NS102
Lecture 10

The distance ladder

Open: *Stairway to Heaven*
Led Zeppelin

Close: *Cold in the Sun*
Red Eyed Legends

GnatSigh News

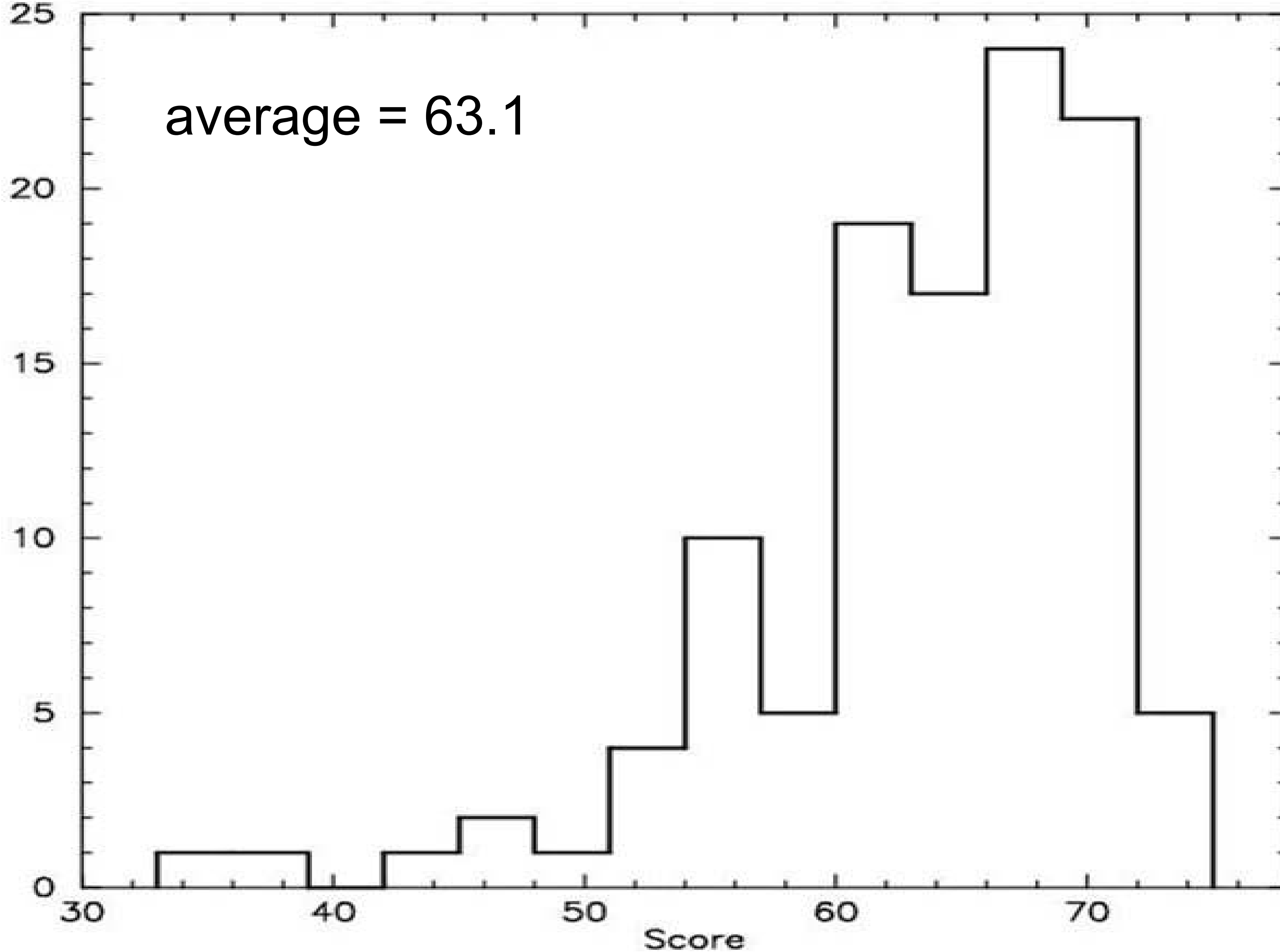
(all the news that fits)

- Website http://home.fnal.gov/~rocky/NS102/
- Need violinist volunteer
- Review logarithms
- Review basic trigonometry (definition of sine, tangent, etc.)
- Exam #1
- Do not memorize eqquations
- Thursday: Original composition “Car horn in G”

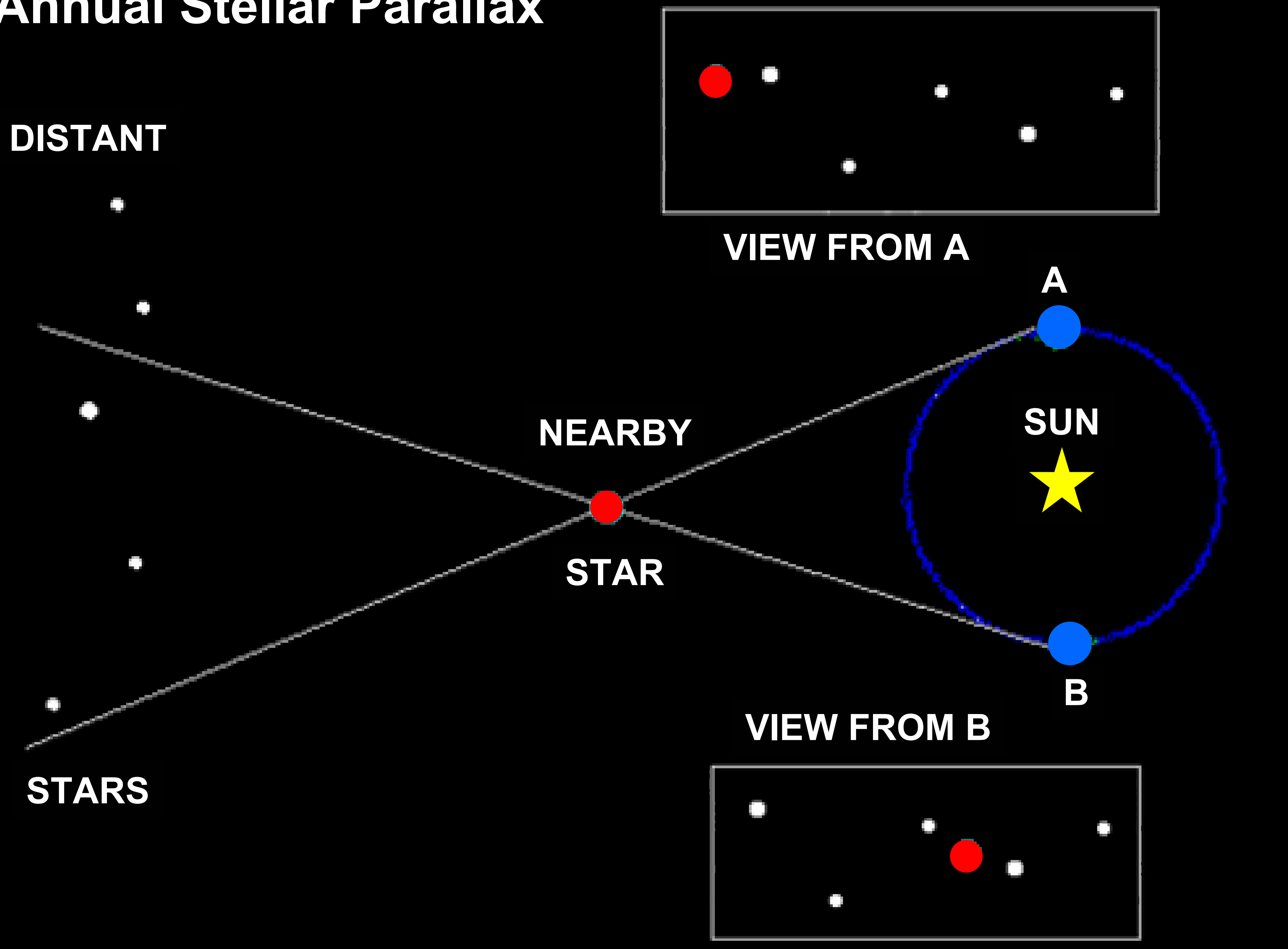
  Shapley-Curtis debate

Lab this week: Non-Euclidean Geometry

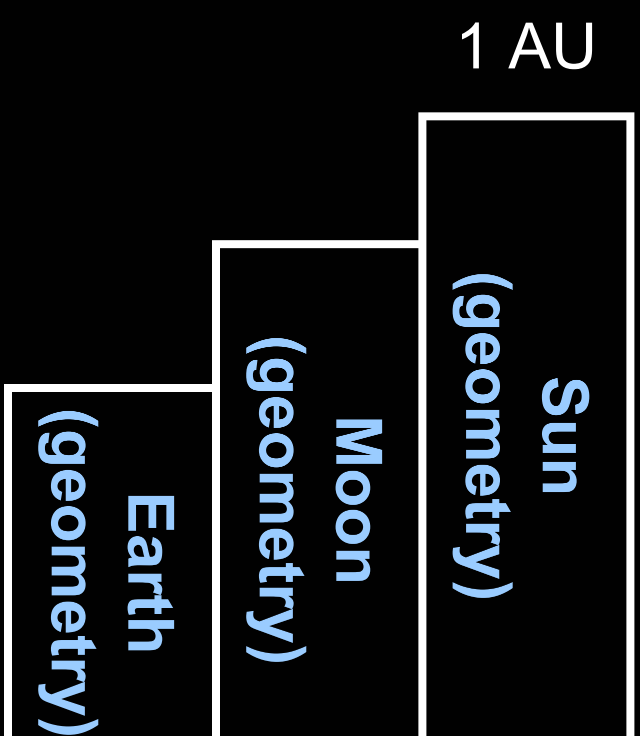
NatSci 102 Spring 2005 Exam #1



Annual Stellar Parallax



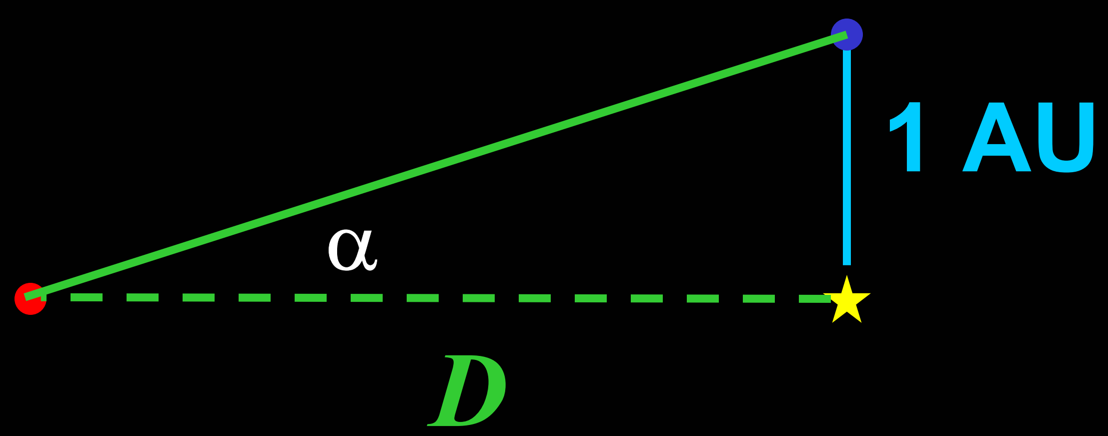
The Cosmological Distance Ladder



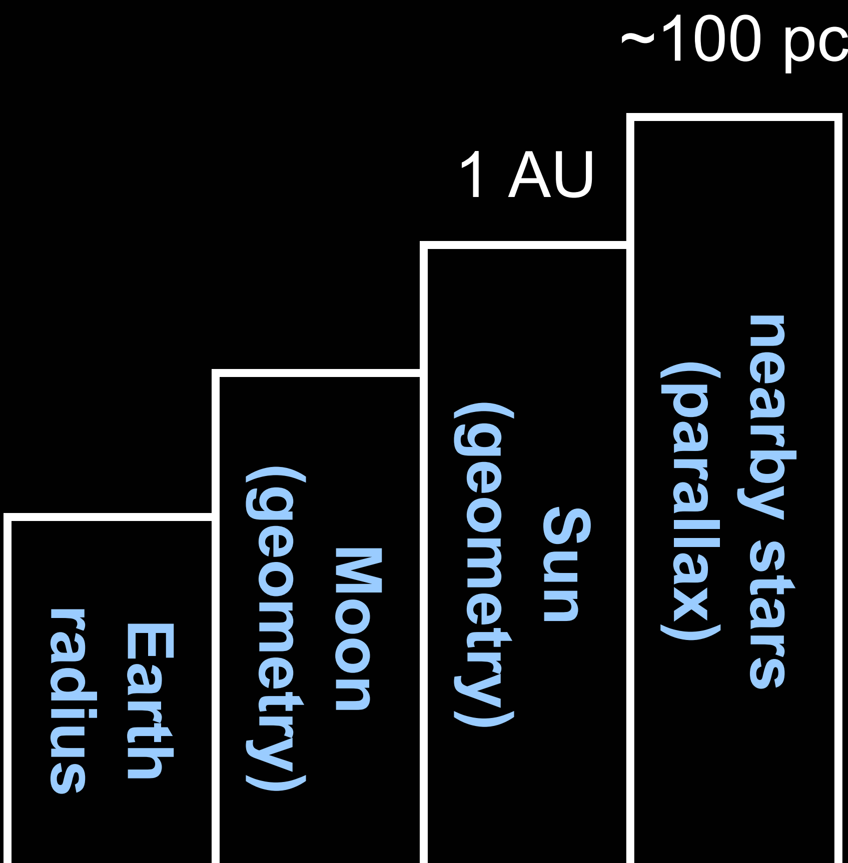
They move
They have different apparent brightness
They have different colors
They change in brightness

$$\frac{D}{200{,}000\ \mathrm{AU}} = \frac{\mathrm{seconds}}{\alpha}$$

$$\frac{D}{\mathrm{pc}} = \frac{\mathrm{seconds}}{\alpha}$$



The Cosmological Distance Ladder



They move

They have different apparent brightness

They have different colors

They change in brightness

For light!!!

$$\text{Intensity} = \frac{\text{luminosity}}{\text{area}}$$

Luminosity property of source

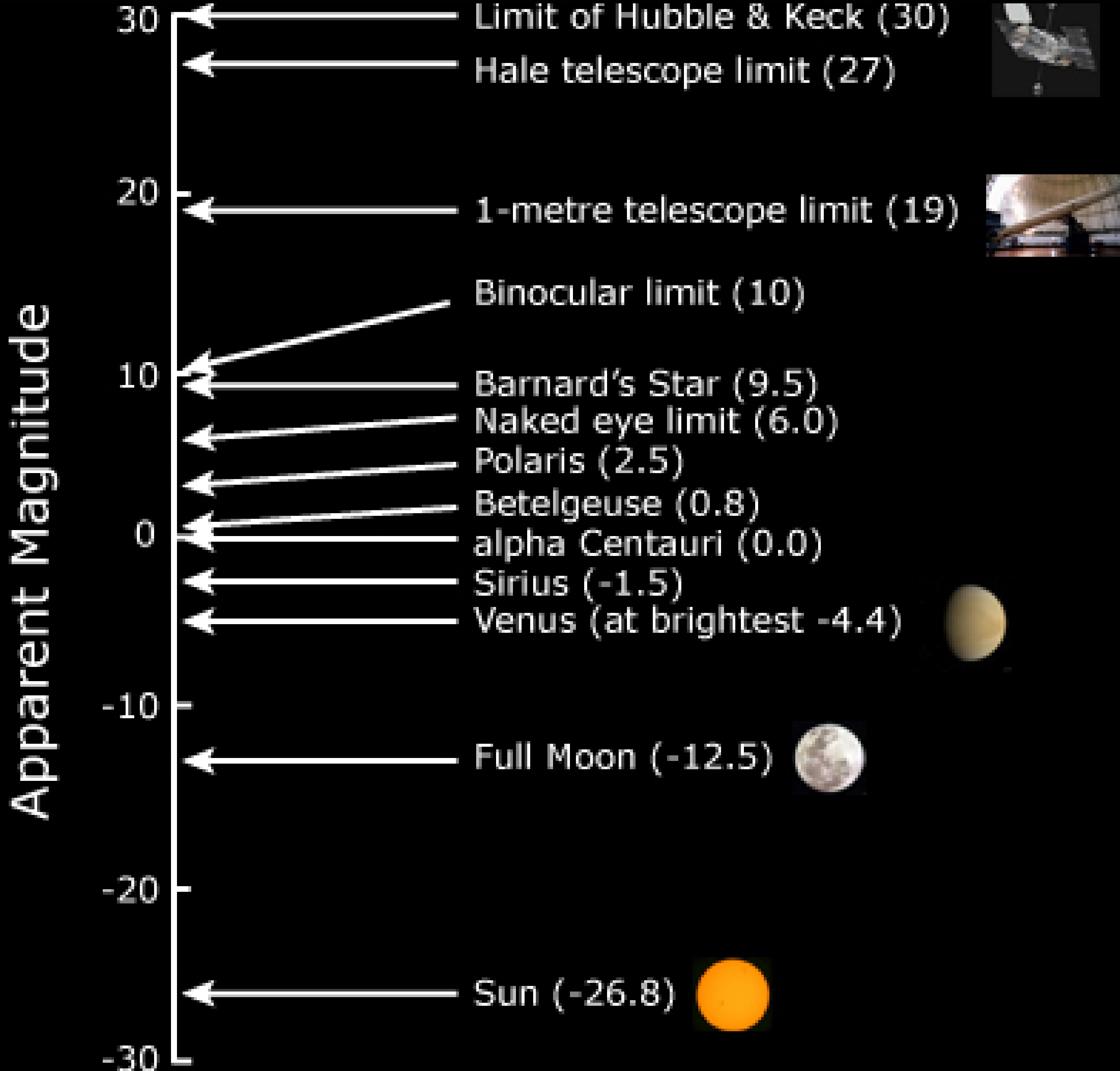
Intensity depends on power and distance between source and detector (R)

$$\text{Intensity} = \frac{\text{luminosity}}{4\pi R^2}$$

Logarithmic Eye

Eyes, like ears, are logarithmetic detectors.

$$m_1 - m_2 \equiv -2.5 \log (I_1/I_2)$$



The luminosity of nearby stars

Measure: intensity of light, I

$$I = \frac{L}{4\pi R^2}$$

If know distance (e.g., parallax) → luminosity

If know luminosity (standard candle) → distance

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\alpha}$$

$$I = \frac{L}{4\pi R^2}$$

$$-26.8 - m = -2.5\log\left(0.137 \text{ watts cm}^{-2}/I\right)$$

Measured

star	parallax (”)	distance (pc)	apparent magnitude	luminosity (solar)
α Centauri	0.75	1.3	0	1.5
Barnard’s star	0.5	2.0	9.5	0.0005
Sirius	0.4	2.5	-1.5	25
Altair	0.2	5.0	0.8	10
Canopus	0.003	330	- 0.7	200,000
Arcturus	0.1	10	0	90
Betelgeuse	0.01	100	0.5	14,000

Intensity of Sun vs. Sirius

Sun $m_S = -26.8$

Sirius $m_I = -1.5$

$$m_S - m_I = -2.5 \log(I_S/I_I)$$

$$10^{10} = I_S/I_I$$

We know the distance to Sirius via parallax

Parallax = 0.4 second

Distance = (1/parallax) pc = 2.5 pc = 2.5 X 200,000 AU
= 500,000 AU

Our Sun ain't the brightest bulb in the box!

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

$$L_{SIRIUS} = 25 \times L_{SUN}$$

For stars we know distance to via parallax:

Measure Distance (R)
Measure Intensity $\longrightarrow$ Know Luminosity

They move

They have different apparent brightness

They have different colors

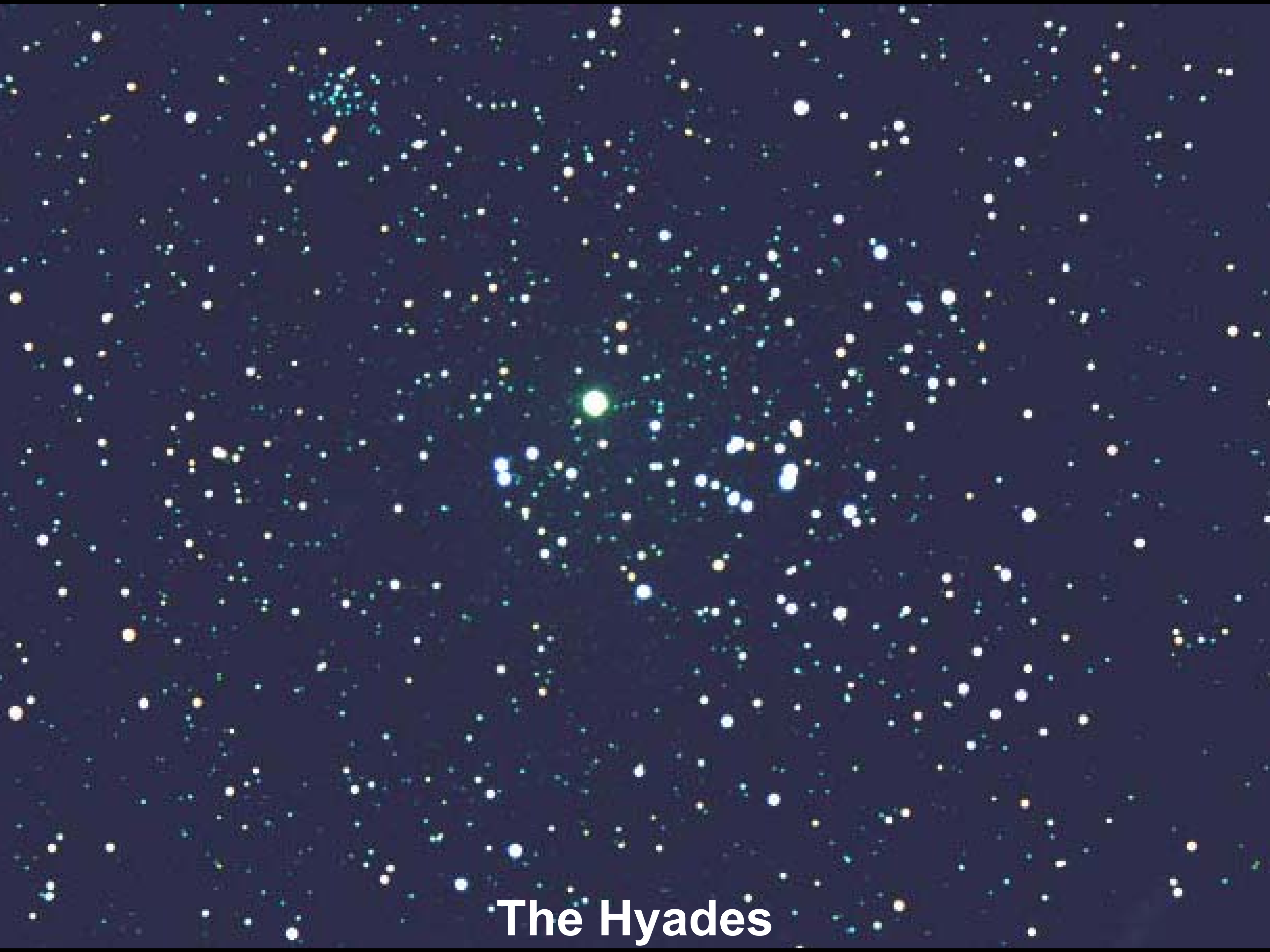
They change in brightness

COLORS OF THE RAINBOW:

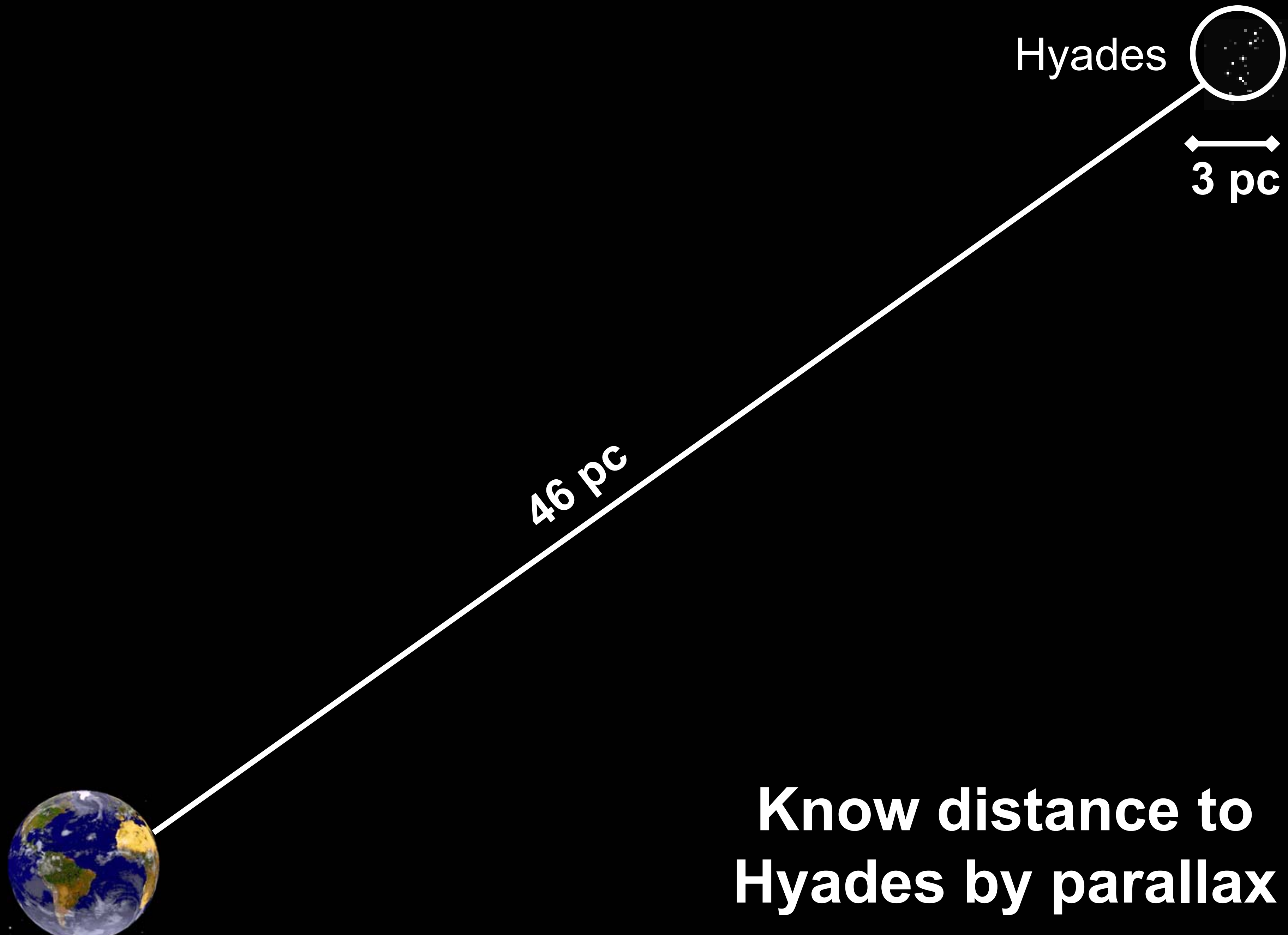
R O Y – G – B I V

Open Cluster (The Pleiades)
130 pc distant

M 45 (Pléiades)
Hyades



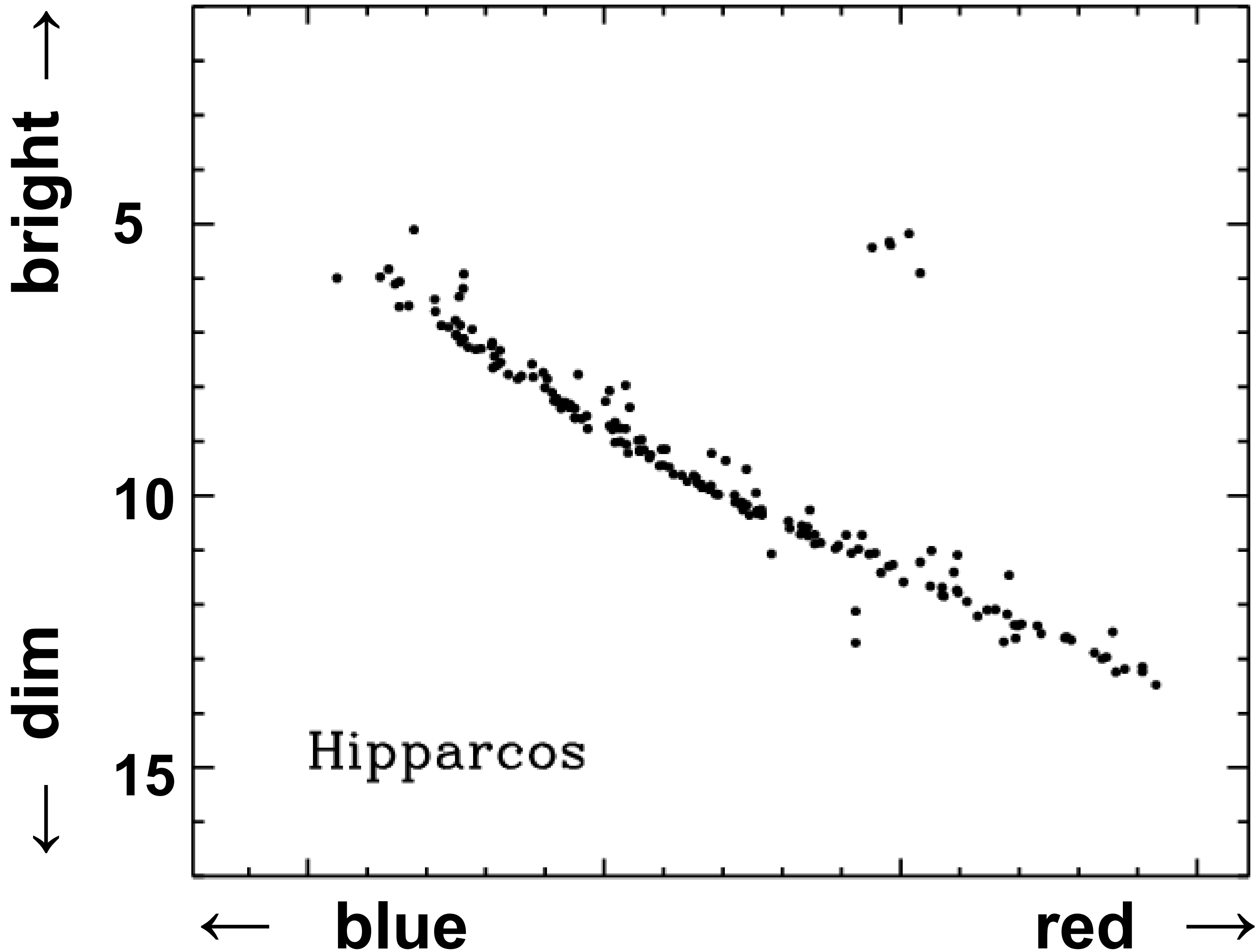
The Hyades



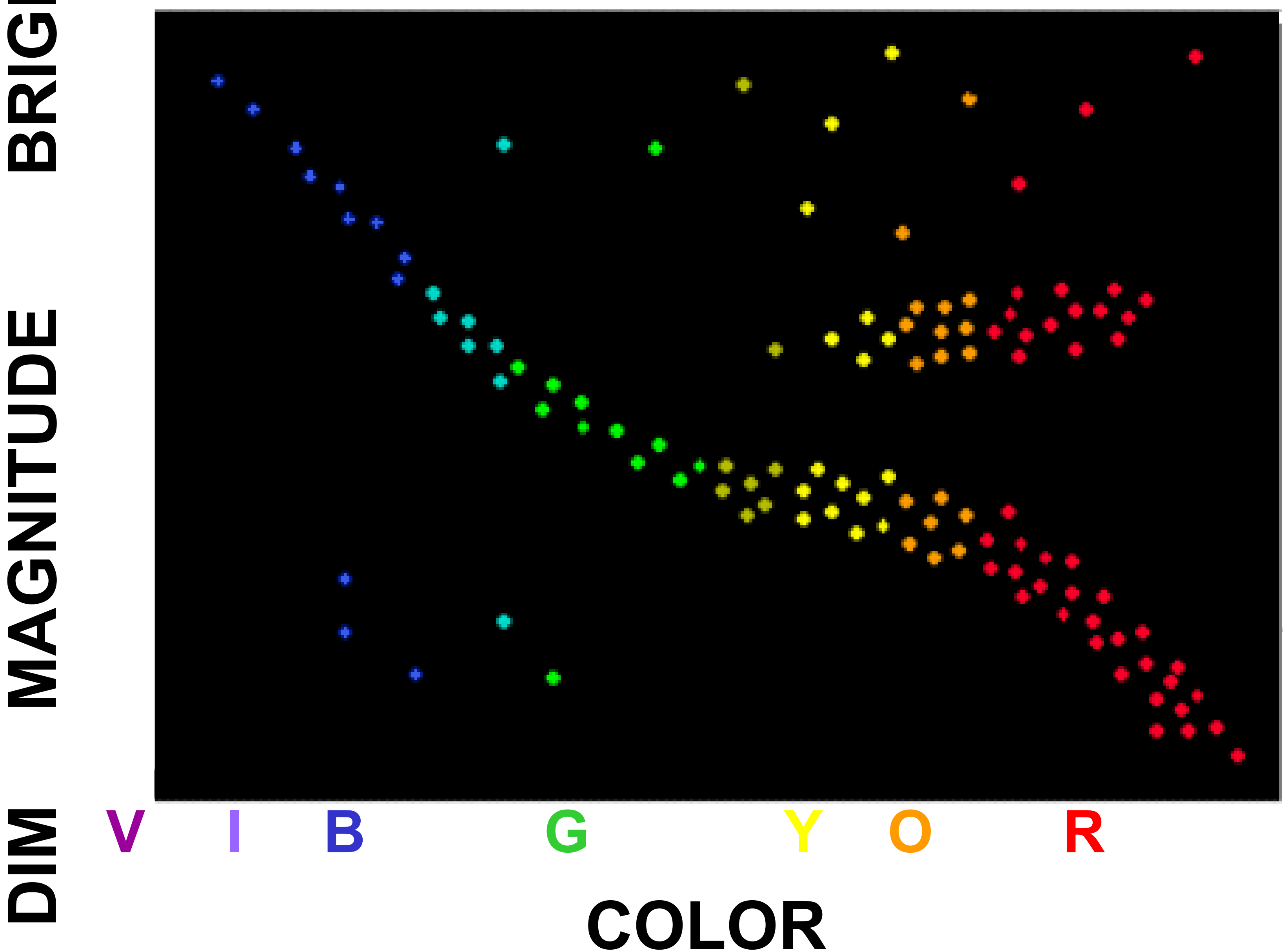
Know distance to Hyades by parallax

Ejnar Hertzsprung (1873-1967)   Henry Russell (1877-1957)

Hyades HR diagram

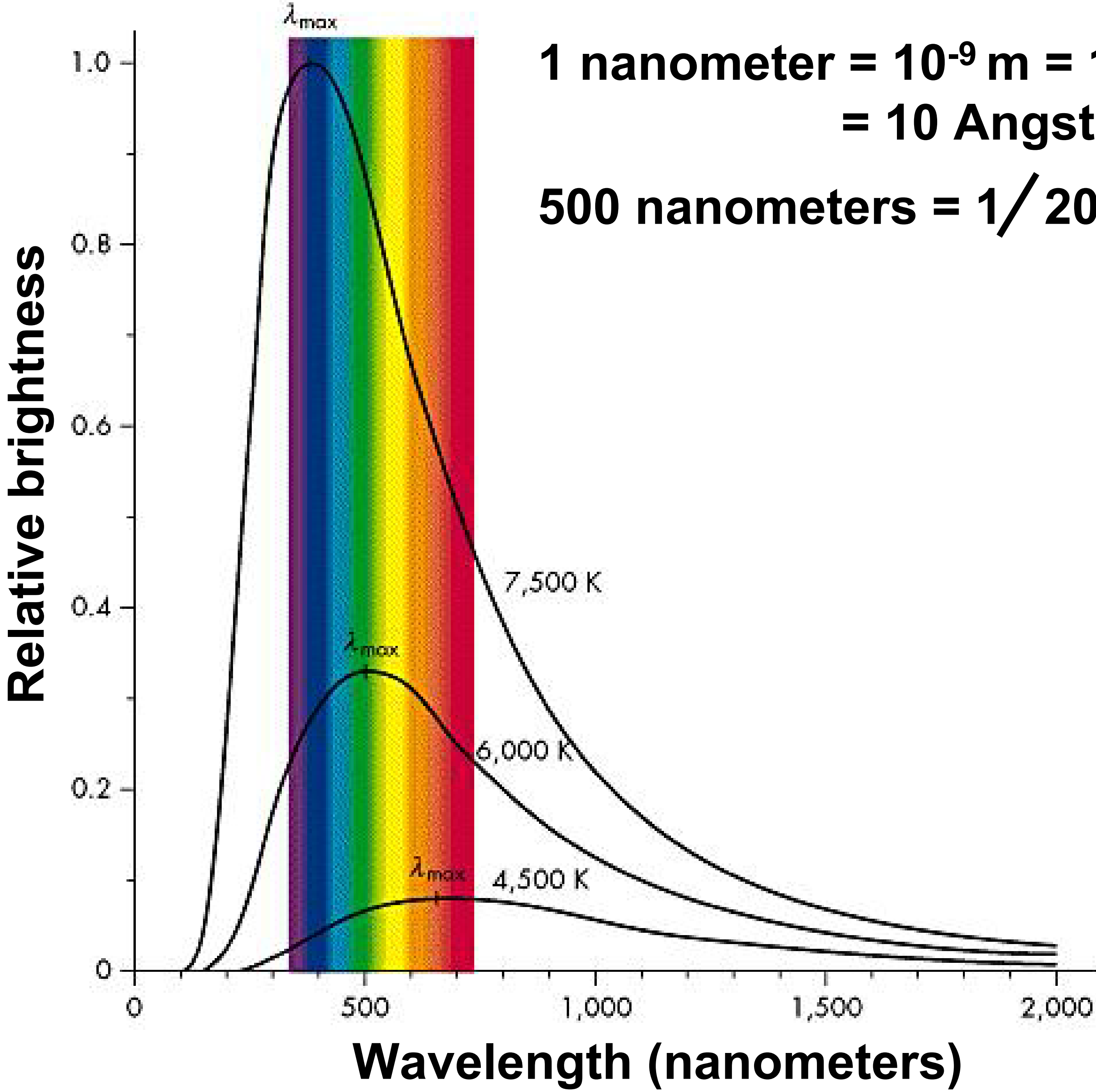


Schematic Hertzsprung-Russell Diagram

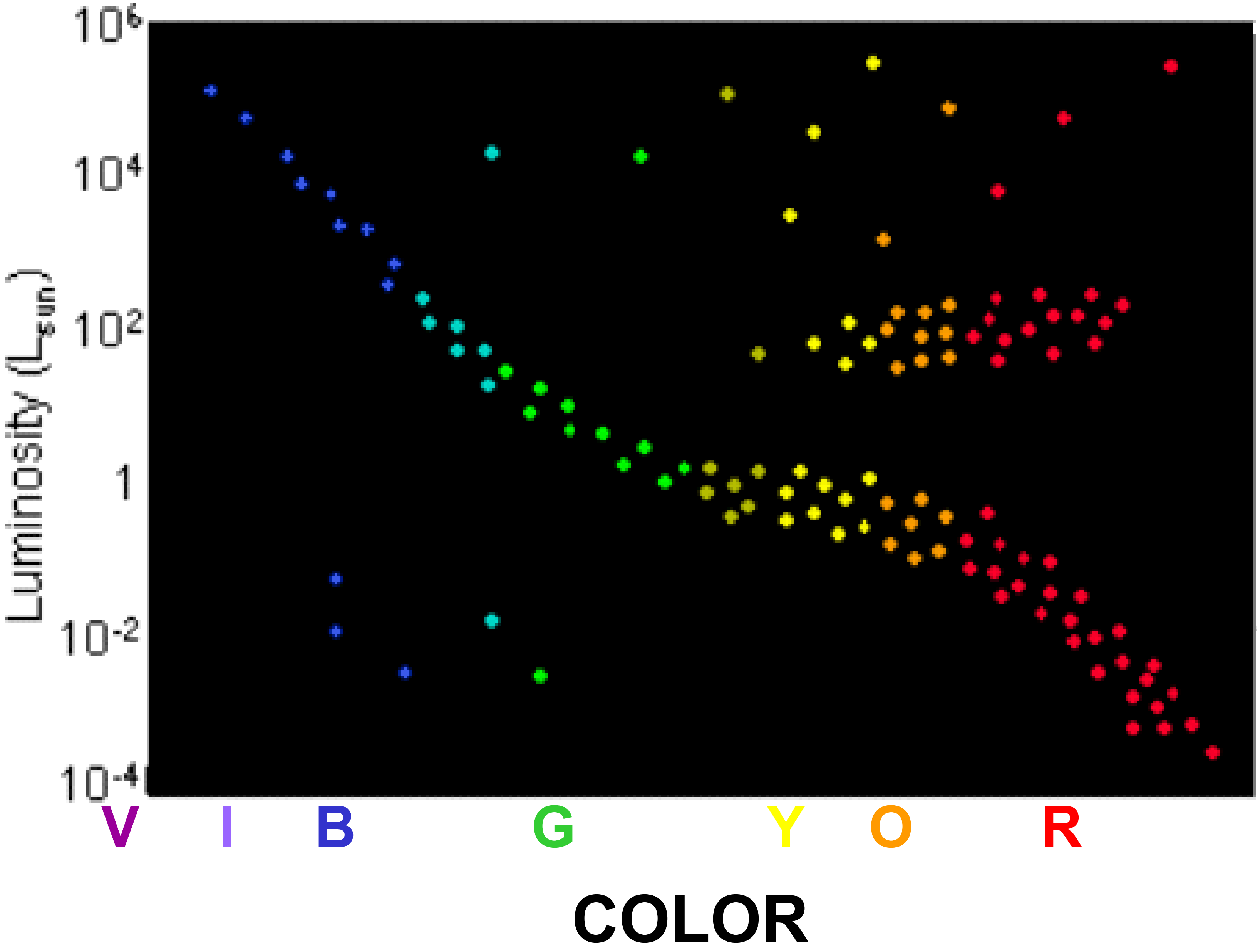


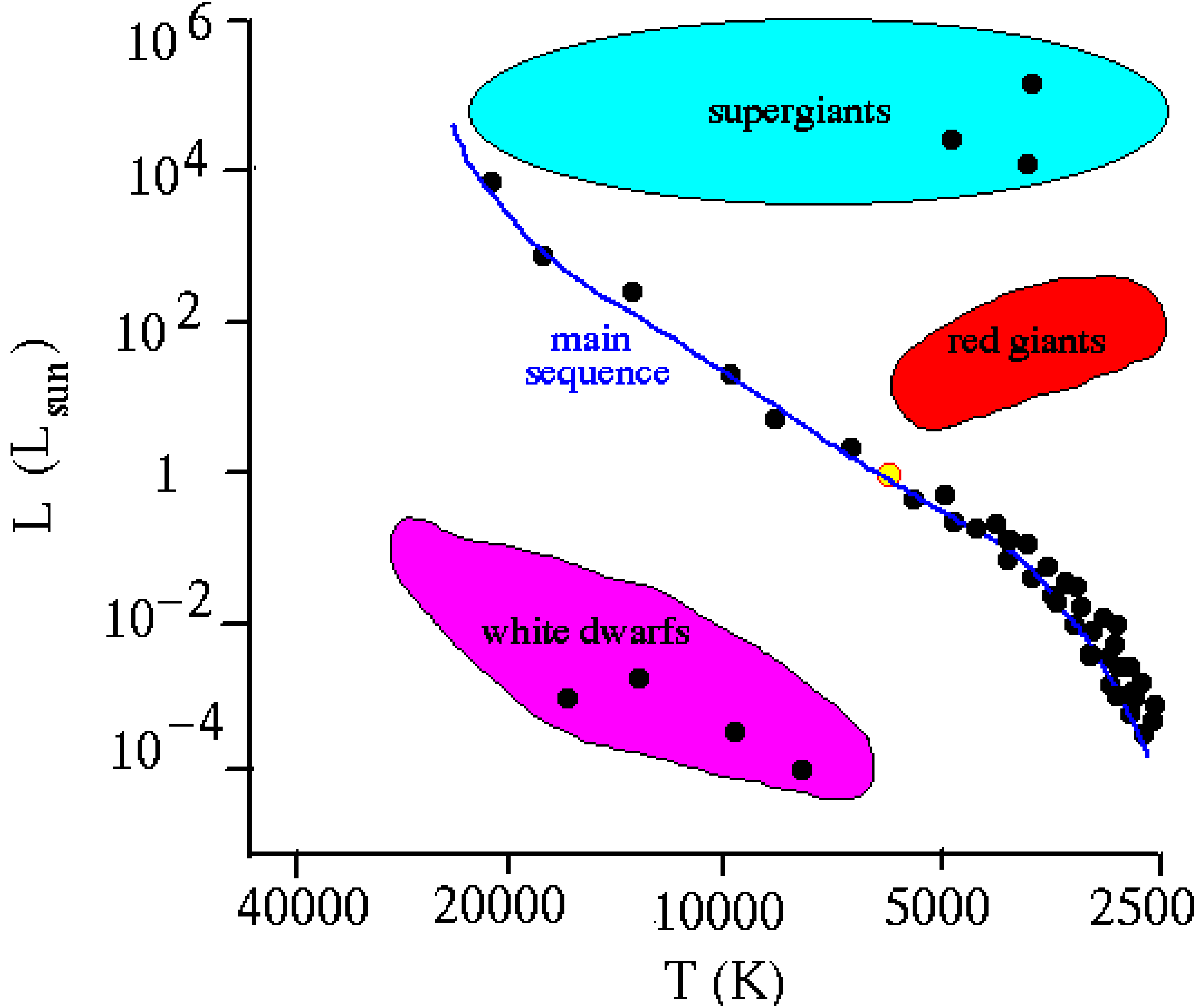
1 nanometer = 10^{-9} m = 10^{-7} cm
= 10 Angstroms

500 nanometers = 1/20,000 cm

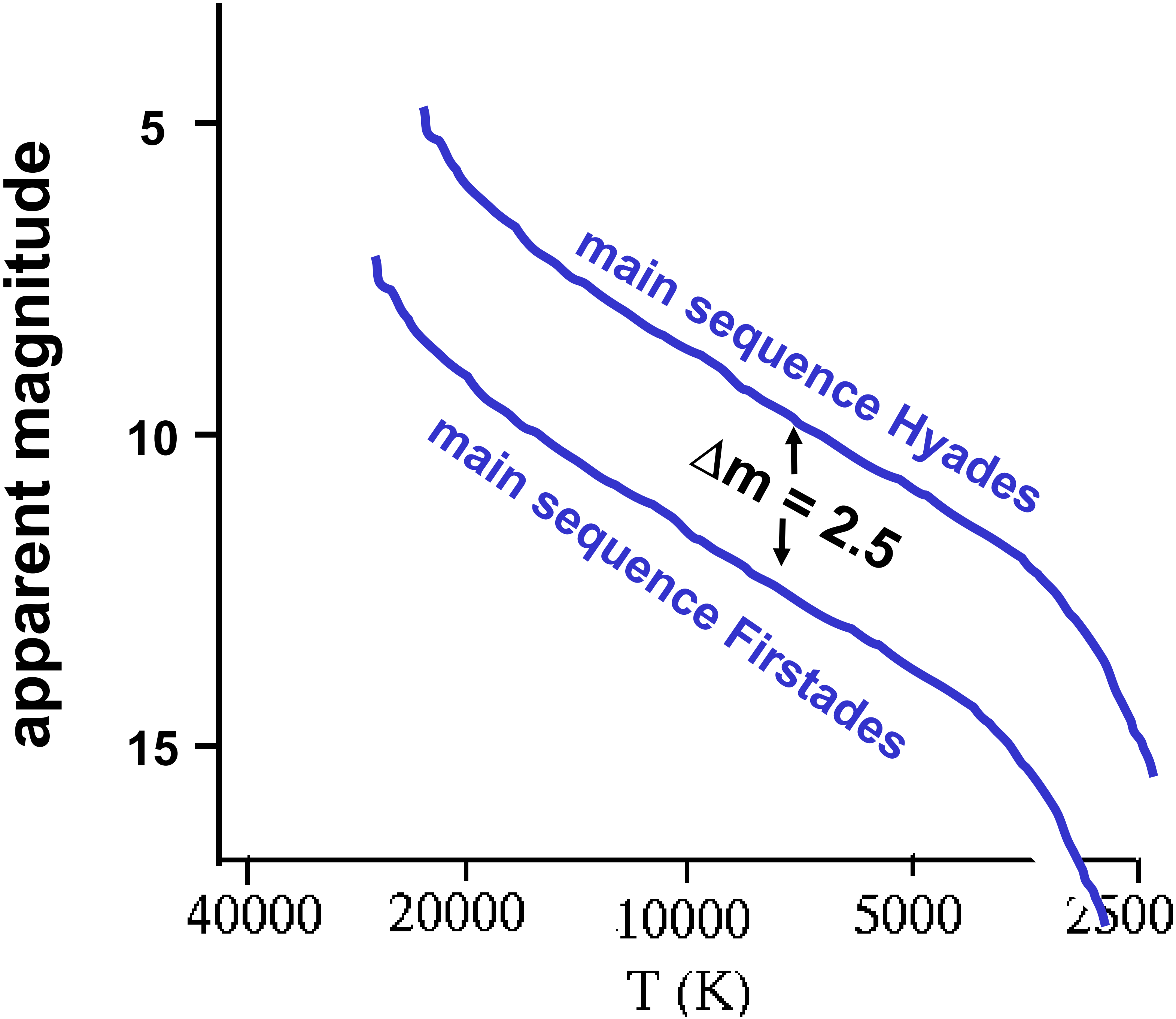


Schematic Hertzsprung-Russell Diagram





10^6
10^4
10^2
1
10^{-2}
10^{-4}
L (L_{sun})
supergiants
main sequence
red giants
white dwarfs
40000
20000
10000
5000
2500
T (K)


apparent magnitude
5
10
15
main sequence Hyades
main sequence Firstades
Δm = 2.5
40000
20000
10000
5000
2500
T (K)

$$m_H - m_F = -2.5\log\left(I_H/I_F\right)$$

$$-2.5 = -2.5\log\left(I_H/I_F\right)$$

$$1 = \log\left(I_H/I_F\right)$$

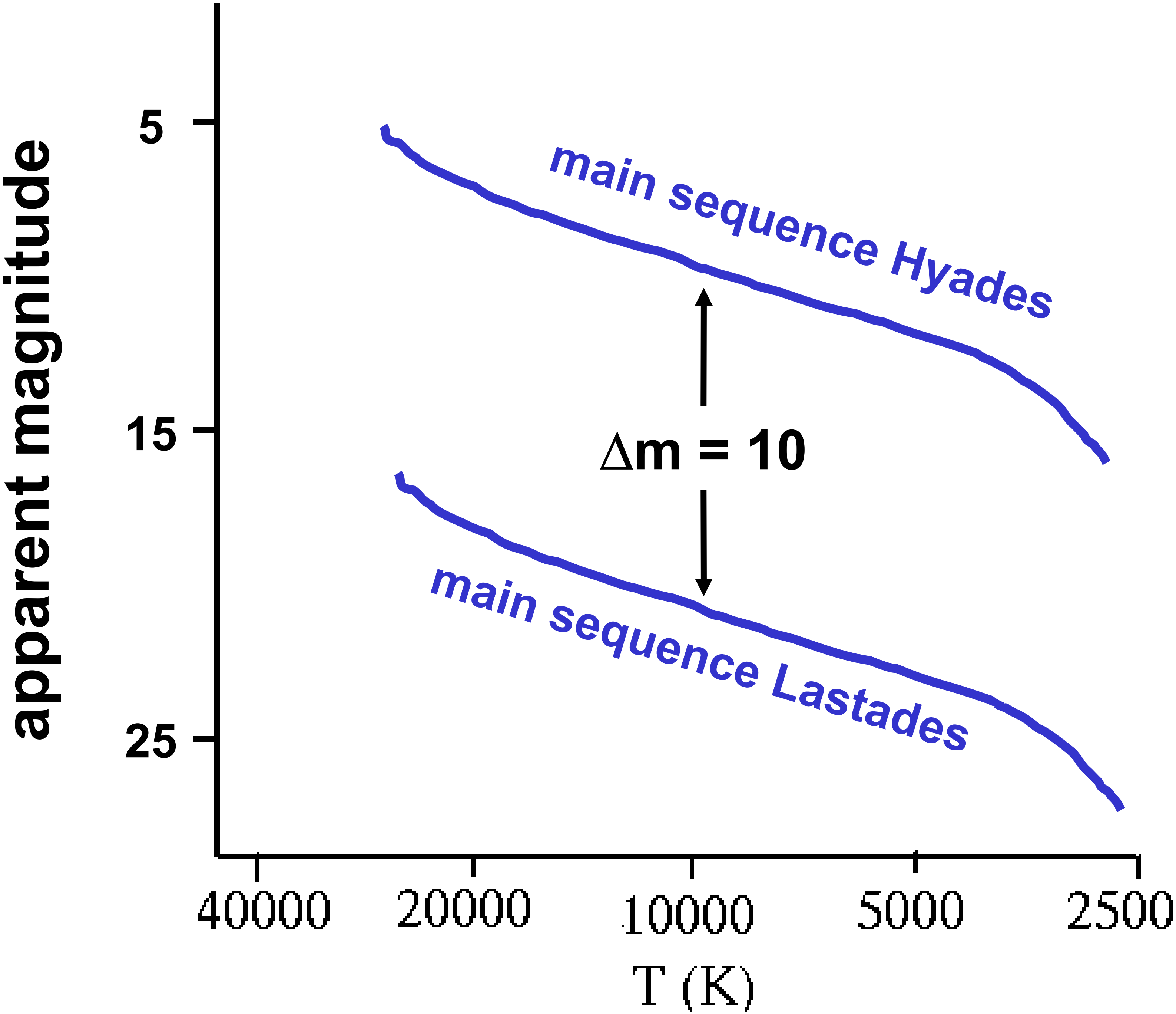
$$10 = I_H/I_F$$

$$I_H = \frac{\text{Luminosity}_H}{4\pi R_H^2} \qquad I_F = \frac{\text{Luminosity}_F}{4\pi R_F^2}$$

$$\frac{I_H}{I_F} = \frac{R_F^2}{R_H^2} \qquad 10 = \frac{R_F^2}{R_H^2} \qquad 3 = \frac{R_F}{R_H}$$

Distances to other clusters

- Construct H-R diagram for cluster
- Measure Δm compared to HR diagram for Hyades
- Compute distance in terms of distance to Hyades
- How far can you go?
- Say most distant open observable cluster is Lastades



apparent magnitude
5
15
25
main sequence Hyades
Δm = 10
main sequence Lastades
40000
20000
10000
5000
2500
T (K)

$$m_H - m_L = -2.5\log\left(I_H/I_L\right)$$

$$-10 = -2.5\log\left(I_H/I_L\right)$$

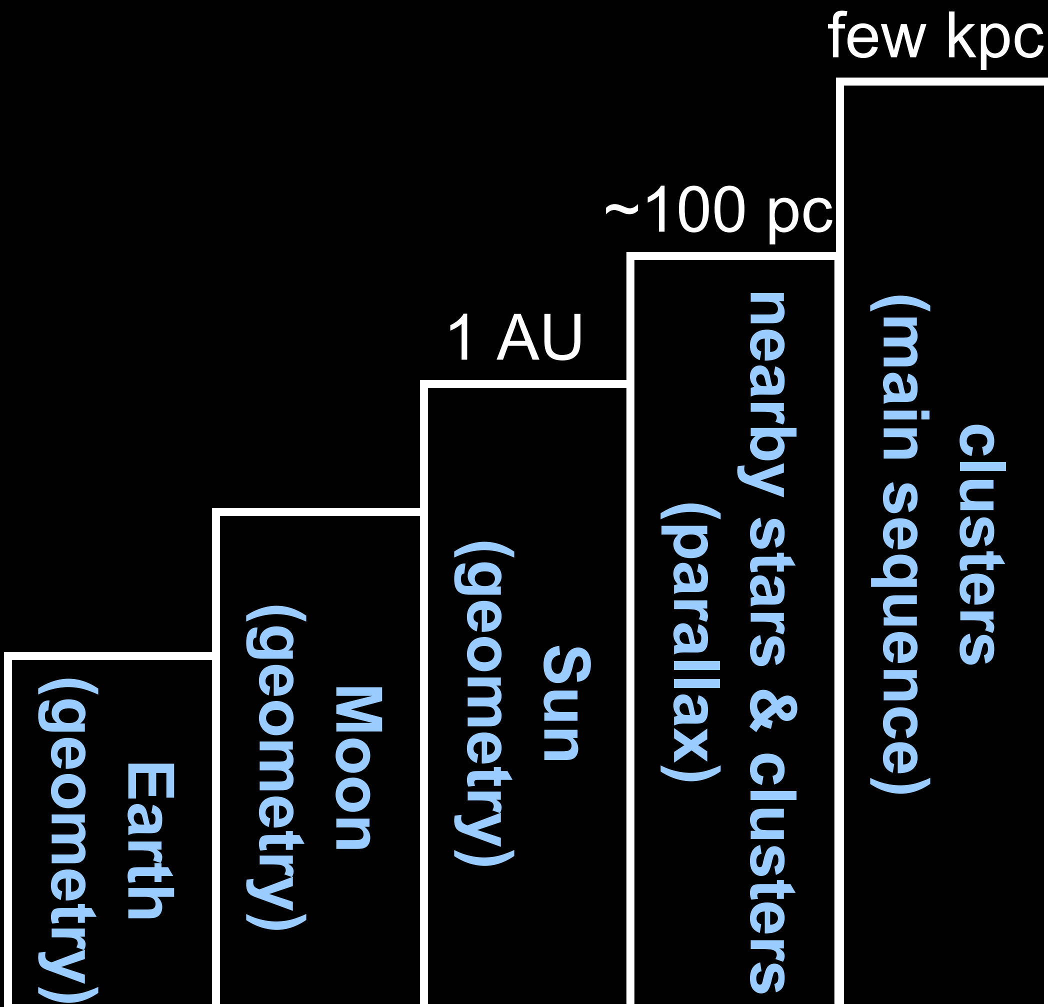
$$4 = \log\left(I_H/I_L\right)$$

$$10^4 = I_H/I_L$$

$$I_H = \frac{\text{Luminosity}_H}{4\pi R_H^2} \qquad I_L = \frac{\text{Luminosity}_L}{4\pi R_L^2}$$

$$\frac{I_H}{I_L} = \frac{R_L^2}{R_H^2} \qquad 10^4 = \frac{R_L^2}{R_H^2} \qquad 100 = \frac{R_L}{R_H} \qquad 4\,\text{kpc} = R_L$$

The Cosmological Distance Ladder

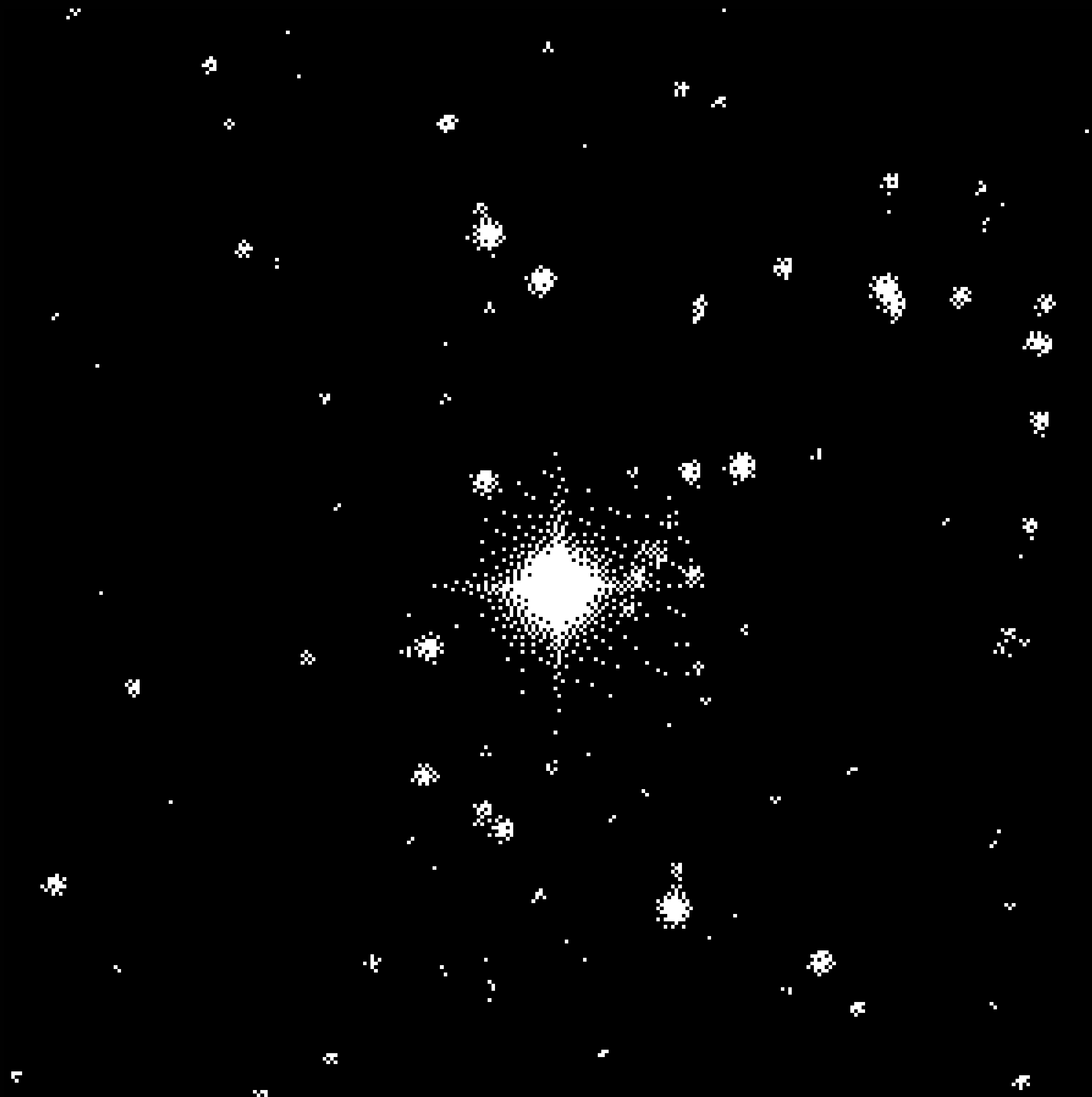


- Main sequence stars are not extremely bright… we need brighter “standard candle”

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

They move
They have different apparent brightness
They have different colors
They change in brightness

RR Lyrae Stars



RR Lyrae Stars

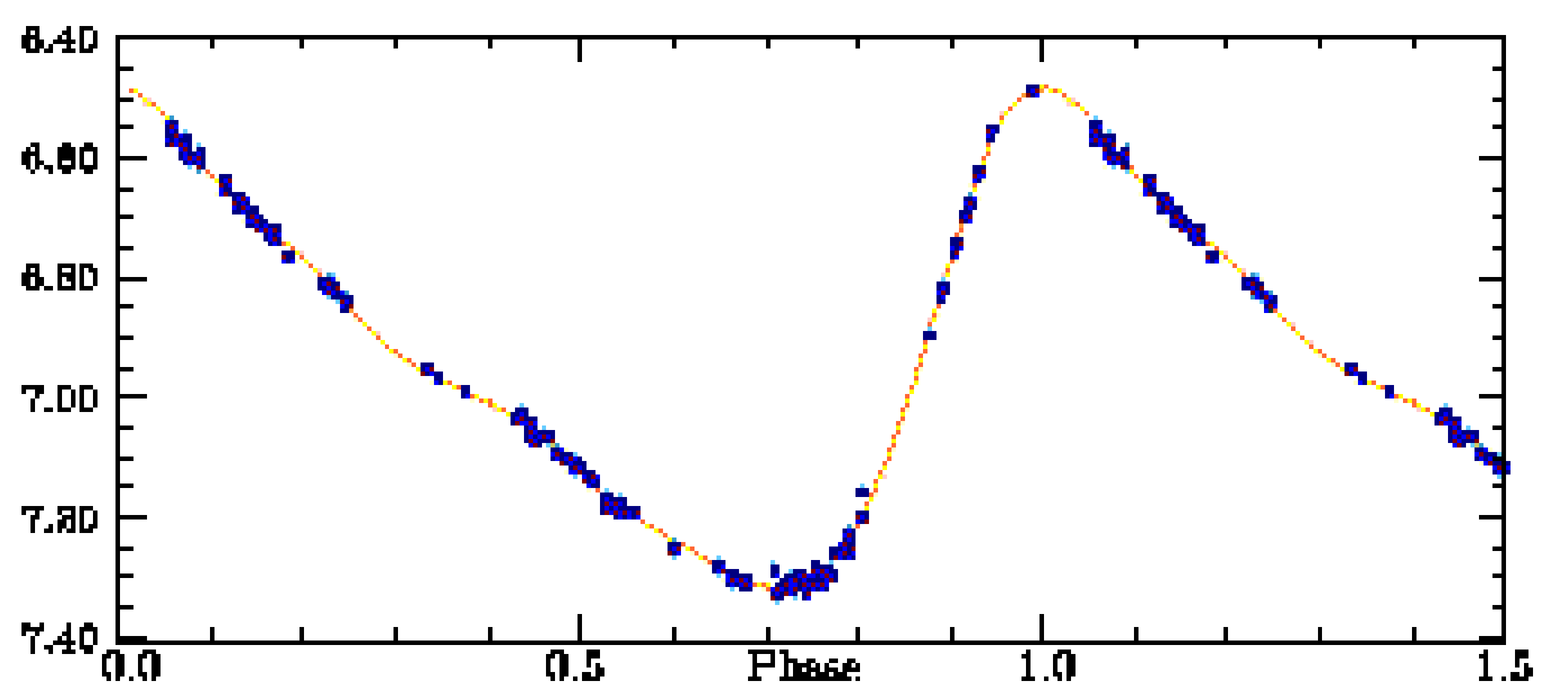
- Class named after a particular star: RR Lyrae

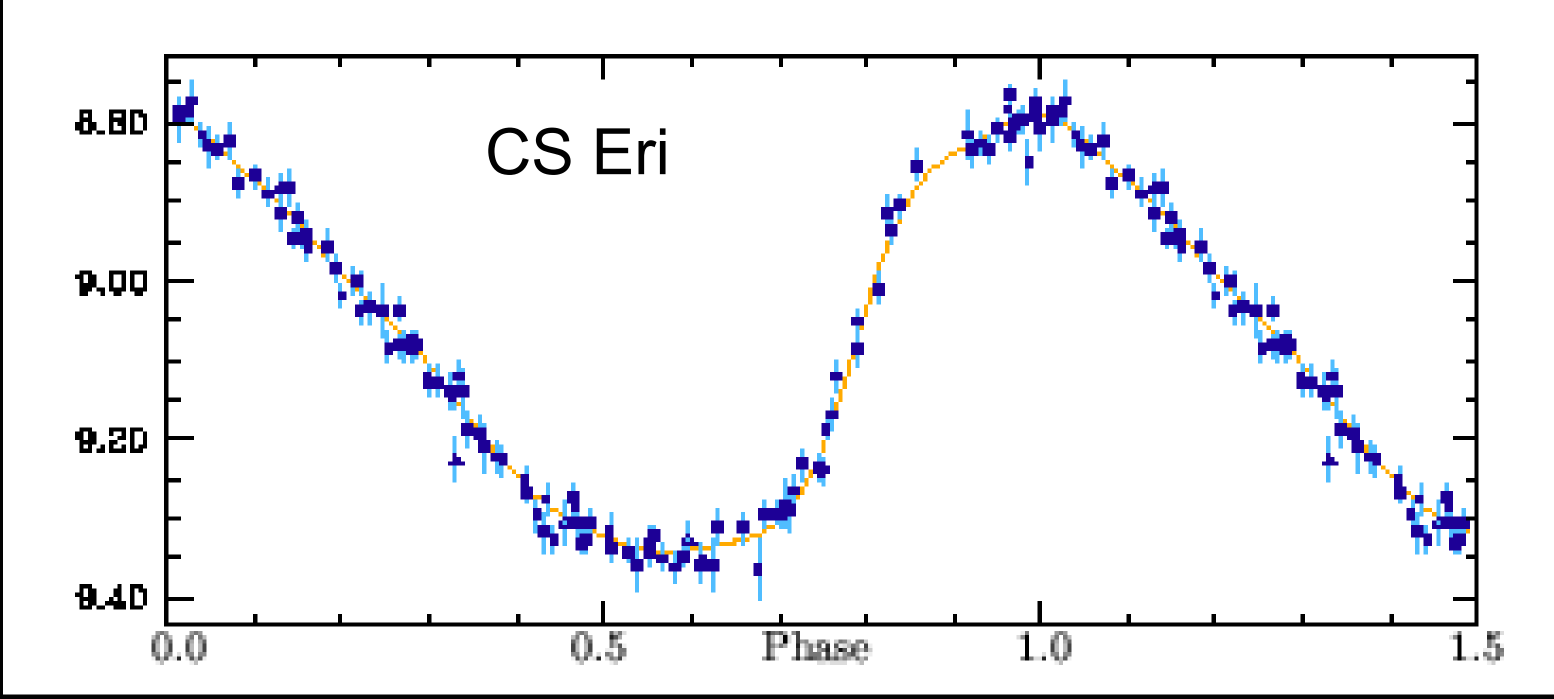
- Compared to the sun
  - half the mass
  - older than sun
  - hotter
  - expended hydrogen … burning helium to carbon
  - pulsates

- Changes brightness with regular period of days

- Luminosity determined by size & temperature
  - for same temperature: larger $\rightarrow$ more luminous
  - for same size: hotter $\rightarrow$ more luminous

- Shrink $\rightarrow$ compressional heating $\rightarrow$ more luminous


6.40
6.60
6.80
7.00
7.20
7.40
0.0
0.5
Phase
1.0
1.5


CS Eri
8.80
9.00
9.20
9.40
0.0
0.5
Phase
1.0
1.5

- Main sequence stars are not extremely bright… we need brighter "standard candle"

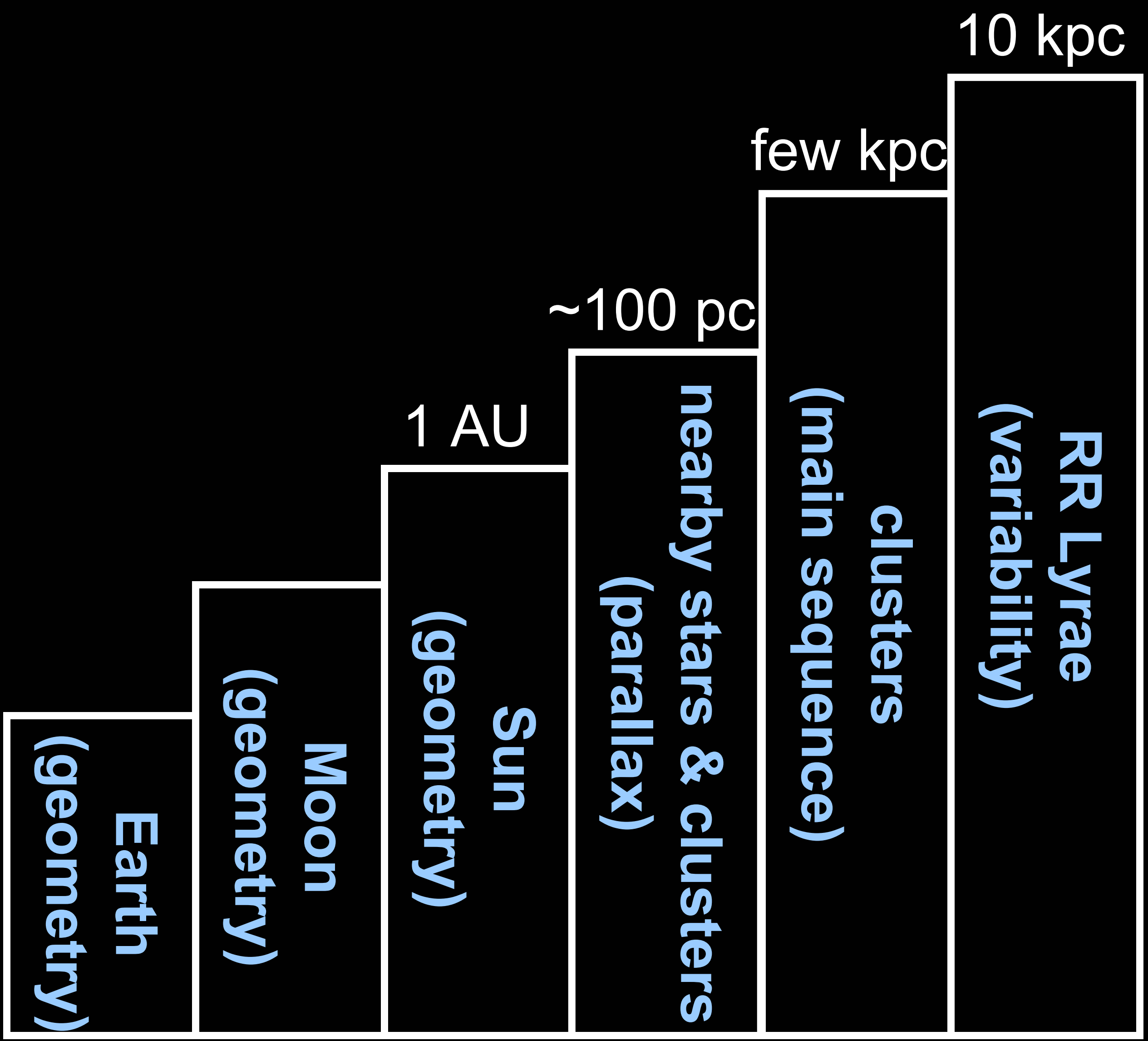
$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

- RR Lyrae stars found in distant clusters we know the distance to via H-R fitting.

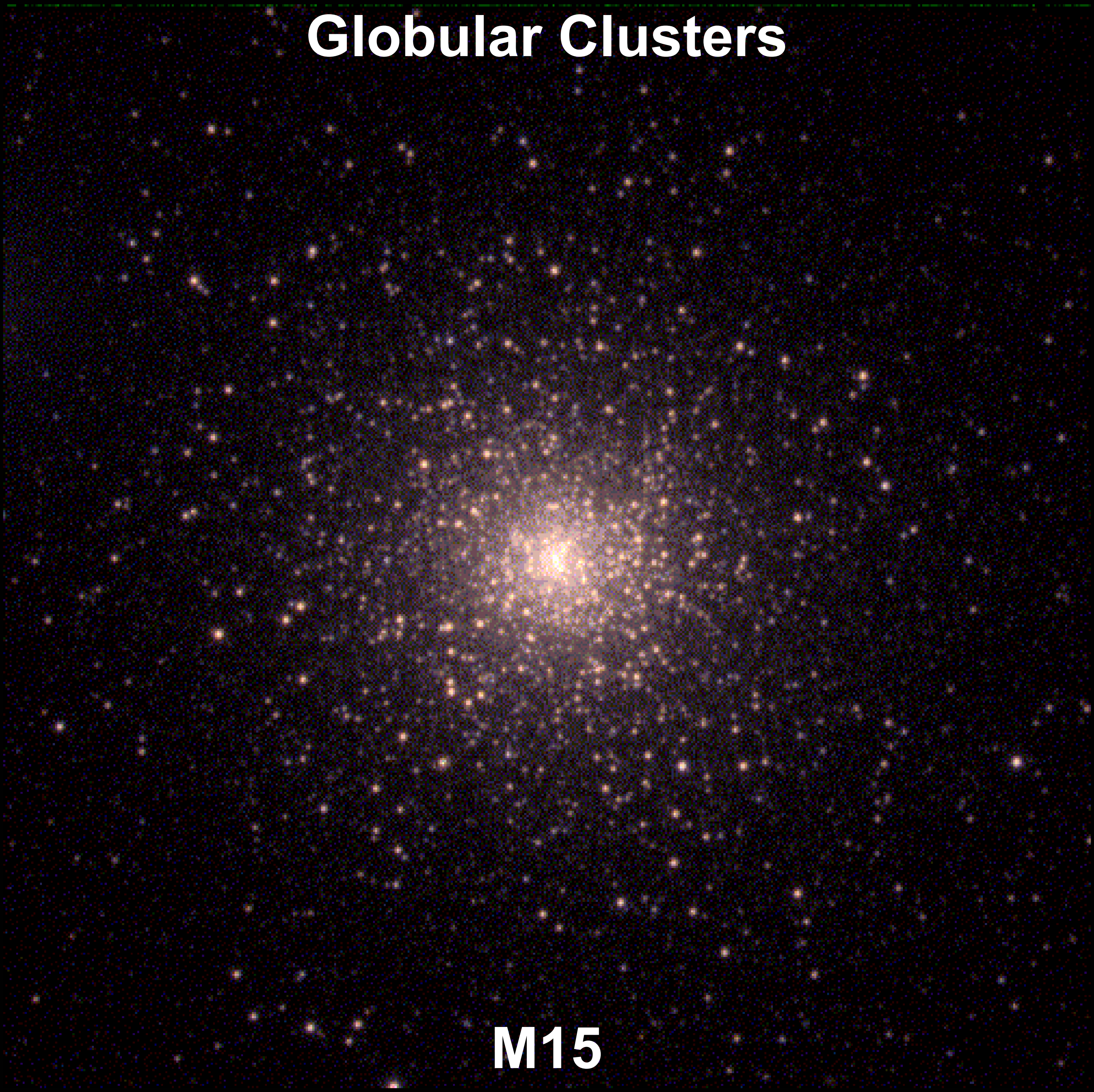
- RR Lyrae stars are identified because their light output changes regularly on a time scale of half to one day.

- They are brighter than the sun by about a factor of 100 and are <u>standard candles</u>. Can see farther away and use as standard candle.

The Cosmological Distance Ladder



Globular Clusters



M15

• Need brighter "standard candle"

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

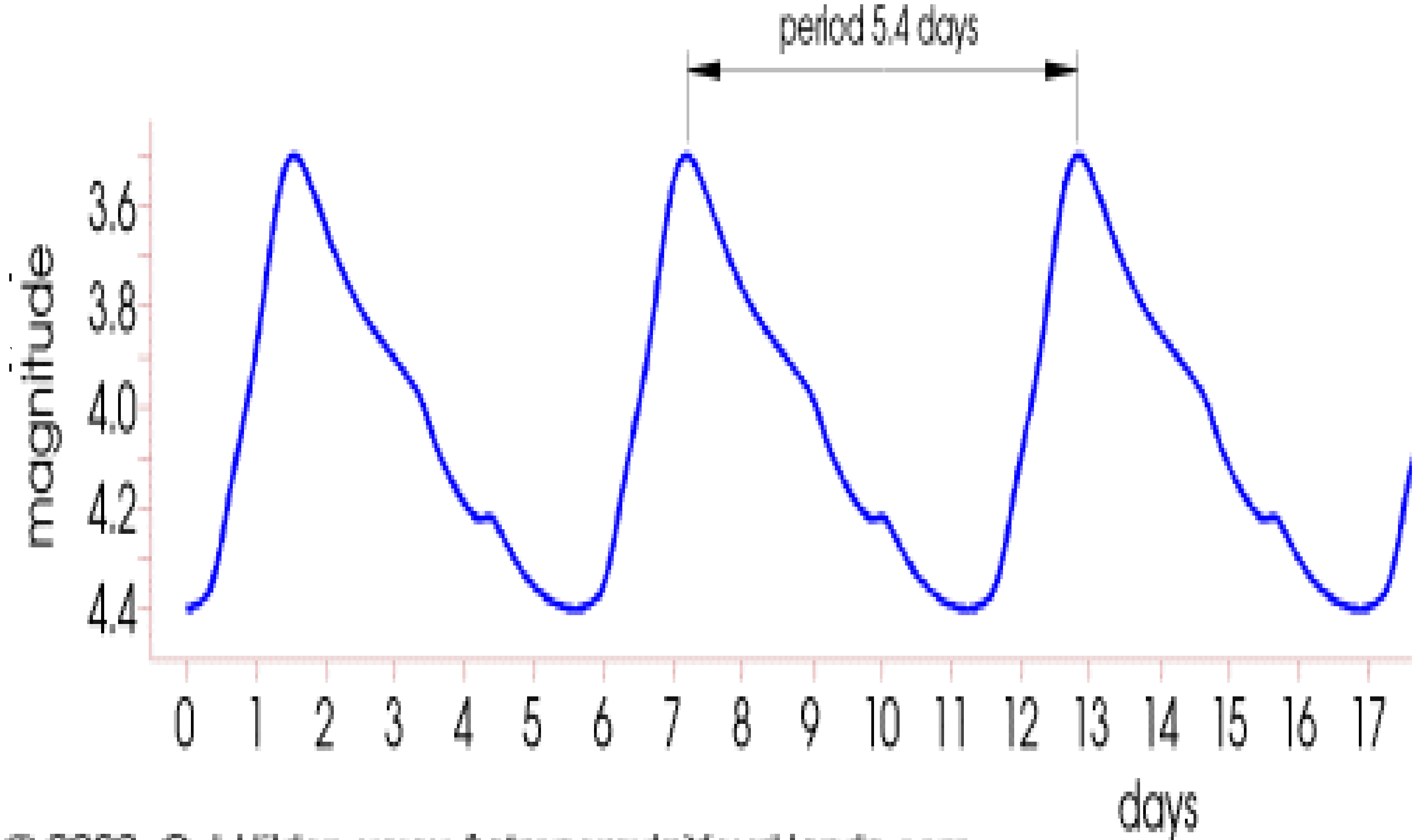
• Other variable stars are brighter: Cepheid Stars (Polaris is a Cepheid)

• Cepheid stars are identified because their light output changes regularly on a time scale of weeks to months. They are very rare.

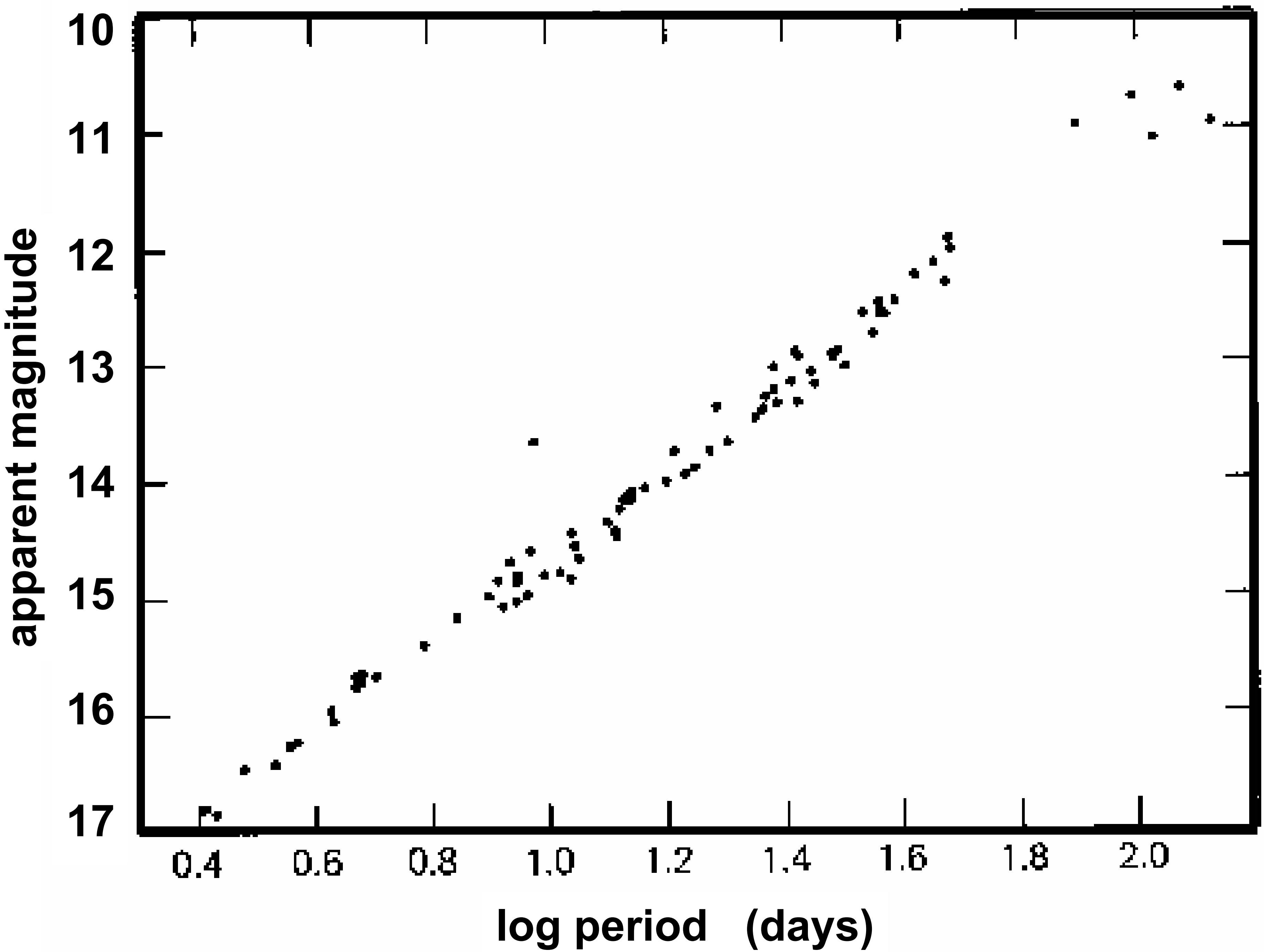
• They are brighter than the sun by about a factor of 10,000 but are <u>not</u> standard candles.

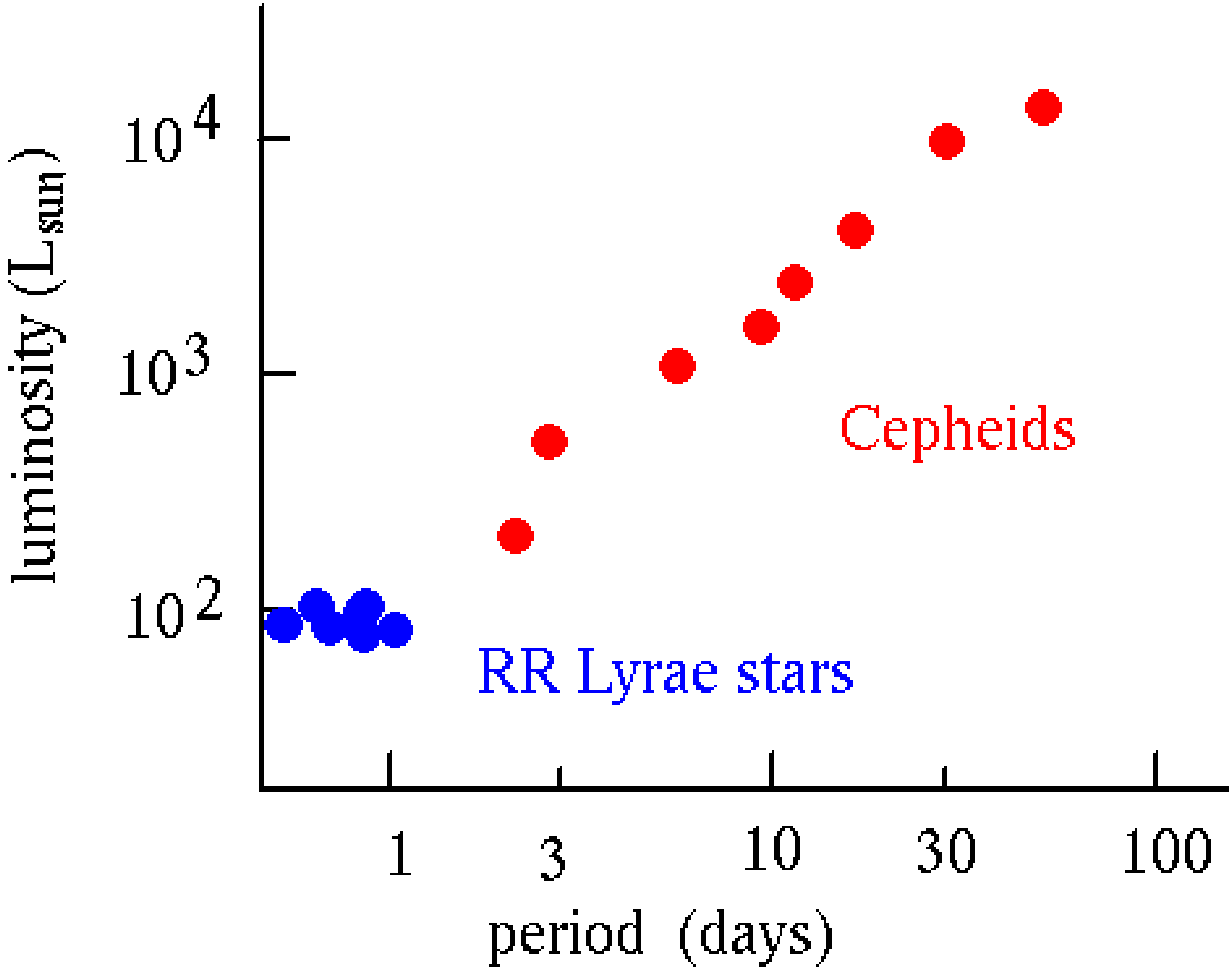
Cepheid Variable Stars

Henrietta Leavitt
1868 - 1921



Light curve of Delta Cephei


10
11
12
13
14
15
16
17
apparent magnitude
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
log period (days)



luminosity (L_{sun})
10^4
10^3
10^2
Cepheids
RR Lyrae stars
1
3
10
30
100
period (days)

Cepheids as distance indicators

For cepheids of known distance

- Measure apparent magnitude of the cepheids

$$I = \frac{L}{4\pi R^2} \quad \rightarrow \text{ know } L$$

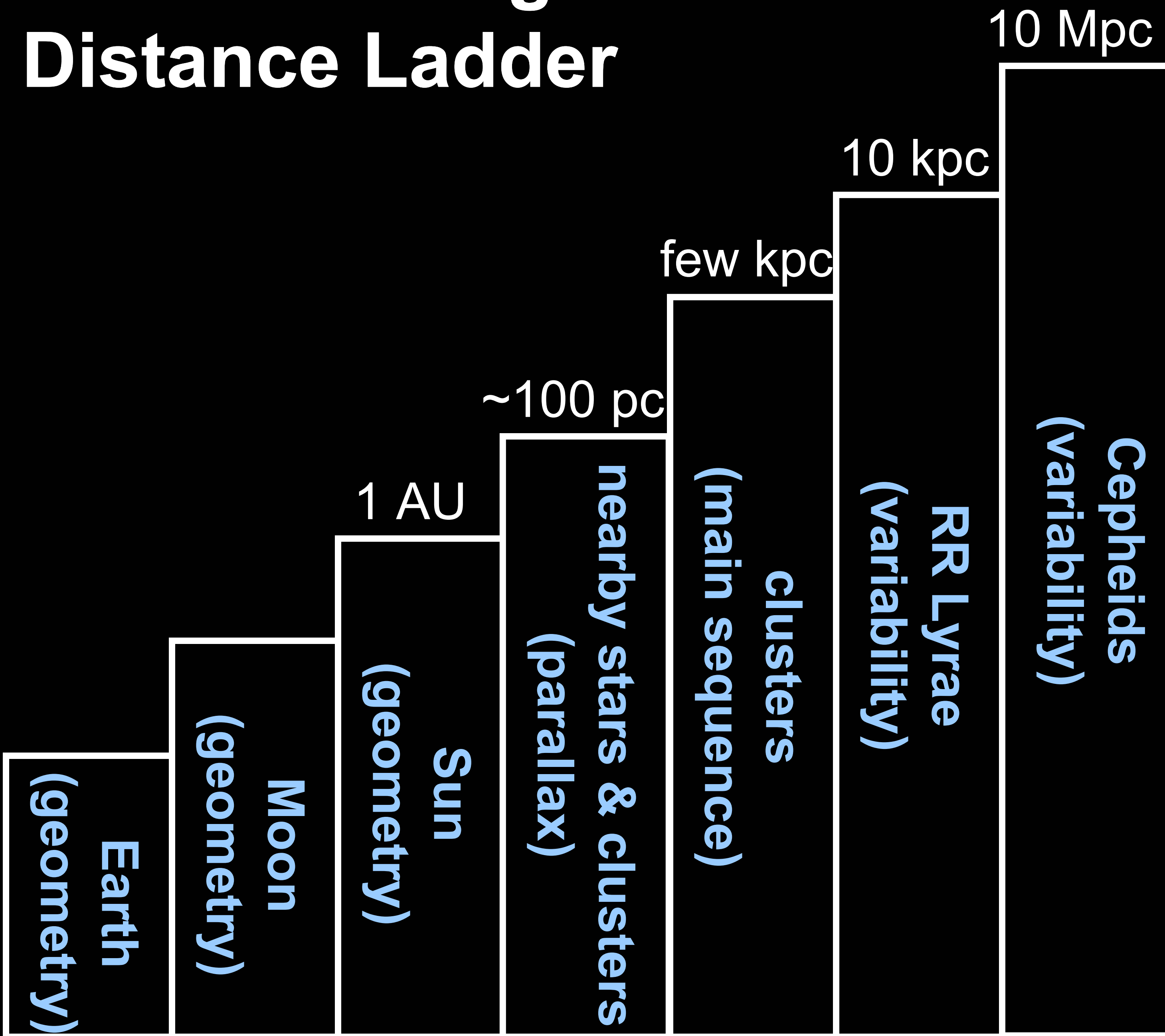
- Measure period of the cepheids
- Calibrate (if know period know L)

For cepheids of unknown distance

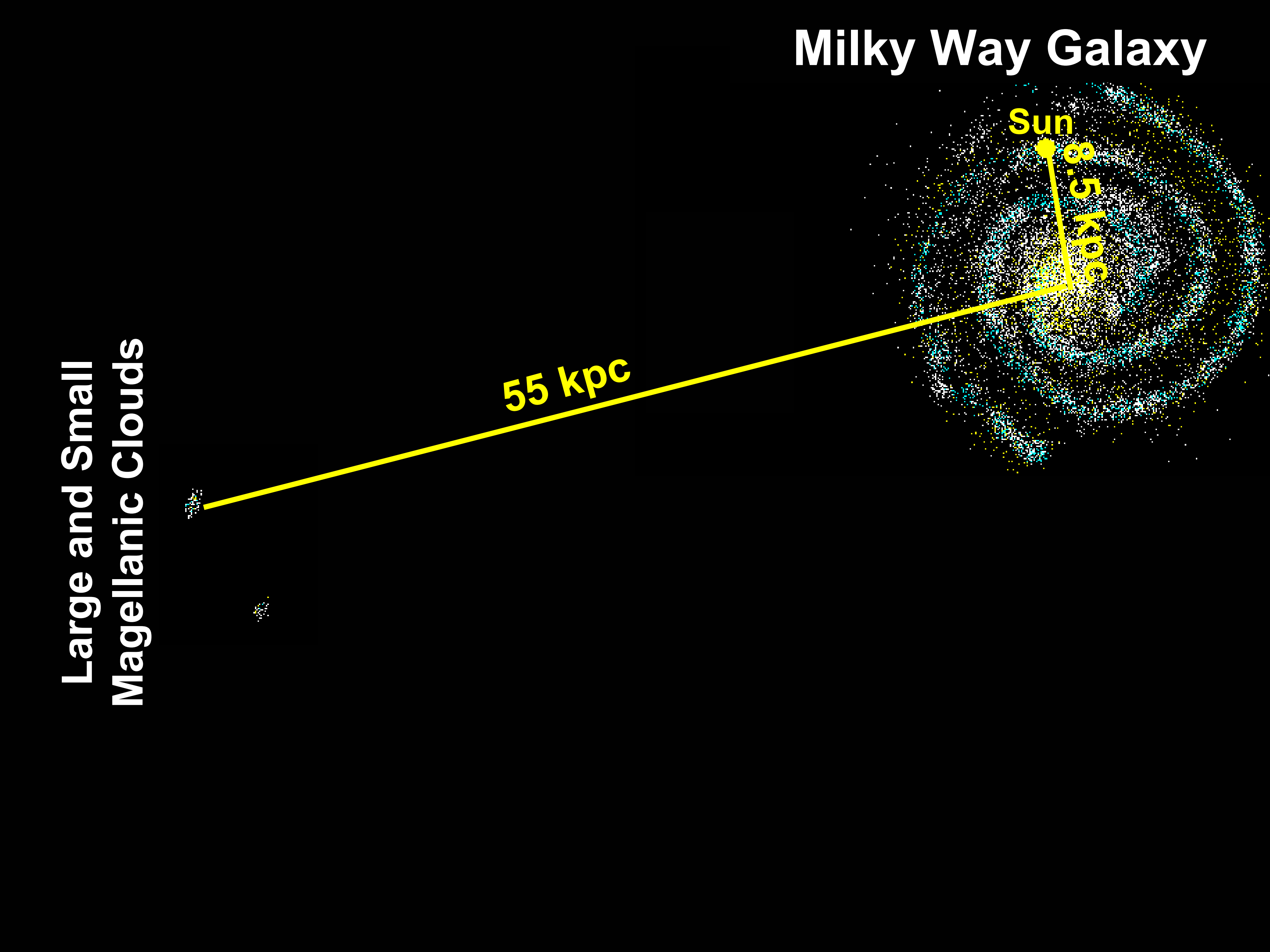
- Measure period….know L
- Measure apparent magnitude

$$I = \frac{L}{4\pi R^2} \quad \rightarrow \text{ know } R$$

The Cosmological Distance Ladder



Large Magellanic Cloud 100 million stars 55 kpc distant



Milky Way Galaxy
Sun
8.5 kpc
55 kpc
Large and Small
Magellanic Clouds