Introduction to Gemini Observatory

A Brief Guide to Telescope, Instrumentation and Development, Operations Processes, and User Support

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1 Introduction

This document provides introductory notes on Gemini Observatory. It covers the technical capabilities of the telescopes, and some organizational aspects. It does not currently describe internal processes such as queue coordination or time accounting, and is relatively brief on aspects such as user support and TAC processes, National Gemini Offices etc. It is intended as a quick guide, and does not supersede the information posted on the web; references to the key web pages are given at the end of each section. The document is normally updated annually, in advance of the May Governance meetings.

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2 Broad Capabilities

Gemini comprises two eight-meter telescopes, located on prime observing sites in Hawai'i and Chile, thus providing access to targets over the entire sky. It provides optical (UV-far red) and infrared (far red to L,M) imaging, spectroscopy, and integral field spectroscopy at a wide range of resolving power and spatial resolutions from seeing-limited to high-Strehl AO. Capabilities are not identical at the two sites, but both Northern and Southern hemispheres are provided with workhorse imagers and spectrometers and more specialized instruments for particular purposes. Visiting instruments provide further niche capabilities, and extension into the mid-IR, at a level supportable by the instrument developers and with scheduling determined by demand. On nights in which facility instrumentation is in use, rapid switching between instruments on the fly (occurring in less time than a typical object slew) enables reaction to changing observing conditions and opens up time domain astronomy.

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3 Site Characteristics

Gemini South is situated near the summit of Cerro Pachón in central Chile, at an elevation of ~2700 m, at latitude -30°. Gemini North is situated near the summit of Maunakea on the island of Hawaii, at the higher elevation of ~4200 m, at latitude +19°. The two sites are separated by almost 90 degrees in longitude.

Seeing and cloud cover statistics are similar for the two sites, but water vapor content is significantly higher (factor of two) at the lower Cerro Pachón site, and there are subtle differences in infrared sky background at the two sites.

Web resources:

1. The Summit Sites page
2. The Observing Conditions Constraints page - note the sidebar, with links to cloud cover, sky background etc. statistics

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4 Telescope Design and Operation

4.1 Telescopes

The two Gemini telescopes are of identical Alt-Az mounted, 8.1 m Ritchey-Chretien optical design (Figure 1), optimized for infrared observations but with deployable baffles to enable work at visual wavelengths. Cassegrain and folded Cassegrain foci support observing with any of three instruments at any given time at each site, with quick switching between them at night.

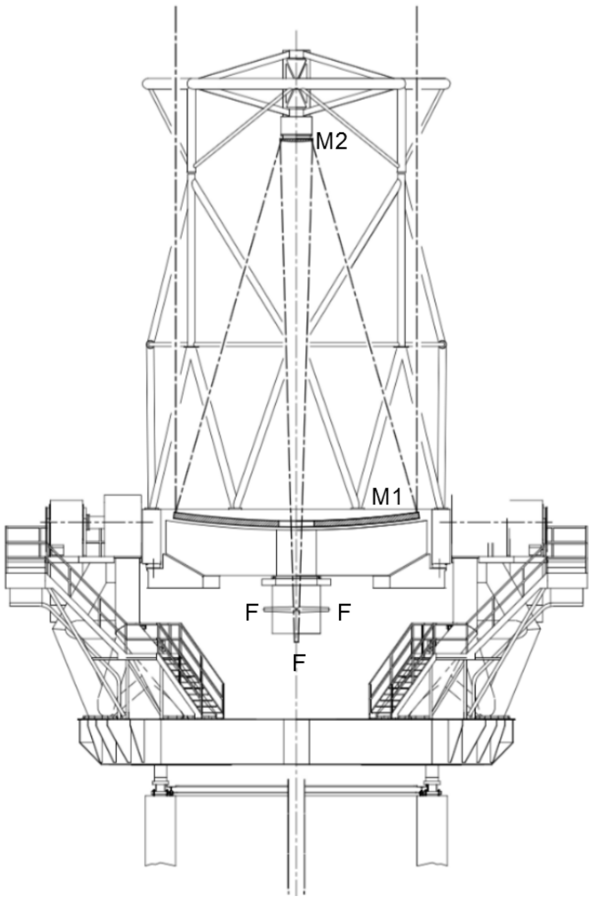


Figure 1: Gemini Telescope Configuration. Fs denote focal stations (of which there are five), M1 and M2 the primary and secondary mirrors, respectively. Note that one of the focal stations is occupied by the calibration unit, GCAL, and one feeds the AO bench (ALTAIR or Canopus respectively for north and south).

The 8.1 m primary mirror (“M1”) is only 20 cm thick, so its figure must be controlled via an active optics system consisting of both air bags and pneumatic/hydraulic actuators, governed by position measurement and lookup tables as a function of elevation. The 1-m secondary mirror (“M2”) is actively controlled in tip-tilt and XYZ position to control tip-tilt, focus, and coma aberrations. M2 is surrounded by a deployable baffle that is fully retracted for infrared work and extended for visual wavelengths. Both M1 and M2, and the “Science Fold” (M3 - see below) are coated in protected silver which provides high reflectivity in the NIR and most of the optical (more uniform than Aluminum), and low emissivity in the thermal wavelengths beyond 2.4 microns. However, the coating reflectivity falls steeply shortward of ~400 nm (Figure 2). The shortest-wavelength filter in the current Gemini facility imager (GMOS) is the “u” filter (350 nm). Modifications to the Gemini North coating chamber, almost complete, will enable controlled reactive sputtering which provides a route to future advanced multilayer silver coatings with potentially greatly enhanced UV reflectance.

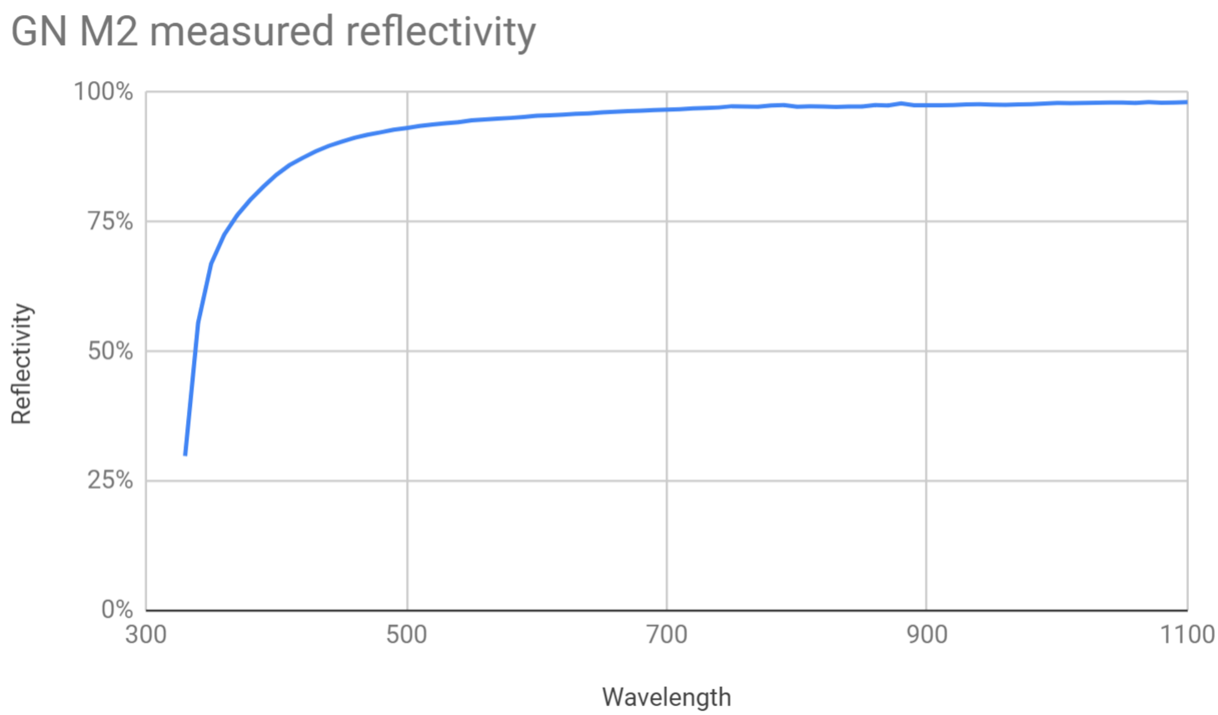


Figure 2 - Reflectivity of the Gemini overcoated-silver coatings (as applied to both the primary and secondary mirrors; this chart applies to one reflection only). The reflectivity remains flat and close to 100% longward of 1.1 microns, the red limit of this plot. See also the Silver versus Aluminium page (see "Web Resources" below). An Aluminium coating would have a significant throughput dip at 800-900nm, but better UV reflectivity.

4.2 Instrument Cluster

The instrument cluster and Acquisition/Guidance (A&G) unit are mounted on a Cassegrain Rotator which enables position angle selection and tracking of the sky's rotation during exposures. The instrument support structure (ISS) has five ports, one upward looking (Cassegrain) port on the bottom and four side (folded Cassegrain) ports. Two of the side ports are "lightweight" ports and do not support the full weight of a standard Gemini instrument. Science instruments are mounted either at the up-looking or side ports. On each telescope, one of the five ports is occupied by the facility Calibration unit (GCAL), and a second port by a facility AO system, leaving three ports for science instruments. At both sites, a small speckle imager (`Alopeke in the North, Zorro in the South) is mounted in the gap between GCAL and the ISS and accessed via a pickoff mirror.

The port and instrument are quickly (within minutes) selected via a deployable "Science Fold" tertiary mirror within the A&G unit. On a typical observing night, this switching is done numerous times. Optical fibers may be used to feed instrumentation on the observing floor, in the Pier laboratory below the telescope (as for MAROON-X and GHOST), or even at a site outside the building (e.g., GRACES). A maximum of four facility instruments are available at either site (a limitation imposed by staffing), of which any three can be in service on the telescope at a given time. Accommodating visiting instruments normally requires the removal of a facility instrument from its port for the duration of the visit. We also have a category of "resident" instruments, which includes `Alopeke and Zorro (the speckle imagers) and MAROON-X (the U Chicago velocity spectrometer at Gemini North), which are installed as permanently at the telescope as facility instruments, but mainly operated remotely by the instrument teams.

4.3 Calibration Sources

The calibration unit GCAL contains broadband lamps for flat-fielding, arc lamps for spectral calibration, and optics to project the emission onto any science instrument via the A&G Science Fold mirror. For the most accurate flat fields, twilight flats are often taken. At present only one instrument (GSAOI) requires dome flats.

4.4 Guiding and Aberration Corrections

Telescope optical aberrations are managed in several ways. At the beginning of every night staff observers perform a full tuning using the facility AO or a high-order Shack-Hartmann wavefront sensor (WFS). Corrections are applied to both M1 (astigmatism, trefoil) and M2 (focus, coma) to flatten the wavefront. For seeing-limited observing, low-order aberrations (focus and astigmatism) are then corrected continuously during science observations by a low-order WFS tracking guide stars adjacent to science targets, while the higher order terms are updated by open-loop models depending on the elevation. Tip-tilt errors due to imperfect tracking and wind-shake are corrected by the articulated M2, to ensure a delivered image quality consistent with the natural seeing. The required control signals are generated by the same low-order WFS as is used for the active optics control.

Gemini has two types of low-order WFS, used for guiding and active optics control during exposures: on-instrument ("OIWFS"), in the focal plane, and one of two peripheral wavefront sensors (PWFSs) in the facility Acquisition and Guiding (A&G) unit. For instruments which have them, the OIWFS is generally preferred for guiding due to its minimal vignetting and low flexure relative to the science detector, but for some targets the relatively small OIWFS patrol field will not contain a sufficiently bright guide star. The PWFSs have a much larger patrol field and can be used with any instrument, but significantly vignette wide-field imaging instruments and have larger flexure; they are most commonly used with narrow-field instruments or for long-slit spectroscopy on single targets.

Adaptive Optics systems (described below) provide internal tip-tilt and wavefront correction to achieve diffraction-limited performance, and typically offload quasi-static aberrations to the telescope, replacing the function of the WFSs.

4.5 Facility Adaptive Optics

Gemini features facility AO systems at each site: single-conjugate, narrow-field (Altair) in the North and multi-conjugate wide-field (GeMS) in the South. Altair may be used in either natural or laser guide star mode, while GeMS always requires the laser to achieve the wide-field multi-conjugate correction. Both systems employ Toptica lasers. In principle, these AO benches employ the visible light from natural and/or laser guide stars to provide an AO-corrected beam to an infrared instrument. In the north, Altair is regularly employed with any of the infrared instruments. In the South, Canopus is currently employed only to feed GSAOI, an imager with enough small pixels to cover the full 90-arcsecond field of view and fully sample the corrected image size. We anticipate feeding FLAMINGOS-2 and GMOS-S (in the very far red) from GeMS in the future, and this is also a possibility for GMOS-N with ALTAIR. More extreme, specialized AO instruments can be mounted at the Cassegrain foci and provide their own dedicated AO correction (e.g., both GPI and NICI when they were installed on Gemini South).

4.6 Objects Moving at Non-Sidereal Rate

Gemini supports observations of non-sidereal targets including planets, planetary satellites, and fast-moving near-Earth asteroids. The TCS and OT accept either orbital elements or an ephemeris file. For guided observations, a non-sidereal target must move less than the diameter of the guider patrol field over the duration of the acquisition + science observation, so observers can set up guiding (on a field star), then complete the observation before the guider reaches its limit. With PWFS-2, the practical rate limit is around 0.5 to 1 arcsec/sec. Observations can also be conducted unguided, with no practical rate limit but with reduced tracking accuracy[1].

4.7 Limitations

- **Gemini is not a "wide-field" observatory**. The maximum achievable unvignetted FOV is 7 arcminutes in radius, and the widest-field imagers currently installed (GMOS and FLAMINGOS-2) have fields of view with diameters of about 5.5 arcminutes.
- **Gemini does not have Nasmyth foci**. The primary mirror sits approximately level with the elevation bearings.

Web Resources

1. The optics page and links therein.
2. Comparison of Silver versus Aluminium coating reflectivities as a function of wavelength from the UV to mid-IR.
3. SPIE paper (Schneider & Stupik 2018) describing enhanced-UV multilayer coatings

[1] The unguided tracking accuracy on short timescales is 1 or 2 arcseconds, limited by low-frequency wind-shake oscillations. On longer timescales, it may, depending on the pointing model, grow to several arcseconds - though this is not based on any specific test.

5 Instrumentation

The table below summarizes instrumental capabilities.

Site	Instrument	Visible	Infrared	Imager	Longslit	IFU	MOS	Pol
South	FLAMINGOS-2		x	x	x		x	
	GMOS-S	x		x	x	x	x	
	GSAOI		x	x				
North	GMOS-N	x		x	x	x	x	
	GNIRS		x	~	x	x		
	NIFS		x			x		
	NIRI		x	x				

5.1 Imaging

The figure below shows the Field of View (FOV) for Gemini facility imagers. The tables which follow it expand on the imaging capabilities at the two Gemini sites.

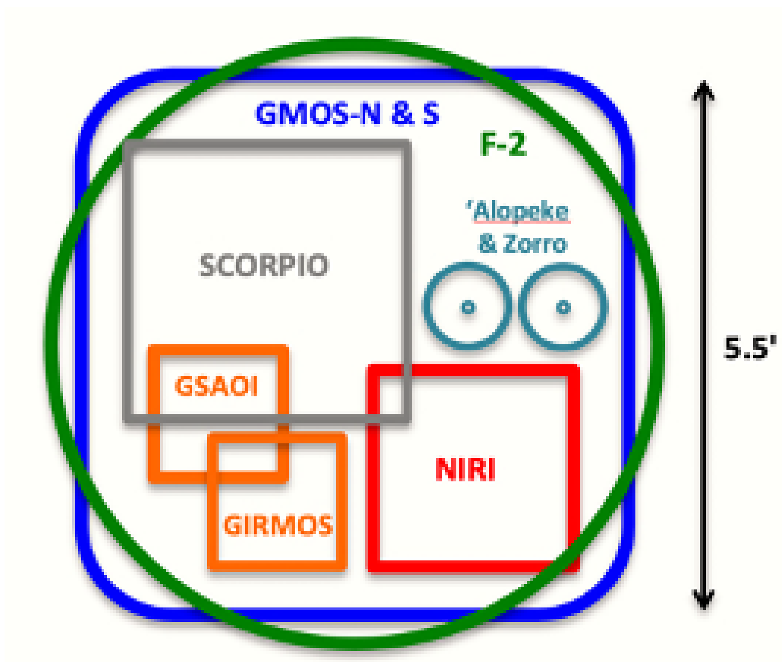


Figure 3: Field of View (FOV) for current and future Gemini imagers. The blue area corresponds to the visible wavelength instruments, GMOS-S/N. GSAOI 85" field of view is fed by the multi-conjugate AO system GeMS, and GIRMOS ~85" FOV to work with the future GNAO facility.

North Facility Imaging

Instrument	Detectors	FOV	Filters	Comments
GMOS-N 0.35-1.05 micron	3x Hamamatsu fully-depleted	5.5x5.5 arcmin	Broad: SDSS. Narrow: Variety	
NIRI* 0.9-4.7 micron	Aladdin III	2x2 arcmin 1x1 arcmin 0.3x0.3 arcmin	Broad: MK Narrow: variety	
GNIRS 0.9-4.7 micron	Aladdin III	90x10 arcsec Small semicircular patch	Broad: MK YJHK Narrow: H_2, PAH	

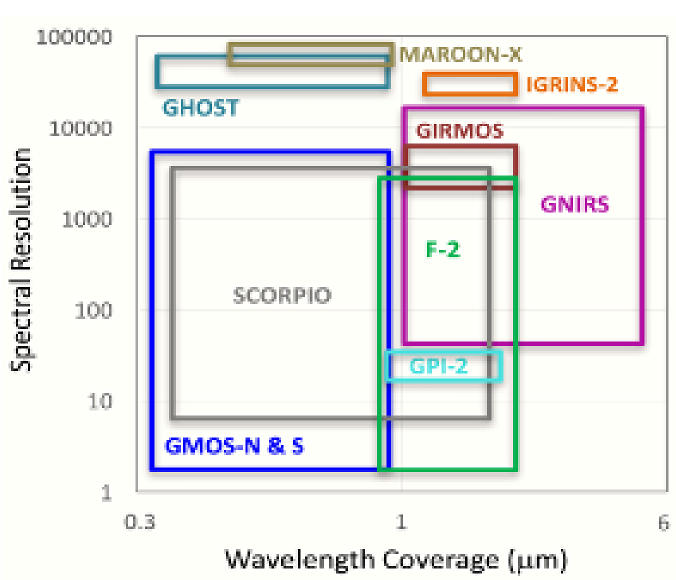
* NIRI will be removed from the regular offering by the end of 2023, and subsequently used only with GPOL as a visitor

South Facility Imaging

Instrument	Detectors	FOV	Filters	Comments
GMOS-S 0.35-1.05 micron	3x Hamamatsu fully-depleted	5.5x5.5 arcmin	Broad: SDSS. Narrow: Variety	
FLAMINGOS-2 0.95-2.5 micron	1 x HAWAII-II	Circular, 6 arcmin	Broad: MK Narrow: variety	
GSAOI 0.9-2.5 microns	4 x HAWAII-II RG	85x85 arcsecond	Broad: MK Narrow: variety	22 filters total. AO corrected images.

5.2 Spectroscopy

The figure below summarizes the properties of Gemini facility spectrometers. The tables which follow it expand on the spectroscopic capabilities at the two Gemini sites.



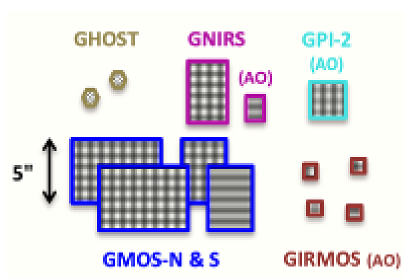


Figure 4 Left: Wavelength coverage and spectral resolution schematic for current and future Gemini spectrometers. GMOS and F-2 provide MOS capabilities. Right: Approximate FOV of integral-field spectrometers, including the community lead GPI-2 (in upgrade phase) and GIRMOS (in design phase).

5.2.1 Long-Slit

North Facility Long-slit spectroscopy

Instrument	Detectors	Resolving power	Wavelength range	Comments
GMOS-N	3x Hamamatsu fully-depleted	630-4400	360-980nm	
GNIRS	Aladdin III	1200-18000	0.9-5.4 micron	Cross-dispersed mode available

South Facility Long-slit spectroscopy

Instrument	Detectors	Resolving power	Wavelength range	Comments
GMOS-N	3x Hamamatsu fully-depleted	630-4400	360-980nm	
FLAMINGOS-2	HAWAII-II	1000 (HK, JH) 2900 (J, H or K)	0.9-2.5 micron	

5.2.2 Integral field

North Facility Integral-field spectroscopy

Instrument	Detectors	Resolving power	Wavelength range	FOV
GMOS-N	3x Hamamatsu fully-depleted	630-4400	360-980nm	5x3.5 arcseconds 5x7 arcseconds
NIFS**	HAWAII-II	5000	0.94-2.4 micron	3x3 arcseconds*

** NIFS is expected to be decommissioned in 2023 or 2024
* Coronagraphic mode available in AO mode, 0.2 or 0.5 arcsecond occulting disk

South Facility Integral-field spectroscopy

Instrument	Detectors	Resolving power	Wavelength range	FOV
GMOS-S	3x Hamamatsu fully-depleted	630-4400	360-980nm	5x3.5 arcseconds 5x7 arcseconds

5.2.3 Multiple-Object (MOS)

North Facility Multi-object spectroscopy

Instrument	Detectors	Resolving power	Wavelength range	Mask type
GMOS-N	3x Hamamatsu fully-depleted	630-4400	360-1030 nm	Carbon fiber, laser cut

South Facility Multi-object spectroscopy

Instrument	Detectors	Resolving power	Wavelength range	Mask type
GMOS-S	3x Hamamatsu fully-depleted	630-4400	360-1030 nm	Carbon fiber, laser cut
FLAMINGOS-2*	HAWAII-II	1000 or 2900	0.9-2.5 micron	Aluminum, laser cut.

* Note: MOS mode now offered

Web Resources

1. Instruments home page. Each instrument page linked there starts with brief description.
2. Instrument two-page fact sheets:
    a. GMOS-N
    b. GNIRS
    c. NIFS
    d. NIRI
    e. GMOS-S
    f. FLAMINGOS-2
    g.
    h. GSAOI
3. Instrument Brochure - poster-style summary of instrumental capabilities.

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6 Visiting Instruments

The Visiting Instrument program exists to (i) provide access to the telescope for instrument builders and (ii) for instruments which are successful in practice, access to them for the whole Gemini community. Visiting instruments mostly provide niche capabilities which are not present in the facility instrument complement. The program itself is described in more detail in the next section. Here we list the current visiting instruments - those which have made a visit in the past or are sometimes offered in the call for proposals.

Gemini Current Visiting Instruments

Instrument	Description
MAROON-X	High-resolution visible-wavelength spectrometer optimised for measuring precise radial velocities of low-mass stars; currently delivering 0.3m/s precision, with future optimisations possible via laser frequency comb and solar calibration unit. Gemini North resident.
`Alopeke	Visible two-channel simultaneous (blue/red) speckle imager with a non-speckle fast imaging mode for rapid photometry. Gemini North resident.
Zorro	Visible two-channel simultaneous (blue/red) speckle imager with a non-speckle fast imaging mode for rapid photometry. Gemini South resident.
TEXES	Mid-infrared (10-20 m) high resolution spectrometer. Resident at NASA ITRF, occasional visitor to Gemini North.
IGRINS	High-resolution near-infrared (H&K bands) spectrometer. Currently nearing the end of a highly successful three-year visit at Gemini South.
POLISH-2	Visible-wavelength polarimeter working in the parts per million regime. Occasional visitor to Gemini North.

Web resources

1. Visiting Instrument Program

7 Development

7.1 Routes to Development

Gemini runs three programs to provide new instrument and adaptive optics capabilities to the Gemini telescopes: an Upgrade Program for current capabilities, a Visiting Instrument Program for community-provided capabilities, and a Facility Program for directed new capabilities. As part of the Upgrade Program we occasionally issue external calls for community-sourced instrument upgrades. These calls can be open, or targeted for certain desired upgrades. Typical funding for these calls vary from ~$100k to $600k and typical projects last 1 to 2 years. The STAC participates in the selection of projects this effort funds. Upgrade calls are made dependent on staff and funding constraints.

Gemini Operations and Development staff cooperatively manage our Visiting Instrument Program to ensure we have the staff to support the accepted capabilities. This program allows users to bring their own instruments (or adaptive optics facilities) to Gemini. If approved by the TAC, the first run of a visiting instrument can be dedicated to the proposer’s science. To bring the instrument back thereafter for additional observations, the visiting instrument PI must also make the instrument available to the Gemini community, as announced in each semester’s call for proposals. Visiting instruments can also transition into an in-kind contribution to our Facility Program. We use the term *transition instruments* to describe visitor instruments that we either may, or have committed to, converting to facility instruments. Currently, MAROON-X and GIRMOS are transition instruments.

Finally, the IDF provides partner-contributed funds for new capabilities through our Facility Program. Traditionally, we have paid for these capabilities entirely by these funds via fixed price, and more recently, shared risk and cost reimbursement contracts. We can also bring facility instruments to Gemini as in-kind contributions with contributing teams receiving some telescope time in return.

We manage these three programs coherently, flexibly, and opportunistically, to obtain the best value for Gemini and maximize the return on our limited Instrument Development Funds.

7.2 Future Instrumentation

7.2.1 GHOST

GHOST is the Gemini High-resolution Optical SpecTrograph being built by a team led by AAO-Macquarie and including NRC-H and ANU. AAO-Macquarie is the project lead and is responsible for the Cassegrain unit for GHOST. NRC-H is responsible for the spectrograph and enclosure and ANU is doing most of the software. The instrument will be at Gemini South and:

- Provide simultaneous, continuous wavelength coverage from 363 nm to 950 nm.
- Have two selectable spectral resolution modes: standard resolution mode with R>50,000 and high resolution mode with R>75,000.
- Obtain a sensitivity of AB mag=16.0, 16.8, 17.9, 17.3, 17.3 and 16.4 in a 1 hour observation for 30 sigma per resolution element in standard resolution mode in dark time (50th sky brightness percentile) at the order centers closest to wavelengths of 363 nm, 375 nm, 450 nm, 550 nm, 900 nm and 950 nm respectively.
- Have the capability to observe 2 targets simultaneously over a 7.5 arcmin diameter field of view in standard resolution mode.
- Provide a radial velocity precision of 200 m/s over the full wavelength range in standard resolution mode, and a radial velocity precision of 10 m/s over the wavelength range from 430 nm to 750 nm in the high resolution mode.
- Spatially sample each target object over a field size of 1.2 arcsec.
- The instrument was delivered and is in the last stages of commissioning. There will be an SV process. Information for the System Verification process and call for proposals is posted on the web site[2].

[2] https://www.gemini.edu/instrumentation/ghost/ghost-system-verification

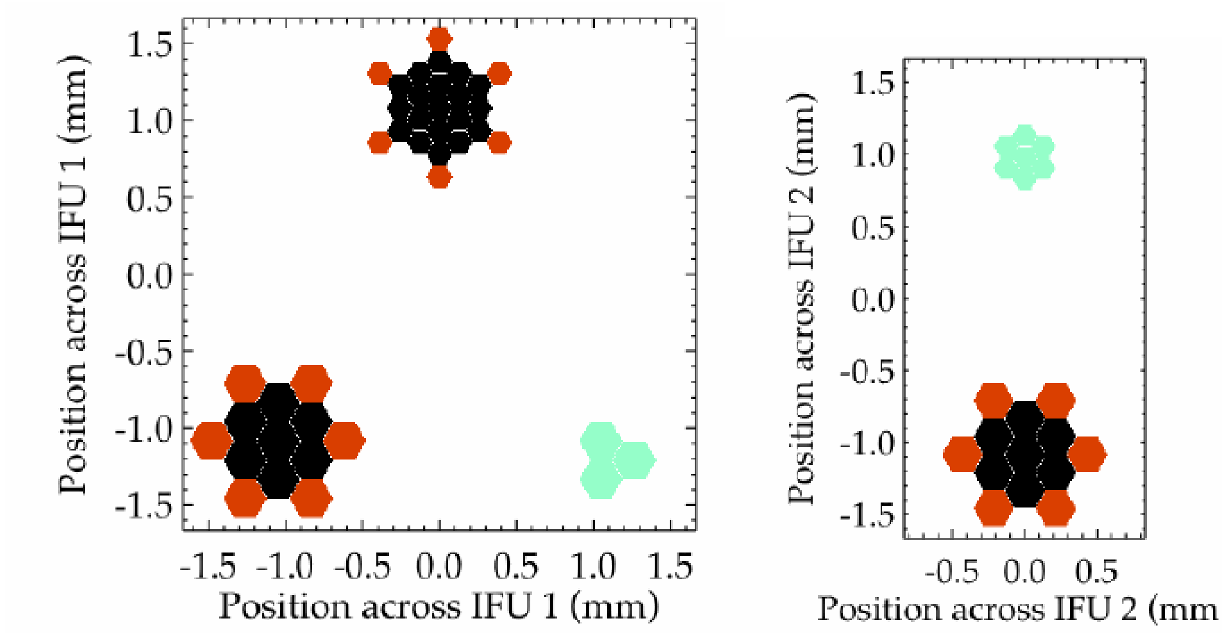

Figure 5: the image-plane microlens arrangements for the 2 GHOST IFUs (green=sky, black=object, red=acquisition & guiding, lower hexagons=standard resolution, upper hexagons=high resolution)

7.2.2 SCORPIO

SCORPIO is Gemini's next new facility instrument and arose out of the Gen 4#3 instrument call. SCORPIO will be an 8-band imager and spectrograph with complete and simultaneous coverage from 0.37 to 2.3 microns over a 3'x3' imaging field or 3' long slit spectroscopy with resolution ~4000. SCORPIO features rapid acquisition and readout to support time-domain discovery and follow-up missions deriving from the LSST and other current and future surveys. Currently SCORPIO is in its build phase, manufacturing components and beginning subsystem assembly. We plan to have the instrument ready for general use by the time LSST survey operations begin. Both projects slipped due to COVID-19 and may be further delayed.

7.2.3 IGRINS2

As part of joining the Gemini partnership, the Korean Astronomy and Space Science Institute (KASI) are building an updated version of the IGRINS instrument as a new facility instrument for Gemini. The team completed its critical design review in 2020 and expect to deliver IGRINS-2 in 2023.

7.2.4 MAROON-X

MAROON-X is a precision radial velocity high-resolution optical spectrograph built by a team from the University of Chicago led by PI Jacob Bean. It is now regularly offered as a visitor instrument at Gemini North with an agreement with the PI build team to continue to do so through semester 2022B. We are discussing possible extensions to the visitor instrument agreement and/or conversion to a facility instrument.

7.2.5 GIRMOS

GIRMOS is a multi-object adaptive optics instrument featuring 4 infrared IFUs being built by a consortium of Canadian institutions led by PI Suresh Sivanandam. The team is designing the instrument to sit behind the GNAO system at Gemini North and offer both imaging and IFU spectroscopy in J-K bands over a field ~2' diameter. The GIRMOS and GNAO teams are working together to help ensure each facility is ready when the other needs it for testing and eventual operations. Gemini is supporting initial design work of the GIRMOS imager and may provide additional support by formally joining the collaboration. We are currently providing the lead GIRMOS systems engineer from our staff.

7.2.6 GeMS RTC

The GEMMA project (see below) will produce not only a new realtime computer (RTC) for GNAO, but an RTC platform that Gemini will use for other AO facilities, including a new GeMS RTC. Initially, the new RTC will have similar performance as the current one, but the new architecture should be much more stable and allow us to update the algorithms for higher performance in ways that are not possible with the current RTC. The timeline for this work is currently uncertain as the GEMMA team finalizes the GNAO and template RTC requirements.

7.3 Current Projects

7.3.2 GEMMA

The GEMMA program is funded by an award from the National Science Foundation. It includes two major instrumentation projects.

GEMMA-GNAO

The Gemini North Adaptive Optics (GNAO) upgrade project will build on experience with GeMS at Gemini South, providing both wide field GLAO and narrow field LTAO correction modes. With a GLAO field-of-view of about 2 arcminutes and LTAO spatial resolution similar to that of JWST, GNAO will take advantage of Maunakea's outstanding conditions for AO, and support a new generation of AO-assisted instruments at Gemini North.

GEMMA-RTC

Part of GEMMA-GNAO, the Real-Time Computer project will create an RTC platform at the facility level, meaning that all Gemini real-time AO systems will be able to employ the same RTC architecture. The new RTC architecture must therefore be adaptable to our current and future AO systems, supporting GeMS at Gemini South (already operational) and GNAO at Gemini North (upon delivery). This will enable our staff to maintain this unique system optimally.

7.4 Adaptive Secondary Mirror-based GLAO

To supplement GNAO, we completed an initial feasibility study of an adaptive secondary mirror (ASM) to Gemini North. This would be the basis for a GLAO system that could serve all instruments without requiring the light to go through an AO Bench. A more complete conceptual design study is being planned as the next step.

Web resources

1. Instrumentation Development
2. Policy on visiting instruments

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8 Proposals for Telescope Time

Gemini offers numerous routes to gain observing time. The following are brief descriptions. All but DD time are restricted to PIs from the participant countries.

8.1 Standard Semesters

For programs of normal length, carried out in the queue or in a visiting mode. The two proposal deadlines are at the end of March and end of September, each followed by a peer review process by the National Time Allocation Committees, which are coordinated by the National Gemini Offices. At the time of writing, the great majority of proposals are from this pool.

8.2 Large and Long Programs

For flagship, high-profile programs requiring a lot of observing time, or a lesser amount spread over multiple semesters. For this there is an annual proposal cycle, with proposal deadlines approximately corresponding to the standard "B" semester deadlines each year. Observing is done by default in Priority Visiting mode (see below) for Band 1 LLPs. At the time of writing, participating partners have devoted 20% of their partner share to the “LLP” time pool. PIs from any participating partner may apply for this time and the amount of time they may be allocated is not limited by the partner share. In 2019, Canada and the US employ the LLP pool.

8.3 Fast Turnaround Programs

Monthly cycle, allowing for quick conversion of ideas into short programs which get executed relatively quickly after submission. There is no dedicated TAC; peer review is done by other proposers in the same month, each of whom are presented with a subset of all proposals to review. Participants who take part contribute 10% of their time to the available pool.

8.4 Director's Discretionary Time

Open to astronomers worldwide, a fixed amount of time per semester (currently 5% per telescope) is set aside for discretionary allocation. Typically used for programs with potential for high-impact scientific return. Proposals can come in at any time and are normally assessed by the Chief Scientist.

8.5 Poor Weather

For programs which can use the worst observing conditions. These can be proposed at any time. Incoming proposals are reviewed by the Head of Science Operations at the site and will be accepted into the queue if it will help fill gaps in the observing schedule during poor weather periods. Observations are carried out by observatory staff and time is not charged.

8.6 AEON

Gemini is part of the AEON network of telescopes incorporating Las Cumbres, SOAR and both Gemini telescopes. Proposals for Gemini time are made to individual partner country TACs, while proposals for other facilities with time allocated by the CSDC/NOIRLab process are submitted to that system. AEON/multi-facility proposals may be for time-domain or static-universe programs, the only requirement being that they make use of multiple facilities.

Web Resources

1. The "Start Here" page (links to descriptions of the modes above).
2. AEON network description

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9 Observing modes

Several modes of observing are available at Gemini, as described below. Note that these are NOT proposal modes; a PI wanting classical mode, for example, would put their proposal into the standard semester process and request classical mode in the proposal.

9.1 Queue

The majority of Gemini proposals are run in queue-scheduled mode. Observations are carried out by Gemini staff members (unless "Priority Visitor" mode is requested and approved - see below)[3]. More details on how the queue is planned and run are given in the "supporting information" section in the web page, linked to in “web resources” below. Note that we also support an “eavesdropping” mode in which a remote PI joins the night staff via video connection when their program comes up in the queue, and takes part in the target acquisition and optionally the data quality assessment.

9.2 Target of Opportunity

For (i) transient events needing follow-up (either immediate or reasonably quickly) and (ii) programs which will have numerous targets which aren't known at the time of the proposal. Target of Opportunity observations are requested via submission as Standard Semester programs. Observations are carried out by observatory staff, as part of the queue. If a ToO program requires immediate execution, the program must include sufficient “payback” time for programs which it ends up overriding.

9.3 Priority Visitor Observing

This is the default for Band 1 Large and Long Programs and can be requested (and granted as a function of availability) for regular queue programs[4]. PIs visit the telescope for more time than they have

[3] Queue observing enabled Gemini to continue observing seamlessly through most of the COVID-19 pandemic, when visiting astronomers were no longer permitted.
[4] Priority Visitor and Classical modes were both placed on hold during the COVID-19 pandemic.

allocated in the semester, and while there can choose to run their own approved program when the conditions are good enough (whether better or worse than requested).

9.4 Classical

Similar to classical observing at many observatories, where observations are scheduled during fixed time slots. PIs come to the telescope to execute the approved program. Programs are still generated well in advance of the observations, as part of the normal Phase II preparation period. Target changes are possible given advance request, enabling a check against existing programs in the queue.

Web Resources

1. The "Start Here" page (links to descriptions of the modes above).

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10 From Accepted Proposal to Executed Observations

Figure below shows the role of the two main software items described in more detail below: the Phase I tool (PIT) and Observing tool (OT). PIs generate their proposals in the PIT, and once passed by the National and International TACs, successful programs are converted semi-automatically into an "OT program", stored in the summit Observing Database, and is executable on the telescope.

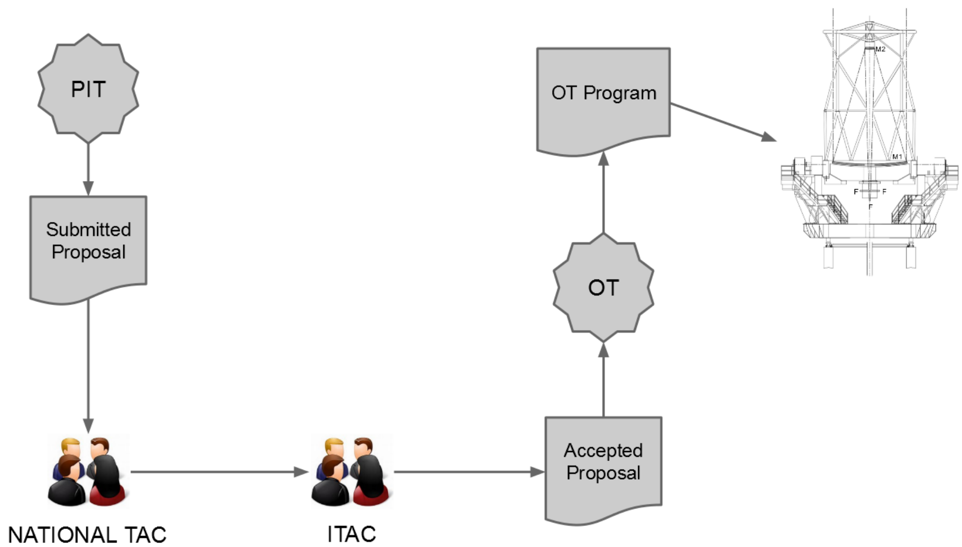

Figure 6: flow from proposal idea through to executed observations on sky

As developed by the PI in conjunction with their support staff, the OT program is an *executable entity* which is "run" on the telescope by the night staff using the observing software. Each observation is selected by the observer and translated into an executable sequence in software called the Sequence Executor. The night staff perform target acquisition, monitor the progress of the observation, and look at incoming data quality, but otherwise the observation proceeds according to the definition in the OT. A significant effort, therefore, is put into ensuring that OT programs are as error-free as possible, in what is called the “Phase II checking period”.

11 Observation Preparation Software

Users of Gemini generate their observing proposals and (for successful programs) executable observing programs using three items of software described below.

11.1 Integration Time Calculator (ITC)

An ITC exists for each Gemini facility instrument. Users specify the properties of their target, including spatial distribution and spectral properties, give the instrument configuration they wish to use, and the ITC gives either spectral (s/n as a function of wavelength) or photometric (s/n in an image) data quality predictions. The ITCs work as web forms and as part of the Observing Tool.

11.2 Phase I Tool (PIT)

The PIT is a downloadable application released once per semester, in which users prepare and submit their observing proposals. The text sections of the proposal (e.g. Scientific Justification) are written using LaTeX or Word templates and the resulting PDF is attached to the proposal. The PIT automatically checks target visibilities, observation duplications, and the likelihood of finding a guide star and produces a well-formatted proposal for submission to the relevant (partner-specific) “backend server” via which the National TACs access the proposals.

11.3 Phase II Tool (The Observing Tool, or OT)

PIs use the OT to generate observations which can be run on the telescope at night. Briefly, it allows the generation of target “components” which slew the telescope, instrument components which configure the instrument, and sequences which then carry out the required offsetting (e.g. nodding along the slit, taking exposures at each position). Most users do not generate their programs from scratch, but follow the process described below.

An OT “program” that contains the targets, conditions, and instrument configurations from the Phase I information is generated from each successful observing proposal. Users sync their programs in the observing databases with the OT application on their computers. These initial programs come with recommended template observations for the observing modes requested. Investigators update these templates and then “apply” the targets and conditions to them to create the executable observations. Changes to the templates can be easily re-applied to all the observations generated from them. Libraries of observations for each instrument that include complete observation examples are also available via the OT. The OT also assists with finding usable guide stars, an important consideration given the small fields of many of the guiders. Finally, the OT checks for problems in the observations and makes suggestions for improvements when possible.

Once investigators have prepared the observations they are stored in the observing databases and are then checked by Gemini National Office and Gemini staff (also see below). After any necessary iterations the observations then become available to be scheduled in the queue or executed by visiting observers.

Target of opportunity observations can be “triggered” using either the OT or via a URL interface that can be accessed programmatically by user applications. The latter minimally integrates Gemini with a network of telescopes capable of following up transients detected by LIGO, ZTF and ultimately Rubin Observatory/LSST via the TOM Toolkit plugin. Collectively known as AEON, this network is an efficient system for following up transients identified by time-domain and multi-messenger surveys, as well as for carrying out static-universe studies requiring multiple facilities.

11.4 Mask-Making Software

Multi-object Spectroscopy (MOS) masks for GMOS and FLAMINGOS-2 are prepared with the Gemini MOS Mask Preparation Software (GMMPS). This allows the user to give priorities to candidate targets, define alignment objects, and visualize the targets and the mask design on an image of the field. GMMPS can also show the results for different GMOS Nod & Shuffle options. GMMPS uses an algorithm to try to maximize the number of slits that can be placed in a mask and can also expand the slits to maximize sky/background regions.

Web resources

1. ITCs
2. Phase I Tool
3. Phase II Tool
4. GMMPS
5. URL API (programmatic trigger of on-hold observations)
6. TOM Toolkit

11.5 Future Changes

We are working on a major upgrade to the Observatory Control System software, replacing the existing observing database with a scalable, relational version and web-based tools for the various stages of proposal preparation, observation preparation and execution. Updated APIs will fully integrate Gemini into the time-domain follow-up network. We expect the Gemini Program Platform (GPP) to be operational by 2025. This work will be enhanced and accelerated by the GEMMA program, which funds a Time-Domain Astronomy project. This project will develop the infrastructure for incorporating Gemini’s telescopes into the Astronomical Event Observatory Network (AEON). The overall goal of this effort is to maximize Gemini’s contributions to discoveries in the TDA era, and Gemini will provide the largest aperture within AEON.

Web Resources

1. OCS Upgrades / GPP (on the Operations Development Page)

12 Operations at Night

Nightly queue operations at the telescope are normally performed by two staff members, operating remotely from the respective base facility. One person operates the telescope (always a member of the Science Operations Specialist, SOS, team) and another carries out the observations by operating the instruments to execute the planned queue (SOS or staff astronomer). The team assesses the observing conditions using available monitoring (seeing monitors, all sky cameras, cloud cameras, weather stations). They then choose the appropriate plan assembled by the queue coordinator (QC) and execute the observations as laid out in the plan. A typical plan contains observations from three to five different queue programs.

In the event of changing conditions, the Observer will switch plan variants as needed to avoid taking data in poorer conditions than required and to minimize the time spent taking data in better than requested conditions. Switching between the three or four mounted instruments is accomplished by moving a fold mirror and happens in a few minutes during the slew to the new target. Some three-quarters of all queue nights use multiple instruments. Due to the large demand for GMOS at both sites there are nights in dark time and good conditions during which only GMOS is used.

As the data are taken, the Observer assesses the data quality in order to make decisions about whether the observation is completed correctly and also to detect any technical problems. All data are transferred directly to the Gemini Observatory Archive and are usually accessible to the user within minutes of being obtained. This is essential for the timely delivery of data from Rapid Target-of-Opportunity (ToO) observations.

For all queue observations a set of standard calibrations (the "baseline calibrations") are taken by Gemini Staff to ensure the long-term utility of data in the archive. The baseline calibration set varies from instrument to instrument and from mode to mode. Baseline calibration data are associated with the science frames in the Gemini Observatory Archive. If additional calibrations are deemed necessary by applicants, for example to achieve a precision beyond that achievable via the baseline set, then these must be included explicitly as part of the Phase I proposal and will be charged to the program.

During Classical runs, a Gemini staff astronomer supports the first night or first half night depending on the experience of the visiting observer. As mentioned before, all Gemini classical observations are pre-planned in the OT.

During Priority Visitor blocks, a Gemini staff observer provides support depending on the prior experience of the visiting team. If and when the staff astronomer is not present, the SOS operating the telescope is always a trained observer and can answer questions. Visitor instruments are also block scheduled and the observing is carried out by the visiting instrument team.

Web resources

1. Queue planning and execution
2. What to expect once you're in the queue

13 Data Reduction and Archive

All Gemini data are archived and available via a web interface at the Gemini Observatory Archive (GOA). Proprietary data are available via secure log-in while public data are available without logging in. Data are added in near real-time from both telescopes during observing.

Gemini maintains and makes available data reduction software for processing data obtained with the Gemini telescopes. In anticipation of future data reduction needs and IRAF obsolescence, we are moving to a Python-based platform. DRAGONS (Data Reduction for Astronomy from Gemini Observatory North and South) is a modular and extensible Python-based pipeline data reduction system designed to meet the requirements of science quality data reduction for our users. Releases have been made for facility imagers and GMOS long slit spectroscopy. Work is ongoing to add further support for NIR spectroscopy. New facility instruments will be delivered with data reduction software that functions within the DRAGONS infrastructure, including Astrodata and the Recipe system. Until DRAGONS fully supports all spectroscopic modes for all the Gemini facility, Gemini IRAF will be maintained. Visiting instrument teams are responsible for providing reduced data to users. Most of these teams are developing reduction software that will work within the DRAGONS framework. Raw data from the Gemini facility instruments are stored as Multi-Extension FITS (MEF) files. DRAGONS and all tasks in the Gemini IRAF package are therefore capable of handling MEF files.

Gemini was a partner with STScI in the development of AstroConda, which bundles a large amount of useful astronomical software in one package and provides an easy mechanism to package, distribute, and install DRAGONS, IRAF, PyRAF, and the Gemini IRAF package. However, Astroconda is no longer supported by STScI and we have replaced it with conda-forge.

Details on getting started using DRAGONS and gemini_iraf are available from the Phase III (post-observing) pages and the individual instrument pages. Additional support is provided via the Gemini Helpdesk discussed in the next section. In exchange for US Phase II support now resting with the Observatory, the US NGO undertakes a program of work to benefit the entire partnership (e.g. workshops with rotating topics at the winter AAS meeting and a web portal for data reduction procedures). The Gemini Data Reduction User Forum was set up for users to trade ideas, scripts, and best practices as well as take part in public, user-driven, collaborative discussions of data reduction processes and strategies. It has not been heavily used, and we may consider other options for the dissemination of such information in the future.

Finally, the GEMMA-TDA project discussed in section 10.5 also includes development of automated data pipelines for rapid delivery of quick-look reduced data so that users can assess the outcome of their observations in real time.

Web resources

1. Phase III (post-observing) pages
2. Gemini Observatory Archive
3. DRAGONS and Gemini IRAF
4. Gemini Data Reduction User Forum

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14 User Support

Support for Gemini users throughout the process from proposal writing to data reduction for scientific analysis and publication is provided in combination between the partner National Gemini Offices (NGO) and Gemini staff. In broad terms, the division of responsibilities between Gemini staff and the National Offices is:

NGO

- Pre-observation (Phase I proposal and Phase II observation definition) and post-observation (data processing) off-site support (but note that the role of the US NGO in Phase II assistance is provided by staff within the observatory).
- First point of contact for user requests, which can be distributed to a wider support network and/or escalated to other National Offices or Gemini staff if necessary (see Helpdesk structure for more details).

Gemini

- Observation execution and on-site support (e.g. via Contact Scientists).
- Expert support for user requests.
- Phase II observation definition support for the US community

The handover of responsibility, from the NGOs to Gemini, for direct communication with users occurs upon acceptance of their detailed Phase II program into the Active Observing Database, except in the case of users from the US for which this occurs with their notification of an accepted proposal at the beginning of the Phase II period.

The Gemini HelpDesk is the primary means by which individuals can make requests for information to the support staff. The support staff are distributed throughout the Gemini partnership: at the Gemini Observatory, within National Gemini Offices and elsewhere. The HelpDesk system takes care of routing, tracking, escalation and aids in the resolution of requests. Users can track the status of their query via the HelpDesk and are e-mailed when work is done on their request.

Web resources

1. Helpdesk
2. Contacts page

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15 Acronyms

A&G	Acquisition and Guider unit
AAO	Australian Astronomical Observatory
AAS	American Astronomical Society
Altair	ALTitude conjugate Adaptive optics for the InfraRed, Gemini North's AO system
ANU	Australian National University
AO	Adaptive Optics
AOC-G	AURA Oversight Committee – Gemini
ARC	Astronomical Research Cameras
ASM	Adaptive Secondary Mirror
AURA	Association of Universities for Research in Astronomy
BFO	Base Facilities Operations (project)
bHROS	bench-mounted High Resolution Optical Spectrograph (a former Gemini instrument)
BTO	Beam Transfer Optics (for laser guidestar system)
CCD	Charge Coupled Device (detector)
CFHT	Canada France Hawaii Telescope
CPI	Cost Performance Index
DD	Director's Discretionary (telescope time allocation)
DM0	Deformable Mirror Zero (one of three GeMS DMs)
DMT	Document Management Tool (Xerox Docushare)
EMCCD	Electron-multiplying Charge Coupled Device
ESPaDOnS	Echelle SpectroPolarimetric Device for the Observation of Stars at CFHT
FT	Fast Turnaround
FTE	Full Time Equivalent
GCAL	Gemini facility CALibration unit
GEMMA	Gemini in the Era of Multi-Messenger Astronomy - NSF-funded AO and operational enhancements.
GeMS	Gemini MCAO System
Gen 4#3	Generation 4 Number 3, a generic name for Gemini's next new instrument after GHOST

GEONIS	Gemini Efficient Optical and Near-infrared Imager and Spectrograph
GHOST	Gemini High resolution Optical SpecTrograph
GIFS	Gemini Instrument Feasibility Study
GIRMOS	Gemini Infrared Multi-Object Spectrograph
GLAO	Ground Layer Adaptive Optics
GMMPS	Gemini MOS Mask Preparation Software
GMOS	Gemini Multi-Object Spectrograph (-S located at Gemini South, -N at Gemini North)
GMOX	Gemini Multi-Object eXtra-wide-band spectrograph
GNAO	Gemini North Adaptive Optics - New multi-conjugate AO system for Gemini North, funded by the NSF GEMMA grant.
GNAOI	Gemini North Adaptive Optics Imager
GNIRS	Gemini Near InfraRed Spectrograph
GOA	Gemini Observatory Archive
GPI	Gemini Planet Imager
GPP	Gemini Program Platform
GRACES	Gemini Remote Access to ESPaDOnS
GSAOI	Gemini South Adaptive Optics Imager
HAA	Herzberg Astronomy and Astrophysics
HIRES	High Resolution Echelle Spectrometer (a Keck instrument)
IDF	Instrument Development Fund
IFU	Integral Field Unit
IGRINS (2)	Immersion GRating INfrared Spectrograph (2)
IR	InfraRed
ISS	Instrument Support Structure
ITC	Integration Time Calculator
IUSP	Instrument Upgrade Small Projects
LLP	Large and Long Programs
LSST	Large Synoptic Survey Telescope
LTAO	Laser Tomography Adaptive Optics
M1,M2,M3	Primary, Secondary, Tertiary (science fold) mirrors
MCAO	Multi-conjugate Adaptive Optics
MEF	Multi-Extension FITS
MOS	Multi-Object Spectrograph

MOVIES	Montreal Ohio VIctoria Echelle Spectrograph
NGO	National Gemini Office
NGS	Natural Guide Star
NGS2	Natural Guide Star Next Generation Sensor
NICI	Near Infrared Coronagraphic Imager (a Gemini instrument)
NIR	Near InfraRed
NIRI	Near InfraRed Imager (a Gemini instrument)
NRC-H	National Research Council Canada - Herzberg
NSF	National Science Foundation (Gemini's Executive Agency)
O&M	Operations and Maintenance
OIWFS	On-Instrument WaveFront Sensor
OT	Observing Tool
PI	Principal Investigator
PIT	Phase 1 Tool
PWFS	Peripheral WaveFront Sensor (numbered PWFS1 and PWFS2)
QC	Queue Coordinator
RfP	Request for Proposals
RTC	Real Time Computer
S/N	Signal to Noise ratio
SOS	Science Operations Specialist
SPI	Schedule Performance Index
STAC	(Gemini) Science and Technology Advisory Committee
SUS	Science and User Support (a Department within Gemini Operations)
TAC	Telescope Allocation Committee
TAO	Telescope / Adaptive Optics Department
TDA	Time-domain Astronomy
ToO	Target of Opportunity
UV	UltraViolet
UVES	Ultraviolet and Visual Echelle Spectrograph (a VLT instrument)
VLT	Very Large Telescope (one of four ESO 8m telescopes)
VTK	Vibration TracKing system
WFS	WaveFront Sensor