White Dwarfs:

The Distant Fate of Stars like the Sun

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Like atoms in matter, stars are the fundamental
building blocks of the visible universe…

Unlike atoms, they are not unchanging. They

- Are born
- Burn hydrogen, helium, etc.
- Run out of fuel
- Change size
- Change mass

Stellar Evolution in a Nutshell (single star)

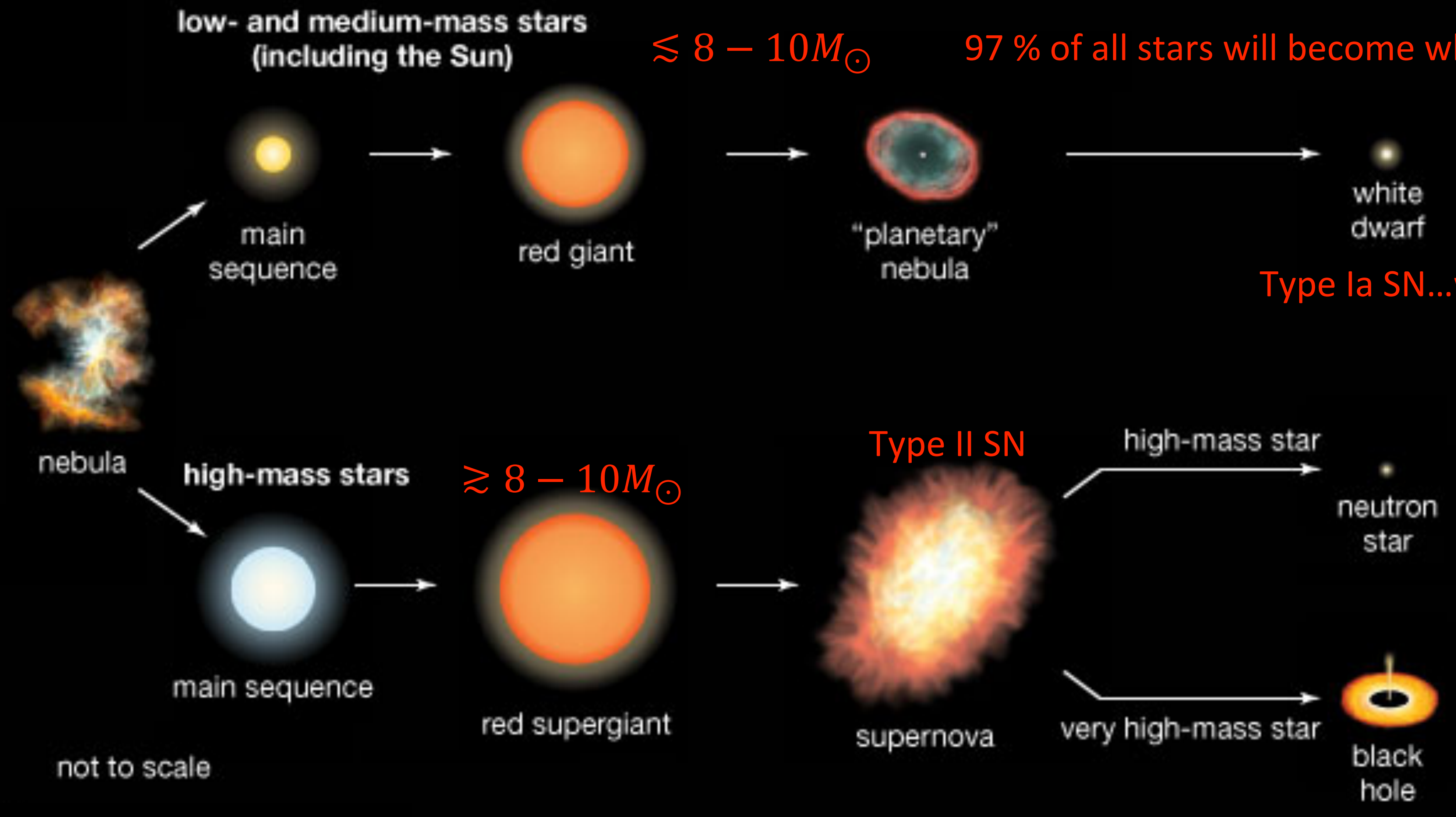
$\lesssim 8 - 10 M_\odot$

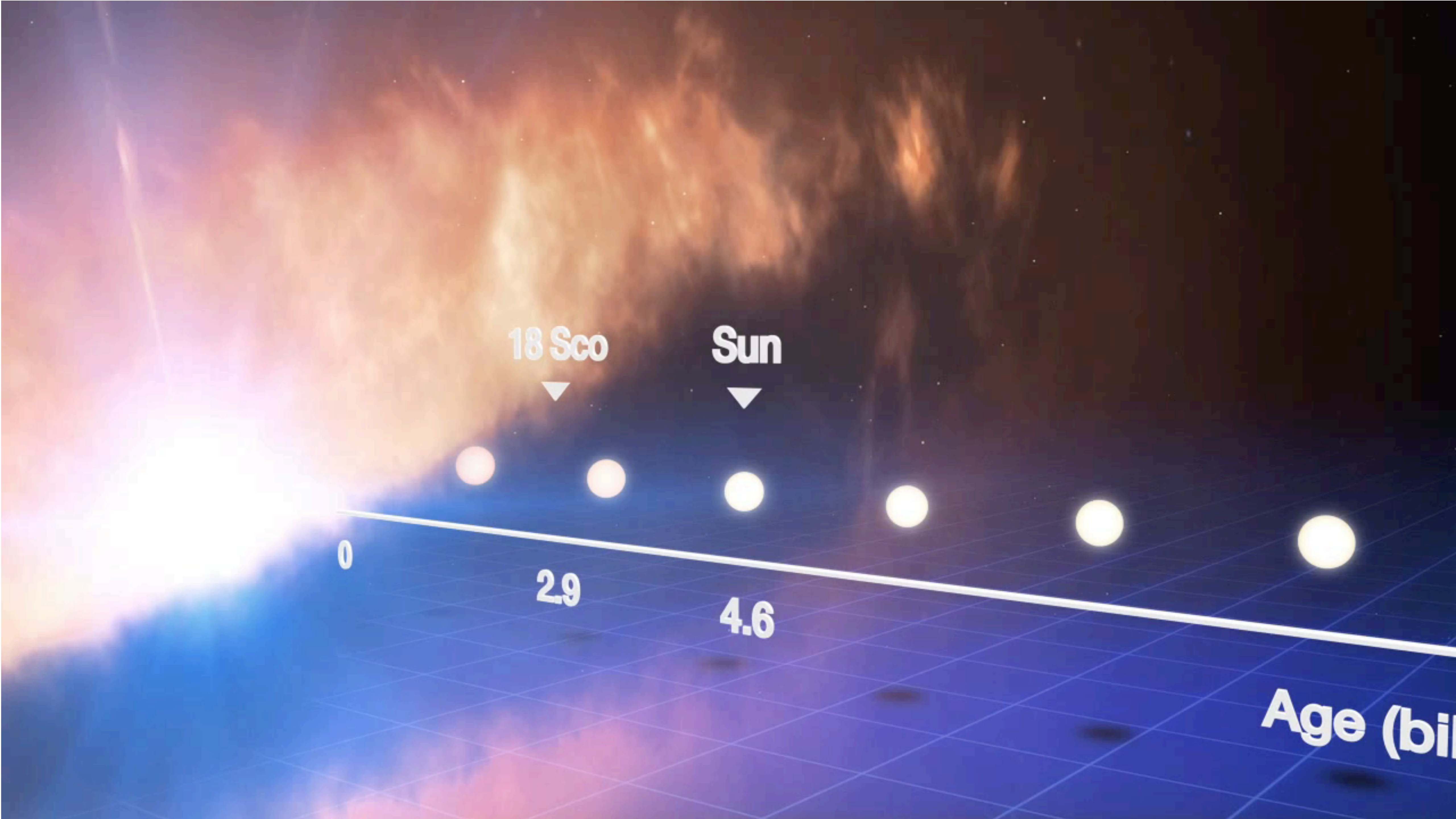
97 % of all stars will become white dwarfs

Type Ia SN…with help

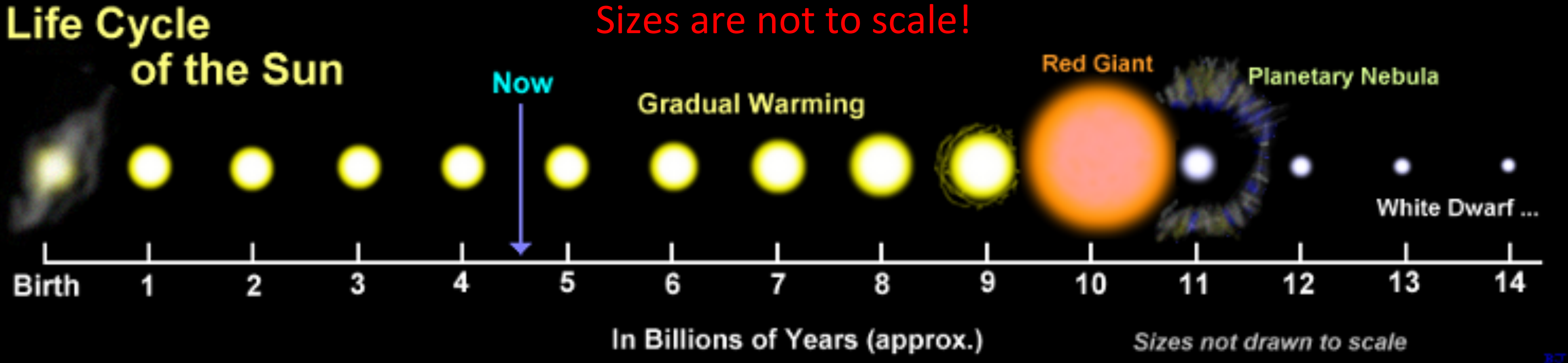
Type II SN

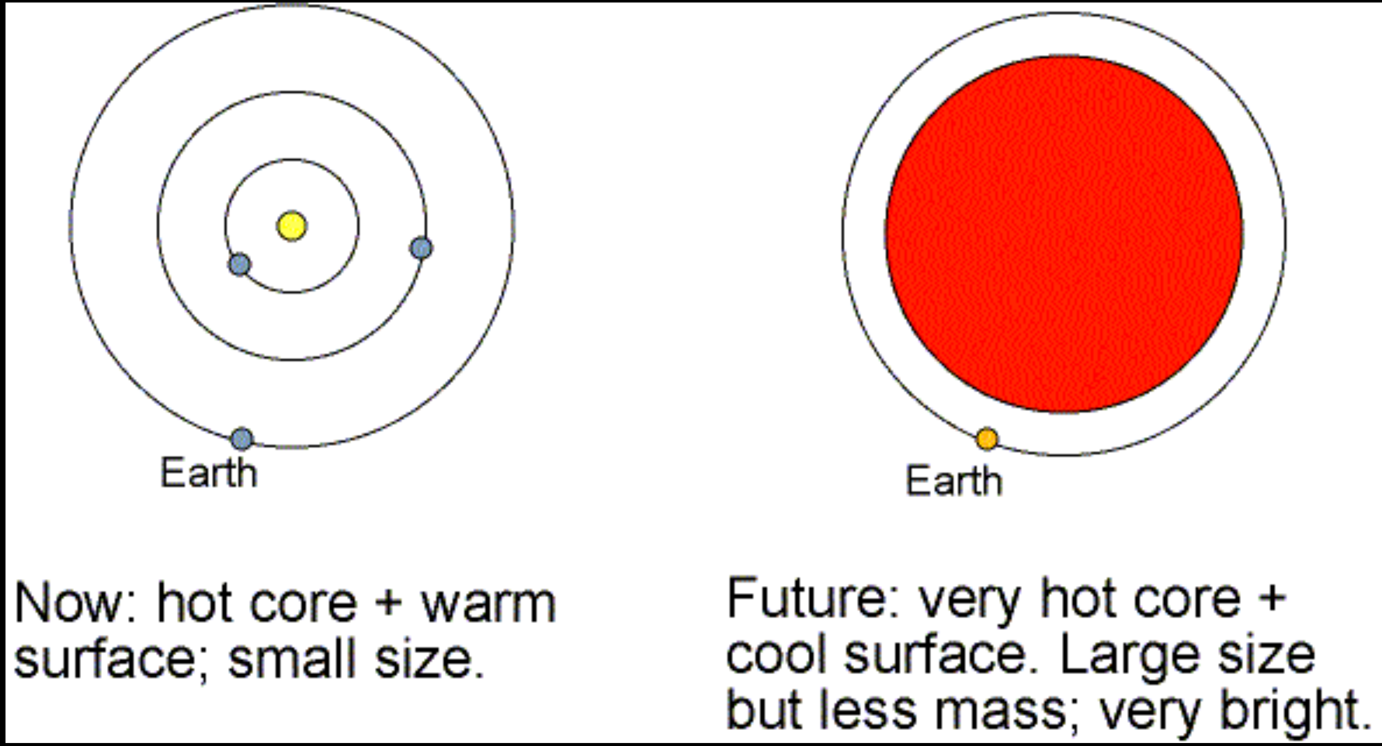
$\gtrsim 8 - 10 M_\odot$




18 Sco
Sun
0
2.9
4.6
Age (bi

Sizes are not to scale!

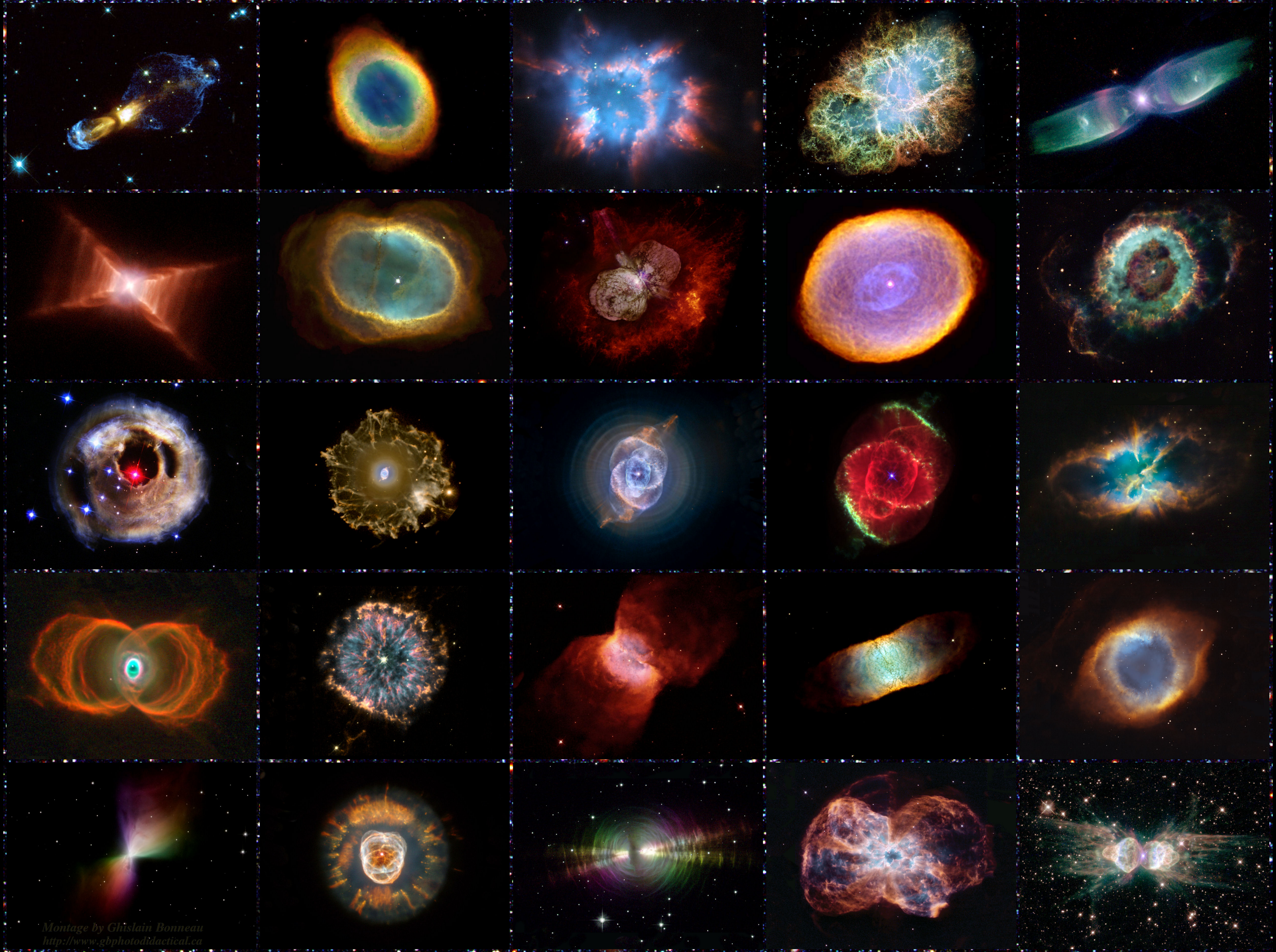




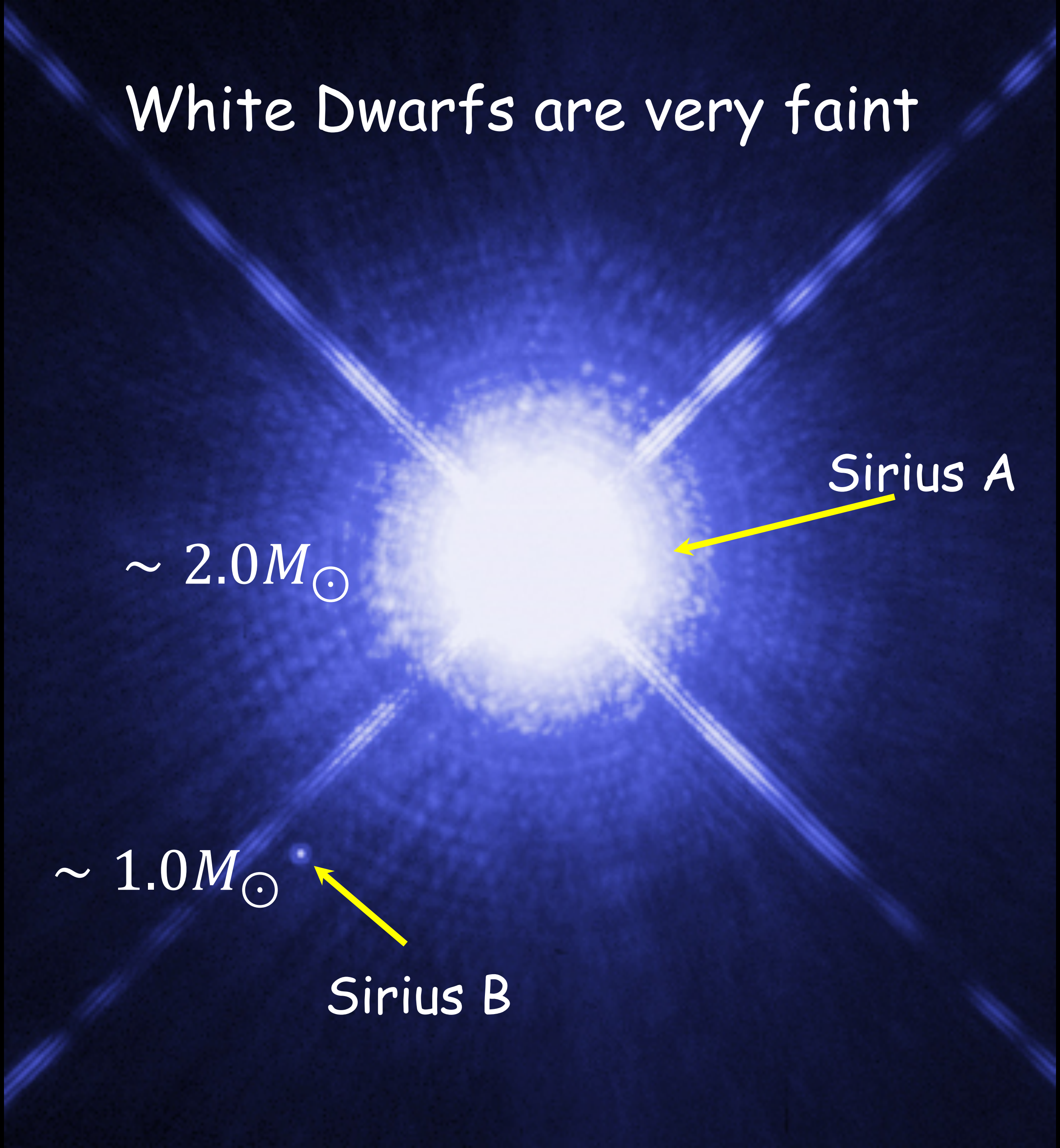
High-mass stars are
hot (blue) and bright
- Have "short" lives

High mass stars are brighter and hotter, and evolve/age more quickly than lower mass stars.

Low-mass stars are
cool (red) and dim
- Live "forever"


Montage by Ghislain Bonneau
http://www.gbphotodidactical.ca

White Dwarfs are very faint



What Are White Dwarf Stars?

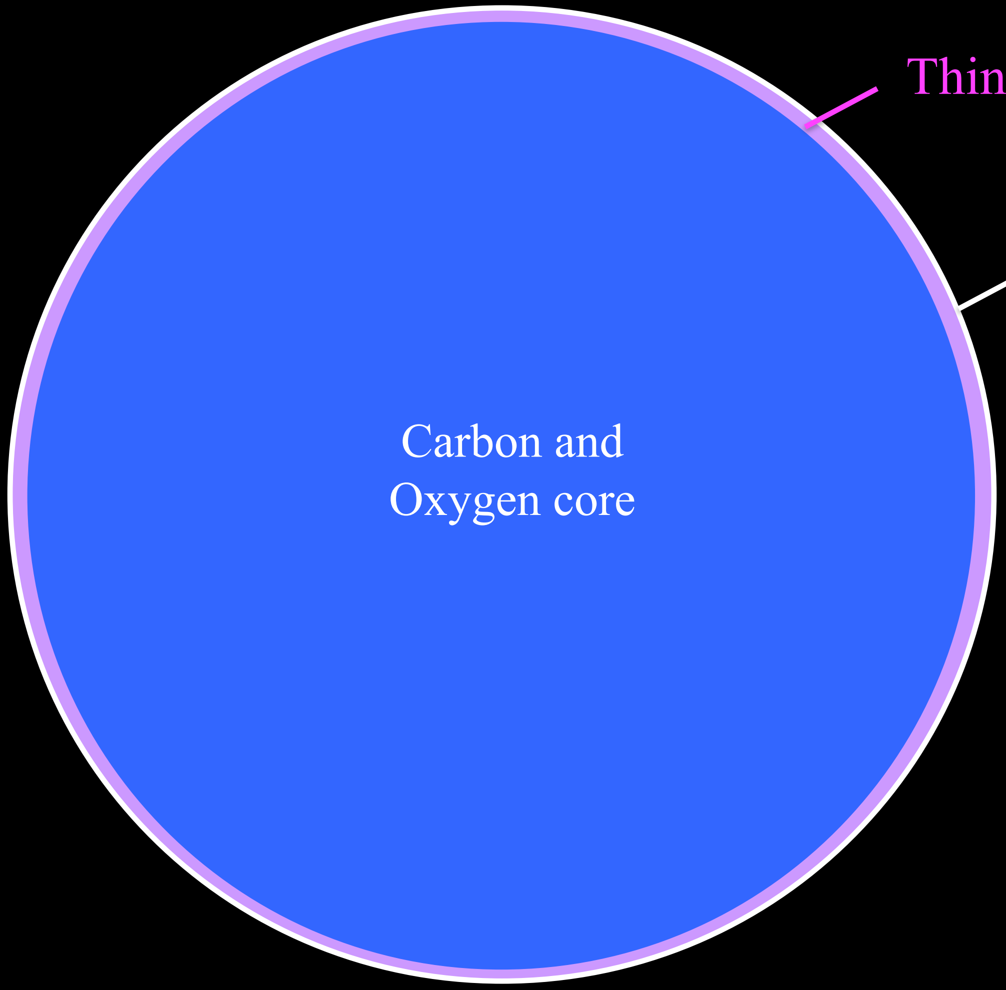
- ***Endpoint*** of evolution for most stars,
  97% of all stars, including our sun
- ***Homogeneous*** in mass and surface composition:
  essentially ***monoelemental*** atmospheres
- ***Uncomplicated*** in structure and composition;
  evolution is just cooling

Their simplicity makes them ideal
Cosmic Laboratories

White Dwarfs are Simple

About the size
of the Earth

About 0.6 times the
mass of the Sun



99%
Carbon/Oxygen

1% Helium

0.01% Hyrdogen

White Dwarf Characteristics:

- "Small" — about the size of the Earth
- "Faint" — because they are small
- "Dense" — about 0.6 $M_{\odot}$ (0.6 solar masses) in the volume of the Earth
  - One "cell phone" of matter from its center would have a mass of $\sim 90{,}000$ kgs, 200,000 lbs (~ 15 African elephants, ~ 11 large T-rex's)
- They are supported from collapsing by "electron degeneracy pressure"
  - The Pauli exclusion principle — electrons don't like to occupy the same physical states $\Rightarrow$ leads to a pressure that doesn't depend on temperature
- "Simple"
  - They have pure, mono-elemental surface layers
  - No nuclear reactions, they just cool with time

Ages of stars are model dependent and need to be calibrated:

For the Sun, we calibrate its age by assuming it formed at about the same time as other objects in the solar system, such as meteorites

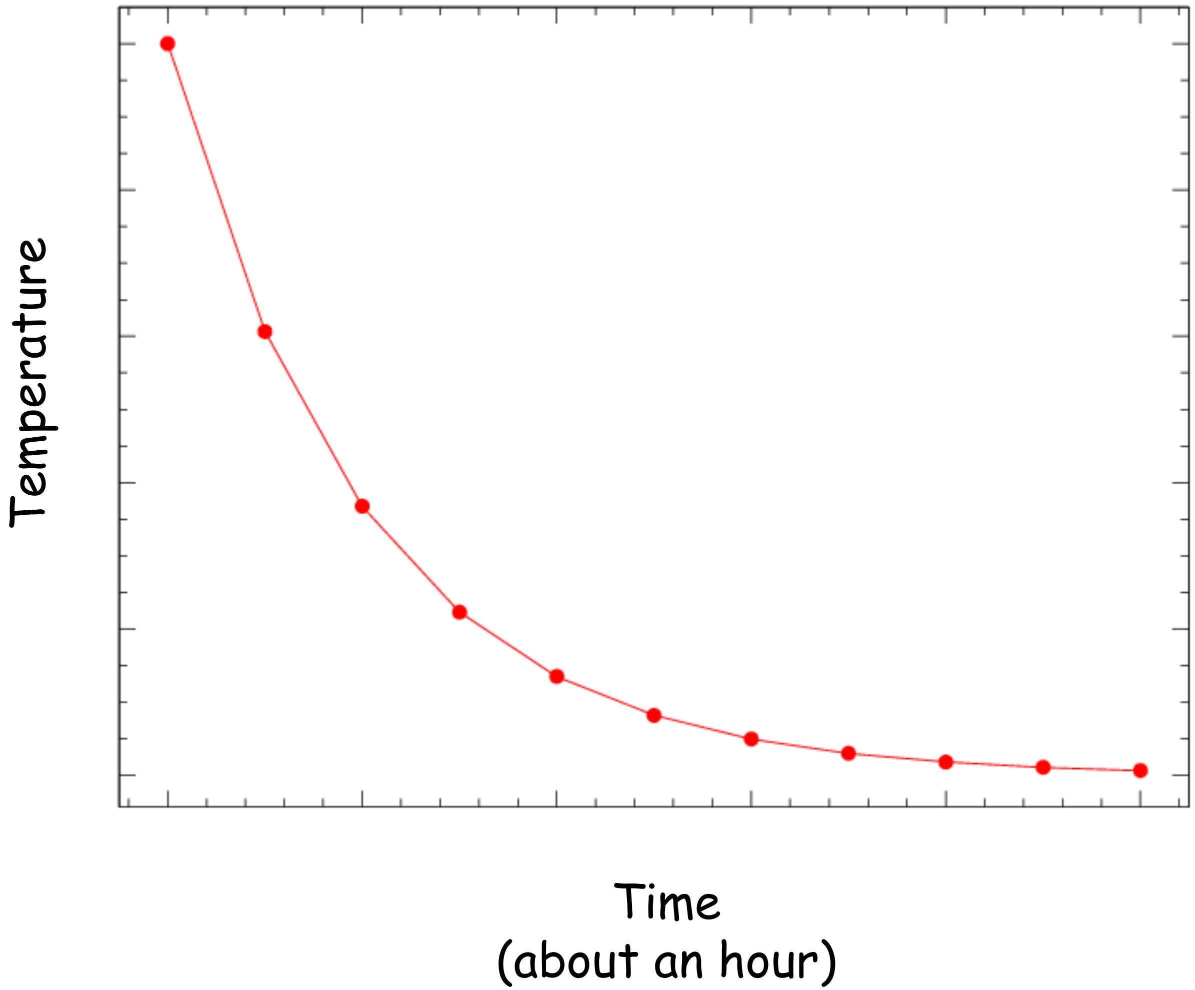
For other stars, we have to use other techniques

In the mid-1980s, estimates for the age of the universe were quite varied, ranging from about 10 to 25 billion years

Many models of stellar evolution suggested that the oldest stars in our Galaxy were 18 to 24 billion years old

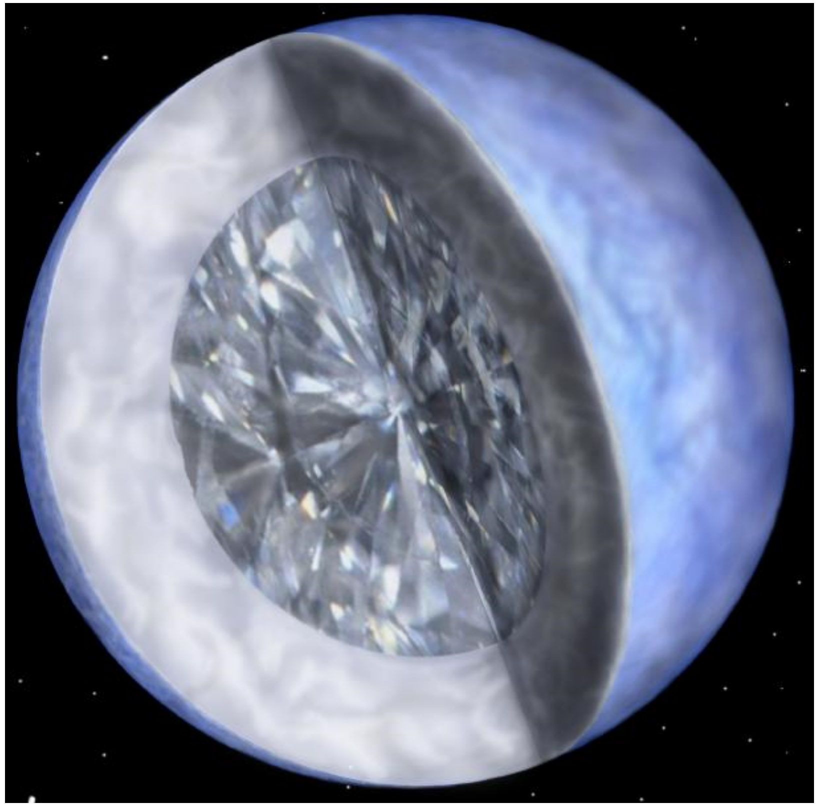
An Independent Method:

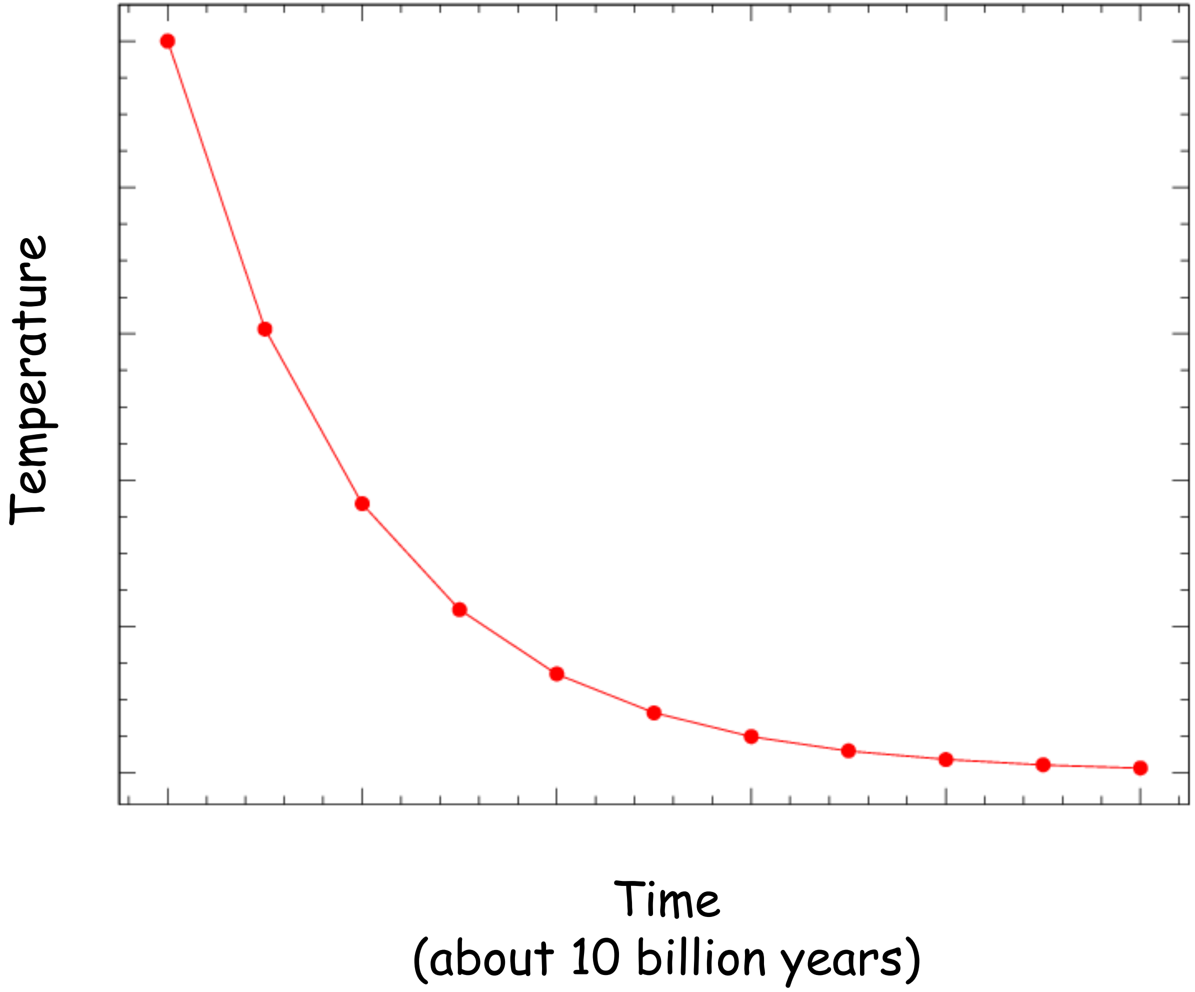
The temperature of the coffee tells you how long ago it was made



White Dwarfs are Cosmic Clocks:

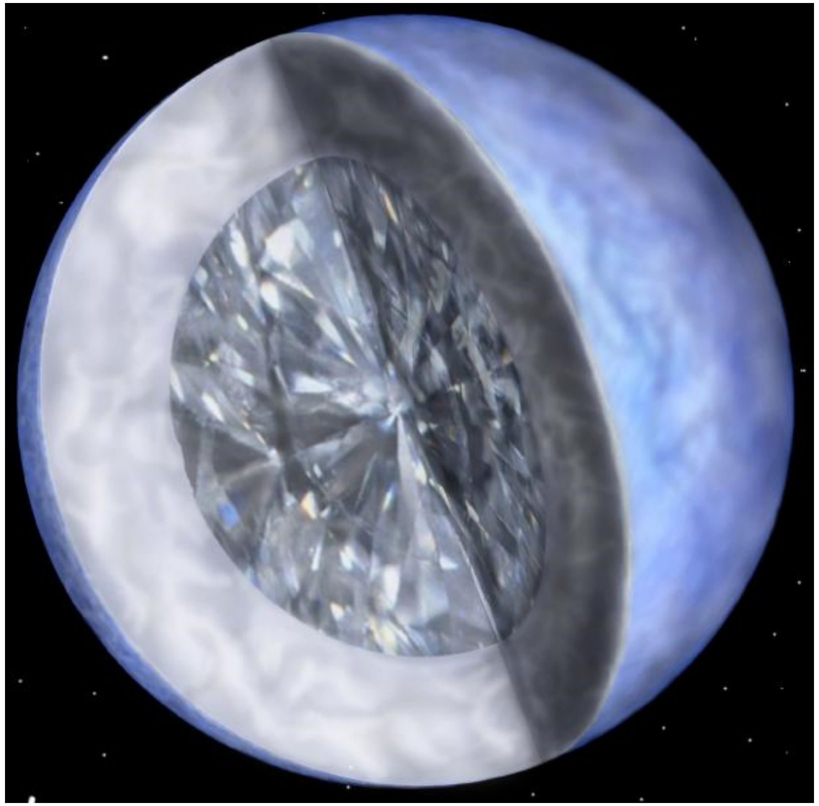
The temperature of the white dwarf tells you how long ago it was formed

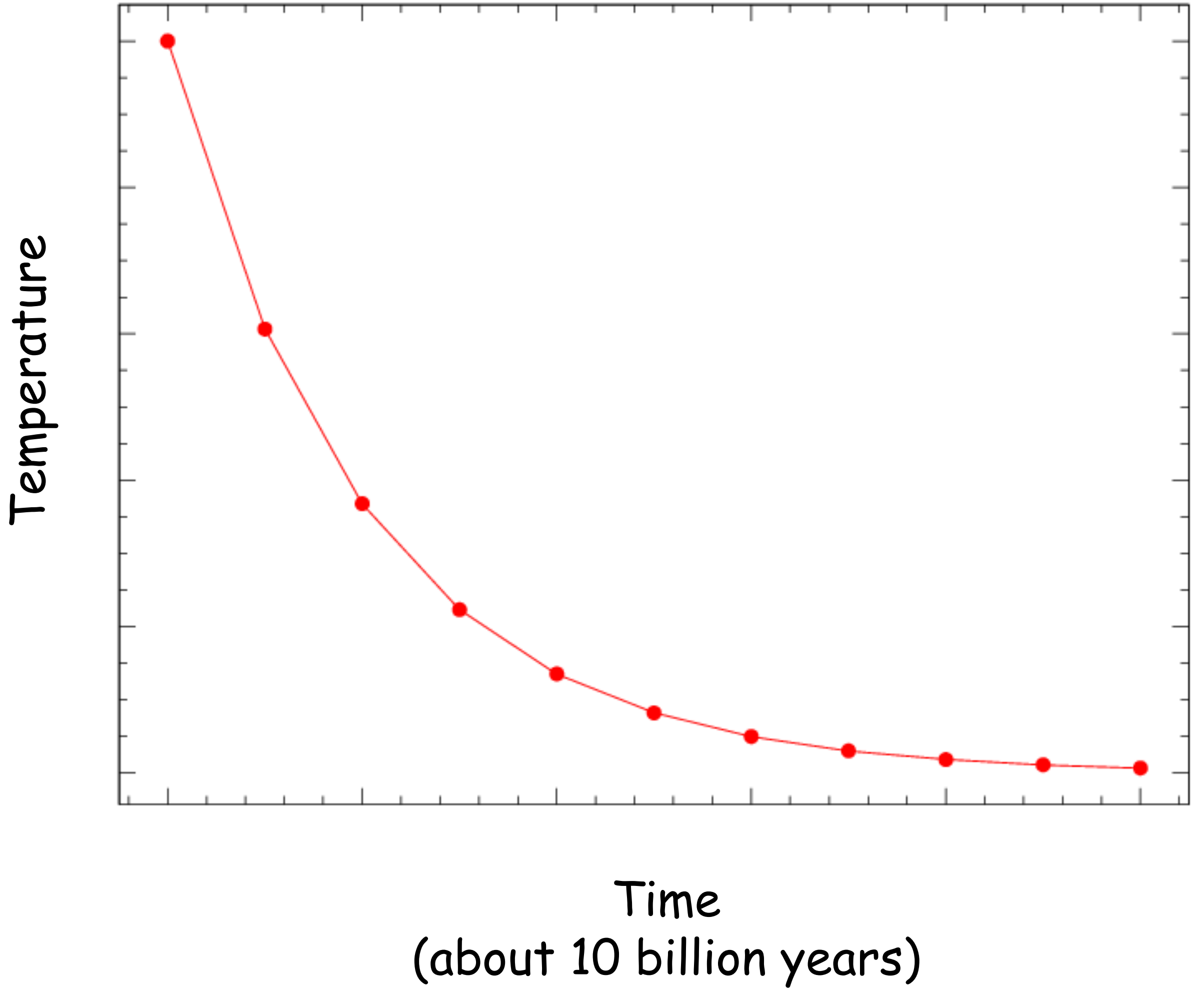




The coolest white dwarfs we see are about ~3800 Kelvin

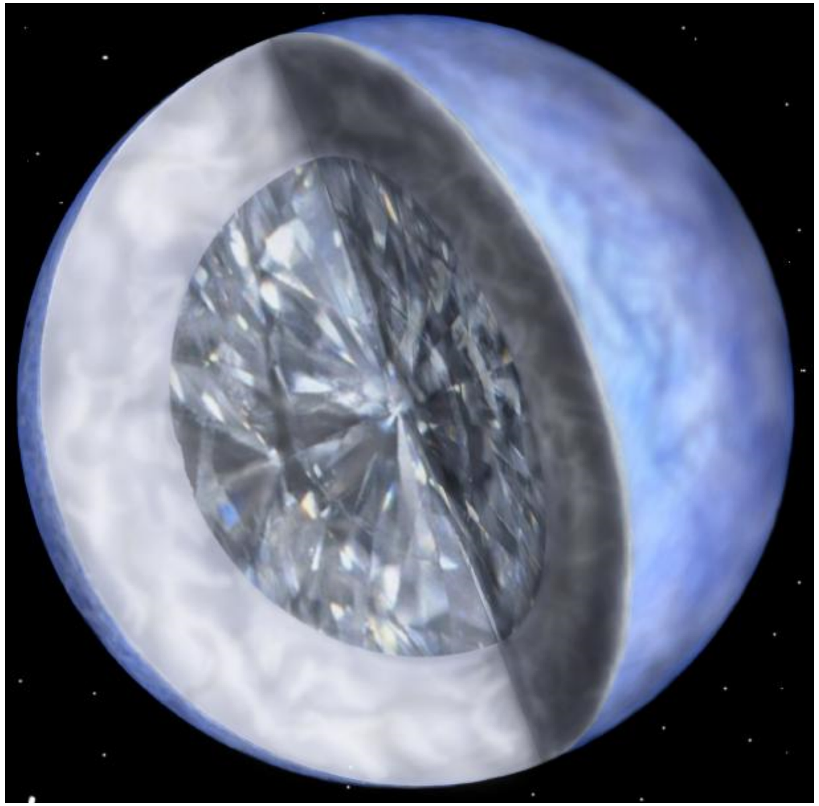
⇒ Our galaxy is about 10 billion years old!

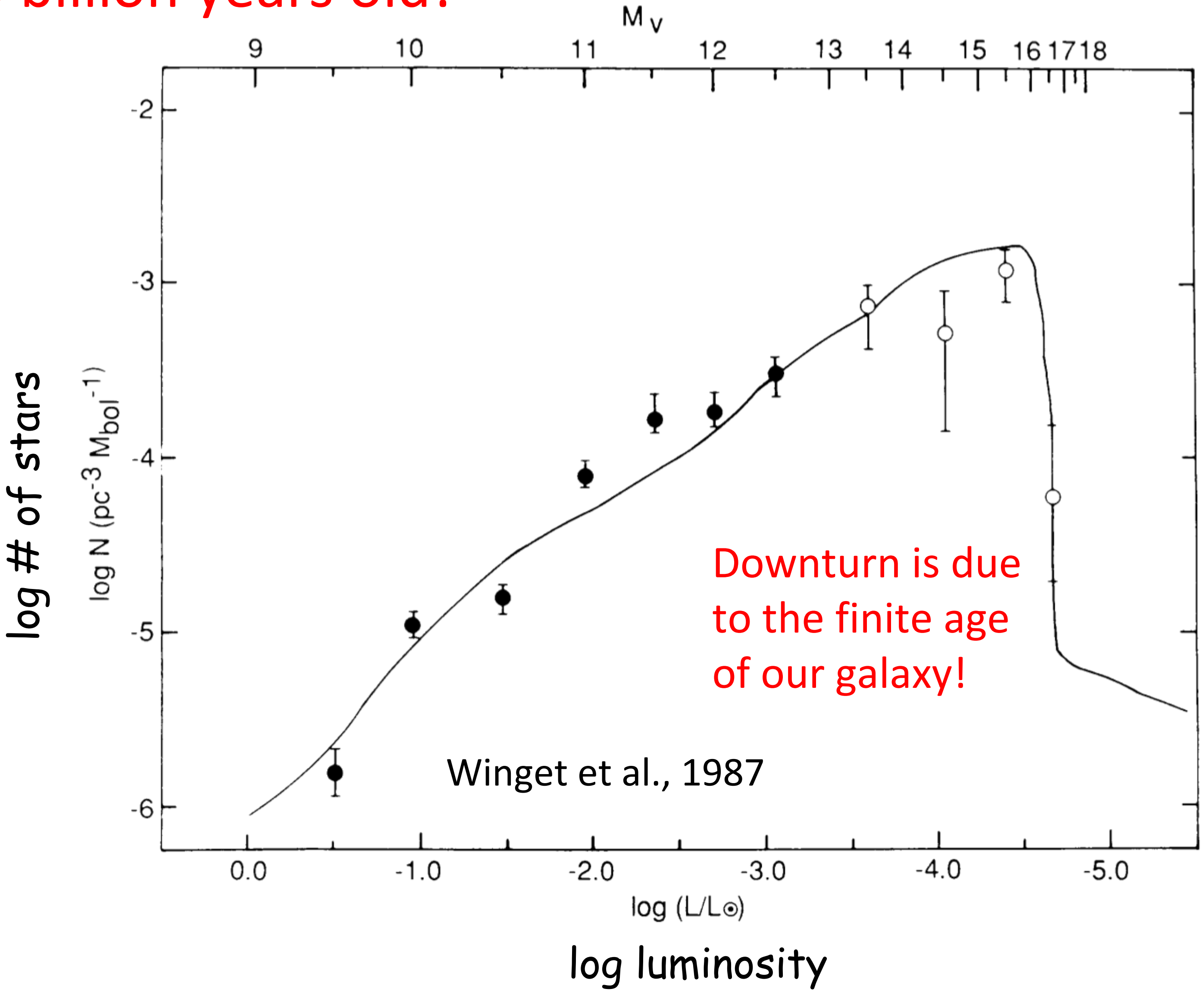




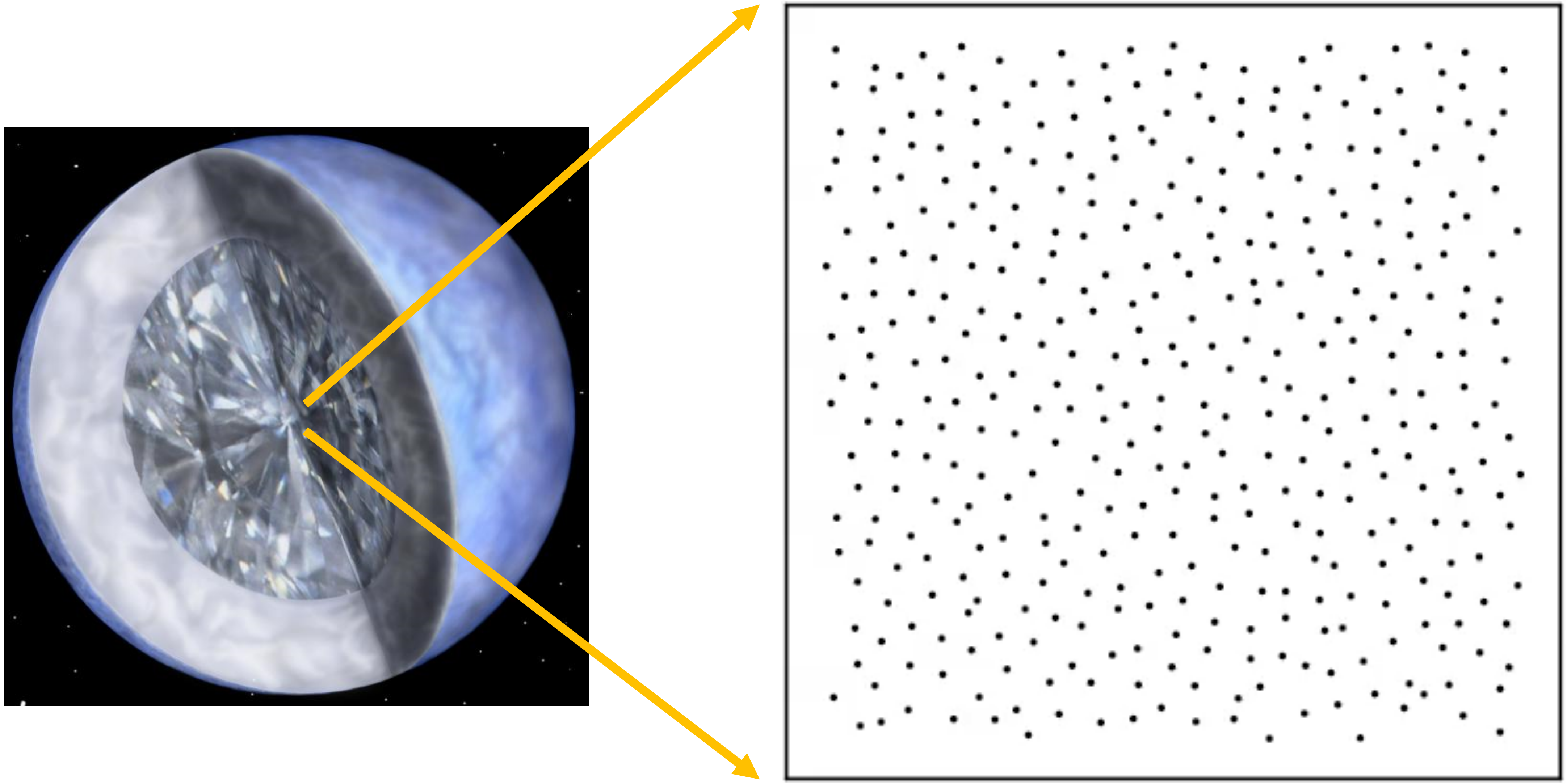
The coolest white dwarfs we see are about 4000 degrees Kelvin

⇒ Our galaxy is about 10 billion years old!





White Dwarfs “freeze” as they cool…



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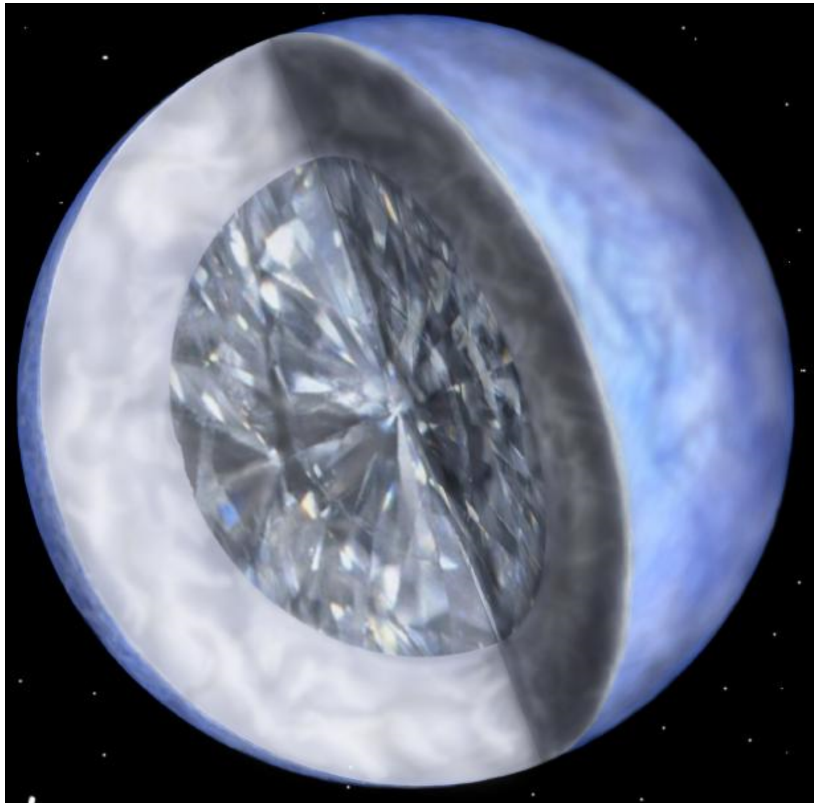

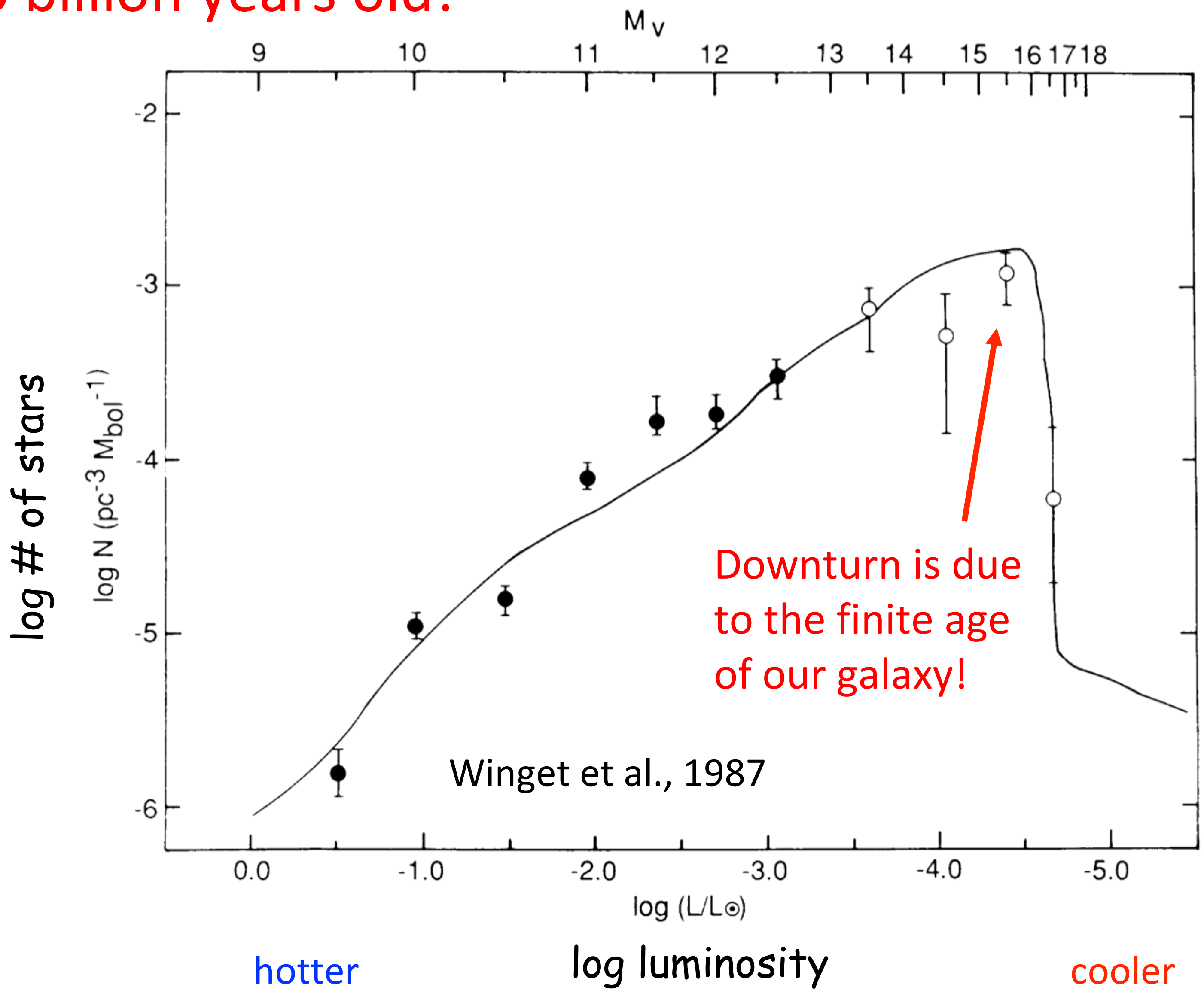

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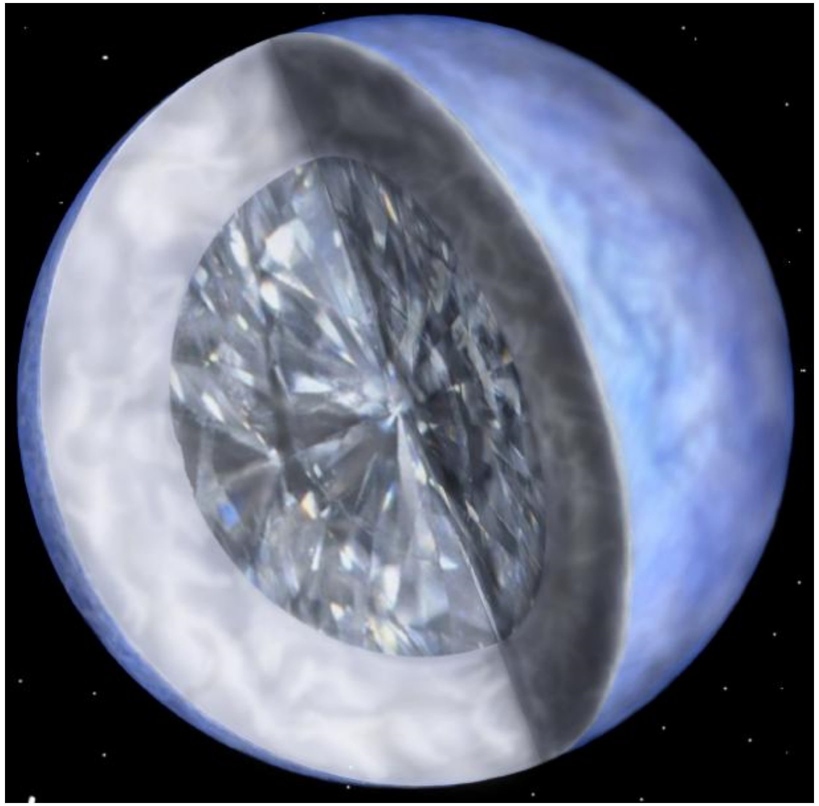
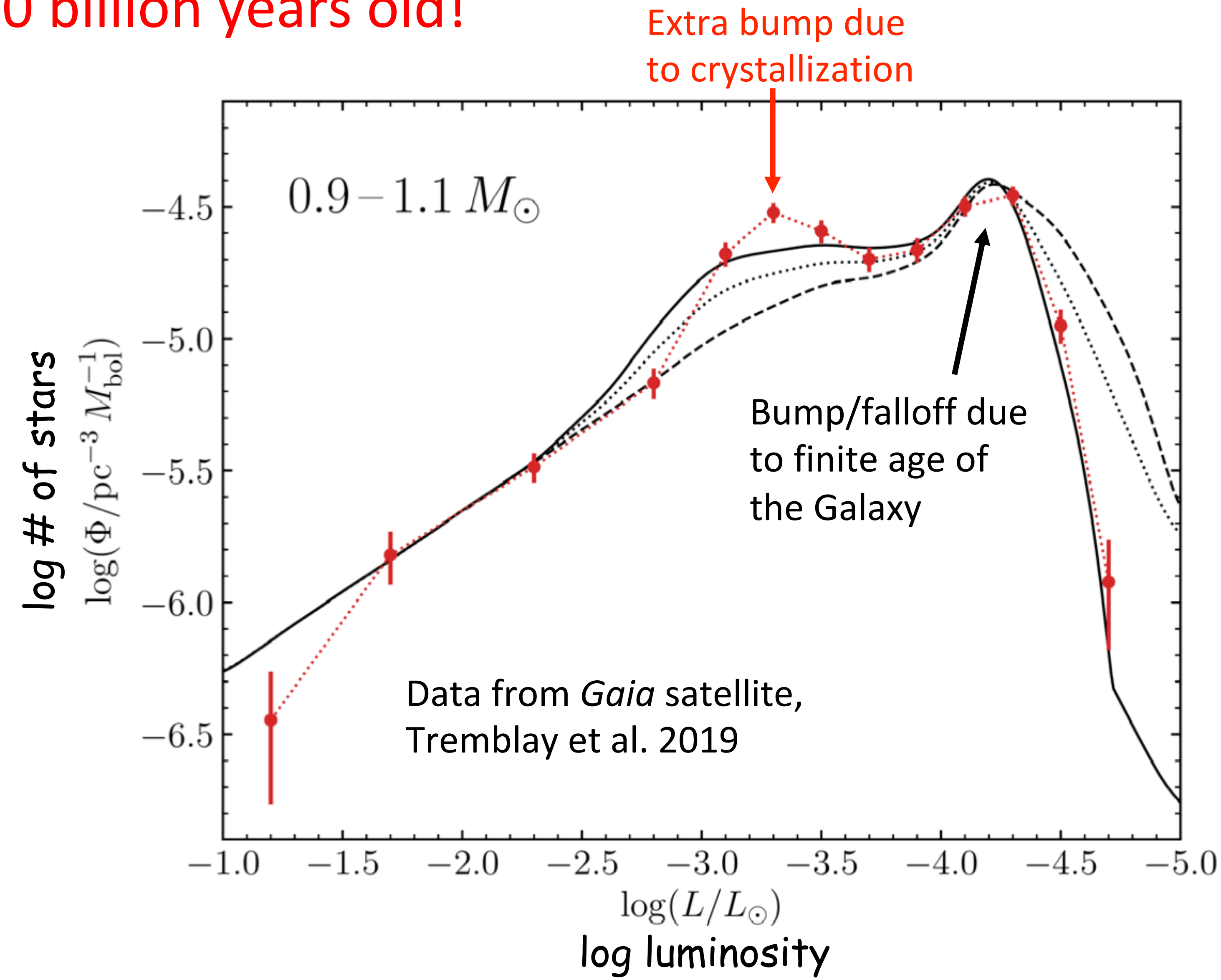
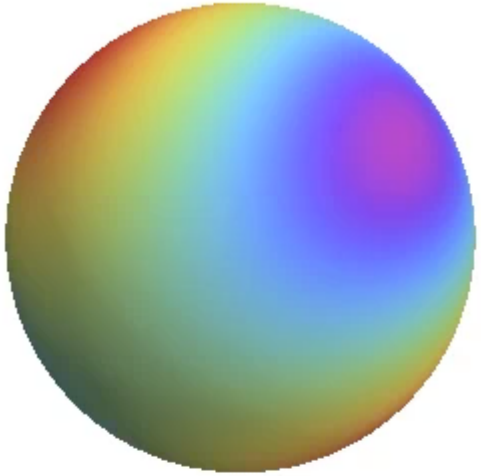


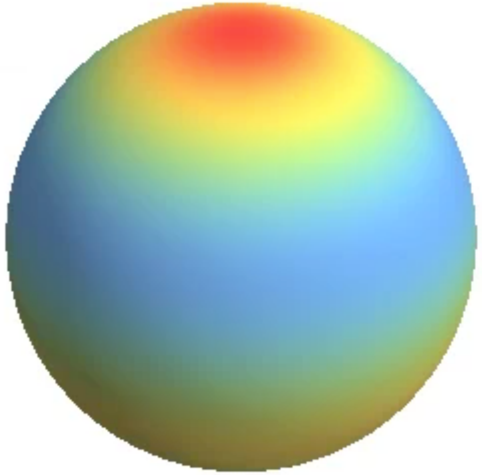


White Dwarfs can also pulsate



l =2, m =1

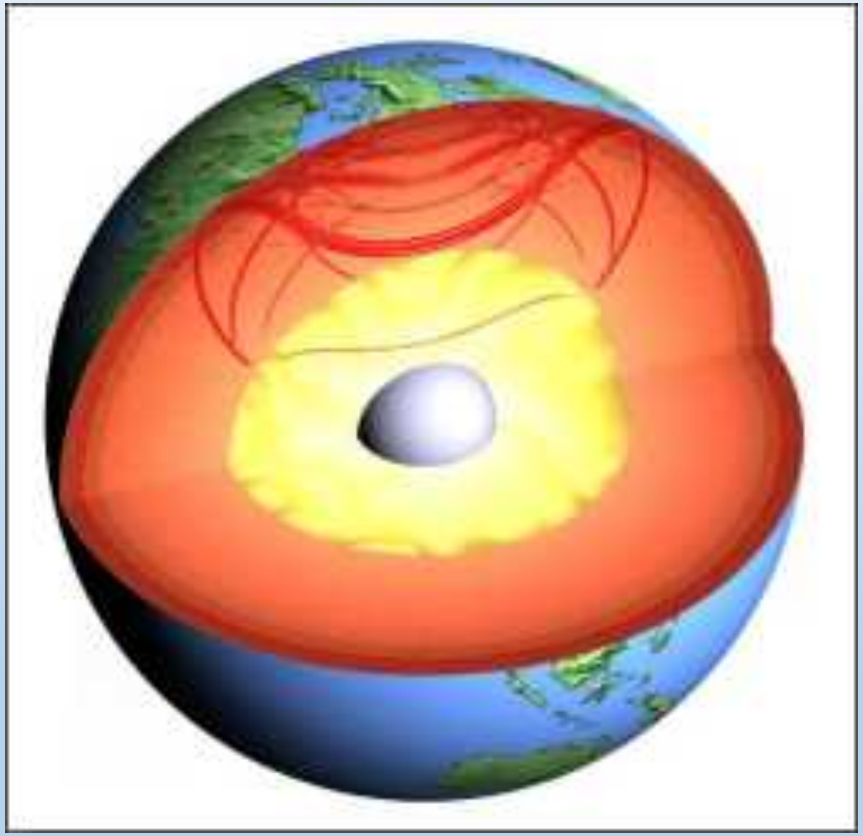
l =1, m =0

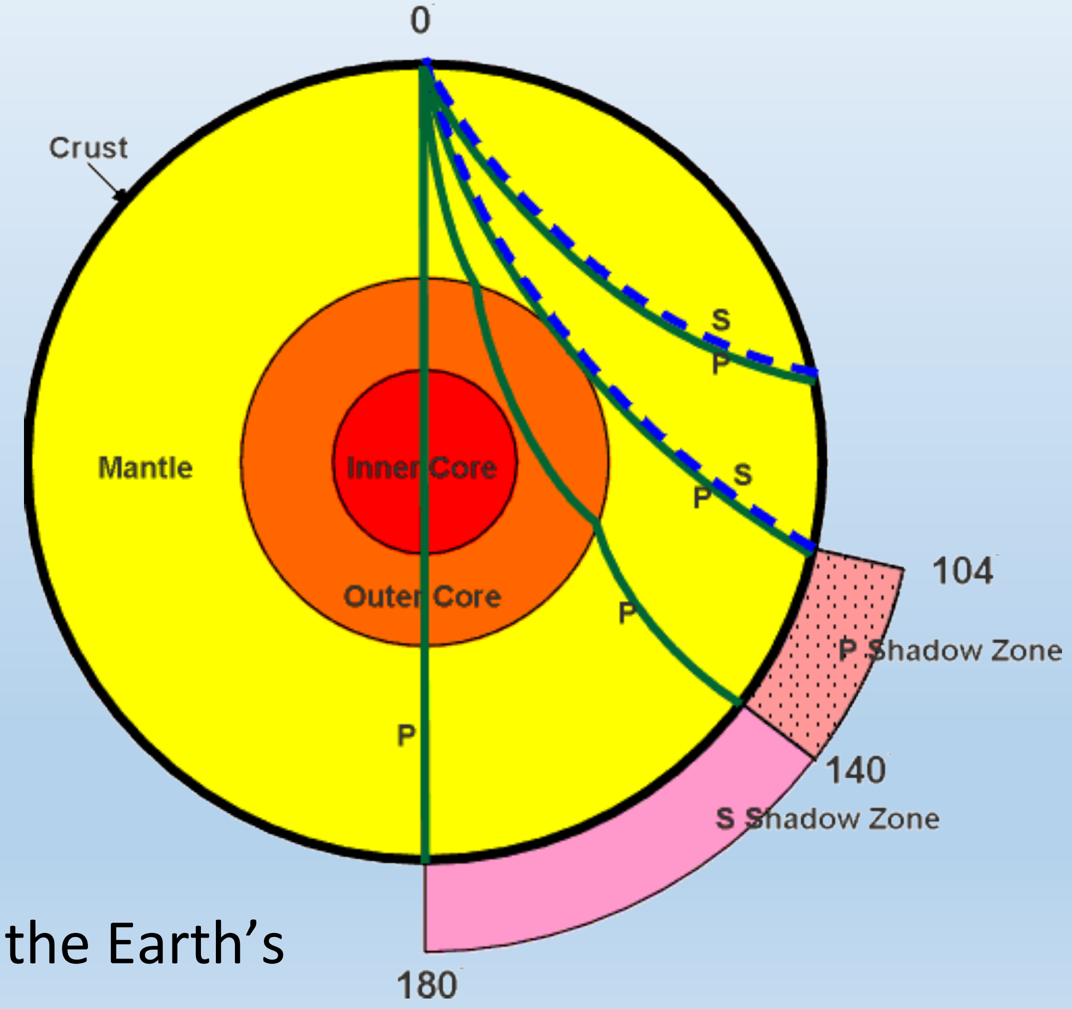


l =3, m =0

How does this help?

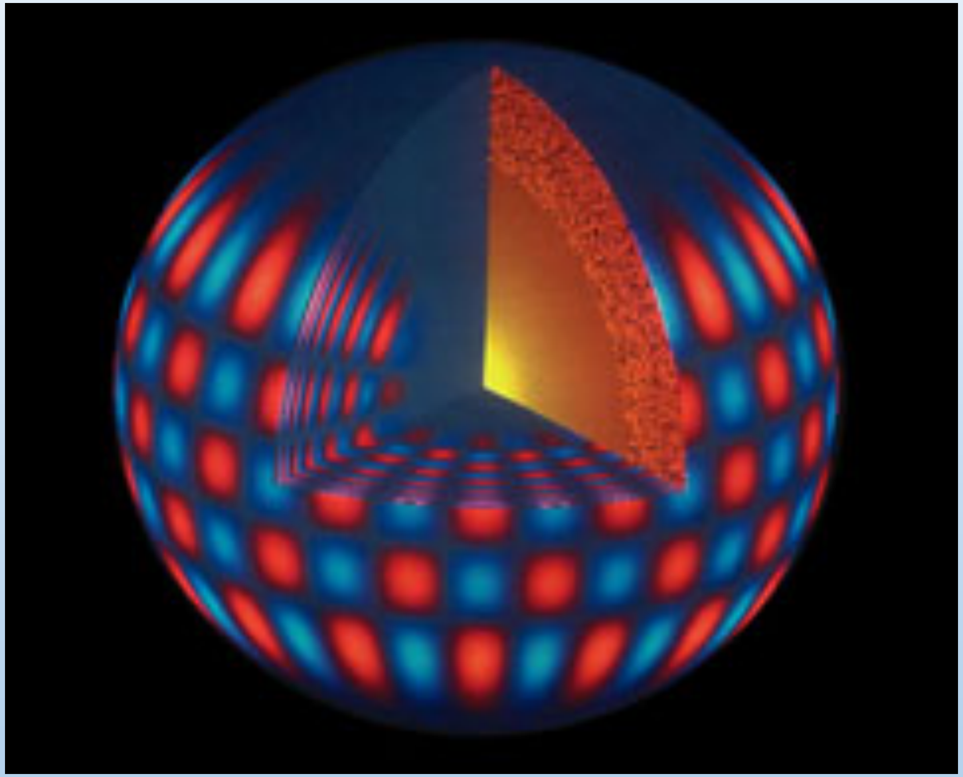
Consider seismology on the Earth…

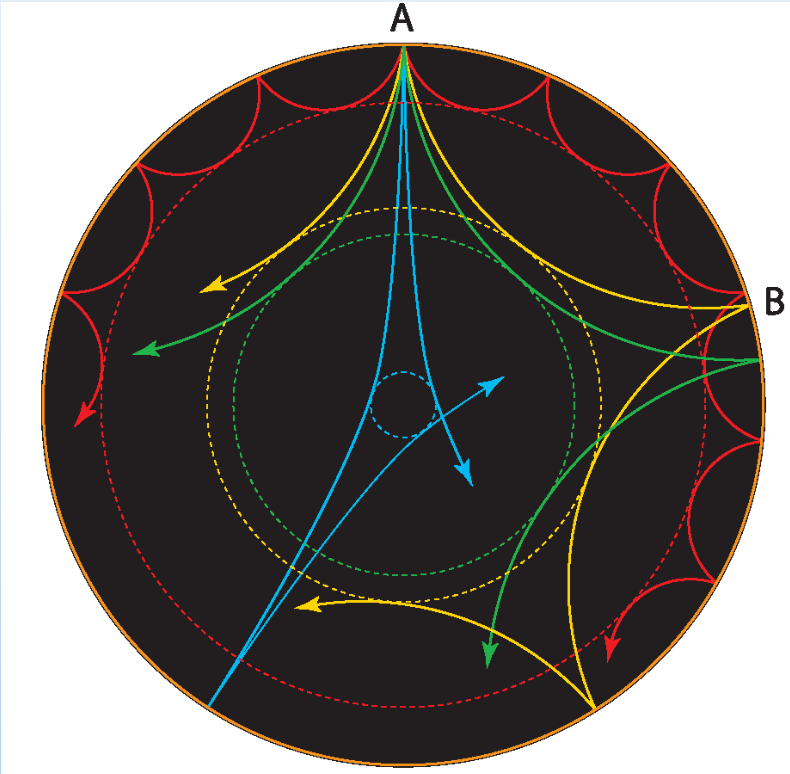




Almost all of our knowledge of the Earth's interior comes from seismology…

Helioseismology:
Studying the Sun through its pulsations

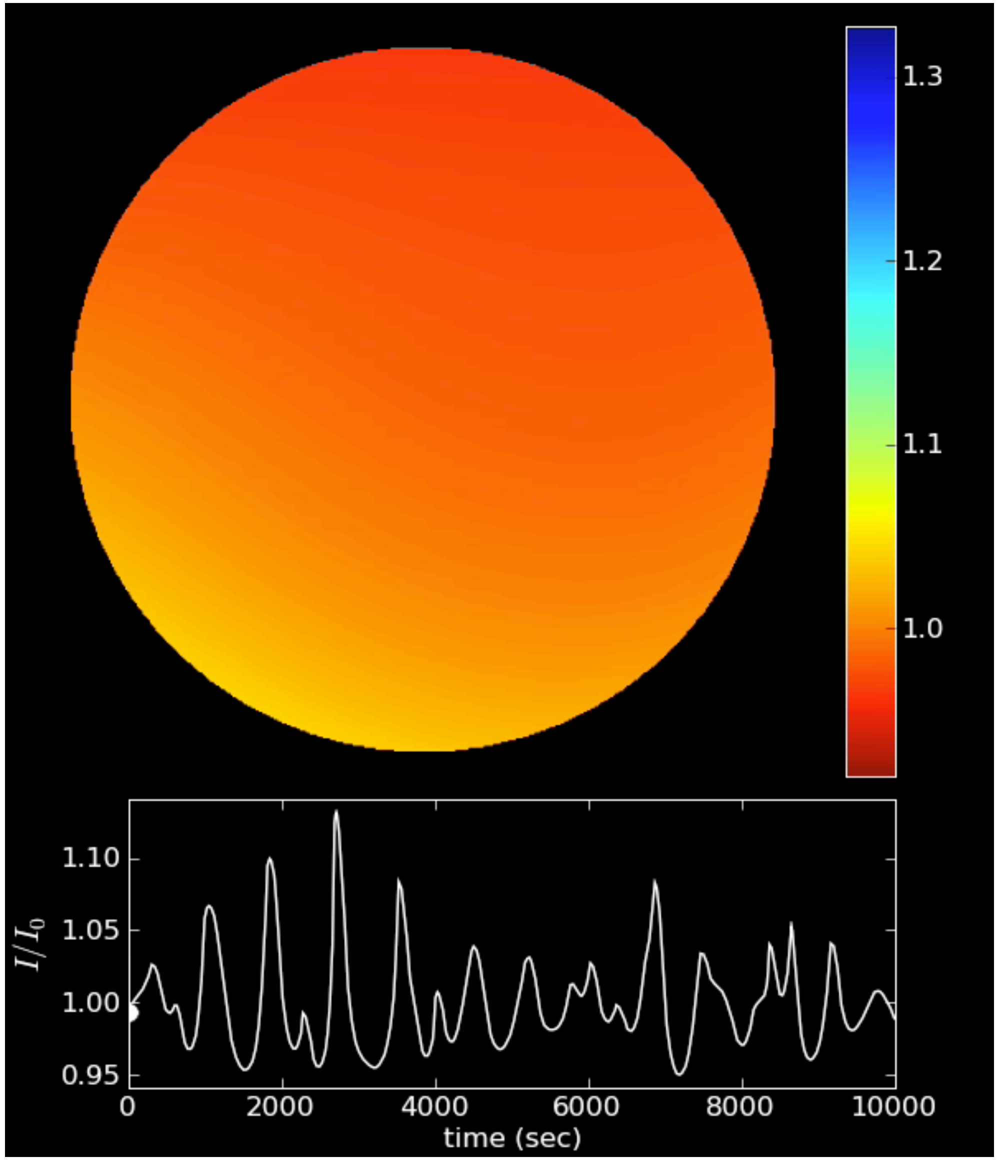




The Sun pulsates in millions of modes simultaneously
We know more about the interior of the Sun than the Earth!

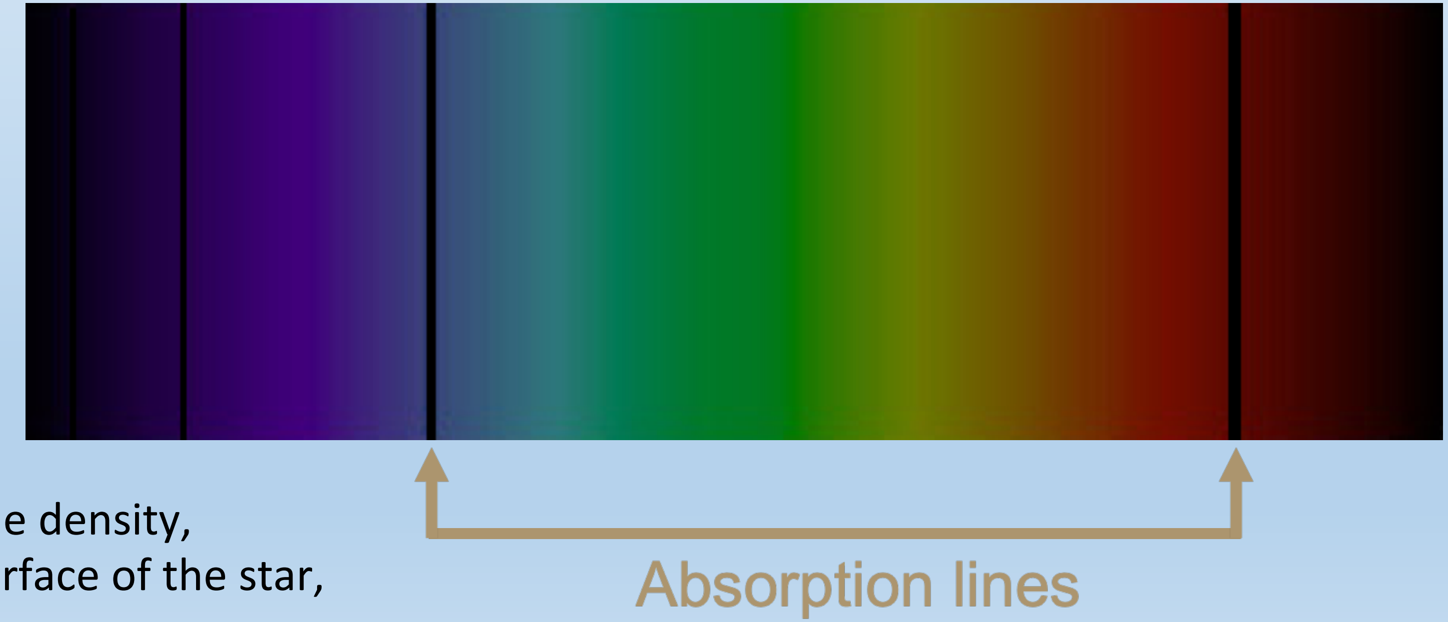
Fortunately, white dwarfs pulsate in dozens of frequencies, which allows a determination of their interior structure

Period (s)	ell	m
422.561	1	1
423.898	1	-1
463.376	1	1
464.209	1	0
465.034	1	-1
571.735	1	1
574.162	1	0
575.933	1	-1
699.684	1	0
810.291	1	0
852.502	1	0
962.385	1	0



But there are still problems…

- We have difficulty measuring their masses
- Different techniques give different answers (up to 30% different)
- The main way we get masses for white dwarfs is from the width of their spectral lines:



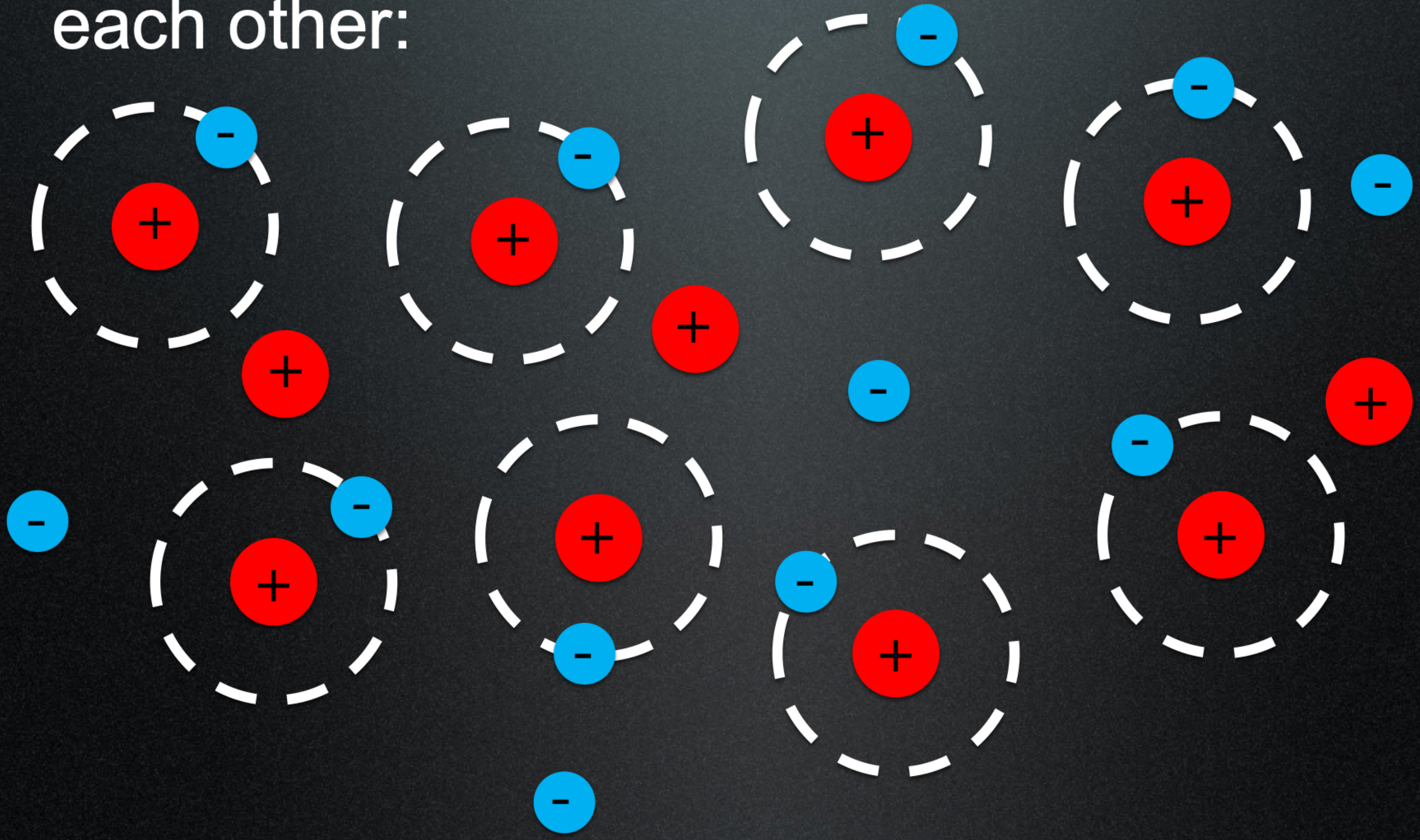
wider lines ⇒ higher mass

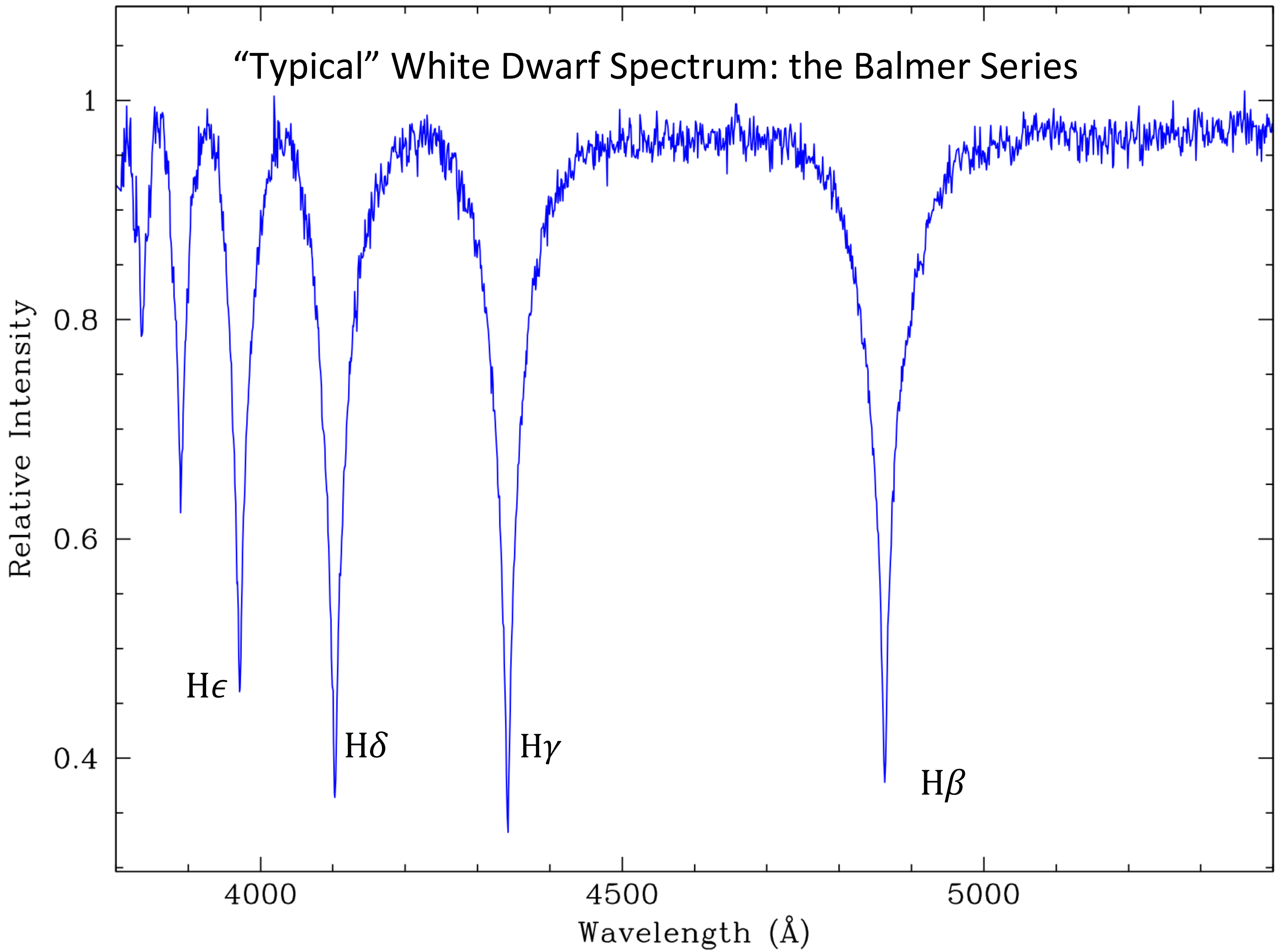
narrower lines ⇒ lower mass

These lines give us information about the density, temperature, and composition of the surface of the star, but only if we know to interpret them

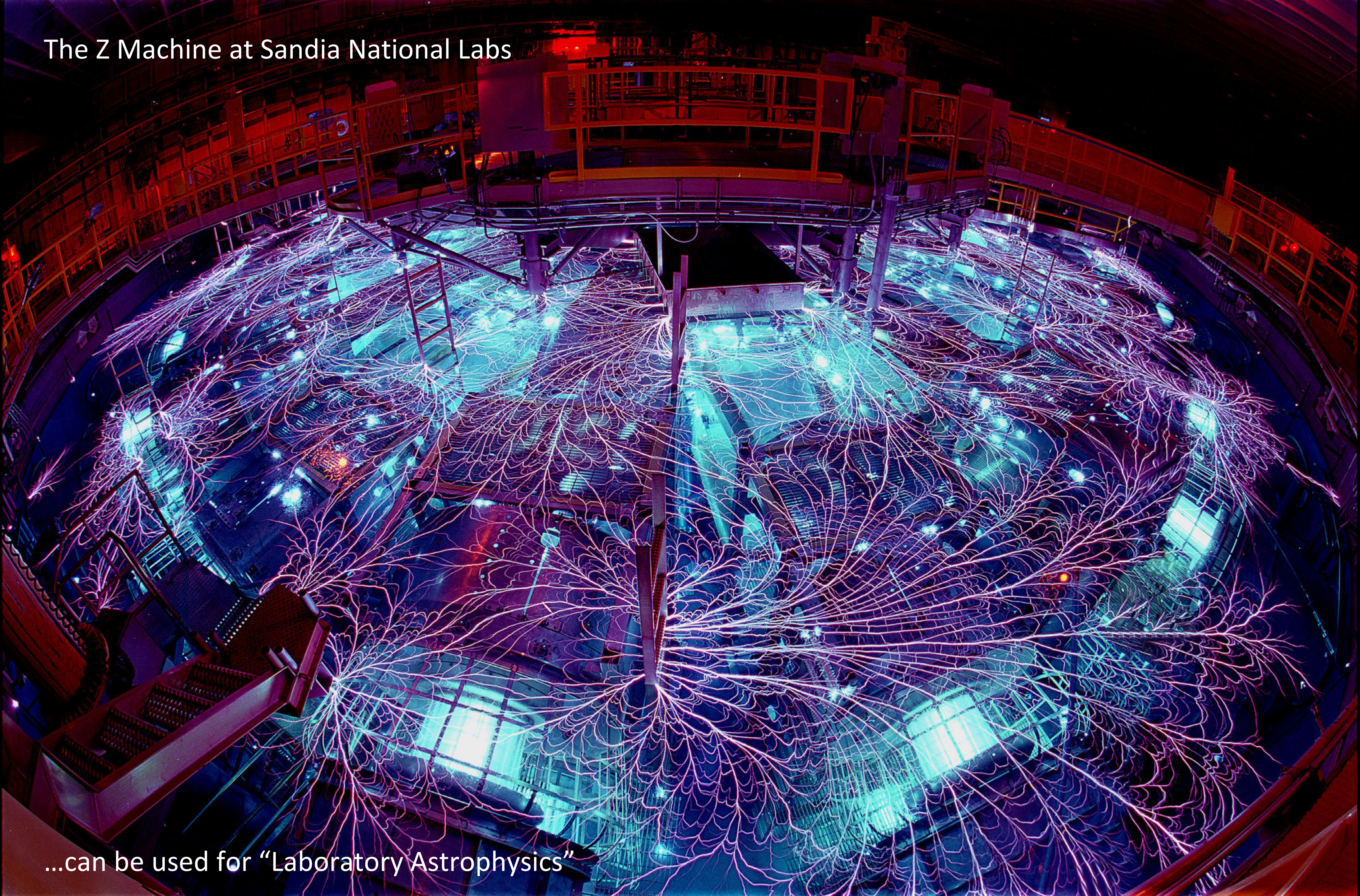
In reality, atoms are never alone…

Nearby atoms, electrons, and ions affect each other:





"Typical" White Dwarf Spectrum: the Balmer Series
Relative Intensity
1
0.8
0.6
0.4
Wavelength (Å)
4000
4500
5000
Hϵ
Hδ
Hγ
Hβ


The Z Machine at Sandia National Labs
…can be used for “Laboratory Astrophysics”


Z East High Bay Camera @ zcameras
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WARNING
Beryllium Can Cause Lung Damage
Cancer Hazard
Authorized Personnel Only
Z ACCESS STATION
1
NO ENTRY
WITHOUT A
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ACCESS BADGE OR
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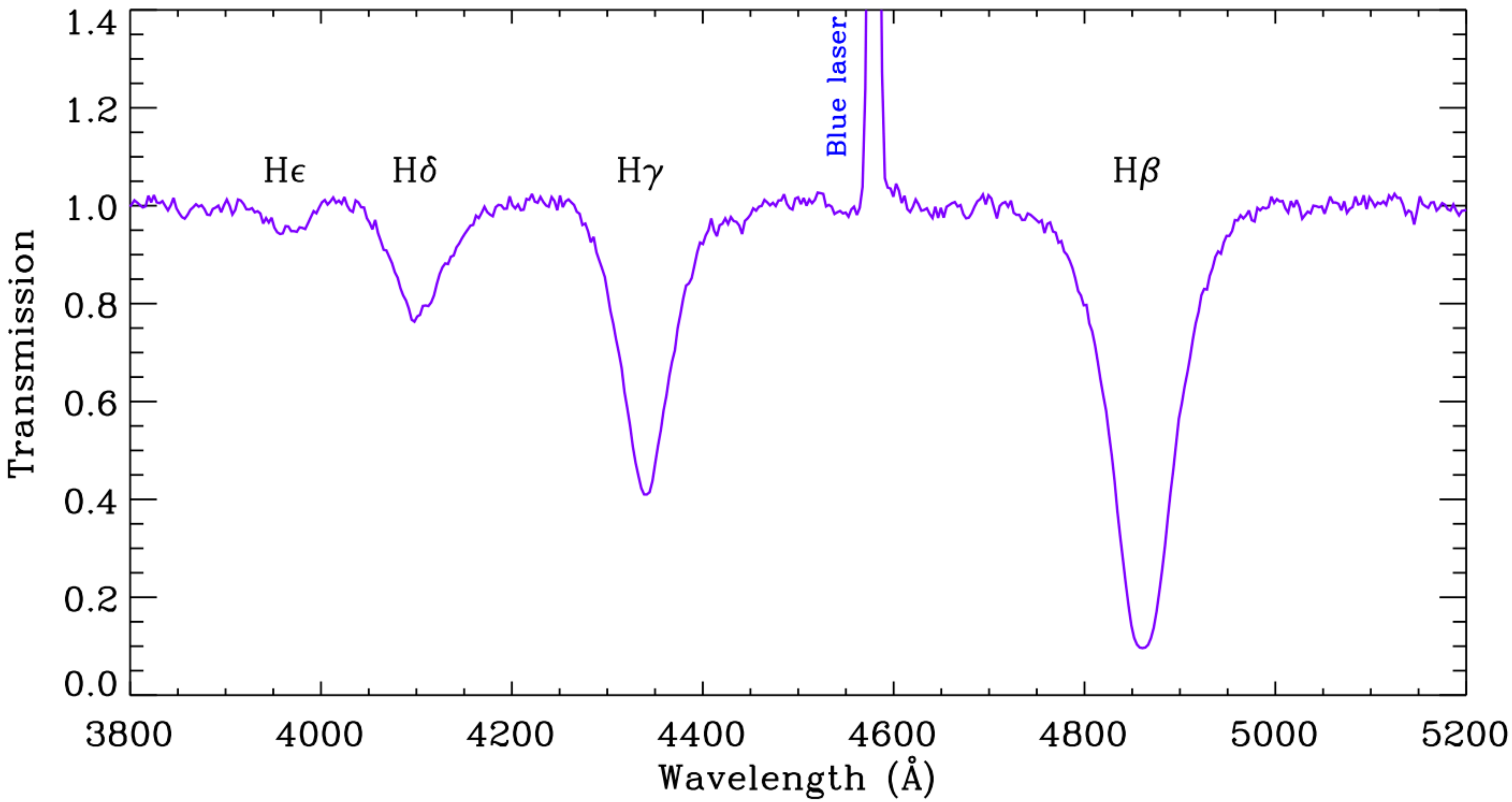
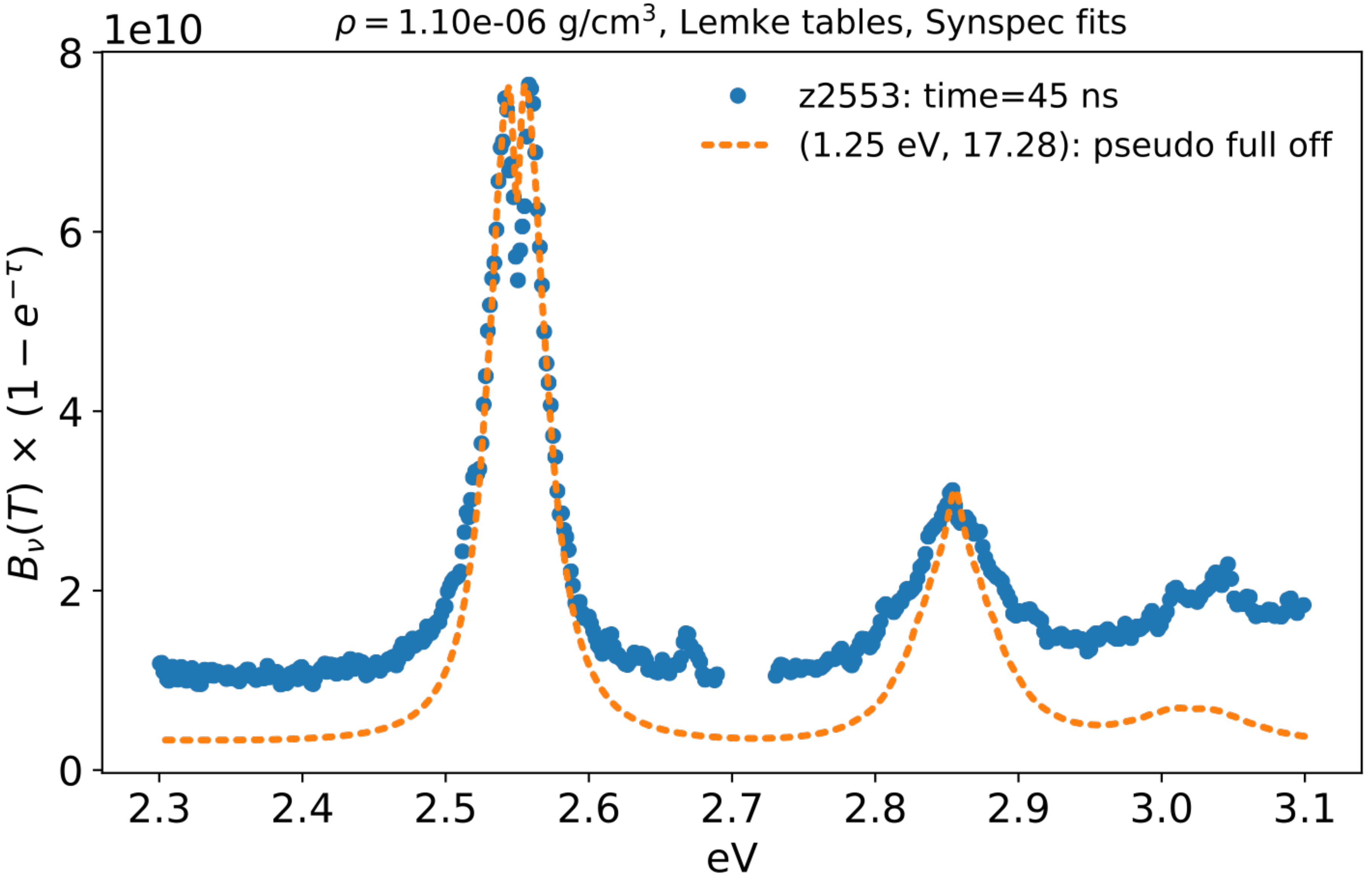
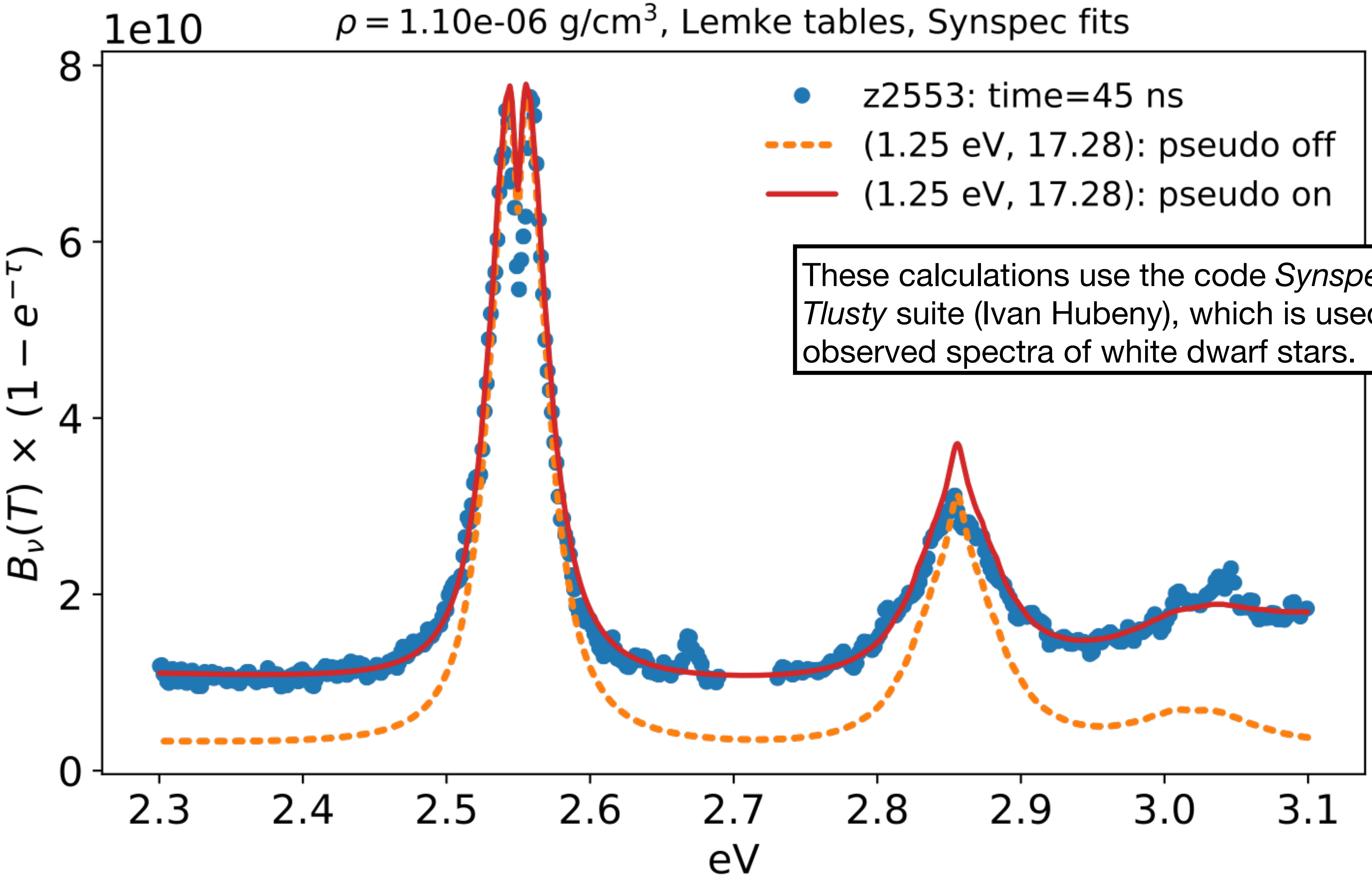

Blue laser
Hϵ
Hδ
Hγ
Hβ
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Transmission
3800
4000
4200
4400
4600
4800
5000
5200
Wavelength (Å)

Effect of the Pseudo-continuum



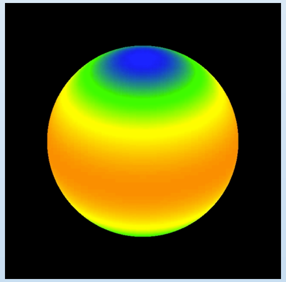
Effect of the Pseudo-continuum



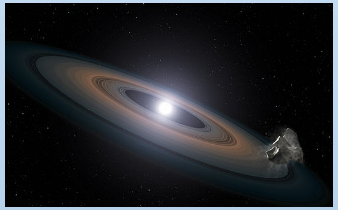
These calculations use the code *Synspec*, part of the *Tlusty* suite (Ivan Hubeny), which is used to fit the observed spectra of white dwarf stars.

Conclusions

- White dwarfs make great chronometers…but we need to know their masses and temperatures
- "Laboratory Astrophysics" experiments can help us better understand the physics in their atmospheres
- We can also learn about white dwarfs because they pulsate
  - see Dr. Barbara Castanheira's talk



- They can also teach us about the eventual fate of our planetary system and those around other stars
  - see Dr. J. J. Hermes' talk

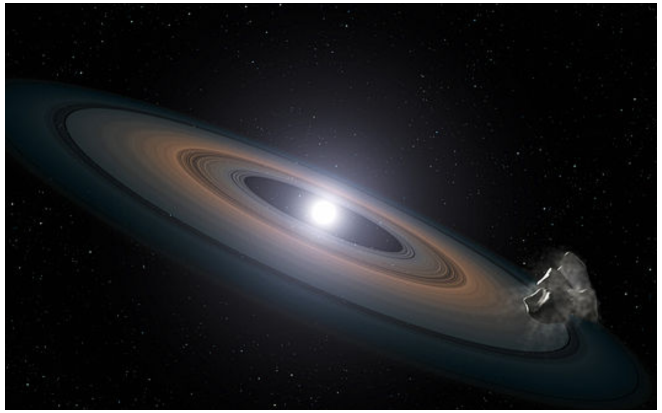


- Type Ia supernovae are ***vital*** for understanding cosmological distances and the evolution of the Universe
  - see Dr. Ken Shen's talk

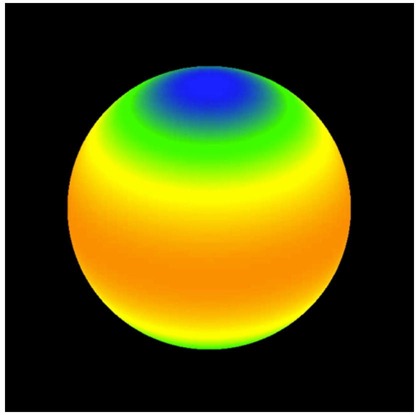
McDonald Observatory
THE UNIVERSITY OF TEXAS AT AUSTIN

Thanks!

…and stay tuned



J. J.



Barbara

Ken

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