Lighting the Standard Candle

Type Ia Supernovae

Edward Brown

Outline

- Why are SNe Ia useful for measuring cosmological distances?
- What are type Ia supernovae (SNe Ia)?
  - How are they made?
  - What makes them explode?

20th Century: some novae are "super"

- 1920's: some novae—"new stars"—are in other galaxies, and are therefore enormously bright
  - $\sim 10^{11}$ brighter than the sun
  - Entire energy output of the sun over $\sim 10^{9}$ yrs, but emitted in a few weeks
- Zwicky (1938) proposed using supernovae as distance indicators

NASA/Astronomy Picture of the Day—H. Bond (STScI), R. Ciardullo (PSU), WFPC2, HST, NASA

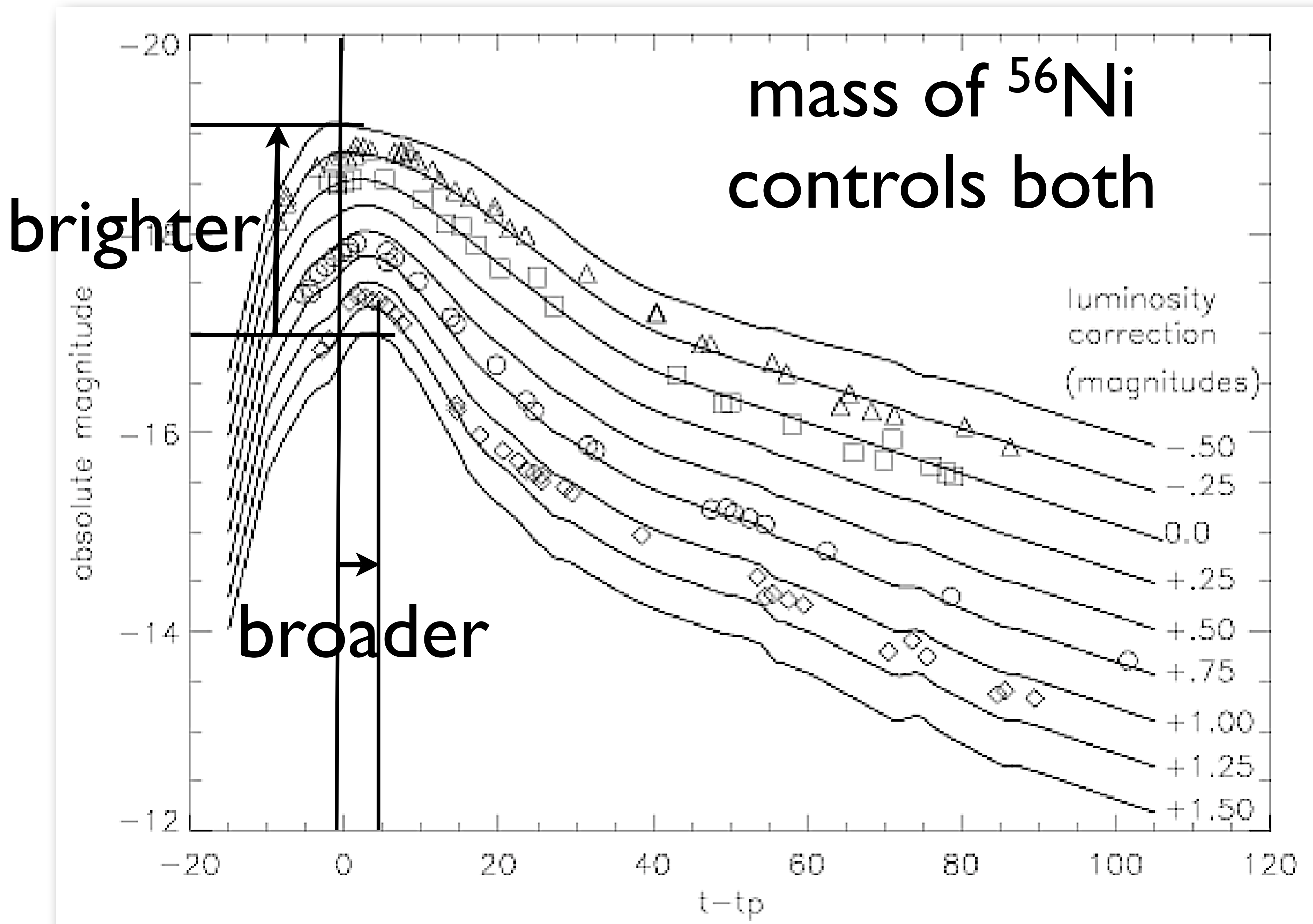
Type Ia SNe

- Type'd from spectral features (Minkowski 1941)
- Lack of H, He features in spectrum
- At peak, strong spectral features from Si, S, Ca, O
- Expansion velocities ~ 10 000 km/s

Standard Candle

- From the Oxford English Dictionary
    - **Standard** an idea or thing used as a measure, norm, or model in comparative evaluations
    - **Candle** In physics, a unit of luminous intensity
- A useful candle for cosmology is
    - bright
    - not too rare
    - easy to detect and measure
    - ideally well-understood and calibrated
- Observations of distant "candles" probe the geometry of the universe.

Calibration—*Broader is brighter*



Phillips relation
Fig. 1 from Riess, Press, & Kirshner (1995)

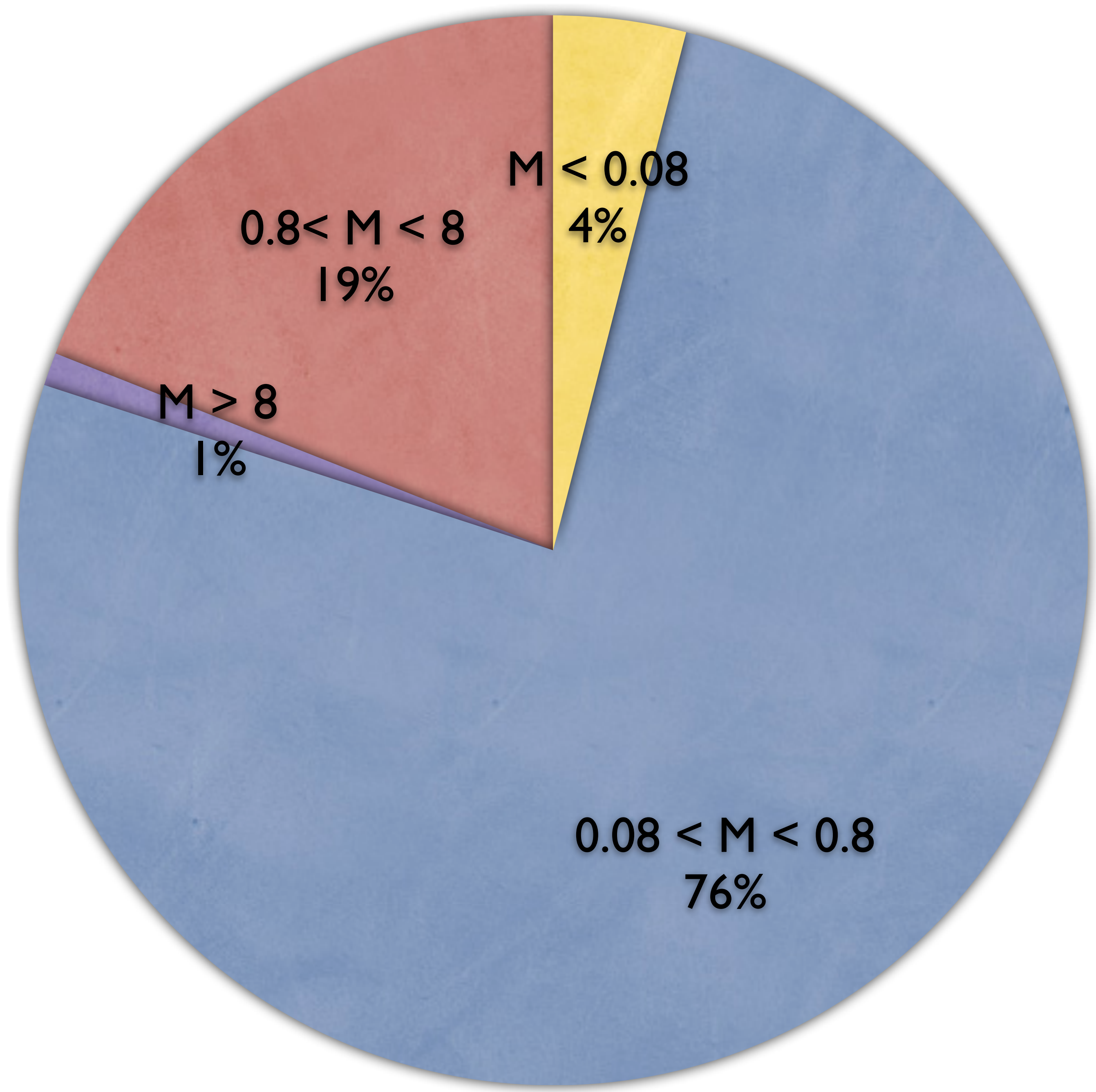
Clues about SNe Ia

- Time to fade consistent with radioactive decay of ^{56}Ni to ^{56}Co (half-life 6 d) and ^{56}Co to ^{56}Fe (half-life 77 d)
- Need about 0.6 M_{sun} of ^{56}Ni
- SNe Ia seen in elliptical galaxies, with no active star formation

Current paradigm: Type Ia supernovae result from the thermonuclear incineration of a carbon-oxygen white dwarf star of mass ≈1.4 $M_\odot$ white dwarf star

Stellar demographics

About 1 star per year is born in the Milky Way

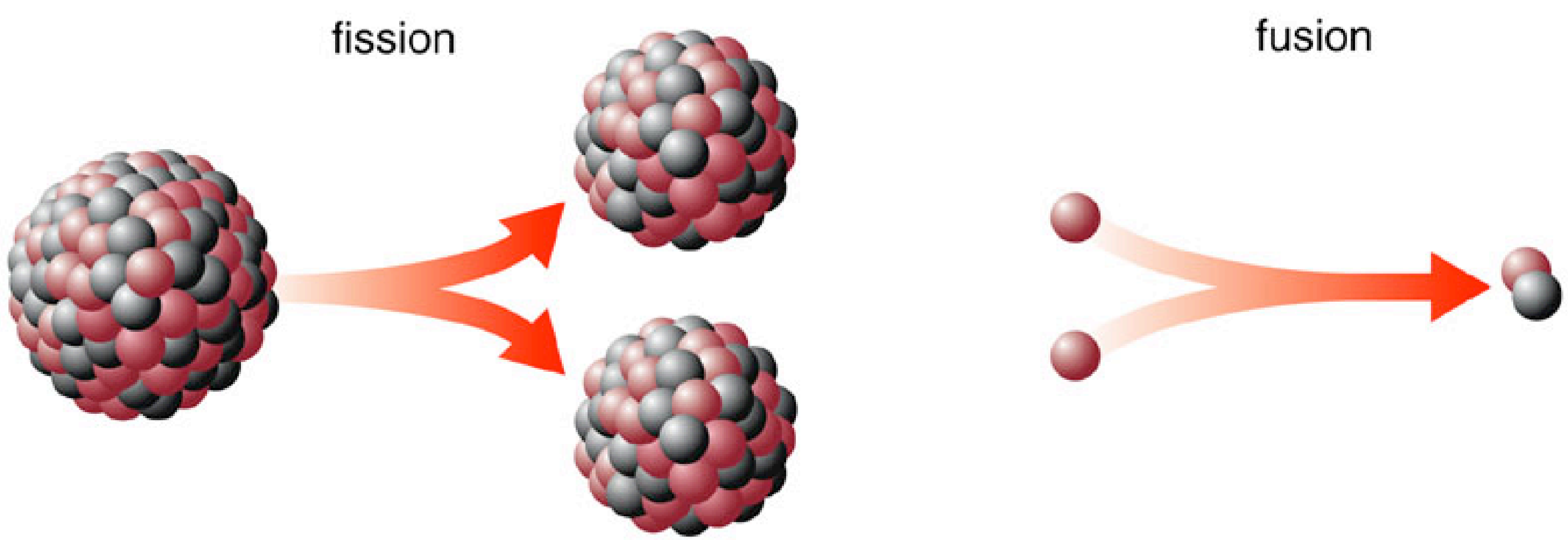


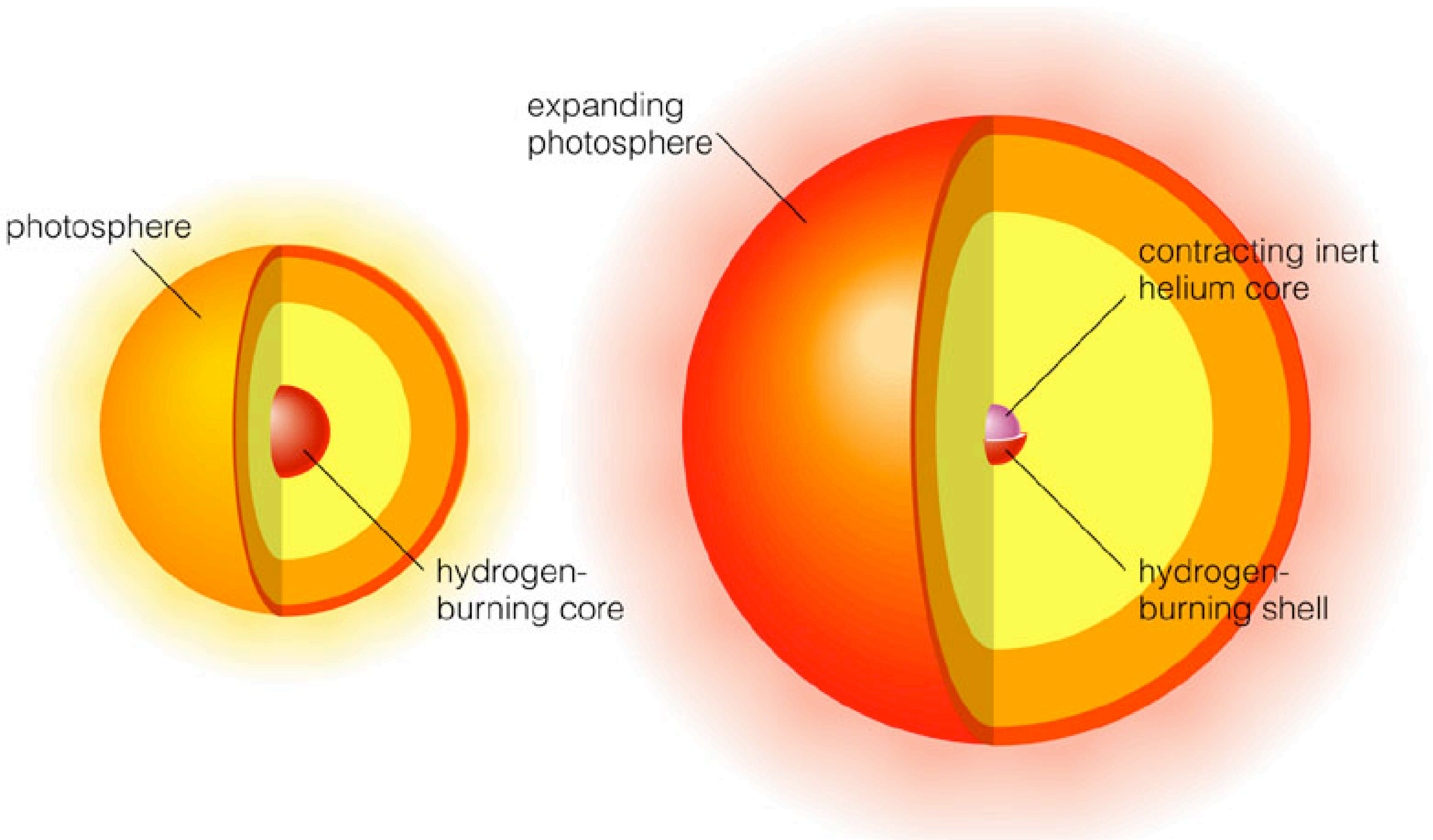
Kroupa 2001

Main-sequence

- Stars spend most of their life on the "main-sequence"
- Balance heat loss, from radiation, with fusion of hydrogen into helium
- The sun is about halfway through its main-sequence lifetime

Fission vs. Fusion



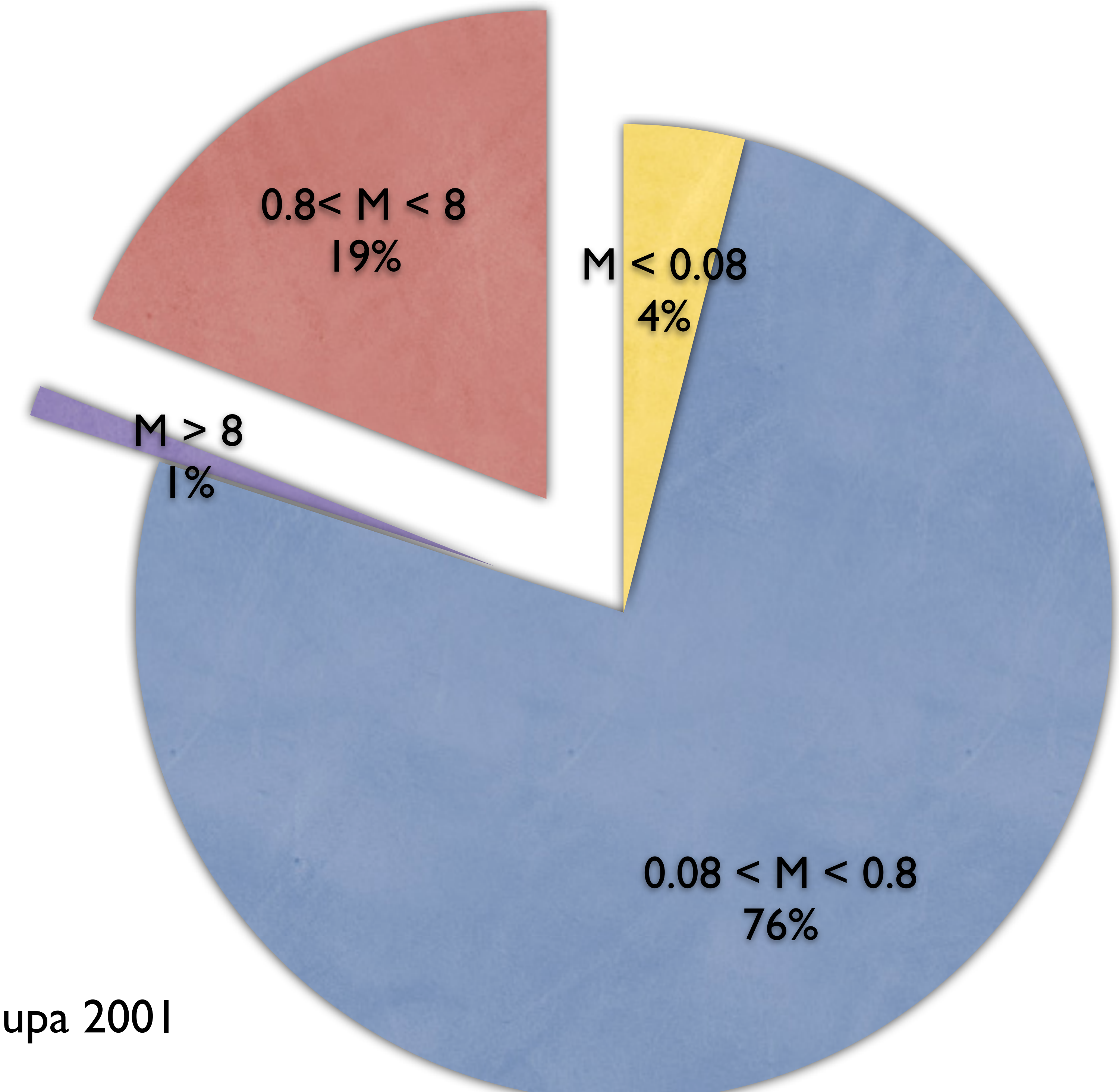


main-sequence star

expanding subgiant

Stellar demographics

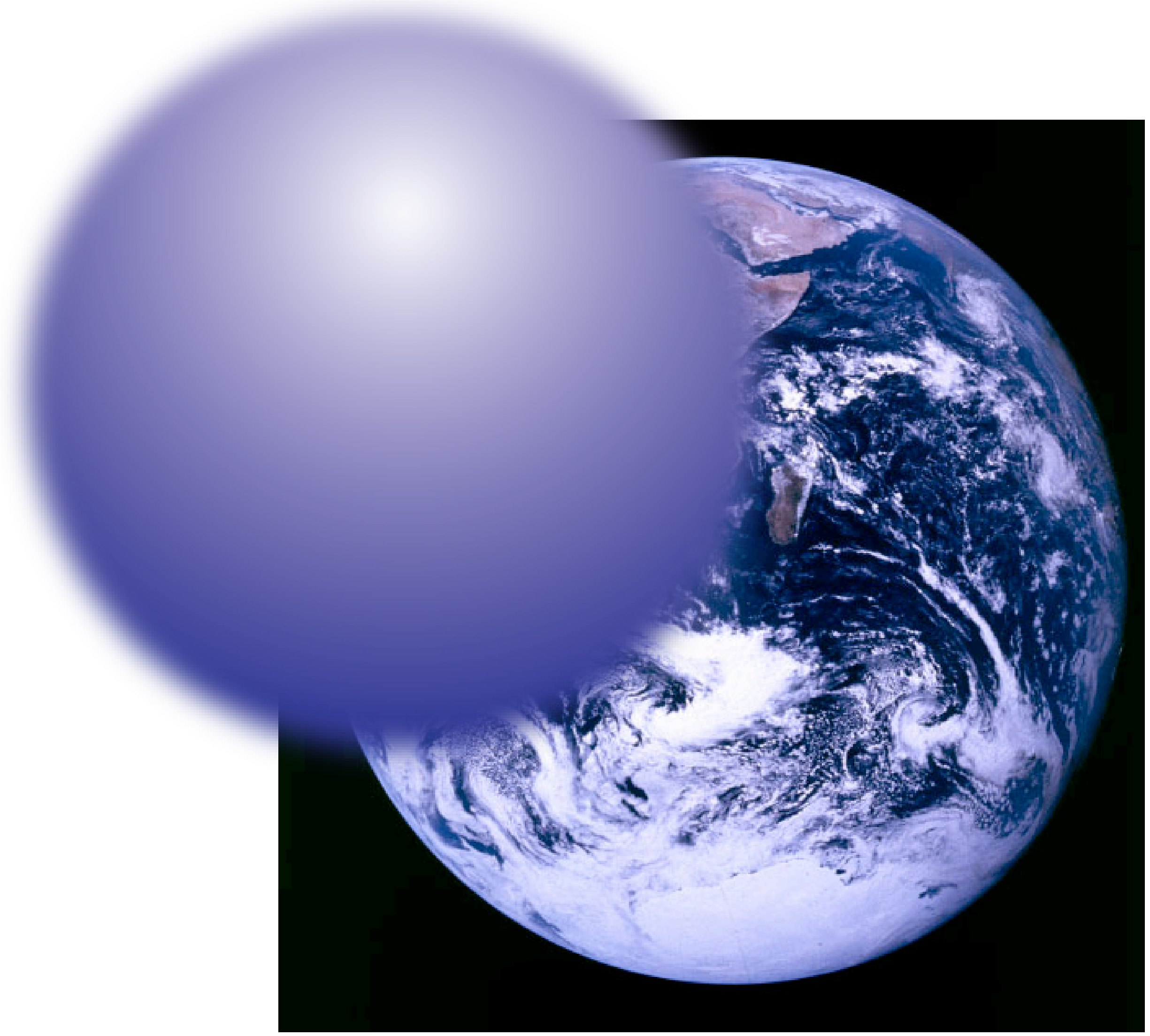
Of the stars that live for < 14 billion years, 19/20 will become white dwarfs



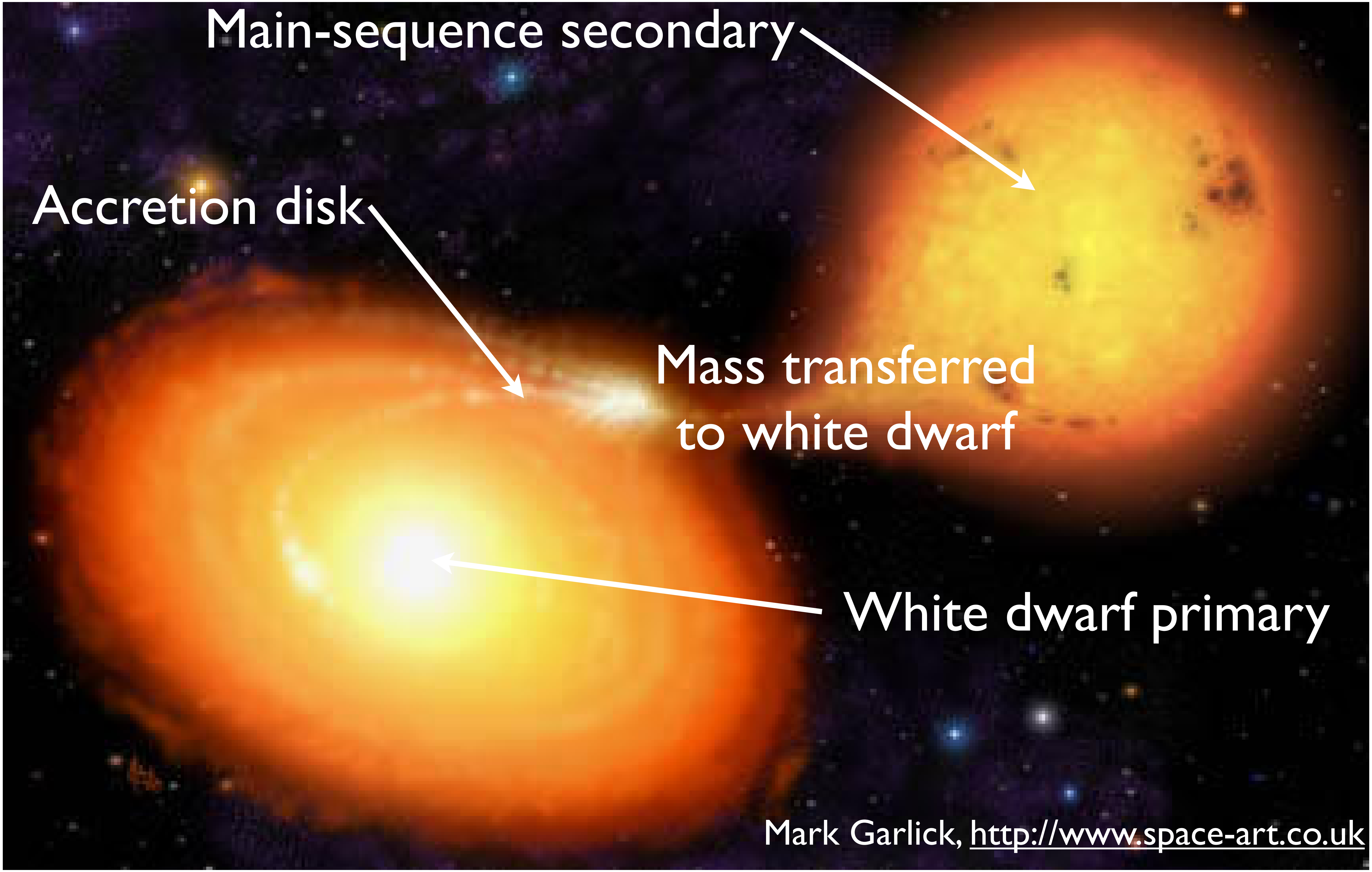
Kroupa 2001

White dwarf stars

- One quart weighs as much as Mt. Everest!
- Made mostly of carbon and oxygen nuclei in a sea of electrons



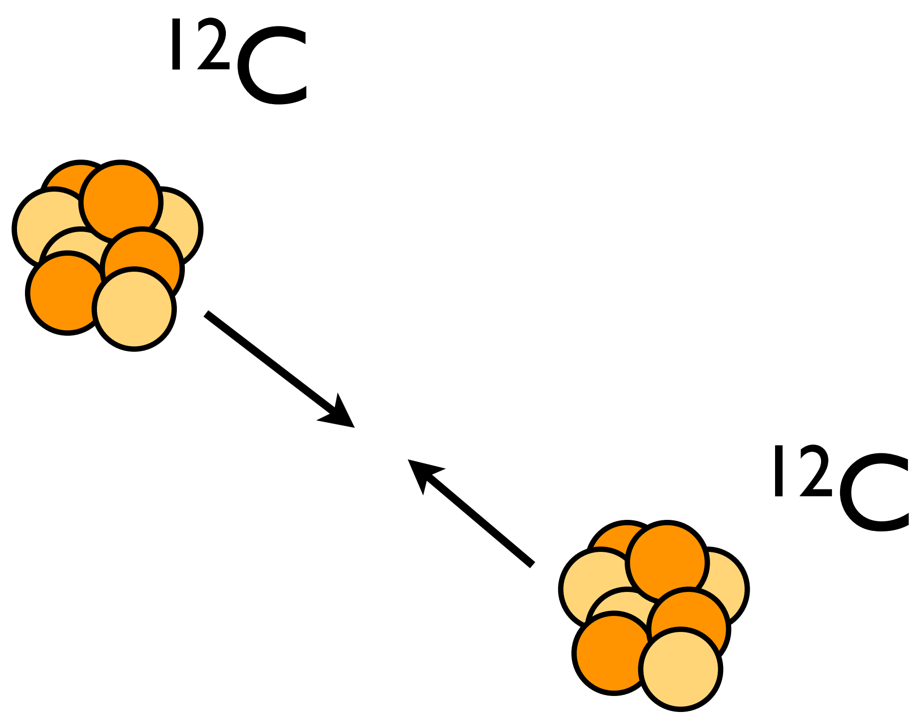
Half of all stars are in binaries

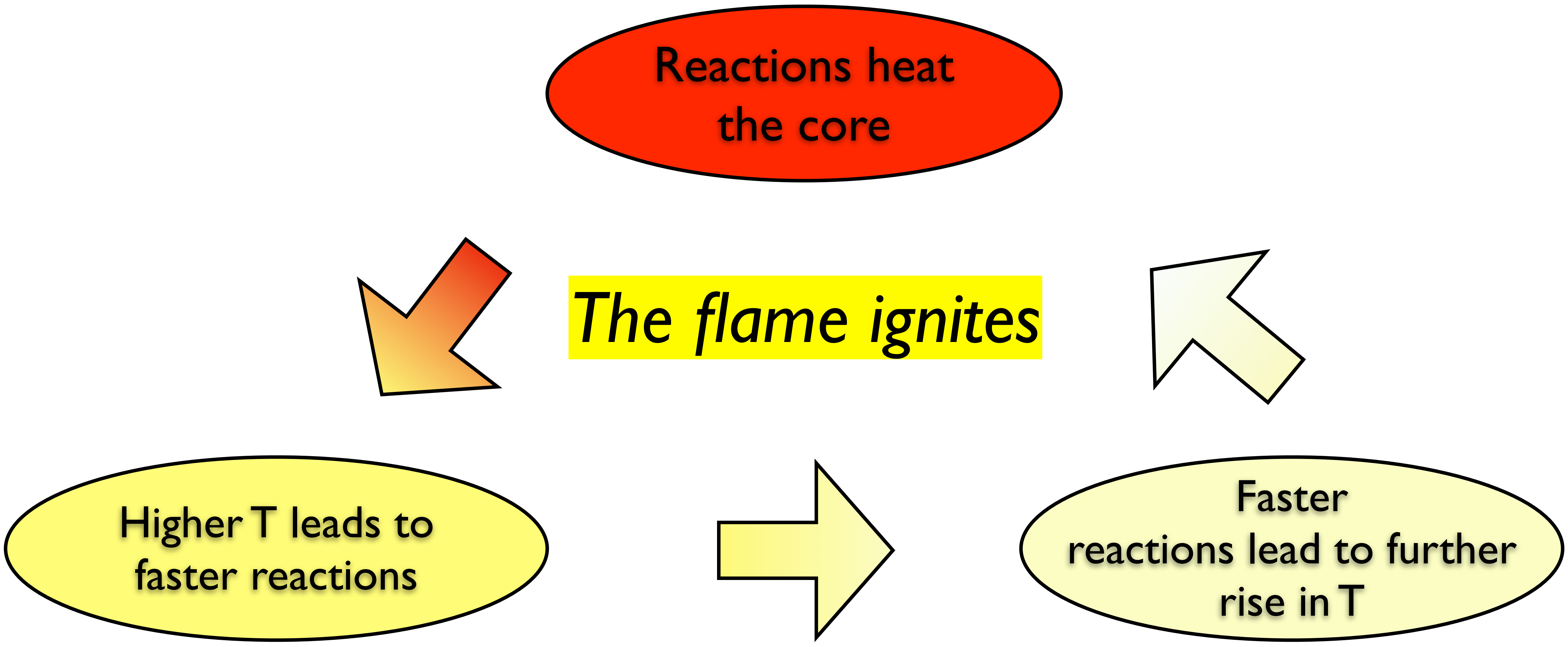


The Chandrasekhar Limit: $M < 1.4\ M_{sun}$

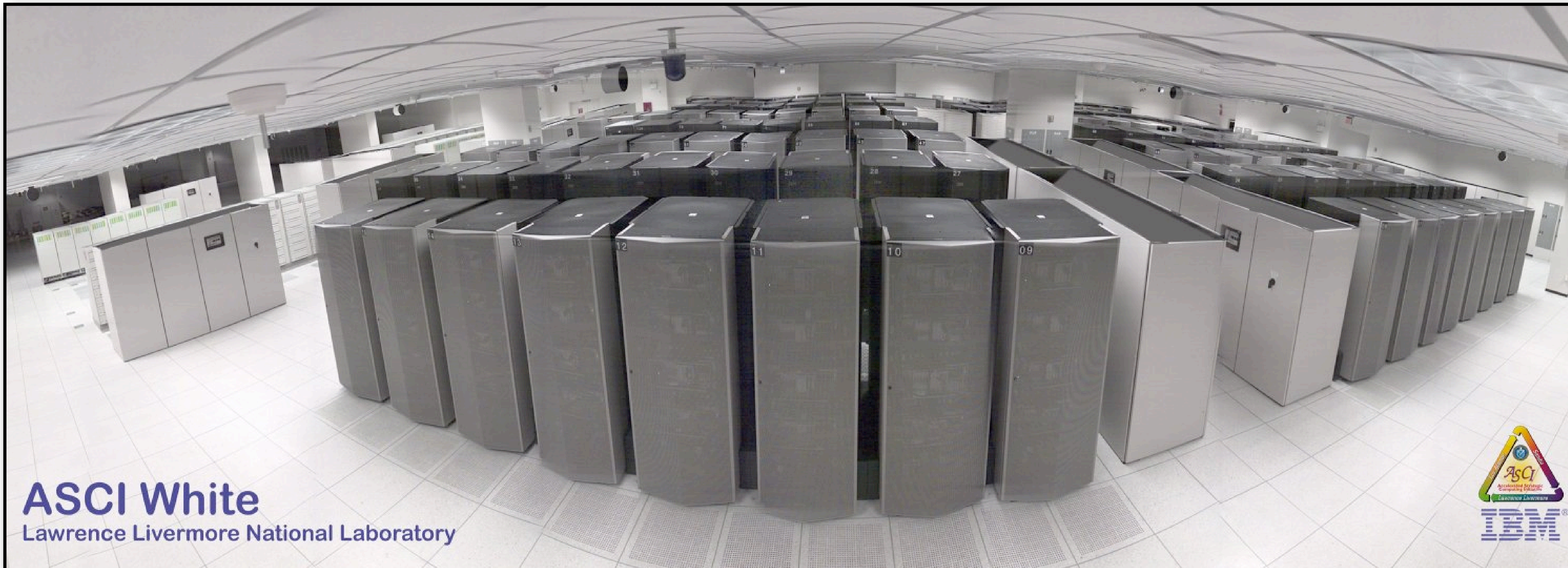
- Self-gravity: More massive white dwarfs are denser
- Chandrasekhar (1910–1995) showed that there is a limit to the white dwarf's mass

When central density and temperature are sufficiently high, fusion of ^{12}C begins to raise core temperature —"burning ignites"



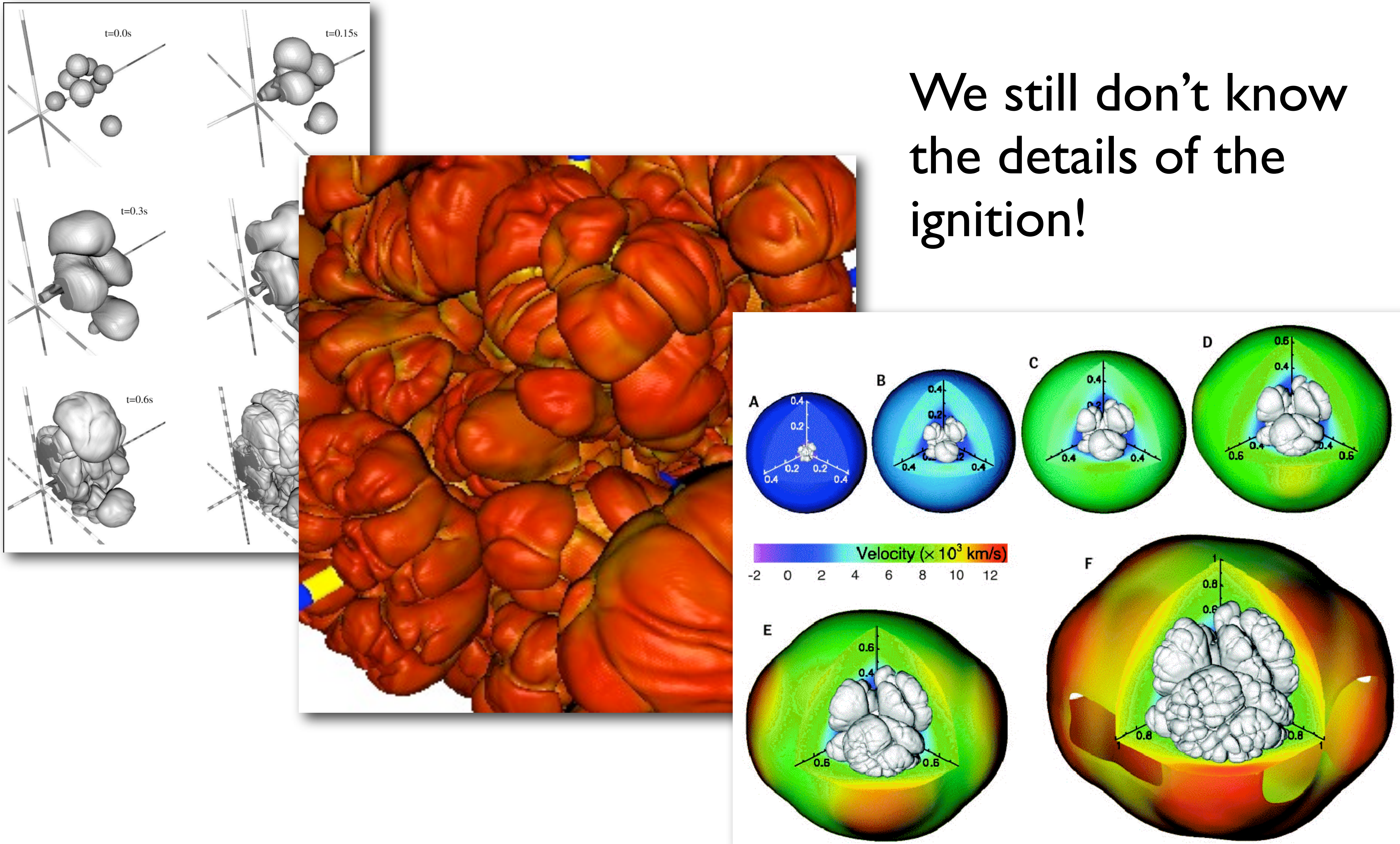

Reactions heat the core
The flame ignites
Higher T leads to faster reactions
Faster reactions lead to further rise in T

Parallel Computing



ASCI White is 10,000 processors
Current machines are at the 100,000 processor level

Sampler of large-scale flame simulations

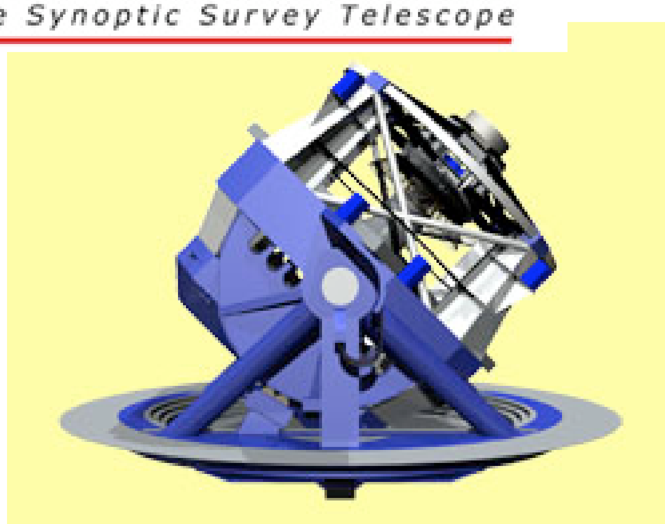


We still don’t know the details of the ignition!

Plots courtesy of Reinecke et al. (2002), Gamezo et al. (2004)

Future looks bright

LSST
Large Synoptic Survey Telescope



Ongoing and future surveys will find hundreds of these supernovae

Can do “population studies”, find rare and potentially interesting events

http://www.lsst.org