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Joseph R. Tufts, Gary J. Hill, Gordon L. Wesley, Phillip J. MacQueen, Lawrence W. Ramsey, "Fiber fed spectral calibration with the Hobby-Eberly telescope," Proc. SPIE 4841, Instrument Design and Performance for Optical/ Infrared Ground-based Telescopes, (7 March 2003); doi: 10.1117/12.461740

Event: Astronomical Telescopes and Instrumentation, 2002, Waikoloa, Hawai'i, United States

Fiber fed spectral calibration with the Hobby-Eberly telescope

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ABSTRACT

The Hobby-Eberly Telescope (HET) imposes unique constraints on the design of a spectral calibration system. Its 9.2 m aperture and queue scheduled operation make traditional dome screens impractical. Furthermore, the changing pupil of the HET's tilted Aricebo design is far more drastic than the simple rotation of traditional alt-azimuth telescopes. Given these constraints we elected to build an internal spectral calibration system (SCS) common to all instruments.

The SCS can feed all HET instruments from a uniformly illuminated Lambertian screen located within the spherical abberation corrector (SAC) at the telescope's second pupil. A moving baffle installed at the third pupil will reproduce, during calibration, the actual HET pupil seen in a science exposure. We eliminated all heat sources at the SAC by locating the lamps in the basement below the telescope and coupling source to screen through 12 600 μm diameter 35 m long fibers.

Keywords: HET, Hobby-Eberly Telescope, Fiber, Spectral Calibration, Moving Baffle, LRS

1. INTRODUCTION

With all other large astronomical telescopes in the post-Palomar era, the HET shares the alt-azimuth design, but it, unlike most, is fixed in elevation. The HET primary is spherical, and stellar tracking is accomplished by moving a spherical aberration corrector (SAC) and instrument package (PFIP), in a well defined way, over the prime focus spherical surface located halfway between the primary (M1) and its center of curvature. The actual telescope pupil becomes the geometric intersection of the SAC pupil and the HET primary, and both its orientation and its shape change continuously during a track.

Proper calibration requires instrument optics to be illuminated identically for both calibration and science exposures. Therefore, the changing telescope pupil observed in a science exposure must be duplicated in a calibration exposure, something which is impractical at the instrument level. We elected early in the design process to locate a pupil mask within the four element SAC. Using a uniformly illuminated SAC pupil at M5, this mask approximates the full telescope illumination pattern and provides the fundamental constraint to any HET calibration system.

The HET spectral calibration system (SCS) accomplishes uniform illumination of the M5 pupil mask (moving baffle) by uniformly illuminating a removable Lambertian screen at the M3 pupil within the SAC (Figure 2). Heat sources are removed from the beam and dome by using fiber optics to couple light from the HET basement to six pairs of feeds arranged in a ring around M2. Although the moving baffle is not yet fully operational, and the benefits of SCS cannot be fully tested; it has been continuously calibrating LRS data for three years with virtually no down time. Typical calibration exposures are 20–200 s to a peak signal-to-noise of 100.

Instrument Design and Performance for Optical/Infrared Ground-based Telescopes,
Masanori Iye, Alan F. M. Moorwood, Editors, Proceedings of SPIE Vol. 4841 (2003)

2. LIGHT SOURCES

Spectral calibration typically involves a spectral flat field, a wavelength calibration, and a sensitivity calibration. Though the ideal flat field has neither shape nor feature, in practice one must settle for a minimization of features in a spectrum which approximates a black body. In high-resolution low-noise spectra this task becomes extremely difficult because of trace element absorption in the lamp glass and filament. For lower resolution data, trace elements are not an issue and we successfully use common halogen lamps.

The ideal source for wavelength calibration has emission only in uniformly spaced equal brightness lines of known air or vacuum wavelength. Again, the ideal doesn't exist and we try to obtain "good" coverage of the spectral region with as many unblended lines as possible. In high resolution, thorium-argon (ThAr) is used almost exclusively. With the LRS we have found a combination of a Ne and HgCdZn works quite well in calibration of the 3900–10000 Å region.

2.1. Continuum/Flat Lamps

The LRS flat field lamps are 10 W GE quartz tungsten halogen (QTH) bulbs. Since most modern QTH lamps contain UV inhibitors to reduce risk of injury, we elected to use an old model GE lamp which doesn't have this characteristic. Unfortunately, at 10 W, they are relatively low in output power and difficult to obtain. Gilway Technical Lamp and Oriel are sources of brighter bulbs which are useful in spectral calibration systems.

In flat fields it is necessary to use a spectrally smooth illumination source. Thus we can only consider filament type lamps; QTH lamps are currently the best option available as they operate at a significantly higher color temperature (typically 3000 K) than do other filament lamps. A significantly reduced lamp life results if a QTH lamp is operated too hot or cold.

With all QTH bulbs operating at approximately the same color temperature, lamp power output is determined *only* by filament size. Operating voltage and current are determined by filament shape (length and cross-sectional area), but output power is determined only by filament surface area. With SCS it is not advantageous for us to use a higher power bulb because the $A\Omega$ product of fiber is constrained by the fiber's numerical aperture (0.33, $f/3$), and the size of the fiber input determined by the diameter of the hexagonal packing arrangement (1.8 mm). In fact, the compact nature of the low-voltage, high current 10 W GE filament make it more point-like and ideal for our particular application. Although $< 1\%$ of light incident on the M3 calibration screen makes it to the LRS slit, the majority of system inefficiency still occurs at the fiber feed. With a filament lamp feeding a fiber system it is just not possible to gain without increasing the size of the fiber bundle.

In SCS we have elected to operate the lamps at a higher-than-spec color temperature and accept the increased rate of bulb failure. We operate 10% over current at a color temperature of 3400 K, and expect bulb failure about once in 50 hours of use. We stabilize the current rather than the voltage to eliminate effects from changing resistances in leads, and it takes about 500 s for a lamp to fully reach a stabilized output. After the lamp has reached steady state, voltage and current are constant to the measurable limits of the power supply.

2.2. Line Source Lamps

Line sources for LRS comparison spectra are Ne, Ar, and HgCdZn discharge lamps from Cathodeon. Ne is widely used as a comparison source in the visible red. In the blue, Ar and Hg are frequently used. We have found the blue Ar lines to be too faint to use in SCS, but a combined mixture of Hg, Cd, and Zn works extremely well. At the time these lamps, were selected they were a McDonald standard and replacements were easily obtained. Unfortunately, replacement discharge lamps are no longer available and we are looking for a suitable alternative.

For HRS spectra, a significantly higher density of spectral lines is necessary, and ThAr is perhaps the most suitable for general use. Unfortunately this lamp is a hollow cathode lamp and is extremely faint. We have not yet found a suitable method which will allow us the use of this lamp with the M5 moving pupil mask. For now, the HRS ThAr comparison lamp and QTH flat field lamp illuminate the spectrograph slit directly.

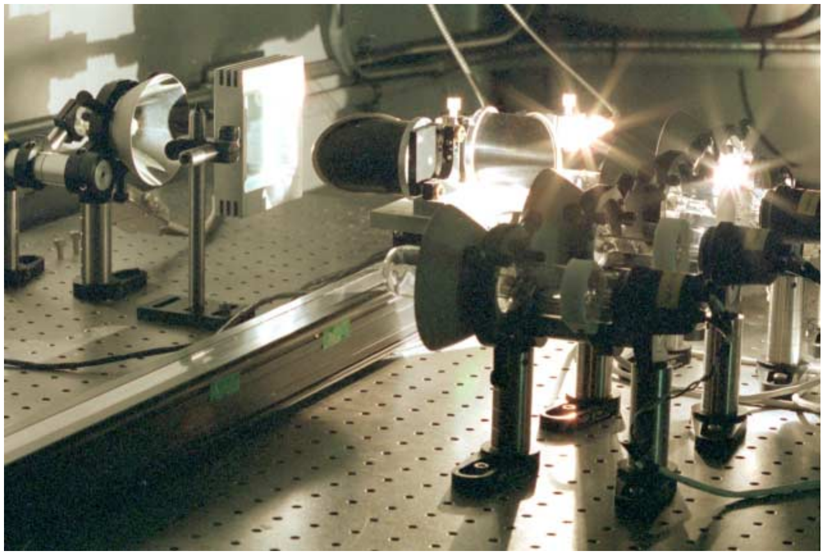

Figure 1. SCS fiber feed stage. The red-optimized fiber bundle is in the near side of the photo while the blue bundle is away.

3. OPTO-MECHANICAL DESIGN

All SCS light sources are mounted on an optical bench with horizontally pointing parabolic reflectors. Between these sources and the fiber-feed stage is a space which allows for color balancing or neutral density filters. The stage travels horizontally to select the desired lamp and on it is an off axis paraboloid which focuses light on the fiber bundle. The off-axis paraboloid has an $f/\#$ corresponding to the inverse of the numerical aperture of the fibers (0.33). Due to the intense heat generated by the flat field lamps it is necessary to locate heat rejection filters in the pseudo-collimated beam. (Figure 1)

3.1. Fiber Feed

The light sources are coupled to the PFIP through two 6 fiber bundles of 600 μm polymer clad fibers from Polymicro. One bundle is red optimized (low-OH silica) and the other is blue optimized (high-OH silica). The fibers are packed in a hexagonal arrangement with an unused center fiber (for illumination symmetry in the active fibers). The cladding is stripped exposing only the core and 60 μm buffer.

Polymer clad fibers are better suited to calibration as they have an increased numerical aperture (0.33 relative to 0.2) compared to silica-silica fibers. This results in a faster allowed optical system. For the Polymicro polymer clad fibers our bundle has an $A\Omega = 1.5$ mm^{2}sr, by comparison an identical bundle of silica fibers has $A\Omega = 0.053$, nearly a factor of three less. With a fixed color temperature lamp this relationship is direct and we put three times as much light on the screen. Furthermore the polymer fibers are less expensive and more flexible mechanically.

In the PFIP the bare fibers illuminate the reflective calibration screen. They are positioned in a ring around M2 pointing down at the eight petal M3 screen. This distance is appropriate for each N.A. 0.33 fiber to fully illuminate, and only slightly overfill, the entire diameter of the screen. From this screen roughly 1% of the light continues through the remainder of the SAC to a focus at the LRS slit plane.

3.2. Calibration Screen

The reflective calibration screen is composed of eight 0.0625 inch aluminum petals in four pairs of alternating 60/30 degree pie slices. One of the narrow petals has a circular "lollipop" on the end to mask the spherical aberration corrector (SAC) entrance aperture. It also reproduces, with reasonable fidelity, the central obstruction of

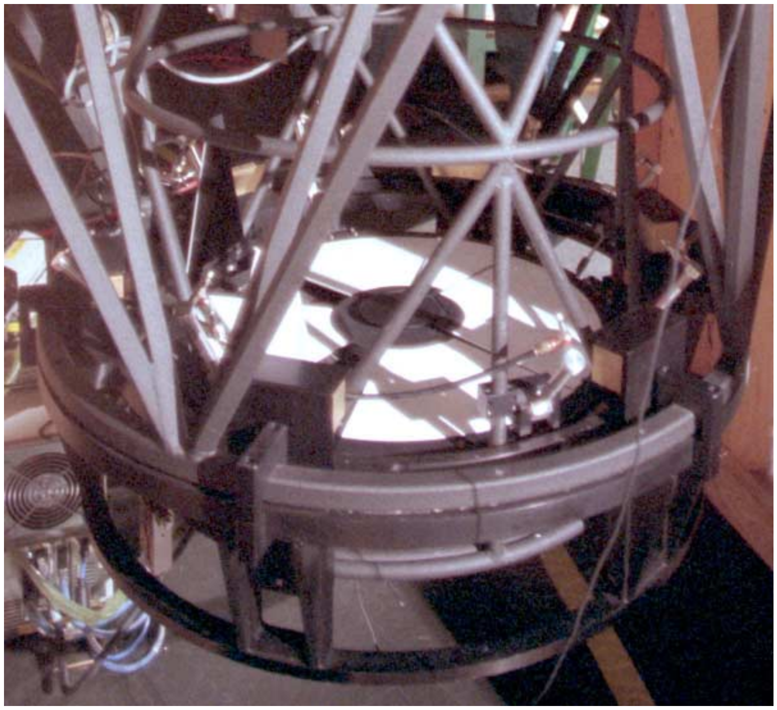

Figure 2. Photograph of the calibration screen during installation.

the telescope in the ray bundle. Reflective surfaces are coated with Labsphere Duraflect which is washable and uniformly reflective out to 1.8 μm (suitable for both LRS-J and JCAM).[1,2] Non-reflective surfaces are coated with VelBlack[3] which is a carbon fiber velvet from Energy Science Laboratories, Inc. and has a reflectance less than 0.02 out to 10 μm.

The petals are independently actuated by Bimba spring return pneumatic linear actuators. A single solenoid valve controls air to all eight cylinders, and the flow is tuned such that insertion and extraction both occur in approximately 1 s. The petals are spring balanced such that a loss of air pressure pulls them out of the beam. Due to the difficulty of welding Invar, the position of individual SAC truss elements is not precisely known. As a result, each of the six degrees of freedom for every petal is independently adjustable in a narrow range about the nominal position.

4. CONTROL ELECTRONICS

The control system is based on a Parallax BS2SX microcontroller. Though a somewhat unorthodox choice for system control, it's built in serial interfacing software considerably reduced cost and programming time. The microcontroller handles serial communication with the the two flat field constant current supplies (HP/Agilent E3634A), the lamp multiplexer/stepper motor driver (Cyberpak Co. HS20),[4] the front panel interface, and the outside world. Additionally, the BS2SX handles power supply start up and lamp warm up, and has a built in EEPROM which stores, for each lamp, appropriate flat field currents, and linear actuator positions. The control system can handle 8 multiplexed discharge lamps (one at a time), two pairs of flat field lamps (up to 150 W each), two independent hollow cathode lamps, and two linear actuators (2000 steps/inch). Most of this functionality is currently unused.

During startup the HP supplies are put into remote mode, their front panel switches are disabled, and limits are set forcing the supply into the more stable constant current mode. As each flat field lamp is turned on the current is ramped up to 10% above the normal operating current, then settled back to the appropriate level

Figure 3. SCS controller front panel. Manual override switches are housed behind the aluminum panel on the right.

(1.6 A). This causes the tungsten halogen cycle to equilibrate nearly and order of magnitude more quickly. The 10 minute warm-up we had expected and the heat output during this period caused us to consider locating shuttered light sources outside the dome. It would now be feasible to consider locating the lamps within the SAC and accepting a 1 minute warm-up loss. After warm-up current is controlled and voltage is stable to within the supply's measurement ability. Voltage is accurately measured across the bulb's terminals through a separate two wire high-impedance interface.

The Cyberpak HS-20 can power two independent stepper motors (with CY-42 Drivers) and handles signals from the Hall effect limit switches (one of which serves as a home). Additionally, the HS-20 reserves four bits (1 power, 3 select) for discharge lamp control, four bits (2 power, 2 select) for flat lamp control, and two bits for hollow cathode lamp control.

5. OPERATION/PERFORMANCE

Typical pre-reduction spectra are shown in Figures 4 and 5. Up to date line identifications with notes can be found at the SCS web page.[5,6] Other information can be found on the HET RA web page[7] by following the "Instruments," "LRS," and "Wavelength Calibration" links.

6. CONCLUSIONS/FUTURE IMPROVEMENTS

An initial design specification of the SCS was to allow calibration during HET segment alignment (stacking). This process is performed with sensors located in the center of curvature tower (CCAS) outside the telescope dome and therefore prevents us from using the traditional dome screen. It was also determined a lengthy lamp warm up procedure would be necessary for optimum stability; a procedure unsuited to the queue scheduled nature of the telescope. The improved HET now uses a segment alignment and maintenance system (SAMS) which eliminates the need for frequent trips to the CCAS, thereby giving us three possible options for the injection of calibration light: the pupil at the primary through the use of a dome screen, the pupil at M3 through the use of the current flip screen, or the caustic of the primary through some other system. The authors still feel that a dome screen is not ideal, but would revisit the relative merits of the other two systems.

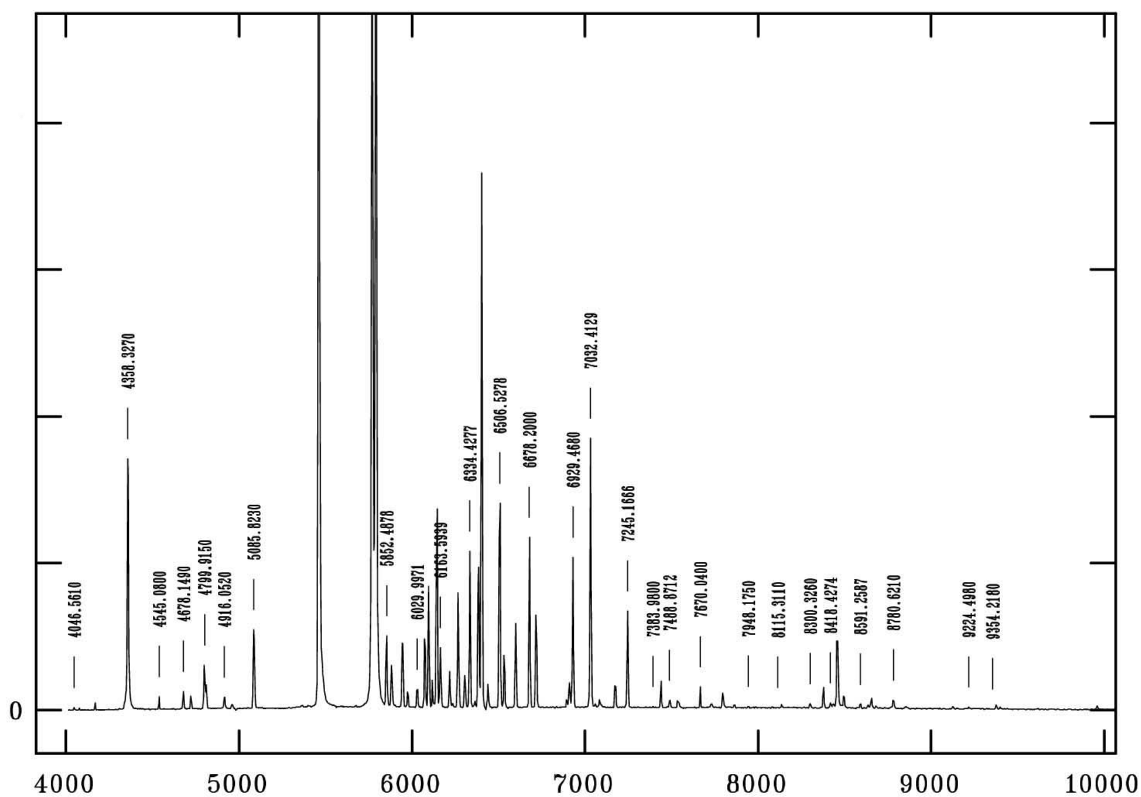

Figure 4. Reduced LRS comparison comparison spectrum (relative flux vs. wavelength in Å). This spectrum is a combination of 200 s Ne and 25 s HgCdZn exposures taken with a 0.5 arcsec pinhole and G1 (300 lines/mm). Dispersion is 4.48 Å/pix, and each vertical hash represents ∼18000 e^-. The forest of lines redward of the bright Hg doublet are due almost exclusively to Ne.

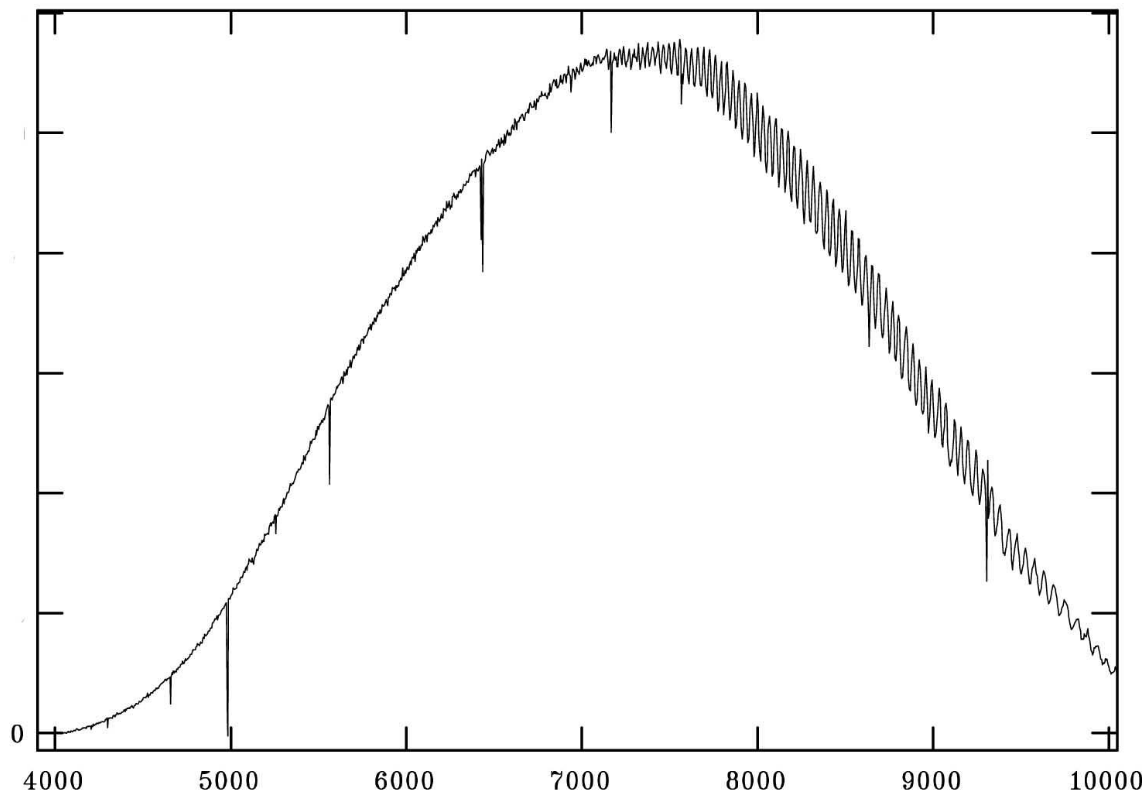

Figure 5. Reduced LRS flat field taken with the same setup as above. The fringes in the red highlight the need for a moving baffle which can mimic the pupil of the HET during a calibration frame. They are an interference effect on the CCD are are highly dependent on pupil shape. This is a 24 s exposure with 1800 e^-/division.

The difficulty of injecting enough flux into the fiber bundles was not fully appreciated early on. The flux delivered to the HRS requires integration times that are much too long to be practical, and it currently uses its own internal calibration system. Likewise, the time required to warm up the flat field lamps has been greatly reduced and it is likely we would consider locating all lamps within the spherical abberation corrector (SAC). One current idea is to use a holographic diffuser at the caustic, another is to use a ventilated diffuse illuminator with the current flip screen. If the fiber system was reconsidered with the same cost constraints, we would use a 12 fiber low-OH hexagonal pack in a single bundle, we would also significantly improve the feed optics.

The SCS has the challenge of supplying the right amount of light to instruments with flux requirements spanning a factor of 1000. Although it works exceptionally well, in its current state, for the low resolution spectrograph, some work needs to be done to make it a more suitable system for the other facility instruments. Fortunately the flip screen, control system, and lamps are ideal, and we need only to rethink the feed.

ACKNOWLEDGMENTS

Leland Engel (PSU) and Joe Macomber (Polymicro) provided significant input on the fiber issue. Leland was especially helpful in determining the minimum bend radius and characteristics of the new fiber technology we chose to use. Without the help and advice of David Doss, neither lamps nor power supplies could have been determined. Rex Barrick, Tom Brown delivered some last minute parts on very short notice. Fiber installation, which proved to be much less trivial than intended, would not have been possible without Craig Nance (Keck) and Jim Fowler. James Bryan and Marsha Wolf provided good leads and alternatives for reflecting screen material.

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