Keck Next Generation Adaptive Optics

KAON 476
NGAO Science Operations
Observing Model Trade Study
WBS 3.1.2.1.10

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1. Introduction and methodology

This document presents the results from the Observing Model Trade Study (WBS 3.1.2.1.10). The Systems Engineering Management Plan states that the Observing Model trade study is to report on the relative merits of various observing models (classical, queue, service) for the NGAO science cases. In particular, it includes the possible impact from weather, space command approval, laser traffic control, instrument inefficiency and time on target to achieve a desired science performance (i.e., SNR). [1]

We propose the following methodology:

2. Present the top-level goals for the observing model
3. Enumerate the assumptions for the study
4. Present and discuss existing observing models
5. Select alternate study-case models and use them for discussion
6. Discuss model implementation priorities and conclude

At this point of the Systems Design, we do not have the necessary information about the science instruments to investigate any issues or options related to instrument sensitivity.

2. The top-level goals for the observing model

A trade study is meaningful only if the observing model goals are defined and case-studies can be developed to compare the various observing models. For this document to be useful, we then need to present a set of the top-level goals that the observing model is striving to achieve.

The overall goal of NGAO science operations is to maximize the science impact of the allocated observing time, given i) the science cases, ii) a performance budget for the instrument suite, iii) an operation-cost for the Observatory and iv) a scientific skill set for the astronomers. There exists a wide range of observing models to accomplish this overall goal, as a function of the instrument functionalities, the Observatory budget and the *modus operandi* and size of the scientific community.

The observing scenarios for the NGAO science cases and the lessons learned from the science operations of the current LGS AO instruments provide the framework for developing the top-level goals for the observing models. The quantitative and detailed analysis of the observing scenarios is yet to be completed, so we restrict ourselves here to the common and important top-level goals from the science cases, and use them to guide our trade study. We propose the following top-level goals:

1. Science-grade quality of the raw data (image quality, completeness of observations)
2. Science-grade quality of the data products (photometry, astrometry, PSF knowledge, WCS calibrations)
3. Science impact from a given data product (number of publications and citations)

And we consider the instrument image quality performance, the Observatory budget and the scientific merit of the astronomy community context-based constrains, that we don't include in our top-level goals. A key-metrics may be produced at later time to help produce an assessment for the achievements of the top-level goals.

3. Assumptions for the trade study

In this section, we list the assumptions used in the trade study:

3.1. The telescope and instruments:

We assume the following:

- The telescope used for NGAO could be either Keck I or II or both.
- NGAO will be installed at the Nasmyth focus(i)
- Changes, particularly electronic hardware and software changes, can be made to major sub-systems: DCS, current and future instrument suite, etc to accommodate for "hot" switches between instruments, parallel command processing

(e.g., setup instrument for nighttime while DCS is reconfigured, science readout while loading the configuration for the next target, etc), scripting and automation.

3.2. The science community

We assume that the science community will be composed of the actual Keck community: UC, Caltech, UH, NASA & NSF/TSIP.

- Each of them has a Time Allocation Committee (TAC), that will allocate time for NGAO.
- All observing proposals will be ranked by the TAC (science merit or any other method).
- We acknowledge that an important fraction of astronomers from this community are skeptical about the cost/benefit of service observing for their science.
- Time Domain Astronomy (target of opportunity or monitoring programs) proposals will be allocated observing time.[2] And we anticipate that no restriction will be made for the minimum observing time allocated (at least for NGAO).

3.3. The telescope schedule

We dot not assume any constrains on the scheduling except for the following:

- Each TAC will be allocated its share of time
- There will be time allocated for Telescope & Instruments Engineering

Particularly, at this point in the study, we are not assuming that the interferometer will be fed by NGAO nor whether it will constrain the telescope day and night schedule.

3.4. Simple observing support paradigm:

We assume the following observing paradigms:

- Observing Assistants (or equivalent-skill staff) will be present at the summit
- The Support Astronomers (or equivalent-skill staff) would be available for support locally (Keck hq) or remotely (Oahu and US mainland)
- Astronomer (from either the science community and/or equivalent-skill staff from the Keck Observatory) would be performing the observations either locally (Keck HQ) or remotely (Oahu and US mainland)
- The requirements for target approval with US Space Command will be automated and be of less than 6 hours. [10] The notification of laser propagation for laser safety will be automated and less than 12 hours. The LGS operations will not required any laser safety observers ("spotters") at the summit.
- The requirements for Laser Traffic Control will include the "first on target" priority rule.[11]

3.5. Observing conditions

From KAON 463,[3] we assume the following observing conditions throughout the year:

- ~20% of the total nights year-round are not usable for NGAO (whether NGS or LGS)
- ~55% of the total nights year-round with photometric conditions (>6h/night)
- ~65% of the total nights with good or marginal cloud conditions (cirrus or partially cloudy), workable for LGS
- ~75% of the total nights with good or marginal cloud conditions (thick cirrus or greatly cloudy), workable for NGS

At this point, we don't assume any constrains for atmospheric conditions (seeing and Cn2 profile, Na layer density profile), or that NGAO will be a bright or dark time instrument (as it may be able to include NIR tip-tilt sensors and acquisition camera).

4. Presentation and Discussion of Existing Observing Models

Observatories worldwide have different ways of observing. Most of them fall in the following two categories: classical, and queue-service observing models.

4.1. Classical observing

This is the model of choice for Keck Observatory and for some other major observatories (Magellan,[4] Subaru, UKIRT, KPNO, CTIO, etc). VLT and Gemini also operate in this mode more than 30% of the time.[5,6] Astronomers from a given institution are allocated time by their TAC for their observations with a given instrument. The observing time is scheduled for a precise date. The astronomers are the observers and service observing is not offered for this mode; P.I.s are in charge of the observing program and can make changes to it (with some restrictions for VLT and Gemini). The observations are performed either locally (e.g, Subaru Control Room on the summit of Mauna Kea) or remotely (e.g., Keck Waimea or UCLA remote observing room). In most cases, the support astronomers are located in the same room as the observers. The observers are responsible for the calibrations of the instrument (VLT and Gemini include facility calibrations as part of the observing plan).

This observing model is potentially directly affected by marginal observing conditions (typically 25% of the nights are lost year-round) and technical problems. Backup programs are the sole responsibility of the observers, and time lost due to weather or technical reasons is not compensated.

Financially, this model is cheaper to operate and relies on a tight community of users; To further control the operational cost, some observatories adjust the requirements for observing support (observing preparation tool, staff support), instrument performance maintenance plan and monitoring, ancillary data products (seeing, PSF reconstruction), data reduction pipelines and data archive.[4] In the classical observing case, there is generally no limit for the proprietary data.

As of today, the classical model requires more instrument and scheduling flexibility to work well for TDA, either Target of Opportunity or Monitoring.[2]

This model gives a lot of flexibility to the astronomers' science programs and works well for regional or national communities. Again, the classical model is also used for less than half of the observing time in larger international observatories like ESO or Gemini.

4.2. Queued-service observing

Queue scheduling does not have to be paired with Service Observing but it appears to be done in practice (ESO, Gemini, CFHT, HET, etc). Yet, none of the ground based observatories are operated in 100% queue-service mode; the queue-service mode represents 40 to 70% of the total observing time.[5,6]

In the queue scheduling mode, the observers are allocated observing time by the TAC. Proposals may be ranked scientifically (class 1, 2, etc), where class-1 proposals are given the highest observing priority. The date for the observations is constrained by the observability of the targets and the observing conditions required for the program. The astronomers have to go through a phase-2 proposal, where all observing details will be listed and reviewed. There is no backup program (class-C proposal may be performed under adverse conditions). The observing program is carried out under the required observing conditions. Overall, there is much less flexibility for the observers to adjust instrument setup, change target priorities or assess the science quality of the data ; On the other hands, Class 1 and 2 science observing programs are performed under optimal conditions and have a higher rate of completion. The time limit for the proprietary data ranges from one to two years.

The Observatory is responsible for the calibration data for the science and the instrument performance, which allows the Observatory to use the same calibrations for different science programs.

This model works great for a large and international community of users who share access to telescopes at remote locations. It requires greater funding and a much greater suite of tools for observing sequences, instrument performance simulations and monitoring, data reduction pipelines and data archive.[7]

This observing model allows the user to switch to a different instrument and program and may become a great advantage during technical difficulties and during the integration of a new instrument. In principle, this should also be a great benefit for AO observations that require good and stable observing conditions.

4.3. Model comparison against the NGAO proposed top-level goals

For the most part, the comparison between these models has been qualitative and relies on anecdotes from:

- astronomers not satisfied with the final data product from the queue mode (data quality); Many times, astronomers claim they would have done a better job of assessing the scientific potential of the data and making decisions to pursue or change the program.
- astronomers losing part or the total of their allocated time due to adverse observing conditions (weather, technical, seeing), sometimes over more than one scheduling period. This leads to delayed publications at best, possible difficulties to request more time, apply for future funding and/or abandoned projects.

- astronomers successful in retrieving and using archive data for their research.
- astronomer, stakeholders and believers in one exclusive model, and sticking to that vision.

The main characteristics of the two models are summarized in Table 1.

	Classical	**Queue-Service**
Scheduling		
Number of nights/semester	180	Account for weather losses
Mode	night/night (>0.5 night)	Program/program (>4 hour)
Obs. Date	Fixed	Flexible
Observations		
Observer	PI et al.	Staff Astronomer
Science priority and observing strategy	Per PI et al.	Per phase-2 and observing staff
Science Calibrations requirements	Per PI et al.	Per phase-2 and observing staff
Observing Requirements		
Atmospheric conditions	Random	Per phase-2 reqts
Telescope/Instrument readiness	Best effort	Optimized / Documented
Observing Risk management:		
Backup options	Limited range	Per schedule and phase-2
Bad weather Impact	Lost allocated time	Delayed observations
Technical problem	Lost allocated time	Delayed observations
Science quality of raw data	Depending on Observing Conditions, Science Instrument readiness, and Observer's decisions	Depending on proposal ranking. May also depend on Phase-2 details and Observer's decisions
Science quality of data product	Defined by Observer Proprietary data No data archival	Defined by Observatory and Observer >18 months proprietary data Archived
Science Impact	Per PI work	Per PI work Per archive access

So far, little has been published to support a quantitative cost/benefit analysis between the two observing models. As J. Miller noticed, [8] most institutions operate in a quite different socio-political framework, with different communities, with different involvement levels in building and supporting the observing facilities, with very different budget rules and constrains.
Yet, the paper from Puxley and Jorgensen[5] provides a great overview of five years of queue scheduling at the Gemini Telescopes and allows us to compare numbers with Keck's experience: [3,9]

4.3.1. Flexible scheduling:

- Both Gemini and VLT reported that their community is now very enthusiastic about the service-observing mode.[5,6] The numbers of astronomers requesting service-observing has been steadily increasing over the fraction 50-50, which the Observatories were designed for. Both observatories are trying to keep the fraction of classical (visitor) mode to at least 30 to 40% of the allocated time.
- VLT and Gemini queue service observing includes seeing limited and AO instruments in different wavelength range, yet it does not affect the entire schedule nor all telescopes at the same time.
- The observing model of choice for the Keck community has been classical. Yet, we observed in 2004-2006 a trend for LGS observers to arrange with other observers and share nights so that each of them would have more than one opportunity to point the laser at the high-priority targets. The choice was based on two concerns: getting the best possible observing conditions and optimizing the coverage of variable sources (Galactic Center, low mass binaries, binary asteroids, time-series of the Crab nebula, etc). Time Domain Astronomy requiring more flexible access to instruments has become an important science driver for the Keck Observatory.

- The share of allocated observing time per P.I. varies within the Keck community; so, will the impact of lost observing time with respect to the astronomer's science goals. LGSAO science operations needs to be more reliable overall, as more LGS nights become shared among a greater number of P.I.s.

4.3.2. Observing support operations:

- Both Gemini and ESO faced challenges for the staffing of the science operations: the number hired was too low, and the learning curve was very steep. ESO notes that NAOS-CONICA (NGS at this point) is mostly operated in classical mode (>60% of the allocated time).
- Keck AO was difficult to operate in both in NGS and LGS as the system was being offered for observing while it was still being optimized. VLT and Gemini had an easier time getting the system operational as they spend more time on characterizing the system performance and defining the operation modes (using preparation and simulation tools).
- Keck has 8 support astronomers for two telescopes, while Gemini science operations require more than 10 and up to 15 Ph.D.-level support persons (per telescope site), not including the scientific staff for each National Gemini Office (~4FTE/2 telescopes) and the support for data reduction tools (~4-5 FTE/yr/2 telescopes). Once fully staffed, Gemini claims it would be able to support 100% service observing.
- The Keck Observatory and Gemini Observatory science operations goals (and achievements?) may differ widely, yet the observing support cost for Gemini appears to be about 4 times the observing support budget for Keck (without including the work effort from the users' community).

4.3.3. Efficiency:

- Once weather losses are removed, the NGS AO instrument open-shutter efficiency numbers reported for Gemini Queue are ~60% under stable conditions (good weather) and ~50% for less stable conditions (variable transparency and/or marginal seeing).
- The open-shutter efficiency for Keck in NGS mode ranges between 40-60% and is 33% in LGS mode (without weather).[9] Gemini North weather losses account for 20% of the available time (Keck LGS metrics is 25% and Keck metrics gives 21%).[2] The technical faults at Gemini North account for less than 10% of the observing time compared to 19% in LGS mode at Keck.

4.3.4. Quality of raw data, science-grade data product and science impact:

- Puxley and Jorgensen[5] report a 2003-2005 publication rate much higher for Queue (126) than for Classical (26), and note a strong correlation of the program completion with the publication of papers based on the program data: as one expects, when the completion percentage increases for the program, so does the publication rate. Gemini Queue proposals are ranked by TAC into three bands, Band 1, 2 and 3, based on science merit (each fraction is respectively 20, 30 and 50% of the Queue proposals). Gemini met the goals of 90% of queue programs completed for Band 1, and 75% for Band 2 (for Gemini North). The goal of 80% of the program of Band 3 being 75% completed is partially met. Gemini AO instruments have not been in operations for a long enough time to support a comparison between Gemini and Keck AO publications.
- 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 extensive 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.
- For Keck, we concluded that 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 well within the range of other Keck instruments like ESI and DEIMOS.
- The numbers for Keck AO publications in the field of galactic astronomy (53%) and planetary science (30%) are still much greater than extra-galactic (23%) even for LGS mode (e.g., see Le Mignant et al. [9] for a discussion of the impact of the Keck LGS commissioning mode for the CATS project). The availability of a suitable guide star for extragalactic astronomy may represent a challenge, but there are other factors that are detrimental:
  - incomplete raw data set: many extragalactic project requires system reliability combined with good and stable observing conditions for period of time (~4-6hours , including the calibrations)

- incomplete science-grade data product: the time and spatial variability of the PSF leads to difficulty to extract accurate information for the photometry, the astrometry and the object intensity distribution. There is presently no AO system on large telescope that routinely provide reliable calibrations for the PSF and for very accurate astrometry.

• ESO/VLT does not present any number for the quality of raw data and completeness of the observing programs. The number of publications for NACO and SINFONI (VLT NGS AO, excluding the VLT Interferometer) has already surpassed the total of Keck AO publications (NGS/LGS + interferometer). *It would be interesting to check the citation index for each system, as well.*
• Both Gemini and VLT have started to make their AO data available to the astronomy community after expiration of a proprietary period. It is too soon to estimate the science impact from archive retrieval.

4.3.5. Conclusions

As said, an exhaustive comparison of the two models is a difficult task. Which one is worth the investment made? Should either the Classical or the Service observing model work so much better than the other one, Gemini and VLT would have it fully implemented (as they are simultaneously supporting both classical and queue).
The full classical observing mode is inept to address any requirements for specific observing conditions required for reliable science operations for one-night observing programs. It's a hit or miss strategy which may lead to lower science impact in the Keck community in the long term, frustration for the astronomers and a steeper learning curve for new AO observers. About 80% of the highest citation Keck papers are in extragalactic, so it is important to build an instrument that fits the extragalactic community. Given the Keck investment in NGAO and the requirements from the science cases, the classical observing mode presents a strategically much-higher risk than the current LGS AO; the service observing addresses the flexibility and observing conditions issues but could potentially be expensive to implement at Keck.
We recommend and anticipate that the NGAO science operations will not be the full classical model nor the full queue-service model. In the next section, we explore some alternatives.

5. Pre-selected Observing Models

Following the discussion in section 4, we propose to compare possible models in-between full classical and queue-service observing. We choose an outcome-oriented approach and list below some of the respective advantages addressing the top-level science operations goals:

- Ensuring the science instrument is developed, delivered, maintained and operated in a way that is well understood, supported and agreed upon with the scientific community, including a realistic staffing with respect to the goals for observing support (FTEs and expertise levels).
- Ensuring there exists strong interaction between the support staff and the scientific community and/or adequate documentation and support tools for the entire phase of an observation program (preparations, observations, calibrations, data reduction, etc), as well as during the instrument commissioning phases (science verification)
- Ensuring there is a process to make **science-driven observing decisions**. Particularly, this may include an efficient way to provide a flexible scheduling method and switch between instruments and programs as observing conditions evolve.
- Ensuring that the **observing program completion** (including photometry and PSF calibrations) is as final as possible.

Below, we are proposing a case-study for three models: a classical-backup, the TAC-Flex (for flexible, not queue!) and the Keck-Flex.

5.1. Classical-Backup

Classical-backup is a poor name to describe a science operations model that would be on the cheapest side of the various model options, yet able to present some minimal flexibility to adapt the science program to the observing conditions. The advantage of such a minimalist approach is that it could be implemented early on, later, or not at all, by the TACs.

The key ideas for that model are to under-allocate LGSAO nights and to decouple the backup program from the primary observations.

In this model, LGSAO proposals would be sorted in two class (e.g., A and B).

- Proposals in Class A (NGS or LGS) would require stable image quality, photometric conditions and at least 4 continuous hours of observations; they are not required to have a back-up program.
- Proposals in Class B have lower requirements on image quality, need not photometric conditions and use any of the compatible instruments. Class B could be considered as the backup proposal class.
- The TAC allocates NGAO time to observers in the two classes independently, as it does now for LGS AO proposals.
- In addition, each TAC makes sure that roughly one LGS night out of 5 is not scheduled (NS). We call that night an NS night. The NS nights may vary in number and distribution throughout the year, depending on weather pattern, science target priorities, maturity of system, etc. The 20% fraction is confirmed by all Mauna Kea studies on weather statistics (note that backup options are not feasible during that time either).
- Each Class A observer is awarded observing time as in the current classical scheduling paradigm. The observer may choose to observe remotely or travel to Hawaii (see Section 6 for a range of observing support options).
- The Class A science program is reviewed and prepared with the help of the observing support tools and staff. Then the program is performed as scheduled.
  - If the data collection for Class A program is 80% satisfactory (criteria to be expressed at a later time), then the program is considered complete.
  - If the observing conditions (weather, faults, etc) prevent data collection, the program must stop and a fraction (to be detailed) of the next available NS night will be reserved for the Class A proposal. Immediately, the observing support will identify a Class B proposal that can be performed given the observing conditions, the instrument setup and the observers' availability (staff and observers' roles to be detailed at a later time)
- If the entire available NS night remains open, it is then allocated to a Class B proposals, or any selected observing program with any instrument that can be used.
- Time Domain Astronomy could make use of fraction of the NS night.

This model makes almost no assumptions on people's buy-in: observers individually, as well as TAC may or may not choose to participate in the program. TAC may adapt the program to fit the observing priorities of their community. It leaves a lot of options open for observing support model, decision making processes, etc.
In this lowest operation-cost model, we are assuming a significant effort for preparing the observations (pre-observing tool, performance simulation, etc), supporting the observations and assessing the raw science-data quality. It is important to rapidly assess the completeness of the observing program. Calibrations may be solely the responsibility of the observers. Requirements for instrument reliability, maintenance and performance monitoring may remain to current level or improve. Any data reduction and archive tools remain an option for each science instrument.

One could prototype and adapt such flexible model with K2 or K1 LGS AO in 08A.

5.2. TAC-Flex

The second case-study model we present for discussion provides a greater ability to perform and complete observing programs under requested observing conditions.

The key ideas for the second model are to allow for flexible scheduling within a given block of allocated night, per TAC and provide an adequate context for remote observing.

- Each TAC allocates observing time either per night (~9-12 hours), half-night (~5-6 hours) or quarter-night (~3 hours or less).

- Each program is ranked in either Class A or Class B. Class A proposals may include a set of well-defined requirements; dark, grey time, photometry, resolution, minimal time on target. Class B proposal are considered secondary science priority for the TAC. Given that photometric nights represent only 50-60% of the night, we would recommend that Class A does not include more than 60% of the proposals.
- This observing support model may include other instruments mounted on the NGAO telescope. Each TAC provides its request of NGAO nights and dark/grey nights for the semester. The observatory coordinates the requests and allocate blocks of night for each TAC. The final Observatory schedule includes TAC blocks of nights and other constrains such as an interferometer run, and maintenance for each instrument.
- Each TAC may have the option to allocate less observing time for a block of night to ensure that each observing program is completed.
- We illustrate some aspects of this TAC-Flexible model in the draft schedule shown in Table 2. For the purpose of clarity, we have assumed that NGAO would be mounted on Keck II and that DEIMOS, ESI and NIRSPEC will still be available in 2010 (which may be doubtful for NIRSPEC). We have also assumed that IF is not fed by NGAO and that NGAO will feed three instruments: a deployable integral field unit (D-IFU), a near infrared camera (NIRCAM) and a visible imager (VIS-IMG).

Scheduled maintenance — Not available
Requested Class A (and B) — Readiness required (Class B)

		TAC		Inst. Request	Instrument availability and status						
Date	% dark	C	F		D-IFU	NIRCAM	VIS-IMG	NIRSPEC	DEIMOS	ESI	other
1/1	0	CIT		NIRSPEC				**C345A**			
1/2	10		CIT		**C453A, C456A,**						
1/3	20		CIT		**C567A, C487A,**			C568B			
1/4	29		CIT		C582B, C564B			C564B			
1/5	39		UC		C764A						
1/6	48		UC			C603B			**C598A**		
1/7	56		UC								
1/8	65		UH								
1/9	75		UH								
1/10	83		CIT								
1/11	91		CIT								
1/12	100		CIT								
1/13	100		UC								
1/14	100		UC								
1/15	100	NOAO		VIS-IMG							
1/16	96	UC		ESI							
1/17	88	UH		ESI							
1/18	80	CIT		ESI							
1/19	73	CIT									
1/20	65		UC								
1/21	57		UC								
1/22	48		UC								
1/23	38		DDT								
1/24	29	UC									
1/25	19		Keck	PCS							
1/26	9		Keck	PCS							
1/27	0		NASA	IF							
1/28	0		NASA	IF							

1/29	0	NASA	IF
1/30	0	CIT	IF
1/31	5	CIT	IF
2/1	15		

Table 2 shows a possible configuration for the month of January 2010. TAC may allocate nights either in classical (C) or flexible (F) mode. For the flexible mode, various Class-A proposals may be in line (C453A, etc) as well as backup programs (C582B, etc). DEIMOS or NIRSPEC could be available in parallel with NGAO possible instruments (D-IFU, NIRCAM or VIS-IMG). The interferometer is not assumed at this point to be an instrument for NGAO.

- The design of the science operations will have to include scheduling tools that can adapt to the TACs and the Observatory. This model will also require the inclusion of preparation and simulation tools to allow the observer to specify the observing condition requirements for the observing program.
- The requirements for flexibility will be shared equally between the Observatory and the TAC, which will help to share the costs. The design for this observing model will include the ability to perform remote observing from various UC/Caltech/UH locations, and possibly from personal laptops and offices.
- Each TAC may have the charge of coordinating with PI astronomers and coordinating the schedule with the observatory using synchronized scheduling tools with automated logic, error checking, and a range of options including email notification to PI and synchronization with other Observatory databases (to be designed).
- The nightly support of astronomers may be done either from Keck HQ or from the remote sites. There may be a lot of potential in having the observing support effort shared by the Observatory and the major TACs.: some of the support staff would be able to coordinate and work closely with the astronomers during the preparation phases, pre-observations, etc. It will certainly help understand some of the issues with the science impact of any instrument and improve the performance monitoring for most instruments.
- There will be a lot of details and options that would need to be explored for such a model including DEIMOS, NIRSPEC and ESI planning, day-calibrations and readiness when an NGAO instrument is used, management for the calibration requirements for each science instrument, development of an accepted phase-2 effort with the observers, etc

This case study illustrates how any significant fraction of flexible scheduling will require a significant investment in observing support tools and a very good coordination between TACs and the Observatory. It will also require observer flexibility in order to save effort on service observing and additional observing support.
This model has the potential to be what a TAC wants it to be: it would work well for the time domain astronomy within a TAC; it may include many options for archiving the calibrations and the science data, some level of service observing at the TAC convenience, development of data reduction pipelines from within the astronomy community, etc.

5.3. Keck-Flex

The third case-study is a so-called Keck-Flex model, a Keck-wide extension of the previous case study. It is unlikely to become an attractive model for the Keck community, but could be considered if the TAC-Flex model was scientifically successful for a reasonable cost.
A Keck-Flex model could include the following features:

- The TAC allocates observing time in a very similar fashion than the TAC-Flex.
- There will be an extensive phase-2 effort for all proposals not scheduled in classical mode.
- A considerable effort will be made at Keck to schedule flexible proposal according to observing conditions, instrument and calibration requirements. We will also consider an additional high-weight requirement to allow the observer to take part of the observations (very likely from a remote site).
- We can anticipate that part of the remote observing paradigm developed for the TAC-Flex model could be deployed and improved for the Keck-Flex. For instance, the observations could be performed with expert service observers with the remote help (phone/video) of the astronomer/PI.

Again, this model would require building an extensive suite of observing preparation tools for all Keck instruments. It will have a very positive impact on time domain astronomy. Here too, many options could be developed for archiving the calibrations and the science data, the fraction of service observing at the Observatory and the community convenience, the development of data reduction pipelines from within the astronomy community, etc. Last but not least, the model would require detailed, realistic and controlled effort planning, which may be best achieved in a phased program.

5.4. Comparison with top-level goals

The Table 3 below show a simple comparison between the 3 models mentioned.

	Classical-Backup	TAC-Flex	Keck-Flex
Scheduling Number of nights/semester Mode Obs. Date	 0.8*180 night/night (>0.5 night) Fixed w/ possible re-allocation	 0.8*180 Program/program (>3 hour) Flexible within windows	 0.8*180 Program/program (>3 h) Flexible within windows
Observations Observer Science priority and observing strategy Science Calibrations requirements	 PI et al. Per PI et al. Per PI et al.	 PI (+ Staff Astronomer?) Per phase-2 and Observer Per phase-2 and Observer	 Staff Astronomer (+ PI?) Per phase-2 and Staff Per phase-2 and Observer
Observing Requirements Atmospheric conditions Telescope/Instrument readiness	 Random Best effort	 Per phase-2 reqts Optimized / Documented	 Per phase-2 reqts Optimized / Documented
Observing Risk management: Backup options Bad weather Impact Technical problem	 Optimized Re-allocated time slot Re-allocated time slot	 Per flexible schedule and phase-2 Delayed observations Delayed observations	 Per flexible schedule and phase-2 Delayed observations Delayed observations
Science quality of raw data	Depending on Observing Conditions and Observer's decisions	Optimized for observing conditions Depending on Phase-2 and Observer's decisions	Optimized for observing conditions Depending on Phase-2 and Observer's decisions
Science quality of data product	Depending on Observer Proprietary data	Depending on Observatory and observer	Depending on Observatory and observer
Science Impact	No data archival Per PI work	Optional data archival Per PI work Per archive access?	Optional data archival Per PI work Per archive access?

6. Implementations Priorities and Conclusions

6.1. Ruling out Queue-service Observing

From our study, we believe it will be very difficult to implement a queue-service mode for the NGAO at Keck for the following reasons:

- A queue-service model cannot be implemented for just one instrument on one telescope. The Keck Observatory would need to dedicate a major effort to adapt other instruments, design, develop and upgrade current instrument observing tools. The Keck Observatory has a very lean science operations model and a queue-service observing model would require a major science operations budget increase (between a factor of 2 and 4).
- The Keck astronomy community does not believe that queue-service mode offers an attractive cost/benefit option for the observing model (though no quantitative data supports this axiom).

Yet, it is critical for the NGAO science goals to guaranty in a systemic way the science-grade quality of the raw data (SNR, image quality and program completeness) and data products (astrometry and photometry calibrations, PSF knowledge). The lean and classical observing model currently in place at Keck would fail to guaranty these science goals.

6.2. Supporting the top-level science goals

Our recommendations aim at finding a model implementation that best supports the top-level goals rather than having to choose between classical and service observing.

6.2.1. Supporting science-grade quality of raw data: SNR, image quality, data completeness

1. Provide an extensive set of tools for instrument performance simulation and observing preparations (AO and science instruments).
   - These tools should be designed with the end-user in mind and would benefit from a collaboration between instrument scientist, software engineers, post-doc (or grad-students) and astronomers.
   - This will require a continued effort to characterize, monitor and document the instrument performance (AO and science instruments).
   - 3 total FTE for the tools development (?), ~ 0.5-1.0 FTE/year for the first 2 years of operations, then 0.2-0.4 FTE).
2. Given a set of requirements for each science instrument (including the AO system) provides a minimal set of tools for data quality assessment, data reduction and *rough* analysis:
   - Level 1 data reduction pipeline to reduced data (background, cosmetic, shift-and-add)
   - Assessment of image quality (SNR, Strehl, Encircled Energy, etc) from the reduced images and cubes. Note that in many occasions, these tools arrive late: it delays the characterization phase for the instrument and impacts the science return during the first phases of operations.
   - The cost should be included in the science instrument development and will be proportional to the requirements. 1 total FTE for the development (?) per instrument, ~ 1.0-2.0 FTE/year for the first 2 years of operations, then 0.3-0.5 FTE).
3. Provide a science operations paradigm (here, mostly scheduling and observing) that optimizes the completion rate for *a significant fraction* (80% - to be confirmed) of observing programs.
   - This requires great coordination and careful planning with the science community, the TACs and the Observatory for development and operations costs. The costs will depend on the model adopted (backup, TAC-Flex and Keck-Flex) and the definitions of various fractions and completion rate for each (if any) class.
   - A phased approach may provide the means to control the costs. Any design for a phased approach will have to carefully look into upgrade options.
   - Instrument switch options during a night, from one night to the next, needs to be investigated: requirements for calibrations, instrument preparation, support and infrastructure requirements, etc
   - There needs to be good communication and feedback process with this astronomy community regarding the scheduling and observing operations options.
   - The Mauna Kea Weather Center produces data (transparency and Cn^2) that could potentially be used for scheduling instruments in advance (days, up to a week?) and provide an important input for scheduling priorities.
   - As a very preliminary estimate: total of 5 FTE for a phase 1 implementation (details TBD)?

6.2.2. Supporting science-grade quality of the data products: astrometry, photometry and PSF knowledge

4. Identify calibration methods, tools and accuracy for astrometry and photometry
   - On-sky calibration methods: identify whether a continued Observatory calibration plan would be valuable to the science community.
   - Other calibration methods: there already exist ways to calibrate the instruments without requiring the use of sky time, either using stable instrument setup and simulation sources, either using ancillary data to monitor the sky transparency at the observed wavelength, seeing, etc.
   - Depending on the number of instruments and observing modes, a combination of these two options could be very effective as it will be easier to switch from one instrument configuration to another, and may save some of the sky time normally devoted to calibrations.

- As a very preliminary estimate: total of 1 FTE for development and 1 FTE for continued support during science operations (details TBD)?

5. Identify calibrations methods, tools and accuracy for PSF knowledge for each science case
   AO data is notoriously difficult to analyze: PSF time and spatial variability (over all scales) affects the photometry and astrometry accuracy for most science areas (high contrast imaging, stellar population, high-z galaxy formation); tiny amount of differential atmospheric refraction in the instrument, between the guide star and the science target affect the absolute astrometry; across the field-of-view; etc. These difficulties have a tremendous impact on 1) the amount of time astronomers spend understanding the data calibration vs. that spent on science questions, 2) delaying the science impact (publications) of the data and results 3) limiting the conclusion and the strength of the scientific results from AO data.
   - Implement the use of ancillary data to monitor seeing, Cn2, Na distribution and wavefront residuals.
   - Use the atmospheric data to feed the simulation tools and predict instrument performance. Implement dedicated tools to monitor wavefront error and reconstruct the PSF across the field of view of the science camera. Note that PSF reconstruction (with or without field variations) has never been routinely implemented on any of the existing Shark-Hartman-based AO systems used for astronomy worldwide.
   - As a very preliminary estimate: total of 3 FTE for development and 1 FTE for continued support during science operations (details TBD)?

6.2.3. Supporting total science impact per data product

Once the raw data and the final data product has been secured and satisfy the science goal requirements formulated by the P.I., there is little the Keck Observatory currently does to support the total science impact. Data archival and retrieval is one of the areas that may be important for a long-term Legacy and attract possible funding. The Observatory can also be a key-player during the early phases of science operations.

6. Develop a plan for data archival
   - Data archival are expensive as they put tighter requirements on the quality and the documentation of data being archived. Yet, as of 2007, data archival exists almost everywhere for the cheapest forms of electronic bit and data transmissions.
   - Cost effective solutions must already exists and should be investigated with the astronomy community. It would facilitate the monitoring of the instrument performance, and enable the possibility of future Keck NGAO science based on archived data.
   - The development of a plan for data archival should only take 0.25 total FTE.
7. Develop a plan for data retrieval:
   - Data which are not archived are likely not retrieved! Data retrieval may not be a high item priority but should not be excluded from the instrument design. This is in the long-term interest for a Keck Observatory Data Legacy; high spatial resolution data like NGAO are likely to be used for any detection of proper motion, distance measurement and in general, in all areas of time domain astronomy.
   - The development of a plan for data retrieval should take less than 0.25 total FTE.
8. Include an extensive science verification phase in the instrument development.
   - A bundle of early science publications is key to document the instrument performance, identify any problem with the science operations of the instruments and communicate on the success of the instruments (and even more importantly if the instrument is privately funded).
   - The Science Verification phase should be managed as other project phases: it should include astronomers from the science community, the science instrument builders and the engineering and scientist staff from the Observatory. There should be calls for key-projects from the community, and each key-project will include the team who worked on the instruments.
   - The science verification phase could absorb as much as 3 total FTE, between defining and documenting the key science verification cases, collecting, analyzing and exploiting the data.

6.3. Controlling the costs:

The Keck Observatory and its science partners have chosen a lean science operations model. Since 2005, LGSAO at Keck has proven to require more observing support load than non-laser instruments.

The NGAO science operations will require the development of innovative solutions to keep science operations costs low. As noted by J. Miller, collaborations between the astronomy community and the Observatory staff help control the costs, while making sure it best serves the community.

6.3.1. Collaborations among institutions

The NGAO Systems Design Phases already gathers scientists, engineers and astronomers from the entire Keck community. This paradigm should be pursued for the science operations: designing and implementing the observing tools, investigating options for a flexible observing model, characterizing the instruments and documenting the performance during science operations. The technology for multi-sites connections has changed in the last 10 years and should allow the community to work more closely with the Observatory. To some degree, we need to reproduce for Keck NGAO operations the synergy that exists between Lick Observatory and UC, between Palomar and Caltech. One could envision that instrument experts/ tools designers/ support staff be shared among facilities (Palomar, Lick, NOAO, MST) to mitigate new hiring costs and allow for professional development.

6.3.2. Phasing costly flexible observing

The LGS AO science operations plan for simultaneous operations for K2 & K1 LGS AO will likely increase the load on the observing support team and may be an opportunity to prototype and implement some of the suggested solutions for the NGAO science operations.
The three study case models we have introduced could represent seed scenarios for successive phases for the NGAO science operations. These phases could be implemented in a way that would benefit the community and the Observatory.

- **Short-term (2007-2009):**
  There are not many restrictions for implementing the Classical-backup model in the current operational paradigm. It requires the TAC to schedule less nights than available and identify the program that would have priority on the NS night. It requires the Observatory to maintain LGS readiness state for the NS night; send more targets to US Space Command than for normal nights. It could be implemented for K2 and/or K1 LGS AO science operations.
- **Mid-term (2009-2015):**
  It is difficult to imagine a model similar to TAC-Flex applied to the current LGS observing model, but it could certainly be done if everyone was satisfied with the cost/benefit of the implementation of the Classical-backup model. There would be a critical need for operations upgrade and improvements: tools to estimate the instrument performance, prepare for the observations, enable reliable multi-site observing, fast switching of instruments, etc.
- **Long-term (2015-2020):**
  A Keck-Flex would certainly be very difficult to implement with the current suite of instruments and from the current observing model paradigm. Again, this model would leave the option for an astronomer or a TAC to participate or not in the process. The implementation of such a model may depend as well on the evolution of the Keck community in 5 years from now: commitment to the TMT program, NASA involvement, new partners, new observing time exchange initiatives with other observatories, etc.

6.4. Final conclusions

We have presented a trade study for the NGAO observing models by first defining top-level goals for NGAO science operations. We then reviewed and discussed the existing classical and queue-service models from the published data. We have presented three case-study observing models to further assess a range of possibilities for NGAO.

We recommend that *the NGAO observing model be neither the lean-classical observing model, nor the queue-service observing model* and we recommend working with our science community to develop a new flexible observing model (possibly phased) for NGAO.
We recommend that the NGAO science operations strongly support the top-level goals that emphasize the need for high quality data products and our given estimate for that effort. This will require *designing and building an extensive suite of simulation and observing tools* for the AO and the science instruments. It additionally requires the *development of reliable and accurate calibrations methods for the photometry, the astrometry as well as the knowledge of the PSF across the science of view*.

We recommend that a *great synergy exist between the Observatory and the community to support the science goals* and minimize the implementation costs.

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