Chapter 19:
Star Formation

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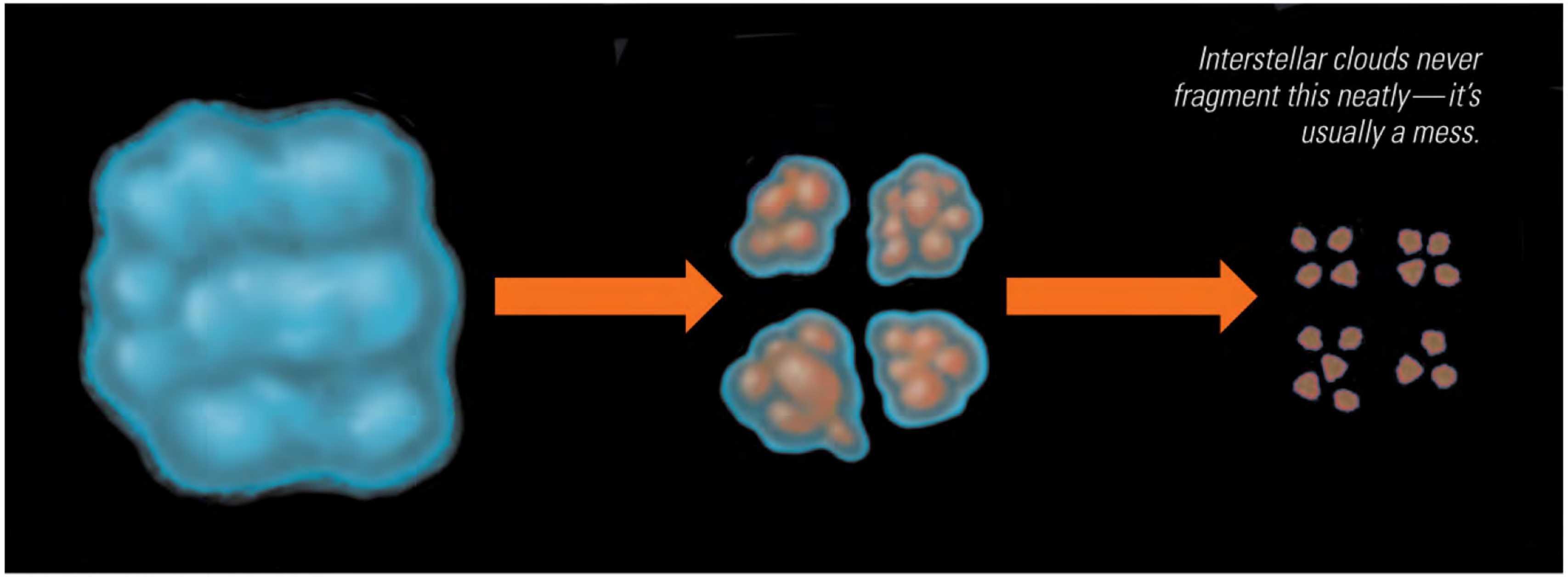
Stages of Stellar Evolution

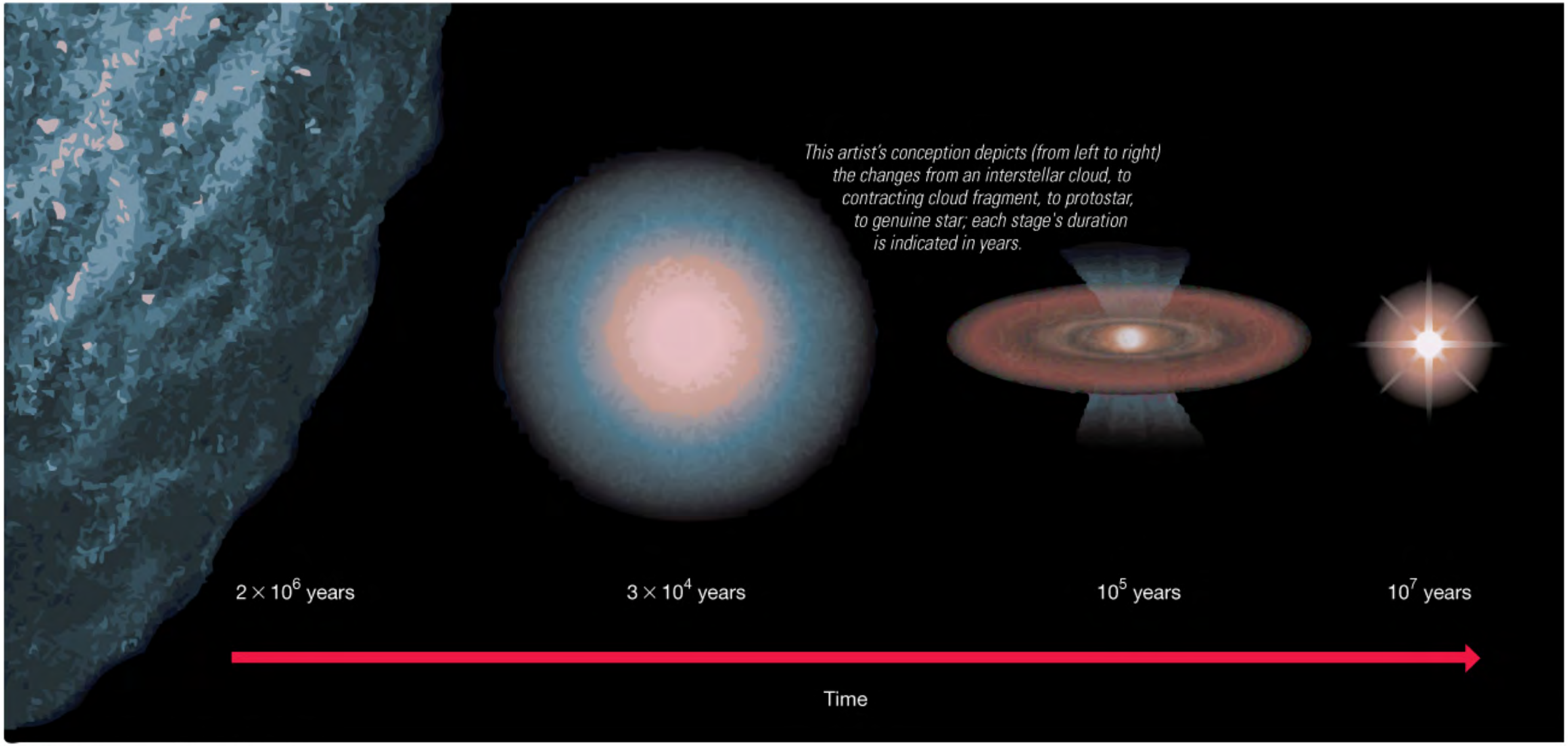
1. **Gas cloud**: at this point, what will eventually become our star is just a cloud of gaseous interstellar medium.
2. **Protostar**: this is a gas cloud that has started pulling itself together, accumulating more and more mass
3. **Pre-main sequence star**: a star that has stopped accumulating mass and has reached equilibrium and begins to burn hydrogen
4. **Main sequence star**: a “healthy” star
5. **Post-main sequence stars**: when “healthy” stars run out of hydrogen to burn, they depart the main sequence (typically as giants), and undergo further evolution dictated by their mass

Gas Clouds and Fragmentation

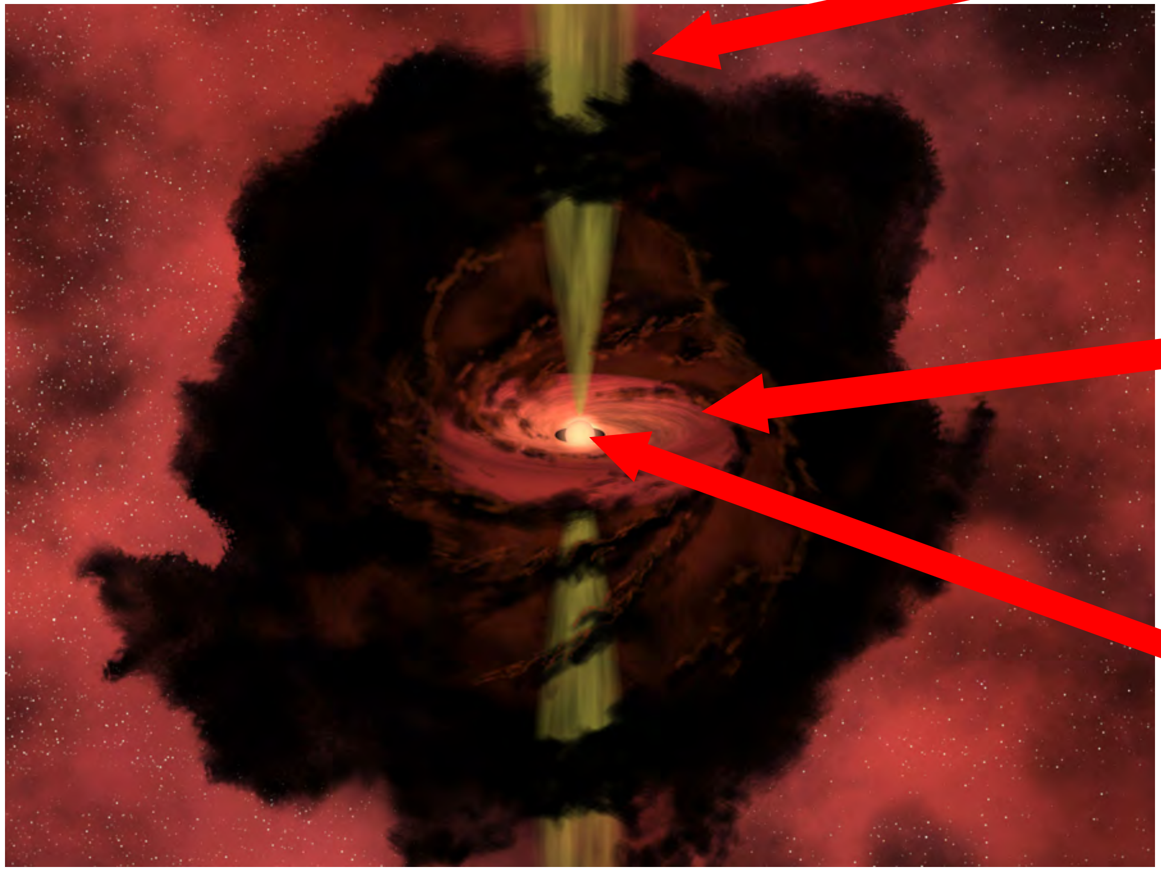
Gas clouds are huge, producing many, many individual stars through the process of **fragmentation**. These fragments become protostars.



Protostar Formation



Protostar Structure



Jet

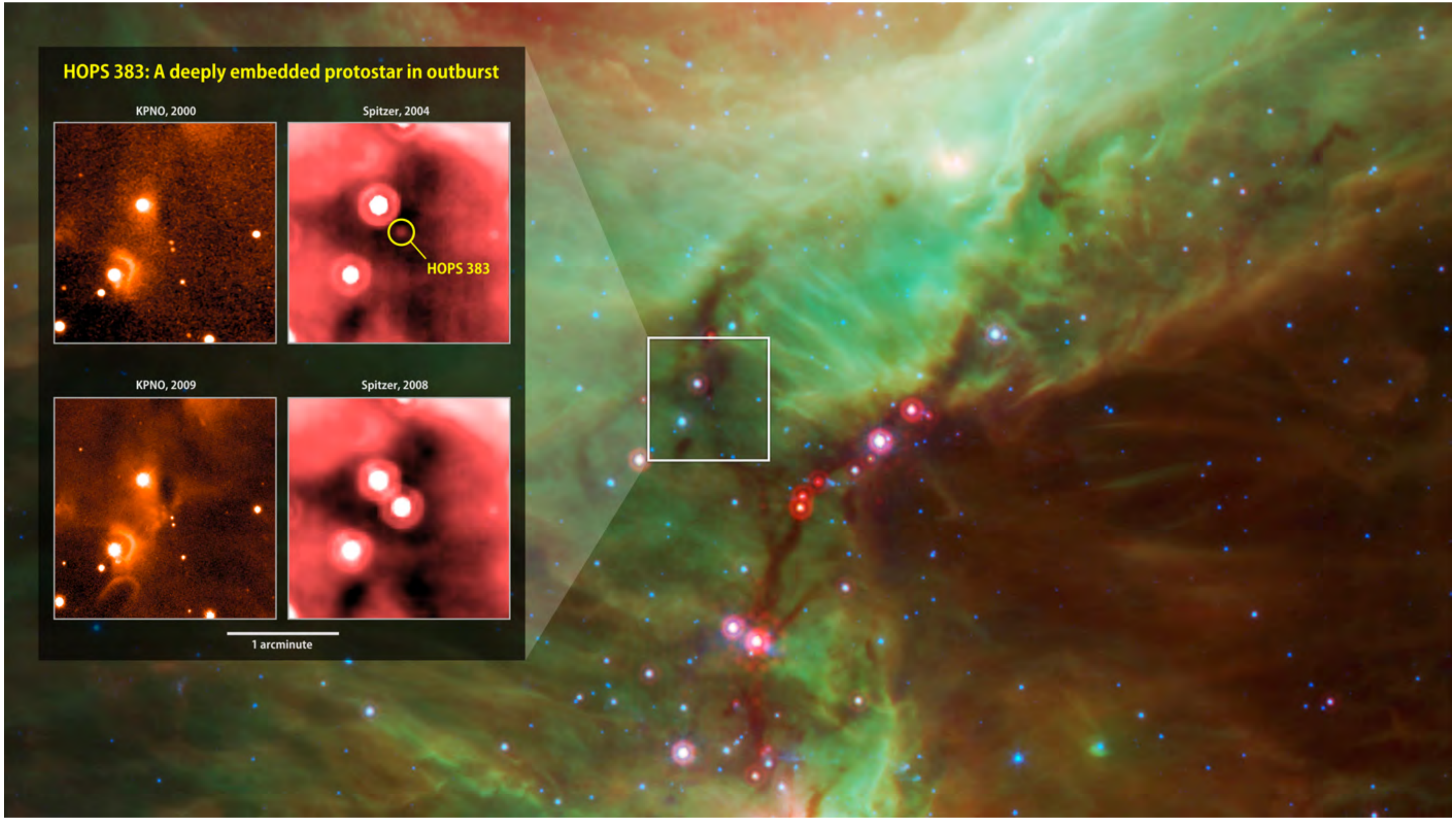
(Protostars are very unstable, and tend to produce much more powerful stellar winds. These form jets. The jet itself can trigger more star formation.)

Accretion disk

(The gas nearest the core falls in very fast, but gas farther away falls in much more slowly. This is known as accretion. Planets often form in the accretion disk.)

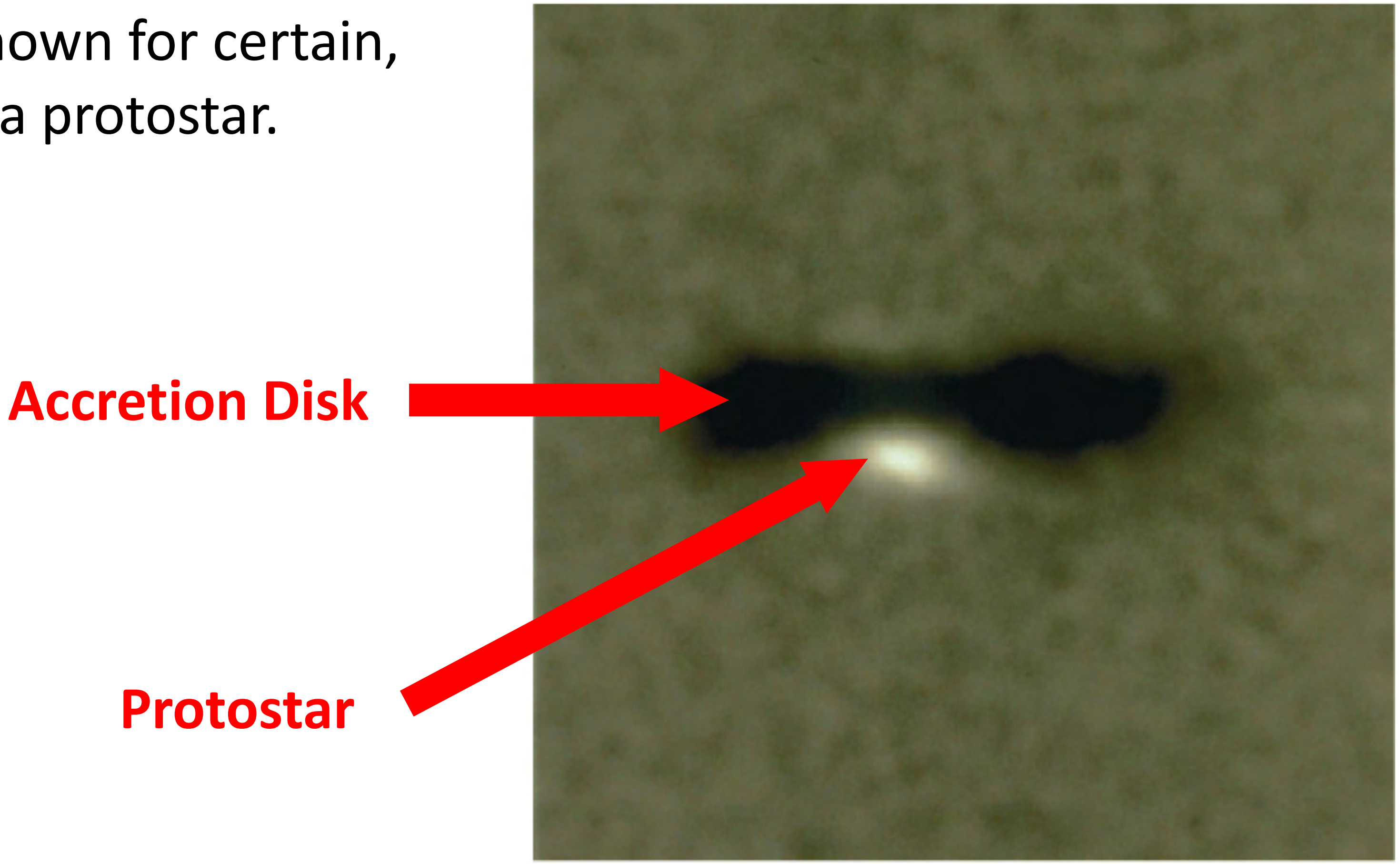
Protostar

Direct Observation of Protostar Formation



Direct Observation of Protostar (?)

It is thought, but not known for certain, that this is an image of a protostar.



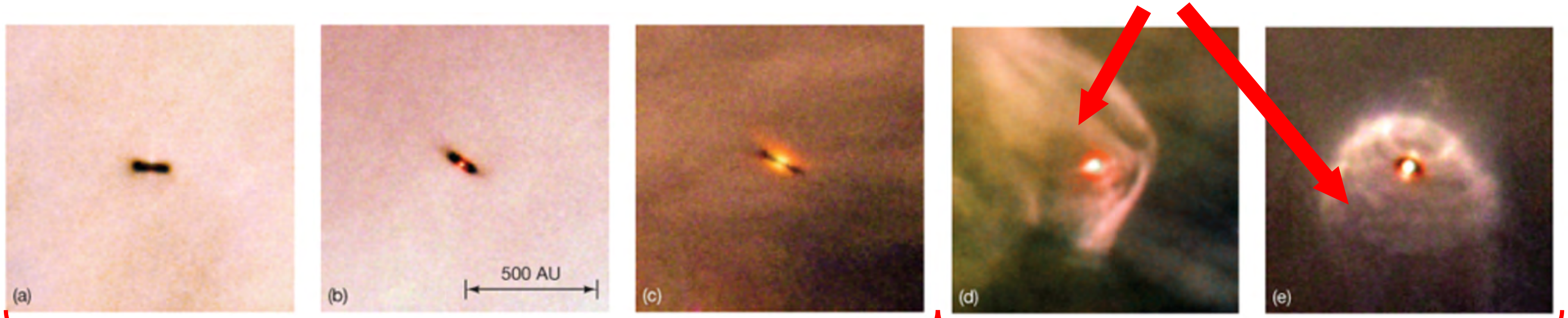
Protostar to Pre-Main Sequence Star

- Protostars are still accreting mass, and are unstable, rapidly changing size and temperature with the added mass.
- As the protostar compresses to a small enough size, the temperature becomes large enough to burn hydrogen. The protostar has now become a pre-main sequence star.
- However, now that hydrogen is burning, there is a “fight” between gravitational pressure inward and thermal pressure outward, causing the star to (more slowly) adjust its size and temperature.
- Once it’s “happy,” it becomes a main sequence star.

Loss of Accretion Disk

- As a protostar becomes a pre-main sequence star, it begins to emit a spherical stellar wind, like the Sun emits its solar wind.
- This stellar wind blows the accretion disk away from the pre-main sequence star, leaving a small ball of gas much like a normal star.

Asymmetrical accretion disk is due to stellar wind

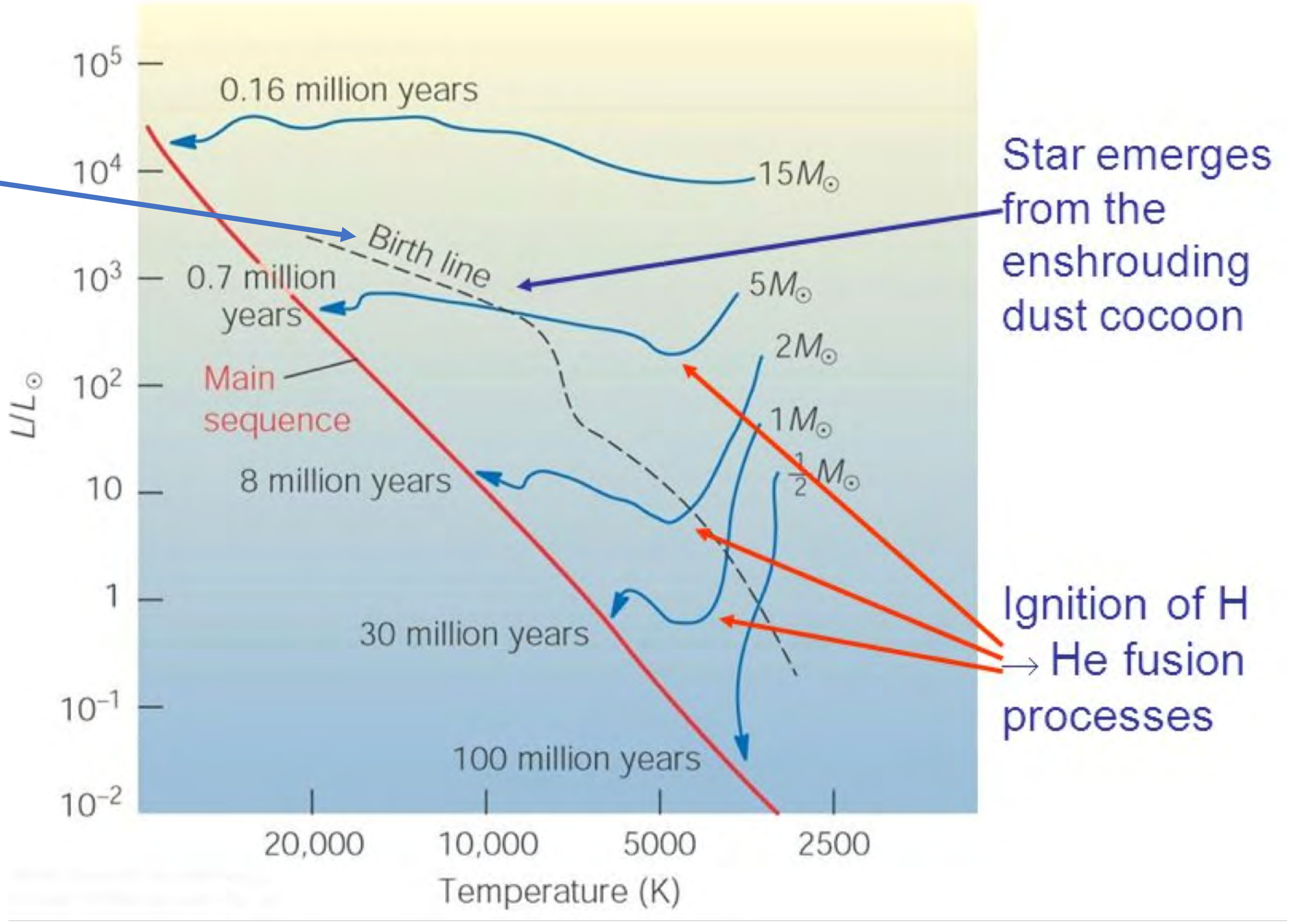


Protostars viewed edge-on

Protostars viewed face-on

HR Diagram of Stellar Birth

The birth line marks the point at which the star stops accumulating gas. This is where protostars become pre-main sequence stars.



Timeline of Stellar Birth

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
3	10^5	10,000	100	10^{18}	10^{10}	Cloud fragment/protostar
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

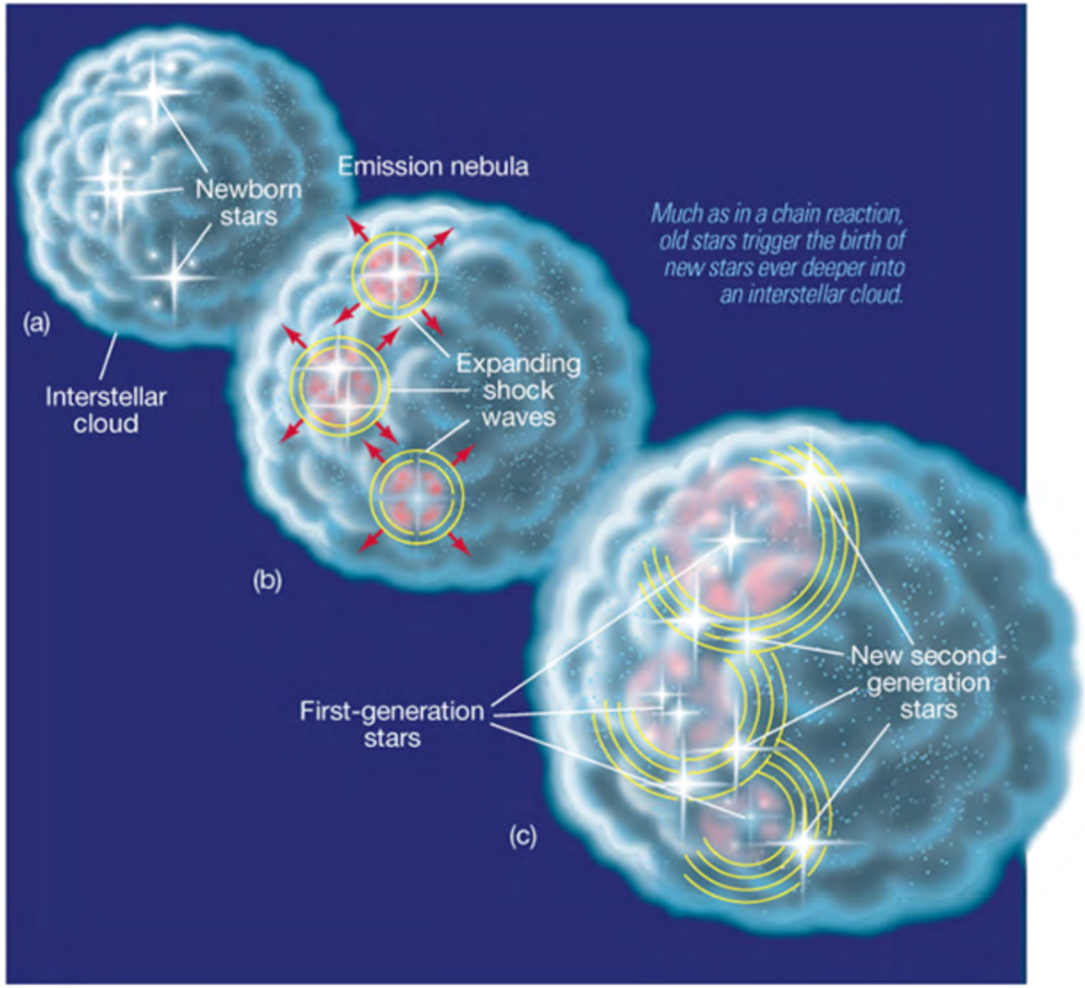
*Round numbers; for comparison, recall that the diameter of the Sun is 1.4×10^6 km, whereas that of the solar system is roughly 1.5×10^{10} km.

No fusion (T < 14 MK)

Hydrogen fusion begins

Conditions for Stellar Birth

- Stars are born when gas can fragment, i.e. when something disrupts a typical, homogeneous gas cloud.
- The most common disturbance is a shock wave within the gas cloud.
  - This will cause the density of the cloud to be maximum at the peaks and troughs of the wave, while density is at a minimum between.
  - These waves are typically produced by **stellar explosions**, a process in the death of a star, which produces very energetic shocks, typically within gas clouds.



Nebulae are Perfect for Stellar Formation

Diffuse red color is the gas that makes up the nebula.

Blue dots are all stars being born. Each dot is a different star.

Brown Dwarfs

- A pre-main sequence star whose mass is too small (less than $0.1M_{\odot}$) don’t have enough gravitational pull to compress itself enough to reach that 14 MK temperature needed for fusion.
- These stars remain cold and very dim, thus hard to see. They weren’t first observed until the late-1980s/early-1990s.
- They are “planet-like,” with stable amounts of hydrogen and helium.

Life on the Main Sequence

TABLE 17.6 Key Properties of Some Well-Known Main-Sequence Stars

Star	Spectral Type	Mass, *M* (Solar Masses)	Central Temperature (10^6 K)	Luminosity, *L* (Solar Luminosities)	Estimated Lifetime (*M*/*L*) (10^6 years)
Spica B*	B2V	6.8	25	800	90
Vega	A0V	2.6	21	50	500
Sirius	A1V	2.1	20	22	1000
Alpha Centauri	G2V	1.1	17	1.6	7000
Sun	G2V	1.0	15	1.0	10,000
Proxima Centauri	M5V	0.1	0.6	0.00006	16,000,000

**The "star" Spica is, in fact, a binary system comprising a B1III giant primary (Spica A) and a B2V main-sequence secondary (Spica B).*