AY 260 Winter 2025
Week 5, Spectrographs
Due Feb 18

In week 3 you designed a reimager for one of three different telescopes. Each had a 150 mm diameter beam. You calculated that they had the following parameters:

On the Keck telescope, primary mirror diameter 10 m, focal ratio f/15:

- Collimator focal length 2250 mm
- Camera Focal length 115 mm

On the Shane telescope, primary mirror diameter 3m, focal ratio f/17:

- Collimator focal length 2550 mm
- Camera Focal length 387 mm

On the Magellan Clay telescope, primary mirror diameter 6.54 m, focal ratio f/5:

- Collimator focal length 750 mm
- Camera Focal length 178 mm

For the telescope you worked on in class (**not** all three), turn your reimager into a spectrograph by putting a grating in the collimated beam. Just consider objects at the center of the field of view. You want a resolving power of about 2500 at the H-α line, 6563 Angstroms.

A digression: why 2500? The inverse of the expression for resolving power is

$$\frac{\Delta\lambda}{\lambda}$$

and that is also

$$\frac{\Delta v}{c}$$

where Δv is the Doppler broadened width of an emission or absorption line that you can resolve. H-α is an important line because it is usually easy to detect. The Milky Way is an average mass galaxy, and its rotation velocity is about 220 km/s. A pressure-supported galaxy (i.e., an elliptical with no star formation) of the same mass as the Milky Way would have a line of sight velocity dispersion of about $\frac{220}{\sqrt{(3)}} = 127$ km/s. Computing $c/127$ and rounding up to a tidy number (since you almost never have the ideal grating to give you an exact resolving power) is 2500. So if you can get a resolving power of about 2500, you can measure the velocity dispersion of average-mass galaxies (at low redshift).

Back to practical matters. You have the following choices for the ruling density of your hypothetical grating:

- 400 l/mm
- 700 l/mm
- 1200 l/mm

1) What are the blaze angles you need to have peak efficiency at H-α for each grating?

2) Which grating gives you a resolving power close to 2500 at H-α?

3) What parameter of your spectrograph can you change to double the resolving power with the 400 l/mm grating? Your options are the beam size, camera focal length and collimator focal length.

4) If you do make that change, what resolution do you get?

5) The design requirements[1] for your reimager were that an object that measures 1 arcsecond FWHM on the sky have an image size at the focus of the camera of 2 15 micron pixels. For your spectrograph, that 1 arcsecond is the width of your entrance slit.

How do the other parameters of your spectrograph have to change to meet the requirement after you make the change in problem 3?

6) What is the f/ratio of your camera after making the change in problem 3?

7) Assuming your spectrograph is a cylinder, what is the length and the volume of your spectrograph? First comput it in the original design, and then again after you made the change in problem 3. Assuming all spectrographs are a constant uniform density, how would the masses compare?

8) What is most challenging about making the change in problem 3? Is it the optical design? Why or why not?

[1]you are doing instrumentation if you have design requirements!