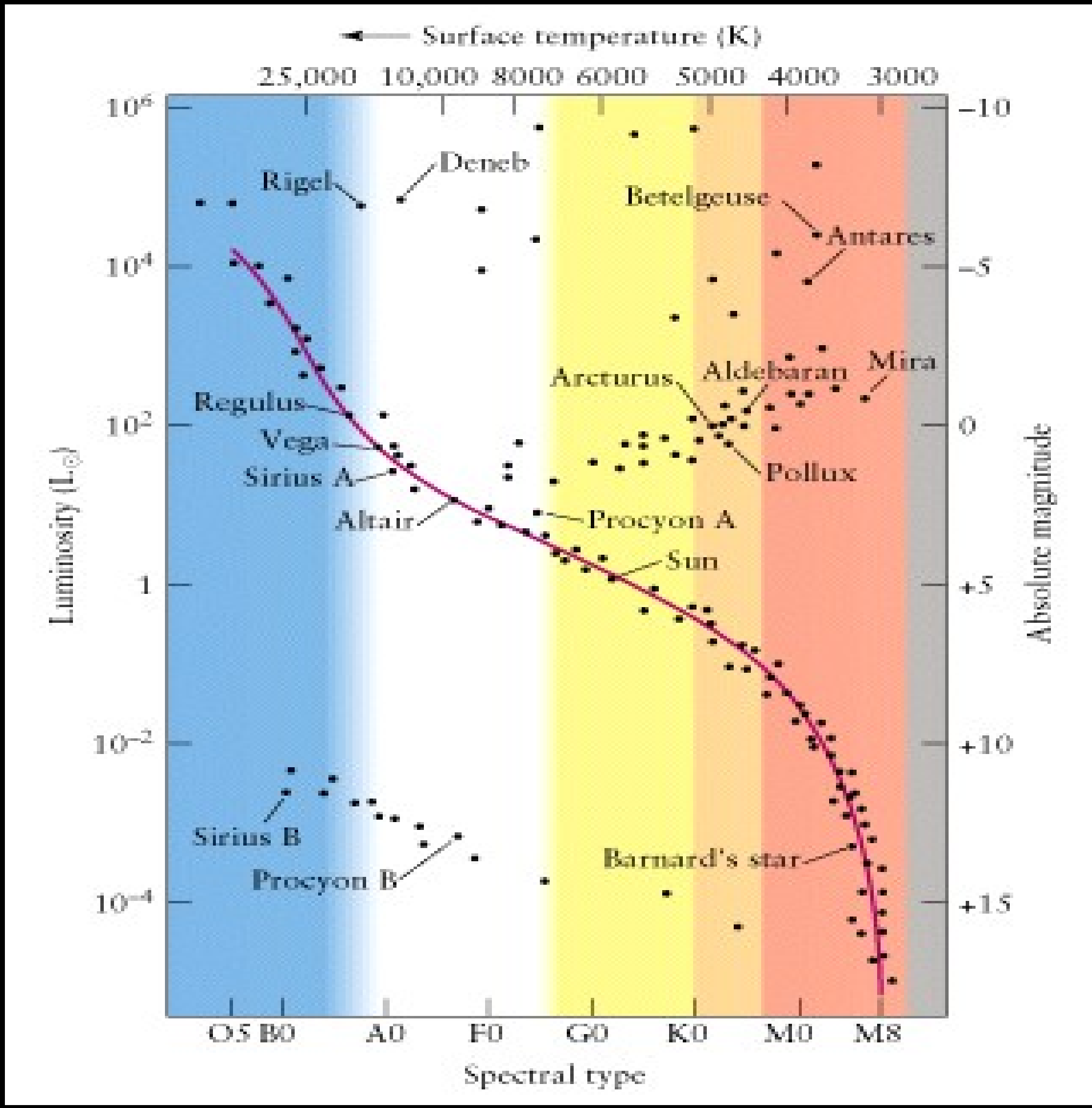
Relativistic Universe

Stars and systems of stars

The H-R Diagram

If a star's absolute luminosity and temperature are both known, they can be plotted against each other. This is called the Hertzprung-Russel (H-R) diagram.

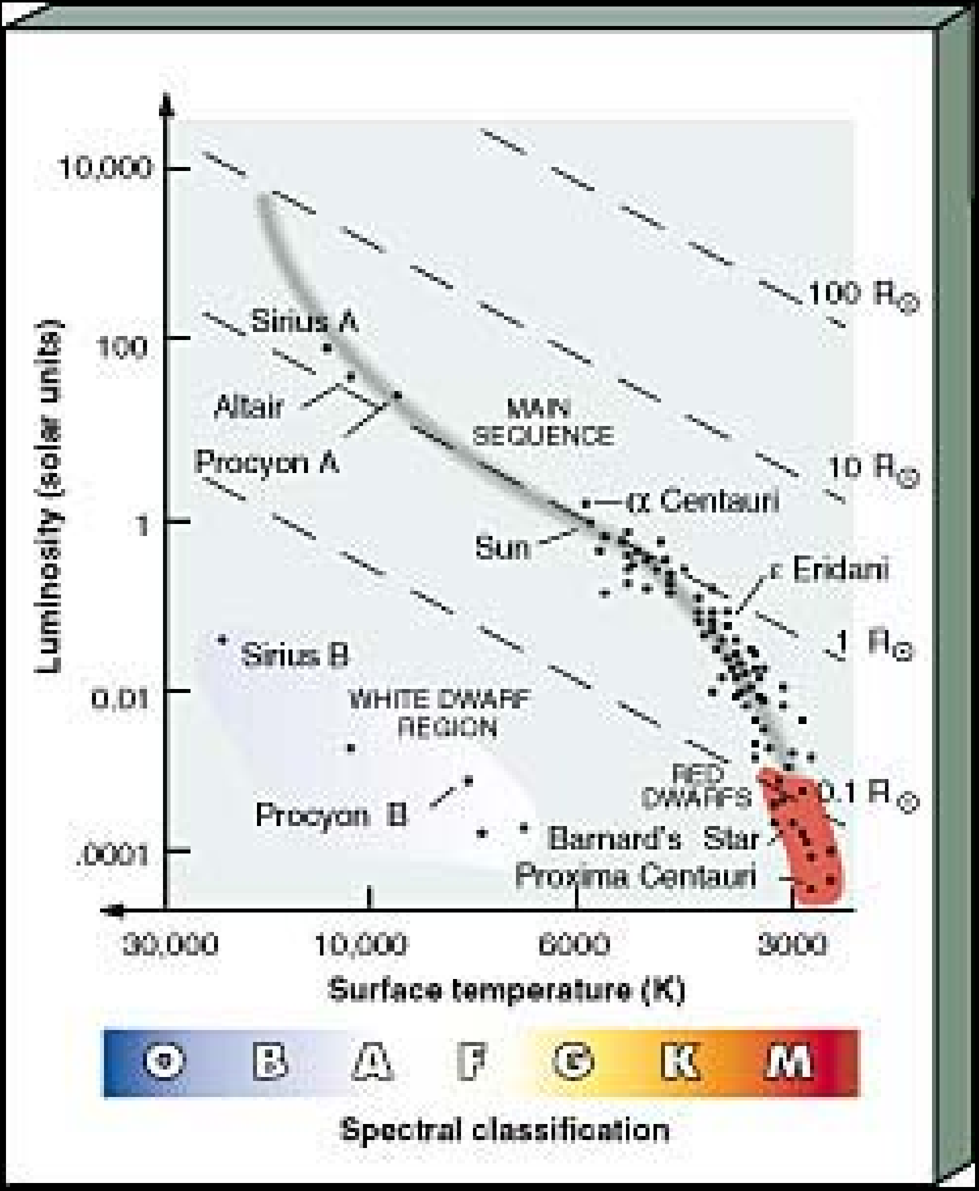
(As usual, the diagram is plotted somewhat backwards. Hot stars are plotted on the left, and cool stars on the right.)



The Sizes of Stars

The relationship between luminosity, radius, and temperature is

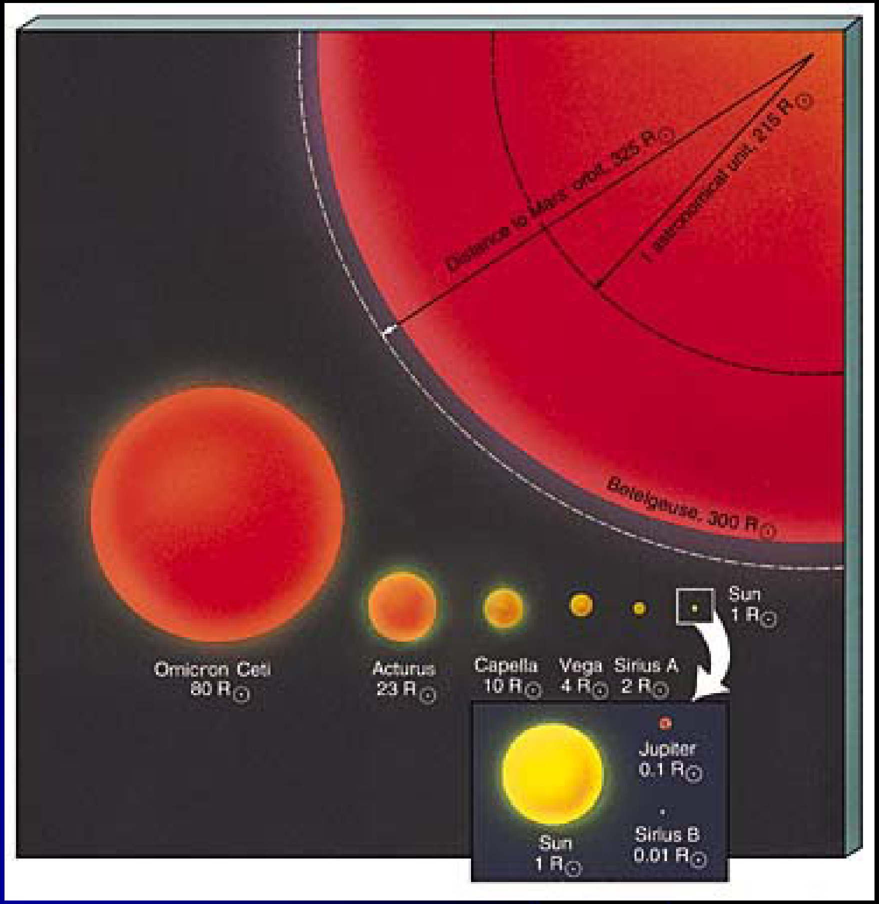
$$L = 4 \pi R^2 \sigma T^4$$

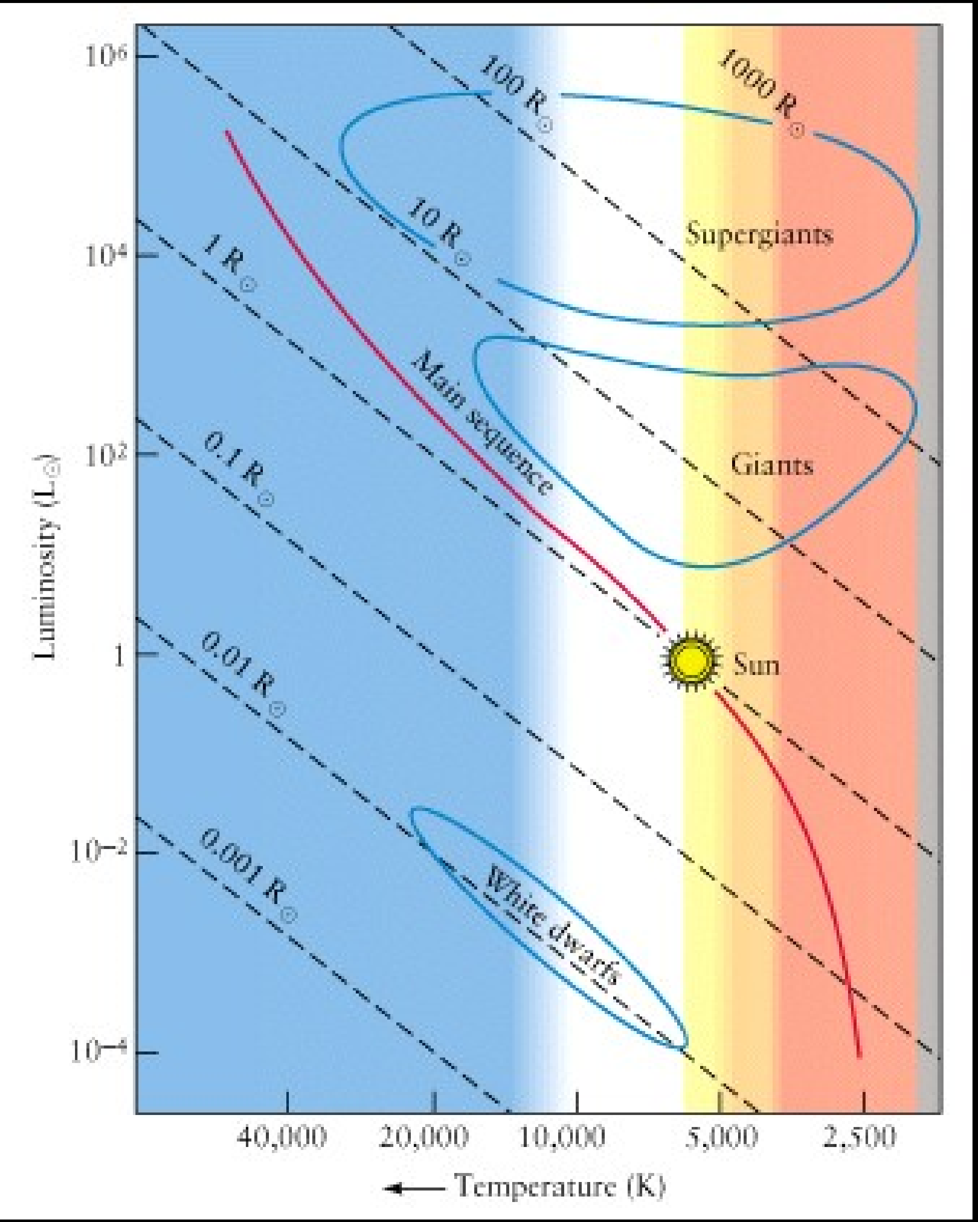


(π and σ are just numbers to make the units come out right)

The Sizes of Stars

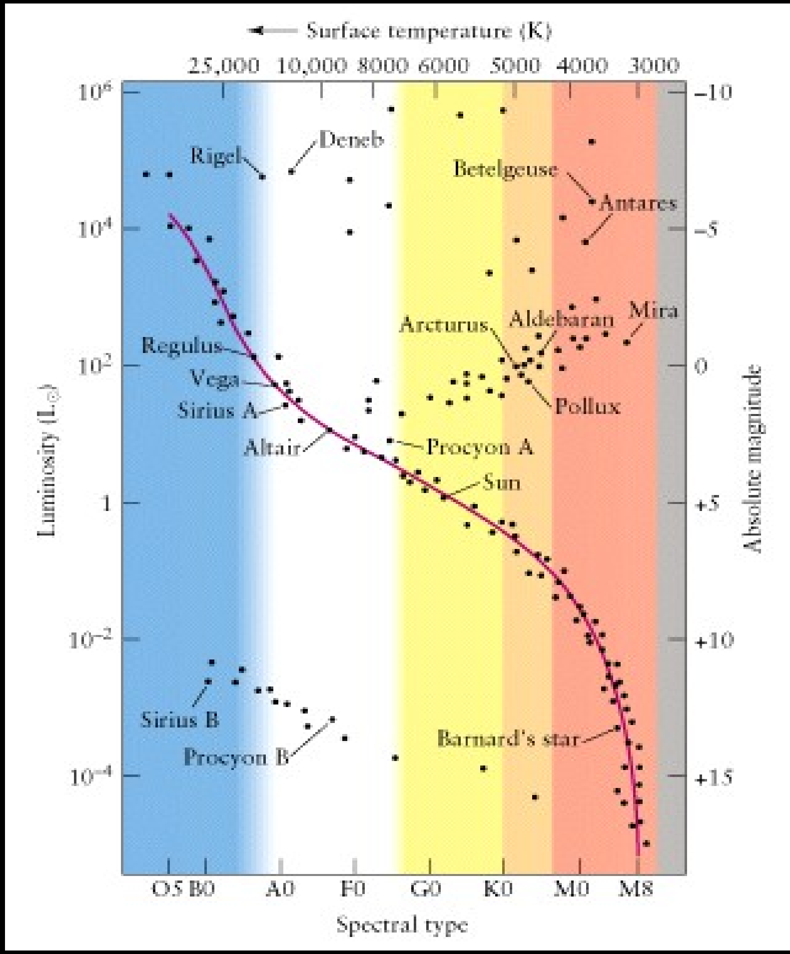
The sizes of stars can be anywhere from 0.01 $R_\odot$ to 1000 $R_\odot$!





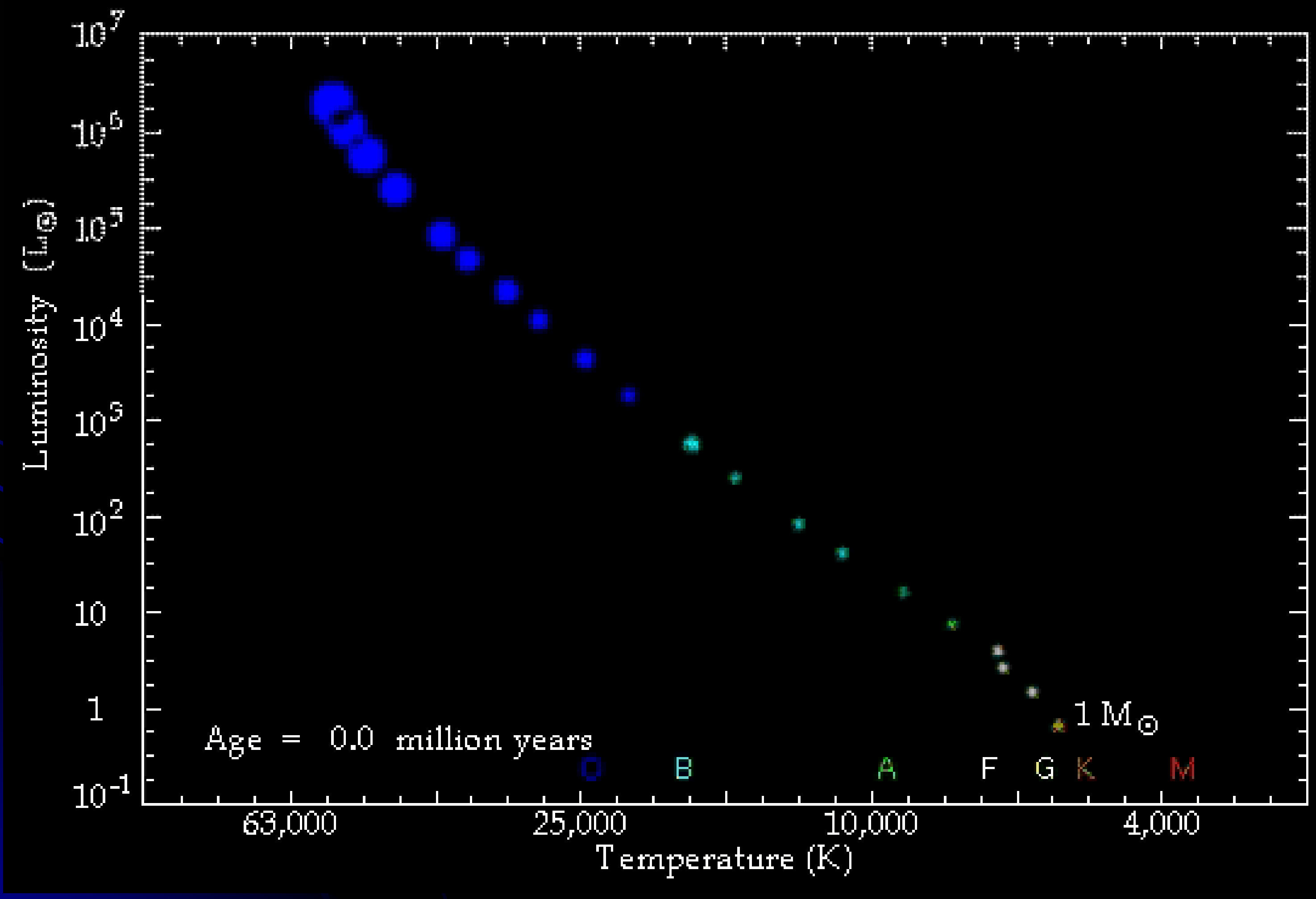
Results from Binary Stars Measurements

1) All stars have masses between 0.1 $M_\odot$ and 60 $M_\odot$
2) Main sequence stars obey a mass-luminosity relation: the brighter the star, the more massive the star.



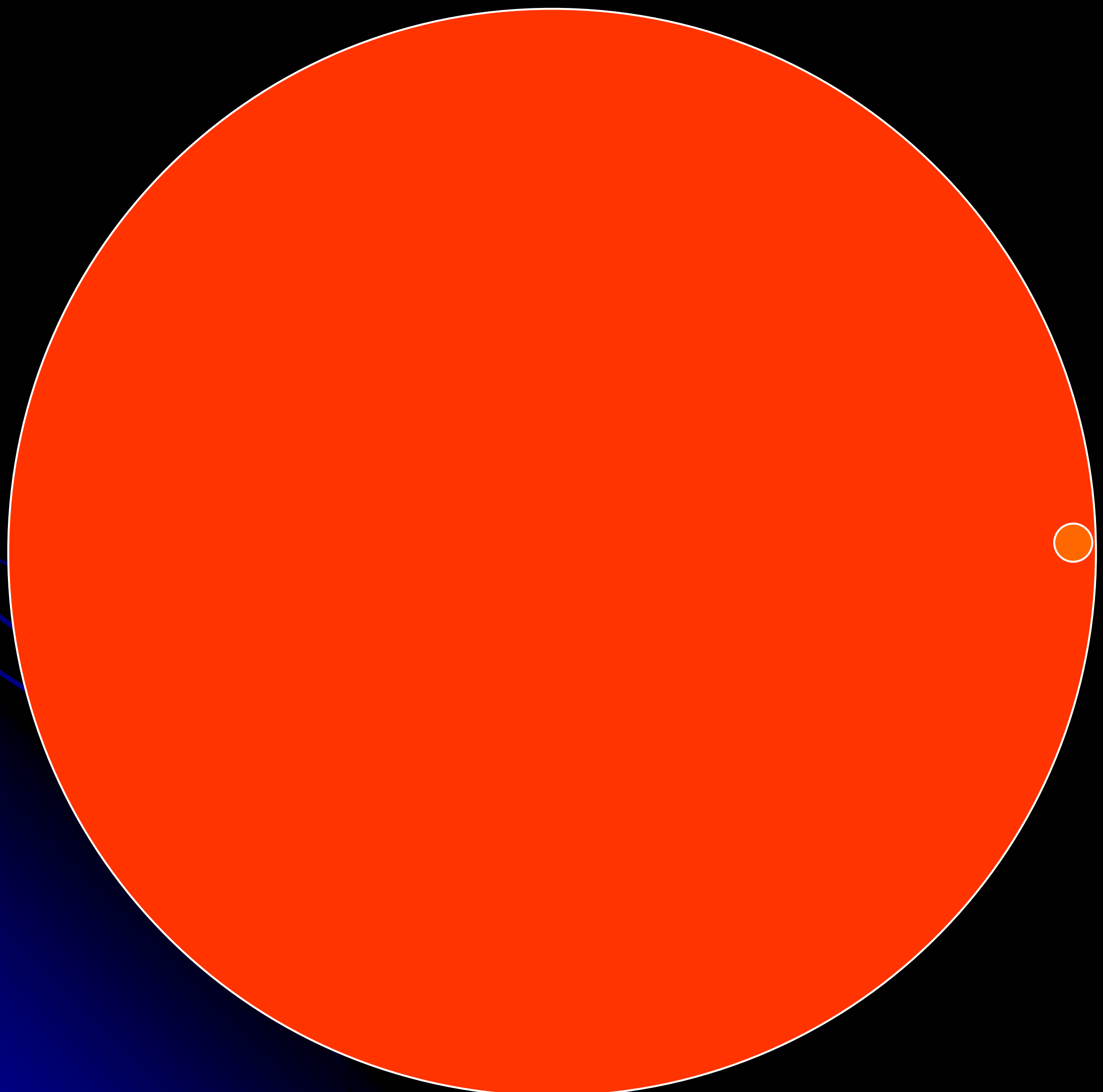
3) The white dwarf stars are all less than 1.4 $M_\odot$
4) There is no pattern to the masses of red giants.

Star evolution movie



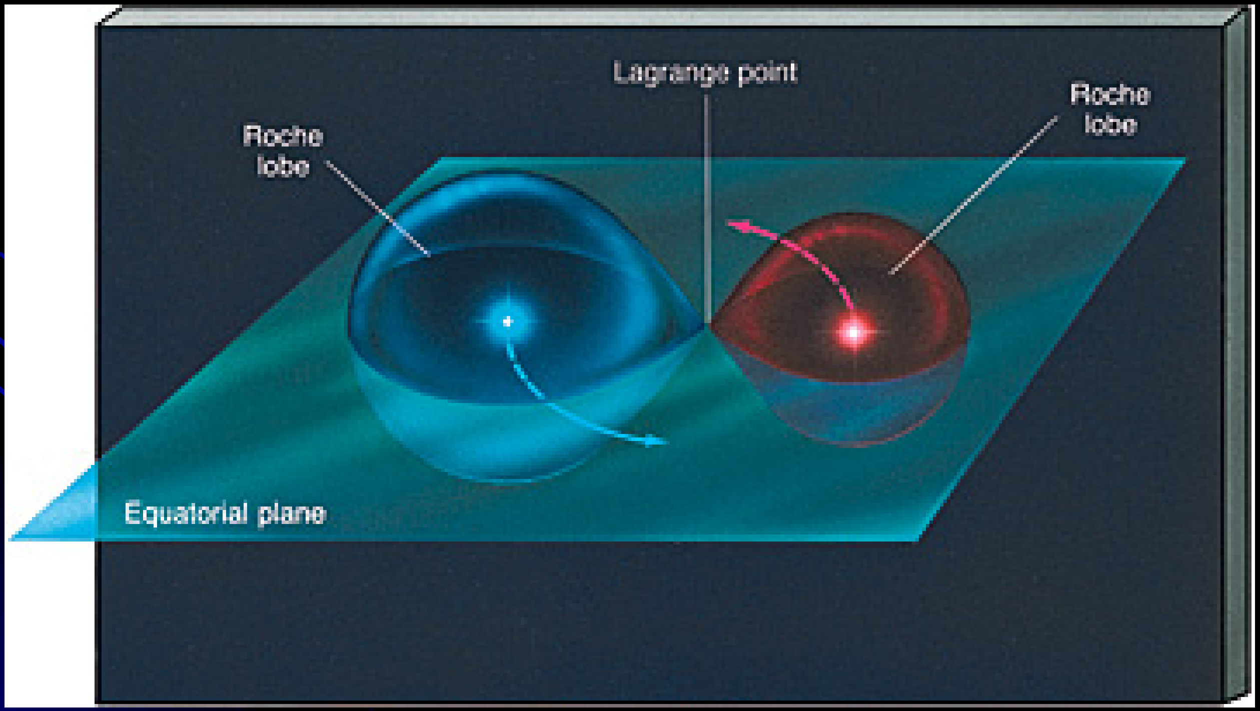
Binary Star Evolution

About half the stars in the sky are binaries.   These stars may begin life as separate entities, but often it does not last.



Roche Lobes

Between any two stars are gravitational balance points, where the attraction of one star equals the attraction of the other. The point directly between the stars is called the Lagrange point. The balance points in general map out the star's Roche Lobe. If a star's surface extends further than its Roche Lobe, it will lose its mass.

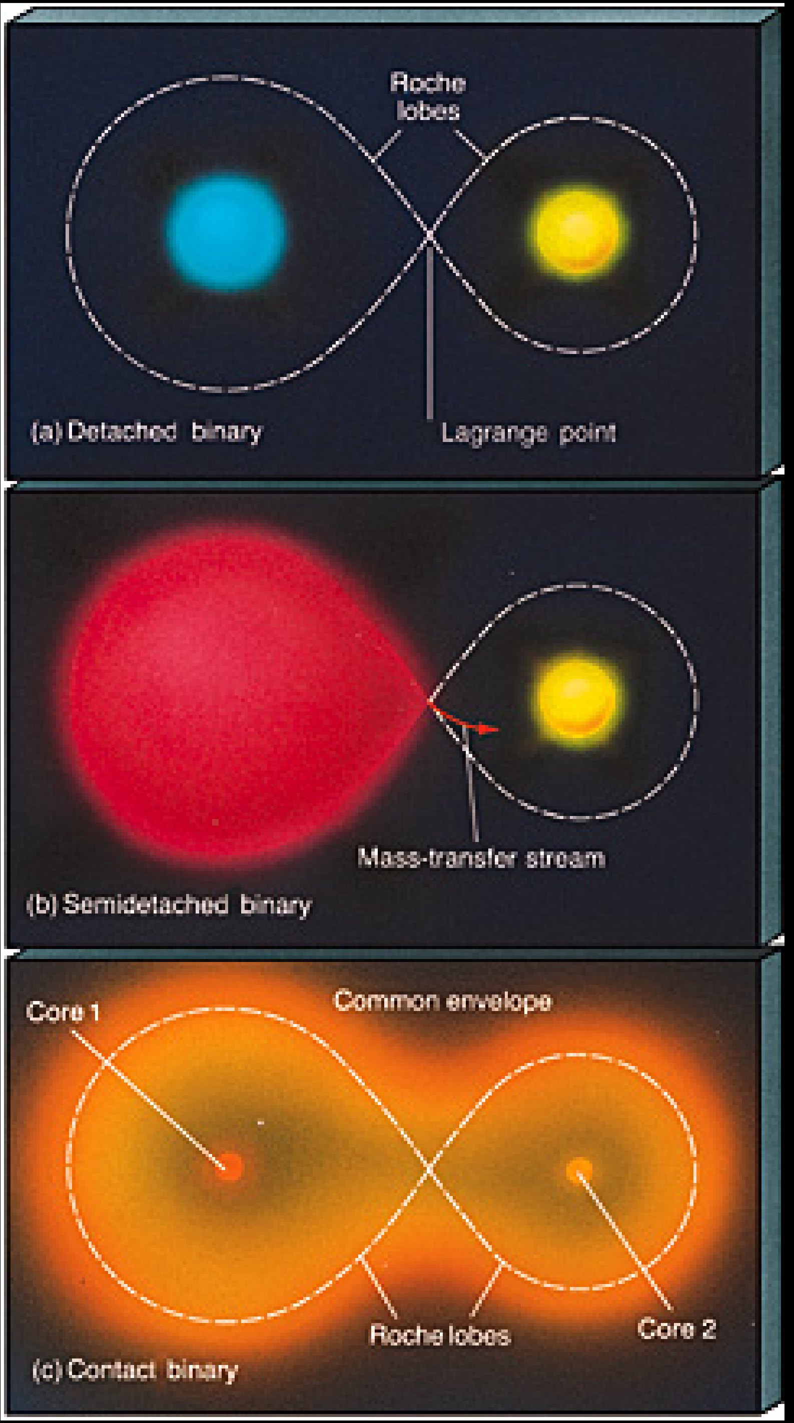


Binary Star Classification

Detached: the stars are separate and do not affect one another

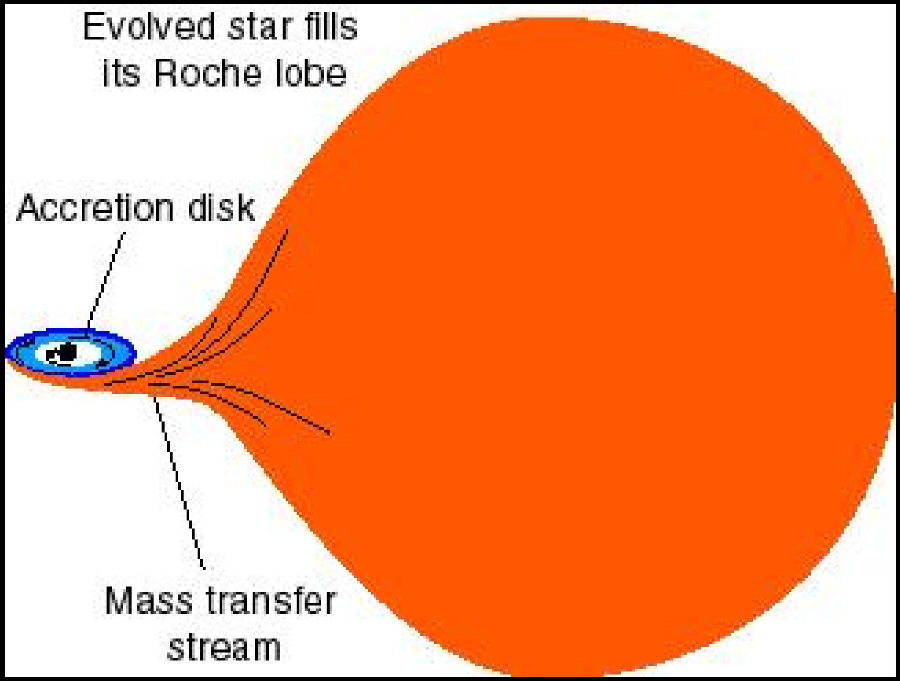
Semi-detached: one star is spilling mass (*i.e.*, accreting) onto the other

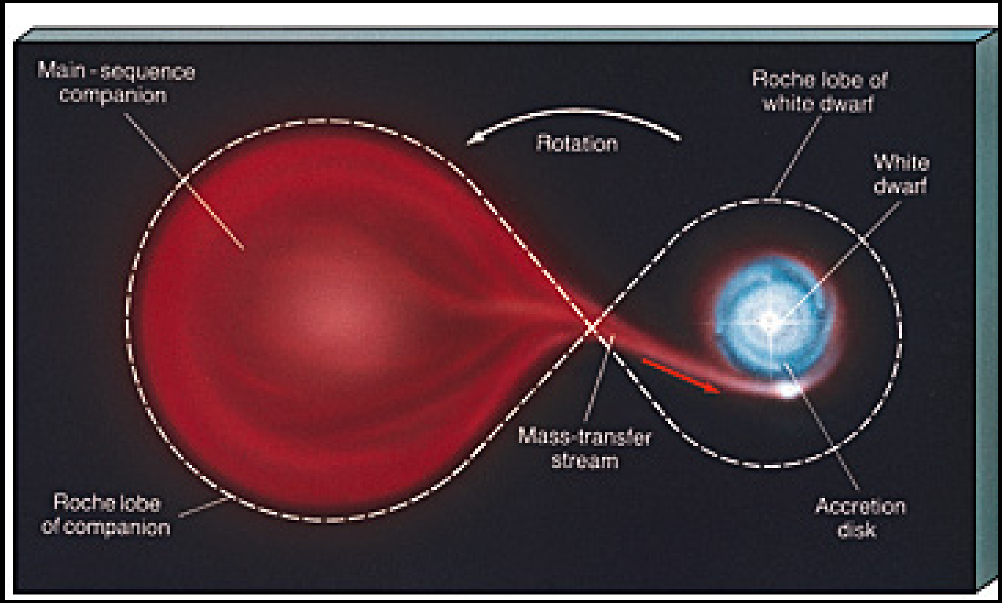
Contact: two stars are present inside a common envelope (*i.e.*, it is a common-envelope binary).



Accretion

If a star overflows its Roche lobe through the Lagrange point, its material will simply go into orbit about the companion. The material will stay in the plane of the system and form an accretion disk.

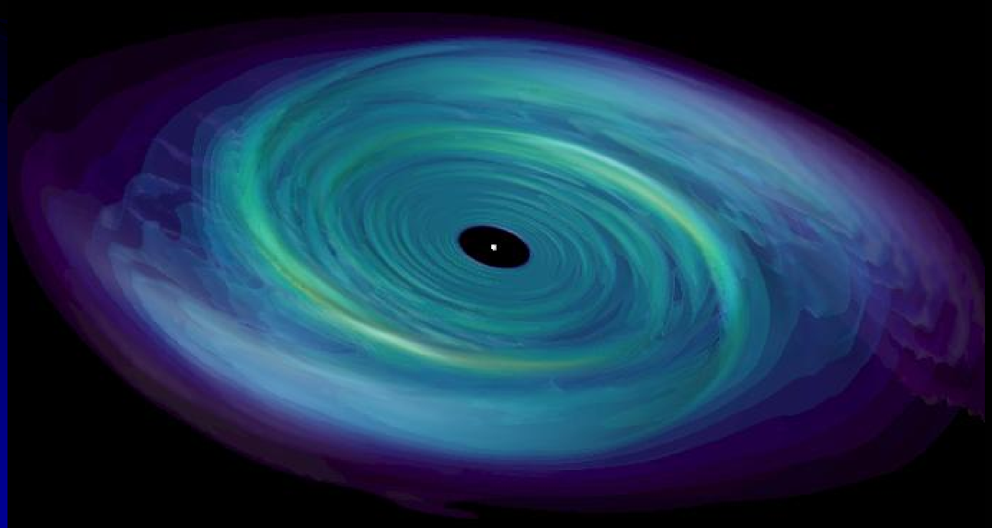




Accretion

According to Kepler's laws, matter close to a star will orbit faster than material further away. If there's a lot of material in a disk, this will cause the atoms will rub up against each other. There will be friction! So

- The material will lose orbital energy and spiral in
- The disk will get ***real hot***.



The faster the gas moves, the greater the friction, and the hotter the disk. If the companion star is compact (white dwarf, neutron star, or black hole), then near the center, the disk will emit **x-rays**!

X-ray Identifications

Because accretion disks around compact objects can get much hotter than stars, x-ray surveys can identify them!

Optical Picture

X-ray Picture

The more compact the object, the hotter the accretion disk, and the more (very high energy) x-rays that are produced.

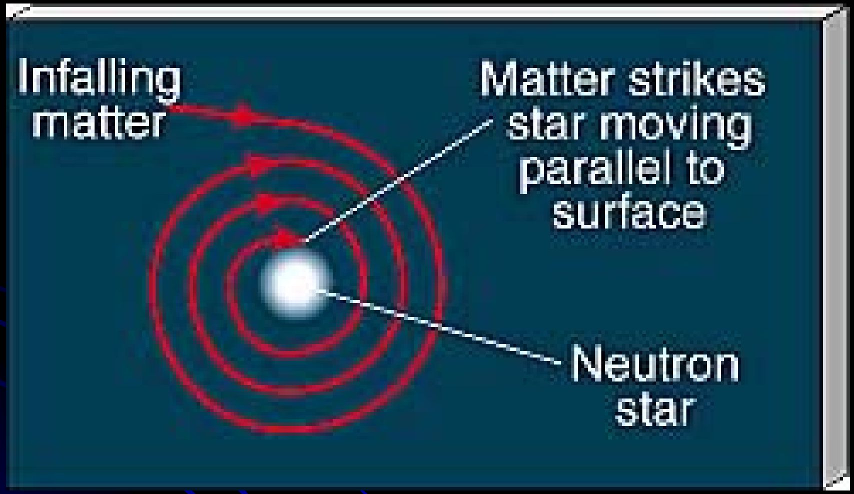
Type Ia Supernovae

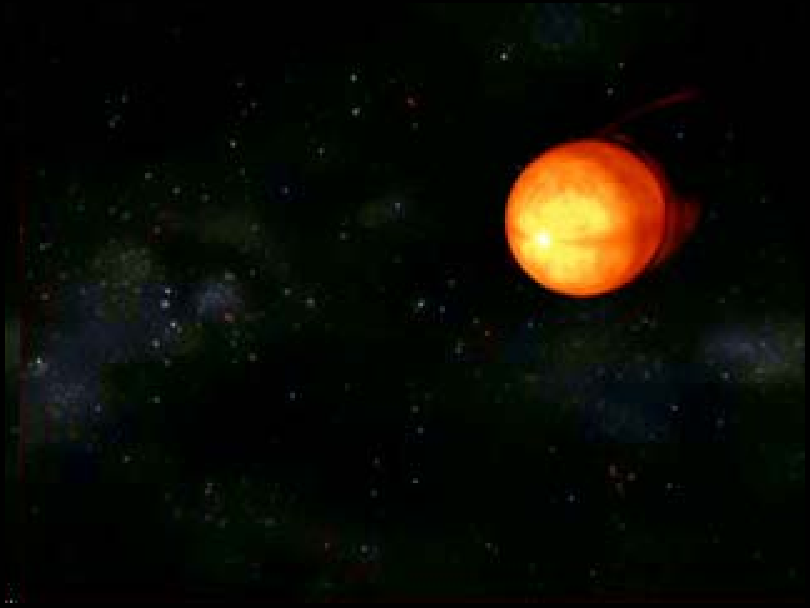
Recall that white dwarfs are held up by electron degeneracy. Their masses must therefore be less than 1.4 $M_{\odot}$. Over time, accretion may push a white dwarf's mass over this limit. If this happens, the star will collapse, and become a Type Ia Supernova.

A Type Ia supernova is just as bright as a regular (Type II) supernova, but it doesn't leave behind a remnant. Models suggest that the star is totally destroyed.

Millisecond Pulsars

When a star explodes as a supernova, the neutron star that is left behind rotates about once a second. However, if a star accretes onto this neutron star, it can cause it to spin 1000 times faster!





Finding a Black Hole

- Identify the optical counterpart of an x-ray binary
- Observe the optical component of the binary
  - Estimate the total mass of the system using Kepler's and Newton's laws
  - Estimate the mass of the visible star from its spectral type, etc.
- Subtract to estimate the mass of the unseen companion
- Exclude possible stellar types based on visibility and knowledge of stellar astrophysics

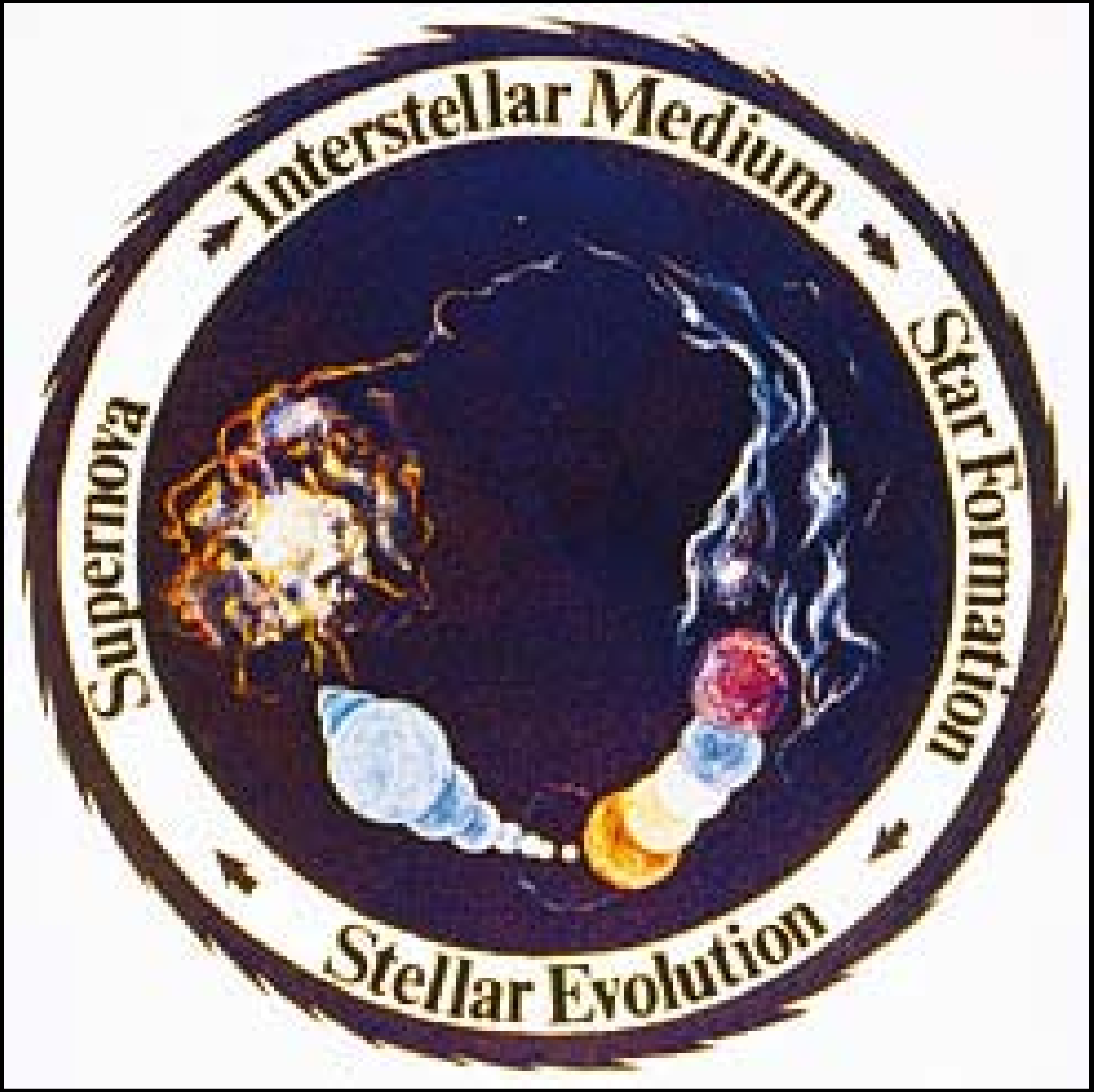
If all possibilities are excluded, you have a **black hole**!

Star Formation and Interstellar Matter

Stars are made from the gas and dust in the interstellar medium.

The gas and dust in the interstellar medium comes from stars.

Material is constantly being recycled.

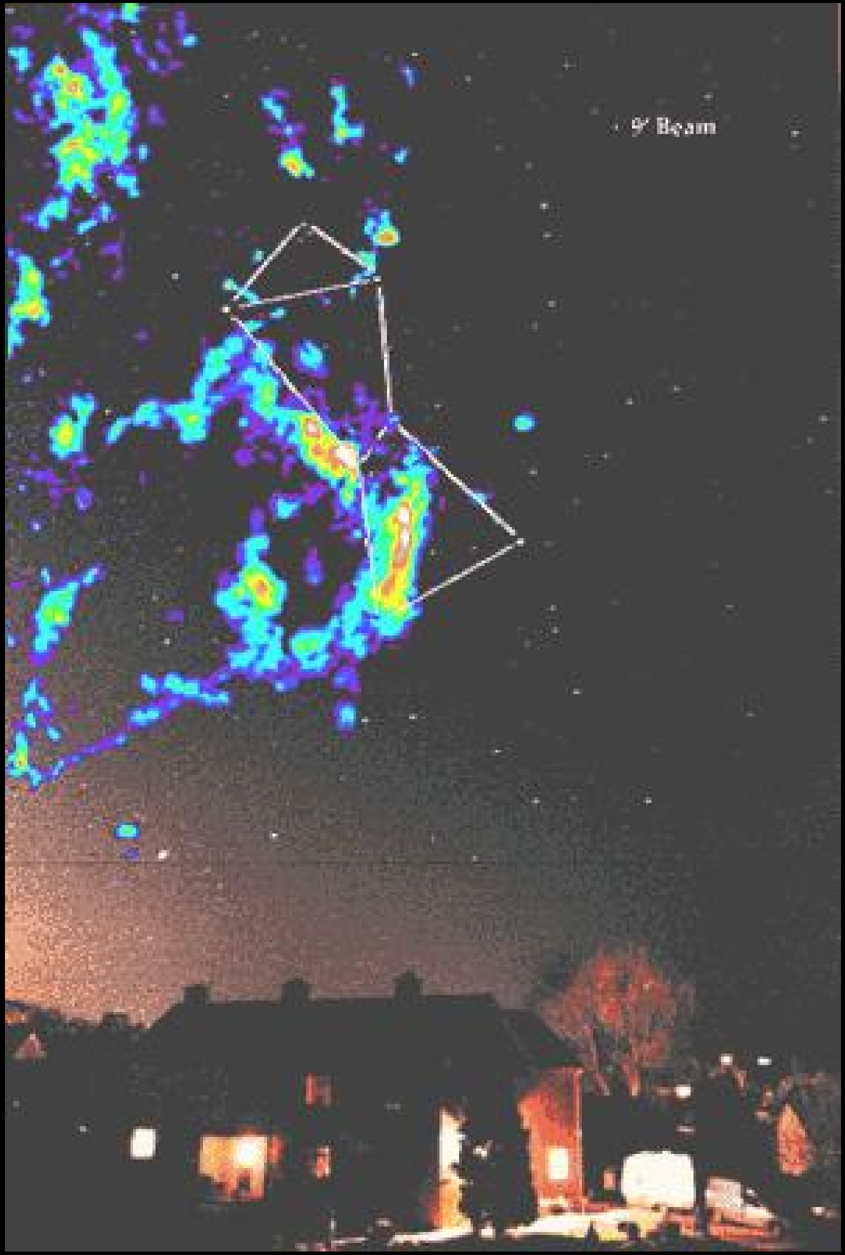


Molecular Clouds

At any time, there is just as much material in the interstellar medium as there is in stars. Much of this matter is far, far from any star. It is therefore *very* cold.

In these cold regions, atoms can stick together to form molecules, such as H_2.

A Giant Molecular Cloud may contain over 100,000,000 $M_\odot$ of material!



The Beginning of Star Formation

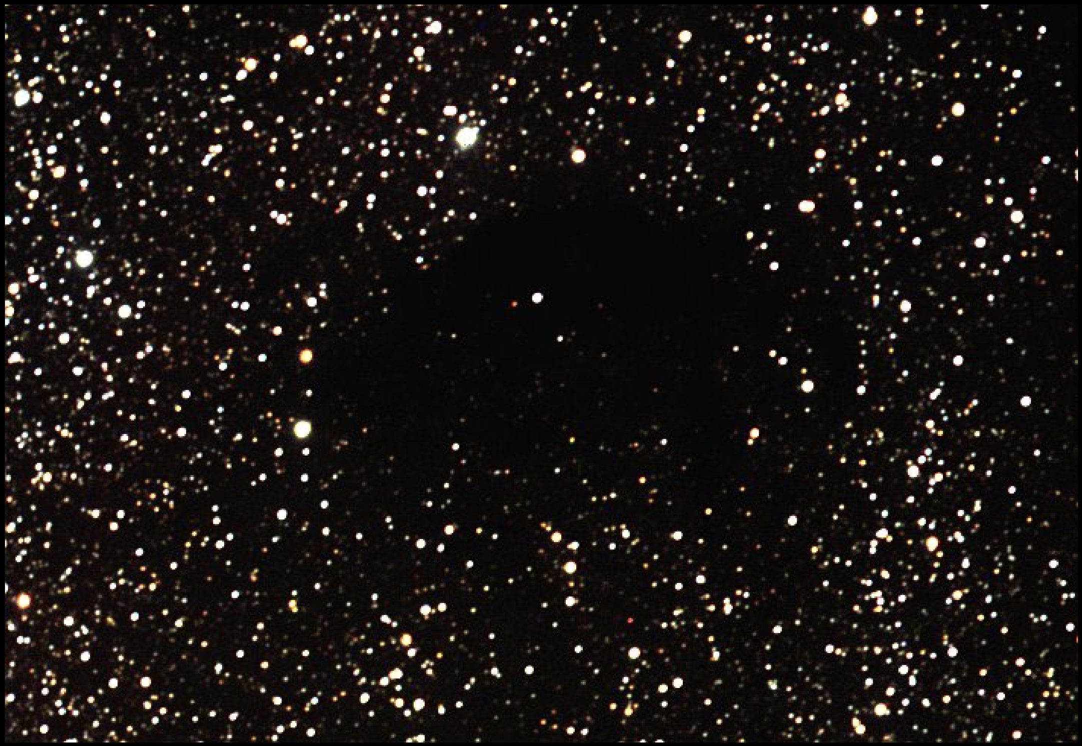
Where there is gas, there is also dust, which absorbs and scatters light. Dust in space can be seen in silhouette, as it blocks out the light from more distant stars.

Cold Clouds

Since dust blocks the light, the temperatures within these clouds can be just a few degrees above absolute zero!

Cloud Collapse

Since the temperature is so low inside these clouds, gas pressure is almost non-existent. There is nothing to stop gravity from condensing the cloud. The cloud will get smaller and increase in density.

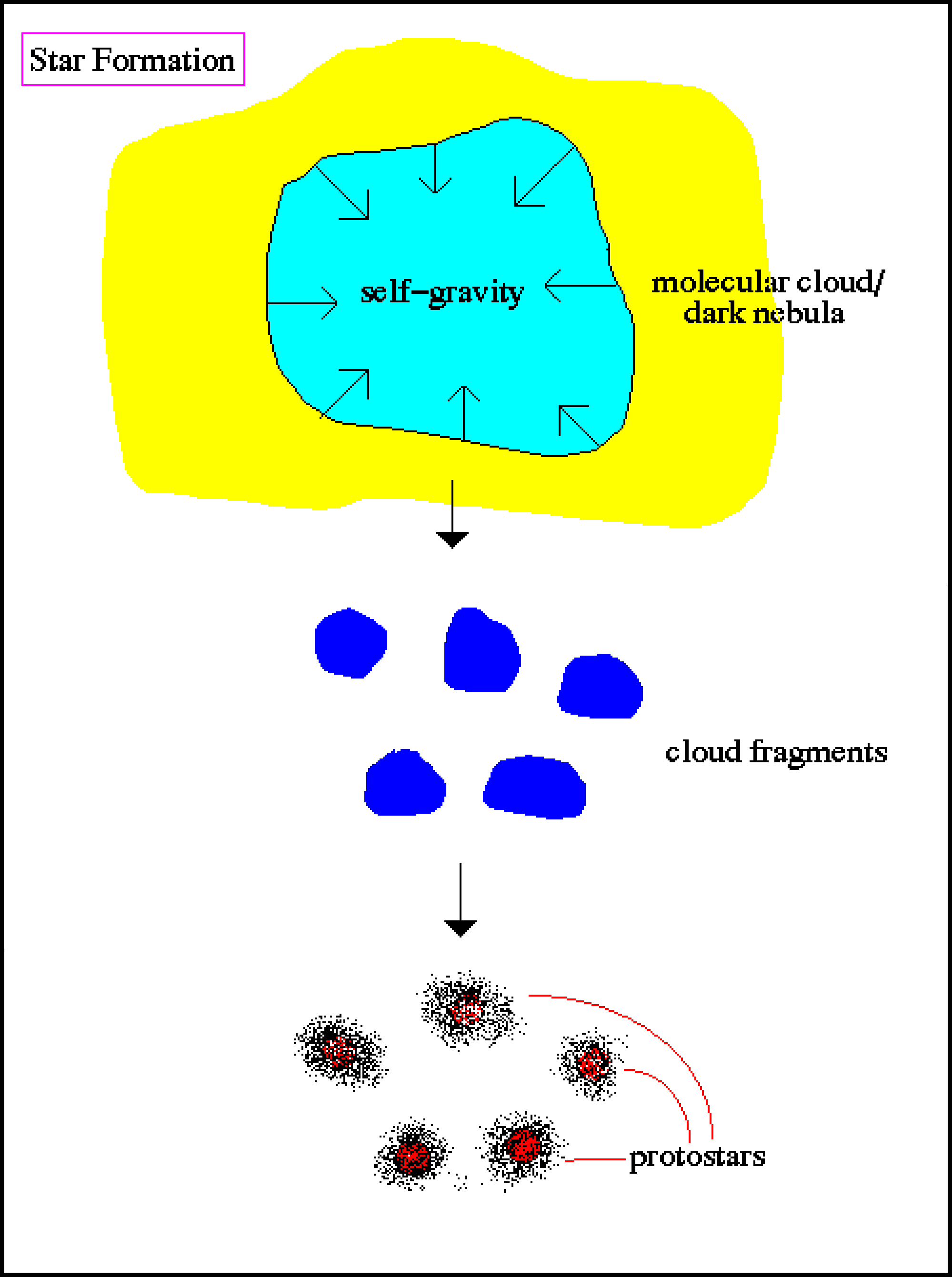


Initial Collapse

Dark clouds are much denser in their center than on the outside, so their inner regions collapse first.

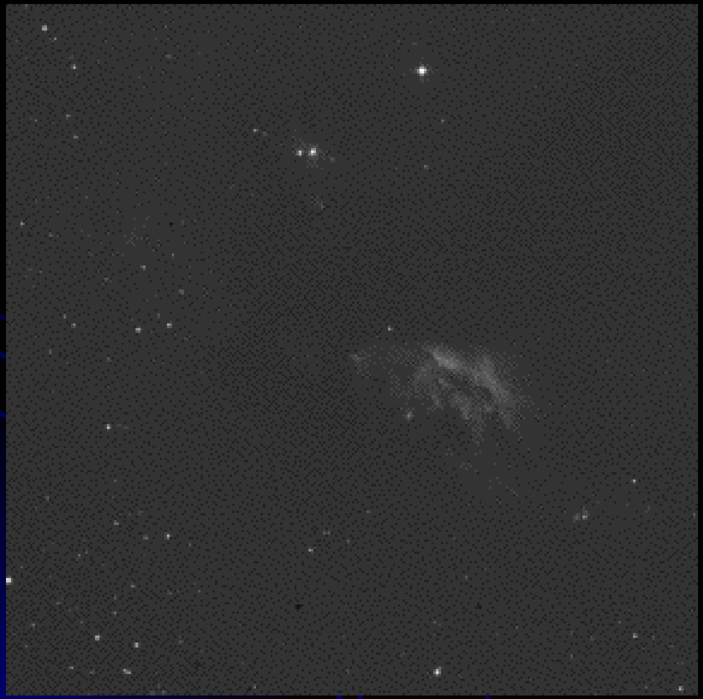
Also, since the clouds are lumpy to begin with, the collapse process causes the clouds to fragment.

Each fragment is a protostar.



Protostars

As the cloud collapses, the pressure in the middle of the cloud increases. Consequently, the temperature of the cloud will increase. The cloud center will begin to emit light, first in the microwave, and then in the infrared.

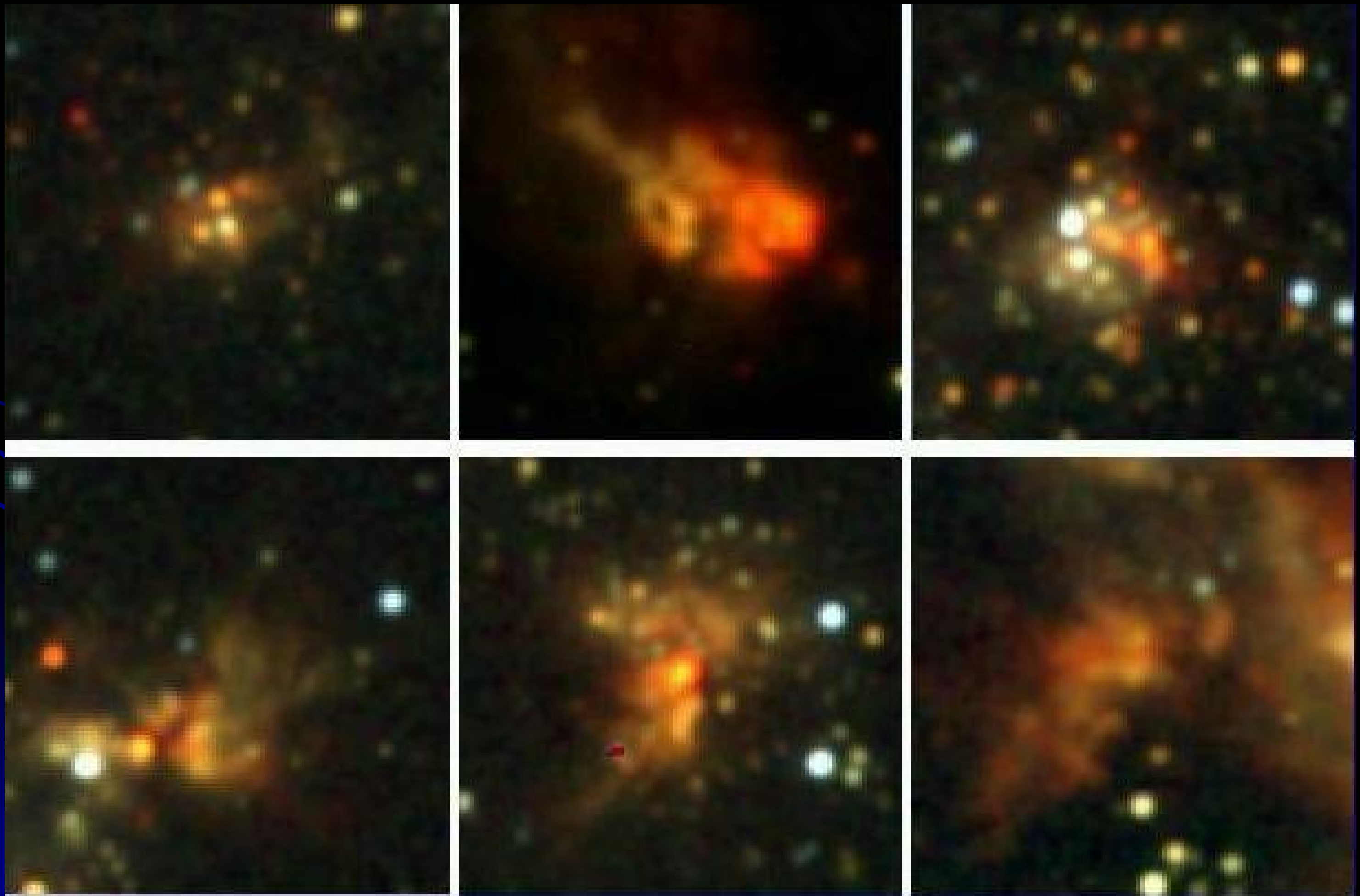


optical

infrared

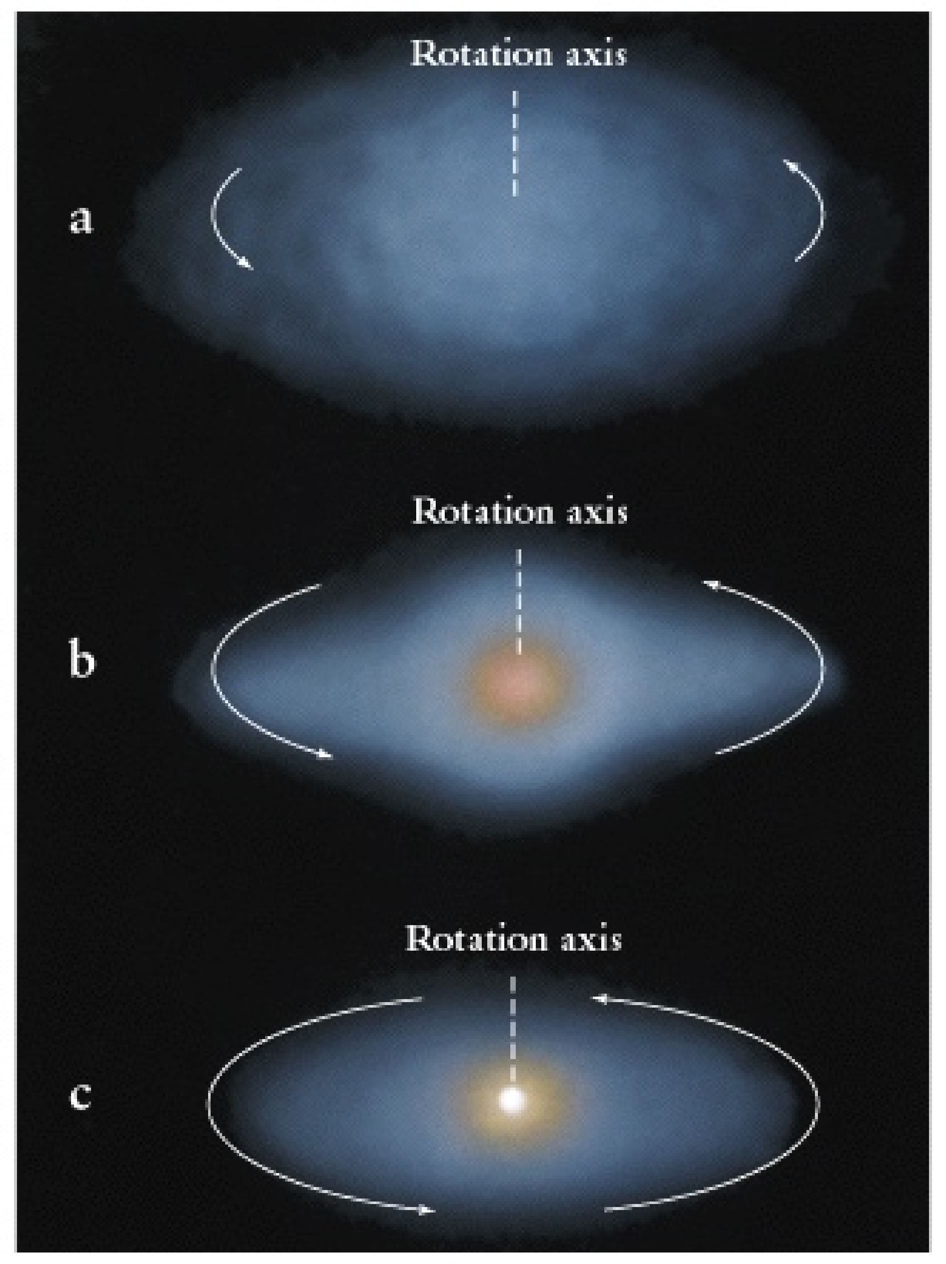
Dust and Young Stellar Objects

Just like in the earth’s atmosphere, the longer wavelength light better penetrates the interstellar dust, while the shorter wavelength light is scattered away. The protostars are totally obscured in the optical, but can be detected in the infrared.



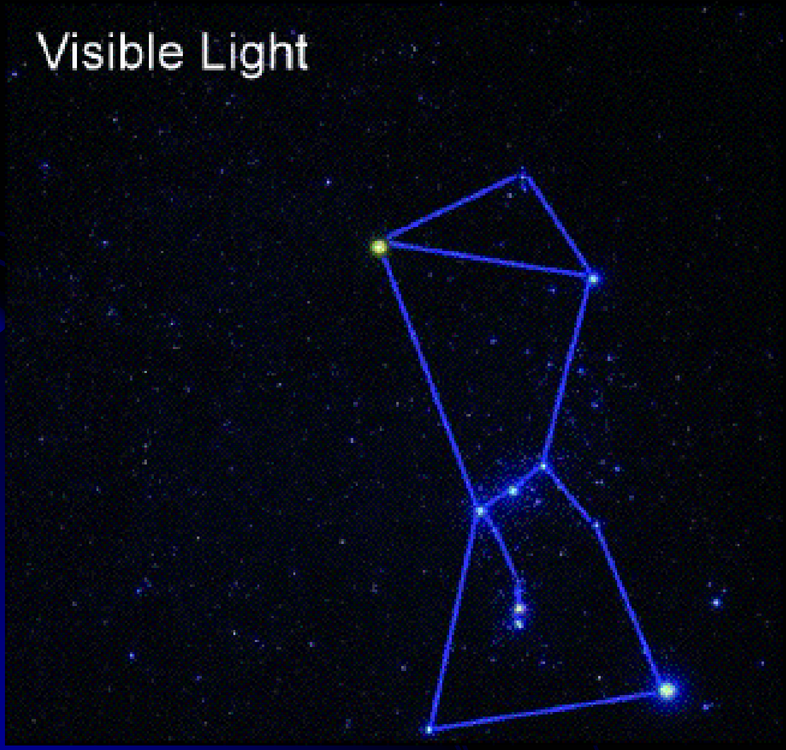
Formation of a Disk

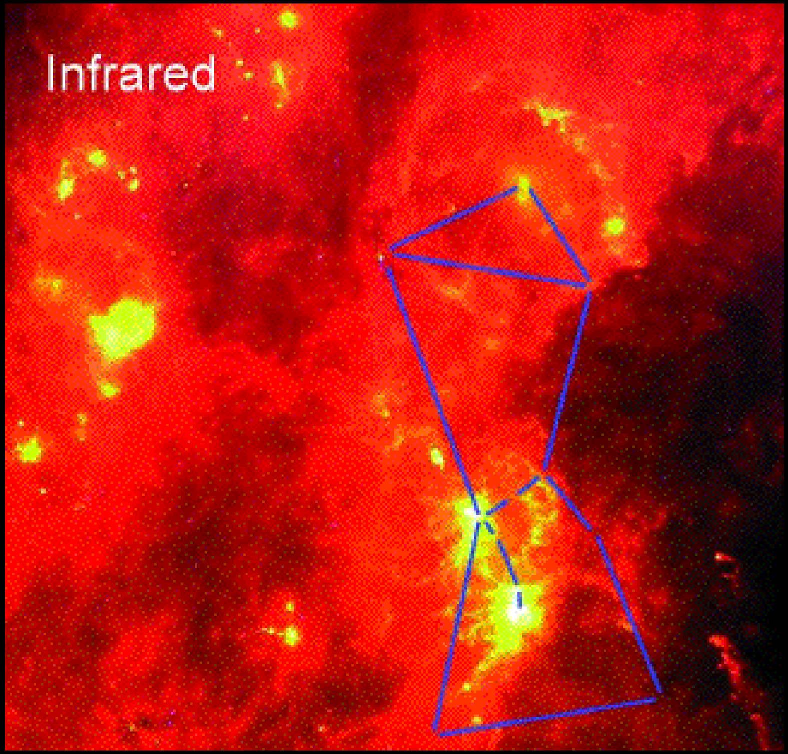
As the cloud collapses, conservation of angular momentum causes the material to spin rapidly. The centripetal force fights the collapse in the plane of rotation, but not at the poles. As a result, the material collapses into a disk.



Star Forming Regions in the Infrared

Due to the friction in the disk, matter flows onto the star. As the star's mass increases, its core grows hotter. At this time, since the star is still surrounded by dust, it is invisible in the optical. But the heat from the star begins to warm the dust.

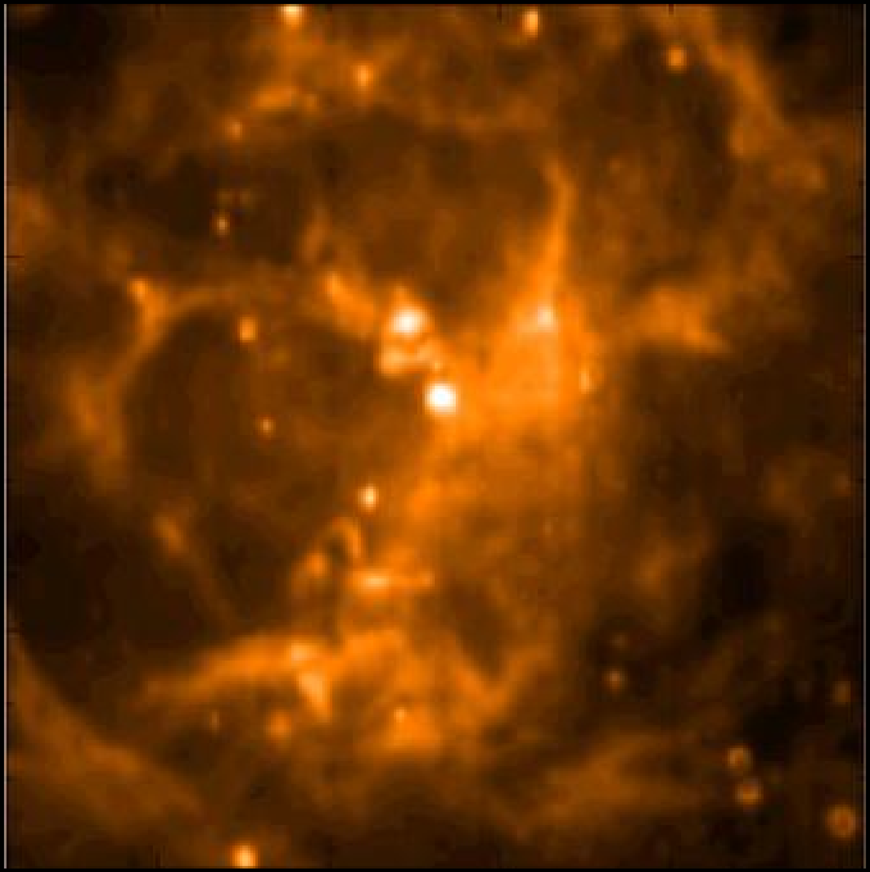




Star Forming Regions in the Infrared

Far infrared observations can not only see the warm dust, but the protostars as well.

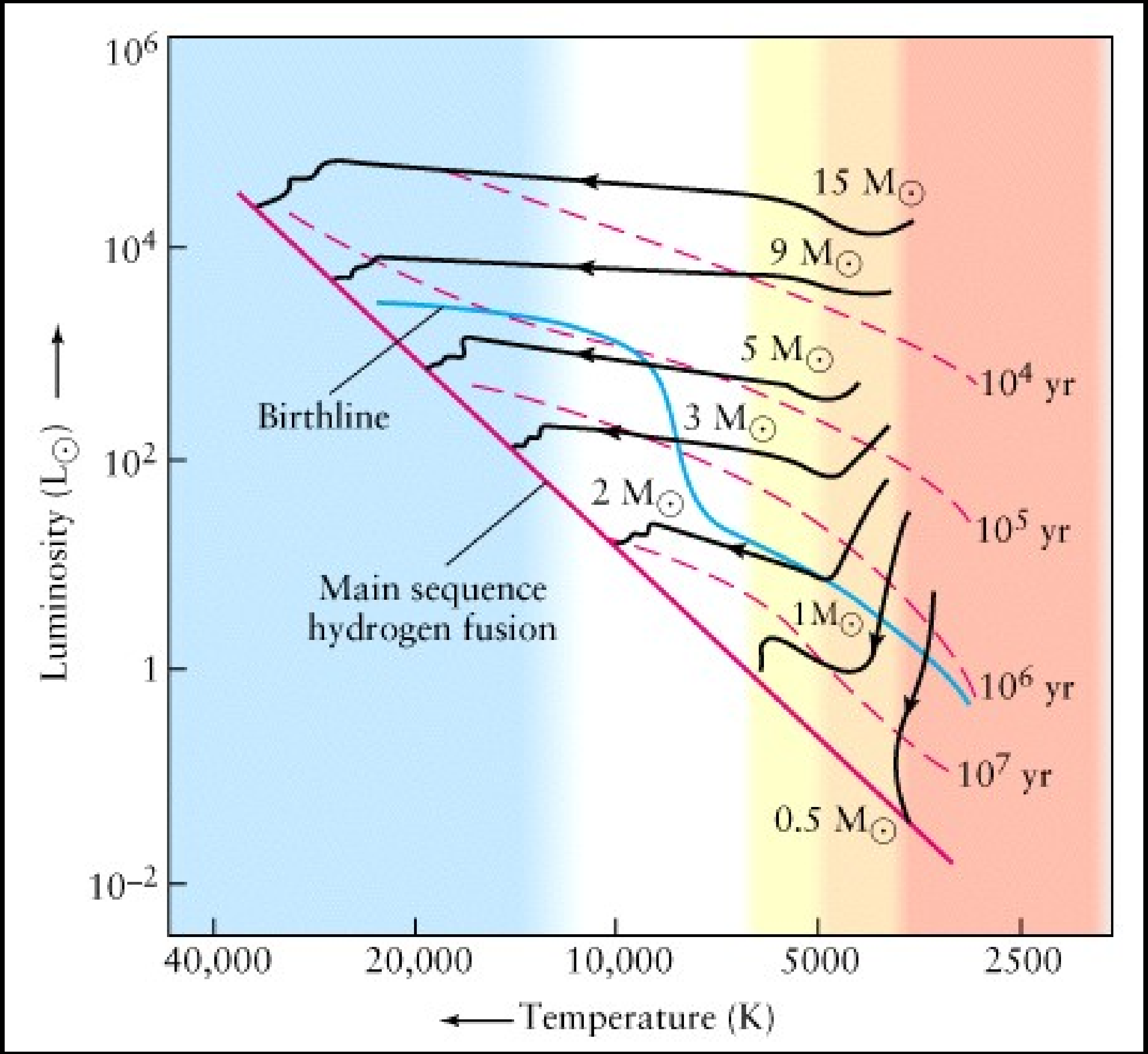
optical



infrared

Star Formation in the HR Diagram

As the gas cloud collapses, the protostar gets smaller and smaller (and, due to the increased central pressure), hotter and hotter. Accretion will cause the mass of the protostar to increase more than 100 times. The star will move towards its place on the main sequence.



Stellar Winds

Eventually, the proto-star will fuse hydrogen in its core. This energy will greatly increase the radiation pressure the photons create on their surroundings. A stellar wind will begin to blow material away.

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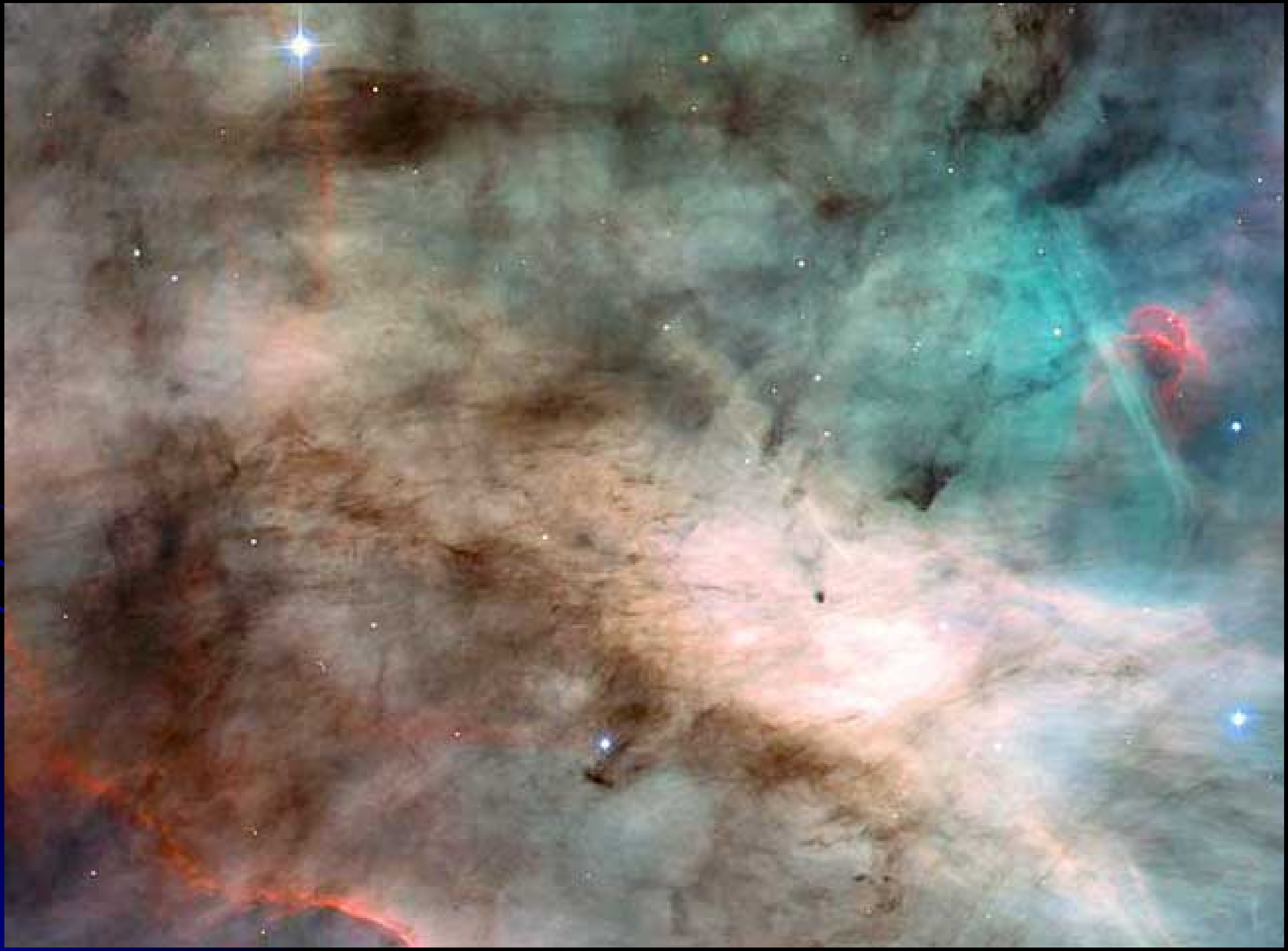
The New Born Stars

As the circumstellar matter get blown away, the star becomes more and more visible.



Reddening and Scattering

Stars behind large piles of dust will be reddened. Other regions will appear blue, due to the scattering by dust.

This is just like the daytime sky.

Ionization and H II Regions

If one of the stars being formed has a mass greater than ~ 5 $M_\odot$, it will ionize the surrounding gas. This is called an H II region.

Emission Lines and Dust

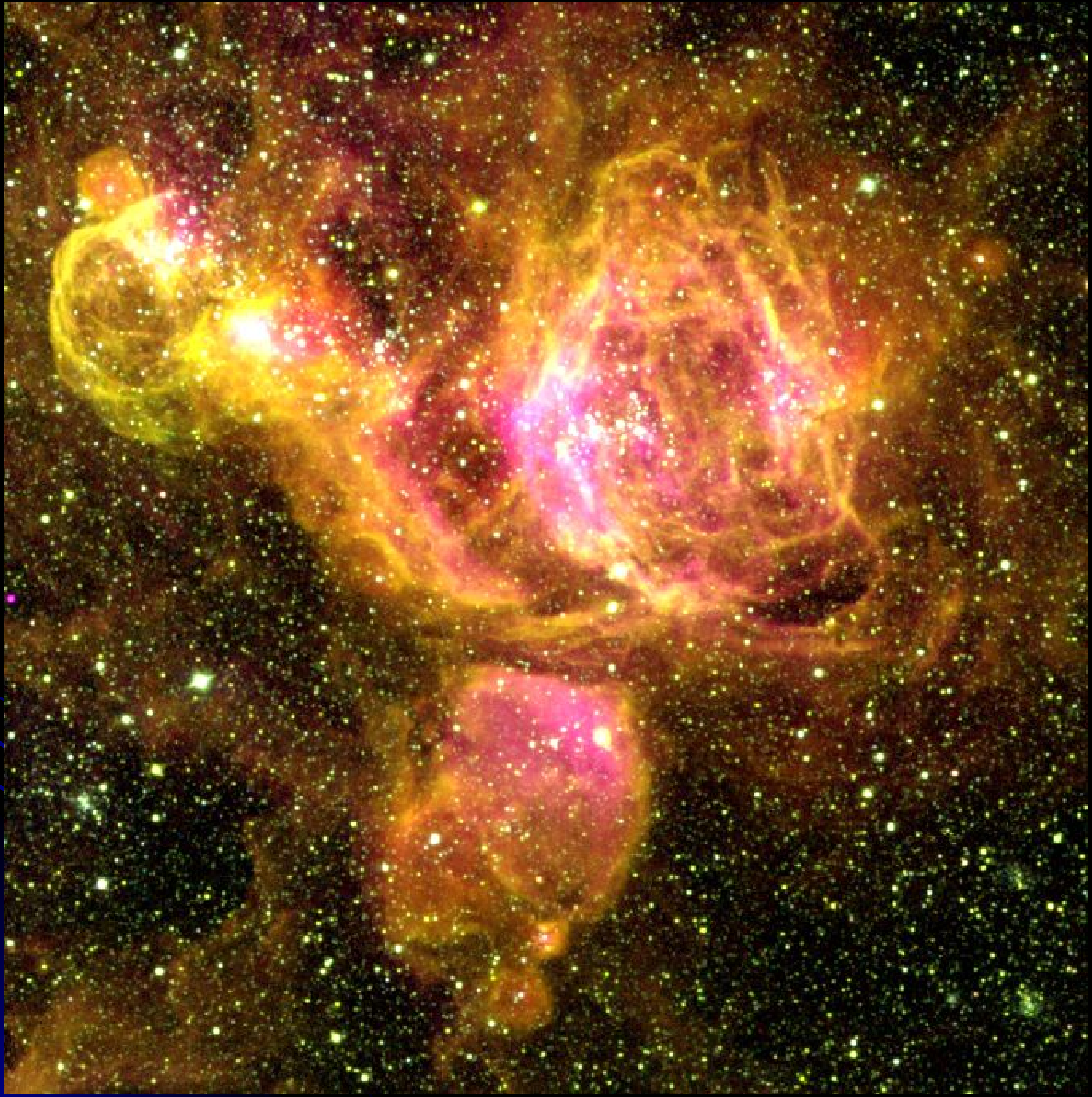
Dust can often be seen in silhouette against the red emission line of hydrogen (at 6563 Å) produced by recombination.

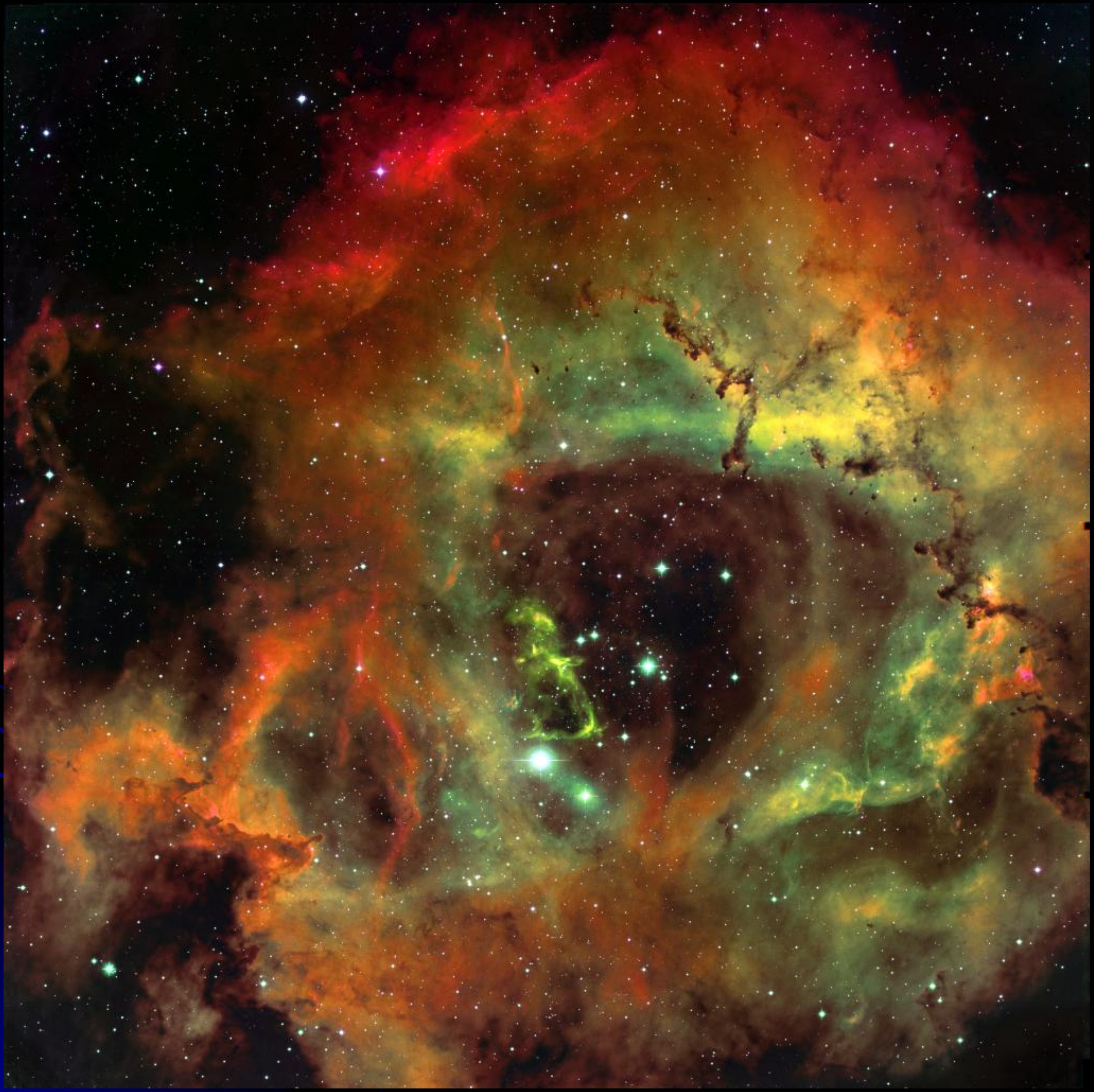


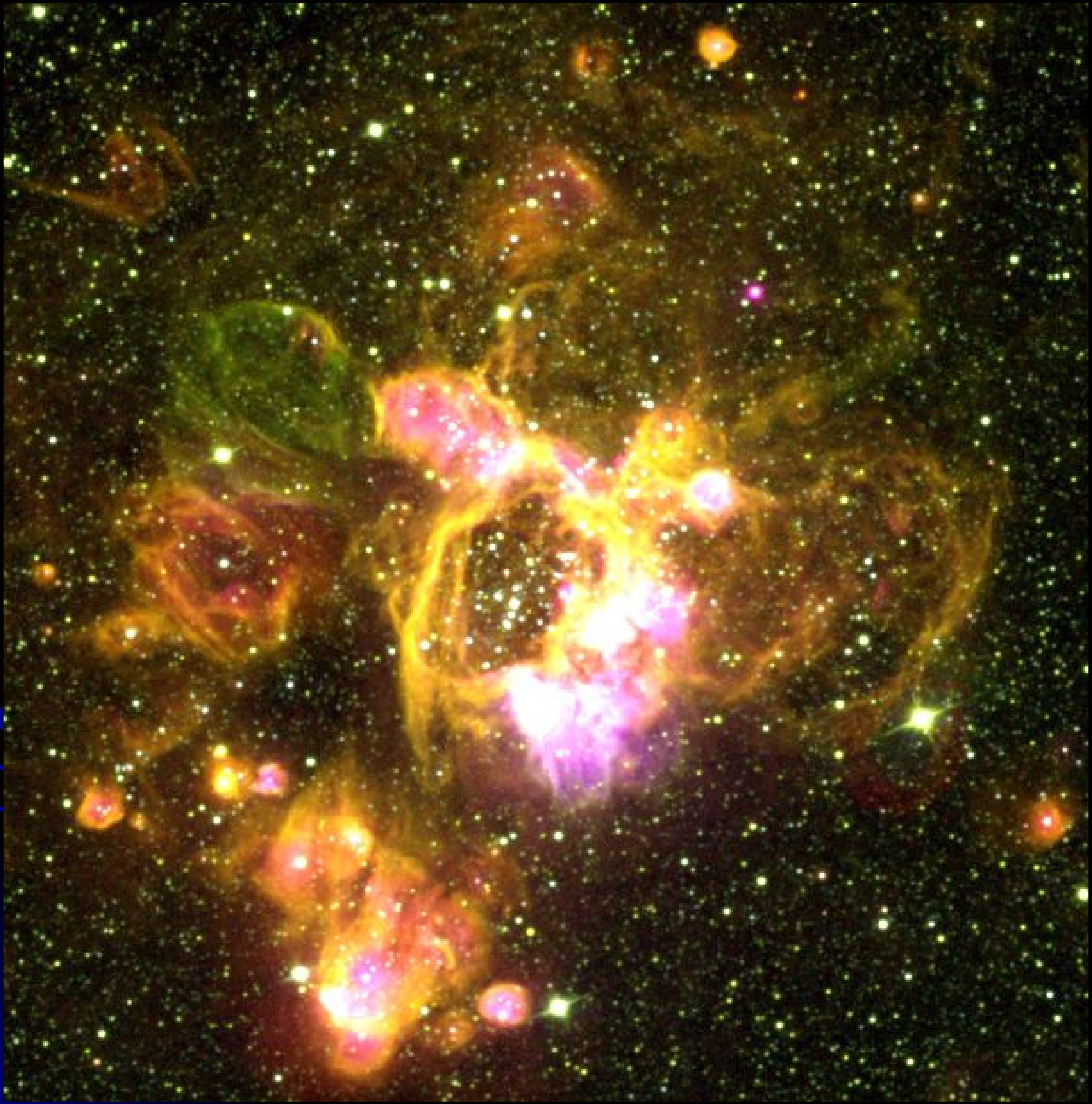


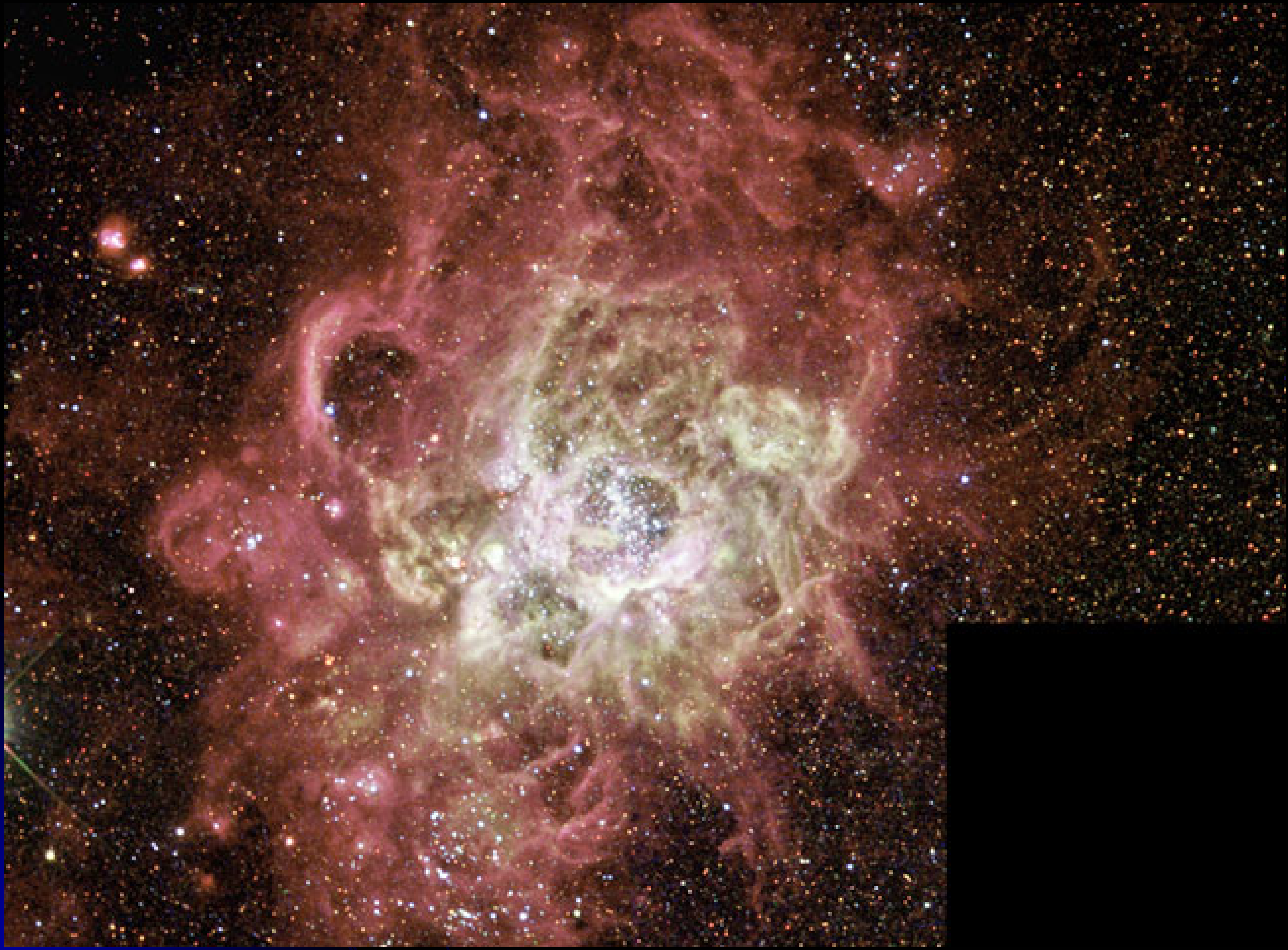

Dispersement

Eventually, most of the interstellar matter is blown away, revealing the newly formed stars.









Cycle of Star Formation

And the cycle repeats. Stars evolve and lose their mass. Supernovae explode and compress the gas. Star formation begins again.