The Stars

Background & History

The Celestial Sphere: <u>Fixed</u> Stars and the Luminaries

The Appearance of Stars on the Sky

Brightness and Brightness Variations

- Atmospheric Effects: "Twinkling"
- Variable Stars & Eclipsing Binaries

Color and Brightness

- Temperature, Color, and Human Vision

The Stars in Space

Pythagoras (~ 550 BCE) through Ptolemy (~140 CE) and Copernicus (~1500 CE):

- Stars <u>on</u> the Celestial Sphere

Thomas Digges (1546-1595)

- Stars <u>in</u> Space
- The Sun as a Star

The Stars: Demographics

Geometry & Kinematics

- Locating Stars: Direction & Distance
- Stellar Motions: Proper Motions & Radial Velocities
  - (Changing direction & Distance)
- Distributions: Multiple Stars, Groups, Clusters, ...
  - Democritus: Nebulae and the Milky Way

Photometry

- Apparent Brightness & Luminosity
  - The Inverse-Square Law for Light
  - Star distances
- Color & Temperature
  - Wien's Law
- Spectroscopy
  - Temperature & Composition
  - Kinematics (The Doppler Effect)

Physical Properties of Stars

What are they?

Luminosity & Temperature (and Size)

Size & Shape

Mass & Composition

Internal Structure & Age

Some Other Questions

How do stars form?

Why do they do that?

How is this related to planets?

How do stars work?

What makes the Sun shine?

How do stars age and die?

Do they do that too?

Do stellar populations evolve?

If so, how and why?

The Distances of Stars

(a.k.a., “Parallaxes”)

This is the starting point for understanding the properties of stars, stellar processes - and the structure of the universe.

Methods

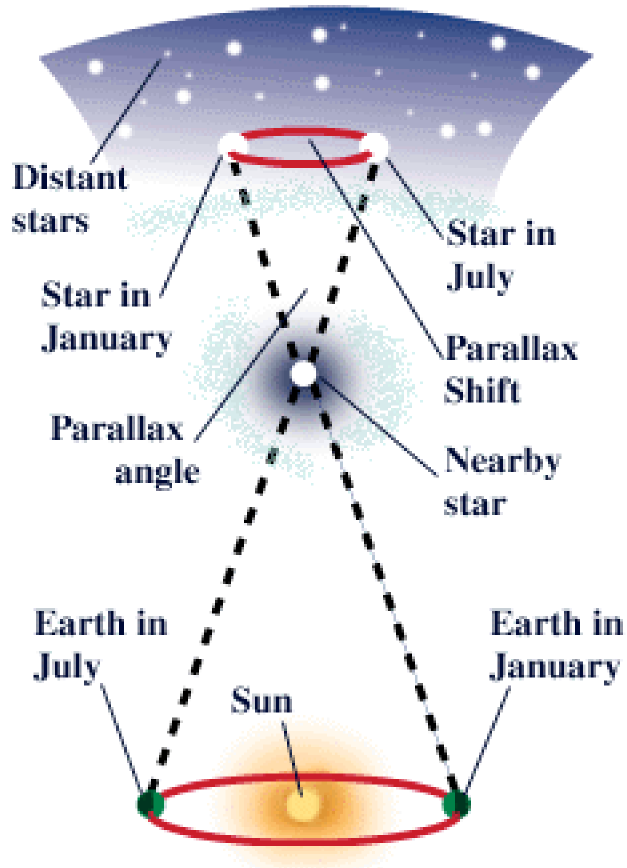
Trigonometric Parallaxes: Triangulation
Photometric Parallaxes: The Inverse-Square Law
and

Moving Group Parallaxes: Size & Distance
Dynamic Parallaxes: Binary Stars
also

Statistical Parallaxes: Stellar Groupings
Indirect Methods: Pulsating Stars

Trigonometric Parallaxes

(The most basic method: Aristotle's Stellar Parallax!)



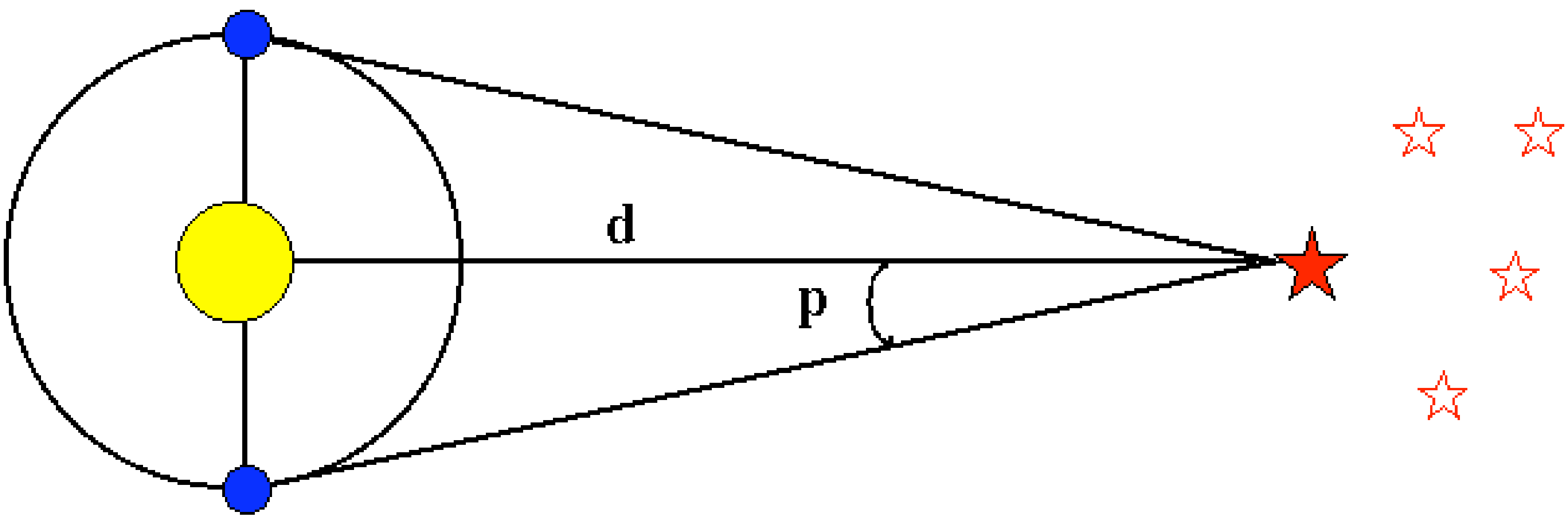
Parallactic ellipse has semimajor axis **p**(in radians) **= a/d**
where a is the Earth's orbital size and d is the star's distance.

The Parsec

For a parallax angle measured in in arc-seconds (“) and a distance measured in parsecs (pc):

$$d(pc) = 1/p(“)$$

1 parsec = 206,265 astronomical units = 3.09 x 10^{13} kilometers



Notes

- First successful measurement of a parallax was of 61 Cygni by Bessel (1838)
- The largest measured stellar parallax, that of α *Centauri*, is 0.75” (d = 1.33 pc)
- **<u>Limited to nearer stars</u> (atmospheric effects and telescope limitations).**

Photometric Parallaxes

Based on the Inverse-Square Law for Light

$$F = L/4\pi d^2$$

If the luminosity L is known, a measurement of the apparent brightness F then allows the distance d to be calculated.

The luminosity L can sometimes be inferred from other observable properties of the star such as its color or the appearance of its spectrum.

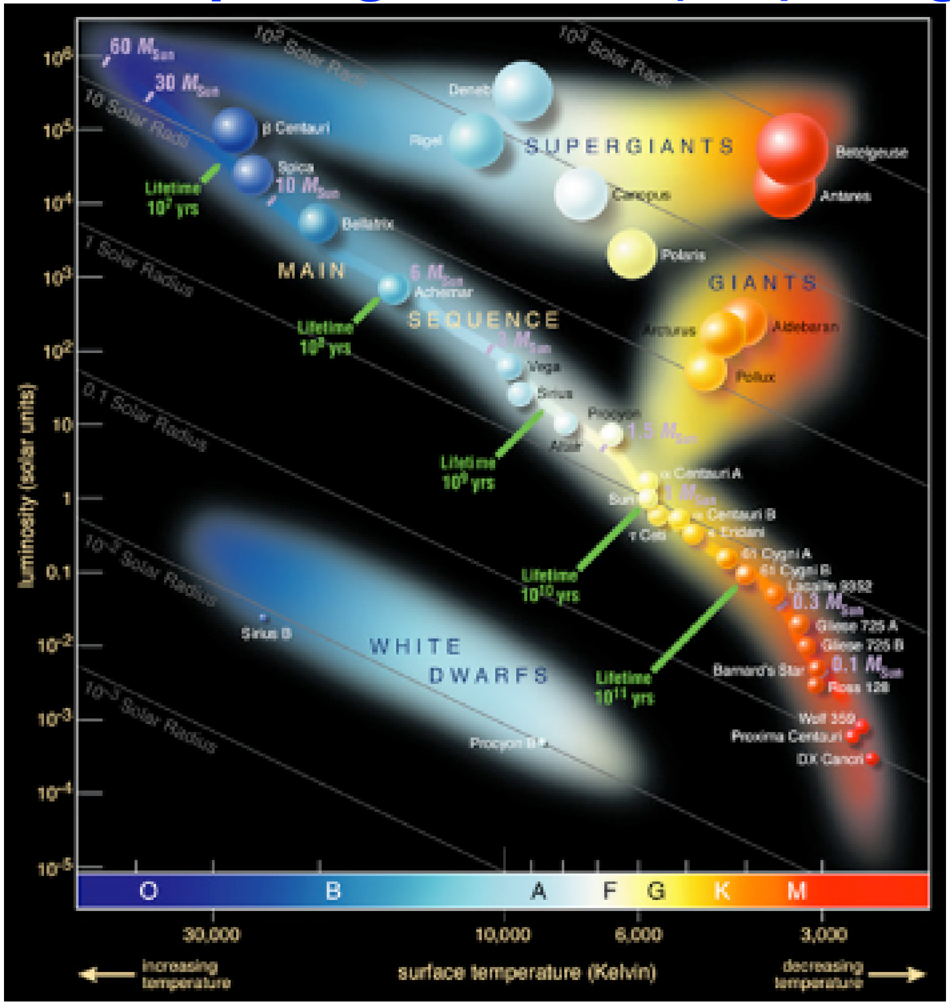
The connection between luminosity and color (or spectrum) can be "calibrated" using stars with trigonometric parallaxes.

Notes

- Again, determining d requires knowledge of the intrinsic luminosity of the star.
- Corrections for effects of interstellar extinction are sometimes necessary
- Otherwise, one is limited in application only by the brightness and resolution.

Stellar Luminosities and Colors

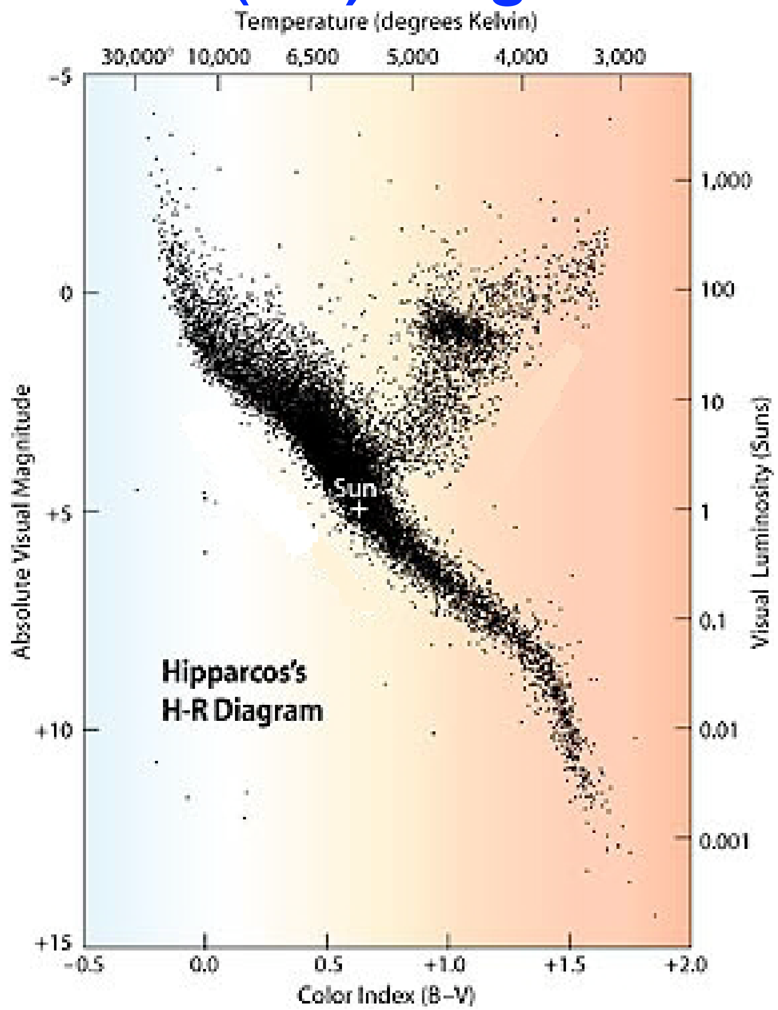
The Hertzsprung-Russell (HR) Diagram



A star's location is determined by its Mass, Composition, and Age.

Stellar Luminosities and Colors

The Hertzsprung-Russell (HR) Diagram for Hipparchos Stars*



Stars whose distances are known from trigonometric parallaxes.

Moving Group (Cluster) Parallaxes

Any moving object will appear to change in apparent size (θ) if its distance (d) changes. The relation is:

$$\frac{\text{Change in Size } (\Delta\theta)}{\text{Size } (\theta)} = -\frac{\text{Change in Distance } (\Delta d)}{\text{Distance } (d)}$$

For a star cluster
(Lots of stars at once!)

If we can measure both its apparent size (θ) and the change in its apparent size ($\Delta\theta$) over some time interval, (Δt), and

If we can measure the (common) radial velocity (v_r) of the stars in cluster.

Then the change in distance is then just $\Delta d = v_r \cdot \Delta t$, and we can calculate the distance from $d = \theta \cdot v_r \cdot \Delta t / \Delta\theta$

Example:

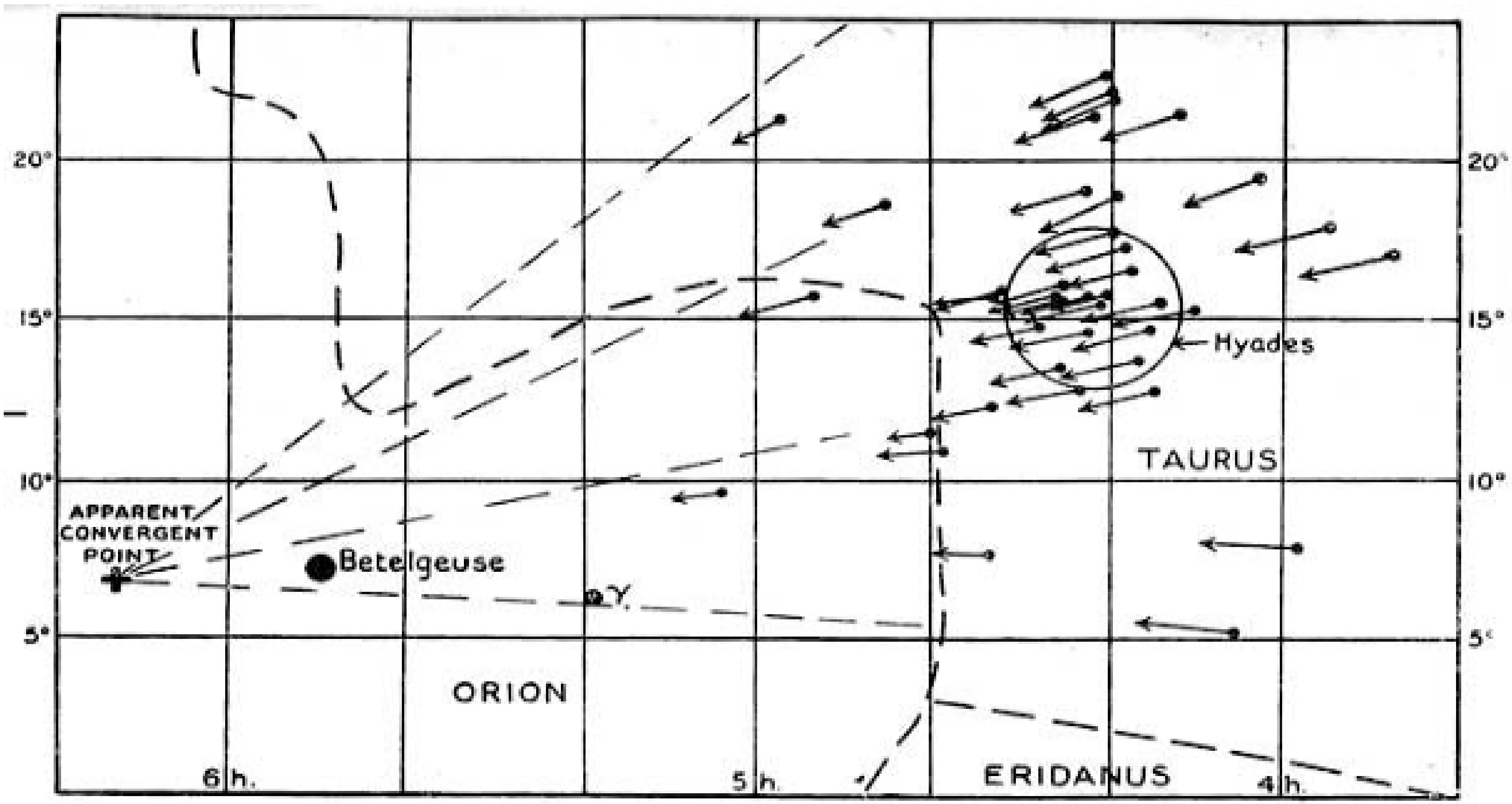
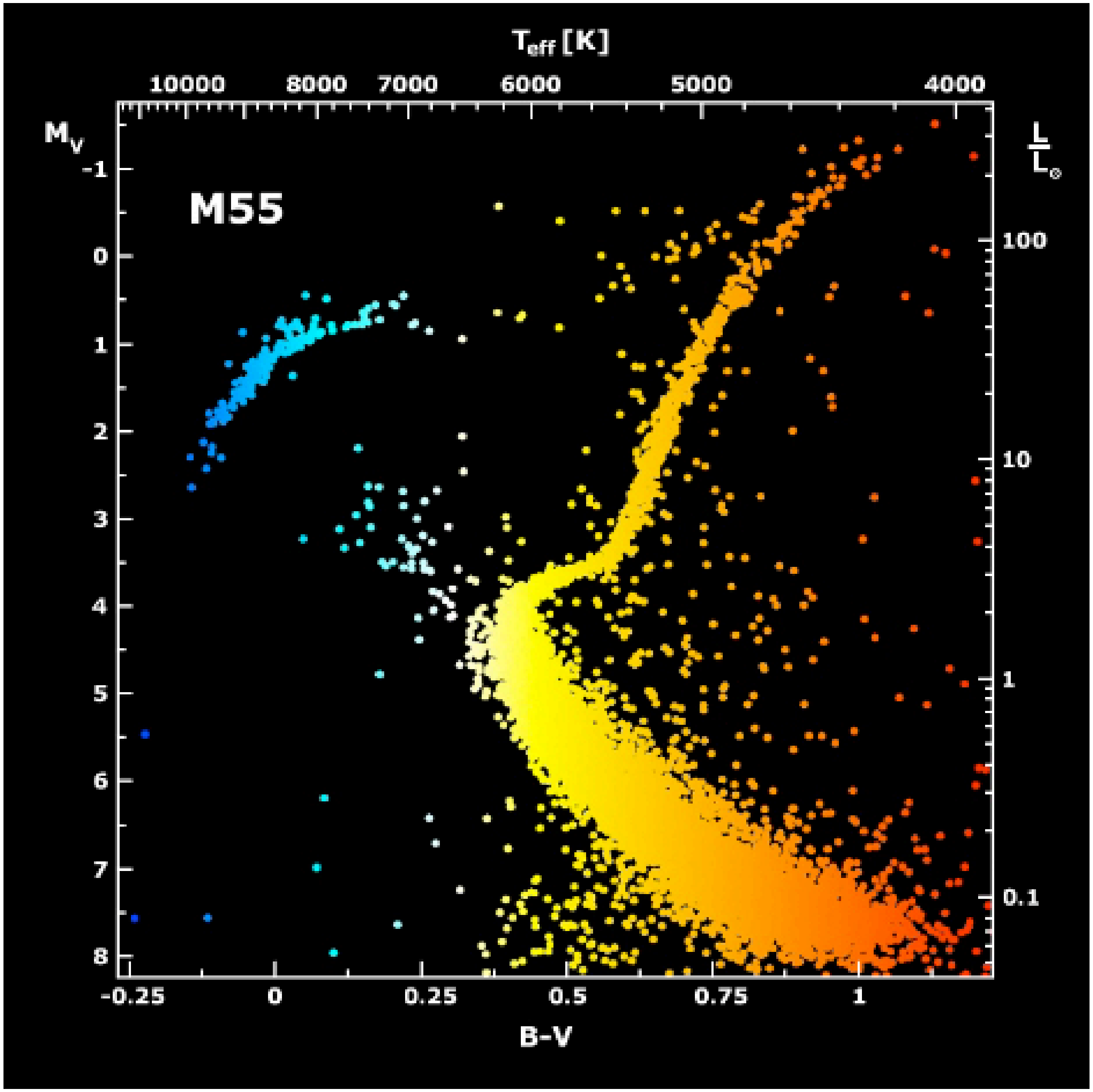


FIG. 4. TAURUS MOVING CLUSTER

Assumption to check: That the intrinsic cluster size D is constant.
Limitations: Nearby clusters so $\Delta\theta$ is measurable in a reasonable time.
Big Benefit: Lots (hundreds, thousands) of star distances at once.



M55
T_{eff} [K]
10000
8000
7000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
-0.25
0
0.25
0.5
0.75
1
B-V
$\frac{L}{L_\odot}$
100
10
1
0.1

Dynamic Parallaxes

The apparent (angular) size θ of an object depends upon its physical size D and its distance d according to

$$\theta = D/d$$

(angular size in radians - generally a very small number)
so if we know an object's physical size and measure its apparent size we can calculate its distance:

$$d = D/\theta$$

For some visual binary stars we can determine the physical separation (D) of the stars by determining the orbital speed (Doppler Effect!) and the orbital period.

Measuring the apparent separation (θ) then enables us to determine the distance (d).

Stellar Distances: Other Methods

Statistical Parallaxes
(The Solar Motion)

Sun's motion provides a baseline for triangulation.
Apply to any group of stars with common luminosity.
Relative distances from apparent brightnesses.
Stellar motions should average to zero, statistically.

Pulsating Stars

Spectra: Changes in "photospheric" size.
Photometry: Color changes give temperature changes.
These observations (R, T) give luminosity (L)
Distance computed from inverse-square law.

Stellar Distances: Summary

Methods

Trigonometric Parallaxes: Triangulation
Photometric Parallaxes: The Inverse-Square Law
Moving Group Parallaxes: Size & Distance

Dynamic Parallaxes: Binary Stars
Statistical Parallaxes: Stellar Groupings
Indirect Methods: Pulsating Stars

Results

Nearest Star (Sun): d = 1 astronomical unit = 0.000005 parsec
Next Nearest Star (α Centauri): d = 1.3 parsec
Typical Local Stellar Separation: <d> ~ 3 parsecs

1 parsec (pc) = 206,265 astronomical units = 3.09 x 10^{13} kilometers
Kiloparsec: 1 Kpc = 1,000 pc
Megaparsec: 1 Mpc = 1,000,000 pc