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Ten Year Review of Queue Scheduling of the Hobby-Eberly Telescope

Matthew Shetrone,[1] Mark E. Cornell,[2] James R. Fowler,[1] Niall Gaffney,[3] Benjamin Laws,[4] Jeff Mader,[5] Cloud Mason,[2] Stephen Odewahn,[1] Brian Roman,[1] Sergey Rostopchin,[1] Donald P. Schneider,[6] James Umbarger,[2] and Amy Westfall[7]

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ABSTRACT. This paper presents a summary of the first 10 years of operating the Hobby-Eberly Telescope (HET) in queue mode. The scheduling can be quite complex but has worked effectively for obtaining the most science possible with this uniquely designed telescope. The queue must handle dozens of separate scientific programs, the involvement of a number of institutions with individual Telescope Allocation Committees, as well as engineering and instrument commissioning. We have continuously revised our queue operations as we have learned from experience. The flexibility of the queue and the simultaneous availability of three instruments, along with a staff trained for all aspects of telescope and instrumentation operation, have allowed optimum use to be made of variable weather conditions and have proven to be especially effective at accommodating targets of opportunity and engineering tasks. In this paper, we review the methodology of the HET queue, along with its strengths and weaknesses.

1. INTRODUCTION

The past three decades have witnessed growing interest in moving from the traditional observatory operation model, in which a single observer (or program) is assigned a series of dedicated nights, to a queue-scheduled mode, where an observatory team obtains observations on a variety of programs submitted by investigators who no longer travel to the telescope themselves. The queue model of observing has been implemented by many major observatories; some of the early adopters, such as *Hubble Space Telescope*, *ROSAT*, and the Very Large Array, have become standards for comparison. The great promise of the queue model of observing is the increase in science productivity of an observatory that arises from the flexibility of choosing from a variety of options at a given time in response to changing conditions and priorities.

This optimization may take many forms, such as observing the highest ranked targets and programs as assigned by an allocation committee, matching the observing conditions to the constraints of the observing programs, permitting rapid access for targets of opportunity (a particularly difficult challenge for dedicated night observing), and allowing for time-constrained observations. An additional benefit of the queue is that experts with the telescope and instrumentation conduct the observations; this allows the Principal Investigator to avoid the time and expense of traveling to remote sites and training on unfamiliar systems, and can lead to better quality data obtained by those who are more experienced with the details of the telescope and instruments.

However, there are disadvantages to implementing queue scheduling. The operational budget of a queue-scheduled telescope, unless it is automated or involves instrumentation that is very simple to operate and maintain, is considerably larger than that of the standard dedicated night model. There are also widely recognized sociological disadvantages to queue operations, which were summarized by Boroson (1996):

> "The arguments from the communities who today use these telescopes or their predecessors against flexible scheduling include 1) doubts about the quality of data taken by observers other than themselves, 2) the loss of their ability to make discoveries by quick follow-up observations, 3) the loss of their overall control of the program (the weather lottery turns into the queue lottery), and 4) the loss of their ability to be creative and innovative at the telescope."

A number of ground-based observatories have experimented with and/or implemented queue observing over the past 10 years; examples of these efforts can be found in Saha et al. (2000), Martin et al. (2002), Robson (2002), Kackley et al. (2004), McArthur et al. (2004), Comeron et al. (2006), and Puxley & Jorgensen (2006). In this paper, we describe the processes and the lessons learned while operating the Hobby-Eberly Telescope (HET) for a decade in a queue mode.

[1] McDonald Observatory, University of Texas, Fort Davis, TX.
[2] McDonald Observatory and Department of Astronomy, University of Texas, Austin, TX.
[3] Space Telescope Science Institute, Baltimore, MD.
[4] Population Research Center, University of Texas, Austin, TX.
[5] W. M. Keck Observatory, Kamuela, HI.
[6] Department of Astronomy and Astrophysics, Pennsylvania State University, University Park, PA.
[7] Information Services, Texas Tech Library, Texas Tech University, Lubbock, TX.

The HET is a 9 m class Arecibo-type optical telescope located at McDonald Observatory near Fort Davis, Texas (L. Ramsey et al. 2007, in preparation). The HET was designed for narrow-field spectroscopy of faint objects; to minimize the cost, the structure has a fixed zenith angle of 35°. The telescope can rotate in azimuth, but during an observation the telescope is stationary; the sidereal motion is tracked by a prime-focus instrument package that moves along the focal surface. The HET primary consists of 91 identical 1 m hexagonal Zerodur segments with a spherical figure; these segments combine to form an 11 × 10 m hexagonal primary mirror. The spherical aberration corrector, carried in the prime-focus instrument package, has a pupil with a diameter of 9.2 m.

The HET can access declinations (decl.) between −11° and +71° (≈ 70% of the sky accessible from McDonald), but because of the fixed altitude of the telescope, the observable area of the sky is a ring centered at the zenith. On a given night, an object is observable at most twice for a period of an hour or two (the precise availability depends on the decl. of the object) as the motion of the celestial sphere causes the object to enter and leave the "observing ring" (see L. Ramsey et al. 2007, in preparation). Figure 1 shows a projection of the "observing ring" in hour angle and declination. Targets at a decl. = 30° have two tracks, each about 1.2 hr long, separated by 4 hr. Targets in the north (decl. > 65°) and south (decl. < −4°) have a single track.

The HET has three facility instruments that are in principle available at all times: the Marcario Low Resolution Spectrograph (LRS; Hill et al. 1998), mounted in the prime-focus tracker; the Medium Resolution Spectrograph (MRS; Ramsey et al. 2003); and the High Resolution Spectrograph (HRS; Tull 1998). The latter two instruments are fiber-fed spectrographs located in an area beneath the telescope structure.

The design of the HET naturally lends itself to the queue mode of observing; indeed, it is quite difficult to efficiently operate the telescope in the standard dedicated night mode. Because each target has only one or two relatively narrow windows of opportunity to be observed on a given night, every observation can be viewed as time-critical. For example, consider an observing project that required one specific object to be observed for a total of 7 hr; this program could be completed in a single night at a telescope with a classical design. However, the same program would require more than three nights at the HET. To effectively execute a single program on a night at the HET, the program must consist of a list of targets whose possible HET observing times nicely mesh with each other (e.g., regularly spaced in right ascension at a given decl.), but even such a carefully constructed plan would suffer practical limitations: standards, high-priority objects that conflict between east and west tracks, and the inevitable glitches that occur during a night would wreak havoc with a tightly packed, time-critical schedule.

Given this situation, queue scheduling of the HET was an integral part of the HET design, allowing the HET to execute temporal projects, targets of opportunity, and surveys as part of normal operations. One additional complication to the scheduling arises from the governance of the HET; the telescope is a joint project of five institutions: the University of Texas at Austin, the Pennsylvania State University, Stanford University, the Ludwig Maximilians-Universität München, and the Georg-August-Universität at Göttingen. Each institution has its own unique share of the time. The queue must also keep the partner shares (including dark and light time) in balance.

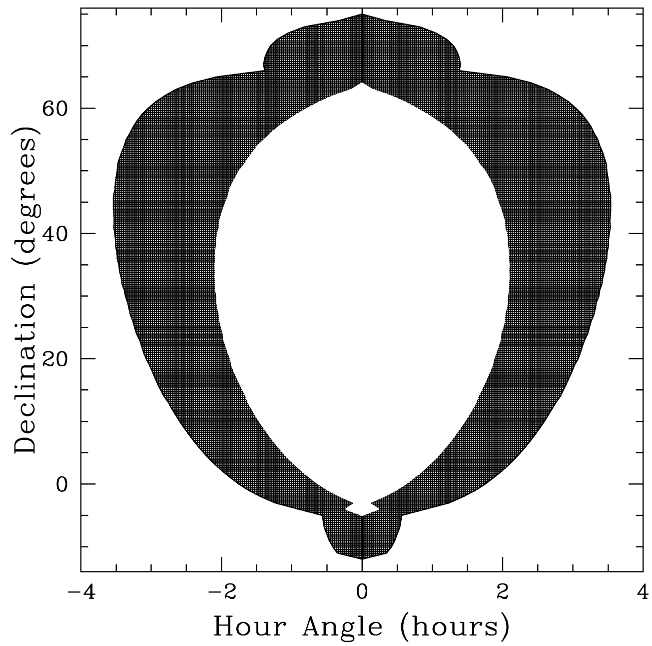

FIG. 1.—Annulus observable by the HET, translated to hour angle and declination. The shaded region is the area observable by the HET. Targets with decl. < −10 or decl. > +70 are not observable by the HET. The longest tracks for the HET are at decl. = +63 and are 170 minutes long.

The next three sections of this paper describe the evolution of operations as experience revealed shortcomings in the scheduling algorithm. Section 5 discusses the queue observing in the larger perspective, and what works well and what does not. The final section presents future plans for the HET queue observing.

2. DEVELOPMENT OF HET QUEUE SCHEDULING

The initial concept for HET operations expected that 85% of the nights would be conducted in queue mode and 15% would be assigned in the classical dedicated observer mode. The staffing proposed for this model was two full-time Resident Astronomers (RAs) and three full-time Telescope Operators (TOs). The RAs were responsible for target selection, configuration of the instruments, execution of the observations, and monitoring of the data quality, while the TOs were responsible for moving the telescope to the science targets, guiding once the target is acquired, and monitoring the weather conditions.

The RAs were expected to be active researchers, with 25% of their time allocated for personal research, access to research and travel support, and access to the HET and McDonald Telescopes through the University of Texas allocation. The TOs were not expected to be active researchers, but have been encouraged to participate (up to 7% of their time) in professional development in approved projects that interest them. To provide adequate staffing for continuous operation of the telescope, the HET facility manager was expected to spend half of the time as a RA.

First light of the HET occurred in 1996 December, but the first formally charged queue observations were not taken until 1999 October. During this time frame, the development of the queue received another level of complexity with the addition of the National Optical Astronomical Observatory (NOAO) to the HET time allocation process. (The National Science Foundation partially funded the HRS and MRS; one condition of this support was that the astronomical community be given partial access to the HET. The public time on HET is administered by NOAO.)

Each institution, including NOAO, was responsible for creating its own HET proposal system, which was denoted "Phase I"; i.e., each participant empaneled an independent Telescope Allocation Committee (TAC), and there was no interaction or coordination between the TACs. The TACs allocate time in hours, not nights; this assignment includes the acquisition, exposure, and detector readout times, as well as any nonstandard calibration requirements. Typical calibrations, such as flat fields and wavelength/photometric calibrations that can be used by many observations for a given night, are considered part of the observatory overhead and are not charged to individual programs. The initial plan adopted by the HET was for the TACs to distribute their share of the telescope time in three priorities, 1, 2, and 3, with 1 being the most important programs. Priority 1 was reserved for targets of opportunity or especially time-critical observations. The expectation was that each TAC would submit a list of programs whose targets were widely distributed across the sky and had an appropriate distribution of required observing conditions (e.g., transparency, seeing, sky brightness).

The five HET partners adopted the McDonald Observatory trimester schedule (proposals every 4 months). At the start of a new period, all proposals from the previous observing cycle were removed from the queue. The TACs do grant long-term status to some programs, but the Principle Investigator (PI) must resubmit a new list of targets at the beginning of each trimester. The NOAO HET TAC operates on a semester schedule; unobserved priority 1 and 2 targets remain in the queue until completed, while priority 3 targets are removed from the queue at the end of each semester. The NOAO methodology of keeping targets in the queue beyond the end of an observing period has the advantage of completing high-priority programs with minimal effort from the PIs and TACs. The five HET partners' methodology of having the PIs submit new proposals each trimester, with the exception of a few programs granted long-term status, offers the advantage of keeping the PIs engaged with the program, reducing their data to the point of being able to offer progress reports to their TACs.

The individual PIs are informed of their allocations by the TACs. To activate the programs, the PIs submit to the HET RAs the "Phase II" information required to execute the observations: (1) the proposal, which includes the science goals of the program and a clear description of the data acquisition process, (2) finding charts for each target, and (3) an electronic file that contains information for each requested observation. This electronic target file consists of a program number (assigned by the TAC), name, coordinates, V-band magnitude of the target, the instrument configuration, the number of visits for the target, the total CCD shutter-open time on each visit, the number of exposures into which that total CCD shutter-open time is to be split, and constraints on image quality, sky brightness, and transparency.

Since the TACs are independent, it is inevitable that conflicts would arise in the accepted programs. Examples include identical observations of the same objects, requests for targets of opportunity (in particular, supernovae and gamma-ray bursts), and a few issues that are produced by the design of the HET (e.g., if one institution gives very high priority to a program consisting of a large number of visits to a specific field, then other targets that are accessible during that time period will rarely be observed). There is no "HET super-TAC" that creates a unified observing program, but we have developed mechanisms for resolving these conflicts.

The RAs examine the Phase II information and identify problems in the overall program. In addition to the conflicts mentioned above, occasionally the combined programs leave a dearth of observations for a specific sidereal time (a "hole in the queue"). Almost all conflicts have been resolved by contacting the relevant TACs; a few cases had to be decided by the HET Scientist, who is appointed by the HET Board of Directors and whose charge is to maximize the scientific productivity of the telescope. The HET Scientist operates independently of the individual partners and the HET staff. The HET Scientist chairs the HET User Committee, which draws its members from all HET partner institutions and both serves an advisory role to the HET Scientist and acts as the conduit of information to the observers at all partner institutions.

The electronic files submitted by the PIs are collected into a single database at HET as a single input file for the queue-scheduling software. The initial software design for queue observations was inspired by Spike, which was developed for the *Hubble Space Telescope* queue (Johnston 1991). The early HET queue software created a Tcl/Tk graphical user interface (GUI) that could present a list of targets available at any given time, sorted by various single-selection criteria. In addition, the software creates a list of the highest priority bright targets and the highest priority dark targets for every 15 minute interval for each night. This basic software package, denoted "htopx," was used through 2006.

While observing, the RA would frequently run htopx throughout the night to plan and update the night's observing schedule in real time. The calibrations needed for the night's suite of observations (frequently obtained with more than one instrument, with occasional multiple configurations per instrument) were also performed, usually at morning twilight.

At the end of each night, all of the data acquired, including the calibration files, are transferred to an ftp site for individual PIs to retrieve. Each approved program has a separate directory to receive those program's observations (only the PI has access to the data for a given program). The calibrations are placed in a directory that all PIs can access. When the data are in place, the PI is notified via e-mail that new data are available; this message also contains any concerns that the RA has regarding the quality of the data, or presents any difficulties that were encountered in the observation. This system allows PIs to provide almost immediate feedback about the quality of the observations or to suggest adjustments to the observing strategy for future observations.

3. EARLY OPERATIONS FOR HET QUEUE AND OBSERVING SUPPORT

One of the advantages of queue scheduling first became clear in the earliest days of HET operations: engineering time and instrument commissioning were much more effectively combined with science observations than with traditionally scheduled telescopes. When an instrument commissioning run had to be rescheduled (often on short notice), it was trivial to shift the telescope back to science operations. Similarly, when a problem arose that required an engineering effort, it was easy to reschedule the science program. Thus, an individual astronomer would not bear the entire cost of the loss of telescope availability. In addition, the local and visiting engineering staff could halt their work for a brief time, when feasible, to allow an observation to be obtained of a high-priority target. Queue scheduling had the added benefit of allowing the engineers to release the telescope to the RA when their work was completed ahead of schedule or had reached an impasse.

The initial plan of having two full-time RAs and the duties of a half-time RA filled by the facility manager proved unfeasible for two reasons: (1) the facility manager was required to spend all of his time with the daytime support staff to keep the facility running smoothly, and (2) there were never any requests from PIs for dedicated time. The HET immediately became a 100% queue-scheduled telescope by default, and hence would be understaffed. To address this staffing shortfall, a third full-time RA position was created.

Target conflicts between the various TACs or PIs have been very rare; since 1999, there have been requesting conflicts with two gamma-ray bursts, four supernovae, and two extrasolar planets. The policy that we developed calls for sharing data among the Target of Opportunity (ToO) requests and for coordinating the instrument setups. For non-ToO targets, our policy has been to observe each request separately according to the queue-scheduling algorithm, and to distribute the data separately.

During early operations, the overhead times charged to each PI's program were found to be highly unpredictable, with some visits taking a factor of 2 longer than the average length, due to technical problems with the telescope, including variable image quality and mirror alignment issues. To give the PIs a sense of predictability during this period of early operations, we set a standardized overhead of 10 minutes per requested visit until the actual overheads could be more predictable, which occurred once full science operations began.

Despite the e-mails that the PIs received each night, the PIs found that they needed a Web-based interface to monitor the progress of their programs. To create this page, it was necessary to access the night reports (where the log of observed spectra were kept), the electronic Phase II (where the log of the completed observations were kept), and a file containing the TAC allocations for each program. Had this demand been anticipated, these various data sets would have been stored in a single database. The resulting Web page shows the observations that have been attempted, the targets in the queue, along with their status (completed or active), and the amount of TAC telescope allocation used for each program.

Target selection by the RAs at the telescope was not found to adequately reflect the TACs' wishes. Most of the time, the RA would be forced to choose from a very wide range of targets, all with the same TAC priority. The three-priority system did not offer enough dynamic range to represent the TACs' scientific ranking. In addition, there were times when significantly poor seeing or transparency limited the available targets, but some types of science could still have been conducted. The TACs did not want their institutions to be charged for the long setup times (due to the difficult conditions) and extended exposures (again due to bad conditions) for these normally easy targets. To address these problems, we developed a new priority scheme, 0–4:

Priority 0.—Time is allocated for targets of opportunity or very time-critical observations. Up to 25% of the priority 1 time can be assigned to priority 0.

Priority 1.—Targets would constitute one-third of the expected partner's observing time during the period including average weather losses and time lost due to engineering and technical problems.

Priority 2.—Targets would make up the second third of the weather-corrected partner share.

Priority 3.—Time would make up the final third of the weather-corrected partner share.

Priority 4.—Time is unlimited, but the expectation is that this time would only be used when normal operations could not be conducted (e.g., moderate cloud coverage or very poor seeing). In addition, priority 4 time would not have any charged overhead and would only be charged at half the nominal conditions exposure time.

The reason for only charging half the nominal conditions exposure time for priority 4 (P4) targets is to give the PI some advantage and incentive to work with data that are acquired under subpar conditions, and to compensate the PI for the extra effort that can be required to reduce such data.

Despite some of the problems mentioned above, some aspects of HET's queue-scheduled observing program were immediately successful (see Ramsey et al. 1998). The RAs were directly involved in informing the PIs of data delivery (and providing comments if useful), and they rapidly responded to comments from the PIs. This highly personalized attention given to the PIs required the RAs to make temporary notes in the PI's Phase II materials and to communicate with the other resident astronomers about these changes. This effectively added a customer service aspect to the job description of the resident astronomer. The TACs and PIs overwhelmingly approved of this aspect of the HET's performance.

To better serve the PIs, several new fields were added to the Phase II files. The first was an option for the PI to request radial velocity, spectrophotometric, telluric, or other types of standards. The second addition allowed the PI to request a standard set of calibrations or to make a request for specific calibrations, such as a wavelength comparison spectrum immediately after their visit. We also created a flag that would allow the PI to group two or more observations together, such as a specific standard to be observed directly after their main target. The final change to the electronic Phase II specifications was the addition of two synoptic-specific fields: one to specify the frequency of the visits, and the second to specify when the visits should occur, using a date string. The latter allows for specifying specific visit dates and/or ranges of dates in which to make visits. A complete list of the entire Phase II format can be found on the HET Observing Support Web pages.[8]

4. FULL OPERATIONS WITH THE HET QUEUE AND OBSERVING SUPPORT

Under full science operations, the typical queue contains 1500 entries, with each entry describing from one to 20 requested visits. The average requested number of visits is 1.9. Typical requested visit times are 1300 s for LRS and 600 s for HRS (the HRS visits are dominated by planet-search proposals, which involve a large number of short visits spread out over the trimester). We typically have 45 programs at the beginning of the trimester. Figure 2 exhibits the cumulative distribution of TAC allocations for each priority. In 2006, the total shutter-open time made up 50.3% of the clear science time. The remaining 49.7% includes target overheads, mirror alignment, science calibrations, and time lost due to problems. In 2006,

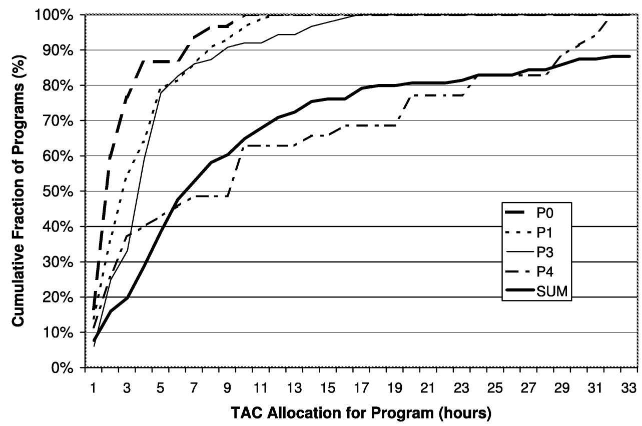

FIG. 2.—Cumulative distribution of TAC allocations in 2006. Typically high-priority times are allocated in small increments to a number of programs. The lowest priority time, P4, is generally allocated in large increments to a few programs (e.g., 50% of the P0 programs were allocated 2 hr or less).

we lost 31.9% of the nights to bad weather and spent 3.2% of the nights conducting scheduled engineering tests.

Our TACs have found that allocating a blend of priority classes to a single program allows the more critical targets to be observed and gives some flexibility to the PIs. The projects that have successfully made use of the lowest priority time, P4, have been programs that submit a large number of targets distributed widely over the sky, with exposure times that are short (<600 s). When the number of submitted programs is compared with partner share, we find a rough average of one program for each 2% share of telescope allocation. The smallest HET partners have roughly 6% share in the observing time. During a trimester, we typically also receive two to five new proposals from the TACs. These are allocated from time that the TACs hold back for unforeseen exciting science, such as ToO programs.

The expectation for the partners was that they would, on average, share equally in all observing conditions. For some of the partners, this has not been the case. For example, in 2006 two of the smaller HET partners had less than 1% of their total submitted targets in bright time (sky brightness constraint $V < 19.5$). The HET Board of Directors and HET User Committee do not have any formal mechanism or policy to deal with this inequity. By the end of the trimester, bright time is largely dominated by P4 targets submitted by the two larger HET partners.

When an observation is completed, the RA attaches a flag to the night report entry to indicate if the observation is charged or uncharged. The charged category is further broken down into acceptable and borderline. In 2006, the borderline observations made up 5.3% of the charged observations. The PIs have the option of requesting an observation be repeated; usually, these are borderline observations that the PI believes are of too poor a quality to use for their analysis. In 2006, PIs

[8] See http://het.as.utexas.edu/HET/hetweb.

TABLE 1
SCIENCE OPERATIONS FTES

Position	FTE
Science Operations Supervisor	0.5
Resident Astronomers	3.5
Telescope Operators	4.0
HET Scientist	0.1

NOTE.—The HET Scientist is not formally a part of the night operations team.

rejected a total of 3.1% of the science-collecting operating hours. From 1999 to 2006, there has been only a single case of a disagreement between an RA and a PI as to whether an observation should be reobserved at no cost to the PI.

Once the HET entered full science operations, it became clear that the HET facility manager could not effectively monitor the nighttime science operations without assistance. A position was created to manage the science operations and supervise the science operations team. The science operations supervisor reports to the facility manager, but also interacts with the TAC chairs and the HET scientist. The science operations supervisor maintains metrics on science operations, approves procedures for nighttime operation, monitors the nightly operations, and makes night-to-night decisions about the operation of the queue, including balancing engineering time with science operations. The science operations supervisor also creates a monthly report for the TACs. This report describes the status of the observing programs and that of the facility, which allows the TACs to make changes to the priorities to ensure that their most important programs are completed.

Under the three-TO/three-RA staffing plan, normal attrition left the HET partially crippled. The rehire and training process takes approximately 6 months, and operations with just two RAs or TOs led to observing inefficiencies, decreased morale, and an increased attrition rate. Just as spares for critical components are required for the telescope, we required a plan for replacement of critical staff. The science operations supervisor would be required to act as a part-time RA during normal operations and to fill in as a full-time RA during any hiring and training periods. A fourth TO was hired, leaving night operations somewhat overstaffed under normal conditions, so extra duties were added to the TO position. These new duties included working in the afternoon with the day staff to assist in telescope maintenance and engineering operations, and working before sunset to prepare the telescope for operations. A summary of the HET science operations staff is given in Table 1. The HET scientist is also included in the table, even though that position is independent of HET operations. The HET has a total of eight full-time equivalents (FTEs) dedicated to science operations. This is 40% of the total FTE compliment for the HET, and is 27% of the total HET budget.

One of the obstacles to program completion was found to be PIs who submit programs with unrealistic observing requests

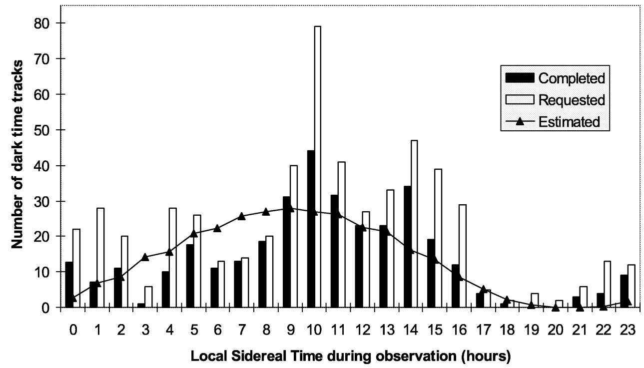

FIG. 3.—Distribution of the completed and requested dark time visits for priority 1–3 in the 2006-1 period. The open histogram represents the requests, while the filled histogram represents the completed visits. The connected triangles give a model of expected completion rates for this period, based on our Web tools. The completed visits fall above the expected completion rates because many of the targets can be accessed in two ST windows (east and west).

(e.g., extreme image quality constraints, expectation of a large number of visits). A Phase I tool was developed to allow the PI to get a sense of which targets and observing programs have a reasonable expectation of being completed. Some TACs require that each PI explain the feasibility of completing the observing program in the allocation period, based on results from this Phase I tool. Although this tool allows a PI to determine if the program is feasible, it does not show conflicts that might arise with other programs in the queue. The most common form of conflict is overly subscribed portions of the sky; the north Galactic pole and the Coma cluster of galaxies are typical examples. A first attempt to understand these conflicts is made by breaking down the queue into histograms based on the sidereal time (ST) for each requested visit and comparing the expected number of visits that may be completed at each ST bin. Figure 1 shows that for targets with declinations between $-3°$ and $+64°$, there are two available windows in which they may be observed (east and west), and that these tracks are often separated by several hours. However, during any given observing period (trimester), some targets may only have a single track available, since the east or west tracks may not be observable because of temporal conflicts with morning or evening twilight.

Figure 3 exhibits the histogram for the 2006-1 period for priority 0–3 dark time (sky brightness constraint of $V \geq 20.6$) targets and includes all visits (east and west). The unfilled histograms are the requested dark time visits in the queue, and the filled histogram are the completed visits. A target at decl. $= 30°$ with a single requested visit will appear twice in the figure, once for the east track and once for the west track. Similarly, completed visits in Figure 3 are double counted for targets with both east and west tracks. The solid line represents our estimate for target completion at each ST, based on the

TABLE 2
PRIORITY MODIFIERS

Modifier	Algorithm	Maximum Magnitude
Priority 0	If P0 then −1	−1.0
Priority 4	If P4 then +2	+2.0
Object availability	$\log[(N_{visits} - N_{request})/(f_{min} * N_{setups})]$	+2.4
Object completeness	$0.6 * (N_{request} - N_{done})/N_{request}$	+0.6
Partner share	$4 * (F_{current} - F_{HET})/F_{HET}$	−1.5
Synoptic modifier	If Date > Date_{max}, then $-0.6 - 0.15 * \log[(\mathrm{Date} - \mathrm{Date}_{max})/(f_{max} - f_{min})]$, else $-0.6 * (\mathrm{Date} - \mathrm{Date}_{max})/(f_{max} - f_{min})$	−1.0

NOTES.—N_{visits} is the number of visits left in the observing period, including any restrictions imposed by firm synoptic deadlines. $N_{request}$ is the number of visits requested by the PI. f_{min} is the minimum length the PI prefers between visits. f_{max} is the maximum length the PI prefers between visits. N_{setups} is the number of exclusive setups that compete with the requested setup. N_{done} is the number of visits completed. $F_{current}$ is the actual cumulative fractional share the partner has. F_{HET} is the cumulative fractional share the partner should have. Date is the current decimal date. Date_{max} is the last day in the preferred observing window.

Phase I program completion expectation tool that is mentioned above and found on the HET Observing Support Web pages. The completed visits exceed the estimated visits between ST 21 and 0 because these are targets with double-counted visits; e.g., the east track falls during the day, but the target was observed in the west track. At the beginning of the trimester, the RAs report to the TACs any programs that are in jeopardy of not being completed because of target density on the sky; e.g., the large number of requested visits over the number expected to be completed at ST = 10 was largely due to one program. The TACs can report this information to the PIs, or they can take any appropriate steps to modify the queue. The RAs can also attempt to exceed the estimated completion rate for an overly dense region by systematically observing targets with two available tracks at STs that are less densely populated, such as STs between 6 and 8. This was done in ST bins 10 and 14.

While the setup times during full science operations were more predictable than during early operations, the setup times charged to PIs were found to be larger, on occasion, than the assumed setup times adopted in the Phase I proposal, which can make program completion in the allocated TAC time difficult. In order to ensure that the program could be completed, and to give the PIs an element of predictability, a cap is placed on the amount of overhead time charged to any requested visit. The overhead cap is instrument dependent.

The choice of targets to observe during night operations is made by the RA, who bases the selection on a balance of object availability (how many more visits can be made to the target during the current trimester), TAC priority, synoptic constraints, and current observing conditions. To assist the RA with these choices and to add a level of standardization, a modified-priority scoring system was created. A set of modifiers are added to the TAC's priority, and the results are sorted to aid in target selection. The modifiers are listed in Table 2, along with the maximum magnitude of the modifier. For targets that have synoptic constraints, the PI can give either a flexible or a fixed range; the synoptic modifier given in Table 2 is for the flexible range. The modified-priority system is tuned such that:

1. The total modifiers on a priority 4 target never allow it to outrank a priority 3 target.
2. The synoptic modifiers on a priority 2 synoptic target can allow it to outrank a priority 1 target.
3. The object availability modifier on a priority 2 target can allow it to outrank a priority 1 target.
4. The total modifiers on a priority 1 target can combine constructively to allow it to outrank a priority 0 target.
5. The total modifiers on a priority 3 target can combine constructively to allow it to outrank a priority 1 target.

The modified-priority system was created and implemented by the RAs, but it is continuously evaluated by the HET User Committee. The system allows for the creation of an initial observing plan for each night by selecting the targets with the highest modified priorities and then filling out the schedule with lower modified-priority targets. The modified-priority algorithm creates a suggested plan for the RA, and it provides some predictability as to the order in which the targets will be observed, which is useful for planning instrument changes. However, as the observing conditions change, the RA is still required to make critical decisions about which targets to observe.

Program completion is one of our critical metrics. For oversubscribed or perfectly subscribed programs (programs that have enough targets to be completed in the TAC-allocated time), the program completion percentage is calculated from the amount of TAC-allocated time completed at each priority. For undersubscribed programs (not enough targets to fill their TAC-allocated time), the program completion percentage is calculated from the completed versus requested shutter-open time at each priority. Figure 4 exhibits the median completion

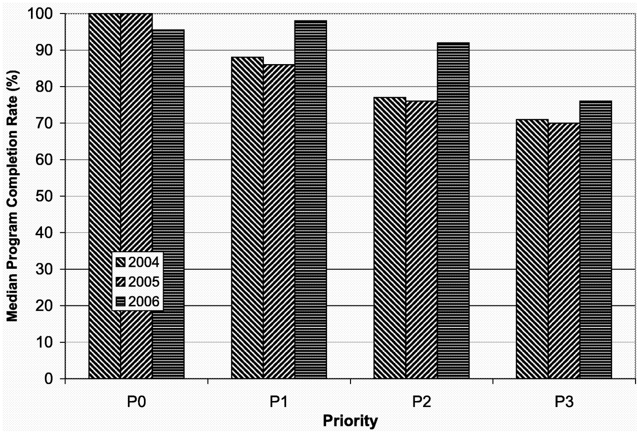

FIG. 4.—Median individual program completion rates for all the programs in 2004, 2005, and 2006. The completion rate for each program is based on the percentage of targets or TAC-allocated time successfully completed. In 2005, the HET staff adopted the modified-priority algorithm. In 2006, the User Committee made significant modifications to this algorithm.

rates for the individual programs from 2004 through 2006. The modified-priority system was implemented at the beginning of 2005, and further modifications were made in 2006 to fine-tune the algorithm. From this plot, we have concluded that our completion rates for the highest priority targets (those with the lowest priority number) are not driven by the algorithm, but by the weather and the feasibility of the program. The lower priority targets have a better completion rate under the modified-priority methodology than under the subjective, RA-specific nightly decisions.

5. REVIEW AND STATUS: SUMMARY OF WHAT DOES AND DOES NOT WORKS WELL

A subjective analysis of the HET science return reveals that we have been most successful by concentrating on target-of-opportunity surveys (e.g., Frieman et al. 2007), synoptic programs (e.g., McArthur et al. 2004; Kaspi et al. 2007), and surveys with a wide distribution on the sky (e.g., Sowards-Emmerd et al. 2005). For more information about completed science programs, see Ramsey (2005) and L. Ramsey et al. (2007, in preparation). Most of the incomplete programs have been pencil-beam surveys (e.g., many visits to a single target, or many targets in a single, small region of the sky). Most of the failed programs have failed due to technical problems at the telescope and are not due to problems with the HET queue-scheduling methods. While the efficiency benefits of queue scheduling under full science operations are documented in the literature (see references quoted in the introduction), we found that in early operations the benefits were even more substantial. The ability to begin or end an engineering effort to attack a subtle or intermittent problem without disrupting a specific PI's allocated time, or the ability to pause engineering for a very high priority science target, made the first years of science operations more productive. Even today, planning an engineering run is far easier on a queue-scheduled telescope than on the traditionally scheduled telescopes at McDonald Observatory.

The basic lesson learned from the Hobby-Eberly Telescope queue-scheduling effort is that a customer-oriented observing effort can be highly successful. While the HET would have benefited from greater software development early on, the evolutionary manner in which the software and observing styles developed has allowed us to understand the needs and improve service to the institutional partners and PIs. Since it is the PIs who ultimately will be analyzing the data, making an effort to involve them as active participants of the process is critical. The HET does this in several ways:

1. The PIs are allowed and encouraged to e-mail the RAs of the Hobby-Eberly telescope during their Phase I and Phase II planning.
2. The PIs have access to their data on a nightly basis.
3. The PIs can make some changes to their Phase II information after submission.
4. The PI can request that observations that may have been compromised by the weather or improperly observed be repeated.

These steps to involve the PI address many (but not all) of the concerns that most PIs have about queue scheduling as summarized by Boroson (1996) and listed in the introduction, but only if the PIs are encouraged to actually examine the data and provide timely feedback to the RAs. In addition, we have allowed our software tools to evolve as the PIs and TACs request new features or interfaces. This necessary evolution arises from a customer-oriented model for the science operations. To further our efforts to improve customer service, we created a survey to be filled out by the PIs after Phase II and again halfway through the trimester. Our response rate for the Phase II survey was 22%, while that for the midtrimester survey was 28%, out of 32 PIs. The results of the survey can be summarized as follows: 56% of the responses had positive comments and no constructive criticism, 19% had constructive comments on our Web documentation, 19% had constructive comments on our Phase II process, and 6% had constructive comments on the instrumentation. While the feedback was moderately useful, we believe the low response rate did not warrant a survey be repeated every trimester, since the vast majority of our PIs are the same from trimester to trimester.

One unique feature adopted by the HET is our poor-conditions priority 4 policy. This has been tremendously useful and successful. Not only have P4 targets been observed under poor conditions, but the short-exposure targets are also useful for filling in between high-priority targets on nights with good weather. Recall that the HET must wait for specific targets to enter the observing annulus on the sky to be observed, so having an abundance of short-exposure targets in the queue to fill in the "dead time" leads to higher scientific productivity. In 2006,

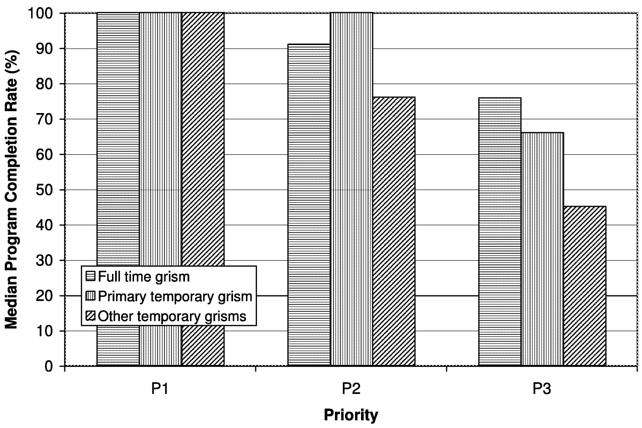

FIG. 5.—Median individual program completion rates for all programs in 2005 and 2006 that used either the permanently mounted grism (LRS_g1), the most requested interchangeable grism (LRS_g2), or the less often requested interchangeable grisms (LRS_e2 and LRS_g3). The completion rate for each program is based on the percentage of targets or TAC-allocated time successfully completed

35.8% of accepted CCD shutter-open time was for P4 targets. Even for a conventional telescope, there will still be reasons to have a large pool of short-exposure targets to be observed in poor weather conditions or to fill in between high-priority time-critical targets. Without some incentive, such as our policy of half-charge for the nominal shutter-open time and no overhead charges, the PIs and TACs would have reduced incentive to submit targets for poor observing conditions, and the queue would be less efficient and the telescope less productive.

Another important lesson that we have learned from running fully queue-scheduled operations at the HET is the need to have a plan for replacement of critical staff. Specifically, we must be able to cope with the normal attrition of TOs and RAs. This plan can be as simple as identifying who will take up the work load until new staff are hired (as is the case for our RAs and the night operations supervisor) or the more extreme measure of having an extra person in the rotation so that the observatory is never understaffed (as is the case for our telescope operators). With the increasing costs of telescopes, the expense of having an additional telescope operator and resident astronomer is small but crucial.

While the staff require considerable training to properly operate a queue, we have found that the TACs and PIs also need training to properly populate the queue. The PIs must have a good working knowledge of how the telescope and instrumentation operate and what their capabilities are. One of the areas in which the HET operations staff have been less successful is in maintaining a living repository of knowledge of how the HET and its instruments are performing. Without this information, the PIs have relied on communication with each other to determine if projects are feasible. This problem could be solved with one more FTE. This additional person could take on the documentation of the facility's capabilities as a principal duty, or else the person could be designated as another RA and then have the documentation duties split among the RAs.

Just as educating the PIs is critical, the TACs must be staffed with people knowledgeable about the telescope's capabilities in order to determine if the science proposals have merit. In the case of the partner institutions, this does not seem to be a problem, since most of the TAC members are or have been PIs. There have been some instances in which programs approved by non-HET partners have not been well suited for the HET; while technically feasible, such programs have a low expectation of completion. For future queue-scheduled telescopes, we recommend that the observatory staff participate in the time-allocation process during early operations until a significant fraction of the TAC members are familiar with the facility. This participation could take the form of nonvoting members or as an external review of project feasibility. We have found that continued interaction with the TACs or a TAC representative is the best approach to maximize each institution's science productivity. Most of our interaction has been in the form of monthly reports from which the TACs can follow the progress of program completion, the institutional shares, and the instrument and facility status. In addition, the TACs' policy of retaining a small percentage of their telescope allocation to be distributed later during the trimester to cover unforeseen opportunities has frequently yielded significant science results.

One of the major ongoing problems we have had in completing programs has come from an unforeseen impact of adding new features and improvements to our instrumentation. One of the reasons that HET works well is that the instrument complement and design allows HET to rapidly change between instruments to take advantage of changes in the observing conditions and to complete the most difficult science that the observing conditions allow. As more features have been added to the HET instrument complement, one of the greatest challenges to queue scheduling has been balancing requests for mutually exclusive instrument configurations. The HET has one instrument, the LRS, that cannot have all modes available all the time. Four grisms are used for LRS observations, but the instrument can hold only two on a given night (grism changes are limited to daytime operations). One of the slots is devoted to the most requested grism (g1). The demand for the remaining dispersers (g2, g3, and e2) is quite unequal, with g2 being the most popular and e2 rarely being requested. Figure 5 displays the completion rates for priority 0–3 LRS programs in 2005 and 2006, divided into three groups: g1, g2, and g3+e2. The median completion rates are roughly equal for the high-priority programs, largely due to the roughly one to four instrument changes per dark run. For the lower priority time (larger priority numbers), the completion rates for the less subscribed setups are considerably lower. This problem was particularly complex when one of the partners with only a small share requested an instrument configuration that cannot be mounted at the same time as one of the more popular configurations. The continuing desire to upgrade to specialized instrumentation must be balanced against the impact that that upgrade would have on the flexibility of the queue to respond to different observing conditions and configurations.

Any new collaboration on a queue-scheduled telescope should have a well-designed plan for dealing with conflicts between the competing target requests and for dealing with partners who wish to specialize in one specific part of the sky or one specific observing style. This last issue can manifest in requests for all dark time or in an institution requesting only one specialty instrument. This situation can lead to the awkward problem of a partner not receiving their full allocation in an observing period which begs the question: what techniques, if any, can be employed to rectify the situation? At the HET we have encouraged any partner who has fallen significantly behind their partner share to submit more targets and have given those targets extra emphasis through the modified-priority algorithm.

6. NEXT GENERATION OF QUEUE SCHEDULING

Our work with HET and its queue methodology is an ongoing program; most of our operations efforts are now going into improving the PI, TAC, and RA software interfaces. We wish to automate many of the features that are currently performed manually. For example, checking the status of a program with respect to its TAC allocation and determining whether the program has used its allocation requires one to manually place on hold any remaining targets for that program. Automation will not only reduce the RA workload, but will also increase reliability by removing the human element from the loop. Some examples of these changes are:

1. Automate the checking of program completion.
2. Allow a PI to add or remove targets directly to or from the queue.
3. Allow the TACs to create programs and allocate time directly to the queue.
4. Create an automated list of calibrations and standards to be taken for each target.

One of the strengths of the HET has been the fast response to PI requests, and we wish to build on this strength. Current requests by PIs for changes to their programs are not common outside of the synoptic programs. Medium-term planning has been more sensitive to the site's variable weather than to changes to PIs' programs, and we anticipate that allowing the PIs greater control over their programs will not change this.

These changes will require a transition from the current HTML-based night reports and Tcl/Tk+tab-delimited text file to an integrated database. Our choice for this upgrade is a MySQL database with a variety of interfaces, including HTML, PHP, JavaScript, and AJAX technologies.

The current working prototype uses PHP sessions to authenticate users, then allows for flexible, individual, and graduated access to program and operational data. Permissions can be granted according to the status of active programs or membership on allocation committees. Access to Web applications to plan, administer, and evaluate programs and to interact with the queue can also be customized. It is envisioned that a well-designed suite of tools that provides timely and accurate information on operational conditions, including queue activity, for PIs, TACs, and observatory staff has the potential not merely to improve efficiency and productivity through automation, but to give all users the power to leverage the advantages of the service model to refine their own programs in a dynamic queued environment.

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