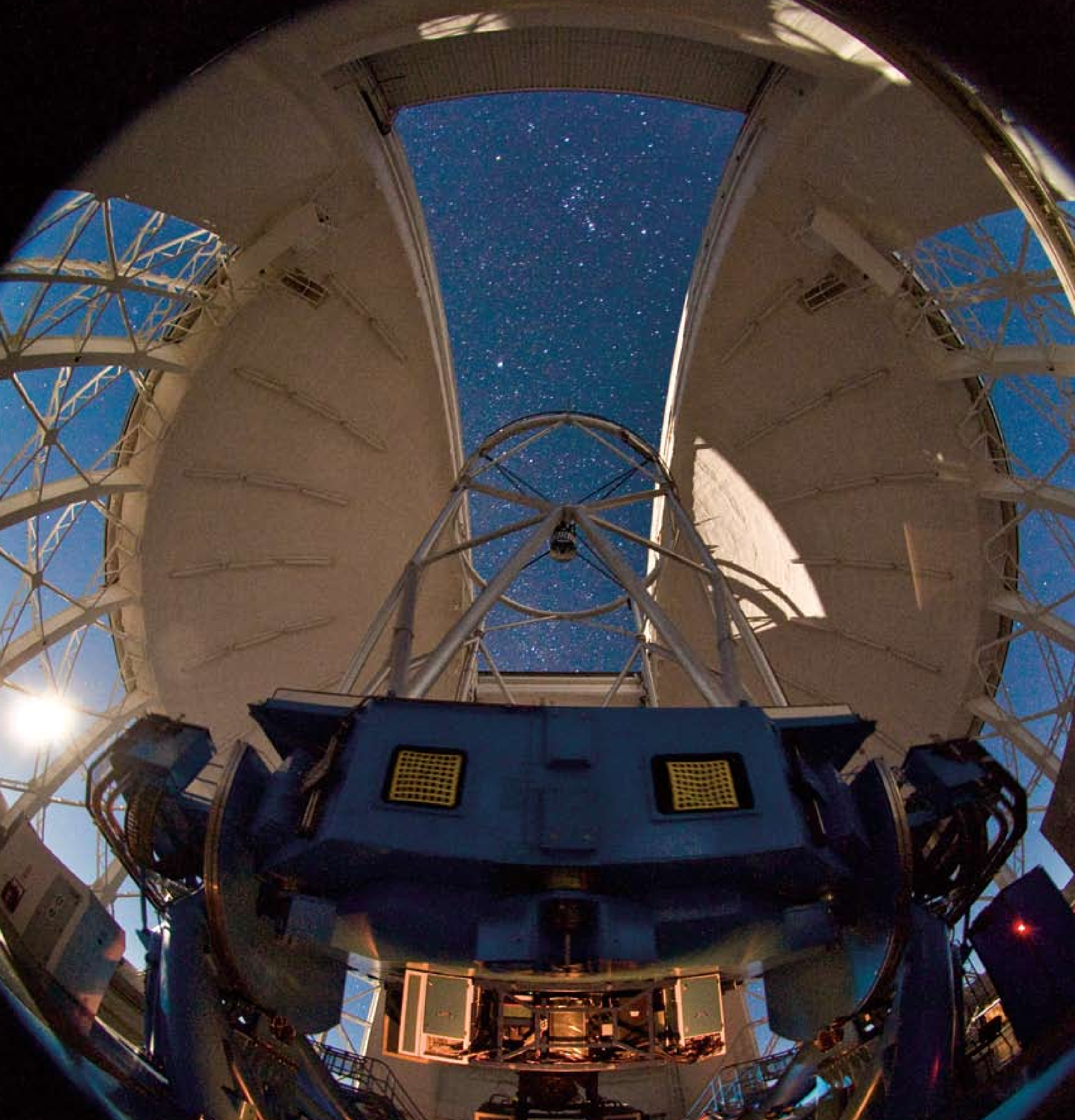
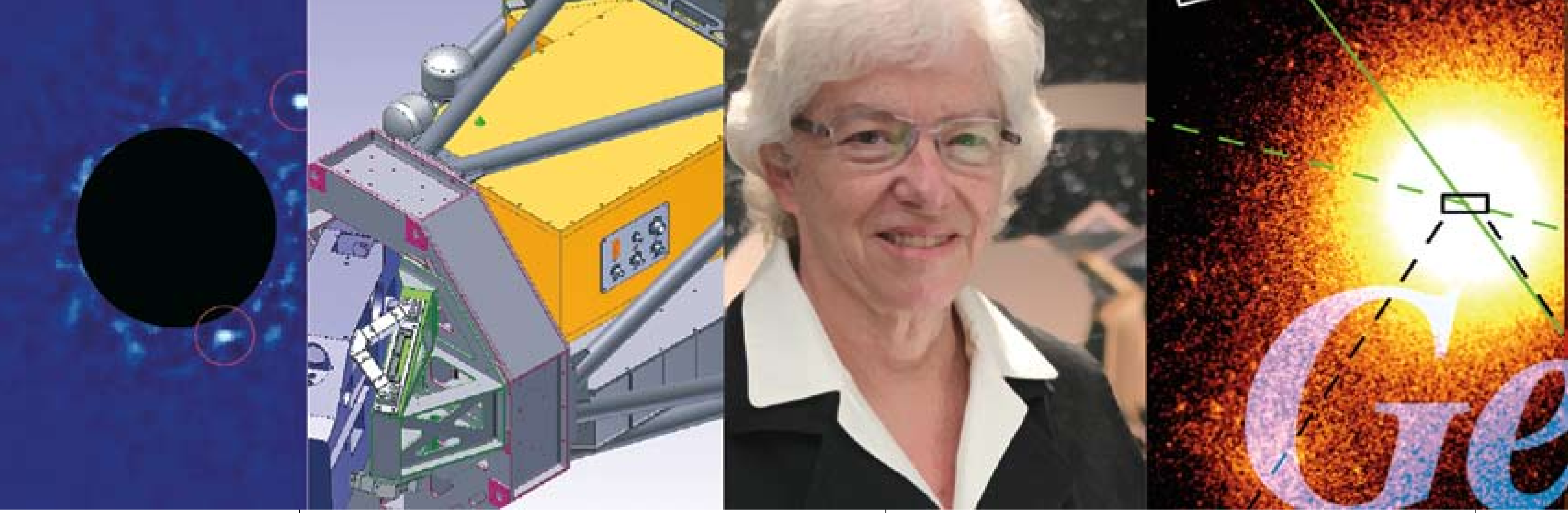
400 Years of the Telescope

400 GeminiFocus

June2009 Publication of the Gemini Observatory





On the cover: Interior of Gemini South obtained in January 2009 during a NICI Planet-Finding Campaign run (see article starting on page 61). NICI can be seen illuminated at the bottom of the moonlit image obtained with a 180-degree fisheye lens. Both Orion and Canis Major can be seen in the open shutter.

400 Years of the Telescope: A Special Issue of GeminiFocus

In the 400 years since Galileo pointed his telescope skyward, astronomy and science have transformed humanity's perception of itself. Today, observatories like Gemini are continuing in this tradition. This issue of *Gemini*Focus is celebrating that spirit by looking back, not only at Gemini's history and its people, but also at the history of science itself as a context for what we do at Gemini: *Exploring the Universe, Sharing its Wonders*.

This special issue of *Gemini*Focus is also being produced in parallel with a feature on progress in telescopes and instrumentation at the European Southern Observatory in their newsletter *The Messenger*.

–The Editors

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by Doug Simons
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Fred Gillett's Legacy

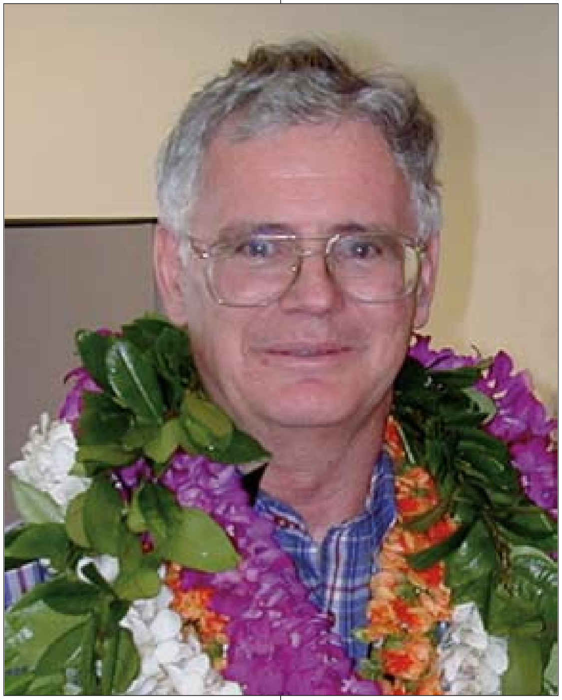
Inspired by the creative genius of the *Gemini*Focus editors and the International Year of Astronomy celebrations occurring around the globe, this edition features some truly remarkable and fascinating accounts of the "birth" of the giant twin telescopes we now call Gemini. Accounts are given of the singular contributions of scientists, engineers, and managers who played crucial roles in the development of Gemini. These include leaders like Sidney Wolff, who brought together the resources in Tucson to take a concept to reality, and Matt Mountain, Gemini's director throughout the construction phase of the project. His vision and tenacity helped lead the project from the drawing board to massive chunks of steel and glass. This issue also features the mathematical genius of Brent Ellerbroek, whom the Gemini Project relied upon heavily in its early days to ground its designs in an emerging technology we now take for granted: adaptive optics. David Crampton and Roger Davies are also featured for their leadership and drive behind Gemini's most scientifically productive instruments, the Gemini Multi-object Spectrographs at Gemini North and South.

The core Gemini engineering and management team–comprised of Dick Kurz, Larry Stepp, Keith Raybould, Jim Oschmann, and Rick McGonegal–is featured as well. I witnessed firsthand the management and engineering wizardry of these key people in the original Tucson project office as they plowed daily through a complex trade space of cost, performance, and scheduling like a snowplow on Mauna Kea this winter! Finally, in this article, I have the privilege of sharing with you my own perspectives on Fred Gillett (pictured at right), the man whose image, on a memorial plaque, adorns the interior of the dome at Gemini North, watching as his "baby" harvests photons that seed tomorrow's discoveries.

Fred was working at the National Optical Astronomy Observatory (NOAO) the first time I met him in 1994. I had just arrived on the scene in Tucson as Gemini's new "systems scientist." Matt Mountain, who was the project scientist at the time, hired me to help interface between Gemini's emerging international science community and the engineering team in Tucson, where low-level design trades were being made almost daily. Though Fred was not formally on Gemini's staff at the time, in practice he was already heavily involved in the project, providing crucial guidance on top-level performance requirements for the telescopes, instruments, and sites.

At the time, I was trying to absorb a huge amount of information flowing across 10 time zones, but I pretty quickly identified a few aspects of the telescope design under consideration that I felt were either incredibly visionary or simply ludicrous. Chief among these was the emissivity specification, as stated in Gemini's Science Requirements Document: *"The fully optimized IR configuration will have a telescope emissivity, including scattering and diffraction, of 4% with a goal of 2% immediately after coating or recoating optics, with 0.5% maximum degradation during operations, at any single wavelength beyond 2.2 µm."*

Having spent my graduate career and first post-doctoral period working on infrared systems on Mauna Kea, I instantly knew how hard it was going to be to reach that goal, which was around three times smaller than what the best ground-based telescopes in the world were currently achieving. It could simply not be done without the invention of new technology. Fred knew that and accepted the challenge by becoming the driving force behind a program to develop advanced protected silver coatings for application on Gemini's optics. He worked meticulously to test one "formula" after another, systematically zeroing in on a combination of materials that would yield not only the desired emissivity, but could also withstand the harsh conditions Gemini's enormous mirrors would experience. Fred used an instrument dubbed the "Two Tummy Toad" (an old single-element lab infrared photometer) and no shortage of liquid nitrogen and patience to painstakingly measure the emissivity of test coatings. This work, which he quietly conducted in a lab in the basement of NOAO, would ultimately lead to the silver coatings that are now used routinely at Gemini and yield a focal plane with ~3% emissivity – *the most sensitive infrared focal plane of any large aperture ground-based telescope.*



Fred's contributions go far beyond the silver coatings, however. He was the "keeper" of the most fundamental telescope performance requirements in a development environment that was occasionally hostile to his vision and, given enormous schedule and cost pressure, liable to settle for the status quo. Fred was as relentless in his pursuit of the ultimate infrared telescopes as he was mild-mannered in his approach. He almost never outwardly got mad—he simply resolved to overcome whatever predicament confronted him. Most of the time, he did just that.

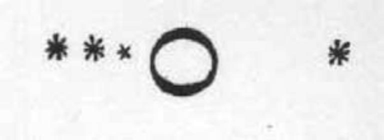
Beyond emissivity, he was just as concerned about ensuring that Gemini meet its fundamental image quality specification to place at least 50% of the 2.2-micron energy gathered by the telescope into an aperture 0.1 arcsecond in diameter, allowing for only tip/tilt correction. Almost as audacious as the emissivity requirement, this single requirement had enormous design implications for Gemini, which propagated across the entire telescope system. On countless occasions it would have been easy to relax this requirement, but Fred never gave up. His passion for image quality is manifested by the spectacular images recorded every night at Gemini, each showing our trademark faint diffraction spikes and stable, smooth point-spread functions.

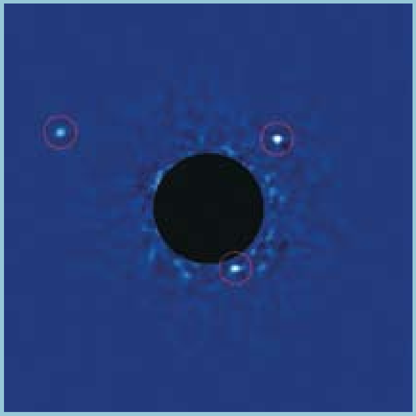
Finally, no account of Fred's numerous contributions to Gemini could be complete without mentioning how he skillfully worked with Al Fowler and Mike Merrill at NOAO to develop the ALADDIN 1024 × 1024 InSb detectors used throughout the astronomy community's instruments today. Gemini funded one of the first foundry runs of these detectors and I was always amazed at how Fred and Al were able to carefully marry InSb detectors of varying qualities with multiplexers, interpret test results arriving regularly from Santa Barbara and NOAO's own lab, and produce the detectors that were eventually used in the Near-infrared Imager and Spectrometer (NIRI), the Gemini Near-infrared Spectrograph (GNIRS), the Near-infrared Coronagraphic Imager (NICI), and the PHOENIX spectrometer.

Beyond the magnitude of Fred's vision, passion, and technical insight, the greatest lesson I learned from Fred as a young astronomer swept up in a huge telescope project was this: always let "science" be your guiding light through complex situations. In a world that is often blinded by complex political, financial, or technical arguments that can lead people in one direction or another, time and time again I watched Fred take the "high road" and unilaterally focus astronomers and engineers on a single simple path forward. I've witnessed heated debates behind closed doors at Gemini on countless occasions, only to be settled when Matt would turn to Fred, who had been quiet the whole time, and Fred would say in his calm no-nonsense voice, "That's all well and good but here's what we need to do..."

I could go on and on about Fred, but will end by simply saying that I have always been amazed by the connections between seemingly small things, like Fred's pioneering tests of silver coatings which only a handful of people really even knew was going on, and the discoveries made at Gemini using those same coatings. Fred did not live to see his vision fully bear fruit at Gemini, but I am nonetheless certain that had he been around to see the Gemini twins we now use every night, he would have been incredibly proud (see text box below). I was blessed to have had the opportunity to work with Fred in the twilight of his career and will never forget the look in his eyes as he walked out of the Hilo Base Facility for the last time with a beautiful flower lei around his neck. At the time, we both knew it would likely be the last time he would set foot in Gemini. I knew that at Gemini, his footsteps would never be filled again.

Fred Gillett would have been particularly enamored by discoveries like the planetary system surrounding HR 8799 which was imaged by Gemini North last year–a telescope Fred played a central role in designing. The stunning image (see image below, right, and article starting on page 44 of this issue) obtained by a team led by Christian Marois of the National Research Council of Canada's Herzberg Institute for Astrophysics and members from the U.S. and U.K., is the first image of a solar system, beyond our own, since Galileo published drawings of the planets in our own solar system (see image below, left, of Jupiter and its four brightest moons) in his book *Sidereus Nuncius*, or *The Sidereal Messenger*. While hundreds of planets have been detected through indirect means in recent years, what makes direct imaging of extrasolar planets so valuable is that, through this technique, it is possible to actually map the orbits of these planets around their host star and measure their masses, luminosities, and chemical compositions. The planets discovered are between seven and ten times more massive than Jupiter and are so young (60 million years) that they radiate copious amounts of infrared radiation, helping us detect them at the 130-light-year distance to HR 8799.

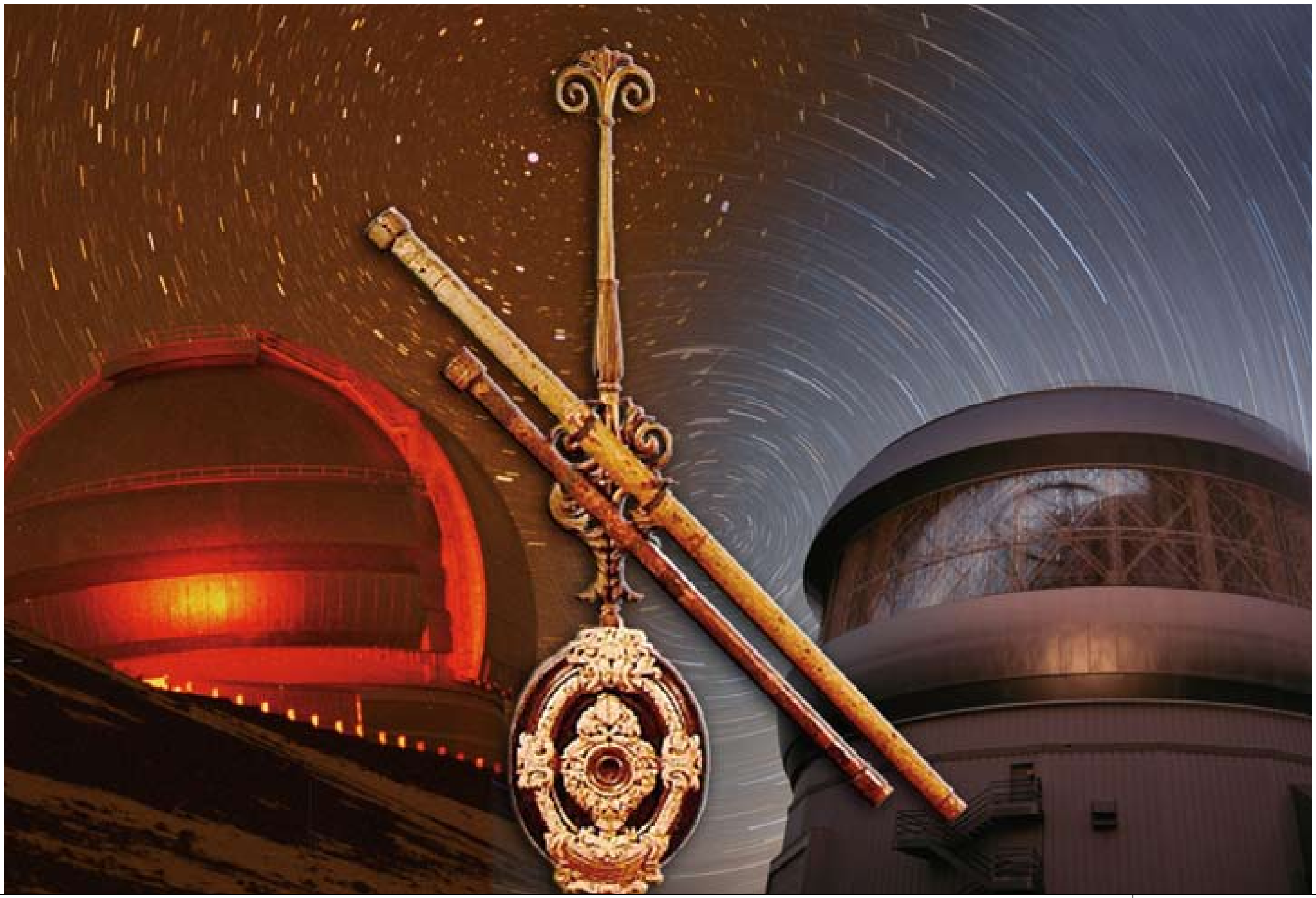




by Jean-René Roy

What Does 2009 Teach Us?

Galileo Galilei and Charles Darwin are towering figures of modern science.
The year 2009 is a celebration of their achievements, and, indirectly of those made by many of their contemporaries.



In late November and early December 1609, Galileo Galilei (1564-1642) observed the sky with a small telescope of his own design and fabrication. Its aperture (30-50 millimeters) was tiny. To minimize aberrations, he had sized down the aperture with a diaphragm. Compared to the giant telescopes of today, his apparatus was extremely modest. Still, the discoveries that it enabled were staggering and rocked the 17th-century scholarly world. The invention and early use of the telescope (with magnifications of 20x to 30x) had a dramatic effect on the course of astronomy.

The Origin of the Telescope

It is not clear who invented the telescope. The design and technology was known for a few decades in Italy, England, and Holland. Some instruments had been used for terrestrial surveys and maritime monitoring of ships coming into or leaving European ports.

Galileo was not even the first person to turn the instrument to the sky. Actually, English astronomer and mathematician Thomas Harriot (1560-1621) may have been the first astronomer on record to observe and make drawings of the Moon as seen through a telescope on July 26, 1609. From Harriot's descriptions, it is clear that his lunar images were of poorer quality than those obtained by Galileo later that same year. Harriot also failed to give the deeper physical interpretation of the nature of the lunar surface and its features as Galileo did so wisely and correctly.

In his recent book, *Cosmos*, author John North writes, "What characterized Galileo, however, was the sheer energy he threw into the whole enterprise, and the attention he drew to the broad cosmological implications of what was to be seen through the telescope." Galileo indeed surpassed his competitors not only as a skillful technician but as an intuitive physicist and a visionary thinker. He inferred that the laws of physics (and geology, in the case of the Moon) extend to the whole celestial "sphere." He stated, in most part correctly, that the Moon was an "earthly world" with mountains and "seas."

Galileo had an astute sense of priority in scientific discovery. Grasping the importance and impact of his telescopic discoveries, he published quickly his finding in his Latin-language work, *The Starry Messenger*, which is still a most pleasant and enjoyable book to read four centuries later. It was published in March 1610, an amazing few weeks after his breakthrough observations, likely driven by Galileo's spirited temperament and his strong desire to promote the heliocentric model. It is impressive that most of his interpretations of the objects and phenomena he described remain valid today.

Figure 1.
Galileo as a young man.

Although better known for his use of the telescope and his efforts at proving and promoting the Copernican views, several works published later in his life demonstrated that Galileo was a great physicist in the modern sense of the word. Through his experiments and analysis of the dynamics of moving bodies, he established the principle of relativity and several laws that served as the basis for Newton's theory of gravitation. He also invited a repositioning of mankind in the universe that collided violently with established views. "One of his greatest strengths had little to do with the mathematization of nature: it was his ability to demolish the insupportable nonsense put forward by so many of his opponents..." writes North. So, for 2009, it is also the greater dimension of Galileo that we wish to highlight.

“History’s Most Influential Book”

English naturalist Charles Darwin (1809-1882) was born 200 years ago. In 1859, he published his most revolutionary work, *On the Origin of Species*. It is arguably, as Harvard biologist Edward O. Wilson wrote, “history’s most influential book.” Darwin presented “one long argument,” as he later put it, for the evidence of evolution of all living beings over long periods of time. He proposed an amazingly simple mechanism to explain this evolution: natural selection.

As with Galileo and his use of the telescope, Darwin was not the first to propose a mechanism for evolution. About half a century before him, Jean-Baptiste Lamarck (1744-1829) had proposed inheritance of acquired characteristics. Many others were developing the idea, in particular English naturalist Alfred Russel Wallace (1823-1913) who had already proposed natural selection. Wallace going public prompted Darwin to publish in a rush the ideas he had developed and published (for inner circles of friends) well before. Wallace courteously recognized Darwin’s priority.

Figure 2.
Darwin as a seven-year-old boy.

Darwin acted in the combined roles of Copernicus and Galileo, providing a new and powerful theoretical framework based on a stunningly exhaustive set of observations. The reception and acceptance of natural selection by contemporary colleagues was, at first, actually relatively swift and easy compared to the obstacles Galileo had to face. In 2009, it is also the greater dimension of Darwin that we wish to highlight.

Genesis and Acceptance of New Concepts

Ancient mariners probably discovered that the Earth was round centuries before Greek astronomers and geographers measured the size of Earth in the 3rd century BC and proved the fact. Aristarchus of Samos (ca. 310 – 230 BC) proposed the first known heliocentric model of the solar system and the great distances of stars. It took almost 2,000 years for the concept to be finally proven and accepted.

The idea of evolution or change is ancient, going back millennia. Like the heliocentric model, it was proposed by Greek philosophers more than two thousand years ago, still as a primitive concept. As summarized by Roman philosopher and poet Lucretius (ca. 99 – 55 BC) in his beautiful book *De Rerum Naturae* (*The Nature of Things*), atoms assemble in various forms. Natural changes are driven by the clinamen (“this unpredictable swerve… at no fixed place or time”), a little random kick that brings matter, objects, and beings together, changes them, or takes them apart.

The spherical shape of the Earth (its sphericity) is a fact. The revolution of the Earth and other planets around the Sun is a fact. Evolution of all living beings is a fact. Newton’s theory of gravitation explains the first two facts; Darwin’s deceptively simple idea of natural selection is the theoretical framework for evolution. As Wilson writes in his work, *From So Simple a Beginning*, “Evolution by natural selection is perhaps the only one true law unique to biological system, as opposed to nonliving physical systems and in recent decades it has taken on the solidity of mathematical theorem.”

Both Galileo’s and Darwin’s discoveries generated enormous debates, especially outside scientific circles. Darwin was certainly less provocative and

Figure 3. *Village of Queilen in southeast Chiloe (Chile), with a view of the interior sea and the Pantagonian Cordillera. In the opening of* On The Origin of Species, *Darwin wrote, "When on board of* H. M. S. 'Beagle', *as naturalist, I was much struck with certain facts in the distribution of the inhabitants of South America, and in the geological relations of the present to the past inhabitants of that continent."*

confrontational than Galileo. However, Darwin's natural selection was more transformational, and resistance to it became much deeper and stronger, especially among the public in general. That resistance endures today.

Why do "new" concepts such as the Earth's sphericity, heliocentrism, the great age of the Earth and evolution take so much time to be accepted? Such acceptance took as long as 2,000 years in the former cases, and a number of centuries for other great transformative ideas. As we know, many of our fellow citizens continue to refuse evolution as a fact, and many more reject natural selection as its driving mechanism, just as they believe in a "young" Earth and ignore that the Earth goes around the Sun in one year, this, more than 450 years after Copernicus. It is humbling to realize that so many of our citizens continue to prefer "comfortable" but wrong depictions of our universe. Why is that?

The Lesson of 2009: Humility and Perseverance

As so many of us have experienced while giving public talks and participating in "debates" about astronomy and science, presenting the modern science view is always well-received by our audiences. However, there are always a few speaking aloud, on behalf of many, who say: "Your arguments are very convincing, but I still do not believe you!"

"2009" invites us, scientists, historians, and scholars, to interrogate ourselves on the challenge of sharing knowledge and understanding our universe as we pile up dazzling discoveries. Are we in the danger of running ahead of ourselves in promoting new efforts to push the frontiers of knowledge faster? Are we putting ourselves at risk in proposing to build newer, more powerful and very costly facilities to explore a universe that a majority of tax-payers refuse to accept. Should we direct our efforts to address their unfounded beliefs? Should we just ignore them?

Underlying Darwin's model are the eons of time needed to produce the millions of species and their complexity seen today on Earth. Darwin's requirement of half a billion years put him in head-on confrontation with the physicists of his time who proposed a short 20 to 40 million years for the age of the Earth. To use the expression of American geologist and historian Martin J. S. Rudwick, Galileo burst the limits of space and Darwin burst the limits of time.

However, these incommensurable scales of space and time are not what disturb people so much in their views of the universe and mankind's place in it. It is the role of chance in the organization of the universe, in the formation of our solar system, and of the Earth, and as the driving mechanism of the evolution of life that rocks their "beliefs." Wilson put his finger on it when he wrote, "Evolution in a pure Darwinian world has no goal or purpose: the exclusive driving force is random mutations sorted by natural selection from one generation to the next." This is the "hard nut" we have to crack.

The concept of chance or randomness transformed modern physics and chemistry through statistical mechanics in the late 19th century and the more fundamental step of quantum mechanics in the early 20th century. Amazingly, the underlying role of randomness in nature was implanted more than 2,000 years ago: yes, the clinamen of the early atomists. Then, as today, this unsettling fact and idea was strongly resisted. It is still considered profoundly repulsive to so many of our fellow citizens. This is our challenge.

What Can We Do?

What can we as scientists do to meet the challenge?

1. We must continue and do more to share our work experience, discoveries, and even our failures with the public.
2. All large scientific projects must fund and maintain strong public education and outreach programs. These programs must avoid triumphalism, spectacle, or entertainment.
3. We must promote rational thinking and critical reasoning, at the same time keeping an open mind on various non-scientific ways of understanding our universe.
4. We must steer away from wishful thinking, boosting expectations, or promising "final answers" to big questions.
5. We must work on creative approaches that bring the scientific community and the public together, in a respectful and fruitful dialogue.

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by Lauren Gravitz

Matt Mountain: A Clear Vision of the Future

Charles Matthias (Matt) Mountain was Gemini Observatory's director from 1994 through 2005, but he gets noticeably uncomfortable when people credit him with the project's success. "I don't think I gave anything particularly unique to this process," he said. "I was just there at the time, and we had a very creative team of people who worked extraordinarily hard to get these two telescopes built." Matt, as usual, is being modest.

When he arrived at Gemini as project scientist in November 1992, the observatory was in its infancy but already mired in conflict. It had a lofty goal, a fixed budget, a controversial mirror technology, and was suffering under the weight of hefty expectations. "I walked straight into this not having a clue what was going on," Matt said. He never broke stride.

During his 13 years at Gemini, Matt managed a diverse team of employees and found a way to create consensus among scientists, legislators, engineers, board members, and seven partner countries. He helped implement, and defend the use of Gemini's adaptive optics. He led a project through terrain littered with political and technical land mines, and emerged on the other side with two optical/infrared telescopes capable of capturing some of the most detailed images ever produced from the ground. "The telescopes exist, to a large measure, because of Matt's efforts from the time he was project scientist through the time he was director," said Wayne Van Citters, a senior advisor for the U.S. National Science Foundation's (NSF) Directorate for Mathematical and Physical Sciences. "He was absolutely instrumental in setting the scientific tone for the telescopes, for what they would accomplish and what they had to accomplish to be scientifically useful and successful. He set the vision for the future of the observatory."

That future wasn't one that the astronomical community was wholly ready for, and Matt frequently found himself and his project under attack. But rather than avoid confrontation, he met it head-on. "He's not someone to shy away from the politics of a situation, because he realized that politics is a lot of what you do," said Jacobus (Jim) Oschmann, who worked alongside Matt for many years as Gemini's systems engineer and project manager. "You can complain about it, or you can participate and try to affect things in a way you think is correct."

(Opposite page)
Matt Mountain

Photo by Will Kirk

Matt may have landed squarely in the middle of a maelstrom, but he brought with him an enthusiasm that never seemed to waver. "The infrared was a regime that had yet to be fully exploited with ground-based astronomy, and Gemini offered the opportunity to try and build the ultimate infrared optimized telescope," he said. The challenges of doing this would tap the creativity and expertise of engineers and scientists from around the world who would ultimately develop the necessary innovations in mirror coatings, structural configurations, and even airflow modeling of the dome and telescope structure. Matt added, "The prospect of building a large infrared telescope, a telescope that was explicitly designed to exploit the infrared, was very exciting."

His passion for the project rubbed off on everyone around him. Wayne Van Citters, who worked with Matt when he was overseeing the construction of Gemini as the director of NSF's Astronomy Division, describes Matt as "one of those guys who has an absolutely infectious enthusiasm for the science that he's dealing with on a very, very broad front. He's one of those people who are visionary," Van Citters continued, "So, I would sit and listen to him talking about the science that he envisioned these telescopes would do—not next year but in five and ten years' time. We were still, basically just talking about pieces of paper, but it was truly inspiring. And although, in some sense, [he was] talking way over my head about some of the science, he could put it down in terms that I could understand and relate with."

The ability to translate science was something Matt believed to be at the very core of his job as both project scientist and director, and is also central to his current position as director of the Space Telescope Science Institute. "The real role of a project scientist is to be a communicator," he said. "To communicate engineering challenges in terms that scientists can grasp and, vice versa, to translate science requirements into something the engineering team can understand."

Sidney Wolff, who spearheaded the Gemini initiative before handing it over to Matt (see Sidney's profile starting on page 20), notes that his ability to communicate was at the center of his success. "One of his initial jobs was to get a consensus on the design requirements for the telescope," she said, adding that it was not a trivial task, and one that required a lot of work with the science committees of each of the partner countries. "He was very sensitive to both what the scientists required and what the engineers needed to know in a timely fashion in order to design the right telescope. I think he straddled the science and engineering worlds very effectively, and he could talk the language of both."

In fact, Matt and the Gemini team placed so much importance on good communication that they occasionally tripped themselves up. "We'd seen poor communications between other observatories with North and South," he said. So, working under the mantra of "two telescopes, one observatory," the team wanted Hilo and La Serena to have seamless interactions and worked hard to create nearly identical computer interfaces with a high-bandwidth link connecting the two. But, shortly after the link went live, the telescope in the north started drastically misbehaving. Engineers in Hilo kept typing commands, but the responses they got back made no sense. Then the Chileans came online and asked what was going on, since the telescope there had suddenly seemed to take on a life of its own. "The guys in the north were actually controlling the telescope in the south and didn't know it because the interfaces were too similar," Matt said. "In our effort to really improve communications, we got obsessional to the point where we overshot." As an example of how well the two Gemini sites are currently connected, the observatory now operates a total of almost 60 devoted videoconferencing systems utilizing the wide bandwidth linking the two sites.

Of all the challenges he was up against, however, the biggest was building two telescopes on two continents under the constraints of a fixed budget set by the U.S. With congressionally mandated funds of $176 million, (capped at $88 million from the U.S. and ultimately upped to $184 million with a limit of $92 million from the U.S.) there was no wiggle room. "We had very limited resources, but very high expectations from one half of the community, and very low expectations from the other half of the community, and we had to walk that tightrope," Matt said. "A lot of the community hated what we did, but we had no choice because we had a limited budget."

With a fixed budget, money was a primary consideration and figured heavily in all decisions, scientific and otherwise. "These were designed-to-cost telescopes, which is very unusual in our field," he said. Because they had such a constrained budget, what began as a purely scientific challenge turned into as much of a project-management one. "We were always running with very little contingency or reserves. We always had to find clever and innovative ways around it."

Some of the problems called for an awful lot of head scratching, especially when it involved carting huge pieces of equipment from one side of the planet to the other. "We had to spend an awful lot of time thinking about that," Matt said. Tunnels in Chile, for instance, are a requisite eight meters wide. The only route up Cerro Pachón was a newly-dug tunnel, through which the team had to move an eight-meter-wide mirror (in a larger crate) and a ten-meter-wide coating chamber. "In the end, the only solution was to pay the Chilean government to make a tunnel that was ten meters in diameter. So now it's the largest tunnel in Chile, and we own two meters of it."

Most of the issues, however, required some tough choices and required Matt to help his team of scientists, engineers, and partner countries think hard about and agree upon what was scientifically necessary. The original plan to erect two different telescopes—one that was infrared optimized and one with broader capabilities—had to be scrapped; it was much more cost effective to build two identical ones. Eliminating Nasmyth platforms, the large metal platforms that typically hold large telescopes' heavy instruments, also lowered the cost, but made for an even more infrared-optimized design. "Gemini is much more of a precision machine than a general observatory, and it was built to be precisely that. It's not completely clear that that's really what the community wanted, but that's what it was built to do," Matt said.

The importance of Matt's proficiency at building consensus in a timely manner can't be overestimated. "We had a goal of achieving first light in 1998. And if you look at other telescope projects, very few of them actually achieve first light when they predict they will," Sidney Wolff said. Gemini North achieved first light in mid 1999 and started science operation in October 2000. Gemini South achieved first light in 2000 and started science operation in October 2001.

Not only did Gemini achieve first light right around its scheduled launch date, it did so with adaptive optics, establishing the observatory as a major player on the astronomy scene. Declaring first light with such a new technology made a statement: "This is the future," said Matt, who had fought hard to ensure that the observatory took advantage of the new technology, and who recruited a world-class adaptive optics team to do so. "Having diffraction-limited images is the future of infrared astronomy," he said. "That was the original vision, and the ability to actually take these diffraction-limited images was the real start." Adaptive optics imaging of the galactic center in the near-infrared using the University of Hawai'i Hokupa'a-36 system has provided legacy data that continue to be used as epoch [2000.0] reference images for the stars at the galactic center.

When results of the Gemini Deep Deep Survey were released a few years later, the community saw the true power of what an 8-meter telescope with superior sensitivity and image quality could do. "We dug as deep as Keck, and we surprised everybody. And that woke everybody up," Matt said. "People missed this subtle fact that if you have a great telescope, and you select for the good seeing by being adaptable about what you're observing, you can go very deep. When [our] 8-meter telescope proved itself to be just as powerful as a ten-meter one, suddenly we were on the map."

Throughout the experience, Matt never lost sight of the importance of a team: of building consensus among disparate partners, and using that consensus to create a cutting-edge scientific machine. Throughout it all, he stepped back and insisted others take the credit. "He has a very healthy dose of modesty, and that comes hand in hand with understanding that these complicated endeavors take a cohesive team of people," Jim Oschmann said. "You might have some superstars, but you can't do it by yourself. None of us could, and he was always conscious of that."

In the end, it was this understanding that made Matt the right person to lead such a diverse group of people to complete such a complex project. "Building a telescope is a tremendously human endeavor," he said. "Once you realize that, life gets considerably easier."

Lauren Gravitz is a scientist-turned-journalist located in San Diego. She can be reached at: lgravitz@gmail.com

by Peter Calamai

David Crampton: An Instrumental Leader

(Opposite page)
David Crampton

When he looks back at his experience with Gemini Observatory's development, astronomer David Crampton realizes just how much Gemini has turned out to be the test bed for many pioneering instrument designs. Most are now regarded as standard for 8- and 10-meter-class telescopes, and are setting the instrument baseline for the Extra Large Telescopes currently being planned. As the leader of the Instrument Group at the Herzberg Institute of Astrophysics (HIA) since 1985, the 67-year-old Canadian scientist was at the center of much of that trailblazing. Today, he remains at the cutting edge by overseeing the instrumentation effort for the Thirty Meter Telescope.

Gemini gained its pioneering reputation as the team planning Gemini worked to create a niche for the telescope in the then-burgeoning field of larger telescopes that included Keck, VLT, and Subaru, Crampton recalled. The team set very high goals and gave birth to an observatory that manages to combine the characteristics of a quick-change artist and a perfectionist.

Crampton's involvement with Gemini began when he chaired an optical and infrared subcommittee of the Canadian Astronomical Society (CASCA) in the late 1980s. "We knew that we had to get involved in one of the large telescopes, and I became quite a strong advocate of joining Gemini," he said. "Gemini came along late in the building of the 8-meter class of telescopes, yet it turned out to be ahead of its time because of being optimized for the near infrared."

At its annual meeting in June 1989, CASCA formally voted to join the international collaboration with the U.S. and the U.K. to build twin 8-meter telescopes in the northern and southern hemisphere (Canadian astronomers later came up with the apt name "Gemini" for the project).

The infrared priority for the Gemini telescopes, however, was established two years later by the U.S. Decadal Survey for the National Academy of Sciences chaired by John Bahcall of Princeton. Crampton said what attracted him and his CASCA colleagues to Gemini as a forefront endeavor was the high priority given to producing good images and on getting all components working together efficiently.

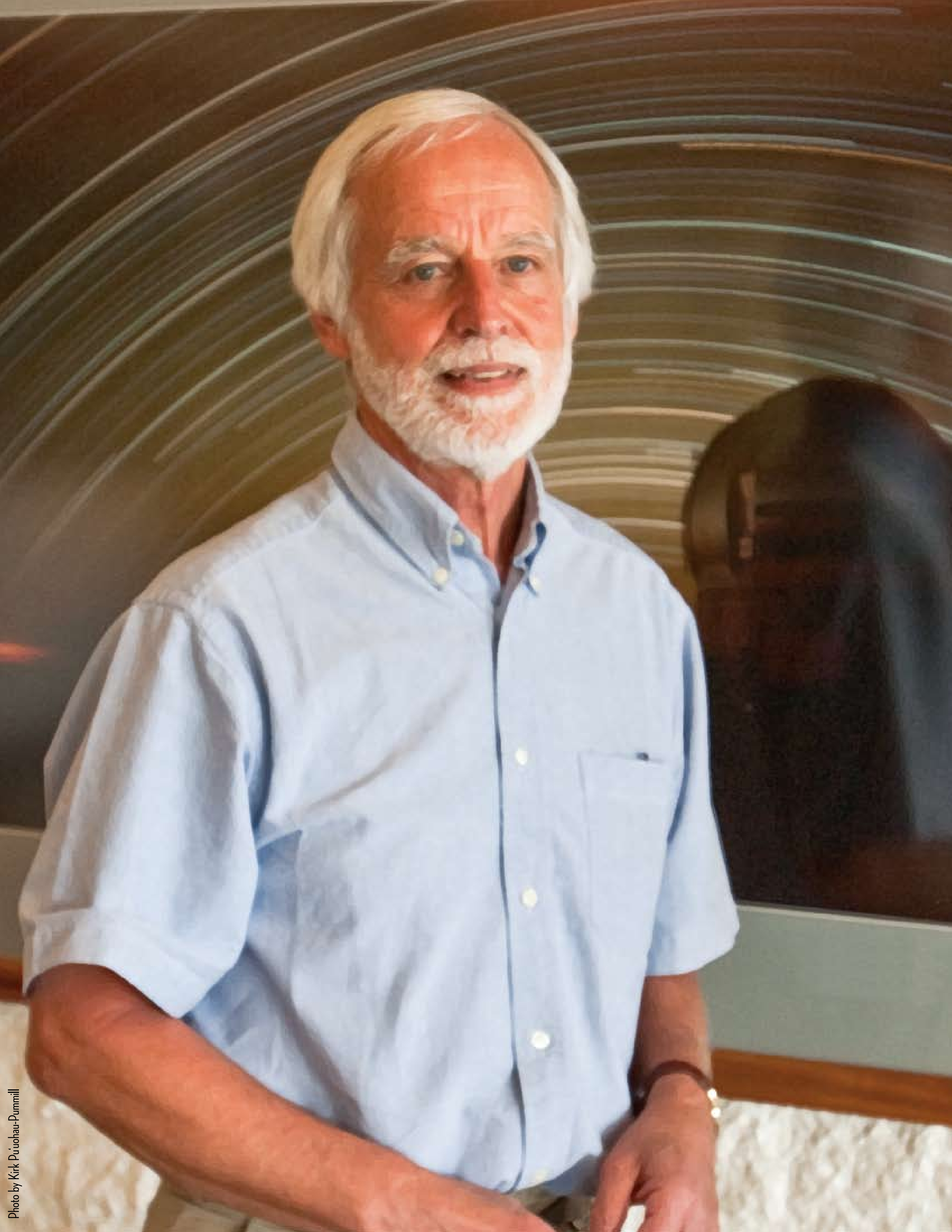

Photo by Kirk Pu‘uohau-Pummill

Crampton's interest in spectroscopy and instrumentation was first aroused by Jack Heard, the University of Toronto professor who supervised his doctoral research. In 1967, the freshly minted Ph.D. came to what was then known as the Dominion Astrophysical Observatory outside of Victoria, B.C., intending, as he now wryly recalls, "to stay only for a few years!"

Still there in 1994, at what became the Herzberg Institute of Astrophysics, Crampton and his instrument group found themselves with two challenging tasks: designing and building the optical assembly and wavefront sensors for two Gemini multi-object spectrographs (one GMOS for each telescope) and designing and building the ALTitude conjugate Adaptive optics for the InfraRed (Altair), the adaptive optics system for Gemini North. The HIA group got the jobs because of its track record or, as Crampton put it, "because we had heritage in both those instruments."

Along with the Observatoire de Paris, HIA had pioneered an innovative multi-object spectrograph (MOS) for the 3.6-meter Canada-France-Hawai'i telescope (CFHT). It allowed users to capture the spectra of hundreds of objects simultaneously. Crampton and his colleagues had also designed and built PUEO (Probing the Universe with Enhanced Optics, also the name of a sharp-eyed endemic Hawaiian owl), an adaptive optics system for CFHT, which was cutting-edge technology at that time.

The Altair system was HIA's task alone, while GMOS was a collaborative effort with the University of Durham and The Royal Observatory in Edinburgh. For GMOS, Crampton was the Canadian principal investigator working with the overall project manager, Rick Munowinski (also at HIA). "I'd describe myself largely as a cheerleader for Altair," he said.

Faced with building two major instrument systems with roughly the same delivery dates, the HIA group had expanded to almost 50, including students, and with the important addition of professional engineers. "I remember being blown away by those guys," he said. "They'd say, we do this and it's going to move by a couple of microns. And by golly, they were right."

Having such engineering expertise was crucial in scaling up from the CFHT MOS system to GMOS, Crampton said. "The big challenge was how to get everything we wanted into GMOS and at the same time not weigh more than two tonnes. We also needed to have a flexure control system. If you have something the size of a Smart® car hanging off the end of the telescope, and you move it around, it will flex."

Based on the experience with CFHT, the HIA team knew there were big returns (and challenges) to be had by having the telescope and instruments stable and precise enough to capture spectra that required all-night, or even multi-night exposures. This would allow Gemini not only to provide more precise measurements than other observatories, as in radial velocities of Milky Way stars, but also to see very deeply into the universe.

The challenges were especially great for the GMOS team, Crampton said. This is because the Gemini telescopes were designed for the near-infrared portion of the spectrum while GMOS operates in the visible. The resulting instrument allowed a maximum field of view seven arcminutes in diameter compared to, for example, Keck's 20 arcminutes.

In an e-mail headed "GMOS vs. the World" sent almost seven years ago to fellow astronomers Matt Mountain and Jean-René Roy, Crampton mused about why GMOS deserved the caché of a forefront scientific instrument:

"First telescope – spectrograph combination that acts as a complete system to exploit large 8-m aperture and improved image sharpness. Instruments for large telescopes are challenging because they must be correspondingly larger while at the same time more precise.... GMOS accomplishes this through carefully engineered design of the structure and its many mechanisms, as well as continually compensating for variations due to changes in temperature and orientation of the instrument as the telescope moves. The entire GMOS system (optics, mechanics, software, detectors) was designed to take advantage of the best images that the Gemini telescope produces."

The HIA instrument chief is especially proud of his team's contributions in four areas: optical coating, mask-making, a multi-tasking component officially known as the Integral Field Unit, and "active optics" as distinct from adaptive optics.

The optical coating aspect underlines the cutting-edge research and development that was routine in GMOS.

Crampton explained that the spectrograph has 14 air-glass surfaces, all of which must be coated. "It's a lot of lenses," he said.

The U.S. military had developed a coating that worked over a broad range of wavelengths but it wasn't very durable. So the HIA team improved the material to yield very high transmission and very wide panchromatic performance. The GMOS coatings, as Crampton pointed out, are unquestionably the best in the world.

A key element of the telescope's active optics system is OIWFS, which stands for On-instrument Wavefront Sensor. In effect, this GMOS component is Gemini's fine-guidance sensor. It allows the massive telescope to be precisely pointed within 10 milliarcseconds and then locked onto a target. Signals sent from the sensor tilt and tip the secondary mirror so the telescope compensates for the effects of wind shake and atmospheric disturbance. "We built all that into GMOS. It was kind of neat," said the normally restrained and self-effacing Crampton.

In addition, the HIA team also developed a procedure that uses lasers to cut exceptionally smooth slits in carbon fiber sheets that are only twice the width of a human hair. This produces highly precise masks to isolate the light from multiple targets for the spectrograph. These slits play a key role in a technique called nod-and-shuffle, a novel method for removing background contamination from the night sky that lets GMOS reach fainter objects than the competition.

While Gemini has boldly pushed out the frontier on both technical and operational fronts, Crampton said the greatest challenges actually lay in two other regions: the attitudinal and the financial: he believes the greatest challenges are likely to continue to be in these two areas.

"It's clear that there is some very exciting science to be done from the ground in the infrared. But astronomers are a pretty conservative bunch of people," he said. "The community was a little bit behind when Gemini began operating, and there weren't a lot of people out there wanting to use an infrared-optimized telescope. There still isn't a very large community of astronomers working in the thermal IR."

Crampton also discussed the continuing disappointment in the Canadian astronomical community that the country's originally pledged 25% contribution to Gemini was scaled back in the summer of 1991 to 14% (after an initial announcement that the country would pull out completely). Since observing time is apportioned relative to financial support, that left Canadian astronomers scrambling for time. "It's hard to compete with people at CalTech who get a couple of nights on the telescope when you only get a couple of hours," he said. With a decision looming on his government's support for the Thirty Meter Telescope, this particular lesson from Gemini is very much on the minds of astronomers in Canada today.

Crampton is confident that (funding issues aside) any new ground-based Extra Large Telescope is going to incorporate the same types of technical innovations pioneered at Gemini. Just as important, however, is that Gemini has defined how the next generation of telescopes will be operated, with its queue service mode and the quick-change observing made possible by seamlessly switching the photon beam from one instrument to another in a few minutes. Such technologies, he said, will continue to expand the scope of what astronomers will be able to do. "This means we can go after supernovae, gamma-ray bursts, and other things that go bang in the night."

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Sidney Wolff: "Call me the First Director"

(Opposite page) Sidney Wolff

Sidney Wolff was effectively the first director of the Gemini Observatory, shepherding the project through the development of its scientific, technical and management proposals, and the beginning of construction, for five critical years in the early 1990s.

"I wasn't called the director until the day I left," Wolff said with a wry grin. That was late November 1994. "On that day," Wolff continued, "they asked what they could do [as a memento] for me, and I said, 'Call me the first director.' I'm not sure I had a title until then."

Wolff's actual title during those interesting times was director of the U.S. National Optical Astronomy Observatory (NOAO), a position that she held until 2001. She had joined NOAO in the fall of 1984 as director of Kitt Peak National Observatory. At this time, the showcase future project for U.S. astronomy was the National New Technology Telescope (NNTT), a behemoth of four 8-meter mirrors in a single mount that was being sold primarily on the growing promise of interferometry. However, there was very little support for it from astronomers not in that specific field, Wolff said.

A new NOAO long-range planning committee chaired by Steve Strom turned the focus toward two 8-meter telescopes, one in each hemisphere, a concept soon endorsed and promoted by AURA, and embraced by key figures such as Eric Bloch of the U.S. National Science Foundation, who were eager to participate in the emerging trend for international partnerships.

The Gemini partnership rode this wave and found the 50% international partnership it needed thanks largely to a shared vision and good timing, she explained.

"This was the era of general-purpose 8-meter telescopes, and we knew pretty early on that the United Kingdom was interested in a partnership, which was advantageous. But," Wolff added, "the good thing was that we, the British, and later the Canadians, really wanted the same kind of facility, for

Photo by Emily Acosta/LSST

doing a similar kind of science. It wasn't just about the money."

When Canada was forced to reduce its contribution during the development phase, it left a 10% hole in the partnership remedied by some deft diplomacy in South America guided by Richard Malow, Wolff said, which led to Argentina, Brazil and Chile joining the project as core partners.

This truly shared vision helped foster a remarkably productive working relationship. "It was quite an effective partnership," Wolff said.

Some memorable scientific policy maneuvering occurred in advance of the Bahcall Decadal Survey of astronomy of 1990, when Fred Gillett led crucial work to define what was really meant by an "infrared-optimized" large telescope—essentially, superb image quality and low emissivity. "Fred deserves a lot of credit" for this, and the resulting high ranking received by a ground-based 8-meter telescope in the Bahcall report, Wolff said.

Technically, most of the basic requirements for an infrared-optimized telescope are similar to visible light facilities, Wolff said, except for a few key decisions, such as the elimination of any Nasmyth platforms on the side of the telescope structure. "The thermal mass [of the platforms] was thought to compromise dome seeing," Wolff explained. "We did some analysis—including studies of high-resolution spectrographs—to persuade ourselves that, with active controls, you could suspend large instruments at the Cassegrain focus and get them to work well, so that is one thing that we did that most telescopes did not, because image quality was the real design driver for Gemini."

From a policy perspective, one point that Wolff identified as a uniquely U.S. issue is how the development of the Gemini management structure at that time did not allow staff of NOAO/AURA to have a seat on the Gemini Board of Directors, which led to a relative lack of influence by the scientists most knowledgeable about Gemini and most familiar with the desires of the U.S. community. "Future partnerships need to be set up in a way that a partner's influence is more appropriate for its level of contributions to the partnership," Wolff said.

Wolff was a visionary and also effective in turning debates about a national large-aperture telescope into a tangible project under construction, backed by an international partnership, said Richard Green, director of the Large Binocular Telescope and a senior director at NOAO during the development and construction of Gemini. "It required an eloquent reiteration of the scientific value of a national facility with access solely on the basis of winning stiff peer-reviewed competition," he said. "Sidney successfully infused the project culture of completion on time and on budget, giving Gemini the potential to be fully competitive with the other large-aperture facilities."

Wolff's skill at juggling the complexities of budget constraints vs. capabilities provides some important lessons for future international partnerships in the next generation of Extremely Large Telescopes should they face legislative budget limits or a growing cost estimate. "Congress legislated a ceiling on the budget for Gemini before we finished the design of the telescope," she noted. The initial completed design, which included multiple foci and a wide-field secondary mirror, was estimated to cost $250 million, when the funding ceiling for the project (set by the U.S. funding cap of $92 million) was $184 million.

Project leaders met the tough lower target "by taking things out, not just by wishful thinking," she emphasized. "In fact, we built what we said we were going to do, for the price we said we were going do it. I think everybody should take pride in that, including Matt [Mountain] and Jim [Oschmann], who brought the telescope home."

Goetz Oertel, president emeritus of AURA, was another key figure in this era, working closely with Wolff and the NSF. "The politics in this project were especially complicated, with Washington and international agencies and legislators entangled in issues that were considered purely technical on most previous large telescope projects," Oertel recalled. "Leadership, good sense, an always thoroughly positive and constructive attitude, and tenacity—Sidney has these qualities in abundance, and she needed all of them."

As for Gemini today, Wolff sees a need for the observatory to do a better job of balancing its desire to exploit its unique features in image quality and infrared optimization, and its ability to have several different instruments mounted simultaneously, with the scientific benefits of providing workhorse-oriented instruments that are in high demand by the community.

"It's tricky" to find this balance, Wolff conceded. The current economic conditions also may limit the progress that can be made on some of the more ambitious instrument concepts to emerge from the Gemini Aspen process, she noted, so it may be time to "rescale" ambitions.

She also sees an opportunity for Gemini to connect effectively with the Large Synoptic Survey Telescope (LSST), an 8-meter survey telescope (see: www.lsst.org), which will share Cerro Pachón with Gemini South, and is Wolff's current project.

"It will take large telescopes like Gemini to follow up on all the transients and exotic objects that we will find, "Wolff said, since LSST saturates at magnitude 17 and reaches its faintness limit at magnitude 25/26. Gemini's ability to change instruments quickly, for example, should enable rapid follow-up of burst sources discovered by LSST. Telescopes that can support only one instrument at a time may well not have immediate access to the most advantageous follow-up instrument when a short-lived burst occurs.

After all of her years on the project directly, and then following it closely as NOAO director, Wolff has obtained only one night of data for her own science (making her partly a victim of the ongoing problem that the U.S. community is so large that very few people can make Gemini their "bread & butter" telescope, she said.) The measurements taken of stellar rotation velocities in the very difficult target cluster R136 in the Large Magellanic Cloud were very good, she said, though the data would have been even more powerful if the calibration data requested as part of the proposal had also been taken. "The Gemini staff did the hard part but not the easy part," she laughed. "Fortunately, we were able to calibrate the data with models."

In the overall picture, "I think that Gemini has been successful in doing what it set out to do," Wolff concluded. "The image quality is good, and the people who get data seem happy with it."

Looking back, Wolff remains especially proud of the technical detail and dedication that went into the nine-month study that successfully convinced an external review board and the U.S. Congress that a thin-meniscus mirror could be fabricated for Gemini and supported effectively. "I think we kept the analysis honest and really worked through the issues very carefully," she stated. "We all ended up better for having gone through it."

Finally, Wolff joked self-deprecatingly that her greatest contribution to the Gemini project was "having enough stamina to endure the controversies because there were a lot of issues. I hope that by dealing with all the political issues, I gave the engineering team enough room to do all the really hard engineering that was required."

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by David Tytell

Brent Ellerbroek: Blazing Gemini's Path to Multi-conjugate Adaptive Optics

(Opposite page)
Brent Ellerbroek

This may be an overused cliché, but when it comes to telescopes, size does matter. It's why George Ellery Hale built the world's largest light bucket, then built one larger, and then built another one larger than that. It's what brought on the age of the 8-meter-class telescope. And it's the reason scientists today are hard at work designing ways to point 30-meter-wide pieces of glass at the sky.

Regardless of how enormous an instrument is, however, all telescopes deal with the same common enemy: the atmosphere. It doesn't matter how pitch-black, cloud-free, or moonless the night air may be, atmospheric turbulence can ruin any observation. For a telescope to make cutting-edge observations, something must be done about the atmosphere. Fortunately, there is a solution. It's called adaptive optics (AO), and it is Brent Ellerbroek who helped make Gemini Observatory a world leader in the field of AO.

Since astronomers know that a star is supposed to appear as a point source, they can understand what the atmosphere is doing between it and the telescope by monitoring the star and observing the distortions. Once the character of atmospheric turbulence is understood, it can be cancelled using a sensor connected to a deformable mirror. This can be accomplished using a real star (a natural guide star, or NGS system), or with an "artificial" star created by shining a spot onto the sky using a laser (laser guide star, or LGS) system. The end result is a practically atmosphere-free observation.

Ellerbroek brought his expertise to Gemini after having already established himself as one of the world's experts in AO systems. After graduating from the University of California Los Angeles with his Bachelor's and the California Institute of Technology with his Ph.D. [in mathematics], Brent joined the Southern California-based Space Sensors Division of Hughes Aircraft Company. He later worked at the United States Air Force Starfire Optical Range in Albuquerque, New Mexico, as a civilian scientist on (at the time) classified LGS AO systems. When LGS technology was declassified in 1992, Ellerbroek was in the position of being able to share his knowledge with the world.

Photo by Rick Peterson

When he began consulting for the twin Gemini telescopes in 1994, the observatory was already developing an ambitious LGS system for Altair on the Frederick C. Gillett Gemini North telescope. As a consultant, Ellerbroek's role was to analyze various aspects of Altair to help the Gemini team make key design and construction decisions.

"From the beginning it was understood that Gemini would want to have a laser-guide-star-operated AO system," said Ellerbroek. "And Altair was built with that in mind."

In August 1999, Brent Ellerbroek joined the team full time as the adaptive optics program manager. At that point, the Altair design decisions were largely complete and the instrument was under construction at the Herzberg Institute of Astrophysics (HIA) near Victoria, Canada.

"I was effectively the technical contract monitor for the work being done at HIA," said Ellerbroek. "They were already under way in doing a good job. The basic concept had been developed, and at that point I was essentially monitoring their work, making sure Gemini would be ready to accept the instrument when it arrived."

Construction went well under Ellerbroek's watch. The instrument arrived at Gemini North in October 2002 and was mounted onto the telescope less than a month later. The first half of 2003 was spent commissioning Altair, and Ellerbroek was heavily involved. But as with any instrument integration, there were bumps along the way.

"It did take some time to tune up," recalled Ellerbroek. "Altair has many background loops that tune the control algorithms to adjust to changing atmospheric conditions. And it took a while to wring out the issues there." An unexpected delay also occurred when the diameter of a seemingly simple "pinhole" had to be changed for optimal operation of the wavefront sensor, requiring the unit to be partially disassembled and then rebuilt.

Finally, calibrating the flexure between Altair and the other instruments on Gemini proved to be one of the more time-consuming challenges. Every possible tilt configuration required its own set of deformable mirror commands to cancel the optical misalignments due to flexure at the azimuth and elevation angles. "As the Gemini telescope tips in elevation, the gravity vectors on all of the telescope's instruments change," he remarked. "There was a lot of painstaking work."

Unfortunately, not every one of the initial Altair analyses proved correct. One of the key design questions facing the instrument team involved understanding at what height to apply the corrections applied by the deformable mirror. We now know that on average, the atmospheric turbulence at Mauna Kea experiences is greatest closest to the ground.

"At the time it was thought that a dominant turbulent layer at Mauna Kea was at roughly six kilometers altitude. And on that basis, Altair had a rather innovative design with a deformable mirror conjugated to that altitude instead of the ground level. That was an example of a fairly fundamental decision, which probably wasn't backed up adequately with the data available," said Ellerbroek. "In retrospect, it would have been better if the Mauna Kea community in general had come up with a better characterization of atmospheric turbulence." The problem has since been corrected with a field lens that images Altair's deformable mirror back down to the ground level.

When asked what he's most proud of from his time at Gemini, Ellerbroek is quick to point to an instrument that's still nearing completion: the Gemini South Multi-conjugate Adaptive Optics (MCAO) system.

If bigger is better when it comes to telescopes, the same is true for AO systems. A traditional LGS system lets astronomers look at more places in the sky than a NGS system does, but the field of view is still limited to the region of space immediately adjacent to the artificial (or natural) laser guide star. MCAO systems increase that available field of view by using more lasers and more deformable mirrors to estimate and correct the full three-dimensional structure of atmospheric turbulence. In other words, more atmosphere is analyzed so more can be subtracted away.

"The thing I remember most is the work I did in transitioning the MCAO project from its original stage as a feasibility study, which was done before I arrived, to a preliminary design-level concept, which was producible enough that it could be carried forward, built, and be implemented in the near future," Ellerbroek recalled. "Had I not been involved with Gemini, Altair would have looked the way it did, and done what it did," he said. "But I don't believe the MCAO system would have looked anything like it did. It might have worked, but the design that was developed is the one that I was most involved with."

That passion for seeing designs become reality explains why Ellerbroek left Gemini in 2003. Altair was about to enter full science operations, and the design for the MCAO instrument was far along. There was, however, another adventure to be had: the Thirty-Meter-Telescope project (TMT). "I came into Gemini halfway," he said, noting that TMT "seemed like an opportunity to get in on a system at the very beginning and follow it through its evolution."

Today, the Gemini South MCAO system is leagues ahead of any other MCAO system under construction. It will likely be the first working system of its kind by a fair amount of time. So it should come with little surprise that the pioneering work Ellerbroek did for Gemini is now being applied to TMT.

"I believe, in general, the best progress is made by taking moderate steps instead of trying to be too ambitious," said Ellerbroek. "Ideally you want to try to build tomorrow's systems using yesterday's technology."

Put differently, when it comes to the next generation of AO instruments, projects like TMT are standing on the shoulders of giants like Gemini. "In many features of the [TMT MCAO] design, you'll see a family resemblance to the Gemini South MCAO system," says Ellerbroek.

Despite the excitement that comes from creating an MCAO system from scratch for TMT, Ellerbroek continues to keep a close eye on what's happening over at Gemini. "From my perspective, I continue to have a lot of interest in the Gemini AO program and in the progress of Gemini in general. I am extremely interested in the continuing progress of Altair and particularly the Gemini South MCAO system," he explained. "We feel the results obtained will be very important to TMT."

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by Aprajita Verma

Roger Davies: Gemini's Early Insider

(Opposite page) Roger Davies

As part of the events for the International Year of Astronomy (IYA) in Oxford, U.K., astronomer Roger Davies recently gave an engaging public talk on the subject of the Gemini telescopes. He regaled listeners with scientific highlights, such as the recent discovery of a planetary family made by an international team led by astronomer Christian Marois (see page 44 of this issue). As an "early insider," Davies spiced the talk with his perspectives on the technological aspects of building the observatory's telescopes, noting that Gemini's "spindly structure...still [is] a revolutionary design."

After describing the key science questions that drove Gemini's initial design, from understanding planet formation to probing the large-scale structure of the universe, he said, "That's the kind of scientific canvas that we were painting. We had to make a number of design choices." These include the fundamental decisions on the primary mirror concept or (as he put it) the "mirror wars," and the adoption of the Gillett infrared-optimized design.

Davies' intimate knowledge of Gemini, forged by years of involvement with the project since its inception, affords him a very unique perspective on the U.K.'s involvement in the Gemini partnership and the development of the observatory. In a recent interview for this profile Davies explained that the Gemini story is one of astronomical ambition and how that ambition was realized through technological development and novel design, while ensuring that the scientific needs of the partner communities were met. As one of the most influential U.K. astronomers involved with the Gemini Observatory, he has been instrumental in forging the multi-country partnership, and has held several key positions in the Gemini management structure, including the lead of the U.K. Gemini Project Office and Chair of the Gemini Board (2002-2004). He is currently the Phillip Wetton Professor of Physics, the Chairman of Physics at Oxford, and the Dr. Lees Reader in Physics at Christ Church.

As a young post-doc, Davies was inspired by the concept of large telescopes. He remembers a defining meeting at the Royal Astronomical Society in the early 1980s where U.S. astronomers presented their

Photo by Keiko Ikeuchi

ambitious concepts for 15- to 25-meter telescopes. In contrast, more modest 4-meter facilities were being discussed in the U.K., where interest was focused on building the William Herschel Telescope and exploiting the U.K. Infrared Telescope (UKIRT). The U.S. ambitions for the future of ground-based astronomy impressed Davies, and played a role in his move to the U.S. in 1982 as a tenure-track staff astronomer at the National Optical Astronomy Observatory (NOAO).

The NOAO director at that time was Geoffrey Burbidge. He recommended that Davies join a "blue-ribbon" panel of distinguished U.S. astronomers on the Scientific Advisory Committee for the National New Technology Telescope (NNTT), chaired by Robert Gehrz. The committee was charged with recommending the design that should be adopted. Davies recalls being slightly in awe of his eminent colleagues, but his participation in this committee was a terrific and intensive experience. In 12 meetings spread over 18 months, the committee determined several key parameters for the planned 15-meter-equivalent NNTT. The committee was asked (among other tasks) to decide between two revolutionary mirror designs: an underfilled aperture comprising four 7.5-meter large mirrors such as those proposed by Roger Angel (Steward Observatory, University of Arizona), and the rival 1- to 2-meter hexagonal segmented mirror concept proposed by Jerry Nelson (University of California).

In Davies' opinion, the primary mirror design was the most crucial and yet most divisive issue for the NNTT. "This was a very dramatic time," he said. "We had to go away to distant parts, and meet secretly..." Eventually, the committee announced its recommendation of the Angel concept in 1984. Unfortunately, the NNTT was not realized due to a lack of funds at the U.S. National Science Foundation, and was replaced by the twin 8-meter telescopes concept in 1987. It was this project that ultimately became the Gemini Observatory. As such, it carried forward some elements of the NNTT design, including the use of a large continuous mirror for the primary, rather than the segmented mirror that was adopted for the W.M. Keck Observatory.

The Decadal Report of the Astronomy and Astrophysics Survey Committee (a.k.a. the Bahcall Committee), referred to the 1990s as the "Decade of the Infrared," and supported many U.S. research programs optimized for this wavelength regime. This included an 8- to 10-meter infrared telescope with high image quality. Around this time it became clear that the U.S. could not build the twin 8-meter facility by itself, and the search for international partners began. Meanwhile in 1987, the European Southern Observatory announced that the Very Large Telescope project (with its plans for four 8-meter telescopes) had won construction approval. At the same time, U.K. aspirations for large telescopes gained momentum when the Science and Engineering Research Council (SERC) commissioned the Large Telescopes Panel (UKLTP) led by Richard Ellis, Jim Hough and Mike Edmunds. They recommended that the U.K. invest in an 8-meter-class facility.

On this basis, the UKLTP secured a grant of £250,000 to establish a team to investigate the design requirements, identify a site, develop a science case with respect to U.K. priorities, and find a partner in this costly endeavor. In 1988, Roger was hired back to the U.K. as the project scientist of the U.K. Large Telescope Project Office to lead the investigation together with Pat Roche and Keith Raybould. Among the challenges this team had to face was the difficult task of balancing the U.K.'s interests with two potential partnerships—with North America (U.S. and Canada) and Spain. This was a controversial issue within the U.K. astronomical community which had long standing relationships with both countries. The debate even captured the attention of the media, including a discussion on BBC Radio 4's *Today* programme, and a cartoon in *The Economist*.

After careful consideration, in 18 months this committed team had done enough for the LTP to produce an interim report that was accompanied by a detailed science case involving contributions from more than 40 U.K. astronomers. This was a significant milestone as it identified the North American partnership to be a more cost-effective and viable option for the U.K. than the Spanish alternative. Although this recommendation was originally rejected by SERC, after some careful negotiations between SERC and the UKLTP and other notable astronomers, they eventually reconsidered and approved the partnership in late 1991. For Davies, Pat Roche, Richard Ellis, and the members of the UKLTP, this was a tremendous achievement. The day the SERC stated its intention to join the partnership is one of Davies and Roche's most special memories, a point when their years of hard work had finally paid off. They, together with their families, celebrated the event at Davies' East Oxford home. During this time, Matt Mountain (then at UKIRT) made a timely phone call to enquire about the outcome of the meeting with SERC. In response, Mountain simply heard the "pop" as Roche opened a bottle of champagne!

The international agreement was signed about 18 months later and the emergence of this new alliance sparked media interest. A plethora of articles appeared in the major U.K. Newspapers (the *Times*, the *Daily Telegraph*, the *Guardian* and the *Financial Times*). Most notably, the media coverage included a leader in the *Times* on August 4, 1993, entitled "*Per Astra ad Ardua*" (a play on the motto of the Royal Air Force) that described the scientific promise of the Gemini Observatory. It is rare, perhaps only once in a lifetime, that astronomers see the fruits of their labor presented in such a public arena. It was a just reward for the efforts invested by many individuals, including Davies, Roche, and the members of the UKLTP, to secure this path for U.K. astronomy.

Davies feels that his greatest contribution to the development of the Gemini telescopes was the critical role he played in forging the partnership. The early nineties were turbulent times with discord in the U.K. astronomical community. The indecision of SERC, as well as setbacks such as Canada's withdrawal threatened the partnership. After some delicate negotiations Canada rejoined and the U.S. brought in Chile, Brazil, and Argentina, which finally established the current Gemini partnership. In 1998, Davies's connections with the Australian astronomical community helped to bring in a new partner and an additional 5% cash injection into the Gemini project.

The telescope concept quickly began to take form in the years that followed. However, it was a continuing source of contention in the community, Davies recalled. Controversially, in the case of the primary mirror, the newly formed Gemini partnership rejected the Angel concept (approved for the NNTT) in favor of procurement from the commercial supplier Corning, causing outrage in the U.S. community.

In the U.K., Davies recalled that the community was divided on the issue of the telescope design. The two main ideas being discussed were a scaled-up version of the Royal Greenwich Observatory's William Herschel Telescope, and an innovative infrared-optimized telescope design being proposed by Frederick C. Gillett and Frank Low. The latter design was not primed for wide-field survey science, which had historically been a strong and active area of research by the U.K. community. At a meeting in Oxford (see article in this issue pg. 42), host of the U.K. Large Telescope Project Office and later to host the U.K. Gemini Support Group, the Gemini Partnership made the pivotal decision to adopt the Gillett and Low design, understandably causing some discontent in the U.K. community. However, as Davies explained, "The fundamental issue was to maximize the performance of the telescope, in particular exploiting the key uniqueness of the Mauna Kea site in delivering exceptional image quality."

Gillett and Low's innovative design provided the means to achieve this goal and ultimately resulted in Gemini's excellent performance in this regime. The design was unlike any other large telescope at the time. The prioritization of infrared image quality determined all aspects of the telescope design. This included the primary mirror being positioned close to the elevation axis, without Nasmyth foci, but with a Cassegrain focus. It also included the undersized secondary mirror, silver-coated primary mirror, and immense dome vent gates which allow air to flow freely over the mirror. Davies said, "This [Gemini] is a revolutionary design. Every aspect of the telescope is aimed at delivering outstanding image quality and sensitivity in the infrared." In essence, the Gemini telescopes encapsulate Bahcall's vision of the "Decade of the Infrared."

From a technical viewpoint, achieving the image quality requirements and low emissivity goals have been the most challenging issues in Gemini's design. It is this prioritization, and the fact that it *is* possible to achieve good image quality, that has influenced the way people think about requirements for future ground-based facilities.

In addition, Gemini has been at the forefront of adaptive optics research and development. Both active and adaptive optics have been ingrained within Gemini's design, culminating in 2006 in the extremely successful laser guide star system. Gemini outperforms many of its rivals and even goes far beyond the original specifications in image quality. Davies cites the ground-breaking detection of the first planetary family with Gemini as testament to the quality of Gemini's imaging performance.

Davies also highlights the detection of old stellar populations at high redshift in the Gemini Deep Deep Survey (GDDS) and the spectral confirmation of the most distant supernovae in the Supernova Legacy Survey (SNLS) as significant advances in our understanding of galaxy evolution and observational cosmology. Both of these programs were conducted with the Gemini Multi-Object Spectrograph (GMOS) instruments, Gemini's workhorse optical instruments and the only instruments that are duplicated on both Gemini telescopes. Davies was the U.K. principal investigator of GMOS, which was built in a joint venture with Canada, led by David Crampton (see profile on David Crampton starting on page 16 of this issue).

Isobel Hook has led the follow-up study of more than 200 supernovae from the SNLS with GMOS, and played a key role in the commissioning of the instrument and analyzing some of the first spectra taken. "Commissioning GMOS was very intense work but the reward of seeing the first data appear was fantastic," she said. The SNLS and GDDS science results were only possible through GMOS's ability to perform observations with the sensitive nod-and-shuffle technique. Although not foreseen at the time of the instrument's design, the GMOS detectors were fortuitously arranged such that the slit is perpendicular to readout direction. This allows the charge to be shuffled in the CCDs. At present Gemini-GMOS provides the only means to perform sensitive nod-and-shuffle observations on 8- to 10-meter-class telescopes.

The GMOS integral field units (IFUs), the first such devices on 8- to 10-meter-class telescopes, were designed and built at the University of Durham during Davies's professorship there by a strong team, including Jeremy Allington-Smith (the U.K. instrument scientist for GMOS and past member of the U.K. Gemini Project Office). "It was great to work with Roger on the two GMOS instruments which turned out so well," Allington-Smith said. "Roger is energetic and enthusiastic, an inspiration to all those who work with him."

At the end of his term as Chair of the Gemini Board in 2004, Davies officially completed his formal roles in the management structure of Gemini. Nevertheless, he remains a strong advocate and a keen proponent of the U.K.'s continuing role in the Gemini partnership.

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by Peter Michaud

Creating a More Perfect Machine

Four hundred years ago, one man fashioned a simple telescope from two small pieces of glass. Using this new invention, Galileo Galilei was able to set humanity on an irreversible course of exploration unparalleled in the history of science. (see article in this issue starting on page 7.)

As the 20th century came to a close, the generations of telescopes built since Galileo's have culminated in giant 8- to 10-meter optical/infrared light collectors perched on remote mountaintops across the globe. The contrast between Galileo's simple telescope and today's super-sized instruments couldn't be more profound. Where Galileo worked essentially alone and pointed his telescope with a simple nudge, today's telescopes require teams of engineers, scientists, and support staff to maintain and operate the multi-story-high harvesters of light that are aimed with nearly infinitesimal precision.

The design and building of the twin Gemini 8-meter telescopes consumed the energies of hundreds of individuals who were committed to revolutionary new ideas and approaches that define the current generation of large telescopes. Unlike the instruments of past generations, Gemini and other large facilities were built by teams of engineers who excelled at managing large complex projects. They worked in concert with scientists from around the world to create ever more *perfect machines*.

This article follows in the spirit of the profiles already presented in this issue of *Gemini*Focus and continues the story of Gemini's design, development, and construction from the point of view of five of Gemini's most influential "creators" (see interviewee's bios throughout this article). Like everyone profiled in this issue, all five of these creators are quick to point out that what they did to build Gemini represents the work of a remarkable team, a team that, in the words of Rick McGonegal, "...was one of the better teams I ever worked on, in terms of everybody being willing to step up and help out or give something to the other guy."

A New Kind of Partnership

For a project like Gemini, the job of designing, building, and refining such a complex scientific instrument required a new kind of partnership–one that engaged multiple countries and experts with experience in professional project management. This focus on project/systems management and discipline is a constant refrain when talking to the team that built Gemini. The need for a different management paradigm for large telescopes like Gemini required a new mindset for astronomers. Dick Kurz reiterated this point: "It is a fact that all of them [the current generation of large telescopes planners] had in common, to differing degrees, ...the recognition that a project of this magnitude takes, if you like, professional management [and] professional system engineering to really carry it off."

In a similar vein, Jim Oschmann laughed when he recalled his job interview for the systems engineer position at Gemini. Someone on the hiring committee confessed to him, "Well, we've been told to hire a systems engineer but to be honest we don't know what they are." As it turns out, the advice about hiring a systems engineer was sound, and the collective project/systems management skills that saturated the early team served Gemini extremely well.

This fact would manifest itself over and over again during Gemini's development; but it was especially apparent when it came to the big picture, and the fact that the project was able to stay on budget and keep very close to the original schedule despite many seemingly overwhelming challenges and constraints.

Mirror, Mirror

The most formidable challenge was–without a doubt–the contentious fight over the selection of the telescope's primary mirror technology. The argument was whether to use a thin meniscus mirror (the technology ultimately adopted for Gemini) or use a lightweighted spin-cast mirror from the mirror lab at the University of Arizona. This controversy was truly a potential show-stopper for Gemini and profoundly impacted the project. Within a week of starting at Gemini, Jim Oschmann remembered wondering, "Oh my god, what have we gotten ourselves into?" In hindsight, however, he pointed out that the project came out technically stronger. "We were also stronger in our ability to communicate with a broad group of people – and help get them onboard," he said.

This issue kept everyone cautious including then-director of Gemini Sidney Wolff. According to Kurz, after he was offered a position at Gemini, Wolff told him about an upcoming review on the selection of mirror technologies and said that "...anyone who took this job before the results of the review were done is absolutely crazy!" (An

Dick Kurz: With a background in high-energy particle physics, Dick Kurz's diverse career has included work as a cosmic-ray physicist at NASA and TRW developing space instrumentation, including one that he said, "…is still running on the Voyager mission." Since leading the engineering effort at Gemini from late 1993 until 1998 as the project's second project manager, he went on to ESO and oversaw the formation of the European side of the ambitious ALMA project in Chile.

Figure 1.
The Gemini South mirror as it emerges from the coating chamber with a fresh coat of protected silver. The coating technology developed at Gemini has resulted in highly durable coatings that have exceeded expectations in performance and is being adopted by other projects like the Thirty Meter Telescope currently under development.

excellent treatment of the Gemini "mirror controversy" can be found the Patrick McCray's book *Giant Telescopes* published by the Harvard University Press.)

As the heart of any telescope, the mirror reflects more than just starlight. In Gemini's case, the mirror is a reflection of innovation and a mindset to experiment with new ideas. Nowhere is this more apparent than in the decision to coat Gemini's mirrors using protected silver in order to meet the strict infrared performance goals set by Fred Gillett and recommended in the Bahcall Report Decadal Survey. Keith Raybould, who spearheaded much of the early work on selecting a sputtering-based coating chamber, has the air of a proud parent over the news of successful silver coatings now lasting three to four years at Gemini. "That's remarkable," he said. "I would never have thought it would have lasted that long. It was very difficult to get the protective layers that would provide a coating that we thought was as durable as aluminum which are the typical coatings of a primary and secondary [telescope mirrors]. That's tremendous!"

Larry Stepp (currently at the Thirty Meter Telescope) pointed out that other telescopes will profit by this success: "We are planning to have similar coating capabilities for the TMT mirrors, using a protected silver coating process that's very similar to that developed by Gemini," he said. "I think that has been a true contribution to the field of astronomy and telescope making."

Today, thanks in large part to the silver coating technology developed at Gemini, the total optical system's thermal emissivity is about 3%; significantly better than any other ground-based telescope and below the value specified in the early Gemini plans.

A Secondary Issue

Of course, bold success is sometimes tempered, and Gemini's secondary mirrors were less successful. Larry Stepp summarized the

Jim Oschmann: After spending 10 years at Gemini, Jim (Jacobus) Oschmann left Gemini in 2002 as Gemini's project manager and associate director of engineering. Since then he has worked as the project manager at the National Solar Observatory and is currently at Ball Aerospace & Technologies Corporation as vice president & general manager for Antenna and Video Technologies. Jim's background in optics and systems engineering began before Gemini at TRW, where he spent some time working under Dick Kurz who is also featured in this article.

situation quite well, “One disappointment was that we intended to provide silicon carbide secondary mirrors because the chopping and fast-tilt secondaries needed to be stiff and light-weight to give good dynamic performance,” he said. “We believed that we were going to be able to get silicon carbide mirror blanks because there were several blank suppliers who said they could provide one-meter-size silicon carbide optics but unfortunately it proved that we were ahead of our time; those types of mirrors are currently available today but they weren’t available in the mid-90s.”

Today, lightweight-honeycomb glass-ceramic mirrors are being used at Gemini as a compromise replacement rather than the envisioned silicon carbide mirrors. However, they do deliver most of the original design specifications.

An Environment for Excellent Images

In comparison to the secondary mirrors, the Gemini enclosures (domes) are another undisputed success. They have helped revolutionize how observatories approach the control of the thermal environment surrounding an astronomical telescope.

“The most distinctive, or the biggest, difference from the other telescopes of exactly the same generation was a very early appreciation for the need to completely flush the dome to maintain as close to open conditions as possible,” said Dick Kurz. This attention to the thermal environment was, according to Kurz, a key factor in achieving Gemini’s stringent image-quality goals. “What in past generations of telescopes had been negligible thermal effects were very much no longer negligible and had to be solved.”

Keith Raybould added that image quality was really the big driver of almost all of the systems. “It just went through everything,” he pointed out. Achieving the image quality targets set for Gemini (50% of light in 0.1 arcsecond at 2.2 microns, with a total telescope system

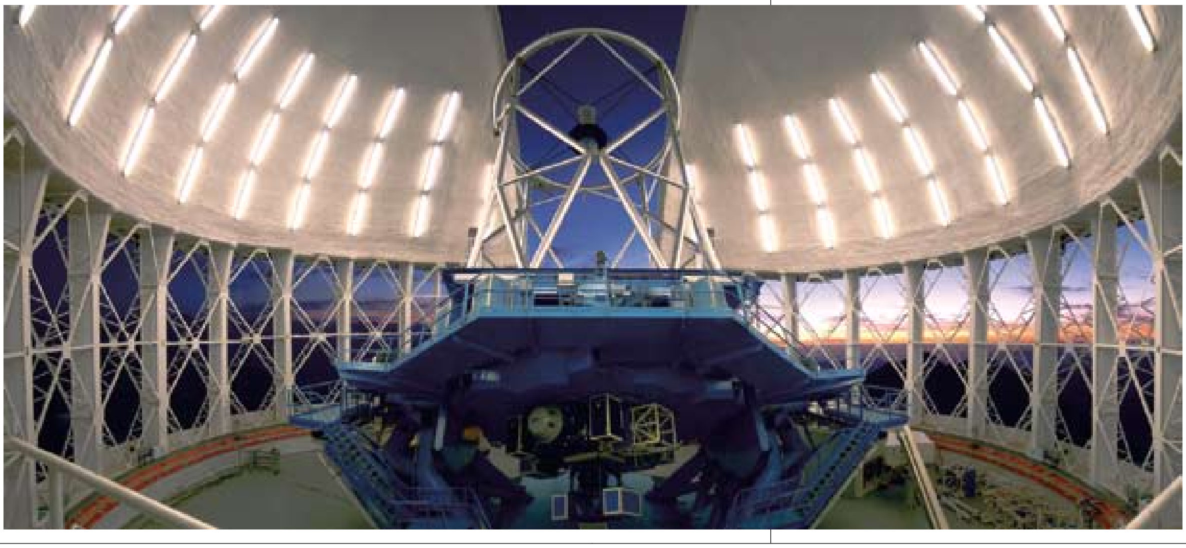

Figure 2.
Gemini South telescope with ventilation gates open for effective cooling of the telescope structure and optics to ambient nighttime conditions. Also apparent is the structure of the telescope which is comparatively lightweight and therefore of low thermal mass which also contributes to an excellent environment for optimal image quality.

Keith Raybould: For the past ten years, Keith Raybould has been chief operating officer at the Monterey Bay Aquarium Research Institute in Monterey Bay, California, developing technologies and test beds for ocean observing systems that, in his words, are: "looking into the ocean depths instead of looking upward to the skies." The ocean observing technologies are being developed to prove the feasibility for an upcoming NSF MRE-FC (major research equipment and facilities construction), project called the Ocean Observing Initiative (OOI). Earlier in his career he worked for the U.K. Large Telescope Project team based at Oxford University and managed the technical developments for a proposal that led to a recommendation that the U.K. partner with the U.S. and Canada on the Gemini project. He joined Gemini in 1991 to help lead the engineering group during construction and stayed until construction was complete in 1999.

Figure 3. *Gemini North telescope showing the ventilation gates fully opened for a night of observations. The support building for the Gemini North enclosure is more compact than at Gemini South due to budgetary constraints in the early development of the project.*

thermal emissivity of less than 4%) was at the core of every error budget. The strict implementation of an error budget was a discipline brought to the project by system engineers experienced in managing complex technical projects. "The error budget for Gemini was very, very rigid," recalled Rick McGonegal. "The error budget became a discipline, trying to prove that you were going to match your error budget, but of course if you've been though these kind of engineering exercises before nobody ever meets their error budget! But, the fact that you have one and everybody's working on it means that in the end somehow it all comes together."

Of course, Gemini's image quality standards were eventually met, but not everyone beyond Gemini's offices shared the team's confidence, as expressed by Rick McGonegal: "As far as I can tell, the imaging and all of that kind of stuff probably outperformed the expectations of people outside of the project," he said. "But, I think inside of the project we were always pretty confident that we could do this."

According to Jim Oschmann, one of the challenges during the commissioning of the optics (when the mirror was being used in open loop mode, without real-time image quality (wavefront) feedback) was meeting project expectations for image quality. "The basic telescope image quality at 2.2 microns was very difficult, not only to meet but to prove we made it," he pointed out. "It was almost impossible to prove in the early years, and I think only over a long period of time with a lot of statistics could you eventually tweak the telescope and have enough data to ensure that indeed it is there, because when you're measuring the total system performance you have the atmosphere [to contend with]. You're kinda chasing your tail a bit in the early months."

A Difficult Start

In retelling the story of a successful large observatory, it is easy to focus on the shiny mirrors and high technology, but lose sight of what might at first blush seem mundane. However, in stories like one told by Keith Raybould, the spirit of the early Gemini team becomes apparent. His preface to the story says it all, "Whenever times get difficult, I always reference back to this [story] because I don't think anything could get as difficult in some sense."

It was late in 1994 when construction was about to start on Mauna Kea and preliminary road and utility work was beginning. "At the same time, we were getting the bids back on the building. The budget was about six or seven million dollars," said Raybould. When the bids came in they were over 10 million dollars more than the budget allowed. "I got those bids on a Tuesday, and we had the full Board meeting on the Thursday of that week!"

Compounding this issue, snow started falling on the mountain, and the contractor working on road and utility modifications reported that their equipment was not suitable for working in such conditions and would cause a significant delay in construction preparations. The team members were in a bind. They had two days before a report was due for the Board, and they had to find solutions quickly that would address the budget shortfall and the real-time unfolding of winter weather complications. In the end, the solutions hammered out by the team over those 48 hours solved many other related problems and made the facility more compact and arguably even more functional and efficient than originally planned. According to Raybould, "We probably saved between eight to 10 million, and it was eight to ten million we didn't have!"

Moving Mirrors

Life was never mundane for the early Gemini team. Logistical coordination for building two telescopes on both halves of the globe was a great challenge and as complicated as might be imagined. Nowhere is this better illustrated than with the transportation of the Gemini mirrors and the challenges they faced. In Chile, the planned construction of a new dam was going to literally flood the existing road to the mountain. A new tunnel was being planned (to Chilean engineering standards) that would not accommodate the width of the Gemini loads. "I was with Paul Gillett looking at different alternatives as soon as we heard that the tunnel was going to go in; that was a real surprise. We looked at whether we could move by helicopter, by hovercraft, all sorts of things," said Raybould. "In the end, the cheapest option was to pay the Chilean government a certain amount of money to redesign the tunnel so we could get the mirror through."

Larry Stepp: Larry Stepp's career in optomechanical engineering led him to NOAO in Tucson where he helped write the original proposal in the late 1980's for an 8-meter telescope project that would ultimately evolve into Gemini. Larry joined Gemini in 1991 as the Optics Group manager and since leaving in 2001, he led the AURA New Initiatives Office for a period and is now heading up the Telescope Department for the TMT out of the Pasadena California office. He says that he, "would welcome the chance to return to Hawai'i someday" for TMT.

Figure 4.
The Gemini South mirror being transported through the Puclaro Dam Tunnel which was enlarged from its original 8-meter width to 10 meters to accommodate the Gemini loads to Cerro Pachón.

Prior to Gemini South's mirror transport through the widened tunnel to Cerro Pachón–and after a long journey on barges in France and deep within a huge ocean-going cargo ship (which, according to Larry Stepp, was probably 1,000 feet long)–it arrived in the middle of the night at the port of Coquimbo, Chile, and was greeted by a group of anxious VIPs and the logistics team. "They made the unusual courtesy of letting some of us come up onto the ship and look into the top portion of the hold where the mirror shipping container had been welded in place on top of a stack of containers," Stepp recalled.

After the crew hooked up the ship's crane to the mirror crate, Stepp immediately headed back to watch the mirror's arrival on the dock. "When the crane operator got the go-ahead, he picked the mirror up, swung it over the side, dropped it down to the pavement, and stopped it about ten inches above the concrete," he said. "He did all of that in about 15 seconds. And it flabbergasted those of us who expected the operation to take half an hour!"

Meanwhile the VIP entourage was still looking into the emptied cargo hold while, Stepp said, "The mirror was set down on the concrete below. It scared me to death, because it was coming down at a good rate of speed and it only stopped at the last moment just before reaching the level of the concrete, and he set it down very gently."

Once the mirrors were safely delivered in both Hawai'i and Chile, the concern for their safety wasn't lessened. Jim Oschmann pointed out that during the delivery process many of the optical contractors actually walked on the mirror's surface. "I've never walked on the mirror," he said, chuckling. "Larry Stepp has walked on the mirror!"

At the time, Larry remembers worrying every time the mirrors were handled and joking that if anything happened, "...it would be at LEAST seven years of bad luck!"

Richard (Rick) McGonegal: With a background in Astrophysics, Rick McGonegal's career has followed an interesting path that led him first to CFHT for about 10 years prior to coming to Gemini to lead the software group during the construction phase of Gemini. He spent from 1992 through 1998 at Gemini, followed by a period in Silicon Valley in the telecommunications industry (and Y2K work) prior to the dotcom bust. Since then he has been working for RCG Information Technology, a U.S.-based Information technology solutions services company with an offshore office in Manila, the Philippines, where he currently resides and serves as the company's president and managing director.

With the mirrors delivered and during the period of Gemini's commissioning late in the 1990s, the ramp-up toward scientific operations began in earnest. The challenges of instrument delivery and integration complicated the situation and added a level of concern for the team. However, work went ahead on integrating operational modes and transitioning the observatory's staff into a fully functioning astronomical observatory.

Changing a Culture

Arguably the most controversial issue was the plan to make queue, or service observing, a major component of Gemini's operational philosophy. Rick McGonegal recalled his early thoughts on implementing this new approach for ground-based astronomy: "Inside the project, a number of us were kind of like, you know, that's never going to work (laughs). But it did. That's the part to me that outperformed it all, because doing that really requires a cultural change [one] that I never thought you'd overcome."

Today, more than 90% of Gemini's observations are queue-based. Similar situations have occurred at other observatories where queue scheduling is being used. From his perspective at the European Southern Observatory's (ESO) Very Large Telescope (VLT), Dick Kurz reflected on the change in attitude toward queue observing. "[There was] a lot of skepticism in the European community about queue scheduling, (service observing), for optical telescopes," he said. "Now it is very much the other way around, ESO has to resist… I think they still try to limit service observing to 50% of the time on the VLTs, but the community now would go to practically 100% queue (or service) observing if they had their choice [but] ESO doesn't have the necessary personnel or resources to support that."

Success Breeds Success

Certainly in shepherding in the cultural transition into queue, (or service) observing, one of the legacies of Gemini will be in the experience gained by successfully implementing this operational mode for a ground-based optical/infrared observatory. Another legacy that McGonegal sees is how the success of Gemini (and all of its generation of large telescopes) impacts the even larger telescope projects now on the drawing boards. "I think we showed it can be done, that we can take these extremely sophisticated technologies and produce extremely high image quality from the ground," he said. "If you look at Gemini, Keck, Subaru and VLT, none were a failure. All of these 8-meter-ish-class telescopes, if they hadn't been successful, I don't think the next generation of larger telescopes would have gotten funding."

Collectively, what became known as the "8-meter Club" (consisting of Gemini, VLT, Subaru – with Keck as an honorary member), created a powerful *ad hoc* consortium. "I was very impressed with ESO, with how willing they [were to share] in annual and semi-annual meetings, where all the big telescopes guys got together and basically opened the kimono and talked about what's really working and what's not working, without the people that would object to us talking about that stuff being in the room," said McGonegal. He was also impressed with the 8-meter community's willingness to talk about what's going on. Although, McGonegal said, "You can't point to any one thing and say 'oh jeez we saved X million dollars because of this,'"

People, Pets and Partners

A final theme that permeates discussions of the early Gemini team is the subject of interpersonal relationships that developed, and the friendships that formed, especially among spouses of team members. Spouses, children, and even pets all contributed to Gemini in a manner that was not always obvious. "We moved, I don't know, 20 to 30 families to Hawai'i and had to be concerned not only about the children in schools but their animals. We had four animals in quarantine, we took turns saying 'hi' to everyone's pets," said Oschmann, who recalled another story of how his wife Michelle became a bit more familiar with the technical aspects of Gemini than maybe he would have intended. As was quite common during commissioning, Oschmann was called in the middle of the night to help solve a problem. Upon awakening and listening to the conversation, Michelle made a suggestion: "Just tell them to turn the wavefront sensor on; it'll work!" she said. Oschmann laughed and added, "And we were talking about wavefront sensing and adaptive optics so that was kinda funny. It was like, 'Oh no, she's been around this too long!'"

In the end, Larry Stepp puts the evolution of Gemini into perspective in his usual succinct and crystallizing manner: "When we were involved in building the telescopes, our entire world was telescope building. Of course, the real purpose for the observatory is not to focus on the construction of it but [to] focus on the 50 years of science it's going to produce. And so it's quite a different perspective to be on the team that's building it with the goals of the construction as opposed to the team that then operates it for decades in successful science."

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Figure 5. *Gemini legacy image of the Orion bullets which demonstrate the extremely high image quality obtained at Gemini as a result of infrared optimization, thermal control, and adaptive optics. Gemini North Laser Guide Star/Altair/NIRI image.*

The following scenario illustrates the Gemini operational vision written in 1995 by Rick McGonegal...

"It is nightfall on Cerro Pachón and the systems operator and staff astronomer are working through the beginning of the night's queued observations. While the system operator is watching the satellite weather map to see how long the current conditions will last, the service observer is discussing with his colleague in La Serena which mix of observations will make the best use of tonight's conditions. They re-run a couple of options through the automatic scheduler since the Hilo crew has asked if Gemini South could run through a few calibration observations to complete last night's Mauna Kea file.

In the same room, an engineer is trouble-shooting an off-line instrument via a videoconference link to the Mauna Kea base facility, where the expert for this instrument is currently working. They compare notes, decide that it is the same problem fixed earlier this month on Mauna Kea, and transfer the patch file.

A few hours later, as the Mauna Kea system operator is running through the nightly start-up calibrations of the telescope pointing and image quality, the system operator for Cerro Pachón starts up a video link. She is having problems with the M1 support system and wants to consult.

While the Mauna Kea telescope automatically runs through its calibration procedure, the two system operators decide that it is the active actuator system that is causing the problem. As the Mauna Kea system operator has been through this procedure before, he logs into the Cerro Pachón M1 support system, using an engineering display and has a detailed look at the actuator's performance. Isolating it to a particular actuator which is misbehaving, he advises the Cerro Pachón system operator how to turn that particular actuator off.

The Cerro Pachón system operator does so and then logs the problem in a distributed problem reporting system that will be used the next day by the day crew and engineering team to repair or replace the actuator.

As the service observer on Cerro Pachón is starting an infrared spectroscopic observation of a high redshift galaxy, it become obvious that there is something peculiar about its emission lines. The service observer decides that it is worth calling the principal investigator in Cambridge, England. After a brief teleconference discussing the different aspects of the spectrum, the PI decides to log on from home and remotely look at the extracted spectrum himself."

by Gordon A. H. Walker

When Gemini Came Into Focus:
The November 29, 1990, Oxford Science Meeting

The first-ever Scientific Advisory Committee (SAC) meeting for the twin 8-meter telescopes project, then known as LT (for Large Telescope, "Gemini" was adopted two months later) began on a cold, grey, damp morning in the Nuclear and Astrophysics Laboratory, Oxford, U.K. (see Figure 1). A session in early September 1990 at the Dominion Astrophysical Observatory in Victoria, British Columbia had been largely devoted to attempting to divide the engineering effort between the partners, but it had also charged the SAC to establish firm performance specifications for the engineers.

In the U.S., the project was essentially the responsibility of the Association of Universities for Research in Astronomy (AURA). Pat Osmer was overall project scientist (PS), and he came to Oxford with Richard Green, the U.S. project scientist, Fred Gillett, and Bob Schommer (of Cerro Tololo Inter-American Observatory (CTIO)). I attended as the Canadian project scientist and René Racine was the other Canadian present. Roger Davies was the U.K. project scientist and attended with Pat Roche, Richard Ellis, and Ian Parry. Also from the U.K. was Keith Raybould, who was considering 8-meter telescope designs and who would go on to be a key player in the success of Gemini. Richard Bingham and Pat Wallace were also there, along with Matt Mountain who had come from Royal Observatory Edinburgh to talk about infrared spectrographs.

We were not alone! There was more than one elephant in the room. Keck had achieved first light just a few days earlier with nine of their 36 mirror segments (full first light would not be achieved until April 1992). The U.S. National Science Foundation (NSF) wanted to know why we would not simply adopt the "proven" Keck segmented 10-meter design and thereby save both time and possibly money. As NSF was the only one with any large telescope funds, they were quite entitled to ask that question. In the October 1990 Congressional markup, $4 million (U.S.) had been set aside for large telescope engineering studies and the purchase of glass, provided there was a satisfactory 50:50 cost sharing between the U.S. on the one part and the U.K. and Canada on the other. Otherwise, there was only $2 million and a cap of $88 million for a single Northern Hemisphere telescope. While there was priority in the U.K. for a large telescope, their senior committee had yet to decide between the U.S.-U.K.-Canada collaboration or one with Spain on La Palma. A decision was expected in December 1990 (but that didn't happen). The Hubble Space Telescope, launched six months earlier, was too bleary-eyed from spherical aberration yet to set it apart in optical resolution, but it remained a potential competitor for imaging (correcting optics were installed three years later in December 1993).

Figure 1. *The Nuclear Astrophysics Laboratory, Oxford U.K.*

That first morning, Fred Gillett and René Racine presented two basic sets of science requirements which, to be met, would demand some ingenuity. Gillett made the strong case that optimum thermal infrared sensitivity required ultra-low emissivity from the telescope mirrors, a large Cassegrain focal-ratio (f/15), a marginally undersized secondary, a small central hole (1.6 meters) in the primary, and images close to the telescope diffraction limit. Only then could we approach the huge potential D^{4} advantage in exposure times (D is the primary mirror's diameter) relative to other large telescopes. The low emissivity level of the Mauna Kea sky dictated an overall reflectivity of › 96% - equivalent to a 4% emissivity. While there was wide appreciation for the remarkable results coming from infrared observations and the development of increasingly large, low-noise detector arrays, at that time there were few infrared astronomers in Canada—where interest was overwhelmingly in the optical.

René Racine then laid out his requirements for optical imaging. His qualifications were unmatched, having been director from 1980 to 1984 of the Canada-France-Hawai'i 3.6-meter telescope, which provided a benchmark of optical performance. He had assessed the contributions to image quality from telescope aberrations, dome and boundary layer seeing, and presented convincing evidence that natural seeing ‹ 0.35 arcsecond occurred some 25% of the time. He proposed a requirement that the image quality delivered by the large telescope must not degrade the best natural seeing by more than 10%. This demanded an image size of ‹ 0.1 arcsecond, similar to Hubble! Racine had been a vocal skeptic of the large telescope and this was his challenge. He made his case and the SAC had no trouble adopting it.

Racine's work with rapid guiding had shown, as had others (such as the Roddiers at the University of Hawai'i), that the introduction of adaptive optics (AO) on large telescopes was inevitable. Adaptive optics correction (as then envisaged) was really only possible over the few seconds of arc covered by the isoplanatic patch (i.e., where atmospheric aberrations are instantaneously the same), so the large focal-ratio infrared field would be ideal. The much later successful introduction of laser guide stars allowed not only greater sky coverage, but also much larger fields. The final optical specification was 0.07 arcsecond full-width half-maximum (FWHM) images with AO over a narrow field, and 0.1 arcsecond images over a narrow field. These also satisfied the needs of the thermal infrared.

The need for extra-high reflectivity led to the development of special silver coatings and the process for regular cleaning of the mirrors. To preserve as much of the ultraviolet part of the spectrum as possible, the silver needed to be specially overcoated. As AO was only expected to be effective at red/yellow and longer wavelengths, the loss of the ultraviolet was not considered a major sacrifice.

It would take another six years for the science requirements document to be completed (see: **http://www.gemini.edu/science/scireq3.html**), by which time it ran to fifty pages. However, those first few hours in Oxford set the most critical requirements for image quality and reflectivity and were essentially those eventually achieved now at the Gemini Observatory. For the thermal infrared, an emissivity of ~3% is regularly achieved from the primary/secondary combination, f/16 was the final focal ratio adopted and the hole in the primary is just 1.18 meters in diameter. All of this is even better than Fred Gillett had hoped for.

Pat Roche took us to an excellent pub that evening. I might have been less relaxed if I had known that Canada would withdraw from the project, albeit temporarily, only a few months later. But, that's another story!

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by Christian Marois

An Exoplanet Family Portrait

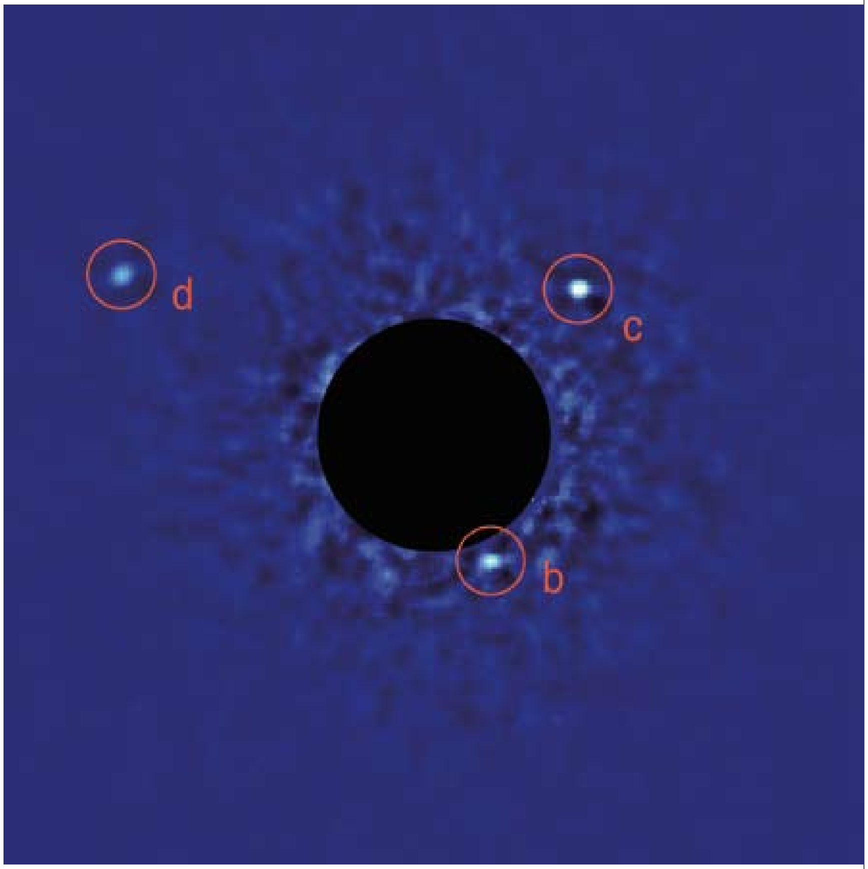


Figure 1.
A K-band (2.2 microns) AO image of the HR 8799 planetary system made using Gemini/Altair/NIRI and acquired on September 5, 2008 (North is up and East is left). The three planets are designated with red circles. The stellar flux has been subtracted using ADI (see text for details) and the central saturated region is masked out. Multi-epoch observations have shown counterclockwise Keplerian orbital motion for all three planets.

What do planets around other stars look like? This question is driving an exciting quest to take pictures of exoplanets. This is challenging work. Until recently, surveys using direct imaging have uncovered only a few candidate worlds–even after much intense effort. These possible planets have been found in systems that are unlike our own in many ways. In addition, there is usually only one candidate world orbiting its parent star, and often it lies at a very wide separation (or distance) of more than 100 astronomical units (AU).

Our team used the Gemini Observatory to capture a spectacular image showing not one, not two, but three planets in orbit around the star HR 8799. They lie at distances similar to those of the outer planets of our solar system. This is the first image of a multi-planet system, and these exoplanets are also the first at separations similar to Uranus and Neptune (which orbit the Sun at 20 and 30 AU, respectively) to be discovered by any

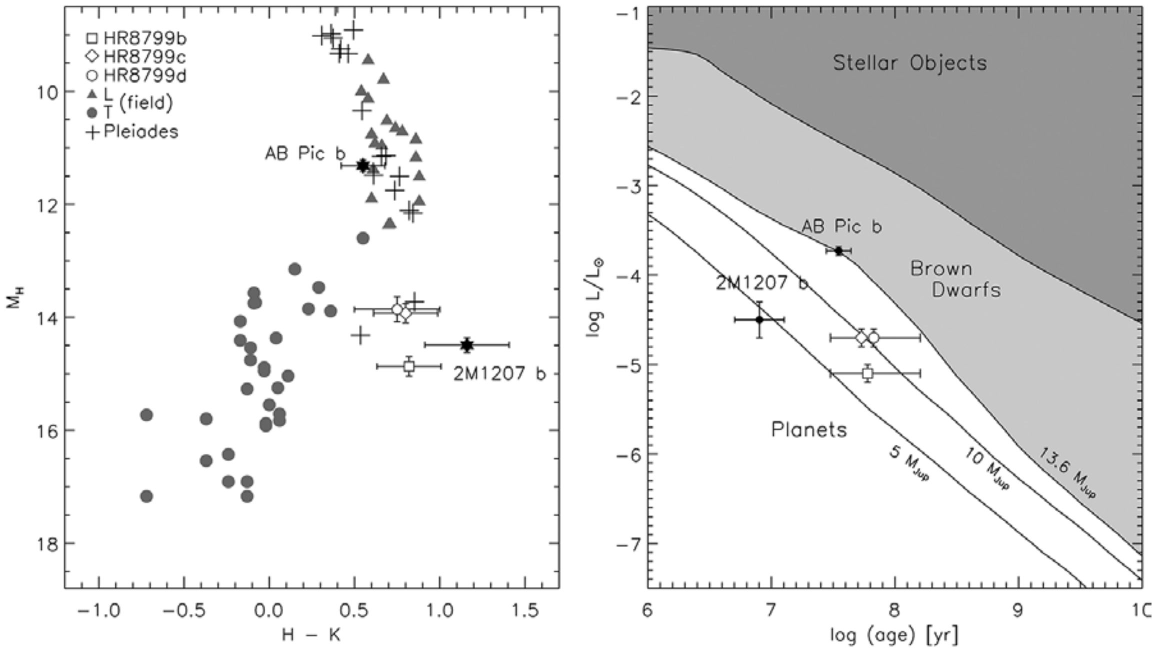


Figure 2.
Left: the planets' infrared color. Lower-mass objects, like 2M1207b (a 7 Jupiter-mass companion to a brown dwarf) and two ~ 11 Jupiter-mass Pleiades candidate members exhibit similar characteristics as the HR 8799 planets. Right: HR 8799 planets plotted on exoplanet cooling tracks. For the estimated age of the system (60 million years), our derived luminosities are consistent with masses between 7 and 10 times that of Jupiter.

means. The near-infrared K-band (2.2-micron) image of the planetary system (Figure 1) was obtained using the Gemini North telescope, the Altair adaptive optics system, and the Near Infrared-imager and Spectrometer (NIRI).

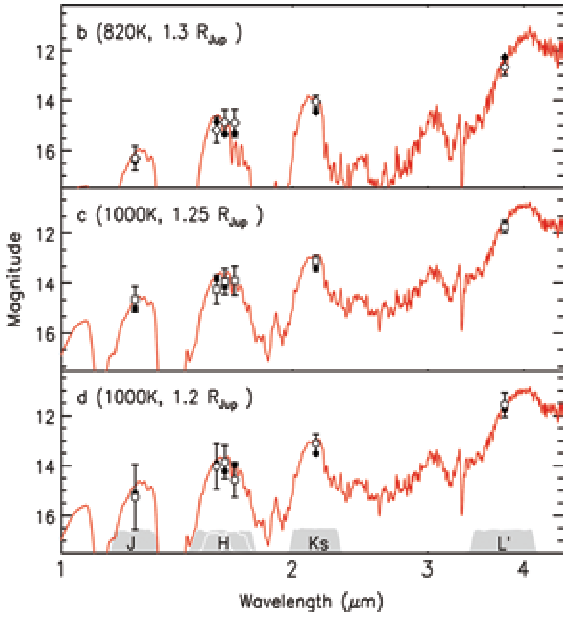
The three planets were found using the "Angular Differential Imaging" or ADI observing technique, which works as follows: after correcting for most of the turbulence in Earth's atmosphere with an adaptive optics system (like the National Research Council Canada Herzberg Institute of Astrophysics' (NRC-HIA) Altair system used on Gemini North), the major component of residual "noise" in the image is stellar light scattered by surface irregularities from the telescope and instrument mirrors and lenses. This residual noise, because of its origin, has a fixed pattern with respect to the telescope and camera orientation. To separate out any possible planets from scattered starlight, the ADI technique relies on the slow rotation of the field of view (induced by the motion of the Earth) that occurs during tracking with an altitude/azimuth telescope. While guiding on the star to keep it registered at the detector's center, the planets appear to slowly revolve around the star and against the fixed pattern of stellar scattered light due to the field rotation. Computer software is then used to analyze a sequence of many images and subtract the scattered stellar halo and reveal any previously undetected nearby faint objects. The overall contrast gain with ADI is a factor of 10-100. This is a major improvement that has opened a new regime, allowing us to search for planets at separations and contrast levels around stars that were previously unreachable.

For the past several years, our team has been involved in two ADI surveys on large 8- to 10-meter telescopes. Our initial ADI survey—the Gemini Deep Planet Survey, led by David Lafrenière—involved the observation of 85 nearby (< 25 parsecs) and young (less than 100 million year old) stars similar to the Sun with the Gemini North telescope. No planets were found, but good upper limits were derived: less than 8% of Sun-like stars have a greater than five Jupiter-mass planet in orbit between 30-300 AU. To remove the late-type bias of the original survey I am currently leading a second survey that is focusing solely on massive young nearby stars—this time using the Gemini, Keck, and Very Large Telescope facilities.

Anatomy of the Discovery

The star HR 8799 was one of the first stars observed. The main reasons for its selection are simply its proximity (it lies 39 parsecs away), its estimated young age (~60 million years), and its infrared excess—evidence that dust is orbiting the star and a possible indicator of planet formation. Two of the three planets were initially found using data acquired at Gemini on October 17, 2007. The system was then studied again in follow-up observations using the Gemini and Keck II telescopes. The outer two planets were also recovered in archival 2004 Keck data and the outermost one found in Hubble Space Telescope data taken with the

Figure 3.
HR 8799bcd synthetic spectra. The open circles are the observed photometric data points (from Keck) plotted with 3-sigma error bars. The filled symbols are the synthetic spectra magnitudes. The synthetic partially cloudy spectrum of each planet predicts the presence of water absorption bandheads in between the J-, H-, K-, and L'-band bandpasses, as well as a mild 1.6-micron methane absorption bandhead for planet "b."



Near-infrared Camera and Multi-Object Spectrometer (NICMOS) in 1998. The three planets are ~ 50,000 times fainter than HR 8799 at 2.2 microns (K-band) and are located at projected separations of 0.63, 0.95, and 1.73 arcseconds (24, 38, and 68 AU, respectively). The measurements from all available epochs confirm that all three objects are co-moving with the star and display counterclockwise orbital motions that are consistent with Keplerian orbits.

The characterization of the three planets' atmospheres is difficult due to their low luminosity relative to the primary. Near-infrared spectroscopy with an integral field spectrograph would require a large amount of telescope time. Instead, we have decided to first concentrate on acquiring accurate photometry of all three objects at 1.2 microns (J-band), 1.6 microns (H-band and methane on/off bands), 2.2 microns (K-band), and 4 microns (L'-band)—a wavelength regime where most of the planet's light is emitted. The colors of these objects are significantly different from those of field brown dwarfs (objects between 13.6 and 75 Jupiter masses, see Figure 2, left), and closer to those of 2M1207b (a ~ 7 Jupiter-mass planetary companion in orbit around a brown dwarf) and two ~ 11 Jupiter-mass Pleiades candidate members. The much redder colors of these objects are due to their lower surface gravities (thus, lower mass) and dust cloud physics.

Since the acquired multi-band photometry is sensitive to most of the emitted light from these objects, it was possible to estimate their total luminosities (a value that is independent of the details of their atmospheric physics) and derive their masses and temperatures from exoplanet cooling tracks (see Figure 2, right). All three objects fall below the dividing line between planets and brown dwarfs (which exhibit short-lived deuterium burning) for the estimated age range of the system (30-160 million years). When compared with the observed photometry, the synthetic spectra derived from the two extreme atmosphere models (fully dusty and dust free) were both unsatisfactory, showing that all three planets are in the transition region between these two extremes. Travis Barman, a member of the team, then constructed intermediate dust cloud atmosphere models by modifying the Phoenix atmospheric code. The result is a fairly good match between the synthetic spectrum and the observed photometry and luminosity of each of the three planets. In addition, the latest HR 8799b HST F160W detection is consistent with the presence of water absorption in its atmosphere and in agreement with the partially cloudy atmospheric models (see Figure 3). The final physical parameters of all three objects (HR 8799bcd) are: 7-10 Jupiter masses, a radius of ~ 1.2 times that of Jupiter, and a temperature of ~ 1000K, thus all three objects are young and warm, partially cloudy (dust clouds) gas giant planets.

Did the planets around HR 8799 form in the same way as the planets did in our solar system? The worlds of our solar system all orbit around the Sun in the same direction, in orbital planes close to the solar equator. This suggests that the planets formed in a disk around the Sun. They may have formed through the process of core accretion, where small dust particles agglomerate to form bigger rocks until planet cores are formed, which then triggers a runaway accretion that attracts a large fraction of the remaining gas and dust to form gas giant planets.

The planets around HR 8799 show a lot of resemblance to this formation scenario. All three orbit HR 8799 in the same counterclockwise direction. The measured orbital motions are nearly perpendicular to the lines connecting the planets to the star, consistent with mostly circular orbits viewed roughly face-on. All three planets would thus be orbiting in similar orbital planes. The star rotation is also very slow compared to other A-type stars, consistent with a pole-on view. Thus, the planets would be orbiting in similar planes close to the star's equator. For these reasons, we conclude that the three planets almost certainly formed in a disk around HR 8799.

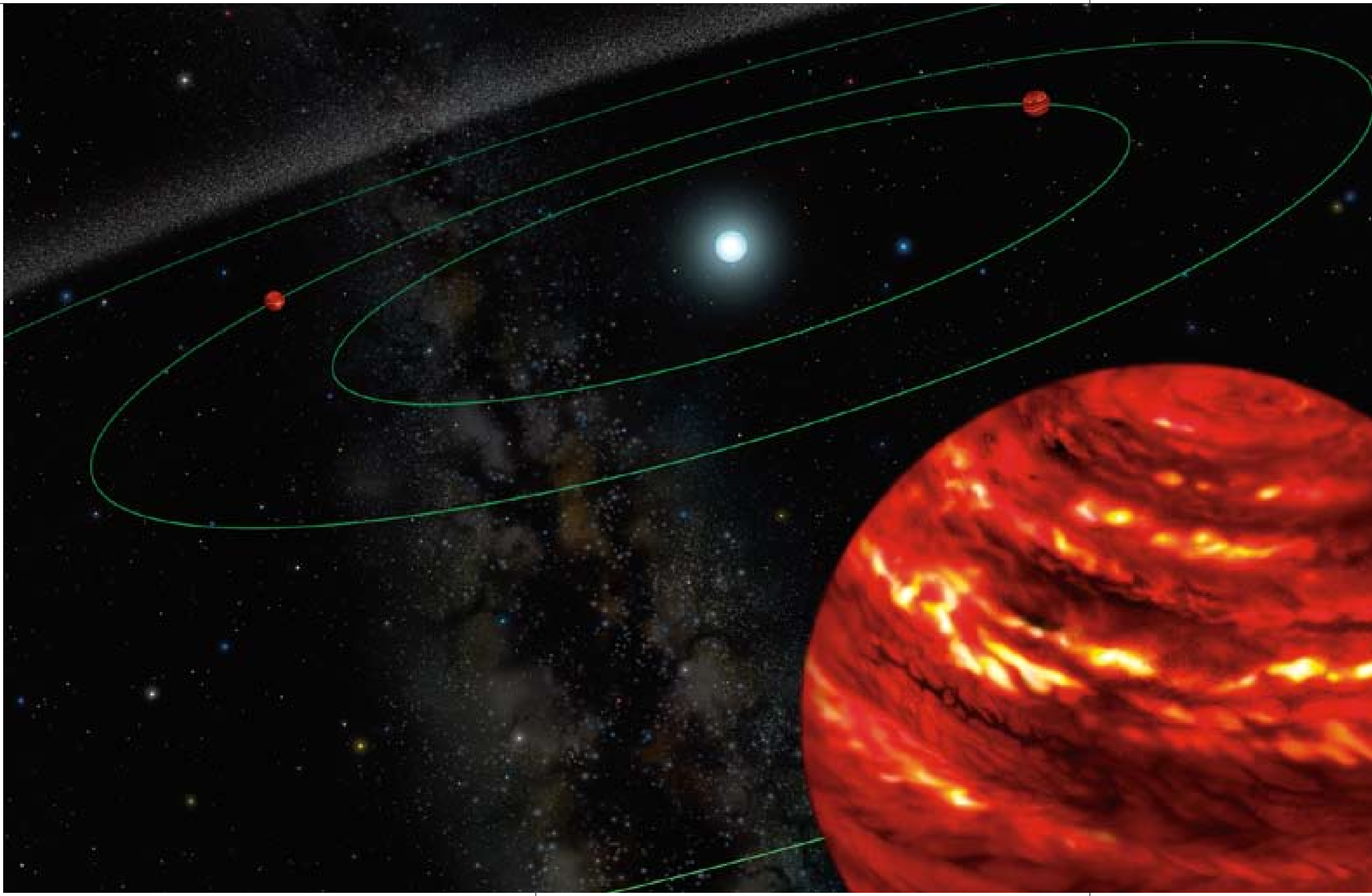


Figure 4. *Artwork of the HR 8799 system as conceptualized by Lynette Cook for Gemini Observatory.*

Even though there is strong evidence that the planets *were* born in such a disk, the details of their formation are not completely understood. The inconvenient truth that the planets are relatively massive bodies and that they orbit their parent star at wide separations is not consistent with our understanding of the core-accretion scenario. An additional issue is that with our current understanding of the model of core-accretion, and taking into account the estimated age of this system, these planets should not have had time to form.

There is an alternate theory for how this planetary system may have formed. It's called "disk fragmentation." In this scenario, gravitational instabilities within the circumstellar disk cause it to fragment into pieces that form into planetary embryos. This alternate formation hypothesis is thought to form planets much faster and perhaps at greater distances from central bodies, thus helping to explain the configuration of the HR 8799 system. In any case, the details of how these bodies came into existence are open for discussion, but the fact that they do exist has been proven conclusively. With time, and the detection of many more planets and planetary systems, we will be able to better comprehend the details of planet formation around stars.

The discovery of the HR 8799 planetary system was an amazing experience—the culmination of about 10 years of dedicated research. We were hoping to find perhaps one planet or a brown dwarf. Finding a complete multi-planet system was just unbelievable. This discovery was also a relief since it showed that systems similar to our own with giant planets in orbit between 5-30 AU do exist around other stars, and that future dedicated exoplanet finding instruments (like the Gemini Planet Imager) will be perfectly optimized to analyze their distribution around stars and determine their physical characteristics. Our massive star survey is still ongoing, and who knows if we will find more planetary systems around other massive stars...

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by Lauren MacArthur

Unveiling Galaxy Bulge Formation with Long-slit Spectroscopy

In the context of the currently favored cosmological Λ-Cold Dark Matter (ΛCDM) model of our universe, the formation and evolution of galaxies remains a major unsolved problem. In particular, the detailed evolution of the bulge and disk components of spiral galaxies is not well represented in current simulations. The data–model discrepancies do not necessarily reflect a failure in the ΛCDM model, but may indicate physical regimes and processes that are either poorly understood or difficult to implement in large simulations. Given the significant challenges faced by current galaxy formation models, guidance towards a true understanding of disk galaxies must come from an observational perspective. Since the mid-1990s, an observational picture has been emerging whereby the dominant bulges of early-type spirals were formed in a manner similar to pure elliptical galaxies, i.e., through violent and rapid processes such as monolithic collapse or major mergers, whereas the smaller bulges of late-type spirals were formed "secularly," though an internal redistribution of the disk material. However, a clear-cut distinction between formation scenarios remains uncertain.

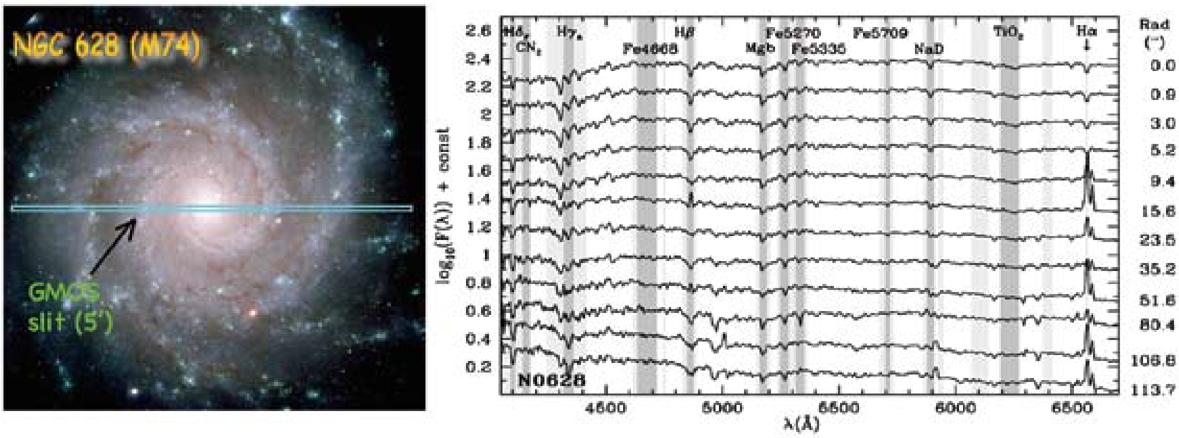

Figure 1. *Left: Gemini/GMOS observational setup for one of our sample galaxies. Background image credit: Gemini Observatory, GMOS team. Right: GMOS spectra as a function of radius for NGC 628. Several dominant stellar absorption-line features are marked as vertical shading.*

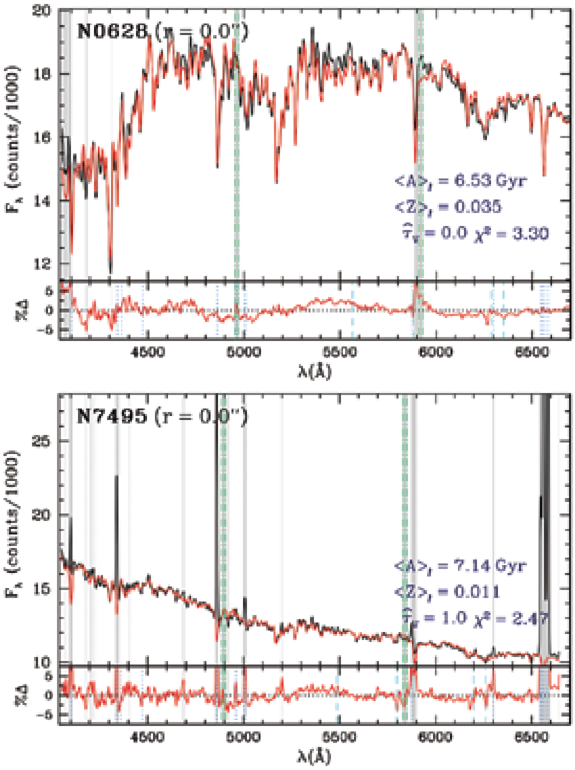

Figure 2. *Comparison of our "full population synthesis" model fits (red) to the observed central GMOS spectra (black) of spiral galaxies NGC 628 (top) and the emission-line dominated NGC 7495 (bottom). The average light-weighted age and Z, effective dust extinction, τ_V, and goodness-of-fit measure, χ^2, of the fits are indicated in each figure. The bottom panels show the percent data–model residuals.*

A detailed breakdown of the age, metallicity (Z), and kinematic properties of the stellar population (SP) content comprising bulges of all types along the Hubble sequence of galaxies is a very a useful probe in discerning between formation scenarios. Information about both light- and mass-weighted quantities is needed to form a comprehensive picture of the star formation history (SFH) of a given system. For nearby galaxies, whose SPs can be resolved into individual stars in deep photometric observations, SFHs can be derived from a detailed analysis of the distribution of their stars in the color-magnitude plane. Beyond our Local Group, however, observations are limited to the integrated light along a given line-of-sight, which must then be deconvolved into the relative fractions of stars of a given population that contribute to the total luminosity. This challenge is especially acute for spiral galaxies that are known to harbor a mixture of young and old stars, and may also suffer from the reddening and extinction effects of interstellar dust. However, with the tremendous recent progress in stellar population modeling, combined with high-quality data from large-aperture telescopes with fast and sensitive detectors, many of these obstacles can now be met head-on.

To tackle these issues, our group collected deep long-slit spectroscopy for a sample of eight nearby spiral galaxies using the Gemini Multi-object Spectrograph (GMOS) on the Gemini North 8-meter telescope. Figure 1 shows an example of our observational setup and extracted radially resolved spectra for the grand design spiral galaxy NGC 628 (also known as M74).

Uncovering the Stellar Populations

The high-quality GMOS spectra were used to develop a "full population synthesis" technique to determine the stellar content of each spectrum. The method consists of an optimized linear combination of Simple Stellar Population (SSP) model templates to the full spectrum while masking regions poorly represented by the models. Each model SSP represents the spectral energy distribution for a single burst of star formation at a given age and metallicity (Z). Establishing the relative contribution of each SSP to the integrated galaxy spectrum thus provides a stochastically-sampled SFH, yielding the true average stellar population parameters for each spectrum. This contrasts with many previous studies, which provide SSP-equivalent values that are heavily biased to the last episode of star formation, which dominates the optical light even when its contribution to the stellar mass budget is minimal. Two examples of our full population synthesis fits are shown in Figure 2. The gray shading indicates regions that are not represented in the models, i.e., any non-stellar contributions, and are thus masked in the fit. These can include the CCD gap regions (green vertical dash-dotted lines), variable sky lines that are difficult to model and subtract accurately (the locations of which are indicated by the dashed and dotted vertical lines), and emission lines from the surrounding gas prevalent

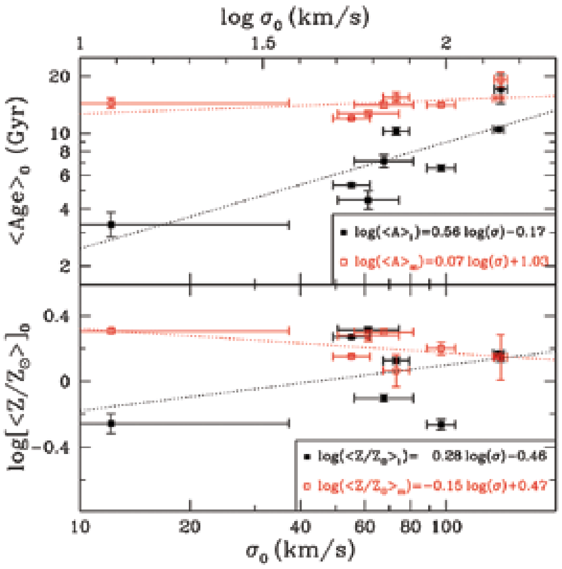

Figure 3. *Average age (top) and Z (bottom) from the full population synthesis fits as a function of central velocity dispersion, σ_0. Black solid squares: light-weighted values. Red open squares: mass-weighted values. The dotted lines are linear regressions to the data.*

in star forming regions (indicated by dotted vertical lines). The masking for each spectrum is determined iteratively by comparing model and data at each pixel and clipping those pixels that cannot be accommodated by the models within the measurement errors. This procedure is a key factor in establishing a faithful representation of the underlying stellar content.

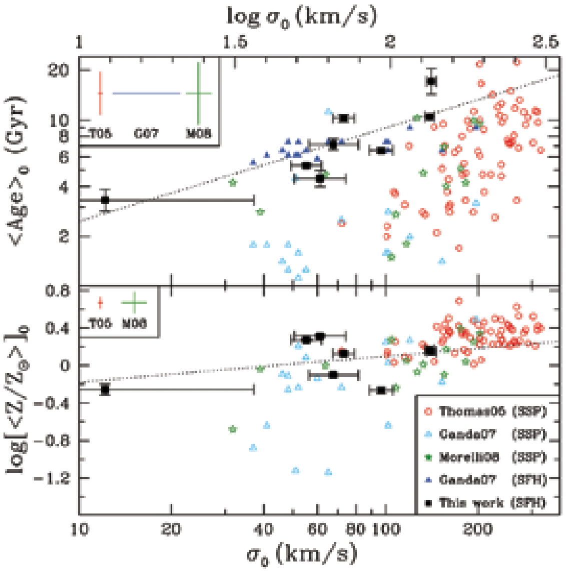

Figure 4. *Average light-weighted age (top) and Z (bottom) as a function of σ_o compared with samples of elliptical and spirals from the literature. The legend at bottom right indicates the source of the data as well as the type of SP parameter predictions (SSP or averaged over the SFH). Error bars for our data are shown on each point.*

Trends with Galaxy Parameters – Clues to Formation

The GMOS spectra also enable kinematic measurements (velocity dispersion and rotation) and the assessment of trends among physical parameters. Figure 3 shows the average light- (black) and mass- (red) weighted central SP values as a function of central velocity dispersion, σ_o, for the eight galaxy bulges in our Gemini/GMOS sample. For the light-weighted parameters, there is a clear trend of increasing average bulge age and Z with σ_o. However, when considering mass-weighted values, these trends disappear, indicating that the mass of all spiral bulges (to the extent that our sample is representative) is dominated by a population of very old and metal-rich stars.

Figure 4 shows our light-weighted values against literature data for spheroids of all types (i.e. pure ellipticals, lenticulars, and spiral bulges). All samples follow the same trend of increasing spheroid age and Z with σ_o. However, when a SFH more complex than a single burst is considered, the slope and the scatter of the age–σ_o relation are significantly reduced.

These results imply that bulge formation is dominated by processes that are common to all spheroids, whether or not they currently reside in a disk. The data also imply that the formation process occurs on shorter timescales for spheroids with the highest central velocity dispersions. It is further noted that the relative contribution to the stellar mass budget in bulges via secular processes, or "rejuvenated" star formation is small, but generally increases in weight with decreasing central velocity dispersion. These results represent strong and fundamental constraints for galaxy formation models.

This work was done in collaboration with J. Jesús González (Universidad Nacional Autónoma de México) and Stéphane Courteau (Queen's University) and has been published in the *Monthly Notices of the Royal Astronomical Society*, 2009, 395, 28.

For further information, see:

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Lauren MacArthur, recently at Caltech where much of this work was completed, is now a postdoctoral fellow at the University of Victoria and the National Research Council Canada Herzberg Institute of Astrophysics (NRC–HIA). She can be reached at: Lauren.MacArthur@nrc-cnrc.gc.ca

by Thaisa Storchi Bergmann

Feeding Versus Feedback in NGC 4151

NGC 4151 is the nearest bright Seyfert I galaxy to Earth and thus harbors one of the best-studied active galactic nuclei (AGN). At a distance of only about 13.3 Mpc (43.3 million light-years), the scale at the galaxy is 65 parsecs (pc) per arcsecond. Its relative closeness makes NGC 4151 an important laboratory for the detailed study of the feeding and feedback processes of its active nucleus.

In optical wavelengths, the emitting gas of the narrow-line region (NLR) has been found to have an approximate biconical morphology, as observed in a previous Hubble Space Telescope (HST) [OIII] λ 5007 narrow-band image, which is shown in the bottom of Figure 1. According to previous studies, our line of sight is outside of, but close to, the edge of the cones oriented along position angle (PA) ~ 60°. Optical spectroscopy reveals outflows along the cones with the approaching side to the southwest. In the radio, it presents a linear structure along PA = 77°, which is not aligned with the bicone.

Although NGC 4151 has been the subject of many previous imaging and spectroscopic studies, we used the Near-infrared Integral Field Spectrometer (NIFS) at the Gemini North telescope to obtain an unprecedented "3-D view" of the galaxy's NLR which allows us to map its excitation and kinematics. The high image quality of NIFS revealed details with a spatial resolution comparable to that of HST, and the spectral resolution provided by NIFS allowed the construction of channel maps along emission-line profiles providing a "kinematic tomography" of the NLR which challenges previous kinematic models of the source.

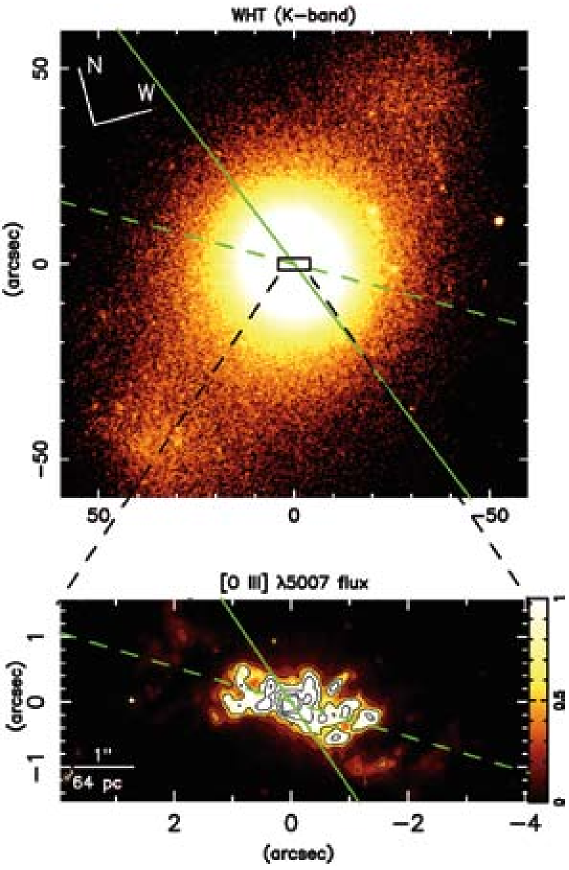
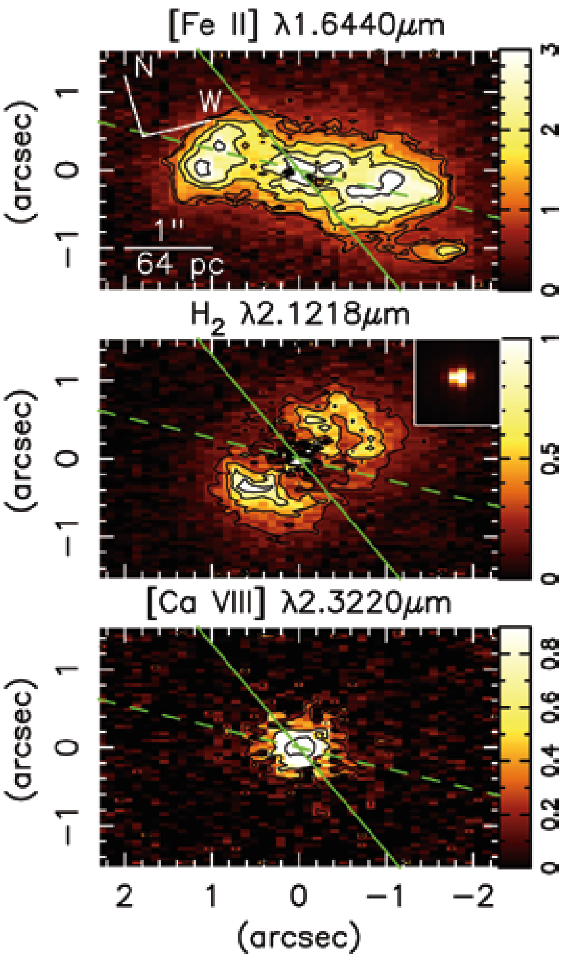


Figure 1.
Top: K-band image of the central 60 × 60 arcseconds of NGC 4151. The continuous line shows the orientation of the major axis of the galaxy, while the dashed line shows the orientation of the bicone. The rectangle shows the region covered by the NIFS observations. Bottom: narrow-band [OIII] image of the NLR obtained with the Hubble Space Telescope shown in the field-of-view of our NIFS observations.

Figure 2.
The three types of intensity distribution. Top panel shows [FeII] intensity distribution, middle panel shows H_2 intensity distribution, and the bottom panel shows intensity distribution in a coronal line. Notice the marked difference between the [FeII] and H_2 intensity distributions.



Observations

We observed the inner 3 × 8 arcseconds region of NGC 4151 on the Gemini North telescope with NIFS operating with the Altair adaptive optics system on the nights of December 12, 13, and 16, 2006, UT, with optical light from the nucleus of NGC 4151 feeding the adaptive optics wave-front sensor. The spectra covered from 0.94 to 2.51 microns with resolving power ≥ 5200 at an angular resolution of 0.12 arcsecond, which corresponds to approximately 8 pc at the galaxy. The resulting "datacube" contains 2,250 spectra, within which we have identified and measured the fluxes of 55 emission lines. Figure 1 presents a K-band image of the central region of NGC 4151 showing its large-scale bar. The central rectangle shows a narrow-band [OIII] image of the NLR within the field-of-view covered by the NIFS observations.

Emitting Gas Intensity Distributions

We have mapped the intensity distributions in 14 emission lines which show three distinct behaviors: (1) for most of the ionized gas the line emission is extended to ~ 100 pc from the nucleus along the region covered by the known biconical outflow; (2) the molecular gas (H_2) shows completely distinct intensity distributions which avoid the region of the bicone, but extend from ~ 10 to 60 pc from the nucleus approximately along the large scale bar and almost perpendicular to the bicone axis; and (3) the coronal lines (high ionization emission lines) show a steep intensity profile, and are only barely resolved. In Figure 2, we illustrate the three types of intensity distributions discussed above.

The distinct intensity distributions support the idea of different origins for the gas species. The ionized gas seems to originate in the biconical outflow itself, while the molecular gas appears to be destroyed by the intense nuclear radiation escaping along the bicone. The origin of the molecular gas is more likely in the galaxy plane in the inner part of the bar. The coronal lines are confined close to the central engine and originate in the inner NLR.

Gas Reddening and Excitation

The presence of many emission lines has allowed the derivation of the reddening along the NLR from the line-ratio maps [FeII] λ 1.64 micron/1.26 micron and Paβ/Brγ, which give an average E(B-V) = 0.5 along the NLR and E(B-V) ≥ 1 at the nucleus.

The high signal-to-noise ratio of the data has allowed us to obtain the line-ratio map [FeII]1.26 micron/[PII]1.19 microns, which is the first such map of an extragalactic source. It traces the effects of shocks produced by the radio jet on the NLR, as indicated by the correlation observed between this line ratio and a radio map of the NLR. The shocks produced by the radio jet probably release the Fe locked in grains and produce the observed enhancement of the [FeII] emission at ~ 1 arcsecond from the nucleus (see Figure 2). At these regions, from the ratios between the many [FeII] emission lines which were possible to measure in the datacubes, we obtain electron densities of ~ 4,000 per cubic centimeter and temperatures of T_e ~ 15,000K for the [FeII]-emitting gas.

From the many H_2 emission lines we were also able to obtain a temperature of T ~ 2100K for the molecular material, much lower than that of

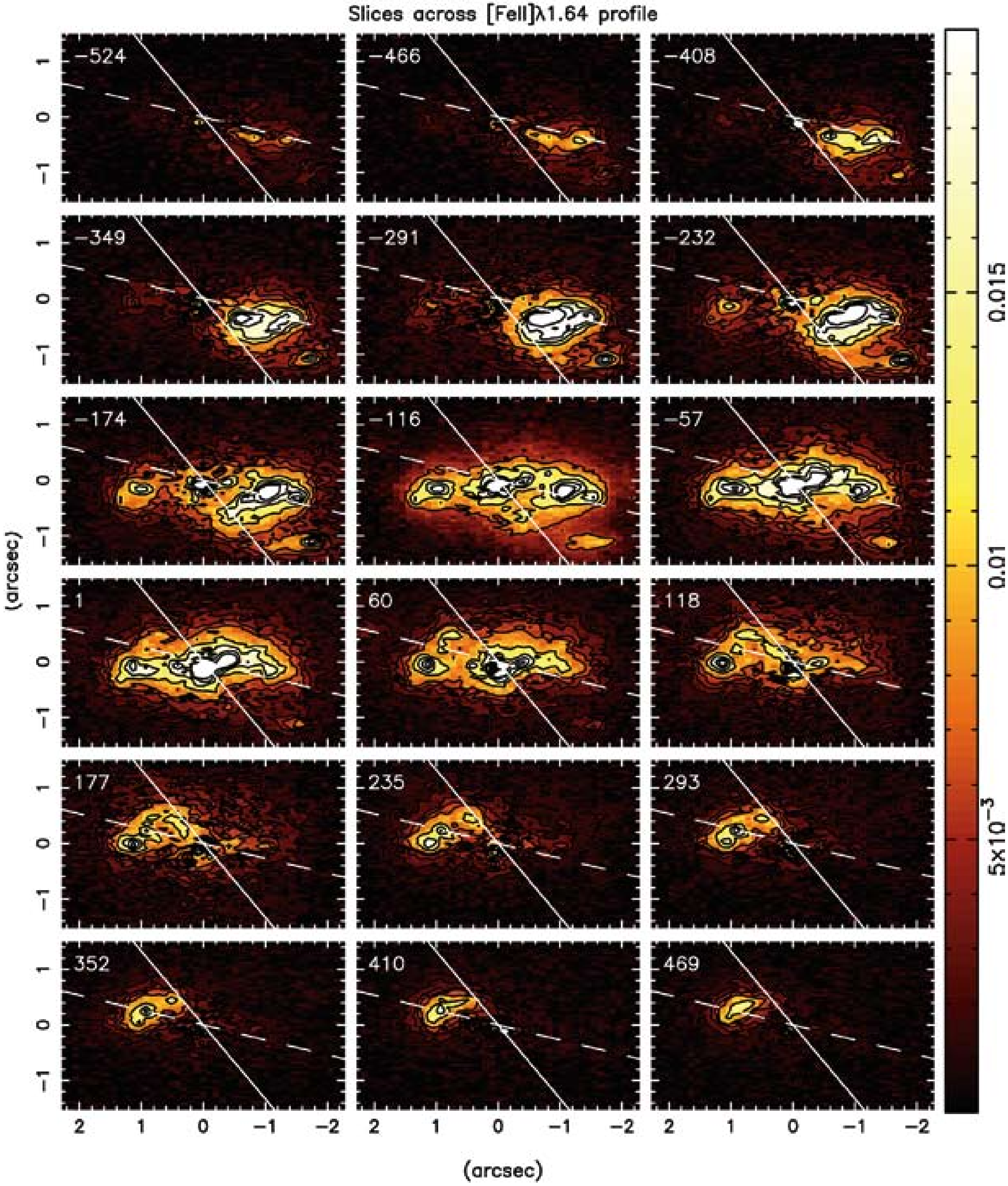


Figure 3. *Channel maps along the emission-line profile of [FeII]λ1.64 micron, where each panel corresponds to a velocity bin centered on the value (in kilometers/second) shown in white in the left corner of each panel. The dashed and continuous lines are the axes of the bicone and major axis of the galaxy, respectively.*

the [FeII]-emitting gas. The heating necessary to excite the molecules may be due to x-rays escaping perpendicular to the cone (through holes in the nuclear torus) or to shocks produced by an accretion flow previously observed along the large-scale bar.

We have also calculated the mass of the ionized and molecular gas, obtaining for the former 2.4 million solar masses and for the latter only 240 solar masses. This small mass for the molecular gas is only that of the "hot skin" of what is likely a much larger (non-emitting) molecular mass reservoir.

Kinematics

The high spectral resolution of the data, combined with the two-dimensional coverage provided by NIFS, allowed the construction of channel maps along the emission-line profiles. These maps provide an "in-depth view" of the gas emission because as we observe the flux distributions at different velocities we are also looking at different depths along the line of sight–assuming that the velocity of the gas varies with the radial distance from the nucleus. This gives us what can be described as a "velocity tomography" of the NLR.

Figure 3 shows the channel maps obtained from the emission-line profile of [FeII]λ1.64 microns. Previous studies using long-slit spectroscopy have concluded that there was acceleration along the NLR. Lower velocities were observed close to the nucleus, which increased to a maximum velocity at ~ 100 pc outward. This acceleration of the gas to such a distance from the nucleus is puzzling and hard to explain. Nevertheless, the channel maps do not seem to show acceleration, at least to the southwest. Notice that, in Figure 3, the highest negative velocities are observed along the axis of the bicone extending all the way from the nucleus to ~ 1.5 arcseconds southwest ~ 100 pc); thus, there does not seem to be an increase of the velocity with distance. Lower velocities are observed away from the axis of the bicone as well as outwards. The lowest velocities of all seem not to come from biconical outflow but from gas in the disk, in the vicinity of the nucleus. Thus, the velocity tomography provides a more complete map of the NLR kinematics than the "classical" radial velocity maps do.

The channel maps along the other ionized gas emission-line profiles are similar to those of [FeII], but the ones along the emission lines of the molecular gas (H_2) are completely different, suggesting circular rotation in the plane of the galaxy.

Our observations are consistent with the interpretation that the H_2-emitting gas may be tracing the gas reservoir which feeds the supermassive black hole at the nucleus. Results supporting this idea are the inflows of HI along the large-scale bar measured in radio observations by Mundell and Shone. These inflows may lead to the buildup of a molecular gas reservoir–the line-emitting "skin" of which we partially observe in the H_2 intensity distribution (see Figure 2). The distinct H_2 emission can thus be considered a tracer of AGN-feeding activity, while the ionized gas emission, which maps the outflowing gas, is a tracer of the feedback from the AGN.

We have grouped the channel maps together in a sequence of velocity bins, generating movies which can be downloaded from: **http://www.if.ufrgs.br/~thaisa/ifu_movies/ngc4151**

The Nuclear Continuum and Constraints on a Dusty Nuclear Torus

Finally, we have used the nuclear spectrum to isolate and constrain the properties of a near-infrared nuclear source whose spectral signature is clearly present in our data. The extranuclear spectra are all blue, suggesting the presence of young stars over most of the field of the integral field unit. Nevertheless, right at the nucleus, there is an unresolved red nuclear source. The near-infrared spectrum was combined with an optical spectrum obtained with the Space Telescope Imaging Spectrograph (STIS) aboard HST. The combined optical and near-infrared continuum is well fitted by a power-law component, which dominates in the optical, plus a blackbody component, with $T = 1308 \pm 50K$, which dominates in the near-infrared. We attribute the blackbody component to emission by a dusty structure, not resolved by our observations, which provide only an upper limit for its distance from the nucleus of 4 pc. This structure may be the inner wall of the dusty torus postulated by the Unified Model of AGN, or the inner part of a dusty wind originating in the accretion disk.

My collaborators in this study are Dr. Peter J. McGregor, who is the NIFS principal investigator, and who obtained the data and did much of the excitation and kinematic modeling, as well as Dr. Rogemar A. Riffel, Ramiro Simões Lopes, Dr. Tracy Beck, and Dr. M. Dopita.

For further information, see:
McGregor, P. J., *et al.*, 2003, *SPIE*, **4841**, 1581, eds. Iye, M. and Moorwood, A. F. M.
Storchi Bergmann, T., McGregor, P., Rifflel, R. A., Simões Lopes, R., Beck, T., and Dopita, M. 2009, *MNRAS*, **394**, 1148
Rifflel, R. A, Storchi Bergmann, T., McGregor, P., 2009, **ApJ**, in press
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Mundell, C. G. & Shone, D. L., 1999, *MNRAS*, **304**, 475

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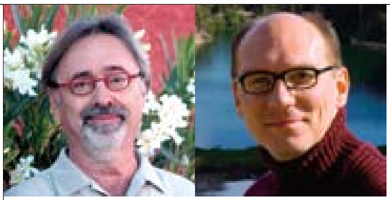

by Jean-René Roy & R. Scott Fisher

Recent Science Highlights

A Freaky Cosmic Dwarf Pair

The object shown in Figure 1 is certainly one of the strangest in our Milky Way. Posing as variable x-ray source SAX J1808.4-3658, this x-ray binary contains an accretion disk-powered millisecond pulsar located at a distance of about 3,500 parsecs (~ 11,500 light-years). It was the first millisecond pulsar system identified among x-ray binaries. Recent observations using the Gemini Multi-object Spectrograph (GMOS) on Gemini South have revealed a large periodic modulation of its quiescent optical emission, showing a light curve with a remarkably regular sinusoidal shape (Figure 2).

The new observations, conducted by a Canadian-Dutch team led by Zhongxiang Wang (McGill University), indicate that the light curve modulation is caused by irradiation of the companion star to the pulsar and not by activity in the accretion disk.

The pair is strange because it is made of an unusual couple with a 2.1-hour orbital period around a common center of mass. The more massive of the two is a 1.4-$M_{\rm Sun}$ neutron star, which is a ball of neutrons about 10 kilometers (km) in radius, spinning on its axis every 2.49 milliseconds. It's the remnant of the supernova explosion of a massive star. The x-ray pulsar activity is driven by the accretion of material from its mysterious low-mass companion. However, the persistence and modulation of its optical light is not well understood.

The companion is also strange—most likely a 0.05 $M_{\rm Sun}$ brown dwarf, comparable in size to Jupiter. The binary separation is very small–about 630,000 km, which is about twice the distance between Earth and the Moon. Not only did the companion survive the explosion of its close-by progenitor, but this dwarf object managed to get pulled inward very close to the neutron star remnant.

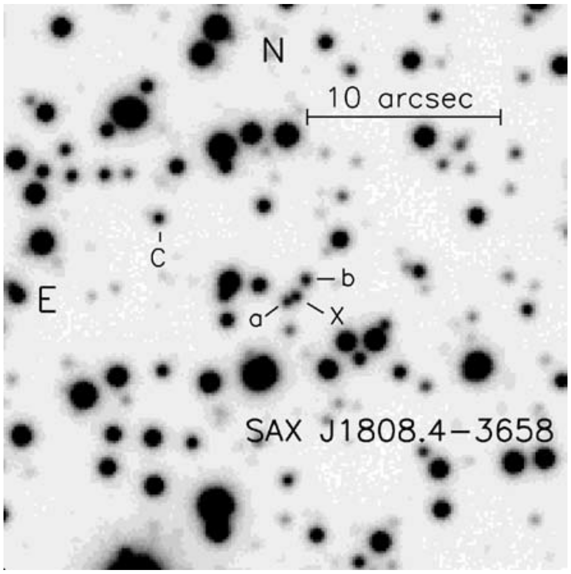

Figure 1.
Gemini South r' image of the J1808.4 field. The optical counterpart to J1808.4 is denoted by an "X" on the image.

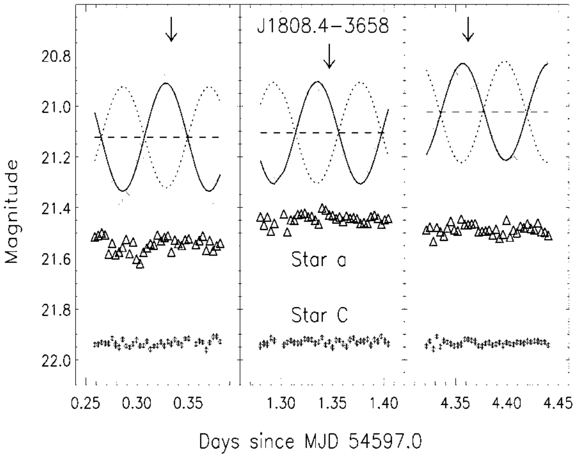

Figure 2.
Top: GMOS r' band light curve of source compared to reference star in images (Figure 1). Three observations were carried out over five days, on May 11, 12, and 15, 2008, in the Gemini queue mode. Average seeing conditions for the three nights were 0.63, 0.58, and 0.70 arcsecond.

This close to the neutron star, the companion experiences strong tidal forces and the brown dwarf periodically transfers mass to the neutron star. That mass gets stored in a disk, which builds up the surface density. Eventually a mass imbalance sends material over to the accretion disk and triggers an x-ray outburst. This occurs once every 2-3 years. The optical modulation (that is, the change of the target's brightness over time) is connected to x-ray irradiation of the companion. The close companion rotates on its axis and the period of that rotation is locked to its period of revolution around a common center of gravity with the neutron star. The area of the heated face visible from Earth varies as a function of orbital phase. The modulated light comes from the irradiated companion while the persistent light comes from the accretion disk.

What will be the fate of this system? At some point, the companion will not be able to overfill its Roche lobe with material and the neutron star will likely turn into a radio pulsar. The companion will be ablated (blown away) by the pulsar wind, leaving an isolated millisecond radio pulsar. Such a pulsar binary is called a black widow system: a radio pulsar that eliminates its companion. The most famous one is the PSR B1957 + 20 system, discovered in 1988.

Betelgeuse and VY Canis Majoris as Future Supernovae

Nathan Smith (University of California-Berkeley), Ken Hinkle (NOAO), and Nils Ride (Lund Observatory) used the near-infrared spectrograph PHOENIX on Gemini South to study the geometry and kinematics of the active circumstellar envelopes around the supergiant stars Betelgeuse and VY Canis Majoris (VY CMa). These two stars are shedding huge amounts of mass as they take their "last gasps," and could explode as supernovae at any time.

Understanding the observable circumstellar envelopes around nearby massive stars can help to predict the types of supernovae we might expect in the event that their progenitor stars explode. Many of the observed properties of supernovae are driven by what happens as the surrounding environments are struck by blast waves.

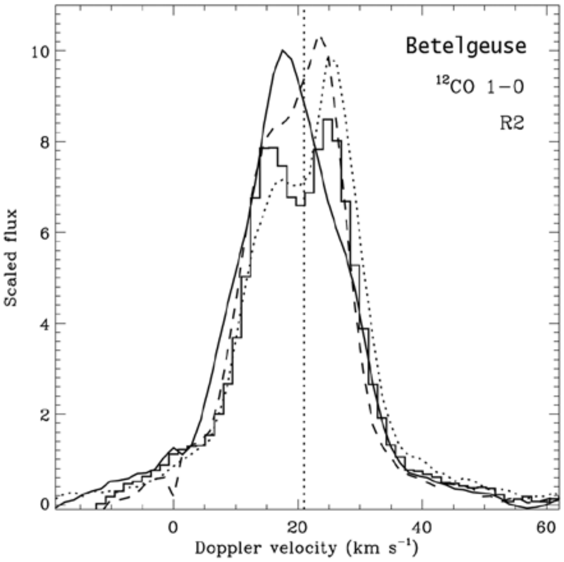

Figure 3.
Right: Spectral tracings of the ^{12}CO 1-0 emission line profile in the shell of Betelgeuse at a few representative positions.

CO emission within 1,000 astronomical units of Betelgeuse reveals that the star supports a clumpy spherical shell. Gas velocities up to +35 kilometers per second (km/sec) are detected within the shell

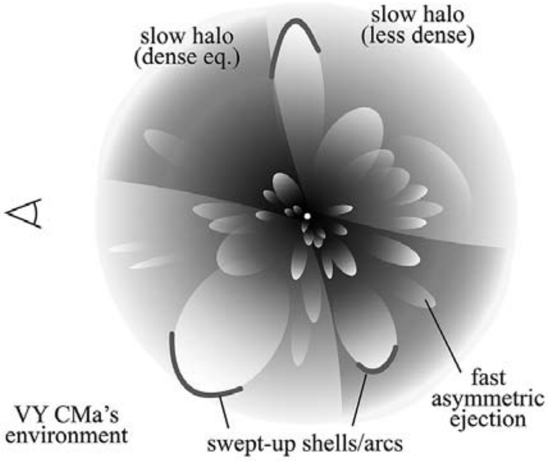

Figure 4.
Diagram of the proposed schematic geometry and structure of the likely pre-supernova environment around VY CMa, consisting of individual asymmetric mass ejections.

(see Figure 3). Betelgeuse's environment appears to be shaped by a steady stellar wind that has had a constant flow of dM/dt ~ 2 x 10^{-6} M_{sun}/year over the past ~ 300 years. If Betelgeuse exploded today, it would produce a luminous Type II supernova with a blast wave expanding at about 15,000 km/sec. During its brightest phase, the wave would sweep through the portion of the envelope that was mapped by PHOENIX.

The more distant VY CMa (which lies about 5,000 light-years away) has experienced prodigious amounts of mass loss. The CO emission is coincident with the bright K I shell in the star's clumpy asymmetric reflection nebula (Figure 4). If the star exploded, the outcome would be different from Betelgeuse's because VY Canis Majoris's current mass-loss rate is 100 times larger than that of Betelgeuse. Its envelope is also very inhomogeneous, which is the result of multiple mass ejections over the last 1,000 years. To a distant observer, an exploded VY CMa would appear as a bona fide Type IIn supernova. The velocity of its blast wave would be a few thousand kilometers per second. This explosion would be moderately luminous and long lasting, and would produce interactions with the surrounding envelope that we could detect for about a decade after the explosion.

The Return of McNeil's Nebula

McNeil's Nebula is back! In late 2003, the young eruptive variable star V1647 Orionis optically brightened by more than five magnitudes, stayed bright for about 26 months, and then declined to its pre-outburst level. Colin Aspin (University of Hawai'i) and his team reports that in August 2008, the McNeil star unexpectedly brightened again, and became as bright as in the previous eruptive event. The team used GMOS-South, NIRI (at Gemini North), T-ReCS at Gemini South and the University of Hawai'i 2.2-meter telescope to monitor this comeback event.

The nebula also appears similar to the last outburst (Figure 5). However, while CO overtone emission is not observed, Brackett gamma and Paschen beta emission are present, as well as strong water vapor bands. The authors propose that the massive accretion event that triggered the previous brightening of the nebula is not over and that it had simply declined in intensity. That decline caused the recent lull. There was also re-formation of dust in the immediate circumstellar environment of the star that had been sublimated by the radiation from the 2003 accretion burst. The current event, which began in early 2008, is due in part to dust cleared by sublimation caused by the "re-powered" star brightening up again.

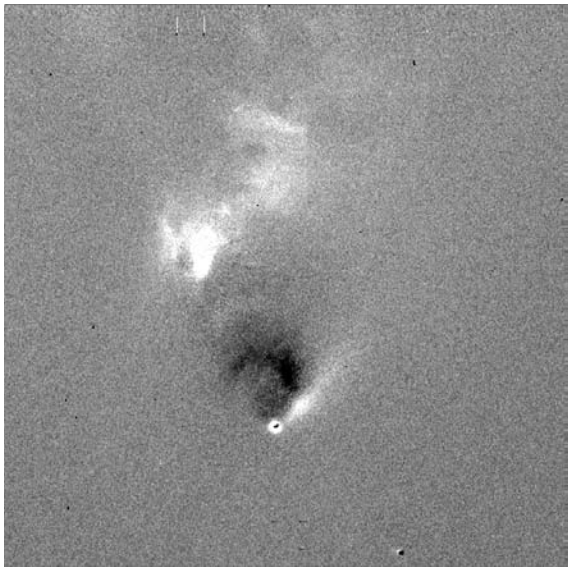

Figure 5.
Image difference in r' band from the University of Hawai'i 2.2-meter telescope between 2008 and 2004 of region surrounding V 1647 Orionis.

A Naked-eye Gamma-ray Burst

Gamma-ray bursts (GRBs) are regularly observed by batteries of telescopes, from small to large, once triggered by the Swift satellite or other alert telescopes. Gemini North and South are regularly brought into the action for imaging and spectroscopy through the rapid response Target of Opportunity (ToO) system. For example, Josh S. Bloom and his team used both GMOS South and North to conduct afterglow imagery of the naked-eye GRB 080319B event at redshift z = 0.97. From the deepest late-time observations, they infer evidence for an optical jet break and a luminous supernova. The object was measured to be as bright as J ~ 4.5 by the PAIRITEL 1.3-meter telescope.

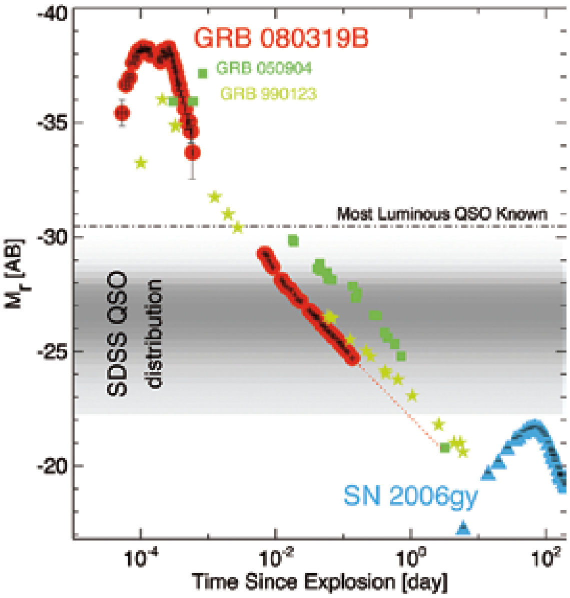

Figure 6. *Rest frame comparison of the most luminous optical/infrared probes of the distant universe, showing the absolute magnitude vs. time of GRB 080319B, of the most luminous QSO known, and of supernova SN 2006gy, one of the most energetic supernovae recorded (From Bloom, et al. 2009,* ApJ 691, 723-737*).*

This event was absolutely extraordinary. For 30 minutes in the rest frame, GRB 080319B was brighter than the brightest known quasi-stellar object (QSO) in the universe (Figure 6). At z = 0.17, the distance of the nearest GRB with a typical luminosity, this event would peak at R ~ 1 magnitude, nearly as bright as the brightest star in the sky. The authors estimate that such events could be detected out to very high redshifts and would remain visible even if placed well into the epoch of reionization. If an event such as GRB 080319B were to occur in own galaxy, at a distance of one kiloparsec (around 3,200 light-years), the optical flash would peak at magnitude about -28.5, several times the brightness of the Sun.

A Cool Dwarf in Aquarius

An international team led by Ben Burningham (University of Hertfordshire) has discovered a brown dwarf that will likely set the record as the coolest body ever detected outside our solar system. The object, named Wolf 940b, and its companion star, a red dwarf named Wolf 940, lie in the constellation Aquarius at a distance of about 40 light-years from Earth. Wolf 940b orbits its star at a distance of around 440 astronomical units, more than ten times farther out than Neptune orbits the Sun. At this distance, it takes Wolf 940b approximately 18,000 years to complete a single orbit. The mass of Wolf 940b is probably between 20 and 30 times that of Jupiter. This places it directly in the regime of "brown dwarfs"–objects that are too large to be considered planets but are too small (and cool) to be classified as stars. With a surface temperature of approximately 570K Wolf 940b is the coolest brown dwarf measured to date. Burningham says that free floating objects with temperatures similar to this have been suspected before, but this is the first time he and his team were able to confirm it. The fact that it is orbiting a star makes it extra special.

Due to such low surface temperatures, objects like Wolf 940b do not emit much visible light. However, they glow brightly in the infrared. Because of its infrared glow, Wolf 940b was initially discovered as part of the UKIRT Infrared Deep Sky Survey (UKIDSS), a large survey project being carried out at the United Kingdom Infrared Telescope (UKIRT) on Mauna Kea. The object was found as part of a wider effort to discover and characterize the least luminous objects in the solar neighborhood. When its proper motion revealed it as a companion to Wolf 940 follow-up observations to determine its nature were initialized.

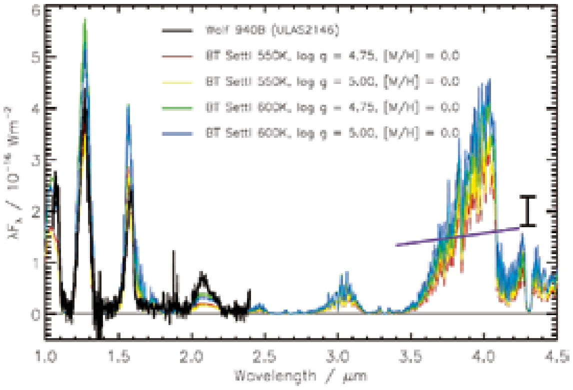

Figure 7. *NIRI spectrum (black line) compared to models of a cool brown dwarf atmosphere with different temperatures and effective gravities. In addition to the JHK spectroscopy, L-band photometry (with error bar) from NIRI is shown as the dark blue line between 3.4 – 4.2 microns (μm).*

Spectroscopy using the Near-infrared Imager and Spectrometer (NIRI) on Gemini North allowed the team to determine the surface temperature of this record-setting brown dwarf (see Figure 7). By comparing the data collected by Gemini to complex atmospheric models, the team was able to assign a surface temperature and a spectral type of T8.5 to the object.

This object is going to continue to provide insights into the processes of cool brown dwarfs and warm planetary atmospheres for some time to come, and finding it was just the first step.

Disappearing Supernova Stars

In a paper published in a recent issue of *Science Express*, Justyn Maund and Stephen Smartt present data from the Gemini Observatory and Hubble Space Telescope (HST) that confirm the disappearance of the progenitors of two Type II supernovae (SNe). The only other supernova progenitor of this sort known to have definitively disappeared was SN 1987A in the Large Magellanic Cloud. Because the identity of the stars found in pre-explosion images has now been confirmed, this work provides the important "nail in the coffin" that shows that now-missing red supergiants were the progenitors. Indeed, this is the first time a red supergiant has been shown to be the progenitor for a Type IIP supernova and confirms a number of standard predictions of current stellar evolution models.

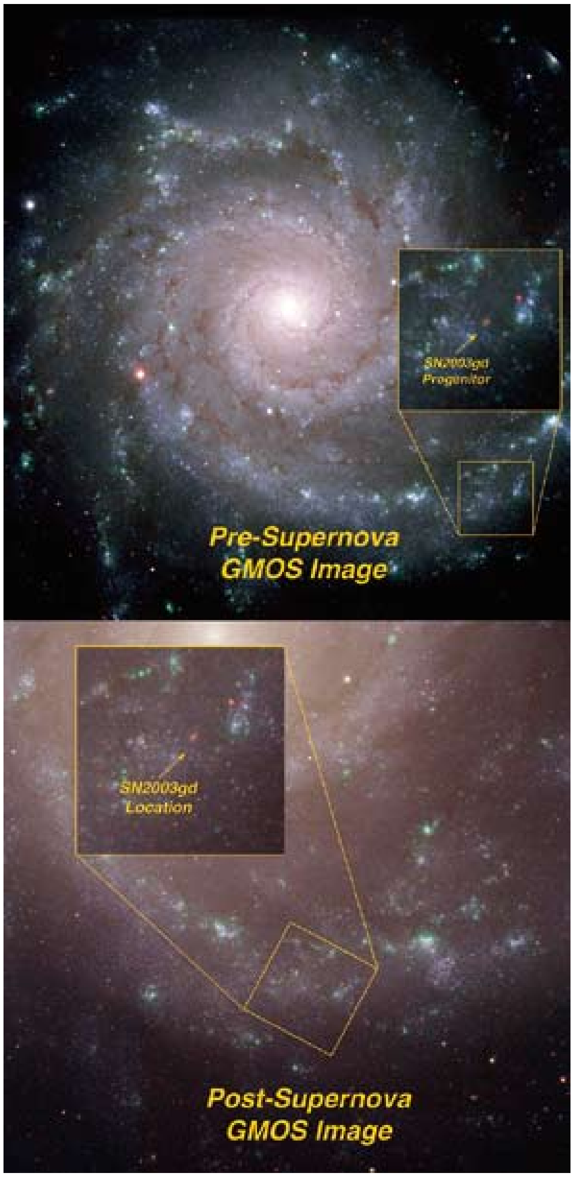

Figure 8.
Pre- and post-images of the galaxy M 74 with inset showing a close-up of the area around SN 2003gd (indicated by arrow). Both images were obtained with GMOS-North and color composite images were made from g', r' and i' filtered images. Pre-supernova images were made in August 2001 and post-supernova images were obtained in September 2008.

The two supernovae, denoted 1993J and 2003gd, both had confirmed pre-existing progenitors identified from archival data. This allowed the researchers to compare pre-supernova identification of the progenitor star with post-supernova observations. Maund and Smartt used a technique where images were taken after SN 2003gd had faded away, and the progenitor star was presumably missing. They then subtracted them from the pre-explosion images. The Gemini observations of 2003gd are shown in Figure 8, which compares pre- and post-supernova views of the progenitor star's region of the galaxy.

Red supergiants are massive stars. Betelgeuse in the constellation of Orion is a good example of one (see the science highlight on page 56 of this issue). They contain at least eight times the mass of the Sun and their diameters are up to 500 times larger. Once they exhaust their supply of fuel and can no longer hold themselves up against their own gravity, they explode as supernovae. The matter that was once inside the progenitor of SN 2003gd is now being dispersed in its host galaxy to help form the next generation of stars.

Absence of Lithium-6 in Exoplanet Host Stars

A team led by Ph.D. student Luan Ghezzi of the Observatorio Nacional Rio de Janeiro, Brazil, has established that there is no detectable amount of lithium-6 in five stars that host extrasolar planets. The team used the bench High-resolution Optical Spectrograph (bHROS) on Gemini South to make the observations.

One of the interesting properties of stars known to host giant planets is that they are systematically metal-rich (by ~0.2 dex) relative to field dwarfs that are not known to harbor giant planets. Two hypotheses have been proposed to account for this excess of elements heavier than hydrogen or helium: primordial enrichment or pollution. The first process indicates that the probability of forming giant planets is a steeply rising function of the intrinsic metallicity of the gas which gave rise to the birth of the star and its planets. On the other hand, the pollution scenario proposes that during the inward migration of giant planets, solid material from a protoplanetary disk is accreted into the convective envelope of the host star.

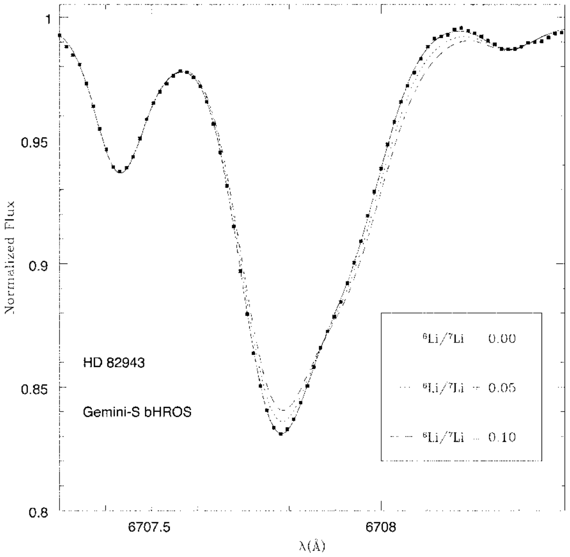

Figure 9. *bHROS spectrum of the known extrasolar planet host star HD 82943 near the lithium doublet at 6707.8 Å. The spectrum (black points) is best fit with a model that indicates there is no appreciable ^{6}Li present in the atmosphere of the star. The result helps rule out the role of external pollution from any extrasolar planet on the spectrum of the host star.*

As this material is depleted in H and He, the star's metallicity (at least at its surface) would be enhanced. The possibility that a planet-hosting star has accreted significant amounts of metal-rich material can be tested using the two stable isotopes of lithium. Both isotopes are destroyed at relatively low temperatures (2,000,000K for ^{6}Li and 2,500,000K for ^{7}Li) inside stars. During the early stages of the evolution of solar-type stars, deep convection destroys most or all of the primordial lithium, with ^{6}Li being destroyed much more efficiently than ^{7}Li. The fraction of Li destroyed is a strong function of the stellar mass, with ^{6}Li being completely destroyed, even in stars where significant amounts of ^{7}Li is preserved. The ultimate point of the scenario is that one should not expect to find any ^{6}Li in solar-type stars. Any positive detection of ^{6}Li could be a strong indication of external pollution.

Using bHROS, high-resolution (R=150,000), high signal-to-noise (S/N = 700-1100) spectra were obtained for five stars that host extrasolar planets. Detailed profile-fitting of the Li I resonance doublet at 670.78 nm revealed no detectable ^{6}Li in any of the sample stars. In Figure 9 we show the bHROS spectrum of target HD82943 as well as model profiles calculated for different ^{6}Li/^{7}Li isotopic ratios. The derived upper limits to the ^{6}Li fraction in these stars are quite small, being typically ^{6}Li/^{7}Li < 0.02-0.03. These upper limits can be translated into limits on the amount of accreted material and show that less than 0.25 to 0.70 Jupiter masses of metal-rich material has been accreted by these particular stars with planets.

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by Michael C. Liu

The Quest for Other Worlds: The Gemini NICI Planet-finding Campaign

The famous novelist George Eliot once wrote, "Men, like planets, have both a visible and an invisible history." Today, this line could easily refer to one of the most exciting developments in contemporary astrophysics: the discovery and characterization of extrasolar planets (a.k.a. "exoplanets"), or planets in orbit around stars other than our Sun. Through a stream of innovations in search methods, our understanding of these objects has advanced in leaps and bounds over the last 14 years, starting with the unambiguous discovery of the first extrasolar planet around the Sun-like star 51 Pegasi in 1995, and up to the announcement of images of planets around the massive stars HR 8799 (see article page 44) and Fomalhaut in November 2008.

Uncovering both the "invisible" and "visible" history of extrasolar planets has been a long-sought goal. This is true not only for modern-day astronomers, but for philosophers dating back to early civilizations who speculated on the possibility of life-bearing worlds other than our own. We now are in a rich and special time for such studies, as the number of known exoplanets is rapidly increasing along with our abilities to study their physical properties. We are learning how and why planets form, and ultimately whether our own solar system represents a common occurrence elsewhere.

The current census of exoplanets now exceeds 300 objects, largely with masses comparable to the gas-giant planet Jupiter, which has a mass about 1/1000 that of the Sun or 300 times that of the Earth. Most exoplanets discovered to date have been identified using the radial velocity (RV) technique, which gathers very precise measurements of the motion of nearby stars (where "radial" means the motion along the line-of-sight from the observer on Earth to the star). Unseen exoplanets around these stars induce a periodic signal in the radial velocity as the planets orbit their host stars, leading to a characteristic increase and decrease in the star's velocity relative to the observer. Given the very large number of exoplanet discoveries so far, one might naturally ask what remains to be learned. In fact, while radial velocity discoveries have led the way in exoplanet research, there is still much that remains unanswered.

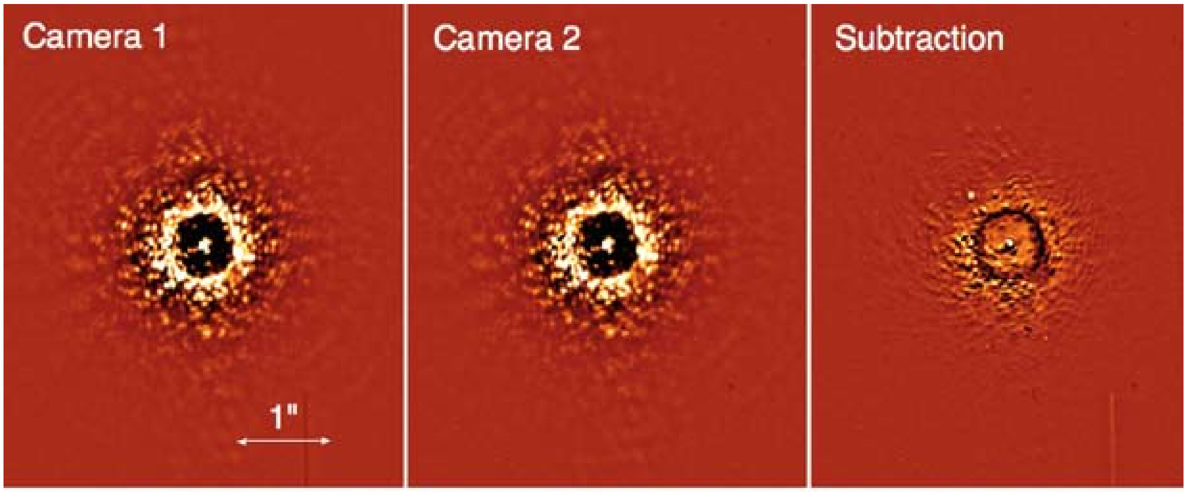

Figure 1. *Speckle subtraction using NICI's dual-channel cameras. The left and center panels are images of the same star taken at the same time at slightly different wavelengths. The difference between the two images is shown in the right-hand panel. The darker circle in the center is due to the coronagraph (which allows about 1% of the starlight through so the precise location of the star can be determined). This example is only one of many exposures that were taken of this star, with the Cassegrain rotator stationary, so any possible real planets would appear to rotate around the star in subsequent exposures. For more details on this technique (called ADI) see pages 45 and 64 for descriptions of the ADI technique.*

Fundamentally, RV discoveries are indirect, and only tell the "invisible" part of the story. Planets are detected by their subtle influence on their host stars, and measuring the duration and intensity of the motion provides the precise orbital properties of the planet–the shape and size of the planet's orbit around its host star. However, direct measurements of the physical properties of the planets are inaccessible with the RV technique. (In about 10% of the cases, this limitation can be overcome when the orbital plane of the planet, by chance, happens to be seen nearly edge-on to Earth and the planet is very close to the star. In this case, the planet will transit, or appear to move across the face of the star, and allow direct measurement of the planet's radius.) Furthermore, nearly all of the exoplanets discovered to date have orbits smaller than 4 astronomical units (AU) from their host stars (for comparison, Jupiter has an orbit of 5 AU and the Earth orbits at 1 AU, by definition). The reason for this derives from two fundamental aspects of the radial velocity search method, namely that more distant planets have longer orbital periods and weaker gravitational influence. Altogether, this means that finding planets at larger orbital distances from their host stars is very challenging for RV surveys.

Direct Imaging

Direct imaging is a powerful method to find and characterize exoplanets. This approach is complementary to the radial velocity method, and thus a host of new information can be learned about exoplanets. Instead of indirectly detecting the tug of the planet on its host star, we would like to be able to directly take images of planets by detecting light from them and then to obtain spectra, thereby allowing us to diagnose properties such as their temperature, surface gravity (a proxy for their mass), and composition. Moreover, since these outer planets are easier to identify by direct imaging, we can study them preferentially. Not only does this open the door to a much larger range of orbital separations than radial velocity methods, it directly explores the "birth region" of gas giant planets, which are thought to form beyond about 4 AU from their parent stars (according to current theoretical models) and then migrate inward to form the population of planets detected by RV and transit searches. Therefore, determining the numbers and masses of planets in this outer birth region can provide critical new tests for planetary formation theories.

Of course, direct detection of exoplanets is incredibly challenging. The planets in our own solar system are visible in our night sky due to reflected light from the Sun. Such a reflected light signal from planets around other stars is far beyond the detection limit for current astronomical instrumentation since the reflected light is very faint and thus swamped by the much brighter glare of the host star; for example, as seen from afar, Jupiter's reflected light would be about one billion times fainter than the Sun.

While detection of starlight scattered from planets seems impractical now, it has long been realized that direct imaging of gas giant planets might be possible by detecting the thermal infrared emission from the planets themselves. Unlike stars, planets have no internal energy generation source. However, they slowly give off the heat stored in their interiors generated during their formation. Thus, when planets are young (up to about 500 million years old), they are much hotter

Figure 2. *Campaign team PI Michael Liu (on screen at right) with Beth Biller and Zahed Wahhaj assist Gemini South System Support Associate Eric Christensen (at left) in the execution of campaign observations using NICI via a remote videoconferencing system between the Gemini South control room and the Institute for Astronomy at the University of Hawai'i in Honolulu.*

and can be hundreds to thousands of times brighter than older planets, especially at infrared wavelengths. This makes younger planets easier to detect, since they are "only" about one million times fainter than their parent star (for Jupiter-class planets). Given the typical distances to most young stars, the expected angular separation of planets from their host star is only about one arcsecond or less. Detecting them is a formidable task, even for the brightest young planets. However, recent advances in high-contrast imaging with ground-based telescopes like Gemini are now making such challenging and compelling observations possible for the first time (see article on page 44).

NICI: Gemini's New Planet Finding Instrument

Gemini's Near-infrared Coronagraphic Imager (NICI) is a powerful new adaptive optics (AO)-enabled instrument for the Gemini South 8-meter telescope. It was designed from the outset for direct detection of extrasolar planets through high-contrast imaging. NICI was built by Mauna Kea Infrared (MKIR) in Hilo, Hawai'i, with Doug Toomey as the Principal Investigator (PI), Christ Ftaclas (IfA/Hawai'i) as the Project Scientist, and Mark Chun (IfA/Hawai'i) as the lead for the AO system. NICI was built for Gemini with funding from NASA.

NICI was designed as a complete end-to-end system for high-contrast imaging, minimizing the wavefront distortions from the atmosphere, telescope, and instrument through a combination of techniques. First, NICI is equipped with its own advanced AO system, based on an 85-element curvature deformable mirror developed by the University of Hawaii's AO group. Second, NICI acquires simultaneous imaging at two wavelengths (e.g., in and out of the 1.6-micron methane absorption band) to counteract the time-variable point spread function (PSF) produced by turbulence in the Earth's atmosphere. Subtraction of the two spectral imaging channels removes the bright (methane-free) glare of the target stars and reveals any faint, ultracool (methane-bearing) planetary companions (see Figure 1). The near-infrared absorption signature of methane is unique to "ultracool" atmospheres (with temperatures less than about 1300K), corresponding to Jupiter-mass planets at ages younger than about 100 million years. (More massive planetary companions, which are too hot to show photospheric methane absorption, can also be identified in NICI imaging.) Third, NICI is equipped with a suite of Lyot coronagraphs for suppression of light from the central star. Fourth, NICI employs an additional observing technique known as roll subtraction, a.k.a. angular differential imaging (ADI), to remove the time-variable PSF. In ADI observations, the Cassegrain image rotator is fixed, allowing the image of the planet to rotate in the field-of-view while keeping the diffraction pattern of the PSF fixed and stable so it can be subtracted away very accurately. Subsets of these methods have been used individually with previous AO imaging surveys on other telescopes but NICI is the first instrument to combine all these techniques into a single instrument.

The Gemini NICI Planet Finding Campaign

NICI provides a powerful new capability for direct imaging searches and the characterization of exoplanets. To take full advantage of this new opportunity, our team is carrying out a major observing campaign with NICI amounting to up to 500 hours of observing time over the next two years. This is the first such large campaign being carried out by the Gemini Observatory; accordingly, the NICI program is also intended to serve as a model for even larger Gemini observing projects carried out with future instruments.

Figure 3.
NICI during a daytime check in January 2009.

The NICI Planet-Finding Campaign assembles a large-scale coherent science program with a unified set of goals, observing methods, and data analysis techniques. While campaign-style science is new to Gemini, large observing programs have been carried out in a number of fields with other major observatories, such as the Hubble Space Telescope and the European Southern Observatory's Very Large Telescope.

The NICI Planet-finding Campaign is designed to address three key science questions:

- What are the mass and separation distributions of planets in the outer regions (5 to 10 AU) of other planetary systems?
- What is the dependence of planet frequency on stellar host mass?
- What are the spectral properties of extrasolar planets?

In order to answer these questions, the NICI campaign is being carried out by a strong, multi-disciplinary, international team, including leading instrumentalists, observers, and theorists drawn from across the Gemini community. I (Michael Liu) serve as the campaign's PI, with Mark Chun (IfA/Hawai'i) and Laird Close (Arizona) as the primary co-investigators. The team also includes Adam Burrows (Princeton); Doug Toomey (Mauna Kea Infrared); Christ Ftaclas, Zahed Wahhaj, and Beth Biller (IfA/UH); Neill Reid (Space Telescope Science Institute); Evgenya Shkolnik (DTM/Carneigie); Niranjan Thatte, Matthias Tecza, and Fraser Clarke (Oxford University); Harvey Richer (University of British Columbia); Jane Gregorio-Hetem, Elisabete De Gouveia Dal Pino, and Sylvia Alencar (Universidad de São Paolo); Pawel Artymowicz (University of Toronto); Doug Lin (University of California-Santa Cruz), Shigeru Ida (Tokyo Institute of Technology); Alan Boss (DTM/Carnegie), Mark Kuchner (NASA Goddard), Chris Tinney (Anglo-Australian Observatory); and Tom Hayward, and Markus Hartung (Gemini Observatory).

The Survey

To achieve the project goals, the NICI campaign team will target a sample of about 300 stars in the extended solar neighborhood. Young stars are a high priority, since planets are expected to be more luminous in their youth. We also prioritize stars having compelling indirect evidence of planetary companions. The campaign sample spans a wide range of spectral types (i.e., stellar mass), which is made possible by the good sensitivity of NICI's curvature AO system for optically faint targets.

We employ high-fidelity Monte Carlo simulations as a novel means to design and plan the campaign. These account for the range in target-star properties (ages, distances, luminosities, masses, and expected AO performance) and allow us to develop robust quantitative metrics for observing: e.g., deeper vs. shallower exposures; more vs. fewer targets; younger, more distant targets vs. older, closer targets, etc. Perhaps most importantly, the simulations provide a means to compare the relative value of all potential targets.

The ranking of targets is done by first simulating, for each star, a large number of planets whose orbits and masses are randomly drawn from the properties of the known RV-discovered planets, and then determining the detectability of these simulated planets with respect to the NICI contrast and sensitivity limits, as predicted by substellar evolutionary models. While young stars generally tend to be favored, this is not automatically so. In some cases, older, closer stars are more favorable than more distant, younger stars—the ability to resolve the smaller physical separations (where planets are more likely to reside) can trump the relative gain in contrast from more youthful planets.

In addition, for the past two years we have carried out a search for nearby, young, low-mass stars as part of our preparatory effort for the campaign. The current young star census in the solar neighborhood is mostly restricted to higher-mass (*A*-, *F*-, *G*-, and *K*-type) stars and contains few *M*-dwarfs. This paucity of *M*-dwarfs is striking, given that they dominate the stellar mass function by number, and is due to the fact that low-mass stars are generally too faint to be included in the optical catalogs that have been mined for nearby young stars. To find this "missing" population, we have been searching for the nearest young *M*-dwarfs using color selection and stellar photospheric activity (i.e., "starspots" and other signs of magnetic stellar "weather") to identify candidates and pursuing follow-up confirmation with optical spectroscopy. This *M*-dwarf search is a key preparatory activity for the NICI campaign to identify promising targets. Such a sample of objects is also of value for a number of other studies, including tracing the evolution of circumstellar debris around low-mass stars. The vast majority of our *M*-dwarfs are not in any published young-star sample, illustrating the novelty of the search method.

Current Status

On-telescope commissioning of NICI for methane differential imaging was completed in 2008, with the Gemini Observatory staff and campaign team working closely together to fully test instrument operation, develop observing techniques, and assess on-sky performance. NICI commissioning data, taken for stars over a wide range in brightness and seeing conditions, were used to refine the campaign simulations and planning. Overall, though work is still ongoing to fully characterize NICI performance, the instrument appears to perform better than any other existing AO instrument for the detection of faint companions inside a radius of about two arcseconds.

The first NICI science run was in December 2008, and since then campaign observations have been carried out monthly during bright time around full Moon. Campaign members have gone to Chile to participate in the commissioning and science runs, and most recently, the team has effectively participated remotely (via videoconferencing, see Figure 2). The Gemini queue system has been a major advantage for this work, since campaign observations are carried out only during suitable seeing conditions. At other times, regular Gemini queue programs well matched to poorer seeing conditions are executed. Following one more science run in April 2009, NICI will be removed from the telescope in May for maintenance and minor upgrades. This is well-timed, since the weather conditions during the Chilean winter are typically unsuitable for NICI observing.

The campaign team plans to ultimately observe about 300 carefully selected stars. As of the end of the summer 2009 observing season (which happens in April at Gemini South), about 120 targets have been observed, with the data processed by our team's pipeline that has been custom-tailored for NICI's unique datasets. While some potentially interesting candidates have been found in the initial set of data (i.e., very faint objects next to the much brighter science targets), the final confirmation that they are real exoplanets, as opposed to background objects, will come with second epoch follow-up imaging to check for common proper motion. If confirmed, multi-band imaging data from NICI, and perhaps integral field spectroscopy from other AO-equipped telescopes, will allow us to study the spectra of these young exoplanets. Spectral information from exoplanets is critical for the characterization of the compositions, temperatures, and masses of these worlds. Determining the "visible history" of extrasolar planets will ultimately help us better understand our own place in the universe.

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by Joe Jensen

Instrumentation Update

To fulfill its mission to explore the universe and share its wonders, Gemini Observatory must upgrade and expand the suite of instrumentation that translates photons collected by our fantastic telescopes into meaningful observations. Since my report in the last issue of *Gemini*Focus (December 2008), Gemini's instrument building teams have made significant progress on a number of fronts.

The Near-infrared Coronagraphic Imager (NICI)

In December 2008, the Near-infrared Coronagraphic Imager (NICI) began an aggressive search for extrasolar planets orbiting young, nearby stars. NICI is a dual-channel infrared imager built by Mauna Kea Infrared and is designed for simultaneous differential imaging at two wavelengths. NICI achieves the high contrast needed to see faint planets by using a sophisticated adaptive optics (AO) system to concentrate the starlight; it also deploys special coronagraphic masks to block most of the light from the bright star. During the first season of observing, the planet search survey team has accumulated observations of some 120 stars, a promising start on this exciting campaign to discover new planets. For more details on the NICI campaign, please see article starting on page 61 in this issue. In addition to campaign observations, preparations for regular NICI observing in semester 2009B have begun. During the southern-hemisphere winter months, when NICI is not scheduled for use, we plan to add some additional focal plane masks and dichroic beam-splitters to improve performance and make NICI more versatile.

GNIRS Repairs

As previously reported, Gemini is working to repair the Gemini Near-infrared Spectrograph (GNIRS) following an overheating accident in May 2007 (see *Gemini*Focus Dec. 2007, pg. 43; June 2008, pg. 39; and Dec. 2008, pg. 63 for more information). The process of getting the lenses, mirrors, gratings, and prisms repaired or replaced

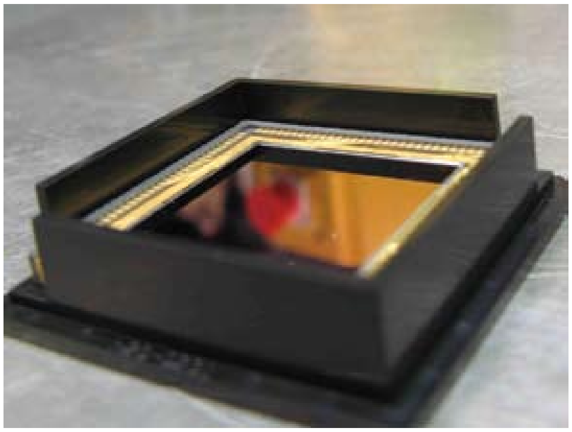

Figure 1. *New Aladdin-3 detector for GNIRS ready for testing at NOAO.*

has taken a long time, but is now complete. The optics have been reinstalled in their mounts and are being aligned in preparation for integration into the GNIRS optical bench. Some optics that we originally thought were fine showed some coating damage after several months in Hilo. They have now been cleaned, re-coated, or replaced. By the time this issue appears in print, we expect to have the instrument fully integrated and ready for further alignment and testing.

To prepare for GNIRS integration and testing, Gemini engineers have cleaned and repaired the cooling systems and dewar, tested for leaks, connected and tested the electronics, cables, motors, and computers, and assembled many mechanisms. They have also been working to get the array controllers ready. Procuring new detectors for GNIRS has taken much longer than expected. After months of delays and returning the detectors to Raytheon for rework, we have finally received two candidate science-grade Aladdin-3 InSb detectors (Figure 1). These two are being tested and characterized at NOAO, and the best one will be shipped to Gemini for installation in GNIRS. Testing in GNIRS is scheduled for the middle of this year, following warm tests with a multiplexer, and cold tests with an engineering grade device.

The infrared On-instrument Wavefront Sensor (OIWFS) for GNIRS is being repaired at the University of Hawai'i. It will be used in the future to improve GNIRS performance with the Altair AO system. The OIWFS optics have been modified and a new filter added to make it much more sensitive. A replacement engineering-grade HAWAII-1 HgCdTe detector has been acquired and testing is now under way with the detector controller. We expect that the OIWFS will be much more useful than it was before the accident, because it will be more sensitive and read out much more quickly. Improvements made to the GNIRS OIWFS may be applied to the NIRI and the Near-infrared Integral Field Spectrometer (NIFS) OIWFS systems in the future.

FLAMINGOS-2

The FLAMINGOS-2 infrared multi-object spectrograph (MOS), being built by the University of Florida, will soon be delivered to Cerro Pachón. At the time this article was written, the FLAMINGOS-2 team and Gemini engineering and science staff had successfully worked through about 90% of the pre-ship acceptance tests (Figure 2). A few lingering cryo-mechanical issues have been addressed, and we are now planning to complete final pre-ship acceptance testing as this issue goes to press. FLAMINGOS-2 is a key part of our planned suite of instruments for Gemini, and we look forward to commissioning it at Gemini South in the near future.

Figure 2. *Percy Gomez, instrument scientist, examines the MOS and decker wheels in FLAMINGOS-2 fore-dewar during acceptance testing last year in Gainesville, Florida.*

GMOS Enhancements

One way to make Gemini's instrumentation more competitive is to upgrade existing instruments. The optical Gemini Multi-object Spectrograph at Gemini North (GMOS-N) is now about 10 years old. The detectors are no longer state of the art, so we have begun the process of replacing them with new, thick CCD detectors that are much more sensitive at red wavelengths and still retain at least as much blue sensitivity as we currently have. The first attempts to purchase new high-performance detectors several years ago were unsuccessful, but we now believe that we will be able to proceed with this project later in 2009. At the time this article was written, bids from CCD vendors had been received, and a contract to purchase new CCDs from the winning bidder was under negotiation.

In addition to new detectors, Gemini is procuring new narrow-band filters for GMOS-North and South. These filters will enable new types of science and provide a matching complement of filters for GMOS-N and GMOS-S. The new filters will include SII, OIII, and HeII. We will also replace the B600 grating (for GMOS-N) with a new one to reduce scattered light (attempts to clean the old grating were unsuccessful). We are also installing red-blocking filters to reduce scattered light for GMOS-N users interested in bluer wavelengths. The filters and grating will be offered for semester 2009B.

When these enhancements are completed later this year, we expect that astronomers using GMOS-N will be able to get better results more efficiently, and make good use of GMOS-N for several more years to come. New detectors for GMOS-S will follow in 2010.

The Gemini Planet Imager (GPI)

The first "Aspen" instrument to be built is the Gemini Planet Imager (GPI), a sophisticated AO coronagraph designed for very high-contrast imaging and integral field spectroscopy. GPI will allow astronomers to detect and characterize extrasolar planets less than an arcsec from bright, young stars. The GPI team is led by the Lawrence Livermore National Laboratory and includes contributions from the Jet Propulsion Laboratory, the Herzburg Institute for Astrophysics (HIA) in Canada, the University of California at Los Angeles, Santa Cruz, and Berkeley, the American Museum of Natural History, and the University of Montreal. More information about GPI and the other Aspen instruments may be found in articles in the December 2006 and June 2007 issues of *Gemini*Focus.

In May 2008, the GPI team held the critical design review (CDR) prior to beginning construction of the instrument. Most of the subsystems passed CDR and began the procurement process. Some elements of the design needed additional work to guarantee that the instrument would achieve the required wavefront stability of a few nanometers, even when mounted on the vibrating telescope and exposed to the elements in the dome. The GPI team worked through the remainder of 2008 to finalize the design, using complex finite element modeling to find ways to stiffen and lighten the support frame. They also continued to mitigate risk by developing key technologies needed for the new micro-actuator deformable mirror and the partially transmissive graded pupil masks. Following a recent review in March 2009, the GPI team resolved all remaining open issues and the CDR process is now complete. The design for GPI is now finished (see Figure 3) and construction of many components is well under way. Delivery of GPI to Gemini South is expected in mid 2011.

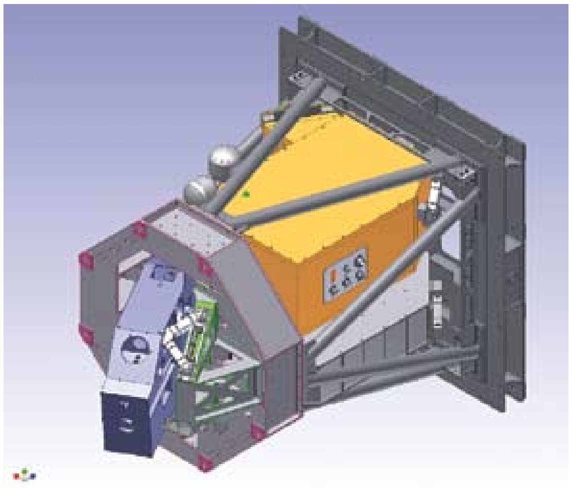

Figure 3.
Final design of the GPI instrument (with covers removed), showing the adaptive optics bench (gray, center bottom), the calibration interferometer (blue, left), and the integral field spectrograph (orange, top). The gray support structure provides a very rigid, low-vibration platform for GPI.

WFMOS Conceptual Design Study Review

One of the most exciting things we accomplished during the last year was to complete two competitive conceptual design studies for the Wide-field Fiber Multi-object Spectrometer (WFMOS), one led by Sam Barden and the Anglo-Australian Observatory (AAO), and the other by Richard Ellis and the Jet Propulsion Laboratory (JPL)/Caltech. Both studies represented large international collaborations that spanned the Gemini partnership. WFMOS is an exciting prospective instrument that could collect 2,400 or more spectra simultaneously over a field of view 1.5 degrees across. WFMOS was the highest-priority instrument to emerge from the Aspen

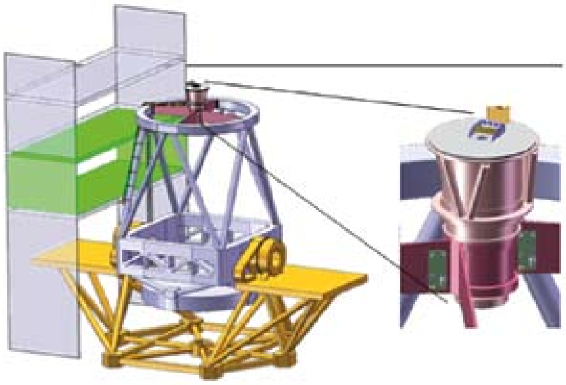

Figure 4.
One possible concept for the WFMOS prime focus instrument. The top end unit contains the wide field corrector, positioning actuators, atmospheric dispersion corrector, instrument rotator, and about 2,400 fiber positioners. The light is fed to a bank of spectrographs located off the telescope in an adjacent room via fiber optic cables.

process, and although it has been slow to mature, it has been supported consistently by the Gemini Science Committee and Board of Directors. WFMOS is being designed as a joint Gemini/Subaru endeavor, and after we procure the subsystems of WFMOS for which Gemini is responsible, they will be installed on the Subaru telescope on Mauna Kea. WFMOS therefore represents a bold new initiative to extend our international collaboration to new communities and partners.

Gemini recently conducted the WFMOS conceptual design study review under the direction of a panel of experts chaired by David Crampton (HIA, see profile on David starting on page 16 of this issue). The two teams presented their designs and bids to build WFMOS to the review panel over a two day period in February. The panel gave the highest rank to the JPL proposal and recommended that Gemini have that team build WFMOS. The panel's recommendation has been forwarded to the Gemini Board of Directors, who will decide in May if Gemini will fund the JPL team to perform next phase of WFMOS design and development.

While the design study teams were working hard to come up with concepts for WFMOS that could work on the Subaru telescope, the team designing HyperSuprime Cam (HSC) for Subaru was also working hard. HSC is a 1.5-degree wide-field imager with excellent image quality designed to measure dark energy using weak gravitational lensing. Subaru is now designing HSC and hopes to complete it and have it ready for installation on the telescope in 2011. HSC and WFMOS are like Siamese twins and will share several critical components, such as the prime focus unit and wide field corrector. By completing HSC, Subaru will provide many of their key parts for WFMOS well in advance of WFMOS being completed sometime around 2015. WFMOS and HSC together provide highly complementary approaches to answering fundamental questions about the nature of dark energy and the growth and evolution of structure in the universe.

WFMOS will be very expensive and require hundreds of nights of telescope time to meet its core science objectives. Gemini and Subaru have been working closely to set the stage for a WFMOS agreement between our two observatories. Since October 2008, a dedicated team of astronomers and leaders from Gemini and the National Astronomical Observatory of Japan (NAOJ) has met several times to define the exchange of time and allocation of resources in support of WFMOS. While many details still need to be ironed out, it is clear that the Gemini and Japanese astronomical communities will greatly benefit from an expanded and equitable exchange of telescope time. Joint participation on the science teams that will address the key questions about dark energy and the formation history of the Galaxy is an essential part of our collaboration.

The next step for WFMOS will take place in May when the Gemini Board will be asked to approve a budget to provide funding for the next phase of WFMOS design development. While the WFMOS conceptual design review panel recommended going with the JPL bid, the AAO proposal will still be under consideration until the Board approves contracts with the JPL team to construct WFMOS. The Board will also need to approve the terms of the agreement with the NAOJ related to the time exchange commitments with Subaru. All the pieces to this complex negotiation and a decision to proceed with WFMOS are expected to be considered in the May meeting of the Gemini Board.

Ground Layer Adaptive Optics (GLAO)

A ground-layer AO system for Gemini North is the final piece of the Aspen program that is still under consideration (see *Gemini*Focus June 2007, p. 11). In 2008, an 18-month study of the turbulence profile on the Mauna Kea summit ridge was completed by Mark Chun at the University of Hawai'i and his collaborators. The extensive data set clearly showed that the ground layer turbulence below 500 meters is uncorrelated with the free-atmosphere seeing, but is strongly related to wind conditions. The ground layer and free-atmosphere turbulence contribute roughly equally to the total seeing, but not always at the same time. The gain that could be realized using a GLAO system on Gemini North would be significant across a wide wavelength range from the optical R-band through the near-infrared, and in practically all seeing conditions (especially when it's a little windy at the summit). Early estimates show that image quality should improve by 0.2 arcsec at 1.6 microns under nearly all conditions, and ensquared energy improvements of about a factor of two are expected.

A decision to proceed with GLAO conceptual design studies is not expected until after the Gemini-South Multi-conjugate AO system is complete and a decision on WFMOS is made.

Summary

Gemini is on the verge of vastly improving its capabilities, both in the north and in the south. We will soon have an upgraded GMOS at Gemini North with significantly better performance than the current version. We will have a rebuilt GNIRS providing moderate to high resolution spectra from 1 to 5 microns. These improvements will complement the existing capabilities, including near-infrared imaging being delivered routinely by NIRI now (with and without Altair laser guide star AO), and the excellent thermal-infrared performance being delivered by Gemini's world-leading protected silver mirror coatings and the MICHELLE spectrograph. NIFS rounds out the Gemini North complement with 1- to 2.5-micron AO integral field spectroscopy with very high spatial resolution.

In about a year, Gemini South will seem like a new observatory. Three major new instruments will soon be ready for regular observations. NICI commissioning has been completed, and it is now in regular use as a planet finder, with additional modes becoming available starting in August. FLAMINGOS-2 will join the Gemini South instruments very soon, providing a wide-field, near-infrared MOS capability to the southern hemisphere for the first time. The GMOS-S spectrograph could get a new set of CCDs in 2010, matching those being installed in the north this year. T-ReCS continues to perform well at thermal-infrared wavelengths to complement MICHELLE in the north. Finally, the incredible performance expected with the new Gemini Multi-conjugate AO system (GeMS, see update starting on next page) will be commissioned later in 2009, as soon as the laser system is delivered. GeMS will feed FLAMINGOS-2 and the Gemini South AO Imager (GSAOI) with a 2 square-arcmin AO-corrected field of view with stable, uniform images. GeMS will be the first laser MCAO system deployed, and it will enable a wide range of new science that depends on the best possible images over a wide field of view.

It is a very exciting time to be working at the Gemini Observatory. The new and improved instruments coming online this year promise to allow our astronomical community to make exciting discoveries that will revolutionize our understanding of the universe. It has been a pleasure for me to participate with the Gemini staff, the Gemini and Japanese astronomical communities, and the instrument building teams who make these new instruments and capabilities a reality.

Joe Jensen is Gemini's head of instrumentation. He can be reached at: jjensen@gemini.edu

by François Rigaut

GeMS Update

Figure 1.
Laser bench support structure which was recently accepted in Santiago.

During the past six months, good progress has been made on the GeMS (Gemini Multi-conjugate Adaptive Optics System) on multiple fronts. We are currently aiming to have the first laser light on the sky at Gemini South by the end of 2009 and start the AO bench technical commissioning in April 2010.

Integration of the CANOPUS optical bench continues in the instrument laboratory at the Gemini South Base Facility. The entire electronics thermal enclosure structure has been stiffened to avoid mechanical contact with the optical table. A redesign of the cooling system is progressing, with additional involvement from Gemini North engineers. The tip-tilt wavefront sensor characterization is well advanced. Reconstructor improvement and tomography work is also underway.

At the end of May, an engineer from the Optical Sciences Company (tOSC) will visit to help commission the remaining real-time computer functionalities. The main remaining CANOPUS tasks are linked to electronics (integration of the laser guide star wavefront sensor motion control in our

Versa Module Europa (VME) hardware architecture) and mechanics (cooling redesign and implementation), which are two areas where we suffer from a lack of resources due mostly to observatory budgetary constraints.

In high-level software, following a detailed definition of the operating sequences (interaction of GeMS with the Telescope Control System (TCS), Telescope Control Console (TCC), and sequence executer (seqexec)), the Gemini Software Group will release first TCC/seqexec/TCS GeMS-compatible version of the software for their mid-year release (June 2009). The various tools and features needed for commissioning of the system will be completed in the software's second yearly release in November 2009. The Observing Tool (OT) and Phase 1 Tool (PIT) GeMS panels and functions are also being worked on.

On the GeMS laser infrastructure front, a weakness identified in the laser service enclosure (LSE) foundation at the end of 2008 has been repaired and the overall structure reinforced. Meanwhile, the LSE and laser bench support structure has been manufactured in Santiago and has recently been accepted (see Figure 1). Assembly of this large beam structure on the "-X" side of the Gemini South telescope will take place during the May 2009 shutdown (as this issue went to press). The LSE itself will be installed thereafter to make sure that the laser infrastructure is ready ahead of the laser delivery by a comfortable margin.

Nearly all components are fabricated and received for the Beam Transfer Optics (BTO). After completing current final control and alignment tests in the lab, the various subsystems will be installed in the telescope and alignment of the laser path from the laser system output up to the Laser Launch Telescope (LLT) will proceed and be completed by the time the laser is installed on the telescope. The last subsystem design work on the laser bench beam stabilization system has been finished.

The Gemini South and Keck (GSK) laser contract is the last on-going contract within the Gemini MCAO program, but it is finally nearing a successful conclusion. The Keck laser factory acceptance testing (FAT) is planned in early May 2009, about two years later than originally anticipated. Meanwhile, the Gemini South laser is going through final integration and testing and its FAT is planned in July. Lockheed Martin Coherent Technologies (LMCT), the GSK laser contractor, currently expects Hawai'i delivery of the Keck laser in June and Chile delivery of the Gemini South laser in early September of this year. While the contract called for design and fabrication of a 20-watt laser for Keck and a 50-watt laser for Gemini South, the current Keck laser performance appears significantly better than expected, with a laser output power in the 40-watt range. However, there are still both technical and contractual reasons that maintain some uncertainty as to the level of performance that the Gemini South laser will provide in operations, so the next couple of months will be key to assess the outcome of this last critical GeMS component.

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by Peter Michaud

Outreach Update:
IYA and Beyond...

When we look back on 2009, I suspect it will be one of those years to be remembered as pivotal in some rather profound ways. There are the obvious global economic and even societal watersheds and meltdowns, but in astronomy the celebration of the International Year of Astronomy (IYA) will loom as a genuine highlight.

Although this issue of *Gemini*Focus will come out at only the halfway point in the IYA celebrations, the Gemini Public Information and Outreach (PIO) office has already left a significant mark on the 400th anniversary of the astronomical/scientific use of the telescope that IYA commemorates.

Gemini kicked off IYA with expanded versions of our two flagship local outreach programs, Journey through the Universe (JttU) at Gemini North and AstroDay Chile at Gemini South. Both programs broke all previous records for participation and impact (see Figures 1 and 2). It was the fifth year for the JttU program and the third for AstroDay Chile. Antonieta Garcia, who led the annual AstroDay Chile event, reflects on its history and future: “I’m amazed when I think that just three years ago we had only four organizations participating in AstroDay Chile. Now we have 21 from Chile and abroad. I can only dream about what our next steps will be.” Both AstroDay Chile and JttU have taken on a forward momentum that is propelling them in exciting new directions and attracting new partnerships and innovative ideas. These include the AstroDay Chile press conference and a new annual science education award for distinguished Chilean astronomy educators. One of the new innovations for this year’s JttU was an all-day Family Science Day at the ‘Imiloa Astronomy Center which attracted over 1,000 family participants. Next year the local office of the Department of Education is working to hold the popular JttU teacher workshop on an assigned teacher training day in order to allow every local teacher to attend.

Most recently, Gemini opened the IYA program “Around the World in 80 Telescopes,” as people around the world toured observatory control rooms as part of a webcast starting at Gemini North (see Figure 3) on the night of April 3-4, 2009 (UT). Every twenty minutes another observatory was featured in the live webcast, and 19 hours after the visit to Gemini North, the event landed at the Gemini South control room. Hosts Scott Fisher and Étienne Artigau (with James Radomski) provided engaging insights into the operation of Gemini’s control rooms and the science that we do each night. As part of this event, Gemini released four new legacy images (two

1

Figure 1. *(Three images at left) More than 9,000 participants enjoyed the 2009 AstroDay Chile on January 31, 2009. It took place in a large tent at the Mall Plaza in La Serena, Chile. This annual event is organized by the staff at Gemini South. The event attracted institutions from across Chile and the world, including the ESO observatories, ALMA, CTIO staff/scientists, and even participants from two planetaria in Argentina.*

2

Figure 2. *Participants in JttU Astronomer's Workshop, which was part of the preparation for scientist's classroom presentations.*

3

Figure 3. *Scott Fisher is interviewed at the Gemini North control room as part of the IYA's "Around the World in 80 Telescopes" live webcast.*

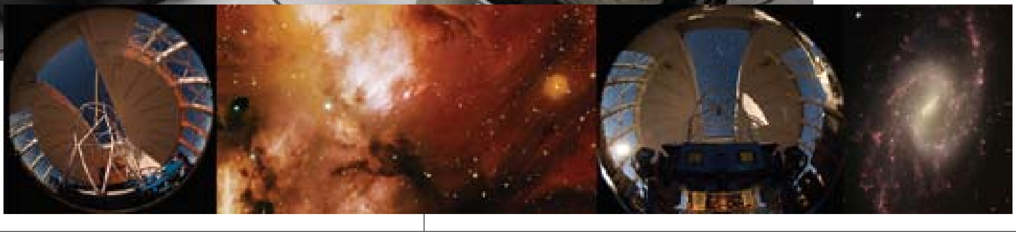

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Figure 4. *Four Gemini Legacy images released as part of the IYA's "Around the World in 80 Telescopes" event.*

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Figure 5.
Scenes from the new 5-minute "About Gemini" video produced for the International Year of Astronomy.

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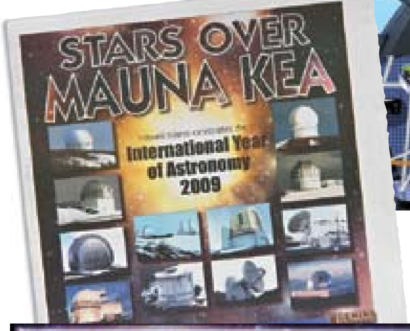

Figure 6.
Cover of the International Year of Astronomy edition of "Stars Over Mauna Kea" newspaper supplement.

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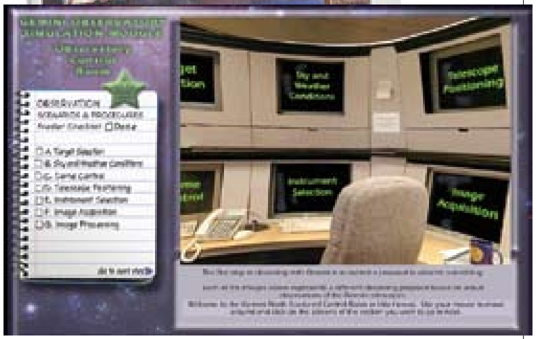

Figure 7.
Screen from the web-based beta version of the Gemini virtual tour observation module. Users can participate in simulated observations using real Gemini data to produce and print a color image.


8

Figure 8.
Screen from the tour of Gemini Legacy images on the Microsoft® World Wide Telescope web interface.

from each hemisphere: one astronomical; and one of each telescope, see Figure 4), and a new five-minute overview and introduction to Gemini (see Figure 5) that can be found (along with the new legacy images, and a link to the archive of the webcasts) at: **www.gemini.edu/node/11248**

Gemini also led the production of the third *Stars over Mauna Kea* "astronomy supplement" for Hawai'i Island newspapers. Unlike the previous two editions, this one was distributed through both of the island's largest circulation newspapers in east and west Hawai'i (*Hawai'i Tribune-Herald* and *West Hawai'i Today,* respectively). A total of 43,000 copies of the 40-page supplement were printed, which is the largest production run ever for local Big Island newspapers (cover shown in Figure 6). Janice Harvey, who is responsible for managing the publication with the *Hawai'i Tribune-Herald,* said, "I'm thrilled every time I see dog-eared copies of the *Stars Over Hawai'i* publication in offices around town, like the one I saw in my doctor's office the other day! It is such a joy to know that we are helping to share the wonders of our universe with our host communities."

In addition, *Hawai'i Tribune-Herald* became a local IYA programming sponsor and is featuring an IYA webpage with downloads of the supplement and a calendar of upcoming IYA events and activities on Hawai'i Island. See: **http://www.hawaiitribune-herald.com/somk/** for more details and to download the entire publication in PDF format.

Another set of PIO initiatives has been evolving rapidly since the last issue of *Gemini*Focus, and it involves the innovative use of the Internet to share Gemini with the world. As this issue goes to press, a beta version of the most popular module from the Gemini Virtual Tour CD has been adapted for Web delivery. The module makes it possible for anyone connected to the World Wide Web to participate in a simulated observation with Gemini using real data and end up with a customized color photo at the end (see Figure 7). In this interactive web-based activity, visitors follow the key steps in making an observation with Gemini, from pointing the telescope to setting the integration times and processing a full-color image. Currently the module is in beta testing, and you can help in this effort by visiting and providing input from the test site at: **www.gemini.edu/vtbeta**

Related to the Web-enabled virtual-tour module is another new web-based product that incorporates the Microsoft World Telescope Network (WTN) to allow Internet users to take a tour through the nighttime sky of some of Gemini's most spectacular Legacy images. To access the tour and download the necessary web plug-ins, visit **www.gemini.edu/wwt.** Figure 8 shows a sample screen from the tour that will soon grow to include all of the Legacy images, as well as recent science results. Additional features are also planned, so stay tuned!

Finally, a new set of 8.5 x 11" Legacy images are now available and can be obtained as PDFs for duplication and distribution. Each sheet includes detailed background text to help the public understand the images and provide context. To download print-ready PDFs, visit the Gemini Image Gallery at: **www.gemini.edu/images**

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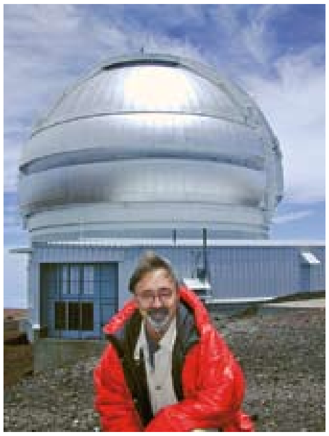
A Tribute to Jean-René Roy



The idea of highlighting many of the key individuals involved in the scientific and technical development of Gemini in this issue of *Gemini*Focus was, in large part, the vision of Gemini's Deputy Director, Jean-René Roy. Not a person to focus on his own accomplishments (a trait shared with all of the individuals profiled in this issue), it perhaps never occurred to him that a huge part of Gemini's story is missing without his inclusion in some fashion.

As it turns out, and as many readers of this publication already know, Jean-René recently announced that he is taking a leave from his current position as the deputy director at Gemini South to accept a "rotator" position at the U.S. National Science Foundation in the Large Facilities Project office. When he completes his assignment at the NSF Jean-René will return to Gemini and explore his next path in life.

Of course, this leaves a tremendous amount of detail unsaid and falls far short of a fitting tribute. However, given that Jean-René would likely find any tribute unnecessary (and something he would have never approved of for anyone else!), we'll share these few words by his colleagues, Doug Simons, Matt Mountain, and Phil Puxley. Jean-René's true impact will live on in the legacy of Gemini's science, which has always been at the core of his passion for this observatory.

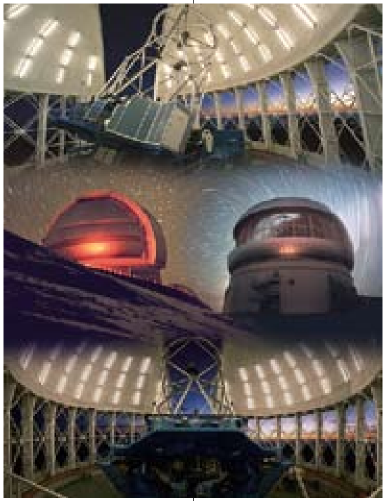
Doug Simons

When Jean-René "introduced" me as the new director to the Gemini staff in 2006, he said the role of director can be summarized as "one part symphony conductor, one part gladiator, and one part coach." Over the two decades I have come to know Jean-René, it is clear he has mastered all three roles and has touched my life through these roles. Let me elaborate...

Jean-René as a symphony conductor: only a handful of people truly understand the complex dynamics involved with running an organization like Gemini. When the Gemini Board is arriving or we have an important review committee on the horizon, Jean-


Photo by Hélène Allard

René is really quite masterful at orchestrating the generation of material required to support such meetings. To do this, he must speak many "languages" (or using this metaphor, play many "instruments") to extract documents from the administrative, science, engineering, and development branches, weave them into a coherent information set, and make sure they are posted electronically by the due date. Then he works his magic during the meetings to offer interpretation or clarification when questions arise. At the end of each meeting, he and I assess the resolutions generated, discuss them with the senior staff, and take a collective deep breath after the last of our visitors departs for home. The underlying skill Jean-René uses to conduct the "Gemini symphony" is his ability to perceive beyond the spoken word and establish connections between naturally disparate entities. In that sense, one of the distinctions between Jean-René and so many of his peers is his ability to connect on many levels with everyone around him. He is as adept at holding a conversation with the Cerro Pachón bus driver as he is with the chair of the Gemini Board (which *he* chaired from 1998-99). Jean-René as a symphony conductor – that's a skill I aspire to have someday as well.



Jean-René as a gladiator: Jean-René served as Gemini's interim director between the time Matt Mountain left to take the helm at Space Telescope Science Institute and the day I started as Gemini's director. In that time, he demonstrated a singular resolve to not "screw around" in his decision-making process and to ensure that his perspective was understood on matters he felt were truly important. For me, the most significant application of this facet of Jean-René's persona is the time he advocated my application for Gemini director.

While nudging me to apply for the position on what seemed like countless occasions, I came to learn later that he was also asserting this perspective in the company of some key individuals involved with the recruitment. For obvious reasons, I did not participate in any of those conversations, but I can imagine how it must have felt for those on the "receiving end" of

Jean-René's whip, as he articulated his perspective with his usual confidence, clarity, and conviction. He expressed faith in my ability to lead Gemini when others had doubt. I can only hope that, since my appointment, I have not disappointed him. Jean-René as a gladiator changed my life through his tenacious support of my candidacy as Gemini director, and I am grateful that I have never been the "lion" in his company!

Jean-René as a coach: my first memory of Jean-René dates back to my days at the Canada-France-Hawai'i Telescope when, as a young post-doc in charge of building the first facility infrared cameras, I gave a project close-out summary to the CFHT Board. I methodically presented the final results of the project including some pretty impressive on-sky test results which demonstrated the system was ready for community access. Right after my presentation, I quietly left the CFHT conference room and began to walk toward the front office. To my surprise, Jean-René put his arm around my shoulder, and told me enthusiastically that was the first time in the history of CFHT that anyone had built an instrument that met budget, spec, and schedule.

Beyond being stunned by his comment, I had no idea how badly I needed to hear his acknowledgement of my efforts. It was a hard slog to build those cameras. Jean-René knew it, and he took the time to personally thank me for my work. To this day Jean-René, who also remembers that presentation, reminds me of how I stood out from the crowd during that presentation, not because of my report but because I was the only person using professional quality color transparencies instead of hand scribbled acetates! "Form over function" comments aside, the fact that one simple "thank you" stuck with me for nearly two decades and acts as the cornerstone in my relationship with Jean-René is a testament to how powerful a few simple words can be. Jean-René, as a coach, gave me a lift in my career when I needed it badly, for which I will always be grateful.

I have tried to illustrate the impact Jean-René Roy has had on my career as an astronomer over the past two decades. Now multiply this by the number of people he has interacted with over his extensive international career, and you can begin to appreciate this man's remarkable impact not only on Gemini, but on all of astronomy.

Doug Simons is the current director of Gemini Observatory and has worked with Jean-René since Doug came to Gemini in 1994 to lead the instrumentation program. He took over the Gemini directorship after Jean-René served as the observatory's acting director from September 2005 - June 2006 following the departure of Matt Mountain.

Matt Mountain

Jean-René has always been part of Gemini's "DNA." As an early chair of the international Gemini Board, within weeks of taking over, Jean-René was confronted with the sudden departure of the project manager. He was presented with his first executive decision, having to approve the appointment of a new and as yet untried replacement (Jim Oschmann, who today is a senior vice president at Ball Aerospace, see bio on page 35). On a very short timescale, Jean-René consulted across the international partnership, subjected the then director (me) to an intensive inquisition on the options and alternatives available, but then went on make the decision.

On joining the Gemini Observatory, Jean-René experienced first hand the complexities of completing and commissioning a modern observatory that spanned two continents, supported by a seven-member international partnership. As a senior member of the management team, Jean-René was exposed to the full range of modern systems engineering and project management techniques required to bring complex large science facilities within the tight budgetary constraints imposed by the Gemini partnership. He saw first hand the advantages and pitfalls of using both an industrial and university culture to deliver complex scientific facilities and instrumentation. In addition, Dr. Roy had to lead the creation of the first full-time science staff in Hawai'i, and manage the interaction between the "construction culture" and "operations culture" that such transitions entail. As he said to me on many occasions, "They never tell you how to do this stuff in graduate school, nor do they tell you how many decisions you have to make before morning coffee!"

Throughout all of this, Jean-René never (okay only rarely) lost his good humor. As he used to remind me on many occasions, "This is only astronomy." But, the one thing he never lost, throughout all the years Jean-René and I have argued, wept, or cheered together, was his infectious intellectual excitement of the potential of the Gemini telescopes.

Matt Mountain is currently the director of the Space Telescope Science Institute (STScI). He came to Gemini in 1992 as project scientist and served as director from 1994 until 2005 when he assumed his current position at STScI. See profile on Matt Mountain starting on page 12 of this issue.

Phil Puxley

Jean-René joined the Gemini Board at about the same time that I joined the Gemini staff, in 1996. After a six month roller coaster ride getting up to speed with the Gemini team (at that time based on the roof of the NOAO building in Tucson) and a lot of travel, I distinctly remember my first board meeting. I recall wondering how the members could possibly stay on top of all the complex construction, operations and partnership issues. In this instance, the answer turned out to be "quite easily" since Jean-René shared a passion for the project that was equaled only by the staff itself. Thus, it was no surprise when I found myself in 1999 in a telephone interview (from the back of a taxi; did I mention there was a lot of travel?) with Jean-René, who was soon to become Gemini North associate director. After a relatively brief but intense handover, in which our own partnership was forged, I left for Chile to become Jean-René's twin at Gemini South.

In addition to our primary responsibility of bringing the two telescopes into steady-state operation, a critical shared task was to prevent the accumulation of the many small "random mutations" (in Jean-René's words) that, like natural selection, can act to drive a divergence of the two telescopes. To those ends, we talked daily via our desktop videoconference stations, often for an hour or more, so that it felt almost like sharing a conventional office.

In addition to shared tasks, we also had specific assignments. No one who has heard one of Jean-René's enthusiastic presentations summarizing the science highlights from the telescopes will forget it. What is remarkable is that this focus on science carried over to such a detailed level that–at any meeting–Jean-René could (and frequently would) go around the table and recall the research results from each of the members of whichever committee was convened. One particularly striking aspect of that taxicab interview back in 1999 was Jean-René's description of how he deliberately "re-invented" his career every 10 years, moving through solar astronomy, ionized nebulae, and then Gemini. So, it is no surprise to me that we now find him moving on to new challenges in his next career.

Phil Puxley currently serves as program director for facilities at the U.S. National Science Foundation where he works primarily on the ALMA project. Until 2006, Phil was associate director of Gemini South, a position that was filled by Jean-René as deputy director at Gemini South.

Paul Hirst, Gemini's project scientist for dataflow systems products, took this photo on a dive trip to the Great Barrier Reef at a depth of about 12 meters while SCUBA diving at the Undine Reef, about 50 kilometers offshore from Cairns. A framed print of this photo hangs on the wall above his desk in the Hilo Base Facility.

Paul Hirst, shot this image on Fuji Provia 100 film with a Canon EOS7e in an Ikelite underwater housing using an Ikelite substrobe and a 28mm lens.

In this photograph taken at sunset, the Cruz del Milenio de Coquimbo can be seen just right of center. This cross, a landmark in Coquimbo, is about 70 kilometers (45 miles) in distance and has a height of 83 meters (272 feet) and a width of 40 meters (131 feet). The structure was dedicated on May 5, 2000.

Ariel Lopez, lead SSA at Gemini South, took this photograph from Cerro Pachón. The exposure is 1/50 second at f/5.6 with an ISO of 1,600 using a 200 millimeter focal length lens.

GeminiFocus

Mauna Kea standing in the calm.

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