# Earth 101
# Introduction to Astronomy

## Stellar Evolution

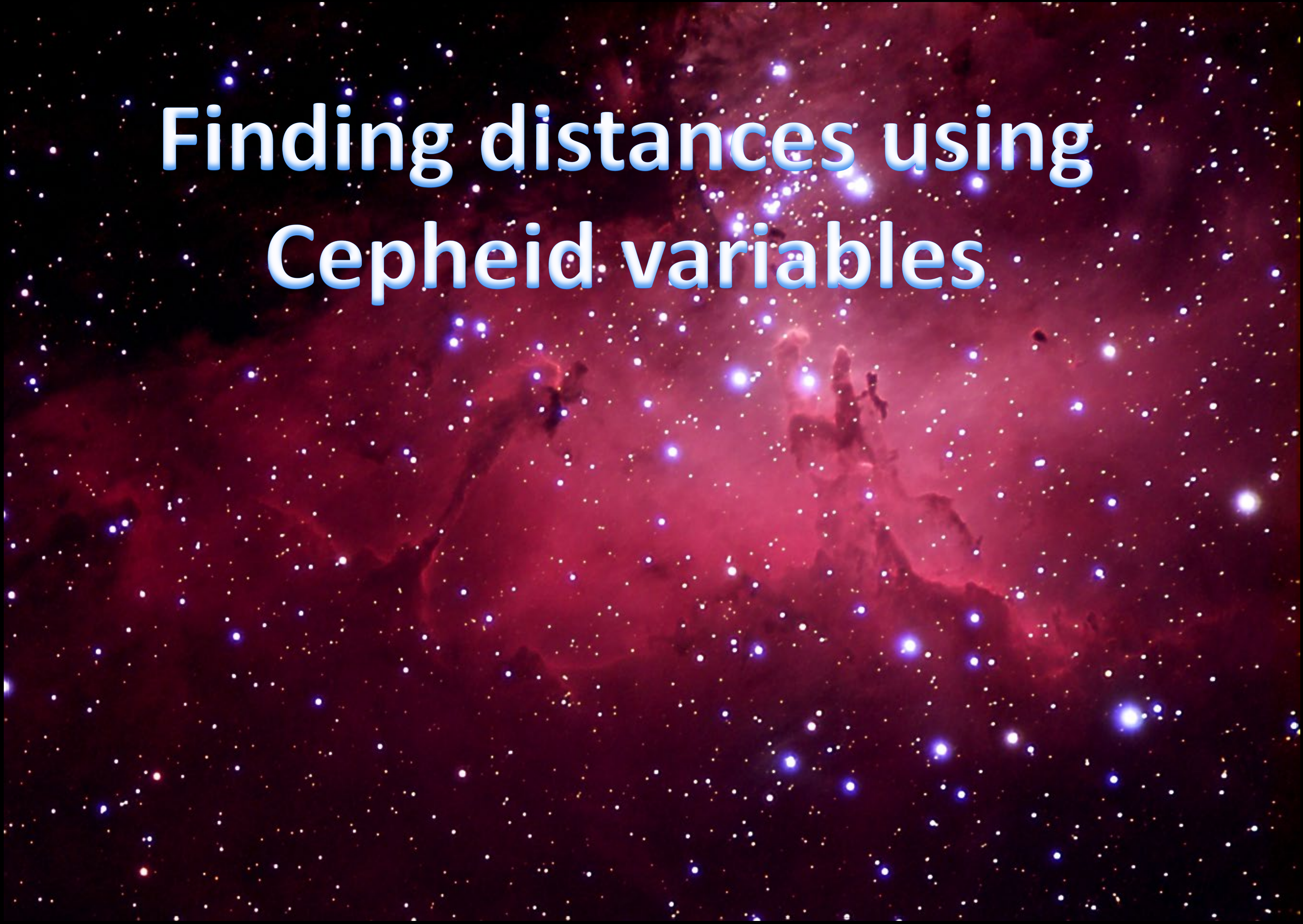
Instructor:
Erin O'Connor

**OpenStax Ch 21**
Stellar Evolution
Cepheid Variables

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

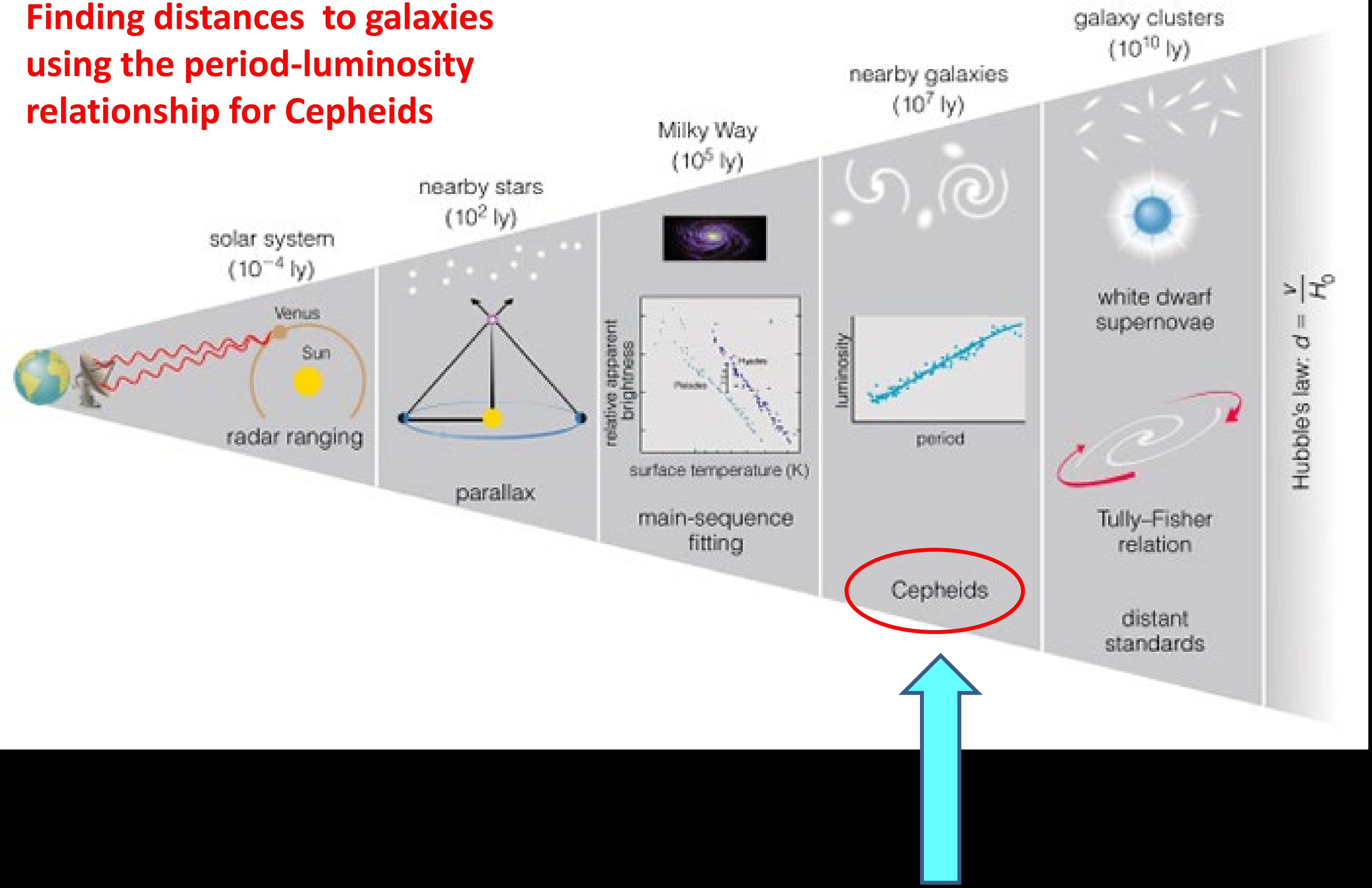
*The Horsehead and Flame Nebula © 2022 Hector Jimenez*

# Finding distances using Cepheid variables



# 2. Finding distances using Cepheid Variables in distant galaxies as Standard Candles

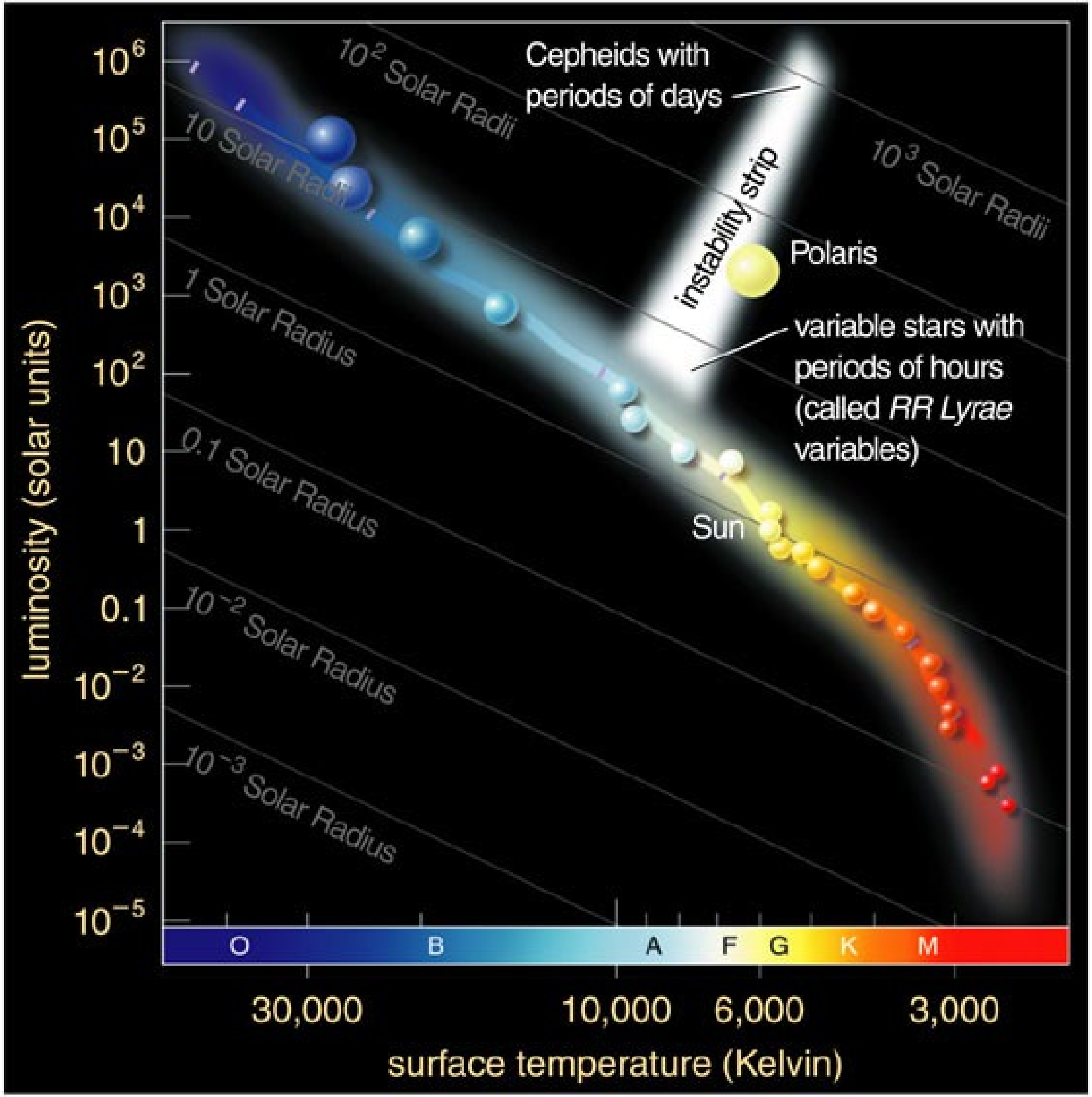
# Finding distances to galaxies using the period-luminosity relationship for Cepheids

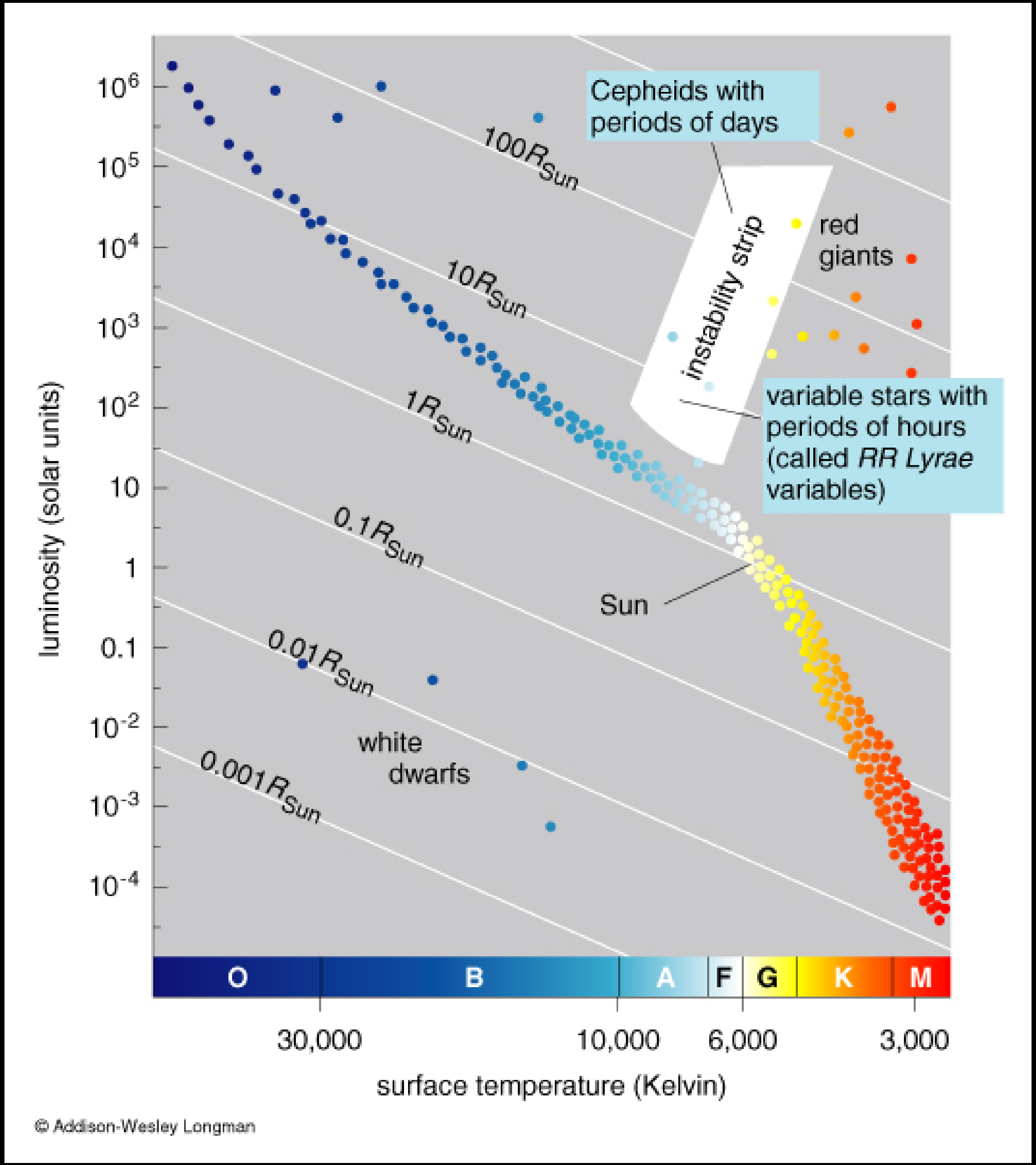


Post-main sequence stars that fuse Helium in a shell around their core.

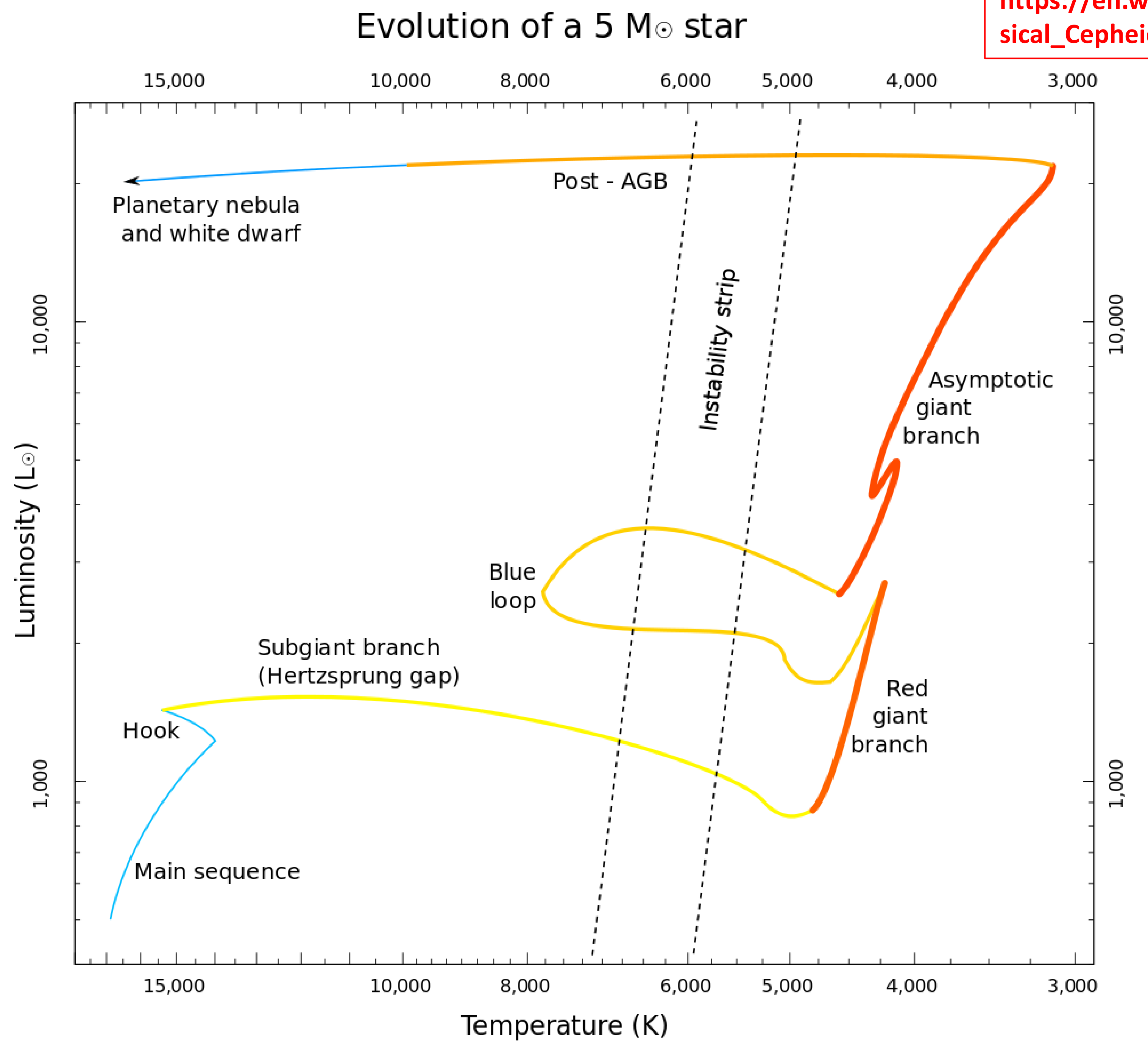
The He-fusing shell undergoes pulsations, increasing in radius – decreasing in temperature – decreasing in radius – increasing in temperature
with periods of a few days to a few weeks.

https://youtu.be/sXJBrRmHPj8



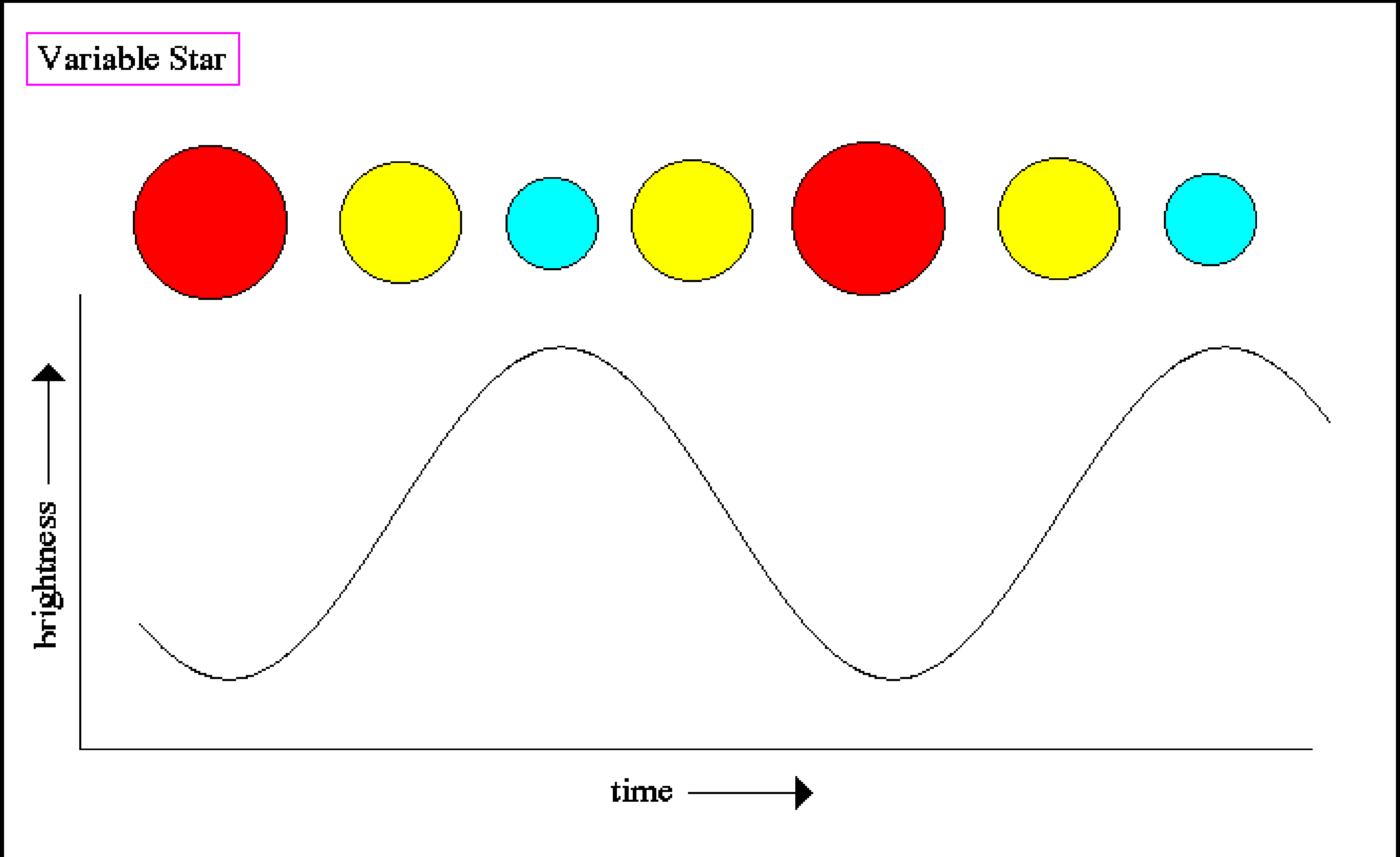



**Post-main sequence stars fusing helium in their cores. They are now unstable, and pulsate with periods that are dependent on their masses**



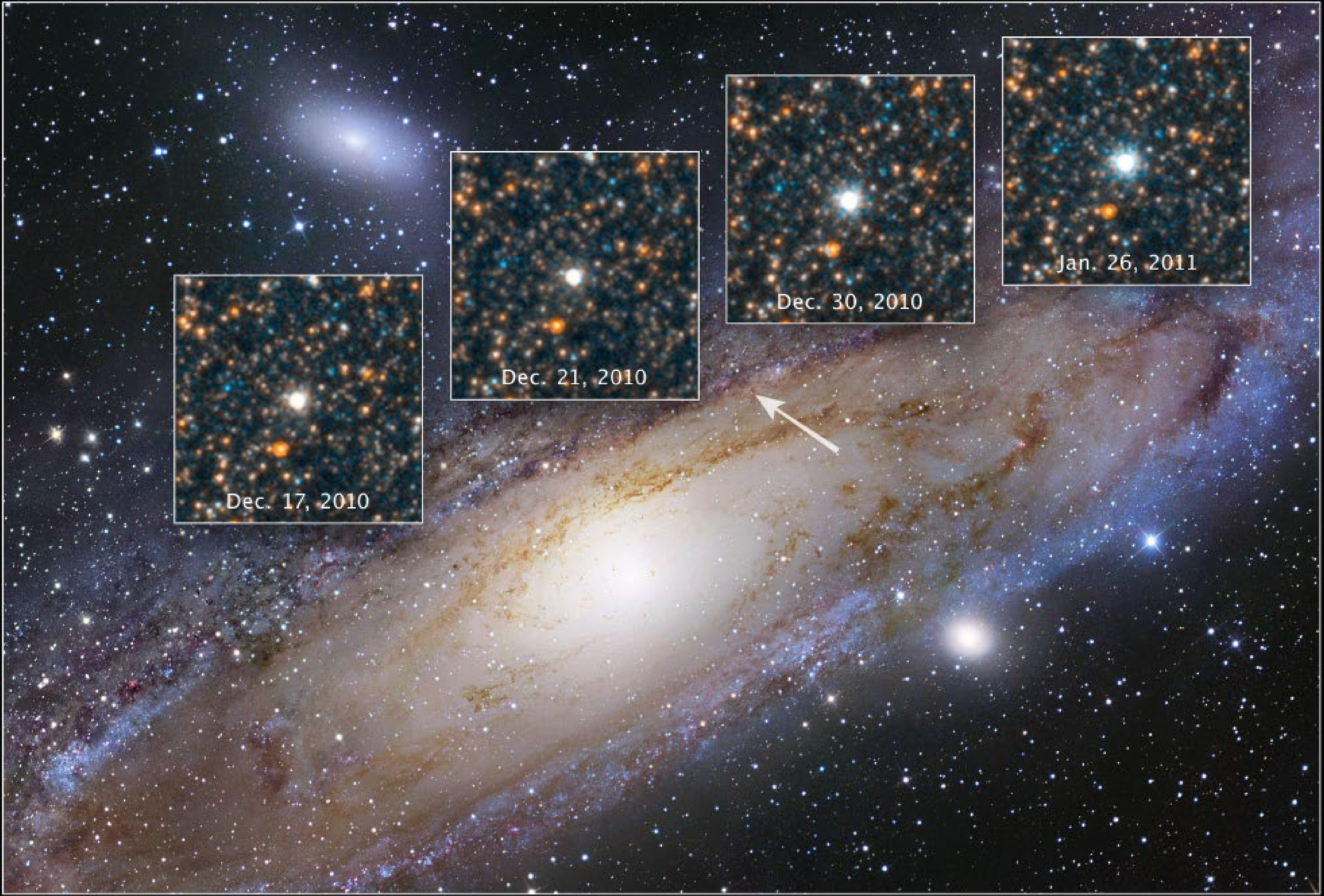

https://en.wikipedia.org/wiki/Classical_Cepheid_variable

As the star gets bigger, its surface temperature cools and it appears redder.
As it contracts it heats up, and its surface temperature increases and it appears bluer.
These are all post-main sequence stars that have exhausted their hydrogen and are fusing helium. As they undergo these pulsations, they oscillate between being red giants and blue giants on the instability strip. **Note that these are not the same as O and B hydrogen-burning stable blue giants on the main sequence.**



Cepheid Variable Star V1 in M31

*Hubble Space Telescope* ▪ WFC3/UVIS

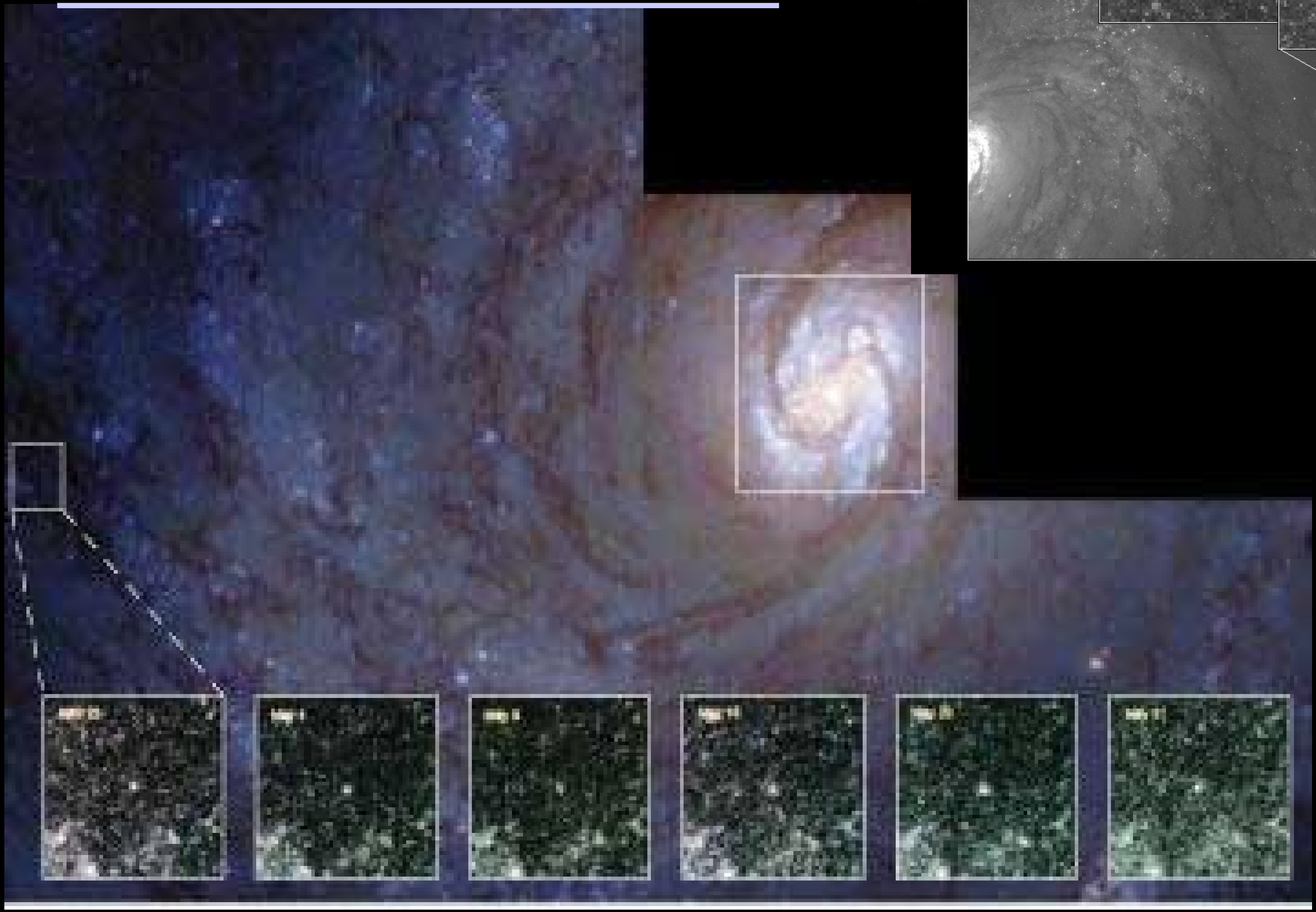


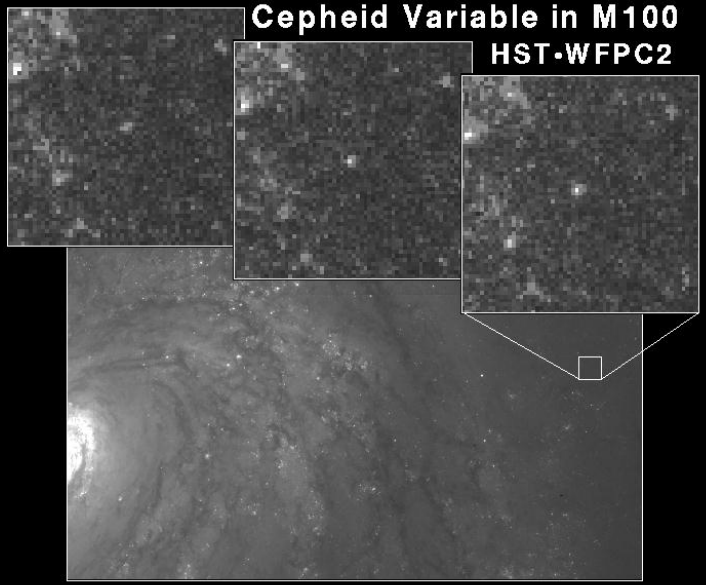

NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

STScI-PRC11-15a

Cepheid variables in M100

an excellent video – click here





**Henrietta Swan Leavitt**
**1868-1921**
**Discovered period-luminosity relation for Cepheids**

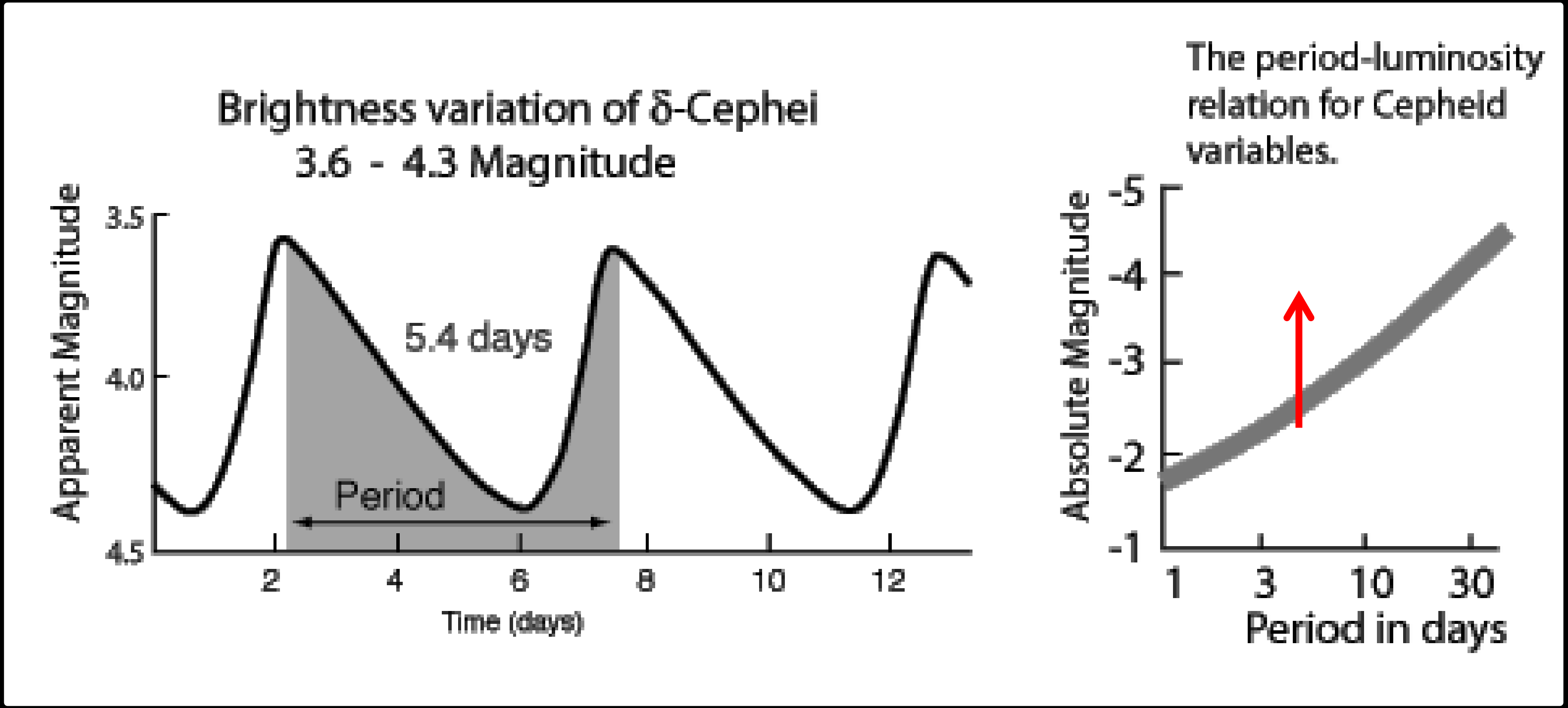
**“Pickering’s Harem”**
**at the Harvard Observatory**

The longer the cycle of pulsation for a star on the instability strip, the bigger its mass and hence the brighter it is.

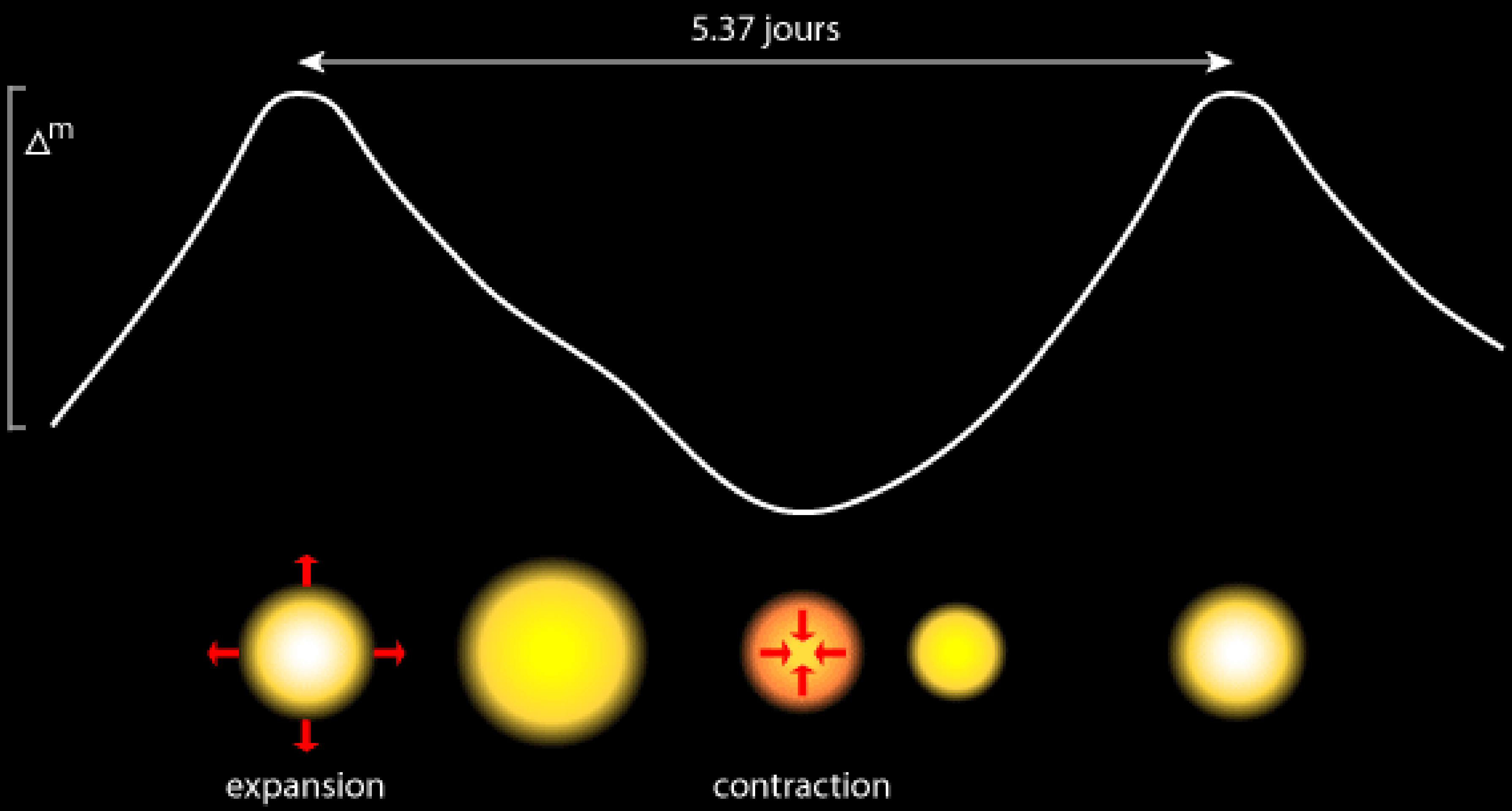
Leavitt figured out that she could calculate a pulsating star's absolute magnitude from its period of pulsation.

Then she could calculate its distance using the distance formula.

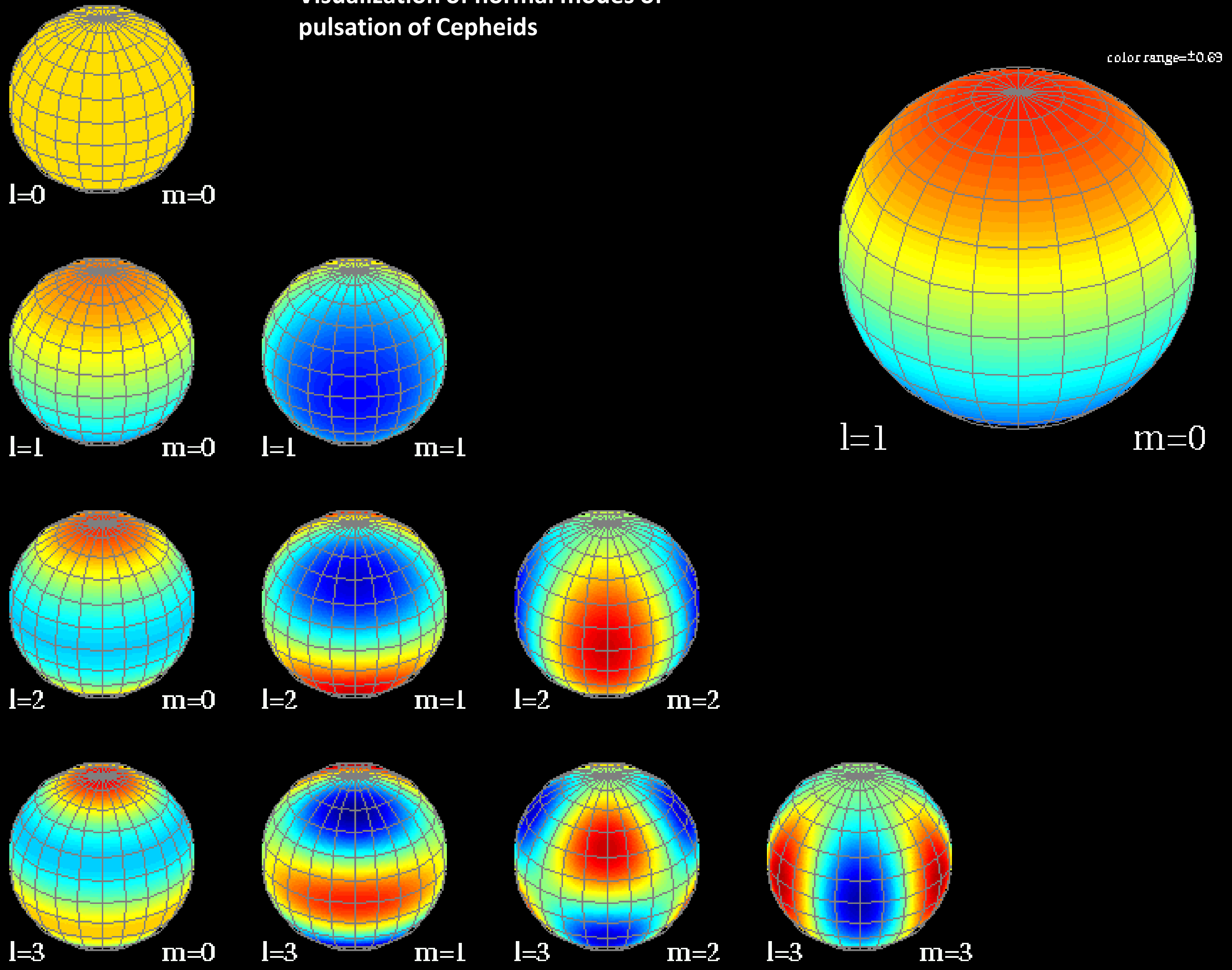
Cepheid variables have been discovered in our galaxy, our satellite galaxies, and other galaxies. They are used as standard candles for determining distances.



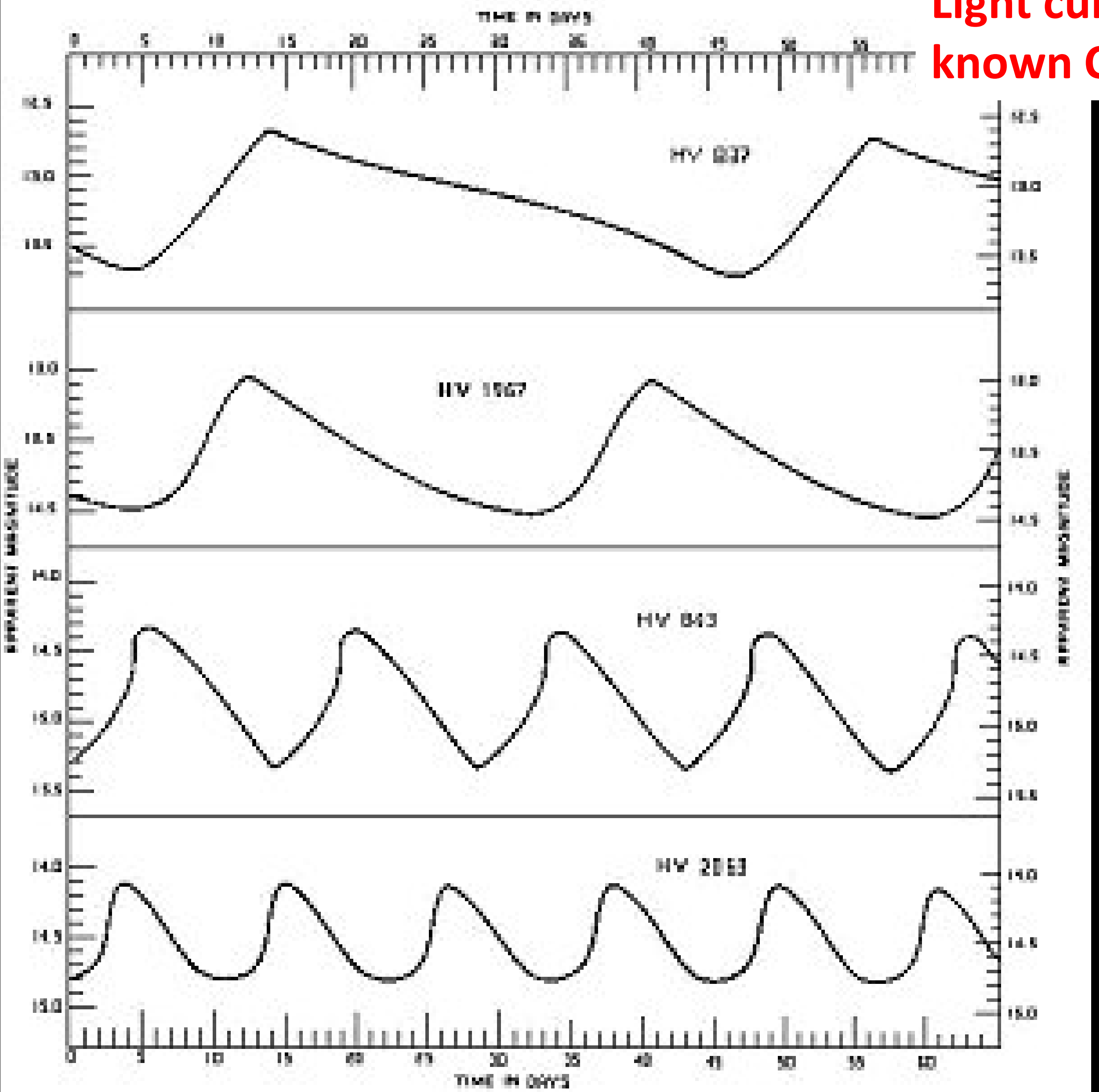
# delta Cephei – prototype for this type of variable star



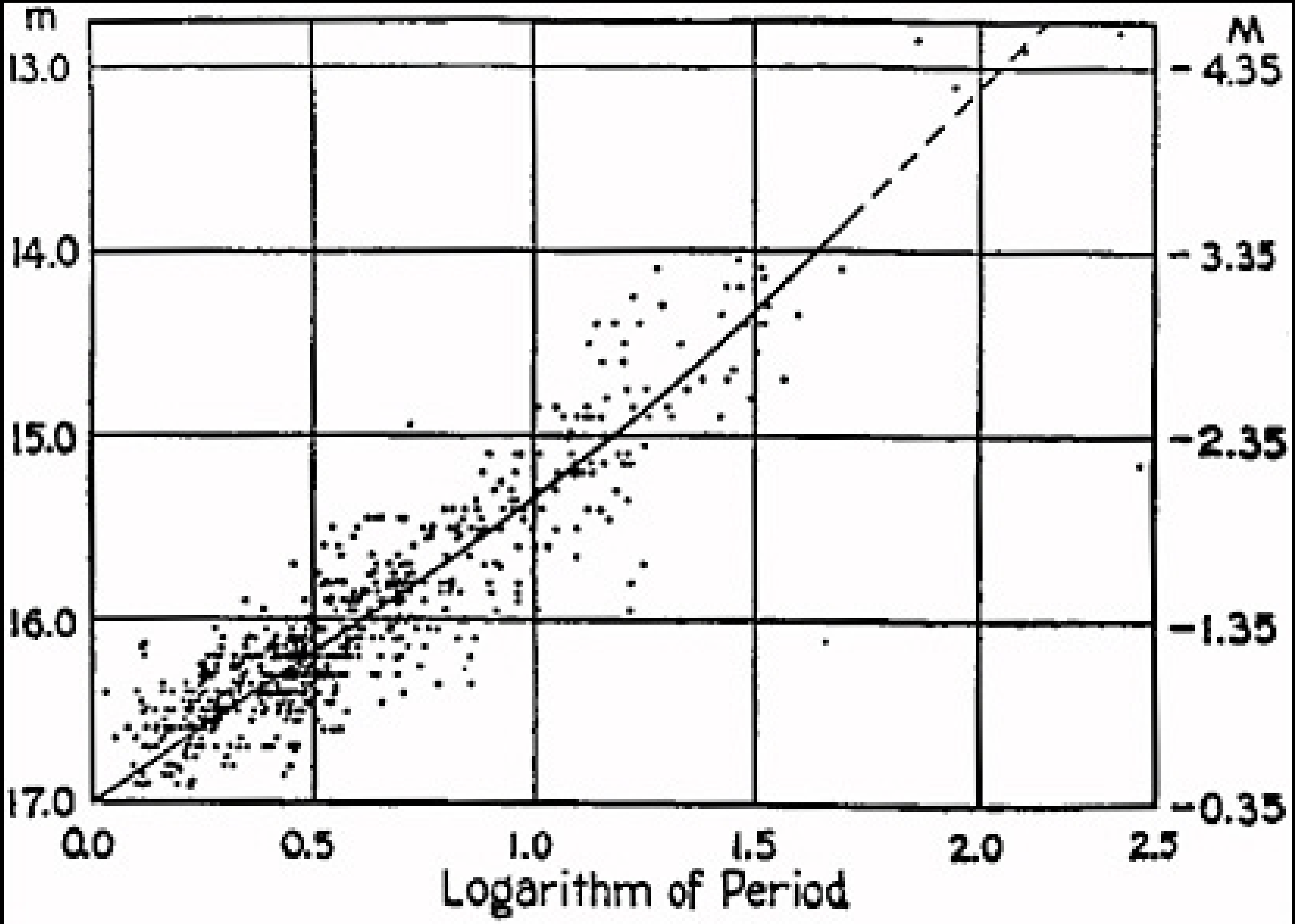
# Visualization of normal modes of pulsation of Cepheids



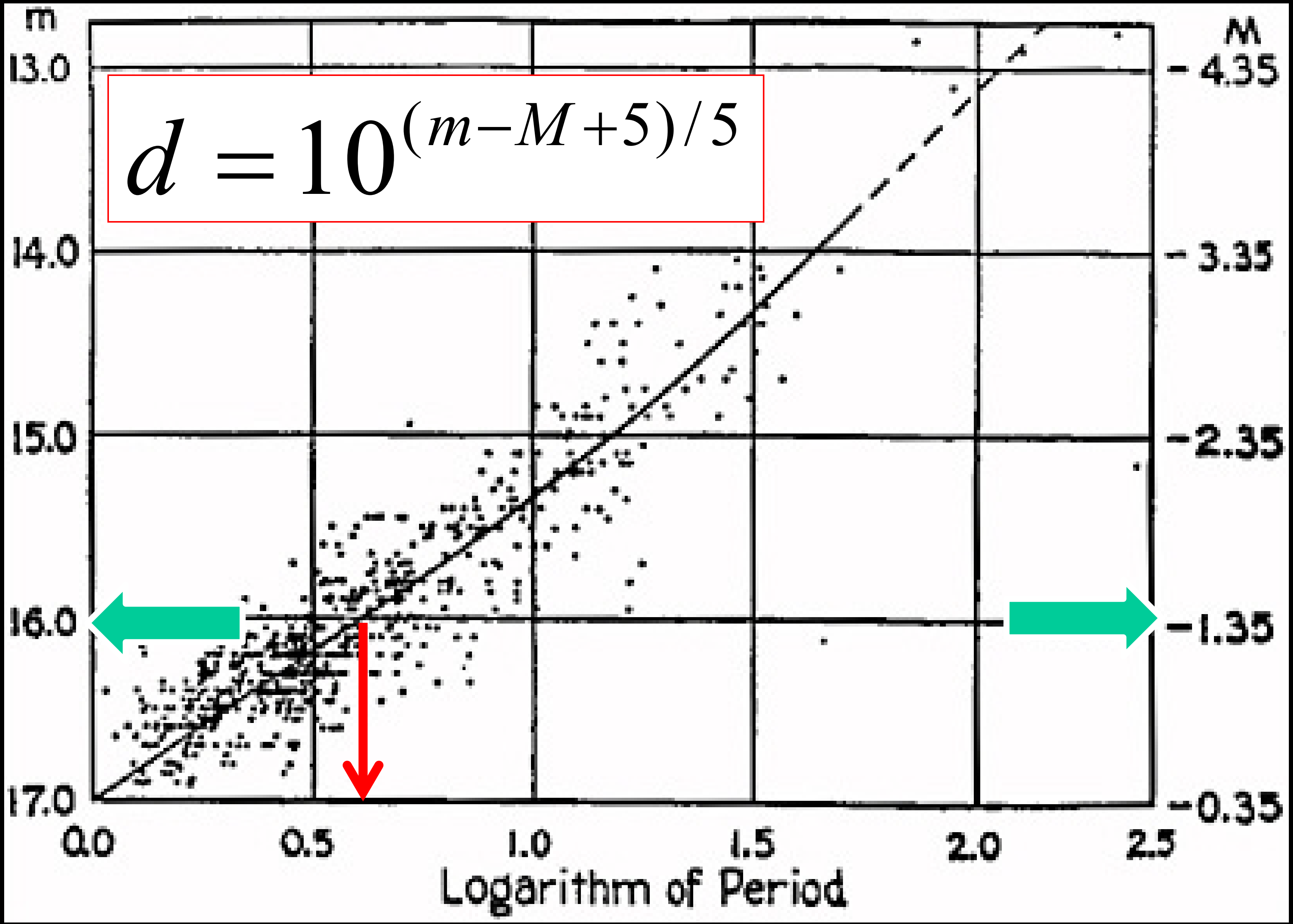
# Light curves for some known Cepheid variables



**Period-Luminosity relationship for Cepheid Variables**
**The longer the period of pulsation = the brighter the star!**

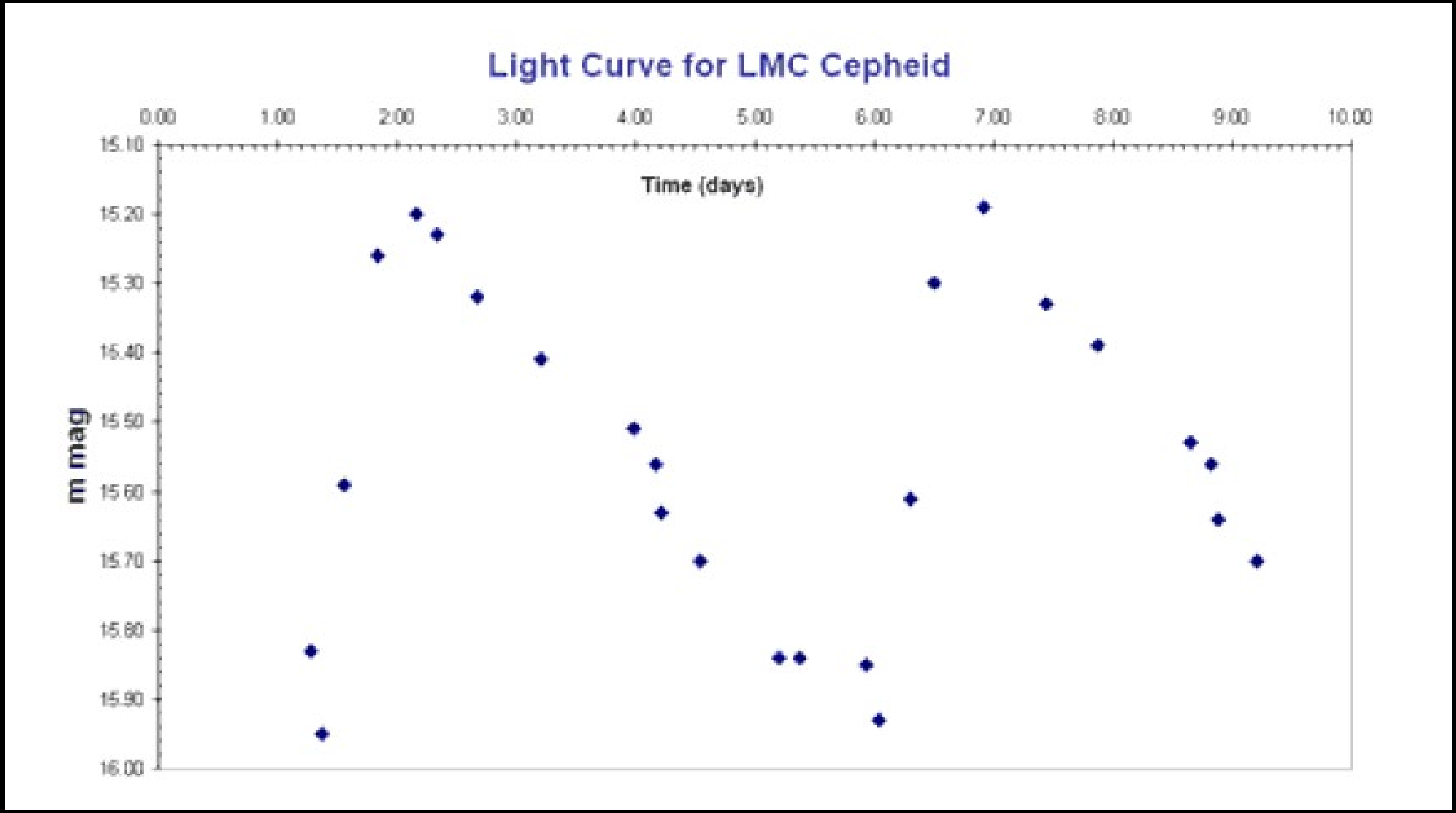


## Using Cepheids to find distances to galaxies!
## If you know m you can find M and then calculate distance!



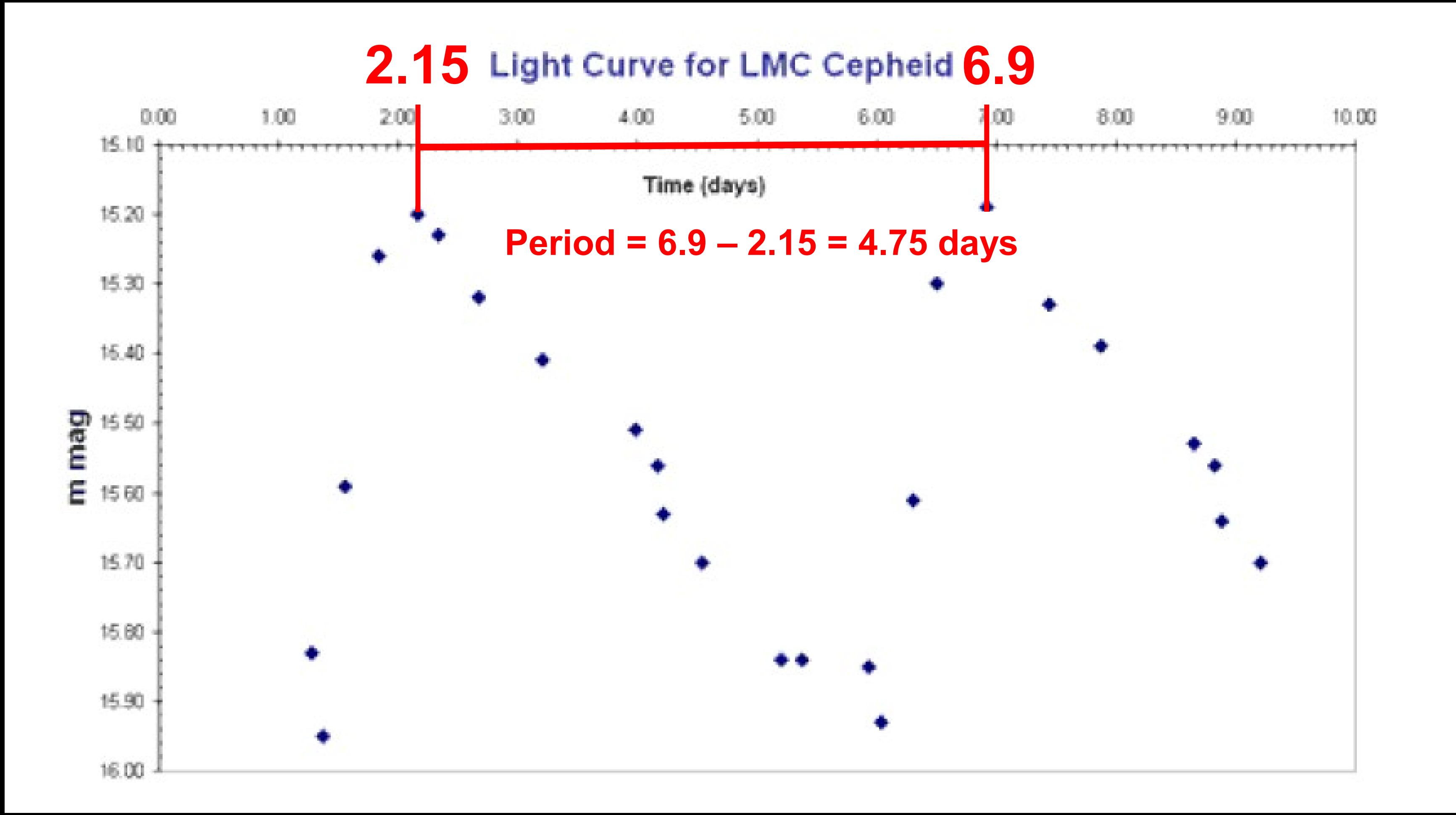

$$d = 10^{(m-M+5)/5}$$

# Lab 7: Finding the distance to the Large Magellanic Cloud using Cepheid Variables.



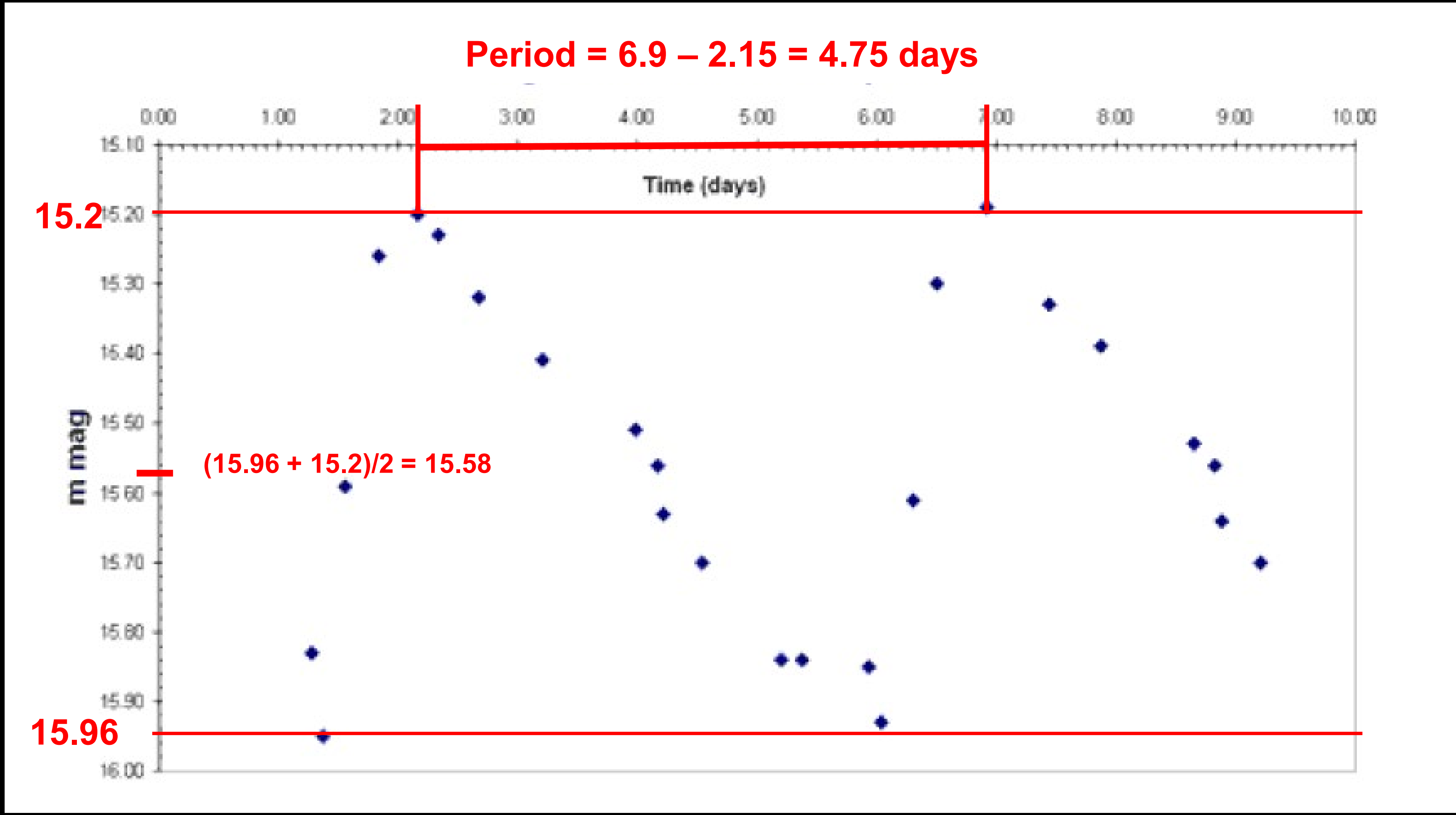

1. Find the period in days from the horizontal axis.
2. Calculate the average apparent magnitude by taking the difference between the magnitude at the peak brightness and the lowest brightness, reading from the vertical axis.

# 1. Find the period:



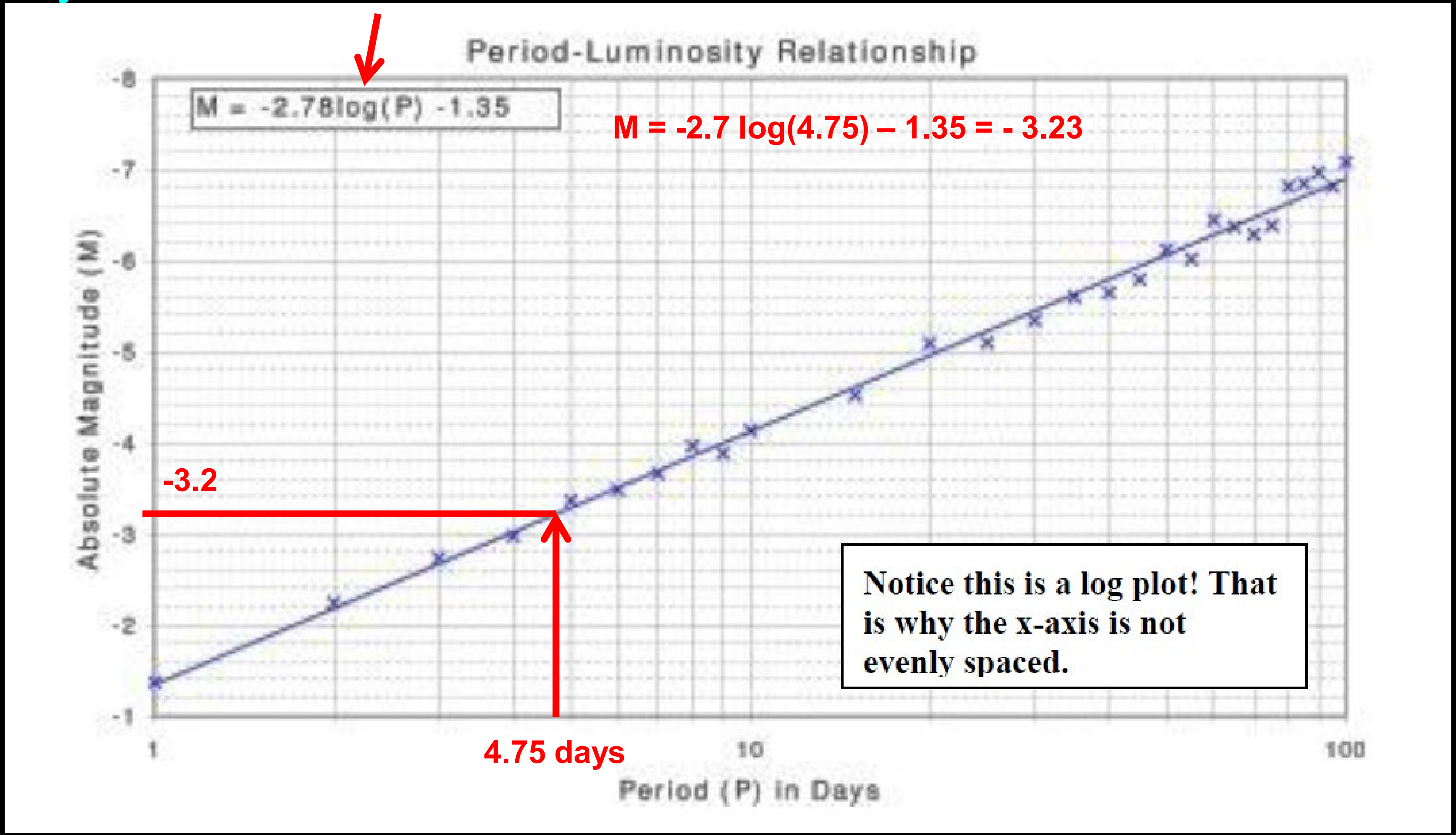

1. Find the period in days from the horizontal axis: 4.75 days
2. Calculate the average apparent magnitude by taking the difference between the magnitude at the peak brightness and the lowest brightness, reading from the vertical axis.

# 2. Find the average apparent magnitude:



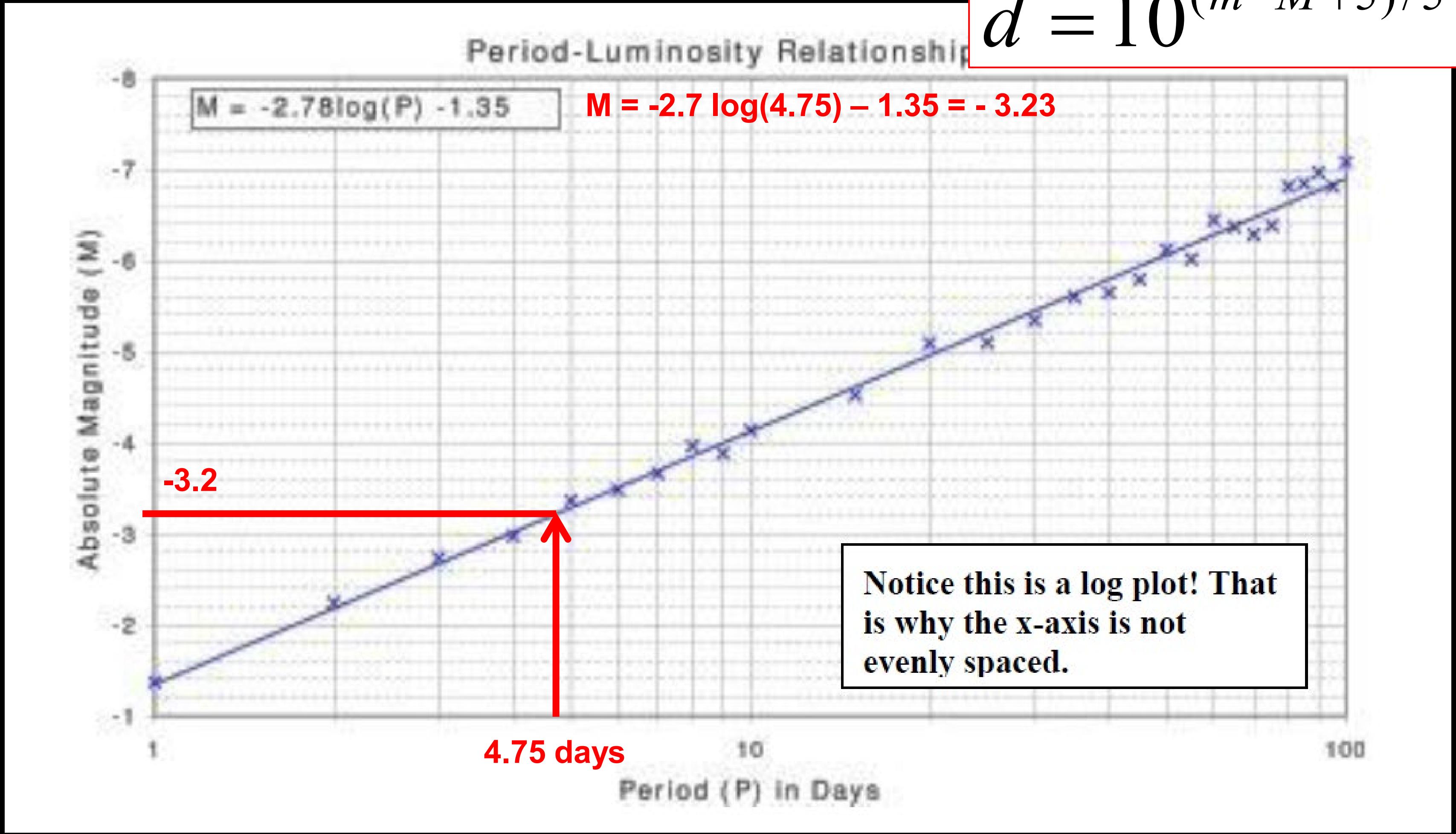

1. Find the period in days from the horizontal axis: 4.75 days
2. Calculate the average apparent magnitude by taking the difference between the magnitude at the peak brightness and the lowest brightness, reading from the vertical axis: 15.58

3. From the period-luminosity relationship for Cepheid variables, find its absolute magnitude by finding the period on the x axis and reading across to the y axis. Or use your calculator and the formula below to find M.



## 4. Calculate its distance using the distance formula:

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




$$d = 10^{(15.58 - -3.23 + 5)/5} = 57800 \text{ pc} = \sim 188{,}428 \text{ ly}$$

Answers:

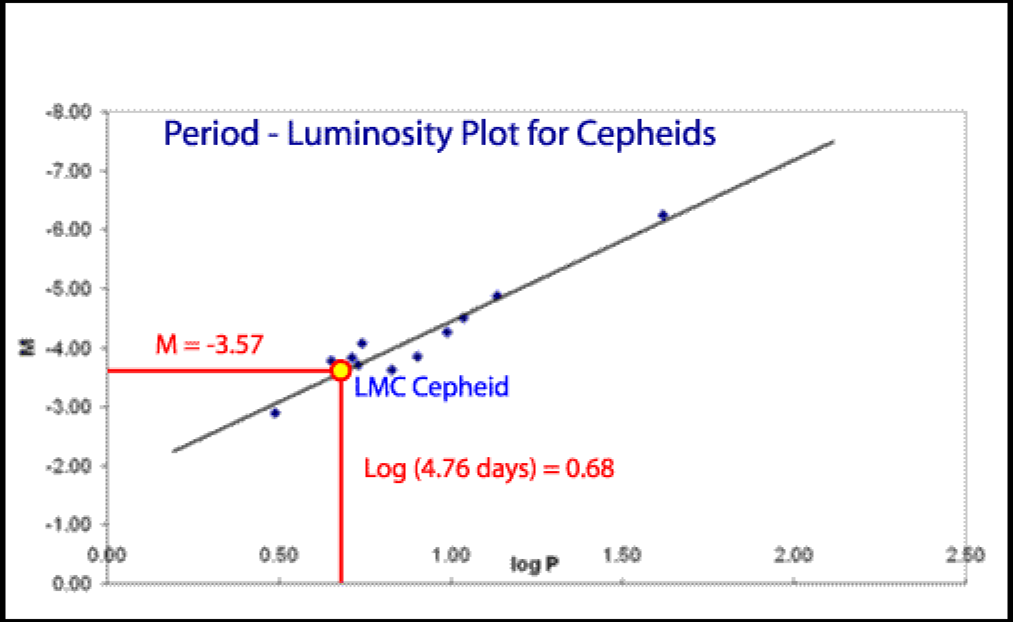
p = about 4.6 days

$m_{average}$ = 15.6

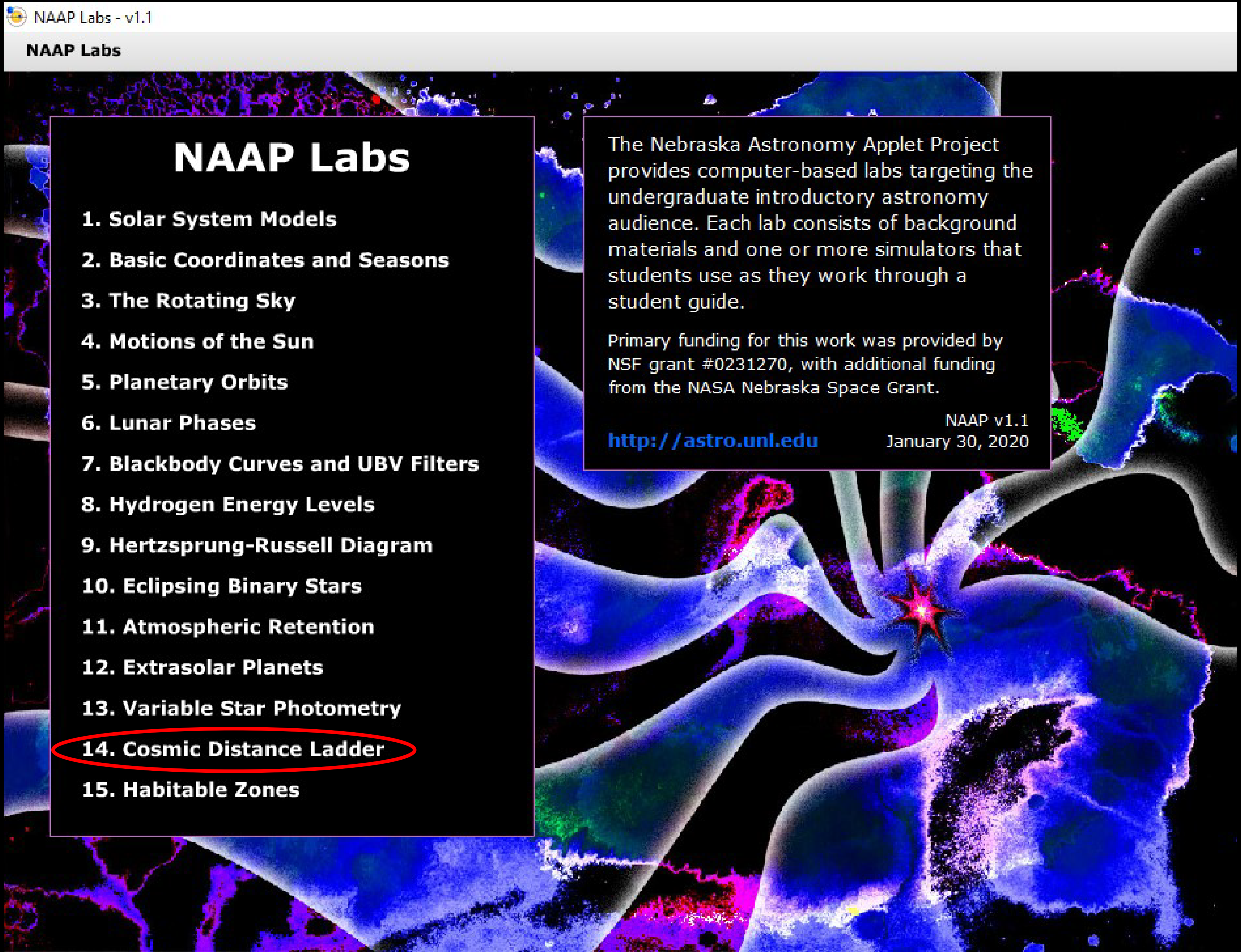
M = -3.14

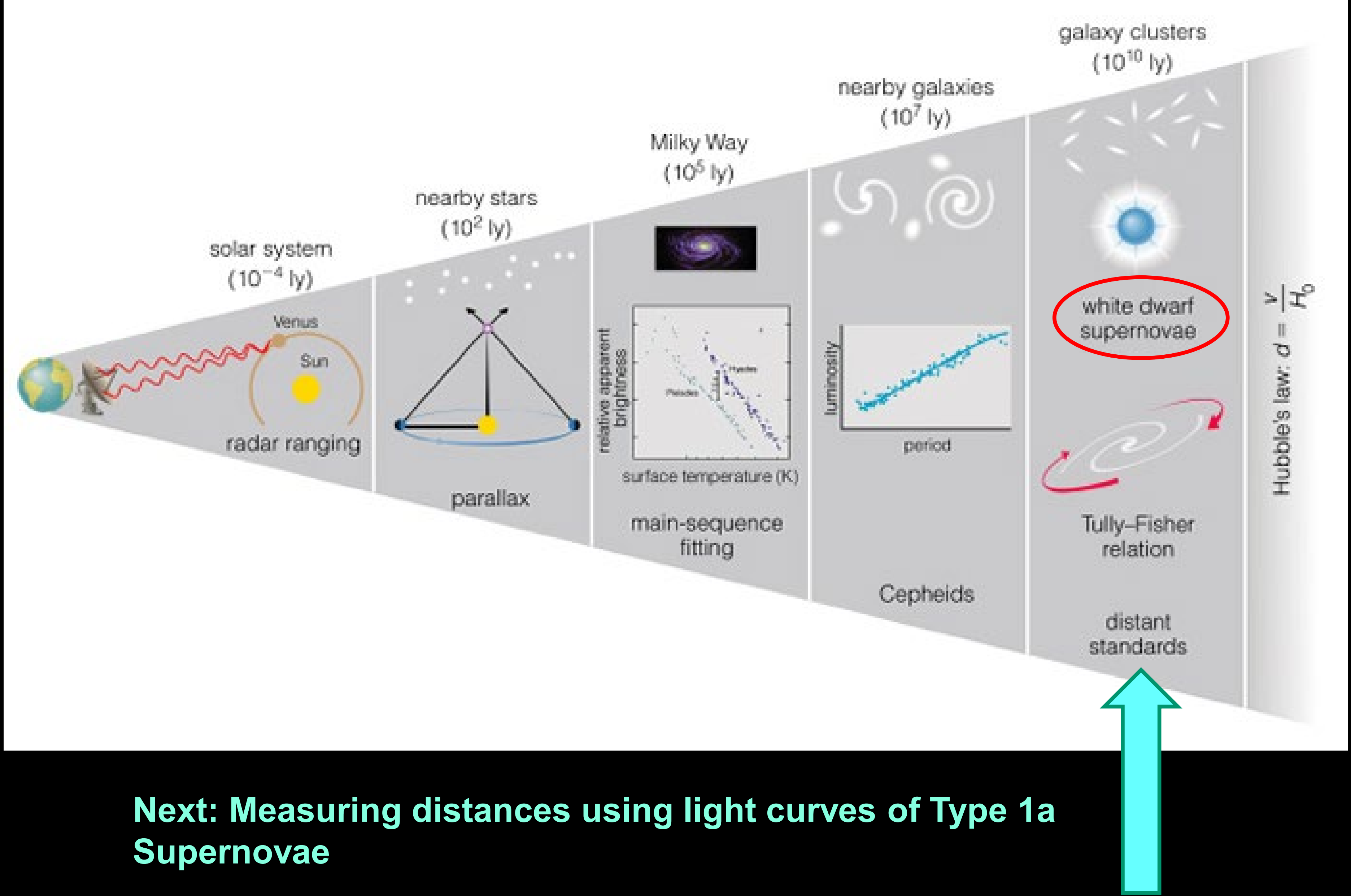
d = 55,975 pc = 182,480 ly

Published values range between ~163,000 ly and 220,000 ly.

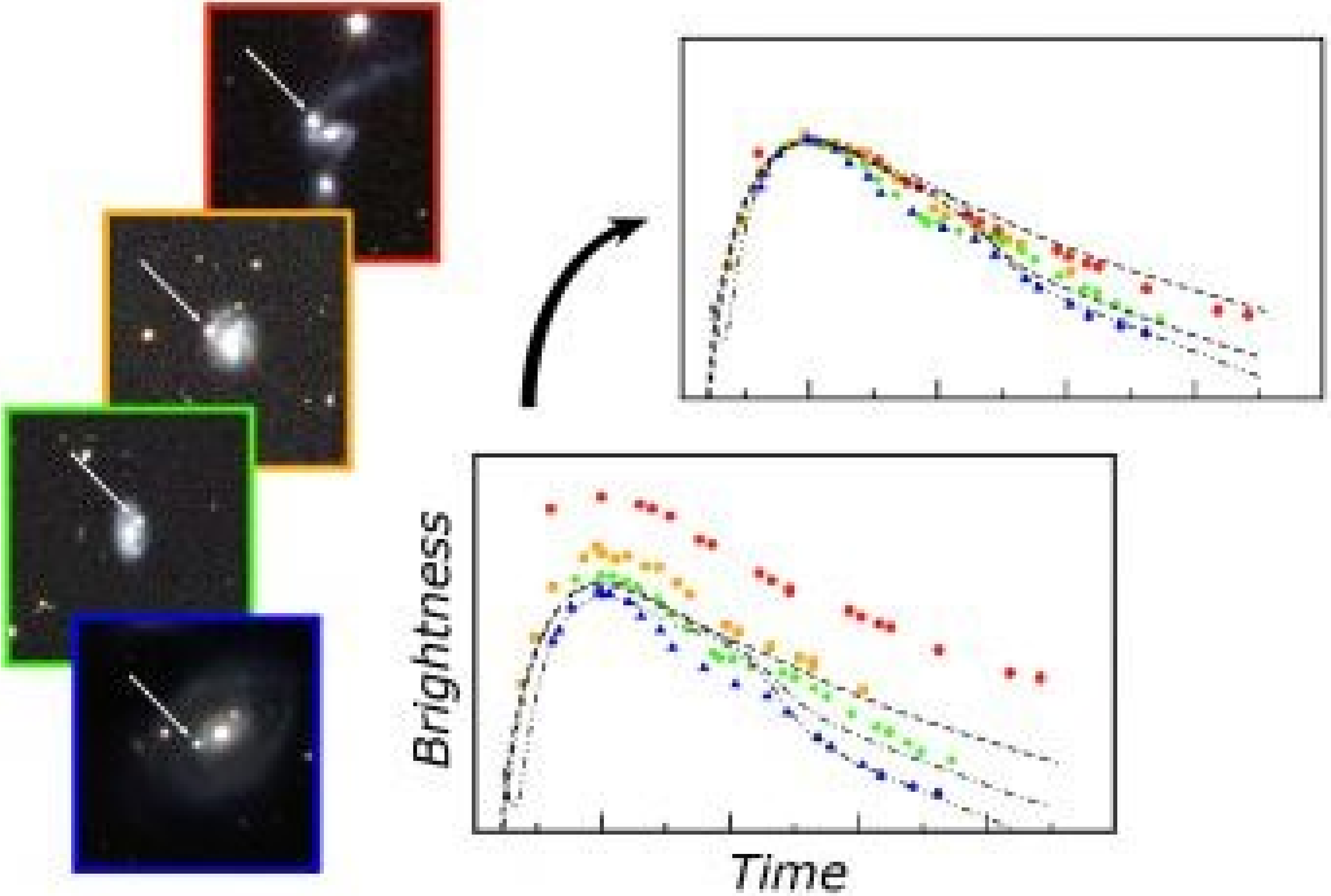



http://www.atnf.csiro.au/outreach/education/senior/astrophysics/variable_cepheids.html


NAAP Labs - v1.1
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.
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




**Next: Measuring distances using light curves of Type 1a Supernovae**




**Light curves of Sne Ia are used as standard candles!**
**Shape of curve → mass → mass-luminosity relation for Sne 1a**

## These light curves are powered by radioactive decay in two stages:

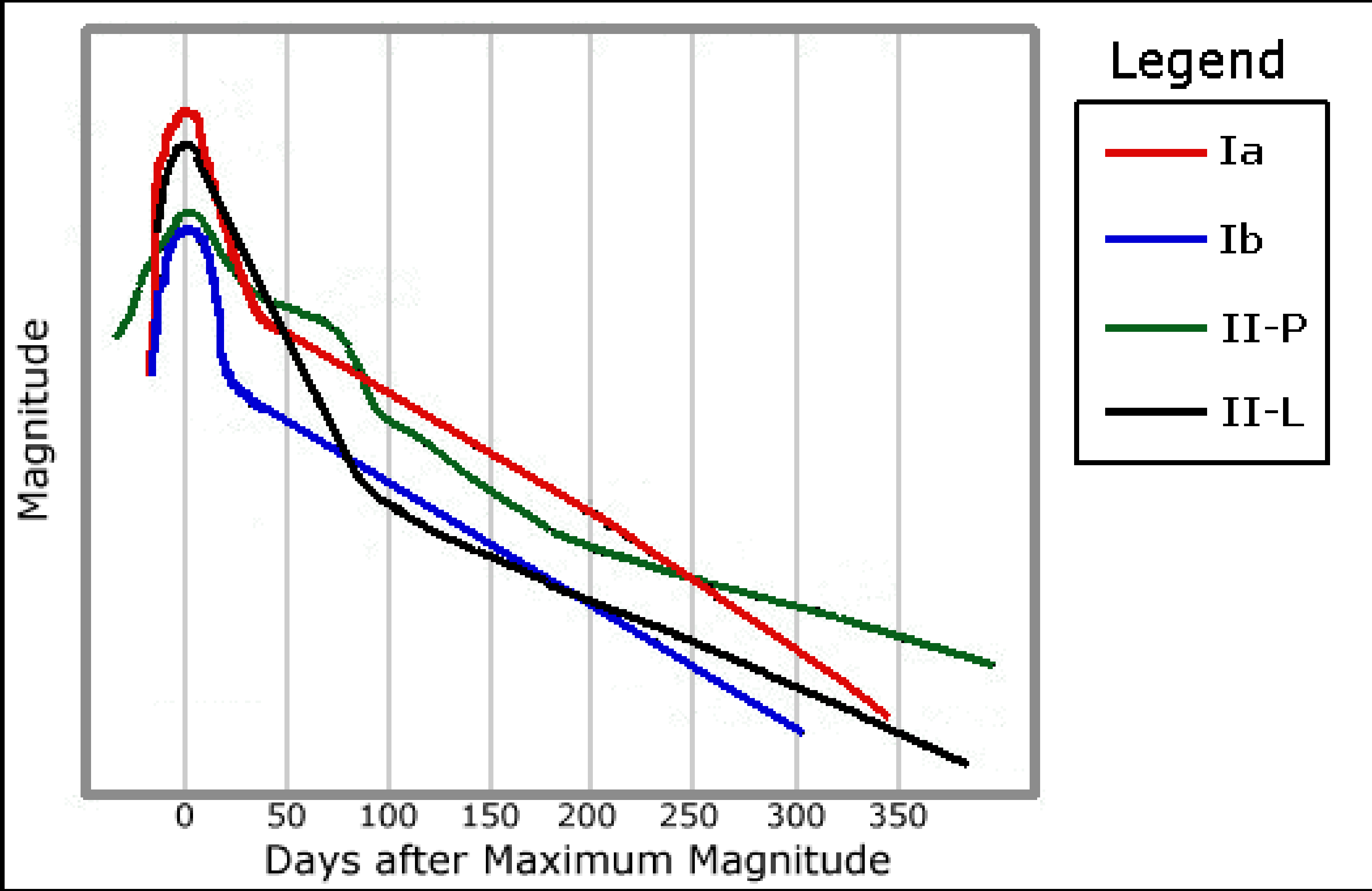
Stage 1 is the decay of $^{56}$Ni to $^{56}$Co This has a 1/2 life of 6.1 days and predicts that the SN luminosity decays at the rate of 11% per day.

$$^{56}_{28}\mathrm{Ni} \;\rightarrow\; ^{56}_{27}\mathrm{Co} + e^{+} + \nu_e + \gamma$$

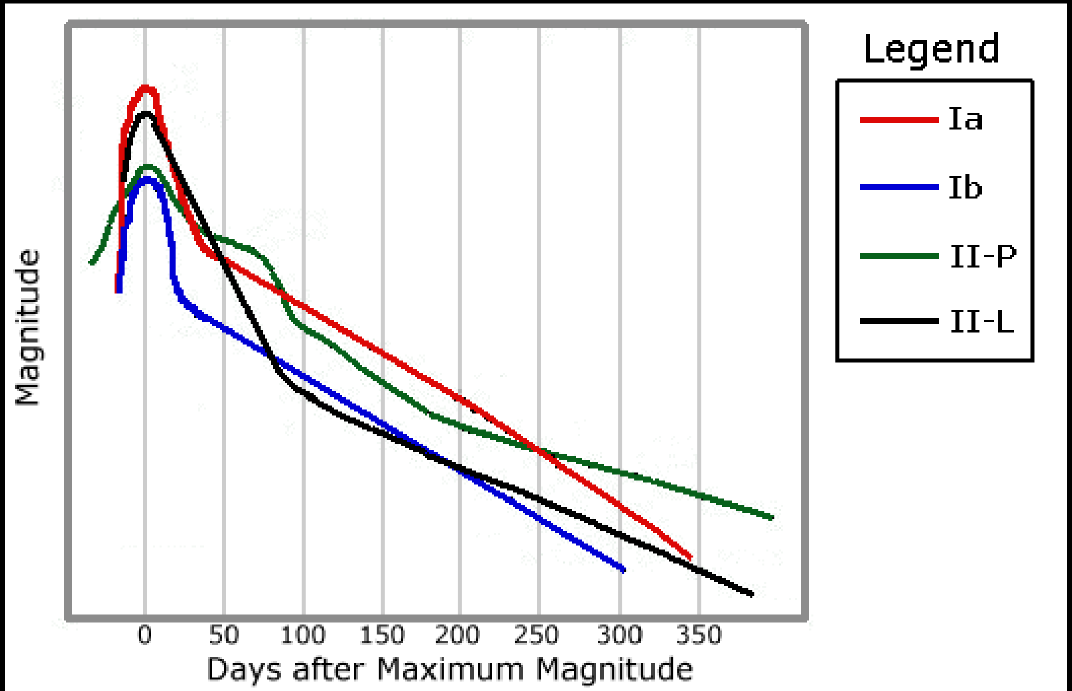
Stage 2 is the decay of $^{56}$Co to $^{56}$Fe. This has a 1/2 life of 77 days and predicts that the SN luminosity decays at the rate of 1% per day.

$$^{56}_{27}\mathrm{Co} \;\rightarrow\; ^{56}_{26}\mathrm{Fe} + e^{+} + \nu_e + \gamma$$

All type Ia supernovae reach nearly the same brightness at the peak of their outburst with an absolute magnitude of **-19.3±0.03**.



All type Ia supernovae reach nearly the same brightness at the peak of their outburst with an absolute magnitude of **-19.3±0.03**.



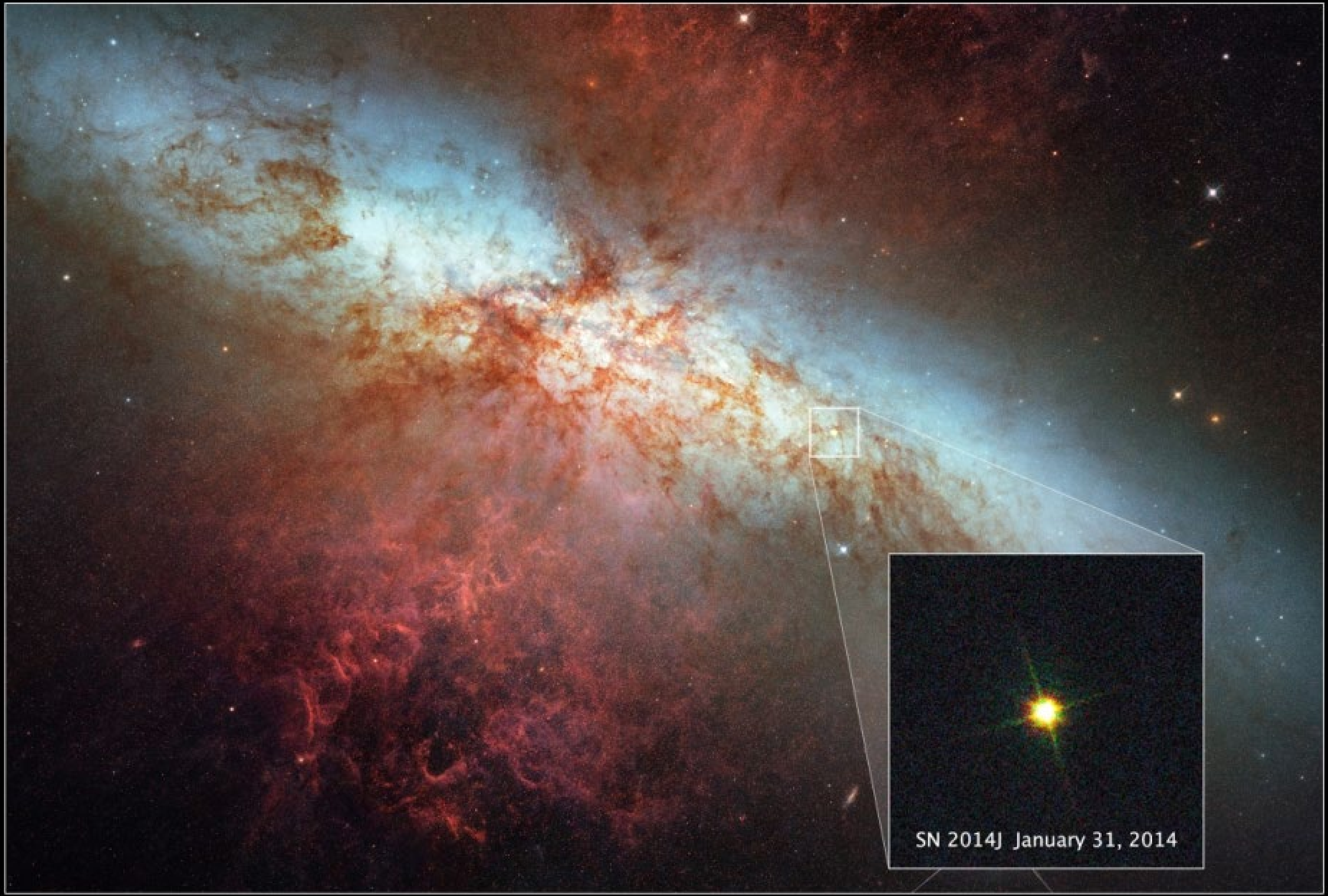

$$d = 10^{(m-M+5)/5}$$

units of d are parsecs
1 pc = 3.26 ly

**Thus, if you can measure the apparent magnitude of a type Ia Sn, you can calculate how far away its host galaxy is!**

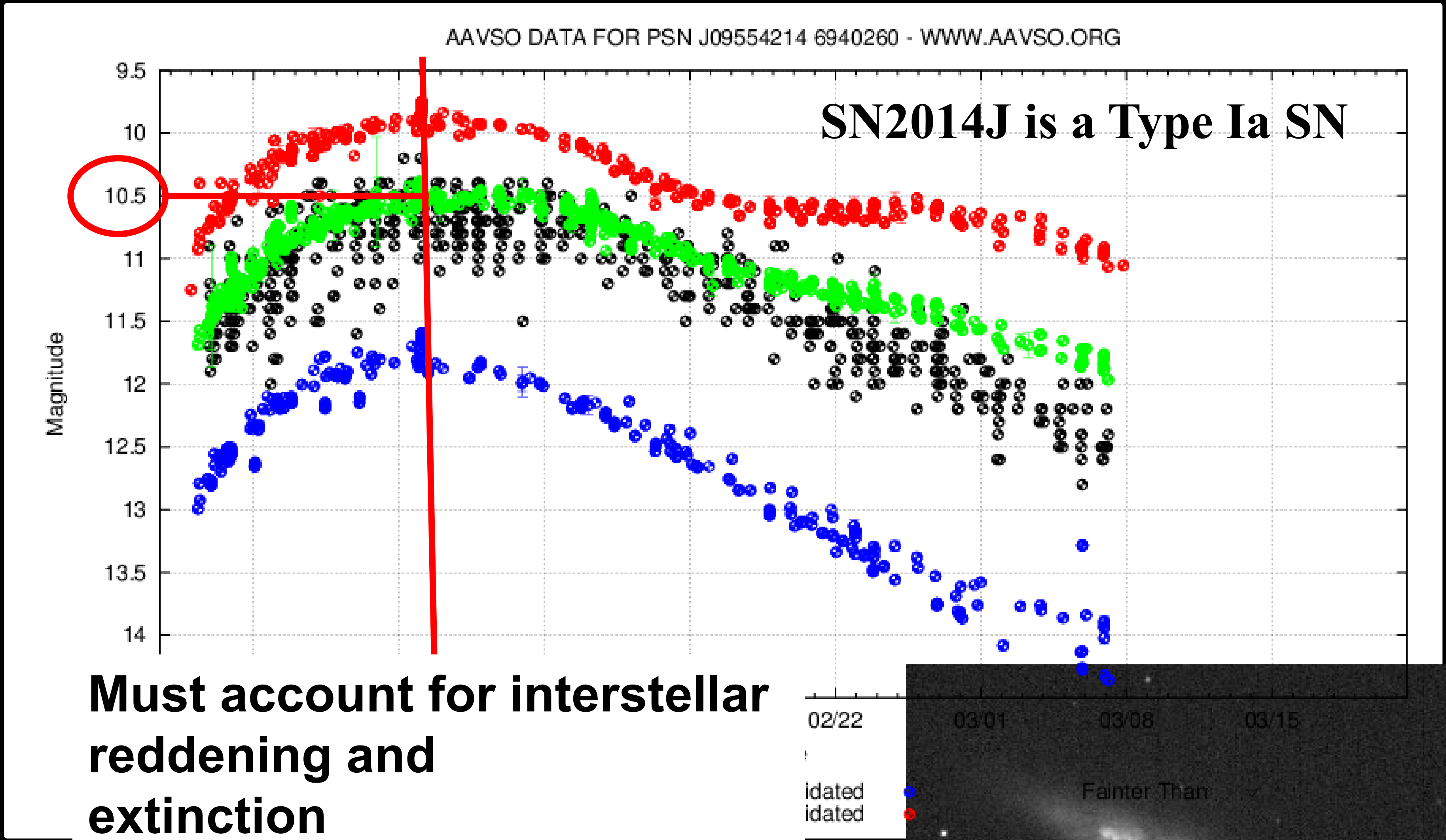
Supernova 2014J in Galaxy M82

*HST* ▪ WFC3/UVIS ▪ ACS/WFC



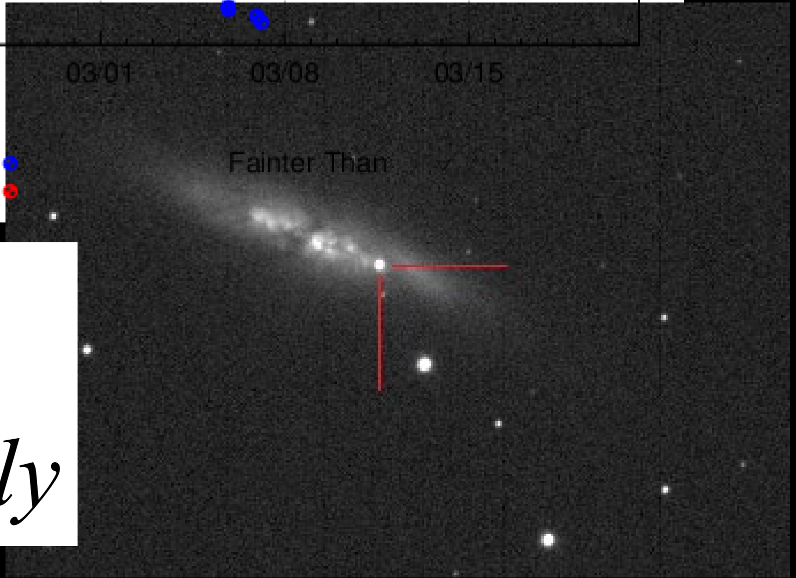

NASA and ESA

STScI-PRC14-13a



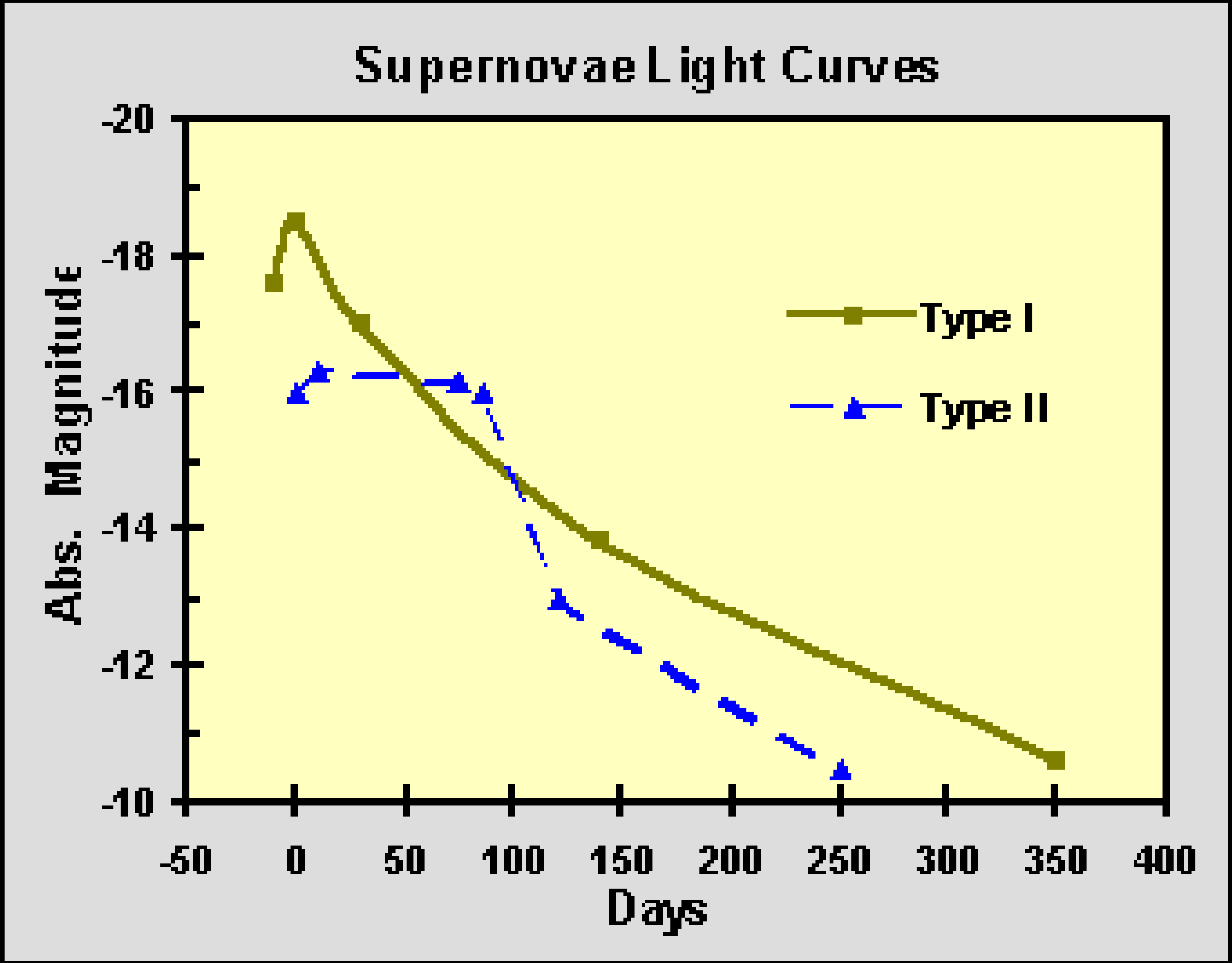

**SN2014J is a Type Ia SN**

**Must account for interstellar reddening and extinction**



$$d = 10^{(9.5-(-19.3)+5)/5}$$

$$d = 5.75\times10^{6}\,pc = 1.87\times10^{7}\,ly$$



Supernovae Light Curves
-20
-18
-16
-14
-12
-10
Abs. Magnitude
-50
0
50
100
150
200
250
300
350
400
Days
Type I
Type II