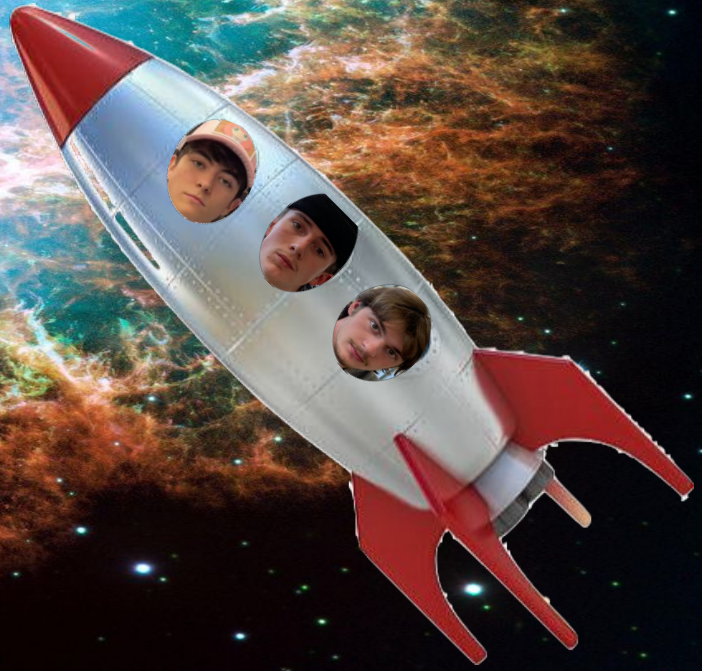
ASTR 311 – Supernovae



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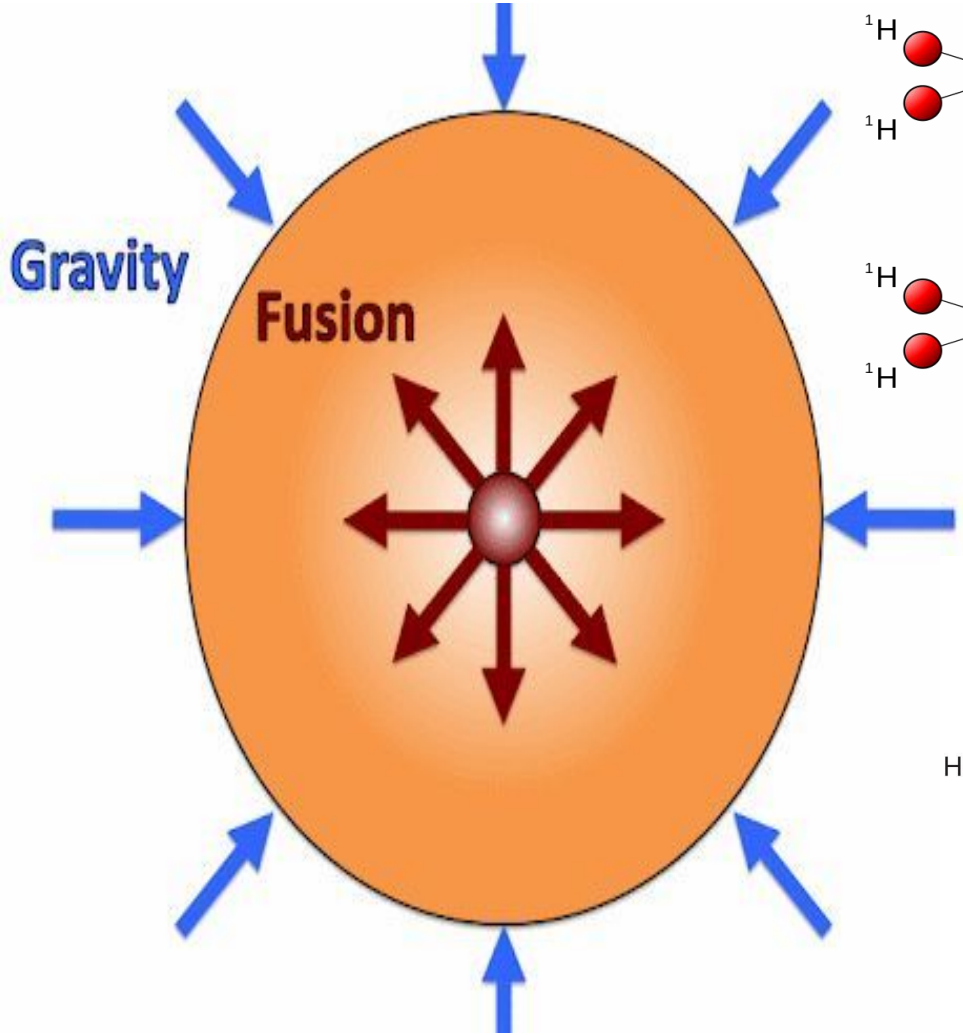
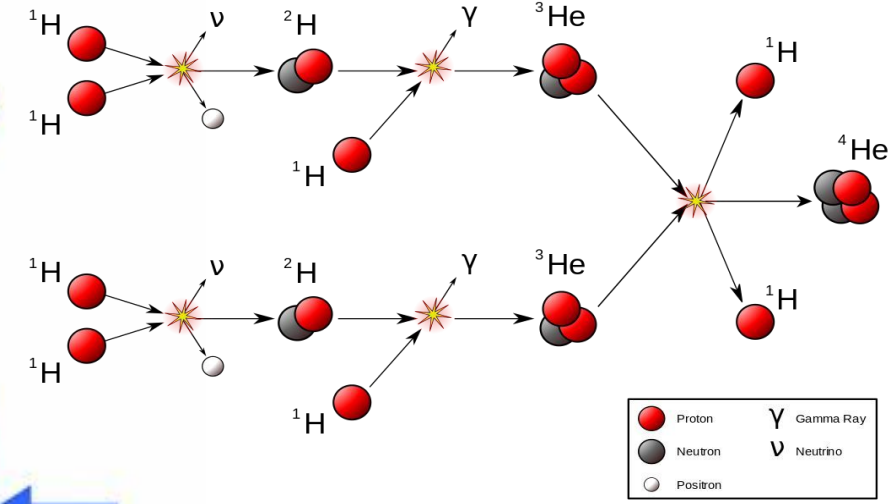
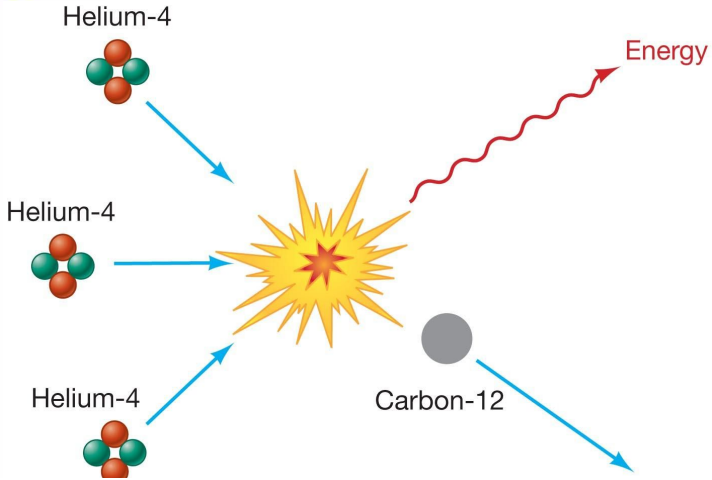
Presentation Overview

- Introduction to Supernovae
- Types of Supernovae
- Causes of Supernovae
- Supernovae Life Cycle
- Supernova Explosion Process
- How Supernovae Affect the Universe
- Famous Instances
- Future Supernovae
- Detection of Supernovae
- Recent Discoveries & Ongoing Research

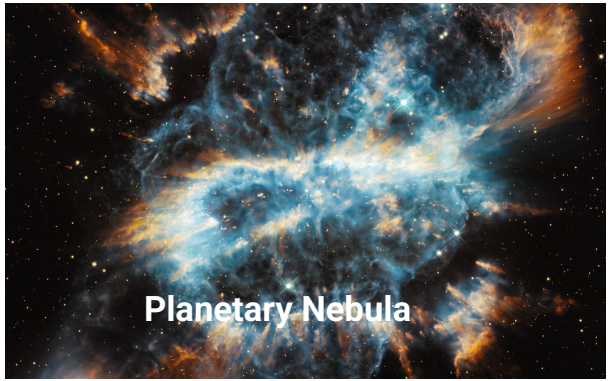
What is a Supernova?


Gravity
Fusion


^{1}H
^{1}H
ν
^{2}H
^{1}H
γ
^{3}He
^{1}H
^{4}He
^{1}H
^{1}H
^{1}H
ν
^{2}H
^{1}H
γ
^{3}He
^{1}H
Proton
Neutron
Positron
γ Gamma Ray
ν Neutrino


Helium-4
Helium-4
Helium-4
Energy
Carbon-12

Low Mass Stars

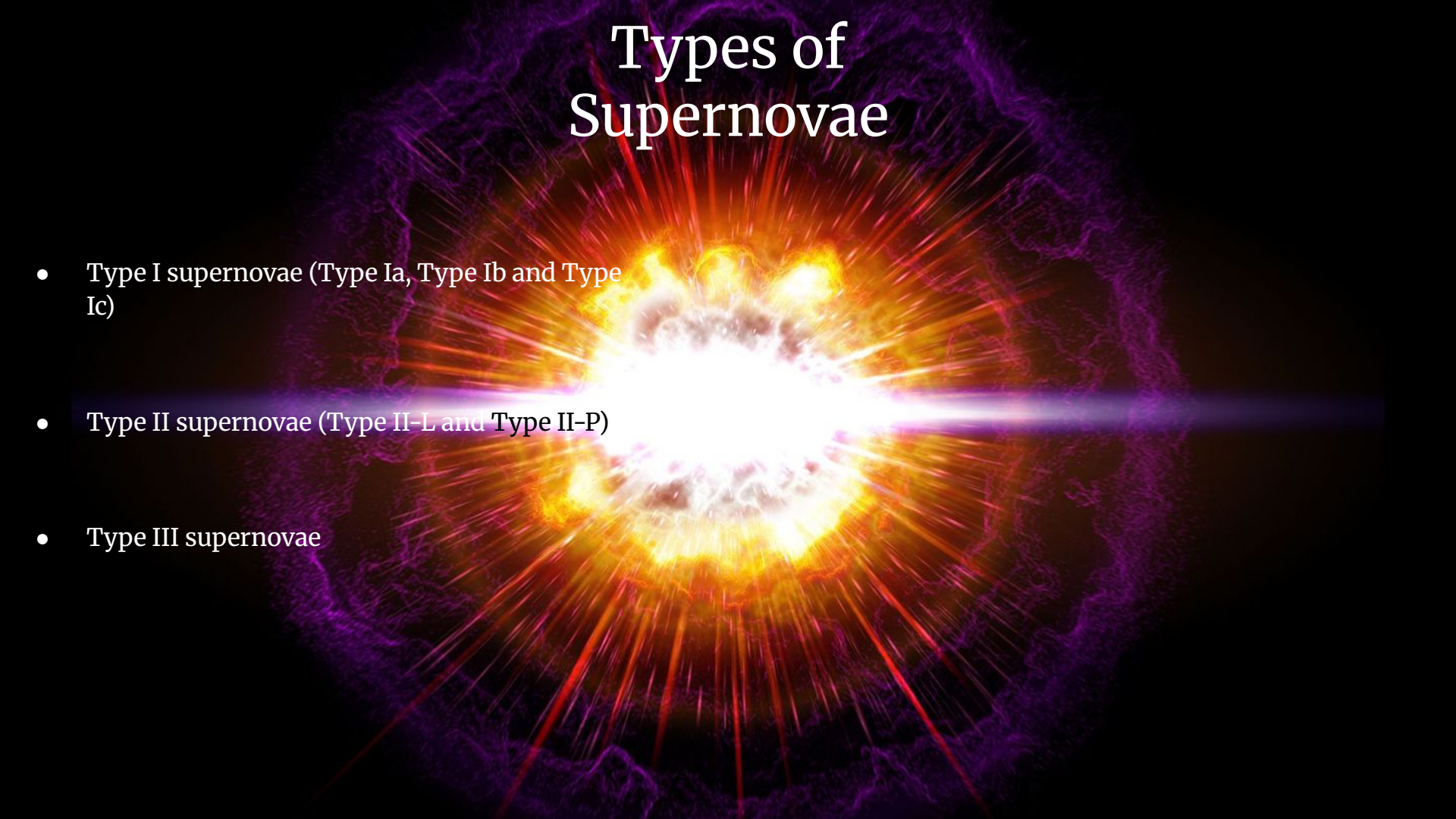


Large Mass Stars

Why do we study them?

- Understand the life cycles of stars
- Origins of heavy elements (like gold and iron)
- Clues about the expansion of the universe
- Insight into black holes and neutron stars
- Impact on nearby space environments
- Cosmic “labs” for high-energy particles

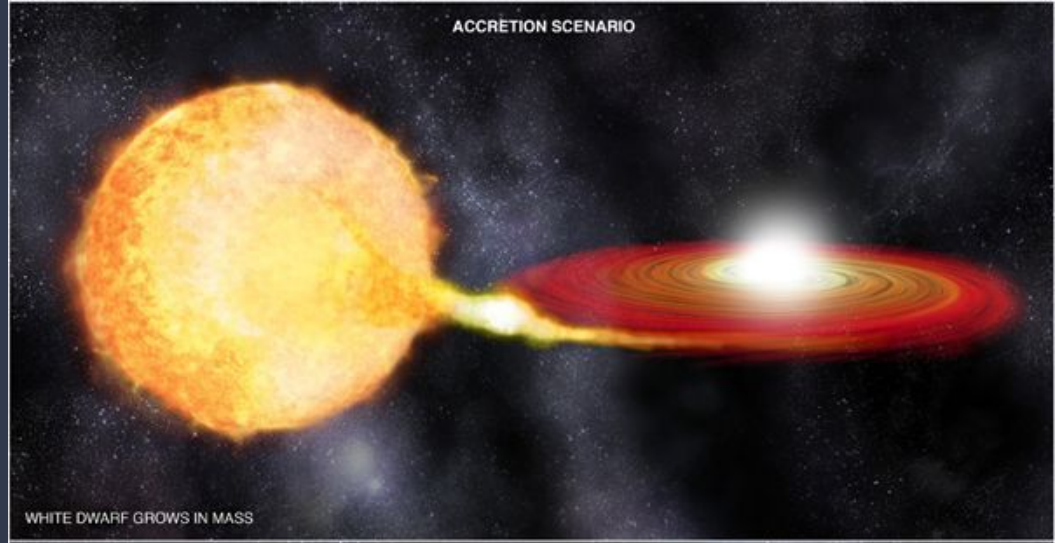
Types of Supernovae

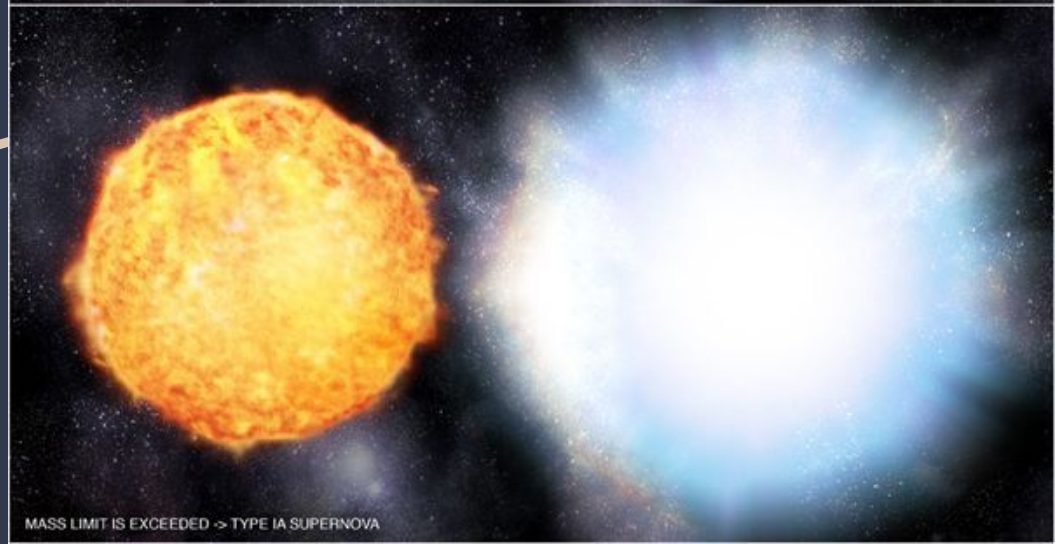


- Type I supernovae (Type Ia, Type Ib and Type Ic)
- Type II supernovae (Type II-L and Type II-P)
- Type III supernovae

Type Ia Supernovae

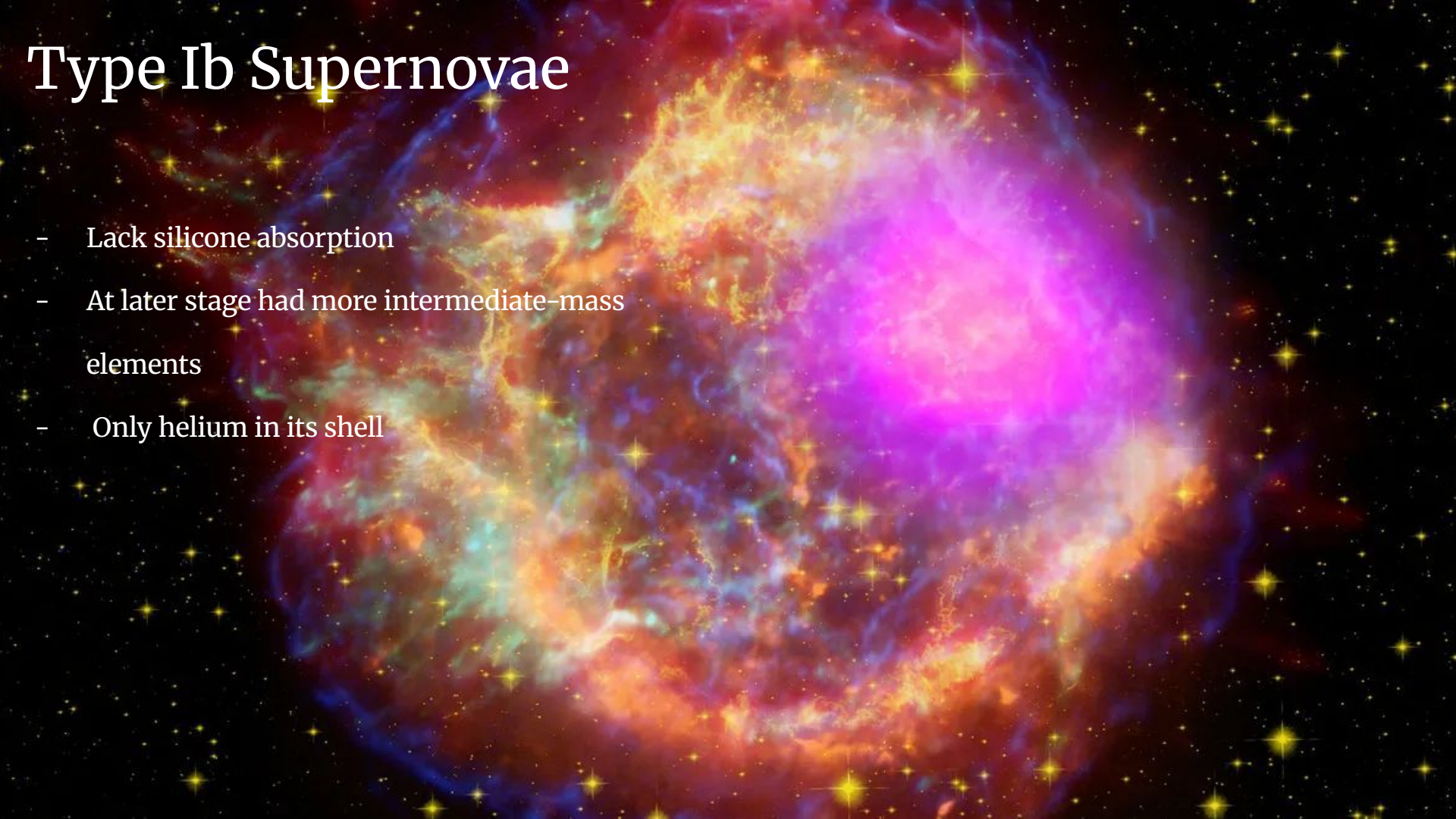
- White Dwarf Star 1.4 solar mass
- Consistent peak brightness
- Brightest of all supernovae
- Little to no hydrogen





Type Ib Supernovae

- Lack silicone absorption
- At later stage had more intermediate-mass elements
- Only helium in its shell



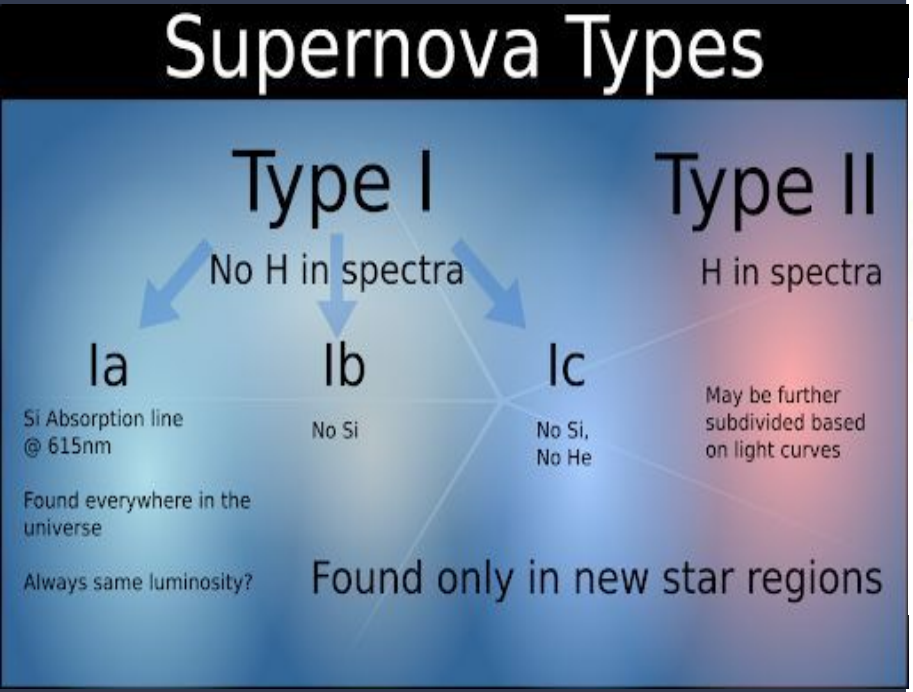
Type Ic Supernovae

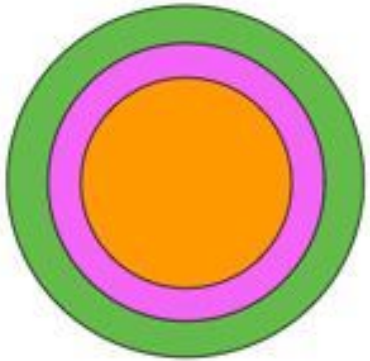
- Difference between type Ic and type Ib supernovae that a type Ic supernova has no helium or hydrogen in its spectra.

Type II Supernovae

- Hydrogen emission lines in their spectra and have light curves that differ notably from those of Type I supernovae
- Two subtypes: Type II-L and Type II-P
- Both hydrogen and helium layer

Diagrams





Type II
H and He shells

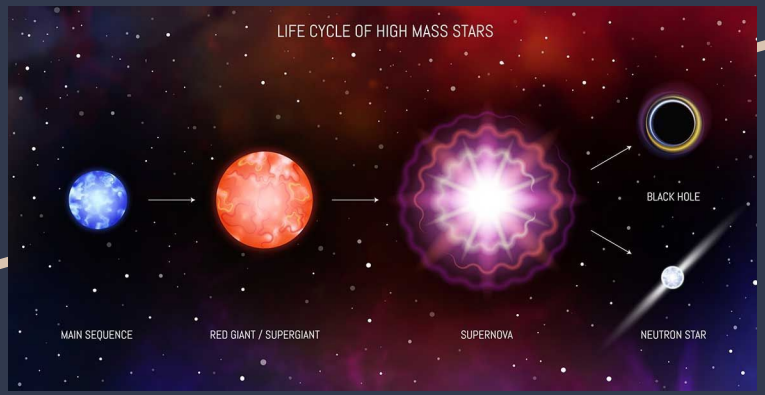
Type Ib
He shell only
no H shell

Type Ic
no H nor He shells

Type III Supernovae

- Also called electron-capture supernova
- Occurs in stars with 8-10 solar masses
- Electrons absorbed by atoms of magnesium and neon
- Reduces the number of free electrons

What Causes Supernovas?



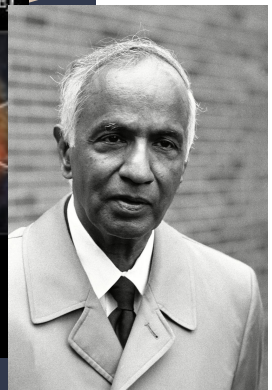
- Two main triggers
  - Core collapse (massive stars - Type II)
  - Runaway fusion (white dwarfs - Type I)

- End-of-life event for certain stars
- Involves extreme pressure, temperature, and gravity
- Releases massive energy - briefly outshines entire galaxy

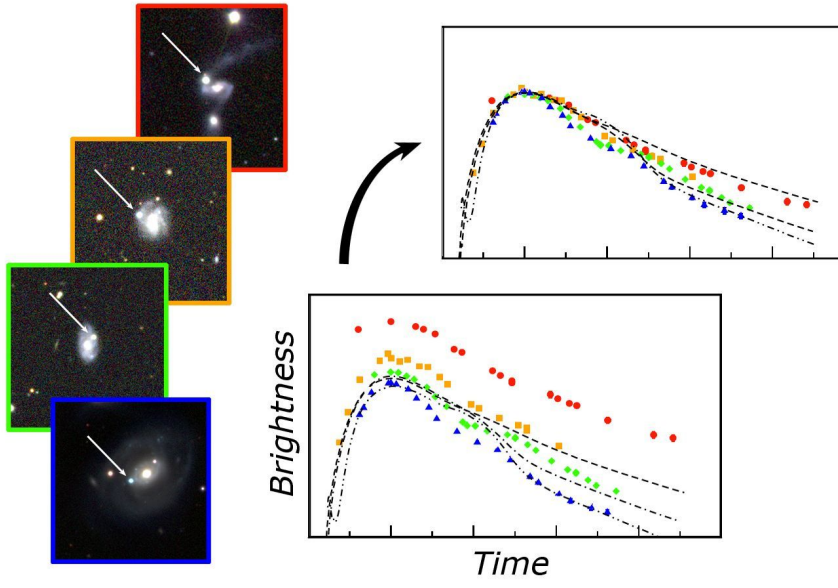
Type Ia: White dwarf accretion

$$M_{Chand} = \frac{\sqrt{3\pi}}{m_H^2}\left(\frac{\hbar c}{G}\right)^{3/2} \approx 3\frac{M_P^3}{m_H^2}$$

$$M_P = \sqrt{\frac{\hbar c}{G}} = 1.22\times10^{19}\ \text{GeV/c}^2$$

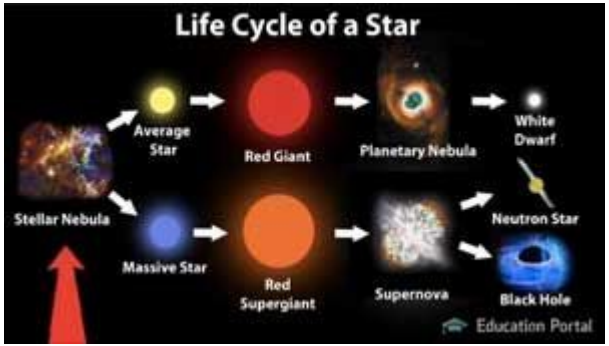


- White dwarf in binary system
- Accretes matter from a companion star
- Mass approaches Chandrasekhar limit (~1.4 solar masses)
- Triggers runaway nuclear fusion
- Explodes as a Type Ia supernova
- “Standard candles”



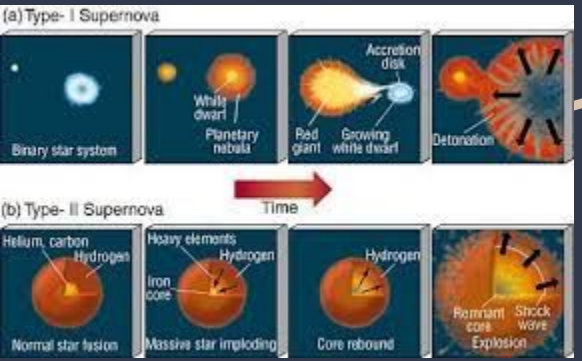
Life Cycle leading to Supernova

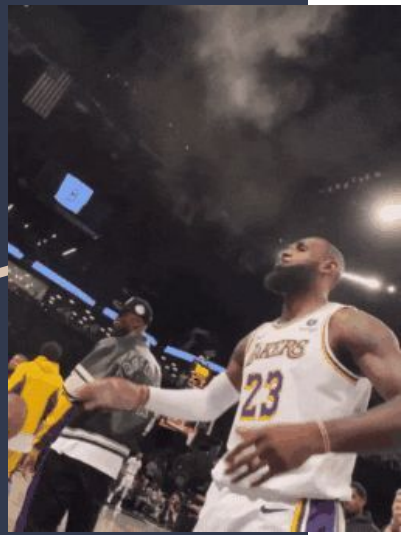
- **SMALL STAR (eg our Sun)**
  - Nebula -> Protostar -> Main Sequence Star -> Red Giant -> White Dwarf **NO SUPERNOVA**
- **MASSIVE STAR (> 8x Sun)**
  - Nebula -> Protostar -> Massive Sequence Star -> Red Supergiant -> Core Collapse -> Type II **SUPERNOVA -> Leaves behind neutron star or black hole**
- **White Dwarf in Binary System**
  - White Dwarf + Companion Star -> **Accretes Mass ->** Reaches Chandrasekhar Limit -> **Type Ia Supernova NO REMNANT**



Supernova Explosion Process

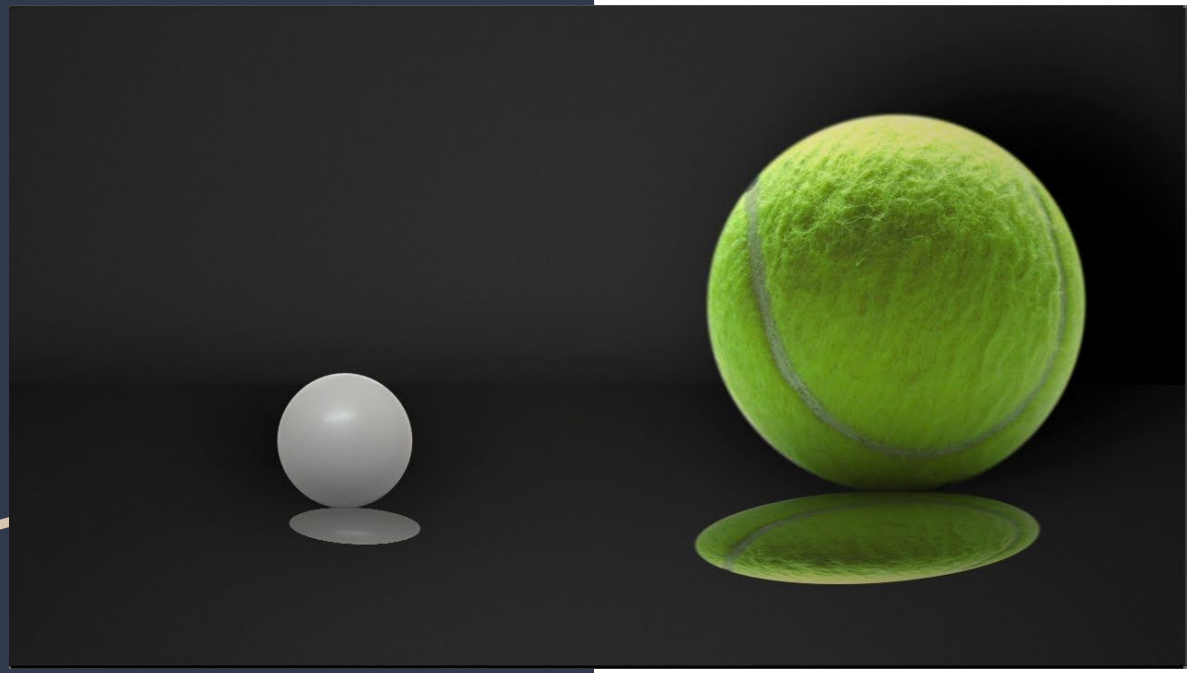
- **Type II Core-Collapse**
  - Iron core builds up -> fusion stops
  - Core collapses in milliseconds
  - Core rebounds -> shockwave forms
  - Outer layers are ejected
  - Leaves behind a neutron star or black hole





- **Type Ia Thermonuclear Supernova**
  - White dwarf gains mass in binary system
  - Reaches **Chandrasekhar limit (1.4 solar masses)**
  - Runaway carbon fusion ignites
  - Star detonates entirely
  - **No remnant** left behind

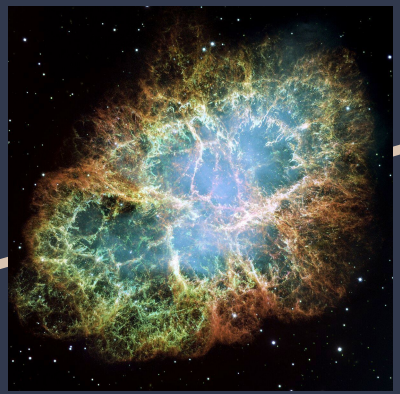
Supernova Visual Experiment



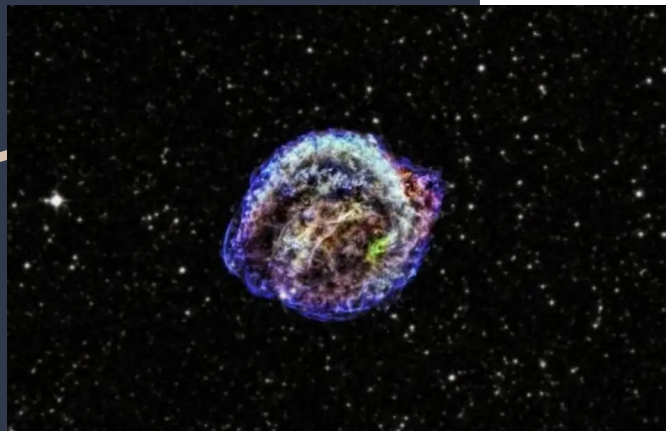
Famous Supernovae in History

- SN 1054 (Crab Nebula)
- SN 1604 (Kepler's Supernova)
- SN 1987A (first observed)

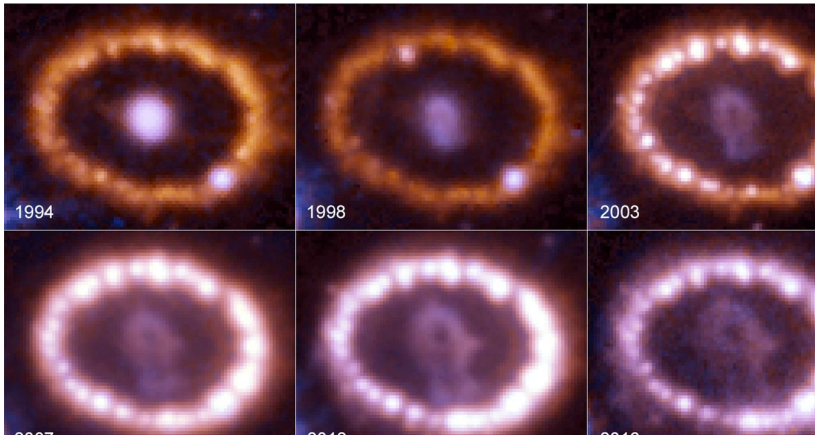
-SN 1054



-SN 1604

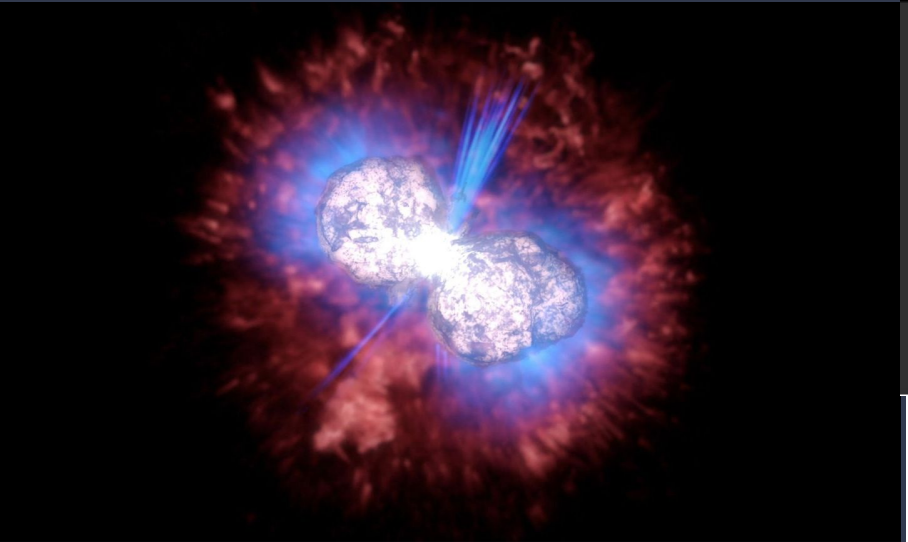


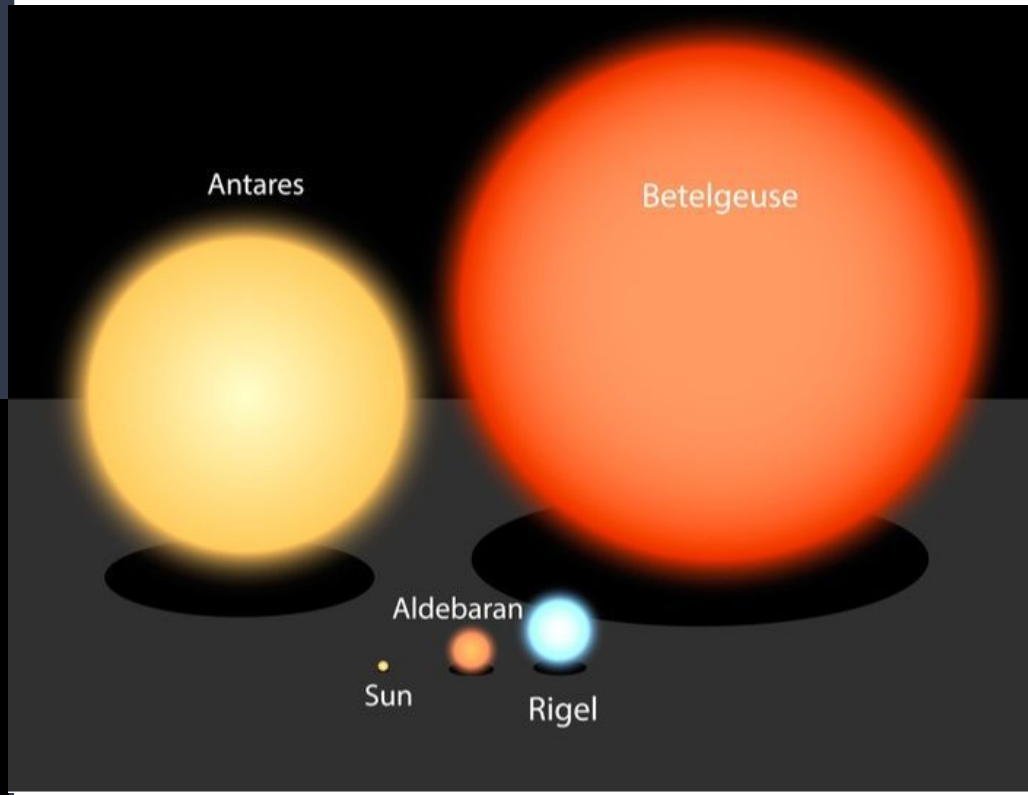
-SN 1987A



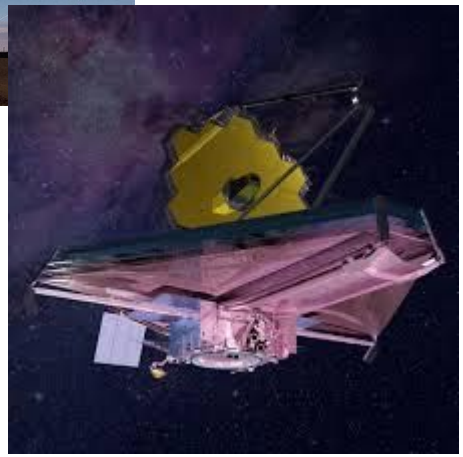
Supernovae in the future

- Betelgeuse
- Eta Carinae
- Antares





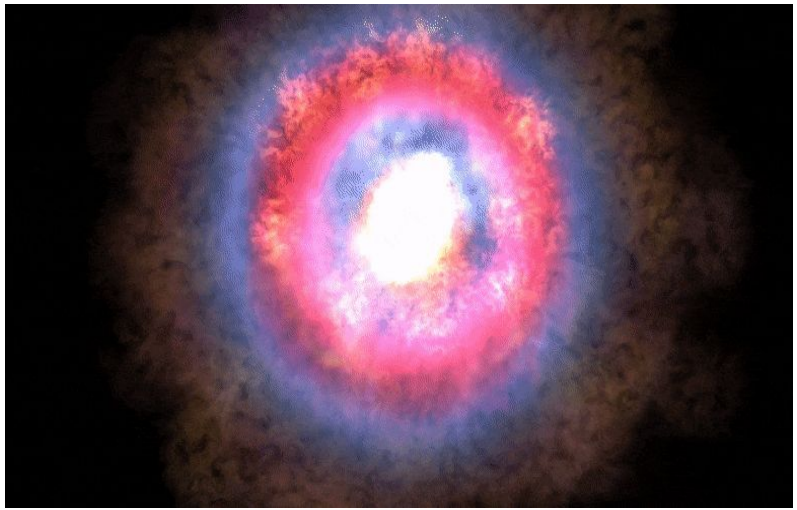
Detecting and Studying



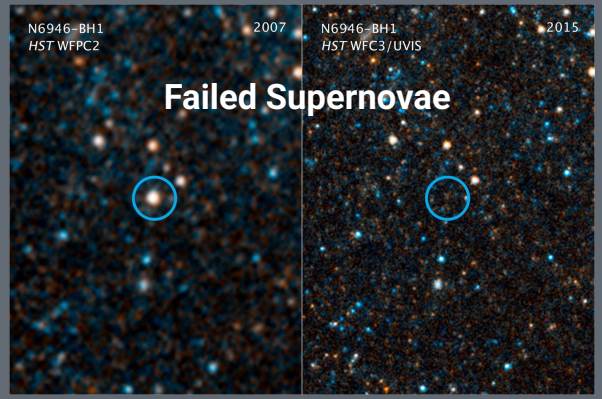
- Telescopes and Observatories
- Supernova remnants and spectroscopy
- Role in measuring cosmic expansion

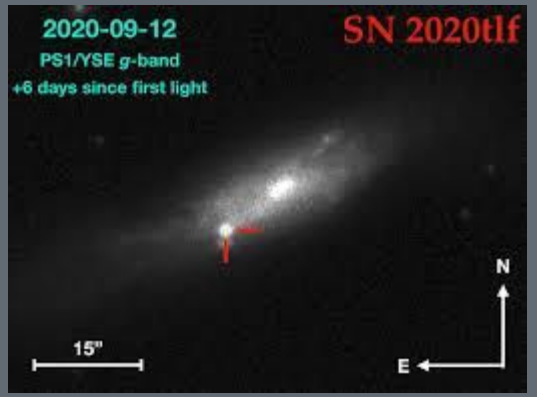
The Role of Supernovae

- Contribution to galaxy evolution
- Connection to dark energy and the expansion of the universe



Recent Discoveries





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- Recent Advances in Supernova Theory https://www.cambridge.org/core/services/aop-cambridge-core/content/view/6ACC07B54EDB5B440843EC4F413418DD/S025292110000796Xa.pdf/div-class-title-recent-advances-in-supernova-theory-div.pdf

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