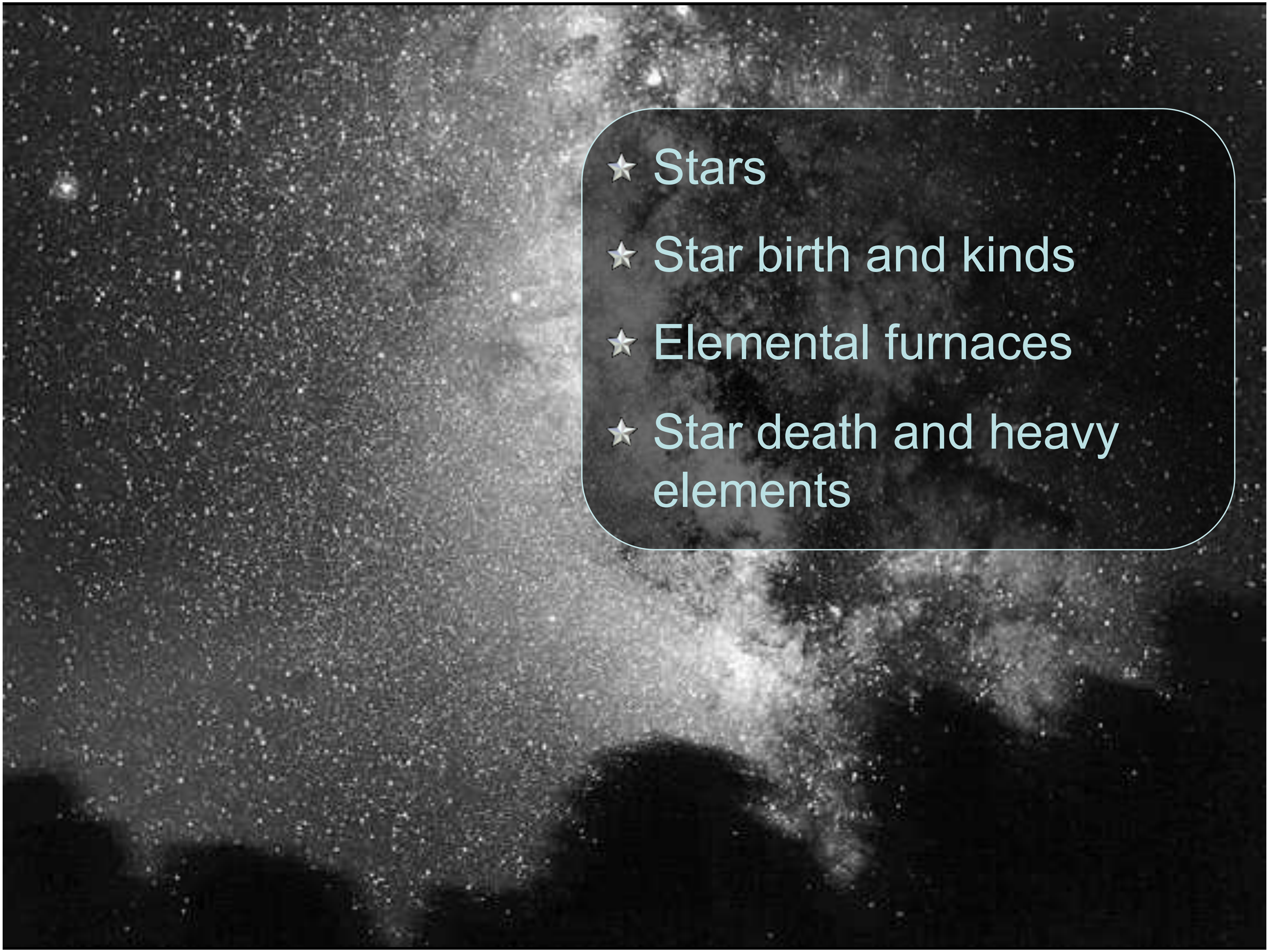

Stars
Star birth and kinds
Elemental furnaces
Star death and heavy elements

Matter was not uniformly distributed as the universe expanded after the Big Bang.

This lumpy universe coalesced under the force of gravity to form stars.

The mutual gravitational attraction of stars within larger lumps led to the development of galaxies.

Galaxy NGC 7742

http://hubblesite.org/

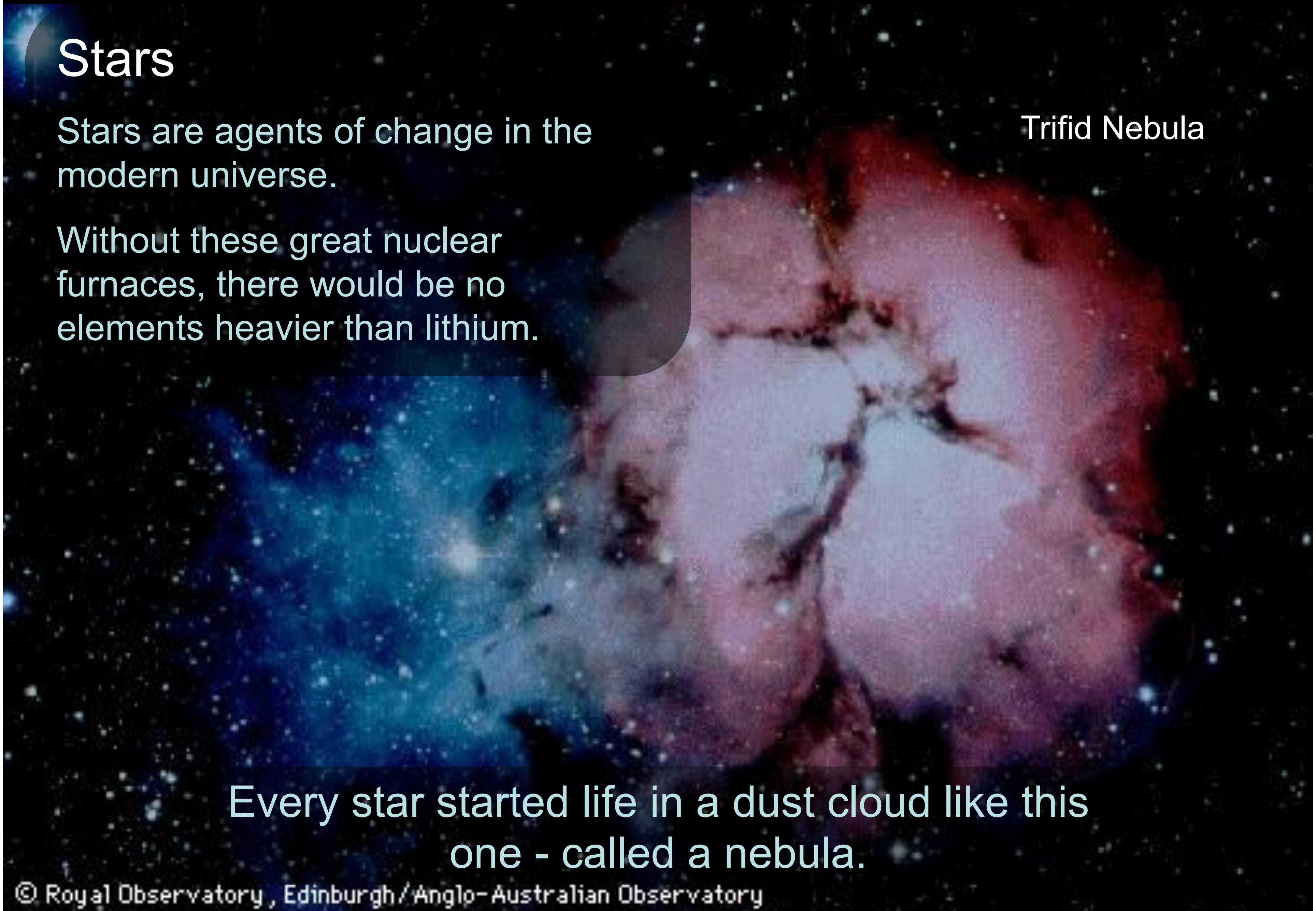
Hubble Heritage

PRC98-28 • Space Telescope Science Institute • Hubble Heritage Team

Stars

Stars are agents of change in the modern universe.

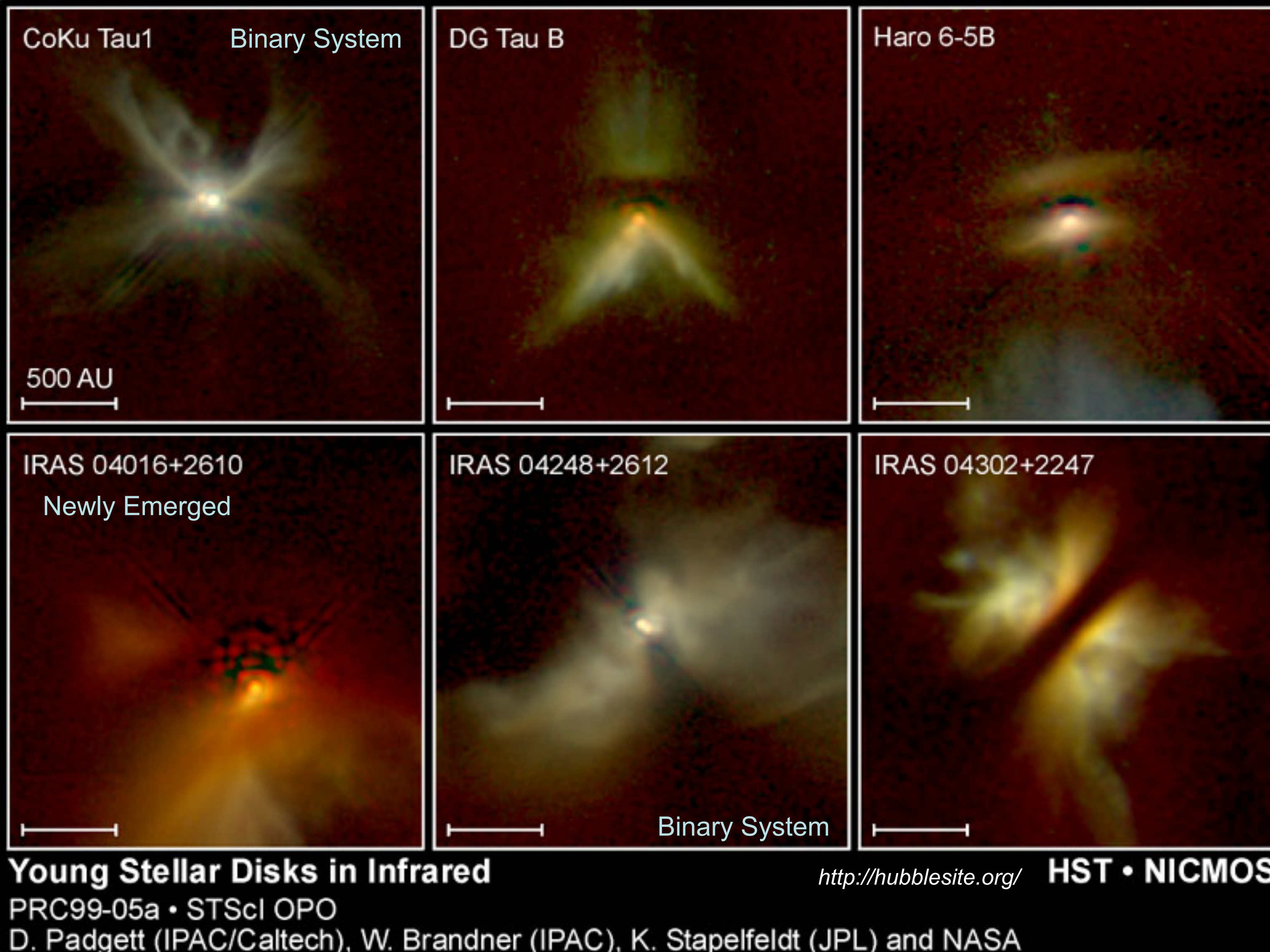
Without these great nuclear furnaces, there would be no elements heavier than lithium.



Trifid Nebula

Every star started life in a dust cloud like this one - called a nebula.

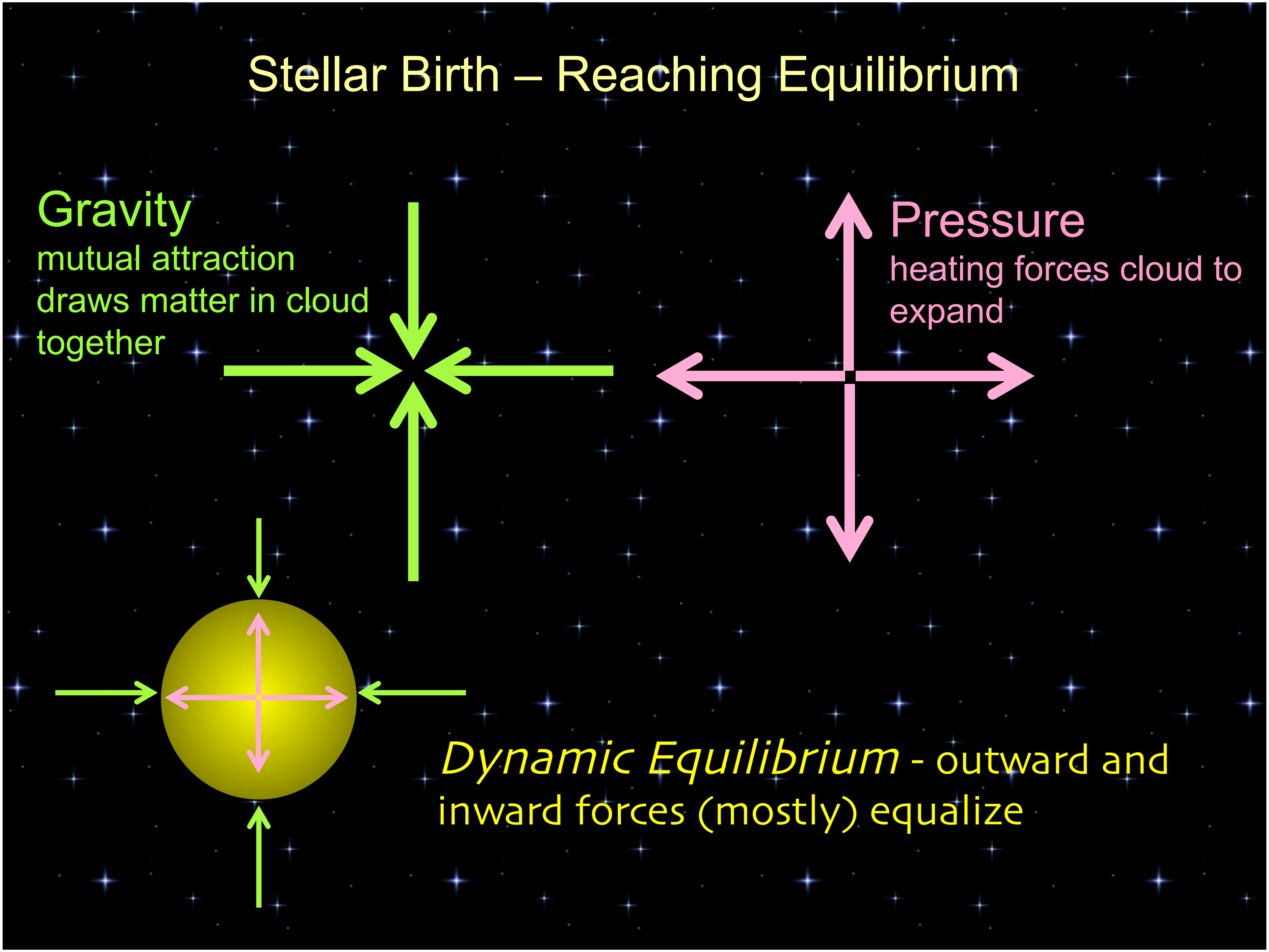
Stellar Nebulae – Birthplace of Stars



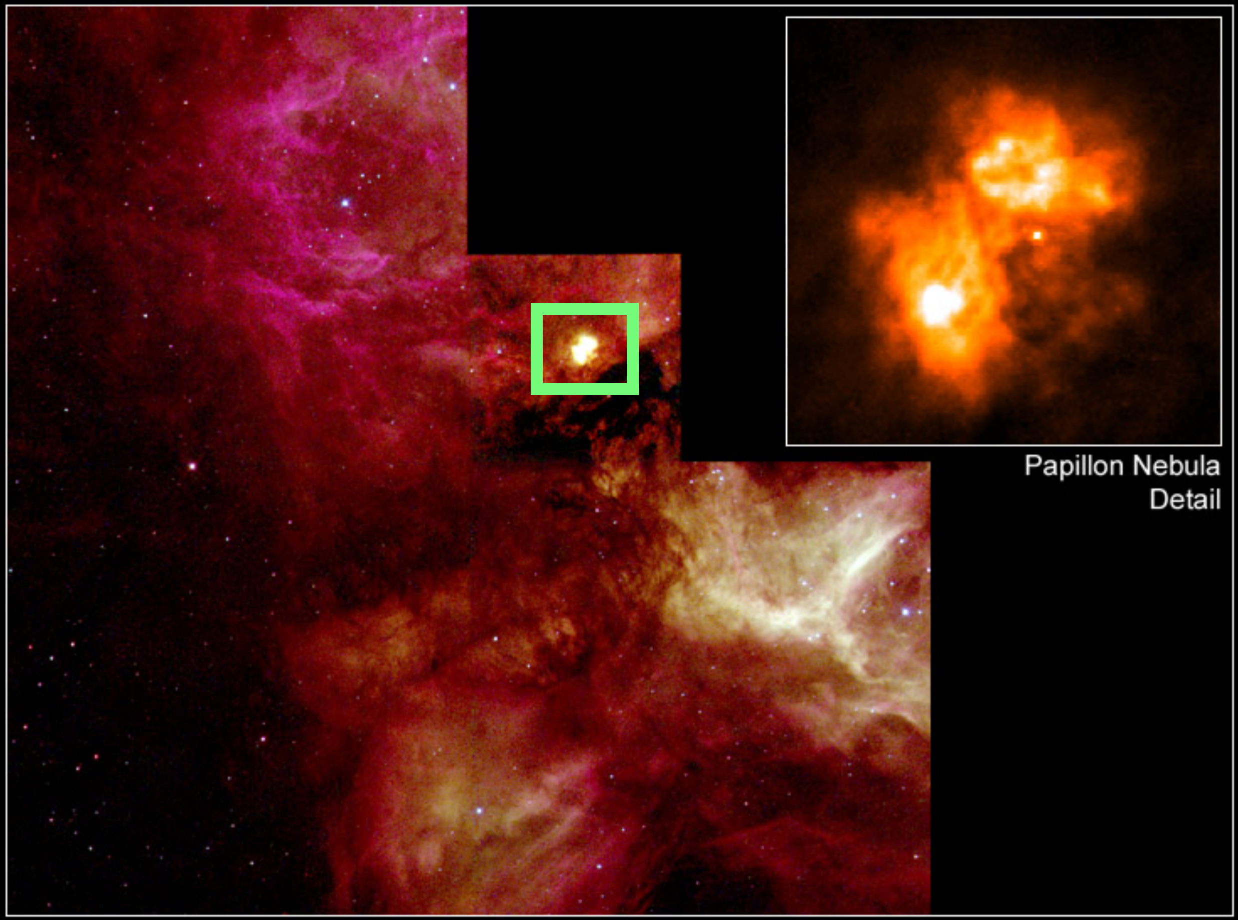
Extremely young stars, 450 light-years away in the constellation Taurus. Most of the nebulae represent small dust particles around the stars, which are seen because they are reflecting starlight. In the color-coding, regions of greatest dust concentration appear red.

A Star is Born

- Clouds of matter (mostly hydrogen) are drawn together by mutual gravitational attraction.
- The concentration of matter at the center of gravity increases, increasing pressure and temperature and somewhat countering gravity.
- Nuclear fusion of hydrogen fires up in the proto-star, adding enormous amounts of heat, and pushing outwards against pull of gravity.
- Star reaches equilibrium between forces, and becomes stable. (or it does not, and fails to become a stable star).


Stellar Birth – Reaching Equilibrium
Gravity
mutual attraction draws matter in cloud together
Pressure
heating forces cloud to expand
Dynamic Equilibrium - outward and inward forces (mostly) equalize

Violent Childhood of Massive Stars



N159 in the Large Magellanic Cloud

PRC99-23 • STScI OPO • M. Heydari-Malayeri (Observatoire de Paris) and NASA

Young, massive star pouring radiation into space. The surrounding gasses are being blown away from the young star, which is also blowing fireballs and blobs into space.

Describing Stars

Luminosity

- Luminosity is a measure of how bright an object (such as a star) appears. The Sun is much brighter than the Moon, or any other object normally seen in the Earth's sky.
- The luminosity of a star as seen from Earth is dependent on both the star's brightness and how far away it is. Brighter and closer stars appear to have greater luminosity in Earth's sky than those that are dimmer or farther away.
- Astronomers determine the absolute luminosity of an object, which would be its apparent luminosity to a viewer approximately 30 light years away.

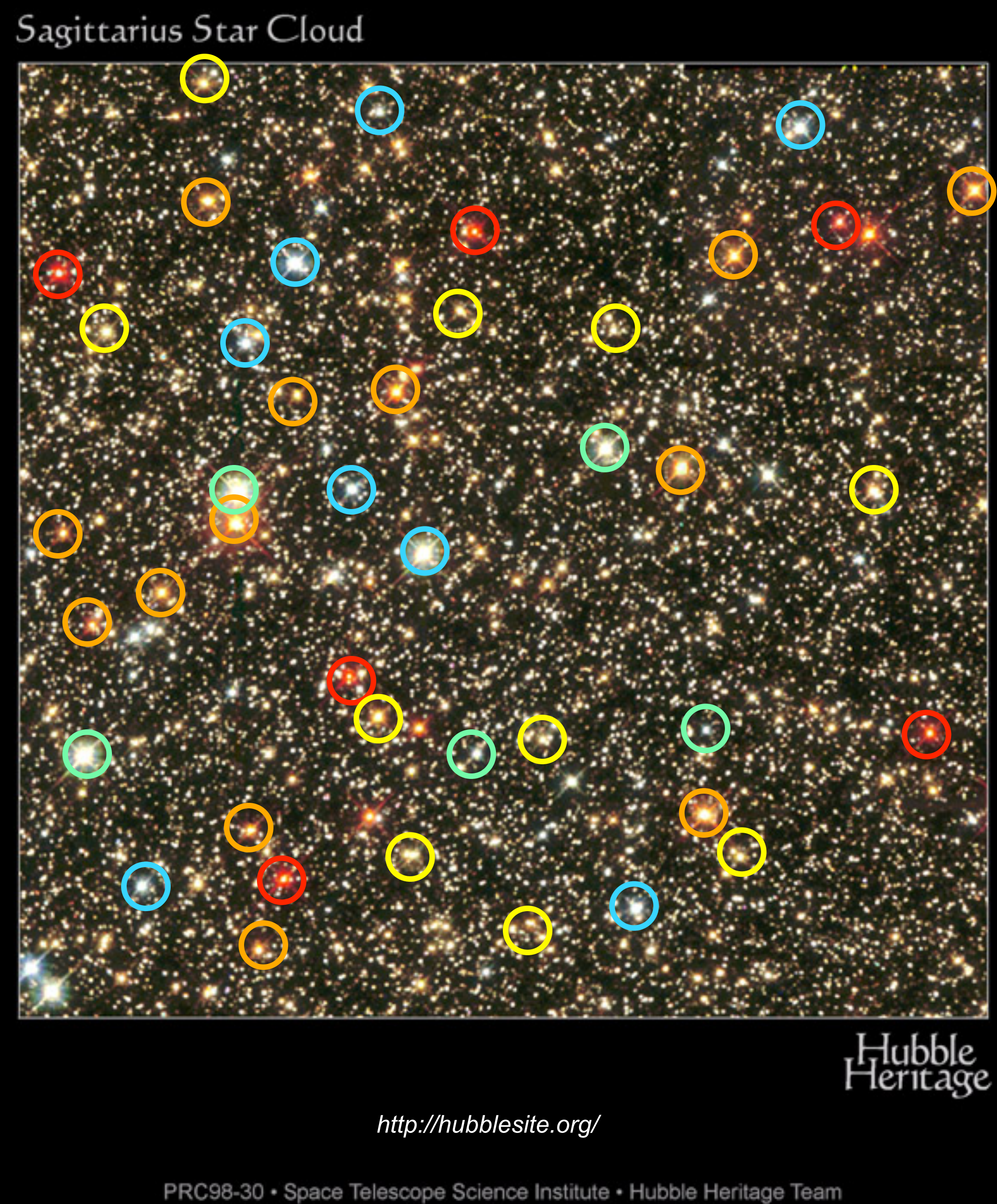
Describing Stars

Star Color

While stars may look white to the naked eye, they are actually quite colorful.

Red
Orange
Yellow
Green
Blue

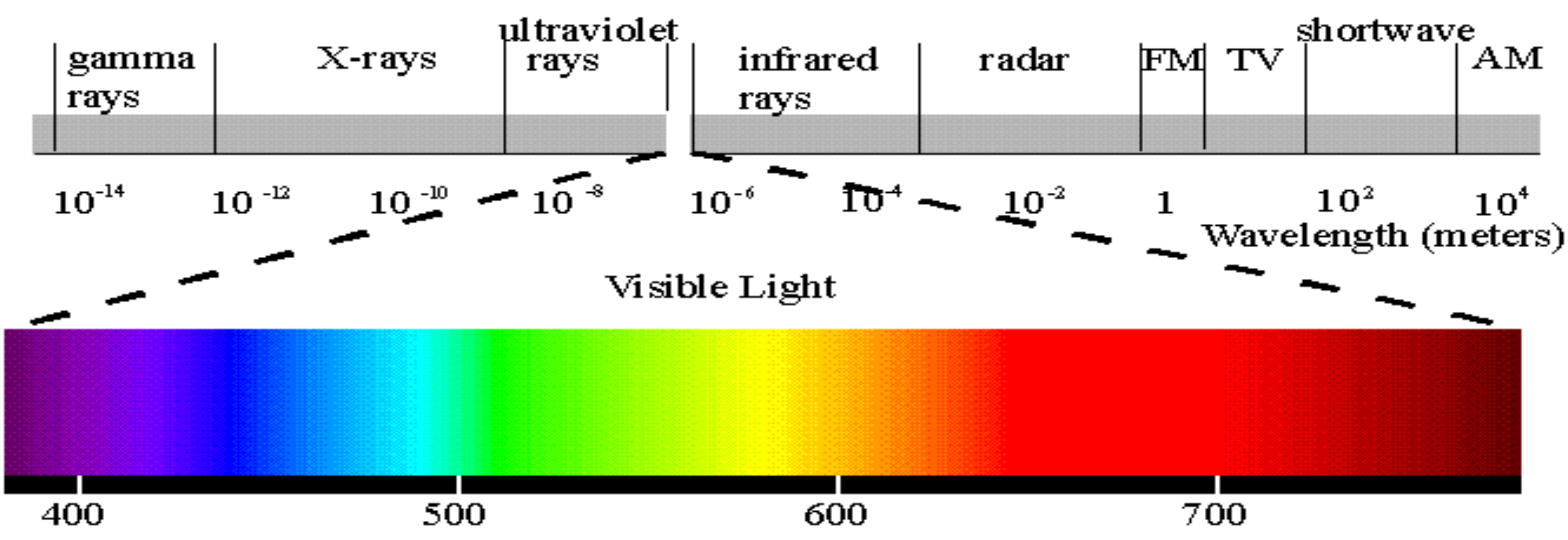
Cooler stars emit longer wavelengths of light (e.g., red), hotter stars emit shorter wavelengths (e.g., blue)



Star Color

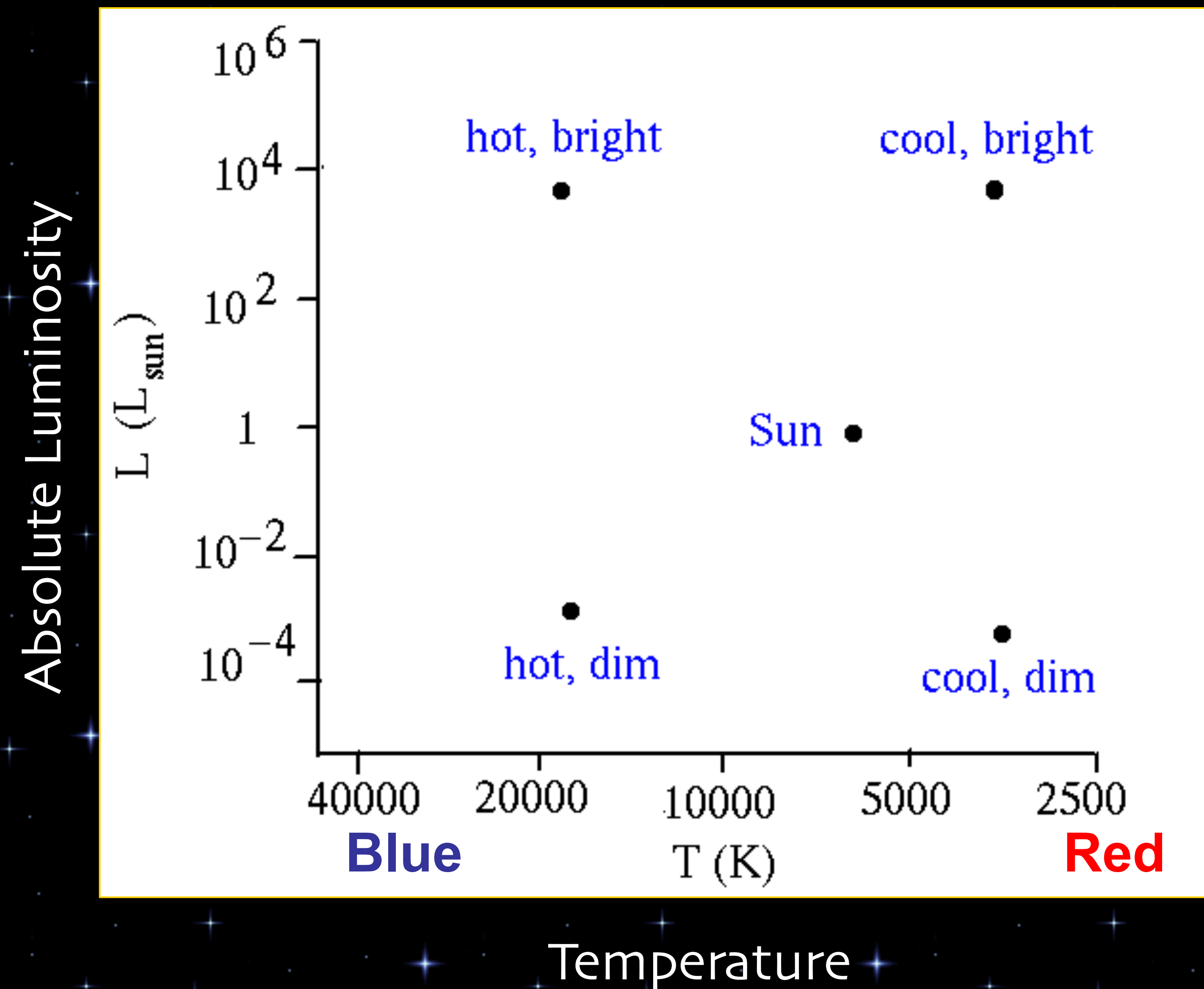
Star color is primarily controlled by one variable – *surface temperature*.

The hotter the star, the shorter the wavelength of light emitted. **Violet** stars are hotter than **blue** stars, which are hotter than **green** stars, and on down the spectrum.



http://www.yorku.ca/eye/spectru.htm

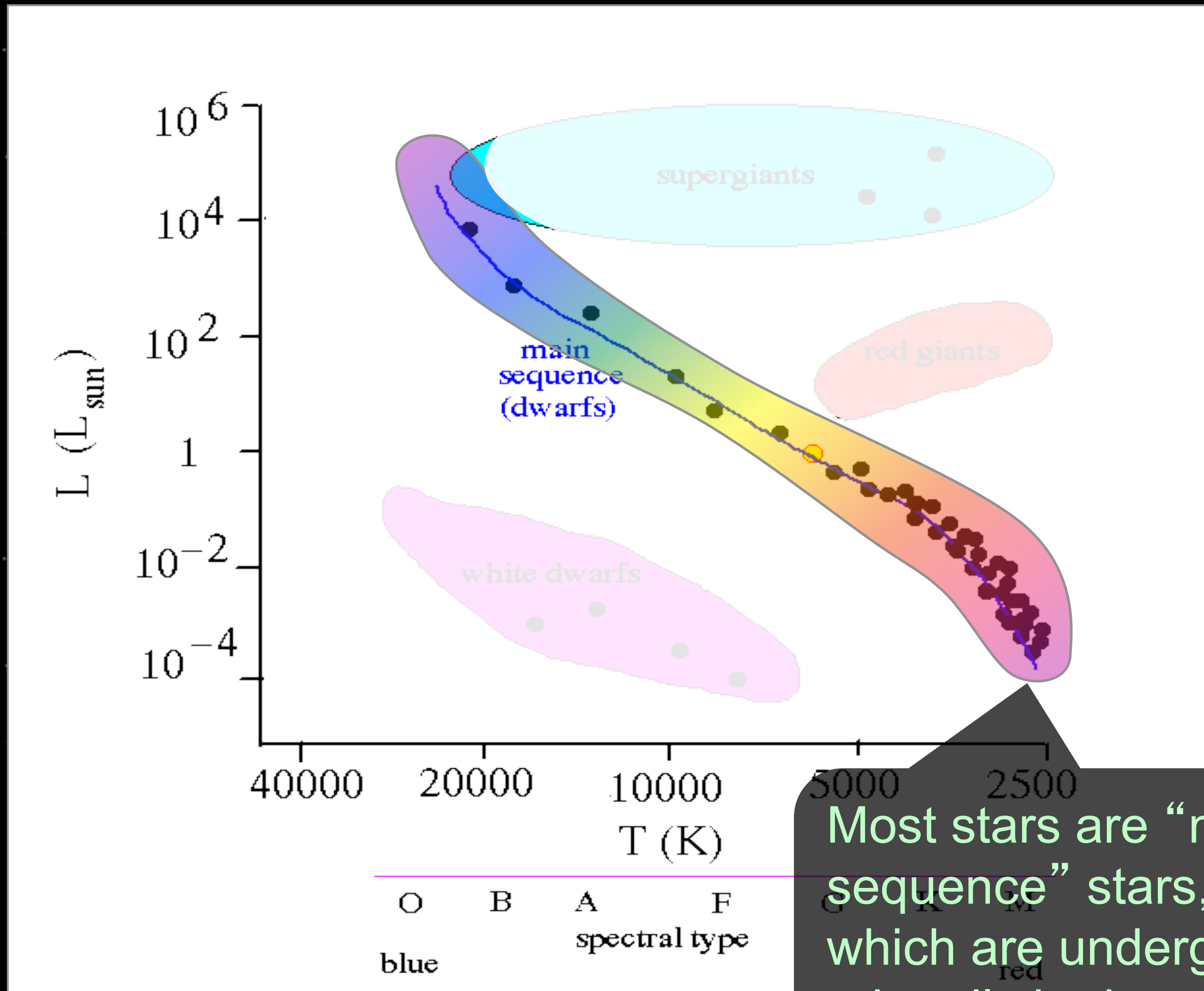
Hertzsprung-Russell Diagram



http://www.astronomynotes.com/

Main Sequence Stars

Absolute Luminosity

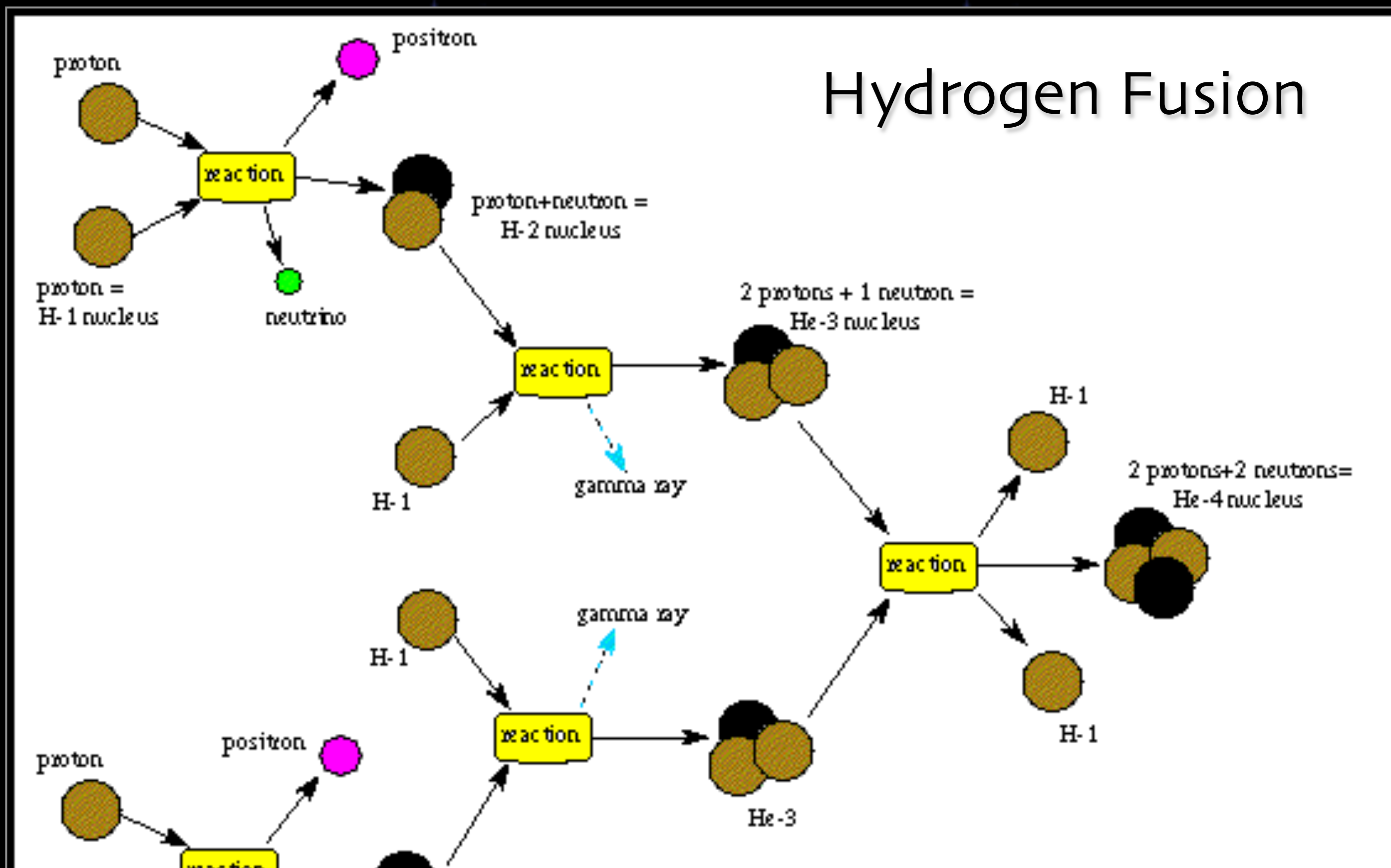


Temperature

Most stars are "main sequence" stars, *all* of which are undergoing primarily hydrogen fusion

http://www.astronomynotes.com/

Main Sequence Stars



The proton-proton cycle. 4 protons (Hydrogen-1 nuclei) are fused to create one Helium-4 nucleus plus energy. The positron is the anti-matter counterpart of an electron. Adapted from a diagram in *Horizons* by M. Seeds (1991).

http://www.astronomynotes.com/

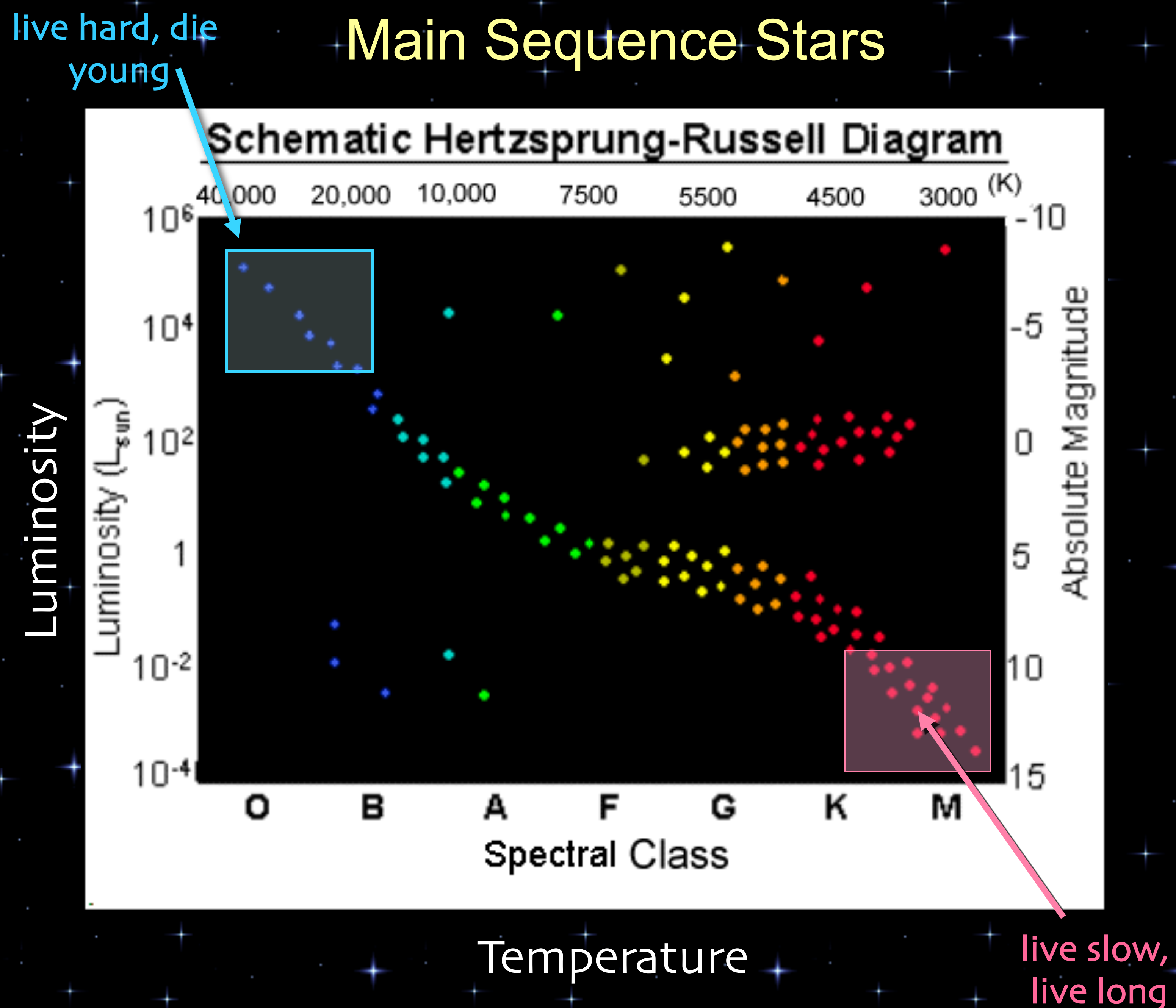
Main Sequence Stars

Star Mass (Solar Masses)	Life Expectancy (millions of years)	Spectral Type	
60.0	3	O3	
30.0	11	O7	
10.0	32	B4	
3.0	370	A5	
1.5	3,000	F5	
1.0	10,000	G2	Sun
0.1	1,000,000	M7	

Larger stars burn through their hydrogen fuel much faster than smaller stars. Some of the smallest stars (red dwarfs) may have been around since stars first formed in our universe.

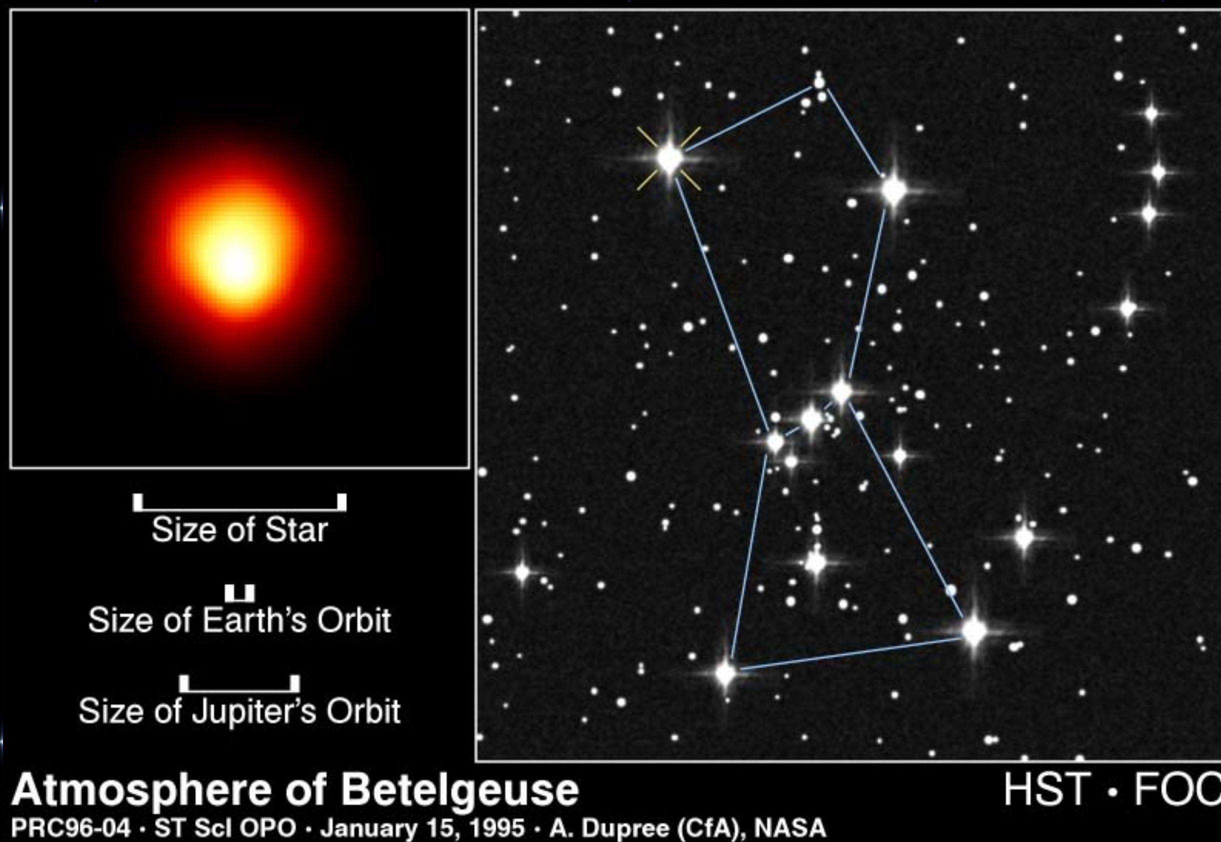
http://www.astronomynotes.com/

Main Sequence Stars



http://www.astronomynotes.com/

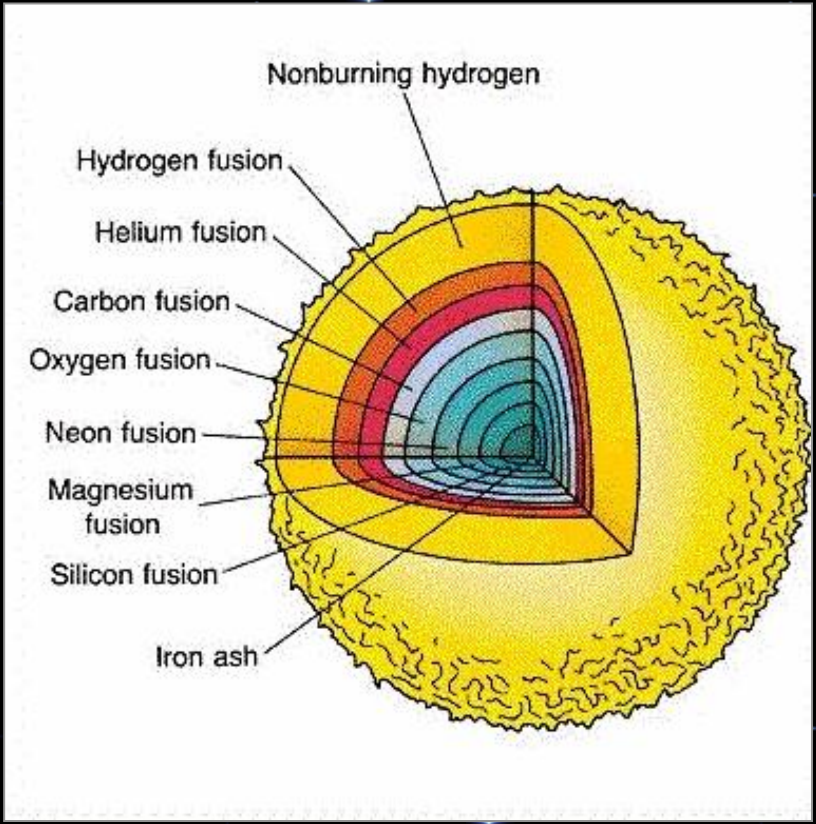
Off the Main Sequence



When the hydrogen "fuel" of a main sequence star is depleted, the star begins to die. Many smaller stars (like the Sun) become red giants as they begin to transform helium to carbon (helium fusion) within their cores.

http://hubblesite.org/

Nucleosynthesis in Old Stars



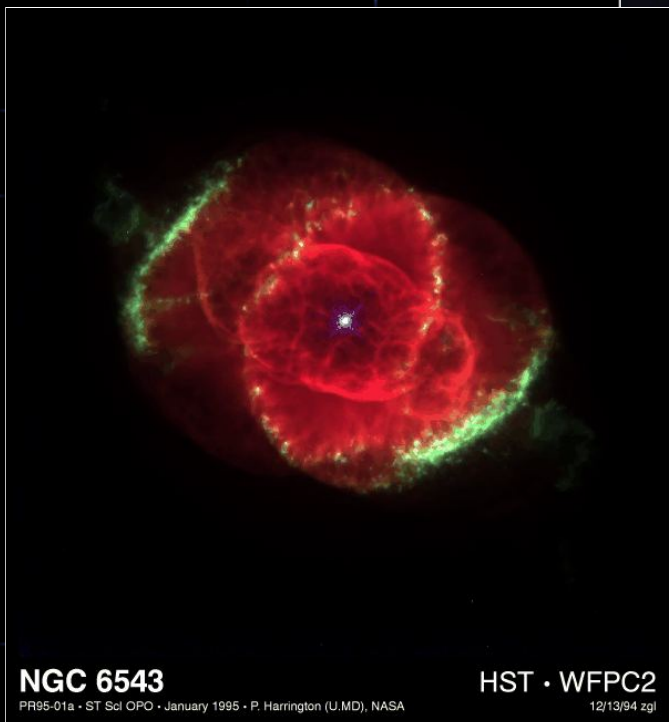
Helium builds up in the core of main sequence stars as they age. Eventually, hydrogen fusion stops in the core as the hydrogen migrates outward.

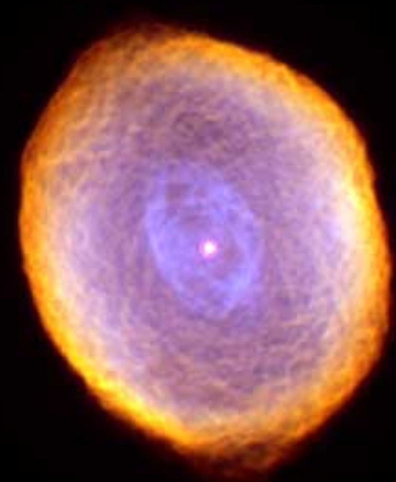
Without counter-pressure in the core opposing gravity, the star collapses inward. The core heats up to the point where helium fusion takes place, forming carbon.

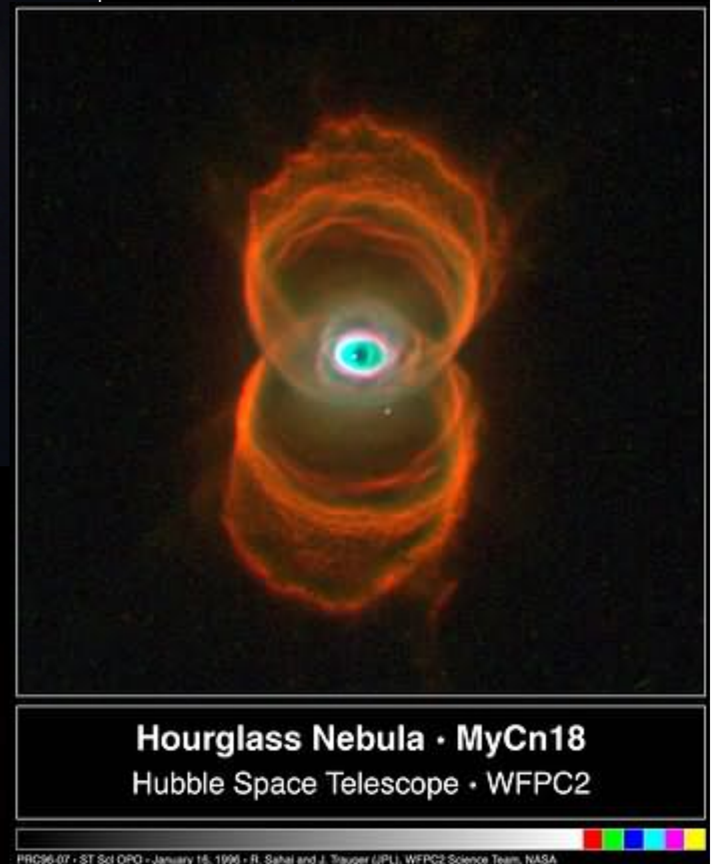
This process can continue to produce heavier and heavier elements up to iron. Iron fusion absorbs energy instead of releasing it, and thus is a dead end for the star. With no heat being produced in the core, the star's structure becomes unstable.

http://www.astronomynotes.com/

"Planetary" Nebulae





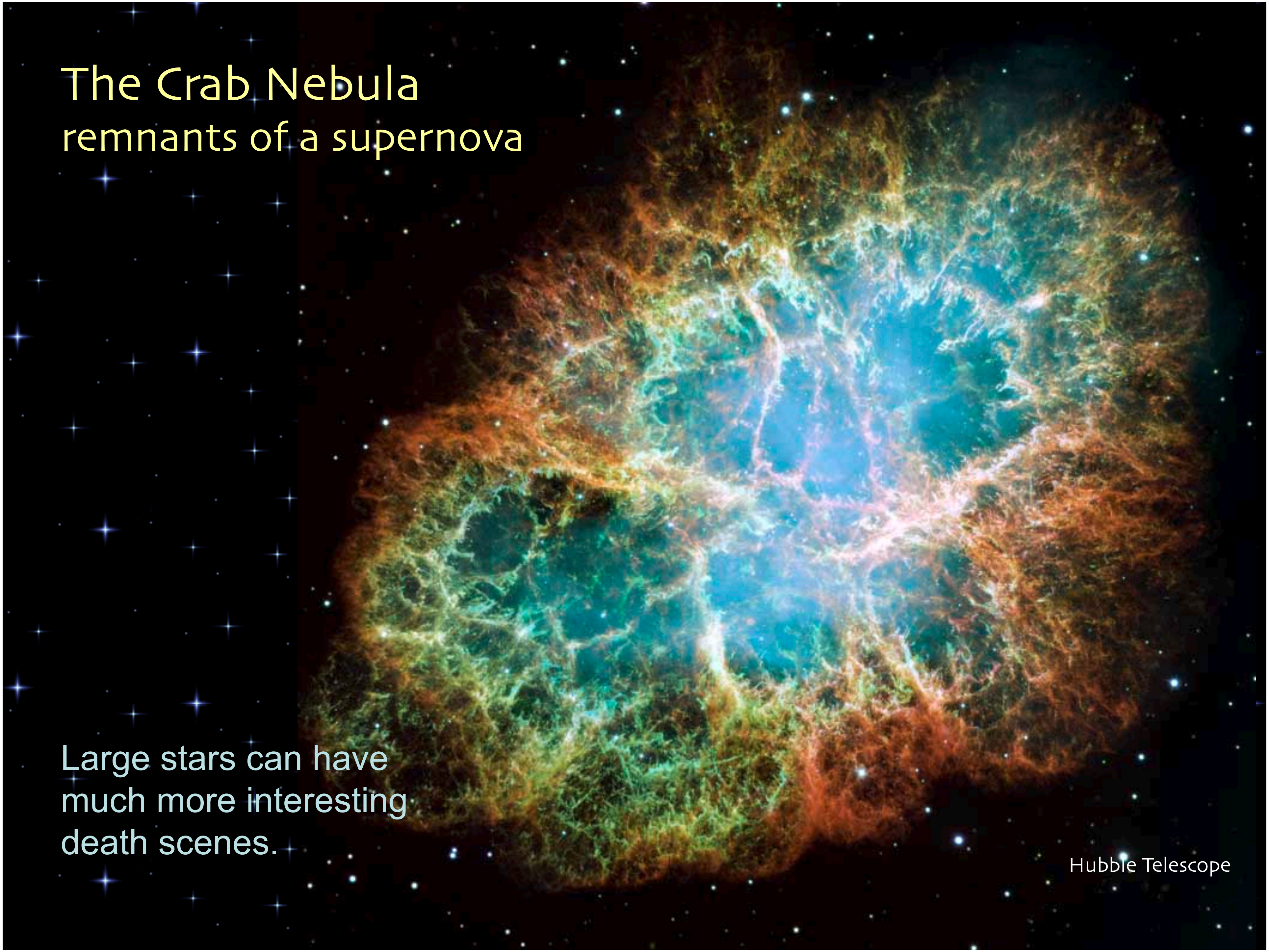


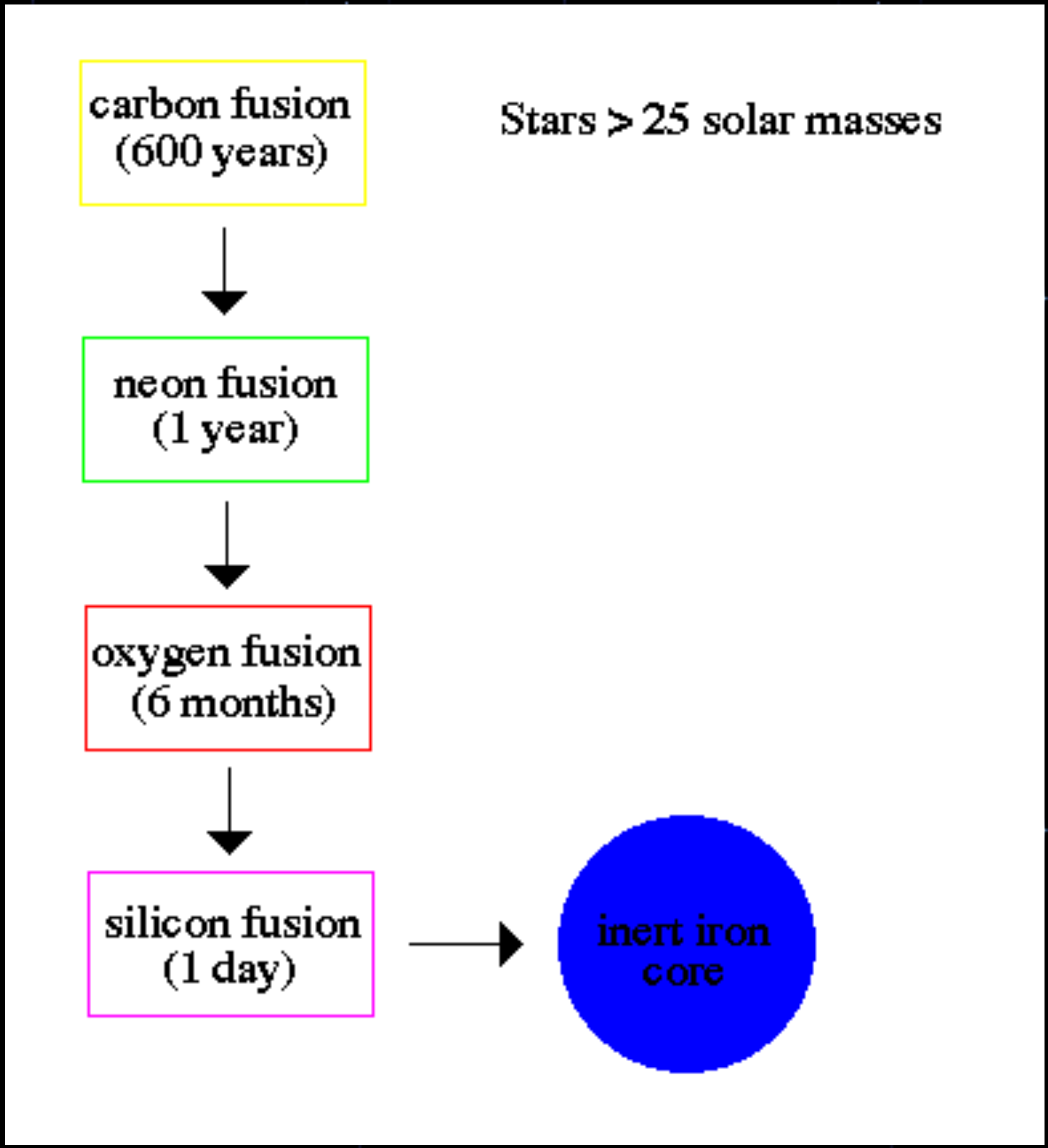
As heavier and heavier elements are synthesized, the star's structure becomes unstable, and it ejects material back to space, forming nebulae.

http://hubblesite.org/

A star can go through multiple smaller explosions before the end.

Eventually, small stars (including Sun-sized stars) either burn out or become tiny, but massive, dwarf stars.


The Crab Nebula
remnants of a supernova
Large stars can have much more interesting death scenes.
Hubble Telescope



The deaths of smaller stars can take millions of years.

Once carbon fusion starts in very large stars, the end comes much more quickly.

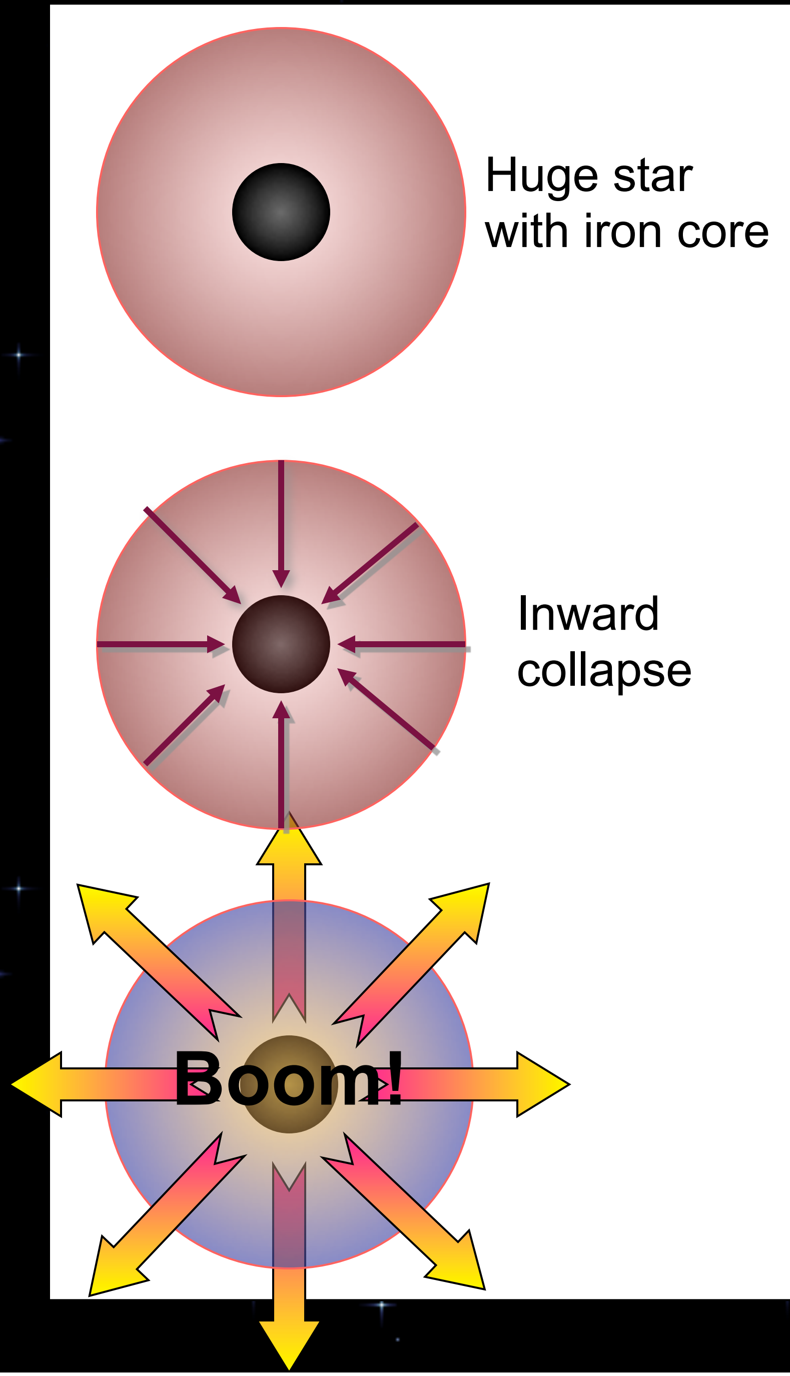
http://www.astronomynotes.com/

Anatomy of a Supernova

Once the iron core stops producing heat, the star shrinks inward until the pressure is high enough in the star's core to combine protons and electrons to form neutrons, which absorbs even more energy.

The loss of heat in the core leads to the collapse of the outer layers at up to 15% of the speed of light.

The neutron core is incompressible, so the collapsing layers rebound off it, forming a massive shock wave that blows the star apart.

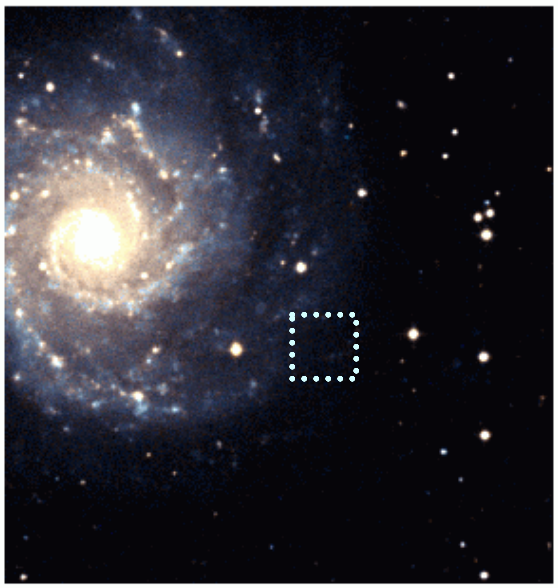


http://www.astronomynotes.com/

Supernova in Another Galaxy

A single supernova can be brighter than an entire galaxy.

M74 - Digital Sky Survey
1990



Mt. Hopkins 1.2m - SN 2002ap
Jan 31, 2002

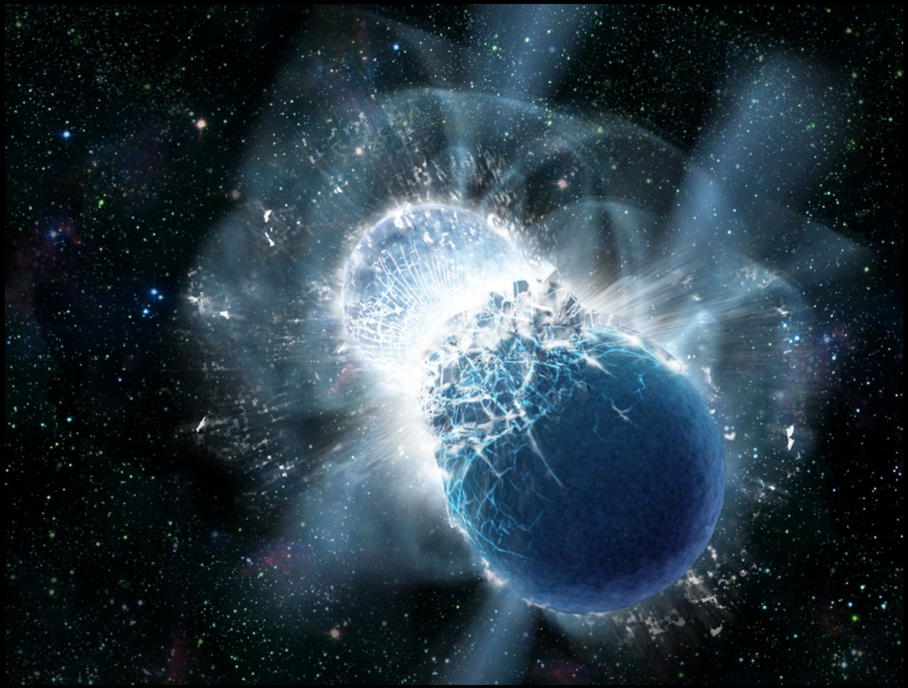
Heavy elements (all the way to uranium, and perhaps beyond) are formed under the massive pressures and high temperatures associated with supernova.

The debris from a supernova spread throughout space, enriching the Universe with heavy elements. Earth's heavier elements were produced in these catastrophic events.

Vela Supernova Remnants

New Data: Kilonovas!

The Hubble Space Telescope has detected distinct energy releases of gamma ray radiation throughout different areas of space. The energy signature indicates that exotic radioactive elements are produced (which then decay), but there is no supernova to make them.



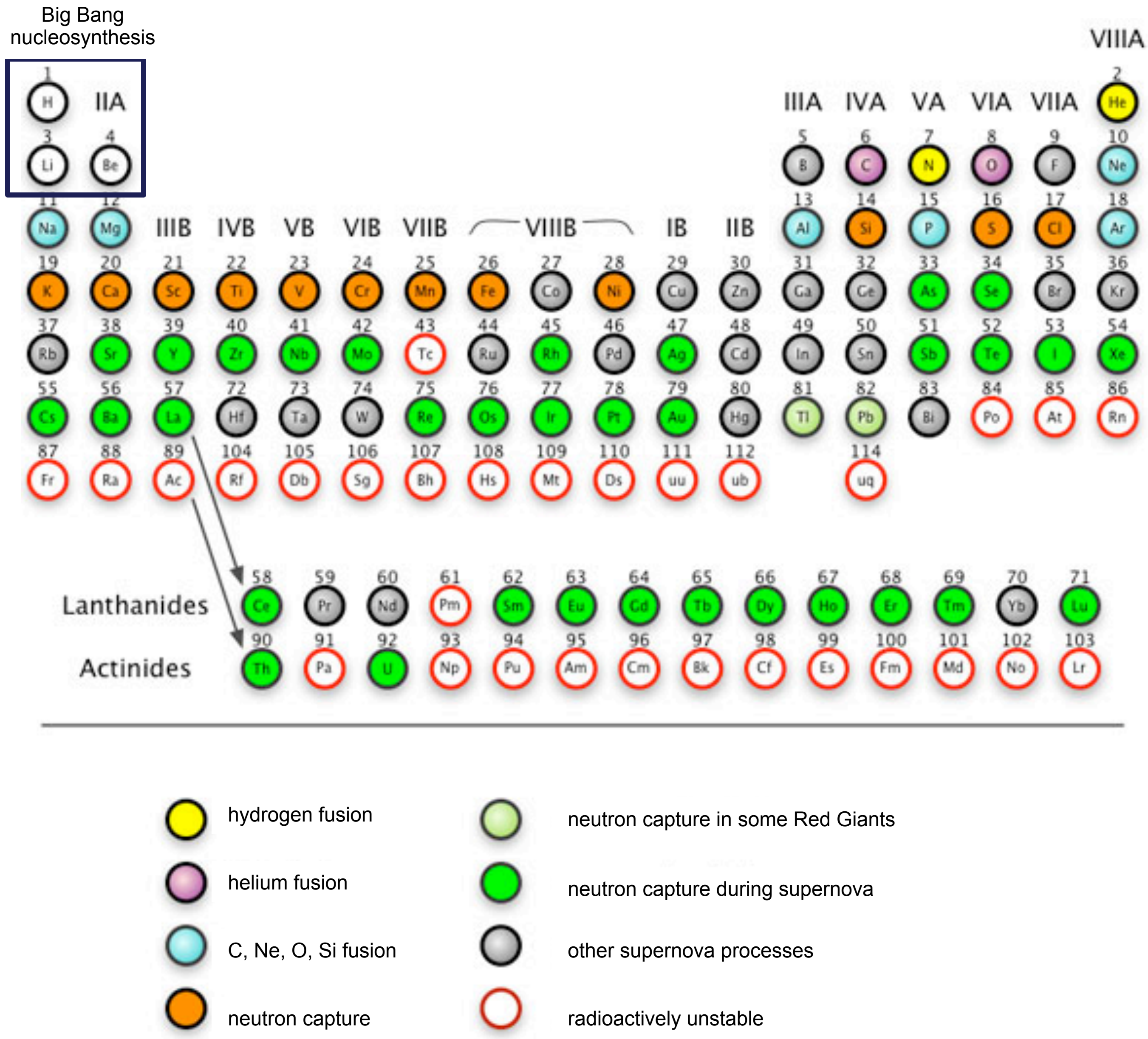
What could cause these weird explosions? One hypothesis is that they are the result of stars colliding – and not just any stars, but the super-compacted neutron stars left over when a giant star supernovas. The core remnants smashed together, causing the neutron to undergo nucleosynthesis and form all sorts of heavy elements.

Some astrophysicists are hypothesizing that most heavy elements present in the universe today (like gold) were primarily produced by these collisions, rather than by supernovas. Others disagree.

Berger, E., W. Fong and R. Chornock. 2013. Smoking gun or smoldering embers? A possible R-process kilonova associated with short-hard GRB 130603B. Astrophysical Journal Letters: arXiv:1306.3960v1 [astro-ph.HE].

http://www.cfa.harvard.edu/news/2013/pr201319_images.html

Nucleosynthesis



http://tingilinde.typepad.com/starstuff/2004/07/we_are_the_dust.html

Bow Shock Around LL Orionis

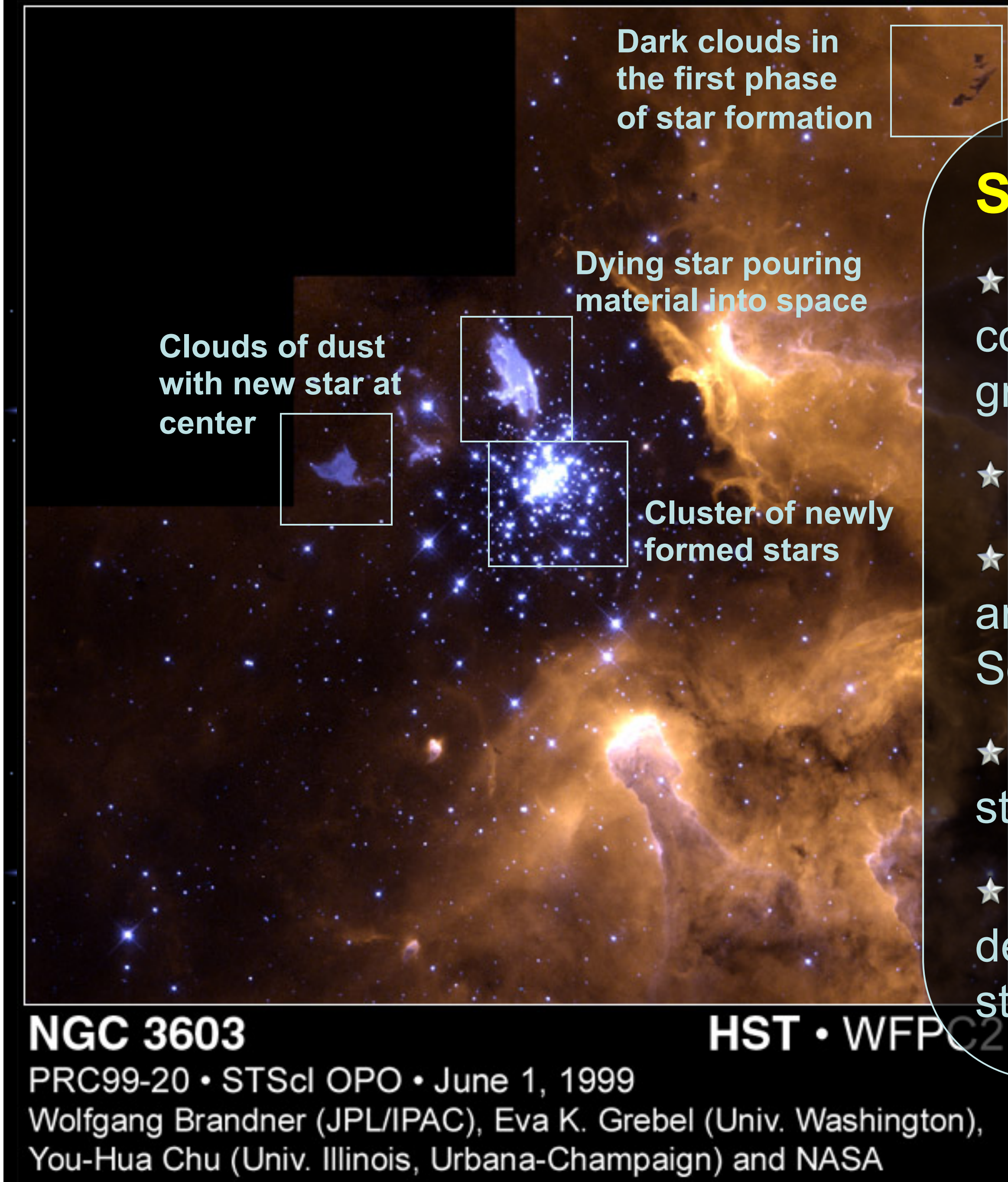
Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC02-05

The shock wave from a supernova can have dire effects on nearby stars.

On the other hand, the supernova may trigger new star formation in a nebula.

These new stars will be enriched in heavier elements.



Star Life Cycle

- ★ Gas cloud in a nebula collapses due to mutual gravitation attraction
- ★ Hydrogen fusion begins
- ★ Star reaches equilibrium and becomes a Main Sequence star (or not!)
- ★ Hydrogen is depleted in star, and star begins to die.
- ★ The mode of death is determined by the size of the star.