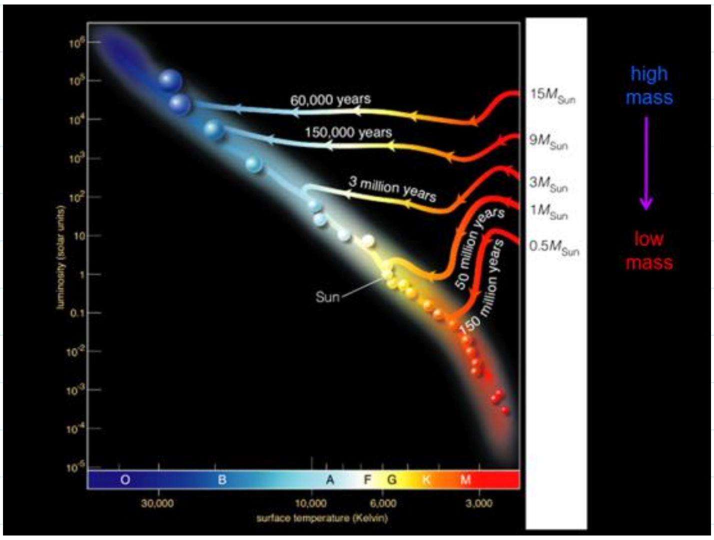
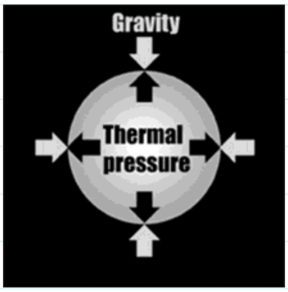
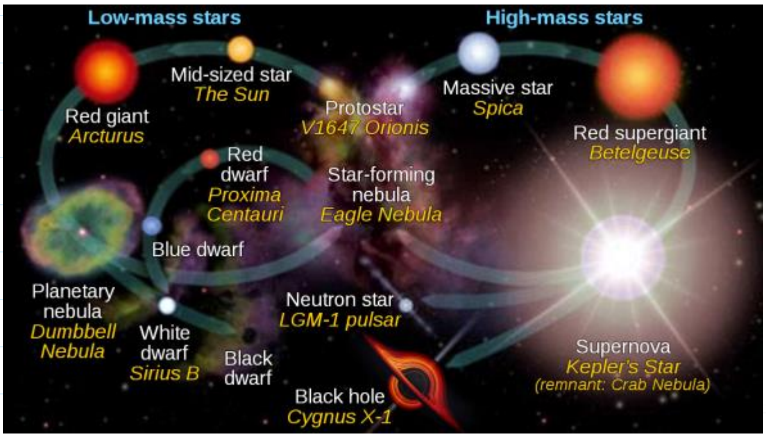
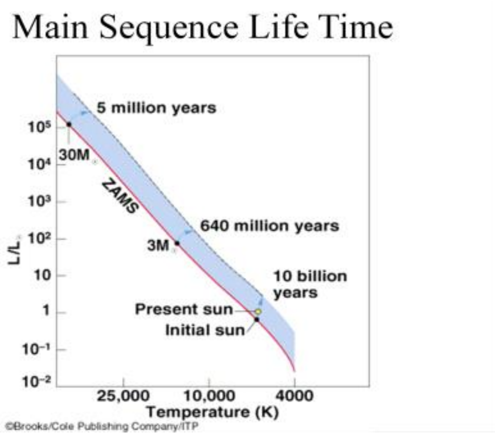
2022 12 21 Star Formation

2022년 12월 17일 토요일 오전 11:37









Stellar evolution of low-mass (left cycle) and high-mass (right cycle) stars, with examples in italics

출처: <https://en.wikipedia.org/wiki/Stellar_evolution>

Cloud collapse 출처: <https://en.wikipedia.org/wiki/Star_formation>

Hydrostatic equilibrium :

The grav force is in balance with the gas pressure + magnetic pressure

(grav force: collapsing; gas pressure + magnetic pressure: inflating)

Gravitational collapse

If the cloud mass ≳ the Jeans mass , the gas pressure is insufficient to support it.

The Jeans mass ≈ $10^3 \sim 10^4\ M_\odot$ depending on T and density.

The end product of a core collapse is an open cluster of stars.

In *triggered star formation*, somel events such as

- Molecular clouds collision
- a nearby supernova explosion
- galactic collisions

might initiate its gravitational collapse to trigger the formation of globular clusters.

As it collapses,

- a molecular cloud fragments. Filamentary structures are ubiquitous in the molecular cloud.
- the fragments become opaque as the density increases.

This raises the temperature and inhibits further fragmentation.
The fragments now condense into rotating spheres of gas that serve as stellar embryos.
complicated with turbulence, macroscopic flows, rotation, mag fields & the cloud geometry.

Protostar

A **protostar** (~10^5yr)

It is the earliest stage in the stellar evolution.

It is a rotating ball of gas that is still gathering mass from its parent molecular cloud.

The phase begins when pressure supported core forms inside the collapsing opaque fragment from a molecular cloud.

It ends when the infalling gas is depleted, leaving a pre-main-sequence star,

which contracts to become a main-sequence star at the onset of H-fusion.

출처: <https://en.wikipedia.org/wiki/Protostar>

A protostar continues to grow by accretion of gas and dust from the molecular cloud, becoming a pre-main-sequence star as it reaches its final mass.
Further development is determined by its mass.

Protostar energy comes from the radiation liberated at the shocks on its surface and on the surface of its surrounding disk. a protostar is not detectable at optical wavelengths, and cannot be placed in the H–R diagram, unlike the more evolved pre-main-sequence stars.

The actual radiation from a protostar is in the infrared and millimeter regimes.

출처: <https://en.wikipedia.org/wiki/Protostar>

pre-main-sequence stars (PMS stars) T Tauri Stars(~10^8yr)

When the surrounding gas and dust envelope disperses and accretion process stops, the star is considered a pre-main-sequence star (PMS star).
The energy source is gravitational contraction, as opposed to H-burning in main sequence stars.

M (PMS star) < $0.5M_\odot$, follows a Hayashi track to join the main sequence.
M (PMS star) > $0.5M_\odot$ follows a Hayashi track, then the Henyey track to the MS.

Main-Sequence Phase

H-fusion
Finally, H begins to fuse in the core, and the enveloping material is cleared away.
This ends the protostellar phase and begins the MS phase on the H–R diagram.

M $\lesssim 1M_\odot$ → The stages of the process are well defined.
M > $1M_\odot$ → the process is not so well defined.

Observations

The protostellar stage is almost invariably hidden away deep inside dense clouds of gas and dust left over from the GMC.

The structure of the molecular cloud and the effects of the protostar can be observed in IR. continuum dust emission & rotational transitions of CO and other molecules are observed in the millimeter and submillimeter range.

the Earth's atmosphere is almost entirely opaque from 20μm to 850μm, with narrow windows at 200μm and 450μm.

출처: <https://en.wikipedia.org/wiki/Star_formation>

Star formation : **protostar→ pre-main sequence star → main-sequence star**

($\sim 10^5$yr) ($\sim 10^8$yr)

- Stars are formed by the gravitational collapse in "stellar nurseries"/"star-forming regions", which are **molecular clouds** (the dense regions of the ISM, a type of interstellar cloud) with much of the hydrogen in the molecular (H_2) form.
- protostars and young stellar objects are its immediate products.
- Stars ultimately contributes to molecular clouds, replenishes the ISM with matter & energy through planetary nebulae, stellar winds, and supernovae.
- Most stars form as part of star clusters or stellar associations.

출처: <https://en.wikipedia.org/wiki/Interstellar_medium>
출처: <https://en.wikipedia.org/wiki/Star_formation>

The Interstellar Medium

How do stars form?

Note the following properties of the stars:

- Stars are often found in pairs.
- Stars are often found in clusters.
- Chemical composition of stars (from spectra) is fairly constant:
  73% Hydrogen, 25% Helium, 2% Other Elements
- Masses of stars range $0.1M_\odot \lesssim M_{\text{Star}} \lesssim 100M_\odot$
- Must be evolving, since they consume fuel and radiate

$V = 22.4\,l = 2\times10\times10^3\,cm^3$

$N_A = 6\times10^{23}$

$\frac{N_A}{V} \approx \frac{10^{23}}{10^4} \sim 10^{19}\,\frac{1}{cm^3}$

Stars form in large clouds composed mainly of H and He, which fragment into smaller clouds which collapse to form stars in a region of space.

출처: <https://en.wikipedia.org/wiki/Star_formation>

The Interstellar Medium (ISM)

- the matter between the stars.
- The chemical composition of the interstellar medium is very similar to that in stars.
  hydrogen > helium > C,N,O...
  - The hydrogen and helium are primarily a result of primordial nucleosynthesis,
  - The heavier elements are mostly a result of stellar evolution.
  - By mass: 70% hydrogen, 28% helium, and 1.5% heavier elements.
  - by number: 91% H, 8.9% He, 0.1% "metals" (atoms heavier than H or He).
- The ISM is not uniform: some regions are denser and are called interstellar clouds.
  10^4-10^6 particles/cm^3
  - In cool, dense ($\approx 10^6$ molecules/cm^3) regions, primarily in molecular form.
  - In hot, diffuse ($\gtrsim 10^{-4}$ions /cm^3) regions, primarily ionized.

Ref) Air at sea level ~ 10^{19} molecules/cm^3,

a high-vac chamber~ 10^{10} molecules/cm^3.

- Regions which are denser than average can gravitationally collapse into stars.
  The coldest clouds form low-mass stars, while giant molecular clouds, which are generally warmer, produce stars of all masses.
  출처: <https://en.wikipedia.org/wiki/Interstellar_medium>
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Main Components of the Interstellar Medium

- Hydrogen: neutral, ionized or molecular

- Other molecules
- Dust

  The thermal pressures in rough equilibrium, also magnetic fields & turbulent motions.

An **interstellar cloud**

- A denser-than-average region of the interstellar medium (ISM).
- Formed by the gas & dust particles from a red giant in its later life.

  I. *diffuse clouds*

  i. H I region - composed of neutral atomic H;

  ii. H II region - ionized or plasma atomic H, ;

  II. molecular clouds - molecular, or dense clouds.

출처: <https://en.wikipedia.org/wiki/Interstellar_cloud>

Terminology : I : for neutral atoms II : for singly-ionized III : doubly-ionized ex)OIII=O^{++}

A **molecular cloud**, (a **stellar nursery** if star formation is occurring within),

is a type of interstellar cloud,

the density and size of which permit being absorption nebulae,

the formation of molecules, mostly molecular hydrogen (H2), as well as H II regions.

출처: <https://en.wikipedia.org/wiki/Molecular_cloud>

A **giant molecular cloud** (**GMC**)

is a assemblage of molecular gas 5 ~ 200 pc in diameter and 1×10^4 ~ 10^7 $M_\odot$.

The average density = 100~1,000/cm^3 cf) that in the solar vicinity = 1 particle/cm^3.

The substructure is a complex pattern of filaments, sheets, bubbles, & irregular clumps.

These giant molecular clouds have

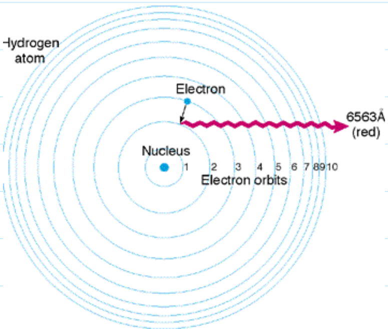
- diameters of 100 light-years (9.5×10^{14} km),
- masses of up to 6×10^6 $M_\odot$,
- and an average interior T ≈10 K.

출처: <https://en.wikipedia.org/wiki/Molecular_cloud#Giant_molecular_clouds>

- About half the total mass of the galactic ISM is in molecular clouds.
- In the Milky Way, ~6,000 molecular clouds, each with $\geq 10^5$ $M_\odot$.
- The nearest nebula forming massive stars is the Orion Nebula, 1,300 ly (1.2×10^{16} km) away.
- Lower mass star formation is occurring in the ρ Ophiuchi cloud complex at 400–450ly.
- The coldest clouds form low-mass stars, while giant molecular clouds, which are generally warmer, produce stars of all masses.

Detection of Ionized Hydrogen

- We can detect Ionized Hydrogen when the free electron **recombines** with the Hydrogen nucleus.
- The electron recombines in an excited state and then jumps down in stages to the ground state.
- When the electron jumps down from the n=3 state to the n=2 state, it emits a **red** photon corresponding to the Balmer alpha transition.
- When the electron jumps down from the n=4 state to the n=2 state, it emits a **blue** photon corresponding to the Balmer beta transition.
- This process is also called **fluorescence**.
- **We can see fluorescent ionizied hydrogen only when hydrogen is illuminated**
- A region of ionized hydrogen glows with a pinkish red colour.
- Astronomers call a region of ionized Hydrogen a **H II region**.
- Since a H II region glows red from the emission of photons, this is also an **emission nebula**.
- Nebula is Latin for cloud or mist.



Emission of red light from ionized H Red light from H emission in the Triffid Nebula.

What causes the ionization?

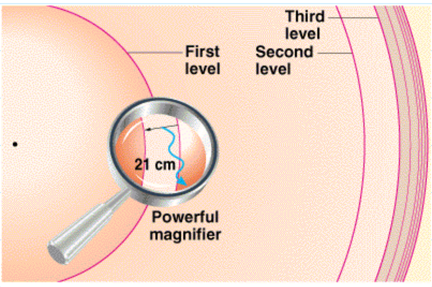
- Type O and B stars are very hot:
  surface temperature greater than 10,000 K.
- Peak wavelength for 10,000 K is in the UV part of the spectrum.
- Light radiated from these stars is very energetic and can easily ionize any neutral Hydrogen surrounding the star.
- Suppose that a type O or B star is born inside of a cloud of neutral H.
- Photons from the new-born star will create a sphere of ionized H (H II) surrounding the young star.
- As the ionized Hydrogen recombines with the free electrons in a high energy state, the red Balmer-alpha light will be emitted.

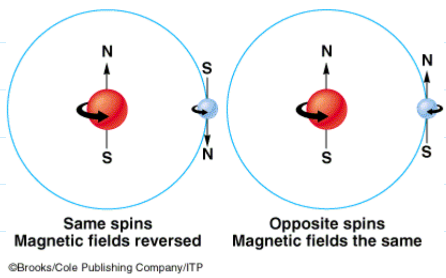
- As time passes, the H will disperse and the star will be isolated.
- Photo of the Rosette Nebula, showing a cluster of young stars.

An emission nebula around hot young stars

Detection of Neutral Hydrogen

- Electrons and Protons have a property similar to spin.
- It's possible to put one electron into the ground state of Hydrogen in two different ways:
  - Electron spin parallel to the Proton spin
  - Electron spin anti-parallel to the Proton spin
- The ground state of Hydrogen is actually two different energy states.
- Spins parallel is a slightly higher energy level than spins anti-parallel.
- If H atom happens to have electron in spin parallel state, the electron will spontaneously "flip" over to the anti-parallel state and emit a photon of energy.
- Since the energy levels are very close the energy of the photon is low, and the wavelength is large, **wavelength = 21 cm** (radio waves).
- We can detect this radiation using a radio telescope.
- Astronomers call a region of neutral Hydrogen a **H I** region.



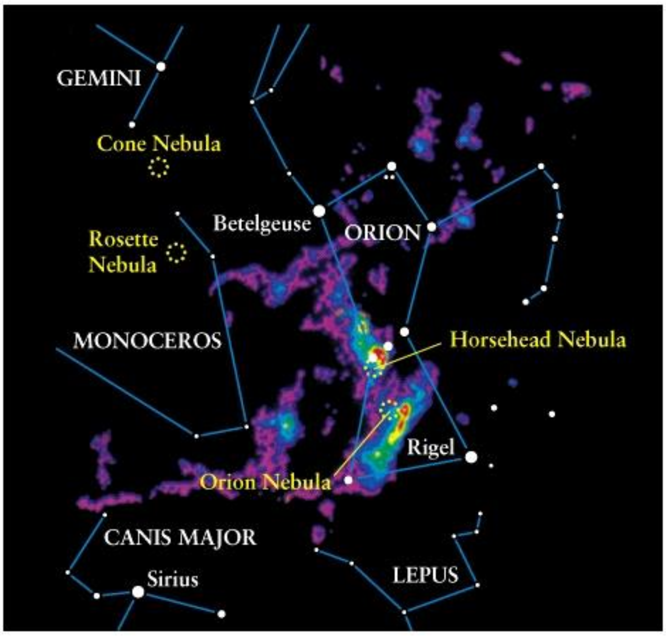


Molecules

- The Interstellar Medium also has dense, cool regions where molecules can be found called **Molecular Clouds**.
- Temperatures less than 100 K.
- Molecules detected include: H_2, CO, H_2O, C_2H_5OH and other complex organic molecules.
- Density of molecules in this room: 2 x 10^{25} molecules per cubic metre.

- Density of molecules in a molecular cloud: 10^9 molecules per cubic metre. (Dense by astronomical standards, but not by Earth standards.)
- Molecules have energy levels:
    - When an electron jumps from one energy level to another a UV photon can be emitted or absorbed which a UV telescope can detect.
    - When the molecule's spin changes a radio frequency photon can be emitted which a radio telescope can detect.
- We can detect molecules by using a radio telescope tuned to the radio waves emitted by the molecules.
- Unfortunately, molecular Hydrogen, H_2, doesn't emit radio waves.
- Usually astronomers try to detect CO instead.
- CO emits at a wavelength of 2.6 mm.
- Typically there are 10,000 H_2 molecules for each CO molecule.

A Molecular Cloud in the Constellation Orion



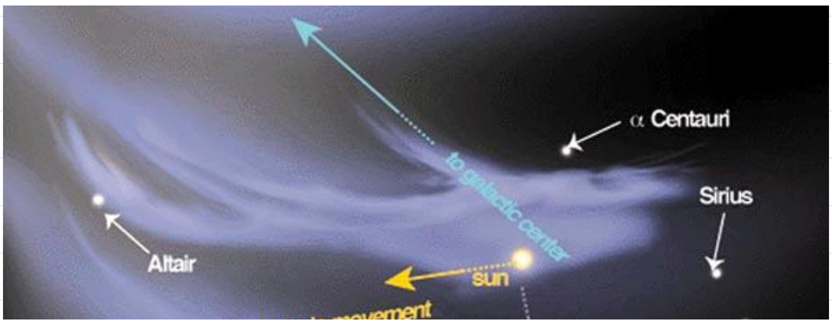
Radio "photo" showing CO emission

Dust

- The interstellar medium is also full of **dust**.
- Dust grains are solid conglomerates of many molecules and atoms including graphite, silicates, iron, ices...
- Typical size of a dust grain is about 10^{-6}m similar to the wavelength of visible light.

The Local Interstellar Cloud (Artist's Diagram)

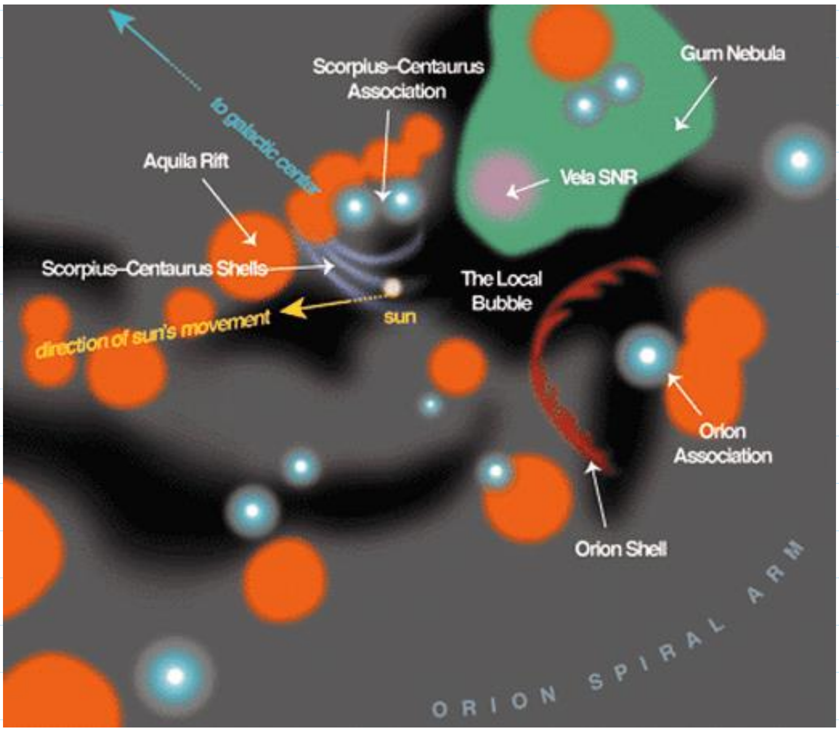
- This diagram shows the location of gas clouds within **10 light-years** of the Sun.
- The purple colour represents a denser region called the **local interstellar cloud**.
- The Sun will exit the local interstellar cloud in about 10,000 years.



- The local interstellar cloud is moving away from a group of young O and B stars called the Scorpius-Centaurus Association.

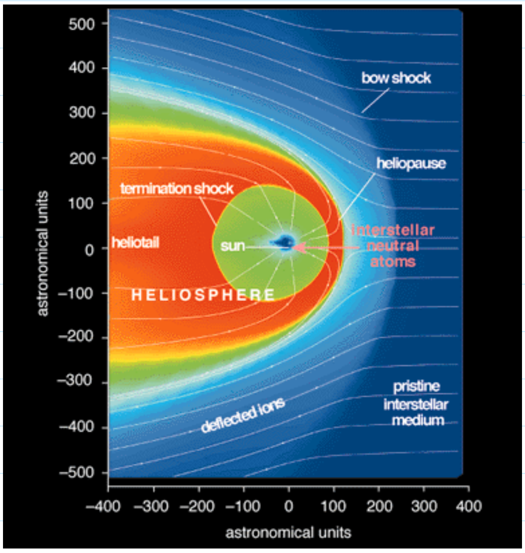
The Sun's Neighbourhood (1500 light-years across)

- This diagram shows the location of the region near the Sun within 1500 light-years.
- The thin purple strips include the local interstellar cloud.
- The darkest regions have the lowest density of any type of gas.
- The Sun has been travelling for the last several million years through the **Local Bubble** a low density region of the interstellar medium.
- The orange regions are cold, dense molecular clouds
- The Gum Nebula (green) is a complex region of ionized hydrogen.



The Heliosphere

- The Sun's magnetic field and the Solar Wind produce a region about 100 AU in radius around the Sun called the **heliosphere**.
- Most charged particles from the interstellar medium are deflected from this region, protecting the Solar system.
- The size of the heliopause is defined by a balance between the force of the Solar wind and the gas pressure of the interstellar medium.
- In about 50,000 years we may enter a denser region of the interstellar region, which may push the heliosphere inwards.
- If the heliosphere were to shrink to a size smaller than the Earth's orbit, charged particles could harm life on Earth.



출처: <https://sites.ualberta.ca/~pogosyan/teaching/ASTRO_122/lect14/lecture14.html>