Interlude 2 Talks
Space Art

Wednesday, December 4

Team 9: Clay Little, Luciano Saporito, Jack Slater, Colby Sorsdal

Team 10: Rachel Williamson, Stella Brockwell, Carter Helmandollar, Guy Rahat

Team 11: Emily MacKenzie, Abby Maher, Margaret McLaughlin, William Rhodes

Team 12: Kira Quintin, Jeannine Brokaw, Alex MacNamara, Jireh Jin Lee

Note 1: Talks will be 10 minutes long.

Note 2: Do not use paragraphs and long sentences.

Send me your PowerPoint or PDF talk by 8am Monday morning.

Interlude 2 Papers
Space Art

If you make your own space art:

- Paper length is 4 pages (instead of 5).
- Art should incorporate some knowledge from the course.
- Quality of art will be graded Pass/Fail.

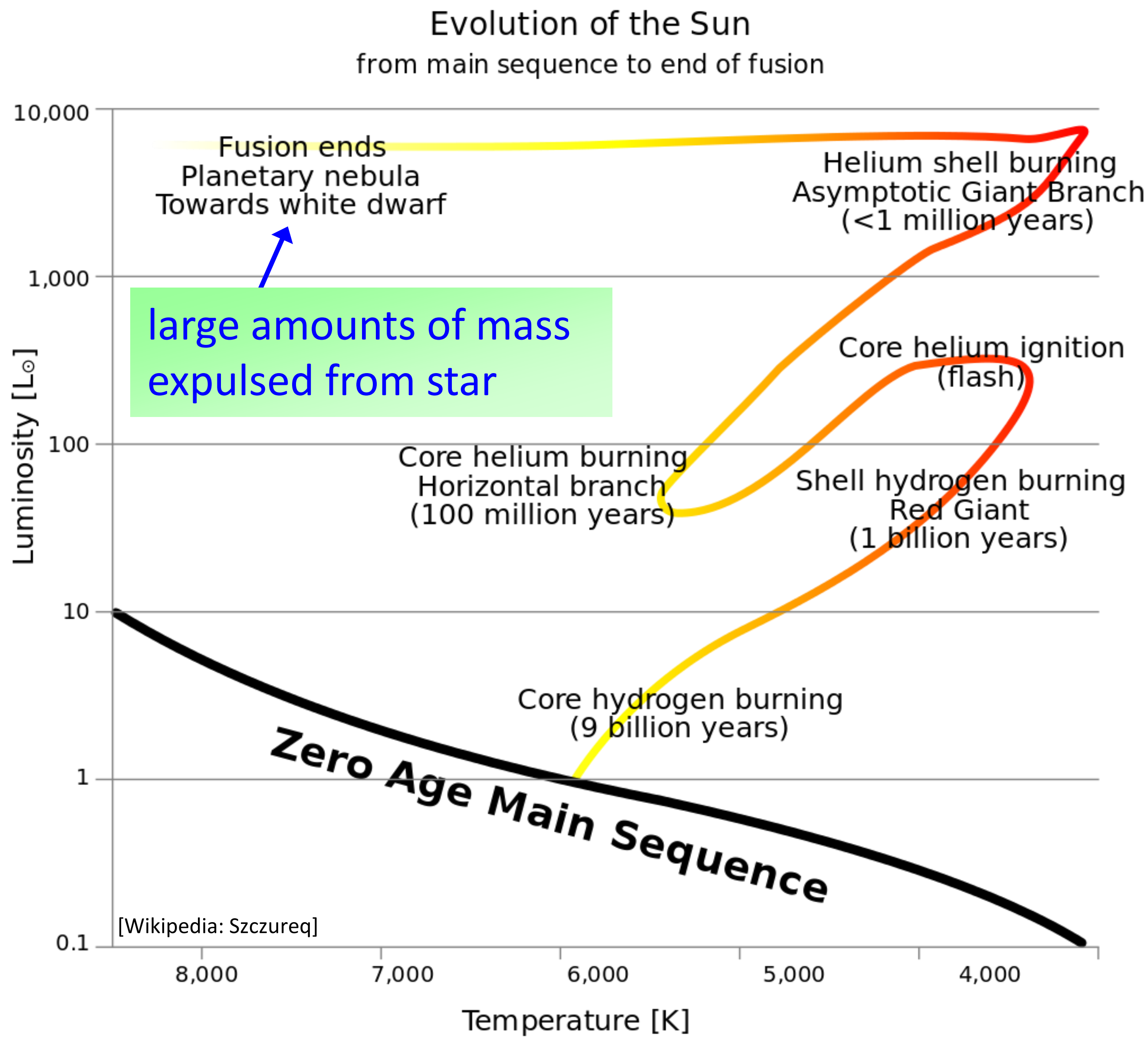
Papers are due in class on Friday, December 6 (last day of classes).

Today's Topics

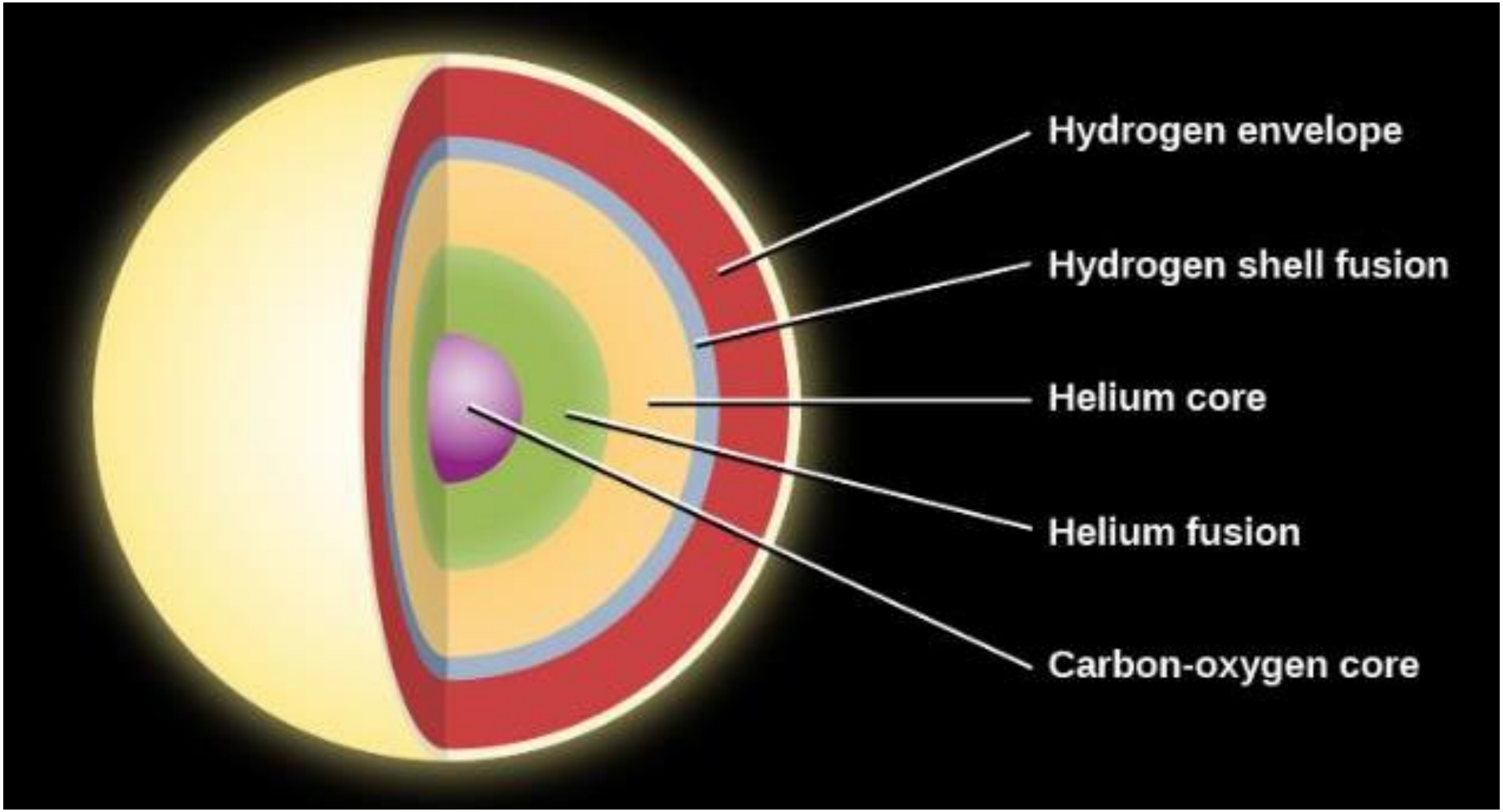
Friday, November 22, 2019 (Week 12, lecture 30) – Chapters 22, 23.

1. Planetary Nebulae.
2. White Dwarfs.
3. Evolution of High Mass Stars.

Red Giant Evolution from Sun-like Star



Structure of Red Giant Star before "Death"



Mass Loss: Planetary Nebula

- Over the course of its red giant phase, a Sun-like star is expected to **shed roughly 50% of its mass**. Gas speed ~ 20-30 km/s.
- This ejected mass becomes a **planetary nebula** with a **white dwarf** at its center.

(note: planetary nebula has nothing to do with planets)

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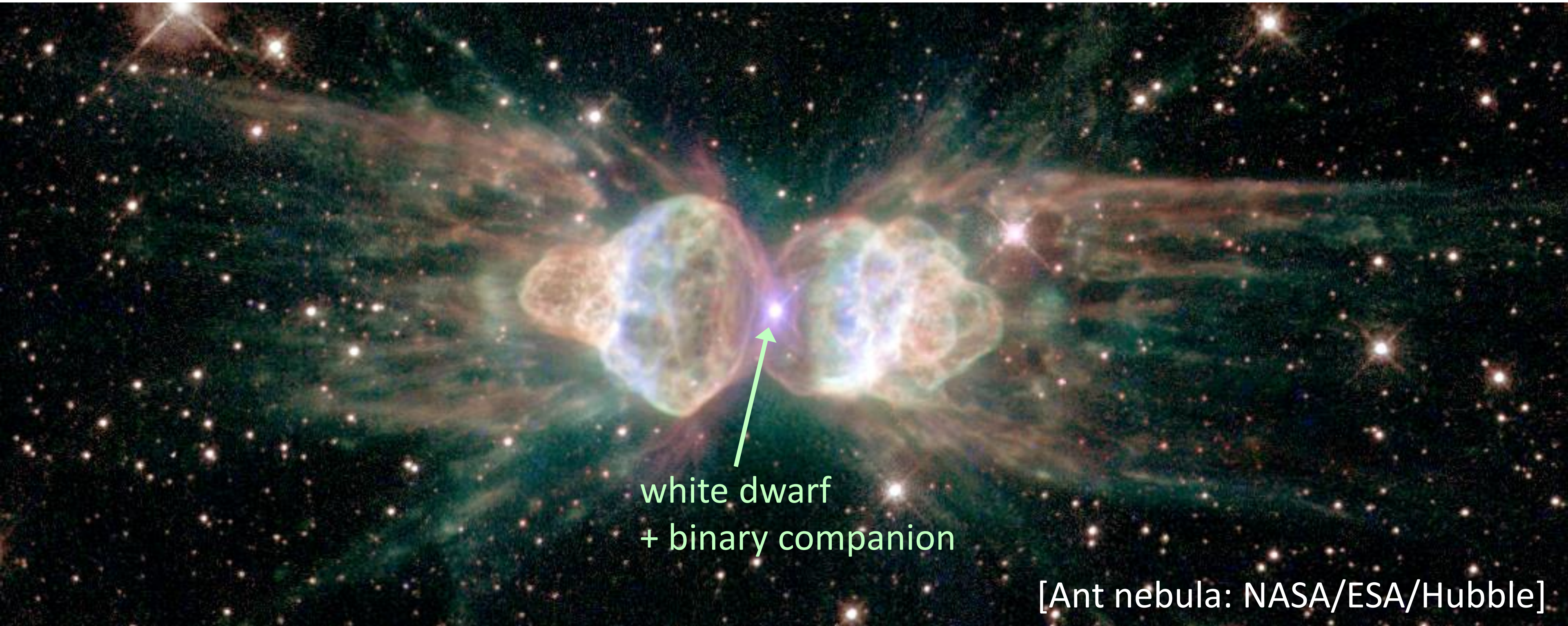

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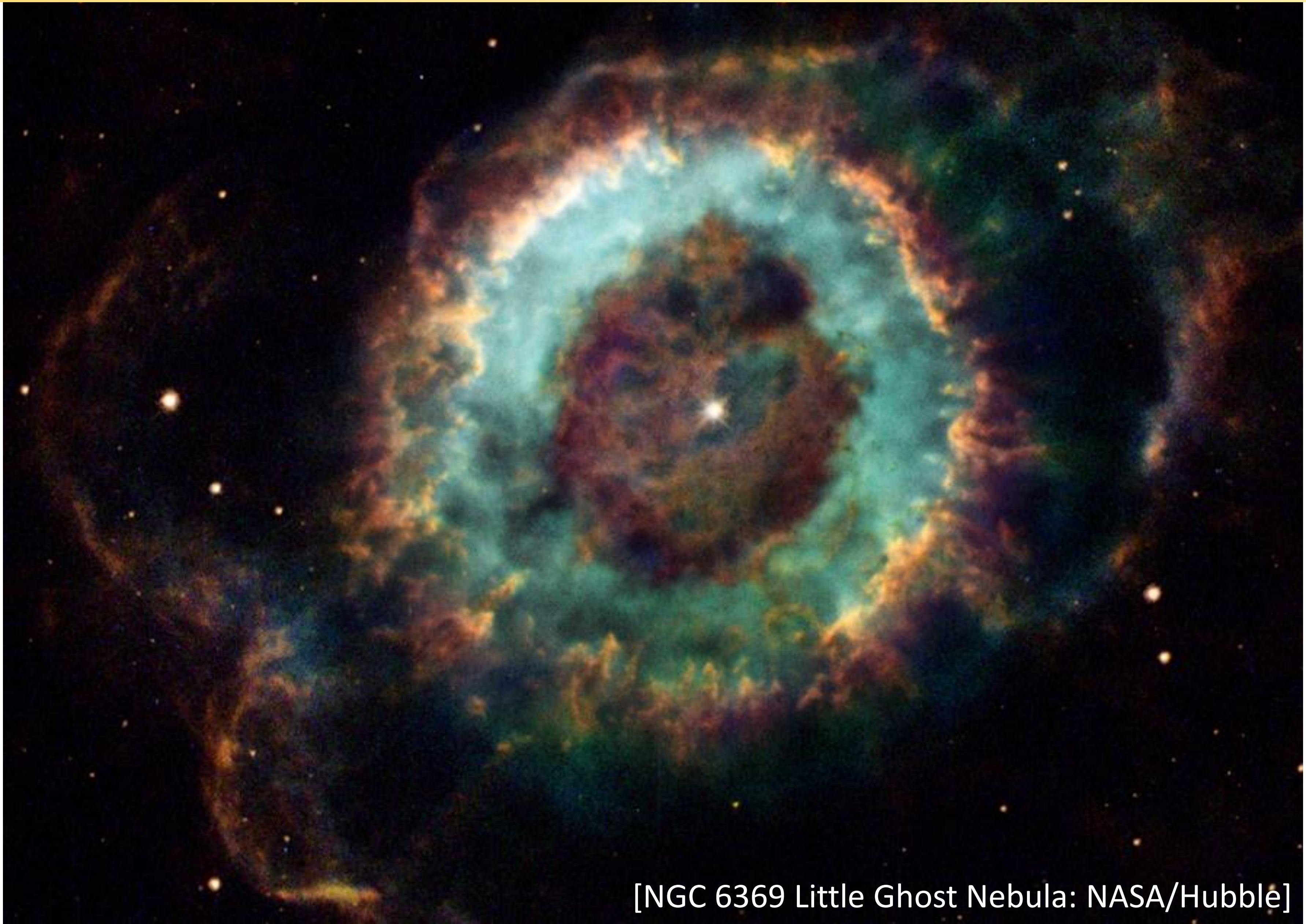

[NGC 6369 Little Ghost Nebula: NASA/Hubble]

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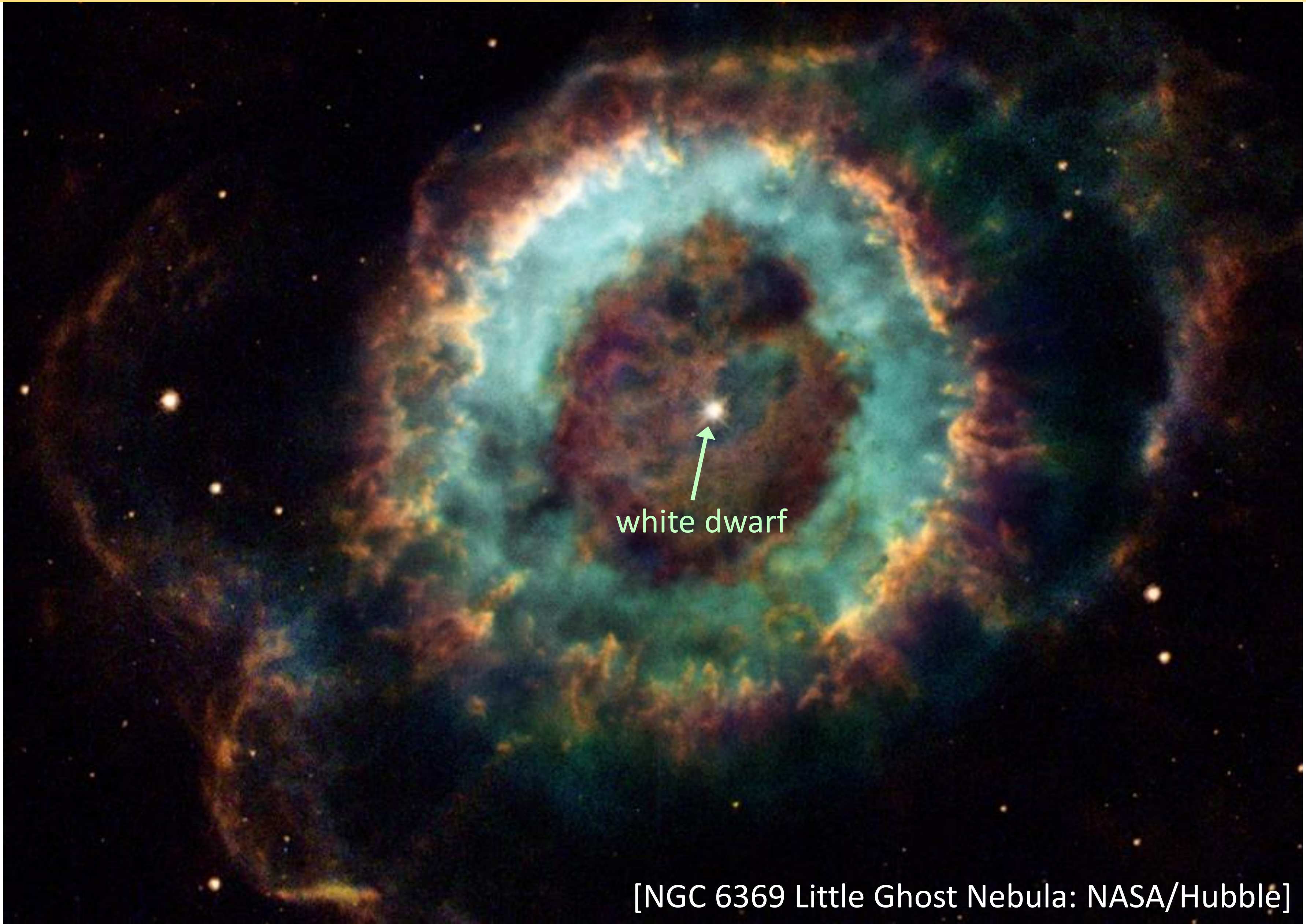

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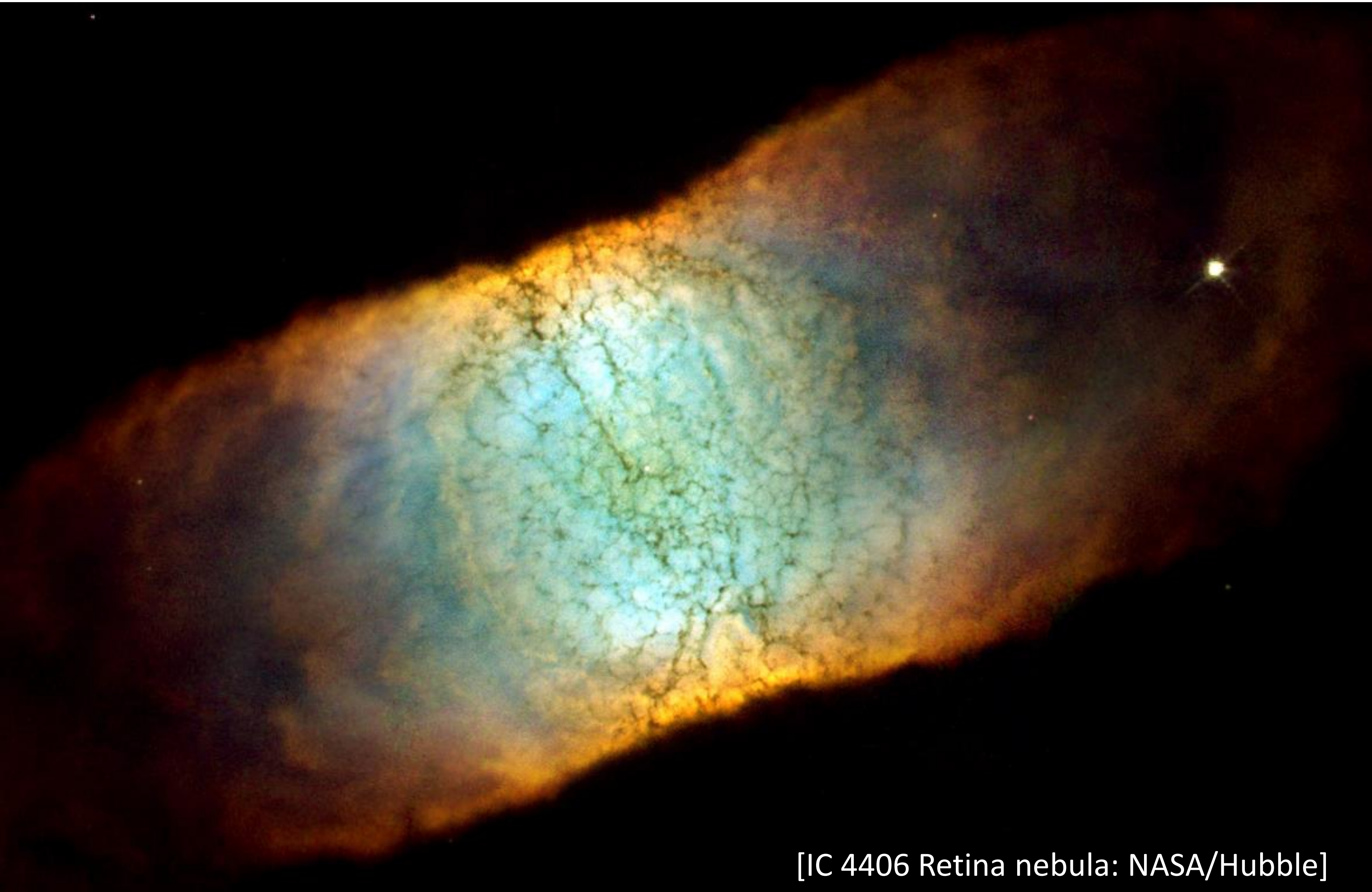

[IC 4406 Retina nebula: NASA/Hubble]

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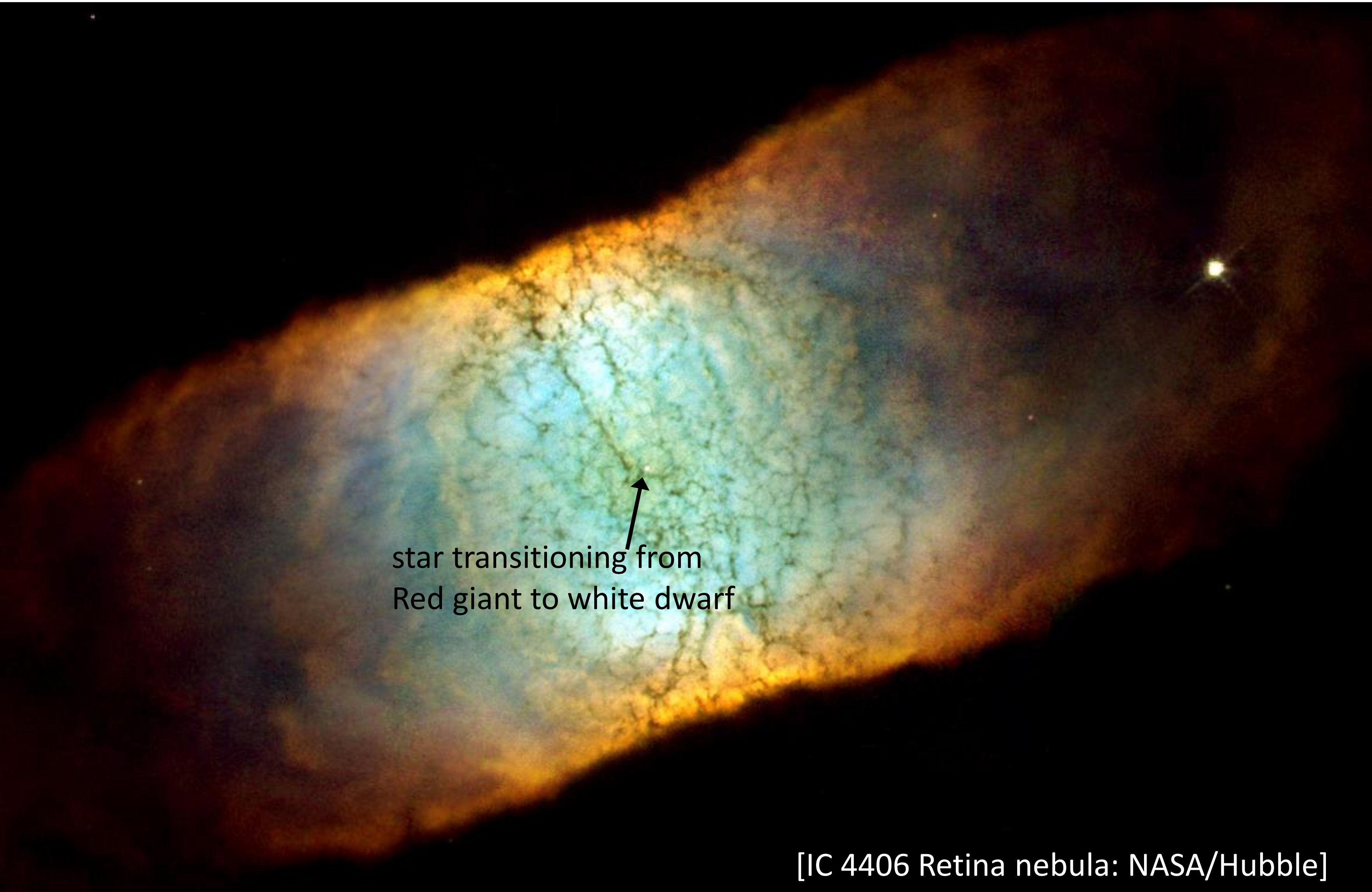

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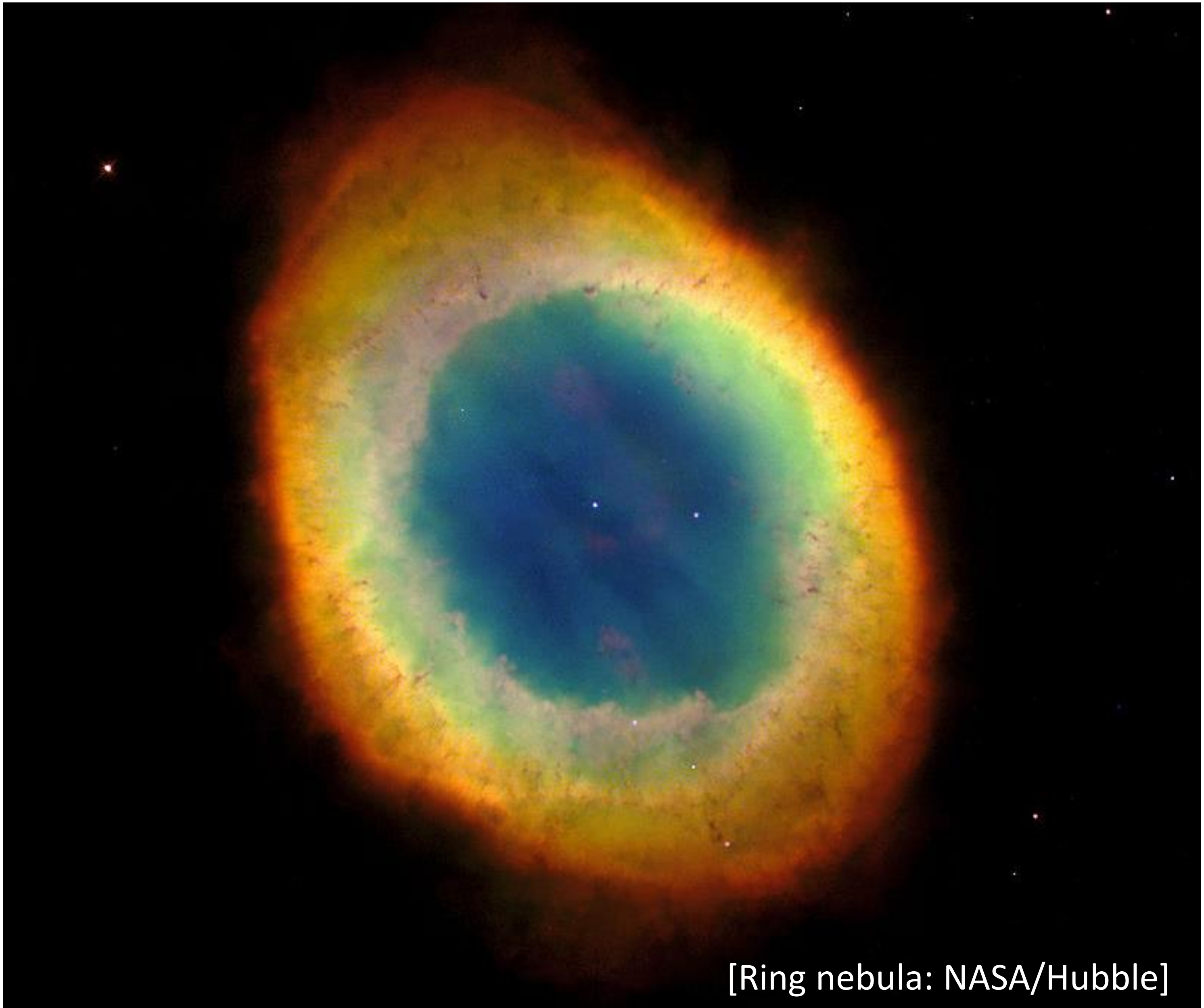
[Ring nebula: NASA/Hubble]

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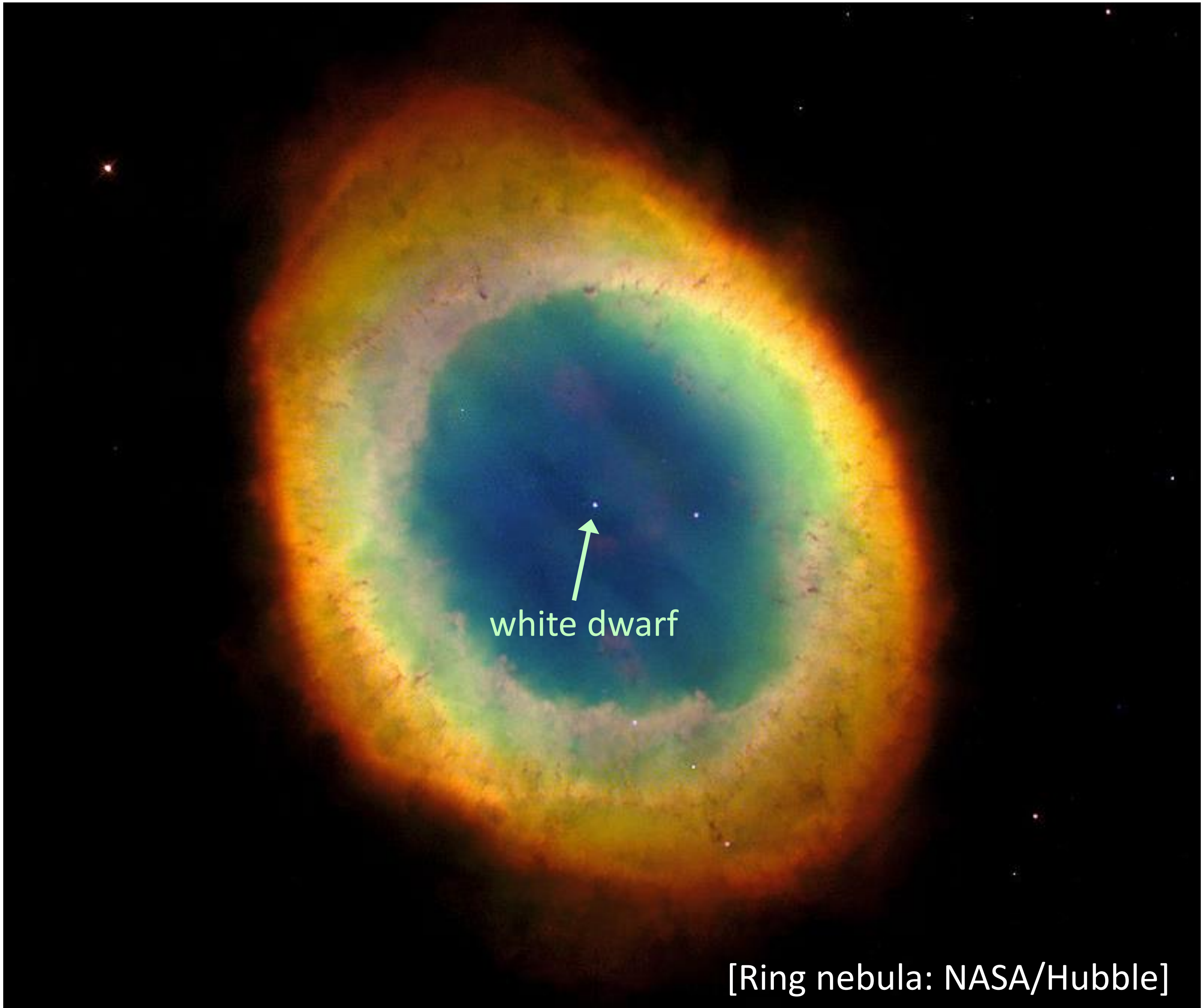

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[Helix nebula: NASA/Hubble]

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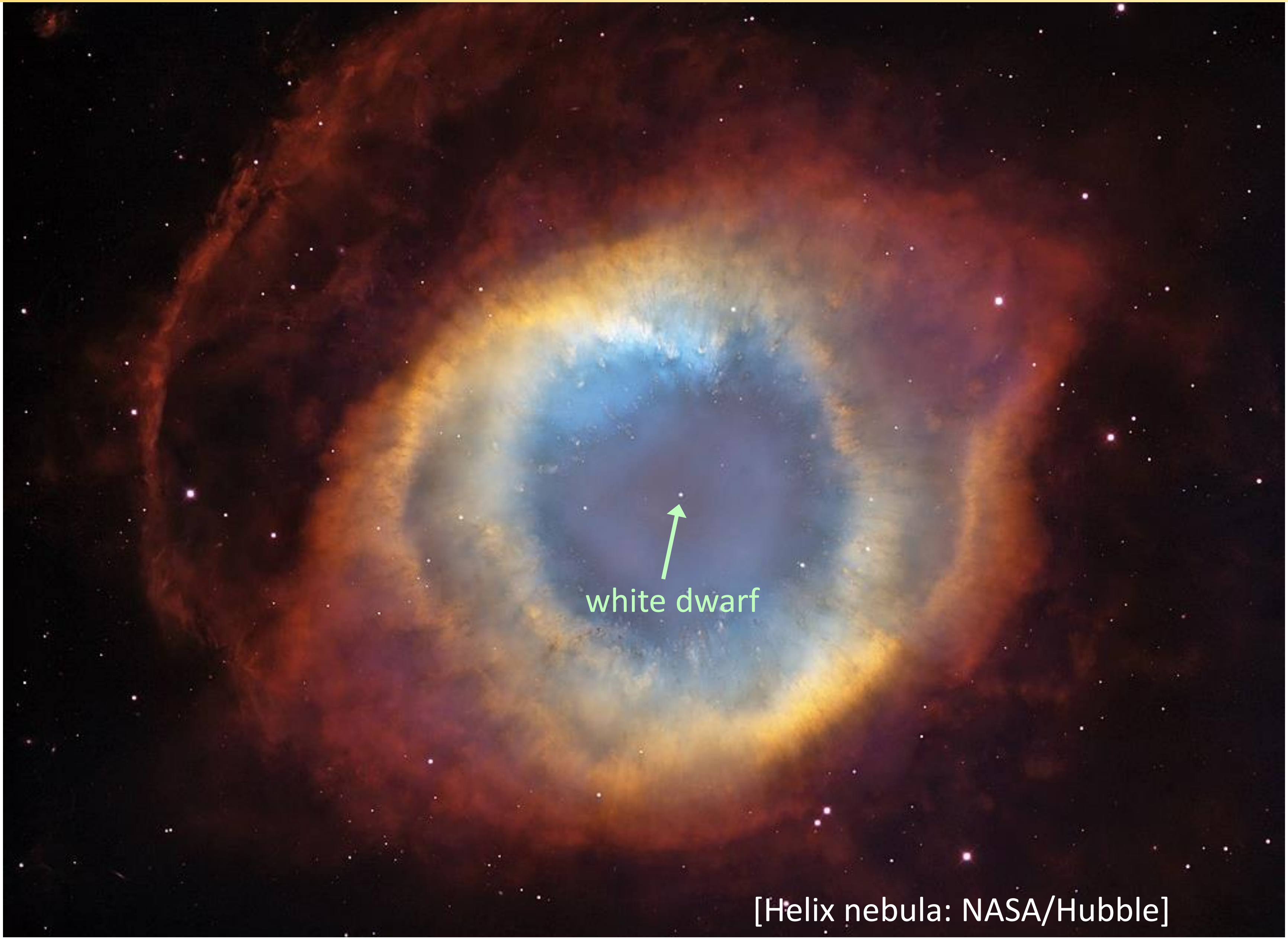

Mass Loss: Planetary Nebula

[M2-9 Twin Jet / Butterfly Wings Nebula: ESA/Hubble]

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[NGC 6302 Butterfly Nebula: NASA/ESA/Hubble SM4 ERO Team]

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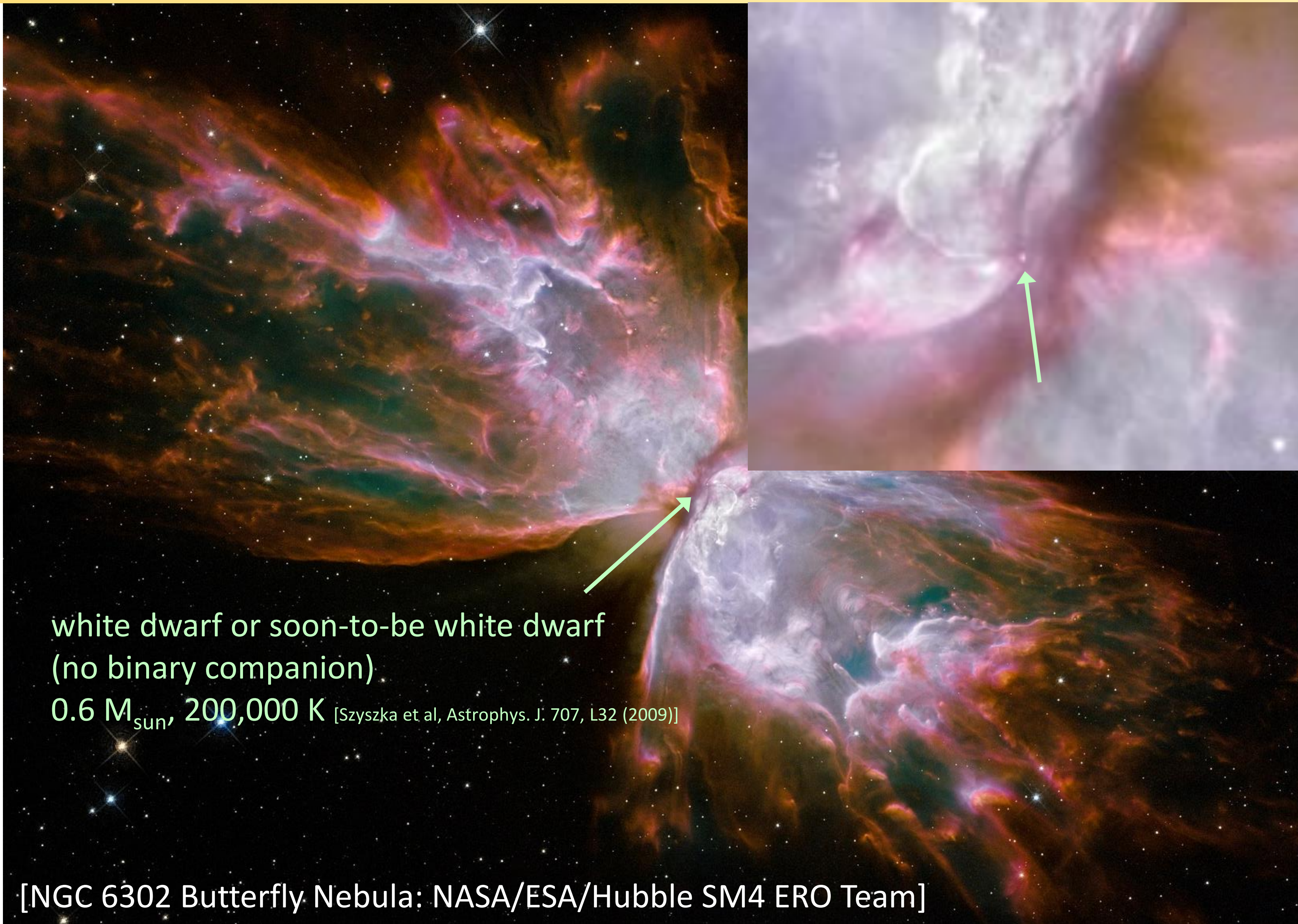
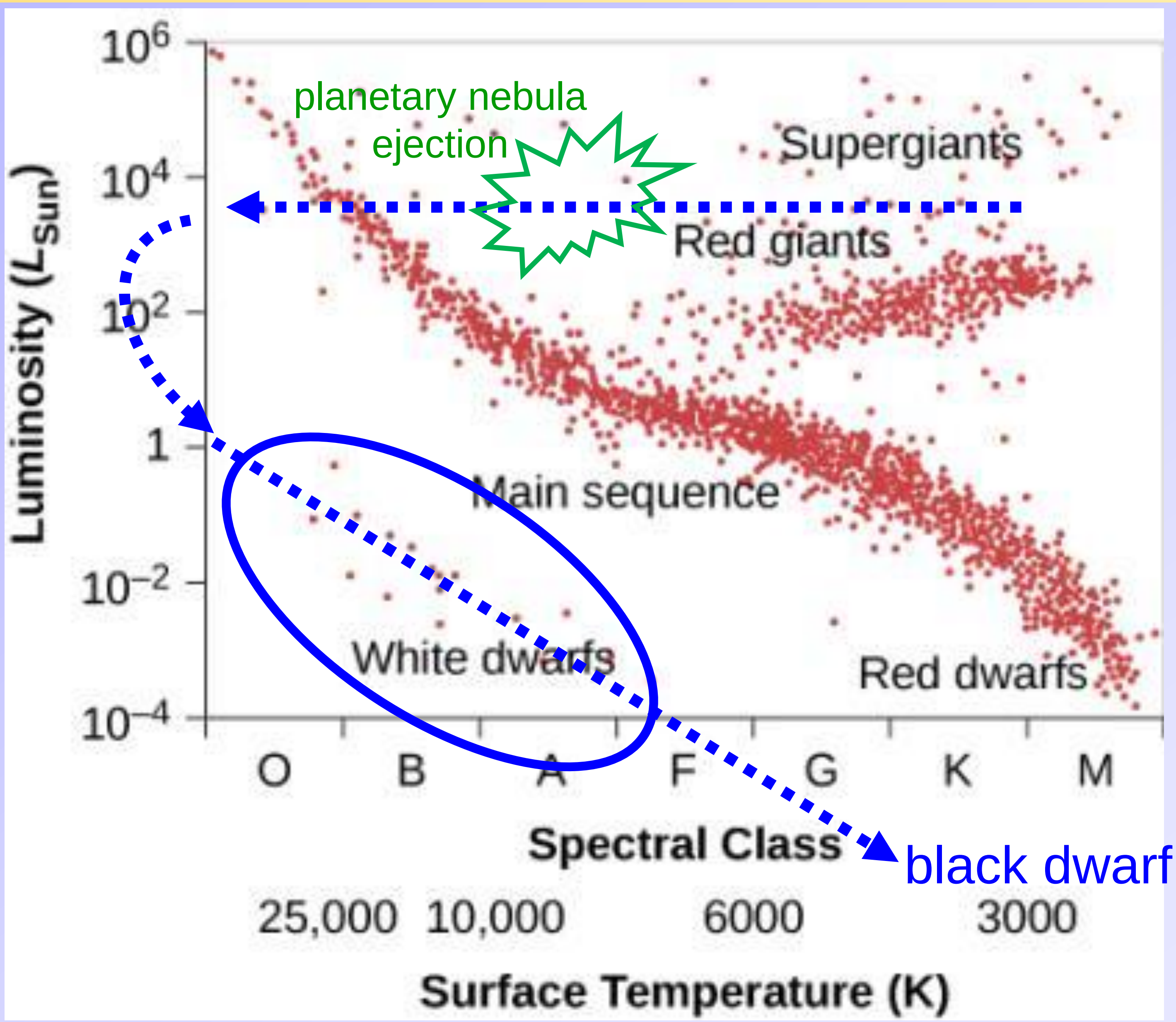


[NGC 6302 Butterfly Nebula: NASA/ESA/Hubble SM4 ERO Team]

White Dwarfs



White Dwarfs

White dwarf

- “Ember” of dead star.
- Does not produce any energy of its own.
  → No fusion
- Starts out “white hot” and cools down to a black dwarf.
- Cools by emitting blackbody radiation.
- Heavier white dwarfs are smaller !!!

[NASA, ESA, H. Bond (STScI), and M. Barstow (University of Leicester)]

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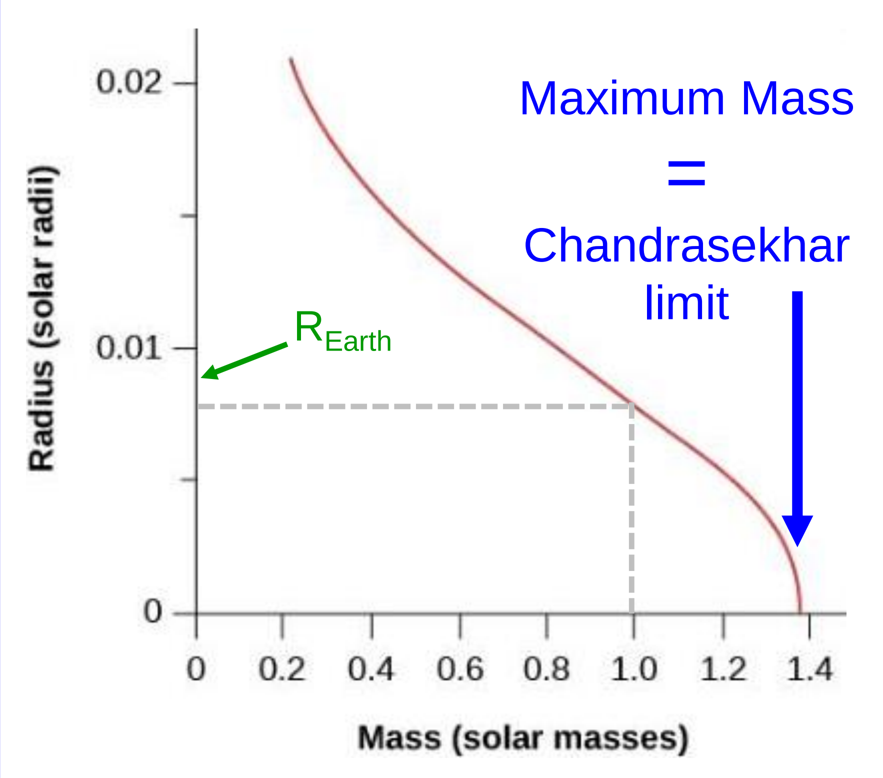

S. Chandrasekhar (1910–1995), Nobel 1983.

White Dwarfs

- A white dwarf is dense enough that ***gravity & pressure are strong enough to overwhelm the electric repulsion*** between nuclei and electrons, but …
- Gravity is counteracted by quantum **"Pauli pressure."**
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White dwarf crystallization

Below ~ 4,000 K, the electric force between nuclei is strong enough to make an ordered arrangement of nuclei, i.e. "**nuclear crystal**."

→ The **core** of the white dwarf **crystallizes**.

→ Some asteroseimology evidence.

Evolution of Massive Stars

Mass is destiny

Evolution of Massive Stars

- Stars with masses above ~ $8M_{Sun}$ can fuse elements above carbon & oxygen.
- The more massive the star, the more elements can produced.

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- Above iron & nickel, fusion does not generate energy.

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Alpha-processes

$${}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{16}_{8}\mathrm{O} + 7.6\ \mathrm{MeV}$$

$${}^{16}_{8}\mathrm{O} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{20}_{10}\mathrm{Ne} + 4.7\ \mathrm{MeV}$$

↓ Mg, Si, S, Ar,
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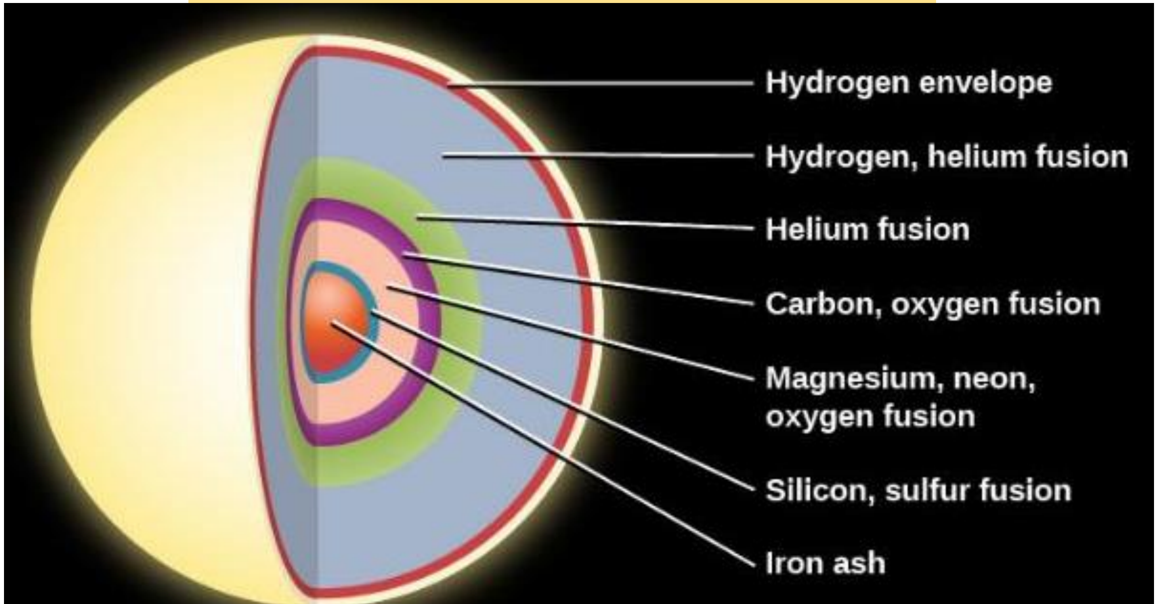
Stellar "onion" of elements



[OpenStax: Astronomy]

Evolution of Massive Stars
Example: SN 1987A

Mass of SN 1987A ≈ $20M_{Sun}$

Phase	Central Temperature (K)	Central Density (g/cm^3)	Time Spent in This Phase
Hydrogen fusion	40×10^6	5	8×10^6 years
Helium fusion	190×10^6	970	10^6 years
Carbon fusion	870×10^6	170,000	2000 years
Neon fusion	1.6×10^9	3.0×10^6	6 months
Oxygen fusion	2.0×10^9	5.6×10^6	1 year
Silicon fusion	3.3×10^9	4.3×10^7	Days
Core collapse	200×10^9	2×10^{14}	Tenths of a second

type II supernova → neutron star typically (or black hole)

Fusion production of iron & nickel

[Table 23.2, OpenStax: Astronomy]

Ultimate Fate of Stars

Initial Mass (Mass of Sun = 1)[1]	Final State at the End of Its Life
< 0.01	Planet
0.01 to 0.08	Brown dwarf
0.08 to 0.25	White dwarf made mostly of helium
0.25 to 8	White dwarf made mostly of carbon and oxygen
8 to 10	White dwarf made of oxygen, neon, and magnesium
10 to 40	Supernova explosion that leaves a neutron star
> 40	Supernova explosion that leaves a black hole

type II supernova

[Table 23.1, OpenStax: Astronomy]

Supernova SN 1987A

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

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

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Note: No neutron star has been detected yet !

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
Radius	7000 km (Earth size)	10 km (city size)
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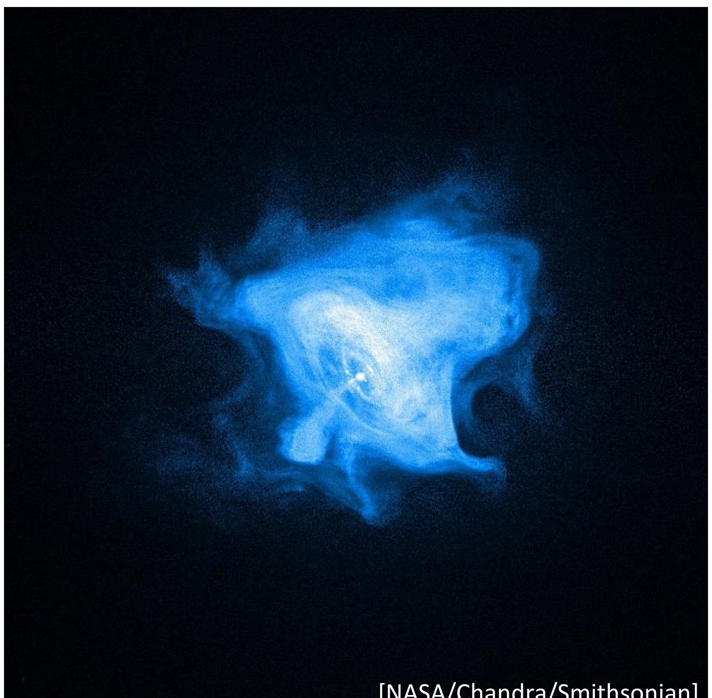

X-ray image of Crab Nebula neutron star, 2008

X-ray + optical images of Crab Nebula neutron star