Impact of B fields on high-mass star formation

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Special credits to I. Ristorcelli (IRAP Toulouse), A. Maury and P. Didelon (CEA-Saclay), and C. Arce (U. Chile)

NIKA2 collaborators for coming projects:
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in the framework of the *Herschel*/HOBYS and ALMA-IMF consortia

Outline

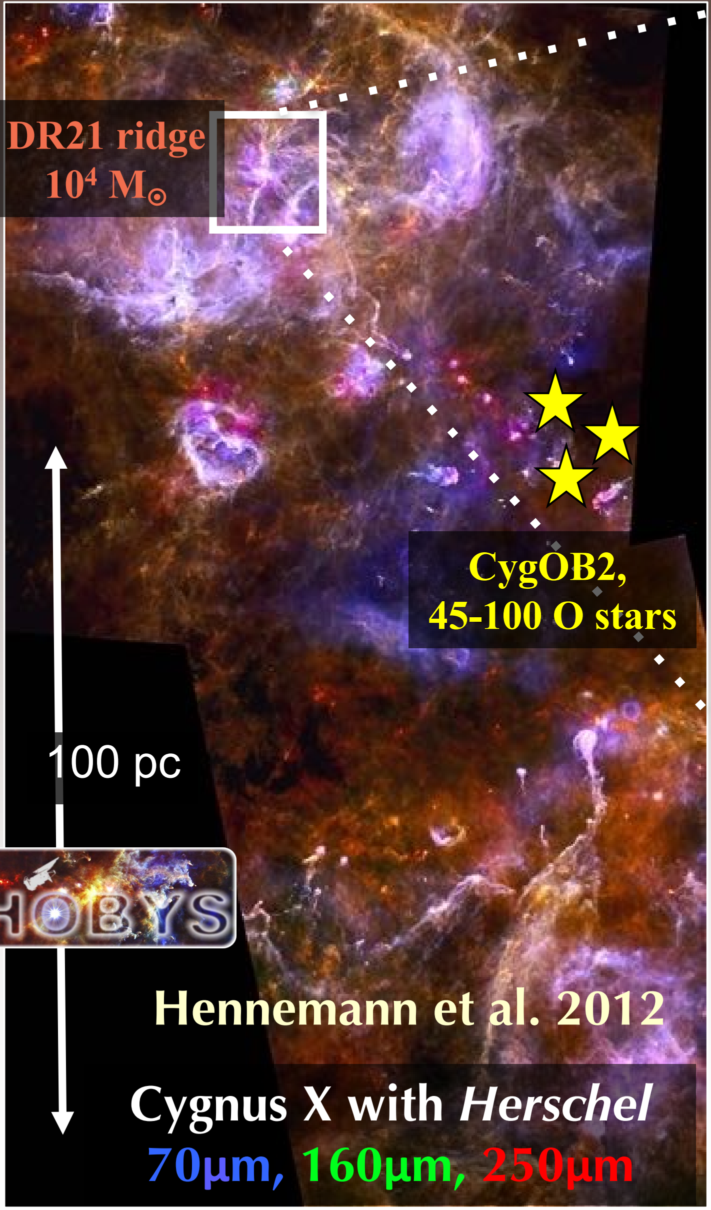
Introduction
- Star formation scenarios
- Expected role of magnetic field

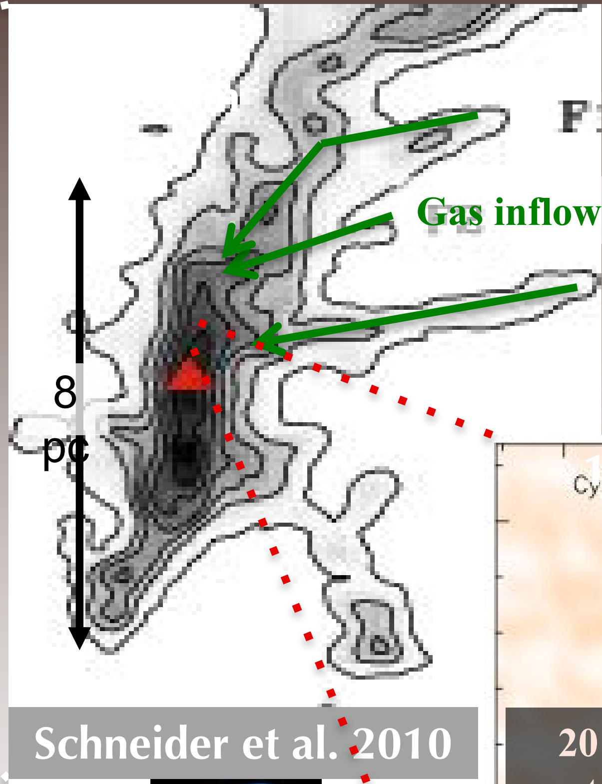
Role of B-field on pc scales
- Investigating the coupling with cloud/clump structure
- Investigating the coupling with gas dynamics

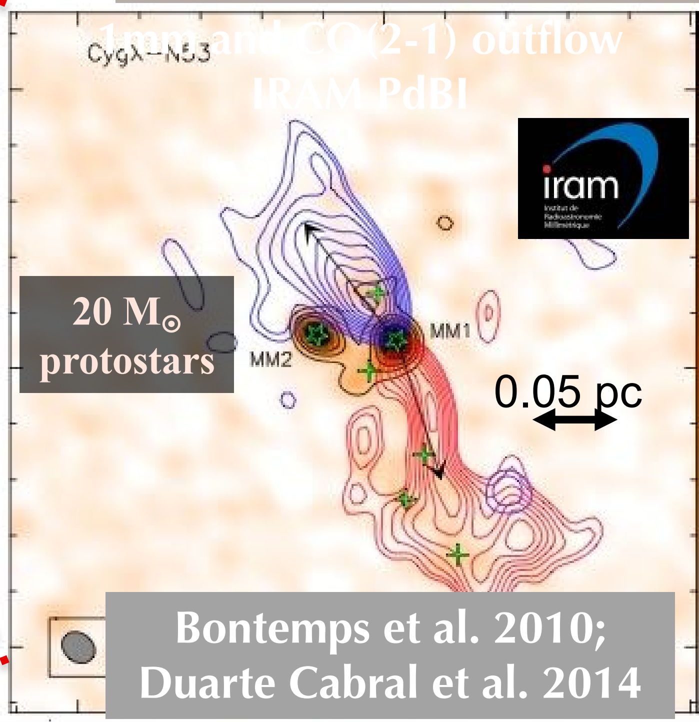
Role of B-field on sub-pc scales
- Investigating the coupling with core ellipticity
- Investigating the coupling with disk, jet and rotation

Conclusion

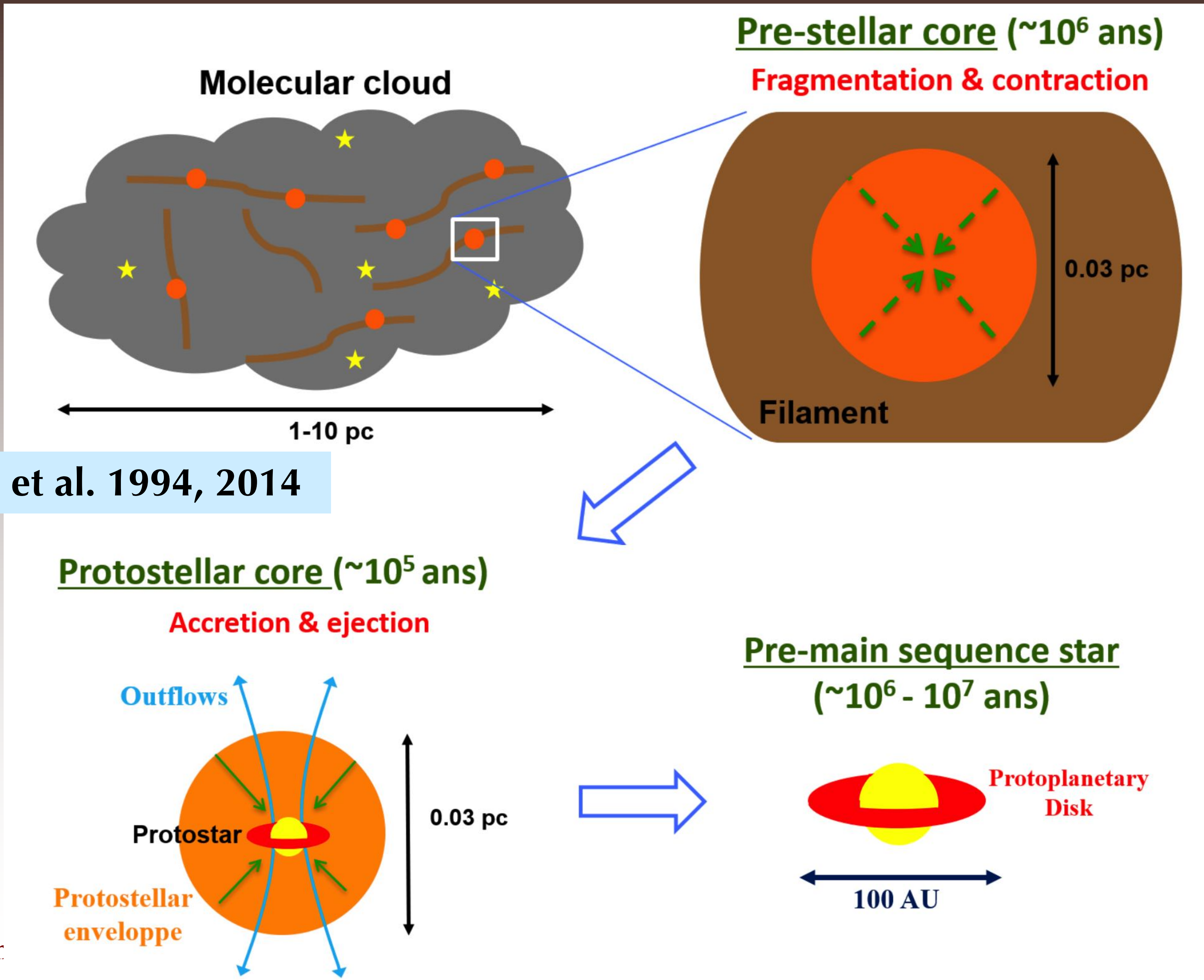
The multi-scale process of star formation: From massive cloud complexes to individual protostars





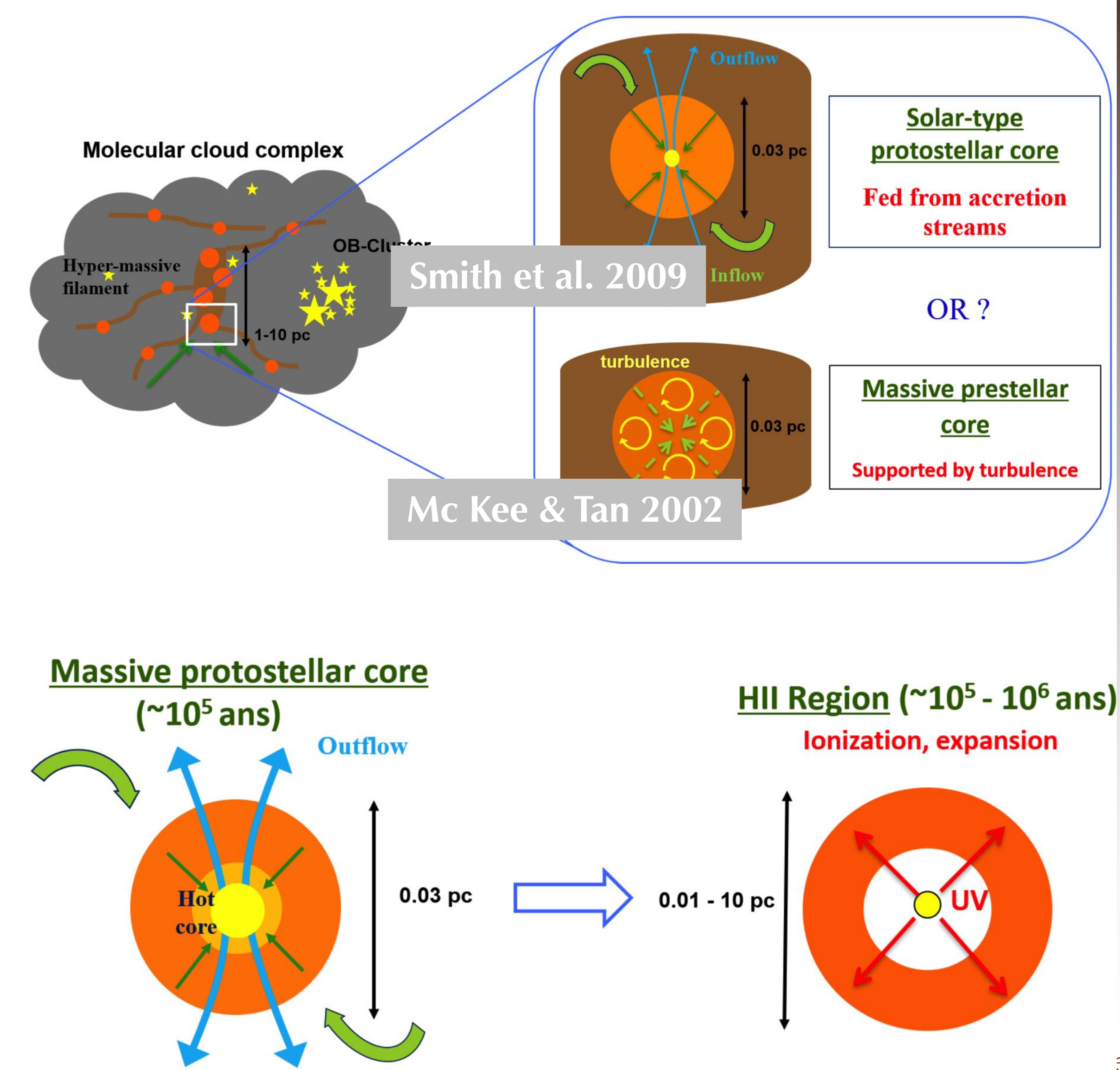


Low-mass star formation scenario



André et al. 1994, 2014

High-mass star formation scenario



Global hierarchical collapse

Stars, cores, and ridges simultaneously grow from the mass of their parental cloud.

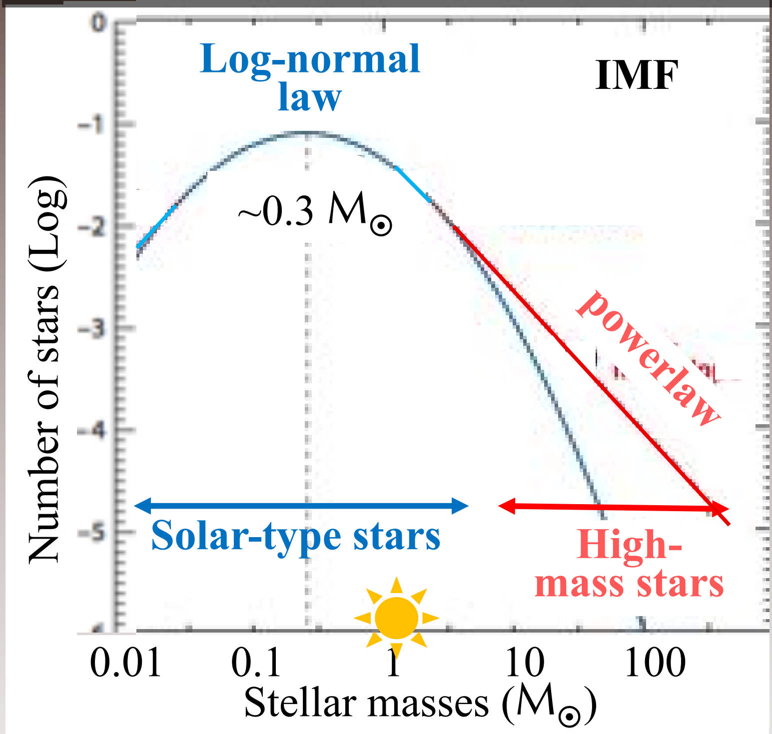
⇒ "clump-fed" model

⇒ No need of a high-mass prestellar core phase

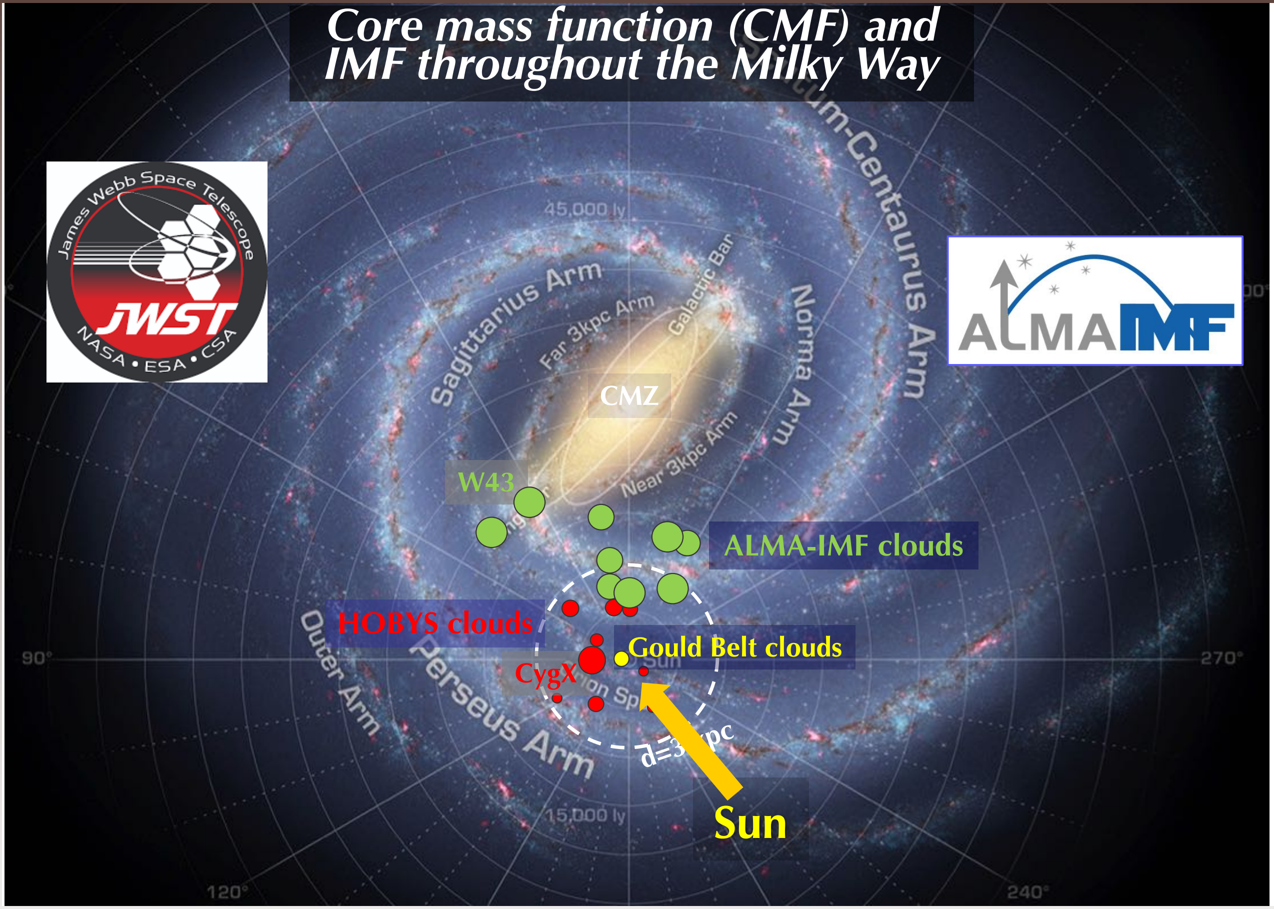
Motte, Bontemps & Louvet ARA&A 2018

Star formation: origin of the stellar masses

Initial mass function of stars (IMF)



Core mass function (CMF) and IMF throughout the Milky Way

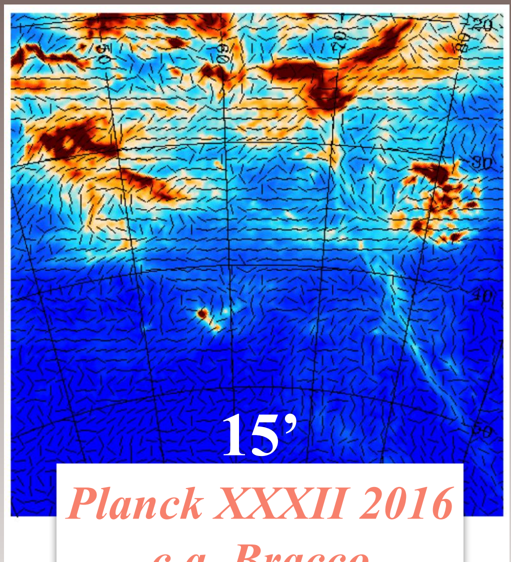


→ **The distribution of core masses (CMF) is expected to vary with the Galactic environment (density, kinematics, magnetic field)**

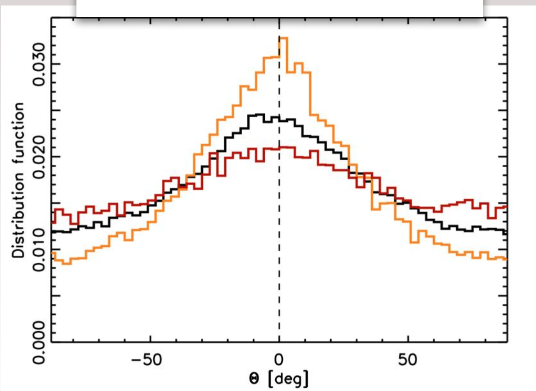
→ **Will the resulting IMF finally be universal ?**

The role of B-field in shaping the ISM through filamentary structures

Filaments in the Diffuse ISM

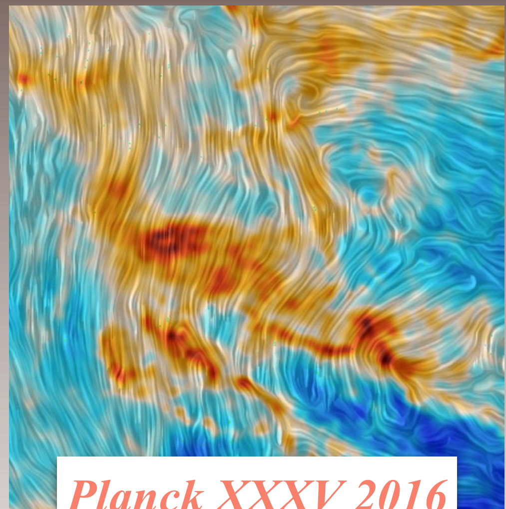


Planck XXXII 2016
c.a. Bracco

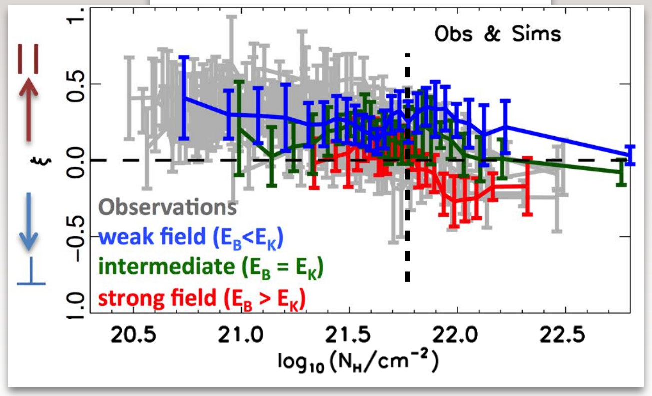


B-fields & filaments mostly aligned

Nearby Molecular complexes

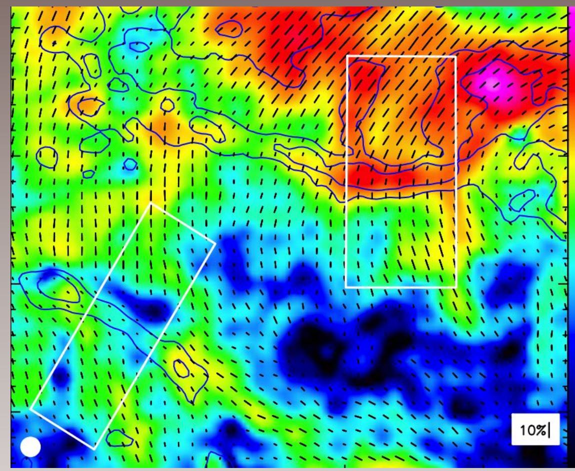


Planck XXXV 2016
c.a. Soler



NH transition between // and perp. orientations

Modeling of Nearby Filaments



Planck XXXIII 2016
(c.a. Arzoumanian)

B-fields within dense filaments do not have the same orientation as in the Background

The role of B-field for star formation

Star-forming material is (partly) coupled to the ambient magnetic field

- @ scales ~1 pc:

B field guides accretion onto star-forming filaments (e.g. Palmeirim 2013)

- @ scales ~0.1-0.01 pc:

B field regulates the collapse and fragmentation (mass segregation, limitation of the fragmentation, e.g. Hennebelle & Inutsuka 2019)

- @ scales ~1000 AU:
  - ➢ B field regulates the geometry of collapsing cores

⇒ B field perpendicular to cores major axis (e.g. Li et al. 2013)

  - ➢ B field regulates the momentum of circumstellar material (magnetic braking, e.g. Pudritz & Ray 2019)

⇒ ejection of jets/outflows along the B field

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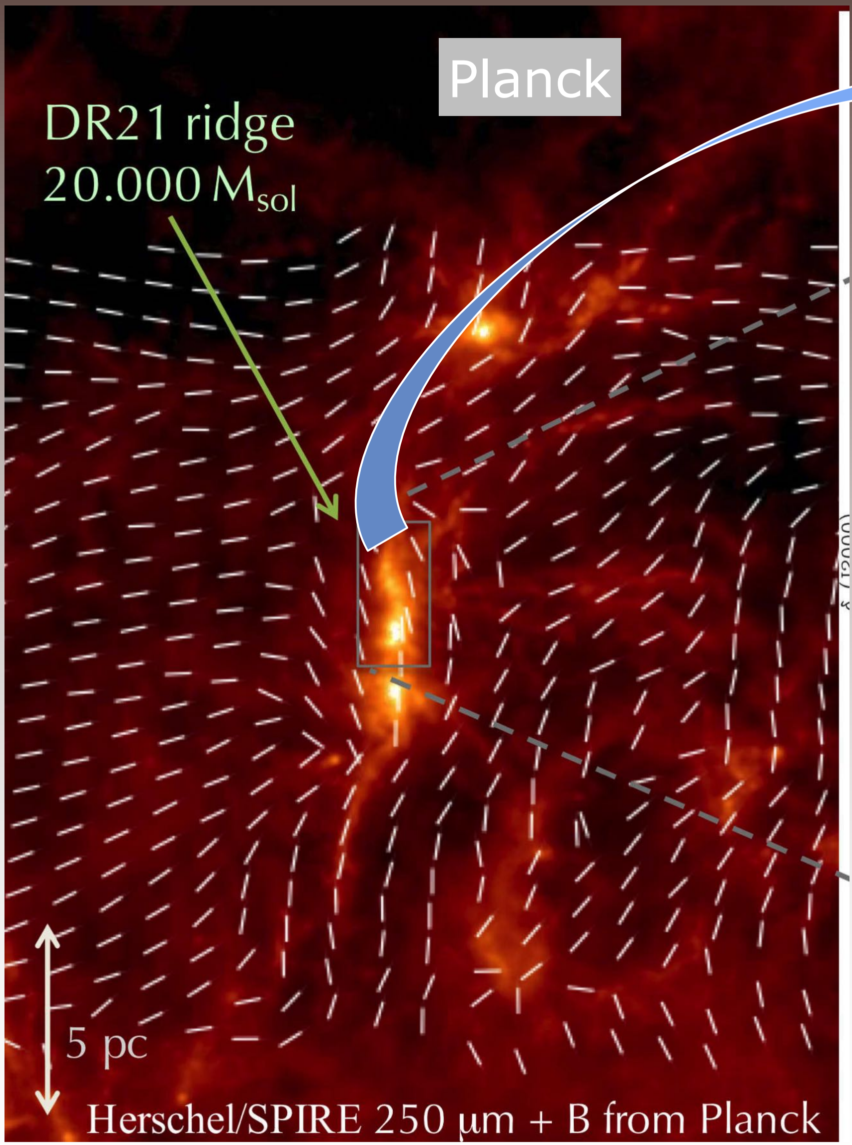
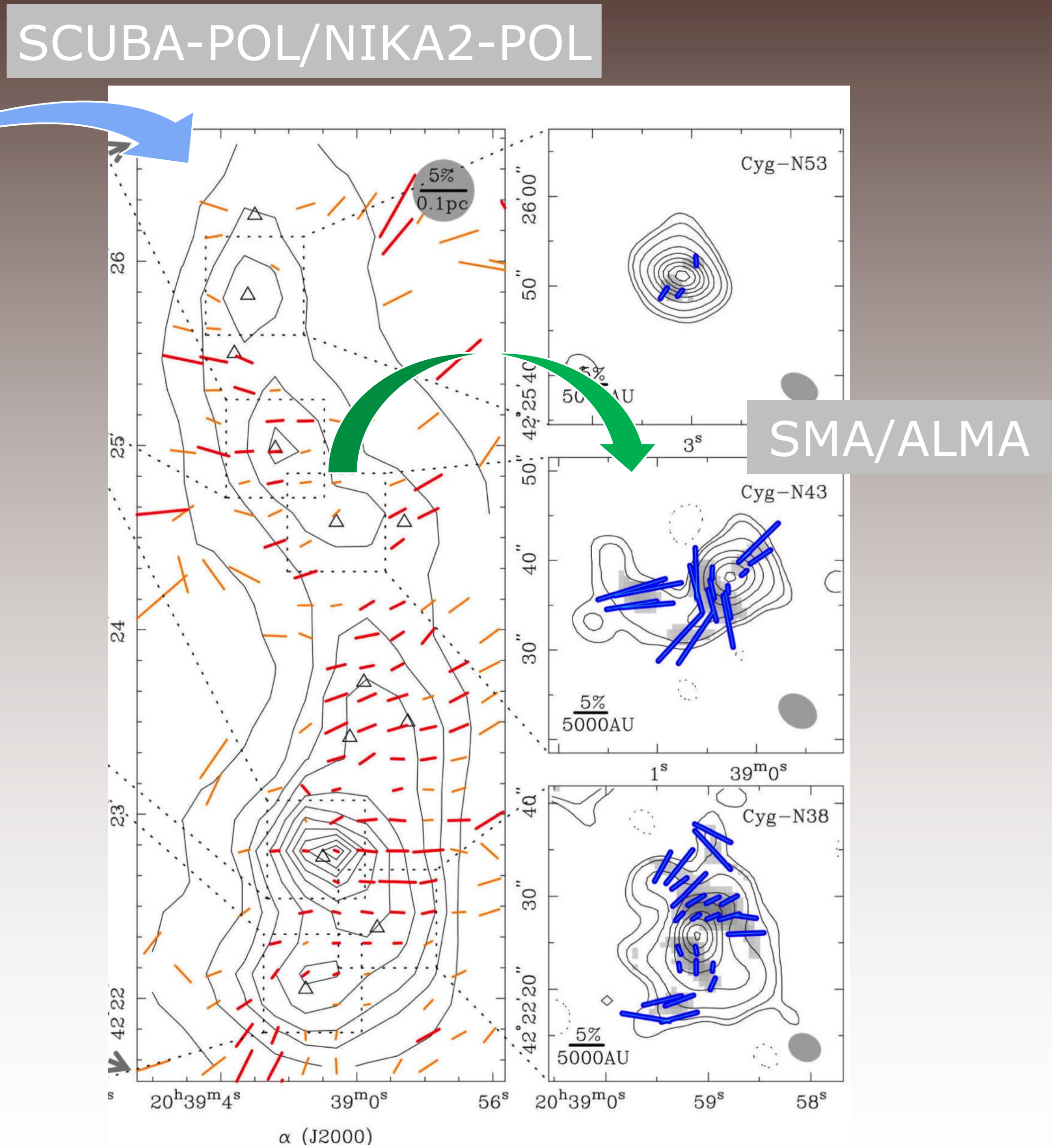
Magnetic field topology from filaments to cores

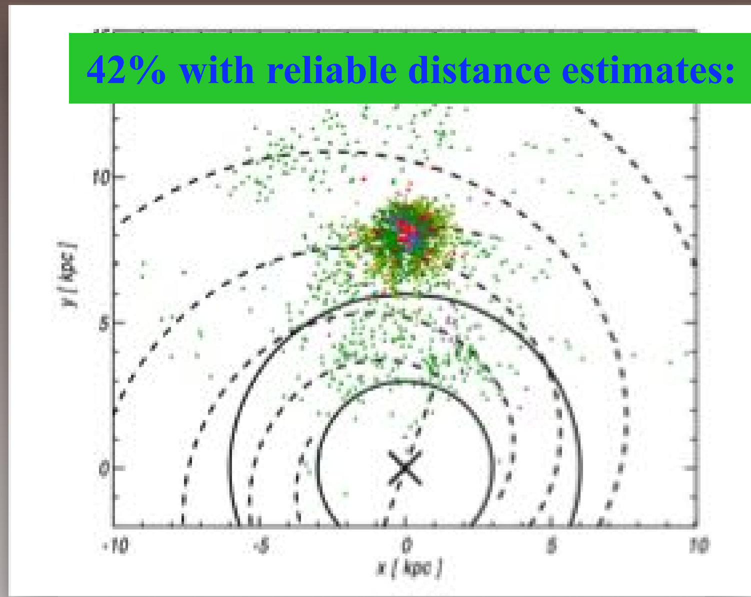




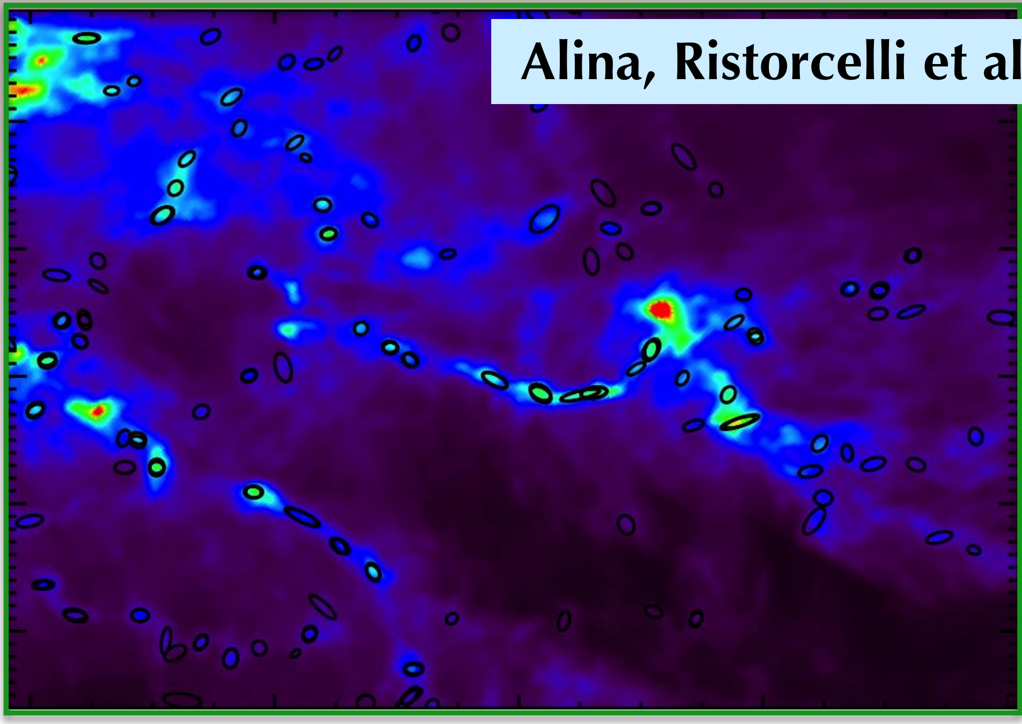
Orientation relative to the B field for star-forming filaments and cold clumps

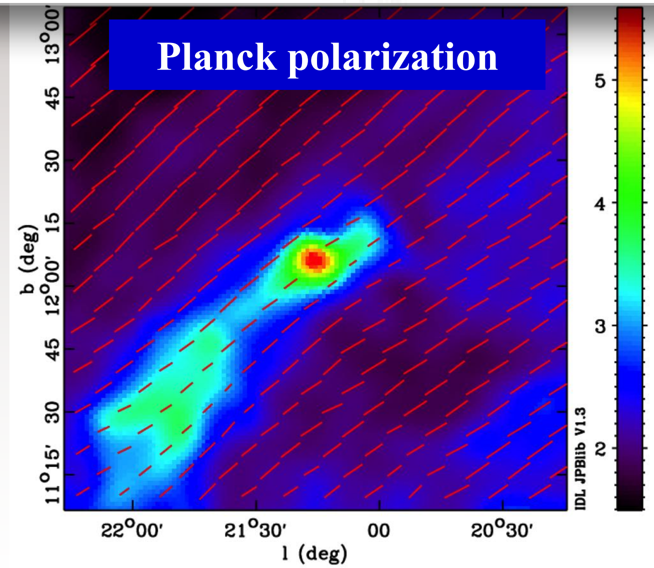
Planck all-sky catalogue of Galactic cold clumps (Planck Collaboration XXIII 2011, XXVIII 2015, c. a. Montier)

⇒ ~13 100 clumps (0.1-1 pc) within filaments



Alina, Ristorcelli et al. 2019





Statistical analysis of the relative orientation

With respect to $B_{background}$

Filaments with n_{H2} > 10^3 cm^{-3}: perpendicular

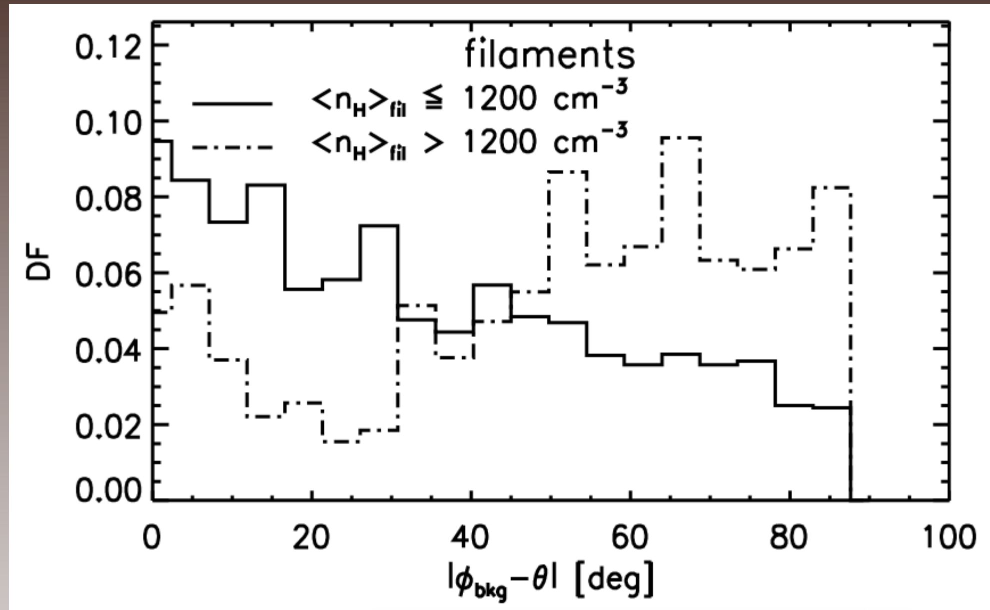
n_{H2} < 10^3 cm^{-3} : align more

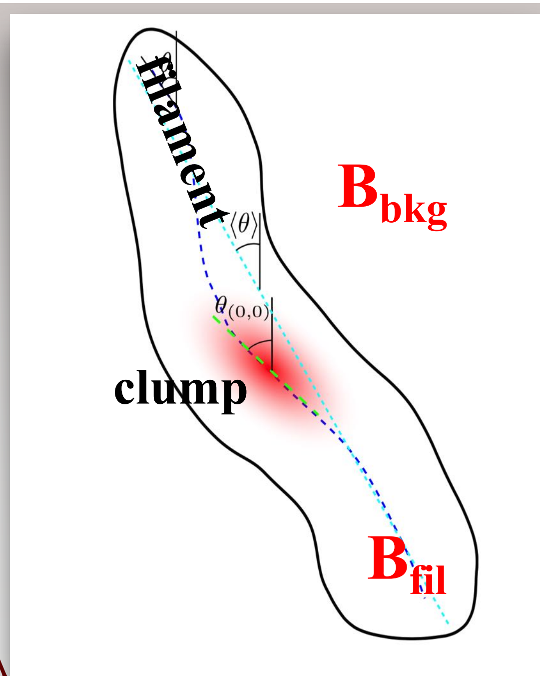
With respect to $B_{filament}$

Clumps with ΔN_{H2} < 4 10^{20} cm^{-2}: aligned

ΔN_{H2} > 4 10^{20} cm^{-2} : both

Alina, Ristorcelli et al. 2019

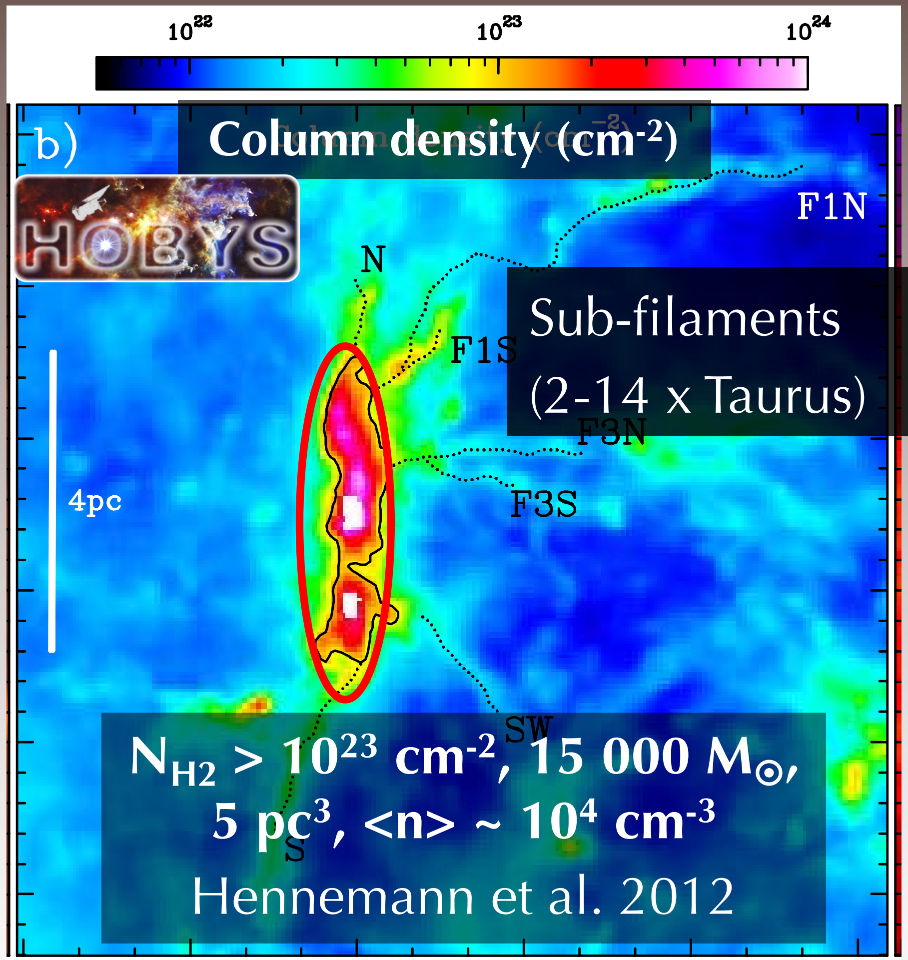


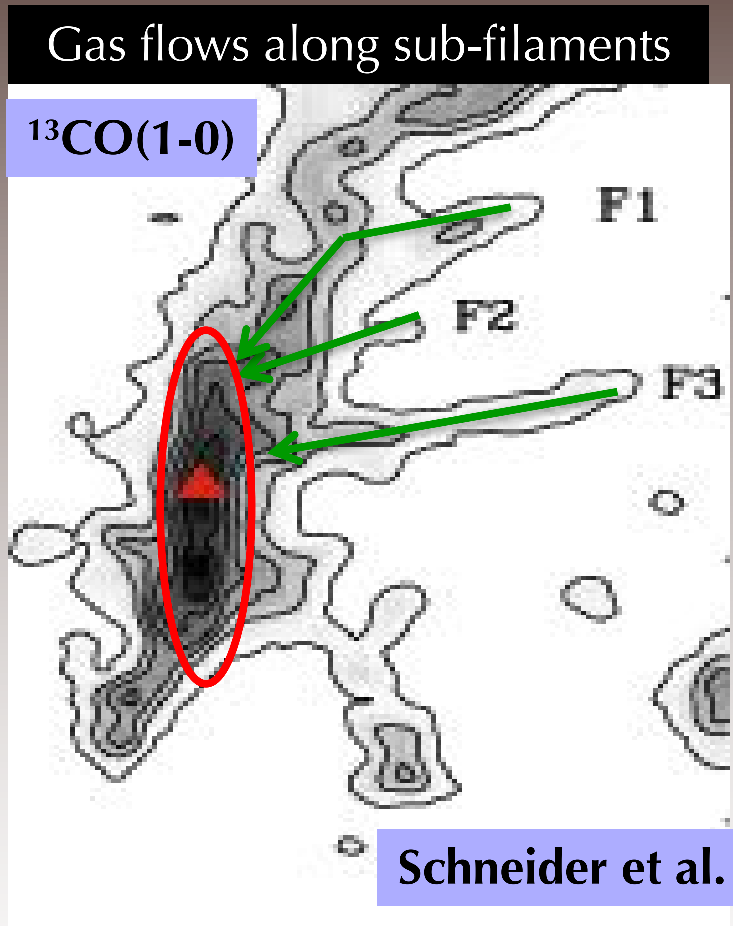


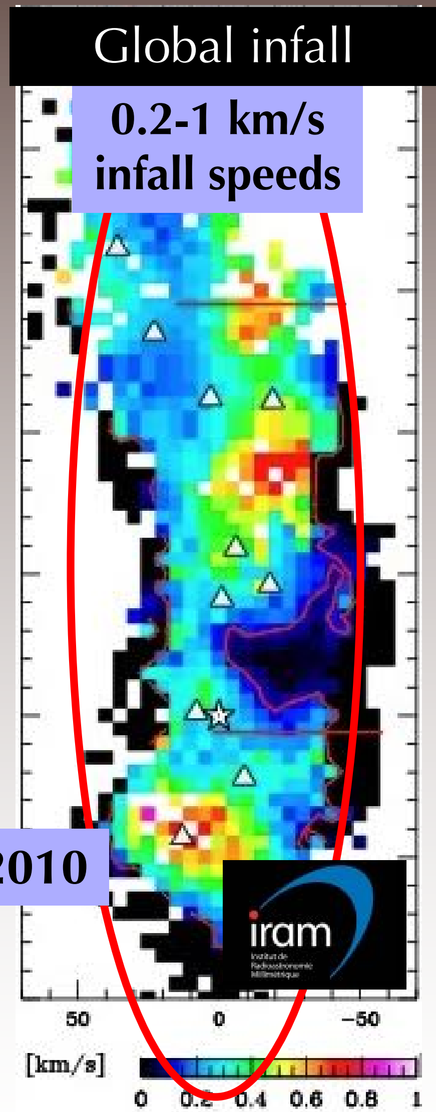
→ **(Partial) coupling between matter and B fields during the formation of filaments and clumps**

NIKA2 follow ups to measure the B_{clump} orientation

Most high-density clouds should form by global collapse and braid of sub-filaments



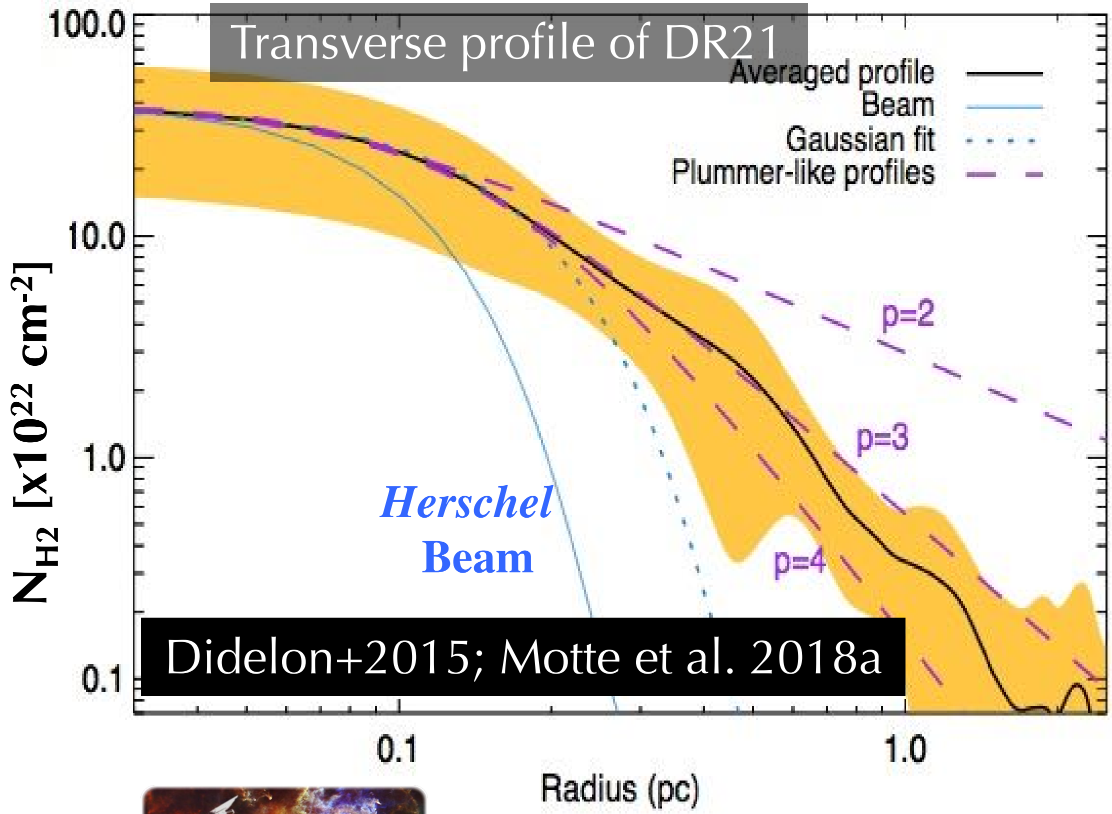




See also Peretto+ 2013, 2014; Henshaw+2014, 2016; Beuther+ 2012; Nakamura+ 2014…

Ridges are braids of filaments whose collapse is slowed by rotation and/or B-fields

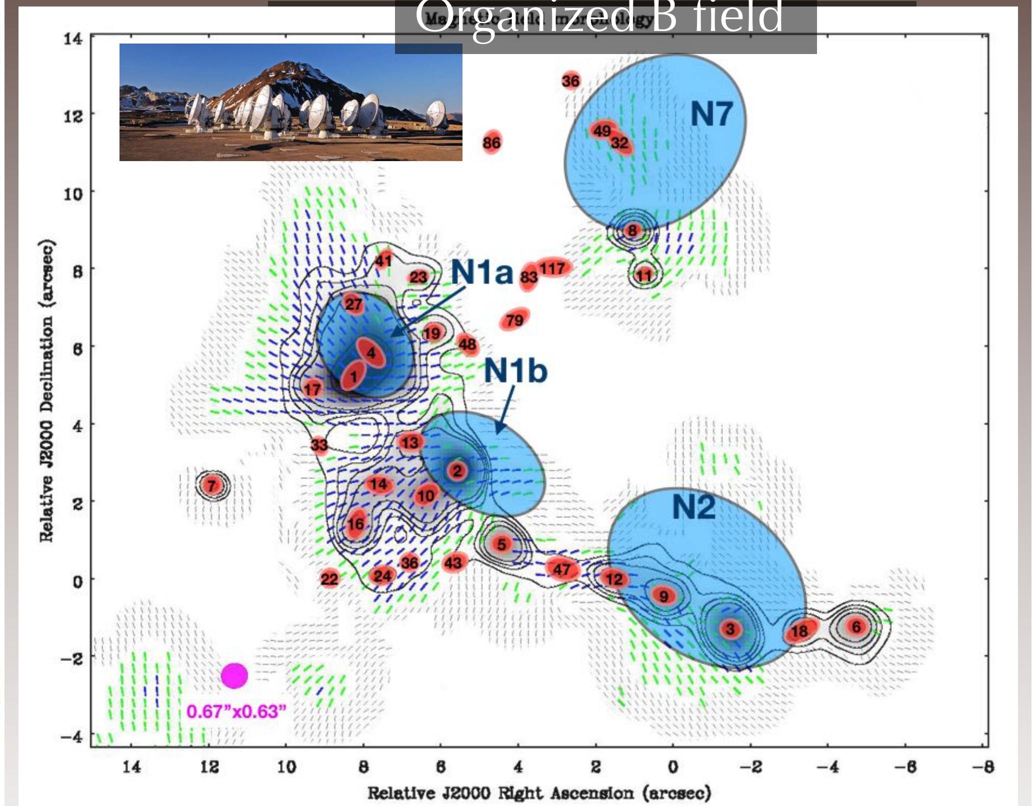
Transverse profile of DR21



Didelon+2015; Motte et al. 2018a

HOBYS

Organized B field



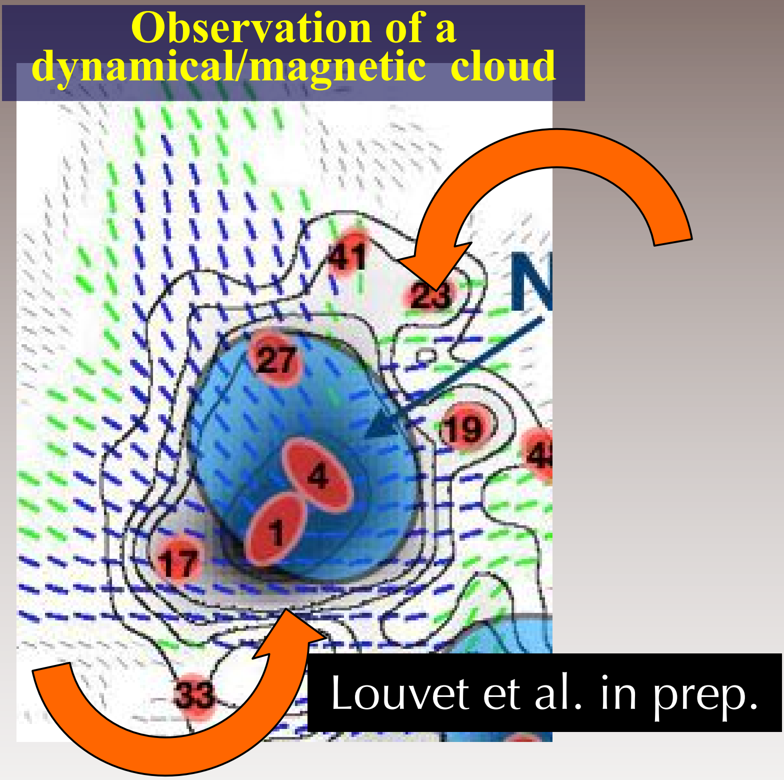
Louvet et al. in prep.; Arce et al. in prep.

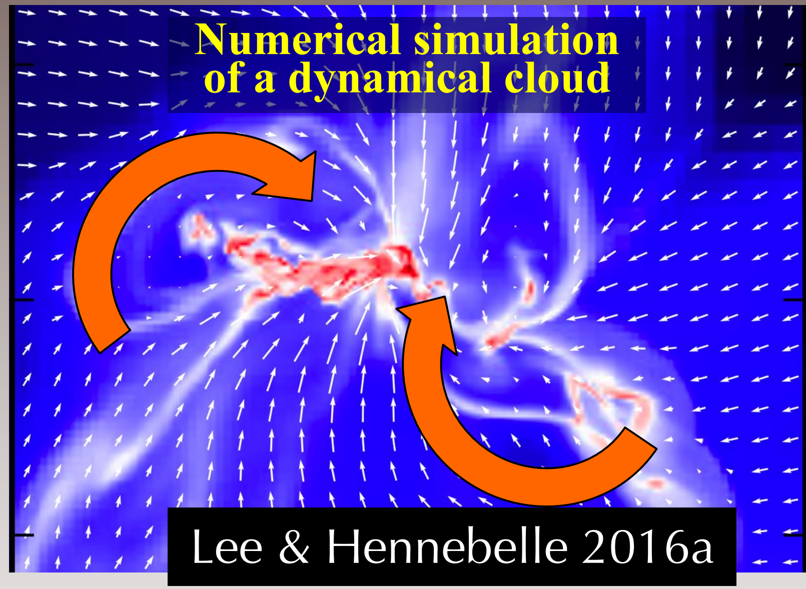
Consistent with PDF studies (Russeil+ 2013; Schneider+2015)and inflow studies (e.g. Wyrowski+ 2016).

⇒ **NIKA2-Pol project toward ridges (B-FUN on DR21, OT Proposal for MonR2…)**

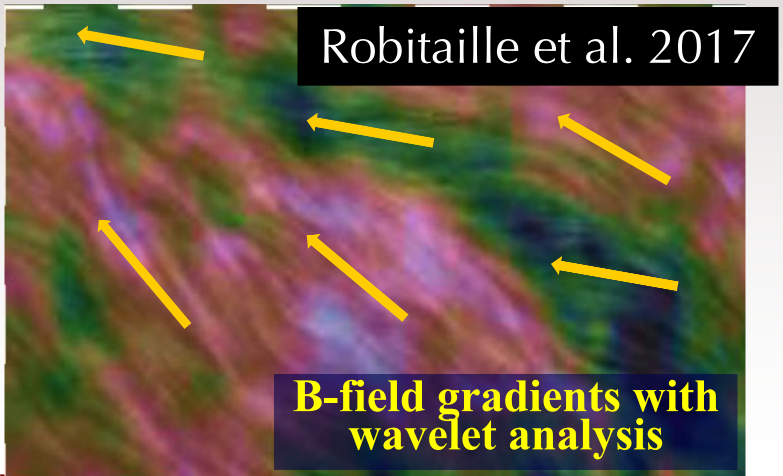
Characterizing the coupling of B-field and gas inflows in high-mass star-forming ridges

Gas inflow and magnetic fields are largely unknown in high-density medium





⇒ combined efforts of observations (inc. NIKA2-Pol project), numerical simulations, and multi-scale analysis



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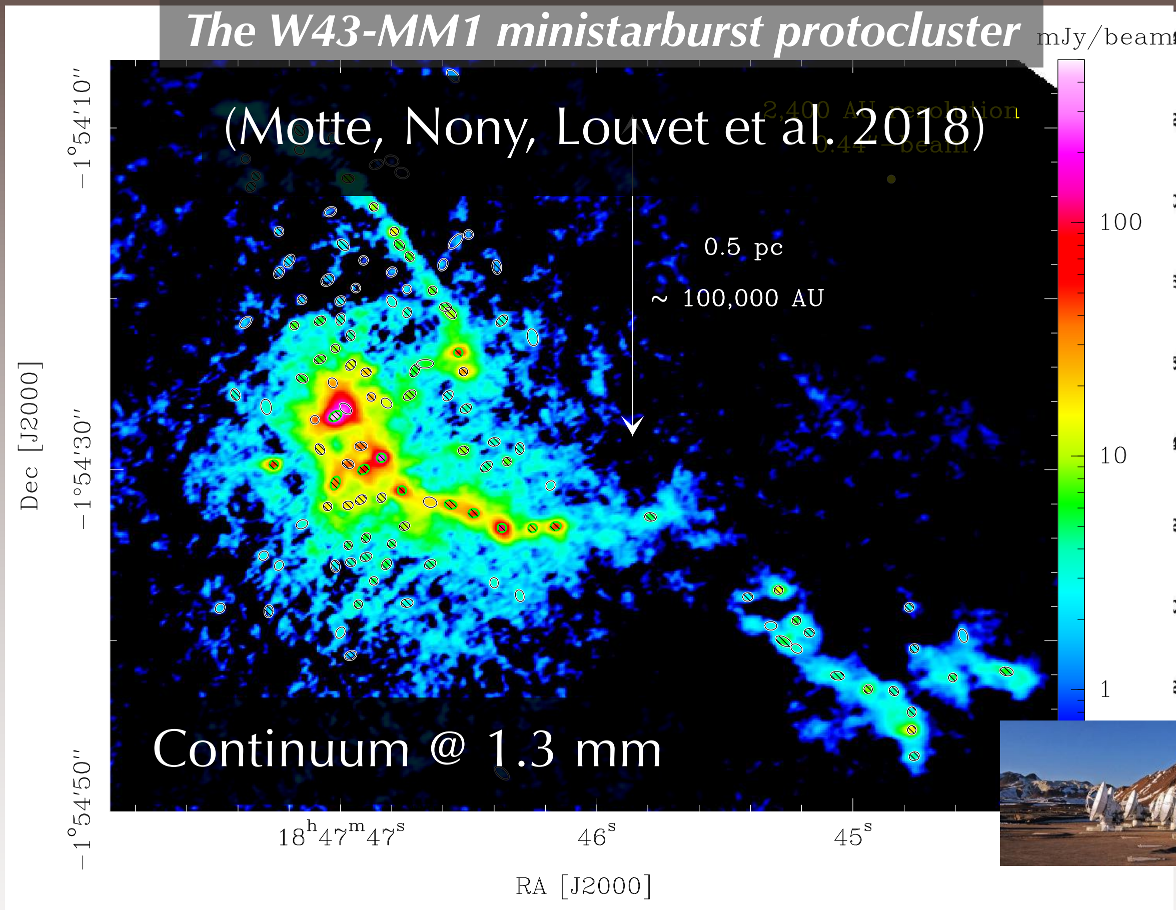
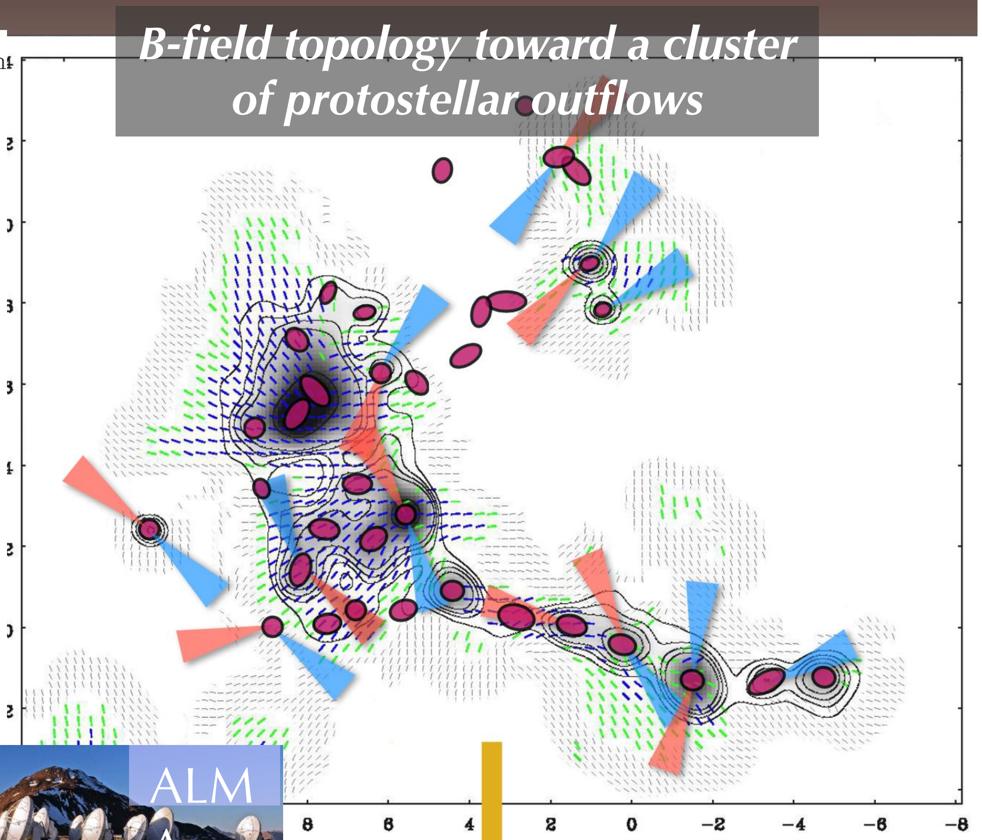
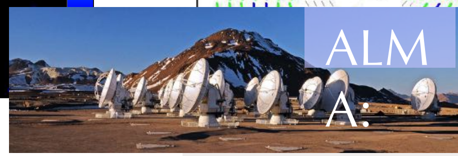
Relative orientation of protostellar cores and outflows with magnetic fields





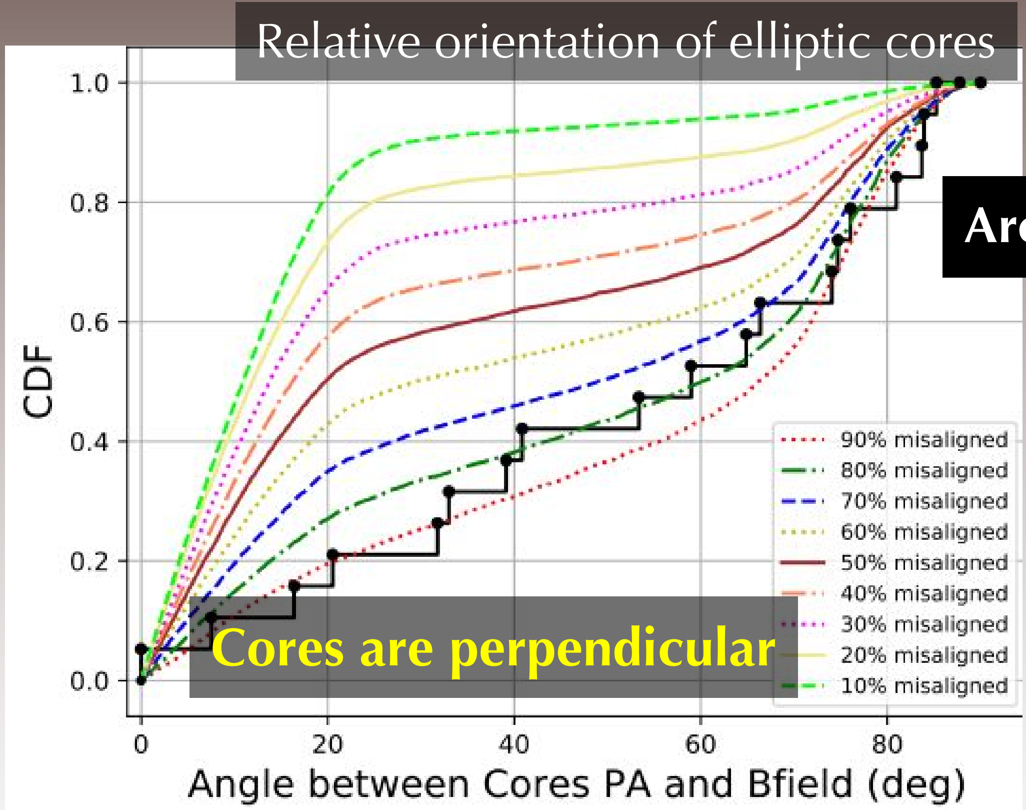


131 cores detected with *getsources* (2000 AU, ~1-100 $M_\odot$)

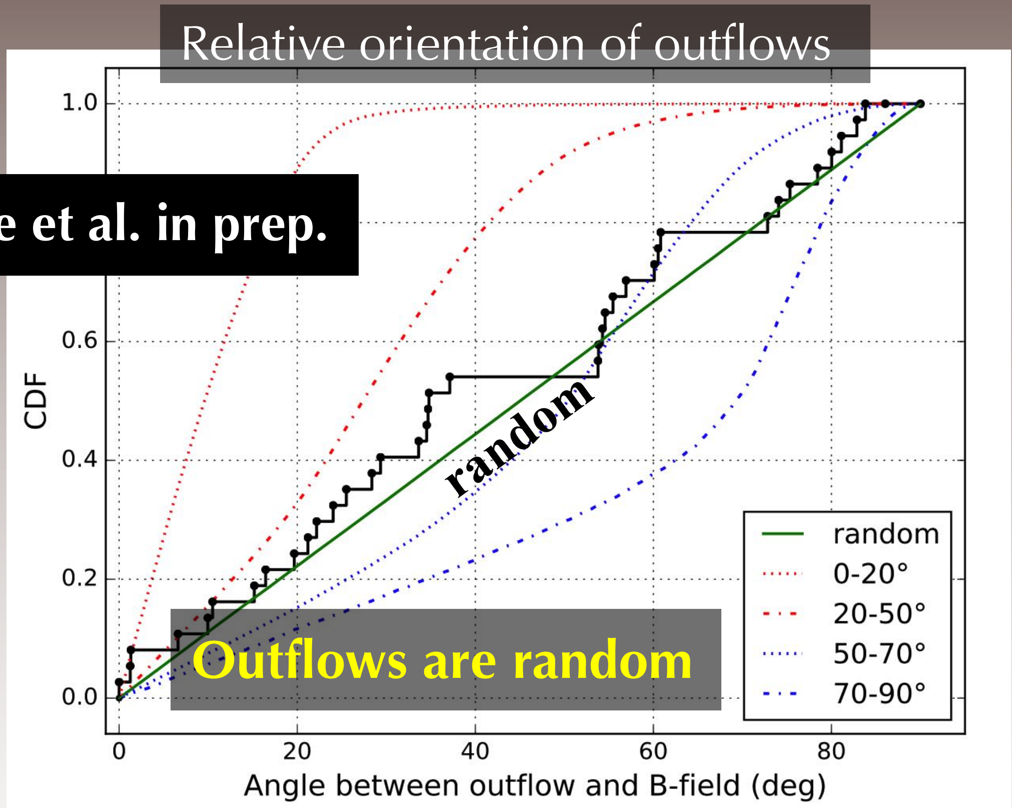
- 44 outflow lobes (CO(2-1) and SiO(5-4); Nony et al. in prep.)
- B-field topology (1.3mm, Louvet et al. in prep. Arce et al. in prep.)

Projected angle of polarization vector with the core big axis and outflows direction

Cumulative Distribution Functions (CDF) of 60 elliptic cores and 44 outflow lobes



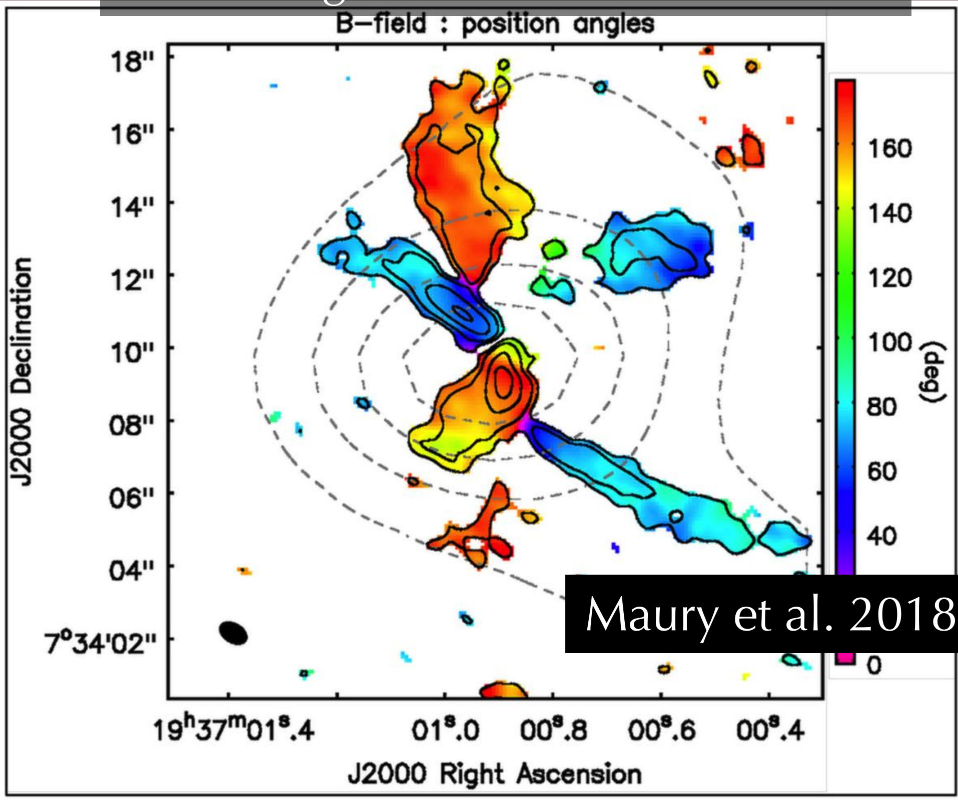
Arce et al. in prep.



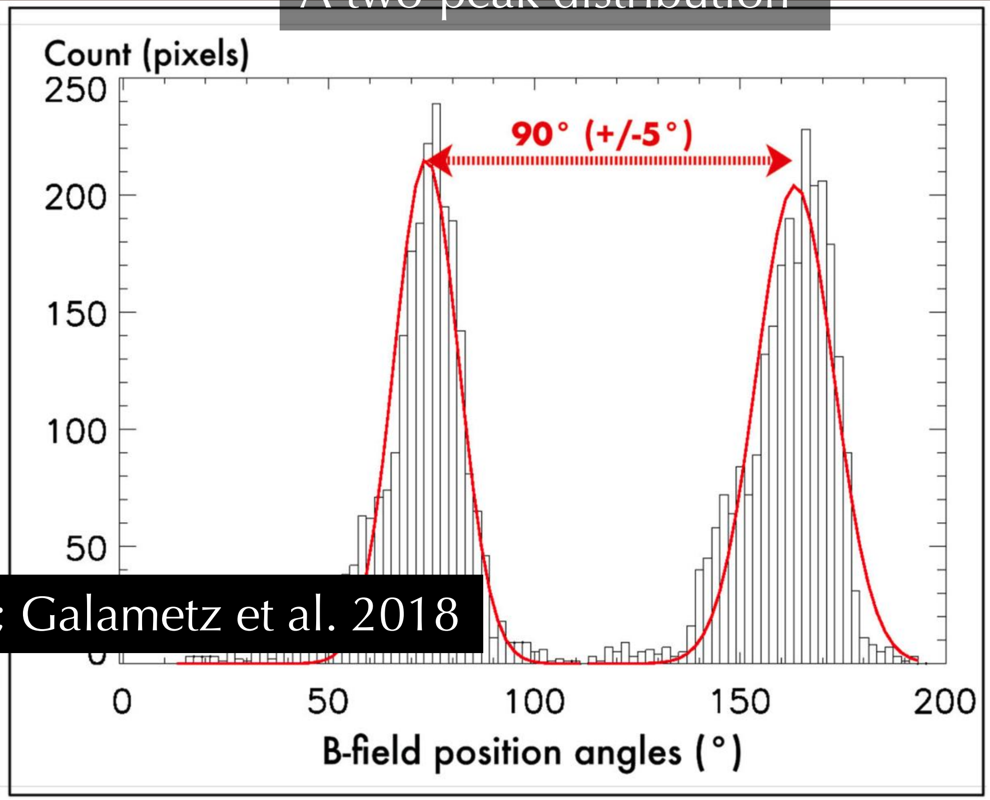
Cores tend to be perpendicular to $B_{surrounding}$ (see also Alina et al. 2019)
Outflows have random directions (see also Hull et al. 2014; Galametz et al. 2019)
⇒ NIKA2-Pol and ALMA-Pol projects toward clusters of cores

Magnetic field and the redistribution of the angular momentum

B-field angle relative of the disk axis



A two-peak distribution



Maury et al. 2018; Galametz et al. 2018

Alignment or misalignment of B-field lines and envelope rotation

⇒ Impact on core/stellar multiplicity

⇒ Heritage of the core B-field depends on the B-field strength

Take-away message

- High-mass star formation

High-mass stars form in high-density, massive, and dynamical filaments/clumps.

The effect of cloud dynamics and its coupling with magnetic fields require investigations on several decades of scales (0.01-100 pc).

- Impact of B-fields on high-mass star formation
  - Complex coupling with gas inflows
  - B-field lines tend to be perpendicular to the cores major axis
- NIKA2-Pol will constrain B fields at the missing scales between Planck and ALMA. We are at the dawn of making major discoveries on the
  - Mass segregation of cores and top-heavy CMF
  - Deceleration of the global collapse measured on pc scales
  - …