Draft by Dan Eisenstein

Dark energy, dark matter, and cosmology are leading topics in modern astrophysics and one of the principle drivers for large optical telescopes.

The study of dark energy requires ambitious work with either very large samples or very precise measurements, or both.

High-redshift supernovae Ia have been the leading route to the cosmological distance-redshift relation. Spectroscopy to determine the redshift and type of the SNe has required major allocations of 8-meter class telescope time [add numbers on how much]. Current work is approaching the systematic limit of current photometry. However, it is likely that future imaging surveys (PanSTARRS, Dark Energy Survey, and LSST) will reduce these errors and keep the need for spectroscopic followup vigorous. It also appears that SNe will remain the dominant dark energy method at $z<0.5$, as cosmic variance limits the other major probes. Searching for evolution in the Ia population is therefore critical, and spectroscopy is a major ingredient.

Weak lensing is a rapidly growing field that will have major impacts on the study of dark energy, structure formation, and galaxy evolution. Most of the imaging to date has been on smaller telescopes (with some from Subaru and VLT), but the need for deep data over most of the sky is one of the key drivers for LSST. Moreover, to extract the best information from weak lensing requires photometric redshifts, which in turn require spectroscopic validation. Validating the samples at the depth of dozens of object per square arcminute is a challenging project. The estimates for required survey sizes in the literature are [in my opinion] likely to be too optimistic (i.e., too small).

Cluster counting will continue to be pursued, particularly with the SZ surveys and deep imaging from DES and LSST. Systematic errors are crucial here, and this will require detailed study of a representative sample of clusters. That implies significant narrow-field spectroscopy as well as deep weak lensing maps. Higher redshift clusters are particularly interesting but will require extensive validation with IR imaging and spectroscopy.

Large galaxy redshift surveys offer multiple probes of dark energy. Baryon acoustic oscillations provide a standard ruler, tracable from the microwave background and largely insensitive to low-redshift astrophysics. This offers a robust route to measuring the angular diameter distance and the Hubble parameter as a function of redshift, likely to precisions better than 1\%. The non-oscillatory portion of the galaxy power spectrum could also produce distance estimates if galaxy bias could be accurately modeled. The large-scale infall measured by redshift distortions provides a direct measure of the growth of structure. Cross-correlation of redshift surveys with weak lensing maps offers a number of important opportunities to constrain galaxy masses and measure the large-scale amplitude of the matter power spectrum. All of these applications are volume starved. Surveys at the level of $(Gpc/h)^3$ are the metric of the field; this drives one to thousands of square degrees at $z\approx 1$ and many hundreds at higher redshift.

Pursuit of direct measures of the Hubble constant will continue to be an important topic. Cross-checking direct measures against the CMB-based inferences from the acoustic oscillations is an important check of our cosmological assumptions about the dark sector. Moreover, precision measurement of H_0 are important for dark energy constraints at low redshifts.

It is likely that other methods for measuring dark energy will mature and will put demands on 8-meter class telescopes. Examples include: measurements of type II SNe; follow-up of standard sirens from LISA; follow-up of high-redshift objects such as radio jets and gamma-ray bursts; follow-up of strong lenses.

In the study of dark matter, the focus has been on smaller scales. This can be probed with mass modeling of low-surface brightness galaxies, which requires large numbers of high-precision (<5 km/s) velocities of individual stars. Surveys of dwarf galaxies around more distant galaxies puts a premium on reaching low surface brightnesses. Small scales are also reached in the study of the Lyman-alpha forest, which favors high-resolution spectroscopy in the blue.

The study of ``fundamental'' cosmology goes well beyond dark matter and dark energy. Studies of cosmological perturbations as detailed above allow us to look for deviations from a power-law initial spectrum, deviations from Gaussianity, minor admixtures of isocurvature perturbations, and primordial gravitational waves, which push our view into the first second of the history of the Universe. These will rely on the combination of CMB data with data from redshift surveys, weak lensing, and cluster counts. Searches for variations in the fundamental constants (fine structure constant, electron-to-proton mass ratio, etc.) will require very high resolution spectroscopy (and exquisite wavelength calibration) on the largest telescopes. It should be expected that other interesting tests will be developed. Many will be applied to survey data taken for other purposes, but some will benefit from directed time on 8-meter class telescopes.

[[[Not sure what we want to say about direct measures of time evolution in the Lyman-alpha forest with very high precision spectroscopy. My initial impression is that this is redundant and uncompetitive with other methods, but some people are gung-ho to spend \$100M on an ELT instrument...]]]

Of course, the study of the evolution of galaxies, clusters, black holes, and the intracluster and intergalactic media are all major topics.

Draft by Chris Johns-Krull

The last Decadal Panel for astronomy and astrophysics listed as a primary science goal the task of mapping out the history of star formation and chemical evolution over all of cosmic time. This includes finding the first generation of stars in the early universe as well as finding the oldest stars in our galaxy and in the local group and comparing the properties of the two sets of objects. Despite the significant progress that has been made over the last several years, this remains a largely unfulfilled goal. A key aspect of this goal is to measure the fundamental properties (temperature, luminosity, metallicity, and gravity) of stars in these different populations. Due to the distance and/or inherent faintness of many of these stars, progress in these areas requires large aperture optical/IR telescopes. Key science drivers for this type of work is to discover and analyze the lowest metallicity stars. These stars contain in their chemical abundance patterns (not just an overall metallicity value) the keys to nature of the first generation of stars that enriched the ISM at the earliest times in the Universe. Surveys such as the Hamburg-ESO survey and the SDSS/SEGUE will continue to uncover low metallicity candidates in need of high resolution follow-up. Another key science question that has recently been thrust to the fore in astrophysics is understanding the origin of the multiple main-sequences now identified in a handful of galactic globular clusters. Again, analysis of the abundance patterns present in these populations will be key to understanding the origin of the different populations. The clearest picture will be obtained by analyzing the inherently faint stars below the main-sequence turnoff where the elemental abundances are unaffected by stellar evolution and the resulting chemical enrichment. All the above science goals require high resolution, high signal-to-noise spectra of a large sample of stars. Because many elements need to be analyzed and the lines from these elements span the wavelength range from the near-UV to the far red, efficient echelle spectrometers on large telescopes will be required.

Another key science goal identified in the last Decadal review is the characterization of extra-solar planets and extra-solar planetary systems. This continues to be a key science driver. The goal of extra-solar planet characterization is a key element in NASA's Strategic Plan and is a key science goal at the NSF as documented in report of the ExoPlanet Task Force, a unit of the NSF Astronomy and Astrophysics Advisory Committee. The last few years have seen tremendous advances in exoplanet characterization through the discovery and follow-up study of transiting exoplanets. The characterization of these exoplanets depends critically on the accurate characterization of the parameters of their host stars, and again, high resolution spectroscopy is a key element in this process. While some of the transiting planets that have so far been most valuable for follow-up studies orbit relatively bright stars, the majority of the known transiting exoplanets orbit relatively faint stars and this trend will continue. As a result, large ground based optical/IR telescopes will be in increasing demand for studying the fundamental properties of these planet host stars.

While it is clear many of the exciting, forefront areas of astrophysics require detailed analysis of stellar properties, the accuracy required in many of these fields is now in sharp conflict with our current, fundamental understanding of stars. For example, the CNO abundance of the Sun has recently been significantly revised by using new hydrodynamic model atmospheres to analyze line strengths. While these new estimates provide better agreement with local ISM studies, they produce solar models that are significantly at odds with helioseismology results. Another area where current spectral analysis of stellar parameters seems to be suffering has been revealed by studies of transiting extra-solar planets. Stellar gravity determined from high resolution spectra are often at odds with those implied by analysis of transit light curves. The light curve results are themselves subject to model atmospheres through the limb darkening laws that are adopted. Recent work has again shown that the new suite of hydrodynamic model atmospheres give different results relative the current industry standard. While it is therefore clear that our ability to measure basic stellar properties is currently challenged by the atmospheric models used, it is not yet clear that the new generation of hydrodynamic models is an improvement. These need to be tested against a host of observations. In particular, high spectral resolution, high signal-to-noise data for stars spanning a range of temperatures, gravities, and metallicities are to compare spectral line shapes to those predicted by the models. Abundance measurements for numerous elements from a number of tracers (ionized and neutral atomic, molecular, strong and weak features) are also needed to test these new generations of models. Some of these tests can be done on brighter stars with smaller telescopes; however, testing will benefit from observations of samples of stars where some properties such as metallicity and age can be at least partially controlled. This of course means observing cluster stars which will require high signal-to-noise data at high spectral resolution (R > 100,000 is best for line shape comparisons) which will require significant time on 6.5 - 10 m aperture telescopes equipped with high very high resolution spectrometers that have a broad spectral grasp.

In some ways, the studies outlined above represent refinements to a relatively mature understanding of solar-like and more massive stars. At the lowest masses though, the mid to late M, L, and T type stars and brown dwarfs, the situation can not really be considered mature. The study of these objects has exploded over the last decade as 6.5 – 10 m telescopes have come on line to study these inherently faint objects. These objects are the most numerous members of our galaxy, yet are in many ways the least understood. A complete census of them in the solar neighborhood is likely incomplete as shown by the SUPERBLINK survey. Measuring basic parameters for these objects such as effective temperature, gravity, and particularly metallicity remains problematic. Due to the large number of these stars nearby, they are emerging as particularly attractive candidates for extra-solar planet research, with the hope that some of them may harbor Earth mass (and like) planets in their habitable zones. Understanding these low mass, cool objects has become a high priority for many areas of astronomy. Progress in this area will require considerable theoretical work on the atmospheres of these objects including the relevant opacities, cloud formation and weather, these new models will demand an increasing array of observational constraints that will require 6.5 – 10 m telescopes to obtain. Additionally, an entire new class of even cooler, fainter objects, the Y dwarfs, are highly sought after and their discovery and characterization will require photometric and spectroscopic observations on 6.5 – 10 m telescopes.

Lastly, many current problems in the study of stellar astrophysics are focussed on the role magnetic fields play in areas such as the accretion of circumstellar material and launching of powerful outflows in very young stars and brown dwarfs, the rotational evolution of stars as they reach and remain on the main sequence, the amount of mixing of materials inside stars and its influence on stellar evolution, to the formation of structure in last stages of post-main sequence evolution as stars form planetary nebulae. In many ways, the magnetic properties of stars are becoming an essential stellar parameter which influences their appearance and evolution. Much progress has recently been made in this area; however, in order to reach many of the most interesting objects such as brown dwarfs and main sequence stars in clusters such as the Pleiades and Hyades, telescopes of 6.5 – 10 m aperture are simply required. Additionally, the data required for these studies is high resolution (R > 40,000) IR (1-3 micron) spectra, and these instruments are practically not present in the US observing system. Polarimetry with such an instrument would be an invaluable resource, but such an instrument does not exist at all in the US system. In order for the US to remain competitive in the study of basic stellar astrophysics, it is clear that significant investment in high resolution optical and IR spectrometers on large aperture telescopes is needed.

Radial Velocity Science on 6.5 to 10 Meter Class Telescopes

Lisa Prato

Examples of the use of radial velocities (RVs) as an astrophysical tool are (1) the determination of stellar radial velocities to identify binary stars, measure dynamical properties, and detect substellar companions,
(2) the identification, in combination with proper motions, of UVW space motions to distinguish stellar populations,
(3) the measurement of galactic rotation curves, and
(4) the determination of cosmological redshifts.

Binary stars across the full spectral type sequence provide a classic, invaluable approach for dynamical measurements of systemic mass functions, component mass ratios, and ultimately absolute stellar masses. Applications of this method range from measurements of the masses of compact objects in binaries with normal, low-mass stellar companions (e.g., Jonker et al. 2005), to improvements in models of early pre-main sequence evolution based on mass ratio deteminations in T Tauri star spectroscopic binaries (overview in Hillenbrand & White 2004). Calibration of the mass-luminosity relation for main-sequence stars, both population I and II, is also enabled by the precise RV measurements which contribute to the determination of absolute stellar masses. In general, reflex motion surveys to search for companion object populations with small mass ratios have increased, enabled by the advent of high-resolution spectroscopy on large aperture telescopes, necessary both for obtaining the highest possible precision as well as extending surveys to the faintest targets. These include, for example, focussed surveys of young late M type stars for brown dwarf and planetary mass companions (e.g., Joergens 2008), surveys of brown dwarfs for planetary mass companions (Blake et al. 2007, 2008), and surveys of young moving groups near Earth for giant planet companions (Paulson & Yelda 2006). The Keck, VLT, Gemini, and Magellan telescopes have played the crucial roles in these studies.

Mapping the space motions of stellar populations to determine membership, location, and dispersions provides insight into the origins of targets as diverse as the Magellanic clouds (Kallivayalil et al. 2006a, 2006b; Paitek et al. 2008) distant clusters in the Milky Way (e.g., Kalirai et al. 2007), and co-moving stellar groups near Earth (Song et al. 2003). The farthest and the lowest mass of these populations require the sensitivity of 6.5 to 10 meter aperture telescopes for accurate determination of the RVs, a key component in the calculation of space motions.

The fundamental structure of galaxies can be approached through dynamical studies of the stellar and gas content. The relationship between the rotation velocity and the stellar dispersion determines how kinematically hot a system is, and hence the form of the underlying structure, particularly relevant to the study of dwarf, irregular, and interacting galaxies (Hunter et al. 2005). Telescopes of 6.5 to 10 meters enable the extension of these studies back in time to high reshift (faint, small) targets, to low-mass but numerous local dwarf galaxies, and to individual stellar populations in large, nearby galaxies.

Many of the underpinnings of modern cosmology rest on the spectroscopic measurement of galactic redshifts. This remains an important diagnostic of galaxy formation and evolution, large scale structure, etc. Large aperture facilities (6.5 - 10 meter) with sensitive instruments capable of multi-object spectroscopy provide access to new populations of targets, for example, those at high redshifts (e.g., Steidel et al. 2005), or with extremely red colors (e.g., Doherty et al. 2005).

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1. High Resolution ISM

The interstellar medium (ISM) is one of the basic constituents of galaxies and one of the essential components of the life-cycle of stars. Thereby studies of the ISM connect to many fundamental areas of astrophysics. The morphology, density, and temperature of the ISM control star formation (Evans 1999), the dynamics of the ISM provides information on the stellar winds for both early and late-type stars (Linsky & Wood 1996; Kudritzki & Puls 2000), the ionization of the ISM provides information on the radiation field (Ferland 2003), and the chemical abundances and enrichment of the ISM provides information about the death of stars and supernovae (McCray & Snow 1979).

Observationally, ISM studies reduce to determining the location and three-dimensional morphology of the ISM and sensitively measure any number of physical properties (e.g., density, temperature, turbulence, kinematics, shock structure, dust content and composition, molecular and atomic abundances). The structures that are studied include bubbles, shells, (that often spill into the galactic halo), planetary nebulae, supernova remnants, star-forming regions, etc. These structures are basic constituents of all galaxies, and tell us something fundamental about how galaxies evolve, how galaxies control internal feedback on processes such as star formation, and how galaxies modulate the infall and outflow of ISM material with their immediate environments.

High resolution spectrographs on large aperture telescopes open up whole new ISM environments, including the Milky Way halo and nearby galaxies, while at the same time providing even more detailed access to Galactic ISM environments. Currently, Galactic ISM environments, such as the local ISM, the canonical nearby low-mass star-forming clouds, Galactic bubbles, shells, and fountains, and many high-mass star-forming regions, are being studied in detail using high dispersion and high spatial resolution optical and infrared spectroscopy. A critical breakthrough in studying these environments was the accessibility of multiple sight lines and multiple diagnostics. More distant environments, such as the halo, ISM of nearby galaxies, and circumstellar material surrounding SNe and GRBs, suffer from a severely limited, if any, accessible sight lines, which prevent anything beyond a simplistic generalization of the ISM properties. Future observations with high-resolution spectrographs, with multi-object or IFU capabilities, or high spatial resolution, on large aperture telescopes, will enable us to produce rich data cubes of absorption line measurements through the ISM environments of our own Galaxy, that will have a strong synergy with exisiting IR databases (e.g., Spitzer, Herschel), radio emission data cubes (21 cm, CO, ALMA), and be able to probe ISM environments of the halo and nearby galaxies.

High resolving power (R $\sim$100,000 – 300,000) is required for this work. In order to measure basic morphological and physical properties from ISM absorption lines, multiple individual components need to be resolved. Cold Na I ISM absorption has been observed with intrinsic $FWHM \sim 0.6$ km s^{-1} (Meyer et al. 2006). To fully resolve such a narrow component is beyond most astrophysical spectrographs, but currently the standard high resolution platforms fall in the 120,000 to 250,000 range (HST, VLT, AAT, HET, etc). In addition, high spectral resolution is required to resolve multiple transitions within molecular bands. Observations taken with a resolving power <100,000 significantly limits the scientific output. The blending of multiple Doppler-shifted ISM environments results in erroneous measurements of basic physical properties.

Numerous ions are available in the optical. The strongest transitions include Ca II (3933 Å) and Na I (5890 Å), and would be the highest priority. Other lines include K I (7699 Å), Ti II (3300 Å). In addition, several molecules are available (CN, CH, CH^+). In the infrared, numerous important molecular transitions are accessible (e.g., CO, H_3^+). Essentially, there are lines of interest from the atmospheric cutoff near 3000 A, into the near-infrared beyond 3 micron, and therefore full coverage is desirable.

ALTAIR White Paper

Role of 8-m class telescopes in optical/IR interferometry

John Monnier

The field of optical interferometry encompasses the familiar method of aperture synthesis imaging as well as specialized techniques such as astrometry and nulling. Today, three interferometric facilities can harness the light-gathering power of 8-m class telescopes. Firstly, the Very Large Telescope Interferometer (VLTI), operated by European Southern Observatory (ESO) on Paranal, Chile, can use any of the four 8-m “Unit Telescopes” (UTs) to achieve baselines as large as 130m, yielding an angular resolution of 1.3 milliarcseconds at 1.65 micron or 8 milliarcseconds at 10 microns. The Keck Interferometer (KI) on Mauna Kea, HI, combines the two 10-m Keck telescopes along an 85-m baseline for near-infrared measurements as well as mid-infrared nulling. Both VLTI and KI have advanced plans for implementing phase-referenced astrometry for exoplanet and galactic center work. Lastly, the Large Binocular Telescope Interferometer (LBTI), under construction on Mt. Graham, AZ, represents a “Fizeau”-style interferometer where the two 8-m apertures are on the same mount, allowing a very wide-field of view and superb mid-infrared sensitivity limited by a relatively short baseline of 22.8m.

The main advantage of including large apertures in an interferometric array is improved sensitivity. The large aperture advantage has been transformative. One can now observe a dozen Active Galactic Nuclei compared to zero with smaller interferometers. One can observe hundreds of T Tauri disks compared to only a handful with smaller arrays. And in the mid-infrared, only AGB stars could be detected in the past, and now young stars, AGN, and all manner of cool dusty objects (as far as the LMC) can be scrutinized with an order of magnitude better angular resolution than single telescope alone. The additional flux also allows high-resolution spectroscopy to be carried out, compared to only broadband data from smaller arrays, and even direct detection of exoplanets is possible with the higher signal-to-noise ratios.

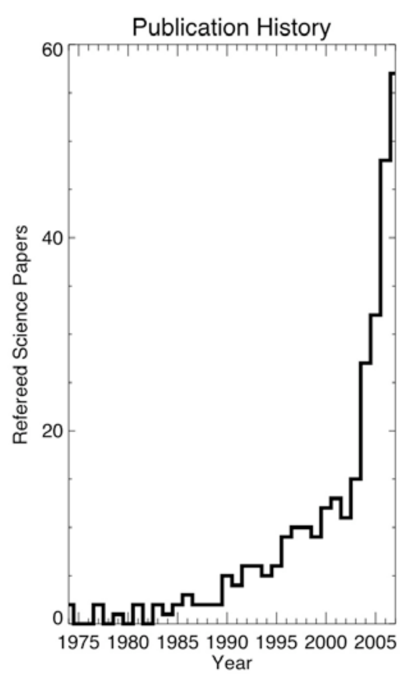

Figure 1. Yearly publication rate for field of optical interferometry (compiled by S. Ridgway, NOAO). Much of the recent spike is due to the commissioning of the VLT Interferometer using 8-m telescopes.

Narrow-angle astrometry allows the separation of two objects to be measured and monitored with high precision, with expected precision as fine as 10 microarcsecond. The PRIMA project on VLTI and the ASTRA project on Keck are nearing on-sky testing, and a new project GRAVITY has begun which is optimizing the VLTI to track stellar orbits near Sgr A* for testing General Relativity and probe the inner pc of the Galactic Center. These projects open a new window for studying the galaxy and require 8-m class telescopes to detect interesting classes of objects.

The Fizeau-style arrangment of the Large Binocular Telescope Interferometer (LBTI) complements the Michelson-style arrays like the VLTI and Keck-I, the former being optimized for relatively modest improvement of angular resolution (NIR ~15 milliarcseconds) but over a wide field of view (30 arcseconds). Roughly speaking, Keck/VLTI arrays are ideal for studying stars and circumstellar environments (and also AGN) while LBTI-style arrays are useful for extragalactic observations. In 2006, the NOAO held a workshop on future directions of ground-based interferometry where plans for future arrays were discussed, including both kilometric arrays and smaller baseline Fizeau-style arrays. The report can be found at http://www.noao.edu/meetings/interferometry/ .

The US astronomical community (via NOAO) currently has limited access to interferometers with 8-m class apertures. While building a new facility is not envisioned in the near future, the NOAO could take steps to obtain access to these capabilities in the same manner as is done for other specialized observing modes, such as wide-field multi-object spectroscopy. Through a stable system of time trades, the NOAO could open up a range of new observing modes to US astronomers, and access to 8-m class interferometers would be a highly desirable new mode.

ALTAIR White Paper

Role of 8-m class telescopes in direct detection of exoplanets

John Monnier, with information provided by GPI team

Gemini Observatory and ESO have both invested significant instrumentation resources in developing “extreme” adaptive optics systems with coronagraphs for imaging exoplanets. Gemini Planet Imager (GPI) and Spectro-Polarimetric High-contrast Exoplanet REsearh (SPHERE, by ESO) both promise to optimally block light from a central source in order to image faint companions close to the host star. In order to succeed in detecting young, self-luminous exoplanets in orbit between 4-40 AU around nearby stars, these instruments must achieve contrast ratios of 10^{-7} with an inner working angle of 3 X lambda/D. In order to achieve the high quality adaptive optics correction of the wavefront, bright guide stars are needed (V 5-9) which limit the most precise measurements to bright galactic objects.

In addition to exoplanets, these extreme-AO systems will allow new studies of low surface brightness emission for circumstellar disks, discovery of brown dwarf companions to nearby stars, detailed studies of dust shells in mass-losing stars, and new searches for solar system bodies. GPI will have an unprecedented ability to detect low-surface brightness disks through dual-channel polarimetry that can remove the unpolarized stellar light while allowing the scattered light from the disk to be detected. Ring and arcs in circumstellar disks provide clues to unseen planets and to the planet formation process in general, and GPI will detect disks closer to stars than previous work, with higher angular resolution, and with an order of magnitude greater contrast ratio.

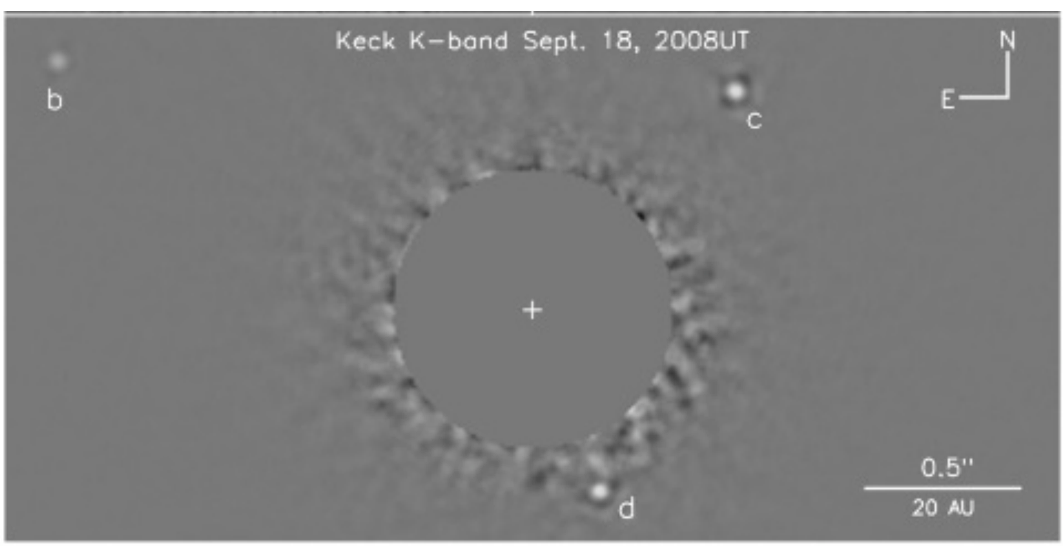

Figure 1. Adaptive Optics image of a multiple planet system around HR 8799 (Marois et al. 2008, Science). The Gemini Planet Imager is expected to find many more systems, extending searches to lower luminosity and more distant systems.

Much of the initial observing with GPI will carried out through large surveys, not through individual PI proposed projects. The large surveys, consisting of up to 420 nights of Gemini time, will be competed for in the near future, independent of the instrument teams. While the final surveys have not been decided yet, the most scientifically rich stellar samples (according to the GPI instrument team) include young stars, A stars, adolescent FGK stars, a 2000-star volume-limited sample, and an unbiased disk survey. Simulations suggest more than 100 exoplanets will be detected by these surveys allowing meaningful statistical constraints on exoplanet demographics focusing on these long period systems that are not easily picked up by Doppler surveys. Furthermore, coronagraphy methods are not limited to the "quiet" main sequence stars like the Doppler surveys and so will permit completely new constraints for planet formation theories for stars more massive than the Sun.

Direct imaging of exoplanets is one key area where US astronomers will have the best access to a crucial new scientific capability. Indeed, by focusing on a few strategic instruments and developing world-class facilities, Gemini will be in powerful position to barter some GPI access with other observatories in exchange for desired instrument access not available within NOAO. The recent discovery of a multiple planet system around HR 8799 suggests the prospects for GPI are promising indeed.

1. Exoplanet Atmospheric Spectroscopy

Transiting (or near-transiting) extrasolar planets provide unique opportunities to measure physical properties of exoplanets and their atmospheres. Physical characteristics of an exoplanet atmosphere can be probed via: (1) resonance line absorption of starlight transmitted through the extended exoplanetary atmosphere during a transit, (2) reflected stellar light of a transiting or near-transiting exoplanet, (3) secondary eclipse measurements in the infrared. These observations provide fundamental measurements of exoplanetary atmospheres, including, albedo, chemical constituents, temperature and pressure profiles, and atmospheric dynamics and mixing. Disentangling signal from the host star and the exoplanet is a daunting task and requires access to large aperture telescopes with the appropriate instrumental capabilities. Indeed, attempts to measure exoplanetary atmospheres in these ways have been made from all major large-aperture telescopes (e.g., Charbonneau et al. 1999; Bundy & Marcy 2000; Moutou et al. 2001; Richardson et al. 2003; Winn et al. 2004; Narita et al. 2005; Bozorgnia et al. 2006; Arribas et al. 2006; Redfield et al. 2008; Snellen et al. 2008). Although ground-based attempts at all three techniques have been made, no reflected light off an exoplanetary atmosphere has been detected, and secondary eclipse measurements in the infrared have only been successful from space.

These measurements are typically on the very edge of the capabilities of the current telescopes and instrumentation. Therefore large aperture telescopes, efficient instrumentation where systematic noise sources are well-characterised, and observational capabilities of observing transient events (e.g., transits, secondary eclipses), are absolutely essential. Observations of many transits will be critical to building up the required signal-to-noise and measuring any temporal behavior. At this point, only a handful of bright exoplanetary host stars are available for studies of this kind, but in the near-future, with the continued success of both ground-based and space-based transit searches, the number and diversity of targets will increase significantly.

Optimal observing wavelengths range from the optical to the infrared. In some cases moderate resolution spectragraphs (R ∼20,000) are important, but of paramount importance is the effeicency of the instrument, and the capability to observe at specific times or intervals, relative to the exoplanetary orbit.

It appears that hot-Jupiters do not share identical atmospheric properties. For example, some exoplanetary atmospheres contain a thermal inversion layer (e.g., HD209458b; Knutson et al. 2008), while others do not (e.g., HD189733b; Charbonneau et al. 2008). Therefore, a large scale effort to do comparative exoplanetology, will be critical to understanding the atmospheric properties of hot exoplanets. In addition, any advances that can be made from the ground, on characterising the atmospheres of hot-Jupiters, lay the foundation for similar future work on Earth-sized extrasolar planetary atmospheres (Ehrenreich et al. 2006), and the relationship between atmospheric properties and habitability (Chylek et al. 2007).

ExoPlanet Research using Precision Radial Velocity Techniques on 6-10m Telescope

Lwr-draft

The field of extra-solar planet studies leaped from a quiet area involving a few “eccentrics” a few decades ago to the forefront of astrophysics. This began in 1992 when the first extra-solar planets were discovered around Pulsars. This discovery of planets around a “dead” remnant of an exploded star was startling as it was the last place astronomers expected to find planets. Four years later the first extra-solar planet around a normal solar-like star was identified, but this so-called “hot Jupiter” was unlike anything anticipated. The existence of over 250 other planet systems with properties very different than our own has brought about a historic paradigm shift and is leading an astronomical renaissance. Extra-solar planet detection using precision radial velocity (PRV) measurements is to date the most productive technique to date for discovering and characterizing extra-solar planet systems. Until recently, PRV searches for planets around nearby stars have been carried in the optical regime on solar-type (FGK) stars. These searches have found planets with masses of 0.02-180 $M_{Jupiter}$ (Butler et al. 2006). However there is great interest in searching for even lower mass planets (terrestrial planets with M ~ M_{Earth}, or 0.003 $M_{Jupiter}$) which are in the Habitable Zone (HZ) of G-M stars. Even when upcoming space missions such as Kepler increase the number of transit discoveries, PRV measurements will remain necessary as the only means to determine masses.

The state of the art for PRV technique is currently a bit better than 1 m sec^{-1} and relies on tracking and correcting for subtle changes in the instrumental spectral response function (SRF) and line position at the 10^{-3} pixel level. This is done either by imposing an I_2 absorption spectrum on the target spectrum, which is limited to wavelengths in the visible spectrum (Butler et al, 1996), or increasingly by using a simultaneous Th-Ar spectrum in a extremely stable spectrograph as most recently demonstrated in ESO’s HARPS (Pepe, et al. 2003, Rupprecht et al., 2004, Lovis et al., 2006).

The ExoPlanet Task Force report to the AAAC (http://www.nsf.gov/mps/ast/exoptf.jsp) details both near term and long term efforts in this area. The science frontiers for PRV surveys on 8-10m telescopes lie is several related directions. The quest for earth mass planets pushes the frontier for PRV work downscale in precision to cm/sec to search for earth mass planets around G & K stars and in photon energy as we look at M stars which emit most of their energy in the NIR. Planets in the HZ around more solar-like stars have radial velocity signatures significantly less than 1 m/sec and will require further improvement in the techniques used in the visible. The low mass of M stars, less than 0.5 solar masses, combined with close in orbits we yield radial velocity amplitudes for planets in the HZ around these stars that are well within current limits of 1-2 m sec^{-1}. It is around the M dwarfs where it is most likely to find planets in the 1 to 10 earth mass range in the HZ using radial velocity techniques at the ~1m/sec precision. Another area ripe for exploitation using current precision is searching for multiple planets by continued precision monitoring of systems with known planets. Building up precision constraints on the structure of exoplanet systems is critical to advances our theoretical understanding of formation and dynamical stability of these systems.

Cadences ranging from several/year to several/week are required in the three major areas noted above. Following over 1000 stars as recommended by the EPTF report will require substantial allocation of telescope time. In addition to achieve a few 10s cm/sec precision in the visible and to establish ~1 m/sec precision in the NIR will require additional investment in instrumentation.