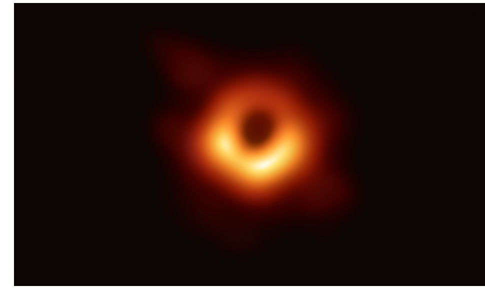
- Angular size of the M87 SMBH



$$R_S = \frac{2GM}{c^2}$$

$$= \frac{2 \times 6.7 \times 10^{-11} \times 9.4 \times 10^{9} \times 2 \times 10^{30}}{\left(3 \times 10^{8}\right)^{2}}$$

$$= 2.8 \times 10^{13} \text{ m}$$

$$\theta = \frac{l}{d} = 206265 \frac{2.8 \times 10^{13}}{16.4 \times 10^{6} \times 3.1 \times 10^{16}}$$

$$= 1 \times 10^{-5} \text{ arcseconds}$$

=10 micro-arcseconds

Distances to Galaxies

- Standard candles
- Cepheid Variables
- Type Ia Supernovae

Standard Candles

- If we know the M_V and A_V of an object we can determine its distance from its apparent brightness
- i.e. we solve

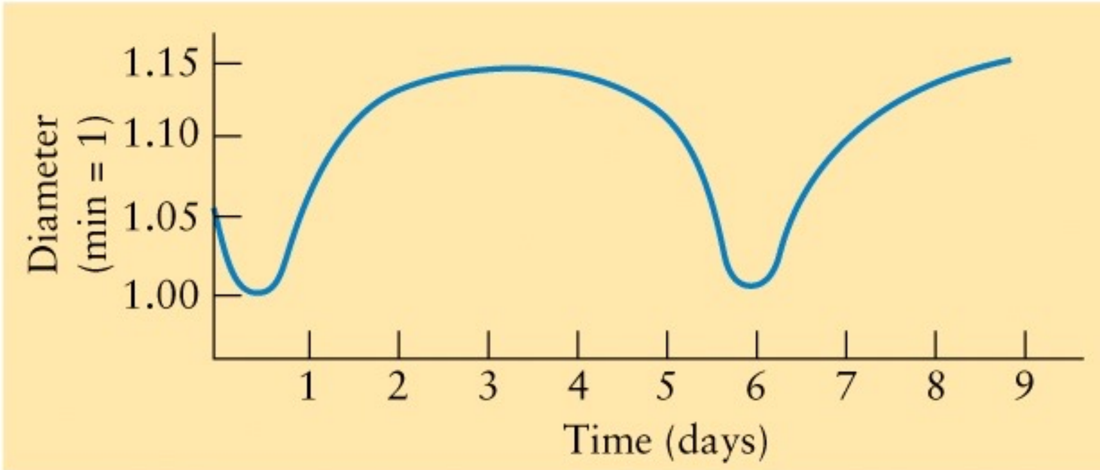
$$m_v - M_v = 5\log d - 5 + A_v$$

for *d*

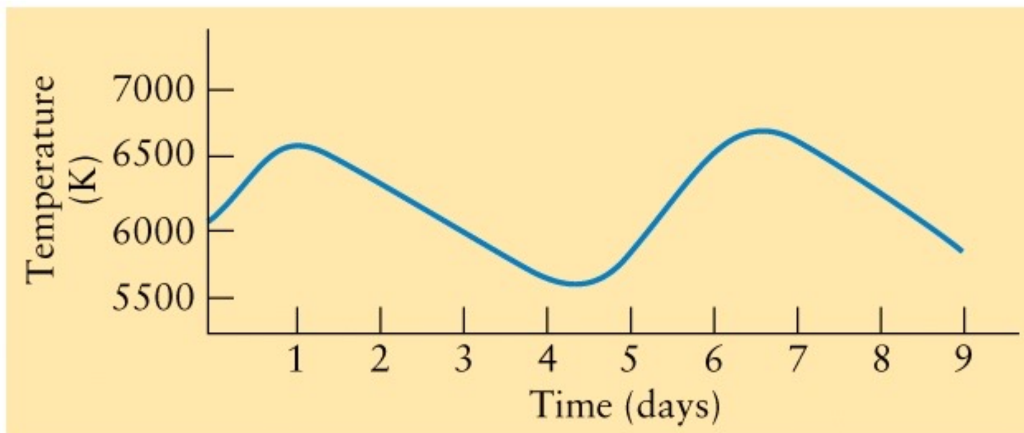
- A good standard candle will be bright, easily recognisable and well calibrated
- You can estimate M_V from the spectral type of normal stars but it is not very accurate
- Certain types of variable star turn out to be the best standard candles

Cepheid Variables

- Some stars become unstable during their evolution and pulsate regularly
- This causes a periodic change in their brightness

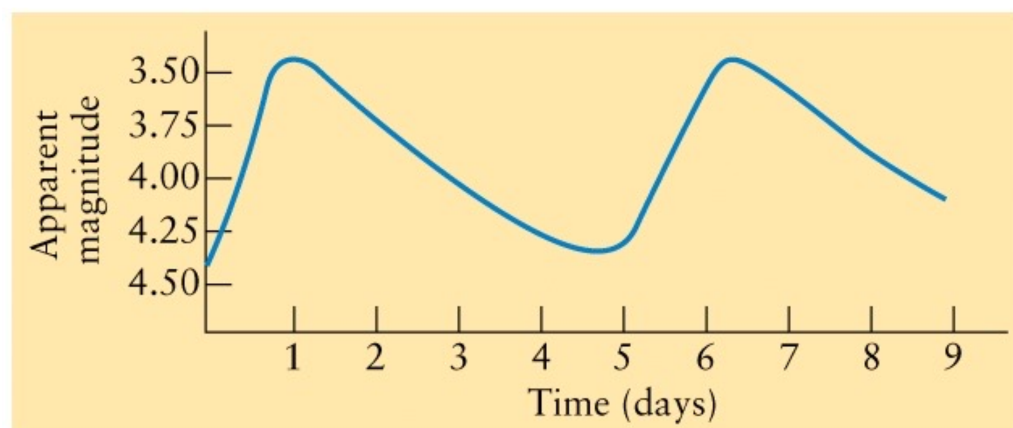


d



c

Physical changes as a
Cepheid pulsates

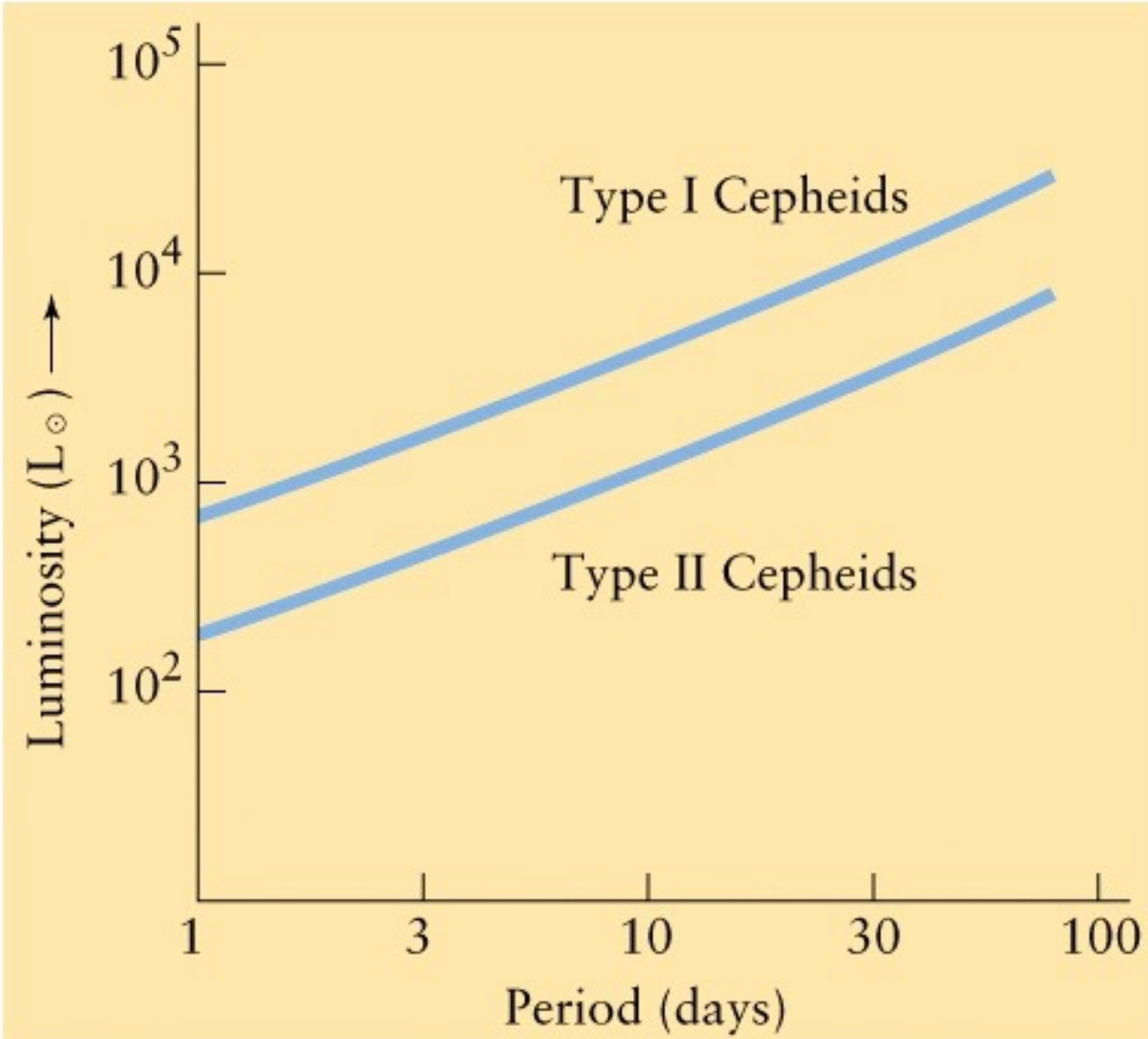


a

From Universe textbook

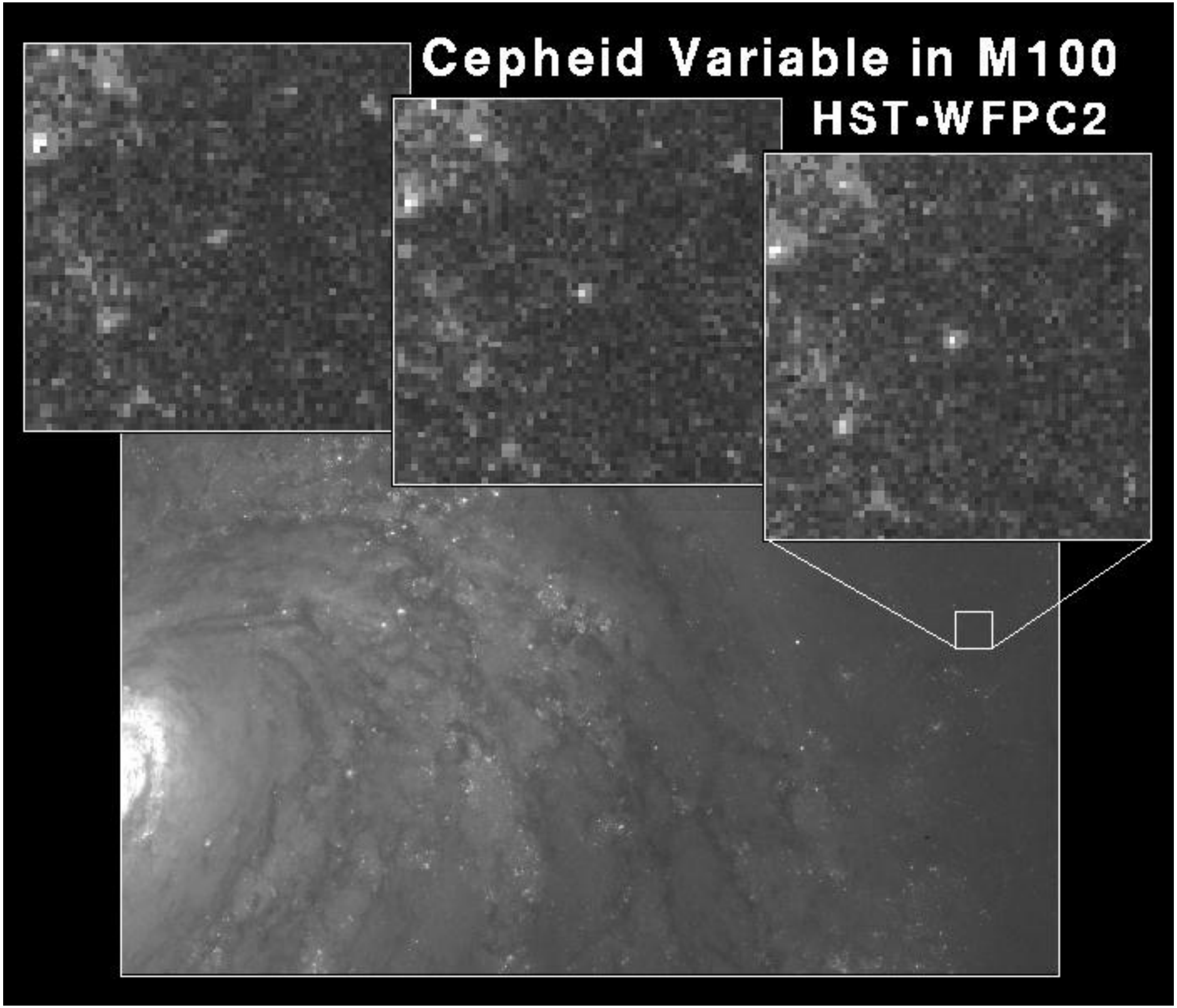
Period-Luminosity Relation

- Cepheid variables show a good correlation between the period of the pulsation and the luminosity of the star
- Period-Luminosity relationship changes with metallicity (Population I or II)



From Universe textbook

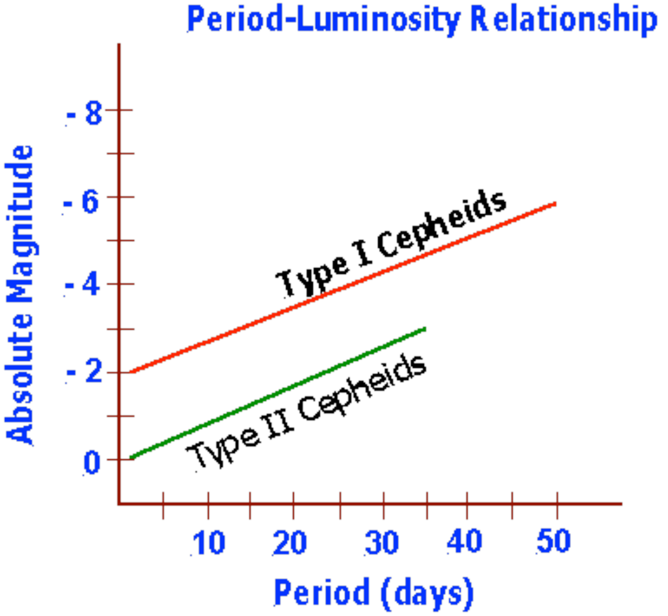
- If you measure the period then you can determine M_V
- Periods range from a few days to weeks
- Can be seen out to Virgo cluster distances



HST. Credit: Dr. Wendy L. Freedman, Observatories of the Carnegie Institution of Washington, and NASA

Class Example

A Cepheid variable has a period of 15 days. Its average apparent visual magnitude is 27.8. How far away is the Galaxy assuming it is a Type I Cepheid and ignoring extinction?



- From the plot a period of 15 days corresponds to M_V= -3.1 assuming it is a Type I Cepheid.

$$m_V - M_V = 5\log d - 5$$

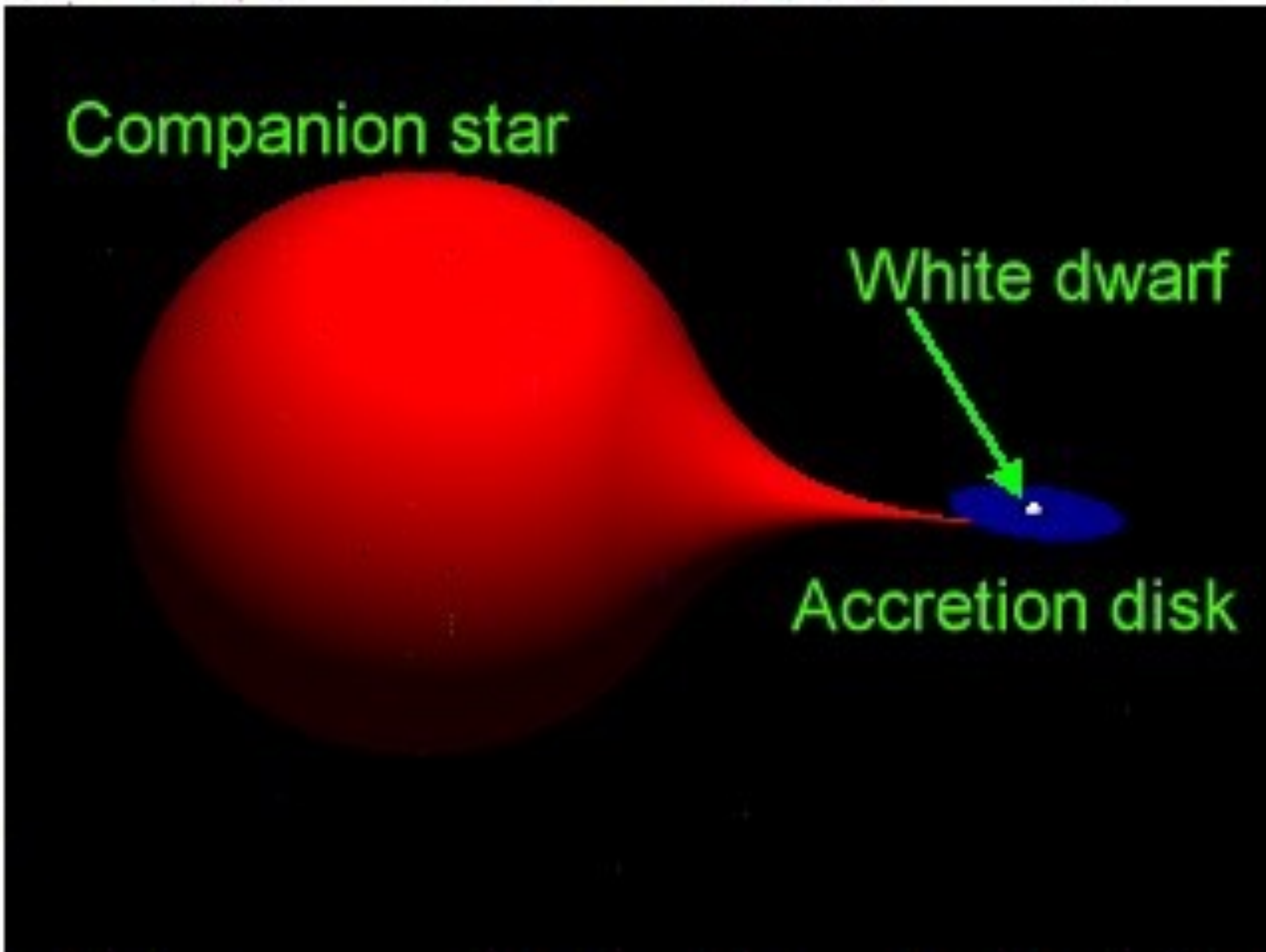
$$\log d = \frac{m_V - M_V + 5}{5} = \frac{27.8 - (-3.1) + 5}{5} = 7.2$$

$$d = 1.5 \times 10^7 \text{ pc}$$

$$= 15 \text{ Mpc}$$

Type Ia Supernovae

- The collapse of a white dwarf at its mass limit is a very controlled explosion
- The brightness at maximum light has been shown to be well understood
- Extremely bright so can be seen to large distances



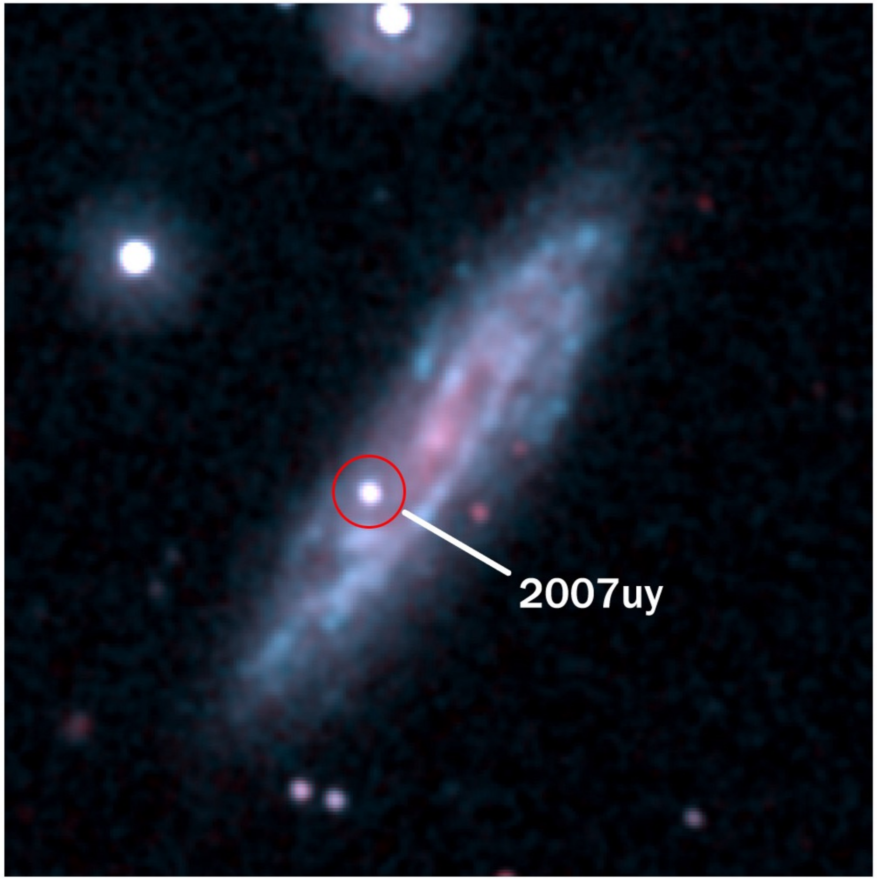
Paul Ricker, University of Illinois

- Need to monitor many galaxies since supernovae are quite rare
- Monitoring needs to be nightly since the rise to maximum light only takes a couple of days

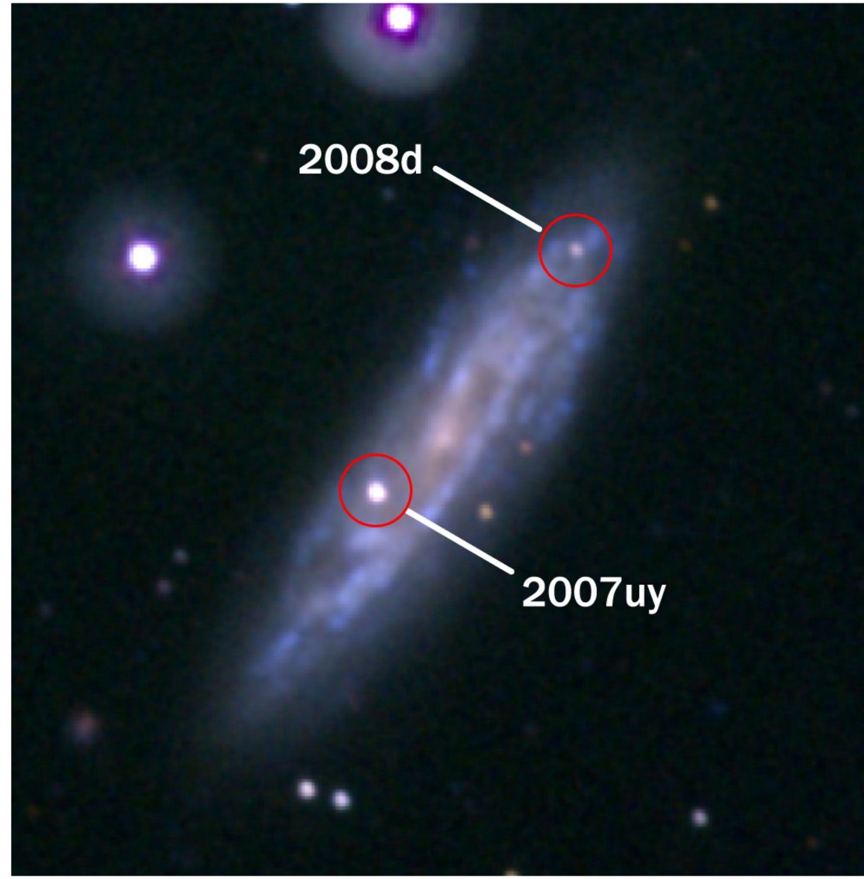
Supernova in M51 seen with 50 cm telescope

Credit: R Jay GaBany (Cosmotography.com)

January 7, 2008

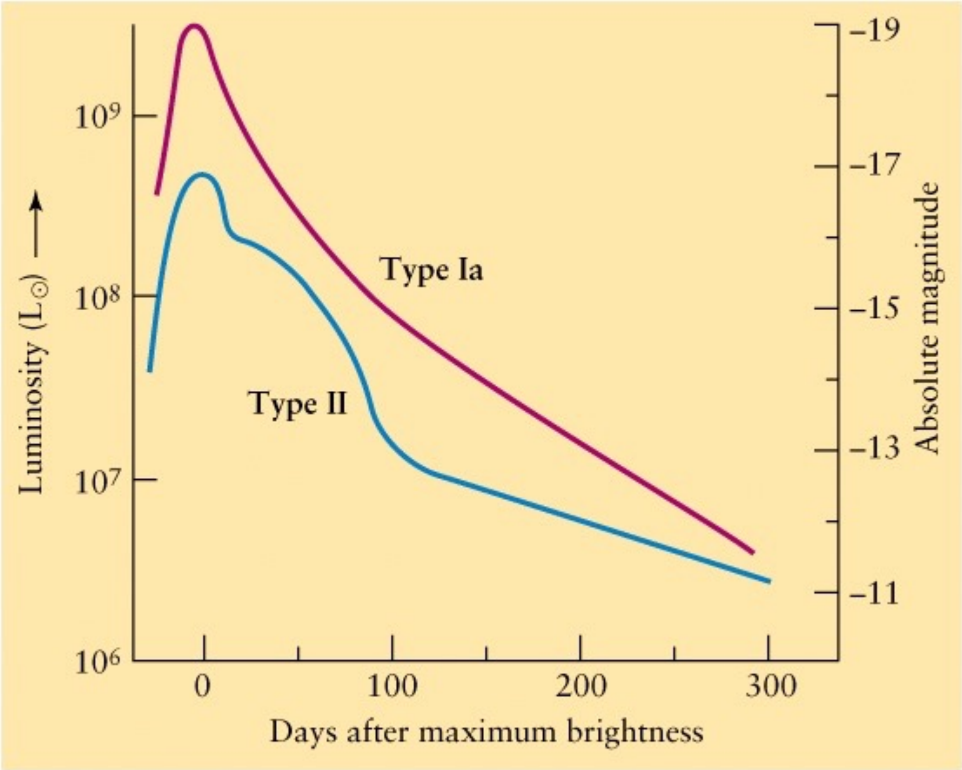


January 9, 2008



Credit: Images courtesy of NASA Swift Team

- Measure light curve to find maximum m_v
- Check light curve shape to ensure it is Type Ia rather than a Type II etc.



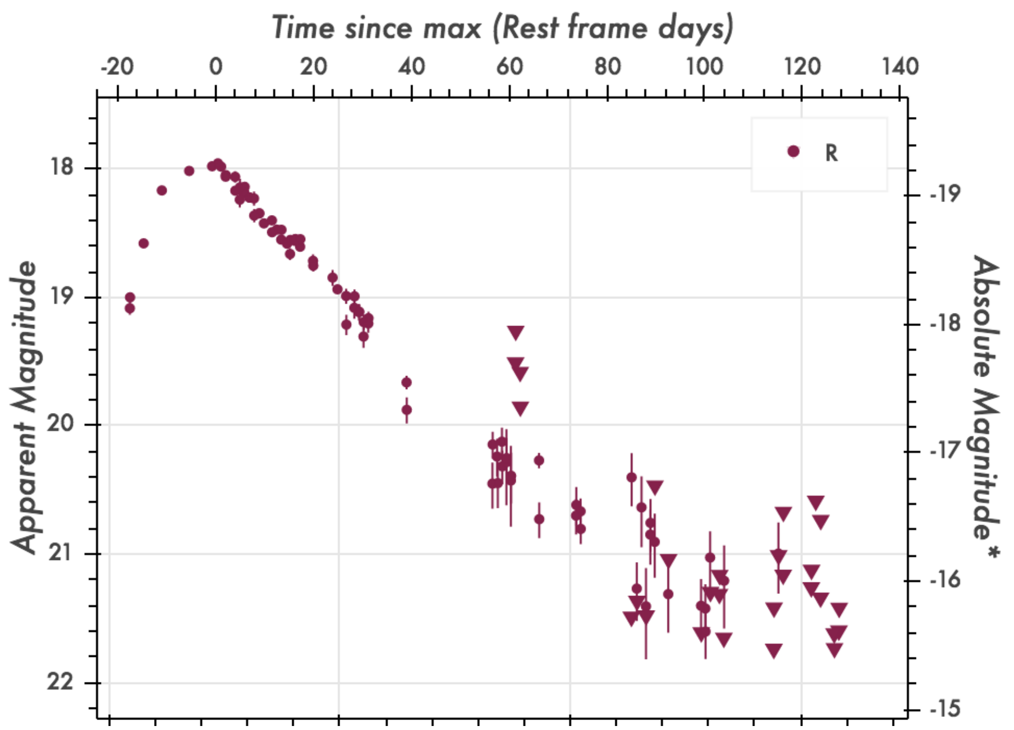
From Universe textbook

Summary

- Standard candles are used to indirectly determine the distances of galaxies
- Cepheid variables and Type Ia supernovae are the most trusted
- The latter can be used to cosmological distances

Class Example

- Using the apparent and absolute magnitude information show below how far away is this Type 1a supernova? Ignore extinction.



https://sne.space/sne/PTF10acnz/