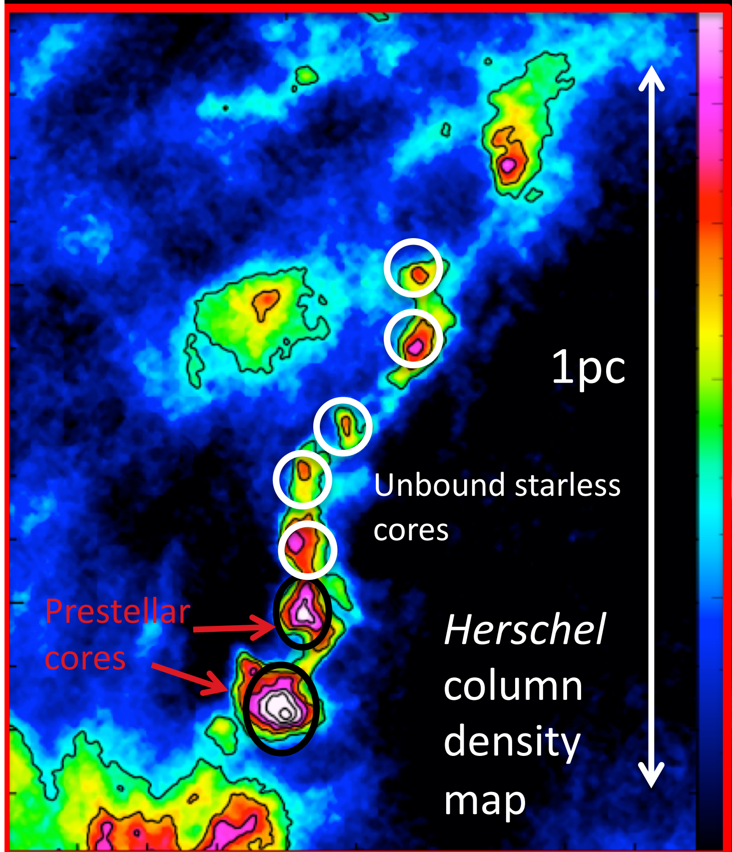
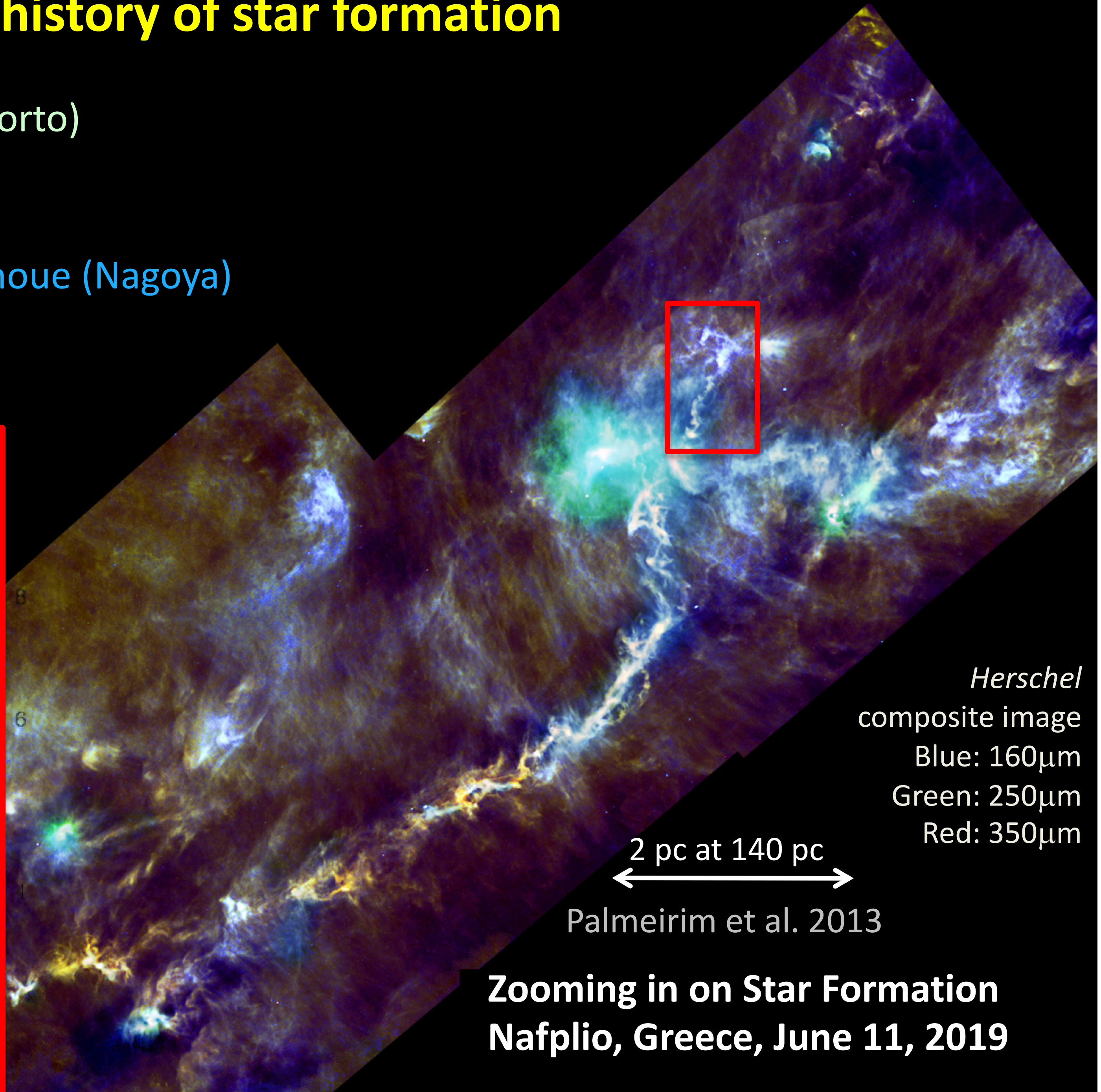
Filament and sheet-like-cloud interaction:

Hint to understand the history of star formation

Doris Arzoumanian (IA/CAUP Porto)

Main Collaborators:
Shu-ichiro Inutsuka, Tsuyoshi Inoue (Nagoya)
Yoshito Shimajiri (Kagoshima)

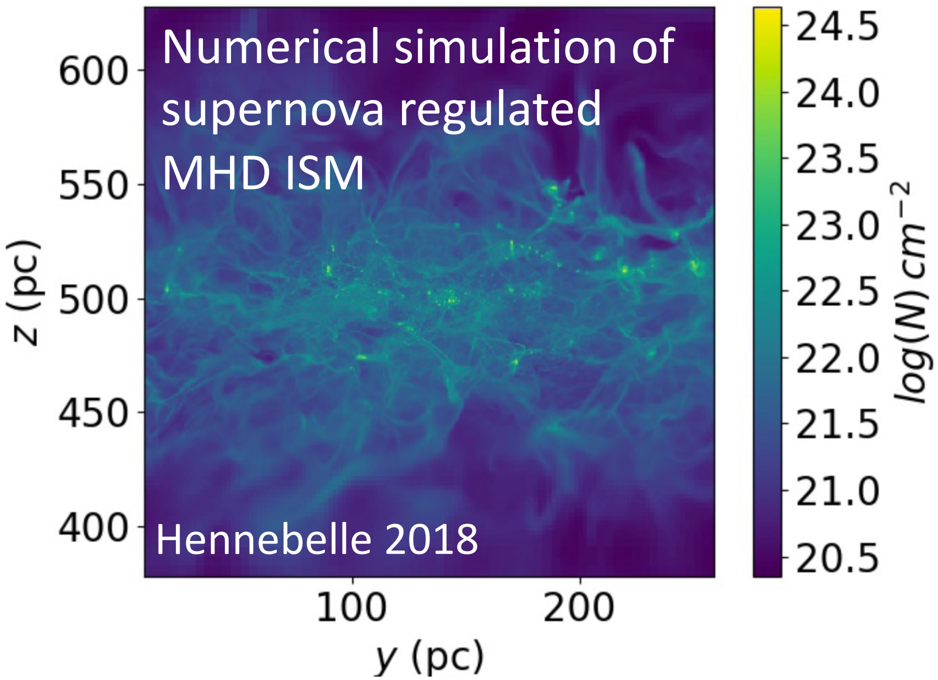


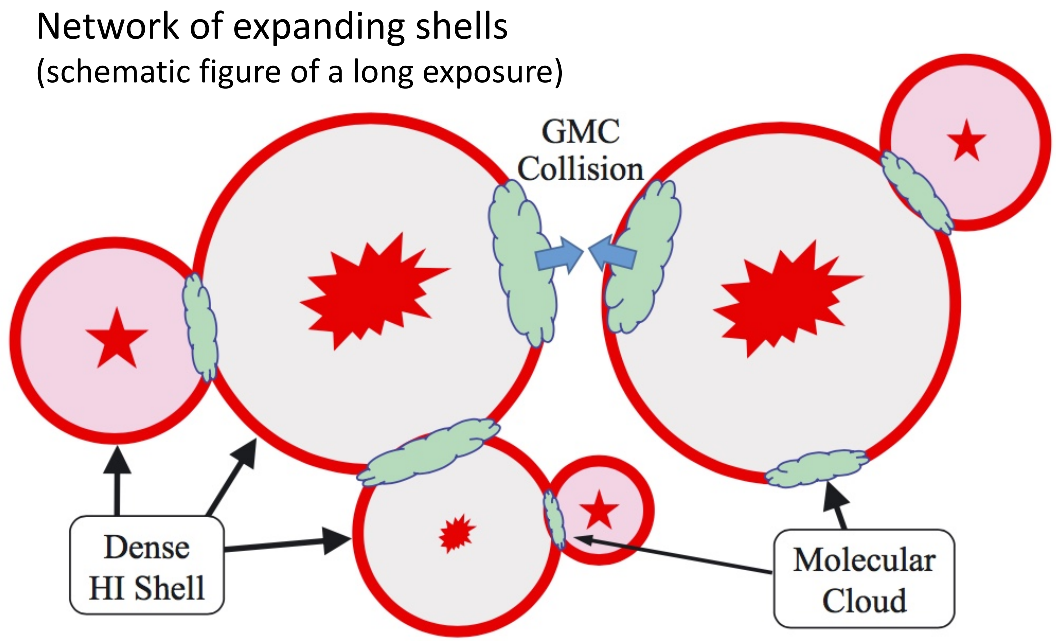


Zooming in on Star Formation
Nafplio, Greece, June 11, 2019

Molecular cloud formation from multiple shock compressions

- Results from observations and simulations: Molecular clouds are filamentary
- Formation of filamentary molecular cloud: From compression of dense and cold atomic clouds by propagating shock waves (e.g., Hennebelle et al. 2008, Vaidya et al. 2013, Ntormousi et al. 2017).
- MHD nature of the ISM: multiple episodes of compressing flows are needed (e.g., Inoue & Inutsuka 2008, 2009, Heitsch et al. 2009, Valdivia et al. 2016, Iwasaki et al. 2019).
- The typical formation and lifetime of molecular clouds (>10 Myr) >> the typical timescale of each shock compressions on average ~1 Myr (e.g., McKee & Ostriker 1977).
- Reorganization of the (density, velocity, magnetic field) structures during each wave passage.





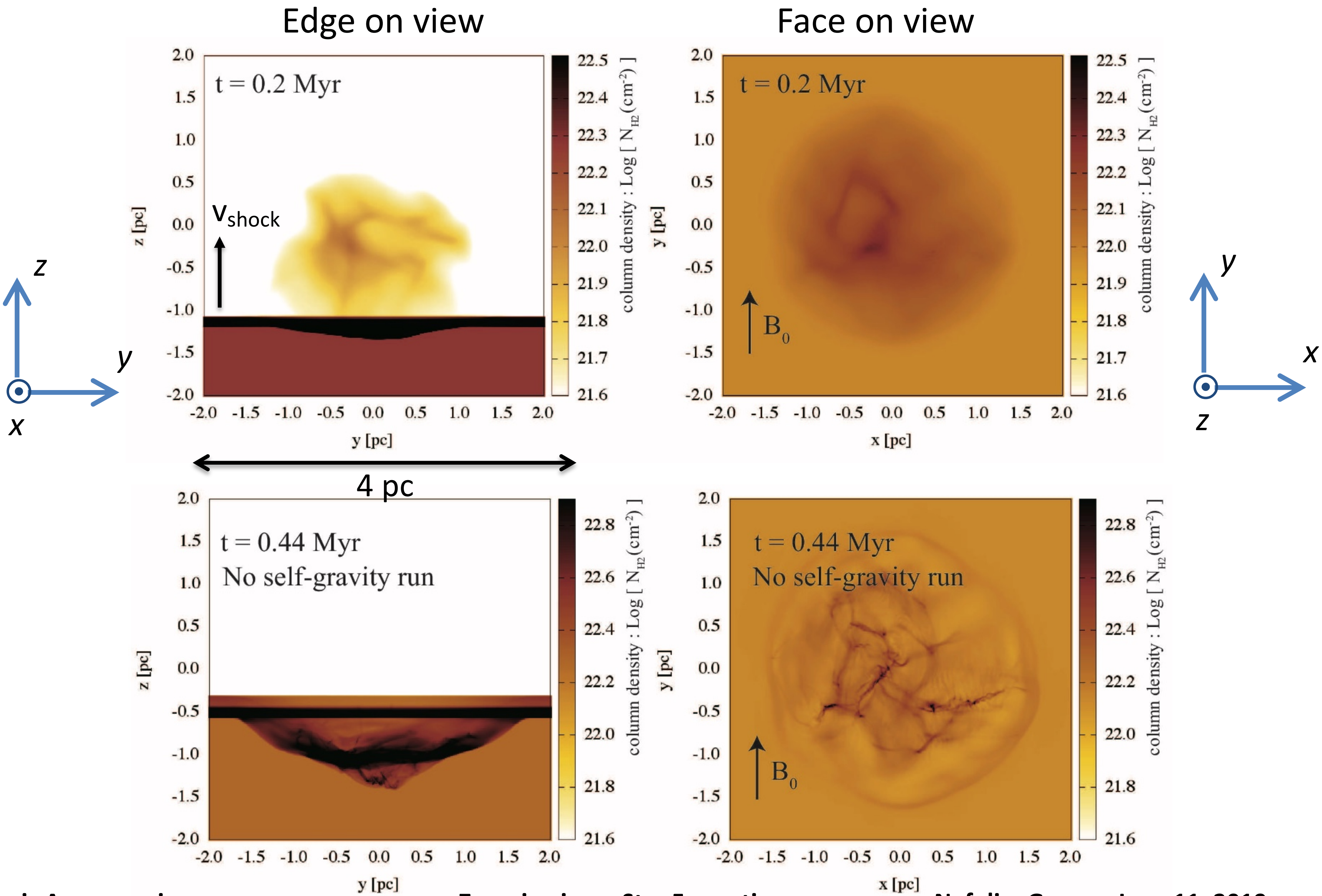
(cf., talks by, e.g., E. Ostriker, T.-E. Rathjen, P. Padoan, D. Seifried)

Inutsuka et al. 2015

1. Formation of filaments induced by shock compression

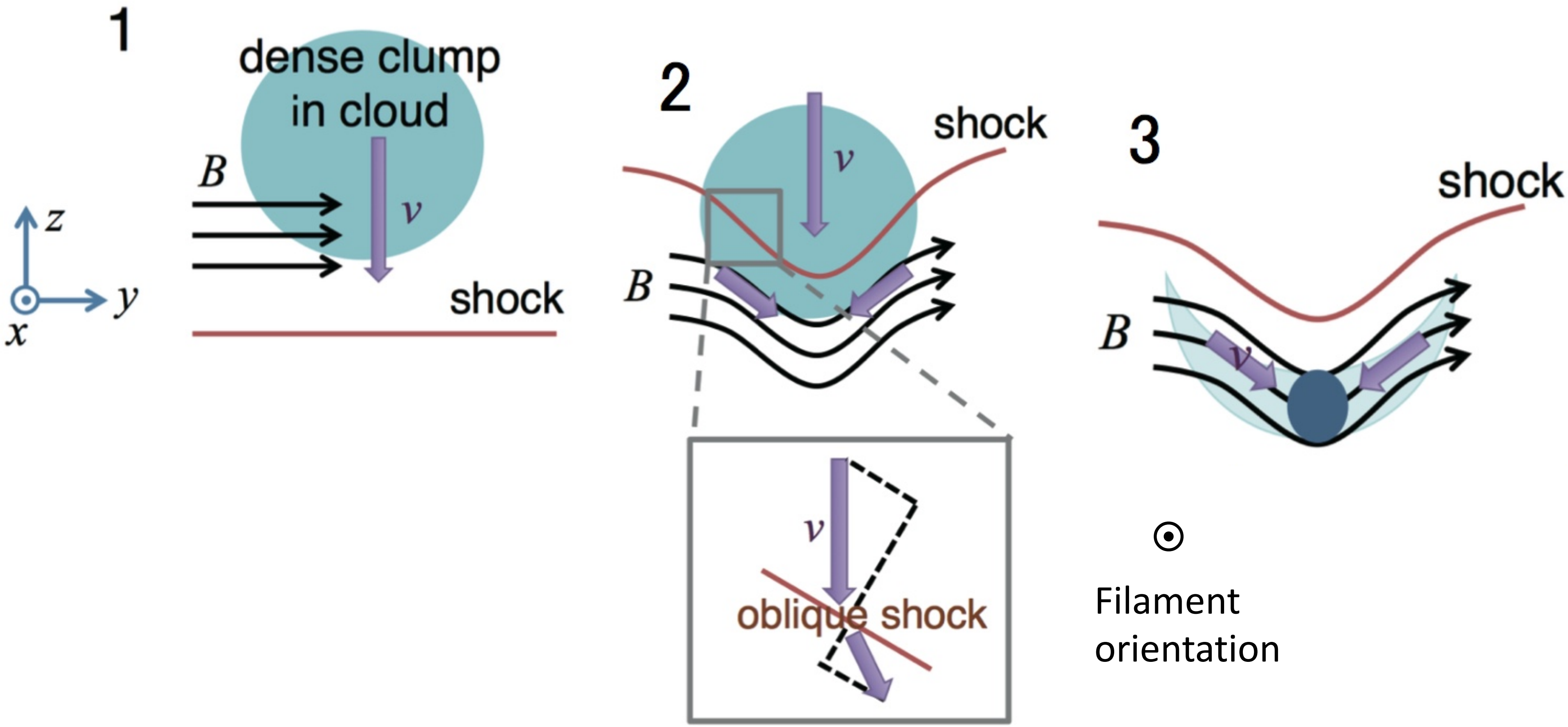
Formation of filaments induced by shock compression

MHD numerical simulation by Inoue et al. 2018



Formation of filaments by accumulation of matter along a curved magnetised sheet-like-structure induced by a shock compression

- Filaments are formed by the postshock focusing flow.
- Filaments are formed perpendicular to the magnetic field lines.
- Filaments are not formed by self-gravity.

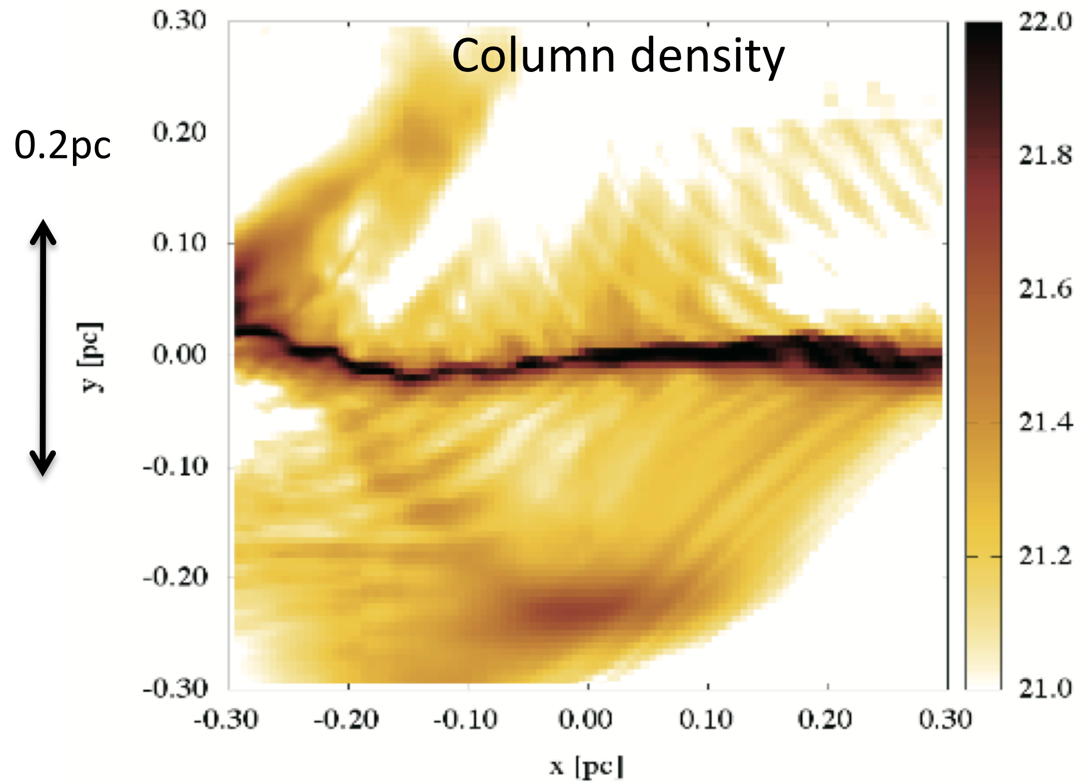


Filament orientation

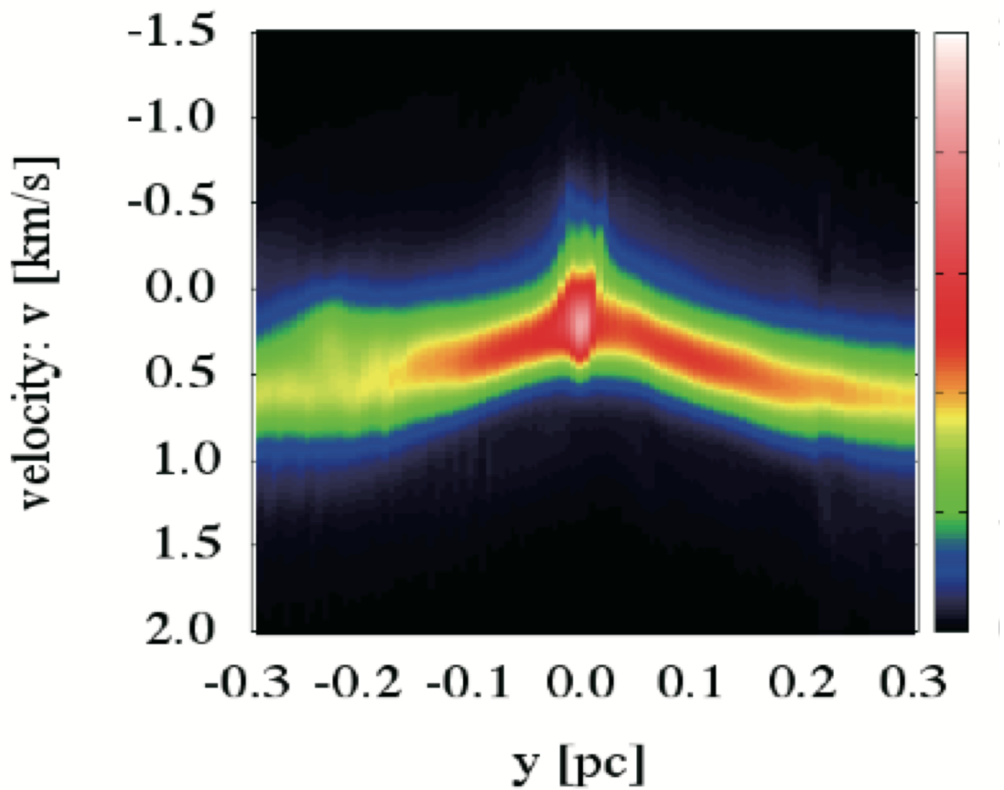
Inoue & Fukui 2013, Inoue et al. 2018, and also Vaidya et al. 2013

Velocity structure of a simulated filament formed by shock compression

Filament from the simulation

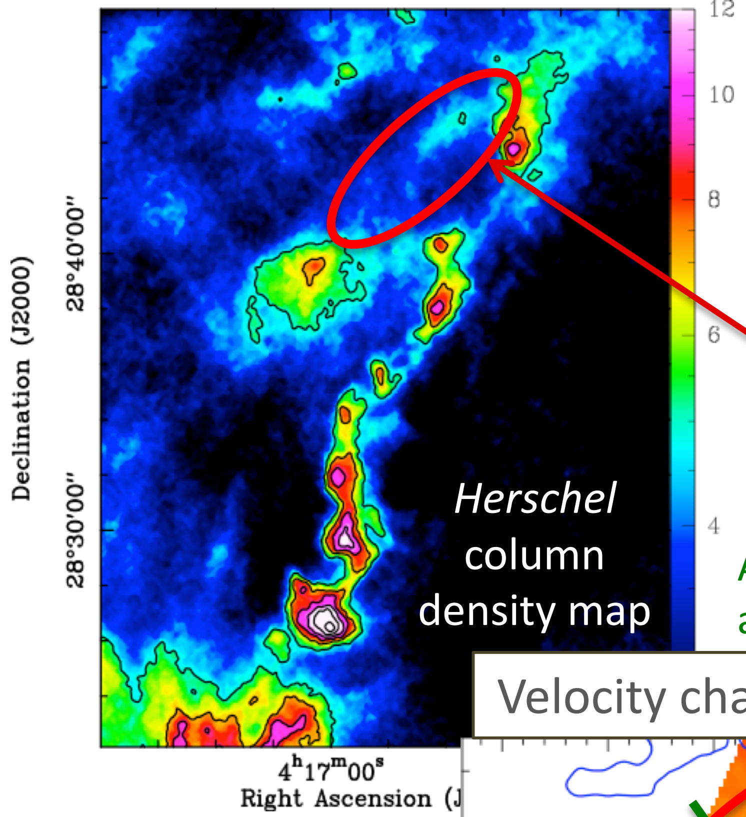


Position velocity diagram



Inoue et al. 2018, Arzoumanian et al. 2018

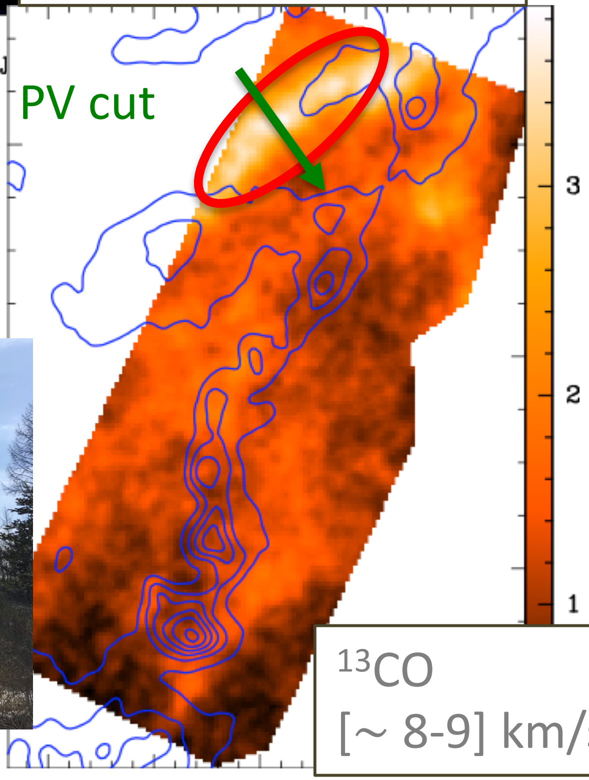
Velocity structure around a low column density baby-filament observed in Taurus



Filament with $M_{line} \sim 1\ M_{sun}/pc$

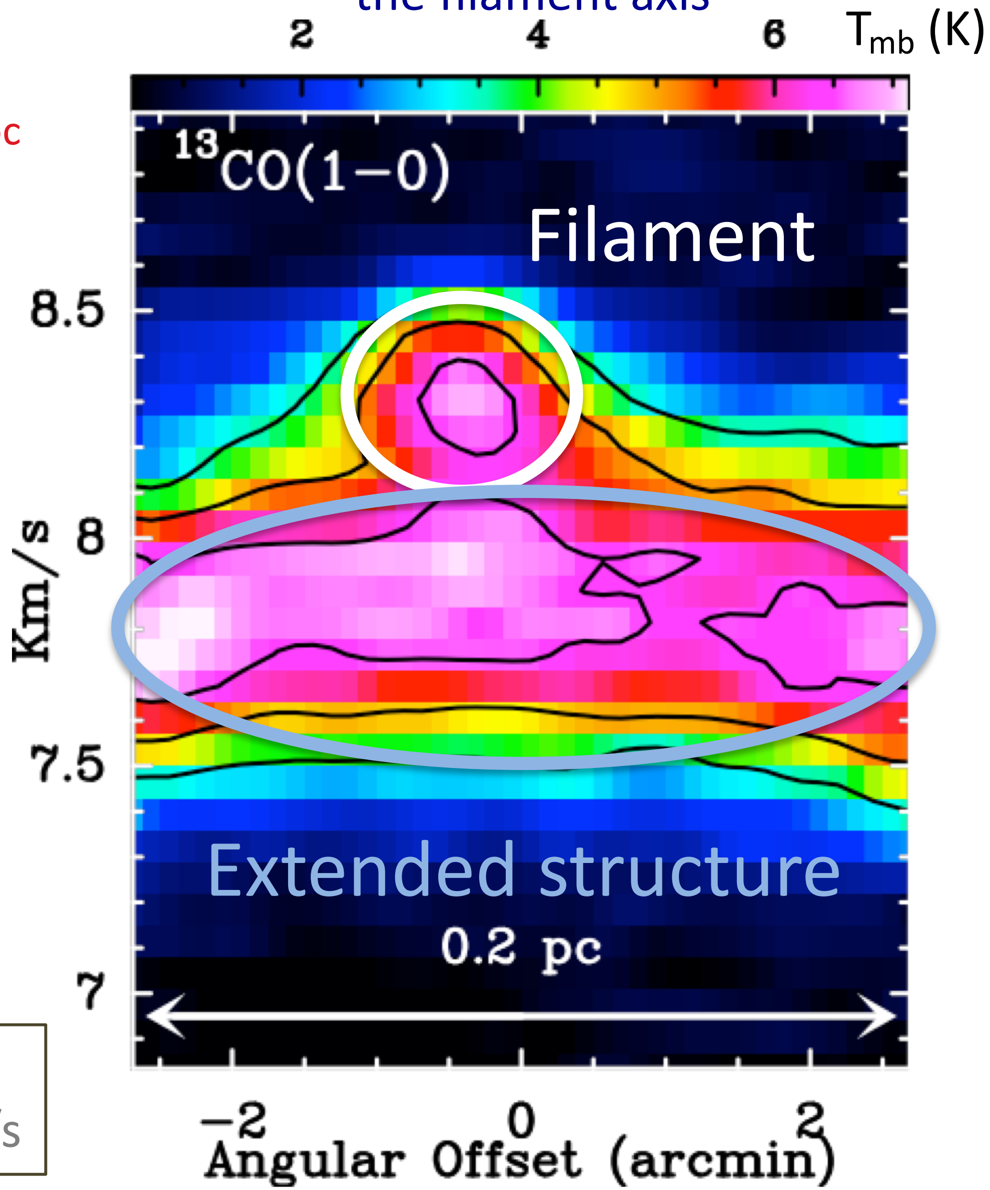
Arzoumanian et al. 2018

Velocity channel map



^{13}CO [~ 8-9] km/s

Position-velocity map perpendicular to the filament axis



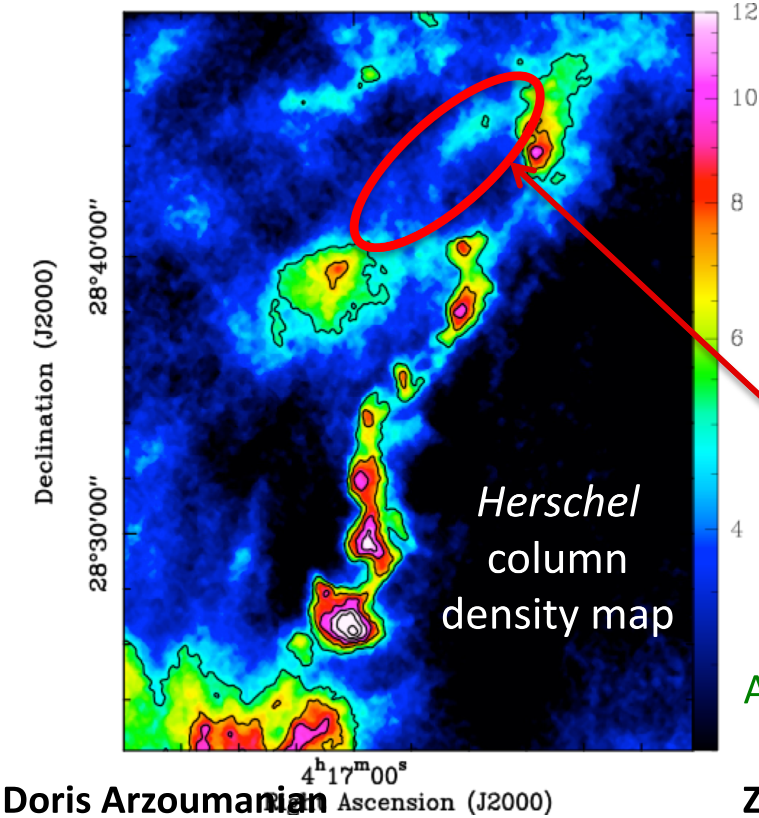
Nobeyama 45m Telescope observations

This baby filament formed by shock compression would evolve and become star forming

- **Now,** the Filament has $M_{line} \sim 1\ M_{\odot}/pc$
  a mass accretion rate of $\sim 48\ M_{\odot}/pc/Myr$

- **In ~ 0.3 Myr,** the filament may reach $M_{line} \sim M_{line,crit} \sim 16\ M_{\odot}/pc$, become gravitationally unstable, and fragment into star forming cores.

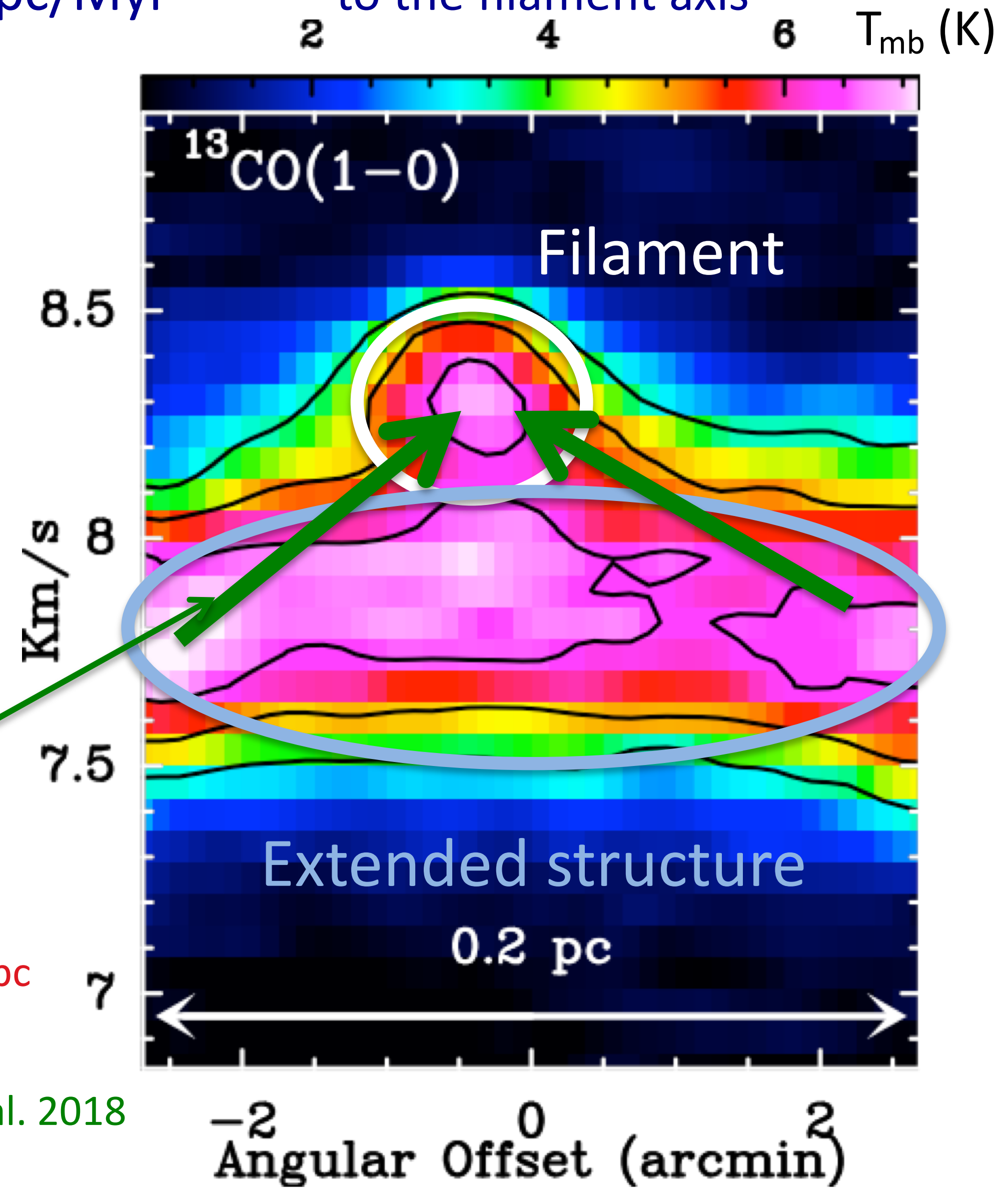
PV map perpendicular to the filament axis



Velocity gradient ~ 0.5km/s over 0.1pc

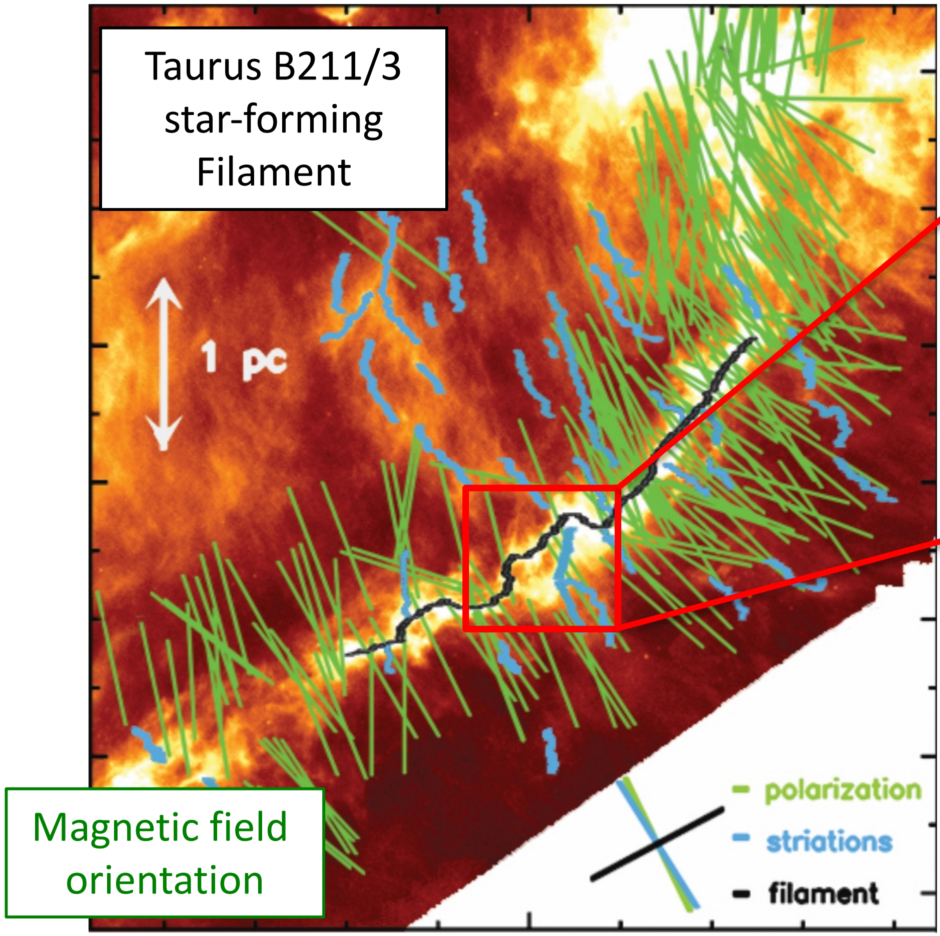
Filament with $M_{line} \sim 1\ M_{sun}/pc$

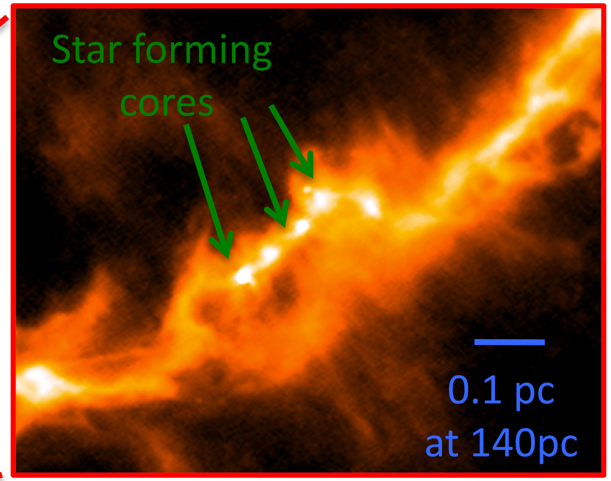
Arzoumanian et al. 2018



Fate of subcritical low column density filaments

- Those perpendicular to the magnetic field lines (e.g., the baby filament) may evolve and become star forming in the future
- Those parallel to the magnetic field lines (e.g., striations) may have a different future





Relative orientation between magnetic field and filaments:
Dense filaments → perpendicular
Faint filaments → Parallel
(e.g., Planck polarization results, Pattle & Fissel 2019, also cf. talk Dana Alina)

Herschel column density map, Palmeirim et al. 2013, also, Shimajiri et al. 2019

2. Interaction between propagating shock waves and filamentary structures

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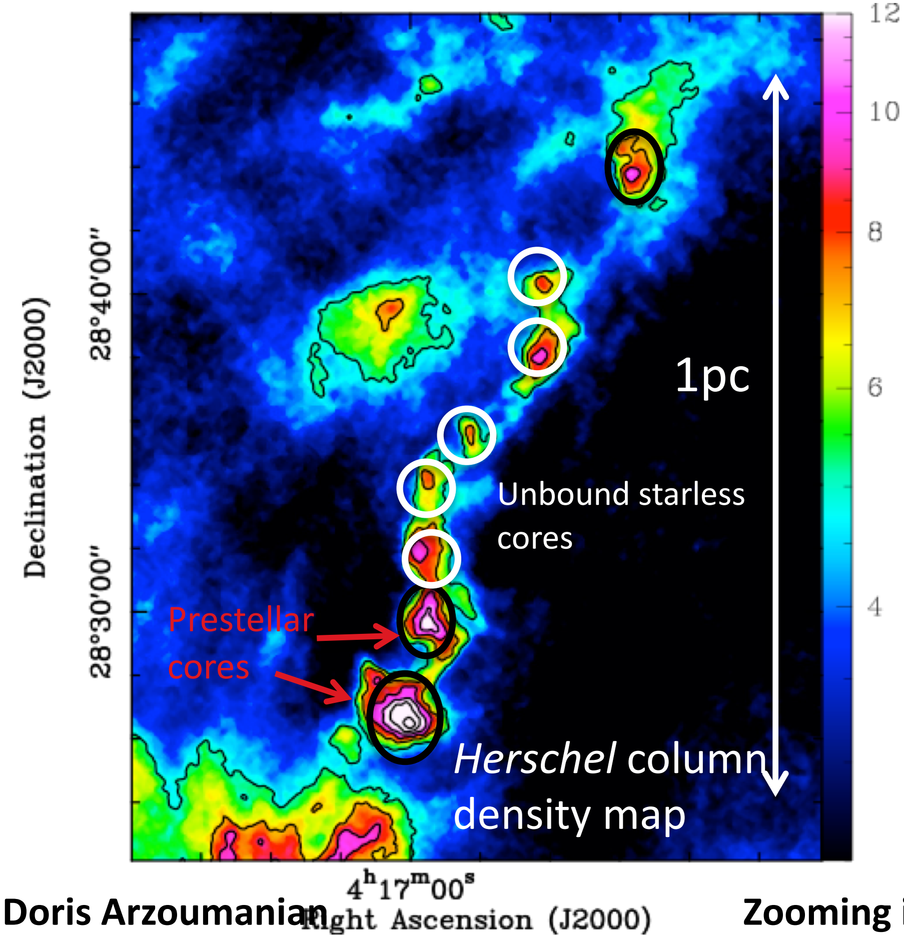
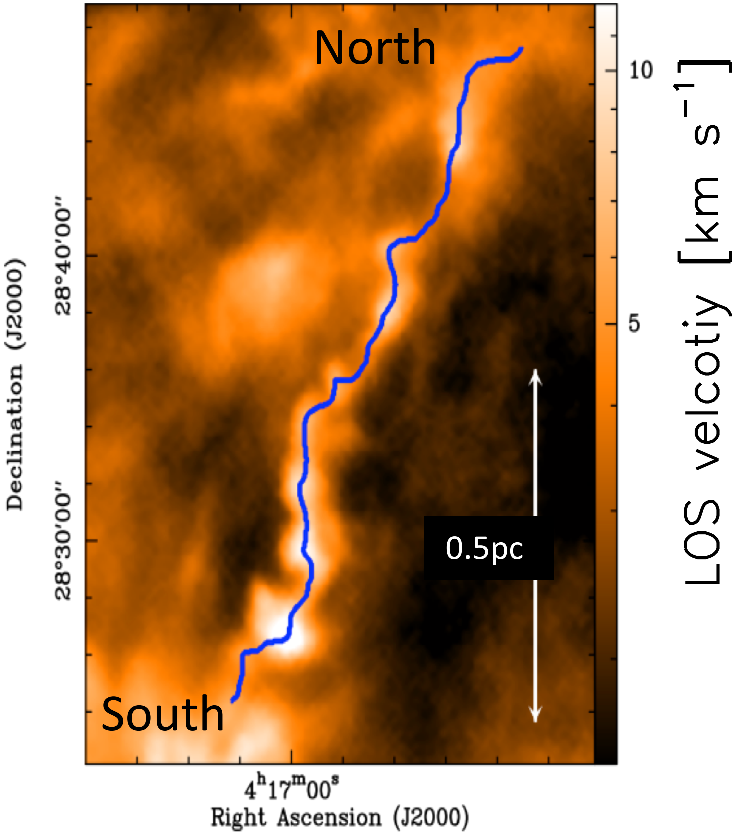


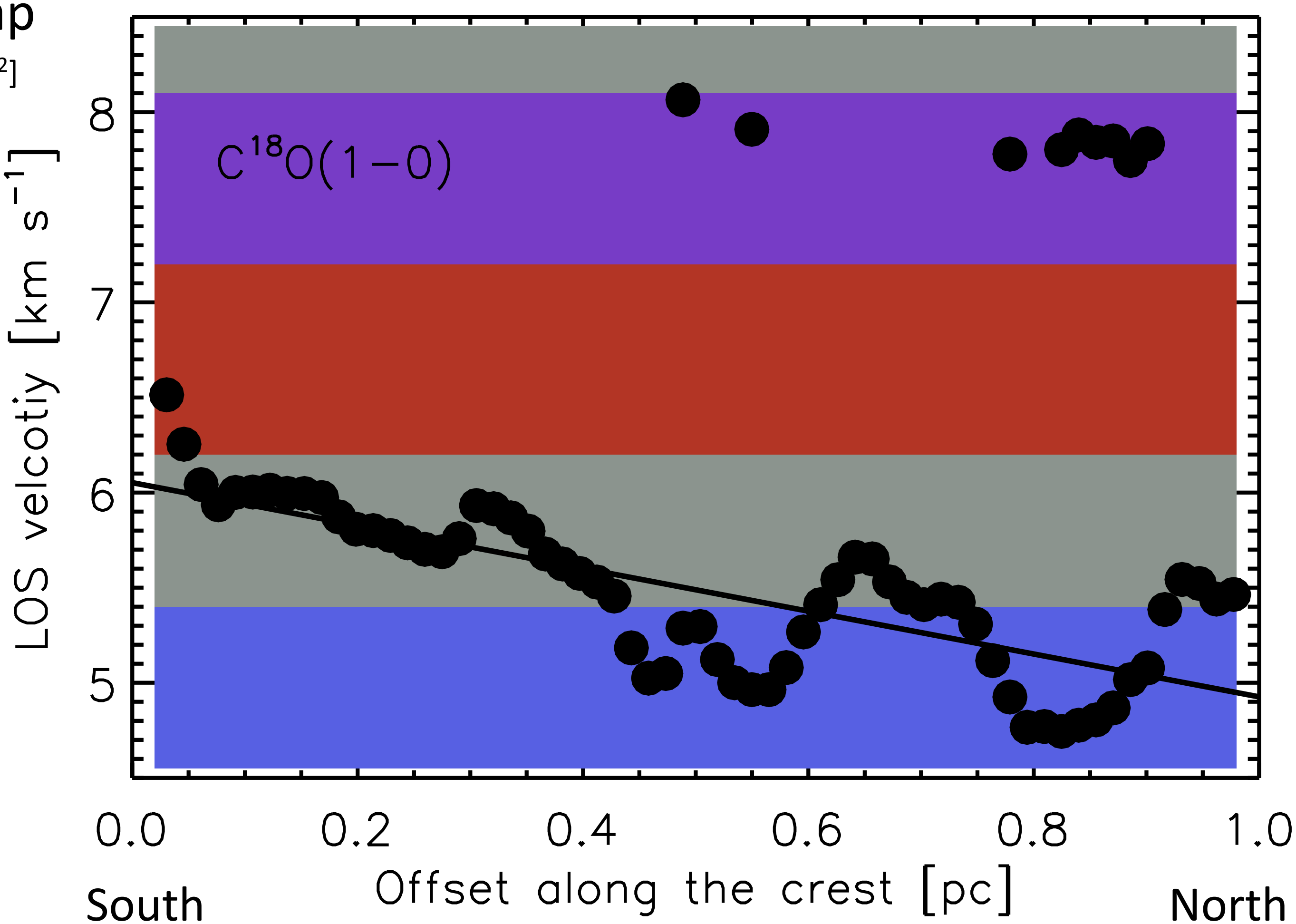
Nobeyama 45m
Telescope observations

Velocity pattern along the crest of the star-forming filament derived from the $C^{18}O(1\text{-}0)$ data

Herschel column density map



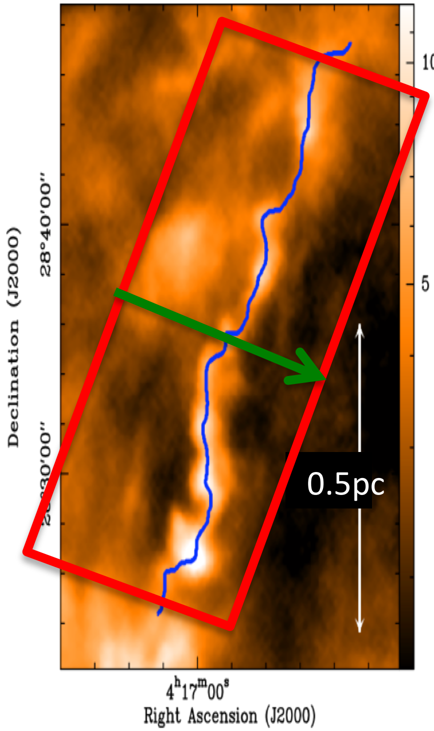
Velocity along the filament crest



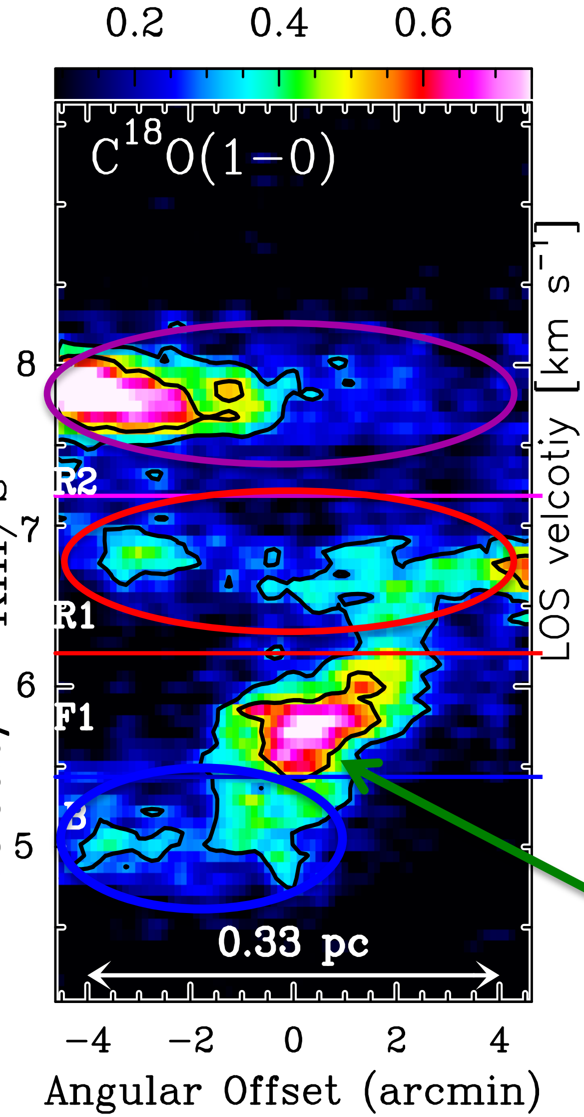
Arzoumanian et al. 2018

Multiple velocity components are observed towards the filament

Herschel column density map



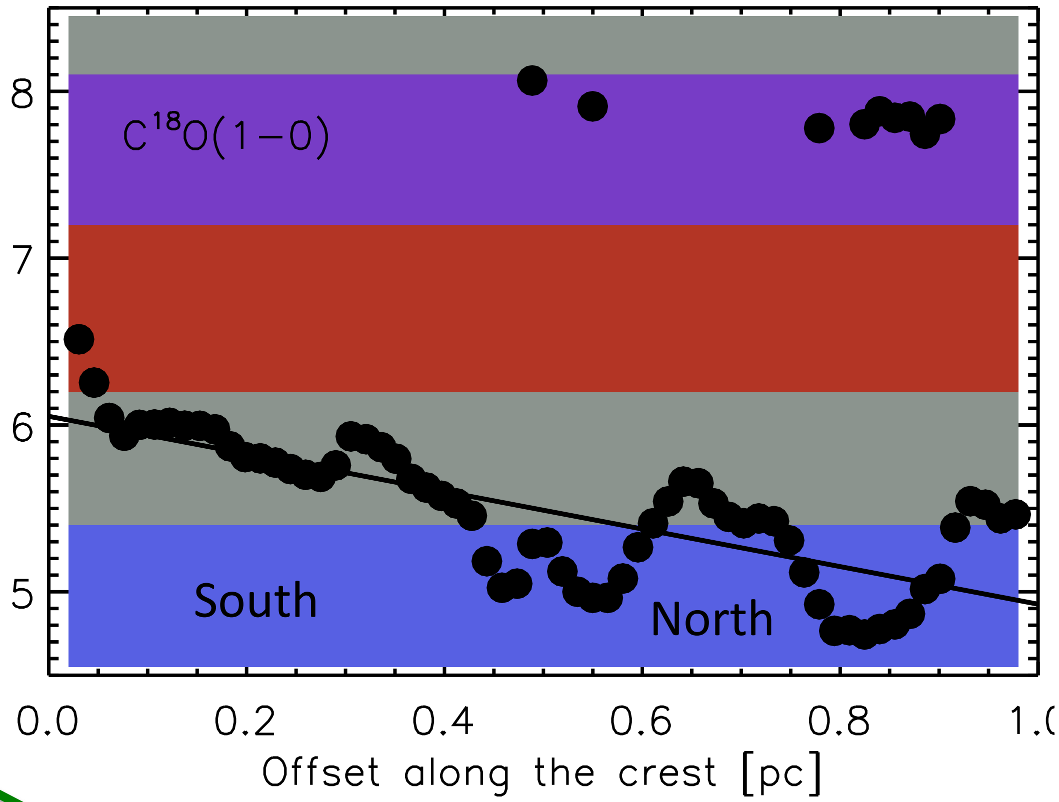
PV diagram
normal to the filament



Velocity Km/s

Position

Velocity along the filament crest

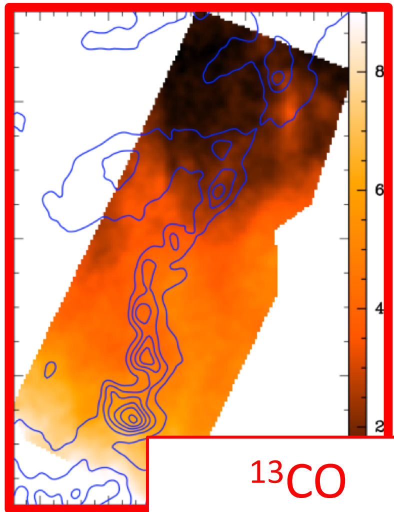


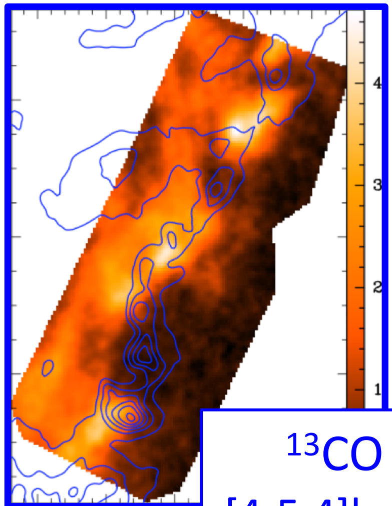
Star-forming filament

$C^{18}O$
[5.2-6.2]km/s

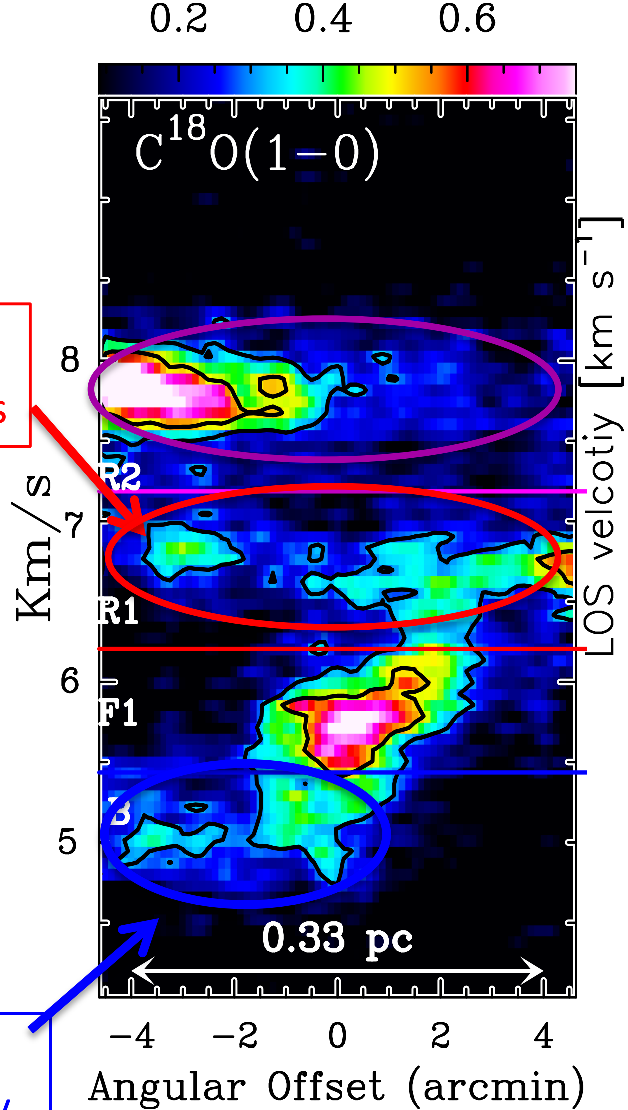
Different spatial distributions of the extended structures with different velocities

Velocity channel maps

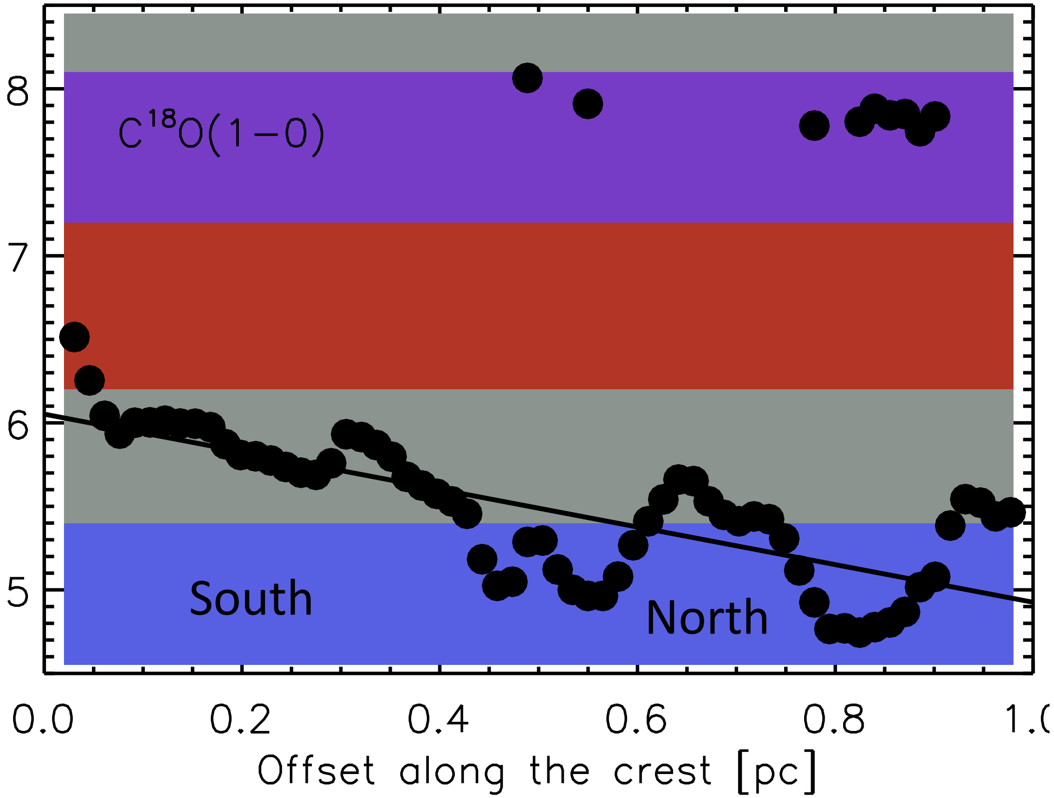




PV diagram normal to the filament

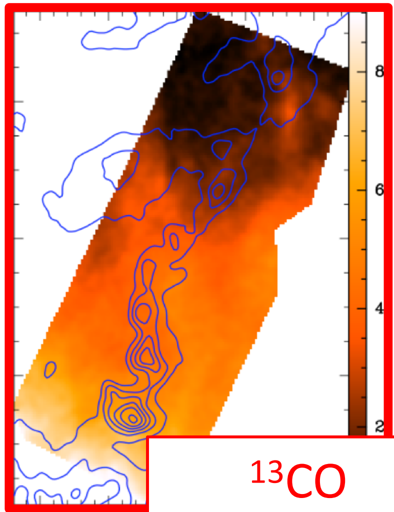


Velocity along the filament crest

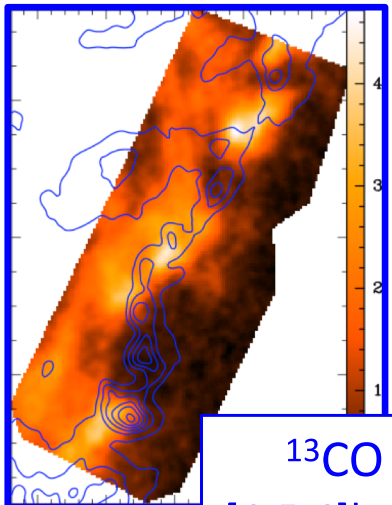


Signature of interaction between the filament and propagating shock waves?

Velocity channel maps

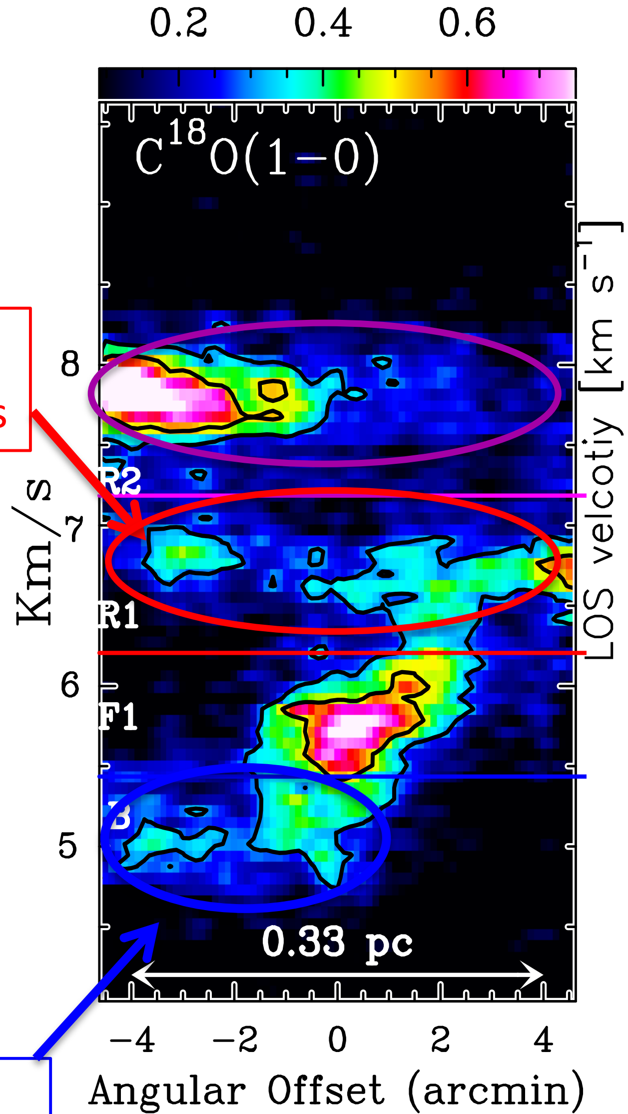


^{13}CO
[6.2-7.2]km/s

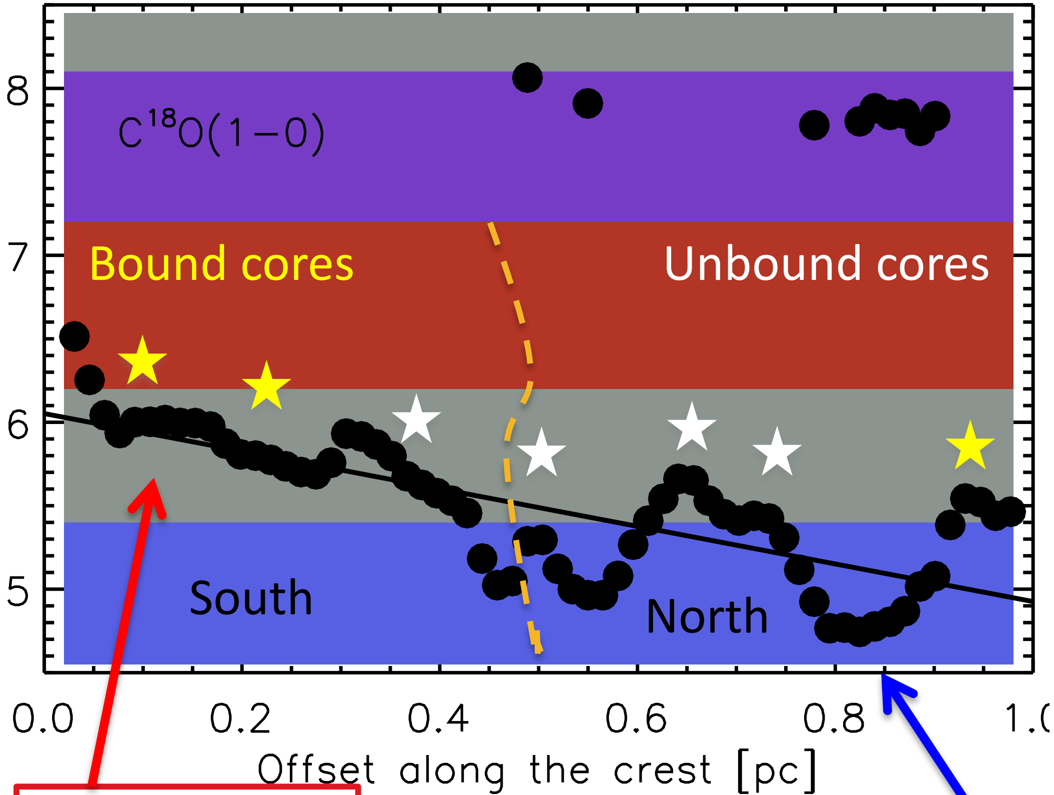


^{13}CO
[4-5.4]km/s

PV diagram
normal to the filament



Velocity along the filament crest



Two waves converging simultaneously compressing the filament

One-sided compression: the shock may be sweeping up the low-column-density parts of the filament

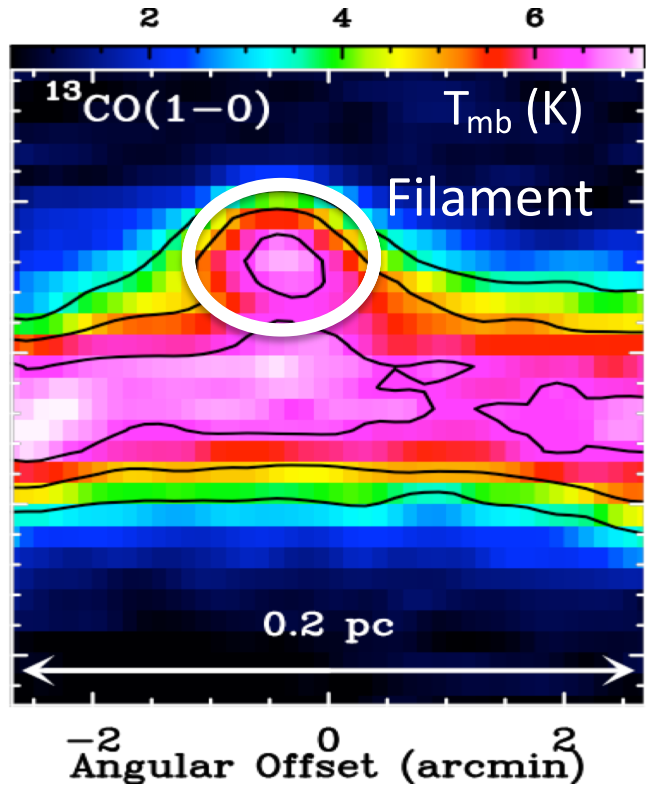
Summary

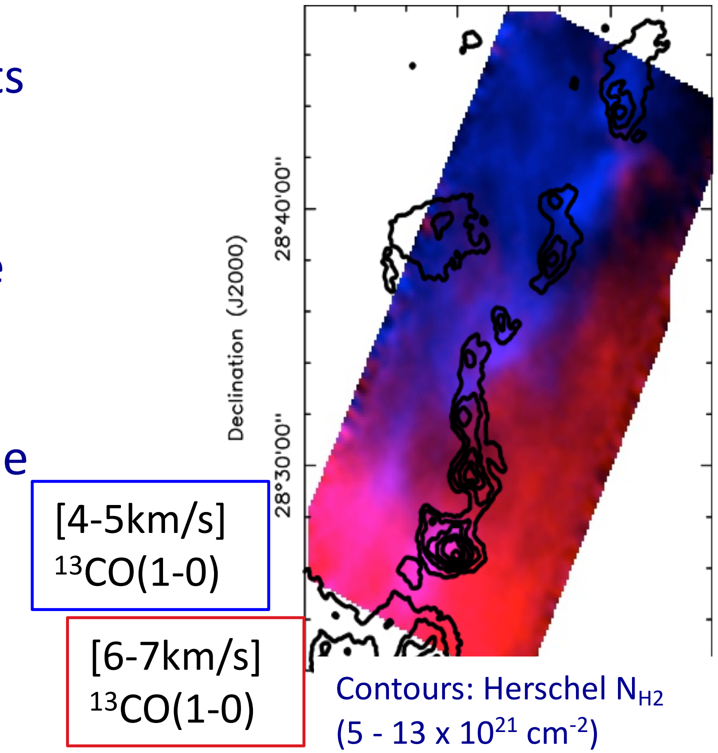
- The propagation of interstellar shock waves
  → key role in the formation and evolution of filaments

- These shock waves may
  → trigger the formation of filaments perpendicular to the magnetic field lines. These filaments increase in M_{line} accreting matter from the surrounding sheet, become gravitationally unstable ($M_{line} \sim M_{line,crit}$), and fragment into star forming cores.
  → interact with already formed filaments
  - resulting in accretion of matter onto the filaments
  - or the removal/disruption of low column density parts

- The present density, velocity, and magnetic field configurations may not be representative of the ones at the formation stage of the molecular cloud

- Such interactions may play an important role in the lifetime of filaments and their star formation activity (implication in the star formation efficiency)





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