O R I O N

Newsletter of the
Friends of Astronomy
Cornell University

Winter 2007

Dear Friends,

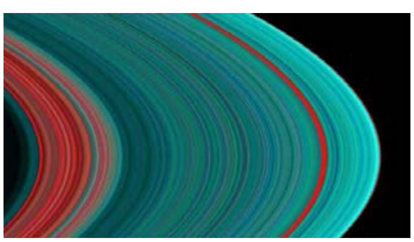
Holiday greetings to one and all, and warmest best wishes for a healthy and happy 2007. It was a great pleasure to see many of you at the special events honoring Joe Burns and Riccardo Giovanelli. Both were memorable events and were enjoyed immensely by the honorees.

This year has been a busy one for Astronomy and Cornell. The Department's major future initiative, the Atacama Telescope Project, continues to make good progress. Very soon we expect to be joined by two international partners: Canada and the UK. Spitzer and the Mars Rovers continue their amazing adventures. For more on the Mars Rovers and good Holiday reading besides, I highly recommend *Roving Mars: Spirit, Opportunity, and the Exploration of the Red Planet* by Steve Squyres and the recently published *Postcards from Mars: The First Photographer on the Red Planet* by Jim Bell.

The New Year promises much excitement and a few challenges, but we know how to deal with both. What never changes is the enthusiasm and interest shown by you, our Friends of Astronomy, in what we do. As always, that is a very important to us.

Happy Holidays,

Joe



Launched in 1997, Cassini is one of the most complex and largest spacecraft ever built. In orbit around Saturn since 2004, it has given us exquisite pictures of its amazing rings. Photo: UVIS, U. Colorado, ESA, NASA.

Greetings

Dear Friends of Astronomy:

It has been an unusual few months since I had to have a surprise heart quadruple bypass surgery. The cardiologist said "We should do the operation no later than the next three days", and then he turned to me and said "That is, if you agree" ! As you know all went very well and I resumed teaching within three weeks and travelling in four weeks.

I want to take this opportunity to thank all of you for the concern that you showed, for your inspiring letters and messages and telephone calls. It meant a lot to me to know that I have so many great Friends. Most of all Patricia carried the daily burden with optimism and courage and she is my Best Friend.

Meanwhile, the Mars Rovers continued to explore Mars and Professor Jim Bell of our Department published a book of fabulous Mars pictures titled *Postcards From Mars* that you will greatly enjoy.

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Contents

Editor
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Back to the Moon: The Allure of Lunar Polar Ice

Don Campbell is our prominent radar astronomer.

NASA's plans to return to the Moon have sparked interest in a question that has been mooted for over forty years: is there water on the Moon? On first thought this seems very unlikely. However, there is a place where water may be present in the moon as *ice*: in the deep craters of the lunar poles.

The rotation axis of the Moon is almost perpendicular to the Earth-Moon orbital plane (the ecliptic) about the Sun. The deviation is only about 1.5 degrees. This means that the rim of the Sun rises a maximum of about 2 degrees above the horizon at the lunar poles and, hence, it never shines on the bottoms of impact craters near the poles. Since the Moon has no atmosphere and the lunar regolith–soil–is a very bad conductor of heat, the temperature of the floors of these craters is less than -173˚C (-280˚F) and ice would be stable for extremely long periods. Where would the water come from? While some could have been out gassed from the interior of the Moon, the most likely source would be from comets and asteroids that impacted the surface of the Moon. After the impact, water molecules would "freeze out" in the cold traps at the poles.

NASA would just love to find water ice on the Moon. Accessible deposits would provide any long-term base much needed water and, potentially, fuel for rocket engines by separating the water into hydrogen and oxygen using solar power.

The idea that there are ice deposits on the Moon was given a considerable fillip in 1992 when probable ice deposits were discovered at the poles of Mercury using the powerful radar systems on the Arecibo telescope and on the 70-meter diameter NASA Deep Space Network antenna at Goldstone in the Mojave Desert. Like the Moon's, Mercury's rotation axis is almost exactly perpendicular to its orbital plane about the Sun so that despite being very close to the Sun, with daytime temperatures at the equator reaching 467˚C (872˚F), it also has permanently shadowed craters at its poles with very low temperatures. Figure 1 shows an Arecibo radar image of the north pole of Mercury made by John Harmon, who is on the scientific staff at Arecibo, and his colleagues.

Photo: *J.P. Stanley*

Why are these bright features in Mercury thought to be water ice? In the 1970s, the Arecibo radar system was used to study the radar reflection properties of the icy surfaces of Europa, Ganymede and Callisto, three of the Galilean satellites of Jupiter. It was found that, unlike reflections from, say, the terrestrial planets, these icy surfaces "lit up" under the radar in a manner similar to a highway sign at night. They also exhibited unusual light scattering properties (high circular

Figure 1: *Jean-Luc Margot's radar image of the south pole showing the areas in permanent shadow (white) based on his radar measurements of the height distribution over the polar regions. Grey areas are thought to be in shadow based on the assumption that impact craters are roughly symmetric. Some of the areas in radar shadow (black) could also be in solar shadow.*

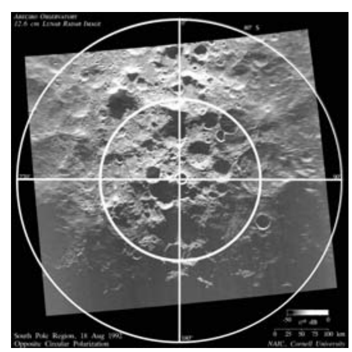

Figure 2. *Nick Stacy's 13 cm Arecibo radar image of the south pole with a resolution of 125 m. Much of this area is in permanent solar shadow. The radar was ~ 7 degrees above the horizon at the pole and the black areas are in shadow under the radar illumination. Shackleton crater, 19 km in diameter, is at the pole; Shoemaker crater, 51 km in diameter, is to its upper right with about 50% of its floor visible to the radar. The Lunar Prospector orbiter was impacted into Shoemaker crater in the hopes of throwing up a cloud of water vapor that would be detectable from Earth.*

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Discovering Things Big and Small

Amelie Saintonge received the 2006 Shelley award for her outstanding research as a graduate student.

When I came to Cornell four years ago, I knew I wanted to study galaxies. That was the plan, and my wish came true since discovering galaxies is part of my daily routine. But there have been surprises along the way, things just as interesting and rewarding.

Soon after I arrived here, I joined the research group led by Riccardo Giovanelli and Martha Haynes. With them (and many, many others), I became involved in the Arecibo Legacy Fast ALFA survey (ALFALFA). The goal of this project is to map a large fraction of the sky to make a census of gas-rich galaxies in the nearby Universe. I soon discovered where my interests laid in this project. I decided I was going to tap into one of the strengths of ALFALFA: its unprecedented sensitivity. Due to the large size of the Arecibo telescope, ALFALFA can detect faint low-mass galaxies that were missed by previous surveys conducted at other facilities. These are the galaxies I set out to study.

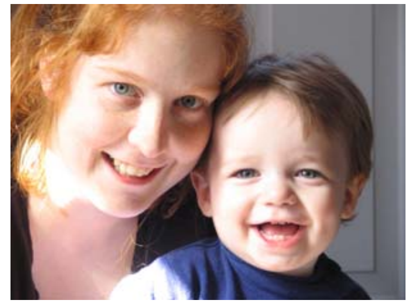
There is a well-known—but still poorly understood—relation between the mass of a galaxy and the abundance of oxygen in it: the lowest mass galaxies have on average the most metal-poor interstellar gas (by metal, astronomers usually refer to anything that is not hydrogen or helium!). The metal content in galaxies is built up by successive generations of stars that pollute the interstellar medium at the end of their lives.

A metal-poor galaxy can therefore be considered a young galaxy, in the sense that it has gone through very few episodes of star formation. This is one of the many reasons why these galaxies are so interesting.

Surprisingly little is known about the detailed processes that led to the formation of the first galaxies and the onset of star formation in them. Star formation is observed in our own Milky Way, but these stars form out of the gas that has been significantly enriched in metals from previous generations of stars. Forming stars out of the primordial gas of the early Universe is certainly a different process. With our current instruments, we can't study in great detail how, when, and where stars formed in the galaxies of the early Universe, but we can look at young nearby galaxies to address these questions.

I use the ALFALFA survey to define a sample of such nearby, gas-rich, low-mass dwarf galaxies. Then I travel to California to re-observe them with the Hale 5m telescope atop Mount Palomar. I use this telescope to obtain high quality optical spectra, which can be used to calculate the abundance of oxygen relative to hydrogen in regions of the galaxies where the interstellar gas is ionized by hot young stars. These observations are very tricky: in order to know exactly where to point the telescope, I need to rely on images of the galaxies taken by members of the ALFALFA consortium in the months or weeks between their discovery and the visit at Palomar. This requires a lot of coordination between members of the team, speedy data processing, and most importantly, clear skies on two separate occasions! And since the most interesting galaxies are unfortunately the faintest, it is only possible to get a spectrum for a few of them every night. But it is worth the effort. Some of the galaxies turn out to be extremely metal-poor and will be important pieces in the puzzle that is the understanding of the star and galaxy formation processes.

A lot of things have happened since I first set foot in the Space Sciences Building. I certainly know a lot more about Astronomy. I had the chance to use some of the largest telescopes in the world, to have more fun with spectra of galaxies than I thought was possible, to build relations with scientists from many institutions and learn from them. I have also learned how to balance the many responsibilities of the life of a graduate student: taking classes and teaching, writing homework and grading some, doing research, preparing talks and papers and in my case, also sharing my love of science with the public.



I've been doing something else, though: raising a child. Going against tradition, I decided to take on the extra challenge of parenthood during graduate school. My son Éloi was born during my third year at Cornell. This of course had an impact on my life as a graduate student. I certainly can't stay in the office as long as some of my colleagues or travel as easily, but on the other hand I was never as efficient and organized, or as good at multitasking as I have become. I like to think that the scientist and the mother in me benefit from each other. There are sacrifices though. The first time I left Éloi to go observing in California, he started to crawl. The second time, it was just after his first birthday and he took his first steps while I was flying back home. But these are just small things compared to the joy of spending a day thinking about things as overwhelmingly big and distant as galaxies and the Universe, and then going back home to play with blocks, trains and playdough. My head is in the clouds, but my feet are firmly on the ground. Life could hardly be better.

-Amélie Saintonge

Astronomy Welcomes Graduate Class of 2006

Jim Bell is our Director of Graduate Studies

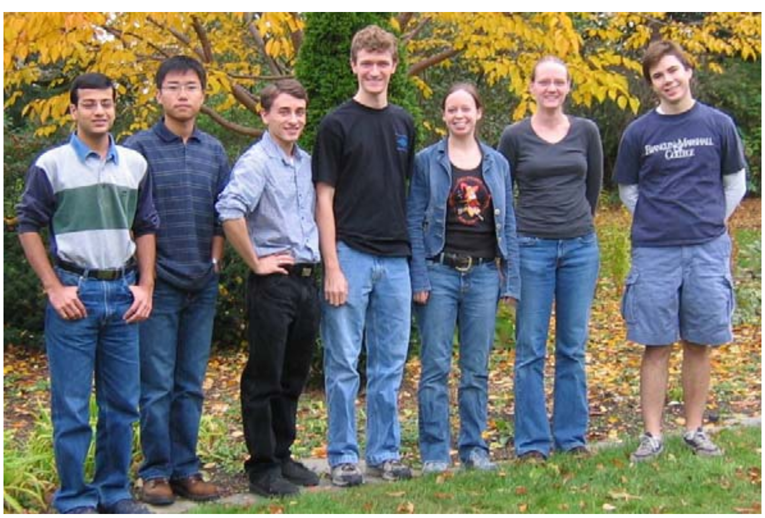
The Department of Astronomy continues to be a dynamic and exciting environment for graduate students. There are now just over thirty Astronomy graduate students in Space Sciences at various points in their Ph.D. studies working on topics in cosmology, radio and infrared astronomy, planetary sciences, and other aspects of astrophysics. Additionally, about a dozen graduate students from the Department of Physics also work in Space Sciences under the direction of our faculty. These are among the best and the brightest young astronomy scholars in the world, using data from the most prominent observatories and latest space missions and defining the frontier of theoretical modeling and data analysis work.

Over the past several years, we have been receiving about 100 to 120 applications per year for graduate studies in Astronomy and Space Sciences, a comparatively large number. We can only accept a small fraction of these students each year, which makes the process of reviewing and selecting applicants painstaking and difficult for faculty members who serve on our admissions committee—there are so many excellent applicants! It hurts to have to turn so many away, but it also helps us all realize how special our graduate students are. They have risen to the top of an intense competition. They are truly the cream of the crop, and it is a great pleasure and privilege for the faculty to be able to work with and mentor these bright young stars.

Our newest graduate students, the entering class of 2006, are a diverse group from around the world with interests that—literally—span the Universe. Nishant Agarwal (Indian Institute of Technology) is interested in studying a number of aspects of theoretical astrophysics and cosmology, including early Universe theories. Ryan Anderson (University of Michigan) wants to learn about the histories of the surfaces and climates of the terrestrial planets, the moons of Saturn and Jupiter, and astrobiology. Wen Fu (University of Science and Technology of China), is interested in learning about galactic formation through observational and modeling studies. Richard Kipphorn (Franklin and Marshall), worked at Cornell as a summer intern while he was an undergraduate, will pursue studies in many aspects of astrophysics, including radio astronomy and especially pulsars, and. Melissa Rice (Wellesley) is interested in planetary sciences and comes to us after spending a year studying terrestrial Mars analog field sites around the world as part of a prestigious fellowship from Wellesley. Laura Spitler (University of Iowa) just spent a year as a German Academic Exchange Service fellow working at the Max-Planck-Institut fuer Radioastronomie in Bonn, is studying radio astronomy and instrumentation. And James Wray (Princeton), who has been awarded prestigious Hertz and NSF graduate fellowships, will be studying planetary science and the potential for life to evolve and survive on other worlds, including Mars and the icy moons of Jupiter and Saturn.

These new graduate students are an incredibly talented and diverse group of young scientists, adding to an already impressive and accomplished graduate student body overall here in Astronomy and Space Sciences. Welcome to Cornell!

- Jim Bell



The Astronomy graduate student entering class of 2006.

From left to right: Nishant Agarwal, Wen Fu, James Wray, Ryan Anderson, Melissa Rice, Laura Spitler, and Richard Kipphorn.

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Letter from Prague

Prague, August 2006

Friends of Astronomy
c/o Patricia Fernández de Castro
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Dear Friends:

Prague is beautiful. From my hotel I can easily get to the banks of the majestic Vltava (Moldau) River. Every day I walk and ride the underground to reach the congress center where 2,400 professional astronomers from around the world are meeting to share the latest results of their research. There are week-long symposia on galaxy evolution, star formation, black holes, and near-Earth objects. I am giving most of my attention to the latter. During the Thursday morning session I described an unusual double asteroid discovered with the Arecibo radar. My presentation—one of 650 delivered at the meeting was well received. In between the scientiûc sessions, however, there is much talk about an important issue that will be decided in Prague: the definition of a planet.

Photo: *.martin*

Ever since the discovery in 1992 of a massive belt of small bodies beyond Neptune (the Kuiper Belt or the trans-Neptunian region), the status of Pluto has been in serious question. With more than a thousand trans-Neptunian objects discovered to date, it has become increasingly clear that Pluto is not unique, but is simply a member of a large population of small bodies in the outer Solar System. This means that astronomers have to deal with the disconnect between the (pre-2006) classification of Pluto as a planet and its status as a trans-Neptunian object. The International Astronomical Union (IAU), which has been the arbiter of planetary and satellite nomenclature since its inception in 1919, is the logical body to sort things out. Several hundred IAU members care enough about the issue that they have chosen to actively participate in the discussions in Prague and to vote on a resolution.

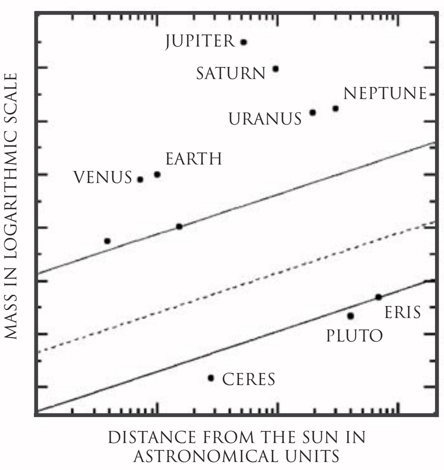
The Pluto situation is quite analogous to that of Ceres. Discovered in 1801, Ceres orbits the Sun between Mars and Jupiter. Because it appeared unique at the time of its discovery, it was immediately hailed as a new planet, and it maintained its planetary status in textbooks for about 50 years. But then astronomers discovered numerous asteroids and revised their thinking and their nomenclature: Ceres is a member of a large population of small bodies. It's not a planet. If Ceres were discovered today in the middle of the asteroid belt, it would never be considered a planet. Likewise, Pluto appeared unique at the time of its discovery in 1930. But if Pluto were discovered today in the middle of the Kuiper belt, it would never be considered a planet.

The most compelling argument showing the distinction between Pluto and the major planets was published in the Astronomical Journal by Steven Soter, a Cornell Astronomy graduate. Figure 1 illustrates the dynamical dominance of bodies in our solar system, i.e. the ability of each object to exercise gravitational control over other bodies in its neighborhood. The eight planets are massive and powerful; they can accrete, scatter, or push around the material in their vicinity. By this measure, bodies like Ceres and Pluto are 100,000 times weaker; they exercise little or no control over their neighborhood. This criterion is what the IAU ultimately chose as the defining trait in its definition of a planet. Pluto—just like Ceres 150 years ago—lost its status as a planet.

The decision did not come without hiccups. The IAU had appointed a committee of seven members to draft a resolution. The committee was composed of at least five certifiable Pluto lovers. In a desperate attempt to maintain Pluto's planetary status, driven by emotion rather than reason, they proposed a criterion that can best be described as "anything round goes." Their stillborn proposal suggested that roundish

Figure 1

Dynamical dominance (or gravitational influence) in the Solar System.



The plot shows the mass of the body as a function of distance from the Sun in astronomical units. The solid lines indicate the divide between Solar System bodies with great gravitational influence and bodies with less gravitational influence. Adapted from S. Soter, Astronomical Journal, *in press.*

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Celebrating Riccardo Giovanelli

Brian Kent works on extragalactic radio surveys with Riccardo. He's also an astrophotographer and an amateur radio operator.

On October 13 and 14, 2006 the Department of Astronomy held a special symposium to celebrate the 60th birthday of Riccardo Giovanelli, Professor of Astronomy. The symposium, entitled "Dark and Dusty Galaxies: Galaxy Surveys with Really Gigantic (RG) Telescopes," explored past and present studies of galaxies in the Universe with some of the world's largest telescopes.

Over 90 guests listened to fascinating discussions and lectures by many eminent astrophysicists, including some of Riccardo's former graduate students and collaborators. Speakers discussed many of the world's great observatories, including the 1,000 foot Arecibo Radio Telescope in Puerto Rico, and the newly planned Cornell Caltech Atacama Telescope (CCAT), which Professor Giovanelli directs. Astronomical topics touched on many of his scientific interests ranging from cosmology and large-scale structure of the Universe to galaxy environments and the search for dark galaxies. Included in the discussions were highlights from the Arecibo Legacy Fast ALFA Survey, an extragalactic hydrogen survey led by Professors Giovanelli and Martha Haynes to study galaxies in the local Universe.

Clockwise from top left: *Riccardo with Fred Young, Jim Gunn, Jean Rowley and Martha Haynes.*

Special guest Jim Gunn, Professor of Astrophysical Sciences at Princeton University, delivered a lecture entitled "The Future of Cosmology," which chronicled the scientific history of the beginning of the Universe, and where scientific studies will head in the coming years. The symposium concluded with a banquet at Cornell's Statler Hotel, where Friend of Astronomy and CCAT benefactor Fred Young served as the Master of Ceremonies. Students, friends, family, and colleagues shared fun memories of Professor Giovanelli and his distinguished career.

-Brian Kent

Letter from Prague

(cont.)

Ceres be reinstated as a planet, that Pluto's satellite Charon become a planet, and that some bodies would become planets on a part-time basis. Not surprisingly, this awkard definition was soundly rejected by the assembly. This sorry episode demonstrated that it is extraordinarily difûcult to come up with a scientiûcally sound *definition* of a planet that includes Pluto. A revised resolution including the dynamical dominance criterion was put forth and was adopted by an overwhelming majority. There are eight "planets" in our solar system, many "dwarf planets", and a multitude of "minor planets" or "small solar system bodies" (Table 1).

Table 1

Summary of the IAU Resolution Defining Three Classes of Objects in Our Solar System

IAU Category	**Dynamical Dominance**	**Roundness**	**Members**
Planet	YES	YES	Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune
Dwarf planet	NO	YES	Ceres, Pluto, and many others
Minor planet	NO	NO	Kalliope, Kleopatra, and many, many others

Although some people find it hard emotionally to let go of the nine-planet picture they grew up with, our allegiance as scientists is to rationality and scientiûc arguments. The decision in Prague was all about scientiûc progress and about recognizing that earlier ideas were inadequate. As I contemplate the sunset from the superb castle that dominates the city, I am reminded that many centuries ago, another planet was demoted. Our Earth ceased to be the center of the Universe and became just one small planet humbly orbiting around a suddenly more momentuous Sun. It was not easy to accept our own demotion, but science in the end prevailed, as it has in the case of Pluto.

Sincerely yours,

Jean-Luc Margot

Back to the Moon *(cont.)*

polarization ratios). The bright features at the poles of Mercury exhibit both of these characteristics and are coincident with the floors of impact craters that are in permanent shadow, leading to the conclusion that they represent deposits of water ice, probably the result of cometary impacts.

In the early 1990s a Cornell graduate student, Nick Stacy, imaged as much of the lunar poles as could be "seen" from Earth with the Arecibo radar system. Figure 2 shows the image that Nick made of the south pole, the first good look that we had of this area of the Moon. It is clear that there are no "bright" reflections from the bottoms of craters similar to what we see on Mercury. No large deposits of clean water ice there! However, there are some areas such as the inner slope of the 19 km diameter (12 miles) crater Shackleton right at the pole, with the same light scattering properties as water ice. This was very exciting—until we realized that there were many other small features, some of which are in sunlight during the lunar day, that have the same properties, casting considerable doubt on the idea that these properties are unique to water ice.

Figure 3. *Arecibo/GBT radar image data from October 24, 2005, for a region covering the south pole and the nearside to latitude ~68^0 S. The south pole is on the left rim of Shackleton. The resolution is 100 m. The yellow color denotes ice-like radar scattering properties of Schomberger A and many other smaller craters.*

Then in 1994 NASA put in orbit about the Moon a small experimental spacecraft called Clementine. It had several instruments designed to study the topography and composition of the lunar surface. Clementine's data hinted at the existence of ice in the inner slope of Shackleton crater. Then in 1998, the neutron spectrometer on the Lunar Prospector, which went into orbit about the Moon, found enhanced concentrations of hydrogen at the poles. The interpretation of Clementine's data, which seems to motivate much of NASA's thinking about a possible a lunar base, is controversial, but not the Lunar Prospector's. The only uncertainties are whether the hydrogen is in the form of water molecules, and whether the ice, if it exists, is evenly distributed or in concentrated deposits.

In an attempt to resolve the issue, a group of scientists–Bruce Campbell and Lynn Carter of the Smithsonian Institution, Jean-Luc Margot (Cornell), Nick Stacy, now with the Defence Science and Technology Organization in Australia, and myself–used a radar system consisting of Arecibo transmitting the signal and the NSF's 100-meter Robert C. Byrd Green Bank Telescope in West Virginia receiving the echo, to image the south pole of the Moon at a resolution of 20 meters (66 ft). This is by far the highest resolution we have ever achieved. Figure 3 shows our results. The radar image covers an area about 200 km (140 miles) wide on the far side of the Moon that stretches down from 68^0 south latitude to the south pole, including Shackleton crater. The color image shows ice-like scattering properties around young impact craters most of which are sunlit during the lunar day and therefore cannot have near-surface ice deposits. We think that rather than being due to ice, these values are related to very rocky terrain in and around these young craters.

These results are contrary to the still generally accepted idea that ice has unique radar scattering properties; they cast considerable doubt on the interpretation of the Clementine measurements. Nevertheless, the Lunar Prospector measurements seem to be solid and, depending on the nature of the high hydrogen concentrations, may be indicative of ice.

Until we have evidence to the contrary, any planning for a lunar base should be predicated on the assumption that any ice is distributed at low concentrations throughout the lunar soil. The Lunar Reconnaissance Orbiter will be launched in late 2008. It will be equipped with a number of instruments aimed at detecting ice at the lunar poles. Perhaps the question will be resolved then.

-Don Campbell

Greetings *(cont.)*

In this issue of Orion, among other topics, you will read why Pluto is no longer classified as a major planet, what is important about our Moon, what we are learning from a survey of galaxies observed with the Arecibo radio telescope, and who are our new graduate students.

We wish you all the very best for the New Year and beyond.

Cordially,

Yervant

You can find old issues of **Orion** at
<http://www.astro.cornell.edu/people/friends/orionnews.php>

Books in Science and the Universe

Observational cosmology has determined the composition of the Universe accurately, but the result is vexing: about three-fourths of the energy density in the Universe is dark energy. In its simplest form, dark energy is a cosmological constant that is dominant today but hasn't been so for very long. It seems that we live at a special time in the history of the Universe.

Theoretical physics has also honed in on a promising theory of all of the forces in Nature: String Theory. That the dark energy is a cosmological constant seems to be very natural in string theory, but at first sight it should be either many, many orders of magnitude larger than what we observe astronomically, or else zero.

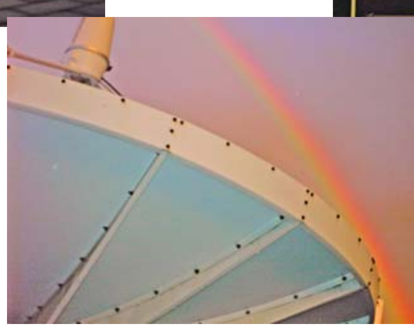
From this dilemma the idea of a "cosmic landscape" has emerged. The basic picture is something like a topographical map with numerous peaks and valleys. You can think of each valley as a different "Universe." The vast majority of these would either fail to expand at all or expand too rapidly to resemble what we observe. However, the sheer enormity of possibilities guarantees that a tiny minority evolve to something like the Universe we observe.

One of the principal proponents of this cosmic landscape idea is Leonard Susskind, professor at Stanford and a Cornell physics Ph.D. Susskind, whose audacious ideas have led the way to this new understanding, has written a lively and entertaining book for the general public called *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*. In it, Susskind gives many strikingly visual descriptions of the content of string theory, and why it appears to allow so many different outcomes for the expanding Universe. He also tackles issues such as whether information is lost or not when matter falls into black holes, a conceptual question that has been resolved by string theory—a resolution that may be central to understanding the landscape.

The Cosmic Landscape reflects Susskind's informal and often unconventional style as a physicist, which makes difficult concepts accessible to everyone. I heartily recommend it to anyone interested in learning some of the ideas behind string theory and the cosmic landscape.

-Ira Wasserman

A View from the Roof of Space Sciences



Double rainbow, November 16, 2006.
Photo: Yervant Terzian

Yervant's Critical Thinking Corner

It is said that when the great mathematician Carl Friedrich Gauss (1777-1855) was a child he was punished in school for misbehaving. He was told to spend time and add all the numbers from 1 to 1000.

Gauss gave the answer in a few seconds!

Here is how he was able to do so. He first paired 1 with 1000, whose sum is 1001. He then paired 2 with 999, whose sum is 1001. Next he paired 3 with 998, whose sum is 1001. There are 500 such pairs the last of which is 500 and 501, that add to 1001.

It can be seen that the numbers from 1 to 1000 can be paired into 500 pairs, each of which adds up to 1001. So the answer is 500 x 1001, which is 500,500.

You have to be as clever as Gauss to figure this out in a few seconds by a simple multiplication.