[07] White Dwarfs (2/15/18)

Upcoming Items

1. Read Ch. 18.2 for next class and do the self-study quizzes

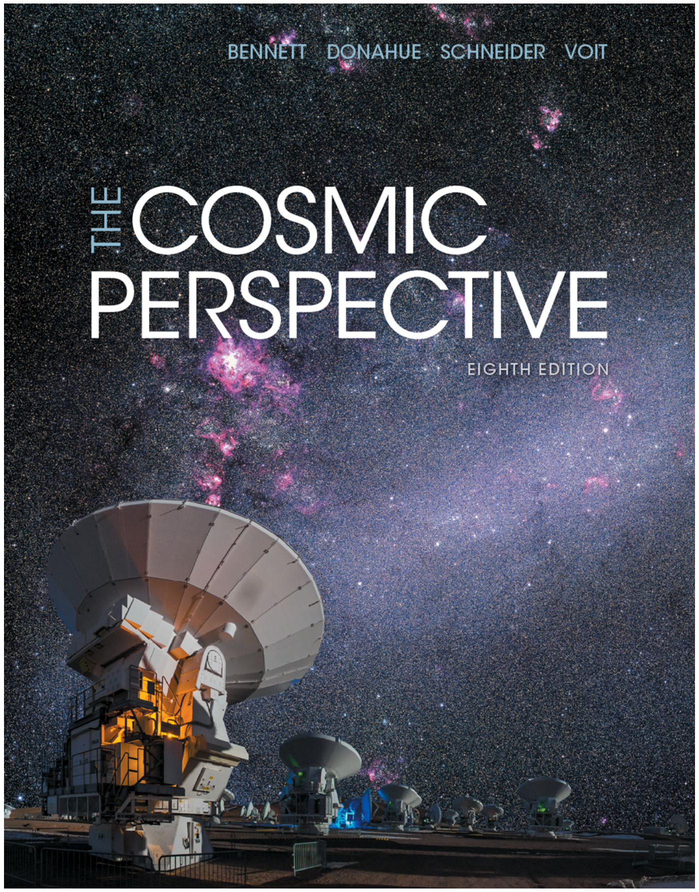
APOD 2/16/17: The Tulip and Cygnus X-1

LEARNING GOALS

Ch. 18.1–18.2

For this class, you should be able to…

- … *describe how white dwarfs and neutron stars form, and describe what happens if mass is accreted onto such objects;*
- … *summarize which characteristics of an explosion's light curve and spectrum are used to determine whether it is a nova, a massive star supernova, or a white dwarf supernova;*



Any astro questions?

In-Class Quiz

1. Which of these is a statement of the uncertainty principle?

A. $\Delta x\ \Delta t \geq \hbar/2$.
B. $\Delta x\ \Delta E \geq \hbar/2$.
C. $\Delta p\ \Delta x \geq \hbar/2$.
D. $\Delta E\ \Delta p \geq \hbar/2$.

Hint: *x=position, p=momentum, E=energy, t=time*
$\hbar$ units: kg m^2 s^{-1}

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A. White dwarf supernova.
B. Massive star supernova.
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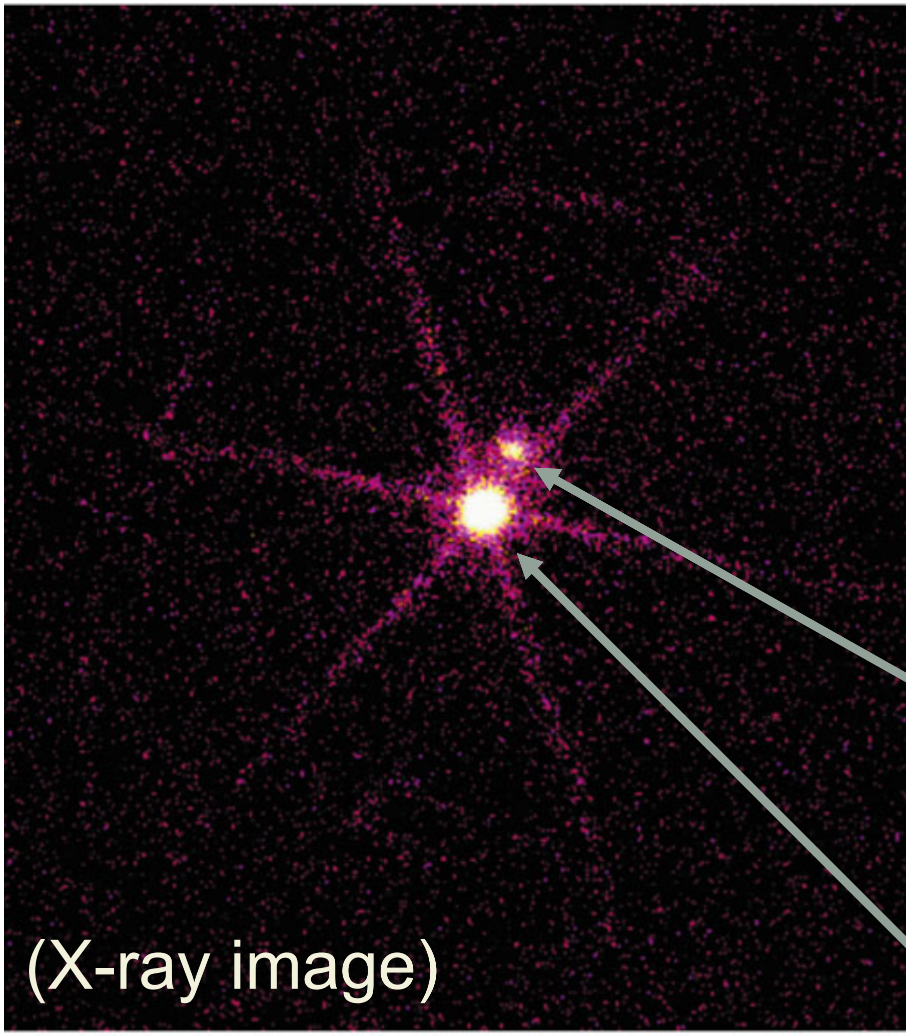
White Dwarfs

- White dwarfs.
  - Cooling ball of helium or C & O supported by electron degeneracy.
  - Very dense material.
  - Accretion can cause occasional outbursts: nova.
  - Accretion or merger beyond 1.4 $M_{\odot}$ limit: white dwarf supernova.
    - Differs from massive star supernova in lightcurve and spectrum.

Degeneracy

- An evil experiment with claustrophobic people...

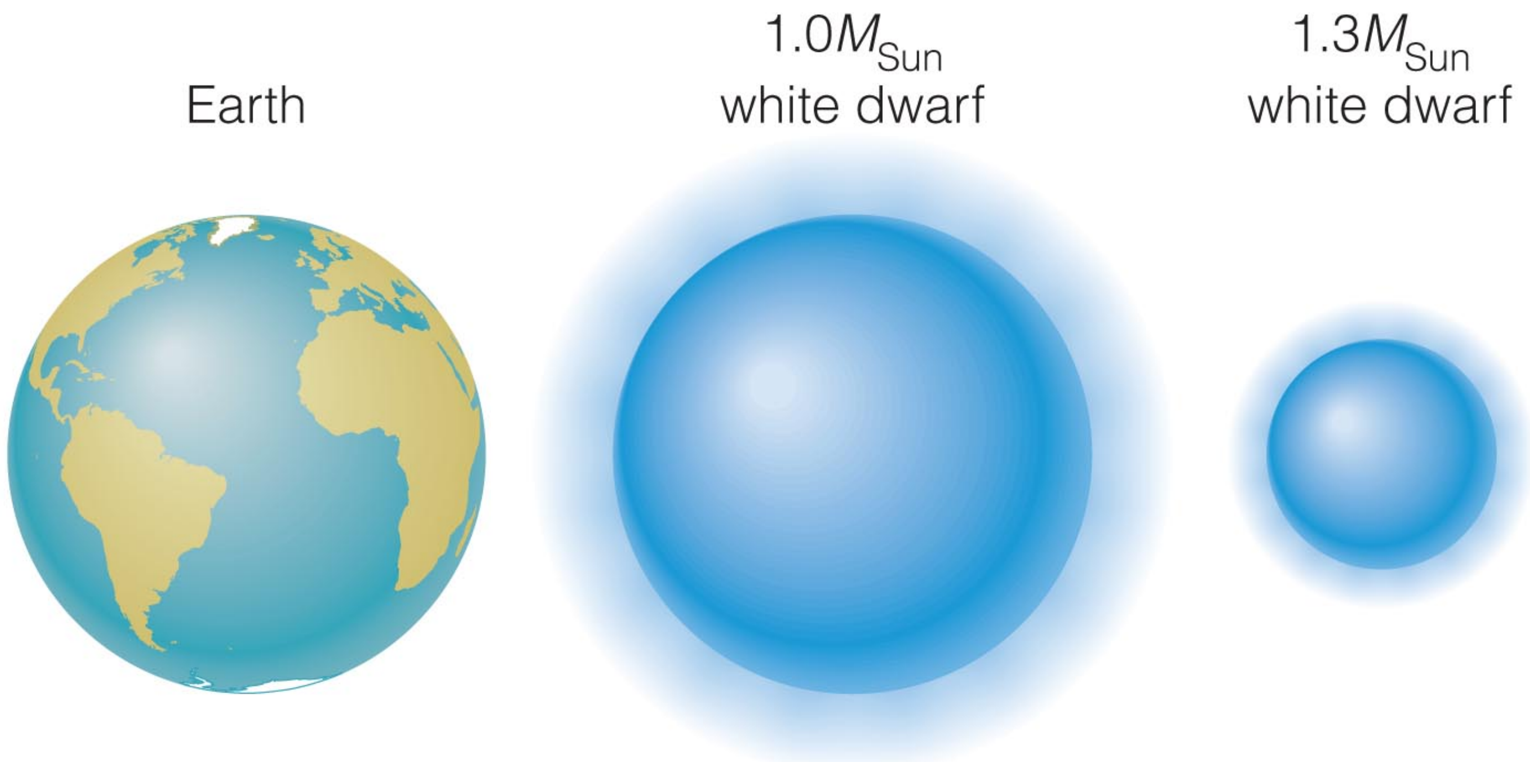
White Dwarfs



- White dwarfs are the remaining cores of dead stars ($M_{initial} < 8\ M_{\odot}$).
- Electron degeneracy pressure supports them against the crush of gravity.

What does this say about their relative temperatures?

Size of a White Dwarf



- White dwarfs with same mass as the Sun are about the same size as Earth.
- Higher-mass white dwarfs are smaller.

Exotic Matter…

- A single teaspoon of white dwarf matter would weigh several tons on Earth! Why?
- White dwarf density is enormous. Example:

Density = (mass) / (volume)

$= (2 \times 10^{30}\ \text{kg}) / ((4/3)\ \pi\ (6 \times 10^{6}\ \text{m})^3)$

$= 2 \times 10^{9}\ \text{kg/m}^3$.

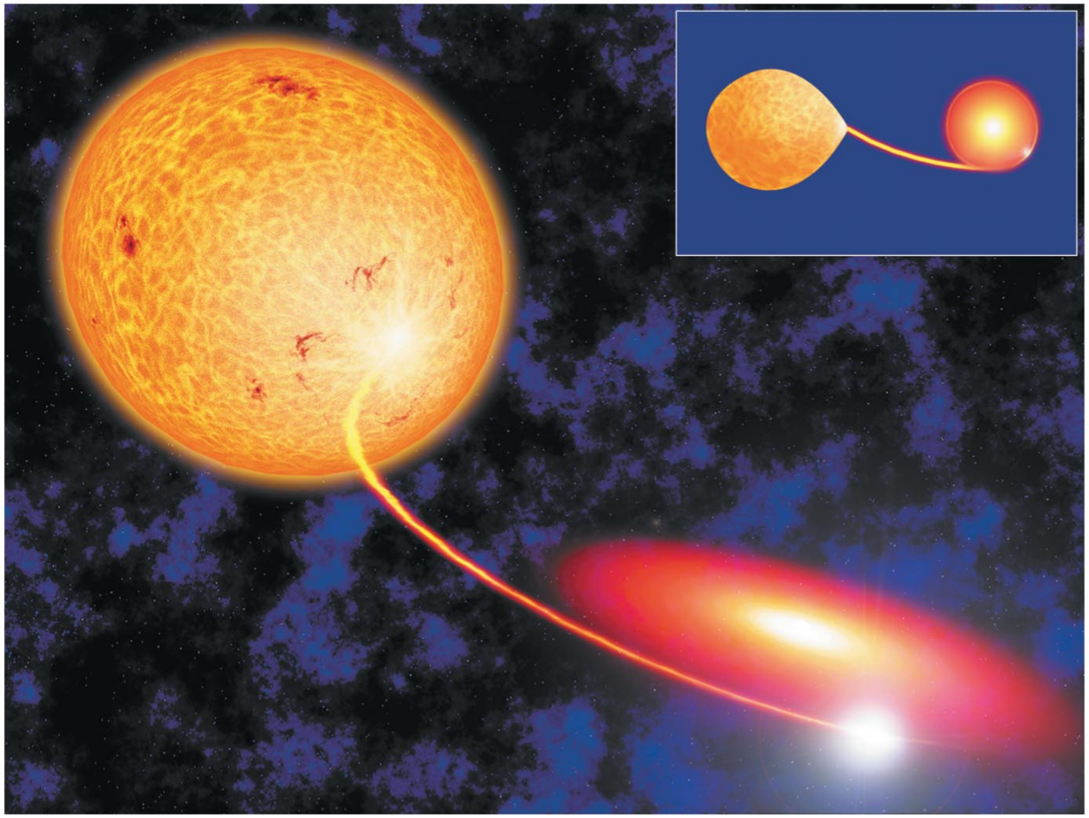
- By comparison, water has a density of 1,000 kg/m^3.
  - So this white dwarf would have an average density 2 million times denser than water!
  - Some white dwarfs can be >100x denser

The White Dwarf Limit

S. Chandrasekhar

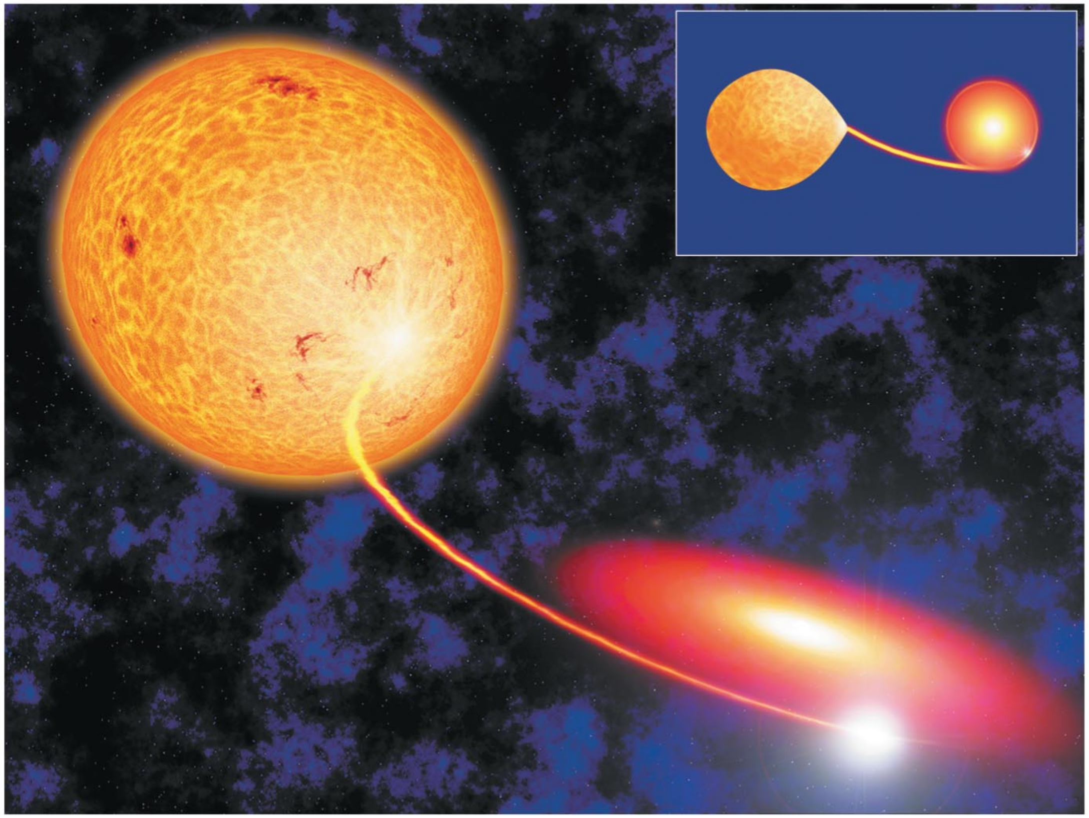
- As you will derive in the homework, degeneracy can't support stars of arbitrarily large mass
- For a white dwarf, the limit is about 1.4 $M_\odot$
- This is called the Chandrasekhar mass, M_{Ch}, in honor of its discoverer
- And it makes you wonder: what if a stellar remnant is more massive than this?

White Dwarf Accretion Disks



- Mass falling toward a white dwarf from a close companion has angular momentum.
- The matter therefore orbits the white dwarf in an *accretion disk*.

White Dwarf Accretion Disks



- Friction in the disk causes material to…
  - spiral in…
  - heat up…
  - and glow.

What would gas in a disk do if there were no friction?

A. It would orbit indefinitely.
B. It would eventually fall in.
C. It would blow away.

What would gas in a disk do if there were no friction?

A. **It would orbit indefinitely.**
B. It would eventually fall in.
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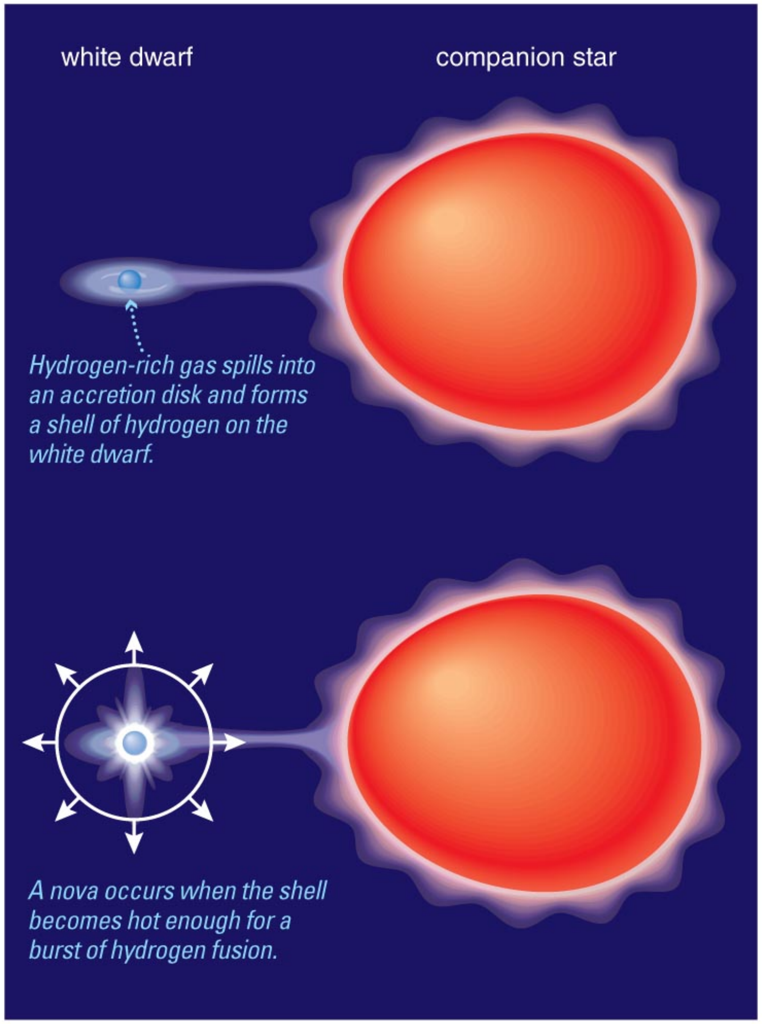
But ”friction” turns out to be a poor description. In reality, the situation is interestingly complex. The real issue turns out to be transporting angular momentum; because the total angular momentum in an isolated gas disk is constant with time, for stuff to move in, other stuff has to move out. What provides the communication within the disk? Magnetic fields are the best candidate for most disks. Loops of fields can connect moderately distant parts of a disk.

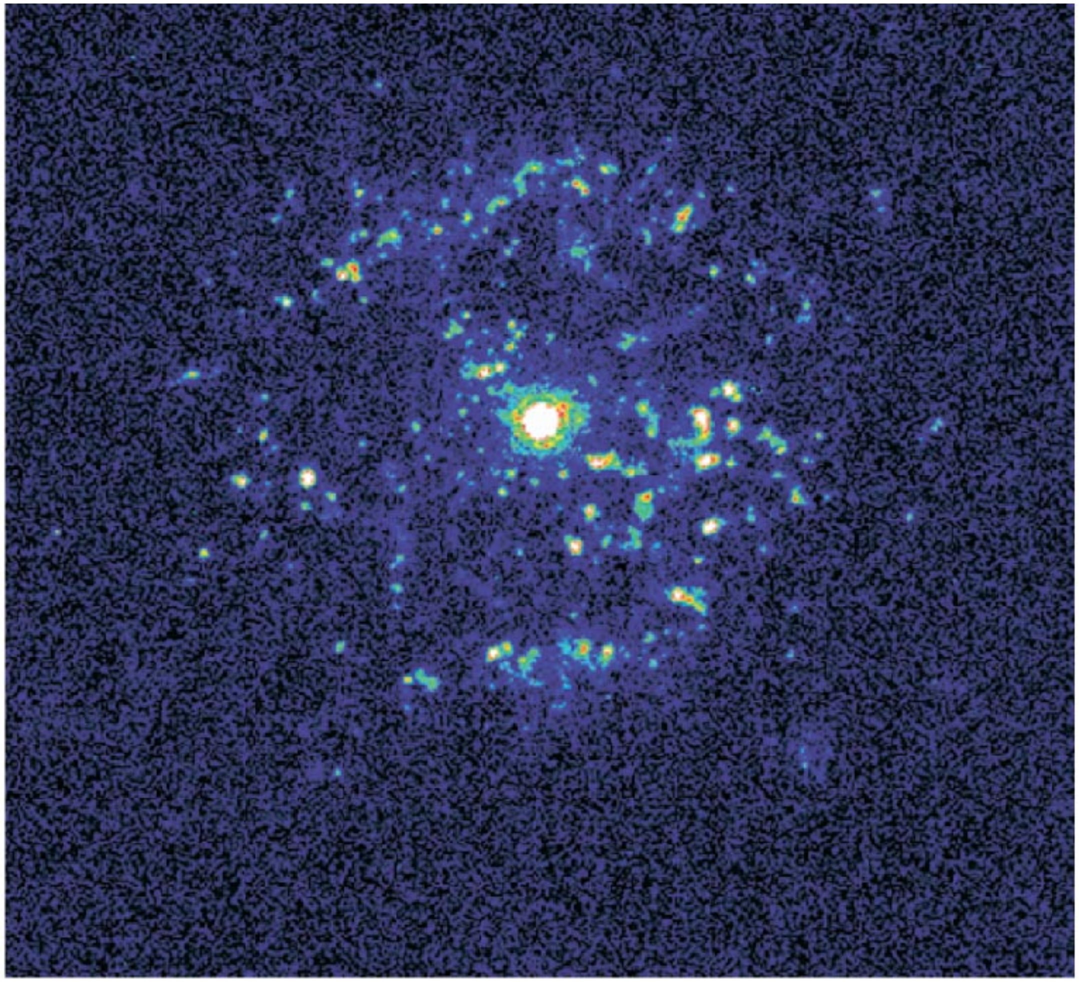
Group Q for you: what happens if the disk is cool enough that it is electrically neutral? This happens in protoplanetary disks. This is a “live question”; no universally agreed-upon answer!

Nova

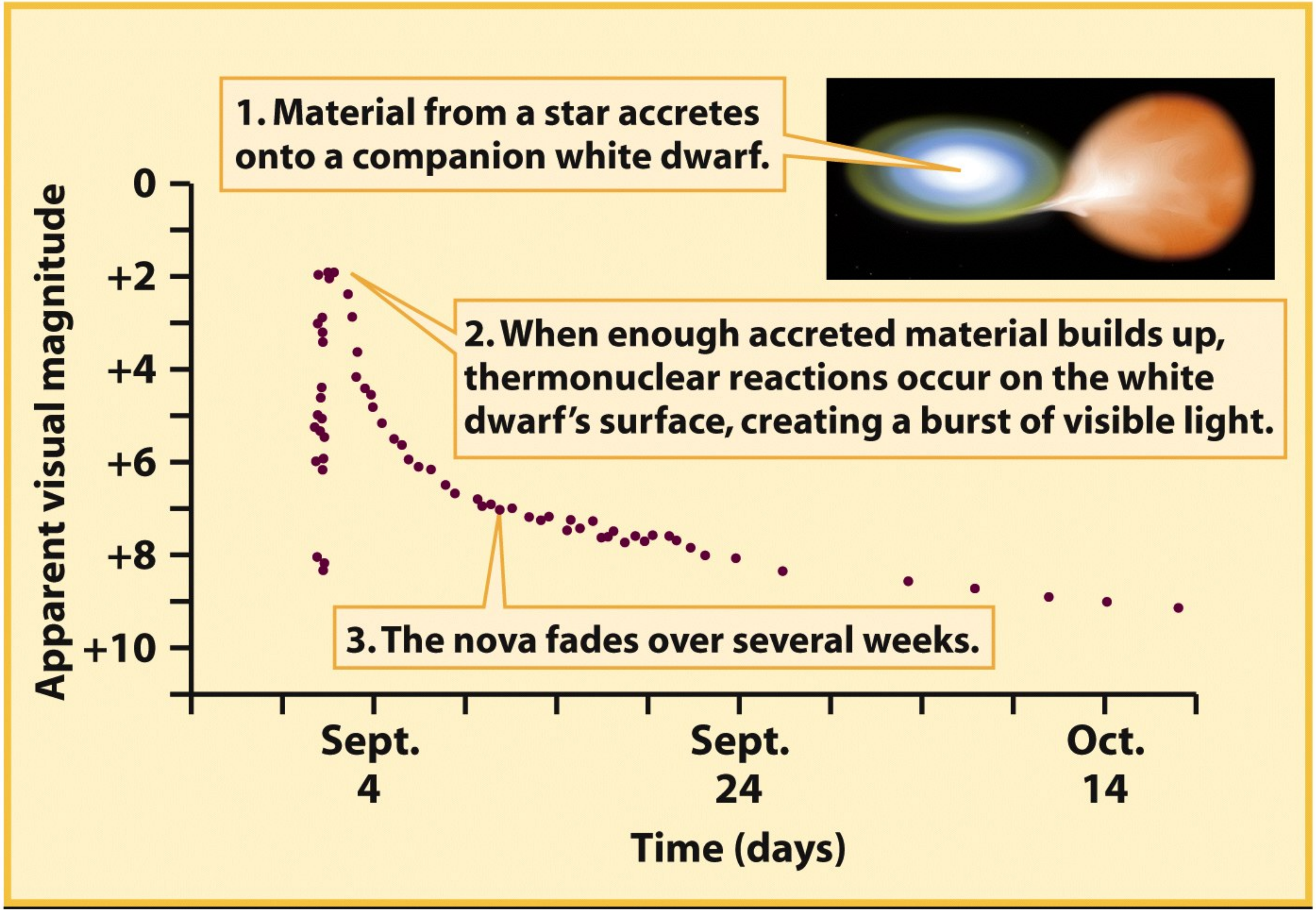


- The temperature of accreted matter eventually becomes hot enough for hydrogen fusion.
- Fusion begins suddenly and explosively, causing a *nova*.
  Why explosively?
  Because the fusion starts in a degenerate state!

Nova



- The nova star system temporarily appears much brighter.
- The explosion drives accreted matter out into space.
  In contrast with neutron stars, on WD the gravitational binding energy per nucleon is much less than the nuclear binding energy released during fusion
- Not clear that the WD gains net mass from accretion!


1. Material from a star accretes onto a companion white dwarf.
2. When enough accreted material builds up, thermonuclear reactions occur on the white dwarf's surface, creating a burst of visible light.
3. The nova fades over several weeks.
Apparent visual magnitude
0
+2
+4
+6
+8
+10
Sept. 4
Sept. 24
Oct. 14
Time (days)

What happens to a white dwarf when it accretes enough material to reach the 1.4 $M_{\odot}$ limit?

A. It explodes.
B. It collapses into a neutron star.
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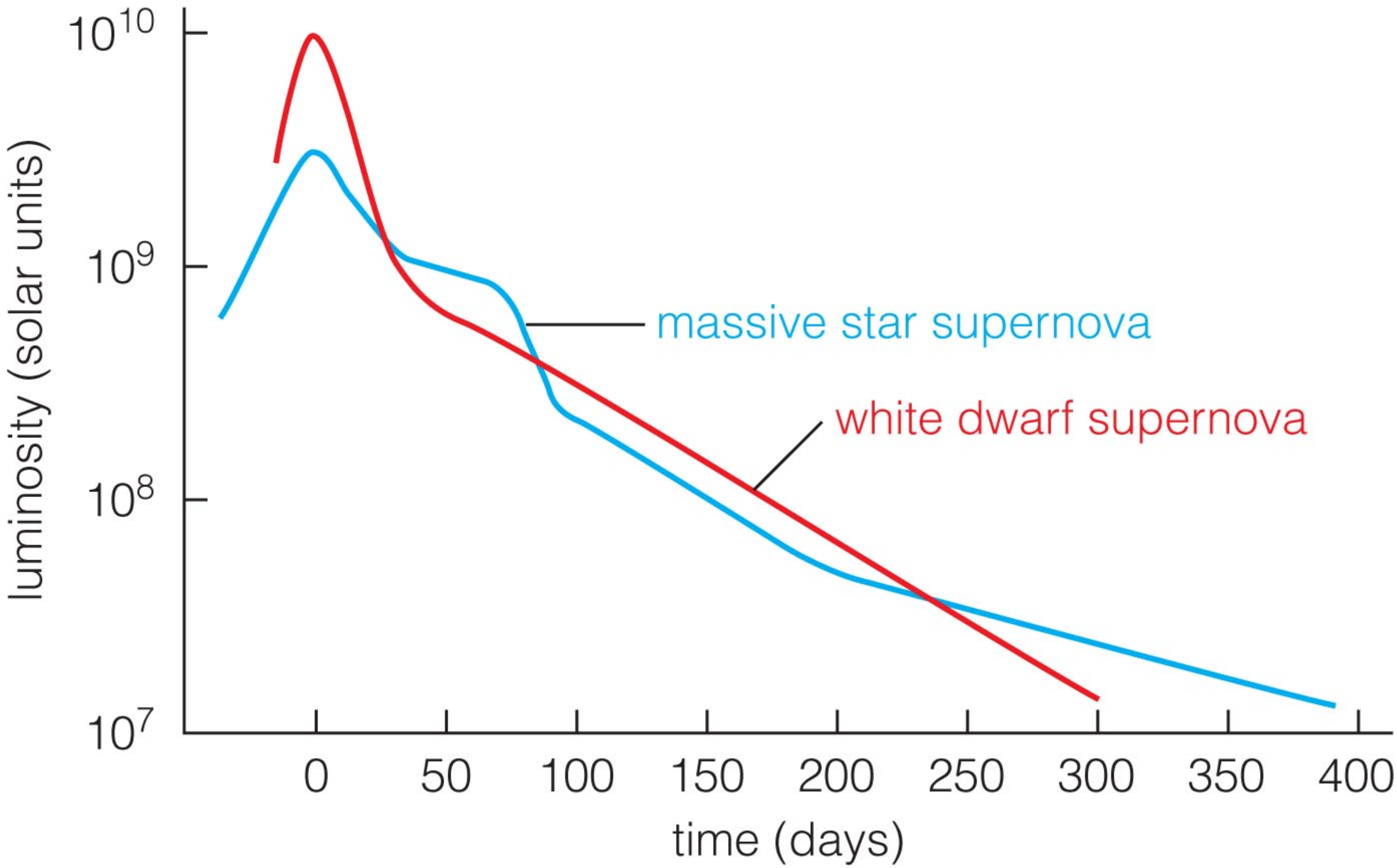
So what are those details? Hint: think about composition and energy, and why there might be an explosion.

Accretion-Induced Collapse?

- An idea that has stubbornly persisted, despite any evidence, is accretion-induced collapse
- The idea comes from the possibility that some white dwarfs that start out very massive have heavier elements in their cores; not carbon and oxygen, but rather magnesium, silicon, and the like
- C/O white dwarfs explode if $M>1.4\ M_{sun}$ because (1) the star begins to collapse, which increases T as well as density, then (2) the C/O fuse, which releases more energy than the gravitational binding energy of the WD, so (3) boom
- If the WD is mainly made of heavier elements, fusion happens, but doesn't release enough energy to explode
- Thus, the story goes, such a WD might collapse to a NS
- This idea has been proposed many times to explain phenomena, until the right explanation is found...
But maybe it happens somewhere!

Two Types of Supernova

- ***Massive star supernova (Type II, Ib, Ic)***:
  - Iron core of massive star reaches white dwarf limit (aka Chandrasekhar limit) and collapses into a neutron star (or black hole), causing explosion.
- ***White dwarf supernova (Type Ia)***:
  - Carbon fusion begins suddenly as white dwarf in close binary system reaches Chandrasekhar limit, causing total explosion.



- One way to tell supernova types apart is with a *light curve* showing how luminosity changes with time.

White Dwarf Nova or Supernova?

- Supernovae are MUCH MUCH more luminous (about 100 thousand times!).
- Nova: H to He fusion of a layer of accreted matter; white dwarf left intact.
- Supernova: complete explosion of white dwarf; nothing left behind.

Supernova Type: Massive Star or White Dwarf?

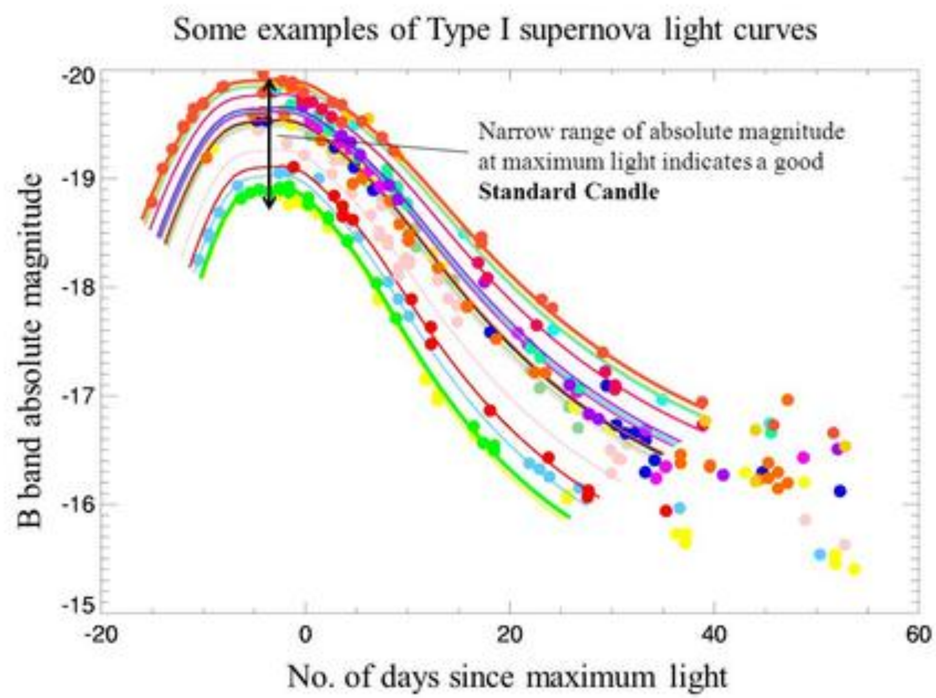
- Light curves differ.
- Spectra differ (exploding white dwarfs don’t have hydrogen absorption lines).

Bonus: Maybe not the whole story…

- Stellar population models suggest there are not enough WD/red giant pairs to explain all Type Ia supernovae.
- Also, often there is no evidence of a surviving giant companion.
- Also, we'd expect accretion to produce bright UV sources; not enough are seen
- Solution? Binary white dwarf mergers!
  Each is below M_{Ch}, but together they are $>M_{Ch}$
  Spiral together because of gravitational radiation

Why Should We Care?

- WD supernovae are standard candles!
  ->excellent cosmology probes
- How can this be? If two WD collide, total mass could be in a wide range
- Key (Phillips 1993): if the light curve dims over a longer time, SN is intrinsically brighter
  Calibrate with close sources
- Can see across the universe
  Led to discovery that expansion is accelerating!



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Is the relation accidental?

- There are lots of relations in astronomy that seem strong, but upon closer examination or more observations, fall apart
- But this one is understood
- If there is more mass in the initial collapsing WD, then fusion produces more Nickel-56
- This decays over time; more Nickel-56 means more total energy emitted, and greater peak luminosity
- But more mass means it also takes longer for the light to escape: thus longer decay time correlates with higher L
- There is still a spread in peak luminosities; understanding that spread is a big focus for many people, as white dwarf supernovae are used to measure subtler effects