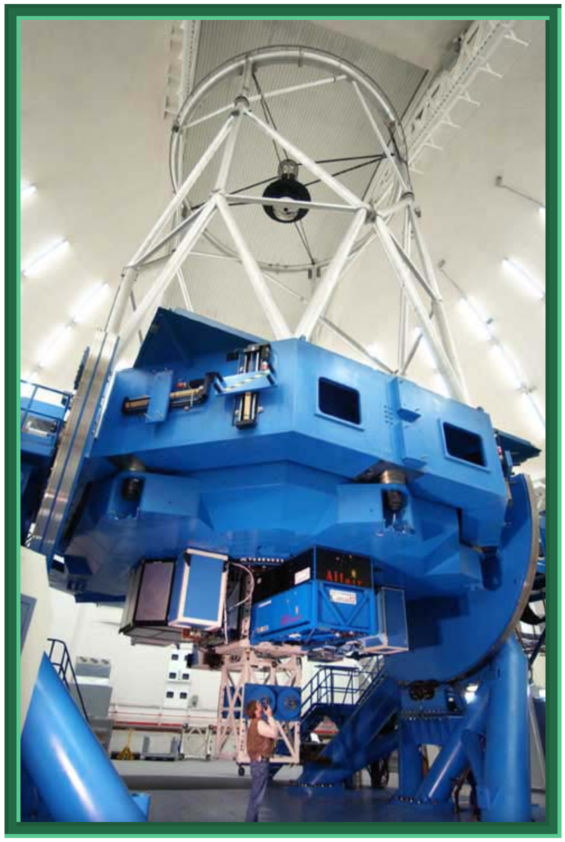
Managing Gemini Observatory's Future Instrumentation Program



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Cover Photograph: Gemini-North is shown with an array of instruments mounted on its Cassegrain rotator, including a facility adaptive optics system ALTAIR, a multi-object optical imager/spectrometer (GMOS), a Near Infrared Imager (NIRI), and a facility calibration unit (GCAL). Though currently state-of-the art, near the turn of the decade some of these instruments will likely be replaced with the next-generation instruments described in this report.

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1.0 Executive Summary

This is a companion document to the science report “Scientific Horizons at the Gemini Observatory: Exploring A Universe of Matter, Energy, and Life”, derived from the 2003 Aspen Workshop on future science at Gemini. The purpose for this document is primarily to (1) describe how Gemini Observatory intends to manage the development program in the future and (2) define cost estimates for the next generation of proposed instruments for the Observatory. It is divided into three sections. The first section includes a top-level description of the instrument development “life cycle” within Gemini, explaining how the Observatory shepherds the development of instruments through a multi-year process. The next section explains the “Aspen process” in more detail and includes brief instrument descriptions and Rough Order of Magnitude (ROM) level cost estimates, useful for budget development purposes, for the most highly ranked new capabilities identified during that workshop. These costs were generated through engineering and management resources provided by 10 organizations worldwide. They range from a low of ~$9M to a high of ~$35M and provide a broad range of potential new research capability for the Gemini Community well into the next decade. Finally, the third section describes changes made recently in the instrument program that will be used to streamline the procurement of instrumentation in the future, reduce the risk of schedule and cost overruns that plagued past Gemini instruments, and through a competitive bid process allocate future instruments to the best teams in the world, all while balancing long term this enormous reinvestment back into the Partnership. Together these three sections give programmatic context to the Aspen Process by explaining where we have been, are now, and will go with Gemini’s instrumentation program.

2.0 Introduction to Gemini's Instrument Development Process

The process used to take instruments from basic concepts to completed systems can be broadly decomposed into 4 components, as shown in Figure 1. This multi-year process begins with Community based strategic planning to define future science directions for the Observatory and roughly the resources needed to reach these goals. From there Gemini's worldwide set of instrument builders are invited to participate in competitive design studies for new instruments. After a down-select phase, instruments are awarded to qualified teams who build them under contract to Gemini. Each of these steps is discussed in more detail below and together they describe a science driven process for defining and developing future instruments. It is admittedly difficult to forecast scientific trends, given the rate of discovery within astronomy today, but this process ensures an instrument set that is well-reasoned with requirements tempered by a vision of where the Observatory should be headed in the context of other ground and space based facilities. Currently Gemini is in the first phase (Science Definition and Long Term Budget Planning) of the development program for its next round of instruments. It is also in the last phase (Completion Phase) for a number of instruments which are being delivered now at Gemini-North and Gemini-South. Maintaining continuity between these beginning and ending steps in the program is crucial to provide a steady stream of state-of-the-art instruments for Gemini's community to use in the future.

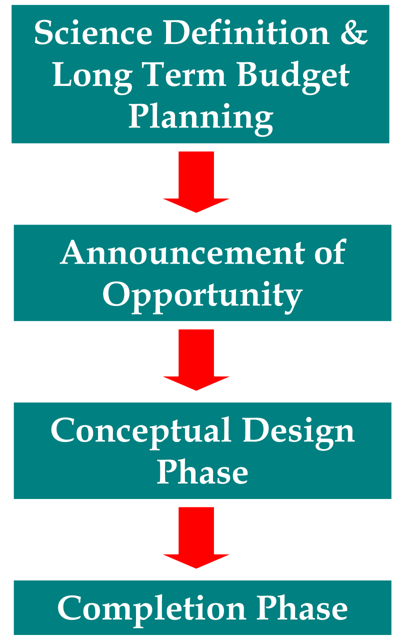


Figure 1 – The basic steps involved with carrying out the proposed instrument program are shown.

It is important to remember that even though many instruments are being delivered now, it takes years to complete the "lifecycle" illustrated in Figure 1. Furthermore, astronomy has always been a technology limited scientific enterprise, and the instruments being delivered now were designed, on average, about 5 years ago. Given that it will take at least 5-7 years from now to build the next generation of instruments for Gemini, the current round of instruments will be over a decade old from a technology perspective, making them obsolete in many ways by the time the next generation of instruments arrive. The time to start building the next generation of instruments for Gemini is clearly at hand, if Gemini is to retain its preeminent role as a leader among ground based observatories.

2.1 Step 1 - Science Definition and Budget Planning

Determining which instruments are developed through the design study level requires input from a variety of sources. Broad community involvement is needed to determine an optimal set of scientific drivers, from which an initial instrumentation suite can be derived. This initial science definition phase is led by Gemini, working in close cooperation with Gemini's National Offices, which act as conduits for astronomers within each Partner country. In essence the National Offices are Gemini's portal to its "customer", the astronomers who will use new instruments at Gemini in the future.

The science definition phase is centered around a series of scientific workshops which are topic based to organize participation along lines of expertise in astronomy. Topics include everything from planetary science and star formation to nearby galaxies and cosmology. The product of these scientific workshops is a series of legacy-caliber science missions that could be pursued with Gemini. A broadly defined set of new instrumentation requirements that will be needed to fulfill these missions is derived from these potential science missions. Beyond providing overall organization, one of the Gemini's primary roles in this process is to provide technical support for astronomers who need guidance on telescope and possible instrument capabilities (e.g., sensitivities, image quality, spectral coverage, etc.). This type of interaction is crucial to ensure that the science objectives defined by the community are technically feasible.

This whole process of mapping science goals into instrument requirements is inherently non-linear and circuitous, with design trades being weighted by various reality factors, including technical feasibility, risk, cost, etc. Though complex, within a year of the culminating international science workshop, Gemini will develop a science mission and corresponding next-generation instrument program, with clear traceability to the science goals identified by its community.

Beyond leading the definition of new instrumentation, Gemini will also modify existing instrumentation if cost-effective approaches to augment capabilities exist. A phased approach to deployment may also be used to maximize the scientific return of instruments. For example, it may not be possible to design instruments in the initial phase with sufficient detector coverage to meet all of the science goals, but sub-populating the focal plane with detectors initially while designing the optical train, array read-out controller, data handling system, etc. to handle an upgraded and fully populated focal plane in the future is a cost effective approach to providing instruments with staged capabilities.

Finally, during this stage preliminary cost estimates need to be generated to support broad trades both between competing instruments and within instruments as different modes are considered for inclusion or deferral. Performance models also need to be developed in order to guide and constrain the process of refining the science possibilities identified in this early stage of the project. Such early cost and performance containment is intended to guide the process of defining scientific capabilities, not overwhelm it, in an early stage where scientific creativity and originality is valuable. This step in the lifecycle of an instrument is explained in more detail in the next section, where the Aspen Workshop is described in detail.

2.2 Step 2 - Announcements of Opportunity

The output of the previously described science definition phase will be a set of design guidelines and rough cost estimates for a set of instruments that can be used to launch frontier science with Gemini. In some cases it may be necessary to fund technology development, at modest levels, to establish the viability of particularly challenging new instruments, reduce the risk of actually developing them, and define cost estimates with much better accuracy for budget planning purposes.

A balanced approach that takes advantage of varying site conditions, spectral/spatial resolution, and wavelength range, with at least some instruments having relatively simple designs leaves the community with varied capabilities that can be used to address both predicted and unforeseen research pathways. Other factors which feed into developing the next suite of instruments includes the long term north/south instrument balance, phasing new capabilities with older ones that are likely to be decommissioned, and in some cases recognizing that finite resources preclude developing some instruments now but they can potentially be built in the next round of development. A good example of many of these issues is GIRMOS. Several years ago, when the Phase 2 instrument set was devised, it was determined by Gemini and the National Offices that the technology needed to make a deployable cryogenic integral field infrared spectrograph was highly uncertain, not to mention any cost estimates for such an instrument. As a result Gemini funded several technology studies to look into both cryogenic fiber based and image slicer concepts for this instrument. One of the concepts which emerged was the novel GIRMOS concept, from the UK/ATC. Even though the design approach to build such an IRMOS was much better defined at the end of that process, the cost (now known with fairly high confidence, thanks to the study) was found to be prohibitively expensive and its applicability with MCAO marginal given typical target sky densities and apparent magnitudes. Now, ~3 years later, an instrument with roots back to GIRMOS has once again emerged, this time on the proposed instrument list from the Aspen Workshop and working behind a Ground Layer Adaptive Optics System, to boost the sky coverage of the instrument. While these steps have necessarily added delays in the development of the world's first cryogenic deployable integral field spectrograph, they have also led to careful assessments of cost, risk, and science capability that will, in the end, lead to an instrument with enormous research potential.

With design guidelines and ROM cost estimates developed for instruments and key areas of technology development, Announcements of Opportunity (AO's) will be released to solicit proposals to conduct design studies and/or development programs. These AO's will be distributed through a variety of mechanisms (e.g., Web pages, advertisements, Commerce Business Daily, etc.) to stimulate interest in a broad range of potential bidders, ranging from the private sector to universities and national laboratories and facilities. The product of the AO's will be a series of proposals, submitted to Gemini, for review by Source Selection Boards (SSBs), which will be chaired by Gemini but will also have membership derived from specialists, consultants, and experts from around the world. They will be relatively small groups with ~5-6 members and use common selection guidelines and criteria with other SSBs used for years successfully by Gemini in its "project days". Selection criteria will range from the quality of the proposal submitted, cost, facilities available, past experience, various merits of the technical approach proposed, etc. Where possible more than one team will be selected to conduct design studies for an instrument since this stimulates competition and ultimately cost reduction.

2.3 Step 3 - Conceptual Design Phase

From here the design study phase for a new instrument is launched, having been selected from a variety of proposals submitted to Gemini. The core product of this step in the instrument's development is sufficient information to make a decision about proceeding with actually building it. During this phase detailed and complex trades will be made between scientific capability, cost, schedule, and risk in a variety of forms. Assessments of exact plate scales, optical throughput, spectral resolution, stability, etc. will be made between the instrument team scientists and engineers, with regular input from the Gemini Observatory, to ensure that high level scientific goals and technical/programmatic constraints are adhered to as trades are made. The design study teams will be given cost envelopes to work within, which were derived earlier by Gemini in consultation with experts in various fields, so that teams do not produce designs which are well beyond the fixed budgets available to design and build instruments. Specific design study deliverables typically include:

- Overall Instrument Design Description – Illustrates all aspects of the design at a level needed to develop a reliable cost estimate for completing the instrument, including mechanical 3D renderings, electronics schematics, optical designs, sensitivity estimates based upon performance models, etc.

- Functional Performance Requirements Document (FPRD) – A document which describes all of the technical requirements the instrument must achieve and substantially acts as the guide for the engineering team to continue with detailed design and fabrication of the instrument.

- Observational Concepts Definition Document (OCDD) – A document which is substantially derived by the instrument science team which describes how the instrument will be used at the telescope. The OCDD and FPRD are cross-linked since scientific performance derived requirements map directly into engineering technical requirements. They will be further refined before being frozen at the CDR level of the design phase of the instrument.

- Unique Interface Control Documents (ICDs) – While Gemini will issue ICDs to define key electrical, mechanical, optical, and software interfaces to the telescope, some interfaces will be unique to an instrument and must be sourced by the instrument team.

- Management Plan – Describes for the remainder of the project the management approach intended to complete the instrument, including how it will be designed, fabricated, integrated, tested, and commissioned at Gemini. This also contains a detailed Work Breakdown Structure (WBS) for the entire project, with costs, manpower requirements, and durations associated within each WBS component. A detailed schedule to complete the design, then fabricate, test, and commission the instrument should also be submitted. A procurement list describing the components and materials that will need to be purchased to complete the instrument and a total cost to complete the instrument is also submitted to Gemini.

- Science and Technical Trade Studies – These describe the derived science applications for the specific design proposed, as well as the results of individual and important technical trade studies conducted during the design of the instrument, e.g., trades between mechanical layout and cooling efficiency, total mass and rigidity of the optical train in a varying gravity load environment, etc.

- Error Budgets – Detailed error budgets applied to the opto-mechanical design of the instrument, indicating allowed positional errors of optical components, wavefront errors, throughput allocations, and demonstrating how errors stack up to meet required image and/or slit-throughput requirements, factoring in telescope and atmosphere errors provided by Gemini.

As mentioned before, if the budget permits, design studies will be issued on a competitive basis between at least two teams. This naturally promotes competition in what will undoubtedly be an expensive arena, leads to greater technical diversity, and since all aspects of the designs are owned by Gemini (except for those agreed to be proprietary) the Observatory can explore taking the strongest aspects of different designs or design teams to merge them into more optimized designs, as well as merging teams into collaborative efforts. Furthermore, design study teams will be given cost envelopes to work within through the Requests for Proposals and, without competition, teams will lack motivation to develop designs that come in *under* the indicated budget available. Despite the higher initial costs of competing design studies, the use of competitive design studies at this early stage in the process has repeatedly been demonstrated to be a net cost reducer in the overall Gemini development program.

2.4 Step 4 – Completion Phase

At this point detailed cost estimates have been derived for instruments and various forms of key or enabling technology identified and, if possible, developed in parallel. Historically, the most risk prone period in this phase tends to be when the first instrument tests are completed, early in the integration phase of an instrument, when unforeseen problems emerge and rework is required. The instrument developer is also at risk as slips accumulate, since running costs are dominated by the on-going unforeseen manpower needed to keep a project going well beyond its planned duration. Management structures and development strategies must be used during Phase 2 to minimize such risks. In general terms this can be done by freezing out decisions early in the process, recognizing that while such decisions may impact performance at some level, they ultimately bring forward the key initial tests of the project and expose issues before they necessarily become time critical to resolve. The use of existing or previously proven designs or technology also reduces risk and is reflected in the types of technology development that would be funded early in the project, through the Conceptual Design Phase. Identifying through a detailed project plan any long lead items that need to be purchased, combined with aggressive procurement methods soon after authorization to build is issued from Gemini, are other methods repeatedly proven by past Gemini instrument teams, to “buy” schedule contingency early in the Completion Phase and reduce the impact of technical problems that do not emerge until the instrument goes into its test phase.

The Completion Phase includes a number of key project milestones on the path toward delivering the instrument. This part of the design work substantially culminates in the Critical Design Review (CDR), which includes deliverables such as:

- Final FPRD and OCDD – Final changes are made to these fundamental design and operational documents up to the CDR, upon consultation with Gemini. Note that the FPRD serves as the basis for the Acceptance Test Plan, while the OCDD serves as the basis for the User's Manual, i.e., though frozen at CDR they are drawn from heavily in subsequent delivered documentation.

- Compliance Matrix – A detailed summary table indicating where the design proposed meets and fails all design requirements listed in the FPRD.

- Final derived error budgets – Again, any changes in error budgets compared to those submitted during the conceptual design phase are made in consultation with Gemini.

- Final system design – This typically includes a complete 3D opto-mechanical model which is sufficiently well developed that fabrication drawings can be immediately extracted. Also included are predicted cooling performance of cryogenic instruments, mass budgets, finite element analyses indicating predicted flexure or thermal performance under varying environmental conditions, etc.

- Software – Detailed software designs, including all ICDs, flow charts, etc. needed to begin coding the actual software, immediately.

- Electronics – Final design documentation for all electronic systems, including cabling descriptions, layouts for wiring throughout the instrument, grounding schemes, all of sufficient depth that the electronics can be manufactured immediately.

- Acceptance Test Plan – In draft form, a plan which describes the procedures needed to verify that the instrument meets all requirements listed in the FPRD, using a variety of tests before the instrument is shipped and after it is connected to the telescope.

- Verification and Commissioning Plan – In draft form, a plan which describes how to systematically characterize the performance of the instrument on the telescope, in all of its modes. Such tests will allow astronomers to formulate observing proposals using the measured performance of the instrument.

- A revised budget and schedule to complete the instrument – Including a WBS showing all the tasks needed to fabricate, integrate, test and commission the instrument.

- Draft manuals – Such manuals should include a user manual, software manual, and service and calibration manual.

- Safety Review – As part of CDR a safety review is conducted to determine if the design meets safety requirements, particularly in the area of installation, maintenance, repair, and operation of cryogenic systems, high voltage drivers, large and potentially dangerous mechanisms, etc.

Some aspects of the design are actually frozen well before CDR. For example, the optical design is often frozen at the Preliminary Design Phase (PDR) because optics are often long lead items and the instrument design substantially flows from the optical design, meaning it is of limited use to delay procuring optics until a later stage.

Actual fabrication of instrument components proceeds from here, with the noted exceptions of key long lead items. The build phase of the project no longer involves detailed or complex design trades with the science team, as all key decisions impacting performance should have been made long ago. Instead this is a period of intense parts procurement, issuance of various subcontracts to machine shops or specialty vendors, careful tracking of components as they arrive, etc. This tends to be a relatively low risk phase of the effort and leads to an integrated instrument that requires extensive testing in a lab environment to verify functionality and performance. As mentioned before, this critical period of initial laboratory testing substantially defines the likelihood of the instrument being delivered on schedule, so steps taken to advance this milestone invariably reduce the risk of schedule and cost growths. Though subsystem testing certainly helps reduce complications downstream with full-up system tests, it is only with the instrument fully integrated that complex system-level interactions, whether optical (focus or light leaks), mechanical (flexure), electronic (unexpected noise), or software (unforeseen control system interactions), are finally recognized and therefore can be addressed. This is particularly the case for large cryogenic instruments, which have long thermal cycle times. For Gemini class instruments, every time rework is required it could take weeks just to thermally cycle the instrument, which adds up to enormous costs over a protracted troubleshooting period.

With the integration and test effort completed, the Completion Phase leads into on-site acceptance testing by Gemini. Typically this involves a team sent by Gemini with expertise in a broad range of engineering disciplines, as well as science and management representatives. They will use an acceptance test plan, which was agreed well in advance and derived from the FPRD, to formally work through all aspects of instrument performance and functionality to verify that contractual obligations have been met. In cases where the instrument fails to meet performance specifications, assessing the impact from a science perspective before making a final pragmatic assessment of the real impact of such problems is needed. All interfaces that can be checked should be verified on-site before the instrument is shipped to either Gemini-North or Gemini-South. In general up to 95% of the acceptance test plan can be executed before the instrument is shipped, with final verification occurring after the instrument is mated to the telescope and final checks on key interfaces are verified and on-sky performance is measured. Finally, at the end of this multi-year process, commissioning can begin, the purpose of that being detailed characterization of the instrument's actual performance, working in conjunction with the Gemini science staff, so that in the future astronomers understand the instrument/Gemini telescope system's performance well enough to design research programs around its capabilities.

3.0 The Aspen Process

On roughly a 5 year basis, which is ultimately synchronized with the funding cycle within the Observatory, Gemini leads a broad sampling of the scientific ambitions of its user base to define the top level capabilities of its next generation of instruments. As mentioned before, a basic element of the strategic planning process within Gemini's instrument program is *community involvement*. Gemini management recognizes that the Observatory acts as a conduit for instrument teams within the Partnership to provide capabilities that enable science for its worldwide constituency of astronomers. In effect, the customers for Gemini's instrument program are the astronomers that use the Observatory for their research. It is therefore crucial that the definition of future instrumentation stems from its customers and the vision they foresee in astronomical research. This periodic external scientific infusion into Gemini's development program is the heart of the "Aspen Process".

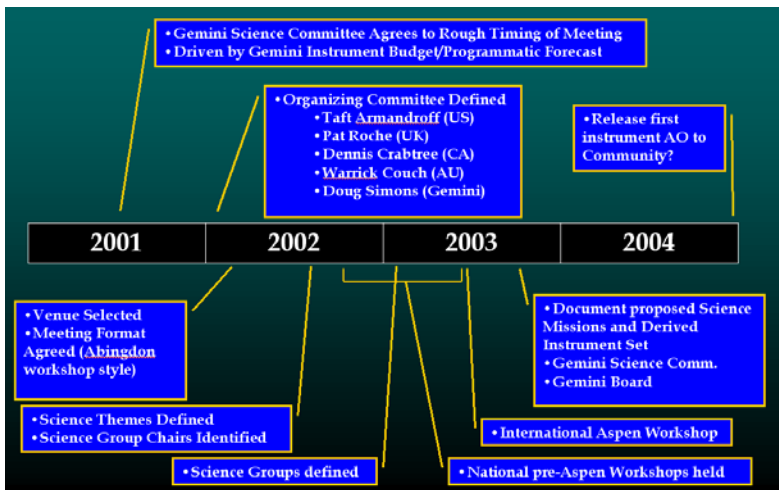


Figure 2 – A timeline is shown depicting Aspen Process milestones over the last 2 years.

The Aspen Process actually started in July 2001, with a decision at a Gemini Science Committee meeting to launch the next round of instruments through a science conference in 2003. Figure 2 illustrates the various steps taken between that GSC meeting in July 2001 and the Aspen meeting in June 2003. The Gemini Associate Director for Instrumentation was tasked to organize the science conference, who in turn recruited lead scientists within several Partner countries to act as the organizing committee. After selecting a venue for the meeting, 4 science themes were defined which together broadly defined a comprehensive set of astronomical research topics. The intent of defining these themes was to structure the workshop and its participants into 4 groups that could focus on a set of research topics, ranging from planetary science to high-z cosmology. The science themes and corresponding group chairs participating in the Aspen Workshop included:

- Chris Tinney: Stars, the Solar System, and Extrasolar Planets
- Michael Meyer/Bob Blum: Star Formation Processes and the ISM
- Rosie Wyse: Structure and Evolution of the Milky Way and Nearby Galaxies
- Bob Abraham: Formation and Evolution of Distant Galaxies and the High Redshift Universe

In parallel with this activity the organizing committee also launched national pre-Aspen meetings within their respective countries in order to develop coherent science perspectives leading into the international workshop. These pre-Aspen workshops were generally structured along the same science themes as the Aspen meeting, and acted as a channel for *many* astronomers to inject their perspectives about the future science direction for Gemini. The Aspen attendees attended these national workshops, thereby provided continuity between all of the various science meetings. The Aspen Workshop, in the end, was attended by 93 people from around the globe, with membership within each science group proportioned according to Partner shares to ensure that each group had a broad international component and therefore received input from each of the various pre-Aspen national workshops. Furthermore, members of the Gemini science staff were present in each science group, which was critical since that same staff will ultimately be users and operators of the instruments which eventually get built as a result of the Aspen meeting.

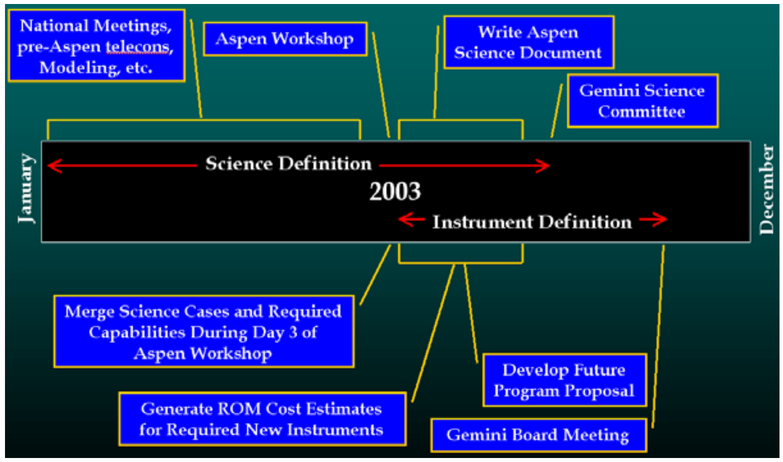


Figure 3 – A more detailed timeline of 2003 milestones in the Aspen Process is shown.

Given the large amount of advance work that went into sampling the Gemini community, the product of the Aspen workshop was in essence the distillation of input from hundreds of astronomers worldwide about where they think Gemini should be headed scientifically and what new capabilities would be needed to support these scientific ambitions. The report which documents the future science mission for Gemini, entitled "Scientific Horizons at the Gemini Observatory: Exploring A Universe of Matter, Energy, and Life", expresses what key questions in astronomy our Community would like to address in the next ~5-10 years at Gemini. It also describes the observations at Gemini needed to achieve these science goals, many of which require advanced new instrumentation. That document ultimately is directed to the Gemini Science Committee (GSC) for comment and review before that body prioritizes the science and corresponding instrumentation as part of a recommendation to the Gemini Board about what should be funded in the next 5 year budget cycle. As seen in Figure 3, the science definition phase of the Aspen Process ends with that recommendation from the GSC to the Board. A second parallel track of activity started with the end of the Aspen Workshop, the so-called instrument definition phase, the first step of which was to take the new capabilities required to support the science mission the emerged from the Aspen Workshop and generate cost estimates for the new instruments and facilities required. This document, combined with the Aspen Workshop science document, establish traceability between the science ambitions of the Gemini community to a set of future instruments, defined by top-level design requirements and a set of rough order of magnitude (ROM) cost estimates.

Finally, it is important to recognize the difference between the 1997 Abingdon Instrumentation Workshop and what occurred in Aspen in 2003. In the former, funding already existed to build the next-generation instruments for Gemini, hence the conference had more of a blend of technical and science discussions than what occurred in Aspen. In contrast, no funds existed at the time of the Aspen Workshop to build new instruments for Gemini, the current 5 year fiscal cycling coming to a close in 2005. As a result the Aspen workshop tended to focus much more on “big questions” in astronomy that can be addressed through new capabilities at Gemini, in the knowledge that the funding agencies would need a comprehensive standalone science case in order to raise the funds needed to support the future Gemini instrument program.

3.1 Aspen Instrument List and Approximate Costs

As mentioned before, a large cost estimate exercise defined the core of the second track of activity in the Aspen Process. Gemini primarily sought the support of its National Offices to help develop these cost estimates, taking advantage of the broad range of expertise available there and recognizing that as future stake holders in Gemini’s instrument program, the National Offices rightly have a role in defining the probable future costs of these instruments. In total 10 organizations supported the cost estimation exercise for the proposed instrument list that emerged from Aspen, including:

- Anglo-Australian Observatory
- Australian National University
- Gemini Observatory
- Herzberg Institute of Astrophysics
- Lawrence Livermore National Laboratory
- National Optical Astronomy Observatory
- University College London
- University of Durham
- University of Montreal
- UK Astronomy Technology Centre

Of course numerous commercial entities also supported this effort, in consultation with the various astronomy organizations listed above. Given the tenuous nature of the designs at this very early stage in the process, these estimates naturally remain approximate. In order to establish uniformity across all of the sources, cost estimates were submitted to Gemini broken down into various capital and labor budget categories, with labor defined in FTE’s and no overhead added. Gemini also issued guidelines about typical costs projected for detectors in the next ~5 years, ranging from a low of $75,000 for a 2048x4096 pixel CCD, to $300,000 for a 1024^2 mid-IR detector, to $500,000 for a 2048^2 NIR detector. Cost estimates include essentially all expenses from “cradle to grave” for new instruments, including funds for initial competitive design studies through commissioning and provision of pipeline data processing software as a standard deliverable for future instruments. Gemini added a nominal overhead to each estimate and again, given the uncertainty in the instrument designs and initial estimates, an additional 25% contingency was added to the estimates in most cases (50% was added to the GLAO system estimate).

Table 1 lists the new instruments that emerged from Aspen as the most popular and supportive of various science objectives articulated during the Workshop. In addition a pair of new facilities will be needed at Gemini in order to support some of these new instruments, namely a new f/6 configuration for one of the Gemini telescopes (for the wide field optical MOS) and an adaptive secondary as part of a ground layer AO system (for the GLAO imager and GLAO spectrometer). This combination of new instruments and facilities will be prioritized through the Gemini Science Committee, but as a standalone list provides an interesting perspective of where the Gemini community feels future instrumentation resources should be invested. In summary, these potential instruments include, in no particular order -

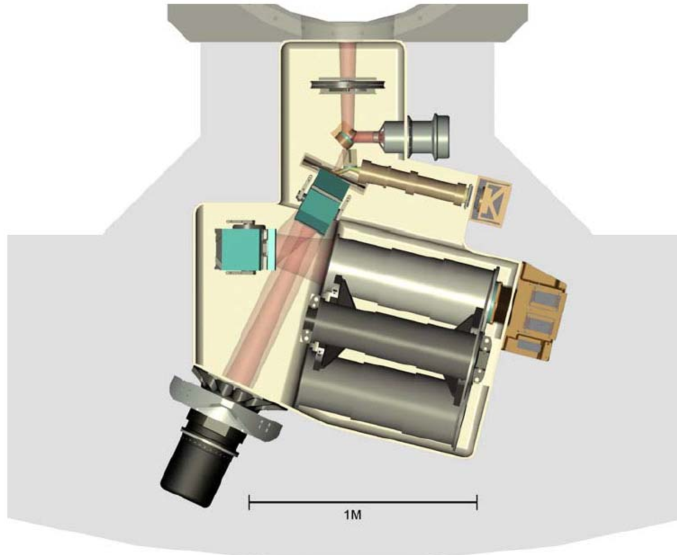


Figure 4 – Adapted from the document "Super-Phoenix: An Advanced Cryogenic Echelle Spectrograph for Gemini", this figure illustrates a 1-5 μm instrument concept that resembles what was identified in the Aspen Workshop as the High Resolution NIR Spectrometer. The Gemini space envelope is shown surrounding the instrument.

- High contrast extreme AO coronagraph – This instrument would be a follow-on to NICI in the search for extremely faint planetary companions to nearby stars and brown dwarfs. Using more than an order of magnitude more actuators in its AO system to provide considerably higher strehls than NICI can provide, the AO portion of this proposed instrument represents a significant technical challenge. Two options are listed for the same instrument – either an IFU front-end to a camera or a dual channel imager (like NICI) would be used. Spectral information is needed to disentangle faint artifacts stemming from seeing or the telescope optics from real companions and either of these approaches stand to provide the necessary imaging and spectral information from the speckles recorded. If funded this trade will be handled through the design study phase of the instrument.

- High Resolution NIR Spectrometer – This is intended to provide the same basic capability that PHOENIX now offers on Gemini-S, but it will be cross-dispersed to provide vastly greater spectral information than PHOENIX, which has very limited spectral coverage given its relatively simple optical design. Like the high contrast coronagraph, this instrument was broadly supported by both the Stars, Solar System, and Extrasolar Planets science group and the Star Formation Processes/ISM group. One of its most interesting applications involved the use of a gas absorption cell to provide high stability near-infrared spectroscopy of low mass stars and brown dwarfs, in search of planets. This is the same concept that has been used successfully in recent years at optical wavelengths, except on Gemini this technique would be pushed to much lower planetary masses than was ever possible by using infrared spectroscopy techniques, which are much more sensitive to these intrinsically faint red objects.

- High Resolution Optical Spectrometer – This instrument is unique in that it is the only UV optimized instrument within the Aspen list. It is intended to provide full spectral coverage from UV to far-red optical wavelengths in a single integration at fairly high (R~50,000) spectral resolution. The science case for this instrument is similar to that developed for HROS, which was of course canceled several years ago within Gemini's instrument program for various reasons. It will be used for ISM studies, metallicity studies in stellar research programs, etc.

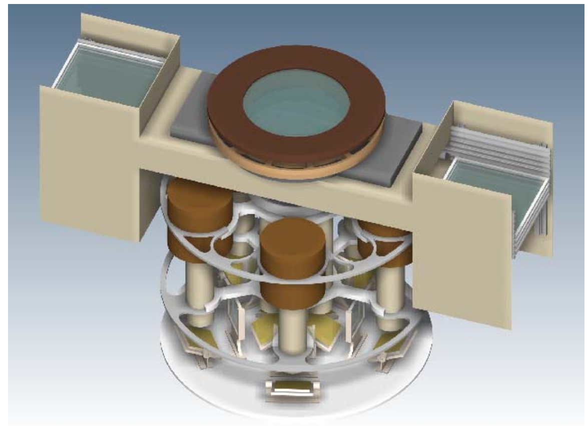


Figure 5 – Provided by the AAO, shown above is an initial concept for a new wide field multi-slit optical spectrometer. It would sample the ~45 arcmin field of the f/6 configuration of the telescope and utilize 5 separate spectrometers to sample the bulk of the field of view.

- High Resolution MIR Spectrometer – This instrument was ranked highly by the Star Formation group, noting a variety of applications in spectral diagnostics of deeply embedded forming star systems. It would be unique in its extremely high resolution, which has been demonstrated by the PI instrument TEXES (Lacy *et al*. 2003, SPIE, Vol. 4841, p. 1572) to be effective at resolving complex molecular features in the cores of star forming disks.

- MCAO Fed NIR Multi-object Spectrometer – One of the instruments proposed to take advantage of the Gemini-S MCAO system, this 1-5 µm MOS emerged as a highly ranked instrument from the Star Formation/ISM science group, with multiple applications to perform detailed high spectral/spatial resolution observations of embedded compact targets in morphologically complex star formation fields. It is proposed to have a spectral resolution of ~30,000 and operate in J, H, K, L, or M over the ~ 2 arcmin field of the MCAO system.

- Wide Field Optical Multi-object Spectrometer – With a field of ~45 arcmin, this instrument is one of the widest field instruments to emerge from the Aspen workshop. It is intended to work in conjunction with a new f/6 telescope configuration and operate from UV wavelengths (0.34 µm) through 0.9 µm. Various spectral resolutions will be possible, ranging from ~3000 to 40,000. When combined with an enormous multiplex gain, achieved by recording spectra on ~1000 targets simultaneously, it could be used for a number of high-z wide field research programs on Gemini.

- AO Fed NIR Spectrometer – Exploration of dark matter is at the heart of the science case for this new instrument, which to first order resembles a wide field version of NIFS. It will be optimized for R~2000-3000 observations in the 2.3 µm CO band head and feature a 20 arcsec field of view with, potentially, variable sampling with the highest spatial resolution used in the center of the field. Using the CO molecular feature, which is common in the spectra of stars that frequent the cores of galaxies, this instrument will be used to measure velocity fields of the stellar component of galactic nuclei. In this way it will be able to map, in a fair amount of detail, the distribution of dark matter circling galactic cores.

- IFU Optical Spectrometer – This instrument is similar in basic concept to that described above, but is intended to have a much larger field and work at optical wavelengths. If built its ~2 arcmin field of view would dwarf the field offered by any current integral field spectrograph (e.g., the GMOS IFU now provides a ~5" field of view). The spectral resolution of observations made with this would be in the 3000-5000 range and, unlike its narrower field NIR counterpart, this instrument would be optimized for natural seeing, not AO. Its main science driver is research in stellar populations, enabling highly multiplexed observations of large numbers of stars in a single observation across the disks of galaxies.

- GLAO NIR Imager – This instrument is arguably one of the simplest to emerge from the Aspen Workshop. It is similar in design to the Gemini South Adaptive Optics Imager (GSAOI), but would have a faster camera in order to provide 0.15 arcsec pixels, which would be matched to sample what is tentatively expected to be delivered from a Ground Layer Adaptive Optics system on Gemini. It would use advanced detectors that can operate from mid-optical wavelengths through 2.5 µm. An option for this instrument would be to include an etalon to yield a Fabry Perot spectroscopy mode. A particularly interesting application for this mode would be to use its advanced low dark current detectors to image fairly large swaths of the sky in between the OH airglow lines, pushing to extremely faint detection level searches for high-redshift targets.

- GLAO NIR Spectrometer – Of considerably greater complexity is the NIR spectrometer that would potentially be used with a new ground layer AO system on Gemini. This instrument would feature 16 deployable cryogenic integral field units, feeding a pair of large format NIR detectors. Like the GLAO imager, this instrument would work at wavelengths as short as ~0.6 µm with a spectral resolution of ~3000. It would deploy its IFU's across a 10 arcmin field and would be particularly valuable in observations of distant, still forming galaxies, and even in "first light" experiments, tracing activity to the edge of the observable universe.

- Fiber Fed Optical Multi-object Spectrometer – This instrument is very similar to the Kilo Aperture Optical Spectrometer (KAOS) and with a field of ~1.5 degrees would offer an enormous multiplex boost to anything that is currently available on Gemini. It requires a new prime focus top-end on Gemini and a fiber feed to an array of spectrometers that would be mounted in the bottom of the telescope pier. Such an instrument would provide

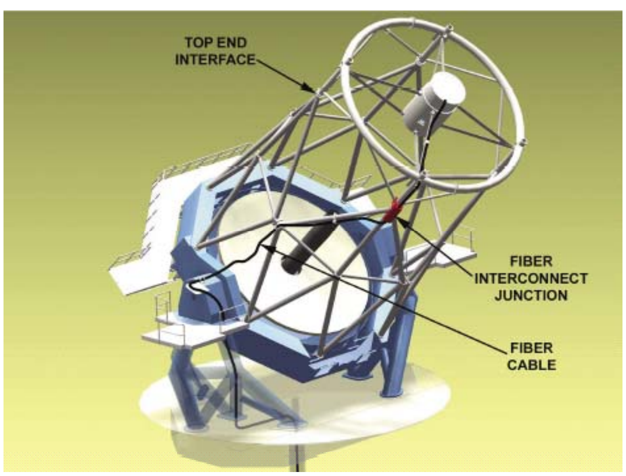


Figure 6 – Adapted from the KAOS Purple Book, on the left is a rendition of the new prime focus top end with several fiber bundles routed down the side of the telescope. These fibers terminate in a series of identical spectrographs which are housed in the pier lab (right).

for a variety of spectral resolutions, ranging from 1000 – 40,000, and use 4000-5000 fibers to select targets across its enormous field of view. Primary science drivers include projects that would "tag" spectroscopically upwards of a million stars, allowing distinct stellar populations within the Galaxy to be identified, offering a unique insight into how the Galaxy was actually formed. It also stands to measure the equation of state of dark energy by detecting the characteristic scale length of acoustic oscillations for extremely high redshift galaxies – a technique that does not have the uncertainties associated with supernovae based measurements of the same parameter.

New facilities are of course also needed to support some of these instruments. These include –

- New f/6 Telescope Configuration – The wide field optical MOS relies on an f/6 beam from the telescope to provide a ~45 arcmin field. This new facility includes a considerable array of new hardware and software, including a new 2 m diameter secondary mirror, facility field corrector, facility ADC, instrument support structure, acquisition and guide unit, various forms of handling equipment, primary mirror baffling, secondary mirror control system, top end structure, and storage space.

- Adaptive Secondary – The GLAO based instruments would require a different type of new top end for the telescope, this one housing an adaptive secondary with nominally ~250 actuators across the back of a thin face sheet. The intent would be to make this new secondary optically compatible with the existing f/16 secondary so the existing ISS and A&G could be used. If possible it would be reverse compatible with the current f/16 based system. As a result the duration of telescope shutdown period needed to make this transformation should be considerably reduced compared to the f/6 configuration change. Consistent with a 10 arcmin field of view requirement, only the up-looking port would be compatible with the GLAO. That ISS port would be partially occupied by an instrument containing the wavefront sensor system and possibly additional active elements to yield the desired level of correction. This system would require the same ~50W sodium laser needed by MCAO but a launch projector that directs the beams over a considerably wider constellation in the sky than MCAO is now designed to support.

Aspen Instrument Summary

Instrument Description	Wavelength Range (µm)	Spatial Resolution	Spectral Resolution	1-Shot λ Coverage	Field of View	Multiplex Gain	Primary Modes	Comments
Extreme AO Coronagraph – IFU or Dual Channel [(a)]	0.9 – 2.5	0.02” IFU sampling; 0.02” imaging	30-300	J, H, or K	3”	1 Object	Coronagraph	10^7 contrast from 0.1-1.5” radius; includes polarimetry mode and IFU foreoptics or dual channel imager
High Resolution NIR Spectrometer	0.9 – 5.0	0.2” pixels	70,000	1.0 – 2.5 µm or 3 – 5 µm	3” slit	1 object	X-dispersed spectrometer + polarimetry	Seeing limited; includes absorption cell
High Resolution Optical Spectrometer	0.3 – 1.0	~1” sampling on sky	50,000	0.3 – 1.0 µm	~1” image slicer	1 object	X-dispersed spectrometer	Assumes image slicer; UV is priority
High Resolution MIR Spectrometer	8 – 17	0.1” pixels	100,000	1%	~3” slit length	1 object	X-dispersed spectrometer	Similar to TEXES
MCAO Fed NIR MOS	1.0 – 5.0	0.05” pixels	30,000	J, H, K, L, or M – long slits; TBD multislit	2 arcmin	100	MOS baseline; X-dispersed option	
Wide Field Optical MOS[(b)]	0.34 – 0.9	0.2” pixels	3000 – 40,000	TBD	45 arcmin	~1000 objects	MOS	f/6 mounted MOS
AO Fed NIR Spectrometer	2.3 (CO band head)	0.05” sampling on sky	2000 – 3000	2.2 – 2.4	20 arcsec	1 object	IFU	Wide field version of NIFS; variable plate scale
IFU Optical Spectrometer	0.45 – 0.9	0.2” sampling on sky	3000 – 5000	500 Å	2 arcmin	1 object	IFU	MEIFU concept
GLAO NIR Imager[(c)]	0.6 – 2.5	0.15” pixels	3000	R, I, J, H, K (Broad band)	10 arcmin	Panoramic	Imager	Assumes NIR detector works out to 0.6 µm; 0.15” pixels critically sample GLAO K-band PSF at 5’; FP used in imager for R~3000
GLAO NIR Spectrometer[(c)]	0.6 – 2.5	0.2” sampling	3000	R, I, J, H, K	10 arcmin patrol field	16 dIFUs	Deployable IFU	dIFU like GIRMOS
Wide Field Fiber-Fed Optical MOS	0.39 – 1.0	~1” sampling	1000-30k	0.4 µm (low res)	1.5°	4000-5000	Fiber-fed spectrometer	Similar to KAOS

Table 1 – A summary of new instruments which were derived from the science discussions during the Aspen Workshop is listed. Instruments have been color coded to link them with the science groups in Aspen. Note that in many cases different science groups identified the need for the same new capability.

Notes:
(a) Only one coronagraph will be built – determining whether it will be use an IFU or dual channel imager will be the subject of a future design study.
(b) This instrument requires a new f/6 top end for one of the telescopes
(c) These instruments require a new Ground Layer Adaptive Optics system, which incorporates an adaptive secondary

Color Codes:
Stars, the Solar System, and Extrasolar Planets
Star Formation Processes and the ISM
Structure and Evolution of the Milky Way and Nearby Galaxies
Formation and Evolution of Distant Galaxies and the High Redshift Universe

Table 2 summarizes the ROM–level cost estimates generated for each new instrument or facility identified during the Aspen Workshop. These estimates cover complete system costs and include such factors as –

- Component Costs
    - Optics
    - Mechanical
    - Electronics
    - Detectors
    - Etc.
- Labor Costs
    - Software
    - Design
    - Fabrication
    - Integration/Test
    - Commissioning
    - Etc.

Labor estimates provided by the aforementioned organizations were uniformly defined in FTE's and a flat USD110,000 cost per FTE was applied by Gemini in the generation of the estimates listed. In addition a 25% level of contingency was added to the total value of each estimate, which is reasonable given the uncertain nature of the instrument designs at this early stage in the process. Through the eventual formal incorporation of cost estimates in Gemini's future Instrument Development Fund (IDF) and Facilities Development Fund (FDF), other factors will be taken into consideration, including inflation, cash flow, sequencing of new instrument and

New Instruments	**Total Estimated Cost (USD)**
Extreme AO Coronagraph	12,961,313
High Resolution NIR Spectrometer	17,260,000
High Resolution Optical Spectrometer	8,495,000
High Resolution MIR Spectrometer	20,481,250
MCAO fed NIR MOS	24,303,750
Wide Field Optical MOS	31,159,375
AO-fed NIR Spectrometer	14,876,625
IFU Optical Spectrometer	14,000,000
GLAO NIR Imager	14,139,375
GLAO NIR Spectrometer	21,592,500
Wide Field Fiber-Fed Optical MOS	31,977,125
New Facilities	
f/6 Telescope Configuration (1 telescope)	33,035,625
GLAO System including Adaptive Secondary	23,535,960

Table 2 – Cost estimates for the various new capabilities described earlier, which are all traceable to the science goals defined in the Aspen Workshop, are summarized. New instruments which require new facilities have been identified with a common color code, since these are in essence system packages.

facility start-ups, etc. Combined these estimates lead to full-up burdened cost estimates to take instruments from a competitive design study phase all the way through commissioning on the telescope. From there operations costs are covered elsewhere within Gemini's budget, which are not reflected in the estimates listed in Table 2. For example, there will be additional costs like new vacuum and cryogenic equipment, storage, networking, electrical power systems (UPS), electronics supplies, new instrument handling equipment, spare parts, etc. The costs for all such facility-wide upgrades and maintenance components have been considered and are covered elsewhere in the Observatory's IDF and FDF budgets.

3.2 Operational Considerations

Beyond the various costs outlined previously, there are other factors that should be assessed as part of the new instrumentation suite that emerged from Aspen. These can be broadly broken down into various categories that logically stem from Table 2. Listed below are summary descriptions of the operational implications associated with several possible scenarios, depending on which subset of the instruments listed in Table 2 are actually built. They are listed in order of decreasing operational impact on the Observatory.

- **Wide Field Optical MOS** – Building this instrument requires a major reconfiguration of one of the Gemini telescopes since it needs an f/6 optical feed. New f/6 telescope components include:
    - Acquisition and Guidance unit
    - Primary mirror baffles
    - Instrument support structure
    - Secondary control system
    - Facility atmospheric dispersion compensator
    - Facility field corrector
    - Secondary mirror
    - Secondary mirror tilt system
    - Top end mechanical structure
    - Assorted custom handling equipment
    - Etc.

  Installing and commissioning all of this new equipment on the front and back-end of a telescope is roughly estimated to require 6 months, during which time no science observations will be possible. Given the major changes required, it is unclear if switching between the baseline f/16 and new f/6 telescope configurations is feasible. Though a detailed assessment has not been made, most existing instruments would likely not function with this new telescope configuration, meaning for a considerably time after commissioning the f/6 mode is complete, the telescope would only be capable of supporting the new wide field optical MOS. In essence, the most likely result of building this instrument would be to dedicate one of the Gemini telescopes to exist in an f/6 configuration with a single instrument, well into the next decade.

- **Wide Field Fiber-Fed Optical MOS** – Because this instrument is fiber fed from the telescope's prime focus, it does not need the major changes required by its "cousin" above. The basic operational concept is to build a new top end that is interchangeable with the existing f/16 top end structure. Signal photons are fed from that new prime focus mounted fiber positioner into a several fiber bundles carrying thousands of fibers which lead into the pier lab, where they are dispersed and recorded by a set of identical spectrometers. Assuming no other instrument occupies the pier lab (true now at Gemini-N but bHROS occupies the Gemini-S lab), room exists to accommodate the large set of spectrometers in the pier lab without removing existing facilities. It is important to note that though Gemini was designed to have interchangeable top-ends, these structures have never been moved since the telescopes were originally constructed and the down-time associated with this procedure remains uncertain. For example, beyond the time needed to interchange all the hardware, it is unclear if the interchange process would preserve the mechanical tuning of the secondary support structure. If the support structure resonances are not the same when the f/16 top end it is put back on the telescope, it may be necessary to retune the f/16 tilt system (a very complex electro-mechanical system), which could take considerable amounts of engineering time. That said, while the operational implications of supporting an instrument like the wide field fiber-fed optical MOS are large, they are not in the same league as the f/6 mode, from a variety of perspectives.

- **GLAO Imager and Spectrometer** - Again, referring to Table 2, building either of these instruments requires a new facility ground-layer adaptive optics system. The heart of this new system would be an adaptive secondary that would nominally provide the same f/16 beam feed as the current top-ends on Gemini. The detailed implementation of an adaptive secondary remains particularly uncertain at the time of this report. The concept developed this far requires, beyond the new adaptive secondary, a fairly complex wavefront sensing system that would be housed in a structure underneath the existing up-looking ISS port, which is the only port that can transmit the ~10 arcmin beam needed by these instruments. Operationally this of course means that unlike ALTAIR and MCAO, which can feed any instrument on any ISS port, only a single GLAO instrument will be operational on a given night and block-scheduling will be needed to support both an imager and spectrometer. The restriction of routing the GLAO beam exclusively through additional hardware on the up-looking ISS port also impacts the space and mass remaining for the imager and spectrometer. While the imager will be a relatively simple instrument and may fit within the space remaining, it is doubtful that enough space would be available for the spectrometer, meaning it may have to be installed on another ISS port and an optical beam feed around the ISS developed to support it. Existing instruments that take advantage of the up-looking port through its lower emissivity or polarization capability would no longer benefit from these features. Finally, though the adaptive secondary would yield an f/16 beam into the other (side port) instruments, unless the adaptive secondary can preserve its optical surface open-loop, new high order wavefront sensors would have to be built into existing instruments to support the adaptive secondary closed-loop on a continual basis. A number of design trades need to be made conducted to sort these GLAO implementation challenges on Gemini, i.e., the first step in building a GLAO system for Gemini would likely be a set of funded design studies to resolve these technical issues, before a final decision to pursue its development is pursued. As a result of the previously described uncertainties a contingency level of 50% has been added to the cost for this new facility, compared to the 25% contingency added to the rest of the new instruments and facilities.

- **Remaining Instruments** – The remaining instruments in Table 2 should not require major telescope changes to make them operational. These instruments include –

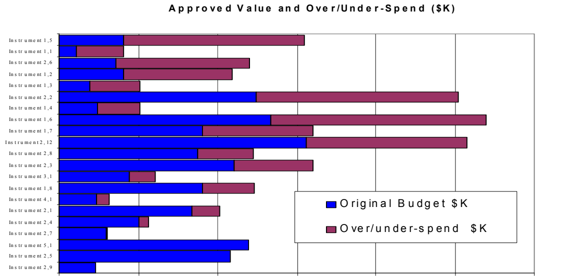
    - Extreme AO Coronagraph
    - High Resolution NIR Spectrometer
    - High Resolution Optical Spectrometer
    - High Resolution mid-IR Spectrometer
    - MCAO fed NIR MOS
    - AO-fed NIR Spectrometer
    - IFU Optical Spectrometer

  Accordingly, though the design concepts for these instruments are preliminary, special operational procedures are not expected to support any of these instruments.

4.0 Changes Over a Decade in Gemini's Instrument Program

Thus far basic questions like how new instruments will be procured and roughly how much they will cost have been addressed. A natural follow-on question is how will Gemini improve the track record within the instrument program to ensure these new instruments meet program-wide goals? Gemini's instrument program has evolved considerably during its ~10 year lifetime. In many ways the changes made in the instrument program have been reflections of the nature of the Gemini Partnership, which also has changed over the years, as the Gemini 8 m Telescope Project has turned into the Gemini Observatory. To date Gemini's instrument program has led to the delivery of 5 facility class instruments, a total of 5 telescope facilities (including ALTAIR, GPOL, and GCAL) and 6 instruments or facilities are still under development (including MCAO). Cleary it is one of the largest instrument programs in ground based astronomy, calls upon an international resource base unlike any other program, and in many respects has been a leader in key technology development beneficial to all of astronomy. Given all the instruments delivered to date, it would seem that Gemini's instrument program is well poised to carry out the design and fabrication of a modern, new suite of instruments that will act as the platform for future observations at Gemini. While true, Gemini's program has also suffered from fairly staggering losses. These losses have been evident in many forms, including enormous cost overruns, multi-year schedule slips, and perhaps most importantly, lost scientific opportunity. Figure 7 illustrates how poor the cost and schedule track record has been for 8 – 10 m instrument programs. While the track record of Gemini's instrument program is arguably improving, the problems of the past cannot be ignored and it is important to recognize the variety of changes made in the program, since its early days, that will lead to improved performance from a programmatic standpoint when the next set of instruments is built.

Competition: The initial round of "Phase 1" instruments built for Gemini were allocated according to Partner shares within the consortium to organizations for a range of reasons, including expertise in a particular technical field, interest in a particular scientific field, etc. This approach to assigning instruments to teams was substantially competition free and while it was an effective means of ensuring that Project funds were distributed uniformly back into the Partners, it failed to award instrument projects based upon broadly competitive merit. This approach has been completely discarded in the current instrument allocation process, which is based upon a fairly conventional competitive bid system. The only restriction applied is that only



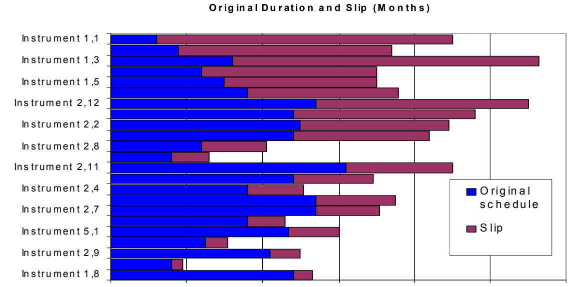


Figure 7 – Data compiled by Adrian Russell at the UK/ATC which depicts schedule (left) and cost (right) overruns that have occurred with 8-10 m class instruments built at a variety of institutions including Gemini. Instrument names have been withheld in this plot. The track record of managing the development this class of instrumentation is demonstrably poor, with cost overruns often exceeding 2-3x the original approved budget and deliveries often being years behind schedule.

Gemini Partner countries can bid on Gemini instruments and that, over time, the instrument development budget should go back into the Partnership according to Partner shares. Given the size of the Gemini consortium in the world-wide arena of astronomical instruments (arguably larger than any other comparable program), this is not a fundamental problem. Gemini still needs to maintain a program that is attractive to a wide range of bidders, being aware that there are many observatories that are competing for the same instrumentation resources. Changes designed to make the program attractive to participate within are discussed below.

Project Management: Again, in the first round of Gemini instruments teams selected had essentially no experience with building instruments of the size and complexity of a Gemini facility class instrument. This new breed of instrument represented a quantum leap for most teams and tried-n-true approaches to managing PI-class instruments where no longer applicable. Nonetheless, poor project management techniques were generally used in the early generation of Gemini instruments, which was a significant contributor to problems like cost overruns, schedule slips, and feature creep. There simply was not adequate oversight, in many cases, to gauge progress against a realistic project plan. This situation was exacerbated by Gemini's approach of not requiring a formal project management structure to build instruments, in essence taking a hands-off approach to dealing with overruns since the instruments were all on fixed price contracts and overruns were therefore not a primary Gemini Project concern. The whole area of project management has been overhauled in recent years, out of recognition by Gemini's instrument teams that their survival depended on it. After all, a 20% overrun in a past ~$500,000 class project could be absorbed elsewhere in most institutions without major implications. A 20% overrun in a $5-10M Gemini instrument was enough to financially cripple the same organizations though. Now, formal project management is required for all teams that are awarded instrument contracts. The full-up cost of an instrument is reevaluated at all major design reviews and cost metrics are forwarded to Gemini on a monthly basis to allow Gemini to detect disasters long before they occur, protecting the interests of both the contractors and Gemini.

Full Costs: In the past Gemini only paid for direct costs (parts and salaries, not overhead or profit) for all of its instruments. Instrument teams had to either forego any overhead payments or seek compensation through an independent arrangement with their national funding agency, as part of the contracting process. This led to a range of complications. First, failure to pay full prices for instruments has proven to be a disincentive to many teams, in a competitive world where other more lucrative opportunities exist. Frankly better compensation existed either financially or through scientific opportunity than was being offered to Gemini's teams. Second, seeking overhead payments through a separate funding track inevitably led to delays in starting projects, as bids are never tied to Federal fiscal cycles. To bypass both of these problems, through increased contributions from the Partner funding agencies, Gemini now pays for the full costs of instruments. Combined with guaranteed telescope time (described below), this makes Gemini's instrument program unique and, as demonstrated through its initial use in the GSAOI proposal process, was proven to attract a range of potential teams to participate in Gemini's program.

Direct Contracting: Concurrently with the key changes in costing structure, mentioned above, Gemini also led an initiative to have the option of using direct contracting with any organization that wins an award to build an instrument. In the past the National Gemini Offices have been the de facto source of contracts for new instruments, not Gemini. A parallel workscope between Gemini and the NGO was then used to establish a formal link to the builder. This approach had several downsides, including the injection of delays as unnecessarily complicated Gemini/NGO workscope negotiations were conducted in parallel with NGO/vendor negotiations. The net advantage to this rather complex structure was dubious, though its roots were in the fixed cost nature of Gemini contracts and role of the National Offices which were expected, on behalf of the respective funding agencies, to ensure that cost overruns were minimized if not eliminated. This structure ensured a role in the National Offices in helping manage Gemini's instrument program, but was demonstrated to be ineffective, given the overruns that occurred anyway. Today, Gemini has the option of direct contracting with any instrument team, which not only reduces contract negotiation periods (again a key stumbling block in starting new instruments) but also better defines the role of Gemini as the true end customer and budget holder in its relationships with its instrument builders. Gemini has also changed its policy regarding contract pricing – while Gemini still only grants fixed price contracts it also reserves contingency within its budgets and works closely with instrument teams to ensure that overruns which do occur are held within the total budget envelope, which includes contingency. This more streamlined and realistic approach to defining the working relationship between Gemini and its instrument builders is revolutionary compared to the original approach and will surely pay dividends in the future. In the case of GSAOI where this approach was first applied, no startup delays were experienced after the winning team was selected – a first in the instrument program.

Redefining a Vendor/Customer Relationship: One of the largest and earliest challenges in building a more viable instrument program has been to develop a different type of working relationship between Gemini and its instrument teams. Initially instruments were built under a "partnership" model, which inevitably led to a fuzzy distinction between Gemini's role as a customer and the instrument builder as a vendor. The previously described contracting model was a manifestation of this problem. Today Gemini uses a much cleaner and more conventional customer/vendor relationship with its teams. Deliverables are defined explicitly in contracts and Gemini controlled payments associated with those deliverables are all defined up-front, to avoid confusion and potential grief later. This more conventional approach benefits both sides of contractual agreements.

Guaranteed Telescope Time: A key new component of Gemini's instrument program is the use of guaranteed telescope (GT) time in exchange for providing an instrument. This has several effects. First, the policy is structured to act as in incentive to institutions which stand to receive up to 20 nights of telescope time in exchange for building an instrument. Second, the actual amount of time awarded is performance driven, so that teams lose GT as the instrument delivery slips. This was designed to provide a built-in motivator within instrument teams. The project scientist now drives closure on instruments from within, who would otherwise suffer very little impact from late instrument deliveries. It was chosen as a practical means of rewarding (and penalizing) a team based on actual delivery performance, without using actual cash, on the expectation that most teams' institutions would resist financial penalties for late deliveries.

These and other changes in Gemini's instrument program have literally overhauled the program at multiple levels over the past decade. Managing such a large program is always a dynamic process, and further changes are likely in the years ahead, but these together changes make Gemini's instrument program attractive (Gemini pays full costs and awards telescope time to builders), much more efficient (direct contracting and there is no need for separate overhead payment negotiations), less institutionally threatening (formal project management and contingency built into budgets is now standard procedure), and structured around fair competition so that over time all Partners have an opportunity to benefit from Gemini's program while ensuring that Gemini's astronomical community benefits from instruments built by teams that have been selected through a conscientious and judicious processes. While the instrument program is no doubt still imperfect, the Gemini Partnership has clearly learned a number of important lessons during the program's first decade and will continue to make changes in the future to ensure its long term success.