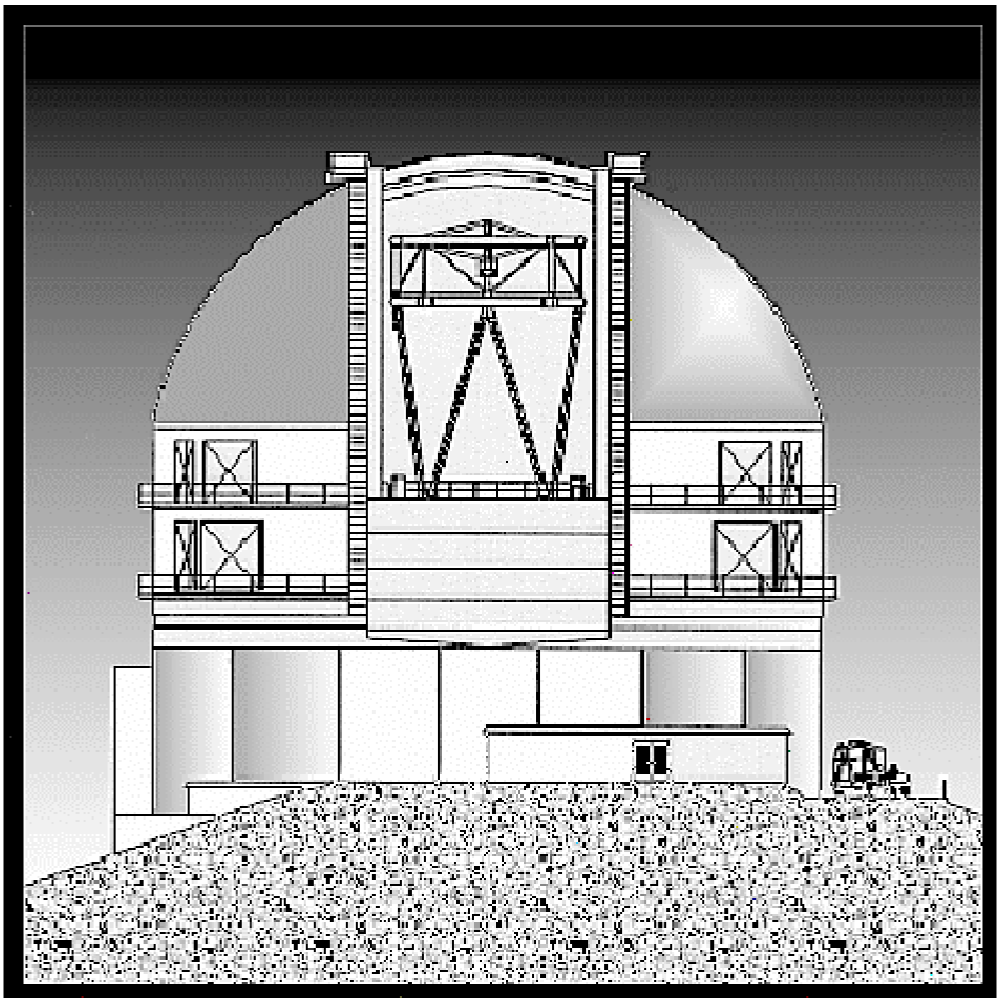
GEMINI
8-M Telescopes
Project

RPT-PS-G0075

Future Gemini Instrumentation
Report of the First Gemini Instrumentation Workshop



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FORWARD

On a cold weekend over the 18-19 January 1997, astronomers from Argentina, Brazil, Canada, Chile, United Kingdom and the United States met in Abingdon, just outside Oxford, England. Amongst the Medieval Abbey grounds and English gardens of Cosener's House, with swans drifting slowly by on the river, these forty-two astronomers settled down to chart the future scientific direction for the Gemini 8M Telescopes instrumentation program. The intent of this first instrumentation workshop was to ask what programs could and should be done on these two new telescopes in the early part of the next Century and how should these potential science programs impact our planning for future instruments?

The workshop split up into four groups, 'Stars and Planetary Systems', 'Star Formation and the Interstellar Medium', 'Galactic Structure and Nearby Galaxies' and the 'Formation and Evolution of Galaxies and Cosmologies.' Over the course of the next two days, in the sessions, over lunch, over dinner and in Pubs across Abingdon, potential Gemini observers debated and argued on where astronomy was going in the next century. In one group I heard a colleague announce, "*everything interesting in astronomy happens at the one parsec scale*", while in the session next door I listened as it was confidently declared that *"the H_o problem is dead, we know the answer to within the experimental errors, lets move on*"-- a heated debate followed.

What I found most remarkable about this "Abingdon Process" was that by the end of the workshop on Sunday, after all the arguments and debates were over, a real consensus emerged on the future directions for the Gemini 8M Telescopes instrumentation program. It is this consensus, spanning all six national astronomical communities making up the Gemini partnership that is described in these proceedings. It is a tribute to the collegiality of our community, the patience and perseverance of our session Chairs and to the hospitality of the UK Gemini Project Office that this workshop was such a success.

Matt Mountain
Director

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SUMMARY OF WORKSHOP RECOMMENDATIONS

The First Gemini Instrumentation Workshop met on January 18, 19 1997 to explore the scientific basis for future instrumentation capabilities on the Gemini telescopes. The workshop addressed scientific issues and opportunities in four broad scientific areas: Stars and Planetary systems, Star Formation and the Interstellar Medium, Galactic Structure and Nearby Galaxies, and Formation and Evolution of Galaxies and Cosmology, and identified the following capabilities as high priority for future Gemini instrumentation beyond the baseline capabilities of the Phase I Gemini Instrumentation Program.

New Capabilities

1) A Natural Guide Star/Laser Beacon Adaptive Optics(AO) system at Cerro Pachon
2) A Near IR Imager with coronagraphic capability at Cerro Pachon
3) A 1 - 2.5μm Multi-object spectroscopic capability at Cerro Pachon, including IFU and multi-slit capability for use with AO corrected images, and wide field multi-object capability over at least 5 arcmin field of view.
4) A&G polarization modulator for Optical/IR at both Mauna Kea and Cerro Pachon
5) A High Stability Lab Spectrometer for Cerro Pachon, with resolutions around 120K and $\geq$300K.

Upgrades to to Phase I Instrumentation

1) A Laser Beacon AO system upgrade at Mauna Kea
2) A Near IR upgrade to GMOS at Mauna Kea
3) An IFU capability for the Near IR Spectrometer at Mauna Kea
4) An 120K capability for HROS at Cerro Pachon
5) Grating improvements for GMOS

Shared Instrumentation

1) The Mid-IR spectrograph (MICHELLE) shared with UKIRT on Mauna Kea
2) The Near-IR High resolution spectrometer (Pheonix) shared with NOAO on Cerro Pachon

1. INTRODUCTION

The Gemini observatory is poised to play a key role in the great scientific investigations of the 21st century. These future scientific explorations will be exciting to both the astronomical community and the general public; including the search for other planetary systems, the formation and evolution of galaxies, and the understanding of star formation. Gemini is in this favorable position because the Gemini telescopes on Mauna Kea in Hawaii and Cerro Pachon in Chile are designed to excel in key areas, e.g. excellent sites, superb imaging quality, throughput and IR emissivity, and the capability to exploit the best observing conditions with innovative scheduling.

However, providing two superb telescopes is only part of the job. If Gemini is to attain this prominent role in astronomy, the telescopes must be operated in a fashion to allow the partner communities to effectively and efficiently carryout frontier observations, and the Gemini instrumentation capabilities have to continue to evolve to exploit new scientific opportunities and technology developments as they become available.

The capabilities of the initial complement of instrumentation (Table 1) will allow the Gemini communities to undertake the broad range of scientific programs identified in the Gemini Science Requirements Document. The on-going instrumentation program is intended to provide the key capabilities beyond those offered by the Phase I instrumentation that will keep the Gemini facilities at the forefront of astronomical research well into the 21st century.

Table 1. Gemini Phase I Instrumentation

Instruments	Wavelength Range	Array Format	Pixel Scale	FOV/Slit Length	Spectral Resolution	Other Capabilities	Upgrade Options
MAUNA KEA							
Multi-Object Spectrograph (GMOS-N)	0.4 - 1.1µm	4k x 6k CCD	0.08”	5.5’ x 5.5’	R~1 k (3 pix) R~3k (3 pix) R~10k (3 pix)	~200 multi slits 0.2” pix IFU	1-1.5µm 0.1" pix IFU
						Imaging	
Near IR Imager (NIRI)	1 - 5.5 µm	1k x 1k InSb	0.02” 0.05 0.11	20” x 20” 50” x 50" 110” x 110”	Filters to R~100	R~700 grism Polarizing prism Near IR WFS (t/t) Coronagraph	
Near IR Spectrograph (NIRS)	1 - 5.5 µm	1k x 1k InSb	0.05” 0.15”	50” 100”	R=2k, 6k, 18k R=0.7k, 2k, 6k.	X Dispersion Polarizing Prism Near IR WFS (t/t)	1 - 2.5 µm 0.05” pix IFU R~30k
Adaptive Optics System (AOS)	1 - 2.5 µm 0.8 - 5.5 µm (goal)	SR=0.4 at 1.6 um, median seeing and bright guide stars		2' dia		natural guide star conjugation to alt. feed all inst. ports 0.5 - 2.5 µm ADC	Laser Beacon
CERRO PACHON							
Multi-Object Spectrograph (GMOS-S)	0.38 - 1.1 µm	4k x 6k CCD	0.08”	5.5' x 5.5'	R~ 1 k (3 pix) R~3k (3 pix) R~10k (3 pix)	~200 multi slits 0.2” pix IFU	1 - 1.5 µm 0.1" pix IFU
						Imaging	
High Resolution Optical Spectrometer (HROS)	0.30 - 1.1 µm	4k x 4k CCD		60”	30k - 80k	Cass mounted Prism X Dispersion	R= 120k Multi object Hi Stab Lab Feed Polarizing Prism
Mid-IR Imager	8 - 25 µm	~256 x 256	0.13”	40” x 40”	Filters to R~100		

In order to ensure the continuing relevance of the Gemini On-going Instrumentation Program, international scientific reviews will be held every two years, providing an opportunity to reevaluate the content and direction of the instrumentation program from a scientific and technical perspective, taking into account changing scientific opportunities, the evolution of technology opportunities, the status of the on-going instrumentation activities, and the availability of funds. The First of these International Gemini Instrumentation Workshops was held at Cosener's House, Abingdon, England on 18, 19 January 1997.

The Workshop assumed that the Gemini Phase I instrumentation program, which is currently in process, will be completed in full.

Section II summarizes the key scientific issues and opportunities identified by the Workshop. These are not intended to be comprehensive but rather to illustrate the type of programs judged to be high priority for Gemini, and are only a small subset of the potentially significant research areas for Gemini. Based on these scientific issues and opportunities, and the special characteristics of the Gemini Telescopes, instrument capabilities were derived, which together with the capabilities of the Phase I Instrumentation Program were judged to address the broad key issues in an effective fashion. Phasing of the instrumentation developments and location on Gemini-N/S were included in the considerations when appropriate. The resulting recommendations of capabilities are outlined in Section III. The recommendations include new instrumentation capabilities, upgrades to the baseline capabilities of the Phase I instrumentation and also instrumentation shared between the Gemini telescopes and other telescopes on the two sites.

The recommendations generated by the Workshop will be adopted as guidelines for formulating the Gemini on-going instrumen0tation program. Due to funding constraints and technological considerations it may not be possible to implement all these recommendations.

II. SCIENCE ISSUES AND OPPORTUNITIES

The Workshop addressed scientific issues in four broad areas; Stars and Planetary Systems, Star Formation and the Interstellar Medium, Galactic Structure and Nearby Galaxies and Formation and Evolution of Galaxies and Cosmology. No attempt has been made to ensure comprehensive coverage of all observational astronomy fields; rather the goal was to identify the key instrumentation capabilities based on illustrative problems from a wide range of astronomical disciplines in order to ensure that the recommended capabilities would enable observations addressing these as well as many other scientific opportunities.

A. STARS AND PLANETARY SYSTEMS

Not only will the Gemini Telescopes and their instruments provide some of the clearest views yet of the most distant galaxies, they offer a golden opportunity to search for the faintest and most elusive of nearby objects, brown dwarfs and planets. The current popular and scientific interest in the giant planets reported to lie close to several bright stars has been galvanized by the recent controversy over the reality of the Jupiter-mass companion proposed for 51 Pegasi, where surface oscillations of the star maybe mimicking the effect of a dynamic perturbation. With Gemini it will be possible to examine the surfaces and circumstellar processes of these and other stars in unprecedented detail. NASA has identified the search for large planets as a key component of its Origins program and the Gemini telescopes are poised to play a key role in this search.

We have identified four critical areas in this field, each of which is at, or simply beyond, the limiting light-grasp, image quality and sensitivity of 4-m class telescopes and in which the particular strengths of the Gemini telescopes will allow them to play major roles:

i) defining the stellar initial mass function by finding and characterizing candidate brown-dwarfs and extra-solar system giant-planets,
ii) studying the physics of nearby stars in similar detail to the Sun,
iii) establishing analogs between the stars in our own and other galaxies,
iv) mapping the structure of magnetic fields, circumstellar discs and accretion phenomena in interacting binary systems with white dwarfs and stellar-mass black hole primaries.

1. BROWN DWARFS AND GIANT PLANETS

Even if all recent "discoveries" are confirmed, giant-planets are much rarer (<5%) as stellar companions than expected, with brown dwarfs rarer still, a singular mystery since there is no obvious reason for the stellar mass function to truncate or flatten below the Hydrogen burning limit. Arguably, GD165B and GL229B (with very different near-infrared colors) are the only known brown dwarfs with direct images (see Figure 1) and spectra have been taken only of Gliese 229B. The Gemini telescopes with their low scattered light, and excellent image quality and near-infrared sensitivity, will be powerful search tools for these very faint companions to nearby stars.

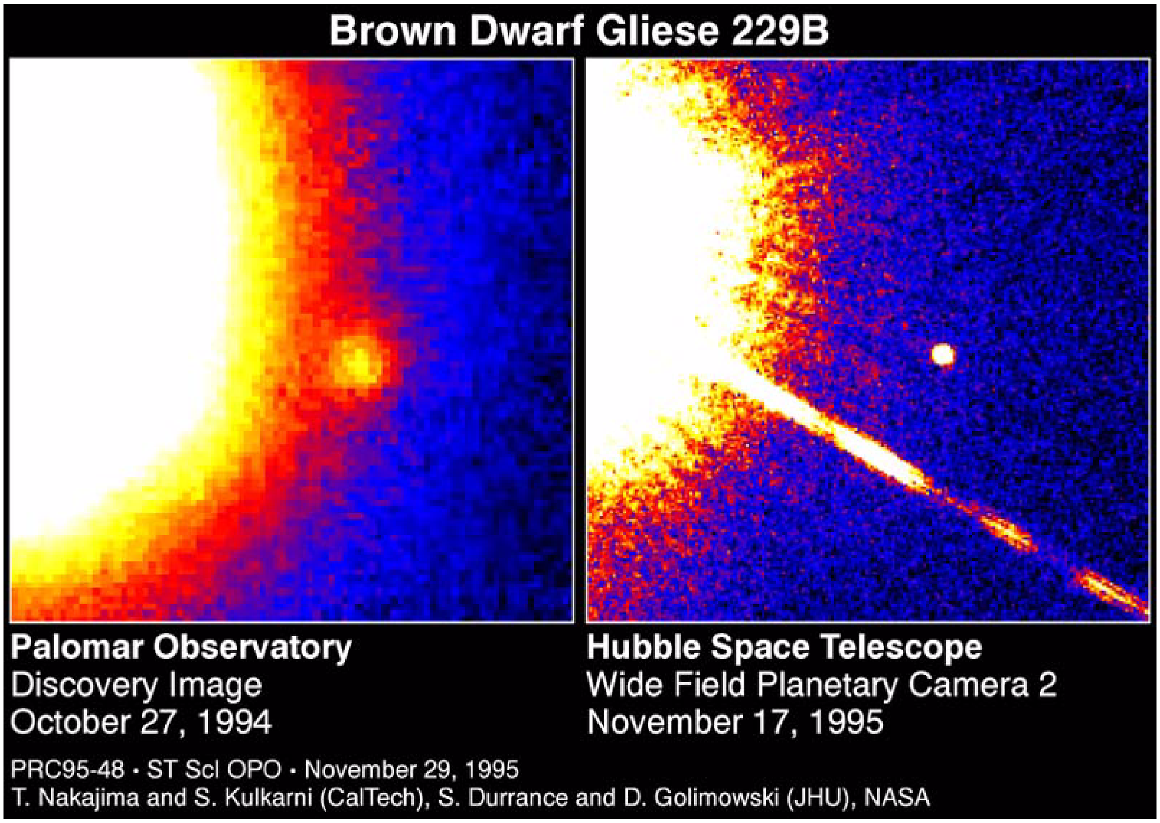

Figure 1. The brown dwarf candidate GL 229B lies 7.2 asec from A and is 10 mag fainter. In the near-infrared with high order AO and coronagraphic optics the Gemini telescopes could detect brown dwarfs and possibly gas-giant planets within a fraction of an arcsec of nearby stars.

a) Direct imaging: speckle-noise severely limits the ability of ground-based telescopes to detect faint, close companions. To limit speckles and compete with the NICMOS camera dictates an AO system giving infra-red Strehl ratios ~1. Only then would it be feasible to search for gas-giant companions between a fraction of an arc second and several arc seconds from nearby (<10 pc) stars.

   Neighboring filters on and off a methane band-head may provide the best sensitivity for this search. Modeling has demonstrated that deep methane absorption leads to wide ranging near-infrared colors for brown dwarfs as they age and cool. The blue near-infrared colors (e.g. J-K < 0) have confused a large number of past searches predicated on detection of red objects.

   A high performance coronagraph on Gemini would allow a statistically significant census of brown dwarf companions to distances of ~100 pc. Any detections of low-mass companions would provide precise astrometry which, with radial velocities, would yield masses, absolute magnitudes, and temperatures, all basic to understanding the sub-stellar mass function, and ultimately the transfer of angular momentum in star formation, and the universal proportion of matter bound up in sub-stellar companions.

b) Precise radial velocities offer the greatest sensitivity at the moment in the detection of, or setting limits to, low-mass companions. For gas-giants, program stars must be observed regularly with a precision of a few m/s at R>100,000. But there must be parallel checks for, and calibration of, intrinsic line variability, plus monitoring of chromospherically active lines, which requires R>300,000 to resolve the stellar lines.

c) Within one or two tenths of an arcsec of the parent star, planetary or Brown Dwarf companions cannot be imaged directly but their spectra may be detectable using phase sensitive spectroscopy because of their large velocity excursion and distinct spectrum. The technique demands exact registration and subtraction of the primary spectrum with "perfect" flat-field calibration. In combination with the coronagraphic AO system, spectra could be obtained of close but spatially resolved faint companions.

2. STELLAR PROPERTIES

a) Convection. There is considerable interest in comparing the level of convection in stars at various stages of evolution, metallicity, rotation, magnetic field strength, etc. with the Sun where our understanding of convection still remains imperfect. Observations covering a range of spectral types would also allow a realistic theory for the changes which depend on evolution, and differences in mass. Convective motions can be estimated from asymmetries in line bisectors derived from high resolution spectra. These would provide new insights into turbulence and dredge up rates providing important data for the interpretation of surface abundances and for understanding the importance of rotation in mixing.

b) Magnetic Fields. For stars with weak integrated magnetic fields like the Sun, Zeeman splitting cannot be resolved. On the other hand, stars with strong fields such as active M-dwarfs are generally too faint for observation with adequate spectral resolution. Thus, results to date are inconclusive. In particular the question of field strength vs. area coverage is ambiguous since it requires detailed modeling of the line profiles, particularly of many lines with different temperature sensitivities and continuum contrasts. Figure 2 illustrates the type of measurements required. Combined optical and IR Zeeman measurements would be invaluable.

c) The connection between rotation, magnetic field strength, angular momentum loss, age and chromospheric/coronal activity is poorly understood at present. For low-mass (often very active) stars, rotation rates are clearly of the order of, or less than, 1 km/sec; the lines can only be resolved with R>300,000. Further, such stars are too faint to achieve the necessary S/N for profile modeling with 4-M telescopes.

d) Basic atomic/molecular data such as the TiO laboratory line lists are frequently in error even among the well studied optical bands. Consequently, attempts to model the atmospheres of cool stars to determine metallicity will fail. In addition, better line data are required to understand how a two component model which includes starspots will alter basic parameters such as temperature and gravity, compared to one component models. Improved TiO data could be obtained from the empirical study of cool stars at very high resolution.

e) Isotopic abundances, where line splitting is very small and the isotope abundance very low, requires careful modeling of very high resolution data.

For this wide range of problems in the physics of stellar atmospheres, stellar line profiles must be resolved which, for late-type stars, demands <1 km/s or R>300,000, at optical and near-IR wavelengths.

3. *STAR-GALAXY CONNECTION*

a) The age-abundance relation in nearby galaxies. HROS observations at R=50,000 can provide detailed abundances out to 1 Mpc by classical techniques at moderate to good S/N. At larger distances, very low S/N HROS observations with good sky subtraction can yield precise radial velocities and thereby mean heavy-element abundances as shown in Figure 3. Long- and multi-slit HROS observations would be particularly suitable in crowded fields of nearby galaxies.

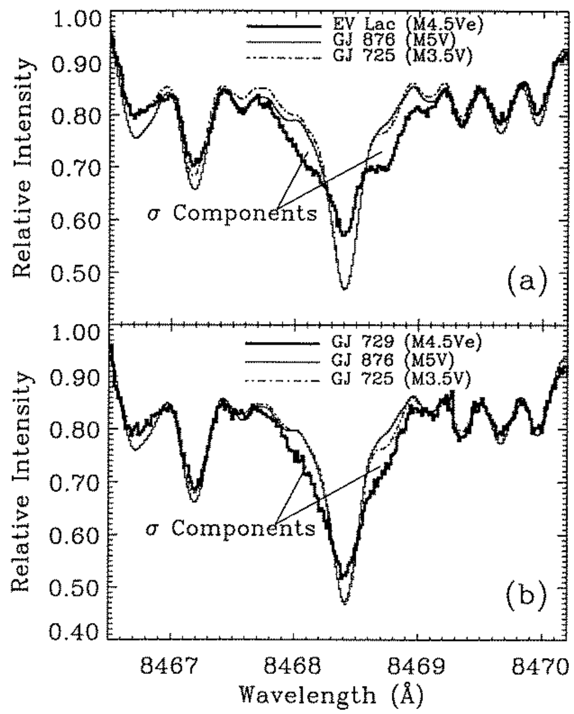

Figure 2. (a) Spectra of EV Lac and two inactive M dwarfs of similar spectral type in the wavelength interval around the Zeeman-sensitive Fe I line at 8468.4Å. (b) Similar plot for Gliese 729. For both stars, the Zeeman split (sigma) components are indicated.

b) Eclipsing spectroscopic binaries in about twenty of the nearest globular clusters (preferentially in the South) would be best observed at R=50,000 for accurate velocity curves. Such velocities would impose unique constraints on stellar evolutionary models and cluster ages.

c) Abundances and luminosities of supergiants measured at R~120,000 in the nearest galaxies will impose limitations on estimates of fundamental stellar properties in different environments, particularly the Magellanic Clouds where accurate abundances and calibrated mass-loss rates as a function of luminosity can be determined. With Gemini the technique could be extended to nearby galaxy groups.

4. *SURFACE MAPPING*

a) Accretion processes: Where there are large differential radial velocities caused by rotation or orbital motion, a source can be mapped by Doppler imaging, but there are fundamental limits on exposure time. To accurately observe a spectral feature with semi-amplitude K in a system with period P at spectral resolution R, the exposure time must be must be less than

$$t = \frac{P\left(\frac{c}{K}\right)}{2\pi R},$$

where c is the speed of light, otherwise features will be smeared by more than the spectral resolution. For example, Gemini will be essential to observe intrinsically faint black-hole binaries where the brightest is V=17 mag and there are several fainter than 20 mag, while there are others without optical counterparts to even fainter magnitudes. Many of these systems are distant and in the galactic plane where reddening makes infrared spectroscopy essential.

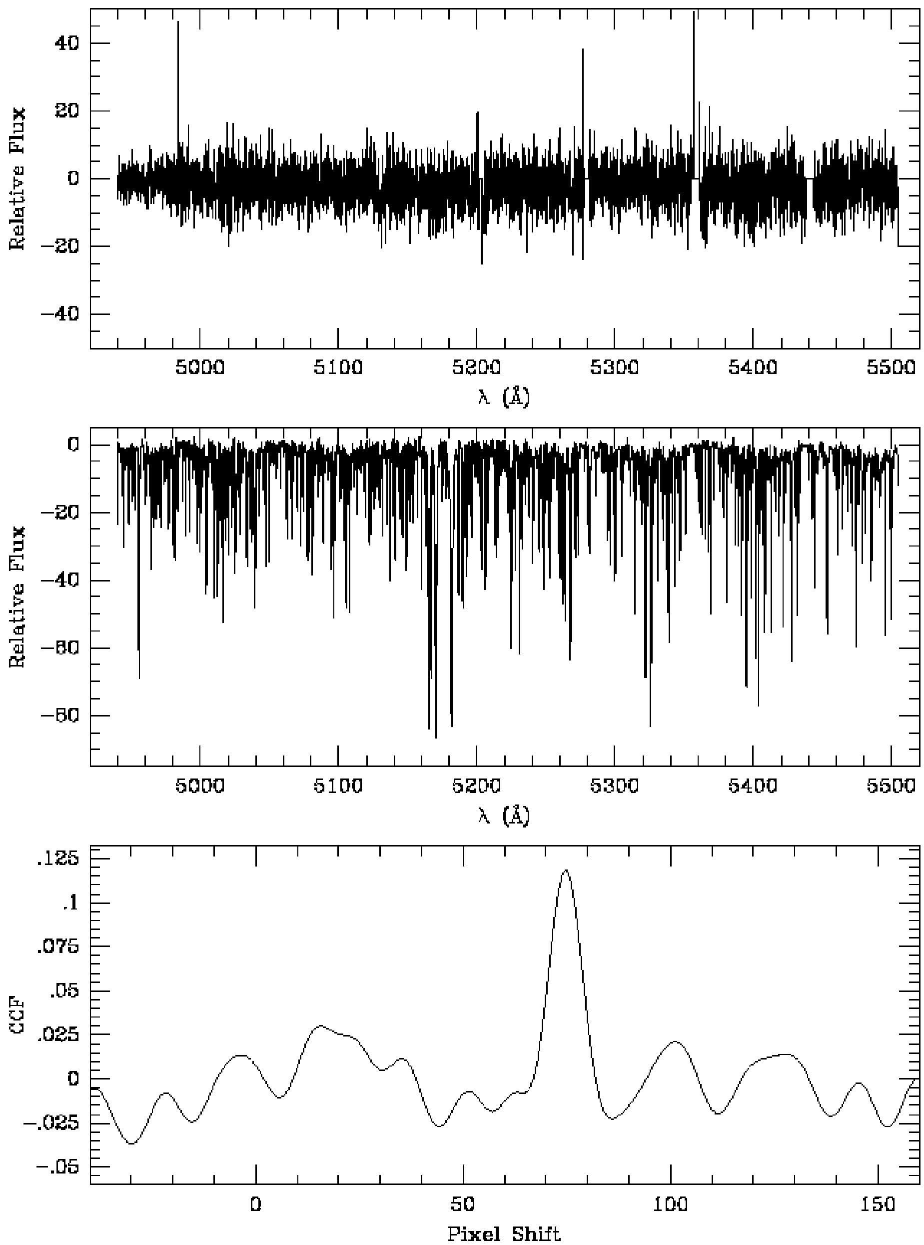

Figure 3. An example of the quality of radial velocities possible from very low S/N spectra. (top) Faint star; (middle) Local standard; (bottom) Cross-correlation function variation with pixel shift.

Flickering (0.1-1 mag on time scales of seconds to minutes) is a fundamental signature of accretion (Figure 4), yet it is the most poorly studied and badly understood phenomenon of the accretion processes. Time-resolved spectroscopy can be used to study flickering in the continuum and emission lines by measuring correlations and delays at different wavelengths. At high spectral resolution, velocity-resolved flickering can be studied across emission lines. The power spectrum of flickering may show a high-frequency break corresponding to the frequency of the innermost Keplerian orbit in the accretion disk (~10 s for a disk around a white dwarf). Spectroscopy at ~1 sec time resolution could test this hypothesis. Flickering studies have so far been restricted to Cataclysmic Variables because most low-mass X-ray binaries (LMXB) are very faint (≤18 mag). Accretion disks in LMXBs have far smaller inner disk radii than those of CVs and are subject to much stronger irradiation effects. Gemini will be particularly important in extending flickering studies to LMXB and to compare flickering behavior for different accretion environments and regimes.

Much of the optical emission in LMXB arises from reprocessing of X-rays and, for a distant observer, its arrival is delayed relative to the X-rays by light travel times of order several seconds. By analyzing simultaneous optical and X-ray light curves one can recover the range of delays present between the two (echo mapping), producing a one dimensional map that resolves the reprocessing sites on the iso-delay surfaces which are nested paraboloids around the line of sight to the X-ray source. Phase-resolved echo-mapping will generate two dimensional maps of X-ray reprocessing sites and accretion flows projected onto the binary orbit (echo tomography). The spatial resolution is set by the time resolution of the observations. This technique was recently applied to Sco X-1 by combining XTE observations with 1-sec time-resolved spectroscopy on 4-m class telescopes. A larger facility such as Gemini will be fundamental to extend echo tomography to fainter LMXBs.

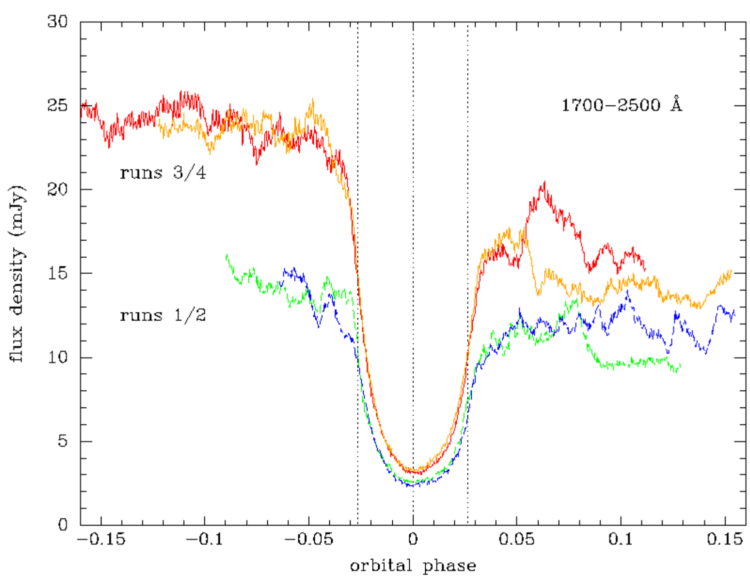

Figure 4. Examples of flickering behaviour for the eclipsing nova-like UX UMa (V~12.5, orbital period= 4.72 hr). The light curves were constructed from time-resolved spectroscopy taken with FOS/HST in August and November 1994 at a time resolution of 5 s. UX UMa was brighter in November than August, which accounts for the difference in the out of eclipse level and eclipse shape of the two data sets.

Simultaneous X-Ray observations (with AXAF or XTE) and time-resolved spectroscopy at high time-resolution (0.1-1 sec) will resolve the structure of the reprocessing sites in LMXBs at different wavelengths to ~ 0.1-1 light seconds.

b) Stellar discs and ejecta: Young and old luminous B stars (e.g. Herbig Be stars, embedded BNtype sources, classical Be stars and B[e] supergiants) tend to have circumstellar discs and/or outflows of uncertain characteristics and origin. Star formation and the formation of planetary systems are central concerns at this time, and there is particular interest in Herbig Be stars and BN-type objects, the massive counterparts of T Tauri stars. The majority of these objects are too distant for their ionized circumstellar discs to be resolved in direct images, even at the 0.1 arcsec level, but there are some exceptions and it will, in addition, be possible to use spectropolarimetry to indirectly “image” (on the scale of a few stellar radii) and to study more extended faint nebulosities where present.

Spectropolarimetry is highly 'photon-starved' since the percentages of linear polarization are typically a percent or so even for Be stars presenting nearly edge-on discs. In the past this has meant that polarimetry has mostly been applied at broad-band rather than high spectral resolution. Spectropolarimetry at a resolving power of ~5000 on 4-metre class telescopes is only feasible to a magnitude of ~12 which excludes all but a handful of embedded sources. Spectropolarimetry at echelle resolution is not a routine option anywhere, but could be implemented at little cost with Gemini/HROS.

5. Instrumentation Requirements

To undertake these programs calls for the following new instrumental capabilities as well as several upgrades to existing Gemini instrumentation (ordering in the lists is not significant):

- Adaptive Optics with coronagraphic capability on GS with equivalent performance to system on GN
- Adaptive Optics optimised for coronographic imaging and with high (>0.9) near-infrared Strehl ratios
- Near-infrared camera optimized for AO coronagraphic use
- Stable bench-mounted optical spectrograph, R=120,000, ~100nm simultaneous wavelength coverage usable with an absorption cell in 500-600 nm range, covering through the H & K lines, plus a R>300,000 mode from 380 to 1000 nm
- High resolution (~100,000) near-infrared spectrograph capable of accurate flat-field calibration. Equivalent to Phoenix with multi-order capability
- Spectrographic capability with R=20,000 to 40,000 covering the HROS/GMOS gap
- Pulse counting detectors with high quantum efficiency

6. Upgrades

HROS: circular and linear polarization analyzers
multi-slits, ~10, up to 1.5’ in length
GMOS: circular and linear polarisers

IFU with 0.1” pixels

NIRS: circular and linear polarisers
R=20,000 to 30,000
1 to 5 micron coverage on both GS and GN

TIMING: 0.1 sec spectral sampling with <0.03 s dead time
<1 ms absolute timing error on time scales of years

B. STAR FORMATION AND THE ISM

1. INTRODUCTION

Before 1980, it was known that stars form in cold, dark aggregates of matter known as molecular clouds. Studies of the stellar populations of young stars just emerging from stellar wombs had provided astronomers with a rudimentary picture of how these objects evolve prior to igniting hydrogen in their cores and becoming stable, main sequence stars. During the 1980s and 1990s, sensitive mm-wave, optical and infrared measurements from the ground, and the pioneering mid- and far-infrared observations from IRAS provided a number of profound surprises and revolutionized our understanding of the star formation process.

The Gemini telescopes will play a central role in our quest to understand stellar and planetary birth more deeply -- by virtue of their potential to provide diffraction-limited images from 1.6 microns to 20 microns, and light gathering power sufficient to permit moderate- to ultrahigh resolution infrared and optical spectroscopy of both deeply embedded and optically-revealed young stars and their circumstellar environs.

2. THE STELLAR INITIAL MASS FUNCTION

IRAS and ground-based infrared images of molecular clouds revealed that some molecular clouds seem to produce new stars quickly and with high efficiency, while others form stars more slowly and convert only a small fraction of their store of molecular material into stars. Moreover, pioneering spectroscopic and photometric observations of stellar clusters embedded within or just emerging from their natal cores suggest that while nature prefers forming low-mass stars in all environments, the details of the stellar mass function vary from region to region.

The advent of sensitive infrared array detectors and their deployment on large telescopes over the past decade has enabled astronomers to penetrate the birthplaces of stars -- molecular clouds and dense molecular cores. Observations with these arrays have revealed young stars forming under a variety of environmental conditions: in isolation, in aggregates of a few tens of stars and in rich, dense clusters of stars. Because these forming stars can be observed at ages $t \ll 1$ Myr, we can be certain that (1) they are located close to their birthplaces; and (2) are relatively isolated from other star-forming events in the cloud. Owing to these favorable circumstances, we can for the first time provide the empirical basis for answering the following fundamental questions: What is the frequency distribution of stellar masses characterizing an isolated star formation site and how does it vary from one site to the next? What initial conditions favor the production of high and low mass stars? Do high and low mass stars form at the same time within a star-forming core? Does the formation of high mass stars require special environmental conditions? Does the frequency of binary star formation differ as a function of environment?

To address these issues require observations which are in principle simple: near-infrared (JHK) photometry and moderate resolution near-infrared spectroscopy (R-2000-5000) which enable determination of stellar effective temperature, interstellar extinction and stellar luminosity. In practice, these quantities are difficult to determine, particularly in the rich, dense stellar clusters which are presently thought to dominate star formation in the Milky Way, because of (1) source confusion; (2) irregular background (owing to the combined effect of complex reflection and emission nebulosity.). To probe the initial mass function over the full range of masses -- from the hydrogen burning to the Eddington limit -- requires (1) light gathering power sufficient to penetrate optically opaque molecular cores in which extinction values may range from 20 < Av < 100 mag. and detect a representative sample of intrinsically faint stars near the hydrogen burning limit: (2) high spatial resolution in order to obtain accurate photometry and spectra in confused regions with high background.

As an example of what we night expect to do with these tools, Figure 5 shows a plot of the HR diagram constructed from OPTICAL photometry and multi-object spectroscopy (multislit in the inner regions; fibers in the outer regions) of the Orion Nebula (Trapezium) Cluster -- recently emerged from its natal core.

That the shape of the IMF may depend critically on initial and environmental conditions is

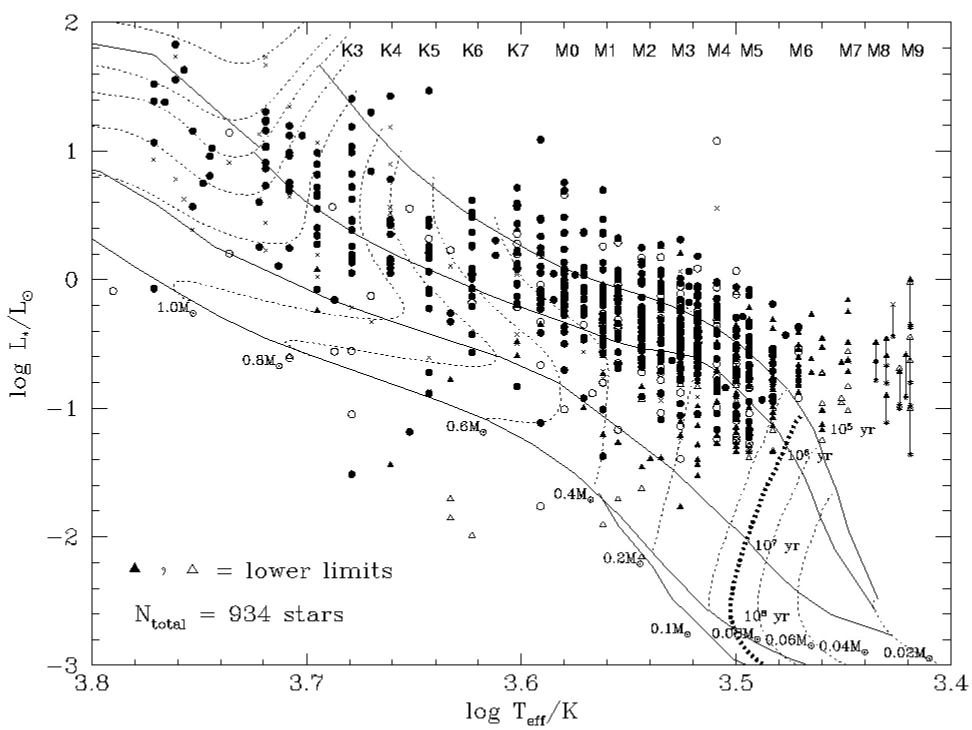

Figure 5: An HR diagram recently constructed by Hillenbrand (1997) from optical photometry and spectroscopy in the Orion Nebula Cluster; the sample comprises more than 900 stars. Superposed on this diagram are evolutionary tracks computed by D'Antona and Mazzitelli (1994).

illustrated in Figures 6 and 7.

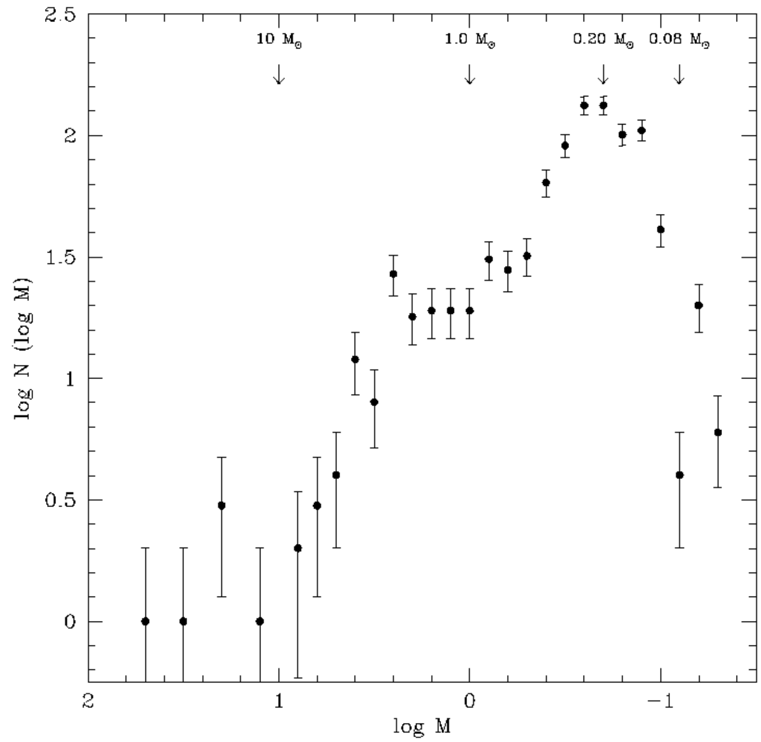

Figure 6: The frequency distribution of stellar masses derived from Figure 4. Note that the IMF in the OMC peaks at 0.2 $M_\odot$ and decreases rapidly toward lower masses. Note that the ages of most stars are t < 1 Myr ,that the distribution of derived masses peaks near 0.2 $M_\odot$ and decreases toward lower masses; and (3) that there appear to be candidate substellar mass objects which appear with a frequency of ~1 % of the total stellar population.

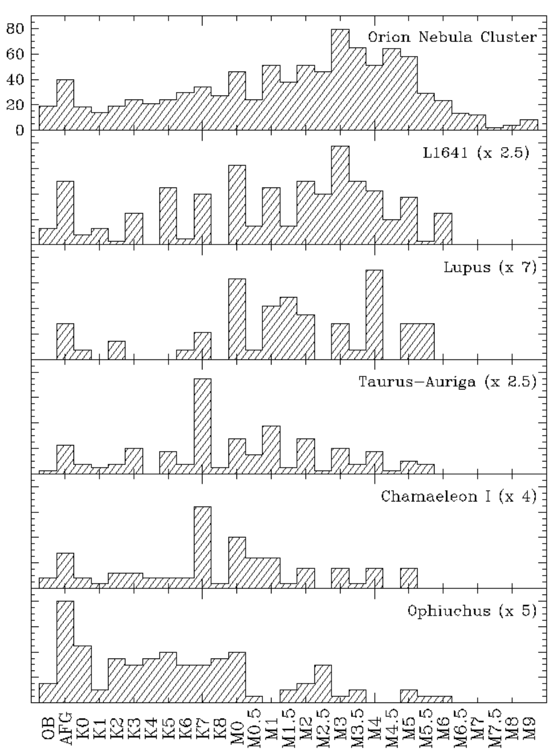

Figure 7. The frequency distribution of spectral types observed in 5 young star forming regions. Among low mass stars with ages t < 3 Myr, spectral types translate almost directly into mass (since PMS evolutionary tracks are nearly vertical in the L,Te plan). Consequently, to the extent that the observed stellar populations in all these clouds are complete, there appears to be a significant difference in the "most probable mass" formed: ~0.5 $M_\odot$ in Ophiuchus and 0.2 $M_\odot$ on the Orion Nebula cluster (Hillenbrand, 1997). Gemini's ability to probe a large number of EMBEDDED clusters out to 2 kpc should enable our gathering a statistical sample robust enough to enable relating initial/environmental conditions to emergent stellar mass functions.

3. *PHYSICAL AND CHEMICAL STATE OF MOLECULAR CLOUDS AND CORES*

The Gemini telescopes will be able to probe the physical structure and ionization state of low density molecular material, and the physical and chemical state of the molecular cores which give birth to stars and stellar clusters from moderate and high resolution near- and mid- infrared spectroscopy of molecular gas and grains spanning a wide range of sizes and compositions. How is the ionization state of a molecular cloud/core related to the efficiency of star formation and the range of stellar masses formed? What chemical paths are followed over the 10^{10} range in density characterizing the star-formation process? What gaseous and solid components form in cores and infalling envelopes and how do these relate to the material which is incorporated in forming solar systems?

The ionization fraction within a molecular cloud is critical in determining the ambipolar diffusion time and therefore the rate of formation of magnetic-flux-free molecular cores. Fundamental to determining the ionization fraction is the probability that an interstellar molecule is ionized by an encounter with a cosmic ray,which is known only very poorly (estimated to have a value of $\sim10^{-17}$/sec). Ionization of molecular hydrogen, H_2, by cosmic rays creates the electrons which support magnetic fields, and subsequent reaction of H_2+ with H_2 creates H_3+, is believed to initiate nearly all of the chains of reactions which lead to the production of complex molecules observed in dark clouds. Now that detection of H_3+ in dark clouds has been shown to be feasible, measurements of absorption lines of it, H_2, and CO (the dominant destroyer of H_3+) will allow accurate determinations of the ionization rate.

Gemini, equipped with high resolution infrared spectrographs operating in the 1 to 20 micron region will play a critical role in determining the ionization state in molecular clouds. High spectral resolving powers ($R > 100{,}000$) is imperative for detecting the weak and narrow lines of H_2 and H_3+ species in molecular clouds (characterized by temperatures $T < 30$ K). High angular resolution (~0.1") will be crucial as, e.g. for H_2, line absorption in the quiescent cloud against the pointlike embedded or background source is known in some cases to be contaminated or filled in by extended emission from fluorescent or shocked H_2 - this effect will be most easily corrected with good image quality and a narrow slit. High sensitivity will enable more deeply embedded sources to be measured, as well as multiple sources in a single cloud. The most accurate value of the ionization rate will come from statistical studies of many clouds combined with knowledge of their sizes from radio/submm mapping.

Gemini can also provide the observational basis for understanding the role of grain chemistry in clouds and determining the abundances of molecules and ices that may later be incorporated into cometary bodies. The relative abundances of molecules in the gas and solid states can be determined by similar absorption measurements of gas sampling the same line of sight. The ISO mission has provided the first extensive observations of solid state absorption features (ices of CO_2, CH_4, etc.) and measurements of gas-phase water abundance in a variety of molecular environments. Ground-based observations of molecular absorption lines in the 3-20μm range for these sources would provide far deeper understanding of the gas and solid phase chemistry which is obtained in these regions. High velocity resolution is required to improve detectivity of complex molecular species, to resolve multiple velocity/temperature components, and (in some cases) to separate telluric from interstellar lines. Examples of molecular abundances that can be measured are CH_4, C_2H_2 (both not observable in the radio), CO, H_2, HCN, NH_3, CS and OCS -- all critical to developing a quantitative understanding of the relationship between gas and solid phase chemistry.

High-resolution spectroscopy (R > 30,000) of molecular transitions in the 1-20μm range towards embedded and background sources in molecular clouds and cores are central to these studies. Near IR wavefront sensors would enable 3-20μm imaging and spectroscopy during early daylight hours.

Magnetic fields almost certainly play a central role in the star formation process. They are important in all stages from the collapse of molecular clouds to the formation and evolution of disks and envelopes. The component of the field in the plane of the sky can be traced through the effects of aligned non-spherical dust grains on the transmission, emission and/or scattering of light. The study of magnetic field directions at high (arcsec) resolution has been confined to the brightest star forming regions. For example, dichroic extinction measurements have been made with imaging polarimetry towards the diffuse unpolarized H_2 emission at 2μm in Orion and through observations of polarized emission and absorption at 17 microns in Orion. As with all polarimetric measurements, Gemini offers very substantial gains but the advantages at these infrared wavelengths are particularly large.

4. EVOLUTION OF DISKS AND ENVELOPES

Pioneering mm-line and IRAS observations of molecular clouds reveal that stellar birth is a violent process, accompanied by rapid infall of gas onto the forming star/disk system, and energetic outflows of atomic and molecular material apparently driven by highly collimated jets of hot plasma. These signatures are obscured from view at optical wavelengths by optically opaque, natal molecular cores.

Gemini will enable detailed study of the structure of YSO envelopes and the processes of infall and outflow in the immediate vicinity (distances ranging from 10 to 1000 AU) of the star/disk system from analysis of adaptively-corrected infrared images and high resolution infrared spectroscopy.

A. OUTFLOWS

The driving mechanism for outflows from young stellar objects (YSOs) has not been observationally identified. At large distances from the star, shocked collimated jets are seen, and high velocity blue-shifted absorption is observed in Hα and NaI. But the properties of the winds at their origin, and even the mass loss rates, remain uncertain and model dependent. If the winds contain a neutral molecular component, as is often believed, then spectroscopy of CO v=0-l lines would provide a means of determining the wind properties. In some high mass YSOs, high-velocity outflowing CO gas is detected in absorption, often with multiple velocity components. A systematic search has not been carried out for low-mass YSOs, largely because the far weaker continuum flux makes observations difficult. As for the case of absorption spectroscopy of YSO envelopes, the large sensitivity gains with Gemini will make such observations practical. Observations of outflows will require more modest resolutions of 20,000 - 40,000.

High spatial resolution imaging in spectral lines probing shock-ionized gas (e.g. [FeII] 1.6 microns) will enable observation of energetic jets emerging from the inner regions of accretion disks such as that associated with HH30 (Figure 8), and the shocked regions which mark the interaction between jets and/or neutral winds and circumstellar material. Such observations are critical to understanding the role played by high energy outflows in terminating infall and determining stellar masses. High angular resolution is crucial in order to probe regions 5-10 AU from the stellar surface -- where the wind/cloud interactions should be revealed.

The origin (disk or star?) and initial collimation region of [FeII] jets can be probed through long-slit spectroscopy using the technique pioneered by Solf and Böhm. (1993) to remove the underlying stellar continuum. For a YSO located in a nearby (d ~ 150 pc) star-forming region,

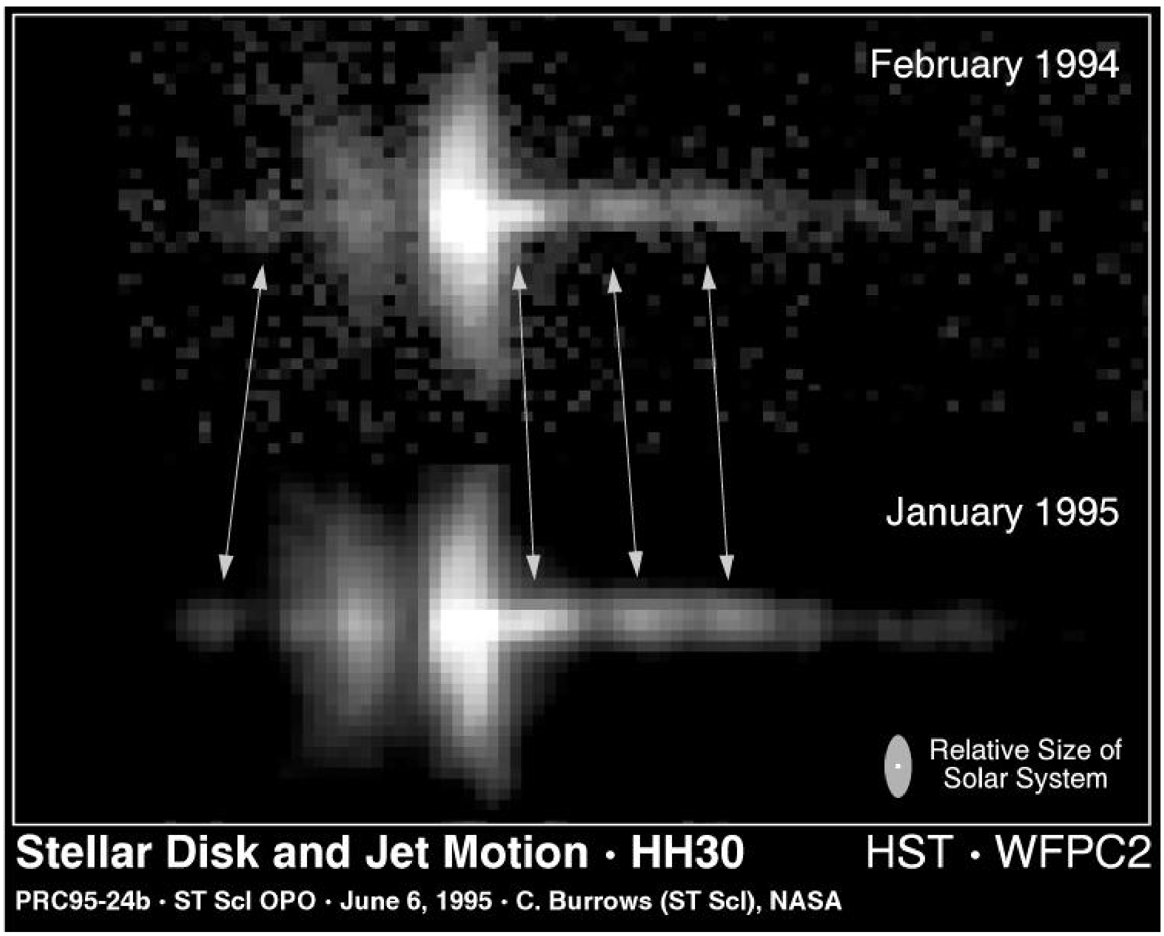

Figure 8: An HST image of the edge-on low mass star associated with the HH30 jet. The opaque circumstellar disk surrounding HH30 appears in shadow against the bright, dish-like scattered-light region (the remnant infalling envelope) seen above and below the disk. Emerging from HH30 is a highly-collimated, ionized jet, believed to be driven by processes related to accretion of material through a magnetized disk. Gemini would have four times the spatial resolution (at 2 microns) as this I-band image, and would enable large samples of objects -many younger and more deeply embedded -- to be analyzed. Critical to the success of these observations is coronagraphic and polarimetric capability: most objects lack the favorable geometry of HH30, in which the central object is obscured by a nearly edge-on disk.

the diffraction limit of Gemini is ~8 AU at 1.65 microns. By obtaining R ~ 20,000 infrared spectra at a variety of position angles, it should be possible to observe jets to within 0. 4 AU of the stellar surface.

B. Accretion

In stages before a young star is optically revealed, high-resolution spectroscopy in the near and mid-infrared provides a means of probing the temperature, density and composition close to the YSO by measurement of absorption features along the line of sight to the system. The kinematics, temperature and column density -- and thus the mass infall rate -- of gas infalling onto the star/disk system can best be addressed through high velocity resolution observations of the CO v=0-l absorption lines at 4.6 microns. Given the expected infall velocities of a few km/s, resolutions of 100,000 to 300,000 are required. The initial composition of envelope material that accretes onto circumstellar disks (and is incorporated into cometary bodies and planetesimals) can be determined through observations of other molecular species in the 3-20 micron region. The relative faintness of solar-type YSOs at these wavelengths currently makes absorption spectroscopy difficult in the near-infrared and impossible in the mid-infrared. Infrared spectrographs on a large aperture, low emissivity telescope will open up this area of research.

High spatial resolution imaging and polarimetry of scattered light regions are required to probe the infalling envelope and disk regions. The 1-5 micron region is critical to these studies with extension to shorter wavelengths for more evolved objects and into the mid-infrared for measurements of the thermal emission. Ideally, the observations would be carried out with a high precision imaging polarimeter sampling stable AO-corrected images. A near IR WFS would be valuable as these objects lie in dark clouds.

The potential of imaging with high Strehl ratios (SR > 0.5) down to wavelengths as short as 1.6 microns in principle enables imaging of circumstellar disks with resolutions of 0.05" (7.5 AU in the nearest star-forming regions; 25 AU in Orion). Observations of scattered light, particularly from the inner regions of these disks, may prove challenging even with coronagraphic rejection of light from the central YSO and polarimetric imaging (owing to the high contrast ratios expected in the case of flat, optically thick disks). However, with AO-fed coronagraphs and polarimetric capabilities, we should be able to probe basic disk parameters: size, surface density falloff at large distances. Moreover, in regions such as the Orion nebula, with sufficiently high backgrounds from nebular emission or scattered light, it should be possible to carry out IR surveys of disk sizes using the "silhouette" technique where the disks are observed in absorption against the bright nebular background. With carefully chosen samples, it should be possible to develop an empirical relationship between disk size and stellar age -- critical for constraining our understanding of disk accretion physics.

Statistical studies of near and mid-infrared excess from young stars provide a means to understand the evolution of dusty circumstellar disks at planetary formation distances of several AU. Sensitive mid-infrared imaging (5 microns to 20 microns) will enable detection of optically thin emission from post-planet-building debris disks. By carrying out such measurements for large samples of stars spanning an age range from 1 Myr to 1 Gyr, we can trace the evolution of emission arising from such disks from their origin to the end of the epoch of maximum bombardment. Gemini -- with its diffraction-limited imaging capability and low emissivity -- will be uniquely well suited to making such measurements. Low-moderate resolution spectroscopy of resolved images of disks would enable detection of features arising from the solid constituents as well (e.g. water, ammonia ices).

However, study of the gas properties of accretion disks requires other techniques. At radial distances of <10 AU, the expected temperatures are sufficient to excite rotational and vibrational transitions of molecules, making infrared spectroscopy well suited to investigate the kinematics, chemistry and evolution of gas in the inner regions of circumstellar accretion disks. Infrared molecular spectroscopy is likely to offer the only method to address various issues such as the radial temperature distribution and vertical structure of disk atmospheres, the timescale for clearing of gas in the inner disk, the formation of giant planets through kinematic detection of disk gaps, and the chemistry in protoplanetary disks. This requires sensitive spectroscopic measurements of the strengths and velocity profiles of emission/absorption lines in the near and mid-infrared (2 - 20 microns) regions. In order to resolve lines originating at distances of a few AU, resolutions of about 100,000 are necessary. Important features to observe include the fundamental transitions of CO near 4.6 microns, the rotational lines of H_2 in the mid-infrared, and various molecular trace species (e.g., H_2O, HCN, CH_4) in the 3-20 Micron region.

In the last few years, important kinematic evidence for accretion disks around both low-mass T Tauri stars and higher mass YSOs has come from high-resolution spectroscopy of CO overtone emission which reveals the velocity signature of Keplerian rotation; for example, Figure 9. In T Tauri stars, the CO traces gas of 1500-4000 K within 0.3 AU of the central star. The radial temperature and column density distribution of the hot gas can be derived from modeling the CO overtone data. The ability to study the physical properties and kinematics of gas at these radii is important since this is the region in which magnetospheric accretion, disk truncation, and the generation of YSO winds are believed to occur. Much of the high-resolution infrared spectroscopy has concentrated on the brighter T Tauri stars over limited wavelength regions. Great gains in the analysis of circumstellar gas can be made with a combination of greater sensitivity from large telescopes and increased wavelength coverage from a crossed-dispersed echelle. For example, observation and modeling of the entire CO overtone band, rather than a single bandhead, can place strong constraints on the gas properties. Current spectrographs with R>=40,000 (e.g. CSHELL, Phoenix) require 10-20 grating settings to cover this region.

The ability to study gas dynamics in such systems suggests the exciting possibility of kinematic detection of newly formed giant planets through their influence on the protoplanetary accretion disk. The data in Figure 9 required 1-2 hours at the IRTF. Both higher S/N and higher spectral resolution are required to clearly define the velocity profiles. In addition, large wavelength coverage is desirable in order to simultaneously observe a number of CO lines and thus derive gas temperatures and column densities. With the large aperture and low emissivity of the Gemini telescopes, a R ~ 100,000 spectrograph will provide about a 3 magnitude increase in sensitivity over current observations, allowing easy observation of solar mass T Tauri stars in nearby star forming regions. The large sensitivity increase will also provide the ability to measure trace species other than CO and open up the study of protoplanetary disk chemistry.

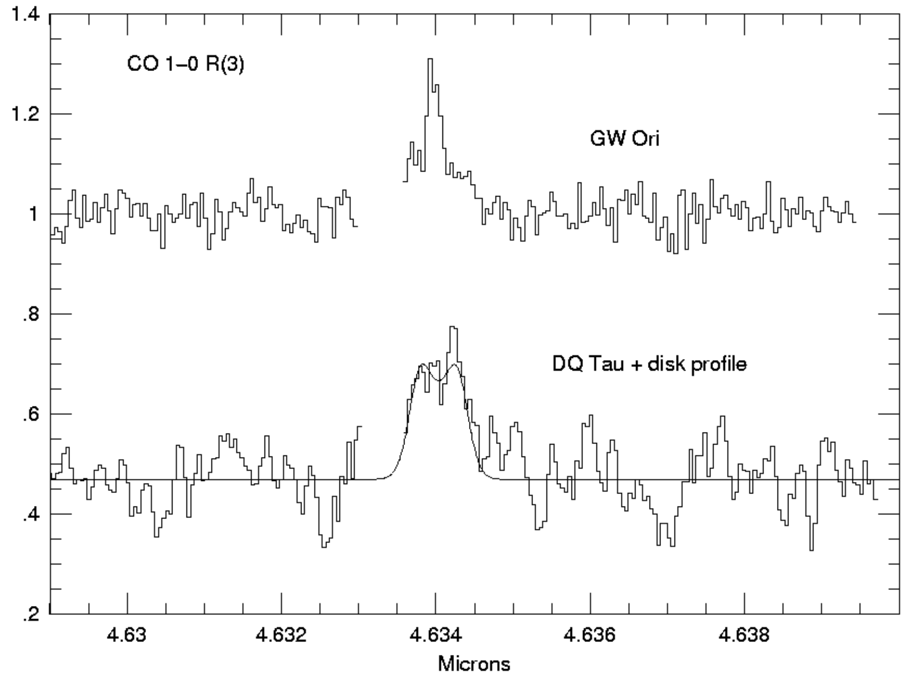

Figure 9: CO v=1-0 R(3) emission in two pre-main sequence spectroscopic binaries, obtained at the IRTF with CSHELL at a resolution of 20,000 (observations by J. Carr, R. Mathieu, and J. Najita). These systems show evidence for active accretion disks, but dynamical theory predicts the presence of tidally cleared gaps in the disks. In the case of GW Ori, an observed dip in the spectral energy distribution at mid-infra red wavelengths provides evidence for a disk gap centered at the secondary distance of 1 AU (Mathieu, Adams & Latham 1991). The fundamental CO emission lines from GW Ori indicate an average rotational temperature of 700 K. Both narrow (unresolved) and broad velocity components are observed; their velocity widths are consistent with gas at radii exterior and interior to the gap, respectively. In the case of DQ Tau, the velocity width is consistent with gas just outside of the expected gap.

5. SUBSTELLAR MASS COMPANIONS AND DEBRIS DISKS

A. SUBSTELLAR COMPANIONS

The Gemini telescopes will be able to obtain images and spectra of substellar mass, close companions of pre-Main Sequence (PMS) stars. Gemini will provide the photon-collecting power to derive accurate effective temperatures from moderate resolution spectra, and luminosities from broad-band photometry, for sub-stellar objects of luminosities as small as 10^{-5} $L_{\odot}$. With high Strehl AO providing diffraction-limited images at 1.6 microns, such objects can be imaged at separations as small as 10 AU from a companion PMS star in the nearest star-forming complexes. By locating substellar mass objects associated with PMS stars, we will 1) be observing them at their earliest evolutionary stages when they are expected to be most luminous, 2) be able to determine their approximate ages (from the ages of their PMS companions), and thereby to confront theories describing the evolution of such objects, and 3) to determine whether low mass companions are likely formed within the circumstellar disk of a parent PMS star, or via a separate fragmentation and collapse process within a common molecular core.

B. DEBRIS DISKS

The discovery by IRAS of optically thin disks associated with nearby stars (β Pic is the archetype) has led to an hypothesis which seems compelling: these disks represent "debris" created by the collision of planetesimals or cometesimals. These observations strongly suggest that a large fraction of solar-type stars are surrounded by disks of solar-system dimension and of mass comparable to or greater than the mass of material out of which our solar system is though to have formed. The subsequent UV and optical observations of transient, red-shifted absorption features appears to provide additional evidence that these disks are populated by comet-like bodies which fall into the parent star with sufficient frequency to enable their demise to be tracked from spectroscopic signatures: metallic ions released from the putative comet as it approaches the surface of the star. What are the properties of these disks and how do they relate to the conditions inferred for the early solar system?

Gemini provides the imaging quality and light gathering power to enable high Strehl ratio, adaptively-corrected coronagraphic imaging of post-planet building disks analogous to that surrounding β Pictoris (see Figure 10). For β Pic, such images would enable mapping and dust surface density and characterization of dust properties from a few to nearly 1000 AU -- providing thereby a unique "snapshot" of a system thought to be similar to the solar system during the epoch of maximum bombardment. Coronagraphic optical imaging will enable surface density and morphology observations to distances of a few AU. Low resolution near- and mid- IR spectroscopy, aimed at detecting ice, silicate and PAH like features, will allow studies of the chemical properties of the solid constituents. Ultra-high resolution spectroscopy of beta-Pic-like objects offers the possibility of detecting and characterizing cometesimals as they spiral into the

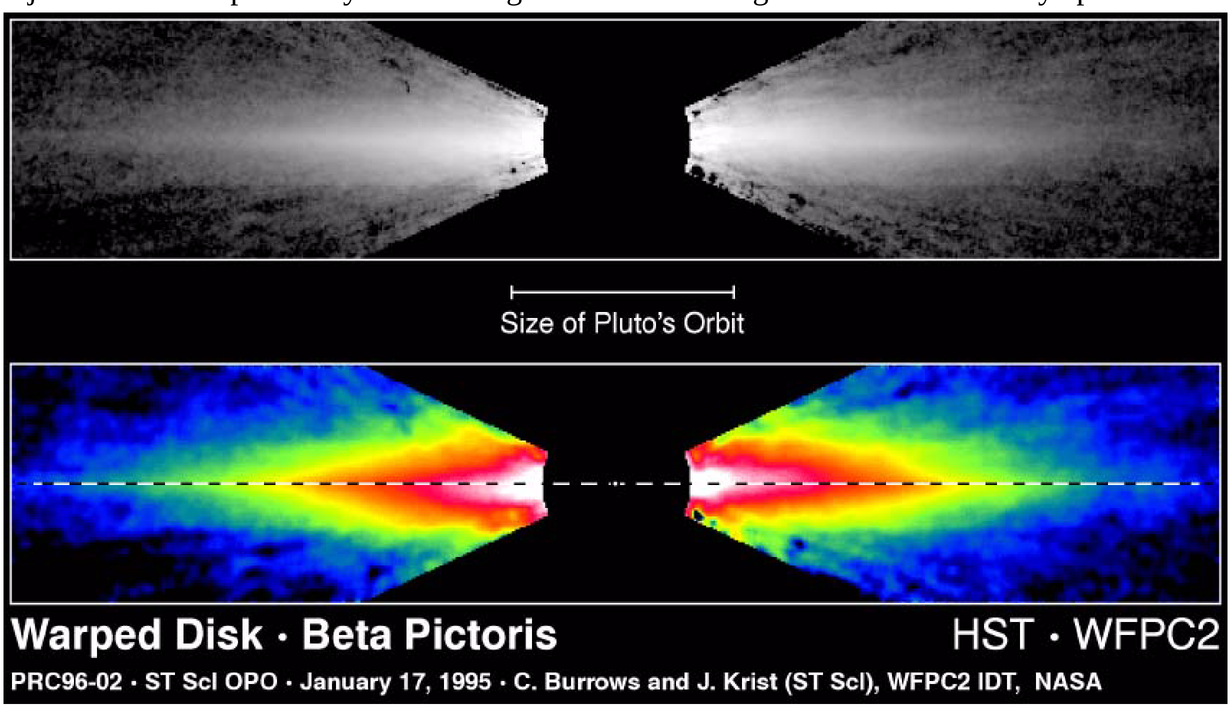

Figure 10: An HST Image of the debris disk surrounding β Pic. The disk is viewed via light scattered earthward by circumstellar dust believed produced as a result of planetesimal or cometesimal collisions in a post-planet building circumstellar disk. The occulted region near the center has a diameter of 5 arcsec, corresponding to 80 AU at β Pic. With a coronagraphic imaging capability at 2 microns, Gemini could probe the structure of the disk to within a few AU of the surface of β Pic.

central object (Figure 11). Observations at ultra-high resolution (R > 500000) which enables tracing the release of molecular and metallic species from the putative comets (NaI, CaII, CN, CH, CH+...) as these bodies approach the parent star.

These observations would provide keys to understanding the chemistry of the solar nebulae, as well as characteristics of the cometary bodies populating debris disks, both key insights into the early evolution of solar systems.

6. REQUIRED INSTRUMENTAL CAPABILITIES

To address these problems requires that the Gemini Telescopes be equipped with:

1) A laser-guide star AO system capable of delivering high Strehl ratios at 1.6 microns and longward (for studying crowded regions of forming clusters; for resolving envelopes and disks).
1) An AO optimized IR imager with coronagraphic capability (for observing high contrast ratio scenes: e.g. envelopes and superplants around forming stars).
2) Polarimetric capability (for diagnosing scattered light patterns produced by infalling envelopes and disks).
3) An IR spectrograph with R~5000 which enables multi-object spectroscopy over the isoplanatic patch at 2 microns; slits and optimally-designed integral field unit(s) are required (for obtaining spectra of embedded YSOs in crowded regions with complex, irregular background emission).
4) Very high spatial resolution (<0.1") and spectral resolution (R >> 30,000) in the 2-25 micron region. GNIRS in its highest reolution mode and/or Phoenix will be needed. Phoenix would

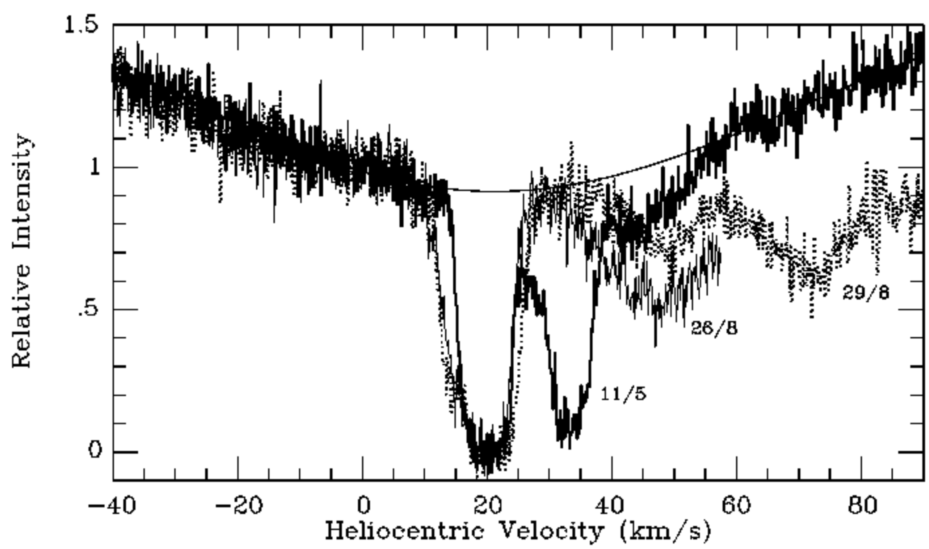

Figure 11: A set of 3 profiles of the Ca II K line in Beta Pictoris taken over a 3 month period at a resolution R=900,000 with the Ultra-High Resolution Spectrograph at the AAT; the spectra have been aligned at the stellar rest velocity (20 km/s). Note the presence of RESOLVED, broad red-shifted absorption which are attributed to the gas released as solid bodies (cometesimals?) are evaporated as they approach the central stars. Gemini, equipped with a fiber-fed high resolution spectrograph could be used to trace the evolution of these and other features over a period of weeks and to compare the derived release rates with those observed for comets in the Solar System.

provide an important near-term high resolution capability for the near-infrared. In the intermediate/long term, a high resolution 1-5 micron spectrograph with greater simultaneous wavelength coverage is highly desirable. In the mid-infrared, Michelle would provide critical capability which will allow a large number of pioneering observations in this largely unexplored wavelength region. In the long-term, resolution R >= 100,000 may be required (for determining kinematics of envelopes, disks, jets; for probing chemistry of gas and solid phase for envelopes and disks).

5) Ultra High Resolution (R>500,000) bench-mounted optical spectrograph. Initial studies would benefit from a R=120,000 mode (for studies of infalling cometary bodies in post-planet-building disks).
6) Near-IR Peripheral wavefront sensor (PWFS) would enable both imaging and spectroscopy beyond 3 microns during early daylight hours -- thus expanding the time available for many of the studies outlined above.

C. GALACTIC STRUCTURE AND NEARBY GALAXIES

1. INTRODUCTION

The Gemini Telescopes will offer a wide range of capabilities for studies of galaxies in the nearby Universe. The overarching scientific theme is exploration of energetic processes occurring on spatial scales of a few parsecs or less. Within this category we considered individual massive stars, compact star clusters extending from young "super star clusters" to the true globular clusters, and ultimately to galactic nuclei. That objects existing on such small spatial scales can have important influences on galaxies is well known, but until the advent of high angular resolution images with the Hubble Space Telescope, the richness of these small but powerful astrophysical systems was only faintly recognized; one illustration is the recent observation of NGC1068, shown in Figure 12. Now is the time for the Gemini Project to plan to undertake essential follow-on studies of high power density astrophysical objects which are best studied nearby. For nearby objects, access to both hemispheres is a major advantage in allowing us to reach key examples of various classes of galaxies.

2. NEW VIEWS OF MASSIVE STARS

A. MASS LOSS AND STELLAR EVOLUTION

The interpretation of the composite spectra of massive stars in extreme environments such as super star clusters and starburst regions requires an understanding of the astrophysics of massive star evolution as a function of metallicity. In particular, the amount of mass loss (which determines the evolution and degree of chemical enrichment) is expected to depend sensitively on metallicity.

By obtaining optical spectra of OB stars in different metallicity environments, it will be possible to determine mass loss rates by using model atmosphere techniques to fit the Hα line profiles and to parameterize mass loss as a function of metallicity. High angular resolution (~0.2") is required to locate single OB stars and a spectral resolution of 25,000 is necessary to resolve the line profiles and to remove nebular contamination.

This project requires that we extend our understanding of stellar mass loss to a wider range of conditions, and that we more effectively combine results from UV space observations with ground-based measurements. Local Group galaxies such as M31 (metallicity > solar) and M33 (steep metallicity gradient down to metallicities < SMC) are ideal candidates for this program (see Figure 13). Expected V magnitudes for normal massive stars are in the range 18-24 mag and a S/N of ~50 is required. Furthermore, for the most luminous stars this program can be observed to well beyond the Local Group with similar S/N.

B. Super Star Clusters

One of the most remarkable results of HST UV and optical imaging of star forming regions is that massive stars can form in very massive compact (~1-10 pc) "super star clusters" (SSCs) of 10^5 - 10^6 M⊙. Near and mid-infrared ground-based observations reveal that some presumably young SSCs are dust embedded (Av~10-20). These optically hidden SSCs may shelter the very youngest and most massive stars. They also give us access to a unique region of parameter space, where the density is sufficiently high that clusters only a few times smaller might be hard pressed to form individual stars and instead could yield some type of supermassive object. Similarly, young SSCs in some ways can behave as single superstars, e.g., by producing a combined stellar winds and intense radiation that could influence the evolution of individual stars within the cluster.

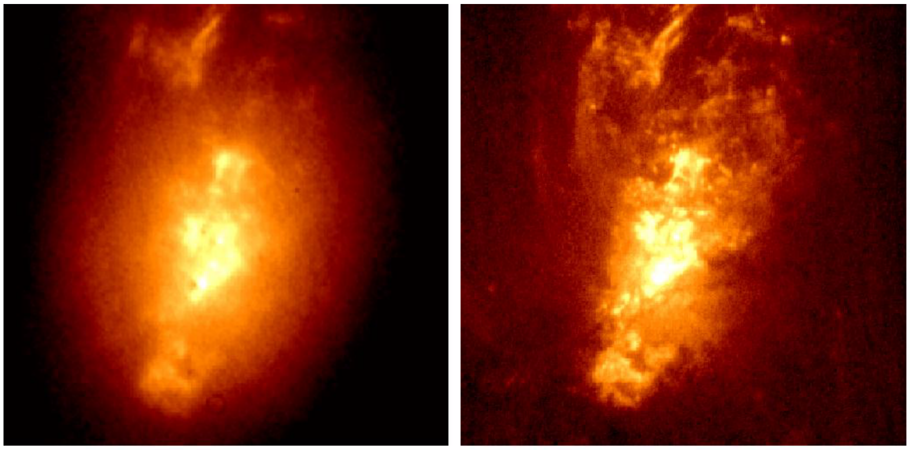

Figure 12: NGC 1068. NGC1068 is the prototype of a Seyfert Type 2 active galaxy. In active galaxies, typically the core shines with the brightness of a billion solar luminosities, and the brightness of the core fluctuates over the period of a few days implying that the energy is being released from a region only a few light-days in extent. The most likely source for this enormous amount of energy is a black-hole with a total mass of 10^8 $M_{\odot}$.

In the case of NGC1068, previous HST observations (left) have shown a number of hot gaseous clouds ionized or heated by the intense radiation from the nuclear source. A torus of opaque dust and gas orbiting the black hole confines escaping radiation to a diverging beam or "cone" of emission. The new HST observations (right) show with unprecedented clarity a much more extensive area of emission, produced by radiation from the active nucleus. An incredible wealth of new and previously unsuspected filamentary detail is also revealed in this near-nuclear gas, embedded within the diffuse emission. The knots and streamers of emission will enable the geometry of this nuclear region to be understood, and will offer new information on the nature of the clouds themselves.

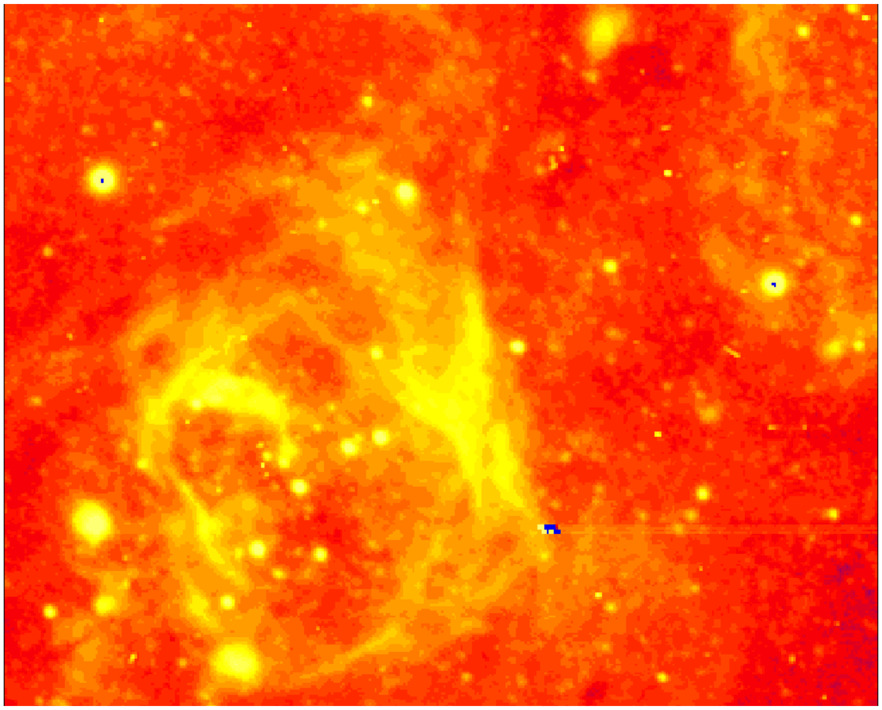

Figure 13. Gas ionized by young stars in M31 shines in the light of the Hα emission line. This HII region is typical of a moderate scale star-forming complex in the M31 "ring of fire". Locations like these provide outstanding opportunities to study properties of relatively metal-rich massive stars. This image was obtained by Jay Gallagher, Wanda Ashman, and Eric Wilcots with the 3.5-m WIYN telescope with 0.6 arcsec FWHM seeing. This false color image is about 1.2 arcmin in width.

Gemini with its unique near and mid-infrared imaging and spectroscopic capability allows the study of dust-embedded SSCs. High spatial resolution and thermal infrared imaging of SSCs will give unique views of the SSCs and surrounding interstellar medium, while near infrared spectroscopy with an IFU will provide identification of the massive winds of pre-Wolf-Rayet and Wolf-Rayet stars (e.g., broad HI, HeI, HeII and NIII emission lines in the K-band).

While evolving through their stellar wind and final supernova phases, massive stars inject large amounts of momentum, kinetic energy, and copious amounts of newly synthesized heavy elements into their surroundings. These concentrated energy flows from numerous massive stars in SSCs will have an influence extending well beyond the cluster and into the surrounding galaxy, e.g., through the production of supershells or galactic fountains.

Another consequence of SSC formation may be short-lived ($<10^7$ yr) zones of metal over-abundances (e.g. C, N, O, S, Ne) which should be observable from optical/infrared emission lines on 10-100 pc scales if these new elements are mixed into a cool ($T\sim10^4$ K) phase of the interstellar medium. Spectroscopic (0.37 - 1.00 microns with R ~ 10,000) mapping of starburst regions in nearby galaxies in the principal nebular diagnostic emission lines, together with Hα velocity maps (R ~ 30,000) with 0.2 arcsec angular resolutions should allow the input and dispersal history of enriched gases produced by evolving SSCs to be quantified.

These programs will need a combination of AO and IFUs (or multiple IFUs?) to feed GMOS giving a field 5.0 arcsec x 0.1 arcsec with proper sampling in the optical and the near IR.

3. *THE FORMATION OF GALACTIC SPHEROIDS*

A. KINEMATICS

The stellar populations and dynamical properties of nearby (i.e. within the local Supercluster) galaxies provide a fossil of record of the galaxy formation process. For example, studies of the kinematics and abundances of globular clusters have played a pivotal role in understanding the formation history of the Milky Way halo. The combination of large collecting aperture and efficient multi-object capability will allow parallel studies with Gemini to be extended out to the distance of the Fornax and Virgo clusters, where the morphological mix of galaxies and their environmental conditions are significantly different from those in the Local Group. The Virgo and Fornax clusters are also potentially key settings in which to test the possibility that galaxies may have first formed in the cores of clusters.

Most of the mass in galaxies is thought to reside in their invisible halos of dark matter. Planetary nebulae and globular clusters provide excellent tracers of the halo gravitational potential and can be studied well beyond the furthest extent of the visible stellar spheroid to measure the total mass. Detailed kinematic studies of the resolved late-type stellar population in the nearest galaxies, combined with the photometric and spectroscopic analysis discussed above, will also help to establish the still obscure relationship of the bulge, disk and halo and their role in the galaxy formation process.

B. STELLAR POPULATIONS

Studies of the old and intermediate-age stellar content, the brightest stars of which can be resolved out to distances approaching 3 Mpc, provide a direct means of measuring chemical abundances and ages. Photometric information alone (e.g. the width of the red giant branch) is not sufficient to disentangle the effects of age and metallicity and spectroscopic information is needed to lift this degeneracy. The red colors of the target stars, coupled with the effects of line blanketing at optical wavelengths among stars with [Fe/H] >/= - 0.3, make the use of data recorded at wavelengths longward of 0.8 microns especially valuable. The crowded nature of the sources makes image quality on the order of ~0.1 arcsec essential. In addition, the spatially variable background created by dust, spiral structure, and star clusters, as well as fluctuations in the unresolved background make the use of two-dimensional spectroscopic techniques essential.

Among the most challenging, but also the most scientifically lucrative, targets for detailed study are the innermost regions of galaxies. These areas are best observed at wavelengths longward of 1 micron to (1) optimize image quality, (2) probe the component that dominates the mass distribution, and (3) provide a direct comparison with the nucleus of the Milky Way, which cannot be observed at optical wavelengths. Nevertheless, when combined with optical or ultraviolet data from the HST, it will be possible, for example, to probe the structures, stellar populations, and interstellar medium in nearby galactic nuclei with unprecedented resolution. An illustration constructed by combining HST plus AO corrected ground-based imaging of the nucleus of M31 is shown in Figure 14.

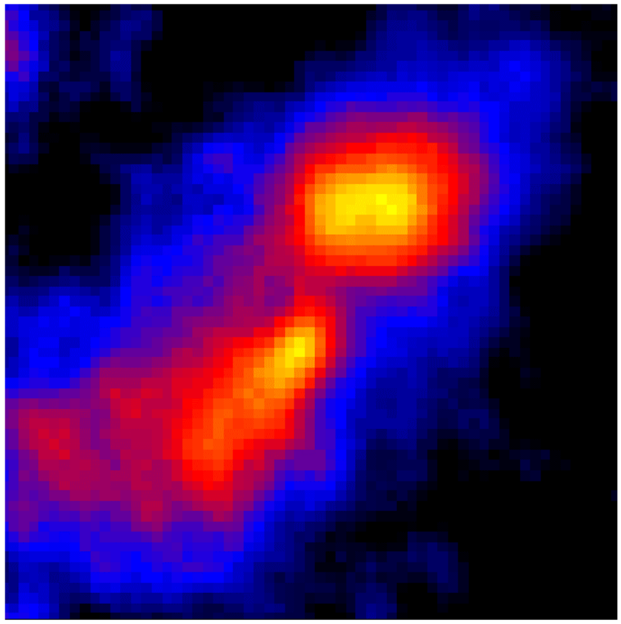

Figure 14. This map displays the color structure of an approximately 2 arcsec by 2 arcsec region around the double nucleus of M31. The two yellow regions are the M31 nuclei, and the space between them has V-K color comparable to that of the surrounding regions, indicating that this gap is likely not due to dust obscuration. This color map was produced by combining an HST WFPC2 F555W "V" band image with a comparable resolution, Strehl 0.5-0.6 K band image obtained with the Adaptive Optics Bonnette on the Canada-France-Hawaii Telescope. These data were prepared by T. Davidge.

C. STELLAR MASS FUNCTIONS

The discovery of the starburst phenomenon in galaxies has provided a new insight into the astrophysics of star formation. Tantalizing evidence has been adduced which suggests the initial mass function (IMF) in "violent" star formation episodes is rather different from the more quiescent star formation in the Solar neighborhood. It appears that the IMF is truncated at both the low mass and high mass ends. Measurements of the stellar mass function for a significantly large sample of galaxies will provide a comprehensive picture of the rate of formation, the star formation history, and the correlation of these with global galaxy parameters.

Studies of this nature are ideally suited for Gemini, as they require near-diffraction limited image quality and large light-gathering power. The diagnostic measurements, which provide information on the stellar mass function are near-and mid-infrared spectroscopy of lines of H, He, various ionic fine structure lines, and the stellar CO absorption feature.

4. NUCLEI OF GALAXIES

A. ORIGINS OF NUCLEAR STARBURSTS

Bars in galaxies are among the major galactic structures that can induce bursts of star formations by causing a redistribution of interstellar gas. To understand this global process of inducing star formation, one must determine the spatial distribution of the starburst population itself and the spatial distribution of the older stellar population that dominates the gravitational potential and of which the massive bar or oval distortion is a part. In addition, the dynamics of the older stellar population must be ascertained in order to derive a gravitational potential that is consistent with the spatial distribution of stars throughout the central starburst regions of the galaxy.

The dynamics of the ionized gas throughout the starburst region gives us a way to examine the response of gas to the gravitational potential. To some degree, these gas motions will deviate from that expected for purely gravitational forces primarily because the starburst itself will energize the ISM by its radiation pressure and mass outflows from the stars and their supemova progeny. A completely self consistent picture might be constructed which demonstrates how the gravitational perturbation (stellar bar) causes redistribution of the ISM, its clumping, and the resultant star formation.

One approach to these issues is to determine (1) the spatial distribution of the old stars by near-IR imaging, (JHK); (2) their dynamics by R = 20,000 2D spectroscopy of the 2.3 micron CO overtone (i.e. the CO-band edge's velocity); (3) the distribution of the youngest stars by mid-IR imaging; and (4) the dynamics of the gas by 2-D spectroscopy of mid-IR emission lines, particularly the [NeII] 12.8 micron emission line which is ubiquitous in intensely star-forming regions.

The bulges of some nearby spiral galaxies also display intense star-formation in a ring of "hotspots" originally described by Sersic and Pastoriza in 1968. Such galaxies are generally Hubble type SB or SAB galaxies, with the size of the ring being about 1 kpc. These features likely form when an inner Lindblad resonance stops the flow of gas towards a galactic center. Some of the nearer nuclear rings have been studied in detail, as, for example, in NGC 3310, which shows a conspicuous ring of giant HII regions. The detection of the near-IR CaII triplet in absorption on the nucleus and in one of the HII regions and the Wolf-Rayet feature at 4686Å in the biggest HII region, implies that star formation started in the ring only a few million years ago.

HST images of hot-spot galaxies further reveal the existence of large populations of super star clusters (SSCs). Observations of these SSCs, e.g. those of NGC 2903 shown in Figure 15, offer us the unique opportunity to study massive star formation processes in a dense and high-metallicity environment, which would be physically distinct from normal massive star formation in the moderate-to-low metallicity, low density OB associations in galactic disks.

Studies of these complex starburst regions require a variety of observations. Using 2D optical and near IR spectroscopy, we can determine the chemical abundances of the gas from the emission line fluxes of [OII], [OIII], [SII], [SIII], [NI], [NeIII] etc. at a spectral resolution of R=5,000. Stellar populations can be explored from the equivalent widths of near-IR absorption lines, particularly the near IR CaII triplet and Paschen series of HI, as well as markers of hotter stars such as OI or HeI lines. In addition, infrared-optical colors and the infrared CO lines can allow us to separate red giants from red supergiants. The identification of the Wolf-Rayet stars can be done from the detection of HeII and HeI emission lines in the K band and in the optical from the standard Wolf-Rayet emission lines from C, N and He. It will therefore be possible to obtain high quality maps of the distributions of massive stars in and around the "hot spot" nuclei

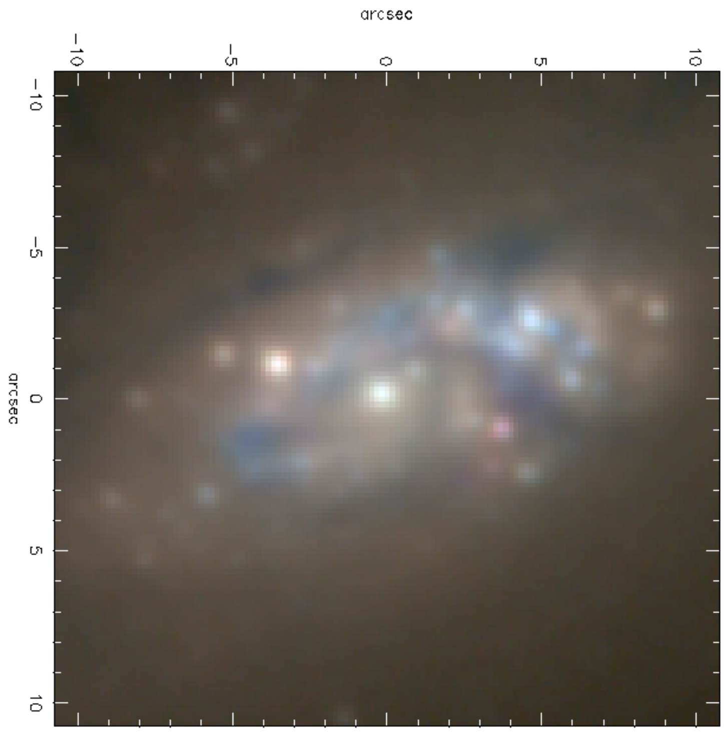

Figure 15. Infrared image of the dusty "hotspot" region surrounding the nucleus (bright central source) of the SBc spiral galaxy NGC 2903. This picture shows the colors in the JHK-bands from observations made with the Palomar Hale 5-m telescope with 0.6 arcsec FWHM seeing. Comparisons with images taken with WFPC2 on the Hubble Space Telescope with resolution comparable to that expected for Gemini in the JHK-bands demonstrate that many of the bright IR condensations around the nucleus are compact super star clusters. These types of clusters are common in starbursts and other areas of intense star formation, and can be readily investigated with large aperture, high angular resolution telescopes operating in the optical through mid-infrared spectral regions. This image was obtained by Alan Watson, Keith Matthews, and John Trauger.

and to thereby directly test models for the formation of these distinctive structures.

B. The AGN-Starburst Connection

The centers of galaxies are the sites of two of the most widely-studied phenomena in astrophysics: starbursts and AGN. These two mechanisms for energy generation power the high luminosities of several celebrated classes of galaxies - "ultra-luminous infrared" galaxies, Seyfert galaxies, "radio" galaxies, and quasars. However, despite intensive and voluminous studies over the past two decades, most of the fundamental issues and controversies remain unresolved. Gemini will be able to provide quantitatively new insights which may provide answers to several of these outstanding questions.

One such issue is the so-called "starbursts-monsters" controversy. In many galaxies where the central regions are dusty, virtually all of the luminosity detected externally is from thermal emission by dust which is heated by an underlying source. This power source could be either a burst of star formation or a "monster" AGN. High angular resolution imaging in the mid-infrared, which showed the infrared source is resolved, would strongly suggest that a starburst is the dominant energy source. Infrared spectroscopic diagnostics can also provide evidence for the presence or absence of a buried AGN and its associated H band lines emission.

There has been growing appreciation of the role of galaxy-galaxy interactions and mergers in stimulating starburst activity, and interactions are also associated with Seyfert (i.e. AGN) activity. There are also simple astrophysical arguments suggesting the starbursts and AGN are causally related and may co-exist in many galaxies, although one of the other may appear dominant. Starbursts can provide the mass flows required to "feed the monster", presumably an accreting high mass black hole, and likewise the outflows driven by an AGN could compress gas and stimulate a burst of star formations. Near- and mid-infrared spectroscopy provide a number of key diagnostics of each type of activity. Measuring the spatial extent of these two groups of diagnostics will reveal the relative contributions of AGN and starburst activity and provide clues to causal relationships. Measurements of the velocity fields to determine such flows will also illuminate this question.

C. INVESTIGATIONS OF MASSIVE BLACK HOLES IN GALAXY CENTERS

The assumption underlying current attempts to understand activity in galaxies is that massive black holes are lurking in the nuclei of most galaxies. Major research efforts working at the angular resolution limits permitted by both ground and space observatories have show that, for a handful of nearby galaxies, massive black holes are present in several instances.

The enhanced flux collection and angular resolution provided by Gemini offers the opportunity to extend the search for massive black holes to a significantly larger sample of galaxies. This will provide a more comprehensive picture of the incidence of massive black holes and permit generalizations on the implications for extra galactic astrophysics, such as what triggers AGN activity, what quenches it, the likelihood that a given galaxy as been in an AGN phase sometime in its past, etc.

The measurements required are stellar absorption line spectroscopy with a long slit or IFU at the highest angular resolution and Strehl ratio, and imaging to obtain the radial surface brightness profile.

5. RECOMMENDATIONS

With a proper combination of upgrades to Phase 1 capabilities and new Phase 2 instruments the Gemini Telescopes will support a wide spectrum of fundamental research on nearby galaxies.

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- The majority of programs in this area would benefit from enhanced angular resolution. Adaptive optics (AO) systems which are capable of at least moderate Strehl ratio imaging in the near IR are a high priority for both Gemini Telescopes. The very encouraging and impressive results from AO systems which are now operating on the CFHT and NTT have illustrated the gains in image quality that can be achieved at IR wavelengths utilizing this technique. The next phase of Gemini instruments should take advantage of AO, and we therefore place AO systems on both telescopes as a top priority. We also noted the importance of instruments to make use of the potentially significant 'low Strehl' improvements in optical wavelength image quality that may be provided by an AO system.

- High spectral resolution measurements will extend our understanding of the physics of luminous stars via slit spectroscopy or small FOV IFUs with R ~ 25,000 in the North and South. This capability will also address the related problem of the stellar content and evolution of your super star clusters, as well as stellar and emission line properties of galactic nuclei. Since all of these programs target objects with small angular sizes, operation at angular resolutions in the 1/4 arcsec range or better would be a great advantage. The spectroscopic capabilities can likely be achieved by an upgrade to the GMOS to operate at higher spectral resolution.
- Many of the most luminous astrophysical sources are deeply embedded in dust clouds, and therefore radiate their power almost exclusively in the thermal infrared. Mid-IR spectroscopic capabilities are needed in the south to properly study unique classes of embedded objects, ranging from protostars in the Magellanic Clouds to some of the best nearby examples of galactic starbursts. This objective might initially be achieved by sharing of Michelle.
- A proper exploration of compact, dusty astrophysical systems also requires the best-possible angular resolution near-IR imaging. A near IR imager is needed at both Gemini sites to produce properly sampled, moderate Strehl images when the AO system is in operation.
- Equally important is a complimentary near IR IFU/multi-slit spectroscopic capability for small fields at high angular resolutions for both sites.

A multi-object capability for HROS would allow a substantial multiplex advantage for work on specific projects in dense star fields, such as those in the Galactic bulge, Magellanic Clouds, or globular clusters.

D. FORMATION AND EVOLUTION OF GALAXIES AND COSMOLOGIES

1. INTRODUCTION

The science topics in this area fall into four broad categories (i) The Evolution of Galaxies; (ii) Studies of AGNs; (iii) Galaxies as Probes of Large Scale Structure; and (iv) Quasars and the High Z Universe. The highlights of those scientific topics are described in the following sections. The scientific topics covered are not intended to be comprehensive but rather to illustrate the type of programs judged to be particularly timely and suited for the Gemini telescopes.

2. GALAXY EVOLUTION

A. CLUSTERS OF GALAXIES EXHIBITING THE SUNYAEV-ZELDOVICH EFFECT AT Z>1

Distant clusters have traditionally been found by either optical or X-ray selection methods and have revealed very few clusters at $z > 0.5$ and none at $z > 1$. Recent results suggest that new radio techniques will revolutionize the study of clusters at $z > 1$. The first technique is to study the fields of very distant radio sources since their properties (e.g. high radio lobe pressures and Faraday depolarized emission) give strong evidence for the dense gaseous environments of rich clusters: indeed, X-ray detections and huge overdensities of red galaxies have recently revealed the first rich clusters at $z > 1$. The second technique is to find high-redshift clusters through their imprint on the cosmic microwave background -- the Sunyaev-Zeldovich (SZ) effect (Figure 16).

The first SZ detection of a massive (~10^{15} $M_{\odot}$) high-redshift (z > 1) system with no known optical or X-ray counterpart has recently been made. Since the magnitude of the SZ effect is independent of redshift this opens up the exciting possibility of finding gas-rich systems at very early cosmic epochs.

The new radio techniques should produce new samples of rich clusters at z>1, and 4-m telescopes can be used to identify galaxies which are plausible cluster members. An 8-m equipped with a multi-object near-IR spectrometer will be required to measure redshifts and velocity dispersions since the key spectral features ([OII] 3727, 4000Å break, [OIII]5007) will all be redshifted out of the optical passband. The angular sizes of these systems will be at most a few arcmin, and so well suited to the near-IR field of view achievable with the Gemini Telescopes.

These new radio techniques provide an argument for situating the best multi-object near-IR instrumentation on the Mauna Kea Gemini Telescope. The discovery of distant clusters via distant radio galaxies will be pursued most vigorously in the North since it is here that the new generation of deep low-frequency radio surveys are concentrated (6C, 7C, 8C, WENSS, NVSS, FIRST). The discovery of distant clusters via the SZ effect, both decrement work at centimeter wavelengths, and increment work at millimeter wavelengths, will also concentrate in the North. The two groups which are routinely producing SZ detections work with the Ryle Telescope in Cambridge and with the CSO on MK. Although facilities such as COBRAS/SAMBA will survey the whole sky it is important to realize that the positional accuracy required for optical-follow-up will require follow-up CMB observations, and existing (and most planned) facilities are in the

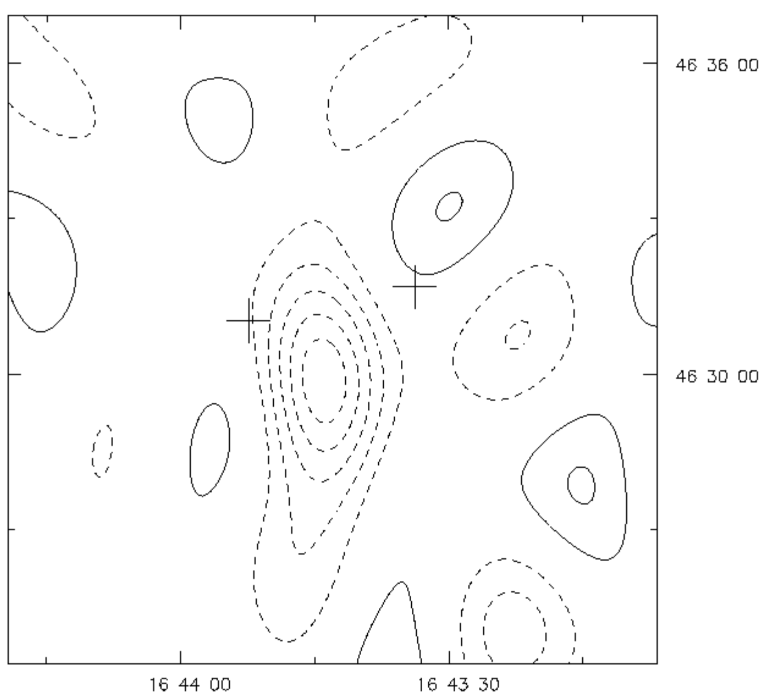

Figure 16: The Sunyaev-Zeldoivich effect detection towards 1643+46, a pair of z=3.8 quasars separated by 198 arcsec (plotted here as crosses). Contour levels are -325 to +130 μJy in steps of 65 μJy; dashed contours are negative. The implied gas mass exceeds 2 x 10^{14} $M_{\odot}$ (or a total mass above 10^{15} $M_{\odot}$ but there is as yet no corresponding detection in the X-ray waveband, or an obvious rich cluster in 4-m near-infrared images. It is hard to escape the conclusion that this is an ultramassive system at z > 1. Optical and near-infrared follow-up will only be possible with telescopes with the light grasp of Gemini.

North (Cambridge, MK, Hat Creek, the planned Arcmin-Microkelvin Imager on Tenerife).

B. Lensed Galaxies and Lenses

For most projects involving gravitational lensing, e.g., studies of high-redshift lensed galaxies, mass determinations of high-redshift (lensing) galaxies, detection and study of dark matter and measurements of the overall geometry (H_o, Ω, Λ) of the Universe, integral field spectroscopy in the visible and near-IR are required. Such observations include redshift and luminosity profile measurements of the source and lensing objects, measurements of the velocity dispersion of the lensing objects (galaxies or clusters), abundance measurements of high redshift lensed objects (taking advantage of the "cosmic telescope effect") and spectrophotometric and line profile monitoring over time scales of many months, with "target-of-opportunity" observations during events. Based on current data, there are 25 z~1 ellipticals lensing background objects per sq. deg., and there are a few dozen clusters with "giant arcs" presently known. An HST image of a “galaxy lens" from the Canada-France Redshift Survey is shown in Figure 17.

Superb, AO corrected images will be extremely advantageous to disentangle the complicated structure of objects and spectra- good images are required in the visible as well as IR since the spectral features of high z galaxies may be in the blue. The IFU should have ~0.1" pixels extending over a ~5" diameter area to simultaneously get spectra of all components or of arcs (see Figure 17). Spectral resolutions from 500 to 5000 with S/N from 5 to 30 are required, depending on the scientific goals. Visible to near-IR wavelengths may be required depending on the redshifts involved, although for many projects wavelengths from 3650Å to 1.4μm will suffice. The lensing galaxies will typically be V ~ 20-23, the arcs or images will have V ~ 21-26.

Queue scheduling will be very advantageous for time-critical observations and combined with

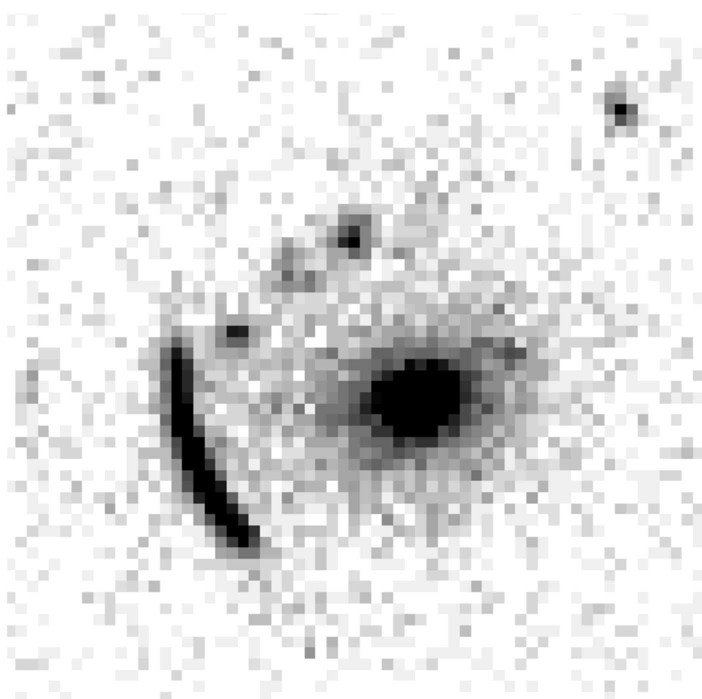

Figure 17. An example of a “galaxy lens" from the CFRS survey. This image is about 6 arcsec wide.

good images may make Gemini unbeatable. Since lenses offer one of the few ways to get quantitative observations of the dark matter (which comprises 95% of our Universe), and measurements of cosmological parameters on truly cosmological scales, this area may provide some of Gemini's most important contributions in the next decade.

C. GALAXIES VERY CLOSE TO QUASAR LINES OF SIGHT

An excess of galaxies very close to the lines of sight of QSOs with high redshift metallic and damped Lyman-alpha absorbers has been detected. The main issue now is to determine whether they are associated with the QSOs themselves or with the absorbers, thus their redshifts need to be determined. The photometric and spectroscopic properties of such objects can be used to study galaxy evolution (e.g. star formation rate histories) at very large look-back times.

If the redshifts of the objects are those of the absorbers, such information will be very valuable to determine the relationship between the absorber and the host galaxy. Moreover, it would be possible to link the information available on the gas (abundances, dynamics, etc from the absorption lines) with those of the stellar populations (ages, histories, etc from colors and spectra), building a picture of the properties of these very high redshift objects.

If the candidates are associated with the QSOs, the effect of its presence on the evolution of close galaxies could be studied, providing information of galaxy formation and evolution in dense environments at early times.

Near-infrared spectroscopy of very faint galaxies very close to bright QSOs at $1<z<4$ can be achieved with Gemini. Measurement of Balmer lines ($H\alpha$ or $H\beta$) and/or [OII] will determine redshifts and star formation rates. Integral field spectroscopy in the near infrared (JHK bands) with high spatial resolution (0.2" or better) is needed to explore lines of sight as close as possible to the QSOs (the impact parameter of damped Lyman-alpha absorbers is expected to be very small). Adaptive optics is therefore required. Spectral resolution of 5000 is needed to suppress the OH atmospheric lines post detection. A S/N of 5-10 or so in the emission lines will be enough for redshift determination and to estimate star formation rates. Color information can be obtained by integrating the spectra over wide bands.

3. THE ASTROPHYSICS OF ACTIVE GALACTIC NUCLEI

A. THE NUCLEI OF NEARBY AGNS

How does material from the host galaxy get down into the central Black Hole in Active Galactic Nuclei? A popular current (but admittedly simplistic) paradigm is that the majority of luminous galaxies contain massive (> 10^6 solar mass) black holes, and that whether or not a given galaxy possesses a active nucleus is largely determined by whether gas can be fed down to the black hole accretion disk (on scales of a parsec of less). Studies attempting to look for causes of such feeding have had mixed results, many have concentrated on the possibility that mergers or interactions provide a mechanism for driving gas to small radii whereas other have explored nonaxisymmetric morphological features. There is a weak tendency for AGN to have low luminosity companions but there are certainly many good examples of AGN with no visible interactions at all. The frequency of large scale bars, either as viewed in the optical or the near IR show no excess for AGN over 'normal' galaxies. There does however seem to be a correlation between AGN activity and strong star formation in the inner regions of galaxies, but a lot of work needs to be done to find the cause of the correlation. A particular regime that has not yet been well studied is the inner 100 pc or so. For the redshifts of interest, this corresponds to scales of a few arcsec. Can one see evidence for unusual star formation, perturbed gas motions or asymmetric stellar distributions?

High Strehl (>0.1) near IR imaging and spectroscopy in J-K bands would be required to tackle this problem. J-K colors would constrain stellar populations over central tens of parsecs (10 pc=0.1 arcsec at closest AGN). IFU spectroscopy would map out stellar and gas dynamics. We would need a sample of around 100 AGN. Such a sample is available for Natural Guide Star AO. The Veron Catalog contains galaxies with 250 AGN with total magnitudes less than 12 and north of -40 degrees, so even correcting for the fact that one can only guide on the nucleus, there are sufficient targets. This application needs adaptive optics and is helped by a coronagraphic capability, and an integral field unit with 5 arcsec FOV minimum, with sampling better than or equal to 0.1 arcsec. For this particular science case, the Natural Guide Star system would be sufficient as one can guide on nucleus. Examples of the advantages of 0."1 image quality are illustrated in Figure 18.

Ironically the problem arises in observing a comparison sample as we do not expect to be able to guide on 'normal' spiral nuclei. The comparison sample would need either a good sample of galaxies at distances around 1/10 of that of the AGN, or alternatively a Laser Guide Star system.

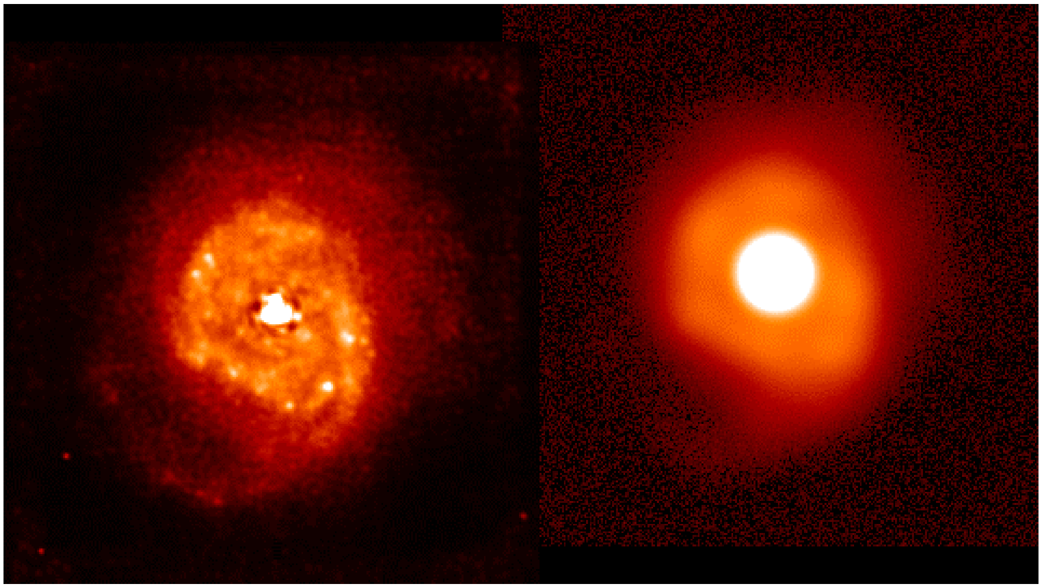

Figure 18: NGC 7469 undergoes an abnormal burst of star formation resulting from the star burst, some clumps that house clusters of red giant stars are revealed within these spiral arms. The cause of the starburst is still unknown. The left-hand image was recorded at the CFHT with the adaptive optics compensation turned "on". The right-hand image is a simulation of what can typically be achieved from a good ground-based telescope without an adaptive optics system. The angular resolution is 0. 13 arcsec in the left-hand image and 0. 7 arcsec in the right side image. The field of view is 10x10 arc seconds. The diffraction limit of the Gemini telescopes corresponds to an angular resolution of 0.045 arcsec at 1.6μm.

A spectral resolution greater than or equal to 5000 is needed to measure velocities of ~10 km/s.

B. THE GEOMETRY AND EMISSION MECHANISM OF AGNS

Imaging- and spectro-polarimetry observations can be powerful diagnostics of the emission mechanism(s) and geometry of extragalactic sources (see Figure 19). The detection of polarized radiation from a source is an indication that either synchrotron emission, scattering (by dust and/or electrons) or dichroic extinction by dust grains is occurring. The degree, wavelength dependence, variability, and spatial extent of the polarized emission allow the determination of the specific mechanism that is responsible and often allow a detailed picture of the geometry of the source to be drawn. Polarimetric observations of AGN and radio galaxies, in the restframe ultraviolet through K have already made vital contributions to our understanding of Seyfert galaxies, broad absorption line quasars, Ultra-luminous IRAS sources, and high redshift radio galaxies. For example, imaging and spectropolarimetric observations of high redshift radio galaxies have demonstrated over the past 8 years that the majority of the spatially extended UV (rest frame) radiation from these objects is produced by scattering of emission from a central AGN, rather than from stars, as originally believed. This is a major change in paradigm, driven by the existence of polarimetry observations of these sources.

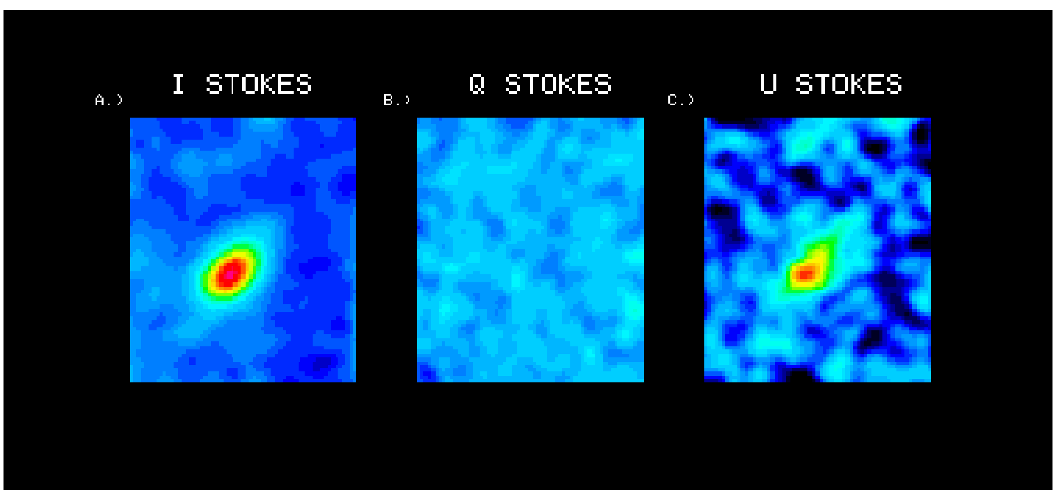

Figure 19. Images of the Stokes I(a), Q(b), and U(c) V-band fluxes from the high redshift radio galaxy (HZRG) 3C 256 (z=1.8). For all images North is up, East is to the left. The field of view of each displayed image is 15.5" by 18.13". Jannuzi et al (1995) obtained these images of the total and polarized emission during two nights of observation with the KPNO 4-m Mayall telescope. Spatially extended linearly polarized (rest frame) emission is clearly detected. The degree of polarization of the observed radiation ranges between 11 and 16% with uncertainties of order 2%. The fact that polarized emission appears only in the U Stokes image indicates that the position angle of the polarized emission is orthogonal to the major axis of the galaxy, which is itself aligned with the extended radio emission from this object. While it had been suggested that the UV continuum of 3C256 might be due to star formation or a protogalaxy based on its extremely blue spectral energy distribution and similar morphology at UV and visible wavelengths, the observed high degree of polarization and spatial extent of the polarized radiation are not consistent with such models. These data lend support to the suggestion first made by di Serego Alighieri and collaborators that the "alignment effect", the tendency for the extended UV continuum radiation and line emission from HZRGs to be aligned with the major axis of the extended radio emission is in large part due to scattering of anisotropic nuclear emission.

While polarimetry is a powerful diagnostic tool, it requires a large number of photons when applied to extragalactic targets. The gains that can be realized by coupling the Gemini telescopes to efficient polarimeters should be quite spectacular both reducing the time that many observations currently require and making other observations possible for the first time. However to fully realize the potential of polarimetry of extragalactic objects with Gemini will require both multi-wavelength polarimetry capabilities (waveplates in the near-UV, optical, and IR and analyzers for GMOS and the IR instruments) and imaging and spectropolarimetry (low to moderate spectral resolution) capabilities. The wide wavelength coverage is required to allow the comparison of the same intrinsic wavelengths of objects at different redshifts and, most critically, to allow adequate wavelength baseline on individual objects where scattering is playing a role to allow the nature of the scatters (dust or electrons) to be determined. Spectropolarimetry allows more detailed studies of sources. For example, the geometries and relative positions of the various entitling and absorbing regions of AGN can be studied in detail (e.g. broad absorption line quasars). Polarimetry capabilities for the Gemini telescopes will allow the full information content of the radiation from extragalactic sources to be extracted.

4. Galaxies as Probes of Large Scale Structure

A. Determining q_o using Supernovae

It is over 35 years since Sandage's classic paper on using the 200 inch to determine the cosmological parameters, and despite considerable efforts and a huge investment of telescope time, the value of the deceleration parameter Ω or Λ have remained elusive. The difference in observed magnitude between q_o=0.1 and q_o=0.5 increases almost linearly with redshift over the redshift range 0 to 3 amounting to 1.5 magnitudes by z=3. In recent years Supenova type Ia's, the most luminous type of SN, have been demonstrated to be very good standard candles and hence powerful tools in deriving the geometry of the Universe. The detection of SNIa's beyond z=l may give a definitive results. The expected magnitudes at z=1.5 for q_o=0.0l are R=28, I=26, J,H=24.5 mag and for q_o=0.5, R=27, I=25, J,H=23.5 mag.

At peak brightness, SN can outshine their host galaxies. If galaxies form in a hierarchical scenario from smaller building blocks, SN may be the easiest tracer of the baryonic matter at z>l since they may outshine all the galactic scale objects at high redshift. Since the surface brightness of protodisks or the stellar component of damped Lyman-alpha galaxies is likely to be low, detection of the host galaxies via their SN may be the only viable approach of detecting galaxies in an unbiased manner at high redshift. Such an approach is independent of $(1+z)^4$ surface brightness effects.

Even if the integrated magnitudes of SN are fainter than the host galaxy, since they are unresolved objects, AO will be of great benefit. Synoptic scheduling is important! to confirm them within 7 days of discovery and then follow the light curves. Searches will benefit from well sampled images at the expense of field of view.

B. Optically Selected Galaxy Clusters at z>1

Clusters of galaxies are the largest gravitationally-bound structures in the Universe, and their abundance and properties can provide strong constraints on cosmological parameters and the power spectrum of the mass fluctuations that give rise to large scale structure. The clustering properties of galaxies at small separations as a function of look-back-time have not been yet established. Studies of the change with redshift of the angular correlation function, will provide new clues for the formation and evolution of structure in the Universe. Samples of galaxy clusters have been built using optical and X-ray selection techniques up to z=1. It is now essential to determine the abundance and the dynamical properties of such objects well beyond z=1, where they can provide the strongest cosmological constraints. For example, the comparison of the faint groups of galaxies recently discovered with the Hickson compact groups of galaxies will allow studies of comparative interactions and dynamical evolution. Moreover, the study of cluster galaxies over a very large look-back-time baseline will substantially contribute to our understanding of the formation and evolution of galaxies, in particular early-types, probably the oldest galaxies in the Universe.

Observations are required in two steps. First, the clusters need to be found in objective, well defined ways, so that sizeable complete samples are built, and second, the candidate clusters have to be characterised dynamically and the evolutionary properties of their galaxies studied. Deep wide-field, multi-color red and near-infrared imaging can be used to select the cluster candidates. Given the relatively low abundance of these objects, several square degrees need to be surveyed to build large enough samples. Sensible photometric filter combinations will enhance the contrast over field galaxies: passively-evolving stellar populations formed at high redshift (such as those in early-type galaxies, abundant in clusters) would have developed substantial 4000Å breaks by z~1.5, thus red (I-J) colors would be a good discriminator at that redshift. Photometry at longer wavelengths would sample higher redshifts. Observations in multiple photometric bands will give an indication of the cluster redshifts. 4m-class telescopes with wide-field optical and near-infrared cameras are ideal for this phase.

An alternative strategy would be the targeted search for galaxies clustered around known high redshift objects (radio galaxies and QSOs). Very deep narrow band imaging targeting the [OII], [OIII] and Balmer emission lines would be needed over moderate (a few square arc-minutes) fields. The choice of wavelength windows should take advantage of the "gaps" existing in the OH sky emission to significantly reduce the background. Again 4-m telescopes would be ideal for this stage. This method can potentially reach much larger redshifts, since galaxies get bluer with z, so multicolor techniques lose sensitivity until the Lyman-break becomes accessible. It also needs a much smaller survey area. However, broad band, "blind" imaging will provide a less biased determination of the abundance of clusters, thus both strategies should be complementary.

Once the cluster candidates have been found, the role of Gemini becomes paramount. Near-infrared spectroscopy of the cluster galaxy candidates will determine galaxy redshifts and cluster velocity dispersions. Galaxy colors and spectroscopic properties will characterize the evolutionary stage of the galaxies. Spectroscopy provides a crucial diagnostic of recent star formation in galaxies. It may be possible to discriminate starburst, poststarburst, red and normal phases like E/S0s. High resolution (~5Å) spectra of galaxies in pairs, groups and clusters at different redshifts, are needed in order to measure equivalent widths and determine star formation rates of galaxies as a function of z, environment and type. Multi-object near-infrared spectroscopy over a field of view of several square arc-minutes is needed. Resolutions of 5000 or so are required to effectively subtract the OH sky lines, and a S/N of 10-15 per resolution element would be adequate for redshift and velocity dispersion determination and to obtain information on star formation rates and galaxy ages. Good image quality essential for good quality spectra. Galaxy surveys now show that the $1 < z < 3$ region is critical to our understanding of galaxy evolution (as it appears to be for QSOs), hence multi-object J band and UV spectroscopy over as large a field as possible (>5') is vital to identify and study the characteristics of the galaxy population at these redshifts.

Redshifts of galaxies with $z < 1$ can be determined from regular "CCD" spectra, but the dearth of features between 160-370nm means that near-IR spectra are essential for $z > 1$. Recent work by Steidel and others indicates that galaxies at $z > 2$ typically have high rates of star formation, so that redshifts of these galaxies may be measured in the ultraviolet (Lyot and the "OB lines" become visible at z =2 at 365nm). This means that it is only the $1 < z < 2$ region that is problematical but, fortunately, enough spectral features (370-450nm at a minimum) are available in the J band where multi-slit spectroscopy is relatively easy.

An important aspect of this work which has a bearing on the instrumentation plans is the interpretation of emission line strengths in terms of star formation rate (SFR). The role environment plays in the star formation cycle in galaxies is still unclear, and it is yet unknown whether there are links between the history of the SFR in galaxies and the evolution of the luminosity function (LF) for different galaxy types. In most cases the strongest emission line from star-forming galaxies is Hα, ([OIII] is sometimes stronger, but its interpretation in terms of SFR is highly uncertain, depending critically on assumptions about the physical conditions). Moreover Hα provides the best measurement of current SFR ([OII] is affected by excitation/metallicity: Hβ is affected by stellar absorption; UV fluxes are strongly affected by uncertainties in stellar population synthesis modeling, and reddening becomes a much more important issue at shorter wavelengths). Having access to Hα at z's as high as possible is of great importance for studies of SFR history. The GMOS upgrade would only reach z=1.5, probably missing the peak of the SFR history of the Universe (z=2?). Having access to the K band MOS would cover that all important era. Careful consideration of the resolution required for effective post-detection OH suppression will enable the best use to be made of the IR array pixels that could be made available in a GMOS upgrade.

Eventually, "cooled-spectrograph" multi-object IR spectroscopy will be required to get longer wavelength coverage on targets of particular interest, particularly when Hα moves into the K-band, ie. for z>1.8. The excellent images delivered by Gemini will give a substantial gain, especially in the K since the half-light radii of these high redshift galaxies are ~0.3".

5. QUASARS AND THE HIGH Z UNIVERSE

A. TEMPERATURE, VELOCITY & ABUNDANCE MEASUREMENTS

Measuring abundances at the highest redshifts is complicated by two things. The first is that the Lyman forest becomes so dense that heavy element lines which fall in the spectral region below the Lyman-alpha emission line in the quasar are only rarely useful, so only the longest wavelength ones provide constraints. The second is that the abundances at the highest redshifts are low so the usual low abundance species (like Zn, Cr) don't give rise to measurable lines. A good way to disentangle dust depletion and abundances is to measure FeII, which has a range of lines from 234-260nm, and the MgII doublet at 280nm. For redshifts above 2.7 the MgII lines are shifted into the infrared, and for $z>3.3$ all are. At the highest redshifts available so far, $z=4.39$, the MgII doublet is in the infrared H window and a number of the FeII lines fall in the J band.

The gas temperatures in the interstellar medium in the Galaxy are typically up to about 10,000K. The low-ionization heavy element absorption systems found in the spectra of high redshift quasars are likely to arise in galactic disks at high redshift, and if this is the case similar temperatures would be expected. For thermally broadened absorption lines the full-width-half-maximum is $21.4\ (T/10{,}000A)^{1/2}$ km/s, where T is the gas temperature and A the atomic weight of the ion doing the absorbing. Thus, for SiII at 10,000K, FWHM =5.3 km/s, and FeII FWHM is 2.9 km/s. To unscramble this sort of temperature from any turbulent motions requires us to resolve the lines at about the level of the narrower ones, so R=100,000 or more is indicated. If these temperatures can be determined they provide a direct comparison with local conditions, and constraints on the heating/cooling at high redshifts. Knowledge of the true line widths also helps firm up abundance estimates.

Keck HIRES has been used at R=50,000 on quasars, and at high S/N one might hope to see a marginal broadening of the lighter element absorption lines. However, multiple velocity component fits to what are sometimes quite complex profiles so far suggest only that the temperatures could be anything less than about 20,000K, with a significant turbulent component. Apparent turbulence may instead be unresolved velocity structure. One cannot claim that higher spectral resolution will result in the systems resolving further into component clouds -- we don't know. However, each previous significant improvement in resolution has revealed more velocity components, and we would expect this to continue until the thermal widths are reached.

An example can be based on a 6 km/s resolution Keck spectrum of the redshift z=4.11 quasar 0000-26 seen in Figure 20.

The case for spectral resolution R=500,000 for quasar absorption has a common thread with that for the R=120,000, to resolve the lines and so measure temperatures and abundances. There is an expectation that there will be cold clouds at high redshifts because stars must have formed then, and there are already indicators in one or two cases of cold material in quasar absorption systems. The presence of molecular hydrogen at redshift z=2.8 towards 0528-250 with inferred spin temperatures of 175K and higher, and the presence of 21cm absorption in some objects with widths of as little as 4km/s, point towards temperatures of a few 100K. Thus we need resolutions in the half - one million range if we wish to attempt to resolve the Fe lines in those systems. It is possible for significant amounts of material to be missed if the velocity widths are low compared with the resolution, and so the abundances inferred are lower than reality. If we are trying to trace the chemical evolution in galaxies through quasar absorption lines it is important to establish

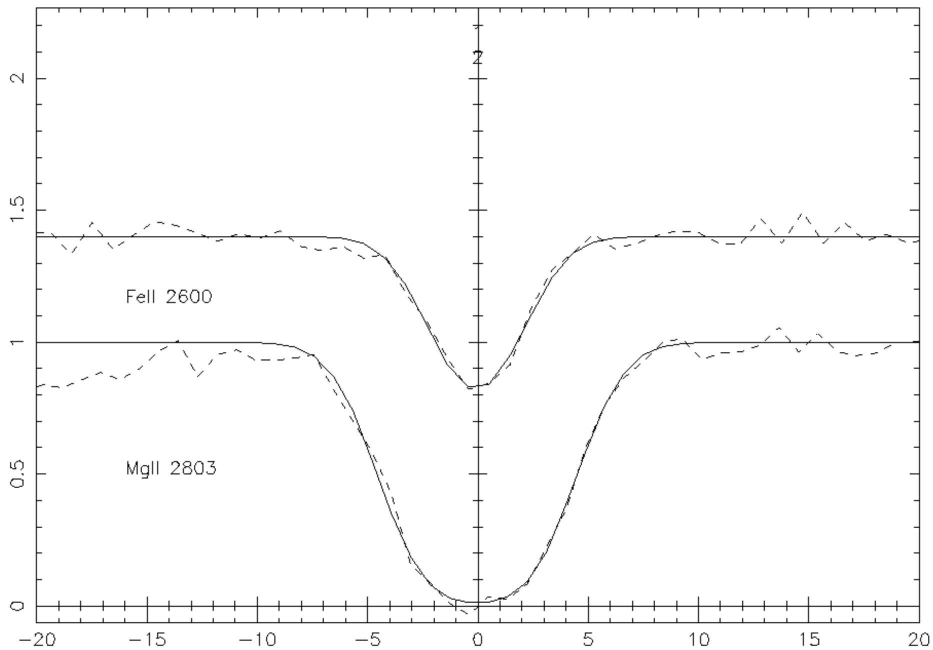

Figure 20. z=4.11 quasar, 0000-26. At redshift z=1.434 narrow FeII and MgII are seen, with simple velocity structure. From the 6 km/s data the line widths are very similar and the temperature is unknown, but less than about 20,000K. A simulation of FeII 2600 and MgII 2803 at T= 15,000K at R=120,000 and S/N 50 per resolution element shows a clear difference between the MgII (lower) and FeII (upper, offset by 0.4 units vertically) line widths (see figure). Some of this is due to the MgII beginning to saturate, but the dominant effect is the different widths because of the different atomic masses. A fit to the simulation gives a maximum turbulent velocity of less than 0.4 km/s, and a temperature error of less than 500K. Data provided by Lu and Sargent (1996).

whether or not we are being misled by low resolution spectroscopic investigations.

Figures 21 and 22 show how this can happen. The first shows a 6 km/s resolution Keck spectrum of the SiII 1808 line at redshift z=1.776 towards 1331+170 (provided by Art Wolfe), with a best fit to the data including a 300K component. In this example the column density in the narrow component is about half of the total. The second is the R=500,000 simulated spectrum at SN=25 per resolution element, along with the fitted profile. A fit to the Keck data with a broader component instead of the narrow one yields a column density for that component about a factor 15 lower.

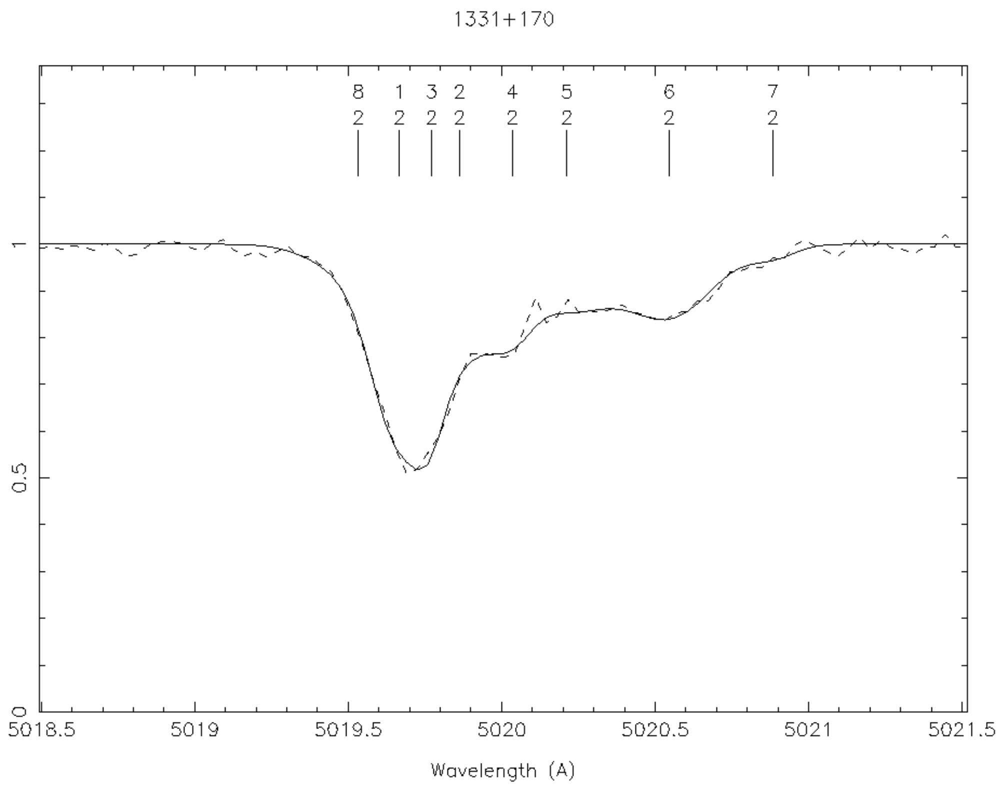

Figure 21. 6km/sec resolution KECK spectrum toward 1331+170.

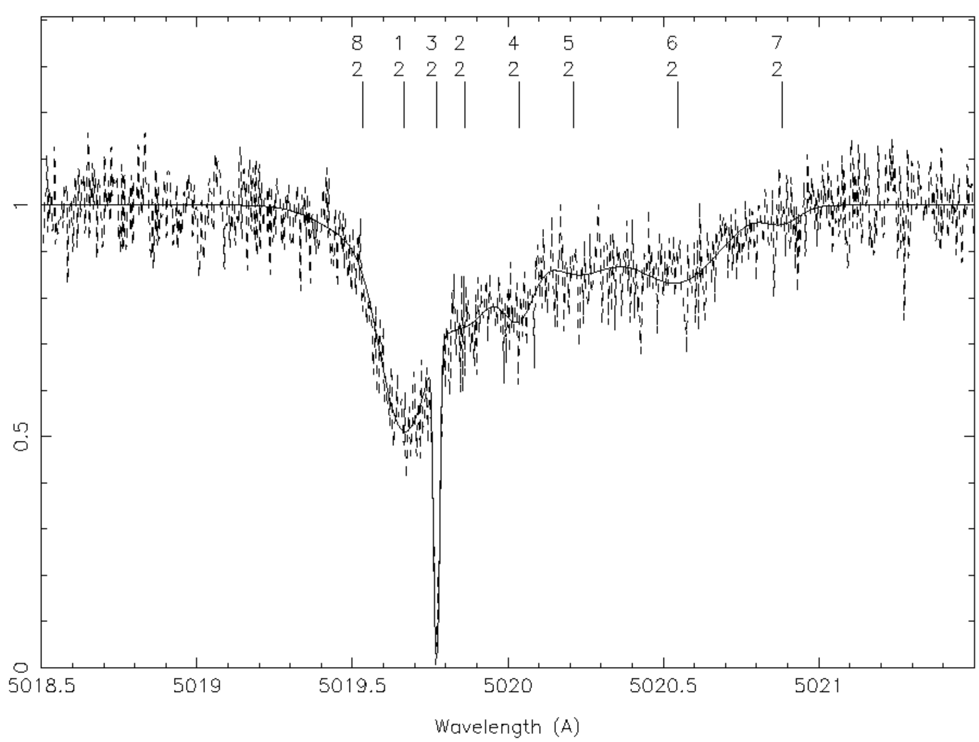

Figure 22. Simulated R=500,000 spectrum toward 1331+170.

6. RECOMMENDATIONS

A. NEW CAPABILITIES

a) The highest priority capability is the provision of multi-object spectroscopy (MOS) at the JHK wavelengths. The need is for MOS over the full IR field of the telescope. The spectrograph would require R=5000 to enable the OH lines to be effectively suppressed post detection (although the exact resolution needed for effective suppression may be lower). The provision of an IFU was seen as essential, more than one IFU may be required to work in all three bands. An IFU with a FOV of 5-10" and 0.05-0.1" sampling was identified as being required for studies in crowded regions and of galactic nuclei. This capability supports a wide range of scientific applications, many of which follow the themes of GMOS science to higher redshift or probe dusty environments. For example: studies of lenses and lensed objects, AGN and normal galaxy nuclei, the properties of groups and clusters of galaxies as f(z) and the study of galaxies close to QSO lines of sight. It was felt that this instrument would have wide applicability and get substantial use at both sites and is therefore required in both hemispheres. The scientific link with deep radio surveys suggest that the initial implementation should be in the north.

b) Laser Guide Stars. Superb Adaptive Optics corrected images in the near IR bands and extending into the visible, and feeding both imagers and spectrographs, will be required to disentangle the complicated structure of objects and spectra of lensed extragalactic systems and galaxies very close to Quasar lines-of sight. Moderate Strehl ratios >0.3 over most of the sky is needed; a Laser Beacon system will be required to achieve this sky coverage.

AO corrected Imaging- and spectroscopic observations will be powerful diagnostics of the emission mechanism(s) and geometry of Active Galactic Nuclei. Good AO correction is required in the J-K bands. A Natural Guide star system will be adequate for the brighter AGN's, while an LBS will be required for the fainter objects and for the comparison sample of 'normal' galactic nuclei.

c) High resolution spectroscopy in the near infrared (JHK). For investigating the interstellar medium abundances in the earliest galaxies, HROS capabilities (R=50,000 and R=120,000) in the infrared are desirable.

Such a capability would also provide a uniform way of investigating FeII/MgII velocity structure, ratio and strength evolution over a wide redshift range, since the MgII lines are accessible from the ground with HROS for z>0.15, and Fell starts to become available at z=3.25.

Ultimately this capability will be needed over a much larger wavelength range than can be provided simultaneously by Phoenix however the group felt that Phoenix would offer an adequate capability for this work in the short term and supported the projects efforts to provide this. The provision of a new instrument for this work that would provide extended wavelength coverage in a single exposure should appear later in the program.

B. UPGRADES

a) AO Polarimetric analyzers for both GMOS's and for the IR instruments. This capability was widely supported as a technique for studying the geometry and emission mechanism in AGNs. This capability should be provided as soon as possible.

b) The R=120,000 camera for HROS is required to disentangle the effects of temperature and velocity in absorbing clouds along the line of sight to quasars.

c) Grating Improvements: There is a broad need to obtain identification spectra in both the optical and IR of VERY FAINT sources that have been discovered in either very deep images (e.g. the Hubble Deep Field) or identified at other wavelengths (e.g. ROSAT, x-ray, or FIRST, radio, surveys). GMOS and the other instruments planned for Gemini are very efficient, however the largest single source of loss in GMOS is the grating efficiency (at 65-70%). Possible high efficiency innovative grating developments would push the capabilities of GMOS to the faintest possible limits.

d) Upgrade GMOS to work in J and part of H. This was considered as a way of providing near term capability for near infrared, full field, MOS, which was the group's highest priority capability overall. Many of the science applications can be addressed with a J-band IFU on GMOS. A significant constraint on the upgrade path is the requirement to retain GMOS optical spectroscopy and imaging at both sites. A number of important and detailed technical questions, such as the exact cut-off wavelength in H (where the thermal background makes uncooled masks uncompetitive) needs to be evaluated before an assessment of the utility of the GMOS upgrade can be assessed compared to a new near IR MOS instrument. The relative timing of the two such developments was identified as a strong scientific driver; if a GMOS upgrade can provide Gemini with a IR MOS capability before it is available at other observatories the group would put this at a very high priority.

III. RECOMMENDED ELEMENTS OF THE ON-GOING INSTRUMENTATION PROGRAM

The scientific perspectives outlined above identified instrumentation capabilities for the ongoing instrumentation program. The rough mapping of science programs onto instrumentation capability is summarized in Tables 2 and 3. Table 2 attempts to summarize new instrumentation capabilities as derived from the scientific discussions, while Table 3 summarizes the capabilities that can be satisfied, at least in the near term, by upgrades to Phase I instrumentation or by the shared use of Michelle or Phoenix. The very strong overlap apparent in Tables 2 and 3 among the different scientific areas leads naturally to a broad consensus for the direction of the ongoing instrumentation program. The broad perspectives concerning the directions for future instrumentation for the Gemini telescopes:

Table 2 - Science Drivers for New Instrumentation Capabilities

SCIENTIFIC PROGRAMS	A&G Polarization Modulator		AOS		IR Imager/ Coronagraph	IR MOS						Hi Stab Lab Spec		
			LGS	NGS		>3' FOV		AO		IFU				
	0.4 - 1μm	1 - 5μm	>0.4	>0.9		30K	5K	30k	5k	30k	5k	150k	300k	500k
A. Stars & Planetary System														
--BD & giant planets				X	X					X	X	X	X	
--physics of nearby stars							X		X				X	
--stars in other galaxies			X		X		X		X		X			
--surface structure/active processes	X	X	X										X	
B. Star Formation & ISM														
--initial mass function			X		X				X					
--molecular clouds & cores														
--disks & envelopes		X	X		X					X				
--young substellar objects			X		X						X	X		X
C. Galactic Structure & Nearby Galaxies														
--massive stars			X						X		X	X		
--star clusters			X		X				X		X			
--galactic nuclei			X		X				X		X			
D. Formation & Evolution of Galaxies/Cosmology														
--evolution of galaxies			X				X		X		X			
--studies of AGN's	X	X	X		X				X		X			
--galaxies probes of HiZ structure			X				X		X					
--QSO's as probes of HiZ universe			X		X						X			X

Table 3 - Science Drivers for Upgrades to Phase I Instruments

	UPGRADES							SHARED INSTRUMENTS	
SCIENTIFIC	**HROS**	**MK AOS**	**GMOS**			**NIRS**		**MICHELLE**	**PHOENIX**
PROGRAMS	**R=120k**	**LB**	**0.1" IFU**	**1-1.5 µm**	**R=25k**	**IFU**	**R~25k**		
A. Stars & Planetary System									
--Brown Dwarfs & giant Planets	X					X		X	X
--physics of stars	X								X
--stars in other galaxies	X				X		X		X
--active stars								X	X
B. Star Formation									
--initial mass function		X							
--molecular clouds & cores							X	X	X
--disks & envelopes		X				X	X	X	X
--young substellar objects		X	X						
C. Galactic Structure									
& Nearby Galaxies									
--massive stars	X								X
--star clusters	X	X	X		X	X	X	X	
--galactic nuclei	X	X	X		X	X	X	X	
D. Formation & Evolution									
of Galaxies/Cosmology									
--evolution of galaxies		X	X	X	X				
--AGN's		X	X	X					
--galaxies as probes of structure		X	X	X	X				
--QSO's & Hi-Z universe	X	X	X	X	X			X	X

1) The ability to obtain near diffraction-limited imaging capabilities at near IR wavelengths, on both Gemini telescopes, through implementation of adaptive optics (AO) is of paramount importance in effectively addressing key scientific issues over the whole range of topics outlined in Section II. Recent advances in the demonstration of the scientific utility of AO and of laser beacon capabilities have highlighted the timeliness of this capability. Efforts to maximize sky coverage by the implementation of Laser Beacon AO technology are of very high priority (see Figure 23). The Gemini telescopes will complement and extend HST performance at Near-IR wavelengths, and will provide spatial and spectral resolution capabilities in the 2-20µm atmospheric windows far superior to the capabilities of ISO and those planned for SIRTF. In the 10 and 20µm windows, the Gemini telescopes will provide diffraction-limited images even without AO.

2) Technological advances in Near-IR arrays enable new innovative instrumentation capabilities that will fully exploit the images delivered by the Gemini telescopes at wavelengths longward of one micron and allow new attacks on key scientific issues throughout the science program; e.g. detailed studies of star formation processes, and extending many extragalactic studies to higher redshift. The development of high performance 1kx1k and 2kx2k Near IR arrays open new possibilities for addressing many of the key scientific issues using Integral-field, multislit, and multi object spectroscopic capabilities at Near IR wavelengths.

   Superconducting tunnel junctions (STJs) may offer the possibility of very high efficiency low resolution spectroscopy from the atmospheric cutoff in the UV to near IR wavelengths. Pulse

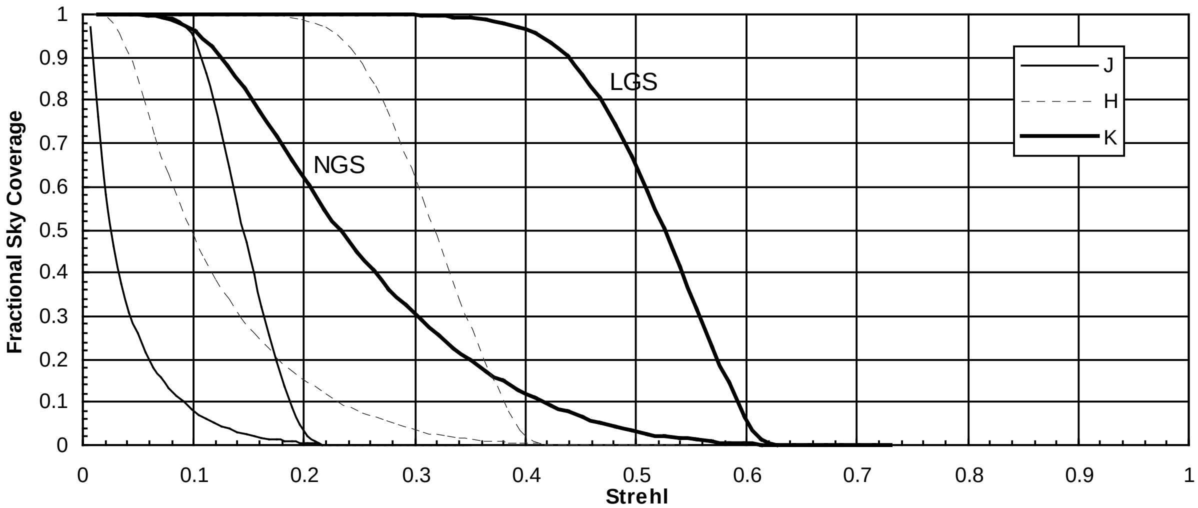

Figure 23. Model comparison of NGS and LGS AO systems at J, H, and K. Input parameters include zenith pointing, average seeing, altitude conjugation, no wind, and a 30° galactic latitude and losses for telescope and the near-infrared imager in its 0. 02" plate scale mode. The NGS model closely resembles the baseline system currently under development for Mauna Kea. All NGS/LGS model parameters were held the same except the LGS used a Near IR tip/tilt sensor and the NGS model used the facility WFS, working in the 0. 4-0.8µm band, to sense tip/tilt.

counting detectors with high quantum efficiency still offer significant advantages in extreme photon-starved problems.

High efficiency innovative grating developments would push the capabilities of the Gemini spectrographs to the faintest possible limits and immersed grating technology could extend the spectral resolution capabilities of GMOS and NIRS.

3) In general, although important scientific applications for wider fields than provided by Gemini's f/16 focus were identified, it is recommended that Gemini should concentrate its instrument development effort on exploiting the baseline f/16 focus. Innovative means for providing the Gemini communities access to wide field capabilities on other large telescopes, such as sharing time with other large telescope facilities, should also be explored.

The study of flickering phenomena in accretion processes requires 0.1 sec spectral sampling with <0.03 s dead time <1 ms absolute timing error on time scales of years.

A more detailed description of the recommended directions for the ongoing instrumentation program is presented in the following sections. The recommendations for new instrumentation capability are discussed first, followed by upgrades to the Phase I instruments and, finally, shared instrumentation.

A. RECOMMENDED NEW INSTRUMENTATION CAPABILITIES

Table 4 summarizes the recommended new instrumentation capabilities and guidelines for performance requirements where appropriate.

Table 4 - Recommended New Instrumentation Capabilities						
Instrument Capability	**Site**	**Wavelength Range**	**Pixel Scale**	**FOV/Slit Length**	**Spectral Resolution**	**Other Capabilities**
NGS/LGS AOS	CP	1 - 2.5 µm 0.5 - 5 µm (goal)	SR > MK NGS AOS SR> 0.9 @ 1.6 µm (goal)	2'		feed to all inst ports conjugate to optimum altitude?
Small Field Optimized Near IR Imager	CP	0.8 - 5.5 µm	0.01" 0.02" 0.05"	~10"x10"		Coronagraph
IR MOS	CP MK/CP	1 - 2.5 µm 1 - 2.5 µm 1 - 2.5 µm	0.1" slits 0.05" 0.15"	~30" dia 5 - 10" >3', 9' (goal)	~5 - 8k ~5 - 8k ~5 - 8k	IFU / coronagraph multi slits multi object
A&G Polarization Modulator	MK/CP	0.4? - 5 µm		TBD		Remote Modulator deployment linear & circular
Hi Stability Lab Spectrograph	CP	0.5-0.7 µm 0.38-1.0µm	TBD	≤1'	120k 300k 500k	absorption cell

1. Natural Guide star (NGS)/Laser Beacon (LB) AO System at Cerro Pachon

The Gemini-S facility will be a superb facility for Adaptive Optics observations. A combined NGS and laser beacon AO system will extend and complement the AO capabilities on Gemini North. The combination of AO implementation at Gemini-S, together with the Laser beacon upgrade and the Phase I NGS AOS for Gemini-N will constitute a powerful integrated AO program for the Gemini telescopes. These capabilities combined with the recommended optimized small field Near IR imager and near IR spectroscopic capabilities will enable new scientific programs throughout the whole scope of scientific issues addressed by the workshop.

When combined with a Near-IR WFS for tip/tilt and fast focus correction, a Laser Beacon AO system would enable high performance AO imaging and spectroscopic observations in dark clouds - one of Gemini's key science drivers. Adaptive Optics optimized for coronagraphic imaging and with high (>0.9) near-infrared Strehl ratios, is a key capability in the search for giant planets around nearby stars.

The Gemini-south site has not been adequately characterized regarding AO parameters such as $C_n^2(h)$ and wind velocity profiles. Specific site measurements, e.g. SCIDAR measurements aimed at characterizing these parameters, should therefore be initiated as soon as possible.

2. IR Imager at Cerro Pachon

1-5µm imaging will be a "workhorse" capability for Gemini, exploiting the superb image quality and extremely low emissivity of the telescopes. Furthermore, Gemini will be a unique platform for coronagraphic observations because of the exceptionally smooth primary mirror, rigorous mirror cleaning program, thin secondary vanes, etc. A small field imager with pixel scales and optics designed to exploit AO performance and t/t corrected images with optimized near-IR coronagraphic imaging capability will address a very wide range of science topics.

3. *IR MOS, 1-2.5μm at Cerro Pachon*

The continued development of large format Near-IR arrays (2kx2k HgCdTe arrays for the 1-2.5μm regime are under development and possibly buttable InSb arrays) provides an opportunity for three powerful new capabilities in the area of 1-2.5μm Multi-Object spectroscopy.

- *5"-10" IFU with coronagraph; R = 5000-8000, R ~ 30,000*

One key Near-IR MOS mode would be a high spatial resolution IFU that adequately samples AO corrected images, possibly equipped with coronagraphic capability. More than one IFU may be required to work in the three Near IR bands. An IFU with a FOV of 5-10" and 0.05-0.1" sampling was identified as being required for studies in crowded regions and of galactic nuclei.

- *Multi-slit MOS within isoplanatic patch R = 5000-8000, R ~ 30,000*

A second mode would be the capability to select numerous objects for spectroscopic study within a FOV consistent with AO isoplanatic patch size, about 20-30" dia. Many applications for this type of MOS will be in crowded complex fields, so multi-slits or even multi-2D capability would be required.

- *MOS within FOV >= 5' R = 5000-8000*

The third key capability is simultaneous spectroscopy of objects over a FOV comparable to that of GMOS at the f/16 focus, particularly for studies of the distant universe. It is noted that over a 9' FOV the telescope emissivity increases by only 1%, making a truly wide field instrument possible.

For many science applications the spectral resolution needs to be optimized to work between the OH airglow lines, between 5000 and 8000, while abundance measurements will require spectral resolutions around 30,000. This capability supports a range of scientific applications, many of which follow the themes of GMOS science to higher redshift or probe dusty environments.

The cryogenic MOS slit masks or other object selection mechanism would have to be changeable during an observation session without warming the spectrometer, or significantly interrupting operations. Similarly the changeover between IFU and MOS operation should not require warming the instrument. A minimum array format for these capabilities is 2kx2k, with a goal to achieve 4kx4k pixels.

Given the complex issues surrounding implementation of the wide range of scientifically compelling MOS capabilities in the near IR, which include the possibilities of implementing upgrades to GMOS and NIRS, the Workshop suggests the following course of action:

- Assess design concepts of new Near IR MOS instruments, including estimates of design/fabrication schedules
- Assess the impact of upgrades to GMOS and NIRS in the overall scientific and programmatic context of the on going instrumentation program
- Develop an optimal approach to implementing the three Near IR MOS capabilities discussed

above.

4. *A&G POLARIZATION MODULATOR / OPTICAL & IR - MAUNA KEA & CERRO PACHON*

Polarization measurements will require implementation of a polarization modulator in the A&G unit above the bottom port. The NIRI and NIRS Phase I instruments can accomodate Wollaston prism polarization analyzers, however, implementation of polarizing capability in GMOS and HROS will require upgrades to the Phase I instruments.

5. *HIGH STABILITY LAB SPECTROMETER - CERRO PACHON*

The High stability Lab in the telescope pier provides a stable environment for precision radial velocity measurements. A fiber-fed, bench-mounted optical spectrograph with R=120,000, usable with an absorption cell in 500-600 nm range, would provide the greatest sensitivity currently for detection of low mass companions. A higher resolution mode, R>300,000 over the 380 to 1000 nm range, would enable many studies in stellar physics, including convection and magnetic fields, and also sufficient resolution for detailed studies of the ISM.

B. RECOMMENDED UPGRADES TO PHASE I INSTRUMENTATION CAPABILITIES

The recommended upgrades to Phase I instruments are shown in Table 5, along with guidelines for performance requirements.

Table 5 - Recommended Upgrades to Phase I Instruments

Instruments	Upgrade Options	Site	Wavelength Range	Pixel Scale	FOV/Slit Length	Spectral Resolution	Other Capabilities	Note
AOS	Laser Beacon	MK						1
GMOS	NIR	MK	1 - 1.5μm	~0.08"	~3'		IFU	2
NIRS	IFU	MK		~0.05"	~1" x 2.5"			3
				~0.15"	~3" x 7.5"			
GMOS	Grating Impr	MK/CP				~25,000	improved grating efficiency	4

Notes:
1) -- goal is to increase sky coverage at similar performance levels as for a Bright natural guide star
2) -- long wavelength cutoff due to room temperature background needs further investigation
-- compatibility with mass, volume constraints on GMOS needs further investigation
3) -- initial step toward ultimate weapon - gain experience in use and demonstrate science performance
4) -- grating efficiency is currently the major limitation in GMOS throughput
-- an immersed grating may provide increased spectral resolution
-- AO correction may allow use of <0.2" slits, thus achieving higher spectral resolution, possibly down to 0.4μm

1. *LASER BEACON AO SYSTEM UPGRADE - MAUNA KEA*

A Laser Guide Star upgrade to the NGS AOS would boost AO sky coverage at moderate Strehl ratios in the near-IR very substantially. The intent is to be able to upgrade the initial NGS AOS for use with a Na Laser beacon in order to achieve moderate Strehl ratios (around 0.5) in the near-IR over most of the sky. Lasers are currently forbidden on MK as are the currently FAA required radar-based aircraft protection schemes. Intensive efforts are underway, led by Keck, to obtain approval for Na laser beacons on MK and FAA approval of alternative passive aircraft detection schemes.

2. GMOS NEAR IR UPGRADE - MAUNA KEA

Upgrade GMOS-N with the addition of a 2kx2k HgCdTe array under development at Rockwell International, to provide high performance multi-object spectroscopy over a roughly 3 arcmin dia field in the 1-1.5µm region. The same camera could also be fed with an IFU. This upgrade provides near term capability for near infrared, full field, MOS capability. A variety of scientific applications were identified that require this capability: studies of lenses and lensed objects, AGNs and normal galaxy nuclei, the properties clusters of galaxies as a function of z and the study of galaxies close to QSO lines of sight. Many of these applications call for a J-band IFU on GMOS.

A significant constraint on the upgrade path is to preserve the optical spectroscopy and imaging capability in the GMOS.

3. NEAR IRS IFU UPGRADE - MAUNA KEA

The NIRS is designed to have significant space in front of the cold slit for an Integral Field Unit (IFU). Because of the "small" 1kx1k format of the NIRS detector, an image slicer concept for the IFU, which maps slices of the image plane into a single long slit, would provide efficient use of the array and require no additional blocking filters. This concept is expected to yield roughly a 20x50 spatial element sampling. We encourage investigation of two plate scales; around 0.15 arcsec/spatial element for non-AO use and around 0.05 arcsec/spatial element for use with AO.

The initial NIRS IFU implementation should be kept relatively simple, since this is a new capability, with little experience concerning implementation or use. Switching between IFU plate scales and between IFU and long slit use should not require warming of the dewar.

Optical design and conceptual implementation work should be initiated as soon as possible.

4. HROS R=120,000 - CERRO PACHON

This capability is required to disentangle the effects of temperature and velocity in absorbing clouds along the line of sight to quasars. The recommended bench mounted R=120,000 capability could also provide for much of the science drivers for this upgrade.

5. GRATING IMPROVEMENTS (GMOS) - MAUNA KEA AND CERRO PACHON

The largest single source of throughput loss in GMOS is the grating efficiency (at 65-70%). Possible high efficiency innovative grating developments would push the capabilities of GMOS to the faintest possible limits. Grating developments to allow spectral resolutions of 20,000 to 30,000 would also fill the gap between the baseline GMOS and HROS capabilities would allow for detailed abundance studies in nearby galaxies.

C. SHARED INSTRUMENTATION

The recommended shared instruments are listed in Table 6, together with their performance characteristics.

Table 6						
Instruments	Wavelength Range	Array Format	Pixel Scale	FOV/Slit Length	Spectral Resolution	Other Capabilities
MAUNA KEA						
MICHELLE	8 - 25µm	~256 x 256	0.18"	46"	R~200, 1k, 20k	
		Si:As IBC	0.10"	26" x 26"	filters	
CERRO PACHON						
PHOENIX	1 - 5 µm	512 x 1024	0.09"	14"	100k (2 pix)	pupil, viewing
		InSb				imaging mode

1. MID-IR SPECTROGRAPH (MICHELLE) (SHARED WITH UKIRT) MAUNA KEA

A Mid-IR spectrometer under development at ROE for use at UKIRT and proposed for shared use on Gemini-N. It will provide spectral resolution from 200 to 30,000, and diffraction limited imaging capability in the 8 - 28µm range. Under the proposed shared-use agreement, MICHELLE would be available at Gemini-N 50% of the time.

It would be very desirable to have MICHELLE available for use at the start of scientific operations on Gemini-N.

2. NEAR-IR HRS (PHOENIX) (SHARED WITH NOAO) - CERRO PACHON

Phoenix is a near-IR high-resolution spectrometer, providing spectral resolution up to 100,000 in the 1-5µm range. It saw first use on NOAO telescopes in 1996.

The shared use of PHOENIX at Gemini-S and possibly Gemini-N should be pursued. Because of the initial scarcity of science instruments on Gemini-S, It would be very desirable to have Phoenix available for scientific use on Gemini-S late in the commissioning period and during early operations of Gemini-S.

Ultimately this spectroscopic capability will be needed with a much larger simultaneous wavelength coverage than can be provided by Phoenix, however Phoenix would offer an adequate capability for the short term. The provision of a new instrument for that would provide extended wavelength coverage in a single exposure should appear later in the on-going instrumentation program

3. NIRS CLONE (GEMINI-S)

NOAO is considering cloning the NIRS for use on the SOAR telescope. The decision to proceed with the duplication of NIRS, hinges on details surrounding the SOAR telescope project. Without SOAR, NOAO cannot use NIRS on any of the NOAO telescopes, and thus would have little interest in cloning NIRS.

The NIRS would be a basic "workhorse" instrumental capability with wide ranging scientific capability on Gemini-South extending into the thermal IR.

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V. ACKNOWLEDGMENTS

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