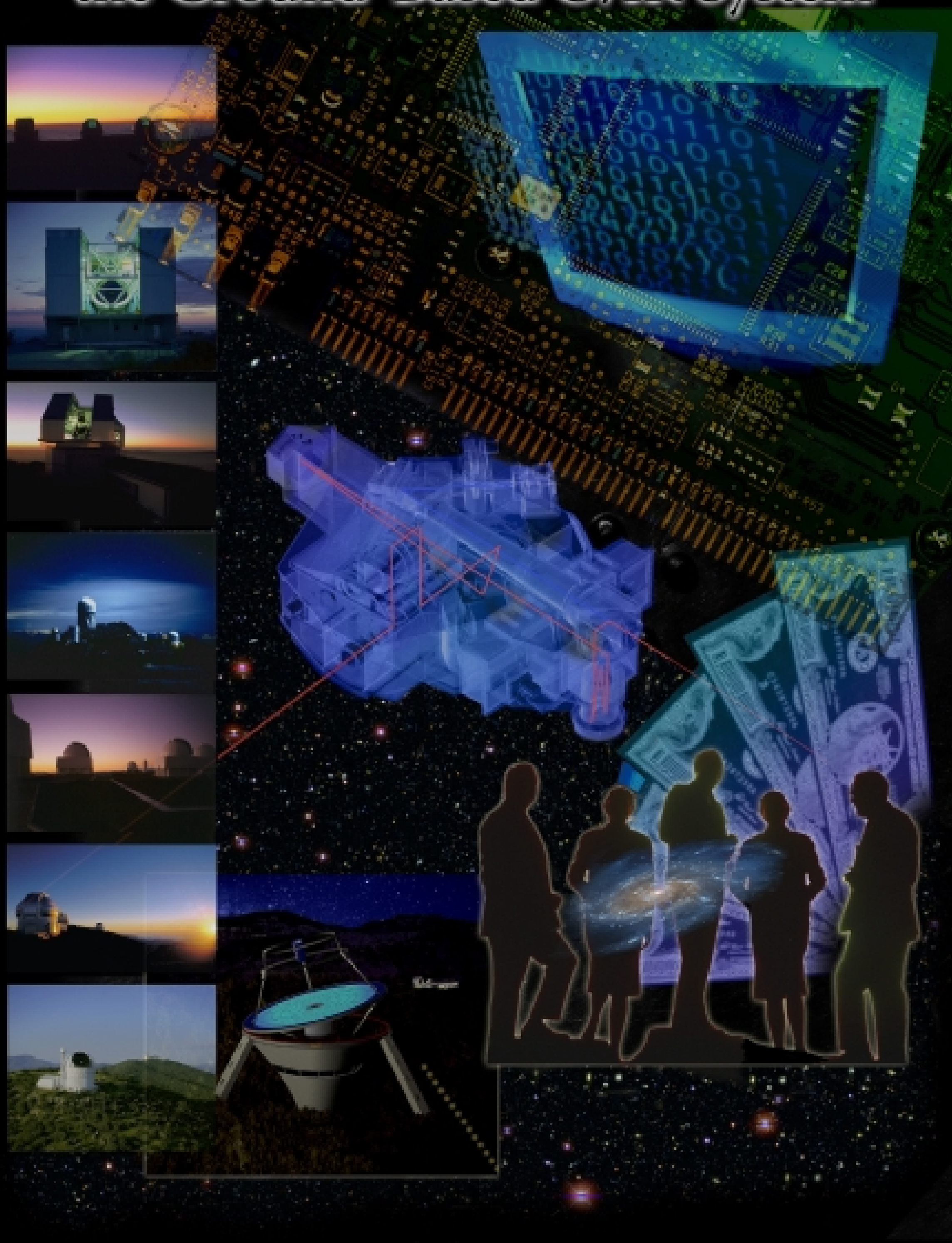
Report of the First Workshop on the Ground-Based O/IR System



Scottsdale, Arizona
October 27-28, 2000

The First Workshop on the Ground-Based O/IR System
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Organizing Committee

Charles Alcock (U. Penn)
Charles Beichmann (JPL/IPAC)
Todd Boroson (NOAO), Co-Chair
James Crocker (Ball Aerospace)
Alan Dressler (OCIW), Co-Chair
James Gunn (Princeton U.)
Garth Illingworth (UC Santa Cruz)
Robert Kirshner (Harvard U.)
Jonathan Lunine (U. Arizona)
Christopher McKee (UC Berkeley)
Richard Mushotzky (GSFC)
Patrick Osmer (Ohio State U.)
John Peoples (FNAL)

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The recent report of the Astronomy and Astrophysics Survey Committee (AASC) lays out a new paradigm for ground-based optical/infrared (O/IR) astronomy, saying that “all facilities, whether nationally or independently operated, should be viewed as a single integrated system.” The report argues that NSF/AST should make investments based on an integrated view of the capabilities and the resources represented by both independent and public observatories. The motivations for this perspective are to use available funding and other resources most effectively, to combine leverage and complementarity with the inherent strength that comes from the diversity of facilities and approaches, and to ensure the community has competitive access to the widest range of cutting-edge capabilities.

What is innovative about the system viewpoint?

1. **Multiple capabilities, used together, make up the system**. Much astronomical research today is carried out by combining observations from multiple facilities, together with archival data and software for processing and analysis. All of these capabilities must be accessible to address the community's scientific aspirations.
2. **Sharing can be more efficient,** leading to a system that is more powerful than the sum of its individual parts. While some capabilities are general and widely desired, others are more limited in interest but have vital application for some important problem. Agreements to share or sell some of the privately owned capabilities allow resources to be used more effectively.
3. **The system is a community-wide concept**. All segments of the community (e.g., researchers from smaller institutions/programs; researchers who work primarily in other wavelength bands but depend upon O/IR data as well) should participate in providing science-based input to identify needed capabilities. This does not mean that all capabilities must be available to all community members, but that the capabilities to undertake the important scientific programs must be accessible in such a way that those programs may be carried out.
4. **Funding at the margin can have a dramatic impact**, and could be used to better cement together the existing elements of the system. Observatories can be encouraged to make choices based, in part, on the perceived advancement of an O/IR system. Outside resources, for example the NSF/AST funding, can be used to encourage consideration of a larger perspective in these decisions.
5. **The system can be implemented in a way that recognizes and maintains the strengths of the US ground-based OIR efforts**, which involve diverse institutions (national centers, private observatories, and universities), different style (single investigator to large groups), and multiple funding sources (national, private, and state). No one envisions a top-down central planning approach that could harm the vitality of the community. Rather the system must recognize the self-interests of the different groups and be organized so that it will be in people’s interest to participate in programs that will simultaneously strengthen the entire national effort. The system must also be flexible and responsive, so that innovative ideas emerging from the community will have a chance of support.

In light of the potential advantages that the system viewpoint could provide, one might ask what activities or processes could be established to aid its positive evolution. The intent is not to force any particular outcomes—or even any particular types of outcome—but rather just to provide a way for groups to understand how their self-interests can be furthered by this system approach. In order to foster discussion along these lines, it was decided to hold a two-day community workshop with the goals of:

- Involving the community in exploring the concept of the system and understanding its elements.
- Structuring community discussions of O/IR-related science goals for the next decade and developing the flowdown to the required capabilities.
- Identifying needed capabilities that do not currently exist (or are in short supply) within the system.
- Beginning the process of developing a strategic plan for the system, from which could come recommendations about programs such as the Telescope System Instrumentation Program (TSIP), the Giant Segmented-Mirror Telescope (GSMT), the Large-aperture Synoptic Survey Telescope (LSST), the National Virtual Observatory (NVO) or other activities, including the planning process itself.

The concept for such a workshop was developed by Alan Dressler and Todd Boroson, the chair and vice-chair, respectively, of the panel on Optical and Infrared Astronomy from the Ground of the Astronomy and Astrophysics Survey Committee (AASC), as a means of continuing and extending the work of that panel. To assist in the process, an organizing committee was recruited to help keep the workshop on track, help synthesize the outcome of the workshop into a report, and advocate the recommendations that would come out of the workshop.

The intent was that these individuals not be representatives of institutions or special interest groups but contribute their ideas toward helping to understand and improve the system. To make this easier to accomplish, it was agreed that observatory directors, who have a financial responsibility to their institution, could not be part of a committee that would be making recommendations that might affect the structure or outcome of programs through which they would be competing for funds. Additionally, rather than limit the membership to O/IR astronomers, the organizing committee included astronomers from outside O/IR as well as members with expertise in the management of large organizations.

The workshop was held at the Radisson Resort and Spa in Scottsdale, Arizona on October 27 and 28, 2000. The choice of Scottsdale was motivated by the desire for a site that would not be associated with any particular observatory, and would be convenient to travel to. The workshop was attended by approximately 80 individuals from 45 different institutions, as well as staff from NSF/AST, AURA, and the NRC. The complete participant list is given in Appendix A of this report. Fifty of the participants were invited by the organizing committee, and 30 responded to an announcement that was publicized on the NOAO Web page and through the AAS electronic newsletter. The workshop expenses, including meals and meeting facilities, and the travel expenses of the invited participants, were covered by NOAO.

The workshop was structured into three sets of presentations, followed by breakout group meetings and a final plenary session that comprised reports from the breakout sessions and a general discussion. The complete workshop agenda is included in Appendix B of this report.

The topics covered by the three sets of presentations were:

1. Introduction to the ground-based O/IR system and its context
2. Elements of the ground-based O/IR system, and
3. Science of the next decade that will rely on the ground-based O/IR system.

The six science areas that were addressed by the presentations and the breakout group deliberations were:

1. *Cosmology Then, Now, and in Five Years: the role of O/IR* (Tony Tyson; Discussion Leader: Tony Tyson)
2. *The Cosmic History of Star Formation and Chemical Evolution* (Pat McCarthy; Discussion Leader: Harry Ferguson)
3. *Testing the Hierarchical Model of Galaxy Formation: The Buildup of Large-Scale Structure and its Relation to Dark Matter* (Michael Rauch; Discussion Leader: Ken Lanzetta)
4. *The Formation of Black Holes and their Relation to Processes such as Nuclear Star Formation, AGNs, and GRBs* (Doug Richstone; Discussion Leader: Matt Malkan)
5. *A Detailed Examination of the Processes of Star and Planet Formation* (Lynne Hillenbrand; Discussion Leader: Mike Meyer)
6. *The Building Blocks of the Solar System, including the Kuiper Belt: the Identification of all Potentially Hazardous Near-Earth Objects* (Mike A'Hearn; Discussion Leader: Heidi Hammel)

The breakout groups were instructed to develop observational projects based on these areas of research and to explore and list the capabilities needed to undertake these projects. The reports of the breakout groups are included in this report as Appendix C.

General Observations

Generally, the workshop was seen as a constructive exercise to most of the participants (including the organizing committee). The structure and the very broad scope seemed appropriate for this, the first workshop. Future workshops might focus on individual components of the system (e.g., software, instrumentation, or small telescopes) or on individual programs (e.g., TSIP). It is clearly important to use workshops such as these to establish dialogues between creators of the proposed system components (instrumentalists, telescope designers) and end users.

One very general observation can be made from the presentations on the large observational facilities. In order to limit the time required to present background information, and also to cast the discussion from the beginning in terms of the ways that facilities must work together, the organizing committee grouped the major observatories into “mini-systems” (Keck/Palomar/Lick, LBT/MMT/Magellan, HET/McDonald, and Gemini/NOAO). While the presenters had been able to assemble all the needed information, they did not, for the most part, present the joint capabilities as a system. This led the committee to conclude that the system perspective is not well-understood, though it undoubtedly guides decisions about capabilities that any observatory will provide. Also, the value of a database of system-wide capabilities was apparent. As an initial step toward this goal, we have compiled the instrumental capabilities presented at the workshop into a table that is included as Appendix D. This table is divided into separate groupings for optical and IR, imagers and spectrographs, and large and medium-size telescopes. Within each grouping, specifications and performance information on each instrument is listed, with color coding to distinguish between instruments that are in use (green), under construction (yellow), or in the planning stage (red).

Recommendations on Instrumental Capabilities

Strong scientific cases were made for a number of instrumental capabilities. Those that repeatedly surfaced in the presentations and discussions include:

- ***Wide field imaging***. In the optical, a number of programs called for LSST, a very wide field imaging capability that would enable studies of the time domain. In the near-IR (NIR), the science cases supported a new generation of wide-field imagers on 4-m-class and larger telescopes. Fields of tens of arc minutes with good sampling of the PSF were desired. This argues for increased emphasis on the development of new, larger format IR arrays.
- ***Medium resolution optical and NIR spectrographs.*** The community would like increased competitive access to this “workhorse” capability as it exists or is being planned for the existing 6.5 to 10-m (hereinafter 8-m-) class telescopes. Almost all scientific programs desired to carry out spectroscopic observations in one or both of these bands on faint objects.
- ***Wide-field optical and NIR Multi-object spectrographs***. The increased emphasis on surveys and on wide-field imaging demands a spectroscopic follow-up capability. Some spectrographs that provide medium resolution over fields of tens of arc minutes (DEIMOS, IMACS, Flamingos) are under design or construction, but the consensus was that this capability should receive additional emphasis.
- ***High-resolution optical and NIR* spectrographs**. The ability to obtain optical and/or NIR spectra at resolutions greater than 20,000 was seen as a critical “niche”

capability, i.e., one that many groups desired to carry out a small fraction of their total program. This creates an obvious opportunity for sharing one or a small number of such instruments on 8m-class telescopes.

- ***Diffraction limited imaging and IFU spectroscopy.*** While the development of adaptive optics is almost a foregone conclusion, the expectation of new capabilities in space reduced interest in diffraction-limited ground-based observation to a lower, but still significant, priority. The emphasis in programs that would use this capability was at red and NIR wavelengths (optimum for planned systems on 8-m-class telescopes). In addition to imaging, several groups desired integral field spectrographs, which would allow spatially resolved spectroscopy over small two-dimensional regions of the sky.

Recommendations on Other Capabilities

High-priority recommendations on a number of other capabilities emerged from the science-based discussions:

- ***Software for data acquisition, reduction, and analysis***. A number of programs recognized the inadequate resources that the community has traditionally invested in software development. New large-format arrays and complex observing protocols involving adaptive optics or simultaneous resolution in time, space, and wavelength will demand substantial planning and increased investment in this area.
- ***Archiving and the National Virtual Observatory (NVO***). As programs become more ambitious, it makes more sense to ensure that their data products are available ultimately to the entire community for data mining, particularly in ways that integrate multi-wavelength and multi-observatory data sets. Within the plenary session, there was a strong call for the archiving of all large, coherent datasets from ground-based observations and for the investment in the NVO that would ensure that it really does enable qualitatively new science.
- ***GSMT and ground-based interferometry***. The community is just beginning to think about some of the more exotic capabilities that have been put on the table. Both GSMT, the 30-meter ground-based diffraction-limited O/IR telescope and an O/IR interferometer were mentioned as facilities that would add substantial value to the mix of capabilities that make up the system.
- ***Access to non-traditional observing modes.*** One obvious consequence of thinking about how facilities are used together is the recognition that the allocation/scheduling mechanisms must support coordinated access to capabilities that may be operated by different organizations and run in different ways. Several groups indicated their desire to see some time available on facilities to be used for observing targets-of-opportunity. In addition, many of the groups pointed out the difficulty of carrying out programs that require simultaneous or sequential observations on a number of one telescopes, especially when or more are space-based facilities.
- ***A new model for the instrumentation, operation, and access to small telescopes***. The participants recognized that the community needs a new way to ensure sufficient and appropriate competitive access to small and medium-size telescopes—which soon will include telescopes as large as 4 meters. There was some discussion of mechanisms through which these telescopes could be effectively instrumented and

shared. One powerful theme was that each smaller telescope should be optimized for and limited to a particular type of observation.

Recommendations on TSIP

- ***The ACCORD Proposal***. ACCORD is a council of directors of the major observatories, public and private, who convene regularly under the auspices of AURA to address common concerns. It was pointed out at the workshop that ACCORD has worked hard to develop acceptable concepts for programs that would support increased community access and additional funds to instrument large telescopes. The recent ACCORD proposal outlining a new NSF program that would address some of the issues identified at this workshop was read with interest by the committee. The committee endorses the idea that the entire community will benefit from broader access to the independent facilities and applauds the incorporation of the option of buying telescope time into the program. The committee would like to see a program in which there is a clear mechanism to address the balance between the two options—buying time and funding instruments—that considers both cost and benefit.

- **A robust relationship between system planning activities and the TSIP program.** While the committee understands the benefit of workshops and reports, it sees the necessity of a substantial relationship between priorities identified from science-based arguments and the goals of TSIP. Put in other terms, it is not merely enough that the report of this workshop be widely distributed, it must exert a measured influence on TSIP, through an Announcement of Opportunity and through the selection process. In addition, there must be feedback on how TSIP funds from previous years have been used to advance the system; this information should be provided at future community workshops as well as made available to the committee that makes selection recommendations.

- ***Accountability in the TSIP program***. The committee believes that TSIP must be different in some ways from typical NSF grants programs. To ensure that the NSF's investment really does advance the system, there must be management of the program. Such management requires that some group be assigned the responsibility of receiving and analyzing reports, participating in design reviews, and working with the instrument teams to identify and solve problems as early as possible. This does not mean that the NSF cannot be flexible in implementing this management or in dealing with problems; it is the very fact that NSF must be flexible that requires the establishment of a management mechanism. This allows responses that could include providing additional resources, descoping an instrument, or ceasing work altogether.

Committee Discussion on a Process for the Positive Evolution of the Ground-Based O/IR System.

The morning following the workshop, the committee discussed the elements of a process that would ensure the positive evolution of the ground-based O/IR system. It was agreed that:

- ***The committee adds value to the process***. Having a committee composed of thoughtful but relatively disinterested scientists, engineers, and administrators that would take responsibility for organizing such workshops, writing the reports, and advocating the recommendations was seen as desirable.

- ***A standing committee could provide continuity and accountability through the process*** While the idea of ad hoc committees assembled for each workshop was considered, there was agreement that it would be more effective to have a standing committee. This would (a) encourage recommendations that had some continuity and (b) provide a mechanism for some accountability through feedback to this committee.

- ***This should be an AURA committee, effected through NOAO***.
  The possibility of this being an NRC committee was discussed. Proponents thought that this would provide more visibility to NSF/AST. Opponents pointed out that it would be difficult to establish such a committee, and that NRC committees have many constraints (FACA, a complex review and approval process) that would make it incompatible with NSF/AST's desire to act quickly.

  The view was also expressed that the job of "organizing the community discussion and formulating it into a strategic plan for the system" is one that is assigned to NOAO by the AASC report (page 182). It is even stated that the test of whether NOAO can be the "effective national astronomy organization" for ground-based O/IR astronomy is the success with which it can take on these new roles. NOAO's organization of the Scottsdale workshop, as well as NOAO staff participation in the workshop and committee discussions, were considered appropriate.

- ***It is inappropriate that this committee report to the NOAO director***.
  After all, the committee will make recommendations that (through some yet unknown process or mechanism) may turn into activities for which NOAO might compete or even be designated. Therefore, it should be considered an AURA committee that NOAO "implements." In practice, having co-chairs, one from NOAO and one from the independent observatories, could be effective. The AURA president could appoint members.

- ***The committee should include some members recommended by ACCORD***.
  It is essential that the independent observatories participate in the evolution of the system; their facilities make up 80% of the telescope capabilities available to the community. It is recommended that when membership on the committee is established, the ACCORD directors be asked for suggestions of people from their institutions who could serve.

Specific Suggestions for the Implementation of TSIP

At the workshop, Dan Weedman, from NSF/AST, informed the organizing committee that he would like to use the results of the Scottsdale workshop to help the NSF implement TSIP, the Telescope System Instrumentation Program.

On December 5-6, 2000, the NRC's Committee on Astronomy and Astrophysics held a meeting at which the O/IR ground-based system and the development of an implementation plan for its evolution were discussed. Presentations were made on the decadal survey and O/IR panel perspectives, the results of this workshop, and the views of NOAO, AURA, and ACCORD. The perspectives of this (workshop organizing-)

committee were represented by Pat Osmer, who presented the outcome of the workshop, and by Alan Dressler, who reported on the views of the O/IR panel.

The organizing committee takes this opportunity to offer some specific suggestions about the implementation of TSIP. These points were not developed at the workshop but were discussed by the committee in the course of writing this report.

- The value of nights made available to the community by an independent observatory within this program should not be an item of continuing negotiation with each proposal, but should be set by agreement in advance of the Announcement of Opportunity (AO) for TSIP.
- The AASC recommendation for the TSIP program included a factor of 2 to be applied to the value of nights to acknowledge the contribution made by the independent observatories in advancing the system. It is essential that this incentive be retained for the instrument part of a combined program. The consequence of this is that proposals to build new instruments that address the needs of the system require an observatory to give fewer nights to the community as do proposals to sell observing time on the same telescope.
- The OIR panel report of the AASC (and the McCray Committee Report before that) recommended flexibility in the manner in which observing time and data would be made available. For instance, some observatories support visiting observers while others might obtain data in a queue-scheduled mode. Another option would be to undertake a survey and make the resulting data products publicly available. The committee endorses this flexibility within the TSIP program.
- A single committee should review all the proposals for this program, whether they are to build instruments or to sell time. Both of these paths are important elements of the plan, and they should be considered an integrated package that advances the system.
- In order to achieve the goal of advancing the system as expressed in the AASC report, the committee would like to see both parts of the program (funding instrumentation and buying telescope time) given a chance to succeed. Initially, it would be wise to announce that a significant fraction of the total funds will be available to each part. It is expected that the balance between the two parts would be adjusted over time in response to scientific arguments.
- The committee recognizes that TSIP is not a traditional grants program. Deliverables and accountability must be clearly stated and agreed on by all participants. It would be valuable for the AO to clearly and explicitly state what commitments are expected on both sides. The committee hopes that NSF can find a way to incorporate the views of the community on the system, as expressed in this report, as a context for the evaluation of proposals to TSIP.
- The committee hopes that TSIP will encourage multi-year agreements in order to provide stability and to facilitate planning of system capabilities. For instruments, this will come about naturally because of the time required to design and build a major instrument. We anticipate, therefore, that following a ramp up in the program, only 20-40% of the funding will be available (not committed to ongoing projects) in any given year to initiate new starts.

***** = Organizing Committee Member

Mike A'Hearn	University of Maryland
Charles Alcock *****	University of Pennsylvania
Taft Armandroff	National Optical Astronomy Observatory
Charles Bailyn	Yale University
Sam Barden	National Optical Astronomy Observatory
Tom Barnes	University of Texas
Steve Beckwith	Space Telescope Science Institute
David Bennett	Notre Dame
Todd Boroson *	National Optical Astronomy Observatory
Scott Burles	Massachusetts Institute of Technology
Adam Burrows	University of Arizona
Kem Cook	Lawrence Livermore National Laboratory
James Crocker *	Ball Aerospace
Roger Davies	University of Durham
George Djorgovski	California Institute of Technology
Alan Dressler *	Observatories of the Carnegie Inst. of Washington
Harry Ferguson	Space Telescope Science Institute
Craig Foltz	University of Arizona
Ian Gatley	Rochester Institute of Technology
Bruce Gillespie	Apache Point Observatory
Tom Greene	NASA/Ames Research Center
Heidi Hammel	Space Science Institute
Lynne Hillenbrand	California Institute of Technology
Garth Illingworth *	University of California at Santa Cruz
George Jacoby	NOAO/WIYN
Nick Kaiser	University of Hawaii
Robert Kirshner *	Harvard University
Ken Lanzetta	State University of New York at Stony Brook
James Liebert	University of Arizona
Jonathan Lunine *	University of Arizona
Roger Lynds	National Optical Astronomy Observatory
Matthew Malkan	University of California at Los Angeles
Robert Mathieu	University of Wisconsin
Patrick McCarthy	Observatories of the Carnegie Inst. of Washington
Robert McLaren	University of Hawaii
Mike Meyer	University of Arizona
Joe Miller	University of California at Santa Cruz
Bob Millis	Lowell Observatory
Matt Mountain	Gemini Observatory
Rich Mushotzky *	NASA/Goddard Space Flight Center
Jerry Nelson *	University of California at Santa Cruz
Gus Oemler	Observatories of the Carnegie Inst. of Washington

Patrick Osmer *	The Ohio State University
Joel Parriott	National Research Council
Bryan Penprase	Pomona College
John Peoples *	Fermi National Accelerator Laboratory
Ron Probst	National Optical Astronomy Observatory
Phil Puxley	Gemini Observatory
Michael Rauch	Observatories of the Carnegie Inst. of Washington
Sun Hong Rhie	Notre Dame University
Doug Richstone	University of Michigan
Abi Saha	National Optical Astronomy Observatory
Ata Sarajedini	Wesleyan University
Mike Shao	NASA/Jet Propulsion Laboratory
Steve Shectman	Observatories of the Carnegie Inst. of Washington
Bill Smith	Assoc. of Universities for Research in Astronomy
Craig Smith	EOS Technologies
Malcolm Smith	National Optical Astronomy Observatory
Bob Stencel	University of Denver
Peter Strittmatter	University of Arizona
Stephen Strom	National Optical Astronomy Observatory
Chris Stubbs	University of Washington
Nicholas Suntzeff	National Optical Astronomy Observatory
David Thiel	University of Denver
Tony Tyson	Lucent Technologies
David Tytler	University of California at San Diego
Jeff Valenti	Space Telescope Science Institute
Tony Tyson	Lucent Technologies
David Tytler	University of California at San Diego
Jeff Valenti	Space Telescope Science Institute
Daniel Weedman	National Science Foundation
Peter Wehinger	Arizona State University
Gary Wegner	Dartmouth College
Rogier Windhorst	Arizona State University
Sidney Wolff	National Optical Astronomy Observatory

Thursday, October 26, 2000

5:00PM Reception

Friday, October 27, 2000 – Ivory Room

8:00 Continental Breakfast

9:00 Welcome, Introduction to the concept of the system and the proposed process for its evolution, Introduction of Organizing Committee, agenda for workshop. *Alan Dressler, Todd Boroson*

9:15 Welcome from NSF. *Dan Weedman*

9:20 Context: The US ground based system as seen by the O/IR Panel; includes GSMT, LSST, TSIP. *Steve Strom*

9:40 Context: The international landscape; includes ESO (and OWL), Japan, UK. *Roger Davies*

10:00 Context: Synergy of O/IR ground-based research with space astronomy. *Steve Beckwith*

10:20 Elements of the system: Keck/Palomar/Lick facilities. Presentation of current capabilities, plans for next 5-10 years. *Joe Miller*

10:40 Break

11:00 Elements of the system: LBT/Magellan/MMT/LCO/FWO facilities. Presentation of current capabilities, plans for next 5-10 years. *Gus Oemler*

Friday, October 27, 2000 – Ivory Room

11:20 Elements of the system: Gemini/NOAO facilities. Presentation of current capabilities, plans for next 5-10 years. *Taft Armandroff*

11:40 Elements of the system: HET/McDonald facilities. Presentation of current capabilities, plans for next 5-10 years. *Tom Barnes*

12:00 Elements of the system: Small and medium-size telescopes. Roles for smaller telescopes, overview of facilities available. *Charles Bailyn*

12:20 Elements of the system: Adaptive Optics/Interferometry. State of the art, developments foreseen over next 5-10 years. *Jerry Nelson, Mike Shao*

12:40 Lunch – Garden Patio

2:40 Elements of the system: Advances in instrumentation. State of the art, developments foreseen over next 5-10 years, challenges. *Sam Barden*

3:00 Elements of the system: Software. State of the art: data analysis, pipelines, archives, visualization and data mining tools; NVO. *George Djorgovski*

3:20 Elements of the system: Observing Modes. Definitions: queues, TOO, surveys, campaigns, supporting and follow-up observations; importance to system. *Chris Stubbs*

3:40 Science: Cosmology – Then, Now, and in five years; the role of O/IR.. *Tony Tyson (Discussion Leader: Tony Tyson)*

4:00 Science: The cosmic history of star formation and chemical evolution. *Pat McCarthy (Discussion Leader: Harry Ferguson)*

4:20 Break

4:40 Science: Testing the hierarchical model of galaxy formation. The buildup of large-scale structure and its relation to dark matter. *Michael Rauch (Discussion Leader: Ken Lanzetta)*

5:00 Science: The formation of black holes and their relation to processes such as nuclear star formation, AGN, and GRBs. *Doug Richstone (Discussion Leader: Matt Malkan)*

5:20 Science: A detailed examination of the processes of star and planet formation. A census of the planetary populations around other stars. Lynne Hillenbrand (Discussion Leader: Mike Meyer)

5:40 Science: The building blocks of the solar system, including the Kuiper Belt. Identification of all potentially hazardous Near Earth Objects. *Mike A'Hearn (Discussion Leader: Heidi Hammel)*

6:00 Instructions to breakout groups: Goals, template (Breakout Rooms assigned)

6:10 Breakout groups (based on six science themes above) meet to begin discussion. Explore most important research areas. Understand linkages to existing capabilities. Identify gaps in capabilities

7:00 Adjourn

7:30 Dinner – **Ballroom 7**

Saturday, October 28, 2000 – Breakout Rooms Assigned

7:30 Continental Breakfast – Garden Patio

8:30 Breakout groups meet separately to continue discussion

12:00 Lunch – Garden Patio

1:00 Plenary session -- Breakout groups report - each 20 minutes – Ivory Room

4:00 Overview of system, discussion of evolution, wrap-up

5:00 Adjourn – Conclusion of meeting for participants

Sunday, October 29, 2000 – Pima Room

8:30 Organizing Committee discussion

12:00 Adjourn

Breakout Group Topics

1. *Cosmology Then, Now, and in Five Years: The Role of O/IR.* Tony Tyson
2. *The Cosmic History of Star Formation and Chemical Evolution.* Harry Ferguson
3. *Testing the Hierarchical Model of Galaxy Formation – The Buildup of Large-Scale Structure and its Relation to Dark Matter*. Ken Lanzetta
4. *The Formation of Black Holes and their Relation to Processes such as Nuclear Star Formation, AGNs, and GRBs*. Matt Malkan
5. *A Detailed Examination of the Processes of Star and Planet Formation.* Mike Meyer
6. *The Building Blocks of the Solar System, including the Kuiper Belt; the Identification of all Potentially Hazardous Near-Earth Objects*. Heidi Hammel

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Breakout Group Reports

Group 1. OIR Ground-Based Cosmology (T. Tyson). Panel: T. Tyson, D. Spergel, M. Smith, C. Stubbs, C. Alcock, R. Kirshner, Matt Malkan, S-H Rhie, S. Burles, J. Gunn

SCIENCE

- *Is the universe accelerating? If so, what is the nature of the dark energy?*
- *What is the nature of dark matter?*
- *Or are DM and DE misunderstood aspects of space-time geometry? If so, we must test GR on cosmological scales via multiple probes.*

To test the foundations of our current models of cosmology and to eliminate specific competing models of the universe containing cold dark matter and dark energy, we need to undertake a variety of probes. The very nature of the problem requires that we probe geometry and the mass structure of the universe over a wide range of look-back times. It will be important to cover a range of epochs, during which dark matter and dark energy were each dominant. Thus, a combination of new observations of the cosmic microwave background fluctuations, the luminosity distance as a function of redshift, and the development of mass structure with redshift are required. This is a multi-facility undertaking, involving space and ground facilities. Ideally, we should probe geometry and structure at redshifts of 1000, 3, 1, and 0.1. The following programs represent our best estimate of the ground-based O/IR component of this effort.

Among the various ground-based O/IR probes of cosmology, several stand out as key to breaking degeneracies: Measure time-evolution of mass structure P(k,z). Count "cluster" masses vs. time N(m,z). Reduce systematics in SN1a probe. Combine with CMB anisotropy. It is important to emphasize probes which are free from baryonic or other assumptions such as source or metric evolution, and where errors can be internally estimated.

THIRTEEN PROBES

***WEAK LENSING*:**

COSMIC SHEAR. Probe wide fields, sufficient to subtend 100 Mpc structures over redshifts 0.2 - 1 (tens of degrees). This is sensitive to both dark matter and dark energy, and may reveal forms of dark energy other than a cosmological constant (quintessence). Measure the mass power spectrum P(k,z) directly. Required observation: multicolor photometry to 28 R mag (5 σ) to get color redshifts and shear over 1000 square degrees. Required facility: 8.4m LSST for at least 5 years of dark time.

CLUSTER MASS NUMBERS N(m,z). Growth of structure proceeds very differently in different cosmologies. Counts of compact mass structures as a function of redshift are exponentially sensitive to dark matter and dark energy in a way that is complementary to cosmic shear and overall P(k). Required observation: same shear survey as above (LSST). Note that little10m spectroscopic calibration follow-up is required, as n(z) for the sources must be known only statistically.

REDUCE SN1a SYSTEMATICS:

Study type 1a SNe over a wide z-range (0<z<1.5) to test for dust and source evolution systematics, as well as tie in zero-points across the full redshift range. Discovery: wide-deep LSST. Spectroscopic confirmation including host: Gemini + Keck. Photometric follow-up including color: LSST. Need about1000 up to z=1.2.

PRIMORDIAL DEUTERIUM:

Combined with CMB, better statistics for the primordial deuterium abundance would yield important consistency checks and would yield a more robust constraint on baryon content of the universe. Required: a bigger, better QSO survey. SLOAN. Then KECK hires spectroscopy. Then, only in the case of big scatter, Phase 2: GSMT with spectroscopic capability.

COSMOLOGICAL TRANSIENTS:

Possible new physical processes, and a dual wavelength test: EXIST + LSST. If transients in large number at very high-z are found with LSST in 20-sec survey mode, this has possible high return. An historical example: qsos. Facility: LSST + petabyte database. Time domain, data-mining.

LENSED SNe:

Measurements of time delay between multiple images of high-z sources lensed by a foreground cluster would probe DM & DE over a key cosmic epoch. This offers the potential of measuring the acceleration directly. Required survey: monitor a sample of clusters via deep repeated imaging. Facility: Gemini, 4m, MMT (0.3”). Follow up: HST, Gemini, (NGST, GSMT). Spin-off: SNe in clusters.

STRONG LENSING H0 AND CLUSTER DOUBLE SOURCE PROBES:

Although more difficult to model, an AO IR Imaging survey of lensed QSO hosts to better sample the lens potential will lead to a purely physics-based measure of H_0. Facility: HST and/or Gemini+ALTAIR.

Similarly, the cluster double-source test using Gemini and similar ground-based telescopes to image in several bands multiply lensed arc systems at moderate and high redshift will lead to a systematics-free measure of a simple function of only Λ and Ω_m. Required: 0.1" imaging + spectra. HST/Gemini/Keck imaging and spectroscopy of several well-mapped clusters.

SZ + WEAK LENSING:

In principle, one can measure Ωm by combining an SZ measurement of the baryon density in clusters with a weak lensing mass map, using the assumption that clusters are fair samples. One does worry about out-of-equilibrium gas. Required: Multi-freq SZ maps + deep optical imaging (10-20' field) . Facilities: SZ multi-freq interferometers and weak lens mass maps with 20" resolution from 6m telescope multi-color deep imaging in 0.5" seeing.

COSMIC FLOWS via SNe:

While providing only one useful point at z=0, a cosmic flow measurement of the local mass density will be an important independent constraint. One would combine P(k,0) with velocity correlation, yielding Ω_m. Facilities: 4-6-m in TOO mode, plus LSST in gray/bright time for discovery.

STRUCTURE IN Ly-a FOREST:

This probes structure formation at a key early time, but is sensitive to ionization history unfortunately. If star formation during these epochs can be understood, then there is some chance of deconvolving ionization. Facilities: Gemini + UV spec R=10000 to study qsos separated by a few arc minutes. Find qsos via SLOAN color or via variability (LSST). Need perhaps100 qso pairs at z=3.

VERY EARLY GALAXIES:

While not a physics-based measure of cosmology, the discovery of fully formed galaxies at z=10 and above would nevertheless be a model-dependent probe of cosmology. Was structure seeded? Facilities: ALMA, NGST, GSMT.

SUPER-MACHO:

Are MACHOs dynamically significant? Are there heavy black holes in the halo? We need to finish the microlensing assay of the halo: 22 is not enough. A larger survey with better images would probe a wider mass range, up to few hundred solar masses and will be more complete. Facilities: future 20% time on 4m +

MOSAIC for finding when SMC is up. Required follow-up 0.5% photometry on Magellan+MAGIC every few days (20th mag) + HST.

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Group 2*: The Cosmic History of Star Formation and Chemical Evolution* (Harry Ferguson). *Participants: Ferguson, Davies, Illingworth, McLaren, Saha, Lynds, Jacoby, Sarajedini, McCarthy, Burles*

In spite of tremendous advances in observations and theory over the last two decades, the issues of how, when, and where baryons are converted into stars over the life of the universe remain a source of major controversy. The breakout group considered a variety of observations that could go a long way toward resolving the controversy, and attempted to summarize the instrumental advances that would enable these observations. Star-formation and chemical evolution can be probed by measuring the integrated light of galaxies, by measuring individual stars (including novae and supernovae) and star clusters, by measuring chemical abundances in interstellar and intergalactic media, and by measuring diffuse background radiation. An aim for the next decade should be to improve the precision of the results from such measurements by an order of magnitude, by a combination of greatly enlarged samples and higher precision measurements. The panel fleshed out several examples.

- **Lyman Break Galaxies z~2-10**
  A breakthrough program would consist of optical and near-IR photometry of roughly 10^5 galaxies, requiring a survey of 20 square degrees to a limiting magnitude AB=26. This would be supported by optical spectroscopy of 10^4 galaxies and near-IR spectroscopy of 100-1000 galaxies. The physics of the galaxy population at these high redshifts would be probed as well by wide-area Lyman-alpha and H-alpha searches, and by a near-IR photometric search for luminous objects (galaxies and AGN) at z>6. For the statistical studies considered here the S/N of the final result often scales linearly with field of view: increasing field-of-view provides a lot of bang for the buck.

  The most crucial instrumentation needs for such projects are:

  a) A wide-field near-IR imager on a 4-m to 8-m telescope, with sub-arcsec image quality.

  b) A wide-field U sensitive imager on a 4-m to 8-m telescope.

  c) An efficient wide-field multi-object optical spectrograph on an 8-m, R ~ 1000 for UV line strengths.

  d) An efficient wide-field multi-object near-IR spectrograph on an 8-m, R ~ 3000 for emission lines, spectral breaks.

- **Galaxy Evolution at z~1-2**
  A breakthrough program would consist of U-K band photometry for 10^6 galaxies, complemented by morphologies from HST/ACS. Moderate-resolution spectroscopy of 10^4 galaxies would test photometric redshifts and provide chemical

abundance information. NIR spectroscopy of 10^3 galaxies would measure the crucial H-alpha and OIII lines. The NIR spectroscopy is challenging; multiplexing can be achieved over small fields with an AO MOS or integral field unit. A wide-field NIR fiber spectrograph would be the most efficient way to build large samples, but they would be restricted to the brightest objects.

The most crucial instrumentation needs for such projects are:

a) Wide-field (0.25 - 1 sq. degree) optical + near-IR imaging on 4-8 m telescope

b) Multiplexing NIR spectrograph R=300 to R=3000 on 8-m.

c) Adaptive optics NIR spectrograph on 8-m

- **Nearby Galaxies; Integrated Light**
The panel considered a variety of projects including studies of detailed two-dimensional kinematics of large samples of galaxies, spectra and photometry of low-surface brightness galaxies and the low-surface brightness outer regions of galaxies (such measurements will not be done by SDSS), surface-brightness fluctuations and fluctuation colors, and the statistics of novae and supernovae (e.g. using LSST). Breakthroughs will come from large samples.

The most crucial instrumentation needs for such projects are:

a) Wide-field optical/NIR imagers with 0.5” image quality on 4-m telescope

b) Arcmin-scale integral-field spectroscopy R < 50 km/s

- **Nearby Galaxies; Resolved Populations**
Projects include giant-branch color-magnitude diagrams for galaxies within 20 Mpc, color-magnitude diagrams to the horizontal branch in all local-group galaxies, spectroscopy of turnoff stars in the Milky-Way and satellites, yielding metallicities, spectroscopy of RGB stars for galaxies within 3 Mpc, measurement of detailed abundance patterns in stars in the Milky Way, construction of spectral libraries, planetary nebula specific frequencies, abundances, and kinematics, and statistical studies of carbon stars in local-group galaxies. HST will supply most of the optical and NIR imaging for small fields, but ground-based facilities are crucial for the wide-field studies of the MW and nearby galaxies, and also for wavelengths longer than ~ 1.8 microns.

The most crucial instrumentation needs for such projects are:

a) Wide-field optical/NIR imagers with 0.5” image quality on 4 m telescope

b) 8-m wide-field fiber-fed spectrograph R~20000 (I~20 mag)

c) High-sensitivity high-resolution (AO) imaging at >2 microns on 8-m telescope

- **QSO Absorption Lines**
Progress will come from spectroscopic follow up of the large samples identified by SDSS and other surveys. Measurements of abundances and abundance patterns in ~10^2 to 10^3 damped Ly-alpha systems and Lyman-limit systems will

allow a direct connection to made to the chemical evolution traced by emission from galaxies. Constraints on chemical abundances in the low-column-density Ly-alpha forest will provide insight into early feedback from star formation.

a) R~1000 spectra, to identify absorbers, 4-m telescope, single-object spectrograph

b) R>~30000 spectroscopy for abundances, 8-m telescope, single-object spectrograph, sub-arcsec image quality

There was not enough time to try to make a more comprehensive list of projects, and to try to synthesize or prioritize the requirements for the various facilities. Perhaps the most keenly felt instrumentation need in this area is for a wide field, high-resolution near-infrared imager on a 4-m to 8-m telescope. This was followed closely by the need for a multi-object NIR spectroscopic capability on an 8-m class telescope. The group did not identify extensive areas needing new types of software or data handling (although the volume of data from a wide-field imager poses a challenge), or pressing needs for observing modes apart from classical or queue scheduling.

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Group 3: *Testing the Hierarchical Model of Galaxy Formation. The Buildup of Large-Scale Structure and Its Relation to Dark Matter* (Ken Lanzetta)

6. SURVEY FOR HIGH-REDSHIFT STRUCTURE USING QSOS AND GALAXIES AS BACKGROUND PROBES

A. Map a region of the sky at high redshifts (roughly z = 3) in Lyman alpha and C IV using QSOs and galaxies as background probes. Objectives are to obtain a picture of the baryon distribution at densities close to the mean density of the universe. Additional information is also obtained about the nature of the background galaxies themselves.

B. Observations: Target objects brighter than V = 24 and redshifts around z = 3. (1) Deep images in four optical bandpasses (B, V, R, I) to a limiting depth of V = 26 over a 10 by 10 arcmin field of view. (2) Multi-object spectroscopy at optical wavelengths (lambda = 4000 - 8000 A) at resolution R = 5000 to obtain a S/N = 20 or higher . (3) Single-object spectroscopy of the occasional very bright pair or triplet of background sources at optical wavelengths at resolution R = 20,000 to obtain a S/N = 20 or higher.

- Telescope: Imaging requires 4 – 8-m telescope.
- Multi-object spectroscopy requires a 30 m telescope with around 0.5 arcsec seeing conditions.
- Observing modes: N/A.
- Software: Automatic echelle spectroscopy reduction package helpful.

2. DEEP WIDE-FIELD MULTICOLOR SURVEY FOR INTERGALACTIC STARS

A. Map the distribution of stars in the low-density regions of the Local Group and compare with hierarchical models of the formation of the Local Group. In particular, search for the missing LSB dwarf galaxies and such galaxies that have been absorbed into the Milky Way halos as tidal streams.

B. Observations: Target half or more of the sky. (1) Images in broad-band M and I and intermediate-band DDO51 to a photometric precision of 0.5 mag and m = 25. (2) Spectra of candidate giants of resolution R = 3000 - 5000 at optical wavelengths spanning lambda = 3900 - 5200 A to obtain a S/N = 30 or higher. Spectroscopy will allow us to verify and select the giants, will give radial velocities, and will give metal abundances. This strategy targets all giants with a luminosity greater than the horizontal branch luminosity to within 800 kpc of the Milky Way. Density of objects might be around 50 per square degree. The synoptic mode of LSST will also allow RR Lyrae stars to be discovered at similar distances, which can also address the science goals. (They are less common than giants, however.)

- Telescope: Imaging requires LSST. Spectroscopy requires wide-field (around 1 square degree) field of view multi-object capabilities. Spectrograph must be stable enough to do radial velocities to within around 10 km/s.
- Observing modes: Spectroscopy may be “piggy backed” onto another spectroscopy program that has similar resolution and wavelength coverage requirements. (Say project 6 above.)
- Software: LSST photometric survey must be accomplished using pipeline software, to provide final, calibrated photometry. Data may have archive potential.

4. WEAK GRAVITATIONAL LENSING SURVEY FOR DISTANT MASS FLUCTUATIONS/SUPERNOVA SURVEY FOR NEARBY FLUCTIONS

A. To measure the power spectrum of mass fluctuations and its evolution versus redshift, together with cosmological parameters, using weak gravitational lensing measurements of distant mass fluctuations and supernova measurements of local mass fluctuations. A single weak lensing observation probes scales of 100 kpc through 100 Mpc.

B. Observations: (1) Imaging observations at a minimum of three optical bandbasses (B, R, I) to a limiting depth of R = 27 over 100 square degrees for measurement of weak gravitational lensing. (2) Whole-sky synoptic survey to detect supernovae in the local universe through 100 Mpc. Bandpass not critical, probably R. (3) Rapid (few days or weeks) spectroscopic follow-up of identified supernovae at moderate resolution and S/N.

- Telescope: Imaging requires LSST on a good site, with good image quality of FWHM < 0.5 arcsec for weak gravitational lensing measurements and normal synoptic survey observations for supernovae. Spectroscopy can be obtain on moderate-aperture telescopes.
- Observing modes: Synoptic mode required for supernova observations.
- Software: Critical to know PSF accurately across image, as a function of position—determination of the PSF versus position must be automated. Final, calibrated images should be produced via a data pipeline. Optimal photometry of galaxies and stars should be produced via a data pipeline, to obtain the absolute highest photometric precision possible given the observations. Synoptic observations must be reduced and analyzed within about a week.

8. KINEMATICS OF A COLUMN DENSITY LIMITED SAMPLE OF GALAIXIES

A. To measure the masses and depths of gravitational potential wells of galaxies as a function of redshift and morphology for a gas column density limited sample. A gas column density limited sample of galaxies selects a representative sample of galaxies that make up the neutral gas content of the universe. Galaxies are selected as damped Lyman alpha absorption systems toward high-redshift QSOs. Use integral field spectrometer to map kinematics of the entire galaxy profiles in O and/or Balmer lines and use high-resolution echelle spectroscopy to establish kinematics of gas along the line of sight to the QSO. Start project with a survey for damped Lyman alpha absorption systems toward faint QSOs, in order to make the rest of the project easier.

B. Observations: (1) Observations of 200 faint QSOs at spectral resolution R = 1000 and S/N = 10 at optical wavelength to verify QSOs and to identify damped Lyman-alpha absorption systems. (2) Intermediate-resolution (R = 5000) integral-field spectroscopy with adaptive optics centered on the QSOs at infrared wavelengths.

- Telescope: Low-resolution QSO spectroscopy requires 8 m telescope with standard low-resolution spectrograph. Intermediate-resolution spectroscopy of galaxies requires 8 m or 30 m telescope with intermediate-dispersion integral field spectrometer that covers a field of a few arcsec on a side at near-infrared (J or H) wavelengths.
- Observing modes: N/A
- Software: N/A

Group 4: *Massive Black Holes* (Matt Malkan)

COSMIC HISTORY OF BLACK HOLES AND THEIR CO-EVOLUTION WITH GALAXIES

1. First, one must **IDENTIFY complete** unbiased AGN samples, *at all cosmic epochs*, (from z=0 to >10 ?)

   Using: multiple techniques (e.g. multicolor photometry, variability).

   REQUIRED RESOURCES: NVO and LSST

2. Next is imaging and spectroscopic **FOLLOWUP,** to **confirm** the identifications, and then obtain accurate **redshifts**, and measure **morphologies**.

   Examples: Deep surveys from *other wavebands* (e.g. Chandra, XMM, SIRTF) will detect large numbers of sources which are extremely faint in the O/IR. More than a third of faint Chandra sources have I > 24.5. In many cases the emission lines are weak, so that a high SNR in the *continuum* will be needed.

   These observations will attack the big science question of: "What does accretion power contribute to the radiative output in all wavebands?"

   REQUIRED RESOURCES: 8-m and 30-m, conventional imaging and multi-object spectroscopy.

3. Finally it will be important to study the detailed **properties of the hosts** (galaxies?), in the early cosmic epochs of their formation and youth, with the ultimate science goal of *Observing the birth of Massive Black Holes*. Intermediate science questions will be the spatial and temporal correlation of accretion power with star formation and galaxy interactions and other disturbances, and measuring dynamics in the near-environment of the galactic nucleus.

   The observational program will use multi-wavelength imaging and spectroscopy of the host galaxies with AGN at Z>3.

   REQUIRED RESOURCES: Imaging and spectroscopy with AO on 8-m and 30-m telescopes, with nulling if possible.

BLACK HOLE ACCRETION PHYSICS

1. *Time variability* provides information about the size and structure of the AGN on sub-parsec scales.

   A) Reverberation mapping of emission lines and IR continuum

   B. Find and study microlensing events in lensed quasars, where the lens acts as a "magnifying glass" for the line- and continuum- emitting regions

   These techniques will be used to determine what are the:

- Distribution of dust heated by the central engine
- Structure of the primary continuum-emitting region—is it an accretion disk?
- Dynamics of gas near the central engine—are the motions dominated by the gravitational potential?

The ultimate science goals to be addressed are the *direct detection of the accretion flow, and a dynamical measurement of the black hole mass*. These must cover the FULL RANGE of BH MASSES, which implies dense sampling over a very wide range of timescales.

REQUIRED RESOURCES: NVO and LSST, with "intervention mode" scheduling, which may require special joint allocation of multiple telescopes/ facilities, for **coordinated multi-wavelength monitoring.**

Possibly related special Target-of-Opportunity observations on moderate-aperture telescopes, in response to :

- BLACK HOLE MERGER ALERTS from *LISA*, for identifications and redshifts
- GAMMA-RAY BURSTS, for time-resolved spectroscopy

STRUCTURE OF THE INNER PARSEC OF NEAREST AGN AND LOW-LUMINOSITY AGN.

How do O/IR compare with VLBA radio/jet structures?

Do different AGN show different "Modes of accretion"?

The ultimate goal is **direct resolution of the accretion flow**, and possible disks, tori and jets.

Obtain *diffraction-limited imaging and spectroscopy* of, for example, NGC1068 (15Mpc), NGC4151 (15Mpc), NGC4258 (7Mpc), M87 (15Mpc), M81 (3Mpc), Circinus (4Mpc)

REQUIRED RESOURCES: 30-m + AO

COSMIC EVOLUTION OF THE NEAR-ENVIRONMENT OF AGN

Measure the evolution of host galaxy bulge parameters, their structure and dynamics. Compare those with and without non-stellar nuclear activity.

What is the cosmic evolution of MBH/Bulge/Velocity dispersion relations?

The ultimate goal of these 3 research programs is a (statistical, at least) understanding of:

How black holes produce accretion power in the Universe.

Obtain *diffraction-limited imaging and spectroscopy* of the surroundings of AGN out to z=0.5—1.

REQUIRED RESOURCES: 30-m + AO, with a very high dynamic range, probably using nulling of the bright nucleus.

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Group 5: *Searching for Origins in Protostars & Planets: Requirements for the O/IR* (Mike Meyer) Participants: David Bennett (Notre Dame), Ian Gatley (RIT), Tom Greene (NASA-Ames), Lynne A. Hillenbrand (Caltech), Jim Liebert (Steward), Bob Mathieu (Wisconsin), Michael R. Meyer (Steward Observatory), Ron Probst (NOAO), Mike Shao (JPL), Steve Strom (NOAO), David Theil (U. Denver), and Jeff Valenti (STScI)

The first ground-based OIR workshop was held October 27-28, 2000 in Phoenix, Arizona. The working group listed above met during the workshop with the following charge: to discuss anticipated advances in the field of star and planet formation in the next decade and report on capabilities required to realize these expectations highlighting those currently lacking in the system. In advance of the meeting, potential participants were contacted via e-mail and invited to join our group. We met briefly at the end of the first day of the workshop, followed by discussions the next morning. Our group decided to choose four topics within our area, and broke into subgroups to address specific science cases within those topics: 1) structure and evolution of the IMF, 2) the assembly of protostars, 3) planet formation and circumstellar disk evolution, and 4) taking measure of the Milky Way. We attempted to choose a broad enough range of science to represent our area, while at the same time advocating programs designed to illustrate specific capabilities important and unique to our discipline. Finally, a summary presentation was made during the plenary session the afternoon of October 28. This report is based largely on that summary.

- **Structure of the IMF and Dependence on Physical Conditions:**
  With the goal of understanding the physical processes responsible for determining the distribution of stellar masses that result from individual star-forming events, we expect that over the next decade the following questions will be addressed. Is the IMF universal throughout the most extreme environments in the Milky Way and local group?

  This will require diffraction-limited imaging on 6-10m telescopes with spectral-imaging capabilities from R = 500-50,000 in order to disentangle contributions of high and low mass stars to the integrated light of barely resolved stellar populations, as well as assess the impact of stars on the local ISM. Does the form of the IMF change abruptly between 0.1-0.001 $M_\odot$? Wide-field 0.5-1.0 degree OIR imaging, 1-10 mas astrometry, diffraction-limited imaging, and OIR MOS (R=300-3000) over 1-10 degree FOV are required with 6-10m telescopes in order to investigate cluster kinematics, assess membership, and fully characterize the IMF in young clusters in the sub-stellar range. Does the sub-stellar IMF vary over cosmic time? In order to constrain the field star IMF, which represents the IMF as integrated over the history of the galaxy, extremely wide-field (~10,000 sq. degrees) multi-color (R)IZJH(K) multiple-pass surveys with 4-6m clear aperture telescopes are needed. Making use of such surveys databases will require special software and data mining techniques.

- **The Assembly of Protostars:**
  Over the past 10-20 years, significant advances have been made in understanding the pre-main sequence evolution of solar-type stars. However, there is still significant debate over how rotating, magnetized molecular cloud cores dissipate turbulent support and collapse to form single or multiple protostellar disk systems. Specific issues include: What initiates collapse? What role do protostellar flows play in carrying away excess angular momentum, dispersing infalling envelopes, and supporting molecular clouds? How does the physics of accretion determine the final mass of a forming star? How does the “zero-point” (initial radius, temperature, specific angular momentum, distribution of circumstellar material) of PMS evolution depend on proto-stellar mass?

  High resolution near- and mid-IR spectroscopy R > 30,000 on large aperture telescopes can provide unique kinematic diagnostics of molecular gas in collapsing cloud cores, rotating disks, and insight into the physical properties of the protostars themselves. The highest possible resolution imaging (with polarimeteric capability) is required to provide constraints on density distributions traced through scattered light (optical/near-IR) and thermal emission (mid-IR). The diffraction-limit of a 30m telescope subtends < 10 AU in the mid-IR at the distance of the nearest star-forming regions (50-150 pc). Diffraction-limited imaging spectroscopy (R = 300-3000) on large telescopes can provide diagnostics of protostar/outflow interactions. As with the IMF studies outlined above, high spatial/spectral resolution over significant fields of view are required. Answering these questions will be crucial to understanding the star and planet formation process.

- **Planet Formation and Circumstellar Disk Evolution:**
  With the discovery of extra-solar planets orbiting solar-type stars within the past five years, studying the formation and evolution of planetary systems has broadened from consideration of our own solar system alone to placing it in context. How does the gas and dust evolve in disks surrounding young stars? Near- and mid-infrared photometric surveys utilizing wide-field imagers on 2-4m telescopes of stars clusters as a function of age will continue to provide constraints on the evolution of circumstellar material from 0.1-10 AU through modeling of spectral energy distributions. In special circumstances, disks can be directly imaged utilizing adaptive optics systems and coronagraphy on large telescopes. As in the study of protostellar disks and envelopes, high resolution near- and mid-IR spectroscopy (R > 30,000) with 6-10m telescopes will provide complimentary disk diagnostics. Where, when, and how frequently do planets form in circumstellar disks? Characterizing the frequency of extra-solar planets over the full range of masses and orbital radii comparable to those found in our solar system will require surveys utilizing a variety of indirect techniques including: 1) precision radial velocities on 6-10m telescopes at R > 60,000, 2)

astrometry over ~ 10 years timescales, 3) wide-field precision photometry (0.001 mag) for transits, and 4) micro-lensing follow-up in the time domain (hours-days). For direct detection of planets, extensions of high contrast, high dynamic range near- and mid-IR imaging to techniques such as nulling interferometry with large telescopes are needed. Follow-up spectroscopy at R = 300-3000 will provide characterization of their physical properties such as temperature (mass), surface gravity (age), and abundances (composition).

- **Taking Measure of the Milky Way:**
  Because galactic structure was not discussed in any of the other panels, we felt it important to give examples of programs that might make specific requirements on the system even though our group was not qualified to provide an exhaustive analysis of this important research topic. Key questions include: What is the structure and ionization state of the major constituents of the ISM? What are the abundances of light element cosmological probes? What can stellar populations tell us about the fossil record of star formation in the MW? What is the extended structure of the MW? Answers to these questions will require facilities such as: 1) wide-field emission-line imaging, 2) extremely wide-field (5 degrees) multi-object spectroscopy, and 3) deep all-sky photometric monitoring.

- **General Aspects of the System:**
  The programs outlined above have a natural synergy with the goals of the NASA Origins Program. Many of these science programs would benefit significantly from coordinated multi-wavelength surveys (x-ray, OIR, sub-mm, and radio). Perhaps unique among the areas covered in the workshop, studies in galactic stellar astronomy (as illustrated by the physics of pre-main sequence evolution) require monitoring on all timescales (e.g. orbital). As with other disciplines, instrument development is key to progress. In particular, continued development of large-format near- and mid-infrared arrays is a must. Within our discipline, these developments can be effectively coupled with education and outreach programs, capitalizing on the intense public interest in star and planet formation research aimed at addressing the question: are we alone?

  Within the ground-based OIR instrumentation program we recommend developing: 1) Near-IR MOS spectroscopy: 0.6-2.5 microns, 1-10' FOV, R=300-3000, 2) High Resolution IR spectroscopy: 1-5/8-13/17-20 microns, R > 30,000), 3) High contrast/high resolution imaging/spectroscopy: 1-28 microns including AO, coronagraphic, and nulling techniques, 4) Wide-field OIR MOS spectroscopy:0.5-1.8 microns over 5 degree fields, and 5) Wide-field OIR photometric survey capabilities 0.3-20 microns. We also support the major ground-based OIR initiatives advocated in the decadal survey report. In order to obtain a complete census of young stellar populations in the solar neighborhood, an all-sky survey that enables optical/infrared time domain observing is essential. Finally, in order to obtain high spatial/spectral resolution near- and mid-infrared observations of very low luminosity protostellar sources discovered by SIRTF and NGST, an extremely large aperture OIR telescope >10m will be required.

> Because star formation governs the structure of the luminous universe and the origins of life, these studies forge significant links to other OIR science goals. We believe that the capabilities outlined above are crucial to realizing the tremendous potential of star and planet formation research in the next decade. Further, they illustrate how increased investment in components of the ground-based OIR system can help to ensure the competitiveness of the U.S. astronomical community in the face of serious international challenges.

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Group 6: *Solar System* (Heidi Hammel)

The Solar System breakout group articulated one primary scientific goal: *the identification and characterization of the (smaller) denizens of the Solar System, in order to understand the formation and evolutionary processes of planetary systems, including our own.* This is not the only program that could be chosen within Solar System research, but was selected as a representative goal which includes capabilities that are broadly applicable to planetary research in general. Other science is equally worthwhile.

Achieving this goal requires three objectives. (1) Create an inventory of Trans-Neptunian Objects (TNOs) and Centaurs, with special attention to the spatial and dynamical extent of the Solar System. (2) Create an inventory of potentially hazardous objects, including Near-Earth Objects (NEOs) and comets; though this inventory is in response to a Congressional mandate, a key science driver is the orbital distribution of such objects. (3) Determine the physical characteristics of the (smaller) denizens of the Solar System – (i) compositional studies of surfaces; (ii) compositional studies of gases; and (iii) studies of multiplicity of small bodies. We address each objective in turn.

Inventory of TNOs and Centaurs

The current state of the art is imaging with large-format CCDs to m=24, or alternatively, pencil-beam surveys which go fainter but are more limited spatially. One thing that is needed is more access to current facilities, especially for follow-up astrometry. Even more critical is a need to push even fainter still. This will be necessary to fully elucidate the size distribution of TNOs at distances beyond Pluto’s orbit. Apertures should be 4 m (current size for surveys) or preferably larger. Good imaging quality is required, but AO capability is not needed for this aspect of the science. An astrometric follow-up on “smaller” telescopes (e.g., 3-m class) is critical; follow-ups need to reach m=24. Queue scheduling is ideal for such a program (the temporal constraints are strong but not severe: follow-up with a few days to a week). LSST, if data are taken in an appropriate fashion, could provide the requisite observations. The key instrument is large-format mosaic CCDs (>8K square arrays). The number currently available is limiting progress in the field. Re FOV: wider is better. Wavelengths are not critical; combined V and R are adequate. Good seeing is helpful, but not a critical aspect. Arcsecond seeing is sufficient.

The most effective survey would utilize both synoptic and long-term observing modes. For example, three clear nights every month for five years would be an acceptable program. One possible mode would be to have TNO survey data go straight into an archive (NVO style).

Inventory of potentially hazardous objects
To create a complete inventory of potentially hazardous NEOs, one needs a whole sky survey every night for many nights. The temporal sampling scheme is critical: three observations with at least one separation being just a few hours and another about a day. Follow-up observations are critical (amateurs have traditionally done this for brighter objects, but this may become less feasible as the limits on object size are pushed down). Because of the rapid motion of NEOs and comets closer than 1.6 AU (for example), the timescale of the initial follow-up is critical – should be within 24 hours. This leads to observing modes such as TOO or intervention (such mode generally do not exist at present).

In comparison, an inventory of comets requires only smaller telescopes, but very wide fields. Very low spatial resolution is adequate (i.e., arcmins). One useful object identification scheme may be comparing images taken in and out of filters centered on known cometary emission lines. Unlike an NEO inventory, which aims for a complete sample, a comet survey would have to be an ongoing program ("the price of liberty is eternal vigilance"). This makes it an excellent candidate for an automated or robotic program.

Current facilities for such work are telescopes ranging from 0.9 to 1.8 m. To push the NEO size limit down to 1 km, wide-field capabilities on a >2-m class telescope are needed. Given the nature of the project, a facility specifically dedicated to the program would be strongly preferred. This is especially true for the comet program. Given that potentially hazardous objects have no preference for northern skies, telescopes in both hemispheres would be preferable for a complete inventory. LSST, if operated in a very specific sequencing mode, could generate the required observations.

The instrumentation needed is wide field (FOV 2-3 degs, vs current arcmins). Spatial resolution is not a limiting factor, nor are wavelengths (V and R are acceptable; although see note about cometary emission lines above).

Current software search capabilities are adequate for NEOs (point sources), but not for comets ("moving fuzzies"). Software modifications would have to be implemented to account for the extended nature of cometary sources.

Physical characterization of Solar System bodies
This objective requires a variety of techniques to explore the diverse environments in the solar system. (a) Understanding the surfaces of TNOs/Centaurs requires reflectance spectroscopy with resolving powers of 1000 from the optical (300 nm) through the near infrared and beyond. The near IR is particularly diagnostic of minerals and organics on TNO surfaces. With this kind of resolution, it may be possible to determine isotopic ratios on distant surfaces (c.f., recent work on C^{12}/C^{13} on Pluto for example). (b) To characterize cometary gases one needs spectral resolution of 10^5 and spatial resolution of 100 mas or better. This will permit new measurements of (for example) C^{12}/C^{13} and D/H in comets. This spectral and spatial resolution is required from 300 nm out to the near infrared. Achieving spatial resolutions of tens of milliarcseconds in the blue will significantly push AO capabilities beyond the current state of the art. (c) Thermal measurements of small

distant bodies, when combined with visible reflectance, are critical for assessments of their sizes. Some Centaur sizes may be obtainable from the ground, given large enough aperture and sensitivity at 10 microns (the majority of TNOs have their peak thermal emission shifted so far into the red that space will be a more viable alternative for detection). (d) Detecting a satellite around a TNO, Centaur, or other small body provides by far the best means of determining the body's mass.   This requires large aperture (for photons) and AO capability.

For surface spectroscopy, a 30 m aperture will be needed (Keck data for the brightest objects remains controversial, and access on this facility is small and shrinking in any case). Note: the 30-m must have moving target capability! For gas spectroscopy, again, moving target capability is a must. One can do the brightest comets with relatively small telescopes (4- to 8-m class), but phase space will be significantly expanded with larger aperture telescopes.

In terms of instrumentation, the number of pixels is very important for both the spectral and the spatial resolutions (i.e., it must be large!). For cometary observations, the UV response should be at least as good as the present Mayall echelle.

The nature of NEOs and comets requires that TOO observing modes be available. Moving target capability required.

Tables Showing Current Elements of the System:
Instruments on Medium (D = 3 – 5 meters) and Large (D ≥ 6.5 meters) Telescopes.**

Information as presented at the *First Workshop on the Ground-Based O/IR System* with additional material gathered from observatory web sites.

****Color coding**: Green: Existing; in use.
Yellow: Under construction
Red: Planned

Table 1

Optical Imagers -- Telescopes > 6.5m					
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 arcminutes	under construction
LBT 8.4m	WFPFC	3600A - 1.2 um	0.26 arcsec/pixel	25 X 25 arcminutes	delivery 2003
MMT 6.5m	Minicam	4K X 4K CCD			???
MMT 6.5m	Megacam	3500A-1.0um; 36 EEV 2K X 2K CCDs	0.08 arcsec/pixel	24 X 24 arcmin	under construction
Magellan 6.5m	MAGIC	2K X 2K CCD	?	?	?
Gemini-N 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	0.08 arcsec/pixel	5.5 X 5.5 arcmin	polarimetry; under construction
Gemini-S 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	0.08 arcsec/pixel	5.5 X 5.5 arcmin	polarimetry; under construction

Table 2 Optical Imagers -- Telescopes 3-5m					
Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/ Status
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;
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	
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 FOV	ADC;
WIYN 3.5m	MiniMosaic	3300A-1um; 4K X 4K SITe CCD mosaic	0.14 arcsec/pixel	9.5 X 9.5 arcmin FOV	
WIYN 3.5m	Tip/Tilt Imager	3300A-1um; 4K X 4K SITe CCD mosaic		4 X 4 arcmin	uses tip/tilt compensation; delivery late 2001
SOAR 4.2m	CCD Imager	4K X 4K CCD	0.08 arcsec/pixel	6 X 6 arcmin FOV	delivery 2003
WIYN 3.5m	One Degree Imager	78 2K X 4K Orthogonal Transfer CCDs	0.12 arcsec/pixel	1 degree diameter FOV	uses OT CCDs to perform tip/tilt compensation; planned

Table 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 1024 X 1024	0.01 - 0.04 arcsec/pixel	10 X 10 to 40 X 40 arcsec	Uses NGS/LGS AO System; coronagraph; grisms; under construction
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	
Gemini-N 8m	NIRI	1-5um; 1024 X 1025 InSb	0.02-0.12 arcsec/pixel	20 X 20 to 120 X 120 arcsec	grisms; coronograph; polarimetry
Gemini-N 8m	OSCIR	8-25 um; 128 X 128 Si:As BIB	0.084 arcsec/pixel	11 X 11 arcsec FOV	grisms;
Gemini-S 8m	Flamingos	1-2.5 um; 2K X 2K HgCdTe		3 X 3 arcmin FOV	delivery 2001
Gemini-S 8m	T-ReCS	8-26 um; 240 X 320 Si:As BIB	0.09 arcsec/pixel	30 X 22 arcsec FOV	spectroscopy also; delivery 2001
Gemini-S 8m	NICI	1-5um; 1024 X 1024 InSb		20 X 20 arcsec FOV	optimized for coronography; delivery 2003
MMT 6.5m	Wide Field IR Camera	JHK simultaneously; 4-8 2K X 2K arrays	0.25 arcsec/pixel	10 arcmin diameter	planned?
Magellan 6.5m	Near-IR Imager	?	0.15 arcsec/pixel	2.5 X 2.5 arcmin FOV	?

Table 4 Infrared Imagers -- Telescopes 3-m to 5-m					
Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/ Status
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
Palomar/Hale 5.0m	Spectrocam - 10	8 - 13 um; Rockwell 128 X 128 Si:As BIB	0.25 arcsec/pixel	15 arcsec	
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 FOV	
NOAO/Mayall 4m	SQIID	J,H,K,L'; 4 512 X 512 InSb	0.39 arcsec/pixel	200 arcsec diameter FOV	simultaneous in 4 bands
NOAO/Mayall 4m	Flamingos	1-2.5 um; 2K X 2K HgCdTe	0.3 arcsec/pixel	10 X 10 arcmin FOV	delivery 2001;
NOAO/Blanco 4m	ISPI	1-2.5um; 2K X 2K HgCdTe	0.3 arcsec/pixel	10 X 10 arcmin FOV	delivery end 2001;
NOAO/Mayall 4m	NEWFIRM	1-2.5um; 4K X 4K HgCdTe mosaic	0.4 arcsec/pixel	27 X 27 arcmin FOV	planned
NOAO/Blanco 4m	NEWFIRM	1-2.5um; 4K X 4K HgCdTe mosaic	0.4 arcsec/pixel	27 X 27 arcmin FOV	planned
SOAR 4.2m	Spartan IR Imager	1-2.5um;		5.4 X 5.4 arcmin FOV	planned?

Table 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 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; under construction
LBT 8.4m	MODS	3000A - 1.0 um	2000 - 15,000	1 degree	48 slitlets; imaging mode; delivery 2002
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; under construction
MMT 6.5m	Hectospec	3500A - 1 um; 2 EEV 2K X 4608 CCD	1,000	1 degree	300 fibers; under construction
MMT 6.5m	Binospec	3900A - 1um; 2 EEV 2K X 4698 CCD	1000-5000	16 X 15 arcmin	multislit; imaging mode; delivery ???
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; delivery 2002
Magellan 6.5m	MIKE	3300A-1um; 2K X 4K CCD	19,000-26,000	6 arcsec slit x-disp; 30 arcsec slit -- single order; 30 arcmin FOV for fibers	x-disp; 400 fibers; delivery late 2001
Magellan 6.5m	LDSS-II	?	low-res	6.4 arcmin FOV	slitlets?
Magellan 6.5m	Double Spectrograph	?	low-mod res	10 X 10 arcmin FOV	?
Gemini-N 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	1000-5000	5.5 X 5.5 arcmin	multislits; IFU; polarimetry; under construction
Gemini-S 8m	GMOS	3600A - 1.1um; 3 EEV 2K X 4608 CCDs	1000-5000	5.5 X 5.5 arcmin	multislits; IFU; polarimetry; under construction
Gemini-S 8m	HROS	3200A-1um; 2 EEV 2K X 4608 CCDs	50,000	1 arcmin long slit	under construction
Gemini-? 8m	High-Stability Lab Spectrograph		100,000 - 500,000		fiber fed; planned
HET 9.2m	LRS	4000A-1um; Ford 3K X 1K CCD	600-3000	4 arcmin FOV	(13) multislits
HET 9.2m	HRS	4200A-1.1um; 2 2K X 4K CCD	30,000-120,000	single object -- fiber fed	

Table 6 Optical Spectrographs -- Telescopes 3-m to 5-m					
Telescope	Instrument	Wavelength - Detector Type, Format	Resolution	Field of View	Features/ Status
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
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/Mayall 4m	RC Spectrograph	Tektronix 2K X 2K CCD	300-5000	5.4 arcmin long slit	multislit
NOAO/Mayall 4m	Cryocam	800 X 1200 CCD	1000	5 X 5 arcmin FOV	multislit
NOAO/Mayall 4m	Echelle	Tektronix 2K X 2K CCD	18,000 - 65,000	2 arcmin long slit	x-disp
WIYN 3.5m	Hydra	SITe 2K X 2K CCD	700-22,000	1 degree diameter FOV	100 fibers; also IFU
NOAO/Blanco 4m	Hydra	SITe 2K X 2K CCD	700-22,000	40 arcmin diameter FOV	100 fibers;
NOAO/both 4m	NGOS	3500A-1.0um; 8K X 8K CCD Mosaic	1000-5000	20 X 40 arcmin FOV	multislit; shared between Mayall and Blanco; planned

Table 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
LBT 8.4m	Lucifer	0.9 - 2.5 um; HgCdTe 2K X 2K	5000 - 10,000	4 arcmin FOV for seeing-ltd, 30 arcsec FOV for diff-ltd	IFU; multislit; imaging mode; delivery 2003
MMT 6.5m	Flamingos - 2	0.9 - 2.5 um; HgCdTe 2K X 2K	low-res	6 arcmin FOV	planned?
Gemini-N 8m	NIRI	1-5um; 1024 X 1024 InSb	1000-3000	2 arcmin long slit	
Gemini-S 8m	Flamingos	1-2.5um; 2K X 2K HgCdTe	2000	3 X 3 arcmin FOV	multislits; delivery 2001
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	under construction
Gemini-N 8m	GNIRS	1-5um; 1K X 1K InSb	1000-18,000	100 arcsec long slit	IFU; imaging mode; delivery 2002
Gemini-N 8m	Michelle	8-25um; 240 X 320 Si:As BIB	3000-30,000		shared with UKIRT; under construction
Gemini-S 8m	Flamingos-2	1-2.5um; 2K X 2K HgCdTe	1000-4000	6 arcmin diameter FOV	multislits; planned

Table 8
Infrared Spectrographs -- Telescopes 3-5m

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	
MMT 6.5m	Flamingos-1	1-2.5 um	low-res	6 arcmin FOV	under construction
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 FOV	multislits; delivery 2001
SOAR 4.2m	Phoenix	1-5um; 1K X 1K InSb	70,000		single order