Today's Topics

Monday, March 24, 2025 (Week 8, lecture 20) – Chapters 22, 23.

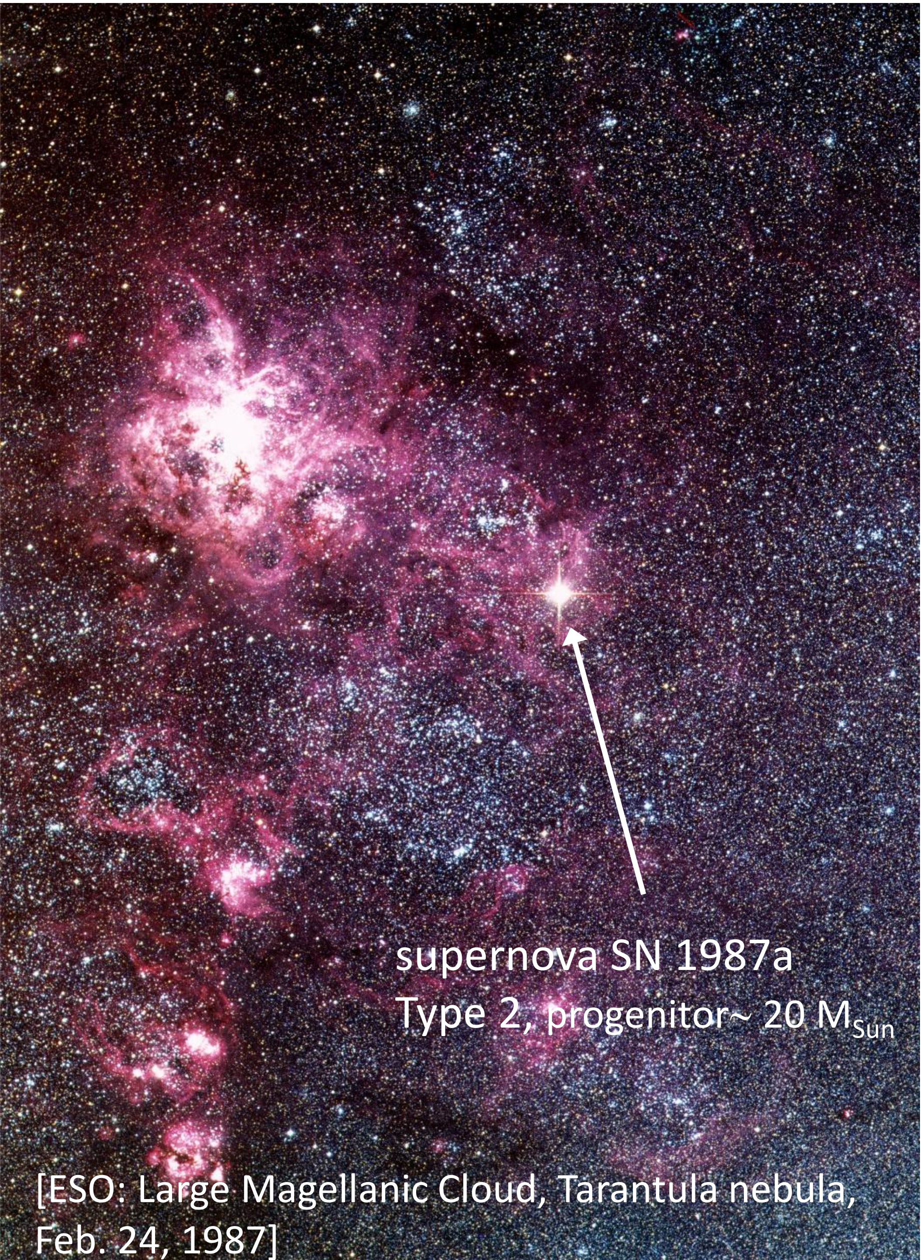
1. Type II supernovas: physics.

2. Supernova remnants.

3. Neutron stars & pulsars.

Interlude 1 Essay is due on Friday, March 28 by 9:00 am on Gradescope.

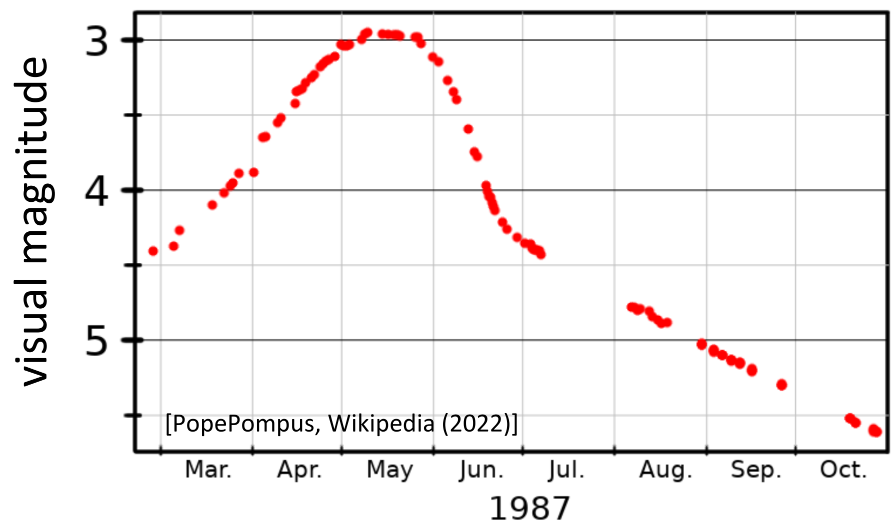
Supernova SN 1987A



[ESO: Large Magellanic Cloud, Tarantula nebula, Feb. 24, 1987]

Type II supernova

→ Core collapses under gravity.
→ Produces a neutron star or black hole.



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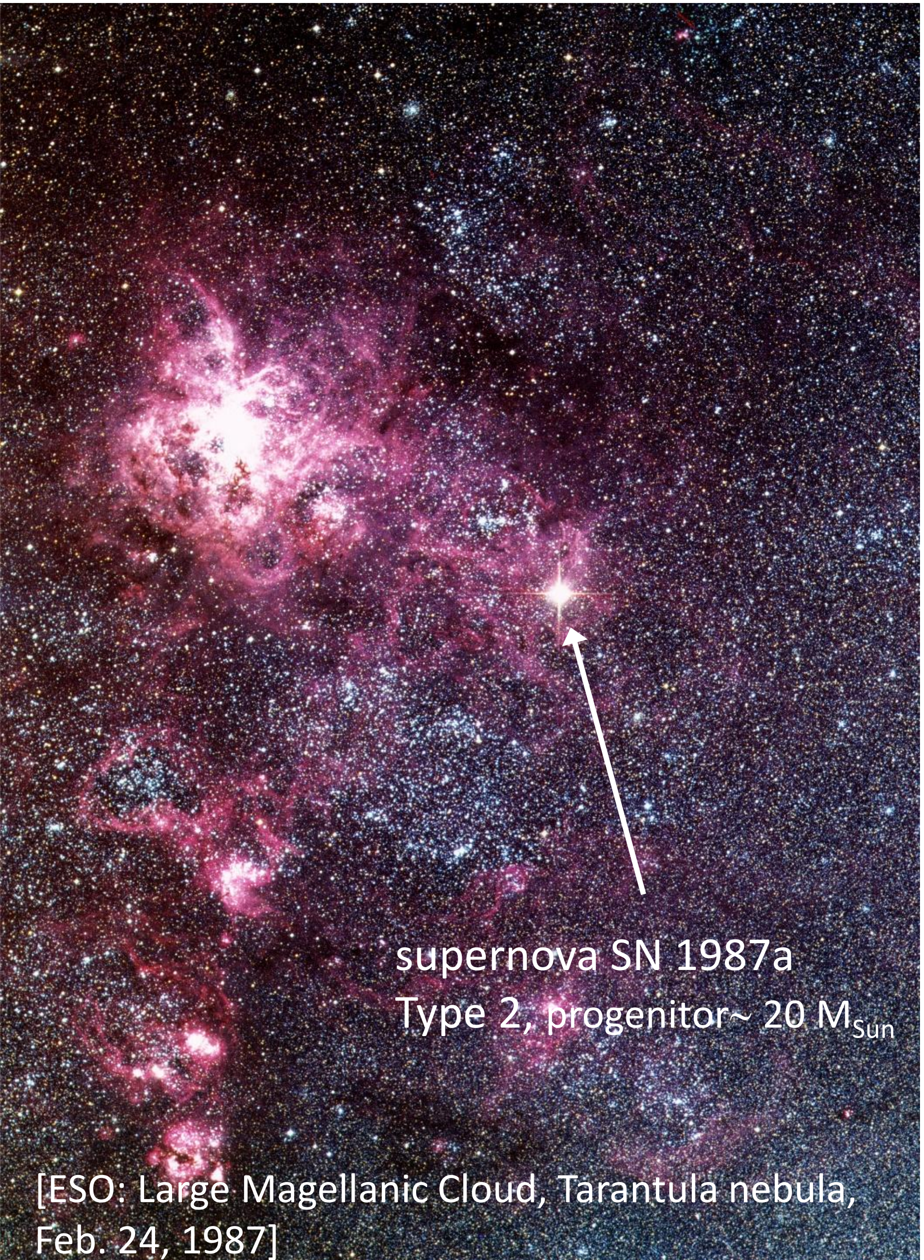

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[NASA, ESA, and R. Kirshner and P. Challis: Jan. 2017]

Note: No neutron star has been definitively detected yet … but there is good evidence for one.

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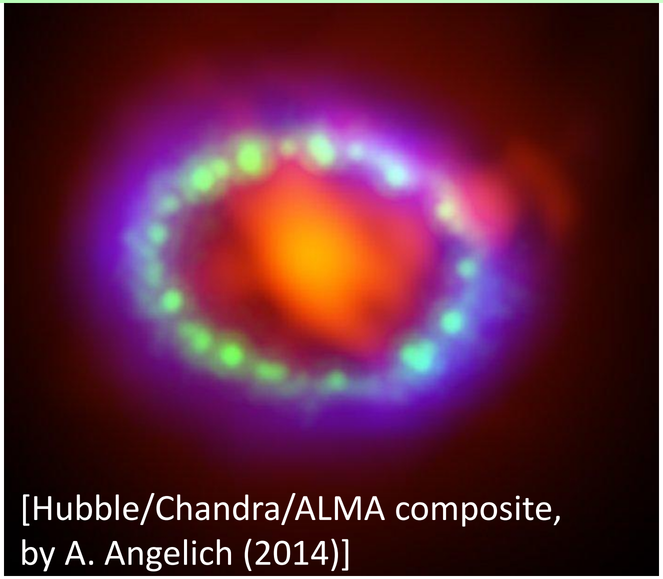

[Hubble/Chandra/ALMA composite, by A. Angelich (2014)]

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[James Webb Space Telescope, M. Matsuura, R. Arendt, C. Fransson, J. Larsson, A. Pagan (2023)]

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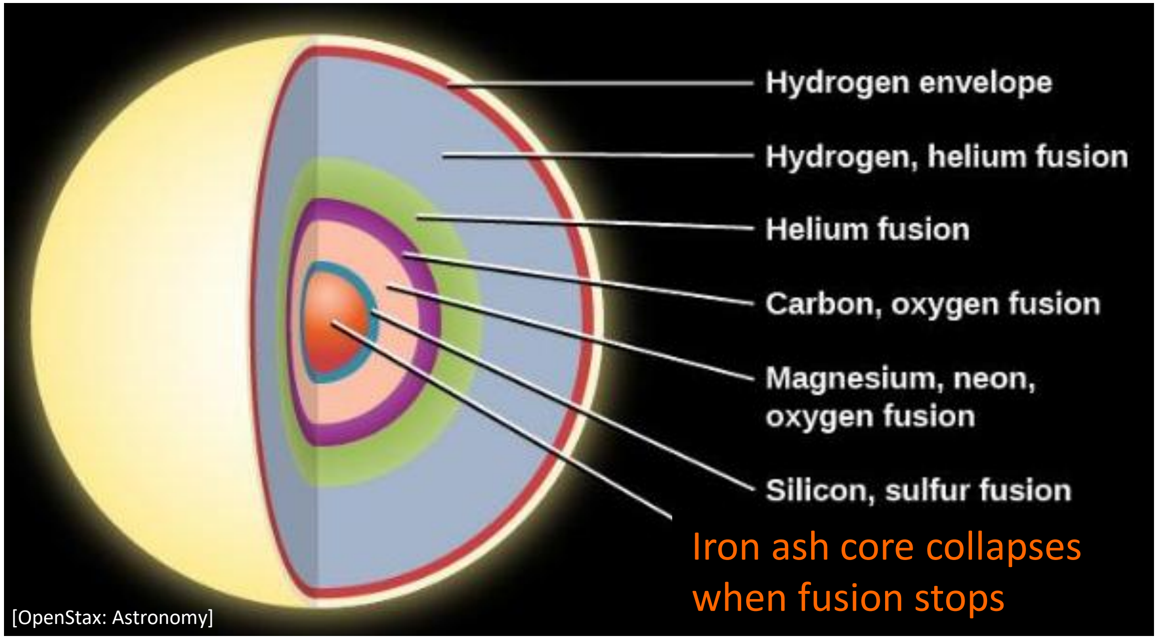
Type II Supernova: *Core Collapse*



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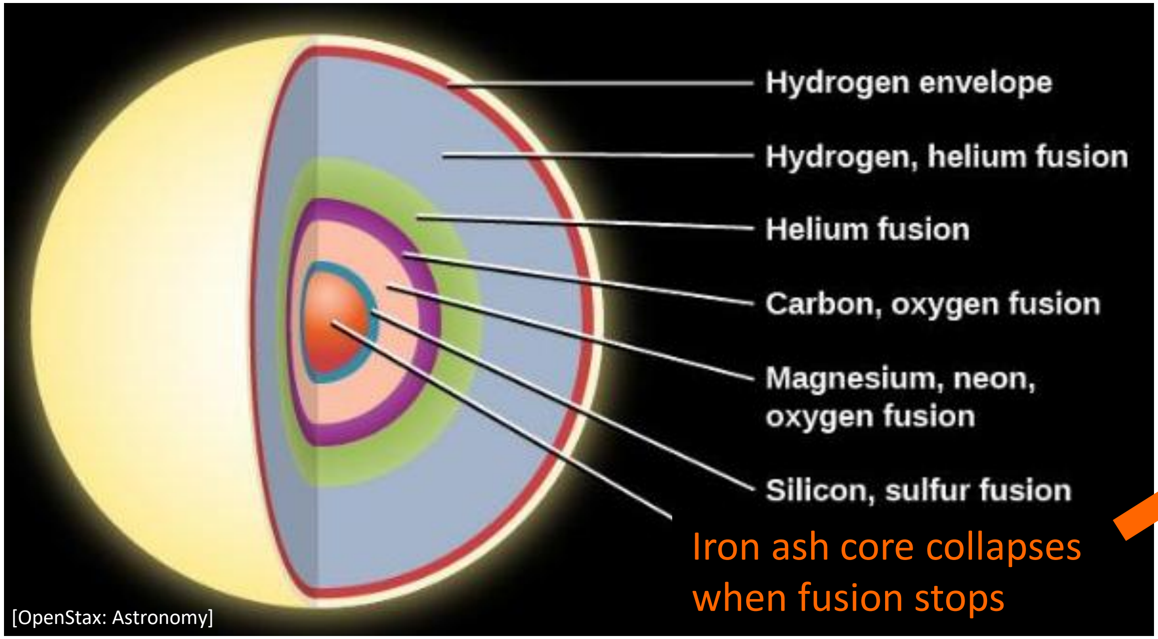

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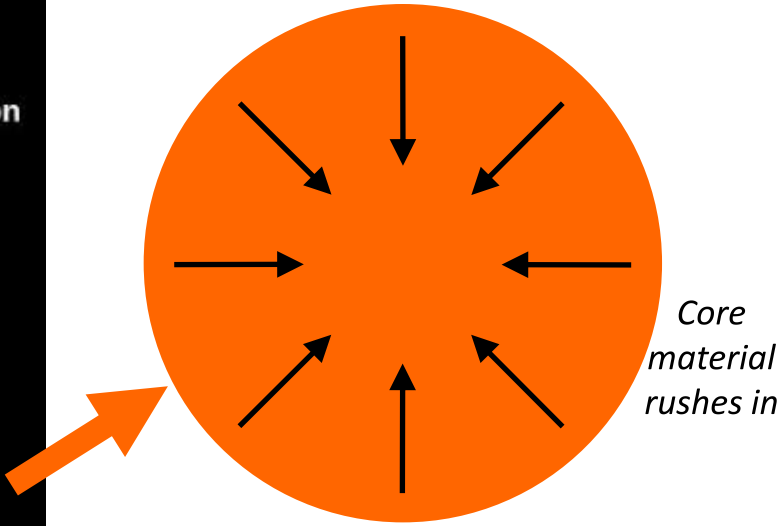

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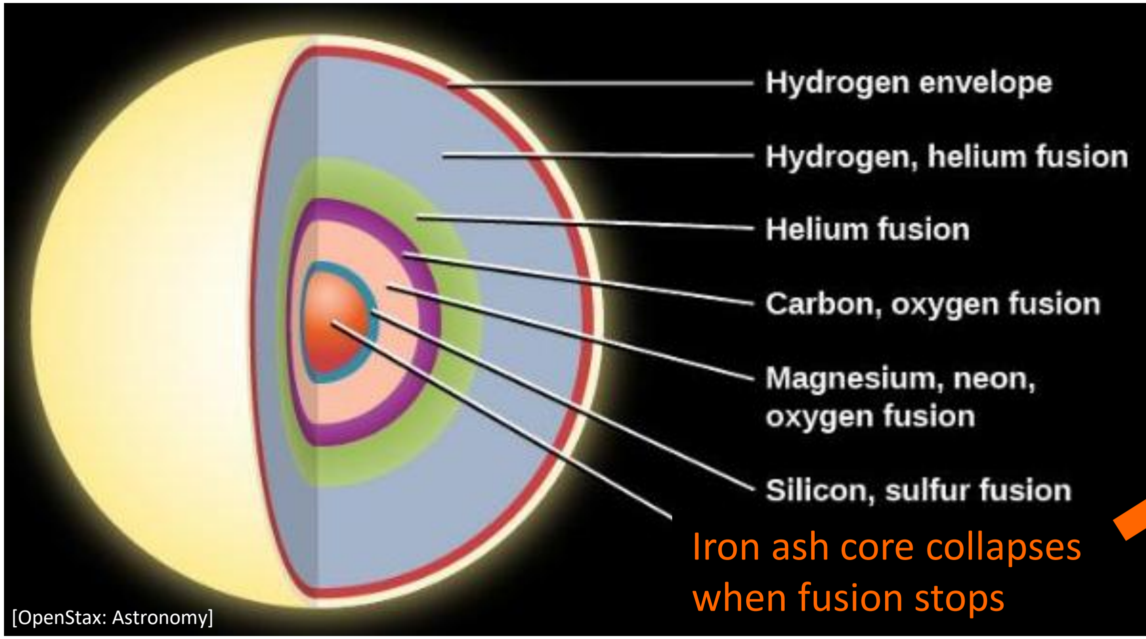

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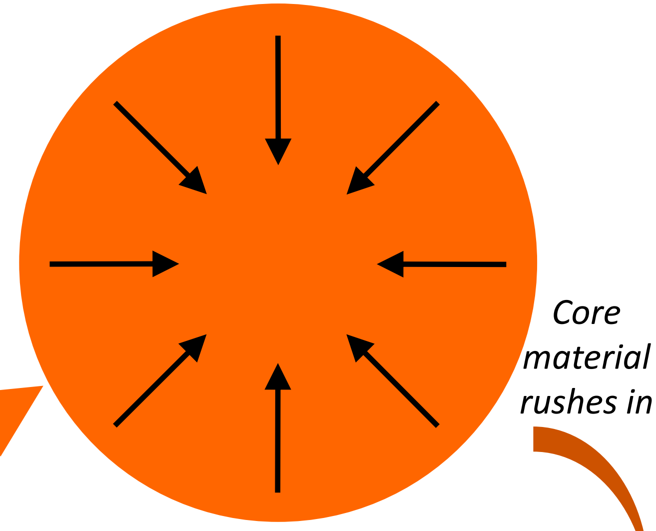
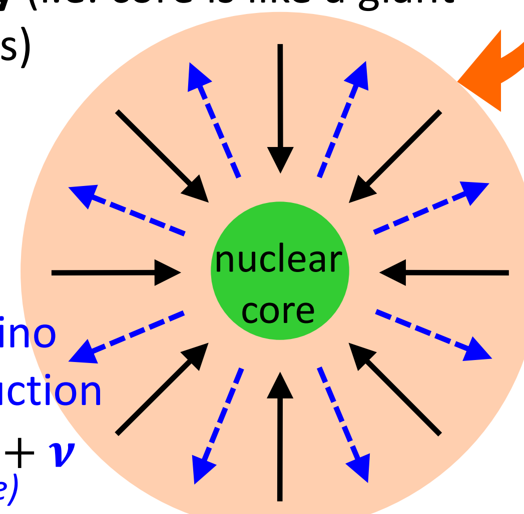


2. Collapses continues to **nuclear density** (i.e. core is like a giant nucleus)



neutrino production

$$p^+ + e^- \rightarrow n + \boldsymbol{\nu}$$

(weak force)

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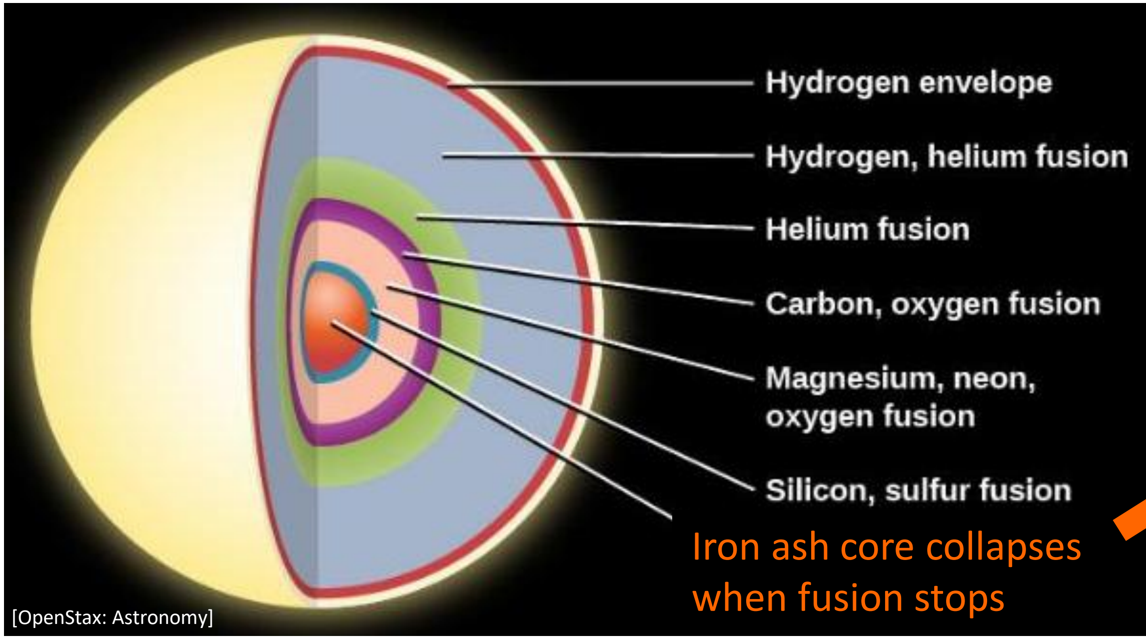

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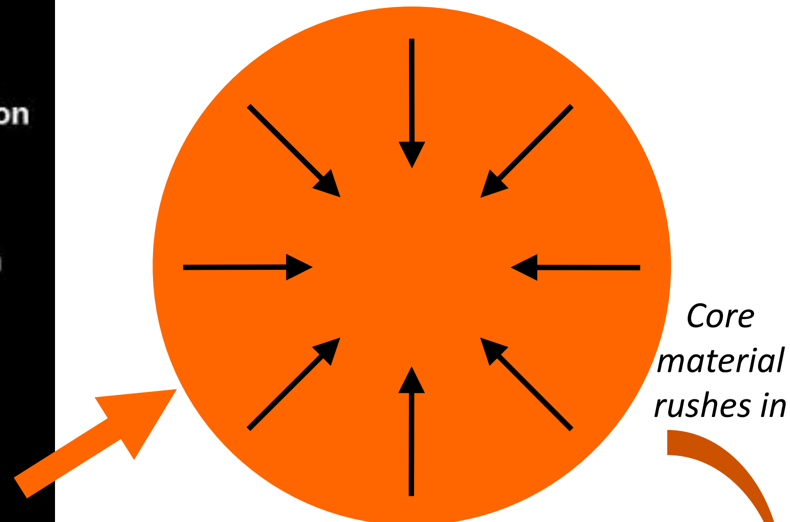

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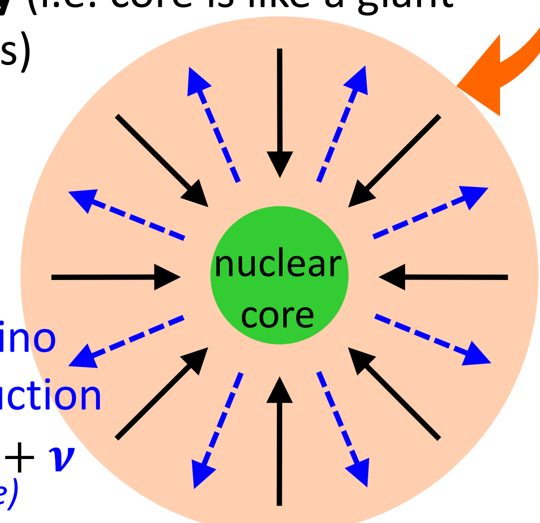

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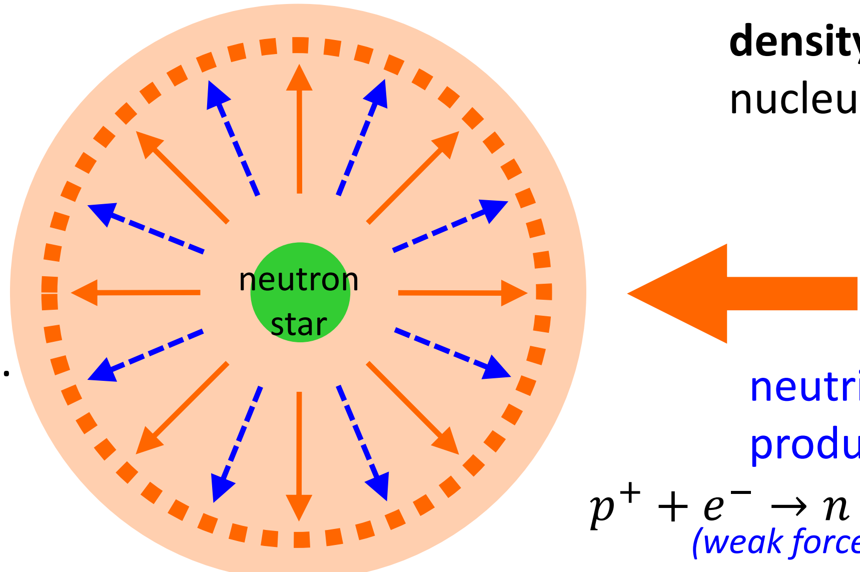
3. In-falling material **rebounds** off **neutron star** core creating an outward moving **shockwave**.
→ Star is blown apart.



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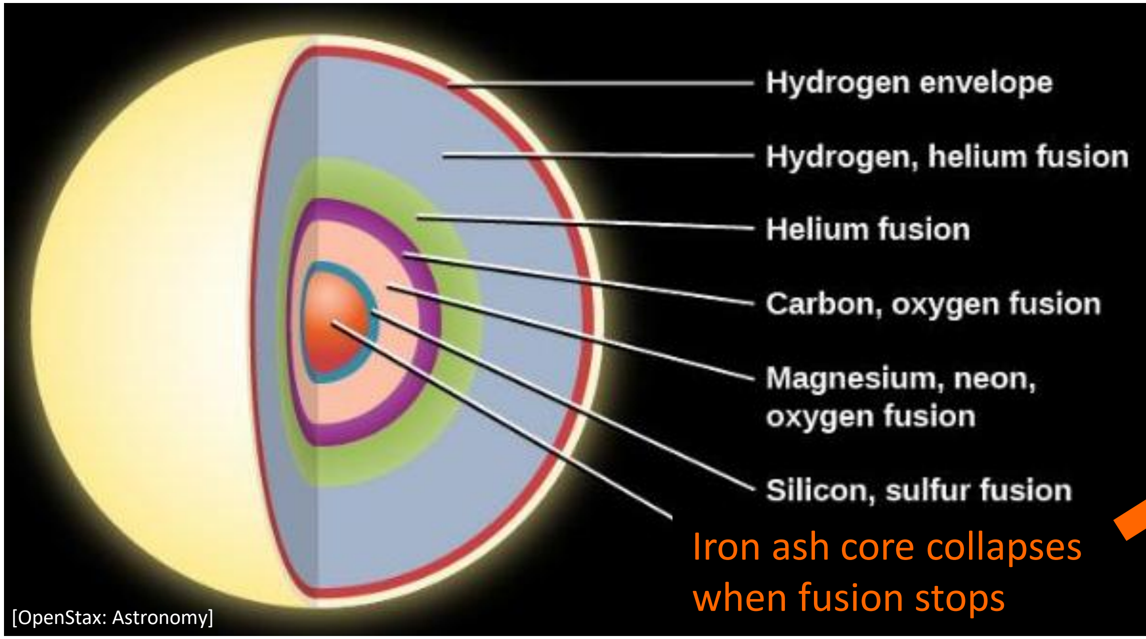

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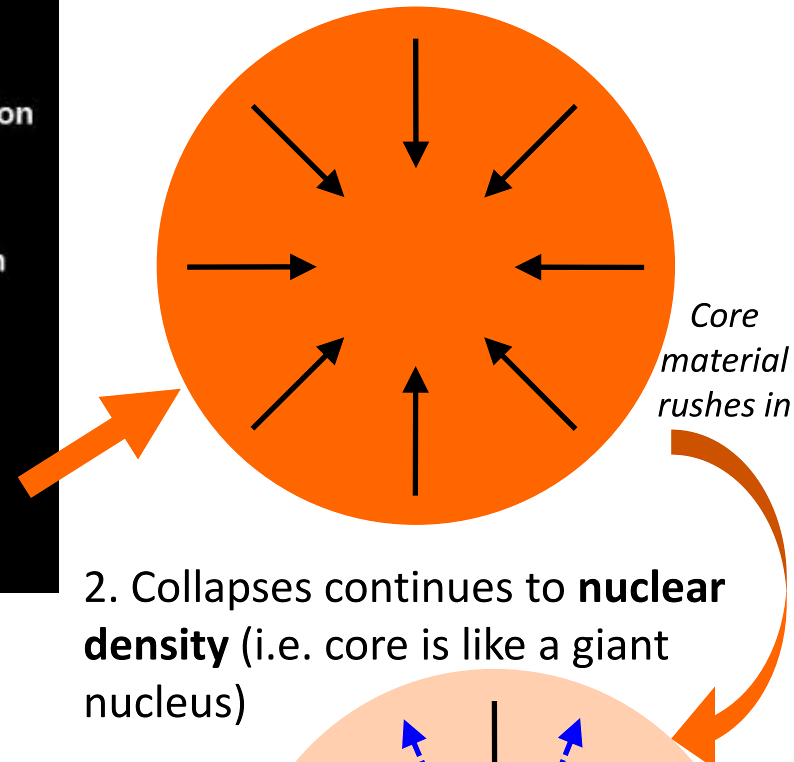

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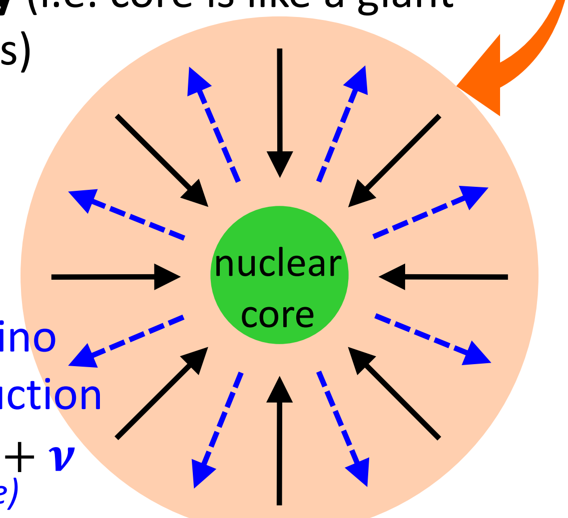

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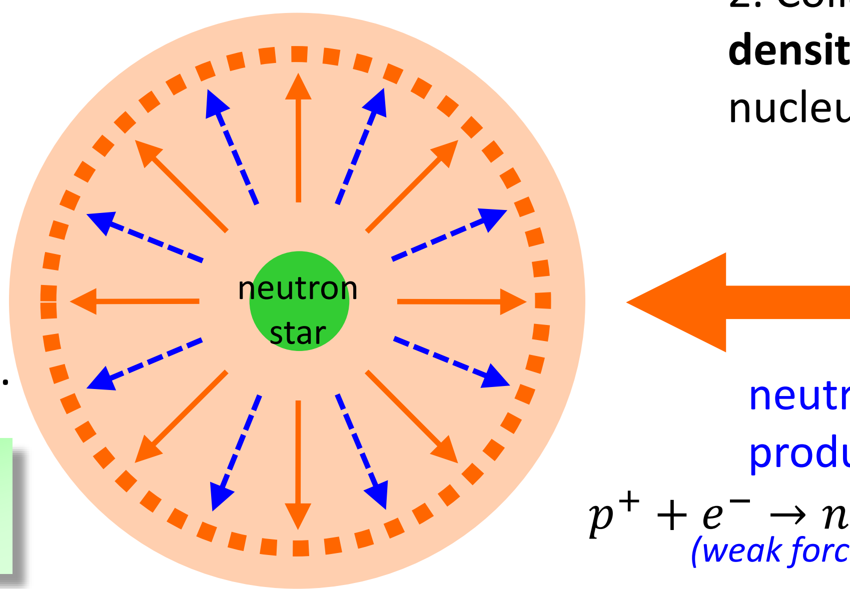

Note: entire process takes a few seconds.

Type II Supernova: *What's produced ?*

Lots of Energy

- Supernovas typically emit about 10^{46} Joules of energy.
  → 100 times more energy than Sun will emit in its lifetime (10^{44} Joules).
- Supernovas shine with a luminosity of 10^9-10^{10} L_{Sun} for a few months.
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Some light & heavy elements

- About 0.01 % of the supernova's energy is released as electromagnetic radiation (e.g. light).
- Most of the light is emitted due to radioactive decay of heavy elements (primarily Ni).
- Supernovas produce some elements heavier than Fe and Ni (up to Rb).

Supernova

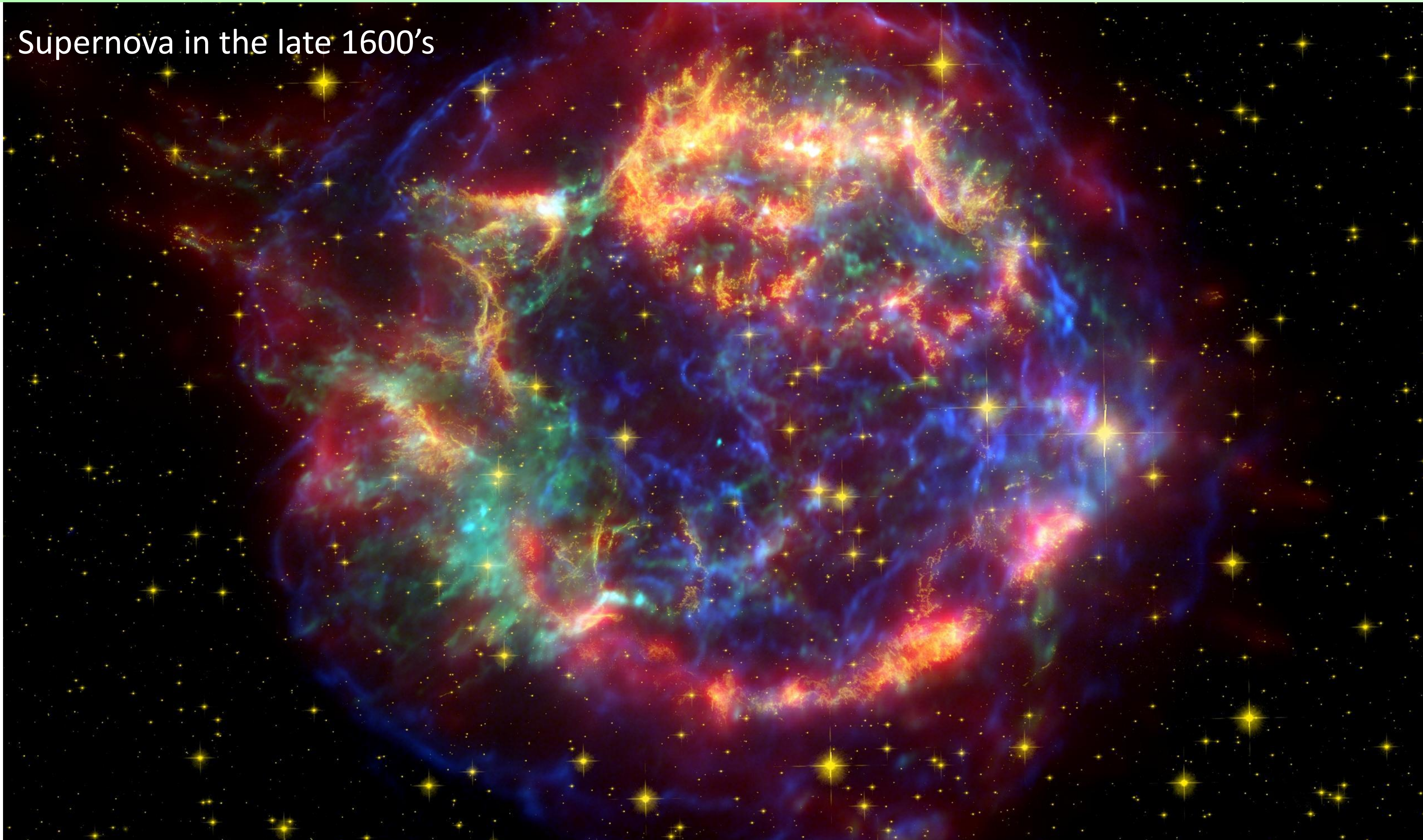
=

gravity powered neutrino explosion
of a massive star

PollEv Quiz: PollEv.com/sethaubin

Cassiopeia A: Supernova Remnant

Supernova in the late 1600’s



Cassiopeia A supernova remnant (type II)

False color composite image from Hubble (optical = gold), Spitzer (IR = red),and Chandra (X-ray = green & blue)

[source: Wikipedia, Oliver Krause (Steward Observatory) and co-workers]

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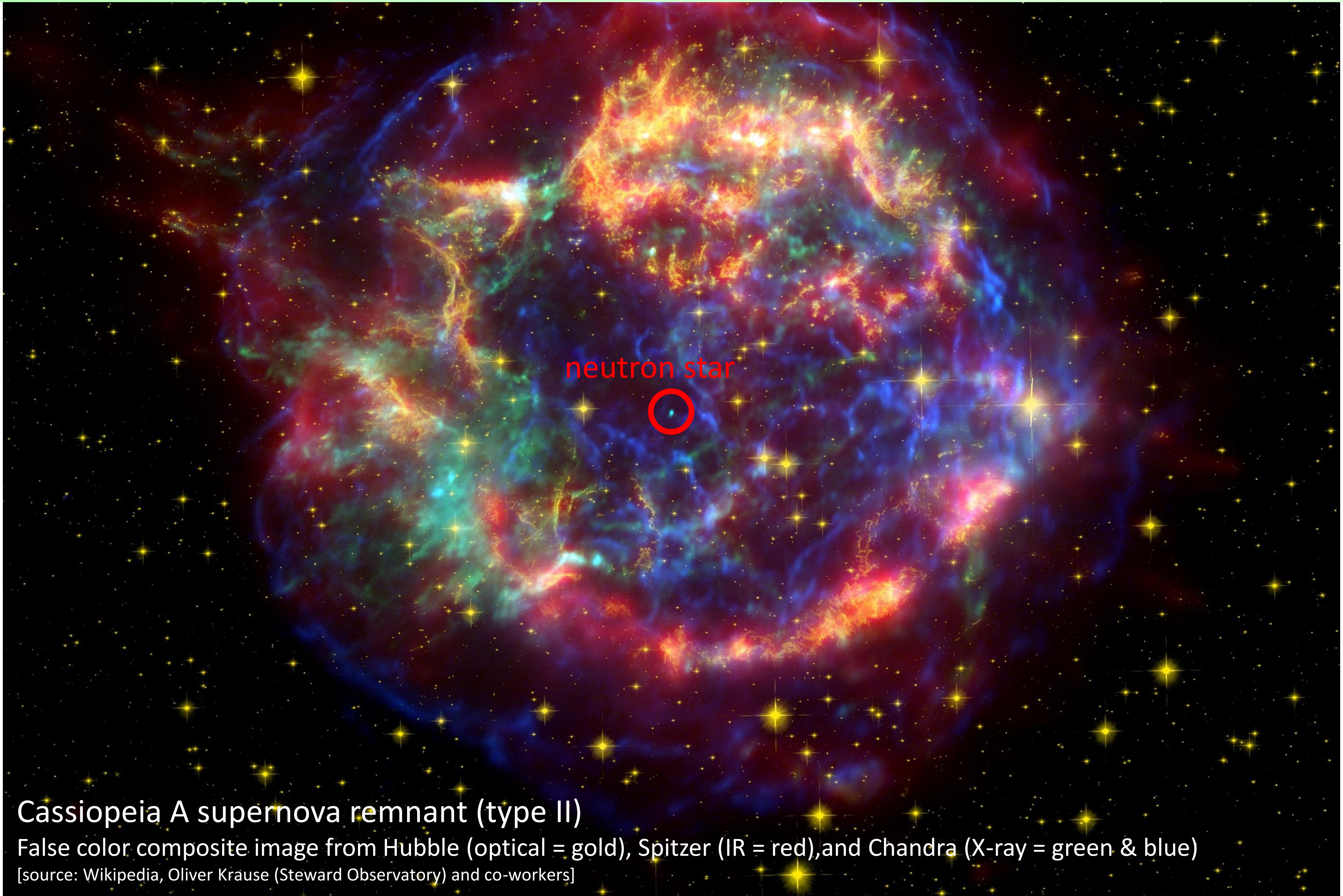

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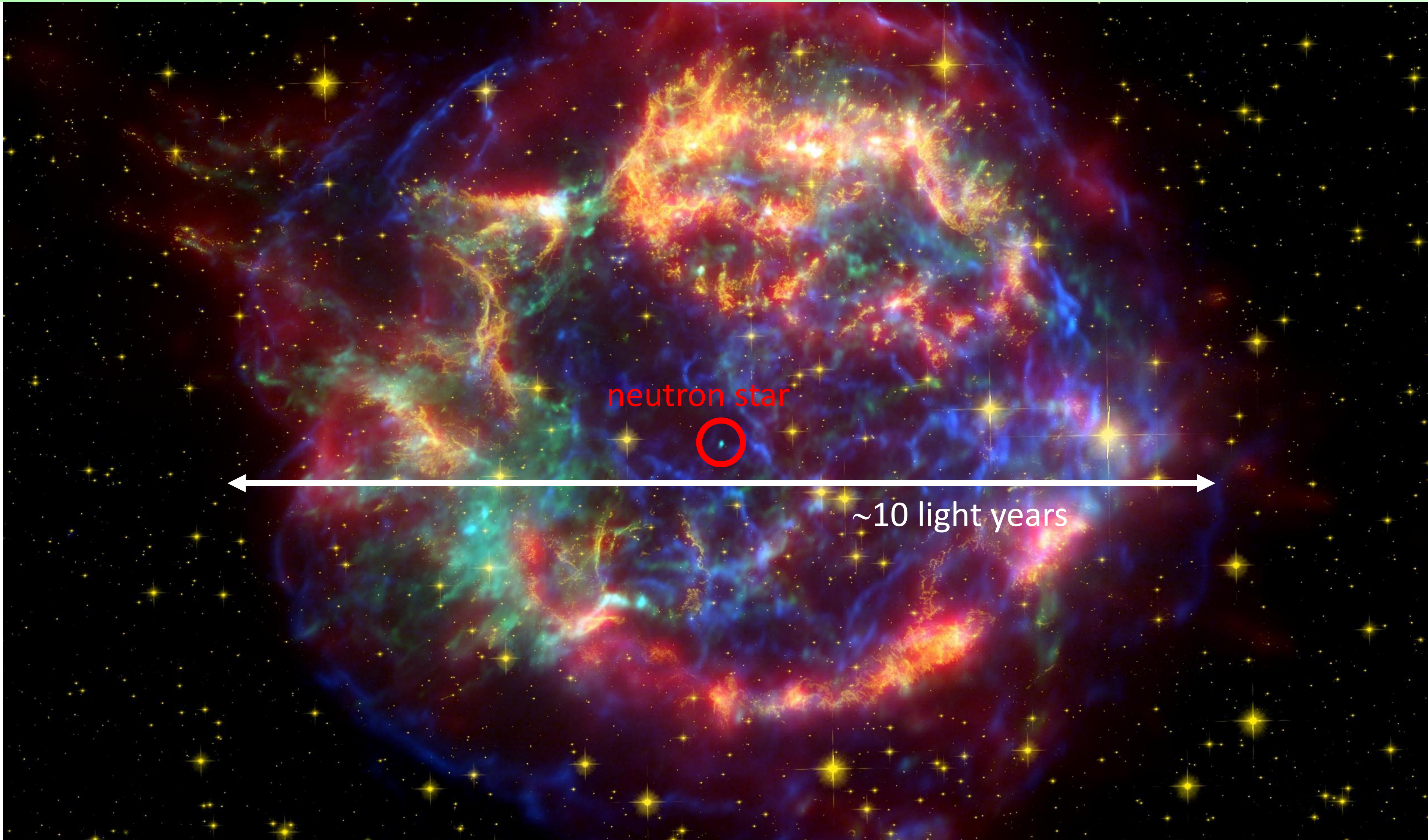

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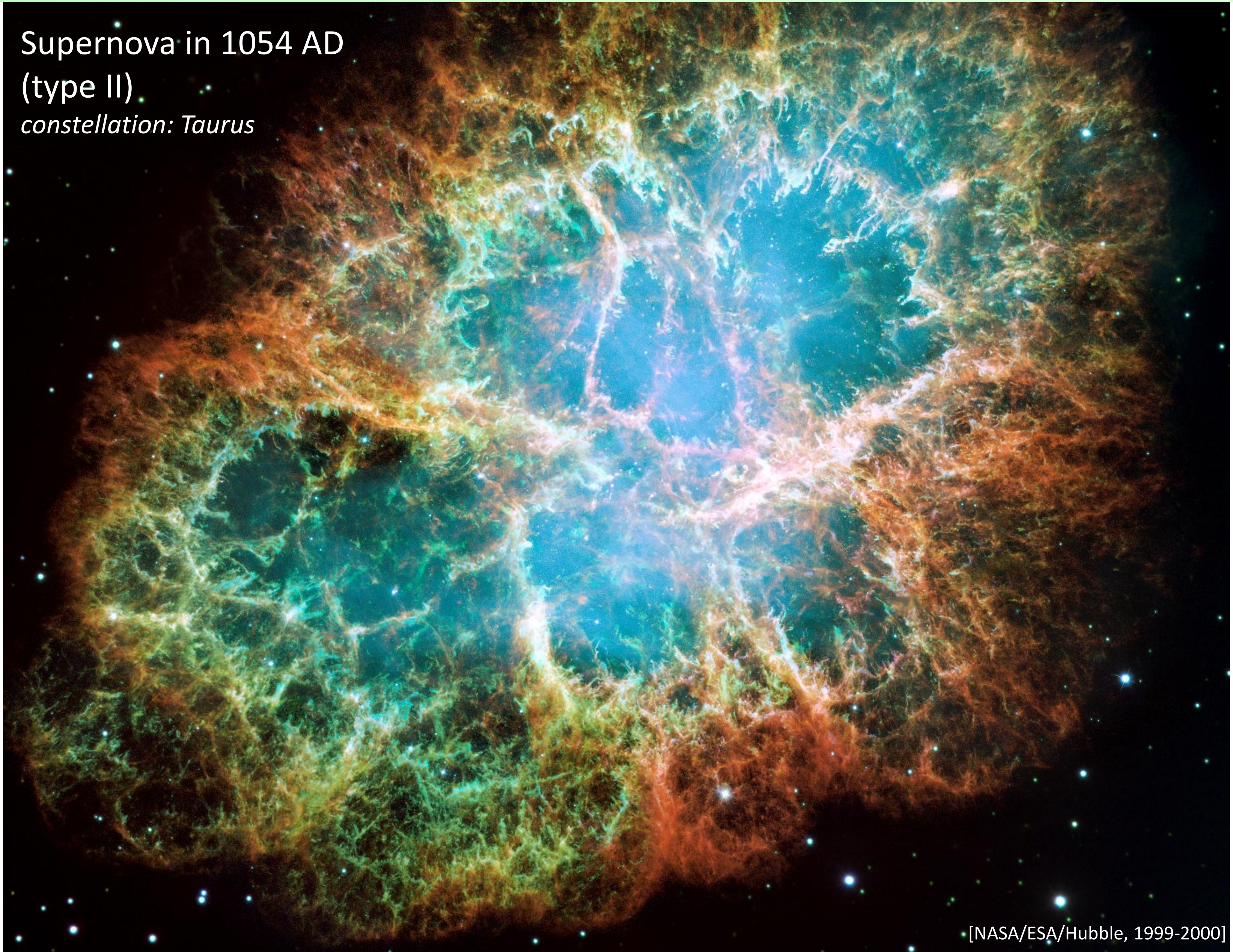
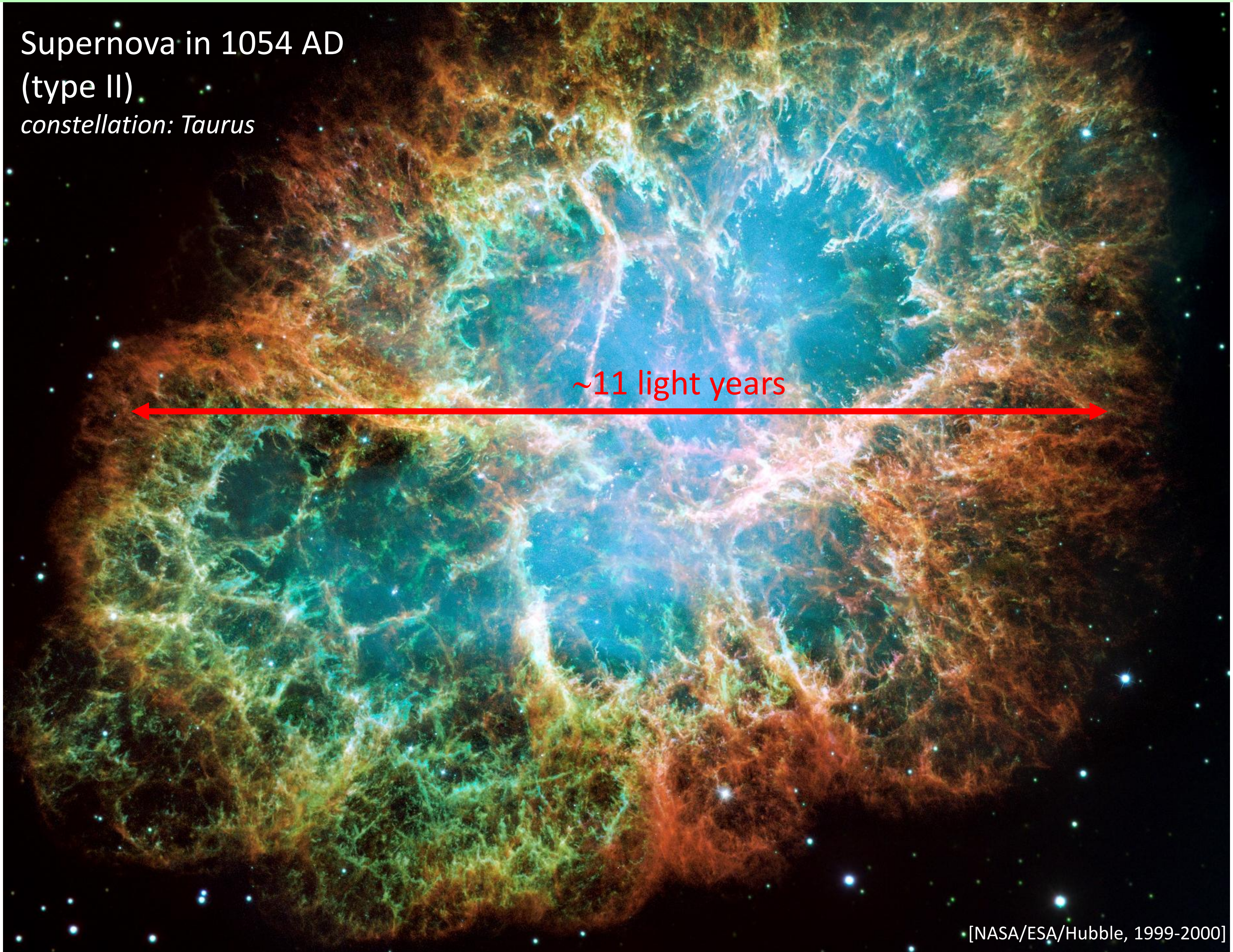
Crab Nebula: Supernova Remnant

Supernova in 1054 AD
(type II)
constellation: Taurus



[NASA/ESA/Hubble, 1999-2000]

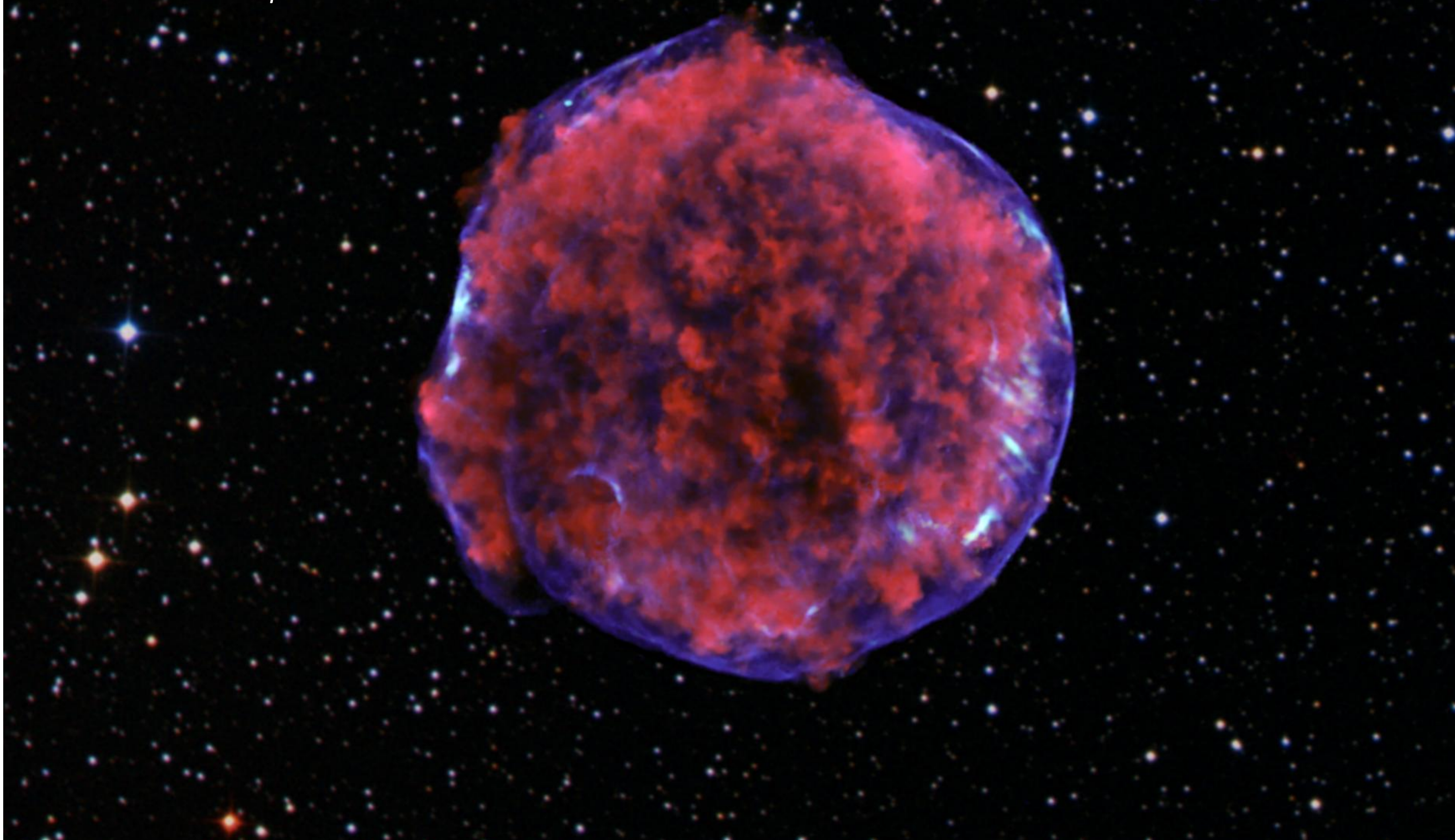
Crab Nebula: Supernova Remnant



Tycho's Supernova Remnant

SN 1572 (type I = white dwarf + red giant binary explosion)

Constellation: Cassiopeia



Composite image: blue = hard x-rays, red = soft x-rays, background stars = optical

[NASA/Chandra (2009)]

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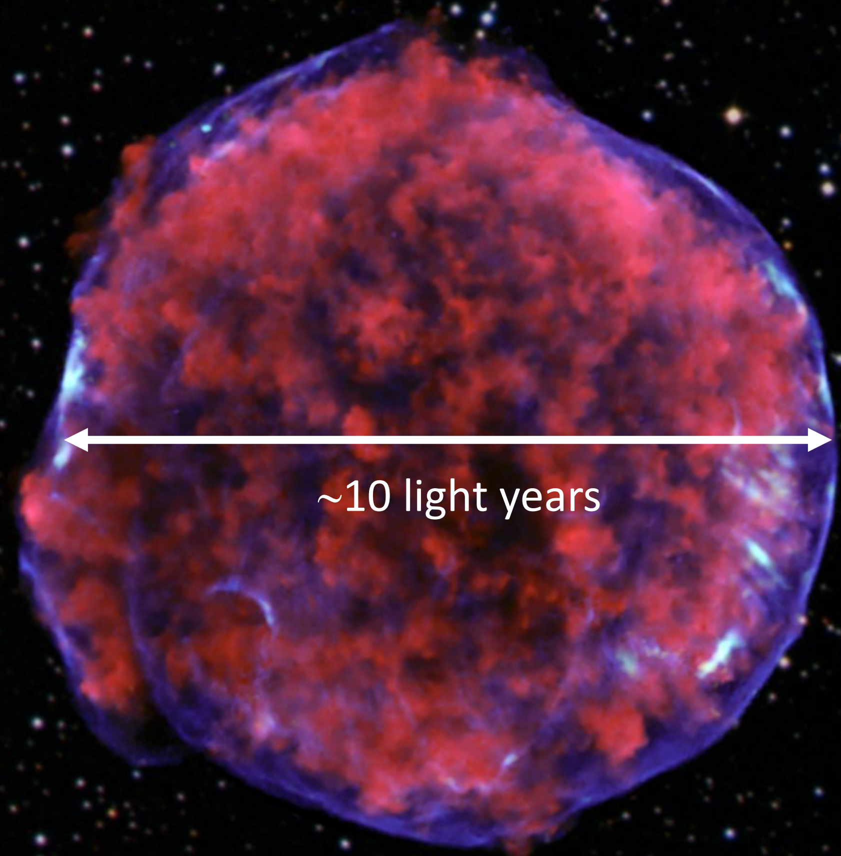

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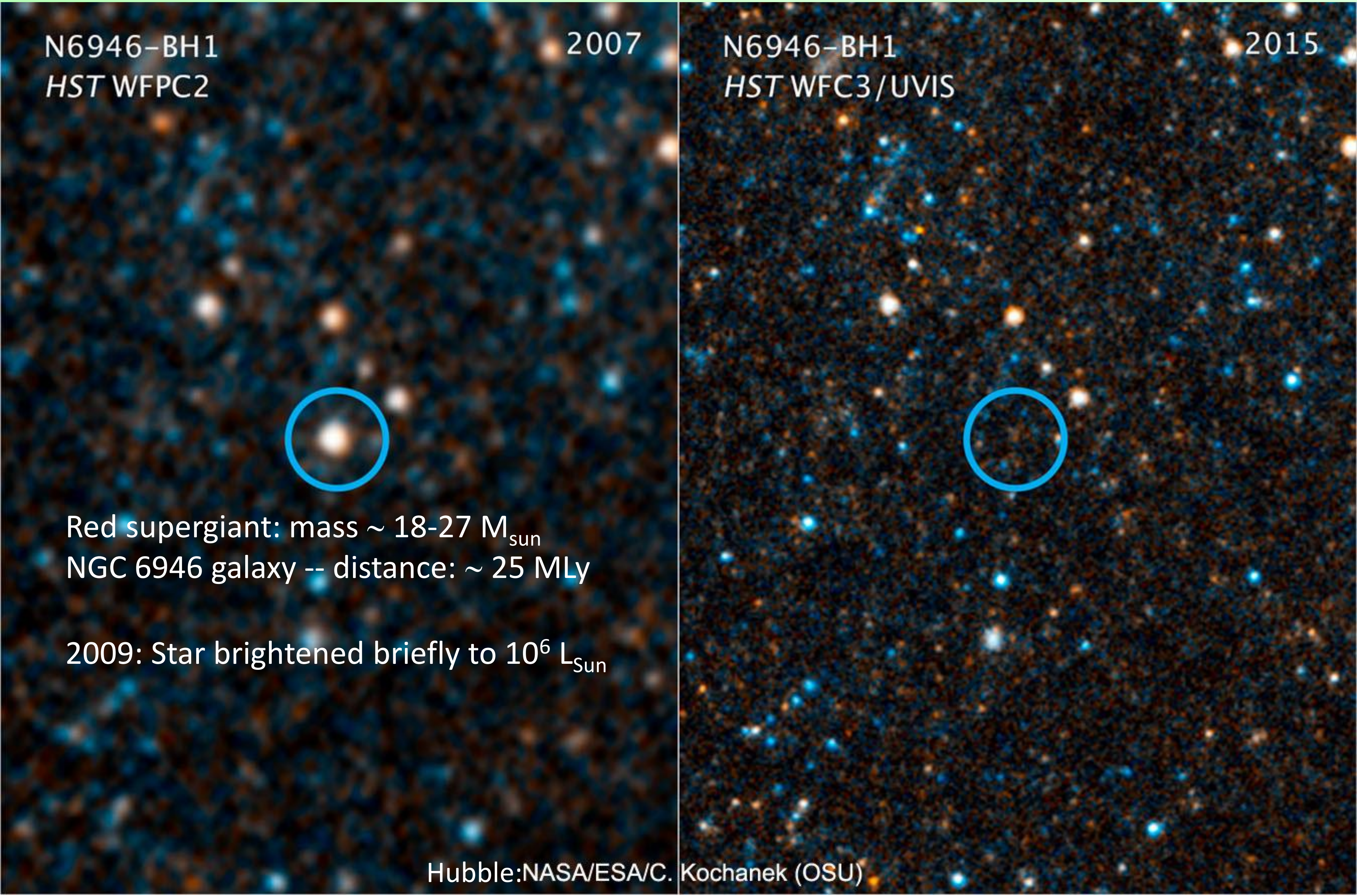
Skipping the supernova ? Giant star → black hole



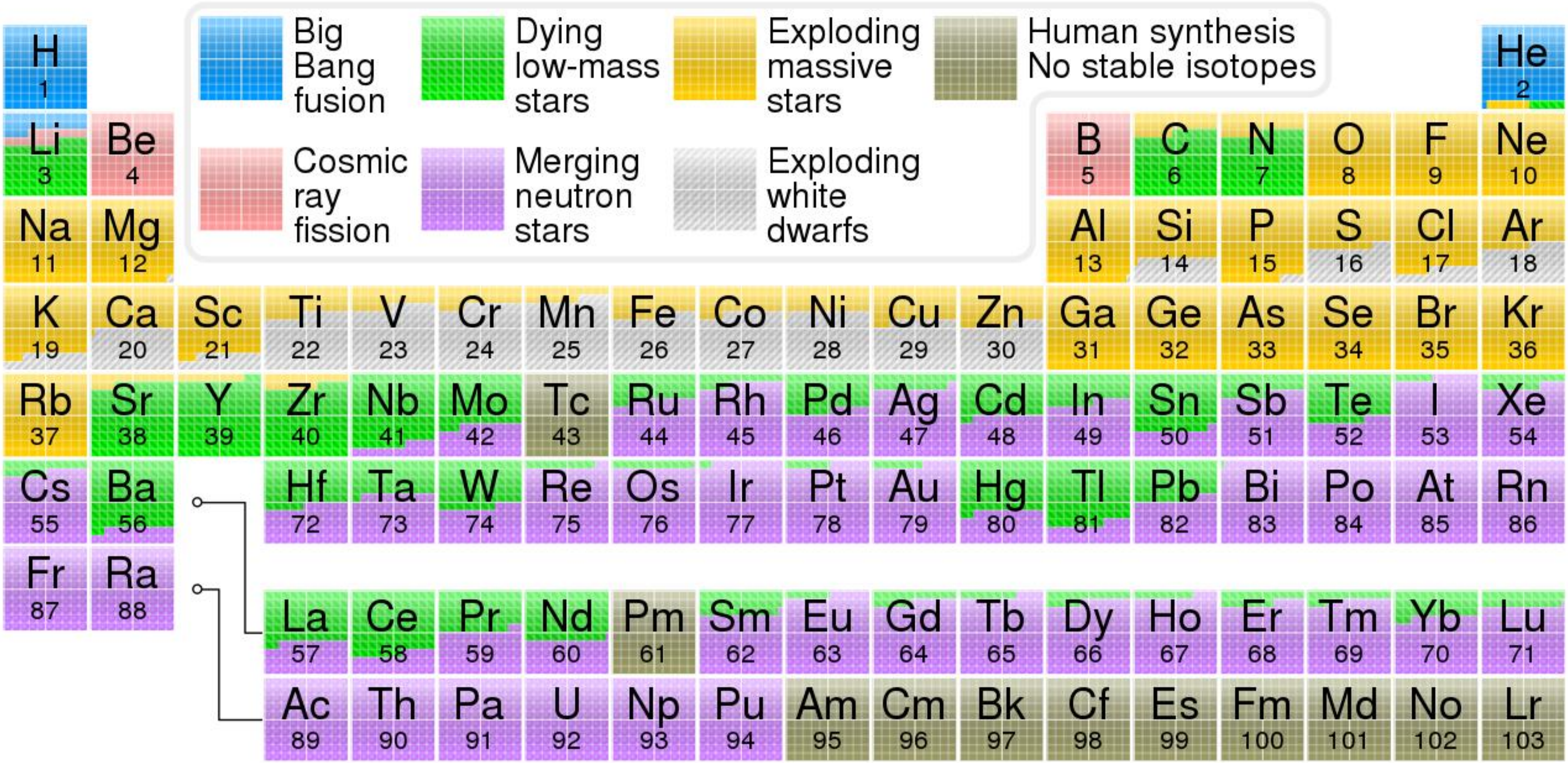
Red supergiant: mass ~ 18-27 M_{sun}
NGC 6946 galaxy -- distance: ~ 25 MLy

2009: Star brightened briefly to 10^6 L_{Sun}

Hubble:NASA/ESA/C. Kochanek (OSU)

Where do heavy elements come from ?

- Supernovae are a major source of heavy elements
- Most of the iron core of a massive star is “dissolves” into protons in the core collapse.
  → the supernova explosion produces its own iron (and other heavier elements)



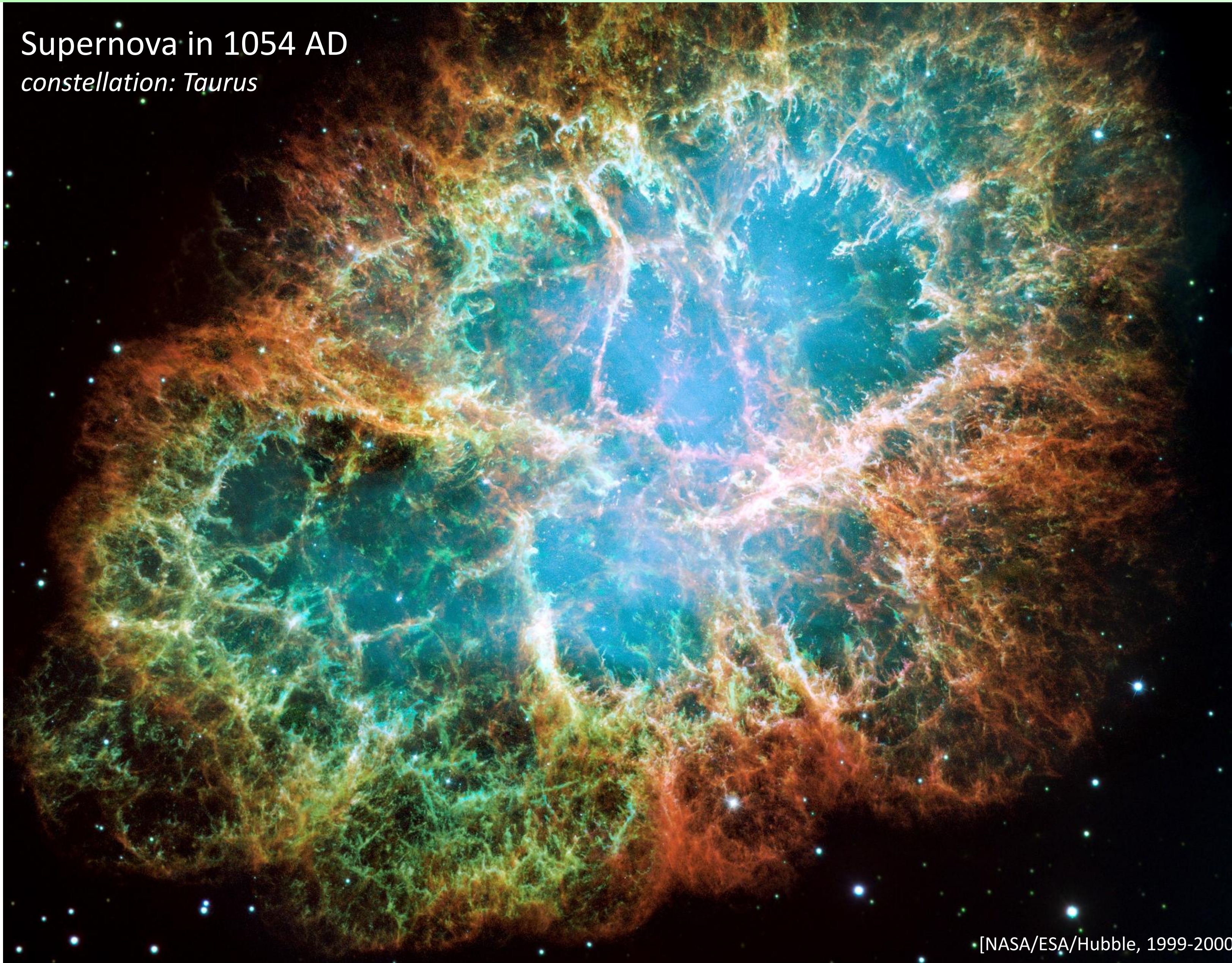
This table give the estimated origin of elements in the Solar System. [Source: Wikipedia, Cmglee (2017)]

Type II Supernova: *What's Left ?*

Initial Star Mass	Outcome	
10-40 M_{Sun}	Supernova → Neutron Star	
40-90 M_{Sun}	Supernova → Black Hole	
>90 M_{Sun}	Direct collapse to Black Hole	(no explosion)

Note: the exact outcome depends on the initial composition (metallicity) star.

Crab Nebula: Neutron Star



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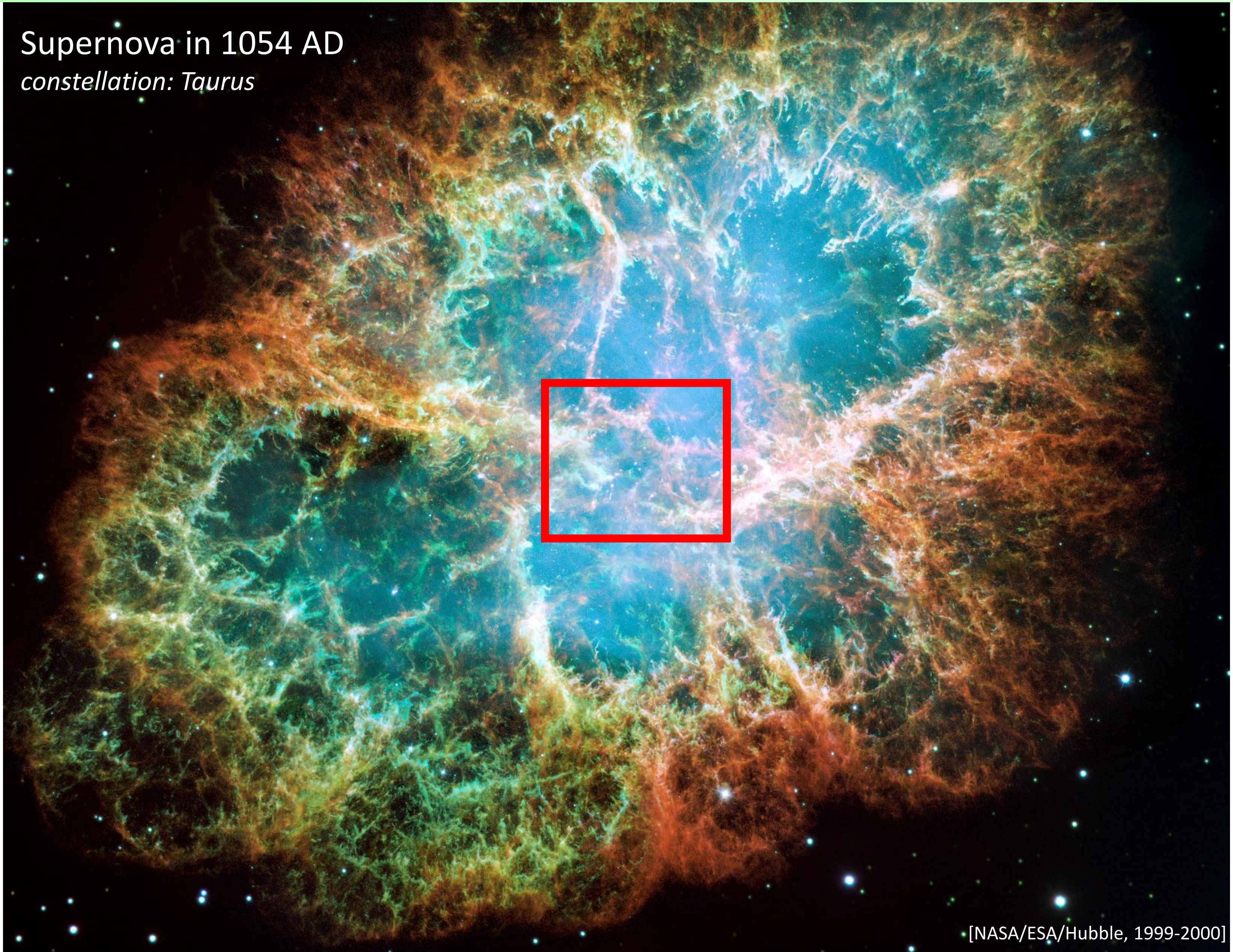

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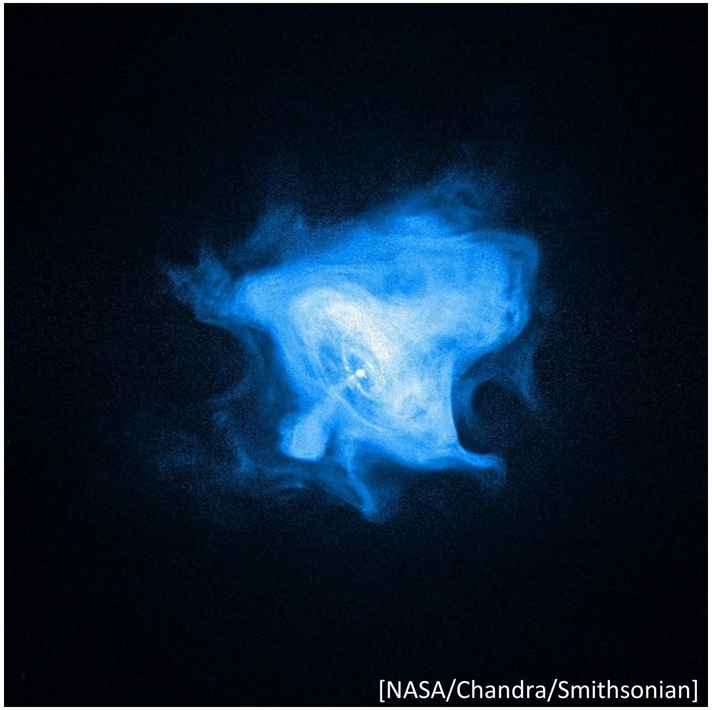
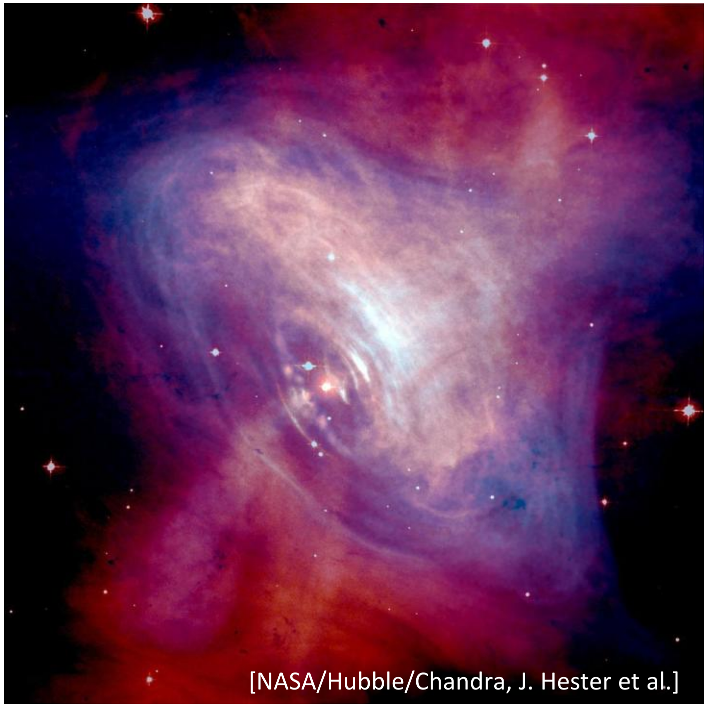


X-ray image of Crab Nebula neutron star, 2008



X-ray + optical images of Crab Nebula neutron star

Neutron Stars

[Table 23.3, OpenStax: Astronomy]

Property	White Dwarf	Neutron Star
Mass (Sun = 1)	0.6 (always <1.4)	Always >1.4 and <3
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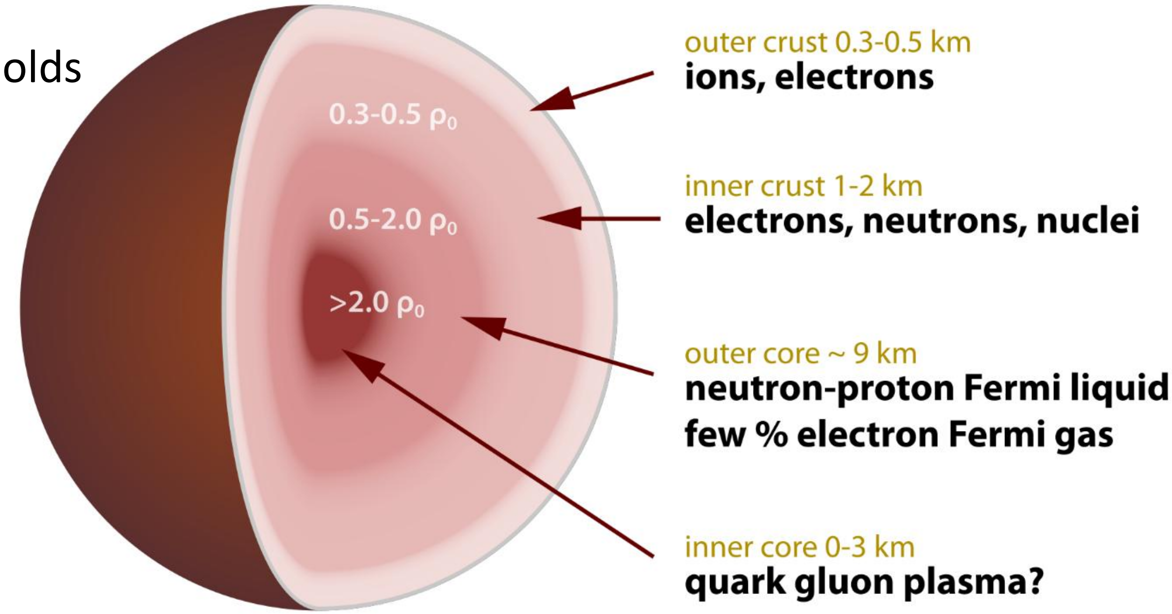

[Wikipedia: Robert Schulze]

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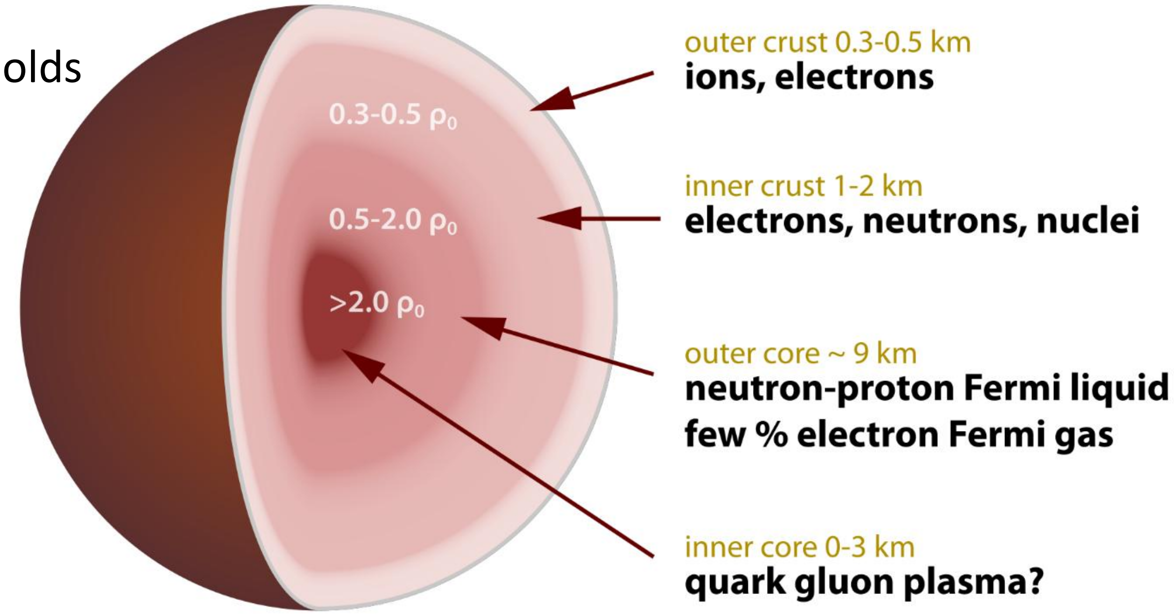
Neutron stars have a **very large magnetic field**: 10^8 to 10^{15} times stronger than Earth's



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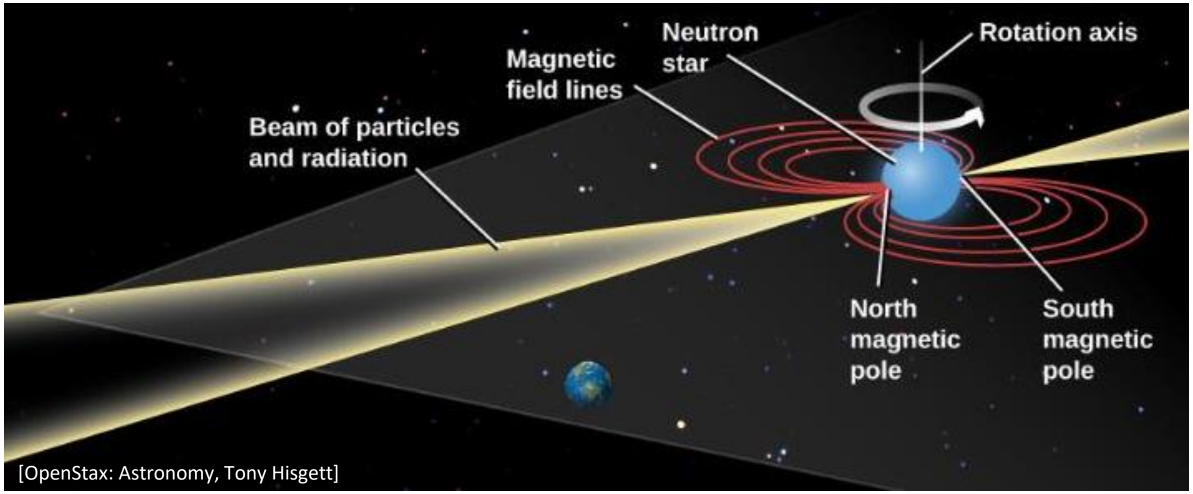
Pulsars: Rotating Neutron Stars



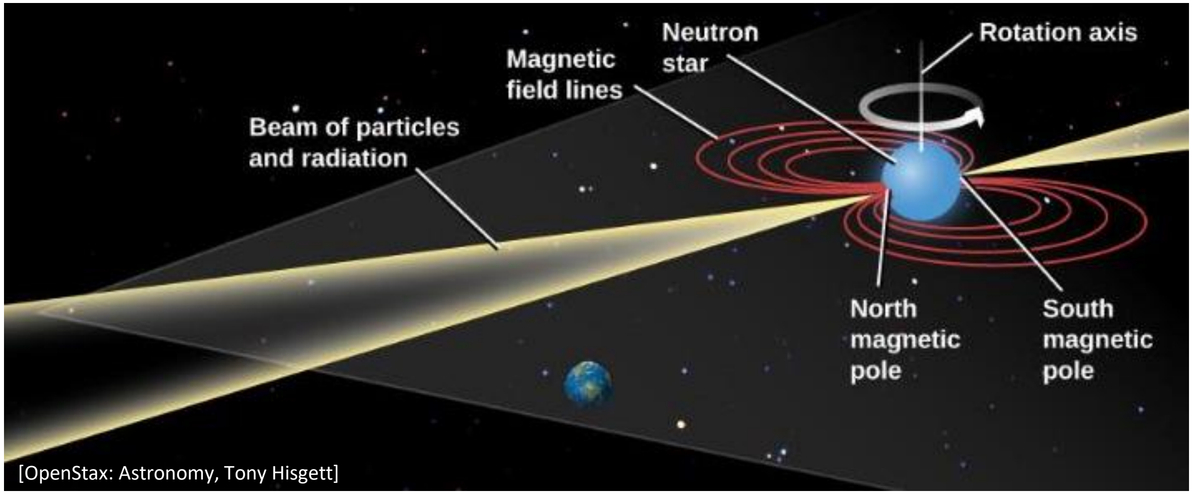
[OpenStax: Astronomy, Tony Hisgett]

- **Beams of radiation from the magnetic poles** of a neutron star can give rise to pulses of emission as the star rotates.
- As each beam sweeps over Earth, we see a short pulse of radiation (like a lighthouse).

Jocelyn Bell Burnell

co-discoverer of pulsars (1967)

Pulsars: Rotating Neutron Stars



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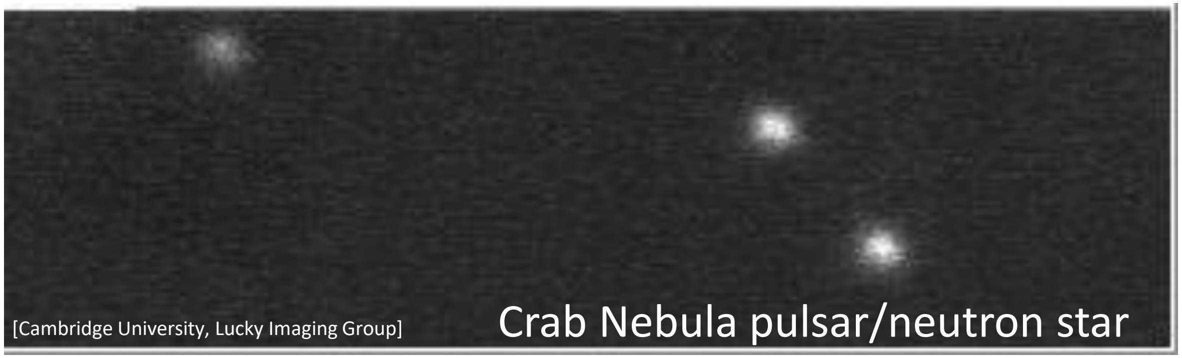

[Cambridge University, Lucky Imaging Group] Crab Nebula pulsar/neutron star

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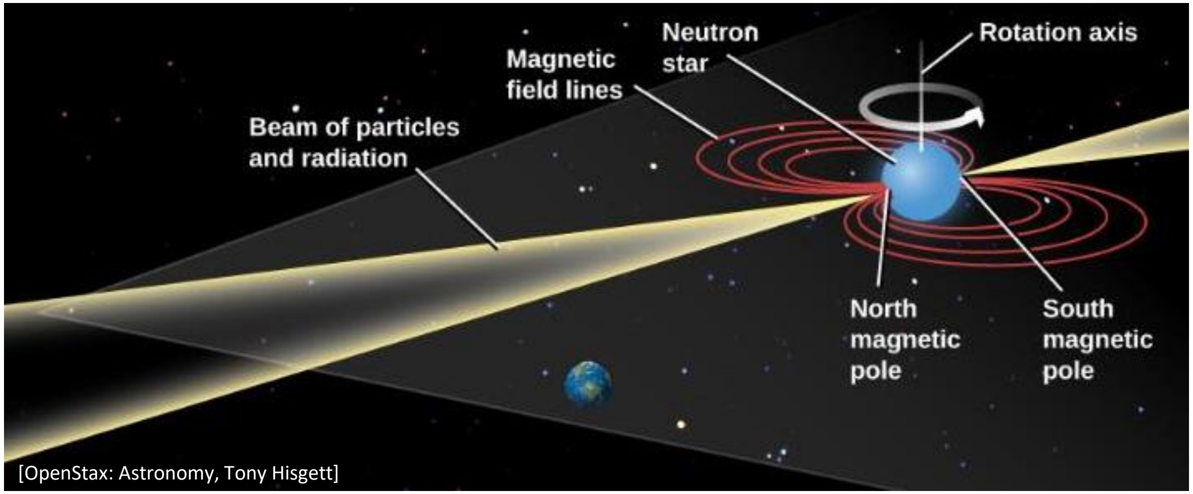

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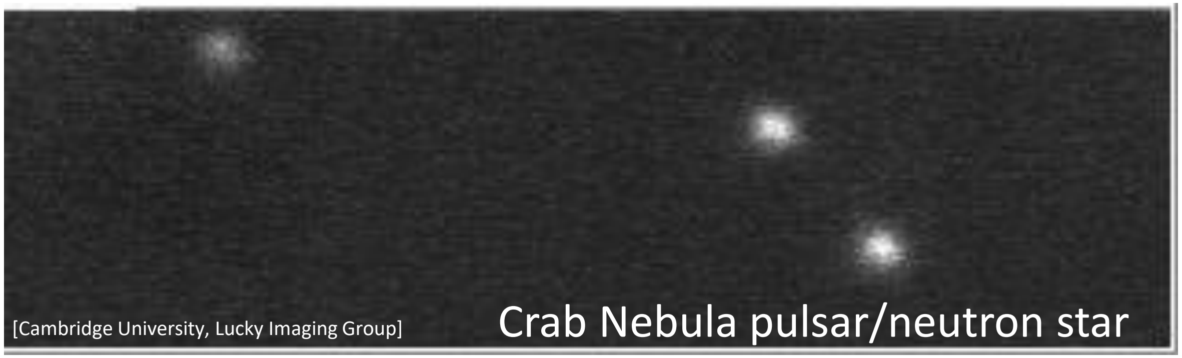
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Typical rotation period:

- Very stable.
- ms to seconds.
- Can change abruptly during a “starquake.”