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Cite as: AIP Conference Proceedings **752**, 3 (2005); https://doi.org/10.1063/1.1893326
Published Online: 28 March 2005

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AIP Conference Proceedings **752**, 3 (2005); https://doi.org/10.1063/1.1893326 **752**, 3

Stellar Astrophysics on the Hobby-Eberly Telescope [1]

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Abstract.
We briefly describe the Hobby-Eberly Telescope (HET) and its present status and give several examples of successful stellar astrophysics programs. The HET was primarily driven by a science mission of conducting spectroscopic surveys. In addition the HET's unique design derives from considering that telescopes are largely used for exposure times of an hour or less at moderate zenith distances and modest image quality that is based on median site seeing which is consistent with a survey mission. We present results from planet searches, large radial velocity surveys, and Sloan Digital Sky Survey follow up programs in this context. The queue-scheduled nature of the HET makes it especially effective at synoptic programs that require a large aperture.

INTRODUCTION TO THE HOBBY-EBERLY TELESCOPE

The Hobby-Eberly telescope (HET) is an international collaboration between The Pennsylvania State University, The University of Texas at Austin and Stanford University in the United States, and Ludwig-Maxmilians Universität München, and Georg-August-Universität Göttingen in Germany. It is located at the University of Texas' McDonald Observatory at an altitude of 2000 meters. This southwestern site remains exceptional among developed US mainland sites for it dark sky.

The HET is a unique large telescope design making use of an Arecibo-like tracking scheme to allow the implementation of a large aperture telescope for moderate cost by keeping the 11-m spherical primary mirror at a fixed elevation of 35°. A 9.2 meter pupil sweeps over the primary mirror as a x,y tracker moves a spherical aberration corrector to track a target. Objects can be tracked for as long as 2.8 hours at the northern declination limit of $+71.6°$ and for 40 minutes at the southern declination limit of $-10.3°$. A four mirror double-Gregorian corrector design combined with the primary mirror and tracking and alignment errors is designed to yield a 0.6 arcsecond image at the center of a 50 mm (4 arcminute) circular science field of view.

The design, performance goals and early testing is described by Ramsey et al. [1], Sebring et al. [2,3] and Ramsey et al. [4]. Early performance and commissioning difficulties are discussed by Hill et al. [5] and Booth et al. [6] but substantial efforts in the last two years to improve telescope systems and master the very complex operations in-

[1] Based on observations obtained with the Hobby-Eberly Telescope, which is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maxmilians Universität München, and Georg-August-Universität Göttingen.

CP752, *Stellar Astrophysics with the World's Largest Telescopes: First International Workshop*
edited by J. Mikołajewska and A. Olech

herent in this telescope concept have brought the HET to routinely delivering site seeing limited images in the 1.3 arcsecond range. We are confident that further improvement will allow us to exceed our original goals. Current status and performance is presented by Booth et al. [7] and Hill et al. [8]. The HET design has been used in the South African Large Telescope (SALT) where they benefited by our mistakes and we have in turned learned from their improvements (Meiring and Buckley [9]).

FIGURE 1. Hobby-Eberly telescope at McDonald Observatory near Ft. Davis, Texas.

HET INSTRUMENTS

Low resolution spectrograph

The Marcario Low Resolution Spectrograph (LRS) is a Grism based instrument with three modes; broad and narrow band imaging over the HET 4 arcminute field of view, long slit and multi-object spectroscopy (Hill et al. [10,11]). The instrument PI is Dr. Gary Hill and Dr. Phillip MacQueen is PI for the CCD system. The optics were partly designed and constructed in Mexico at IAUNAM (Cobos et al. [12]). This was the first instrument on the HET being commissioned in Spring 1999. It was funded primarily by UT Austin, Stanford University and Ludwig-Maximilians-Universität München. Three grisms are available resolutions of $R = 600(4150 - 10100\ \text{Å})$, $1300(4300 - 7300\ \text{Å})$ and

$1900 (6250-9100 Å)$. Space constraints on the Prime Focus Instrument Package (PFIP), where the LRS resides, limit only two grisms in the instrument at a time. The position angle of the PFIP can be rotated to set up to arbitrary angles allowing exposures of more than one object simultaneously in the long slit mode and maximizing the number of objects in the remotely configurable 13-slitlet MOS unit.

Medium resolution spectrograph

The Medium Resolution Spectrograph (MRS) is the newest instrument on the HET and is more fully described Ramsey et al. [13,14]. It is a versatile, fiber-fed echelle spectrograph designed for a wide range of scientific investigations and includes single-fiber inputs for the study of point-like sources, synthetic slits of fibers for long slit spectroscopy, 9 independently positionable probes for multi-object spectroscopy, and a circular fiber integral field unit. The MRS consists of two beams. The visible beam has wavelength coverage from 450 - 900 nm in a single exposure with resolving power between 5300 and 20000 depending on the fibers configuration selected. This beam also has capability in the ranges 380 - 950 nm by altering the angles of the cross-disperser gratings. A second beam operating in the near-infrared has coverage of 900 - 1300 nm with resolving power between 5300 and 10000. Both beams can be used simultaneously and are fed by the HET Fiber Instrument Feed (FIF) which is mounted at the prime focus of the telescope and positions the fibers feeding the MRS (Horner et al. [15]). The MRS was funded by Penn State University, Robert E. Eberly and the Eberly family trust and the US National Science Foundation. The PI is L. Ramsey and commissioning began in summer 2003. There are numerous modes on the MRS and at this time, on the simplest modes in the visible beam are used in routine queue operations.

High resolution spectrograph

The High Resolution Spectrograph (HRS) design enables R = 15000 to 120000 spectroscopy on the HET and is described by Tull [16]. It is an adaptation of the white pupil design used on the UVES. It is a fiber coupled, bench mounted instrument with a 420 to 1100 nm wavelength coverage. The HRS is designed for single object use with either 2 or 3 arc-second fibers and a choice of 0, 1, or 2 sky fibers. It uses the same Fiber Instrument Feed as the MRS. The HRS was funded by UT Austin and the US National Science Foundation and commissioned in Spring 2001. The instrument PI was Dr. Bob Tull and Dr. Phillip MacQueen PI for the CCD system. The HRS has proved to be particularly potent for very high precision radial velocity surveys.

SCIENCE WITH THE HET

The HET is a powerful yet limited telescope; a fact that is clear when one looks at the $\sim$\$20 million cost for this 9 meter class telescope. The limitations inherent in the HET design primarily effect scheduling and operational flexibility. Given this the HET will be especially competitive when used with the following criteria in mind:

- Target classes are uniformly distributed on the sky
- Target objects have sky surface densities of a few per square degree or a few per square arcminute
- Time critical observations with time scales of days and longer are of interest
- Spectroscopy in the visible and near infrared yield the required astrophysics

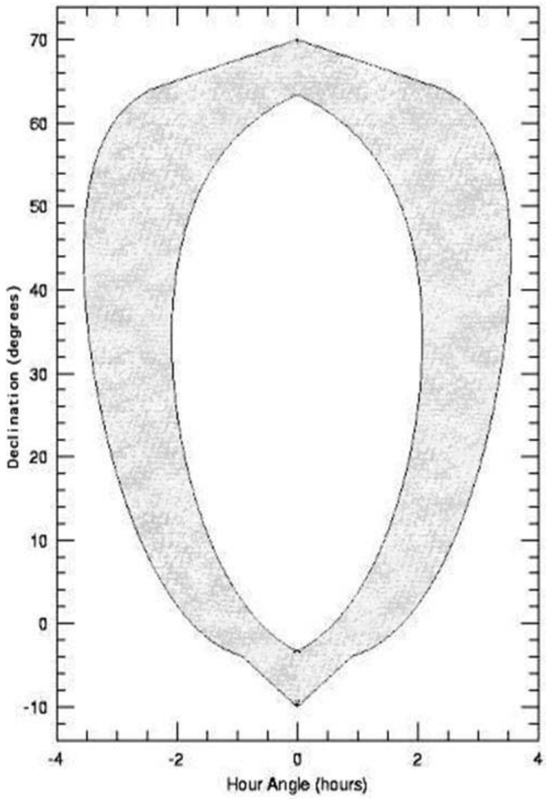

FIGURE 2. Sky access of the HET is illustrated by the shaded area.

The Hobby-Eberly telescope is a 100% queue scheduled telescope. This mode of operation is made necessary by the design of the telescope. Key to understanding this is appreciating the region of the sky that can be accessed at any given time as is illustrated in Figure 2.

All programs on the HET can be classified as survey, synoptic, target of opportunity (ToO), or more traditional programs. Survey programs that are best suited for the HET are those that have large numbers of targets distributed all over the sky or over large areas of the sky. For these programs there are usually several potential targets at any time in the access area shown in Figure 2. Pencil beam surveys, ones which have large number of objects concentrated in a small range of RA and DEC, are less suitable for the HET as any given area can only be accessed twice per night typically for two hours. Studies of the areas such as the Hubble Deep Field or star formation regions typify such programs.

Programs that study the time domain in objects, or synoptic programs are also well suited for the HET especially if the interval of interest is days or longer. These programs require multiple visits to a target or visits on a specific date or dates. While the queue nature of the HET is an asset here, for programs to be successful they have to have high priority relative to all other programs accessible in the same time interval.

Target of opportunity programs are related to synoptic but differ in that they are triggered at some point of time during the observing semester. Programs for Gamma Ray Bursts (GRBs), supernova and nova outbursts typify this type of observation. Of course to be executable at all, the target must be in the sky access ring of the HET as illustrated in Figure 2 at the time of observations.

More traditional programs are those that require long exposure times on a few objects. These will often require multiple tracks and, while they can be done, are not as well suited for the HET. We provide tools on the HET web page so observers can calculate the number of tracks that are likely to be available and estimate the feasibility of their program. Extensive programs in this category must have high priority to have an expectation of being completed.

Successful use of the HET requires that observers must adapt to the nature of queue observing and the HET queue in particular. Observers must make sure that their program is feasible to complete on the HET. At any given location on the sky, there are a limited number of tracking opportunities during an observing trimester. Observers should also honestly assess the competitiveness of their program on HET. During the execution of their programs, observers must promptly look at their data and decide if their program goals are being met. Again the opportunities for any given program diminish with time. This places strong emphasis on communications between the PI and the HET resident astronomers conducting the observations is vital, especially when establishing a new program.

STELLAR ASTOPHYSICS WITH THE HET

As of September 2004 there have been 60 papers published in refereed journal using data from HET. For about 75% of those papers, HET was a significant contributor to the paper. In the early work (2000-2002) HET publications benefited greatly form working with SDSS collaborators. Papers that are based nearly 100% on HET data are common recently. Of the total number of publications 37%, or 22 papers, are stellar astrophysics.

Surveys

To date, survey science, along with synoptic science, has produced the largest number of stellar astrophysics papers with 7 publications. The first stellar astrophysics done on the HET was limited to using the LRS and was mostly due to productive collaborations with the Sloan Digital Sky Survey teams working on M, L and T dwarf stars (Leggett et al. [17], Schneider et al. [18], Geballe et al. [19].). An early LRS survey also studied the spectral properties of faint UV bright stars found on object prism surveys (Eracleous et al. [20]) and more recent LRS observations have been used to complement photometric identifications of cool white dwarfs (Kilic et al. [21]). Yong and Lambert [22] used an earlier medium-resolution commissioning instrument to survey 134 candidates for cool subdwarfs. Allende-Prieto et al [23] conducted the first survey with the HRS using $R = 120000$ high S/N spectra to look at the convective shifts of over 1200 FeI lines to show clear evidence of a greater shift in weaker lines and an increase in amplitude for more luminous stars.

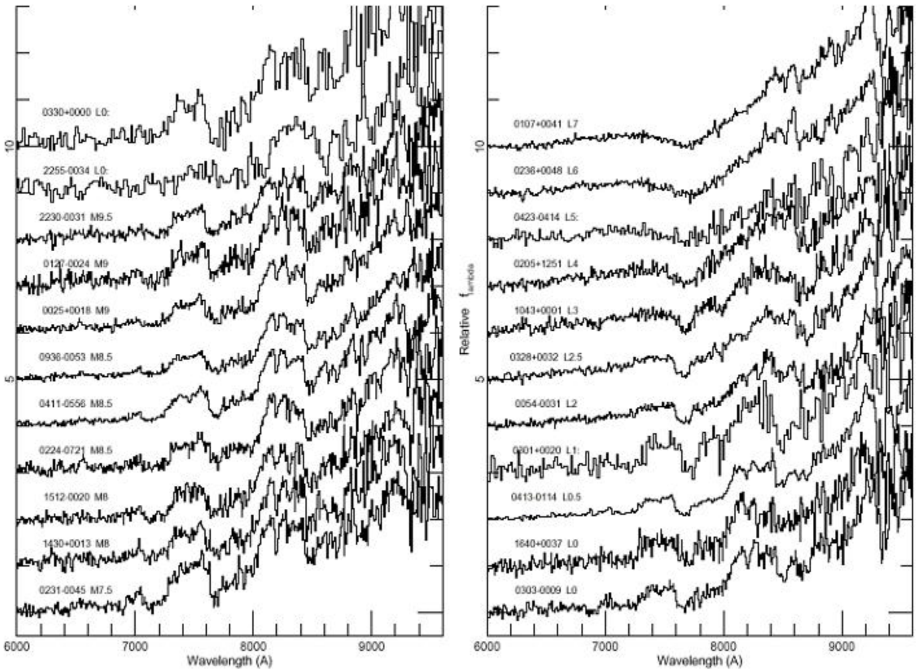

FIGURE 3. HET spectra of M, L and T dwarfs obtained using the LRS.

One of the early survey results was that of Schneider et al. [18] which showed that SDSS colors allow identification of L and T dwarfs with a very high success rate. They also showed that a combination of factors, the disappearance of TiO and VO in the i band for latter types, the presence of strong NaI and KI in the i band and the disappearance of 840 nm TiO and FeH in the z band, made the SDSS $i-z$ color insensitive to spectral type from M7 to L4.

Synoptic Science

Synoptic science comprises most of the recent papers and has the highest proportion of papers that depend mostly on HET data. This is not surprising given the high effectiveness the HRS on HET has for Radial Velocity surveys which account for 5 of the 8 papers in this category to date (Endl et al. [24], Paulson et al. [25,26], Cochran et al. [27] and McAuthur et al. [28]). Indeed all the publications in this category have depend upon HRS data. Smaller synoptic programs have looked at stellar activity (Lopez-Santiago et al. [29]), variability in the NaD line to find evidence of comet infall (Mendelowitz [30]) and transient features in the sodium lines in young stars for evidence of planetesimal infall (Chakraborty [31]). Likely the most important paper in the synoptic category is that by McArthur et al. [28] where they obtain lovely data showing the existence of a Neptune mass planet in the ρ^1 Cancri system. The high precision of the HRS and the flexible queue schedule of the HET made this and the discovery of another planet (Cochran et al. [27]) possible over a very short time scale. Figure 4 is a summary of recent HRS measurements compiled by Dr. William Cochran and his collaborators in the HET planet search program where measurements less than 5 km/sec are routine.

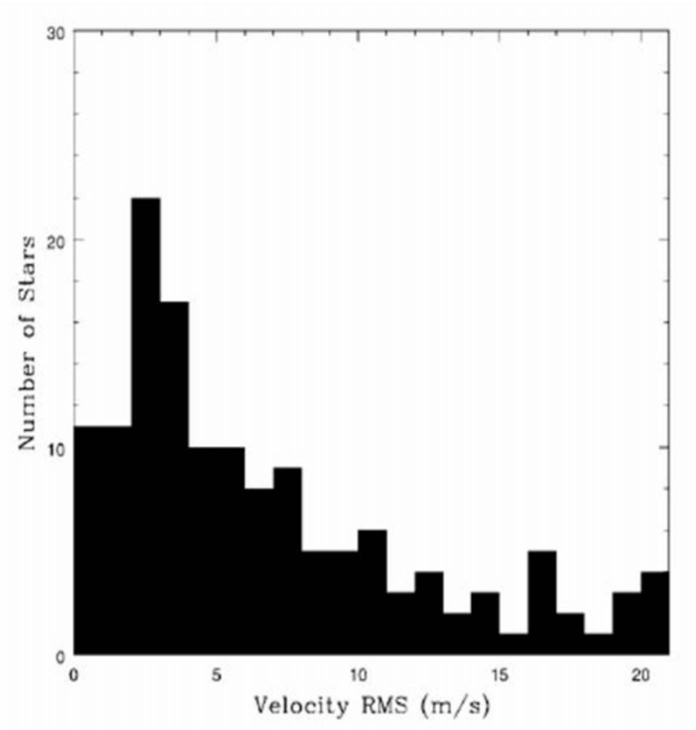

FIGURE 4. Histrogram showing the radial velocity precision of the HET for a survey of F and K stars with V magnitudes ranging from 6 to 10.

Target of Opportunity Science

Target of opportunity science has not yet hit stride with the HET. While such programs should be well suited for HET, they have lagged primarily because of the lack of robustness in our operation until this last year. In spite of these difficulties, some results have been published. Indeed one of the first papers from HET used the LRS to observe a 4.2 hour eclipsing dwarf nova (Gansicke et al. [32]). More interesting results were obtained on SN 2003du where an nice LRS time series showed the evolution of the Ca II infrared triplet thought to arise in the circumstellar environment (Gerardy et al. [33]). We have had a limited success with GRB's (Schaefer et al. [34]) but hope to do better in this area in the future.

Traditional Stellar Astrophysics

While more traditional programs are not HET strength, thoughtful and patient work can pay off. Matthew Shetrone, who is the lead astronomer at HET, and collaborators has published several papers probing aspects of stellar evolution [35,36,37]. Also, a very nice "traditional" study was carried out by Mandell et al. [38] where they used $R = 120000$ very high S/N spectra of the Li line region in Li poor stars ^{6}Li that would be evidence for accretion of planets.

FUTURE PROSPECTS

As the performance of the HET continues to improve we anticipate an increase in the productivity of the telescope and its instruments. The MRS has been in the queue observing mode for less than a year and the number of programs using it is increasing. In addition, both the LRS and the MRS will have J band (0.9-1.3 micron) capability within a year. We expect that most stellar astrophysics will continue to be done with the HRS followed by the MRS.

ACKNOWLEDGMENTS

The success of the HET is due to a large number of people. In addition to the authors and co-authors cited above I would like to acknowledge the many contributions of Gary Hill, Phillip MacQueen, Polilas Palunas, Marsha Wolf. I also appreciate the continued hard work by the HET support team lead by John Booth which includes Gordon Wesley, Edmundo Balderamma, Linda Brindle, George Damm, Fernando De Valesco, Jim Fowler, Paul Peterson, Robert Poenisch and Mike Ward, HET resident astronomers Steve Odewahn, Brian Roman and Matthew Shetrone, telescope operators, Frank Deglman, Vicky Riley and Martin Villareal.

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