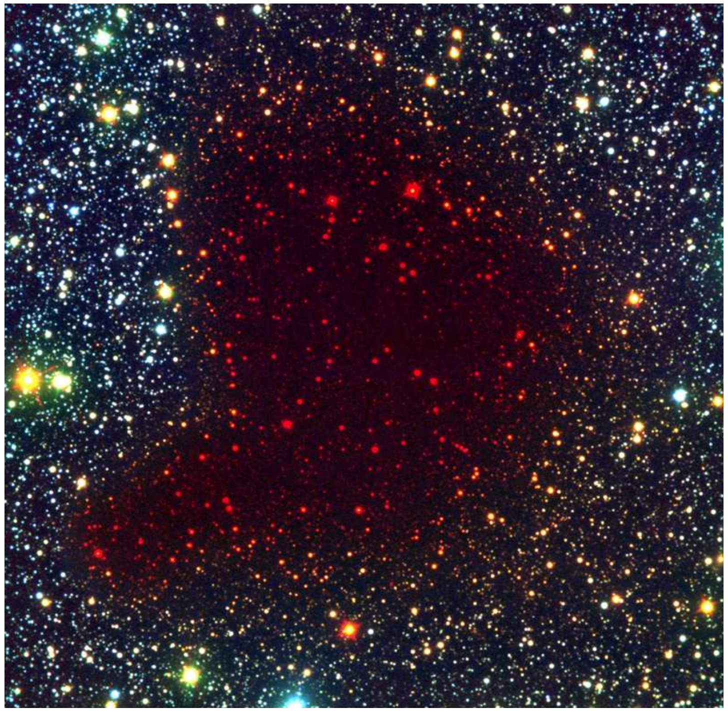
Stars: Formation

Optical View of B68 (ESO; VLT/FORS1)



IR View of B68 (ESO; VLT/FORS1 + NTT/SOFI)

Stellar Birth

Stars are born in "Giant Molecular Clouds"

Typical GMC parameters (e.g., Orion):

- large clouds: typical diameters 50–100 pc
- contain lots of molecular gas (H_2, CO, alcohol,. . .).
- typical temperatures: 10–20 K (coolest regions in the interstellar medium)
- typical particle densities $n \sim 10^6$–$10^{10}\,\mathrm{cm}^{-3}$

Stars are born in groups out of collapsing Molecular Clouds.

Collapse triggered, e.g., by collisions of clouds or shocks caused by nearby supernovae.

Stellar Birth

Criterion for collapse: Cloud is instable, i.e., gravitation is stronger than thermal pressure.

In terms of thermal and gravitational energies, this means

$$\frac{3}{2}\frac{M}{m_{\rm p}}kT - \frac{3}{5}\frac{GM^2}{R} \le 0 \tag{8.1}$$

which can be expressed as

$$\frac{M}{R} \ge \frac{5}{2}\frac{kT}{Gm_{\rm p}} \quad \text{or} \quad \frac{4\pi}{3}\rho R^2 \ge \frac{5}{2}\frac{kT}{Gm_{\rm p}} \tag{8.2}$$

$\Longrightarrow$ Depends on R, collapse thus possible for

$$R > R_{\rm J} = \sqrt{\frac{15kT}{8\pi Gm_{\rm p}\rho}} \sim \sqrt{\frac{kT}{Gm_{\rm p}\rho}} \tag{8.3}$$

where $R_{\rm J}$ is called the Jeans radius.

Stellar Birth

Plugging in typical numbers, i.e., $T \sim 50\,\mathrm{K}$, particle density $n = 10^5$ H-atoms cm^{-3} (=a mass density of $\rho = nm_{\rm p} \sim 1.7\times10^{-9}\,\mathrm{g\,cm^{-3}}$) gives $R_{\rm J} \sim 0.2\,\mathrm{pc}$.

For a given Jeans radius, the mass within $R_{\rm J}$ is the Jeans mass

$$M_{\rm J} \sim \frac{4\pi}{3}R_{\rm J}^3\rho$$

. . . which has typical values of 50–100 $M_\odot$, i.e., larger than one star!

In reality things are more complicated: ISM contains magnetic fields

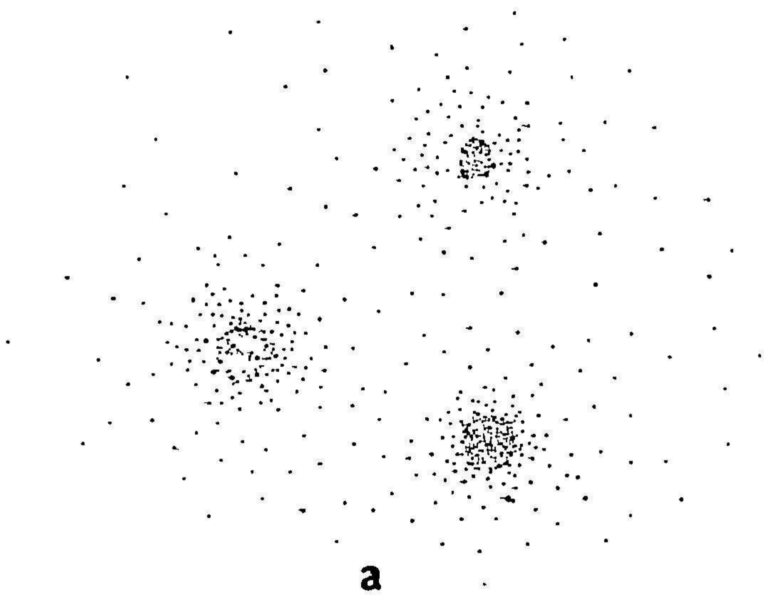
$\Longrightarrow$ Particle motion $\perp$ B-field lines difficult

$\Longrightarrow$ stops gas from collapsing.

This is good since Jeans formalism alone predicts too strong star formation.

$\Longrightarrow$ Need star formation with magnetic fields

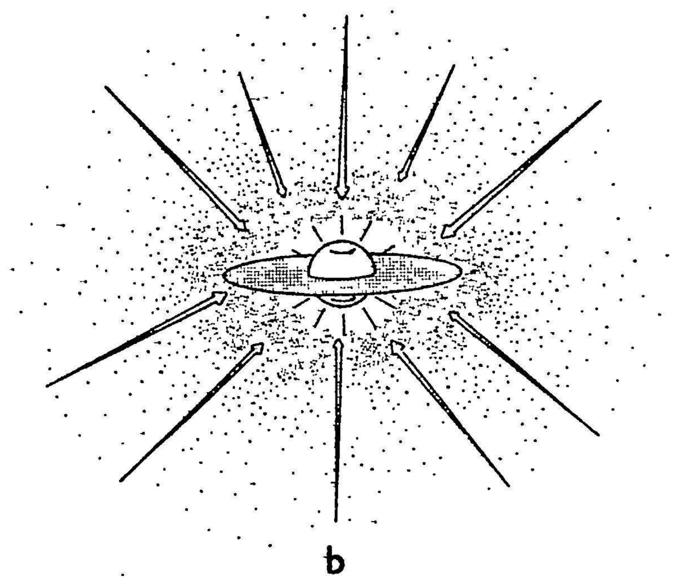
See Shu et al. (1987, Annual Reviews of Astronomy and Astrophysics 25, 23) for the gory details.



Shu et al. (1987, ARAA 25, 23, Fig. 7)

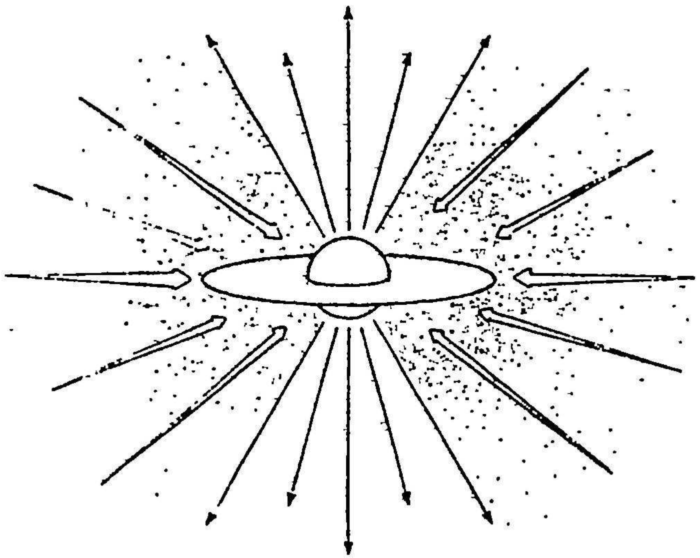
Stellar mass cores form from fragmentation of larger pieces.

Note: fragmentation only along B-field lines.



Shu et al. (1987, ARAA 25, 23, Fig. 7)

Protostar forms with surrounding disk (“inside out collapse”) once core hot enough to allow fusion ($T > 10^6$ K)



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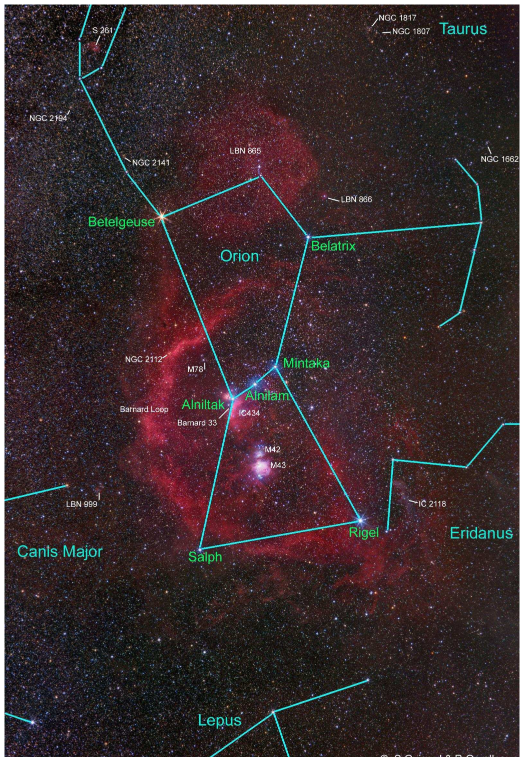
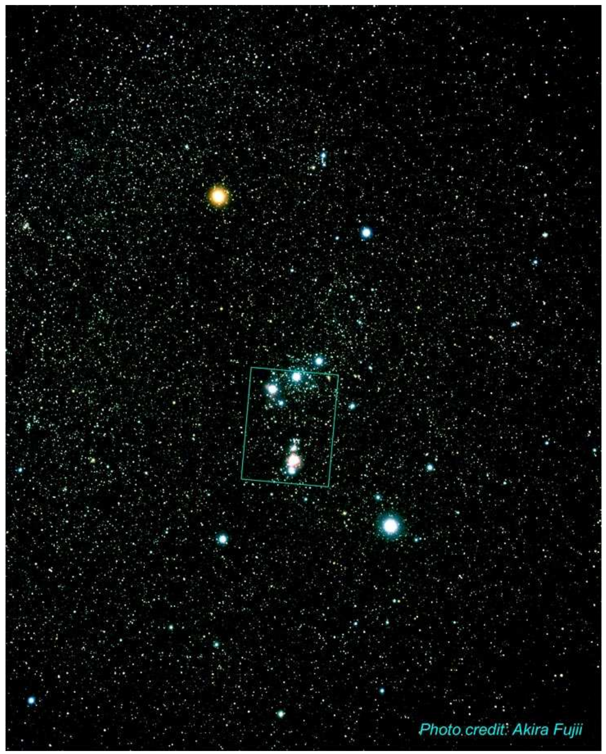
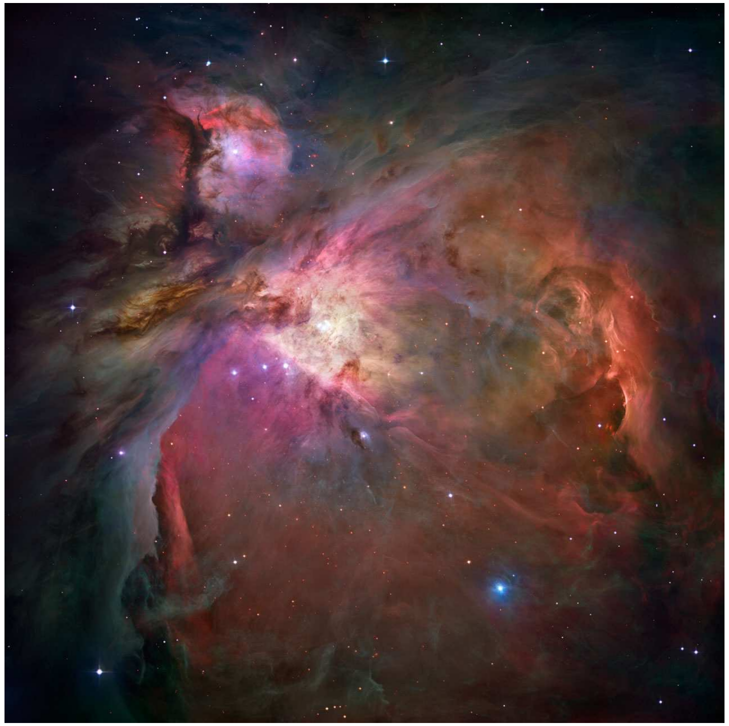
Shu et al. (1987, ARAA 25, 23, Fig. 7)

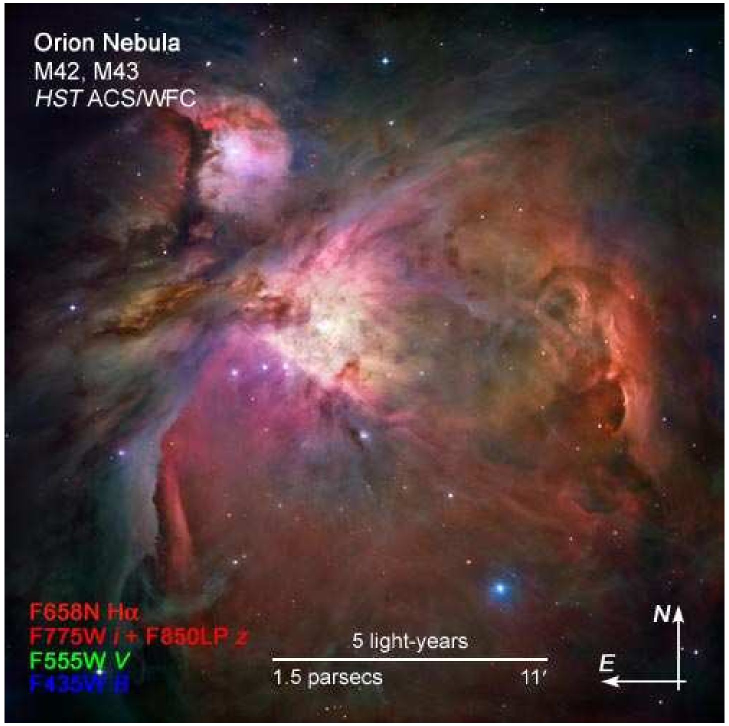
Stellar wind forms bipolar outflow

Orion (Bayer's Uranometria; image ©USNO)



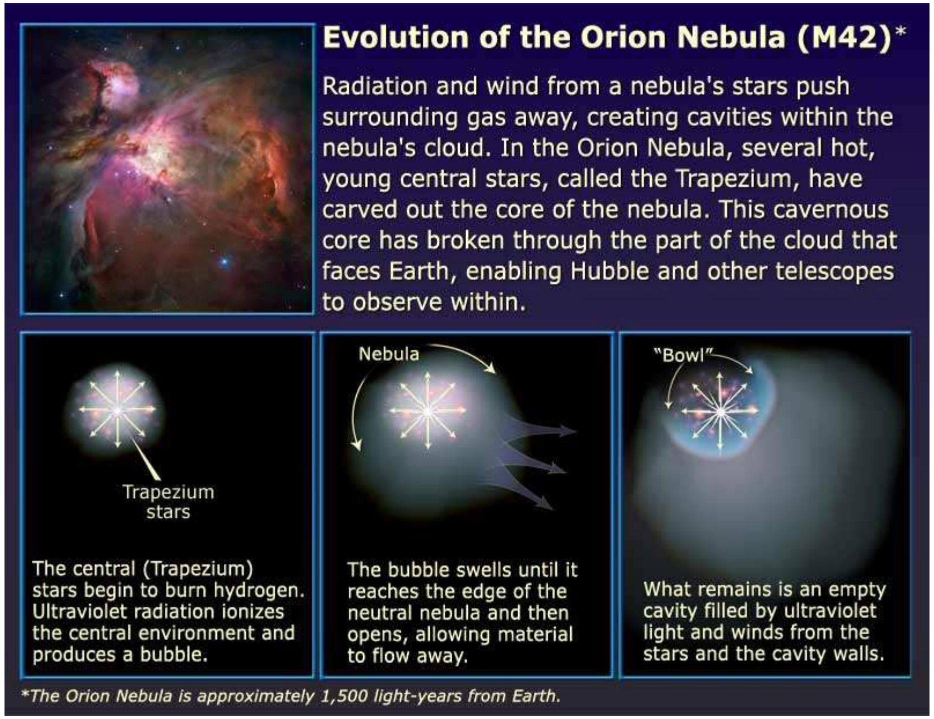






Orion Nebula; R. Gendler

Orion Nebula; R. Croman



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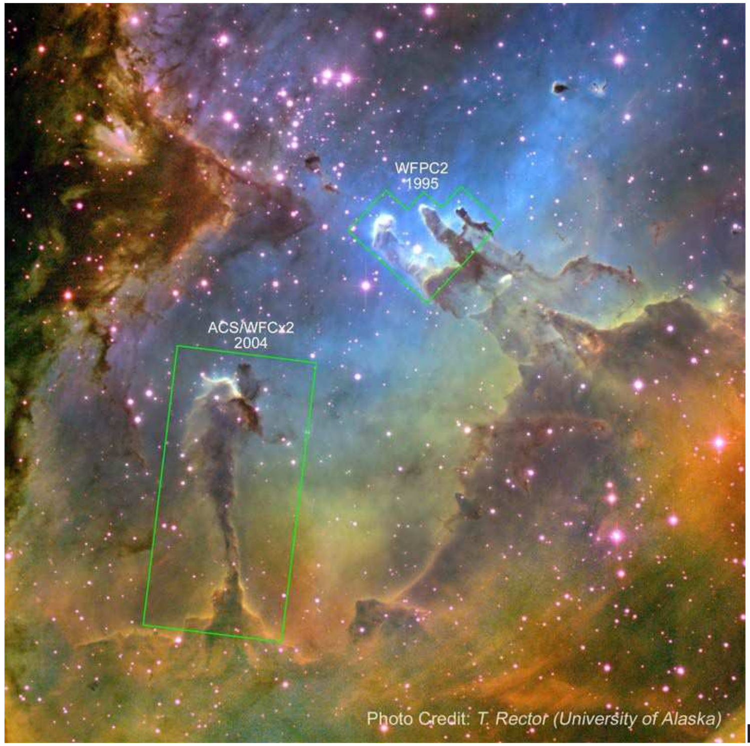
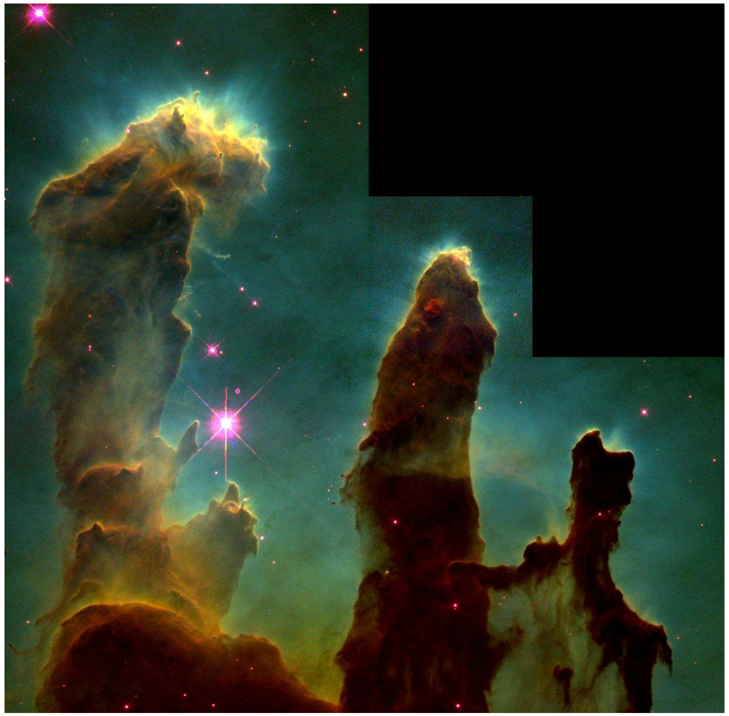
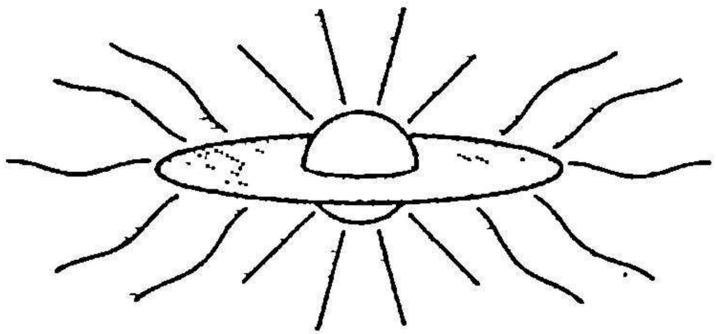


Eagle-nebula (M16)



"pillars of creation" in Eagle Nebula (M16)



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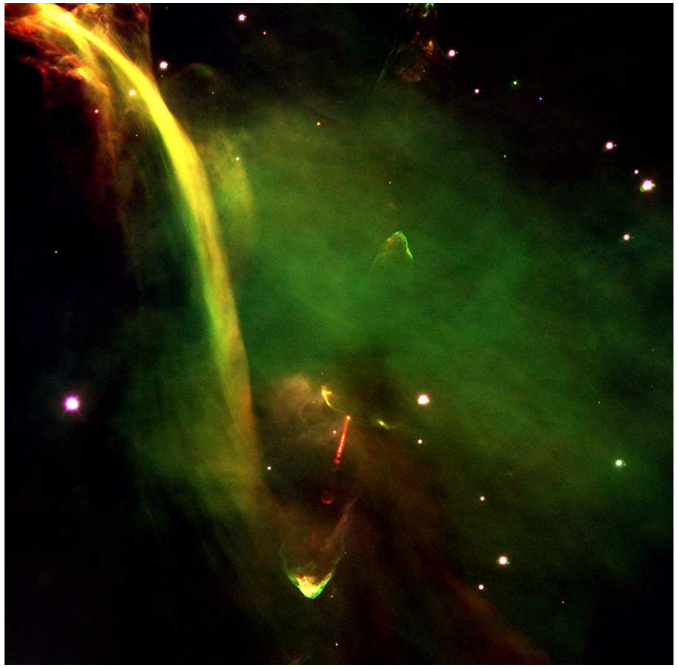
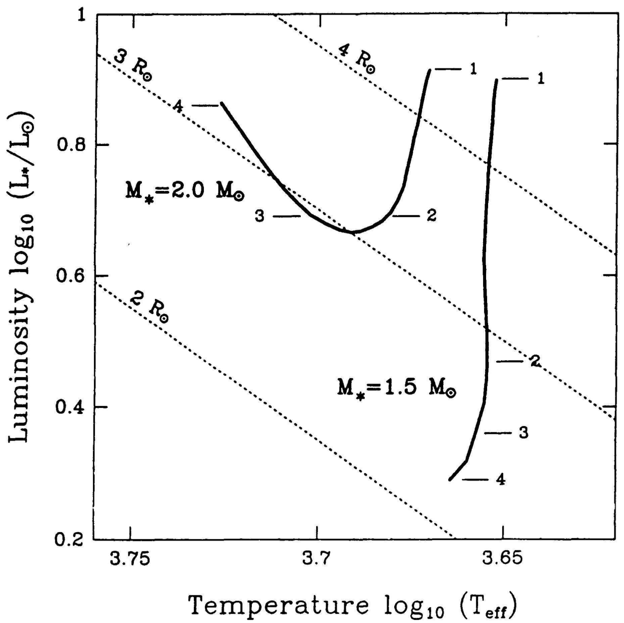
Shu et al. (1987, ARAA 25, 23, Fig. 7)

Star has reached zero age main sequence (ZAMS) plus circumstellar disk.
Some disks produce fast collimated outflows (jets): Herbig Haro Objects



HH34 in Orion (ESO VLT KUEYEN/FORS2)

Herbig Haro Objects: shocks and jets/outflows produced during formation of stars.



Palla & Stahler (1993, ApJ 418, 414; numbers are time in 10^6 years)

Stellar Evolution from protostar to ZAMS takes a few million years.

Pleiades (R. Gendler; $d = 150$ pc, diameter: 5 pc, 3000 stars

Once stars have formed, strong UV radiation removes residual dust (still seen as a reflection nebula) and an open cluster is formed.

Zero Age Main Sequence

Once star has collapsed and nuclear fusion has started: zero age main sequence (ZAMS) is reached

The Main Sequence is the result of steady state fusion (“burning”) of hydrogen into helium in stellar centers.

. . . longest phase of stellar evolution (10 billion years for Sun)

Stellar structure defined by balance between pressure inwards due to gravitation and pressure outwards due to energy release (“hydrostatic equilibrium”).