The University of California Observatories

Self Study 15 July 2011

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http://www.ucolick.org/~bolte/UCOSelfStudy9August2011.pdf

1. EXECUTIVE SUMMARY

Since 1888, the University of California (UC) has pooled its systemwide resources for research in astronomy and astrophysics to maintain a share in world-leading observatories. The 1m-class telescopes at Lick Observatory were the most powerful in the world when commissioned in the late 1800s. In 1959, the Lick Observatory 3m telescope was completed and was the second largest telescope in the world for the next fifteen years. In 1993 and 1996 the Keck Observatory 10-m telescopes were completed and were the most powerful ground-based telescopes ever built. UC faculty on all campuses have had guaranteed access to forefront astronomy facilities for more than 130 years. Through its leadership role in the Thirty-Meter Telescope project, UC is proactively looking to ensure that this access to world-class facilities continues into the next generation of astronomy facilities. No single campus could afford to participate in state-of-the-art facilities: astronomy and astrophysics are perhaps the finest examples of the University of California's "Power of Ten".

The University of California Observatories (UCO) is the organization charged with operating Lick Observatory on behalf of all UC campuses, and with designing and fabricating instrumentation for both Lick and Keck Observatories. UCO is also the organization that provides the platform for gathering input on the strategic direction for UC astronomy optical and infrared (O/IR) facilities and the means to initiate new activities for systemwide benefit.

UCO headquarters and main laboratories are on the UC Santa Cruz campus, and a second major lab specializing in instrumentation for infrared observations is located on the UCLA campus. UCO's track record for providing Lick and Keck Observatories' instruments is outstanding. All of the instruments at Lick Observatory have been built in the UCO labs. In addition, five of the major instruments at Keck Observatory have been designed and built in the UCO labs, and many major subsystems of the remaining and in-progress instruments have been designed or fabricated in our Santa Cruz labs. We have also carried out the major focal-plane upgrades for the optical spectrometers, and have designed and fabricated the Keck 1 atmospheric dispersion compensator. There are several planned new instrumentation projects and a major new initiative in adaptive optics for the Keck Observatory. UCO is taking either the lead role or is responsible for one or more major subsystems for all of these projects.

The model for UCO is to have a largely self-contained organization that can carry out the business of operating and equipping Lick Observatory and providing scientific leadership, instrumentation and technical support for the Keck Observatory. Many of the activities are specialized and outside the expertise and purview of standard university services. Much of the instrumentation is state of the art and there is a component of the work that requires original research and the development of new approaches and new products.

Our academic faculty members are integral to carrying out UCO's mission. Over the last fifteen years, ten different members have served as Principle Investigator for a Keck or Lick Observatory instrument. The unique arrangements for UCO faculty allow recognition and reward for activities carried out that benefit UC astronomy system wide along with the usual teaching, research and service functions of the University of California faculty.

The success of this approach is well documented in terms of scientific productivity, awards and other recognition of UC astronomy faculty, graduate student outcomes, grant and gift awards to UC astronomy faculty and growth of astronomy programs in the UC system.

The proper context for considering UCO within the UC system is to think of the Lick and Keck observatories as the laboratories for UC astronomers on all campuses, and UCO is the organization that optimizes these facilities on behalf of all UC astronomers. The Keck operations and UCO budget lines cover the full costs of operating those facilities and, in the case of the Keck Observatory, constructing the UC fraction of the facility. For state support of other academic areas, the costs of building lab facilities on each campus, the costs of operating those lab buildings and the generally much larger start-up costs for faculty in laboratory scientists is the equivalent investment.

2. BRIEF HISTORY

2.1 Telescopes

Lick Observatory on Mount Hamilton formally became a part of the University of California (UC) in 1888, when construction of the main building with its 36-inch refractor was completed. A second world-class telescope, the 36-inch Crossley reflecting telescope was installed shortly thereafter, making Lick Observatory the first permanently occupied mountaintop observatory, with the two largest telescopes in the world. Between 1910 and 1950, telescopes were built at Mt Wilson and Mt Palomar that rivaled and then significantly surpassed those at Lick Observatory. The completion of the 3-meter Shane telescope at Lick Observatory in 1960, then the second largest in the world, once again provided UC scientists with facilities at the forefront of astronomical research.

In the 1980s, led by UC Berkeley physicists Jerry Nelson and Terry Mast, work began to design a primary mirror and telescope that would enable an enormous leap forward in telescope capability and give University of California astronomers preferred access to facilities at the leading edge of astronomical research. This led to a partnership between the University of California, the California Institute of Technology (Caltech) and the National Aeronautics and Space Administration (NASA) to build and operate the two Keck Observatory 10-m telescopes on Mauna Kea in Hawaii, which were completed in 1993 (Keck 1) and 1996 (Keck 2). The capital costs of building the observatory and its headquarters were borne by Caltech via a grant from the Keck Foundation. The operations and focal-plane instrument costs are paid for by both UC (5/6ths) and NASA ($1/6^{th}$) [the NASA arrangements are reconsidered every five years via a renewable cooperative agreement] through March 2018, at which time the UC-integrated contribution will be equal to the initial Caltech capital investment. After March 2018, the UC annual obligation is reduced by a factor of two, from ~$15.8M/year to ~$7.9M/year, and Caltech will make up the difference in operations costs.

2.2 Faculty, staff and laboratories

In the early decades of Lick Observatory, astronomical research at UC was conducted largely by the scientific staff resident at Lick Observatory on Mount Hamilton, who held the faculty-equivalent title of Astronomer. With the growth of astronomy programs in the university, first at Berkeley and later at

Los Angeles and San Diego, Lick Observatory increasingly became a systemwide facility serving the entire UC system. When Clark Kerr became UC's President in 1960, he decided to incorporate the freestanding UC research institutions, including Lick Observatory, into the university campus structure. In response to Kerr's goal, in 1967 the Lick Observatory Astronomers, instrument designers and builders, and most of the administrative staff moved to the new University of California, Santa Cruz (UCSC) campus, leaving behind a small administrative, technical and maintenance staff on Mount Hamilton. The faculty-level Astronomer positions were converted into "80/20" positions—80% Astronomer with the Observatory and 20% ladder-rank faculty with the UC Santa Cruz Department of Astronomy and Astrophysics.

By the time of the move to Santa Cruz, there were active research astronomers on most of the UC campuses and over the next decade every campus but UC San Francisco built observational astronomy programs. Researchers from the Lawrence Berkeley National Laboratory, Berkeley Space Sciences Laboratory and the Lawrence Livermore National Laboratory also were granted access to Lick Observatory telescopes. As the first of the Keck telescopes was nearing completion in 1988, the University of California Observatories (UCO) was created as a Multi-campus Research Unit (MRU), to support the Keck and Lick Observatories. UCO was formed by modifying and enhancing an existing Organized Research Unit, which was Lick Observatory.

UCO headquarters and labs at UCSC did not have a strong capability in developing instrumentation for the infrared (IR). In recognition of the excellent IR facilities and scientists at UCLA led by Professor Ian McLean, UCO was expanded in 1998 to incorporate the UCLA IR Lab, with Professor McLean as an Associate Director of UCO. Approximately $300K/year of UCO funds are used to support this facility.

3. MISSION STATEMENT

As defined during its creation, the Mission Statement for UCO is to:

- Provide UC astronomers with continuing access to world-class O/IR facilities
- Design and build advanced equipment for the Lick and Keck Telescopes, including major optics, instruments, detectors, and software systems
- Maintain and operate Lick Observatory on Mount Hamilton, for use by scientists and students from all UC campuses, the Lawrence Berkeley Lab and LLNL
- Provide an administrative interface for UC and scientific support to the Keck Observatory
- Support through its faculty and facilities graduate and undergraduate teaching and the training of astronomy Ph.D.s throughout the UC system
- Conduct forefront research in astronomy and astrophysics
- Provide an organization that can unite and coordinate astronomy groups throughout the UC system in support of the Keck and Lick Observatories
- Represent the interests of UC O/IR astronomers in external forums such as Keck Observatory and on the national and international level

Future facilities: UCO also provides the natural focus for ensuring that UC astronomers continue to have preferred access to the world-leading facilities of the future. In the 1950s Lick astronomers and staff successfully pursued funding for the Lick Observatory 3m telescope, then designed and constructed that telescope. In the 1980s and early 1990s this happened again to produce the Keck Telescopes. Over the last decade UC, primarily through UCO, has played a key role in the project to design and build a 30-m Keck-style telescope, the TMT.

4. UCO STRUCTURE

4.1 Overview

UCO is a relatively standalone organization with all the components required to carry out the Observatory mission. The components are listed here.

- **Administration and Governance**
- **UCO 80/20 Faculty**
- **Laboratories**
  - Engineering and project management
  - Detectors
  - Optics fabrication testing and handling
  - Adaptive optics
  - Mechanical fabrication
  - Astronomical coatings
  - Software
- **Administrative & Business Services**
  - Contracts and grants
  - Financial Analysis
  - Human resources and payroll
  - Administration
  - Purchasing and business services
  - Facilities Administration
- **UCLA IR Laboratory**
- **Completed Projects**
- **Ongoing and Potential Future Projects**

4.2 Administration and Governance

UCO is a University of California Multi-Campus Research Unit (MRU) headquartered on the Santa Cruz campus. Appendix 1 contains an overview organizational chart for the Unit and several pertaining to major sub-units. The Director is supported by an executive assistant, an assistant director for administrative affairs, a faculty-level associate director charged with oversight of Lick

Observatory, a faculty-level associate director for instrumentation, and a chief engineer/project manager who supervises the technical laboratories. The MRU operates its own administrative and business services, including contracts and grants administration, human resources and payroll, purchasing, and facilities administration.

The UCO Director reports to the Dean of the UCSC Division of Physical and Biological Science on matters related to academic personnel (hiring, advancement) and space—as if the Observatory were a Department and the Director a Department Chair. On MRU budgetary issues the Director reports to UC's Vice President for Research in the Office of the President. The arrangements between UC's Office of the President, UCO and UCSC regarding budgetary matters are described in an MOU that was last updated in 2003.

Five committees with systemwide representation provide input to the UCO Director, establish policy, and facilitate communication between the campuses on astronomy-related issues. The principal vehicles by which UCO leadership keeps updated on the needs and interests of the wide UC A&A community are the UCO Advisory Committee, the Keck Science Steering Committee and the TMT Science Advisory Committee. These are described in more detail below.

UCO Advisory Committee: The UCO Advisory Committee (UCOAC) advises the Director on the full range of policy and operations of UCO, including short-term and long-term planning. The UCOAC also evaluates new UC astronomy initiatives. Each campus has at least one representative on the committee. For the past several years, UCLA and UCB have had two members on the UCOAC. Also in attendance at every meeting is the UCO Director, the UCO Associate Director for Lick Observatory, the UCO Assistant Director for Business and Operations, the Lick Observatory superintendent and the UC co-Chairs of the Keck SSC and TMT SAC. The committee meets quarterly for a full day and holds telecons as necessary when issues arise between meetings that require discussion or decisions. Present membership is given in Appendix 2. In addition to providing advice to the Director, the UCOAC is the representative body charged with keeping astronomers throughout the system apprised of UCO activities and with gathering systemwide input on issues of importance to UCO-managed facilities. This is a very important and very effective committee.

Time Assignment Committees: The second type of advisory committee is the Time Assignment Committee (TAC). There are two TACs. One is charged with reviewing proposals for time on the Lick 3-m, and the second is charged to evaluate proposals for the Keck telescopes. The Keck TAC is particularly important. This committee is composed of astronomers from the UC community and is split into a Galactic TAC and an Extragalactic TAC. Each TAC meets twice each year, and proposals are graded by each TAC member prior to the face-to-face meeting. Proposals are discussed at the meeting and there is an opportunity for each TAC member to change their assessment after discussion. Telescope time is awarded on the basis of the Committee's final rankings of the proposals. This is an extremely important and challenging activity, as more time is requested than is available and the overall level of the proposals is very high. The TAC term for any one member is three years. Members of the TACs for semester 2011B are listed in Appendix 3.

Science Advisory Committees: Two more committees are important for UC astronomy. The Science Steering Committee (SSC) for Keck Observatory is the group that establishes the Keck Observatory Scientific Strategic Plan and advises Keck Observatory on all matters that affect its science capability, including selecting instruments and instrument upgrades. A similar committee for the Thirty-Meter Telescope is called the Science Advisory Committee (SAC). These committees have

members from other partners in each project. UC members are responsible for representing the UC interests. The UCO Director is an ex-officio member of both committees.

4.3 UCO 80/20 faculty

There are fourteen faculty positions at Santa Cruz associated with UCO. These are "80/20" positions with 80% of the appointment in the Observatory and 20% in the UCSC Department of Astronomy & Astrophysics. UCO faculty fill the positions of UCO Director, Associate Director for Lick Observatory, Associate Director for Instrumentation, co-Chair of the Keck Science Steering Committee and co-Chair of the Thirty-Meter Telescope (TMT) Science Advisory Committee.

Activities associated with the 20% appointment: The 20% appointment in the Department of Astronomy & Astrophysics carries with it teaching responsibilities of one quarter-long class per year and associated Department committee duties. This fraction of the costs (salary and benefits) of the positions is part of the UCSC budget. UCO faculty members effectively have annual course relief to allow them to carry out Observatory duties associated with the 80% of the appointment. Ian McLean at UCLA partially serves in the same type of position, using UCO funds for summer salary. Faculty from any campus are eligible. Others who have had class buyouts or summer salary provided for them to carry out UCO activities in recent years are Gary Chanan (UCI), Andrea Ghez (UCLA), Alex Filippenko (UCB) and Betsy Barton (UCI).

Activities associated with the 80% appointment: The most visible Observatory roles are as Principal Investigators and co-PIs for instrumentation projects, and for proposals to fund new capabilities at Lick and Keck. In the last decade, Steve Vogt, Sandy Faber, Joe Miller, Mike Bolte, Connie Rockosi, Xavier Prochaska, David Koo, Claire Max, Rebecca Bernstein, Ian Mclean (UCLA) and James Larkin (UCLA) have all been PIs for TMT, Keck or Lick instruments. The importance of having practicing astronomers as instrument PIs has been demonstrated many times over. UCO faculty members are also integral to generating the external funding required to carry out these new projects. The funding source for new instrumentation at Keck and Lick is usually the NSF ATI or MRI programs. Developing concepts, project schedules and budget is a significant activity that involves the PIs, engineering and the UCO business office.

UCO faculty members also serve as the UC Chairs of two important committees, the Keck Observatory Science Steering Committee and the TMT Science Advisory Committee. These are committees with members drawn from all campuses, but the Chair positions are particularly time consuming and require regular interactions with the UCO Director. Other UCO faculty duties include telescope scheduling at Lick and Keck, serving on internal reviews of projects, advising undergraduate and graduate students, mentoring postdocs, overseeing development activities (e.g. coatings lab research), managing a systemwide archive and data pipeline development effort, and carrying out excellent research in astronomy and astrophysics. UCO faculty also serve an important role through membership on various important national committees, such as the National Academies Astronomy and Astrophysics Decadal Survey (ASTRO2010), the National Optical Astronomy Observatory's (NOAO) Oversight Committee, the National Science Foundation's Astronomy and Astrophysics Advisory Committee (AAAC) and the Association of Universities for Research in Astronomy, among others. These activities increase the visibility of UC astronomy, allowing for the steering of the national priorities for funding in astronomy, and providing a mechanism for keeping abreast of national and international astronomy trends.

UCO faculty and technical staff are a resource for other faculty members systemwide, and for faculty at Caltech and other institutions associated with the Keck Observatory who have instrumentation ideas but lack the expertise on their campuses to evaluate the concepts or develop them to the level of

proposal readiness. As a result of participating in these programs at the concept phase, we often take on major roles in delivering the final instruments. There are several recent examples:

- Concept by Professor Harland Epps for the Keck MOSFIRE optical design (PI Ian Mclean, UCLA)
- Concept by Professor Harland Epps for the Keck Cosmic Web Imager cameras (PI Chris Martin, Caltech)
- Concept by Professor Rebecca Bernstein for the Thirty-Meter Telescope Wide-Field Optical Spectrometer
- Concept by Associate Professor Rebecca Bernstein for the SASIR instrument (Co-PIs, Xavier Prochaska, UCSC and Josh Bloom, UCB)
- Concept by Associate Professor Rebecca Bernstein for the next-generation Keck precision radial velocity spectrometer (Co-PIs, Geoff Marcy, UCB and John Johnson, Caltech)
- Concept by Researcher Donald Gavel and Professor Claire Max of major components of the Next Generation Adaptive Optics System for the Keck Observatory
- Concept by Associate Professor Constance Rockosi for a DEIMOS focal plane upgrade

80% of the salary+benefits cost of each UCO faculty position is part of the UCO budget, which is funded centrally from the Office of the President (the other 20% of the funding is part of the UCSC campus budget). These 80/20 positions are fiscal-year appointments rather than academic-year appointments and can be supplemented with no more than one month of summary salary from outside grants. At a given rank, fiscal-year monthly salaries are lower than academic-year monthly salaries so the positions in terms of salary are not the equivalent of academic year + two months of summer salary, but rather are academic year + 1.4 months. Promotion and merit cases for UCO faculty are conducted by the Director and the criteria are strongly weighted toward Observatory responsibilities. This is a significant strength of the 80/20 model. The criteria for advancement recognize instrumentation design, bringing instrument projects to completion, and other duties that serve the greater UC astronomy community.

There is no direct UCO support of research for UCO 80/20 faculty. For traditional programs of astronomical research, UCO faculty compete for funding from the NSF, NASA, STScI and other sources, as is the case for UC faculty on all campuses.

It is crucial that UCO faculty have regular Senate positions in the UC faculty system. The Observatories could not carry out its mission without a group of high-profile faculty members who carry out forefront research, can interact at the right level in Washington D.C. and with UC top-level administration in Oakland, can be plugged into national-level activities, and can operate from a position of mutual respect with our partners (e.g. Caltech). Tenure-track faculty positions are the only way to attract and retain this level of people. With this model for the UCO 80/20 positions, UCO faculty are required to have a fraction of their time available for forefront research programs and to pursue external funding for those programs, graduate student training and postdoc mentoring, and to carry out the usual service to the astronomical community and public. The fraction of time devoted directly to UCO service is equivalent to teaching one class per year and 1.4 months of summer salary. In practice, the service to UCO for any one specific faculty member can vary markedly over time, and it is the three or five year average that should be considered in any assessment. The reality of any organization is that different members play different roles to build the whole. Diversity in skills and interests is one of the strengths of the UCO faculty in support of the UCO mission. Averaged over

time and over the entire 80/20 faculty, this model has worked extremely well. Our program has produced leadership for a large number of very successful instruments and other technical programs and is seen as a research powerhouse.

Appendix 4 contains the current list of UCO 80/20 faculty.

4.4 Laboratories

In the Santa Cruz labs, we have mechanical engineers, electronics design and fabrications specialists, and a full machine shop that enable us to design, fabricate, deliver and commission entire instruments for the Lick or Keck Observatories and also to manage projects of this magnitude (~$10M for a Keck Observatory instrument).

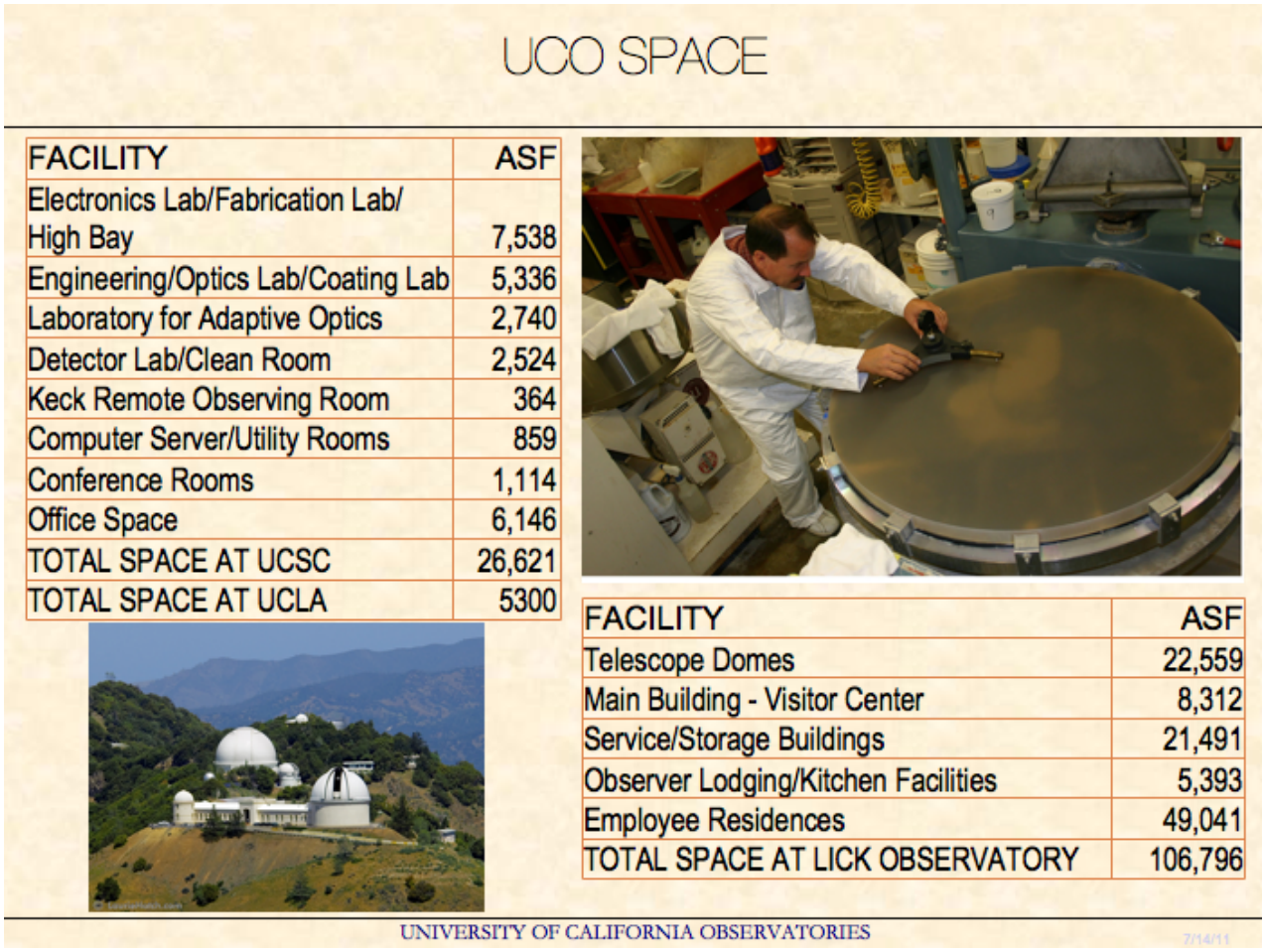


Figure 1: MRU space distribution

A key component of our success is a core staff that is hard-funded with state dollars. There are significant advantages to this model, compared to predominantly soft-funded, project-specific efforts. For each large project that is undertaken with soft funding there is a staffing ramp-up period at the beginning of the project and often a premature staff exodus when the end of the project is in sight. UCO's model has allowed us to (1) efficiently carry out major instrumentation projects for Lick, Keck and TMT with a group of engineers and technicians with deep experience in astronomical

instrumentation, (2) maintain a base of expertise to support those instruments after delivery, in some cases for years, and, (3) have the expertise to generate very capable and competitive proposals for new undertakings at the Observatories. Between major instrument projects, we employ the same personnel for maintaining and continuously upgrading the capabilities at Lick and Keck observatories.

4.4.1 Engineering and Project Management

Our engineering staff is comprised of six mechanical engineers and one electrical engineer. Two of these primarily work as project managers. The expertise of the group is broad, but we have particular strength in space-frame structures, cryogenic systems and FEA.

4.4.2 Detectors

We maintain a laboratory in which we can fully characterize and optimize CCD detectors and deploy full detector systems to Lick Observatory and Keck Observatory. The guiders at Lick Observatory were also developed and are maintained by UC Santa Cruz staff. The CCD lab is current staffed with three detector specialists. The lab includes a clean room, highly accurate facility for measuring QE of detectors, vacuum cleaning oven and flatness measuring facility.

4.4.3 Electronics

Our electronics lab has two staff members and have provided design, fabrication and installation of electrical and electrical mechanical systems for Mt Hamilton and Keck instruments.

4.4.4 Optics fabrication and handling

Our lead optical fabrication specialist has produced many of the lenses in use in the Keck Observatory spectrometer cameras and the two secondary mirrors for the Keck telescopes. In addition to the tradition lens and mirror fabrication tools we have a single-axis profilometer that can handle up to 2m in diameter.

4.4.5 Instrument and component fabrication

We have a fully-equipped mechanical shop with three CNC mills and specialized equipment for welding difficult material. We current have four fabrication specialists.

4.4.6 Software

The scientific programming group develops all software for Keck instruments from motor control through user interface guis. This groups is also responsible for all observatory software at Lick Observatory and maintains other software systems such as the Keck proposal and TAC support software. This group is currently staffed with five individuals.

4.4.7 Laboratory for Adaptive Optics

In 2004, the Gordon and Betty Moore Foundation made a $9.3M, five-year grant to UCO to outfit a laboratory for carrying out research in advanced adaptive optics (AO) systems. The Laboratory for Adaptive Optics (LAO) is the result of this grant. The LAO facility is 2,740 square feet of high-quality lab space equipped with four large optical benches and a large class 100 cleanroom. The instrumentation includes a Phase-Shifting Diffraction Interferometer (1nm rms absolute wavefront accuracy), Zygo Fizeau Interferometer and a polarization Quadrature Interferometer.

The initial LAO programs were intended to demonstrate the high-contrast imaging concepts required for direct imaging of extra-solar planets and to build a laboratory bench for simulating multi-conjugate AO on a 30-meter telescope. In the four years since the LAO was established, we have taken on additional projects:

- Villages: the first MEMS-based AO system working in open-loop mode
- GPI concept demonstration
- GPI assembly, end-to-end testing
- Partnership with BMM on MEMS development (including 2011 ATI award)
- Pyramid wavefront sensing
- MCAO testbed for Keck Next-Generation AO and TMT AO concepts

The LAO funding from the G&B Moore Foundation was explicitly for five years and to build a lab. At the completion of the Moore Foundation grant the LAO was incorporated into UCO. Current staffing is a Director and three specialists/research scientists.

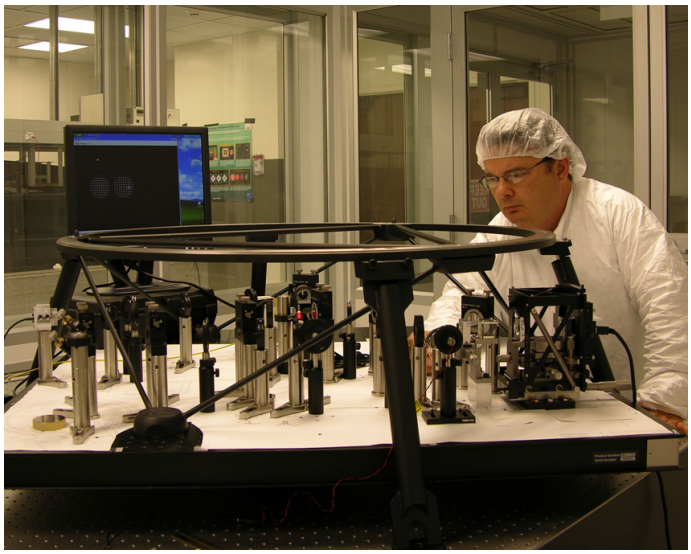


Figure 2: Villages MEMS-based AO system in the LAO cleanroom

4.4.8 Astronomical Coatings Laboratory (ACL)

We have for many years had an interest and expertise in high-performance reflection coatings. Four years ago this expanded into anti-reflection (AR) coatings, as we were unable to get suitable commercial coatings for the prisms in the Keck 1 atmospheric dispersion compensator. We embarked on a program to apply hardened solgel coatings to the prisms and succeeded in producing what may be the best broad-band optical AR coatings in use in astronomy.

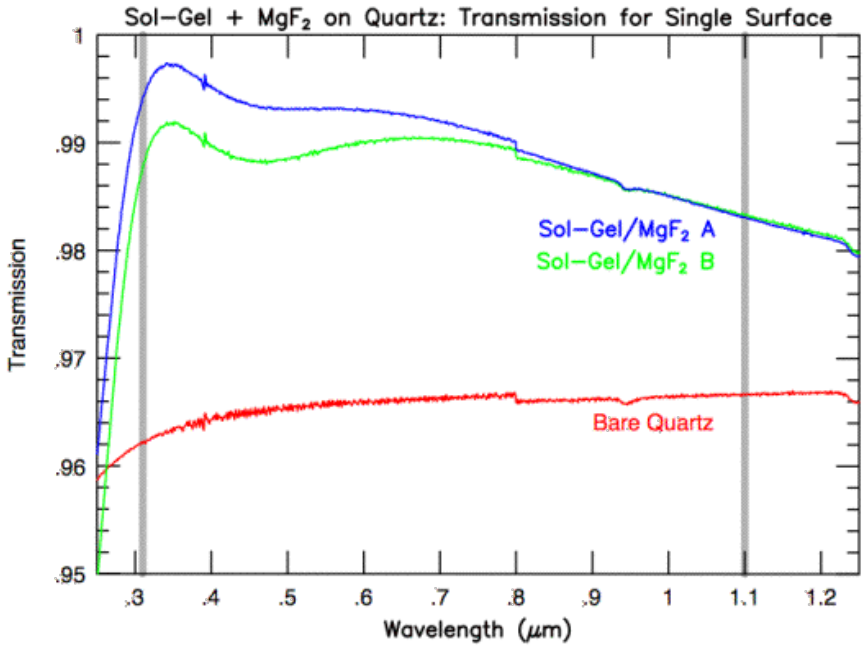


Figure 3: UCO Astronomical Coatings Lab Solgel Transmission Curve

Starting in 2005, we revived our work in high-performance reflective coatings, specifically UV-response enhanced, protected silver coatings. Such coatings were developed and applied for the HIRES collimator mirrors in the 1990s and there has long been an interest in using enhanced, protected silver coatings for the Keck 2 telescope. Improved throughput at wavelengths longer than 380nm and an increase in the time between segment re-coatings are the goals. These goals are even more important for the Thirty-Meter Telescope, and with a work package from that project, we initiated a series of tests of new processes and "recipes" for UV-enhanced protected silver-based coatings. This work has been very productive and we have recently been awarded a $500k NSF Advanced Technology and Instrumentation grant in 2010 to upgrade our equipment and carry out an enhanced development effort.

The immediate goals for the ACL are to improve the coating and hardening process for AR coatings based on Solgel to the point that applying these coatings is routine and completely predictable and to carry out a matrix of enhanced, protected silver coatings with the goal of meeting the specifications of the TMT.

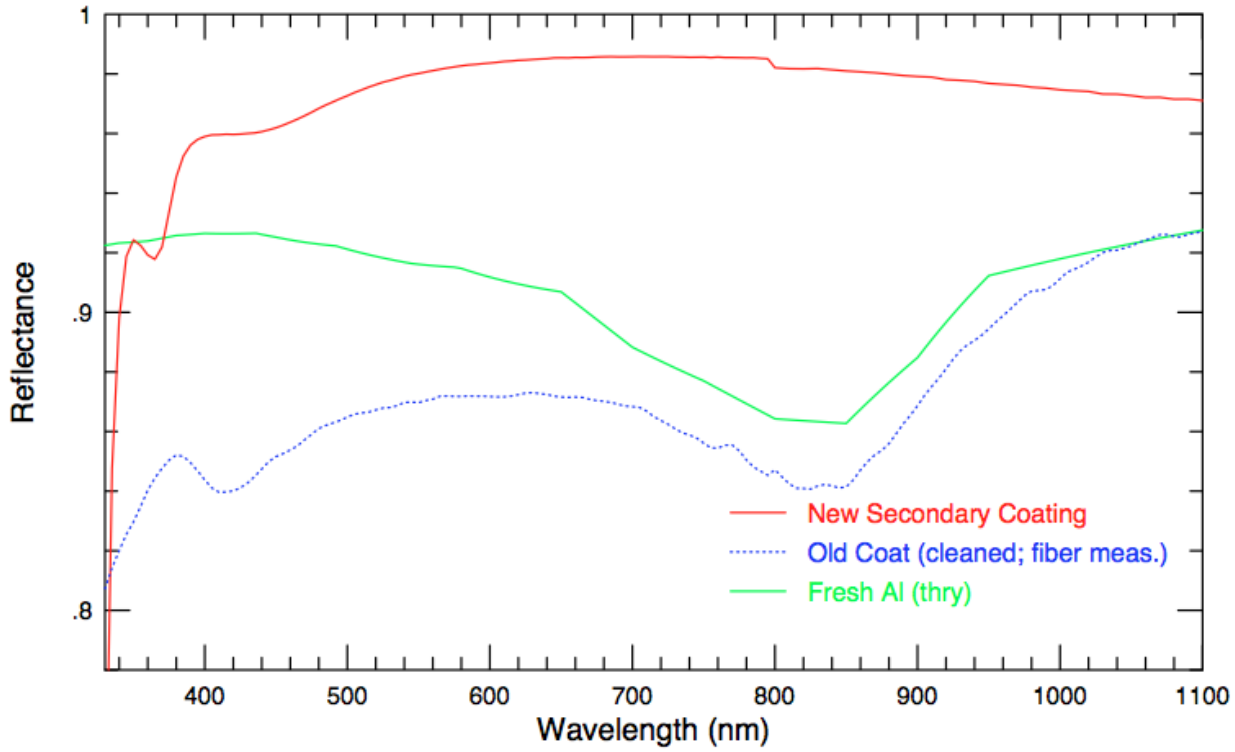


Figure 4: Example enhanced silver coating from UCO ACL

4.5 UCLA Infrared Lab

In 1989, Eric Becklin and Ian McLean joined the faculty at UCLA and started a laboratory for infrared instrumentation. They were later joined by James Larkin and most recently by Michael Fitzgerald. This has been a great success with the delivery of two major instruments to the Keck Observatory, the NIRSPEC infrared spectrometer in 1999 and OSIRIS, an integral field imager and spectrometer that works behind AO in 2005. McLean is the PI on a third major instrument being delivered to Keck in 2011 and built in collaboration with Caltech and UC Santa Cruz: the multi-slit imager and spectrometer MOSFIRE. The IR Lab has also designed, built and delivered the Gemini multi-band imager to Lick Observatory, other imaging IR cameras for Keck (K-cam and SHARC), FLITECAM for the SOFIA airborne observatory, the spectrometer for the Gemini Planet Imager and the detector electronics for the Keck NIRC2 imager. Expertise in instrumentation for the near-IR has not been duplicated in Santa Cruz and the two centers are very complementary.

The TMT first-light instrument IRIS, an IFU spectrometer and imager designed to be used behind AO has James Larkin as PI and will be led out of the UCLA IR Lab.

The UCLA IR Lab is affiliated with UCO and the IR Lab Director Ian McLean is an Associate UCO Director receiving a stipend and one or two months of summer salary annually. Between $300k and $400k is directed to UCLA in support of the IR Lab annually. In addition to support for the Director position, these funds provide some base support for the lab staff to help maintain continuity between major projects.

http://irlab.astro.ucla.edu/

4.6 Administrative & Business Services

UCO is a complex organization with a broad range of activities combining traditional university research activities with some that are unique to the Observatories and unique to the host campus UCSC. Examples include design and fabrication of custom instruments, advanced technology development, Observatory operations and management of our UC-wide organization. We also support other university business activities such as contract and grant management, recharge and retail operations. We carry out these activities within the framework of University policy, but also need to be expert in compliance with state and federal policy and regulations as well as maintain good working relations with the many central campus support units.

We have been fortunate to have good longevity with our staff. Because of their experience, they are able to resolve unusual problems or issues as they arise (e.g., shipping and receiving sensitive instrumentation weighing tens of thousands of pounds to remote locations such as Keck Observatory (14,000 ft) and Lick Observatory (4,200 ft) or coordinating a wireless microwave link from Lick to Santa Clara to upgrade the bandwidth. Although in some cases it may appear as if some of the UCO business services are redundant with central campus services (e.g., purchasing and staff human resources), it has proven very cost and time efficient to directly manage the delivery of these activities.

For example, for UCO's technical labs, developing specialized expertise within our business office has proven to be a very effective approach . In particular, contracts for work packages with TMT and Keck, developing budgets for instrumentation proposals, HR activities for non-standard positions, and purchasing of unusual, often sole-source, equipment and services is relatively routine for our experienced staff, but would prove complicated one-time endeavors for University central offices. Additionally, we are able to exert control and influence over the timing of our transactions rather than competing with UCSC activities and priorities. This has been extremely useful for us to meet external contract deadlines or to handle emergency repairs at the Observatory.

4.6.1 Contracts and Grants

UCO staff performs pre- and post- administration for all contracts (e.g. Keck and TMT projects) and federal grants (instrumentation and science). Total funds flowing through UCO over the last five years have averaged ~$11M/year.

4.6.2 Human Resources and Payroll

The UCO Director serves as the Principal Officer with direct authority for staff. UCO staff manages the full range of HR activities from recruitment, performance management, merit and award programs to termination. Further we operate as an autonomous unit working on issues related to Affirmative Action, Labor Relations, Workers Compensation and managing the permanent Staffing List. HR challenges that arise include recruiting specialized technical positions and managing remote and residential Observatory employees.

UCO HR is responsible for the payroll of 190 employees within the unit (93 academic employees (including Astronomers, Specialists, Researchers, postdoctoral researchers, and graduate student researchers) 62 career and 20 part-time staff (covering non-represented, technical unit, clerical unit, service unit, and skilled crafts unit employees) and 15 students. UCO manages 2 title codes that are unique within the system (Astronomers and Telescope Technicians) and several others that are unique at UCSC (SR Development Engineers, Laser Spotters, Water Plant Operator).

1.1 Financial Analysis

UCO financial staff manage a complex group of accounts across two campus locations. In addition to state-funded operational accounts, we support the analysis and billing operations of three recharge activities: technical facilities labor, computing services, and Lick Observatory lodging, as well as one retail business—the Lick Gift Shop. We also maintain gift and endowment accounts in addition to supporting all instrumentation proposals and managing non-federal contracts. Staff perform analysis and prepare reports on a monthly and ad hoc basis.

1.2 Administration

UCO staff provide administrative support to the Director, Associate and Assistant Directors, Technical Facilities Manager, faculty and researchers. This includes website, mail, copy, conference and event planning support as well as publications coordination. Having a high public profile results in numerous requests for information and non-UC access to the Lick Observatory. Staff also support Donor Relations and events, as well as our Summer Visitor Programs hosting about 2,400 people annually.

4.6.3 Purchasing and Business services

UCO has two buyers with $50,000 authority—the only buyers outside of the campus Purchasing Department. In addition to managing the procurement of all goods and services for the unit, the staff is responsible for travel reimbursements, cash handling, Lick lodging reservations and billing, equipment management and insurance.

4.6.4 Facilities Administration

UCO staff directly manage all aspects of operating 26,621 square feet of laboratories, technical shops, and office space distributed among six buildings at UCSC. This total excludes office space for Astronomers, postdocs and graduate students, all of which fall under the Department of Astronomy and Astrophysics.

UCO is also responsible for the operations and long-range planning of Lick Observatory at Mount Hamilton, 14 miles east of San Jose. Located at 4,200 ft on California Highway 130, this campus comprises 52,362 square feet of domes and science support buildings and 54,434 square feet of observer dorms and employee residences.

In addition to the maintenance and operations functions at Lick, UCO staff become involved in areas that most university departments take for granted. Examples of this include operating remote lodging facilities for observers, a water plant under California regulations and receiving training in CERT (Community Emergency Response Team). Lick Observatory lost its dedicated UCSC police officer in December 2010 because of campus budget cuts. Currently, we have a short-term contract with the Santa Clara County Sheriff's Office for 30 hours coverage during the high risk days (Fri-Sun) and season (through mid-September). We are also in the process of planning and implementing security equipment, such as gates, to protect property and employees. First response fire-fighting units come from the San Jose City Fire Department during the non-fire season and from the CalFire Station at Smith Creek during the fire season. The former takes one hour to arrive, the latter about 25 minutes. This is especially a concern as there are no buildings with fire sprinklers on the Lick campus. Medical response via helicopter or ambulance is about 30-45 minutes. Local Lick staff are frequently involved in assisting with non-UC emergencies because of their remote location on a public highway. In 2005, Lick Observatory received and managed a $500K FEMA grant for extensive vegetation fuels management. All of these activities require support from both Lick and UCSC based staff.

4.7 UCO Major completed laboratory projects

KECK OBSERVATORY	LICK OBSERVATORY
Keck secondary mirrors (1990)	KAST Spectrometer
HIRES spectrometer (1993)	Hamilton Spectrometer
LRIS camera optics	Laser Guide Star AO
ESI spectrometer (2000)	APF Spectrometer
DEIMOS spectrometer (2001)	Prime Focus Camera
HIRES focal plane upgrade	Villages MEMS AO system
Keck 1 Atmospheric Disp Compensator	Gemini multi-channel imager (UCLA)
LRIS-R focal plane upgrade (2010)	
MOSFIRE (UCLA/Caltech/UCSC)	
NIRSPEC near-IR spectrometer (UCLA)	
OSIRIS near-IR IFU AO spectrometer (UCLA)	

4.8 Current and potential UCO lab projects

Lick Observatory

- Shane AO (funded by $2M NSF MRI)
- APF commissioning/robotic operations
- Gemini II/Triplespec MRI program with junior faculty/UCLA IR Lab

Keck Observatory

- KCWI cameras, coatings (funded by TSIP)
- SHREK
- NGAO
- DEIMOS focal plane upgrade
- Infrastructure upgrades
- OSIRIS grating upgrade
- NIRSPEC, NIRC2 and OSIRIS detector upgrades (UCLA IR)

TMT

- MOBIE (UCSC lead institution)
- IRIS (UCLA lead institution)
- Design/prototyping efforts (M2/M3 support, coatings, global error budgets, etc.)

4.9 Lick Observatory facility work

Maintaining and upgrading the Lick Observatory instruments, telescopes and physical facilities is carried out by a combination of the on-site staff and the UCO lab personnel. These activities are wide ranging: troubleshooting software, electronics and mechanical problems, installing new detectors in instruments, the repairing and upgrading of unique mechanical systems, and bringing on new facilities (e.g. the APF) are examples. The challenges for maintaining the physical infrastructure at Lick Observatory are significant. Many of the mechanical systems were built decades ago and in some cases upgrades and repairs require fabricating custom parts. This is possible because of our personnel skill set and facilities in Santa Cruz.

5. UCO BUDGET

5.1 UCO Funding Background

When UCO was formed in 1988 after a system-wide review, it was agreed that the original Lick Observatory budget should be increased by $2.7M/year in recognition of the increased responsibilities of the new unit. The goal of the steady-state budget of the new MRU was to provide adequate stable funding for the formation of a core of high-quality individuals—astronomers, engineers, technicians, fabrication specialists, purchasing/contracts/HR/compliance experts—to provide support for the UC astronomy effort at the Lick and Keck Observatories. Creation of the Keck Observatory added to the UC astronomical research facilities the equivalent of nearly one full Keck Telescope for its own use, and the increase of the original Lick budget was designed to ensure that UC realized the scientific return it expected from the addition of this powerful facility.

The budget ramp-up negotiated in 1988 was partially implemented in fits and starts as UC and the state of California went through economic rich and lean times. After the last UCO review in 2000, the recommendation was to implement the full increase to properly leverage the opportunities for UC provided by the Keck Observatory, but again fiscally challenging times resulting in budget reductions in FY03 and FY04. In FY04 the UCO budget was essentially the same as when the MRU was formed in 1988.

In 2006, as part of the negotiations to appoint the new UCO Director, $1M was agreed to be added to the annual UCO budget. In FY09 and FY10, part of this increase was reversed with permanent budget cuts totaling $550K. Additional one-time cuts of ~$625k were also taken during this time period.

In the following sections, we including income and expenditures from our base state support, grants or contracts related to instrumentation or infrastructure projects and gifts. Excluded are grants to UCO faculty for carrying out research. There is additional budget information in the sections on Lick Observatory operating expenses and on Keck Observatory unreimbursed contributions.

5.2 Current UCO budget

5.2.1 Operating Budget

The UCO budget has funding from multiple sources. The major state-funded component comes directly from the UCOP Office of Research. Lick Observatory is inventoried as part of the UCSC campus and a second, smaller, component of state funding for operations and maintenance at Lick Observatory is a part of the UCSC campus budget. Additional sources of income arrive through projects funded by the Keck Observatory, TMT, and federal agencies. These are always tied to specific projects. There are also endowments, some established more than 100 years ago, that generate

annual funds, again in most cases to be spent on specific programs. Ongoing fund-raising activities generate one-time funds for UCO projects. The detailed income breakdown for the last three years is shown in Figure 5.

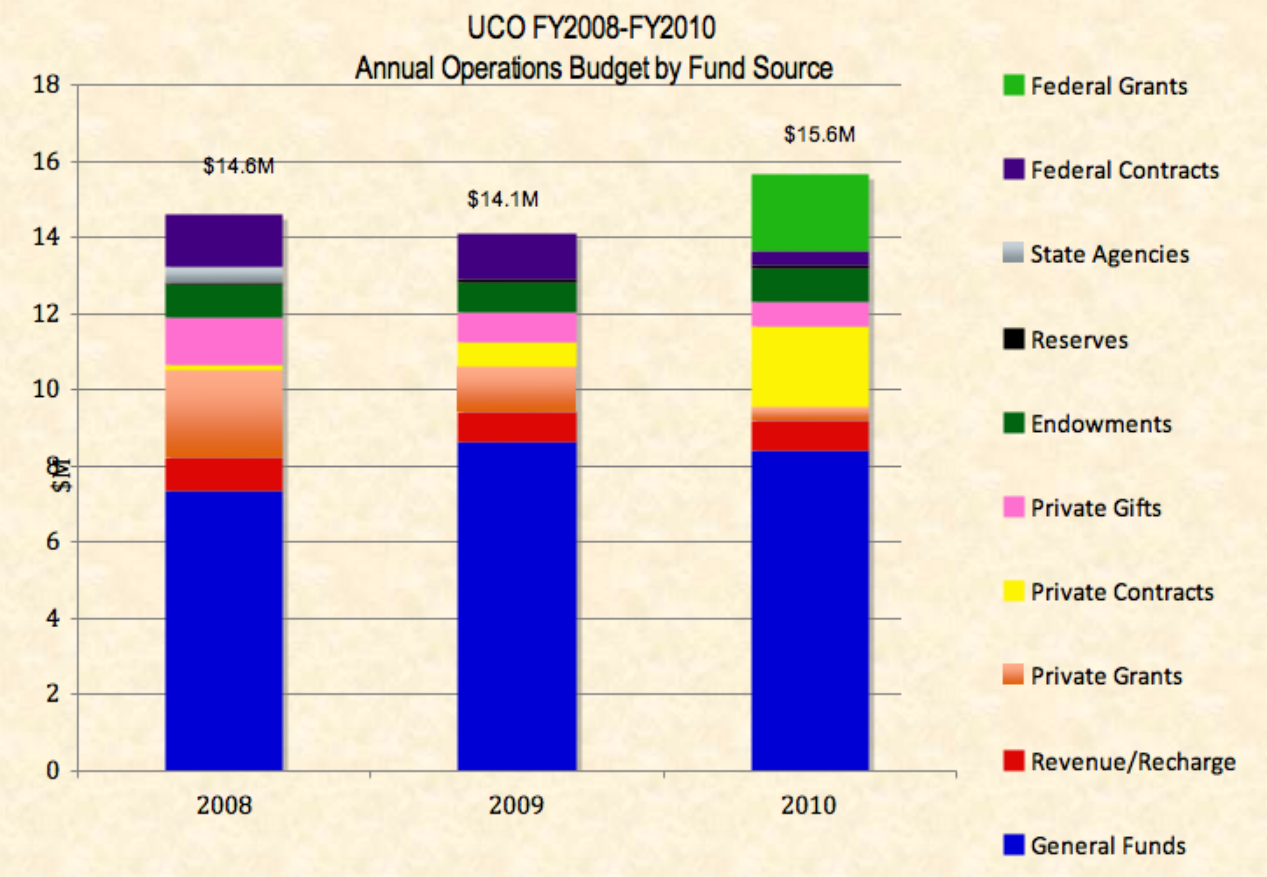


Figure 5: UCO Budget over past three years by fund source. "Private" gifts, grants and contracts refer to non-state, non-federal organizations such as the Moore Foundation.

5.2.2 Expenditures

The three principal areas for expenditures are (1) operation of Lick Observatory, (2) lab personnel and (3) UCO faculty salaries. Figures 6 shows the annual expenditures by funding source over the past three years and Figure 7 shows the detailed expenditures by expense category show expenditures for each of the past three years.

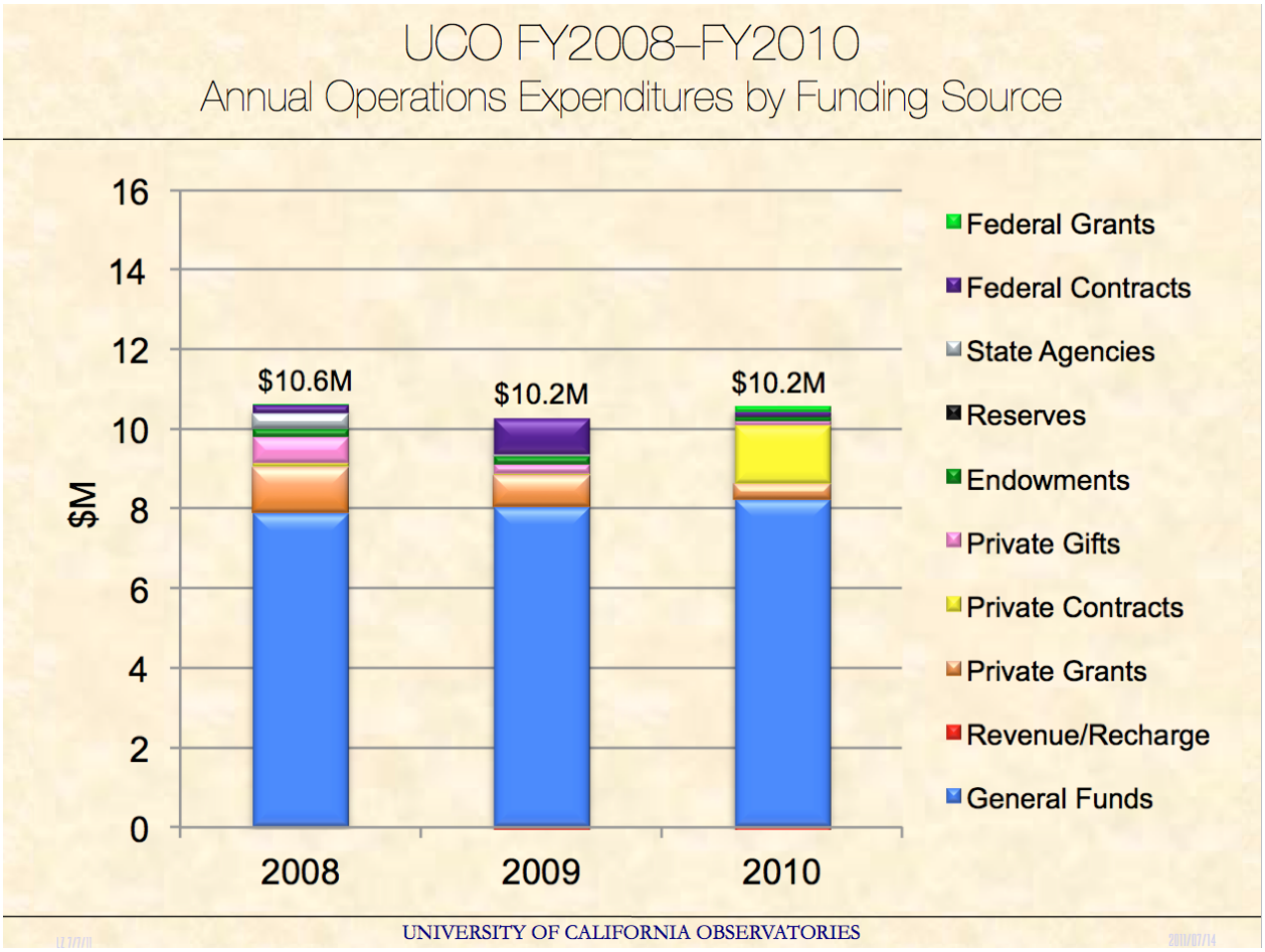

UCO FY2008–FY2010
Annual Operations Expenditures by Funding Source
$M
16
14
12
10
8
6
4
2
0
$10.6M
$10.2M
$10.2M
2008
2009
2010
Federal Grants
Federal Contracts
State Agencies
Reserves
Endowments
Private Gifts
Private Contracts
Private Grants
Revenue/Recharge
General Funds
UNIVERSITY OF CALIFORNIA OBSERVATORIES

Figure 6:

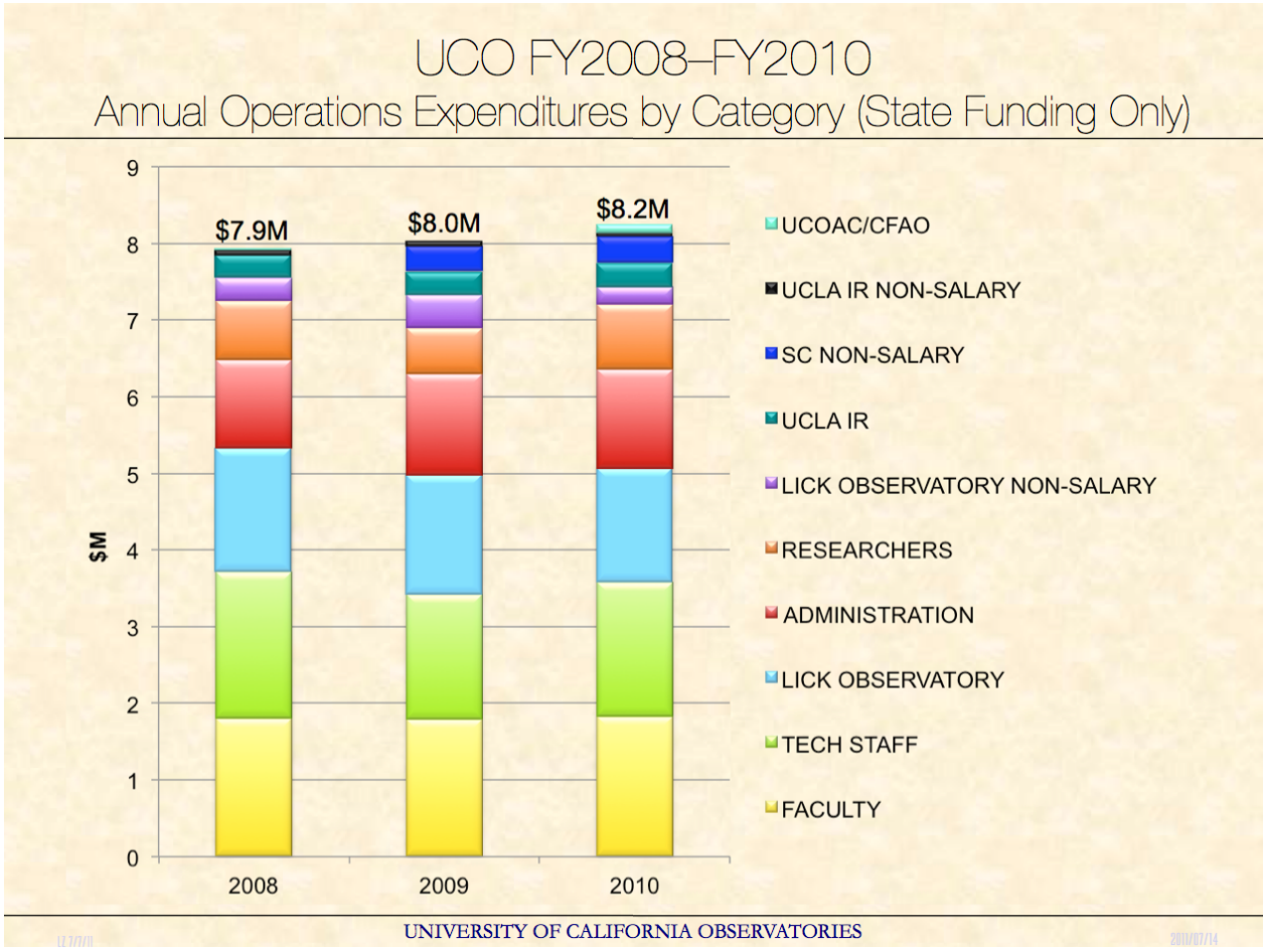


Figure 7: Annual UCO expenditures by category, state funding sources only.

5.2.3 Revenues outside of state funds

Many of the projects we undertake have associated funding. These are mostly work packages from the TMT project and Keck Observatory and federally funded grants and contracts. The totals vary from year to year, but average ~$1M/year. Figure 8 shows the distribution of revenue-producing programs over the last three years.

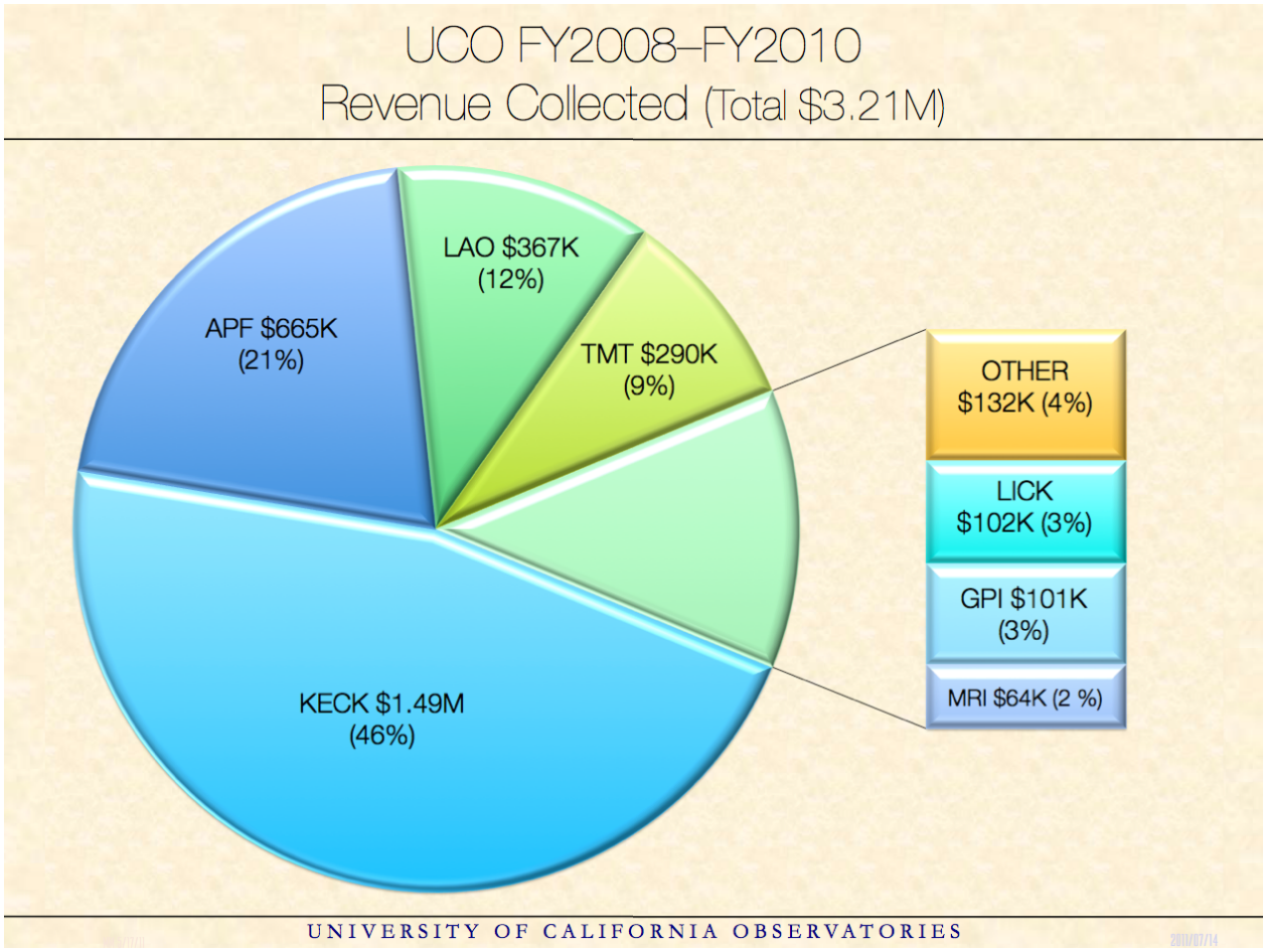


Figure 8: Non-state revenue FY08-10. Three-year totals for technical labor recharge.

6. LICK OBSERVATORY

6.1 Overview and Recent History

Lick Observatory has been owned and operated by the University of California since 1888. The telescopes there ranked among the largest and most capable in the world though the 1980s. The instrumentation at Lick Observatory has always been built in the labs in Santa Cruz, UCLA and, for a few more recent instruments, UC Berkeley. Lick Observatory instrument and facility upgrades and maintenance are performed by a small on-site staff and by the staff of the Santa Cruz labs.

The inventory of telescopes and instruments available at Mt Hamilton is given in Appendix 5. The primary research telescope is the Shane 3-m telescope, which is scheduled 363 nights per year and has a full instrument complement covering the atmospheric cutoff at 320nm to 2.2μ and spectral resolution ranging from broad-band imaging to R=60000 spectroscopy (1.2" width slit).

Several high-profile programs have been carried out using the 3m in the last decade. The 3m telescope and Hamilton echelle spectrometer provided the data for the initial Marcy/Vogt/Butler/Fischer extrasolar planet program and continue to be used in that role today. The 3m + Kast low-resolution spectrometer, used in combination with the Katzman Automatic Imaging Telescope, a robotic telescope designed to discover supernovae, also housed at Lick Observatory, has provided the data

that have significantly improved understanding of supernovae in the nearby universe. This has been a crucial aspect of refining SNIa as standard candles with sufficient precision to lead to the discovery of the acceleration of the expansion of the universe. A third example of a far-reaching program from the last decade is the development, in partnership with LLNL, of the 3-m laser-guide-star Adaptive Optics system. This was the first LGSAO system put into regular use for astronomy research and was the prototype for the very successful system that was built at the W.M. Keck Observatory.

Starting in 2005, we undertook an effort to make the 1-m and 3-m telescopes accessible via remote observing stations at each of the UC campuses with astronomy programs. This has proven to be a very useful capability and has led to a dramatic increase in demand on the telescopes for science and, in the case of the 1-m telescope, for use as part of graduate and advanced undergraduate classes. In the following section the supporting data are shown. We have also spent significant UCO resources in the last five years to upgrade aging systems and infrastructure at Lick Observatory. During the peak of the Keck instrument-building phase, there was a lull in some activities at Lick Observatory because the Santa Cruz labs were completely occupied. In the last five years, staff from the Santa Cruz labs have been involved in a number of upgrade and renewal efforts. We have used the proposal demand for instruments and trouble tickets for lost time to establish the priorities for the upgrade work.

The recent programs include new guiders, an updated telescope control system, new detectors for the most-used spectrometers, updated motor-controller systems, improvements to the AO bench, remote control for slit-room mechanisms and an optics maintenance program.

In 2008 a system-wide committee to evaluate the future of Lick Observatory was convened. The committee had several meetings over the next year. The report of the Lick Observatory Strategic Planning Committee is available here at this website:

http://www.ucolick.org/lospc/index.html

6.2 Role of Lick Observatory in 2011

By 2011 standards, Lick Observatory telescopes are no longer world leading in aperture, and the Mt Hamilton site is increasingly compromised at some wavelengths by the lights of the San Jose. Nevertheless, Lick Observatory continues to be an important facility for UC astronomy on a number of fronts. The primary roles of Lick Observatory in 2011 are:

- Forefront research not requiring the aperture of Keck
- Keck-supporting observations (e.g., brighter objects, calibrating objects, identifying Keck targets)
- As a test bed for developing new instrumentation and technologies (e.g., adaptive optics, laser guide stars, CCD detectors, telescope control software, specialized observational techniques)
- Projects that require long-term, regular observations (e.g., searching for planets around other stars, supernovae studies, AGN monitoring)
- Graduate student training in A&A research and instrumentation
- Undergraduate training in A&A research and instrumentation
- Public Outreach and Private Fundraising

6.3 New Facilities at Lick Observatory

In 1997, the first new telescope to be commissioned at Lick Observatory since 1959 was the Katzman Automated Imaging Telescope (KAIT). It was funded by the Katzman family, NSF, internal UCO funds and other donations, with Alex Filippenko (UCB) as the PI. From the beginning, it was planned as a robotic telescope to be used for discovering nearby supernovae. It has been very successful, discovering ~850 nearby supernovae since its completion. Paired with the 3-m telescope plus Kast spectrometer, the KAIT data have been the basis for a very productive program to better understand and characterize supernovae of all types, in particular SN1a. The impact of KAIT has been remarkable given the modest size (0.8m) of the instrument. This demonstrates the value of a single-purpose, dedicated instrument.

In 2011, we will complete commissioning of a second robotic facility, this time dedicated to radial velocity searches of extra-solar planets. The Automated Planet Finder is a 2.4-m telescope with an echelle spectrometer mounted on one of the Nasmyth platforms. The spectrometer was designed by Steve Vogt (UCSC) and is optimized for throughput, stability and radial velocity measurement precision. The telescope and dome were built under contract by two companies, EOS and EOST. The spectrometer was designed and built in the UCO labs. The project was funded by the Navy, NASA, private gifts and UCO funds. It was delayed because of problems with the dome and telescope, but at the end of 2010 these items were accepted after extensive testing by UCO staff. In April 2011 the spectrometer was successfully installed in the dome.

Geoff Marcy (UCB) and Steve Vogt (UCSC) will have primary use for this telescope with a fraction of the time made available to the general UC community.

6.4 Lick Observatory Use by Campus

Faculty, research staff, postdocs and graduate students from all ten UC campuses and the associated labs are eligible to apply for time at Lick Observatory. Starting approximately five years ago the efforts were completed to enable remote use of the Nickel 1-m and Shane 3-m telescopes from any of the eight campuses with astronomy programs. The Nickel 1-m is now used primarily via the remote option and the 3-m ~40% of the nights. Figure 9 shows the use of the 3m telescope by campus over the past five years.

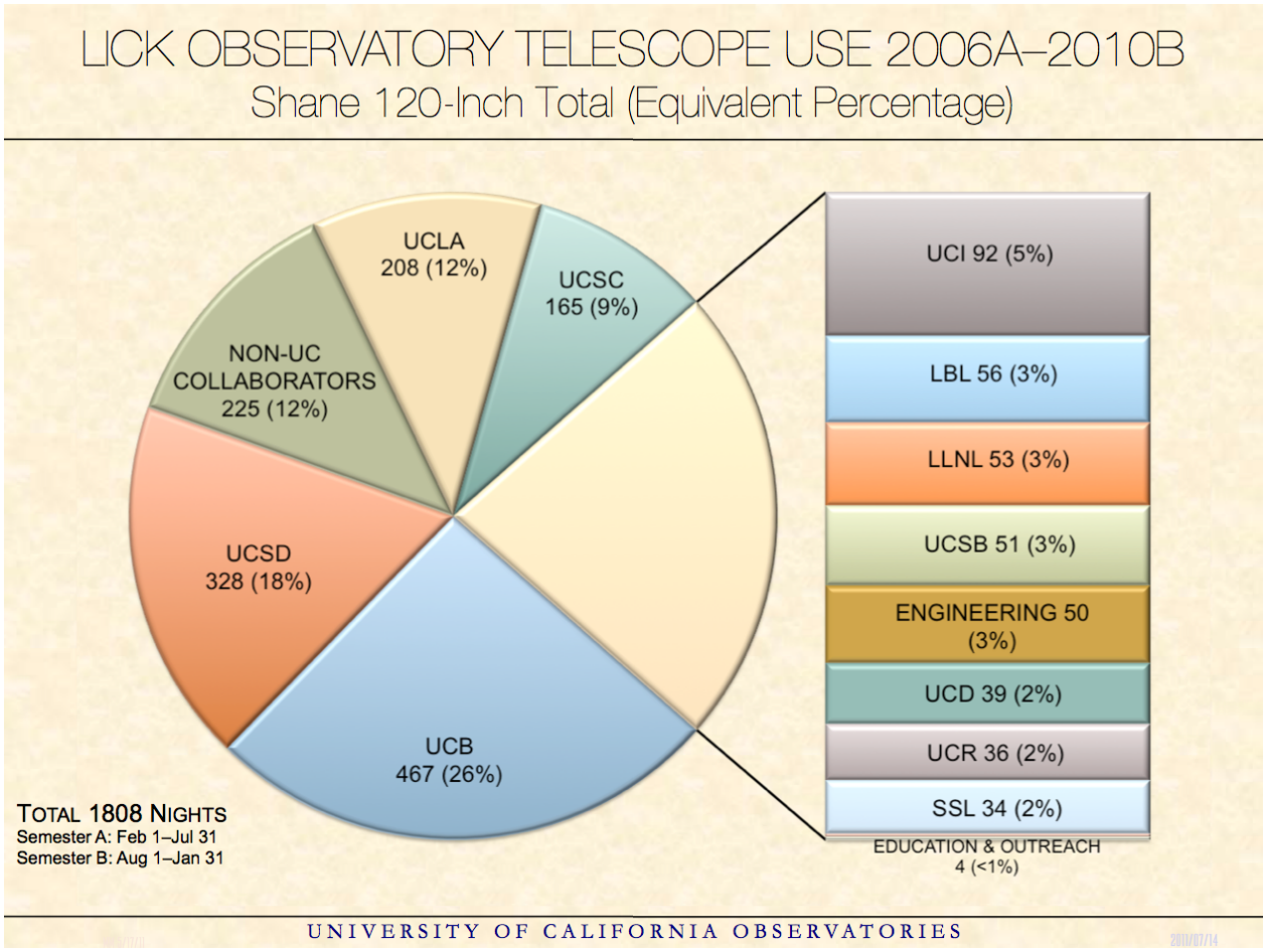


Figure 9: Use of the Shane 3-m telescope by campus.

6.5 Lick Observatory Programs: Science

There is a wide range of short-term programs carried out using the Lick Observatory telescopes. A few of the larger programs will be highlighted here. One significant advantage of having full control over the facility is that we have the ability to carry out long-term (in some cases lasting many years) programs or particularly large programs that require many nights in a shorter time period. Below are listed a few of the high-profile on-going programs.

Extra-solar planets: Starting in 1995, one of the most successful of the groups searching for extra-solar planets was led by Geoff Marcy using the Hamilton spectrometer at the 3-m telescope. Steve Vogt designed and, in the Santa Cruz labs, built the spectrometer and was a member of the team. This program continues, using the 3-m and CAT telescopes to feed the Hamilton Spectrometer. Starting in 2010 we have major programs (>30 nights/semester) underway and planned for, as part of Kepler mission follow up. In the first, all Kepler stars with candidate planet systems are being observed to identify grazing eclipsing binary stars, and to determine Teff, log(g) and [Fe/H] for those stars hosting planets. The second is to carry out abundance studies of the giants in the Kepler field for which excellent stellar seismology data are available. There are a number of goals for this latter program but one of the most interesting is to establish for the first time a precise age-metallicity relation for the Galactic disk and thick disk.

Nearby Supernovae:

Over the years 1998–2010, the 0.76-m Katzman Automatic Imaging Telescope (KAIT) project, led by Professor Alex Filippenko in close collaboration with Research Astronomer Weidong Li (both of UC Berkeley), conducted the world's most successful search for nearby supernovae. Discovering more than 800 of them during the Lick Observatory Supernova Search, it was responsible for about half of all relatively young, bright supernovae discovered during that time interval. Undergraduate and graduate students were heavily involved in this work. The discoveries were immediately announced to the astronomical community, providing a steady supply of objects to study by other supernova researchers. In conjunction with the imaging discovery work from KAIT, the Filippenko team has utilized the 3-m Kast spectrometer for follow-up spectroscopic observations and the KAIT and Lick 1-m Nickel Telescope to produced detailed multi-band light curves.

There are many interesting results based on these observations and approaching 200 journal papers. Among the highlights with major implications for broad areas of A&A research are the most reliable supernova rates ever determined as a function of galaxy morphology and luminosity, and the refinement of the Hubble diagram for nearby Type Ia supernovae, helping secure the low-redshift anchor for studies of the accelerating expansion of the Universe and dark energy

Other results these have lead to are to (a) identify and quantify the properties of new subclasses of core-collapse supernovae resulting from massive stars with partially or highly stripped envelopes; (b) provide a link between long-duration gamma-ray bursts and some of the most highly stripped core-collapse supernovae; (c) establish new subclasses of supernovae characterized by ejecta interacting with circumstellar gas to varying degrees, and draw connections between these subclass and different types of very massive, evolved stars; (d) reveal new types of supernovae that may result from unusual or partial explosions of white dwarfs; (e) observationally determine the probable progenitor stars of some specific supernovae; (f) reveal through spectropolarimetry that many supernova explosions are quite aspherical, and that the degree of asphericity among core-collapse supernovae increases with increasing pre-explosion envelope stripping of the progenitor; and (g) show that even relatively "normal" Type Ia supernovae (the thermonuclear runaways of white dwarfs near the Chandrasekhar mass limit) exhibit considerable heterogeneity in their spectral and photometric properties. This last point was crucial to the development of methods to calibrate Type Ia supernovae for accurate cosmological distance determinations.

Reverberation mapping of AGN: The Lick AGN Monitoring Project (LAMP) is a large program of reverberation mapping of active galactic nuclei (AGNs), centered on a 64-night allocation at the 3-meter Shane telescope in Spring 2008, and followed by a 69-night observing program in Spring 2011. Reverberation mapping uses the time variability of broad emission lines to examine the size and structure of the broad-line region in AGNs, and results from reverberation mapping are used for fundamental calibrations of the mass scale of supermassive black holes in quasars. The LAMP team includes faculty, postdocs, and students from five UC campuses, including the research groups of Aaron Barth (Irvine), Tommaso Treu (Santa Barbara), Gabriela Canalizo (Riverside), Matthew Malkan (Los Angeles), and Alex Filippenko (Berkeley). Results from the 2008 observing campaign include new measurements of black hole masses in eight AGNs, a new calibration of the relationship between black hole mass and host galaxy velocity dispersion for active galaxies, and calibration of scaling relationships between broad-line region size and multiwavelength indicators of AGN luminosity. The most significant new result from the 2008 LAMP program was the high-quality detection of a velocity-resolved reverberation signal in the galaxy Arp 151 and other targets. The velocity-resolved reverberation response in the broad H-beta emission line provides unique and powerful constraints

on the kinematics of the broad-line emitting gas, and the observations have been interpreted using new dynamical modeling techniques that directly constrain the broad-line region geometry and black hole mass. Since 2009, the LAMP collaboration has published nine refereed papers. Analysis of the large dataset from the 2011 observing campaign is under way with very promising initial detections of velocity-resolved reverberation, and in 2011 the LAMP collaboration was awarded a $500K NSF collaborative grant to support their work.

These long campaign-style runs are arranged to allow mixing in observations for other TAC-approved programs using the same instrument and have been encouraged.

6.6 Lick Observatory Programs: Instrumentation and Test-bed Activities

Lick Observatory has a long history of innovative instrumentation starting with the early adoption of photographic plates in the 1890s. More recently, the AO system and laser guide star developed at the Lick 3m was the prototype for the AO system implemented at the Keck Observatory and the precision radial velocity techniques that allow the detection of extra-solar planets were developed at Lick Observatory then applied to Keck HIRES observations. Lick Observatory was used as the site for the "Vulcan" experiment that was a test-bed for the *Kepler* mission.

Below are listed the experiments/prototype instruments currently active at Lick Observatory.

- Villages: This is a UCSC Laboratory for Adaptive Optics AO experiment that is the first to use MEMS deformable mirrors and open loop correction. It is the basis for some of the Keck Next Generation AO concepts.
- OSETI: This is an experiment led by Frank Drake of the SETI Institute to carry out scans of the sky for powerful non-terrestrial optical lasers. The prototype system was demonstrated on the Nickel Telescope and some private funds have been obtained to build a more powerful system, probably to be housed at Lick Observatory.
- UCB POLISH experiment: This is an instrument that has achieved polarimetry measurements of one part in 10^6 for stars brighter than V=9. The goal of the experiment is the direct detection of exoplanets.
- UC Davis Spatial Hetrodyne Spectrometer: Walter Harris and Sona Hosseini at UC Davis have NASA funding to build a tunable spatial heterodyne optical spectrometer that produces up to R=100000 spectra in the optical over a large field of view.
- UCB Marchis FIRST experiment: This is a clever experiment that works behind AO at the 3-m telescope. The AO-corrected image is fed into nine single-mode fibers and recombined interferometrically to create images at the diffraction limit of the 3m with contrast 10^6.

6.7 Student training

The Lick Observatory telescopes have long been used as the training ground for observationally-oriented graduate students in the UC A&A programs. Increasingly, students in UC use primarily the Keck telescopes as the source of their data, obtaining access through their faculty advisors. Nevertheless, it remains true that a large number of graduate students use the Lick 3m and 1m telescope each semester and the numbers have been increasing as the remote-observing stations have been completed.

Unlike the case for the Keck telescopes, graduate students in UC are eligible to apply for time as PI at the Lick telescopes. There is an endowed fund, the Davidson fund, that is specifically to support independent work by UC graduate students at Lick Observatory.

Using Davidson funds, we have initiated an annual Graduate Student Workshop hosted by UCO at Lick Observatory. Incoming graduate students from around the system spend four days and three nights at Lick Observatory using the telescopes and attending workshops on observational and data reduction techniques. One goal of this program is to be an incubator for student-led programs at Lick. This has the added bonus of introducing students across the system to one another.

With the advent of remote observing capability we have seen more and more demand for the Nickel 1m for use in undergraduate A&A and physics advanced labs. Because of the monetary and time expenses associated with traveling to Lick Observatory for a class of undergraduate, this has not been a use of the telescopes in the past. It has been come routine and provides an excellent new education and training opportunity with very low overhead for the observatory as the demands of a night used for a class are no different than those of a regularly scheduled science night.

6.8 Public Outreach and Fundraising

6.8.1 Public Outreach Programs

Lick Observatory's Visitor Center is visited by more than 30,000 people per year. Open four days per week in the winter and seven days per week the rest of the year, the Center has a number of exhibits and astronomical photographs on display, and tours are given frequently on the historic 36-inch refracting telescope. Special tours are often arranged for scientific and industrial conferences in the area. There is a gift shop offering numerous books, photographs, posters, and other items. In 2010, using funding from a NASA EPO grants, there was a major facelift of the displays at Mt. Hamilton with fourteen new monitors installed with all new program materials.

During the summer, when the weather is predictably good, Lick Observatory conducts two major public outreach programs. The Summer Visitors Program is run on six Friday evenings. It features a lecture on recent astronomy research by an astronomy professor from one of the UC campuses, viewing through the 36-inch and 40-inch telescopes, and additional viewing through telescopes set up in the parking lot by local amateur astronomers. Attendance is limited to two hundred visitors per night. The tickets go on sale in April and are typically sold out within a few days.

Also during the summer, "Music of the Spheres" concerts are held in the Visitor Center on six weekends. These popular events feature Bay Area music groups, viewing through the 36-inch Great Refractor and the Nickel 1-m telescopes and an astronomy lecture given by a UC faculty member. In addition to providing a public service, we use these events as part of our stewardship and "friend raising" activities. Tickets go on sale for the summer events in April and typically sell out on the first day of availability.

We have been exploring partnerships with other Bay Area science centers. For example, we have had several live web casts from Lick Observatory to the San Francisco Exploratorium during astronomical events of particular interest to the public. In the last year we have hosted a group from the Exploratorium at Lick Observatory and made a visit to the Exploratorium to build on the existing programs.

Finally, Lick Observatory continues to be the backdrop for a number of documentaries that feature UC faculty.

6.8.2 Fundraising at Lick Observatory

Lick Observatory is visible from throughout the Bay Area. Because of the rich history, current science programs and spectacular setting, it is an excellent venue for fund-raising activities. In the last five years we have had ~$1.5M in gifts to support activities from infrastructure upgrades to support of instrument projects at the Observatory. There is a similar amount set aside in planned giving pledges.

6.9 Papers based on data obtained with Lick Observatory telescopes

There are ~35 papers per year published based on data obtained with the Lick Observatory telescopes, primarily based on 3-m data. Figure 10 shows the number of refereed journal articles per year for the last decade. Starting in 2006 a number of instrument upgrades were initiated. The full list of titles, authors and journal of the publications is available at the link here:

http://www.ucolick.org/lospc/index.html

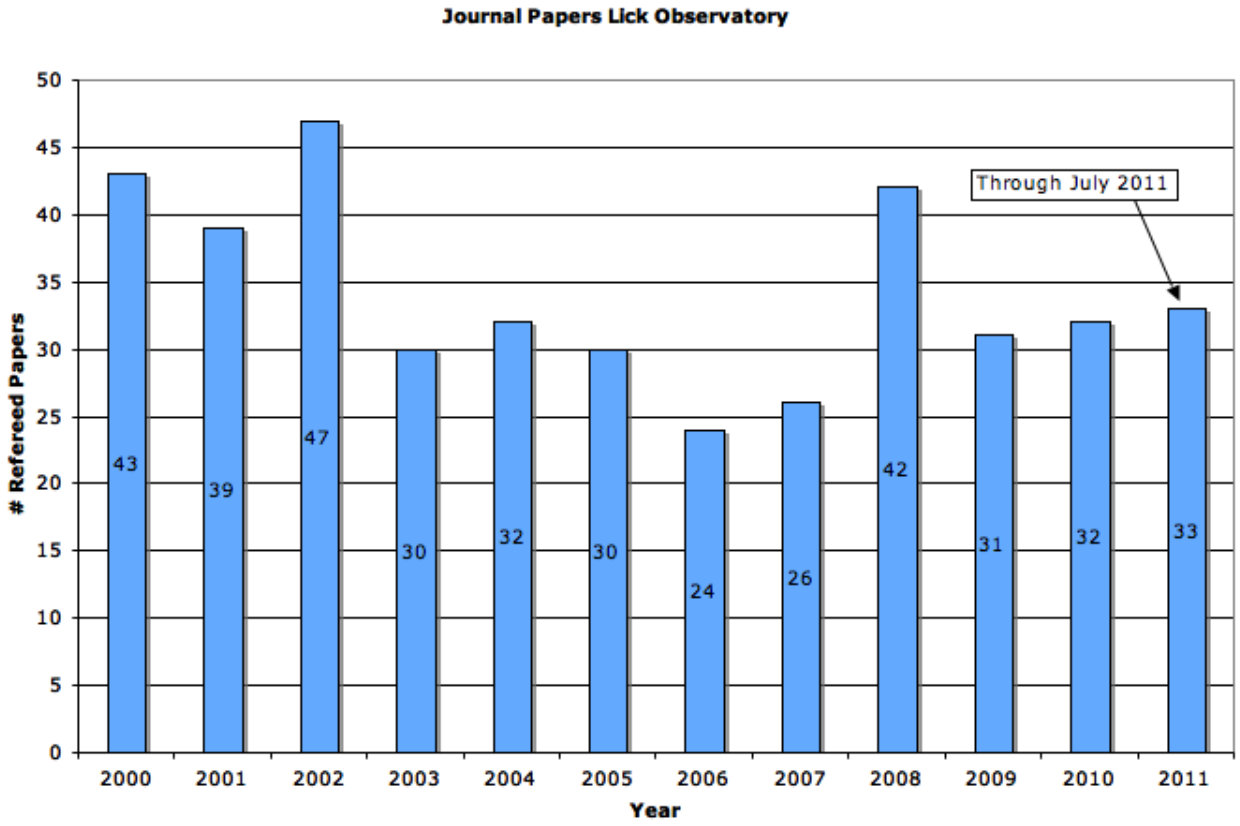


Figure 10: Papers and average citations for Lick Observatory-based journal papers

6.10 Lick Observatory Budget

There are two parts to the Lick Observatory budget. The "direct" costs are those expenses associated with on-site costs of operations and maintenance. There are additional costs in Santa Cruz associated with administration and business services and support in the labs. Figure 11 shows the past three year expenditures broken down by function. Figure 12 shows the past three-year expenditures by funding source. The fraction of the UCO budget spent at Lick Observatory has been declining. Although we have been able to keep nightly readiness for observing very high and have managed to upgrade key observing capabilities, the current level of expenditure is not sufficient to maintain the basic

infrastructure of all the buildings and we have had to concentrate on the 3m building, one set of dorms and the main building that is used for public outreach.

Ranging from 53 to 123 years old, the Observatory buildings are showing their age with failing systems and hazardous materials, all of which are costly to repair and mitigate. In the UC system, deferred maintenance funding dried up in 2004 . Staff coordinate construction and repair projects through the campus Physical Planning and Construction group. We have had to fund critical repairs (e.g., generator repairs) by reallocating maintenance salaries. In the past ten years, both the number (35% reduction) and make-up (from 4 to .5 skilled craft) of the maintenance staff has declined—from 7.95 to 5.13 FTE beginning 7/1/11.

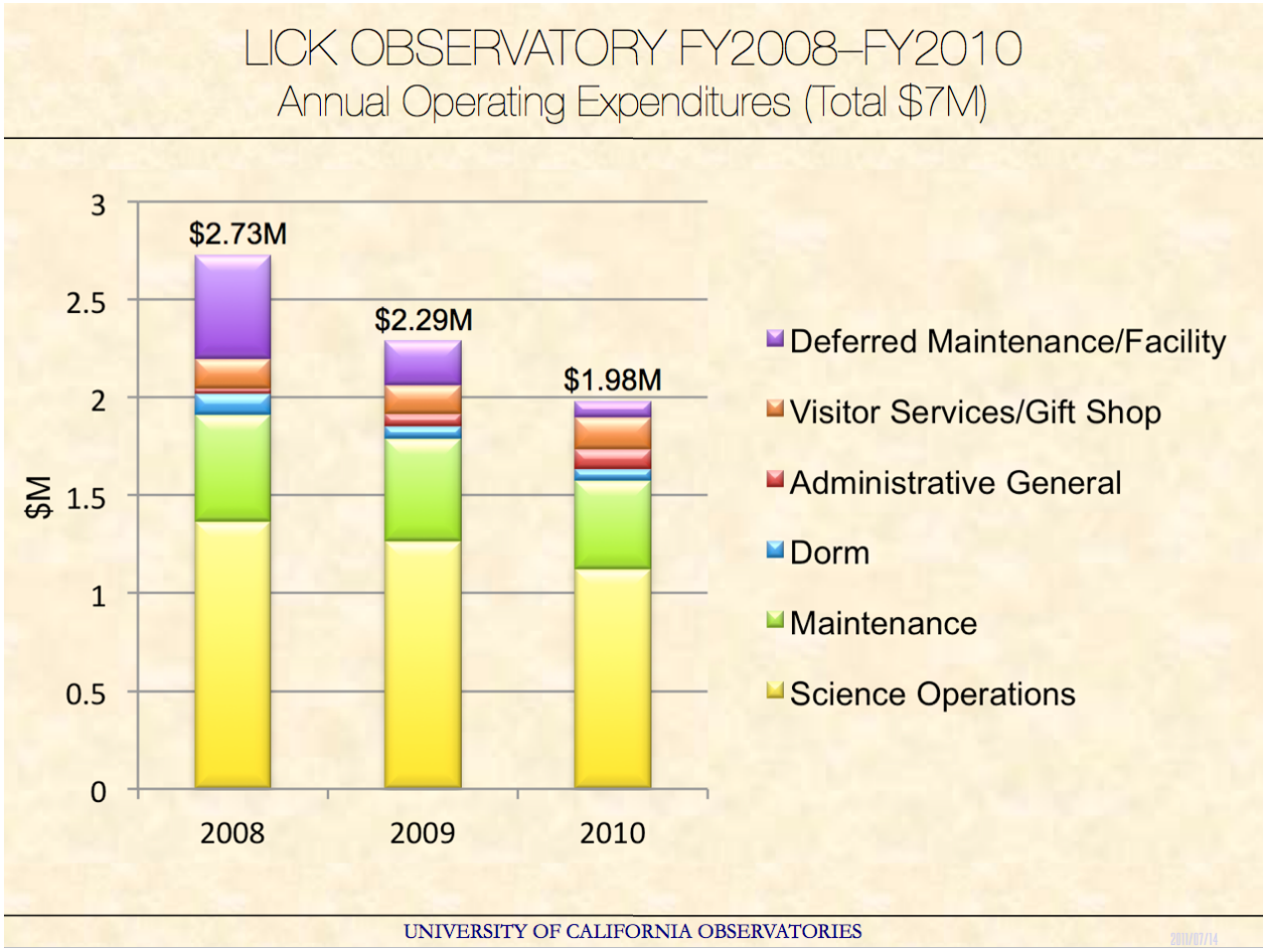


Figure 11: Lick Observatory expenditures by category

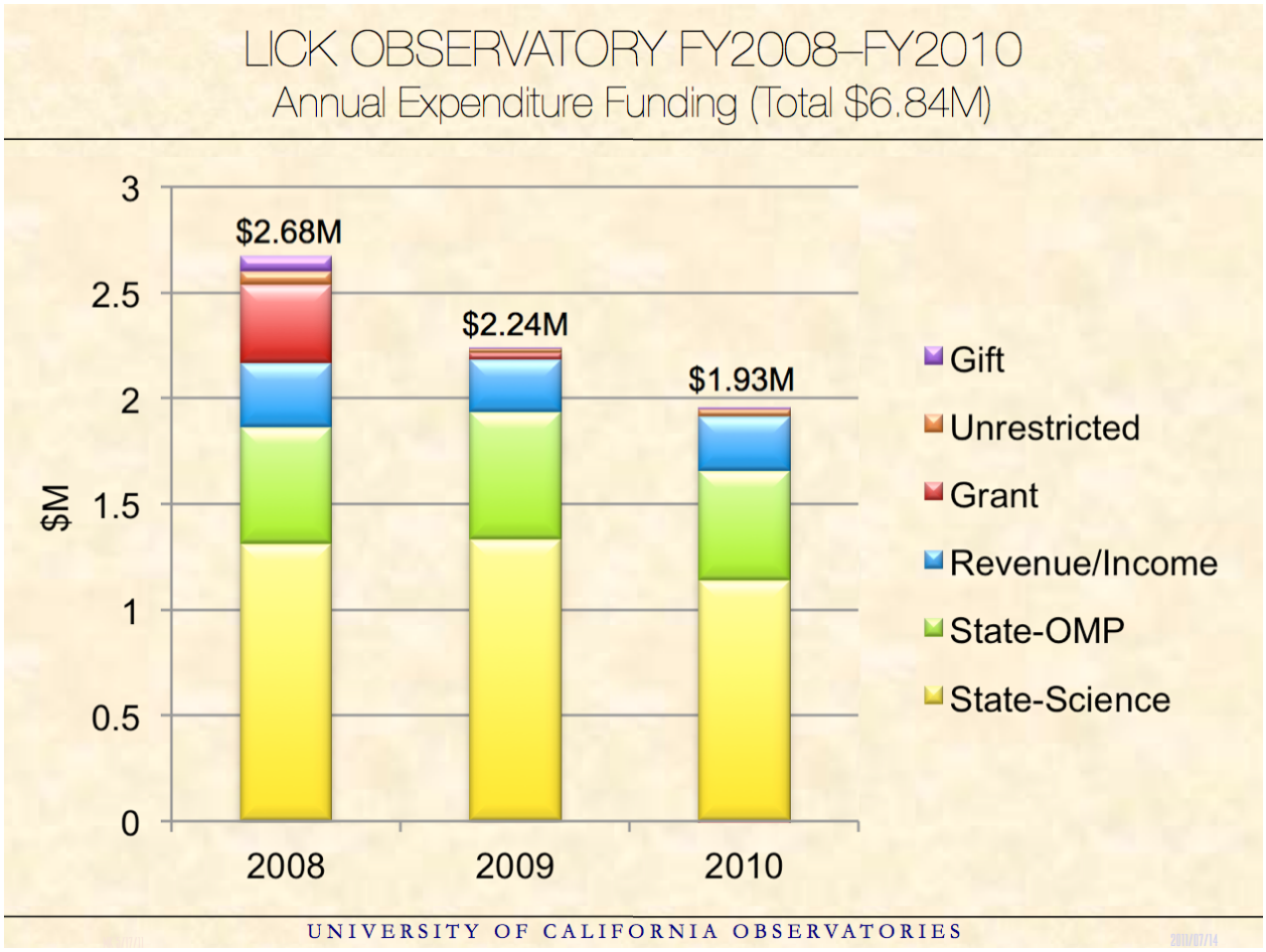


Figure 12: Lick Observatory expenditures by funding source.

7. KECK OBSERVATORY

7.1 Overview of UC's Role and the Impact of Keck

Keck Observatory, with its two 10-m telescopes, has been a spectacularly productive facility. It was the first of the generation of 8- to 10-m telescopes. By demonstrating the feasibility of moving past the 5-m primary-mirror barrier and by demonstrating the enormous additional scientific reach of a 10-m primary mirror, Keck Observatory's advent led to a burst of building activity in the late 1990s and first decade of the twenty-first century that has resulted in seven 8- to 10-m telescopes completed around the world.

The design breakthrough for the Keck primary mirror was made by UC faculty, and five of the major instruments have been designed and built at UCSC and UCLA. For the first several years of its existence, astronomers with access to the uniquely powerful Keck Observatory telescopes had an enormous advantage in the field of observational O/IR astronomy. Keck access guaranteed to faculty at UC made it possible for the relatively small astronomy programs at UC Irvine, Santa Barbara, Davis and Riverside to hire top-notch young faculty and grow into excellent astronomy programs. The resulting human resource of excellent O/IR faculty throughout the UC system is an important by-product of the investments in the Lick and Keck Observatories and must be considered when making future strategic plans.

As the 20th anniversary of first light for the Keck 1 telescope approaches, the scientific productivity of the Keck Observatory remains at the top of ground-based observatories despite the fact that the operating and new instrumentation budgets of Keck Observatory are significantly smaller than those of the main competitors, the VLT, Gemini and Subaru.

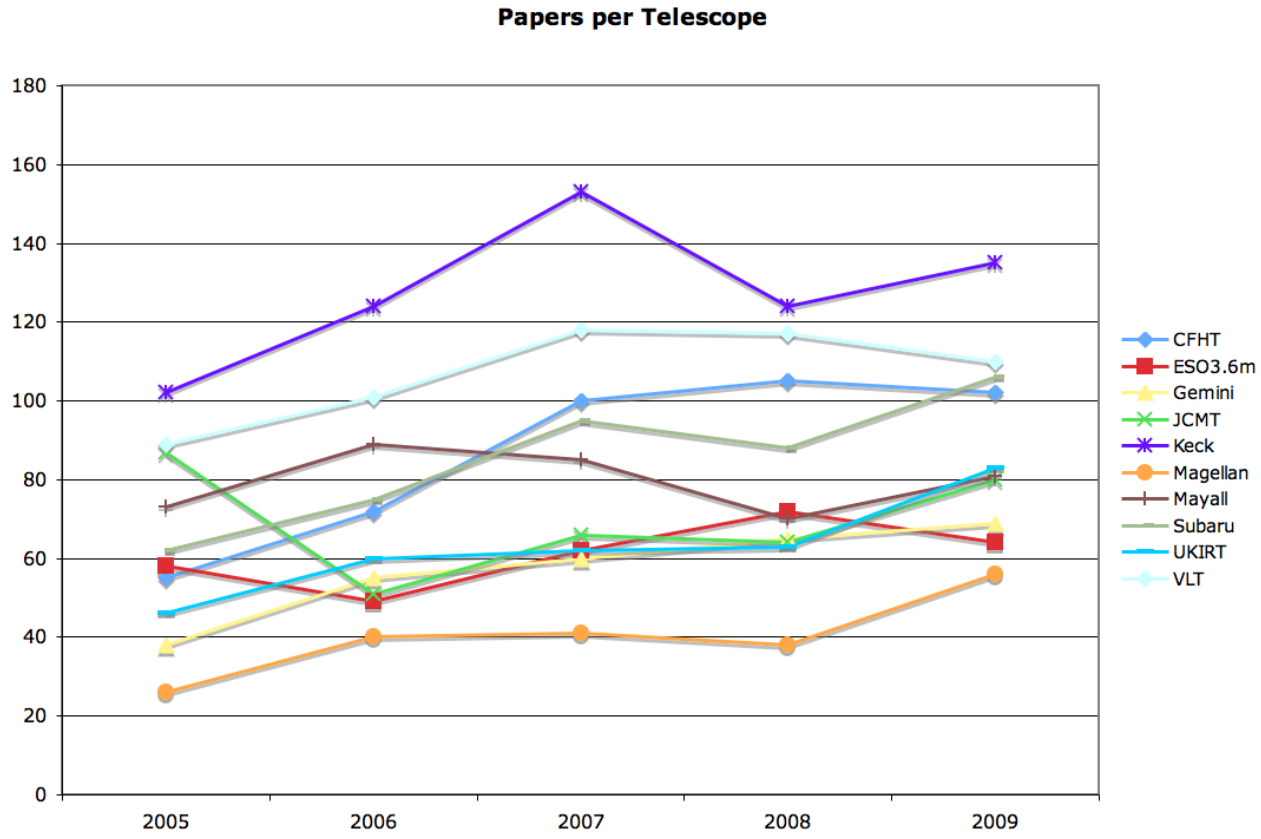


Figure 13: Papers published per telescope for several groundbased facilities. Data compiled by Dennis Crabtree CADC.

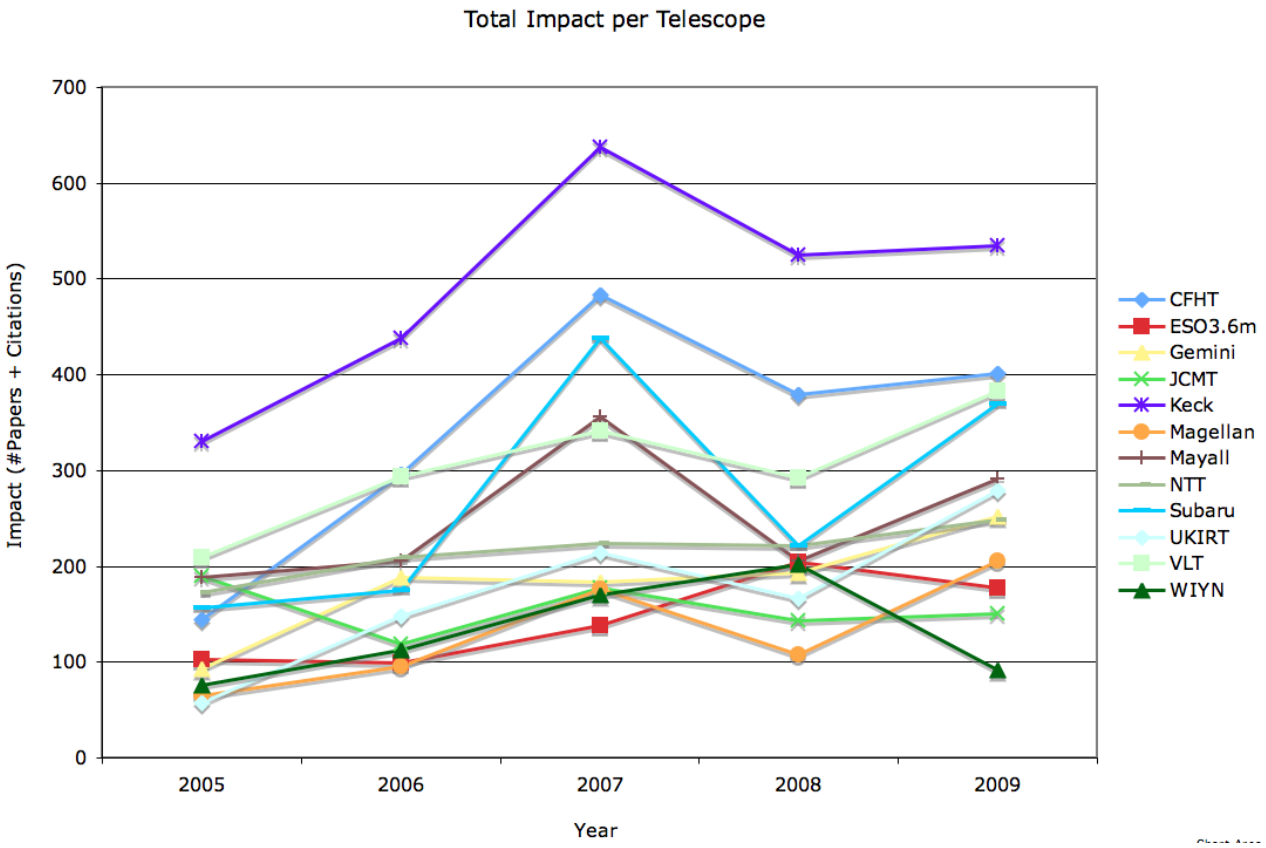


Figure 14: Publications plus normalized citations. Data: D Crabtree CADC

7.2 W.M. Keck Observatory Agreement

UC pays 5/6th ($12m in 2011) of the annual Keck operations budget for~220 10-m nights (33%) per year. The University of Hawai'i has 12.5% (10% of Keck 1, 15% of Keck 2) in exchange for access to the site, NASA has 17%, engineering has ~4%, and UC and Caltech split the remainder. The current arrangement is based on an agreement between UC and Caltech, originally executed in May 1985 and amended in May 1993, to add the second Keck telescope to the contract. The current agreement runs unmodified until March 31, 2018. At that time the UC obligation for operations will be reduced by a factor of two while retaining the same access to the telescopes. The agreement does not expire in 2018 but the nature of the commitments by UC and Caltech enters a different phase.

The 1993 agreement states:

Term of Agreement. This Agreement shall begin as of the Effective Date and shall continue until it is terminated (i) pursuant to paragraph 15 as a result of the default of the Institutions, or (ii) by mutual agreement of the Institutions. The Institutions expect that this or any successor Agreement shall continue as long as the W. M. Keck Observatory is useful for astronomical purposes."

Paragraph 15 referred to in the quote describes conditions of and penalties for default of the agreement.

The UC obligation starting April 1, 2018 is:

Post-March 31, 2018 Obligations. UC shall contribute to CARA, 50% of all W. M. Keck Observatory Net Expenses incurred by CARA after March 31, 2018. ("Net Expenses" means the total of CARA's Capital Expenses and Operating Expenses, after they are offset by all non-UC and non-Caltech contributions applied to pay for

or reimburse for such expenses.)

In summary, on March 31, 2018 the UC contributions to the Keck Observatory through operations and focal plane instrument funding will be equal to the original Caltech capital contribution with correction to constant year dollars. After that time, the UC access rights are unchanged, however the UC annual obligation will be reduced by a factor of two with Caltech obliged to provide the difference.

7.3 UCO Role at Keck Observatory

7.3.1 Leadership

Overall responsibility for the W.M. Keck Observatory is held by the California Association for Research in Astronomy (CARA) Board of Directors. This 501(c3) corporation has two members, UC and Caltech, and the Board comprises three Directors each from UC and Caltech. NASA has a non-voting liaison to the Board and the Keck Foundation has a non-voting member of the Board. The UCO Director is one of the three UC CARA Board members.

Scientific leadership for Keck Observatory is primarily through the Keck Science Steering Committee (SSC). UC and Caltech each have three voting members on the SSC, and each provides one of two SSC co-Chairs. The UCO Director is an ex-officio member of the SSC. The SSC meets quarterly, twice in California and twice in Hawai'I, and is the body that establishes science priorities for the Observatory and maintains the Observatory Strategic Plan. NASA has two representatives and the University of Hawai'i has one representative.

7.3.2 Instrumentation

There are no capabilities at the Keck Observatory for building instruments. Keck instruments are built at the UCO labs at UCSC and UCLA, and at Caltech. Although originally the Keck instruments were to be split 50–50 between UC and Caltech, the larger number of capable instrument PIs in the UC system led to a larger number of instruments being built in UC labs. In recent years, Caltech-led instruments have utilized some aspects of the UC labs (e.g. the detector for the NIRC2 camera, optics and camera systems for KCWI). The most recent major instrument for the Keck Observatory, MOSFIRE, was a joint project between Caltech, UCO-UCLA and UCO-Santa Cruz. For the UCO Keck instrument projects, materials costs and staff labor are recovered. Salaries for academic faculty and staff are not charged to Keck projects. *Design and fabrication of instruments for Keck Observatory is one of the most important activities of UCO.*

Since ~2002, instruments for Keck Observatory are funded primarily through the NSF Telescope System Instrumentation (TSIP), the NSF Major Research Instrumentation (MRI) and Advanced Technologies and Instrumentation (ATI) programs, and by private philanthropy. Developing fundable proposals with realistic schedules and budgets is another area in which UCO has proven to be increasingly important. Feasibility studies are funded at some level by WMKO, but for the last decade, UCO has regularly subsidized these activities with engineering studies and budget estimates. The total extent of unreimbursed UCO contributions to WMKO is discussed in section 7.3.4, below.

A final comment about Keck instrumentation: a number of UCO employees have been with the Observatory for many years. This provides a valuable knowledge base for troubleshooting, repair and upgrades of the Keck instrumentation suite that has often been exercised.

7.3.3 Mainland Observing Stations

Starting ~10 years ago, one of the UCO–Santa Cruz academic staff members, Bob Kibrick, initiated a program to enable fully-remote observational capabilities at Keck from observing stations at the UC campuses. These stations were originally used in "evesdrop" mode, but soon proved sufficiently reliable and responsive that they were approved for mainland-only observing. Kibrick's model has now been adopted at a number of observatories worldwide.

The hardware for remote stations has been purchased and maintained via a gift to UCO, and Kibrick maintains the software. This capability has opened up a number of new observing modes. In addition to remote observing rooms at the eight UC campuses with A&A programs, the same systems have been established at Yale, Swinburne, LBNL and Caltech.

UC use of the mainland observing system has leveled off at ~70 nights per semester in evesdrop mode with at least one member of the team physically present at Keck headquarters and ~75 nights per semester in mainland-only mode for which no member of the team is present in Hawai'i.

7.3.4 Support for Keck Instrumentation and Infrastructure

The Keck Observatory is the most important facility currently available to UC astronomers. UCO policy is such that resources used to enhance the Keck Observatory are well spent. The majority of work carried out for Keck Observatory is paid for as part of a work package, however there are some expenses routinely not charged to Keck projects, and there are circumstances in which non-reimbursed expenditures are approved.

Time of academics, faculty and academic researchers, is never charged to Keck Observatory projects. Other circumstances in which UCO carries out work for which Keck Observatory is not charged are the labor costs of some instrument repairs and the final costs of some fixed-price contracts.

Estimates for these unreimbursed expenses for the past three years are presented below. Academic researcher costs are included but not the cost of faculty time.

WMKO Cost Contribution by UCO
Fiscal Years FY08-FY10
July 1, 2007 – June 30, 2010

	Description	FY2008	FY2009	FY2010	Total
1	Project Labor (reported)	$148,572	$363,993	$73,094	$585,659
2	Academic / Researcher Labor (est.)	$327,334	$336,575	$203,263	$867,172
3	Other Unfunded Costs	$8,693	$11,157	$14,631	$34,481
4	Remote Observing facilities at UC campuses	$43,723	$50,351	$21,395	$115,469
	Total Unreimbursed WMKO support by UCO	**$528,322**	**$762,076**	**$312,383**	**$1,602,781**

Footnotes:

1 *Project Labor represents all labor reported to timecard system that was not reimbursed by WMKO purchase order or subaward.*

2 *Academic / Researcher Labor costs are est. salary+benefits based upon Stover & Kibrick reported time spent. Academic time is generally not charged to the projects.*

3 *Other unfunded includes UCO Remote Observing Operating Costs, equipment for data reduction and any other unfunded Keck related costs.*

4 *UCO funded capital equipment costs to establish remote observing sites at UC campuses*

7.4 UC Keck Time Allocation and Scheduling

UCO is responsible for managing the UC time allocation of Keck nights. In the last five years software to support on-line applications and on-line evaluation for the Time Allocation Committee (TAC) have been developed and put into operation. UCO provides the software, travel and administrative support for the TAC.

7.5 Keck Usage Statistics

The UC Keck time allocation committees evaluate proposals based on scientific merit. There is no component of entitlement in allocating time, and the evaluation process is blind to the campus of the proposer. The simple instructions to proposers can be found here:

http://www.ucolick.org/keckobs/keckguide.html

UC ladder-rank faculty, including emeriti, at all UC campuses are eligible to apply for Keck time through UCO. Research faculty in long-term appointments at the UC campuses, LBNL, SSL, LNLL, and LANL are also eligible to apply, with no more than 20% of the available time going to this category of proposer. Postdocs and graduate students are not eligible to apply for time as PI. There are no restrictions on UC faculty applying for Keck time through other US community channels: NASA time, TSIP time or Gemini exchange nights. UC policy on eligibility is available here:

http://www.ucolick.org/keckobs/keckpolicy.html

The number of individual UC PIs per semester has ranged from fifty-two to fifty-nine during the last five years, with typically 110 nights available per semester shows the oversubscription for the last six semesters. This number is likely a lower limit to the demand, as PIs have learned what is a "reasonable" request over the years.

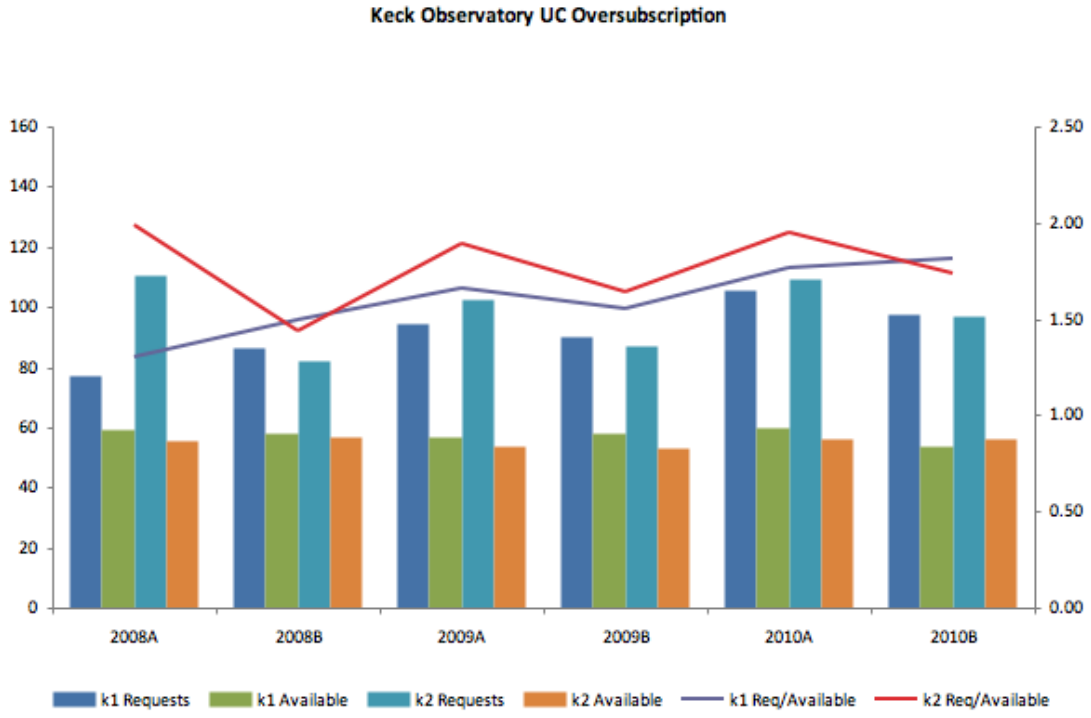


Figure 15: Oversubscription rate for UC Keck time

Two special types of requests are possible for UC time. "LMAP" is for large (in total number of nights) multi-semester programs for which the entire dataset is required in order to get the most significant results from the program. The two examples of this to date are the DEEP1/2/3 surveys and the Marcy/Vogt extra-solar planet radial velocity search which ran through semester 2008B. There is also a Target of Opportunity option which requires interrupts of up to one hour per night for TAC-approved programs. These sorts of special request categories are discussed and approved by the UCOAC. The instructions and descriptions for these time request categories can be found here:

http://www.ucolick.org/keckobs/lmap.html

http://www.ucolick.org/keckobs/too.html

The distribution of time by campus over the last eight semesters is shown in Figure 16. The UCSC totals include the majority of the time allocated for the DEEP2 and DEEP3 surveys.

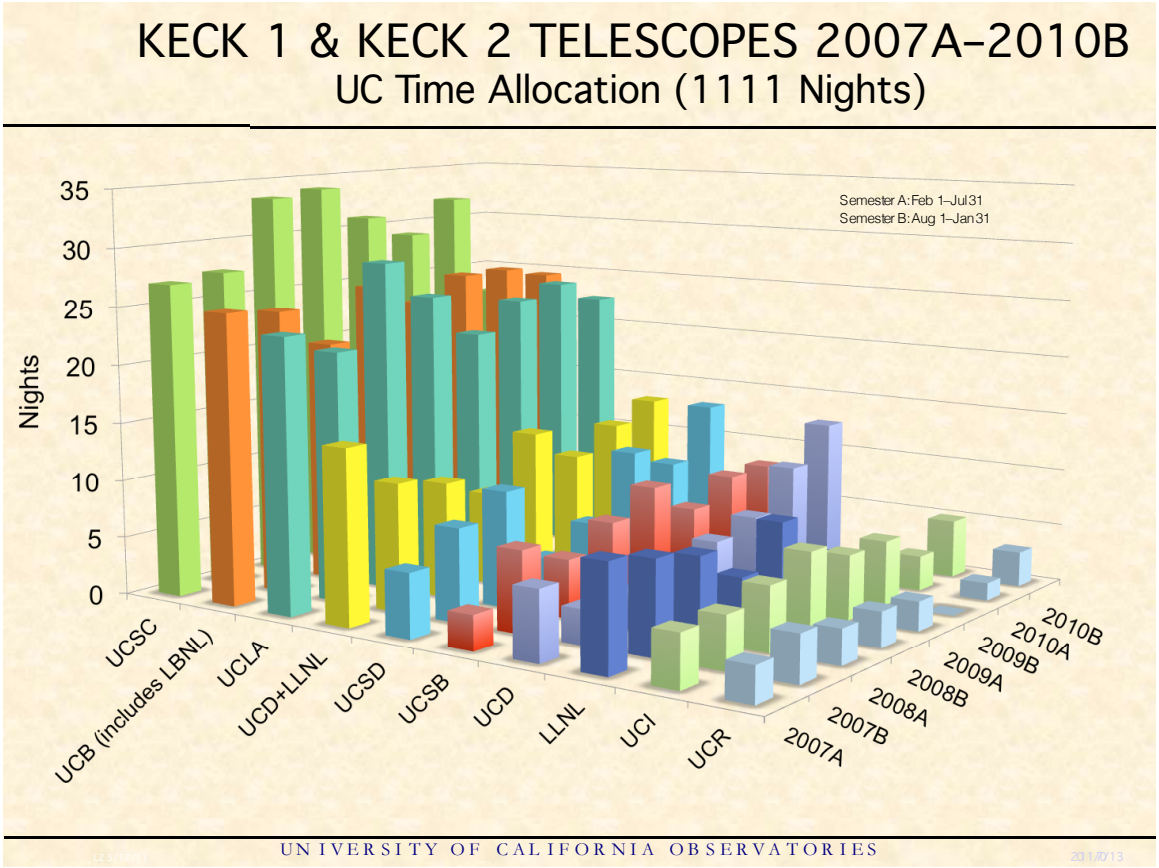


Figure 16: Distribution of UC nights on Keck by campus

Figure 17 shows the distribution of Keck nights by campus normalized by the number of PIs on each campus.

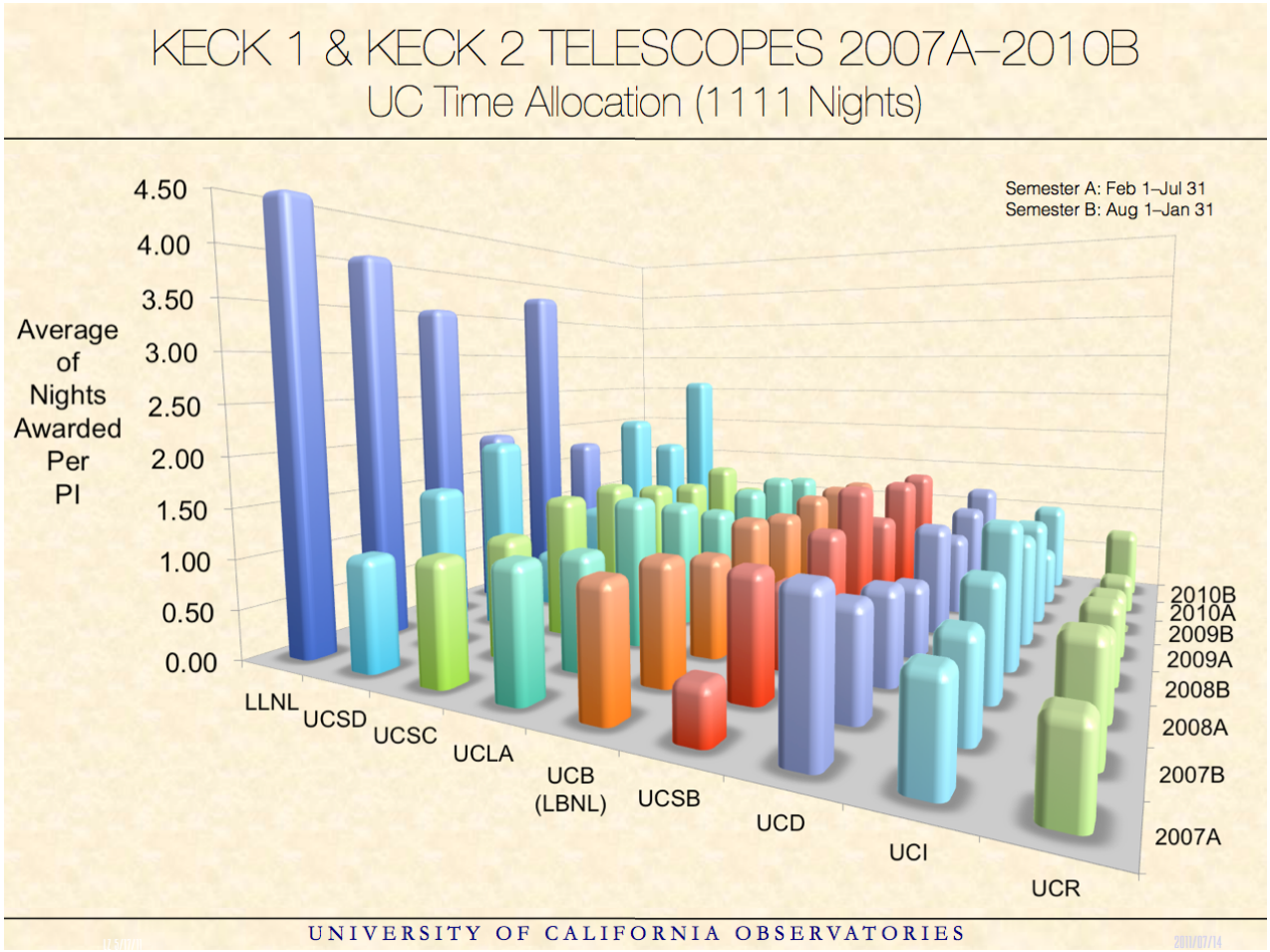


Figure 17: Distribution of nights normalized by # of PIs per campus

7.5.1 Graduate studies with the Keck Observatory

In 2010 the 100th dissertation was completed by a UC graduate student that was based on data obtained at the Keck Observatory. Although graduate students are not eligible to apply as PI for Keck time, the practice is for faculty to use their access to support student programs. The number of dissertations completed per year based on Keck data has steadily increased since 1994. In 2009 there were fourteen Keck-based dissertations.

8. THIRTY-METER TELESCOPE PROJECT

Note: most of the information about the TMT project will be presented to a subset of the committee at the Aug 11 sessions.

The Thirty-Meter Telescope (TMT) project originated in 1999 as the "CELT" project initiated by UC and Caltech. The UC/Caltech community was the natural one to lead the way to the next generation of giant telescopes. This was the community that had had the most opportunity to press the science

limits of the 10-m telescopes and the Keck telescope highly-segmented primary mirror was an easily scalable design: an feature appreciated when the Keck primary was being developed. The original plan was to replicate the Keck experience using private funding to build a next-generation facility first.

In 2004 it became the TMT with AURA and ACURA (consortium of Canadian Universities) joining and pledging $17.5M to match the UC contribution and CIT contributions to the Design Development Phase of the project. The UC and Caltech contributions were based on a gift to both universities from the Gordon and Betty Moore Foundation (GBMF). AURA, representing the US NSF, was forced to withdraw from the project at the end of 2006. An additional $7.5M was granted to UC by the Moore Foundation to ensure the completion of the Design Development Phase in the absence of AURA and the NSF as a partner.

In fall of 2007, the GBMF pledged $200M toward the construction of the TMT: $100M to UC and $100M to Caltech. This pledge carried a requirement of matching funds in the form of $50M each from UC and Caltech.

To reach the ~$1B cost of construction it was required that additional partners be found. After considering the competing projects, the GMT and E-ELT, three countries selected TMT: Japan, China and India. The consortium of partners is currently preparing linked proposals to fund the capital cost and initial 20 years of operations of the TMT.

9. EVIDENCE OF ACCOMPLISHMENT

As described in Section I, the primary mission of UCO is to support, enhance, and advance facilities and instruments for forefront research in astronomy by University of California scientists. UCO faculty are charged with supporting this goal and conducting their own research. In the following sections we separately discuss the systemwide research accomplishments enabled by UCO support of the Lick and Keck observatories and the research accomplishments of UCO faculty and staff. The measure of success of this effort is the quality, quantity, and, most importantly, impact of the research done with the facility by faculty, research scientists, postdocs, and students. Education, both undergraduate and graduate, is a second important part of the mission. Finally, mentoring of postdocs is part of the mission as is public outreach.

9.1 Research: UC wide

9.1.1 Science Programs

There are a large number of very high profile and high impact programs underway by UC astronomers based on data obtained with the Lick or Keck telescopes. Many pages could be filled summarizing just a fraction of them. Below are listed the topics of some of the highest-impact programs from the last decade.

- Extra-solar planet discovery and characterization via precision radial velocity studies [separate programs with Marcy (UCB) as PI and Vogt (UCSC) as PI]
- Direct imaging surveys for extra-solar planets and proto-planetary disks [Macintosh (LLNL)]
- Galactic Center studies: Supermassive black hole, extreme star formation environments [Ghez (UCLA), Morris (UCLA)]
- Acceleration of the expansion of the Universe: [Filippenko (UCB), Perlmutter (LBNL)]
- Characterization and evolution of galaxies from z~1 to the present: [DEEP1/2/3 surveys: [Faber/Koo/GuhaThakurta (UCSC), Davis (UCB), Treu (UCSB), Shapley (UCLA)]

- Characterization of the intergalactic medium and the evolution of chemical abundances from z=6 to the present day: [Prochaska (UCSC), Martin (UCB), Wolfe (UCSD)]
- Discovery of galaxies at very early times and evolution of galaxies from z=6 to z=3 [Illingworth (UCSC), Martin (UCSB), Treu (UCSB), Mobasher (UCR)]
- The detailed distribution of Dark Matter in halos via gravitation lensing studies: [Treu (UCSB), Fassnacht (UCD)]
- M31 stellar populations, structure and merger history: [Guhathakurta (UCSC), Rich (UCLA)]
- Characterization of gamma-ray bursts: [Bloom (UCB), Prochaska (UCSC)]
- Galaxy clusters at z>0.8: [Lubin (UCD), Stanford (LLNL), Illingworth (UCSC), Wilson (UCR)]

9.1.2 Training and Education

UC A&A programs are among the strongest in the US. They are attractive to prospective graduate students and to postdocs. There are many metrics for graduate programs. Here we will choose two simple metrics: one that demonstrates the effectiveness of the UC programs for attracting and training excellent observationally oriented graduate students and the success of the programs at attracting the best of the observationally oriented postdocs in the country.

The Hubble Postdoctoral Fellowships are among the most prestigious fellowships in the world and these fellowships are most often awarded to young observational astronomers. Since the program was initiated in 1991, 35 graduates from UC A&A programs have received and accepted a Hubble Fellowship. Among the top seven US institutions for producing Hubble Fellows, Berkeley is tied for 4th and Santa Cruz is ranked 6th.

Institution	Number of awarded Hubble Fellowships
Caltech	24
Princeton	19
UC Berkeley	18
Harvard	18
U Arizona	15
UC Santa Cruz	12
U Chicago	7

In a similar vein, UC A&A programs have been very attractive to Hubble Fellow recipients with a total of 45 Hubble Fellows selecting one of the UC A&A programs for their host. Nationwide, three of the UC programs are ranked in the top eight for numbers of Hubble Fellows hosted.

Institution	Number of Hubble Fellows Hosted
Caltech	21
UC Berkeley	19
U Arizona	16
UC Santa Cruz	14
Princeton	14
U Chicago	10
UCLA	7
Harvard	6

9.1.3 Awards/Recognition UC

Approximately 100 UC faculty use the Lick and Keck Telescopes for their research or work closely with results of studies using these telescopes. This group has received a remarkable level of recognition. Eighteen are members of the National Academy of the Sciences, and in the last fifteen years we have had UC faculty receive nine Packard Fellows, five Sloan Fellows, a Kavli Prize winner, two Bower Prize winners, two Gruber Prize winners, three Shaw Prize winners and twenty-two various AAS prize fellows.

9.1.4 Contracts and Grants systemwide

NOTE: THIS SECTION IS INCOMPLETE IN THE JULY 15, 2011 VERSION OF THE REPORT. FIGURES ARE STILL COMING IN FROM SOME OF THE CAMPUSES.

Show the extramural support for A&A for each of the UC campuses by funding source. These plots show the funds in the year they are distributed to the campuses for the last three years.

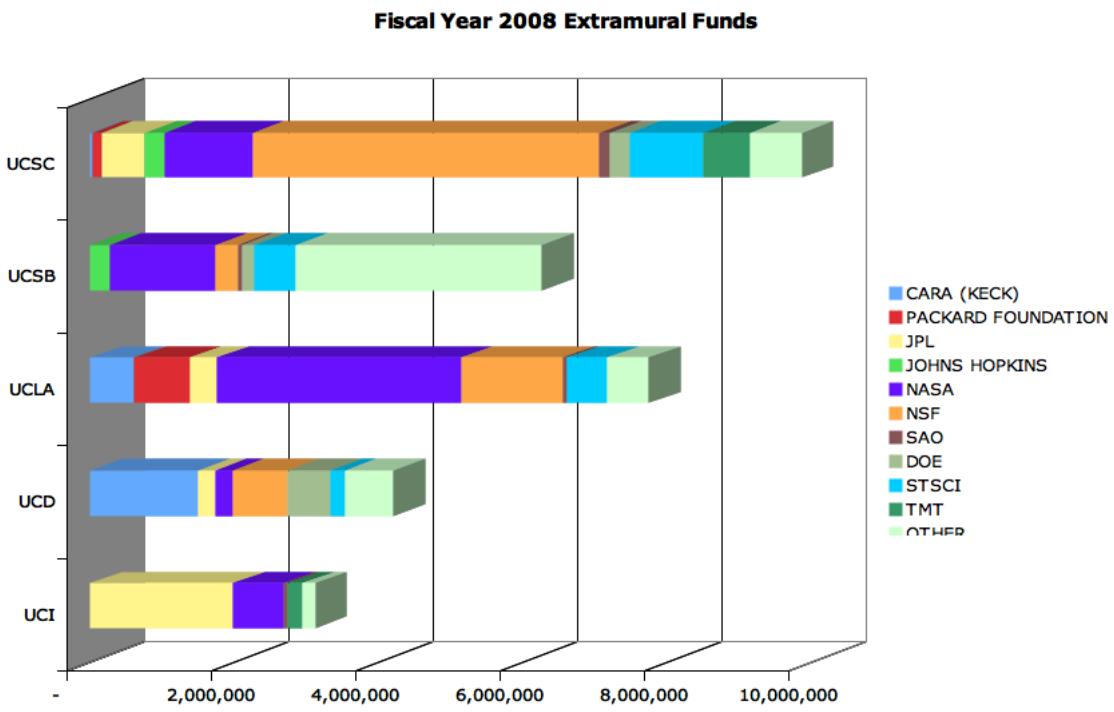


Figure 18

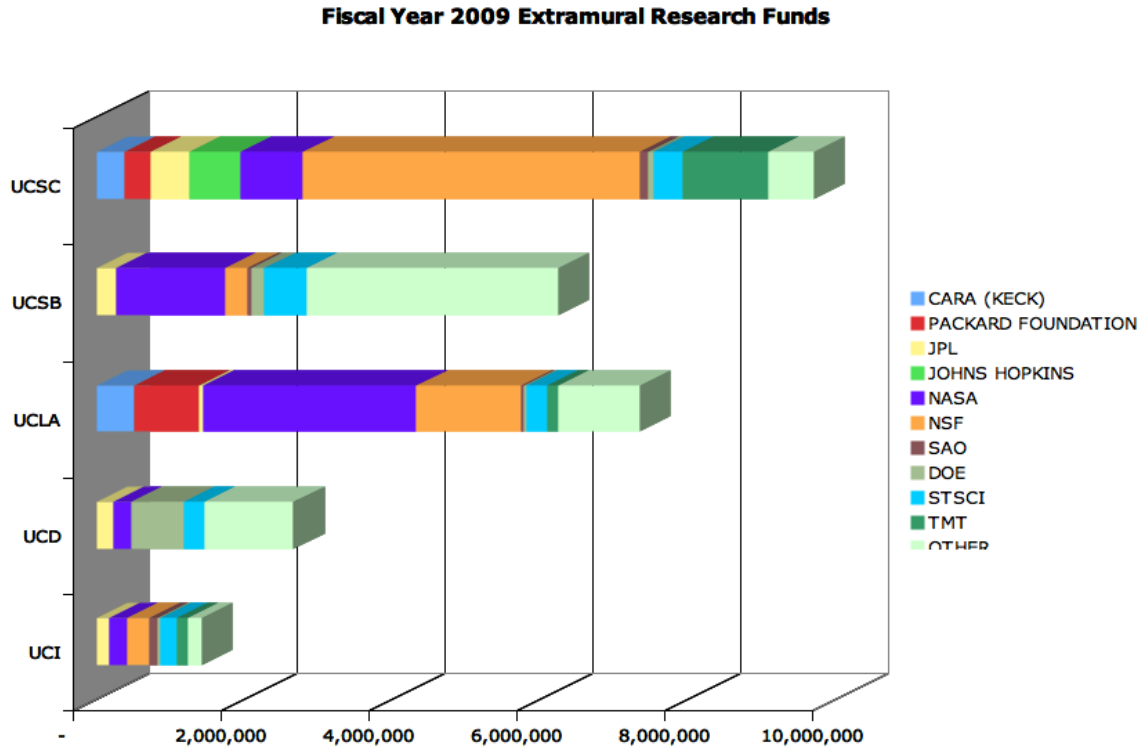


Figure 19

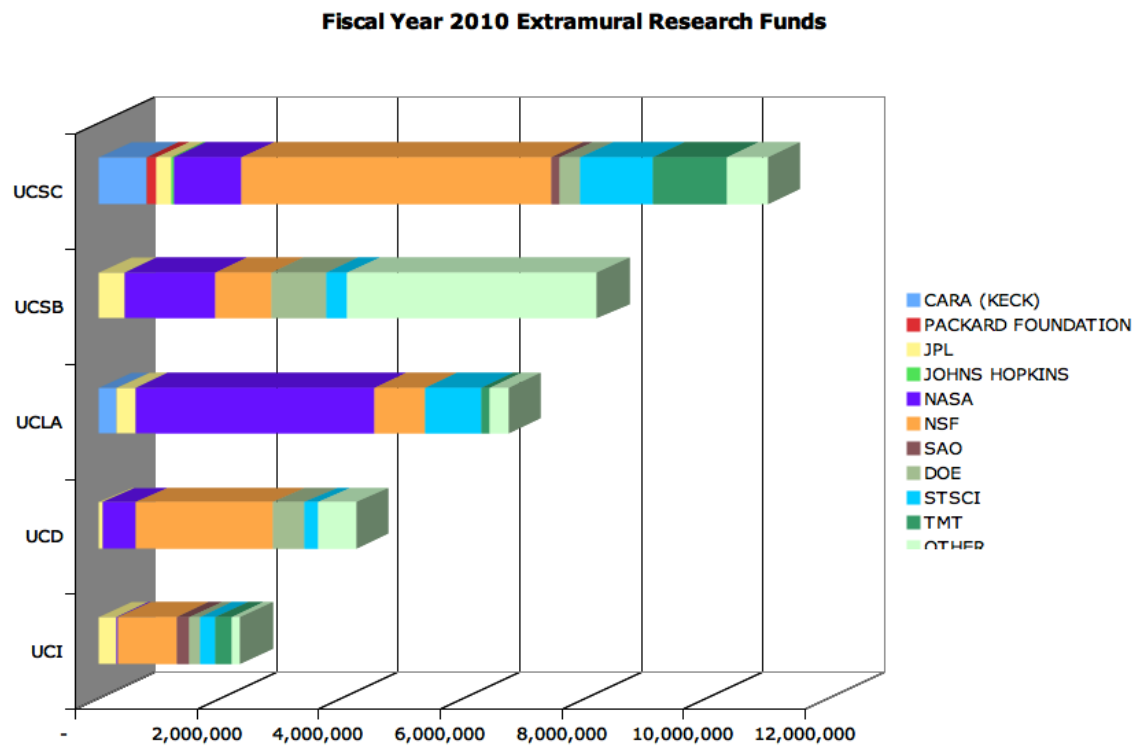


Figure 20

9.2 Research: UCSC

As discussed above, having faculty associated with UCO who are active at the forefront of astronomical research is crucial for carrying out the UCO mission. There are currently twelve UCO faculty members and the research track record, including research related to new instrumentation for large telescopes, is outstanding.

9.2.1 Science

UCO 80/20 faculty have a distinguished record in astronomical research. The research areas are broad ranging and in several cases the Santa Cruz based programs are world leading. The thumbnail highlights are presented below.

- Vogt is a member of one of the most successful of the programs worldwide discovering extra-solar planets,
- Smith is carrying on a long Santa Cruz tradition of using detailed abundance measurements in the atmospheres of globular cluster and field red giants to better undertand nucleosynthesis and mixing processes in old stars,
- GuhaThakurta leads an effort that has revolutionized our understanding of the stellar populations and structure of the M31,
- Bernstein has developed a technique to measure detailed chemical abundances from integrated stellar populations and is applying this to infer the formation histories of clusters and halos around Local Group galaxies

- Brodie is one of the senior leaders of the "SAGES" program that is systematically characterizing the globular cluster and halo populations of galaxies across the range of Hubble types to investigate the formation history of elliptical galaxies and the halos of spirals,
- Rockosi is one of the two leaders of the Sloan 2 and Sloan 3 "SEGUE" programs investigating with unprecedented precision the properties of the Galactic inner and outer halo,
- Faber and Koo are the leaders with Marc Davis (UCB) of the DEEP1/2/3 projects characterizing galaxy evolution from intermediate redshifts to the present and more recently are PIs on the largest program ever approved on the Hubble Space Telescope
- Max is using AO-based imaging and spectroscopic data to understand the physical process surrounding the merger of galaxies containing supermassive black holes
- Prochaska is perhaps the world's leading expert on the intergalactic medium and the chemical evolution of the diffuse gas Universe
- Illingworth is the leader of the team that has made use of the ACS on HST and Keck to discover and characterize the most distant known galaxies

9.2.2 Instrumentation

The design on modern, forefront instruments for large telescopes is another form of research and of course if of great value to all in the community who use those instruments for more traditional science programs. Among the UCO faculty we have some of the most accomplished and capable instrument PIs in the world.

- Vogt was the PI for the Hamilton coude spectrometer that produced the data leading to the discovery of many of the first 100 known extra-solar planets and the PI for the Keck HIRES spectrometer that has been provided the basis for the majority of discoveries of extrasolar planets. His latest spectrometer is just now being commissioned on the Lick Observatory Automated Planet Finder.
- Sandra Faber was the PI for the DEIMOS multi-object spectrometer and imager at the Keck Observatory. This spectrometer provided the data for the very successful DEEP ½ and 3 surveys and is one of the most request Keck instruments.
- Claire Max was project scientist for the Lick Observatory laser guide star AO system and instrumental in bring that system to the Keck Observatory where it has been the most productive AO system in the world by far through 2011. She is also the Project Scientist for the Next Generation AO system for Keck.
- Rebecca Bernstein is PI for the MIKE echelle spectrometer at the Magellan 6.5m telescope and the optical designer for several other instruments include the FIRE spectrometer (also at Magellan and the Dark Energy Survey camera. Since come to Santa Cruz she has become the PI for one of the three first light instruments for the TMT: a wide-field optical spectrometer called MOBIE. She has also been involved in initial optical designs for a next-generation high-precision radial velocity spectrometer optimized for extra-solar planet detection at Keck and the SASIR multi-channel JHK survey camera proposed for a 6.5m telescope at San Pedro Martir.
- Jason Prochaska is PI for a novel deployable tertiary mirror concept at the Keck 1 telescope that would enable much more efficient use of the telescope for Target of Opportunity and time-critical cadence observation programs.

- Connie Rockosi was PI for the upgrade of the Keck LRIS-R detector system, is part of the Keck Cosmic Web Imager optical IFU spectrometer and has recently received conceptual design study funds for an upgrade of the DEIMOS 8-CCD focal plane array.
- Harland Epps has provided the optical design for cameras and instruments at leading facilities all over the world. Locally, his designs are crucial parts of the Keck instruments LRIS, ESI, DEIMOS and MOSFIRE and of the most-used Lick Observatory instrument the Kast double spectrometer.
- Jerry Nelson has provided the primary mirror design and designs for a large number of important subsystems for the Keck and TMT telescopes.

9.2.3 Undergraduate and graduate education

UCO 80/20 faculty participate fully in the A&A graduate program at UCSC. The graduate student program typically has ~40 students shared by the UCO faculty and Department of Astronomy and Astrophysics faculty. In the last three years our graduates have done very well on the postdoc job market with five Hubble Fellows, an Einstein Fellow at MIT, Sagan Fellow, Berkeley Chancellor Fellow and a Miller Fellow. Among our current students, nine are supported with NSF Graduate Fellowships. We are one of the few graduate programs in the US that has students working in the field of astronomical instrumentation including AO.

9.2.4 Contract and Grant Activity

UCO faculty have been very successful supporting research activities through the usual federal agencies. The figures 18, 19 and 20 show the amounts awarded over the last three years for extramural funds. This total includes instrumentation projects.

9.2.5 Awards and Recognition

In addition to the individual awards listed below, the program at Santa Cruz has twice been ranked at the top of the Institute for Scientific Information (ISI) ranking for impact based on citations. UCSC A&A was #1 for the period 1994-1998 and again for the period 1997-2001 (UC Berkeley was ranked #2 for this period).

Among the twelve UCO faculty, three are members of the NAS (Faber, Nelson, Max). Nelson was awarded the 2010 Kavli Prize. Faber was awarded the 2009 Bower Award, the Heineman Prize in 1985 and is the 2011 AAS Russell Prize winner. Vogt was awarded the 2002 AAS Tinsley Prize. Rockosi was awarded a Packard Fellowship in 2006. Prochaska is a 2011 Humboldt Fellow.

UCO also has the distinction of having the largest number of female faculty members and the largest fraction of female faculty members in the US for programs with more than five astronomy faculty.

10. UCO FUTURE

UCO, with its origins in Lick Observatory, has a history stretching back more than a century. Key to properly planning the structure and function of the UCO labs and personnel going forward is the status of the three observatories associated with the University of California: Lick, Keck and TMT. Each is discussed in more detail below with a focus on the role that UCO will play in their future. In general, the UCO role is managing these facilities on behalf of UC, maintaining science capabilities already in existence and, most importantly, developing new capabilities and implementing them. The right mix of administrative, design, fabrication and science capabilities is constantly evolving as are the needs of the UC astronomy community. For example, in response to needs not being met in the commercial world, in recent years there have been changes as the emphasis on fabrication in the labs

has decreased and the emphasis on R&D research in AO and astronomical coatings has increased. However, although details will evolve, the basic UCO model has proven very effective.

A systemwide UC-Astronomy Task Force was commissioned in 2011 to consider the future of UC facilities for A&A research. This group identified three top priorities for the next two decades: maintain access to the Keck Observatory, continue to add to the Keck capabilities through the UCO instrument and AO labs and secure guaranteed access for UC to the TMT. These goals for UC establish that the UCO model of the last fifteen years, thoughtfully evolved, is very appropriate for the coming decades.

10.1 Lick Observatory

Lick Observatory has remained a vibrant center for UC astronomy despite the limitations of the site and age of some of the facilities. This is the result of a steady and thoughtful evolution of the policies and capabilities at Lick in response to the changing landscape. The systemwide committee that was convened in 2008/2009 to consider the strategic future of the observatory concluded that UC derives very significant value in four areas: science, technology development, student and postdoc training and public outreach and that it is a very cost effective facility.

The Santa Cruz labs, administration and business services are required for efficient operation of Lick Observatory. The trend for the last four decades has been to have a steadily smaller on-site staff and to carry out more of the activities required to maintain and upgrade the facilities at Lick using resources based in Santa Cruz. With the move toward remote observing and robotic facilities, this trend will continue. For Lick Observatory public outreach efforts, the longer-term goal is to partner with other institutions and migrate that responsibility, including budget, to a standalone organization largely independent of UCO. With major new capabilities, the next generation AO system and the Automated Planet Finder, under construction or just being commissioned, it is very likely that UCO will have as one important role continuing to operate Lick Observatory for at least another decade.

10.2 Keck Observatory

The Keck Observatory, as demonstrated in Figure 13 and Figure 14, remains at the forefront of productivity for ground-based observatories. UCO will continue to provide scientific and technical leadership at Keck Observatory, through participation in science leadership, WMKO management and through the development of new instrumentation. The Keck Observatory will be the primary facility for UC observational astronomy in the coming decade, and UCO will help to insure that Keck remains the forefront, ground-based observatory.

Although the era of building major new instruments every few years is likely past, it is crucial to continually bring new capabilities to the telescopes. The Keck Science Steering Committee, under the leadership of UC and Caltech, maintains a "living" scientific strategic plan that lays out a number of the highest-priority new capabilities for which funding will be sought. Leading or building major subsystems in these projects is a high priority for UCO (Santa Cruz and UCLA) for at least the next decade. The current Keck Scientific Strategic plan has the following new capabilities identified:

- **Next Generation Adaptive Optics:** This is an ambitious program to design and implement a MEMs-based, multi-laser AO system that will provide significantly higher Strehl over a larger field, a well-characterized and more uniform PSF, significantly greater sky coverage, much lower backgrounds at longer wavelengths, and greater throughput. Many of these concepts are being proven now at Lick Observatory and through the UCO LAO. When the funding for this major program is found (~$60M) UCO will play a key role in the development and delivery of this system. Approximately $3M has been spent to date and the

project held a successful Preliminary Design Review in June of 2010. Claire Max is the Project Scientist for NGAO, LAO Director Don Gavel is one of the Co-Is, and Mark Morris and Andrea Ghez at UCLA are the leaders of the Science Team.

- **Deployable tertiary for Keck 1:** This is a project to replace the tertiary tower and mirror at Keck 1 with a system that can deploy the tertiary or stow it out of the way in just a few minutes. This would allow for rapid access of instruments installed at Cassegrain and those at both Nasmyth platforms to enhance Target of Opportunity options at Keck, allow cadence observations, allow the scheduling of multiple instruments in a single night and to optimize programs to conditions. It would also reduce the risk and complexity of daytime instrument changes. Study money has been granted, and the conceptual design is underway at UCSC with X. Prochaska as PI.
- **Detector upgrades:** Upgrading detectors in existing instruments is a very cost effective way to improve observing efficiency and in some cases add new capability. On the SSC list are upgrades to NIRC2, NIRSPEC and the DEIMOS array. All these would be carried out at UCSC or UCLA. In July 2011, UCO-Santa Cruz received a $50k grant from WMKO to initiate a study of the DEIMOS 8-CCD detector array.
- **Optimized radial velocity spectrometers:** Two concepts are under study for building a fiber-fed, high-throughput R~70000 spectrometer optimized for radial velocity work. A concept study has been funded by WMKO with Rebecca Bernstien and Geoff Marcy as co-PIs.
- **Wide-field, multi-object R~15000 spectroscopy:** A fiber fed "Flames" type of instrument has long been on the list of needed capabilities at the Keck Observatory.
- **Next Generation high-resolution 1-5μ spectrometer:** With MOSFIRE being commissioned, the low-resolution mode of NIRSPEC may see reduced demand. Discussion of an R=20000 – 40000 spectrometer for the near-IR to replace NIRSPEC have been initiated. This effort would be led out of the UCLA IR Lab.

This is a long list of projects and certainly not all will be going forward. However, even a subset of this list represents a decade of activities at the UCO labs in Santa Cruz and at UCLA. We are currently involved in feasibility studies for most of these concepts and contributions by our technical and budget teams are the basis for the proposals to funding agencies. For the next decade, the Keck Observatory will remain as the principal astronomy facility for UC faculty and the support for Keck will be the top priority for UCO.

10.3 Thirty-Meter Telescope

UC is one of the founding partners of the TMT project. The TMT has its technological foundations in the UC finely-segmented mirror design which has been proven by the success of the Keck Observatory, and, after 20 years of experience with the 10m Keck telescopes, the UC community has had the opportunity to find the boundaries of 10m telescopes. The UCO 20-year record of building world-class instruments for Keck is also an important heritage that UC brings to the TMT project.

For this latter reason, the UCO labs are leading the first-light instrumentation projects for the TMT. MOBIE is the wide-field optical spectrometer led out of Santa Cruz and IRIS is the integral field spectrometer and imager to be used behind AO at the TMT and is led out of UCLA. The total budget for these two instruments is ~$90M (FY10) and each is an enormous undertaking. Neither lab currently has the personnel to design and build instruments of this scale. However, when TMT

funding is available, that problem can be solved. A more difficult issue is the renewal of infrastructure for instrumentation, particularly at the Santa Cruz labs. This is discussed further below.

There will very likely be some differences in the UC and UCO approach to supporting the TMT compared to the Keck Observatory. UC "owns" ~36% of each Keck telescope and UC astronomers have access through NASA time and NSF TSIP time. The UCO in-kind contributions to Keck instrument projects and other direct support of Keck Observatory is easily justified as being of clear benefit to the UC astronomy community. An advantage of supporting Keck in this way is we get to make the decision, based on the expected return to the UC community, of when and how to apply these resources. If UC is only a 15 – 18% partner in the TMT, it is less obvious that UCO contributions of un-reimbursed TMT-related expenses, can be so justified. One practical ramification is that adding a share of TMT to the UC facilities does not require a large expansion of the base support of UCO that might be otherwise expected. Facility issues aside, the organization would need to grow, however, it would do so based on long-term soft funding.

For continued work on Keck instrumentation and even more so for the development and fabrication of TMT instruments, UCO requires an investment in laboratory and shop infrastructure. Investments in equipment and buildings at the level of a few million dollars is a requirement. This will be discussed in more detail after the review committee tour of the UCO shops during the site visit.

10.4 Some parting thoughts

The UCO model has been very successful throughout the Keck era. Centralization of the UC A&A facilities management and leadership is perhaps the most successful and visible example of the UC "power of ten". No single campus could afford to be involved in forefront ground-based facilities in 2011, but with the combined 10-campus resources, UC has been able to build a world-leading A&A research program.

To maintain this UC A&A research leadership requires maintaining the Keck Observatory instrumentation and AO systems at the cutting edge and ensuring a UC role in the next generation of giant telescopes. UCO is central to achieving these goals. To successfully meet the challenges of TMT instrumentation, there are several aspects of the UCO infrastructure that require upgrades. The Laboratory for Adaptive Optics is an example of a very well-equipped modern lab thanks to an ~$5M investment in equipment by the Gordon and Betty Moore Foundation. A similar level or larger investment is required to bring the update the TMT fabrication facilities on the UCSC campus. There will be strong competition for building post-first generation TMT instruments. Given our heritage, experience and deep expertise developed in Keck instrumentation, UC is well positioned to become a center for TMT instrumentation: to achieve this, we require a suitable facility for full assembly of a TMT-scale instrument.

A fair question to consider is what it means for UCO if the TMT project does not go forward. In most areas, the current organization remains, by design, ideal for the continued support of the Lick and Keck Observatories. Many of the facility and equipment upgrades necessary for TMT instrumentation are also required for the continuing work for Keck instrumentation, however, our base highbay facility is large enough for Keck instrument assembly and testing.

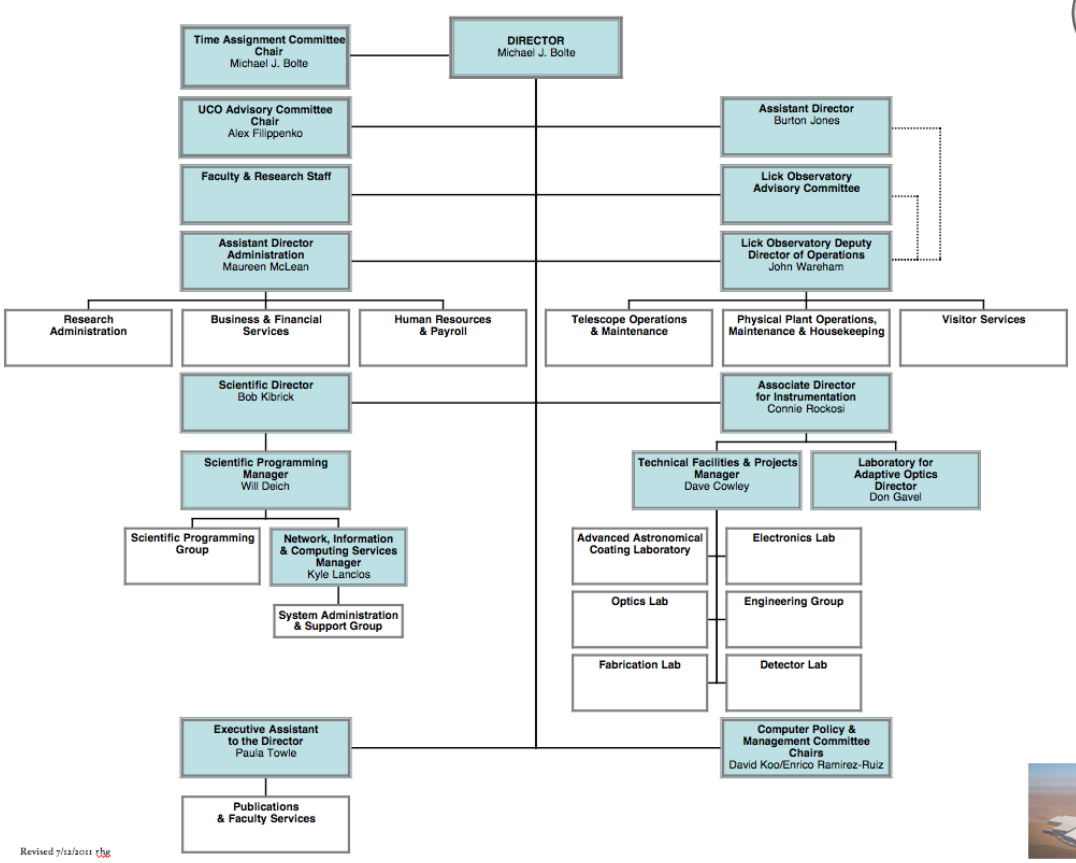
Although the major facilities already in place or in the advanced planning phase have dominated the discussion in this selfstudy, UCO is very well placed to become involved in, and in some cases crucial to, other initiatives on behalf of UC astronomy. There are a number of such opportunities already underway such as the 6.5m San Pedro Martir telescope and SASIR imaging instrument/survey, the LSST, and BigBoss. There will certainly be additional projects on all scales in the future. UCO is a

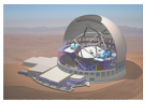
center of project and technical expertise for developing any programs that UC faculty initiate and which, through the UCOAC, generate a consensus of support.

UCO has a long track record of managing Lick Observatory and evolving the policies and capabilities of the observatory to meet the evolving needs of the UC A&A community. UCO played a central role in making the Keck Observatory a reality for UC A&A and has been crucial for maximizing the value of that facility to our community. This Keck Observatory story is being carried out again for the next generation of ground-based telescopes, specifically the TMT. The UC-Astronomy Task Force has identified these facilities as being at the heart of UC A&A program great success over the past decades and, in particular it identifies Keck and TMT and the facilities to build instrumentation for these telescopes, as the key to maintaining the UC world-leading activities in A&A research. The model for UCO has met these needs very well while at the same time providing a research program that is routinely ranked among the top six nation wide.

Appendix 1: UCO ORGANIZATIONAL CHARTS

UNIVERSITY OF CALIFORNIA OBSERVATORIES
2011–2012

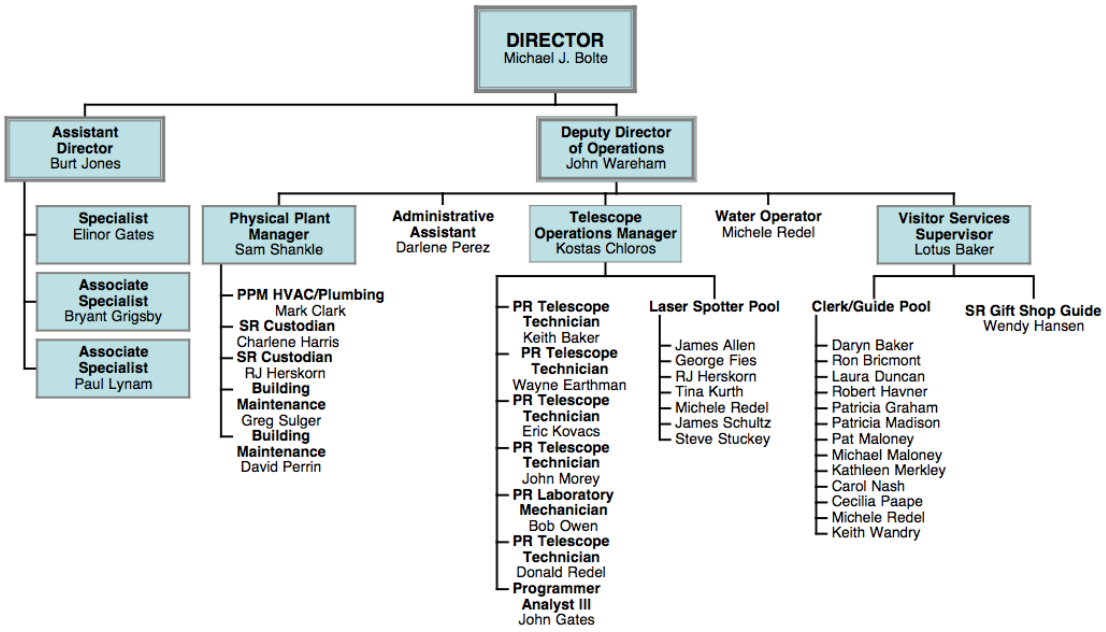




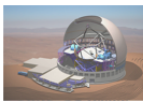
UNIVERSITY OF CALIFORNIA OBSERVATORIES

LICK OBSERVATORY

2011–2012



Revised 5/12/2011 rbg



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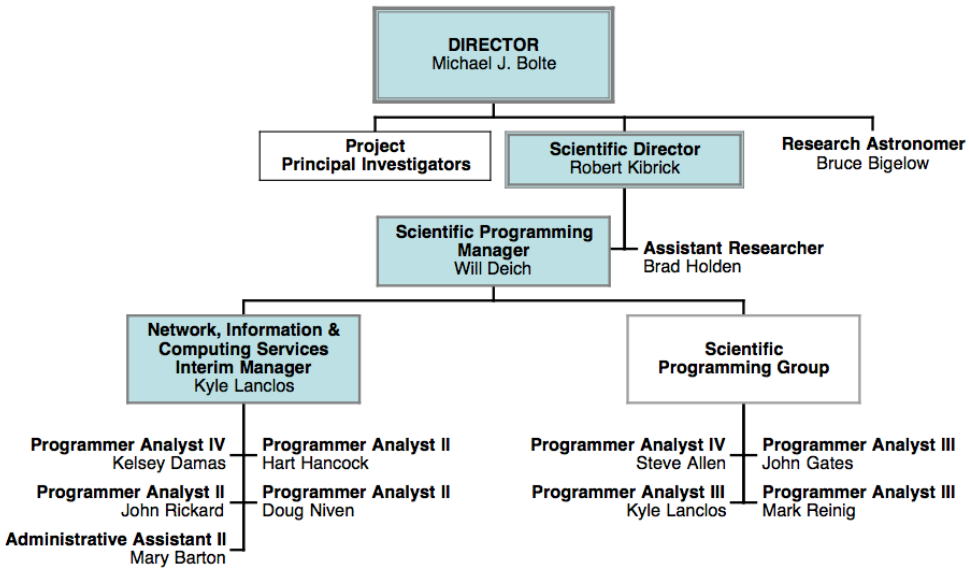
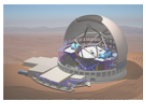
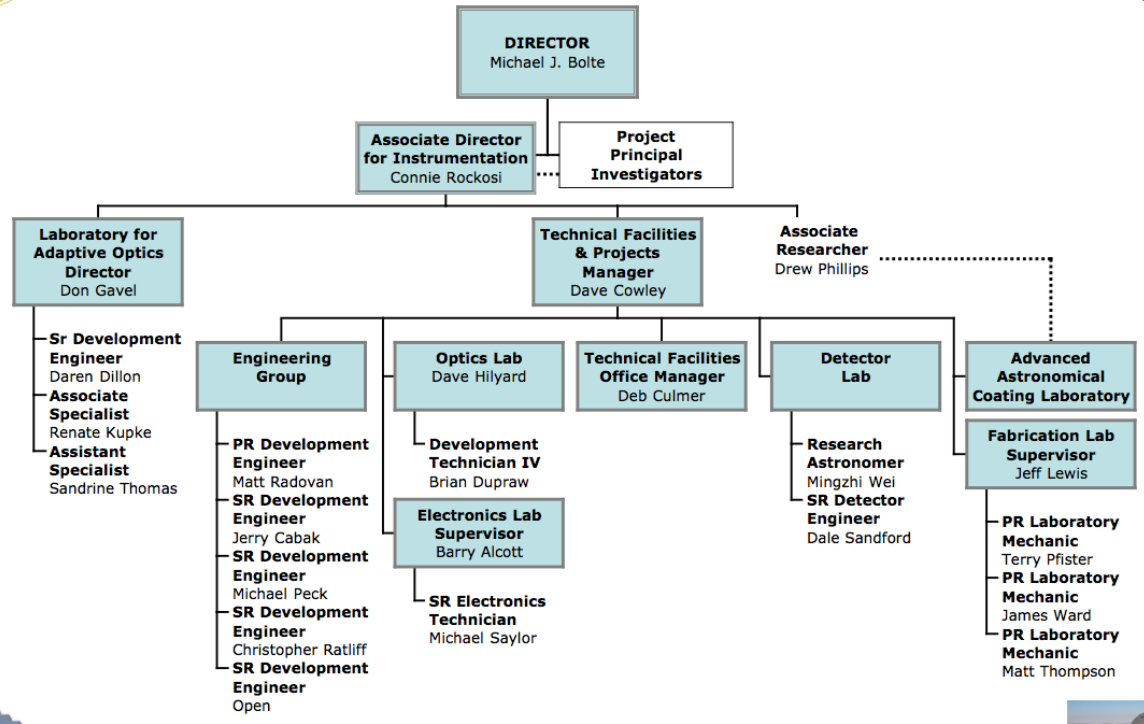
TECHNOLOGY DEVELOPMENT
2011–2012



Revised 7/5/2011 tbg



UNIVERSITY OF CALIFORNIA OBSERVATORIES
TECHNICAL FACILITIES
2011–2012



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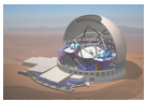
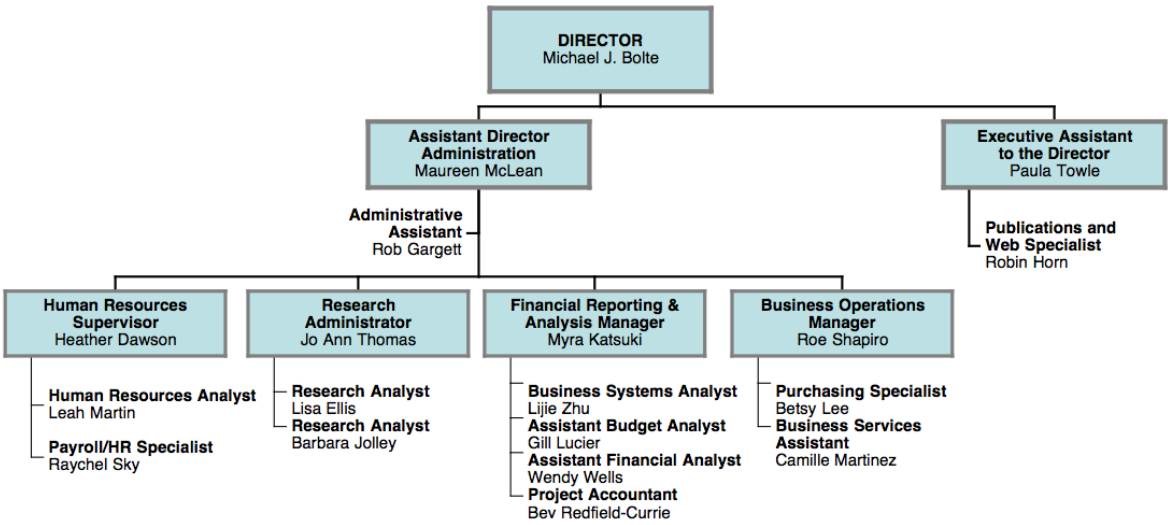


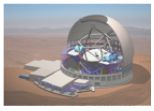
UNIVERSITY OF CALIFORNIA OBSERVATORIES
ADMINISTRATIVE AND BUSINESS SERVICES

2011–2012



10.5

Revised 5/12/2011 rhg



APPENDIX 2: UCO ADVISORY COMMITTEE

- Alexei V. Filippenko, UCB (Chair)
- Michael J. Bolte, UCSC (Director)
- Gabriela Canalizo, UCR
- Gary Chanan, UCI
- Lori Lubin, UCD
- Geoff Marcy, UCB
- Claire E. Max, UCSC & CfAO
- Ian McLean, UCLA
- Jerry E. Nelson, UCSC
- Michael Rich, UCLA
- Tommaso Treu , UCSB
- David Tytler, UCSD

Ex-Officio UCOAC Members

- Garth D. Illingworth, UCSC, SAC co-chair
- Burton Jones, UCSC
- Maureen McLean, UCSC
- J. Xavier Prochaska, UCSC
- John Wareham, Lick Observatory

10.6 APPENDIX 3: UCO TIME ASSIGNMENT COMMITTEE 2011

- Aaron Barth
- Rebecca A. Bernstein
- Michael J. Bolte
- Sandra M. Faber
- Alexei V. Fillipenko
- Bradley M. Hansen
- Bruce Macintosh
- Crystal Martin
- Claire E. Max
- Bahram Mobasher
- Alice Shapley
- Graeme H. Smith
- Martin White

APPENDIX 4: UCO FACULTY 2011

- Rebecca A. Bernstein
- Michael J. Bolte
- Jean P. Brodie
- Harland W. Epps
- Sandra M. Faber
- Puragra Guha Thakurta
- Garth D. Illingworth
- David C. Koo
- Claire E. Max
- Jerry E. Nelson
- J. Xavier Prochaska
- Constance M. Rockosi
- Graeme H. Smith
- Steven S. Vogt

10.7 APPENDIX 5: Lick Observatory Facilities

Lick Observatory is located on Mt Hamilton east of San Jose at an elevation of 1,280m (4200ft). There are nine telescopes at Mt. Hamilton. In 2011, there are four that are scheduled regularly for science observations with a fifth anticipated to come on line in the spring of 2011. The 36-inch Great Refractor is used for viewing by the public and sometimes for live webcasts at the Exploratorium of special astronomical events.

Telescope	Instrumentation	Focus	Resolution ($\lambda/\Delta\lambda$)	Comments
3-meter (1959)	Kast double spec	Cass	500-3000	--Hamilton spectrometer-based precision RV program. --1st AO/Laser GS system for astronomy use --$2M NSF MRI program for AO+IRCAL major upgrade
	Hamilton echelle	Coude	25000-60000	
	Prime focus camera	Prime	5-100	
	Gemini dual-channel IR imager and spec	Cass	5-500	
	AO + IRCAL	Cass	5-500	
APF 2.4m (2011)	high-R spectrometer			Robotic telescope dedicated to RV planet searches
Nickel 1m (1979)	Imaging Camera			Used for graduate and undergraduate classes and summer visitor observing
	Optical SETI high-speed camera			
	VILLAGES optical AO testbed			
KAIT 0.6m (1993)	imager			Robotic telescope targeting supernovae
CAT (0.6m) (1979)	Hamilton Echelle High-R Spectrometer			
SuperLotis				