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Early science results from the Hobby-Eberly Telescope[#]

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ABSTRACT

We present science results from the first four months of early operations of the Hobby-Eberly Telescope (HET). During this period the HET was used for science approximately two weeks per month centered on new moon. We discuss the types of science program that are best suited to the unique nature of the HET and give examples of surveys and synoptic observations that are ongoing. The Marcario Low Resolution Spectrograph is the only facility instrument currently in service, so the science results from this instrument are emphasized. Future facility instruments are briefly discussed, along with a description of current HET performance.

The HET is a unique telescope that is the prototype for a new generation of cost-effective large telescopes. It has a unique tilted-Arecibo design that is able to access a wide range of declinations by rotating the telescope structure in azimuth. A star tracker follows objects for between 40 minutes and 2.5 hours, depending on declination. These physical constraints make it essential that observations be carefully planned and that the HET be queue-scheduled. Currently, the HET is regularly delivering science observations in queue-scheduled mode, but image quality is typically between 2.0 and 3.0 arcsec, due to thermally-driven primary mirror stack degradation and dome seeing. These problems are being addressed by the primary mirror edge sensor project and by removing heat sources from the tracker prime focus instrument package, and we expect to be delivering images within the 1 arcsecond specification in 2001.

Keywords: Hobby-Eberly Telescope; Instruments: Marcario Low resolution Spectrograph; Quasars, X-Ray Sources, Clusters of Galaxies, Radio Sources, Seyfert Galaxies: variability.

1. INTRODUCTION: OVERVIEW OF THE HET AND INSTRUMENTS

The HET[1,2,3] is a unique telescope with an 11 m hexagonal-shaped spherical mirror made of 91 1 m Zerodur™ hexagonal segments that sits at a fixed zenith angle of 35°. It can be moved in azimuth to access about 70% of the sky visible at McDonald Observatory in west Texas. HET is a collaboration of the University of Texas at Austin, Pennsylvania State University, Stanford University, Georg-August-Universität, Göttingen, and Ludwig-Maximillians-Universität, München. The pupil is 9.2 m in diameter, and sweeps over the primary as the x-y tracker follows objects for between 40 minutes (in the south at $\delta = -10.3^{\circ}$) and 2.8 hours (in the north at $\delta = +71.6^{\circ}$). The maximum track time on a single object per night is 5.5 hours and occurs at +63°. These track times are quoted for an 8 m effective aperture since the pupil partially falls off the mirror near the extremes of the tracks. The HET was dedicated on Oct. 8, 1997, and achieved operational status in 1999. Detailed descriptions of the HET and its commissioning can be found in refs 1-5. Figure 1 shows the HET telescope and identifies its major components. Currently, the HET is operating with its first facility instrument, the Marcario Low resolution Spectrograph (LRS), [5-9] which rides in the Prime Focus Instrument Package (PFIP) on the tracker, allowing it to image as well

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[#] Based on observations obtained with the Hobby-Eberly Telescope Low Resolution Spectrograph. The Marcario Low Resolution Spectrograph is a joint project of the Hobby - Eberly Telescope partnership and the Instituto de Astronomía de la Universidad Nacional Autónoma de México (IAUNAM). The Hobby – Eberly Telescope is operated by McDonald Observatory on behalf of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximillians-Universität München,and Georg-August-Universität, Göttingen

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as take spectra, and a simple fiber-coupled echelle spectrograph (UFOE). The High Resolution Spectrograph (HRS)[10] will be the second facility instrument and is partially installed in the basement spectrograph room under the telescope, internal to the pier. The Medium Resolution Spectrograph (MRS)[11] is under development at PSU and is expected to enter commissioning at the end of the year. The HRS and MRS are fed by fibers from the fiber instrument feed (FIF)[11] that is part of the PFIP.

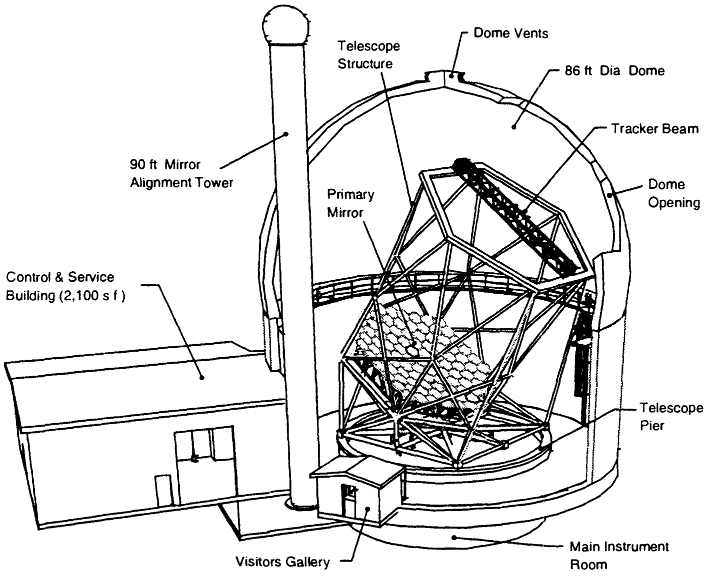

Figure 1. Overview of the HET facility, identifying its principal components

The principal niches for the HET will be large surveys and synoptic observations of time variable phenomena, taking advantage of the queue-scheduling of the telescope[1,3]. In fact, since the HET is difficult to use effectively for single projects under a traditional nightly scheduling system, it is likely to be the *only* large telescope used exclusively in queue-scheduled mode. As such, the HET will become the premier facility for synoptic observations, from AGN to binary star systems, to extra-solar planets. We highlight a pair of such projects below. The HET works most effectively when objects are distributed randomly, with a sky density of fewer than one object per square degree. Objects that fit within the 4-arcmin diameter field of view of the HET can also be observed efficiently. As a result, follow-up of the new generation of large multi-wavelength surveys will be a major focus of HET science. We highlight projects based on the Sloan Digital Sky Survey (SDSS)[12,13], the NRAO VLA Sky Survey (NVSS) [14] and Faint Images of the Radio Sky at Twenty cm (FIRST)[15] radio surveys, and deep X-ray data from the Chandra satellite[16].

2. HET INSTRUMENTS AND PERFORMANCE

Currently, the HET is making queue-scheduled observations with the Marcario Low Resolution Spectrograph (LRS) which is the first facility instrument, and with a simple bench-mounted fiber-fed echelle spectrograph (UFOE). The UFOE is primarily a test instrument, providing important experience with fiber-fed observations, but it is also useful for various science projects on brighter objects requiring resolving powers of several thousand. In addition, the use of two instruments provides important tests of the HET queue ahead of the delivery of the next facility instrument. The High Resolution Spectrograph (HRS) and the Medium Resolution Spectrograph (MRS) are both fiber fed, and we expect the HRS to be commissioned during the summer. In addition, two instruments are in development to push the wavelength coverage into the near infrared. The J-CAM project will add an optimized camera to the UFOE to extend its coverage to 1.35 μm, and the LRS-J project[17] will extend the coverage of the LRS to 1.35 μm with multi-object capability. A detailed description of current HET performance and the instruments can be found in ref 5 in the companion proceedings.

2.1 Current HET Imaging Performance

The HET is a prototype for a new breed of cost-effective large telescopes. As such, it is essentially a test-bed for engineering and operations concepts designed to minimize cost while maintaining performance. In particular, the primary mirror[18], based on a steel truss, and the star tracker[19] were key to realizing the project for the modest cost of $16M. Here we describe the current performance compared to specifications, and look forward to the realization of full performance.

The HET is a complex opto-mechanical system with no natural axes: everything is time-dependent from the tracking trajectory on an object to the stack of the primary mirror (PM). In order to obtain an observation, the segments of the PM must first be stacked in tip-tilt using a laser located in the center of curvature alignment sensor (CCAS) tower. Once the mirror is stacked, the telescope is moved to the azimuth of the observation using the air-bearing system[20] by which the telescope rides on the pier. The rate of motion is a rapid 3° per second. At this point, a trajectory for the tracker is loaded into the tracker control computer from the telescope control computer, and the track typically starts within 5 minutes of the end of stacking. This trajectory controls the x-y position of the tracker, and the six hexapod legs and rotation axis that manipulate the payload. In order to track an object accurately, the tracker payload must be maintained on the focal sphere of the spherical primary mirror, and must be pointed accurately perpendicular to it. The tracker has six axes: x,y, focus (z), tip (θ), tilt (ϕ), rotation (ρ). In order to maintain image quality during a track, the "mount model" needs to accurately maintain the 4-mirror corrector in the PFIP perpendicular to the PM within 25 seconds of arc, and in focus to within 10 μm. The tracker is actively guided in x,y, but the other axes run open-loop. The mount model is many-layered, with models for the shape of the tracker beam, the alignment and focus of the corrector with respect to the PM, and the changes of these with position angle (PA) on the sky. The natural PA of the HET is parallactic angle (ρ=0), and the PFIP allows rotations of +/-114 degrees from this angle. During a track, the PFIP rotates (up to +/-19.4° in the north) to maintain a fixed PA on the sky.

Early in 1999, the dominant contribution to image quality came from θ, ϕ errors that result in significant coma due to misalignment of the corrector with the normal to the primary. A laser alignment fixture allowed this contribution to be modeled and reduced to a negligible level. There still remain inaccuracies in the model for the alignment and focus of the corrector as it is rotated in ρ, which result in comatic images at some PAs, but these images will be improved shortly. Otherwise, the tracker-related elements of the image quality are now negligible compared to the destack of the PM segments and dome seeing.

The primary mirror segment stack slowly degrades with time due to changes in the truss temperature. It was expected that the shape of the steel truss could be modeled as a function of temperature, and adjustments made to the segment positions to compensate. In this way, the specification of holding the image size in the absence of seeing to 0.6 arcsec EE(50) for one hour could be reached. EE(50) is the diameter of the image that contains half the light. However, on top of such gross shape changes, there is a stochastic, temperature-driven node-to-node shape change that causes tip-tilt errors of ~1", and causes noticeable destack of the PM segments if the temperature changes by as little as 0.5 Celsius. These movements are thought to be non-elastic shifts of the truss and are not amenable to modeling. In any case, the results of these effects are that the PM cannot be stacked in tip/tilt to much better than 1.0" EE(50) in the absence of seeing (the smallest is 0.89" compared to the specification of 0.15"), and that the stack typically degrades to an unacceptable degree in about 1 hour.

The CCAS, a polarizing shearing interferometer, was delivered untested, and many bugs are now systematically being worked out. It is expected that the instrument will be operational later this year for fine alignment of the PM. The above effects notwithstanding, on stable nights with slow temperature changes, the stack has maintained for several hours at a time. In the near future, the PM shape will be maintained by the Segment Alignment Maintenance System (SAMS)[21], which will use inductive edge sensors, and is scheduled for delivery in 2001. Until that time, only modest gains in PM stack quality are likely to be made.

The remaining contribution to image quality, as with any telescope, is dome seeing. The HET specifications for open heat sources were tight, and were designed to minimize the thermal energy introduced into the dome and particularly into the optical beam from sources on the tracker. In developing the PFIP on an accelerated schedule, the specifications were set aside in order to speed delivery of all the systems, so as to start scientific evaluation of the HET as soon as possible. Currently heat sources on the PFIP do degrade the seeing significantly in some conditions (particularly when there is no wind), but will be addressed within the next 6 months. We have used a 10 μm camera to image the dome environment and identified important heat sources to be eliminated. It is possible to monitor the seeing by observations of individual mirror segments, and the best images have been sub-arcsecond. The combination of mirror destack and seeing account for the currently delivered 2-3" images of the HET. Images as good as 1.6 arcseconds EE(50) are achieved at the start of some tracks, and we are confident that once the dome seeing issues are addressed and the SAMS is in place, the HET will consistently deliver 1-1.5" images, meeting specifications. Additionally, the SAMS edge sensors will keep the mirror shape for weeks, increasing observing efficiency markedly, and surpassing specifications.

The throughput of the HET is close to specification. There are 5 reflections to reach the prime-focus FIF and 6 to the LRS, so high reflectivity coatings are essential for the HET. Denton Vacuum FSS-99™ enhanced silver was chosen, which has high reflectivity at wavelengths above 400 nm, and is better than bare aluminum for λ>380 nm. Accounting for central obstruction, the pellicle guider, and the atmosphere, the predicted on-axis efficiency is 54% at 600 nm for prime focus and

52% delivered to the LRS. We have encountered some degradation of these coatings in practice, and Denton Vacuum has recoated the corrector mirrors. The reason for the degradation is that the blue reflectivity of the coatings was specified too tightly, leading Denton Vacuum to use a thinner than normal sapphire protective overcoat. This thinner coating met the specifications, but proved not to have the durability of earlier Denton Vacuum FSS-99 coatings. The PM segments now have typical λ = 600 nm reflectivities of 88%, rather than 98%, and the on-sky throughput of the HET is 49%, deduced from LRS throughput measurements (next section).

2.2 Present HET instruments: The Marcario Low Resolution Spectrograph

The Marcario LRS is an efficient imaging spectrograph with grism dispersing elements. It has three modes of operation: imaging, longslit spectroscopy (LS) and multi-object spectroscopy (MOS). The instrument is described in detail in refs 6-9. Currently it is operating with the LS and imaging modes, and the MOS unit is undergoing commissioning as described in a paper in the companion proceedings[22]. A series of longslits (1.0, 1.5, 2.0, 3.0, and 10.0 arcsec wide) may be selected, each 4-arcmin long. Typically, observations are obtained with the 2.0 arcsec wide slit due to the present imaging performance of the HET. A selection of 12 broad band and blocking filters are carried at any one time, along with two grisms. There are currently two grisms available: grism 1 is 300 l/mm covering 407 to 1170 nm at a resolving power R~300 with a 2 arcsec wide slit; grism 2 is 600 l/mm covering 426 – 730 nm at R~650. Grism 1 covers more than one octave of wavelength, and is used with blocking filters GG385 or OG515 depending on which part of the wavelength range is needed. Grism 2 is also used with the GG385 blocking filter since the LRS has sensitivity down to 360 nm.

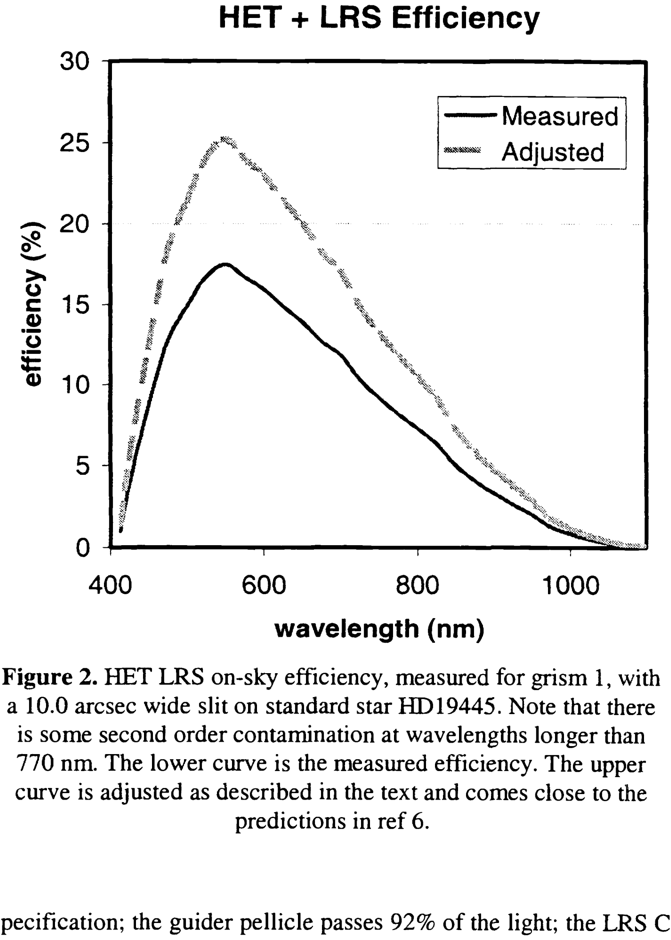

Figure 2. HET LRS on-sky efficiency, measured for grism 1, with a 10.0 arcsec wide slit on standard star HD19445. Note that there is some second order contamination at wavelengths longer than 770 nm. The lower curve is the measured efficiency. The upper curve is adjusted as described in the text and comes close to the predictions in ref 6.

Figure 2 shows the on-sky throughput of the HET plus LRS as measured on a standard star with a 10.0 arcsec wide slit. The efficiency is expressed as the fraction of photons incident on the atmosphere that are detected by the LRS CCD, and peaks at 18%. Note that predictions of LRS on-sky efficiency[6] peaked at about 25% for this grism. That prediction did not include the guider pick-off pellicle which takes about 8% of the light, and assumed that the Denton FSS-99 silver coatings met specifications. We have carefully considered the differences between the predicted model and reality, and we can account for them as follows. The HET primary mirror reflectivity loss is at 90% of specification; the guider pellicle passes 92% of the light; the LRS CCD has RQE~90% rather than the 98% modeled; and the grism efficiency is 75% rather than the 85% assumed. Each of these factors is about 10%, leading to a modified *predicted* on-sky efficiency of 17 %, exactly as measured. We expect to gain back a factor of 1.25 when the primary mirror is re-coated, the pellicle is replaced, and the CCD is upgraded, giving 22% peak efficiency. Additionally, we are investigating upgrading the grisms with volume holographic (VH) gratings[23], which promise a further gain of 1.3 times in throughput raising the peak to 29%. In any case, 18% on-sky efficiency is certainly competitive with spectrographs on other large telescopes.

The LRS has been commissioned during the spring and entered science operations on October 6, 1999. This commissioning period allowed us to characterize the performance of the HET and LRS and to make significant gains in improving the operational efficiency of the telescope. Descriptions of the LRS and the first science observations are in press[13,16,24], and we can summarize the results:

- The LRS meets requirements for throughput, image quality, and usability. Objects as faint as v=24 have been observed successfully, with integrations between 10 and 60 minutes.
- Setup on typical objects takes no more than 10 minutes. It is important to minimize setup time due to the limited on-object track time of the HET. The tracker allows very accurate slit position angle settings, needed for rapid setup of the MOS.
- The tracker meets specifications, pointing is within 20 arcsec and can be improved further.
- The delivered HET image quality is compromised by the thermally-driven de-stack of the mirror segments. Rapid temperature changes cause small, unpredictable, motions of the individual segments, making the initial stacking of the mirror difficult, and limiting the typical observation time to 30-60 minutes. The best seeing recorded was 0.75 arcsec. (for a single mirror), but the best images on stars were 1.6 arcsec., typically degrading to 2.5 arcsec. by the end of the observation. Most observations were obtained with a 2-arcsec. wide slit, and the slit losses are significant.
- Regular re-stacking of the mirror results in a significant operational overhead on many nights. No other system contributes significantly to lost observation time.
- The operations and scheduling software is robust and mature, and is supporting the first scientific queues which started in October.

The HET is an innovative design and is a prototype. It has taken longer than envisioned to commission, but has succeeded in all its goals except for the stability and accuracy of the primary mirror segment alignment. The thermally driven de-stack of the primary mirror segments will be overcome with the Segment Alignment Maintenance System (SAMS) edge-sensor project. Outfitting the 91 mirror segments with edge sensors will provide the feedback to close the control loop on the primary mirror shape. At that point the HET will exceed its image quality and efficiency goals, delivering 1 arcsec images in good seeing and allowing observations all night. The HET consortium awarded the SAMS contract on 25 August 1999 and it is scheduled for completion in mid 2001. Considering that HET cost only $16M to build and commission, and has already spawned a clone in the Southern African Large Telescope (SALT) [25], the performance that we will ultimately achieve with the SAMS will be very impressive.

2.3 Future HET instruments

A more detailed description of the future instruments for HET can be found in ref 5 and references therein. Here we summarize status and predicted performance of the instruments currently under development. The next facility instrument to be delivered will be the HRS[10], due this summer. It is a fiber-fed cross dispersed echelle spectrograph utilizing a 31.6 line/mm R4 echelle from Spectronic Instruments. Currently the optics are installed, except for the large refractive camera and the CCD detector system, which will utilize a pair of EEV 2k x 4k CCDs. The instrumental wavelength coverage is 420 to 1020 nm, with the exact wavelengths dependant on the resolving power and cross dispersion. The native resolving power is R=34,000 for a 1 arcsec aperture, and the two pixel resolving power limit is 120,000. Fiber image dissectors will provide the higher resolutions by slicing the output of the science fibers from the FIF. The primary science drivers for the HRS are searches for extra-solar planets and studies of the formation and early stages of the evolution of the stellar population of the Galaxy.

A J band enhancement to the UFOE test spectrograph is due for delivery in late spring. J-CAM replaces the camera and detector with a custom f/1.6 camera optimized for 0.9 to 1.35 μm, and a HAWAII 1024^2 HgCdTe infrared array. The echelle and cross-disperser grating will also be replaced. This instrument will deliver the entire wavelength range from 0.9 to 1.35 μm at resolving power R=5,000 (2 arcsec diameter fiber) simultaneously onto the detector. The highest resolving power (2 pixels) is R~15,000, and will be achieved with a 0.67 arcsec wide slit at the fiber input to the spectrograph. This instrument is particularly designed to observe high redshift Mg II absorption lines in QSO spectra, and will provide an important test bed for the IR arm of the MRS, prior to its development.

The MRS[11] is divided into two arms, with the visible arm (450-900 nm) to be delivered at the end of the year. The IR arm (950-1350 nm) will be developed on a longer timeframe. The MRS is being constructed at PSU along with the fiber instrument feed (FIF). MRS is a dual-beam fiber-fed echelle instrument with resolving powers of 3,500 to 20,000. The visible beam is under construction and the infrared beam is in design. The FIF provides the MRS with multiple fiber-feed options, including 10 multi-object probes, 30-arcsec. fiber "longslits", an integral field unit, a sliced fiber for R=20,000, and a scrambled fiber for precision radial velocities. For reference, a 2-arcsec diameter fiber gives a resolution of R=5080. The design will allow spectroscopy as blue as 380 nm without defocus. A pair of EEV 2k x 4k CCDs will provide simultaneous wavelength coverage form 450 to 920 nm with the 316 l/mm cross disperser grating. For multi-object spectroscopy a 600 l/mm cross disperser is needed to separate the orders, with 65% of the wavelength range accessible in a single exposure.

The J-band extension to the LRS (LRS-J) will replace the optical camera and CCD system by a f/1.0 catadioptric camera with a HAWAII array at its focus. The project is described in ref 17. The aim of this enhancement is to provide multi-object capability at wavelengths up to 1.35 μm, in order to follow features in galaxies out to redshifts z~2. The conceptual design of this camera is well advanced, and we hope to commission it in about a year, on the same time-frame as the delivery of the SAMS edge-sensor system. The upgrade will also include two VH grisms with predicted peak efficiencies of 90%, giving R~2000 with the 1.3 arcsec wide MOS unit slits, and peak efficiency of ~25% on the sky.

3. SCIENCE FROM THE HET LOW RESOLUTION SPECTROGRAPH

At the time of writing, the HET has been obtaining scientific observations with the LRS and UFOE for about five months. In this early operations phase, science is scheduled for two weeks per month, centered on new moon, with a week of instrument commissioning and a week of engineering. We expect this mode of operations to continue at least through the end of 2000. Here we highlight a few representative projects that are underway with the HET LRS, in order to illustrate the current performance in practice. These observations require the telescope to be operating robustly in queue-mode, as described above.

3.1 Follow-up of the Sloan Digital Sky Survey: high redshift QSOs and Brown Dwarfs

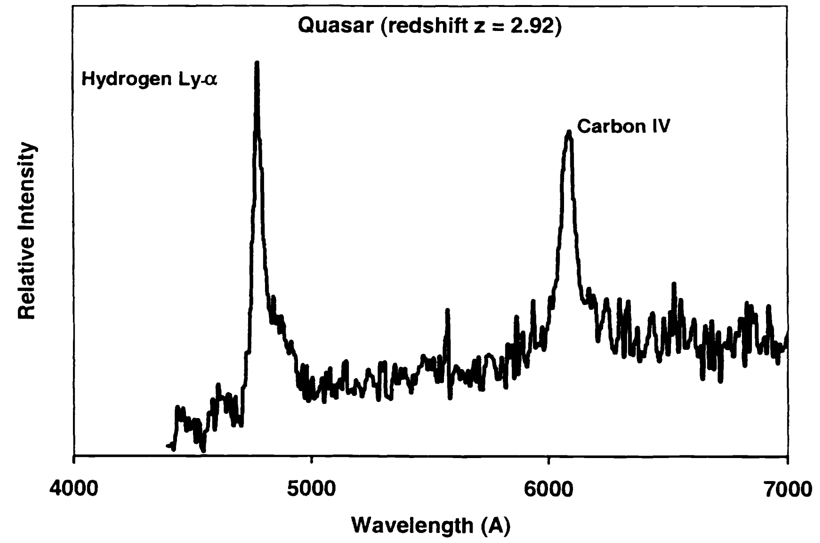

Figure 3. The first QSO spectrum obtained with the HET LRS. This r=20 SDSS QSO candidate was observed in a 15 minute exposure in early instrument commissioning. To date, the LRS has obtained spectra of 26 SDSS QSO candidates.

One of the principal strengths of the HET will be the ability to follow-up significant samples of objects from the ongoing large optical, infrared, and radio surveys. D.P. Schneider (PSU) and X. Fan (Princeton) are leading a program to identify a large sample of high redshift QSO candidates from the SDSS[12] in order to establish the high redshift QSO luminosity function and determine if there is a drop-off in QSO number density at high redshift. These candidates have colors indicative of QSOs at z=3 or greater. At these redshifts the combination of a strong Ly-α emission line and Lyman forest absorption causes the optical colors of QSOs to differ markedly from those of stars. Figure 3 shows the first QSO observed with the LRS. Schneider et al.[13] report the first HET LRS observations of SDSS QSO candidates obtained with 10-15 minute exposures during commissioning, including the identification of a r=24 L0 field brown dwarf star, for which a spectrum was obtained in 25 minutes (figure 4). Subsequently, during fall 1999 a total of 26 SDSS QSO candidates have been observed with HET, of which 18 were confirmed to be QSOs with redshifts $3.6 < z < 4.7$. Nine L-dwarf candidates have also been confirmed.

The SDSS follow-up project has been important in demonstrating that the HET can be used efficiently to observe large samples of objects –one of its primary missions. The goal of 10-minute set-up time on typical objects has been realized, and was essential for the efficient observation of the sample.

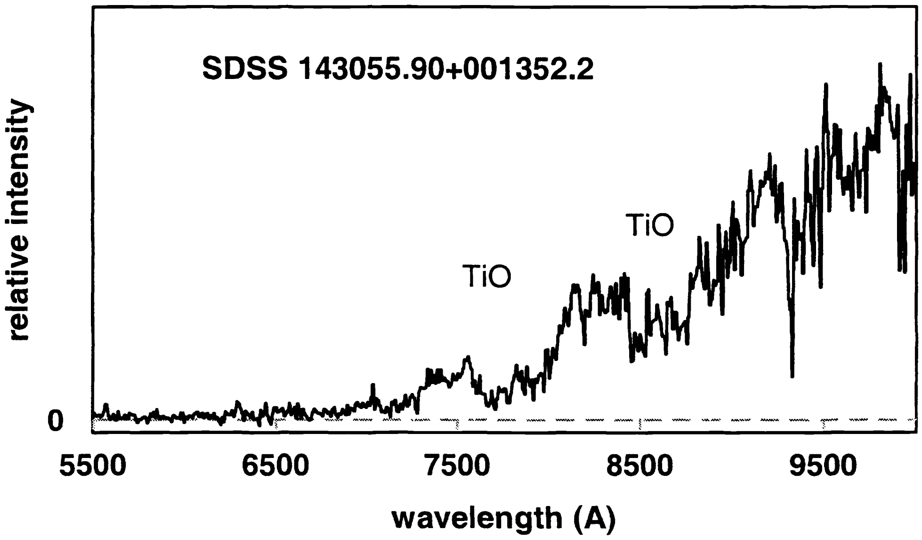

Figure 4. L0 field brown dwarf star discovered among a sample of QSO candidates. Note the strong TiO molecular bands

3.2 Chandra Sources and the Nature of the X-Ray Background

The Chandra Satellite Advanced CCD Imaging Spectrometer (ACIS) instrument team at PSU led by G.P. Garmire is conducting a very deep hard and soft X-ray survey of the Hubble Deep Field (HDF) which should resolve the X-ray background into discrete sources if current models are correct. It is predicted that the hard X-ray background radiation is emitted by AGN at a variety of redshifts that are often missed in surveys at other wavelengths due to obscuration. An initial 44 ks exposure of the field of the z=0.516 cluster CRSS J0030.5+2618 reached 2-8 keV flux densities ten times fainter (4×10^{-15} erg cm^{-2} s^{-1}), and detected a source density ten times higher (~600 deg^{-2}), than previous measurements[16]. We have used the HET LRS to obtain optical spectra of four of these sources, revealing AGN at z = 0.129, 0.269, 0.247, and 1.665, to R=21.7, with 15-20 minute exposures under typical conditions. These data identify half the hard X-ray sources in the field, consistent with predictions based on models of a population of obscured AGN at a wide range of redshifts, with the unidentified sources most probably lying at redshifts above z=0.5. All but one of the hard band sources have soft-band counterparts consistent with results obtained at brighter flux densities, so if the large remaining fraction of hard X-ray background flux is due to a population of very steep spectrum sources, they must contribute significantly at even lower individual flux densities.

3.3 The TexOx Survey: distant galaxy clusters

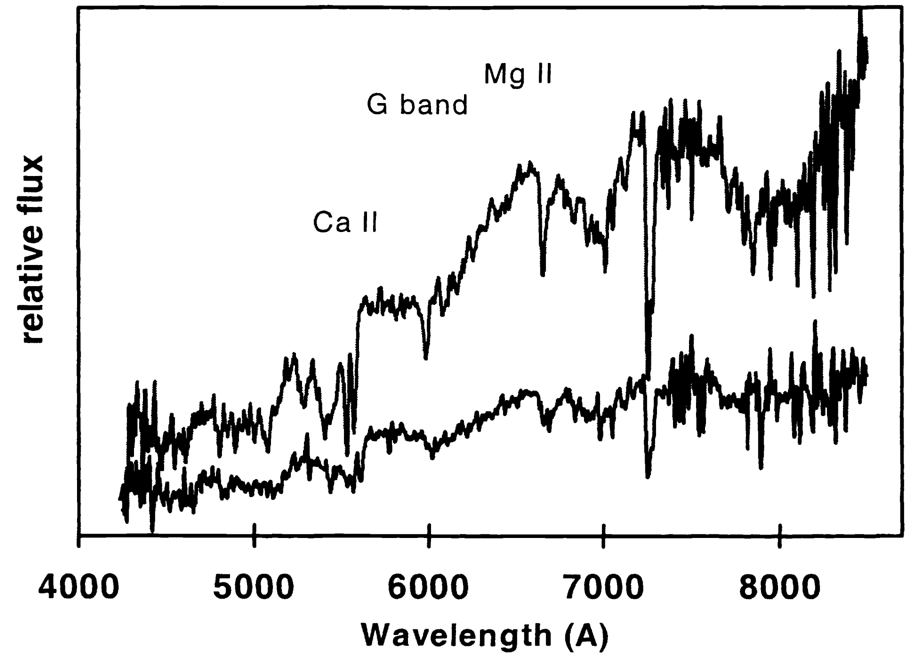

Figure 5. Spectra of a pair of galaxies in a rich TexOx survey cluster at z=0.41. These two spectra were obtained simultaneously in a 30 minute exposure with the LRS using the 300 l/mm grism and 2-arcsec. wide longslit.

The TexOx cluster survey[24] is finding distant galaxy clusters by looking for clumps of radio sources in the NVSS radio survey. At faint-enough radio flux density limits there is a reasonable chance that a cluster of galaxies will have several radio AGN, and this chance increases rapidly towards higher redshift due to the dramatic evolution of the radio source population. The survey (a collaboration of S. Rawlings (Oxford) and G.J. Hill (Texas)) has imaged about 100 radio-cluster candidates in the R and I bands, revealing intermediate redshift clusters (z~0.5) in about 30% of the cases, and a sample of these have been observed with the HET LRS to obtain redshifts. Figure 5 shows a pair of galaxies in a rich cluster at z=0.41, obtained simultaneously by rotating the PFIP to align the slit. This type of setup requires little extra overhead compared to a setup at the parallactic angle (which is the natural axis of the HET LRS slit). The exposure time was 30 minutes and the galaxies have R~19.5 and 20.5 respectively. The LRS multi-object spectroscopy (MOS) unit will be ideal for such observations, once it is commissioned, allowing up to 13 objects to be observed simultaneously.

A companion survey called TexOx-1000 (TOOT) aims to obtain redshifts for 1000 radio sources selected from deep low-frequency surveys to S_{151} = 0.1 Jy. The aim of TOOT is to determine the evolution of radio sources of all types, and particularly whether there is a high redshift cut-off in the radio luminosity function. Additionally, this survey will reach a high enough surface density of sources to use them as tracers of large-scale structure. To date, redshifts have been obtained for ~50 sources.

3.4 Synoptic Programs: the HET Echo Mapping Project (HEMP)

Major observational studies of the time variability of AGN spectra have succeeded in probing the central regions of active galaxies by observing the time-lag between variations of the continuum and of the broad emission lines (primarily Hβ). These datasets derive scale sizes of a few 10s of light days, but have required heroic efforts to coordinate observations on many telescopes over time-scales of months. The HET is superbly suited to such studies since it must be queue-scheduled to operate, and we have initiated the HEMP project to obtain detailed echo-mapping data on a number of bright AGN (led by W.F. Welsh and E.L. Robinson at UT). Not only can the spectra be obtained with an optimal sampling of about every-other day, but the aperture of the HET allows signal-to-noise ratios of ~100 per resolution element, higher than has previously been obtained for entire lines. Hence, the response of the broad-line emission to changes in the ionizing continuum can be measured as a function of velocity, allowing the structure of the broad emission line region to be disentangled to an unprecedented degree.

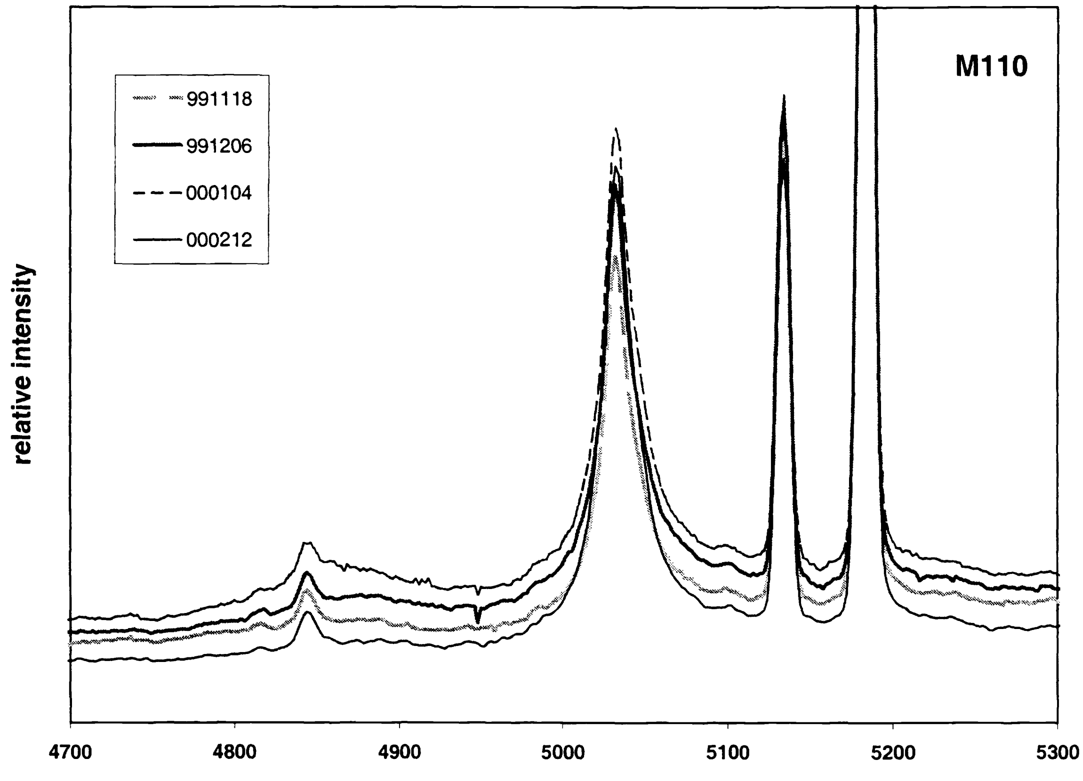

Figure 6. Time series spectroscopy of the type I AGN M110. The spectra have R=600 and have been normalized to the strength of the [OIII]λ5007 emission line. This bright Seyfert 1 has been observed roughly once per week since mid November, 1999 in a pilot study for HEMP. In addition to the strong H-β and [OIII] λλ4959,5007 emission lines there is broad He II λ4686 emission. Note the evolution of the continuum brightness and H-β. Specifically, in the earliest spectrum the continuum has begun to rise but H-β has not yet reacted. As time passes the continuum peaks and H-β gets stronger. In the last spectrum, the continuum has returned to its quiescent level, but H-β is still strong. In addition there is a very broad red component of He II that reacts more quickly than H-β. Note the superb repeatability of the [OIII] emission lines. Data courtesy of W. Kollatschny[26]

3.5 Targets of Opportunity: X-ray Transients

The queue-scheduling of the HET allows another reactive mode of operation in response to targets of opportunity (TOO). This time is meant primarily for "unexpected" events, so that such observations can be obtained even if they have not been submitted to peer-review by the TAC. The Chair of each institution's TAC approves such observations. A certain amount of "discretionary" time is set aside, which can be used to respond to unexpected events, and this mode has been triggered in the case of the new bright X-ray transient XTE J1859+226, discovered on 1999, Oct 11 by the RXTE satellite[27]. Early evidence suggested that this source is a galactic black-hole system, and within four nights the HET had obtained the first spectrum (Figure 7, lower spectrum), showing strong H-α (EW=2.2 Å) and He II emission lines with weak, but very broad absorption wings[27]. The absorption feature is the diffuse interstellar band at 6284 Å. Poor weather precluded observation earlier. This observation was an important milestone for the HET, since it demonstrated the TOO mode and obtained an observation of the object on the first possible night. Subsequent observations were obtained every few days until Nov 18, when the object became unobservable by HET for the season. A total of 17 spectra were obtained, giving a unique set of data on this outburst. During the course of the observations, the optical brightness dropped approximately one magnitude from its peak at V~15.3 mag; the X-rays also dropped substantially, but it had not returned to quiescence by the end of November. HST observations were also obtained on three separate visits in October and November. The HET data reveal huge variations in the emission line strengths, particularly in H-α. Over the course of approximately one month, the H-α emission line evolved from very strong and single-peaked, to very weak and double-peaked. The dramatic decrease in the line strength is most likely due to the decreasing X-ray irradiation of the disk and companion star, and demonstrates the crucial role irradiation plays in line formation in these X-ray transient outbursts.

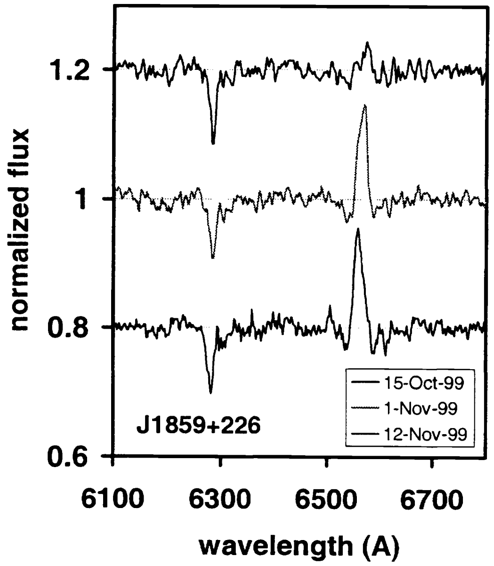

Figure 7. Spectra of XTE J1859+226 in the region of H-α, obtained with HET LRS on Oct 15 (bottom), Nov 1 (middle), and Nov 12 (top), 1999. Note that the spectra have been normalized to unity and shifted arbitrarily to separate them. The S/N ratio of the spectra is ~100.

4. SUMMARY

We are approaching the first anniversary of LRS first light on the HET. In that year, we have made enormous progress in all aspects of the telescope performance, and have transitioned from commissioning to early science operations. The HET does not yet meet specifications in delivered image quality or operational efficiency, but it is taking very interesting data consistently for two weeks each month. We should meet the image quality requirements, delivering 1.0 arcsec on the best nights, and surpass the operational efficiency goals, in about a year when the SAMS edge sensor system is delivered.

In the meantime, several new and interesting instruments will come on line and national access (through NOAO, courtesy of NSF funding for the HRS and MRS) begins in June 2000.

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