Astro 121, Spring 2014
Week 8 (March 20)

Topic: Telescopes and imaging
Break: Sara

Topics: This week we'll discuss telescopes: telescope designs, aberrations, image scale in the focal plane, angular resolution.

Reading for next week: There's a lot of highly detailed material out there; I've tried to come up with some things that give you a flavor of the complexities involved while still being accessible without a lot of prior work in optics. I'd suggest reading things in the order given here:

- Chromey, Chapter 5, through Section 5.4. Skim through Sections 5.1–5.2, which should be mostly review if you've had some optics. Also just skim through Section 5.5 to get a sense of the kinds of aberrations that exist.

- Chromey, Chapter 6, Sections 6.1 and 6.2. In both this chapter and the previous one, don't get bogged down in the lens/mirror equations, as we aren't going to be doing a lot of quantitative optics calculations (aside from diffraction limit and focal plane scale).

- Birney et al., Chapter 6. This is a less technical discussion, with clearer diagrams of different telescope designs.

- Berry and Burnell, Section 1.5. This discusses image sampling and includes the important Nyquist theorem. Note: Berry and Burnell call the focal ratio *N;* Birney calls this f/, and Chromey calls it $\mathfrak{R}$. I will refer to it as f/, since that seems the most common usage (although admittedly one has to be careful writing this in mathematical expressions given the slash).

- Kitchin, *Astrophysical Techniques*. Just look at the figures on pp. 72–76 to get a feel for the different types of aberrations.

- Roth, *Compendium of Practical Astronomy, Volume 1*. Look at the images of spherical aberration on p. 72, coma on p. 74, and note the Dawes criterion (not covered elsewhere) on pp. 104–105.

Problems

Note: several of these problems require extra information. I strongly encourage you to dig around on observatory web sites to get extra detail that will give you some insight into the characteristics of the telescopes discussed here.

1. The *plate scale* (a term from photographic days, but still used) or *image scale* of a telescope/camera system is the amount of angle on the sky that is imaged onto a particular linear size on the detector, e.g. a number of arcsec/mm.

    a. *Derive* (don't just look up) an expression for plate scale in units of arcsec/mm given the telescope diameter D in meters and telescope focal ratio f/. (The symbol f/ is often used for the ratio f/D; Chromey calls it $\mathfrak{R}$. For example a telescope with f/D = 8, i.e. focal length 8 times the primary mirror diameter, is referred to as an "f/8 telescope.") Show a diagram illustrating your derivation; it's fine to represent a telescope as a lens rather than a mirror – it's much simpler that way.

b. Convert this to units of arcsec/pixel, given a pixel size p in microns (which are the units usually used for CCD pixels). That is, come up with an equation for the plate scale in arcsec/pixel, given f/ and p in microns.

c. Use your expressions for a. and b. to determine these quantities, as well as the total field of view, for the van de Kamp telescope (f/7.8, 24-inch) and CCD camera (Apogee U16M), and for our rooftop 8" telescopes (Meade LX200GPS telescopes, with SBIG ST-10XME CCD camera). How well do these setups sample the seeing here (3" typical)?

d. Why do we almost always bin our CCD observations 2x2 when using the PvdK telescope? Can you think of any circumstances when it would be advantageous *not* to bin?

e. A telescope with a large f/ is referred to as a "slow" design, while a telescope with a small f/ is referred to as a "fast" design. Why? When might you want to use each kind? For this question, hold the aperture diameter fixed when comparing faster vs. slower designs.

f. Why is it hard to build a large-aperture, slow telescope?

2. Look at some CCD images taken with the van de Kamp Observatory telescope. Do you see any evidence of any of the aberrations shown in Fig. 5.34 in Chromey? Explain how you judged this.

3. The Hubble Space Telescope has had several cameras: WFPC/2 (for optical, replaced by ACS) and NICMOS (for near infrared); most recently, the Wide Field Camera 3 (WFC3) was installed, which works at both visible and infrared wavelengths.

   a. Calculate the diffraction limit of HST at 550 nm and at 2 microns.

   b. For each of these four cameras (WFPC/2, NICMOS, ACS, WFC3), calculate whether stellar images should be undersampled, critically sampled, or oversampled.

   c. Find HST images of stars (especially brighter stars) taken with the various cameras, and see if you can relate them to your answers to part b. What would you expect stellar images to look like, if taken with a telescope in space?

4. At what wavelengths is the Keck telescope limited by diffraction rather than atmospheric seeing?

5. Chromey, problem 5.8, on observing Mars with different telescopes.

6. Up until about the 1960s, all major telescopes were equatorial mounts. Now many are alt-az mounts. Why do you think this is?

7. Alt-az telescopes have a hard time observing objects that are within a few degrees of the zenith (and thus will sometimes be limited in their control software from pointing there at all). Why? (Hint: think about the telescope tracking as the object moves.) See also Chromey problem 6.1, which is essentially the same question.

8. Calculate the length of the Sproul refractor. Why do you think it has such a focal length? What is the focal length of the van de Kamp telescope? How does this compare to its overall length?

9. Rules of thumb, round 3. (Time to find that third hand!) The diffraction limit of a telescope is typically written as $1.22\ \lambda/D$. But that's in radians, which aren't very practical. Show that the diffraction limit in arcseconds is roughly $1/4\ \lambda/D$ where λ is in microns and D is in meters.

10. Chromey 6.9, on the detection threshold for HST vs JWST.