Astro 500 Problem Set #2

Use definitions and numbers given in the class notes.

1. Dragonfly is a novel telescope made up of 8 × 6in camera lenses used in parallel to feed 8 CCDs. Each lens points at the same part of the sky, covering 2.6° x 1.9°. Each CCD pixel spans 2.8 arcsec on the sky. The hallmark of this optical system is that the optical coatings of the lenses are exquisite; there are 8 surfaces, each with only 0.5% losses per surface. The filter transmission in the *V*-band is 90%. The CCD detector QE is 55% in the *V*-band, and has a read-noise of 10 e- rms. Assume the sky foreground is all in a uniform continuum, and that there is no moon.

   a) Write down an equation that accounts for the total system efficiency as a product of atmospheric absorption, CCD quantum efficiency, and the number of optical surfaces with various fractional losses per surface.

   b) What is the limiting exposure time to remain sky-limited in the *V*-band ? (Ignore atmospheric losses.)

   c) What is the narrowest bandpass ($\Delta\lambda/\lambda$) that could be used for a single, sky-limited exposure over a one hour exposure?

2. SALT has an 11m entrance aperture (pupil). The SALT corrected focal plane is fed at *f*/4.3. The RSS collimator accepts this f/4.3 beam. However, the *f*-ratio of the RSS camera, which reimages the telescope focal plane onto the CCD detector, is about f/1.9. The detector has 15-micron (μm) pixels.

   a) How large of an area (mm^2) is 1 arcsec^2 at the telescope focal plane?

   b) Calculate how the RSS change in *f*-ratio (from collimator to camera) magnifies or de-magnifies the focal scale at the RSS detector. Draw a picture if you need to. How large (in mm) is 1 arcsec at the detector? How many pixels are there in 1 arcsec^2?

3. Now calculate the effective collecting area of the SALT telescope and RSS spectrograph in Fabry-Perot mode. For purposes here, consider each Fabry-Perot etalon pair to be a tunable filter. The effective collecting area is the collecting area (in m^2) for the equivalent system with no losses of any kind (including atmosphere). Assume you are observing in a wavelength range in the *V*-band with clear skies. Here are some other relevant facts:

   - The SALT entrance aperture is under-filled. This means part of the entrance aperture is not covered by mirrors and does not collect light. A fraction of the aperture is also obstructed by the tracker and payload. The filling factor, including both of these effects is 69.19% when the payload is centered on the primary, i.e., only 69.19% of the entrance aperture collects light that is deliverable to the focal plane.
   - SALT has a primary mirror coated with aluminum, with 75% reflectivity (the mirrors are dirty), and four mirror surfaces in the spherical aberration corrector, each with coatings achieving 80% reflectivity (the coatings have degraded).
   - The RSS spectrograph has 23 air-glass surfaces, each coated to transmit 96% of the light at 550nm, a CCD with a quantum efficiency of 85% at 550 nm, etalon pairs with 4 surfaces each transmitting 97% of the light, and an order-blocking filter with 90% transmission.

4. Here you will make observations with SALT and RSS in the *V*-band region at some spectral resolution $R = \lambda/\Delta\lambda$ defined by the etalon(s). Assume that the detector read-noise is 2.5 e^- per unbinned pixel, and that the payload is centered on the primary. For R=12500, two etalon pairs are needed.

a) How does resolution (R) relate to the band-pass, in nepers?

b) Write down an expression relating the number of detected photo-electrons as a function of the sky brightness (broad-band magnitudes), the band-width (nepers) used to make the observations, the total effective collecting area, and the exposure time.

c) Calculate the number of photons arcsec^{-2} second^{-1} as a function of resolution (R) for dark-sky conditions (no moon) assuming similar sky brightness as given in the notes.

d) Use the 10% rule (shot-noise from sky-photons should be 10 times larger than detector noise) to calculate the exposure times to be sky-photon limited for R = 500, 2500, 12500 observations with RSS on SALT. Assume you bin the detector 2x2 before reading it out.

e) If the seeing is typically 2.5 arcsec FWHM, what binning could you use and remain critically sampled (2 pixels ~ FWHM), and by what factor would this reduce your exposure times in (d)?