# Gemini and the existing telescopes

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**Abstract**

By the end of 2001, the two Gemini telescopes will be in full operation, with the UK community having access to about 70 nights per year on each. With the WHT, UKIRT and the AAT, the community has access to over 600 nights per year of 4-m time. It is clear that most programmes will continue to be conducted on our existing telescopes, with Gemini being used only where the programmes cannot be completed on the 4-m instruments. Gemini has the advantages of large collecting area and active optics to ensure that observations are site-limited. However it also has a restricted field of view (<10 arcmin) and, initially will have a restricted instrument suite. The excellent sites and ability to apply aluminium or silver coatings to the telescope mirrors will ensure high throughput.

Gemini is well-suited for deep observation over small fields, with the best results obtained over fields where tip-tilt or higher degrees of correction are effective ($\lesssim$ 3 arcmin). The largest gains arise where the full gain of the increased area is realised, in near- diffraction-limited observations e.g at thermal infrared wavelengths and with adaptive correction in the near-infrared, and in photon-starved applications such as high spectral resolution, faint object spectroscopy.

Many programmes carried out with Gemini will rely on supporting observations from 4-m telescopes for target selection and complementary observations such as sample completion, simultaneous measurements in different wavebands etc. In the next decade, the UK will have access of right to almost one half of an 8-m telescope in a world where about a dozen 8–10m class telescopes will be in operation. We enjoy a much greater fraction of the total 4-m telescopes and it will be imperative that they are used effectively with Gemini in order to ensure that our highest priority scientific programmes are completed efficiently.

*Key words:* Gemini, Telescopes, Instruments

## 1 The Large Telescope Boom

Ground-based astronomy is undergoing a worldwide revolution. Within 5 years, there will be almost as many 8-m class telescopes as current front-line 4-m telescopes (Table 1). This boom in telescope construction is similar to, but on a much bigger scale than, the 4-m telescope construction period in the 1970s and 1980s. Through the investments by the Research Councils into the AAT, UKIRT and WHT, the UK emerged from that period with a substantial fraction ($\gtrsim 10\%$) of the global 4-m telescope collecting area. The UK has access by right to 50% of the AAT, 85% of UKIRT and 60% of the ING telescopes. Through its contributions to Gemini, the UK community will have a 23.8% share of the observing time, amounting to $\sim$70 nights/year on each of the Gemini telescopes. This is equivalent to about 3% of the global large telescope time, and emphasises the importance of our 4-m telescopes in the UK ground-based portfolio. The UK has access to almost half an 8-m telescope but 2 whole 4-m telescopes (and with the welcome approval of the VISTA wide-field survey telescope through the Joint Infrastructure Fund, that imbalance will be increased further).

The UK needs to use all of its telescopes effectively to ensure that our programmes can be completed on the right facilities. Most programmes will continue to rely on 4-m telescopes for most of their data.

## 2 Gemini's Mission

The primary goals of the Gemini telescopes are:

- Complete Sky coverage from excellent sites on Mauna Kea in Hawaii and Cerro Pachon in Chile.
- Excellent image quality: the telescopes and enclosures have been designed to minimise thermal disturbances which could degrade the images delivered by the atmospheres. The specification requires an intrinsic image quality better than 0.1 arcsec at $2\mu$m.
- Large Collecting Area ($50\text{m}^2$) coupled with high reflectivity coating for maximum throughput
- Low infrared emissivity: careful design of the telescope structure coupled with the capability of coating the telescope mirrors with silver will reduce the emission from the telescope in the critical IR windows beyond $2\mu$m and increase the reflectivity at wavelengths longer than $0.4\mu$m.
- Queue scheduling to exploit best conditions effectively and match observations to the prevailing conditions.

Table 1
Large Telescope Projects

| | | | |
|---|---|---|---|
| Keck (Hawaii) | 2 x 10-m | 1993,96 | U.California, Caltech,NASA |
| Gemini-N | 8-m | 2000 | US,UK,Canada,Chile,Australia,Brazil,Argentina |
| Subaru | 8-m | 2000 | Japan |
| VLT (Chile) | 4 x 8-m | 1999-2001 | Europe |
| Gemini-S | 8-m | 2001 | US,UK,Canada,Chile,Australia,Brazil,Argentina |
| Magellan | 2 x 6.5-m | 2000, 2002 | Carnegie Institute, Harvard, MIT, Michigan |
| LBT (USA) | 2 x 8.4-m | 2002 | U.Arizona, Italy, Germany, Ohio |
| Hobby-Ebberly | 9.2-m | 1999 | U.Texas, Penn State, Stanford, Germany |
| MMT | 6.5-m | 1999 | U.Arizona, Smithsonian |
| GTC (La Palma) | 10-m | 2003 | Spain + |
| SALT (South Africa) | 9.2-m | 2003 | S Africa, U.Texas, Ruttgers U, Poland + |

Gemini serves a very large user community and must provide versatile telescopes and instruments. Under background-limited observations, the gains are greatest in regions where image quality is best. This means that the greatest gains over existing facilities are in near-diffraction-limited observations in the infrared, photon-starved measurements at high spectral resolution in the visible/near-infrared, or high time resolution. Low Signal-to-Noise observations where the extra collecting area makes measurements feasible are another key area for Gemini, but the greatest scientific impact in the early years of operation are are likely to come with adaptively corrected images in the near-infrared. Gemini is a Cassegrain telescope with a maximum 10 arcmin field, so it will be used mostly for deep and detailed measurements over relatively small fields.

Gemini will operate from 0.3 to 30 $\mu$m and will be equipped with a number of imagers and spectrometers; a polarization facility is expected to be commissioned shortly after full operations of the northern telescope start in mid-2000. The initial instrument complement is listed in Table 2.

In the longer term, an IR multi-object spectrograph, laser guide star (LGS) adaptive optics, and a high-stability optical spectrograph have been identified as key requirements for the instrumentation programme. Provision of Optical/IR Integral Field Units is scheduled early on in the use of the spectrographs.

While Gemini offers a maximum field of 10 arcmin, the best image quality will be attained within the isokinetic or isoplanatic patch, and so within a few arcsec to few arcmin of the guide star, depending on wavelength and conditions. Results with the HST and ground-based AO systems clearly show the benefits of high resolution. Half-arcsec images in the near-IR are now routine on Mauna Kea, but expectations are pushing to 0.3" under good conditions. Gemini estimates a median K band image size of 0.35 arcsec with tip/tilt.

Table 2
Initial Gemini instruments

| Instrument | Date | | |
|---|---|---|---|
| GMOS Multi-object spectrograph | 2000,2001 | 0.4–1.0 $\mu$m | R$\lesssim$ 10000 |
| HROS High resolution spectrograph | 2001 | 0.2–1.0$\mu$m | R= 50000 |
| NIRI 1-5 $\mu$m imager | 1999 | 0.02–0.1 arcsec/pixel | |
| GNIRS 1–5 $\mu$m spectrometer | 2002 | 0.05, 0.15 arcsec/pixel | R$\lesssim$18000 |
| MIRI 8-25 $\mu$m imager | 2001 | 0.08 arcsec/pixel | |
| Michelle 8–25 $\mu$m spectrometer | 2001 | $200 < R < 20000$ | Shared with UKIRT |
| Phoenix 1–5 $\mu$m spectrometer | 2001 | R=60000 | Shared with CTIO |
| Altair 0.8-3.0 $\mu$m | 2001 | Deployable AO System | |

More details can be found http://www.gemini.edu

The telescope emissivity goal is 2% with Ag mirror coatings. This contributes to the huge gains anticipated at 2-12 $\mu$m for some programmes. Deep 11 micron observations effectively open up a new window for observations of faint compact objects (e.g. HDF ISO galaxies will be detectable in long integrations in the mid-infrared). It will also lead to high sensitivity for spectroscopy between the OH lines in the K band with IR spectrometers.

We can anticipate that Gemini's forte will lie in detailed small-field observations where Integral Field Units and 3D Spectroscopy will become increasingly important in unravelling contributions from different components in crowded, complex regions.

## 3 Complementary Observations - A snapshot in 1997

Meetings were held in the US, the UK, Canada and South America in 1997 to examine requirements for complementary observations to Gemini on other space and ground-based facilities (Puxley et al 1998). A wide variety of science topics was presented which need a range of supporting observations. Striking interest was evident in wide field (30 arcmin or greater) optical and near-infrared imaging surveys across the communities. On average a typical night of Gemini follow-up requires between one-half and one night of supporting observations (with wide variance). Imaging with good angular resolution ($\sim$0.25 arcsec or better) was often cited for preparatory observations, so that ground-based AO systems as well as the HST and its archives are important resources. Another key requirement identified was quick-response access to Gemini triggered by a variety of external events on other telescopes and satellites.

The combination of Keck + HST provides an excellent example of the enormous impact of large telescopes and superb image quality on some areas of astrophysics, with the most obvious example probably being high redshift galaxies. The gains in sensitivity obtained with the Keck telescopes appear to be greater than the ratio of collecting areas would suggest. The combination of a 10-m telescope, good image quality, high transparency and an efficient spectrograph (LRIS peak efficiency is $> 30\%$) provides a substantial advantage (plus lots of observing time for some projects!). It is not feasible to increase the primary mirror size, but we need to ensure that everything else on the 4-m telescopes is optimised for their programmes, especially instrument performance and image quality. We particularly need to pay attention to: detector QE, noise performance, operational overheads, optical coatings, filter and grating efficiency. New technologies may help, including volume phase holographic gratings, but large gains can also come from maximising the multiplex gain over wavelength range, field, resolution and number of objects or spatial elements.

### *3.1 Gemini and the 4-m telescopes*

Multi-telescope programmes will be common. A number of approaches will be important, including 4-m imaging for target selection, spectroscopy for partial or initial assessment and target refinement and e.g. combined optical-IR programmes where targets may be substantially brighter in the IR. Many samples will straddle the 4-m/8-m sensitivity range while calibrations and templates may be possible on smaller telescopes. Simultaneous observations with other ground-based and/or satellite telescopes and monitoring programmes will also call on the existing telescopes. Natural 4-m programmes include wide field surveys for efficient target selection, surface brightness-limited observations, source noise-limited observations (typically high S/N observations), some astrometric programmes - e.g. linking IR, radio and optical frames, regular monitoring and some high resolution observations. Because of the much greater fraction of time available on the 4-m telescopes, it will be possible to conduct larger scale programmes.

A key requirement is to ensure that highly-rated programmes that require access to more than one telescope are not jeopardised.

A number of telescopes are investing in panoramic CCD cameras for wide-field imaging programmes (Table 3). This is a ferociously competitive area. IR wide field imaging is much less congested, and offers large scientific gains, but the UKIRT developments and the VISTA project imply that the UK should not develop the ING telescopes in this direction.

Through LGS adaptive optics, Gemini is aiming at good all sky correction in the near-IR. However, AO on large telescopes is (even) hard(er) than on

Table 3
Optical Imaging — The Competition

| Telescope | Aperture | CCD Camera Array Size | Field |
|---|---|---|---|
| WHT | 4.2-m | 4k x 4k | 16 arcmin |
| INT | 2.5-m | 4 x 4kx2k | 34 arcmin |
| KPNO | 4-m | 8kx8k | 35 arcmin |
| (or | 0.9-m | | 59 arcmin) |
| CTIO | 4-m | 8kx8k | 35 arcmin |
| CFHT | 3.6-m | 8kx12k | |
| ESO | 2.2-m | 8kx8k | 32 arcmin |
| Subaru | 8.2-m | 10kx8k | 30 arcmin |
| SDSS | 2.5-m | 30 2kx2k | |
| CFHT | Megaprime | 36 4kx2k | 1degree (2001) |
| MMT | Megacam | 36 4kx2k | 24 arcmin |

4-m telescopes and there are real advantages for 4-m apertures in extending the utility of AO correction into the red spectral regions, especially for spectroscopy. The scientific opportunities from developing a fully functioning LGS AO system are potentially enormous, and the field is still open to be the first observatory to operate routinely for scientific programmes. This opportunity will not remain open for much longer with many observatories actively pursuing this goal. There are very substantial gains for spectroscopy (background rejection) and 3-D techniques with LGS AO. Furthermore, many targets will be relatively bright, exploiting the improved resolution rather than faint limiting magnitudes.

## 4 The Future

Most, and perhaps two thirds of 4-m programmes will have at most indirect links to Gemini, but the worldwide investment in large telescopes will have a profound impact on the astronomy that the 4-m telescopes are best suited for. Within the UK, we need to establish much better coordination and collaboration between our optical/IR telescopes, and that may require some intermediate body between the telescope boards and the UK Ground-Based Facilities Committee. It will be essential that the overall scientific programme is assessed when the time allocation panels meet, which may mean that some parts are allocated time even though in themselves, they do not appear to provide exciting science. Good image quality is likely to be a key requirement - many proposals will depend on this more than aperture - and there are enormous opportunities for LGS adaptive optics. In practice proposals follow instruments as well as telescopes, so that timely deployment of innovative instruments will be essential. The WHT provides a natural platform for testing and early exploitation of new techniques and developments. These innovations must get ahead of the competition and produce astronomical results early if they are to provide maximum returns.

## References

[1] Puxley P. et al., 1998, Proc SPIE, 3349, 380.