Gemini's Instrumentation - Overview

New and continuously evolving instrumentation plays a key role in Gemini's exploration of the universe by providing its astronomical community with the tools needed to ask—and answer—fundamental astrophysical questions. Thus, the development of new instruments and facilities is a critical and central observatory function. This is an ongoing process that takes into account the continuing evolution of scientific discovery and knowledge, the new questions they produce, the rapid pace of technological innovation, and lessons learned from the development of the previous generation of instruments.

Figure 1 – Laser AO operations on Mauna Kea are arguably the most advanced on any site worldwide, as demonstrated here with sodium lasers being concurrently propagated by Keck, Subaru, and Gemini. The considerable experience Gemini is gaining from the ALTAIR LGS system is being incorporated into MCAO at Gemini-S. Photo credit: Subaru Observatory

Since Gemini has operated primarily in the multi-instrument queue mode at both sites since mid-2005, a key instrument requirement is the functional integration of its automated control systems with those of the telescope operational systems. All mounted instruments are available during the night for execution of observations from our queue. This approach allows for increased flexibility and agility in the manner we use the various optical/near and mid infrared instruments, particularly when applied to targets of opportunity.

Figure 2 – Gemini's instrumentation program is summarized above.

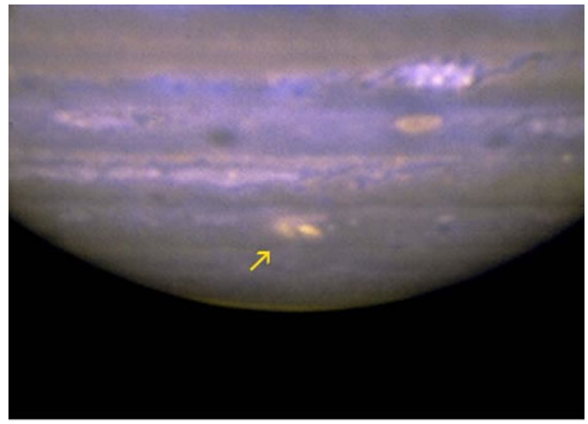
Within the next 2-3 years, Gemini's instrument program will offer the Gemini community a wealth of advanced capabilities to use for conducting research. Particularly exciting new capabilities include instruments like FLAMINGOS-2 and GSAOI. When fed by Gemini's multi-conjugate laser AO system, these instruments will provide the Gemini community with a unique and rich tool set for conducting research, with obvious synergies to emerging major new facilities like ALMA and LSST.

In the pages that follow, brief updates are given for the new instruments that have either just been commissioned or will be offered within the next 2-3 years at Gemini. Additional information about Gemini's existing instruments is available on our web page (www.gemini.edu).

New Instrument Capabilities – Gemini North

GMOS-North: Multi-Object Spectrograph and Optical Imager

GMOS-N is among the most popular instruments offered by Gemini. Capable of imaging a 5.5 arcmin field of view and collecting moderate-resolution (R~4000) spectra for several hundred objects at a time, GMOS-N epitomizes the "workhorse" portion of Gemini's instrument suite. In addition GMOS has been outfitted with a 1500-element IFU sampling a 5×7 arcsec field. The GMOS detectors can actively compensate for variations in sky emission using "nod and shuffle" technology, which significantly boosts their sensitivity compared to comparable spectrometers. To further enhance GMOS-North Gemini recently purchased new CCD detectors which will increase its red sensitivity by about a factor of two and enable new science at wavelengths approaching 1 µm. These same fully-depleted Hamamatsu detectors are being used in Subaru's Suprime-Cam and additional information about them can be found via http://www.naoj.org/Observing/Instruments/SCam/ccd.html.



ImageCredit: Imke de Pater (UC Berkeley), Heidi B. Hammel (Space Science Institute), Travis Rector (University of Alaska Anchorage), Gemini Observatory/AURA

Figure 3 – The recent comet impact of Jupiter is a good example of the flexibility of Gemini's queue based science operations. On the first opportunity to view the impact site since its discovery, MICHELLE was used on Gemini-N to record this mid-IR image of the impact site in Jupiter's upper atmosphere. This single image beautifully illustrates several key strengths of Gemini Observatory (fast response, image quality, infrared optimized).

GNIRS: Near-IR Spectrograph

GNIRS is Gemini's premier near-infrared spectrograph that was very productive and highly popular at Gemini-South until it overheated in an accident in 2007. GNIRS is being repaired for use on Gemini-North, and is scheduled to be re-commissioned on Mauna Kea early in 2010. GNIRS is a long slit cross-dispersed spectrograph sensitive from 1 to 5 µm with spectral resolutions from 1700 to 18,000. Its most popular mode is its low resolution cross dispersed configuration, which permits simultaneous sampling at J, H, and K in a single integration at R~1700. It is important to note that GNIRS will return to service enhanced from its previous configuration. Beyond installing a new and improved science detector, GNIRS will be commissioned with ALTAIR to support ultra-narrow slit science applications. This will be particularly powerful for complex fields and/or compact targets which have a high dynamic range (e.g., extra-solar planets).

ALTAIR: Adaptive Optics System

ALTAIR can use both natural and artificial laser guide stars. ALTAIR routinely delivers near diffraction-limited images with Strehl ratios of ~0.3 in the near-infrared (1 to 2.5 µm) across NIRI's 20-arcsec field of view. A wide field mode is also offered which ground-conjugates ALTAIR, enabling spectacular images when ground layer seeing dominates. The sky coverage with the laser guide star mode is about 40% due to the requirement for a reference tip-tilt guide star within the accessible field of view. In the future we anticipate modifications to ALTAIR's laser to increase its power/reliability, and we will upgrade its tip/tilt sensor to reach fainter guide stars and significantly increase its sky coverage.

New Instrument Capabilities – Gemini South

NICI: Near-Infrared Coronagraphic Imager

NICI is a 1 to 5 μm coronagraphic imager delivered to Gemini South in 2007. During its commissioning phase the combination of NICI and Gemini-S was demonstrated to yield exceptionally high contrast imaging within ~1 arcsec of bright stars. To achieve this NICI has a specialized dual-channel camera with a dedicated Lyot coronagraph and an 85-element curvature-adaptive-optics system optimized to directly detect massive self-luminous extra-solar planets around nearby stars. NICI spectrally differences two images taken simultaneously at two slightly different wavelengths bracketing the strong near-infrared methane features found in substellar (planet-mass) objects. Both cameras have an imaging field of view 18 arcsec across. NICI is currently about half way through a large 500-hour campaign to discover planets around nearby young stars.

MCAO: Multi-Conjugate Adaptive Optics

MCAO is a new adaptive optics system which compensates for multiple atmospheric turbulence layers. It is in final stage of construction and will be deployed at Gemini South in 2010. The MCAO system includes the AO bench "Canopus" containing eight wavefront sensors and three deformable mirrors, a 50 W five-beam sodium laser system to produce a constellation of laser guide stars, the beam transfer optics and a laser launch telescope. Collectively the subsystems are called the Gemini MCAO system (GeMS) and will correct a ~1 arcmin field of view from 1 – 2.5 μm. FLAMINGOS-2 and GSAOI (described below) will be the principle recipients of the MCAO beam feed, providing unprecedented wide field AO imaging and spectroscopic capabilities at near-infrared wavelengths to the Gemini community.

FLAMINGOS-2: Near IR Imager and Multi-Object Spectrograph

FLAMINGOS-2 is one of the most exciting new instruments at Gemini. It is a near-infrared imager and multi-object spectrometer with a 6 arcmin field of view that it is sensitive from 1 to 2.5 μm. FLAMINGOS-2 was delivered to Gemini South in July 2009 and will soon be commissioned. It will take up to ~80 spectra at a time using masks that can be installed during the daytime. It will also take advantage of the new MCAO system at Gemini South starting in 2010.

In addition to its baseline imaging, single slit, and multi-slit modes, FLAMINGOS-2 will be configured to work with a tunable filter composed of two Fabry-Perrot etalons in series thanks to a team led by Roberto Abraham at the University of Toronto. The tunable filter is complete and awaits integration with FLAMINGOS-2 at Gemini South. In addition Gemini procured a set of ultra-narrowband fixed wavelength filters to take advantage of the dark gaps between bright atmospheric OH emission lines in the J-band. The combination of these fixed and tunable extremely narrow-band filters will allow Gemini astronomers to search for high-redshift galaxies with a variety of strategies.

GSAOI: Gemini-South AO Imager

GSAOI will provide diffraction-limited imaging from 1 to 2.5 μm across an 80 arcsec field of view provided by MCAO. The camera optics in GSAOI are configured to yield higher spatial resolution than FLAMINGOS-2 and feed an array of 4 HAWAII-2RG detectors which are close-butted. GSAOI's advanced detectors will yield both low noise and extremely low dark current so that, when used in conjunction with GSAOI's extensive filter set, astronomers will be able to record extremely deep, high resolution images on a range of targets at many discrete wavelengths.

Instruments Currently Under Development

The Gemini Planet Imager (GPI) is a specialized AO coronagraph designed to detect self-luminous planets around young stars. A large collaboration, led by Bruce Macintosh of the Lawrence Livermore National Laboratory (LLNL), is designing and building GPI. GPI has its own on-board high-order AO system and apodized pupil masks. Importantly, GPI will also have a sophisticated interferometer incorporated into the AO system to further reduce wavefront errors to a remarkable few nm rms. It will also have a unique integral field spectrograph to help identify planets and characterize their atmospheres. After commissioning in 2011, GPI will be used for an extensive science campaign, likely involving hundreds of nights over several years, in an attempt to not only image but spectroscopically characterize extra-solar planets. Similar to the NICI campaign, the GPI campaign will encourage participation across the entire Gemini community.

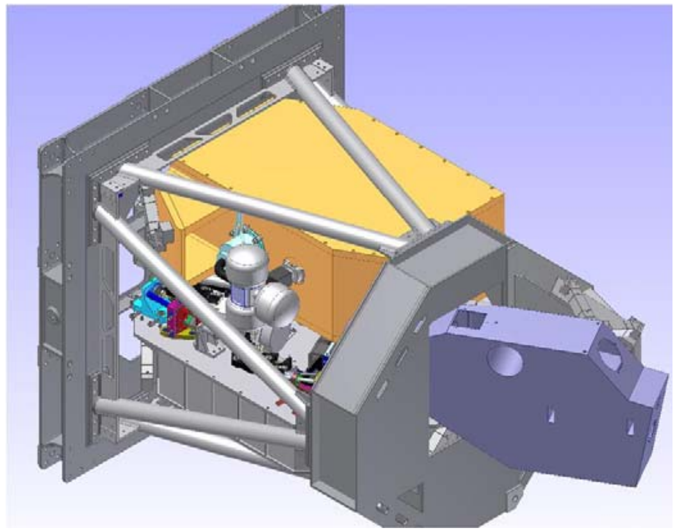


Figure 4 – The Gemini Planet Imager design is shown, featuring a high order AO system (bottom) which feeds a coronagraph and integral field spectrograph. In addition an extremely sensitive interferometer (seen on the back of the instrument) is used to achieve high order AO correction.

The latest Gemini instrument development program efforts, of which GPI is a part, are the result of a major collaborative process, organized by Gemini and its user-based Gemini Science Committee, to discern the Gemini community's most significant science and derivative instrumentation needs on a decadal scale. This has come to be referred to as the "Aspen Process" in recognition of the location of the final meeting of the Gemini community in 2003 that produced definitive science goals and a proposed instrument suite to achieve those goals. During the current Gemini funding cycle (2006-2010), the Aspen instrument program has been in full swing. Several instrument concepts were explored, but except for GPI, none were advanced beyond the competitive conceptual design study phase due to funding issues within the Partnership agencies. These instruments were the High-Resolution Near-Infrared Spectrograph (HRNIRS), the Precision Radial Velocity Spectrograph (PRVS), and the Wide field Fiber Multi-Object Spectrometer (WFMOS). While these ambitious instrument projects would no doubt have delivered world-class science, the funding during the past five years was insufficient to make any of them a reality.

Plans for Future Instruments

The previous summary captures the essentials of Gemini's instrument development program and is provided to yield context to the important next steps in Gemini's instrument program, expressed below. The factors that must be considered while devising the next generation of instruments for Gemini are sundry and interwoven. These include:

- Future science opportunities, as expressed by the community,
- Emerging technologies which stand to leverage Gemini's existing capabilities,

- Synergies and competition with other observatories,
- Time exchange opportunities with cooperating facilities,
- Striking a balance between “workhorse” (general purpose) and “niche” (specialized) instruments,
- Engineering and science staff resources needed to operate the entire instrument suite,
- Risk management, including costs, contracting, and technical development risks, and
- Replacing an aging set of Phase 1 instruments, some of which will be nearly 20 years old at the end of the next funding cycle (2015) and will be difficult to repair and maintain due to parts obsolescence and lack of access to the expertise of the original instrument builders.

Devising a long-range instrumentation plan that incorporates all of these factors, while also working within budget constraints, is challenging. In light of the Gemini Board’s recent major Aspen-program descope, the Observatory is working with the Gemini Science Committee (GSC), National Gemini Offices (NGOs), and ultimately the Gemini community to define the next set of instruments that could be built within the nominal ~USD30M planning budget defined by the Board for 2011-2015. Community input will be blended with the Observatory’s focus on resource, technology, and inter-observatory cooperation issues, to define a workable path forward. Some top-level guidelines used in this planning process included:

- Working with other communities and observatories to align our science goals to avoid an “arms race” that yields winners and losers in what should be a universally accepted scientific quest.
- Playing to Gemini’s strengths by exploiting existing investments and design features of the telescopes,
- Avoiding trying to do everything for everyone, while also avoiding disenfranchising a large portion of our diverse community.
- Engaging other observatories to expand our community’s scientific opportunities through innovative time-exchange programs, aligning long-range development plans to avoid instrument duplication, and sharing resources when “win-win” situations can be identified.

Taking all of these strategic and scientific factors into consideration, the types of instruments that are under consideration as initially defined by the GSC include –

- Cross Dispersed High Resolution Infrared Spectrometer
- Cross Dispersed High Resolution Optical Spectrometer
- Medium-Resolution Full Wavelength (0.4 – 2.5 μm) Spectrograph
- OH Suppressing Imager/Spectrograph
- Ground Layer AO Development Program
- Near Infrared Imager (NIRI replacement; wide field; perhaps including tunable filter)
- ALTAIR Upgrades (e.g., increase sky coverage)
- GMOS+ (advanced optical imager/MOS)

It is important to recognize that these are *representative* of the types of instruments that might be built using funds from the next 5 year (2011-2015) budget cycle. We anticipate that, given the scale of these instruments, it will be possible to build 2 of them for the nominal USD30M planning budget we are currently using. Additional community input will be gathered prior to 2011, when a new funding stream begins and procurement activities for these new instruments will occur. This timescale will ensure that the instruments pursued are consistent with the community’s needs. In any case, the trend illustrated above is to not pursue “Aspen class” instruments and instead focus on a next-generation set of workhorse instruments to replace the older instruments on Gemini.