Sky Brightness at the Hobby-Eberly Telescope

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Abstract

The Hobby-Eberly Telescope (HET) at McDonald Observatory has a 9.2 m effective aperture, and has been in operation since October of 1999. The telescope is used on a cue-based system, where astronomers give observing instructions to resident astronomers at the observatory to run the telescope and take the data. One feature that would be of use to the HET astronomers is the ability to quickly calculate the sky brightness for that evening with a sample spectra. The software that accomplishes this is a combination of IRAF scripting, Python, and C.

1 First Step

The process begins with a raw, unreduced image of a low-resolution spectra taken with (insert instrument). The IRAF script takes two arguments: the file name of the image, and a bandpass (i.e. UBVRI). The IRAF script takes the image and grabs the bias and trim sections from the header with `imget`. These values are then passed to `colbias` to subtract the overscan from the image.

The `apall` routine is then used on the bias-subtracted image. `apall` is instructed to fit a single aperture to the starlight in the spectra, and to perform a sky subtraction. The sky is fit with a 3rd order Chebyshev polynomial in the region 50-200 pixels away from the starlight. The output of `apall` is a "two-layer" image. The first layer is the 1D spectrum of the star. The second layer is the 1D spectrum of the sky. `imcopy` is used to separate the images. The 1D sky spectra and the bandpass argument are then passed into the Python routine, which was made into an executable to facilitate use in the IRAF script.

2 Number Crunching

The Python script first reads the .fits file (the 1D sky spectra) and converts it into an array. A second array of equal length is formed to define the corresponding wavelengths from known values given the grism and spectrograph used. A text file containing the wavelength solution is fit with a polynomial via least-squares to form a wavelength solution as a function of pixel number. The system efficiency of the HET varies with wavelength
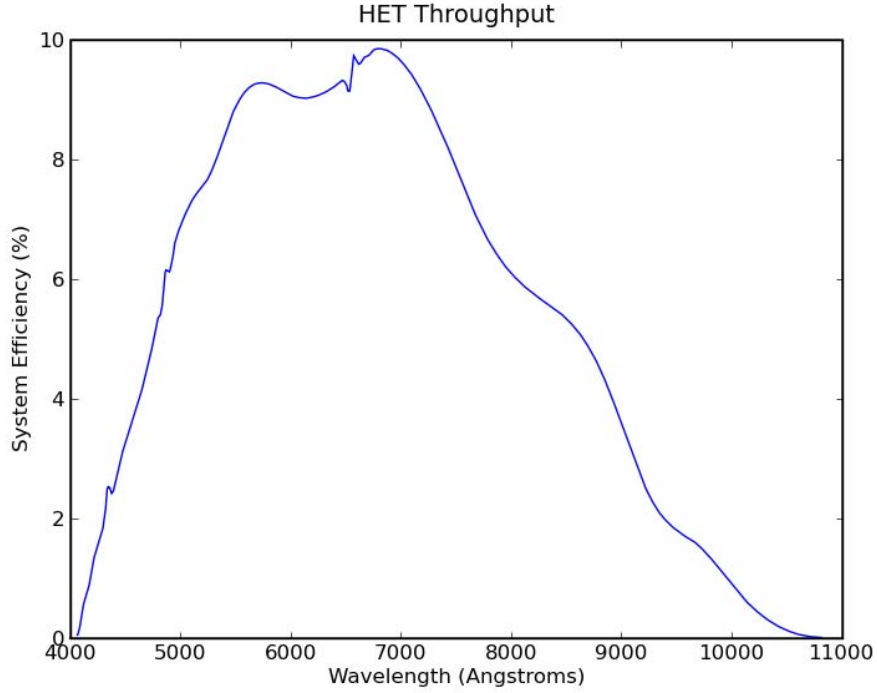
Figure 1: Throughput efficiency for the GR300 grism on the Low Resolution Spectrograph (LRS) at the HET.

(throughput efficiency), which are given as a table on the HET webpage (Figure 2). In order to determine the total energy from the photons over a certain wavelength range, the spectra values are summed over a wavelength range specified by the bandpass (Equ. 2).

$$
\begin{align}
S_1 &= \sum_{i=1}^{N} \frac{n(\lambda_i)T(\lambda_i)gch}{e_f(\lambda_i)\lambda_i} \tag{1}\\
S_2 &= \sum_{i=1}^{N} T(\lambda_i)\frac{1}{2}(\lambda_{i+1} - \lambda_{i-1})\\
E &= \frac{S_1}{S_2(1 \times 10^{10})}
\end{align}
$$

$n(\lambda)$ are the CCD counts as a function of wavelength. The code emulates Johnson-Cousins UBVRI filters by multiplying the spectra function by the response curve, $T(\lambda)$, of a chosen filter. The wavelength dependent efficiency, $e_f(\lambda)$, is produced by interpolating the throughput data from the HET website[1]. g is the CCD gain, and c and h are the speed of light and Plank's constant respectively. The integral is essentially summing the De Broglie energies at each wavlength increment $d\lambda$. So, you have the energy per photon at a

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[1]http://hydra.as.utexas.edu/?a=help&h=26

certain wavelength, mulitiplied by the number of photons given by the spectra. The spectra function, $n(\lambda)$, is not interpolated, which is fine since we are summing column by column.

At this point, we have the total energy E in the wavelength range. The expression for determining flux is given by Eq. 2.

$$F = \frac{E}{Af} \frac{1}{sa} \tag{2}$$

The fact that the flux is energy (E) over aperture area (A) is fairly straight forward. f is the fill factor for the HET. The HET's primarly mirror cannot track in azimuthally. The tracker assembly that houses the low-resolution spectrograph moves to track the target across the mirror. That being said, the aperture is defined by what the area that the tracker "sees." Sometimes, part of the aperture drifts off of the primary mirror, so you only have some fraction of the total light gathering power. A program called `docheckfill` (a C program given as the HET website) produces the fill factor given the pointing information in the image header. The fill factor is simply a percentage of the total aperture being utilized. Furthermore, the HET does not use the full area allotted to a 9.2 m aperture to begin with, since there is a 3.17 m obscuration in the center. The area of the obscuration is simply subtracted from the area of the assumed 9.2 m case. Sky brightness is expressed in units of magnitude per square arc second. So, s is the spectrograph slit width in arcseconds, and a is the summing aperture used in `apall` expressed in arcseconds.

With the flux, it is a simple matter to calculate the sky magnitude (Eq. 3).

$$m_{sky} = 2.50 \log_{10} \left(\frac{F_{sky}}{F_{Vega}} \right) + m_{Vega} \tag{3}$$

Vega is used as the standard for comparison. Vega's flux and magnitude are chosen to correspond to the appropriate passband (UVBRI) (Table 1).

Band	Flux (W/m^2)	Magnitude
U	3.886×10^{-12}	0.020
B	6.452×10^{-12}	0.024
V	3.711×10^{-12}	0.026
R	2.202×10^{-12}	0.033
I	1.093×10^{-12}	0.029

Table 1: Flux and magnitude values used for Vega [2].

3 Important Features and Use

Usage of the program is quite simple. In the IRAF `cl` environment, command "skybright file_name.fits" and the program will print the sky brightness. If you instead command "skybright file_name.fits object=yes", the program will instead compute and print the object magnitude. A sample IRAF session would look like this:

```
cl> skybright lrs731567.fits
Sky Brightness
V magnitude = 21.4856962471
R magnitude = 20.4678095181
I magnitude = 19.5688869056
```

When the program runs, it automatically prints out as many passbands as the wavelength solution for the particular grism in use will allow. For instance, for the G1 grism, only V, R, and I are available. This being said, the code can adapt to use different grisms. However, the throughput data and the wavelength solutions must be chosen to match that grism before the integration.

4   Testing

The program was tested against photometric images taken by the HET. The star fields used were NGC2264, NGC7790, NGC7006, and M92. Using `imexamine`, the flux of a few choice stars and the surrounding sky flux were recorded. The fluxes were compared to known magnitudes, and the sky magnitudes were then derived [3, 1]. These were then compared to LRS spectra with the GR300 (G1) grism in place (Table 2).

Date	Moon	V (Im.)	V (Spec.)	R (Im.)	R (Spec.)
Aug. 16 2007	10.7%	21.05 ± 0.30	21.55 ± 0.06	20.85 ± 0.15	20.87 ± 0.10
Oct. 20 2007	58.9%	19.91 ± 0.13	21.13 ± 0.11	19.76 ± 0.10	20.50 ± 0.12
Mar. 2 2008	29.0%	21.05 ± 0.05	21.34 ± 0.05	n/a	n/a
Mar. 28 2008	64.6%	21.14 ± 0.04	20.56 ± 0.76	n/a	n/a
Jul. 22 2008	75.8%	19.34 ± 0.03	19.37 ± 0.02	19.55 ± 0.14	19.27 ± 0.01

Table 2: Comparison of photometric sky brightness values with magnitudes computed via LRS spectra and the "skybright" software. The moon values were obtained from http://www.briancasey.org/artifacts/astro/moon.cgi

Overall, the values from the software seemed to produce slightly dimmer values than what the photometry showed. Additional photometric images from the 30" Telescope at McDonald Observatory were used for further testing 3. Only three images and five spectra (three for R) were available for comparison, but in contrast, they seem brighter than the 30" photometry data.

Images: V: 21.154 ± 0.091 R: 20.576 ± 0.404
Spectra: V: 20.800 ± 0.304 R: 20.188 ± 0.056

Table 3: Photometry from the 30" Telescope compared with the "skybright" software

The fact that the HET filters are a bit brighter than the results from the program may be because of a red leak within the V filter as shown in Figure 2. The program itself
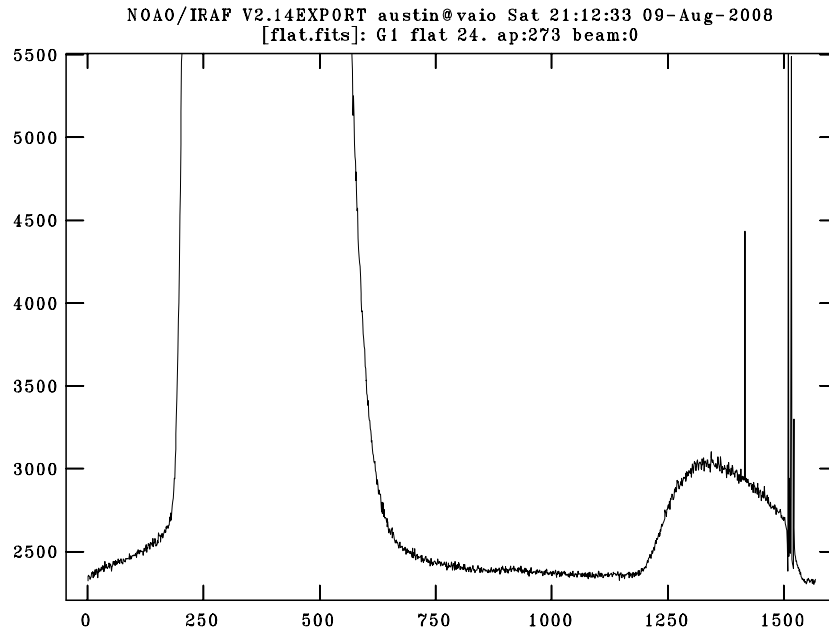
Figure 2: This is an LRS spectra with the V filter, and GR300 grism in place. The figure is zoomed in to show the red leak.

takes less than a few seconds to execute, and is not very computationally expensive. The host computer for the software requires Python 2.5 with the modules Scipy, Numpy, and PyFITS, as well as IRAF. The program has been successfully installed and run on the MCS computer at the HET for the GR300 grism. Some of the primary uses of the code will be to determine if the sky brightness meets an astronomer's science requirements for the evening, for diagnostic purposes, and to be able to track trends in sky brightness.

References

[1] C. A. CHRISTIAN, M. ADAMS, J. V. B. Video Camera/CCD Standard Stars. *Astronomical Society of the Pacific* (Apr. 1985).

[2] J. B. HOLBERG, P. B. Calibration of Synthetic Photometry Using DA White Dwarfs. *The Astronomical Journal* (2006).

[3] S. C. ODEWAHN, C. BRYJA, R. M. H. Improved CCD Standard Fields. *Astronomical Society of the Pacific* (July 1992).