Polytropic models of filamentary molecular clouds

I - Structure and stability & II - Helical magnetic field

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Sub-structure formation in starless cores

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Introduction

Recent observations made by the Herschel Space Observatory and the Planck Satellite have shown that molecular clouds are made by networks of filaments, shaped by interstellar turbulence and magnetic fields. We analyse the stability of filamentary molecular clouds with the help of cylindrical polytropic models with and without helical magnetic fields. We then focused on the growth of hydrodynamical density perturbations and the formation of sub-structures and fragments in pre-stellar cores.

How to model your filament:

The density profile ρ in the radial direction can be characterised by:

- flat density ρ_c inner part of size $\varpi_{flat} = (0.03\pm0.02)$ pc
- power law envelope extending to a radius $\sim 10\ \varpi_{flat}$
- a *softened* power-law profile
- α parameter related to its physical state if α=4 filaments are isothermal

$$\rho(\varpi) = \frac{\rho_c}{[1+(\varpi/\varpi_{\rm flat})^2]^{\alpha/2}},$$

The power-law slope observed with Herschel satellite is $\alpha = (1.6 \pm 0.3)$ [1]:

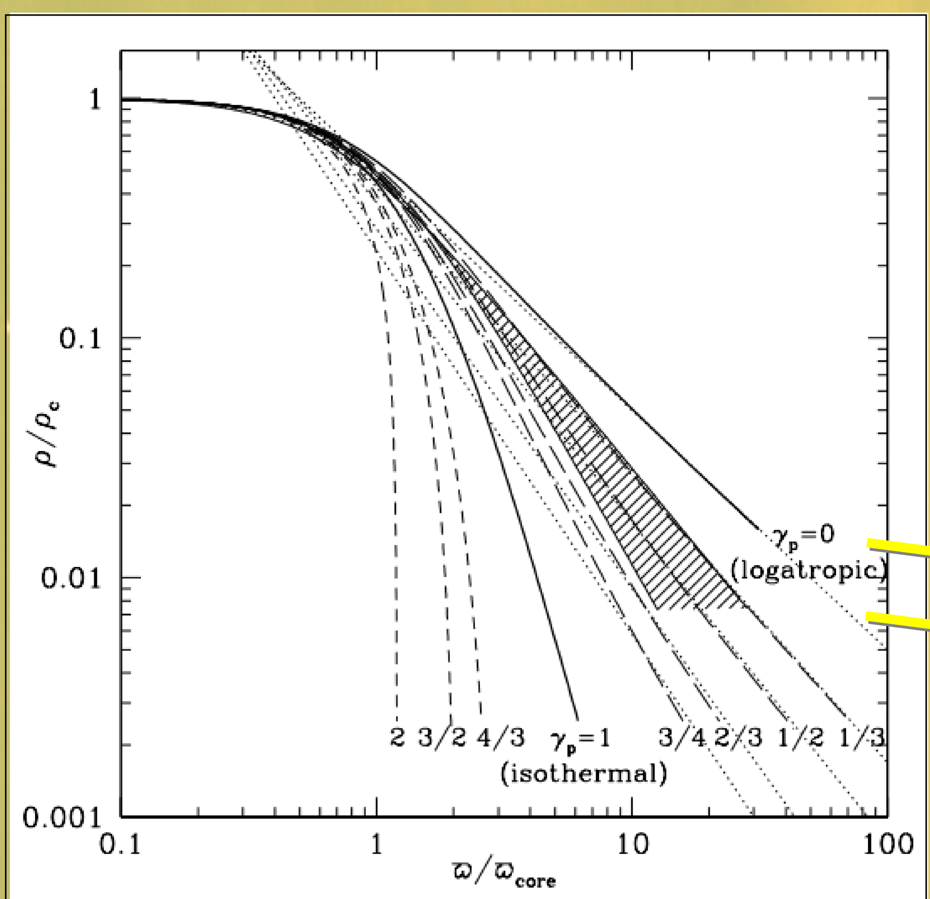
❗ *gas in these filaments obeys a non isothermal equation of state* ❗

❗ Better using polytropic cylinders:

- gas pressure *p* parametrized by a polytropic equation of state
- γ_p polytropic exponent, related to its physical state
- K measure of the filament's entropy

$$p = K\rho^{\gamma_p},$$

Structure of filaments



$$\varpi_{\rm core} \approx 0.047 \left(\frac{\sigma_c}{0.26\ {\rm km\ s^{-1}}}\right)\left(\frac{n_c}{2\times10^4\ {\rm cm^{-3}}}\right)^{-1/2}\ {\rm pc.}$$

σ_c= velocity dispersion of the filament
n_c = central density of the filament

Normalised radial density profiles of polytropic cylinders T&G I[5].

•thick solid lines the are isothermal ($\gamma_p = 1$) and logatropic ($\gamma_p = 0$)
•Dotted lines are the singular solutions (scale - free)
•Hatched area corresponds to the observed mean density profile with $\alpha = (1.6 \pm 0.3)$.

well reproduced by polytropes with **1/3 ≲ γ_p ≲ 2/3**

❗ *support against gravity needed* ❗

Outward increasing temperature gradient	Turbulence
T(surface)=150K ❗ TOO HOT	Stay tuned! *Toci et al. in prep* Magnetic field See next sections

Stability of filaments

- Unstable to longitudinal perturbations i.e. varicose instability [4]
- Stability to radial perturbation determined by solving the equation for radial motion for small perturbation in cylindrical symmetry [3]

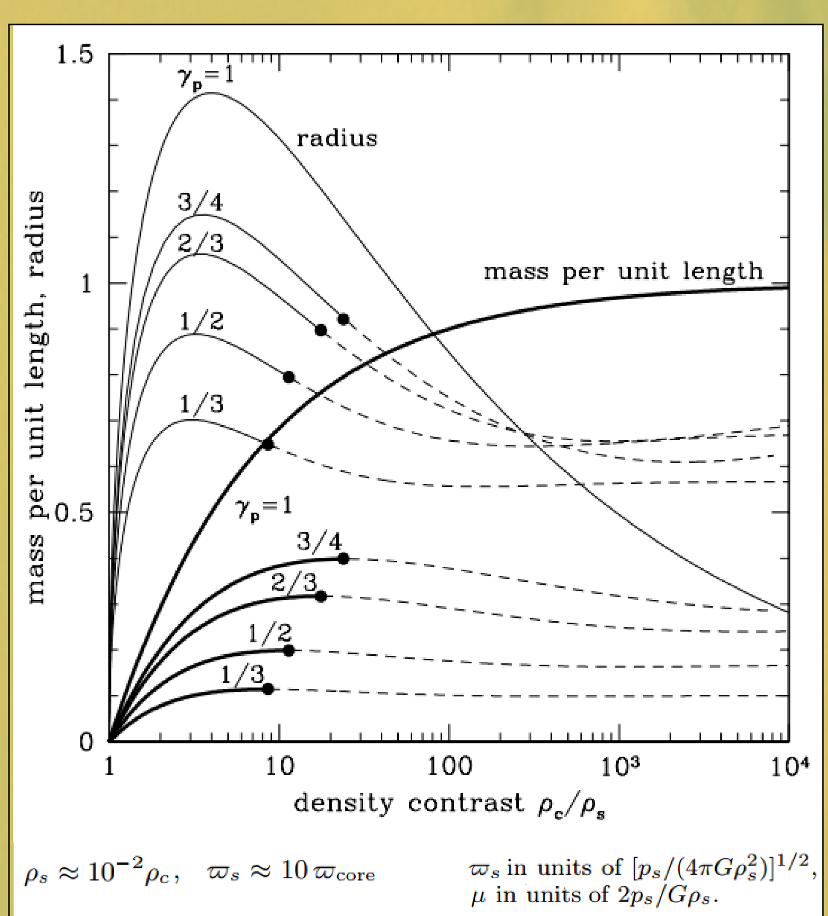
Thick curves: mass per unit length μ
Thin curves radius ϖ_s
as a function of the density contrast.

❗ *Isothermal solution always stable* ❗

- Dots: critical points
- *Stable part*: solid lines
- *Unstable part*: dashed lines

$0 \lesssim \gamma_p < 1$
increasing ρ/ρ_c first expansion then contraction until a critical value.

- Equilibria exist above the critical value but are *unstable* ❗



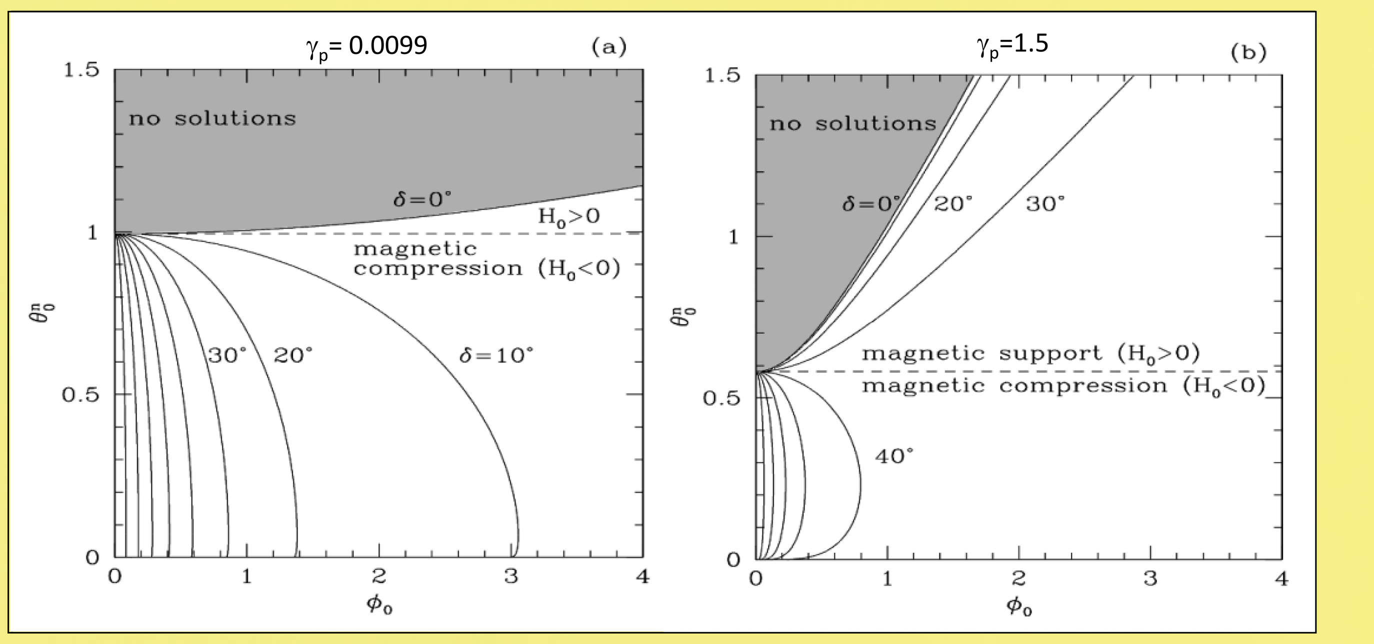
Magnetostatic filaments

The evolution of a real filament can be analysed as a series of polytropic magnetostatic solutions [6]:

- Helical magnetic field with poloidal and toroidal components defined in terms of scalar functions $\Phi(\varpi,z)$ and $\Psi(\varpi,z)$ [4], δ pitch angle :

$$\mathbf{B}_p = \nabla\times\left(\frac{\Phi}{2\pi\varpi}\,\hat{\mathbf{e}}_\varphi\right), \qquad B_\varphi = \frac{\Psi}{2\pi\varpi}, \qquad \tan\delta = \frac{|B_\varphi|}{|B_z|}.$$

- Solutions in the field-strength vs. density in adimensional units, different δ



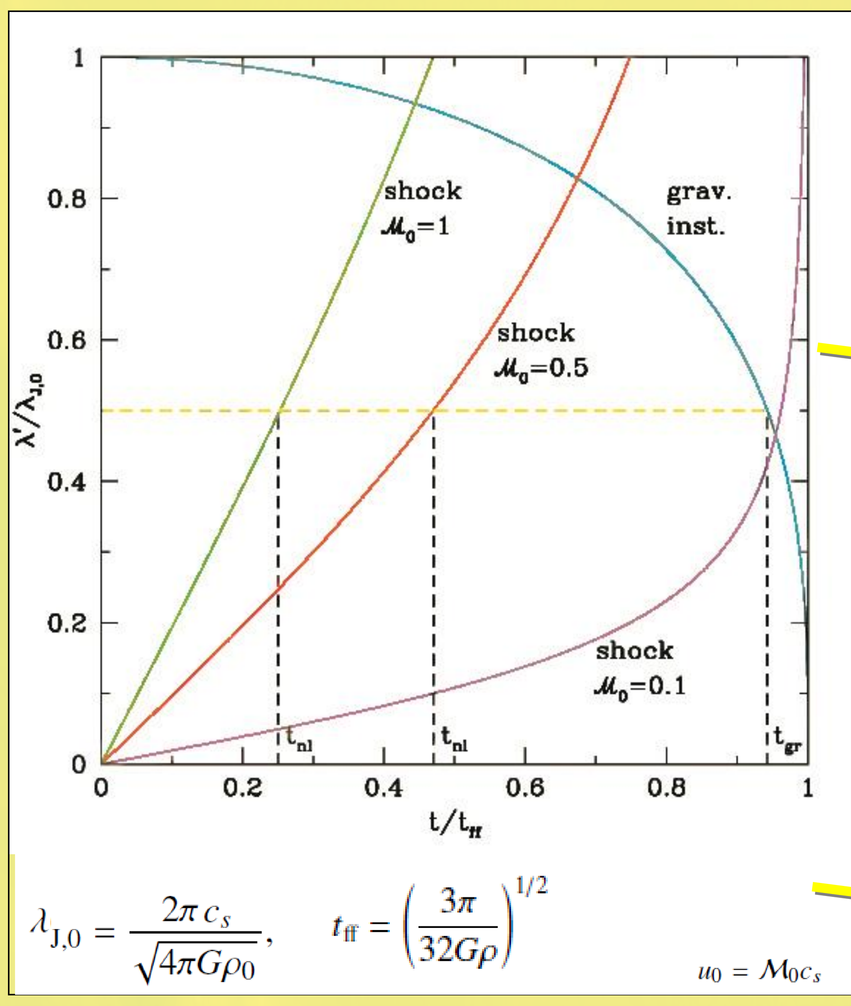
- H_0 dimensionless constant; deviation of poloidal field from force-free
- γ_p= 0.0099 quasi logatropic
- γ_p= 1.5 best fit value for observed filaments

$H_0 > 0$ Lorentz force directed outward → *support to the cloud* ❗
❗ $H_0 = 0$ Force free field, δ and density fixed
$H_0 < 0$ Lorentz force directed inward → *compression* ❗

The fate of of perturbations

Can the evolution of small-scale hydrodynamic perturbation in a contracting core lead to fragmentation? [7]
Competition between several time-scales & amplification of the initial amplitude:

- The time to reach the non-linear stage t_{nl}
- The time to become gravitationally unstable t_{gr}
- The time-scale of the global collapse t_{ff}
- The initial wavelength of the perturbation λ'



$$\lambda_{J,0} = \frac{2\pi c_s}{\sqrt{4\pi G\rho_0}}, \qquad t_{ff} = \left(\frac{3\pi}{32G\rho}\right)^{1/2} \qquad u_0 = \mathcal{M}_0 c_s$$

- $t_{nl}(t)$&$t_{gr}(t)$ for different Mach numbers vs initially Jeans stable perturbation

With turbulence observed in the starless cores initially stable fluctuations *do not become gravitationally unstable* ❗

Growth of solenoidal perturbations vorticity increases ❗	Magnetic fluctuations ❗ Stay tuned! *Toci et al. in prep* & Magnetic instabilities ❗

References

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