

# Impact of B fields on high-mass star formation



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& Fabien Louvet (U. Chile)**



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

NIKA2 collaborators for coming projects:

P. André, A. Andrianasolo, B. Ladjelate, N. Peretto, N. Ponthieu, I. Ristorcelli, A. Ritacco, J.-F. Robitaille...

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

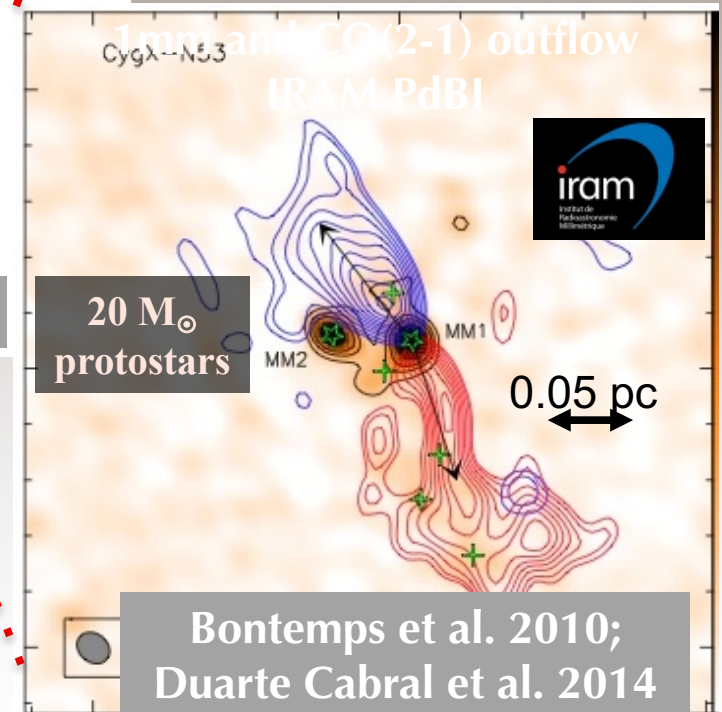
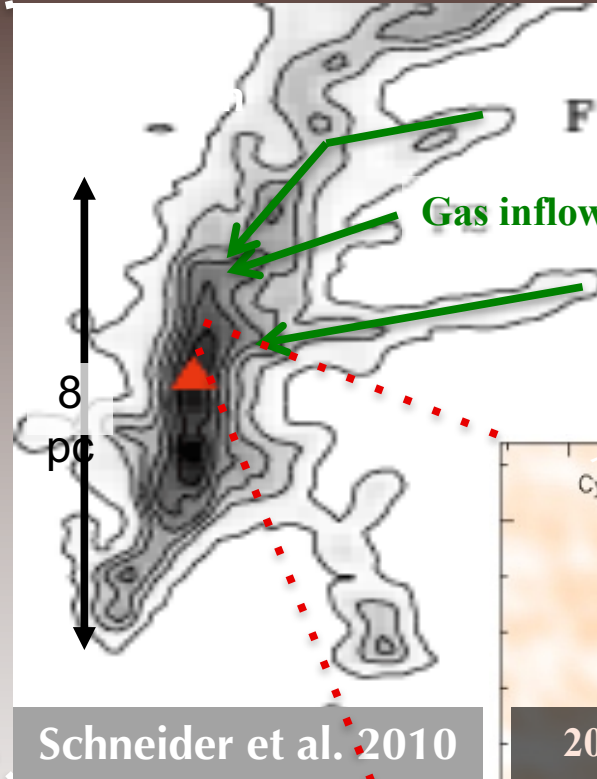
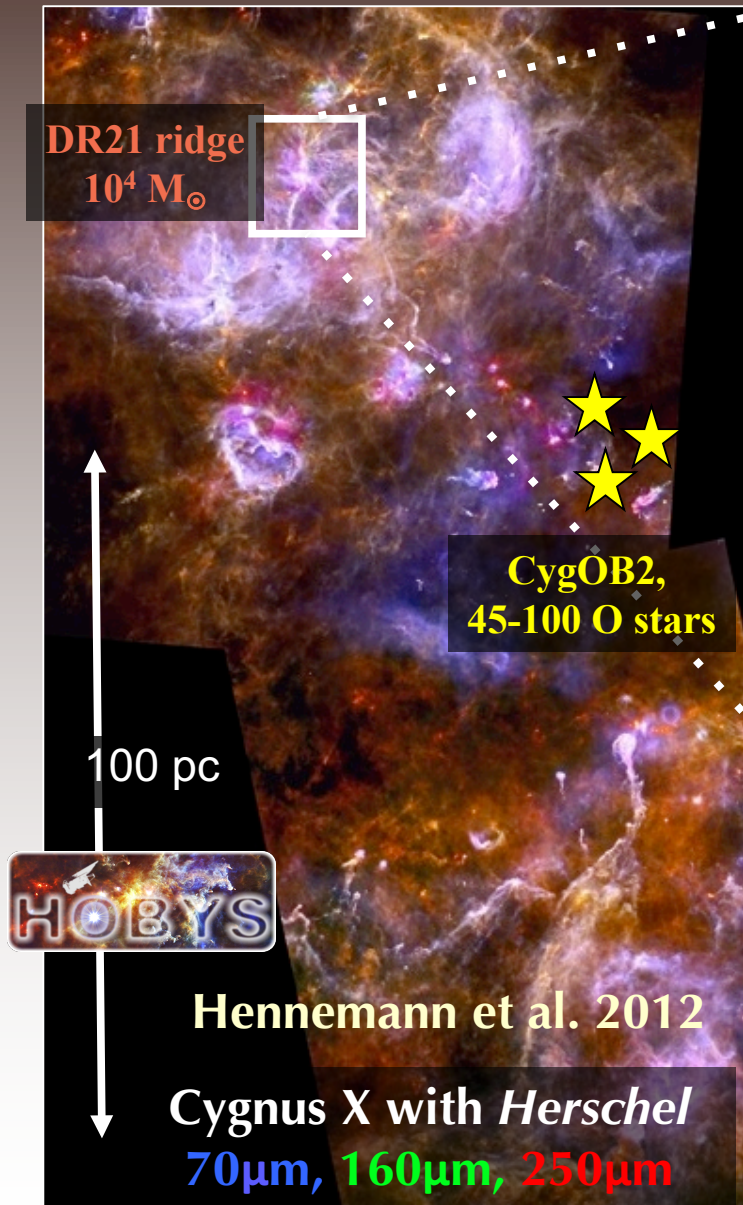
- Investigating the coupling with cloud/clump structure
- Investigating the coupling with gas dynamics

## Role of B-field on sub-pc scales

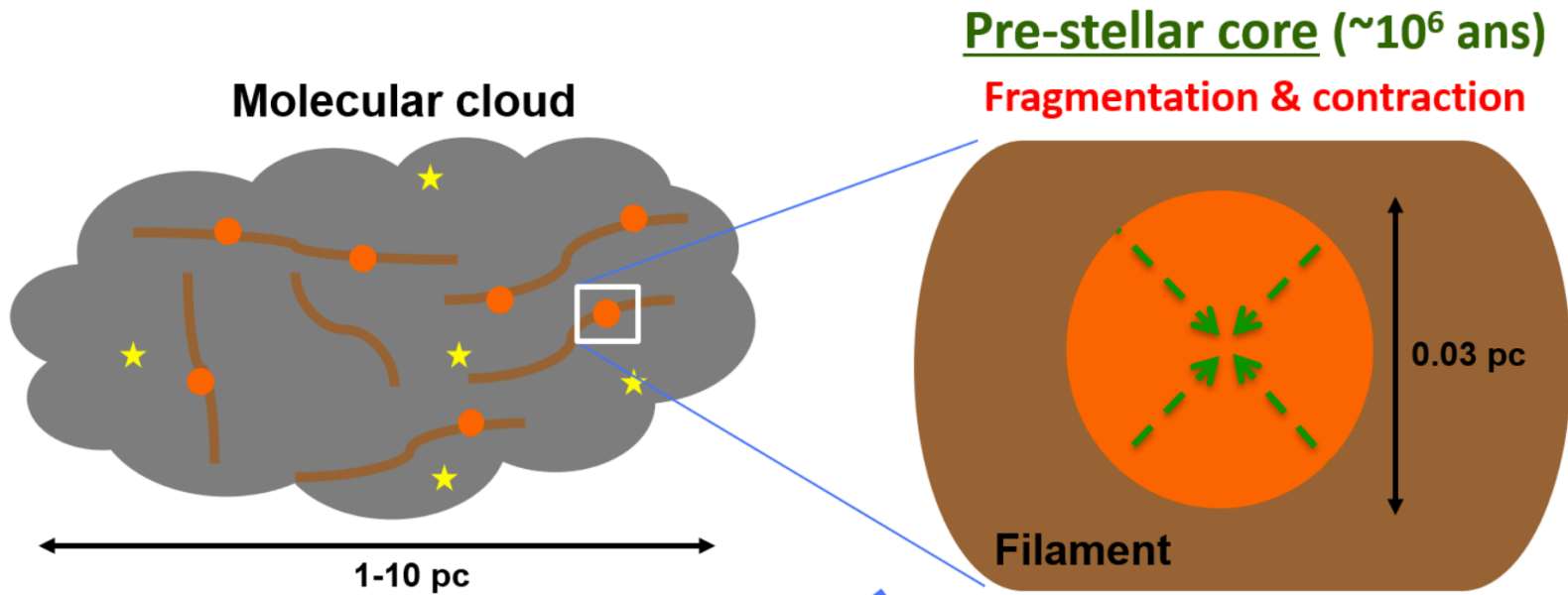
- Investigating the coupling with core ellipticity
- Investigating the coupling with disk, jet and rotation

## Conclusion

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

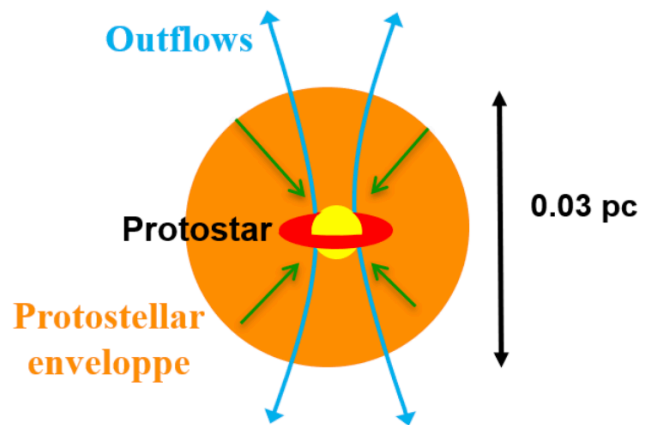


# Low-mass star formation scenario



André et al. 1994, 2014

**Protostellar core ( $\sim 10^5$  ans)**  
**Accretion & ejection**

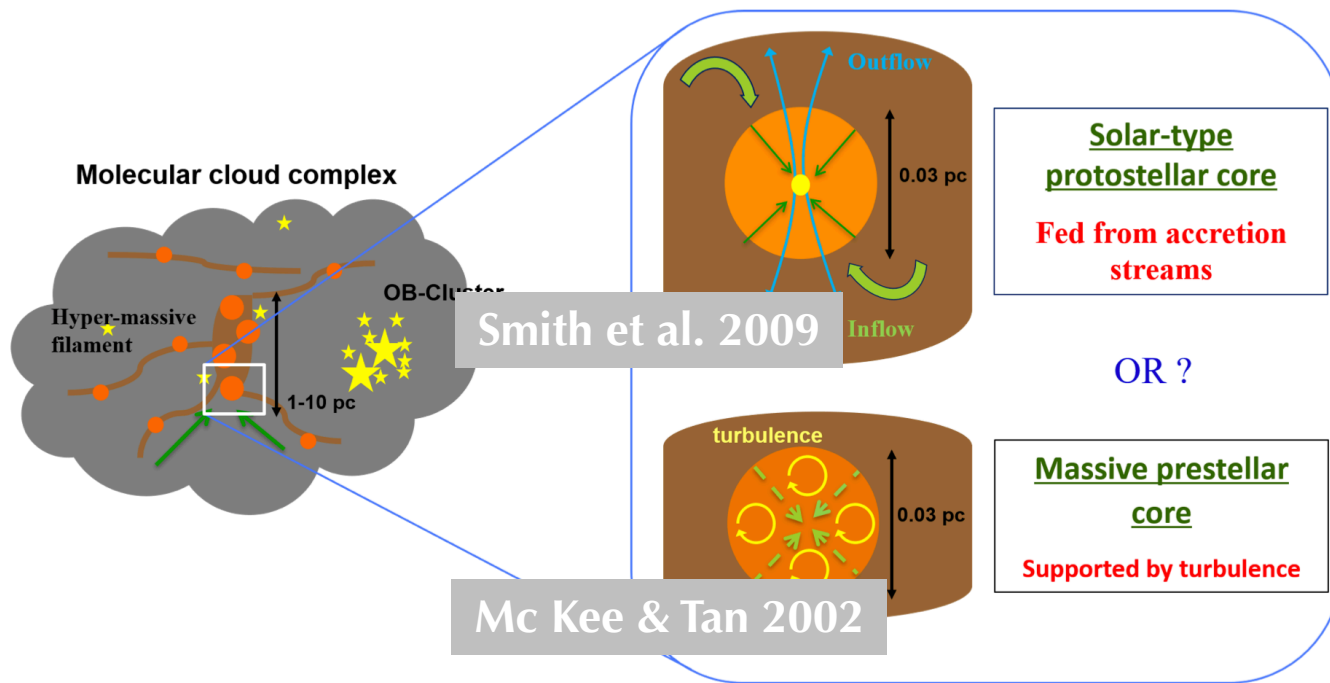


**Pre-main sequence star**  
**( $\sim 10^6 - 10^7$  ans)**





# High-mass star formation scenario



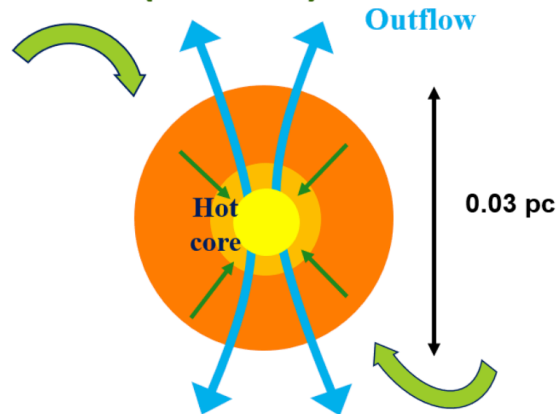
## Global hierarchical collapse

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

⇒ "clump-fed" model

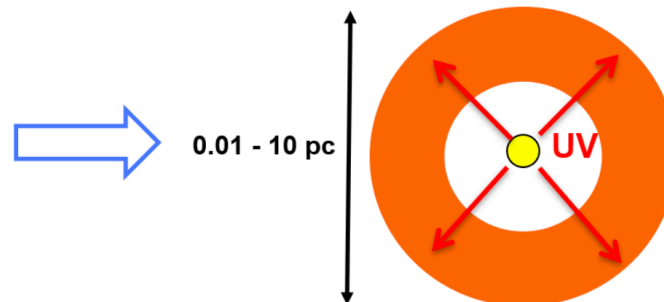
⇒ No need of a high-mass prestellar core phase

## Massive protostellar core (~10<sup>5</sup> ans)



## HII Region (~10<sup>5</sup> - 10<sup>6</sup> ans)

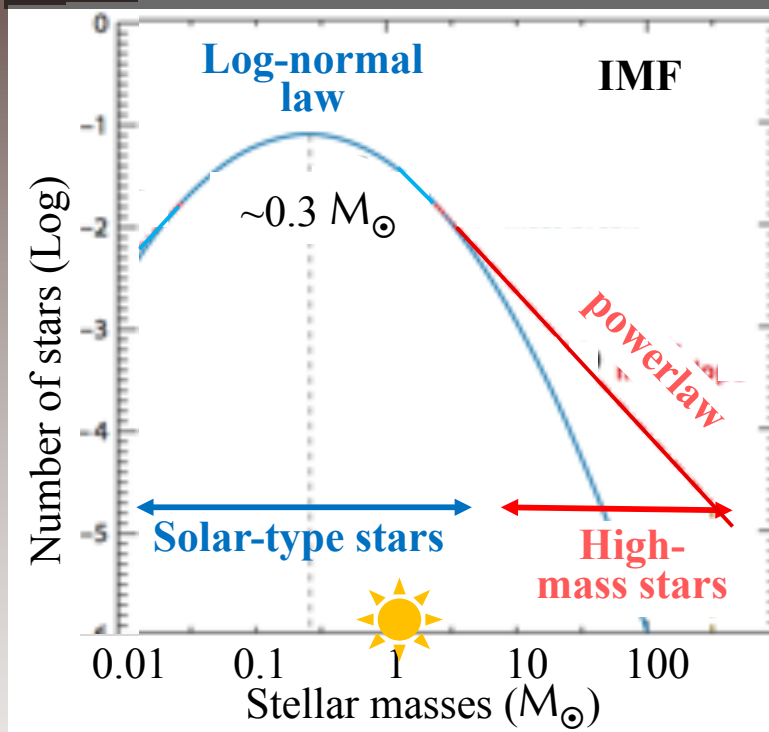
Ionization, expansion



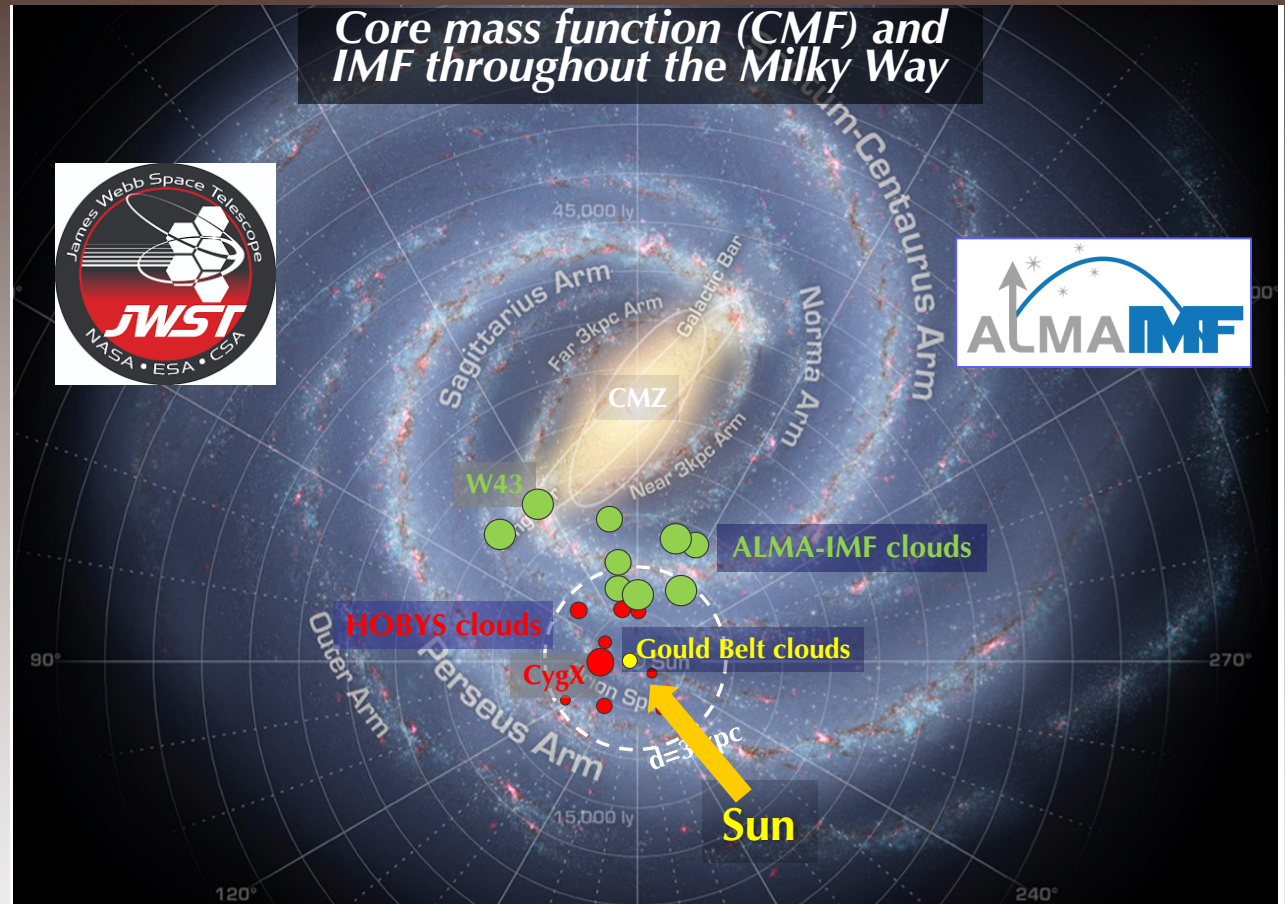
Motte, Bontemps & Louvet  
ARA&A 2018

# Star formation: origin of the stellar masses

Initial mass function of stars (IMF)



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

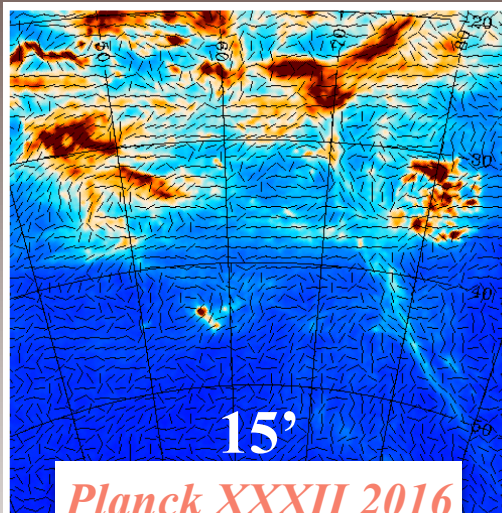


- The distribution of core masses (CMF) is expected to vary with the Galactic environment (density, kinematics, magnetic field)
- Will the resulting IMF finally be universal ?

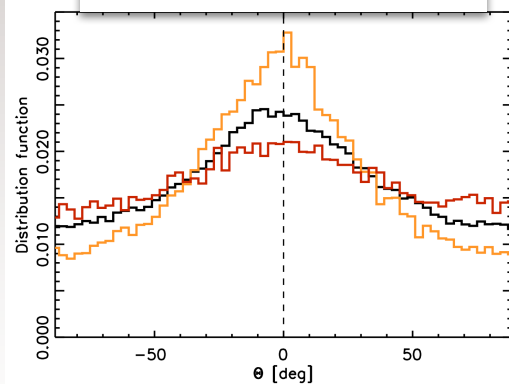


# The role of B-field in shaping the ISM through filamentary structures

## Filaments in the Diffuse ISM



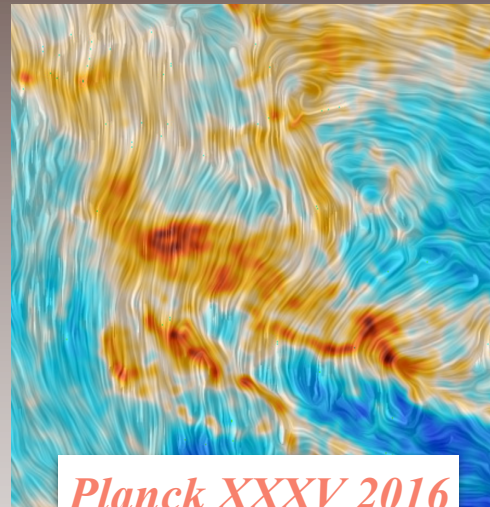
Planck XXXII 2016  
c.a. Bracco



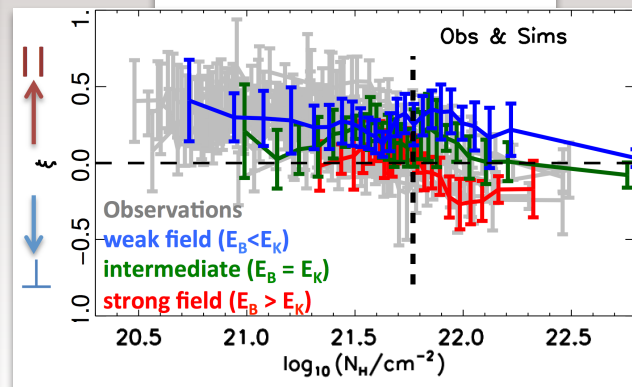
B-fields & filaments  
mostly aligned

mm Universe @ NIKA2, June 5, 2019

## Nearby Molecular complexes

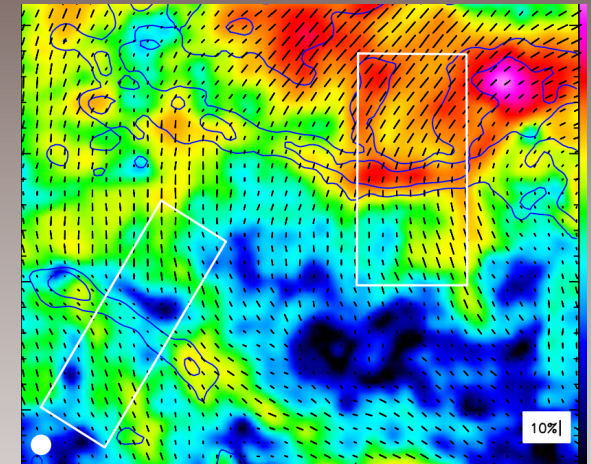


Planck XXXV 2016  
c.a. Soler



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

F. Motte & F. Louvet, IPAG & U. Chile

# The role of B-field for star formation

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

- @ scales  $\sim 1$  pc:

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

- @ scales  $\sim 0.1-0.01$  pc:

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

- @ scales  $\sim 1000$  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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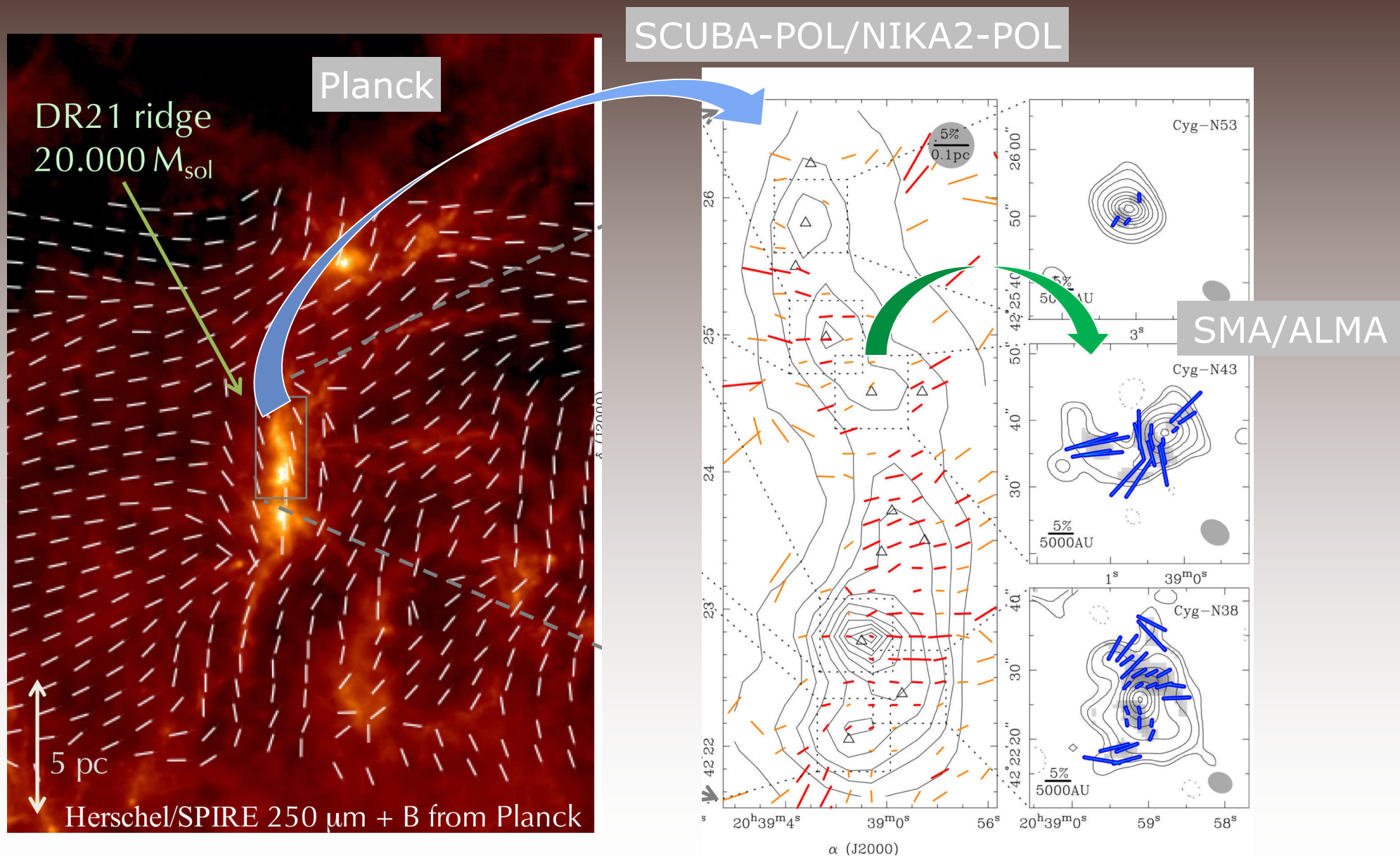
- Investigating the coupling with cloud/clump structure
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- Investigating the coupling with core ellipticity
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## Conclusion

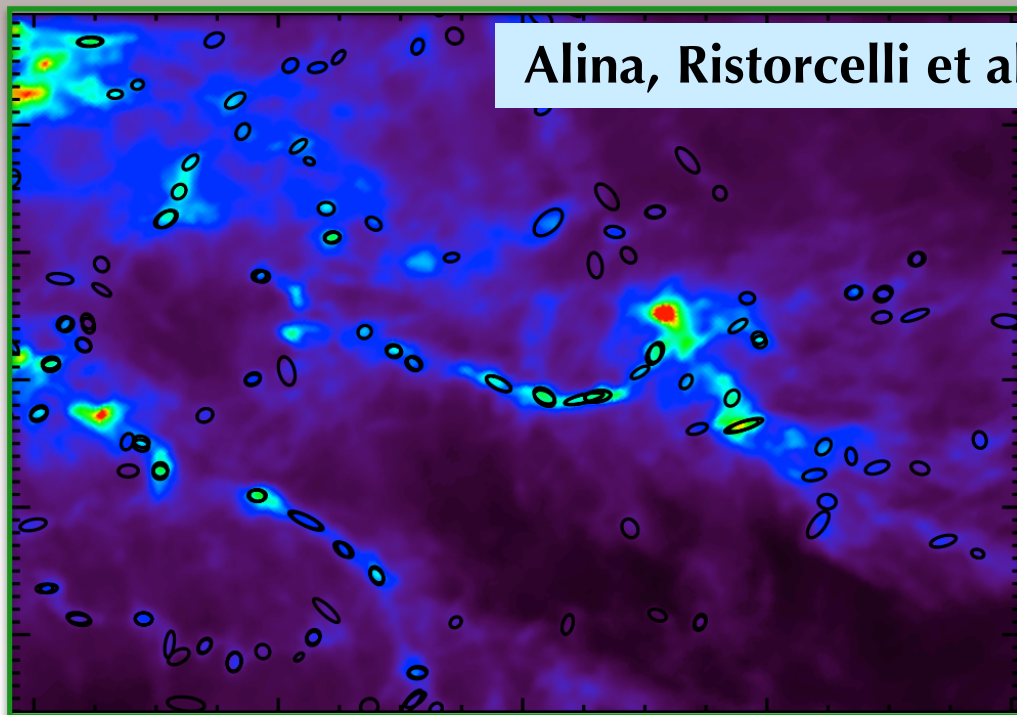
# Magnetic field topology from filaments to cores



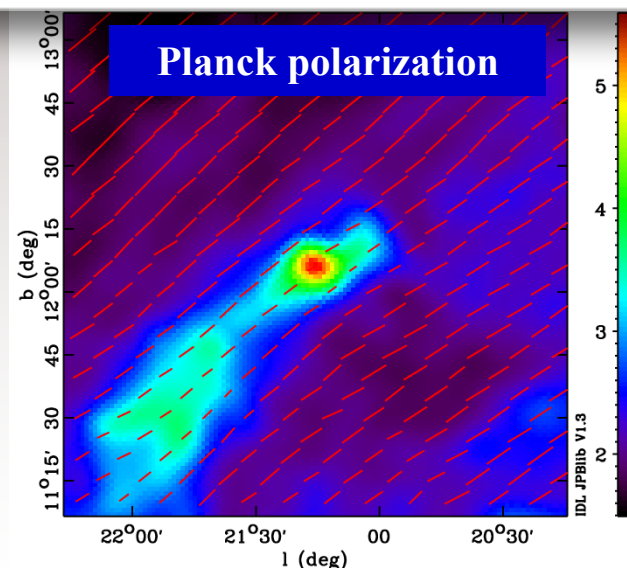
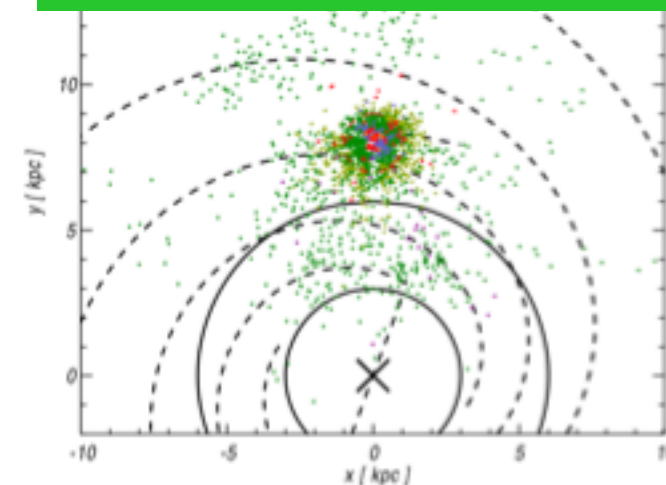
# Orientation relative to the B field for star-forming filaments and cold clumps

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



42% with reliable distance estimates:



# Statistical analysis of the relative orientation

## With respect to $B_{\text{background}}$

Filaments with  $n_{\text{H}_2} > 10^3 \text{ cm}^{-3}$ : perpendicular  
 $n_{\text{H}_2} < 10^3 \text{ cm}^{-3}$ : align more

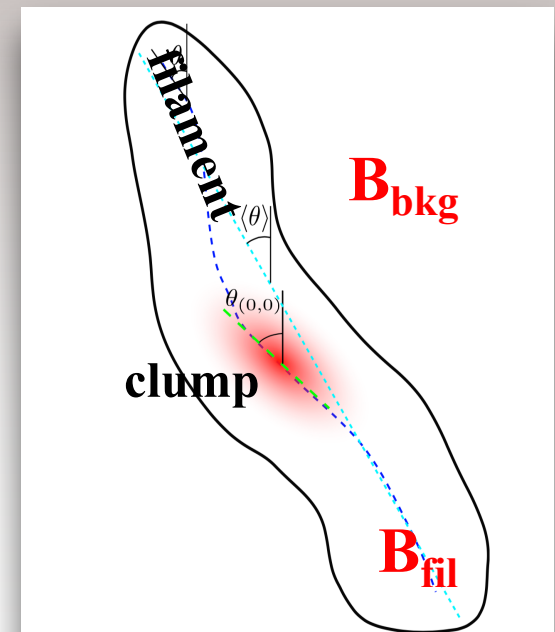
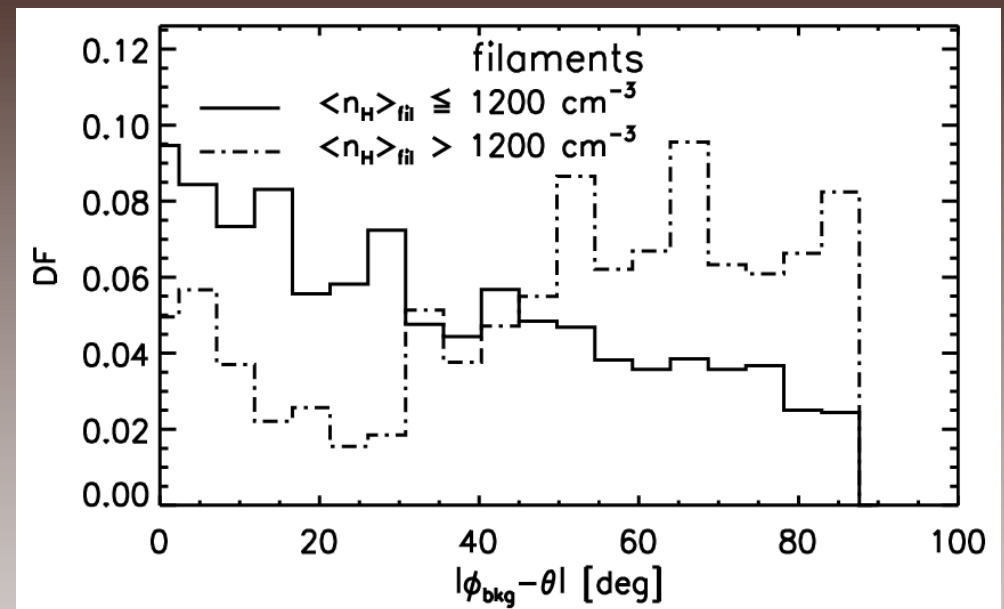
## With respect to $B_{\text{filament}}$

Clumps with  $\Delta N_{\text{H}_2} < 4 \cdot 10^{20} \text{ cm}^{-2}$ : aligned  
 $\Delta N_{\text{H}_2} > 4 \cdot 10^{20} \text{ cm}^{-2}$ : both

Alina, Ristorcelli et al. 2019

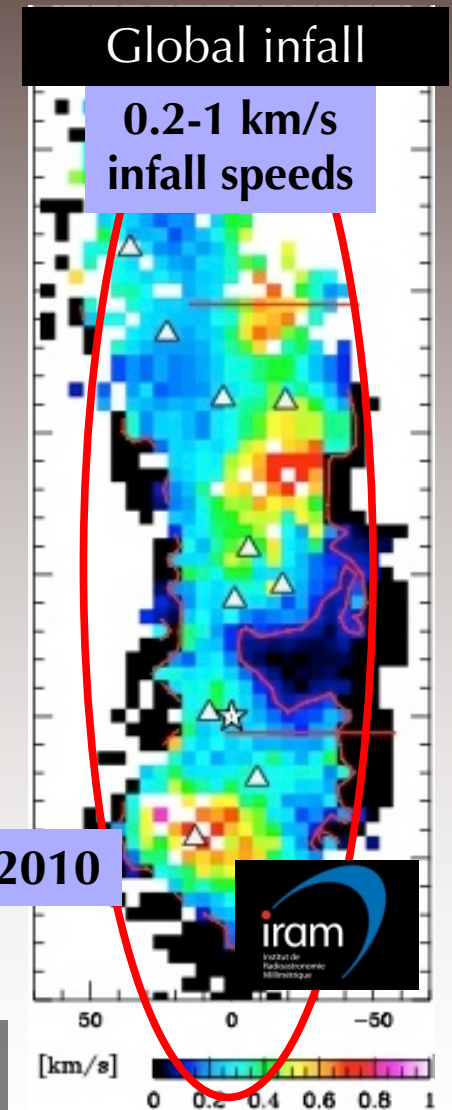
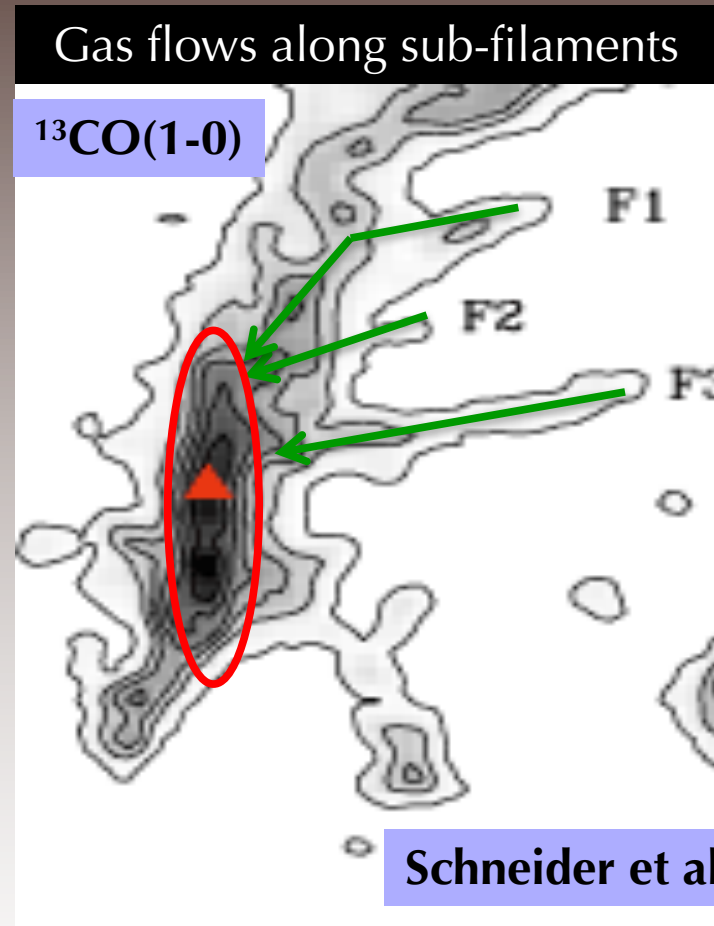
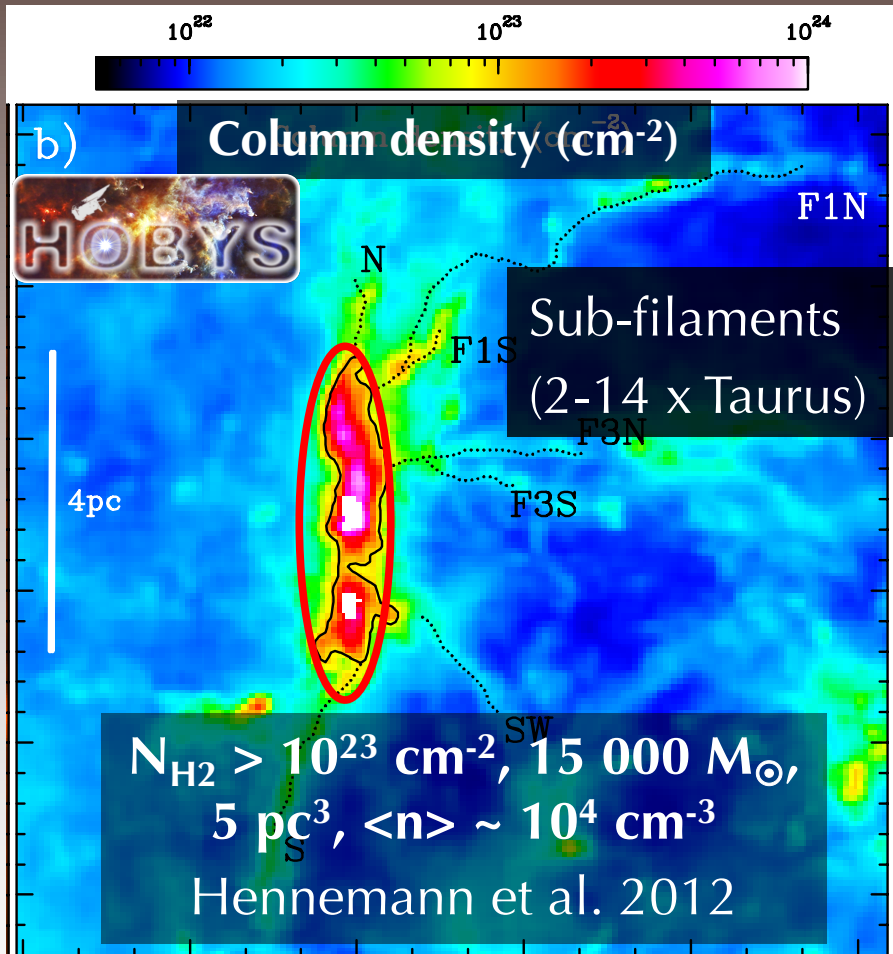
→ (Partial) coupling between matter and B fields during the formation of filaments and clumps

NIKA2 follow ups to measure the  $B_{\text{clump}}$  orientation



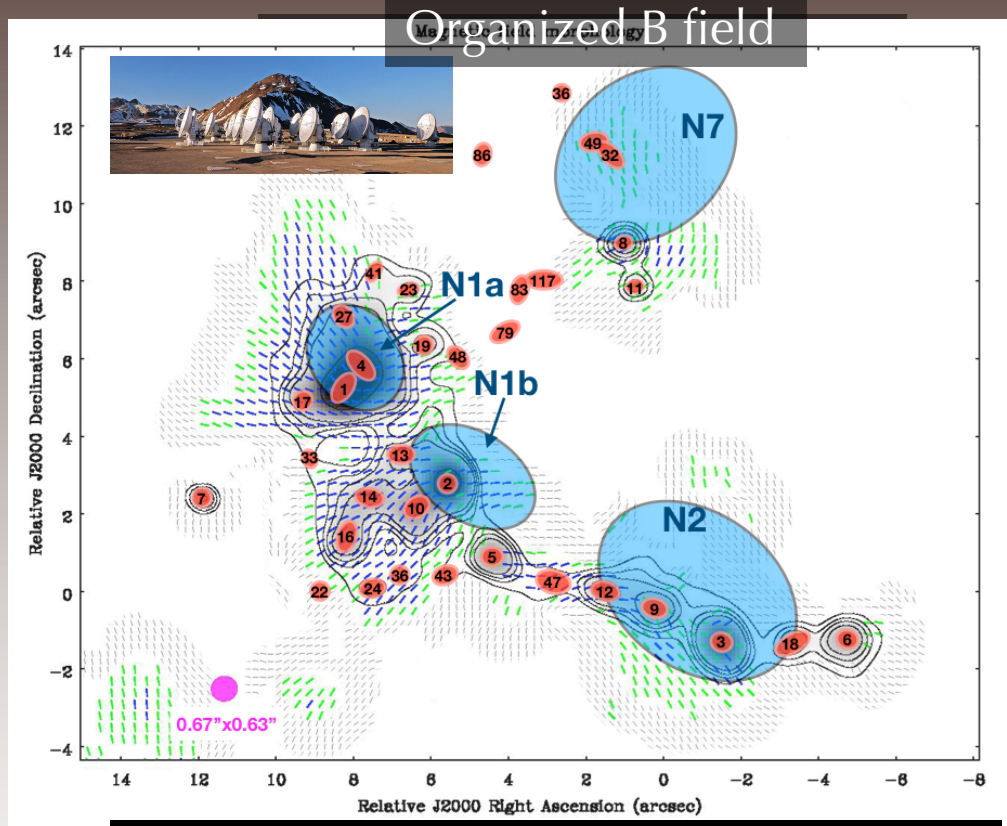
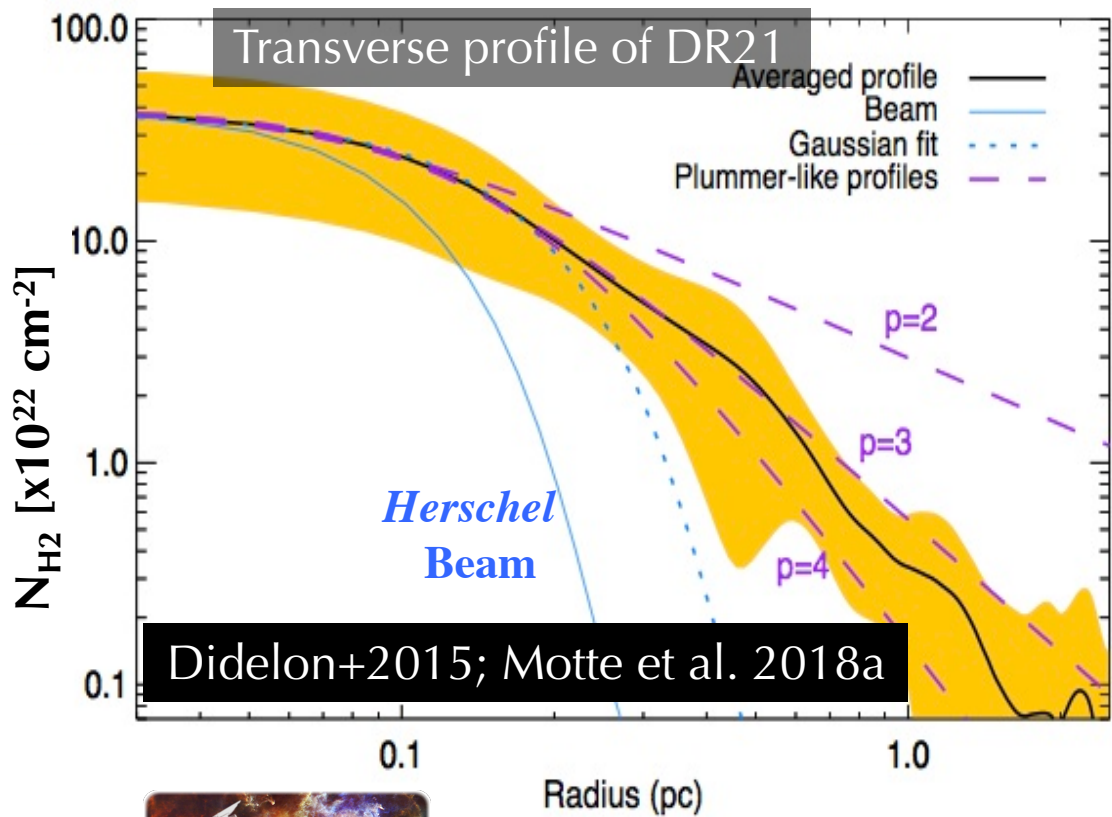


# Most high-density clouds should form by global collapse and braid of sub-filaments



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



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

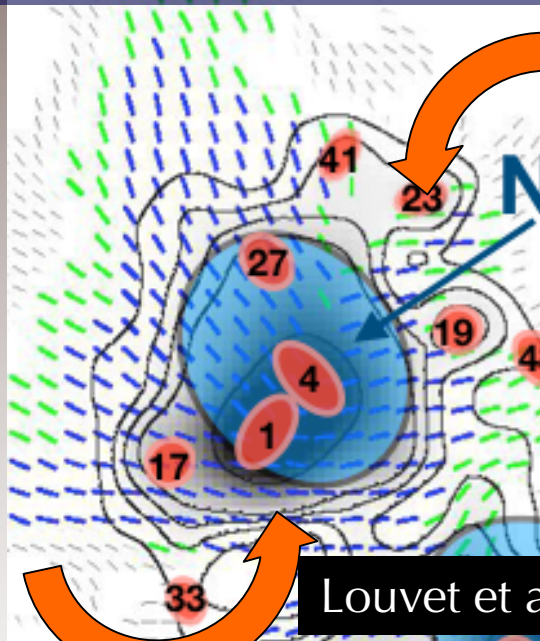
Consistent with PDF studies (Russeil+ 2013; Schneider+2015) and inflow studies (e.g. Wyrowski+ 2016).

⇒ **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

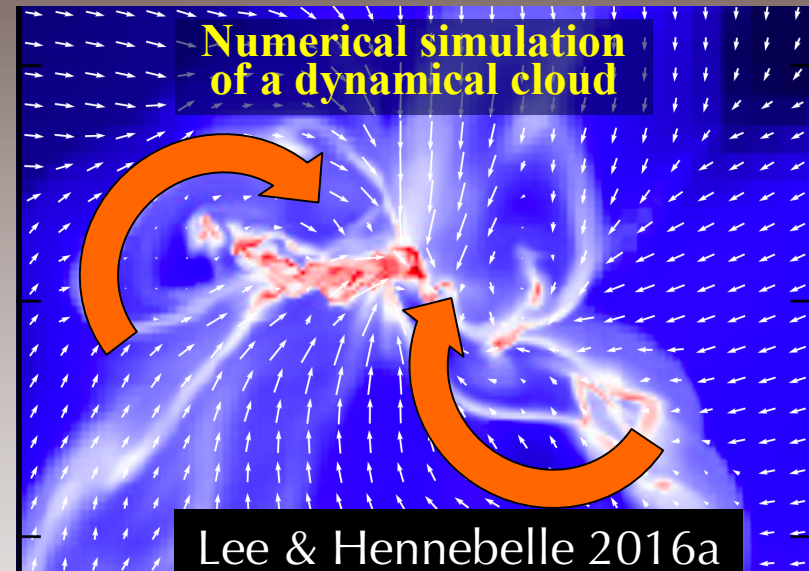
Gas inflow and magnetic fields are largely unknown in high-density medium

Observation of a dynamical/magnetic cloud



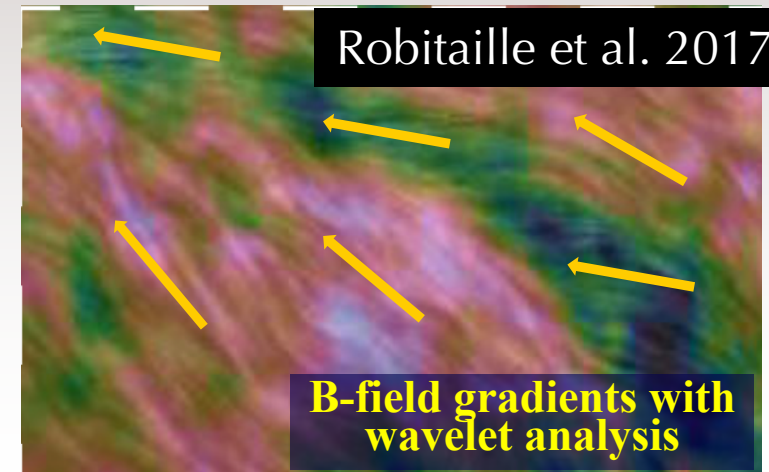
Louvet et al. in prep.

Numerical simulation of a dynamical cloud



Lee & Hennebelle 2016a

Robitaille et al. 2017



B-field gradients with wavelet analysis

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



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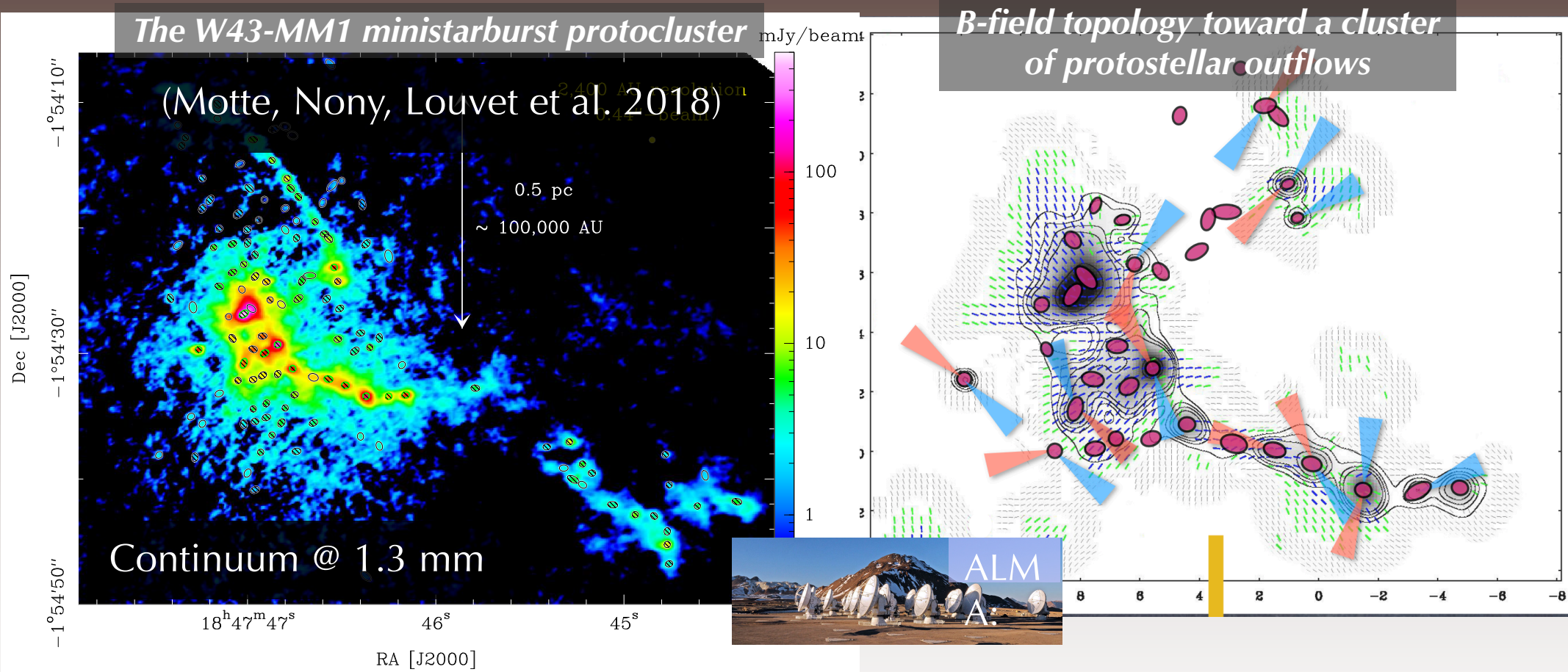
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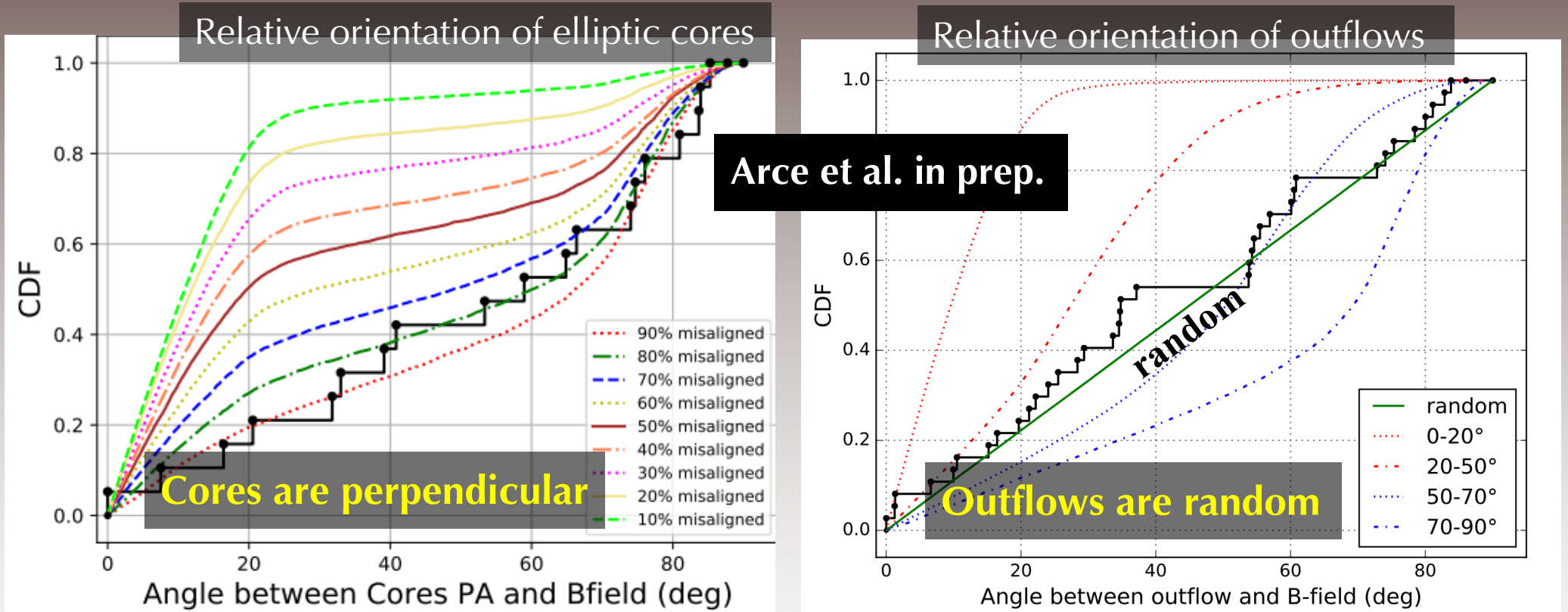
# Relative orientation of protostellar cores and outflows with magnetic fields



- 131 cores detected with *getsources* (2000 AU,  $\sim 1$ -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

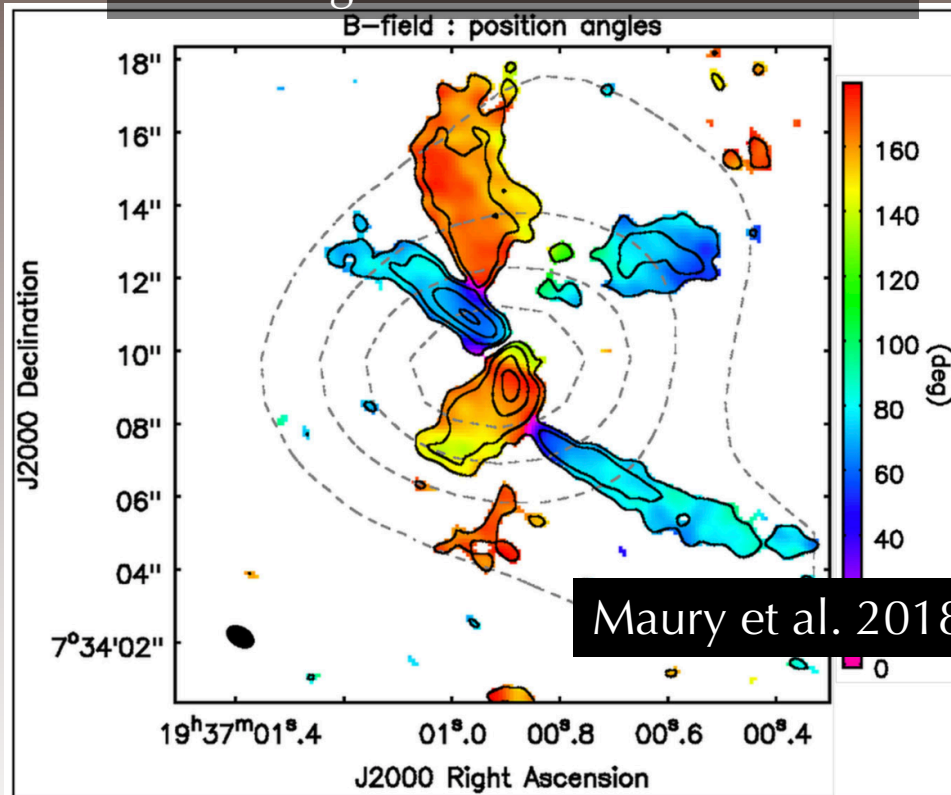
Cumulative Distribution Functions (CDF) of 60 elliptic cores and 44 outflow lobes



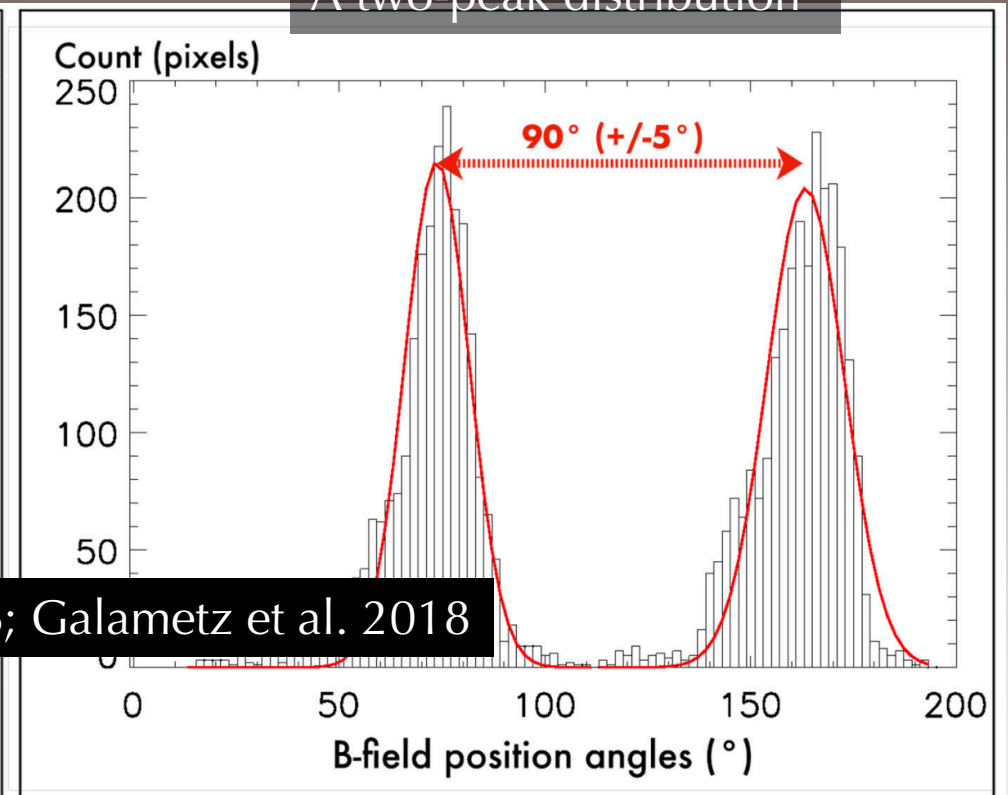
Cores tend to be perpendicular to  $B_{\text{surrounding}}$  (see also Alina et al. 2019)  
 Outflows have random directions (see also Hull et al. 2014; Galametz et al. 2019)  
 ⇒ **NIKA2-Pol and ALMA-Pol projects toward clusters of cores**

# Magnetic field and the redistribution of the angular momentum

B-field angle relative of the disk axis



A two-peak distribution



**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
- ...