

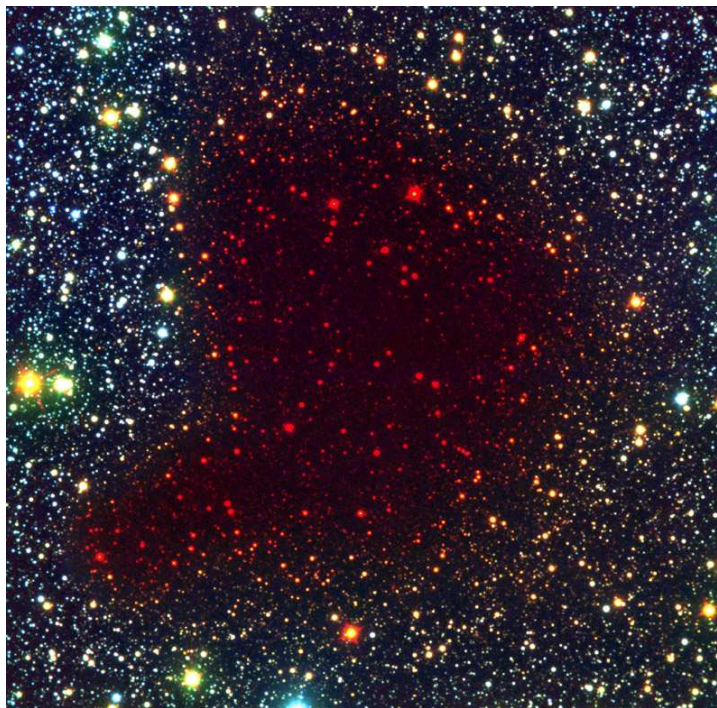


8-1

Stars: Formation



Optical View of B68 (ESO; VLT/FORS1)



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



8-4

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 $n \sim 10^6\text{--}10^{10} \text{ cm}^{-3}$

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

$$\frac{3}{2} \frac{M}{m_p} kT - \frac{3}{5} \frac{GM^2}{R} \leq 0 \quad (8.1)$$

which can be expressed as

$$\frac{M}{R} \geq \frac{5}{2} \frac{kT}{Gm_p} \quad \text{or} \quad \frac{4\pi}{3} \rho R^2 \geq \frac{5}{2} \frac{kT}{Gm_p} \quad (8.2)$$

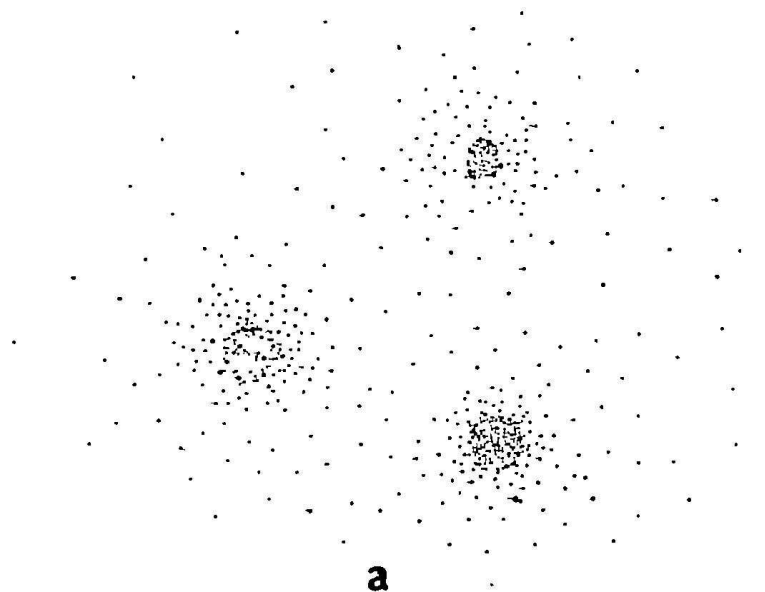
⇒ Depends on R , collapse thus possible for

$$R > R_J = \sqrt{\frac{15kT}{8\pi Gm_p\rho}} \sim \sqrt{\frac{kT}{Gm_p\rho}} \quad (8.3)$$

where R_J is called the Jeans radius.

Stellar Birth

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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.



Stellar Birth

Plugging in typical numbers, i.e., $T \sim 50$ K, particle density $n = 10^5$ H-atoms cm^{-3} (=a mass density of $\rho = nm_p \sim 1.7 \times 10^{-9} \text{ g cm}^{-3}$) gives $R_J \sim 0.2$ pc.

For a given Jeans radius, the mass within R_J is the Jeans mass

$$M_J \sim \frac{4\pi}{3} R_J^3 \rho$$

... 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

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

⇒ stops gas from collapsing.

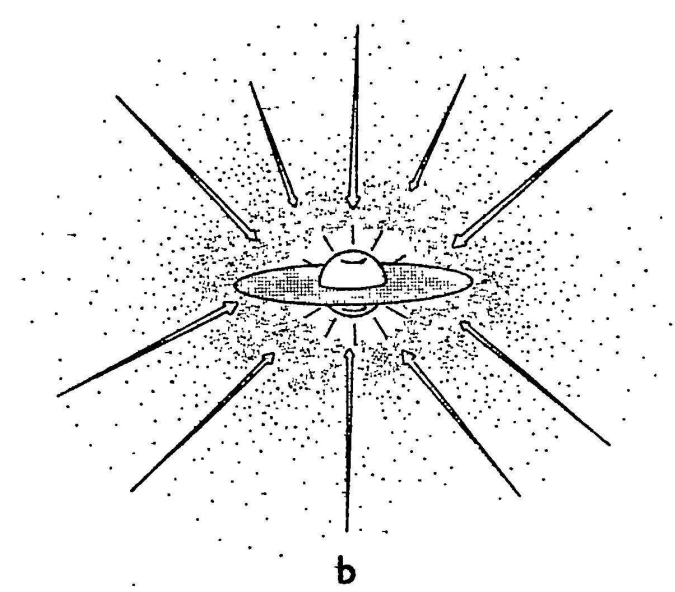
This is good since Jeans formalism alone predicts too strong star formation.

⇒ Need star formation with magnetic fields

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

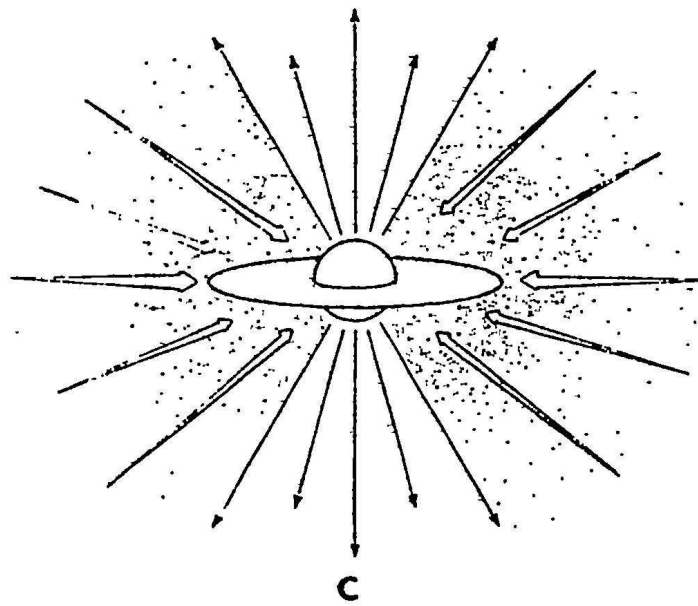
Stellar Birth

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

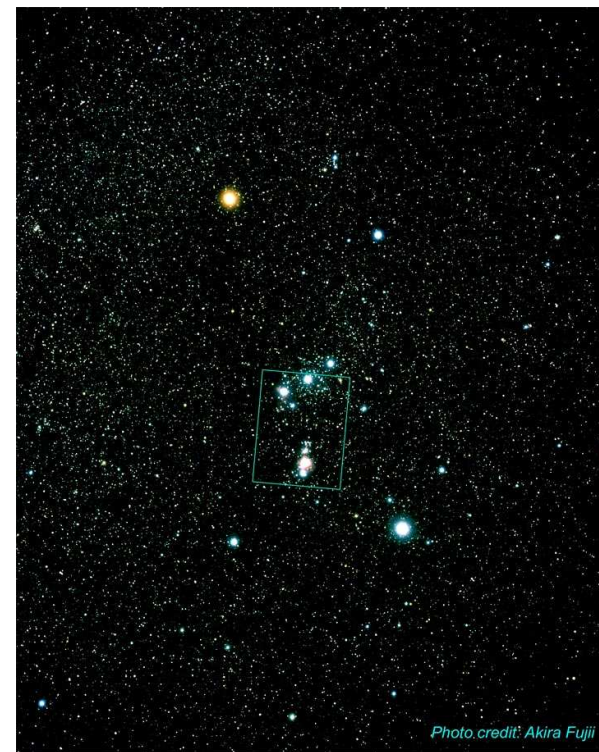
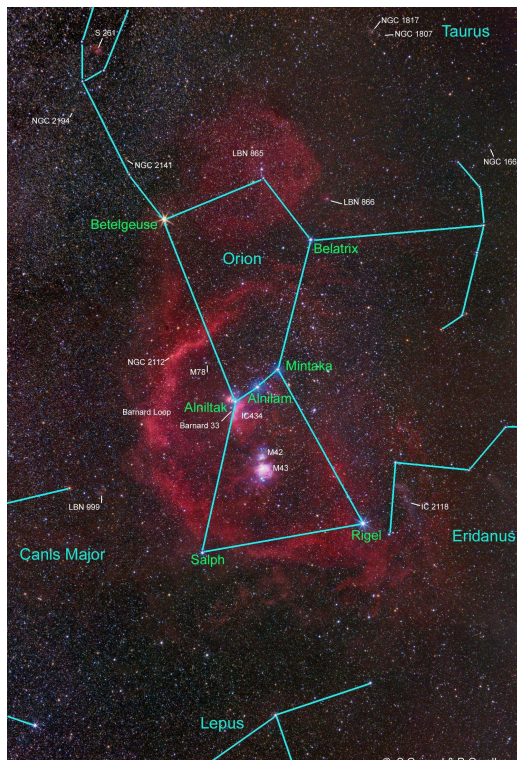
Protostar forms with surrounding disk ("inside out collapse") once core hot enough to allow fusion ($T > 10^6$ K)

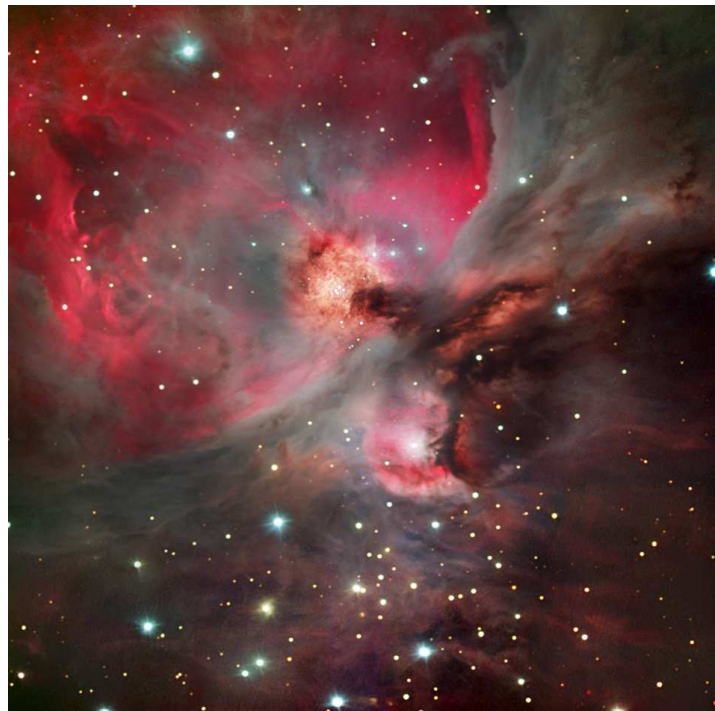
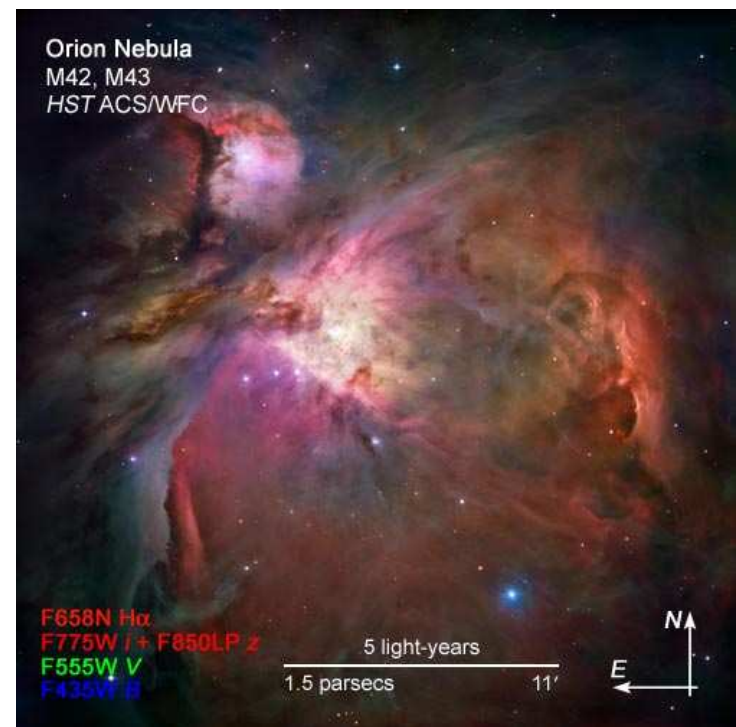
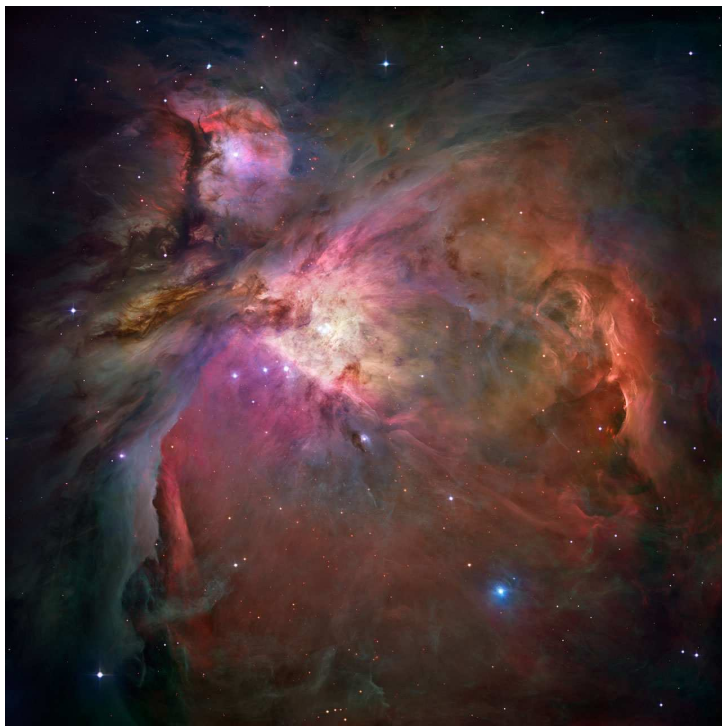


Shu et al. (1987, ARAA 25, 23, Fig. 7)
Stellar wind forms bipolar outflow



Orion (Bayer's Uranometria; image ©USNO)



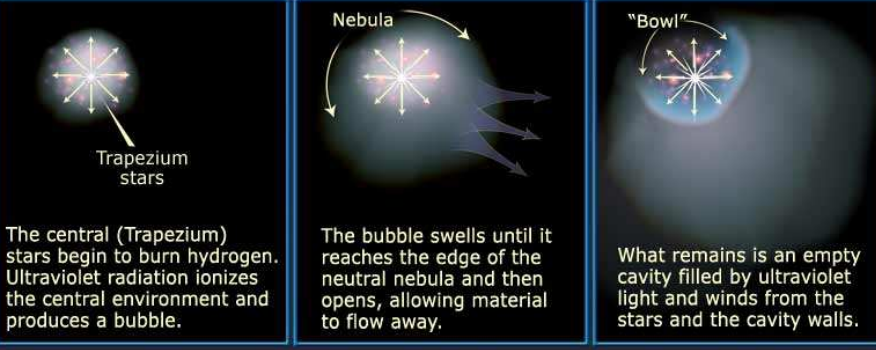


Orion Nebula; R. Gendler



Orion Nebula; R. Croman

Evolution of the Orion Nebula (M42)*



Radiation and wind from a nebula's stars push surrounding gas away, creating cavities within the nebula's cloud. In the Orion Nebula, several hot, young central stars, called the Trapezium, have carved out the core of the nebula. This cavernous core has broken through the part of the cloud that faces Earth, enabling Hubble and other telescopes to observe within.

Trapezium stars

The central (Trapezium) stars begin to burn hydrogen. Ultraviolet radiation ionizes the central environment and produces a bubble.

Nebula

The bubble swells until it reaches the edge of the neutral nebula and then opens, allowing material to flow away.

"Bowl"

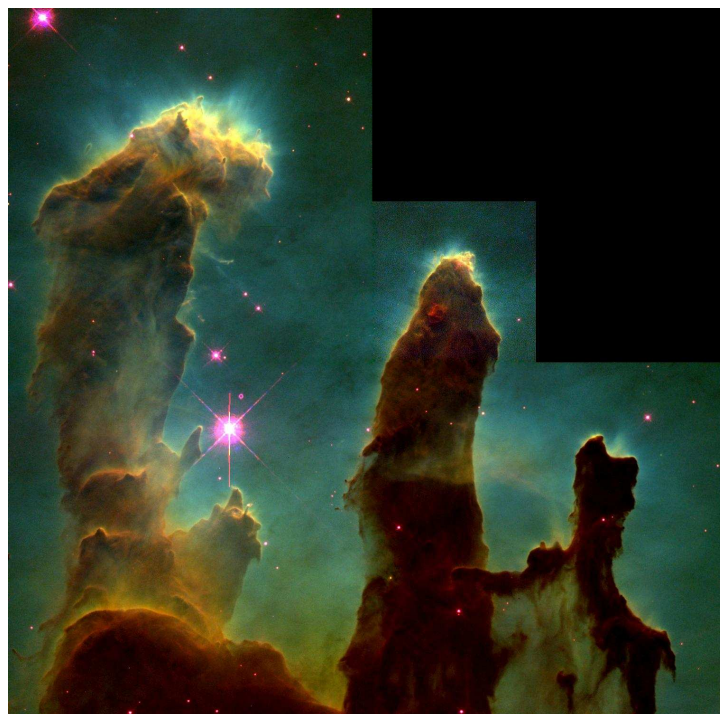
What remains is an empty cavity filled by ultraviolet light and winds from the stars and the cavity walls.

*The Orion Nebula is approximately 1,500 light-years from Earth.

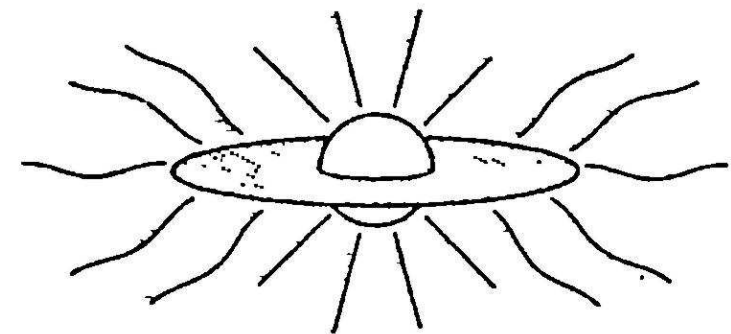
STScI



Eagle-nebula (M16)



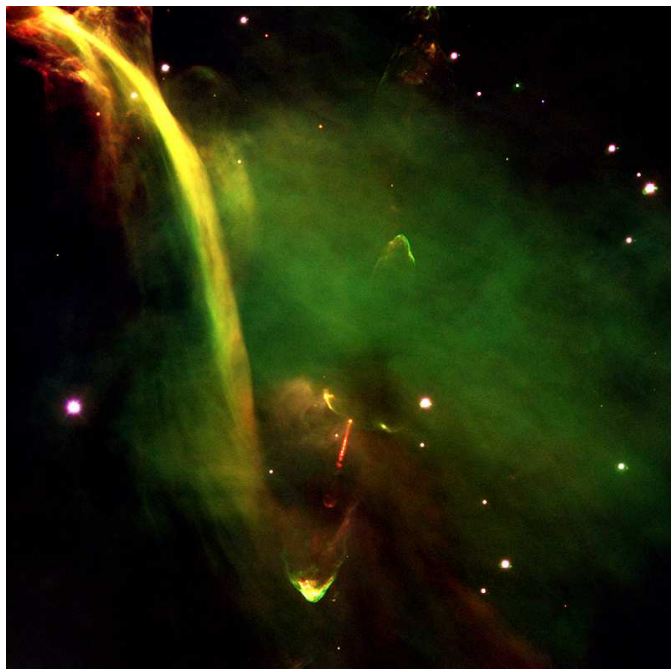
"pillars of creation" in Eagle Nebula (M16)



d

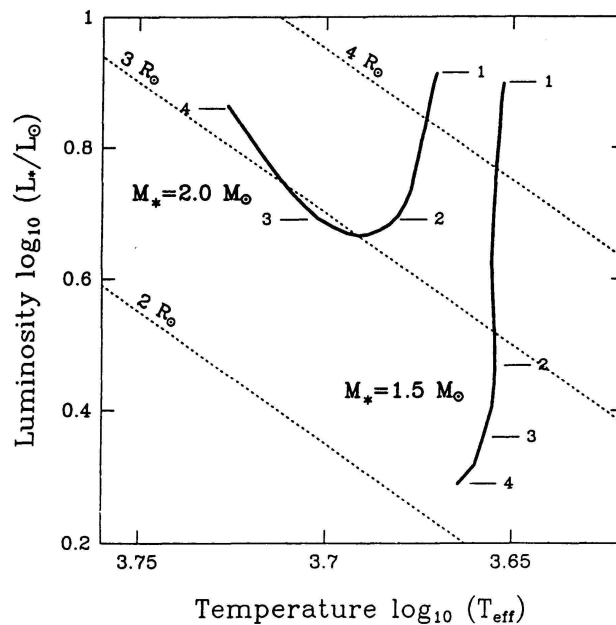
Shu et al. (1987, ARAA 25, 23, Fig. 7)

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

8-24

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").