
Chapter 19
Star Formation
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Learning Goals:

19.1 Star – Forming Regions

19.2 The Formation of Stars Like the Sun

19.3 Stars of Other Masses

19.4 Observation of Cloud Fragments and Protostars

19.5 Shock Waves

19.6 Star Clusters

19.1 Star-Forming Regions

- Our universe is renewing itself.
- Most of the stars are billion years old.
- Emission nebulae glowed because of young stars, few million years old.
- Star forming regions are observed everywhere in and beyond the Milky-Way.
- Magellanic clouds (170,000 ly) show rich region of young blue stars.

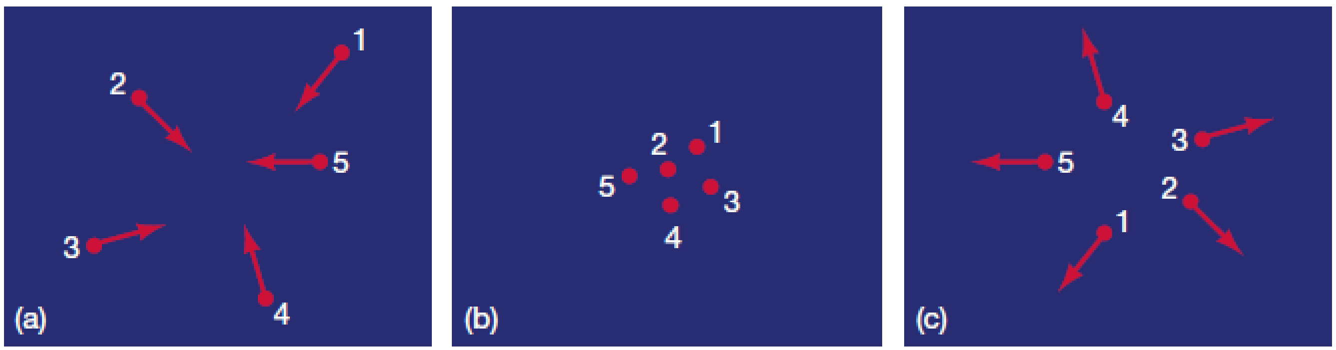
19.1 Star-Forming Regions

- Stars form when cold dark clouds start to collapse under its own weight
- Heats up as it shrinks ➔ its center is hot enough for nuclear fusions to begin.
- At this stage, the collapse stops and star is born.
- Questions:
    1. What starts the collapse?
    2. How and why does it end?
    3. What determine the mass of the stars?

19.1 Star-Forming Regions

Gravity and Heat.

- **Gravitational force**: influenced by the gravitational attraction of all particle neighbors – increasing mass → stronger shrinking
- **Temperature**: Movement of molecules generates heat.

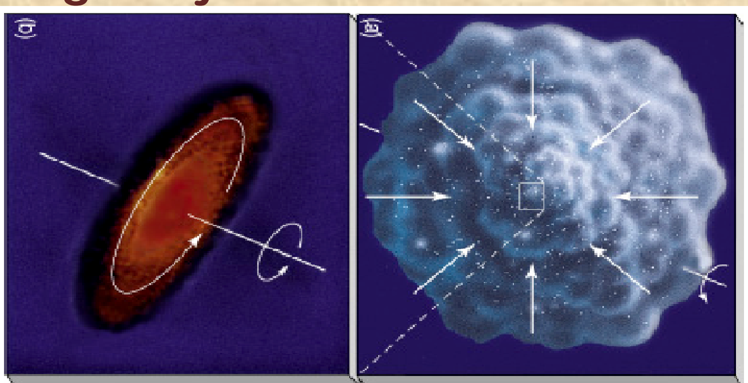


- **A competition between heat and gravity.**
- **Speed of atoms & molecules increases with temperature ➔ higher pressure**
- **➔ Prevent nebula from further collapsing.**
- **10^{57} atoms should be accumulated (10^{25} grains of sand on all the beaches).**

19.1 Star-Forming Regions

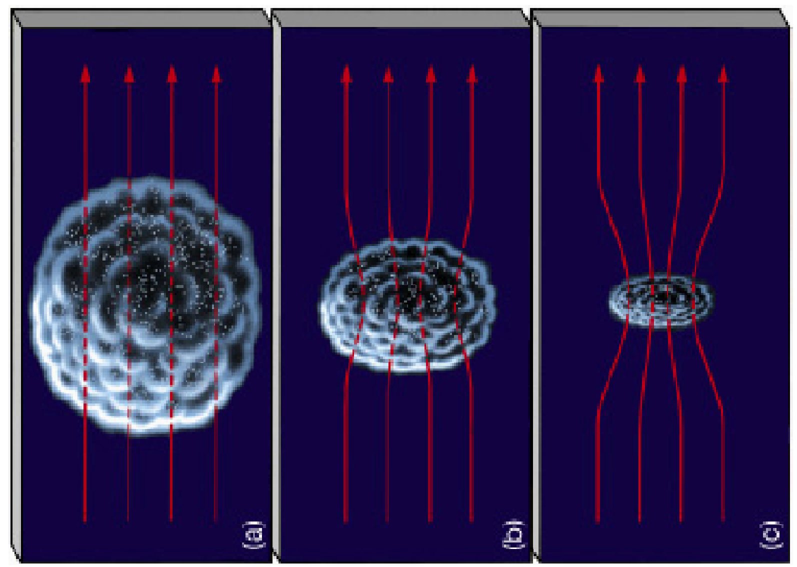
Rotation – spin

- material to remain part of cloud and not be spun off into space gravity force applied it
- rotating cloud must spin faster to conserve its angular momentum
- Cloud size decreases when spin faster, more mass to attract inward.
- Rotation opposing the inward pull of gravity



Magnetism

- It hinder a cloud's contraction
- As a cloud contracts, it heats up, ➔ (partly) ionize the gas
- B – fields control over charged ions.
- Ions are tied to the field.
- B-lines follow the contraction of the clouds ➔ B-field stronger ➔ pull matter upward ⊥ ions motion



19.2 The formation of Stars Like The Sun

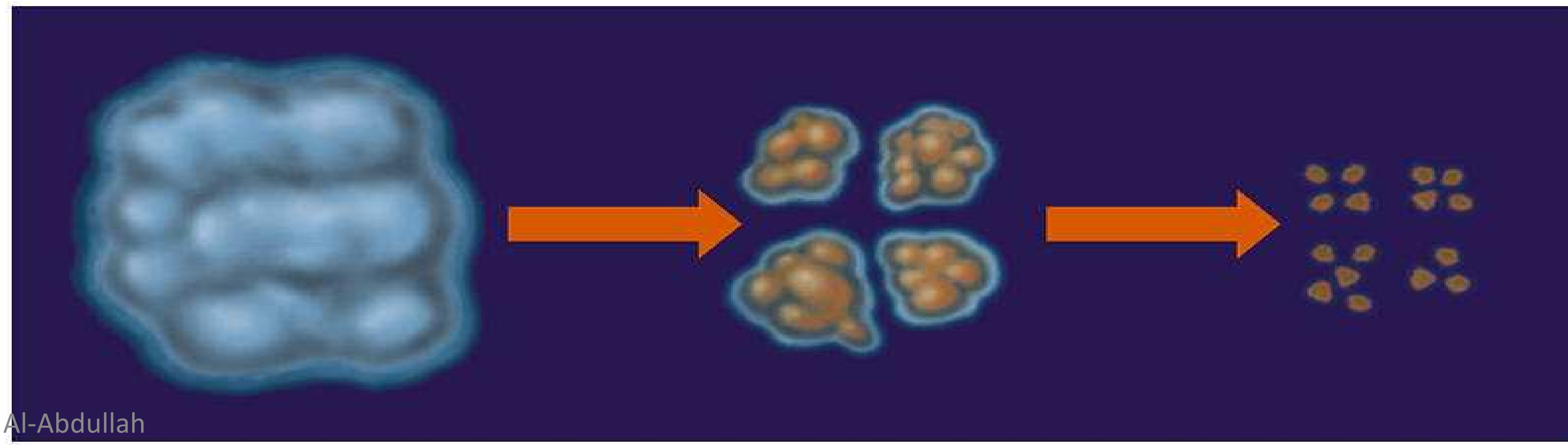
- **The star formation begins when gravity dominates over the heat of the cloud. At this point the cloud will contract on its way to becoming a real star.**

TABLE 19.1 Prestellar Evolution of a Solar-Type Star

Stage	Approximate Time to Next Stage (yr)	Central Temperature (K)	Surface Temperature (K)	Central Density (particles/m^3)	Diameter* (km)	Object
1	2×10^6	10	10	10^9	10^{14}	Interstellar cloud
2	3×10^4	100	10	10^{12}	10^{12}	Cloud fragment Cloud fragment/protostar
3	10^5	10,000	100	10^{18}	10^{10}	
4	10^6	1,000,000	3000	10^{24}	10^8	Protostar
5	10^7	5,000,000	4000	10^{28}	10^7	Protostar
6	3×10^7	10,000,000	4500	10^{31}	2×10^6	Star
7	10^{10}	15,000,000	6000	10^{32}	1.5×10^6	Main-sequence star

Stage 1: An Interstellar Cloud

- A dense interstellar clouds are truly vast maybe tens of parsecs.
- Typical temperatures are about 10 K throughout, with a density of perhaps 10^9 particles/m^3, $10^{14} – 10^{15}$ km diameter
- Clouds contain thousands of times the mass of the sun
- When collapsing, the cloud breaks up into thousands of smaller fragments, each possibly becoming a star.
- Few million years for collapsing fragments.
- Most astronomers think that the process of star formation is triggered when some external event



Stage2: A Collapsing Cloud Fragment

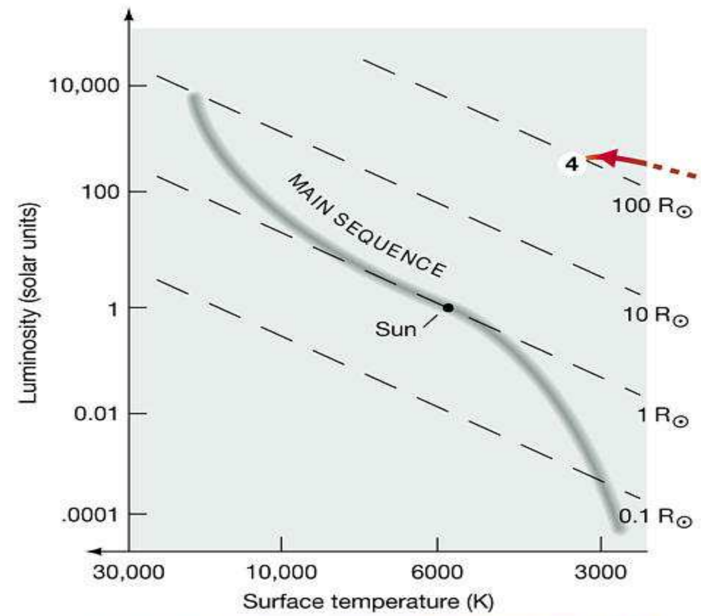
- The central of the cloud's density is roughly 10^{12}particles/m^3, M=1—2 $m_\odot$
- Average temperature of fragments is not much different from that the original (the central temperature equal 100 K)
- All the energy releases in the collapse is radiated away, but T at the center increases.
- Fragments continue to contract so the temperature + pressure increase and fragmentation to cease

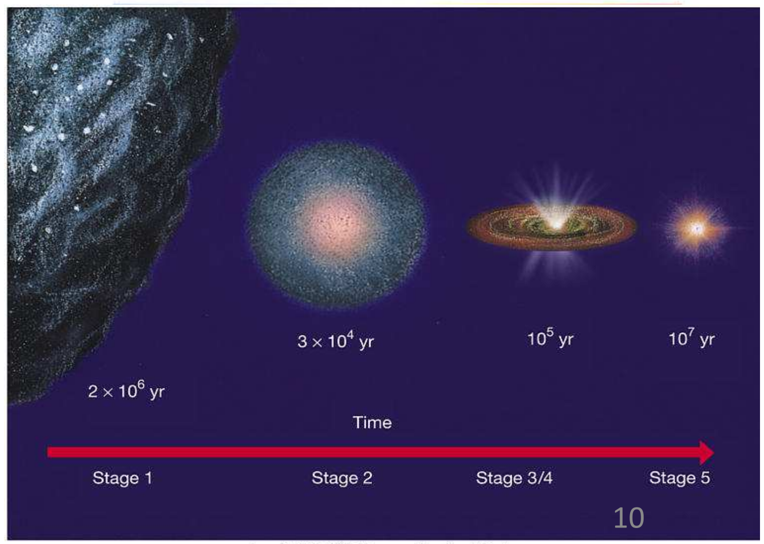
Stage3: Fragmentation Ceases

- The size of our solar system still 10,000 $R_\odot$, Solar system size.
- The central temperature reached 10,000 K (inner region becomes opaque)
- The density increases much faster in the core of fragment than the outer of cloud (cool + thin) {central density: 10^{18}particles/m^3, 10^{-9} kg/m^3, opaque}
- Protostar is the dense and opaque region at the center of cloud (star birth).

Stage4: A Protostar

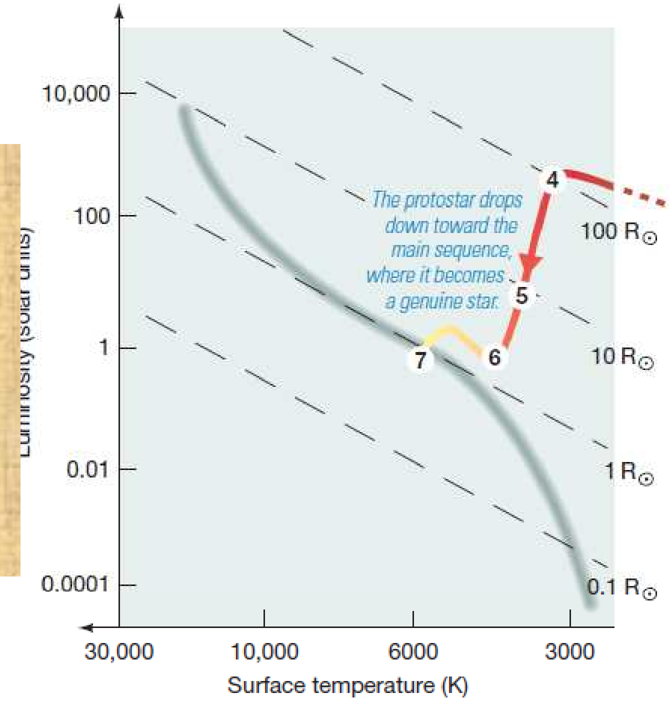
- At 10^5 yr → central T = 10^6 K, but less than 10^7 K, no nuclear fusion.
- Size of Mercury orbit. Surface T = few x 10^3 K.
- Knowing R & T → Luminosity (>1000$L_\odot$) due to falling materials.
- As the protostar finds itself on the H-R Diagram it plots out its evolutionary track.
- The early track is called the Kelvin-Helmholtz contraction phase.
- Spin faster and flattens (Protostellar disk, 100A.U.). Contraction slows. Gravity dominates.
- As protostar drops towards the main sequence it is said to be on the Hayashi track.
- Stars on the Hayashi track exhibit violent surface activity which leads to strong protostellar winds. This is the T Tauri phase, named after the protostar T Tauri.





STAGE5: Protostellar Evolution

- Protostar shrunk to about 10 times the size of the sun
- The surface temperature is about 4000k
- The luminosity about 10 times the solar rate (the central temperature has reached about 5million k)
- The gas is completely ionization.
- The core still cold for nuclear fusion to begin
- Luminosity decreases ➔ contraction is weak.

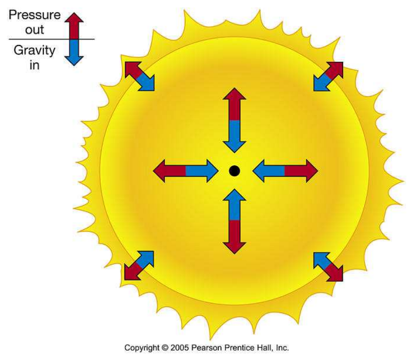


STAGE6: A Newborn Star

- After 10 million years we now have a true star.
- 1 $M_\odot$ object has shrunk to a radius of about one million km
- Central temperature is 10^7 K , enough to ignite nuclear burning,
- Protons being fusing into He nuclei in the core and star is born.
- Surface temperature is 4500K, luminosity less than the solar value (0.67 $L_\odot$)

STAGE7: The Main Sequence at Last

- The central temperature increases to 15 MK and the surface temperature reaches 6000 K.
- Central density 10^{32} particle/m^3, 10^5 kg/m^3
- The star reaches the main sequence just about where our sun now resides
- Pressure and gravity are balanced
- Nuclear energy generated in the core = Energy radiated from the surface



19.3 Stars of Different Masses

Stages 1-7 are valid for only a 1-solar mass stars.

Stars of others masses exhibit similar trends, but different Hayashi tracks.

$0.3M_{\odot}$, $1M_{\odot}$, $3M_{\odot}$ traverse the H-R diagram in the same manner.

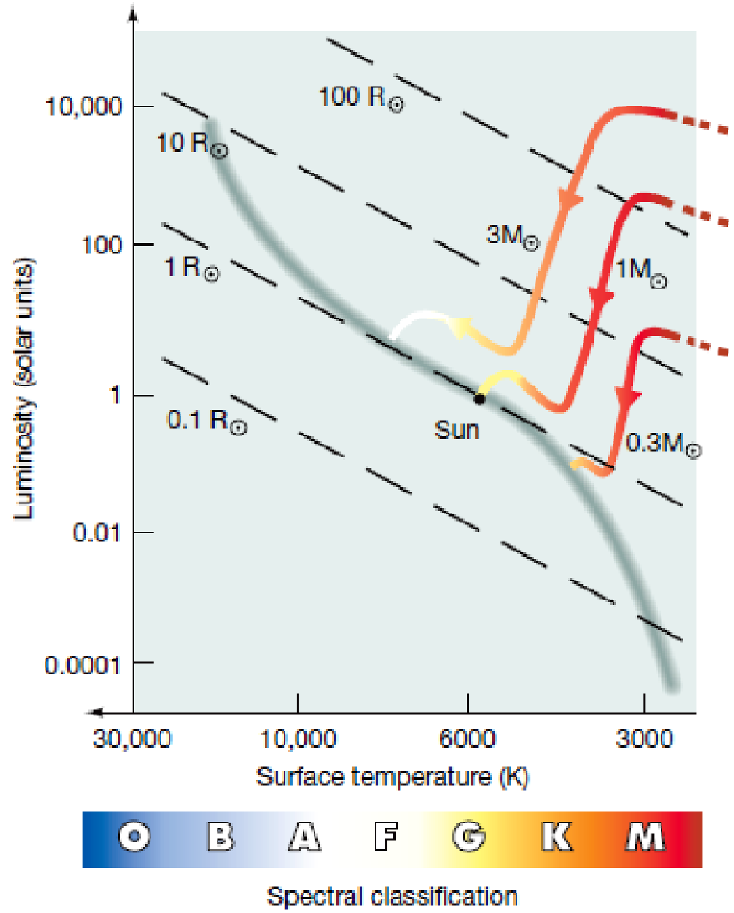
The time for the interstellar clouds to form a M.S. star depends on its mass.

O-type stars is formed in 1/50 the time taken by the Sun.

M-type star needs a billion years to form.

Our sun needs almost 50 million years

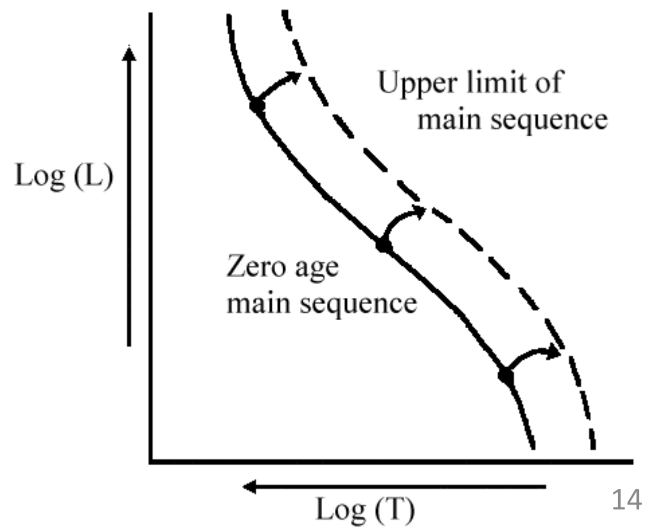
Regardless of its mass, the prestellar evolutionary track is the main sequence.



19.3 Stars of Different Masses

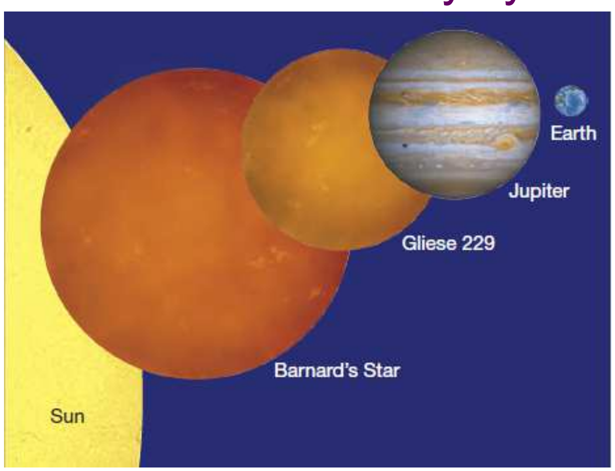
The Zero-Age Main Sequence (ZAMS).

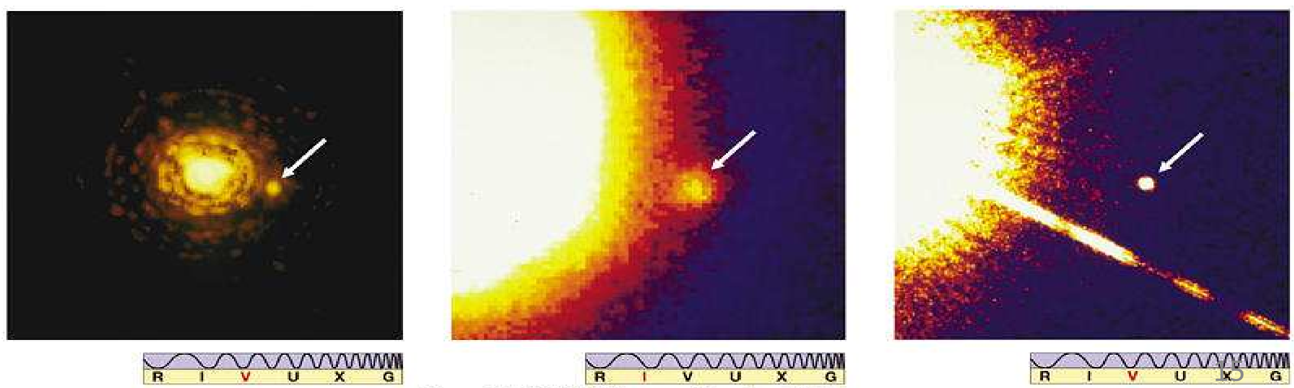
- **A star is reached the main sequence when H-burning begins in the core.**
- **The main-sequence line predicted by the theory is called (ZAMS).**
- **If the gas consists the same element (H) ➔ ZAMS line will be a well-defined.**
- **The composition of a star affects its internal structure (opacity) ➔ the luminosity and temperature will change → broadness of the line.**
- **Stars with more heavy elements → cooler and less luminous than stars have the same element.**
- **the main-sequence is not an evolutionary track-stars do not evolve along it.**
- **stars on the main-sequence, spending most of its life in one place**



19.3 Stars of Different Masses

- Failed Stars: Cloud fragments are too small to become stars.
- Jupiter never evolved beyond the protostar stage, no enough gas to increase gravity and heat to start fusion reaction.
- Theory: Min. mass of gas needed to generate a nuclear-fusion core is $0.08M_{\odot}$.
- Brown Dwarfs: Small faint cool low-mass stars originated from prestellar fragments of mass ranging from $0.012M_{\odot}$ ($12\ M_{Jupiter}$) to $0.08M_{\odot}$ ($80M_{Jupiter}$).
- Difficult to observe, # of brown dwarfs is huge in the Milky Way Galaxy, almost 50 are seen at distance of 1,500 light years.
- Found in a binary systems, total number comparable to real stars in our Galaxy.





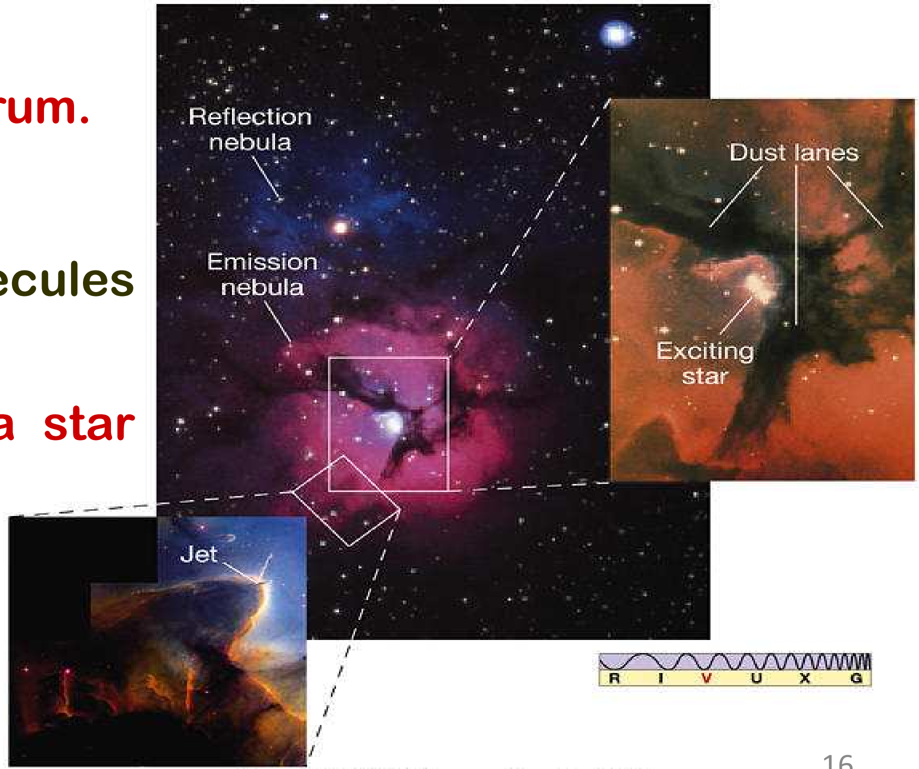
19.4 Observations of Cloud Fragments and Protostars

How can we verify the theoretical picture?

Observing many different objects, interstellar clouds, protostars, young stars, at different stages of their evolutionary paths.

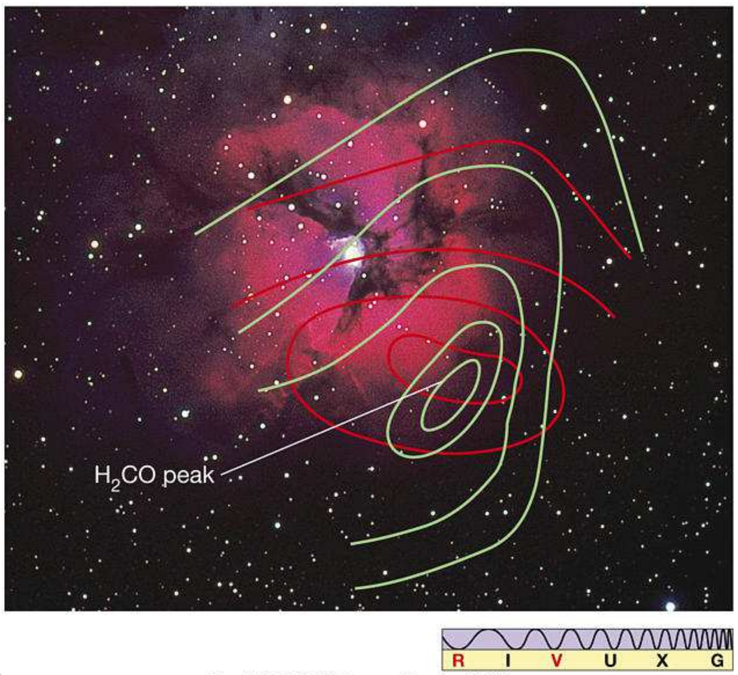
Evidence of Cloud Contraction:

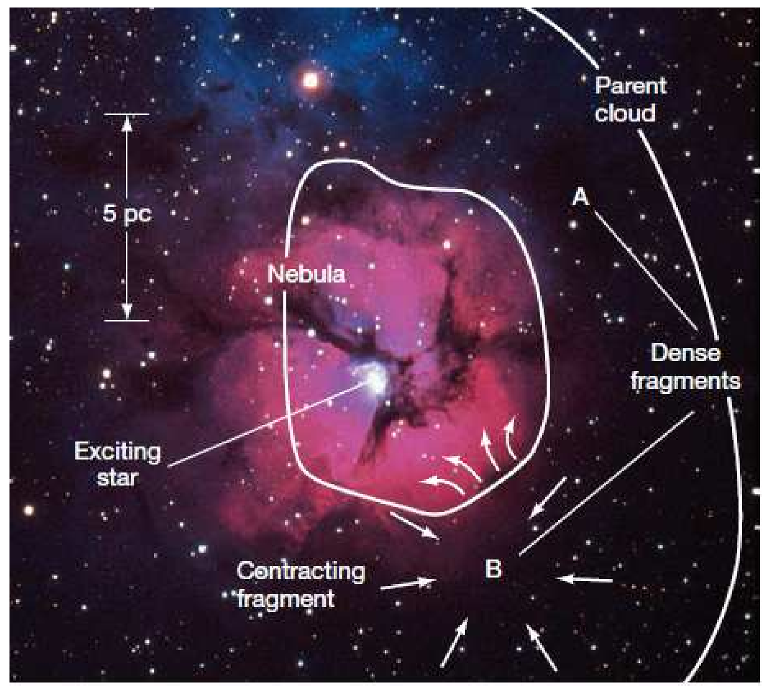
- **Stages 1 & 2 are cold, no visible spectrum.**
- **Computer calculations predict it.**
- **radio emission of interstellar molecules within these clouds.**
- **Emission nebula are sign spots of a star birth (M20), stages 6 & 7.**



19.4 Observations of Cloud Fragments and Protostars

- Region surrounding M20 seems to be contracting.
- contour map of amount of formaldehyde (H_2CO) abundant in the darkest interstellar region → Contracting and fragmenting.
- in A & B regions; density: $10^8 \rightarrow 10^9$ particles/m^3, $T=20 \rightarrow 100$ K. Doppler Shifts of radio waves in A ➔ clouds are infalling
- Emission nebula forms one or more massive stars, O-type ➔ glowing regions.





Evidence of Cloud fragments: Orion Nebula,

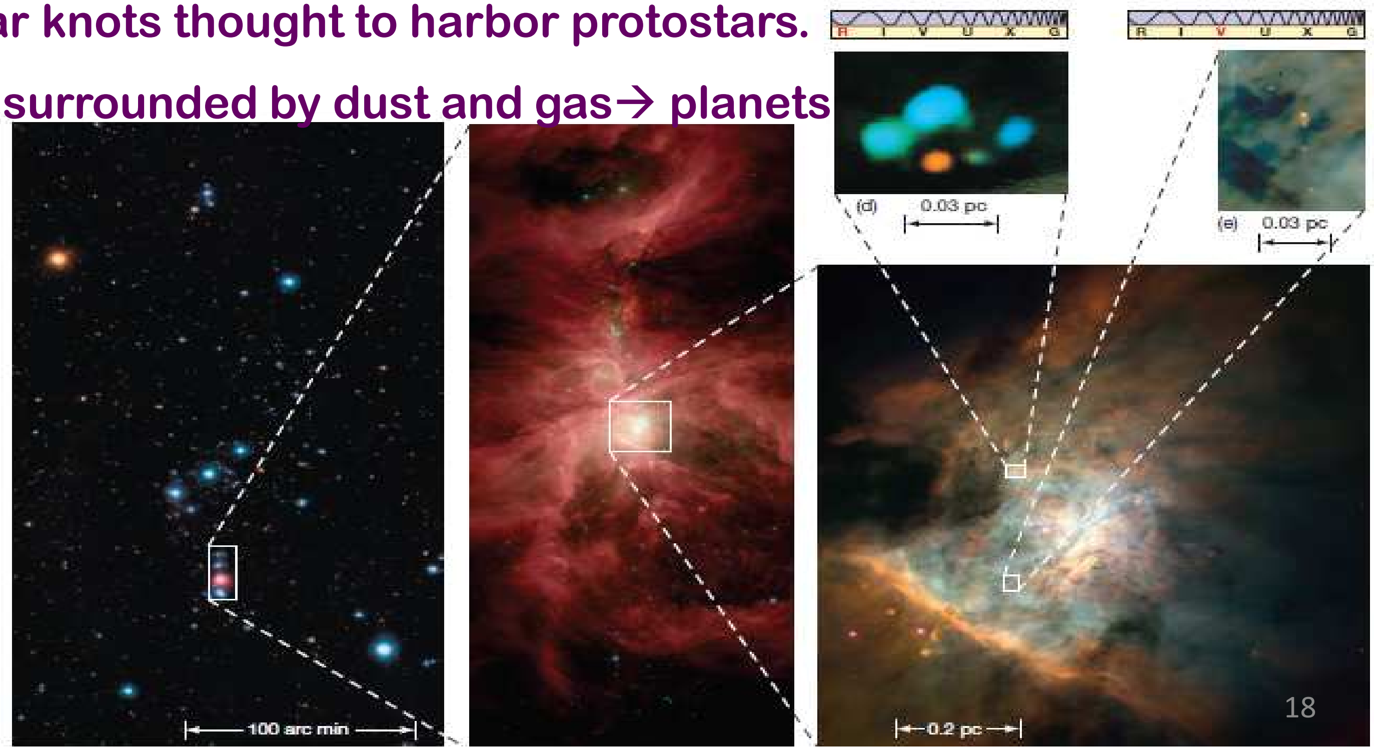
Prestellar objects, stage 3.

(a&b) bright nebula, O-type stars, surrounded by a dense molecular cloud.

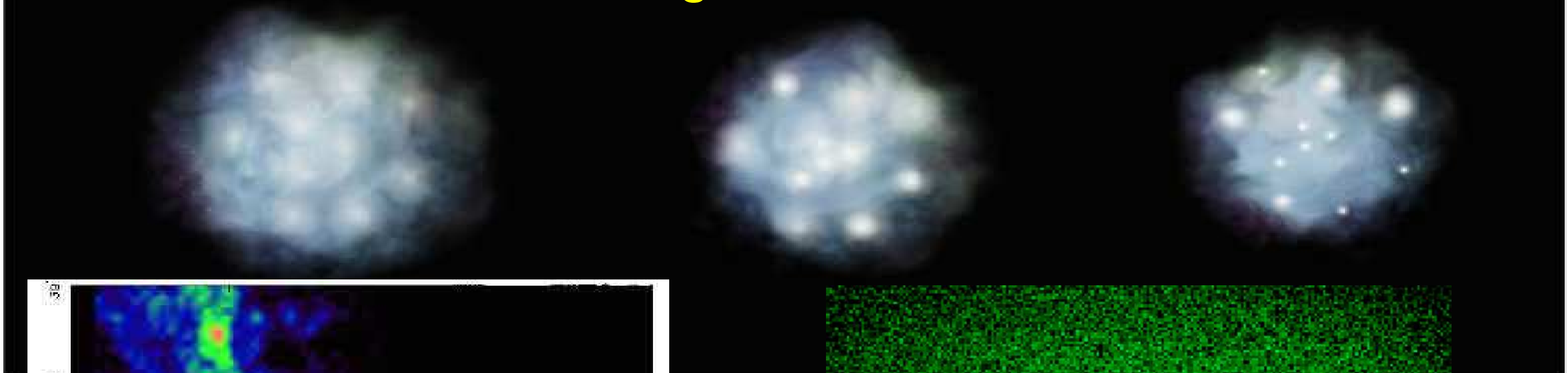
(c) Radio image of intensely emitting molecular sites. 10^{10}km, 10^{15} particle/m^3

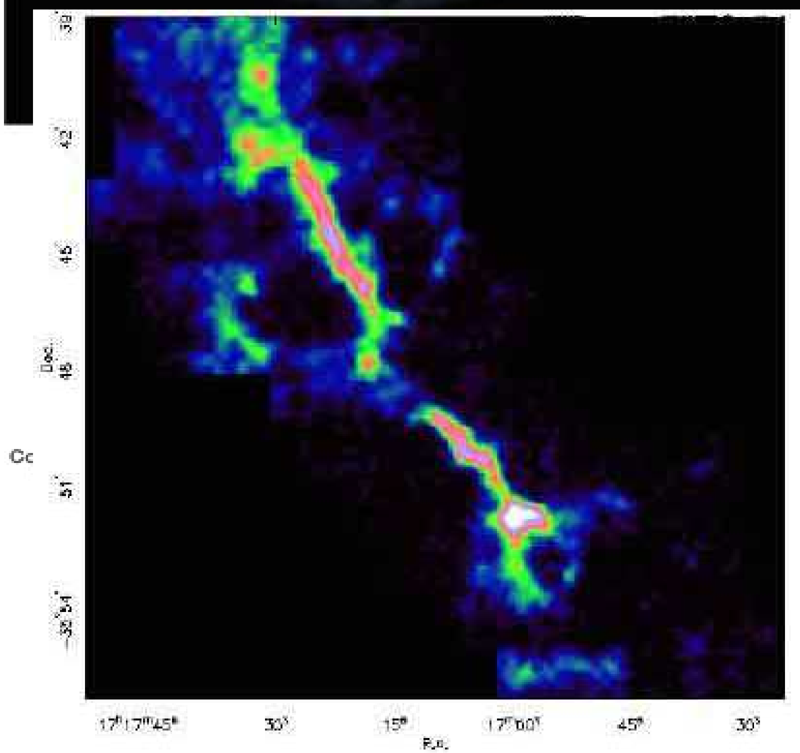
(d) Visible image nebular knots thought to harbor protostars.

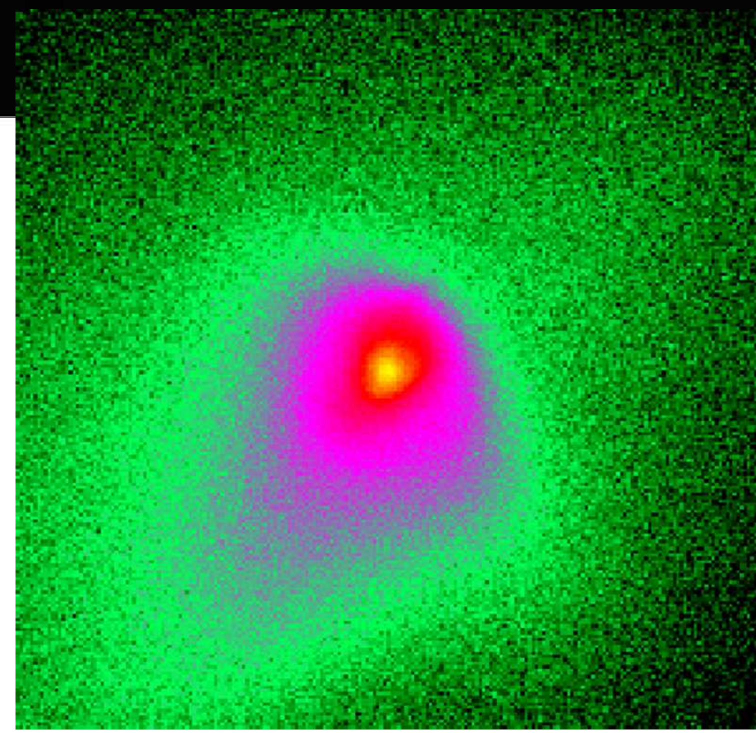
(e) Several young stars surrounded by dust and gas→ planets



19.4 Observations of Cloud Fragments and Protostars

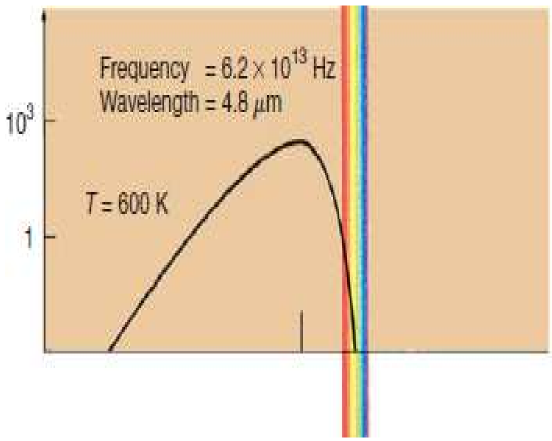




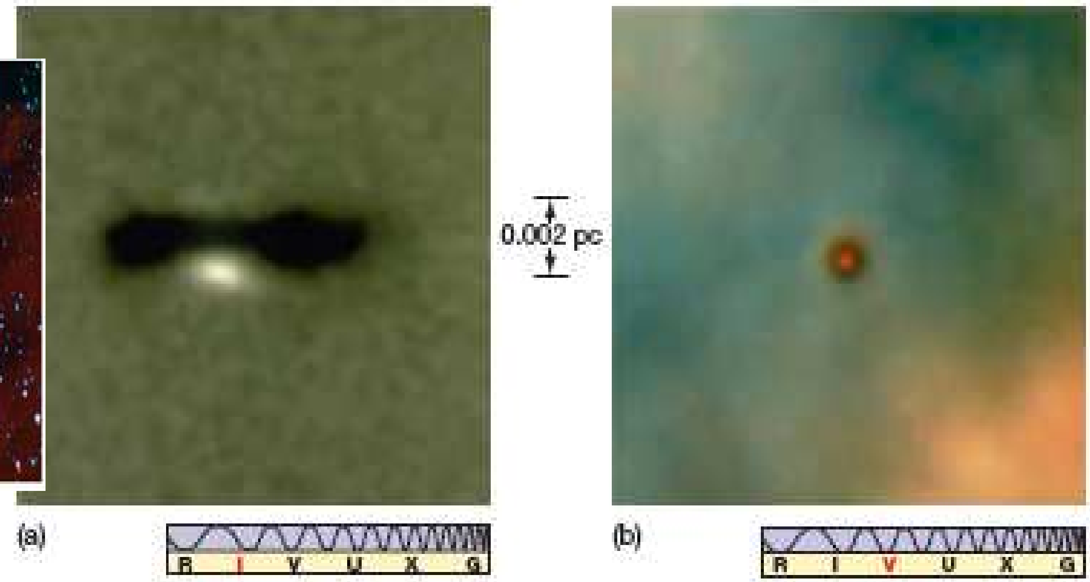


Evidence of Protostars

- prestellar objects, stages 4→6.
- Wien's Law: High T → emission of shorter wavelengths → shining objects (IR).

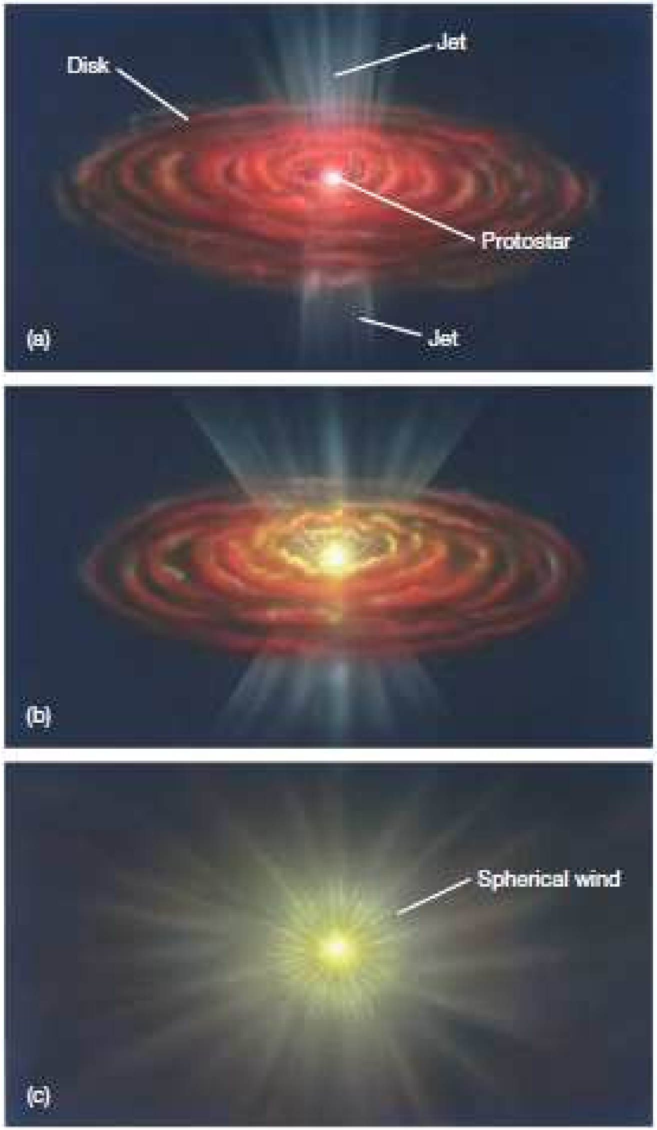


- A dim, young star called Herbig-Haro 46. The star's atmosphere, at 600 K, radiates mainly in the infrared.
- Around stage 4



- Low-mass protostars, dirty disks in the Orion region, showing heat and light emerging from their centers in IR region.
- Signature of an object on the Hayashi track, around stage 5.

Protostellar winds



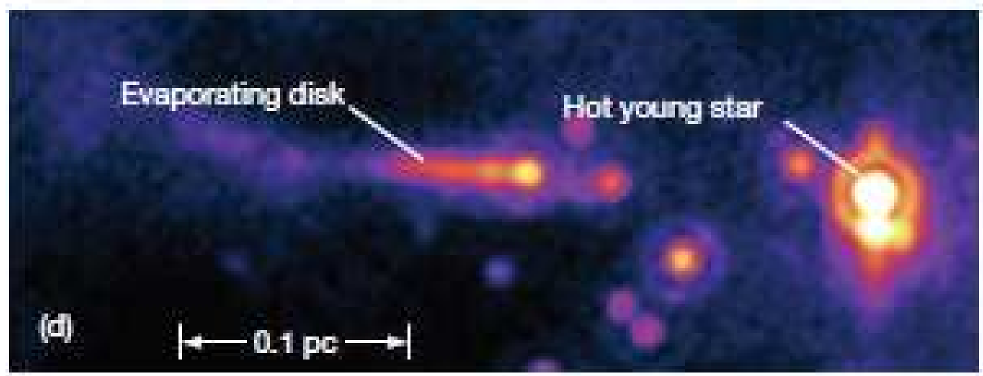
Radio and IR observations, violent surface activity.

Gas expanding outward at speed of 100km/s.

Nebular disk around protostar; intense heating and strong bipolar jets ⊥ disk, source for planets.

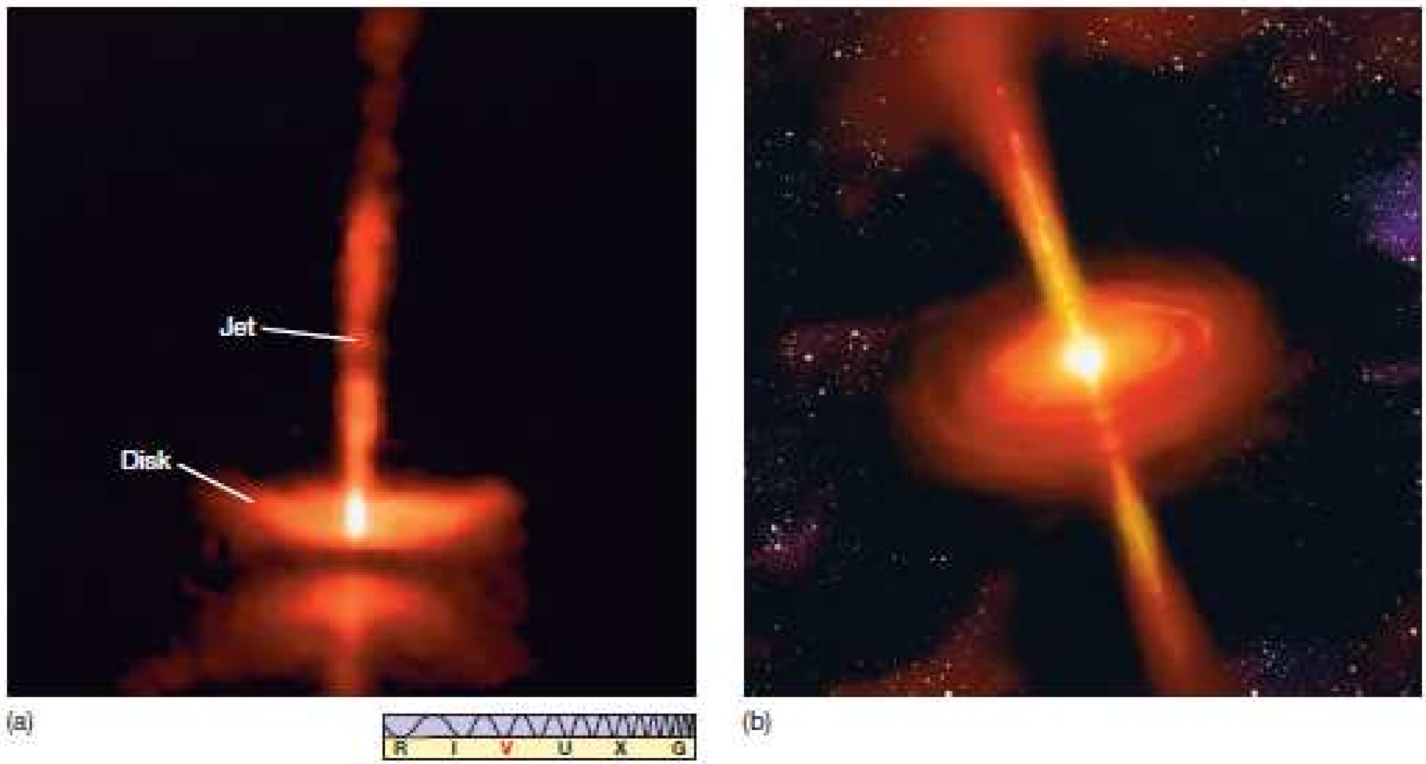
as the disk blown away by the jets→ jets fan out.

Spherical winds, winds flow away from the star, destroy the disk.



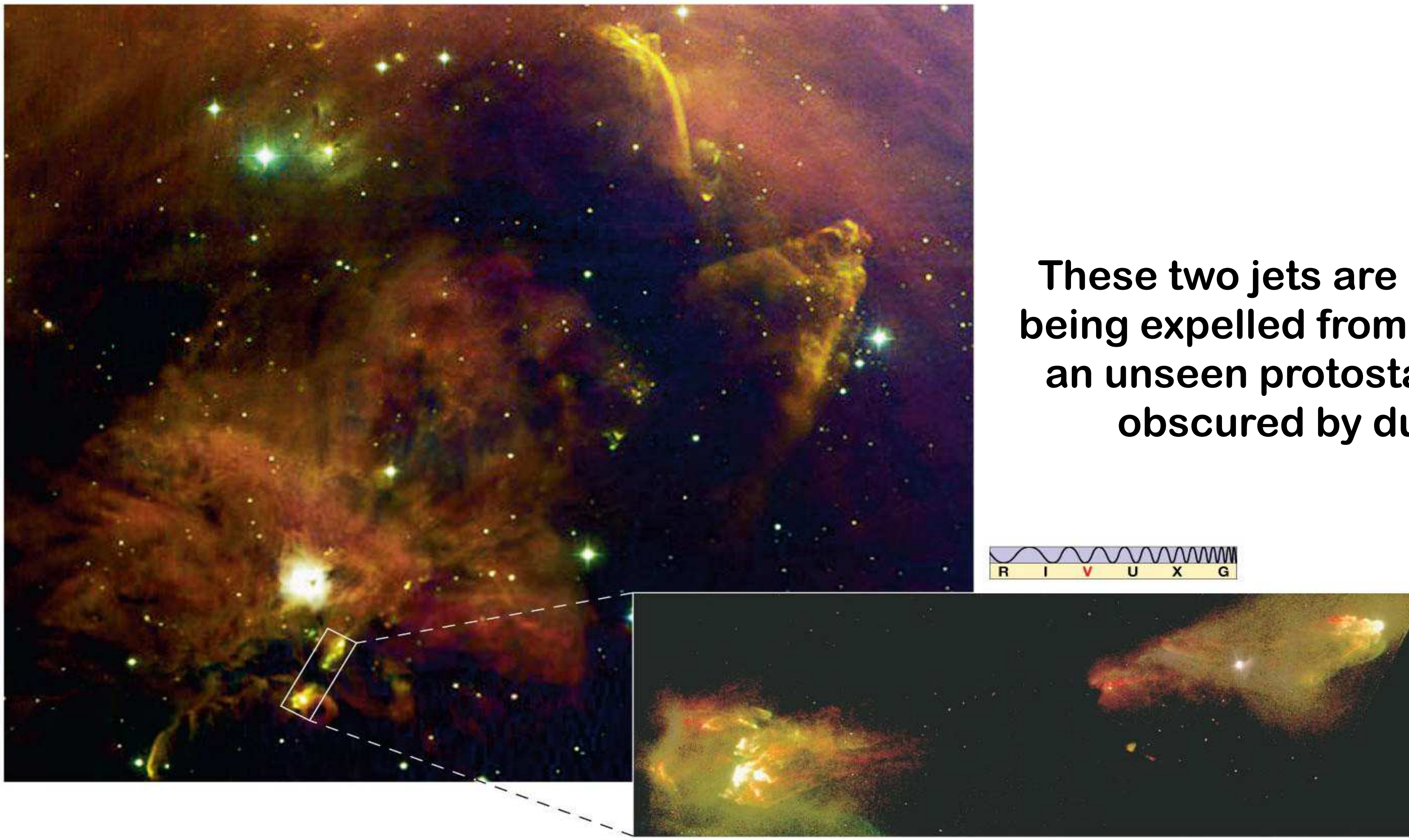
o Around stage 6

Protostellar winds



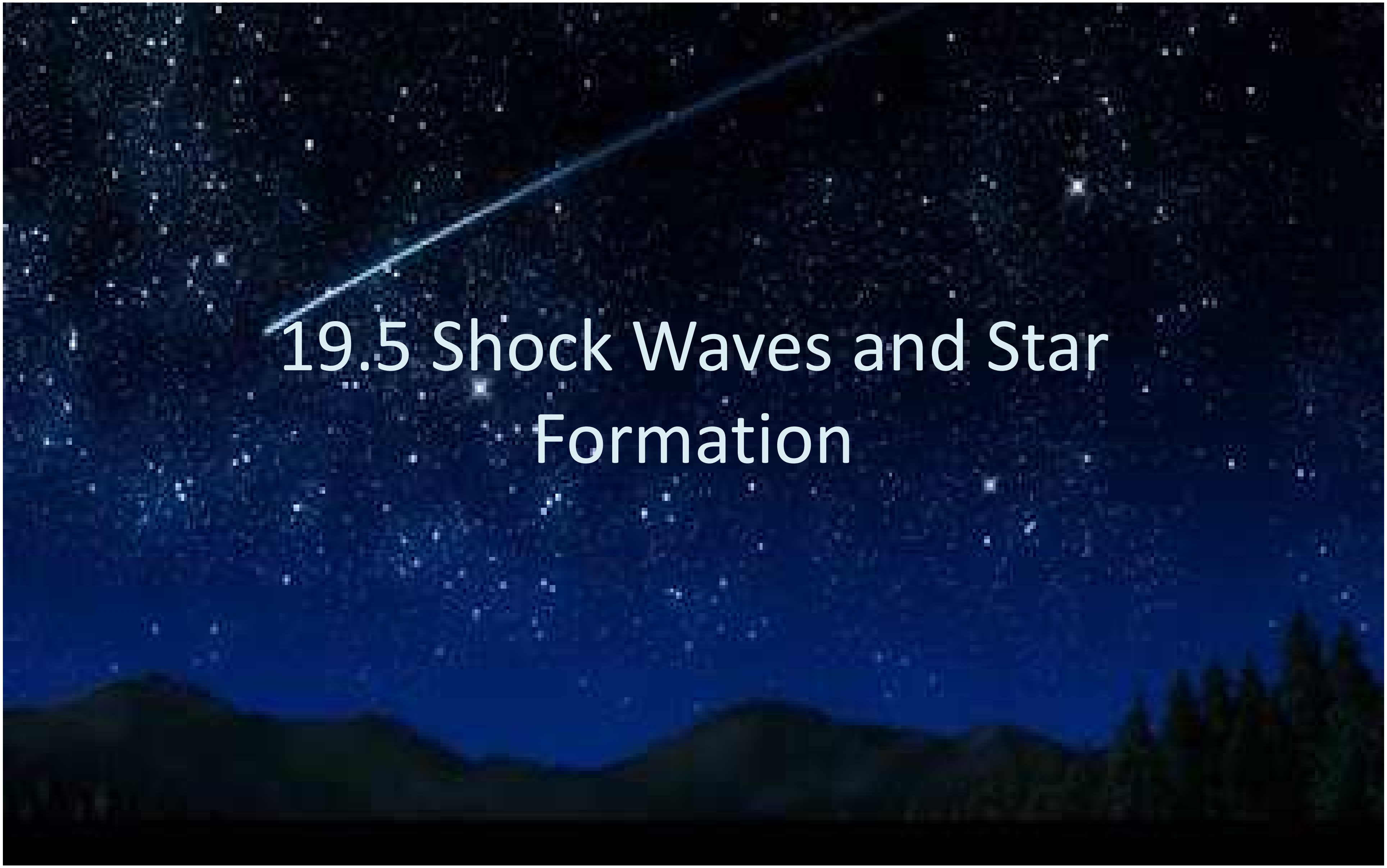
HH30, Herbig-Haro, illustrating a real example of the bipolar flow, along with an artist's conception of a young star system

Protostellar Outflow



These two jets are matter being expelled from around an unseen protostar, still obscured by dust

19.5 Shock Waves and Star Formation



19.5 Shock Waves and star Formation

Interstellar space: clouds, fragments, protostars, stars, nebula ➔ interact in a complex fashion.

Expanding waves of matter outward by high T and P in the nebula.

Shell of gas rush rapidly through space ➔ Shock Waves

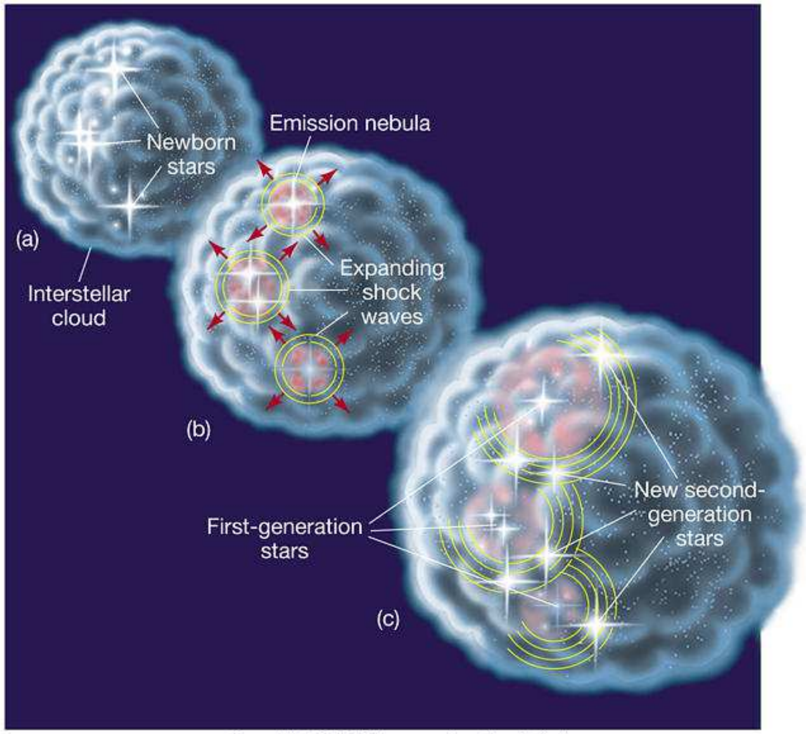
As the waves crash into the surrounding molecular cloud → interstellar gas compressed.

Push thin matter into dense sheets.

Triggering mechanisms needed to initiate star formation.

shock waves squeeze a cloud from many directions.

natural gravitational instabilities take over → fragmentations.



19.5 Shock Waves and star Formation

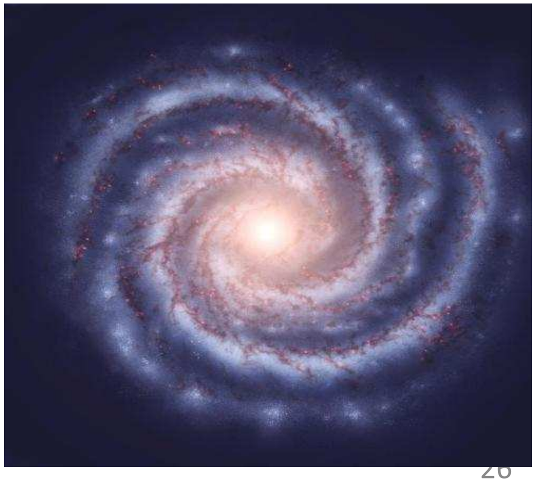
Other triggers:

a) Death of a nearby-like star (planetary nebula)

b) Supernovae

c) Interaction between galaxies

d) Spiral-arm waves that plow through the Milky Way



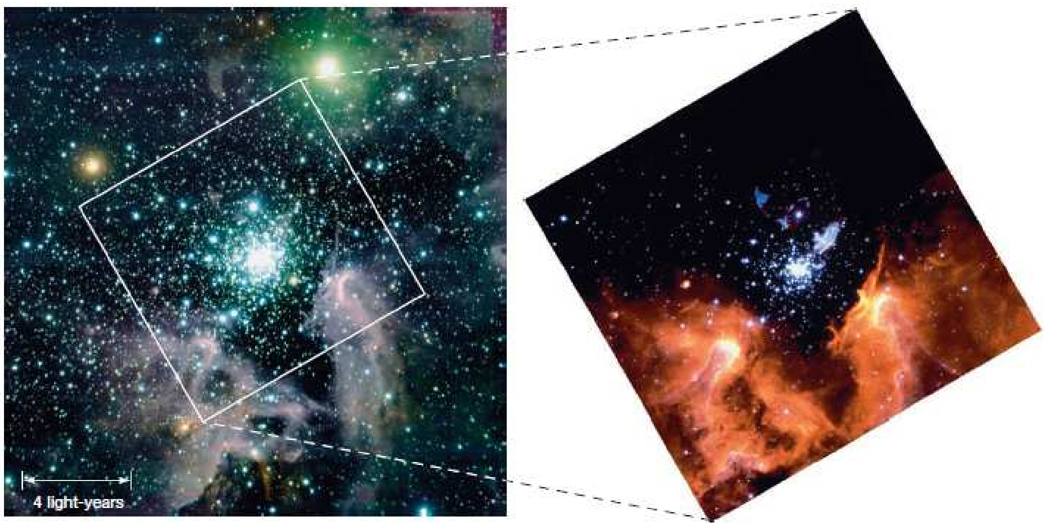
19.5 Shock Waves and star Formation

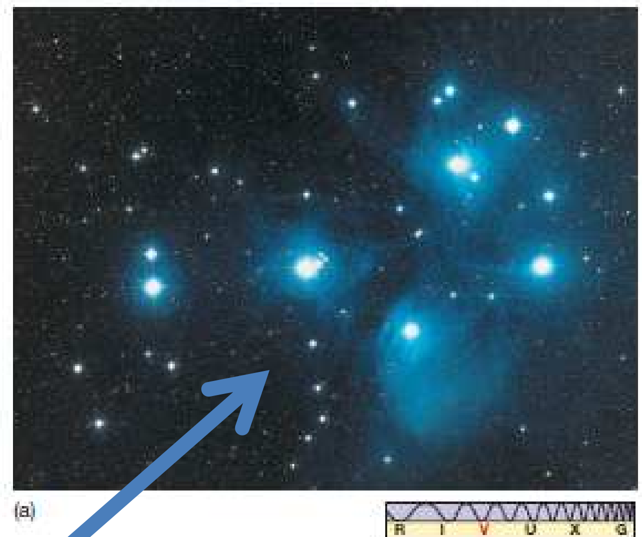
Star-forming region in galaxy NGC 4214 (13 million light-years distant), which may represent several generations in a chain of star formation.

19.6 Star Clusters

The end result of the collapse of a cloud is a group of stars, all formed from the same parent at the same time and lying in the same region ➔ ***Star Cluster***

The factor distinguished one star from another is the ***mass***.





Open Cluster – example: Seven Sisters (Pleiades)

Loose, irregular cluster, found in the plane of the Milky-Way.

Typically contains few hundreds – few thousands of stars, few parsecs across.

19.6 Star Clusters

Open clusters → Pleiades contain stars in almost all parts of the main sequence.

No very bright stars. The bright 6-7 stars left the H-R diagram.

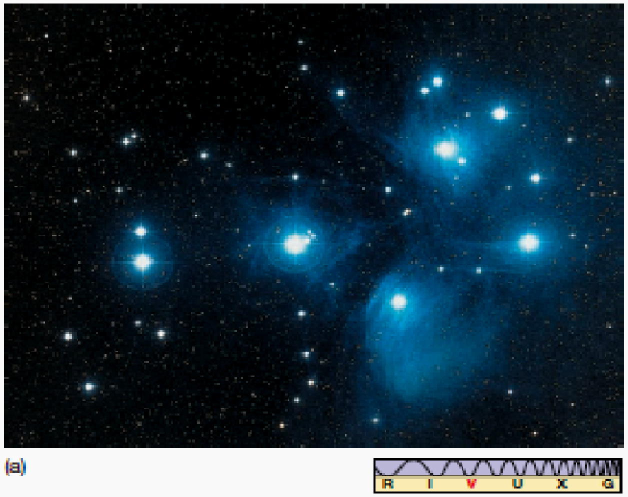
No evidence of the cluster's birth, estimated age is less than 100 million years, B-Type age.

Less massive stars, but extended clusters are known as *associations*.

Contains few hundred bright stars, spans many tens of parsecs. Very rich in young stars.

Those containing many pre-main sequence T Tauri stars ➔ T associations,

Those with prominent O- and B-Type stars are called ➔ *OB associations*.



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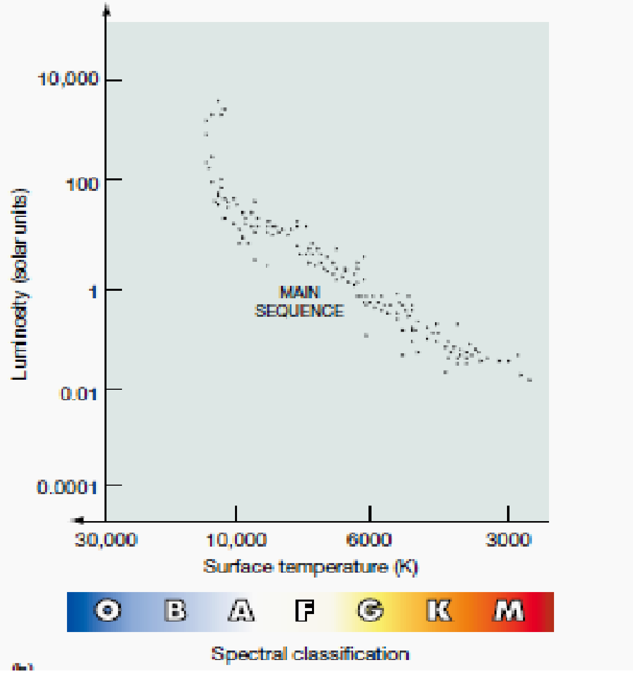


19.6 Star Clusters

Trapezium in Orion
OB associations

T Tauri associations

The main difference between associations and open clusters is simply the efficiency with which stars formed from the parent cloud

19.6 Star Clusters

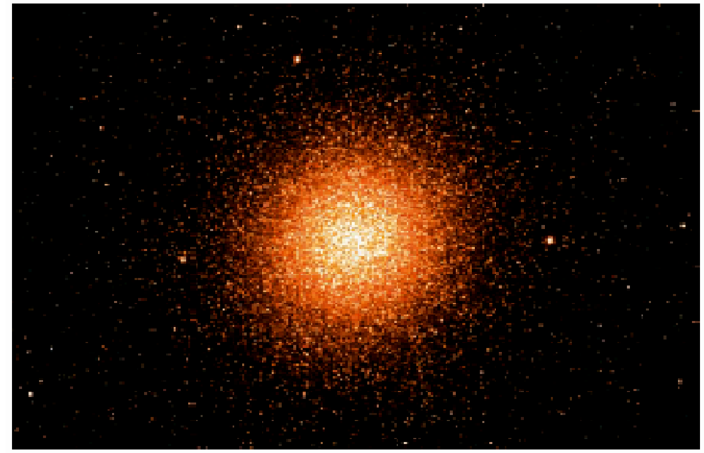
Globular clusters→ Spherical and found away from the Milky-Way plane.

Contains up to million of stars, spread out over about 50 pc.

Omega Centauri, right figure →

Lack of upper-main sequence stars, no stars greater than 0.8 M⊙, O- through F-type exhausted their nuclear fuel and disappeared.

Most stars are at least 10 billion years old. Oldest known stars in our Galaxy.



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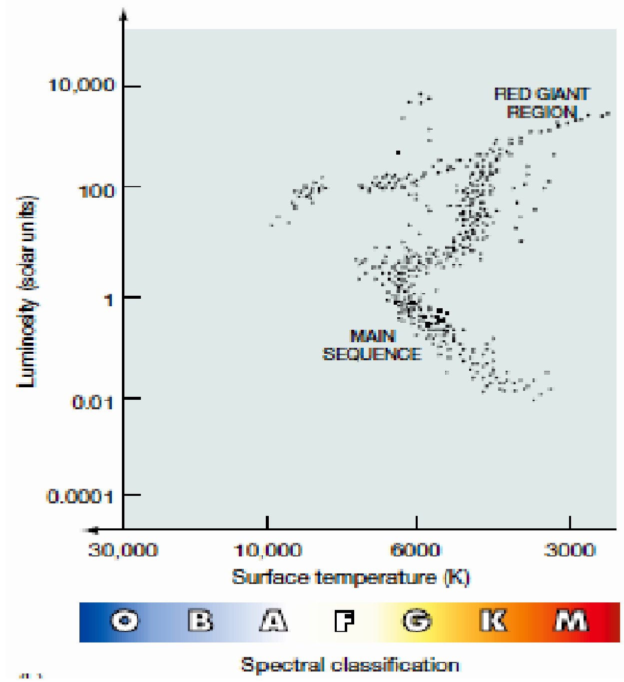

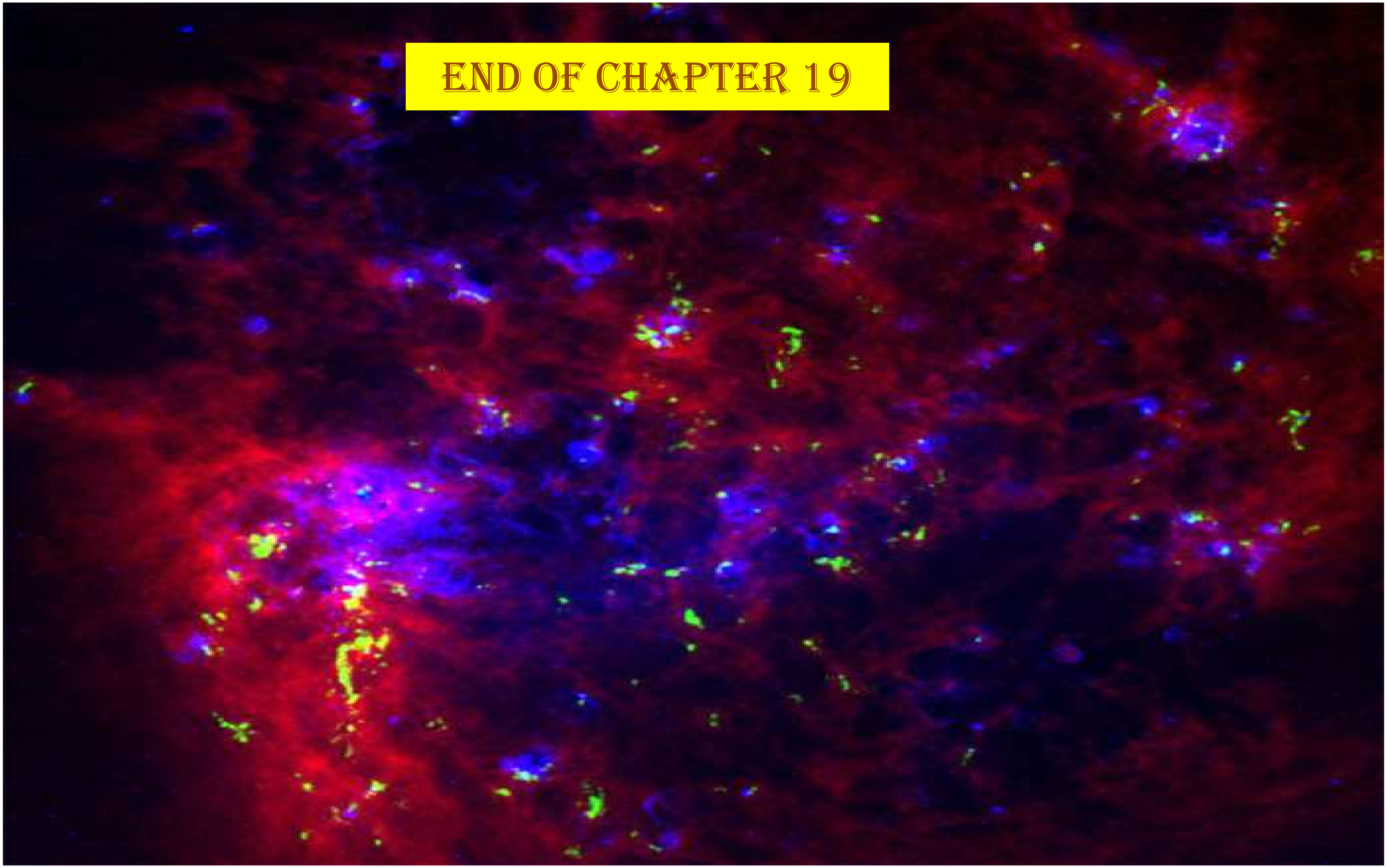
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