KAON 463:
Lessons learned for Keck LGS Operations Weather Impact, Efficiency & Science Operations Model

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1. Introduction

In this note we will present the lessons learned with the Keck LGS AO system and its science instruments operations (2004-2006) with the design of NGAO in mind. The lessons learned from the Keck LGS operations model are numerous and belong to various categories: data products, observing efficiency and uptime, weather impact, observing and support tools, facility-class, etc. We will try to summarize what we know about the main components that are weather impact, efficiency and science operations model. This KAON will be used for inputs and reference for NGAO system design studies.

2. The LGS efficiency database (2004-2006)

There are many metrics to estimate the observing efficiency of an instrument and there are pros and cons for each of them depending on the author's role in the operations. We propose here to look at the Observing Efficiency from the point of view of the astronomer who was allocated observing time by the TAC to pursue a given scientific project. Therefore, for the sake of this discussion, any time not spent on observing targets for the prime science proposal is considered "lost time".

The pie chart below represents the observing efficiency for the 101 LGS AO nights with Keck II from Nov. 2004 till July 2006. This period includes some allocated nights where the system was in its early integration, during shared-risk science mode. The distribution of the 101 allocated night is not uniform throughout the period. A more comprehensive introduction and discussion of the operations for Keck II LGS AO system is presented in Le Mignant et al. [1,2].

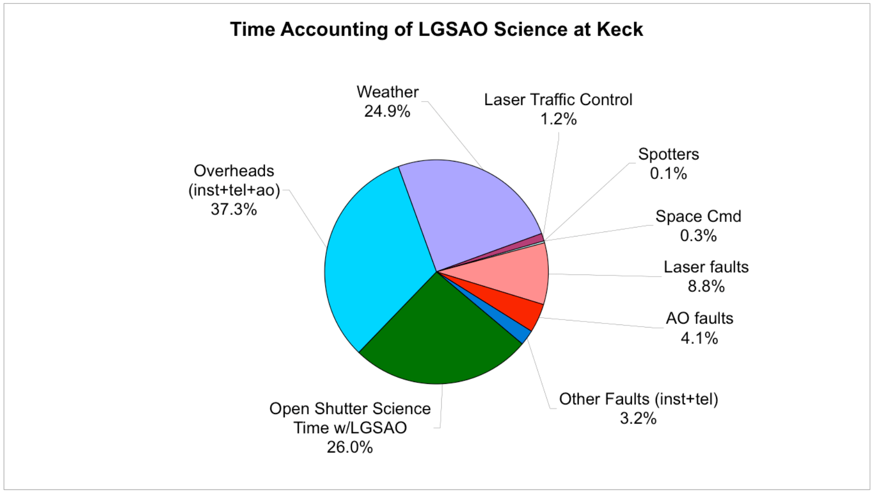

Fig. 1: Observing efficiency from the LGS AO system at Keck between November 2004 and July 2006.[2,3] This pie chart has been updated in Aug. 2006.

We will only discuss the main points of the statistics.

- 26%: The open shutter time represents ¼ of the time allocated. Note that this open-shutter time includes some science target acquisition overheads (centering the object on the science array, checking saturation, etc), any calibration data recorded during the night as well as any LGS science data recorded under marginal observing conditions (bad seeing, strong winds, etc). On the other hand, any data acquired on NGS backup target is not included in the open-shutter time.

- 25%: The time loss due to weather represents another ¼ of the allocated time. In LGSAO mode, the system becomes "not usable due to weather" when there is more than one magnitude of extinction, plus any time the dome is closed for humidity, precipitations, strong winds, etc. The time spent on NGS AO backup is counted as weather.

- 37%: The total amount of time spent on setting up the system, reading out the science array, writing data to disk, dithering, etc account for 37.3%. The main limitation here comes from the fact that all commands for instrument/telescope/AO/laser are performed serially.

- 16%: System downtime due to observing system faults is 16.1%. Half of this fraction comes from the laser system. About 10 laser faults lasted half-nights or more. The AO faults are happening very frequently, more than 50% of the AO nights. Procedures are in place to detect and auto-recover from the AO faults in most cases.

- 1.5%: Laser traffic control (LTC), including space command calls, represents a minor fraction of the time loss. It is not clear that we are impacted one telescope more than another. Note that there is bias (that exists for some of the other time loss categories as well): the time loss due to LTC only impacts the science when everything else in the system goes well. This may have triggered more frustration for the observers and more demand to fix this problem than other real loss time issues.

3. Focusing on the weather impact

If bad weather is acknowledged as being an important factor for the science impact from NGAO and its science instruments, the possible remedies include high-scientific-merit NGS AO backup, flexible scheduling of other instruments, or queue scheduling. Any flavor of those may require significant changes to the observing methods and support models for the Keck Observatory.
In this section, we propose to review the possible impact from weather on NGAO science operations based on current LGS statistics, Keck metrics, UKIRT metrics, an AURA TMT report and an ESO report on Mauna Kea.

Below, we will refer as *usable time* to define the fraction of time when scientific observations can be performed. This include photometric conditions and spectroscopic conditions (cirrus and thicker clouds). In addition different studies have different requirements photometric conditions (no clouds at all in the sky for the entire night, >6h without any clouds, less than 2/10 of the sky, etc)

3.1. The weather report from the LGS efficiency database

25% of the time allocated between 2004 and 2006 was lost to weather, including:

- 18 entire nights (18%)
- the rest is marginal weather conditions (heavy clouds, humidity, precipitations) that happened over ~20% of the open nights.

From this limited statistic, we conclude that the usable fraction of nights is 75%, the photometric nights represent less than 62% of the nights (100 – 20 – 18).

3.2. The Keck Weather impact from the metrics system (2002-2006)

In order to estimate the possible weather impact for NGAO, we present a brief analysis of the data recorded in Keck metrics system.[3] We collected the monthly-averaged data for each telescope since January 2002 (data in November and December were not available due to earthquake recovery effort).

At Keck, the time reported "lost to weather" is closed-dome situation or equivalent (very thick clouds, humidity, winter conditions, etc), where no science data can be collected; and does not include thick cirrus and marginal conditions where observations for a backup program are still feasible. Hence, this data base may represent well a lower limit for the bad weather impact.

The top graph from Fig. 2 shows that the Keck I and II data are within a few percent. There is a high dispersion of the data during the year and for a given month. The weather impact per month varies from ~80% in March 2006 to ~2% for June 2003. The worst reported month for the observations is March, while the best months are in the summer.

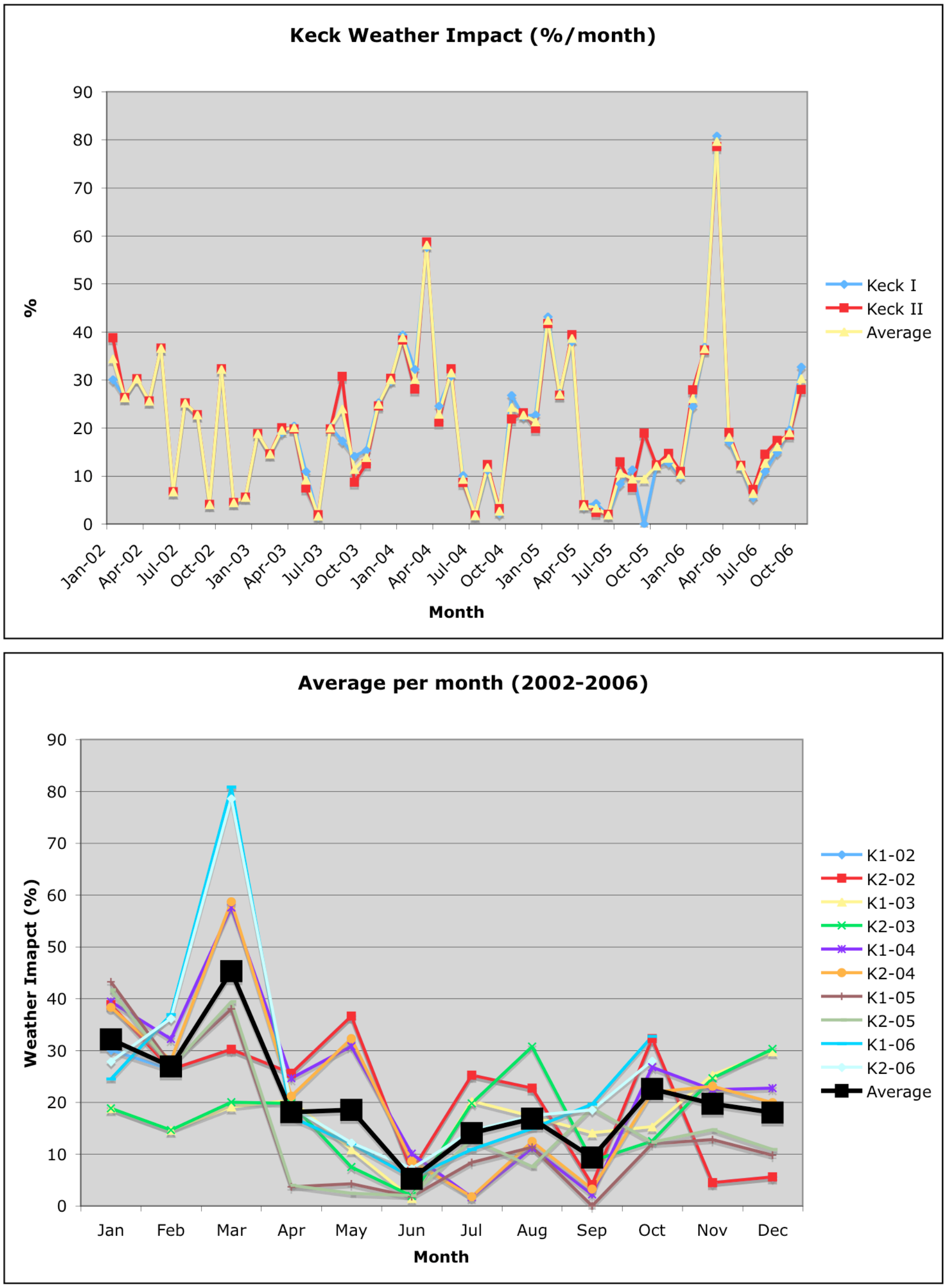

Fig. 2: Weather Impact at Keck as reported by the Keck metrics system.
Up: Month by month since 2002. **Bottom:** Average by month for the period 2002- 2006

We conclude that the average time loss due to bad weather (2002-2004) is 20.6% at the Keck Observatory. As expected, this fraction is slightly better than the LGS statistic (~25%).

At this time, the Keck metric sample data does not allow us to make any further conclusion on photometric nights .

3.3. UKIRT data base (1985-1996)

The UKIRT study is not being cited per se, but is reported in the Gemini observatory web page on Observing Constrains[4]:

> “Data logged nightly by the UKIRT Telescope Operators over a ten-year period (1985 September 13 to 1996 August 4) have been analysed. Their reporting includes cloud cover (in eighths), cloud type and the number of usable and available hours. The data may be summarised thus:
>
> **Usable time:** excluding nights for which no information was available (e.g. due to telescope shutdown) approximately **three-quarters of the available time** (31419 out of 43427 hr) was identified as "usable" i.e. the telescope was open and data were collected.
>
> **Cloudless**: of the usable time 62% (19371 hr) was noted as being "cloudless". It is recognised that this is a subjective assessment e.g. it is difficult visually to detect thin cirrus in a dark sky. There are, however, two caveats: (a) we have included in this value only nights which were classified as cloudless throughout and (b) there may be a partial compensation from nights which were recorded as having some cloud cover (1/8 or 2/8, say), and which are treated as having these conditions all night, but which may have experienced substantial clear periods. [..]
>
> **Thin cloud**: the UKIRT cloud cover and cloud type often were logged as a single value for an entire night. To estimate the time during which thin cloud was present, we have taken the nights explicitly reported as "thin cirrus" and added the fraction (1.0 - cloud cover) of nights reported as having "cirrus" (with a cloud cover of 4/8 or less). The UKIRT data shows these conditions occuring 23% (7096 hr) of the usable time. [..]”

In addition Gemini mentions that for their own operations, they have concluded that 50% of the usable time is actually photometric and that, thin cloud and thick cloud are each present 20% of the usable time. The total does not sum up to 100 of the usable time, this may be due to a rather conservative number assumed for the photometric fraction.

We conclude from this information that the usable fraction of the nights is ~72% of the total time (either photometric or spectrometric), ~50% of the total nights are photometric (no clouds at all for the entire night) .

3.4. Other sources of data and reports

Two main reports were written in 2003: one for ESO and one for AURA. The ESO report on Mauna Kea is part of a site summary series[5] (available in the public domain). It provides a good overview of the previous studies for the observing conditions since 1968. Particularly, the report re-analyzed the 1970-1978 data from Kaufman and Vecchione,[6] and concludes that 45% of the nights at Mauna Kea are photometric (entire cloudless nights) and 67% of the nights are less than 50% cloudy (usable fraction). The seasonal trends for the weather are summarized as follow: a maximum of useful nights in February, and two minima in October and April[6], a weather variability of a factor 3 to 7, due mainly to low level clouds (fog, rain, high humidity) and an average total impact variable by a factor from year to year. Note that ~4% of the nights are lost every year due to strong winds.
In addition, the ESO report confirms the fact that Mauna Kea presents excellent conditions for seeing: yearly median of 0.5” (+/- 0.1 for seasonal variations) and a slower high altitude wind flow (average of 25.4 m/s at the 200mb level).
The report mentions the very good quality of the site for optical and UV extinction. It also notes some advantages over lower (hence higher-temperature) sites for the NIR observations.
Finally, the report looked into the long-term trend of the weather based on 50 years of Mauna Loa data. It concludes that the site is significantly more affected by global atmospheric warming (~3.7 deg/century) than by ENSO phases (El Niño Southern Oscillations). It also notes that the atmospheric warming is much more important than other lower-altitude sites (0.7 deg/century). The ENSO show a strong influence on the precipitation variations, but not on the atmospheric temperature.

“A Comparison of Satellite-Observed Cloud Cover and Water Vapor at Mauna Kea and Selected Sites” is a study conducted by Dr. Erasmus in 2003 for the New Initiative Office, AURA Inc.[7] The AURA study remains confidential and only general conclusions for Mauna Kea will be reported here. The study from 1997-2002 data reports that ~77% of the nights are usable (less than 4/9 of the nights covered by clouds). 58% of the nights were reported as photometric (more than 6h of photometric conditions for a given night) and 19% spectroscopic (cloud coverage for less than 4/9 of the night).

We have revisited the Kaufman and Vecchione dataset by performing our own analysis with a different % cloud bin size and look into the weather impact as a function of cloud coverage fraction. For each month, we present in Fig. 3 the fraction of nights that are less or equal than 20% cloudy, between 30 and 80% cloudy and finally the nights with a cloud fraction of 90% or more. The figure shows that the best chances to have almost entire clear nights (0-20% clouds) are in the winter (Dec-Jan-Feb), while April and October present higher probability for cloudy nights. There is a seasonal trend for the night with varying conditions (30-80% cloudy): a factor 2 less numerous in the winter. The total nights that are less than 90% cloudy peaks in February and July.

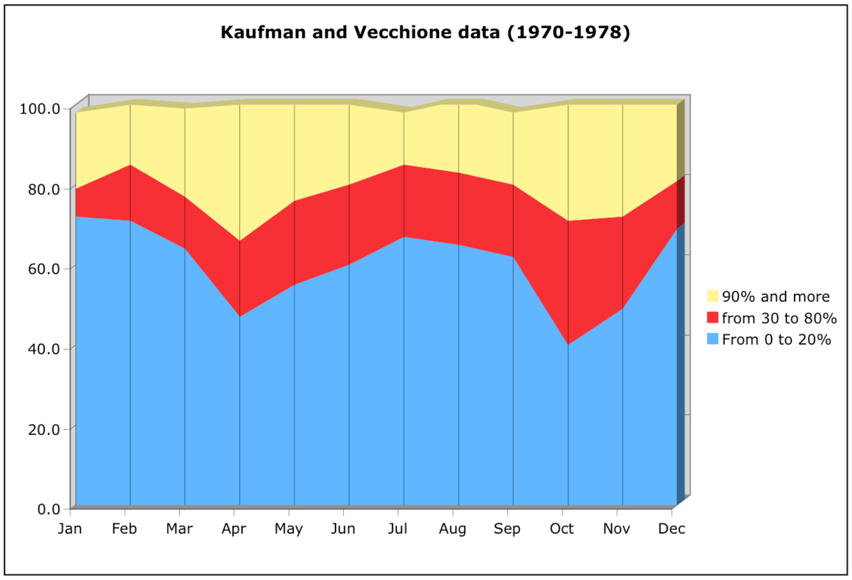

Fig. 3: We have reprocessed the data set from Kaufman and Vecchione and present the results with various cloud coverage fractions. We present the fraction of nights with less than 20% cloud coverage, then between 30 and 80%, and finally 90% and more.

3.5. Conclusions on weather impact

The data presented above were built with a slight different purpose, collected in different ways, therefore have a slight different meaning. The goal of this sections is to anticipate for the weather impact during NGAO operations and decide on the most suitable science operations models. We shall look for the trends here and possibly set our goals to reach a 5-10% accuracy with high confidence.

The Keck data may not reflect well the partially-or totally cloudy conditions, but it provides a lower-limit for the number of nights strictly not usable (~20%). The variability from year to year and the data range from 1970 to present days may be seen as an obstacle to extract reliable numbers, yet it is likely to provide a good overview for the future observing conditions. We do not have any data that could provide information on the evolution of marginal weather conditions with time. While it may be that a warmer atmosphere temperature indicates less snow or ice, it does not mean less precipitation.

The data set and reports presented here agree (with an exception for the Keck metrics though) within a few percent in the fraction of usable nights (~70-75%), photometric (~50-55%) and spectroscopic nights (~20-25%).

From the data presented here, we speculate that NGAO should anticipate for:

- ~ 20% of full nights year-round not usable for NGAO (NGS or LGS) with likely at least an additional 5-10% not usable by LGS.
- ~55% of the nights year-round with photometric conditions > 6h/night
- ~65% of the nights year-round with good or marginal cloud conditions (cirrus & partially cloudy), workable for LGS

4. Main limiting factors for higher observing efficiency

In this section we present the main factor that limits our ability to be more efficient during observations with the current AO and laser systems at the Keck II telescope:

1. Serial (vs parallel) algorithms for processing command:
   Almost all commands within a given sub-system (science instrument, AO, telescope, Laser) and among various system (DCS /inst/AO) during slew, setup, acquisitions, dithers, etc are implemented in a serial way. There are various reasons for this: no requirements on overhead during design phases, hardware requirements, systems built by different partners, systems designed and integrated at different times, etc.

2. Under-designed telescope pointing and acquisition systems:
   The Keck II telescope pointing performance is ~20 arcsec for various random positions in the sky. The pointing accuracy is improved by regularly slewing to a catalog star for pointing adjustment. The NGS stars are sometime fainter than V=18 mag. and become more difficult to identify. The identification of stars and field recognition lack automation. The final centering accuracy on the science array is currently limited by the absolute positioning accuracy of the field selector (field-steering mirrors in NGS, tip-tilt sensor stage in LGS) and the ability to correct perfectly for the differential atmospheric refraction (limited knowledge of the color of the NGS).

3. Under-designed AO nodding/dithering hardware and software:
   The current accuracy for the field selector presents a limit for precise nodding along a slit, centering behind an occulting mask, centering and dithering on a small IFU field-of-view, etc. In addition, the current dialog between the science instrument, the telescope and the AO system during dither is plain serial (no move triggered till the instrument is fully idle, no field selector move during the telescope move, etc) and quite limited (e.g., NGS and LGS treated too similarly, limited error handling for faulty moves, etc).

4. Under-designed science instrument readout
   Taking an exposure with the science instrument is currently the only way to check for saturation and centering. In most cases, it takes ~10seconds between the end of an exposure and its display. For OSIRIS, it is very difficult interpret the data from the raw images for the non-expert user; the time lag from exposure finished to display on the on-line reduction pipeline is at least a minute (not counting any recording of a background frame). This overhead is sometime comparable to the acquisition time for each target. In addition, the instrument readout overhead comes currently in play at each frame. The online reduction and display overheads comes in play each time there is a decision to make before recording the next frame.

5. Facility class instrument:
   - Aging and/or complex Instrumentation: Downtime due to hardware at Keck has been mostly produced by aging (WFC) and complex (laser) technology. Spares are expensives and sparcely available. The maintenance of the WFC became very difficult. The laser presents challenges for its maintenance, reliability, alignment and operations costs.
   - Under-designed ancillary systems: The keck observatory does not have an efficient way of monitoring the photometry, the outside seeing, or collect data for PSF monitoring and characterization, etc
   - Minimal maintenance, calibrations and performance monitoring for science instruments, AO and laser. The Keck observatory observing support group can not allocate the effort to perform a high-quality monitoring of the performance of the science instruments. The documentation for the astrometry, geometrical distortions, PSF variations across the field, etc is currently very limited.

6. Use of visible light sensors
   The use of visible CCDs and APDs for the science target acquisition, the tip-tilt and low-order wavefront sensing forces us to start the observations during plain dark time. It is also much more sensitive to the moon light. The Keck starts propagating the laser at 12 deg twilight for “LGS AO checkout”, but science observations only starts at least 15 min after this. Using longer wavelength (near infrared?) detectors for the acquisition camera, and the low-order sensors will allow Keck NGAO to use the twilight and dawn time zones and use the system on faint stars even during grey and bright (moon) time.

7. Under-designed Operations (Laser traffic rules, overall cost including energy)

The current operation model for Keck LGS never went through a design process and suffer from patching and upgrades for the procedures, the algorithm, the tools, etc. This flexible and pragmatic approach may have been a benefit in the short-term but it presents a clear impact on the operation costs. The Keck routine operations include a nightly “NGS/LGS AO systems checkout and calibrations” on the sky, which takes time from the science observations. The laser traffic rules are missing a clear assessment on the real impact on other observatories science operations, as well as an assessment on the possible impact on satellite. The communication with US space command is very manual (fax, etc), and precludes from observing routine targets without the 72 hours notice. The aircraft safety method requires a lot of human presence and interactions. The overall cost of the LGS operations (spotters, support, electricity for laser and chillers, etc) had not been well anticipated and reviewed.

5. Science operations for the Keck community

In this section, we review some of the experience for the science operations of current Keck AO instruments. We are not aware of any published accounts from the science operations for other systems at Gemini or ESO.
We present our experience in three different ways: working with the astronomy community, working with the AO/Laser/science instrument builders and working in a given observing support paradigm.

5.1. The astronomy community using AO instruments

The Keck community using the LGS AO instruments is a rather small community (~25 different PIs) from our partner institutions (primarily, UC, Caltech, UH and NASA).
It is a community that is willing to adapt their observing priorities according to the performance of the instrument during shared-risk science period. The adaptability has allowed the community to get first-light for instruments in a faster way, at a higher cost/risk for their science.
The relatively small size of the AO users community at Keck has allowed for great interactions between the support staff and the observers. It has also allowed some observers to trade their time and optimize the observability on their first priority targets.

Rather than having a formal commissioning period, the Keck community uses the notion of shared-risk science. First there was a period of science validation, which included teams from partner institutions and Keck: 5 refereed science papers were published from this collaboration. Then came the period of TAC allocated time shared-risk science. Here again, the collaboration between science and instrument teams for the Keck II LGS benefited to both teams: some of the data taken during the shared-risk science was used to assess the performance of the instruments, rather than allocating dedicated engineering time. This method should be extended and better coordinated for both teams. Note that formalizing and coordinating the shared-risk science to asses instrument performance is very similar to the commissioning work done elsewhere!
The shared-risk observations method has had a very positive impact for planetary and galactic science, where results were published quickly after shared-risk science. On the other hand, the science impact from the LGS shared-risk extragalactic science was much more limited. This may have caused by a combination of the following: the instrument performance was not adequate for the science requirements (image quality and stability over long exposures, photometry and efficiency); the experience of the extragalactic astronomer for the observations, data reduction and data analysis were not as matured as for planetary and galactic sciences (modeling of the field-variable PSF, use of ancillary data to constrain the observations, data reduction tools) ; and the challenges for extragalactic sciences from AO data were not well anticipated.
In Feb. 2007, we studied the science impact for the Keck LGS AO nights from Nov. 2004 to Jan. 06. These nights were primarily allocated to astronomers with a competitive AO science experience. Out of 55 allocated nights, 15 were *fully* (>7h of lost time) lost to weather or technical problems and 12 were *partially* (3h < lost time < 7h) lost. Twelve refereed papers were published from 10 nights (including 3 nights, partially lost). We are not aware of any paper that was published based on the backup science programs.
We can conclude that experienced astronomers were very productive when they were able to perform their observations: at least 1 paper for 3.3 nights (nights not fully lost) as of Feb’ 07 and 1 paper for 4.6 nights (including lost nights) . These values are in well within the range of other Keck instruments like ESI and DEIMOS, and higher than for NGS AO (NGS AO was integrated with an engineering-grade science camera). We do not know how these values compare with similar AO instruments at Gemini and VLT.

In this small community, astronomers develop their own skills for observing strategies with AO instruments and assessing which data calibrations are required. In this way, observers have often pushed the limits for the instruments for their type of science, they have developed their own observing methods, and overcame their own data reduction challenges. Again, there are pros and cons of this observer-initiative based method for the overall science impact across the various astronomy fields. Also, the high level of observer initiatives may have allowed the observatory to keep a lower support priority for instrument performance and calibrations, compared to comparable-size observatories (e.g., Gemini, VLT) or space facilities.

5.2. The AO instrument build process

There has been a lot of flexibility for the building of the Keck AO instruments, particularly for the requirements for LGS AO science operations (including the facility-class aspects). Laser and AO have been built with a best-effort approach, which permitted to be first on sky. Many aspects of performance and operations have been implemented when the instrument was already used in shared-risk science mode. The AO development team is very involved in the shared risk period (operations and further development), making the operation dependent on development experts. When these experts become weary from supporting operation, the performance, efficiency and reliability are observed to decline. The management for the commissioning and operations review processes have been very flexible as well. The operations transitions lasted a year and included developing and implementing new tools for operations. A maintenance plan for the AO and laser which was not included in the early requirements is still being developed and integrated at the Observatory.

Also, note that the Observatory had to face unanticipated impacts and cost associated with operating the laser (use of telescope daytime, electricity, laser support staff, laser safety personnel cost, etc).

5.3. The science operations paradigm

The shared-risk science mode allowed for early use of the instrument on sky in a context of classical scheduling. This requires for most observers to have their own backup program either in NGS mode or with NIRSPEC.

The classical observing paradigm may prevent new challenging programs which call for specific observing conditions to be successful. On the other hand, in a flexible scheduling paradigm, the instrument failures have less impact on the Observatory science impact and the possibility of optimizing the observing conditions for a science case increase the chances for an optimal science impact.

Given its budget and priorities, the Observatory is currently not keeping a good track of the instrument performance: documenting the sensitivity, the image quality, the geometrical distortions, etc. This would benefit directly to the science and lead to an easier traceability of possible problems. It would require some level of archiving for the calibration data and the results.

As instruments become more and more difficult to use, more and more expensive to build and operate, they require more and more tools to: plan the observations; predict the performance; automate the observing sequences; and reduce the data. Given its current observing support paradigm, the Keck observatory has just started realizing the possible benefit of such tools.

It is very likely that a complex instrument like NGAO will require building tools to simulate the performance of the instrument (instrument setup, observing strategies and efficiency, sensitivity, image quality and stability, acquisition and guide stars) whether used in classical mode or not.

6. Conclusions:

The Science Operations Requirements for the first generation of the Keck LGS AO instruments was not a priority during the design and the development of the LGS program. This was a choice that benefited to some aspect of the science, while it may have some negative impact in the longer term.

The recent NSF/AST Senior Review [8] confirms that "the full costs of operating, maintaining, upgrading, exploiting [..] are many times the costs of construction. Realistic life cycle costing for the Observatories that are under construction or consideration is an essential part of strategic planning"

It may be still be profitable for the Observatory and the Keck community to investigate the feasibility of integrating some of these conclusions for the development & integration of the Keck I LGS AO system and its instruments.

For the longer term, in the case of NGAO, we are in a position to investigate the possible science operations models and select a model that best fit the need and requirements from the science community and the Observatory.

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7. Bibliography

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