SPICAによる分子雲磁場の観測と星形成機構

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Importance of B-field in the ISM

Energy densities of the ISM ingredients

Diffuse ISM (n~1cm^{-3}, T~6,000K, Δv~5 km/s, B~3mG)

$$\varepsilon_{\rm turb}(=\frac{\rho\Delta v^2}{2}) \sim \varepsilon_{\rm mag}(=\frac{B^2}{8\pi}) \sim \varepsilon_{\rm th}\left(=\frac{n\,k_B T}{\gamma-1}\right) \sim \varepsilon_{\rm CR} \sim 1 \text{ eV/cc}$$

Molecular clouds (n~300cm^{-3}, T~10K, Δv~5 km/s, B~10 mG)

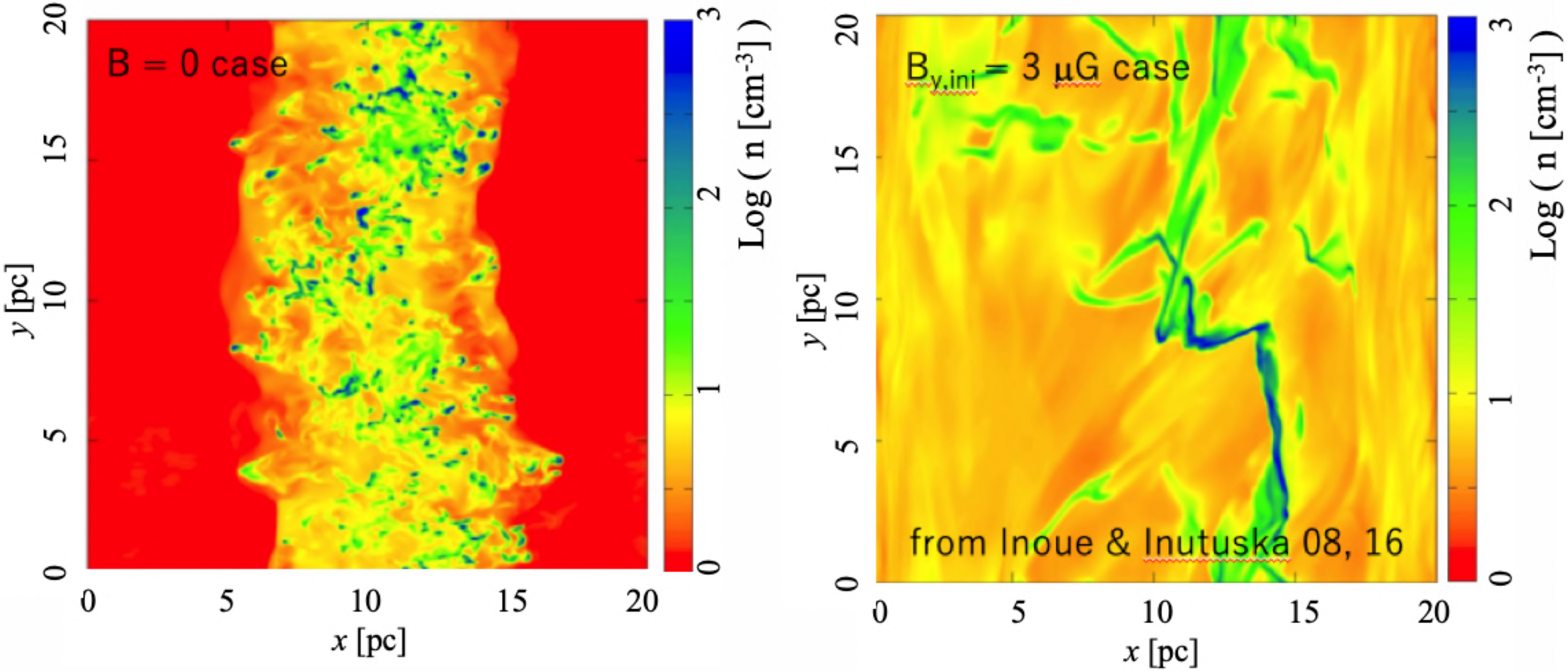
$$\varepsilon_{\rm turb}(=\frac{\rho\Delta v^2}{2}) \gtrsim \varepsilon_{\rm mag}(=\frac{B^2}{8\pi}) > \varepsilon_{\rm th} \sim \varepsilon_{\rm CR}$$

B-field always plays major role on the ISM dynamics.

Interplay of Cooling & B-field

Radiative cooling leads structure formation toward SF

Shock compression makes the ISM unstable by inducing runaway radiative cooling.
→ Structure formation by cooling condensation.



Effect of B-field influence a lot to the gas condensation through the Lorentz force (magnetic pressure/tension).

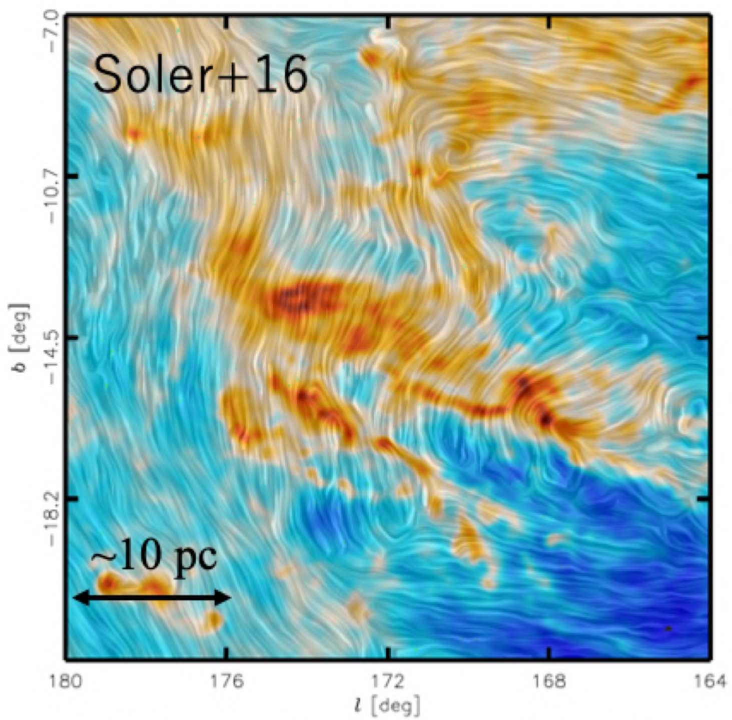
Far-infrared polarimetric imager (B-BOP)

B-BOP can observe B-field direction from low-N_H of Av ~0.5 mag..

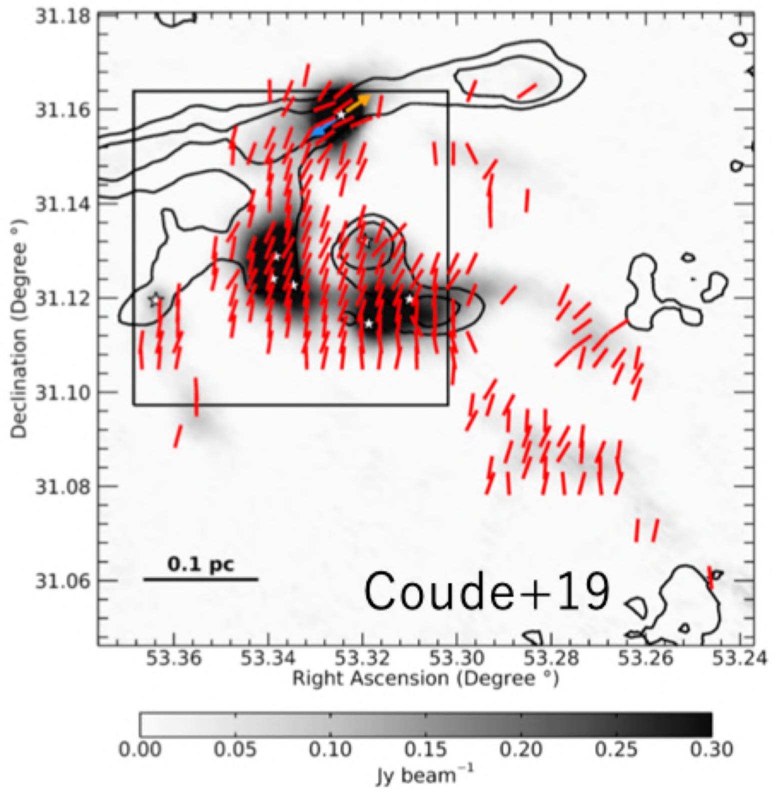
Resolution ~ 9''-32''

従来観測： PLANCKは分解能が低い(~10')、BISTROは高分解能だが高密度領域に注目

B structure by Planck at 353GHz



Magnetic field and column density measured by Planck towards the Taurus molecular cloud.



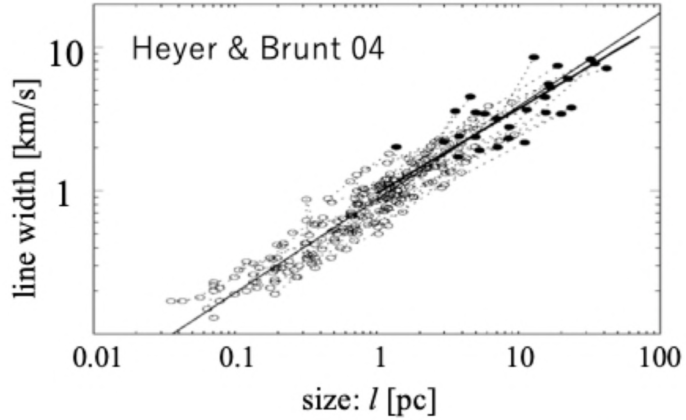
The Perseus B1 star-forming region in 850 μm dust polarization from POL-2

Turbulence vs. B-field in Molecular Cloud

Turbulence vs. B-field

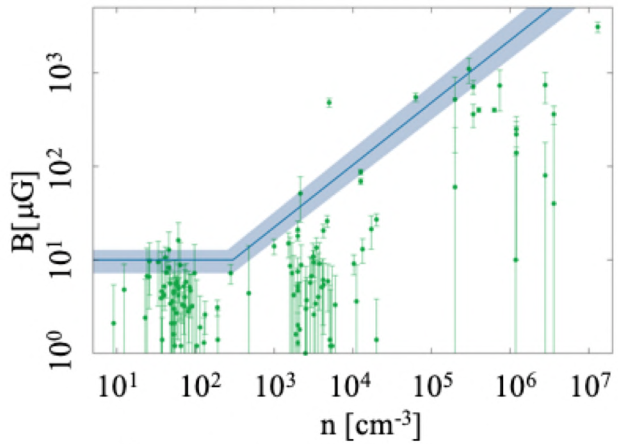
✓ Turbulence is measured by line-width:

Larson's law: $\Delta v \sim 10$ km/s $(L/100\ \text{pc})^{0.5}$



✓ B-field is measured by Zeeman effect

Crutcher relation: $B \sim 10\ \mu G\ (n/300\ \text{cm}^{-3})^{0.5}$



✓ Alfven-Mach number of the turbulence: $M_A = \frac{\Delta v}{B/\sqrt{4\pi\rho}} \sim 10\ (L/100\ \text{pc})^{0.5}$

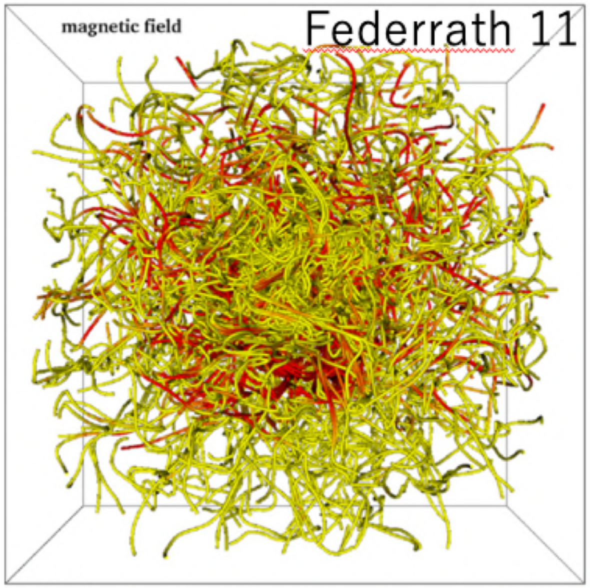
Turbulence is expected to be super-Alfvenic in MCs.

B-field Orientation and Strength

Severe conflict between theory and observation（~10pc scale）

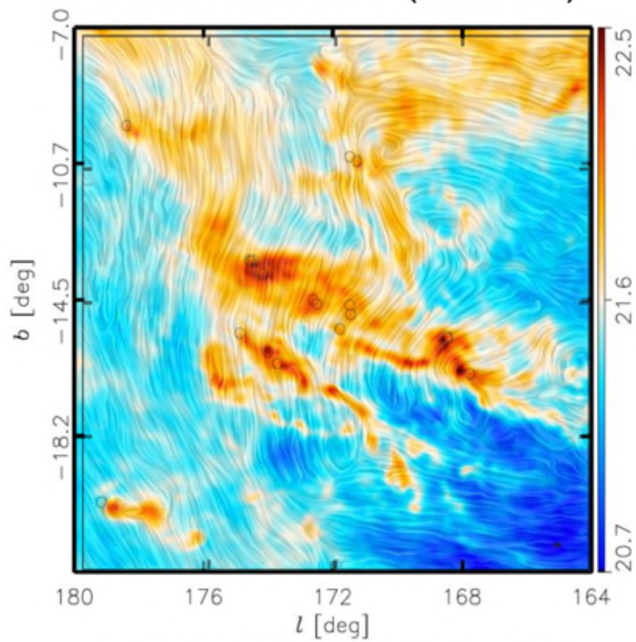
Theory shows that if B-field is weaker than turbulence, we should observe random B-field (no polarized emissions)

Simulated super-Alfvenic MC



weak B+turbulence → random ***B***
→ no polarized mission

Observed MC (Taurus)

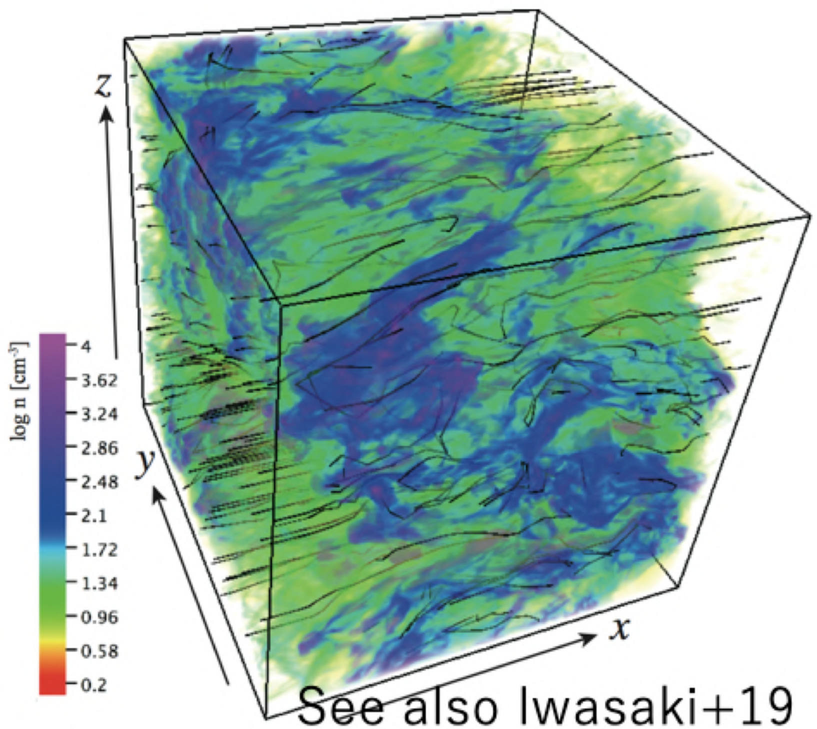


ordered ***B*** → strong ***B***

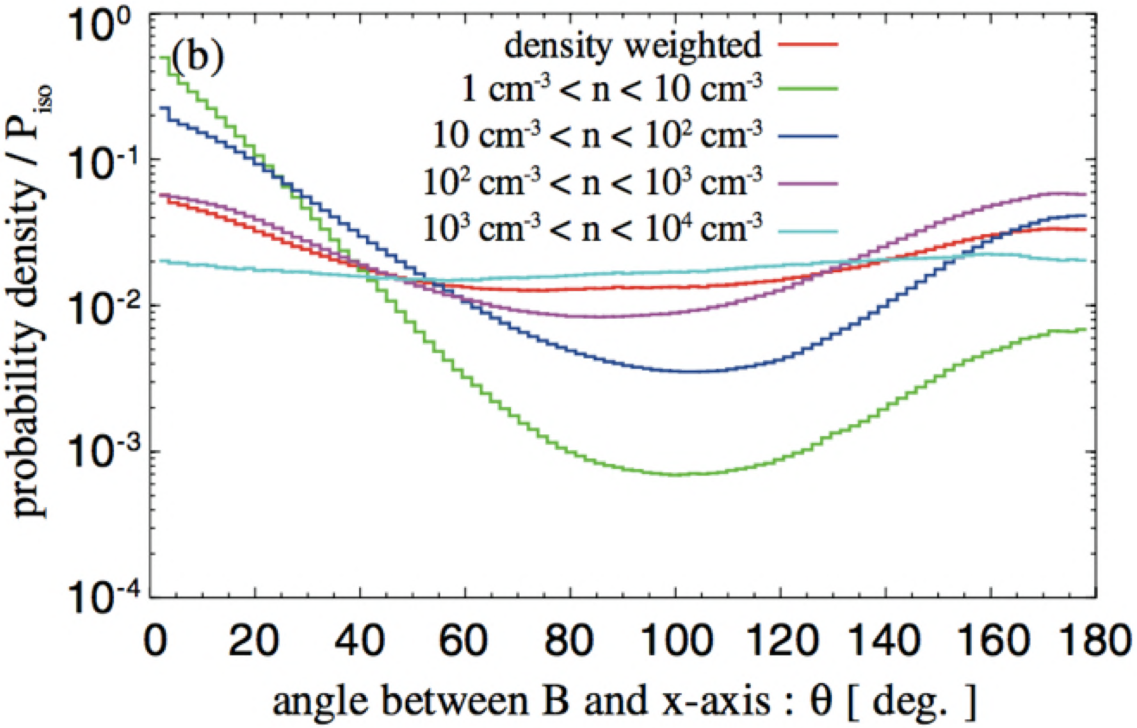
Observed B-structure is very different from naive theoretical expectation.

Prediction by Inoue & Inutsuka (2012)

Turbulence can be highly anisotropic and there is no conflict between theory/observation



See also Iwasaki+19



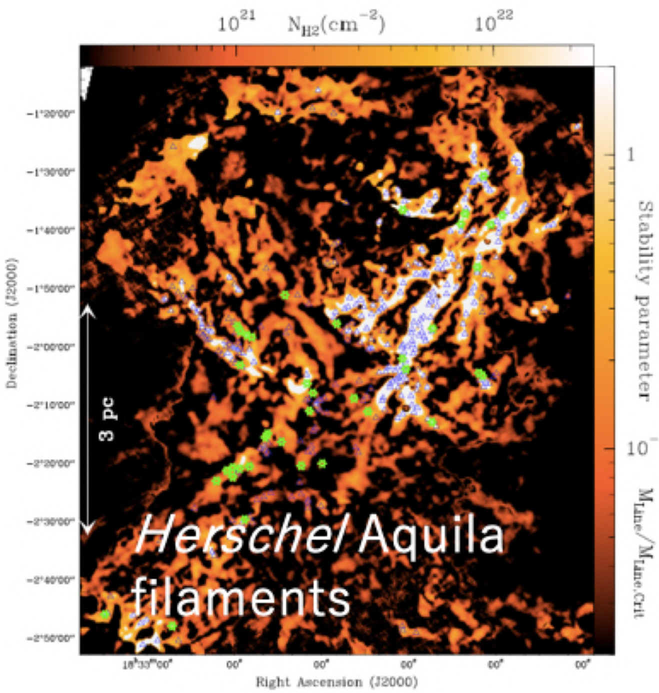
Our prediction can be proven by B-BOP thanks to the high sensitivity.

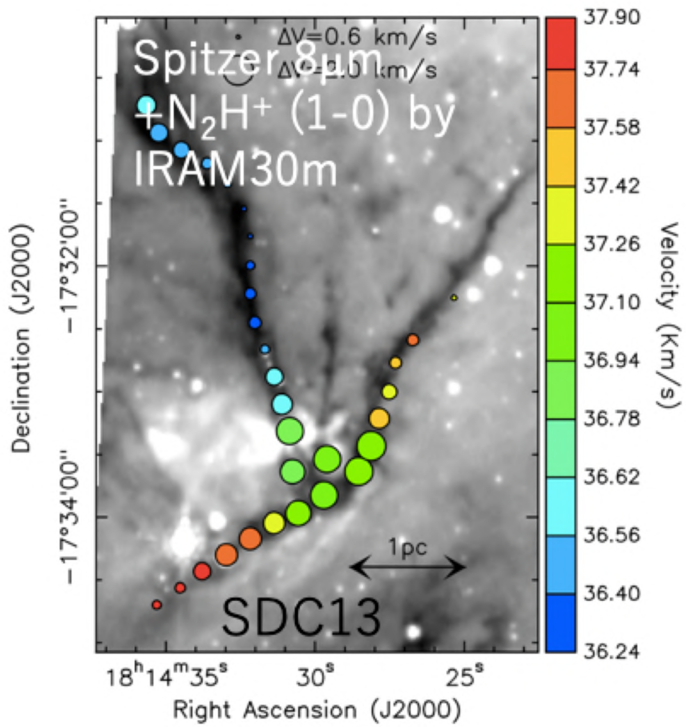
Dense Filaments in Molecular Clouds

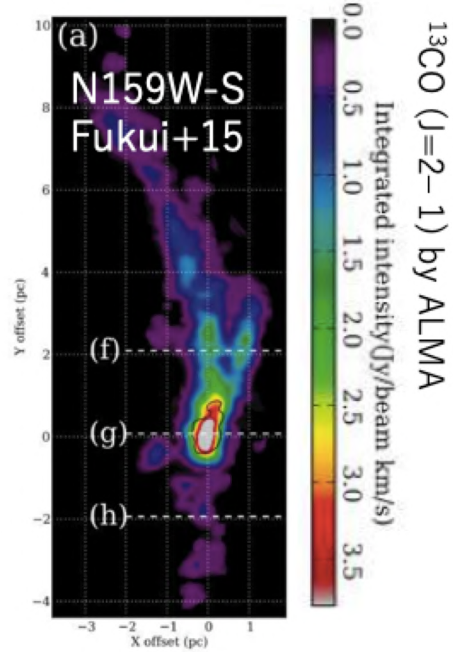
Molecular filaments (>1 pc length, 0.1 pc width) are shown to be the site of stellar core formation.

SF condition : $\lambda_{line} > \lambda_{crit}$ for GI (Andre+10)

Even massive stars are suggested to be formed via filaments(Peretto+13, Fukui+14, Shimajiri+19)



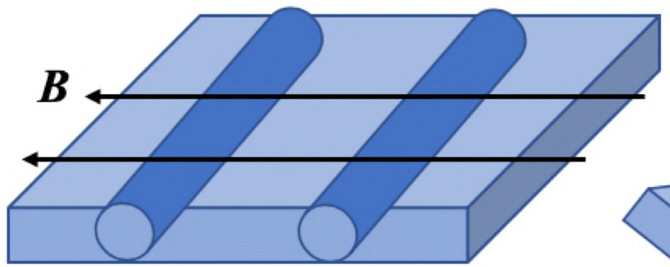


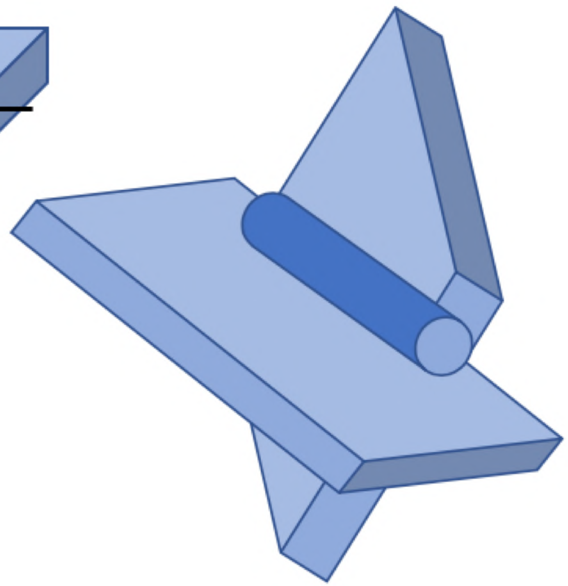


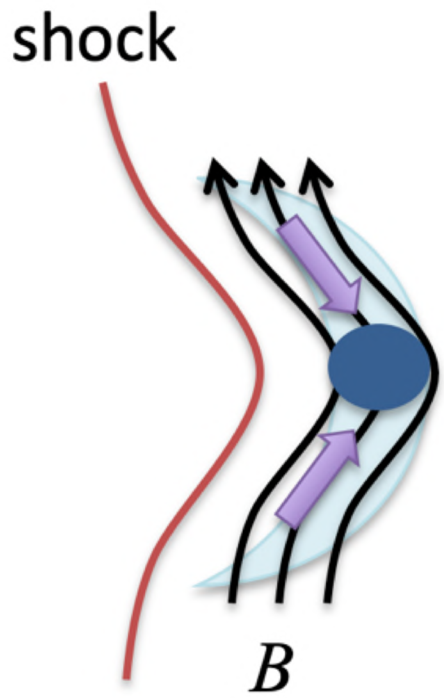
How Filaments are Formed?

Many theoretical scenarios have been proposed

- ✓ Gravitational insta. of molecular sheet (e.g., Nagai+98)
- ✓ Turbulent sheet-sheet collision (e.g., Padoan 00)
- ✓ MHD shock compression (Inoue & Fukui 13; Vaidya+13)







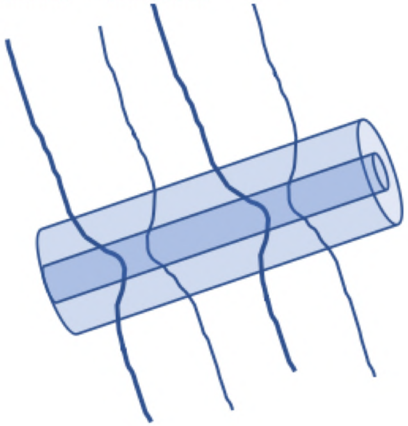
Can we distinguish these scenarios by SPICA?

Filament B-field Structure and Observation

Tomisaka (2015) method

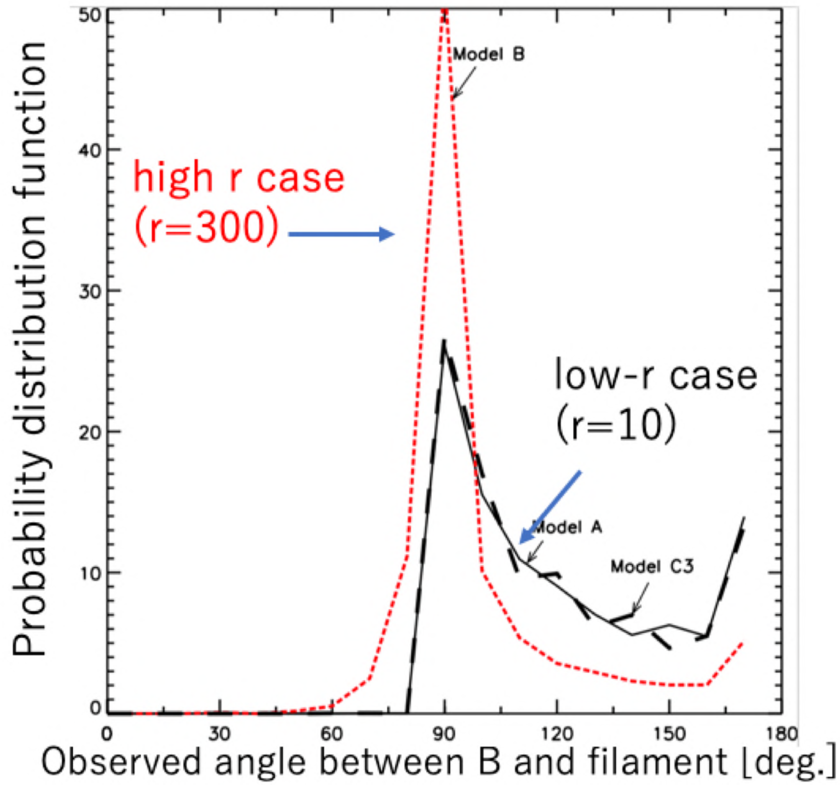
Observed B-field angle to the filament depends on density structure of the filament

$r = \rho_{center}/\rho_{surface}$ can be measured.



High-r suggests that the filaments are formed through gravitational process.

Low-r filaments can be formed through non-gravitational processes, which haven't been reached to gravitationally-critical line-mass.



Summary

SPICA B-BOP can reveal B-fields structures in molecular clouds that enable us to understand physical character of turbulence and origin of star-forming filaments in molecular clouds.

For the filaments, due to their narrow widths of 0.1 pc, we cannot expect increase of target number comparing with Herschel.
However, we can exceed Herschel, if we combine data from SPICA and grand-based telescopes such as LMT.

We can get more precise physical conditions of molecular cloud cores by B-BOP via “hourglass structure” of B-fields.