Earth 101
Introduction to Astronomy

Stellar Evolution

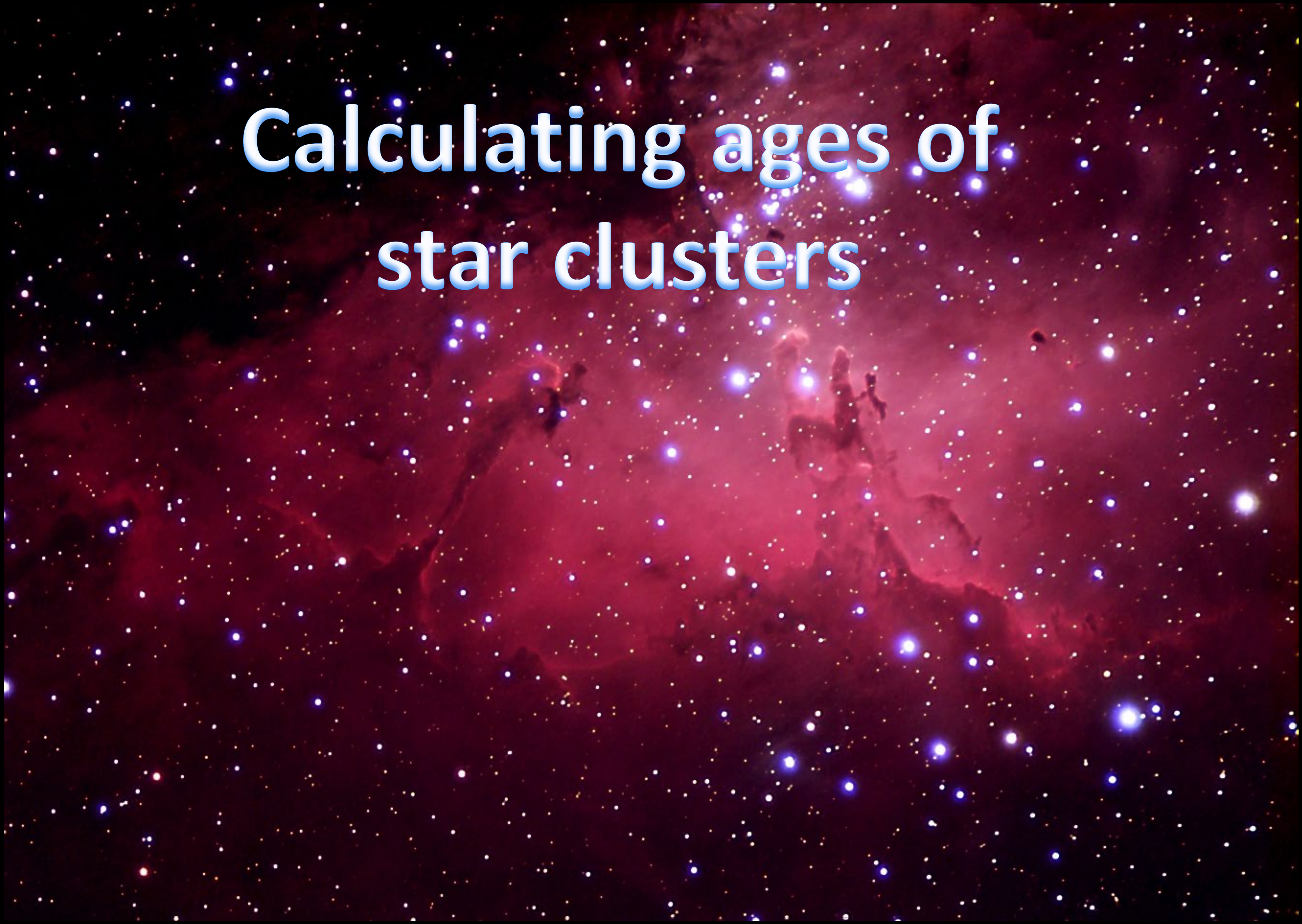
Instructor:
Erin O'Connor

OpenStax Ch 21
Stellar Evolution
Star Clusters
Turn-Off Point

Photo/Material Credit:
- Fred Marschak
- Dr. Jatila van der Veen
- Erin O'Connor + others

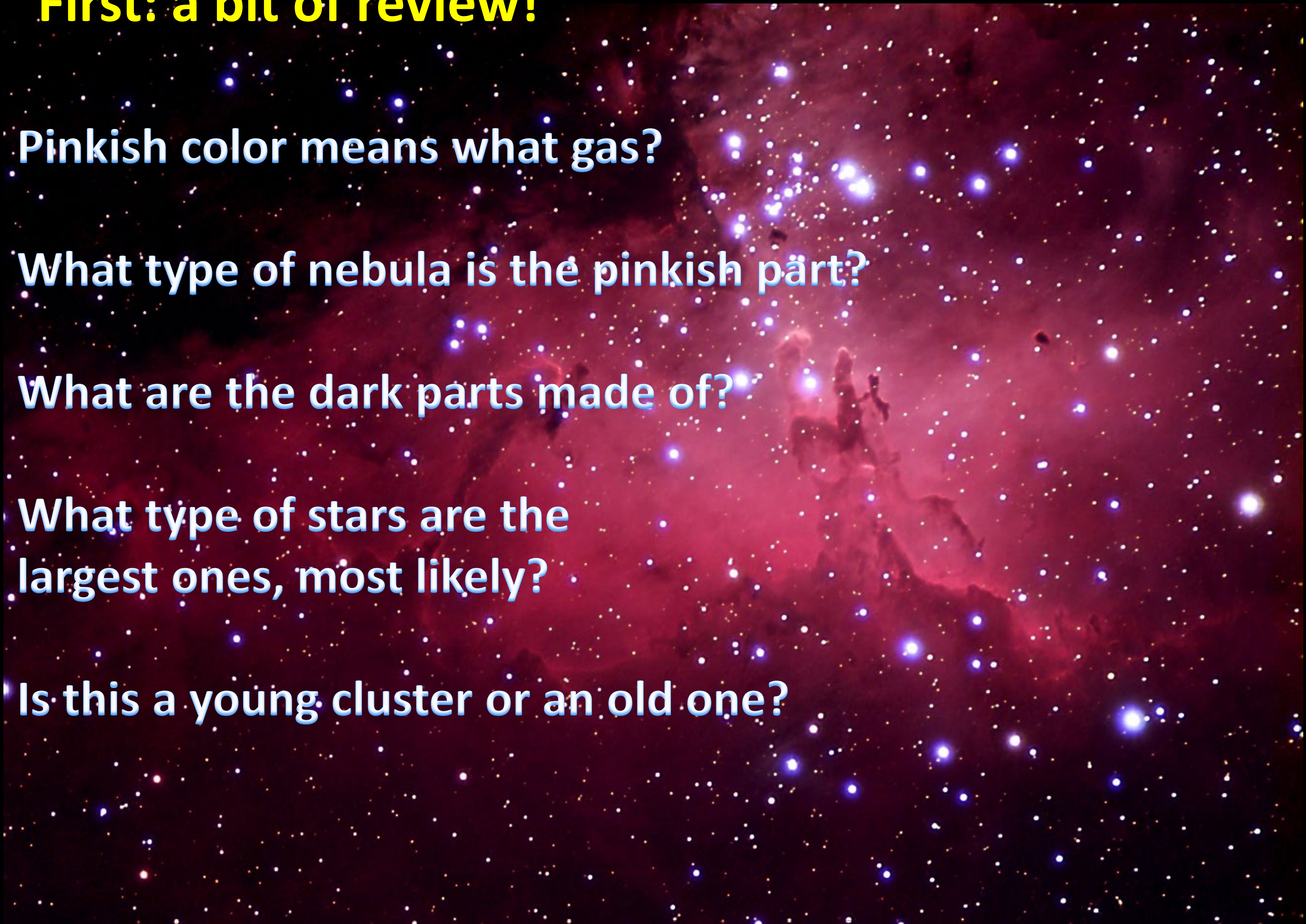
The Horsehead and Flame Nebula © 2022 Hector Jimenez

Calculating ages of star clusters



1. Finding ages of star clusters from the turnoff points on the HR diagram of Red Giants

First: a bit of review!



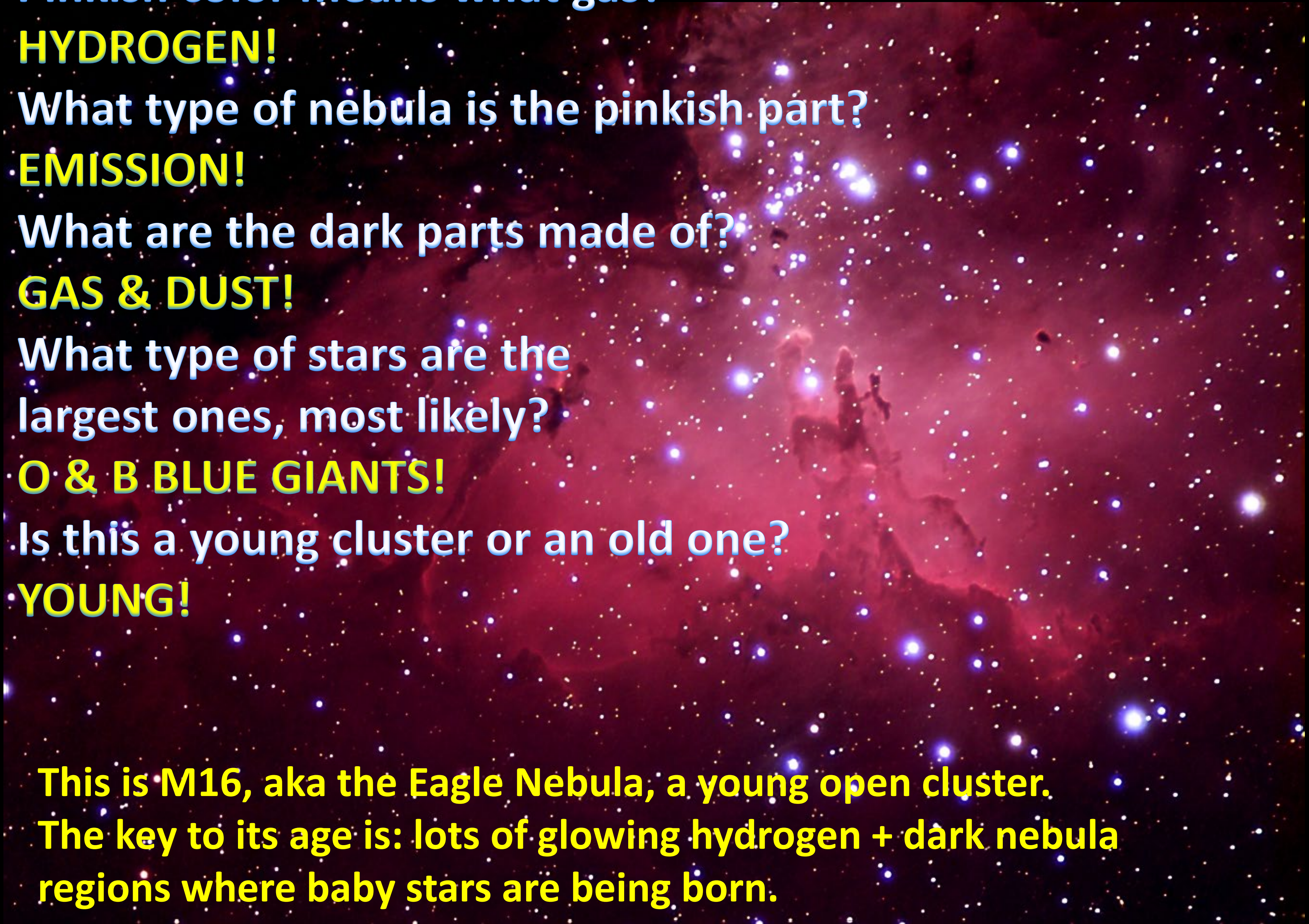
Pinkish color means what gas?

What type of nebula is the pinkish part?

What are the dark parts made of?

What type of stars are the largest ones, most likely?

Is this a young cluster or an old one?



Pinkish color means what gas?

HYDROGEN!

What type of nebula is the pinkish part?

EMISSION!

What are the dark parts made of?

GAS & DUST!

What type of stars are the largest ones, most likely?

O & B BLUE GIANTS!

Is this a young cluster or an old one?

YOUNG!

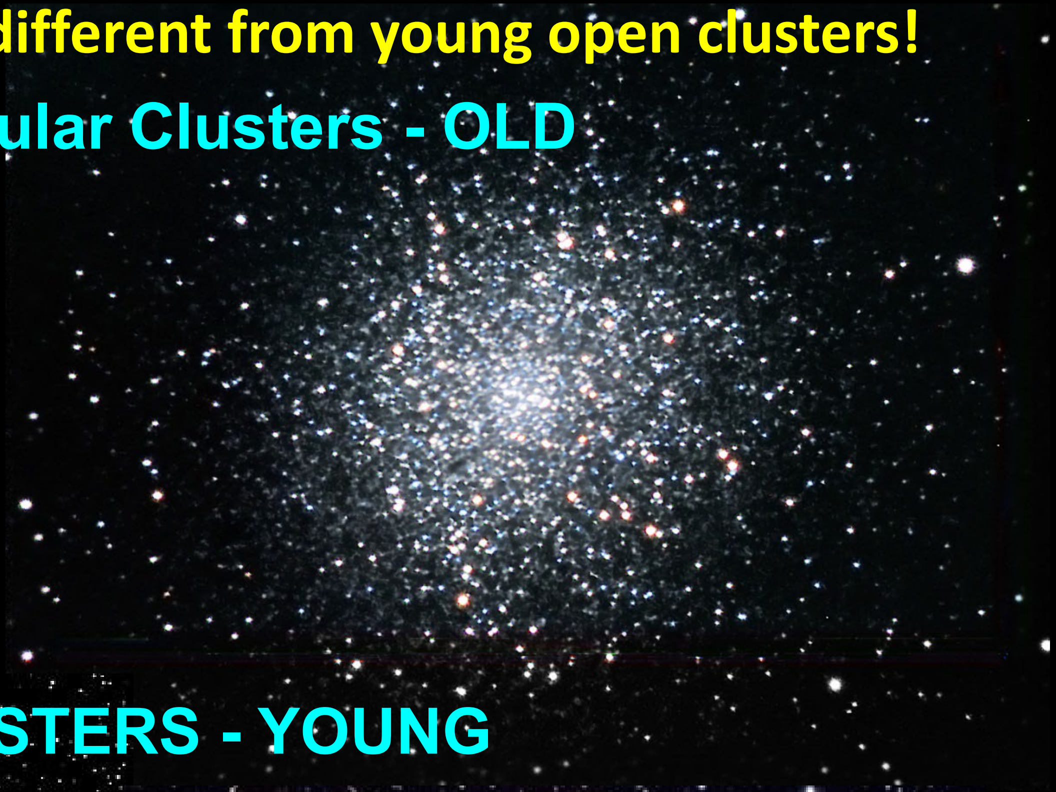
This is M16, aka the Eagle Nebula, a young open cluster.
The key to its age is: lots of glowing hydrogen + dark nebula regions where baby stars are being born.

Globular Cluster M13 in Hercules
an OLD cluster

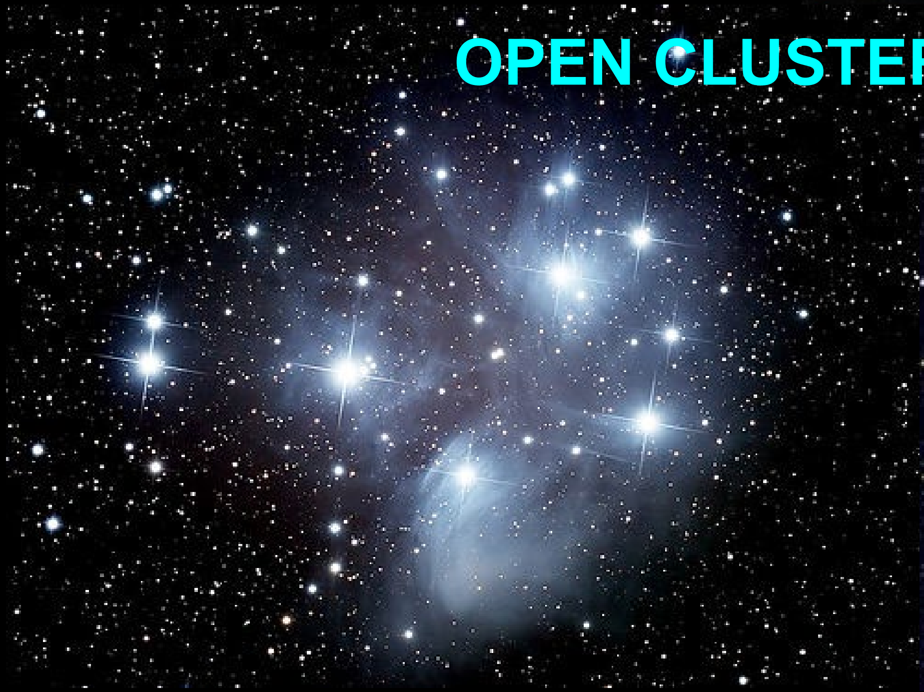
The Pleides – a young open cluster with hot O and B blue giants in Taurus

Old globular clusters look different from young open clusters!

Globular Clusters - OLD



OPEN CLUSTERS - YOUNG



Importance of Star Clusters:

- All stars at the same distance from us

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- Stars of different sizes, in different stages of evolution, but all are the same *age because they formed at the same time from the same nebula.*

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- Turn off point: Where the stars that have exhausted hydrogen in their cores are leaving the main sequence and becoming red giants.

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- ***We can estimate the age of a cluster from the luminosity of the stars that are just leaving the main sequence – i.e., they have run out of hydrogen in their cores and are becoming red giants.***

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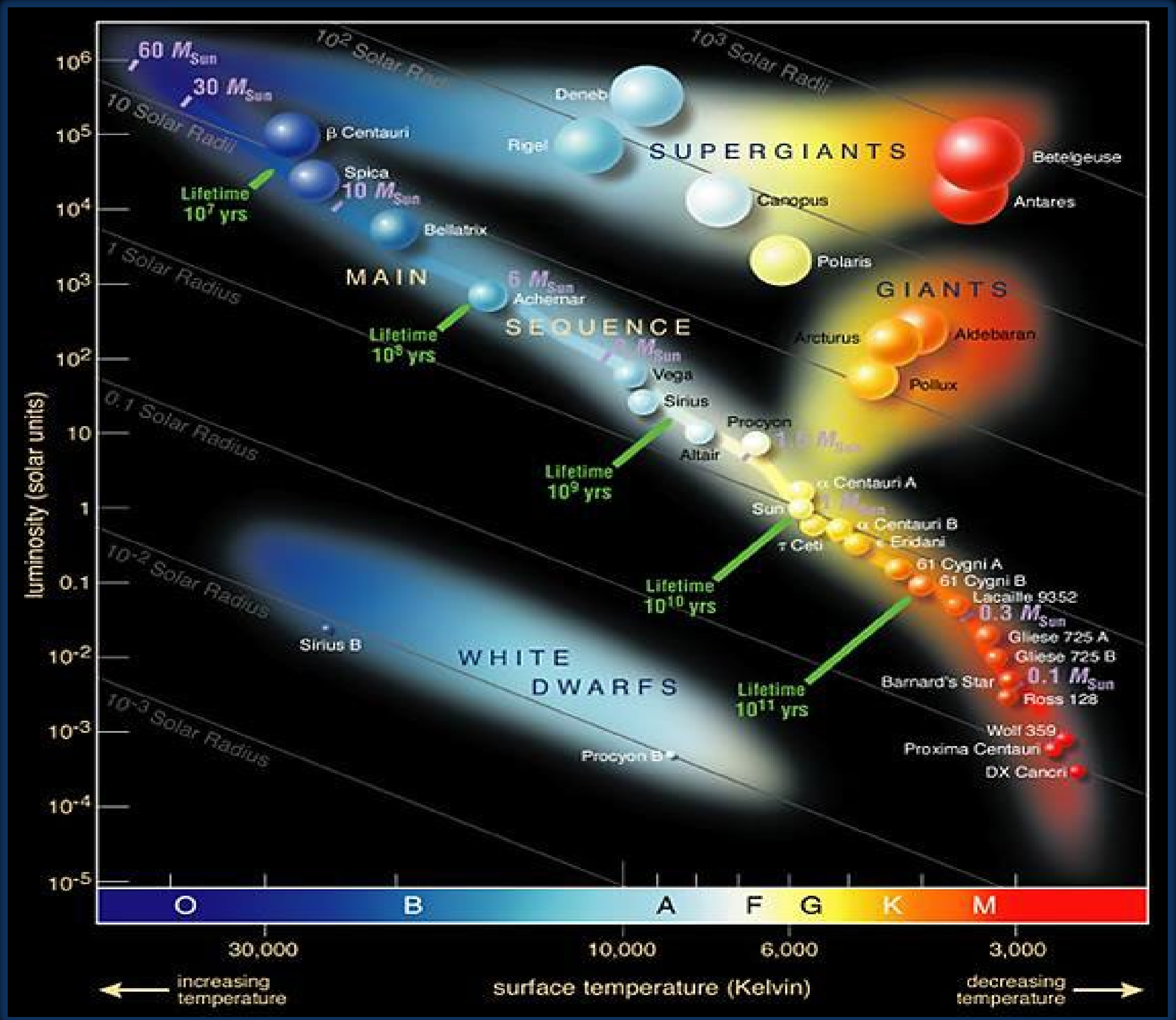
- ***We can estimate the age of a cluster from the luminosity of the stars that are just leaving the main sequence – i.e., run out of hydrogen in their cores.***
- ***We can estimate the distance to the cluster by comparing its HR diagram with the HR diagram***

Recall:

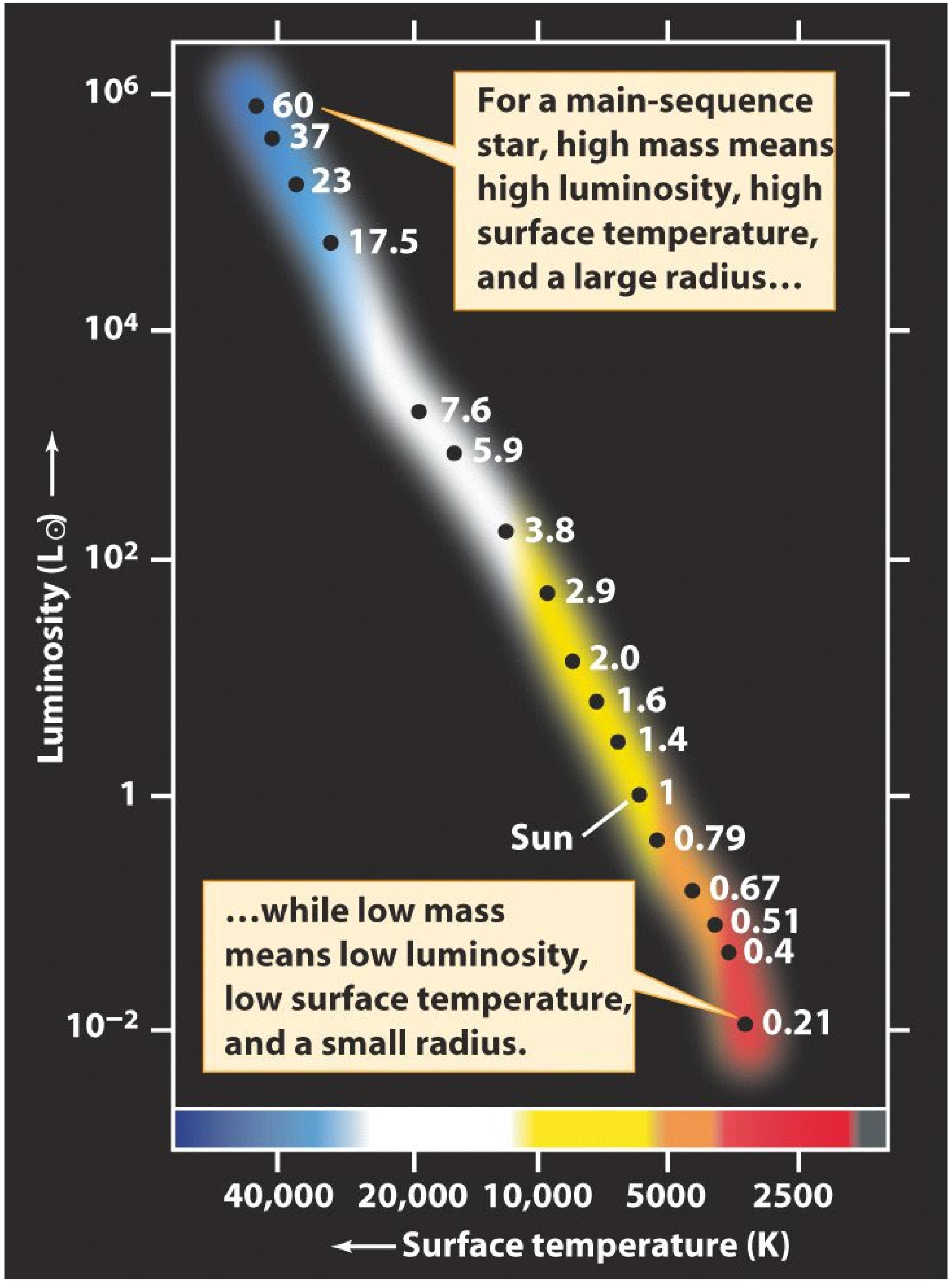
Where a star begins its life on the Main Sequence, and how it 'lives' and 'dies' is determined by how much mass it has to start with.



More mass

faster rate of nuclear fusion

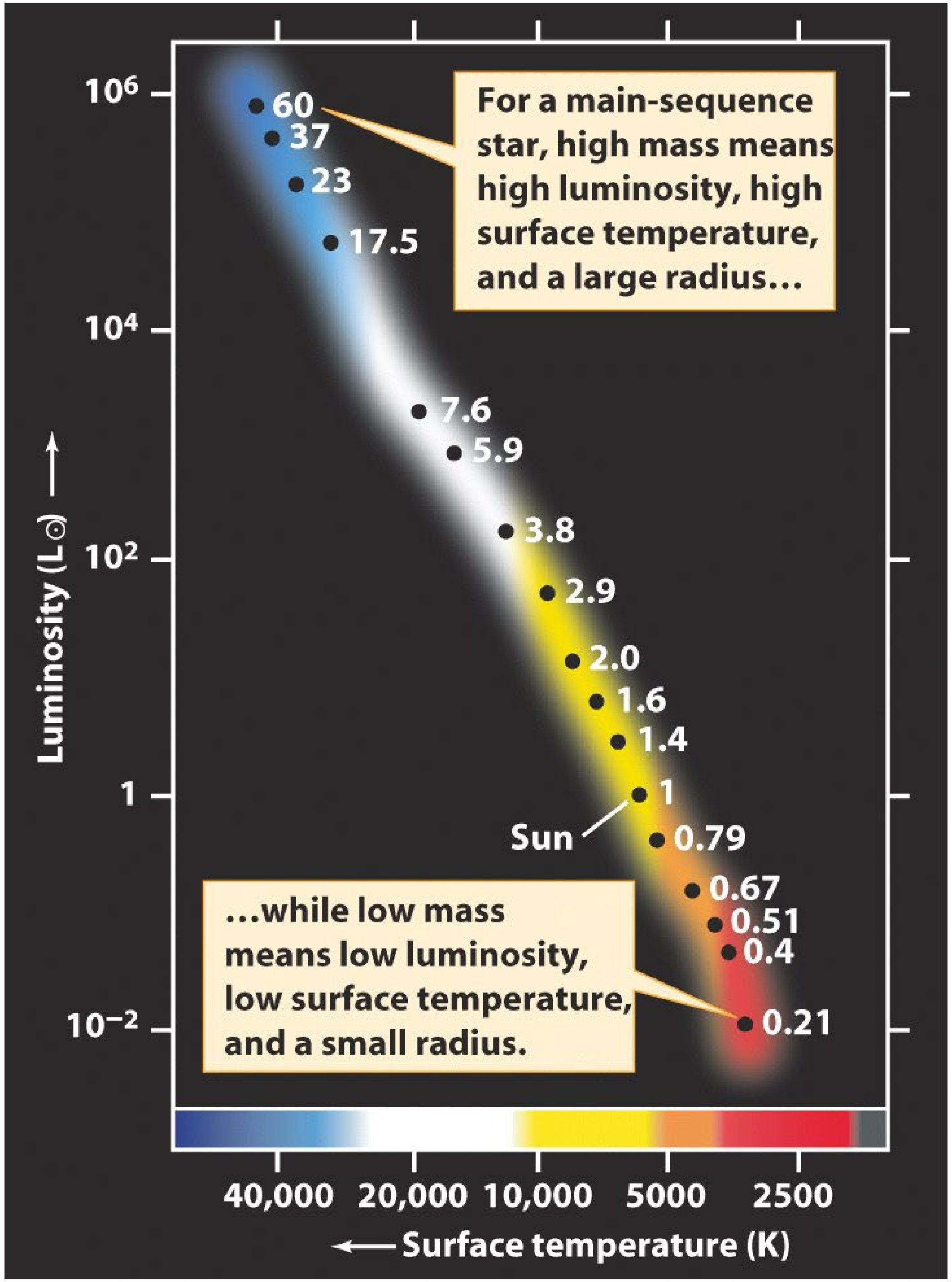
shorter lifetime

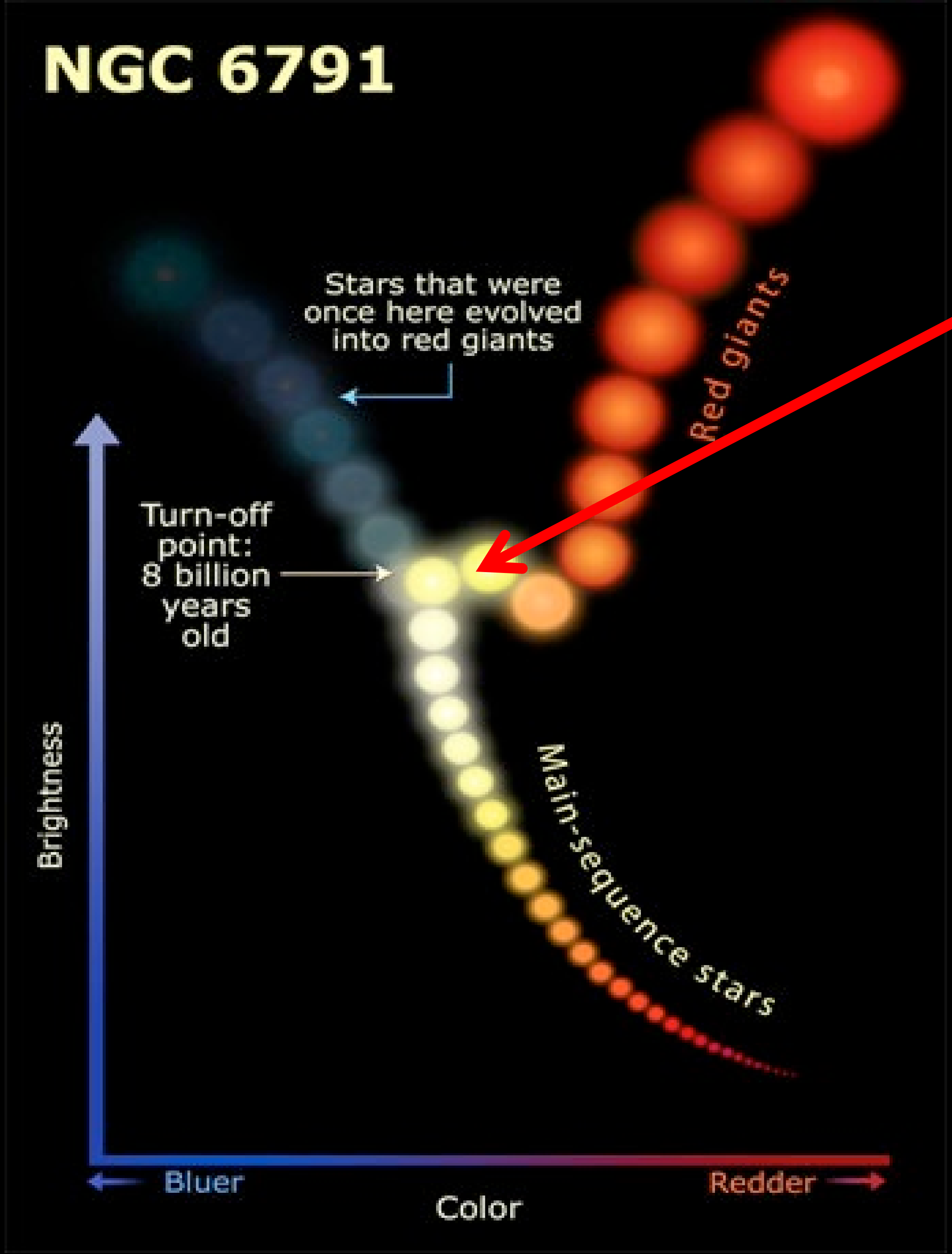


Recall:
You can calculate a star's PREDICTED lifetime on the main sequence by its luminosity.

$$T = \frac{1}{L^{.7143}}$$

This is the predicted age when the star will run out of hydrogen in its core and turn off the main sequence, towards the red giant branch.





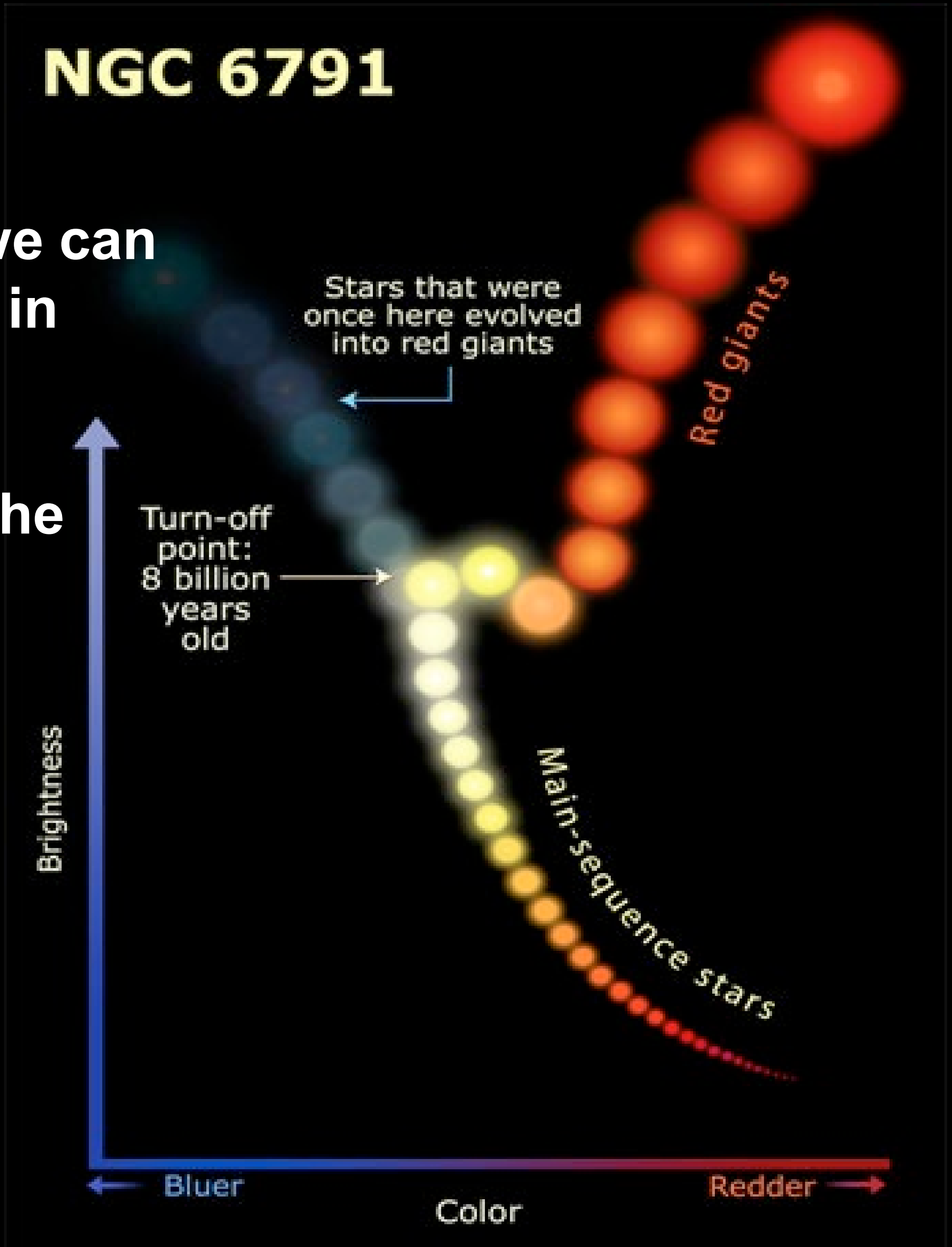
Turn off point:
where stars leave the main sequence, having exhausted their hydrogen fuel, and become red giants.

The luminosity of the stars at the turn off point tells the age of the cluster.

$$age = \frac{1}{L^{.7143}}$$

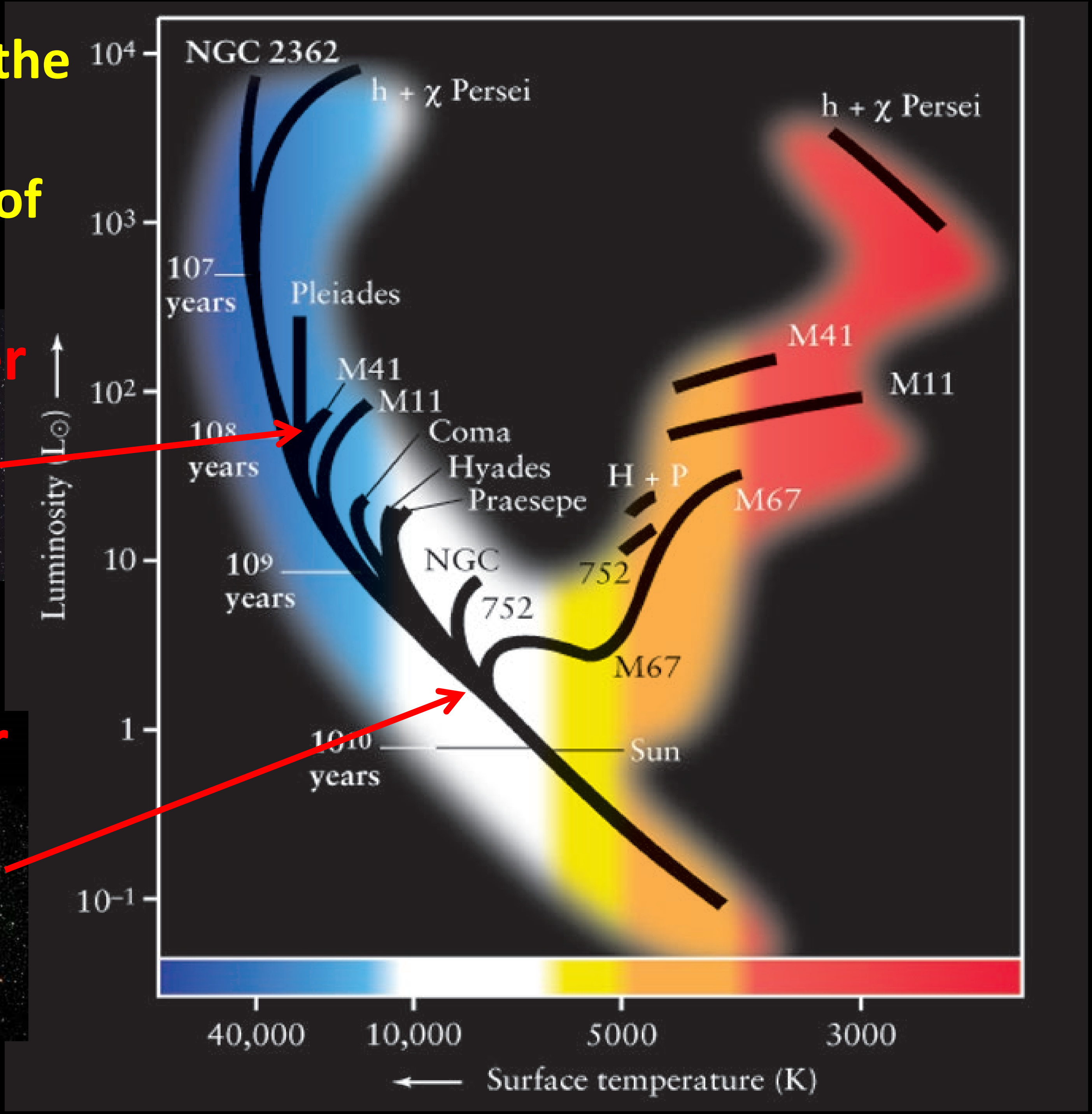
Since we know
how long a star of a
certain MASS will
stay on Main sequence, we can
tell how old the cluster is in
terms of the predicted
lifetime of the Sun,
from the turnoff point of the
stars that are just at the
point of becoming
red giants.

$$age = \frac{1}{L^{.7143}}$$



Luminosity at the turn-off point gives the AGE of the cluster!

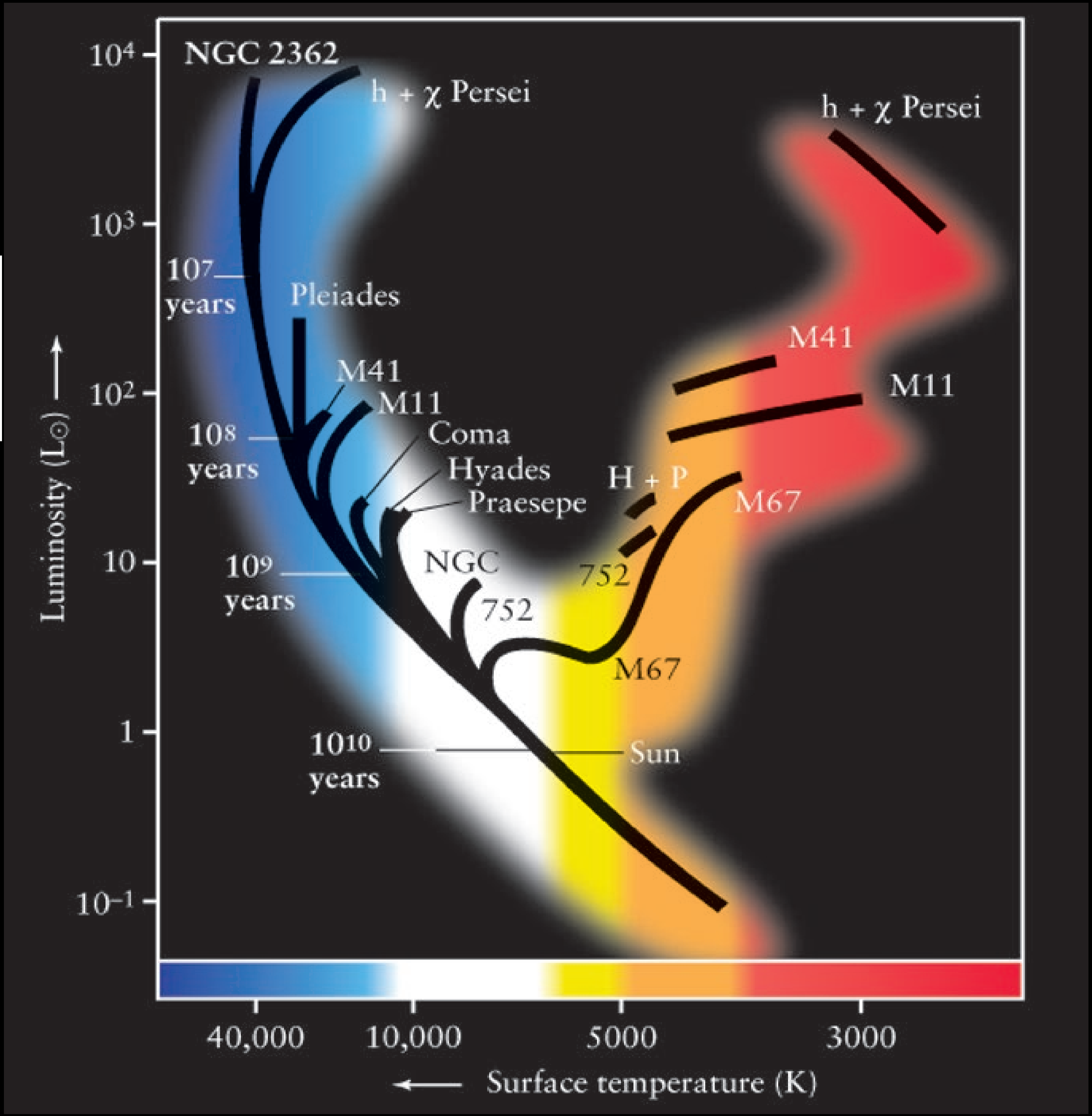
$$age = \frac{1}{L^{.7143}}$$



To find AGES of star clusters:
Find luminosity at turn-off point.

$$age = \frac{1}{L^{.7143}}$$

in solar lifetimes



Pleiades cluster – young B – A stars are leaving the main sequence

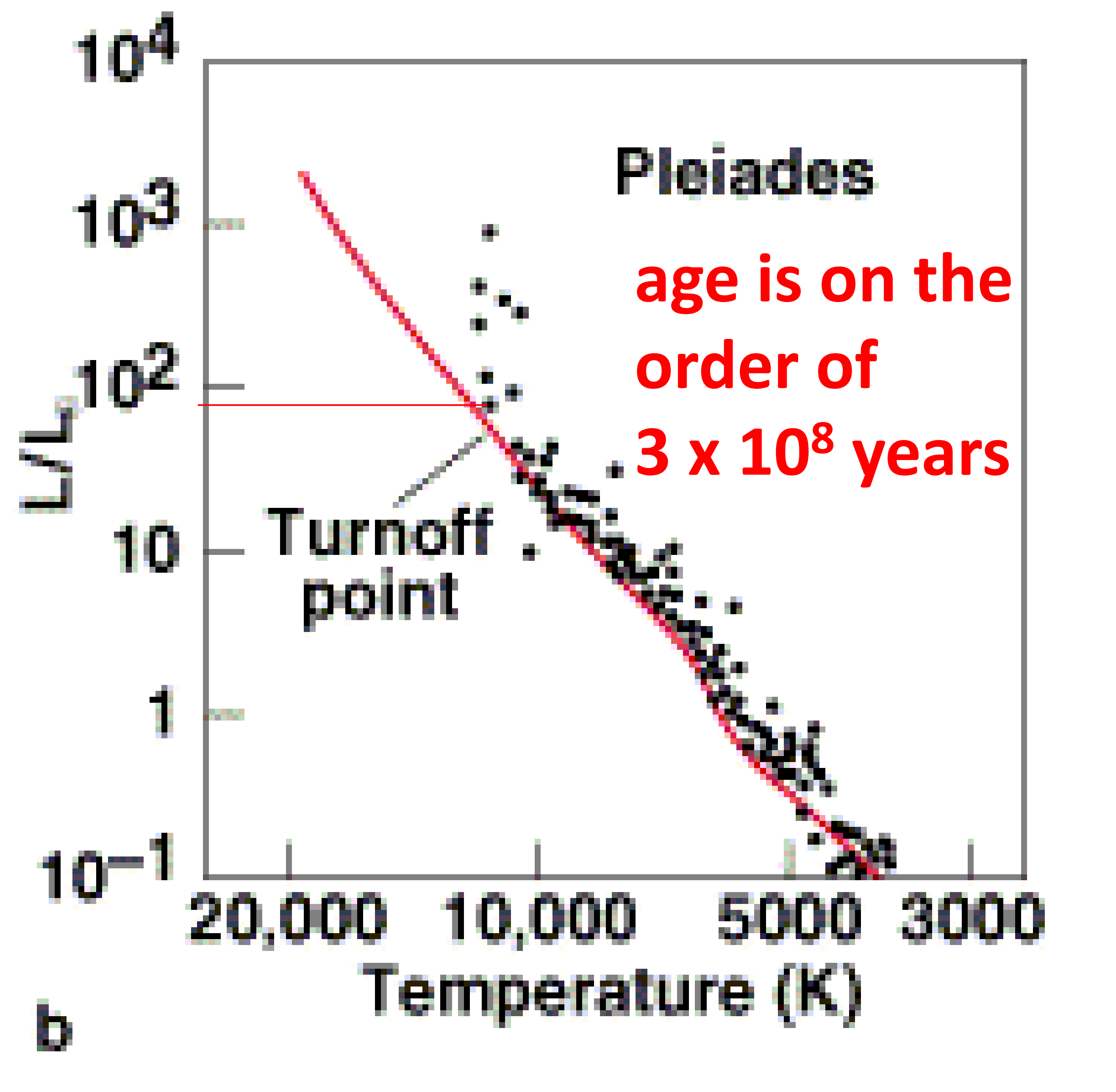
$$age = \frac{1}{L^{.7143}}$$

L at Turnoff point is around 95L_{Sun}

$1/95^{.7143}$

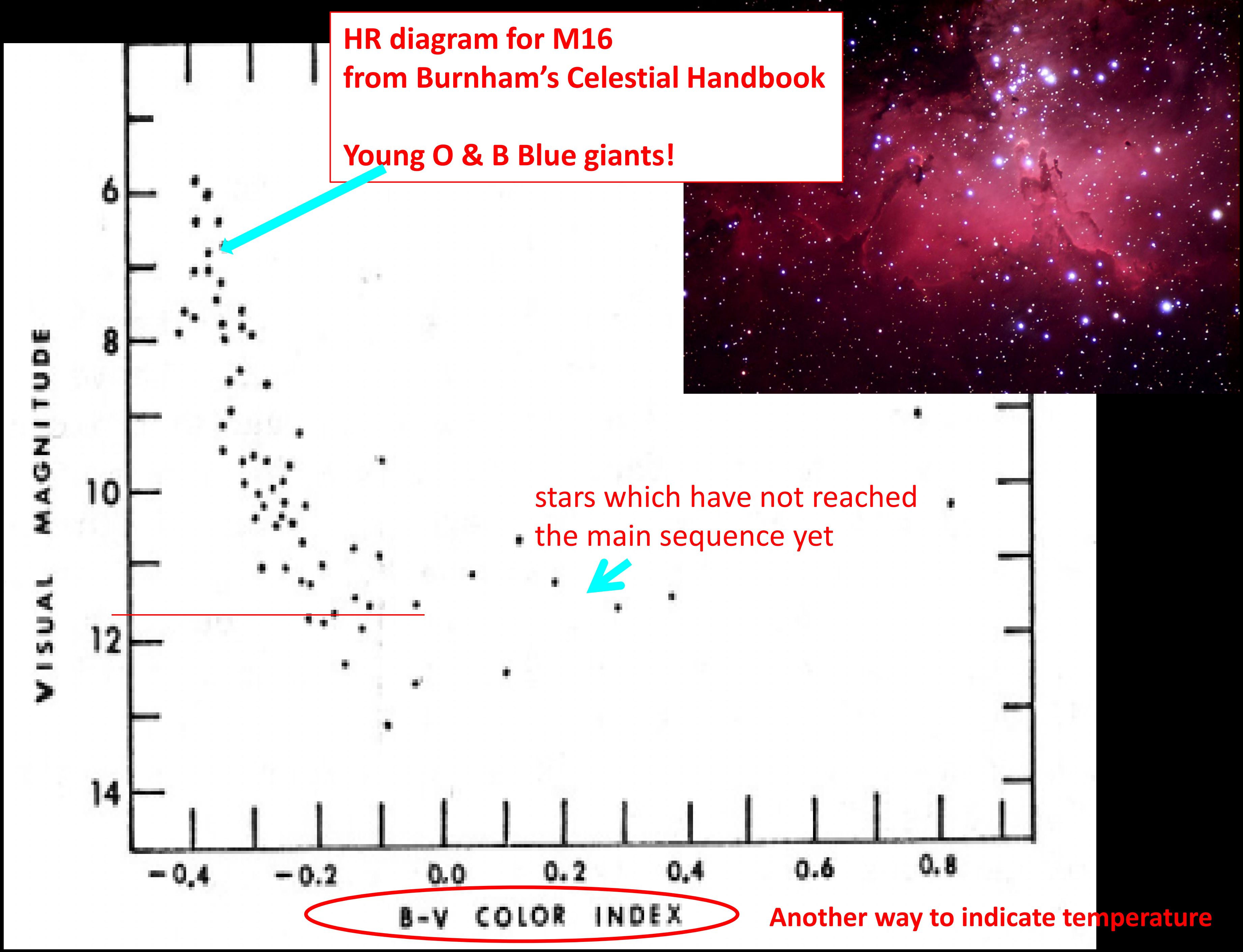
$= 0.386 T_{Sun} =$

~386 million years



HR diagram for M16
from Burnham's Celestial Handbook

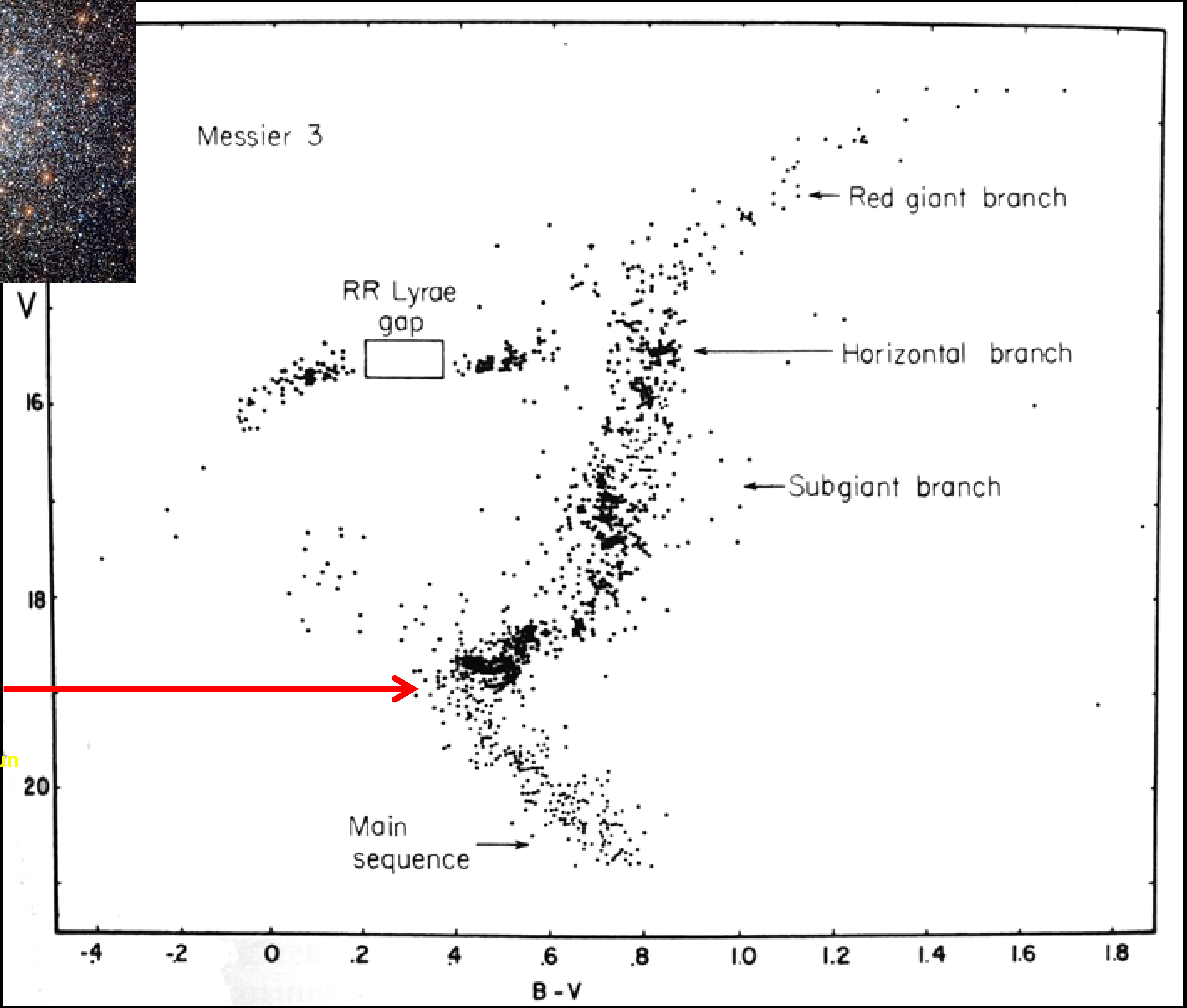
Young O & B Blue giants!



stars which have not reached
the main sequence yet

Another way to indicate temperature

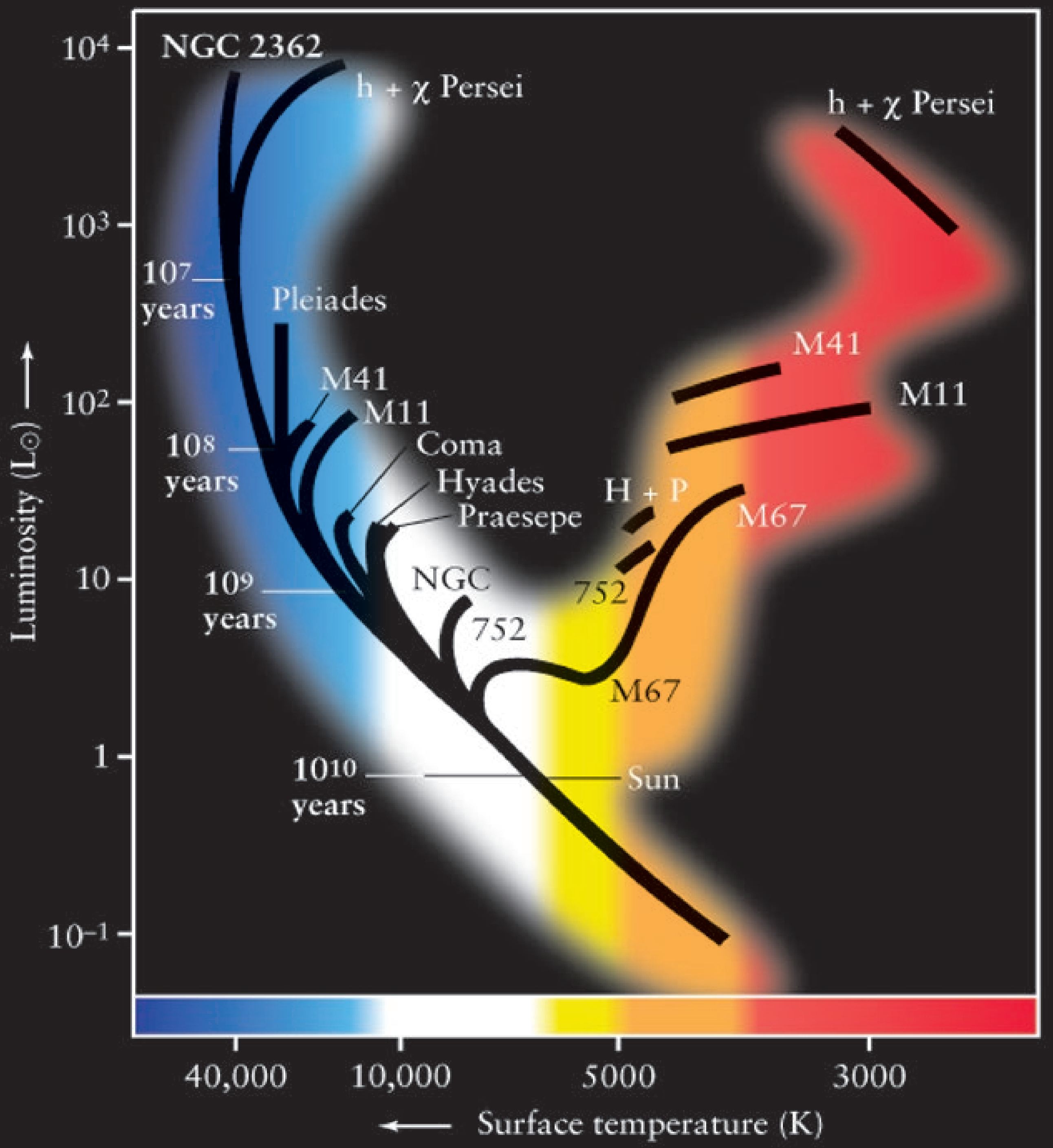
M3 - old globular cluster



turn off point
L ~ 0.8 L_{sun}
$T=1/.8^{.7143}=1.1T_{Sun}$
~11 Gyr

Review:
Given a diagram like this one, rank the following star clusters from oldest to youngest:

- a. Pleiades
- b. M11
- c. NGC 2362
- d. M67
- e. Coma Cluster



Given a diagram like this one, rank the following star clusters from oldest to youngest:

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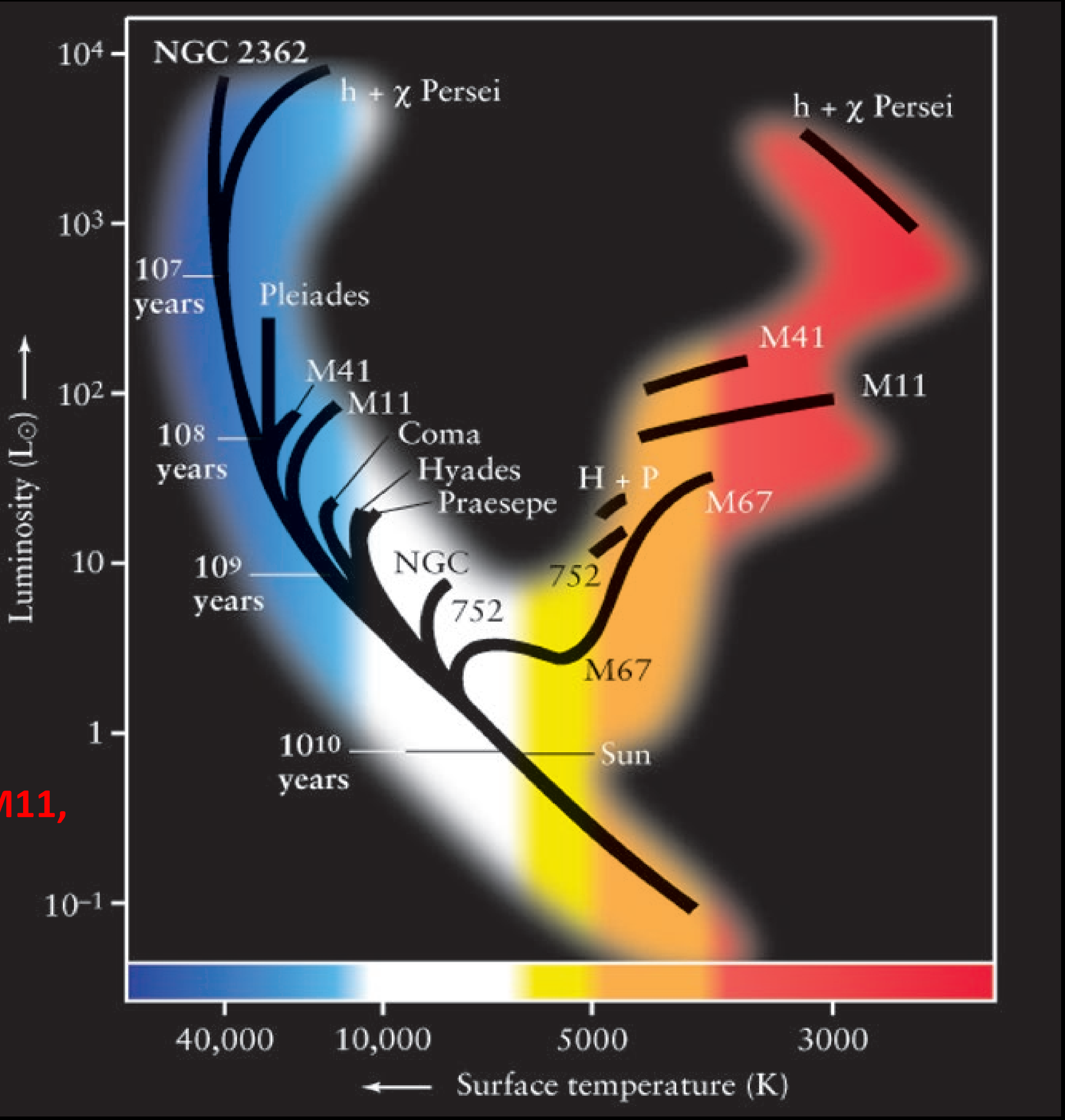
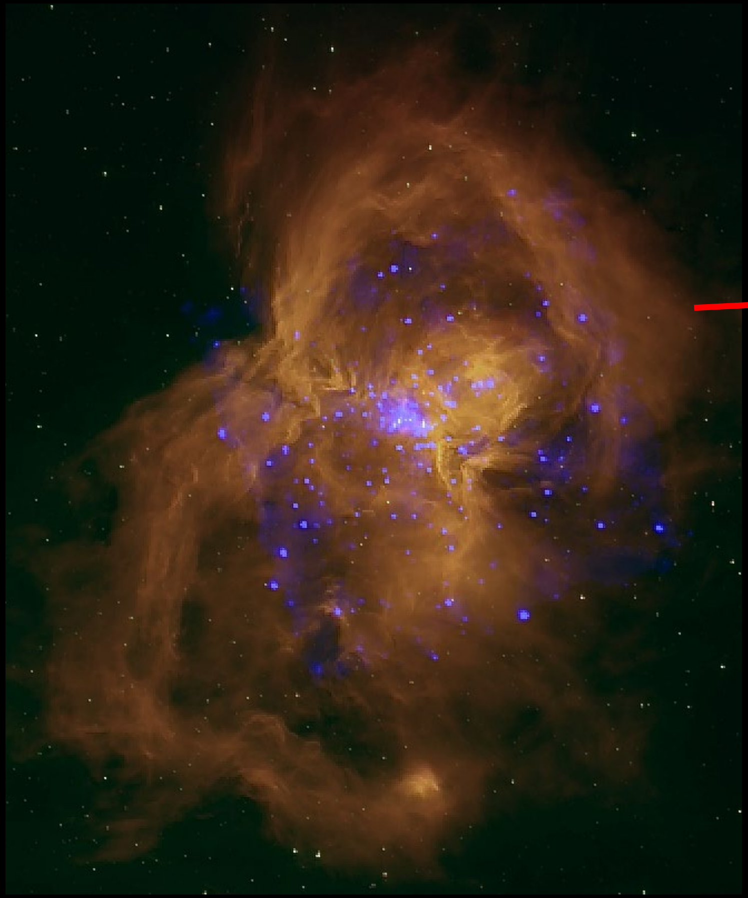
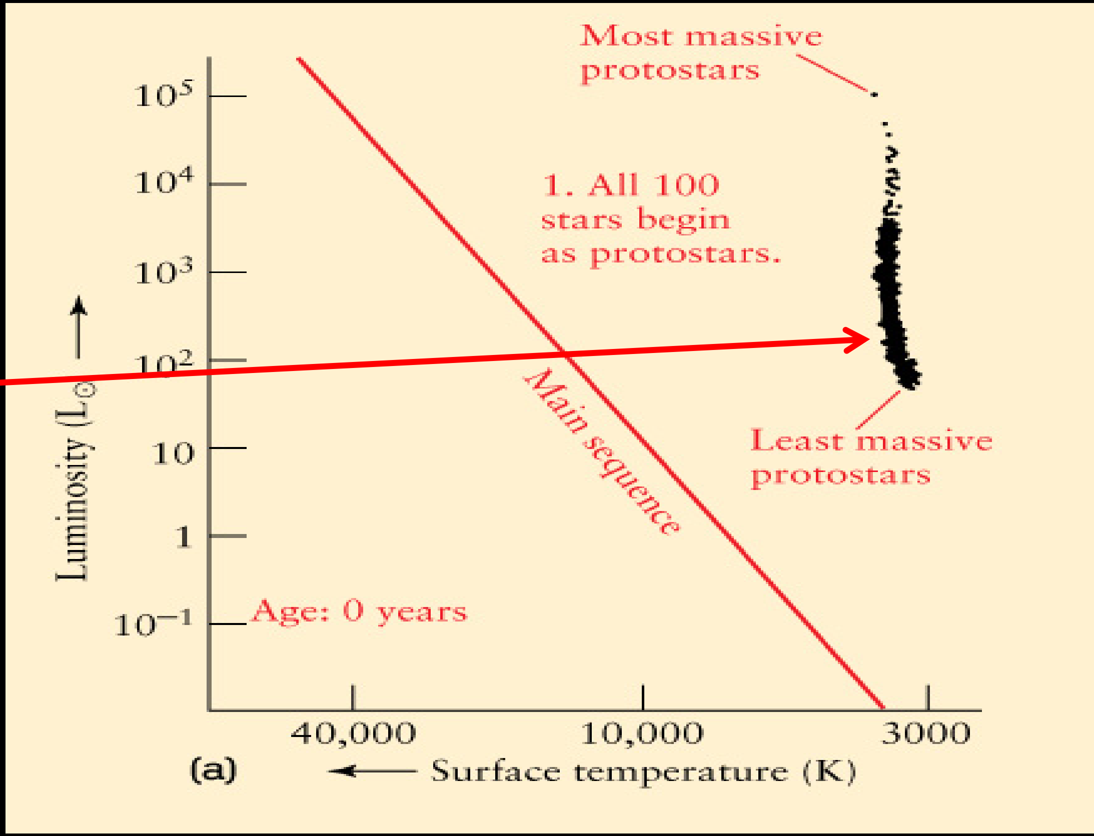
M67, Coma Cluster, M11, Pleiades, NGC 2362

d – e – b – a – c

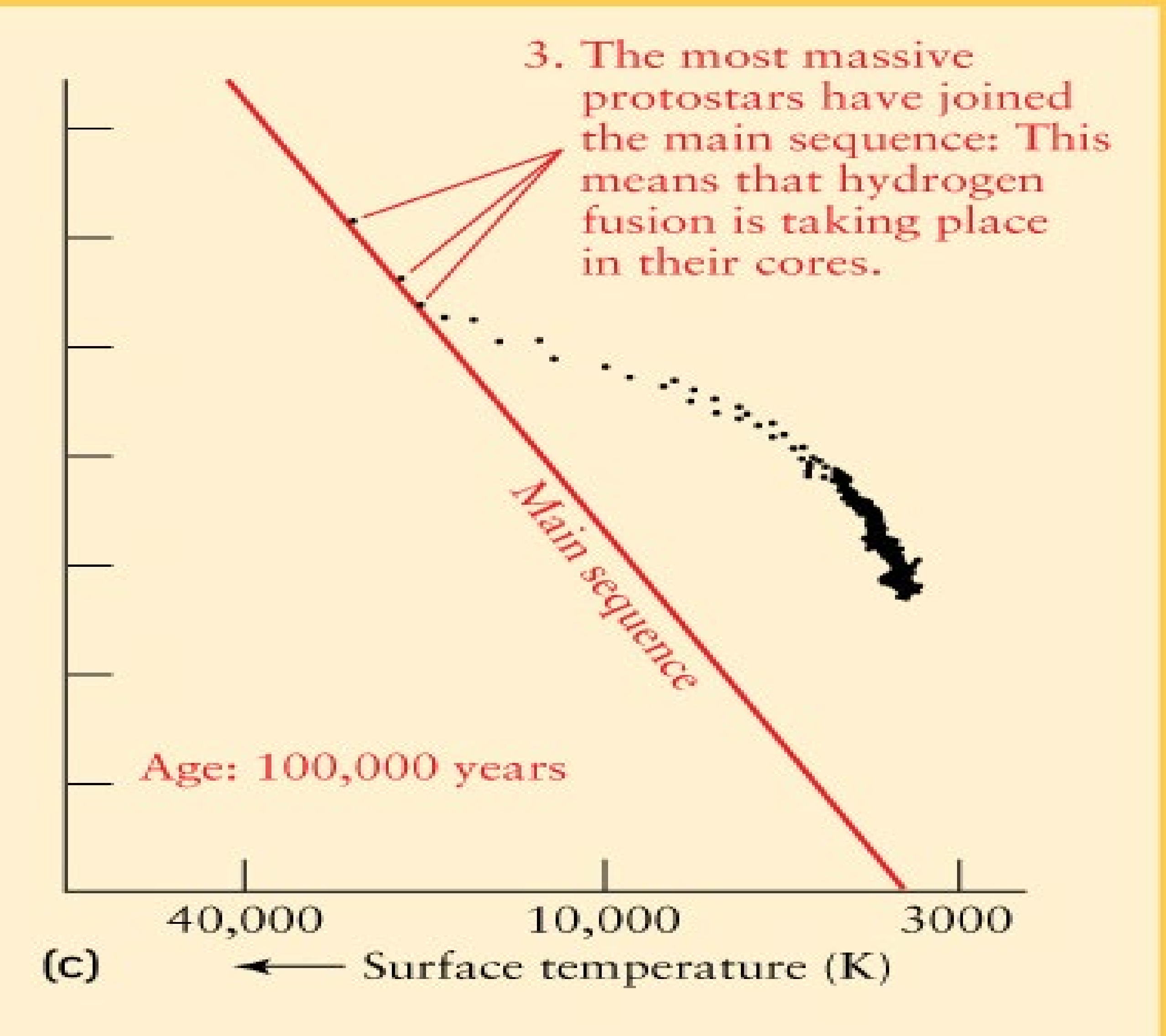


Recognizing evolution of star clusters from their paths on an HR diagram:



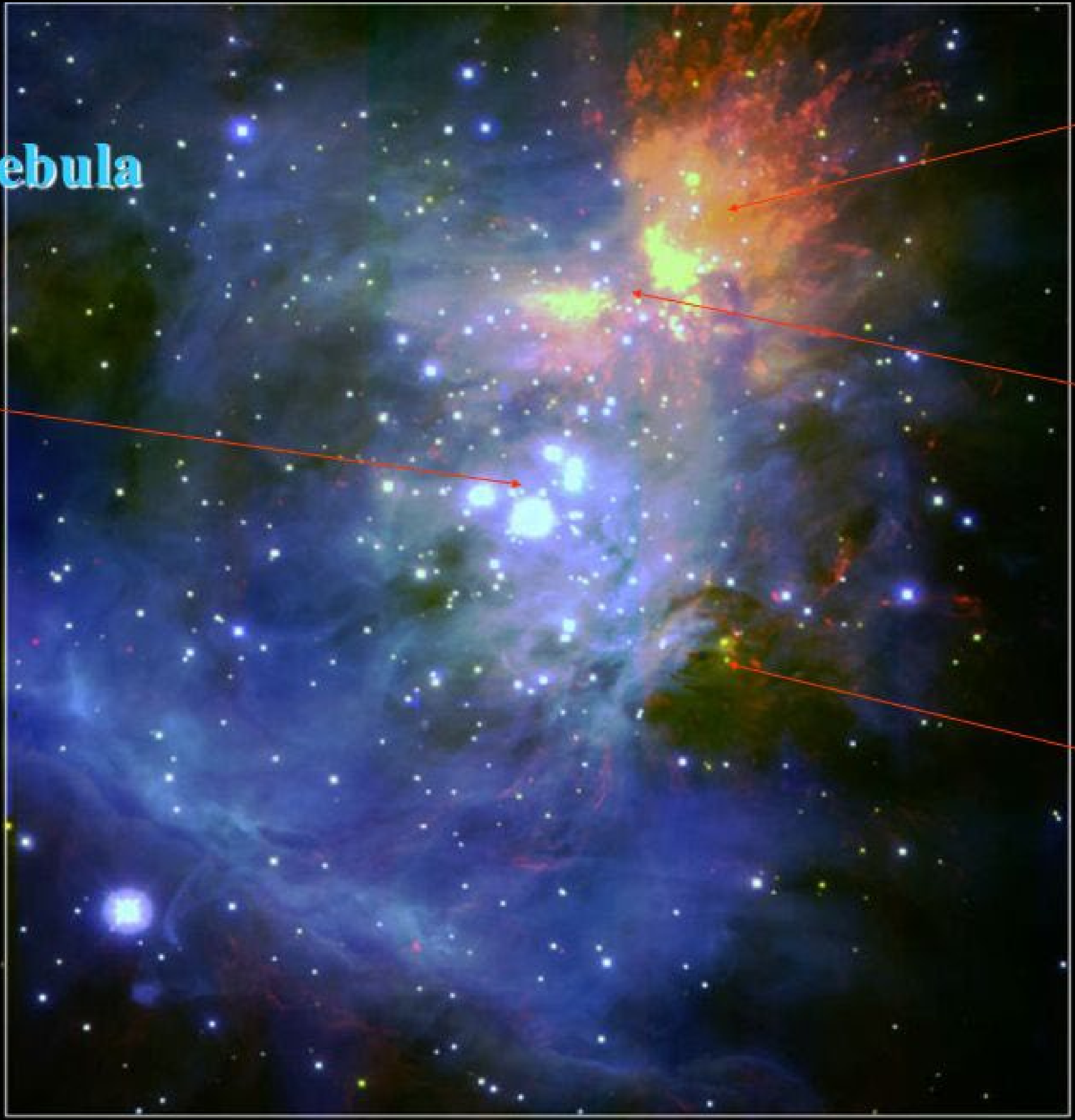


Region W40: Star forming region in our galaxy
Young O and B stars produce ionizing radiation which pushes out the gas forming an HII region (ionized hydrogen). Image taken with Chandra and Spitzer telescopes.



A star-forming region in Orion Infrared composite from the Herschel Space Telescope blue: 70 microns green:160 microns red: 250 microns

Orion Nebula



Trapezium

(L = 10^5 L_o
t < 10^5 yr)

OMC 1
Outflow
(H_2
t = 3,000 yr)

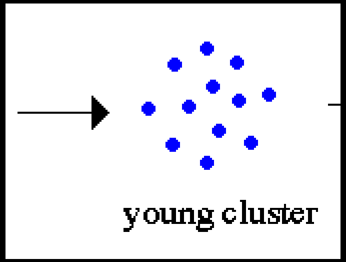
BNKL
(L = 10^5 L_o
t << 10^5 yr)

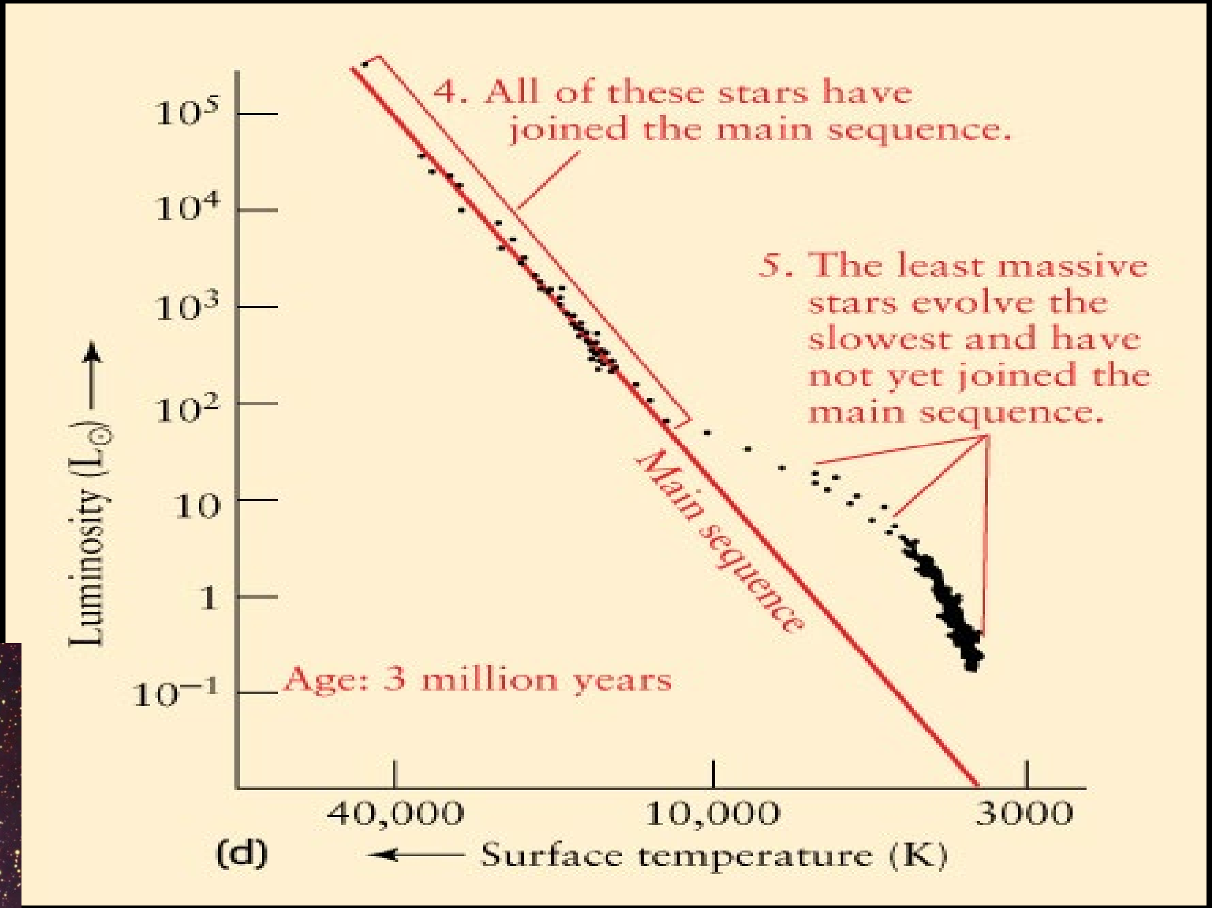
OMC1-S

(L = 10^4 L_o ,
t < 10^5 yr)

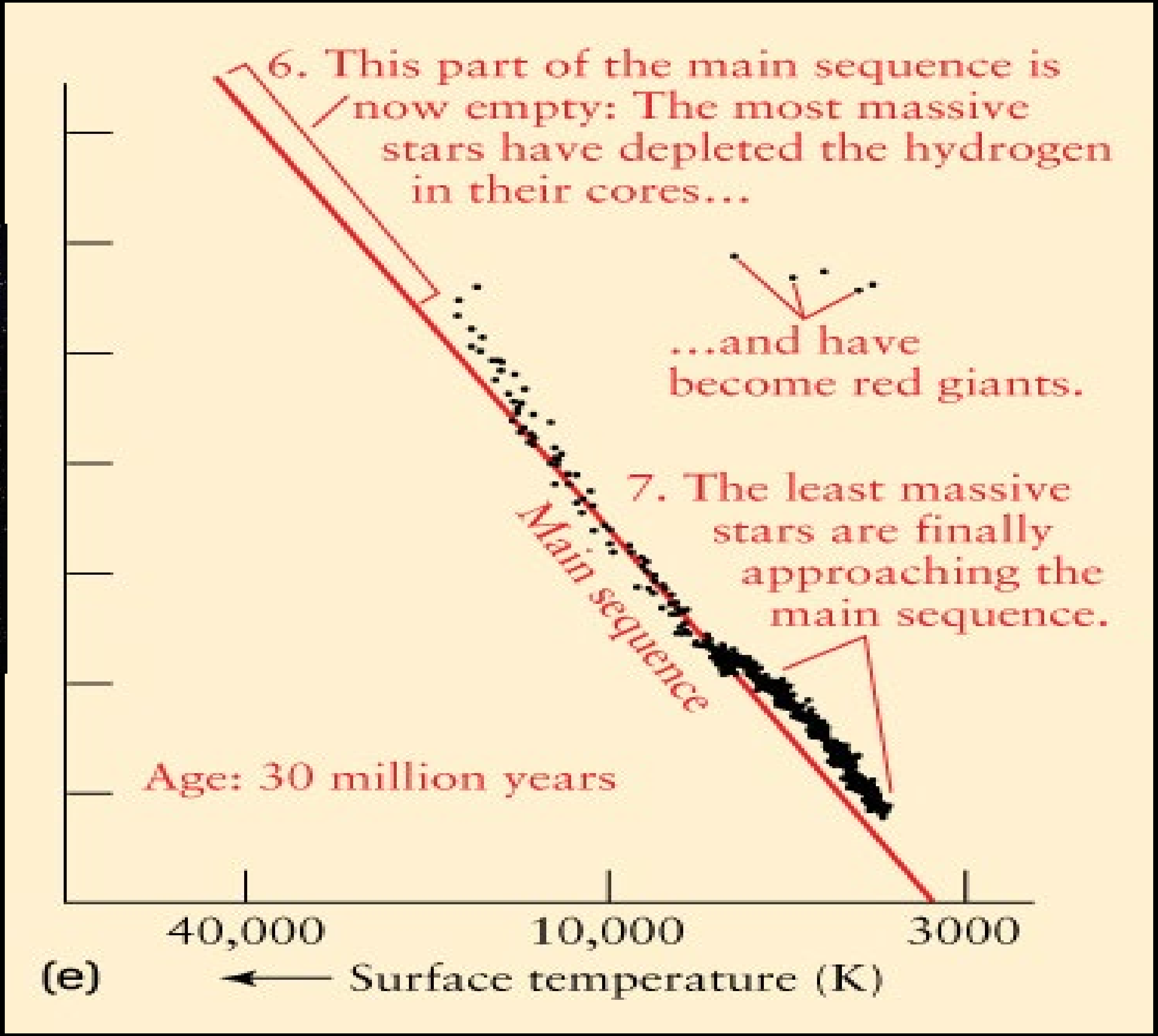
Orion Nebula
Subaru Telescope, National Astronomical Observatory of Japan

CISCO (J, K′ & H_2 (v=1-0 S(1))
January 28, 1999

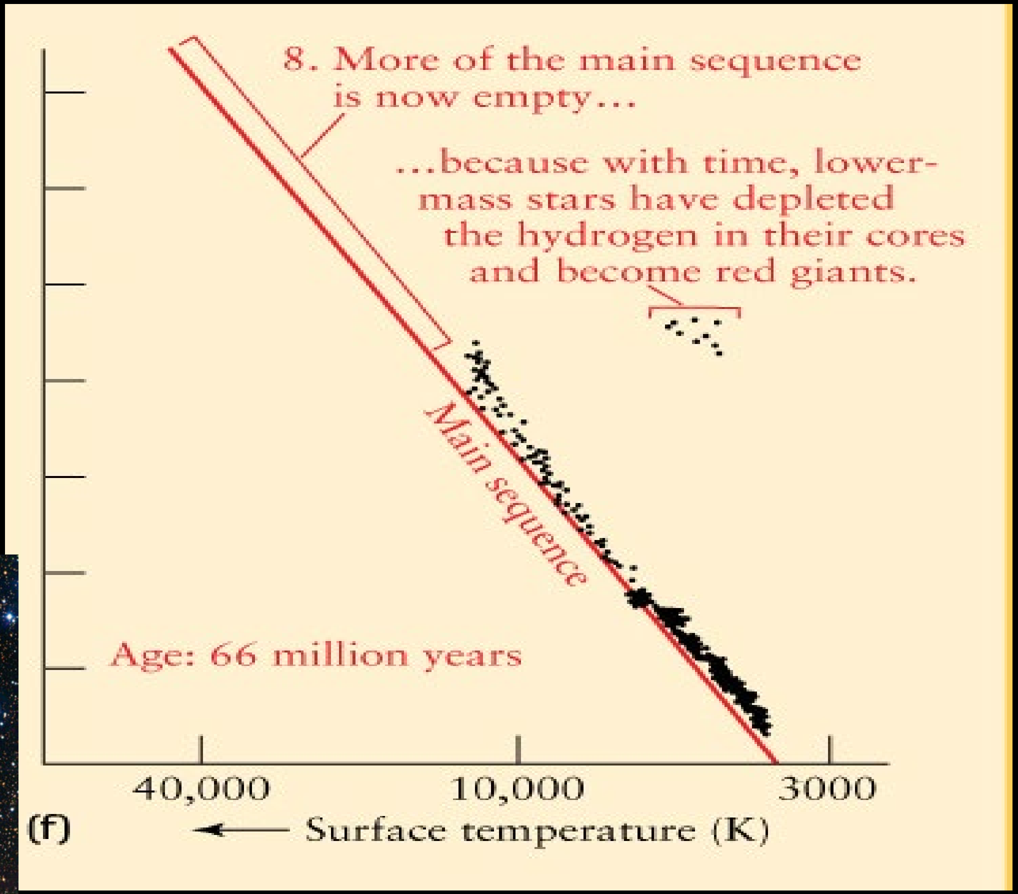




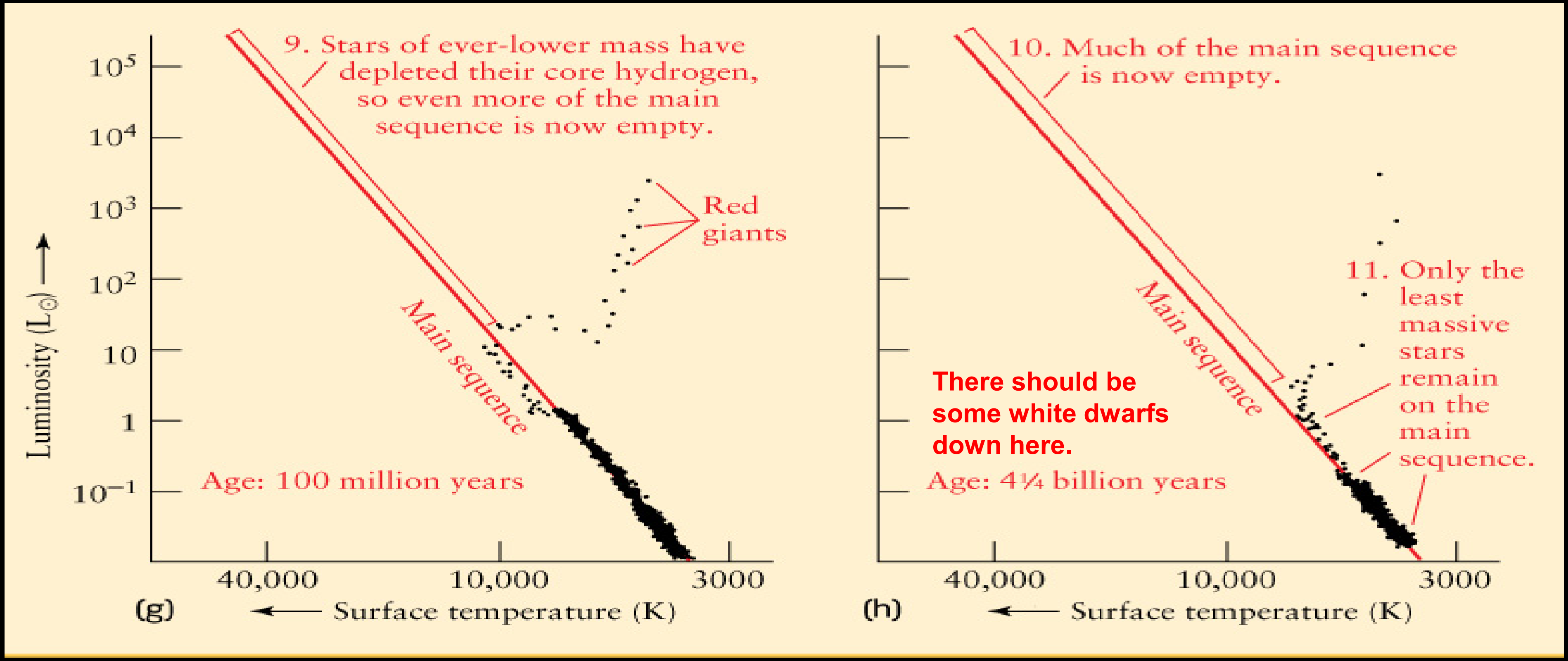
Example: The Pleiades open cluster



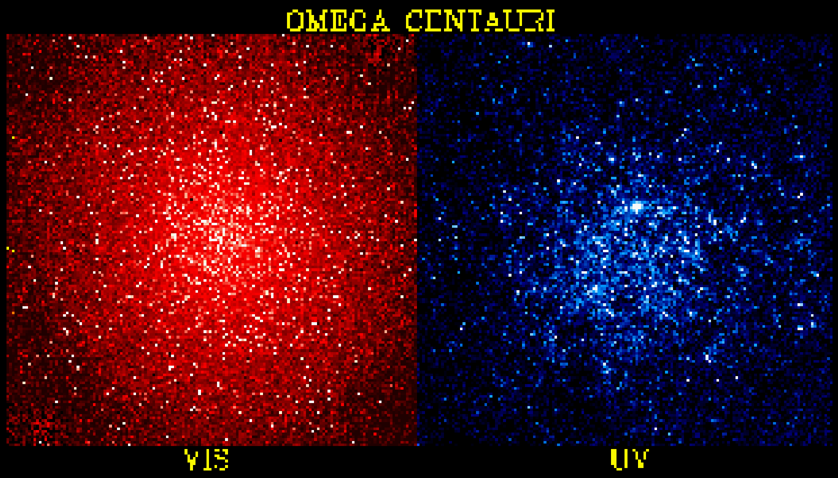
Jewel Box cluster
open cluster ~ 14 my
Red giant and some
pulsating variable
blue giants on the
instability strip

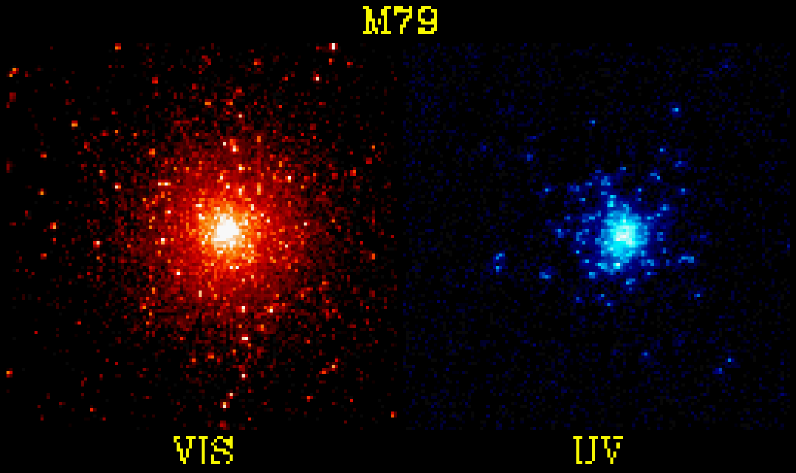


A middle aged star cluster
The Wishing Well Cluster,
in constellation Carina.
NGC 3532, around 300 my old,
contains around 400 stars.
European Southern Observatory.

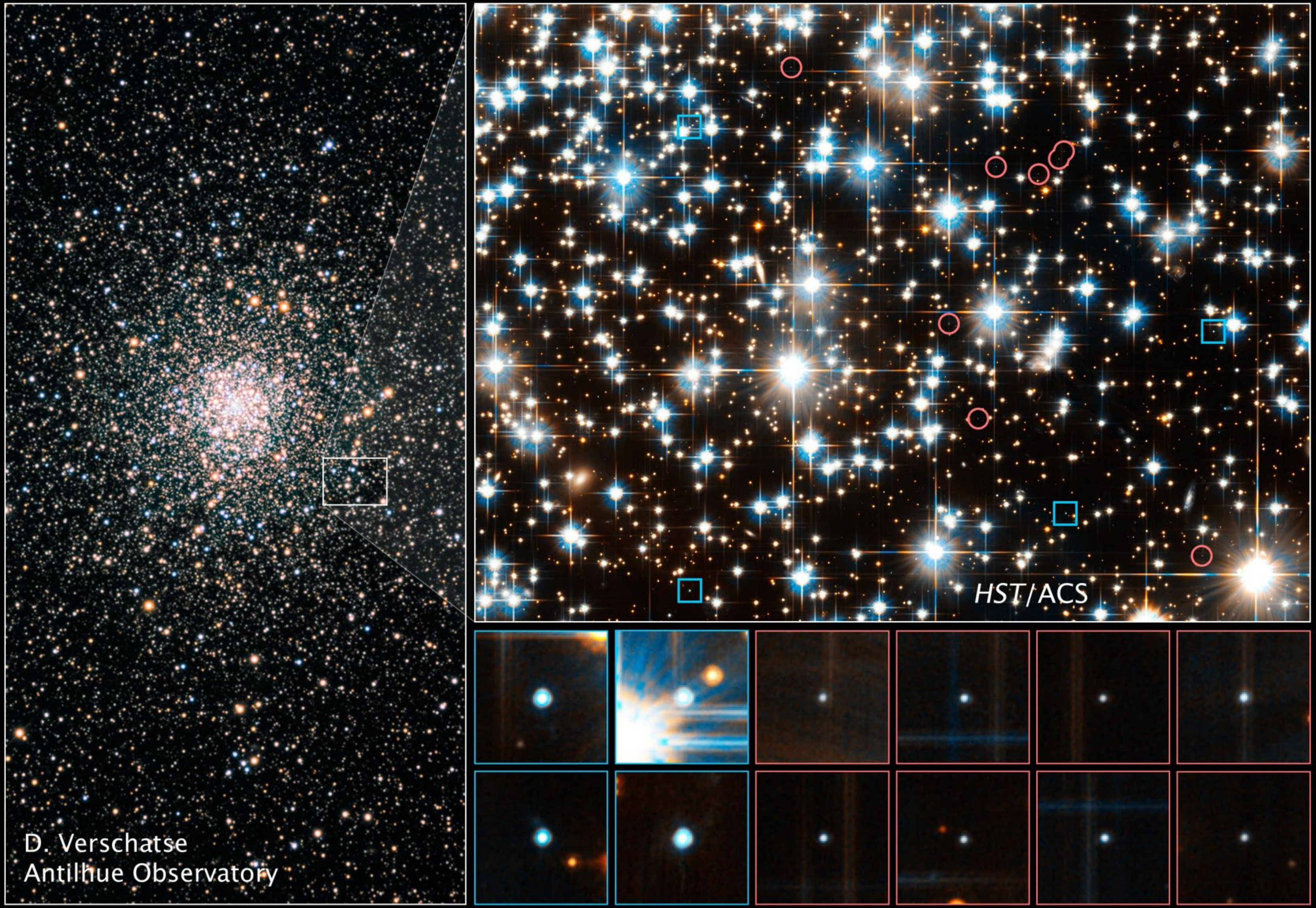


Old globular clusters





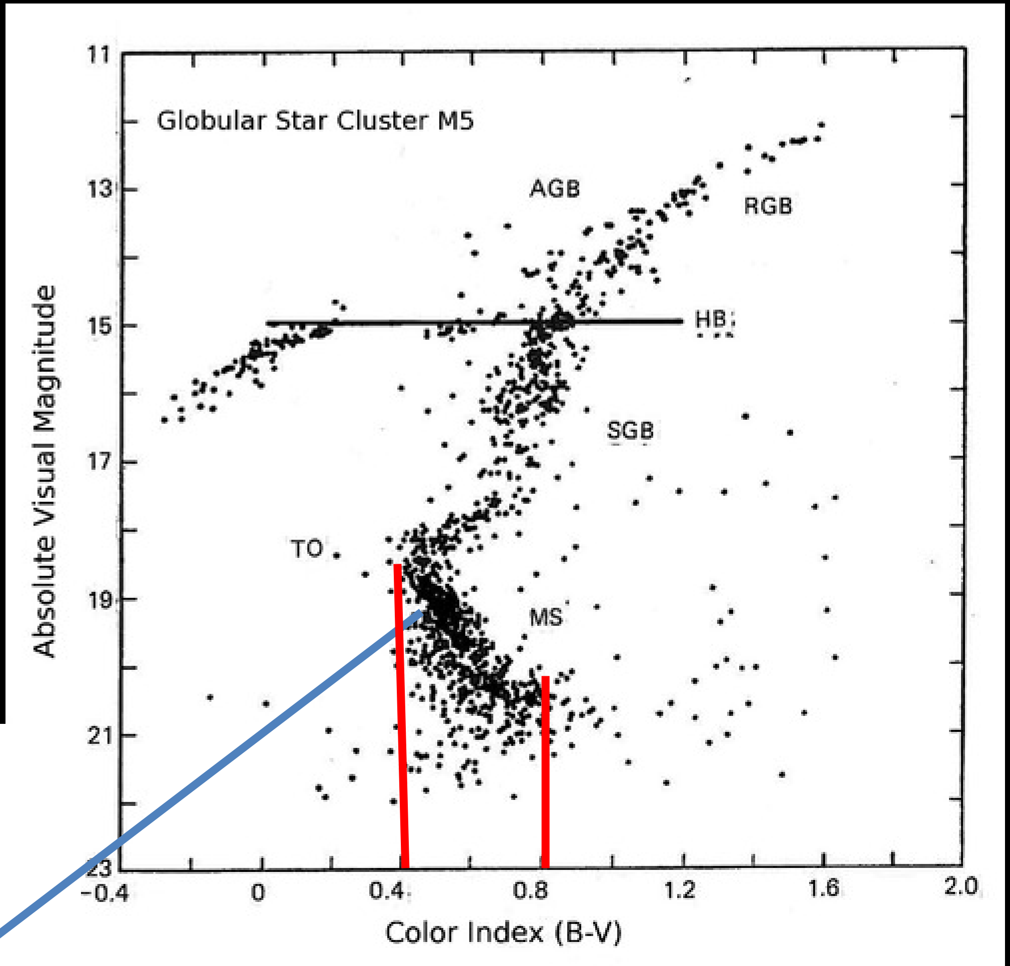
White Dwarf Stars in Globular Cluster NGC 6397 ▪ *Hubble Space Telescope* ACS/WFC

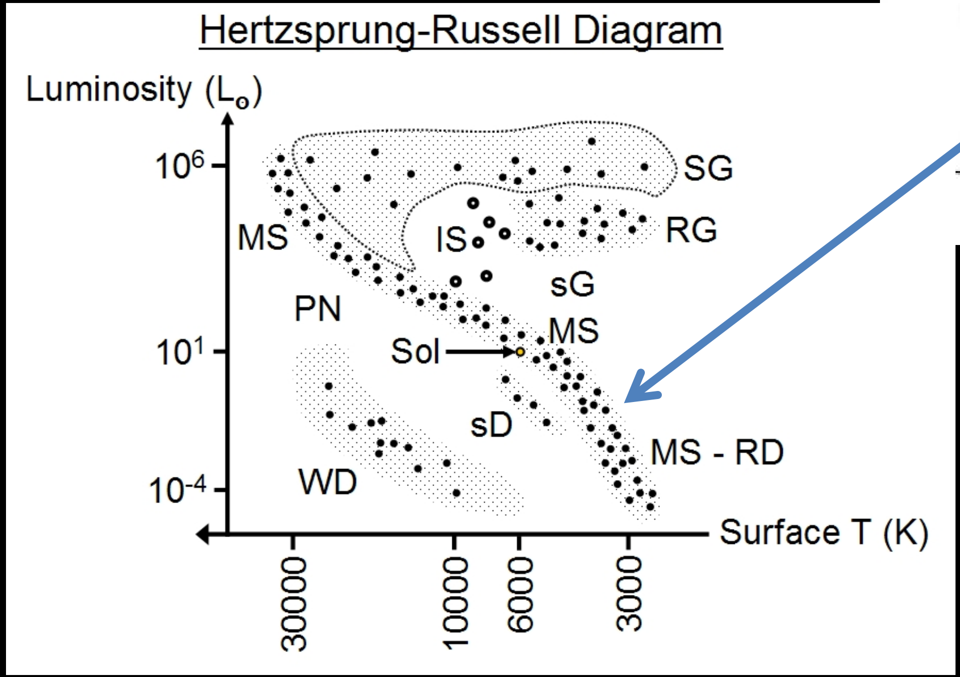


NASA, ESA, and H. Richer (University of British Columbia) ▪ STScI-PRC07-42

HR diagram for globular cluster M5. TO denotes turn off point.

Where does this star cluster fit on the general HR diagram?

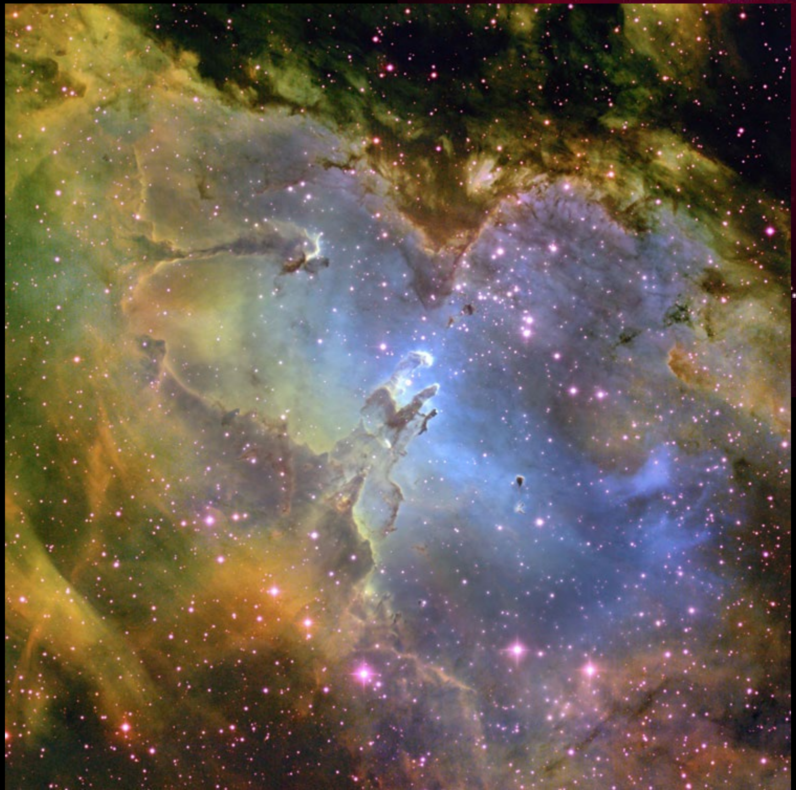




B - V index tells temperature

The stars that are still on the main sequence are red dwarfs. So it must be a rather old cluster.

M16, in Serpens
a very young open cluster in which stars are still forming



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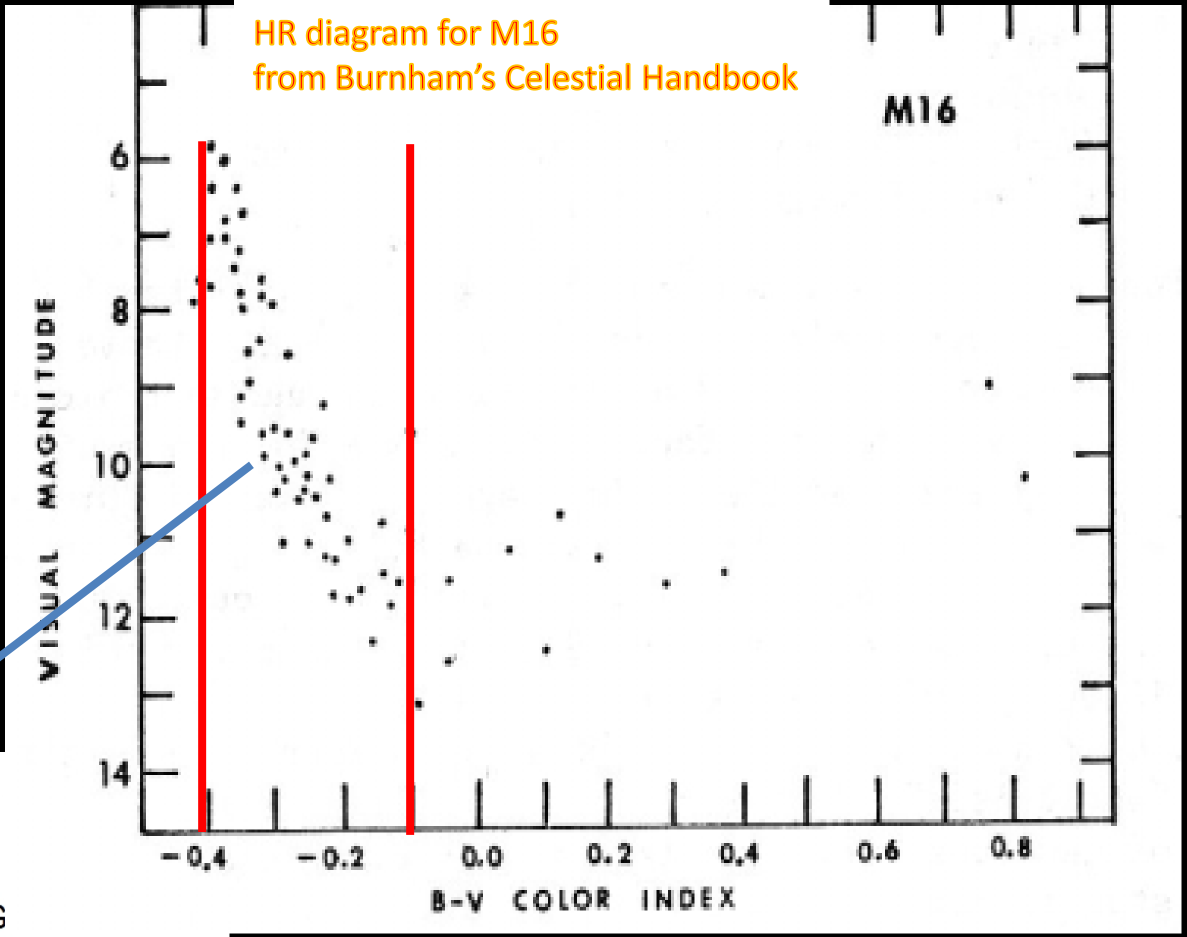
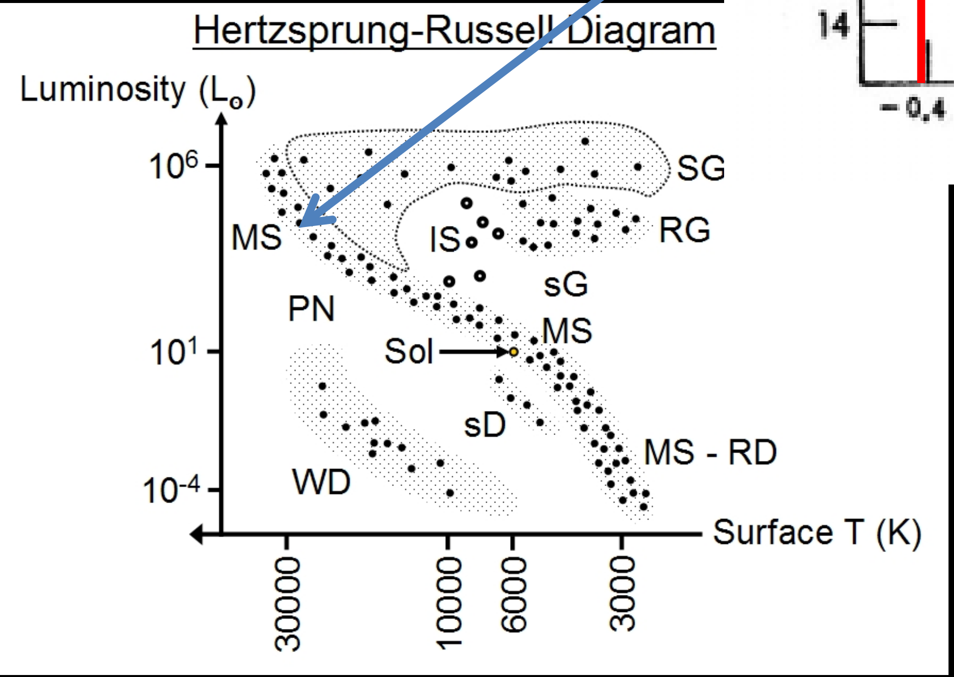
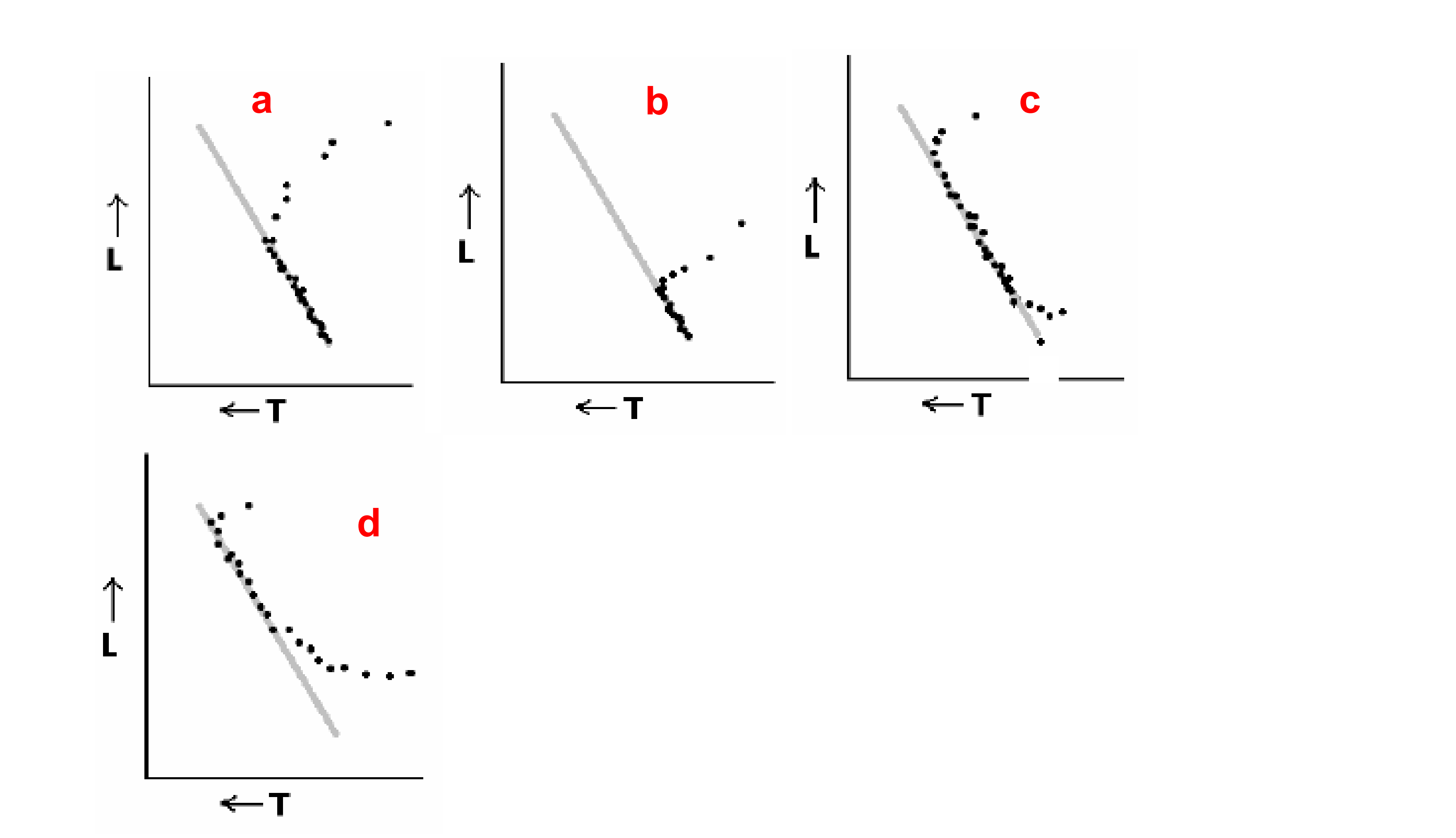




B - V index tells temperature

The stars that are still on the main sequence are hot, young O & B stars, which you would expect for a young cluster.

Group Exercise:
Rank these clusters from youngest to oldest, and explain your reasons.



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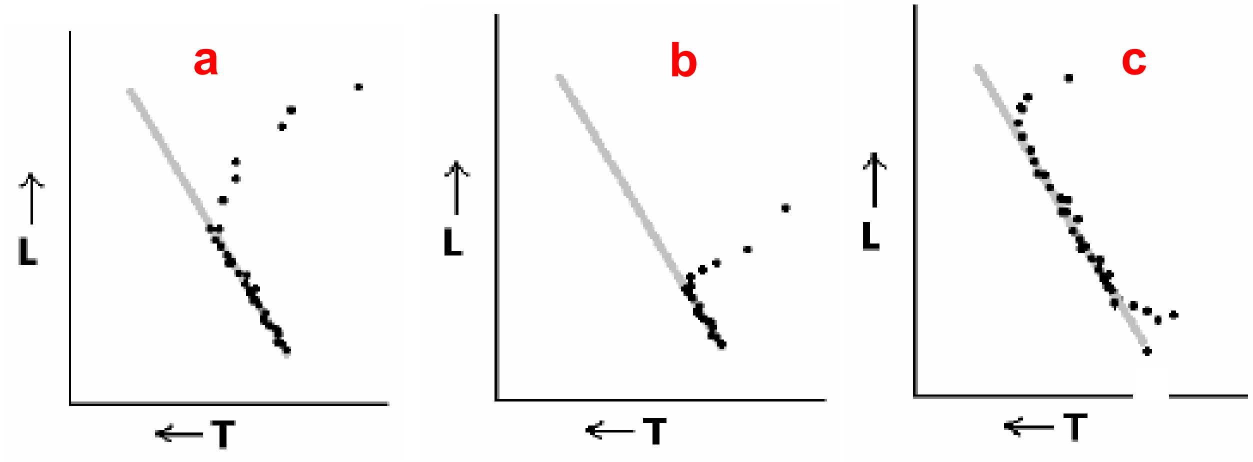

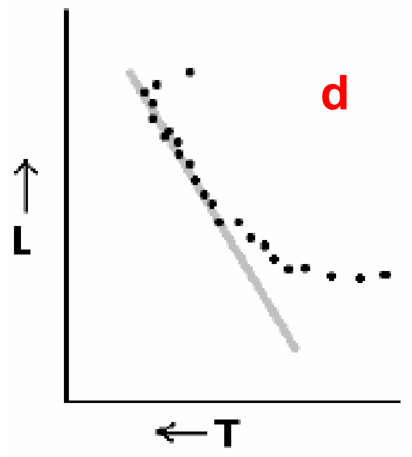

Youngest: d – because the stars just leaving the main sequence are hot, young O and B stars

Oldest: b – because the stars just leaving the main sequence are cool, old red dwarf stars

Ranking from youngest to oldest: d, c, a, b

A question for you:

Consider two stars (called #1 and #2) in the **same star cluster**. Both stars have the **same surface temperature** of 4000 K, but star #1 is a main-sequence star while star #2 is a red giant with 1000 times the luminosity of star #1. What can we conclude?

A. Star #2 is older than star #1.
B. Star #2 is younger than star #1
C. Both stars are the same age; star #2 is more massive than star #1, and will most likely end its life as a supernova.
D. Both stars are the same age, but when they formed star #2 was less massive than star #1.
E. Nothing can be said about the relative ages or masses of these two stars.

Answer

Consider two stars (called #1 and #2) in the **same star cluster**. Both stars have the **same surface temperature** of 4000 K, but star #1 is a main-sequence star while star #2 is a red giant with 1000 times the luminosity of star #1. What can we conclude?

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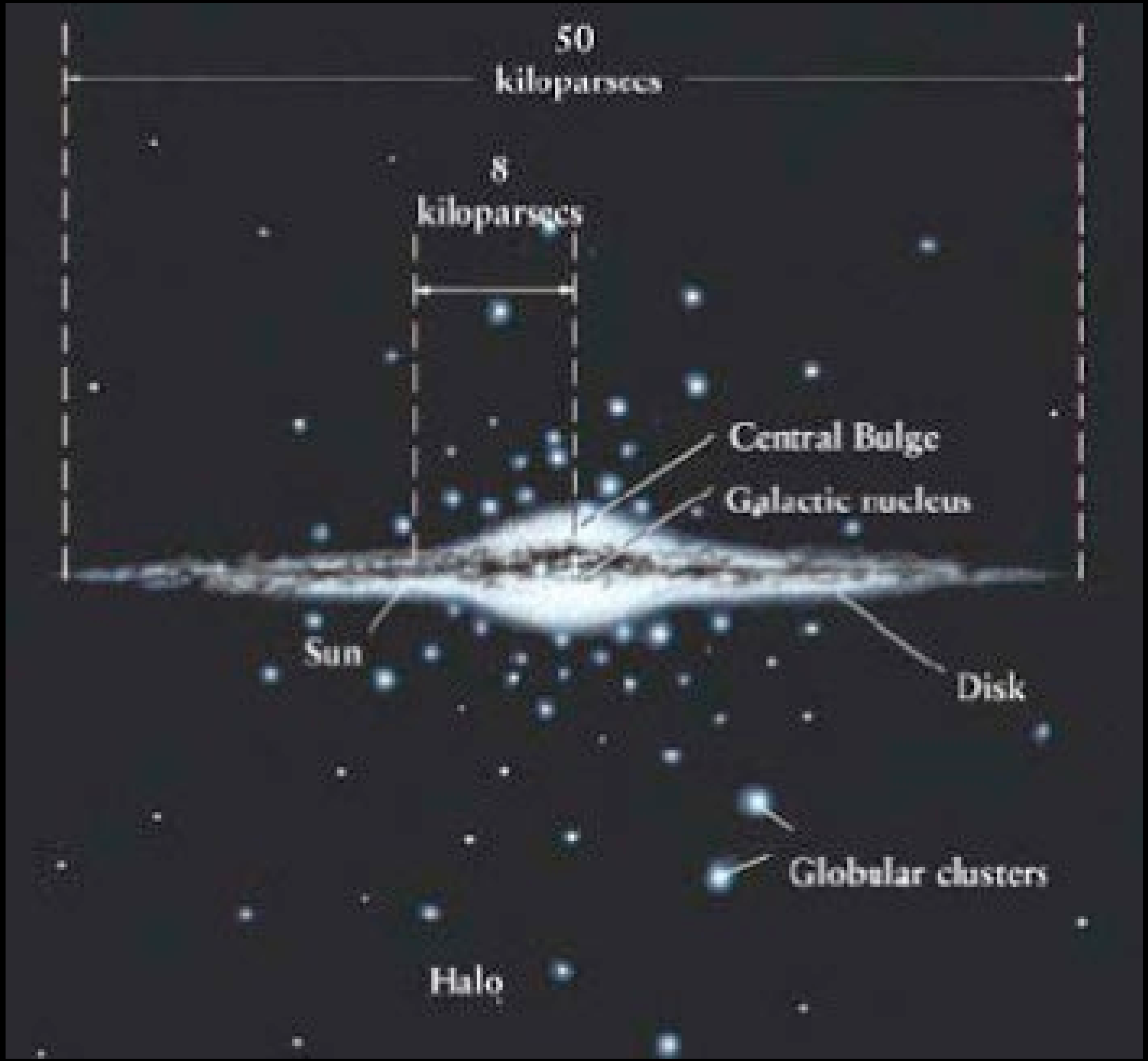
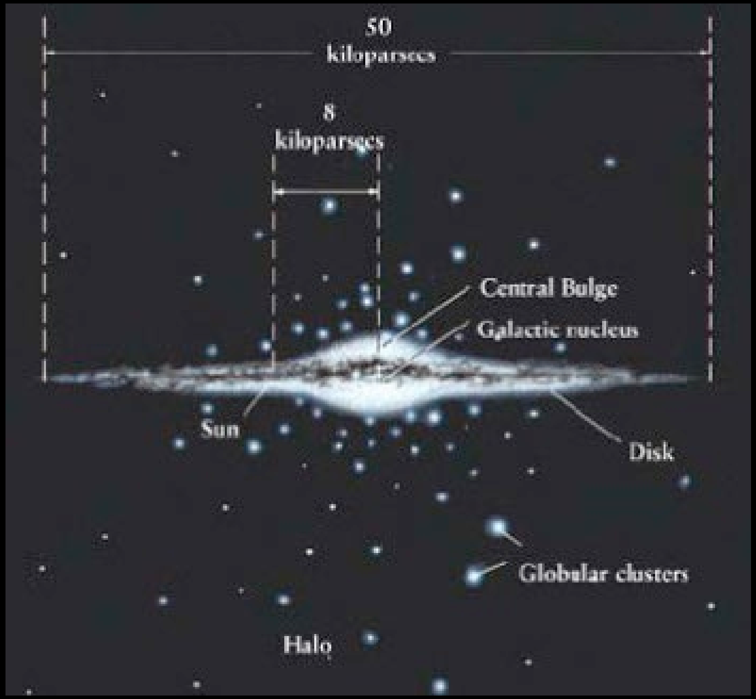


Old globular clusters surround the center of our galaxy, while open clusters , where new stars are still forming, are located in the spiral arms.

Using the ages of globular clusters around our Milky Way Galaxy, we get an age of about 12.6 BY.

(Universe is 13.8 BY old, so ours is a rather old galaxy.)



Globular cluster in Serpens, M5

If we can figure out where the stars in a cluster fit on the HR diagram, we can calculate the distance to the cluster.

Why? Because the HR diagram gives Absolute Magnitude.

1. We measure apparent magnitudes for, say, 100 stars in the cluster.

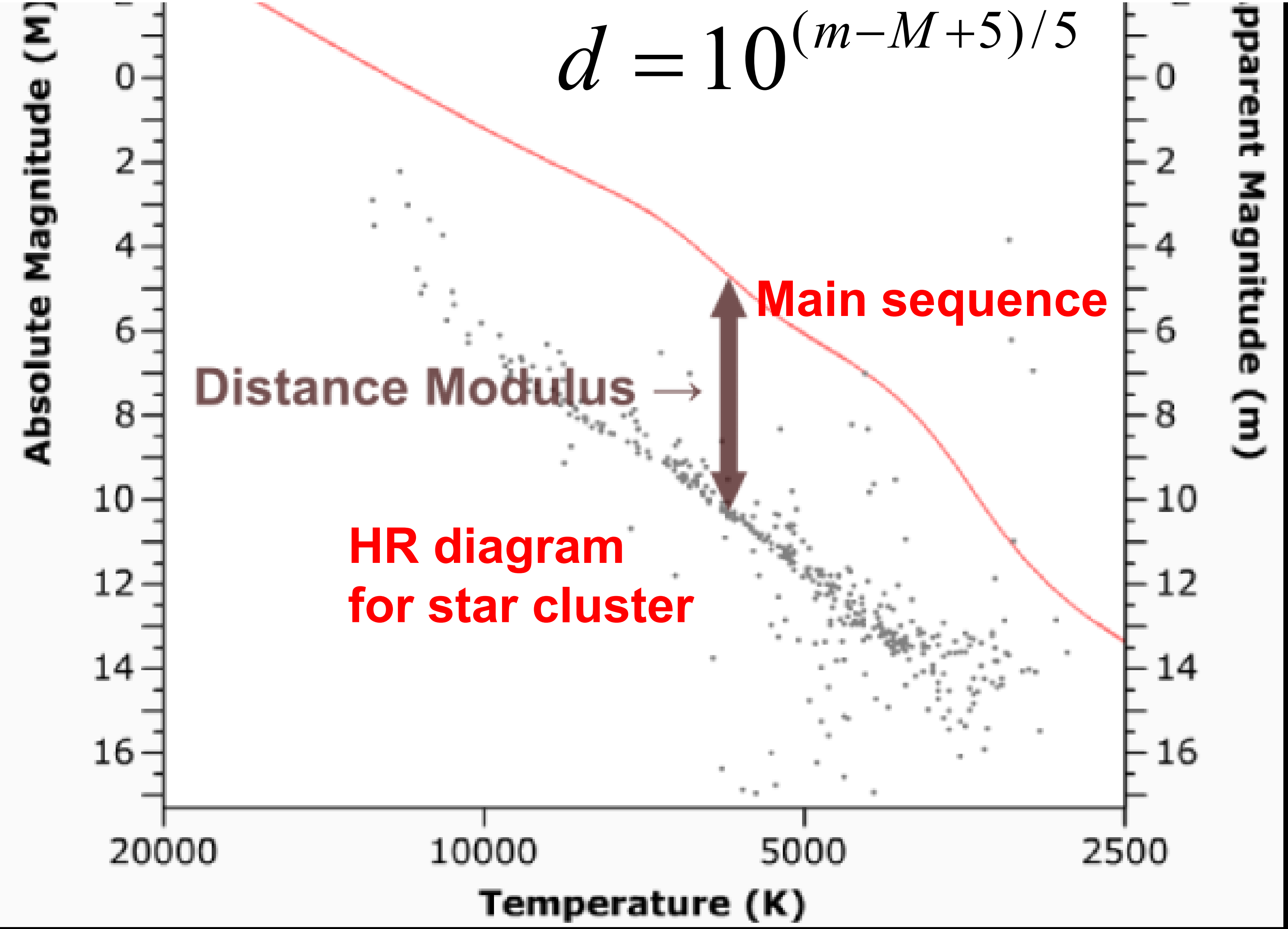
2. We measure color temperature by looking at the stars in Blue (B) and Green (V) light, and sometimes also Red (R). The brighter they are in B, the hotter; the brighter in R, the cooler they are.

3. We plot an HR diagram for the cluster, and try to match its shape to the published HR diagram.

4. Then we can get an idea of what the absolute magnitudes should be, and finally we can use the distance formula to find their distance in parsecs.

If you can measure the apparent magnitudes of stars in a cluster, and see how they fit on the main sequence, you can estimate where they *should* lie on the main sequence and find the distance to that cluster using the distance formula.

$$d = 10^{(m-M+5)/5}$$



NAAP Labs - v1.1

NAAP Labs

NAAP Labs

The Nebraska Astronomy Applet Project provides computer-based labs targeting the undergraduate introductory astronomy audience. Each lab consists of background materials and one or more simulators that students use as they work through a student guide.

Primary funding for this work was provided by NSF grant #0231270, with additional funding from the NASA Nebraska Space Grant.

NAAP v1.1
January 30, 2020

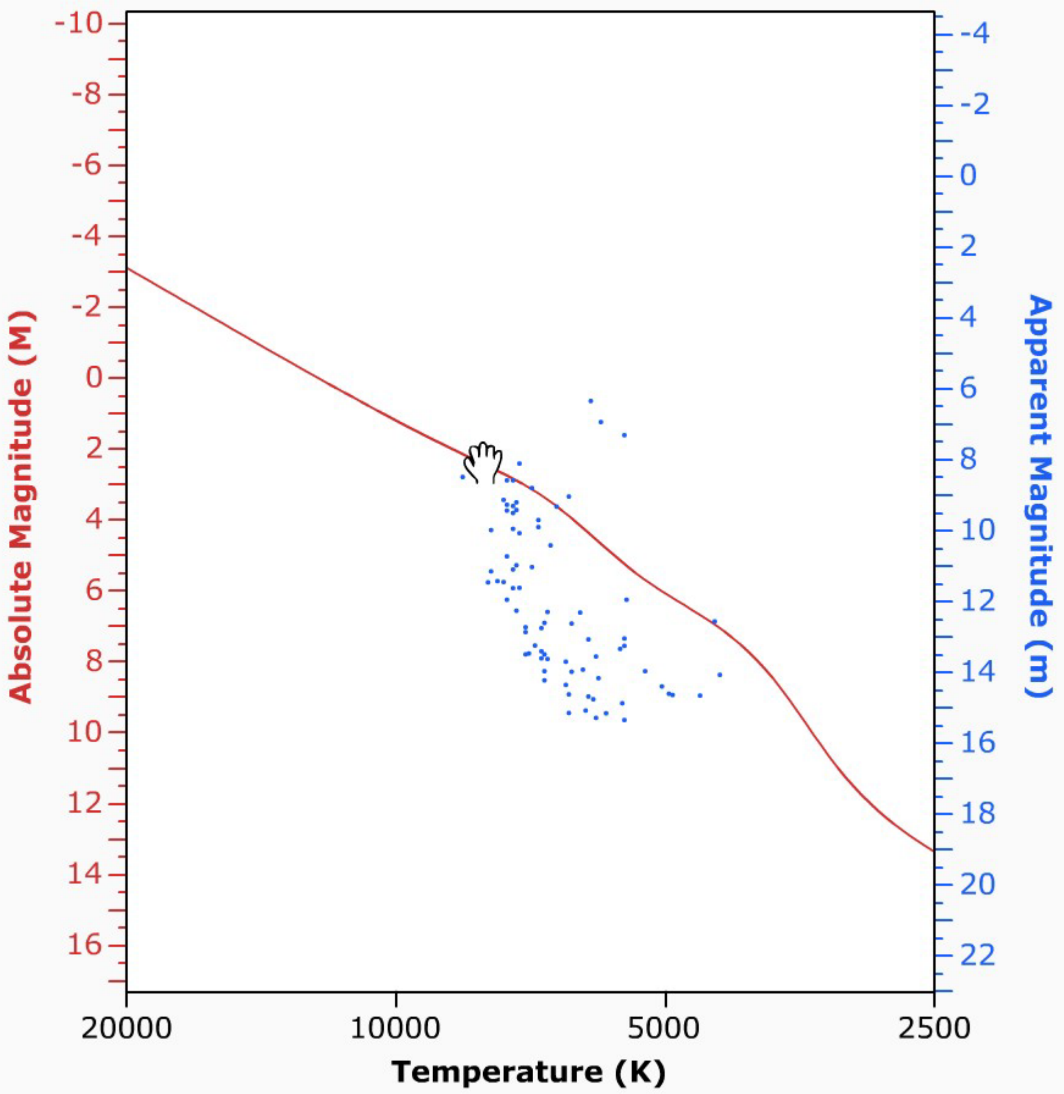
http://astro.unl.edu

HR Diagram Star Cluster Fitting Explorer

HR Diagram Star Cluster Fitting Explorer

reset about

HR Diagram



Cluster Selection

chi Persei

Diagram Options

☐ show horizontal bar

Distance Modulus Calculator

$$\boldsymbol{m} - \boldsymbol{M} = -5 + 5 \log_{10} \boldsymbol{d}$$

[ ] - [ ]

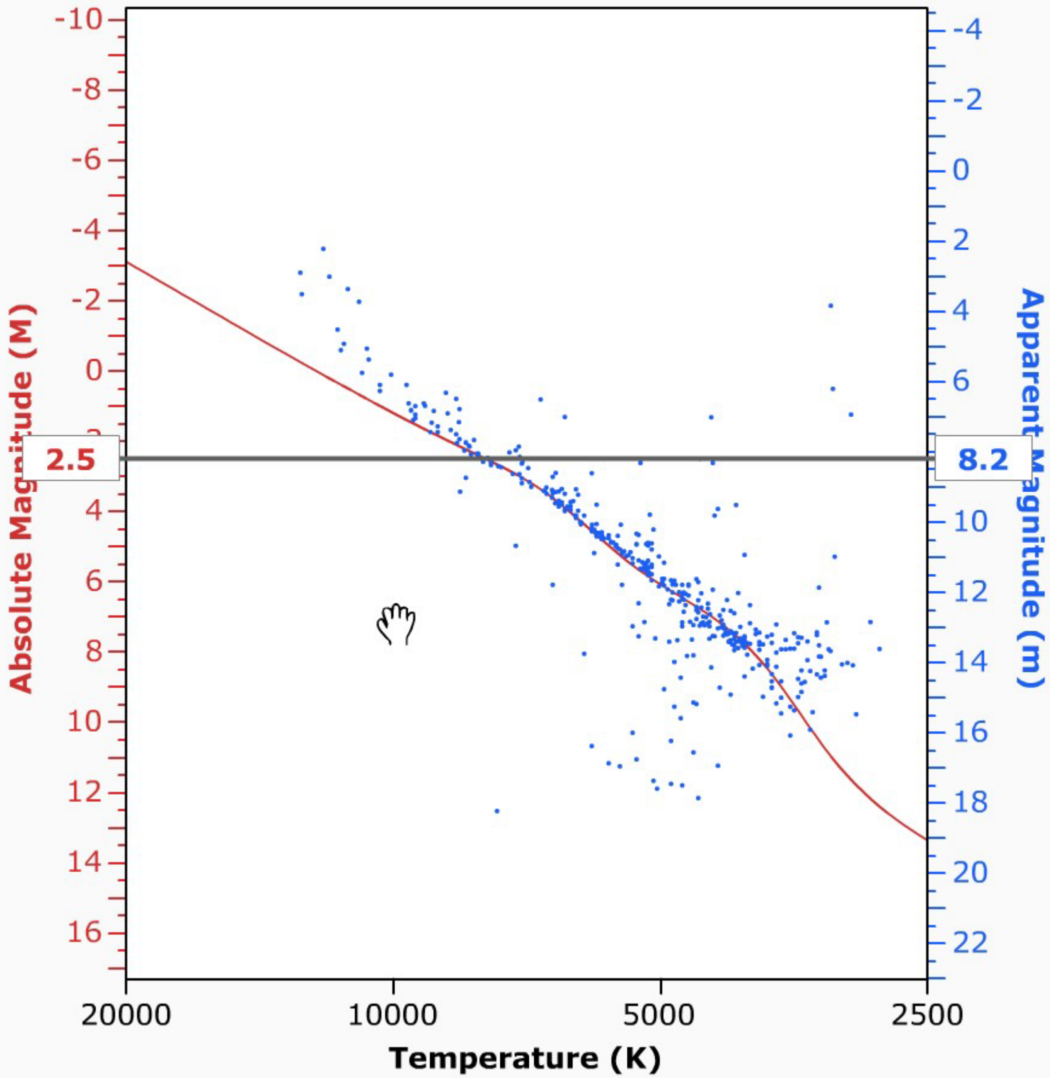
… = -5 + 5 log10 …

HR Diagram Star Cluster Fitting Explorer

HR Diagram Star Cluster Fitting Explorer

reset about

HR Diagram



Cluster Selection

Pleiades

Diagram Options

☑ show horizontal bar

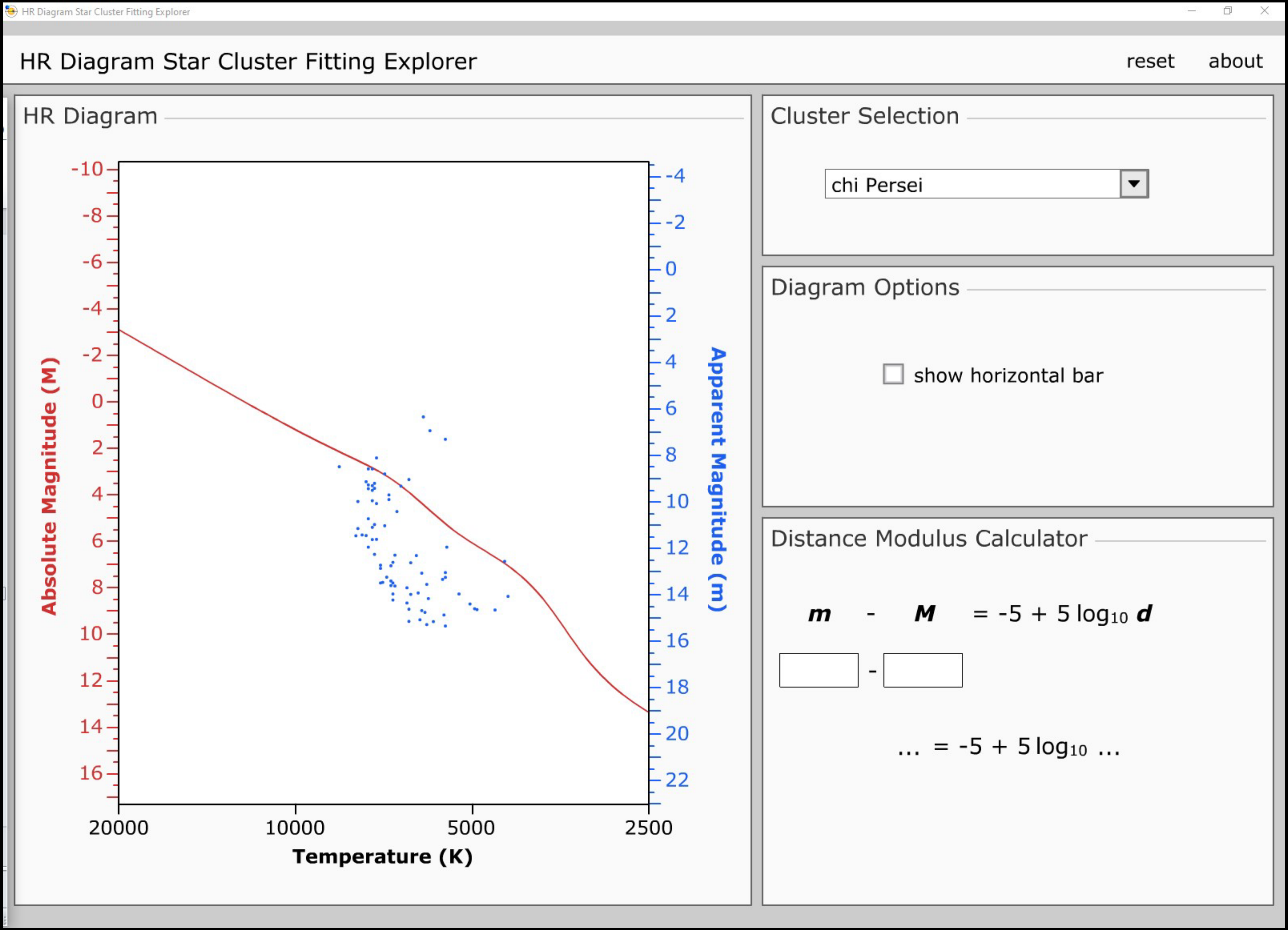
Distance Modulus Calculator

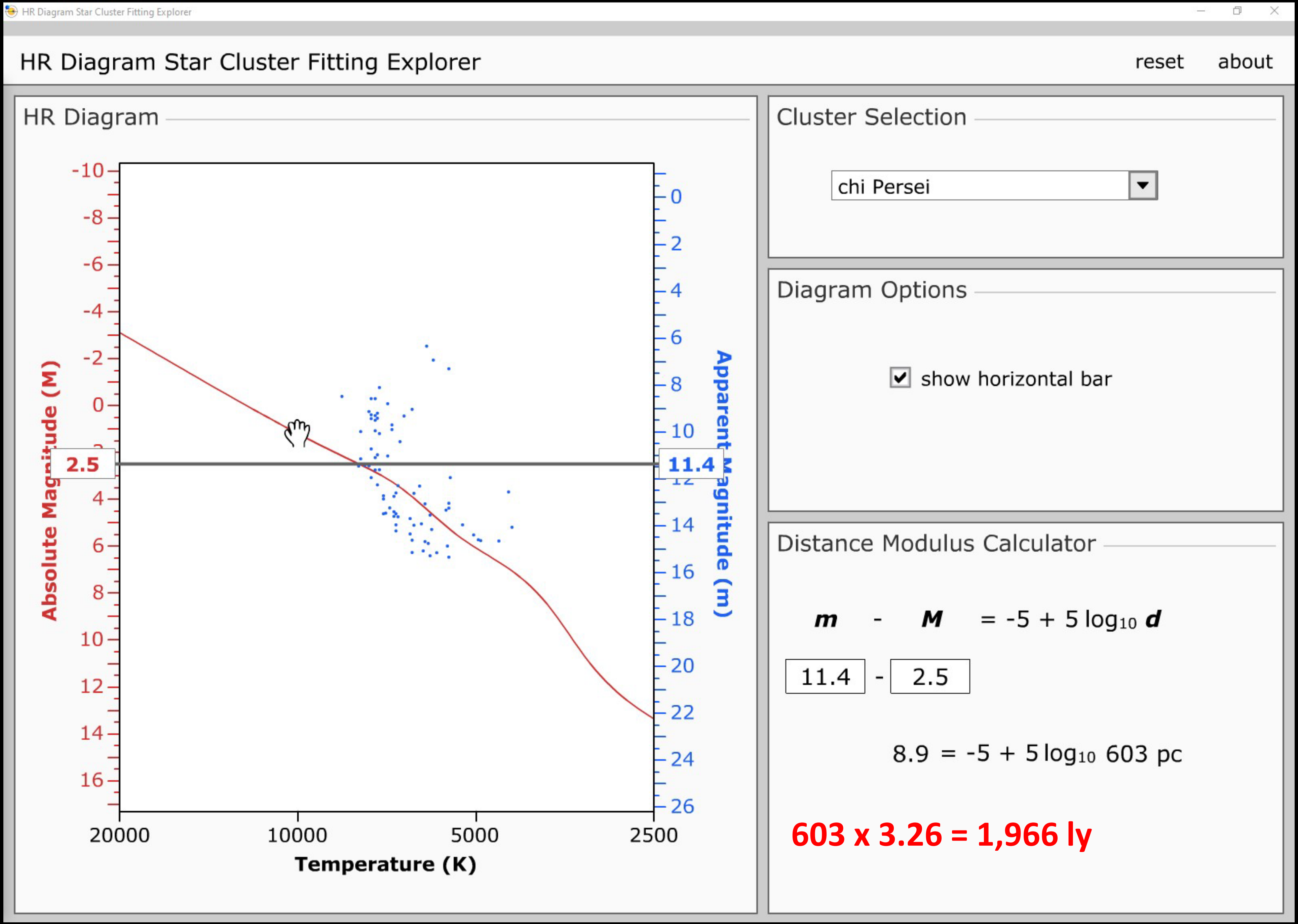
$$m - M = -5 + 5 \log_{10} d$$

8.2 - 2.5

$$5.7 = -5 + 5 \log_{10} 138 \text{ pc}$$

138 x 3.26 = ~ 450 ly


HR Diagram Star Cluster Fitting Explorer
HR Diagram Star Cluster Fitting Explorer
reset
about
HR Diagram
Absolute Magnitude (M)
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
Apparent Magnitude (m)
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
20000
10000
5000
2500
Temperature (K)
Cluster Selection
chi Persei
Diagram Options
show horizontal bar
Distance Modulus Calculator
m - M = -5 + 5 log10 d
-
... = -5 + 5 log10 ...


HR Diagram Star Cluster Fitting Explorer
reset
about
HR Diagram
Absolute Magnitude (M)
Apparent Magnitude (m)
Temperature (K)
20000
10000
5000
2500
2.5
11.4
Cluster Selection
chi Persei
Diagram Options
show horizontal bar
Distance Modulus Calculator
m - M = -5 + 5 log10 d
11.4 - 2.5
8.9 = -5 + 5 log10 603 pc
603 x 3.26 = 1,966 ly

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NAAP Labs

NAAP Labs

1. Solar System Models
2. Basic Coordinates and Seasons
3. The Rotating Sky
4. Motions of the Sun
5. Planetary Orbits
6. Lunar Phases
7. Blackbody Curves and UBV Filters
8. Hydrogen Energy Levels
9. Hertzsprung-Russell Diagram
10. Eclipsing Binary Stars
11. Atmospheric Retention
12. Extrasolar Planets
13. Variable Star Photometry
14. Cosmic Distance Ladder
15. Habitable Zones

The Nebraska Astronomy Applet Project provides computer-based labs targeting the undergraduate introductory astronomy audience. Each lab consists of background materials and one or more simulators that students use as they work through a student guide.

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