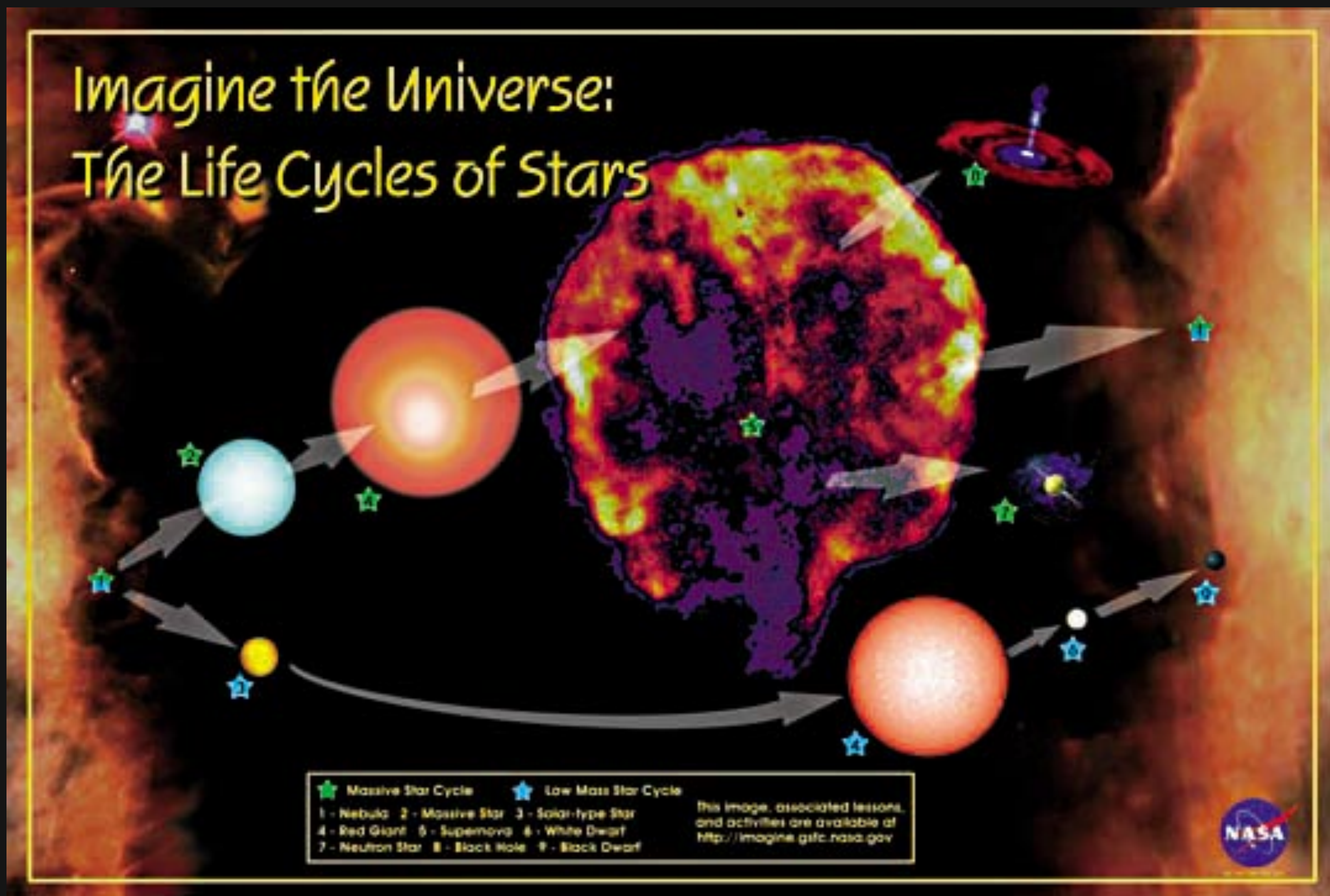
The Life Cycles of Stars

Dr. Jim Lochner, NASA/GSFC



May 15, 2001

Twinkle, Twinkle, Little Star ...

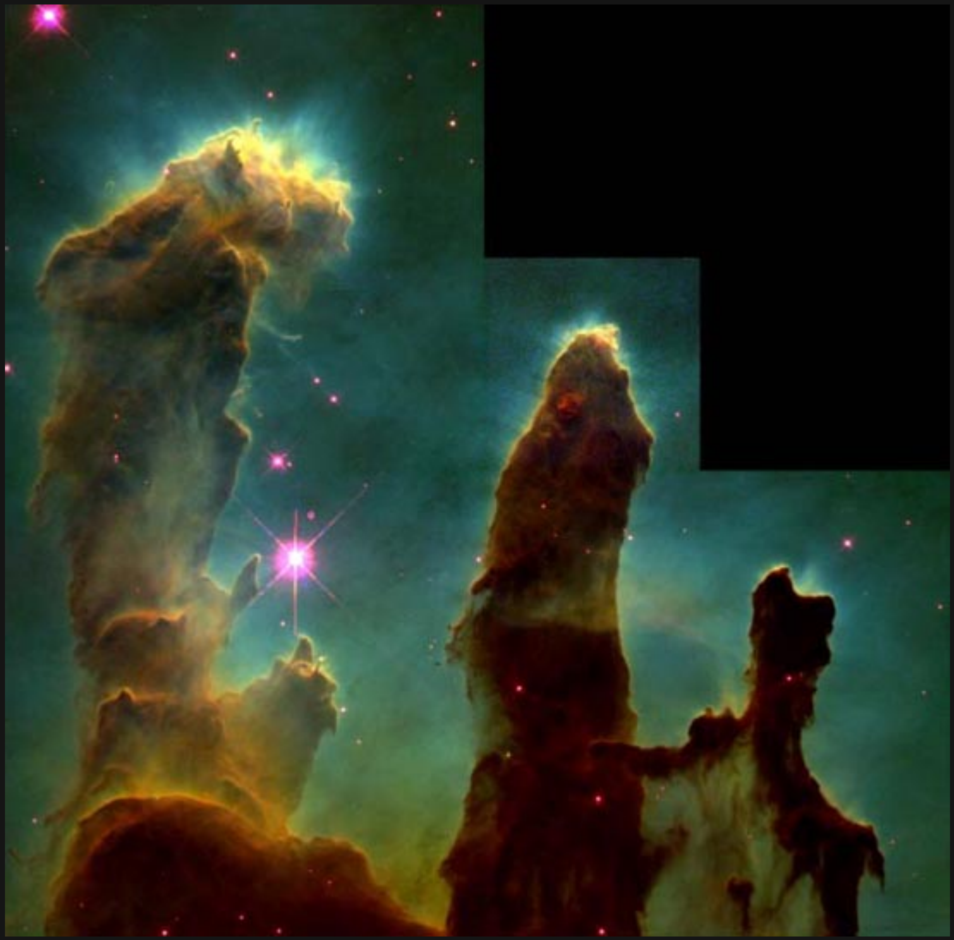
How I Wonder What You Are ...

Stars have

- Different colors
  - Which indicate different temperatures
- Different sizes
- Different masses

The bigger it is, the hotter and the faster a star burns its life away.

Stellar Nursery

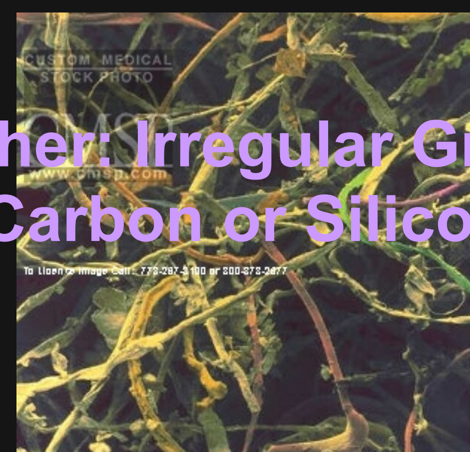


Space is filled with the stuff to make stars.

Stars start from clouds

Clouds provide the gas and dust from which stars form.

But not this kind of dust



Rather: Irregular Grains
Of Carbon or Silicon

Collapse to Protostar

Stars begin with slow accumulation of gas and dust.

- Gravitational attraction of Clumps attracts more material.

$$F = \frac{G m_1 m_2}{r^2}$$

- Contraction causes Temperature and Pressure to slowly increase.

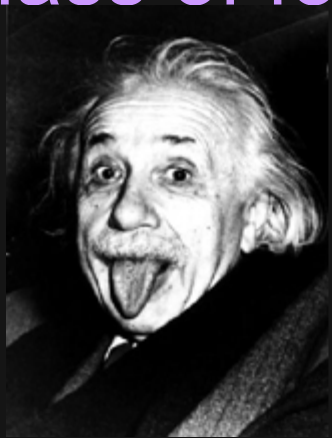
Nuclear Fusion !

At 15 million degrees Celsius in the center of the star, fusion ignites !

$4\ (^{1}H) \dashrightarrow\ ^{4}He + 2\ e^{+} + 2$ neutrinos + energy

Where does the energy come from ?

Mass of four ^{1}H > Mass of one ^{4}He



$E = mc^2$

Fusion by the Numbers

$4\,(^{1}H) \rightarrow {}^{4}He + 2\,e^{+} + 2$ neutrinos + energy

Mass of 4 ^{1}H = 4×1.00794 amu

= 4.03176 amu

Mass of 1 ^{4}He = 4.002602 amu

Difference in mass = 0.029158 amu

= 4.84×10^{-29} kg.

$E = Dmc^2 = (4.84 \times 10^{-29}\ kg)(3 \times 10^{8}\ m/s)^2$

$E = 4.4 \times 10^{-12}$ J

How much Energy

$4\ (^{1}H) \rightarrow {}^{4}He + 2\ e^{+} + 2$ neutrinos + energy

Energy released = 25 MeV

= 4×10^{-12} Joules

= 1×10^{-15} Calories

But the sun does this 10^{38} times a second !

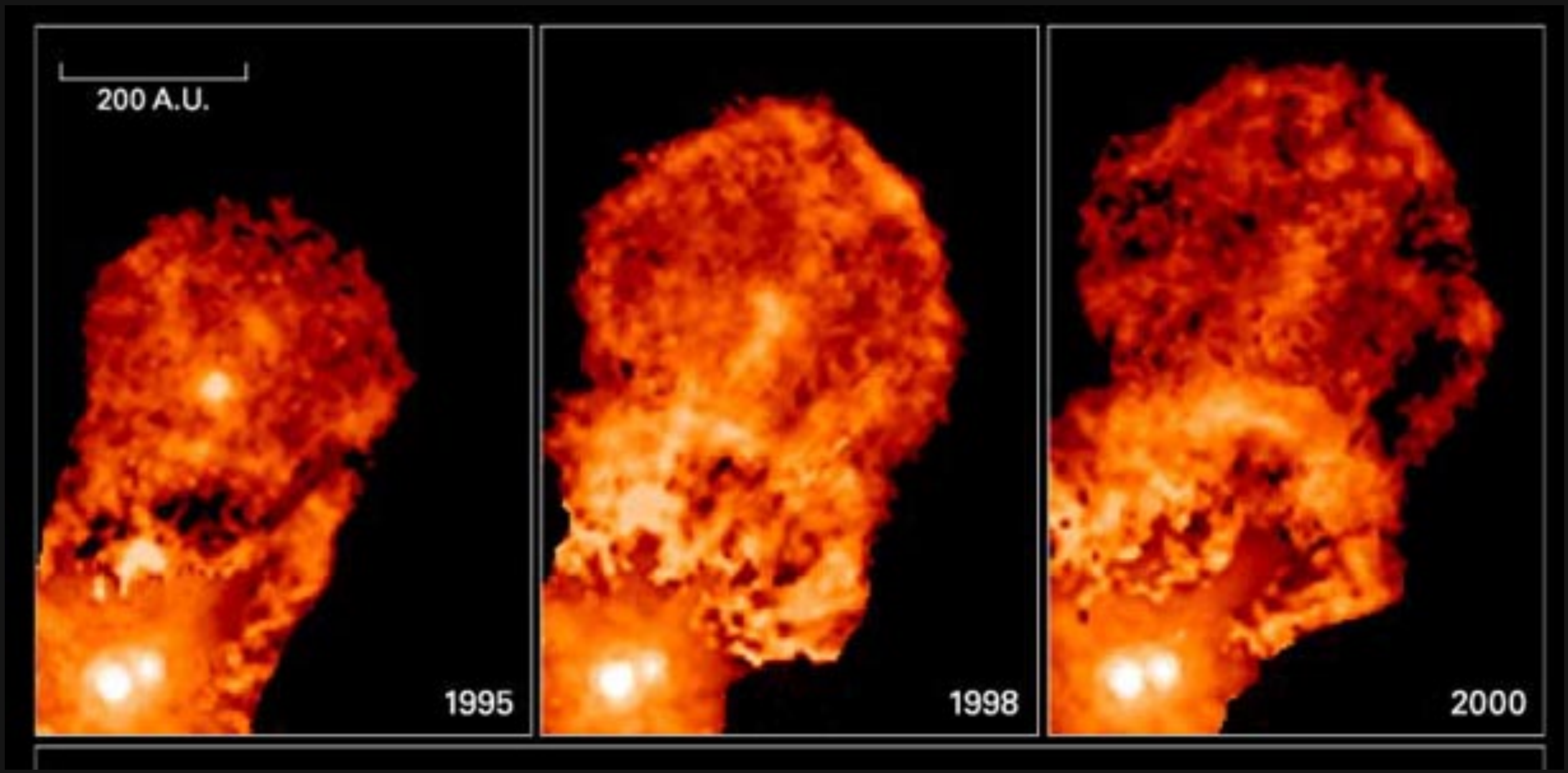
Sun has 10^{56} H atoms to burn !

A Balancing Act

Energy released from nuclear fusion counter-acts inward force of gravity.

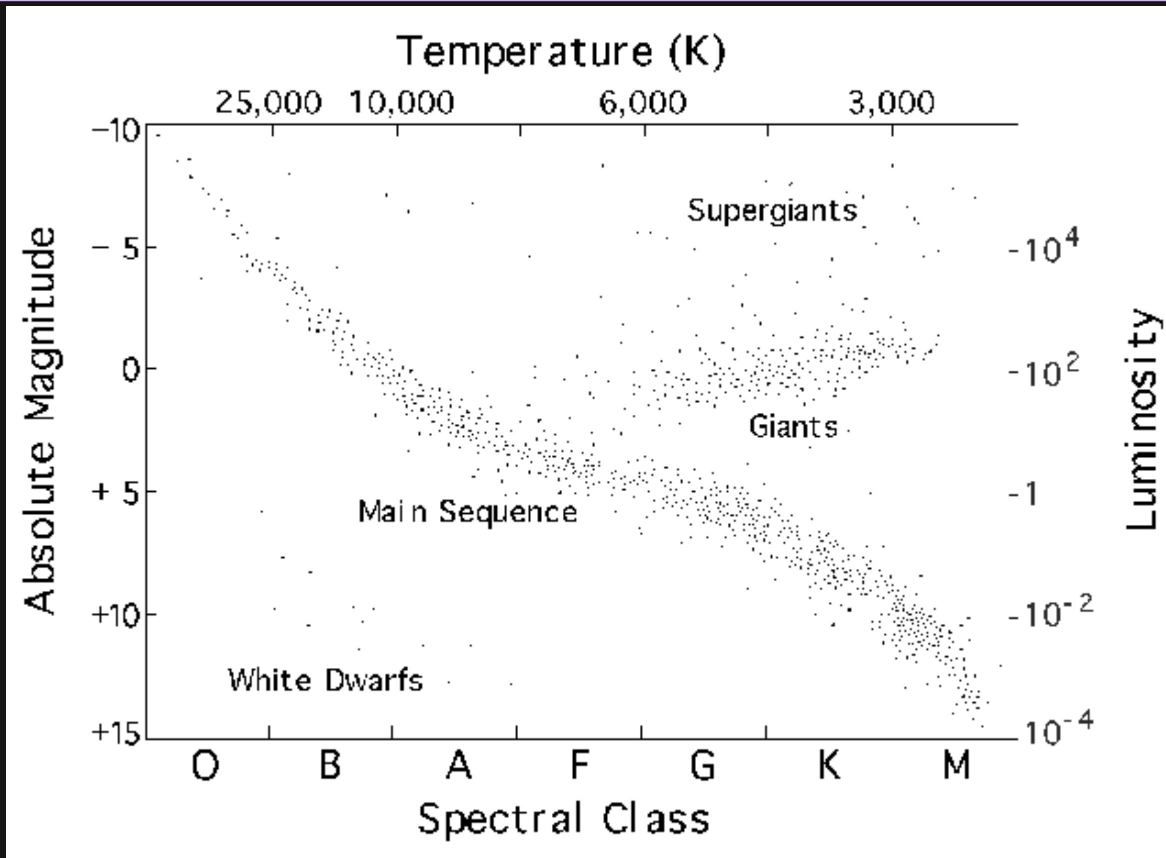
Throughout its life, these two forces determine the stages of a star’s life.

New Stars are not quiet !

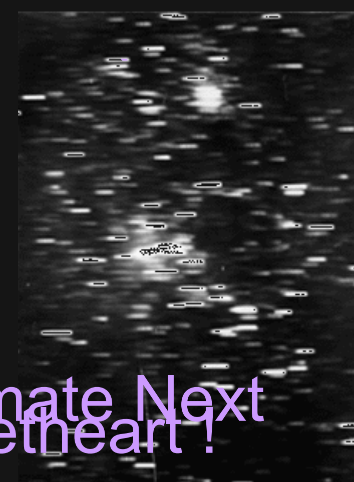


Expulsion of gas from a young binary star system

All Types of Stars



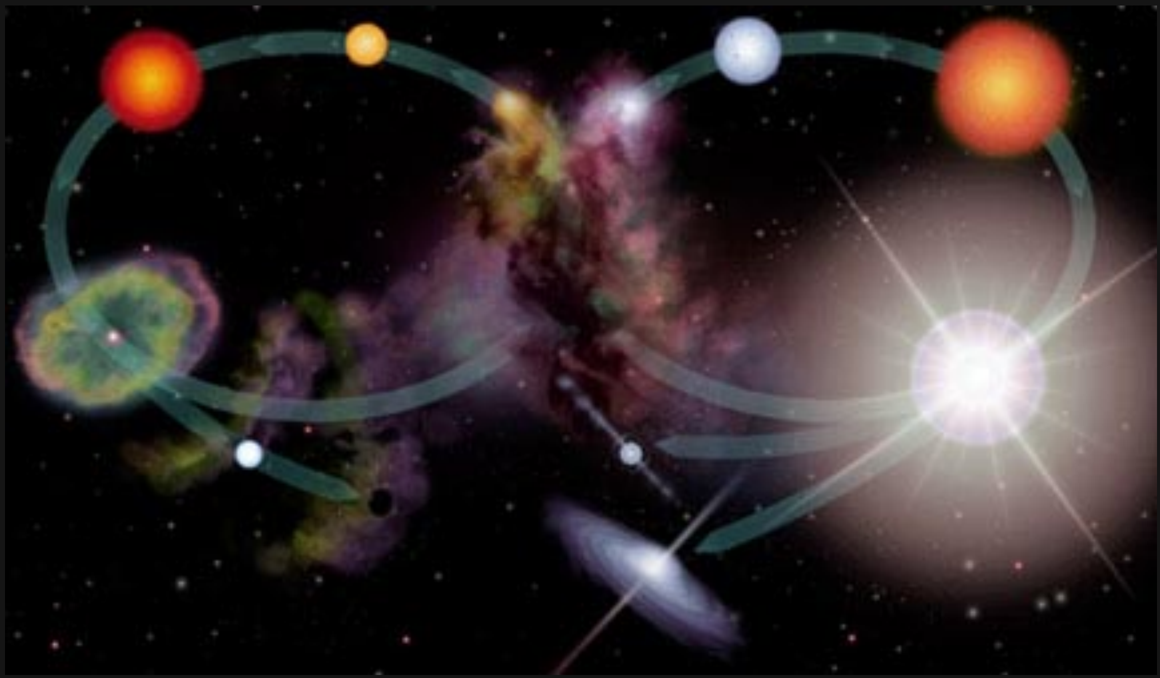
Annie J Cannon



Oh Big And Ferocious Gorilla, Kill My Roommate Next Saturday !

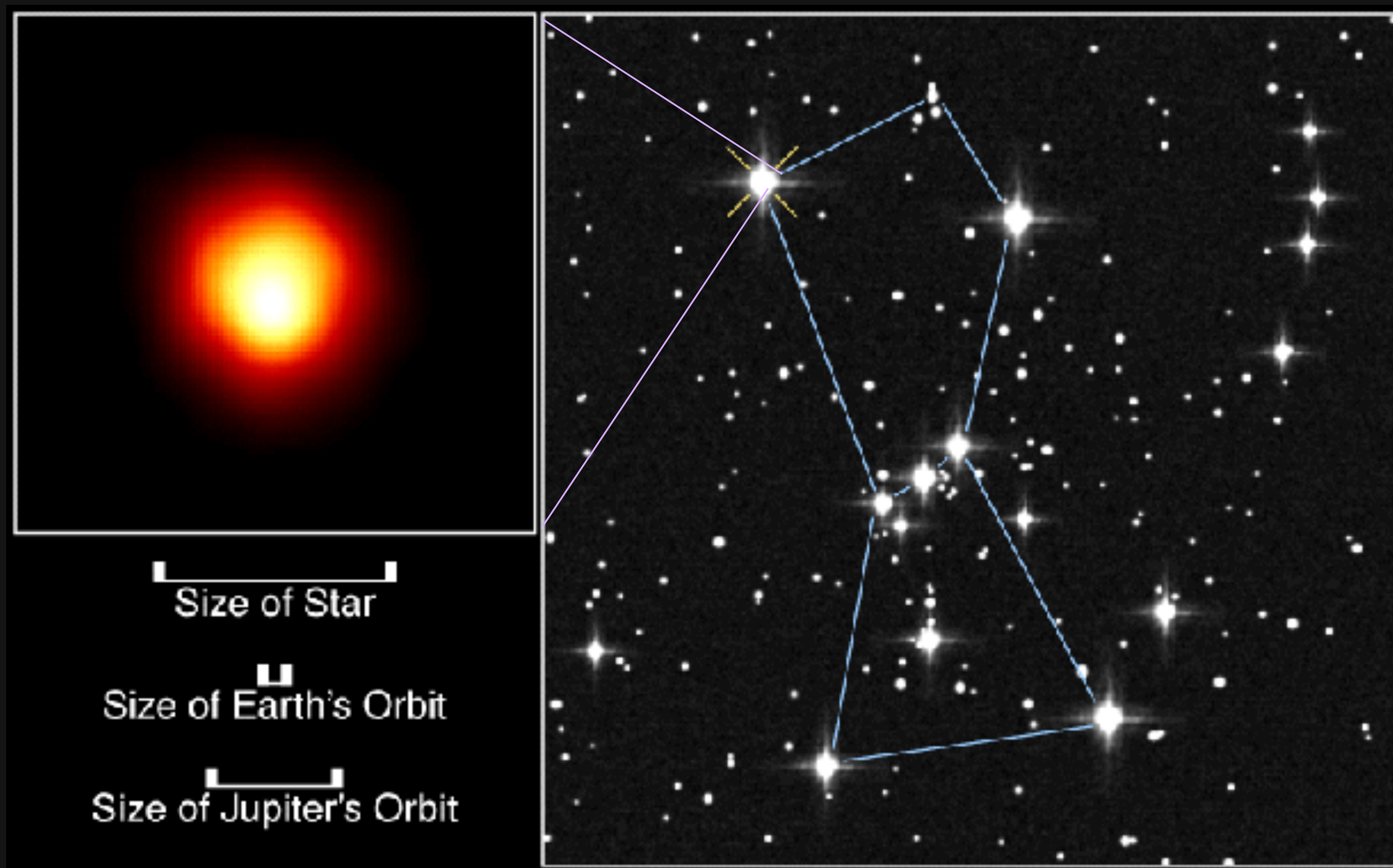
Oh! Be A Fine Girl - Kiss Me Right Now Sweetheart !

Reprise: the Life Cycle



Sun-like Stars   Massive Stars

The beginning of the end: Red Giants



Red Giants

After Hydrogen is exhausted in core,

- Core collapses, releasing energy to the outer layers
  - Outer layers expand
- Meanwhile, as core collapses,
  - Increasing Temperature and Pressure ...

More Fusion !

At 100 million degrees Celsius, Helium fuses:

$3\ (^{4}He) \dashrightarrow {}^{12}C + \text{energy}$

(Be produced at an intermediate step)

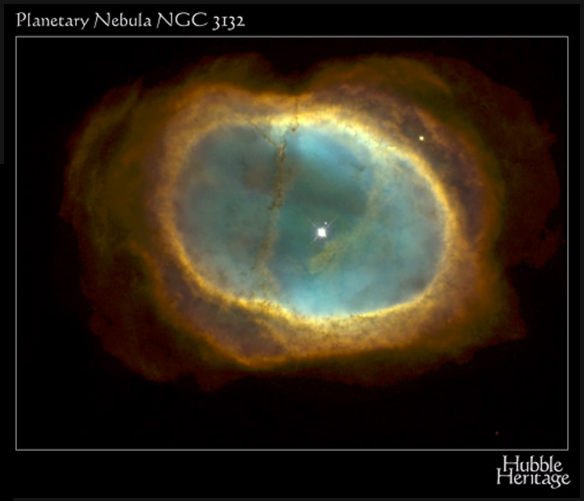
(Only 7.3 MeV produced)

Energy sustains the expanded outer layers of the Red Giant

The end for solar type stars

After Helium exhausted, outer layers of star expelled

Planetary Nebulae



White dwarfs

At center of Planetary Nebula lies a White Dwarf.

- Size of the Earth with Mass of the Sun "A ton per teaspoon"
- Inward force of gravity balanced by repulsive force of electrons.

Fate of high mass stars

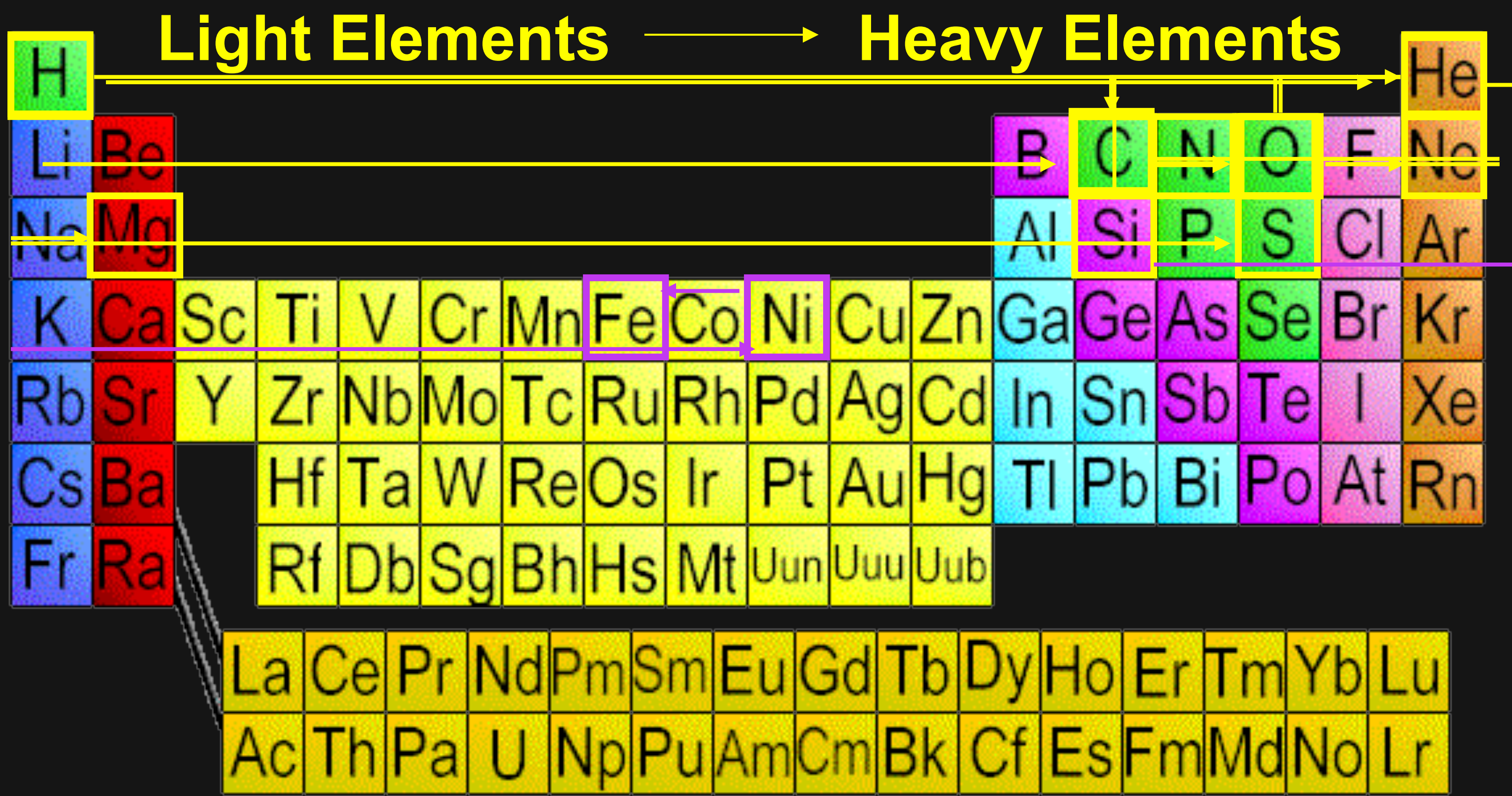
After Helium exhausted, core collapses again until it becomes hot enough to fuse Carbon into Magnesium or Oxygen.

- $^{12}C + ^{12}C \rightarrow ^{24}Mg$

  OR $^{12}C + ^{4}H \rightarrow ^{16}O$

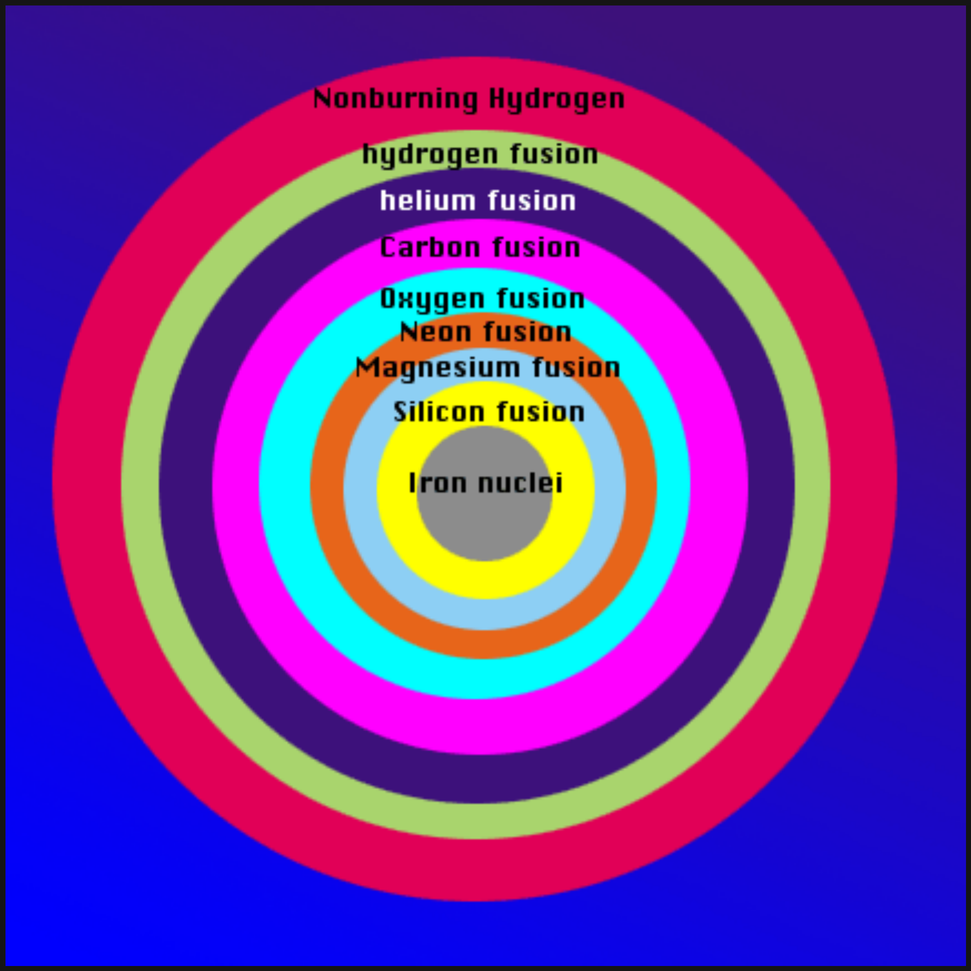
Through a combination of processes, successively heavier elements are formed and burned.

Periodic Table



^{28}Si + [illegible] ^{56}Fe

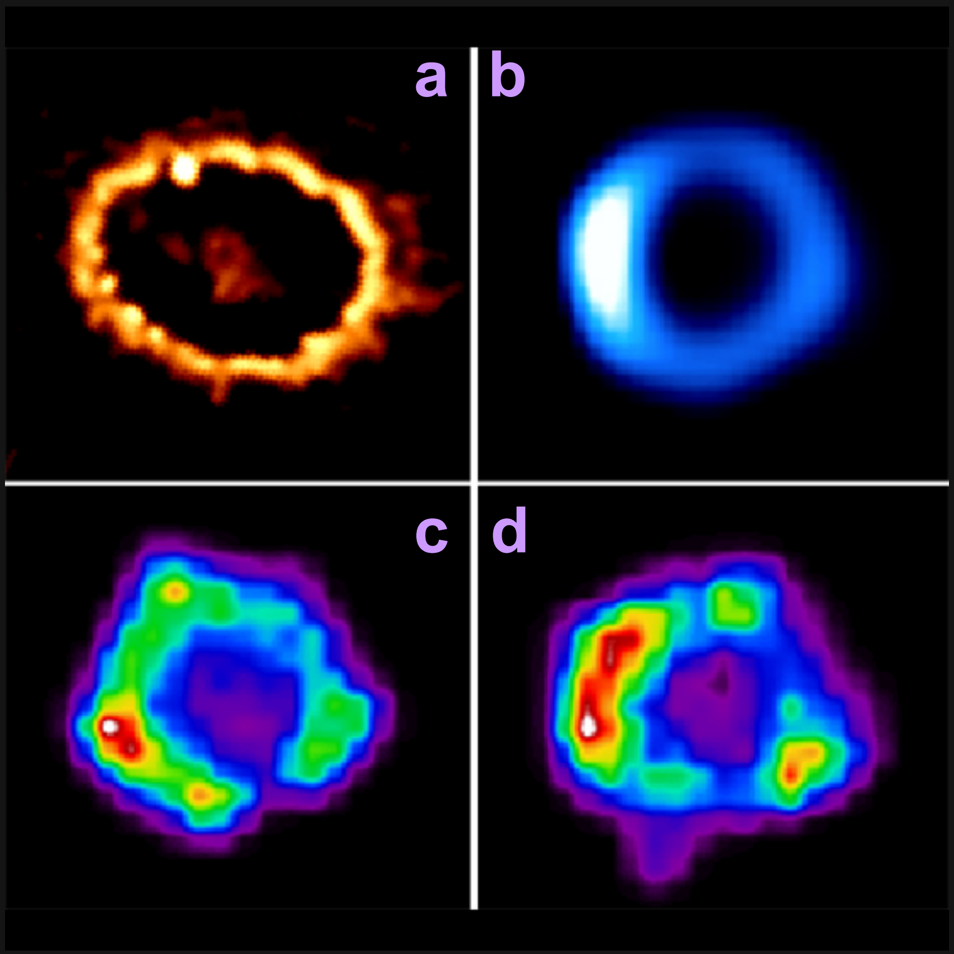
The End of the Line for Massive Stars



- Massive stars burn a succession of elements.
- Iron is the most stable element and cannot be fused further.
  - Instead of releasing energy, it uses energy.

Supernova !

Supernova Remnants: SN1987A

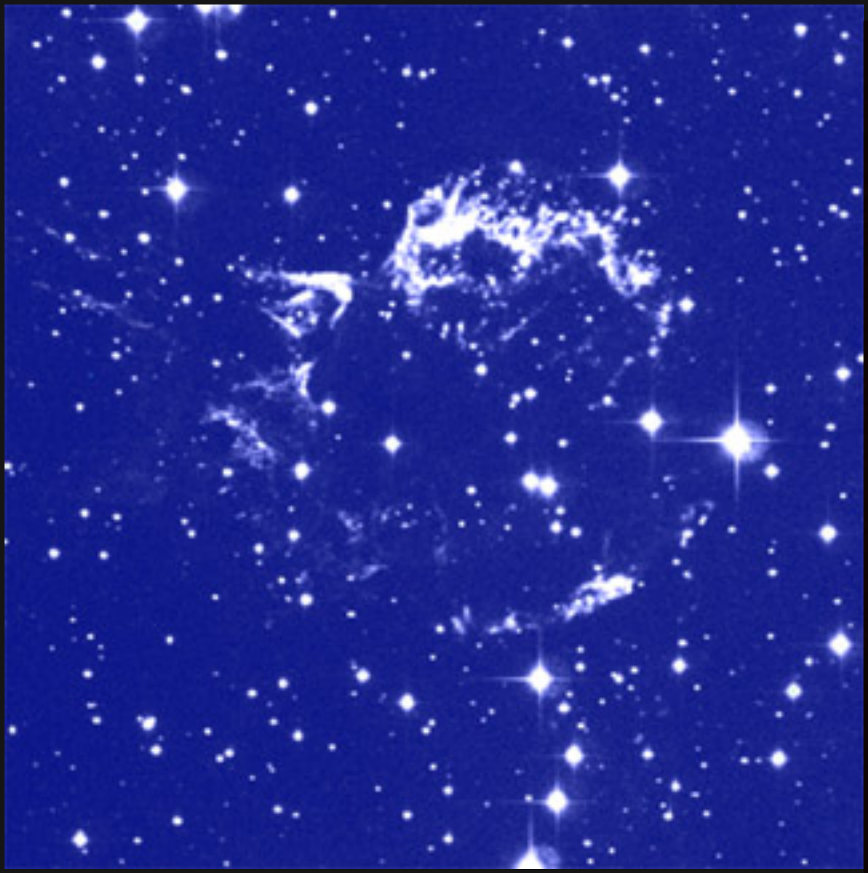


a) Optical - Feb 2000
- Illuminating material ejected from the star thousands of years before the SN

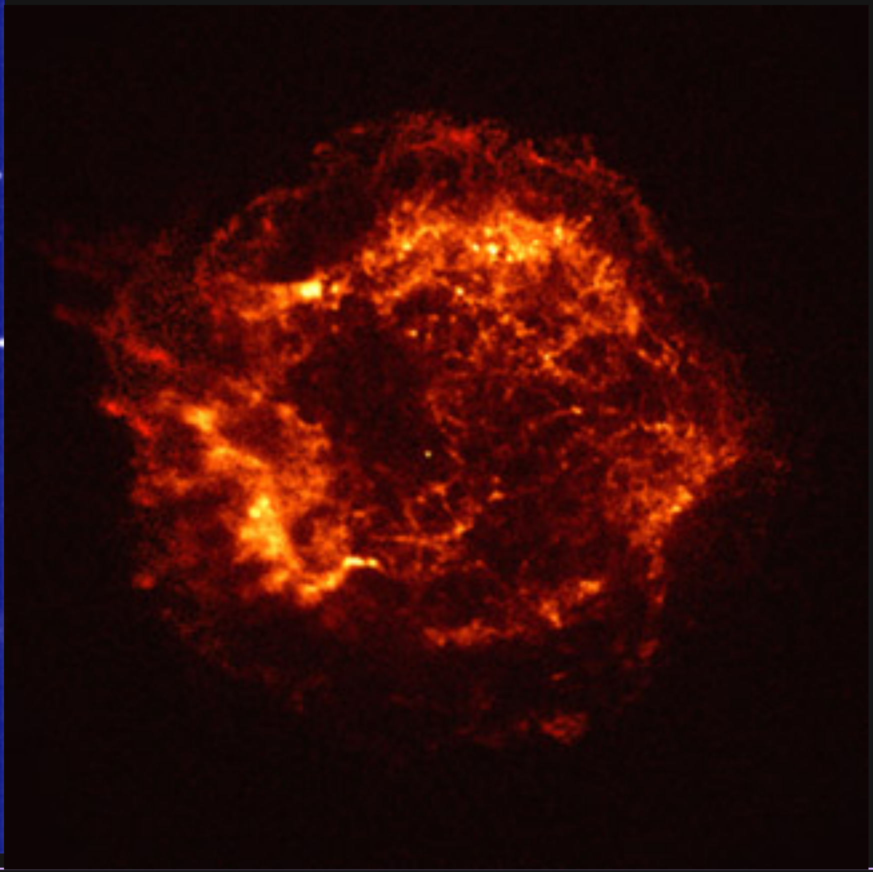
b) Radio - Sep 1999
c) X-ray - Oct 1999
d) X-ray - Jan 2000
- The shock wave from the SN heating the gas

Supernova Remnants: Cas A

Optical



X-ray



What's Left After the Supernova

Neutron Star (If mass of core < 5 x Solar)

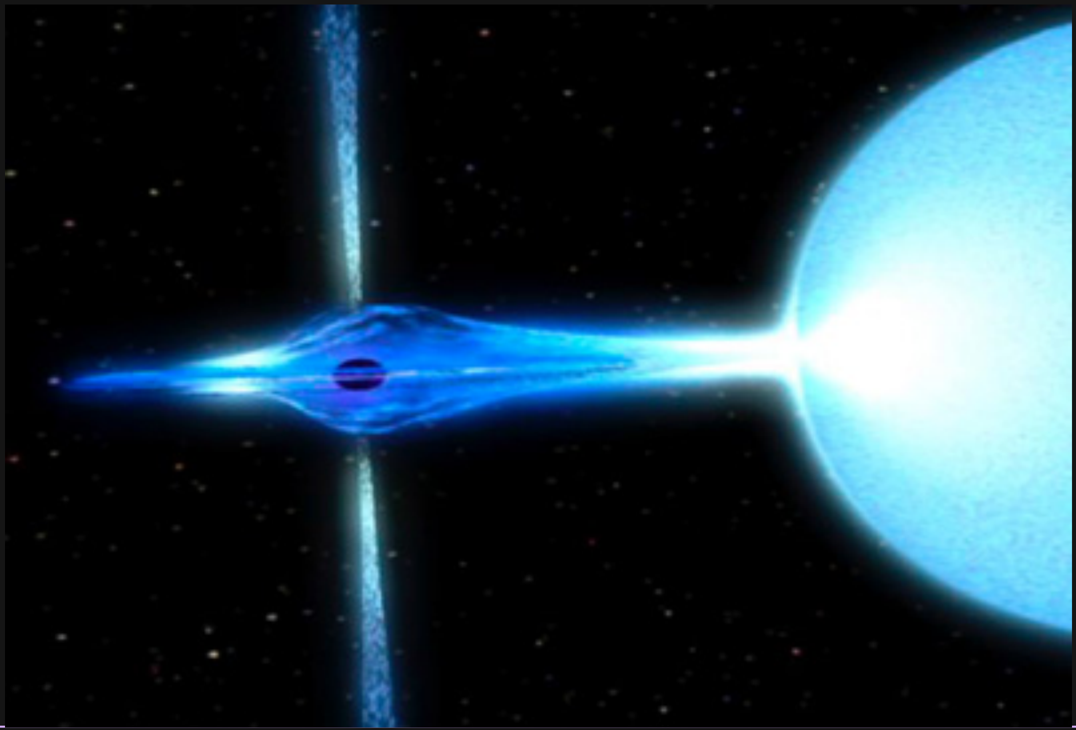
- Under collapse, protons and electrons combine to form neutrons.
- 10 Km across

Black Hole (If mass of core > 5 x Solar)

- Not even compacted neutrons can support weight of very massive stars.

A whole new life: X-ray binaries

In close binary systems, material flows from normal star to Neutron Star or Black Hole. X-rays emitted from disk of gas around Neutron Star/Black Hole.

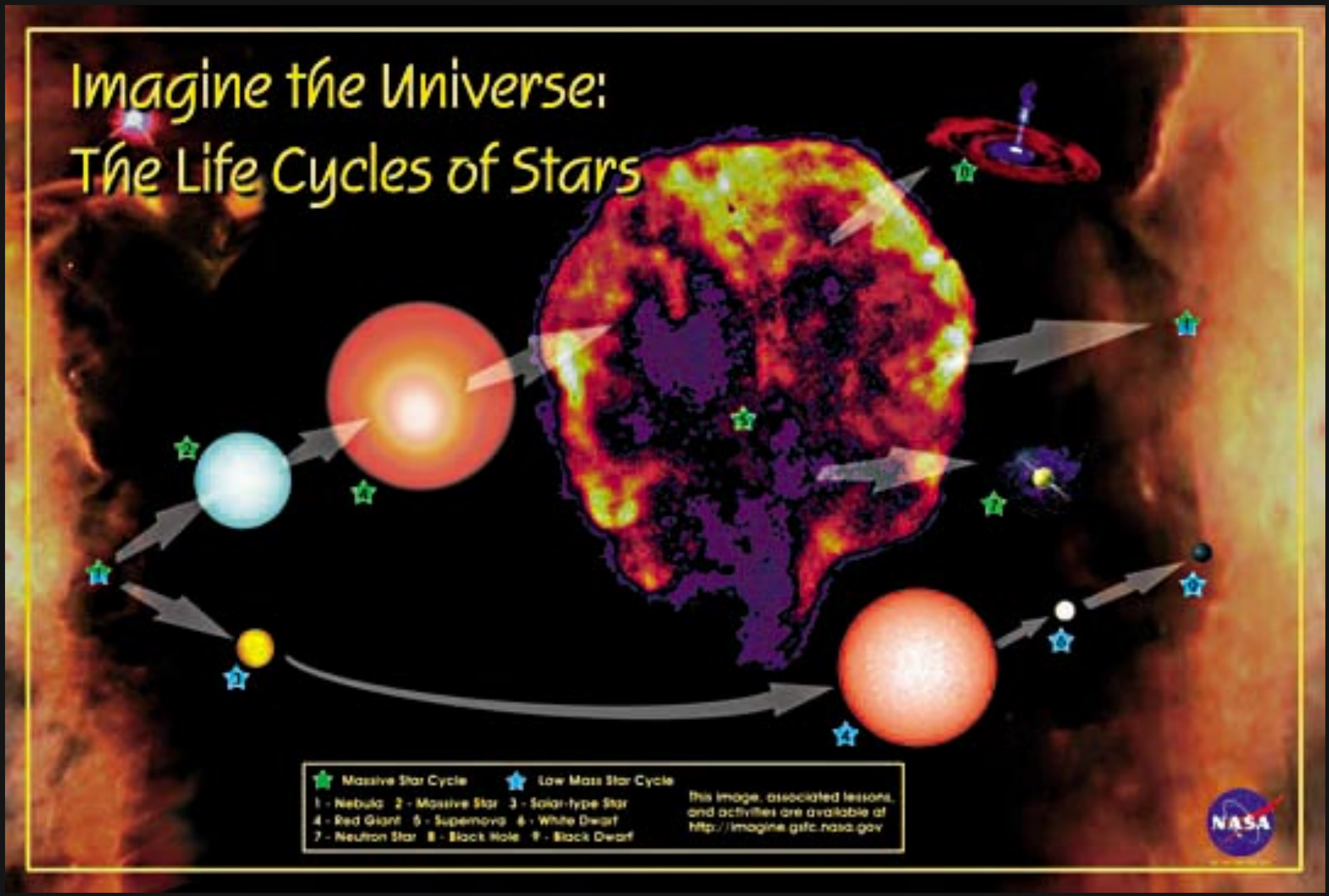


SN interaction with ISM

Supernovae compress gas and dust which lie between the stars. This gas is also enriched by the expelled material.

This compression starts the collapse of gas and dust to form new stars.

Which Brings us Back to ...



Materials for Life Cycles of Stars

This presentation, and other materials on the Life Cycles of Stars, are available on the Imagine the Universe! web site at:

http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html