Program **The University of California Observatories: The Administrative, Technical, and Visionary Arm of UC Optical-Infrared Astronomy**

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Section One: Program Overview

[Section One – suggested 3 pages]

What is UCO? A personal view….

"I always point out that the UCLA IR Lab is simply an instrument-building lab. It is a division of UCO, which should have several sorts of instrument labs. I always think of UCO as the *overall managing entity* for all the optical-infrared observatories supported by the UC system. This entity represents UC astronomers in the highest level of negotiations concerning current and future shared facilities, interacts with the leaders of those observatories – such as Keck and TMT – and handles all of the committee structures needed for participation in shared governance, scientific guidance, allocation of telescope time, and financial oversight. UCO also sponsors innovation in the development of future telescopes, adaptive optics systems, optical-infrared instruments, detectors, software, data archives, and management methods. UCO represents the UC Astronomy & Astrophysics community by being a part of the community, contributing to the scientific output of UC, and garnering international acclaim through the achievements of its faculty, staff, and collaborators. If UCO did not exist, we would soon need to invent it. How else could we organize access to the Keck and Lick telescopes? Who would represent UC on the Keck Science Steering committee or the CARA Board? Who would be our counterparts to the leadership of external partners like the Caltech Optical Observatories? How would we conceive 'telescopes of the future', like Keck and TMT?

"UC A&A needs UCO."

---- Prof. Ian Mclean
Director, UCLA Infrared Laboratory
Assoc. Director, University of California Observatories

Mission and Goals

Since 1888, the University of California (UC) has pooled its systemwide resources for research in Astronomy & Astrophysics to maintain a pre-eminent share in world-leading observatories. The 1-m class telescopes at Lick Observatory were the most powerful in the world when commissioned in the late 1800s. The Lick 3-m telescope, completed in 1959, was the second largest telescope in the world for the next fifteen years. The twin Keck Observatory 10-m telescopes, completed in 1993 and 1996, are still the most powerful ground-based optical telescopes in the world.

Through these efforts, qualified UC researchers now enjoy access to the world's most advanced observing facilities, on all UC campuses and at both national laboratories. Planned UC membership in the Thirty-Meter Telescope project (TMT) ensures that this access will continue into the next generation. No single campus could afford to create state-of-the-art facilities of this scale – Astronomy & Astrophysics is the quintessential example of UC's "Power of Ten".

The University of California Observatories (UCO) is the organization charged with *creating and maintaining* this network of resources. UCO operates Lick Observatory and designs and fabricates instrumentation for Lick, Keck, and TMT. UCO creates the planning arena for UC optical-infrared (hereafter "O/IR") facilities and the means to launch new ones like Keck and TMT. Finally, UCO astronomers exercise scientific leadership both internally and externally and represent UC interests in the external partnerships with Keck and TMT.

NOTE: The concept of "instrumentation" on telescopes may require explanation. A telescope gathers and focuses light, and attached to the focus are possible instruments that analyze and detect the light. The most common instruments are cameras, which take direct images, and spectrographs, which disperse light into a spectrum and detect it. The power of a telescope is to a great extent determined by its instrumentation. UCO instruments are renowned for having state-of-the-art high efficiency, resolution, and sensitivity.

UCO's headquarters and main laboratories are at UCSC, and a second major lab specializing in infrared instrumentation is at UCLA. Subdivisions at UCSC include the Center for Adaptive Optics (CfAO), which is now focused on teaching

adaptive optics and other educational activities, the Moore Laboratory for Adaptive Optics (LAO), which houses optical equipment for AO experiments[1], and the Advanced Astronomical Coatings Laboratory, which develops reflective and anti-reflection optical coatings for astronomical applications. The scientific leaders of UCO are UC faculty and senior researchers. Thirteen faculty at UCSC, called "Astronomers", bear principal responsibility for optical instrumentation, telescope technology, and operating Lick Observatory. Three more faculty are professors at the UCLA IR lab, where they lead infrared instrumentation. Many more faculty throughout the system participate in UCO, notably through teaching, fund-raising, public outreach, and membership on key UCO governance committees.

Activity 1: Ensure that Keck Observatory provide world-class observing capabilities to UC researchers.

The dream of a 10-m (400-inch) telescope to surpass the Palomar 200-inch began at UCSC in 1977. A subsequent partnership between UCO and LBL yielded the *segmented mirror concept,* which became the genesis of all schemes to build telescopes larger than 8 meters. The *twin Keck telescopes* on 14,000-foot Mauna Kea, completed in 1993 and 1996, unleashed a wave of giant telescope building that swept the world – there are now 16 telescopes with primary mirrors larger than 5 meters. UC pioneered the breakthrough technologies that enabled the state-of-the-art telescopes of today.

UCO actively supports UC observers at Keck. It manages the time-assignment process that awards UC Keck nights through competitive peer review. It designs, furnishes, and trouble-shoots internet–based remote-observing facilities on all eight astronomy campuses. Through memberships on key committees, UCO faculty provide scientific oversight of new instrumentation and budgetary priorities. The UCO technical staff support and extend the Keck staff, which is deliberately kept lean. UCO supports fund-raising and outreach efforts at Keck, for example, the upcoming Keck Gala 20th Anniversary celebration in March 2013, for which UCO is the UC coordinator.

Activity 2: Design, build, and maintain state-of-the-art instrumentation to equip the telescopes at Keck.

Instruments make or break a telescope. Modern astronomical instruments are multi-million dollar projects that are conceived and executed by skilled specialists. The great success of Keck is due in large part to *superior instrumentation*, and history shows that instruments are most successful when *led by senior faculty*. UCO has dominated instrument-building at Keck, having led or co-led 6 out of 9 current instruments and built major subsystems for 2 more (see list in Appendix 4). The UCO instruments HIRES, DEIMOS, ESI, OSIRIS, NIRSPEC, and MOSFIRE are household names to astronomers around the world. UCO instrumentation faculty lead instrument strategic planning, write proposals to fund new instruments, and provide a crucial reservoir of technical expertise for Keck. The top 6 instrument projects now being developed at Keck all include an essential UCO role.

Instrument faculty face constant technical, budget, and schedule pressures, and their instrument contribution is often in addition to their own personal scientific research. Their work is a *service* that enables the research programs of fellow astronomers. Over decades, UC has assembled a stellar array of faculty members with the interest, skill set, and experience to lead major instrument projects, but many are now retiring. Care and attention will be needed to attract the next generation of UCO faculty to lead future instrumentation projects.

Activity 3: Develop the astronomical technologies of the future, for Keck and beyond.

UCO has repeatedly revolutionized astronomical technology. Examples are the 10-m Keck telescopes (Activities #2,3), the upcoming Thirty-Meter Telescope (TMT; Initiative #1), and world leadership in adaptive optics (Initiative #2). These advances happened because technically minded scientists were given the freedom to explore the state of the art. The skills and vision of such leaders extend beyond the boundaries of current projects, as they track technical developments broadly and bring the most promising in-house for further development. Supporting such leaders means supporting efforts that are *creating new futures,* not just simply reaping the fruits of today. Current examples include the Advanced Astronomical Coatings Laboratory, which is developing a revolutionary non-tarnishing coating for astronomical mirrors, and the Shane

[1] *Adaptive optics* is an advanced technology that corrects the wave fronts of incoming light for atmospheric distortions, and thus permits large ground-based telescopes to see more sharply even than *Hubble*. AO is the next big revolution in telescope technology, and UCO has consistently been the world leader.

3-m Adaptive Optics, which is bringing adaptive optics down from the near-infrared into visible wavelengths. Budget exigencies must not be allowed to kill off future investments like these.

Activity 4: Support and promote graduate, undergraduate, and postdoctoral teaching and training.

The telescopes and laboratories of UCO support a wide variety of teaching and training programs from high school on up. This training depends crucially on access to the UCO telescopes and instrumentation, while discoveries made at UCO enrich all UC astronomy classes more broadly. Student usage is documented in later sections of this report and in the Questionnaire in Appendix 4.

Activity 5: Provide a wide array of observing services at UC's Lick Observatory on Mount Hamilton.

The principal instrument of *Lick Observatory* is the Shane 3-m telescope, a heavily used all-purpose research reflector. Among other discoveries, it was responsible for most of the early detections of exoplanets orbiting other stars and for helping to characterize the class of supernovae that was subsequently used to discover the accelerating expansion of the universe. Other telescopes are the 40-inch Nickel reflector, used for imaging and as a test bed for novel instrumentation; the 30-inch robotic KAIT reflector, which has conducted one of the world's most successful supernova searches that has bolstered studies of the accelerating universe; and the historic Lick 36-inch Great Refractor, a beautifully maintained treasure of nineteenth century science and a prime draw on Visitors Nights (Activity #8).

UCO operates and maintains the Lick telescopes and associated facilities at Mt. Hamilton, builds new telescopes and instruments for Lick, provides observing instruction and support, runs the peer-review process to award Lick telescope time, provides mountain lodging for on-site observers, provides remote-observing stations on all campuses, maintains the public archive for Lick data, and manages the hiring, performance, payroll, etc., of all staff. It leads scientific planning and priority setting for Lick programs through the UCO Advisory Council and planning workshops. As custodian of the 3,600 acres atop Mount Hamilton, UCO coordinates with Caltrans, the Santa Clara County Sheriff's department, campus facilities at UCSC, and various entities that use the land. The 36-inch refractor and Main Building are UCO's prime venue for fund-raising, public education, and outreach activities (Activity #8).

Activity 6: Design, build and maintain forefront telescopes and instrumentation at Lick Observatory.

Lick has a distinguished track record of pioneering astronomical instrumentation. Historic firsts at Lick include the first TV guide camera on a telescope, the first fully digital spectrometer, the first laser guide-star for adaptive optics, and the first iodine cell for precision Doppler spectroscopy (which opened the floodgates for the "exoplanet revolution"). Adaptive optics at Lick gave birth to the current AO system now at Keck. Much Lick technology is eventually transferred to Keck. For example, the Hamilton and Kast spectrographs on the Lick 3-m pioneered designs that later became part of Keck workhorse instruments HIRES, LRIS, ESI, and DEIMOS, and Keck AO began at Lick.

Two state-of-the-art projects at Lick are now close to first light. The Automated Planet-Finder (APF) is a 2.4-m telescope and spectrograph built to search for Earth-like planets around the nearest stars using Doppler motions. The APF will be Lick's first fully robotic telescope for spectroscopy and will start regular operations this summer. The Shane 3-m second-generation adaptive optics system has a brighter laser guide star and faster atmospheric correction that will open up *Hubble*-quality diffraction-limited imaging on the Shane telescope for a rich array of projects.

Activity 7: Conduct forefront research in astronomy and astrophysics.

Path-breaking research using UCO facilities is done by astronomers on all eight UC astronomy campuses and at LBL and LLNL. Firsts from the O/IR program include: 1) the discovery of hundreds of planets orbiting other stars, 2) proof of a million solar-mass black hole at the center of our Galaxy, 3) the fact that the expansion of the Universe is *accelerating*, contrary to intuition, and 4) the invention of the segmented-mirror technology that spawned the current wave of giant telescopes. Statistics show that UCO telescopes are extraordinarily productive. More papers per telescope originate from Keck than any other ground-based observatory (25% more), and they are also cited more, for a total impact (papers × citations) that is 50% larger than competitors (see Keck PRG report). These finds have resulted in a dazzling array of

prizes including two Kavli Prizes, two Gruber Prizes, two Shaw Prizes, a Crafoord Prize, MacArthur Award, a Nobel Prize, and a National Medal of Science. UC also dominates astronomy prizes at lower levels (see Prizes in Appendix 4).

Activity 8: Support science, enrich the cultural life of the community, and share the wonders of astronomy with the citizens of California.

UC O/IR astronomers feel privileged to be California's designated explorers of the Universe and to "voyage the cosmos" using the awe-inspiring telescopes provided by the University of California. The public feels a deep connection to our science, and we in turn feel a compelling obligation to "report back from the depths of space".

UCO programs to educate and inspire the public are extensive. The historic Great Refractor and Main Building are unique venues for public viewing, lectures, and exhibits. The Lick *Music of the Spheres* and *Friday Night Visitors* programs sell out each summer. UCO hosts two websites, publishes a quarterly e-newsletter, and the newly founded *Friends of Lick Observatory* group is raising private support. UCO astronomers are constantly in the news via press releases, news stories, and TV documentaries, which garner extensive, favorable press for the University of California.

UCO faculty have founded distinguished science education programs. A CfAO spin-off is the Institute for Scientist and Engineering Educators (ISEE) at UCSC, which is refining university science teaching for diverse audiences. A new collaboration to enrich K-12 teachers was launched this year with the Center for Science Education at UCB, and UCO is partnering with the Tech Museum in San Jose to develop astronomy exhibits and robotic telescopes for visitor use. Further details on our education and outreach efforts are described in Section Three and the Questionnaire in Appendix 4.

Initiative 1: Oversee the design and construction of the Thirty-Meter Telescope. Design, and build TMT instrumentation. Represent UC's interests in the TMT community to ensure success by UC astronomers.

The *Thirty-Meter Telescope* is one of three extremely large telescope (ELT) projects in the world. The others are the 22-m Giant Magellan Telescope and the 38-m European Extremely-Large Telescope. All are billion-dollar projects funded by consortia of universities and nation-states, and all were inspired by the Keck segmented-mirror concept. The TMT partners are UC and Caltech (founders), Canada, Japan, China, India, and the US NSF. The design is complete, and partner details are now being finalized with a target date of spring 2014 to launch construction. UC astronomers will receive 15-19% of observing time, with more time available through collaborations. First light is scheduled for 2021.

The science thrust of TMT is adaptive optics, for which the AO technologies developed by UCO are key. Using AO, TMT will see nearly *100 times fainter than Hubble* and *10 times sharper*. The views of the cosmos through TMT will be truly breath-taking. With good PR, TMT has the potential to eclipse *Hubble* as astronomy's flagship in the public eye.

Most of UC's buy-in to TMT is provided by a $125 M gift from the Moore Foundation, which carries the requirement that UC raise an additional $50 M. The intention is to raise this sum through private donations. UC's share of annual operating costs is expected to be ~$6.5 M/year; this sum will be freed up in 2018 when UC's operating obligation for the Keck Observatory is reduced by a factor of two. It is therefore extremely important that the *$6.5 M released from the Keck obligation be redirected to TMT operations*. That UC can buy into one of the world's largest telescopes with essentially no increase in annual expenditures is a once-in-a-generation opportunity.

UCO's role in TMT will be similar to its role in Keck – managing UC's observing time, staffing science and governing groups, providing overall science and technical leadership, promoting collaboration amongst the partners, and building instrumentation. UCO is leading the design and fabrication of two out of three TMT first-light instruments – the IRIS high-resolution infrared imager at UCLA, and the MOBIE optical spectrograph at UCSC. Each of these is a $30-50 M project, bigger than the scale of previous UCO instruments. Actual construction will be financed by contracts from the project to UCO. However, renovating the UCO lab facilities at UCSC is required, and plans for this are underway.

Participation in TMT is a great opportunity, but it is also is a *sine qua non* for continued UC excellence. Most of the great powers in O/IR astronomy are joining ELT partnerships – without such access, UC will quickly be surpassed.

Initiative 2: Lead construction of Keck Next-Generation Adaptive Optics.

The *Keck Next-Generation Adaptive-Optics (NGAO)* system will be a tremendous advance over the current system. With three laser guide-stars and much better wave front correction, NGAO on Keck will regularly produce images *4 times sharper* and *16 times fainter than Hubble.*

UCO contributed heavily to NGAO's conceptual design and aspires to lead the project and have a major share of the construction. To promote this, we propose to make seed-funding available from the UCO budget to jumpstart design and fund raising. NGAO provides fabulous scientific opportunities, capitalizes on AO experience gained at Lick and Keck, exploits capabilities at the UCO Lab for Adaptive Optics, and pioneers technologies that will be used for AO on TMT.

Initiative 3: Expand and invigorate training programs in astronomical instrumentation.

Despite the importance of astronomical instrumentation, PhD programs that *teach instrument-building skills* are surprisingly few. The UCO lab facilities at UCLA and UCSC provide ideal hands-on training environments that can be further expanded and exploited. Initiative #3 would add an undergraduate component, broaden the programs by connecting with engineering departments, coordinate among campuses, and advertise widely to attract the best students. A focused effort could yield a powerful program for astronomy, with spin-off training in related technical fields.

Initiative 4: Institute new models of doing business, at Lick Observatory and elsewhere in UCO.

With the advent of Keck and TMT, UCO continues its historic march towards telescopes of larger aperture. However, the telescopes at Lick Observatory remain a vital resource – for training and public outreach as well as research (Activities #4,7,8; Initiative #5). The systemwide Astronomy Task Force (Section Two) in 2011 recommended continued operation of Lick Observatory but with efforts to find a new funding model to lower UC costs. We propose here a *five-year commitment to continued operations at Lick Observatory,* in "spartan" mode, meanwhile searching for new funds. Five years is adequate to complete ongoing projects, meet existing commitments, mesh with TMT construction, and cultivate alternative sources of support. Over these years, we will be developing the new business model for Lick Observatory.

A second new program would provide *compensation for service* for highly engaged UCO faculty around the system, many of whom put in nearly as much effort as the UCO faculty at UCSC and UCLA. All faculty in the new program would be required to set goals and milestones and undergo performance reviews, in return for flexible financial compensation such as summer salaries. Such a program would help engage the best talent around the system for UCO, share UCOP support more broadly, and strengthen community ties and loyalty to UCO. It is a major centerpiece of Initiative #4.

UCO has been striving to operate more efficiently on all fronts. Labor is being tracked more carefully in the UCSC shops. Remote observing facilities have been instituted on all campuses, which we reckon save at least $1 M annually in travel funds to telescopes. Videoconferencing and teleconferencing are routinely used. On-line telescope application and surveys have been instituted. Major adjustments to duties and schedules have been made at Lick to deliver the same service with fewer personnel, and new revenue sources are being explored (Section Two). New tools to be introduced include efficient accounting and project tracking software (needed for the large TMT instrument projects), software tools for e-commerce and scheduling, and rebuilding and refurbishing the UCO instrument shops to ready them for TMT.

Initiative 5: Exploit high public interest in astronomy for the benefit of UC and the state of California.

In Section Three, we reflect on the importance of UCO to the state of California, particularly if UC-trained foreign students are permitted to remain in the US, as seems likely. In that case, UC will suddenly become even more crucial as a magnet to draw international talent to our state, but….we will simultaneously be competing with 49 other state university systems that have the same idea. Astronomy, with its high public profile, has t*wo unique assets* that will aid UC and California in this new era – it is an ideal vehicle for trumpeting CA's technical prowess, and second, the Keck and TMT properties on Mauna Kea are key beachheads to the rest of the Pacific Rim. Initiative #5 would harness the public visibility of astronomy – together with other outstanding ORGS programs – to promote UC research more effectively with the goal of positioning UC and CA even more visibly among the intellectual and technical powerhouses of the world.

Section Two: Alignment to Systemwide Principles *[Section Two – suggested 10 pages]*

Principle 1: Act as one system of multiple campuses to enhance UC's influence & advantage.

Objective 1: Provide UC faculty and students with access to unique facilities, resources, and/or opportunities that sustain and extend UC's competitive advantage.

Consideration #1: What opportunities, resources, or facilities provided by the program can uniquely leverage UCOP funds to position UC as a world leader in research, scholarship, and/or creative work?

NOTE: A separate PRG report is being prepared for Keck Observatory. The two reports, Keck and UCO, should be read together, as many of the arguments overlap. The report here is prime, while Keck gives backup. Note also that Objective 1 mentions only faculty and students, whereas UCO's mission to provide world-class observing facilities extends to postdocs and UC research scientists. We have included both of these classes in our client population statistics.

Overview of UCO facilities: A major reason for UC leadership in O/IR astronomy is the high-quality observing facilities operated by UCO. UCO facilities comprise: • twin 10-meter telescopes at Keck Observatory on Mauna Kea and their instrumentation, • 4 research telescopes and associated instrumentation at Lick Observatory on Mount Hamilton (led by the Shane 3-m reflector), • instrument-building labs and Lick maintenance facilities at the UCSC Instrument Laboratories, • instrument-building labs at the UCLA Infrared Laboratory, • remote observing rooms on eight campuses, and • the Main Building and 36-inch refractor used for education and outreach at Lick Observatory. Subdivisions at UCSC are the Adaptive Optics Laboratory, the Advanced Astronomical Coatings Laboratory, and the Center for Adaptive Optics.

The twin Keck telescopes are the best in the world, according to productivity metrics given in the Keck report, with Lick, though smaller, offering special advantages. Lick data played a role in fully *half* of the discoveries in *UCO's Greatest Hits* (see Appendix 4). Lick is UCO's prime test-bed for new technologies that make their way to Keck – two new high-tech projects, Shane AO and the 2.4-m Automated Planet Finder (APF) telescope, are underway at this very moment. Long-term monitoring of variable astronomical objects over weeks or months is much more feasible at Lick. UC lab classes get live astronomical data, and grads and postdocs can apply in their own names and run their projects from start to finish, providing a unique training experience. In short, it is Keck and Lick *together* that have made UC O/IR astronomy a world-leader.

Staffing and activities: The bulk of UCOP funds to Keck and UCO are used to operate *facilities,* where they principally pay salaries. At Keck, employees maintain and service the telescopes, instruments, and domes; remove instruments from the telescopes and mount new ones according to the observing schedule; troubleshoot equipment and execute repairs; receive and commission new instruments that are delivered from UC and Caltech; operate the telescopes at night for observing; train and assist observers; write software to control instruments; write instrument manuals to instruct observers; operate lodging facilities for visiting observers; and engage in public outreach and fund-raising. Keck research scientists design and build new Keck instrumentation, especially adaptive optics systems. The Keck staff numbers 116 employees. UCOP funds UC's share of Keck's operating costs, which is 5/6 of $16 M (see Keck PRG report).

UCO employees work at UCSC and Lick Observatory. Ten FTE work at Lick Observatory, where they operate and maintain the telescopes with duties similar to those at Keck. A technical staff of about 20 people at UCSC assists the Lick staff with mountain operations and also builds new instruments for Lick and Keck. A business/administrative staff of 12 individuals supports these functions. Finally, UCOP funds pay 80% of the salaries of 13 UCSC faculty (termed "Astronomers") who function as scientific managers, instrument PIs, guardians of UC interests at Keck and TMT, and spokespersons for UC O/IR astronomy. Starting in FY14, the Astronomer salary money (approx. $2.6M) is proposed to be split off from the UCO budget and returned to the UCSC campus. UCO also passes $300 k of UCOP funds directly to the UCLA IR Lab, where it supports summer salaries and essential technical and administrative infrastructure. NOTE:

UCOP funds are NOT used to pay the research costs of individual UC astronomers *anywhere* in the system – costs such as student/postdoc salaries, summer salaries, page charges, etc., are paid for by science grants to the researchers themselves.

UCO facilities costs: UCOP funds to UCO facilities support Activities #1,2,3,5,6 and Initiatives #1,2,4. The breakdown across Lick, Keck, and TMT is shown below. Activity dollars from the budget table in Appendix 1 have been assigned to categories at the three sites, as indicated in the top line, where "A5" means Activity #5, etc. "Total" includes the UCSC Astronomers; subtracting these off yields the lower line, which is how the budget will be presented starting in FY14. UCSC and UCLA do not appear as separate sites since their costs are distributed across sites and activities.

Table 1. UCO Facilities Budgets in FY12 (UCOP funds only)

	Lick Observatory		Keck Observatory		TMT Observatory
	Operations	Instruments	Operations	Instruments	Development
How computed	A5+I4	A6	A1	A2+A3/2+I2	I1+A3/2
Total	$1,698,853	$907,153	$226,866	$2,485,643	$935,205
W/o Astronomers	1,584,436	$792,736	$112,449	$2,153,833	$672,045

Using the "total" values above, $6.3 M of UCOP funds was spent on facilities in FY12, which was 75% of UCOP expenditures (see Appendix 1). Of this fraction, 42% was spent on Lick, 43% was spent on Keck, and 15% was spent on TMT. With Astronomers removed (from both the sub-amounts and the total), $ 5.3 M, or 91% of UCOP funds, was spent on facilities. Of this fraction, 45% was spent on Lick, 43% was spent on Keck, and 13% was spent on TMT. (NOTE: Keck totals here do not include the $13.0 M sent directly to Keck by UCOP for operating funds. This amount will be reduced by half starting in April 2018 under the current agreement with Caltech.)

Non-facilities expenditures: Expenditures here include Activity #4 (teaching/training), #7 (research), and #8 (EPO), and Initiative #3 (instrument training), #4 (business initiatives) and #5 (expand EPO). These activities are largely staffed by faculty, and with Astronomers, they totaled $2.1 M.

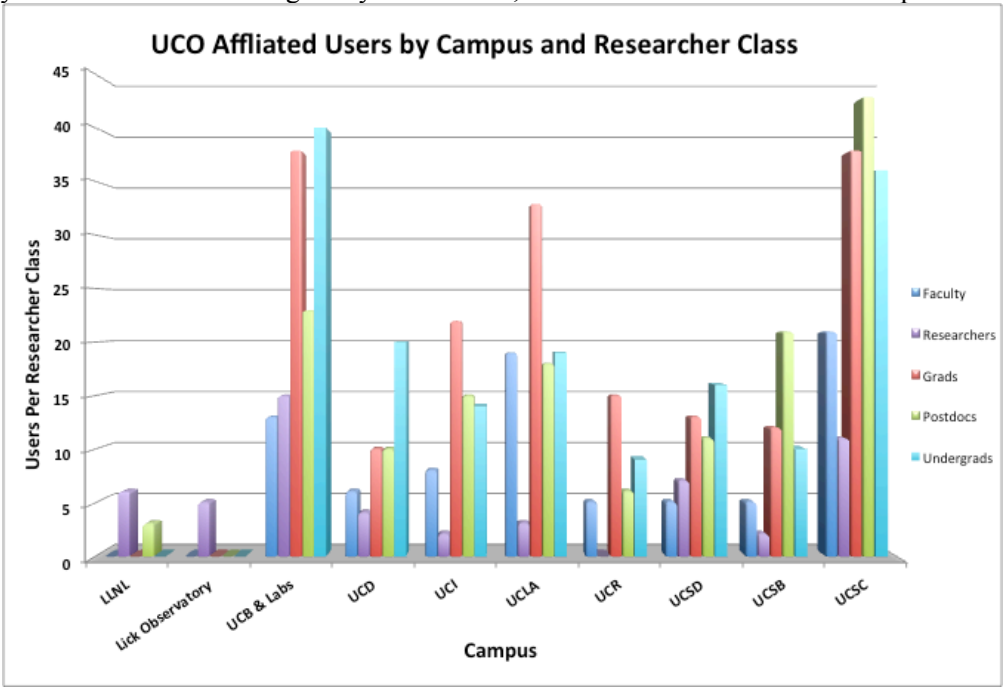
Leveraging UCOP funds: UCOP funds are leveraged mainly through facilities, which faculty use to attract grants and gifts. This leveraging can be expressed in several ways. In FY12, core UCOP funds amounted to $7.6 M, vs. $4.8 M received from external funds (Appendix 1), for a leveraging factor of 1.63. $300 k was passed on to UCLA, where it raised another $600 k in contracts, for a leveraging factor of 3. The sum of all UCO-related grants to UC astronomers in FY12 was $16.8 M (Appendix 2), which is comparable to UCOP's contribution of $20.5 M to Keck + UCO, for a leveraging factor of 1.8. (Note that when the Keck contribution goes down by half in 2018, the leveraging would increase to 2.2 if other numbers stay constant.) Finally, *all* UC astronomy grants were $54 M/yr in 2006-2010 (*Cost of UC Astronomy* report, in prep.), so if UCOP funds are taken to be the nucleus of the program, the leveraging factor is 3.7.

However, leverage estimates that use grant returns vs. UCOP funds are biased against astronomy, as they charge the full operating costs of telescopes to astronomy, whereas the UC cost of laboratories (e.g., for lab scientists) is not included. The *Cost of UC Astronomy* report compares the *lifetime* research investments by UC in astronomers vs. laboratory scientists and shows that the two are comparable. The difference is that the facilities investment for astronomers is centralized (and visible) at UCOP but embedded in the campus expenditures for laboratory scientists.

Finally, we note that it was dependable UCOP support year after year that ultimately yielded $125 M from the Moore Foundation for the Thirty-Meter Telescope – a leveraging factor that is *17 times* the annual UCO budget.

Consideration #2: What is the scope of access to these unique systemwide opportunities, resources or facilities for UC faculty, students and researchers? How does it go beyond that which could be achieved through a single campus initiative or activity?

Profile of UCO affiliated researchers: Appendix 2 lists *632 affiliated researchers,* including 82 faculty, 55 research scientists, 150 postdocs, 181 grad students, and 164 undergrads. Affiliated researchers are limited to those that directly used UCO facilities, such as telescopes and laboratories, in the last three years – theorists and other types of astronomers are not included if they did not use UCO. The nature of the usage is shown in Appendix 2. Affiliated researchers are spread across the eight astronomy campuses, Lick, LBL, and LLNL. A plot of their distribution by campus is shown below – UCSC has the largest number, followed by UCB and UCLA. These data show that UCO's impact across the system is extremely broad – UCO is serving many researchers, most of whom are students and postdocs.



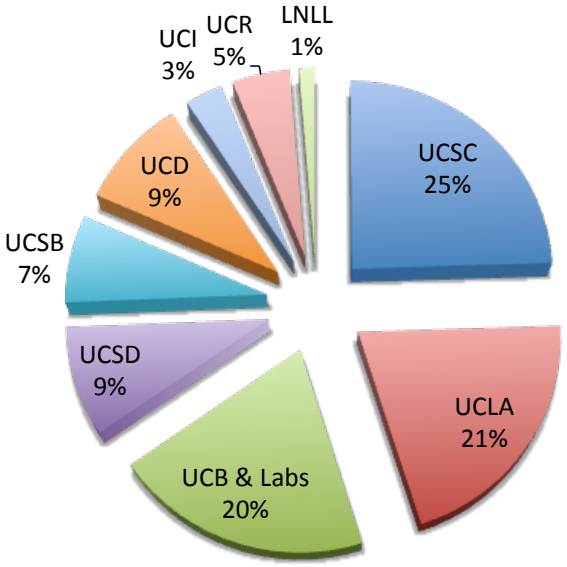
Telescope usage: The connection that each of these researchers has with UCO facilities is shown in the Usage table. The great majority of researchers use the telescopes, which are supported by UCOP funds under Activities #1,2,3,5,6 and Initiatives #1,2. UC faculty and senior research scientists anywhere in UC, LBL, and LLNL can apply for Keck time; researchers of *all* types (including students and postdocs) can apply for Lick time. Observing time at both sites is awarded competitively based on peer review by Time Allocation Committees (TACSs), which are populated by UC astronomers from all campuses, managed by the UCSC Astronomers, and supported by UCO administrative and computing staff. Lick time is fully subscribed, and Keck time is highly oversubscribed.

Telescope usage by campus is shown below. Seventy-five researchers were PIs at Keck in the last three years, and 74 researchers were PIs at Lick. The overlap was only 22; hence there would likely be a significant increase in Keck demand if Lick were closed. Half of Lick PIs were grads and postdocs, and an estimated 110 additional grads and postdocs were Co-I's at Keck, highlighting the importance of UCO telescopes to teaching and training (Activity #4; Initiative #3). Keck nights are nearly uniform across campuses when normalized by the size of the faculty in each department.

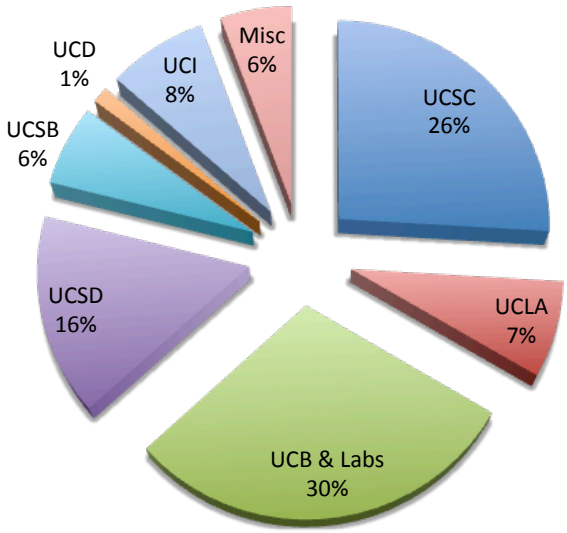
Shane 3-m usage by campus and researcher type is shown in the second figure (all Keck PIs are either faculty or senior researchers, so Keck is not shown). Shane use is more variable across campuses, with strongest faculty users at UCB and UCI and strongest postdoc users at UCSC and UCSB.

Non-telescope usage: In addition to telescopes, Appendix 2 indicates that 37 researchers used the UCO instrument laboratories to build instruments, of whom 12 were faculty and 12 were students or postdocs (Activities #2,7 and Initiatives #2,3). Thirteen researchers (including 11 faculty) stressed the importance of UCO (including Lick) for education, public outreach, and development (Activity #8; Initiatives #4,5). These data were gleaned from an on-line Questionnaire that was sent to all faculty and senior researchers asking about the total impact of UCO on their careers. Full replies are available in Appendix 4, where astronomers speak at length about the importance of UCO in their own words.

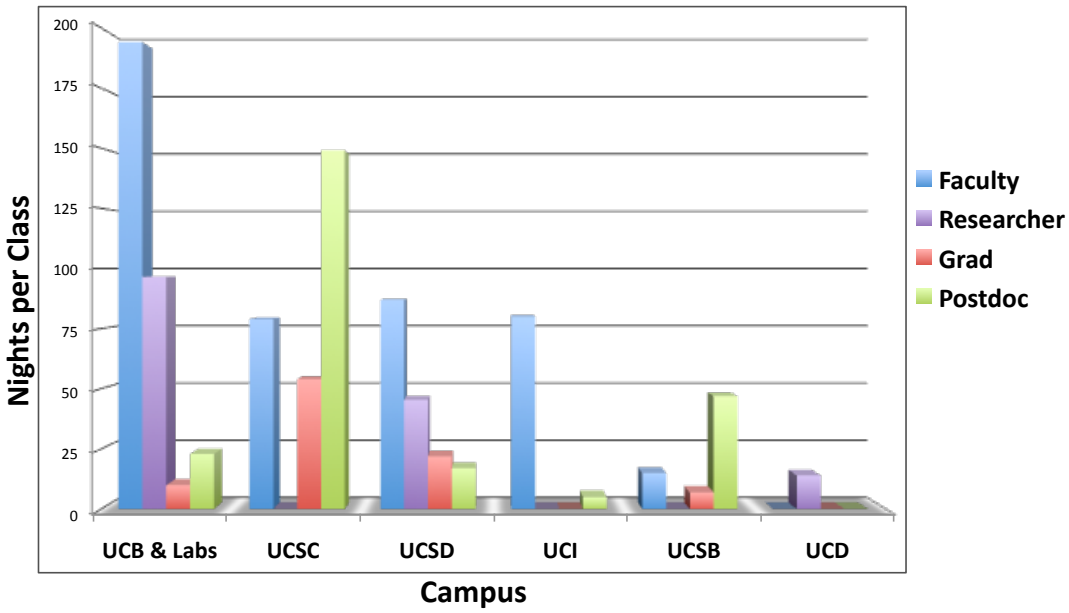
Keck Use by Campus, 2010-2012



Shane 3-Meter Use by Campus, 7/1/10-6/30/13



Shane 3-Meter Use by Researcher Class, 7/1/10-6/30/13



The importance of UCOP funds: The magnitude of UCO facilities is much larger than could be assembled by a single campus. The original capital investment at Keck is $330 M (in 2012 dollars), plus annual operations of $16M/yr. These funds are provided by UC, Caltech, and NASA collectively; UC's share of 42% is larger than any single campus could afford. The UCOP annual budget of $7.5 M for Lick is also large compared to the scale of typical campus initiatives. *Pooling systemwide resources through UCOP is what makes it possible for UC to operate Keck and Lick.*

Moreover, observatories, like battleships, require a *minimum crew* to operate – fall below this, and the place must close. Add to this the fact that observatories have *long useful lifetimes* of order a century and one sees that UC's commitment to astronomy rests on having *dependable long-term support.* We can and should assess what that level of support needs to be, but the current funding model based on annual operating funds through UCOP is indispensable.

- Consideration #3: How do the unique systemwide opportunities provided by program help attract and retain faculty, researchers, technical staff and students, significantly enhancing campus recruitment/retention efforts?

Impact on UC personnel: Access to UCO telescopes has been a major factor in raising UC astronomy to world-leading status. In the wake of Keck, 23 new astronomy professors came to UC after 2001, a growth of 20%; four have come in the last three years. Most of the growth took place at campuses that previously had small or no O/IR programs. The lure of excellent telescopes has created world-class departments practically overnight, which in turn fosters excellence in sister departments such as theoretical astrophysics, space sciences, physics, geophysics, and planetary science.

UCO facilities have had a major impact on career choices, as demonstrated by the Questionnaire. The replies from 71 faculty and 21 research scientists are tabulated in Table 2. An overwhelming 88% report that the presence of UCO facilities were crucial or important in their decision to come to UC, and 94% say that these facilities were crucial or important in their decision to remain at UC. Ninety-seven percent report a crucial or important impact by UCO on their research directions. The individual replies, which are available in Appendix 4, express very powerfully the impact of UCO facilities on all aspects of researchers' careers. As might be expected, retention has been outstanding – *not a single UC observer* has left for another academic department in over a decade, which is highly significant given the deluge of offers that have come to most UC professors in these financially difficult times.

Table 2. Impact of UCO on Faculty and Research Scientist Career Decisions

	Impact on coming	Impact on staying	Impact on research program
Crucial	76%	81%	91%
Important	12%	13%	6%
Crucial or important	88%	94%	97%

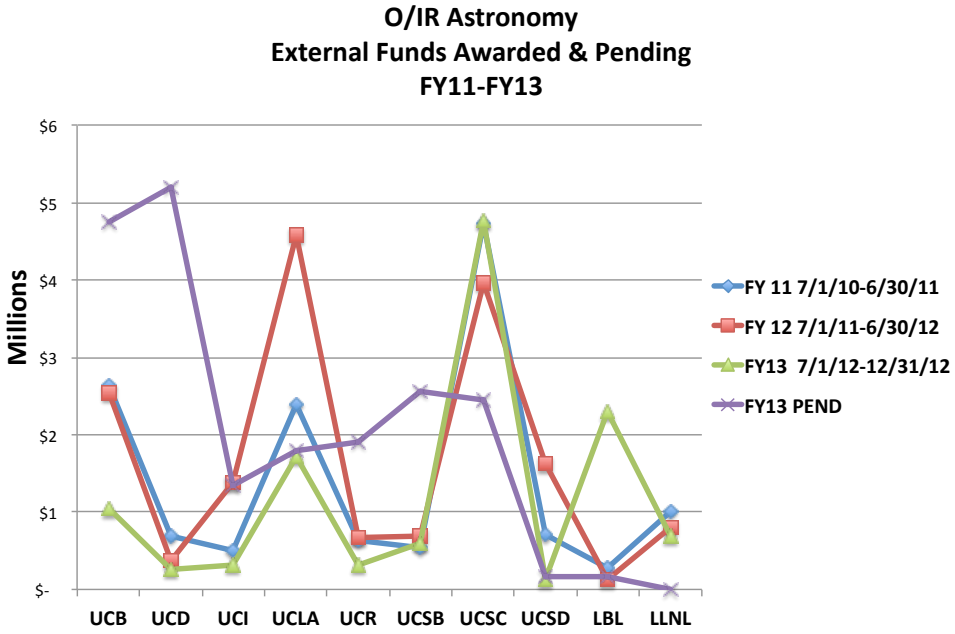
We reiterate that in no case does appointment to the University of California carry guaranteed telescope time, for faculty or students – all access to telescopes is *competitively peer-reviewed*.

Quality of UC astronomers: To quantify this, a database was created of peer universities from the 35 astronomy departments in the recent National Academy graduate program rankings. The size of the UC faculty is 14% of the faculty in these institutions. In comparison, UC faculty have won 20% of major international prizes to astronomers, 22% of all prizes to astronomers awarded by the American Astronomical Society, and comprise 25% of National Academy astronomers. The performance of junior UC astronomers is even more impressive: 32% of Pierce and Warner Prizes by the American Astronomical Society and 32% of Packard Fellowships have gone to junior UC astronomers in the last ten years, for an over-representation of *more than a factor of two*. For more details, see Prizes in Appendix 4.

Objective 2: Enable successful competition for sponsored research projects and grants for which proposals from a single campus would be substantially less competitive.

- Consideration #1: How does the program enable successful competition for sponsored research projects and grants for which proposals from a single campus would be substantially less competitive?

Total grants and gifts: Appendix 2 lists external grants and gifts associated with UCO. Observing logs at Lick and Keck were screened to find the total list of "UCO observing PI's" in the last three years. UCO Advisory Committee members were asked to add individuals on their campuses who have significant UCO interaction but who were missed by this list. Grants persons on each campus were asked to provide a list of *all* grants to these persons since 7/1/2010, and titles and comments were screened to remove unrelated grants. The criterion used for relevance was that the grant or gift would not have existed without UCO. The figure below shows total grant + gift activity for the last three years by campus. The largest campuses on average are UCB, UCLA, and UCSC, which are also the largest faculties.



Instrument grants and gifts: Grants and gifts were then divided into two groups, instrumentation/facilities on the one hand, and science. Items in the former category build or improve UCO facilities and are included in the UCO operating budget as non-UCOP funds (Appendix 1). Instrument grants totaled $5.2 M over FY11, FY12, and FY13 (6 months), which was 12% of total grants in the same period. Keck instrument projects usually involve multiple labs at UCLA, UCSC, Caltech, and WMKO, with one lab as leader. A typical Keck instrument has a price tag of $5-15 M, and funds come mainly from Keck operations and federal grants. Keck partners have also been raising an extra $2.5 M per year for instruments by exchanging Keck nights at $100 k per night. Federal proposals submitted in FY13 included $1.5 M to build a new tertiary mirror for Keck I plus several proposals to fund instrument upgrades. Every proposal opportunity at NSF and NASA is used to apply for Keck instrument money.

Instrument grants and gifts play a major role at Lick as well. The APF telescope and spectrograph were initiated by a grant of $6 M from the US Naval Observatory, and later grants and gifts totaling $4 M were used to complete the project. The Shane Adaptive Optics system and laser were funded with $2 M from the NSF and $380 k from the Moore Foundation. A donor has been approached for $360 k to fund a spectrograph upgrade for the Shane 3-meter.

In summary, instrument grants help to pay staff salaries at UCSC and UCLA and also cover some of the operations costs at Lick Observatory. The core UCOP budget was $7.55 M in FY12, and non-UCOP income was $4.8 M (Appendix 1). Non-UCOP funds thus comprised 39% of the operating budget in FY12.

Science grants and gifts: The second category of grants and gifts supports scientific research. These pay the research expenses of individual UCO affiliate researchers and are *not included in the UCO budget*. The total science grant income in FY11, FY12, and FY13 (6 months) was $37.8 M on all eight astronomy campuses and both national labs. Analysis in

the *Cost of UC Astronomy* report shows that the return on astronomy grants relative to UC research investment is near the median of other sciences.

Private giving: A special opportunity given to astronomers is the chance to raise funds from private donors, who often wish to contribute to the quest to understand the universe. *Every world's-largest telescope from the Lick 36-inch refractor to the Keck 10-m telescopes was built by private funds.* Keck was enabled by two gifts from the Keck Foundation in 1985 and 1991 totaling $144.6 M ($276 M in today's dollars), and gifts by the Moore Foundation of $125 M to each of UC and Caltech have launched the Thirty-Meter Telescope. The Moore grants came about because of UCO's previous success with Keck, which was achieved using UCOP funds.

Other (historic) private gifts to UCO include $9.8 M from the Moore Foundation to create the UCSC Laboratory for Adaptive Optics plus contributions of $600 k and $380 k to APF and Shane AO. The KAIT robotic telescope at Lick was financed in part by a private donor, and its highly successful supernova search helped improve our confidence in the discovery of the accelerating universe. Over decades, many donors gave a total of $3.8 M to the Lick endowments, which return $156 k yearly, mostly used for graduate and postdoc support, lodging expenses at Mount Hamilton, and support for the data archives and historical collections. In short, UCO astronomers are attuned to the need for development and are currently pursuing multiple programs at UC and at Keck with multi-million dollar goals.

To summarize, UCO has successfully raised large sums to *build new telescopes* such as Keck, TMT, and APF; has raised some of the money needed to *instrument them*; but finds it difficult or impossible to find *operating funds* from grants and gifts. This is why UCOP funds are vital – to finance operations and to supply instrument funds that cannot be found from other sources.

Campus support: The UCSC campus provides $430 k per year for maintenance at Lick Observatory (Appendix 1). As the host campus, UCSC also provides central business services and infrastructure plus 26,000 sq ft of laboratory space and offices for about 30 people (not including academic offices). At UCLA, the campus provides 2000 sq ft of laboratory space, offices for ~15 people, salary support of ~$160 k per year, and accounting and purchasing support.

How UCOP funds are used to compete for external support: UCOP funds operate the telescopes, which are the basis of all astronomy science grants. UC observers have preferred access to UCO facilities, which makes their proposals much more competitive than those of other astronomers, who have to compete for time at national observatories. Preferred Keck access is especially attractive. UCOP funds are also used to prepare instrument proposals and to provide matching funds for them. The exchange of Keck nights to support instrument construction converts additional UCOP funds into seed money for Keck instrument proposals. Finally, UCOP funds pay 80% of Astronomer faculty salaries at UCSC and summer salaries at UCLA, which enables them to write highly competitive instrumentation grants and engage in fund-raising for UC (e.g., the $125 M Moore Foundation grant for TMT).

- Consideration #2: How does the program's approach to program management, research project development, and research project collaboration build systemwide engagement, consensus and support that encompasses (and benefits) multiple campuses?

Management and governance: Organization charts for UCO are shown in Appendix 4. We have a Director and four Associate Directors (for the UCSC Instrument Laboratories, the UCLA IR Laboratory, the Thirty-meter Telescope, and Lick Observatory). The UCLA IR Lab Associate Director is a UCLA faculty member; the others are UCSC Astronomers. The chief committee below the Director is the UCO Advisory Committee (UCOAC), which has eight members from each astronomy campus, the four Associate Directors, and 6 *ex officio* members; the UCOAC charter is in Appendix 4. Two science advisory committees – the Keck Science Steering Committee (Keck SSC) and the Thirty-Meter Telescope Science Advisory Committee (TMT SAC) – link to UCO's partner communities. UCO representatives to these committees are also *ex officio* members of the UCOAC. There are two Keck Time Assignment Committees (Galactic and Extragalactic) and one Time Assignment Committee for Lick. Altogether, 27 seats on governance committees are held by senior faculty and researchers around the system. Members of all committees are appointed by the Director with guidance from the

UCOAC. Memberships are broadly distributed among the campuses, the committees meet two to three times a year, and terms are typically for three years.

In addition to these standing committees, UCO has convened a Strategic Planning Committee this year under the aegis of the UCOAC. This committee, which has broad representation from all campuses, is meeting now to advise on operating Lick and on strategies to maximize UC's benefits from Keck and TMT.

UCO also reports upwards to a systemwide Review Board that was created this year by the VPRGS. Its purpose is to review UCO policies and strategic plan and to advise ORGS on the UCO budget. The Board consists of 13 members, of whom roughly half are UC astronomers and half are UC administrators. This board is new; the first meeting was in December 2012. The Board charter and membership are in Appendix 4.

Systemwide engagement: The eight astronomy campuses and two national labs collaborate on observing programs (Activities #1,5) and on conducting forefront research (Activity #7). The governance structure unites all campuses. UCSC and UCLA collaborate in instrument building (Activities #2,3,6; Initiatives #1,2,3). UCLA, UCB, and UCSC collaborate on public outreach, teacher training, and fund-raising (Activity #8; Initiative #5).

A further mechanism to foster collaboration is *Large Multi-Year Approved Programs (LMAPs;* http://www.ucolick.org/keckobs/lmap.html), which encourage *UC multi-campus teams* to compete jointly for especially large amounts of telescope time. LMAPs are a special chance to break new scientific ground. Famous Keck LMAPs are the DEEP surveys of distant galaxies and Doppler surveys that broke open the exoplanet world; a current Keck LMAP, led by junior faculty, is observing distant galaxies with MOSFIRE. Lick hosted an LMAP to monitor black holes. LMAPs release large data sets to the community and win grant support and plaudits for UC.

Distribution of UCOP funds to campuses: UCO does not typically spread funds among campuses but rather creates centralized facilities at Keck and Lick that all campuses use. Nearly all UCOP funds are spent at UCSC and Lick; $300 k supports the instrumentation group at UCLA, which develops IR instrumentation for the Keck and TMT telescopes. A small amount of funds is disbursed to cover travel expenses to governance committee meetings.

Principle 2: Promote efficient inter-campus collaborations & systemwide economies of scale.

Objective 1: Ensure efficient operation/management of shared resources, research results, facilities, systems, and/or staff.

- Consideration #1: How does the program operate/manage systemwide shared research resources, facilities, systems, and/or staff more efficiently than might be managed by a single campus program or initiative?

As phrased, this question does not quite fit UCO, since our facilities are of such a scale that no single campus could create or operate them. But as a result, the individual campuses are able to hire faculty and guarantee them access to world-class facilities *without additional start-up funds*, which increases the efficiency of hiring new faculty. In addition, UCO attempts to maximize efficiency in other ways:

Intercampus collaborations: UCO governing committees connect UC astronomers and foster collaborations. Identical remote observing systems are duplicated economically on each campus and save travel funds. UCLA and UCSC share expertise and personnel between their two labs. Instrument projects are collaborations of several labs in which each site specializes: UCSC in optics, coatings, and detectors; UCLA in IR spectrographs, IR detectors, and cryo-cooled systems.

Research efficiency: Efficient use of telescope time is an astronomical imperative, and each night is carefully pre-planned. Science productivity is maximized by having written proposals peer-reviewed and ranked by the Time Assignment Committees; nights are awarded according to rank. Having smaller telescopes available at Lick increases Keck efficiency, as all projects that can be done at Lick are redirected there, and UC astronomers use Lick facilities to

carefully vet and design programs for Keck. At both Keck and Lick, nightly trouble logs are used to select and fix the most pressing problems, with the goal of achieving 80% of time observing on target.

Budgetary efficiencies: The UCO staff at UCSC + UCLA was 79 in FY07 but declined to 57 in FY13. Strategies to maintain services despite cuts have included: elimination of all non-essential functions; consolidation of functions in single employees; demanding that each employee do more and have broader skills; outsourcing work (but union rules interfere); fewer observatory vehicles; tighter tracking of time spent on repairs at Lick. This spring will feature a 360-degree review of the UCO business office.

The FY14 Lick crew of eight is now as small as it can be for 7-night-a-week Shane operations. Reducing to 5 nights was considered, but the gaps in data seriously impair science without yielding significant savings. Creative scheduling has managed to use the same staff to cover both night and day duties. In 2013, we will inaugurate a one-month closure over the holidays (during bad weather) and reduce the number of instrument changes.

New revenue sources: Many possibilities have been explored: Observing fees of $500/night on Shane at Lick: being discussed, but burden on students and postdocs would be high, and it is possible this would lead to a dramatic reduction in demand for the facility. Include Lick operating fees in science grants: possibly, but no returns until two years from now. Renting out the 3-m: no market yet identified. Rental of Main Building for corporate and private functions: space is small, expected revenue not large. Open commercial restaurant in the Lick diner: cost of renovating for commercial use is large ($50 k). Expand Lick summer visitor programs: yes, will start summer 2013. Open camping facility at Lick: yes, will start in 2013. Make the Lick gift shop profitable: yes, now staffed with part-time labor – visitor programs and gift shop now cover Main Building maintenance. Advanced Astronomical Coatings Laboratory: new patents may have market value. "Renting" technical staff to other Keck projects: being explored. Seed instrumentation grants with more UCO labor to make more competitive: adopted. Private fund-raising: many initiatives are in play, including donors for APF planet searches, various Lick surveys, Keck Next-Generation Adaptive Optics, and Kast spectrograph upgrade. Refurbishing the UCSC instrument labs: $10 M requested from UCSC, which will seed projects at TMT and Keck with much greater return.

Cost comparisons for Keck Observatory: Keck operates two 10-m telescopes on Mauna Kea, Hawaii. The annual cost is $16.0 M for operations and infrastructure (not counting new instruments, major repairs, or fund-raising/outreach), hence $8.0 M per telescope. The Gemini Observatory operates two 8-m telescopes, one on Mauna Kea and one in Chile. The cost computed in the same way is $30.3 M, or $15.2 M per telescope. Canada-France-Hawaii Observatory operates a 3.6-m telescope on Mauna Kea, Hawaii. Operations are $7 M/yr for this relatively small, solo telescope. The European Southern Observatory operates four 8-m telescopes in Chile. Operations in 2011 cost 16.9 M Euros ($24 M), plus 242 FTE. Converting FTEs to dollars using $100 k per FTE yields a cost of $48 M, or $12.0 M per telescope. Keck is operating its 10-m telescopes for ½ to 2/3 of the costs of other telescopes that are smaller and less complex.

Cost comparisons for Lick Observatory: Lick operations in FY12 were $1.70 M (Table 1 above), plus $0.43 M from UCSC for facilities maintenance (Appendix 1) for a total of $2.13 M. The bulk of this was for the Shane 3-m. Reduction is planned in FY14 to $1.9 M, for a cost of $5.2 k per night. This compares to $6.5 k per night for the 3.5-m at Apache Point, $3.3 k for the 3.8-m UKIRT infrared telescope (a simple single-purpose telescope), $7.4 k for the Palomar 5-m, and $27 k for the 3.6-m at CFHT. Costs for Lick in FY14 will be lower or comparable to these other observatories.

- Consideration #2: Is the program's operational efficiency periodically evaluated and how are recommendations for improvement implemented?

UCO has been the subject of two recent reviews, which are attached in Appendix 4. Highlights are below:

The Astronomy Task Force (ATF) (http://www.ucolick.org/documents/aft_report.pdf) met in the spring-summer of 2011. It was comprised of 14 UC astronomers from nine campuses and labs and was charged by UCOP to determine a set of priorities for future system-wide investment in UC astronomy over all sub-disciplines. The survey identified the following prioritized recommendations:

1. ***Ensure the long-term success of UC leadership within the TMT project.*** UC should play a leadership role in the development of TMT's telescope design and instrument suite and should commit to shifting $6.5 M/yr in 2018 from Keck operations to TMT operations when that portion of Keck operations returns to UC.

2. ***Keep the Keck Observatory at the cutting-edge of 10-m class telescopes and maintain UC's current share of the telescopes.*** UC should design and construct new instruments and new adaptive optics systems for the Keck Observatory. This requires UC to keep its instrumentation labs strong (at UCSC and UCLA).

3. ***Strengthen support for development and construction of instrumentation and adaptive optics.*** UC facilities, instruments, and personnel are vital to UC's leadership in both Keck and TMT and to the success of these observatories. UC should focus system-wide funding on labs capable of building next generation AO and instrumentation.

4. ***Continue funding Lick Observatory at current levels, while exploring new funding models.*** Lick was ranked fourth in priority after Keck and TMT and their instrumentation. Lick is a valuable facility, but UCOP investment should be reduced over the long term.

The UCO External Review (http://www.ucolick.org/documents/externalreview_report.pdf) met in August 2011. It was conducted by ten eminent international leaders in astronomy and astrophysics and it also reported to UCOP. Below are the key findings:

1. ***Assessment of UC astronomy and astrophysics****:* The committee judged that systemwide UC astronomy and astrophysics research is at the forefront in the U.S. and in the world. The committee noted:

"*UC leadership in astronomy through observations on the Keck and Lick telescopes has produced some of the most important astronomical discoveries of the past 15 years, including ground-breaking work on exoplanets, cosmology, and black holes.*"

"Overall, astronomy has grown to become one of the flagship programs in the UC system, as measured by National Academy of Sciences memberships, major international prizes, and other esteem indicators."

2. ***Assessment of UCO performance:*** The committee found that UCO has been very effective in managing the shared facilities for UC astronomical research and in providing leadership to enable a UC role in, and UC access to, the next generation of forefront ground-based O/IR facilities:

"*By all criteria, the performance of UCO as an organization that supports and advances observational astronomy within the entire UC system has been excellent.*"

3. ***Assessment of the UCO model:*** The committee strongly supported the current UC model for centralized UC astronomy facilities, including the role of UCSC Astronomers:

"The committee is convinced that the presence of a core staff of UCO research faculty instrumentalists in stable appointments is a key element in UCO's success."

"Our committee believes that the University's considerable past and future investment in astronomical facilities is best served by a multi-campus organization that exploits the economies of scale in a centralized group on the one hand and the strength of the University of California multi-campus system as a shared cross-campus organization as well."

4. ***Report recommendations:*** The principal recommendations of the committee were that the UC astronomy community should undertake more comprehensive strategic planning and there should be a strengthening of the governance structure for UCO within UC.

We believe that the Activities and Initiatives described in this report are consistent in all respects with the findings and recommendations from these two external reviews.

Lick operations review: UC's stringent budget climate has caused UCOP's investment in Lick to be scrutinized. A planning workshop was held in September 2012, followed by deliberations this winter to examine every aspect of Lick operations. The conclusions are that a) Lick is playing an important role in UC teaching, training, and research; b) Lick increases Keck efficiency by off-loading a substantial fraction of observing demand; c) Lick facilities such as the Main Building and 36-inch refractor are prime venues for UCO's education and outreach programs and these programs would be seriously damaged if these facilities were closed; d) major investments have been made in two forefront projects (Shane AO and the APF telescope) that require five more years of operations to bear fruit; e) commitments have been made to donors and federal agencies for these projects that would involve moral, and perhaps legal, repercussions if cancelled; f) in five years, TMT construction will be entering its final phase, at which point it will be appropriate to review Lick's role going forward; g) five years is a reasonable time interval over which to search for external donor support; h) modest further reductions in operating costs are possible without compromising the basic functions of the Observatory and should be instituted in FY14 (so-called "spartan" mode, which is still being finalized); and i) costs of mothballing Lick are not known; a study needs to be undertaken to determine them. For all these reasons we recommend that UCOP *commit to five more years of Lick operations* with the intention of reviewing this plan at the end of Year Four.

Keck operations review: An operations review is also underway at Keck, the first in 15 years. A goal is to evaluate the amount spent on operations versus new instrumentation and to augment the latter if possible. More money for instrumentation would benefit UCO, as some of that money would likely go to the UCSC and UCLA instrument labs.

Objective 2: Demonstrate systemwide research engagement and collaboration beyond that present on a single campus.

- Consideration #1: How does the program regularly engage multiple campuses to encourage and identify opportunities for collaborations and broader participation that can extend (and leverage) UC's existing research expertise and resources across UC campuses?

UCO strategies for community-building and multi-campus collaborations include: periodic newsletters to inform the community, planning workshops like the one last September for Lick Observatory, LMAP observing proposals involving multiple campuses, the annual systemwide graduate workshop at Lick for new PhD students, ongoing UCSC-UCLA instrument collaborations, and the dense network of UCO governance committees. Collaborations for fund-raising and outreach are growing – the *Friends of Lick Observatory* Board has astronomers from UCSC, UCR, UCB, and UC astronomers from multiple campuses will be speakers at the upcoming 20th Anniversary Keck Gala, where summit tours for prospective UC donors will be offered. In short, collaborations support virtually every Activity and Initiative in UCO.

- Consideration #2: How does the program engage additional UC campuses, similar programs, and/or external organizations to promote collaboration, leverage resources, share administrative functions, and avoid duplication of effort to achieve higher efficiencies?

UCO already engages every available UC campus; UCM will be added whenever it hires an O/IR astronomer. UCO's collaborations with Keck partners are nearly as close as those inside UC. This is remarkable since UC and Caltech were formerly fierce rivals, yet have developed deep bonds in Keck during the last twenty years. Our two institutions still constitute the core leadership of Keck, but the cadre of talented scientists at WMKO who run Keck are also peers, and relations with the junior partners NASA and the University of Hawaii are also excellent.

The point is: UC astronomers are skilled collaborators, both with each other and with external groups. This talent is widely acknowledged in the scientific community. It was Keck's success, both technical *and* political, that was seminal in birthing TMT, which has now grown to become the first "Pacific Rim" telescope involving Canada, Japan, China, India, and California. UC and Caltech have shown the world how to partner to build "big glass".

Principle 3: Serve the State and citizens of California.

Objective: Collectively impact Californians through research in multiple regions of the state

- Consideration #1: How does the program demonstrate UC's commitment to public outreach and inclusion, citizen engagement, and broader public education?

The following summary is based in part on replies to the Questionnaire sent to UCO faculty and senior researchers, which inquired about their use of UCO facilities for teaching and EPO. A summary of their replies is in Appendix 4.

Lick Observatory public programs: Located close to the Bay Area, Lick Observatory receives some 25,000 visitors a year, who view exhibits and tour the historic 36-inch Great Refractor. AAA calls Lick a "GEM Attraction", a "must-see" site of exceptional interest and quality. Based on feedback received, our visitors agree (see EPO, Appendix 4). Twenty-five hundred guests attend the summer *Music of the Spheres* concerts and *Friday Night Visitor* programs, where they are briefed on forefront research and view through the refractor. Special events are added, such as the Transit of Venus in 2012, which attracted two thousand guests. The visitor programs are self-supporting through the gift shop and admission fees. *Friends of Lick Observatory*, established in 2012, is a new channel for outreach and fundraising. Thanks to its excellent location and unique facilities, Lick serves as the focal point of all UC Astronomy & Astrophysics EPO efforts.

Public talks: Virtually every UCO astronomer gives public talks, which are immeasurably enriched by data from Keck and Lick. If students and postdocs are included, we estimate that UC O/IR astronomy probably generates more than a thousand talks a year, primarily within the state of California.

Center for Science Education collaboration: UCO has signed an MOU with UC Berkeley's *Center for Science Education* to develop and fund EPO programs related to Lick Observatory. Two thrusts are identified: a Lick Observatory Teacher Workshop (LOTI), and a project with San Jose's *Tech Museum of Innovation* to develop exhibits and a robotic telescope.

Adaptive optics education: The Center for Adaptive Optics is a former NSF Science and Technology Center that spun off from UCO and has now remerged with it. AO has cross-cutting application to retinal imaging and biological microscopy and is of interest to industry and health scientists as well as astronomers. CfAO runs a week-long *Adaptive Optics Summer School* at UCSC. Attendees in 2010-12 have averaged 60 per year and come from 7 UC campuses, 51 universities, 16 observatories, and many labs and companies from around the world. The School was launched under NSF funding, continued under UCOP, and is now self-sufficient. CfAO's graduate course in adaptive optics is taught live via video-conferencing to students all over UC and the world, including industry.

ISEE at UCSC: A further spin-off from CfAO is UCSC's *Institute of Scientist and Engineer Educators,* a unique training program that prepares science/engineering grads for their teaching role as future professors. ISEE supports diverse learners with inquiry-based science teaching techniques. In the last three years, 160 graduate students have been trained as professors, and 200 California community college students transferring to UCSC have been helped.

Science Internship Program: Founded by UCSC Astronomers, SIP is a one-of-a-kind program that pairs high schoolers with UCSC research teams for 6-10 summer weeks of intensive science immersion. Students become full-time team-members and contribute integrally to cutting-edge scientific discoveries. One-third of SIP students were semi-finalists in the 2012 Siemens competition. To SIP, we can add dozens of NSF summer REUs hosted throughout the system.

COSMOS Summer Schools: The UC COSMOS summer programs are aimed at talented high school students interested in STEM careers and hopefully headed for leadership roles in California and across the nation. UCO astronomers lead COSMOS astronomy "clusters" at UCI, UCD, and UCSC, where Keck and Lick data strongly enrich the curricula.

Female-friendly programs: The UCO astronomy programs are leaders in welcoming female scientists to academia. A third of UC astronomy graduate students systemwide are female, and UCSC has five female astronomy professors, the largest in the nation. Two years ago, a study showed that Astronomy & Astrophysics accounted for *half* of all female physicists in the UC system.

Teaching and training of UC students: Consideration #1 above stresses public outreach, but the most-repeated refrain of the Questionnaire is the impact of UCO facilities on *UC students.* Professor after professor cites the powerful inspiration

that comes from giving students real astronomy data, taking them observing, or even just letting them see the telescopes. The Questionnaire in Appendix 4 gives many examples.

An introduction to scientific thinking: For many students, astronomy is the only contact they will have with the scientific method. Of UC undergraduates now enrolled, *35,000 (20%)* have or will take a Gen Ed astronomy class. Through astronomy, students learn that magical thinking has no place in science and that facts have value in understanding our world. Astronomical images of "spaceship Earth" hanging in the void of outer space bring home the fragility of our environment. In fact, astronomy has played a central role in understanding climate change. The first inkling of rapid change came from models of the asteroid impact that extinguished the dinosaurs 65 million years ago. The first example of a runaway planet-wide greenhouse effect was Venus, whose surface temperature exceeds 800 degrees F because of a thick atmosphere of carbon dioxide. The lesson from astronomy is that *planets can go bad,* and we must take care to protect our own. An even deeper lesson is that human beings arrived here by physical law and must live within its limits. These concepts are fundamental to environmentalism.

- Consideration #2: How does the program deliver significant system-wide impacts, either locally or across multiple regions of California, in economic, social, environmental, energy, health, security, and/or other areas of public interest?

The answer to this question might mention high-tech spin-offs, such as two NSF Science and Technology Centers (the Center for Particle Astrophysics (UCB) and the Center for Adaptive Optics (UCSC), or the use of adaptive optics for retinal imaging, or a CfAO spin-off company (http://irisao.com) that manufactures micro-electro-mechanical (MEMS) devices. But a higher-stakes issue looms – if US immigration laws are altered to permit educated émigrés to remain here, *UC's image will become much more important to the state of California*. First, a word about astronomy in the media.

Astronomy and the media: UC gets a huge media "bang for the buck" from spending on UCO. Astronomy mentions in the media dominate the physical sciences and lead all sciences generally after health and medicine. Astronomy funding is 1% of the US science and engineering research budget, but astronomy's media impact is 10x greater, based on *Discover Magazine's* top 600 science and engineering stories for the last six years – i.e., instead of 6 stories, astronomy had 58. UC's share was even bigger: among those 58 stories, 10 mentioned UC by name, whereas the expected number (based on ORGS's astronomy funding as a fraction of national R&D) was 0.2, an over-performance by a *factor of 50.*

These broad statistics are backed up by specific examples. Googling "exoplanets NYT" yields as the first item (out of 4 million) a story mentioning G. Marcy (UC Berkeley) and S. Vogt (UC Santa Cruz) – recognized leaders in one of the fastest growing and popular astronomy fields. Googling "black holes NYT" yields as the second item (out of 5 million) the discovery of the biggest black holes by professor C.-P. Ma (UC Berkeley) and graduate student N. McConnell. More examples could be added, such as the Galactic Center black hole (Ghez), the first galaxies (Illingworth), the accelerating universe (Perlmutter and Filippenko), breakthrough images of exoplanets (Macintosh), etc., etc. – all "hot" topics dominated by UC O/IR astronomers. It is a rare *NOVA* or *Discovery Channel* program on modern astronomy that does not mention, or in many cases prominently highlight, research done by UC astronomers. "UC Astronomy in the News" catalogs press releases by all UC astronomy departments (http://www.ucolick.org/news). For the last four years, UC astronomers have averaged over *forty per year*.

These facts are notable because of the pivotal role that astronomy has come to play in the "media war" among nations. A virtually unique combination of technical difficulty plus popular interest makes astronomy a *preferred arena* in which nations vie to demonstrate their technical prowess. The Canadians have chosen astronomy as a signature science. The Europeans decided to challenge US hegemony in just two areas, the Large Hadron Collider but also the European Southern Observatory. The signature science project of Japan is Subaru Observatory. India exploited Secretary of State Clinton's recent visit to announce their joint partnership in the Thirty-Meter Telescope. China's new president Xi Jinping made it a point to personally address the International Astronomical Union meeting in Beijing, where he committed China to excellence in O/IR astronomy, including the Thirty-Meter Telescope. In the heated arena of international science, it is highly significant that, in O/IR astronomy, UC has attained a prowess that is *on a par with whole nation-states*.

The coming brainpower competition: We turn next to US immigration laws, which are poised to permit foreign students to remain in this country. This change will alter California's economic strategy profoundly. Previously, UC educated foreign students but then had to send them home, which limited our appetite for such students. Allowing such students to

remain here will unleash overnight *UC's inherent power to attract and educate a superior California workforce,* but we will not be alone – 49 other state universities will have exactly the same goal. Overnight, the world's *best public university system* will be worth billions…and the value of having highly visible programs of *international stature* will be immense. UC must foresee this moment, and invest.

This is what Initiative #5 is all about: "Exploit the high public interest in astronomy for the benefit of UC and the state of California." We can imagine a campaign to present the Thirty-Meter Telescope as "California's" telescope, where a whole generation of school children grow up with the telescope as it is constructed and, through it, learn about astronomy, engineering, optics, project management, etc. – the possibilities are rich. But astronomy is not alone. By consolidating and trumpeting the excellence of *systemwide research*, ORGS can be UC's natural vehicle to advertise, world-wide, the university's technical and intellectual pre-eminence. Success will mean immense gains for the state of California. UC will be not merely relevant to California, it will become its *prime economic weapon*.

Astronomy as a focus for building Pacific Rim partnerships: The final point, in the same vein, is astronomy's potential for forging links to Pacific Rim countries. In Keck, UC has already created a valuable foothold in Hawaii, the geographic focal point for the Pacific Rim. Our proposed partners in TMT – Japan, China, Canada, and India – are major Pacific Rim countries. The TMT agreement obliges partner countries to contribute in-kind technology to the project, and UC instrument teams have already been trolling through Japan, India, and China to find partners, and in the process building institutional ties. Building TMT on Mauna Kea, where Canada, US, and Japan already have major telescopes, creates the possibility of even larger collaborations – a "Pacific Rim Mega-Observatory", if you will – and astronomers are already talking about this. In short, the TMT partnership now taking shape in Hawaii is a unique opportunity for UC to project its eminence and power to a whole new audience that will be crucial to California's future in the 21st century.

Section Three: Program Budget Narrative

[Section Three —suggested 2 pages]

Provide a brief narrative describing how UCOP systemwide funds are used to support the program's activities and initiatives (described in Sections One and Two).

Describe how your program distributes and prioritizes the UCOP systemwide funds by including a description of how your program would be impacted by the following UCOP budget scenarios.

Table 3. UCOP Expenditures by Activity/Initiative in FY12

Activity/Initiative	Expended K$	% Total Expenditures
Activity 1: Ensure Keck Observatory world-class service to UC observers	$227	3%
Activity 2: Design, build, maintain state of the art instrumentation at Keck	$1037	12%
Activity 3: Develop new technologies of the future for Keck & beyond	$1290	15%
Activity 4: Support/promote grad, undergrad and postdoc teaching/training	$568	7%
Activity 5: Wide array of observing services at UC Lick Observatory	$1699	20%
Activity 6: Design, build, maintain forefront telescopes & instrumentation at Lick	$907	11%
Activity 7: Conduct forefront research	$621	7%
Activity 8: Public outreach, education & development	$278	3%
Initiative 1: Build and operate TMT	$290	3%
Initiative 2: Next Generation AO at Keck	$1104	13%
Initiative 3: Expand training programs in astronomical instrumentation	$28	
Initiative 4: Institute new & more efficient ways of doing business	$286	3%
Initiative 5: Promote UC and California science worldwide	$85	1%
TOTAL	$8420	

Budget narrative: In FY12, UCOP expenditures totaled $8.4 M. Keck Observatory activities (A1,A2) consumed 15% of expenditures; Lick Observatory (A5,A6) consumed 31%; future technologies (A3,I1,I2) consumed 31%; education, public outreach, and development (A4, A8, I3, I5) 12%; research (A7) 7%; and business innovation (I4) 3%. Table 3 below condenses information from tables in Appendix 1. In round numbers, Lick Observatory consumed about one-third of the budget, future technologies one third, and the remainder scattered throughout the remaining one third.

Table 4 compares total expenditures for UCOP vs. non-UCOP funds broken down by budget categories in Appendix 1. There are no expenditures reported in Overhead (since they are not applicable to UCOP funds), Sub-grants (since UCO does not issue sub-grants), or Carry-Forward liens. Salary & Benefits commanded 88% of expended UCOP funds and non-salary expenditures only 12%. This distribution is viable because 54% of non-UCOP funds were available to cover major expenditures in Facilities/Infrastructure, and Lab Expenses and Equipment.

Table 4. UCOP vs. non-UCOP Expenditures by Budget Category in FY12

Category	Expended K$ UCOP	% Total UCOP Expend	Expended K$ Non-UCOP	% Total Non-UCOP Expend
Salary & benefits	$7139	85%	$2011	42%
Overhead			$131	3%
Facilities/infrastructure	$88	1%	$500	10%
Laboratory expenses	$532	6%	$856	18%
Equipment (capitalized)	$12		$815	17%
Equipment (non-capitalized)	$71	1%	$413	9%
Sub-contracts (UCLA)	$300	4%		
Sub-contracts (other)			$103	1%
Sub-grants (specify UC or other)				
Outreach/engagement/education	$278	3%		
Carry-forward (defined as liens)				
TOTAL	$8420		$4829	

Base budget for the ±25% exercise: The budget of UCO has recently been altered due to the shift of the UCSC Astronomer salaries to the UCSC campus, which is due to take place on July 1, 2013. In choosing a base budget for the ±25% exercise, we have elected to take the nominal budget of $7.5 M and subtract off the Astronomer transfers and related academic support to obtain the base budget that will be at the discretion of the Director going forward, namely $4.8 M. The +25% scenario then generates $1.2 M in new funds, and the -25% scenario subtracts that amount.

Status of Lick operations: A strategic planning exercise for UCO is now underway, with first results expected in March. The committee is expected to develop a strategic plan that is broadly consistent with priorities enunciated in the ATF report and the External Review. These priorities (see Principle 2/Objective 1/Consideration 2) give first priority to observing at Keck and TMT (equal), next priority to building instruments for Keck and TMT, and fourth priority to operating and instrumenting Lick, meanwhile looking for new revenue models for it.

Choices in the +25% and -25% budget scenarios must be consistent with these priorities, with major investments going to Keck and TMT. Increased seed support for Keck instruments from the UCO budget is needed. A healthy level for instruments is $2.5 M, larger than the $1 M presently available now in the Keck operating budget. This gap has been filled by selling ~25 nights per year to external parties at $100 K per night, but it is not clear that this market will persist. Infrastructure repairs are also needed at Keck, which will consume much of the revenue from selling nights for the next five years. At TMT, it is important to invest significant resources now in order to gain a toehold in future projects.

For all these reasons, we wish to direct more UCO technical manpower toward Keck and TMT, but not at the expense of irreparably damaging Lick. Many reasons were given above why UC should commit to a further five years of operations

at Lick. In the flat or +25% scenarios, it is highly probable that we can keep Lick open. If less money were available in the -25% scenario, it is probable that Lick will have to close.

+25% scenario: The increase is 0.25 x $4.8 M = +$1.2 M. The following is a prioritized list to show how these funds would be spent, together with the initiatives they would support. These priorities have been vetted by the UCOAC.

• *Assoc. Director for Adaptive Optics ($150 k):* Next-Generation Adaptive Optics is the highest-priority initiative for Keck (Initiative #2). The total program will cost $50 M, is technically challenging, and involves teams at UC, Caltech, and Keck. A senior leader is needed to lead the team, oversee the final design, and coordinate fund-raising. An excellent candidate is currently available, but an offer is needed immediately. Both salary and startup support are being sought from UCSC; $150 k for startup is assumed to come from UCO in FY14. The UCOAC regards this hire as critical.

• *Ensuring the future of the UCLA IR Lab ($150 k/yr):* The UCLA IR Lab may lose key personnel because of funding uncertainty. Currently, UCO provides annual support of $300 k, which is about a third of the budget. An additional $150 k would ensure continuity of key personnel. The IR Lab is vital for both Keck NGAO and TMT (Initiatives #1 and 2). In the opinion of the UCOAC, this item is also critical.

• *Keck and TMT instrumentation ($400 k/yr):* These funds provide seed money for state-of-the-art Keck and TMT instruments. Included are Next Generation Keck AO (Initiative #2), three powerful detector upgrades at Keck (Activity #2), and software infrastructure for TMT (Initiative #1). Work seeded by these funds would strengthen proposals to donors and federal agencies. These allocations are consistent with ATF rankings giving top priority to Keck and TMT.

• *Compensation for service for highly engaged UCO faculty ($160 k/yr):* Faculty on other campuses are working nearly as intensively in service to UCO as faculty at UCSC and UCLA. A formal compensation program would set up a formal process for awarding support, with defined goals, milestones, and performance reviews. Such a program would engage the best talent around the system, share UCOP support more broadly on multiple campuses, and strengthen community ties. This program is a major centerpiece of Initiative #4 (new ways of doing business).

• *TMT instrument assembly facility at UCSC ($300 k):* The UCSC Instrument Laboratories were built in "temporary" buildings in 1965. The space lacks clean rooms and modern climate control and is too small to assemble the huge instruments of TMT. The cost of rebuilding the facility is $10 M. $300 k is needed in FY14 to begin design, project planning, and environmental impact statements.

• *Fellowships for astronomical instrumentation ($100 k/yr):* Initiative #3 would expand PhD and postdoctoral training for astronomical instrumentation. Funds would be allocated to campuses on a one-to-one-match basis. $100 k would support two fellows, who could be on any campus. This pilot program would be used to attract further donor funds.

• *Full-time public relations and development professional ($100k/yr):* UCO communication needs are intense. A full-time professional would raise the quality of our media materials, tighten community relations, steward prospective donors, and partner with other UC units to advertise UC's importance to California. This individual is key to Initiative #5.

The total cost of these proposals in FY14 is $1.360 M, slightly more than the $1.2 M in the +25% scenario.

-25% scenario: The budget decrease would be 0.25 x $4.8 M = -$1.2 M. The only feasible option consistent with the ATF priorities would be to close Lick. Closing Lick would save both operations and instrument funds, which total to $2.4 M (not including Astronomer salaries, Table 1). However, closure costs of unknown amount would also be incurred. In the event that there would be net savings, they would be disbursed according to the priorities in the +25% scenario.

Though closing Lick would satisfy the -25% scenario, it would also entail severe damage to active and successful research programs, external funding, student training, and public outreach programs. Closing Lick is a very undesirable outcome and would do great harm to UC's core missions in education and research. We reiterate again our opinion that UC should commit to operating Lick for the next five years, which means a continued strong budget for UCO in that period.

Appendix 3: Program Director Biosketch *[Director Biosketch not to exceed 1 page]*

Sandra M. Faber is Interim Director of the University of California Observatories, University Professor at the University of California, Santa Cruz, and a staff member of the UCO/Lick Observatory. She is an observational astronomer with primary research interests in cosmology and galaxy formation. Some of her major discoveries include the first structural scaling law for galaxies (called the Faber- Jackson relation), large-scale flow perturbations in the expansion of the Universe caused by superclusters of galaxies, and ubiquitous black holes at the centers of galaxies. In 1984, she and three colleagues from UCSC and Cambridge University presented the first treatment of galaxy and cluster formation based on "cold dark matter," which has since become the standard paradigm for structure formation in the Universe.

Faber was one of three astronomers who diagnosed the optical flaw in the Hubble Space Telescope, and she played a major role in its repair. She established the scientific case for the twin Keck 10- m telescopes, which inspired a subsequent wave of giant optical telescope building all over the world. From 1994-2005 she was Principal Investigator of the DEIMOS spectrograph, a large optical multi-object spectrograph for the Keck 2 telescope that is the most powerful instrument of its kind in the world. She and colleagues used DEIMOS to conduct the DEEP2 redshift survey of the distant Universe, which collected spectra of 50,000 distant galaxies and exploited the immense power of Keck to see and study galaxy formation 10 billion years back in time. She now leads the CANDELS project, the largest project in the history of the *Hubble Space Telescope*, to extend our view of galaxy formation back nearly to the Big Bang. She has co-authored nearly 250 scientific papers, and her work has been cited over 37,000 times.

Faber received her BA degree in Physics from Swarthmore College and her PhD in Astronomy from Harvard. She is a member of the U.S. National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. She serves on the boards of several organizations including the Carnegie Institution of Washington, Annual Reviews, and (until recently) the Harvard Board of Overseers. From 2005-2011 she chaired the Astronomy & Astrophysics Department at UC Santa Cruz. She has received the Heinemann Prize of the American Astronomical Society, the Antoinette de Vaucouleurs Medal of the University of Texas, the Centennial Medal of the Graduate School of Arts and Sciences of Harvard University, and five honorary degrees. In 2009, she was awarded the Bower Award and Prize for Achievement in Science from the Franklin Institute in Philadelphia, and in 2012 she received the Bruce Medal of the Astronomical Society of the Pacific, the Russell Prize of the American Astronomical Society, and the Karl Schwarzschild Medal of the German Astronomical Society, all for lifetime scientific achievement. In 2013, she received the National Medal of Science from President Obama. She lectures widely on cosmology and the history of the Universe.

Appendix 4: References and Key Publications

General websites:

University of California Observatories (all Activities and Initiatives)
Keck Observatory (Activities #1,2,3,7,8; Initiatives #2,5)
UCLA Infrared Laboratory (Activities 2,3,4,6,7; Initiatives #1,2,3,4)
Thirty-Meter Telescope Project (Activity #2; Initiative #1)
Lick Observatory (Activities #5,6; Initiative #4)
Center for Adaptive Optics (Activity #4,8; Initiative #2,3)
Moore Laboratory for Adaptive Optics (Activity #3; Initiative #2)

Facilities and Activities:

Picture Book of UCO Facilities
Keck Observatory Annual Reports
Lick Observatory Newsletters
List of Keck Instruments and Upgrades and Where Made (Activities #2,3)
The MOSFIRE Infrared Spectrograph for Keck, illustrating the size and scale of typical Keck instruments:
McLean et al., Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE), v. 8446, id. 84469J, 2012. (Activity #2,3)
Education and Outreach Programs (Activity #8; Initiative #5)

Usage of UCO Facilities: A Questionnaire to Affiliated Faculty and Research Scientists (December 2012):

Impact of UCO facilities on coming to UC, retention, research choices
Personal comments: Impact of UCO on education, outreach, and fund-raising (8 pages)
Personal comments: Full Questionnaire responses (38 pages)

Management and governance:

Charts of UCO Organization and Governance Structure
UCSC Astronomers Responsibilities List
UCO Advisory Committee Charter (UCOAC)
UCO Advisory Committee Membership List
UCO Board Charter
UCO Board Membership List

Recent external reviews:

Report of the Astronomy Task Force on UC Optical Infrared Astronomy (ATF, July 2011)
Report of the UCO External Review Committee (August 2011)

Achievements and recognition:

UCO's Greatest Hits (greatest astronomical discoveries from UCO telescopes in the last two decades)
Prizes and Awards Won by UC Astronomers