Filters and Fluxes

1 Blackbody Radiation

Recall from intro astronomy that a hot dense gas, or black body radiator will radiate at all wavelengths. The shape of the curve is dependent upon the temperature, T of the substance, not the composition. There are two useful laws which describe the blackbody. **Wein's Law** incidates that the wavelength, λ of the peak radiation is inversely proportional to T:

$$\lambda_{max} = \frac{0.0029}{T}[m] \quad (1)$$

and the **Stephan Boltzmann Law** shows that the total energy produced by the object depends on the 4th power of the temperature:

$$E_{Tot} = A\sigma T^4 F = \sigma T^4 \quad (2)$$

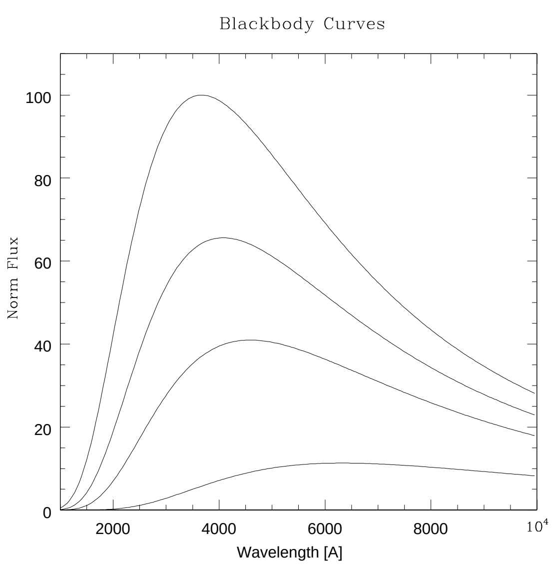

Figure 1: Blackbody radiation curves for 10^4K, 9000K, 8000K and 5800K (solar) objects.

Many people get confused about the different terms used to describe energy and radiation and use them incorrectly. Some definitions:

- **Luminosity** - (L) total energy per second emitted in all directions over all λ. We usually cannot measure L.
- **Flux** - (F) total energy per unit area per sec per unit wavelength

What we measure at the telescope is the Flux of an object. However we use filters to isolate specific wavelength ranges. Ideally filters would be pieces of glass which allow 100% of the energy through between λ_1 and λ_2 and 0% of the energy elsewhere. The manufacture of filters dictates that we don't have perfect transmission in the desired region, and often light leaks in outside of the desired region.

2 Magnitude Scales

The ancient Greeks were the first to use a "magnitude" system, listing stars that where the brightest as being of "first importance" or first magnitude, and the next brightest stars as being of second magnitude etc. It was in the 19th century that an astronomer by the name of Pogson quantified this scale. The sensitivity of the eye is logarithmic. Pogson noted that the difference of 1 mag was equal to a brightness difference of 2.512, and Δm = 5 was a brightness difference of 100.

$$m = -2.5log_{10}(B) + c \quad (3)$$

where B is the brightness (or flux through a filter) and c is a constant. The constant is necessary because we a priori do not know how to translate the "counts" we get through an instrument or brightness estimate naked eye to an absolute scale, without measuring something of a known flux.

3 Colors and Filters

What is the color of a star? When we see it naked eye, we are noting at what wavelength λ_{max} falls from Wein's law above. We accomplish this astronomically by using filters which isolate specific λ intervals. There are a large number of filter systems in use today, ranging from wide band which lets in a lot of light to very narrow band filters which lets in very little light. One of the common broad band systems is the Kron-Cousins system. The specifications are listed in the table below.

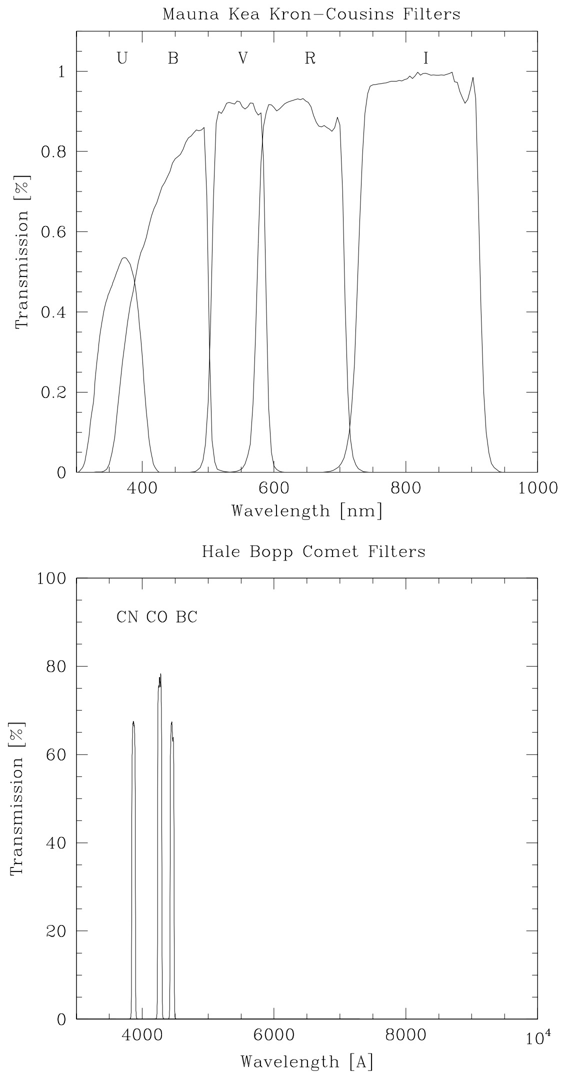

Figure 2: Transmission curves of the UBVRI filters for Mauna Kea – Kron-Cousins system [top], and some narrowband comet filters [bottom].

Usually filters are characterized by the "effective wavelength", λ_{eff} which is essentially the middle of the filter, and the "width". Because the filters don't pass through light with a perfectly rectangular form, instead of saying the width, we use a more specific measure of the full width of the filter at half the maximum transmission. This is called the FWHM.

Colors of stars or other objects are measured by getting magnitude differences through different filters. For example, Fig. 3 shows the spectrum of the sun, a 5800K blackbody superimposed on the filter transmission curves for the U and R filters.

Filter	λ_{eff}	$\Delta\lambda$
U	3600	1000
B	4380	1077
V	5450	836
R	6460	1245
I	8260	1888

There is not much flux coming through the U filter, but a lot of flux through the R filter. There would be even more flux through the V filter. If we had a much cooler star, there might be very little flux in the U and B filters but a lot in the I filter.

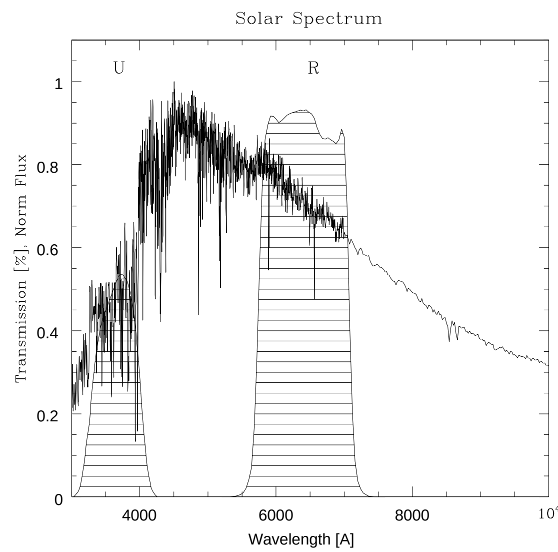

Figure 3: Normalized spectrum of the sun, with the transmission curves of the U and the R filters plotted.

The color is represented as a difference in magnitudes. For example the B-V color is given by:

$$\Delta m = m_B - m_V = B - V = +2.5 log_{10}(\frac{F_V}{F_B}) \tag{4}$$

The more negative the value for colors, the hotter the star is. Effectively the color is a measure of the slope of the blackbody curve. The colors of the sun in the Kron-Cousins system are:

In reality, a lot of things besides just the filter transmission curve determine how much light

Bands	Color
B-V	0.62
V-R	0.36
R-I	0.28

from the star actually makes it to the detector and is counted. The detector is not equally sensitive at all λ. The detector quantum efficiency, DQE is a term which relates how efficient the detector is in detecting all the light. Ideal would be 100%, or a DQE of 1. Fig. 4 shows the quantum efficiency of one of the primary CCD detectors at the University of Hawaii 2.2m telescope on Mauna Kea. As you can see, they are not very efficient in the blue.

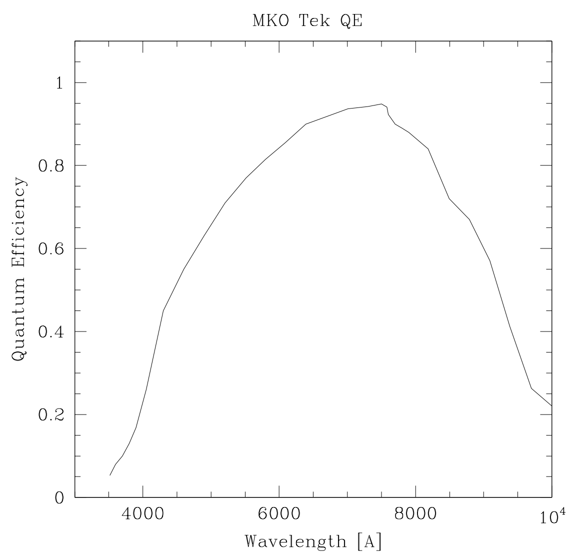

Figure 4: DQE of the Tek 1024 CCD detector for the UH 2.2m telescope on Mauna Kea.

In addition to the non-ideal filter transmission, and efficiency of the detector, each lens in the astronomical instrument absorbs a little light (generally non uniformly with λ), and each reflection off of a mirror results in light loss (sometimes more than usual if the mirror is dirty). In addition to these problems, however, the sky itself, while appearing dark, is not. This is because molecules in the atmosphere during the day are exposed to sunlight and it takes awhile for the excited electrons to drop back down and re-radiate their light at night.

As can been seen in Fig. 5, the sky is at its darkest in the blue wavelengths, and gets progressively worse because of molecular emissions as we move toward the red and infrared wavelengths. The really strong green line at $5577\AA$ is from an oxygen transition.

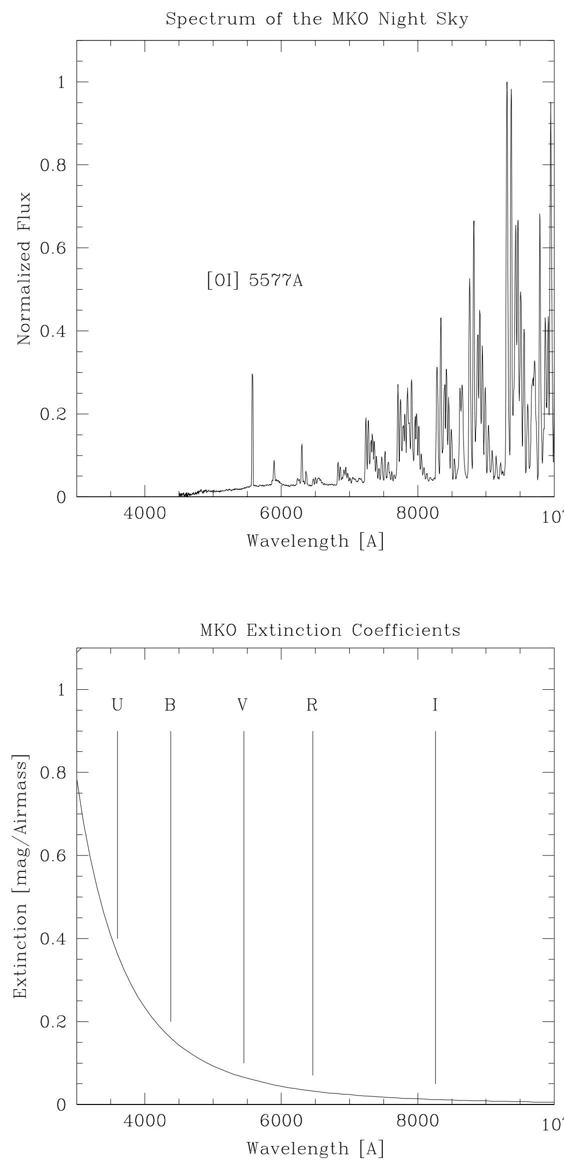

Figure 5: Brightness of the night sky from Mauna Kea. (b) Extinction coefficients for Mauna Kea.

Finally, in addition to the sky being bright, the dust and gases in the atmosphere both scatter the incoming light and absorb it. The more atmosphere the star light passes through the more light is removed. This is called **extinction**. Light interacts best with things that are comparable to it in scale, and the particles in the atmosphere are best matched in scale to the U and B wavelength regions – and extinction is particularly bad here.

Fig. 6 shows how much light in mags / airmass (where 1 airmass is the amount of atmosphere light passes through if it comes in perpendicular – *i.e* from the zenith).

4 Julian Dates

The Julian Day calendar begins on 4713 BC on January 1 at noon, and each day is numbered consecutively to the present. (see handout on the Julian day system for a discussion of its origins). This system is extremely useful in astronomy because it allows (unlike the normal calendar system) us to easily compare observations taken at different times separated by long intervals to search for changes.

The JD calendar begins at noon, so we don't have the inconvenient problem of having the date change during the middle of our observing night.

Below are some examples using the JD table passed out in class. Remember this JD table has subtracted off 2,450,000 days just to make tabulating it easier. Since the JD begins at noon, but our normal days begin at midnight, the JD for any start of the calendar day will be x,xxx,xxx.5. The numbers in this table have had the 0.5 rounded up (just to make it fit on the page).

4.1 Example 1

The JD for January 24, 2003

```
  2,450,000.0
     +2,640.0
        +24.0
         -0.5
-------------
 =2,452,663.5
```

4.2 Example 2

What is the JD at 3:30pm on January 24, 2003. First we convert 3:30pm to a 24 hour system = 15:30. Then we have to convert to Universal time, since the JD is based on Greenwich England. To convert to Greenwich Mean Time (GMT):

$$GMT = HST + 10hr \qquad (5)$$

Thus, 15:30 is 25:30, which is into the next day. So this is really 01:30 on January 25, 2003. We have to convert to fractional hours, and the fraction of the day: 1:30 = 1.5 hrs. Fraction of the day is 1.5/24 = 0.0625. So taking our result from above which was Jan 24, 2003 (let's assume it was GMT), we have to add 1.0625 days

```
  2,452,663.5000
        +1.0625
----------------
 =2,452,664.5625
```

4.3 Example 3

The sunset in Honolulu on January 24 is at 6:17pm HST. What is the JD?

- Convert to UT: 6:17 = 18:17 = 28:17, or 4:17 on Jan 25.
- Compute the fractional day: 4:17 = 4.28333, f = 4.28333/24 = 0.178472
- Add to the JD for the start of 1/25/03

```
  2,450,000.0000
     +2,640.0000
        +25.1785
         -0.5000
----------------
 =2,452,664.6784
```