Lecture 6: Stellar Distances and Brightness
Sections 19.1-19.3 in book

Key Ideas about Distances
Distances are the most important and most difficult quantity to measure in astronomy.
Method of Trigonometric parallaxes
direct geometric distance method
Units of distance
parsec (parallax arcsecond)
light year

Why Are Distances Important?
They are necessary for measuring
Energy emitted by a object (that is, converting brightness to luminosity)
Masses of objects from their orbital motions
True motion of objects through space
Physical sizes of objects
But distances are hard to measure. For the stars, we resort to using GEOMETRY.

Method of Trigonometric Parallax
Relies on apparent shift in position of a nearby stars against the background of distant stars and galaxies.
p=parallax angle.

Parallax decreases with distance

Closer stars have larger parallaxes

Distant stars have smaller parallaxes

Stellar Parallaxes

All stellar parallaxes are smaller than 1 arcsecond.
The nearest star: Proxima Centauri
    Parallax of p=0.772 arcsec

First parallax observed in 1837 by Bessel for the star 61 Cygni

Use photography or digital imaging today.

1 arcsec=1/1,296,000 of a circle and is the angular size of a dime at 2 miles or a hair width from 60 feet.

Parallax Formula

\[ d = \frac{1}{p} \]

p=parallax angle in \textit{arcseconds}
d=distance in \textit{parsecs}
Parallax Second = Parsec (pc)

The parsec (pc) is a fundamental distance unit in Astronomy
“A star with a parallax of 1 arcsecond has a distance of 1 parsec”

1 pc is equivalent to:
206,265 AU
3.26 Light years
3.085x10^{13} km

Light Year (ly)

The light year (ly) is an alternative unit of distance
“1 light year is the distance traveled by light in one year”

1 ly is equivalent to
0.31 pc
63,270 AU

Examples:
α Centauri has a parallax of p=0.742 arcsec. Derive the distance.

A more distant star has a parallax of p=0.02 arcsec. Derive the distance.

Limitations:
If stars are too far away, the parallax will be too small to measure accurately
The smallest parallax measureable from the ground is about 0.01 arcsec
Measure distances out to ~100 pc
Get 10% distances only to a few parsecs
But there are only a few hundred stars this close, so the errors are much bigger for most stars.
Blurring caused by the atmosphere is the main reason for the limit from the ground.
From space:

Hipparcos Satellite
- Errors in parallaxes of 0.001 arcseconds
- Parallaxes of 100,000 stars
- Good distances out to 1000 pc

GAIA Satellite
- Positions and motions for about 1 billion stars
- Parallaxes for > 200 million stars
- Precision of 10 microarcseconds
- Reliable distances out to 10,000 pc away (includes the Galactic Center at about 8000 pc away).

When we know the distances to the stars, we can see the constellations as the three dimensional objects they actually are. Example: Orion.

Other Ways of Measuring Distances
They exist! (which is good, since we can’t measure parallaxes for that many stars, and certainly not for stars outside the Milky Way)
But they are indirect, and rely on assumptions such as:
- This star has the same luminosity as the Sun
- This star has the luminosity given by a model
We will return to this in much more detail when we start talking about galaxies.

Stellar Brightness
Key Ideas

Luminosity of a star:
- Total energy output
- Independent of distance

Apparent Brightness of a star depends on
- Distance
- Luminosity

Photometry
How “Bright” is a Star?

**Intrinsic Luminosity**
Measures the Total Energy Output per second by the star in Watts
*Distance independent*

**Apparent Brightness:**
Measures how bright the star *appears to be* as seen from a distance
Depends on the *distance* to the star

**Inverse Square Law of Brightness**
Consequence of geometry as the light rays spread out from the source at the center.
(See Figure 19-4)

\[ B \propto \frac{1}{d^2} \]

The apparent brightness of a source is inversely proportional to the square of its distance from you.

**Implications**
For a light source of a given Luminosity

Closer=Brighter
    2x closer=4x brighter
Further=Fainter
    2x further=4x fainter

**Apparent Brightness of Stars**

The *apparent brightness* of stars is what we can measure

How bright any given star will appear depends on 2 things:
    How bright it is physically (*Luminosity*)
    How far away it is (*Distance*)

Related through the inverse square law

\[ B = \frac{L}{4\pi d^2} \]

At a particular luminosity, the more distant an object is, the fainter its apparent brightness becomes as the square of the distance.
Does a star look “bright” because
   it is intrinsically very luminous?
   it is intrinsically faint but very nearby?

To know for sure you must know either
   the distance to the star, or
   some other, distance independent property of the star that clues you in about
   its intrinsic brightness

Measuring Apparent Brightness

The measurement of apparent brightness is called *Photometry*
Two ways to express apparent brightness:
   as Stellar Magnitudes
   as Absolute Fluxes (energy/second/area)
Both are used interchangeably.

Flux Photometry
Count the photons from a star using a light-sensitive detector:
   Photographic Plate (1880s-1960s)
   Photoelectric Photometer (photomultiplier tube ) (1930s-1990s)
   Solid State Detectors (photodiodes or CCD) (1990s-present)

Calibrate the detector by observing “standard stars” of known brightness

Measuring Luminosity

To measure a star’s luminosity to need two measurements: the apparent brightness and the distance

\[ L = 4\pi d^2 B \]

The biggest source of uncertainty is in measuring the distance to a star.

Practical Issues
We can measure the apparent brightnesses of many millions of stars. But only have good distances (parallaxes) for only about 100,000 stars. Therefore only that number have *direct* estimates of their luminosities. Since luminosity depends on
distance squared, small errors in distance are effectively doubled (a 10% distance error gives a 20% luminosity error)

Example Problem

If the Sun quadrupled its mass, what would the circular speed of the Earth need to be to stay in orbit at its present radius (pick the closest answer)?

(a) It would need to be 2 x slower
(b) It would need to be 2 x faster
(c) It would need to be 4 x slower
(d) It would need to be 4 x faster