NOAOGEMINISCIENCECENTER

TUCSON, ARIZONA • LA SERENA, CHILE

The Gemini Planet Imager

James R. Graham (University of California at Berkeley) & Bruce Macintosh (Lawrence Livermore National Laboratory)
for the Gemini Planet Imager Team

The Extreme Adaptive Optics Coronagraph (ExAOC) was identified during the Gemini Aspen Instrument Process as one of four next-generation instruments for the Gemini Observatory. It was conceived as a high-performance adaptive optics coronagraph optimized for delivering very high contrast at small angular separations, suitable for detecting extrasolar planets.

The results of conceptual design studies were submitted for consideration to the Gemini Board in early 2005, and the Board has now approved contracts to proceed with the design and construction of this instrument. The primary science mission of this instrument, now more euphoniously designated as the Gemini Planet Imager (GPI), is to detect self-luminous extrasolar planets at near-infrared wavelengths.

Detecting an old, cold Jupiter-like planet a billion times fainter than the Sun at visible and near-infrared wavelengths is probably a task for the Giant Segmented Mirror Telescope (GSMT). A young (100 million-year old) Jovian mass planet is *only* a million times dimmer than its parent star in the near-infrared! These are still undetectable by the Hubble Space Telescope (HST) or existing ground-based adaptive optics (AO) systems if the object lies within a few arcseconds of its host, but are within reach of the next generation of AO systems.

The GPI combines four techniques to achieve this "firefly next to a searchlight" contrast. A high-order AO system uses 1,800 active actuators on a silicon Micro-Electro-Mechanical System (MEMS) deformable mirror to control fast-moving atmospheric wavefront errors. State-of-the-art optics (λ/200 surface quality), combined with a nanometer-accuracy infrared interferometer, reduce and remove quasi-static wavefront artifacts. A sophisticated diffraction control system (a variant of a Lyot coronagraph) removes the Airy pattern. Finally, the science instrument is an integral field spectrograph, which will use multi-wavelength information to reject artifact speckles and allow characterization of discovered planets. Figure 1 shows a simulated GPI image. Ultimately, in hour-long exposures, GPI should be able to detect objects more than ten million times fainter than their parent stars, e.g., able to detect planets out to ages of ~1 billion years (depending on their mass) at a separation of 5—50 astronomical units (AU) from their parent star.

Why do we need direct detection to find more planets, when nearly 170 Doppler-detected planets are already known? Kepler's third law, $p^2 = a^3$, provides the reason. For reliable detection using a method that measures orbital motion, a significant fraction of an orbit must elapse. The Doppler searches, which began accumulating significant quantities of data about a decade ago, now probe out to 4.6 AU, although about half of the known planets lie within 0.9 AU. In another five years, they will have reached as far as 6 AU. It is therefore impractical to explore the outer regions, say 30 AU, of solar systems, except by direct imaging.

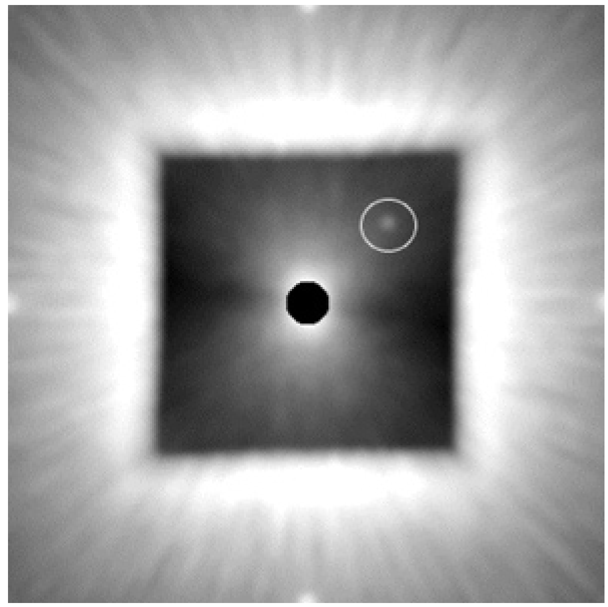


Figure 1. Simulated 20-second Gemini Planet Imager (GPI) broadband integration showing a 5 Jupiter-mass extrasolar planet in a 6 AU orbit around a 200 million-year old solar-type star at 10 parsecs (33 light-years) from Earth. The star is located behind an occulting spot. The square "dark hole" region created by GPI's spatially filtered wavefront sensor and its MEMS deformable mirror is 1.8 arcseconds on a side. This is a direct broadband image (created by combining all wavelength channels in the integral field spectrograph) with no post-processing. In hour-long exposures, GPI will be 13 times more sensitive, and multiwavelength planet detection should enhance sensitivity by another factor of ten.

Extrapolation of current trends in planet abundance with the semi-major axis of their orbits suggests that the number of detectable planets will increase at least linearly with the outer limit of the survey, so we expect direct imaging to yield hundreds of planets.

continued

The Gemini Planet Imager continued

More significantly, the abundance of planets beyond 5 AU holds clues to their formation processes and migration mechanisms. If Jovian planets can form by gravitational disk instabilities, as well as core accretion, then the outer regions of solar systems could have abundant Jovian and super-Jovian mass planets.

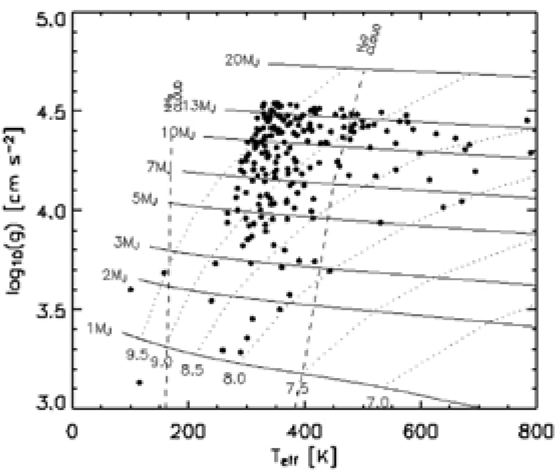


Figure 2. The distribution of atmospheric properties of GPI-detected exoplanets from a Monte Carlo simulation of a survey of the solar neighborhood. The solid lines show the evolution of exoplanets ranging from 1–20 Jupiter masses (Burrows et al. 2003). Dotted lines are isochrones labeled in log_{10}(billions of years [Gyr]). The detected planets (filled circles) are drawn from the field survey of nearby (< 50 parsec) stars (no age cut). The population straddles the water cloud condensation line at about 400 Kelvin (dashed), and a few objects lie below the ammonia condensation curve (dashed). The only known astronomical object that lies on this plot is Jupiter, with T_{eff} = 120 Kelvin and $log_{10}\,g$ = 3.4.

Perhaps the most alluring aspect of direct planet detection is that it opens up planetary atmospheres for spectroscopic study. Understanding these atmospheres will be a challenge, as direct detection will yield discovery of the first objects with temperatures between that of Jupiter (125 Kelvin) and that of the coolest T dwarfs (700 Kelvin; see figure 2). These are objects in which H_2O and NH_3 cloud condensation is expected to occur. Once we understand this new class of atmosphere, and learn to infer composition and chemical abundances, we will have an entirely new method for exploration of planet formation and evolution.

GPI will extend its science reach through the addition of imaging polarimetry to its capabilities, allowing unprecedented sensitivity to resolved debris disks. Broader science objectives for GPI include solar system targets and evolved stars. The field of ultra-high-contrast imaging is unexplored in general, and is likely to lead to many new and unanticipated discoveries. GPI will be able to produce complete information about the environment of any stellar target brighter than *I* = 8 magnitude.

Gemini has recently commissioned an international team of astronomers and engineers, led by Bruce Macintosh, to design and build GPI. Bruce is a physicist with the adaptive optics group at the Lawrence Livermore National Laboratory (LLNL). As the lead institution for this project, LLNL is responsible for project management and systems engineering; project manager David Palmer is also a staff member at LLNL

Other principal GPI team members include Rene Doyon (Université de Montréal), Ben R. Oppenheimer (American Museum of Natural History [AMNH]), Les Saddlemeyer (Herzberg Institute of Astrophysics [HIA]), Don Gavel (University of California at Santa Cruz Laboratory for Adaptive Optics), James R. Graham (University of California at Berkeley), James Larkin (University of California at Los Angeles [UCLA]), and Kent Wallace (NASA Jet Propulsion Laboratory [JPL]).

Mechanical design and overall software will be led by HIA. Optical design and real time systems will be designed at LLNL. The science integral field spectrograph will be designed and built at UCLA. NASA JPL is responsible for the precision infrared wavefront sensor. The coronagraphic diffraction control system will be designed and tested at AMNH. The data reduction pipeline will be designed and implemented at the Université de Montréal. Strong science leadership will be provided by an international science team coordinated from UC Berkeley. The GPI has an extensive test and integration program planned at the Moore Lab for Adaptive Optics at UC Santa Cruz.

The GPI project is now underway, with its preliminary design review scheduled for June 2007, test and integration through 2010, and first light planned on Gemini South for late 2010.

Phoenix: Five Years of Commitment to Gemini South

Ken Hinkle & Verne Smith

March 2006 marked the fifth anniversary of the last Phoenix run at Kitt Peak before the instrument began its journey to Gemini South. Phoenix is a high-resolution, 1- to 5-micron spectrograph built by NOAO in the 1990's for use at the *f*/16 foci of NOAO telescopes. First light occurred on 21 August 1996 at the Kitt Peak National Observatory 2.1-meter telescope. While the optical design of Phoenix (Hinkle et al., 1998, SPIE, 3354, 810) is very simple, Phoenix embraced several innovative features, including a million-pixel Aladdin I array that was very large at the time.

NOAO agreed in 2000 to share use of Phoenix with the Gemini Observatory. Gemini is an *f*/16 telescope and the designed slit width of Phoenix (0.34 arcsec on Gemini) is a reasonably good match to the typical delivered image quality at Gemini South. One feature of the Gemini/NOAO contract was the upgrade of the Phoenix detector to an Aladdin II array. The Aladdin II has proven vastly superior to the Aladdin I used at Kitt Peak. The installation of this detector array marked the beginning of the excellent performance that Phoenix currently exhibits.

Phoenix was transported by a combination of truck and Boeing 747 air cargo plane from Tucson to Cerro Pachón in September 2001. A small team from Tucson was at Pachón to meet the instrument when it arrived. The NOAO team worked with a Gemini team led by Manuel Lazo to install Phoenix on Gemini South. Our scientific staff contact at Gemini was Claudia Winge. Claudia and Manuel have continued as Gemini support for Phoenix over the last four years, and have contributed greatly to the smooth operation of the instrument. Over the same period, a number of NOAO staff members have helped support Phoenix: Bob Blum deserves special recognition for long hours spent executing queue observations with Phoenix.

As part of the sharing arrangement with Gemini, NOAO provides observing support. Phoenix was initially a queue instrument. However, Phoenix is interfaced to Gemini differently than Gemini facility instruments. With the refinement of Gemini queue observing, the status of Phoenix was changed to a classical-only instrument. Support is essentially the same from the NOAO perspective, and we greatly enjoy meeting and working with Phoenix classical observers.

The first night of observations with Phoenix at Pachón was 16 December 2001. While 80 percent of the night was used for alignment to the telescope and performance of other engineering functions, two hours were used to take spectra. The first light spectrum was of FU Ori. These data were published in an *Astrophysical Journal* article by Hartmann, Hinkle, and Calvet in 2004.

However, it was the Demonstration Science program that resulted in the first refereed paper based on Gemini/Phoenix spectra: "Chemical Abundances in 12 Red Giants of the Large Magellanic Cloud from High-Resolution Infrared Spectroscopy," published in late 2002 by Smith et al. in the *Astronomical Journal*. These data were taken in February 2002, and regular queue observing began in semester 2002A.

A steady stream of Gemini/Phoenix papers began appearing in 2003 and continues today. Eighteen papers that span a broad range of topics are now in the refereed journal literature.

Phoenix on Gemini South has been a versatile scientific tool. Some examples of its scientific range are studies of detailed elemental and isotopic abundances in red giants from many different stellar populations such as the Magellanic Clouds, the Galactic Bulge, various globular clusters, as well as halo and disk field stars (figure 1). High-resolution infrared spectra of brown dwarfs have been studied for deriving physical parameters, as well as for measuring very accurate radial velocities and projected rotational velocities. Additional papers include the study of accretion onto massive young stars still in the process of formation, mapping the distribution of H_3^+ in the interstellar medium, or probing the physics of Fu Ori stars. Phoenix data have also helped set limits on the relative abundances of aluminium isotopes (including the radioactive nuclei Al-26) in planetary nebulae.

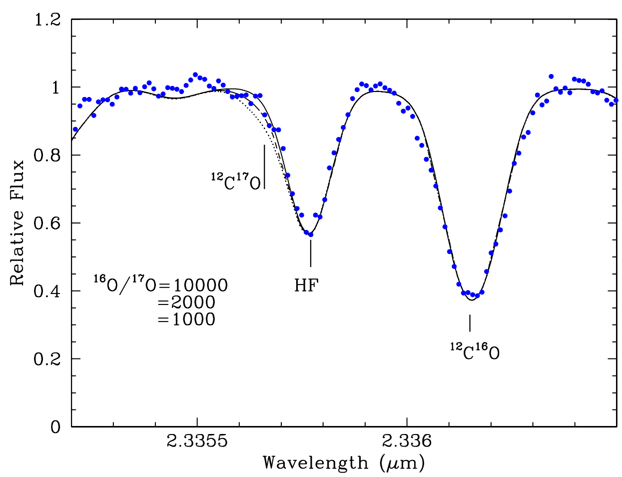


Figure 1. Spectrum synthesis of the M III component of the X-ray binary GX 1+4 (Hinkle et al., 2006, ApJ, 641, 479). The derived abundances demonstrate that the M giant star in the system is a first ascent red giant, with a mass less than 1.22 M_{sun}. The neutron star primary is the more massive star. The neutron star is a textbook case for an accretion-induced collapse supernova. The orbital period, 3.2 years, was also derived from Phoenix spectroscopy and is by far the longest of any X-ray binary.

continued

Phoenix continued

The scientific versatility of Gemini/Phoenix is well illustrated in two of the most recent papers using its data:

Keivan Stassun (Vanderbilt University) and co-investigators used high-resolution Phoenix spectra to derive radial velocities in a double-lined binary brown dwarf system (which also is eclipsing). The combination of radial velocities plus photometric light curve allows for the determination of many of the fundamental properties of these two young brown dwarfs (members of the Orion Association), including accurate masses (0.054 ± 0.005 M_{sun} and 0.034 ± 0.003 M_{sun}) and radii (0.669 ± 0.034 R_{sun} and 0.511 ± 0.026 R_{sun}). This is the first time such accurate physical parameters have been determined for brown dwarfs (2006, *Nature*, 440, 311; also see the Science Highlights section of this *Newsletter*).

Nathan Smith (University of Colorado) used the high spectral resolution of Phoenix and excellent image quality delivered by the Gemini telescope to generate spatial and kinematic spectral maps of the Homunculus Nebula surrounding the very massive, evolving star Eta Carinae. Smith focused on the 2.12-micron H_2 and the 1.6435-micron [Fe II] lines to build a physical and kinematic picture of the Homunculus. The mass of the nebula was derived to be about 10 M_{sun} and was ejected over a period of less than five years during the star's 19th century outburst. The bipolar shape of the nebula results from an inherently asymmetric ejection mechanism during the outburst and was not shaped by a companion (2006, *Astrophysical Journal*, in press).

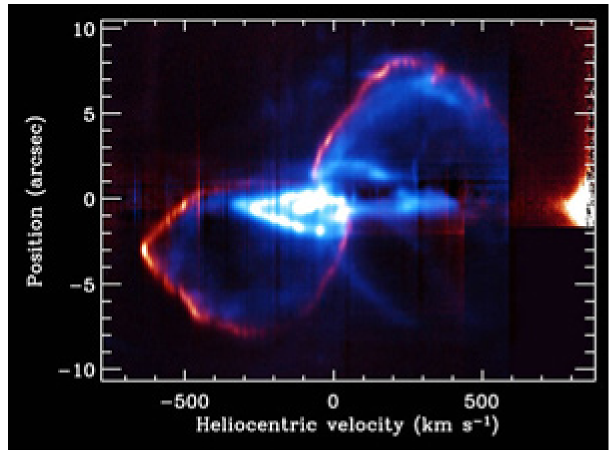


Figure 2. Phoenix has been used in the "long slit" mode to map the spatial versus velocity structure of Eta Carinae (N. Smith, 2006, ApJ, in press). The excellent image quality delivered by the Gemini telescope facilitates studies of this type. This image combines 2.12-micron H_2 (outer edge) with 1.6435-micron [Fe II] (distributed toward center).

The great diversity of science enabled by high-resolution infrared spectroscopy provided by Phoenix, coupled with the light-gathering power of Gemini South, demonstrate the importance of this capability for future astronomical research.

Gemini HelpDesk: Helpful Hints for Users

Tom Matheson & Sally Adams

Do you have a question about using Gemini but can't find the answer? The Gemini HelpDesk provides a quick and easy way to submit your question to someone with the answer. This is a Web-based interface through which you can make a request for information directly to your National Gemini Office (NGO) and Gemini Observatory staff. The NGO for the United States is the NOAO Gemini Science Center. To enter HelpDesk, go to *www.gemini.edu* and click on *HelpDesk*. You will see that there are two options for submitting a request—Regular HelpDesk request and Phase II-related request.

Phase II-Related Request
On the HelpDesk page, if you click on the link *Request regarding an existing Phase II program*, you will see that the program asks for your Gemini program ID (e.g., GS-2004B-Q-3 or semester GS-2004B-Q and ID 3). This is a streamlined interface to HelpDesk for Phase II science program queries, which sends your request directly to the NGO support person for your program. You should **always** use this option for a question about your Phase II. Make sure that the program ID is correct.

continued

Gemini HelpDesk continued

Regular HelpDesk Request
If you click the *Regular HelpDesk ticket* link, you will be asked to enter the Gemini partner country of your home institution and the topic of your query. The system uses this information to assign your question to the appropriate person.

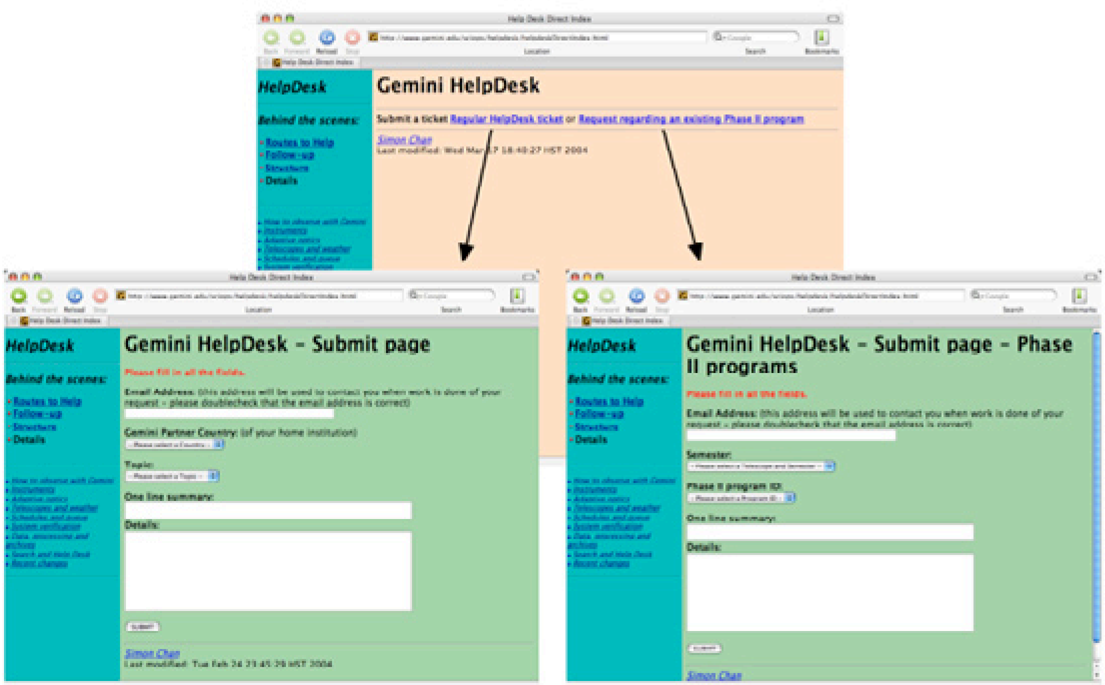
These queries are first directed to the NGO staff who field requests for information from their own community: this is Tier 1. Queries that cannot be answered at this level are escalated to Tier 2 support consisting of either NGO-designated experts or Gemini staff who respond to queries from the entire community. Queries that cannot be answered at this level are escalated to Tier 3 support, who are all Gemini staff.

Regular HelpDesk queries are categorized into three broad subject areas:

- instrumentation
- telescope performance and capabilities
- the proposal and observing process

Each of these subject areas is subdivided further: see the drop-down menu for all topics. Choosing the correct topic for your question will facilitate getting an answer. Sometimes it is not clear which topic you should select, so this table illustrates some ideas about associating topics with the subject of your question. Perhaps the most common mistake in choosing a topic is selecting a specific instrument, such as GMOS or GNIRS, when the actual question is about problems with the Gemini IRAF software.

If your question is about	**Choose this topic**
Instrument performance	That particular instrument
Reduction software problems	Gemini IRAF
Phase II	Phase II-related request
Writing a proposal for using Michelle	Michelle
Downloading data	Gemini Science Archive
Observing strategy–for example GNIRS	GNIRS



Screen shots showing two options for submitting a query to the Gemini HelpDesk

New NGSC Staff

Taft Armandroff & Verne Smith

We are very pleased to announce the following additions to the scientific staff of the NOAO Gemini Science Center (NGSC). Please join us in welcoming them.

Katia Cunha joined the NGSC Staff as an Assistant Astronomer on 1 February 2006. Katia previously held an AURA US Gemini Fellowship. She is an expert on stellar abundances and galactic chemical evolution. Already a major user of Phoenix on Gemini South, Katia is assuming a major role in NGSC's support of US users of the bHROS and Phoenix spectrographs.

Dara Norman is the second recipient of the NGSC Postdoctoral Fellowship, starting on 1 February 2006. Dara's research expertise and interests include gravitational lensing, the large-scale structure of the Universe, and quasars. She previously served as an NSF Postdoctoral Fellow. Dara will participate in the support of US users of the GMOS spectrographs.

NGSC Instrumentation Program Update

Taft Armandroff & Mark Trueblood

The NGSC Instrumentation Program continues its mission to provide innovative and capable instrumentation for the Gemini telescopes in support of frontline science programs. This article gives a status update on Gemini instrumentation being developed in the US, with progress since the March 2006 *NOAO/NSO Newsletter*.

NICI

The Near Infrared Coronagraphic Imager (NICI) will provide a 1- to 5-micron dual-beam coronagraphic imaging capability on the Gemini South telescope. Mauna Kea Infrared (MKIR) in Hilo is building NICI, under the leadership of Doug Toomey.

NICI is in the final assembly and testing phase of the project. The deformable mirror was installed in the NICI adaptive optics (AO) system, and the AO system was fully integrated and tested. The NICI AO system is performing well in correcting various types of static aberrations that have been introduced into the input beam. Dynamic testing of the AO system has begun.

Elevated background signal on the NICI arrays has been traced to small light leaks in the detector baffling. These were found by placing a light source at the location of the detector and examining the external view with night vision goggles. An attachment for the baffle to eliminate the light leak has been fabricated and installed. In addition, the initial complement of NICI filters has been installed in the filter wheels. As of late April, NICI has been cooled, and full system testing is underway.

As of the end of March, MKIR reports that 99 percent of the work to NICI final acceptance by Gemini is complete.

continued

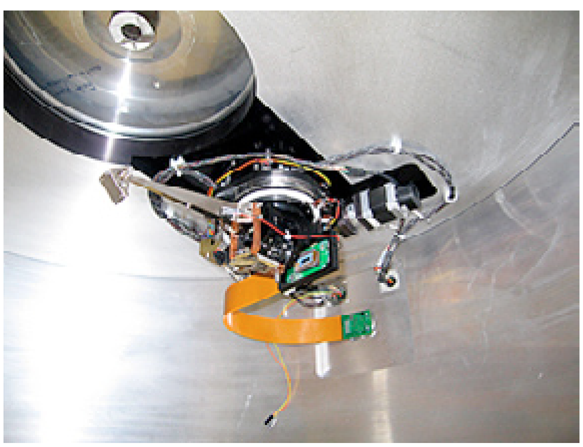
NGSC Instrumentation Program continued

FLAMINGOS-2

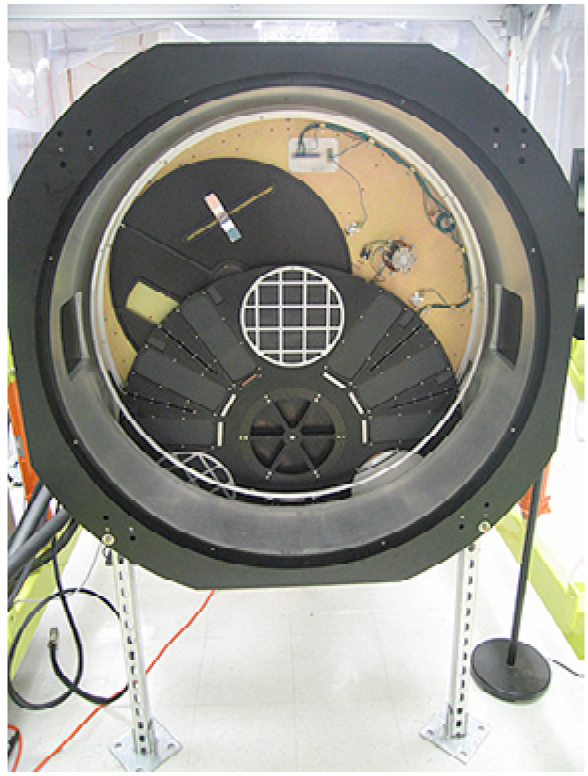
FLAMINGOS-2 is a near-infrared multi-object spectrograph and imager for the Gemini South telescope. FLAMINGOS-2 will cover a 6.1-arcmin-diameter field at the standard Gemini *f*/16 focus in imaging mode, and will provide multi-object spectra over a 6.1 × 2-arcmin field. It will also provide a multi-object spectroscopic capability for Gemini South's multi-conjugate adaptive optics system. The University of Florida is building FLAMINGOS-2, under the leadership of Principal Investigator Steve Eikenberry.

The FLAMINGOS-2 Team is continuing with the integration and testing phase of the project. The On-Instrument Wavefront Sensor has been delivered, tested, and integrated with the rest of the instrument. The two low-resolution grisms have been received, tested, and installed. Test images through the imaging optics were obtained for the first time using the engineering-grade HAWAII-2 array. The resulting image-quality measurements are encouraging.

As of mid-April, Florida reports that 92 percent of the work to FLAMINGOS-2 final acceptance by Gemini has been completed.



The FLAMINGOS-2 On-Instrument Wavefront Sensor is shown mounted in the dewar.



The front end of the FLAMINGOS-2 multi-object spectrograph (MOS) dewar is shown. Note the wheel containing selectable MOS plates.