## 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.


Distant Stars
$\mathrm{p}=$ 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 $\mathrm{p}=0.772$ 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

$d=\frac{1}{p}$
$\mathrm{p}=$ parallax angle in arcseconds
$\mathrm{d}=$ distance in 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
$3.085 \times 10^{13} \mathrm{~km}$

## 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:
$\alpha$ Centauri has a parallax of $\mathrm{p}=0.742$ arcsec. Derive the distance.

A more distant star has a parallax of $\mathrm{p}=0.02$ 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 $\sim 100 \mathrm{pc}$
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 $10,000 \mathrm{pc}$ 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

