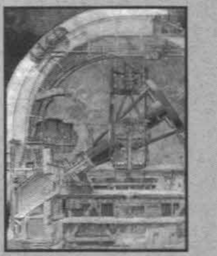
Autumn 2001



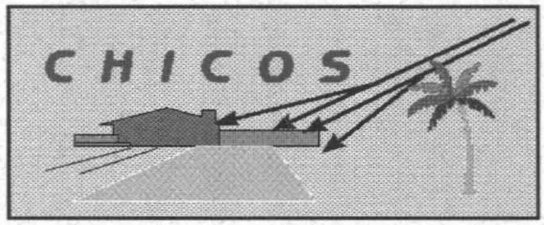
CALTECH PMA COMMUNIQUÉ

A Publication for Caltech's Physics, Mathematics & Astronomy Division No. 4

California HIgh school Cosmic ray ObServatory (CHICOS)

Robert D. McKeown

CHICOS is a collaborative project involving Caltech, Cal State Northridge, UC Irvine, and local high school physics teachers to site a large array of particle detectors at high schools in the Los Angeles area. This array will be capable of detecting and characterizing a sample of the highest energy elementary particles ever observed. The project will offer students and teachers



in local high schools a unique opportunity to collaborate with researchers at Caltech and address fundamental issues at the

continued on page 6

Notes From the Chair

Thomas A. Tombrello, Jr.

This is the fourth newsletter in this series that was created to keep us in contact with our alumni and friends. The contents represent a few of the highlights of the Division's activities. This spring we received acceptances from two new professors: Wilhelm Schlag, Associate Professor of Mathematics; and Danny Calegari, Assistant Professor of Mathematics. Schlag works in harmonic analysis and Calegari in topology.

We have received a substantial contribution toward the construction of a 100,000 square foot building that will unite our efforts in astronomy and astrophysics. A preliminary design is under consideration; the remainder of the funds required are the goal of an active campaign. At the present time research in these fields is spread among four buildings: Robinson; Downs; West Bridge; and Bridge Annex. Putting these related groups into proximity will improve communication and take advantage of shared laboratory and seminar areas. This building will be constructed on the south side of California Boulevard across from East Bridge. This site creates a unified south campus cluster in astronomy and astrophysics with the SIRTF Science Center and IPAC, which are nearby. ◆

PMA Alumni and Post Docs - Come Back to Campus!

The Spring of 2002 will see a special event on the Caltech campus - a full-fledged Division Reunion sponsored by Physics, Math, and Astronomy in collaboration with the Caltech Alumni Association. Talks by faculty, poster sessions, good food and drink, time for socializing, and a few lab tours - as well as a chance to renew ties to old acquaintances and to make new friends - all this will make the program a memorable one. Watch your mailbox for date and reservation information, and this fall stop by the Alumni Association web site at **http://www.its.caltech.edu/~alumni** for more details. Meanwhile, make sure we have your e-mail address so we can notify you of plans as the pieces fall into place. It's going to be a great time for all PMA friends - join us!

INSIDE

FACULTY HONORS & AWARDS 2

EARTHSHINE 2

ASKING NEW QUESTIONS ABOUT THE UNIVERSE: NASA/IPAC EXTRAGALACTIC DATABASE 3

THE CALIFORNIA EXTREMELY LARGE TELESCOPE (CELT): A PROGRESS REPORT 4

CALTECH ESTABLISHES INSTITUTE FOR QUANTUM INFORMATION 4

PMA RADIO ASTRONOMY PROJECT 5

HONORS & AWARDS

Tom Apostol
Corresponding Member of the Academy of Athens

Roger Blandford
Tetelman Fellow at Yale for 2001
Siemens Lecturer at Munich

Judy Cohen
Fullam Award

Richard Ellis
Lansdowne Lecturer, University of Victoria
Senior Visiting Fellowship, Japan Society for the Promotion of Science

Sunil Golwala
APS Particle Physics Dissertation Prize

Steven Gubser
European Physical Society's Gribov Medal

Fiona Harrison
Presidential Early Career Award

Dirk Hundertmark
2001 ASCIT Teaching Award

Shri Kulkarni
Fellow of the Royal Society of London
Sackler Lecturer, Princeton University
Named the John E. and Catherine T. MacArthur Professor of Astronomy & Planetary Science

Andrew Lange
Named the Marvin L. Goldberger Professor of Physics

Rahul Pandharipande
Packard Fellow

Charlie Peck
2001 ASCIT Teaching Award

Earthshine

Robert Tindol

Scientists have revived and modernized a nearly forgotten technique for monitoring Earth's climate by carefully observing "earthshine," the ghostly glow of the dark side of the moon.

Earthshine measurements are a useful complement to satellite observations for determining Earth's reflectance of sunlight (its albedo), an important climate parameter. Long-term observations of earthshine thus monitor variations in cloud cover and atmospheric aerosols that play a role in climate change.

Earthshine is readily visible to the naked eye, most easily during a crescent moon. Leonardo da Vinci first explained the phenomenon, in which the moon acts like a giant mirror showing the sunlight reflected from Earth. The brightness of the earthshine thus measures the reflectance of Earth.

In a recent issue of the refereed journal Geophysical Research Letters, a team of scientists from the New Jersey Institute of Technology and the California Institute of Technology report on earthshine observations showing that Earth's albedo is currently 0.297, give or take 0.005.

In the early 20th century, the French astronomer André-Louis Danjon undertook the first quantitative observations of earthshine. But the method lay dormant for nearly 50 years, until Caltech team leader and professor of theoretical physics Steven E. Koonin coauthored a paper in 1991 describing its modern potential. The present data are the first that are precise and systematic enough to infer the relative health of Earth's climate.

"Earth's climate is driven by the net sunlight that it absorbs," says Philip R. Goode, leader of the New Jersey Institute of Technology team, Director of the Big Bear Solar Observatory, a Distinguished Professor of Physics at NJIT. "We have found surprisingly large — up to 20 persent-seasonal variations in Earth's reflectance. Further, we have found a hint of a 2.5-percent decrease in Earth's albedo over the past five years."

A 2.5-percent change in reflectance may not seem like much, but if Earth reflected even 1 percent less light, the effect would be significant enough to be a concern when studying global warming.

Koonin notes that "studies of climate change require well-calibrated, long-term measurements of large regions of the globe. Earthshine observations are ideally suited to this, because, in contrast to satellite determinations of the albedo, they are self-calibrating, easily and inexpensively performed from the ground, and

continued on page 7

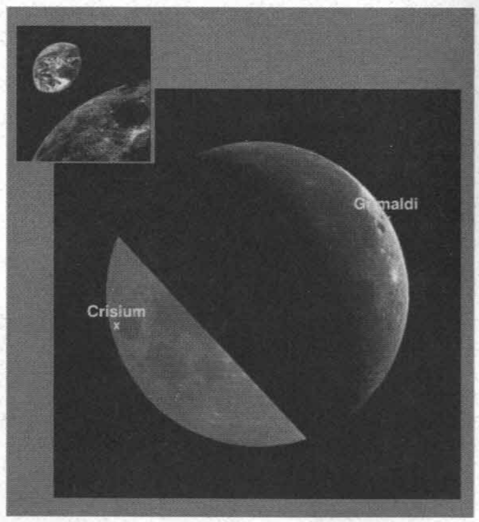


Figure 1 shows a Big Bear Solar Observatory lunar image from Dec. 12, 1999, in the main panel. A neutral density filter attenuates the sunlit crescent in the upper right, making the earthshine visible on the balance of the lunar disk. Precise comparison of the intensities of two lunar regions (labeled Grimaldi and Crisium) allows monitoring of Earth's changing reflectance. The inset contains a simulated image of a gibbous Earth as it would be seen by an observer standing on the moon.

Asking New Questions about the Universe: NASA/IPAC Extragalactic Database

Barry F. Madore, Joseph Mazzarella, George Helou

It is being called "ASTRO-GRID" in Europe and the "VIRTUAL OBSERVATORY" in the United States. And on both sides of the Atlantic the plan is to provide rapid and seamless access to the massive catalogs and terabyte imaging databases now being populated by ground-based and space-based telescopes. The hope in astronomy is that by unleashing the power of the Internet on rapid-access and high-powered compute facilities, a whole new paradigm for research and discovery will emerge.

But discovery is a multitextured tapestry. One can discover rare objects, new classes of objects, new relationships among objects; and even "discover" the nature of previously known objects. Indeed, much of discovery is a process — one that is incremental and relative to what is already known, already discovered. So, equally-rapid access to the legacy of past discoveries, existing observations and published data is also a vital part of the vision of an integrated electronic view of the sky.

For the past 13 years, astronomers at the California Institute of Technology have been building, maintaining, and systematically expanding the capabilities of a comprehensive on-line database designed to capture all that is currently known about the extragalactic sky, and offer it back to the community in support of research and discovery.

The NASA/IPAC Extragalactic Database (NED) is the longest continuously funded project at the Infrared Processing and Analysis Center (IPAC). The NED Team, its computers and their on-line databases are located in the Morrisroe Astro Sciences Laboratory on the Caltech Campus at 770 S. Wilson. Drs. Barry F. Madore, Joseph Mazzarella and George Helou are the research astronomers who provide both the day-to-day administration of and the long-term vision for NED, while a team of programmers, archivists and scientific data-entry personnel keep NED poised at the cutting edge of data content, data access and archive interoperability.

At the heart of NED is a meticulously maintained and carefully linked database of about 4 million extragalactic objects (galaxies, quasars, radio and infrared sources, etc.) drawn from a full century of surveys and individually published discoveries made at wavelengths from the gamma-ray regime to the radio, and collected from ground-based telescopes and space-based missions. Cross-identifications, spanning 10 decades of the electromagnetic spectrum, allow "on-the-fly" construction of spectral energy distributions built from data originally found in hundreds of papers and made over decades of time. Redshifts for 170,000 objects combined with the high-precision positions in NED allow users to make sample cuts across the sky, both within the local supercluster and out into the high-redshift Universe. Optical images are available for all 3.7 million objects, being immediately extracted from on-line digital copies of the POSS, which was derived from plates taken at Caltech's Palomar Observatory in the north and at La Silla in the south. Unique collections of radio, infrared, optical and ultraviolet images for 10's of thousands of additional objects are also on-line and linked to the individual objects through the NED face.

continued on page 7

HONORS & AWARDS

John Preskill
2002 Lorentz Chair, University of Leiden
Andrejewski Lecturer for the Fall of 2001

Tom Prince
Chief Scientist at JPL

Anneila Sargent
University of Edinburgh Science Festival Lecturer
Philips Visitor at Haverford College for Spring of 2001
Associate of the Royal Astronomical Society

Wal Sargent
4th Icko Iben, Jr. Distinguished Astronomy Lecturer
Henry Norris Russell Lectureship, American Astronomical Society

Ed Stone
NASA's Distinguished Service Medal

Keith Taylor
2001 Maria and Eric Muhlmann Award of the Astronomical Society of the Pacific

Mark Wise
APS Sakurai Prize

Nai-Chang Yeh
Achievement Award of the Chinese-American Faculty Association, Southern California
Fellow of the Institute of Physics & title of Chartered Physicist

Ahmed Zewail
Foreign Member of the Royal Society (London)

SSC/IPAC
Their web tutorial "Infrared Astronomy" receives award from AAAS

The California Extremely Large Telescope (CELT): A Progress Report

Richard Ellis & Chuck Steidel

A recent analysis of discoveries from telescopes of all apertures led to the perhaps surprising result that as much exciting work is still being done with telescopes whose mirror diameters are less than 2 meters as with the largest, most powerful facilities. This demonstrates a continuing need for a versatile approach in exploiting the rich variety of physical phenomena observed in the cosmos, not all of which are beyond reach of modest aperture telescopes. However, it would be foolish to use this conclusion to argue against building giant telescopes, plans for which continue to drive the direction of world astronomy and hence remain central to Caltech's leadership in the subject. The Palomar 200-inch and later both Keck telescopes have inspired generations of Caltech astronomers to a breadth of discoveries many of which were unforeseen when those facilities were first proposed.

For many reasons the time is ripe for considering the construction of a telescope larger than the two Kecks. Foremost, astronomy is undergoing a major transition from an era of exploration, where few of the basic parameters were even loosely constrained and researchers were concerned primarily with undertaking inventories, to one of physical understanding where a detailed account of the origin and transformations that occur during the lifetimes of stars, planets and galaxies represents the new challenge. Detailed studies demand focused efforts with powerful instruments; such campaigns have long been a successful hallmark of Caltech research. Astronomers now seek chemical and physical properties not only for bright, local sources but also for large numbers of fainter, more distant or representative examples. Moreover, the Kecks are now established facilities with the first phase of instrumentation largely in place. Whilst their unique role is being challenged by a number of comparable facilities reaching maturity, by demonstrating the success of the segmented mirror approach, they provide the basis upon which yet larger primaries can be contemplated. Given the long lead time in developing forefront facilities, now is the time to consider the logical next step.

At a meeting of the CARA Board in Hawaii in July 1999, Caltech and

continued on page 9

Caltech Establishes Institute for Quantum Information

by John Preskill

Caltech's PMA and EAS Divisions have jointly established the Institute for Quantum Information (IQI), supported by a five-year grant from the National Science Foundation. The goal of the IQI is to advance the foundations of quantum information science (QIS), an emerging field that draws on physics, mathematics, computer science, and engineering. Broadly speaking, QIS addresses how the principles of quantum physics can be harnessed to improve the acquisition, transmission, and processing of information.

QIS derives much of its intellectual vitality from three central ideas, all of relatively recent vintage. The first important idea is quantum computation. We have learned that a computer that operates on quantum states instead of classical bits can perform tasks that are beyond the capability of any conceivable classical computer. For example, finding the 200-digit prime factors of a 400-digit composite number would take billions of years on today's supercomputers. But for a quantum computer it would be an easy problem, not much harder than multiplying two numbers together to find their product. The boundary between "hard" and "easy" — between problems that someday will be solved and problems that never can be solved — is essentially different in a quantum world than in a classical world.

The second important idea is quantum cryptography. You can communicate privately with another party over the Internet, but the security of that communication is founded on assumptions about the computational resources that are available to a potential adversary. In contrast, if you were able to communicate by transmitting quantum states (like photon wave packets traveling in an optical fiber) instead of classical bits, you could achieve a higher level of privacy founded on fundamental laws of physics. Quantum cryptography is based on the principle that it is impossible to collect information about the state of a quantum system without disturbing the state in a detectable way.

The third important idea is quantum error correction, which has greatly boosted our confidence that large-scale quantum computers really

continued on page 10

PMA Radio Astronomy Project

Ravinder S. Bhatia & Brian G. Keating

The value of an early introduction to science is immeasurable, but it can be intimidating to a young person with scientific curiosity to approach a scientific institution. To encourage the participation of young people, it is important for the scientific community to extend itself to the public, and to foster the bonds of collaborative participation. These interactions are vital to the continuing support of science by the public. Working with a cutting-edge academic institution can be an invaluable resource for a public school. My postdoctoral colleague, Dr. Brian Keating, and I have therefore developed a coordinated program of mentoring and outreach with local schools. The aim of this collaboration is modest - to encourage young people to pursue the sciences as a hobby or legitimate career goal - but the potential dividends are unlimited. We recognize the substantial leverage that we as scientists have for public school education: a few hours of our time per month can have enormous benefits on the quality of science education in our local public schools. By adding our time spent at a school with the resources of Caltech (machine shop, electronics shop, etc.) we can ensure that we are successful in this endeavour.

The Radio Astronomy Project team.

In December 1999 I volunteered for a weekend with the Planetary Society's Planetfest here in Pasadena to coincide with the culmination of the Mars Polar Lander mission. At that event, I met a group of students from Littlerock High school together with their Astronomy teacher, Lee Syer. Littlerock High is situated an hour's drive north of Pasadena in the Antelope Valley. As we anxiously waited for news from the Mars landing, we discussed the different space missions being flown together with the latest advances in astronomy and also how Caltech was playing such an important role in many of these missions. I invited the class to tour the Caltech campus and the Observational Cosmology laboratories where we build instruments to observe the Cosmic Microwave Background. Although the Polar Lander mission was not a success (subsequent analysis indicated that the landing had been a little harder than expected), this meeting initiated what was to be fruitful collaboration between Caltech's PMA Division and the local community.

We felt it was particularly important to work with Littlerock High as a school that is from a low income area and where so many of the students are from ethnic minorities. We arranged the much anticipated visit to Caltech for the students, and in return visited their school regularly to give classes on science, particularly chemistry and astronomy. We then embarked on a longer project for the Astronomy students to design a satellite mission which would measure the depletion of the Earth's stratospheric ozone layer. Our goal was to give the students real-world problems and encourage them to discover solutions on their own, as opposed to lecturing to them. We structured this as a project that would be undertaken at a government lab, with Littlerock High as a contractor to Caltech as the customer. The students worked under real world scenarios, with an emphasis on teamwork and communication skills. The 30 sophomores, juniors and seniors worked in groups of 5 to 6 people on various parts of the satellite. They organised their teams into a program manager, three systems engineers, an accountant, a graphics designer, an editor and team leaders in charge of the individual technical teams. Team responsibilities were Structural Design, Onboard Power, Payload, Thermal Design, Attitude and Orbital Control System, Launch

continued on page 11

CHICOS *(from page 1)*

forefront of present-day astrophysics and particle physics. Due to the ethnic and racial diversity of the Los Angeles high schools it is expected that this program will provide a novel mechanism for broadening the participation of underrepresented groups in society in scientific research. Thus, in addition to establishing an important experimental facility for ultra-high energy cosmic ray studies, this project will provide an exceptional educational opportunity for high school students in the Los Angeles area.

The project is coordinated through the Kellogg Radiation Laboratory at Caltech under the direction of Professor of Physics Robert McKeown. Cal State Northridge provides a coordinated educational program for high school teachers to enable their participation in the research project and its incorporation in the high school curriculum. Initial funding for the project has been provided by a grant to Caltech from the Weingart Foundation.

During the last decade, the community of high-energy cosmic ray physicists has constructed a number of very large (1-100 sq. km) arrays to study cosmic rays at the very highest energies ever detected (10^{20} eV). These particles are over one hundred million (10^8) times more energetic than those that can be produced in modern accelerator laboratories. The astrophysical origin of these particles is still unknown, but it has been generally assumed that they are protons accelerated in extreme extragalactic astrophysical environments. These particles produce huge "showers" of many secondary particles when they collide with atomic nuclei in the upper atmosphere; the most energetic of these showers can simultaneously trigger detectors over a several kilometer radius at the earth's surface. The rate of incidence at the highest energies (10^{20} eV) is quite low: in a 100 square kilometer area one observes only about one event per year. Therefore, it is essential to sample a large surface area (hundreds of square kilometers) to observe a significant number of these ultra-high energy particles.

Figure 1: Crew of students, high school teachers, and research personnel retrieving detectors in the mountains of New Mexico in summer 2000.

In the last several years, the largest previously built array (in Japan) has produced extremely interesting results (see article *Science*, vol. 281, August 14, 1998, page 893). It appears that these primary particles can be more energetic than previously thought. Before these data became available, it was generally expected that there would be a dramatic decrease in flux above 10^{20}eV due to inelastic scattering (pion photoproduction) with the cosmic microwave background (known as the GZK cutoff). The failure to observe this cutoff in the flux has generated substantial interest and much speculation. It is possible that the observed events are not due to primary high energy protons (as was generally assumed) but exotic new particles such as a light gluino. Alternatively, it may be possible that the UHE protons are generated at relatively nearby (say < 20 Mpc) astrophysical sites. These results have energized this field and there are several proposals to build even larger arrays over the next few years. The primary research goal is to collect more events at these ultra-high energies and characterize their energies and apparent direction of origin.

The Los Angeles basin is quite unique in that there is a very large area (> 5000 km^2) of uniformly dense population with available high school

continued on page 8

Earthshine *(from page 2)*

instantaneously cover a significant fraction of the globe."

The new albedo measurements are based on about 200 nights of observations of the dark side of the moon at regular intervals over a two-year period, and another 70 nights during 1994-95. Using a 6-inch refractor telescope and precise CCD at the Big Bear Solar Observatory, the researchers measure the intensity of the earthshine.

By observing simultaneously the bright "moonshine" from the crescent, they compensate for the effects of atmospheric scattering. The data are best collected one week before and one week after the new moon, when less than half of the lunar disk is illuminated by the sun. When local cloud cover is also taken into account, Earth's reflectance can be determined on about one-quarter of the nights.

The study relies on averages over long periods because the albedo changes substantially from night to night with changing weather, and even more dramatically from season to season with changing snow and ice cover. The locations of the land masses also affect the albedo as Earth rotates on its axis. For example, the observations from California easily detect a brightening of the earthshine during the night as the sun rises over Asia, because the huge continental land mass reflects more light than the Pacific Ocean.

"Thus, the averaging of lots of data is necessary for an accurate indication of a changing albedo," Goode says.

It is significant that the earthshine data suggest that the albedo has decreased slightly during the past five years since the sun's magnetic activity has climbed from minimum to maximum during that time. This supports the hypothesis that the sun's

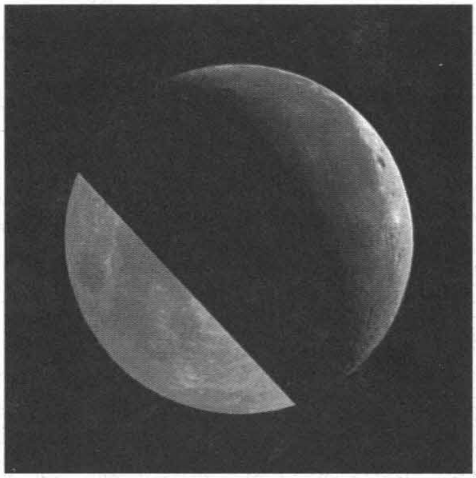


Figure 2 is the Dec. 12, 1999 lunar image alone, with no labeling or inset.

magnetic field plays an indirect role in Earth's climate. If supported by further observations, it would explain why there seem to be so many signatures of the sun's 11-year activity cycle in Earth's climate record, but the associated variations in the Sun's brightness are too weak to have an effect.

The researchers plan continuing observations from Big Bear. "These, supplemented with additional observations from a planned worldwide network, will allow even more precise, round-the-clock monitoring of the earth's reflectance," Goode says. "That precision will also make it possible to test connections between solar activity and Earth's climate."

"It's really amazing, if you think about it," Koonin says, "that you can look at this ghostly reflection on the moon and measure what Earth's climate is doing."

The study was funded by both NASA, beginning in 1998, and the Western Center for Global Environmental Change, during 1994-95. Beyond Goode, other members of the NJIT team are Jiong Qiu, Vasyl Yurchyshyn, and Jeff Hickey. Beyond Koonin, other members of the Caltech team are C. Titus Brown, Edwin Kolbe (now at the University of Basel), and Ming Chu (now at the Chinese University of Hong Kong). ◆

Questions *(from page 3)*

NED is multiwavelength in its holdings and highly connected on campus and to the outside world. For instance, within IPAC the Infrared Science Archive (IRSA) is the primary archive for the 2-Micron All-Sky Survey (2MASS) project which just this year completed its imaging survey in three near-infrared bands, covering the 1-2 micron region of the electromagnetic spectrum. With the last observations now in hand, the final archive will be released in about 2 years and will contain at least 350 million objects. Of these there will be on the order of 2 million resolved galaxies. Many of these are already in NED with direct electronic links to detailed observations and full-resolution images provide by IRSA. NED also provides its users with direct access to relevant observations and archive holdings at a multiplicity of sister databases beyond Pasadena, and literally around the world. At the click of a button NED links users from its objects to images, catalogs and other relevant holdings at STScI in Baltimore, MD to HEASARC in Cambridge, MA to the VLA and NRAO archives in Socorro, NM and Charlottesville, VA respectively. And, with equal ease, secondary searches are initiated for the user by NED at the CDS in Strasbourg, France. And finally, all data within NED itself is referenced to the published literature and hyperlinked to NASA's Abstract Data System (ADS) located at the Smithonian Institution in Cambridge, MA.

At present the NED server responds to a Web hit every 2 seconds, corresponding to an average of one million Web hits per month. Usage has been doubling every 18 months since NED first went on-line in 1988; and there is no indication of any slowdown. These requests originate from astronomers working in all corners of

continued on page 8

Questions *(from page 7)*

the world and at all times of day and night.

But the archiving of data, and the support of discovery is not all that NED provides. Building on this infrastructure and its strong links to the published electronic literature the NED Team also provides a Knowledgebase for Extragalactic Astronomy and Cosmology, called "LEVEL5". This component of NED has high-level information, tabular data and a broad collection of atlases, catalogs, seminal papers and review articles in electronic form and individually hyperlinked by references to the journals and by objects back to basic data frames in NED proper.

From the original pixels to the extracted data, from objects to classes, from spectra to redshifts, from galaxies to largescale structure, from information to knowledge, the NED Team at Caltech is providing today a coherent electronic environment for the extragalactic researcher that is designed to grow and to thrive in the age of the Virtual Observatory.

As the Virtual Observatory comes on-line, with its unimaginably large datasets and the individual pixels from which they were derived, NED is already set up to be a portal through which the extragalactic community will link past knowledge and present data with the future surveys. Discoveries will be made through NED in the full context of what is already known. Discoveries will be made by seeing new surveys in the context of what is already cataloged at a host of complementary and diverse wavelengths. Discovery will not be limited by ignorance or by privileged access, but only by the imagination of our users. NED can be reached via the Web by pointing to:
http://nedwww.ipac.caltech.edu.
LEVEL5 can be found on the main interface panel or accessed directly at:
http://nedwww.ipac.caltech.edu/level5/.

CHICOS *(from page 6)*

in-frastructure. We have obtained 164 scintillation detectors (see Figure 1) from a decommissioned cosmic ray experiment in New Mexico, and are presently working to instrument these detectors in an array with area of about 400km^2.

Each site will have a detection system with a computer to acquire data, and would operate in an autonomous mode using GPS time-stamping of events. The data from each site would be transmitted via internet to a central computer at Caltech where the data would be logged, analyzed, and accessible to the high schools. The availability of existing infrastructure in the Los Angeles school system with internet connections, power, shelter, and willing collaborators provides an excellent opportunity to develop such a large array. Very capable PC's, GPS receivers, and high-speed computer network connections are all recent technical developments that are now ripe for exploitation in a project like CHICOS. We presently plan to deploy this array in the next 3 years (2001-2003). The proposed network of sites is shown in Figure 2.

An educational program for high school teachers at California State University at Northridge (CSUN) will provide these teachers with the necessary knowledge to participate in CHICOS and also to incorporate relevant aspects into the high school curriculum. CHICOS will afford these teachers with a unique opportunity for professional development and participation in forefront research. They will be engaged in a program to develop high school level curriculum materials relevant to cosmic ray research that

continued on page 10

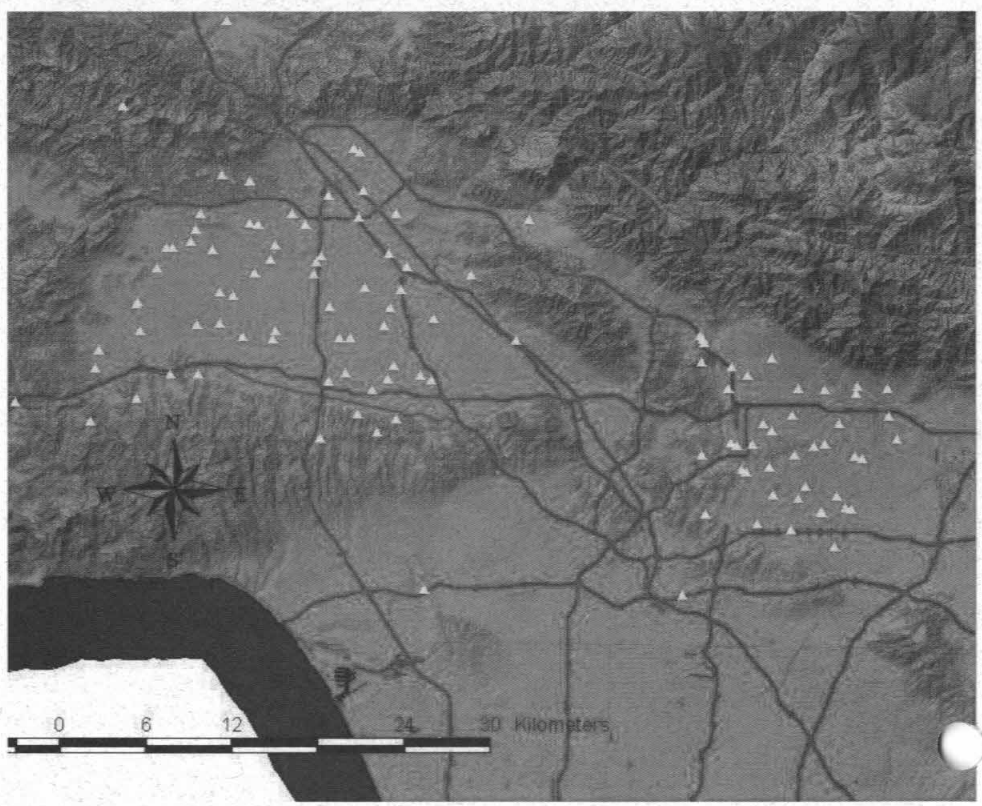


Figure 2: GIS map showing the proposed siting of CHICOS stations in high schools and middle schools in the San Fernando and San Gabriel valleys.

CELT *(from page 4)*

the University of California agreed to participate in a jointly-funded preliminary design study for a 30 meter segmented mirror telescope entitled CELT (prononced kelt) and the first phase of this activity is nearing completion. Conceptual design at the technical level is being coordinated by engineering effort at Caltech and UC led by Jerry Nelson (UCSC, former Project Scientist for the Keck telescopes, Caltech class of 1965, BS). Through a Steering Committee co-chaired by one of us (CS), we expect to deliver a report later this year which will include the scientific rationale in the context of other ground and space-based opportunities, a basic concept for the telescope and its components, and most importantly, those key technical studies that must be addressed in a second, more detailed, design phase which will rigorously justify feasibility and provided a well-argued cost.

What might CELT look like? Figure 1 gives an impression based on a recent design. Despite the legacy of Keck there are numerous differences. Structurally, the telescope is closer to a radio telescope than a traditional optical reflector. The primary focal ratio (f/1.5) is faster than that of Keck and the skeletal design incorporates the need to support a small secondary mirror whilst minimizing the effects of wind-buffeting in an optimized enclosure. The primary segments are also slightly smaller (0.5m sided hexagons c.f. 0.9m) . Although 30 times as many segments will be needed as for each Keck primary, expected economies in fabrication through multi-segment polishing and advances in active control make this a feasible proposition. The number of focal stations upon which instruments are mounted has also been reduced. The Cassegrain focus has been dropped following flexure difficulties noted with instruments on 8-10m telescopes; two large Nasmyth decks (each possibly arranged in two storeys) will be accessed with an adjustable tertiary mirror.

A demanding area which is receiving particular attention at Caltech is adaptive optics (by Rich Dekany (Caltech class of 1989, BS), who chairs the relevant working group). Unlike Palomar and Keck, which both had successful adaptive optics (AO) units retro-fitted, CELT will include AO from the outset. The benefits of AO with a 30m aperture are truly enormous...but so are the challenges! The diffraction limit at a wavelength of 2 microns corresponds to an impressively fine physical scale (< 100pc) for even the most distant sources where the combination of a large aperture ensures CELT will outperform any projected space facility. The key question is the field of view over which this remarkable performance could be attained. Dekany has proposed a set of staged experiments with the Palomar 200-inch to demonstrate the key image sharpening technologies and these have been incorporated into a forward-looking plan for the observatory.

In addition to the exciting option of adaptive optics correction over a 1-2 arcmin field, the hyperbolic primary delivers an impressive seeing-limited 20 arcmin field of view. Instrumenting such a field for multi-object spectroscopy has been addressed by Keith Taylor (who co-chairs the instrument working group). Taylor proposes a novel arrangement of deployable units each of which dissects the images of faint galaxies to secure resolved spectroscopy with the unprecedented signal/noise essential for dynamical and chemical analyses. A major requirement in the currently-conceived suite of CELT instrumentation is large format (4K by 4K) infrared detectors. An alarming number of such (currently unavailable) detectors will be needed to fully realize CELT's scientific gains. To remedy this, a strategic alliance has been formed with the Rockwell Science Center whose staff (e.g., Selmer Wong, Caltech class of 1992, MS & PhD, 1996) are actively involved in formulating and costing a detector plan. The benefits can, of course, also be realized on Caltech's existing telescopes.

Finally, where should CELT be located and for how long would it be unique? George Djorgovski chairs a site working group that is examining, without prejudice, mainland US and Chilean sites alongside that on Mauna Kea, Hawaii. Despite anecdotal evidence and obvious logistic, economic (and political!) considerations, Djorgovski and the Steering Committee are approaching this as methodically as time permits, gathering site-specific data and coordinating efforts with meteorological experts. Concerning the question of uniqueness, it should come as no surprise that plans for 30m telescopes (and larger!) are being hatched elsewhere. The key to success may well turn out to demand prior experience with segmented mirror technologies and finding the resources required to maintain our lead in design engineering. ◆

Figure 1: A recent conceptual design for CELT - a 30 meter mirror telescope. The f/1.5 primary consists of 1080 segments, each 0.5 meters on a side. Instruments are located on each of two Nasmyth platforms.

Quantum *(from page 4)*

can be built and operated someday. The power of a quantum computer derives from its ability to process coherent quantum states, but such states are very easily damaged by uncontrolled interactions with the environment — a process called decoherence. Thus quantum computers are much more susceptible to error than conventional digital computers. But we have learned that quantum states can be cleverly encoded so that the debilitating effects of decoherence, if not too severe, can be resisted. In principle, then, even very intricate quantum systems can be stabilized and accurately controlled.

The scientific mission of the IQI is to elaborate and develop these ideas, and to otherwise illuminate the essential differences between quantum information and classical information. We aim to better understand the capabilities of quantum computers, and to bridge the vast gap between the theory and practice of quantum information processing by conceiving new approaches to the physical manipulation of coherent quantum states.

A variety of Caltech groups in both the PMA and EAS Divisions have already been engaged in QIS research for several years. The IQI consolidates, expands, and enhances these activities by providing a focal point for QIS research on the Caltech campus. Faculty, research staff, and students from both Divisions interact, promoting the communication and collaboration across disciplinary boundaries that will be essential to the further development of the field.

Central to the IQI's scientific program is a vigorous visitor's program that brings to Caltech the world leaders of the QIS research community for both long-term and short-term visits. The IQI also supports postdoctoral scholars drawn from backgrounds spanning the disciplines relating to QIS. The visitors and postdocs affiliated with the IQI occupy space in Steele and Jorgensen laboratories, generously provided by the EAS Division.

PMA faculty connected with the IQI include Valentine Professor of Physics Jeff Kimble, Associate Professor of Physics Hideo Mabuchi, Professor of Theoretical Physics John Preskill, Professor of Physics Michael Roukes, Professor of Electrical Engineering, Applied Physics, and Physics Axel Scherer, and Feynman Professor of Theoretical Physics Kip Thorne. EAS faculty include Professor of Control and Dynamical Systems and Electrical Engineering John Doyle, Associate Professor of Electrical Engineering Michelle Effros, and Associate Professor of Computer Science Leonard Schulman.

In the 21st century, information technology will play an increasingly important role in our daily lives. We can also anticipate that thinking about how information can be encoded and processed will facilitate progress in basic science. Though quantum theory is now over 100 years old, we are just beginning to learn some of the profound ways in which quantum information differs from classical information. The IQI aims to lead the quest for a deeper understanding of the role of information in fundamental physics.

More about IQI activities can be found at http://www.iqi.caltech.edu/.

CHICOS *(from page 8)*

closely coupled to the California state science education standards. The educational component of CHICOS has been developed over the last year by Professor R. Seki of CSUN, who will administrate this program as the CHICOS Associate Director for Education.

In the future we would like to expand the scope of this project to cover a larger fraction of the Los Angeles area and include a much larger percentage of the high schools. Increasing the area to over 1000 km^2 would establish a major world-class facility in ultra-high energy cosmic ray physics that would compare with the largest presently envisioned arrays (such as the Pierre Auger project that is beginning in Argentina). Not only would CHICOS then be a premier facility for ultra-high energy cosmic ray research in the Northern Hemisphere, but the educational program would then reach more than 10,000 high school students and 300 high school teachers. This proposed project would have a major impact on both cosmic ray research and high school science education in the Los Angeles area. Clearly, CHICOS represents a unique and timely opportunity to combine state-of-the-art research and high school education. ◆

PMA cont. *(from page 5)*

Vehicle, Orbital Requirements and Telemetry. They in turn subcontracted the detailed CAD design drawings of the spacecraft to be done by Littlerock's Design class. To facilitate communications between Littlerock High and Caltech, the school purchased a fax machine and the speaker phone for the Astronomy classroom, and the students set up their own email account. The students had the added task of making a scale size hardware mock-up of their design and this was important to help translate their concepts into something a little more tangible. Ricardo Paniagua from the Caltech PMA/GPS machine shop provided valuable assistance on hardware build.

Over the course of the project, the students investigated the chemistry behind the depletion of stratospheric ozone. They elected to fly the Total Ozone Mapping Spectrometer (TOMS) instrument, which has already flown on several NASA missions. The use of a previously designed instrument allowed them to complete the design of the spacecraft bus and mission aspects within the allocated project time. They were also then able to use clearly defined power, volume and mass figures for the instrument. The total mass of their spacecraft design was 1127 kg and the required power was 2.4 kW. Insertion into a low Earth Polar orbit was to be accomplished using a Pegasus launch vehicle.

In order to formalise the final project presentation, this was given at Caltech to an external review panel of engineers and scientists from JPL and TRW who provided extremely useful feedback to the students on their design. This took the project to a new level of professionalism and formality which we feel was important for the students to be exposed to: it made it clear that we felt that they had something worth saying. KTLA interviewed the students and staff and filmed parts of the presentation, which was featured as an item on their news show that night. Articles were published in the Daily News, the Caltech 336 and the Antelope Valley Press. At this visit, the Caltech Career Development Center provided very valuable advice not only on careers but also on scholarships to fund college attendance, which is of particular importance to these students at a Title 1 (low income) school. Student feedback was extremely encouraging. Several of the them commented on how much the program has broadened their horizons. The visits to Caltech were very enjoyable and enlightening. Especially useful were the organizational skills learned during the program. None of the students had worked on a project of this magnitude before, and all agreed they had grown dramatically through the process.

Our follow-on project this year is the design and construction of two radio telescopes for which we have secured funding from the PMA Division and the Irvine Foundation. The design is a simplified version of the polarimeter Dr. Keating constructed for his PhD thesis and uses commercially available satellite television components operating in C (3-5 GHz) and Ku (10-14 GHz). The commercial hardware (e.g., dish and low-noise amplifiers) is readily available and the remaining electronics and software will be purchased from surplus retailers. The assembled system will have sufficient sensitivity to detect galactic synchrotron radiation, and thermal emission from the Moon, the Sun and even the Cosmic Microwave Background! We are currently fielding the prototype on the roof of the Robinson building. Once that is functioning, we will help the Littlerock students assemble their telescope on the roof of their own school building.

Ultimately, our aim is to build up a self-contained telescope 'kit' for schools and colleges which lets them get a radio telescope up and running with the minimum time and difficulty. Radio astronomy is a uniquely powerful tool since it allows students and teachers to conduct observations during school hours. The telescope is robust and easily deployable, but powerful enough for students to conduct scientific observations. In this way we hope to introduce many young students to the fascination and joy of astronomy.

It has been gratifying for us to receive so much financial support and encouragement from the Caltech community. It is difficult to imagine this project being possible at another institution. The greater Caltech community (PMA Division, Caltech Y, Minority Student Affairs, Career Development Center, and our postdoctoral advisor Professor Andrew Lange) have provided us with the necessary financial and logistical support to make this project a success. We particularly value the freedom to commit time away from our own research as postdoctoral scholars. For ourselves, this outreach project has proved to be a valuable component of our own education and serves as a satisfying complement to our astronomical research. ◆

California Institute of Technology
Division of Physics, Mathematics, and Astronomy
Mail Code 103-33
Pasadena, CA 91125

Address Service Requested