

Astro 121, Fall 2005
Week 7 (October 19)

Topic: Telescopes and imaging
Break: Steve

Topics: Next 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:

- Bradt, *Astronomy Methods*, Chapter 5, through Section 5.4. (We'll cover the material in Section 5.5, on adaptive optics, later in the semester.) You can skip pp. 106–109, on non-focusing systems.
- Berry and Burnell, Chapter 1, skipping Section 1.3. This is a nice overview of the basic principles of image formation without getting too technical. Note that their notation is somewhat non-standard: telescope aperture diameter is more commonly written as D (they use A) and focal ratio is commonly written as $f/$ (or Bradt's \mathfrak{F}); Berry and Burnell use N , inexplicably. Though some of this material overlaps with Bradt, take particular note of Section 1.5, which discusses image sampling and include the important Nyquist theorem.
- Karttunen et al. *Fundamental Astronomy*, Section 3.2. This gives a good basic overview of some basic optics, and types of telescopes. There's a fair amount of overlap with Bradt, but Karttunen has more pictures (so it's worth just browsing through it to look at the figures and captions), plus it has more discussion of telescope mountings and refractors vs. reflectors.
- Kitchin, *Astrophysical Techniques*, pp. 41–56, pp. 66–84. You can gloss over the math; just get a feel for the concepts, especially the different types of aberrations.
- Roth, *Compendium of Practical Astronomy, Volume 1*, not required, but some nice images of spherical aberration on p. 72, coma on p. 74, and especially mention of the Dawes criterion (not covered elsewhere) on pp. 104–105. (Note who the translators of this book are!)

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 an expression for plate scale in units of arcsec/mm given the telescope diameter D in meters and telescope focal ratio $f/$.
 - b. Convert this to units of arcsec/pixel, given a pixel size p in microns (which are the units usually used for CCD pixels).
 - c. Use your expressions for a. and b. to determine these quantities, as well as the total field of view, for the Sproul refractor and CCD camera, 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, 1" occasionally)?
 - d. 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? Why is it hard to build a large, slow telescope?
 - e. Design the telescope for the new science center! Budget constraints limit us to no more than 24" diameter. What should the telescope $f/$ ratio be? (Typical values are about $f/7$ to $f/10$ for this type of telescope. What are the tradeoffs here?) Given your choice of $f/$ ratio, what size pixels should the chosen CCD camera have?
2. The Hubble Space Telescope has had several cameras: WFPC/2 (for optical, now replaced by ACS) and NICMOS (for near infrared).
 - a. Calculate the diffraction limit of HST with WFPC/2 and ACS (at 550 nm), and NICMOS (at 2 microns).
 - b. Find both WFPC/2 and NICMOS images on the web that contain bright stars. (Be sure that the WFPC/2 images come from *after* the servicing mission that corrected the spherical aberration!) Why do they look so different? (You may want to work out some of the quantities from problem 1 to help you think about this.) Also take a look at some ACS images and compare them to WFPC/2 images. Looking at images of stars (i.e. point sources) will work best for this problem; extended objects won't tell you as much.
 3. At what wavelengths is the Keck telescope limited by diffraction rather than atmospheric seeing?
 4. Up until about the 1960s, all major telescopes were equatorial mounts. Now most are alt-az mounts. Why do you think this is?
 5. 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. Be quantitative if you can.)
 6. 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.
 7. Higher spatial resolution obviously improves your ability to separate closely-spaced objects. Less obviously, it also improves your ability to detect very faint objects. Explain why. Be at least somewhat quantitative in your answer. (Think about signal-to-noise ratios.) To see this in action, search the web for images of the Galactic Center taken with and without adaptive optics.