1 Keck Observatory in the Next Ten Years: The Science Steering Committee Perspective

Preface

The Keck Science Steering Committee (SSC) devoted most of two meetings in March and April 2001 to consider the next ten years of the Keck Observatory. This is a natural point to be evaluating the direction of the observatory. For the first time since Keck first light there are other telescopes of similar size in operation: Gemini North, Subaru and the VLT telescopes all have some instruments and are regularly scheduled for science operations. It will be difficult to maintain the status that the Keck Observatory has enjoyed of being the undisputed leader in optical/near-IR observational astronomy. Simply because the Kecks were the first 10m-class telescopes in operation, Keck telescope-based research has dominated many areas of forefront astronomical research. Simply by becoming operational, many of the other large telescope facilities are now competitive. These competing facilities are significantly better-funded for both operations and instrumentation, presenting a challenge for the Keck to remain competitive in the future.

Executive Summary

As the Observatory and instrument complements on each telescope have matured, the emphasis in SSC priorities is increasingly in issues related to efficiency. Specific high priority projects for are listed here:

1. Detector/controller upgrades for HIRES and LRIS-R. Improved quantum efficiency at all wavelengths, larger spectral coverage per spectrometer setting and large decreases in CCD readout time are the principal goals. Detector upgrades are a very cost-effective means of updating existing instruments. To maintain state-of-the-art detectors requires that we participate in detector development efforts.

2. Improved guiders/acquisition systems. We would like to see a significant effort, led by CARA personnel, to significantly upgrade the performance and function of the Keck instrument guiders. Added features that would reduce setup over head and improve the quality of data and instrument performance are closed-loop auto-focus, condition monitoring and image continuous image quality evaluation and optimization.

3. Development of metrics and procedures for evaluating and monitoring efficiency, image quality and instrument throughput. This is closely tied to the previous item and this would also be a CARA-led effort with the instrument scientists playing a large role. An increase in the number of instrument scientists would be required.

One of the primary roles of the SSC is to evaluate and recommend the new instruments to be undertaken for the Observatory. We have identified three areas for which we have strong needs: wide-field near IR imaging and multi-object spectroscopy, wide-field mid-IR imaging and high-resolution mid-IR spectroscopy and instruments to take advantage of the laser-guide-star AO system. As we have moved into the steady-state funding era for instrumentation, there are insufficient funds to address all of these needs. We are currently funding design studies and considering funding through completion two instruments over the next five years.

1. KIRMOS (Keck Infrared Multi-Object Spectrometer) Near-IR imaging/multislit spectrometer completing an extensive Phase A study in the Fall of 2001.
2. OSIRIS, an 'integral-field' spectrograph and OH-suppressed imager designed for use behind the AO bench. This instrument 2-dimensional spatially resolved spectra to be obtained over the AO-corrected field.

Additional important issues requiring Observatory resources that are currently not available or that are further out in timescale are listed here.

- Mid-IR (5-25 micron) imaging and spectroscopic capability
- Near-IR detector upgrades (NIRC2/NIRSPEC)
- Mirror coating improvements in the long term (silver on KII, hybrid coating KI)
- AO development (MCAO?), AO instruments/interfaces
- Increased Instrument Scientist complement
- Resources for innovative instrument development (e.g. tunable filter imaging)
- Atmospheric dispersion compensation for at least LRIS and DEIMOS
- Development of a strategic plan to allowed continuing participation in detector development efforts.

1.1 Efficiency

It is easy to overlook the gains to be made by totaling many small efficiencies with photons that fall on the ten-meter mirrors and maximizing the time spent each night with the shutter open on science targets. There are many areas in which we could improve, resulting in an increase in total system throughput. The aperture advantage of the 10m telescopes compared to GEMINI, SUBARU and the VLT telescopes ($\sim$ 8.4m) can easily be lost if our overall efficiency is lower than that of the other facilities. One metric for evaluating the efficiency of the Observatory is the fraction of 'open shutter' time per year (corrected for time lost to weather). This is only one aspect of the issue. Total throughput of the telescopes+instruments including losses to poor focus, degraded image quality, or poor mirror reflectivity is an equally important aspect of efficiency.

1.1.1 Efficiency with Photons

There are two main areas in which we can improve the efficiency with which we utilize photons that land on the primary mirrors. One is to maintain state of the art detectors in all instruments in terms of quantum efficiency and area of the focal plane covered with pixels. As has been discussed for the past few years, we could make quantum efficiency improvements of up to a factor of three at some wavelengths and at least 20% over all wavelengths with detector upgrades for HIRES, LRIS-R, LRIS-B, ESI and LWS. For HIRES and both sides of LRIS the planned upgrades will also increase the wavelength coverage or slit length for a given instrument configuration. Figure 1 shows the quantum efficiency verse wavelength for the current Keck CCDs along with the QE curves for the newly available MIT-LL devices.

The second obvious area in which efficiency could be improved is maintaining a high-reflectivity coating on the primary, secondary and tertiary telescope mirrors and instrument collimator mirrors. Segment exchange for the primaries has proven to be difficult and some of the segments are up to 30% below their 'fresh' reflectivity by the time they are swapped out and realuminized. As discussed in the next section, segment exchange also removes a significant number of nights each year from science observations. K1 requires mirror coatings that provide good reflectivity down to the UV atmospheric cutoff at 300nm for LRIS-B and HIRES. K2 has no instruments that operate blueward of 380nm. For interferometry, each telescope will be used at 10 microns. One obvious solution to the segment exchange difficulties would be to continue to work with LLNL on a protected silver/aluminum mirror coating that gives excellent reflectivity from 300nm to 20 microns with much greater durability and lifespan than aluminum. To tool up to be able to deposit this sort of coating on the segments would be a major and expensive undertaking. Smaller steps that should be investigated in the shorter term are (1) protected silver for the K2 mirrors, (2) protected aluminum for K1 and cleaning procedures that can decrease the degradation of reflectivity between segment exchanges.

1.1.2 Efficiency with Time

As is the case for improvements in efficiency with photons, increasing the amount of time with the shutter open on science targets is equivalent to having a larger telescope. There are four areas in which improvements could be made.

1. Number of engineering nights. The number of engineering nights for the past few years has been high due in part to the large number of instrument commissioning nights

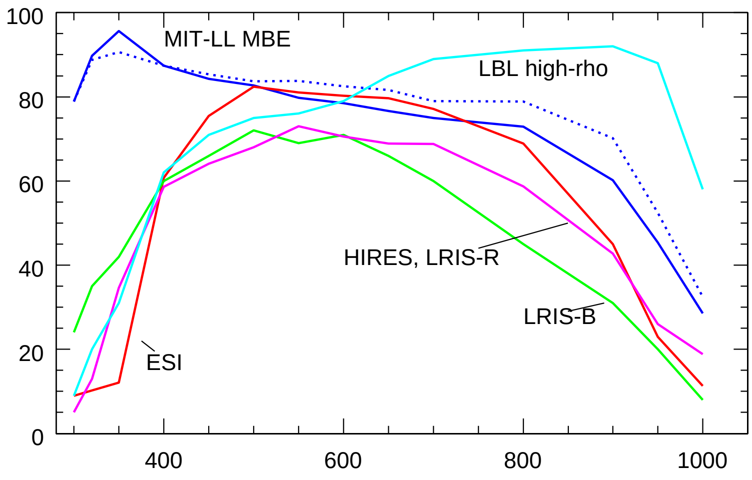

Figure 1: Current Keck CCD QE curves along the MIT-LL MBE device curve. The solid blue line is the measured quantum efficiency from a device with a single-coat AR layer optimized for 350nm. The dashed blue curve shows the expected curve for one of these devices with a multi-layer broader-band coating.

and the time required to debug new instruments post-commissioning. After DEIMOS commissioning, (2002A), there will be a few year hiatus in which no new instruments will be arriving and hopefully the teething problems of relatively new instruments requiring engineering nights will also decrease as these problems get solved. A major source of engineering time will remain in the form of segment exchange nights. An idea to consider is an amount of time each year when the observatory is closed to night-time operations to allow efficient access to the summit for facility-related engineering tasks (similar to the current September 2001 shutdown of Keck II).

2. Detector readout time. The newer CCDs and controllers can be clocked out at much higher rates, generally through a larger number of on-chip amplifiers than the older generation of chips (HIRES/LRIS). There is a very significant gain in efficiency to be

realized when the CCD upgrades for these instruments are completed. For example, ESI with its 2k x 4k pixel CCD is read out of two amplifiers in 38 seconds. LRIS-R with a 2k x 2k pixel detector requires 2$\times$ as long to read out of two amplifiers. In a typical night, the CCD is read out between 20 and more than 100 times. Daytime calibration observations are currently limited on most instruments by readout overhead.

3. Acquisition. Accurate pointing, fast slewing and rotator setting and guiders that image deep and update rapidly can reduce set-up overhead significantly. The visible-light guiders for Keck instruments are particularly in need of an upgrade and the entire area of near/mid-IR guiding has so far been largely ignored.

4. Autofocus, photometric monitoring. Observers spend a significant amount of time focusing the telescope, often with less than perfect results. Particularly for spectroscopic observations, automatic focus routines using the guider images would take up no observing time and could monitor focus better than most observers. The guiders could also monitor photometric conditions and evaluate image quality as an aid to observers.

   The last two items suggest an effort directed at upgrading the current guiders at Keck. Higher bandwidth guiding, improved contrast control, near-real-time flat-fielding, closed-loop focus and real-time conditions monitoring and display would be the goals.

1.2 New Instruments

As shown in the figure below, in 2001 there are some clear regions in 'Spectral resolution/wavelength' space and imaging area where Keck is missing capabilities. The most obvious are intermediate resolution, multi-slit capability in the near-IR, wide-field near-IR imaging, and wider-field mid-infrared imaging. Some new instruments that fill the gaps are currently under consideration. The steady-state instrument funding level of \$$\sim$ 2.4M/year allows about one new major instrument and upgrades of existing instruments every four or five years. This is insufficient to maintain state-of-the art capabilities on both telescopes covering the wavelength range from 300nm to 20 microns.

1.2.1 New Instruments Already in the Planning Phases

Two instruments are in the pre-Preliminary Design Review stage. KIRMOS is designed to fill in the large gaps for near-IR wide-field imaging and multi-object spectroscopy (0.9-2.5 microns). OSIRIS is an 'Integral-field' spectrometer designed to work behind AO. With OSIRIS, NIRC2, SHARC, and sometime use of NIRSPEC with the AO system, we have a solid complement of AO instruments.

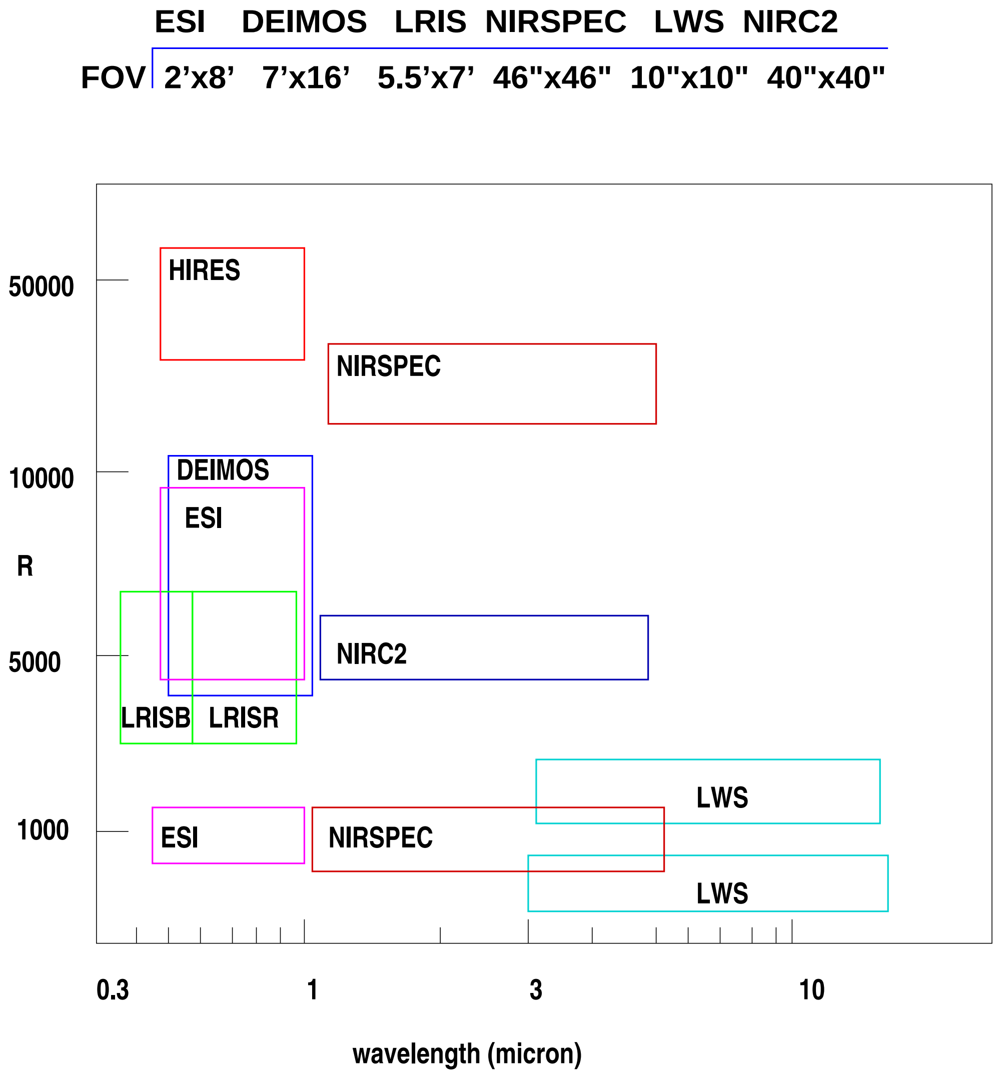

Figure 2: The Y2001 spectroscopic capabilities of the Keck Observatory.

1.2.2 New Instruments Outside of the Current Funding Envelope

There is a strong need to upgrade the Keck Observatory mid-infrared capability. LWS is a Phase-I instrument with a field of view more than a factor of 10 smaller than similar instruments on other large telescopes. For several reasons it is not feasible to upgrade the detector in LWS to a larger more modern one. *A new mid-infrared imager and spectrograph is needed.* It is possible that the mid-IR needs will require two instruments, a low-R spectrometer and imager and a high-R ($\sim$ 50000) spectrograph. With the airplane-based SOFIA and the SIRTF satellite poised to become operational within the next three years, there will be a revolution in mid-IR astronomy. Although hampered by higher backgrounds and limited transmission in ground-based mid-IR work, the Kecks can prove to be very complementary because of the much smaller diffraction limit of the 10m primary compared to SOFIA or SIRTF.

There are currently no plans to populate the second side of DEIMOS. This would be a very cost effect way to essentially add another telescope for certain types of surveys. The size of the DEIMOS field of view at present (the largest for any of the Keck instruments) is only 20% of the Magellan IMACS spectrograph and only 40% of the VLT VIMOS spectrograph, both instruments that will be commissioned within a year of DEIMOS.

Large-field imaging has not been a capability of the Kecks at any wavelength. A mosaic-CCD camera at cassegrain (with substantial focal reducing optics) would give a $20' \times 20'$ field; a prime focus imager could be even larger although requires a PF corrector. This is a current Subaru capabilty and it may be that the most effective approach will be to trade time with Subaru in the near term[1]. However, it may be that in the future it will be highly desirable for the CARA community to have a wide field optical imager for survey applications linked to future extremely large aperture telescopes.

An instrument that would be very powerful and versitle with combined with the a tunable narrow-band imager. Similarly, there are currently no fiber-fed systems at Keck. Fibers are a very efficient means of adding multiplexing capability to a new or existing instrument.

AO instruments for K1.

1.3 Instrument upgrades

Upgrading detectors and adding capability to existing instruments is very cost effective in terms of dollars and human effort. In Appendix 1 we list upgrade possibilities each of the current instruments along with rough guesses at the associated costs.

Associated with instrument upgrades would be the maintenance of an aggressive detector and detector-system development effort. In the past, we have often “tagged along” with other, better funded, observatories, sometimes missing out of the leading edge of new detector technologies because we depended on the others to take the development risks (by the time one can buy detectors “off-the-shelf”, others have had them for 1-2 years). We have recently adopted a more proactive approach, and we are beginning to see the benefits. If there are detectors than we envision being important for future instruments (e.g., large format near-IR arrays for KIRMOS) we must make sure that they happen. One way of doing this is by seeking partnerships with other observatories (e.g., ESO) for major detector development programs.

1.4 New Facility Capabilities

1. ADC. Particularly with the new blue side of LRIS and when DEIMOS is commissioned, the need to correct for differential refraction is crucial for direct imaging and

[1]Of course, in order to make trades attractive, it will be necessary to have complementary unique facilities; it is not clear which of the Keck capabilities will be “tradeable” in the near future

multislit spectroscopy in the optical. The ADC project has been funded since the early days, but has languished due to lack of effort and the absence of a PI to see it through.

2. Keck 1 Laser. The current plan is to have the K1 AO system be used only for interferometry observations with natural guide stars. The K2 NGS AO system has proven to be very powerful and popular and when the laser guide star system is in place, it will be significantly more powerful. Upgrading the K1 AO system to laser guide stars will increase the Keck AO capability and move some of the observing demand pressure from K2 to K1.

3. MCAO. There is currently no development plan for adaptive optics at the Keck observatory. Both UC and Caltech are heavily invested in adaptive optics developments at Lick and Palomar, but it is not clear how or if these efforts will benefit Keck in the future. It is time that the SSC and the Directors begin thinking about how such efforts can be coordinated.

4. High-strehl AO to 500nm. There is huge potential science benefit to pushing diffraction-limited performace into the visible.

1.5 Keck Personnel

This is an area best addressed by Fred Chaffee and his associate directors. We note only that having a sufficient number of top-notch instrument scientists is crucial. These are the people who see the instruments in operation over many nights and are best capable of identifying problems or improvements, implementing changes and documenting instrument status.

The instrument scientists are also the principal source of information for observers on instrument usage and are the front line for troubleshooting problems during the night. We feel the number of instrument scientists should be increased by two or three.

At present, there is much more that could be done in terms of monitoring of instrument performance, maintenance of calibration information, software tools, all of which could significantly improve overall efficiency and scientific output.

1.6 Long-Term Concerns

In this section we list some concerns that have been discussed over the past year when considering future paths ofr the observatory. These concerns are not addressed in detail and are listed in no particular order.

Instrument funding levels are a major concern. At the time the funding levels for instrumentation were established, no instrument for an 8 – 10m telescope had been built. Instruments have proven to be more expensive to build that anticipated. Based in part on the Keck pioneering experiences, the steady-state instrument budgets for the other 8m telescopes are significantly larger than that of Keck. There is no way to make the telescopes larger, however maintaining state-of-the-art instruments and detectors is possible and required to keep the Keck telescopes competitive. Given the list of currently-identified new instrument and upgrade needs, the current budget falls about $5M short over the next five years. It has proven fruitful in the past few years to be proactive in becoming involved in detector initiatives. This will be difficult to continue at the current funding level. There is an associated issue of maintaining critical-mass instrument groups on the UC and CIT campuses. The timescale to completion of major instruments is currently too long (approaching 8 years for DEIMOS and NIRC2). Alternative means of managing projects or changing the ratio of in-house to contracted work maybe should be considered.

The Keck telescopes do not perform at the level of other 8m telescopes in terms of pointing accuracy, guiding and delivered image quality. These are fundamental issues that the CARA staff recognize, but do not currently have the manpower to address.

Data archiving and first quality data pipelines would allow more efficient use of the data and allow the larger astronomical community access to the Keck telescopes. Again there is no man-power available to even draft a plan for archiving/pipelining, much less implement any sort of plan.

The balance of instruments and observing-time demands on the two telescopes needs to be addressed as does the vailability of focal stations.

To date, there has been little participation on the part of the SSC or general Keck user community in the planning of Keck interferometer use and development.

The relation between Keck and CELT needs to be considered carefully. Given that the two projects are being undertaken by the same institutions and individuals, it must be possible to make them mutually beneficial.

1.7 Financial Considerations

Here add up the new instrument/upgrade costs, new facility capabilities costs and added personnel costs and compare with the budget.

- Current project instrument total through 2005: $12.5M
- Currently planned projects with very rough costs:
  1. HIRES CCD upgrade $0.8M
  2. LRIS-R CCD upgrade $0.5
  3. DEIMOS completion $1.0M

4. ESI CCD upgrade \$0.3M
5. ADC \$0.5M (beyond already-allocated funds)
6. OSIRIS \$4.5M
7. KIRMOS \$7M
8. IR detector upgrades
9. CCD/IR detector initiatives
10. misc upgrades/enhancements \$0.1M/year

1.8 Appendix 1: Current Instruments and Upgrade Paths

- ESI:

  1. Detector upgrade to a better quality MIT-LL high-resistivity device, or LBL very-high-resistivity, or MIT-LL MBE-process device. The spectrograph is designed around a 2k x 4k (15 micron) detector, so there is no upgrade path to larger field of view or even larger spectral coverage.
  2. Filter-wheel IFU units (these are being developed).
  3. Second, higher-R grating.

- HIRES:

  Detector/controller upgrade. This project is already underway. There are several important gains possible. The current plan is to use a MARCONI, UV-optimized CCD mosaiced with a red-sensitive CCD (likely MIT-LL high-ρ device), or a mosaic of two MIT-LL MBE process CCDs, which may be available to us by the end of 2001. This will give improved quantum efficiency at all wavelengths (particularly in the blue and UV), larger wavelength coverage per exposure, reduced readout noise by at least a factor of 2, improved sampling for narrow slits and reduced readout time from 120s to $<$ 40s. The cost estimate for the project (not yet approved) is $\sim$ $900k including the cost of the detectors [**Mike–is that true?**].

- LRIS:

  1. A blue-side detector upgrade. This is underway, with a mosaic of 2 2k x 4k Marconi CCDs. Currently planned for implementation in early September.
  2. Red camera CCD upgrade. The red side would would benefit by going to a dewar with a two-CCD mosaic of 2k x 4k, 15μ-pixel devices with fast readout electronics, better QE, and reduced fringing. The result would be a (slightly) longer slit, better sampling, improved throughput, reduced readout noise, reduced fringing amplitude (the main systematic limiting faint object observations) in the red and reduced readout time.
  3. A deployable integral-field unit.
  4. A flexure compensation system for the red side CCD. A system was designed and built (but not implemented) for the blue side; a similar approach could be used for a red side system.
  5. Additional grisms, and spectrum-shifting wedges (allows more control over the wavelength range seen by the detector) for LRIS-B.

- LWS:

  No upgrade path specifically identified. What is needed here is an instrument with a significantly larger FOV and also a high-spectral-resolution ($R \sim 50000$) capability. These might have to be separate instruments.

- NIRC:

  No upgrade path identified, but KIRMOS will replace most NIRC capabilities (exceptions: speckle imaging, 3-5 micron capability) on a timescale of five years. The gain in field of view for IR imaging programs will be approximately a factor of 64. The forward-cass module could be de-commissioned once KIRMOS and a replacement for LWS are on completed.

- DEIMOS:

  Adding the second side would double the instrument capabilities for some survey projects; this second side could be added for a fraction of the cost of the initial DEIMOS.

1.9 Appendix 2: Operations and Instrument Funding for Observatories

Table 1:

Observatory	Description	Operations (yearly, US $)	Instruments (yearly, US $)
Keck	two 10m telescopes	$8.7M	$2.5M
Subaru	8.2m telescope		
VLT	four 8.2m telescopes		
Gemini	two 8.4m telescopes		