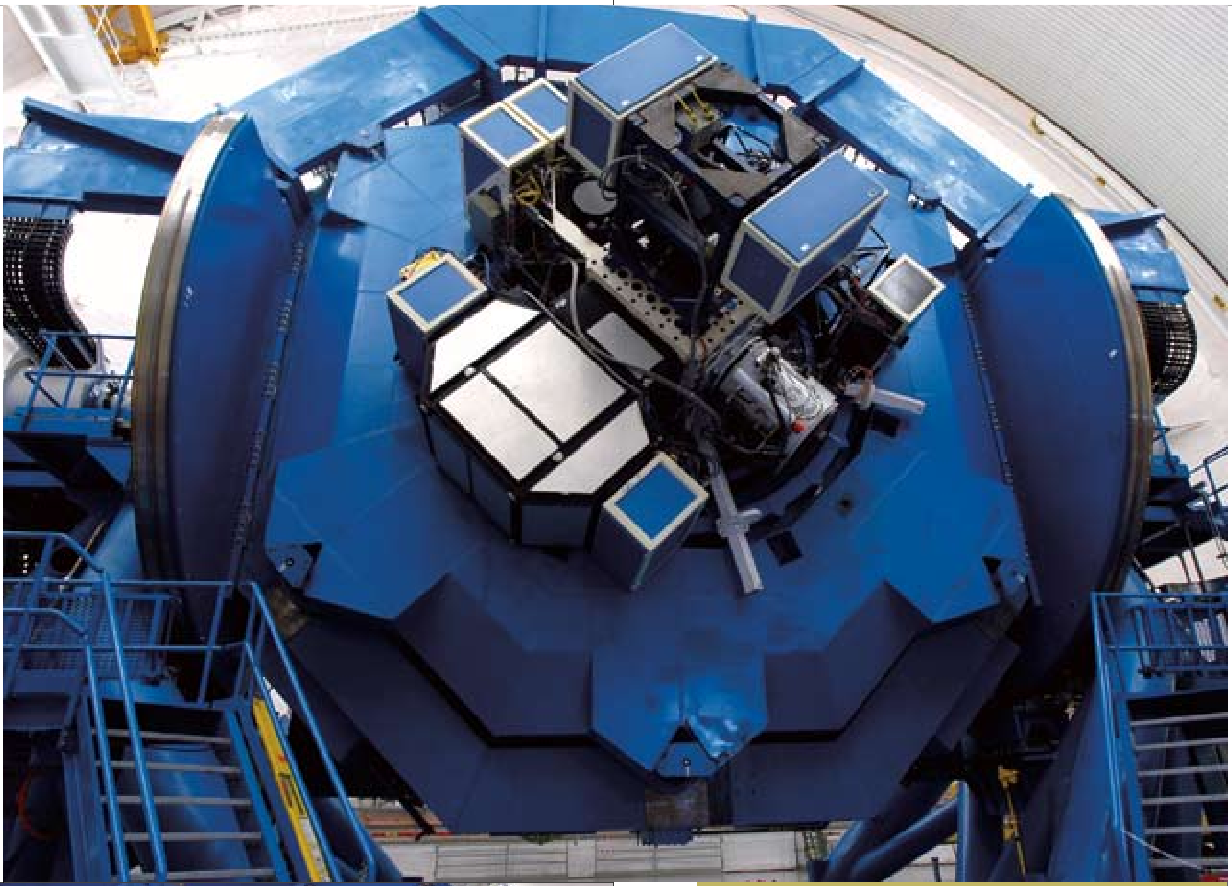
GeminiFocus

Newsletter of the Gemini Observatory

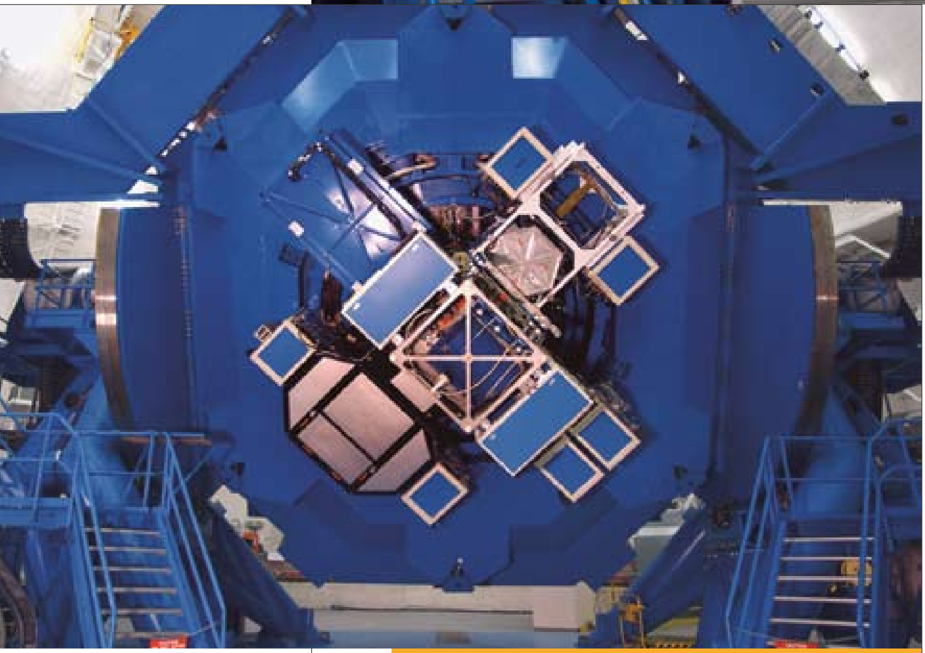
December2005

Gemini Legacy Image / NGC 6559 / T. Rector, University of Alaska Anchorage

Fully populated instrument cluster on Gemini South with GMOS at 8 o'clock position, Calibration Unit at 11 o'clock, GNIRS at 2 o'clock (hidden), Phoenix at 4 o'clock and T-ReCS at center.



Gemini South Instrument Cluster / M. Urzua



Gemini North Instrument Cluster / K. Pu'uohau-Pummill

Fully populated instrument cluster on Gemini North with GMOS at 8 o'clock, ALTAIR at 11 o'clock, NIRI at 2 o'clock, Calibration Unit at 4 o'clock, and MICHELLE at center.

Gemini's Instrument Clusters – A Powerful Approach to Observing

Gemini's unique instrument clusters represent what is likely the most optimized collection of astronomical instrumentation ever assembled on any single ground-based astronomical telescope. Each cluster has as many as four instruments on each telescope covering the optical, near- and mid-infrared wavelength range from 0.4 to 25 microns.

The current Gemini system of instruments allows for multi-instrument queue observing because the instruments are "alive" and ready to observe at any time. At Gemini North, adaptive optics can be used for near-infrared imaging and spectroscopy on demand in an efficient "point and shoot" mode. Because of these systems, Gemini North and South have begun to realize gains in efficiencies and data quality that are unprecedented. For more information on this topic, see the articles: "Observing Efficiency at Gemini Observatory" and "Gemini Queue Operations and Completion Rates" starting on page 54 of this issue.

GeminiFocus
Newsletter of the Gemini Observatory

In This Issue:

Gemini Legacy Image / NGC 520 / T. Rector, University of Alaska Anchorage

Managing Editor, Peter Michaud

Science Editor, Jean-René Roy

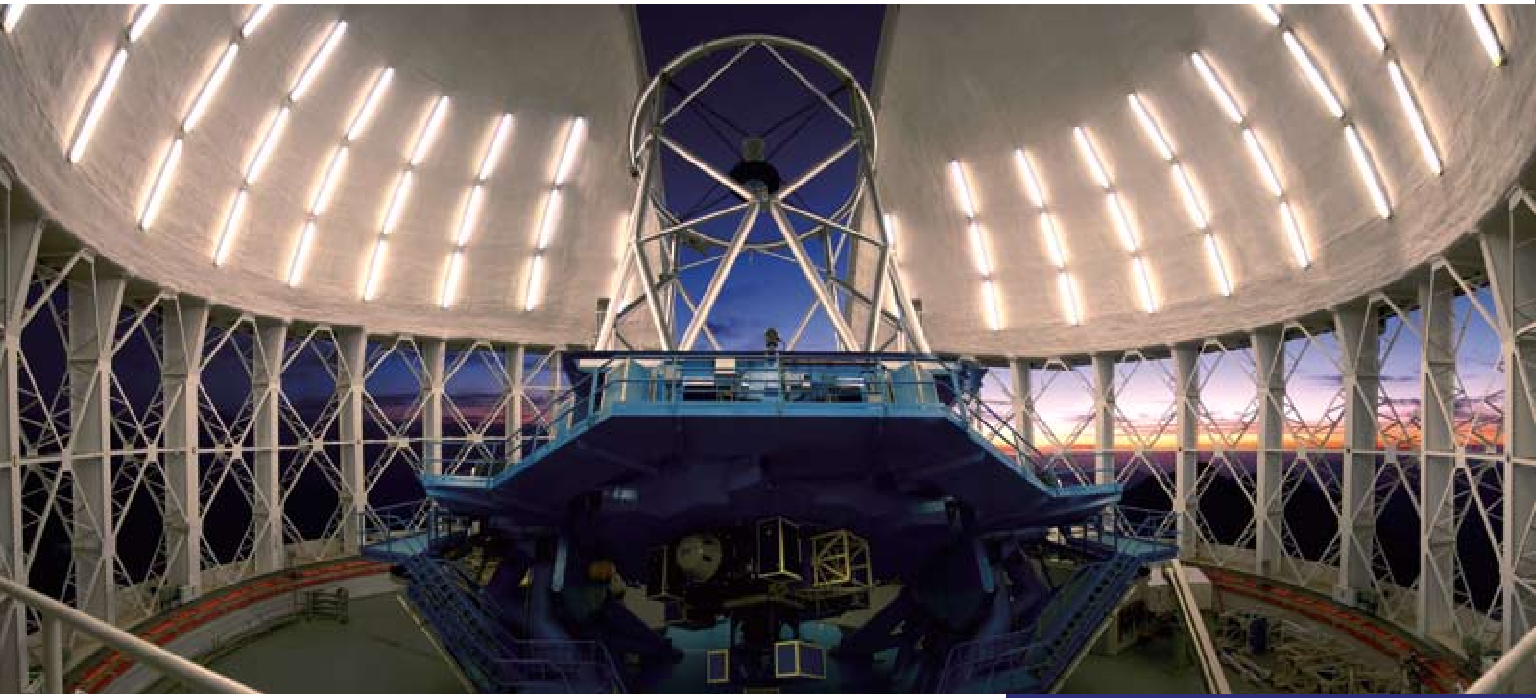
Associate Editor, Carolyn Collins Petersen

Associate Science Editor, Rachel Johnson

Designer, Kirk Pu'uohau-Pummill

by Jean-René Roy
Acting Director

Gemini: The First Five Years



Gemini South at Sunset / P. Michaud

"The GSC is now reassured that, as judged by most quantitative measures, the Gemini Observatory has now evolved into an efficient, productive and competitive facility."

This is what Jim Dunlop (University of Edinburgh, UK), Chair of the Gemini Science Committee (GSC), wrote in his report following the October 2005 GSC meeting. His words reveal that five years after starting science observing at Gemini North, and four years for Gemini South, the Gemini partnership has delivered twin optical and infrared telescope systems that are at the forefront of astronomical research. The Gemini telescopes are now fully operational and producing science results in a competitive way as described in the article, "Gemini Publications: Growth and Impact" starting on page 38.

As reported in other articles in this issue of *GeminiFocus*, several metrics now demonstrate that the Gemini telescopes have a healthy on-the-sky efficiency, including the availability of nights for science programs and shutter-open efficiencies of our various instruments (see "Observing Efficiency at Gemini Observatory" starting on page 54). Most science observing (and nighttime engineering) at Gemini is done via the queue mode. After some "learning," the science program completion rate has gone up significantly following adjustments (like roll-over of Band 1 programs for two additional semesters) and the use of improved planning tools (see the article "Gemini Queue Operations and Completion Rates" starting on page 58). With the successful implementation of a multi-instrument queue, (including "point-and-shoot" adaptive optics with ALTAIR at Gemini North), the Gemini telescopes are able, in the same night, to execute optical, near-infrared and/or mid-infrared observations, as driven by real-time sky conditions and the available queue programs that match existing conditions.

Gemini's unique protected silver coatings, (now on all mirrors), combined with tight cleaning procedures, provide optical systems with the highest consistent throughput and performance (especially in the infrared). Combine this with 0.6 arcsecond root-mean-square pointing accuracy across the sky and a fine image quality of ~ 0.5 arcsecond full-width-half-maximum (median) at V band and it is evident that our users have fine science machines available to support their research.

Since the third quarter of 2005, Gemini observers have been receiving their data electronically from the Gemini Science Archive (GSA) operated under a contract with the Canadian Astronomy Data Centre at the Herzberg Institute of Astrophysics in Victoria, B.C., Canada. An increased effort is currently underway to improve the data flow system at Gemini and to enable more robust quality assessment.

With many significant successes behind us, we do have some serious challenges that will be addressed in the coming years.

First, Gemini's high fraction of queue mode programs has resulted in the reduced presence of observers at the telescopes. While some observers are happy not to travel to Hawai'i or Chile to be present when their observations are taken, many do desire to see how the telescopes and instruments work, and additionally, would like to understand the "Gemini system." Paradoxically, in fulfilling the request of the Gemini Board to establish a 100% queue system, we will also be allowing for the possibility of classical programs that are shorter than the current three-night minimum requirement. We are working at improving the communication between Gemini staff and queue observers because we believe that observer's input is extremely valuable. We also wish to invite researchers, especially graduate students and post-doctoral fellows, to visit the Gemini facilities for extended periods. These visits may correspond to periods when a researcher's program is likely to be executed in the queue. Your National Gemini Office can help organize and coordinate such visits.

Second, the *Aspen Program* represents one of the most ambitious investments in ground-based astronomical instrument development for this decade. As reported by Doug Simons in his article, "Why the Aspen Program Now?" starting on page 7, the Aspen instrument program is about to begin the construction phase of the Extreme Adaptive Optics Coronagraphic Imager (ExAOC), which will be contracted to a consortium led by the Lawrence Livermore National Laboratory. Several critical milestones must also be met during the coming year to secure the full funding and cash flow that will enable the construction of the other Aspen instruments. This involves the success of important conceptual design studies that will need to be completed in the third quarter of 2006 for final Gemini Board decisions in November 2006.

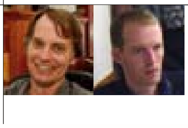
With the implementation of observing time exchanges between Gemini and Keck in 2005A (five nights of MICHELLE on Gemini North for five nights of HIRES on Keck), as well as between Gemini and Subaru starting in 2006B (five nights of GMOS-North/South, and NIFS for five nights of SuprimeCam), the "giants" of Mauna Kea have pushed their collaboration up a notch. In addition, there are several on-going collaborations between the

Gemini and Keck laser guide star propagation captured by Akihiko Miyashita from the Subaru Observatory

engineering teams of Gemini, Keck and Subaru as even more ambitious ventures are pursued. Gemini and Keck have joined together to produce two high-power solid-state lasers for adaptive optics laser guide star systems. This time-critical partnership will result in a 20-watt laser for Keck I and a 50-watt laser for multi-conjugate adaptive optics at Gemini South. A contract was signed with Lockheed Martin Coherent Technologies, Inc. at the end of September 2005 for the delivery of the lasers in 2007. The technology used in these lasers is based on the successful solid-state sodium laser delivered to Gemini North in early 2005 by the same company.

The joint study by Subaru and Gemini of a powerful wide-field multi-object spectrograph (WFMOS) is also progressing. This is an ambitious project that will lead to the "federating" of our operations even further. During the WFMOS science campaign Subaru and Gemini would become true partners. In several ways, Gemini, Keck and Subaru are streamlining new development efforts, and coordinating instrument building in a more strategic way that exploits each observatory's unique niche, while providing each observatory's users with access to the best facilities to accomplish their scientific goals. By bringing together the resources of our systems and staffs, we create an outstanding combination of public and private investments involving national and international infrastructure and facilities. This impulse for tighter integration arises from the management of each organization seeking to streamline their operations, rationalize their development programs, and coordinate engineering resources. This will also broaden our user's interactions with others in previously distinct astronomical communities and provide the best tools to push forward the frontiers of our knowledge about the universe. Through this collaboration Gemini, Keck, and Subaru are building the links that will define new paths to help ensure the success of even greater challenges posed by projects like the Atacama Large Millimeter Array (ALMA), the Thirty-Meter Telescope (TMT), and the Overwhelmingly Large telescope (OWL).

Jean-René Roy is Acting Director of the Gemini Observatory and can be reached at: jrroy@gemini.edu



by Doug Simons &
Joe Jensen

Scientific Horizons at the Gemini Observatory:
Exploring A Universe of Matter, Energy and Life

Why the Aspen Program Now?

It has been said countless times over the past few centuries—since the birth of modern astronomy with the invention of the telescope – that we live in a "*golden age*" of astronomical discovery. This is natural in a field of science that has truly unbounded potential for discovery. While geologists catalog a finite supply of rocks, entomologists classify insects on the verge of extinction, and meteorologists seek to perfect ever more complex models of the same terrestrial atmosphere, astronomers look to the sky each night examining celestial objects that, in many cases, have never been seen before. Astronomers conduct experiments on such grand scales that no earth-bound laboratory could ever accommodate our needs. We hypothesize about nothing less than the ultimate origin and destiny of the universe. In such a rich research environment, all generations of astronomers count themselves among the lucky few who have witnessed and participated in a "*golden age*" of discovery.

So what makes the current golden age unique and what is Gemini's role in it? For millennia questions of innate interest to humans have remained unanswered: Does life exist elsewhere? What is the universe made of? Where did everything come from? What is the fate of the universe? These questions have stood the test of time as insurmountable monuments in the face of ever more sophisticated scientific assaults. What makes our generation's claim to be living in a golden age unique is that, unlike all previous generations, we are actually on the verge of answering these questions. The 21st century will, in all likelihood, be identified as the era when the first extra-solar terrestrial planets are found, some perhaps harboring the unmistakable spectral

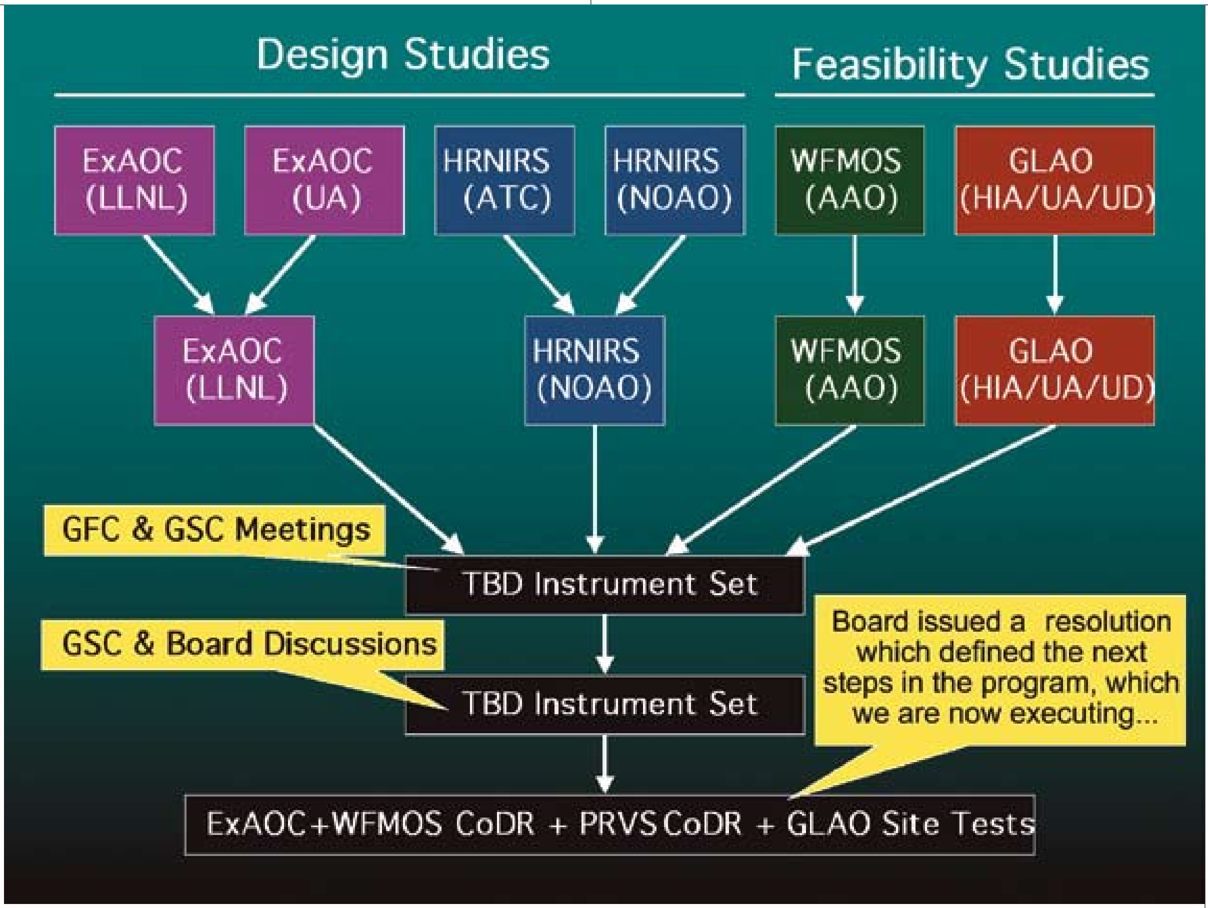


Figure 1. A decision flow diagram for the Aspen Program, summarizing key milestones in the program through mid-2005.

signatures of life. It will also be the century in which we come to terms with a new and deeper understanding of the bulk of the matter and energy in the universe—basic entities whose true nature we are only now beginning to understand.

Of course the 20th century was filled with important discoveries in astronomy, including the expansion of the universe, the discovery of the faint microwave whispers of the Big Bang, and the detection of such bizarre beasts as black holes, which defy the space-time fabric of Einstein's theoretical invention. While all are important, (and more such discoveries await today's intrepid legion of astronomers), what is probably more significant is that through these discoveries we have come to recognize how little we actually know about the universe. This renewed introspection about our realm of existence has almost religious overtones because of the profound nature of the discoveries awaiting us. Our understanding of the universe nonetheless remains firmly grounded in the tried and true principles of science that have carried us this far quite faithfully. Furthermore, we have no reason to expect that the advances in technology, which have taken us so far in astronomy, won't propel us to much greater heights in our tireless quest for discovery.

We also live in an age when the fields of physics and astronomy are inextricably linked. Modern physicists are increasingly reliant on the ultimate particle accelerator, the Big Bang, to understand the nature of matter and energy under the most extreme conditions, which only existed in the first instant after the universe exploded into reality. It was at this singular moment in the entire history of the universe that matter and energy were merged into a shared state. Over time, the universe cooled and evolved into the stars, planets, radiation, gas, and dust that we now struggle to understand. The path physicists must take in the quest for their "holy grail," a unified theory of "everything," is being paved by astronomers. Interestingly, astronomers and physicists have stumbled upon the same path in recent years, albeit from separate directions. This isn't due to some complex set of sociological or technological reasons. It is much simpler than that. It is because we are all compelled to answer the same questions:

Are we alone? What is the universe made of? Where did everything come from?

Events like the merging of physics and astronomy, the inner recognition of how little we know about the universe, and a technology revolution that is yielding tools of discovery unlike any conceived by our ancestors, are all signs that this age is truly unique. This age is "golden" and it is the Gemini community's job to harvest this potential knowledge through remarkable new instrumentation under development in our Aspen Instrument Program (the *Aspen Program*).

The Aspen Decision-Making Process

Thanks to the efforts of more than one hundred astronomers, engineers, project managers, and others around the world, a tremendous amount of progress has occurred since the last report about the Aspen Program. This effort recently culminated in a set of reviews which included the two conceptual design studies for the Extreme Adaptive Optics Coronagraph (ExAOC) led by Lawrence Livermore National Laboratory (LLNL) and the University of Arizona (UA), a pair of conceptual design studies for the High-Resolution Near Infrared Spectrometer (HRNIRS) led by the National Optical Astronomy Observatory (NOAO) and the United Kingdom Astronomy Technology Centre (UK/ATC), a feasibility study for the Wide Field Fiber-Fed Optical Multi-Object Spectrometer (WFMOS) led by the Anglo-Australian Observatory (AAO), and a feasibility study for the Ground Layer Adaptive Optics (GLAO) system, which was led by the Herzberg Institute of Astrophysics (HIA) in collaboration with UA and the University of Durham. These six studies (Figure 1) were completed and reviewed in a continuous sequence of meetings in Hilo, Hawai'i in March 2005 by four panels that provided the observatory with expert guidance on the science, technical, and management components of each study. In the case of ExAOC and HRNIRS, these reports also contained a down-select recommendation between the teams competing to build these instruments.

Not long after each panel's report was submitted to Gemini, a key part of the "equation" needed to frame the overall scope of the Aspen Program was defined during the Gemini Finance Committee meeting held in April 2005, in Victoria, B.C., Canada. During this meeting the observatory presented the summary-level results of the various Aspen instrument studies to demonstrate the viability of the cost estimates generated, the risk analyses formulated, and the science cases that were developed in considerable detail. The primary outcome of this critical meeting was the definition of the overall Aspen Program budget, which was defined for planning purposes to be U.S. $75 million, with a nominal cash-flow over the 2006 to 2010 time frame. It also set constraints on the rate at which funding could be committed to various instruments. Though this was not a firm commitment by the funding agencies at the time, this was something of a watershed event in the program. It sent a clear message of confidence in Gemini's development program, the methods used to define costs, schedules, and risks by the various study teams, and excitement about the science potential of Gemini's future program.

Using the overall spending-profile defined at the Gemini Finance Committee meeting, and the nominal spending-profiles for the studies submitted to Gemini, it was possible to distill all of the possible scenarios down to a handful that were worthy of continued consideration given various program constraints. The real challenge at that point was defining an Aspen package that fit within the nominal U.S. $75 million budget, since the total cost of the Aspen Program, based on the estimates generated through the aforementioned studies, was about U.S. $100 million. The observatory worked closely with the Gemini Science Committee and Board during May and June 2005 to search through a complex trade-space of cost, science, and risks to define an Aspen instrument package that would ultimately provide a compelling scientific product and represent a reasonable programmatic trade. This package was articulated through a Gemini Board resolution that is available via Gemini's website (Homepage: "General Announcements"). In summary, the next round of development in the Aspen Program includes:

Extreme Adaptive Optics Coronagraph (ExAOC). Approval was given to build an extreme AO coronagraph to look for planets in accordance with the down-select recommendation to award this project to the consortium led by LLNL (Bruce Macintosh PI), in collaboration with the Herzberg Institute of Astrophysics, Universities of California at Santa Cruz, Berkeley, and Los Angeles, the Jet Propulsion Laboratory, the American Museum of Natural History, and the University of Montreal.

Wide-Field Multi-Object Spectrograph (WFMOS). WFMOS was ranked highest scientifically among the Aspen instruments, and approval was given to proceed to the next step in its development, namely a competitive set of design studies which will serve as bids to build this instrument. Importantly, only the Subaru implementation of this instrument will be considered during the conceptual design study phase.

High-Resolution Near-Infrared Spectrograph (HRNIRS). HRNIRS will only be pursued if WFMOS is not developed further after the completion of its design studies. Like ExAOC and WFMOS, the science case for HRNIRS is clearly compelling; however, given budget constraints, a trade needed to be made among the Aspen instruments, and higher scientific priority was given to ExAOC and WFMOS.

Ground-Layer Adaptive Optics (GLAO). Following the successful feasibility study of this advanced adaptive optics (AO) system, approval was given for the next stage of development in a ground layer AO system at Gemini. This next step is to pursue a one-year site testing campaign on Mauna Kea to make high-resolution observations of the low altitude turbulence above Mauna Kea. Results of this site testing program will be fed back into the GLAO performance models generated during the feasibility study to determine the performance viability of GLAO at Gemini North, before a decision is made to proceed with its next phase of development.

Precision Radial Velocity Spectrograph (PRVS). Approval was given to study, (at the conceptual design level), a near-infrared (presumably J+H) bench-mounted precision radial velocity high-resolution spectrometer that would be capable of performing the planet search originally envisioned for HRNIRS, except on a significantly faster timescale. A decision to build PRVS is dependent upon several factors and will be made as part of the general assessment of the next steps in the Aspen Program in late 2006.

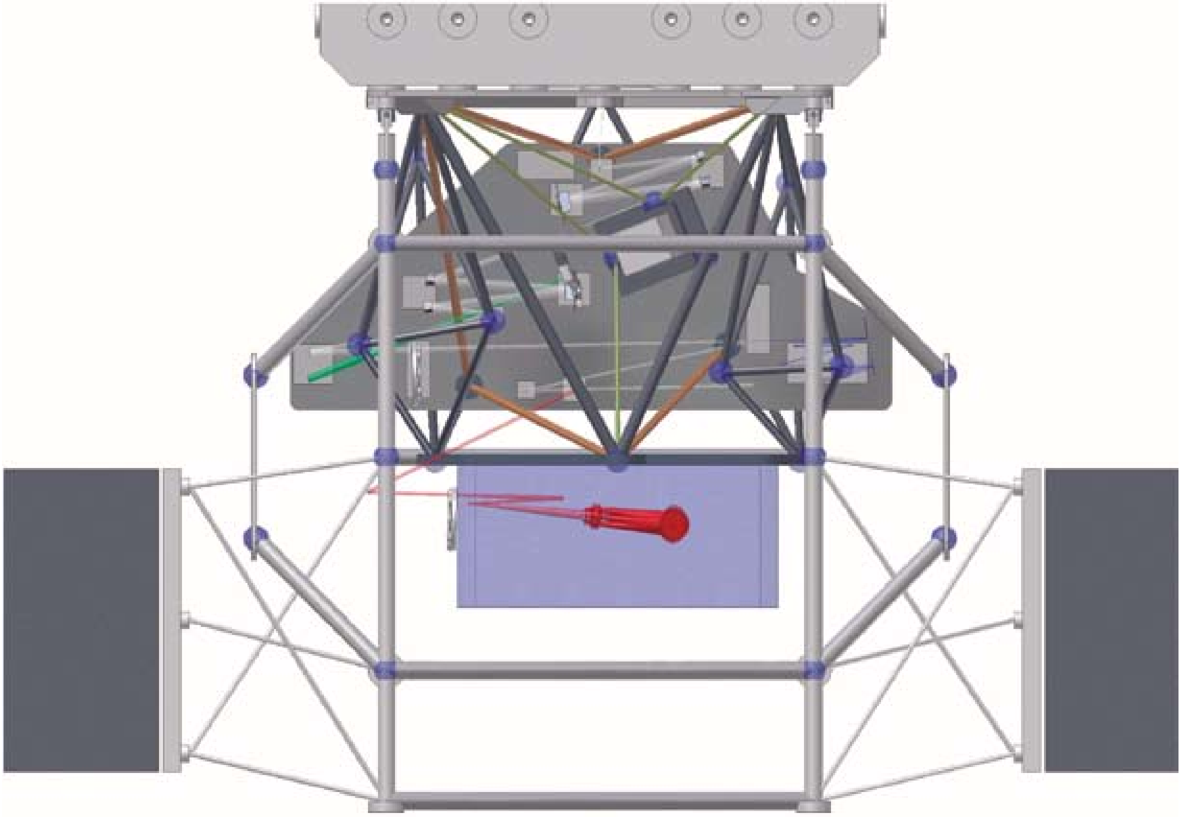


Figure 2.
A CAD rendering of ExAOC, without its protective covers. The adaptive optics bench in ExAOC is at the top, just below the instrument support structure (ISS) and nestled within a space frame support structure. Behind that is an integral field spectrograph designed to record a low-resolution spectrum of each point in ExAOC's field.

Combined, these activities committed roughly a third of the projected Aspen budget, and triggered another intense round of design study activity. In late 2006, the Gemini Board will decide about commitments for the next phase of the Aspen Program.

New Instruments to Tackle New Science

It cannot be overstated how ambitious the next generation Aspen instruments will be compared to Gemini's current set of instruments. Through the *Phase 1* and *Abingdon* development programs, our "front line" instrument set has been delivered to both Gemini telescopes and now provides our user community with state-of-the-art systems sensitive from optical to mid-infrared wavelengths. These current instruments will be used for many years and comprise the backbone of Gemini's instrument development program. Vastly more challenging and scientifically aggressive instrumentation is to be built under the Aspen Program than ever attempted before at Gemini. Consistent with our new "golden age" of astronomy, next-generation instruments being designed for Gemini will support experiments on a grand scale within observational astronomy to make significant progress in research that simply could not be accomplished with any of the current generation of instruments available at Gemini, (or any other observatory for that matter). The new Aspen instruments carry with them costs that are anywhere from five to ten times those of our previous instruments. The technical challenges of these instruments are also rather daunting, as some will require development of new technologies. To help mitigate these risks, the teams building Aspen instruments will make rigorous use of systems engineering and a variety of project management techniques to control costs while preserving core capabilities. Also, a significant amount of contingency funding will be held in reserve to deal with unforeseen challenges while building these instruments.

So, the question remains: Why pursue such costly and risky instruments? There are many answers to this question. In the end, it is because we are embarking on a bold new line of exploration within the Gemini community and with these risks comes the expectation that we will open new windows of discovery.

First, let's take a detailed look at ExAOC and its science mission. Figure 2 shows the overall assembly of this instrument as proposed by the team led by LLNL. It consists of several components that work together as a highly integrated system to achieve the phenomenally high contrast ratios demanded by this instrument's science case. Light enters ExAOC via a two-stage adaptive optics system, which includes a low-order "woofer" and a high order "tweeter" pair of deformable mirrors. Together these mirrors provide extremely high strehl ratios (~ 90%), but that alone falls well short of what is needed to actually detect faint companions to bright stars. In addition, an interferometer is used to sense slowly varying non-common-path wavefront errors that would otherwise lead to super-speckles, which are difficult to distinguish from planets in the field. This interferometer feeds corrective signals back into the adaptive optics system to suppress super-speckles and creates a highly corrected beam that is fed into a high performance coronagraph.

The coronagraph is a crucial ExAOC component, designed to obscure light from the central host star and spatially filter the beam before it is passed downstream. Finally, an integral field spectrometer is used to record spectra across the entire ExAOC field. Low-resolution spectral images can be used to perform spectral differencing across spectral

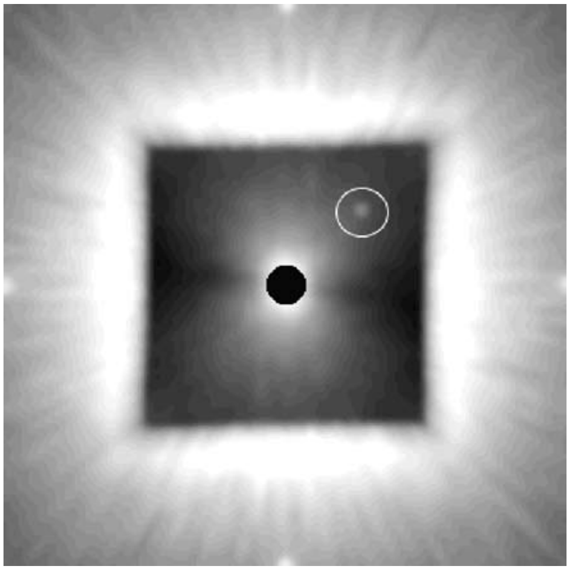


Figure 3.
A 20-second simulated image with ExAOC. The off-axis circled object is a 5 $M_{Jupiter}$ 200-million-year-old planet 0.6 arcseconds away from its host star.

features like methane in the atmospheres of gas giant planets to further enhance the total system contrast performance. Figure 3 (previous page) shows a simulated ExAOC image of a planet orbiting a nearby young star. While ExAOC shares several common "strategies" with NICI to perform high contrast imaging (e.g., a differential imager fed by a built-in AO system), it represents a major step forward in developing coronagraphic technology for use on Gemini. Furthermore, it is designed to work much closer to bright stars than NICI, and its use is expected in a major planet searching campaign starting in about 2010.

Planets around other stars are being discovered on an almost routine basis through current optical radial velocity campaigns by several teams. While this on-going spectroscopy is obviously important, ExAOC is designed to make measurements that are complementary and fundamentally different from those possible with current radial velocity techniques. Specifically, ExAOC will directly measure the masses of detected planets by mapping their orbits (removing the inclination ambiguity of radial velocity techniques), allow direct calibration of mass-luminosity relations for planetary models, and through direct spectroscopic measurements, permit detailed characterization of extra-solar planets for the first time. Furthermore, radial velocity techniques are only just beginning to detect gas-giant-sized planets at (and beyond) the distance of Jupiter from their host stars (5 AU), primarily due to the need for complete orbital sampling. In contrast, ExAOC will search for gas-giants at and beyond 4 AU from their hosts, with fairly rapid confirmation, and help answer the question of how common planetary systems like our own might be in the Milky Way Galaxy. For all of these reasons, observations with ExAOC promises breakthroughs in the field of extrasolar planetary research complementary to radial velocity studies, as we move from an era of counting extrasolar planets to characterizing them.

Along the same lines as discovering new planets, Gemini is launching studies into a high-resolution near-infrared spectrometer to attack a key portion of the HRNIRS science case—namely the search for terrestrial-class planets in the habitable zones of low-mass stars. Again, the PRVS concept is being developed as an option to consider when the results of the other Aspen studies are completed in 2006. The phase-space targeted by PRVS is quite different from that of ExAOC and existing optical radial velocity spectrometers. PRVS will target low-mass stars, which are intrinsically bright at near-infrared wavelengths. They should exhibit measurable reflex motion in the presence of small (super-Earth) type companions, including those in the habitable zones of these stars, the most common in the Milky Way Galaxy. This is essentially "uncharted water" in astronomy and PRVS research could play an important role in determining how common terrestrial-class planets are, which helps answer the question of how common life is in our galaxy. The combination of PRVS-based searches for super-Earths and ExAOC-based searches for Jupiter-class planets will allow the Gemini community to discover and characterize planets that have never been observed before, and yield a much more complete "picture" of our neighbors in the Milky Way Galaxy.

While ExAOC and PRVS will focus on our stellar neighbors, another instrument will be used for explorations of distant stars and galaxies to yield insights into fundamental physics and the formation of our galaxy. WFMOS, an instrument with unprecedented spectroscopic capabilities, is intended to catapult science dependent upon wide-field multi-object spectroscopic observations forward by offering nearly an order of magnitude boost in multiplex gain over any other instrument available today. Figures 4 and 5 show how WFMOS might look in place at Subaru, as derived from the AAO-led feasibility study for this instrument. The baseline concept involves the use of an Echidna-type fiber positioner (similar to what has been under development for Subaru's fiber spectrograph FMOS), to position up to ~4,500 fibers across the large 1.5-degree instrument field of view. It relies upon a combination of low- and high-resolution (R ~ 3000 and 40,000, respectively) spectrometers mounted off the telescope to support a range of science applications. The enormous multiplex gains will in turn mean that a substantial investment will be needed in the pipeline processing system to handle the ~ 20,000 spectra that will potentially be generated each night by WFMOS.

WFMOS is being proposed for use at Subaru for a number of reasons, not the least of which is that it can likely use the same wide-field corrector as the Hyper-Suprime Camera, a wide-field optical imager under parallel development at Subaru capable of imaging a two-degree field. This instrument's wide-field corrector is arguably the most challenging component to manufacture for both of these instruments, hence sharing resources to secure its design and fabrication helps ensure its successful completion. The scientific, technical, and programmatic synergies between WFMOS and Hyper-Suprime have motivated Gemini and Subaru to enter a new regime of joint instrument development that will benefit both of our user communities. If the project goes forward following a successful design study phase, Gemini and Subaru will split the costs of the instrument and enter into a telescope time-exchange program. The net outcome will provide Gemini and Subaru users with research tools that would otherwise not be available to them. This type of collaboration is another indication of the magnitude of the investment and scientific reward in the future of astronomy, as the current "fleet" of 8- to 10-meter telescopes around the world are used to conduct large-scale experiments in astrophysics that were impossible just a decade ago.

Arguably, the WFMOS science case is among the most compelling in the entire Aspen Program. The two main components include a survey of galaxies at two epochs ($0.5 < z < 1.3$ and $2.5 < z < 3.5$) to gauge the time-evolution of dark energy, and a survey of over one million stars to identify and disentangle the formation history of our galaxy. The dark energy survey is predicated upon measuring with great accuracy the physical size of large-scale structures in the universe. By measuring the fundamental scale of the universe, as defined by its largest structures, at epochs before and after the time dark energy became dominant in the universe, the time derivative of the universe's equation of state will be measured, providing information about the nature of dark energy and the long-term destiny of the universe.

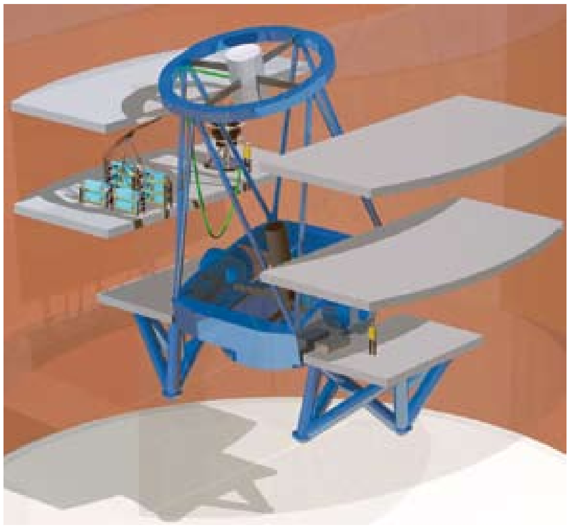


Figure 4. WFMOS shown at the Subaru Telescope. The spectrometers are located on the middle Nasmyth platform, connected via fiber bundle to a new fiber positioner at the prime focus of the telescope.

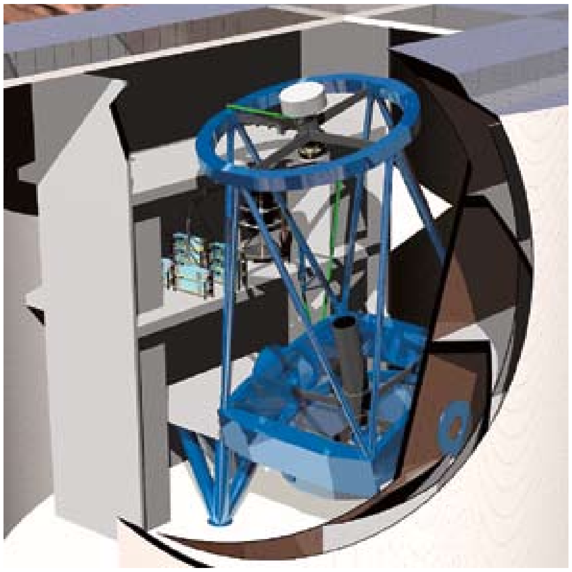


Figure 5. Another view of WFMOS on Subaru shows a bank of spectrometers, which are fed by the fiber bundle color-coded green.

Beyond these large-scale surveys, an instrument that is capable of generating thousands of spectra concurrently essentially opens "windows" on many research fronts, including a range of smaller-scale (i.e., individual PI-class, but nonetheless important), research programs. Although the instrument is targeting specific science missions, like any instrument in astronomy that is capable of probing the universe at new wavelengths or resolutions, WFMOS will likely have many applications beyond those originally conceived.

Finally, Gemini is continuing to assess the viability of a ground layer adaptive optics (GLAO) system on Gemini North, after the basic feasibility of such a system was demonstrated through its recently completed initial study. The concept involves the use of an adaptive secondary mirror (Figure 6, next page) that would provide all of the functionality of the current secondary, (i.e. tip/tilt, focus, and chopping) and, with the use of a new wavefront sensing system, yield impressive adaptive optics closed loop performance. Gemini is planning to build new acquisition and guiding units for both telescopes and, if GLAO is pursued, one of them would include the additional laser guide star wavefront sensors necessary to support full AO correction through an adaptive secondary mirror. The GLAO implementation would use a constellation of laser beacons, similar to what will be used for MCAO, but require less power spread over a wider field.

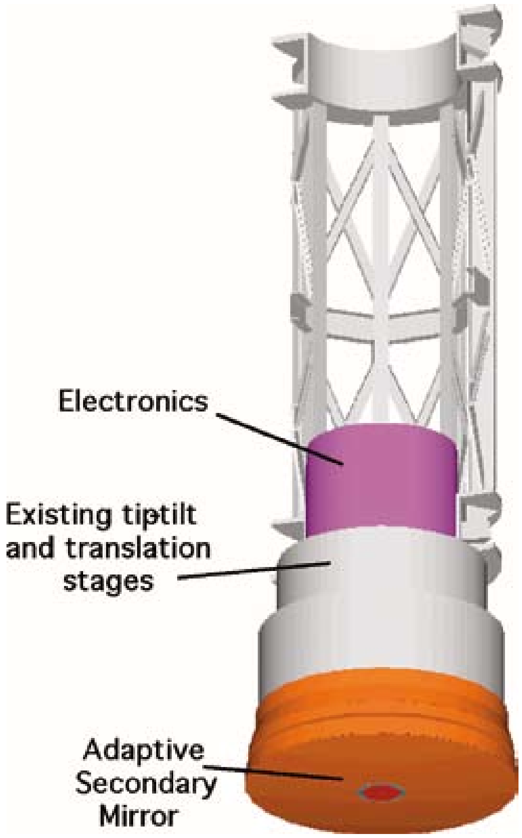


Figure 6. The GLAO baseline concept includes the use of an adaptive secondary mirror, seen in this CAD rendering.

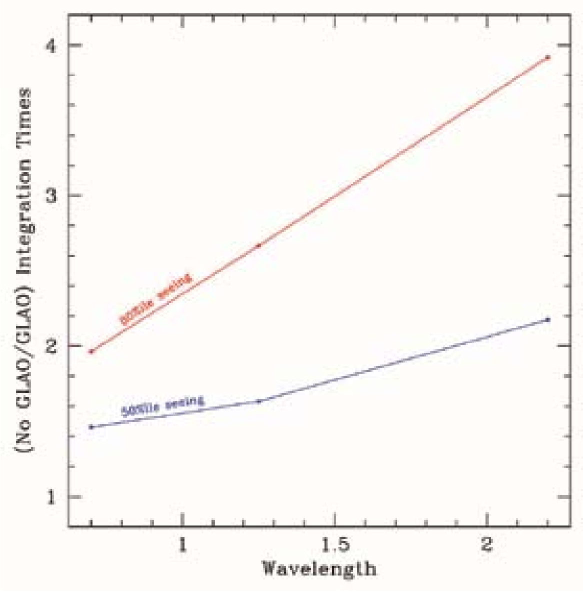


Figure 7. The theoretical gains of using a GLAO system at Gemini are shown in this plot of the reduction in integration time using a GLAO system as a function of NIRI wavelength and seeing.

One of the most interesting results of the feasibility study is that GLAO actually provides the most significant gains when the seeing is the worst, unlike conventional AO systems, which tend to perform best when the natural seeing is very good. As shown in Figure 7, the point source sensitivity gains made possible by GLAO are quite remarkable in the near-infrared and will be provided over a ~5-7 arcminute field. So while the strehl ratios across a GLAO-corrected field will not be nearly as high as multi-conjugate adaptive optics (which operates over a 1- to 2-arcminute field), the equivalent of excellent natural seeing should be achievable on most nights using GLAO. Obviously, for slit spectroscopy, where energy coupling through the slit is the key performance metric, GLAO should provide dramatic boosts in sensitivity. It is also important to note that the GLAO concept proposed is reverse-compatible with all instruments currently deployed at Gemini and it will be possible to operate the adaptive secondary mirror in open-loop mode while delivering the same core functions as Gemini's current secondary mirror.

So what's the "catch" with GLAO? The models used in the feasibility study relied upon previous (2000) Cerro Pachón site testing, since adequate data did not exist for Mauna Kea in time for the feasibility study. Therefore, before proceeding with GLAO at Gemini North, a one-year site testing campaign will be conducted on Mauna Kea to measure the low altitude (~1-2 kilometers) turbulence structure above the summit with fairly high fidelity (nominally expecting ~100-meter line-of-sight resolution). This data will then be used to re-evaluate the performance of a GLAO system at Gemini North, using the models developed during the feasibility study. If the performance looks promising, the next step in this program would be to take the basic design generated during the feasibility study and develop a conceptual design in an effort to better define the cost, schedule, and performance of a GLAO system at Gemini North.

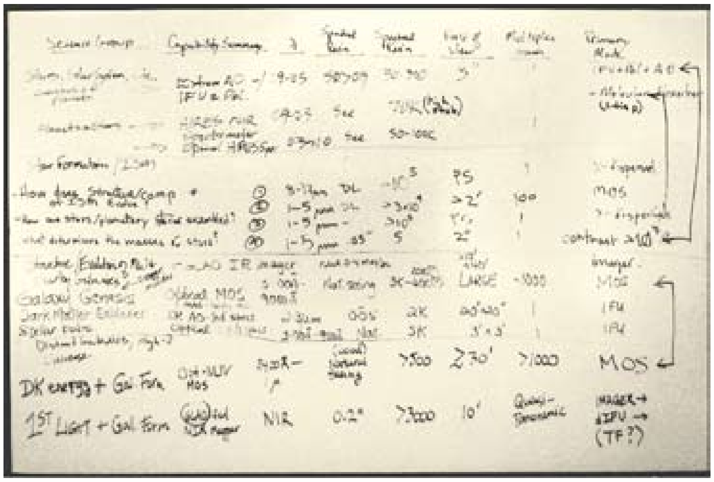


Figure 8. A photograph from June 2003 captures the initial Aspen "war plan" which summarized the entire Aspen Program, in its infancy.

A Fast Paced Program…

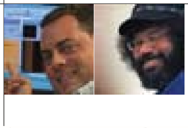
Gemini's Aspen Program has come a long way at a remarkably fast pace. Figure 8 has not been widely seen, but at the end of the Aspen conference in June 2003, I asked that a photograph be taken of a white board, when the excitement of the conference started to turn into the reality of getting on with a tough job. I realized that in five to ten years time, after we are done building these new instruments and executing the Aspen science mission, it would all be traceable to that one white board, created in that single moment in time. Some readers may recognize the hand-writing of the science group chairs at Aspen in Figure 8. I asked the chairs to write down the "big questions" in astronomy that their groups identified as well as the top-level capabilities required to conduct the science missions of their respective groups. We then collectively looked for common threads across the groups and, despite widely different scientific ambitions, reached consensus astonishingly fast. I think everyone surrounding that white board could see the intrinsic scientific value in the various components of the Aspen Program, even if a specific instrument's capability wasn't their personal favorite.

Notable in this very first draft of our "war plan" are terms like "DK energy," "1st Light," "Galaxy Genesis," and "Census of Planets" all mapped into things like MOS's, imagers, and coronagraphs. About 20 months later, what started as scribbles on a white board were transformed into literally thousands of pages of documents detailing how such instruments would work, what they would cost, how fast they could be built, and what type of science they would enable. This achievement required the direct involvement of over a dozen major research institutions across the Gemini Partnership, and the entire partnership owes a debt of gratitude to these institutions for the contributions they have made to the Aspen Program. This proves what I have mentioned privately and publicly for several years, that: "*…one of the Gemini Partnership's greatest assets is the depth and breadth of the teams it has building its instruments.*"

Where do we go from here? While it is important to pause every now and then to see how far we've come, there's an enormous amount of work that lies ahead. We will maintain the same pace that has served us so well thus far in developing the new Aspen instruments. Clearly the next major milestone in the program arrives near the end of 2006, when we will again decide which of the instruments under consideration will be built. By then, the construction of ExAOC will be well underway, but choices will have to be made about WFMOS, HRNIRS, PRVS, and GLAO that will obviously have deep implications for our user community. And, not long after that, we will begin the process of planning for another generation of instruments, to answer more questions in astronomy, some of which, I dare say, we haven't even imagined yet.

Doug Simons is the Gemini Associate Director of Instrumentation at the Gemini Observatory and can be reached at: dsimons@gemini.edu

Joe Jensen is the Instrument Program Scientist at the Gemini Observatory and can be reached at: jjensen@gemini.edu



by David Harker &
Charles Woodward

Gemini North Observes DEEP Impact

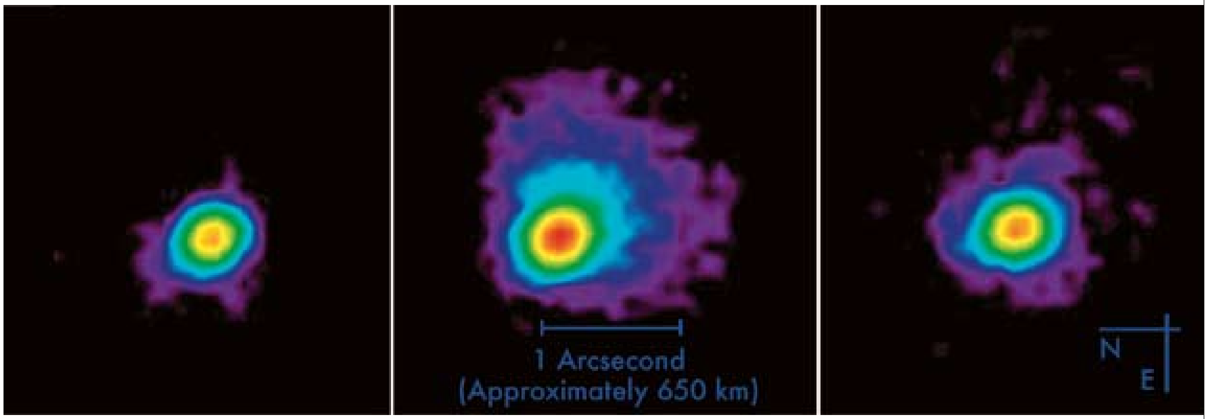


Figure 1. Gemini North MICHELLE mid-infrared false color images of 9p/Tempel 1, ten minutes before impact (left), 3 hours after impact (center) and 24 hours after impact (right). Scale and orientation are identical for all images.

The *Deep Impact* Opportunity

The *Deep Impact* event provided a unique opportunity to explore the sub-surface layers of material below the highly processed surface of the short-period, Jupiter Family comet, 9P/Tempel 1 (9P). Materials excavated from the interior of 9P resulting from impactor penetration (on July 4th, 2005 at 05:52:02 UT as seen from Earth) provide a cometary "core sample," enabling comparison of grains found beneath the surface to those released into the quiescent coma. As part of a coordinated ground-based observational effort, we obtained a time series, mid-infrared spectrophotometric record of the Deep Impact event with the MICHELLE imaging spectrograph on the 8-meter Gemini North telescope on Mauna Kea, Hawai'i.

Observations at mid-infrared wavelengths near 10 microns encompass a spectral region where continuum and band emission from carbonaceous and silicate grains can be used to deduce the mineralogy, size distribution, and other physical characteristic of cometary dust. The Gemini data sets are uniquely valuable because they cover a time period that began just before the encounter and ended after the impact, and enabled us to record the dynamical evolution of the ejected material. The pre-impact spectrum of 9P was smooth and featureless, well modeled by thermal emission from a bare asteroidal surface. Dust released by the impact was clearly detected, highlighted by the appearance of a pronounced silicate dust emission feature. Analysis of the MICHELLE spectrum taken an hour after the impact suggests that the number of sub-micron-sized silicates excavated and released into the coma increased markedly. The number of amorphous carbon grains, contributors to the featureless emission outside the silicate resonances (wavelength $\lambda \leq 8.2$ microns and $\lambda \geq 12.4$ microns), i.e., the 10-micron continuum (Figure 2) also increased. Evident in this spectra is a sharp peak at 11.2 microns due to emission from relatively transparent (i.e., poorly absorbing), magnesium-rich crystalline olivine. Orthopyroxene was not clearly evident in these spectra of 9P.

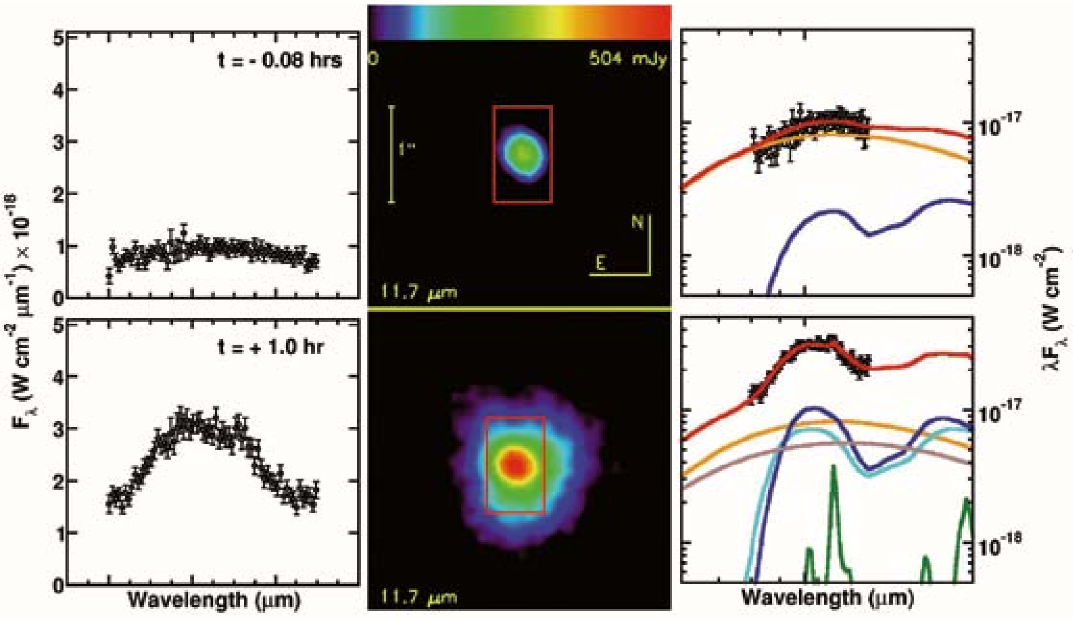


Figure 2. *Imaging and spectroscopy of two temporal epochs of comet 9P/Tempel 1 obtained before and after impact. For both epochs, the 10-micron spectrum (left column F_λ (W cm^{-2} µm^{-1}) with 1-sigma error bar), and an 11.7-micron image (center column) is shown. The thermal model (right column λF_λ (W cm^{-2})) for both epochs is plotted on top of the observed spectra. For both epochs, the on-source integration time for each is 100.8 seconds. The size of the extraction aperture for all spectra is a 0.6 × 1.0 arcsecond rectangle 390 × 650 kilometers centered on the brightest part of the coma, and is indicated in red in each image. Plotted model components are the: total model SED (red line); STM nucleus flux (orange line); amorphous olivine (blue line); amorphous pyroxene (cyan line); amorphous carbon (brown line); and crystalline olivine (green line).*

Models suggest that the dust ejected into the 9P coma as a result of the impact was a mixture of grains with a composition of amorphous carbon, amorphous pyroxene, amorphous olivine, and magnesium-rich crystalline olivine. The derived grain size distribution peaked near 0.3 microns. The amorphous grains are derived to be slightly porous, whereas the crystalline grains remain solid. Interpretation of the Gemini (with MICHELLE) spectra also permit an estimate of the total ejected dust mass (noting that this quantity is modestly dependent on the cutoff of the model grain size distribution). At one hour after impact, the total mass of dust within our beam (with a projected area 390 × 650 kilometers) was calculated using the fit Hanner grain size distribution cutoff at 1 and 100 micron grain radii, and resulted in 7.3×10^4 kilograms and 1.5×10^6 kilograms, respectively.

The post-impact evolution of the 9P spectra was intriguing, with signatures that reveal the impact's effect on nuclear activity. Roughly two hours after impact, the strength of the silicate feature was in decline (measured with respect to the local continuum). To drift entirely out of our beam (centered on the region of peak nucleus plus coma surface brightness) over this time period, grains would need to have a minimum velocity projected onto the sky of 130 meters per second. Our measured decrease in silicate feature strength in the hours after impact has a number of consequences including: (1) the small silicate grains population excavated as an immediate by-product of the explosive penetration of the nucleus, were moving faster than 130 meters per second; (2) no new continuous and persistent source at the impact site was established to replenish the small grain population.

The relative masses of mineral grains changed, and the size distribution also evolved towards larger grain radii in the hours following impact as grains drifted through the beam. Twenty-six hours after the impact the coma dust mineralogy was similar to that observed pre-impact. The grain size distribution peaks at grain radii in the range of 1.5—1.8 microns, larger than pre-impact grains. In addition, all sub-micron grains released by the impact appeared to be cleared out of the inner coma region within a 26 hour period.

Deep Impact and Comets

Surprisingly, the physical characteristics of dust excavated from sub-surface layers in 9P are remarkably similar to pristine grains present in the comae of highly active (jet-dominated) Oört Cloud comets such as C/1995 O1 (Hale-Bopp) and C/2001 Q4 (NEAT). This observed similarity may be because the new populations of post-impact 9P coma grains were associated with, or were stimulated to fragment by their association with, volatiles released from a temporally transient active area triggered by the Deep Impact event. Alternatively, grains trapped within the matrix of subsurface ices and volatiles in 9P are unaltered agglomerates of truly primitive solar nebula condensates. In the nominally active or quiescent coma of 9P, larger dust grains (≥ 0.9 microns) with predominately amorphous olivine composition are present, presumably originating from the highly processed nuclear surface of this Jupiter Family comet. These larger olivine-type grains could be aggregates of sub-micron mineral subgrains that display substantially reduced spectral contrast resonant features due to their incorporation into aggregate grain structures. Anhydrous chondritic porous interplanetary dust particles with infrared spectra (bulk aggregate) similar to amorphous olivine and lacking in crystalline resonances are 1- to 10-micron-sized porous aggregates dominated by sub-micron subgrains of amorphous silicates, which also contain abundant fine-grained amorphous carbon. Infrared spectra of microtomed thin sections of these particles in the lab show distinct resonances of embedded submicron crystals. However, the presence of fine-grained amorphous carbon coatings on the surfaces of siliceous subgrains may make their mid-infrared resonances indistinct. The fragmentation of such aggregate porous particles could free their submicron constituents to make their mid-infrared resonances distinguishable in contrast with the observable continuum. In the Deep Impact ejecta, the presence of abundant amorphous olivine, crystalline olivine, along with amorphous carbon and amorphous pyroxene makes a fragmentation scenario plausible.

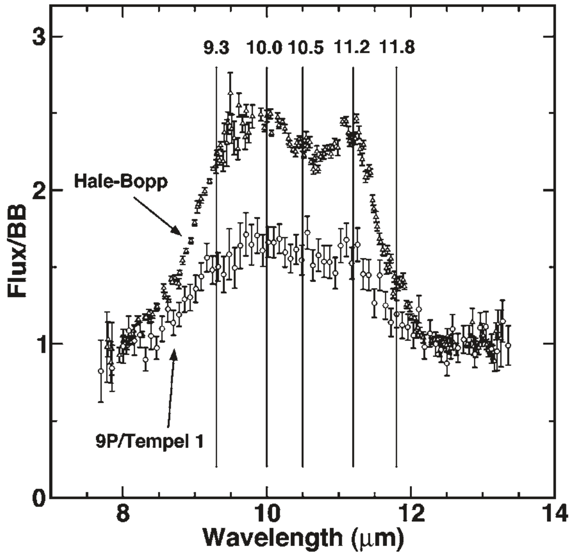


Figure 3. A comparison of blackbody continuum normalized spectra of Jupiter Family comet 9P/Tempel 1 (open circles) at t = +1.0 hour post-impact (287 K blackbody) to the Oört Cloud comet C/1995 O1 (Hale-Bopp) obtained post-perihelion on June 22, 1997 UT (r_h= 1.7 AU; 283 K blackbody) (open triangles). The labeled vertical lines identify possible crystalline silicate features including Mg-rich crystalline olivine (10.0, 11.2, 11.8 microns) and orthopyroxene (9.3, 10.5 microns).

However, perhaps the differences in the coma dust characteristics observed between Oört Cloud and Jupiter Family comets are semantic and only "skin deep." This would present us with two formation scenarios for icy planetesimals: 1) comet 9P formed in the same area of the solar nebula as that of the Oört Cloud comets, but its dynamical history differed in that it was not ejected from the inner regions of the solar system out of the Oört Cloud. It has been suggested that as many as a third of all comets formed in the Jupiter-Neptune region did not get scattered into the Oört Cloud; or 2) the solar nebula was very homogeneous even by the time of icy planetesimal formation. Such a scenario would suggest that processed material (crystalline silicates) were not only formed early in the history of the solar nebula, but were then transported out to large radii to be incorporated into comets.

This work was made possible through the use of Gemini North, MICHELLE, and National Science Foundation, and NASA grants awarded to the authors. We were awarded time on Gemini North in conjunction with Keck and Subaru. Our collaboration with the team at Subaru (led by Dr. Seiji Sugita) was invaluable in focusing our observations during the night of impact. The results from our study were published in the September 16, 2005 issue of the journal *Science*.

David Harker is an Astronomer at the University of California, San Diego and can be reached at: dharker@ucsd.edu

Charles Woodward is an Astronomer at the University of Minnesota and can be reached at: chelsea@astro.umn.edu

Cometary Bodies – A Primer

Comet nuclei are the frozen reservoirs of dust and ices left over from the early solar nebula. The properties of the dust grains and the abundances of volatiles in cometary nuclei probe the temperatures that solar nebula materials were subjected to prior to protoplanetesimal formation. Although comets contain some of the most primitive materials in the solar system, directly observing this material is a problem because the outer layers of the parent bodies (the nuclei) have been subjected to processing mechanisms such as collisions, particle bombardment, and ultraviolet and cosmic ray irradiation. These can change the morphology or shape (but not the mineralogy) of the dust grains.

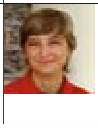
Comet Hale-Bopp / P. Michaud

The composition of small, volatile-rich icy bodies in the solar system, that have been subject to processing provides an astro-geochemical record enabling us to infer the physical conditions during the planetesimal formation epoch some 4.5 billion years ago. Among these icy "leftover bodies" are two important collections of small, planetesimal-sized objects called long- and short-period comets. Long-period comets originate in the Oört Cloud, have orbital periods ranging from several hundred to millions of years, and have diverse orbital inclinations. Oört Cloud comets probably formed near the giant planets and were gravitationally expelled by them from the early solar nebula into the Oört Cloud. Some of these comets may have originated in the trans-Neptunian region and pushed inwards to Jupiter before being scattered to the Oört Cloud. These nuclei are subject to evolutionary processing (i.e., "weathering") during their Oört Cloud "cold storage," primarily from radiation exposure in the interstellar medium. Thermal exposure from passing hot, massive O-type stars and supernovae explosions led to a devolatilization of the surfaces of the comet nuclei to depths between 1-50 meters (3-150 feet). Radiation bombardment from interstellar ultraviolet radiation and galactic cosmic rays may have polymerized the organics to create a "glue'" that holds small surface grains together to form larger aggregates. Oört Cloud comets are thought to contain mostly "pristine" solar nebula materials that are released into the coma during a perihelion passage.

Short-period comets come in two varieties. The majority, called "Jupiter Family" comets, have periods less than 20 years, small orbital inclinations, and aphelia near or beyond Jupiter. A small subset of the short-period comets are the "Halley-type" comets which have periods between 20 and 200 years, large inclinations, and are probably Oört Cloud comets perturbed into smaller orbits. Jupiter Family comets formed near Neptune and were scattered outward to create the scattered disk (dynamically "hot") population of the Kuiper Belt. Neptune's outward migration pushed other icy planetesimals outward to create the classical disk (dynamically "cold") population of the Kuiper Belt. The hot disk population is likely to scatter into Jupiter Family comet orbits. As residents of the Kuiper Belt, the Jupiter Family comets suffered collisions and are thought to have broken off of larger objects. Evolutionary mechanisms act to age the surface of these comets in a fashion similar to Oört Cloud comets; however, the effects of evolution are mitigated by the young surface age of the Kuiper Belt objects.

Once such an object becomes a Jupiter Family comet, solar radiation becomes the primary evolutionary mechanism. The lower activity of Jupiter Family comets (the production rates of coma gases and dust from the nuclear surface and from jets), compared to Oört Cloud comets, is attributed to their many close perihelion passages. Repeated periods of sublimation and re-freezing in Jupiter Family comets reduces the reservoir of volatiles possibly many feet deep in the nucleus, de-hydrogenates the surface carbonaceous grain material (leading to a lower silicate-to-amorphous carbon ratio), and alters the grain morphology (leading to larger, more solid grains).

In addition to differences in parent body evolution, there may be systematic differences in the composition of the dust contained in Oört Cloud and Jupiter Family comets. These may reflect differences in nebula temperature, the degree of radial mixing of inner nebula materials to the outer radial regions, or the extent of nebular shocks which can, for example, lead to different compositions and crystalline-to-amorphous silicate ratios between Jupiter Family and Oört Cloud comets.



by Inger Jørgensen

Star Formation in Rich Galaxy Clusters

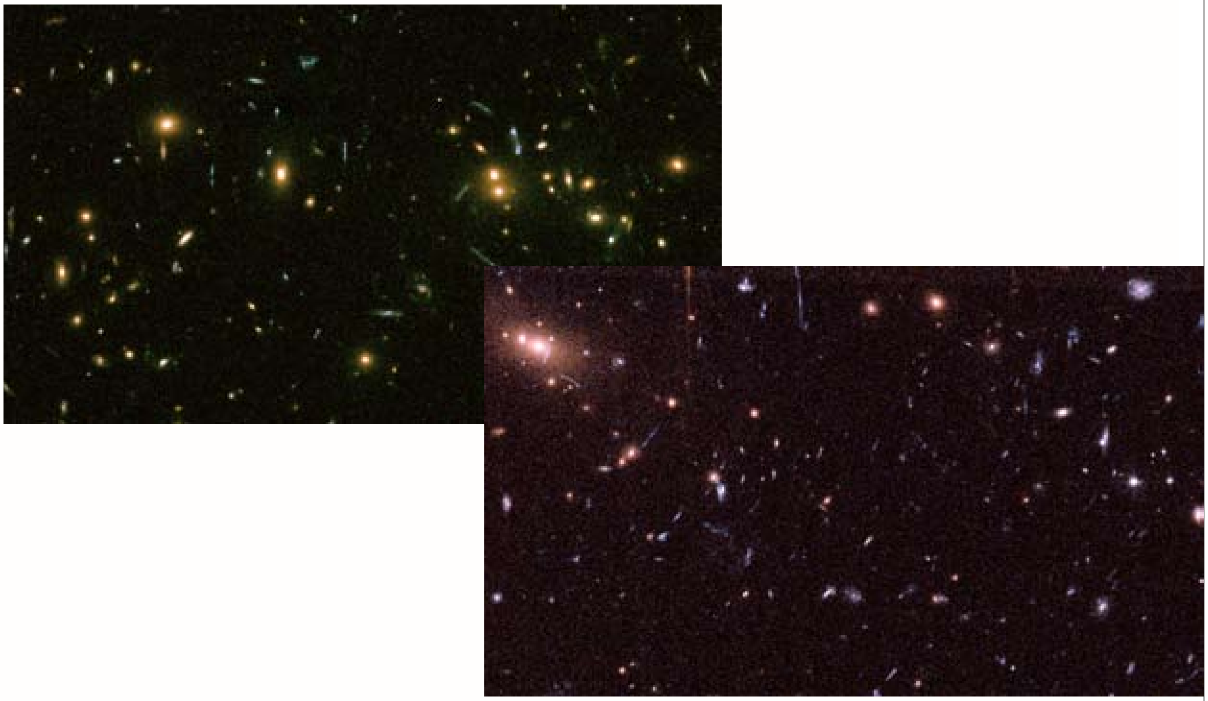


Figure 1. The central 75 × 45 arcsecond field of each of the clusters RXJ0152.7-1357 ($z=0.83$) and RXJ1226.9+3332 ($z=0.89$). The images cover approximately 0.6 × 0.35 Mpc at the distance of the clusters. The color images are made from HST/ACS observations. RXJ0152.7-1357 has observations in r' (630nm), i' (775nm), and z' (925nm). RXJ1226.9+3332 has observations in F606W and F814W, only. On both images most of the cluster members appear as yellow/orange. The many faint blue and very elongated objects are gravitationally lensed background galaxies. The gravitational lensing shows, in agreement with the X-ray data, that both of these clusters are very massive.

In the simplest model for the evolution of elliptical and lenticular (E/SO) galaxies, called pure passive evolution, it is assumed that intermediate redshift ($z \approx 0.2$-1.0) galaxies with no ongoing star formation will have no further star formation, and will passively age into E/SO galaxies similar to those seen at $z \approx 0$. According to this model, the only difference between the stellar populations in the intermediate redshift E/SO galaxies and in the $z \approx 0$ E/SO galaxies is an age difference equal to the look-back time to the intermediate redshift galaxies.

Previous tests of the pure passive evolution model have used either the luminosity function of the E/SO galaxies or the color-magnitude relation. In addition, the Fundamental Plane, which relates the masses and the mass-to-light ratios of galaxies, has been studied for the brightest five to ten E/SO galaxies in each cluster. In general, all of these previous results are consistent with passive evolution and a major star formation episode at a redshift of $z=2$ or higher.

Our deep spectroscopic observations of E/SO galaxies in two rich clusters at redshifts of $z=0.8$ to 0.9 obtained with Gemini show that these galaxies cannot evolve by pure passive evolution into their counterparts in the local universe. The pure passive evolution model has proven too simplistic. This conclusion is based on our observations done as part of the Gemini/HST Galaxy Cluster Project. Our observations are about two magnitudes deeper compared to previous high signal-to-noise spectroscopy at comparable redshifts. Furthermore, we use measurements of several absorption lines to study in detail the mean ages, metal content, and α-element abundance ratios. This has not been done previously at this high a redshift. The α-elements are primarily made in the most massive stars.

In the Gemini/HST Galaxy Cluster Project we aim to map the star formation history of galaxies as a function of redshift and galaxy mass in rich clusters. The sample covers 15 rich clusters with redshifts between 0.15 and 1.0, selected based on their x-ray luminosity. We have adopted a lower limit on the cluster x-ray luminosity of L_X(0.1-2.4 keV) = 2×10^{44} ergs/second. For reference, the Coma cluster at $z = 0.024$ has L_X (0.1-2.4 keV) = 7.3×10^{44} ergs/second. We adopt a ΛCDM cosmology with a Hubble constant of 70 kilometers per second per megaparsec, a universal mass constant $\Omega_m = 0.3$, and a constant of acceleration $\Omega_\Lambda = 0.7$.

For each of the selected clusters we have obtained high signal-to-noise optical spectroscopy of 30-50 member galaxies using the Gemini Multi-Object Spectrographs (GMOS) on both Gemini telescopes. We cover approximately 1.7 × 1.7 megaparsecs in each cluster, equivalent to about one square degree at the distance of the Coma cluster. At redshifts of 0.8 - 0.9 we observe galaxies as faint as i' = 22.7 magnitude (half the luminosity of the Andromeda Galaxy (M31)). The high signal-to-noise spectra make it possible to determine the strength of various absorption lines. We adopt the Lick line index system for measuring these strengths. With the aid of stellar population models, the measured line indices can be related to luminosity-weighted mean ages, metal content, and α-element abundance ratios [α/Fe]. We also measure the internal velocity dispersions of the galaxies. High spatial resolution imaging from the Advanced Camera for Surveys or the Wide-Field Planetary Camera 2 on the Hubble Space Telescope (HST) is used to determine effective radii, surface brightnesses, and quantitative morphological parameters.

Using this large database we are able to address detailed questions about the star formation history of the galaxies that include the epoch of the major star formation period, and the star formation time scales, as well as the dependence on the cluster environment and the masses of the galaxies. Many of the clusters have x-ray imaging from XMM-Newton or Chandra, making it possible to relate the properties of the stellar populations of the galaxies to the x-ray morphology and surface brightness of the x-ray gas.

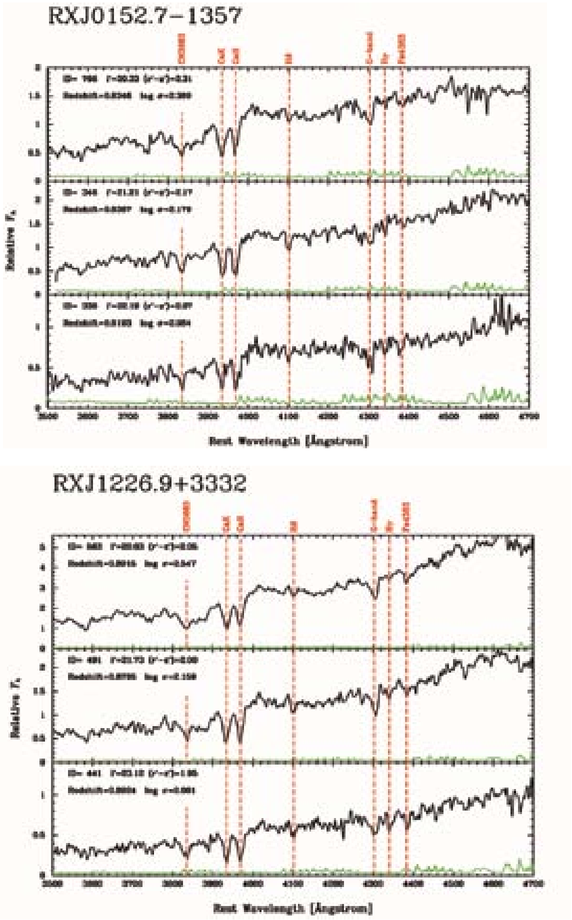
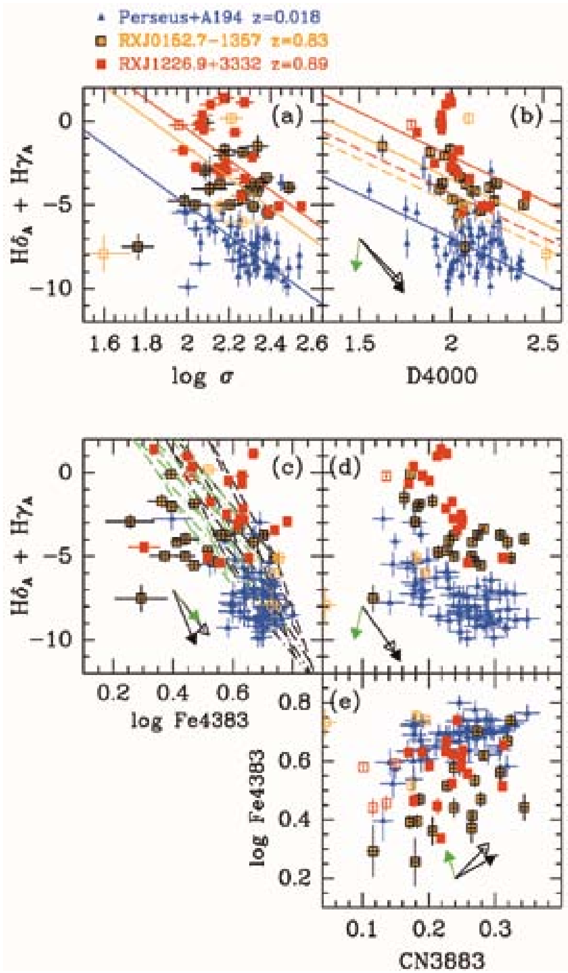


Figure 2. Example spectra of galaxies in RXJ0152.7-1357 (z=0.83) and RXJ1226.9+3332 (z=0.89). Black lines are the spectra; green lines represent four times the random noise. The total exposure time for the RXJ0152.7-1357 galaxies is 21.7 hours, while the total exposure time for the RXJ1226.9+3332 galaxies is 36 hours. CN3883 marks the main feature included in the broad passband for this index.

Our sample includes four clusters with redshifts above 0.8. We have analyzed in detail the data for two of these clusters, RXJ0152.7-1357 at $z = 0.83$ and RXJ1226.9+3332 at $z = 0.89$. Figure 1 shows color images of the cores of these clusters based on the HST/ACS imaging. RXJ0152.7-1357 is thought to be in the process of merging from two clumps of roughly equal mass. The x-ray morphology supports this view, showing two distinct concentrations of x-ray gas that coincide with the peaks in the galaxy distribution. RXJ1226.9+3332 on the other hand has a fairly spherical x-ray morphology and may be a relaxed cluster at high redshift.

Figure 3.
The line indices for the Balmer lines Hδ and Hγ, the 4000Å break, iron and CN versus each other and the internal velocity dispersions (log σ) of the galaxies. Open points are emission-line galaxies (not included in the discussion). Arrows show model predictions of the approximate change in the indices for changes of Δlog age=+0.3 (solid black), metal content of +0.3 dex (open black), and Δ[α/Fe]=–0.2 dex (green). The lines in (a) and (b) are discussed in the text. Panel (c) shows model grids for [α/Fe] =0.2 (black) and [α/Fe]=0.5 (green).



Example Gemini spectra from both clusters are presented in Figure 2 (previous page). The most important indices for the purpose of investigating the ages, metal content, and α-element ratios of the clusters are the combined Balmer line index for Hδ and Hγ, $H\delta_A + H\gamma_A$, the iron index, Fe4383, the CN index, CN3883, and the measurement of the 4000Å break, D4000.

The observations of RXJ1226.9+3332 were obtained using the nod-and-shuffle mode on GMOS-North, enabling very accurate sky subtraction. This makes it possible to reach the required signal-to-noise for galaxies as faint as i’≈23 magnitude at $z = 0.89$, and also measure the Lick line indices for all lines bluewards of about 470 nanometers in the rest frame of the cluster. The total exposure time for the $z = 0.89$ galaxies is 36 hours with a median seeing of 0.65 arcseconds and the majority of the observations were obtained in photometric conditions. We have been able to obtain similar data for the $z = 1.0$ cluster in the sample. These observations would have been impossible without the nod-and-shuffle mode.

Figure 3 highlights the main conclusions based on the spectra of the E/SO galaxies in RXJ0152.7-1357 and RXJ1226.9+3332. The Balmer lines (Figure 3a) are much stronger in these clusters compared to our low-redshift comparison sample in the Perseus and the Abell 194 clusters, which both are at $z = 0.018$. This is expected due to the age sensitivity of these lines and the fact that, based on the pure passive evolution model, we expect E/SO galaxies at this redshift to appear significantly younger than nearby E/SO galaxies. The data shown in Figure 3a can be interpreted in support of this model and we derive the redshift for the major star formation epoch, z_{form}, to be $2 < z_{\mathrm{form}} < 4$. However, when we use the other available line indices, the picture is no longer this simple. The strength of the 4000Å break, D4000, is also expected to depend on the mean age of the stellar populations in the galaxies. Using simple stellar population models, we can then make a prediction of where the high-redshift galaxies should fall in the HδA+HγA vs D4000 diagram, if we assume that the strong Balmer lines are due only to an age difference. The dashed lines on Figure 3b show this prediction and can be compared with the measured offset marked as the solid lines in the same figure. The difference is approximately 6 and 3 sigma for RXJ0152.7-1357 and RXJ1226.9+3332, respectively.

The two indices $H\delta_A + H\gamma_A$ and D4000 also depend on the metal content and the α-element abundance ratios. The arrows on Figure 3 show the approximate dependence according to stellar population models. From Figure 3b it now becomes clear that, according to these models, the only “solution” to the apparent inconsistency between Figure 3a and b may be that the strong Balmer lines in the high-redshift galaxies are due in part to the α-element abundance ratios, [α/Fe], being higher than found in the local universe. We have estimated using several line indices that for RXJ0152.7-1357 the difference is roughly 0.2 dex. For RXJ1226.9+3332 the difference is somewhat lower. The other panels on Figure 3 support this conclusion. It is especially striking that the iron index Fe4383 is very weak in the majority of the

RXJ0152.7-1357 galaxies. This illustrates that the high [α/Fe] may in fact be caused by iron being under-abundant, rather than the α-elements being overabundant relative to galaxies in the local universe. The unusually high [α/Fe] is in contradiction to the pure passive evolution model. Pure passive evolution cannot change [α/Fe] and therefore the E/SO galaxies in these clusters at z = 0.8-0.9 cannot age passively into galaxies similar to local E/SO galaxies.

Two main questions arise from these data: (1) how did the galaxies acquire these unusually high α-element abundance ratios, and (2) how can the galaxies evolve into E/SO galaxies similar to those seen in rich clusters in the local universe?

Because α-elements originate primarily from very massive stars, while the iron-peak elements are created from lower-mass stars, the time scale for their formation is different. This is the basis for the most widely accepted process that can lead to a stellar population with a high α-element abundance ratio. If the star-formation time scale is very short, then the α-elements from the massive stars are recycled into the second-generation stars. The iron peak elements created later are not recycled as efficiently. Thus, the answer to the first question may be that the time scale for star formation in these galaxies was very short compared to our low-redshift comparison sample. The galaxies in RXJ0152.7-1357 are most extreme in this sense. By using the x-ray data for this cluster, we have also found that galaxies located in the outskirts of the two merging sub-clumps seem to have not only high [α/Fe] but also lower metal content and younger ages than the majority of the cluster galaxies. We hypothesize that this is due to the effect that cluster merger has on the star formation in these galaxies. Short-lived star formation bursts might have been triggered as a result of the merger.

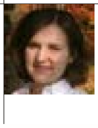
The answer to the second question about the evolution of the galaxies into E/SO galaxies, similar to our low-redshift sample is probably more challenging, since we must find a mechanism that will lower [α/Fe], while at the same time not produce a lot of new stars. One possible solution could be mergers between these high [α/Fe] galaxies and galaxies with lower [α/Fe], as long as such mergers do not trigger significant star formation. The low [α/Fe] galaxies may be disk galaxies that have experienced star formation over a much longer time period, and therefore have low [α/Fe]. However, not only is it difficult to identify such a population of galaxies in the cluster, since only 10 percent of our sample in RXJ0152.0-1357 is consistent with [α/Fe] = 0, it would also be quite unusual if such mergers did not lead to new star formation.

As part of the Gemini/HST Galaxy Cluster Project, we are now in the process of analyzing the Fundamental Plane for these two clusters. We expect that this will put further constraints on the star formation history of the galaxies and maybe pose more challenges to the current modeling of galaxy evolution.

The detailed discussion of the results for RXJ0152.7-1357 is presented in Jørgensen, et al., 2005, AJ, 129, 1249. We have also published an analysis of our spectroscopy of galaxies in the lower redshift cluster RXJ0142.0+2131 at z = 0.28, (See Barr et al., 2005, AJ, 130, 445).

The Gemini/HST Galaxy Cluster Project team members are Inger Jørgensen, Marcel Bergmann, Jordi Barr, Kristin Chiboucas, Katy Flint, Roger Davies, David Crampton, Maela Collobert, and Marianne Takamiya. The team includes Gemini staff as well as researchers from the UK, the US and Canada.

Inger Jørgensen is the Head of Science Operations at Gemini North and can be reached at: ijorgensen@gemini.edu



by Julia D. Silge

GNIRS Unveils the Black Hole in Centaurus A

Figure 1.
Centaurus A as imaged by the Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile. Photo courtesy of Eric Peng, Herzberg Institute of Astrophysics and NOAO/AURA/NSF.

The nearby galaxy Centaurus A, also known as NGC 5128, is a remarkable object. New data from the Gemini Near-Infrared Spectrograph (GNIRS) has revealed surprising information about what lies at the center of this galaxy. Its optical appearance is striking, with a rich complex disk of dust and gas that cuts across the round body of this elliptical galaxy (Figure 1). It was also one of the first astronomical radio sources ever detected. More than just historically interesting however, Centaurus A is an important object for our understanding of central black holes in galaxies, galaxy mergers, active galactic nucleus activity, and the relationships among these components during galaxy formation and evolution.

As galaxies form and grow, their different components interact to assemble galaxies as we see them around us today. These interactions are understood at a wide range of levels, from quite well to not at all. One link that appears clear is the relationship between black hole mass and galaxy kinematic properties (how the stars in the galaxy are moving as a whole). This relationship has been seen in ever-growing samples of nearby well-studied galaxies and has been found reliable and to have small scatter.

In order to understand the underlying reasons for this relationship, we need to study galaxies that have more diverse characteristics. Current samples of galaxies are not very heterogeneous; these well-studied galaxies have been so thoroughly examined because they lend themselves well to normal optical techniques. These techniques are not successful when applied to a more difficult type of galaxy, such as Centaurus A, which is heavily obscured by dust. At optical wavelengths, the central nucleus is nearly invisible, veiled by a rich dust lane. Such obscuration hampers kinematic measurements made using optical data, and the central black hole of a galaxy like Centaurus A cannot be measured using normal optical techniques.

Working at near-infrared wavelengths offers an effective solution to studying such problematic galaxies. Near-infrared light is more transparent to dust and minimizes dust extinction in galaxies. Infrared observations have inherently better spatial resolution than optical observations because our atmosphere is more stable in these wavelengths. This is important when studying black holes because we need to trace how the stars are moving in the very central regions of the galaxy. Also, very luminous young stars often dominate the visible light from galaxies, while the infrared light is dominated by the older stars that are more massive and dominate the actual dynamical structure of the galaxy.

With motivations like these, a team led by Alessandro Marconi studied the black hole of Centaurus A using near-infrared gas dynamical measurements. They found a black hole mass of $\sim 2\times10^8$ solar masses. This is about ten times higher than the mass that we would expect from the kinematics of Centaurus A and the known relationship between black hole mass and galaxy kinematics. If this black hole measurement is correct, Centaurus A would have the largest offset ever measured from this relationship. It can be difficult to interpret gas dynamics, however, because the motions of gas particles can be affected by interactions with each other, not just gravity alone. Since the result of this study appeared so unusual and the method has some uncertainty, many were unsure what to conclude about the black hole of Centaurus A. What was needed to understand this galaxy was a different way to ask the question, to use the motions of the stars instead of the gas.

To do this, and study the black hole at the center of Centaurus A, I worked with collaborators Karl Gebhardt (University of Texas at Austin), Marcel Bergmann (NOAO Gemini Science Center), and Doug Richstone (University of Michigan) to combine new near-infrared spectroscopic data from Gemini South with near-infrared imaging data and sophisticated modeling techniques to constrain the stellar dynamical properties of this galaxy, including the mass of the giant black hole at its center. We used GNIRS during system verification time shortly after it was installed on the telescope. This project was one of the first done using this new instrument.

The Gemini observations measured the internal kinematics of the galaxy, or how the stars that Centaurus A is made of are moving. Looking at the motions of the stars is the best way to measure the mass content of a galaxy, since the only thing that affects the stellar motions is the gravitational pull of the galaxy's mass. Figure 2 shows the stellar kinematic data. Each panel represents a different spatial location in the galaxy with the radius *r*, the distance from the galaxy center, as shown. The right panels show data along the dust disk and the left panels show data perpendicular to the dust disk. In each panel, the black line shows the observed galaxy spectrum from that location and the red line shows the fit to the data, which gives us the kinematic information. The measure of the amount of random stellar motions (σ) is reported for each spatial location.

With the data prepared, we constructed a family of models to compare to the data using the techniques first introduced by Karl Schwarzschild in the late 1970s and described by Karl Gebhardt

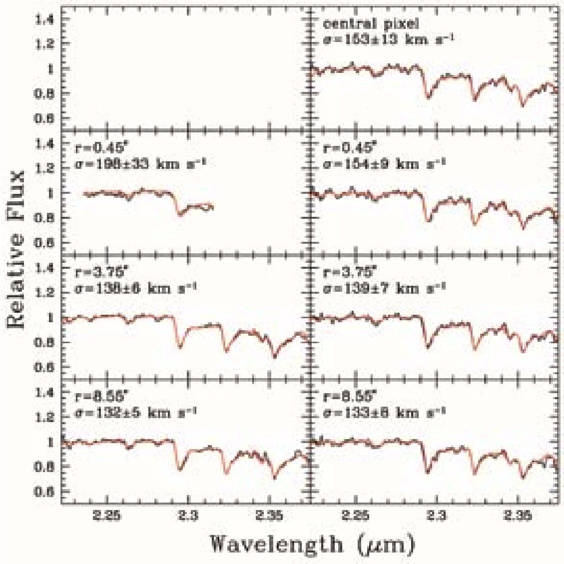


Figure 2. Rest-frame spectra for seven example spatial locations in the galaxy (black lines) and for the kinematic fit for that location (red lines). The distance from the galaxy center (*r*) and the measure of the amount of random stellar motions (σ) are reported for each of these locations. The left panels show data from the axis perpendicular to the dust disk; the right panels show data from the axis parallel to the dust disk.

and colleagues in 2000. The models have different values for the mass of the central black hole, how massive the stars of the galaxy are compared to their brightness, and how the galaxy is oriented relative to our viewing angle on the sky. We can compare each model with the observed data and find the one which gives the best match. How much better or worse the match becomes as those three quantities change tells us how precisely we can measure those values.

Centaurus A is a particularly complex galaxy which proved to be more difficult to model than galaxies previously studied with this technique, but we found that our results were not strongly affected by the dynamical complexity of this fascinating, if somewhat messy, galaxy. Despite these difficulties, we were able to obtain a reliable measurement of the central black hole of Centaurus A using the data from Gemini South.

Our result for this black hole's mass is surprising. We find a black hole mass of $2.4\,(+0.3, -0.2) \times 10^8$ solar masses for our best-fit model, with only moderately smaller values for models with different assumptions about the galaxy's three-dimensional orientation. This result is in good agreement with the gas dynamical estimates of the black hole mass and confirms that Centaurus A has the largest offset ever measured from the relationship between black hole mass and galaxy kinematic properties. The central black hole of Centaurus A is five to ten times larger than expected by comparing to normal galaxies as a whole. This remarkably high black hole mass suggests that it assembled before the host galaxy finished growing. A recent observation of one of the most distant objects ever discovered has a similar implication: a $z = 6.42$ active galaxy was found to have a black hole that appears to have too much mass relative to its host galaxy (compared to normal galaxies we study close to us). This very distant galaxy and Centaurus A appear to stand out from the census of well-studied black holes in local galaxies. Also, our result does not fit in well with current theoretical explanations of black hole growth in galaxies. These theories paint a picture of a galaxy and its central black hole growing together in an intimately linked rate of growth.

Why is Centaurus A such an unusual galaxy in this respect? We don't have a clear answer at this point, but two notable properties likely hold the key to understanding its oddness. Centaurus A is the product of a recent merger. In the not-too-distant past, two galaxies crashed together to make Centaurus A what it is today: a messy, dusty galaxy with an unusually disturbed appearance. Also, it has an active nucleus; its central region is busy with what we believe is the violent growth of its black hole. Having a discrepant black hole mass does not fit perfectly with what we know about either of these important characteristics, but the use of near-infrared kinematics holds a lot of promise for answering questions about Centaurus A and has implications for others as well.

Many active galaxies and all recent merger galaxies are significantly dusty and thus inaccessible to optical spectroscopy. Using an instrument such as GNIRS with the techniques we used to observe Centaurus A, we can reliably measure the kinematics of such galaxies. We can study more galaxies that share these characteristics with Centaurus A and begin to dig deeper into why it is such an oddity. In recent years, astronomers have made great strides in learning about the supermassive objects that reside at the centers of galaxies; using near-infrared kinematics, we can do the same for the enshrouded, hidden black holes of galaxies like Centaurus A.

Our team's paper: "Gemini Near Infrared Spectrograph Observations of the Central Supermassive Black Hole in Centaurus A," was published in Volume 130 of the *Astronomical Journal*, pages 406-417.

Julia Silge is an Astronomer at Yale University and can be reached at: julia.silge@yale.edu

by Chad Trujillo

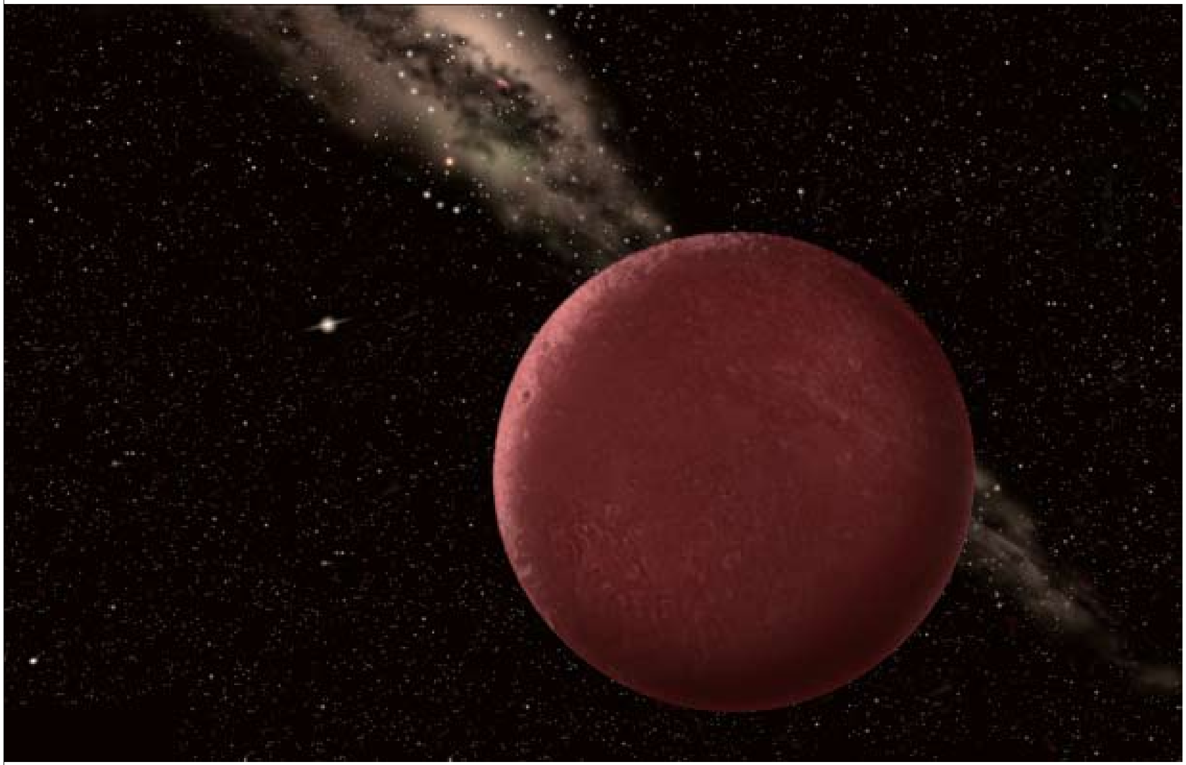


Figure 1. Artist's conception of what a distant, large Kuiper Belt object might look like. Gemini Artwork by Jon Lomberg

Gemini Focuses on New Kuiper Belt Worlds

This past year will be remembered as a landmark period in terms of outer solar system discoveries. The three minor planets with the greatest absolute magnitudes (and if albedo is assumed to be constant among minor planets, the largest diameters) were found during this period. They are 2003 UB313, 2003 EL61, and 2005 FY9. Although their names (provisional designations created by the Minor Planet Center) are somewhat forgettable, their physical properties are not. The largest of the three, 2003 UB313, is the first object larger than Pluto discovered orbiting the Sun since Neptune's discovery in 1846. The next largest object—2003 EL62—at two-thirds the diameter of Pluto, is no less interesting because it is actually a ternary system. Its primary is the most rapid large rotator known in the solar system. It spins so fast that it is deformed into an oblate shape called a triaxial ellipsoid. The third discovery, 2005 FY9, has a likely size somewhere between one-half to two-thirds the diameter of Pluto. It is unique in its extreme methane ice absorption features. All of these bodies are in the Kuiper Belt, the region of the solar system beyond Neptune, and are referred to as Kuiper Belt Objects (also often called trans-Neptunians, even though not all of their orbits cross Neptune's).

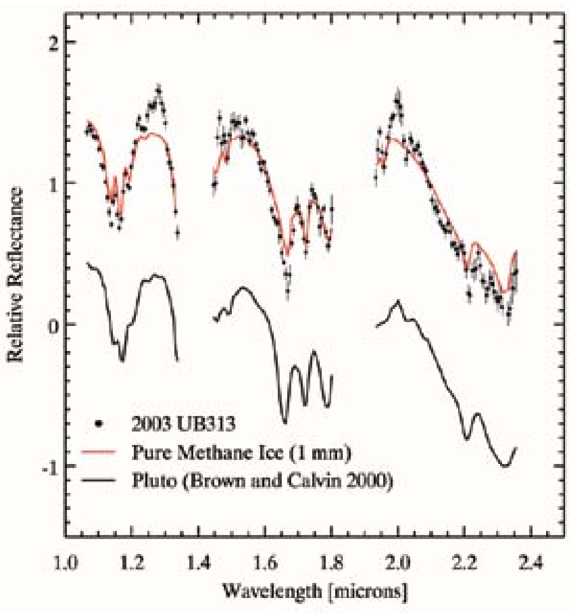


Figure 2. Reflectance spectra of 2003 UB313 from Gemini NIRI. Pluto and 2003 UB313 show very similar properties at this scale.

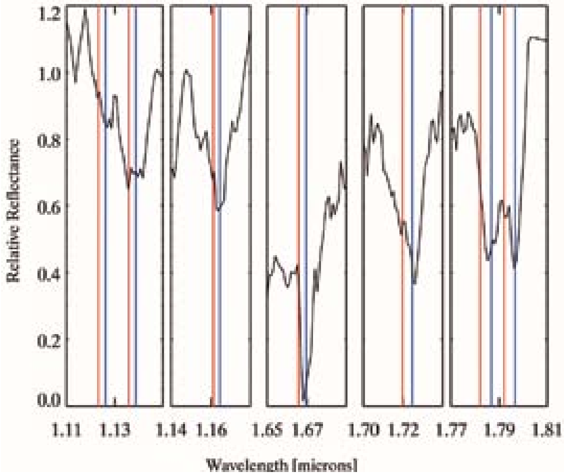


Figure 3. Close up of 2003 UB313 methane absorptions from Gemini NIRI. Red lines indicate methane ice dissolved in nitrogen (such as seen on Pluto), while blue lines indicate pure methane ice band centers. Note that in all cases, the methane ice on 2003 UB313 is pure.

In this article, I will discuss what we know about the physical state of these three largest of the minor planets and the role that Gemini, Keck, and smaller telescopes have played in investigating them.

Pluto's Long Lost Twin: 2003 UB313

Minor planet 2003 UB313 was found this year as part of an ongoing project at the Samuel Oschin 48-inch telescope at Palomar Mountain to look for the largest distant bodies in the solar system. It was clear from the moment it was discovered that 2003 UB313 was a unique object. Its parallactic distance of 97 astronomical units (AU) makes it the most distant known object in the solar system, superseding its closest distance rival Sedna (discovered last year) at 89 AU. Combining 2003 UB313's distance with its apparent visual magnitude of 18.5 indicates that it must be larger than Pluto (however, Spitzer measurements will soon place an upper limit on its size).

Because 2003 UB313 is such an unusual object, we wanted to learn more about its surface composition. Using director's discretionary time granted for the Gemini Near-Infrared Imager (NIRI), we were able to take spectra of this object less than a month after its discovery. The data were astonishing because they showed very deep methane ice absorption features. At first glance (Figure 2), it appears that 2003 UB313 and Pluto have very similar surfaces because their spectra are both dominated by methane ice features. However, it is important to note that on Pluto, nitrogen is actually thought to be the main surface component, but since it is very difficult to detect from the ground, methane dominates the Pluto spectral signature in the near-infrared. By carefully examining the wavelength where the methane absorption takes place, we see that for 2003 UB313 the methane is pure, rather than dissolved in nitrogen as it is on Pluto (Figure 3).

This difference most likely has environmental origins. Although 2003 UB313 is larger than Pluto, it is three times farther from the Sun, causing a reduction in vapor pressure that makes it very difficult for methane to become dissolved in nitrogen. Since Pluto is currently at 31 AU from the Sun and heading outward to aphelion at 49 AU, we expect that the fraction of nitrogen-free methane may increase with time as the planet cools. Unfortunately, since aphelion for Pluto occurs in August 2113, we will not be able to easily examine this possibility in our lifetimes.

One recent finding that makes 2003 UB313 seem even more like Pluto is that it has a satellite. The tiny companion was found using the Keck Adaptive Optics Laser Guide Star system. Its orbit has not yet been measured, but plans are underway to do this.

The Most Extreme Body in the Solar System: 2003 EL61

Although 2003 UB313 may be the largest minor planet, 2003 EL61 may be the most interesting. It is rich in water ice, also has a moon and rotates extremely rapidly. Initial observations of 2003 EL61 showed that this body is both bright (its visual magnitude is 17.5) and distant (at 51 AU), although it is likely not as large as 2003 UB313. Near-infrared spectra of 2003 EL61 from both Gemini and Keck show that it is very different from 2003 UB313 because its surface is covered with water ice. In fact, using a Hapke grain model we can model the spectrum of 2003 EL61 using 100% crystalline water ice with no additional components needed (Figure 4). Water ice is not an unusual component in outer solar system bodies; it has been measured on several Kuiper Belt objects. It is also a component predicted by dynamical theory, and we expect that the observed comets have their birthplaces in the Kuiper Belt. Since the sublimation of water ice is the prime process of generating comet tails, one would expect that Kuiper Belt objects would also have water ice if dynamical theories are correct. Although the presence of water ice on several of these objects does not prove the dynamical theories, it is consistent with that picture. However, the fact that the ice is crystalline is quite unusual. This has been seen on Quaoar (the largest minor planet known until this year). In fact, it has been suggested that since crystalline water ice is unstable at Kuiper Belt object temperatures, recent resurfacing may explain its presence. However, for 2003 EL61 it is difficult to imagine how recent resurfacing could account for water ice over the entire surface.

Although the composition of 2003 EL61 is not spectacular, its dynamical state is. Visible observations of 2003 EL61 several months after its discovery show that it is in a state of extreme rotation, with a period of 3.9 hours. At a diameter of more than 1,000 kilometers this makes it the fastest large rotating body in the solar system. (There are smaller near-earth asteroids which rotate even faster. However, they are monolithic, meaning that their geologic strength far outweighs gravity.) 2003 EL61 is rotating so fast that it is deformed.

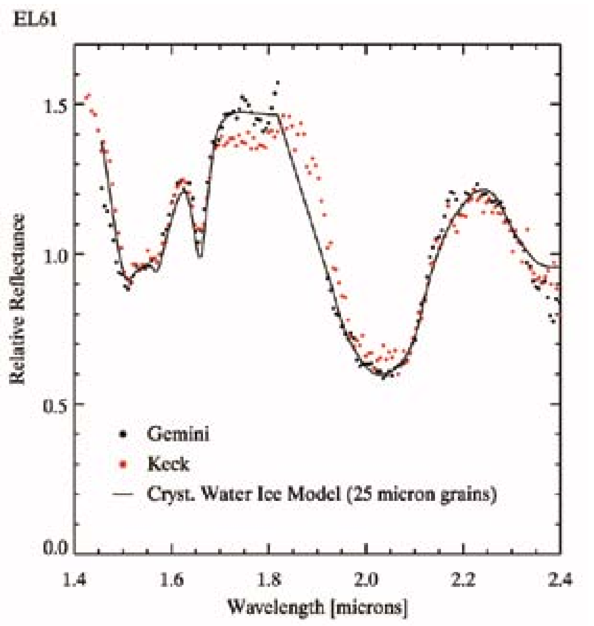


Figure 4. 2003 EL61 from Gemini and Keck. Spectra from both telescopes are of similar quality and show similar results. The model is a 100% pure crystalline water ice model.

Subramanyan Chandrasekhar's 1969 theory on rotating objects tells us that for a large body, where gravity dominates over internal strength, fast rotation deforms the rotator. This is the case for the Earth, many other large solar system bodies, and any body which at rest would be spherical. These are "strengthless," meaning that their internal strengths (i.e. the strength of the rocks that make up the bodies) are vastly overcome by gravity. At rest, a body is spherical, and as it spins faster it becomes oblate (a triaxial ellipsoid). The shape and density of the body can be entirely determined by the magnitude of the photometric variations and their period. We find that 2003 EL61's density from Chandrasekhar's tables to be 2,600 to 3,340 kilograms per cubic meter, somewhat more dense than Pluto (about 2000 kilograms per cubic meter) or pure water ice (900 kilograms per cubic meter). We also find that the primary is dramatically deformed into a triaxial ellipsoid (something like a squashed rugby ball) with length/width and length/height ratios no less extreme than 1.3 and 2.0, respectively.

We have yet another way to measure the body's physical properties. Using the Keck Laser Guide Star Adaptive Optics system (LGS, yielding angular resolutions of about 0.1 arcseconds) we find that 2003 EL61 is a binary with a nearly edge-on circular orbit with maximum separation of 1.4 arcseconds and a minimum separation of less than 0.2 arcseconds. We have measured this orbit, which directly provides the mass of the system: $4.2 \pm 0.1 \times 10^{21}$ kilograms, or 32% the mass of Pluto. Combining these results from the spin rate of the primary and the orbit of the secondary, we know quite a bit about 2003 EL61: its total length must be between 1,960 to 2,500 kilometers across, with a visual albedo of greater than 0.6. In comparison, water ice on Earth has a visual albedo of 0.8, consistent with our near-infrared spectral results. Pluto is about 2,274 kilometers in diameter, with a variable albedo of between 0.49 and 0.66.

We have only scratched the surface of knowledge about this body, as any formation scenario must take into account the fact that it has water ice on the surface (and thus could not be heated to an extreme amount), it is in a rapid rotational state, and it has two moons. A collisional origin could explain such features, but there are other binary formation mechanisms also consistent with the body, such as dynamical friction.

The Brightest Kuiper Belt Object: 2005 FY9

The minor planet 2005 FY9 was found in spring 2005 and is the brightest known Kuiper Belt object, with a visual magnitude of 17.2. The planet Pluto is the arguable exception to this statement, but since the International Astronomical Union recently ruled that Pluto retains its planet status in perpetuity, 2005 FY9 is the next brightest Kuiper Belt object. Simply being bright is not especially unusual, and since 2005 FY9 is at 52 AU, it is very unlikely to beat 2003 UB313 in size. However, near-infrared spectra obtained at Keck show extremely prominent methane absorption features, even more saturated than those seen for 2003 UB313 or Pluto. Together, both 2005 FY9 and 2003 UB313 are the only two Kuiper Belt objects with very strong measured methane absorption bands. (Sedna is reported to have possible methane bands, but confirmation of this is difficult because of its low signal-to-noise ratio.) Methane is of particular interest because any formation scenario must create 2005 FY9 in a cold enough region of the solar system that methane does not sublimate during the formation process.

The Big Picture

There are several questions that must be asked regarding common observations among these objects. The first is, why have all three of the intrinsically brightest minor planets been discovered in the past year? It is difficult to answer this question, but part of the explanation is that people who have seen these bodies before did not notice that they were moving with respect to the background stars. This is the case for all-sky surveys such as the Digital Sky Survey, where previous positions for 2005 FY9 (for example) have been found in data from 1955 in the original Palomar Sky Survey. However, many groups (including ours) have been looking for bright Kuiper Belt objects for years. The other part of the reason that nobody has found these three particular objects is because all have high inclinations with respect to the ecliptic, and all were discovered at least 14 degrees from the ecliptic. They spend most of their time at these inclinations. In fact some bodies such as the Plutinos (Kuiper Belt objects in 2:1 resonance with Neptune) favor perihelia (when they are brightest and most detectable) out of the plane of the solar system, so in some sense this may be expected.

The second peculiarity is that three of the four largest Kuiper Belt objects (including Pluto), have satellites: Pluto, 2003 UB313, and 2003 EL61. Although it is difficult to draw quantitative conclusions from such a small sample, it does suggest a common process for the creation of the satellites, which may be linked with formation scenarios of the early solar system. Dynamical work and more characterization of the found moons' orbits are needed to constrain this possibility.

Third, of the four bodies with intrinsically high absolute magnitudes, three have prominent methane absorption features (Pluto, 2003 UB313 and 2005 FY9) while the remaining body (2003 EL61) has very strong water ice signatures. To date, it has been very difficult to examine the surfaces of typical Kuiper Belt objects because of their extreme faintness in the near-infrared, so only the surfaces of the brightest bodies have been studied. Now with infrared capabilities such as at Gemini we can study these bodies with less difficulty. It is possible that further comparisons between these newly discovered bright bodies and the fainter Kuiper Belt objects may determine if the bright ones have significantly more ices. If so, this argues for a fundamental physical difference between the large and small Kuiper Belt objects. This must be explained either by formation scenarios or global geologic processes.

We expect that in the near future, very careful studies of all three of these newly discovered bodies will be attempted. This may uncover molecules that are difficult to detect, such as nitrogen ice and carbon dioxide, as found on Pluto. The presence of these volatile ices will help constrain the thermal environments present during the formation of the large Kuiper Belt objects, and may help us determine if atmospheres may be present. Additional satellites may also be found as deeper surveys are performed, and any compositional differences between primary and secondary objects may be identified. In addition, our ongoing survey has the potential to find still more of these objects, but only if their inclinations are high, since we have searched nearly all of the sky near the ecliptic. We hope to be able to find more bodies such as these, but as we have searched most of the sky already, we cannot be sure if these are the last of the great minor planets, or if future surveys will prove that they are just the first.

Chad Trujillo is a Science Fellow at Gemini North and can be reached at: ctrujillo@gemini.edu

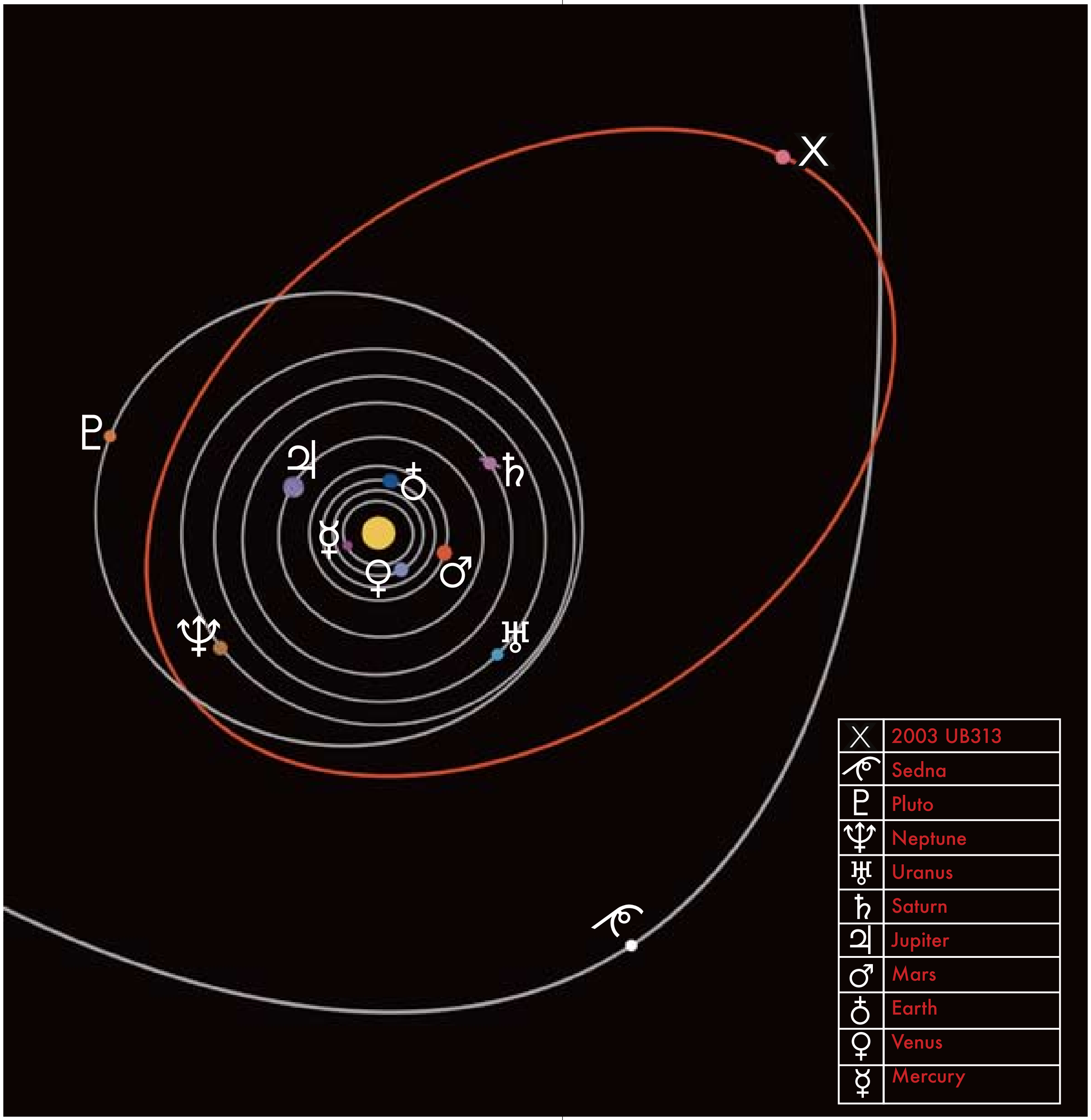
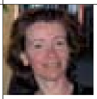


Figure 5. Projection of relative orbits of major solar system bodies.



by Sandra Savaglio

Gemini Deep Deep Survey and the Mass-Metallicity Relationship in Galaxies

In the 1970s, the biggest observatory of the time was the 30-year-old Palomar facility. CCD detectors were not yet being used on astronomical instruments to collect data from the sky, astronomers were still struggling with low-sensitivity photographic plates, and the most powerful computers were as big as a room and didn't have the capabilities equivalent to any of today's laptops. However, even at that time, astronomers knew that bigger galaxies in the universe were also chemically more evolved than smaller galaxies.

The origin of what is now called the mass-metallicity relation in galaxies is still controversial. After more than three decades of research and observations, theories dealing with this phenomenon still lack the information coming from an important fundamental parameter: cosmic time. We don't know whether the mass-metallicity relation was in place in the past history of the universe or how different it was in the past from what is observed today.

More precisely, we didn't even have a clue about these issues until now. A recent study based on data taken at the Gemini North telescope shows for the first time that the mass-metallicity relation in galaxies already existed at redshift $z = 0.7$ (seven billion years ago), at a time when the universe was about half of its present age (Figure 1). Not only was the relation clearly reflected in the galaxies as they existed at that time, but it was also different from the one we see in the nearby (and more recent) universe.

The data used for this study were taken as part of the Gemini Deep Deep Survey (GDDS). The project benefitted from a number of factors that, when combined, allowed this difficult discovery to be made. First, faint targets were efficiently observed thanks to the fantastic capabilities of the Gemini Multi-Object Spectrograph (GMOS), working in "nod-and-shuffle" mode. Second, the GDDS galaxies were combined with a sample of brighter galaxies observed as part of the Canada-France Redshift Survey (CFRS), doubling the size of the initial sample. Third, optical and near-infrared photometry of the galaxy integrated light (from the Las Campanas Redshift Survey and the CFRS) allowed stellar mass measurements for the sample, through extensive modeling of the stellar population. As a result, the 56 galaxies in the sample cover a very large range in stellar mass and metallicity (a factor of 400 for mass and almost 10 for metallicity). One of the key factors in the process—the ability to extend the baseline in the parameter space—was made possible by the deep spectroscopy performed by GMOS.

Metallicities were measured with a standard technique that uses fluxes from emission lines originating in regions of star formation. This technique is particularly appropriate when studying distant galaxies, because they can be detected in spectra even if the signal from the stellar continuum is very weak. The main difficulty arises when the minimum set of emission lines necessary to derive the metallicity is redshifted to the near infrared. This happens for redshifts larger than 1. Near-infrared spectroscopy is much harder to perform than optical spectroscopy, and so obtaining data for a sizable sample of galaxies is a very challenging task.

The GDDS study measured the mass-metallicity relation for the highest redshift for which optical observations are still useful. The average redshift of the sample is $z = 0.7$. The time interval spanned by the total sample is not small, about 3.5 billion years. Yet the relation is significant, and it gives a striking result: smaller galaxies show a larger deviation from the local mass-metallicity relation (Figure 1). In other words, while the big galaxies quickly reached high metallicities at high redshifts, the small galaxies at similar redshifts are, through star formation, still in the process of enriching their gas components with metals. As part of the GDDS investigation, the rate of enrichment through star formation was modeled as a function of the galaxy mass. The observed mass-metallicity relation can be reproduced remarkably well if the period of star formation is long in small galaxies, and more concentrated in time (or "bursty") in big galaxies, or (in the language of cosmology), if the e-folding time is inversely proportional to the initial mass of the galaxies.

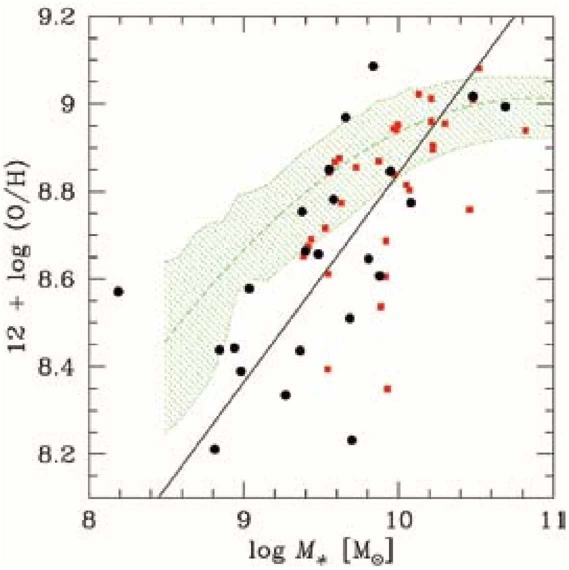


Figure 1. This shows stellar mass and metallicity of 56 galaxies at redshifts between $0.4 < z < 1$ observed as part of the Gemini Deep Deep Survey (black dots) and Canada-France Redshift Surveys (red squares). The black straight line shows the linear bisector fit of the distribution. The green area is the best-fit polynomial (and 1σ dispersion) derived for local galaxies in the SDSS.

A very important application of the GDDS study is the first attempt to model the metallicity evolution empirically over cosmic time as a function of galaxy stellar mass (Figure 2). This was done in the following way: first, the present-day mass-metallicity relation, derived from 53,000 Sloan Digital Sky Survey (SDSS) galaxies, was shifted in its stellar-mass axis to match the newly discovered distribution of galaxies at $z = 0.7$. The same was done to match the region covered by the

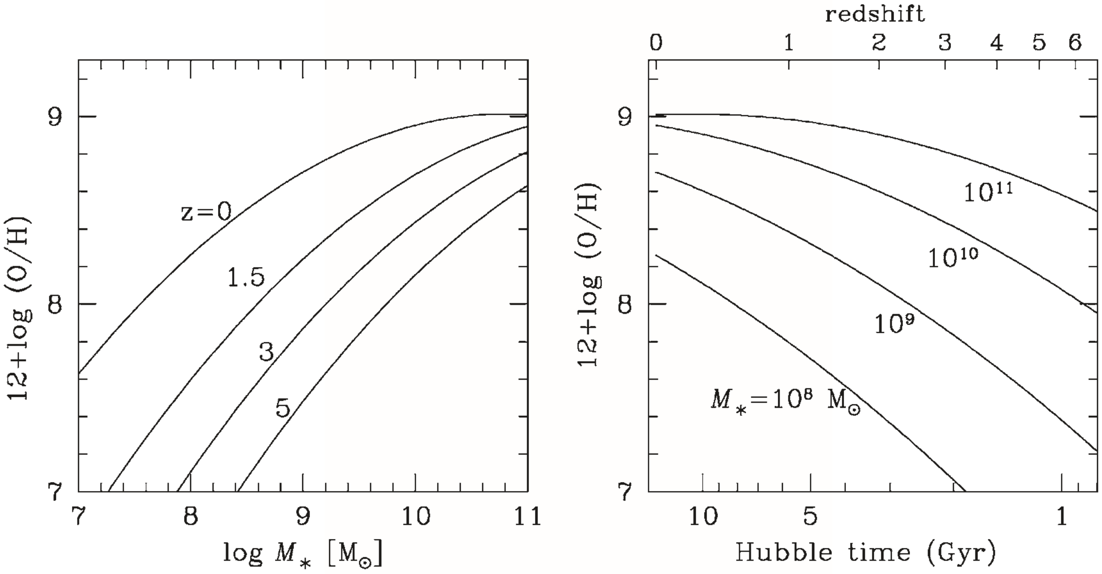


Figure 2. This empirical model was derived from the observed mass-metallicity relation at $z = 0.7$ and $z = 0.1$. It gives the metallicity of a galaxy as a function of its stellar mass for different redshifts (left), or the metallicity of a galaxy as a function of its redshift for a given stellar mass (right).

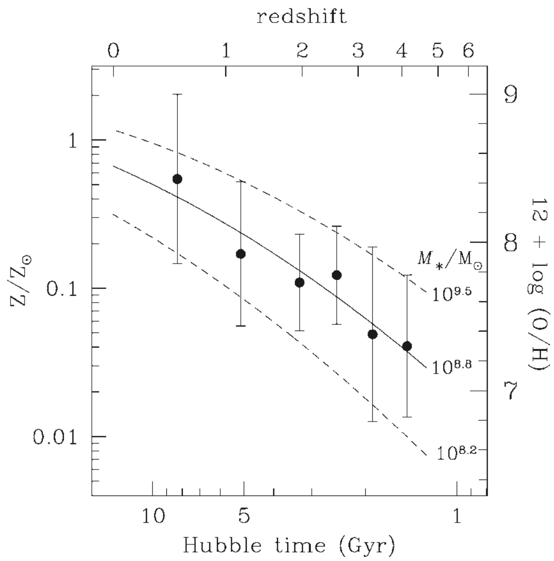


Figure 3. Redshift evolution of the average metallicity (in redshift bins) of DLA galaxies. The solid line is our empirical model at one single parameter: the stellar mass. The best fit is obtained if the stellar mass of DLA galaxies is, on average, $10^{8.8}$ times the solar mass. The dashed lines show the dispersion in the predicted stellar mass.

few galaxies studied at the even higher redshift of $z \sim 2.3$ (For $z = 2.3$ this is 2.7 billion years after Big Bang and at $z = 0.7$ it is 7.2 billion years after the Big Bang). These two offsets and the zero-point relation were combined to derive an equation that gives the metallicity as a function of Hubble time and galaxy stellar mass.

Although very simple (and at the same time powerful) the accuracy of this empirical model has to be tested by using larger samples of galaxies at different, possibly even larger, redshifts. It is interesting to apply it to distant galaxies, discovered using completely different techniques, to make predictions on their stellar mass. One such set comprises a class of galaxies known as damped Lyman-alpha systems (DLAs). DLAs are galaxies that happen to cross the line of sight of point-like, powerful distant and unrelated sources: quasars. In that regard they are perfect candidates because their signatures (absorption lines) in quasar spectra allow a wide investigation of their chemical state, but not of their stellar mass. In fact, because quasars are much brighter than normal galaxies, detailed measurement of the foreground galaxy emission (necessary to estimate its mass) is basically impossible. It's like trying to read a book while facing into sunlight. However, this does not affect the absorption lines. In fact, the brighter the background quasar, the better the absorption detectability. As a result, there are nearly 200 DLAs with measured metallicity across a very large redshift interval (from 0.1 to 5).

For this reason DLAs are a perfect test of our empirical model, and help to derive the stellar mass. They are a matter of intense scientific discussion because their typical metallicity is much lower than galaxies we see today, that is, generally 1/10 of the metallicity of the Milky Way Galaxy. The result of our empirical model (shown in Figure 3) suggests that DLA galaxies have a stellar mass on the order of 1/100 of the Milky Way's. Interestingly, this holds basically true all the way from the closest DLAs to the most distant ones.

The next step will be to measure metallicity and mass simultaneously in more galaxies at similar or higher redshifts, and to test our predictions. Models of galaxy formation will have an extra non-free parameter to deal with: the typical metallicity of a galaxy as a function of time and mass. The GDDS research confirms recent findings that show big galaxies to be very active in the first half of the history of the universe. Small galaxies dominate the scene during the second half. It will be interesting to see if, and how, the most popular theories of galaxy formation, (the hierarchical models, that postulate the formation of big structures through the mergers of smaller ones), will face this additional challenge.

Other team members involved in this work are Karl Glazebrook (Johns Hopkins University), Damien Le Borgne (University of Toronto), Stephanie Juneau (Steward Observatory), Roberto Abraham (University of Toronto), Hsiao-Wen Chen (University of Chicago), David Crampton (NRC Victoria), Pat McCarthy (Carnegie Observatories), Ray Carlberg (University of Toronto), Ron Marzke (San Francisco State University), Kathy Roth (Gemini Observatory), Inger Jørgensen (Gemini Observatory) and Rick Murowinski (NRC Victoria).

The paper on these findings will be published in an upcoming issue of The Astrophysical Journal and can be found at the URL: http://xxx.lanl.gov/abs/astro-ph/0508407.

Sandra Savaglio is an Astronomer at Johns Hopkins University and can be reached at: savaglio@pha.jhu.edu

by René Doyon

The Gemini Deep Planet Survey (GDPS)

This year marks the tenth anniversary of what will undoubtedly be declared one of the major scientific discoveries of the 20th century: the detection of the first planet outside the solar system. Thanks to novel and more precise instrumentation, 51 Pegasus b was discovered by the Doppler technique—measuring the tiny reflex movement of a parent star induced by an orbiting planet. Today, no less than 168 planets in 144 planetary systems have been identified by a related technique that uses radial velocity measurements.

These objects include the now-famous transiting system HD209458b, whose light curve has provided a direct measurement of the planet's radius. Even its atmospheric constituents have been probed by Hubble Space Telescope (HST) at optical wavelengths. More recently, Spitzer Space Telescope made a direct detection of the infrared radiation from the planet.

Aside from the important statistical fact that gas giant planets do exist in more than 7% of nearby F, G, K and M (main sequence) stars, and more preferably around metal-rich ones, the wealth of radial velocity data has also unveiled the existence of "hot Jupiters"—gas giant planets orbiting very close to their parent star in scorching hot regions clearly not conducive to the formation of Jovian planets (which are made mostly of volatile gas). It is now believed that those worlds were likely formed at larger distances beyond the so-called "snow line," (where water and other volatiles would condense out of the cloud of gas and dust that form a planetary system) and migrated inward either through disk-planet dynamical interaction and/or planet-planet gravitational interaction.

Clearly, it has been a very busy and exciting first decade for the still-infant discipline of exoplanetary science. We have yet to probe and search at relatively large (> 5-6 astronomical units (AU)) semi-major axes, a parameter-space impractical for the radial velocity technique since it requires long baseline measurements patiently acquired over a significant fraction of one orbital period. For planets like Jupiter and Saturn, this time frame corresponds to 12 and 29 years, respectively. Direct imaging is the only viable technique for finding such planets and to provide a better inventory of planetary systems and obtain insights into their formation mechanism.

Detecting planets around stars by direct imaging is a daunting task since planetary companions are very faint and lie in the glaring halo of the primary. Since the luminosity of exoplanets decreases with time, the most promising strategy for detecting them photometrically is to search around nearby young stars, and ideally around the least massive ones for which the planet/star brightness ratio is most favorable. The first planetary mass companion discovered with this technique (by a team led by Gael Chauvin) occurred in 2004 using the Very Large Telescope. The planetary companion has an estimated mass between two and five Jupiter masses and lies at 45 AU (0.8 arcseconds) from the 8-million-year-old, 25 Jupiter-mass brown dwarf identified as 2MASS J1207334-393254 within the TW Hydra association.

The Gemini Deep Planet Survey (GDPS) is an ongoing exoplanet survey using the Near Infrared Imager (NIRI) and the ALTAIR adaptive optics system on Gemini North. GDPS is aimed at the detection of ~2 Jupiter-mass planets at semi-major axes greater than a few tens of AU around nearby young stars. The sample comprises ~100 nearby F, G, K and M stars selected from several catalogs of young stars with estimated ages less than ~150 million years. The median distance of all stars in this sample from the Sun is 22 parsecs.

The project was initiated in 2004 and first-epoch observations have already been completed for 78 stars. Some 55 of these show at least one candidate companion in the 22 × 22 arcsecond NIRI field of view. Since background contamination is significant, the GDPS team is currently seeking time to secure second epoch observations to assess companionship of all candidates.

The main limitation of current high-contrast imaging on both HST and ground-based telescopes is the quasi-static speckle noise with a time scale on the order of several minutes (compared to milliseconds for atmospheric speckles). Quasi-static speckles are simply the imprint of the quasi-static component of the combined telescope-plus-instrument wavefront error. Without reference calibration, the contrast performance rapidly saturates after a few minutes of integration time and this is a major obstacle for detecting faint planets. One popular and efficient technique to suppress the quasi-static noise on HST is to roll the telescope slightly by a few degrees, displacing any companion angularly, but not the quasi-static speckles. Subtracting the two images at two different roll angles strongly attenuates the speckle noise while preserving the companion as a positive/negative signal in the residual image. This so-called "roll-deconvolution" technique has been used successfully to detect the companion to 2M1207 at a second epoch, confirming that it is orbiting the brown dwarf.

The GDPS survey uses a slightly different speckle suppression technique called Angular Differential Imaging (ADI). It consists of acquiring a sequence of relatively short exposures with the image rotator turned off. This is the optimized configuration for stabilizing the point-spread function since both the instrument and telescope optics are always stationary relative to one another. The main difference between ADI and roll deconvolution is that the latter yields one or a few roll subtracted images while ADI produces a continuous set of residual images whose number is limited only by the total integration time and the exposure time of individual images, usually ~30 seconds. The ADI technique results in a larger set of residual images and better performance.

Experience on Gemini has shown that ADI improves companion sensitivity by a factor of ~5 for short exposures. More significantly, sensitivity increases nearly as the square of the integration time. This is an important achievement given that high-contrast imaging is normally limited to a few minutes of integration as mentioned above. Thanks to ADI, it is now possible to integrate for hours and reach faint planets around bright stars. Figure 1 shows a typical contrast curve obtained with ADI on Gemini which certainly qualifies as some of the best data of its kind obtained on 8- to 10-meter-class telescopes.

ADI on Gemini reaches a Δm of 12.7 at 1 arcsecond in 45 minutes, which is one magnitude better than that obtained with VTL/NACO by Elena Masciadri and team in 22 minutes, (although the latter performance did not improve with integration time). For a Sunlike star at a typical distance of 20 parsecs, the Gemini performance with ADI translates to a companion mass limit of $\sim 2\,M_{Jup}$ at 50 AU or closer for later spectral types.

How many planets should we expect to detect with GDPS? Figure 2 shows a Monte Carlo simulation as an attempt to answer this question. Evolutionary models together with the known H-band brightness of our targets were used to calculate the H-band contrast of each hypothetical planet. The simulation suggests a significant and encouraging detection rate of ~20%. Previous imaging surveys on the VLT and Keck suggest a paucity of relatively massive ($>$5-10 M_{Jup}) planets at large separations. The better sensitivity of GDPS will provide tighter constraints for the occurrence of a few M_{Jup} planets beyond ~50 AU and more massive ones at smaller semi-major axes.

The GDPS survey should be completed at the end of 2006, and is currently one of the most sensitive exoplanet imaging surveys on any 8- to 10-meter-class telescope. The next step will be the Gemini Near-Infrared Coronagraphic Imager (NICI) campaign. The spectral differential imaging capability of NICI coupled to its coronagraph and a curvature sensor adaptive optics system should improve the performance of GDPS especially at sub-arcsecond separations. By the end of this decade, Gemini will have the Extreme Adaptive Optics Coronagraph in operation, an instrument designed to reach contrasts of $\sim 10^{-7}$ at 0.5 arcseconds. High-contrast imaging and the search for exoplanets are both poised for a bright future at Gemini.

The GDPS team includes astronomers from Canada (myself as principal investigator, David Lafrenière, René Racine, Daniel Nadeau, Ray Jayawardhana, Doug Johnstone), US (Ben Oppenheimer, Andrew Digby, Christian Marois, Bruce Macintosh, James Graham & Paul Kalas), UK (Patrick Roche) and Gemini Observatory's (François Rigaut).

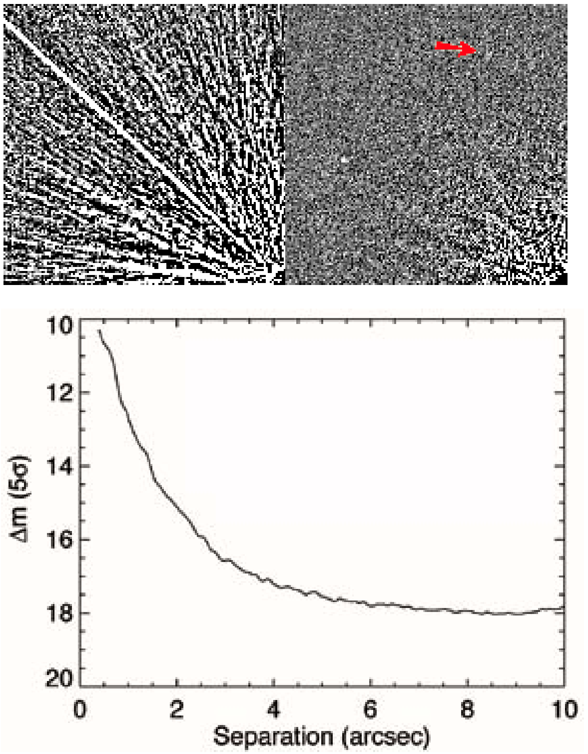


Figure 1. Contrast performance (5-σ in 45 minutes) as measured on Gemini in ADI mode. The images at top show the relative performance with (right) and without ADI (left). Both images are shown at the same scale; a low-pass filter has been subtracted from the image on the left. The faint (H~22) companion (indicated near the 11 o'clock position) is buried in speckle noise but unveiled after ADI processing.

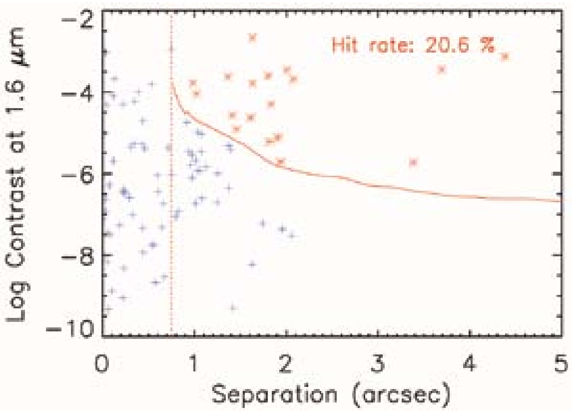
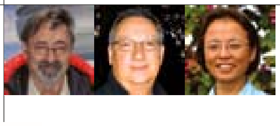


Figure 2. A Monte Carlo simulation of a planet population for the GDPS sample. The solid (red) curve is the 5-sigma detection limit observed on Gemini with ADI. Points above the curve represent positive detections. The dotted vertical line shows the typical saturation limit (0.75 arcseconds) to the left of which planets cannot be detected.

René Doyon is an Astronomer at the Université de Montréal and can be reached at: doyon@astro.umontreal.ca



by Jean-René Roy,
Dennis Crabtree
Xiaoyu Zhang

Gemini Publications: Growth & Impact

Introduction

From a governmental science policy viewpoint, the role of astronomers is to turn money into scientific results. The agencies that fund astrophysical research are looking for a return on their investment. As in all scientific fields, the tradition and the research process require making these results public for sharing and verification. In the case of astronomy, direct applications are not sought. Its research process contributes to enrich the pool of human knowledge. Still, astronomers want their productivity measured and the value of the new knowledge base they build assessed and recognized.

Gemini is a large international observatory run on behalf of six partner countries: the United States, United Kingdom, Canada, Australia, Brazil and Argentina. How do we determine whether Gemini is producing science at a competitive level compared to other large 8- to 10-meter-class telescopes? By measuring our output and comparing it to the output of other telescopes in the same class. This paper describes how Gemini measures its productivity and competitiveness.

Science Productivity: Why and What?

Why do we want to measure our science results? We have several “constituencies” with vested interests in our work. In most countries of the modern world, astronomy is funded by government agencies, ministries or by generous benefactors (rich individuals, families or company donations). Beyond the need of self-assessment, astronomers are also accountable to their "customers." For organizations like Gemini, our customers are the national science agencies, as influenced by the users and the public. It has always been the custom for observatories, astronomy groups in universities, and industrial laboratories to report their findings and to present lists of publications as both a demonstration and legacy of their activities.

There are several ways to measure this productivity. The number of refereed publications in well-recognized journals is a standard method. Furthermore, the number of citations is recognized to be an acceptable metric of the impact of these papers. As Mohamed Gad-el-Hak wrote on page 13 of the September 2004 issue of *Physics Today*, "Although far from being infallible, the entire enterprise of citation index and impact factor is better than the alternative, straightforward bean counting."

However, as warned by several commentators, impact factors can become an unyielding yardstick and their excessive use may be damaging. Writing in *The Chronicle of Higher Education*, Robert H. Austin (Princeton University) adds, "The impact factor may be a pox upon the land because of the abuse of that number."

It is understood that other criteria, often of a more qualitative nature, can and should be used for international organizations like the Gemini Observatory. These criteria include: the number of high-caliber users, the impact of the journals that authors use to publish their findings, the uniqueness of the science produced, the impact on innovation that the papers have and the effect of new enabling technologies developed by the observatories (e.g. adaptive optics, laser technology, science archives).

Gemini Publications: Statistics

Gemini maintains an up-to-date database of papers based wholly or in-part on Gemini data that appear in the main refereed astronomical research journals. These journals consist of: *The Astrophysical Journal, The Astronomical Journal, Astronomy & Astrophysics, Monthly Notices of the Royal Astronomical Society, Publications of the Astronomical Society of the Pacific, Science*, and *Nature.* In a few exceptional and well-assessed cases, we also count papers from "secondary" journals. As of October 28, 2005, there were 186 papers based on Gemini data. Gemini's qualifying criterion is the same as that used by Hubble Space Telescope (HST) and European Southern Observatory/Very Large Telescope (ESO/VLT). To qualify, papers based on their output, must employ in an original way an image, spectrum or data set produced by Gemini to derive new scientific results. No attempt is made to fractionate papers per telescope used in the case of papers based on the use of two or more other facilities. Hence, the same paper may be counted several times, (for example by Gemini, Keck, and Subaru) if it includes data from any of these telescopes.

Gemini North started executing general-user science programs on October 23, 2000. The Galactic Center (Center of the Milky Way Galaxy) had been imaged with the University of Hawaii's Hokupa'a 36-QUIRC Adaptive Optics system in a special campaign a few weeks earlier. At Gemini South, the start of science for the general user community was on October 4, 2001, almost a year later than

NAME	INSTRUMENTS	SEMESTERS
Hokupa'a	Visitor adaptive optics imager - GN	2000B-2002A
OSCIR	Visitor mid-infrared imager – GN and GS	2000B-2001B
NIRI	Near-infrared imager/spectrograph (grism) - GN	2001A-Present
GMOS-N	Optical multi-object spectrograph/imager - GN	2001B-Present
MICHELLE	Mid-infrared spectrograph/imager - GN	2004B-Present
Phoenix	Shared high resolution near IR spectrograph - GS	2002A-Present
GMOS-S	Optical multi-object spectrograph/imager - GS	2003B-Present
T-ReCS	Near-infrared spectrograph - GS	2003B-Present
GNIRS	Near infrared spectrograph - GS	2004B-Present

Table 1. Names of the main visitor and facility instruments at Gemini that are the sources of most of the papers described in this article. GN indicates the Gemini North telescope and GS indicates the Gemini South telescope.

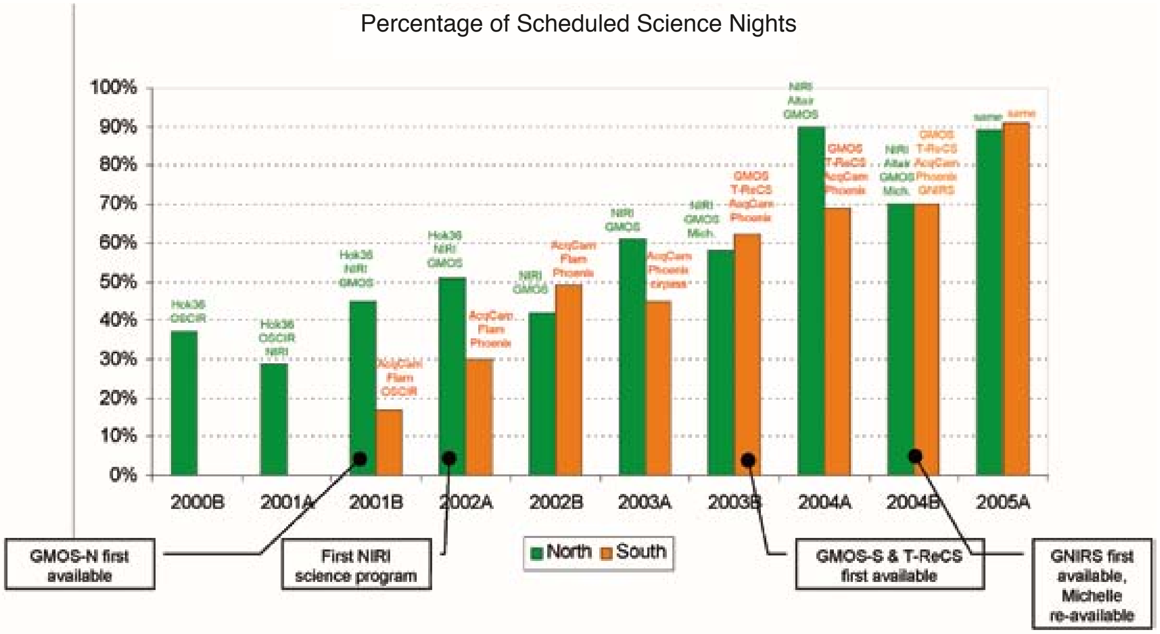


Figure 1.
History of science time availability at Gemini North (green) and Gemini South (orange). This represents scheduled time and does not include time lost to weather and technical faults. The remaining time is used for the commissioning of instruments and telescope engineering tasks.

at Gemini North. Figure 1 shows the evolution of science availability at Gemini North (green) and Gemini South (orange), i.e. fraction of nights scheduled for science (loss to weather or technical faults not included). The names of the instruments as they became available are also shown above the bars. Most Gemini papers published so far are based on data sets obtained in the period between late 2000B through 2003B.

“*Quick Start*” Science

The OSCIR mid-infrared imager/spectrometer, the Hokupa‘a adaptive optics system, the FLAMINGOS-1 near-infrared imager/multi-slit spectrometer, and the CIRPASS near-infrared spectrograph were visitor instruments at Gemini North that “filled holes” while waiting for facility instruments to arrive. Some early instruments had serious initial problems (e.g. the Near-Infrared Imager (NIRI) and FLAMINGOS-1), which hampered their regular use. In the case of NIRI, these problems have now been corrected and this instrument is now one of our most reliable. Others instruments like the two Gemini Multi-Object Spectrographs (GMOS) and MICHELLE showed a high degree of reliability from the beginning. Table 1 (previous page) lists the Gemini instruments referred to in this article.

Not surprisingly, the first wave of papers came from OSCIR and Hokupa‘a-36 on Gemini North. Even though these were among some of the most complex instruments (a mid-infrared camera and an adaptive optics system) used to commission Gemini North, their scientific output was healthy. It is interesting to note that offering these two capabilities attracted astronomers who had no previous experience with the mid-infrared regime and adaptive optics. Thirteen “archive” papers have appeared that are based on Hokupa‘a imaging of the center of the Milky Way in the year 2000, and two of them are considered “high impact.” OSCIR stands out in two ways: it has the smallest fraction of completed programs, and was one of the most productive in terms of papers.

The first “visitor” instruments (OSCIR, Hokupa‘a-36, CIRPASS and FLAMINGOS-1) had limited periods of availability (two to four semesters). Their retirement created a discontinuity for users, possibly generating a break in data flow and hence an interruption in the flow of publications.

The question remains, was having “visitor” instruments a good idea? We had little choice, and it was difficult using them to commission the telescopes, since they had not been designed or built for integration into the Gemini system. However, we learned a lot about science operations (including queue planning and execution) and the telescope systems. The lesson learned is clearly to start science with a real suite of facility instruments. This can only be beneficial to early science output, as has been demonstrated by VLT and Subaru.

Publications From the Gemini Telescopes and Different Instruments

Gemini is a partnership of six countries, with Chile and the State of Hawai'i as hosts. Considering this international character, it is remarkable that more than 54% of the Gemini papers are published in *The Astrophysical Journal*, the journal that has the highest average citation number per paper.

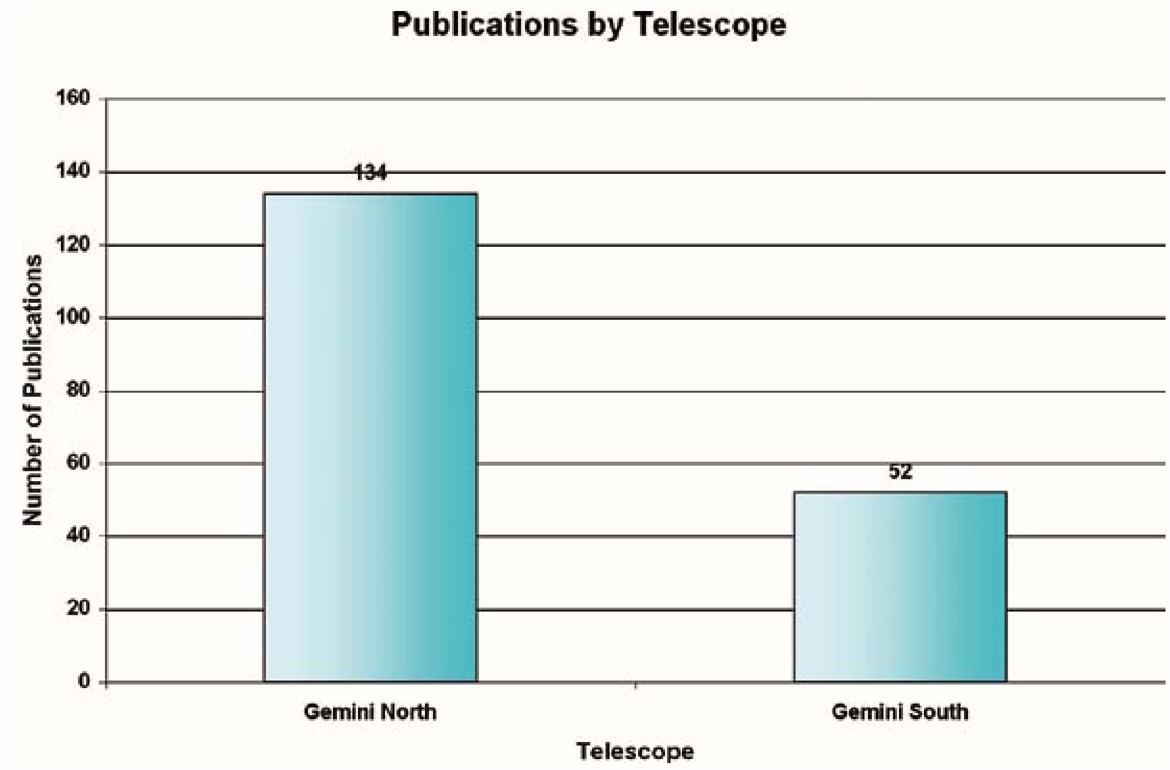


Figure 2. Papers produced by each Gemini Telescope. Note that the Gemini South Telescope science operation started one year later (October 2001) then at Gemini North (October 2000).

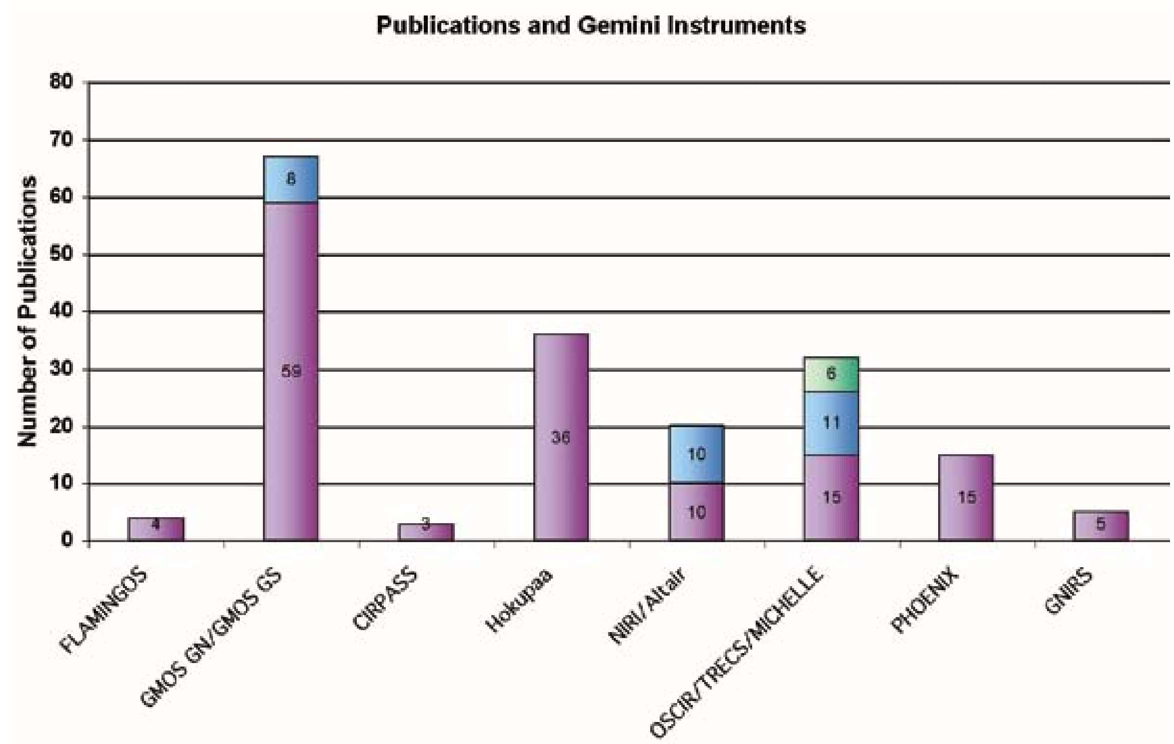


Figure 3. Gemini North and South instruments (visitor and facility) and the number of papers they produced.

In Figure 2, we show the papers for both the Gemini North and South telescopes. There *is* a difference, and most of it can be explained by the fact that Gemini South came on line at least one year later than Gemini North. It suffered even more than Gemini North from the delay in delivery of its facility instruments. For example, GMOS-South started science about 1.5 years after GMOS-North.

The phased ramp-up of publications for the two telescopes compares well with the apparent, but understood, lag for Gemini South. One should also note that the time lost due to weather has been greater for Cerro Pachón than for Mauna Kea for a few successive years.

As shown in Figure 3, the number of papers per given instrument varies greatly. A fair way to compare this is to compute the number of hours required for an instrument's data to result in a paper. The papers published in any given year will be based upon data acquired over a considerable period of time. For example, 2004 VLT publications utilized data between 1999 and 2004. Papers appear typically two to three years after the data was acquired. For simplicity, we have taken the total number of papers published so far or in press (up to late October 2005), and divided this by the total number of hours charged to the programs executed by the same instrument up to the end of semester 2004B. This provides an index of instrument productivity as shown in Table 2 which lists the numbers of papers and the respective productivity indices. Not surprisingly, OSCIR and Hokupa'a-36 (now retired instruments) appear to be the best performers (i.e. have the smallest productivity index values). However, one sees also very healthy numbers with some "young" instruments, such as the Thermal-Region Camera Spectrograph (T-ReCS) and MICHELLE, both mid-infrared imagers and spectrographs.

We have reasons to assert that the high-resolution infrared spectrograph, Phoenix suffers from low paper productivity. However, its productivity index is not that far behind GMOS-North and NIRI/ALTAIR. More worrisome appears to be GMOS-S. Again, this may be an issue of its rather recent availability, and of the time required to handle the large data sets from our optical instruments that offer complex configurations like multi-object spectroscopy and integral field unit

Figure 4.
Year-by-year ramp-up of publications from different instruments up to October 28, 2005.

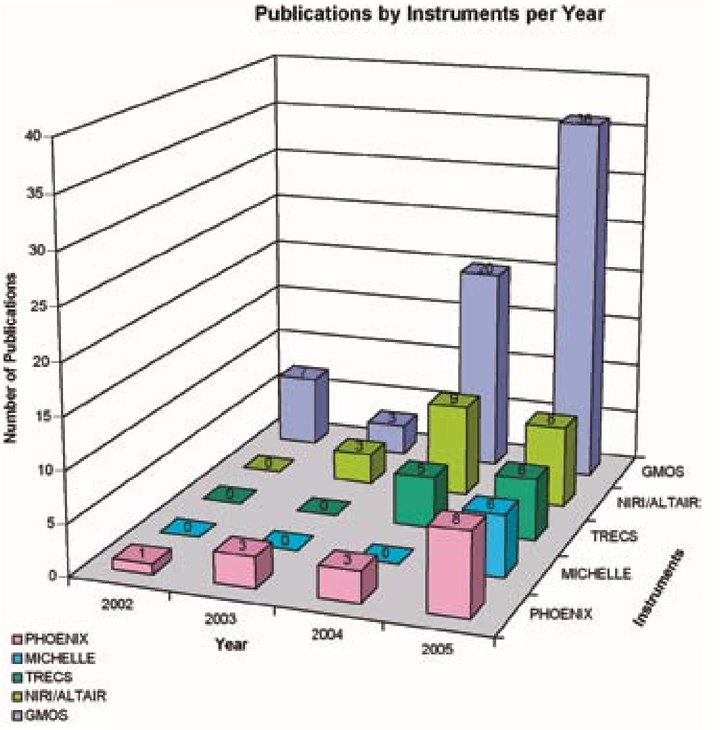


Table 2.
Number of papers and "productivity index" (number of charged hours from 2000B to 2004B divided by number of papers up to October 28, 2005) for the main Gemini instruments.

Instrument	# of papers	Hours per paper
"Old" Instruments		
Hokupa'a-36 (adaptive optics imager)	36	22
OSCIR (mid-infrared imager)	15	23
GMOS-N (optical MO/IFU spectrograph)	59	41
NIRI+ALTAIR (Near-infrared imager/spectrograph)	10(NIRI) + 10(NIRI+ALTAIR)	49
Phoenix (near-infrared spectrograph)	15	67
"Young" Instruments		
GNIRS (near-infrared spectrograph)	5	22
T-ReCS (mid-infrared imager/spectrograph)	11	28
MICHELLE (mid-infrared spectrograph/imager)	6	28
GMOS-S (optical MO/IFU spectrograph)	8	102

(IFU) spectroscopy. It took some time for GMOS-N to produce a large number of papers, but it is certainly doing so now (Figure 4). We expect a similar ramp up for GMOS-S that started executing science programs in July 2003.

Assessment

One quarter of all Gemini papers to date are based on the use of adaptive optics, either Hokupa'a-36 or ALTAIR. Measured in hours per paper, the infrared instruments are more productive. The best are the mid-infrared instruments (OSCIR, T-ReCS and MICHELLE) with an average of 23 hours of observing time on each to produce one paper. Currently 38 hours are required to produce a paper with near-infrared instruments (Phoenix, NIRI/ALTAIR, Hokupa'a, GNIRS, FLAMINGOS-1, CIRPASS), and 54 hours for optical instruments (GMOS-N/S and Acquisition Camera). The average for all Gemini instruments is 40 hours per paper for the period 2000B-2004B (inclusive). The high apparent productivity is attributed to the more generous "discovery space" in the infrared. For example, in the mid-infrared, many sources are being looked at for the first time and reveal considerable new details when observed with the sensitivity and high spatial resolution of the Gemini telescopes. It is not uncommon to have Gemini papers based on less than one-hour total elapsed observing time. In contrast, the optical domain has now been explored for centuries requiring large data sets and significant amounts of telescope time to produce breakthroughs and new knowledge.

Paper output as measured by institutional affiliation of first author is roughly in line with partner shares. The exceptions are the United Kingdom and Chile (where the fraction of papers are significantly below their share), and Brazil (which is significantly above its share). Gemini staff members have been first authors on 12 papers and co-authors on 41 papers.

Observing Modes

Gemini is "fed" by nine Time Allocation Committees (TACs); there are six TACs from the partner countries, two from the hosts and one for Gemini staff proposals. The merging process is done by the International TAC (ITAC; this body, made of one representative for each TAC, recommends selected proposals to the Gemini director), which controls about 90% of the telescope time that is effectively scheduled. Most of the remaining time is allocated directly by the director for director's discretionary (DD) time

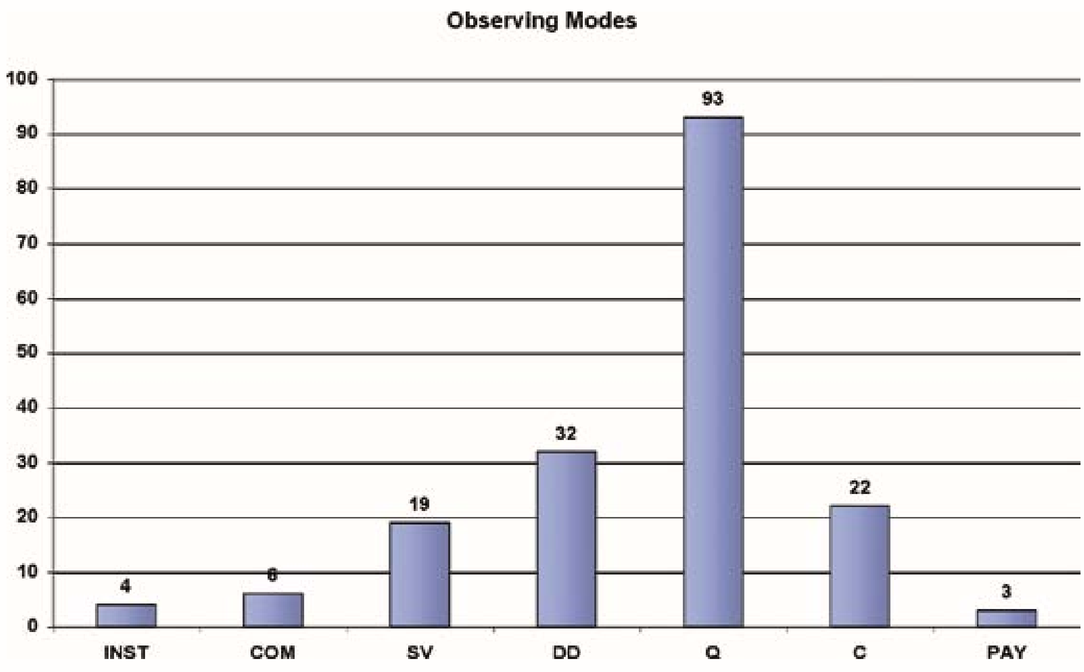


Figure 5. Papers from the different types of telescope time allocations: instrument description (INST), commissioning observations (COM), system verification (SV), director's discretionary time (DD), queue observing mode (Q), classical observing mode (C) and payback time to the team providing and supporting the visitor instruments (PAY).

or system verification (SV) in the case of newly commissioned instruments. As shown by Figure 5, DD and SV produce close to 30% of the papers despite the small amount of total time allocated to these programs. It is interesting to ask why such allocations appear four times more effective than the normal TAC process (61% of the papers). Several explanations for the high productivity of DD time are plausible. One thing is clear: DD proposers appear more committed to their program and are better organized at reducing and publishing their data in a timely manner than the average TAC selected PIs or teams. The director actually uses such criteria to allocate time. One can only encourage the TACs to be more selective and take an aggressive "investment strategy."

How Do We Compare?

We have compared the history of paper output from the 8- to 10-meter class ground-based telescopes: Gemini, Subaru, VLT and Keck. To do this, we have phased all telescopes to have a matching Year 1, defined as the first year when a significant number of papers (more than one or two) were published. Admittedly, this is somewhat arbitrary but much easier to define consistently than events like "first light" or the start of facility construction. In general, the first year of significant publications is about one year after the start of science operation. Figure 6 shows the growth of the papers for Keck (Year 1 is 1994), VLT (Year 1 is 1999), Subaru (Year 1 is 2000) and Gemini (Year 1 is 2002), irrespective of whether the observatory is multi-telescope.

We take into account the number of telescopes at a given observatory in Figure 7, where we normalize paper output as the number of papers per year per telescope. However, because new telescopes need to ramp up, this may introduce dips in the history of paper output. For example, Keck II came on line in 1998, hence the dip in that year (Year 5). The same applies for Gemini where Gemini South was brought on line in 2003 (Year 2). The VLT telescopes came on line one year after each other, hence a flat growth line in the first several years. We note that the growth of VLT and Subaru papers is spectacular. It is early, but assuming that the total number of Gemini publications will reach 80 in 2005 as is currently predicted, the growth of Gemini papers matches the history of Subaru and VLT for the first four years. The three observatories under performed Keck I in this early phase, but overtook their 10-meter "competitor" in the fifth year. To keep in line with the Subaru/VLT growth, Gemini will need a total of 130 papers in 2006. We believe this is achievable. Some tactful pressure on Gemini principal investigators to write up their results in a timely manner as well as judicious use of DD allocations may help.

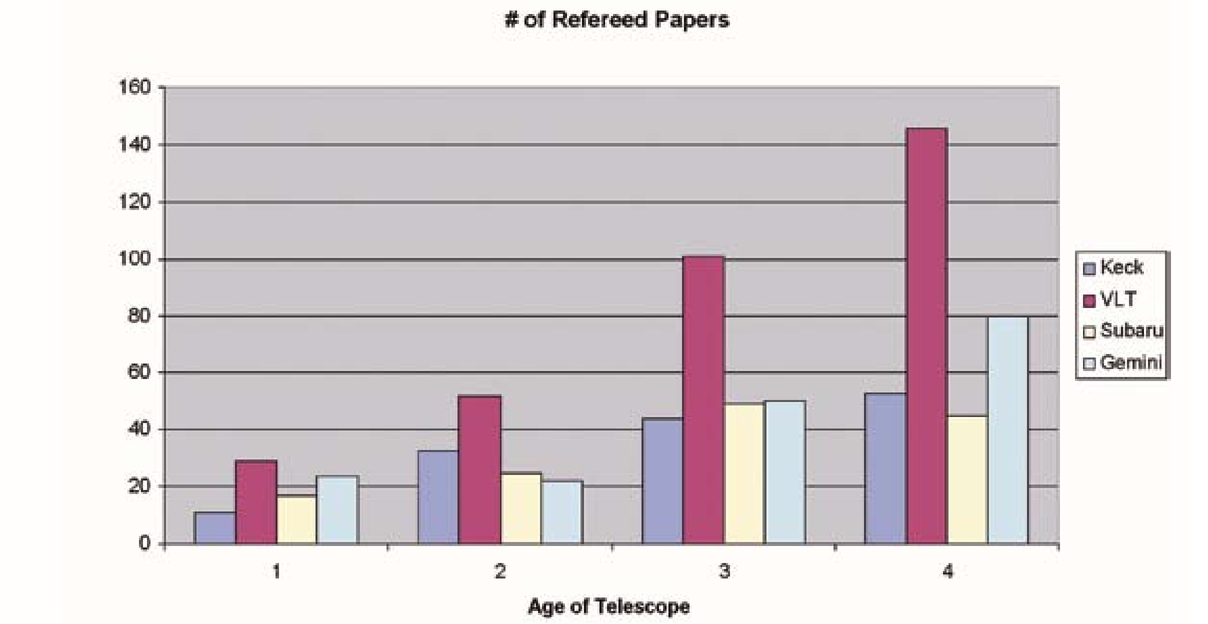


Figure 6. Comparative history of paper output for Keck, VLT, Subaru and Gemini. The "Age of Telescope" axis is normalized so that Year One is the first year of significant number of published papers. Year One corresponds to about one year after the start of science operation. Year One is 1994 for Keck, 1999 for VLT, 2000 for Subaru and 2002 for Gemini. This graph does not take into account the fact that VLT and Gemini have four and two telescopes coming on line during their early years, while Subaru and Keck (initially) were one-telescope observatories.

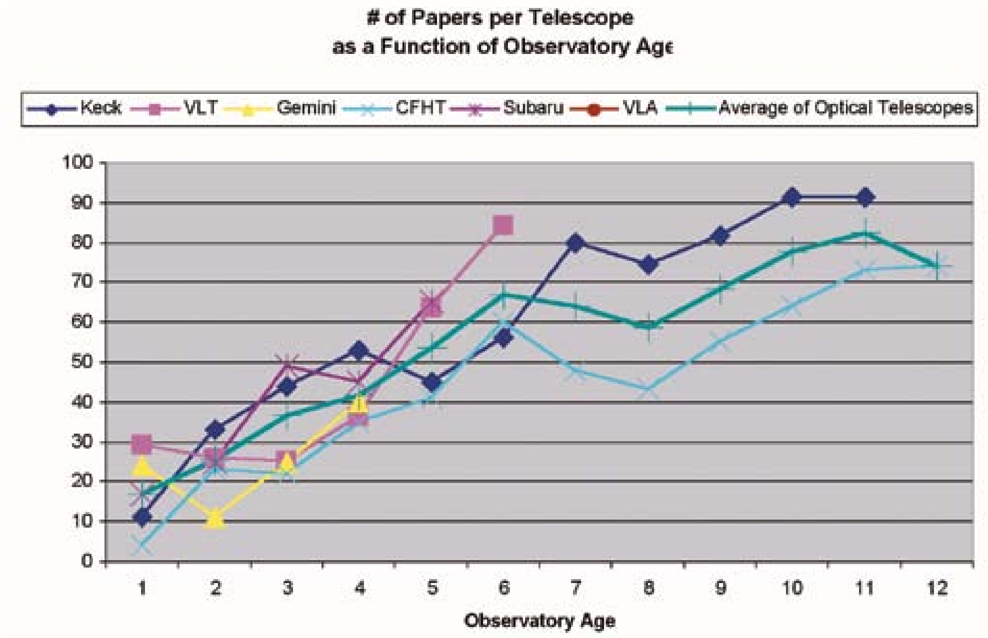


Figure 7. Comparative history of paper output from Keck, VLT, Gemini, CFHT, Subaru and the average of optical telescopes, on the number of papers per year per telescope. 40 papers per telescope are forecast for Gemini's fourth year in 2005.

Citations and Impact

Of the 104 Gemini papers published by the end of 2004, 98 have now been cited at least once. We can assess the impact of Gemini papers based on the number of citations that are compiled from the NASA Astrophysical Data System (ADS) database. The citation history of Gemini papers is still extremely short but is sufficient to make preliminary comparisons with other comparable facilities. We normalized citations to the median citation numbers of all *Astronomical Journal* (AJ) papers for the year corresponding to the Gemini paper. We use this reference to create five classes of impact (I) (minimal when $I < 1$ Median AJ Paper, very low when $I = 1$ to 2, low when $I = 2$ to 5, moderate when $I = 5$ to 9, and high when $I > 9$). These classes are used to define an *Impact Citation Function (ICF)*. It is interesting to compare ICF values for Gemini, Keck, Subaru, as well as HST papers. While HST ICF values are based on several thousand papers, Keck a few thousand, Gemini, and Subaru have a few hundred.

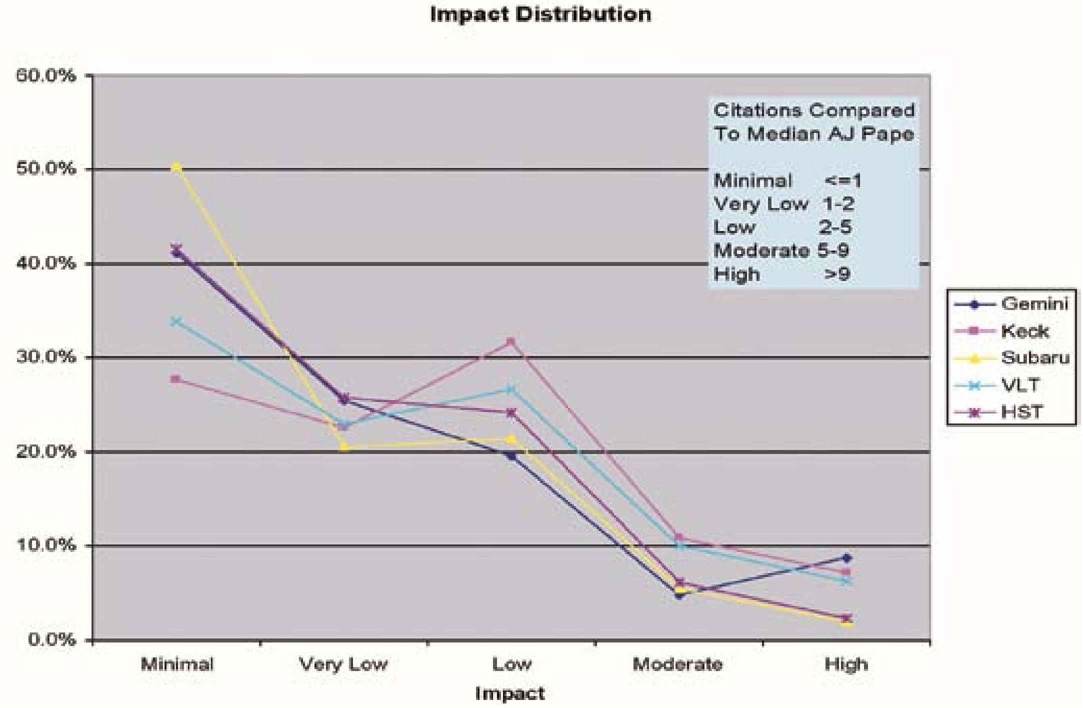


Figure 8. Impact Citation Function of papers from Gemini, Keck, Subaru, VLT and HST as of mid 2005. The ICF values for HST are based on more than 5,000 papers, that of VLT on close to 1,000 papers and those of Gemini and Subaru on 158 and 200 papers respectively.

As shown in Figure 8, the *ICF* is, at first glance, close to universal for most observatories. Like the Initial Mass Function (IMF) for the distribution of the masses of stars, the *ICF* is surprisingly consistent and appears to depend little on the observatory age or history. For example, HST and Gemini a have strikingly similar *ICF*, except for an apparent higher fraction of Gemini papers in the high impact category ($I > 9$). Closer examination shows that Keck has the flattest *ICF*. A flat *ICF* distribution is most desirable, since it indicates a smaller number of low impact papers and more high impact papers. Clearly, despite its very young history, the Gemini *ICF* is already healthy.

Conclusions

Gemini's first three years of paper production matches the historical growth of VLT and Subaru, but under-produces compared with Keck I. We conclude that Gemini's early paper production was somewhat limited by the use of visitor instruments, although these proved very valuable, indeed life-saving, in many other ways. GMOS-N and Hokupa'a have produced the most Gemini papers thus far, while OSCIR and Hokupa'a have proved to be the most efficient at turning telescope time into publications so far.

Gemini's scientific publications have also been well cited, with only 6 out of 104 papers published through 2004 having zero citations as of September, 2005. The impact distribution of Gemini papers compares very favorably with that of the VLT, Subaru and HST. However, the Keck telescopes have produced relatively fewer low impact papers (and more high impact papers). We believe that as Gemini matures the impact distribution of its publications will evolve to more closely resemble Keck's.

This year (Year 4 in telescope years), Gemini North is likely to produce at least as many papers as Keck I at age four (Figure 9). Gemini's goal for 2006 is a total of ~130 papers from Gemini North and South, which would surpass Keck's production in Year 5. A more ambitious goal for "steady-state operations" in 2008 and beyond is 200 or more papers per year. This means 100 papers per telescope, or about one paper per 20 hours of queue observing (or ~3 nights per classical observing period). Our goal is also to have Gemini's impact distribution function be flatter than it is currently. These are very challenging goals and our strategies for achieving them include:

1) attract high-caliber and well-organized teams that are more likely to produce high-impact papers;
2) sensitize NTACs and ITAC to the niche areas where Gemini excels;
3) use director's discretionary time strategically;
4) implement regular follow-up of PIs holding

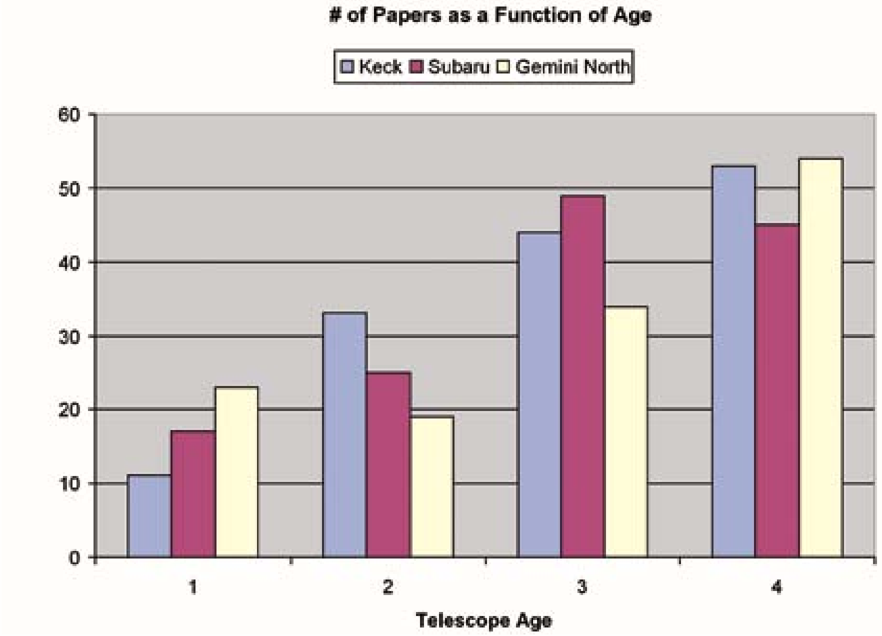


Figure 9. Growth comparison of papers produced by single telescopes: Keck I, Subaru and Gemini North telescopes during their first four years.

significant Gemini data sets;
5) promote publicly available data sets thorough the Gemini Science Archive;
6) increase on-sky science time and ensure high-quality data; and
7) accelerate distribution of Gemini data via electronic distribution from the Gemini Science Archive.

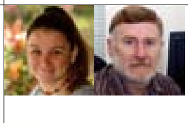
Jean-René Roy is the Acting Director of the Gemini Observatory and can be reached at: jrroy@gemini.edu

Dennis Crabtree leads the Canadian National Gemini Office and can be reached at the Herzberg Institute of Astrophysics at: Dennis.Crabtree@nrc-cnrc.gc.ca

Xiaoyu Zhang is the Librarian for the Gemini Observatory and can be reached at: xzhang@gemini.edu

Authors	Title	Year	Journal	Obs. Mode	Instrument	Citations	Impact
Glazebrook, Karl; et al.	A high abundance of massive galaxies 3-6 billion years after the Big Bang	2004	Nature	Q & DD (1/3)	GMOS	54	18.00
Genzel, R.; et al.	The Stellar Cusp around the Supermassive Black Hole in the Galactic Center	2003	ApJ	DD	Hokupa'a-36	73	12.17
Schödel, R.; et al.	Stellar Dynamics in the Central Arcsecond of Our Galaxy	2003	ApJ	DD	Hokupa'a-36	60	10.00
Abraham, Roberto G.; et al.	The Gemini Deep Deep Survey. I. Introduction to the Survey, Catalogs, and Composite Spectra	2004	AJ	Q & DD (1/3)	GMOS	26	8.67
Close, Laird M.; et al.	Detection of Nine M8.0-L0.5 Binaries: The Very Low Mass Binary Population and Its Implications for Brown Dwarf and Very Low Mass Star Formation	2003	ApJ	C	Hokupa'a-36	48	8.00
Metcalf, R. Benton; et al.	Spectroscopic Gravitational Lensing and Limits on the Dark Matter Substructure in Q2237+0305	2004	ApJ	DD	CIRPASS	23	7.67
Kaspi, V. M.; et al.	A Major Soft Gamma Repeater-like Outburst and Rotation Glitch in the No-longer-so-anomalous X-Ray Pulsar 1E 2259+586	2003	ApJ	DD	NIRI	43	7.17
McCarthy, Patrick J.; et al.	Evolved Galaxies at z>1.5 from the Gemini Deep Deep Survey: The Formation Epoch of Massive Stellar Systems	2004	ApJ	Q & DD (1/3)	GMOS	21	7.00
Stanway, Elizabeth R.; et al.	Three Lyalpha Emitters at z ~ 6: Early GMOS/Gemini Data from the GLARE Project	2004	ApJ	Q	GMOS	21	7.00
Rhoads, James E.; et al.	A Luminous Lyalpha-emitting Galaxy at Redshift z = 6.535: Discovery and Spectroscopic Confirmation	2004	ApJ	Q	GMOS	21	7.00
Smartt, Stephen J.; et al.	Detection of a Red Supergiant Progenitor Star of a Type II-Plateau Supernova	2004	Science	SV	GMOS	20	6.67
Reipurth, Bo; et al.	IRAS 05436-0007 and the Emergence of McNeil's Nebula	2004	ApJ	DD	NIRI & GMOS	14	4.67

Table 3.
The current top 12 Gemini publications ranked by impact as of September 20, 2005. Observing Mode notations are the same is in Figure 5.



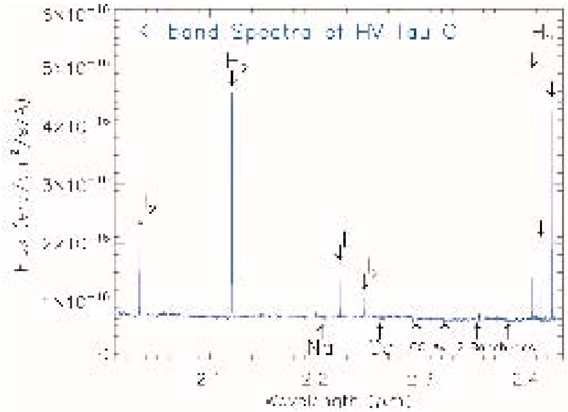
by Tracy Beck &
Peter McGregor

NIFS
Sees First Light

NIFS being installed on Gemini North in early October 2005. Jan van Harmelen (ANU) is in foreground and Chris Carter (Gemini) is behind the instrument. Photo K. Pu'uohau-Pummill

The Near-Infrared Integral Field Spectrograph (NIFS) first observed the night sky over Mauna Kea during the early evening hours of October 18, 2005. A tremendous team effort by staff from the Gemini Observatory and the Australian National University (ANU) allowed first light with NIFS to occur before the end of evening twilight. The first star observed was centered within 0.2 arcseconds of the center of the NIFS field. This is a remarkable feat considering the fact that the NIFS IFU has a very small field of view.

NIFS is an image-slicing integral field unit built by the Research School of Astronomy and Astrophysics at the ANU, and is designed to be used exclusively with the Gemini North facility ALTAIR adaptive optics system. It delivers R ~ 5000 imaging spectra over a small 3 x 3 arcsecond field of view on the sky. The NIFS delivery to Gemini North comes just two and a half years after its predecessor was destroyed in the fires that raged through Canberra, Australia in January 2003.

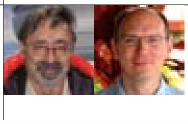


First light NIFS K-band spectrum of the star HV Tau C

NIFS will be a powerful new tool to study the structure and kinematics of a wide range of astronomical targets, from the search for black holes in the center of galaxies to the ability to resolve structures on the surfaces of planets in our own solar system. The on-sky commissioning has progressed smoothly and is scheduled to be completed by mid-November, 2005. A Gemini community call for System Verification (SV) proposals with NIFS will be released in early December 2005 and SV observations will be carried out during scheduled time in January 2006.

Tracy Beck is a Science Fellow at Gemini North and can be reached at: tbeck@gemini.edu

Peter McGregor is the NIFS Project Scientist for Gemini and can be reached at Australia's Research School of Astronomy and Astrophysics at: peter@mso.anu.edu.au



by Jean-René Roy
& Scott Fisher

Recent Science Highlights

The Origin of Titan's Methane Atmosphere

Over 82 separate nights the Gemini North and Keck I telescopes mapped the clouds of Saturn's largest moon Titan during a coordinated monitoring imaging campaign during the moon's 2003-2004 and 2004-2005 apparitions. Henry G. Roe (CalTech) and a team including Gemini's Chad Trujillo, found that Titan's recently discovered short-lived mid-latitudes clouds cluster near 350 degrees west longitude and 40 degrees south latitude. They can last as long as one Earth day before dissipating. The observations point to a localized surface event such as geysering or cryovolcanism as a possible trigger for the formation of these clouds.

The team used adaptive optics systems on both Mauna Kea telescopes to map Titan's surface and atmospheric features at a spatial resolution of about 300 kilometers as shown in Figure 1 inset images. At Gemini North, the nightly monitoring of Titan with ALTAIR, (the facility adaptive optics system), was done as a test for multi-instrument queue observing, a mode that is now fully implemented.

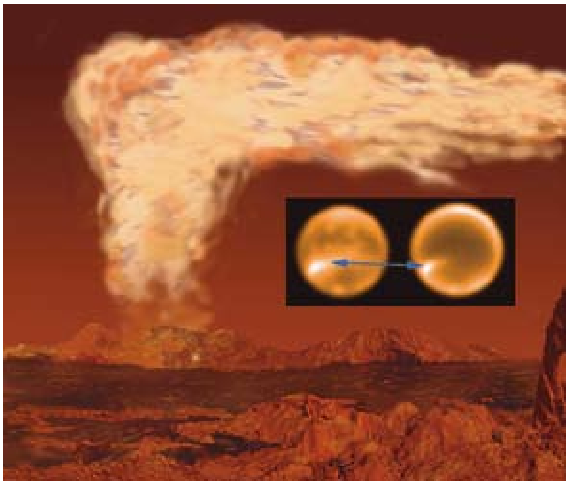
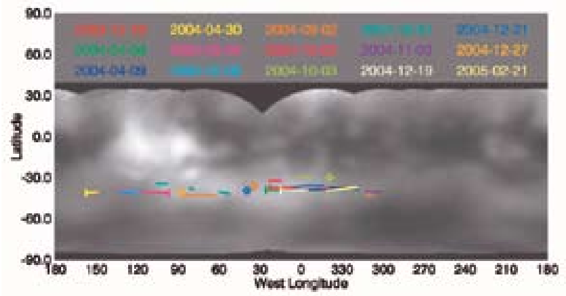


Figure 1. Artist's conception of methane cryovolcano/geyser on Titan with Gemini ALTAIR adaptive optics images (inset) with cloud and surface features indicated by blue arrow. Gemini artwork by Jon Lomberg.

The origin and survival of the methane atmosphere on Titan has been a long-standing unsolved problem. The imaging by Huygens of surface channels in January 2005 revealed that this moon has an active methane hydrological cycle. Because photochemical processes should destroy methane on a time scale of ten to a hundred million years, the presence of methane on Titan indicates that there is a replenishing source on Titan's surface. The Gemini and Keck observations have likely found one such currently active source, betrayed by the formation of short-lived clouds.

Titan's mid-latitude clouds are nearly always extended in longitude and often appear in groupings of several clouds along a line nearly parallel longitudinally (Figure 2). The thermal structure of most of Titan's troposphere is controlled by radiative rather than convective

Figure 2. Locations of all mid-latitude clouds observed to date, shown over a surface map of Titan created from the Keck imagery. Diamonds refer to clouds smaller than the 300-kilometer spatial resolution.



processes which makes the atmosphere prone to instabilities below about 15 kilometers. This means that simply raising the humidity to 100% by injecting methane from a source at Titan's surface will lead to convective clouds. Injection of methane into the atmosphere by geysers or during cryovolcanic activity appears the most plausible triggering mechanism for the mid-latitude clouds observed. This process must be sporadic and localized to be consistent with the Gemini/Keck observations. The possible driving mechanism for such geologic activity could be the tides produced on Titan due to its eccentric orbit around Saturn.

The Supernova Legacy Survey Team Presents Its First Year of Gemini Results

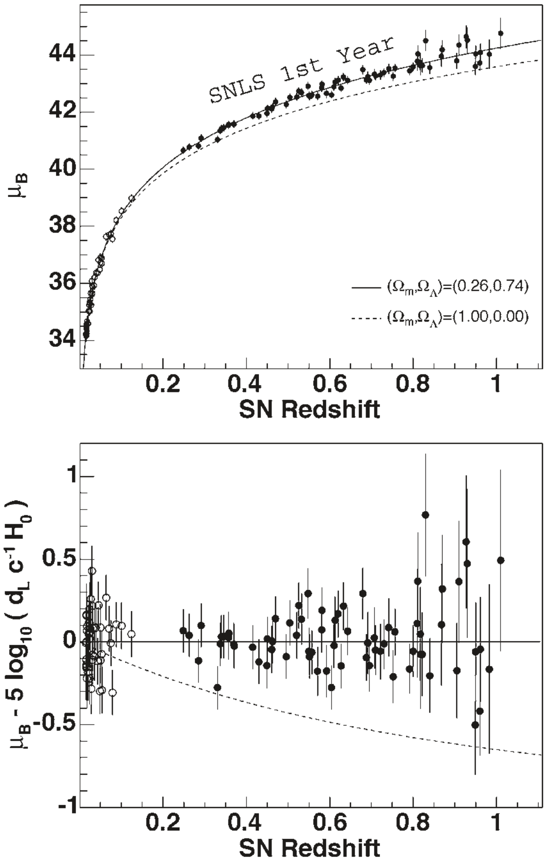
Two large North American and European teams led by D.A. Howell (University of Toronto) and another by P. Astier (LPNHU, Centre National de la Recherche Scientifique (CNRS) and Universités Paris VI & VII) published the first set of spectra of high-redshift supernovae based on the Supernova Legacy Survey (SNLS) conducted with MegaPrime/MegaCam at the Canada-France-Hawaii Telescope. A large fraction of the supernova spectra have been obtained with the Gemini telescopes.

SNLS uses Type Ia supernovae as standard candles to study the acceleration of the universe. Programs are underway at Gemini and other large telescopes to characterize the dark energy driving this expansion by measuring its average equation of state, w=p/ρ. Dark energy is a new, unaccounted-for form of energy that opposes the self-attraction of matter (due to gravity) and accelerates the expansion of the universe. The equation of state defines the time dependence of the dark energy density. The goal of the SNLS is to obtain 700 well-observed Type Ia supernovae in the redshift range between 0.2 and 0.9 to increase the statistical significance for values of w.

The SNLS uses the Canada-France-Hawaii Telescope Legacy Survey imaging data for supernova discoveries and light curves. Over the course of a year, four fields are imaged every four days. New supernova candidates are discovered throughout the months as light curves are being built. Then, 8- and 10-meter class telescopes are used to do follow-up spectroscopy to confirm the identity of the supernovae and determine their redshift. Gemini North and South generally observe the faintest, highest redshift ($z>0.6$), where the unique nod-and-shuffle mode on the Gemini Multi-object Spectrograph (GMOS) provides a reduction of sky line residuals in the red part of the spectrum. Typically, candidates are sent to Gemini only if they are in the magnitude range between 23 and 24.5. Lower-redshift candidates are generally observed with the Very Large Telescope, Keck and Subaru Observatories.

Observations for the SNLS are executed in queue mode at Gemini, which allows astronomers to specify the desired observing conditions. Spectra are obtained with image quality better than 0.75 arcseconds and photometric conditions. Gemini data are usually delivered within a day or two of

Figure 3. A Hubble diagram of Supernova Legacy Survey and nearby Type Ia supernovae, with various cosmologies superimposed. Bottom plot shows the residuals for the best fit to a flat Λ cosmology.



the observations, and the team performs "real-time" reduction of the spectra. Ninety percent of Type Ia supernovae were observed within 0.5 magnitude of maximum light, and over half of them were observed within 0.1 magnitude of maximum brightness. It is clear that the flexibility provided by queue observing plays a significant role in optimizing the efficiency of the spectroscopic classification of targets in the SNLS.

In the first year, 71% of candidates have been confirmed as Type Ia supernovae, compared to 54% using the methods of previous surveys. The median redshift of the Gemini Ia supernovae is z = 0.81. Over the five-year course of the survey, using well-proven selection methods tested on Gemini, the team hopes to add ~170 more confirmed Type Ia supernovae than would have been possible using previous methods, and aims to spectroscopically observe ~1,000 supernova candidates during the whole SNLS project.

This is a large, on-going program and cosmological fits to the first-year SNLS Hubble diagram give the following results: $\Omega_M = 0.263 \pm 0.042$ for a flat ΛCDM model; and $w = -1.023 \pm 0.090$ for a flat cosmology with the constant equation of state w, when combined with the constraint from the recent Sloan Digital Sky Survey measurement of baryonic acoustic oscillations. After only two years of operation, the SNLS has already demonstrated its advantages over all previous ground-based supernova surveys.

Metal-Rich White Dwarf GD 362 is an Asteroid Cruncher

Recent deep imaging with the mid-infrared imagers and spectrographs T-ReCS (Gemini South) and MICHELLE (Gemini North) have significantly advanced our understanding of the surrounding planetary systems of young and old stars. For example, we reported on the superb imaging of the protoplanetary disk around the young (ten million-year-old) star Beta Pictoris in the June 2005 issue of *GeminiFocus* (pages. 11-13). Now some tantalizing planetary events have been found happening around an ancient (five billion years-old) white dwarf star. The star GD 362 is located about 25 parsecs (~80 light-years) away.

For a long time GD 362, has been one of the two most metal-rich white dwarf stars known. While normal white dwarfs do not show any metals, there are exceptions. Many mechanisms have been proposed to explain metal abundance anomalies in some white dwarfs, including the scooping of metals from interstellar clouds as these stars move around the center of our galaxy, but no scenario has yet been found that really works. In 2003, Mike Jura (UCLA) proposed that metals could be accreting from the disintegration of old asteroids getting too close to their dead parent star. Using MICHELLE on Gemini North, a team lead by Eric Becklin (UCLA) and including Gemini astronomers Inseok Song and Jay Farihi, detected a relatively strong infrared excess associated with GD 362 as show in Figure 4. These data provide very strong evidence in support of Jura's model.

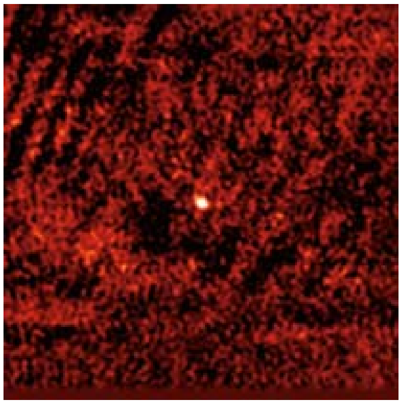


Figure 4. Mid-infrared MICHELLE image of GD 362 showing the mid-infrared emission measured at 1.4 ± 0.3 milli-Janskys at 11.3 microns. The emission would be due to an asteroid straying within the tidal radius of GD 362 and breaking apart under tidal forces. The cascade of self-collisions creates a dust disk.

The infrared excess is likely produced by circumstellar dust close to the white dwarf. The Gemini results strengthen the argument that photospheric metals in white dwarfs may be the result of accretion of circumstellar matter. In the case of GD 362, the most likely possible origin is an asteroid venturing close enough (within the star's Roche radius) to the white dwarf and being tidally disrupted. The debris from ongoing collision events would form a disk, in a process analogous to scenarios theorized for the formation of the rings around Saturn and other planets in our solar system. Over time, this dust falls on the white dwarf and pollutes its atmosphere, making it appear unexpectedly metal-rich.

V2116 Ophiuchi, The Freakiest Pair of Stars

The star V2116 in the constellation Ophiuchus is unique among currently known so-called symbiotic stars, those stellar pairs that show a combination of spectral signatures belonging to different types of stars. This is not surprising because the pair is a late-type M giant star with a neutron star as a companion. The object is also remarkable for being a very bright, hard x-ray source. The companion is actually a slow pulsar with a rotational period of two minutes. This object has the strongest magnetic field ($\sim 3 \times 10^{13}$ Gauss) ever measured for an astronomical object.

Using the near-infrared high resolution spectrograph Phoenix on Gemini South and three other telescopes, Ken Hinkle of the National Optical Astronomy Observatories (NOAO) led a team that studied the least-strange object of this intriguing pair—the late-type M star. The team determined the dynamical properties of the pair and derived the elemental abundances of the red giant, finding it to have near solar abundances. They found that the orbital period of the system is 1,161 days, by far the longest of any known x-ray binary, and determined a mass of 1.22 M_{Sun} for the giant. This makes it the less-massive member of the pair. From the derived giant radius of 103 solar radii, the M giant is not currently filling its Roche lobe. Hence, the mass transfer of the red giant to the neutron star is through a stellar wind, rather than Roche-lobe overflow.

The existence of x-ray binaries like V2116 Oph is proof that a binary system can survive a supernova explosion. In the case of V2116 Oph, the current M giant star is the least massive component. In the original low-mass binary, one member became a white dwarf, and then underwent mass accretion from the lower-mass companion. This resulted in a supernova explosion and subsequent collapse to the current neutron star state. With its very long orbital period, near solar abundances, its runaway nature, and the extraordinary presence of a neutron star in a multiple years-long orbit, V2116 Oph is quite unique in the Milky Way.

Proplyds Aplenty in a Mid-Infrared Mosaic of the Orion Nebula

The Orion Nebula has long been a favorite target for telescopes both large and small. The extreme youth of the stars within the nebula and its relatively close distance (about 460 parsecs or 1,500 light-years) make it an archetypal source for studying star formation across the entire stellar mass spectrum. Recently a team led by Nathan Smith (University of Colorado) used T-ReCS on Gemini South to study this complex by constructing a new 11.7-micron mosaic of the central nebula region. The diffraction-limited map (fwhm ~0.35 arcseconds) covers an area of 2.7 × 1.6 arcminutes, which includes the BN/KL region, the Trapezium, and the Orion Molecular Cloud-1 (OMC-1) South (Figure 5).

Excluding the BN/KL complex there are 91 thermal-infrared point sources detected within the mosaic. Of these point sources 27 are known proplyds (protoplanetary disks); that is, they are objects with "silhouette disks" associated with them in optical Hubble Space Telescope images. However, more than 30 of the 91 sources are "naked" stars that show no extended structure in optical light. The detection of mid-infrared emission from these naked stars is intriguing since it means that they do have circumstellar dust disks associated with them and those disks must be comparable in size to the solar system. In total the fraction of all visible sources in the mosaic region with 11.7-micron excess emission, from both proplyds and unresolved disks, is close to 50%. This work also shows that proplyds and naked stars with excess infrared emission are not distributed randomly throughout the nebula. Indeed, there is a strong anti-correlation in their spatial distribution with proplyds clustered close to the source Θ^1 Ori C and the other sources found preferentially farther away. This suggests that the proplyds trace the youngest (half-million-year-old) age group in the region, near the Trapezium, and that the other infrared excess stars are members of the older (between one and two million years old) Orion Nebula Cluster.

There is also a large amount of complex extended emission detected within the mosaic including limb-brightened dust arcs near all of the proplyds within 30 arcseconds of Θ^1 Ori C. The data also reveal that the star Θ^1 Ori D is associated with the brightest arc in the Ney-Allen Nebula. The team proposes that this is because Θ^1 Ori D is the closest member of the Trapezium to the background cloud. The last variety of extended structure present in the mosaic is thermal emission from dust associated with Herbig-Haro jets. This is the first detection of mid-infrared continuum emission from dust within the body of a collimated Herbig-Haro jet or bow shock.

Another unique aspect of this work is the way the mosaic was created. All imaging observations made with T-ReCS are obtained by chopping the secondary mirror between the "on-source" position and an "off-source" position 15 arcseconds away. These two frames are then subtracted from each other to remove the overwhelming sky background inherent in ground-based mid-infrared imaging. In the case when a source is larger than the 15 arcsecond chop throw, it may introduce spurious structure during the subtraction if there is emission present in the off-source frame (i.e. the reference frame is not blank). To circumvent this issue during the creation of the Orion mosaic, the science team used a clever "step scan" technique. The observers took a series of adjacent images starting on blank sky well away from the emission of the nebula and then offset the telescope exactly 15 arcseconds between each step. Thus the on-source frame of one pointing was (in effect) the off-source frame of its neighbor. Correctly subtracting the frames as they scanned across the nebula let the team effectively remove any beam contamination, since they could all be bootstrapped back to the original pointing (which was well off the nebula). While there are some issues with this technique (not guiding in the off-source frames, for example) this result shows that for bright extended sources we can produce high resolution mosaics of large regions of the sky.

Jean-René Roy is the Acting Director of the Gemini Observatory and can be reached at: jrroy@gemini.edu

Scott Fisher is a Science Fellow at Gemini North and can be reached at: sfisher@gemini.edu

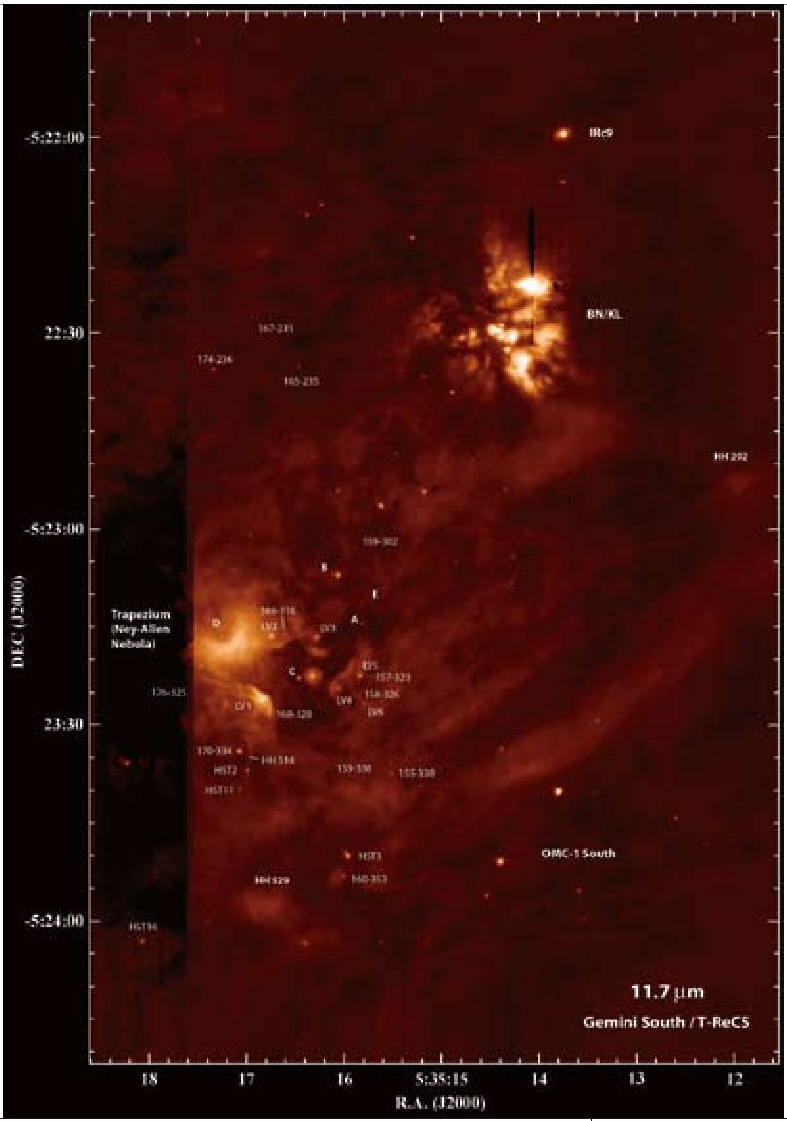
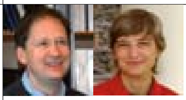


Figure 5.
T-ReCS mosaic of the inner region of the Orion Nebula complex at 11.7 microns. Labels identify proplyds seen in Hubble Space Telescope images as well as major features of the nebula. The region along the left side of the image is an artifact of "over-subtraction" of bright diffuse emission in the reference beam.



by Phil Puxley &
Inger Jørgensen

Gemini by Moonlight / P. Michaud

Observing Efficiency at Gemini Observatory

Optimizing observing productivity is achieved by maximizing the time collecting useful photons, while ensuring that the "best" program is being observed for the available sky conditions. This article examines the first of these two issues, the observing efficiency. A companion article (beginning on page 58) examines queue planning and program completion at Gemini.

Since August 2004 we have been routinely monitoring the "*shutter-open efficiency*" of every usable science night on both Gemini telescopes. This database of more than 400 data points allows various aspects of the observatory science operations to be examined and for us to draw some robust conclusions.

The *shutter-open efficiency* is defined as the sum of all science exposures plus calibrations obtained between evening and morning nautical twilight divided by the total usable time available. For Gemini's optical and near-infrared instruments (GMOS-N and S, GNIRS, NIRI/ALTAIR and Pheonix) the science and calibration times are obtained directly from the data frame FITS header exposure time and coaddition keywords. For mid-infrared instruments (MICHELLE and T-ReCS) each data set is usually the result of a sequence of exposures taken at the two secondary mirror (chop) and telescope pointing (nod) positions required for accurate background cancellation. The mid-infrared efficiencies would need to be divided by a factor of 3.7 to provide on-source integration time in the absence of chop/nod overheads. (Recently, higher resolution mid-infrared spectroscopic observations have been taken in the "stare-and-nod" mode, which has a smaller correction factor, but this affects relatively few observations and is ignored in this analysis). The usable time is simply the time between nautical twilights minus any time lost due to weather or technical faults. Hence, the efficiency reflects factors that include: overheads resulting from slewing and acquiring a new target, reconfiguring the telescope and instrument, offsetting the telescope and re-acquiring the guide star during observing sequences, detector readout, and changing to the next queue observation.

Table 1 shows the average efficiency for nights with a single instrument during which the observing conditions were recorded as good (e.g. photometric and good seeing) or stable, but not good (e.g. stable through clouds and/or stable with poor seeing), this represents roughly half of the total usable nights. This table also indicates the highest recorded efficiency value for each instrument, but it should be noted that this is subject to bias because the number of nights is not equivalent for all instruments. Nonetheless it can be seen that the peak *shutter-open efficiencies* typically exceed 80% and the average values are in the range of 60-70%. These values are comparable for all instruments on both telescopes. As might be expected, the two GMOS instruments have among the highest efficiency values because individual exposure times tend to be longer for optical observations. The results in table 1 compare very favorably with those reported elsewhere for other large telescopes.

The facility near-infrared imager (NIRI) can be used independently, in the direct f/16 telescope beam, or fed by the ALTAIR adaptive optics (AO) system. The measured efficiencies have maxima of 78.0% (NIRI) and 80.7% (NIRI/ALTAIR), and averages of 61.4 ± 8.5% (NIRI) and 60.7 ± 8.6% (NIRI/ALTAIR), and are therefore statistically indistinguishable. This demonstrates the tight integration of the AO sub-system with the overall instrument and telescope sequence control software that is evident (e.g. Table 1) for all Gemini instruments. It is possible that the NIRI and NIRI/ALTAIR efficiency distributions might be statistically different in that NIRI/ALTAIR has a distribution tail extending to lower values which could result from the NIRI programs preferentially including more spectroscopic observations (with longer exposures). However, the relatively few standalone NIRI nights compared with frequent mixed NIRI and NIRI/ALTAIR means that this is not a very robust result.

Essentially every night on both telescopes is scheduled as a possible multi-instrument queue night. This means that more than one instrument might be used depending on the detailed queue plan for that night and the actual observing conditions. Table 2 shows the efficiencies obtained on nights at Gemini North when either GMOS or NIRI (including NIRI/ALTAIR) were used exclusively (due either to the plan or weather) compared with nights when both GMOS and NIRI + NIRI/ALTAIR were used. Although the individual numbers of nights are small (there were only two cases where GMOS and NIRI (with and without ALTAIR) were used), taken together the results show that the multi-instrument night efficiencies are intermediate between those for GMOS and NIRI + NIRI/ALTAIR individually. This data

Instruments	Shutter-open Efficiency (%)	
	Max.	Average
GMOS-North	87.5%	70.2%
NIRI	78.0%	61.4%
NIRI/ALTAIR	80.7%	60.7%
MICHELLE	87.8%	58.7%
GMOS-South	87.1%	66.6%
GNIRS	83.8%	60.0%
T-ReCS	80.7%	69.6%
Phoenix	77.9%	60.4%

Table 1. Maximum and average observing efficiencies for single-instrument nights.

Instruments	Shutter-open Efficiency (%)	
	Average	
	Weather stable or good	#nights
GMOS-North	70.2%	35
NIRI	61.4%	5
NIRI/ALTAIR	60.7%	19
GMOS-N/NIRI	64.6%	20
GMOS-N/NIRI/ALTAIR	57.9%	5

Table 2. Efficiencies of GMOS-North, NIRI and NIRI/ALTAIR independently and when combined on multi-instrument queue nights.

indicates that multi-instrument queue observing is as efficient as single-instrument observing and there appear to be no significant overheads for swapping instruments or additional calibrations. In addition, multi-instrument observing has significant advantages for optimally exploiting the existing observing conditions and achieving high queue program completion rates (see the accompanying article in this issue starting on page. 58).

Figure 1 shows the maximum and average good/stable condition efficiencies discussed above as well as the efficiencies obtained under less-stable observing conditions. A detailed statistical analysis (2-sample Kolmogorov-Smirnov) of the distributions underlying these averages is revealing. Considering the varying sample sizes, it shows that there is no conclusive evidence that the efficiency under less-stable conditions is any worse overall than under good conditions. Indeed, for both GMOS instruments, NIRI and NIRI/ALTAIR the nights of maximum efficiency were recorded as having less stable (e.g. variable seeing and/or cloud cover) conditions. Hence the queue planning appears to be very effective at producing the necessary contingency plans that allow the observer to use the telescope at maximum efficiency. Under the poorest usable conditions (occurring 10-15% of the time) the efficiency is seen to be down uniformly by about 20% reflecting the difficulty, even with good queue planning, of chasing holes in clouds or brief periods of reasonable image quality on highly variable nights.

One final question of interest remains, and that is: How does the queue observing efficiency compare with classical (visiting) observing? Unfortunately the relatively few classically-scheduled nights to date at Gemini do not allow us to draw firm conclusions. However, it appears that the efficiency under good conditions is indistinguishable between the two observing modes, although with unstable conditions the classical efficiency is likely to be less. This can be understood if the visiting observers are well-trained and able to stick to their planned programs when conditions are favorable. But when conditions are variable, a classical observer will lack the range of backup observations, (and experience with other available instruments), to make the most of the circumstances. We caution however that these comparisons are complex and subject to several possible biases. For example many classical programs are allocated time in that mode because they are less sensitive to weather. It is also important to recognize that shutter-open efficiency is not necessarily the same as scientific productivity.

Finally, we turn to the issue of how the time not collecting photons (the "shutter-not-open" time) is used. This part of the analysis is very

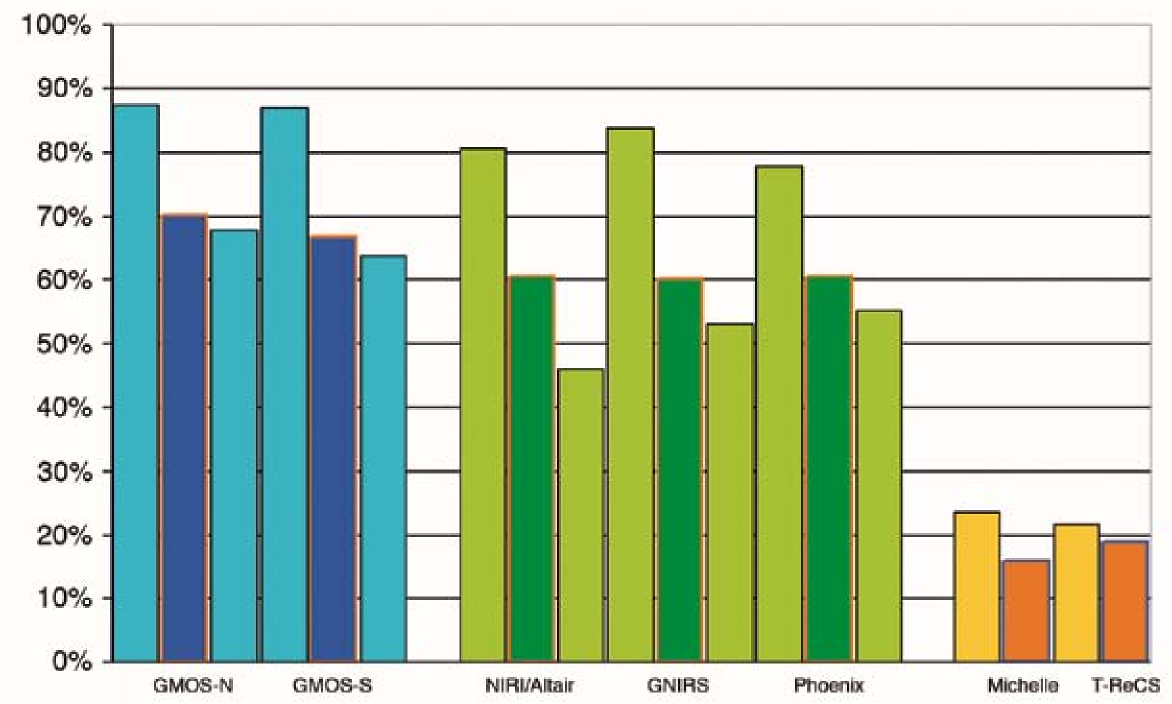


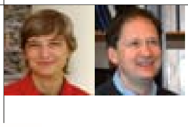
Figure 1.
For each optical (blue) and near-infrared (green) instrument there are three columns showing the single-night observing efficiency: (leftmost) maximum, (center and highlighted) average under good or stable observing conditions, (rightmost) average under less stable conditions. For the mid-infrared instruments only the maximum and good-condition averages are shown and the values have been corrected to on-source and for chop/nod overheads as is accepted convention.

much a work in progress. However, from a detailed monitoring campaign conducted with FLAMINGOS-I on Gemini South in October 2002, and from examination of semester 2003B GMOS-North target acquisitions, we can provide some initial results. The median time to slew and acquire a target is about six minutes for imaging modes (FLAMINGOS-I and GMOS), 15 minutes for long-slit spectroscopy, 28 minutes for long-slit spectroscopy of faint targets (i.e., distant supernovae), 14 minutes for MOS masks, and 19 minutes for Integral Field Unit spectroscopy. (The latter value has improved since these data were obtained). These values are comparable to those reported publicly for other telescopes e.g. for VLT (and FORS, VIMOS) in the P77 Call for Proposals.

Until the current semester we have not had the ability to easily explore the efficiency within a given night or for individual instrument modes, or how the shutter-not-open time was used. Recent work on the software infrastructure, in part to support automated time accounting, now captures time-stamped events for all telescope slews, telescope and instrument reconfigurations and data collection. This information will enable a more comprehensive examination of the issues addressed in this article as well as other issues. It will also allow us to prioritize the areas in which further improvements in efficiency can be made.

Phil Puxley is the Associate Director of Science Operations and the Head of Gemini South, he can be reached at: ppuxley@gemini.edu

Inger Jørgensen is the Head of Science Operations at Gemini North, she can be reached at: ijorgensen@gemini.edu



by Inger Jørgensen and
Phil Puxley

Gemini Queue Operations & Completion Rates

The execution of queue scheduling for observation programs using Gemini Observatory has undergone some significant changes recently. At the start of semester 2005A, Gemini North switched to the operation of queue nights in "multi-instrument queue" mode. This means that nights are no longer assigned to just one instrument. Instead, a combination of instruments, matched to the observing conditions, are used to execute programs in the queue. In June 2005, Gemini North began integrating telescope and instrument engineering tasks into the queue, mixing science programs with critical engineering tasks. At Gemini South the implementation of this approach was hampered by poor weather during semester 2005A but now Gemini South also operates primarily in a multi-instrument queue mode.

Science programs using the various facility instruments, as well as engineering tasks, all complement each other and are available for all usable observing conditions. Thus, by having all instruments available on any given night, we can ensure that highly-ranked science programs requiring the best possible conditions have a good chance of being completed. At the same time we are able to make effective use of poorer observing conditions.

Each night of queue observations is planned in advance by a "queue coordinator," and plans are made for all possible observing conditions. This ensures that the queue observer can smoothly change between plans in the case of changing observing conditions.

The content of the queue has also changed. With the support of the Gemini Board, a smaller allocation for the Bands 1 and 2 scientific rankings were implemented starting in semester 2005A. The current size of the bands is approximately 20%, 25% and 55% for Bands 1, 2, and 3, respectively. (Band 4 was eliminated beginning in 2005A). Starting with semester 2004A, the national Time Allocation Committees have had the freedom to recommend rollover status for Band 1 programs, so that they can stay in the queue for an additional two semesters after their initial scheduling if not completed.

The completion rates for high-ranked Gemini queue programs have improved as a consequence of these changes to queue planning and execution, as well as the queue content. Figure 1 shows the completion rates as of mid-September 2005 for all queue programs (Bands 1-3) at both telescopes since semester 2003A. Note that Target-of-Opportunity programs have been excluded from the figure because completion of these programs depends primarily on the principal investigators supplying sufficient targets, rather than the details of queue execution at the telescopes. Figure 2 shows the same information for the "mature" instruments Gemini Multi-Object Spectrograph (GMOS-North/South), and the Near-Infrared Imager (NIRI).

The completion rates in band 1 at Gemini North during the period 2003A to 2005A averaged 80%, while at Gemini South the average completion rates were 64%. If we assume that the observatory completes the incomplete programs with rollover status from 2004B and 2005A, those averages will change to 83% and 72%, respectively. But more important is the fact that the completion rates for band 1 programs in 2005A at both telescopes could exceed 90%, with a 100% completion rate for the mature instruments (GMOS-N, GMOS-S and NIRI).

Band 2 completion rates are significantly lower, with averages of 33% and 31% for Gemini North and Gemini South, respectively. The completion rates in Band 2 also appear to be quite instrument-specific. Prior to 2005A this may have been due to weather variations in the fixed observing blocks for a single instrument, and/or the maturity of the instrument. The most mature instrument, GMOS-N, has average completion rates in Band 2 of roughly 50%, while GMOS-S is reaching similar or higher completion rates for Band 2 in 2004B and 2005A. The rather low completion rate in 2005A for NIRI and NIRI/ALTAIR programs (10%) is due to mechanical problems with ALTAIR that made the instrument unavailable for large fractions of the semester. The completion rate for GMOS-N Band 2 programs in the same semester is above 60%.

The completion rates for band 3 are quite low—on average about 18%. A low completion rate for Band 3 programs is to be expected since the queue is overfilled once weather losses are taken into account. However, seen from the point of view of telescope science productivity, the important issue is whether we deliver complete data sets that enable the principal investigators to publish their results. The fraction of started programs that are also completed (the red bar on the figures) provides such a measure. Full queue planning for all instruments at Gemini North started in 2005A, and it is quite clear that it had a very large effect on how we spend the time used on Band 3 programs. In 2005A 80% of started programs in Band 3 were in fact completed, while only about

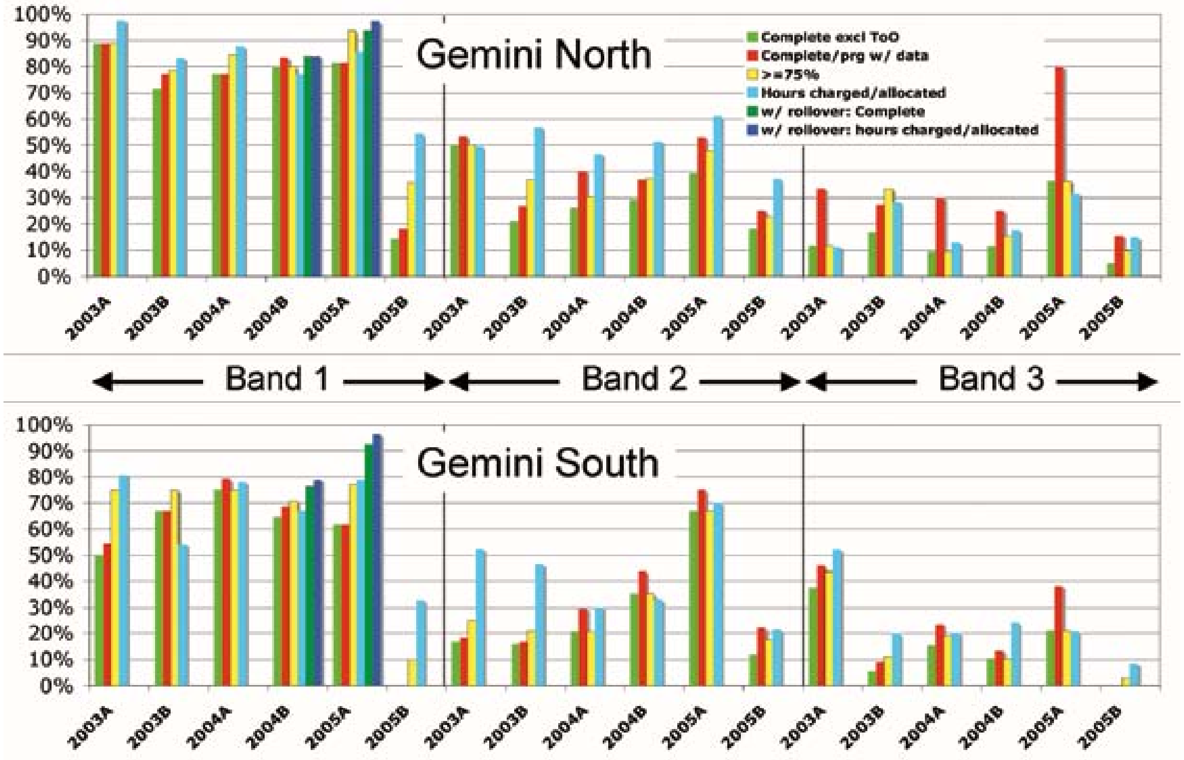


Figure 1. Completion rates as of mid-September 2005 for Gemini North and Gemini South. For semesters 2004B and 2005A the figure also shows the projected completion rates and charged time, under the assumption that all programs with rollover status will be completed.

30 % of the time allocated in Band 3 was charged. Similar, but smaller, effects can be seen for GMOS-N in 2003A and 2004A. GMOS-N is the only instrument for which all queue nights have always been planned by a queue coordinator.

Based on the recent changes and improvements to the queue execution, as well as the change of band sizes, we have put forward a set of goals for queue program completion to be reached by the end of semester 2006A. These goals apply to all facility instruments at both telescopes and are stated as follows:

Band 1. 90 % or more of the queue programs are completed, in the sense that 100 % of their requested data have been acquired or all their allocated time has been used. For a given semester the final completion rates for Band 1 are calculated after the rollover status has expired.

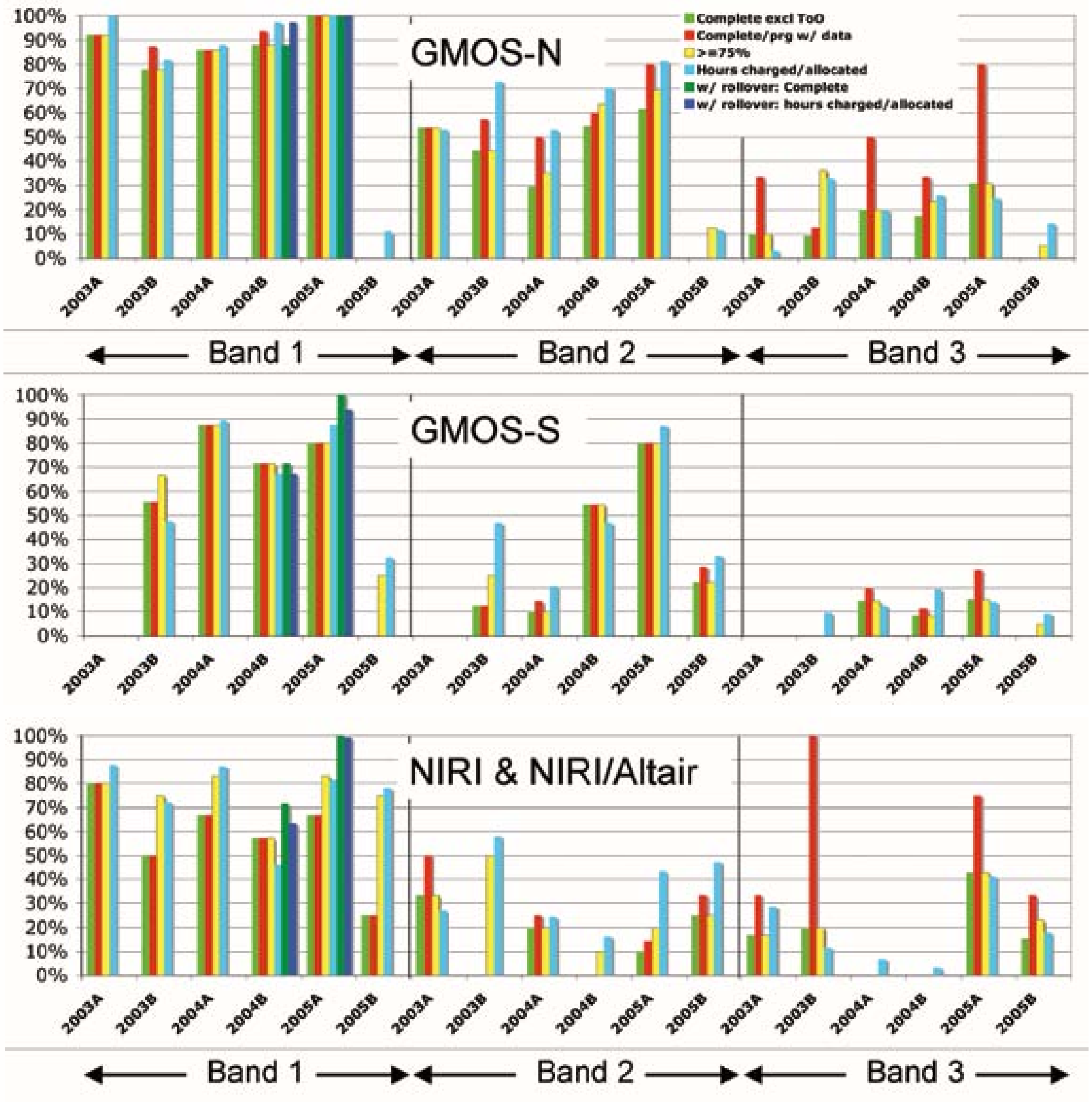
Band 2. 75 % or more of the queue programs are completed.

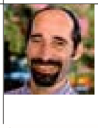
Band 2 and 3. 80 % of started queue programs should have at least 75 % of the requested data obtained. This excludes programs for which the only data obtained was GMOS pre-imaging.

Inger Jørgensen is the Head of Science Operations at Gemini North, she can be reached at: ijorgensen@gemini.edu

Phil Puxley is the Associate Director of Science Operations and the Head of Gemini South, he can be reached at: ppuxley@gemini.edu

Figure 2.
Same information as Figure 1 for only the "mature" instruments GMOS-N, GMOS-S, and NIRI.





by François Rigaut

ALTAIR Upgrades Report

There has been a flurry of activity on and around the ALTAIR adaptive optics (AO) system during 2005A. First and foremost, we have been commissioning the laser and launch systems (described on page 34 of the June 2005 issue of *GeminiFocus*), and upgraded ALTAIR to work in Laser Guide Star (LGS) mode. This effort continued into 2005B with two runs, in August and September. ALTAIR's upgrade included a tip-tilt/focus wavefront sensor system, designed at the Herzberg Institute of Astrophysics (HIA) in Canada, and installed by Gemini personnel. All of the work to date has concentrated on commissioning the many new functions necessary for LGS AO. We have proven that we can efficiently acquire both the laser and tip-tilt natural guide star (NGS), and we have closed many loops (LGS, tip-tilt NGS and various offloads) for hours at a time.

A couple of issues prevented us from transitioning into performance and science commissioning. The main issue is related to the laser launch telescope (LLT) primary mirror. Due to a thermal design error in the mirror mount, the LLT primary mirror suffers from a heavy optical aberration, resulting in poor LGS spot size, typically 2 arcseconds. A new LLT primary mirror mount has been redesigned and built, and the mirror is being re-polished. A January 2006 delivery is expected.

The laser has generally been behaving as expected, requiring acceptable preparation and maintenance overheads, and delivering about an equivalent V = 9.5-magnitude star under average conditions. One issue currently being addressed is related to the early aging of the non-linear (frequency-converting) crystal, which is apparently being damaged by the high-power beam. Spare

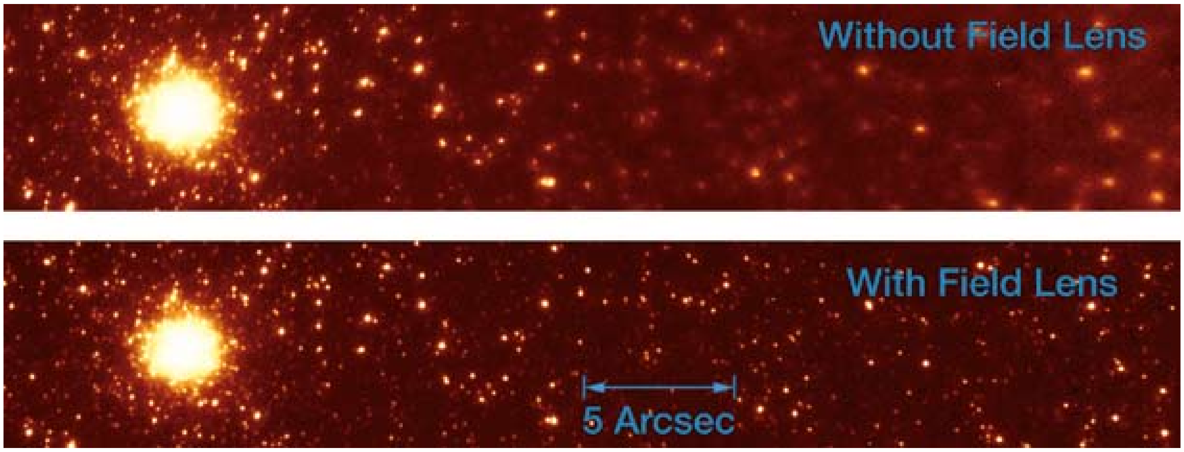


Figure 1. These images show the core and central region of M33 in the H band with ALTAIR. Top: field lens out. Bottom: field lens in.

crystals are being tested and a National Science Foundation-funded program is also underway to develop newer and more robust *Periodically Poled Stoichiometric* $LiTaO_3$ (PPSLT) crystals with higher conversion efficiencies.

As a result of these two issues, the ALTAIR LGS commissioning is currently on hold, and will be resumed once we receive the refigured LLT primary mirror.

Field Lens

In parallel with the LGS upgrades, and following a recommendation from the Gemini AO Science Working Group and the Gemini Science Committee, a field lens was designed, installed and tested in ALTAIR. This field lens addresses the issue of the mis-conjugation of the ALTAIR deformable mirror. ALTAIR was designed under the assumption that the main turbulence layer was 6.5 kilometers above the Mauna Kea summit. This did not turn out to be the case. Indications from recent turbulence monitoring runs show that about 60% of the turbulence is at ground level. Several solutions were investigated to mitigate this problem. We settled for the retrofit of a field lens (at the ALTAIR input focus) that optically re-conjugates the ALTAIR deformable mirror to ground level. This configuration has been tested several times since its installation in August 2005 to probe as many different atmospheric circumstances as possible.

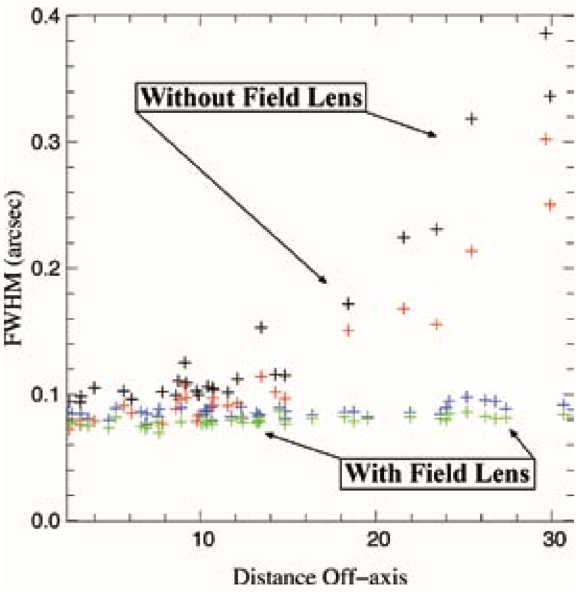


Figure 2. Radial and tangential full-width-half-maximum (fwhm) versus off-axis distance (in arcseconds) based on H band images of M33 shown in Figure 1. Black and red crosses are radial and tangential fwhm measurements (respectively) without the field lens and blue and green crosses are radial and tangential fwhm measurements (respectively) with the field lens engaged.

In all cases, the field lens results in larger isoplanatic angles, or better off-axis corrected image quality. Results ranged from marginal to absolutely stunning. Figure 1 shows an example of very good image improvement, obtained using the core and central region of M33 as a target on August 18, 2005. The field of view is 38 × 6.5 arcseconds. The loop was locked on the core of M33 (about R = 14.5). The top panel shows an H band image in the regular mode of ALTAIR, i.e. without the field lens. The bottom panel shows the same field and wavelength under approximately the same conditions (both images were taken within a period of 30 minutes of each other), but with the field lens inserted. As seen in Figure 2, the difference is striking. We acknowledge that this was a particularly favorable circumstance, as most of the turbulence was at or close to the ground. However, this does not seem to be exceptional, as we have done two other sets of images that showed similar improvements.

The field lens does come with some limitations. Three potential detrimental effects were tested during engineering/commissioning: 1) ghosts, 2) throughput loss, and 3) pupil/cold stop mismatch. We did not detect any ghosts, even at large contrast. The lens is uncoated (this is a temporary silica lens, that will soon be replaced by a CaF_2 (fluorite) lens), and we measured an expected 8% throughput loss. The pupil/instrument cold-stop mismatch is a result of the nature of the field lens. However, we did not detect significant background increase.

Finally, we are also on track to commission the ALTAIR Field Lens + NIRI in F/14 mode. Figure 4 shows an image of the planetary nebula M2-9 obtained in early September in this mode. The guide star (the central star of the nebula) was relatively faint, hence the correction performance is only moderate (about 100 milli-arcseconds full-width-half-maximum), but the image quality is remarkably uniform over the entire field of view.

We expect that ALTAIR/NIRI (f/14 & f/32) with the CaF_2 field lens will be offered for regular scientific use starting in semester 2006A.

François Rigaut is the Senior Scientist for Adaptive Optics at the Gemini Observatory and can be reached at: frigaut@gemini.edu

Figure 3. Color mosaic composite of J, H and K-band images of M33 core region using NIRI and ALTAIR with field lens at f/32. Note the uniformity of stellar images to the edge despite wide field (for adaptive optics) of 39×21 arcseconds.

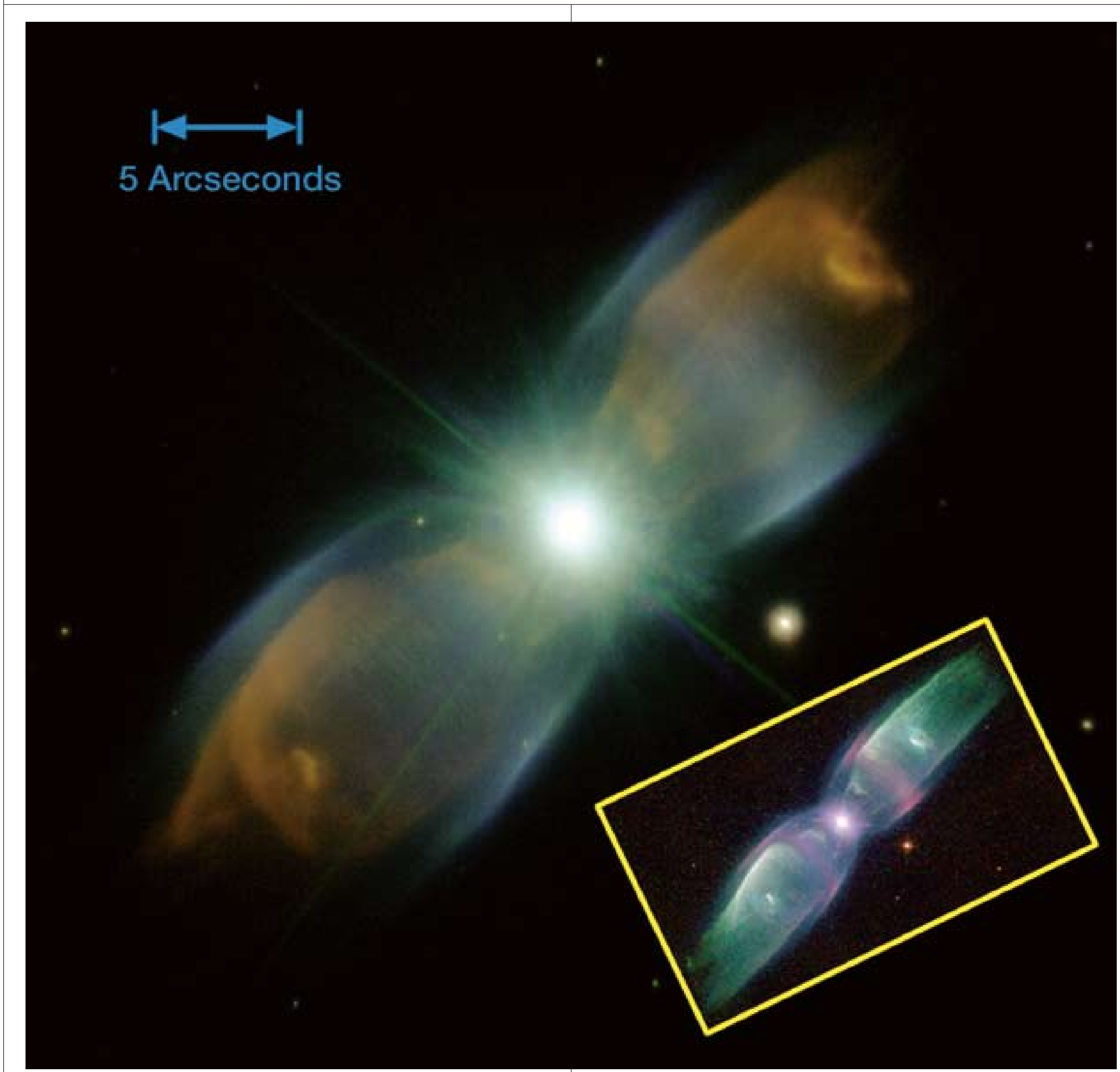


Figure 4. Color composite (center) of the planetary nebula M2-9 using ALTAIR adaptive optics images in the following bands: K' (green), K+H2=1-0 (violet) and FeII (orange). Field of view is 38.5×42.5 arcseconds with NIRI at f/14. Inset: HST WFPC2 optical image (1997).

by Carolyn Collins Petersen

From Astronomy to Zeus

Gemini Observatory's science program relies on a huge pipeline of data that begins at the telescope and makes its way out to the world through a complex set of nested computers and networks. The observatory counts on programmers and information technology experts to deliver data to the right places at the right times. This includes everything from keeping the networks running to maintaining an active World Wide Web presence for the observatory.

Jason Kalawe is the man behind the Gemini web portal, and beyond that, the go-to person for server administration and much more. He is part of the observatory's Information Systems Group and his official title is Web Master. However, as he likes to point out, his job goes far beyond keeping Gemini's Web page up and running.

"There are seven web servers that I administer," he says. "Half of my time is spent working on press releases/announcements (working with graphics and styling the pages). The other half is spent helping users with issues they have with the various websites and web servers." Those issues can be anything from updating web pages for the Gemini internal web site to more obscure tasks like compiling PERL modules for development users.

Jason also spends a great deal of time dealing with issues that are not always obvious to the computer users who depend on Gemini's networks and portals for their information and work. Most of this is administrative work, and often involves maintaining applications compiled from source code and utilizing programs like MYSQL, PHP, and PERL.

"The most enjoyable part of my job is spending time working on projects that require scripting," he said. "I have written all of the website reporting/status PERL scripts, a script to maintain our new podcast RSS feed, and a bunch of other things for the external website too numerous to list."

When he came to Gemini from the *Hawai'i Tribune-Herald* newspaper (where he worked as a layout artist after leaving college), Jason expected to continue doing design and graphics for the observatory. "I was in for a huge shock," he said. "The web servers ran Zeus web server software, not the Apache software that I was experienced with. The operating systems on all the web servers were Solaris."

Although Jason had only used Linux machines previously, he adapted to the observatory's needs quickly. "Since working here, I've done way more server administration than graphic design," he said. "I particularly enjoy working with Zeus and Solaris, and I'm very impressed at how open Gemini is at adapting and utilizing emerging technologies."

As a programmer, Jason likes to tinker with an old Sun Ultra 5 at home, and regularly contributes to several open source projects outside of his Gemini work. "I contribute code to an iCal calendering project and maintain a Mac OS X widget which interfaces with python for the Xbox Media Center Project," he said.

The majority of his home life is taken up with renovating the house he and his wife Jessie bought before starting his career at Gemini. When they're not busy with drywall, Jason and Jessie do manage to pursue some outside interests. Jessie manages her parents' woodworking business and dances the hula weekly. They have two daughters: Lahapa, who at the age of five is busy in her Hawaiian language immersion elementary school and also dances hula, and three-year-old Lehiwa, whose current interests Jason describes wryly as "slapping people in the face and strangling the cat."

In his remaining spare time, Jason enjoys cooking Asian food, an interest he traces to his grandfather. "My grandfather was a well regarded Chinese chef," Jason said. "He died when I was 8, so I didn't have a chance to know him that well. I cook as way to connect with him."

Jason also collects current vinyl records, but he doesn't own a turntable. So, how does he listen to the music and what does he do with the albums? "I download a lot of music," he said. "However, instead of buying CDs of the albums that I download, I purchase vinyl copies. I'm getting nice big album cover art, and liner notes that I can actually read without squinting. Some stuff isn't available here, so I import them from the UK occasionally." It's a solution that marries his digital interests with his artistic side, much as his work at Gemini does in support of the diverse information needs of the observatory.

Gemini South Astronomer Brings Young Stars Into Focus

Every night Gemini Observatory delivers a constant stream of science data to astronomers, technicians, and information specialists. On-site astronomers and science fellows are tasked with supporting science observations, telescope commissioning, and participating in the full range of science activities at Gemini. This also includes following their own research programs in specialties that include everything from solar system objects to cosmological questions.

Bernadette Rodgers is one of Gemini South's very capable Science Fellows stationed at Cerro Pachón in Chile. She has spent the past two years as the instrument scientist for the Gemini Near-Infrared Spectrograph (GNIRS), following its development from acceptance through commissioning and now regular queue operations. She also handles the astronomer support schedule for Gemini South. "I really enjoy the challenges, getting things like the instruments, software, and user information working for the first time," she said.

On Cerro Pachón Bernadette pursues her research interests in Herbig Ae/Be stars. These are stars that bridge the gap between low-mass stars like the Sun (or smaller) and the high-mass varieties like Eta Carinae and others that will one day end their lives as supernovae. Currently she is using near-infrared spectroscopy as well as near-infrared imaging with adaptive optics to gain more insight into these stellar newborns in the late stages of formation in clouds of gas and dust. "These are less well-studied than solar-type and low-mass young stars," she said, "but they do have some extremely interesting and curious things that are truly unique to these stars."

Their uniqueness stems from the "pre-natal" disks that surround the stars. These are places where planetary formation can occur. Stellar spectra tell astronomers a lot about the composition, physical conditions, and dynamical motions in these disks. In particular, Bernadette is interested in a subclass of these objects called the "UXOR" stars.

"These stars are surrounded by circumstellar material and vary in brightness by as much as 90% in the optical," she said. "One theory for their brightness variations is that the star is occasionally obscured by large 'clumps' of material in the circumstellar disk, but this interpretation is still fairly controversial. If it's true, the clumps are very interesting with respect to planet formation. For very large and dense ones think of super-Jupiter-sized thick clouds orbiting close to the star."

Bernadette's interest in astronomy goes back to her days as an undergraduate computer science major at the University of Delaware, but she didn't consider astronomy as a career until the late 1980s, when she went to New York University for a master's degree in physics. That led to a job at NASA's Ames Research Center. In 1994 she began work on her doctorate at the University of Washington and did her thesis research on intermediate-mass young stars. She fell in love with Chile during an observing run at Cerro Tololo Inter-American Observatory in 1998 when she noticed that Gemini South was under construction. "We decided then that if I had the chance I would try to get a position there," she said. "I applied to Gemini when I was just finishing my graduate work, and specifically asked for Gemini South. The timing was perfect."

Bernadette's interests extend to other "young stars," specifically, the children of Chile who are interested in astronomy. Recently Gemini South led an effort to produce an educational video about Gemini astronomers and the work they do. Bernadette was featured in the series and in it she talked about her research, personal life and skillfully preformed a hands-on demonstration of some basic principles of moon phases.

According to Gemini South's Public Information Specialist Antonieta Garcia, Bernadette's support of the program was a big reason for its success. "Everyone was very busy at the time," she said, "but Bernadette found the time to be available, did the whole presentation in Spanish, which is her second language, and brought her own children into the production." This commitment to astronomy education is a strong reflection of Bernadette's outgoing manner and professional outlook.

Gemini South's Site Manager Diego Maltes comments that Bernadette and her family have integrated extremely well into the region around the Gemini offices in La Serena. "You can always count on her to help out whether it be to give Christmas gifts to deprived children or go out of her way to help at work," said Diego. "I remember one time she had arranged to wait on the side of the road for a ride to the summit, when the vehicle didn't show up, she hitchhiked so she could get to the summit on time for an observing run, like I said, you can always count on Bernadette!"

While Bernadette's science brought her to Chile for her fellowship, she is joined by husband Peter and their two children, 9-year-old Joshua and 5-year-old Amy. They live outside La Serena on a "parcela" that they bought, and where Peter built their home. Peter is a "stay-at-home" dad who maintains the house and an orchard of fruit trees and grapevines, accompanied by a handful of chickens.

In her off hours, Bernadette spends most of her time with her family. They like to ski, camp, hike, and travel to interesting places when they can. In all, her move to Gemini South has been a fantastic experience. "I enjoy the people very much," she said. "We have a wonderful community at Gemini South, and my family and I love living in Chile and getting to know the country, the people and the culture. And I enjoy observing and being on the mountain on a beautiful night when everything goes well. It's a great feeling."

"Rising above the mists of Hilo, Beacon of celestial knowledge; Polished Mirror.....Matt Mountain"

"Millions of thanks for giving all of us the opportunity to work with you in the unique adventure of building the two Gemini telescopes and successfully bringing them into full science operation as a forefront astronomical observatory. The Gemini telescopes and their instruments are now producing outstanding science results, and we are poised to become an established world-leader in several key areas of astrophysical research. These include distance galaxy evolution, the dynamics of the Galactic Center and proto-planetary disk evolution.

You have brought together and fostered an incredibly rich workforce that is diverse in skill, experience, nationality and gender. Your directorship has been most remarkable, as exemplified by your creative management style and the team you have brought together during your eleven years at Gemini. We are all proud to be part of this superb and unique team. You have empowered the entire Gemini staff to feel like full participants in this very competitive scientific environment.

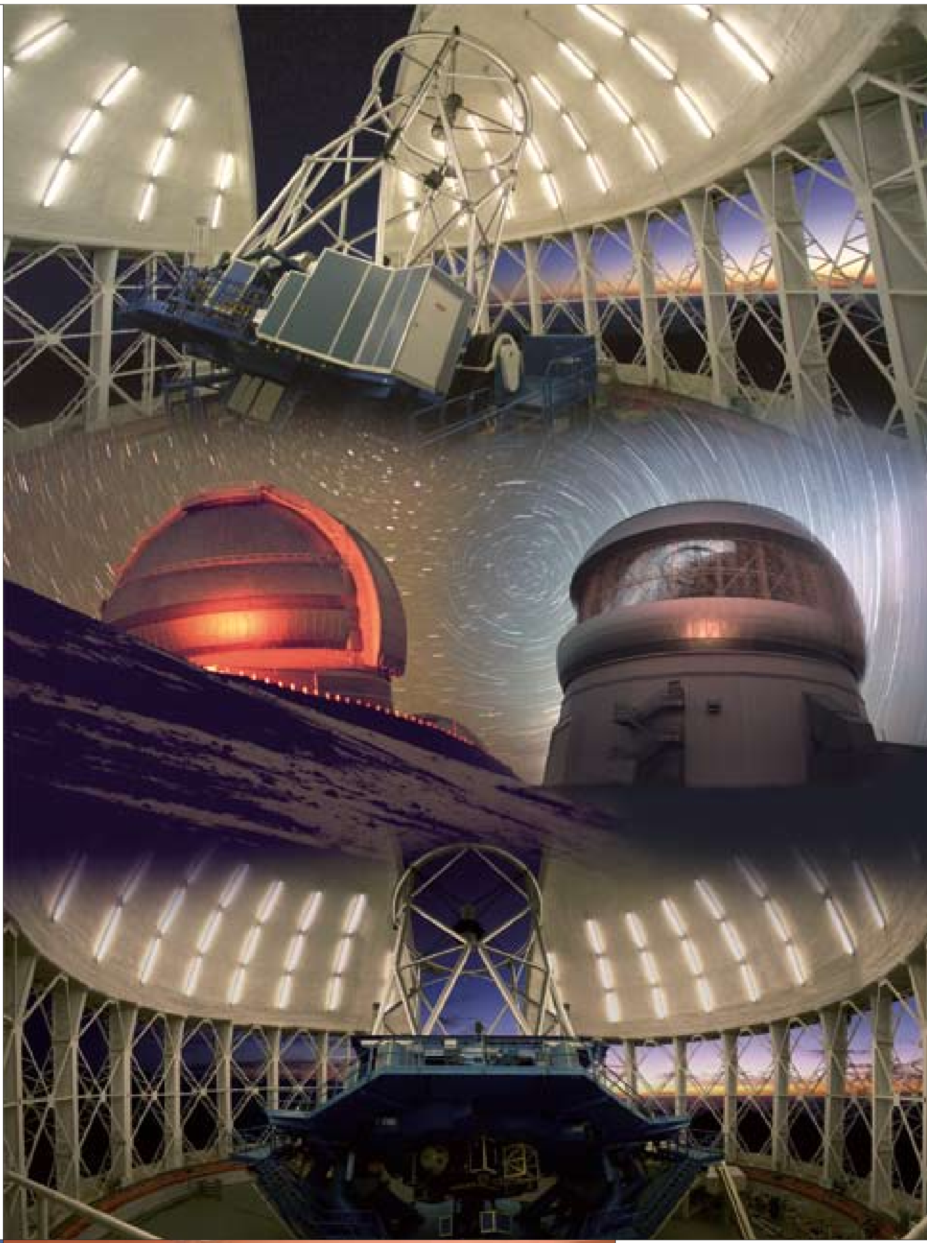
You have created a new culture of quality and sophistication of service to our communities that is essential for the success of a modern astronomical institution.

Just as the name of George Ellery Hale is associated with the 5-meter Palomar telescope, the name of Matt Mountain will mean Gemini. You have led and inspired all of us in this magnificent adventure.

In is no surprise to us that you have now been called to lead the completion of the most ambitious astronomical space facility ever built, the James Webb Space Telescope.

We wish you the very best in your challenging new job at the Space Telescope Science Institute."

Jean-René Roy - Hilo Hawai'i, July 2005



GeminiFocus
Newsletter of the Gemini Observatory

Gemini North "Invisible Dome" / P. Michaud / K. Pu'uohau-Pummill

Gemini Observatory
Northern Operations Center
670 N. A'ohoku Place Hilo, Hawai'i 96720 USA
Phone: (808) 974-2500 Fax: (808) 935-9235

Gemini Observatory
Southern Operations Center
c/o AURA, Casilla 603 La Serena, Chile
Phone 011-5651-205-600 Fax: 011-5651-205-650

Gemini Partner Agencies:

NSF

United States

PPARC

United Kingdom

NRC·CNRC

Canada

Australian Government
Australian Research Council

Australia

LNA

Brazil

Conicet

Argentina

GOBIERNO DE CHILE
CONICYT

Chile

AURA

Gemini Observatory is an international partnership managed by the Association of Universities for Research in Astronomy under a cooperative agreement with the National Science Foundation.

www.gemini.edu