# Distances and Ages: What can the stars tell us?

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# How old is the universe and the things in it?

Everything astronomers do is based on bootstrapping our way up

Example: knowledge about

Earth
→ Sun
→ Other Stars
→ Star Clusters
→ Our Galaxy

Models of the Sun indicate it is $\sim 4.5$ billion years old.

However, this age is mainly fixed by the age of the Earth

- geologists have determined the Earth's age to be 4.5 billion years
- astronomers use this information to calibrate their models of the evolution of the Sun

There is feedback in the other direction, too:

- Models indicate the Sun is about 30% brighter than it was 4 billion years ago
- Geologists have found the Earth's temperature to be roughly constant over that time span
  $\rightarrow$ Geologists have a little problem

## Back to the Sun...

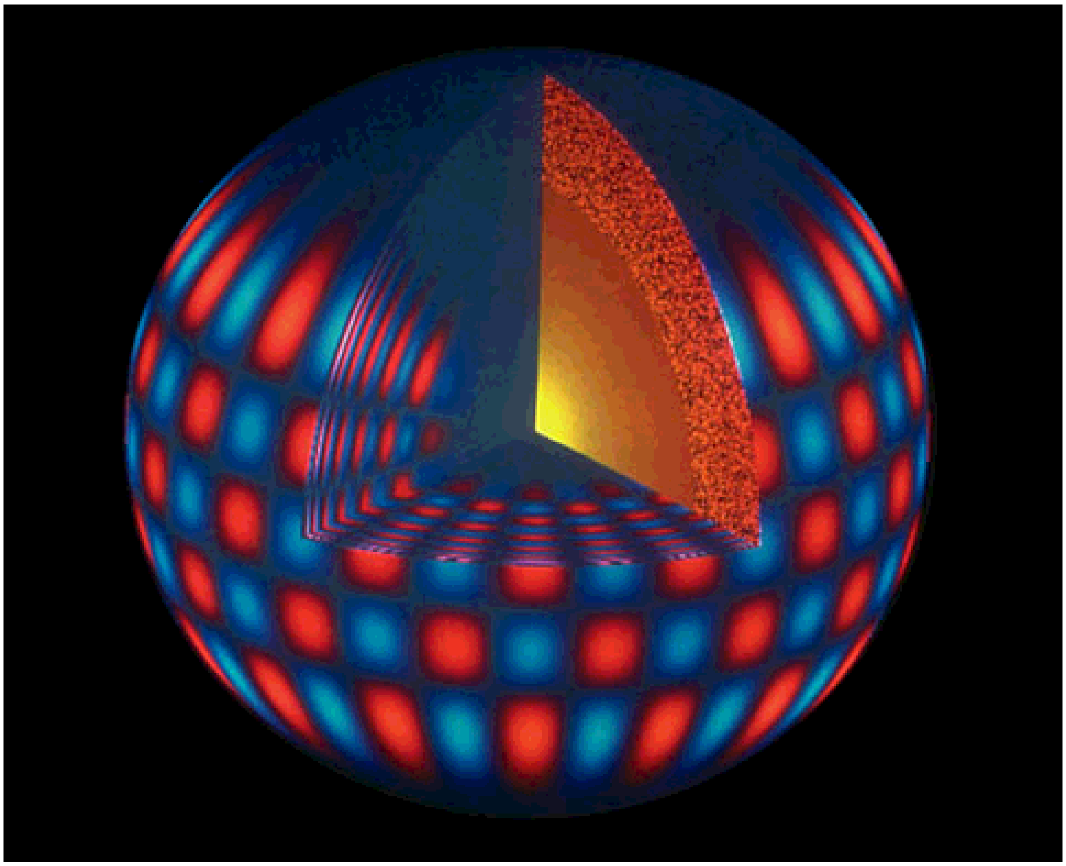
Physics in solar models is calibrated against the present-day Sun. We match

- Age
- Luminosity
- Radius
- Mass

But we have even more information on the Sun than this, because...

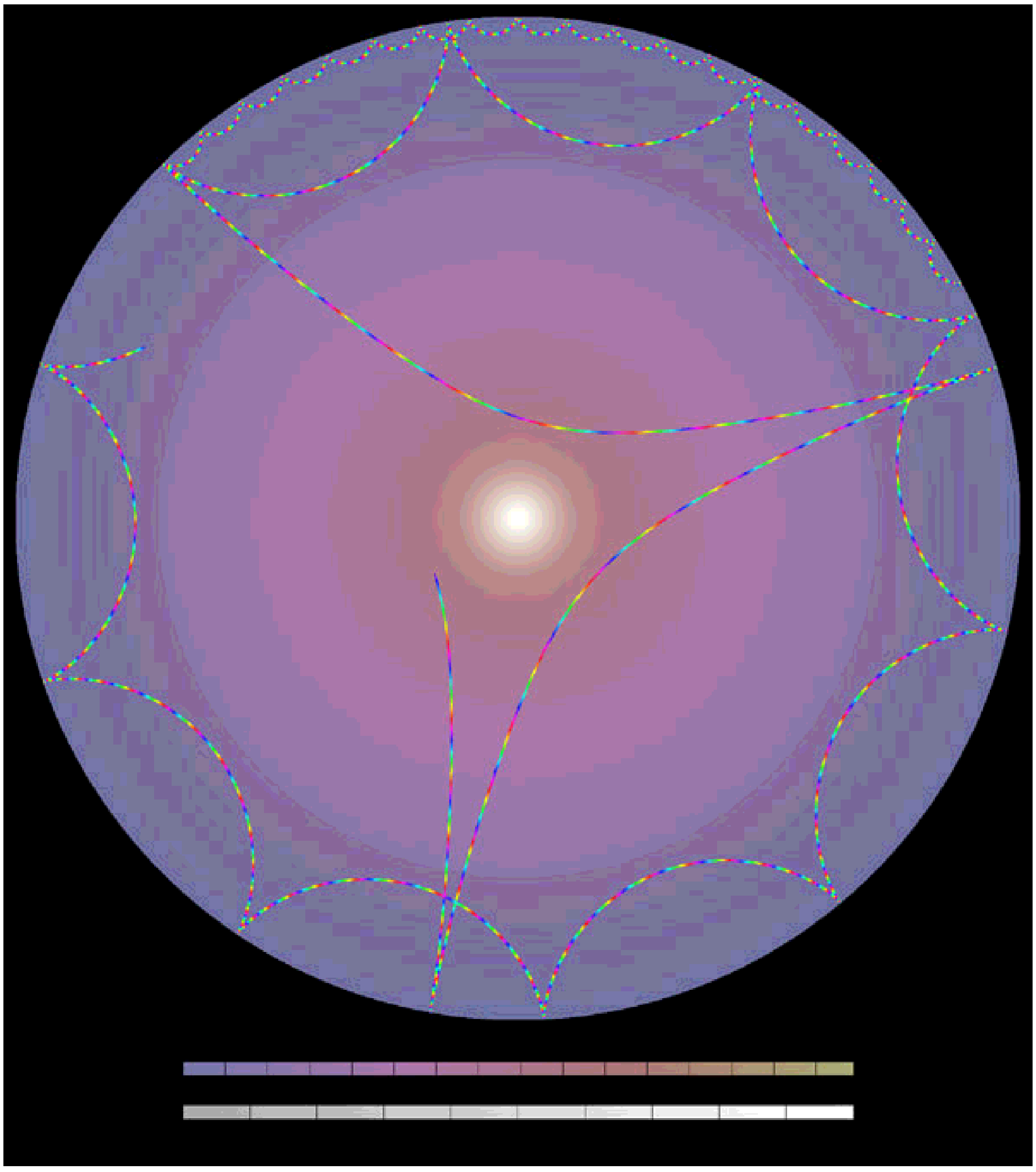
# The Sun Pulsates

In thousands of modes simultaneously, actually



The study of the pulsation modes of the Sun is called "Helioseismology"

The sound waves propagate through the Sun the same way earthquakes do through the Earth:

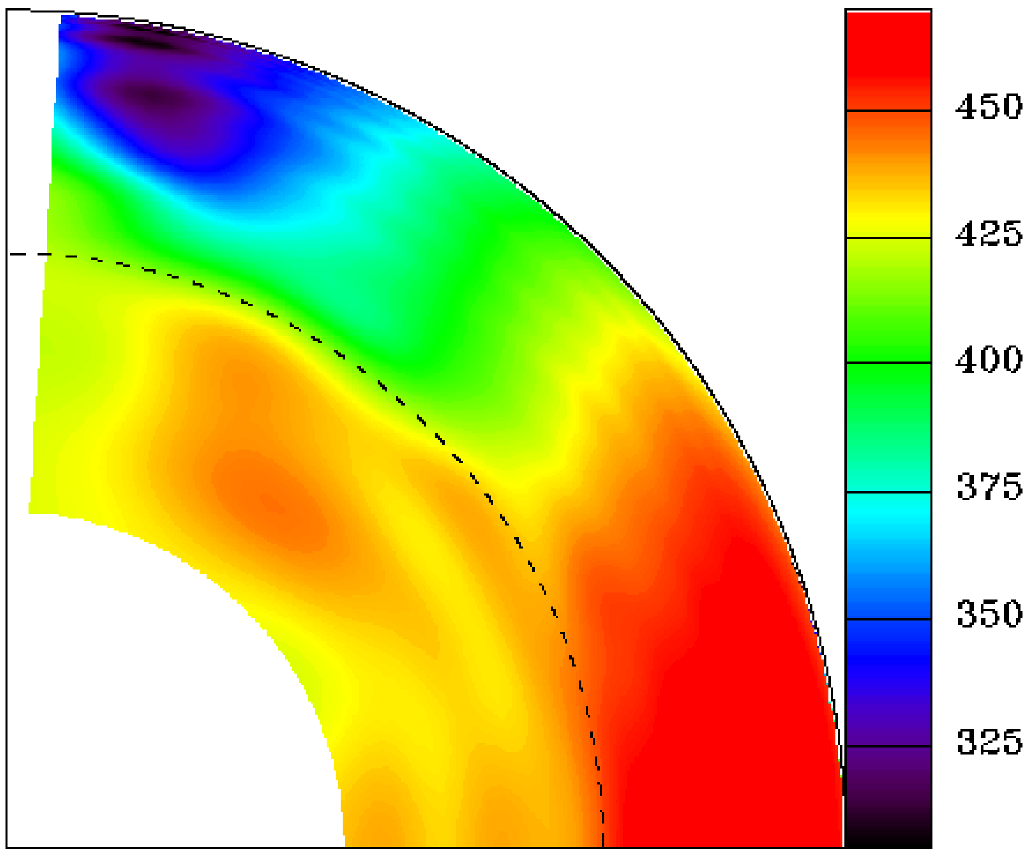


By analyzing these thousands of frequencies, we can learn about the Sun's interior structure. We call this doing "inversions":

- sound speed as a function of depth (accurate to 0.5%)
- differential rotation with depth
- diffusion/settling of elements seen to occur
- temperature of core can be more accurately inferred

# It's amazing to see

the results of a rotational inversion




- inner part rotates as a solid body
- outer part rotates differentially:
  equator is faster than the poles

## Besides the pretty pictures, why is helioseismology important?

- Temperature at center important for solar neutrino problem
- Helium diffusion affects Globular Cluster ages (including He diffusion reduces the inferred ages by 10%: $\sim$ 1.5 Gyrs)
- Differential rotation in Sun may be a clue to its internal magnetic field or large-scale fluid motions.

# White Dwarf Seismology

White Dwarf stars also pulsate

- much larger amplitudes (good news)
- much fainter objects (bad news)

We have been able to determine that

- masses $\sim 0.6\ M_{\odot}$
- rotational periods $\sim 1$ day
- thickness of their H and He layers

# Why is this important?

This allows us to build better models of white dwarfs, so that we can accurately model how fast they cool

This is important because white dwarfs provide an independent method of estimating the age of the Galactic Disk

New concept:

White Dwarf Luminosity Function (WDLF)

$$\text{WDLF} = \frac{\#\text{ of white dwarfs}}{\text{parsec}^3\ \text{M}_{\text{bol}}}$$

White dwarf cooling gives an age of

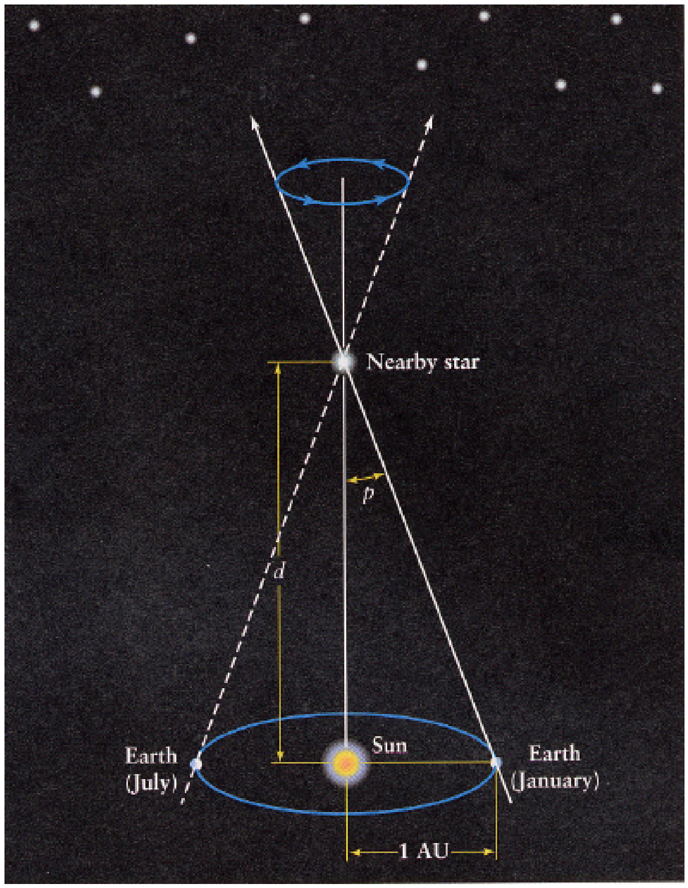
$$9.5 \pm 1 \text{ Gyr}$$

for the age of the Galactic Disk

- totally different physics than for M-S stars
- gives an independent age estimate
- implies that the Galactic Disk is younger than the halo by a few Gyr

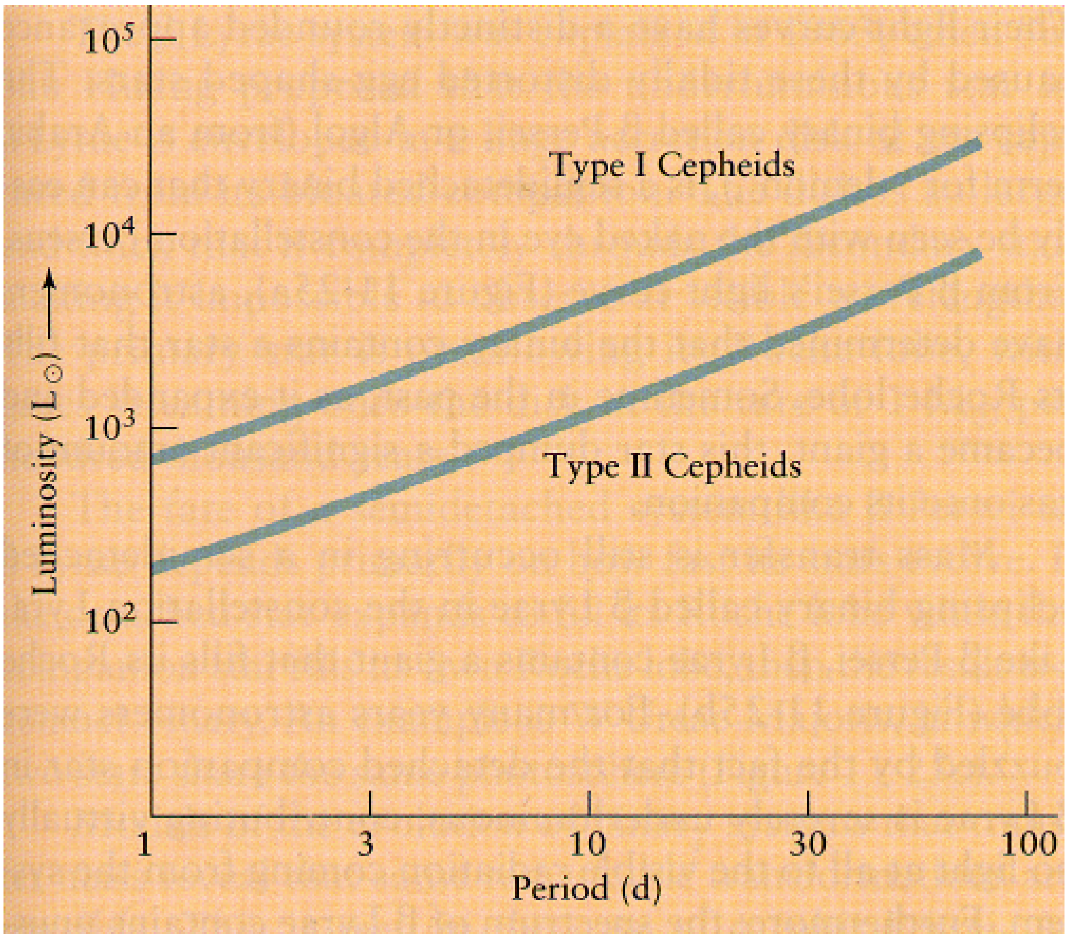
# What about stellar distances?

- parallax for nearby stars (out to $\sim$ 500 pc)




- the Cepheids
  - yet another type of pulsating star!
  - they are radial pulsators

The most important thing about Cepheids is their Period-Luminosity relationship:




There are two types of Cepheids:

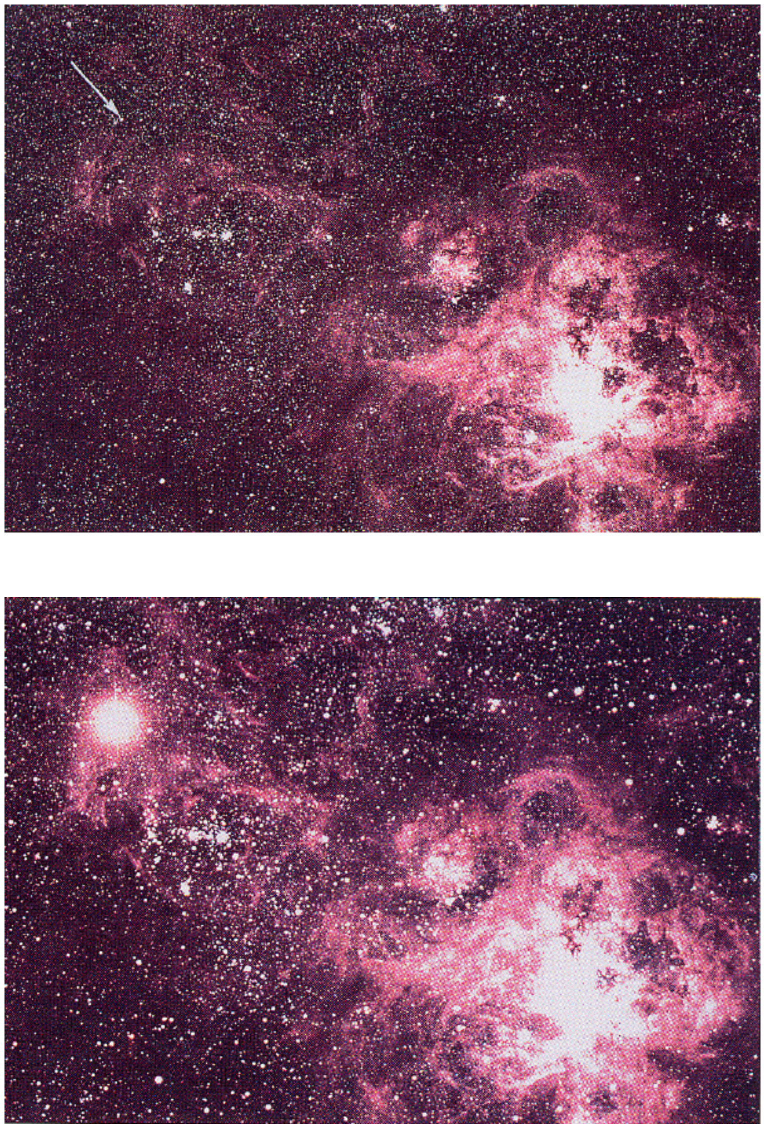
- metal-rich, more luminous (Type I)
- metal-poor, less luminous (Type II)

That there are two types of Cepheids was not recognized until the 1950's

This led to a systematic error in derived distances $\rightarrow$ the size of the universe doubled overnight!

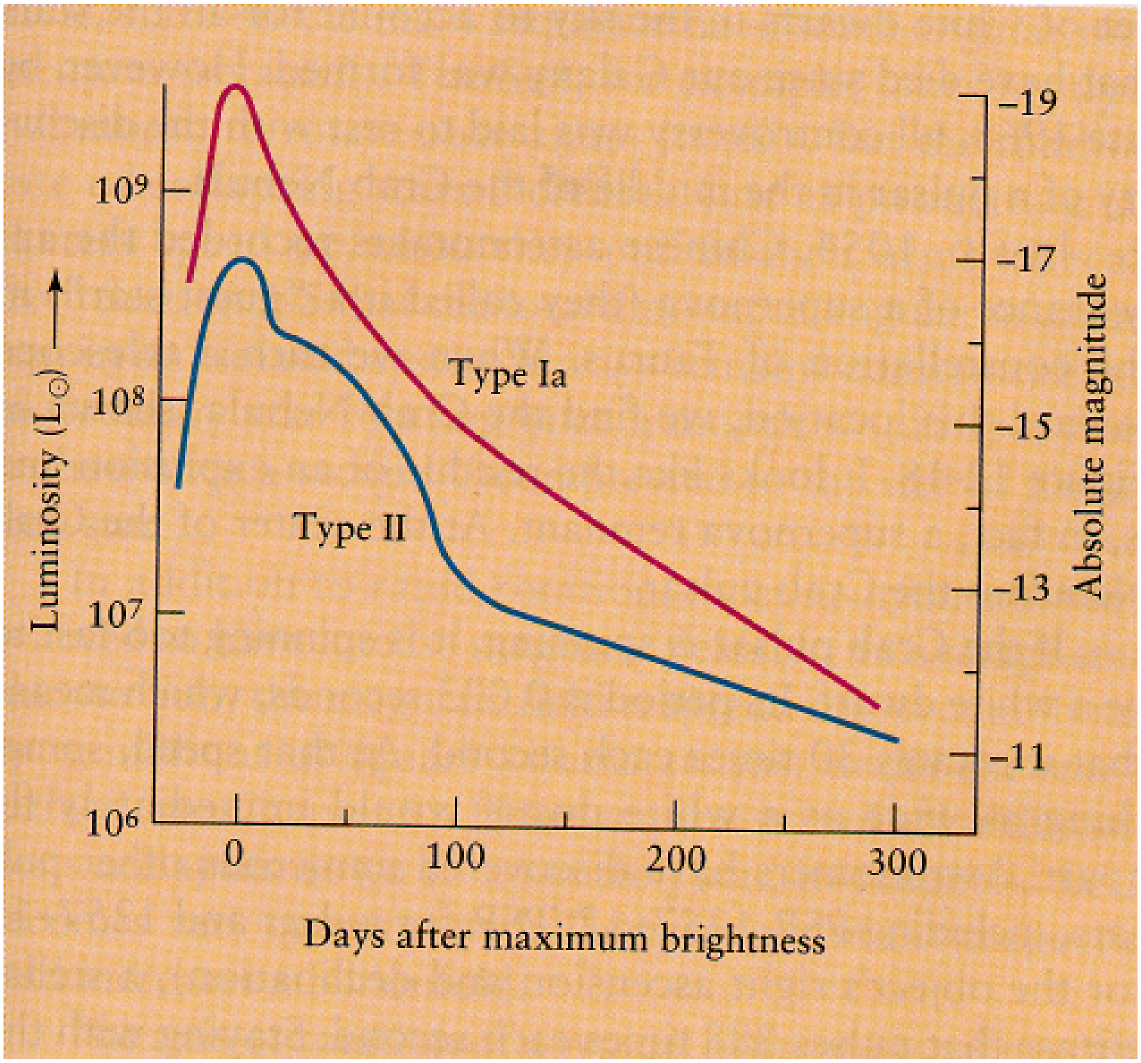
So a correct understanding of the nature of these stars is vitally important

# Final Topic: Supernovae



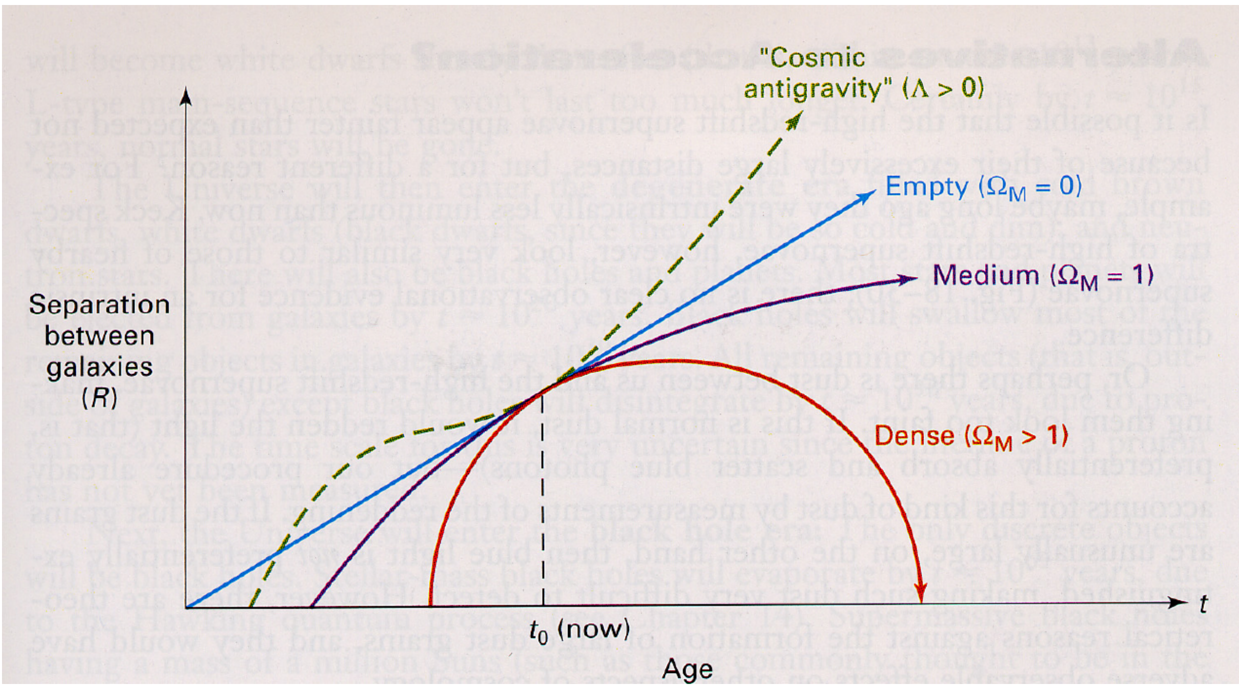
Supernova 1987a

The absolute luminosity of Type Ia supernovae can be inferred from the shape of their light curves:




→ they can be used as distance indicators

The ultimate fate of the universe. . .




recent very distant supernovae measurements favor the “Cosmic Antigravity” $(\Lambda > 0)$ universe

Only time will tell. . .