AS.171.618 Observational astronomy / Zakamska / Homework 3 / March 13, 2020

Problem 1 (3 points): observing proposals. I have reviewed the proposal drafts. Those of you who have some idea about the expected fluxes plugged these fluxes into ETC and got some reasonable exposure times (it's a good idea to check the literature and see whether this kind of science is done with these kinds of exposure times!).

But what I think is really difficult is the connection between objects and proposed observations. When we write a paper, we describe observations, then we describe measurements from these observations, then we describe what kinds of hypotheses / models we test with these measurements, then we describe what we learned from this modeling, then finally we talk about implications for the field: what did we learn that's new and interesting and important?

Proposals are challenging because you have to have this entire arc in your mind and start from the end of this process. So the proposals will go like this:

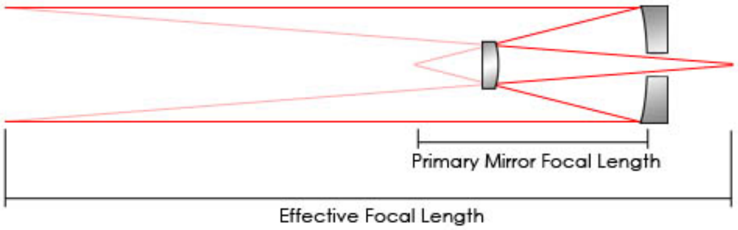
Science justification
-- BLAH is a major problem in astrophysics / here are some super-interesting related topics [some of you are well-versed in this from reading papers and said the relevant buzz words!]
-- BLAH are models / hypotheses that are interesting but untested
-- Here we propose such and such observations. Using these observations we will obtain such and such measurements.
-- Using these measurements, we will test hypothesis 1, hypothesis 2 and hypothesis 3.

Experimental design
-- Target selection [many people are struggling with explaining why these particular objects are the ideal objects to test blah hypothesis]
-- Why that many targets?
-- Instrument configuration: why this telescope? why this instrument? why this filter? why this grating? why this grating setting?
-- Signal-to-noise -- how do we predict the expected fluxes? From first principles? From expectations from the literature? What is the requisite weather / why? [Those of you who had some estimated fluxes found this easier.]

The goal by March 13 is to have something in each of these paragraphs, and have half of the paragraphs more-or-less complete. You will have ~10 references. Submit your updated draft.

Problem 2. Observing a nebula (2 points for each bullet point).

Consider a telescope with a primary mirror diameter of 2.0m. The focal length of the primary is 6.0m and that of the Cassegrain secondary is −3.0m. The two mirrors are separated by 4.0m.



Above: *How a Cassegrain telescope creates a long effective focal length in a short tube. The actual length of the telescope is barely longer than the separation between the two mirrors.*

(a) What is the effective focal length of the telescope in its Cassegrain configuration?
(b) What is the scale at the primary focus and Cassegrain focus? (The 'scale' tells you how many arcsec apart are two stars whose images are separated by 1 mm in the focal plane; the scale is therefore measured in "/mm. This value is relevant for calculating how big of a detector you need to install and how big its pixels need to be to probe a given angular separation on the sky.)
(c) For on axis rays, how large must the secondary be to intercept all the light reflected from the primary?

We want to use this telescope to observe the [OIII]5007 Angstrom emission line from a round, uniformly emitting planetary nebula which subtends an area of 10 arcsec^2. The [OIII]5007 flux, above the atmosphere, of this nebula is 10^{-15} erg cm^{-2} s^{-1}, and we will observe it at primary focus using a narrow band filter having a transmission curve that is flat topped with peak transmission of 80% centered at 5000A and resolution R=100, and essentially zero transmission beyond this width. Assume that the atmosphere's transmission is 88% at zenith, the reflectivity of the mirrors are 89% each, and that the brightness of the sky is 1.5×10^{-17} erg cm^{-2} s^{-1} A^{-1} arcsec^{-2} at 5000 Angstroms. The source is observed at a zenith angle of 45 degrees, with a CCD having pixels 15μm on a side, a quantum efficiency of 70% at λ=5000 A, 15e- read noise (per pixel), and a dark current of 0.03 e- s^{-1} pixel^{-1}.

(d) Rank the efficiency losses in the system due to atmosphere, telescope mirror, filter and detector (from largest loss of photons to smallest). Calculate the effective area of the entire system. (The effective area is the area of an ideal loss-less system that collects the same number of photons per second from the object as the real system.)
(e) Calculate the rate at which photons from the object are detected per pixel and the rate that photons from the sky are detected per pixel.
(f) Consider the pixels that are detecting the light from the nebula. How do the values for the total read noise, dark-noise, sky-noise, and object-noise depend on the time of integration t? How does the total noise depend on t? (Remember that independent errors are combined in quadrature.)
(g) How long must we integrate to reach a signal-to-noise ratio of 3? How long must we integrate to reach a signal-to-noise ratio of 10? Which source of noise is the most important in these two cases?