# The Cosmological Distance Ladder

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- We can't even leave our solar system.
- But, We of course, can watch and think!

# Notion and Estimation of Distances

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Laying down measuring rods – most direct but obviously too limited.

One needs to make abstractions, generalizations and assumptions.

Here are two historical examples:

# Height of the Great Pyramid?

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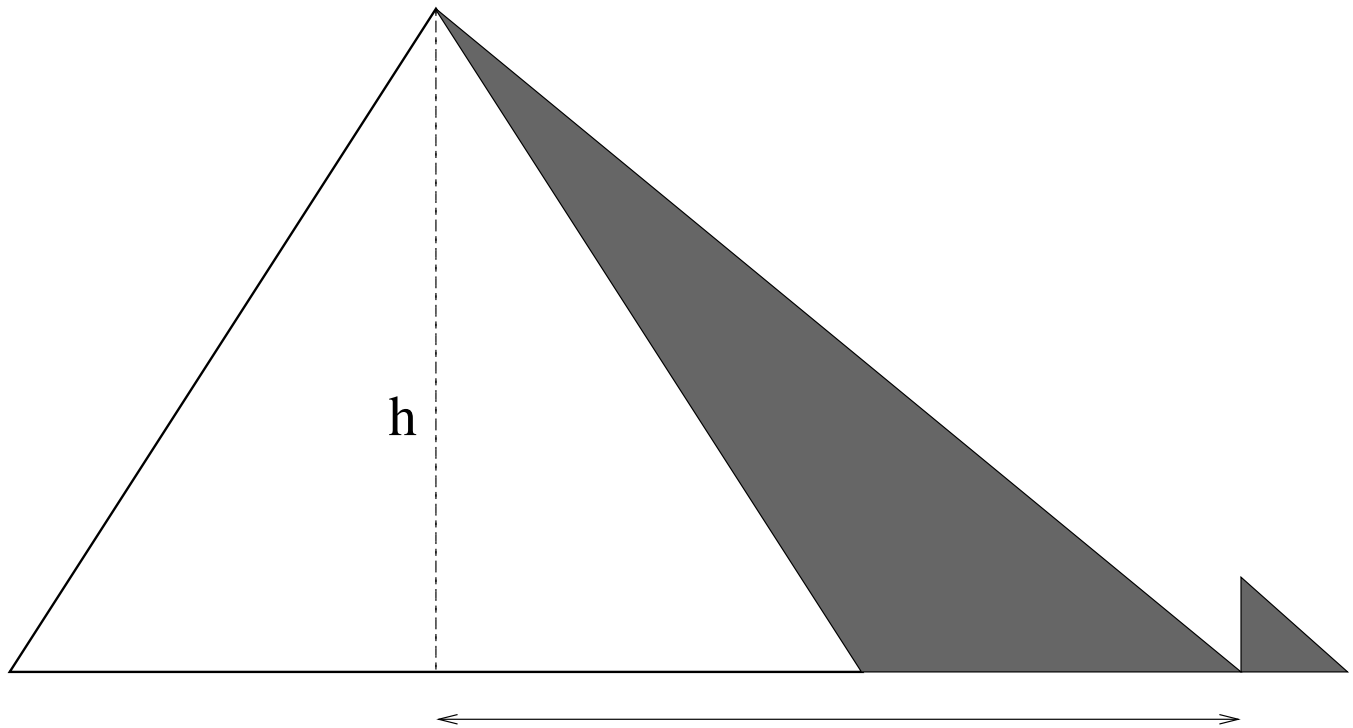
(Thales $\sim$ 600 BC : $\sim$ 150 m ) uses of shadows and similar triangles –



# Radius of Earth

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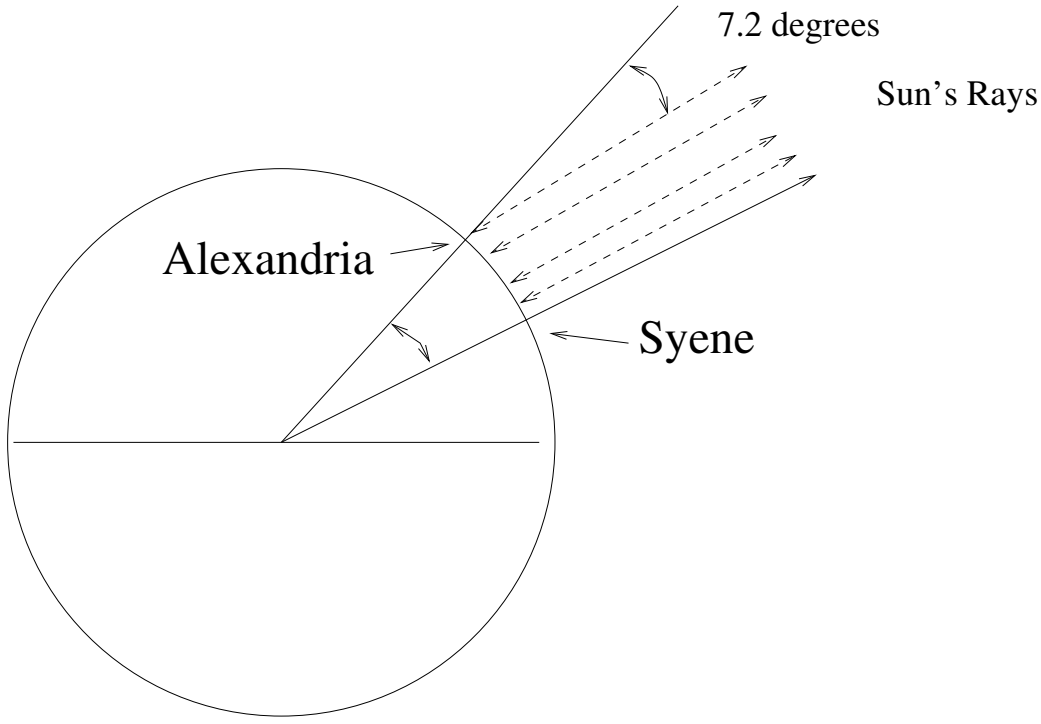
(Eratosthenes $\sim$ 240 BC: $\sim$ 4000 miles).




Accepted value (Poseidonius-Ptolemy: 2800 miles) was wrong but encouraged explorers!

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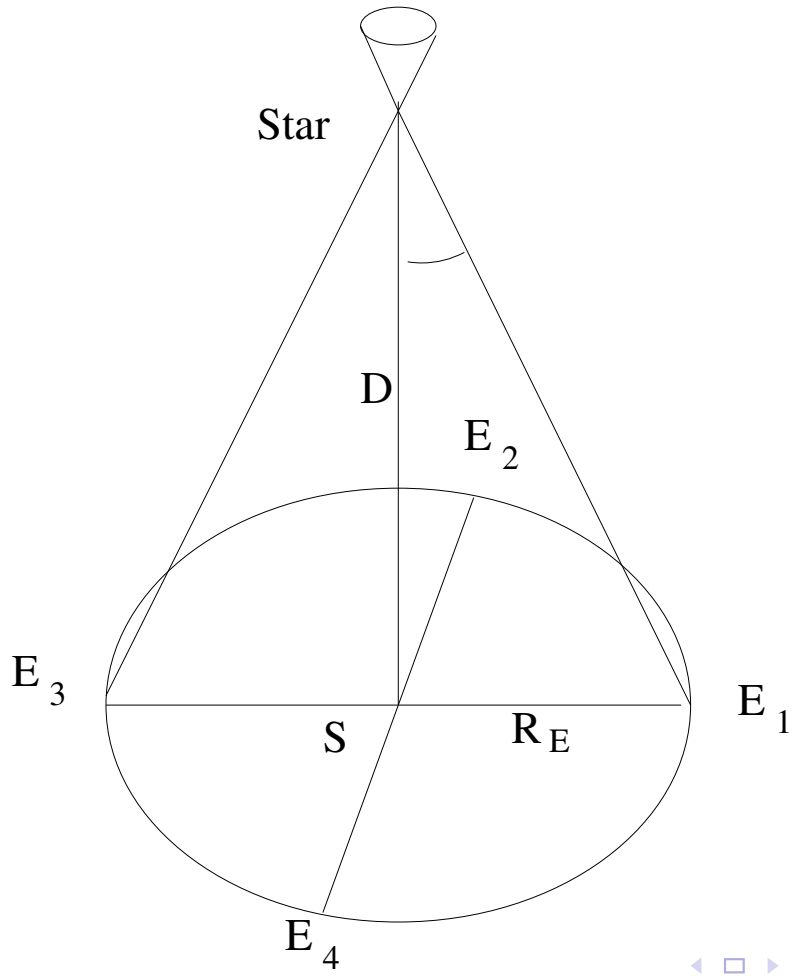

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- Flamsteed (1712) made precise catalogue for differential parallax but had errors;
- Huygens got Sirius to be 27,664 AU away; Newton compared Saturn and Sirius and got 800,000 AU.

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- Herschel discovers binary systems ($\sim 1800$);
  These enabled Struve to set criteria for selection of candidates for parallax determination – should be bright with large proper motion or wider binaries.

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- Method is reliable up to about 90 pc. One has exhausted the relatively direct method based on geometry to estimate distances and many more objects are still left!

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With the known atomic spectra from labs, we can also determine the Doppler Shift to infer the Radial Velocity of stars and we measure their proper motion.

# (Open) Clusters of Stars

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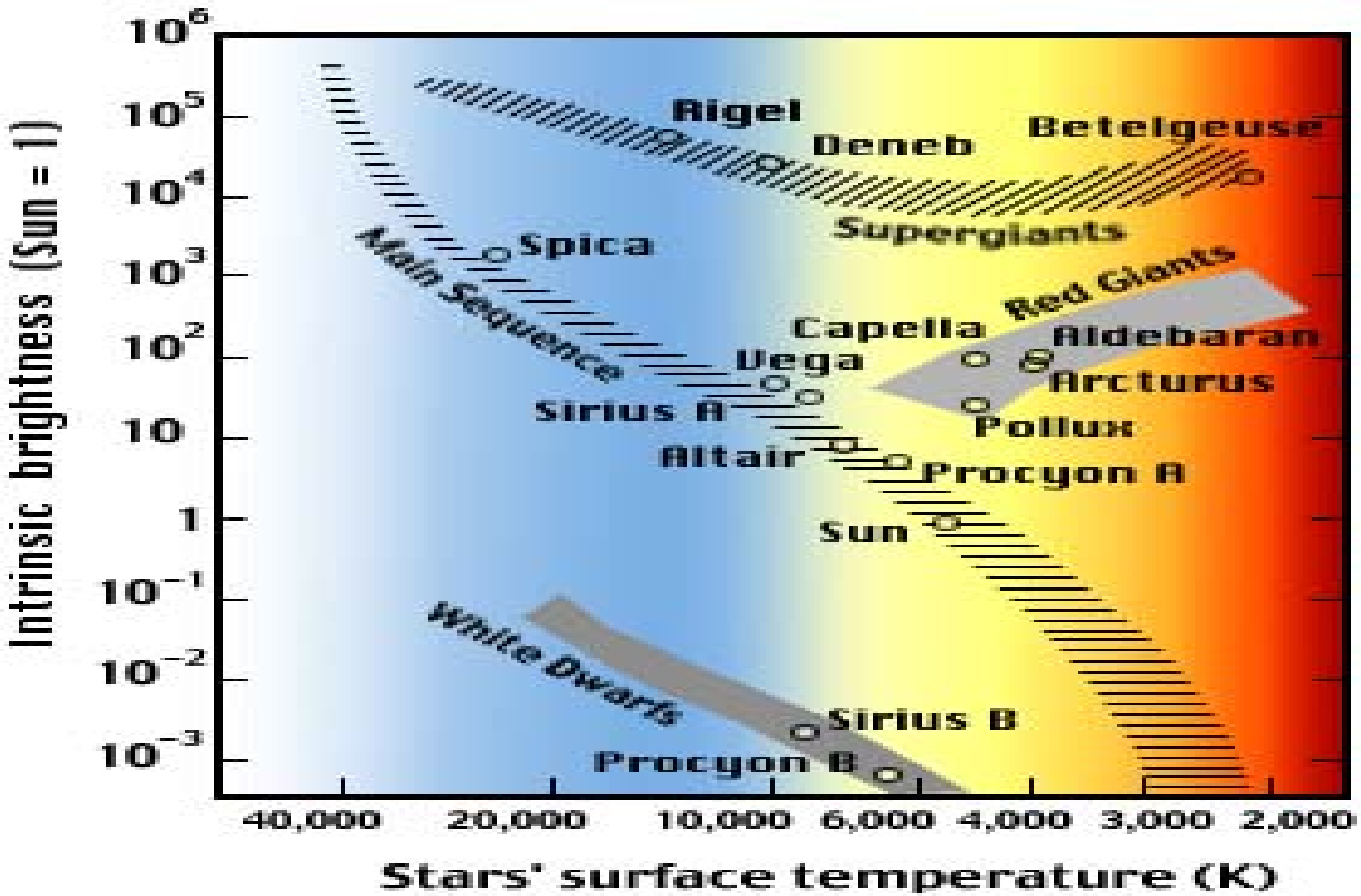
Moving Cluster Method: If we can determine the transverse velocity, we can obtain the distance from the proper motion.

Identify an open cluster whose stars move together and appear to converge to a common point (direction). This gives the transverse velocity. The cluster identification and common direction is inferred by statistical analysis.

This is applied to the Hyades open cluster (1908) and gives the distance to be $\sim 46$ pc.

This cluster has many different spectral types and is useful for next method.

Hertzsprung-Russell Diagram: Plot absolute luminosity versus spectral type. observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_1ai.html



Main Sequence Fitting Method: Pick a cluster, identify its main sequence band in terms of apparent luminosity, match with a known cluster's main sequence in terms of absolute luminosity and infer the distance to the cluster.

This gives distance up to about 100,000 pc.

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In 1923 Hubble observed Cephids in the Andromeda 'nebula' and estimated the distance to be about 275,000 pc: Andromeda 'nebula' is extra-galactic!

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Novae and brightest stars of a galaxy $\longrightarrow 10^7$pc.

Brightest galaxies of a galactic cluster and Super-novae $\longrightarrow 10^{10}$pc.

# Summary of the Distance Ladder

| Rung | Distances up to | Method |
|---|---|---|
| I | $< 30$ parsecs | Kinematic (Parallax) Methods |
| II | $< 10^5$ parsecs | Main Sequence Photometry |
| III | $< 10^6$ parsecs | Variable Stars |
| IV | $< 10^7$ parsecs | Novae, Brightest Stars etc |
| V | $\sim 10^{10}$ parsecs | Brightest Galaxies, Super-Novae etc |

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Further Reading:

Measuring the Universe - Stephen Webb, 1999.