Special GSC Meeting, Tucson AZ
23-24 April 2007

GSC Recommendation Regarding Aspen Instrumentation

The GSC met in Tucson on April 23 and 24. We first reviewed the goals of the Aspen workshop: to define critical questions of modern astrophysics and how they might be answered, what we call transformative science; and instruments that enable new science dealing with unforeseen questions, which is occasionally referred to as PI science. The GSC then discussed the four instruments with the "Aspen" package: the Gemini Planetary Imager (GPI), the Wide Field Multi-object Spectrograph (WFMOS), the Precision Radial Velocity Spectrometer (PRVS), and the initial stage of a Ground Layer Adaptive Optics (GLAO) system. We discussed each instrument in some detail, and concluded, as expected, that all four remain capable of producing transformative science, as envisioned in the workshop and in later meetings. The GSC also spent time discussing the enabling science each instrument might provide. Short summaries of our evaluations of the instruments' strengths in transformative and enabling sciences are attached.

The GSC agreed with prior decisions regarding GPI, and that construction and deployment should be undertaken as soon as possible.

A sequence of possible decisions was presented to the GSC regarding PRVS, WFMOS, and GLAO. For PRVS, the Board will face a decision in May 2007 whether to proceed with the PDR, and a decision to proceed through CDR as early as May 2008, with a final decision for funding for construction in May 2009. Also in May 2007, the Board will be expected to rule on proceeding with CoDR for WFMOS, which would be followed by a decision to proceed to PDR as early as November 2008, a decision to proceed to CDR in November 2009, and a possible decision to commit the final construction funds in 2010. The next GLAO milestone, to proceed to CoDR, is expected in November 2007, with the decision to proceed to PDR expected as early as May 2009. The decision to proceed to CDR might be taken in November 2010. All decision dates beyond those in 2007 are necessarily less certain in schedule and outcome.

The Board has asked the GSC to recommend a *"decision tree for optimizing the scientific return from the available budget for Aspen instrumentation incorporating key decision points in the next few years"*. The GSC found this a daunting challenge given the uncertainty of "the available budget".

The GSC understands that uncertainties in the funding sources for the Aspen instruments requires that Gemini manage the development of these instruments in a way that is not ideal in the long term. Given that not all instruments have yet to undergo CoDR, step-by-step funding of these is currently reasonable, but not without risk, especially if the process continues into the long term. Instrument builders may prefer to pursue opportunities involving more certainty of long term funding and eventual success than feel at the mercy of circumstances beyond their control on multiple occasions. Also, any relationship with Subaru will be made more difficult to maintain while there is no certainty of an eventual positive outcome. The GSC feels that while the current budgetary circumstances dictate the current step-by-step funding model for Aspen, they urge both Gemini and the Board to ensure that such an arrangement is not continued into the long term as this in itself will increase the risk to the entire Aspen process. Once reasonable cost estimates are available, the Board should commit to fully funding an instrument, beginning with the highest priority one.

To respond to the Board's charge, the GSC used the discussions of the three instruments, WFMOS, PRVS, and GLAO, to prioritize them according to transformative and enabling science. The discussions did not result in unanimous recommendations, but the preferences were very clear. In order of highest priority, the GSC endorsed

1. WFMOS
2. PRVS
3. GLAO

Thus, in the presence of only scientific priority, the Board is encouraged to always act to expedite the WFMOS effort. Thus, if the Board finds at its meeting in May 2007 that it has funds sufficient to support either the PDR effort for PRVS or the CoDR stage for WFMOS, that the latter should be supported. However, the GSC offers additional a couple of observations for the Board's consideration.

First, the "stop work" order on WFMOS has created a major credibility problem for the Board. Teams preparing to build any instrument, WFMOS or PRVS, may not be anxious to dedicate the time and money instrument proposals require. Failure to provide support for either PRVS or WFMOS could end completely the efforts to build one of the major Aspen instruments, and could complicate the "surviving" instrument as well. If PRVS is not supported and the team disbands, it may be hard to convince WFMOS teams that they are on a path to success. The Board is urged to demonstrate its commitment to WFMOS by both word and deed. Because the costs are so high and the impact on the other two instruments is so great, risk reduction is essential, and the GSC urges the Board to proceed to obtain two cost estimates.

Second, the recent excitement about the discovery of a 5 $M_{\oplus}$ planet around the M3 dwarf star Gl 581 (Udry et al., *Astron. & Astrophys*, in press) demonstrates that the primary science goal of PRVS is both very timely and of very wide interest. Note that this discovery was made using an optical spectrometer, HARPS, which has a velocity precision of 1.5 m sec^{-1}, comparable to that proposed for PRVS, but the reach of HARPS to faint M dwarfs is limited. The GSC believes that the Board should commit as soon as possible to the construction of PRVS, modulo the priorities discussed above. If the Board cannot do so, the GSC expects that other instruments, perhaps with lesser capabilities, will begin design and construction soon. The Gemini partnership would thereby lose out on a major scientific quest, and the associated enabling science discussed in the attached summary. Firm go/no go decisions for both WFMOS and PRVS should be made as soon as possible.

Third,, the lower prioritization of GLAO and the lack of urgency in its initiation, suggests to the GSC that the Board may wish to defer the GLAO CoDR and subsequent stages until funding for both WFMOS and PRVS are identified.

The GSC is very worried that the Aspen process may result in only GPI, which will provide transformative science but perhaps less enabling science that the other instruments. The Gemini partnership and its scientific communities deserve a more expansive science legacy than a single such instrument.

APPENDICES
(A)
WFMOS – I. Extragalactic Science with WFMOS

What will WFMOS do?

It will carry out two redshift surveys:
~2x10^6 galaxies at z~1
~5x10^5 galaxies at z~3
WFMOS will thus produce a spectroscopic database on galaxies that is essentially the equivalent of the SDSS at each of z~1 and 3. This will provide tremendous advances in the studies of galaxy formation and evolution, in particular, their dependence on environment and in the context of the growth of large scale structure. Very large samples are needed for this kind of investigations, similar to the transformative advances that have been produced in understanding local galaxies properties by the SDSS. As with SDSS, the bulk of the science will not be generated by the survey team, but by others mining their data-set. WFMOS can be seen as adding the time dimension to SDSS.

New competition since the original concept study

Currently there is NO OTHER projected wide-field large aperture spectroscopic facility, in an era of a dozen deep imaging surveys, and so even in 2015-2017 WFMOS will be immensely competitive for a very wide range of science. Examples might include follow-up of multi-wavelength surveys, and studies of the inter-relationship between the intergalactic medium and galaxies.

If we look more specifically at Dark Energy, the landscape has changed over the last couple of years. Reports in the UK and USA have reaffirmed the crucial importance of Dark Energy. Baryonic Acoustic Oscillation (BAO) surveys continue to play a key role, due both to:

- their ability to probe dark energy at high redshifts (and hence probe non-lambda models).

- their relatively simple systematic effects: weak dependence on the properties of whatever is being surveyed, and direct tie to the length scale measured in the microwave background.

A BAO survey targeting z~0.7 is now underway using AAOmega at the AAT, and one using FMOS on Subaru will start soon. Neither are really competitors to WFMOS, being an order of magnitude less capable.

On a 5 year timescale, the competition we currently know about may come from SDSS-3 (After Sloan 2, AS2) and HETDEX on the Hobby Eberly Telescope. Neither is yet fully funded, but both have a reasonable probability of proceeding. AS2 comes within a factor of 2 of WFMOS, but is targeted at z~0.5, and hence has minimal sensitivity to non-lambda models. The performance of HETDEX is less certain, principally due to the uncertain luminosity function of Ly-alpha emitting galaxies, and aliassing effects due to its sparse sampling approach. In the best-case scenario, it may provide a dark energy constraint at z~3 comparable to that obtained by WFMOS. But it provides no constraint at z~1. Furthermore, it will not be useful for the wide-ranging galaxy evolution science probed by WFMOS, due to its Ly-alpha selection (Ly-alpha is too optically thick to be a useful tracer of galaxy properties). In addition, the WFMOS team are considering the new approach of using Ly-α forest absorption as a probe of dark energy, which HETDEX cannot do, and which could allow much tighter constrains on dark energy with a smaller expenditure of telescope time.

The situation remains very fluid, and further delays in proceeding with WFMOS will undoubtedly increase the number and power of the likely competitors. In particular, the ADEPT space mission concept and SKA radio astronomy 21cm surveys may be very potent competitors in the longer term.

"Enabling" Science

WFMOS in its low-resolution mode will be of vital interest to the "Galactic Archaeology" program, as described below, including stellar population metallicities and dynamics in much of the local group.

A brief sample of other "PI" science includes:

- Wide-field studies such as the distributions of dwarf galaxies in different environments, such as clusters, filaments, and voids.
- Measuring the evolution (in redshift) of the black hole mass function in AGN, using reverberation mapping in thousands of AGN.
- Galaxy cluster studies: WFMOS will be able to obtain simultaneous redshift data for related and unrelated galaxies in superclusters and clusters.
- Studying the inter-relationship between the intergalactic medium (as probed by QSO absorption lines) and galaxies at high redshift.

WFMOS – II. Mining the Fossil Record of the Milky Way

Introduction

The WFMOS Facility, when realized through its marriage to the Subaru Telescope, will provide the Gemini partners with the tools necessary to deconstruct chemically and kinematically the stellar history of the Milky Way. This ambitious 'near-field' cosmological approach to understanding galaxy formation can only be undertaken for this one galaxy in the Universe, providing a complement to the more statistical 'far-field' cosmological studies. In its high-resolution mode (R ~ 40,000), WFMOS opens a truly unique window of parameter space, one which will not be matched by any 8-10m class competitor, even looking forward 10 years hence.

Transformative Science

The legacy of up to a one million star survey of the Galaxy at R ~ 40,000 cannot be overstated – the ability to chemically tag individual stars and trace them to their nascent birth clouds demands a high-resolution capability in order to probe the nucleosynthetic fingerprints of not only massive and binary star supernovae, but the full range of elemental probes of low- and intermediate-mass asymptotic giant branch stars and neutron capture. Indeed, the origin of the latter elements remains one of the Key Science Questions for the New Century (Connecting Quarks with the Cosmos) and provides a natural bridge to the nuclear astrophysics community. This connection has already begun to be realized, with the astronomical observations obtained during SEGUE (a part of SDSS-II), funded in part by the Physics Frontier Center JINA: Joint Institute for Nuclear Astrophysics. There is clearly a desire in the nuclear astrophysics community to build upon this involvement (see quote below). WFMOS will contribute directly and immediately to this Key Science Question, as one cannot expect to understand the origin of the elements without confrontation of fundamental nuclear physics and theory with the most primitive objects in the Universe – the metal-poor stars which will be examined en masse by WFMOS. In lockstep with pursuing the origin of the chemical elements, the ambitious forensic de-construction of the Milky Way will be undertaken– no other planned facility has the capability to do so over the coming decade. The 'Galactic Archaeology' program with WFMOS will dovetail nicely with the astrometric program of ESA's Gaia mission – the latter will provide unprecedented structural information for billions of stars, but not the associated chemistry of these stars – WFMOS is the only facility capable of providing this missing 'phase space' information.

Supporting the Needs of the Broader Gemini Community

One clear strength of the WFMOS facility is its ability to satisfy the needs and desires of a large fraction of its partners across all countries, above and beyond the obvious 'Galactic Archaeology' survey, through its flexibility and power as a PI instrument. WFMOS data will constrain fully many of the most important questions of contemporary astrophysics, ranging from the aforementioned origin and evolution of the astrophysical sites of the elements, to the nature of the mass function (in particular the Initial Mass Function) of the stars which formed the first elements, a detailed inventory of the nature of stars throughout the Local Group (e.g., the important low-luminosity dwarf spheroidal galaxies; extended streams which are likely to have arisen from the ongoing destruction of the building blocks of the halo; the stellar populations of M31 and M33), and a potential probe of the three-dimensional structure of the interstellar medium (through various atomic and molecular absorption features). This knowledge provides the basis for understanding the formation and evolution of galaxies in general. No claim to fully constrain the manner in which galaxies form and evolve will be complete without being able to satisfy the constraints that will be imposed on this process by detailed knowledge of the stellar populations of the Milky Way, in particular the build up and evolution of its halo population.

There are important collateral benefits associated with the support of WFMOS – High Performance Computational (HPC) modeling of galaxy formation and evolution is one of the primary growth fields in astrophysics. Rapid advances in both hardware and software/algorithms over the past 5-10 years have revolutionized the field from one dependent upon pure collisionless N-body simulations with uncertain transformations to the observervational plane, to one where entirely self-consistent treatments of baryonic and non-baryonic physical processes are feasible. However, such rapid advances can only reap appropriate scientific benefit when accompanied by comparable advances in our knowledge of a system's "boundary conditions". This is where WFMOS will provide invaluable information – with dozens of elemental abundances derived for up to a million stars in the Milky Way (in addition to exquisite radial velocities, obtained during the corse of these same measurements), modelers will have several tens of millions of datum to tie down their HPC efforts. In the present era, where modelers have at best several thousand such points, this anticipated three-orders-of-magnitude expansion of phase space coverage excites the HPC community to a degree that matches that of the observers who will drive the WFMOS Galactic Archaeology survey.

Postscript

In terms of its contribution to 'Galactic Archaeology', the GSC ranks WFMOS highly because of its large scientific return, its appeal across a broad range of astrophysical interests in the Gemini community, and its potential for bringing the Gemini and Subaru communities closer together. This leveraging of facilities has proven to be a strength of the Gemini program, and we encourage its continued application.

The Link to Nuclear Astrophysics

Below is a quote from the white paper of the town meeting "Study of Nuclei/Nuclear Astrophysics", held in Chicago in January, 2007, which engaged over 300 nuclear physics professionals from around the US, and which sought to assemble input for the nuclear physics community's long range planning.

"Another important development in nuclear science since the last long range plan is the growing connection with other fields driven by significant investments in interdisciplinary initiatives. Especially the field of nuclear astrophysics has undergone a transformational change into a truly interdisciplinary endeavor where astrophysicists and nuclear physicists work together to tackle the key problems in the field. The Joint Institute for Nuclear Astrophysics (JINA) has been the major driver in this accomplishment, others important efforts include nucastrodata.org at ORNL, and initiatives by individual research groups. *As a consequence, not only have the connections between nuclear physicists and theoretical astrophysicists greatly improved, but nuclear astrophysicists, including nuclear scientists, have begun to take a more active role in astronomical observations, for example through the JINA engagement in the SEGUE observational campaign. It is critical for the future of the field of nuclear astrophysics to continue and further broaden these developments."*

(B)

PRVS: Earth-like Planets Orbiting M Stars; Nearby Neighbors in the Habitable Zone

Finding and characterizing extra-solar planets is a rapidly expanding area of modern astronomical research. There are few, if any, areas of science that capture the public imagination more effectively. Research results in this dynamic sub-field of Astronomy & Astrophysics are frequently in the news and are regularly listed among the top 10 or 100 science discoveries of the year, decade and even millennium. Extra-solar planetary research is now and will remain one of the leading intellectual endeavors as it addresses fundamental questions concerning the origins of our cosmic environment and the origins of life. Instruments designed to search for planets around M-dwarfs will address the fundamental question of *how common are extra-solar earth-like planets in an environment that could support life.* The PRVS strategy of searching for terrestrial planets around M dwarfs has recently been validated by the discovery of a super-earth at a distance from the M3 dwarf GJ 581 that would support liquid water (Udry et al 2007)

Of the over 200 extra-solar planets discovered to date using a variety of techniques, the vast majority have been discovered using Precision Radial Velocity Doppler techniques which measure the tiny Doppler shift signature caused by a planetary companion. PRVS applies this technique in the near infrared (NIR) at the frontier of precision Doppler techniques. This will be an important complement to previous Doppler planet search programs, which have left the numerous M dwarfs largely unexplored, since the NIR region of the spectrum is where the cool M-type stars emit most of their energy. PRVS will extend the successful search techniques used in the visible to the NIR with expected precisions in the 1-3 m/sec range. The overwhelming majority of the Sun's stellar neighbors are cool, lower-mass M dwarfs. Of the ~150 stars lying within 8 parsecs, there are ~120 M dwarfs but only 15 solar-type G dwarfs. M dwarfs are intrinsically faint at visual wavelengths (15 to 10^6 times fainter than the Sun), but are much more luminous in the near-infrared. Thus, an M4 dwarf at 20 parsecs has V~14, which is beyond the reach of optical surveys, but with J~9.5, it is readily accessible to high-precision infrared radial velocity observations.

Since M dwarfs have lower masses than solar-type stars, a planetary companion of given mass at a particular separation produces a larger reflex motion in the parent star. Since the ambient temperature of a planet depends on the insolating flux, planets orbiting M dwarfs have much cooler temperatures than those orbiting solar-type stars. Consequently, key temperature zones, such as the Habitable Zone ("HZ ≡ liquid water sustainable on a planetary surface; Kasting et al, 1993) and the ice-line (the inner radius where ices survived in the protoplanetary disk) lie at smaller radii, with r ∝ $L^{-0.5}$. The HZ lies at ~1 AU and the ice-line at ~4 AU in the Solar SystemThe change of period of the HZ and ice line as a function of stellar mass enables important studies of planetary formation processes by observing the final outcomes in a large number of extrasolar systems through the habitable zone and ice line regions. Such studies are intractable for solar type stars due to the decade-long timescales involved.

The sensitivity and precision of PRVS will allow many hundreds of mid to late M stars to be studied for the presence of terrestrial planets in the habitable zone and will create synergies with space missions such as COROT, Kepler and Terrestrial Planet Finder/Darwin. The COROT/Kepler synergy is particularly compelling, since PRVS is the only instrument on the horizon with the capability to confirm the radial velocity orbit of planetary candidates detected around low mass stars, where the transit amplitude and period are most favorable for the detection of terrestrial mass, habitable zone planets. COROT was successfully launched in Dec 2006, and Kepler will launch in October 2008, and therefore a PRVS capability is scientifically urgent to establish the status of transiting planet candidates. Although there is currently great uncertainty in the TPF mission in the US, Darwin remains a priority in Europe, and is currently being proposed as part of the Cosmic Vision 2015-2025 for a possible launch in 2018. The discovery of terrestrial mass habitable zone planets with PRVS will leave a key scientific legacy to enable these missions, since there will be known targets that will guarantee successful characterization of the terrestrial planets with for TPF/Darwin.

PRVS is uniquely suited to Gemini's niche as high image quality infrared telescope. In addition to the transformative science provided by the precision radial velocity capability, PRVS will be a uniquely powerful high resolution near infrared spectrometer that will be a powerful tool enabling a wide range of astrophysics. The two competitive CoDR studies identified more than two dozen secondary science cases, covering stellar astrophysics, star formation, galaxy formation and cosmology. PRVS is immediately ready to proceed with construction of an instrument that will answer scientifically compelling questions about terrestrial mass planets and play a critical role in the scientific landscape of extrasolar planet studies.

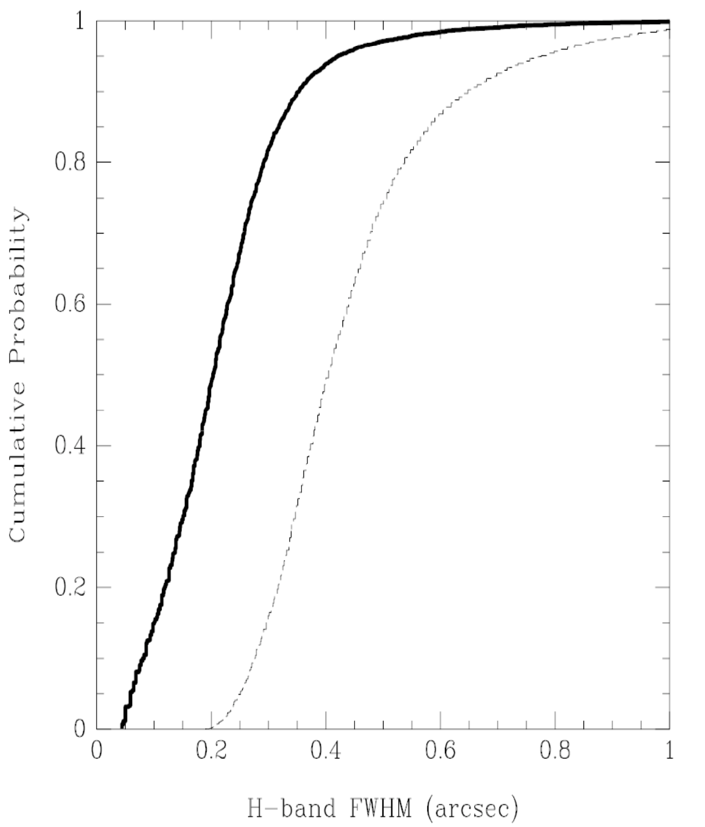
(C)

Summary of the science case for GLAO on Gemini North

GLAO will provide Gemini with diffraction limited high-Strehl mid-IR images across the telescope's full FOV, with all near-IR instruments receiving a low-order corrected beam across a field up to 10′. The system is projected to deliver image quality currently at the 20th percentile in 60-80% of the observing conditions. These capabilities will enhance many areas of Gemini science output and provide the best mid-IR capabilities available to any Earth bound observatory.

Highlights of Science Case: GLAO enables efficient surveys of large areas for first light objects, providing a factor of 4 improvement of speed for individual spectra compared to natural seeing and a large multiplexing advantage over conventional AO systems; d-IFUs and the improved GLAO image quality will produce a significant multiplexing advantage for surveys of velocity fields which will shed light on dark matter on galactic scales; finally the improved image quality and uniform point spread function (PSF) produced by GLAO will facilitate proper motion studies within the Local Group. Even while these specific Aspen science cases are addressed, an important feature is that every non-diffraction limited Gemini science proposal will benefit from a GLAO facility. Appendix B of the GLAO Feasibility Study Report describes a full range of science applications from local stellar studies through cosmology that will benefit from GLAO.

Performance Gains: Image quality statistics will be drastically altered by GLAO; image quality conditions that occur only 20% of the time currently, will occur 60-80% of the time when GLAO is operational (see figure). These GLAO-improved seeing statistics will ensure that top ranked proposals which require good image quality will be successfully carried out and, in general, will ease scheduling constraints and improve the operational efficiency of the observatory. Improved image quality also translates into shorter exposure times and an increase in the number of programs which can be executed. Gemini should realize a net 50% improvement in overall efficiency.



Anticipated improvement (dark line) in cumulative IQ distribution using GLAO compared to natural seeing at GEMINI North.

Survey Efficiency of GLAO: The large GLAO-corrected FOV and a potential d-IFU spectrograph will make Gemini a more efficient survey telescope, while improving the efficiency and performance of every seeing limited instrument at all scientific wavelengths.

Mid-IR Diffraction Limited Imaging: The Adaptive Secondary Mirror (ASM) will enable high Strehl ratio mid-IR observations. High priority observations that sometimes are now missed because of image quality constraints will be much more secure with GLAO. This improvement in image quality statistics will make scheduling programs easier and increase the operational efficiency of the observatory.

Phased implementation: A natural phased development of GLAO is feasible, greatly reducing the risk, while delivering exciting science at each stage. Initially the ASM can be deployed using the "normal" AO WFS system, immediately enabling the high-Strehl mid-IR capability. The second step will be to deploy LSG-GLAO to provide a wide correction to Flamingos-2, GMOS and other instruments. The final step will be to deploy GLAO specific instrumentation such as Multi-Object AO and a d-IFU.

(D)

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