

# Supernovae and Neutron Stars

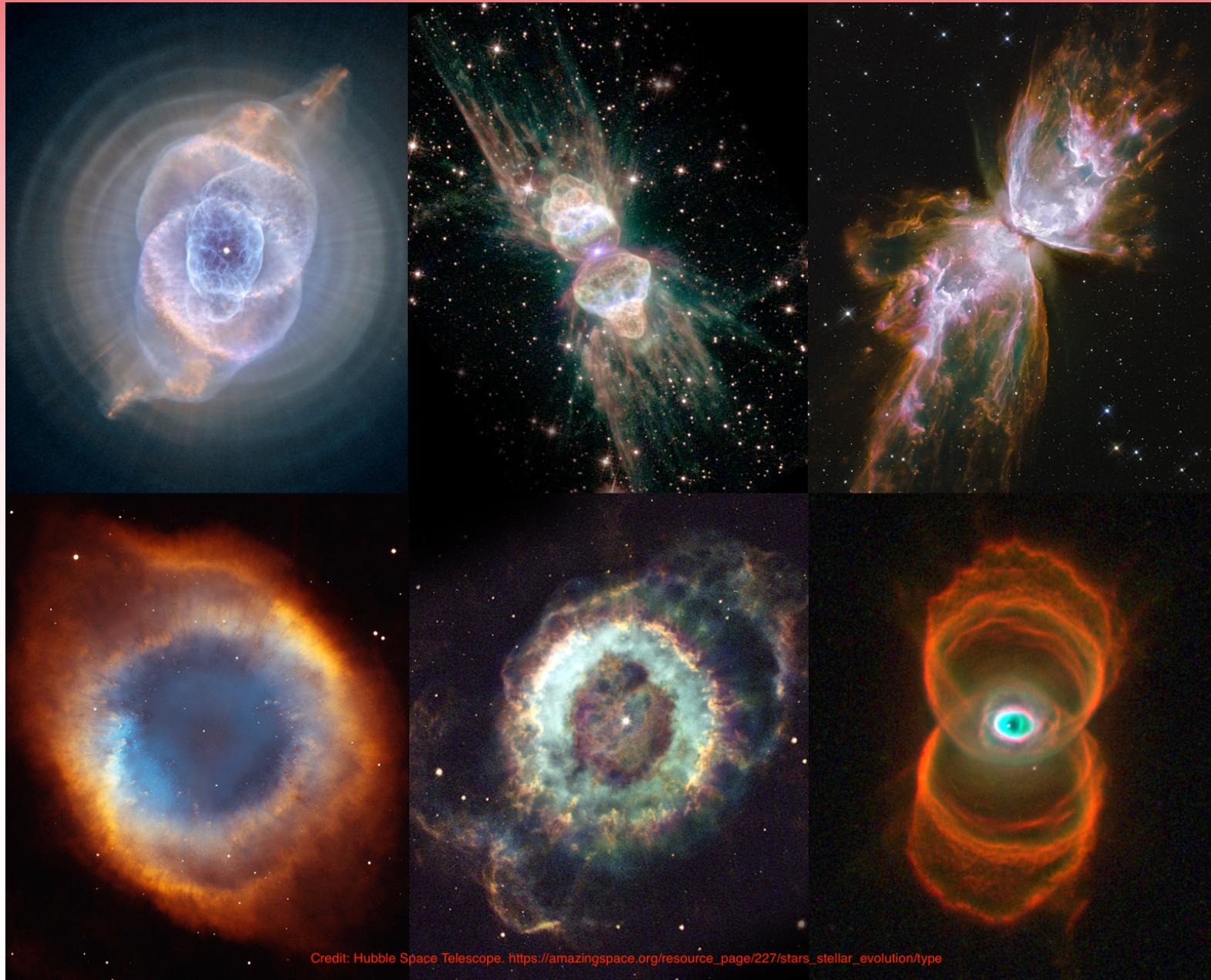
*Physics 090*

2020-04-29

# Endgames of Stars—By Size

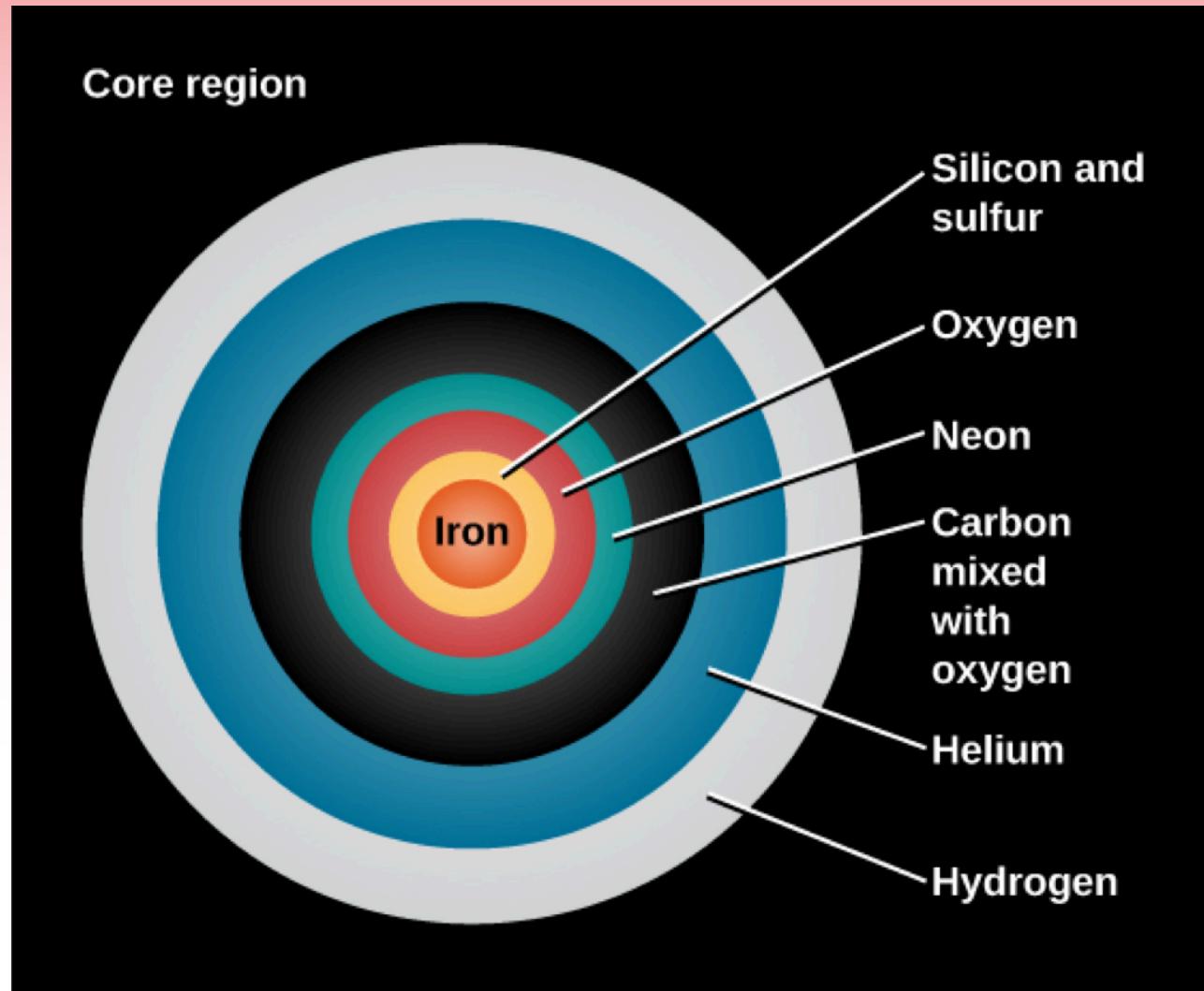
Initial Mass (Mass of Sun = 1) <sup>[1]</sup>	Final State at the End of Its Life
< 0.01	Planet
0.01 to 0.08	Brown dwarf
0.08 to 0.25	White dwarf made mostly of helium
0.25 to 8	White dwarf made mostly of carbon and oxygen
8 to 10	White dwarf made of oxygen, neon, and magnesium
10 to 40	Supernova explosion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

# "Planetary" Nebulae in Our Galaxy



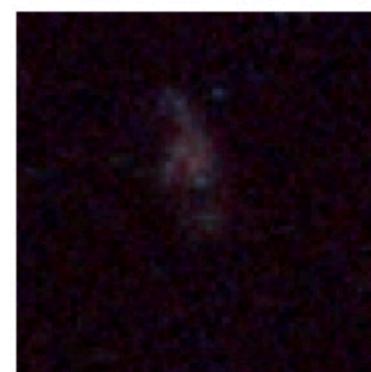
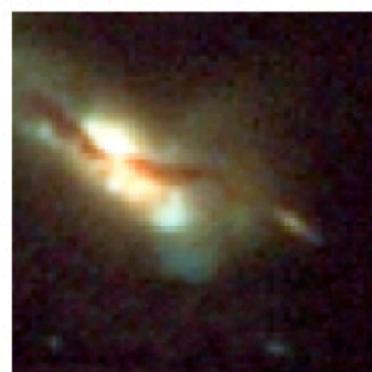
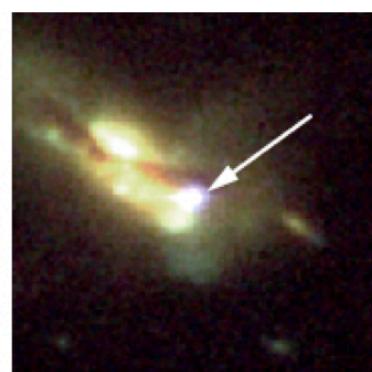
Credit: Hubble Space Telescope. [https://amazingspace.org/resource\\_page/227/stars\\_stellar\\_evolution/type](https://amazingspace.org/resource_page/227/stars_stellar_evolution/type)

# End of Fusion — Massive Star >8x Sun



# Supernovae Observed in Other Galaxies

(None in our Galaxy in >300 years)



HST04Sas

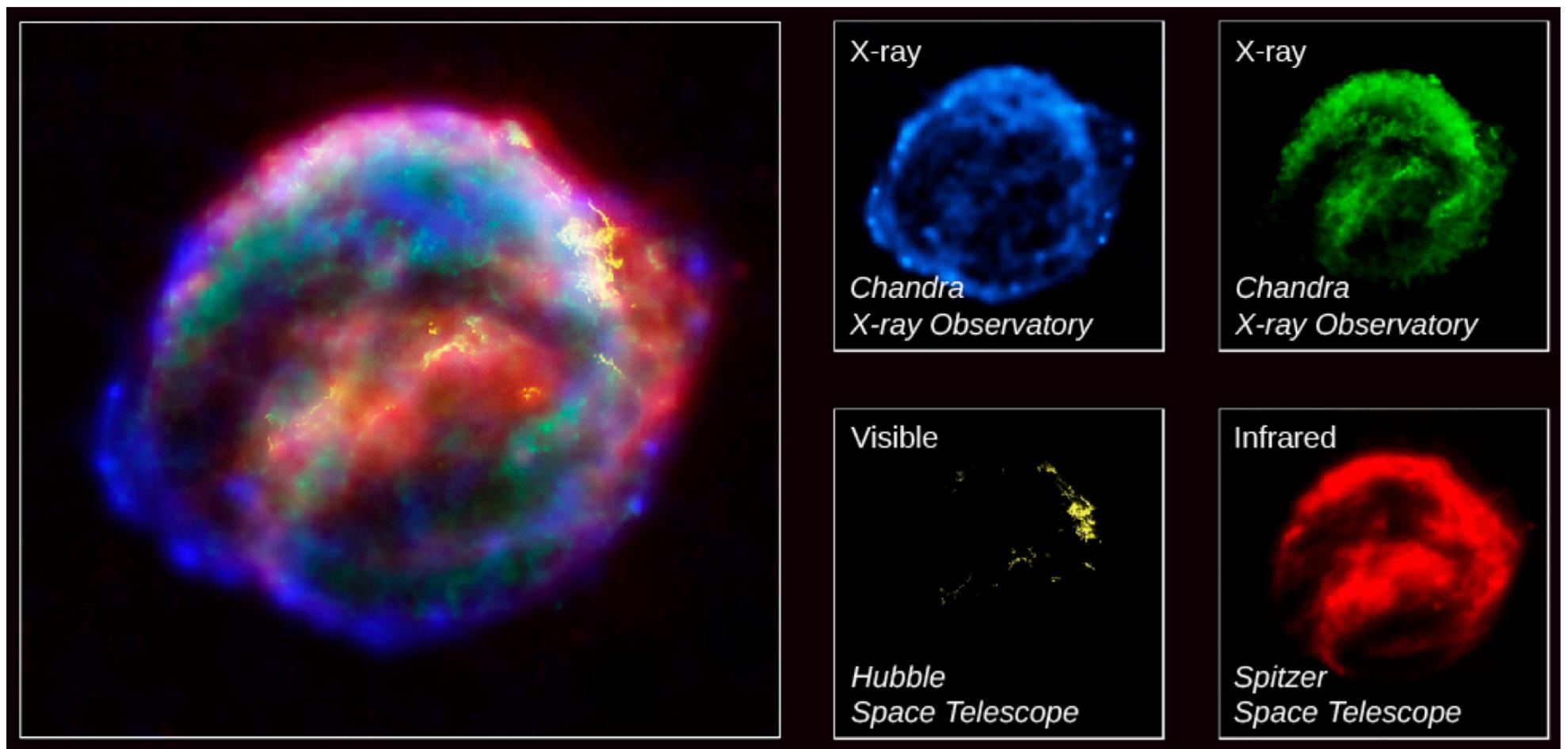
HST04Yow

HST04Zwi

HST05Lan

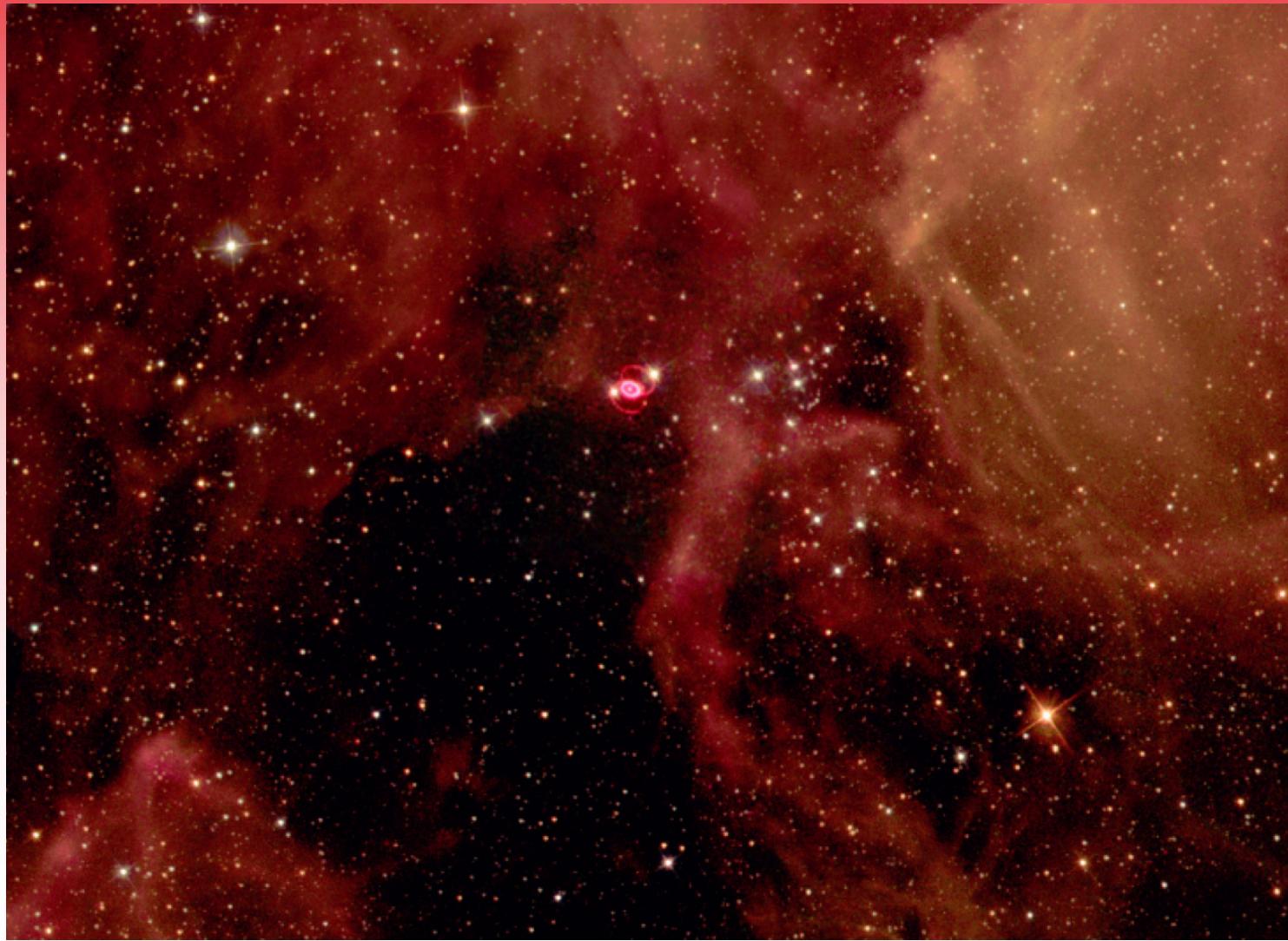
HST05Str

# Composite Image Kepler Supernova Today

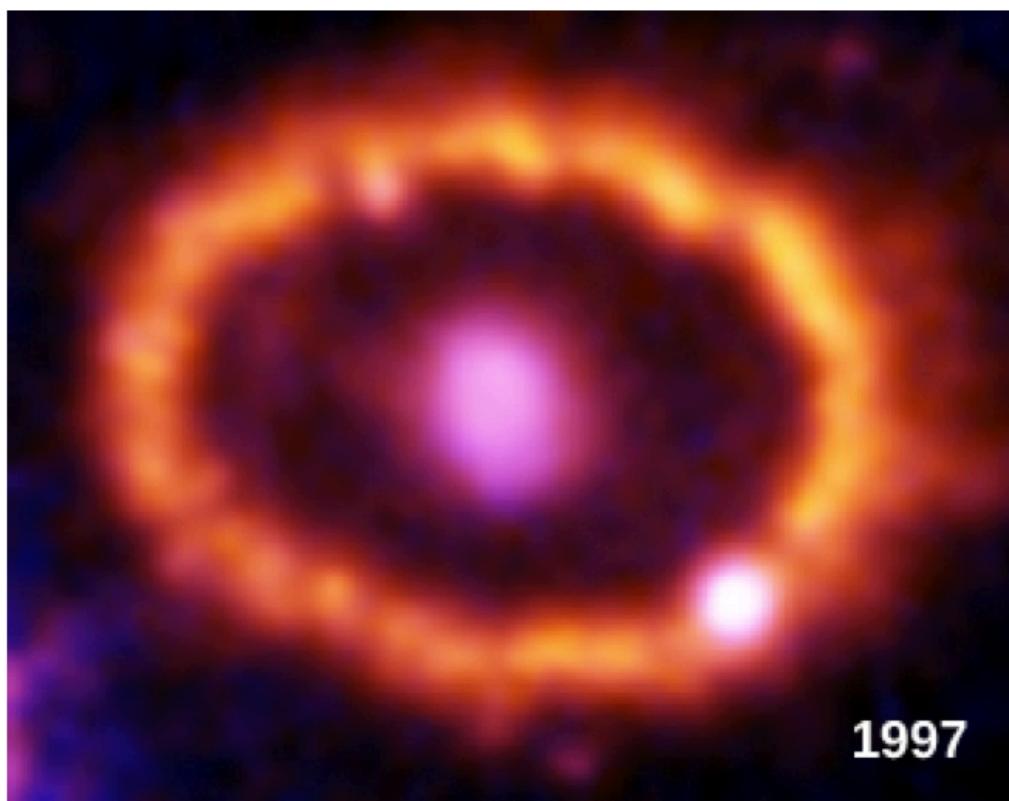




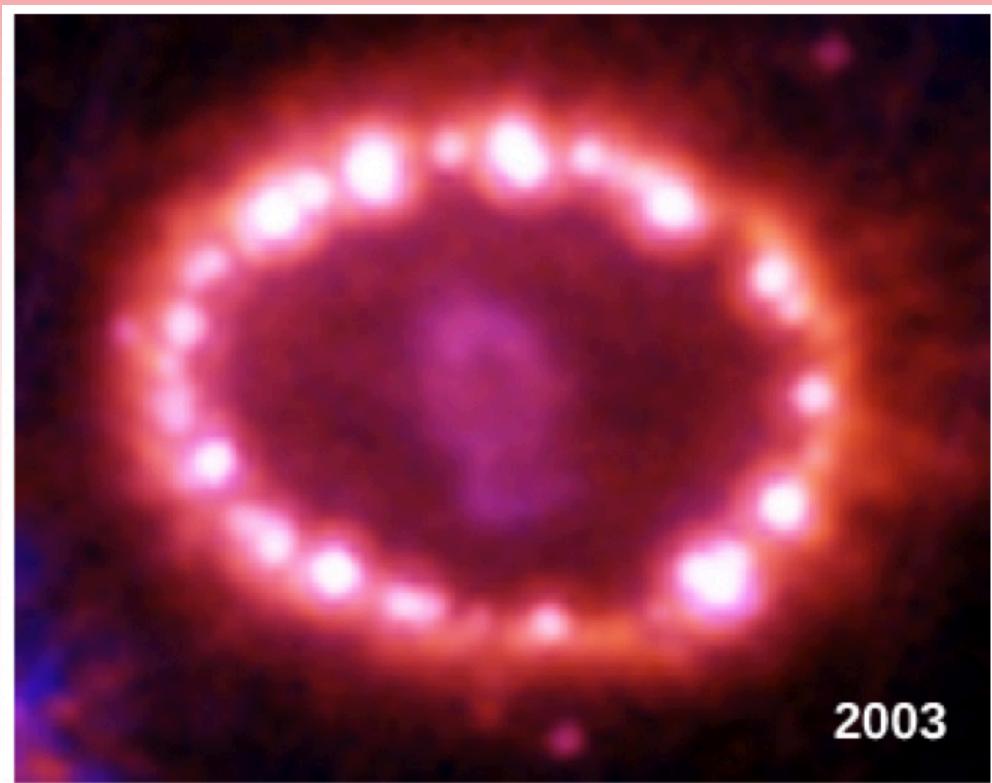
Composite Image  
Supernova 1006



Hubble Space Telescope Image  
Supernova 1987A



1997



2003

Evolution of  
Supernova 1987A

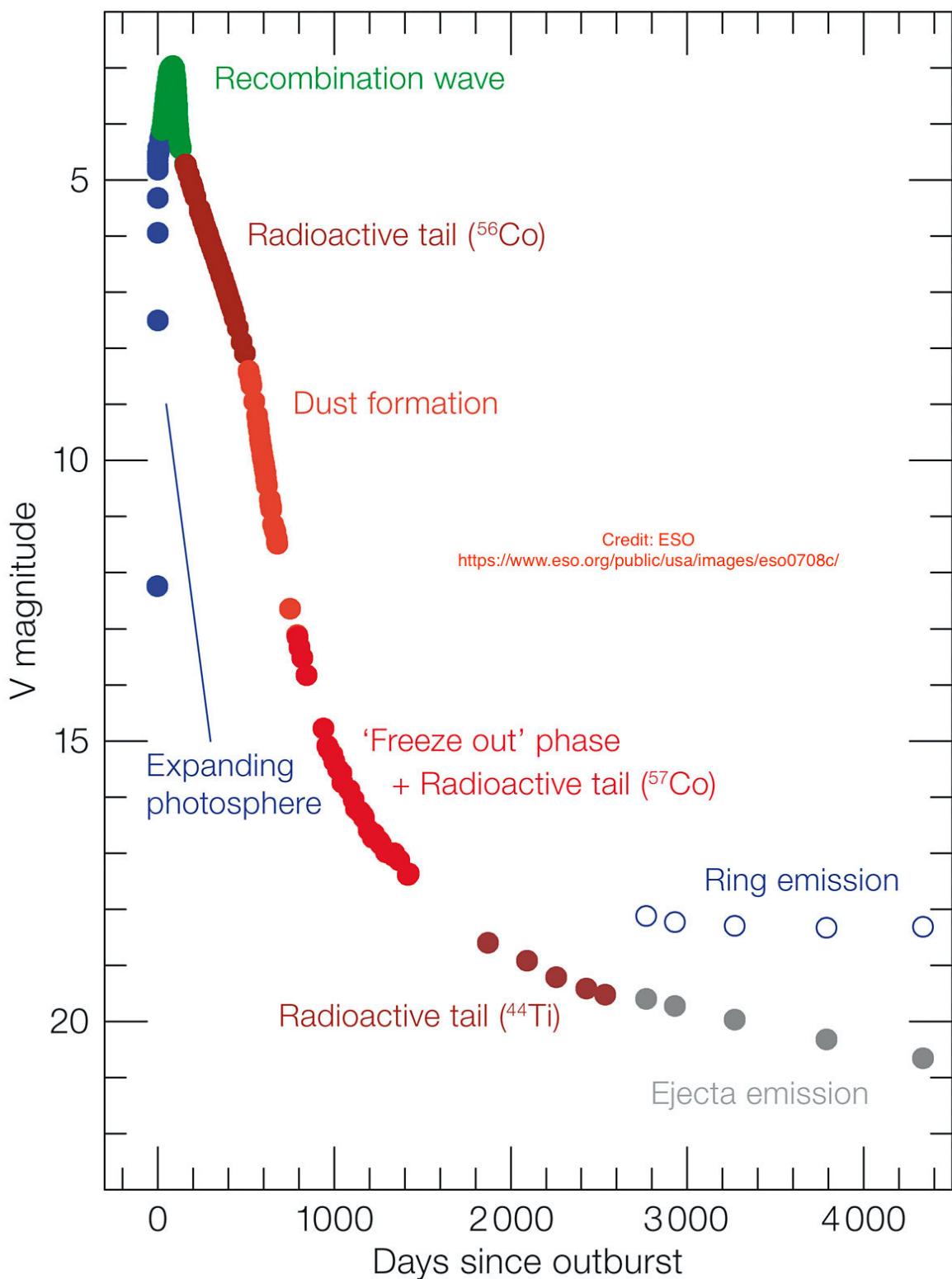
# The Life History of the Star Leading to Supernova 1987A

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

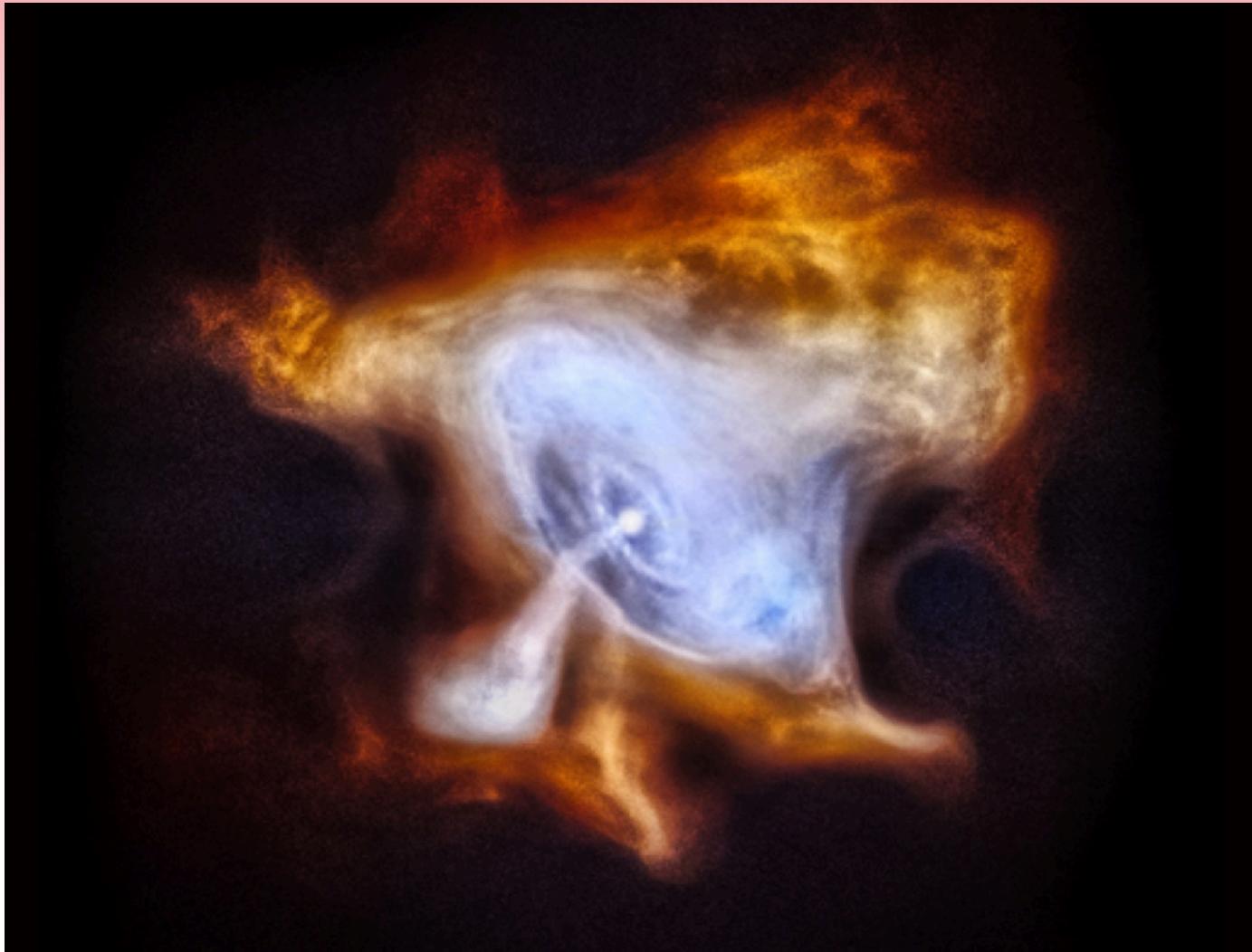
# Light Curve

## Supernova 1987A

### European Southern Observatory



# Neutron Star in Crab Nebula (Supernova of 1054)



# Pulsars—Spinning Neutron Stars

