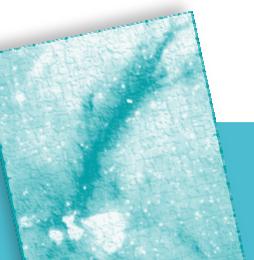


ALMA Observations of G351.776–0.527:

Probing Outflow–Filament Alignment in a Star-Forming Ridge

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L. Testi (UNIBO), T. Pillai (Haystack Observatory)



Background:

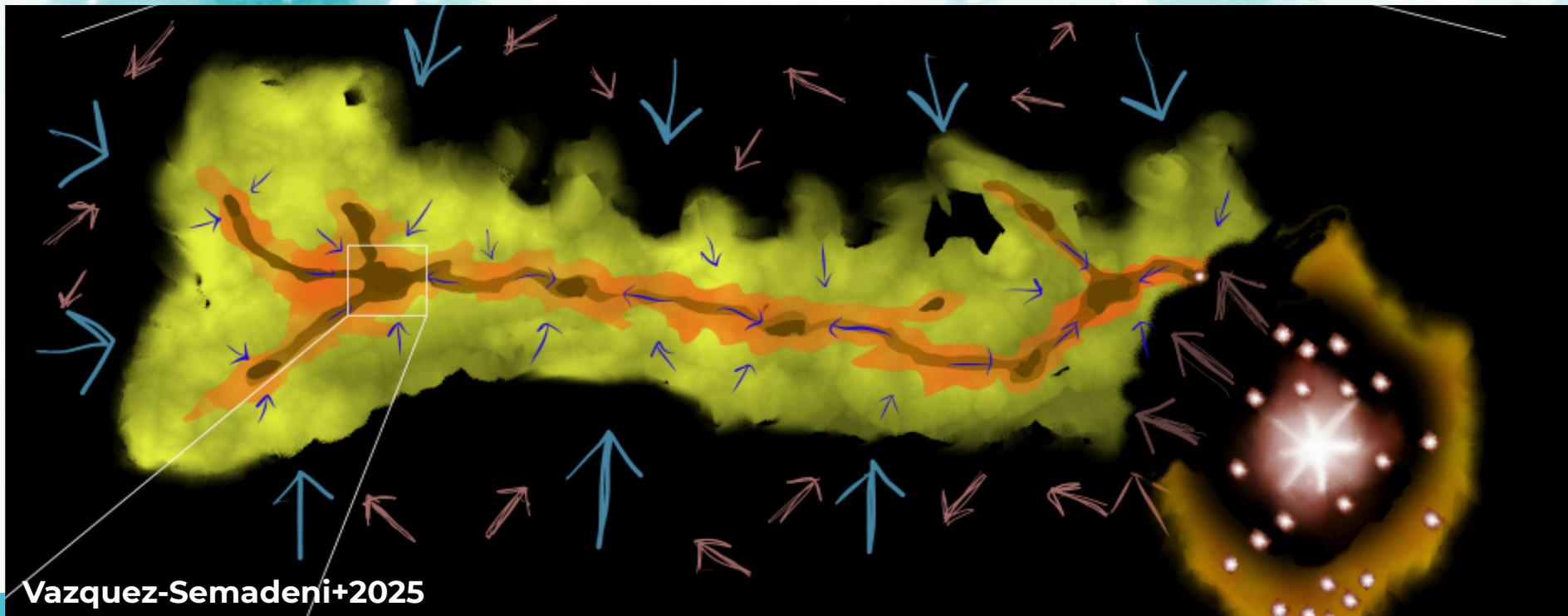
- Traditional view of **Molecular Clouds**: nearly **hydrostatic structures** supported by turbulence and/or magnetic field
- Challenging view of **MCs**: structure **undergoing continuous accretion** from their environment, **not** systematically **supported** against collapse by turbulence nor magnetic fields (**Global Hierarchical Collapse, Vazquez-Semadeni+2025**)

Clouds, filaments, clumps and cores within them are a density hierarchy

➔ *each of them accrete from its respective environment and its mass is continuously replenished by this accretion*

Filaments have a key role in the GHC scenario

- They **transport mass** from parsec scales to protostellar scales and **continuously feed** star forming clumps/cores: **they act as accretion channels**
- Protostellar accretion **does not depend** on the initial core mass but it **depends on** the duration and rate of accretion from the large scale



Key questions:

- size of the mass reservoir
- **the importance of magnetic fields relative to turbulence and gravity**

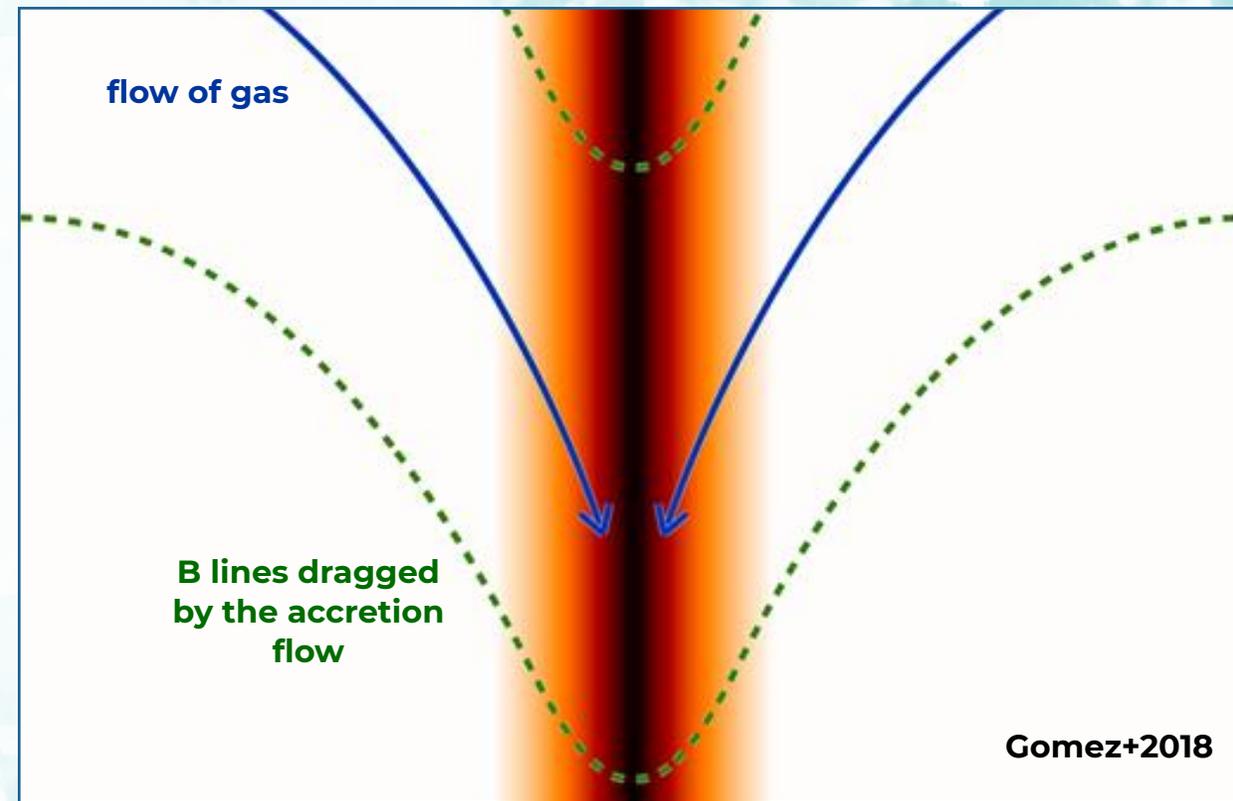
Observational tests:

- filamentary accretion toward hubs
- **intensity/direction of magnetic fields**

GHC scenario:

B field is dragged by the collapsing gas, its structure reflects the gas flow

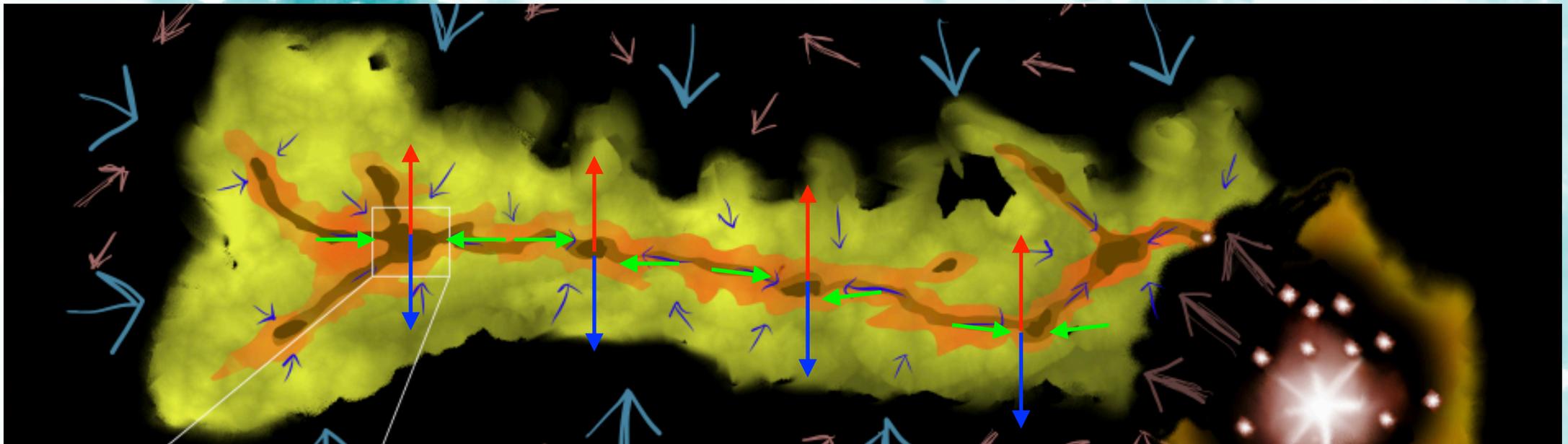
- **around the filament:** the accretion flow is perpendicular to the filament \Rightarrow *B is mainly perpendicular*
- **at high densities:** the gas flow is along the longitudinal axis \Rightarrow *B turns parallel to the filament*
- **at the spine:** B becomes perpendicular because field lines must connect from opposite sides of the filament \Rightarrow *'U'-shaped B structures*



B-field observations are difficult, involve many uncertainties

If filaments inherit angular momentum from the ISM and transfer it to the embedded star forming cores, the rotation axes of newly formed protostars should be coherent along the filament, and perpendicular to the longitudinal axis of the filament **at least as long as local gravity and turbulence takes over**

⇒ the orientation of outflows and of the spine of the filament should be related!



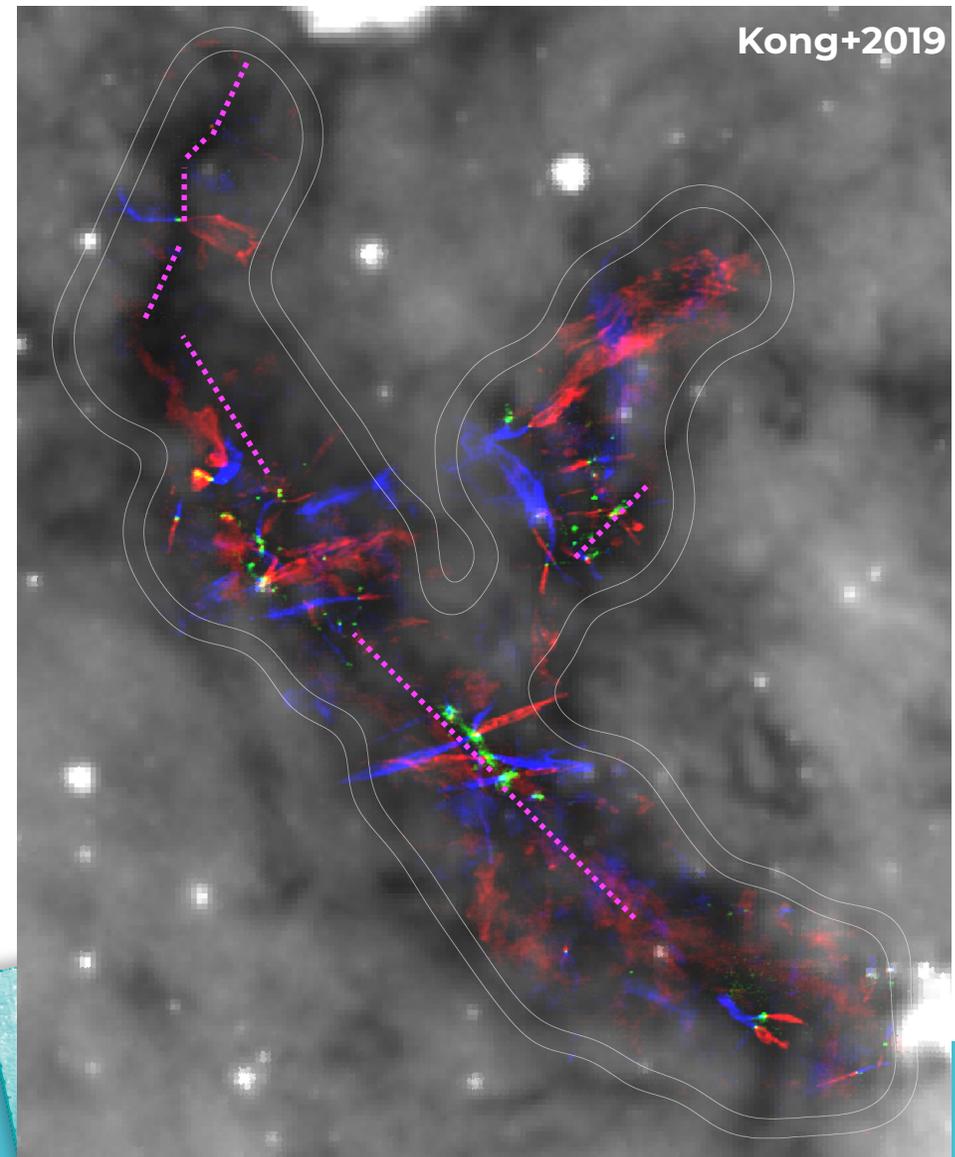
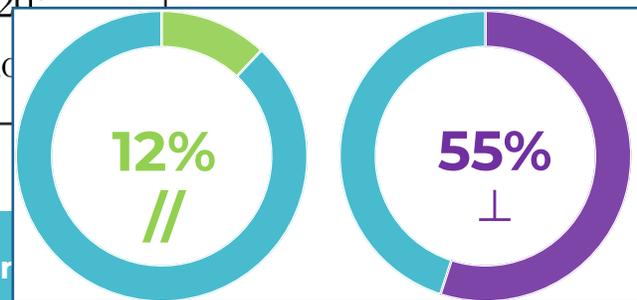
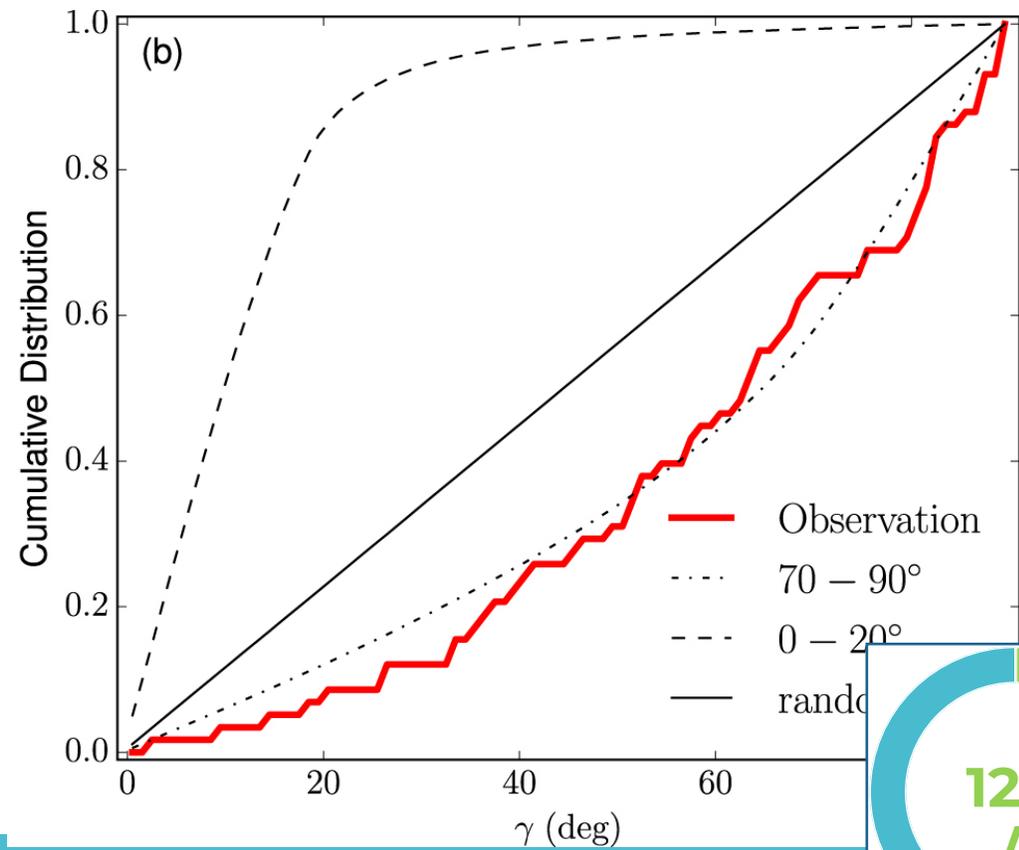
Is there a correlation between outflow/filament orientation?

- extremely young source (IRDC G28.37+0.07)

Kong+2019

$$\gamma = |\text{PA}_{\text{out}} - \text{PA}_{\text{fil}}| = \text{angular separation between outflow and filament position angles}$$

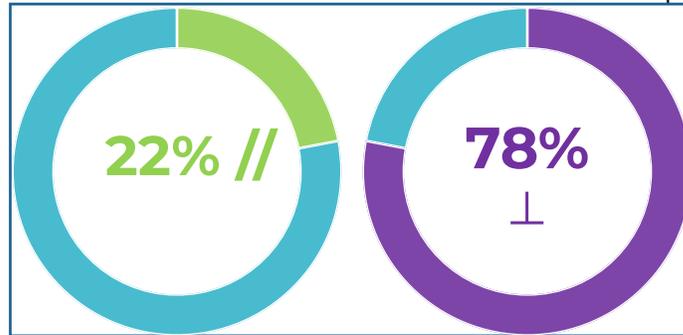
3D Monte Carlo simulations projected onto 2D



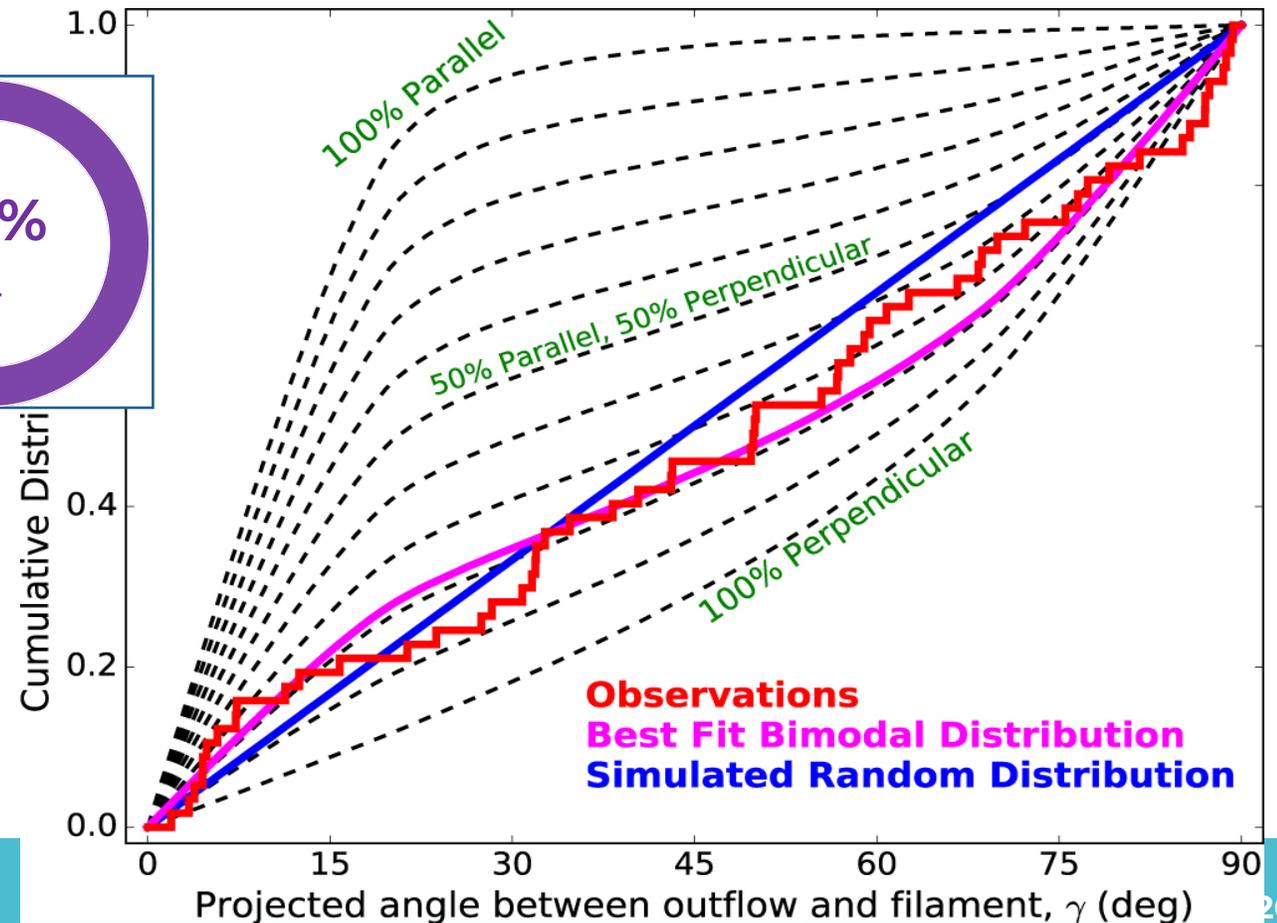
Is there a correlation between outflow/filament orientation?

BUT results are quite controversial till now:

- evolved massive and luminous clumps with HII (Baug+2020): **outflows randomly orientated**
- other sources (e.g., Stephens+2017): **mixed population** (20% parallel, 80% perpendicular)



Mixed populations



Stephens+2017

Probably different mechanisms at act!

- different processes for filament formation
- turbulence, multiplicity etc at small scales
- Evolution/feedback/gravity

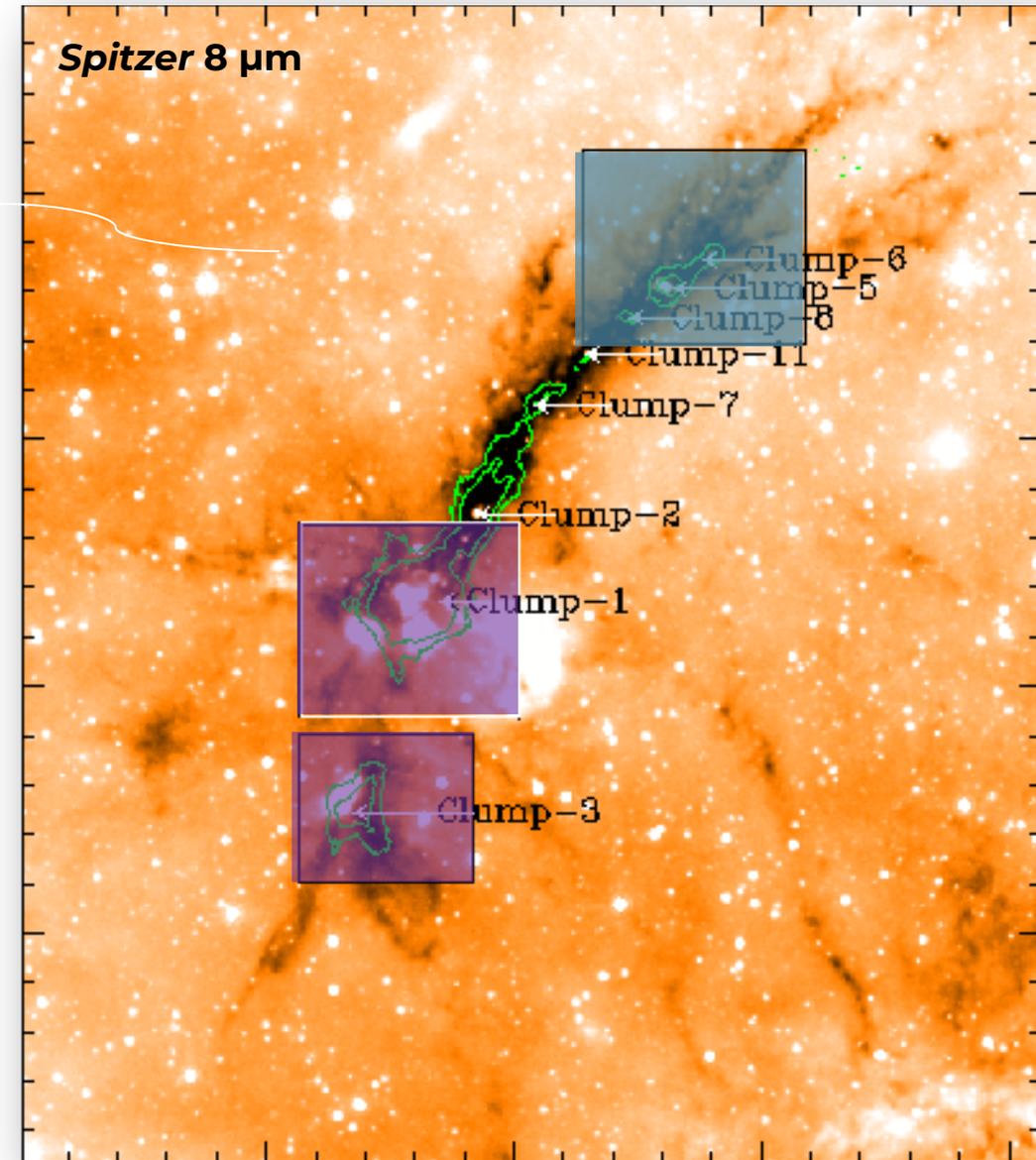
IRDC G351

- massive SF cloud (2 kpc, 10400 M_{\odot} , Leurini+2019)
- hosts different phases of SF

Northern region: quiescent (dark even at 70 μm) and cold (~ 12 K), similar to the conditions of IRDC G28.37+0.07

Southern region: Clump-1 and Clump-3 active sites of massive SF, host HII regions, multiple outflows..

Clump-1 satisfies the selection criteria of Baug+2020



ALMA observations

band 3 observations (149-pointing mosaic + ACA + TP,
beam $\sim 2''$, $\Delta v = 0.2/0.5$ km/s)

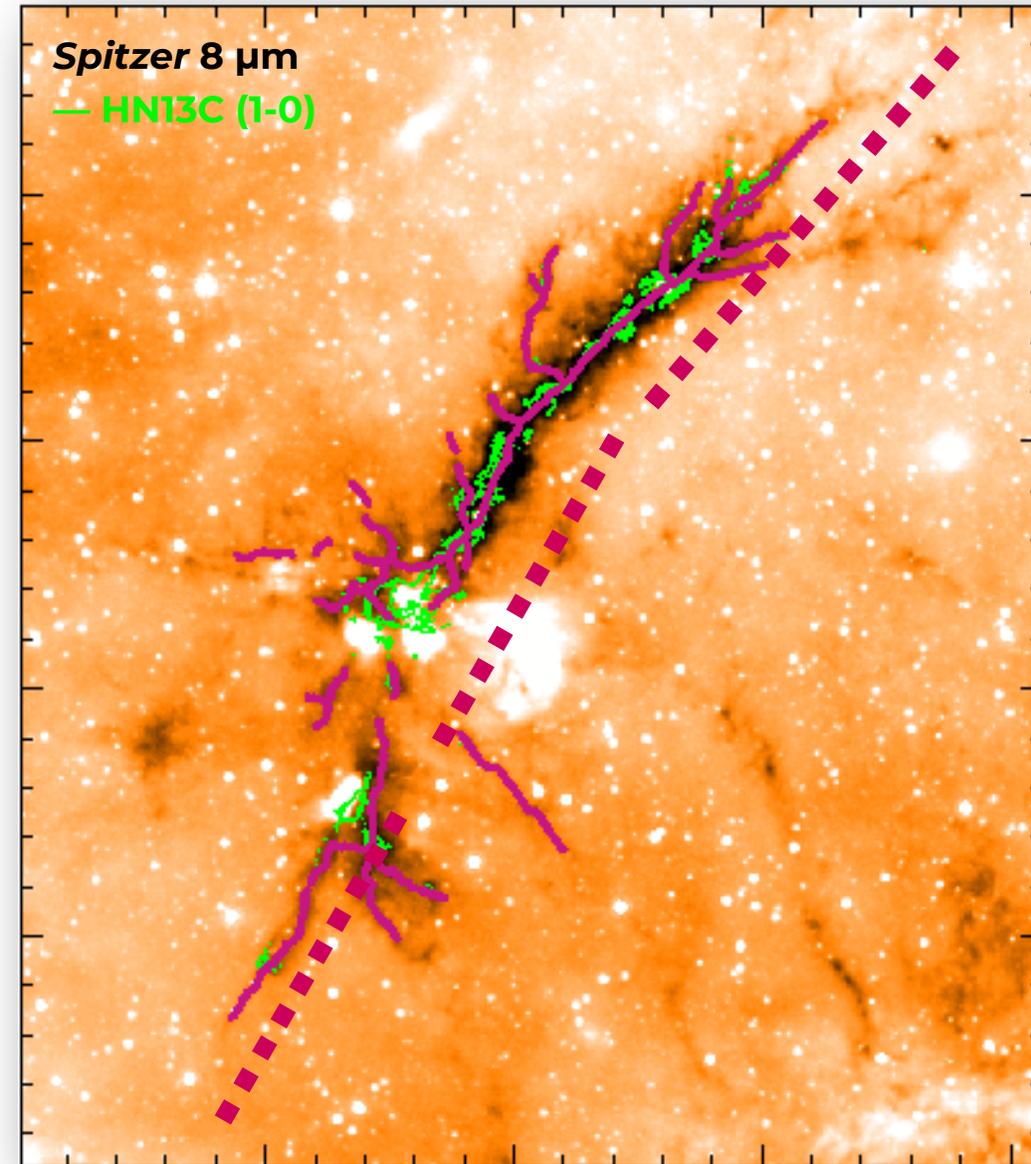
I. **HN13C (1-0)** \rightarrow tracer of dense gas

II. **SiO(2-1)** \rightarrow unambiguous tracer of shocks

HN¹³C clearly traces the highest extinction region of the filamentary network but it is too noisy

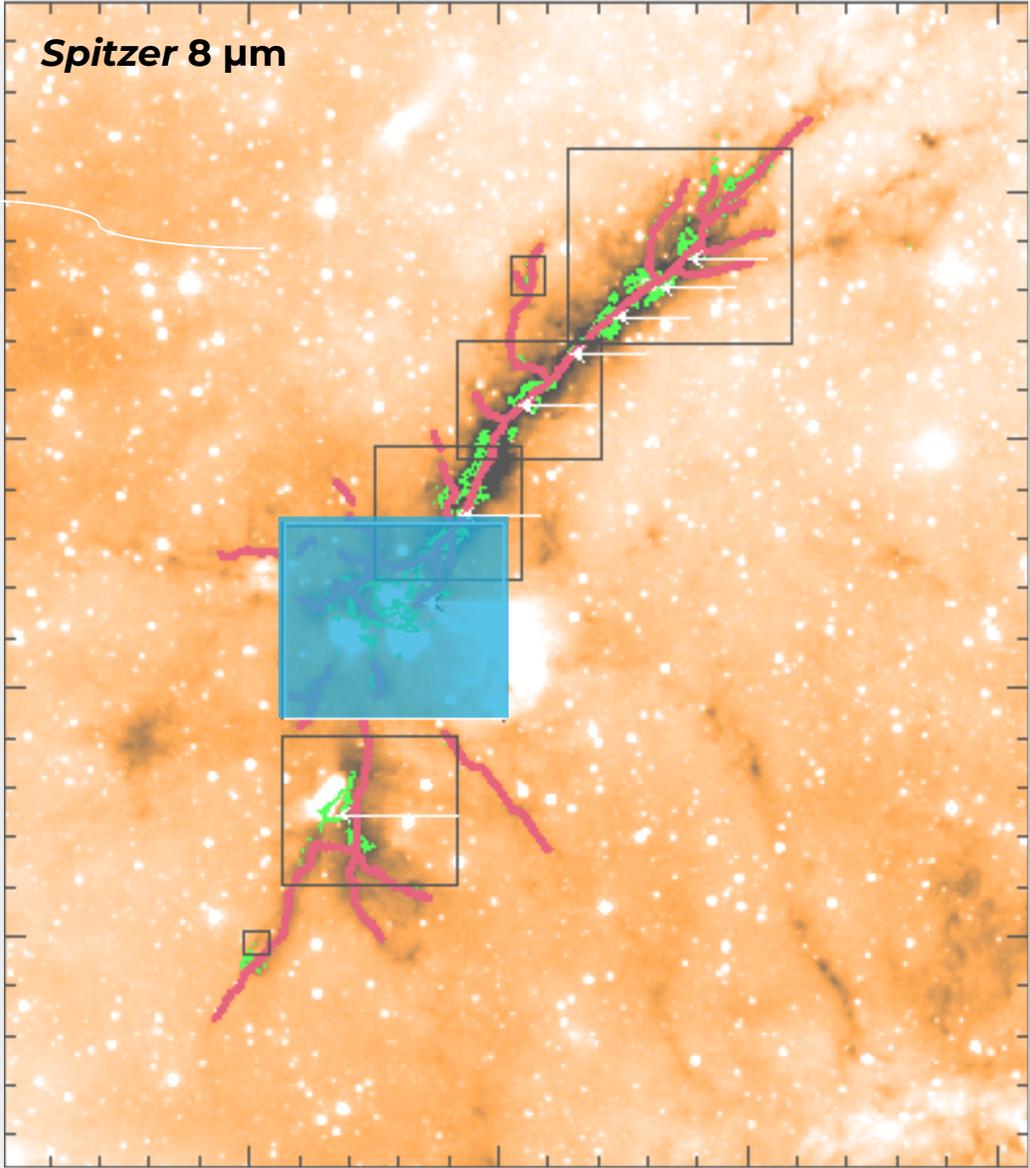
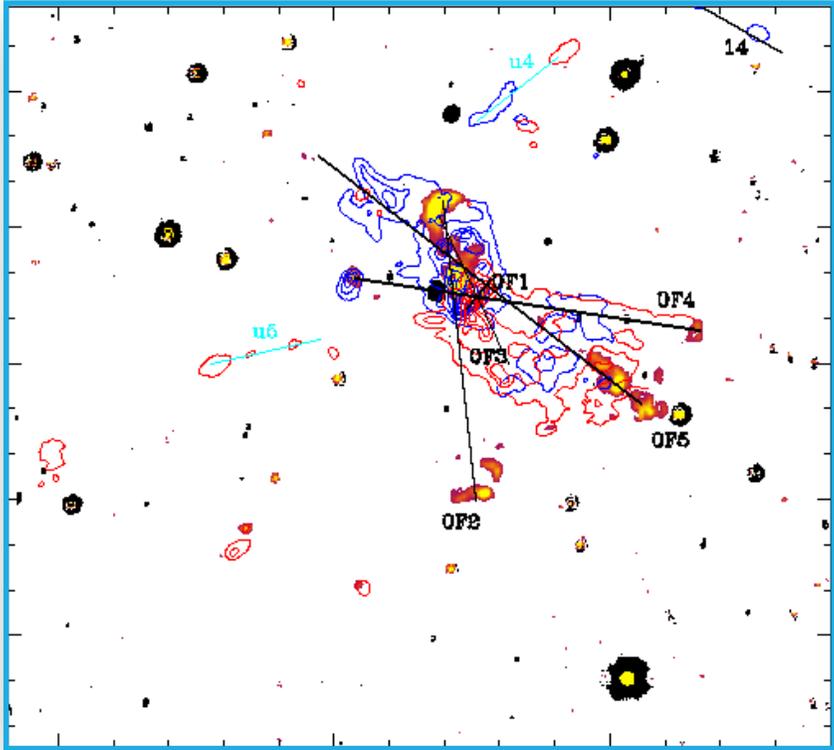
Spitzer 8 μ m matches ALMA resolution and have enough sensitivity on the weakest structures

The **orientation angle** of the main filament relatively **constant**, south steeper than the north



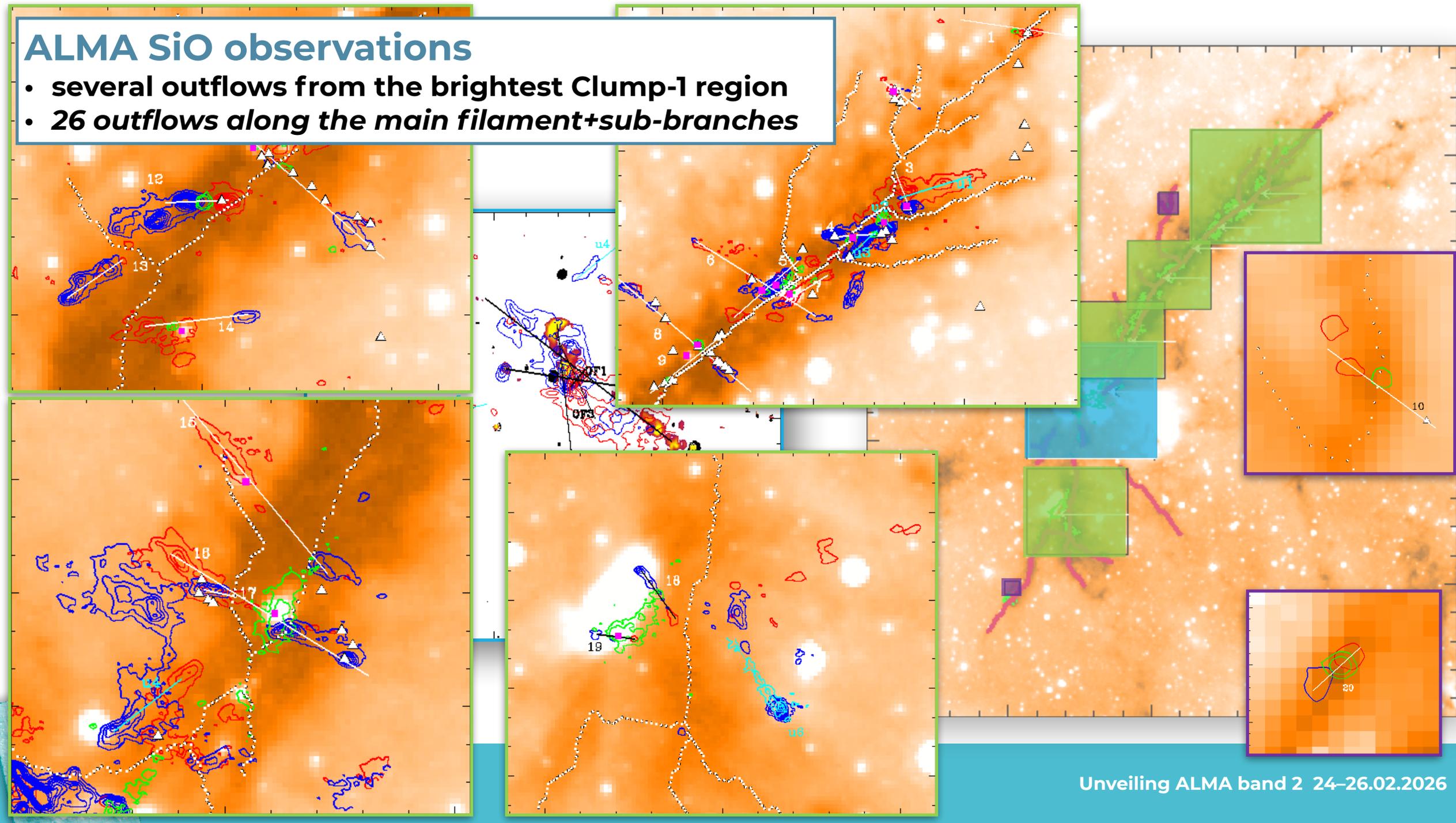
ALMA SiO observations

- several outflows from the brightest Clump-1 region
- 26 outflows along the main filament+sub-branches



ALMA SiO observations

- several outflows from the brightest Clump-1 region
- **26 outflows along the main filament+sub-branches**

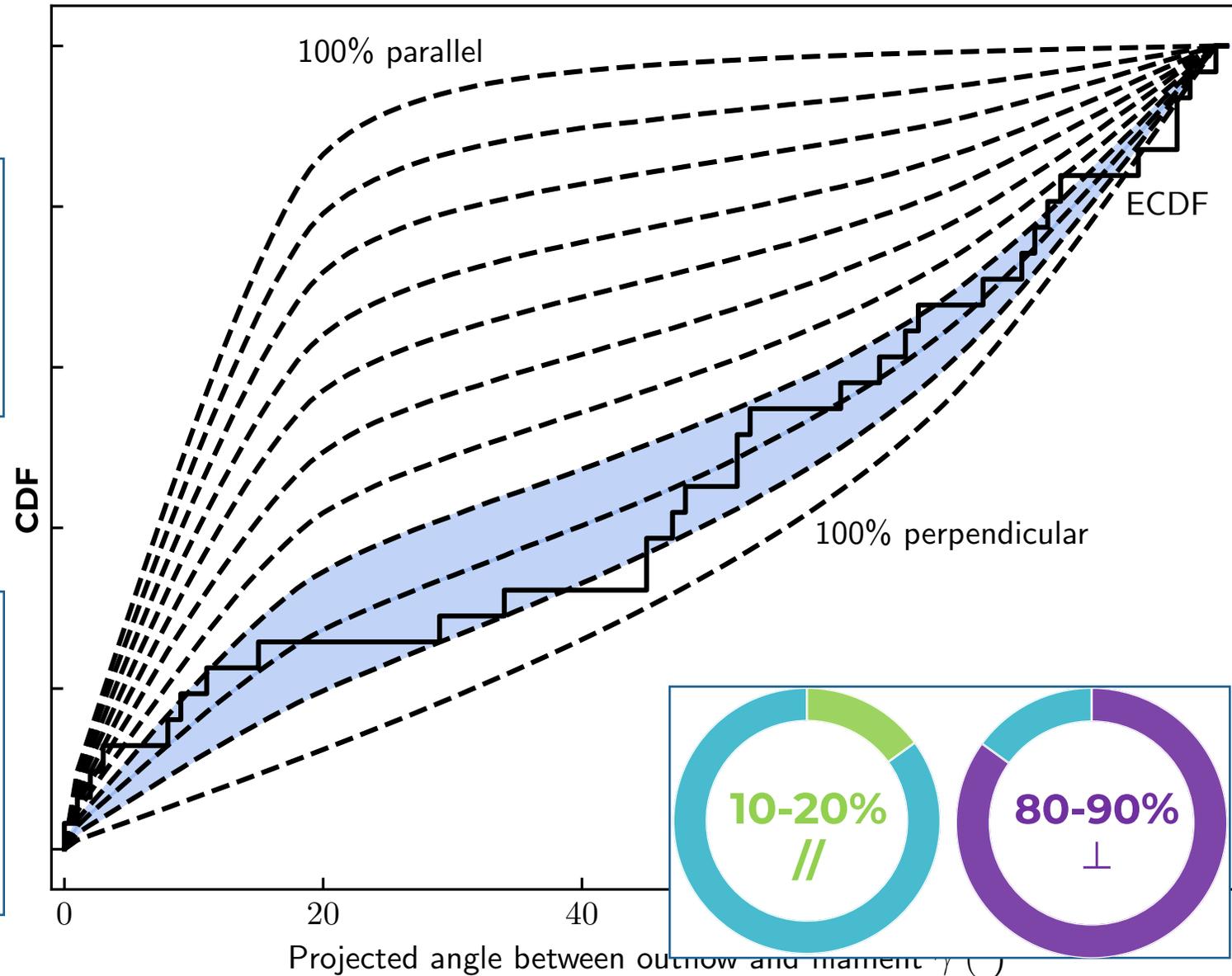


Outflows in G351

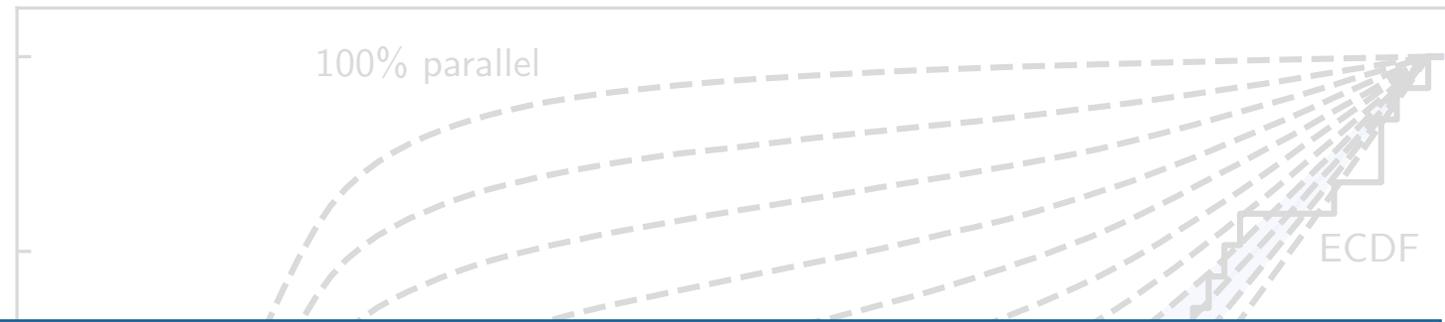
Best fit:
mixed population of parallel (10-20%)
and perpendicular (80-90%) outflows
with the majority of outflows
perpendicular to the filament!

In G351:
- 14 out of 31 outflows have $\gamma > 60^\circ$
- 12 out of 22 if we exclude Clump-1

In the quiescent part only:
- only 3 out of 14 have $\gamma < 20^\circ$
- 7 have $\gamma > 70^\circ$



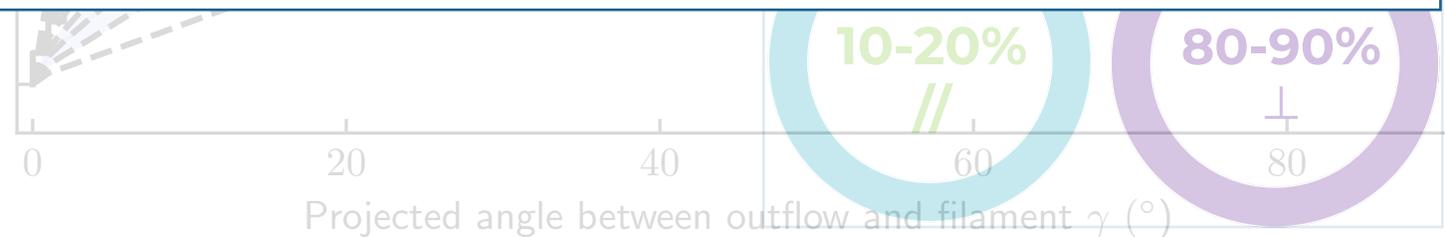
Outflows in G351



However, the statistics in the more evolved regions is too low to correlate the outflow/filament orientation with the evolutionary state

Possible limitations:

- SiO may not give us the full picture \Rightarrow **we probably miss a population of less energetic outflows**
- NO reliable (strong and unambiguous) tracer of the dense gas in our ALMA setup \Rightarrow **the spine is defined on IR data with all their issues (e.g., extinction and saturation on Clump-1)**

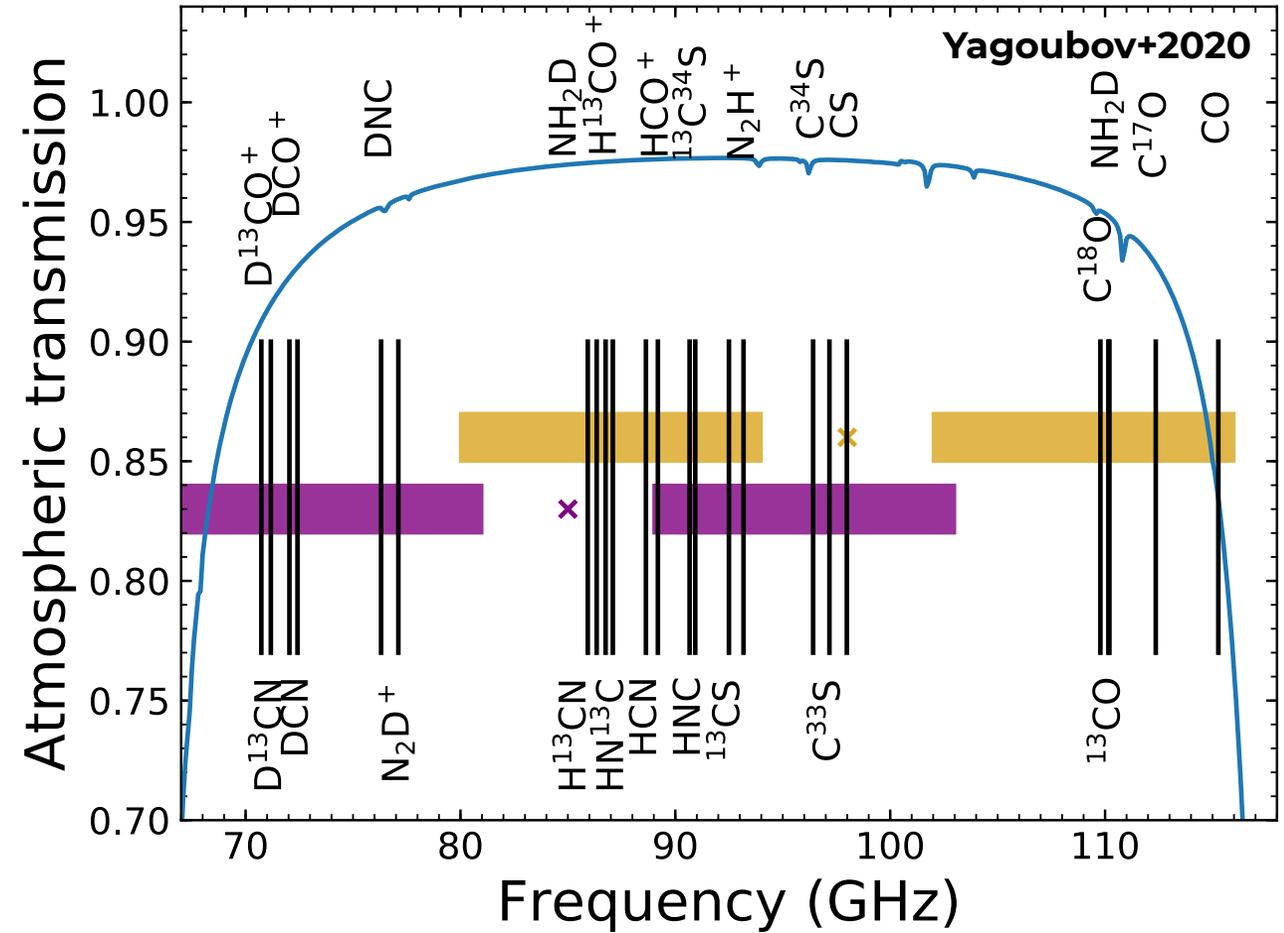


ALMA Band-2 receiver (WSU 2030)

New ALMA band-2 receivers in will be fundamental!

Simultaneous observations of:

- **SiO(2-1) and $^{13}\text{CO}(1-0)$ in USB for a complete view of molecular outflows**
- **$\text{N}_2\text{H}^+(1-0)$, $\text{H}^{13}\text{CO}^+(1-0)$ as tracer of dense gas (density structure, spine ...)**
- **Deuterated species for the kinematics of the quiescent cores to test their relation to the kinematics of the whole filament**



Thank you for your attention!