In [1]:
```
import numpy as np
```

1. The SDSS ugriz photometric system is an ABNU system. The SDSS g bandpass has an effective wavelength of about 4800 A. What is the monochromatic flux at 4800 A of an object with g=12, in BOTH $F\nu$ and $F\lambda$ units?

In [2]:
```
# energy flux is 12 mag fainter than reference flux. For Fnu
fnu=10**(-0.4*12)*3.63e-20
print('Fnu: {:.2e}'.format(fnu))
# Flambda is Fnu * c / lambda**2
c=3.e10
lam=4800e-8
flam=fnu*c/lam**2/1.e8
print('Flambda: {:.2e}'.format(flam))
```

```
Fnu: 5.75e-25
Flambda: 7.49e-14
```

2. Imagine you are observing an unresolved binary star system where one star has V=16 and B-V=0.5 and the companion has V=18 and B-V=0.8. What will you observe for the V and B-V of the combined system?

In [3]:
```
v1=16
v2=18
b1=16+0.5
b2=18+0.8
# combined mag by taking -2.5 log (F1 + F2). photometric zeropoint doesn't matter: it cancels
v=-2.5*np.log10(10**(-0.4*v1)+10**(-0.4*v2))
b=-2.5*np.log10(10**(-0.4*b1)+10**(-0.4*b2))
print('V: {:8.2f}\nB: {:8.2f}\nB-V: {:8.2f}\n'.format(v,b, b-v))
```

```
V:    15.84
B:    16.38
B-V:     0.54
```

3. The limit of most ground-based high precision photometry is about 1 millimag = 0.001 mag. What fractional uncertainty in photon flux does this correspond to? What S/N?

From propagation of uncertainty,

$$\sigma_m = 1.086 \frac{\sigma_F}{F}$$

In [4]:
```
frac=(.001/1.086)
sn=1/frac
print('fractional uncertainty: {:.3f}\nS/N: {:.2f}'.format(frac,sn))
```

```
fractional uncertainty: 0.001
S/N: 1086.00
```

4. If you want to measure a source to S/N=1000, how many photons do you need to collect? Do you think you need to include background and/or readout noise in your calculation? Why or why not?

In signal limited regime, $S/N = \sqrt(S)$, $S = 1000000$ photons. To get this many photons, almost certainly a bright source, i.e. much brighter than background, and also certainly much more than any readout noise! So signal-limited is appropriate.

In [5]:
```
print(1000**2)
```

```
1000000
```

5. If you're looking at star with V=10 with a 1m diameter telescope in a rectangular bandpass of width 1000 A, centered at 5500 A, how long do you have to observe to reach S/N=1000? You should make reasonable estimates about atmospheric transmission, telescope throughput, filter throughput, detector sensitivity, etc. and state what they are.

In [6]:

```
lam=np.arange(5000,6000)
at=0.8 # atmospheric transmission
tt=0.8 # telescope transmission
ft=0.8 # filter transmission
dt=0.8 # detector sensitivity
h=6.63e-27
c=3.e10
# photon flux:
f=10**(-0.4*10)*5500e-8/h/c*3.63e-9
# photons = area * flux * efficiency * delta(lambda)
cnts=np.pi*50**2*f*at*tt*ft*dt*1000
print('photons/s: ', cnts)
cnts=np.pi*50**2*f*at*tt*ft*dt*np.ones(lam.size)
print('photons/s: ',cnts.sum())
# exptime is desired counts / photon flux per s
print('exptime: {:.2f}'.format(1e6/cnts.sum()))
```

```
photons/s:  322912.13104481815
photons/s:  322912.13104481815
exptime: 3.10
```

6a. You are taking a spectrum of a faint star and determine that in a 3600s exposure, you will get 100 photons/pixel from the star and 500 photons/pixel from the background. Your detector has a readout noise of 5 electrons/pixel. If you take a single exposure, what will the S/N per pixel be?
6b. Given the information in (a), what do you think about the advisability of splitting your exposure into several pieces? Explain your reasoning, giving pros and cons of splitting.

per pixel:

$$\frac{S}{N} = \frac{S}{\sqrt{S + B + \sigma_{rn}^2}}$$

In [7]:

```
sn=100/np.sqrt(100+500+25)
print(sn)
```

```
4.0
```

Readout noise corresponds to 25 electrons, as compared with 600 photons for the Poisson statistics. So readout noise is relatively small.

If we were to allow it to be 10% of total, then can't go less than 250 counts in S+B, i.e., no less than ~30 minutes. So caan split into two. Advantage of splitting is, e.g., for cosmic ray rejection.

7. In orbit, the "background" is not significantly darker than it is from the ground in the optical from a good dark moonless site, because it comes from zodiacal light. Nonetheless, the Hubble Space Telescope is able to see stars significantly fainter than can be seen from the ground with a comparable sized telescope. Explain how this can be.

Images are sharper because there is no atmospheric seeing (only diffraction). So to integrate over a point source, you can use a much smaller aperture (smaller solid angle) so you include less background. Since the images are so much sharper, this is very significant for faint objects.

8. Imagine you measure the brightness of a star to an accuracy of 10%. You then repeat the measurement and average the two to get a brightness estimate. What is the expected uncertainty of the average brightness?

Uncertainty goes down by $\sqrt{N}$, i.e. $\sqrt{2}$. This is true for fractional uncertainty because for two measurements, S_A and S_B, each with uncertainty $0.1S$, the uncertainty of the mean is:

$$\sigma^2_{<x>} = \frac{1}{2^2}(2(.01S^2))$$

$$\frac{\sigma_{<x>}}{S} = \sqrt{\frac{.02}{4}} = 0.0707$$

In [8]:
```
.1/np.sqrt(2)
```

Out[8]:
```
0.07071067811865475
```

9. Imagine you want to observe the Orion nebula at RA=5h30, DEC=-5 degrees, with the 3.5m from APO (latitude~33 degrees). You want to use the telescope efficiently, i.e. spend all of your time on target. You can request either one full night, or two half nights. Which would you prefer, and why? If you prefer a full night, what month would you like it in, and why? If you prefer two half nights, what month (or months) would you like them in, and do you want A or B halves?

At declination -5, can observe at airmass<2 for only about 6 hours. Optimum time at midnight is December, when nights are long, so can't use full night because the nights are much longer than 6 hours. Instead, prefer half nights, either B halves in Oct/Nov, or A halves in Jan/Feb, because you want Orion to transit in the middle of the half you are observing in.

In [ ]: