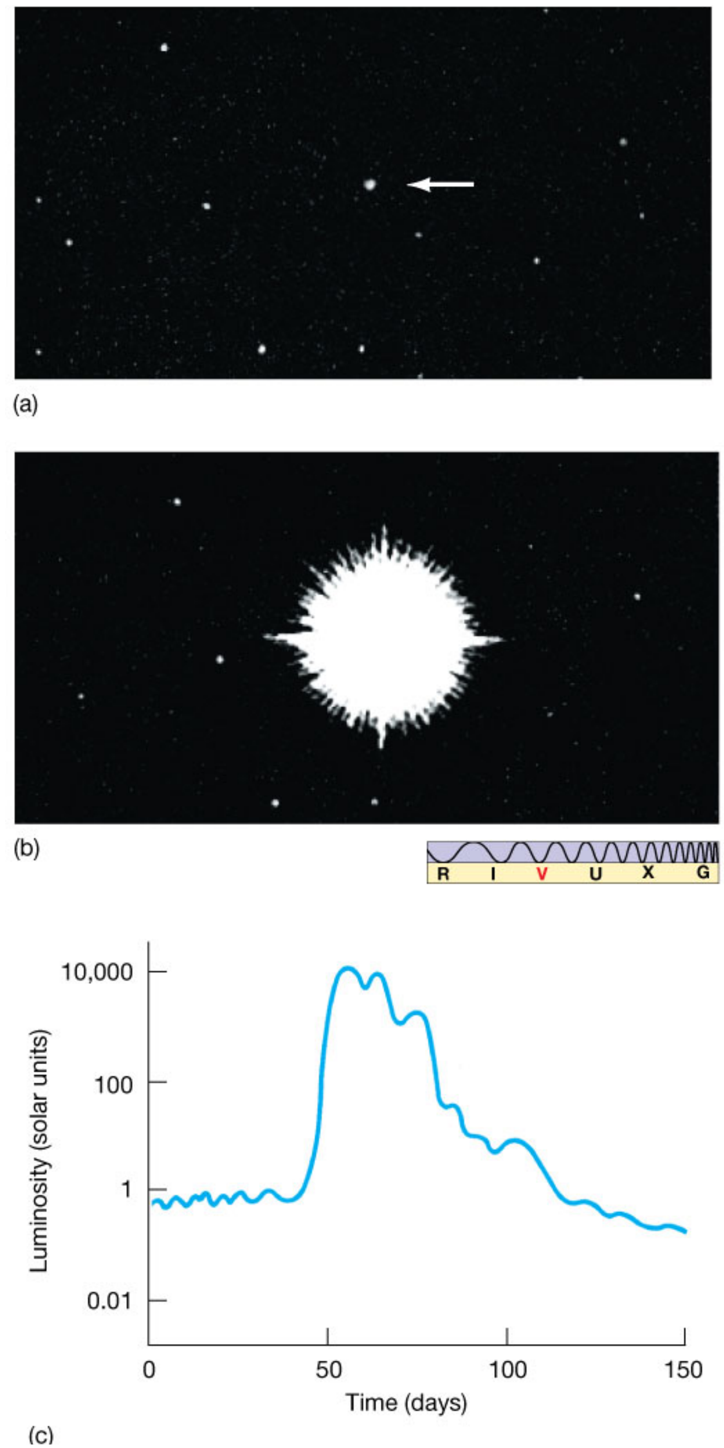
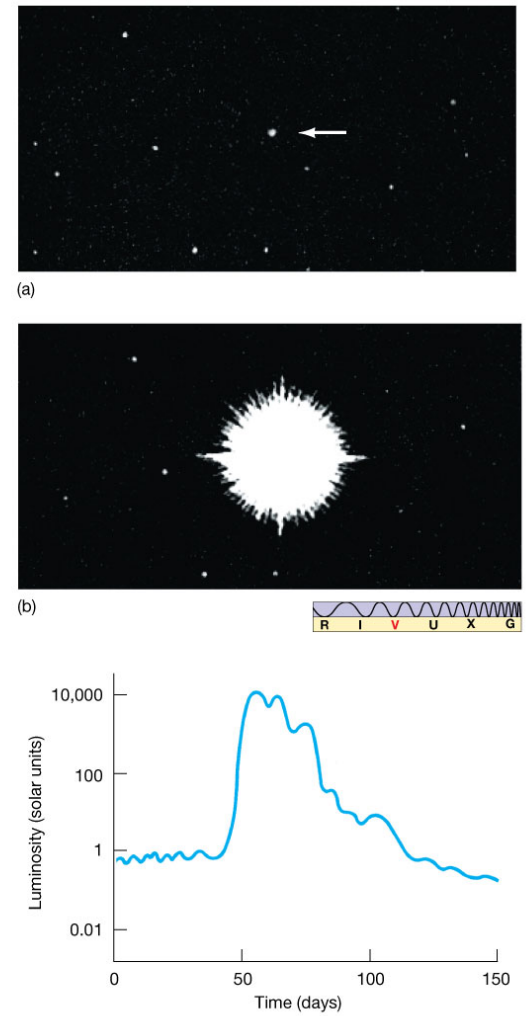
Chapter 21
Stellar Explosions

21.1 Novae - Life after Death for White Dwarfs



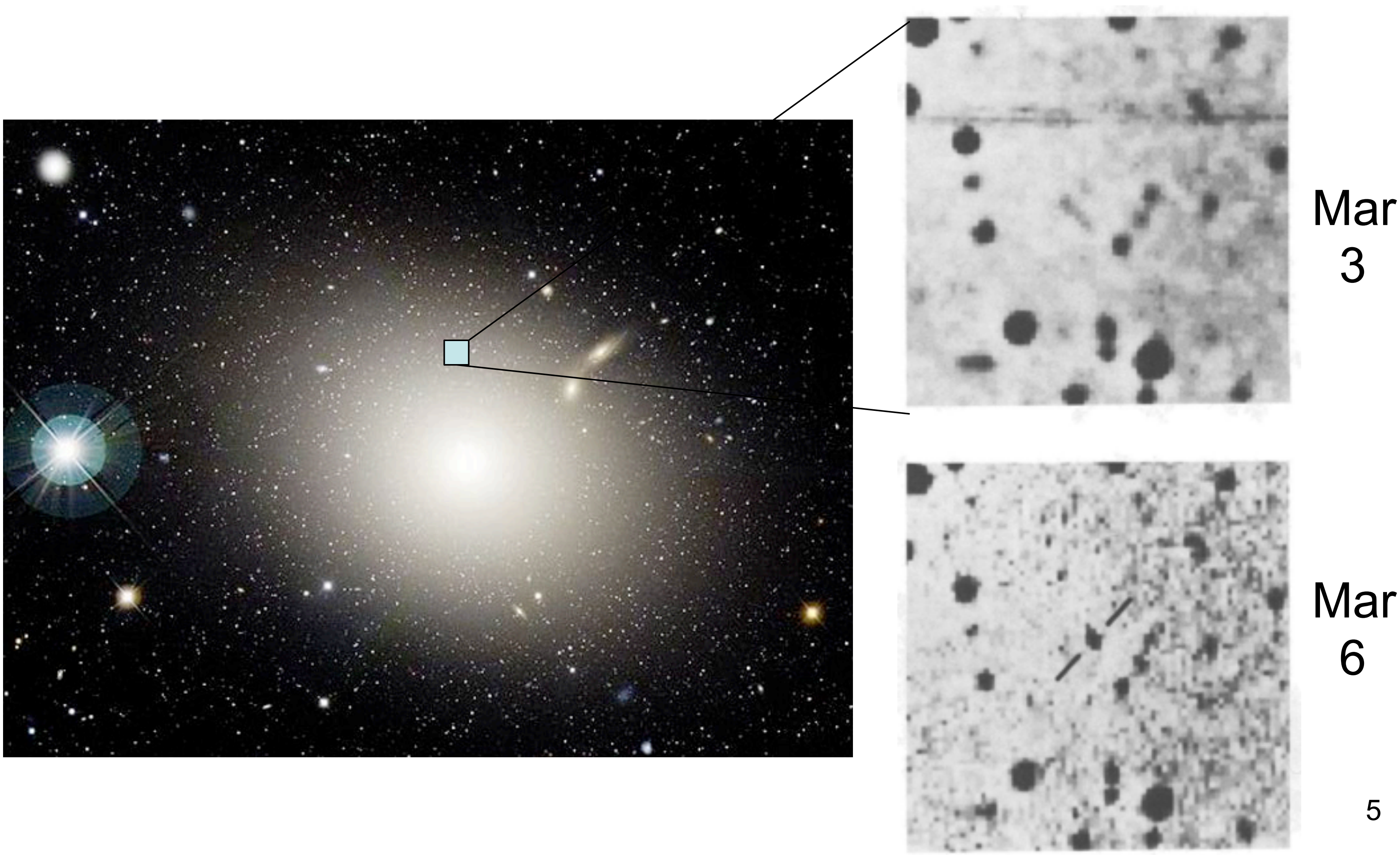
21.1 Novae - Life after Death for White Dwarfs

- **Nova** - a star that flares up very suddenly and then returns slowly to its former luminosity:
- about 20-30 per year in Milky Way
- reach $10^{5\text{-}6}\ L_{\odot}$!
- can brighten by 10^{8}X! (text says less)

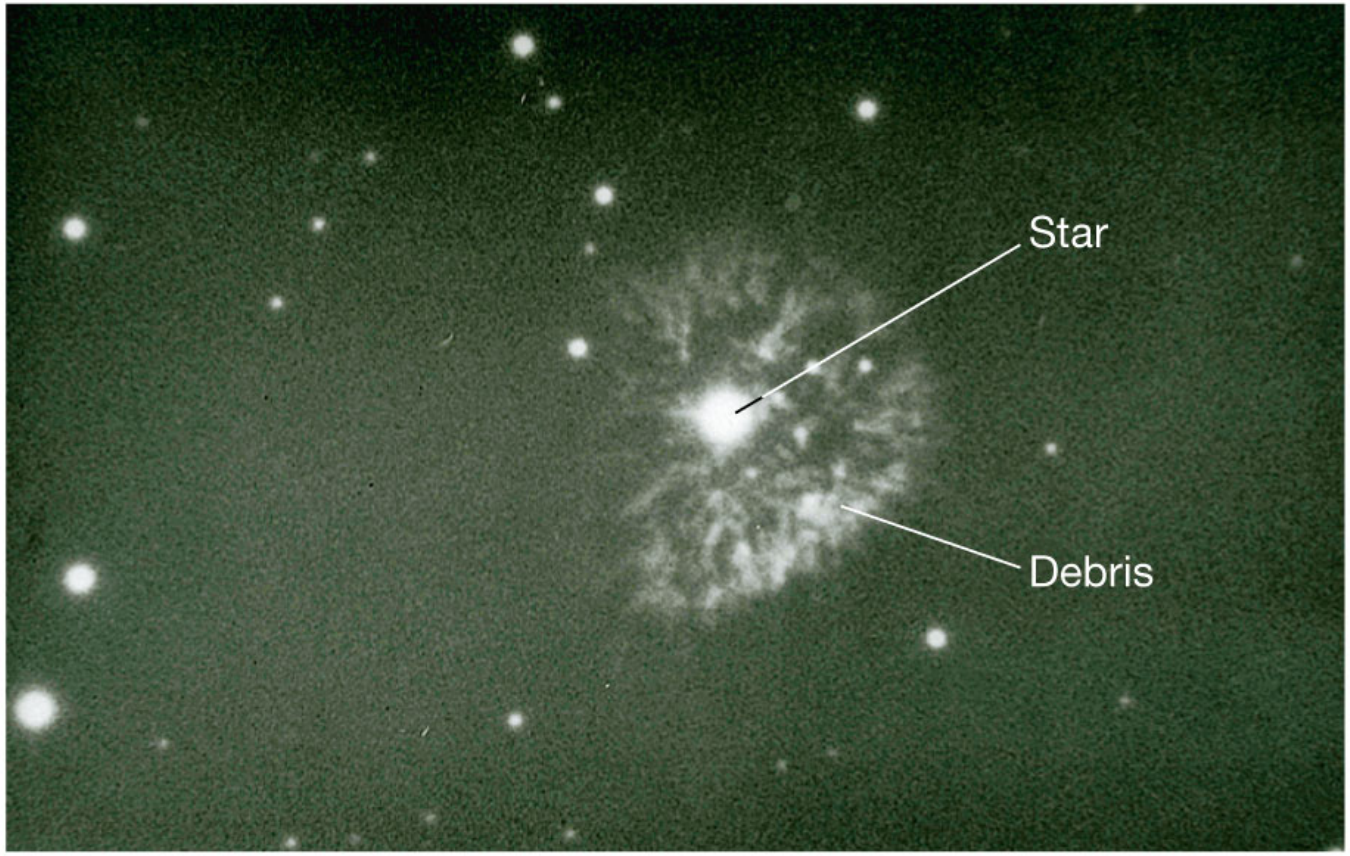


(a) (b) (c)

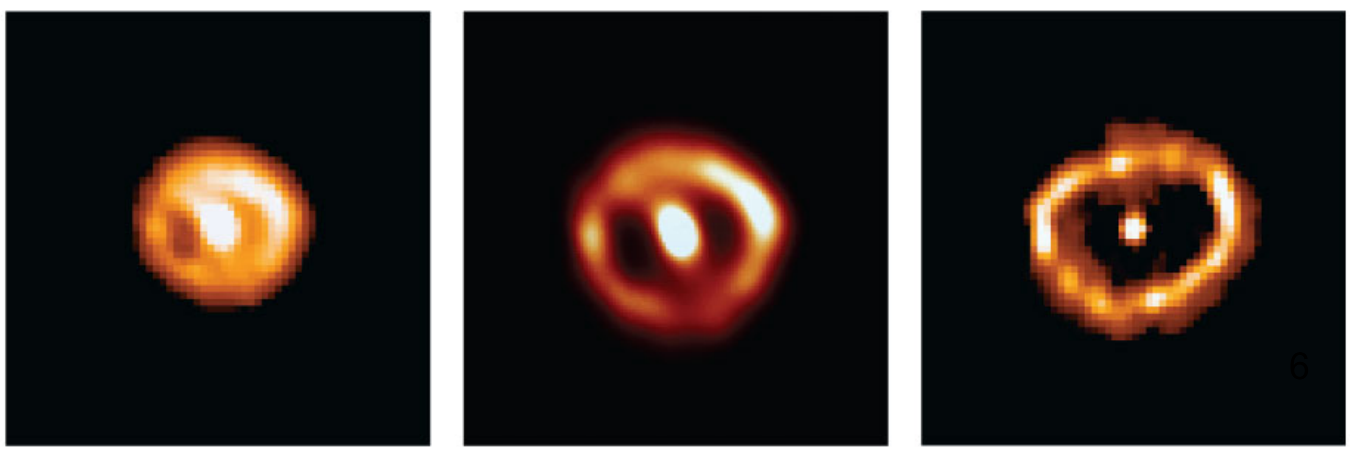
Nova in M87, d=20Mpc



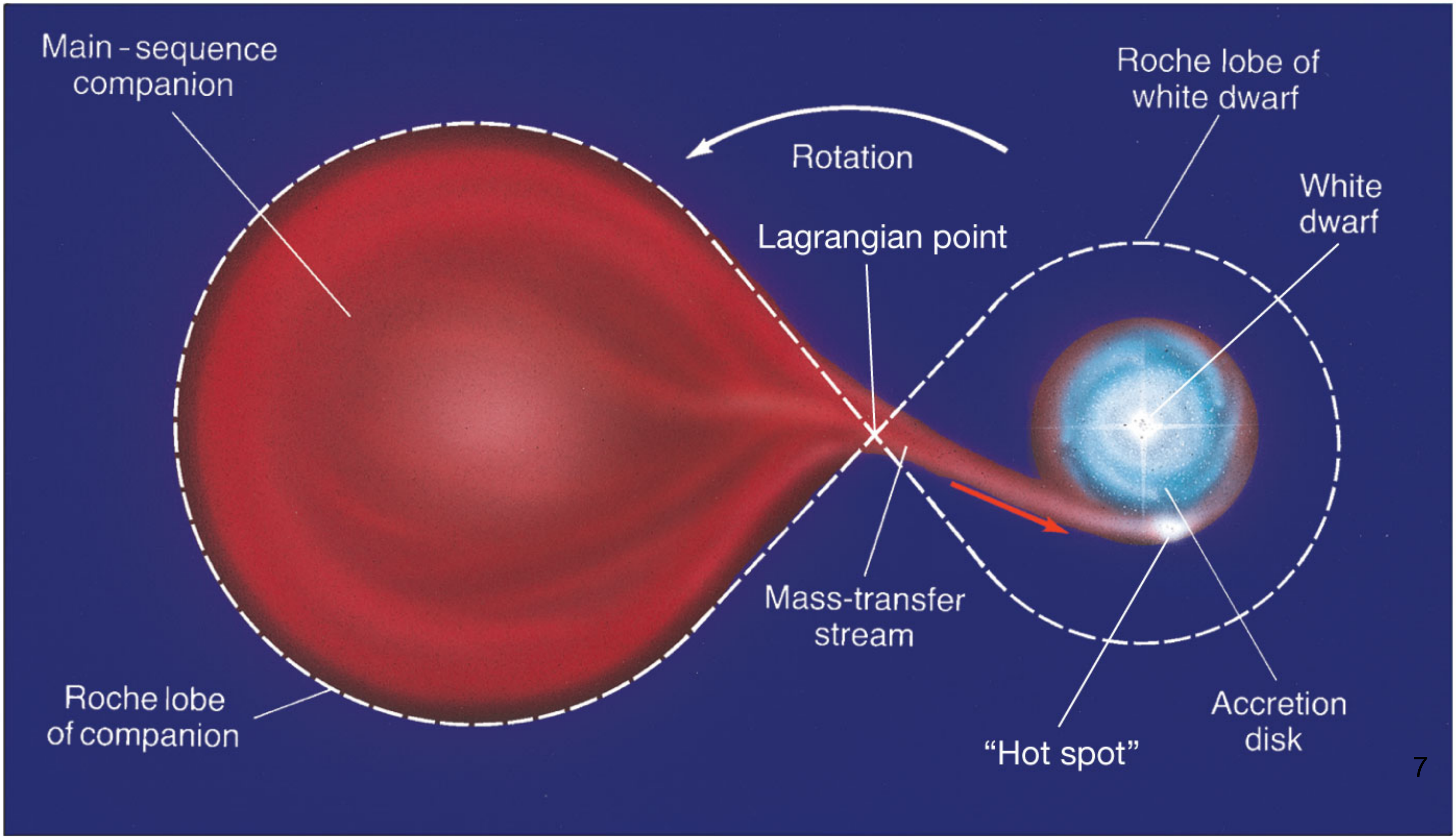
ejected material



(a)



What Causes Novae?

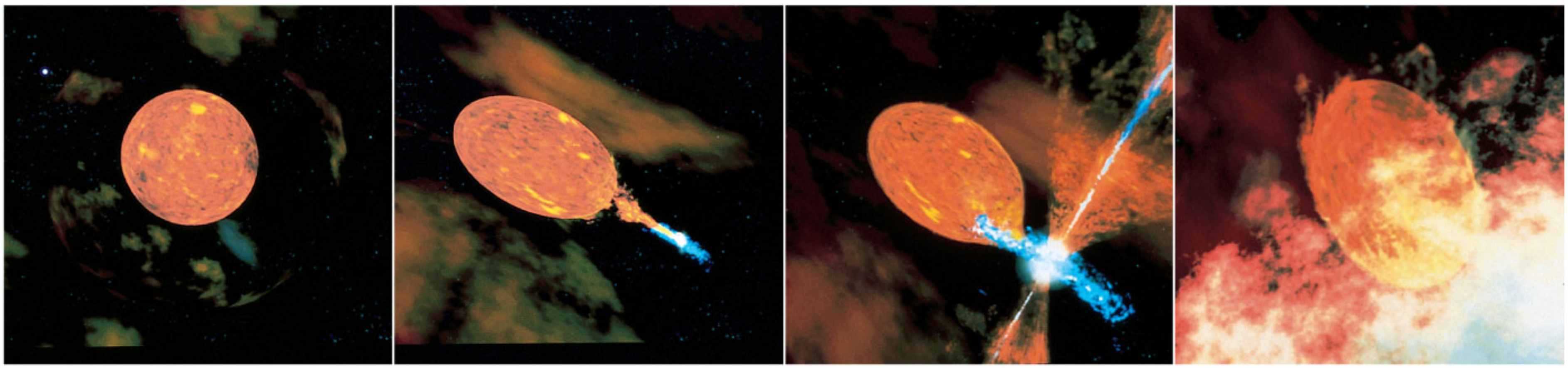


Recurrent Nova

Courtesy of:

The Wright Center, Science Visualization Lab
Tufts University/ D. Berry

Novae

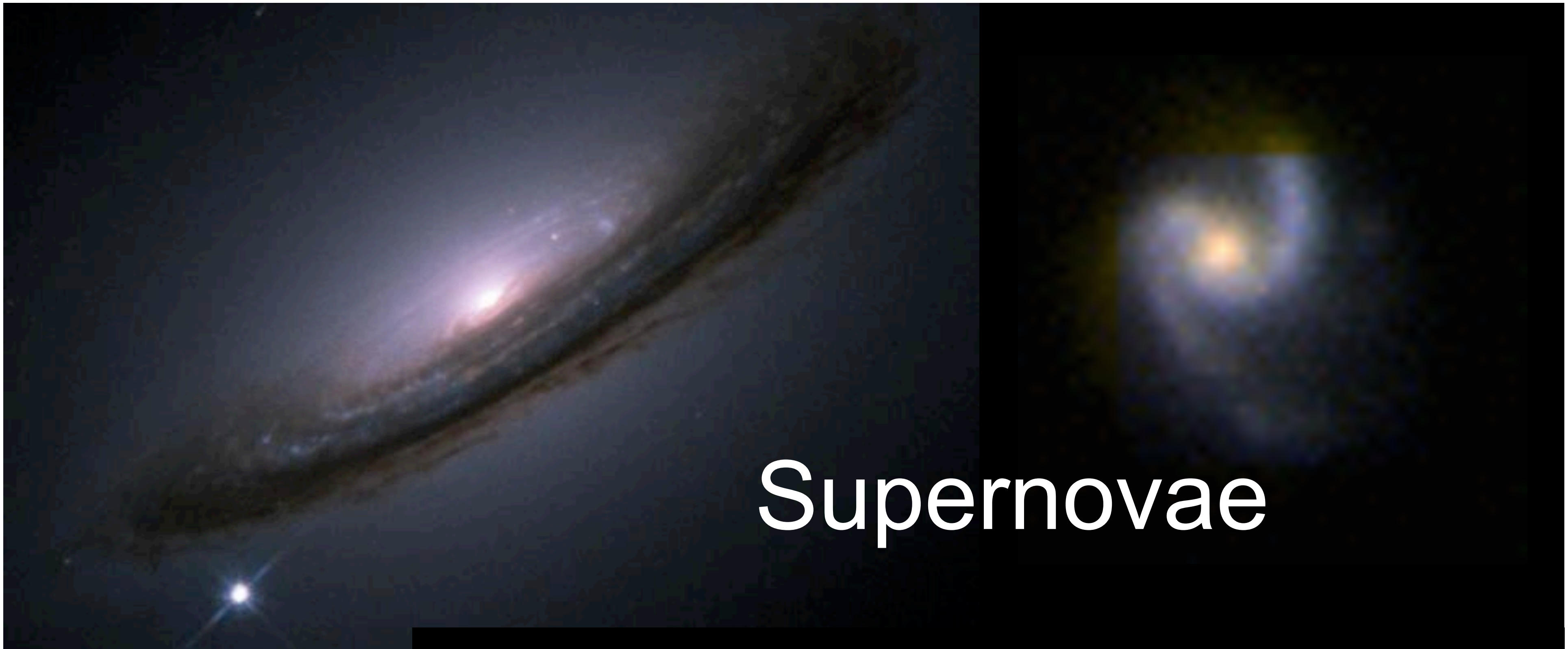


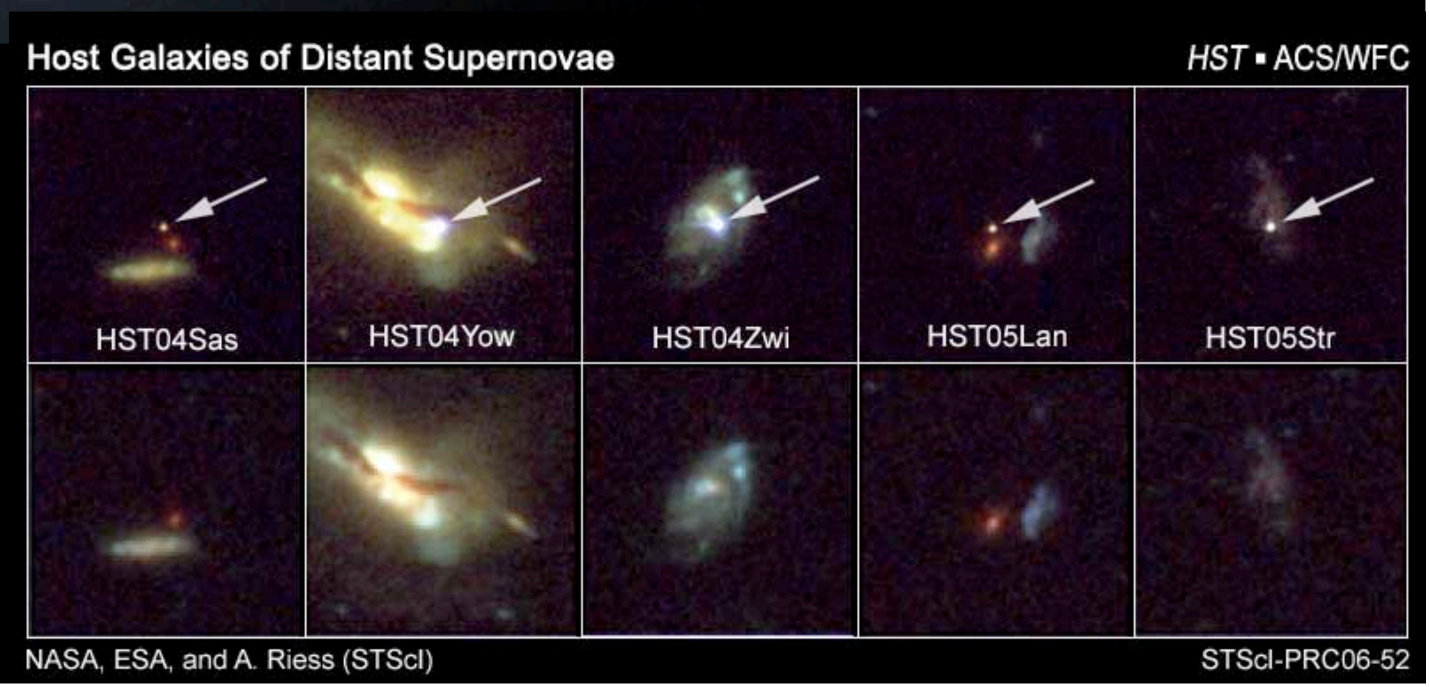
- Material accreted from evolving companion
- Burst of fusion when enough has been accreted

A bit like a **Type Ia Supernova**?

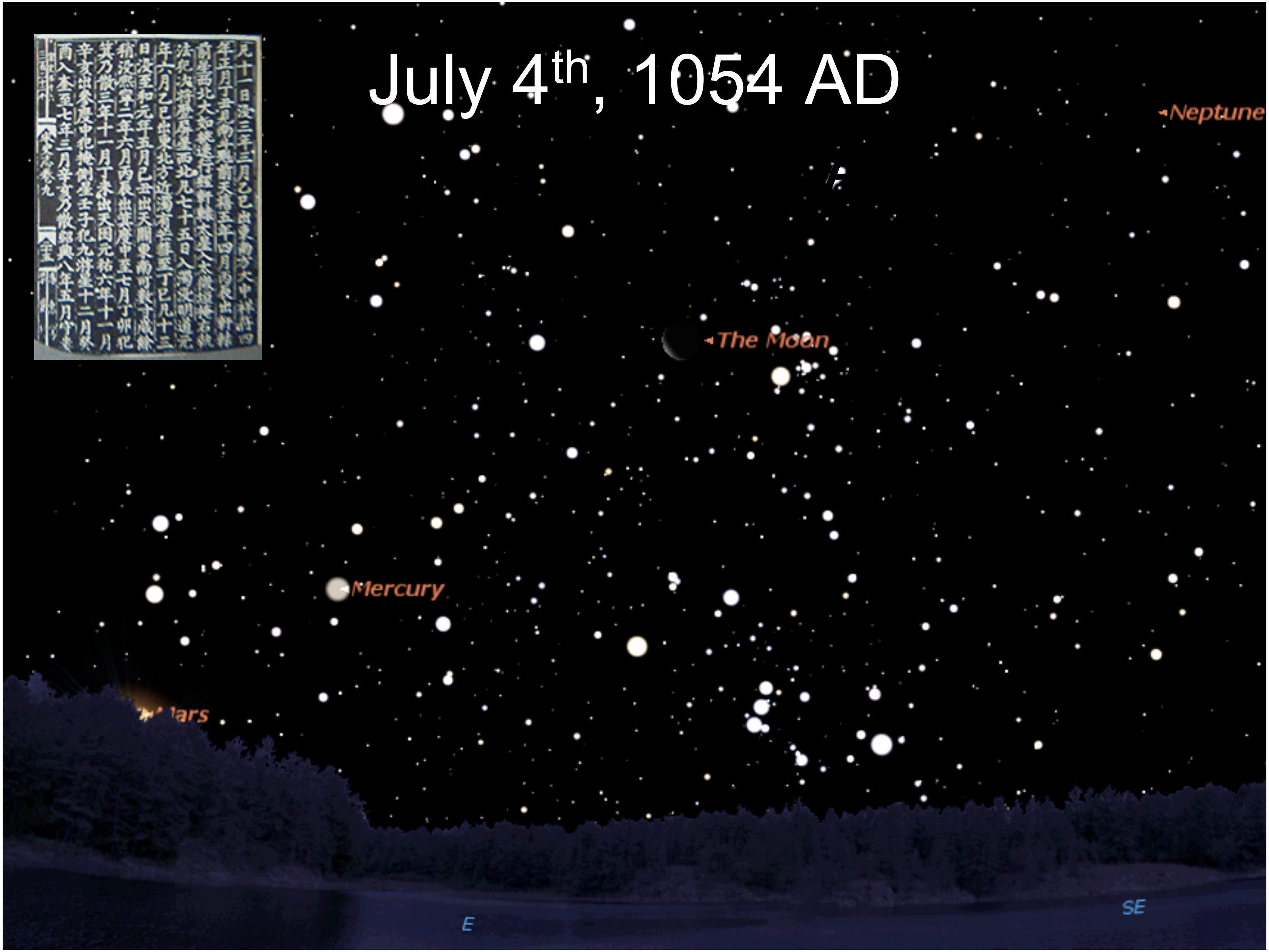
But … there is an alternate mechanism for
Type Ia supernovae

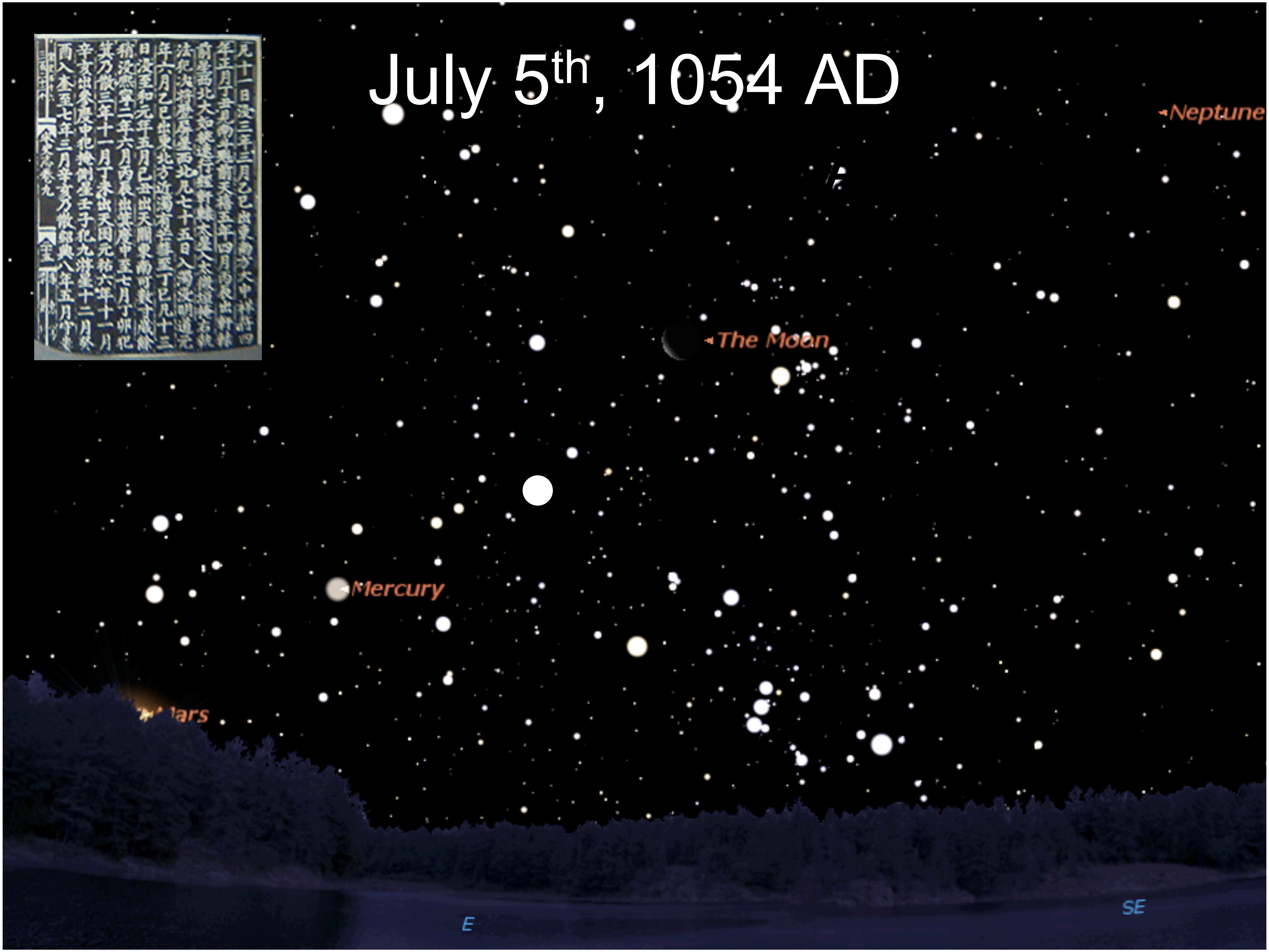
Supernovae



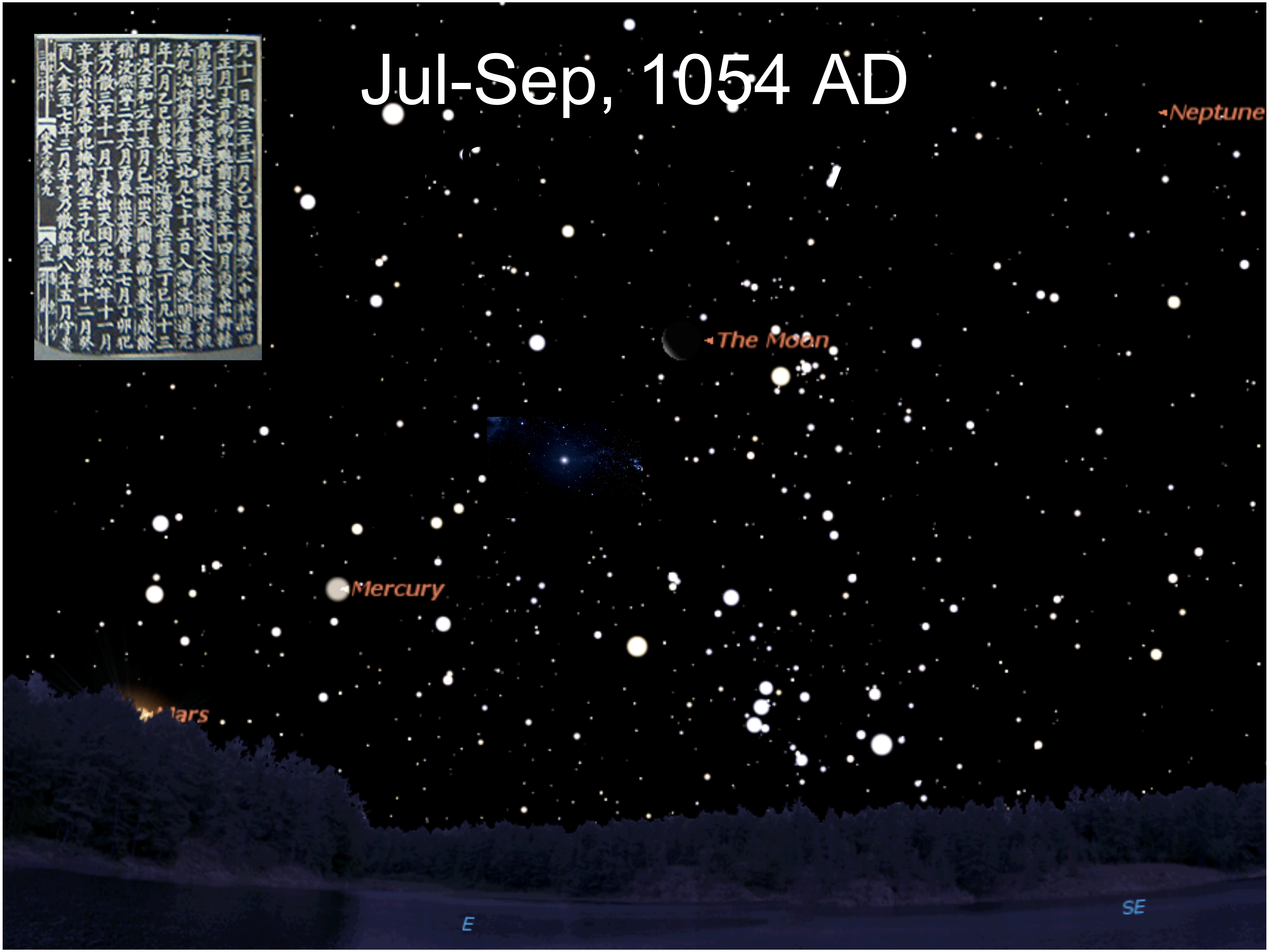

Host Galaxies of Distant Supernovae
HST ▪ ACS/WFC
HST04Sas
HST04Yow
HST04Zwi
HST05Lan
HST05Str
NASA, ESA, and A. Riess (STScI)
STScI-PRC06-52

July 4th, 1054 AD




July 5th, 1054 AD
Neptune
The Moon
Mercury
E
SE

Jul-Sep, 1054 AD



凡十一日沒三年三月乙巳出東南方大中祥符四
年正月丁丑見南斗魁前天禧五年四月丙辰出軒轅
前星西北大如桃速行經軒轅大星入太微垣犯右執
法犯次將歷屏星西北凡七十五日入濁沒明道元
年六月乙巳出東北方近濁有芒彗至丁巳凡十三
日沒至和元年五月己丑出天關東南可數寸歲餘
稍沒熙寧二年六月丙辰出箕度中至七月丁卯犯
箕乃散三年十一月丁未出天囷元祐六年十一月
辛亥出參度中犯掩側星壬子化九游星十二月癸
酉入奎至七年三月辛亥乃散紹興八年五月守婁

July 5th, 1054 AD

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前星西北大如桃速行經軒轅大星入太微垣掩右執
法犯次將歷屏星西北凡七十五日入濁沒明道元
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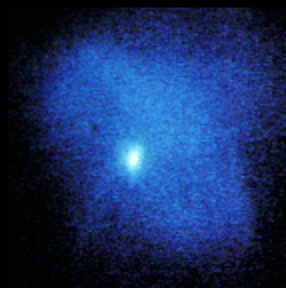
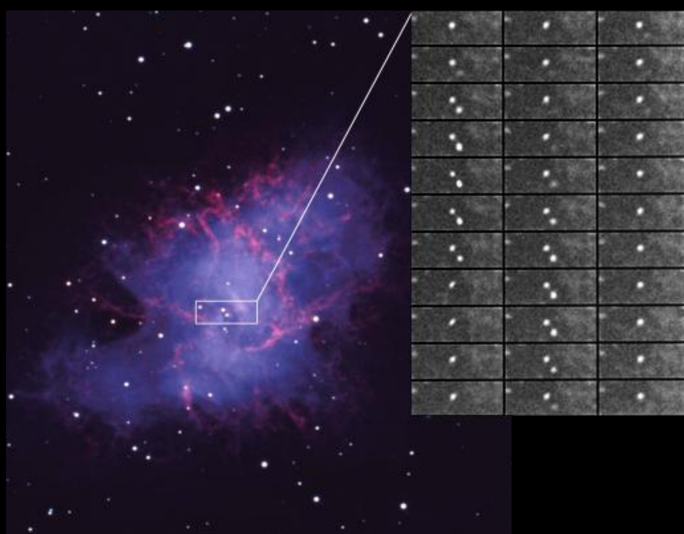
辛亥出參度中犯掩側星壬子犯九游星十二月癸
酉入奎至七年三月辛亥乃散紹興八年五月守婁

宋史志卷九

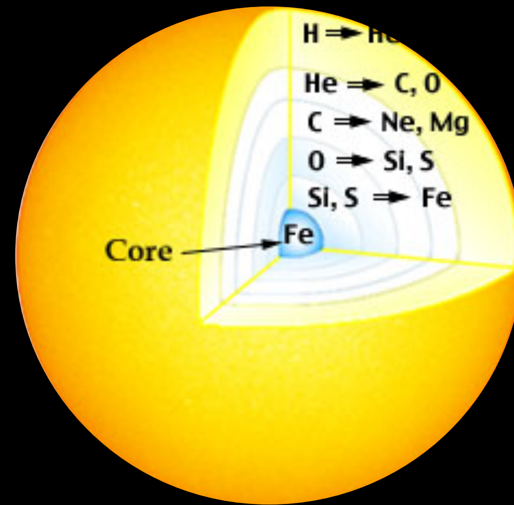
Chaco Canyon, NM

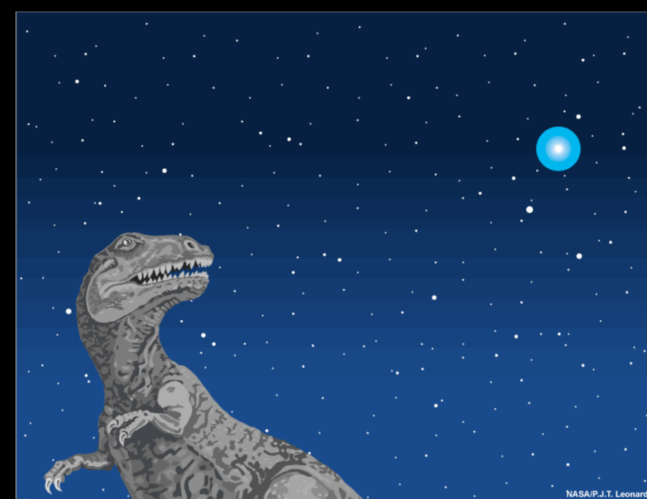
Now



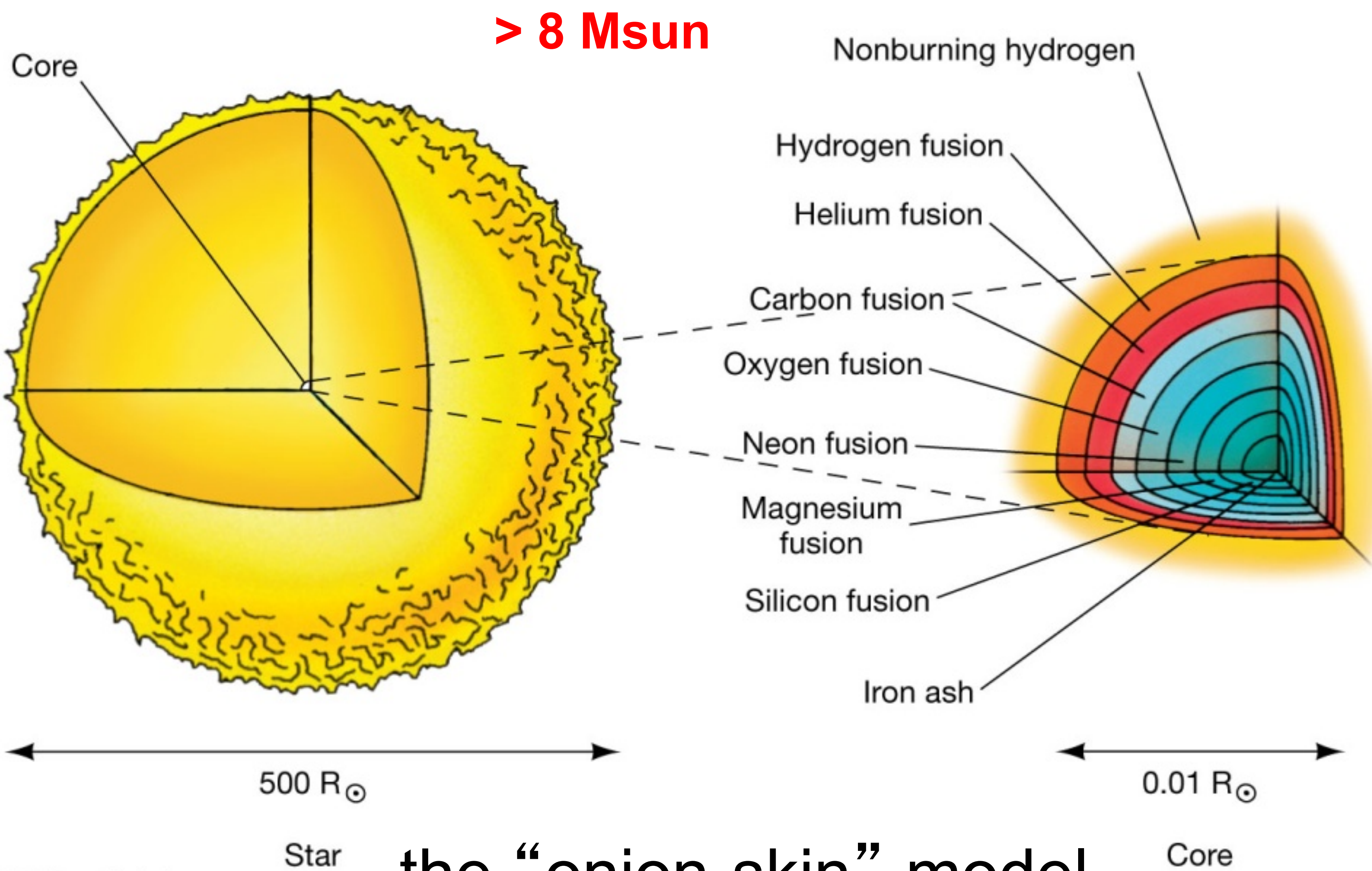


Why are Supernovae Interesting?





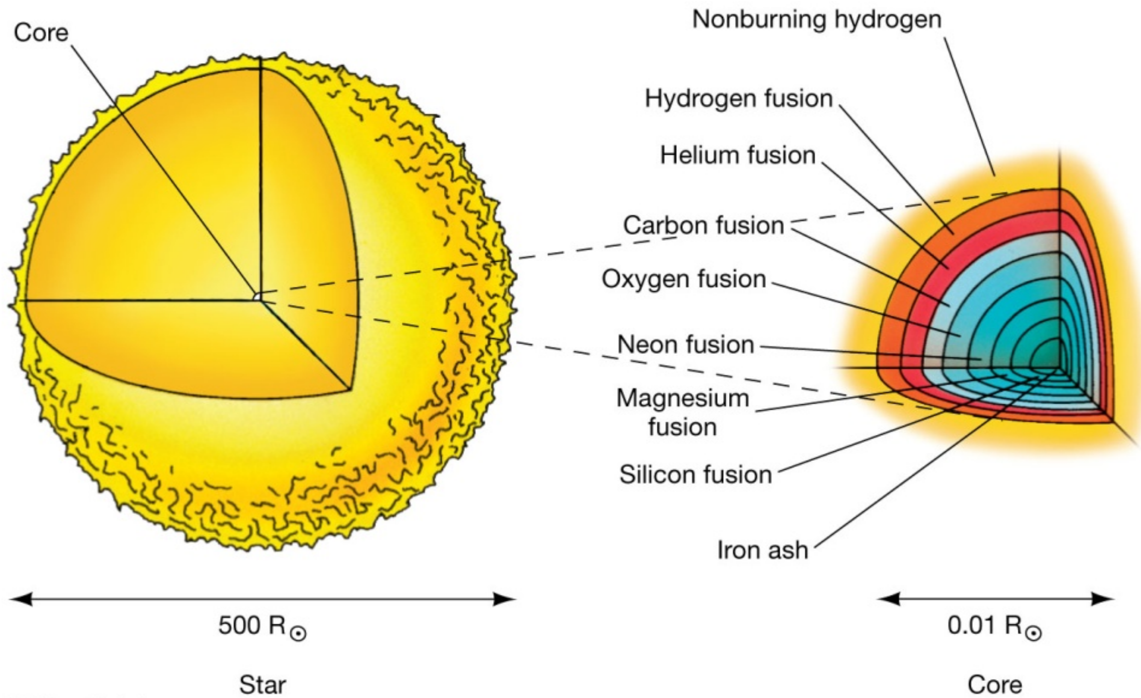
21.2 End of a **High-Mass** Star



the "onion-skin" model

21.2 End of a High-Mass Star

- Star can fuse elements up to iron
- Evolution accelerates:
  - C burning 10,000 y, iron core lasts 1 day



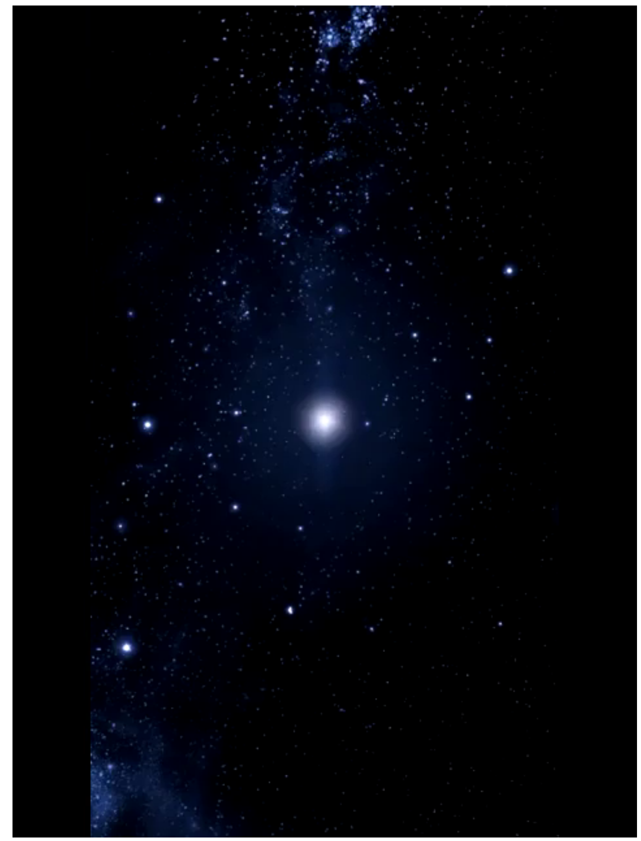
the "onion-skin" model

21.2 End of a High-Mass Star

- Fe core collapses – giant implosion – "core collapse"
  - Why collapse?
- Density goes up → protons and electrons combine to form neutrons + neutrinos (which escape)
- A **neutron star** – like a giant nucleus! Density 10^{15} kg/m^3

21.2 End of a High-Mass Star

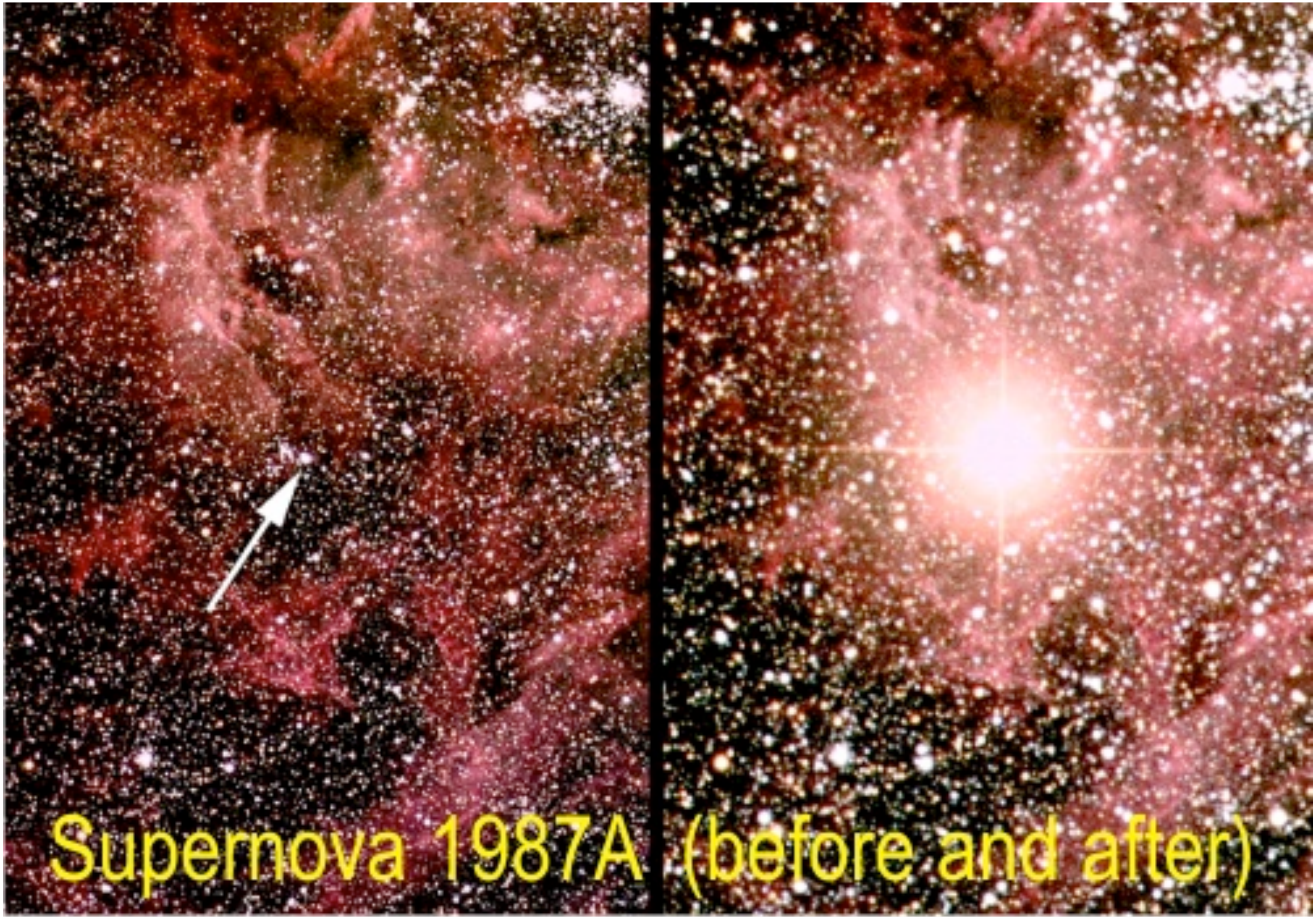
- Neutron stars have a limit to their mass – around 3 $M_{\odot}$
- If the core left behind after a SN is >3 $M_{\odot}$, then it will collapse to a **black hole**
- Stars with *initial* M >20 $M_{\odot}$ produce black holes, 8-20 $M_{\odot}$ produce neutron stars



21.2 The End of a High-Mass Star

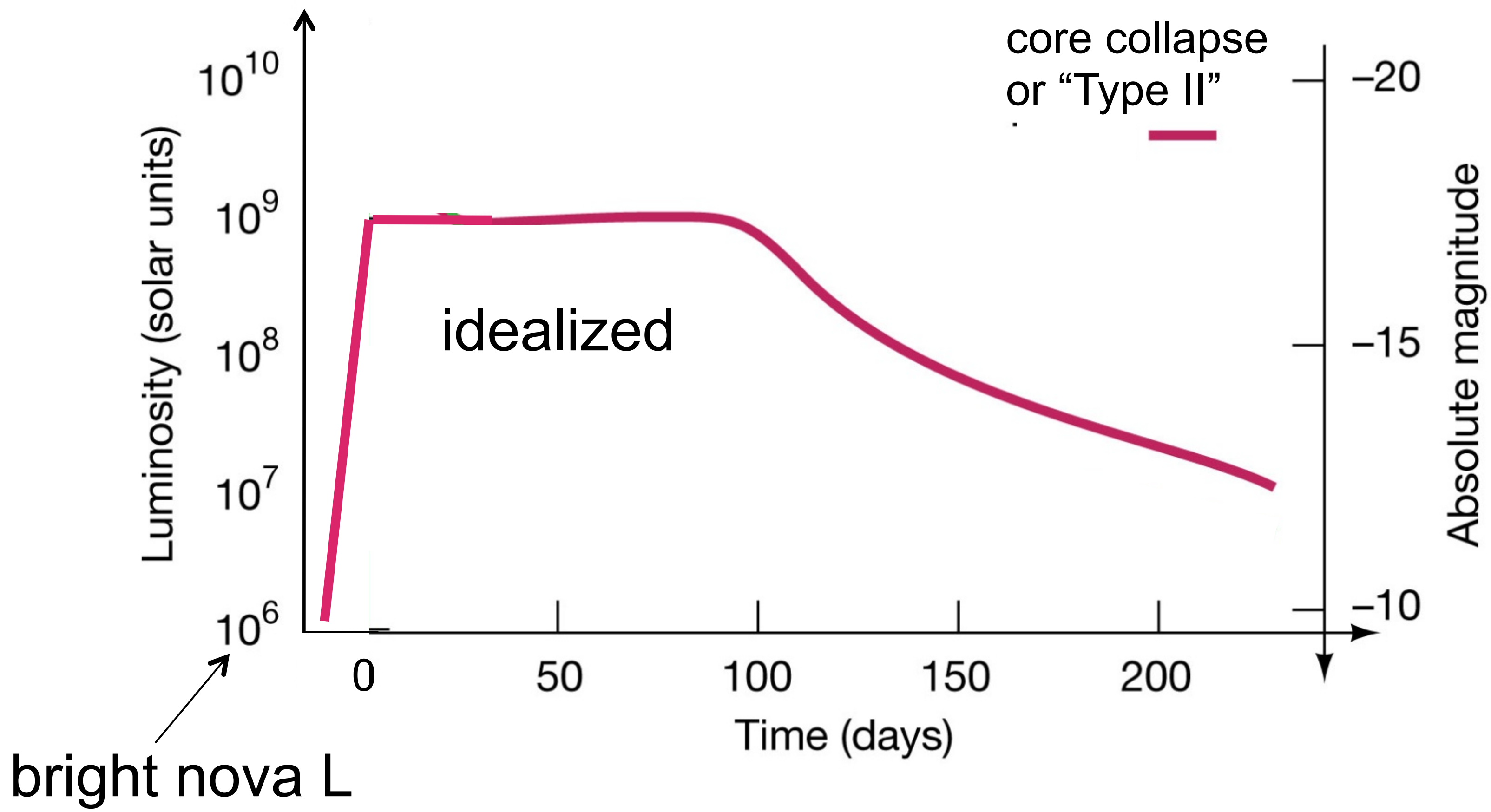
core collapse supernova – outer layers fall in, "bounce" off core


Comet Wilson
SN 1987A


Supernova 1987A (before and after)

21.3 Supernovae

A core-collapse supernova is incredibly luminous—as can be seen from these curves—and *more than* a 1000 times as bright as a nova:



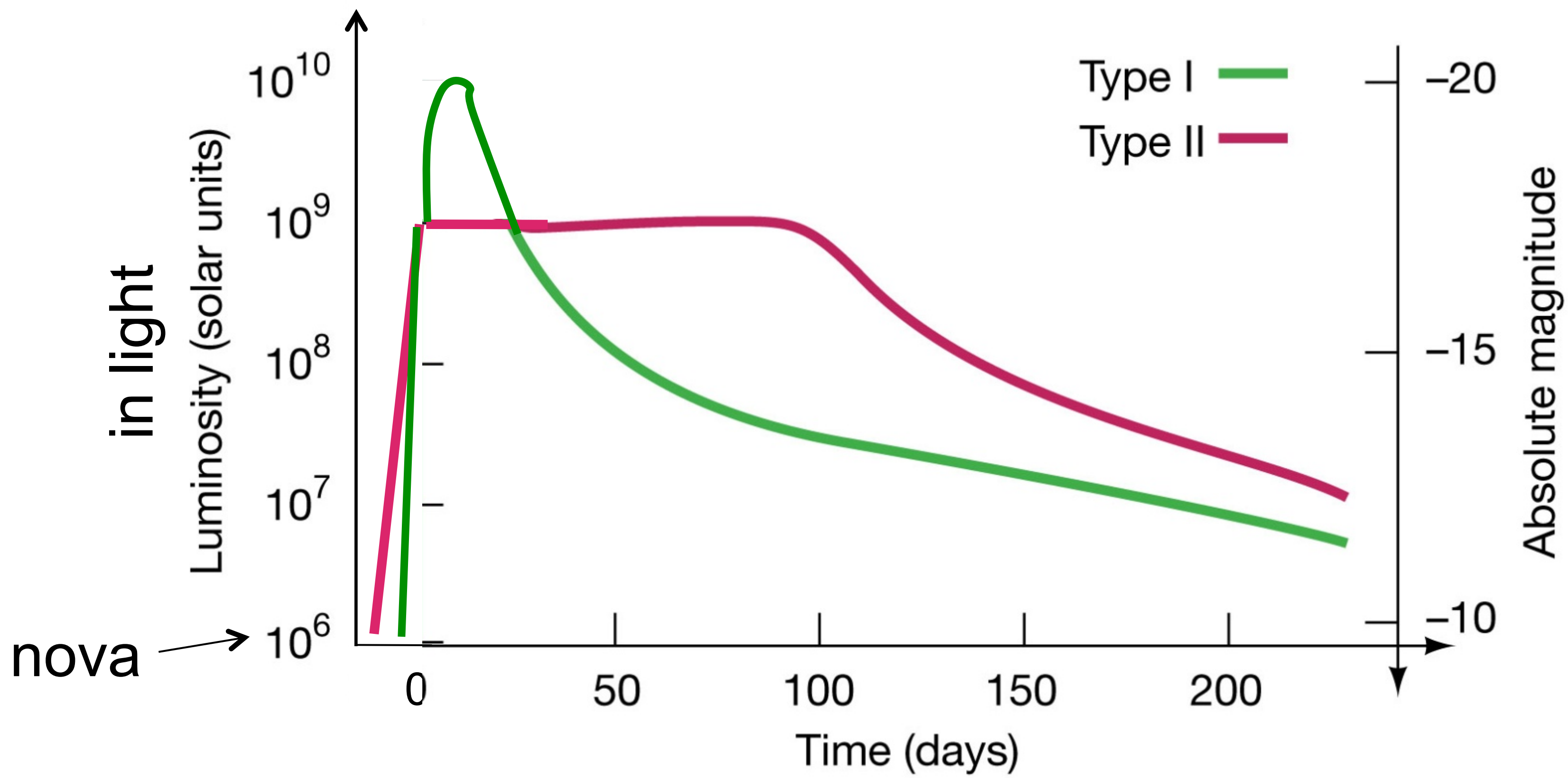
Shockwaves Hit the Ring of Supernova 1987A

Courtesy of:

NASA/STScI/T. Goertel

Type Ia Supernovae

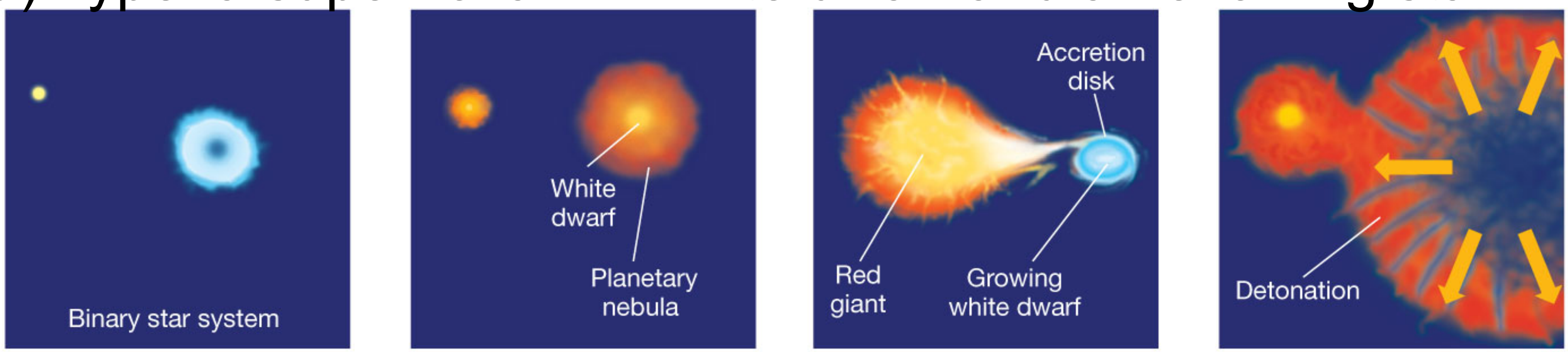
A Type Ia supernova is incredibly luminous—as can be seen from these curves – often 10 or more times a core collapse SN.



21.3 Supernovae

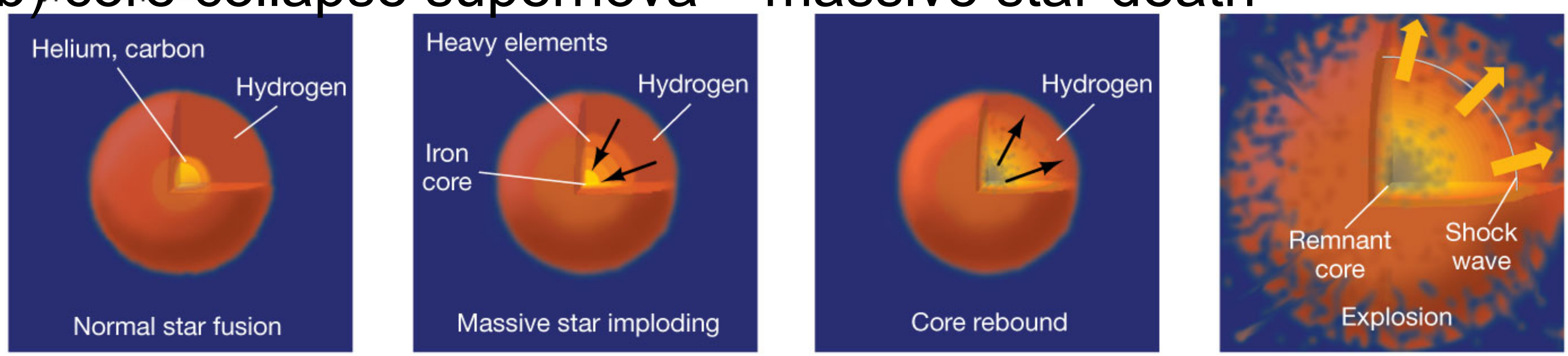
Summary of the two different types of supernovae:

(a) Type Ia supernova – 1 white dwarf and an evolving star …



… or 2 white dwarfs

(b) core collapse supernova – massive star death



Energy output of supernovae

Hans Bethe
(1906-2005)
Nobel 1967

	core collapse	Ia
light	0.001	0.01
expanding material	1	1.3
neutrinos	100	0.1
total	~100	~1.5

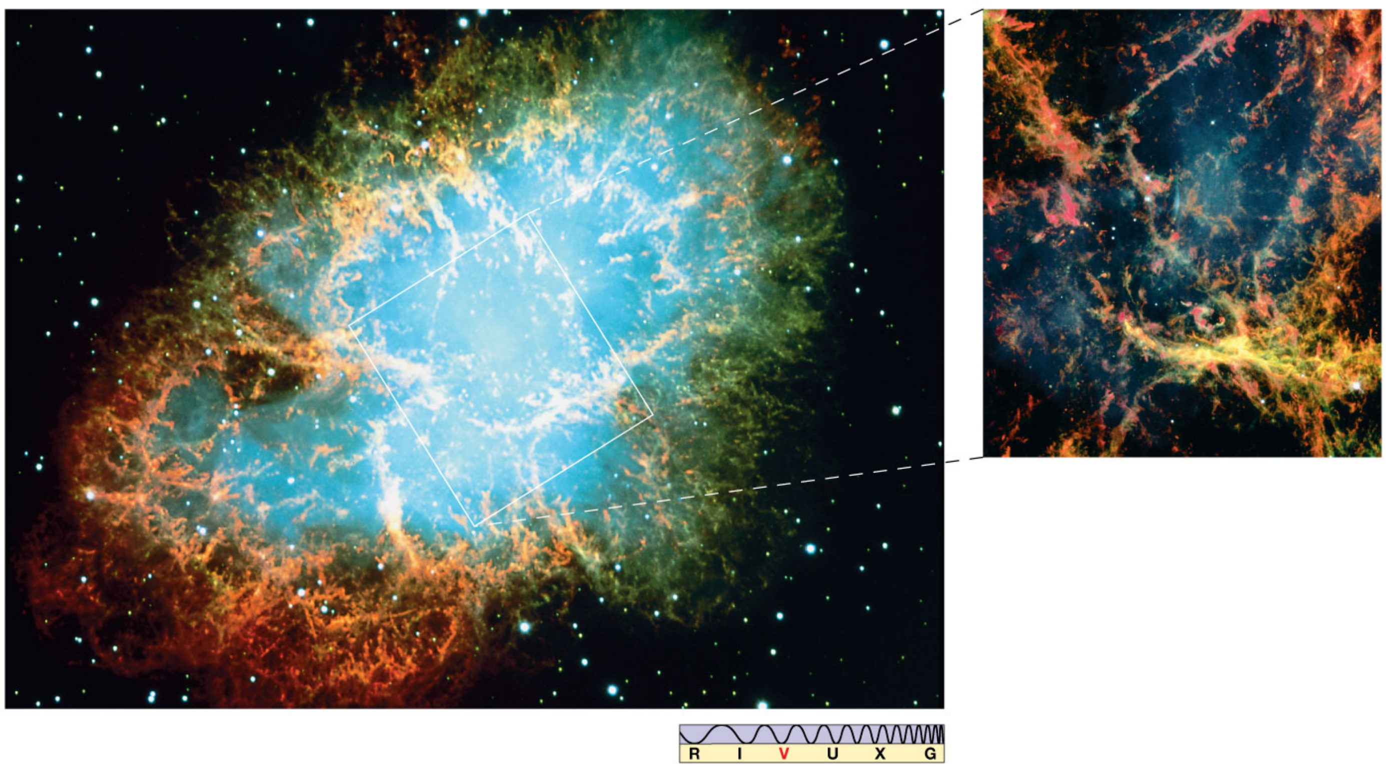
in units of 10^{51} erg = 10^{44} Joule = 1 Bethe

(total energy release by sun over its lifetime is ~1 Bethe)

Supernova remnants

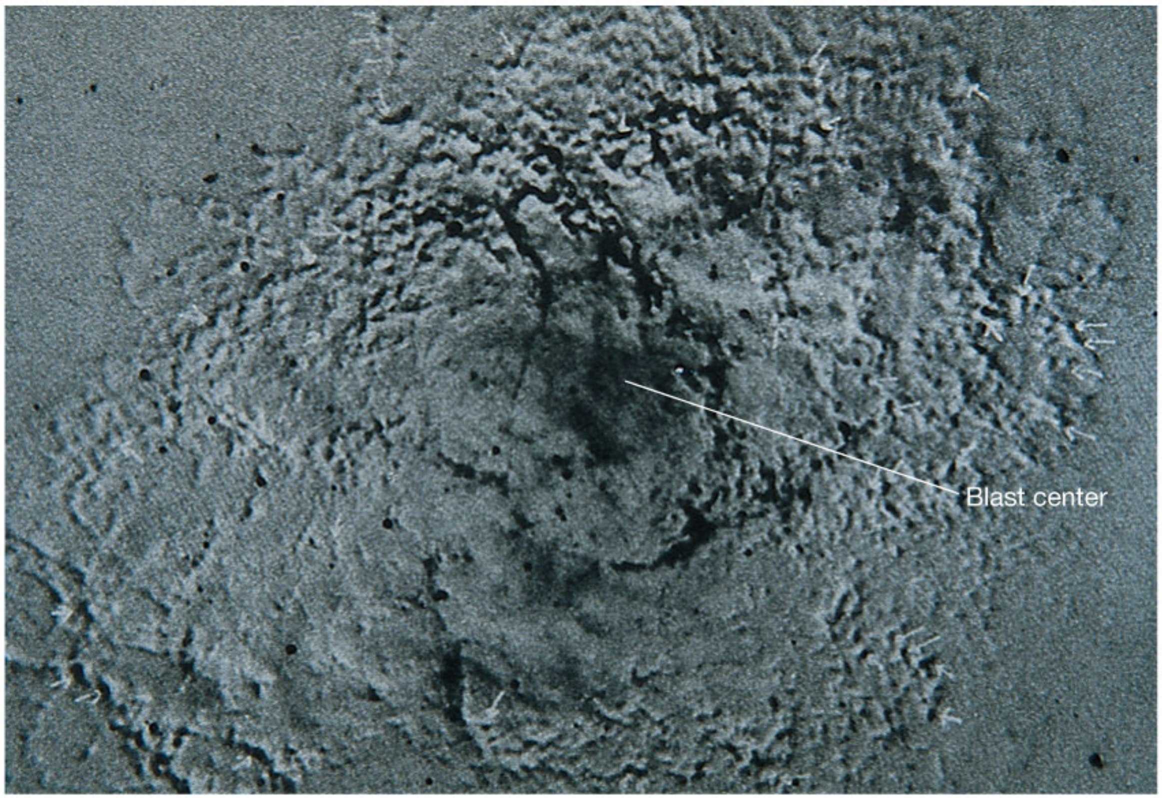
Supernovae leave remnants—the expanding clouds of material from the explosion (expansion v up to 10,000 km/s)

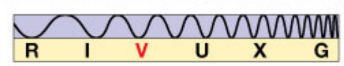
The Crab nebula is a remnant from the supernova explosion that occurred in the year 1054.



21.3 Supernova Remnants

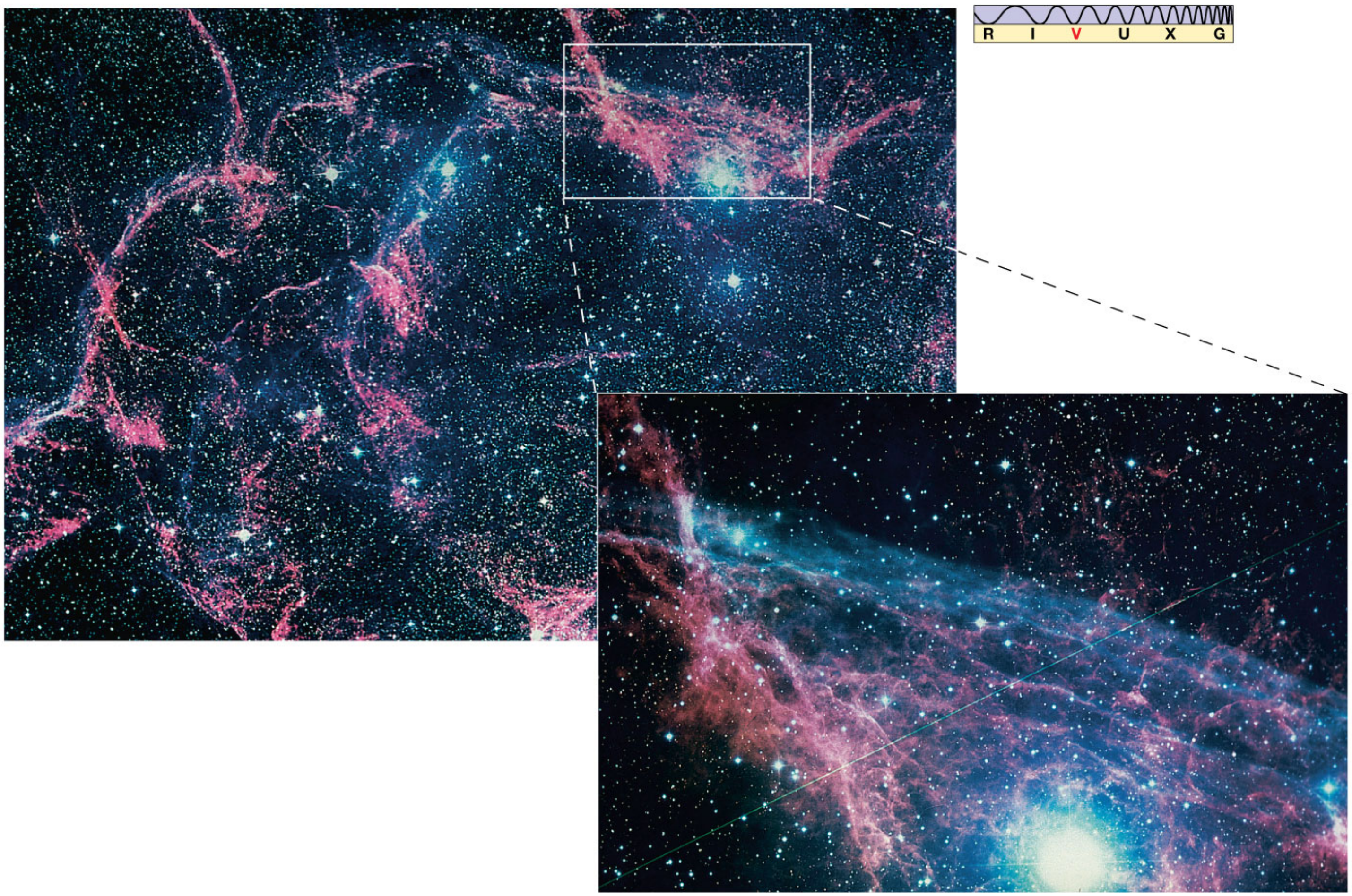
The velocities of the material in the Crab nebula can be extrapolated back, using Doppler shifts, to the original explosion.





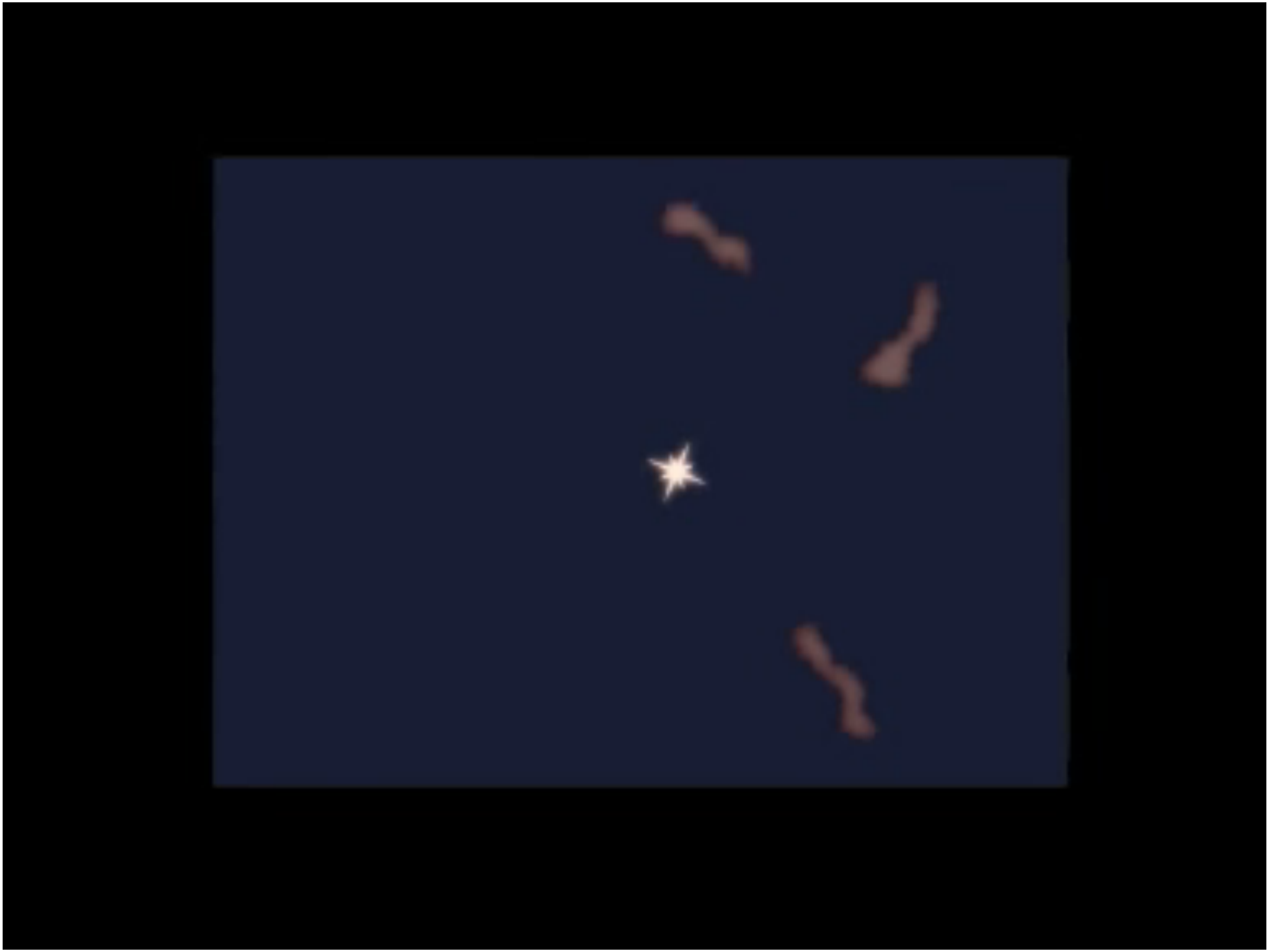
21.3 Supernovae

This is the Vela supernova remnant: Extrapolation shows it exploded about 9000 BCE



Light echoes of supernovae

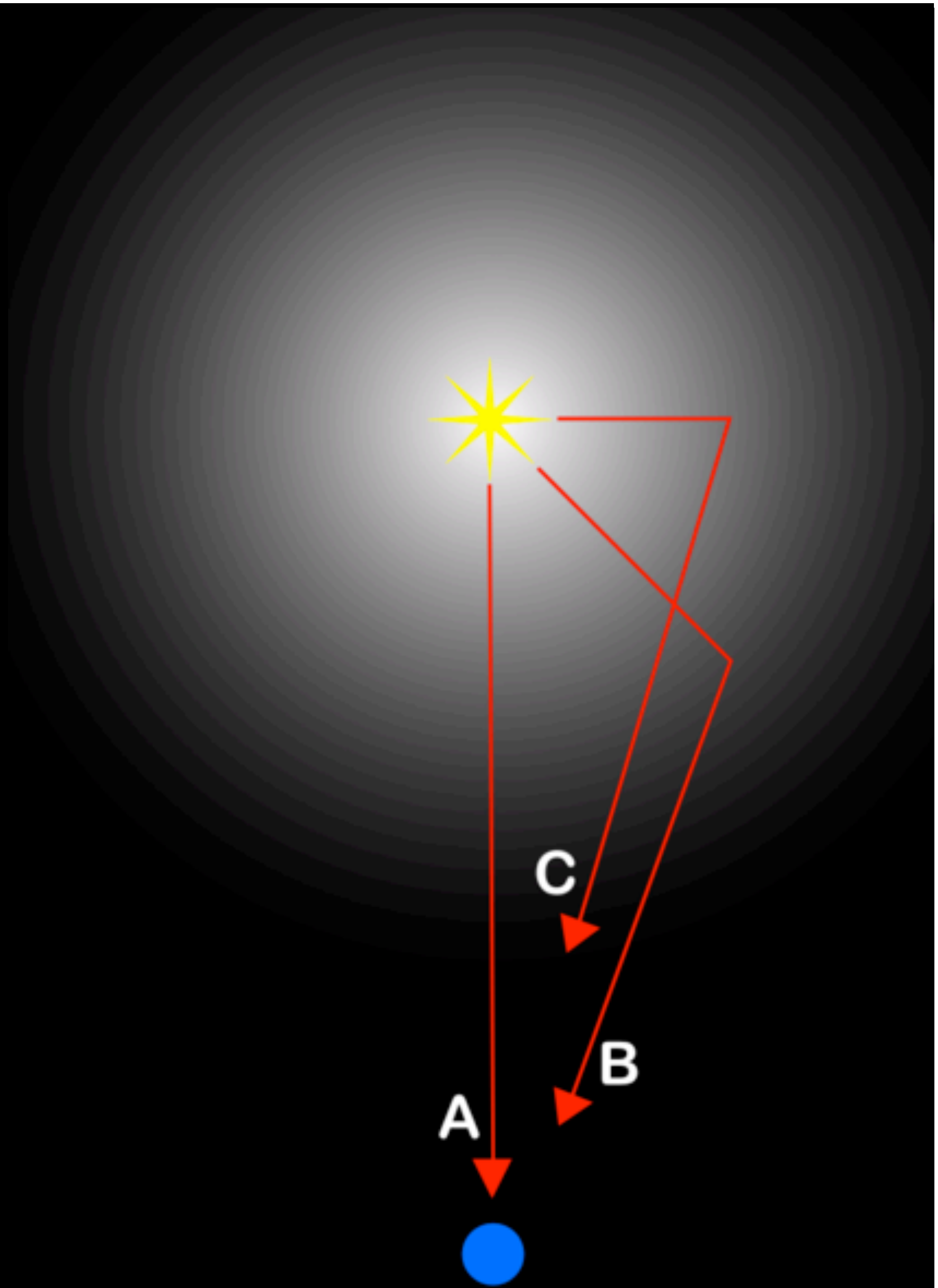
http://www.youtube.com/watch?v=RdtEMI0WWeU
http://chandra.harvard.edu/photo/2008/snr0509/



Light Echo

Why useful?

Important: not motion of material!



Mass Loss from Giant Stars

The sequence below, of actual Hubble images, shows a very unstable red giant star as it emits a burst of light, illuminating the dust around it. This is a *light echo*.

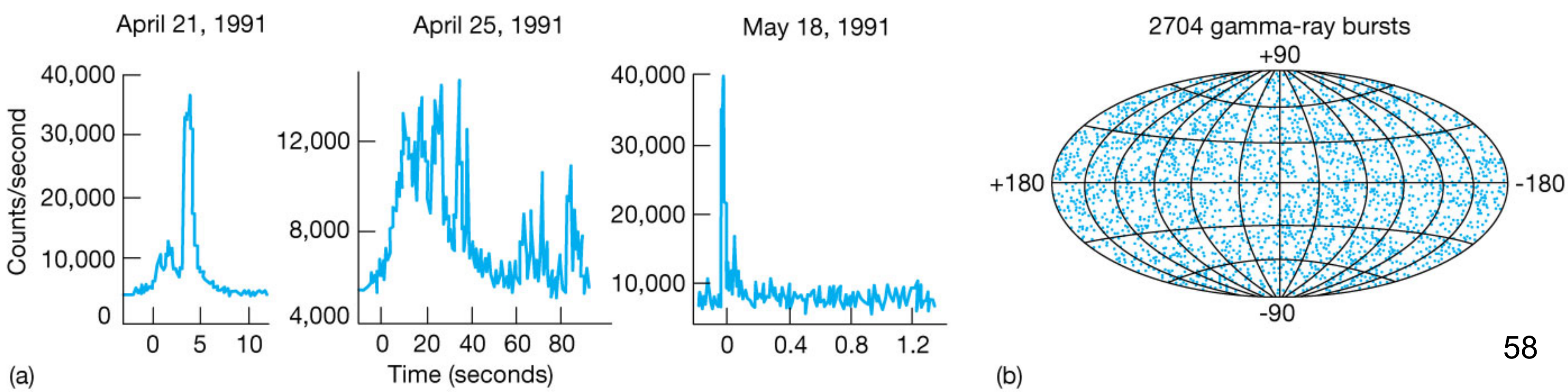
Light Echo

Courtesy of:

NASA/STScI/H. Bond

Gamma-Ray Bursts (22.4)

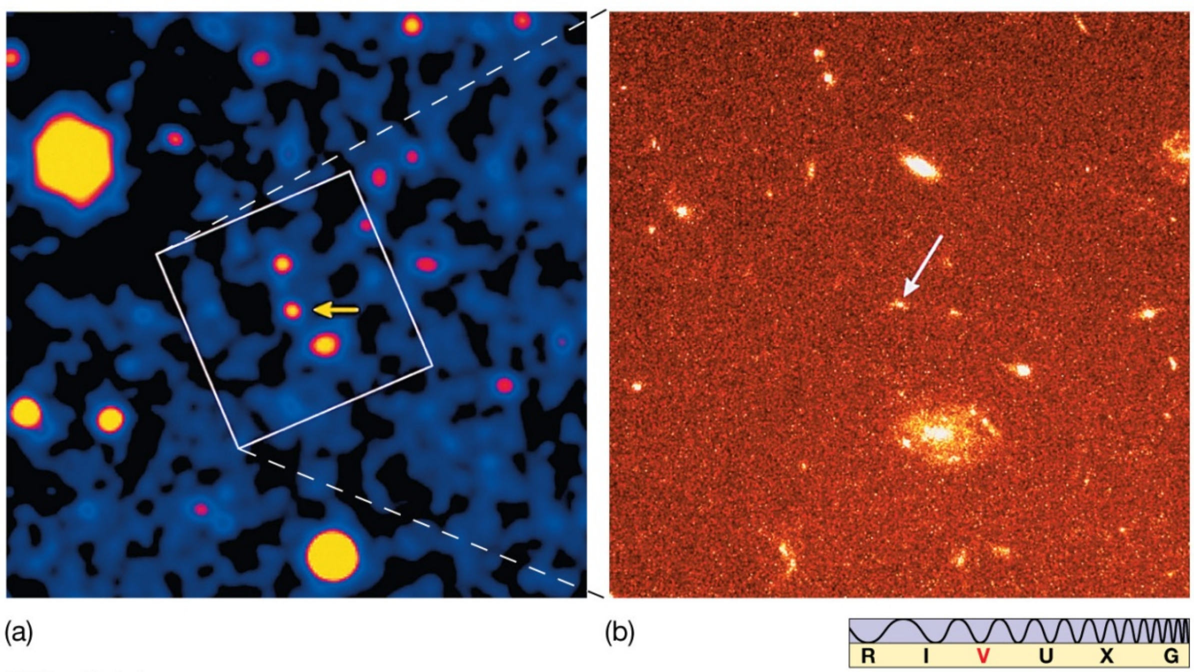
- first, what are gamma rays?
- discovered by satellites looking for violations of nuclear test-ban treaties.
- map of where the bursts have been observed shows no "clumping" of bursts anywhere, particularly not within the Milky Way.
- Therefore bursts originate from outside our Galaxy.



Gamma-Ray Bursts

Distance measurements of some gamma bursts show them to be very far away—2 billion parsecs for the first one measured.

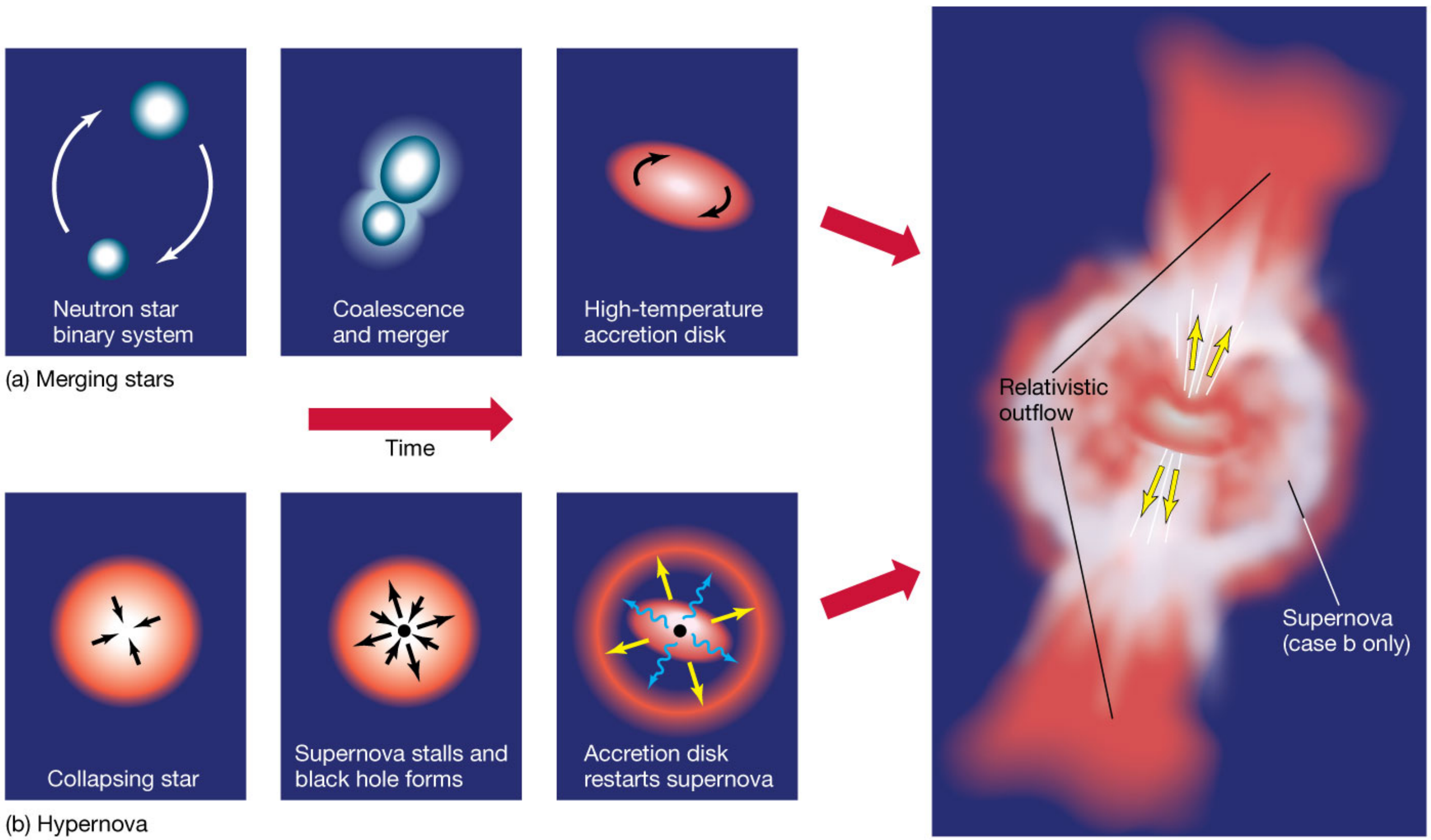
Occasionally the spectrum of a burst can be measured, allowing distance determination:



(a) (b)

Gamma-Ray Bursts

Two models—merging neutron stars or a hypernova …



When Neutron Stars Collide

http://svs.gsfc.nasa.gov/vis/a010000/a010700/a010740/

Summary of Chapter 21

• A nova is a star that suddenly brightens and gradually fades; it is a white dwarf whose larger partner continually transfers material to it.

• Stars initially greater than eight solar masses can have fusion in their cores going all the way up to iron, which is stable against further fusion.

• The star continues to collapse after the iron core is found, implodes, and then explodes as a supernova.

• Stars less massive than 8 solar masses initially lose mass and eventually become a white dwarf with mass less than 1.4 solar masses

Summary of Chapter 21 (cont.)

- Two types of supernovae
  - Type Ia (low mass, older)
  - Core-collapse or “Type II” (young, massive)
- Heavier elements created during supernova explosions
- Gamma-ray bursts

20.4 Evolution of Stars More Massive than the Sun

TABLE 20.3 End Points of Evolution for Stars of Different Masses		
Initial Mass (Solar Masses)	**Final State**	**Remnant**
less than 0.08	(hydrogen) brown dwarf	
0.08–0.25	helium white dwarf	
0.25–8	carbon–oxygen white dwarf	$< 1.4\ M_\odot$ white dwarf
~~8–12 (approx.)*~~	~~neon–oxygen white dwarf~~	
$8 - 20\ M_\odot$	Core collapse supernova	$< 3\ M_\odot$ neutron star
$> 20\ M_\odot$	"	$> 3\ M_\odot$ black hole

Type Ia supernovae are different! (from binary stars, two mechanisms, both involve white dwarf mechanism)