GEMINI
8-M Telescopes
Project

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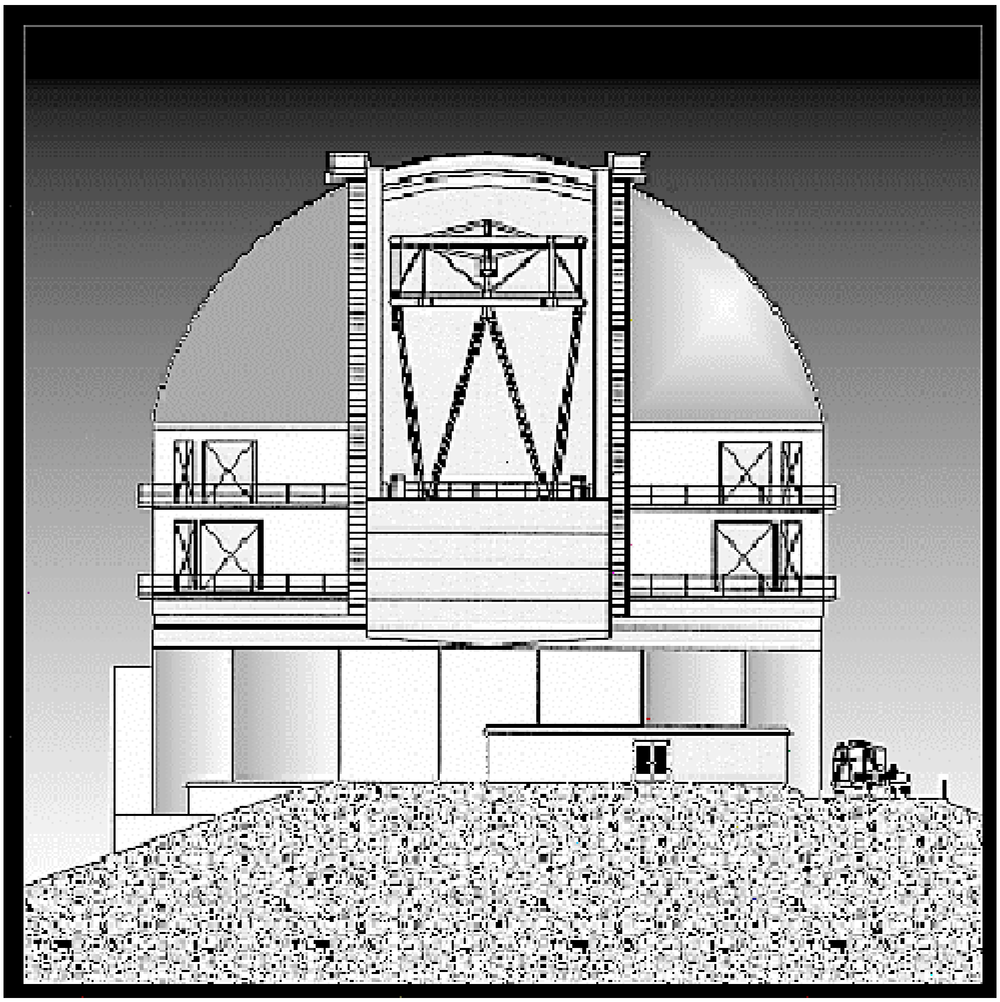
Principles Behind the Gemini Instrumentation Program



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PRINCIPLES BEHIND THE GEMINI INSTRUMENTATION PROGRAM

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1. Introduction

The design of the Gemini 8-m Telescopes has been driven by the following science requirements;

- Two 8m Telescopes at superb sites
- Image Quality better than 0. I arcseconds at 2.2 microns
- Broad wavelength coverage with special emphasis on infrared optimized performance
- Versatility

What becomes evident as we begin to explore the parameter space defined by these science drivers is that, unsurprisingly, the requirements for the telescopes and instruments become interlinked when we try and design an instrument complement to exploit sites like Mauna Kea and Cerro Pachon.

2. Instruments as an integral part of the telescope system

The basic principle behind these expected large gains in signal-to-noise of the new large telescopes compared to our 4m class telescopes is that in the background limited regime,

$$\text{Signal/Noise} \propto \text{Telescope Diameter (D) / Image Diameter (q)}$$
or
$$\text{Signal/Noise} \propto D^2 \text{ for diffraction limited observations}$$

With a Gemini spectrograph, how faint will it be possible to go using 0. I arcsec compared with what we can currently do on 4m telescopes? The collecting area will increase by $(8/4)^2$ and the sky noise will change by a factor of (8/4) (0.1/3), hence the sky noise will drop by a factor of ~4 in going from 3 arcseconds slits on UKIRT to 0.1 arcsecond slits on Gemini. Recent shift-and-add results from the IRTF and UKIRT are showing it is already possible to get 20-30% of the 2.2-micron flux from a point source within 0.12 arcsecond (Shure, et al., 1994, Puxley, et al., 1994). In addition, the new 1024 x 1024 arrays would allow the complete 1-2.5 micron spectra to be taken in a single exposure; the UKIRT spectra had to be taken as six independent exposures. Consequently, making some allowances for slit losses (Ellerbroek, et al., 1994), a Gemini IR spectrograph could repeat the same type of observations on compact objects 4-5 magnitudes fainter.

It will not just be at infrared wavelengths that new science will be possible by exploiting the background limited sensitivities of Gemini. ***Figure 1*** shows a cluster of galaxies imaged with the HST in the R band (before its refurbishment) compared to a ground based image of the same region taken in ~1 arcsecond seeing. Alan Dressler, who obtained this image, (Dressler, et al., 1994), believes he may have discovered a "nascent cluster of galaxies at redshift z ~ 2". The only reliable way of determining the redshift and gain some insight into the nature of these possible early epoch objects is to measure their spectra. However as these galaxies have R magnitudes ~ 22-24, this will be a fairly challenging undertaking on 4m telescopes. Not only will sub-arcsecond slits be required to distinguish and isolate individual objects, but also to reduce the sky contribution to keep the spectra from becoming completely swamped by sky background noise. A novel approach to obtaining spectra of such complex objects being investigated for Gemini is integral field spectroscopy (see ***Figure 2***). In this approach both spatial and spectral information is simultaneously measured by imaging the object onto a lensiet array or fibre bundle (see for example Allington-Smith et al this proceedings) and the individual spatial elements are then separately dispersed through the spectrograph.

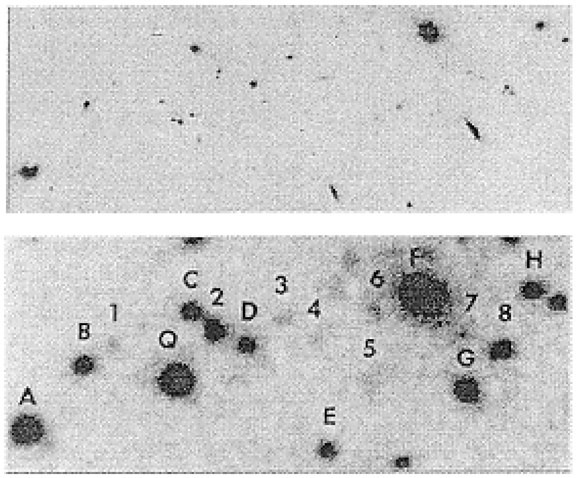

Figure 1. HST and Ground-Based Images from Dressler.

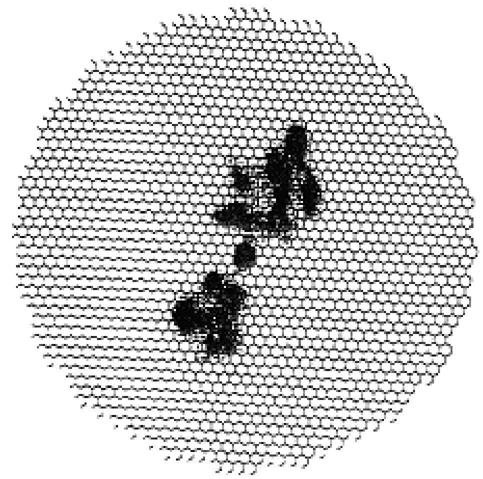

Figure 2. NGC 4151 in OIII observed with HST. Integral field spectroscopy with 0.1 arcsecond lenslet array.

Just from the perspective of the telescope performance required to exploit both these observational techniques, we will have to go beyond conventional "autoguiding" on Gemini. Analysis has shown that to ensure the telescope does not degrade the image quality beyond 0. I arcsec;

- uncompensated flexure must be kept below < 0.01 arcseconds (6 microns movement in the focal plane)
- focus and tip/tilt errors caused by wind buffeting and temperature changes will have to be corrected to <0.04 arcseconds
- to reduce wind bounce to these levels tip/tilt signals must be sampled at ~ 200Hz
- the latency of those signals must be < 500μs

What about atmospheric turbulence effects? Even if we simply sense tip/tilt and focus, the further off axis we go, the amount of atmospheric decorrelation increases. Therefore to exploit the best seeing and adequately correct the simplest atmospheric turbulence effects (tip/tilt and defocus) guide stars must lie close to the science object. For instruments that need to exploit the best conditions, especially for infrared instruments on Gemini, we have chosen to sample the guide field close to the instruments focal plane by using wavefront sensors mounted as integral parts of the instruments.

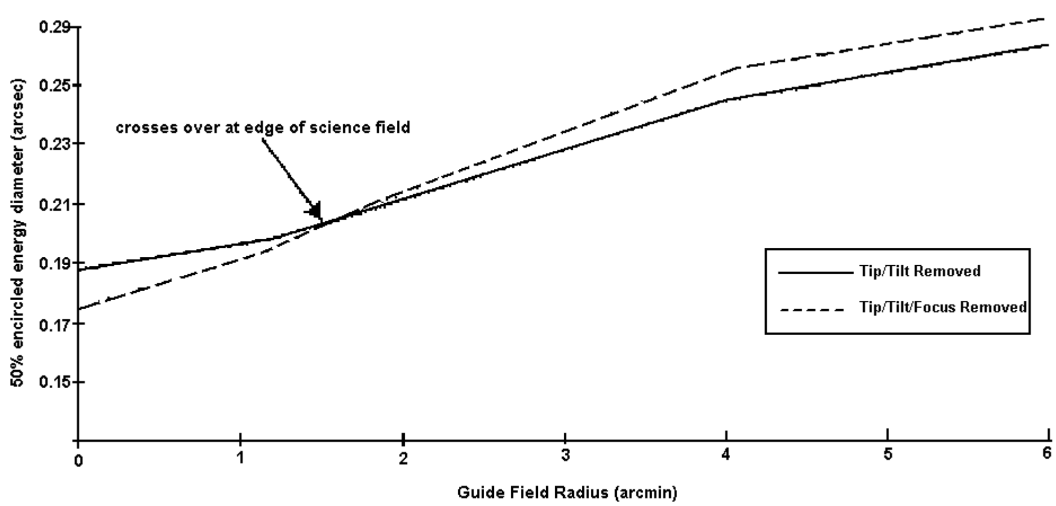

Figure 3. Comparison of Image Quality with Tip/Filt and Tip/Tilt/Focus Removal (best seeing)

3. Multiple Instruments for Adaptable Observing

Our increased understanding of the effects of dome and mirror seeing combined with the use of sophisticated control techniques to maintain telescope alignment and reduce the effects of wind buffeting mean that in conditions of good seeing the Gemini telescopes will deliver images of 0.1 - 0.2 arcseconds. In conditions of median seeing, the delivered images will be ~ 0.4 - 0.6 arcseconds. Telescope emissivities of 2 - 4% will reduce the background for thermal infrared observations by factors of up to 4 compared to conventional telescopes at those wavelengths where the atmospheric emissivity drops below 1 - 2% (e.g. the 10μm window).

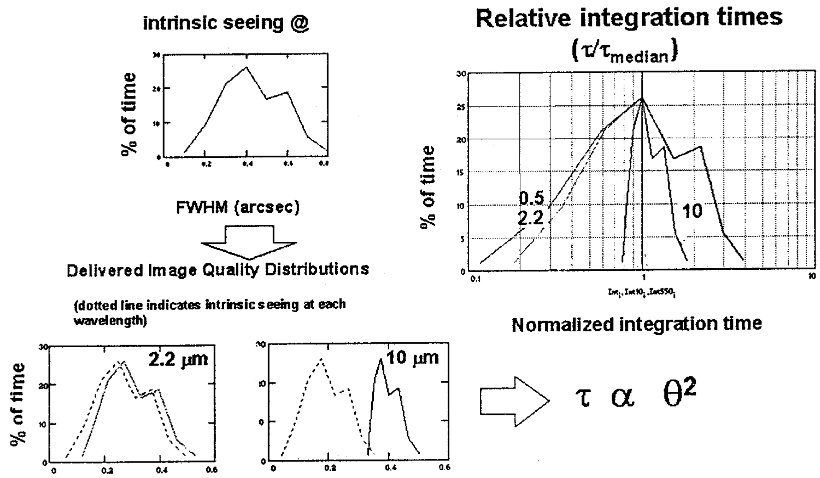

Figure **4.** Expected distribution of delivered image quality and how this translates to a spread in required integration time for compact sources.

Figure 4 shows the expected distribution of delivered image quality at 0.55μm and 2.2μm for the Gemini telescopes, assuming the intrinsic seeing follows the histogram from Racine et al. (I 99 1), scaling the seeing as $\lambda^{1/5}$ and using detailed servo models for the telescope's performance. What is apparent is that, if the goal is to observe small compact objects at shorter wavelengths either with small pixels or small slits, the length of an observation will vary by factors of 4-10 depending on atmospheric conditions. What ***Figure 4*** shows in addition is that at 10μm**,** where diffraction is the dominant contributor to the delivered image quality, the integration times are less sensitive to atmospheric seeing variations -- so in poor seeing conditions switching to a 10μm instrument would be a more optimum choice for Gemini.

For a higher IR optimized telescope on a good infrared site it is not just seeing variations that can necessitate a change in observing strategy; water vapor variations are important too. With such a telescope the integration time required for thermal IR observation is more strongly dependent on variations in the atmospheric emissivity. For example, at 19μm, the integration times can be halved if the water vapor column density changes from Imm H_2O to 0.3 mm H_2O. So at thermal infrared wavelengths low telescope emissivity means we are more sensitive to atmospheric emissivity changes.

Consequently a key part of the Gemini observing concept will be the ability to quickly adapt to changing atmospheric conditions at Mauna Kea and Cerro Pachon by switching from one instrument to another. To realize this observing concept Gemini must be capable of supporting multiple instruments which can be quickly "brought on line".

4. The Gemini Instrument Support Structure.

Figure 5 shows the instrument mounting concept being developed by Gemini. The five sides of the instrument support structure cube can be configured for at least three instruments, two of which can weigh up to two tonnes each. In addition a facility calibration source and an adaptive optics module can be mounted on two of the faces. Both the calibration unit and the Adaptive optics module can feed any of the F/16 instrument ports using a retractable science fold mirror in the center of the ISS.

The large mass of the entire instrument cluster must not contribute to a degradation in the telescope performance, therefore to exploit the very best conditions each instrument must include;

- An on-board wavefront sensor integrated with the instrument to reduce differential flexures <0.01 arcseconds (6μm relative movement)

- Counter weights to ensure that the mass and mass-moments of the entire cluster remain balanced around the cassegrain rotator axis at all telescope orientations to ensure tracking errors are kept below <0.01 arcseconds for I hour observations

- Heat exchangers on all instrument electronics to ensure no more than 50W per instrument dissipates into the telescope enclosure.

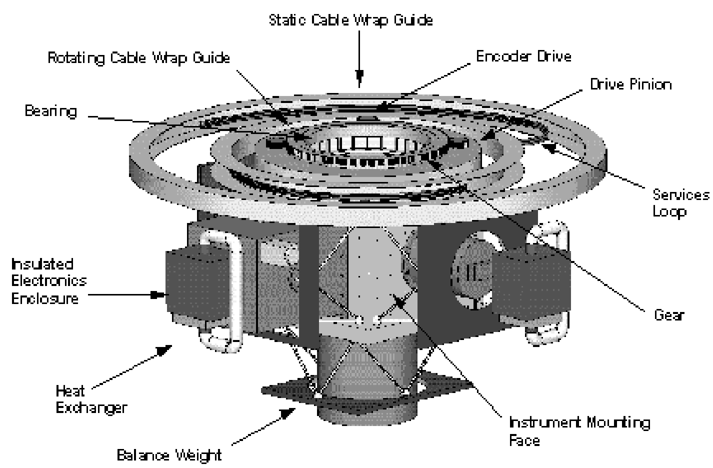

Figure 5. Cassegrain rotator instrument mounting concept.

5. The Gemini Instrument Complement

The current instrument complement planned for Gemini is given in ***Table 1.*** The range of capabilities from the UV, Optical and IR as a function of spatial resolution and spectral resolution for each site is shown in ***Figure 6*** for Mauna Kea and ***Figure*** 7 for Cerro Pachon.

Table 1. Initial instrument complement.

Mauna Kea	Cerro Pachon
• Near IR Imager	• Multi-Object Spectrograph
• Near IR Spectrograph	• High Resolution Optical Spectrograph
• Multi-Object Spectrograph	• Mid IR Imager*
• Mid IR Imager	*(*Can be transferred for first light)*
• Shared Instrumentation	• Shared IR Instrumentation with CTIO
- Fiber Feed to CFHT	- Phoenix
- Michelle (UKIRT)	- Commissioning Imager

References.

1. Shure, et. al., *"NSFCAM, a new infrared array camerafor the NASA IRTF"*, 1994, SPIE Symposium on Astronomical Telescopes & Instrumentation for the 2 1 st Century, Kona, Hawaii.

2. Puxley, et. al., *"Performance of the ALICEIIRCAM-3 system on UKIRT"*, SPectrum - Newsletter of the Royal Observatories No. 2, June 1994.

3. Dressler, et. al., *"A nascent cluster ofgalaxies at z=2?* ", 1993, Ap.J.L. 404, L45.

4. Ellerbroek, et al., *"Adaptive optics performance for the Gemini 8-m Telescopes Project"*, 1994, SPIE Symposium on Astronomical Telescopes & Instrumentation for the 21 st Century, Kona, Hawaii.

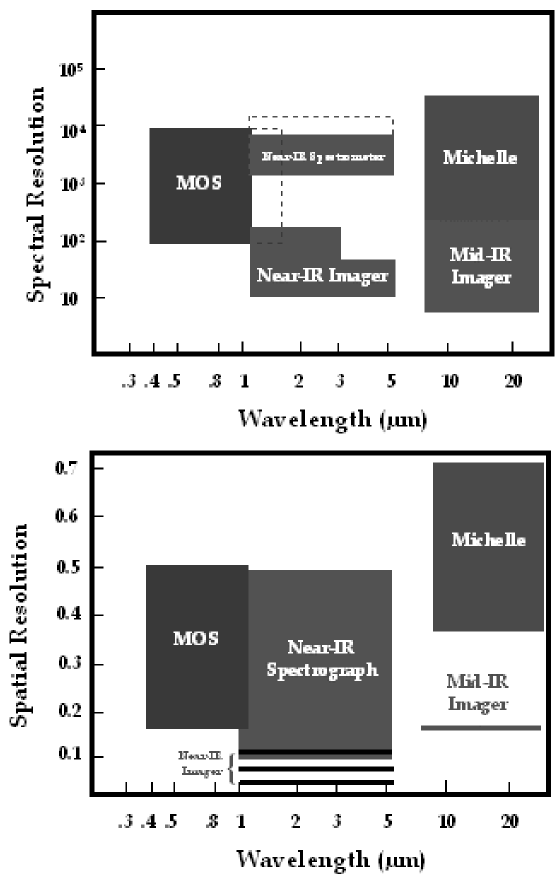

Figure 6. Spatial and spectral resolution capabilities for Mauna Kea instrumentation.

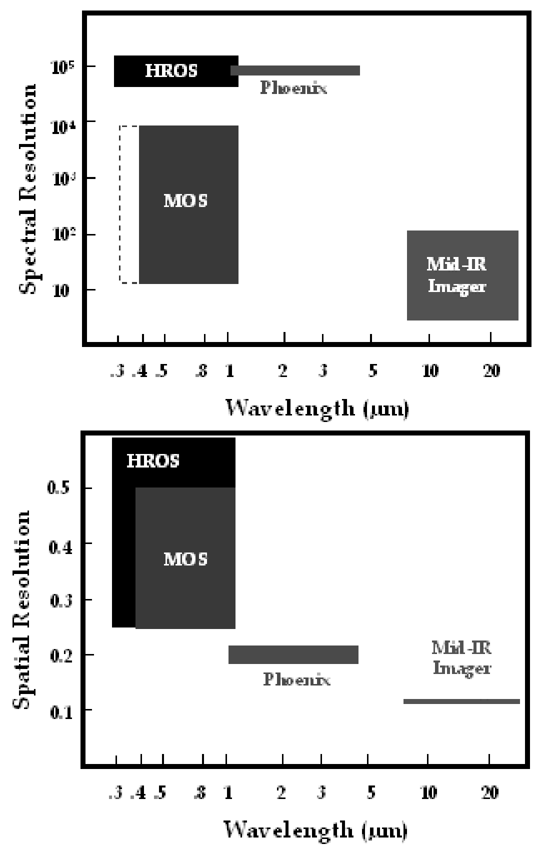

Figure 7. Spatial and spectral resolution capabilities for Cerro Pachon instrumentation.