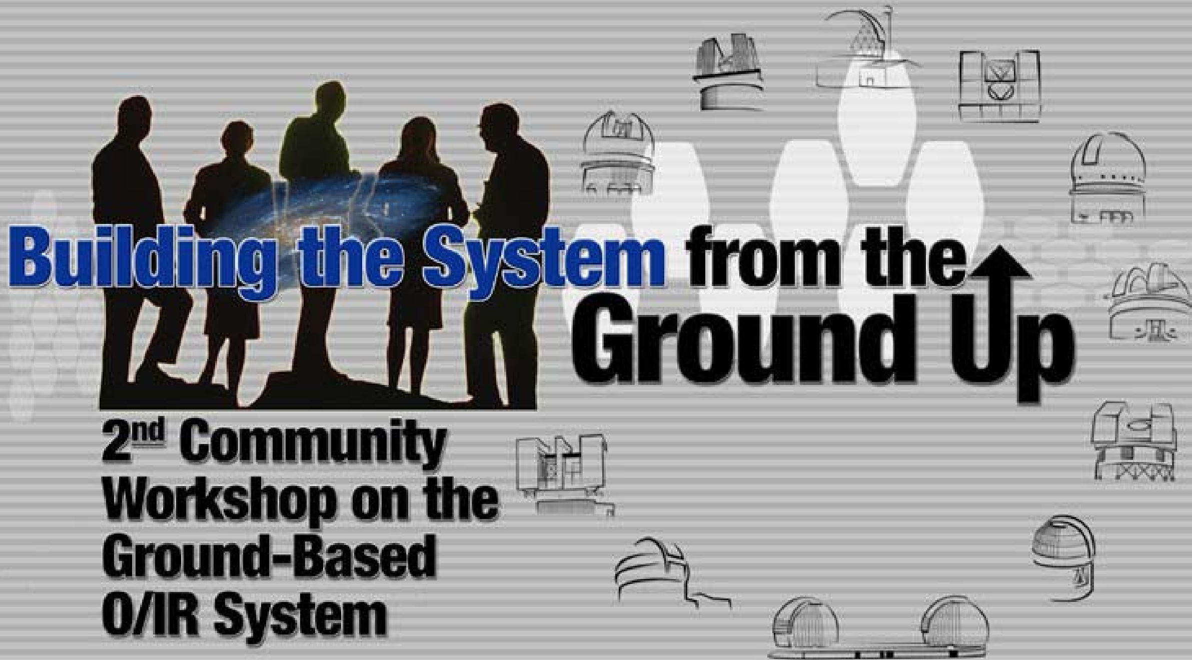
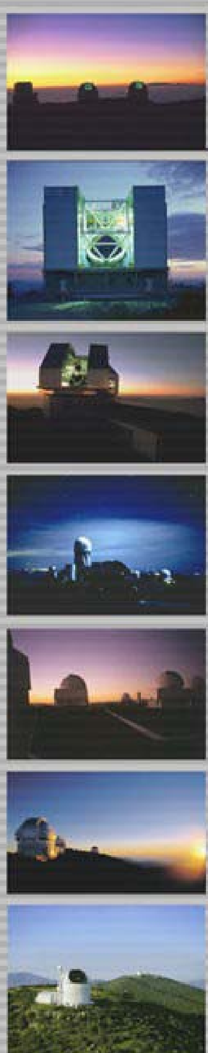
Building the System from the Ground Up

2nd Community Workshop on the Ground-Based O/IR System





REPORT OF THE ORGANIZING COMMITTEE

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Todd Boroson (NOAO)
Debra Elmegreen (Vassar College)
Tom Greene (NASA)
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Pat Osmer (Ohio State U.) Chair
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EXECUTIVE SUMMARY

The second workshop on the ground-based optical/IR system, *Building the System from the Ground Up,* was held in Alexandria, Virginia on May 13 and 14, 2004. Sixty-three participants discussed the evolution of the system of ground-based O/IR facilities, including (1) large telescopes and TSIP, (2) small and medium sized telescopes, (3) instrumentation, and (4) software, archives and the NVO. Following presentations, breakout groups, and plenary discussion, the organizing committee makes the following observations and recommendations:

- TSIP has succeeded very well in developing a system perspective around the large telescopes, and now PREST is poised to invigorate the small telescopes. TSIP rules should continue to evolve to ensure the best benefit to all users and providers within the system.

- The inclusion of medium sized (2.5-5m) telescopes in the system is essential. The TSIP program rules should be modified to be more attractive to them, and institutions with telescopes of this size should be helped to arrange consortia and time swaps.

- Data reduction pipelines, data archives, and good community data access and support are becoming increasingly important to the system at all levels (and for all telescope sizes).

- Broad consensus emerged that NOAO should become involved in providing services in developing data reduction pipelines, stewardship of public archived data, facilitating instrumentation collaborations, and enabling institutions to form telescope operating consortia.

BACKGROUND

The First Workshop on the Ground-Based O/IR System was held in October 2000, following the release of the report of the Astronomy and Astrophysics Survey Committee (AASC), the McKee-Taylor decadal survey. The AASC report argued for a new paradigm for establishing strategic priorities in U.S. ground-based optical/IR astronomy, one that would take an inclusive perspective, creating a virtual "system" from the combination of public and private facilities. Integral to this new approach was a community-based forum which would explore the concept of the System and develop priorities in the context of science goals, identifying needed capabilities and creating mechanisms by which these might be developed. These were the goals of the first workshop. For the report of the first workshop, see http://www.noao.edu/gateway/oir_workshop/report .pdf

Since that first workshop, a number of new programs derived from specific recommendations of the AASC report have enhanced the viability and the visibility of the System perspective for ground-based O/IR facilities. Initial work on the two large joint public/private telescope projects, the Giant Segmented Mirror Telescope (GSMT) and the Large Synoptic Survey Telescope (LSST), has begun. The Telescope System Instrumentation Program (TSIP), conceived from the outset as a driving force to provide incentive to participate in the System, has completed three successful annual proposal cycles. The Adaptive Optics Development Program (AODP), a new TSIP-like grants program also advocated in the AASC report, has completed its first year. And the National Science Foundation (NSF) has recently announced the Program for Research and Education with Small Telescopes (PREST), a program similar to TSIP but for smaller telescopes, which, to judge from initial inquiries, will be extremely popular.

The motivation for this second workshop, *Building the System from the Ground Up*, came partly from these programs—which require continuing guidance in the form of updated priorities—and partly from a desire to extend the System perspective in new directions. As in the case of the first workshop, a committee was assembled to help plan and run the workshop, to synthesize the outcome of the workshop into this summary report, and to advocate whatever recommendations might arise from the workshop.

To raise community awareness of the workshop and to incorporate as many good ideas as possible into the planning process, a survey questionnaire was widely distributed to the U.S. community about six months before the workshop. The survey proposed a number of potential workshop topics, and also solicited comment on those and related topics from recipients. The survey received 130 responses; the majority of respondents thought that a general workshop aimed at updating the priorities for the existing programs would be most useful. However, significant numbers also voted for specific areas of discussion, including smaller telescopes, instrumentation collaborations, and data-related areas such as archives and software pipelines. Based on these responses, the organizing committee decided to hold a workshop that would combine a general overview of the state of the ground-based O/IR System with discussions of the specific areas mentioned above.

Held at the Holiday Inn Select in Alexandria, Virginia on May 13 and 14, 2004, the workshop was attended by 63 individuals from 45 different institutions, including staff from NSF/AST and AURA. The complete participant list is given in Appendix A of this report. The workshop was widely publicized in advance through announcements in newsletters, the

NOAO Web site, and via the questionnaire itself. The majority of the workshop expenses were covered by NOAO.

The workshop was structured into two sets of prepared presentations, followed by break-out groups and their associated reports and discussions. The complete agenda is included in Appendix B of this report. The first set of presentations laid out the current state of the elements of the system, and identified system-related issues associated with each of these elements. Discussion time was provided after each presentation for shorter prepared contributions. The second set of presentations focused on science areas, and as in the first workshop, attempted to link the questions of current interest to the needed capabilities of the future. The break-out groups discussed the four specific areas of interest that had been identified through the pre-workshop questionnaire:

- *Evolution of Capabilities for Large Telescopes; TSIP: Guidance and Priorities* (Discussion leader: Alan Dressler)
- *The System(s) of Small and Medium-size Telescopes* (Discussion leader: Terry Oswalt)
- *Building Better Instrumentation and Stronger Collaborations* (Discussion leader: Darren DePoy)
- *Issues of Archives, Software, and the National Virtual Observatory* (Discussion leader: Marc Postman)

The reports of the break out groups are included in this report as Appendix C. Science justification and motivation were integrated into each break out group discussion and are implicit in the recommendations and reports.

GENERAL OBSERVATIONS

In the broadest sense, the US ground-based O/IR system comprises a diverse set of telescopes and instruments, the software and data archives that process and store information, and—most importantly—the people who build the infrastructure (both hardware and software) and actually do the exciting science in our discipline. We vigorously endorse the consensus view expressed at the workshop that US science draws great strength from maintaining a diversity of apertures, instruments, and wavelength coverage.

This document presents our Committee's distillation of the discussion at the workshop and includes recommendations to address the issues identified. The goal of the workshop was to continue the ongoing process of exploring ways in which the system might be strengthened by (1) optimizing the suite of instruments deployed on existing telescopes, (2) increasing access to both facilities and archival data sets, and (3) drawing upon and enhancing elements of the System, in a coordinated way, for training and education. Our Committee notes its impression that the discussion of the System in this workshop was constructive and seemed to reflect a consensus view that the System concept could be used to benefit the entire community.

NSF has established two peer-reviewed grant programs that are specifically crafted to support the ground-based O/IR system. One, the Telescope System Instrumentation Program (TSIP) was established in 2002 to (1) fund the creation of cutting-edge instruments for the new suite of large-aperture telescopes, and (2) to increase community access to the considerable observing resources that have been developed mostly with non-federal funds. We see the TSIP program as having been very successful on both fronts.

More recently, the NSF announced a second System-related initiative, the Program for Research and Education for Small Telescopes (PREST), with the first round of proposals due in June 2004. PREST is designed to re-invigorate the vitally important telescopes of smaller aperture that play a crucial role in undergraduate training and education, in tandem with their use as research tools. While it is still too soon to evaluate the effectiveness of the PREST initiative, we certainly applaud the recognition of the importance of maintaining a vital and accessible network of telescopes of modest aperture. A review of the accomplishments, current status, and areas of concern for the TSIP and PREST programs is found in the next section of this report.

Three topics can be identified as recurring themes of the workshop discussion:

1. The tension between avoiding duplication of instruments and providing scientific opportunity to individual scientists,

2. The growing importance of archival data sets, and the necessity of making investments accordingly, and

3. The need to properly train both the existing and next generation of astronomers to make efficient use of both observing resources and archival data.

INSTRUMENTATION AND ACCESS

While there is obvious merit in coordinating the instrumentation suite across the ground-based O/IR System, not all astronomers have equal access to all facilities. If, for example, a high resolution IR spectrograph is placed on telescope “A”, while telescope “B” has a coronagraph, unless the two respective clientele have access to each other’s facilities there will be loss of both opportunity and healthy scientific competition. Since we clearly cannot afford as a community to equip each and every telescope with all conceivable instruments, an obvious solution is somehow to provide appropriate access across the System though trading of telescope time. Although there have been successful instances of this, it is not widespread. Furthermore, no “clearinghouse” exists in which these time swaps could be explored and consummated. We urge the community to explore ways in which the trading of telescope time could be facilitated, and then let market forces determine the nature and details of these arrangements.

INVESTMENTS IN ARCHIVES

As the National Virtual Observatory (NVO) concept gains traction in the astronomical community, there is a growing appreciation that archival data sets, accessed through the Web across distributed data collections, will play an increasingly important role in the astronomy of the future. The ground-based O/IR system facilities will be an important contributor to this worldwide trend. Interpreting optical and IR data taken through a variable atmosphere adds a serious complexity to the generation of credible data products and catalog archives. The 2004 System workshop participants recognized that a change is under way, from a “business model” in which individual scientists would obtain data at the telescope to be reduced at their home institution, to a model where the instruments have associated data reduction pipelines that would generate images from which instrumental artifacts have been removed. Achieving this objective will require a re-balancing of investment in the System infrastructure, and our section on the TSIP program provides one suggestion on how this might be accomplished.

EDUCATION AND TRAINING

A third common theme identified in the 2004 workshop related to education and training. Many institutions offer some kind of observational astronomy course in which the smaller aperture facilities play a vital role. We strongly endorse the educational value of students having real on-the-sky experience. This is often a transformational experience for students. Furthermore, as we enter an era in which archival data play an increasingly important role, we need to incorporate the requisite observing skills into the curriculum. We encourage the educational community to identify opportunities to share the fruits of curriculum development efforts, and to identify and share best practices for both hands-on and cyber-observing.

The following sections of this report are organized according to the workshop format, with these general observations followed by a more detailed discussion of the TSIP and PREST programs, followed by recommendations on each of the areas discussed by the four break-out groups: (1) large aperture telescopes (> 6m) and TSIP, (2) telescopes of small (< 2.5m) or moderate (between 2.5m and 6m) aperture, and PREST, (3) instrumentation, and (4) analysis software and data archiving

TSIP AND PREST:
NSF PROGRAMS THAT TIE THE SYSTEM TOGETHER

TSIP, the Telescope System Instrumentation Program, was the highest priority medium-size initiative recommended for ground-based O/IR astronomy in the NRC decadal survey *Astronomy and Astrophysics in the New Millennium*. This program has the two-fold goal of (1) improving instrumental capabilities within the ground-based O/IR System by funding development of large facility instruments, and (2) of enhancing broader access to the facilities of the independent observatories by providing time on these facilities to the community. TSIP has an annual proposal cycle that includes a solicitation; receipt of proposals to design and/or build large instruments or other facility improvements; proposal evaluation and review by an external panel; negotiation of sub-awards with successful proposers; ongoing oversight of the instrument development, and integration of the new observing time into the periodic NOAO telescope time allocation process. This program is now concluding its third annual cycle since its inception, with $4 million for awards having been made available to the program in each year.

TSIP proposals of two types are allowed. Instrumentation proposals are for the development of new, large, facility instruments. Such proposals may be for instruments for telescopes of any aperture. These proposals require the provision of telescope time equal in value to 50% of the funds received. Improvement proposals are for facility improvements. Such proposals are limited to facilities that operate telescopes of aperture greater than 6 meters. These proposals require the provision of telescope time equal in value to 100% of the funds received. In its first three years, TSIP funds have been awarded to four instruments for four large telescopes and have provided access by the community to about 135 nights on these large telescopes. No improvement proposals have been received. No proposals for telescopes of aperture less than 6 meters have been received.

Review of TSIP proposals is by an external peer review committee. In addition to the two NSF review criteria of scientific merit and broader impacts, the TSIP review process considers the relevance of the proposed new capability to the community's "system" priorities. Guidance on community priorities has come principally from the report from the first workshop on the ground-based O/IR system, held in October 2000.

FACILITY INSTRUMENT PROJECTS SUPPORTED BY TSIP

- OSIRIS, a Near-IR spectrograph with an integral field unit as its entrance aperture for the Keck telescopes. OSIRIS provides sufficient spectral resolution to resolve (and work between) the OH lines, thus substantially lowering the sky background. TSIP has supported this instrument from the end of its design phase through completion ($2,500,000 total). It is now in a final integration phase, and is expected to be delivered to Keck in the next few months.

- KIRMOS, a wide-field Near-IR multi-object spectrograph for the Keck telescopes. KIRMOS consists of a focal plane assembly that allows the remote insertion of a slitlet mask, coupled to a large transmissive-optics spectrograph with a 4096 × 4096 detector array. TSIP supported this instrument through two years of design work ($2,200,000 total). Development was stopped after its preliminary design review and de-scope options are being explored.

- MMIRS, a medium-field Near-IR multi-object spectrograph to be shared between the MMT and Magellan telescopes. MMIRS is based on the design of Flamingos, an instrument produced by the University of Florida. It utilizes slitlet masks in a focal plane wheel. TSIP is currently supporting the design phase of this instrument with the intention of continuing that support through the fabrication phase ($2,700,000 total).

- MODS-2, a medium-field optical multi-object spectrograph for the LBT. MODS-2 is an exact duplicate of MODS-1; two spectrographs are required for the two identical foci of the Large Binocular Telescope. At this time, negotiations are in progress for TSIP support of this instrument through fabrication ($2,600,000 total).

In addition to providing funding to support the development of these new instrumental capabilities, the TSIP program, which has just completed its third proposal cycle, will have provided time to the broad community on four large telescopes, specifically:

— 53 nights on the Keck telescopes
— 26 nights on the MMT
— 26 nights on the Magellan telescopes
— 24 nights on the Large Binocular Telescope

This TSIP time typically consists of only a few nights per semester per telescope and has been highly oversubscribed (factors of 2.5 – 4).

It is clear that the TSIP program has accomplished what it was intended to do. It has provided new, needed capabilities to the ground-based O/IR system. It has provided a funding avenue for the independent observatories to instrument their telescopes. It has leveraged the private resources of these independent observatories. It has made some time on all large facilities available to the broad community. In all these ways, TSIP has encouraged the recognition of the ground-based O/IR system as a valid context for planning, decision-making, and carrying out scientific research. It has given every astronomer a stake in every participating facility.

PREST

The success of TSIP allows us to consider the next step. One such step is the desire to extend this system perspective to smaller telescopes. Recognizing this, NSF/AST has announced the Program for Research and Education with Small Telescopes (PREST). PREST seeks to take a system-like approach, funding instrumentation and improvements to small telescopes (0.5 – 2.5m) and requiring, in exchange, community access to those facilities. While it is only in its first annual cycle, PREST will require the same sort of community guidance and coordination as TSIP if it is to develop the small telescopes into an equally effective system.

While PREST has the potential to aid the development of small telescopes to become a system, there is a range of telescope aperture from 2.5 to 6.5 that has not been effectively addressed. Because these telescopes exceed the allowed aperture, they are not eligible for consideration under the PREST program. In addition, they are not well suited to funding under TSIP, for two reasons. First, these telescopes have capital costs that are not large compared with the modern, complex facility instruments that can be built for them. Second, they are in general so old that they would be considered to be completely depreciated. Thus, the calculation of the number of nights to be returned through the application of the TSIP rules would result in a very large number, typically hundreds. This is seen as sufficiently undesirable that no such TSIP proposals have been made.

A final need is the updating of the capabilities that are seen as high priorities for TSIP support. The first workshop was held almost four years ago, and the TSIP review panels have recognized that this guidance has become increasingly out of date, both because scientific interests have evolved and because some of the desired capabilities have come into being, either through TSIP funding or otherwise.

LARGE TELESCOPES AND TSIP

TSIP is regarded as working well, both for providing observing time to the community and for supporting new instruments. The committee recommends several modifications to the rules of the TSIP program to account for (1) changing circumstances for the large telescope and instrument component of the system and (2) recognition that additional factors, such as instrumentation for medium-sized telescopes and data pipeline and archiving issues, may be important to the community.

Experience is showing that the cost to operate large telescopes and their instruments and have them operate with high efficiency is high and often greater than originally estimated. This is becoming a problem for at least some of the consortia. The U.S. large telescopes are not supported at the VLT level. If the U.S. telescopes and instruments cannot perform at a world-competitive level, then we will have a system-level problem. The (existing) TSIP option of selling time to the community under the 100% rule provides a possible solution to this problem.

Unneeded duplication of instruments on large telescopes is not yet a problem, but the group believed that the community should already be looking out for creative approaches, such as trading observing time, to broaden access to specialized instruments.

RECOMMENDATIONS

- Improvements to instruments and their software, properly justified as adding new scientific capabilities or improving scientific productivity, should be eligible for TSIP support under the 50% rule.[1]

- Upgrades to facilities and operations that improve productivity or add to scientific performance should also be eligible for the 50% rule. However, routine maintenance and operations are not eligible for the 50% rule.[2]

- TSIP could act as a short-term telescope broker if a group wanted to obtain financial support in return for a 100% return of telescope time per dollar awarded (the 100% rule). The sense of this recommendation is to provide a simple path for an observatory to sell telescope time—without the need to justify the observatory's use of those funds.

- Pipeline data reduction, defined as removing the instrumental signatures from the data and doing the basic calibrations for non-expert users, and data distribution to the entire community via archiving, should be required as part of a TSIP instrument proposal. The cost of the software effort would be an allowed expense (and the 50% rule would apply). Alternatively, the team could propose to use NOAO capability for this effort at no charge to the team (NOAO would charge its costs to TSIP). In the case of an instrument built or supported prior to this requirement, there could be a proposal to TSIP to obtain the needed support for either work by the team or by NOAO, as just described.

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[1] For reference, the 50% rule means that the proposing group makes available to the community observing time of value equal to 50% of the TSIP award. The group can also offer effectively to sell observing time to the community at cost through TSIP; this is called the 100% rule.

[2] The 50% rule appears to be regarded as fair by both proposers and community representatives. The consensus was that it should not be tinkered with.

SMALL AND MEDIUM TELESCOPES

The community of small and medium telescopes encompasses many different approaches to the System. Small and medium telescope users and users at small institutions are overlapping but not identical groups. Some users are part of private consortia, while others rely primarily on national facilities. Some groups are better served by robotic or remote observations, while others require on-site observing. Thus, the System needs to accommodate and incorporate many different elements. One essential element in a successful System is communication, and that entails astronomers being aware of what is available and what collaborations and sharing and trading of resources might be possible.

There are both science and educational goals for using small and medium telescopes. Science drivers include time domain and time-critical observations such as variability and target-of-opportunity projects, multi-λ precursor and follow-up observations of larger telescopes and space missions, wide-field imaging, surveys, and high-overhead observations such as calibrations and bright targets. Educational drivers include the training of undergraduate and graduate students in observations and instrumentation, and public outreach for adults as well as K-12 students. In both cases, the number of nights is more important than the number of photons collected; these purposes cannot be served by having a smaller fraction of larger telescope time.

Despite the fact that both research and education rationales for smaller telescopes are compelling, the detailed requirements and constraints on telescopes used for these purposes are somewhat different. Thus, it is probably better for mini-systems of smaller telescopes to form independently in a bottom-up manner. Regional consortia of colleges and universities might share facilities used primarily for education. Somewhat larger telescopes, used primarily for research (including particularly research involving students) might join together in more distributed consortia, and agree to share telescope time. Broad community access could be provided through federal investment of one kind or another.

The SMARTS consortium is a model for how a system of small and medium research telescopes can be developed using formerly public observatory facilities. It has enjoyed enormous success at CTIO by having several private partners and also returning valuable observing opportunities for the public. One key element for the SMARTS success is that each telescope in the system has a dedicated instrument, driven by science priorities, so that there is no need for instrumentation change. A similar system could, in principle, be formed with smaller telescopes at KPNO. It is clear that the support infrastructure that already exists within NOAO is a vital element for success. Such infrastructure allows SMARTS, for example, the possibility of hiring a portion of several different engineers' workloads, rather than the need to hire each of these people full-time. Another model of a SMARTS-like system is the McDonald observatory system, where regional private rather than public telescopes are used.

Another important element of the System might be the development, through collaborations of existing telescopes, of an interferometric network, or a network for time-critical observations such as occultations, SNe, and GRBs.

The NSF AST officers are to be commended for the development of the new PREST program, which is viewed with great excitement as a mechanism to channel funds into small telescopes. Although the program is in its infancy, it is expected to serve the System well and will undoubtedly evolve.

Since the small and medium telescope observations provide data that can support a wide variety of projects related to larger telescopes and space missions as well as curricular and educational goals, it is important that these data become part of the NVO. Therefore, it is important to have clear guidelines for the appropriate incorporation of all data.

RECOMMENDATIONS

- Establish a central Web page to serve as a home base on telescopes, instruments, and availability.

- Information about capabilities and access is critical—ISTeC is out of date and does not provide the right information. Goals include allowing researchers to find capabilities matched to their needs and facilitating collaborations. Include regular AAS sessions dedicated to developing the small/medium telescope components of the System.

- The appropriate federal role in the system(s) of small and medium telescopes is that of a facilitator of consortia (e.g., providing technical support services) or of the System as a whole. As with TSIP, federal funds should be used to improve capabilities and provide community-wide access.

- It is desirable to further encourage participation of medium telescopes in TSIP itself.
  - Potential proposers should be reminded that the telescope time provided to the community is not required to be nights assigned to individuals, but could include access such as allowing a single large survey to be carried out, so long as the community was involved in its definition and data were made available in a timely way.
  - To level the playing field in the TSIP process for older, medium-sized telescopes, the proposers could use the present day value of their telescope for the cost basis of the proposal and the amount of time to be returned to the community.
  - For telescopes where NOAO is already a major partner and observing time is being provided to the community, the fraction of the observing time to be returned to the community by the proposing group can be reduced correspondingly.[3]

- PREST, like TSIP, should be guided by a system perspective. After the initial cycle, the guidelines for PREST should be reviewed to ensure that the program develops a set of complementary capabilities with broad access.

- Data archiving is no less important for small and medium telescopes. Simple mechanisms for making data useful and available to the entire community should be developed, with proper account taken of the interfaces and protocols being established by the NVO effort.

[3] This point should be worked out carefully and in more detail to ensure that it is fair to all parties. For instance, it might be advisable to limit this situation to telescopes in which NOAO is no more than a 50% partner.

INSTRUMENTATION

The System has progressed since the last workshop, and some of its fastest growth has been in the development and delivery of new scientific instrumentation. Gemini has come online with a suite of optical and near-IR spectrographs and cameras, and TSIP has funded the development or study of several near-IR and optical spectrographs for large telescopes. Similar and other sophisticated instruments, particularly large format wide field cameras, have also been designed or fabricated for medium-sized telescopes. These types of instruments were identified as having very high priorities in the report from the first System workshop.

Developing these instruments has required a considerable commitment of labor and funding and has had its fair share of technical and management challenges. Numerous participants in the second workshop noted that development of modern instrumentation for large telescopes requires a larger scale of effort, systems engineering, and management than to which most US ground-based instrumentations groups are accustomed. These groups have had to develop new engineering management skills and have added personnel, sometimes after experiencing problems and setbacks. There was a general consensus expressed at the workshop that it is difficult to incorporate significant graduate student involvement in modern instrument development due to the extra engineering discipline and sheer scope of work now required for cutting-edge instruments.

These new instruments are also more expensive and more time consuming to develop and operate than the previous generation, so it is increasingly important to make strategic decisions about what types of observatories should have what sorts of instruments. A breakout group of approximately 20 astronomers discussed this issue and arrived at the following comments and recommendations.

There is still a diverse variety of cutting-edge science to be done with large telescopes, so it is worthwhile to allow and even foster duplication of some complex instrumentation capabilities for them. For example, many fields (e.g., young stars, initial mass function, high z galaxy studies, searches for first light objects, stellar populations, etc.) require moderate resolution visible and near-IR spectra of hundreds or thousands of very faint objects to characterize their populations. Completing such surveys will require hundreds of nights, so it is very valuable to have visible and near-IR multi-object spectrographs (MOSs) on several large telescopes. Duplicating such capabilities also allows greater access by all US astronomers, from both public and private institutions. It is also desirable for most or all large telescopes to have some sort of optical or near-IR cameras and AO systems. More specialized mid-IR, coronagraphic, polarimetric, and spectroscopic (very high resolution or IFU) instruments are certainly needed on some large telescopes but definitely not all of them.

Given the cost, effort, and time required for their development, the instrumentation breakout group concluded that it was not wise to duplicate complex instruments for medium-sized telescopes unless this fills a specific scientific or community need. Many medium telescopes are focusing their efforts into more specific observing projects (and thus fewer instrument changes) and are simplifying their operations for efficiency and cost reasons. These telescopes can still do state-of-the-art science in several areas, particularly when large amounts of observing time are dedicated to specific projects. These telescopes are very well suited for wide-field visible and near-IR imaging, and at least one or two of them with some public access should be equipped with capable mosaic cameras. It also makes sense for *every* general-purpose medium telescope to have some kind of basic visible or near-IR capability. Medium telescopes also need more high resolution spectroscopic instruments (R > 20,000). There is still significant important scientific work to be done in this regime (i.e., bright stars and precursor studies for large telescope projects), but mid-sized telescopes have lost some capabilities. For example, the Phoenix near-IR spectrograph was moved from the NOAO 4m telescopes to Gemini.

RECOMMENDATIONS

- Improved visible and near-IR detectors are needed, and federal resources should be invested into their development. There was discussion but no clear consensus on how organized this investment should be (e.g., individual grants vs. specific long-term programs). George Jacoby noted an ACCORD initiative for CCD development in which he is collecting expressions of interest for a shared foundry run.

- Instrument groups should collaborate more often, and this could be encouraged with some sort of Web-based coordination. Instrument development is becoming increasingly specialized and few groups have adequate expertise or facilities in all areas. It would be natural for NOAO to establish and maintain such a Web site.

- Basic data reduction pipeline software should be included in the delivery of all facility instruments that receive significant public funding.

- In general, a need is seen for more instrumentation to work in the 3—5 μm range and more instrumentation to make polarimetric observations.

SOFTWARE, ARCHIVES, AND THE NVO

The working group on software held extensive and wide-ranging discussions on the rapidly evolving role of "virtual facilities" in the ground-based O/IR system. There is a clear evolution within the ground-based astronomy community towards recognizing that both archival data and project-specific observations constitute important resources for both research and education. The successes of SDSS and 2MASS in developing accessible, homogenous data *catalogs* are clear examples of the value of digital astronomical archives. At the same time, it is obvious that there is a threshold that is both historical and cultural to overcome. Traditionally, most ground-based O/IR data has been privately owned, protocols for acquiring data, calibrations, and metadata have been diverse and incomplete, and few observatories have deemed it worthwhile to develop the infrastructure to store, pipeline-process, or distribute data. This must change if the users of ground-based O/IR data are going to participate in the new era of the virtual observatory.

There is a common misconception that the National Virtual Observatory is developing simple procedures for archiving data or even the means to provide archive services. On the contrary, the initial NVO effort is limited to a *demonstration* that interfaces and standards can be defined that will make the federation of archives and creation of new kinds of tools possible. The NVO will develop interoperability and data exchange formats, but it will not provide *content*; that is the job of independent archives and data centers. In the ground-based O/IR community, those archives and data centers do not exist. Such centers are necessary for a number of reasons:

- They provide an efficient means for providing physical curatorship of data sets, particularly large ones.

- They provide a reliable, long-term solution for providing access to important data products, including conformance with evolving community data standards.

- They can provide scientific curatorship of ground-based O/IR data, including scientific knowledge about the characteristics of datasets, what calibration information or metadata are associated with them, how they have been processed, and how to use them correctly.

- They can serve as focal points or coordinating sites for the development of new tools that are appropriate for and driven by ground-based O/IR data.

In the establishment of ground-based archives and data centers, the experience of creating and operating such facilities for space-based astronomy missions should be utilized.

In addition to the research aspects of the virtual observatory, there are also important educational aspects. First is the realization that the existence of the virtual observatory provides a dramatic new resource for educational and public outreach at all levels. The need to keep this connection strong is vital. Second, the knowledge that is needed to exploit the archived data sets must be an integral part of the training for young astronomers. Graduate programs should be integrating more computer science into their curricula, and collaborations between astronomy and computer science programs should be strengthened.

RECOMMENDATIONS

- In order for the users of ground-based O/IR data to participate in the emerging virtual observatory, properly funded archive centers must be established to ingest, distribute, and enhance the scientific value of such data.
- Ground-based O/IR facilities must recognize the challenge of producing archive-friendly data; observatories should establish prescriptions for acquiring calibration data that support archival research.
- A wide variety of metadata is critical also. One essential need is the availability of standardized data on the status of the local atmospheric conditions (e.g., cloud coverage).
- Whatever the mechanism for providing access to data, compliance with VO standards and protocols must be maintained in order to facilitate the inclusion of their data into the global VO network.
- VO and archival-based research must become an integral part of undergraduate and graduate-level curricula.

Appendix A

WORKSHOP PARTICIPANTS

Sean Adkins	Keck Observatory
James T. Annis	Fermi National Accelerator Laboratory
Taft Armandroff	National Optical Astronomy Observatory
William G Bagnuolo	Georgia State University
Charles D. Bailyn	Yale University
Thomas G. Barnes III	University of Texas, Austin
Karen S. Bjorkman	University of Toledo
Todd Boroson	National Optical Astronomy Observatory
Kem H. Cook	Lawrence Livermore National Laboratory
Phillip Crane	NASA
Michelle Creech-Eakman	New Mexico Institute of Mining and Technology
John K. Davies	Astronomy Technology Centre
David De Young	National Optical Astronomy Observatory
Darren L. DePoy	Ohio State University
Alan Dressler	Carnegie Observatories
Debra M. Elmegreen	Vassar College
Craig Foltz	National Science Foundation
Linda French	Illinois Wesleyan University
Eileen D. Friel	National Science Foundation
Karl Glazebrook	Johns Hopkins University
Robert W. Goodrich	Keck Observatory
Richard F. Green.	National Optical Astronomy Observatory
Thomas Greene	NASA
Suzanne L. Hawley	Michigan State University
Klaus-Werner Hodapp	University of Hawaii
Peter Hoeflich	University of Texas, Austin
George Jacoby	WIYN Observatory
Luke Keller	Cornell University
Arlo U. Landolt	Louisiana State University
James W. Liebert	University of Arizona
Steve Lubow	Space Telescope Science Institute
Patrick McCarthy	Carnegie Observatories
Christopher J. Miller	Carnegie Mellon University
J. Ward Moody	Brigham Young University
Jeremy Mould	National Optical Astronomy Observatory
Patrick S. Osmer	Ohio State University
Terry D. Oswalt	Florida Institute of Technology

John Peoples	Fermi National Accelerator Laboratory
Randy Phelps	National Science Foundation
Marc Postman	Space Telescope Science Institute
Ronald G. Probst	National Optical Astronomy Observatory
Hernan Quintana	Pontificia Universidad Catolica de Chile
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Keivan G. Stassun	Vanderbilt University
Lisa Storrie-Lombardi	California Institute of Technology
Guy S. Stringfellow	University of Colorado
Christopher Stubbs	University of Washington
Alan Tokunaga	University of Hawaii
Bruce A Twarog	University of Kansas
Alan Uomoto	Carnegie Observatories
Wayne Van Citters	National Science Foundation
Alistair R. Walker	National Optical Astronomy Observatory
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P. Frank Winkler	Middlebury College
Donald G. York	University of Chicago
Eliot F. Young	Southwest Research Institute
Stephen E. Zepf	Yale University

Appendix B

WORKSHOP AGENDA

WEDNESDAY, MAY 12

6:30 – 8:30 P.M. *Welcome Reception – Outdoor patio*

THURSDAY, MAY 13

7:30 A.M.	Continental breakfast and registration outside conference area	
8:30	*Introduction/ State of the System*	P. Osmer, T Boroson
9:00	Welcome from NSF	C. Foltz
9:15	*The System of Large Telescopes (6–12 meters)*	T. Boroson
9:45	*The System of Smaller Telescopes*	C. Bailyn
10:15	General discussion on telescope capabilities, including short contributions: S. Adkins (Keck), R. Goodrich (Keck), J. Annis (FNAL)	
10:45	Break	
11:15	*Instrument Development*	T. Armandroff
11:30	General discussion on instrumentation, including short contributions: R. Probst (NOAO); others	
12:30 P.M.	Buffet lunch	
1:30	*Software, NVO, Archives*	D. De Young
2:00	General discussion: Software, NVO, Archives	
2:30	*High-z Galaxies: Status, Important Questions, and Needed Capabilities*	P. McCarthy
3:00	Discussion	
3:30	Afternoon Break	
3:45	*Stars: Status, Important Questions, and Needed Capabilities*	S. Hawley
4:15	Discussion	
4:45	*Planetary Systems: Status, Important Questions, and Needed Capabilities*	E. Young
5:15	Discussion	
5:45	Introduction to tomorrow's breakout sessions	T. Boroson
6:00	Adjourn	
7:00 – 8:30 P.M.	Dinner	

FRIDAY, MAY 14

7:30 A.M.	Continental breakfast served outside conference room area	
8:30	Breakout Sessions (4) 8:30 – 11:00 A.M.	
11:00	Break	
11:15	Presentation of breakout group on medium/small telescopes	T. Oswalt
11:45	Discussion	
12:15	Buffet lunch	
1:30 P.M.	Presentation of breakout group on instrument development	D. DePoy
2:00	Discussion	
2:30	Presentation of breakout group on software/archives	M. Postman
3:00	Discussion	
3:15	Presentation of break-out group on large telescopes/TSIP	A. Dressler
3:45	Discussion	
4:00	Wrap-up	
4:30	Adjourn	

SATURDAY, MAY 15

9:00 A.M. – 12:00 P.M.	Organizing Committee meeting

Appendix C

REPORTS OF THE BREAK-OUT GROUPS

Group 1 *Evolution of Capabilities for Large Telescopes; The Telescope System Instrumentation Program: Guidance and Priorities*

Participants: Alan Dressler (Discussion Leader), Pat Osmer, Bob Goodrich, Jim Liebert, Pat Barnes, Tom Greene, Jeremy Mould, Pat McCarthy, Eliott Young.

The following are Group 1 recommendations regarding the TSIP proposal process.

- Upgrades to research instruments should qualify for TSIP proposals. Properly justified so as to show an enhancement of science capability, such proposals should be eligible for the "50%" rule.

- Upgrades to infrastructure that can be shown to improve productivity and/or add to the scientific performance of the facility should also be allowed and eligible for the 50% rule, but the burden is on the proposer to show how such gains will be realized. This type of proposal is distinct from one to provide funds for routine operation or maintenance, for example as discussed in (3).

- Given the two modifications suggested above, TSIP should allow—even encourage—brokering of telescope time under the 100% rule, by greatly simplifying the proposal process for the provision of telescope time in exchange for NSF support, on a year-to-year basis or over a period of years, as the TSIP Review Panel recommends. This kind of proposal should be streamlined, requiring only a description of the facility (telescopes, instruments, capabilities) with which the Panel can make a recommendation based on the value of the offered nights to the astronomical community.

- "Pipeline" data reduction should be required as part of future TSIP proposals. (For purposes of this discussion, a "pipeline" is a software system that removes instrumental signatures and produces calibrated data, as appropriate for the instrument, and can be used by a non-expert.) To accommodate this, proposals can include funding for software specialists under the 50% rule. NOAO might consider providing in whole or in part some of the needed software, taking advantage of in-house expertise, if a suitable arrangement can be worked out with the TSIP proposer. Proposals for retro-fitting instruments—especially TSIP-supported instruments—with a pipeline data reduction system should be encouraged. The work could be done either by a proposer or in collaboration with NOAO, as above.

- Telescopes with apertures less than 6-m are already able to propose to TSIP. Until now, however, such proposals have been discouraged by the fact that these telescopes are already depreciated and therefore the "cost per night" becomes so small as to make prohibitive the large number of community nights required under the 50% rule. We suggest that, in order to "level the playing field" with the new generation of large telescopes, TSIP proposals for smaller telescopes be allowed to "re-capitalize" by showing the cost of a comparable facility if built today and depreciated over a 20-year period.

The following are comments and recommendations on the effectiveness of the current TSIP program:

- Duplication of instruments is not yet seen as a problem. For example, no TSIP-funded instrument is slated to be used only 10-20% of the time. On the other hand, those involved with overseeing and running the program are looking forward to moving beyond IR spectrographs (OSIRIS, MMIRS, KIRMOS)

- The TSIP proposal process, as coordinated by NOAO, is working very well. We identified "better descriptions of instrument capabilities at the proposing facility" as something that could and should be improved.

- Reports of how observing actually went on TSIP nights have been spotty; this can and should be improved.

- Better observing manuals for available instruments would be a big help, and adequate data pipelines, as discussed above, are crucial.

Up to this point, most of the satisfied TSIP observers have used the Keck telescopes, where a good level of support is available. A few visiting observers expressed some frustration regarding their use of the MMT, which is, after all, still relatively new. It will be important in future to track satisfaction with the newer facilities such as MMT, Magellan, HET. The lesson to be learned, obviously, is that we should allow a facility to mature sufficiently before allocating TSIP observing time—this includes the efficiency of telescope operations and the performance (and variety) of instruments. Future TSIP plans include readiness reviews, which our panel strongly supports.

The panel identified one looming, large problem: Some of the U.S. large telescopes are supported at a marginal level, very spare compared to ESO's VLT facility, for example. Will this continue, and will we be competitive with such lean operating budgets? If not, where will the needed operating funds come from?

Group 2 *The System(s) of Small and Medium-size Telescopes*

Participants: W. Baguolo, C. Bailyn, K. Bjorkman, J. Davies, D. Elmegreen, L.French, E. Friel, R. Green, K. Hodapp, P. Hoeflich, A. Landolt, J.W. Moody, T. Oswalt (Discussion Leader), J. Peoples, R. Phelps, G. Stringfellow, A. Tokunaga, B. Twarog, A. Uomoto, A. Walker, R. Wilhelm, F. Winkler, D. York, S. Zepf.

NOTE: Nearly all participants contributed to the discussion summarized here and should be considered a "co-author" of this report

Oswalt opened the breakout session on small telescopes by providing some background on small telescopes (tentatively defined as <6.5m by the meeting organizers). The recently published "The Future of Small Telescopes in the New Millennium" was noted as a good background reference (Oswalt 2003). Over 120 co-authors have provided sound scientific reasoning for building a true system that involves telescopes of all apertures. The essential functions of small telescopes fall into three general areas: (1) education, from K-12 through post-doctoral training; (2) research, especially for unique projects involving time domain, long-term, synoptic, and/or survey work; and (3) "gateway" function, i.e., as a test-bed for new instrumentation, modes of operation and "proof of concept" studies.

Several challenges impede the acceptance of small telescopes as part of a national (or international) "system." Clearly, the push to build ever larger facilities has been accompanied by a kind of "aperture envy" that overshadows the actual importance of smaller telescopes. Budget constraints prevent many small observatories from being upgraded and used to full advantage. This is compounded by the fact that most small observatories are geographically isolated, often lacking local infrastructure or expertise to make them as productive as they should be. Last, but not least, the scientific community has a number of misconceptions about the "cost-effectiveness" of telescopes (Abt 1994, 2003; Ben & Sanchez 2003; Gopal-Krishna & Barve 1998; Leverington 1997).

Several "opportunities" were outlined that would increase the astronomical community's chances of achieving a true System. Automation and remote Web access enormously improves accessibility and productivity, and markedly lowers operations costs. Standardized instrumentation and software increase reliability and productivity. More small observatories need to be operated by consortia and collaborations like NURO, SARA, SMARTS, WIYN, etc., because such organizations provide broader financial, technical, and user bases. Small observatories need to take a bigger role than they already do in public education and outreach programs (e.g., ASTRO, HOU, IDEA, REU, etc.). More funding sources like PREST are needed that specifically target the strengths of small observatories. Finally, the small observatory community needs to be more active and achieve better representation on governing, policy and advisory boards.

To spur general discussion Oswalt proposed a straw man "Small Telescope Decadal Plan," which would build from the PREST foundation in FY05 by helping to modernize some current facilities and possibly even fund some new facilities. NOAO could serve as the administrative center of the new National Telescope System Consortium (NSTC)—as a coordinating body for representatives from system members (even those whose facilities are not on NOAO sites). NSTC could provide a national resource for technical support, standardized archiving, instrumentation, and software, AURA representation, scheduling, etc. Member obligations could include a 10% community observing time, modest annual "Joint-

Use Fee" (to support NOAO's administrative costs). Perhaps the idea could be jump-started by PREST support for several individual sites, based upon scientific merit review. This straw man was viewed by some as a "top down" approach, and less desirable than a "bottom up" approach involving individual observatories and small consortia working independently. How a System can be built up in the current funding climate without some central coordination isn't apparent.

Prior to the meeting, the break-out session was asked to focus on two questions:

- How should PREST evolve?
- Should TSIP include "medium aperture" 3-m to 6-m telescopes?

It was quite clear from the outset of the discussion that the very large number of participants in our break-out group (by far the largest of the four groups)—and the fact that many of those interested in TSIP were in another session—prevented our group from reaching a strong consensus on either of these issues. However, there was enough common ground to list the following ideas as tentative outcomes of the discussion. Except for the recommendation to separate small and medium telescopes in future discussions, what follows is not listed by priority, only in the general order that they appeared in our discussion.

GENERAL COMMENTS

- Separate sessions for small (<2.5m) and medium (3-6m) telescopes are essential. These two groups face very different challenges and have very different opportunities. This was by far the strongest sentiment expressed during our general discussion (note that in the Kluwer books cited above, "small" was defined as $\leq$4m, i.e., those telescopes most likely to be privatized or closed during the next decade).

- Small telescopes in the system need to be driven primarily by unique key science projects. General access and "single PI" projects should be scheduled between primary key project assignments.

- Interest exists in a 2-m class "national undergraduate telescope." It was suggested that the Calypso 1.3-m or the KPNO 2.1-m telescope might be converted to this type of use. However, some felt that such a telescope would not work well under the standard NOAO TAC system because the review process does not adequately account for the educational value of projects. Also, observers from smaller institutions do not in general have the time to become as familiar with all the instrumentation details—one person suggested that such a telescope should have a pre-decided research program that students could elect to participate in, rather than a suite of projects selected by a TAC-style process.

- The small telescopes to be included in a national system should be more "SMARTS-ified," i.e., more facilities should form consortia and partner with NOAO or large private facilities that can provide essential facility infrastructure support, in exchange for public access.

- Other modes of operation than consortia need to be developed that allow general community/general purpose access for small projects (former NOAO model).

- More consortia need to be developed to operate existing and to create new small facilities. These then need to be organized to form a higher level consortium to deal with broader "System" needs, opportunities, and a voice at the national decision-making level. Whether NOAO plays a role in the development of this structure was left as an open question.

- NOAO should provide some essential services to the small telescope community, perhaps on a 'full cost recovery' basis, outside the NOAO mountain sites.

- Small telescopes would benefit greatly from "mass production" of imaging detectors, small spectrographs, and polarimeters by larger institutions, either public or private. Production of such standardized equipment might constitute a viable substitute and/or complement to PREST/TSIP public access requirement. It may, in fact, be more cost-effective to produce several instruments at a time than just one.

- NOAO can serve as the focus for standardization in small hardware design and production (see above).

- NOAO can provide standardized image processing software ("next generation IRAF"), telescope control s/w and NVO archiving for small telescope community.

- A mechanism by which privately-operated small telescopes at isolated sites can participate in the System needs to be developed.

- Care must be taken to account for the differences between small telescopes that are operated by large institutions versus those operated by small institutions.

- Rather than creating a system via a "top down approach'" that involves NOAO (or other large organization) setting its ground rules and standards, the small telescope community should organize a structure for itself and then partner with NOAO potentially as its host or coordinating agency for public access. This seemed to be the best compromise between those that preferred strict "bottom-up" versus "top-down" approaches. Let's pursue both and "meet in the middle".

- Meetings of the small telescope community need to be more regular, preferably at least annually, perhaps at winter AAS meetings in order to maximize participation and public input. Everyone agreed that this 2nd Community Workshop was an excellent venue.

- Standards and pipelines need to be created by which data generated by the small telescope community can be smoothly and usefully archived in the NVO.

- The solar, planetary and radio community of small facilities needs to be included in the small telescope system, or a separate system needs to be developed that caters to their special science drivers, needs, and problems.

- Better communication channels need to be developed by which small facilities can exchange technical information, operating procedures, and collaboration opportunities. ISTeC (http://astro.fit.edu/istec/), a Web-based directory of small telescope sites, is a good start, but it does not provide a venue for the system-wide exchange of information. Either the AAS or NOAO would be a good host for such a service.

- New venues for the publication and dissemination of technical solutions, instrument design, operating and scheduling modes, etc. need to be created, to avoid "re-inventing the wheel" at each site and to facilitate the production of uniform data for NVO.

- The small telescope community needs to set its priorities, and be willing to close some existing sites in order to make room for the refurbishment of productive existing sites and the creation of new state of the art small telescopes—'we need to control our appetites'.

- The small telescope community needs better representation on the governing boards of NOAO and large private sites, as well as input at the national policy-making level.

- A balance between student experience with real observing data and archival data research needs to be struck. Dependence upon only one or the other is unhealthy. Developing NVO will not eliminate the need for building a system that includes small telescopes.

COMMENTS MOST RELEVANT TO PREST

- PREST will almost certainly need to be expanded at least several-fold in coming years to accommodate the expected high proposal pressure, as evidenced by the demand likely to occur during the FY04 competition.

- IF NOAO is a major focus of the small telescope system, the added duties and costs should be supported by an appropriate mix of federal (NSF) funds via PREST and contributions from participating small telescope members (in kind, via personnel, and fees).

- PREST should evolve in a manner that produces a good mix of federally and privately funded "urban renewal" programs that build the small telescope system. As stated by a participant, "If private money were enough, the system would have been built by now." Both sources of support need to be effectively tapped and responsibly evaluated.

COMMENTS MOST RELEVANT TO TSIP

- Science drivers are the most important consideration for TSIP projects.

- Support was strong for carving a special niche within the current TSIP program to accommodate the unique amortization of capital that 3-6m telescopes face. A different (case by case) weighting scheme needs to be devised to be fair for both public access and owner time. The group felt it would be easier to "lower the bar" on TSIP than to "raise the bar" for PREST to accommodate these telescopes. Mandating more than ~10% community nights was viewed as a psychological barrier to attracting TSIP grant applications.

- TSIP "community access" formula could at least partly include the value of making data available "instantly" or at least very quickly, or by commitment to constructing an extensive archive. The principle should be on valuing a night (or its equivalent) on perceived scientific return, which is improved with a new instrument.

- The biggest current need for standardized instrumentation seems to be for: a) moderate resolution single-object spectrographs, b) medium field CCD OIR imaging systems and c) A/O devices that can increase the efficiency of existing small telescopes.

- State-of-the-art IR detectors cost ~$0.5M; with electronics and associated equipment can total $3-4M.

CONCLUSION

In order to achieve a true System as envisioned by the decadal survey, a broader cross-section of its constituencies needs to be involved in planning and policy-making meetings like the present one. We're off to a good start; this breakout section was very well-attended (see Table 1 for a list of those who signed in). As Arlo Landolt pointed out near the end of our session, "Fifty years ago we set about building a System." It's now time to build one for the 21st century!

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Group 3 *Building Better Instrumentation and Stronger Collaborations*

Discussion Leader: Darren L Depoy

The discussion in the Instrumentation break-out session centered on two issues: (1) the duplication of instruments on various classes of telescopes and (2) priorities for future instruments. There was essentially no discussion on several issues that were thought to be important, e.g., the organization of collaborative efforts to build very large and costly instruments, increasing the involvement of students and postdocs in instrumentation projects, and the saturation of current instrumentation group capabilities. These topics are important, but time did not allow for any meaningful discussion to take place.

Participants in the session reached agreement that there are some instruments that are needed on all large (> 6.5m) telescopes. The feeling was that there was a sufficiently large number of science programs that these instruments could be used heavily on many telescopes. The instruments included a moderate resolution optical spectrograph, a moderate resolution near infrared spectrograph, a near infrared imager, and some sort of adaptive optics capability that could feed all these instruments. There was some sense, but no consensus, that some sort of 3-5 micron instrument is needed.

There were many instruments discussed that are clearly needed on some, but not all, large telescopes. These included wide field optical imagers, highly-multiplexed spectrographs, high resolution spectrographs, coronagraphs, 8-25 micron instruments, and polarimetric capability. The feeling amongst the session participants was that the science programs that required these sorts of instruments, although interesting and important, probably did not require these sorts of instruments on all large telescopes.

The participants decided that there was no single instrument that was needed on all small (<2.5m) and medium (2.5-6.5m) telescopes. The possible exception was a direct CCD imager for small telescopes, since such an instrument is easy, useful, and relatively inexpensive. Further, the participants felt that more wide field optical and infrared imaging and high resolution spectroscopic capability was needed on a larger number of medium telescopes.

The participants felt that the installation of moderate resolution optical and near infrared spectrographs on large telescopes was developing well; nearly every large telescope has such instrumentation (or is in the process of building it). There is clearly a need for additional wide-field, highly multiplexed near infrared instruments, however, although it was recognized that such instruments are expensive and difficult to build. The highest priorities for future instrument noted by the participants were high resolution optical and near infrared spectrographs (for large and medium telescopes) and wide field imagers (optical and near infrared) or medium telescopes in both hemispheres. It was also noted that some kind of robust, efficient, and easy-to-use AO capability needs to be on all large and some medium telescopes. There were clearly other examples of instruments needed on all sizes of telescopes; the participants favored 3-5 micron instruments of any kind, additional instruments capable of very precise radial velocities (<10 m/sec), polarimetric capabilities of any kind, and spectrographs with massive multiplexing.

The participants also recognized the need for improved detector performance and access. In particular, there is strong support for efforts to fund development and acquisition programs for detectors with lower noise, higher q.e., and faster read rates. Lower cost and improved access to better detectors would be beneficial to the entire community.

Group 4 *Issues of Archives, Software, and the National Virtual Observatory*

Participants: K. Cook, S. Lubow, C. Miller, M. Postman (discussion leader), H. Quintana, N. Sharp, C. Smith, L. Storrie-Lombardi, and C. Stubbs

The archiving and distribution of high-level science products are proven methods for optimizing the scientific output of astronomical facilities. NASA archive centers have led the way in this arena for years but the ground-based OIR community is now seriously addressing the requirements and funding needed to efficiently handle the data volumes being generated by modern instrumentation. Indeed, the ground-based archive facilities must tackle the challenging issues of variable atmospheric transparency, very large data volumes (approaching a TB per night in some cases), and frequent instrument changes. Participants in this break-out group. discussed their views on how to ensure that data archives and data mining applications for the ground-based OIR observatory "system" can achieve their potential both for the current scientific community and for the education of future scientists.

The most important recommendation the group made was that there must be properly funded archive centers to ingest, distribute, and enhance the scientific value of ground-based OIR data. Given the diversity of data, a single archive facility is probably not sufficient. The NASA model has shown that data centers succeed when they are staffed by scientists who have an active research interest in the data being hosted. The typical NASA data center has 10 – 20 FTEs dedicated to overseeing archiving and scientific enhancement of the data. A comparable level of staffing would be appropriate for the typical ground-based OIR facility. The NOAO Science Archive is already on its way to establishing the capabilities to serve the data retrieval and data exploration needs of its user community.

The classical observing mode used by many ground-based observatories leaves the details of how science data are calibrated up to the individual observer. To make optimal use of the data being archived, components of the ground-based OIR system should provide their observers with archive-friendly prescriptions for acquiring calibration data that facilitate the availability of well-calibrated data. We recognize that one cannot easily impose requirements on how and when to calibrate ground-based science data. However, if "painless" scripts and tools are available to do just that it is likely that the level of high quality data be maintained and, at the same time, will make data mining services more powerful by ensuring a large amount of homogeneously calibrated data. An essential need is the availability of standardized data on the status of the local atmospheric conditions (e.g., cloud coverage). As independent institutions often share the use of mountaintop sites, the cost for setting up photometric monitoring equipment can be shared as well.

Data must be both accessible *and* useful. This means that there is a need to support the generation of metadata. While most observatories do provide relatively complete information on pointing, observing mode, exposure times, etc. there is also a need to provide information linking science data to calibration and meteorological data. While services being proposed and developed for Virtual Observatory (VO) application can likely handle linkages between complimentary data from different sites, the task of linking associated science, calibration, and weather data will likely fall to the individual observatory centers. Furthermore, as observatories begin to develop their own data access and query tools, it is recommended that compliance with VO standards and protocols be maintained in order to facilitate the inclusion of their data into the global VO network. This is now becoming relatively easy to do and does not impose any constraints on the data format other than the use of FITS.

As ground-based data archives grow in size and popularity and with the cost of instruments for large telescopes running between a few to tens of millions of dollars, the need to establish comprehensive data management and processing plans is critical. The archive working group shares the view expressed elsewhere in this workshop that future TSIP instrument teams should be required to include a funding request for the development of an associated data processing pipeline that will be available at the time of deployment and that produces *at least* level-2 (instrumental signature removed) science products. The evaluation of all future TSIP proposals should include a serious assessment of such a data management plan. This policy will benefit everyone—the verification of the instrument will proceed efficiently, useful data will be available for archive ingest at the time of commissioning, and the time to the first science results will hopefully be minimized.

Finally, but by no means least important, we feel there is the need to nurture the development and distribution of undergraduate-level curriculum and materials focused on VO and archival-based research and results to facilitate the teaching of how large databases are transforming astronomical research. The intent here is to introduce the concept that significant astrophysical discoveries do not always require new data but rather sometimes require analyzing existing data in new ways. This will be especially relevant as the sky is catalogued to greater depth and across a broad dynamic range in wavelength. The earlier this concept is presented to students, the better prepared they will be if they choose to pursue a career in science, in general, and astronomy, in particular.

Appendix D

CURRENT INSTRUMENTS
IN THE GROUND-BASED O/IR SYSTEM

Table D.1
Optical Imagers: Telescopes > 6.5 m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/ Status
Keck 10m	Echellette Spectrograph and Imager (ESI)	3900 -1.1um; MIT/LL 2K X 4K CCD	0.153 arcsec/pixel	2 X 8 arcmin (1.1 X 1.9 arcmin for facility filters)	
Keck 10m	LRIS	4000A - 1um; Tek 2K X 2K CCD	0.22 arcsec/pixel	6 X 8 arcmin	
Keck 10m	DEIMOS	4100A - 1.1um; 8k X 8K CCD mosaic	0.12 arcsec/pixel	5 X 16 arcmin	
LBT 2 X 8.4m	Large Binocular Camera	3600A - 1.2 um	0.23 arcsec/pixel	24 X 24 arcmin	Under construction
MMT 6.5m	Megacam	3500A-1.0 um; 36 EEV 2K X 2K CCDs	0.08 arcsec/pixel	24 X 24 arcmin	
Gemini-N 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	0.08 arcsec/pixel	5.5 X 5.5 arcmin	
Gemini-S 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	0.08 arcsec/pixel	5.5 X 5.5 arcmin	
Magellan 6.5m	MAGIC	2K X 2K CCD	0.069 arcsec/pixel	2.4 X 2.4 arcmin	

Table D.2
Optical Imagers: Telescopes 3 m to 5 m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Palomar/Hale 5.0m	COSMIC	Tektronix 2K X 2K CCD	0.28 or 0.40 arcsec/pixel	9.7 X 9.7 or 13.6 X 13.6 arcmin	
Palomar/Hale 5.0m	Large Format Camera (LFC)	3300A - 1 um; six 2048 X 4096 SITe CCDs	0.18 arcsec/pixel	approx 24 arcmin diameter	
SOAR 4.2m	CCD Imager	4K X 4K CCD	0.08 arcsec/pixel	6 X 6 arcmin	Delivery 2004
NOAO/Mayall 4m	CCD Mosaic Imager	3300A-1um; 8K X 8K SITe CCD mosaic	0.26 arcsec/pixel	36 X 36 arcmin	ADC
NOAO/Blanco 4m	CCD Mosaic Imager	3300A-1um; 8K X 8K SITe CCD mosaic	0.27 arcsec/pixel	37 X 37 arcmin	ADC
ARC 3.5m	SPICam	3300 A - 1 um; SITe 2K X 2K CCD	0.14 arcsec/pixel	4.8 X 4.8 arcmin	
WIYN 3.5m	MiniMosaic	3300A-1um; 4K X 4K SITe CCD mosaic	0.14 arcsec/pixel	9.5 X 9.5 arcmin	
WIYN 3.5m	Tip/Tilt Imager	3300A-1um; 4K X 4K SITe CCD mosaic		4 X 4 arcmin	Uses tip/tilt compensation
WIYN 3.5m	One Degree Imager	78 2K X 4K Orthogonal Transfer CCDs	0.12 arcsec/pixel	1 degree diameter	Uses OT CCDs to perform tip/tilt compensation; planned
Lick/Shane 3.0m	Whitford PF Camera	3500 A - 1 um; SITe 2K X 2K	0.3 arcsec/pixel	9.8 X 9.8 arcmin	ADC

Table D.3
Infrared Imagers: Telescopes > 6.5m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Keck 10m	LWS	3 - 25 um; Boeing 128 X 128 Si:As BIB	0.08 arcsec/pixel	10.2 X 10.2 arcsec	
Keck 10m	NIRC	1 - 5 um; InSb 256 X 256	0.15 arcsec/pixel	38 X 38 arcsec	Speckle mode; R=100 grism
Keck 10m	NIRC 2	1 - 5 um; InSb 024 X 1024	0.01 - 0.04 arcsec/pixel	10 X 10 to 40 X 40 arcsec	Uses NGS/LGS AO System; coronagraph; grisms;
Keck 10m	SHARC	0.85-2.4um; 1024 X 1024 Hawaii-2	0.019 arcsec/pixel	19.5 X 19.5 arcsec	Behind AO system
Gemini-N 8m	NIRI	1-5um; 1024 X 1024 InSb	0.02-0.12 arcsec/pixel	20 X 20 to 120 X 120 arcsec	Grisms; coronograph; polarimetry; AO optional
Gemini-S 8m	T-ReCS	8-26 um; 240 X 320 Si:As BIB	0.09 arcsec/pixel	30 X 22 arcsec	Spectroscopy also
Gemini-S 8m	Flamingos-2	1-2.5 um; 2K X 2K HgCdTe		3 X 3 arcmin	Delivery 2005
Gemini-S 8m	NICI	1-5um; 1024 X 1024 InSb		20 X 20 arcsec	Optimized for coronography; delivery 2004
Gemini-N 8m	XAO Coronagraph	0.9-2.5 um	0.01 arcsec/pixel	> 3 arcsec FOV	IFU; planned
MMT 6.5m	MIRAC3	2-26um; 128 X 128 Si:As BIB	0.14 or 0.28 arcsec/pixel	18.2 X 18.2 or 36 X 36 arcsec	
Magellan 6.5m	MMIRS	0.9 - 2.5 um; HgCdTe 2K X 2K	0.15 arcsec/pixel	2.5 X 2.5 arcmin FOV	Delivery 2006; TSIP funded

Table D.4
Infrared Imagers: Telescopes 3 m to 5 m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Palomar/Hale 5.0m	WIRC	1-2.5 um; 2048 X 2048 HgCdTe	0.25 arcsec/pixel	8.7 X 8.7 arcmin	
Palomar/Hale 5.0m	Spectrocam - 10	8 - 13 um; Rockwell 128 X 128 Si:As BIB	0.25 arcsec/pixel	15 arcsec	
SOAR 4.2m	Spartan IR Imager	1-2.5um;		5.4 X 5.4 arcmin	Under construction
NOAO/Blanco 4m	OSIRIS	0.9-2.4um; 1024 X 1024 HgCdTe	0.16 or 0.40 arcsec/pixel	93 X 93 or 233 X 233 arcsec	
NOAO/Mayall 4m	SQIID	J,H,K,L'; 4 512 X 512 InSb	0.39 arcsec/pixel	200 arcsec diameter	Simultaneous in 4 bands
NOAO/Mayall 4m	Flamingos	1-2.5 um; 2K X 2K HgCdTe	0.3 arcsec/pixel	10 X 10 arcmin	
NOAO/Blanco 4m	ISPI	1-2.5um; 2K X 2K HgCdTe	0.3 arcsec/pixel	10 X 10 arcmin	
NOAO/Mayall 4m & Blanco 4m	NEWFIRM	1-2.5um; 4K X 4K HgCdTe mosaic	0.4 arcsec/pixel	27 X 27 arcmin	Under construction
ARC 3.5m	Grim II	1-2.5 um; 256 X 256 HgCdTe	0.11, 0.24, or 0.48 arcsec/pixel	30, 60 or 120 arcsec	Grisms
ARC 3.5m	NIC-FPS	0.85 - 2.5 um; 1024 X 1024 HgCdTe	0.27 arcsec/pixel	4.6 X 4.6 arcmin	R=10,000 Fabry-Perot etalon
Lick/Shane 3.0m	Gemini IR Camera	1-5 um; HgCdTe 256 X 256 & InSb 256 X 256	0.7 arcsec/pixel	3 X 3 arcmin	Short and long wavelength channels operate simultaneously; polarimetry
Lick/Shane 3.0m	IRCAL	0.9-2.5um; Rockwell PICNIC 256 X 256	0.075 arcsec/pixel	19.4 arcsec	Uses NGS/LGS AO System; coronagraph; grisms

Table D.5
Optical Spectrographs: Telescopes > 6.5 m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Keck 10m	Echellette Spectrograph and Imager (ESI)	3900 -1.1um; MIT/LL 2K X 4K CCD	1000-10,000 in single order or echellette mode	8 arcmin slit in single order; 20 arcsec slit in echellette	
Keck 10m	HIRES	3500A - 1 um; Tektronix 2K X 2K CCD	30,000-80,000	slit length up to 70 arcsec	x-disp; typically 1200-2500A coverage per exposure
Keck 10m	LRIS	4000A - 1um; Tek 2K X 2K CCD	300-5,000	longslit up to 7.5 arcmin;	multislit on milled aluminum plates
Keck 10m	DEIMOS	4100A - 1.1um; 8k X 8K CCD mosaic	1000-5000	5 X 16 arcminutes	multislit on milled aluminum plates
HET 9.2m	LRS	4000A-1um; Ford 3K X 1K CCD	600-3000	4 arcmin	(13) multislits
HET 9.2m	MRS	4500-9000A	5000-20,000	9 fibers	NIR beam planned
HET 9.2m	HRS	4200A-1.1um; 2 2K X 4K CCD	30,000-120,000	single object -- fiber fed	
LBT 2 X 8.4m	MODS	3300A - 1.1 um	2000 - 8000	6 X 6 arcmin	holds 25 masks with multislits; imaging mode;under construction;2nd unit TSIP funded
Gemini-N 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	1000-5000	5.5 X 5.5 arcmin	multislits; IFU; polarimetry
Gemini-S 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	1000-5000	5.5 X 5.5 arcmin	multislits; IFU; polarimetry
Gemini-S 8m	Bench-HROS	3200A-1um; 2 EEV 2K X 4608 CCDs	130,000	single object -- fiber fed	delivered; awaiting commissioning
MMT 6.5m	Double-Beam Spectrograph	3100A - 1um; 1200 X 800 & 3K X 1K CCDs	500-5000	150 arcsec long slit or 10-20 arcsec slit for x-disp	x-disp; typically 1200-2500A coverage per exposure
MMT 6.5m	Hectoechelle	3500A - 1 um; 2 EEV 2K X 4608 CCD	30,000	1 degree	240 fibers
MMT 6.5m	Hectospec	3500A - 1 um; 2 EEV 2K X 4608 CCD	1,000	1 degree	300 fibers
MMT 6.5m	Binospec	3900A - 1um; 2 EEV 2K X 4698 CCD	1000-5000	16 X 15 arcmin	multislit; imaging mode; delivery 2005
Magellan 6.5m	LDSS-II	?	low-res	6.4 arcmin	slitlets?
Magellan 6.5m	IMACS	3600A - 1.0 um or 3900A - 1.05um; 8K X 8K SITe CCD mosaic	1800 or 10,000	15 X 15 arcmin or 27 X 27 arcmin	1000 multislits; IFU; imaging mode

Table D.6
Optical Spectrographs: Telescopes 3 m to 5 m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Palomar/Hale 5.0m	Oke Double Spectrograph	3100A - 1um; 2 1024 X 1024 CCDs	1000-5000	128 arcsec long slit; multislits are 15 arcsec long each	Blue and Red channels operate simultaneously; (8) multislits; polarimetry
Palomar/Hale 5.0m	Norris Spectrograph	4000A - 1um; 2K X 2K CCD	500 - 2000	20 arcmin diameter	150 fibers, each 1.5 arcsec diameter
Palomar/Hale 5.0m	COSMIC	Tektronix 2K X 2K CCD	1000-2000	13.6 X 13.6 arcmin	multislit on photographic film
NOAO/Blanco 4m	RC Spectrograph	Tektronix 2K X 2K CCD	300-5000	5.4 arcmin long slit	
NOAO/Blanco 4m	Hydra	SITe 2K X 2K CCD	700-22,000	40 arcmin diameter	100 fibers
NOAO/Blanco 4m	Echelle	Tektronix 2K X 2K CCD	18,000 - 65,000	2 arcmin long slit	x-disp
NOAO/Mayall 4m	RC Spectrograph	Tektronix 2K X 2K CCD	300-5000	5.4 arcmin long slit	multislit
NOAO/Mayall 4m	MARS	1980 X 800 Hi-resistivity CCD	1000	5 X 5 arcmin	multislit
NOAO/Mayall 4m	Echelle	Tektronix 2K X 2K CCD	18,000 - 65,000	2 arcmin long slit	x-disp
ARC 3.5m	DIS III	3700 A - 1 um; 2 Marconi 2048 X 1024 CCDs			Blue and Red channels operate simultaneously
ARC 3.5m	Echelle	3500-9800 A; 2K X 2K SITe CCD	37,500	1.6 X 1.6 arcsecond aperture	cross-dispersed
WIYN 3.5m	Hydra	SITe 2K X 2K CCD	700-22,000	1 degree diameter	100 fibers; also IFU
Lick/Shane 3.0m	Hamilton Echelle Spectrometer	3800 A - 1 um; 2K X 2K CCD	60,000 - 100,000	2-6 arcsec long slit	
Lick/Shane 3.0m	Kast Double Spectrograph	3000A-1.1um; 2 Reticon 1200 X 400 CCDs	500-3000	145 arcsec long slit	Blue and Red channels operate simultaneously

Table D.7
Infrared Spectrographs: Telescopes > 6.5m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Keck 10m	LWS	3 - 25 um; Boeing 128 X 128 Si:As BIB	100 or 1400	10.0 arcsec long slit	
Keck 10m	NIRSPEC	1 - 5 um; InSb 1024 X 1024	2000 or 20,000	42 arcsec long slit in low-res mode; 12 or 24 arcsec long slit in x-disp mode	x-disp
Keck 10m	OSIRIS	1 - 2.5 um; 2048 X 2048 Hawaii-2	3800	1.28 X 0.32; 3.20 X 0.80; 6.40 X 1.60 arcsec	IFU; behind AO; commissioning late 2004; TSIP funded
LBT 2 X 8.4m	Lucifer	0.9 - 2.5 um; HgCdTe 2K X 2K	5000 - 10,000	4 arcmin for seeing-ltd, 30 arcsec for diff-ltd	multislit; imaging mode; under construction
Gemini-N 8m	NIRI	1-5um; 1024 X 1024 InSb	1000-3000	2 arcmin long slit	
Gemini-S 8m	Phoenix	1-5um; 1K X 1K InSb	70,000		single order
Gemini-S 8m	T-ReCS	8-26um; 240 X 320 Si:As BIB	100-1000	22 arcsec long slit	
Gemini-S 8m	GNIRS	1-5um; 1K X 1K InSb	1000-18,000	100 arcsec long slit	IFU; x-disp
Gemini-N 8m	Michelle	8-25um; 240 X 320 Si:As BIB	3000-30,000		shared with UKIRT;
Gemini-S 8m	Flamingos-2	1-2.5um; 2K X 2K HgCdTe	1000-4000	6 arcmin diameter	multislits; delivery 2005
Gemini-S 8m	High Resolution Near-IR Spectrograph (HRNIRS)	1-5um; 4K X 4K InSb	30,000; 70,000	2 arcmin	cross-disp; multi-obj (15 slitlets) mode behind MCAO
MMT 6.5m	Flamingos-1	1-2.5 um	low-res	6 arcmin	
MMT 6.5m	MMIRS	0.9 - 2.5 um; HgCdTe 2K X 2K	low-res	6 arcmin	TSIP funded

Table D.8
Infrared Spectrographs: Telescopes 3 m to 5 m

Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/Status
Palomar/Hale 5.0m	Spectrocam - 10	8 - 13um; Rockwell 128 X 128 Si:As BIB	100 & 2000	15 arcsec long slit	
SOAR 4.2m	Phoenix	1-5um; 1K X 1K InSb	70,000		single order
NOAO/Blanco 4m	OSIRIS	1-2.5um;1024 X 1024 HgCdTe	3000		uses tip/tilt compensation
NOAO/Mayall 4m	Flamingos	1-2.5um; 2K X 2K HgCdTe	2000	10 X 10 arcmin	multislits