Astro 121, Fall 2005
Week 9 (November 2)

Topic: Spectroscopy
Break: Andy (the following week: Micah)

Reading for next week: As with the previous topic (telescopes), there's a lot of highly detailed material out there. Each of the following references has some useful material, but also may have the potential to be confusing. Here is a range of references, in roughly decreasing order of priority; look at several of these, but don't feel compelled to read all of them. You may also find it useful to consult a basic optics book (or the *Diffraction Gratings Handbook*) to remind yourself about multiple-slit diffraction.

- Berry and Burnell, Chapter 9. This is a pretty gentle start, giving some of the basic terminology and an overview of several kinds of spectrographs.
- McLean, *Electronic Imaging in Astronomy,* pp. 76–80. This is the opposite of Berry and Burnell—just dives right in with some of the highlights, presented fairly quickly without a lot of extra information. The level of math here is more like what we're interested in, though.
- Walker, *Astronomical Observations*. pp. 151–169
- Kitchin, *Astrophysical Techniques*, pp. 301–320; pp. 334–355. Don't get bogged down in the math, especially in the first section. However, this does give an idea of how the way the various orders appear on the chip is a function of grating properties. The first section defines some terms, though we don't care (much) about prisms.
- Palmer, *Diffraction Gratings Handbook*, Chapter 2. This book is a free publication by a leading manufacturer of diffraction gratings. It has a nice overview of the basic physics of diffraction gratings.
- Howell, *Handbook of CCD Astronomy*. Chapter 6. Below, I haven't asked you explicitly about detector and data-reduction aspects of spectroscopy, but read over this chapter to get a feel for them, and we'll talk about them in seminar if we have time.
- Roth, *Compendium of Practical Astronomy, Volume 1*, pp. 300–313

Important concepts:

For each of these topics, **I'd like you to be prepared to give a short (~ 5–10 minute) explanation in seminar** (using the board or document camera for diagrams or derivations as you need to). If you want to pre-arrange among yourselves who will give the formal presentation on each bit, that's OK with me, but as usual **each of you should work all of these out, and I will ask you to hand in written explanations**. Be prepared to explain all of the following:

1. *Parts of a spectrograph*. What is the role of each of the following elements of a spectrograph? Telescope, slit, collimator, disperser (grating or prism), camera, and detector. (The first and last should be obvious, but they are there to give the complete list in order.) Roughly diagram the path

of two different wavelengths of light through the spectrograph, showing how the light passes through each element of the spectrograph.

2. *Spectrograph efficiency*. Walker arrives at an expression for the efficiency of a spectrograph fairly quickly (in just two pages) because he glosses over a lot of hidden assumptions about how a spectrograph is put together. If you can understand those assumptions, then you understand spectrographs fairly well, but it takes a bit of work. So: derive equations 5.3, 5,4, and 5.6 in Walker, and give a diagram with your derivation. Some hints:

   a. Ignore the r factor (given in Eq. 5.5); also note that Walker's k variable is simply the pixel size of the detector.

   b. Think about where the collimator must be placed, and what diameter it must have, if it is to be able to intercept light from the entire primary mirror. Use this to derive a relationship between $f/_{\text{telescope}}$ and $f/_{\text{Collimator}}$. (Note that Walker's notation is different here.)

   c. Think about what the diameter of the camera mirror must be if it is to intercept all of the light from the collimator. Use this to derive a relationship between the diameter of the collimator and the diameter of the camera.

   d. Now you have all the pieces you need to get Walker's equations. But it still takes some thinking. Feel free to come see me if you're stuck. (This is true with any problem, of course, but with this one in particular I think there's a bit more likelihood of getting stuck…)

3. *The grating equation*. Derive the grating equation, $m\lambda = d(\sin i + \sin \theta)$ where i is the angle of incidence and θ is the angle of reflection, d is the spacing between grooves in the diffraction grating, λ is the wavelength of light, and m is an integer. (Do this for the two-slit transmission case, which is a little easier to think about than a reflection grating, though the latter are what is generally used in astronomy.) Note that the angles are defined so that all angles on one side of the normal to the grating are positive, and all angles on the other side are negative. Why isn't the angle of all of the outgoing light from the grating slits equal to the angle of the incoming light?

4. *Spectral resolution* How is it defined? What factors does it depend on? (It's not only the properties of the grating or prism, though those do matter.) In practice, how could you measure it? What is the equivalent of Nyquist sampling (discussed last week) when we're talking about spectra rather than images?

5. *The slit*. If you took a spectrum of a star without using a slit in your spectrograph, what would that spectrum look like? (To help with seeing this, please sketch the resulting spectrum using colored pencils.) What sets the spectral resolution of such a spectrum? You might look on-line to see if you can find an example of a slitless spectrum of an extended object—I know Chandra has taken some of supernova remnants. What is "long-slit" spectroscopy, and what is it used for? Find some examples (e.g. in ADS) of long-slit spectra.

6. *Blazing*. What does it mean to blaze a grating? Why is it done? (Kitchin Figures 4.1.10 and 4.1.11 and the accompanying discussion are helpful here.) [There's not a great explanation of this in any of our readings, so I'll take the responsibility of explaining this one; just look over Kitchin (and possibly McLean) to understand the terminology.]

7. *Objective prism spectroscopy* What is objective prism spectroscopy? What are its advantages and disadvantages? Find an example of an objective prism image/spectrum.

8. *Echelle spectroscopy*. What is an echelle spectrograph? What are the basic optical elements in an echelle spectrograph, and how do they differ from a simple single-order spectrograph? What are the advantages and disadvantages of an echelle? (Whoever does this as a presentation should talk to me; I have some example echelle spectra you could look at.)

9. *Integral field spectroscopy*. What is integral field spectroscopy? How does it work? There's no good information on this in any of our reading, but you can find information on existing integral field units (IFUs) on-line; I'll put a few links on the course web page, though you can certainly find more on your own.