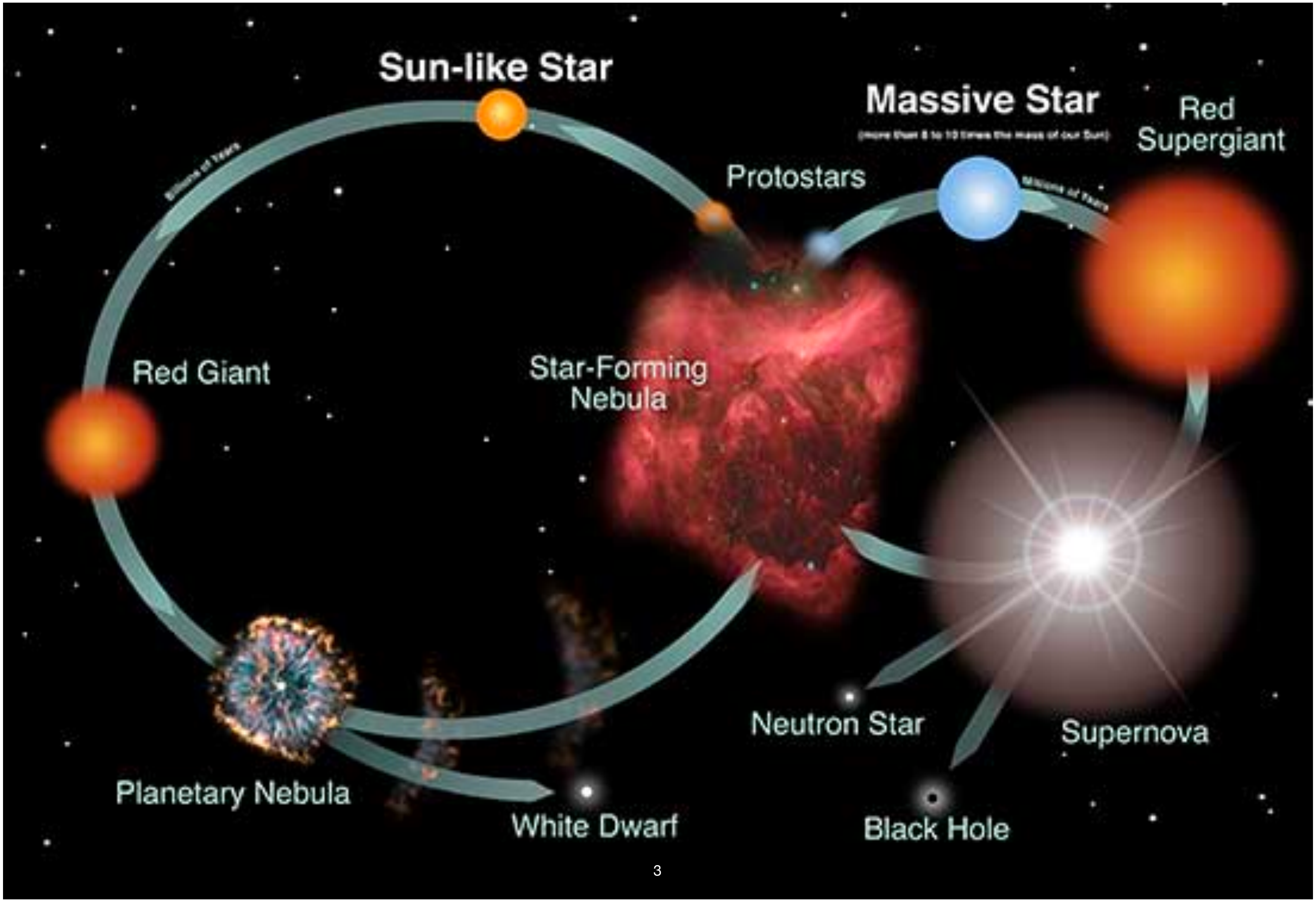
Stellar Life Cycle

Polaris and dust

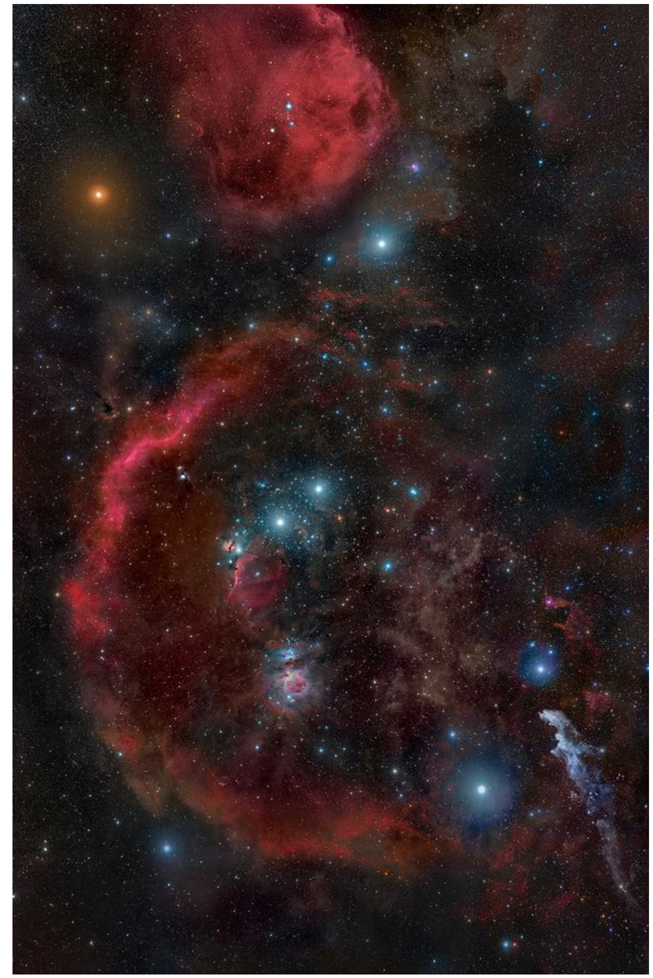
- Stars form from dusty gas clouds
- Most of the clouds are dark but some are lit by nearby stars
- Clouds are huge (100s light years, millions of suns' mass) and cold (15 K typical)
- Mostly H_2 molecules, but also CO, dust, etc.


Sun-like Star
Massive Star
Red
Supergiant
Protostars
Red Giant
Star-Forming
Nebula
Neutron Star
Supernova
Planetary Nebula
White Dwarf
Black Hole

- Orion’s stars are mostly in front of a huge dark cloud
- Orion Nebula is forming hot stars, which are blowing away the cloud they formed from. It’s in a crater in the front of the cloud driving a “champaign flow” toward us.
- Starlight and winds sculpt the cloud into interesting formations
- UV light ionizes hydrogen and makes it glow: Note the pink colors of some cloudy areas.

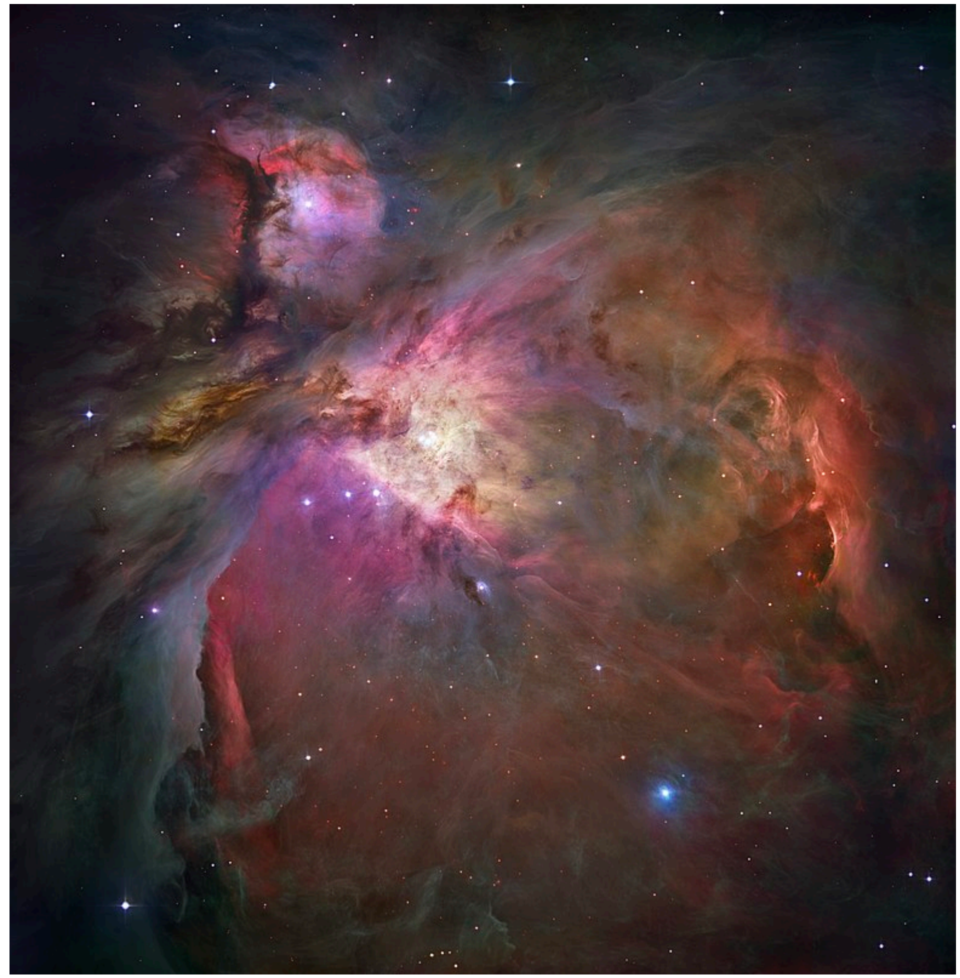
Orion shows ongoing star formation

- This is a very long exposure of Orion.
- Most of the stars are in front of a dark cloud
- Barnard’s Loop (red semicircle) is an expanding shock driven by hot stars
- Betelgeuse is an aging star in the upper left
- The Orion Nebula is a star forming region breaking through the front surface of the cloud.



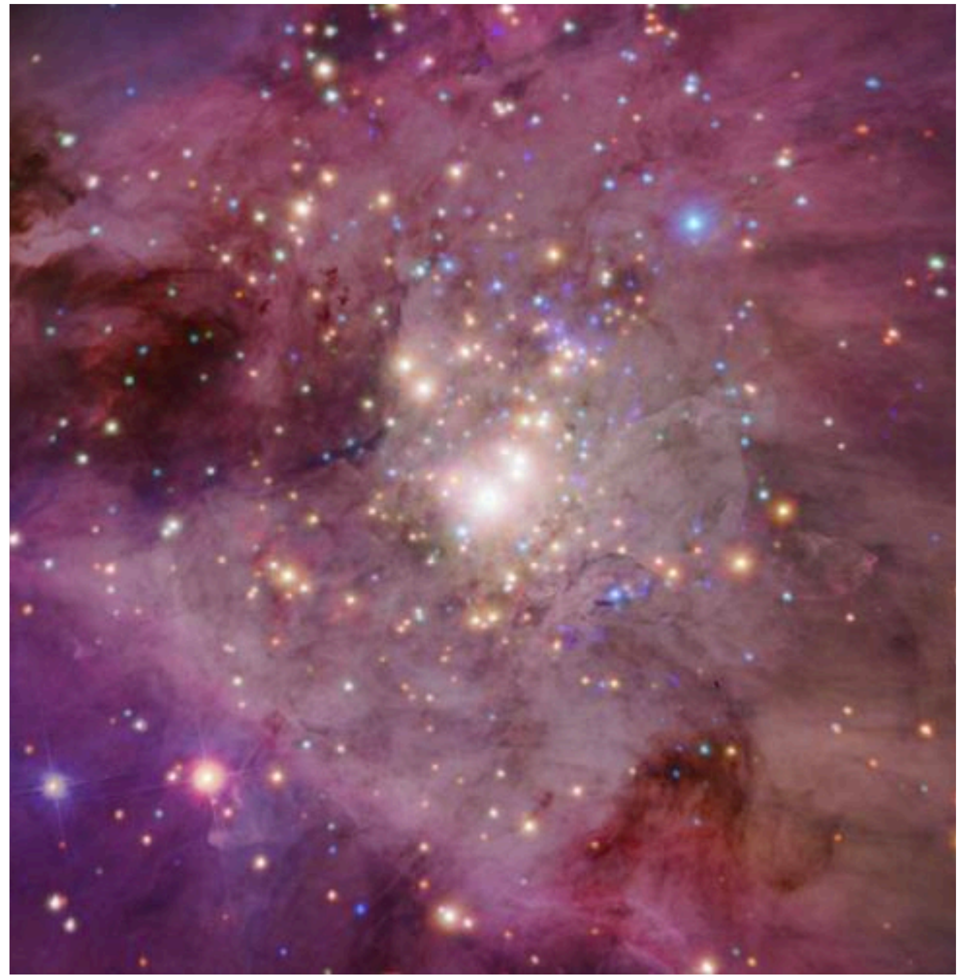
Orion Nebula

- Hot stars formed in the dark cloud.
- Their light and winds are blowing a hole in the front of the cloud.
- We're looking into a bowl-shaped divot with the hot young stars lighting it up.
- New generations of stars are forming, still embedded in the dark cloud behind the nebula.
- Distance 1500 light years



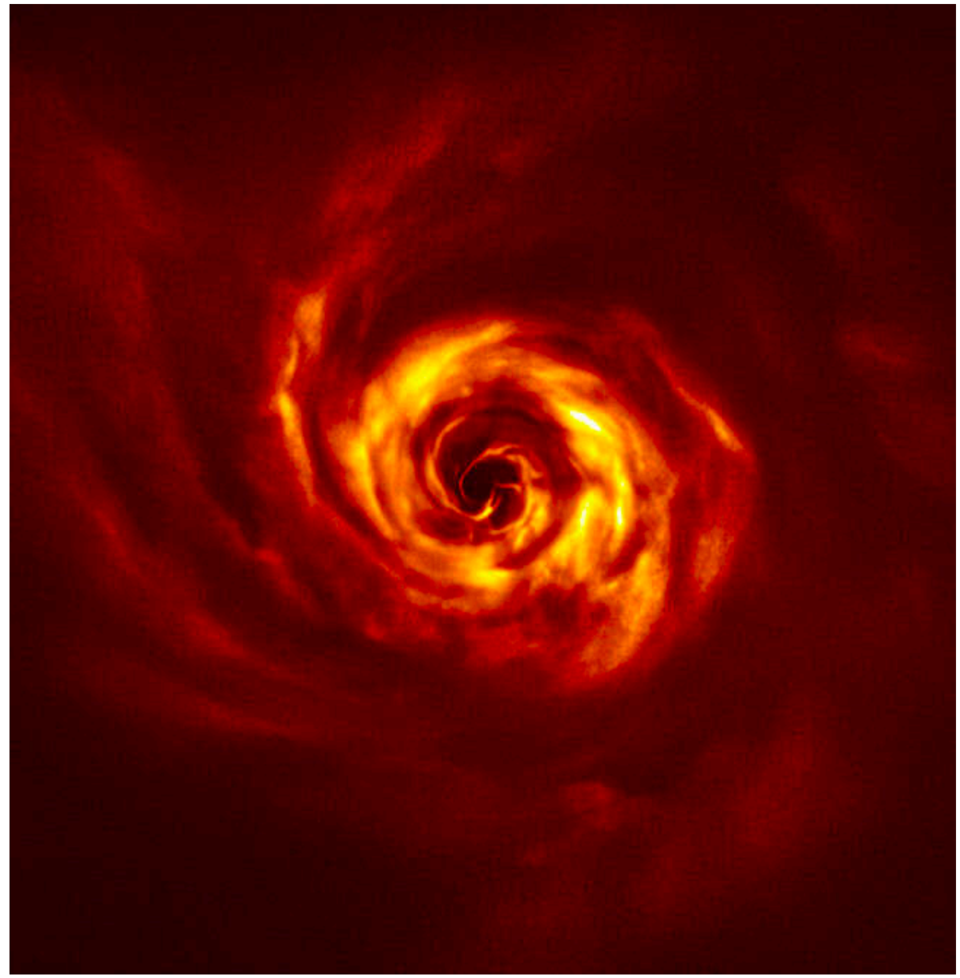
Orion Nebula in x-rays

- The wispy stuff is from Hubble, seen in visible light.
- The blue & orange points are young stars forming within the dark cloud, mostly behind the optical nebula.
- Every young star is an x-ray source
- The x-rays they emit can be seen through the cloud.



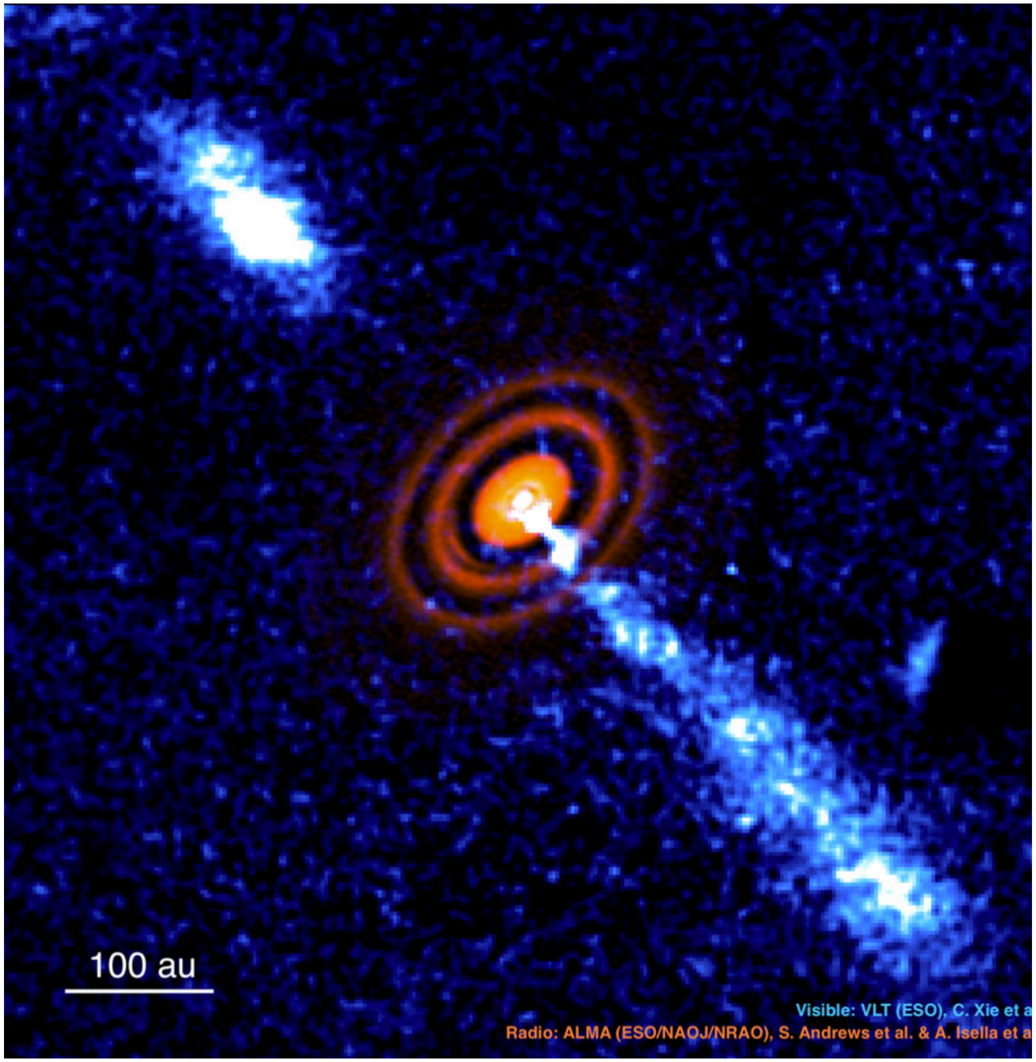
Star Formation

- Next, a few images of stars forming in nearby dark clouds.
- This is AB Aurigae. Note the spiral swirls of infalling gas.

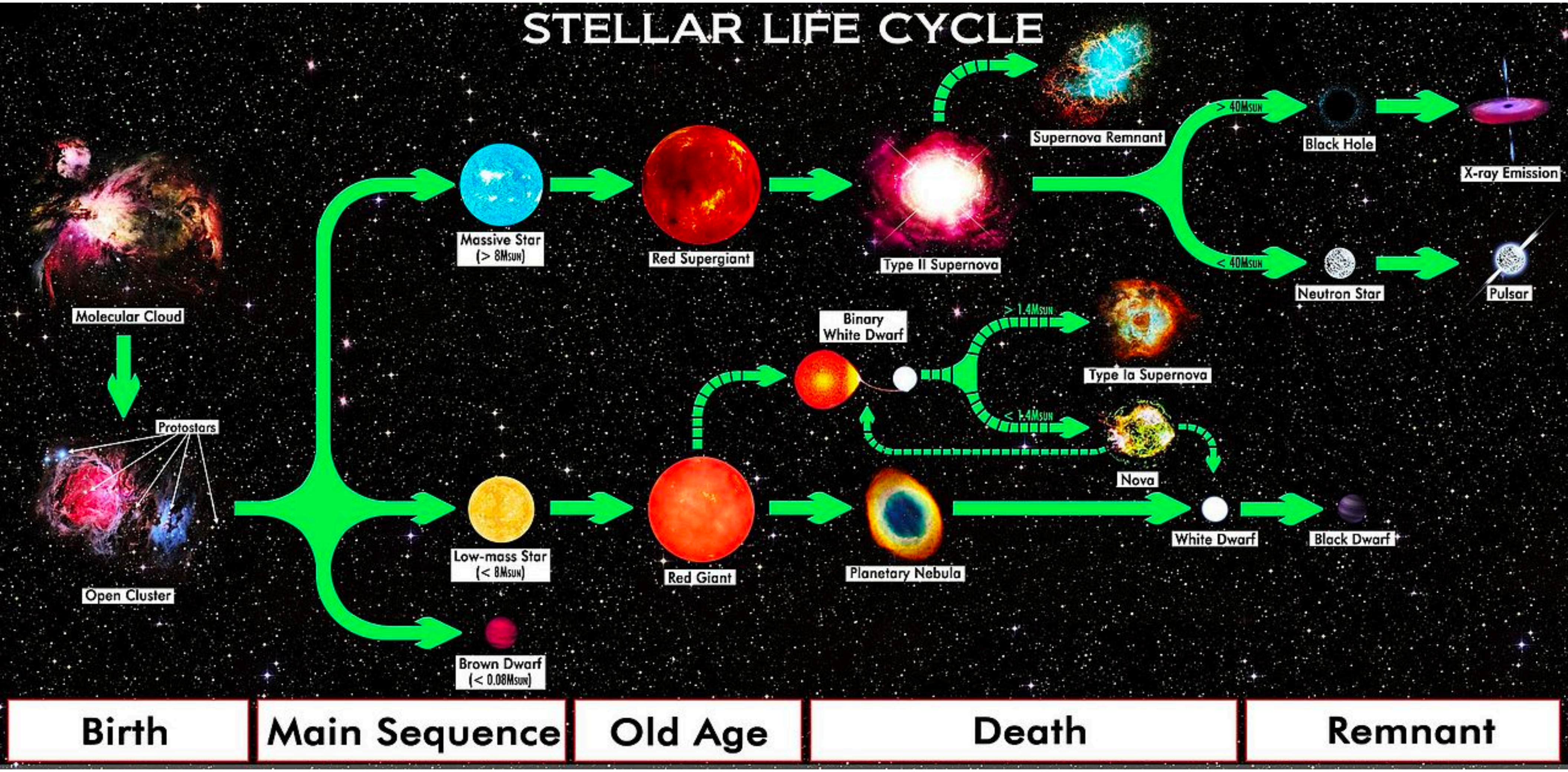


- This is NGC 602, a young cluster of stars. Note the fingers pointing at the center of the cluster.
- Lower mass stars are forming in those fingers, holding them together with gravity.

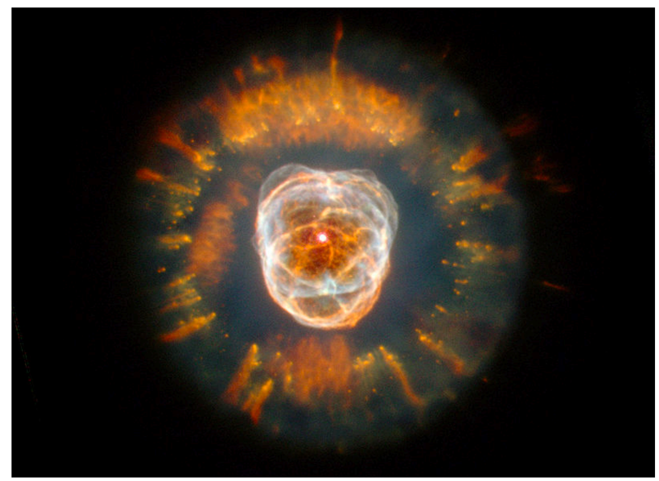
- Composite pic of a forming star, HD 163296
- Orange is submillimeter showing a disk with gaps (are there planets in the gaps?)
- Blue/white is visible light from the VLT in Chile, showing jets of material ejected along the rotation axis.



- When core H runs out, the core begins to shrink due to gravity.
- This makes it hotter and denser, and for a while the rest of the H can fuse.
- When the inner core is essentially pure He, it shrinks quite a lot, gets hotter and denser, until finally it's hot enough to fuse 3 He nuclei into Carbon.
- All the extra radiation coming from the core fluffs up the envelope of the star, so the visible surface expands and becomes cooler (and redder).
- Betelgeuse is in this phase now.
- Fusing He goes much faster than fusing H did. And when the He is gone, fusing C, O, Ne, etc. go even faster, until…
- Iron. After you get iron-group elements no further nuclear energy is available, and gravity, finally, wins.

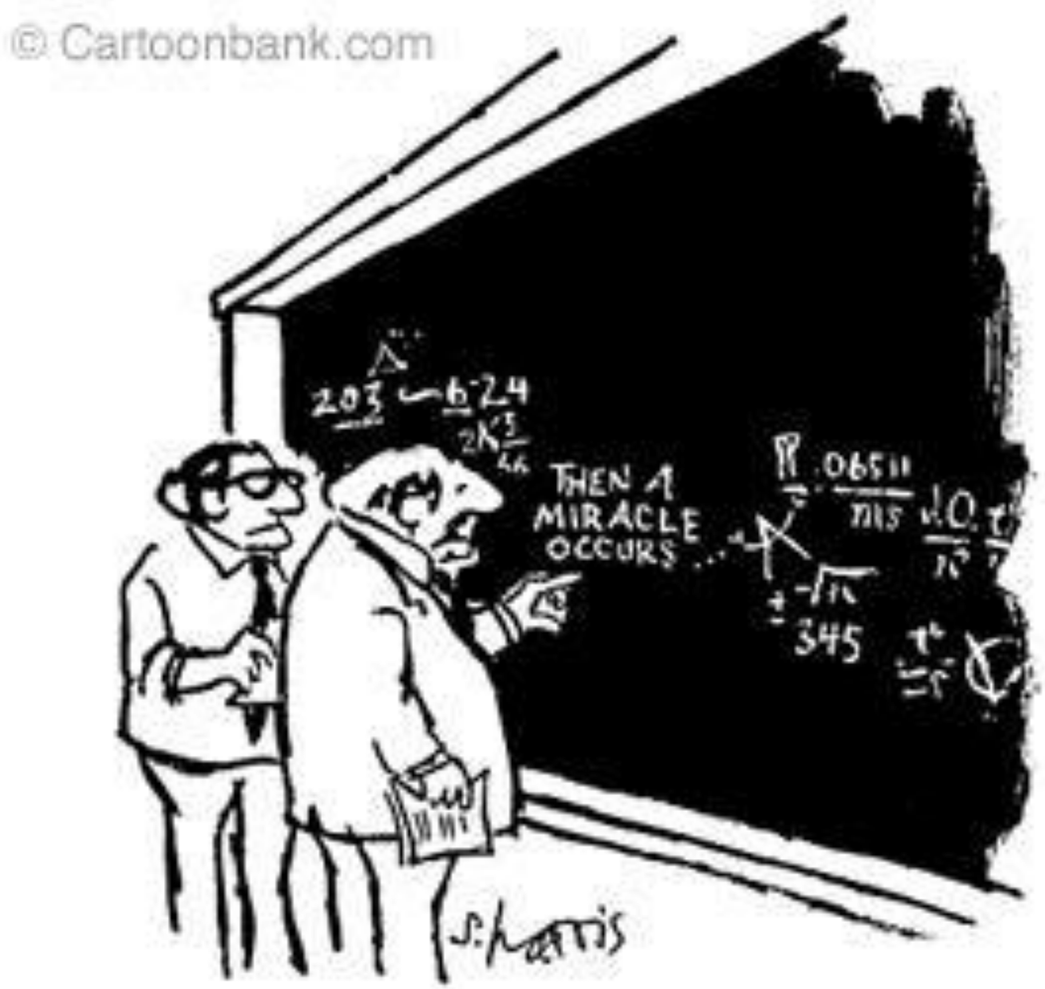

STELLAR LIFE CYCLE
Molecular Cloud
Protostars
Open Cluster
Massive Star (> 8Msun)
Low-mass Star (< 8Msun)
Brown Dwarf (< 0.08Msun)
Red Supergiant
Red Giant
Type II Supernova
Supernova Remnant
> 40Msun
< 40Msun
Black Hole
X-ray Emission
Neutron Star
Pulsar
Binary White Dwarf
> 1.4Msun
< 1.4Msun
Type Ia Supernova
Nova
Planetary Nebula
White Dwarf
Black Dwarf
Birth
Main Sequence
Old Age
Death
Remnant

- What happens next depends on the mass of the star.
- Low-mass stars have lifetimes longer than the current age of the universe… Nobody knows what happens next.
- Sunlike stars' cores contract until the electrons won't compress any more, gently puff off the surface layers of the star, expose the very hot core, which cools to a white dwarf star (mass ~ 1 M-sun, size like the earth). The hot core lights up the nebula made from the stellar envelope to make a "Planetary Nebula."
- Cores of stars over 8 M-sun collapse dramatically, exploding the stars as Supernovae.
- But first some really pretty pictures of deceased sunlike stars.



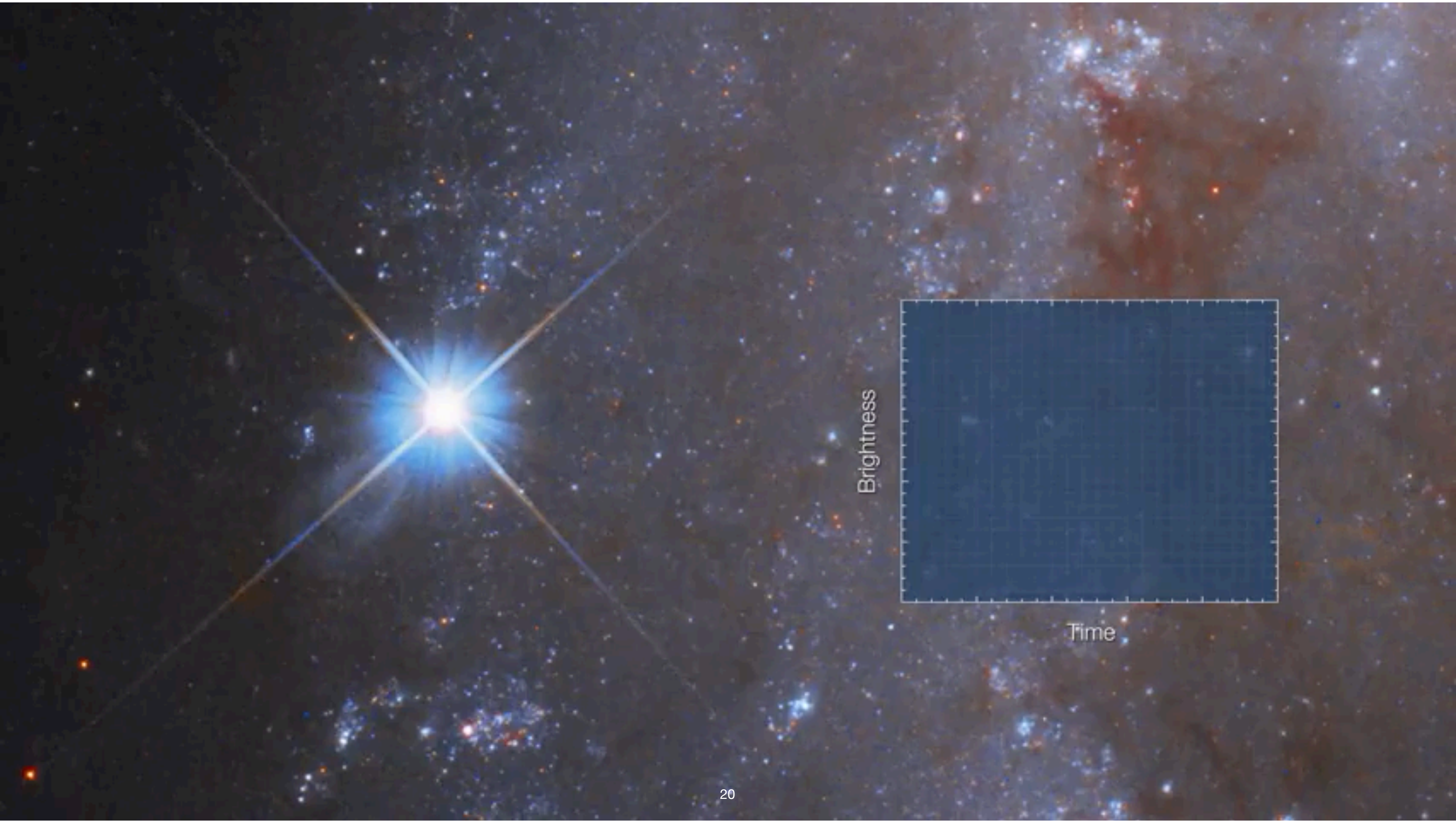
- The gas in the planetary nebula is returned to the galaxy at large to make into new generations of stars and planets.
- Since (almost) all nuclei heavier than He are formed in stars, this is where we came from. Carl Sagan: “We are star-stuff.”
- The white dwarf has no further energy source, so it cools until it’s no longer bright enough to see.
- White dwarfs made of C and O in close binary systems can get enough mass from the companion star to reactivate the fusion reaction and detonate the star. This is called a “type 1A supernova.” They seem to be all about the same brightness and can be used as distance indicators in faraway galaxies.

- The core of the massive star is collapsing.
- When it reaches the density of an atomic nucleus (or a bit more), the neutrons strongly resist further compression, forming a “neutron star”. Mass up to about 2 M-sun, size about 10 km (city sized). Often rotating very rapidly, with very strong magnetic fields.
- Somewhere in here, in a manner poorly understood…

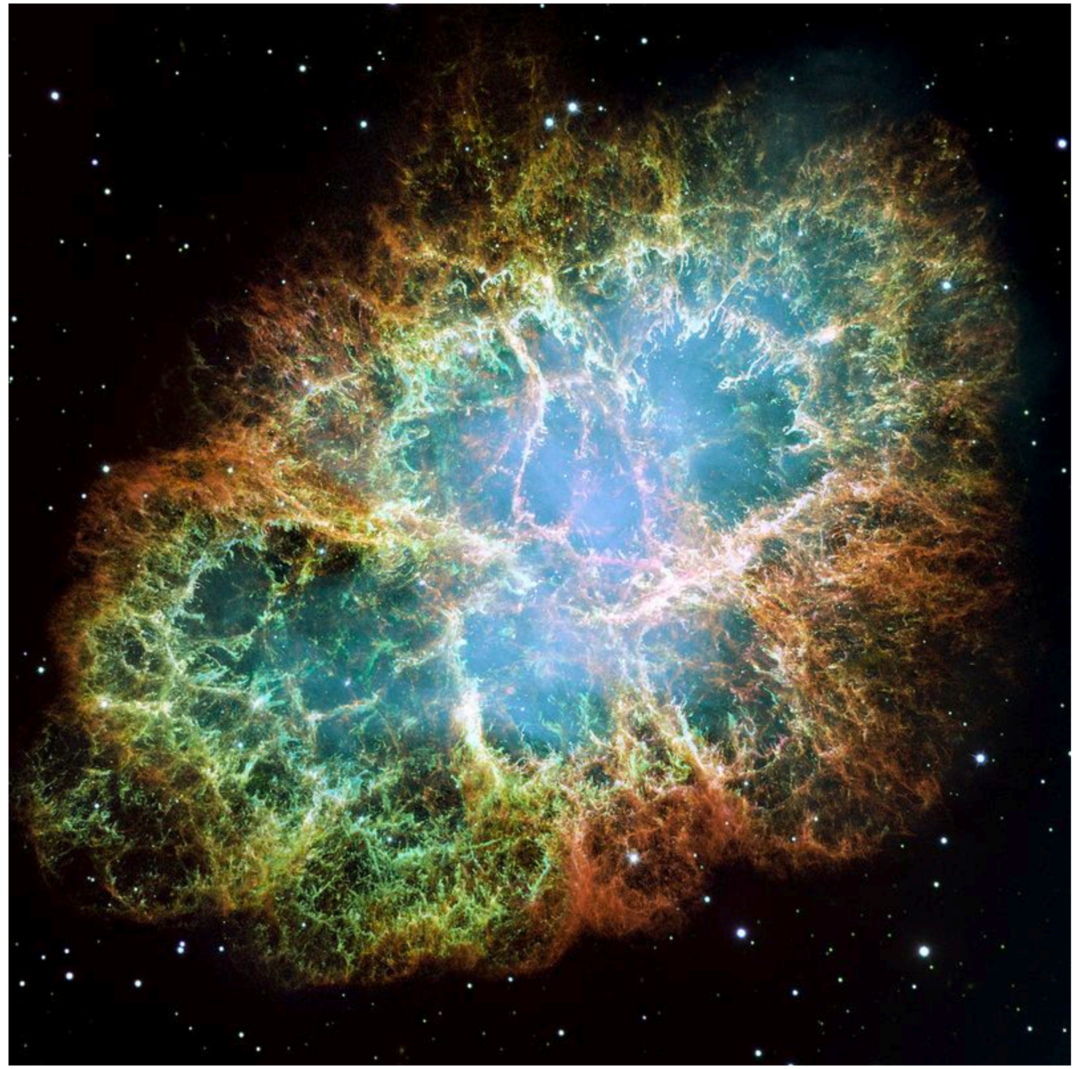


"I think you should be more explicit here in step two."

- … the star blows the envelope away in a Type II Supernova.
- Many of the nuclei synthesized over the lifetime of the star are scattered into space, where they can be made into future generations of stars and planets.
- Additional nucleosynthesis occurs during the explosion itself.
- Perhaps the neutrons can resist further collapse, and a neutron star will appear.
- If not, a black hole forms and (we think…) everything collapses to a mathematical point (“singularity”).
- The supernova can be as bright as the rest of the galaxy combined, for a few weeks. Here’s one in galaxy NGC 2525, fading.


Brightness
Time

- The Crab Nebula is the remnant of a supernova observed by the Chinese in 1054
- The colored filaments are ejecta from the star, observed in optical with Hubble.
- The blue glow is x-rays from high-energy electrons spun up in the magnetic field of the neutron star.
- The neutron star spins 33 times a second and flashes like a lighthouse. “Pulsar”



Cassiopeia A Supernova Remnant

- A Chandra X-ray Observatory image of the remnant of the supernova Cassiopeia A ("Cas A") from the 1680s.
- Colors represent different elements in the ejecta
- Blue is the blast wave
- White dot is the neutron star (it doesn't pulse).