



# O R I O N

## Newsletter of the Friends of Astronomy Cornell University



Dear Friends,

As I write this on November 30, it is snowing in Ithaca—hardly the earliest snowfall ever, but still it must conjure nostalgic memories of Cornell for all of you. And it reminds me that you will get this issue of Orion in December, so I would like to take this opportunity to wish all of you Happy Holidays. I would also like to thank you for your continuing generosity in supporting our department. I would like to single out for special mention the Josephine Hopkins Foundation, which supported two undergraduate students doing research in the department last summer, and has recently awarded us additional funds for next year. Thanks to Lee and Nancy Corbin for arranging this.

Some of you attended the DPS meeting here in October, and it was great to see you. Almost exactly one year from that meeting, on October 9-11, 2009, we are going to have a Friends of Astronomy Symposium. Along with a full slate of stimulating lectures on the future of astronomy, this symposium will feature a birthday dinner on October 10, 2009 for Yervant Terzian, who will turn 39 once again next year.

And speaking of Yervant, I am sure all of you would like to join me in congratulating him on receiving the Republic of Armenia's highest honor for scientific achievement, the Gold Medal from the Armenian Ministry of Science and Education. Mazel Tov, Yervant!

I also have very sad news to note: Ed Salpeter died just before Thanksgiving. Ed was a great scientist and an even greater man, whose genius and humanity touched us all.

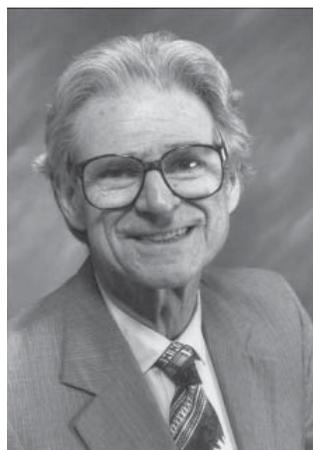
Best wishes,

Ira

### Greetings

It seems this Fall semester at Cornell has been extremely intense. Most of the time eager students talk and ask me questions not just about astronomy, but about 'everything,' including our recent Presidential elections, the global economic situation, the prospects of global warming, and yes, about planets around other stars and the chances that there is life on other planets. My experience suggests that the current Cornell students are very concerned about the future and are working very hard to make this world a better place for all.

In our Department we are also working very hard in teaching and research. In this issue of the Orion you can read about some of the exciting projects we are involved in. To bring you up to date about



*Edwin S. Salpeter*

1924-2008

Annual Review of Astronomy and Astrophysics

Winter 2008

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## The DPS Meeting at Cornell

*Jim Bell studies the geology, geochemistry, and mineralogy of planets, asteroids, and comets. He also directs the Department's Graduate Studies program.*

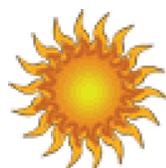


*Jim Bell, from Cornell, and Beth Clark, from Ithaca College, were responsible for organizing the DPS meeting.*

The 40th annual meeting of the Division for Planetary Sciences (DPS) of the American Astronomical Society was held on campus from October 10-15, over Fall Break. The meeting was a phenomenal success—even the weather and the foliage came off perfectly! More than 850 colleagues registered for the meeting, and almost 600 oral and poster presentations were given. Scientific highlights included special sessions on extrasolar planets, the latest space mission results, and new lunar science results. Most of the meeting was webstreamed live on the internet, and archived versions of the sessions will be available for viewing online following the links on the DPS home page (<<http://dps.aas.org>>). Another highlight



*Pre-concert dinner. From the left, Sandy Bricker, Jean Rowley, Carolyn Sampson, Ira Wasserman, Ed Hewitt, Betty Rowley, Bill Bellamy and Patricia Fernández de Castro*



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*The meetings at the Statler Auditorium.*

### Send us your e-mail!

Or update your address or phone number ...



Send a note to  
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included a phenomenal concert performance of Holst's *The Planets* and Roberto Sierra's *Anillos* by the combined Cornell and Ithaca College symphony orchestra, performed to a sold out audience in Bailey Hall. The music was accompanied by animated slideshows assembled by Astronomy Department faculty and students, showing photos from the latest missions to the planets. It was truly a pleasure being able to host the world's pre-eminent planetary scientists for a spectacular fall meeting in Ithaca!

-Jim Bell

### Greetings

(cont.)

our work, we are announcing a Friends of Astronomy Symposium here on campus from October 9 to 10, 2009. We hope to see all of you here in Ithaca. I would be especially happy to celebrate my birthday with you, as Ira has said in his letter to you. Please save the date!

On a sad note however, we are all going to miss Ed Salpeter, who died recently. His pivotal works will remain forever.

We wish you the very best for the Holiday Season.

Yervant Terzian

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## My First Year at the Most Human of Endeavors

*Second year graduate student Carl Ferkinhoff is the current president of the Astronomy Grads Network. When not doing coursework or research he enjoys singing with the Cornell University Choral and doing science outreach.*

Aristotle identified our ability to reason as the trait that sets humans apart from other forms of life. While current science may suggest that the ability to reason, at least on some level, is found in other species also, we have used the ability to reason in ways that truly make humanity unlike anything else on the planet: We have used reason and logic to understand the world around us. This is what I believe Aristotle meant; using reason to learn for the sake of learning. In this light, what can be a more human endeavor than astronomy and looking at the heavens with a questioning eye, searching to understand how we came to be?

Almost halfway into my second year as a graduate student, I find myself looking back on how I began my “human endeavor” and specifically my first year at Cornell. I started off on this path in my senior year of high school, when I read *Black Holes and Time Warps: Einstein’s Outrageous Legacy* by Caltech astrophysicist Kip Thorne (my roommate now works in Kip Thorne’s collaboration with Saul Teukolsky here at Cornell!). Thorne’s book gave me a glimpse into the realm of astronomy that has stuck with me ever since. It inspired me to study physics at Gustavus Adolphus College and participate in an internship here at Cornell during the summer of 2004. These experiences further opened my eyes to the power of science and the potential of continuing my studies at Cornell. After graduating, however, I first taught high school physics and chemistry in Baltimore for two years. It was after teaching that I arrived here, far above Cayuga’s waters, last fall.

Initially I was concerned that my time away from academia had left me ill-prepared for the rigors of graduate school. On reflection, these concerns were unwarranted. One reason why even a teacher of two years can find success here at Cornell is the Department’s academic program. At many institutions there are strict graduate course requirements. At Cornell, this is not the case; in concert with their advisor and special committee, students can choose the courses that best serve their academic needs and research interests. A second reason that helps us succeed is the spirit of science that pervades the Department. Professors, research associates and fellow graduate students are a community of scientists all deeply involved in research.

At first I was continually amazed at all that was going on around me. I would say to myself, “Wow, they control the Mars rovers on the 4<sup>th</sup> floor.” “Wow, these professors discovered evidence for the large scale structure of the Universe, and I’m their teaching assistant.” “Wow, I can discuss astronomy with leaders in the field twice-a-week over a cup of coffee, attend lunch talks on different topics from relativity to planetary science throughout the week, and learn about cutting-edge research in astronomy at the Thursday colloquium.”

These might seem like the sentiments of a star struck first-year grad student, but I think they are more than that. They reflect the level at which grads are part of the Department and especially how quickly new students are made a part of it. A week after arriving I began doing research with Gordon Stacey developing instruments for sub-millimeter astronomy (the wavelengths between infrared and radio). Throughout the year I joined other grad students for lunch with each week’s colloquium speaker. Rachel Bean randomly called on us to answer questions during cosmology to ensure we understood the key concepts. This community even extends beyond academics. On Halloween my quantum mechanics professor wore a cardboard cutout mask of Lev Landau (winner of the 1962 Nobel Prize in Physics) for the entire lecture. For Thanksgiving, Jim Bell opened his home to me and two other grads to enjoy a traditional feast. Grads and professors alike sang their favorite karaoke tunes during the Department holiday party. From day one I felt a part of the community.

My fellow graduate students in the Department were a third indispensable aspect of my first year. With students that have very disparate scientific interests, backgrounds, and personalities, you might think that life for first year grads would be solitary. This is not the case. Whether it is playing on the Big Bangers summer softball team, planning and participating in Astronomy Grads Network activities or lending assistance with research and homework, grads form a welcoming and supportive community for new students.

The other first-year graduate students were also very important. Last year there were ten of us, the largest class the Department has had in recent decades. This large group of students made the most tortuous parts of my first year more palatable. Courses like Quantum Mechanics, Electrodynamics, Cosmology, and Astrophysics Processes, while interesting, are nonetheless a considerable amount of work. Having other students to tackle them with you makes the all-night study sessions survivable.

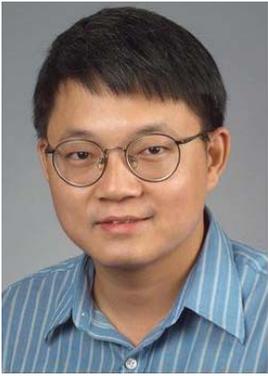
Just as Aristotle identified reason as our defining characteristic, the education theorist Paulo Freire stated, “Education is the act of freedom.” My first year in graduate school was just that, an education in science and astronomy that freed my thoughts from things around me and everyday life to focus on the heavens. It is an education that set me firmly on a path to be an astronomer and fully participate in the most human of endeavors, science!

-Carl Ferkinhoff



# Cornell Astronomers Visit Beijing

*Dong Lai works on neutron stars and black holes.*



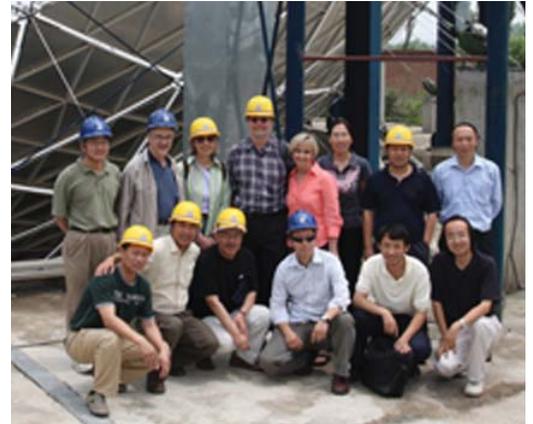
Last June 16<sup>th</sup> to 20<sup>th</sup>, a group of Cornell astronomers including Don Campbell, Jim Cordes, Martha Haynes and Dong Lai spent a week in Beijing. The main purpose of our visit was to attend the workshop “Science and Technology with Large Radio Telescopes,” which was organized jointly by Cornell and the National Astronomical Observatories of China (NAOC), and supported by a Cornell Jeffrey Lehman fund for Scholarly Exchange with China and the Chinese Academy of Sciences.

Astronomers at NAOC are pursuing the construction of a new radio telescope, the Five hundred meter Aperture Spherical radio Telescope (FAST). When completed, FAST will be one of the largest radio telescopes

in the world, sharing many technical commonalities with the Arecibo Telescope which Cornell operates for NSF. Currently, several major survey projects using the Arecibo’s new ALFA system are underway (including the ALFALFA project for extragalactic HI studies led by Riccardo Giovanelli and Haynes and the PALFA project

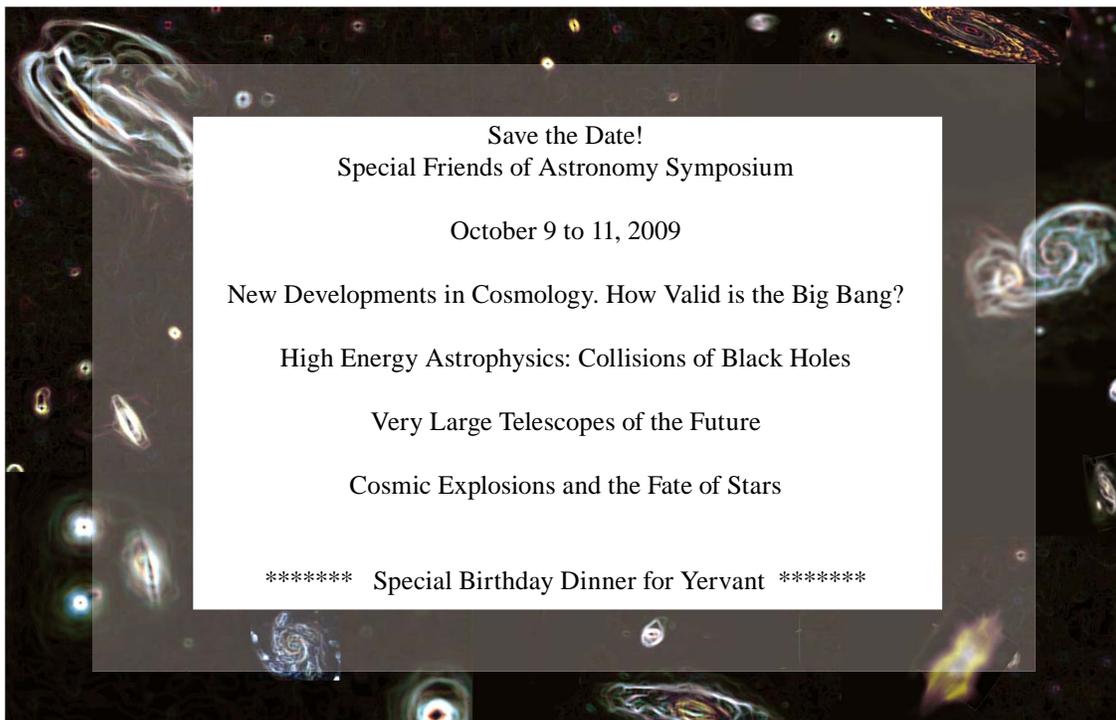
for pulsar studies led by Cordes) and are expected to produce major results in the next few years. The FAST Scientists are keenly interested in Cornell’s expertise in radio astronomy. During the meeting, we gave detailed presentations on various science and engineering aspects of Arecibo, and discussed with the NAOC astronomers possible future coordinated science and technical programs.

In addition to meeting with NAOC astro-nomers, we also spent an afternoon with the faculty and students of the Department of Astronomy at Peking University (PKU) and visited the newly established Kavli Institute for Astronomy and Astrophysics at PKU.



*Cornell visitors and the FAST scientists at the Miyun Observational Station (the site of the FAST 50 meter prototype).*

-Dong Lai



Save the Date!  
Special Friends of Astronomy Symposium  
October 9 to 11, 2009  
New Developments in Cosmology. How Valid is the Big Bang?  
High Energy Astrophysics: Collisions of Black Holes  
Very Large Telescopes of the Future  
Cosmic Explosions and the Fate of Stars  
\*\*\*\*\* Special Birthday Dinner for Yervant \*\*\*\*\*

## SOFIA:

# NASA's New Airborne Infrared Observatory

*Gordon Stacey is involved in building pioneering infra-red instrumentation to study the interstellar dust in galaxies.*

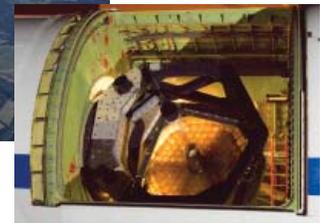
A Boeing 747SP aircraft races down the runway at NASA Dryden. Hitting 180 miles per hour, the nose tilts up and the aircraft surges into the sky. An hour later at 41,000 feet, a massive door opens up in its aft fuselage and a 2.5 meter telescope obtains its first light from stars. In a past life, this jet was part of Pan American World Airlines long-haul fleet. Delivered in May 1977, the 50<sup>th</sup> anniversary of Charles Lindbergh's flight from New York to Paris, the aircraft was christened the *Clipper Lindbergh* by Lindbergh's widow, Anne Morrow Lindbergh. The *Clipper Lindbergh* was sold to United Airlines in 1986, and retired from service in 1995. But it is now May 2009, and following ten long years of aircraft upgrades and massive modifications, the Clipper Lindbergh begins a new life as the platform for NASA's premier airborne observatory, the Stratospheric Observatory for Infrared Astronomy (SOFIA). This is the SOFIA facility's first science flight, and a far-infrared camera designed and manufactured at Cornell University is mounted on its telescope, ready to deliver unprecedented images of the gas and dust ring enveloping the super massive black hole at the center of our Galaxy.

SOFIA is NASA's third generation open port airborne telescope dedicated to infrared astronomy. Each new generation brought a factor of 3 increases in aperture, and a factor of 9 increases in light gathering power over its predecessor. SOFIA's heritage began in the late 1960's with a 30 cm telescope in an open port on a Lear Jet, and runs through the 21 year lifetime of the Kuiper Airborne Observatory (KAO, 1974 to 1995). The KAO was a modified C141 "Starlifter" with a 90 cm telescope peering through an open port. Cornell's presence was very strong in these missions. Half a dozen Cornell faculty have created more than a dozen different instruments for these facilities. Of the roughly 60 students world-wide who obtained their Ph.Ds using the Lear Jet or KAO, **about a third were from Cornell University**. Many exciting phenomena were discovered using these facilities. KAO discoveries included water in the atmosphere of Jupiter and in comets, the locations and types of stars hidden in their natal molecular clouds in the Milky Way and other galaxies, the presence of a ring of gas and dust circulating around the Galactic Center black hole, and the discovery of the rings enveloping Uranus by (then) Cornell professor James Elliot and his Cornell Ph.D. student Ted Dunham.

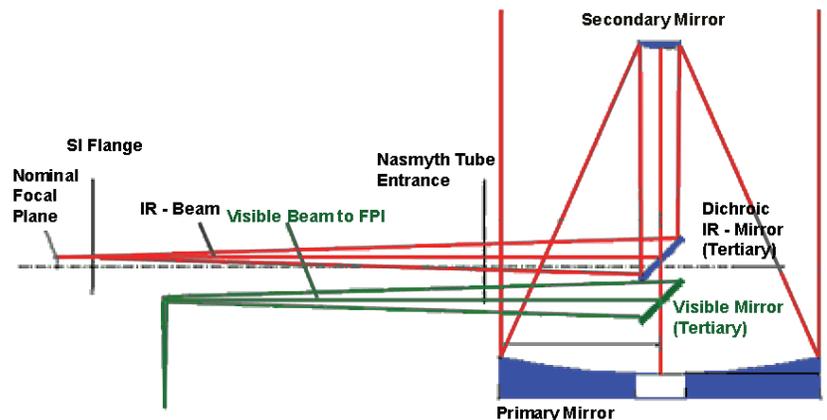
The SOFIA observatory is an international project with 80% participation from the United States (NASA) and 20% from Germany (DLR, the German space agency). The aircraft and its modifications were provided by the US and the telescope was provided by Germany. The aircraft modifications were significant. To observe in the mid to far-IR requires an open port in the side of the aircraft. The aircraft had a 4.8 m (16 foot) telescope opening cut into its fuselage behind the wings. This was by far the largest hole ever cut into a 747 aircraft, and required the addition of a pressure bulkhead ahead of the telescope opening so that the aircraft itself could still be pressurized. Needless to say, much computation, modeling, and prototyping went into the design of the hole and the covering door.



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Above, SOFIA Observatory in flight and close-up of the telescope through the open cavity door. The primary mirror was not yet aluminized (photo: Tom Tschida/NASA 08-0067-24). Below, the optical system of the telescope.



## Barbara Asks!

**Q.** How does a supernova form, and what effect would its explosion have on objects in its vicinity?

**A.** Supernovae are gigantic stellar explosions. They come in numerous types, the most famous of which are Type Ia and Type II. Type Ia supernovae are associated with the total explosion of a white dwarf star arising from unstable nuclear burning. Type II supernovae are associated with the collapse of massive stars, and are the events that accompany formation of a neutron star or perhaps a black hole. A good rule of thumb is that, at its peak, a supernova is as bright as a galaxy—that is, about 1 billion to 100 billion times brighter than the Sun. How long they maintain such gargantuan brightnesses depends on the supernova type, but generally it is days to months.

What would be the consequences for life on Earth of a very nearby supernova? First, let me assure you that the Sun will not explode as a supernova. The reason is that its mass is simply too small. Ultimately, the Sun will form a white dwarf star, with a relatively mild burp of gas called a planetary nebula. The white dwarf that will remain will not be dense enough to trigger unstable nuclear burning. Moreover, the Sun has no companion star to donate mass to it, so once it forms a white dwarf it will not change its mass significantly. It will therefore sit in space, a cooling ember much like a piece of glowing charcoal, in quiet retirement.

While we do not have to worry about the Sun exploding as a supernova, we should worry that some other nearby star might. A famous supernova formed the Crab Nebula and the pulsar, a neutron star, found inside it. It was observed with the naked eye in 1054, well before the invention of the telescope. It could be seen during the daytime for about three weeks, as an object about as bright as the Moon. Afterwards, it remained visible at night for more than a year, despite the fact that, as we know now, the Crab Nebula and pulsar are about 6,000 light years away. However, although superstitious observers imputed terrestrial significance to the sudden appearance of a new, bright star in the sky, nobody on Earth suffered dire consequences from the Crab supernova directly.

How near would a supernova have to be to be as bright as the Sun? As a round number, let's assume that a supernova is typically ten billion times brighter than the Sun. Then it will be as bright as the Sun if it is at a distance given by the square root of ten billion, or 100,000, times the distance from Earth to the Sun. This distance is about 1.5 light years. Given that the nearest star to the Sun, Alpha

Centauri, is about 4.5 light years away, all supernovae ought to be fainter than the Sun.

From detailed astronomical observations, we know that supernovae occur once every 50-100 years or so in a galaxy like the Milky Way. Thus, there have been between 50 million and 100 million supernovae in the Galaxy over the 4.5 billion year age of the Sun and solar system. Since supernovae occur in the disk of our Galaxy, which has a radius of perhaps 60,000 light years, we might expect that the nearest supernova to our solar system over its entire age was at a distance of at least 6 light years. Over the past million years or so, during which time perhaps 10,000-20,000 supernovae have exploded, we would expect the nearest one to have been at least 100 light years away. These estimates assume that supernovae explode uniformly across the disk of our Galaxy, which is actually not quite true, so the expected distance to the nearest supernova could be somewhat larger.



*Composite of digitally combined X-ray, optical, and infrared light images of Cassiopeia A, which is thought to be the remnant of a supernova that was observed in 1680. About 10,000 light years away toward the constellation of Cassiopeia, this is the most recent supernova observed in our galaxy. O. Krause (Steward Obs.) et al., SSC, JPL, Caltech, NASA.*

Even at such large distances, there would be a prodigious flux of high energy radiation and cosmic rays at the Earth. Mal Ruderman, a famous astrophysicist at Columbia University, considered the effects of this radiation in a paper in *Science* magazine in 1974. From the point of view of survival of animals and plants, the most important impact would be the destruction of much of the ozone layer of the atmosphere, which protects the Earth's surface from harmful ultraviolet radiation. Fortunately, some ozone would remain, enough to continue to protect the surface regions, even for a supernova within 50 light years of Earth. Moreover, supernovae only illuminate Earth significantly for a relatively short amount of time, at most about a year, and the ozone layer would recover after the bombardment

were over.

Another impact of all of this high energy radiation would be the ionization of atoms in the atmosphere, which then would extend the ionosphere to lower altitude. This affects radio communication—only a consideration within the past century or so, but clearly something we rely on. Such an effect was observed on August 27, 1998, when the soft repeating gamma ray burster, 1900+14, had a strong outburst. This was not a supernova, but nevertheless it showed how an energetic event at great distance—about 20,000 light years for 1900+14—can have palpable terrestrial impact.

-Barbara Burger (for the question)  
-Ira Wasserman (for the answer)

# New Instructional Techniques in Astro 1101: Demonstration of the Celestial Sphere Abstraction with a Webcam and Globe<sup>1</sup>

*Jamie Lloyd researches planets around other stars, a new and exciting field in Astronomy. Here he describes hands-on exercises he has used to help students understand the motions of the celestial sphere.*

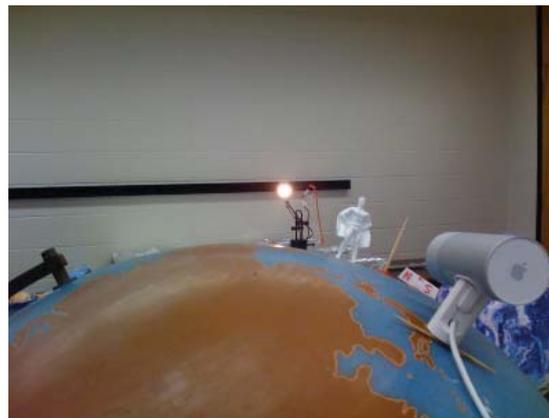


Astronomy 1101 is a large and popular lecture course in Astronomy, which has been taught at Cornell for more than twenty years. I frequently

encounter former students at Alumni Weekend who recount being infected with excitement for Astronomy in Yervant's 101 course. Terry Herter followed Yervant, and now the baton has passed to me, with an extra digit added to accommodate the new four-digit course numbering system. I still aim to instill in students an appreciation of the awesome beauty of the universe and the science of Astronomy. The modern era presents me with new challenges and opportunities in terms of the background of the students as well as new technologies with which to teach.

The understanding that the motions of the stars and the sun through the celestial sphere are the result of the rotation of the earth combined with its orbit around the sun is not only an important piece of general knowledge, but central to Astronomy in ways as diverse as the simple task of locating objects to observe with a telescope, the understanding of the cause of the seasons, the Copernican revolution, and cosmological principle. Thus, a primary goal of many Astronomy 101 classes is to provide students with an

appreciation of what they see in the night (and day) sky. The motion of the sun, moon and stars is often taught. However, students in Astronomy 101 classes typically have limited, fragmented experience of the motions of celestial objects. It can come



*Demonstration of sunrise. The webcam is placed on the surface of the globe to provide an observer-eye view of the "celestial sphere." A toothpick on a magnet provides a vertical reference, and a small white tag indicates north, south and east directions. A miniature Superman provides an immediate visual cue that the webcam sees an observer-eye view. A halogen desk lamp simulates the sun. The camera and references are set on the globe to indicate that the observer is looking east, with north to the left and south to the right. The globe can be rotated and the path of the rising sun demonstrated (see movie at <<http://astro.cornell.edu/~jpl/papers/aer/sunrise.mov>>).*

as a surprise to many that the sun is not necessarily directly overhead at noon, or that the stars rise and set following a path just like the sun. Students who have lived in cities their entire lives have limited experience noticing the motions of the heavens; approximately half of the students in Astronomy 1101 at Cornell have never seen the Milky Way. The abstraction of the celestial sphere is the primary tool by which these motions are taught, but students often have insufficient experience observing the rotation of the night sky to appreciate the concept of a rotating celestial sphere. While students are frequently able to learn the appropriate facts to describe the path of the stars and sun in the sky, many struggle to understand what the celestial sphere is, and why the model works.

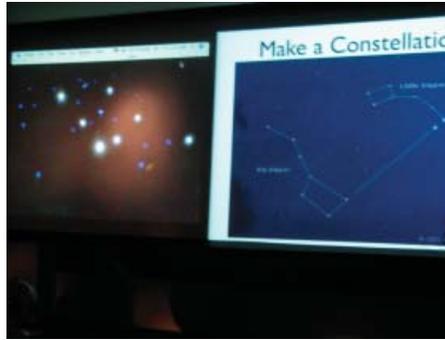
Conceptualizing these motions requires thinking in spherical geometry, with an observer on a moving, rotating, angled platform. For many students, forming this mental image is a much more difficult step than simply accepting as prior knowledge that the earth rotates and orbits the sun. The demonstration apparatus we use in Astro 1101 seeks to ease the student's conceptualization by providing a physical model of a rotating earth with a direct connection to the rotating observer's viewpoint through the use of a webcam. The challenge of imagining the view of an observer at the equator or pole or intermediate latitude can be replaced with the simple experiment or observation of simply placing the webcam on the surface of a globe to directly measure that viewpoint.

<sup>1</sup> A paper on these demonstrations is in press in the *Astronomy Education Review*.

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Demonstrations such as these give students a chance to improve their understanding and get excited about taking on some of the extraordinary intellectual challenges that Astronomy presents to us, such as thinking in spherical geometry. In Astronomy 1101 we now aim to help open the students' minds to how science can help them understand the simple and beautiful things we see in the universe around us.

-Jamie Lloyd



*“Make your own constellation.” Students were handed flashlights and asked to make a constellation. To the right, the constellation the students made. On the left, the view from the web camera on the globe. Students learn from this demonstration how stars in constellations are distributed throughout space and how the constellations move through the sky.*



## SOFIA

(cont.)

### Technical Specs

The telescope is a 2.7 m diameter (2.5 m clear aperture) Cassegrain reflecting telescope with a bent Cassegrain (Nasmyth) focus that is accessible to the astronomical instruments. The light from the secondary mirror hits a “dichroic” tertiary mirror that reflects the mid to far-IR light to the science instruments mounted on the Nasmyth port. This then transmits the optical light to a second tertiary mirror that reflects the optical light from the source to a “focal plane imager” (FPI). The primary mirror is made of a very low thermal expansion glass called Zerodur (Schott, Germany). The telescope is balanced on a spherical hydraulic (oil) bearing made of cast iron with an outer diameter of 1.2 m. The hydraulic spherical bearing is very precisely mounted into its retaining collar since rather tight (40 mm, or 0.0016”) oil gaps need to be achieved. The retaining collar/spherical bearing assembly is mounted into a pressure bulkhead which seals the aircraft cabin from the telescope environment. The telescope is gyroscopically stabilized on source, and pointing corrections are made by applying spinning up electro-motors that transfer torque to the system. As the aircraft rolls, pitches and yaws during flight, these motions are all taken out by the telescope

stabilization system so that the pointing stability should be about 0.2” when the SOFIA facility is fully operational. The scientist sits forward of the telescope in a shirt sleeve environment running the telescope and science instrument. It is amazing to watch the telescope “move” with respect to the fuselage in flight as it maintains its inertial lock on the stars while the aircraft rolls, pitches, yaws through the atmosphere. The moving parts of the telescope mirror and assembly weigh an impressive 9 metric tons.

### Research

SOFIA’s unique wavelength regime is the mid to far-infrared (4 mm to 320 mm)–wavelengths that are nearly totally obscured to ground based observatories by the presence of water vapor in the Earth’s atmosphere. (It is this “blanket” of absorbing water vapor (and CO<sub>2</sub>) that prevents the Earth’s surface from cooling drastically at night). SOFIA will fly at an altitude of 45,000 feet, which puts it above 99.8% of the water vapor in the Earth’s atmosphere, opening the mid to far-infrared spectral regime to astronomical observations. If, as planned, SOFIA flies 120 times a year and each flight lasts from 8 to 10 hours, astronomers will make hundreds of scientific observations per

year for its full 20 year lifetime.

Why pursue mid to far-infrared astronomy? In a nutshell, there are two reasons: (1) interstellar extinction and (2) gas cloud energetics. Stars form from the gravitational collapse of giant clouds of molecular gas (cleverly termed giant molecular clouds, GMCs) in galaxies. By Earth’s standards, these clouds are incredibly dusty. If the Earth’s atmosphere were as dusty as an interstellar cloud, you would have difficulty seeing the end of your outstretched arm! Interstellar dust is typically the size of a visible photon, so that when these photons strongly interact with it, they are absorbed, or scattered– extinguished in astronomer’s jargon. Because of this extinction, light that is visible to our eyes (and CCD cameras) with wavelengths near 5000 Å is unable to escape from the dusty cores of GMCs, and one can not observe the birth of a star in the visible bands. However, since mid and far-infrared photons have wavelengths hundreds of times larger than the size of an interstellar dust grain, the light only weakly interacts with the dust and one can observe the star formation process in the mid to far-IR. The day to day analogy is that while one may not be able to see one’s neighbor

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# The Square Kilometer Array:

## The Future International Giant Radio Telescope

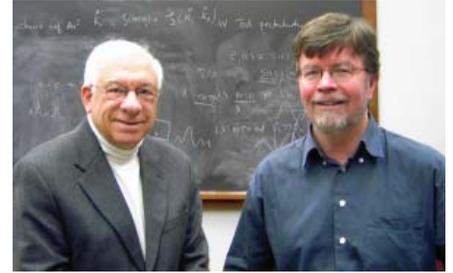
*Yervant Terzian and Jim Cordes have been associated with the SKA since its inception.*

In the early 1930s Karl Jansky, an engineer at Bell Labs in New Jersey, discovered that radio waves were being emitted from the Milky Way galaxy. Suddenly we could observe the universe 'looking' through radio waves (*i.e.*, wavelengths from about one millimeter to a few meters). In the decades that followed, impressive and crucial observations made with this means shaped our understanding of the universe. To mention only a few discoveries, quasars (nuclei of dead galaxies that harbor giant black holes) and pulsars (the collapsed cores of dead stars) were first detected at radio waves; cold neutral hydrogen, which exists in the interstellar medium of galaxies, was detected at a wavelength of 21 centimeters; and the remnant energy of the hot Big Bang, which has now cooled to 3 degrees above absolute zero, was detected at millimeter waves.

Advanced technologies in building sensitive radio telescopes with sophisticated electronic receivers made such great discoveries about the universe possible. Today the radio telescope with the largest collecting area is the Arecibo radio telescope, which has an aperture close to 20 acres! Located in Puerto Rico, it was built by Cornell University in the early 1960s. Since then it has been operated by the University for the National Science Foundation as a National Center. A second important radio telescope is the Very Large Array, which, with its 27 networked antennas, each 85 ft. in diameter, makes deep images of the sky. The VLA, operating since the 1980s in New Mexico, resolves radio sources on the sky that are closer than one arc second apart. It is now being upgraded to provide much greater sensitivity.

Even though we have come to understand the universe to a much greater degree than before, there are many areas where we need more sensitive and detailed observations to fill the gaps in our understanding of its evolution. One important area of research is the early universe, particularly the era of the formation of the first

galaxies, which can be studied by observing their neutral hydrogen emissions. Another is making detailed observations of the formation of stars and planets; still another uses pulsars as clocks



*The Arecibo giant radio telescope on the island of Puerto Rico.*

to test Einstein's Theories of Relativity and to detect long-wavelength gravitational waves.

In order to study such topics, we need to make observations with a radio telescope that is much more sensitive and that has the ability to survey the sky more efficiently than what we have now. Radio astronomers around the world have been thinking on how to achieve such an instrument. After a decade of work, our answer is to construct a radio telescope array that has a combined surface area of about one square kilometer. This will be composed of several thousand parabolic antennas, each of the order

of 12 to 15 meters in diameter, connected electronically with fiber optics. Half of the antennas will be clustered within an area of about five kilometers; there will be remote stations of antennas as far as 3,000 kilometers. The required computing power for the SKA is about 1 followed by 15 zeros (a thousand trillion) operations per second, which will become available in the next decade.

In the year 2000 the international radio astronomy community signed a Memorandum of Agreement to work towards the realization of the SKA. An International SKA Steering Committee was established, composed of equal number of members from the US, Europe and the Rest of the World (this Committee is now called

Continued p. 11



*SOFIA, telescope door open, on the ground at Dryden Flight Research Center on March 10, 2008. Photo: Tom Tschida/ NASA 08-0067-10.*

in a Tucson dust storm, one can surely call her on a cell phone which uses much longer wavelength light (radio waves). Therefore, one can observe star formation in the mid to far-IR. The mid to far-IR is also important energetically. For example, to form a star, a cloud must collapse. As it collapses, gravitational potential energy is converted in kinetic energy, which heats the cloud. This added heat adds thermal pressure to the cloud; this pressure resists further collapse. If the cloud is unable to cool, the thermal pressure from the heated gas will eventually halt the collapse, thereby preventing the formation of a star. The cloud, however, cools—the gas through molecular and atomic spectral lines, most of which lie in the mid to far-infrared, and the dust through thermal dust continuum emission in the far-infrared.

Under the direction of Professor Terry Herter, Cornell University has built one of two first light instruments for SOFIA. The **F**aint **O**bject **i**nfr**a**Red **C**Am**e**ra for the **S**O**F**I**A** **T**elescope (**F**OR**C**A**S**T) is a two channel mid/far-

IR camera with selectable filters for imaging in the dust continuum at 4-8, 16-25, and/or 25-40 mm regions. FORCAST can provide simultaneous images at long and short wavelengths using a type of arrays that were originally developed for the Spitzer Space Telescope Infrared Spectrometer under the direction of Professor Jim Houck at Cornell. To operate properly, these arrays need to be held at very low temperatures ( $< 6$  K). To maximize sensitivity, the optics and filters within the instrument must also be cooled to very low temperatures. The arrays, optics, and filters are cooled to their requisite temperatures with liquid helium and liquid nitrogen cryostats within the FORCAST instrument itself.

FORCAST will obtain astronomical images at several wavelengths (colors). The detailed images tell us the structure of the source, and the relative flux at the various wavelengths reflects the size and temperature of the dust, and the amount of dust along the line of sight within the source.

FORCAST will have a long lifetime on SOFIA, and be used for many scientific investigations. Among the first will be the imaging of the “debris disks” known to circulate around nearby stars. These dusty disks are thought to be either material left over from planet formation or fresh material

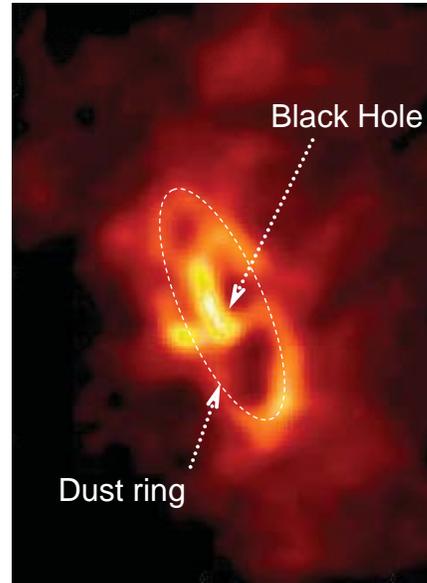
injected into the system by collisions between asteroid-sized bodies. The dust is heated by the visible light photons from the central star, and re-emits in the thermal infrared—near the peak of FORCAST’s capabilities.

**F O R C A S T** can discern the mass, size, temperature, and even composition of the dusty rings providing clues to their origins, and the origins of planetary systems. In addition, the morphology of the ring—is it asymmetric?—provides evidence for planets within the rings.

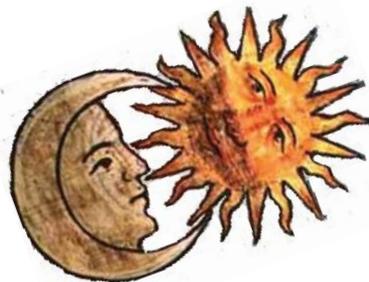
A second major project will be to image the ring of gas and dust orbiting the 4 million solar mass black hole in the center of our galaxy. This ring contains the mass

of 10,000 suns of material that should fall in towards the inner regions within 10,000 years. What happens to this material? Presumably it eventually funnels down to the black hole itself, and when it undergoes final accretion gives off tremendous energy manifest as a brilliant flare from the nucleus. Will this happen soon? No one knows for sure, but if it happens in May of 2009, FORCAST will be on SOFIA recording the event!

-Gordon Stacey



*Image of the Galactic Center dust ring at 38 mm wavelength taken with the author’s Cornell instrument, KWIC on the KAO (Cornell PhD. Harry Latvakoski).*





The Very Large Array radio telescope in new Mexico. Image courtesy of NRAO/AUI.

the SKA Science and Engineering Committee. In addition, an SKA Project Development Office was established with significant staff, now housed at the University of Manchester in the UK. Government Funding Agencies from some 17 countries now meet regularly to discuss models for funding this project, which will cost around two billion dollars.

Radio astronomers in the United States have taken a leadership role in the SKA project and have formed a US SKA Consortium of Research Universities and Institutes. Cornell Professor Yervant Terzian chaired the US SKA Consortium from 2002 to 2008. Another Cornell Professor, James Cordes has been succeeded him. Jim is also the Principal Investigator for the US SKA Technology Development efforts that are funded by a \$12 M, 4-year grant from the National Science Foundation.

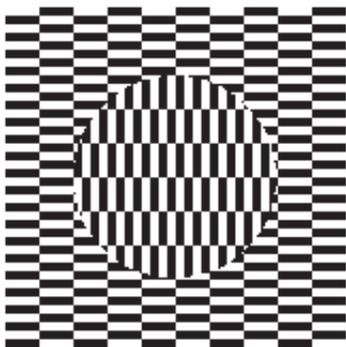
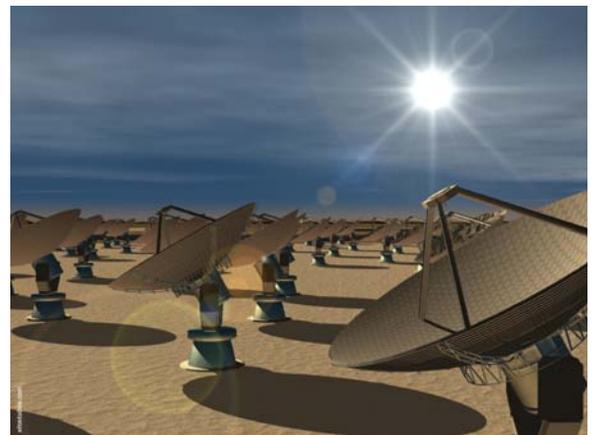
Professor Terzian has also been the Chair of the International Working Group on Siting the SKA. After five years of detailed work, proposals from China, Australia, Argentina/Brazil, and South Africa were selected as serious op-

tions to site the telescope. In 2006 the Funding Agencies requested a short list of acceptable sites; the International SKA Committee voted for one in Western Australia and one in South Africa. The government of each of these two countries has decided to construct a prototype radio telescope array on them to demonstrate their functionality. It is anticipated that the governments, via their Funding Agencies, will make a final site selection within the next two years.

The promise that such a quantum leap in technology to construct extremely sensitive, accurate and complex instruments holds resides not only in the questions we know we need to answer, but also in the exploration of unknown and unanticipated discoveries.

-Yervant Terzian and Jim Cordes

Artist's view of a section of the Square Kilometer Array.



Japanese artist Hajime Uchi invented this illusion, which is named after him. The central disk seems to float above the checkered background because random eye movements are independent in the horizontal and vertical directions. The brain then interprets the disk and the background as corresponding to separate independent objects



## Thanks to the Friends!

The Department has much to be grateful for. Thanks to all of you for the generous gifts we have received in the course of the year. Lamarr L. Parsons '09 (Astronomy) was the 2008 Terzian Scholar; his scholarship is supported by an endowment established by the Friends in honor of Yervant. Thanks too to Lee and Nancy Corbin for arranging generous donations from the Josephine Lawrence Hopkins Foundation that funded two summer research students in 2008 and colloquia speakers and a summer research student in 2009. Finally, many thanks to all the Friends who have contributed towards the publication of Orion. We appreciate your help and will continue doing our best to bring you all the news of Cornell Astronomy and the FoA!

## Books in Science and the Universe

*The Cosmic Perspective* by J. Bennett, M. Donahue, N. Schneider and M. Voit (Pearson-Addison-Wesley Publ. 2008).

In this [Orion](#) you will read an article by Jamie Lloyd on how Astronomy 101 is taught at Cornell. *The Cosmic Perspective* is the textbook that is used by the students in this course. It is perhaps the most complete and up-to-date book in introductory astronomy today. Not only does it touch on all the topics necessary to describe the fascinating universe we live in, but it also puts special emphasis on the physics that we use to understand it. The descriptions are very clear and thorough and easy to follow.

The 24 chapters in the book start with ‘Our Place in the Universe’ and ‘The Science of Astronomy.’ Next come chapters on motion, energy, gravity and the nature of light and a chapter on telescopes. Prepared with this knowledge, the book continues with the solar system and other planetary systems around other stars. Next comes a discussion on space and time and Einstein’s relativity theories that is followed by several chapters on stars, their birth, life and death. Our galaxy, the Milky Way, and the evolution of galaxies and cosmology are then described. The last chapters on cosmology are extremely well done and are up-to-date with the most recent discussions on dark matter and dark energy. The concluding chapter dwells on ‘Life in the Universe.’

What makes this text superb is its clarity in explaining complex problems that can be easily understood by the students. The book is illustrated by hundreds of majestic space photos, diagrams and graphs that assist in understanding the various topics. At the end of each chapter the authors also have sections on ‘Mathematical Insights’ for those who like to see the real formulas, and ‘Common Misconceptions’ to explain why your thinking may not be correct!

If you always wanted to be an astronomer, this is a great starting point.

-Yervant Terzian



## Yervant’s Critical Thinking Corner



### A. Happy Birthday!

How likely is it that two people have the same birthday in a crowd of 40 people? It is about 90% likely, so it is a safe bet.

Think of the probability  $P$  that a room with people has no shared birthdays. The probability of at least one shared birthday is then one minus  $P$ . Now you are having a party and your guests are arriving one at a time. When your first guest arrives then there are two of you, and her birthday can be on any of the 365 days of the year, so chances are 364 out of 365 (0.9973) that her birthday is different from yours. When the third person arrives, the probability that there are still no shared birthdays is 0.9973 times the probability that the third person has a different birthday from the other two, 363/365, which is 0.992. With a fourth person, the probability that there are no shared birthdays is 0.992 times 362/365, which is 0.984 and so on. When there are 10 people the probability that there are no shared birthdays is 0.88 (88%). With 23 people it is about 50%, with 40 people it is 10% which means that there is 90% probability that there is a shared birthday. With 50 people in a room the probability of a shared birthday is 97%.

Here is another way to see this. In a TV talk-show, the above probabilities were mentioned and the host could not believe the surprising results. So he turned to the audience of some 500 people and said “My birthday is on December 10. Is there anyone else with the same birthday?” There was silence. This may be fine since we are talking only of probabilities, but note that the “birthday problem” does not ask for a match with a *particular* birthday, but asks for the probability of there being *any* matches among the people in the room. Each additional person brings a birthday with them, providing more opportunities for a match, and that is why the probability for a match seems surprisingly high.

### B. Errors

Can you find the two errors in the title of this book?

“THERE  
ARE TWO  
ERRORS IN THE  
TITLE OF  
THIS BOOK”

Answer: (1) There are two ‘THERE’ in the title. (2) It says that there are two errors, but there is only one!