their "Big Bang"-style sacred cows.

Portrait of Hypatia of Alexandria (370-415), who designed the astrolabe for navigation.

The joy of discovery—that uniquely human quality—was usually the only reliable ally for these female heroes, whose lives were not about personal ambition, fame, or fortune.

For thousands of years, women have been at the forefront of astronomy. In the famous library at Alexandria, Egypt, Hypatia (370-415), a dedicated follower of Socrates and Plato, designed the astrolabe for navigation, along with a table of positions of stars that was used for more than 1,200 years by sailors around the world.

Caroline Herschel (1750-1848) and her brother, William, had two great passions, music and astronomy, and they built the world's largest telescope, considered to be the eighth wonder of the world at the time. They discovered Uranus, comets, and numerous nebulae, but it was Caroline's rigorous method that became the foundation of modern observational astronomy.

American Women Astronomers

Maria Mitchell (1818-1889) was the first to discover a comet in America, but had to defy the authorities at Vassar College, where she was head of the astronomy department, to carry out her work. She objected to the rules from the Vassar principal, which were obsessively concerned with creating proper ladies instead of enthusiastic learners. Mitchell violated many rules including the campus curfews, by calling her class at 3 A.M. to see a lunar eclipse.

Henrietta Swan Leavitt (1868-1921), an expert on variable stars, was reduced to working as a human computer (doing the tedious and time-consuming astronomical calculations) at Harvard's observatory, yet she discovered a method of measuring the size of our galaxy and the universe, which was considered to have been the greatest scientific advancement in 10 years.

Many thought that she had the best mind in the department, but she was personally barred by the department head, Edward Pickering from more advanced astronomy classes at Harvard. Some say that research of variable stars was set back several decades by this decision.

Another "computer," Antonia Caetana Maury (1866-1952), left Harvard because she used spectrograms to learn about entire life cycles of stars and their composition, while the department head, the same Pickering, only wanted to classify stars by brightness. If Harvard could not compete

Maria Mitchell (1818-1889) was the first in America to discover a comet.

> **"We need imagination in science. It is not all mathematics, nor logic, but is somewhat beauty and poetry."**
>
> *—Maria Mitchell, astronomer*

Courtesy of Grasslands Observatory

Some of the women astronomers who worked evaluating photographic plates at the Harvard College Observatory, under the direction of astronomer Edward Charles Pickering. The photo dates from around 1900.

with the newer, more powerful telescopes at observatories situated at more ideal viewing locations, Pickering was determined to at least impress the world with the sheer volume of raw data, and he increasingly put less emphasis on analyzing that data.

Years later, Maury did return to Harvard but was treated as an outsider in her own office and again barred from more advanced studies or research.

> **"Science is about making connections where there were none before. For that reason a broad education is as crucial as development of technical skill. Reading great literature, seeing art in all its forms, and internalizing them are challenges of understanding nature."**
>
> —*Margaret Geller astronomer*

More Pioneers

To name just a few of the women astronomy pioneers discussed in the book:

• Nancy Roman (born 1925) helped to design and build almost every NASA orbiting observatory during the 1970s and 1980s.

• Vera Rubin (born 1928) shocked the world of astronomy when she discovered clumps of galaxies that were not randomly distributed, as suggested by the Big Bang Theory.

• Margaret Geller (born 1947), who was told by her elementary school teacher that girls should not study science or math, went on to discover structure in the universe which again disproved all the prevalent theories.

These efforts continue with Carolyn Spellman Shoemaker (born 1929) who still spends 12 to 13 hours each day at the U.S. Geological Survey labs in Flagstaff, Ariz., in planetary astronomy, searching for asteroids that might threaten Earth. She developed a stereo machine that more easily allows astronomers to find any moving objects in near space.

The book ends with a few pages of photos and short personal profiles of many young and promising women starting careers in the cutting-edge research projects around the world. The last, and perhaps most provocative page of these youthful profiles has a blank photo and an empty profile that needs to be filled, merely asking, "You?"