

Scheduling and Executing Phase II Observing Scripts on the Hobby*Eberly Telescope

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ABSTRACT

We describe our scheme for scheduling and observing with the Hobby*Eberly Telescope¹ (HET). The HET will be operated 85% of the time in a queue-scheduled, service observing mode. Principal Investigators (PIs) use software planning tools to determine how to make their observations with the HET, and submit proposals for telescope time to local Time Allocation Committees (TACs). Once time has been granted, PIs submit detailed observing scripts which instruct HET Operations how, when, and under what conditions data are to be taken. These scripts are compiled into a relational database which is used to schedule the telescope. Observations are scheduled using TAC and PI-assigned priorities to rank plans relative to one another. Resident astronomers use these priorities plus a set of simple precedence rules to determine which objects are to be observed each night. The execution of observation scripts is mostly automated, with the software commanding the telescope position and building data acquisition macros for each instrument. Aside from building and running the nightly observing queue, the Resident Astronomers are responsible for identifying targets, starting exposures, and validating data quality. They may also revise the observing queue in real time as conditions change. We discuss our initial experience working with this system, scheduling and executing observations during the commissioning of the HET.

Keywords: Service Observing, Queue Scheduling, Observing Scripts, Planning Tools

1. INTRODUCTION

The HET[†] is a 9.2-meter optical telescope currently being commissioned at McDonald Observatory in West Texas. To reduce the price of such a large aperture telescope to fit the \$13.5 million budget, the telescope was designed with a fixed elevation angle. The telescope rotates in azimuth to reach a particular declination on the sky and tracks objects using an Arecibo-style tracking mechanism² (see Figure 1). Because it can only reach objects when they are within an elevation range of 49° to 61°, it must potentially wait until a particular time for a given object to become observable. As most objects are observable for only one to two hours each night, many projects will require exposures of a single or many objects distributed over many nights. Thus, detailed scheduling is required to maximize telescope effectiveness.

To most effectively schedule observations, minimize the number of observers at the telescope at any one time, and promote the best scientific use of the facility, the HET will operate in a queue-scheduled, service observing mode 85% of the time. Projects from various investigators will be interleaved and executed by resident Ph.D. astronomers working at the telescope site. The other 15% of the telescope time will be used for engineering, and for projects that lend themselves to classical style observing through large target lists, sensitive instrument setups, and so on. Even during classical style observing time, detailed scheduling by the PI will be crucial to maximizing the productivity of this unique facility.

We have adopted a phased scheme of operations similar to that used by the Hubble Space Telescope^{3,4}. Phase I begins with the PI using software planning tools to determine if/how their project can be carried out on the HET⁵. They then write proposals for telescope time to their local TACs. Time is allocated in terms of required exposure time, and not in terms of specific nights. Each local TAC ranks the projects from its institution and allocates time to each. This information is then transferred to HET Operations. Upon acceptance, the project enters Phase II. The PI uses the same software tools as available in Phase I to rigorously plan their exposures on an object-by-object basis. The PI writes an observing script to carry out these observations and submits it to the HET Operations staff⁶. Each script contains object information, instrument setup information, and detailed instructions on how to make all of the observations for this project.

[†] The HET is operated by McDonald Observatory on behalf of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universität München, and Georg-August-Universität Göttingen.

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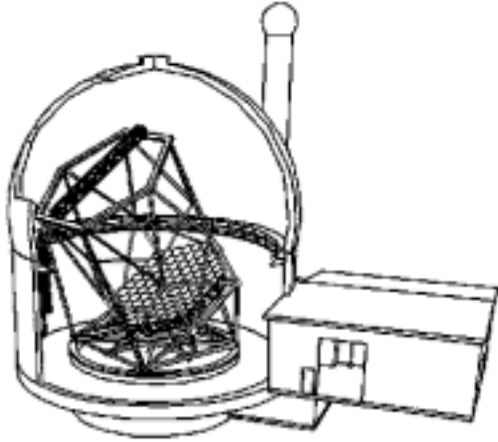


Figure 1 – a schematic of the HET. This picture shows the fixed elevation of the telescope and its segmented mirror design. The telescope is free to rotate in azimuth to access a particular declination. Across the top of the telescope is the tracker mechanism that moves in six dimensions (three linear: x , y , and z , and three angular: ρ , θ , and ϕ) to track objects across the focal sphere of the telescope.

It is then up to the HET Resident Astronomers to schedule and execute these observations. Once data are acquired, the PI is notified electronically and can examine the new data and revise his/her plan as needed.

In this paper, we will summarize the concepts and tools currently in use during HET commissioning. We will discuss how we plan to schedule observations, our current and planned software, and our initial experiences. We will also discuss our first efforts in scheduling HET observations during commissioning. Since much of what we are doing is not specific to the HET, we will highlight those areas that are unique, and enumerate the simplifications we have made, and the impact that these simplifications have, on our ability to obtain scientific results effectively and efficiently.

2. PLANNING OBSERVATIONS WITH THE HET

2.1 Phase I — Observing Proposals

Observing on the HET begins with writing a proposal for telescope time. Each of the five partner institutions has a Telescope Allocation Committee (TAC) that divides that institution's share of HET time among their investigators. The details of this proposal process are different for each institution. To enable potential PIs to write proposals, whatever the proposal format, we created software tools with which to explore and verify that a given observation can be carried out with the HET. These tools are available for any

investigator to download from the HET Operations web site[‡].

The lowest level of the planning tools is a set of standalone C programs that calculate information about observing with the HET. PIs can use high level tcl/tk GUI interfaces or can run the standalone programs directly, or as part of scripts, to develop personalized planning tools. The planning tools include a task to model the result of a single exposure of an object (Figure 2). This is the tool we expect most observers to use to determine if a given observation can be made with the HET. The user supplies basic information (e.g., position on the sky, instrument configuration, date of observation) and the program calculates useful facts about observing this object with the HET (e.g., optimum azimuths for the telescope, predicted sky brightness on a particular day at the given angular distance from the moon, maximum length of a track). Once all of this is determined, the tool can then calculate facts that are important for a proposal, such as the amount of observing time required to achieve a specific S/N, the S/N ratio that will be achieved after a specified amount of time, or the limiting magnitude at which a specified S/N will be achieved over a full track of the HET at a particular declination and azimuth.

Once PIs have submitted their proposals, the TACs have ranked them, and time has been allocated, the local TACs tell HET Operations which projects and PIs have been awarded time and provide a relative ranking for each project. Operations staff then inform the PIs that will be using queue-scheduled time that they must submit an initial observing script. This concludes the Phase I proposal process.

2.2 Writing Observing Scripts

PIs must be able to tell the HET operations staff how to carry out the observations for their project. Because of the wide range of computers and operating systems in use at the partner institutions and our limited software development resources, we chose not to develop a complex, GUI-based tool like RPS2⁷ to create observing scripts. Rather, HET observing scripts are written in plain text using a simple keyword and value language. A PI may use any text editor to construct these scripts. The same tools that were used during Phase I to plan a project are used now by the PI in Phase II to specify exactly how to make each observation. Once a PI has determined how best to make the observations, an observing script is written to communicate the details to HET Operations staff. The basic idea of the script is to provide as much detail as is required to obtain the desired scientific result, but not so many specifics as to make the observation impossible to schedule.

[‡] URL — <http://rhea.as.utexas.edu>

2.2.1 Building Observing Scripts: Templates and Macros

Observing scripts are made up of building blocks called templates, each of which represent a separate observational concept. These templates include:

1. Summary – information about the investigators as well as the proposal scientific abstract.
2. Constraints – constraint information such as seeing limits and sky brightness limits.
3. Object/Calibrator – position, magnitude, and acquisition information about the objects to be observed.
4. Lamp/Flat/Dark/Bias – specific information about how to take calibration frames.
5. Macros – allow the PI to reduce repetitive typing by writing custom macros for the project.

Breaking the information down in this way allows the PI to use the same template more than once in a single observing script, or to recycle the templates in different projects.

Templates are then combined together to construct observing “plans”. Each plan is a sequenced set of templates that describe all aspects of the observations as well as a sequence for the exposures. In the HET scripting language there are two ways to sequence observations. One can “do” an observation, which means that it is to be scheduled to be executed next, with no intervening observations. This command would be used to obtain calibrators (e.g., flats or a calibration star) immediately after an object, for example. The other method is to “schedule” the observation. When one schedules an observation it can be obtained at the next convenient time in the night or, in the case of flats, darks, and bias frames, sometime the next morning. Other observations can take place before the scheduled observation is executed. One benefit of scheduled observations is that observations can share calibration frames. In addition to exposures, one can do or schedule “waits” to sequence observations with specified intervening periods of time.

Once all the templates and plans for a given project are written, they are concatenated into a single observing script. The script’s syntax can be checked by e-mailing it to a special address at HET Operations. Upon receipt, the script is automatically checked and any errors or warnings are returned. Similarly, final scripts are submitted to a different e-mail address. Upon approval by the software, the new scripts are filed away to be incorporated into the HET queue scheduling system.

At a predetermined time each day, the databases that are used to schedule the telescope are recompiled to incorporate any new or modified scripts that were submitted during the previous 24 hours. At that point the databases are frozen for the night. Any new projects or revisions must be submitted prior to that time to be considered for the night. PIs can revise their plans at any time up to that point, subject to various constraints including the original amount of allocated time, etc. After the databases are frozen, they are transferred over the network from Austin to the telescope facility itself to be used for that night’s observing.

2.2.2 Time, Signal-to-Noise, and the HET

One unique feature of the HET among optical telescopes is that its effective aperture varies as a function of time while an object is tracked across the primary mirror. Because of this variation, the throughput of the HET can change by as much as 40% with tracker position, independent of all other observing conditions. Like all other ground-based telescopes, the throughput varies according to changes in the transmission of the atmosphere and seeing. In a classically scheduled system, observers usually scale their exposure times based on their own educated “gut reaction” to the initial quality of the first few data frames acquired. In a queued environment, where the PI is not present during the observations, this is not possible.

To address the problems associated with throughput variation and no PI on hand, the PI can specify integration times in advance in two ways. The first allows the user to specify a fixed exposure time for each observation, as is done for

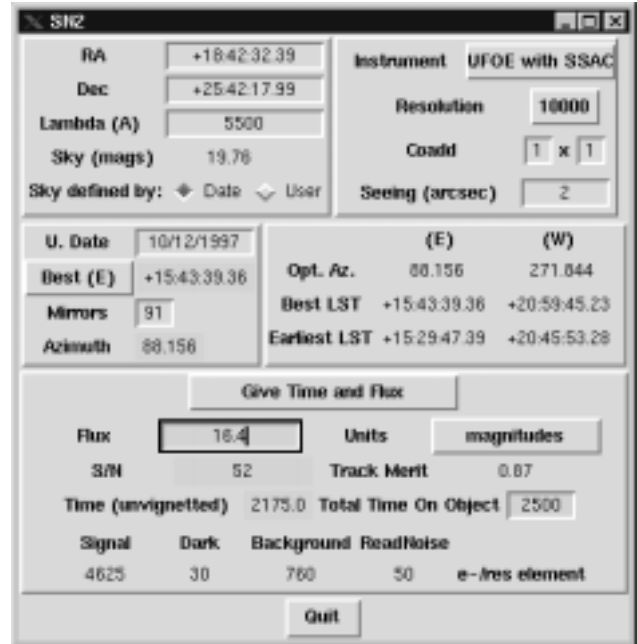


Figure 2 – The signal-to-noise estimator for the HET. Given basic information about the observation, this tool computes when and for how long an exposure can be made, and the expected performance from the HET under various conditions.

space-based observations, for example. This method allows the PI to sequence observations such as short term variability studies or ones that require rigid scheduling to fit many exposures into the restricted tracking window of the HET. The second, and more common, method allows users to specify a scaleable exposure time. The base exposure time is calculated by the PI assuming that there is no vignetting on the HET and that the seeing and atmospheric transmission are nominal. At the telescope, once the start time, telescope azimuth, atmospheric transmission, and seeing conditions are specified by the Resident Astronomer for the observation, the base exposure time is scaled to conserve the number of object photons that will be collected. Though this is very similar to having the PI specify a target S/N, we have chosen instead the middle ground between specifying how the data should appear and specifying how the observations are performed to make sure that the PI has some idea in advance of how long an observation will take.

3. SCHEDULING

The key to making the HET scientifically efficient is the scheduling of queued observations. During commissioning, of course, observing efficiency has been a secondary priority relative to completing the integration of the hardware and software for the facility. However, we will outline below our planned scheme for scheduling the HET during full-up operations.

3.1 Prioritization for scheduling

Recall that a “plan” is a list of related exposures (e.g. an object exposure plus the required flats and lamps), and a “project” is the entire set of plans submitted by a PI for one science proposal. The goal of scheduling is to select individual plans from the list of all plans making up all projects submitted to date, and construct a schedule of observations to make in a night. In order to select a single plan from the list of objects observable at any one time, we must be able to rank the proposals according to schedulability and merit. It is easier to start scheduling the least flexible plans first and then fill in with other projects. Thus, we define five classes for projects that map onto how flexible we can be in scheduling them. We list them below, with least flexible to schedule first:

1. time/phase critical observations (including objects for which the observing season is ending).
2. observations that span many nights.
3. observations requiring visits to many objects in a single night.
4. observations that require a single object and a flux/atmospheric calibrator.
5. observations of single objects.

In addition to sorting projects into these classes, we also flag observations which require rare conditions (e.g., outstanding seeing) and those that can be done during poor conditions (e.g., 40% atmospheric transmission) so we easily identify the projects that can or should be executed when these conditions arise. Because scheduling complex plans can be difficult if not impossible, in real-time, the HET operations staff will preschedule plans at the beginning of the observing semester from classes 1, 2, and 3 into several different nights during the coming semester. Then they determine the optimal observing periods for plans in classes 4 and 5. Finally, the Resident Astronomer can bin the observing periods for each project to determine whether its observations cluster around a particular time. He/she can therefore determine if there are preferred periods during the observing season for concentrating on particular projects.

On a nightly basis, the resident astronomer will use these classes to start making a schedule for that night. As a starting point, one could try to observe the most difficult to schedule plans first and then fill in with the simpler to schedule ones. However, we must also meet the requirement of completing the highest ranked projects as quickly as possible. We apply a set of rules of thumb:

1. We will complete an open plan before starting any other plan.
2. We will observe an object from a started project that is approaching the end of its observing season.
3. We will observe an object from a project that is closer to completion over one from a project with many object left.
4. We will advance an open project rather than start a new one.
5. We will start work on the highest priority project available at the time.
6. We will start a new project as early as we can to maximize the chances of finishing it.

Note that the observing windows for the HET are always at roughly a constant elevation, so rule 6 does not imply in any way observing objects at a less than optimum airmass. These precedence rules are similar to the concepts used to drive queue scheduling at WIYN⁸. Though new procedures have since been developed, the initial effectiveness of queue-scheduling the WIYN telescope was criticized by some as it tended to complete only the top few projects in the queue and ignore all other projects. One major difference between HET and WIYN is the limited amount of observing time for an object (e.g., a given RA and Dec) each night. Because we have to observe a minimum of between 8 and 14 different objects each clear night that are well distributed across the sky, just to fill up the time, we will likely be forced to work on

more than one or two PIs' programs in a night. We therefore do not believe that the above rules of thumb will result in our working very hard on only the few highest ranked projects. Instead they will tend to drive us to work on many different projects just to be able to observe all night in the limited HET observing window.

One aspect of this scheme for scheduling that remains undetermined is how to balance schedulability with TAC and PI assigned priority. Currently we have no experience in determining when it is appropriate to choose a low priority observation because it is difficult to schedule versus when to execute an "easy" project that has a high priority. This will need to be worked out by building trial schedules based on various assumptions. Only by finding what mixture of the two cases gets the highest priority science completed in the long term will we be able to determine how to optimize the trade-offs.

3.2 Partner Share

As in other consortium projects (e.g., Gemini), each of the HET partners has a percentage share of the telescope time. It is up to the operations staff to make sure that each partner gets its proper share of time. Pending agreement from the governing board, the amount of time that is billed to an institution for an exposure will be scaled to remove the effects of the changing aperture, atmospheric transmission, and seeing during the observation. Overhead time due to actions taken which are not in a plan, such as the time required to rewind the tracker between observing scripts, will not be counted as part of an observation. Overhead time that is encumbered due to the nature of targets or the accuracy of information in a script, such as a difficult identification of a target or manually selecting guide stars, will be billed as time on the clock. Thus, observations made during periods with low atmospheric transmission will "cost" the same as if they were made under optimal conditions. This billing procedure allows the partner TACs and PIs to concentrate on doing the best science possible and not on micro-managing when observations should be made, in an attempt to conserve their share of time.

As mentioned above, TACs from each institution rank the projects submitted from their own institution. There is no relative ranking of projects from different institutions. Thus, another selection rule comes into play when there are several otherwise equal plans to choose from. The requirement that we balance the partner shares will cause us to choose randomly among plans from the various partners, weighting the random draw according to the relative partner share. The time-scale over which the partner shares must work out has not been resolved. Nor has the issue of balancing the amount of bright and dark time used by each institution, though it is clear to most that we will have to equitably share in the amount of dark time. One proposed method of balancing lunar phase allows institutions to trade time in a free market system. Actual methods of implementing these balancing schemes have not yet been worked out.

3.3 Night-to-night and Real-time Scheduling

At the heart of queue scheduling the HET is night-to-night and real-time scheduling. That is, sequencing observations for a night and then adjusting that sequence in real time as conditions change. Varying conditions prevent us from preparing a schedule for a night more than a few hours in advance, and we must allow for changing that plan during the night. Filtering in the afternoon can weed out objects that need not be considered for tonight, and we can choose to limit which instruments or instrumental setups are used in any given night. Since the problem of producing an optimal schedule is not deterministic, we will be satisfied with producing a "reasonably good" schedule that works on projects we want done and uses the telescope time wisely. To date we have a limited amount of experience with scheduling observations on the HET. We are currently working with a largely manual scheduling system based on lists of objects that have been filtered according to various constraints imposed by the state of the telescope and instrument hardware. By experimenting with this system and the precedence rules described above, we hope to refine the selection rules and relative weights and find any shortcuts that can be used to construct workable schedules. We will eventually automate many of the steps outlined here.

3.3.1 Building a nightly observing schedule

Our current system works as follows. At the start of each night, the resident astronomer examines the long-term schedule to determine if any new projects must be started, which "difficult to schedule" plans have been prescheduled for that night, which projects are best suited to the current conditions, and which projects are of highest priority for the night. Using a forecast for the night's conditions and the prioritization discussed in section 3.1, the resident astronomer uses software tools to determine what projects can be executed at different times during the night (Figure 3). He/she then works through this list, selecting objects and writing them into a schedule file, to try to fill the available time with observations, allowing some time for the usual unexpected events.

Once this schedule file is constructed, it can be loaded into the same software that was used to construct the schedule to monitor the status of the nightly plan as time passes. The display updates automatically, and is used to keep up

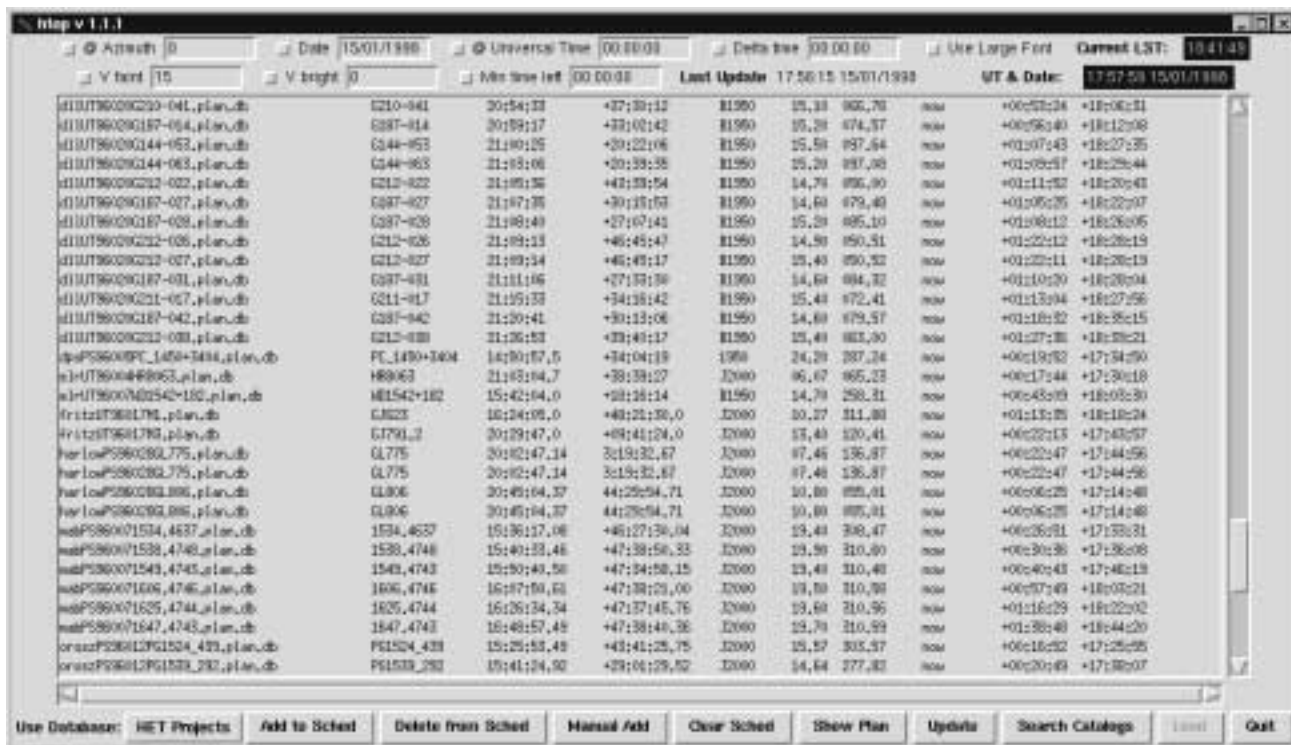


Figure 3 – The HET’s initial scheduling tool. This tool reads a database of objects and determines when and for how long an object can be observed with the HET. The user can enter constraints such as object brightness, the starting time of the observation, and the azimuth setting of the telescope. The tool then filters the database to eliminate all objects that do not meet these constraints and displays the results in a tabular form. This tool is being used during commissioning to select objects for engineering tests and to build a nightly observing schedule.

with the schedule, to prepare for upcoming objects, and to make real-time adjustments as conditions change. By watching this display and examining the current conditions, the resident astronomer can decide if the current plan is working, or if changes need to be made. If the resident astronomer finds that the changes in conditions decrease the effectiveness of the schedule, he/she will work on rescheduling the remainder of night. In the future, the scheduling tool will also keep track of each project’s status, which plans have been started, project completion status, and relative priority in the queue.

3.3.2 Plan Execution

When a plan is to be executed, the resident astronomer loads that plan into the plan execution tool (Figure 4). This tool takes all of the information provided by the PI and displays it in an easy-to-digest format. It allows the resident astronomer to send coordinates and move commands to the telescope, display any finding chart provided by the PI, and, when fully automated instruments are on-line, set up the instrument as described by the PI from a single GUI. It also allows the resident astronomer to take test frames to examine the behavior of the instrument and/or the sky conditions. As data comes in, this tool logs the data file and marks it for backup and transfer. Finally this tool allows the resident astronomer to test how an alteration in the requested exposure times or a change in the weather conditions will impact the data quality.

During data acquisition, the resident astronomer’s task is to set up the instrument while the telescope is being pointed by the telescope operator. Once the telescope has been moved to the requested coordinates, the resident astronomer then identifies the target based on the information supplied by the PI. This may be as little as a description of the object and coordinates or as sophisticated as a digital finding chart with the object(s) marked. Once the object is identified and marked, the telescope operator places the object on the boresite of the instrument. Next, the resident astronomer estimates the current seeing and transmission and updates those values in the execution tool (Figure 4). Eventually, this information will be provided automatically by the guider systems. He/she may then either allow the software to determine the integration time based on the information provided by the PI in the plan or he/she may use a variation on the Phase I planning tools to examine how making slight changes in the exposure length will change the S/N that the PI has expected. When data comes in, it is automatically backed up to tape locally and is transferred over the Internet via ftp from the HET site to the data archive located Austin. Frames are also displayed in real time on the resident astronomer’s computer



Figure 4 – Our initial plan execution tool. This tool both informs the resident astronomer of what needs to be done as well as creates scripts to be executed by the instrument control system once all manual setups are taken care of. The scientific abstract for the project and any additional comments the PI intends for the resident astronomer to read are displayed. Finally, a list of queued calibrations that are needed to complete this and any previously executed plans are displayed as a reminder of what must be done to complete all open plans. From this interface, the resident astronomer can go into a manual operations mode to run the instrument directly to examine instrument performance or to alter the way a plan is executed.

console. Using this display and several IRAF quick-look tasks, he/she can make changes in how the remaining frames will be acquired. Further, the resident astronomer can examine the data to determine if the parameters as described in the plan are sufficient to obtain the data required for the project. If the data quality is too low and there are no other contributing factors leading to the poor data quality, the resident astronomer may choose to put the entire project on hold pending further interaction with the PI.

3.3.3 Data Distribution and Verification

Once data is received in Austin, the data file header is examined to determine which project or projects need that file. The data are then sorted into the directories for each project so PIs can retrieve related files easily. At the end of each night, e-mail is sent out automatically to all PIs who have new data. They are instructed as to how to retrieve the data over the network using either ftp or a web-based system. In addition to e-mail notification, the users can finger their accounts on the HET data distribution computer at any time to find out if unretrieved data exists for any of their projects.

The PIs are responsible for retrieving their data in a timely fashion. For most projects, we expect this time scale to be weekly. For projects that require strong PI interaction, this time scale could be overnight. Faster response will not usually be helpful, as each object is observable for only approximately an hour. Once the data are retrieved, the PI or his/her collaborators can analyze the data using whatever tools they are familiar with. Using what they learn from this exercise, the PI may wish to revise his/her plan to better use the remaining time allocated to their project.

4. EXPERIENCE/RESULTS

To date, we have had limited experience with scheduling the HET, due to other priorities in commissioning such a new and complex telescope. Because of the uncertainty in how the telescope and instruments would initially perform relative to their final performance, we limited the initial pool of potential observations. These test objects required spectra taken at a moderate resolution ($R \equiv \lambda/\Delta\lambda = 10,000$) without any calibrating objects aside from normal flats, darks, and bias frames (i.e., in schedulability class 5). We also limited our selection to projects from astronomers directly involved in the commissioning of the telescope.

Initially our nightly tool simply determined which objects were observable during a given time range and displayed them. Using this information with their own set of priorities for testing certain subsystems of the telescope, the commissioning team scheduled objects to be observed throughout the night. On nights when the other telescope systems were well behaved, we were able to acquire science data that was used to characterize the system. Planning took about an hour during the afternoon or evening prior to observing. We were able to schedule hourly observations and get data on every object scheduled. Collaborators at Penn. State reduced the data the morning after it was taken and had feedback for us the following afternoon. We expect to operate in this mode for the remaining months of commissioning. As the rest of the system becomes more robust and we gain more experience with scheduling and executing observing plans, we will introduce more features and more complex projects to the software and system. Using this early incarnation of the HET scheduling system, we have demonstrated that once the telescope systems are fully operationally and robust, we have an effective method of obtaining science with the HET.

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