APO FUTURES COMMITTEE REPORT

December 11, 2006

by

Scott Anderson, University of Washington
Tim Heckman, Johns Hopkins University
Jon Holtzman, New Mexico Univerisity
Rich Kron, University of Chicago
John Stocke, University of Colorado
Ed Turner, Princeton University
John Wilson, University of Virginia
Donald York, University of Chicago, chair

with support from

Bruce Gillespie, Apache Point Observatory

And with significant contributions from

Kurt Anderson, New Mexico State University
Michael Evans, University of Washington
Josh Frieman, University of Chicago
Suzanne Hawley, University of Washington
Michael Shull, University of Colorado
Michael Skrutskie, University of Virginia
Rene Walterbos, New Mexico State University

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Executive Summary

This report addresses the future of the Apache Point Observatory, focused on the period 2008-2013. The Futures Committee was asked by the ARC Board of Governors (BoG) to address modes of operation and funding for operations for the Apache Point Observatory and all telescopes belonging to ARC at that site.

Member representatives of all ARC member institutions had six face-to-face meetings and five, 1-hour phone conferences between May, 2004 and February, 2006. Our recommendations to the Board are listed below, in order of the items in our charge, which charge is included in the body of the report.

The goal is here to outline the future of the observatory. In general, there are three options. First, pursue a full-up operations model similar to that of SDSS-II, with collaborative 2.5m/3.5m projects that keep the mountain activities and programs at the current level. This would involve a mix of Federal and private funding. Second, develop a funding model that allows current and/or new partners to operate both telescopes based solely on private funding. From this base, Federal funds would be sought for instrumentation, but not for operations. Third, continue with the current ARC funding and partnerships and close the 2.5-meter telescope. We recommend the second option, though the first option should not be ruled out, should opportunities arise.

The basic question we dealt with was how to take the best advantage, scientifically, of the telescopes now available to us. Our two, main recommendations follow.

- 1) We recommend rapid instigation by the ARC Board of Governors (BoG) of a program that will lead to authorization of a subset of proposals to raise funds for continued surveys with the 2.5-meter telescope, possibly in conjunction with the 3.5-meter telescope. White papers for candidate projects should be solicited by the BoG and screened by an ARC committee. That committee would down-select to a few, and those selected would be authorized by the BOG to raise funds in the name of ARC. The ARC Board of Governors would specify the funding model that would be needed for ARC to carryout any of the programs. An important corollary to this recommendation is that a planning exercise is necessary to document parts of the APO infrastructure and staff mix that are tied to FNAL, and to reach agreements for ownership and maintenance as needed by the institutional plans and needs of FNAL and of APO. [This report and the recommendations were substantially completed in January 2006. An ARC committee carried out this process during the summer of 2006.]

- 2) A robust **funding model for the future** may result by adding more ARC partners and allocating time to them from both the 3.5-meter and 2.5-meter telescopes, to achieve a mountain operations base that is independent of Federal funding. Partners analogous to current SDSS-II, non-ARC partners could then contribute to instrumentation and science needs of the projects on the 2.5-meter in which they are interested and share access to the data from those projects with ARC. This involvement of outside partners is working well for SDSS-II and access to funds for instrumentation may be obtained through Federal grants.

Specific recommendations on 3.5-meter telescope systems and operations are included in Section 4. Many of these involve items best handled by a Director's Instrumentation Committee, which should be established.

Our response to the items of the charge to the committee, item by item, follows.

- We examined various **styles of operation** of the 3.5-meter telescope. The current, extremely flexible style of operation based on remote access with specialized software is so powerful and beneficial to the departments of the Member Institutions that we recommend that it continue, with staff augmentation in the area of instrumentation support.

- We found a number of **new, large programs** (>150 nights) that could involve **collaborations among the ARC institutions**, all associated with prime surveys of the 2.5-meter and follow-up observations on the 3.5-meter. After extensive deliberation, we feel the 2.5-meter should be used for such large and significant programs and should not be thought of as being available for a large mix of small programs in the way that the 3.5-meter is currently used. These large programs may generate Federal and/or private funding, before the summer of 2008 and it may be possible to carry out several large programs in parallel.

  The extensive, PI-driven collaborations currently being carried out on the 3.5-meter (10-150 nights) will continue to occur. The Director should encourage such science collaboration among ARC institutions for other programs, as well.

- We identified several specific **new opportunities,** and the SDSS collaboration has identified several more, which involve use of the 2.5-meter, alone, or in conjunction with the 3.5-meter. We recommend rapid instigation by the ARC Board of Governors of a program that will lead to authorization of a subset of proposals to raise funds. White papers for candidate projects should be solicited by the BoG and screened by an ARC committee. That committee would down-select to a few, and those selected would be authorized by the BoG to raise funds in the name of ARC. The ARC Board of Governors would specify the funding model that would be needed for ARC to carry out any of the programs.

- The anticipated programs of the collaboration scientists for the 3.5-meter telescope programs depend on maintenance and **upgrade of the existing instruments and gradual evolution to new instruments.** One new, facility instrument is contemplated within the next 1.5 years (TripleSpec, from the University of Virginia). A second can be built in the 2008-2013 time frame. The Director should begin a long-term study of the possibilities; a high-resolution, near-IR spectrograph is the best choice at this time.

- **Upgrades to the 3.5-meter telescope and current instruments** based on the science needs of the collaboration should focus on increasing instrument throughput or telescope/instrument operating efficiency. A plan is already in place for a number of such upgrades to the telescope and the existing instruments before 2008. Suggested further upgrades for the period 2008-2013 are listed. The current level of Capital Improvements Funding (CIF) funding is essential to this effort. There are staffing and infrastructure issues that must be addressed as well.

- **The balance of funding for upgrades, between the telescope and the instruments**, should be determined by the Director in light of opportunities to increase throughput and efficiency in each area. The opportunities may favor either the telescope or the instruments at any one time based on the available skill set of the observatory staff or of staff of the Member Institutions at a particular time

- The current **balance of telescope time** use between science, instrument testing and education (grad students of public outreach) has evolved based on user interest and is the model of choice for the telescope future. Most time is used for science, about one instrument per year is brought for engineering testing, many students use the telescope in the course of their graduate work and a small amount of time is used for outreach. About 7% of the total time is required for routine maintenance.

- The **current distribution of science time** on the 3.5-meter is very productive for the ARC scientists and all related policies should be continued. There are seven partners in the use of the 3.5-meter, with shares from 6% to 25%, averaging about 14%. There are some 25, partner institutions in SDSS II, who share access to the data, based on pre-arranged agreements.

- **Collaboration with other private telescopes** in time trades is being actively pursued, as a way to effectively increase the instrument suite available to ARC scientists, but this does not appear to yet be a viable way to accomplish that goal.

- The common ground between scientific interests of ARC scientists that suggests future ARC projects, beyond the use of the current telescopes, lies in time-domain astronomy. Specific suggestions are made in the body of the report, but we recommend that, for the time being, ARC focus on the use of the existing facilities.

1. Introduction

1.1 Background of the Report

The Board of Governors (BoG) of the Astrophysical Research Consortium (ARC) charged the Futures Committee for APO to examine operating modes for the period beyond 2008. The members of ARC are The University of Chicago (UC), the University of Colorado (Boulder, CU), the Institute of Advanced Study (IAS), Johns Hopkins University (JHU), New Mexico State University (NMSU), Princeton University (PU), the University of Virginia (UVa), and the University of Washington (UW). The committee consists of Scott Anderson, UW; Josh Frieman, UC (since, resigned); Tim Heckman, JHU; Jon Holtzman, NMSU; John Stocke, U. Colorado; Ed Turner, Princeton. Don York, UC, is the chair. The IAS did not appoint a member to the committee. Ex-officio members are Kurt Anderson, Site Director, NMSU; Bruce Gillespie, Site Operations Manager, APO; Rich Kron, Director, SDSS; Suzanne Hawley, Director of the 3.5-meter telescope. Rich K. represented Chicago interests after J. Frieman resigned.

Rene Walterbos, Chair of the ARC Board of Governors sat in on some meetings. Mike Shull (CU) and Steve Majewski (UVa) attended the January 2006 meeting at JHU. Michael Strauss (PU) replaced Ed Turner on phone conferences when Ed was unavailable. Mike Evans (ARC) attended some meetings. John Wilson and Mike Skrutskie, both of UVa have participated in some meetings, after it became clear that UVa would become an ARC member. Jian Ge and Stan Dermott, U. Florida, attended one meeting, to discuss a possible use of SDSS for a UF planet search.

Meetings were held, in turn, at the ARC member institutions and local APO users were invited to sit in on the meetings. The meetings were held at times and places that would maximize attendance. We did not meet at NMSU or Princeton, but did have a meeting at all other member institutions, as well as one at O'Hare Airport and one at the Lodge in Cloudcroft, NM.

The report is laid out as follows. Section 1 contains a history of the committee and the charge, as well as an overview of the observatory. Section 2 gives a description of the two main projects, the 3.5-meter program and the 2.5-meter telescope used for the Sloan Digital Sky Survey, including modes of use and notable scientific accomplishments.

Section 3 develops a baseline description of the both telescope systems, while details of state of the infrastructure and of the instrumentation are developed in appendices. Appendices, referenced in Section 3, include a detailed outline of ongoing and future upgrades to the telescope and the instruments.

The future possibilities for scientific use of the 3.5-meter telescope and of the 2.5-meter telescope are reviewed in sections 4 and 5, respectively. Section 6 includes a list of possible initiatives that ARC may wish to consider for implementation in the 2008-2013 timeframe. Funding of the observatory in the timeframe 2008-2013 is discussed in section 7.

1.2 Charge to the Committee

The charge to the Committee from the ARC Board of Governors (BoG) is as follows:

For the time frame 2008-2013, the Futures Committee will examine:

1) New operating styles (e.g., use of TSIP; collaborations with other, private telescopes to exchange instrument use or do major scientific projects together; large projects that require inter-institutional collaborations within ARC, at a higher level than current programs; and matters such as queue scheduling, service observing and the like);

2) Specific large science projects that could involve collaboration among ARC institutions;

3) Science programs based on the 2.5-meter and 3.5-meter telescopes, working together;

4) New instruments that ARC needs, given the particular, current faculties at the institutions and future plans of the various departments;

5) Science-driven upgrades to current instruments, as well as to the telescope;

6) The optimal relative expenditures for new instruments, instrument upgrades and telescope upgrades;

7) The balance of telescope time use for science, education and instrument testing;

8) The current distribution of observation time and funding shares on the 3.5-meter telescope and the likelihood of a need for new partners, depending on funding scenarios;

9) Collaboration with other private telescopes as a way to provide ARC members with access to other instrument capabilities, in exchange for observing time on ARC facilities;

10) Possible other telescopes that ARC might build, either at APO or elsewhere.

1.3 Overview of the Apache Point Observatory

The Apache Point Observatory has a 3.5-meter reflector, a 2.5-meter reflector (currently used for the SDSS), a 20-inch photometric telescope and a one-meter reflector (NMSU). The 3.5-meter is used by over 50 scientists from seven institutions: the University of Washington (UW, 25% share of the time, effective January 1, 2007); The University of Chicago (UC, 17%); Princeton University (PU, 15.625%); New Mexico State University (NMSU, 15.625%); Johns Hopkins University (JHU, 8%), The University of Colorado (CU, 12.5%); and The University of Virginia (UVa, 6.25%), for astronomy programs of interest to the faculties. These interests include research and education (graduate students). There is a small, university–by-university, public outreach program, associated with the Visitor Center at the National Solar Observatory, near APO; the Alamogordo Space History Museum, about 40 miles from the Observatory; the Adler Planetarium in Chicago; and the Sommers-Bausch Observatory and Fiske Planetarium at the University of Colorado.

These institutions and the Institute of Advanced Study are incorporated in the State of Washington as the Astrophysical Research Consortium. The Institute for Advanced Study is a member of ARC but does not share time on the 3.5-meter telescope.

The 3.5-meter telescope is equipped with a number of facility-class instruments and visitor instruments. It was established to provide research opportunities for the members, based on shared needs derived from the very different programs of each Member Institution .

In the framework of the ARC incorporation plan and documents, collegial, shared-use of the 3.5-meter telescope has continued, new members have been added to the 3.5-meter project and the project that became the Sloan Digital Sky Survey developed and was integrated into observatory operations. Most of the on-site staff consists of NMSU employees reporting to a full time Site Operations Manager. The staff has increased from 5 at the 1994 dedication to 27 today and the number of on-site personnel running the various experiments is now as high 25 on a given calendar day.

The 2.5-meter telescope has now completed the five-year Sloan Digital Sky Survey (SDSS-I). From July 1, 2005 to June 30, 2008, three major research programs are underway: a focused supernova search; SEGUE, a study of stellar motions and abundances in the halo of the Milky Way; and a "legacy" survey to finish the imaging and spectroscopic aspects of the main SDSS-I survey. These projects use the original SDSS hardware and software, in addition to some new software. The three programs are collectively called SDSS-II and are fully funded, by the Alfred P. Sloan Foundation, by the National Science Foundation (NSF) and by the numerous scientific partners, some of whom were part of SDSS-I, but some of whom are newly signed up just for SDSS-II. The photometric telescope serves to obtain absolute calibration of fluxes measured by SDSS-I and SDSS-II.

The twenty-five partners of SDSS II are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, Cambridge University, Case Western Reserve University, the University of Chicago*, Drexel University, Fermilab*, The Institute for Advanced Study*, the Japan Participation Group*, Johns Hopkins University*, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA)*, the Max-Planck-Institute for Astrophysics (MPA)*, New Mexico State University*, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University*, the United States Naval Observatory* and the University of Washington*. (Asterisk denotes the members of SDSS-I.)

For the next two years, little change is envisioned in the operation of the Observatory. Instruments are stable and a few will be upgraded. It is expected that one new instrument will be deployed on the 3.5-meter (TripleSpec, described below). Jian Ge is doing experiments with his planet-finder spectrographs during bright time, on the 2.5-meter telescope, in preparation for submitting a final proposal to the ARC Board to use the 2.5-meter telescope in the post-July 2008 time frame.

The ARC Board of Governors judged that we needed a long-range plan, beyond June 30, 2008, that accounts for the use and funding of the observatory. The goal of this report is to propose the elements of an Observatory operations plan for the five years after June 30, 2008. This report is the response to that need.

2.0 The main systems of the Observatory

2.1 The 3.5-meter telescope

2.1.1 Description of the 3.5-meter system

The 3.5-meter telescope is a general purpose telescope equipped with an echelle spectrograph; a medium- to low-resolution spectrograph (DIS); an optical, CCD imager (SPIcam); and an IR imager (NIC-FPS). There are two visitor instruments that reside at the telescope: a tunable, Fabry-Perot imager (GFP), including filters for eliminating higher orders of the etalons, that can be used for narrow band imaging; and CorMASS, a low-resolution, NIR spectrometer (UVa). There is one special instrument used for a lunar ranging experiment (APOLLO, PI-Tom Murphy, from UCSD, sponsored for telescope time by UW).

The 3.5-meter telescope has a unique operating style: individuals do most of the observing from their homes or home institutions using a common, remote interface (TUI). Astronomers from the Member Institutions (MIs) travel to the observatory less than 30% of the time, to train students or colleagues, or to do instrument work. The basic block of schedule time is 1/2 night, but can be longer or shorter on request. It is this particular style of operations that has fostered many of the strengths of the Observatory listed below.

The telescope is operated by the Astrophysical Research Consortium for the Member Institutions. Each MI has its own time allocation committee.

Proposals are solicited about two months before each quarter. The time allocation committees forward their ranked lists of submitted proposals, along with implementation details, to the Director. With the help of Observatory staff, a schedule is created and announced to the consortium members. Nights are awarded to each institution according to its shares. The time assignments, the result of the building of an integrated schedule, are announced by the Director, two to four weeks before the beginning of a given quarter.

The ability to apply for time quarterly and to obtain the time within as little as two month of proposing is unique among telescopes of the 4-meter class, as is the full remote observing capability for all prime instruments. By arrangement, time for transient targets of opportunity can be obtained in just a few minutes.

A complete profile of the users and the institutional research interests is included in Appendix A. The scientists perform research in diverse areas from planet research to Galactic structure to star formation and evolution in local galaxies to cosmology. A summary of research papers published since the telescope began operations is given in Appendix B.

There are provisions for changing the capital value of the shares of Member Institutions, for adding new members and for the selling of time by current members. Capital shares of Member Institutions can also change depending on various contributions to instrumentation of the observatory.

ARC is in a position to start new projects. Based on the model evolved from adding the SDSS project, an activity that includes partners that are not members of ARC, there is flexibility in how such projects are funded. In the case of SDSS, an Advisory Council of partners selects key staff and raises funds, all business transactions being handled by the ARC Board of Governors. With some exceptions, the telescopes and the instruments at the Observatory are owned by ARC.

The observing system is extremely flexible. Over 11 years since the dedication (May 10, 1994), many types of programs, in style and scope, have been done by ARC astronomers.

--There have been numerous instances in which astronomers have taken data from the main SDSS survey and used the 3.5-meter telescope to follow-up interesting objects, leading to discoveries such as the highest redshift QSOs, the brown dwarf stars, unusual binaries (Cataclysmic Variables and White Dwarf/M-star pairs) and the clustering of A stars in the halo of the Milky Way.

--A number of very long-term (up to five-year) programs have been completed. Examples include a five-year study of diffuse interstellar bands, studies of periodic behavior of cataclysmic variables, a study of light curves of gravitationally lensed QSOs and a study of abundances of stars in a volume limited sample in the Solar neighborhood.

--A large supernova search that uses the SDSS telescope for imaging, in the Fall, along with immediate follow-up at the 3.5-meter and other telescopes, is underway (40 half nights in the Fall of 2005, to be repeated in 2006 and 2007). The program is to test the dark energy paradigm by getting spectrophotometry of a large number of Type Ia supernovae. Much preliminary testing with the 3.5-meter telescope was done before the program plan was set out, by coordination of institutional proposals to the Director. About140 SNe have been found from z=0.1 to 0.3, in the first season.

--Three or four times per quarter, programs are carried out that require specific timing to coordinate with astronomical events or with an observation by an Earth-orbiting satellite.

--Forty-one Ph. D. theses have been completed with the telescope and at least fourteen more are in progress or near completion. Such activity depends on stable instruments that are substantial and available for many years. (See Appendix C1.)

---Member Institutions have used the telescope for graduate student training and as a recruiting tool. Such activity is most prominent at the University of Washington. In 2004, for instance, 65% of thesis students (10 out of 17) were using the 3.5-meter telescope as their primary source of data. Currently, all UW graduate students receive a first-year course on observing centered on travel to and use of the 3. 5-meter telescope. A similar activity is ongoing at the University of Colorado, for graduate students as well as undergraduates.

--There are a number of collaborative programs across the institutions. Examples include a program to follow-up of gamma-ray bursts with immediate imaging and spectroscopy (CU, UC, JHU); the supernova search already mentioned (UC, UW, PU, JHU and dozens of non-ARC investigators); and a program to vet halo stars (standard candles) as background sources for determining distances to Galactic high-velocity 21-cm clouds of gas (UC, NMSU, PU and SDSS collaborators);

--Astronomers (ARC and non-ARC astronomers) have brought 15 new instruments to the Observatory over 12 years, to test and to use for science. The most heavily used now is the Goddard Fabry-Perot Imager which has been operating for several years at APO; other such instruments are discussed later in the report.

--The general astronomical community has benefited by collaborative use of the telescope and instruments. The amount of telescope time shared with non-ARC scientists over the last 10 years ranged from 15 to 30% per year.

2.1.2 Scientific accomplishments (1998-2005)

Items followed by a double asterisk were done in conjunction with discoveries from SDSS. The research papers containing the cited results are listed in Appendix B.

- **Active Galactic Nuclei**

    - Confirmation, using SDSS candidates, of the highest redshift QSOs**.
    - Observational confirmation of reionization of the intergalactic medium at the end of the Dark Ages (the Gunn-Peterson effect)**.
    - Largest systematic survey of gravitationally lensed QSOs**
    - Confirmation of the quad QSO (a four, later five image gravitational lens), the largest separation of QSO lensed objects known at the

time (14 arcsec)**. (A lens with a separation of 22 arcseconds has since been found).

- Confirmation of 59 QSO-QSO pairs (not lenses). The study led to the definitive measurement of the clustering of QSOs on small scales.
- Expanded studies of the environments of QSOs using background QSOs in pairs to study absorption lines near foreground QSOs.**
- Follow-up studies of "weird" BALs, the apparent, extensive outflows from QSOs.**
- First gravitational lens time delay to measure the Hubble constant (Q0957+561) with complete statistical limits on microlensing over weeks and months.
- Determination of nuclear sizes of AGNs with a multi-telescope team doing reverberation mapping (NGC 5548).

Galaxies

- Numerous imaging detections of GRB afterglows and confirmation of host galaxies. The near-IR, NICFPS observations indicate that many are reddened or at very high redshift. (2002-2006: Gamma Ray Burst Circular Network (GCN) 1245, 1299, 1744, 1765, 1808, 2040, 2037, 2139, 2140, 2239, 2916, 3212, 3217, 3246, 3561, 3566, 3567, 3583, 4604, 4611, 4753, 4861, 5079, 5126)
- Determination of the luminosity function of galaxies in galaxy clusters at $z<1.2$ (on going).
- Study of V-K color evolution of Type Ia SNe that can be used to determine host galaxy extinction.
- In conjunction with observations from the Hubble Space Telescope, the demonstration that dwarf galaxies are primarily responsible for metal enrichment of the low-z intergalactic medium.
- Follow-up of emission line galaxies found in the KPNO International Spectroscopic Survey.
- In conjunction with HST, provided an initial measure of the ultra-faint quasar surface density.
-

Galactic Structure

- Spectroscopic confirmation of the halo nature of clustered stars from SDSS photometric data, now interpreted to be halo star streams from the breakup of dwarf galaxies as they merge with the Milky Way.**

- Follow-up and confirmation of the existence of a new Milky Way companion, with luminosity intermediate between globular clusters and dwarf spheroidals.**
- Demonstration that the X-ray luminosity function of clusters of galaxies may be independent of redshift.

Stars and interstellar medium

- Spectroscopic confirmation of approximately 45 Type Ia supernovae, near $0.1<z<0.2$. (SDSS II SNe, 3 year, survey)**
- Calibration of the abundance scale for 2.5-meter, star surveys.
- Extended demonstration of the high uniformity of near-IR lightcurves in nearby Type Ia SNe, with applications to supernovae as cosmological standard candles.
- Discovery of a black hole of a neutron star from a system with an X-ray burst.
- Doppler tomograms from optical spectroscopy, combined with contemporaneous Chandra X-ray observations, revealed the disk structure and boundary layer conditions of cataclysmic variables (CVs).
- Discovery of low accretion rate, magnetic CVs and their possible evolutionary link to other CVs.
- Demonstration that variability Ae and Be stars is caused by occultation by foreground dust clouds, similar in size to those of the stars themselves.
- Infrared studies of H2 “shrapnel-like” outflows from young stellar objects (YSOs), using the 2.12 molecular hydrogen and the 1.27 and 1.6 micron [Fe II] lines to get proper motions and radial velocities.
- Spectroscopic follow-up of SDSS to construct the largest white dwarf catalog.**
- Discovery, using SDSS candidates, of some of the first field brown dwarf stars.**
- Discovery of two classes of diffuse interstellar bands (DIBs): those correlated with C2 molecules (hence, dense clouds of molecular hydrogen) and those (the best known, strong DIBs) associated with neutral hydrogen but not with molecules of any type.

- Discovery of jets in particular Herbig-Haro objects (GSFC Fabry-Perot).
- Detection of 135 emission lines from a small H II region at the core of the post-AGB star and nebula known as the Red Rectangle. Many of these represent the first astronomical detections of the lines.

Solar System

- First follow-up observations of a number of newly discovered moons in the Solar System.
- Time-dependent imagery of the Jovian atmosphere, in conjunction with space satellite imaging.
- Selection of highly variable lines of oxygen in the atmosphere of Venus.
- Construction of a full, optical/near-IR data cube of Mars at opposition.

2.2 The 2.5-meter telescope (SDSS)

2.2.1 Description of the 2.5-meter system

The 2.5-meter telescope for SDSS has only two instruments, one for imaging and one for spectroscopy. The telescope is used routinely by professional, on-staff, astronomers, to carry out observations in the two modes.

The imaging mode is instrumented with a CCD camera covering, side-to-side and top-to-bottom, about 2.5-degrees. The camera is divided into 6 columns and 5 rows. Each row has a different set of broad-band filters, bonded to the second corrector of the telescope, which corrector is also the common window for the CCD dewars. The five filters are SDSS u, g, r, I, and z. A large gap between the columns of CCDs is filled in by using two sky scans, one offset by a few arcminutes from the first. Complete sky coverage is thus achieved, with a slight overlap of scans built in for calibration purposes.

Absolute photometry, accurate to 0.01-0.02 magnitudes, is made possible by using a 20-inch telescope to tie SDSS stars to brighter standard stars. Astrometry to 0.1 arcsec or better is done by reference of brighter SDSS stars to the USNO-B/USNO-A catalogue.

The spectroscopic mode (R~1800, 3900-9200A) consists of a plug plate of area seven square degrees that holds 640 fibers, half of which go to each of two double spectrographs, each spectrograph having a red and a blue camera. Together, the cameras yield a 4096 pixel spectrum that extends from 3900A to 9200A with a resolving power of ~1800. Nominally, four, 0.25 hr exposures yields a signal-to-noise ratio of 4 at i - band magnitude 20. With three-arcsec fibers, given the surface brightness of the night (dark) sky, this is close to the sky limit. One can co-add spectra, obtaining gains that are approximately quadratic with exposure time.

A partial list of publications from SDSS is found in Appendix D. Papers mainly from 2005, with a few from 2004, are listed. As of July, 2005, the full list runs to 800 publications, roughly one-half of which were written by astronomers outside the SDSS collaboration. These papers have had a substantial impact: 40 have been cited 100 or more times, a standard criterion for an "influential" paper. For 2004, the SDSS leads all telescopes in citations per paper and lags only the Hubble Space Telescope and the Keck telescope in total citations of all papers (Trimble et al., *PASP*, **117**, 111, 2005). Theses done or on-going by students are ARC institutions, based on SDSS data, are listed in Appendix C2. Students from ARC institutions have done twelve PhD theses with SDSS data and six more are in progress.

In thinking about the future, it appears that the spectroscopic capability will remain unique, while the imaging capability will be duplicated, in part, by new imaging surveys such as PanSTARRS and the Large Synoptic Survey Telescope (LSST). The spectroscopic equipment has good longevity, including the plug plate system (plate drilling, shipping, plugging and handling at the site.) There are issues involving property transfer from FNAL, routine telescope maintenance, documentation for the long term, and migration of software to a third generation of survey projects for the 2008-2014 timeframe, all of which need to be addressed soon. If the science required for the extended, spectroscopic surveys requires use of the SDSS imaging camera, then an analysis will be needed soon of the feasibility of keeping it operational and for how many years. If the 2.5-meter is to continue its survey operations or be re-purposed, a document defining a future operations plan must be constructed soon.

A large part of the SDSS systems engineering, 2.5-m telescope maintenance, and pipeline data processing has been directed by, and/or conducted by, FNAL scientists, engineers, programmers and technicians. In one post-2008 scenario, FNAL might not be a participating institution. If the 2.5-meter telescope is to be kept operational after SDSS-II, it is important to capture the FNAL engineering and technical expertise and transfer it to ARC custody. This also includes property transfer agreements, the possibility of FNAL staff being rehired by ARC, and an inventory of all relevant documentation, records, and spare parts. We envisage this process taking as long as a year or more, which means the process needs to be initiated by the end of 2006 in order to make a smooth transition by early 2008.

2.2.2 Scientific accomplishments (2000-2005)

A partial list of publications of the SDSS project (primarily abstracted from the final report to the Sloan Foundation).

- **Technical Survey**

  - Obtained precise imaging of 9500 square degrees of sky in 5 filters and spectra of about 1 million objects.
  - Calibrated photometrically, to 2% in all filters, and astrometrically, to <0.1 arcsec.
  - Created public data archives for over the entire, main survey. (See http://www.sdss.org/dr5.)
  - Created and published the largest catalogues of QSOs (>200,000 so far), galaxies (over 100 million) and various types of stars ever made, with well defined selection criteria to enable their use for statistical purposes.

The Large-Scale Structure of the Universe

- Determined the power spectrum of galaxies over the largest scales ever made.
- Determined the power spectrum of the Lyman alpha forest absorption lines from intergalactic space at high redshift.
- Combined these last two results to verify the flatness of the Universe, the constitution of dark energy, dark matter and baryonic matter to new levels of precision.

- Placed new upper limits on the mass of the neutrino, and showed it cannot affect the amount of dark matter.
- Precisely confirmed compliance of the data with the standard Big Bang model with the inflationary paradigm, ruling out interesting deviations from the simple inflationary predictions.
- Detected the baryon oscillations (shadows of acoustic waves near z=1000, the time of decoupling of matter and radiation), confirming that gravity enhances the degree of clustering of matter with time.

Quasars

- Found the candidates that let to confirmation of the 19-highest redshift QSOs, reaching to z~6.4 and that these QSOs are remarkably similar to QSOs at lower redshifts. The relation between QSOs and star/galaxy formation were evidently present at the very earliest times.
- With follow-up of the high-z QSOs, discovered the Gunn-Peterson effect, long predicted to be a consequence of a neutral Universe before reionization by QSO and/or radiation from the first galaxies.
- Discovered that the ratio of low-luminosity to high-luminosity QSOs is higher in recent times than in earlier times, possibly a sign of global evolution in the character of QSOs.
- Confirmed the long suspected obscuration of some QSOs by dust in their host galaxies, using hints from SDSS spectra and confirming the high absolute luminosity of the optically faint objects using X-ray and far-infrared (*SPITZER*) follow-up observations.
- Showed that the recently discovered relationship between galaxy bulge mass in stars and mass of the central black hole holds over a factor of 10^4 to 10^5 in black hole mass.
- Completed the most extensive catalog of X-ray source optical identifications (7000 of an expected 10,000)

Galaxies

- Showed that dark matter masses scale with luminous mass of galaxies over scales from 25 kpc to 1 Mpc, using distortion of galaxy shapes by gravitational mass (weak lensing).
- Detected weak lensing of QSOs by the general gravitational field on large scales.
- Detected the Sachs-Wolfe effect, the imprint of the current

distribution of galaxies on the map of cosmic background radiation.

- Showed unequivocally the mass-metalicity relationship in modern galaxies (below a mass of 10^{11} solar masses, metalicity decreases with mass).
- Defined carefully the relationship between the simple morphological parameters of galaxies (shape, central concentration, color).
- Discovery of at least four, new, very low-mass galaxies in our Local Group, too faint to have been seen in the past. These objects are of very low mass and may be the first of many such small objects that make up a previously unknown population of galaxies. (As of Nov. 2006, this number is now 10.)

The Structure of the Milky Way

- Showed that the disk of the Milky Way is wreathed in star streams, thought now to be the remnants of galaxies swallowed by the Milky Way as the mergers built up our Galaxy.
- Discovery of the tidal tail of the globular cluster Pal 10, and two other globular structures, showing for the first time the dispersal of such objects and suggesting that the population of globular clusters was once larger than it is today.

Stars

- Discovered and classified in a new sequence, hundreds of brown dwarf stars of type T and L, the lowest mass stars known.
- Discovered hundreds of carbon stars, stars with mysteriously high abundances of carbon, possibly from massive companions that are no longer visible.
- Characterized the full range of properties of degenerate remnant stars (white dwarfs) for the first time while more than doubling the known number of such objects. The breadth of types and the number of objects are important to understanding the history of star formation in the Galaxy.
- Discovered a star rocketing out of the Galaxy at 700 km/sec, possibly the first known example of a star ejected in a gravitational encounter with the super-massive black hole at the center of our Galaxy.
- Identified candidates for neutron stars by identifying those X-ray

sources that are in SDSS blank fields.

Asteroids

- Showed that asteroids in separate families (objects with common orbital parameters) have the same colors, hence abundances and aging histories. The observation (based on >100,000 asteroids) is consistent with the long-held hypothesis that objects in families are parts of common parent bodies and therefore are shards of a few, single, larger bodies, broken up early in the history of the Solar System.

3.0 A baseline for planning: the way it is now

3.1 The Observatory site.

Appendix E includes a complete analysis of the state of the site and the maintenance that will be necessary before 2008, as well as what will be needed after that time. The site is in good shape and is well maintained. Most needs can be accommodated within the normal operations budget. Depending on the future use of the site and the level of staff presence on a daily basis, it may be prudent to plan for replacement of the trailers with more permanent structures, a matter that is not factored into current budget projections.

In modern times, observatories usually have productive lifetimes of between 30 and 50 years. We have striven to maintain APO in a condition that gives the impression that it is less than five years old. Parts of the site are approaching the age of twenty years, and as the newer facilities also age, maintenance costs will increase if we choose to keep the "five-year-old" requirement. We currently spend roughly 5% of the operations budget on recapitalization and maintenance annually. In future years, we will need this budget item to rise to 8% or more annually, or a general decline in the condition of the site infrastructure will result.

3.2 The 3.5-meter telescope and Instruments

Appendix F includes a discussion of the status of the telescope and the maintenance and upgrades that are necessary over the near term and the long term. We define maintenance issues to be matters related to keeping the telescope system operating at the current level of performance. Upgrades are improvements to the system science performance (whether by changes to the telescope or to the instruments).

The major maintenance issues are related to the telescope drives, the telescope motion controllers and the enclosure rotation (mechanical) system. These are discussed in Appendix F.

A detailed breakdown of the current instrumentation and upgrade paths is given in Appendix G. Instrumentation will continue to evolve. Current work (2006-2008) is described in Appendix H. An infrared spectrometer (TripleSpec) will be added to the suite of instruments. Upgrades will occur to make operations more efficient for DIS (new gratings and optics coatings) and NIC-FPS (tunable Fabry-Perot etalon, a grism, additional narrow band filters and a larger detector). Minor, shared-cost upgrades can be made to the Fabry-Perot. An instrument group will begin regular meetings to deal with upgrades and planning for new instruments.

The analysis in Appendix H includes cost estimates for maintenance and upgrades, discussed separately for the telescope (H1 and H2) and the instruments (H3). The result of this plan is that anticipated costs will require at least the current levels of CIF funding ($330K per year, as of January 2006).

3.3 Operation of the 3.5-meter telescope for science.

The observatory operations plan has supported the most general types of collaborations and usages. Examples include: two hours assigned to a project every other night, over several years; five hours assigned every other night over two months; shared use of the 2.5-m and 3.5-m telescopes for common science; target-of-opportunity interrupts (supernovae, GRBs, flare stars); as well as conventional observing programs (20 to 500 hours, assigned randomly in time). The faculties of each institution are constantly changing and adding new observing programs and new collaborations with major facilities. We expect this type of operation to continue for the short term as well as for the foreseeable future.

3.4 The SDSS system, near-term

The SDSS telescopes, instruments and operations will be maintained in their current state for the duration of the SDSS-II project.

Apart from funding matters, the issues of telescope staffing and maintainability (knowledge transfer) need to be handled. These may lead to a re-arrangement of the observatory staff and how it operates, to a more unified observatory structure rather than separate structures that exist to support each telescope.

4.0 Future of the 3.5-meter telescope

A major challenge facing many observatories is how to maintain and improve instrumentation while keeping operating costs to a reasonable level (<10% of capital costs). The approach taken by ARC has been to use the original set of instruments provided by member institutions, to continue to upgrade the valuable remote observing capability, and to provide some funds for upgrades of instruments and of the telescope (the CIF) New instruments have been obtained by addition of new members (e.g., NIC-FPS and TripleSpec) and by providing limited telescope availability for people building new instruments (adaptive optics, AOTF, APOLLO, GFP, and CorMASS, as examples). The Observatory system creates the ability to observe remotely and gives each instrument a special capability that is not available anywhere else.

Generally, this approach has been successful, at least judging from the degree of user satisfaction with the current and planned instrument suite. Our remote observing capability, and our use of it for special programs and for routine programs, is a unique resource. The recognized capability of APO is not a set of one-of-a-kind instruments but a set of capable instruments that can be used remotely. It is desirable to add new instruments, also remotely operable, but the mode of obtaining new instruments by the addition of new members cannot continue, as it gives up the most precious commodity, observing time, at some level.

We have experimented with other observing modes, to test the boundaries of efficiency and to explore cheaper modes of operating. One such mode is to hire observers to make most of the observations. The spectroscopic follow-up of the SDSS-II supernova search involves heavy participation of APO observing specialists and they are an integral part of the project. The program requires use of the 3.5-meter telescope for ten nights per month, every other night in dark or gray time for 1/2 night. It is clear that this level of activity is not sustainable with the current observing staff and that more staff would have to be hired to provide such support at a sustained level. This mode is not viable as a way to reduce operating costs.

We have used queue scheduling for one instrument (the GFP): we put the GFP on the telescope in a dedicated manner for three to six nights per quarter. A higher level of such scheduling of a block of full nights takes away the advantages of flexible observing for other programs, and could not be sustained, except for infrequent opportunities.

The Director has explored the trading of time with other 4-meter class telescopes, such as SOAR and WIYN. The approach has been to work on a case–by-case basis to let natural collaborations between astronomers from the different projects drive the level of need. Only in rare instances have such cases been seen and they can be handled within the context of our current operations.

Our conclusion is, however, that the observatory can continue to operate in the current fashion, allowing astronomers at Member Institutions to start new projects and supporting ongoing, special projects with more specialized equipment (user-furnished equipment). The instrument suite can be made more diverse through exchanges of observing time with other observatories, which exchanges are already being experimented with. With the National Observatories exploring ways to divest themselves of telescopes, and with the fact that telescopes of the 3.5-meter and smaller class have, in the past ten years, made most of the major discoveries in astronomy (dark energy, extra-terrestrial planets, and GRB afterglows, for instance) the availability of our flexible 3.5-meter telescope will only grow with time, and that, for many years.

Our recommendations, overall, for the time frame 2008–2013 are

--Retain the current, very flexible operations style with remote observing. This style, by its nature, allows movement to a more focused program should one arise in the future. All stakeholders want to continue to have access for their professional science projects and for the training of students.

--Encourage major upgrades to current instruments (specifically noted for each instrument) through proposals for Federal or private funding, with support from CIF to leverage those funds. Examples of such opportunities include the placing of a larger detector in NIC-FPS and the placement of a lower-noise CCD in the echelle. Both will be $400K-class upgrades.

--Add an AO system to the telescope that is general enough to improve the image quality for all instruments. This item would have higher priority but for two reasons. First, no group of ARC astronomers could be identified as having the required technical expertise as well as a natural interest. Second, telescopes of similar aperture have not had much success with systems delivered by others (supposedly, as turn-key systems). The committee recommends that a study group be constituted to look into how ARC can gain the improvement in efficiency inherent in a working AO system, for the time frame after July 1, 2008. If opportunity arises, the Director might want to consider an earlier implementation, by deferring other CIF items.

--Add incremental capabilities such as wide-field, multi-object capability, perhaps part of the 2.5-meter spectroscopic infrastructure. Provision for a one-half degree field, Gascoigne corrector was designed into the 3.5-meter telescope, so this is the maximum field one can easily have. A work group including Ed Turner (PU), John Stocke (CU), Scott Anderson (UW) and Rene Walterbos (NMSU) was consulted during the Futures process. They will continue to interact with the Director's instrument group.

--Add a new, major, facility instrument in the time frame 2008-2013 (e.g., a wide-field imaging-focal reducer; multi-dichroic, multi-band imager; high resolution IR and/or optical spectrograph). During our discussions, the last choice was preferred, but the matter needs further discussion. The Director should form a standing, instrument subgroup to continuously review the state of the instruments and the paths to new instruments, replacement instruments or upgrades of existing instruments.

--Keep the site, enclosure, telescope and instruments in peak operating condition.

--Keeping CIF funding levels at least at the current mark ($330K as of January 1, 2006), and seeking outside funds for new instruments and upgrades will be required to keep the telescope and instruments at a competitive level.

--There are some issues about the site and support staff that will need attention. The staff is aging and we need to initiate a plan of hiring that provides training to new, younger staff in anticipation of retirements of present, skilled staff. As soon as possible, we need to augment the staff with a skill set more oriented to instrument maintenance (~$100K per year.) Finally, the appearance of the site would be improved if the "temporary" trailers could be removed. Future use of the 2.5-meter telescope should include planning for adequate space in substantial buildings so the trailers can be taken out.

--We have not addressed the costs of the known, major maintenance items that will be required in the time frame between 2009 and 2013. However, we provide a well-considered list of such items (Appendix F) and suggest that a group led by the Site Operations Manager develop the required cost estimates. This will need to be done as part of the funding discussions discussed in section 7, below. A comprehensive list of upgrades is included in a document by Kurt Anderson, attached as Appendix I.

5.0 Possible future projects for the 2.5-meter

The 2.5-meter telescope will end its funded activity in 2008. The spectroscopic facilities will still be state of the art, while the camera serves a survey function that is being taken up by many other telescopes. It may be that the availability of a well-established method of uniform photometric and astrometric calibration would make the SDSS camera the camera of choice for limited use for some primarily spectroscopic programs. In this case, the life of the camera might be extended for a few years, but a detailed analysis of the personnel to support it (hardware, software and operations) and of the availability of replacement parts would have to be done to be sure this is feasible.

We discussed the use of the 2.5-meter telescope in the standard 3.5-meter mode, but the telescope is made for surveys and the operations cost of using it for single sources appears to be prohibitive. The ability to marshal projects of sufficient interest to provide funds depends on the survey nature of the project.

A number of possibilities have been discussed for use of the 2.5-meter system:

---a) Jian Ge (U. Florida) wants to use the 2.5-meter telescope, long term, for a planet search using radial velocities (ASEPS). A test run has been made at the 2.5-meter telescope, following a prototype instrument run at Kitt Peak and a second run at APO, in 2005. The goal is to achieve 10 m/sec precision on one million stars to 11th magnitude. He expects to observe some 1 million stars for planet detection, with some on a long-term basis to find systems like our own (which require many years of observation because of the these are systems with multiple, massive planets). In all, up to 100,000 planets may be observed.

A group of ARC scientists, expert in planet discovery issues, was convened to review the Ge plan and to make a recommendation. The committee consisted of Eric Agol (UW), Kurt Anderson (NMSU), Phil Armitage (CU), Andy Davis (UC), Holland Ford (JHU), M. Strauss (PU) and Zhi-Yun Li (UVa). This group found the Ge project to be of high merit on several grounds, mainly based on the broad, survey nature of the project. Furthermore, it was determined that there was enough interest at the ARC institutions to expect involvement of ARC partners in the planning, fund raising and scientific observations and analysis. It was felt that the repeated observations for follow-up using the 2.5-meter telescope itself was probably an inefficient use of the time. The follow-up of the SDSS discovery observations is critical to the scientific success of the project, is not yet well specified and planned for, and must be included in the fundraising plans. All of these three items must be dealt with in a final proposal to the ARC Board.

Ge also proposes that he can only use 100 fibers at a time and that the other 540 could be available to ARC astronomers. During the 2005 test run, a plate was drilled for a set of his fibers and a set of SDSS fibers. Data were successfully obtained for both projects, simultaneously.

--b) A near-infrared, spectroscopic survey using the 2.5-meter telescope has been proposed. There are a number of extensive imaging surveys (2MASS, VISTA, for example). However, there is no IR spectroscopic survey underway or planned that is comparable with what could be done with the SDSS systems, and a new spectrograph, in the timeframe 2008-2013. The fibers and plate drilling apparatus can be maintained, but new spectrographs would have to be built.

A separate work group was set up, reporting to the Futures Committee, to evaluate the science that could be done with such an instrument. Members were Scott Anderson (UW), John Bally (CU), Al Harper (UC), Gillian Knapp (PU), Steve Majewski (UVa), Tom Harrison (NMSU), Mike Skrutskie (UVa), John Wilson (UVa), and Rosie Wyse (JHU). The group concluded that survey abundances of Galactic disk stars is the prime science to be done. One issue is that the spectrographs could not be done and commissioned by July 1, 2008, though imaging with the current SDSS camera might be required in the near term to prepare for the IR, spectroscopic survey.

--c) A survey of young stars in the Milky Way. A synoptic, spectroscopic survey of all candidate young stars lying within a few kpc of the Sun will characterize the birth environments of stars with ages less than a few hundred million years, the period during which planet formation is completed. Some SDSS imaging may be included. Other imaging surveys will provide critical information on the star forming regions. (John Bally, CU).

---d) One could do deep imaging or spectroscopic studies (co-adding images) of regions around particular QSOs (sets of QSOs over a wide field) which are to be observed with HST/COS to match galaxies with absorbers. This is one use that would involve the current SDSS camera, since the bright QSOs observable with HST are not all covered by the main SDSS survey. The program could be followed-up with a deeper spectroscopic survey of specific, additional QSOs that have interesting locations compared to foreground galaxies.

---e) SDSS has left the objects brighter than 15 (g magnitude) without calibrated photometry and spectrophotometry. The 2.5-meter telescope could be reconfigured to cover this magnitude range (stopping down the telescope, or scanning the sky faster). A careful look at the problem might show that there is an alternate way to accomplish this goal, but it would seem to be a natural follow-on for ARC and would not require much time.

--f) Special imaging surveys (e.g., narrow-band surveys) could be done with a new camera or a retrofitted camera, defined to be complementary to the new imaging surveys from other projects.

---g) The 2.5-meter telescope could be run in the 3.5-meter mode, using only spectroscopy. The plug plates would have to be designed and the survey aspects of the telescope would still have to be used to make funding practicable. This could be done in a variety of ways. A simple suggestion would be to provide one plug plate with a central dense pack of fibers or other arrangements, possibly with a new guide system (the current one uses 10 stars particular to each plate). This could be used to make 3-D maps of large galaxies to survey the kinematics of a large magnitude-limited sample.

More complicated would be a use that retains the plug plate system for one or up to three projects, simultaneously.

In any case, it is possible that the current use of SDSS spectroscopy could continue. It is likely that the plug plates will be more complicated, incorporating dense packs or long slits of fibers, to map galaxy kinematics, and that the fibers might go to both infrared and optical (current + Ge) spectrographs.

---h) Buy into PanSTARRS by offering to do 2.5-meter spectroscopic follow-up of PanSTARRS targets. Likewise for follow-up of existing SN searches. This option implies using the full spectroscopic system, as is, but the surface density and nature of variables at the appropriate limiting magnitudes is still being evaluated. If the numbers are <10 per square degree, they might best be done in a piggy-back mode, but if they are much larger, a more extensive survey of its own might be justified. (Note: DGY explored with Nick Kaiser and Tony Tyson, the respective PIs of PanSTARRS and LSST, the possibility of a collaborative relationship, with SDSS doing spectroscopic follow-up of variables from the two projects. The discussions were not encouraging. This occurred in the summer of 2006.)

The ARC Board asked the SDSS project to suggest additional options for use of the 2.5-meter telescope, including the interests of existing partners who are not members of ARC. Rich Kron, SDSS Director, transmitted the results of the ensuing discussion at the March 2006 meeting of the SDSS Collaboration at Los Alamos.

--i) An extended SEGUE survey of Galactic stars, with a goal of including a large number of stars in the GAIA astrometry project of the European Space Agency. This would involve a new, 4000-fiber, robotic positioner. Abundances and three dimensional space motions (including the GAIA data) would be obtained at the rate of over 2 million stars per year to a limit of 17.8 magnitudes. The survey would address issues of the shape of the Galactic gravitational potential, the role of stellar streams in building the Milky Way and the detailed shapes of stellar associations. Some work could be done immediately, while the spectrograph is being built, with existing equipment.

--j) A short-term extension of the SDSS-II supernova survey. The survey would take an additional 12 months beyond July 1, 2008. The impetus for the extension includes newly realized issues with the baseline, low-z data on SN Type Ia standard candles from other sources and the value of having these directly from SDSS for standardization.

--k) Two, independent approaches to detecting the baryon oscillations (a fixed scale imprint in the distribution of galaxies from the time of decoupling) found in SDSS-I, extended to higher redshifts. One would modify the SDSS spectrographs, install new fibers and perhaps a robotic positioner. Redshifts for 1 million galaxies from $0.5<z<0.8$ would be obtained over four years, assuming full-time use of SDSS dark time. A modest amount of imaging time would be needed. A second approach would replace the fibers and the spectrographs, and require less SDSS time, but still extend over four years.

There thus appear to be at least six or seven appropriate, competitive proposals for continuing use of the SDSS spectroscopic capability (with modest imaging requirements) for the July 1, 2008 to June 30, 2013 time frame.

We recommend that the ARC Board of Governors solicit white papers soon, commission a review process and approve a reasonable number of proposals for fund-raising. [Such white papers were solicited and reviewed during the spring of 2006.]

From the details of the various projects, we have developed a funding strategy and operations model, given in section 7, for the Board to consider.

6.0 Potential new facility projects for ARC

We explored various possibilities for ARC to construct new telescopes to carry out science of common interest to the current members. These are recorded here as a record of our discussions. However, the committee does not recommend initiating any of these at the present time. Our discussions ended by focusing on the funding of the two existing telescopes for the five-year period under study.

6.1 Time-domain astronomy

ARC was conceived by a group of astronomers who had a common interest in the flexible facility now realized, but whose major research interests were diverse. There is no common, intellectual thread that weaves through the ARC consortium, though there are a number of critical mass, cross-institution groups who are successfully using the telescope for common goals.

There is one technical thread of wide interest, that of time-domain astronomy. We have already mentioned a number of programs on the 2.5-meter and 3.5-meter telescopes that involve time-domain astronomy. UW is involved as partner in LSST and more and more ARC or ex-ARC personnel are involved in PanSTARRS. Neither project addresses the time domain below three days, but the intellectual interests of the Member Institutions cross topics where this domain is critical. A project focused on short time-domain astronomy could be the next large project of the consortium. We have already mentioned a modest move in this direction: buy into PanSTARRS (or other project of choice) by providing follow-up spectroscopy for transients, using the existing 2.5-meter spectroscopic system. ARC could also consider buying into LSST ($25K per institution per year for a corporate membership).

Two possibilities of much larger scope have been discussed.

---**SDSS GONG, a set of 2.5-meter telescopes**, fixed, and drift scanning, but with fast-attack telescopes ready at hand. This worldwide array could start with the 2.5-meter telescope at APO after SDSS II-is finished. Then, other telescopes could be built to expand the sky coverage, to provide continuous coverage of a strip of sky around the celestial sphere. The other telescopes would not need to be pointable (scan the equatorial stripe). Software could be adapted from the SDSS project. Science would be focused on transients of >1 minute timescales, initially. This project came from Ed Turner.

---**Kiloscope, an array of small telescopes with high sky coverage**, to find and, with large telescopes at hand, study transients in detail. This project would be installed at a site with large coverage of a circumpolar region (e.g., Dome C or Dome A in Antarctica). Small Schmidt telescopes of 0.5-meter diameter, or so, with no moving parts and with segmented CCDs, would provide snapshots every few seconds. The science would be focused on 5 second to 4 month light curves of all types of SNe (to 20th mag for the shortest time scale, successively deeper for longer time scales), including GRBs and orphan afterglows. Additionally, it could possibly obtain a Southern SDSS, using hundred's of thousands of co-added images. The project could be run by ARC, much as SDSS has been run, with outside, international partners, but overall oversight from the ARC Board of Governors. This project came from Don York.

6.2 Six-meter telescope

JHU and UC have expressed interest in a larger telescope to carry out an SDSS-like survey (millions of galaxies) out to redshifts of three. The Chicago interest is in technology development for an even larger telescope, ultimately in Antarctica, that would use an adaptive primary mirror. The main development required is in the control system for the <0.5-meter segments in the primary. The JHU interest is directly in the Northern survey to the noted redshifts of a substantial sample at higher redshift than SDSS can achieve. Karl Glazebrook and Don York put forward different aspects of this proposal. The telescope would use the southern most site of the Observatory.

6.3 IR MIDEX survey

At the first meeting of the Futures Committee, interest was expressed in building a space-based, sky-survey telescope to work beyond 3 microns. We have three institutions with expertise in satellite work (CU, JHU, PU). The current situation with NASA missions makes it unlikely than an opportunity to do this will arise in the foreseeable future.

6.4 A second 3.5-meter telescope.

We discussed the construction of another telescope, to be operated incrementally in parallel with the current 3.5-meter telescope. The cost would be kept low by implementing designs using well-developed technology and by mounting on the new telescope instruments built for the existing 3.5-meter telescope. The telescope could be built on the third site at APO or elsewhere, but operations would be optimized if it were placed at APO. There are two motivations for this suggestion. First, all ARC users want more time allocated in the present manner. (Of course, this desire is independent of corporate funding mechanisms, and funding would have to be new money.) Second, the NSF Senior Review now ongoing may substantially reduce the access by American astronomers to medium-size telescopes. With many surveys now planned, in multiple time domains and multiple wavelength regimes, there could be a niche for a modern telescope that is cheaper to operate than current, public telescopes (because of newer technologies and innovative operational strategies).

The two noted motivations could be combined if ARC, for instance, built the new telescope with new NSF funds (saved from other NSF operations as a result of the Senior Review) and received part of the time in return for operating the telescopes, and in recognition of the fact that instruments would be provided by ARC, by moving some from the current telescope to the new one.

Gaining one half of the time could be easily worth it if the telescope used new technology but were not a copy of the 3.5-meter. The costs of operations can be reduced by applying the lessons learned in the construction of the 2.5-meter and 3.5-meter telescopes. Furthermore, new attributes such as AO, again, using new technology developed elsewhere, could be used to provide a telescope with substantially smaller images and improved throughput, even without achieving diffraction-limited performance.

(Note: The Senior Review report was published about 5 days before the final compilation of the current report. The above opportunity would, in fact, seem to exist, but someone would have to work with NOAO to make it happen.)

7.0 Funding models

7.1 Models of operation

We identified three possible scenarios for operation modes and associated funding needs in the 2008 timeframe. These are as follows.

--A. The 2.5-meter telescope is taken out of service, and we continue with business as usual on the 3.5-meter. This makes operating the 3.5-meter telescope more expensive due to taking on the current 2.5-meter share of site infrastructure. The current estimate is that there will be a 30-50% increase in the annual operations costs. Either the current partners will have to assume this additional cost burden, or more partners will have to be added to keep costs the same at the expense of losing telescope time. Either way, the cost per night will go up.

--B. We could continue operations of the 2.5-meter telescope as an ARC telescope, operating it in one of three modes.

i) Operate in a mode similar to the current operation of the 3.5-meter telescope. We deem this a very inefficient use of resources because the 2.5-meter telescope is made for surveys.

ii) Operate in a more survey-oriented way that takes advantage of some current SDSS pipelines and infrastructure but does not cost as much as the current, full SDSS operations (i.e. doesn't use the full complement of 8 observers and/or the full support structure currently in place at Fermilab.) This model is discussed in more detail in section 7.4, below.

A very rough estimate is that perhaps we could operate both the 2.5-meter and 3.5-meter telescopes at about 2-3 times the current operations costs for the 3.5-meter telescope alone. In this case additional 2.5-meter observing time is added into the mix available to ARC partners, so if we add new partners to keep the total shares similar, the cost per telescope night would perhaps not change drastically. However, additional funding to support new instruments on the 2.5-meter telescope would be required unless we only use the existing spectrographs (and use the camera only if available, but with very little support).

iii. We could keep the 2.5-meter telescope running as a fully funded survey telescope with several, interleaved programs; full pipeline processing; etc., i.e. in a similar mode to the current SDSS-II operations. We know that that costs about five times the current 3.5-meter operations budget. Even with new partners, it is unlikely that we can afford to operate in this way entirely from institutional contributions. Significant government and/or foundation funding would probably be required for this option. This of course would require a coherent and well-documented science case for a large, multi-institutional proposal.

7.2 Resources needed for 3.5-meter telescope

For the 3.5-meter telescope, we anticipate maintaining the current funding levels for the time through the end of SDSS-II. For the period beyond that, there will be major site maintenance issues, some upgrade issues to gain higher efficiency and, eventually, the issue of dealing with the possible closing of Sunspot (recommended in the now published Senior Review Report). We provide a list of possible tasks, but recommend that a more specialized effort be made to determine the likely costs. In the final section on our recommended approach to funding, we assume that the current funding levels, with inflation, will be adequate to operate the 3.5-meter system.

7.3 Resources needed for 2.5-meter telescope

The projects listed in section 5, for the 2.5-meter telescope continuation after July 1, 2008, range in cost from <$1M to >$10M, including instrumentation and operations over 4-5 years. If several of the projects can be operated in parallel, the cost of operations could be reduced on a per-project basis, but at a loss of science to each project.

7.4 A recommended approach to Funding

In light of the tightened budgets at the Federal level, we recommend that ARC try to find a way to cover, with private funds, the cost of the site operations of both the 3.5-meter and the 2.5-meter telescopes. This means, for instance, covering current costs of the 3.5-meter, extrapolated into future (inflated) dollars, as well as covering the costs for the 2.5-meter increment of site operations staff; telescope maintenance; maintenance and operation of the existing spectrographs and fiber plugging system, including plate drilling; and costs of a set of baseline software needed for the current spectroscopic system. Call this restricted set of operations expenses Ops-A, representing the costs of a leaner mode of operating the 2.5-meter telescope than is currently in use.

Each project, if accepted by ARC and successful in obtaining funds, would pay their share of Ops-A costs, prorated by time allocated to the project, as well as the full costs of new instruments, modifications of current hardware, development of new software and maintenance of any current resources that are not likely to be common to most projects. Examples of these last costs include the maintenance and running of the imaging pipeline and the SDSS camera. Call these additional costs, Ops-B.

As a reality check, we assumed one model in which two new ARC partners would be found and the shares of current and new ARC members would be roughly equalized. Each member would receive a share of 3.5-meter observing time. Each member would also have the right to join in one of several projects on the 2.5-meter telescope, as well. Each 2.5-meter survey project would have outside, collaborating members who would pay a fair share of the costs. We assumed that the total number of collaborating institutions would be 5, for a single project that would have Ops-B costs of $0 to $8M. The new, full ARC partners would contribute to the new, operations budget (the 3.5-meter budget plus Ops-A) possibly paying a capital fee to join a 2.5-meter project as well. We estimate that the operations costs thus allocated would suffice to run the mountain. Any proposals for funding of Ops-B costs on behalf of a 2.5-meter project would be obtained from Federal agencies or from private foundations by the respective project teams that require the additional costs of Ops-B type.

On this model, each ARC partner would have the same costs per year as they now pay (2005 $). Each (outside) collaborating institution would pay about $125K per year for their share of Ops-A costs, plus $0 to $2M for the Ops-B costs. The former costs go down if there are multiple survey projects, though the latter costs remain the same. Larger projects may have or need more collaborators, depending on the results of the collaboration efforts in raising money for Ops-B costs. The details can easily change to satisfy each institution, but the end result will be similar.

The Ops-B costs would then be divided between partner institutions that join specific, 2.5-meter, survey projects as collaborating institutions, following the models of SDSS-I and SDSS-II. These partner institutions would also pay their share of the Ops-A costs associated with the 2.5–meter operation. Federal funds would be applied for to cover the incremental operations costs above and beyond the previous Federal investments (or private foundation donations) that led to the existing infrastructure, as well as new costs required by the new science (instruments and science expenses).

A detailed, strawman budget was provided to Mike Evans, for further consideration as the Board desires.

8. Funding Summary

Under the first scenario, closing the 2.5-meter telescope, costs to individual member institutions would not change much, unless members make private agreements to sell or buy time. As noted in the report, maintenance costs will increase as the facility ages (from 5% to 8%). In flation must also be accounted for. We assume the funds set aside for mothballing the telescope are adequate for that purpose.

Under the preferred model (Ops-B) for operating the 2.5-meter telescope, the costs to current members of ARC would not change but their shares would include access to the 2.5-meter surveys and to re-negotiated shares in the 3.5-meter telescope. The details would depend on the relative interests of each institution in the programs available to the two telescopes.

We recommend that ARC proceed to solicit white papers for 2.5-meter survey projects to be implemented after July 1, 2008, while funding arrangements are being discussed. By the end of the summer of 2006, fund raising guidelines should be given to those groups selected to fundraise for their submitted projects, along the lines noted above. The success of the fund raising will then determine whether the mountain can continue to operate as it does now, or whether the Ops-A mode will have to be adopted. [The solicitation and selection process took place in the summer and fall of 2006.]

9. Conclusions

We conclude that the operations of the 3.5-meter needs no major adjustments. The maintenance costs may rise a bit as the facility ages and as more sophisticated instruments require a different skill mix among the support staff (~1FTE additional may be needed). The closing of the solar observatory, from which we obtain fire protection, emergency services and water, will need to be addressed over the next five years. The current allotment of funds for new instruments and for upgrade of the science performance of the system (telescope plus instruments) can be kept at the present level, allowing for inflation.

The most serious consideration in the near term is that the infrastructure costs of the Observatory have been shared with the SDSS project. Either a way must be found to continue the SDSS operations or a new funding arrangement, probably involving more partners and higher operations costs to ARC members, will need to be expected.

Prospects for continuing the SDSS operations with forefront surveys were exhaustively explored. A concerted effort will be necessary to mold these possibilities into a funded, coherent activity based on support raised by the project teams.

Our detailed recommendations with regard to the 3.5-meter instruments and upgrades are given in section 4 (page 26). Our key recommendations on overall funding are given at the beginning of the executive summary. Our integrated response to the questions raised in the charge to the Committee are at the end of the Executive Summary (pages 5-7).

Appendix A: Institutional faculty and staff

The University of Chicago
(all faculty but only research staff that use the 3.5-meter)

John Carlstrom - experimental cosmology and star formation
Fausto Cattaneo - numerical astrophysics, supernovae
Hsiao-Wen Chen - extragalactic research, faint galaxy statistics, QSO absorption lines.
James W. Cronin - very high energy cosmic rays
Kyle Cudworth - star clusters, stellar distances
Scott Dodelson - large-scale structure, cosmic microwave background
Vikram Dwarkadas - simulations of stellar explosions, interaction of stellar outflows with the interstellar medium
Lucy Fortson - high energy astrophysics, gamma-ray astronomy, education
Joshua Frieman - cosmology, particle physics
Priscilla Frisch - interstellar medium and its interactions with the Sun
Michael Gladders - cosmology, clusters of galaxies, strong lensing
Nick Gnedin - intergalactic medium, large scale simulations
Geza Gyuk - asteroids, cosmology, education
Doyal A. Harper - infrared&sub-millimeter experimental astrophysics
Roger Hildebrand - far-infrared polarimetry, magnetic fields in interstellar clouds.
Lewis Hobbs - primordial nucleosynthesis, interstellar matter, galactic structure
Wayne Hu - cosmology, CMB
Stephen Kent - internal dynamics of galaxies and galaxy clusters, dark matter, gravitational lens systems
Edward Kibblewhite - adaptive optics, large-scale structure
Alexei Khoklov - numerical algorithms and large-scale numerical simulations, experimental astrophysics, numerical general relativity, fluid dynamics, combustion and explosions
Rocky Kolb - cosmology, particle physics
Arieh Konigl - astrophysical hydrodynamics and magneto hydrodynamics, star formation, jets, QSOs
Andrey Kravtsov - numerical astrophysics, cosmology
Richard Kron - optical studies of galaxies, large-scale structure
Donald Q. Lamb - relativistic astrophysics, physics of compact objects, gamma-ray astronomy

Robert Lowenstein - infrared instrumentation, planets
Stephan Meyer - experimental cosmology, cosmic microwave background anisotropy measurements
Richard Miller- dynamics of galaxies, clusters of galaxies, star clusters
Takeshi Oka - astrophysical laboratory spectroscopy, planetary atmospheres
Angela Olinto - cosmology, particle and nuclear astrophysics
Patrick Palmer - radio astronomy
Eugene Parker - astrophysical fluid dynamics and magneto hydrodynamics, solar and stellar physics
Paolo Privitera - particle physics, very high energy cosmic rays
Clem Pryke - cosmic microwaves, cosmology
Robert Rosner - astrophysical fluid dynamics and magneto hydrodynamics, solar and stellar physics
Noel Swerdlow - history of the exact sciences
Simon Swordy - cosmic rays
James Truran - relativistic astrophysics, stellar structure, nucleosyntheisis
Michael Turner - cosmology and particle physics
Peter Vandervoort - stellar and galaxy dynamics
Daniel Welty - diffuse molecular clouds, interstellar medium in the Magellanic Clouds
Grace Wolf - Chase - star formation, education
Donald G. York – interstellar and intergalactic medium

University of Colorado

P. Armitage - planet formation, accretion disks, black holes.
T. Ayres - stellar atmospheres, radiative transfer, stellar winds
F. Bagenal - outer planet magnetospheres and the Io plasma torus
D. Baker - inner planet Magnetospheres and space physics
J. Bally - star formation and molecular clouds
M. Begelman - cosmic X-ray sources, gamma-ray bursts, accretion disks, AGN, black holes
N. Brummell - computational Fluid Dynamics, solar physics
J. Burns - clusters of galaxies, radio astronomy
J. Darling - radio astronomy, masers, high-z molecules
E. Ellingson - galaxy evolution, quasars, clusters, starbursts
R. Ergun - inner planet magnetospheres and space physics
L. Esposito - planetary rings and solar system dynamics, planet

formation.
J. Glenn - star formation and molecular clouds, far-IR/sub-mm galaxies
N. Halverson - cosmic microwave background and SZ-effect
A. Hamilton - cosmology and large scale structure
B. Jakosky - planetary surfaces and surface-atmosphere interactions
J. Linsky - stellar atmospheres, radiative transfer, stellar winds
R. McCray - supernovae and supernova remnants
N. Schneider - outer planet magnetospheres and the Io plasma torus
R. Perna - cosmic X-ray sources, gamma-ray bursts, accretion disks, AGN, black holes
J. M. Shull - intergalactic and interstellar medium, galaxy formation
T. Snow - Interstellar medium
J. Stocke – Interstellar medium, cosmic X-ray sources, AGN, archaeoastronomy
J. Toomre - computational Fluid Dynamics, solar physics
B. Toon - planetary atmospheres

Johns Hopkins University

Steve Beckwith - circumstellar matter, astronomical instrumentation
Bill Blair - supernovae and supernova remnants, cataclysmic variable stars
Paul Feldman -spectroscopy, space physics, planetary and cometary atmospheres
Holland Ford - stellar dynamics, stellar populations, active galactic nuclei and astronomical instrumentation
Riccardo Giacconi - high energy astrophysics, the X-ray background
Tim Heckman - galaxy evolution, active galactic nuclei
Dick Henry - the UV background
Julian Krolik - active galactic nuclei and high energy astrophysics
Warren Moos - Experimental space astrophysics and plasma physics
David Neufeld - Interstellar medium, molecular astrophysics
Colin Norman - Theoretical astrophysics
Alex Szalay - Cosmology, galaxy formation
Ethan Vishniac - cosmology, magnetohydrodynamics, accretion disk dynamics.
Rosie Wyse - galaxy formation and evolution

New Mexico State University

Kurt Anderson - AGN, galaxy structure, white dwarfs
Nancy Chanover - planetary atmospheres
Chris Churchill - quasar absorption line systems
Tom Harrison - CVs and binary systems
Jon Holtzman - stellar populations, galaxy structure
Anatoly Klypin - numerical simulations of galaxy formation and evolution
Bernie McNamara - binary stars, star clusters, proper motions
Jim Murphy - atmosphere of Mars, extrasolar planets
Nicole Vogt - galaxy formation and evolution
Rene Walterbos - ISM, star formation in nearby galaxies
Bill Webber - cosmic ray astrophysics

Princeton University

Neta Bahcall - large-scale structure, clusters of galaxies
Bruce Draine - insterstellar medium, dust physics
Jeremy Goodman - disk dynamics, stellar dynamics, plasma physics
Rich Gott - large-scale structure, general relativity
Jim Gunn - observational Cosmology, instrumentation
Ed Jenkins - quasar absorption lines, UV astronomy, ISM
Jill Knapp - brown dwarfs, mass loss from stars, Galactic structure
Robert Lupton - instrumentation, software, data mining
Jerry Ostriker - cosmology, high-energy astrophysics, Galactic structure
Bohdan Paczynski- variable universe, accretion astrophysics
David Spergel - cosmology, planet-finding, Galactic structure
Alice Shapley - high-redshift universe; galaxy evolution
Michael Strauss - galaxies, quasars, large-scale structure
Jim Stone - accretion disks, numerical magnetohydrodynamics
Scott Tremaine - dynamics; solar system formation, supermassive black holes
Ed Turner - gravitational lenses, quasars, extrasolar planets

University of Virginia

John F. Hawley - computational astrophysics, accretion disks
Phil Arras - stellar and planetary physics, relativistic astrophysics
Roger A. Chevalier - supernovae, gas dynamics
Kelsey E. Johnson - starburst galaxies, star clusters, star formation,

galaxy evolution
Robert E. Johnson - dust grains, sputtering processes, planetary rings and magnetospheres
Zhi-Yun Li - interstellar medium, star formation, active galaxies
Steven R. Majewski - Galactic structure and evolution, quasars, deep surveys, astrometry
Edward M. Murphy - Galactic structure, interstellar medium, high velocity clouds, UV and radio astronomy, education and public outreach
Robert W. O'Connell - extragalactic astronomy, space astronomy
Robert T. Rood - stellar evolution, nucleosynthesis
Craig L. Sarazin - Interstellar medium, X-ray astronomy, clusters of galaxies
William C. Saslaw - cosmology, radio galaxies, stellar dynamics
P. Kenneth Seidelmann - astrometry, solar system astronomy, celestial mechanics
Michael F. Skrutskie - Infrared instrumentation, sky surveys (2MASS), Galactic structure and stellar populations, low-mass stars and brown dwarfs
Trinh X. Thuan - extragalactic astronomy, evolution of galaxies, observational cosmology
Charles R. Tolbert - astronomy education, Galactic structure, photometry, 21 cm radio astronomy
Mark Whittle - active galaxies, star formation in galaxies

Staff & Post-docs likely to be involved in 3.5-m

Jeffrey S. Bary - Star formation, IR spectroscopy, education and public outreach
Remy Indebetouw - Massive star formation, interstellar medium, instrumentation
Matt Nelson - Instrumentation
Richard J. Patterson - Astrometry, Galactic structure, dwarf galaxies
Dawn Peterson - Star and brown dwarf formation
Ricardo P. Schiavon - Stellar evolution, population synthesis, globular clusters, elliptical galaxies
Anne Verbiscer - Photometric properties of planetary ices
John Wilson - Infrared instrumentation and astronomy

University of Washington

Eric Agol - compact objects, extra-solar planets, lensing
Scott Anderson - X-ray sources, QSO surveys, compact binaries, IGM
Bruce Balick – planetary nebulae, nebular hydrodynamics, numerical modeling
Bill Baum (Emeritus) – globular cluster systems in ellipticals, distance scale, density in local Universe
Karl-Heinz Bohm (Emeritus) - stellar structure, stellar atmospheres, stellar outflows, Herbig Haro and T Tauri stars, jets
Erika Bohm-Vitense (Emeritus) – stellar atmospheres; transition Layers, barium stars, cepheids
Paul Boynton - experimental tests of general relativity, neutron stars, accretion
Don Brownlee - astrobiology, solar system dust, evolution of planet systems
Julianne Dalcanton - galaxy formation, high z clusters, dark matter content of galaxies
Suzanne Hawley - dwarf galaxies, magnetic stars, low mass stars
Paul Hodge (Emeritus)- Local Group, star formation, H II regions, meteorite craters
Craig Hogan - Theoretical and observational cosmology, SNe, baryonic mass and ionization in the early Universe
Zeljko Ivezic – Surveys, radiative transfer, dust around AGN and young stars
Ivan King – dynamics of globular clusters, structure of galaxies
Julie Lutz – observations of planetary nebulae, symbiotic stars
Tom Quinn – solar system bodies, N-body computations, large-scale structure
Woody Sullivan – 21-cm galaxy studies, rotation curves, SETI, astrobiology, history of astronomy
Paula Szkody – cataclysmic variables, magnetic and non-magnetic white dwarfs, multi-wavelength studies.
George Wallerstein (Emeritus) – ISM, chemical composition of stellar atmospheres, evolution of globulars, nucleosynthesis

Appendix B: Publications from Use of the 3.5-Meter Telescope

Compiled by Rene Walterbos and Bruce Gillespie. [This section needs checked for completeness and some reformatting-DGY, 11/07/06.]

BAAS abstracts are excluded. Planet circulars, telegrams and GCNs (GRB announcements) are included. Some papers may have been missed.

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Tramposch, Jonica, Homer, Lee, Szkody, Paula, Henden, Arne, Silvestri, Nicole M., Yirak, Kris, Fraser, Oliver J., Brinkmann, J. 2005, PASP, 117, 262 *"SDSS J210014.12+004446.0: A New Dwarf Nova with Quiescent Superhumps?"*

Tumlinson, J., Shull, J.M., Giroux, M.L., Stocke, J.T., 2005, *The hot intergalactic medium-galaxy connection: two strong absorbers in the PG1211+143 sightline,* ApJ 620, 95

Walawender, J., Bally, J., Kirk, H., Johnstone, D., 2005, *Multiple outflows and protostars in Barnard 1*, AJ 130, 1795

Appenix C: Theses from Apache Point Observatory

Appendix C1: Theses from the 3.5-meter Telescope, Done by Students at ARC Instituions

Theses from the 3.5-meter telescope

According to current reporting, 41 PhD theses have been completed that contained a major component of 3.5-meter data. In addition, at least 14 are in progress.

University of Chicago

Gordon Richards, 2000, The Possible Circum - QSO Origin of Some QSO Absorption Lines *ApJS*. 133. 53.

University of Colorado **(imminent or in progress)**

Josh Walawender "Outflows from Massive Stars in Orion, Perseus, Cepheus"

Brian Keeney "Galaxies associated with Intergalactic Lya Absorbers"

Meredith Drosback "Diffuse Interstellar Bands"

Nathaniel Cunningham "Proper Motions of H2 in Herbig-Haro Outflows"

Fred Hearty "Infrared Emission from High-z Dusty Galaxies"

Quyen Hart "Evolution of AGN in Clusters of Galaxies"

COLORADO UNDERGRAD HONORS THESES USING APO

Stephanie Fawcett "Hidden AGN in Galaxy Clusters"

Fonda Day "Absorbing gas and galaxies toward Ton 28"

Johns Hopkins University

Kuenley Chiu - Examining Quasars at the Peak of the Luminosity Function -- Cloning, Discovery, and Implications for High Redshift, 1/18/2006

Leslie Hebb - Photometric Monitoring of Open Clusters: Low-Mass Eclipsing Binary Stars and Stellar Mass-Luminosity-Radius Relation, 10/14/2005

Adrian Pope - Precision Cosmology from Large-Scale Galaxy Clustering with the Sloan Digital Sky Survey, 10/24/2005

Christy Tremonti - The Physical Properties of Low Redshift Star Forming Galaxies: Insights from the Space-UV and 30,000 SDSS Spectra, 1/21/2003

New Mexico State University

Nancy Chanover - 05/1997 - Advisor: Reta Beebe, "Temporal Variations in the Vertical Structure of Jupiter's Atmosphere"

Percy Gomez - 5/1998 - Advisor: Jack Burns, "A Study of the Dynamics and Substructure of a Sample of Nearby Abell Clusters of Galaxies"

Nichole King – 12/1999 – Advisor: Rene Walterbos "Luminous Blue Variables and Related High Mass Evolved Stars in M31 and Their Surprising Environments"

Charles Hoopes – 12/2000 – Advisor: Rene Walterbos "The Properties and Ionization Sources of Diffuse Ionized Gas in Spiral Galaxies"

Neal Miller – 05/2001 – Advisor: Kurt Anderson "A Radio Perspective on Galaxy Evolution in the Cluster Environment"

Christopher Garasi -06/2001 – Advisor: Jon Holtzman "Magnetic Fields and Cluster Cooling Flow Hypothesis"

Salman Hameed – 06/2001 – Advisor: Jon Holtzman "Massive Star Formation in Early-Type Spirals"

Dawn Gelino (Leeber) – 09/2001 – Advisor: Tom Harrison "Modeling Infrared Ellipsoidal Variations: Determining the Masses of Black Holes in Soft X-Ray Transients"

Denise Stephens – 11/2001 – Advisor: Mark Marley "1 To 4 um Photometry and the Near Infrared Classification of L and T Dwarfs"

Chris Gelino – 07/2002 - Advisor: Mark Marley, "A Multi-Wavelength Search for Photometric Variability in L Dwarfs"

Peregrine McGehee – 05/2005 – Advisor: Kurt Anderson " Magnetospheric Accretion in Substellar Objects"

Joe Helmboldt- 12/2005 - Advisor: Rene Walterbos, "Star Formation at the Extreme Ends of the Hubble Sequence"

Bhasker Moorthy - 08/2006 - Advisor: Jon Holtzman, "Bulges of Spiral Galaxies: Stellar Populations, Structure, Kinematics, and Dynamics"

NMSU Masters Theses

Heather Bogue - 2003, Advisor: Tom Harrison, "Determining the Component Masses of Cataclysmic Variables"

Carla Adams - 2004, Advisor: Nicole Vogt, "Extremes of Galaxy Evolution: Tracing Star Formation in Local Spiral Galaxies"

Sarah Bates - 2005, Advisor: Jon Holtzman, "New M31 Globular Clusters derived from the SDSS"

Pey-Lian Lim - 2006, Advisor: Jon Holtzman, "Hi-Res Spectroscopy of a Hipparcos Sample within 100 parsecs"

Princeton University (1995-present)

Tomislav Kundic – 10/1995 – Advisor: Turner "High-Redshift Quasars, Gravitational Lensing and Cosmology"

Lori M. Lubin – 9/1995 – Advisor: Bahcall "Detection and Analysis of High Redshift Clusters from the Palomar Distant Cluster Survey"

James Rhoads – 1/1997 – Advisor: Spergel "Stellar Populations, Dust and the Near Infrared Appearance of Galaxies and Gravitational Lenses"

Xiaohui Fan – 11/2000 – Advisor: Strauss "A Survey of High Redshift Quasars from the Sloan Digital Sky Survey"

SeungJung Kim – 6/2001 – Advisor: Strauss "Detecting Clusters of Galaxies in the Sloan Digital Sky Survey"

Iskra Strateva – 12/2003 – Advisor: Strauss "Balmer Line Emission from the Accretion Disks Surrounding the Supermassive Black Holes in Active Galactic Nuclei"

Bart Pindor – 10/2003 – Advisor: Turner "A Search for Strongly-Lensed Quasars in the Sloan Digital Sky Survey"

Joe Hennawi – 8/2004 – Advisor: Spergel "Topics in Gravitational Lensing: Clusters, Quasars and the Cosmic Microwave Background"

University of Washington, Seattle

Guillermo Gonzalez (1993), A Study of the UV-bright Stars in Omega Cen and the Type II Cepheid ST Pup

Bryan W. Miller (1994), The Recent Star Formation Histories of Dwarf Galaxies in the Sculptor and M81 Groups

Douglas Russell Ingram (1996), Starlight Correlated with Damped Lyman alpha Absorbers

Bernhard Beck-Winchatz (1998), A Morphological and Multicolor Survey for Faint QSOs

Donald Wayne Hoard (1998), Accretion and Structure in the SW Sextantis Stars

Stefanie Wachter (1998), Optical and Infrared Constraints on the Evolutionary States of Low Mass

X-ray Binary Stars

Brooke P. Skelton (1999), Giant H II Regions in M33

Kevin Krisciunas (2000), RR Lyrae Stars and Type Ia Supernovae: Discovery and Calibration of Astronomical Standard Candles

Ted K. Wyder (2000), The Stellar Populations and Star Formation History of NGC 6822

Bernadette Rodgers (2001), What's Happening Around Herbig Ae Stars?: Investigating Circumstellar Activity in Young Intermediate Mass Stars with Optical and Near-Infrared Spectroscopy

Daniel B. Zucker (2001), A Multiwavelength Study of the Local Group Starburst Galaxy IC 10

Christopher S. Laws (2004), The Chemically Peculiar Nature of Stars with Planets: Searching for Signatures of Accretion in Stellar Photospheres

Antonino Miceli (2005), LONEOS RR Lyrae Stars as Probes of Galactic Structure and Formation

Gajus Miknaitis (2005), Supernovae and Dark Energy

Andrew West (2005), HI Selected Galaxies in the Sloan Digital Sky Survey

Marcel Agueros (in progress), Identifying Stellar X-ray Sources from ROSAT and SDSS

John Bochanski (in progress), Low Mass Stellar Luminosity and Mass Functions

Ricardo Covarrubias (in progress), Does Metallicity Affect the Fate of Massive Stars?

Kevin Covey (in progress), Probing Star Formation
in Clusters and the Field

Oliver Fraser (in progress), Long Period Variables
in the Local Group

Anil Seth (in progress), The Formation and Evolution of
Late-type Galaxies

Lucianne Walkowicz (in progress), Observations of
Chromospheric Lines in Cool Dwarfs

Peter Yoachim (in progress), Thick and Thin Disk Stellar
Populations in Disk Galaxies

Appendix C2: Theses from the 2.5-meter telescope, done by students from ARC institutions (compiled by Rich Kron)

According to current tabulations, students at ARC institutions have completed 16 PhD theses using predominantly SDSS data. In addition, twelve are in progress.

Theses Completed

The following theses are listed as "completed" on the SDSS thesis page, as of November, 2006. The project number listed is the number of the posted SDSS project that produced the thesis work. In general, the student's name is listed first and that of the advisor(s), second.

A Survey for Resolved LSB Stellar Populations in the Local Group
(Beth Willman, Julianne Dalcanton) Project 159. July 2000

Identifying Strongly-Lensed Quasars in the SDSS Imaging Data
(Bart Pindor, Ed Turner) Project 161. August 2000

Emission-line properties of galaxies: large-scale structure, active nuclei, and metallicity. (Lei Hao, Michael Strauss) Project 122. November 2000

A Survey of High-Redshift Quasars from the Sloan Digital Sky Survey
(Xiaohui Fan, Michael A. Strauss) Project 119. December 2000

Environmental Dependence of Galaxy Properties in Clusters found in the Sloan Digital Sky Survey (Rita S.J. Kim, Michael A. Strauss)
Project 158. February 2001

Measuring scale dependence of bias using galaxy-galaxy lensing and galaxy clustering (Jacek Guzik, Uros Seljak) Project 129. June 2001

Expected Biasing Model Constraints from SDSS Galaxy Angular Clustering
(Ryan Scranton, Scott Dodelson) Project 133. July 2001

The Nature of Star Forming Galaxies in the SDSS
(Christy Tremonti, Tim Heckman & Guinevere Kauffmann)

Project 134. July 2001

The evolution of Brightest Cluster Galaxies from SDSS data
(Yeong-Shang Loh, Michael Strauss) Project 135. August 2001

Search for and Analysis of Extra-Tidal Stars in the Globular Cluster Pal 5
(Connie Rockosi, Don York) Project 160. November 2001

Search for and Analysis of Extra-Tidal Stars in the Globular Cluster Pal 5
(Connie Rockosi, Don York) Project 160. November 2001

Spectral Variability of Quasars in the SDSS
(Brian Wilhite, Richard Kron) Project 137. November 2001

Double-Peaked Broad Emission Lines and the Geometry of Accretion in Active Galactic Nuclei (Iskra Strateva, Michael Strauss, David Schlegel, Lei Hao, Zeljko Ivezic, Li-Xin Li, Pat Hall, James Gunn, Nadia Zakamska) Project 132. October 2002

Constraining Compact Dark Matter with Quasar Equivalent Widths from the SDSS (Craig Wiegert, Josh Frieman) Project 142. EDR. July 2003

Probing galaxy-mass higher order correlation functions with Weak Lensing (David Johnston, Joshua Frieman) Project 153. August 2003

Type II Quasars from the SDSS
(Nadia Zakamska, Michael Strauss, Julian Krolik, others (see author lists for individual papers)) Project 155. October 2003

Magnetospheric Accretion in Substellar Objects (Peregrine McGehee, Kurt Anderson, Suzanne Hawley) Project 193. May 2004

SDSS theses "in progress" (date given is posting date on SDSS website)

An Empirical Measure of Galaxy Evolution in Clusters
(Vandana Desai, Julianne Dalcanton) Project 152. July 2000

HI Properties of Galaxies: SDSS Counterparts to HIPASS and HIJASS Sources (Andrew A. West, Julianne Dalcanton, Diego Garcia-Appadoo, Mike Disney) Project 259. September 2000

Galaxy correlations as a function of stellar mass
(Nikhil Padmanabhan, Uros Seljak) Project 146. August 2002

Low mass stellar luminosity function from correlated SDSS/2MASS photometry (Kevin Covey, Suzanne Hawley) Project 157. October 2003.

Matched Filter Techniques for Finding and Characterizing Clusters in 2D and 3D (Feng Dong, Jim Gunn) Project 156. October 2003

Extraction of DLA and BAL features from SDSS spectra
(Don York, Yusra Alsayyad) Project 195. October 2003

Star Formation in Early-type MAIN Galaxies
(Joe Helmboldt, Nicole Vogt, Jon Holtzman, Rene Walterbos)
Project 246. February 2004

Low Mass Stars in the SDSS: Photometric Determination of the Luminosity Function and Mass Function (John Bochanski, Suzanne Hawley)
Project 261. August 2004

Distant Minor Planets in the SDSS: Discovery and Characterization (Andy Puckett, Rich Kron) Project 297. October 2005

Lopsidedness in star-forming and active galaxies
(Timothy Reichard, Timothy Heckman, Gregory Rudnick, Guinevere Kauffmann, Jarle Brinchmann) Project 333. May 2006

Posted thesis projects not completed, but with at least one paper submitted

Spectral decomposition of quasars using KL transform
(Ching-Wa Yip, Andrew Connolly, Daniel Vanden Berk, Zhaoming Ma, Joshua Frieman, Mark SubbaRao, Alex Szalay, Gordon Richards, et al.)
Project 209. September 2001

Differential surface density of galaxies versus dark matter; dark matter halo ellipticity (Rachel Mandelbaum, Uros Seljak, Christopher Hirata, Nikhil Padmanabhan,Tamara Broderick) Project 272. February 2005

Appendix D: Selected publications from the 2.5-meter (SDSS)

Title	First Author	astro-ph	Journal
A Snapshot Survey for Gravitational Lenses Among z>=4.0 Quasars: II. The 4.0 < z < 5.4 Sample	G. Richards		AJ submitted
Bivariate Galaxy Luminosity Functions in the Sloan Digital Sky Survey	N. Ball	0507547	MNRAS submitted
SDSSJ102111.02+491330.4: A Newly Discovered Gravitational Lensed Quasar	B. Pindor		AJ accepted
Ultracompact AM CVn Binaries from the Sloan Digital Sky Survey: Three Candidates Plus the First Confirmed Eclipsing System	S. Anderson	0506730	AJ submitted
Quantitative Morphology of Galaxies from the SDSS I: Luminosity in Bulges and Disks	L. Tasca	0507249	MNRAS submitted
Ellipticity of Dark Matter Halos with Galaxy Weak Lensing	R. Mandelbaum	0507108	MNRAS submitted
SDSS J0246-0825: A New Gravitationally Lensed Quasar from the Sloan Digital Sky Survey	N. Inada	0506631	AJ accepted
Fourier Phase Analysis of SDSS Galaxies	C. Hikage	0506194	PASJ submitted
The SDSS View of the Palomar-Green Bright Quasar Survey	S. Jester	0506022	AJ 130:873 (2005)
New Low Accretion-Rate Magnetic Binary Systems and thier Significance for the Evolution of Cataclysmic Variables	G.D. Schmidt	0505385	ApJ accepted
Characteristic QSO Accretion Disk	N. Pereyra	0506006	ApJ submitted

Temperatures from Spectroscopic Continuum Variability			
Magnetic White Dwarfs from the SDSS II. The Second and Third Data Releases	K. Vanlandingham	0505085	AJ 130:734 ff(2005)
Dark Matter and Stellar Mass in the Luminous Regions of Disk Galaxies	J. Pizagno	0504581	ApJ submitted
Topology Analysis of the Sloan Digital Sky Survey: I. Scale and Luminosity Dependences	C. Park	0507059	ApJ accepted
Eleven New DAVs from the Sloan Survey	F. Mullally	0502520	ApJ 625:966 (2005)
The Color Selection of Quasars from Redshifts 5 to 10: Cloning and Discovery	K. Chiu	0504001	AJ 130:13 (2005)
Binary Quasars in the Sloan Digital Sky Survey: Evidence for Excess Clustering on Small Scales	J. Hennawi	0504535	AJ submitted
Detection of Cosmic Magnification with the Sloan Digital Sky Survey	R. Scranton	0504510	AJ accepted
Spectral Variability of Quasars in the Sloan Digital Sky Survey. I: Wavelength Dependence	B. Wilhite	0504309	ApJ accepted
Detection of the Baryon Acoustic Peak in the Large-Scale Correlation Function of SDSS Luminous Red Galaxies	D. Eisenstein	0501171	ApJ submitted
The Nature of Nearby Counterparts to Intermediate Redshift Luminous Compact Blue Galaxies. II CO Observations	C. Garland	0502055	ApJ 624:714 (2005)
Cataclysmic Variables from SDSS IV. 2003 Year	P. Szkody		AJ 129:2386 (2005)

Systematic Errors in Weak Lensing: Application to SDSS Galaxy-Galaxy Weak Lensing	R. Mandelbaum	0501201	MNRAS 361:1287 (2005)
SDSS ~J210014.12+004446.0: A New Dwarf Nova with Quiescent Superhumps?	J. Tramposch	0501178	PASP 117:262 (2005)
The SDSS u-band Galaxy Survey: Luminosity Functions and Evolution	I. Baldry	0501110	MNRAS 358:441 (2005)
Active Galactic Nuclei in the Sloan Digital Sky Survey: II. Emission-Line Luminosity Function	L. Hao	0501042	AJ 129:1795 (2005)
Active Galactic Nuclei in the Sloan Digital Sky Survey: I. Sample Selection	L. Hao	0501059	AJ 129:1783 (2005)
Large Scale Clustering of Sloan Digital Sky Survey Quasars: Impact of the Baryon Density and the Cosmological Constant	K. Yahata	0412631	PASJ accepted
An Empirical Calibration of the Completeness of the SDSS Quasar Survey	D. Vanden Berk	0501113	AJ 129:2047 (2005)
The Sloan Digital Sky Survey Quasar Catalog III. Third Data Release	D. Schneider	0503679	AJ 130:367 (2005)
Intergalactic Stars in z~0.25 Galaxy Clusters: Systematic Properties from Stacking of Sloan Digital Sky Survey Imaging Data	S. Zibetti	0501194	MNRAS 358:949 (2005)
The RASS-SDSS galaxy cluster survey. III Scaling Relations of Galaxy Clusters	P. Popesso	0411536	A&A 433:431 (2005)
The Intermediate-Scale Clustering of Luminous Red Galaxies	I. Zehavi	0411557	ApJ 621:22 (2005)

The Small-Scale Clustering of Luminous Red Galaxies via Cross-Correlation Techniques	D. Eisenstein	0411559	ApJ 619:178 (2005)
Cosmic Homogeneity Demonstrated with Luminous Red Galaxies	D. Hogg	0411197	ApJ 624:54 (2005)
{\em XMM-Newton} and optical follow-up observations of three new Polars from the Sloan Digital Sky Survey	L. Homer	0411175	ApJ 620:929 (2005)
Rotation Velocities of Two Low Luminosity Field Galaxies	J. Pizagno	0410672	ApJL submitted
A Comprehensive Model for the Monoceros Tidal Stream	J. Penarrubia	0410448	ApJ 626:128 (2005)
Colors, Magnitudes and Velocity Dispersions in Early-Type Galaxies: Implications for Galaxy Ages and Metallicities	M. Bernardi	0409571	AJ (2005)
The Linear Theory Power Spectrum from the Lyman-alpha Forest in the Sloan Digital Sky Survey	P. McDonald	0407377	ApJ submitted
The Nature of Nearby Counterparts to Intermediate Redshift Luminous Compact Blue Galaxies I. Optical/H I Properties and Dynamical Masses	C. Garland	0407438	ApJ 615:689 (2004)
A New Milky Way Companion: Unusual Globular Cluster or Extreme Dwarf Satellite?	B. Willman	0410416	AJ 129:2692 (2005)

Appendix E: The maintenance needs of the site

Bruce Gillespie

Overview: I have long held a goal for the APO site infrastructure (*i.e.*, everything except the telescopes, instruments, and operational computer systems) that we maintain it to a level that it looks, feels, and performs like it is half its real age, or less. We have spent a good deal of effort and budget on infrastructure maintenance and improvements over the years, and I am pleased to often hear comments from visitors that the site looks and feels like it's no more than five to ten years old. There are certainly notable exceptions to this guideline (*e.g.*, the emergency diesel generator), which are mentioned briefly below. The bigger issues, risks, and longer-term maintenance items are summarily listed at the end of the report.

The projected state of APO infrastructure in 2008

1. Grounds: The seven acres of site grounds are, and will continue to be, in good condition. An outstanding issue is the need for additional forest clearing in the up-wind, down-slope direction below the telescopes. This would give us better protection from a potentially catastrophic forest fire, and there are apocryphal indications that it may improve the site seeing.
2. Opns Building: Although we have kept the Don Baldwin Operations Building in mostly like-new condition, by 2008 we will need to address some refurbishment items that affect most 20-year old structures. These include exterior and interior painting, replacing the linoleum flooring, kitchen cabinets and counters, and appliances. Also, some of the rooms will be ready for replacement carpeting. We are currently replacing the boiler for building heat, but I expect the domestic hot-water heater will be near the end of its service life in 2008.
3. Dorms: We have nine rooms and twelve beds on site, plus overflow housing at NSO. We average about six people sleeping on site, but the traffic volume varies widely. I don't foresee the need for additional housing by 2008. By 2008 (or sooner), the major visible maintenance needs for the dorms will be new carpeting and exterior and interior paint. Some of the dorm furniture is also getting a little dog-eared, and the mattresses will need to be replaced. The domestic water heaters and washer/drier will be close to the end of their service lives, and the kitchen appliances in the new dorm will be more than a decade old, which is nearly as much life expectancy as you normally get for items like refrigerators, microwave ovens, etc.
4. Vehicles: We should replace the Ford pickup soon, before 2008. The Chevy Tahoe (SUV) and International truck (for LN2 hauling) will both be ripe for trade-in by 2008. We need a forklift at the site—we are using a hand-me-down vintage forklift on loan from NSO, but it is no longer available to us.
5. LAN: The 100baseT local fiber net at the site is relatively new, and should not require any significant upgrades for several years.

6. Internet: The high-bandwidth microwave link to the Internet is brand new and has ample capacity. By 2008, it is possible that the local phone company will be able to provide broadband support to APO by fiber, which would be worth considering as a replacement.
7. Phones: The site telephone system was replaced a couple of years ago with a VoIP system that is working well as is easily expandable. We need to buy some spare parts for the system.
8. Roads: The 1-mile spur to APO was resurfaced last year, and should be in good shape for several years. It will need to be resealed in 2007 to help protect the new top coat. The asphalt at the site is in pretty good repair in general, but it should have its stripes repainted in the next couple of years.
9. Shop: The majority of the machines in the shop are quite old, but in good condition. All of the larger machines are on loan from FNAL and have the potential of being removed in 2008 if FNAL terminates its relationship with ARC.
10. Storage: There has always been a need for more permanent storage space at APO. Unless there is a plan to address this, we have been and will be short several thousand square feet of storage space at the site in 2008. We are currently using the basement of the 3.5-m telescope, and several rental storage units (both on- and off-site) in the interim.
11. Trailers: We have two SDSS office trailers at the site (rentals) and a house trailer at NSO (owned by us). They are adequate for their purposes but an aesthetic eyesore. By 2008, they will be approaching middle age for trailers, requiring an increasing level of maintenance to keep them in presentable, usable condition.
12. SDSS Support Building: The Support Building will be in close to like-new condition in 2008. There are no major maintenance issues. Exterior repainting will be needed by 2008.
13. Water, Septic: Since we have reason to believe the NSO will remain intact at Sunspot at least through the end of this decade, there is no concern about availability of potable water via the existing arrangement. Our site's septic system has been routinely maintained and has no known deficiencies except the need for larger clean-outs; if a new facility is added to APO, a second septic tank and field will need to be added.
14. LPG: The propane tank and site distribution system are robust and relatively maintenance free. There should be no need for any major repairs of enhancements to this system by 2008, except the tank will need repainting soon.
15. Compressed air: The SDSS added a high-grade compressed air system to the site a few years ago. The system has a service life that will last well past 2008; it does, however require a considerable amount of routine maintenance.
16. Fire alarm and suppression: We recently replaced our antiquated site-wide fire alarm system, and the new system should be serviceable for many years. Also, the Sunspot fire department loaned us a fairly respectable fire truck, which is permanently on-

station at APO. Our fire extinguishers have been recently tested and recertified, and our outdoor fire-fighting equipment is in good shape.

17. Electricity, power conditioning, and lightning: Aside from some tree removal under the power lines coming to the site, little, if any, maintenance is required for our electricity feed. The site power distribution system is in good shape. The "layered" surge protection systems are in good order, and UPSs and fiber optic data lines further protect sensitive systems. A substantial lightning protection system has been installed over the years, and is annually checked for degradation. The emergency backup diesel generator has been well maintained over the years, and probably has a good decade of life left. Its power-generating capacity is sufficient for current and expected site loads through 2008; if a new, major facility were to be built at APO, buying a bigger backup generator may be necessary.

18. LN2: The site uses more than 600 gallons of LN2 per week, which is purchased in Alamogordo and hauled by our staff to the site. This system works well, and the only maintenance foreseen is the repair and/or replacement of some number of the 180-liter dewars used for transport.

19. Mirror coatings: We continue to aluminize our small mirrors at NSO and the two primary mirrors at Kitt Peak. Both arrangements have advantages and disadvantages, but should suffice through 2008 and beyond. On the near-term horizon is the possibility that a 4-meter-class aluminizing tank will be installed at the Starfire Optical Range facility in Albuquerque, which would give us another potential coating resource for our larger mirrors.

20. Meteorological monitoring: Since we are highly dependent on solid weather and site conditions monitoring, our met systems have been vigorously maintained and upgraded over the years. I expect they will remain in their current robust condition through 2008 and beyond, and no further enhancements are planned. A weak spot is the DIMM seeing-monitor telescope, which has had persistent maintenance problems

21. Documentation systems: Given the eclectic manner that ARC builds things, our site documentation systems are of uneven completeness and quality, albeit generally adequate. This includes inventory records as well as technical engineering documentation. By 2008, I do not expect this to change for better or for worse.

22. Security, safety: The site security systems are largely unobtrusive. We have signage that is designed to keep the public off the site after hours and at night. There have been no serious security incidents at the site for over a decade (knock on wood).

23. Website: Our website is generally perceived as adequate, if not sterling, in usefulness to the public and ARC users. We are working to improve the 3.5-m telescope and instruments information pages; no other significant changes are envisioned by 2008.

24. Utility computers and servers: We strive to keep our utility computer and server hardware and operating systems at the "n minus one" level of being at, or near, the current generation, which is believed by some to be the most cost-effective paradigm. We have been well served by this strategy, and plan to continue it through 2008 and beyond.

25. Public outreach: There are generally a few tens of thousands of tourists that visit APO each year, and we usually print and distribute nearly this number of site information brochures. We continue to give guided tours to school and special interest groups, at a rate of ~30 per year. Working closely with SDSS and NMSU public affairs, we contribute to the occasional press release. We host and support various film crews at the site, a few annually. We have dedicated exhibit space at the NSO Astronomy and Visitors Center at Sunspot; the material on display needs to be updated before 2008.
26. Staffing: Although not strictly infrastructure, it is worth mentioning that the staff at APO will begin to undergo significant turnover (to retirement) over the coming years—a substantial fraction of the current staff are in their fifties. Since the APO staff is comprised of many individuals with non-overlapping areas of expertise, the issue of bringing the "next generation" on board to train with the retiring staff members remains an unsolved problem.

Major long-term risks and maintenance items

Site Storage

Trailers

Manpower

Forest fire

NSO support

Mirror coatings

Appendix F: Maintenance and upgrade of the 3.5-meter

System	Status	Maintainability	Upgrade	Perform-ance
Enclosure	Overall, the enclosure is in pretty good condition at this time. We have concerns that significant maintenance will become necessary over the coming years.	Site staff have knowledge, experience, and documentation. We depend on NSO Sunspot for use of heavy equipment and labor when needed.		
Shutters	Drive systems recently overhauled. Still need to replace worn cam-following rollers, and linear track on porch showing wear.	May have to farm out future heavy repairs to outside contractors. Major mechanical failures possible, would be expensive and time-consuming to repair.	Flat-field screen?	Adequate
Rotating building	Defective enclosure wheels replaced several years ago, new wheels seem to be performing well. Some continuing flattening of rotation track may lead to future problems.	Rotation servo (slaved to telescope azimuth motion) crude and undocumented. Have spare enclosure wheel, but not much else in way of electro-mechanical spares. Flattening of rotation track may require replacement or upgraded enclosure drive motors.	Add add'l ventilation louvers to rear of rotating building to increase airflow for better thermal management and dome seeing. Replace bridge crane to enable finer motion control for optics handling. Also, redesign the rotation servo to allow faster azimuth slews.	Adequate, if a bit slow.
Stationary	No problems, except lower enclosure becoming crowded with storage items.	No long-term maintenance issues, except possibly exterior painting.	Build a separate storage building to allow removal of objects in lower enclosure, which contribute	Adequate

			to thermal inertia of the telescope.	
Telescope	The telescope is in pretty good shape. Image quality, throughput, pointing/tracking, and up-time are all good. Areas of concern include drives and drive controllers, mirror supports stability and safety, realuminization.	The main recurring maintenance item is periodic rebuilding of the drives for alt, az, and rotator. Other routine maintenance is for optics cleaning/coating, mechanical repair/lube, etc.		
Optics	Optics deliver tight psf when telescope is collimated. Coatings maintained and monitored. Primary mirror has small cracks in cell ribs, monitored yearly. Primary mirror supports are barely adequate and require careful tuning. 2ndary and tertiary supports and drives malfunction and require annual repairs.	Mirrors CO2 cleaned regularly, washed annually, realuminized every few years. Primary mirror will need major repairs if rib cracks start to grow. Mirror support systems need at least annual attention.	Aluminizing facility for primary mirror. Also, protected optimized coatings for 2ndary and tertiary. Redesign supports and drives for 2ndary and tertiary mirrors. Enhance primary mirror support to allow higher altitude operation.	Good, would be excellent if supports and drives were redesigne d.
Mount	In good condition, well-maintained. Some damage to main thrust bearing at bottom of cone during initial construction, being monitored. Some concern about flexure if more instruments added to primary mirror cell.	Routine annual lubrication and periodic adjustments.	None envisaged.	Adequate

Drives	A major trouble spot. Drive speed reduction boxes need complete rebuilding every year or so. Have CIF project to build complete spare boxes to minimize telescope down time. Also considering redesign to direct drive. Also, drive controllers considered obsolete and nearly unmaintainable. Motion encoding is relatively crude by today's standards.	Until the spare drive boxes are fabricated, expect 1+month of down time each year to rebuild existing boxes. Also, if drive controllers fail hard, expect significant down time until a repair or redesign can be effected.	Upgrade to direct-drive system. Upgrade drive servos. Upgrade encoders to tape system.	Blind pointing is usually good to a few arcsecond s, tracking is good to a few tenths per hour.
Instruments	(See Appendix G.)			
DIS	In good condition. Recently upgraded with new detectors, mechanical cryo cooling, new slit viewer camera, and reconditioned grating mechanicals. UV throughput a problem, as is "notch" in wavelength throughput in the break between the red and blue legs of the spectrograph. Throughput with one or more gratings seems to be lower than expected.	Should not need major maintenance in next few years. Mechanical cryo cooling system a weak spot, should be better spared. Good support from Princeton for other potential problems. Documentation fair.	Replace/repair optics to recover UV sensitivity. Replace weak throughput grating(s). Fix dichroic splitter to remove sensitivity notch. Enable multi-slit.	TBD
SPIcam	Working well. Only problems are small FOV, mechanical cryo cooling system sometimes needs service, and low-level pattern noise.	Should not need major maintenance in next few years. Mechanical cryo cooling system a weak spot, should be better spared. Do not have good technical support within ARC for other problems, e.g., low-level pattern noise. Documentation fair	Add fore-optics to give larger FOV, tip-tilt.	TBD

GRIM2	Nearing end of usable life. Detector is small and often exhibits missing quadrant. Maintainability an issue. Will be largely replaced by NIC-FPS with larger, more capable detector.	GRIM2 is a sealed can, with virtually no easily serviced components except exterior electronics. Documentation good, but only one person at UChicago has expertise to do any major repair work.	None envisaged.	TBD
Echelle	Working well. Some minor problems with LN2 filling system.	Only major maintenance is periodic pumping of camera and spectrograph. Documentation good, and fairly good technical support at the moment but could diminish. Motor controllers difficult to maintain.	Put broad-band AR coatings on all refractive optics. Obtain low-noise detector and replace camera.	TBD
Fabry-Perot	Works well, but remote operation not yet established (being tested this month). Have had recurring problems with shutter. Relatively narrow FOV.	Little maintenance required, and access to PI support for future problems is pretty good.	Add fore-optics to give larger FOV, tip-tilt. Add more filter holders for permanent mounting.	TBD
Shack-Hartmann	Works well, no known problems.	Maintenance requirements are minimal.	None envisaged.	TBD
NA2 guider	Roper-Photometrics camera being replaced this month with new Apogee camera to improve reliability. Johnson filter set added to filter wheel.	Maintenance requirements should be minimal for new camera.	None envisaged.	TBD

NIC-FPS	In final integration and test stage at Boulder. Expected at APO during Q4 2004 for commissioning on telescope.	Maintenance requirements unknown, have asked instrument developers to deliver maintenance procedures with instrument.	Replace detector with 2k x 2k device for wider FOV.	TBD
APOLLO lunar ranger	Laser on telescope, first lasing test expected by end of 2004.	We expect maintenance to be the responsibility of the PI.	None envisaged.	TBD
FastCAM	Installed on telescope, has problems with fast frame-rate operation that are being worked.	Minimal maintenance requirements.	None envisaged.	TBD
Telecom and LAN	Telescope has 100Base-T fiber system, 6 spare cables, easy to add more. Connected to site LAN. Site connected to Internet with T1 line to Las Cruces, upgrade to experimental 10 Mb microwave line underway.	Minimal maintenance requirements.	None envisaged.	TBD
Computers	A mishmash of Apple, DEC, SUN, PC-based and other platforms. Have mostly been upgraded every three or so years. Systems have adequate operational capacity.	Minimal maintenance requirements. Continue upgrading machines every three years or so.	None envisaged.	TBD
Documenta-tion	An eclectic set of drawings, documents, and computer files loosely organized on our web page. Most of the time, we can find what we need. CAD commonality is still a big issue.	A small fraction of an FTE is spent on maintaining documentation.	Use professional support to reorganize and maintain documentation.	TBD

s/w	A many-authored suite of operational software, from telescope and instrument motion control and data acquisition, up to and including data reduction and analysis s/w. Remark being replaced by TUI, and operating systems being kept current. Systems backed up regularly.	This task would be better served if the site had a full-time system administrator. Currently, our Systems and Network Manager spends about half his time on s/w maintenance.	Full-time systems administrator.	

Appendix G: 3.5-meter instruments and their upgrade paths

G1. Overview

The 3.5-meter telescope has four main workhorse facility instruments: DIS, echelle, SPIcam, and NIC-FPS. The goal is that these be fully supported by site personnel, and have supported remote user interfaces (TUI for all but SPIcam, which currently has its own command-line interface). Several other instruments have been used at the telescope, with varying levels of support. The echelle is permanently mounted on the NA1 port; the other instruments are all used at the NA2 port. Relatively rapid instrument changes (15 minutes) are straightforward and commonplace.

G2. Dual-Imaging Spectrograph (DIS)

DIS is a dual-channel spectrograph, originally built at Princeton, that is capable of delivering spectra across the entire optical window from 3500-10,000 A. There is a dichroic that splits the beam at about 5350 A, after which is passes through two independent cameras and is imaged onto two independent detectors. Gratings are mounted as pairs, one for each channel; we currently have low, medium, and high-resolution gratings giving dispersions of 0.6 to 5 A/pixel. The instrument is usually operated with a long slit; several of these exist that have reflective surfaces, enabling the use of a separate slit-viewing camera. It is possible to use slit masks, but this capability has rarely been used; it also requires using the imaging mode for target acquisition. The spectrograph camera and detector assemblies were replaced around 2002, with larger format eep depletion device) for the red channel in an effort to reduce the severe fringing seen longward of 7500 A, 2) purchase of additional gratings to improve throughput, and investigation of the possibility of having 3 grating pairs mounted simultaneously (instead of having 2 pairs plus an imaging mode), 3) replacement of blue prism assembly to improve near-UV throughput, and 4) installation of new dichroic and blue camera assemblies to move split wavelength to around 6000 A. The plan is to do these improvements largely using CIF funds. [Upgrades 1, 2 and 3 took place during 2006]

G3. ARC Echelle Spectrograph (ARCES)

The echelle spectrograph was built at the University of Chicago, and gives R=37000 cross-dispersed spectra, with a 1.6x3.2 arcsec slit, useful for work even when seeing is poor. The faint object performance is limited by the read noise of the CCD and by the pixel size. The coverage is continuous from 3600A to 10,000 A and the reduced spectra are blazeless. While the orders are closely packed, there is no cross talk that is measurable at a S/N of 3000/1. The effective limiting magnitude is 14th V for A stars. (Wang, S., Hildebrand, R., etal 2003, ARCES: an echelle spectrograph for the Astrophysical Research Consortium (ARC) 3.5m telescope, *SPIE* 4841, 1145.)
)

Three upgrade paths are obvious: overcoat the large internal optics; install a new CCD with 1-electron read noise, 13-micron pixels. The guider is excellent, capable of guiding to 18th magnitude (Wang et al., 2002). These upgrades would double the resolving power and move the limiting magnitude to 17.5, or so, depending on the read noise of the CCD. Pursuit of a detector upgrade awaits the identification of an available low-noise device.

G4. Seaver Prototype Imaging Camera (SPIcam)

SPIcam was constructed at the University of Washington. It is a direct imaging camera that uses a 2048x2048 CCD, providing an image scale of 0.14 arcsec/filter; with this scale, the detector is usually operated in 2x2 binned mode. Three-inch filters are used; UBVRI and SDSS filters are the most commonly used. With broadband filters and detector readout noise <6 electrons, most observations are sky-limited. No recent upgrades have been made directly to SPIcam; however, CIF funds were used to significantly improve the baffling of the telescope, which has been demonstrated to result in significantly better flat-fielding performance and photometric accuracy.

A possible future upgrade would be to construct a focal-reducing camera to take advantage of the full detector (although this would require some rework of the baffling), but a viable design/implementation has not yet been developed, so timescale is still undetermined.

G5. Near Infrared Camera and Fabry-Perot Spectrometer (NIC-FPS)

NIC-FPS was constructed at the University of Colorado, and obtained by ARC as part of the agreement made when CU joined ARC. NIC-FPS provides infrared imaging capability using a 1024x1024 Rockwell HgCdTe array. The scale is 0.27 arcsec/pixel and the instrument includes a set of broad- and narrow-band filters. Recent improvements include significant improvements in detector noise, as well as the installation of a grism providing low-resolution (R~300) spectroscopic capability (Hearty et al., 2004).

Future upgrades include the implementation of a Fabry-Perot mode (purchase of a new controller is required, which is being pursued by CU), which is likely in the <2008 time period; the instrument was also designed with the possibility of an upgrade to a 2048x2048 detector, but there are no immediate plans to pursue this.

G6. Goddard Fabry-Perot (GFP)

The Goddard Fabry-Perot (GFP) was constructed by Bruce Woodgate (GSFC) and Povilas Palunas (UT) and others, has been in permanent residence at the 3.5-meter telescope for four years. This instrument includes a collimated beam cavity, a camera that includes a 1024x1024 STIS CCD, a finger for coronagraphic work, and a complete set of blocking filters. There are three etalons, which give complete coverage from 4000A to 9000A with various resolving powers, typically 300-600. With the two-inch etalons, the full field is 3 arcminutes, but the narrow band pass bull's eye is about 1.5 arcminutes. (This is the dimension of an area that has a filtered width of R~300-400. There is a gradient in velocity, outward, of the band center). The instrument is remotely operable and is currently queue scheduled. (Kulkarni, V., Woodgate, B. et al., *Astrophysical Journal*, **636**, 30, 2005)

Hardware upgrade paths include addition of a tip-tilt mode, installation of a lower noise, larger format CCD, installation of a grism for multi-object spectroscopy at a resolving power of 1500 (to resolve the O II doublet), and construction of filter holders for all 40 filters, with a purged box on the telescope level to hold them all (to allow random scheduling of the instrument with 100A bandpasses at all wavelengths from 3800-9000A). These upgrades would likely be undertaken at the expense of the PI, although contributions from the CIF would be plausible if sufficient user interest and support existed. In addition, it has been considered whether some effort should be put into making the GFP more of a facility instrument, by allowing hardware support by on-site personnel with additional training, and/or by documenting/improving the user interface and providing a data reduction package.

G7. Cornell Massachusetts Slit Spectrograph (CorMASS)

CorMASS is a low low-resolution near-IR spectrograph built under the leadership of John Wilson and Mike Skrutskie while they were at Cornell and UMASS, respectively. It provides R~300 cross-dispersed spectroscopy, and includes a slit-viewing camera. It has been used at a variety of telescopes, including the APO 3.5-meter telescope for a portion of 2004. It recently returned to APO and is expected to be available there until the commissioning of TripleSpec (see below). No remote interface is available or currently planned; the observing specialists have been trained to operate the instrument.

G8. A new, IR spectrgraph (TripleSpec)

TripleSpec is a future NIR spectrograph, currently under construction in a collaboration between University of Virginia, Cornell, JPL, and Caltech. The plan is that one copy of it will be available at the 3.5-meter telescope starting in 2007 as part of the agreement for UVa to join ARC. TripleSpec will provide cross-dispersed IR spectroscopy at R=3600, using a Hawaii-II

2048x2048 detector (although it only requires 2 quadrants to be functional), and will include a K-band slit viewing camera. Development of the instrument is expected to be closely coordinated with site personnel to allow on-site maintenance and a fully supported user interface; the plan is that this instrument would become a full facility instrument.

G9. Apache Point Lunar Laser Ranging Operation (APOLLO)

APOLLO is an instrument that has been constructed under the guidance of Tom Murphy (UCSD), which will be used to do laser ranging of the moon on a regular basis over the next five years, starting when its capability has been demonstrated. It consists of a pulsed laser beam that is delivered outward through the telescope, and a photon-counting array of avalanche photo-diodes to detect returning photons.

G10. Acousto-Optical Tunable Filter (AOTF)

An imaging camera using a tunable acousto-optical filter, the AOTF, has been used at the 3.5-meter telescope by Nancy Chanover (NMSU) and collaborators; the original instrument was built at Goddard, and a second one has been constructed at NMSU. This provides tunable narrow-band imaging. Due to the nature of the tunable filter, the system throughput is relatively low; the system has been used primarily for planetary observations. No remote interface is available.

G11. High-speed photometry (Agile)

An NSF proposal was submitted by Anjum Mukadam (UW) to construct a high-speed CCD photometer and was recently funded. Plans are being made to build this instrument to be fully integrated into the 3.5-m telescope and its remote observing systems.

Appendix H. The telescope and instrument upgrades, 2006-2008.

H1. Projects underway.

The projects currently underway and expected to be completed before July 1, 2008 are as follows. [Note that these estimates were the best available as of Jan. 2006 and do not take account of real costs for those items completed since then.]

--The top end will be made more stable, improving seeing. The runout cost for this project, to be completed this year, is ~$200K. [This was officially completed in the fall of 2006.]

--New drive boxes will be built for the main telescope motion disks and installed in the summer of 2006 (or earlier, if failures of the current boxes occur.) This project will extend the life of the boxes and reduce maintenance costs. The cost is ~$55K. (See below, on the cost of completely new, direct drive boxes.)

--Upgrade and maintenance of the user interface, TUI, will continue, improving observing efficiency for users. This is 10% of one FTE, which comes from CIF funding.

These three bullets come to $265K.

H2. Near-term projects on the 3.5-meter telescope

Additional tasks that have not started but should fit into the CIF funding before June 2008 include the following:

--The drive controllers and servos need to be replaced. The technology is old and spares are not available any longer. This project reduces risk of down time. The cost is about $200K.

--The tertiary mount needs to be rebuilt (in the manner similar to what is now being completed for the secondary. The cost is $100K (all numbers are very rough estimates.)

--Telescope autofocus needs to be implemented. The purpose is to increase efficiency of observing by always having the possibility of having the smallest image possible. The mechanicals are all in place for this, we just need the software. The cost is $100K.

--As a contingency, if the new drive boxes fail to produce the expected longer life, we may need to build new, direct drive boxes on the SDSS model. We will not know until the new boxes have been in operation for a while. Cost: $200K.

--The addition of an atmospheric dispersion corrector at the Nasmyth 2 focus would increase the throughput of the telescope spectrographs at all wavelengths (currently, one has to make a choice to optimize one wavelength). The cost is about $50K

--The enclosure servos need to be upgraded, following recent failures and inadequate documentation. The cost is ~$20K

H3. Near-term instrumentation projects

Excluding SDSS-like direct drive boxes, this section comes to $470K.
3.5-meter instrumentation

--For NIC-FPS, the grism other parts may be purchased. Some new funds may be provided for the Fabry-Perot implementation. The total expected cost is ~$60K.

--For TripleSpec, funding for a new detector will be provided and ARC will support a design review. The total expenditure is expected to be ~$200K.

--Based on an ARC-funded JHU trade study, about $115K is needed for needed upgrades to DIS. A new, red detector to reduce fringing is already in hand.

These instrument upgrades include costs of $375K.

H4. Funding summary

The total for projects being considered for pre-2008, CIF funding is $265K (Section A8.1) plus $470K (A8.2), plus $375K (A8.3), for a total of $1,100K against a projected budget of $930K. Some items will need to be deferred, at the discretion of the Director.

Appendix I. K. Anderson long-term planning document

This document reflects the original vision of the observatory, including aspects that were dropped in budget cuts, as well as the detailed rationale for a number of upgrades, including those emphasized in the report.

[A Word version of the current pdf document is needed to be integrated into this larger document.]