

Mid-Infrared Astronomy at the Gemini Observatory: Capabilities and Recent Scientific Highlights

Adwin Boogert

The International Gemini Observatory twin 8-meter telescopes, located in Hawaii and Chile, provide the US community with access to the most sensitive mid-infrared (7–26 micron) instruments on the planet. Gemini telescope optics have been coated with silver to enhance their mid-IR reflectivity and reduce their emissivity to a few-percent level. Near diffraction-limited images are commonly seen at both sites in the N- and Q-band windows: 0.4 arcsec at 10 microns and 0.6 arcsec at 20 microns.

Although surpassed in sensitivity by satellite missions, Gemini's mid-IR instruments are at least an order of magnitude higher in spatial and spectral resolution, and offer unrivaled detailed complementary and follow-up observations of the brighter mid-IR emitting objects in the sky. Gemini's flexible queue-based observing mode guarantees that observations are done during the dry, cirrus-free conditions required by many mid-IR programs.

Gemini's mid-IR facility instrumentation suite consists of the Thermal Region Camera and Spectrograph (T-ReCS) on Cerro Pachón, and the mid-infrared imager and echelle spectrograph Michelle on Mauna Kea. The Texas Echelle Spectrograph, TEXES, was available in the 2006B semester as a guest instrument. Watch the call for proposals for future TEXES observing opportunities. Both Michelle and T-ReCS offer imaging and low- and medium- resolution ($R=100-1,000$) spectroscopy in the atmospheric windows between about 7 and 25 microns.

The echelle modes of Michelle and TEXES extend the available spectral resolving power to values as high as 100,000, and Michelle's newly commissioned imaging polarimetry mode provides a capability unique to 8-meter class telescopes. T-ReCS and Michelle have been at the telescope for about 2.5 years, and a

steady stream of studies that attack a wide range of astrophysical problems is being published.

Debris Disks

The high spatial and spectral resolution of Michelle and T-ReCS make these instruments ideally suited for studies of debris disks. Tedesco et al. (2005, *Nature*, 433, 133) resolved the edge-on debris disk around the A5V star β Pictoris. Imaging photometry in five filters between 8 and 25 microns revealed a clump of dust at 50 AU from the star that is warmer than its surroundings. This dust is likely composed of small grains produced by collisions between planetesimals.

Based on 10-micron spectroscopy with Michelle, a similar conclusion was drawn for the solar-type star BD +20 307 by Song et al. (2005, *Nature*, 436, 363). Spectral signatures of small crystalline silicate grains were observed in the prominent 10-micron emission band, and most likely result from collisions within an asteroid belt 10,000 times more massive than the asteroid belt in our solar system.

Orion Nebula

Although Gemini's maximum chop throw of 15 arcsec can significantly complicate mapping emission on large scales, an 11.7-micron mosaic of the inner 2 arcmin of the Orion nebula was obtained by applying special mapping and reduction techniques (Smith et al., 2005, *AJ*, 130, 1763; figure 1). The image contains nearly 100 distinct point sources, highlighting the extreme complexity of this crowded star-forming region. One of the many inferences that can be drawn from this data set is that the numerous stars detected at 11.7 microns possess 1- to 2-million year old dust disks, smaller than the approximate size of Pluto's orbit, as they lack extended structure in T-ReCS and HST images.

continued

	Michelle	T-ReCS
location	Hawaii	Chile
wavelength coverage	7–25 microns	7–25 microns
imaging FOV	32×24 arcsec	29×22 arcsec
imaging pixel size	0.10 arcsec	0.09 arcsec
imaging polarimetry	Yes	No
spectral resolving power	200–30,000	100–1,000
spectral pixel size	0.18 arcsec	0.09 arcsec
slit widths	0.18–1.44 arcsec	0.26–1.30 arcsec



Mid-IR Astronomy at the Gemini Observatory continued

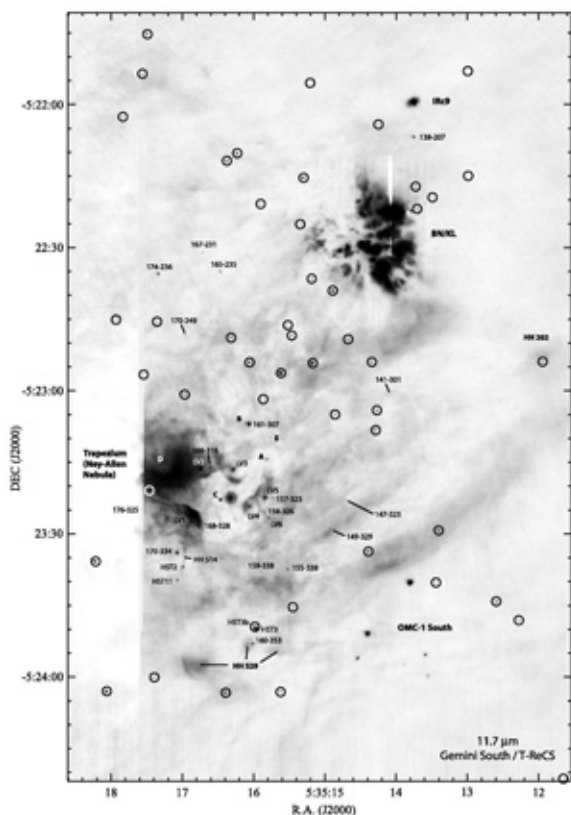


Figure 1: Image mosaic at 11.7 microns of the Orion Nebula made with T-ReCS on Gemini South. In these high spatial resolution images, proplyds seen in HST images are identified, as well as a few other major features of the Orion Nebula. Faint and unresolved (non-proplyd) infrared stars, likely surrounded by solar system-sized dust disks, are circled (from Smith et al. 2005, with permission).

Supernovae

Investigations of the production and properties of dust in relatively nearby supernovae give an indirect glimpse of what may be the dominant source of dust and metals in the early universe. Following a Spitzer Space Telescope detection of infrared (IR) emission from the region of the nearby galaxy NGC 6946 containing the remnant of supernova 2002hh, Barlow et al. (2005, *ApJ*, 627, L113) used Michelle to isolate the supernova remnant from neighboring emission sources. With data uncontaminated by emission from the surrounding objects, the team could construct the spectral energy distribution of the supernova remnant itself, estimate the mass of gas and dust in the remnant, and determine that the most likely source of the dust was an episode of mass loss from the central star before the supernova occurred.

T-ReCS has been used to carry out a similar, detailed investigation of supernova 1987A. In figure 2, one image from a time series shows a clumpy ring of dust excited by the supernova blast wave (Bouchet et al., 2006, *ApJ*, 650, 212 and 2004 *ApJ*, 611, 394).

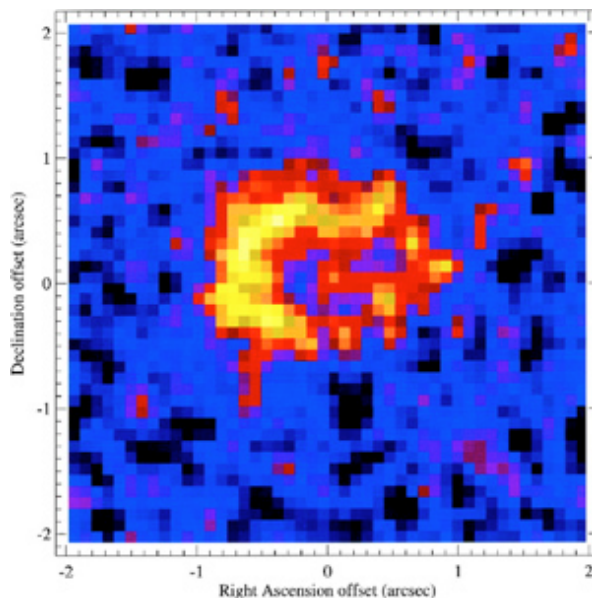


Figure 2. This T-ReCS observation of supernova 1987A in the N-band filter at day 6067 shows silicate dust lighting up as the blast wave hits the progenitor circumstellar envelope (Bouchet et al., 2004). The central 0.32-mJy point source corresponds to dust in the ejecta of the supernova, and is detected in 23 minutes of on-source integration time. See Bouchet et al. (2006) for 11.7- and 18.3-micron images at day 6552.

Active Galactic Nuclei (AGN)

The high spatial resolution of Michelle and T-ReCS has also provided insight into the nature of the inner regions of AGN (figure 3). Copious amounts of 10- and 20-micron emission are observed toward these sources, as is predicted by the unified model of AGN in which a toroidal cloud of dusty gas partly obscures the central supermassive black hole. The torus has not been resolved in even the closest of these galaxies and mid-IR size limits significantly constrain theoretical models of the torus.

AGN often exhibit considerable mid-IR emission not directly associated with the torus itself. A case in point is the Seyfert galaxy NGC 1068, in which only 30 percent of the emission in a 1.2-arcsec-diameter aperture comes from the central point source. The extended mid-IR emission from NGC 1068, and from other galaxies in studies by Roche et al. (2006,

continued



Mid-IR Astronomy at the Gemini Observatory continued

MNRAS, 367, 1689; arXiv: [astro-ph/0610583](https://arxiv.org/abs/astro-ph/0610583)), was mapped by spatially resolved spectroscopy using both Michelle and T-ReCS. The profile and depth of the 9.7-micron silicate absorption feature in several galaxies is observed to vary on very small scales, along with the shape of the continuum and the flux in fine structure lines. This is consistent with the presence of an inclined layer of dust obscuring both the unresolved torus and its extended ionization cones. The detection of emission features from aromatic hydrocarbons on sub-arcsec scales in the Circinus galaxy, tracing near-nuclear star-forming regions, further demonstrates a level of complexity that can best be addressed using high spatial resolution observations.

The 7–25 micron imaging and medium- and high-spectral resolution capabilities of Michelle, T-ReCS and TEXES, as well as Michelle's newly commissioned imaging polarimetry mode, have opened up poorly charted regions of discovery space in the mid-IR. For more technical information on Gemini's suite of mid-IR instrumentation, please consult www.gemini.edu. Follow the 'MIR Resources' link for a wealth of information dedicated specifically to observing in the mid-IR. The NOAO Gemini Science Center provides Gemini support for the US astronomical community (www.noao.edu/usgp/).

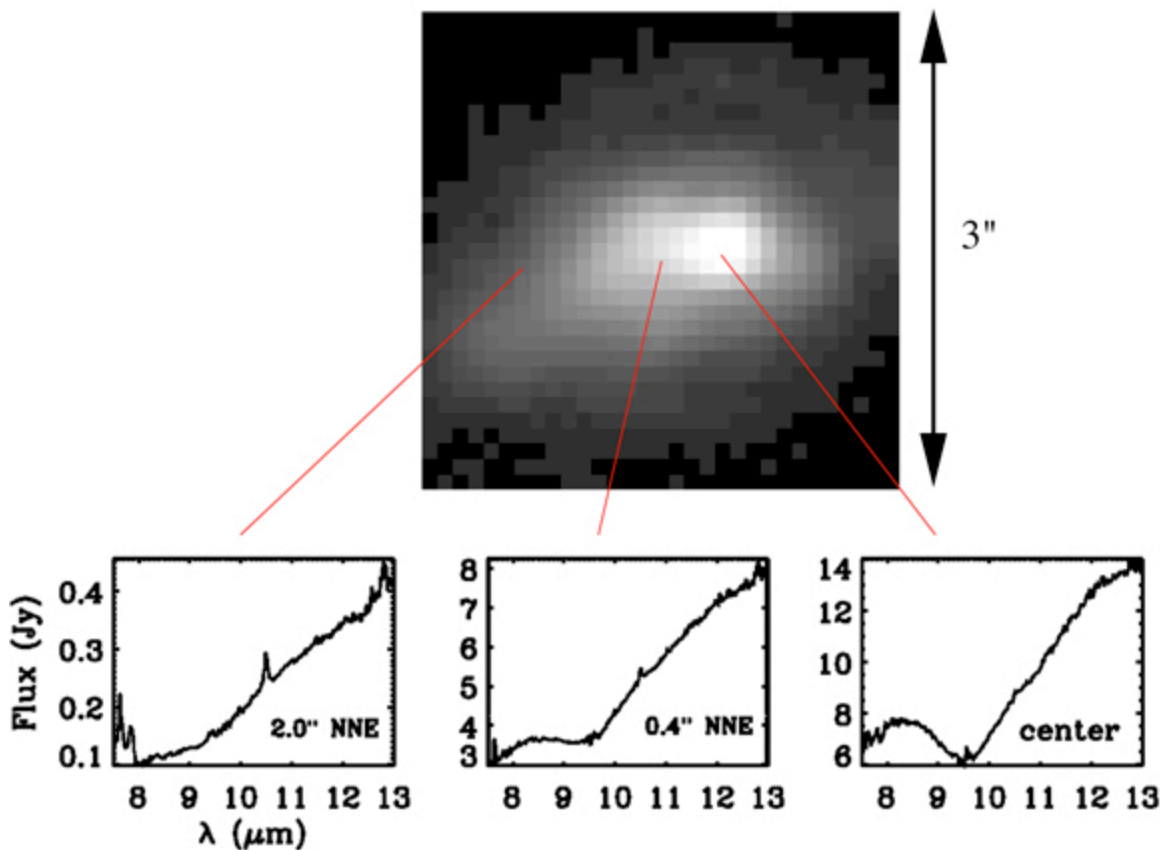


Figure 3: This 11.7-micron image from Michelle of the nucleus of the Seyfert 2 galaxy NGC 1068 shows a bright compact nucleus and extended material at 0.4-arcsec spatial resolution (Mason et al., 2006, *ApJ*, 640, 612). In low-resolution Michelle spectra, the depth of the 9.7-micron silicate absorption band and the 10.5-micron [S IV] emission line vary considerably on sub-arcsec scales. The Spitzer point spread function covers the entire area shown here.



Gemini Near-infrared Integral Field Spectrometer

Robert Blum & Peter McGregor (Australian National University)

The Gemini Near-infrared Integral Field Spectrometer (NIFS) went into general science operations during semester 2006B at Gemini North. NIFS is currently waiting final commissioning with the facility laser guide star system, also scheduled for semester 2006B.

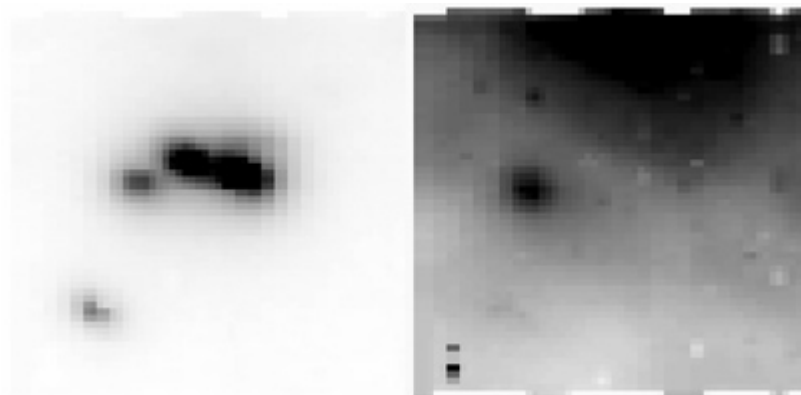
The near diffraction limited pixel scale (0.1 arcsec by 0.043 arcsec) of NIFS is a good match to the delivered image quality at Gemini North when used in tandem with the facility adaptive optics module, Altair. NIFS is now routinely used with Altair in its natural guide star (NGS) mode.

An example of a NIFS/NGS observation is shown in the figure below, where NIFS and Altair were used in July 2006 to image this 3-arcsec field toward a Galactic ultra-compact HII region. A continuum region centered at 2.17 microns (left panel) was extracted from the NIFS K-band data cube (which has a spectral resolution of $\sim 5,300$). This continuum was then subtracted from the Brackett gamma spectra in the data cube to produce a Brackett gamma map of the region (right panel). The map

reveals a compact emission source near the corresponding continuum object and strong extended emission to the north (top) of the frame.

The Gemini IRAF (v1.9) NIFS package was used to extract these maps and to build the data cube from which they were extracted. This release of NIFS

data reduction tools marks a major milestone, providing NIFS users with a baseline set of tools that enable the construction of fully calibrated data cubes. The package includes basic data cube display tools, as well as the ability to extract one-dimensional spectra in user-defined apertures selected on the two-dimensional spatial image.



NIFS images of the ultracompact HII region G45.45+0.06 (north is up, east left). The left panel shows the continuum near 2.17 microns, while the right panel is a continuum-subtracted Brackett gamma map. These spectral regions were extracted from the NIFS K-band data cube ($R=5,300$). The angular resolution along pixel rows is 0.1 arcsec (each independent pixel is represented by two image pixels), while the resolution along the columns is 0.043 arcsec per pixel.

Gemini Science 2007 Conference Update

Katia Cunha & Verne V. Smith

The second conference on Gemini science results will be held 11–13 June 2007, at the Mabu Thermas and Resorts in Foz do Iguaçu, Brazil. A Gemini Users meeting will take place at the same venue on June 14.

The primary purposes of this conference are:

- To highlight Gemini science results.
- To promote the capabilities of the Gemini telescopes and instruments to the community.
- To enhance scientific collaboration within the community.
- To define new science avenues.
- To increase acquaintances among Gemini users.

The format of the meeting will include 20-minute oral presentations focusing on scientific results from the Gemini North and Gemini South telescopes, as well as poster sessions. The one-day Gemini Users session will include presentations on future Gemini instrumentation and software development, as well as ample time for general discussion.

Further meeting details can be found at www.lna.br/~gsm2007/. There is no registration fee for the conference, and registration is now open. Watch for updates on the conference Web site as plans for the meeting progress.



Gemini Data Reduction Working Group

Tom Matheson

The mission of the Gemini Observatory is not only to deliver high-quality data from its many world-class instruments, but also to provide the tools to process that data into meaningful scientific results. The development of the Gemini-IRAF package is one major (and ongoing) example of this effort. Gemini recently hired a Project Scientist for Dataflow System & Products, and has constituted the Gemini Data Reduction Working Group (GDRWG) to oversee an expansion of the entire process.

The GDRWG is an offshoot of the Gemini Science Committee that will advise the Gemini director on issues relating to tools and methods used to process the data produced by the observatory. This includes providing tools for current users, as well as ensuring that the observatory can monitor data quality and that future users of the Gemini Science Archive will be able to explore the data fruitfully.

The first meeting of the GDRWG was held in Hilo, Hawai'i, from 11–12 October 2006, to lay out preliminary plans and

goals. As this will be an ongoing effort, in my role as the chair of the GDRWG, I welcome comments or questions about the process and our plans (matheson@noao.edu).



The Gemini Data Reduction Working Group at Gemini Headquarters in Hilo, Hawai'i, 12 October 2006.

The Gemini-Subaru Time Exchange Program

Verne V. Smith

The NOAO Gemini Science Center (NGSC) would like to remind US astronomers of the Gemini-Subaru time exchange program, begun in semester 2006B. This agreement exchanges service observing time at Subaru for queue observing time at Gemini. The Subaru instruments currently available to the Gemini community are Suprime-Cam (wide-field optical imaging) and MOIRCS (near-infrared imaging and multi-object spectroscopy). In exchange, the Subaru community has access to queue mode observing on GMOS (both North and South) and NIFS.

This agreement will likely be continued in semester 2007B. Announcements regarding this Subaru exchange program are posted on the Gemini Web site call for proposals link (www.gemini.edu), and on the NGSC Web site (www.noao.edu/usgp). US proposals for semester 2007B should be submitted with NOAO proposals by the December 2007 NOAO deadline. For 2007A, the agreement allowed a total of 50 hours of Subaru service observing. Gemini recommended a minimum request of five hours, with larger programs encouraged. Potential applicants should note that there were some special rules for 2007A proposals. For instance, proposals had to be submitted using the Phase I Tool (PIT) with "Subaru" selected as partner.

Direct questions about the Subaru exchange program to Verne Smith (vsmith@noao.edu).



NGSC Instrumentation Program Update

Verne Smith & Mark Trueblood

The mission of the NGSC Instrumentation Program is to provide innovative and capable instrumentation for the Gemini telescopes in support of frontline science programs. This article gives a status report on Gemini developments in the US since the June 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) of Hilo is building NICI, under the leadership of Doug Toomey.

The NICI Pre-ship Acceptance Test was held the week of September 18–22. Additional testing of thermal emissivity and other items was held the following week, and the instrument was declared ready to ship to the Gemini Hilo Base Facility (HBF).

NICI was lifted onto the Subaru BSIT truck and transported to the Gemini HBF on October 18 (figure 1). The instrument was unloaded and inspected by MKIR and Gemini personnel, including Gemini Observatory Director Doug Simons (figure 2). NICI will undergo flexure testing on the Gemini Flexure Test Facility, following additional inspection and minor reconfiguration.

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



Figure 1. NICI is lowered by crane onto the Subaru BSIT truck at MKIR's Hilo, HI, facility.



Figure 2. Gemini Observatory Director Doug Simons (right) inspects the new NICI instrument on a Gemini standard instrument air pallet in the Gemini Hilo Base Facility instrument bay, where it will undergo flexure testing.

FLAMINGOS-2

FLAMINGOS-2, a near-infrared multi-object spectrograph and imager for the Gemini South telescope, 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. This instrument 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 University of Florida team now expects the R-3,000 grism to be delivered by the end of 2006, meeting or exceeding its design throughput. Current work is focused on issues of image quality, reliability, and flexure. Once these factors are addressed, work will turn to preparation for the Pre-ship Acceptance Test.

As of October, the University of Florida team reports that 94 percent of work toward FLAMINGOS-2 final acceptance by Gemini is complete.