**Lecture 2: telescopes**

1. Purpose of telescopes.
   1. **What are three major purposes of a telescope?**
      1. To increase collecting area
      2. To magnify an image
      3. To connect to a detector that can integrate over time
   2. Magnitudes
      1. Let's talk now about how astronomers quantify brightness and color.
      2. Brightness of stars described in a system of magnitudes.
      3. Estimated by eye originally by the ancient Greek astronomers, such as Hipparcos.
      4. System was extended to faint stars (visible through telescopes).
      5. Quantified in modern form in the 1850s, by Pogson (who studied asteroids)
      6. A “logarithmic” scale.
      7. Brightness is often referred to as “flux”
      8. magnitude = -2.5 log flux + constant
      9. So bigger the number, the fainter the object
      10. brightest star mag = -1.5 (Sirius)
      11. faintest stars visible in dark site 5-6
      12. Note that it depends on how good your eyes are! The main issue is the sky background; if you have poor eyesight it blurs the stars a bit and they are harder to distinguish from the sky.
      13. each 2.5 in magnitude is factor of 10
      14. So difference between Sirius and faintest visible is 7.5 or 1000X!
      15. telescopes make it possible to see much fainter objects
      16. In a dark site, a pair of binoculars can get you to 10-12 or more
      17. There are a number of 4-m telescopes that can get to 25 ish! 10000X fainter than you can see!
      18. HST, the 2.5m in space, can get close to 30
      19. **How much fainter is 30 than you can see with your eye (assuming it is 5 mag)?**
2. Collecting area
   1. **What is area of a circle?**
   2. You can think of a light as a beam of particles, called photons, coming from the source to you.
   3. As light comes towards a circle like this, how much will be collected by the smaller circle relative to the bigger circle? **More or less?** Bigger circle is 100 times radius of small one -- **how much more?**
   4. The pupil of your eye is a few mm across
   5. How much light you collect is related to diameter of pupil
   6. That’s why your pupils dilate in the dark, narrow in bright light
   7. One point of a telescope or binoculars is to simply increase this total collecting area
   8. As we’ll see in a bit, also we can design a telescope to magnify, and to connect to a detector to collect more light over time.
3. Telescopes need to focus
   1. But you can’t just build a big bucket and put a detector at the bottom
   2. Light from a star in a particular direction comes in parallel rays
   3. A design like this would mix this star’s light with that from nearby stars
   4. Instead we need a device that takes light from a range of directions and “sorts” it
   5. This is what we mean by “focusing” a telescope
4. How do eyes focus
   1. Our eye’s of course do this -- how do they work?
   2. Well, imagine that you had no lens in your eye: just a pupil and a retina
   3. **What would be the problem with this set up?**
   4. This would allow you to distinguish directions but in a very fuzzy way
   5. This is what’s known as a “pinhole camera”
   6. It doesn’t distinguish nearby directions very well
   7. Instead, the lens in your eye bends the light in such a way as to focus it on your retina
   8. It works through “refraction”, which causes light to bend when it goes from glass to air
   9. The bending occurs because the speed of the light changes
5. Refracting telescopes
   1. The first telescopes worked according to the same principle
   2. Lenses were invented for the purposes of glasses in the Netherlands
   3. Hans Lippershey, a spectacle maker, used this principle to design a telescope for seeing at a distance; applied for patent in Netherlands in 1608 (but not sure he was the first to build it)
   4. Galileo’s contribution was to start using it the next year to look at the night sky
   5. Basic idea of this design is to collect light, focus it, let it diverge, and then re-"collimate" it into parallel rays that enter the eye: objective collects more light than your pupil AND the set up changes small angles to big ones.
   6. **What does this set up do to the orientation of the image as you perceive it?** It flips it.
   7. Binoculars work pretty much the same way, but of course with both eyes; two important parameters for binoculars: radius of lenses and magnification
6. Refracting telescopes
   1. Refracting telescopes were the standard way to build a telescope up until about 1900
   2. The largest ones reached about 1m in diameter
   3. But: very hard to cast 1 meter sized glass lens
   4. Focal lengths get very long (20 meters for Yerkes!)
   5. Chromatic aberration: blue and red light focus differently in refractor
7. Reflecting telescopes
   1. For that reason, almost all modern telescopes (and the ones we’ll use in this course) are “reflecting” telescopes
   2. Easier to design with shorter focal lengths
   3. Easier to cast: don’t need to be solid chunk of glass, just a surface
   4. No chromatic aberration
   5. Most basic reflecting telescope is a parabolic dish
   6. Light from a very distant source is focused at the focal plane
   7. The first telescopes you’ll use in this course (the Meades) are “Cassegraine” design
   8. Hole cut out of primary, secondary mirror added
   9. Lots of variations: e.g. the “Dobsonians” you’ll use are Newtonian design (b)
   10. Don’t have time to discuss, but there are LOTS of optical considerations here!
8. Eyepieces
   1. A key issue here is the role of the eyepiece
   2. You don’t want to put your eye at the focal plane of a telescope
   3. Because your eye is trying to focus the light itself
   4. The eyepiece takes the light after it starts diverging from the focal plane
   5. And it makes the rays from each directional parallel again
   6. Same principle for refracting and reflecting telescopes
   7. Then your eye can interpret parallel rays the way it normally does
   8. But! The angular separation between two sets of rays is INCREASED
   9. This is what is known as magnification
   10. Basically, your eyes usually work across a “field of view” of 45-60 deg
   11. A telescope + eyepiece takes 1 deg or so FOV and expands it to that angular scale
   12. So you see things “zoomed in”
   13. This is the second major thing a telescope gives you (in addition to collecting area)
   14. The magnification value is given by the ratio of the telescope focal length to the eyepiece focal length: f\_o/f\_e. Thus a longer eyepiece will give you less magnification.
   15. This is an important element of observing: you always want to start with a longer eyepiece to get a big field of view to help find your object, then if necessary move to a shorter eyepiece for a more magnified view
   16. As an example: a 2m focal length telescope and a 40 mm eyepiece. **What is magnification and FOV?** m = 2000 mm / 40 mm = 50X, or about 1 deg FOV
9. Equatorial telescopes
   1. The first kind of telescopes we will use in class are “equatorial” telescopes.
   2. They are designed to naturally rotate in the same manner the Earth does, at same rate
   3. **How long will it take for an equatorial telescope to turn all the way around?**
   4. This means that they rotate once per (siderial) day (or every 23h 56m)
   5. Once they have their axis aligned, and are “tracking”, if you point to an object, it will stay at the center of your field of view! very convenient and easy
10. Alt-Az telescopes
    1. The second kind of telescope we will use in class are “alt-az” telescopes
    2. These give you control over altitude and azimuth
    3. Easier to design, more intuitive to use (at first)
    4. Harder to set up to track (and requires computer to do calculations)
    5. Classic version, which we will use, is the “Dobsonian”
11. Devices:
    1. **Why do we put detectors on the back of telescopes instead of just looking through them?** Exposure time, and doing quantitative analysis
    2. In the old days we used photographic plates: like film
    3. very low efficiency: 5% or so
    4. Your eye is close to 100% efficient in detecting photons!
    5. Hard to convert data into format automatically analyzed by computers
    6. Since late 90s we have used digital devices: 90% efficient
    7. Easily imported into a computer for automatic analysis
12. Colors
    1. Remember light can be broken up into wavelengths, that correspond to colors
    2. "Detectors" on your retina are rod and cone cells
    3. Most sensitive are rods
    4. Cone cells are sensitive to three sets of wavelengths, but less sensitive; so for faint objects your sense of color is diminished.
    5. between 400 and 700 or so nanometers (wavelength of light is small)
    6. This is how you tell wavelength apart; your brain evaluates the ratios of responses between these cones; e.g. in a rainbow you see blue give way to green give way to red in this set of ratios
    7. It is also why there are three primary colors; with red green and blue added you can mimic any set of ratios for any wavelength; and some ratios that don't correspond to a single wavelength of light and so don't appear in the rainbow, like brown.
    8. In astronomical instruments, a similar strategy is used with filters to create "blue" or "red" images. When you see RGB computer images, they are synthesized from these "multiband" images.
    9. We can take the magnitudes measured in different bands, and subtract them. This is like a ratio of fluxes. It tells us the colors of stars and galaxies. There are red stars and blue stars!
13. What are the telescopes that exist?
    1. Refracting telescopes: mostly used for amateurs and planetary photography (technical reason: no diffracting spikes)
    2. Small reflecting telescopes like we will use and are common among amateur astronomers; only rarely used in professional astronomy
    3. Range of sizes of professional reflecting telescopes, from 1-m to 10-m
    4. You want them to be in dry, dark, empty places: Chile, Hawaii, SW US
    5. But, the atmosphere still blurs the light, and blocks UV and IR
    6. Motivates space telescopes like Hubble: very SHARP images;
14. Next time: orbit and rotation of the Earth and how it affects our observations.