The physical and the geometrical properties of simulated cold HI structures

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05/03/2021

Credit: Teun van der Zalm

Outline

- Introduction
- Analysis tools
- Simulations
- Results
- Discussion
- Conclusions

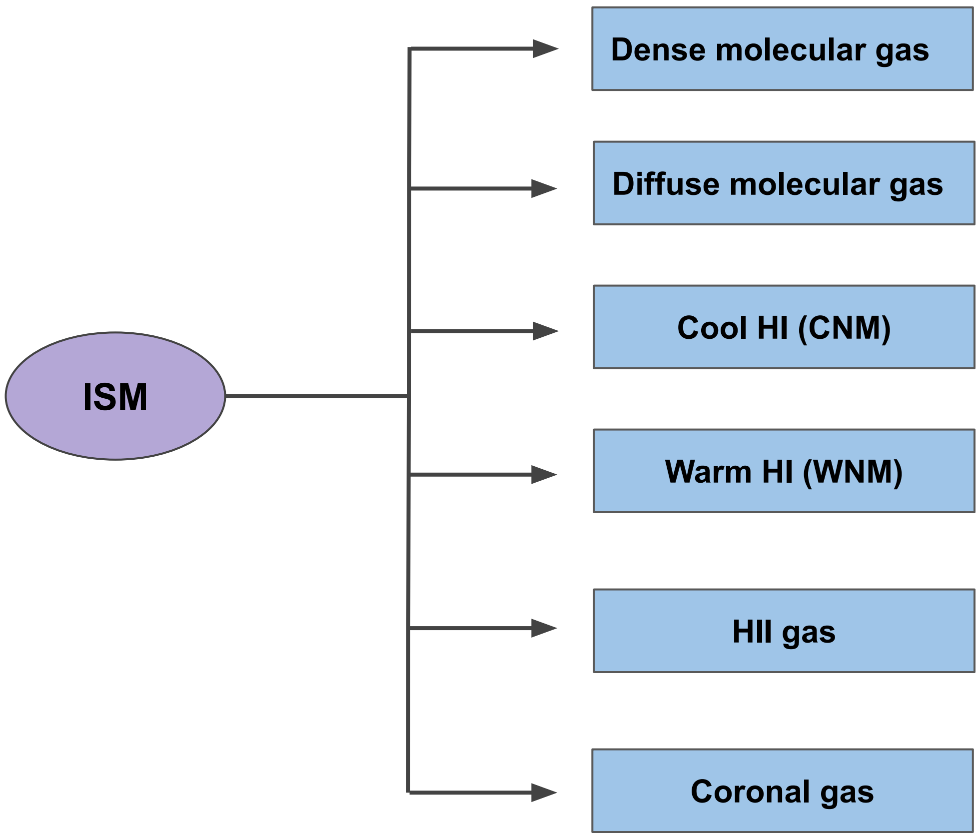
Introduction

1. What is this paper?

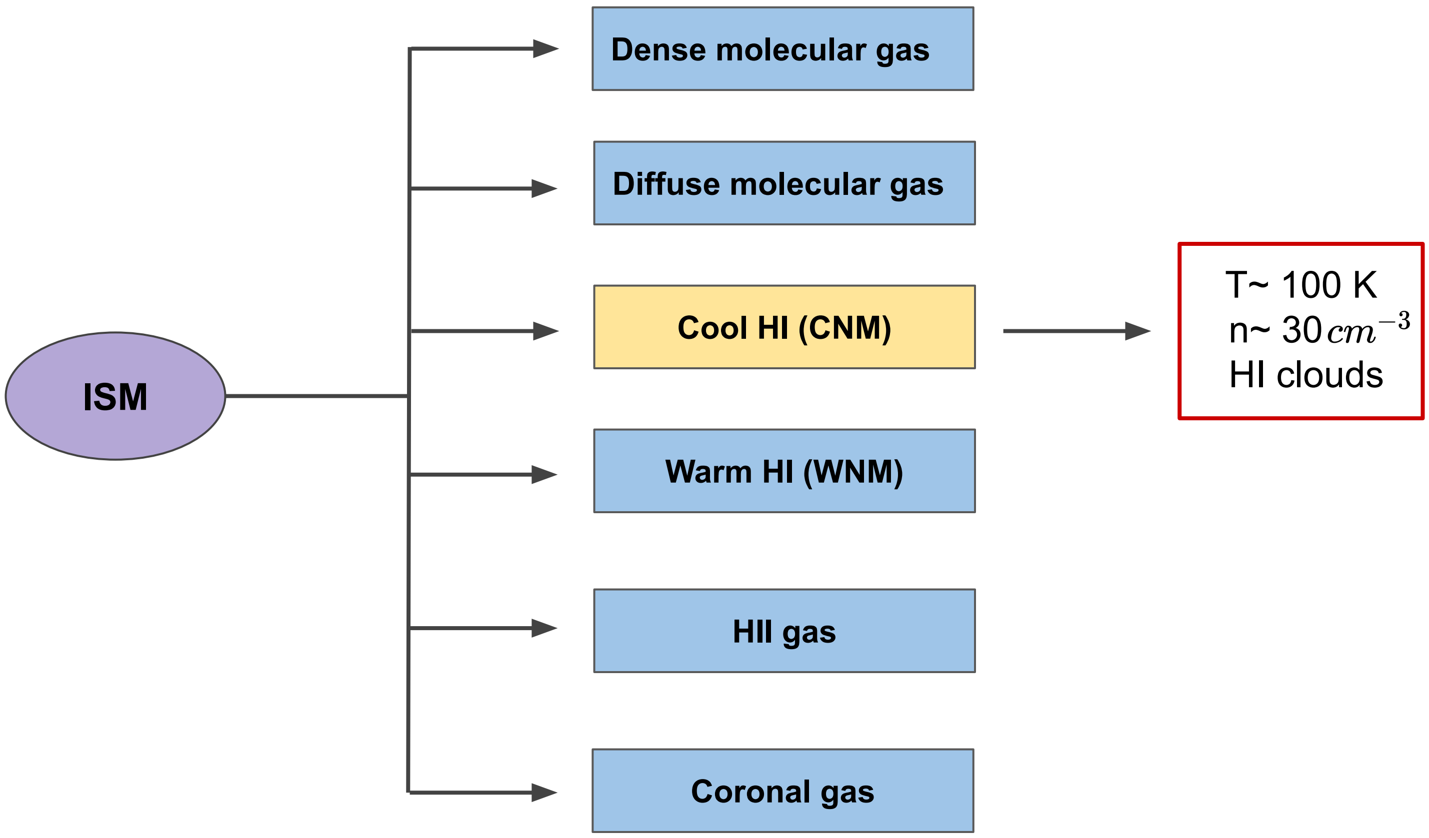
2. Why is this interesting?

3. How is this study carried out?

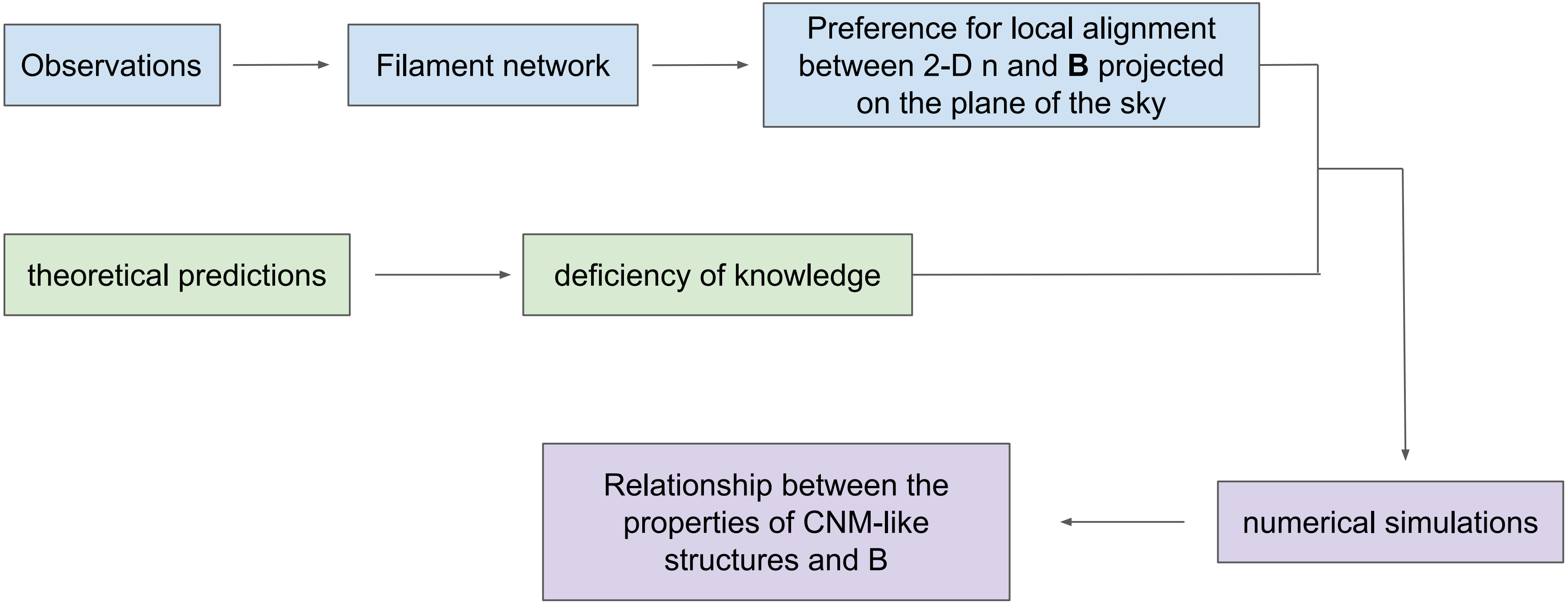
ISM


ISM
Dense molecular gas
Diffuse molecular gas
Cool HI (CNM)
Warm HI (WNM)
HII gas
Coronal gas

ISM


ISM
Dense molecular gas
Diffuse molecular gas
Cool HI (CNM)
Warm HI (WNM)
HII gas
Coronal gas
T~ 100 K
n~ 30 cm^{-3}
HI clouds

CNM


Observations
Filament network
Preference for local alignment between 2-D n and **B** projected on the plane of the sky
theoretical predictions
deficiency of knowledge
numerical simulations
Relationship between the properties of CNM-like structures and B

Objective of the paper

A detailed **statistical analysis** of the possible connection between the general **physical** properties, the **morphological** properties and the **geometrical** properties of magnetized CNM-like structures!

Analysis tools

- Shape descriptors
- Kernel density estimations
- Directional Statistics

Shape descriptors

Asphericity

Prolatness

Shape descriptors

Asphericity

Prolatness

$$A_3 = \frac{1}{6}\sum_k \frac{(m_k - \overline{m})^2}{\overline{m}^2}$$

m_k : eigenvalues of $M_{ij} = \sum_k \mu^k x_i^k x_j^k$

$$\overline{m} = \frac{1}{3} r_g^2$$

$$r_g = \sqrt{g_1 + g_2 + g_3}$$

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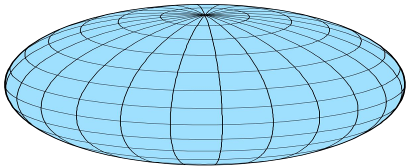
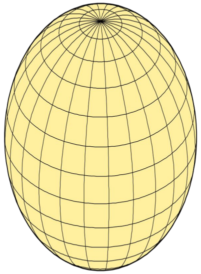


oblate

prolate



Credit: Tomruen

Directional statistics

They don’t take into consideration the orientation but only the direction $\longrightarrow$ $\theta \in [0, \frac{\pi}{2}]$

$$\overline{R} = (\overline{C}^2 + \overline{S}^2)^{\frac{1}{2}}$$ $\longrightarrow$ measures the concentration of θ values

$$\overline{R} << 1 \qquad \qquad \overline{R} \sim 1$$

$$\overline{C} = \frac{1}{n} \sum_{j=1}^{n} cos\theta_j \qquad \overline{S} = \frac{1}{n} \sum_{j=1}^{n} sin\theta_j$$

Simulations

Data from 5 models →

- **B00S** → 0 μG → HD
- **B01S** → 0.4 μG
- **B05S** → 2.1 μG
- **B10S** → 4.2 μG
- **B20S** → 8.1 μG

(0.4–8.1 μG: MHD)

B: initially uniform and // x-axis

Simulations

Each simulation:

- reproduces the thermal conditions of HI gas in the solar neighbourhood
- represents a cubic box with 100 pc by side
- is initially at rest with a uniform density (2 cm^{-3}) and temperature (1500K)
- is in the thermally unstable regime according to a cooling function (Wolfire et al.2003)

~ 1500 simulations (300 for each model)

Results

1. Physical properties of clumps $\longrightarrow$ B, n, β_p, P_{th}, M_{rms}, M, M_{Arms}, M_A
2. Morphology $\longrightarrow$ γ, β, A_3, S_A
3. Relative alignments $\longrightarrow$ θ_B, θ_v, R, θ_{vB}, θ_{vL}

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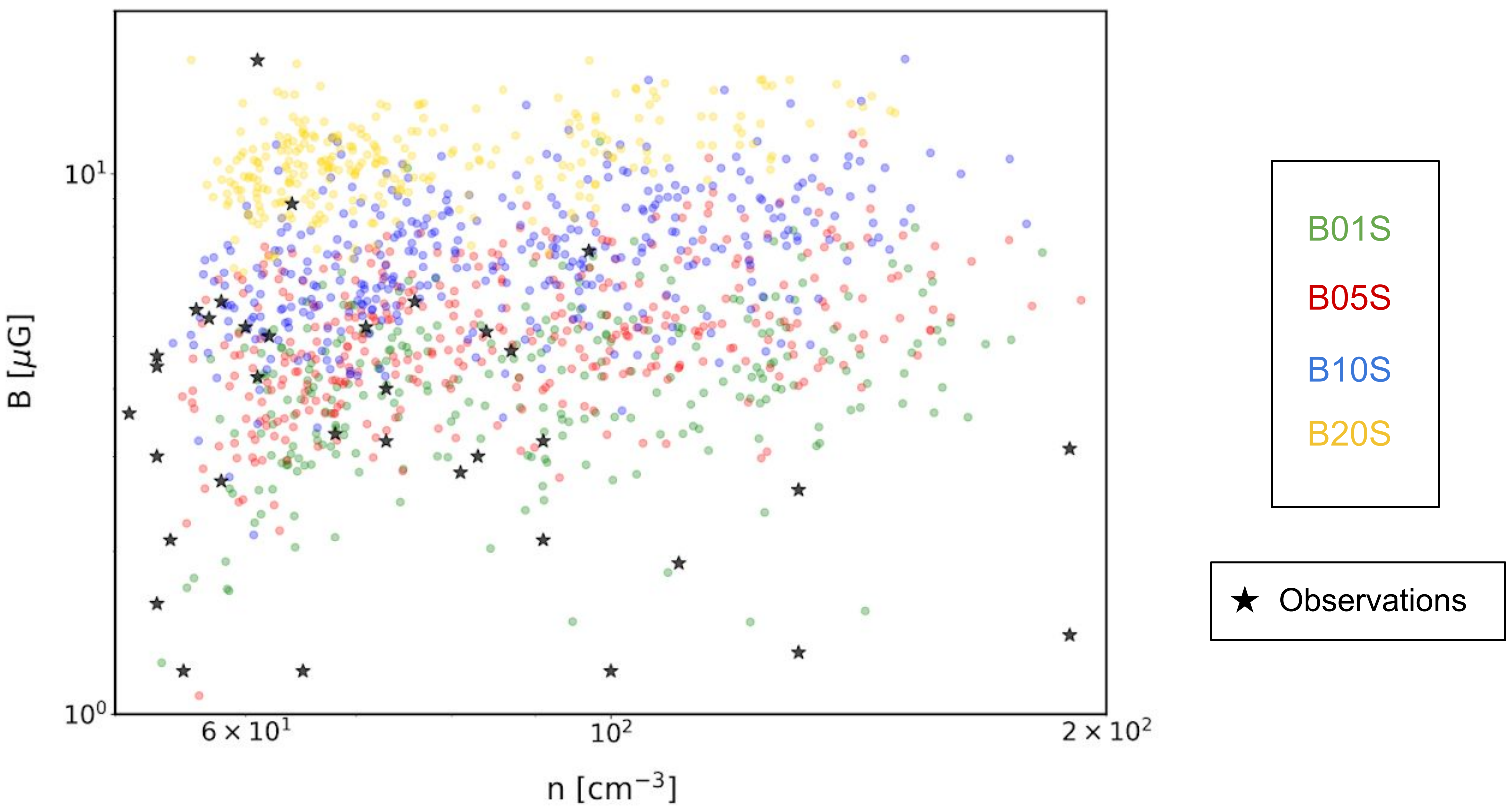
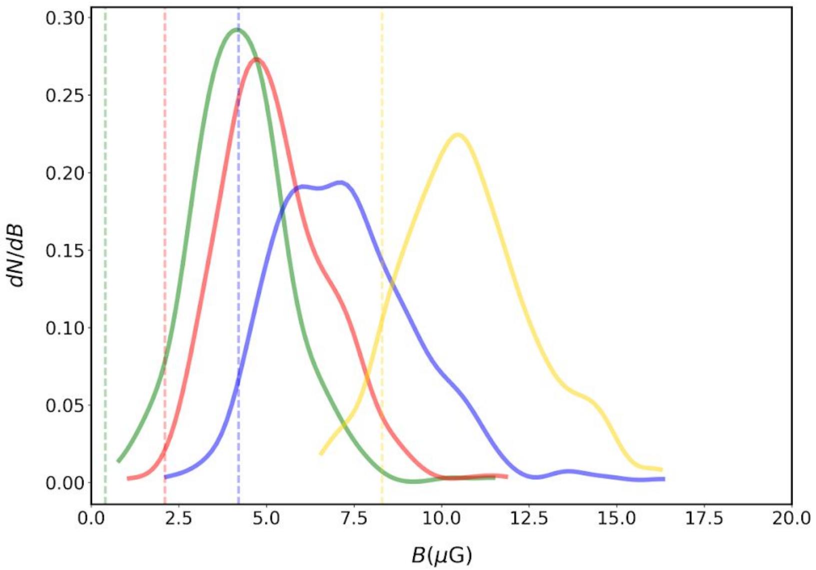
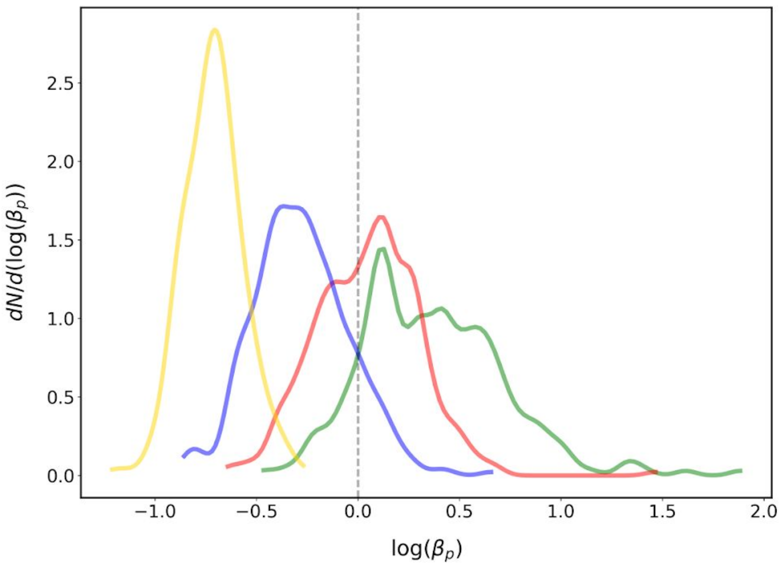


Physical properties of clumps





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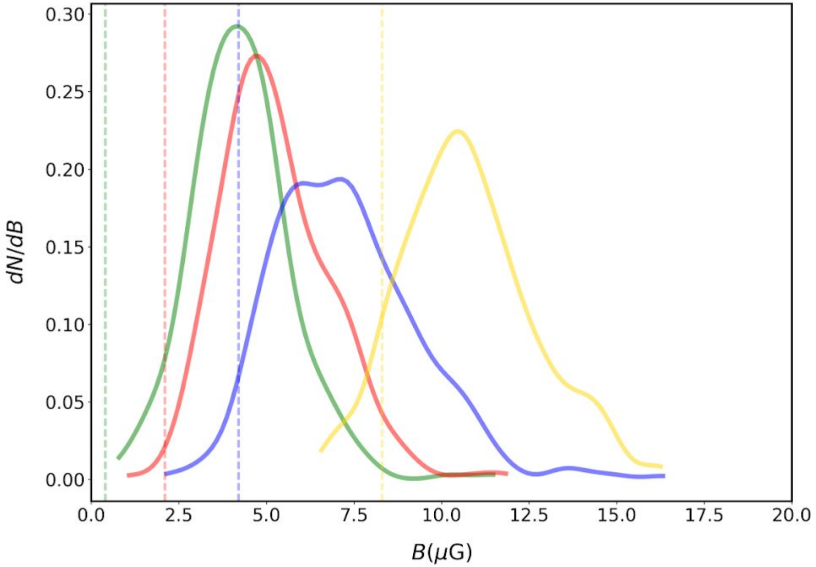
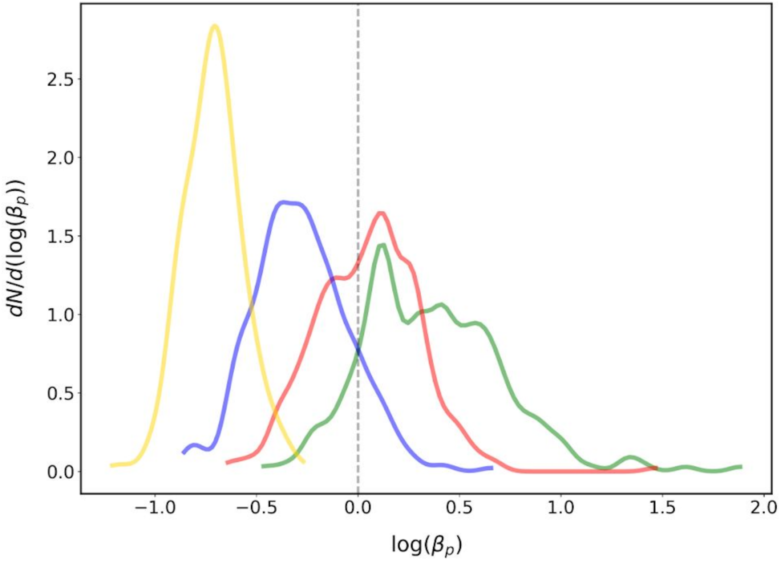
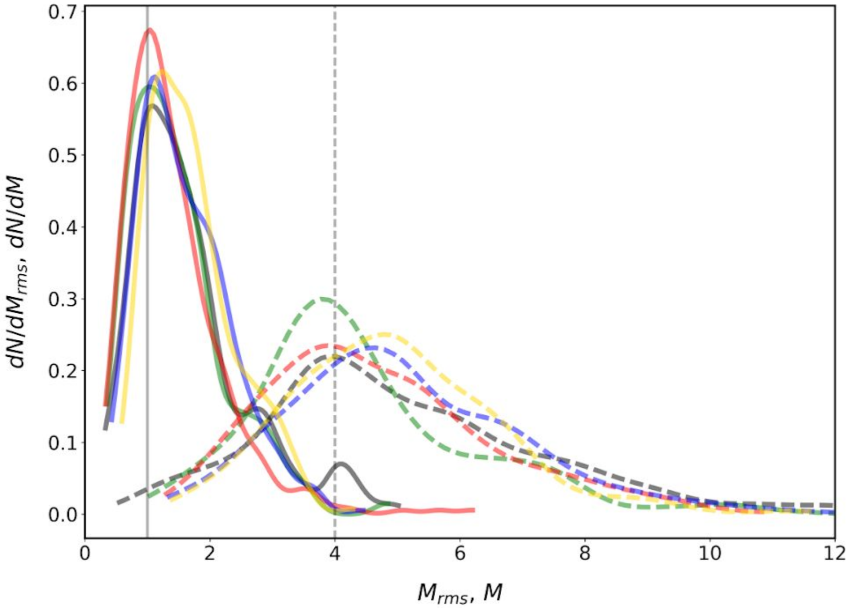
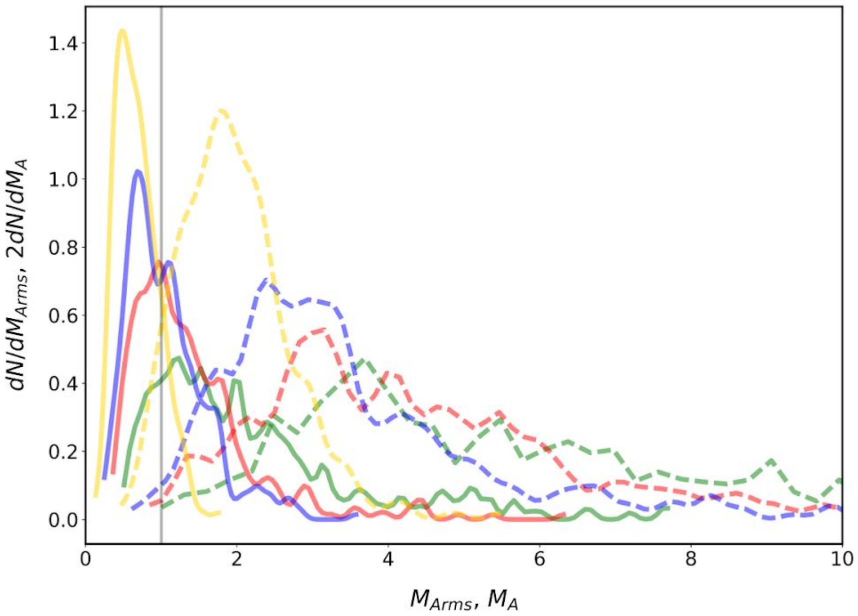




$$\beta_p = \frac{P_{th}}{P_b}$$

Physical properties of clumps





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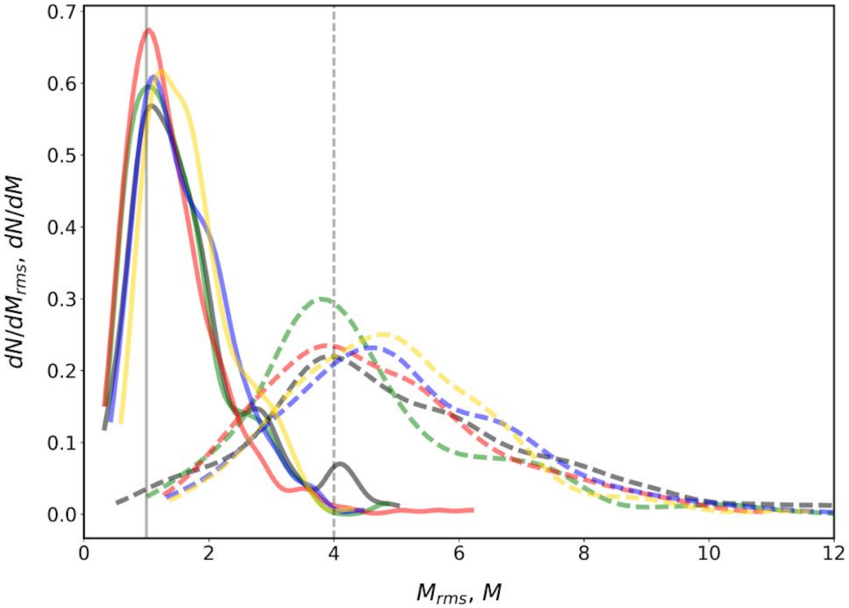
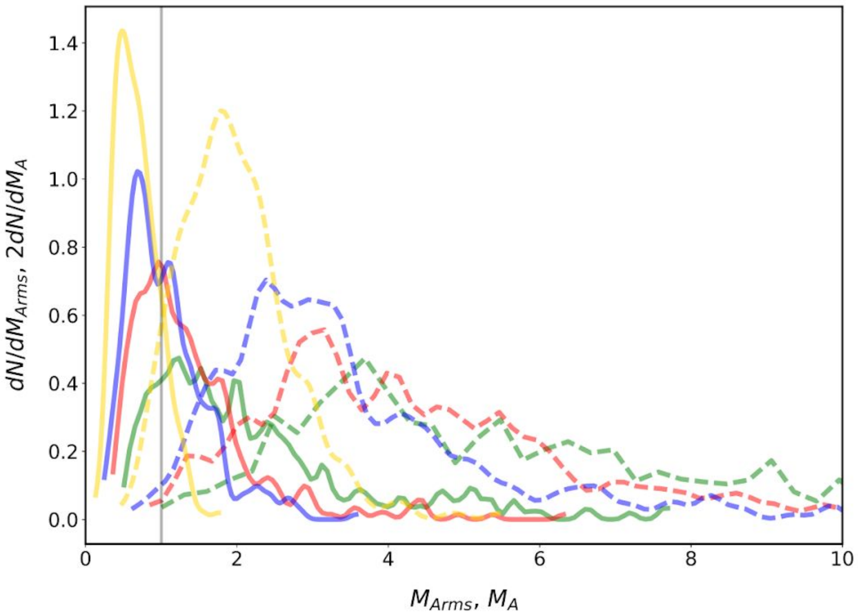
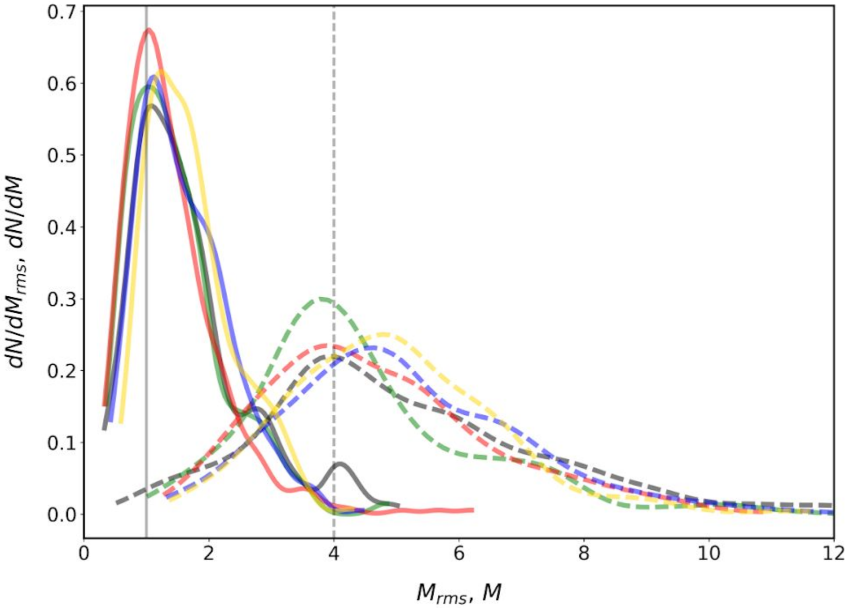


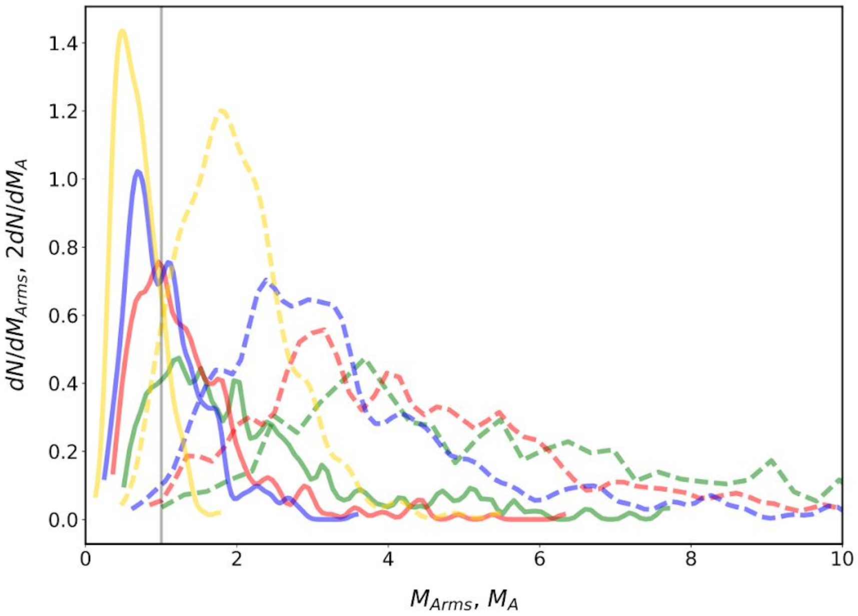


$$M_{rms} = < \frac{v_{rms}}{c_s} > \qquad v_{rms} = |v - \overline{v}|$$

$$M = < \frac{v}{c_s} >$$

Physical properties of clumps





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$$M_{Arms} = < \frac{v_{rms}}{v_A} > \qquad M_A = < \frac{v}{v_A} >$$

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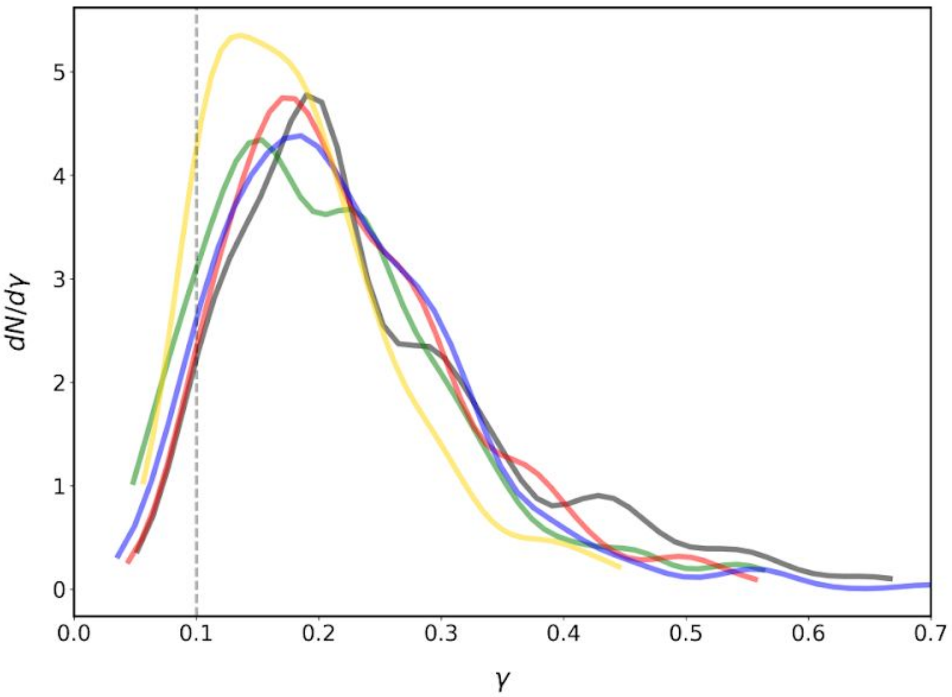
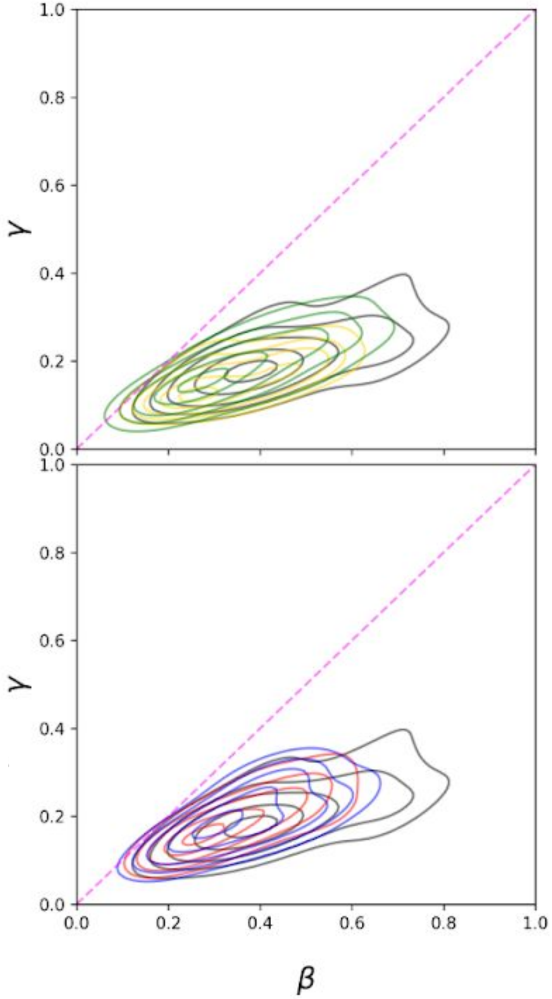
Morphology



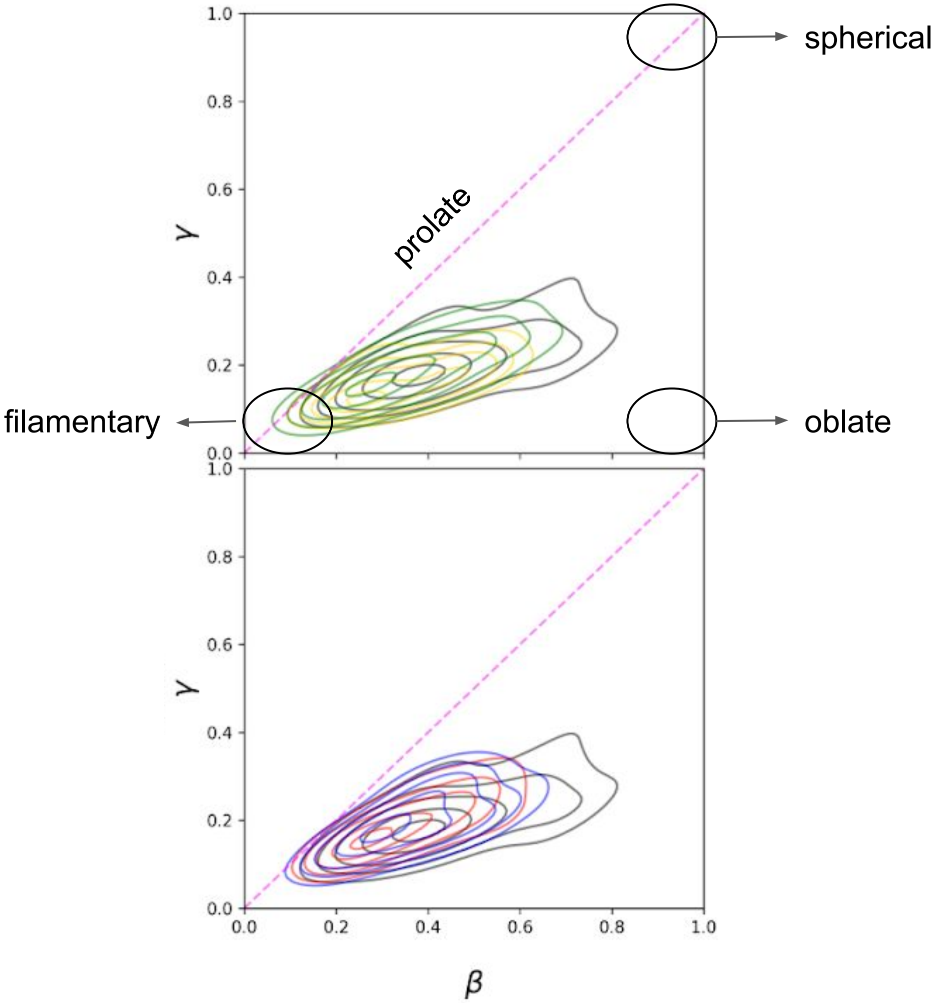
$$\gamma = \frac{smallest\ semi{-}axes}{largest\ semi{-}axes}$$

Morphology



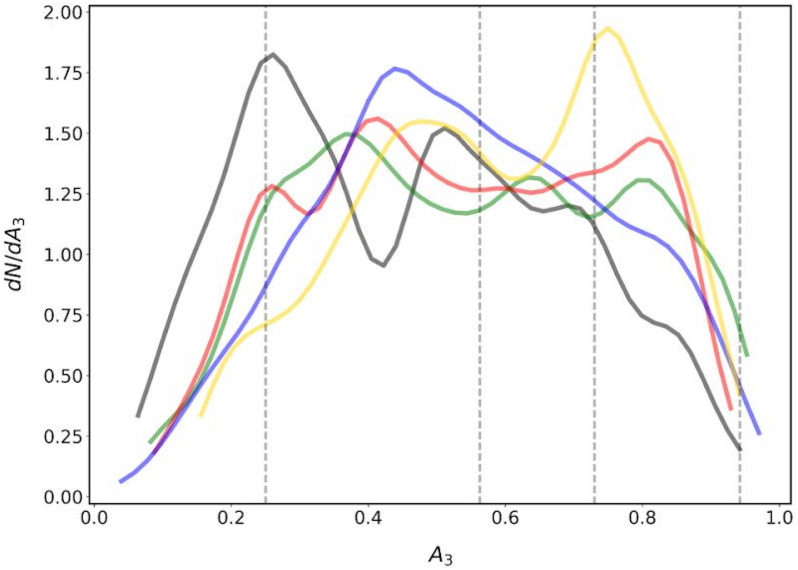
$$\beta = \frac{intermediate\ semi{-}axes}{largest\ semi{-}axes}$$

Morphology

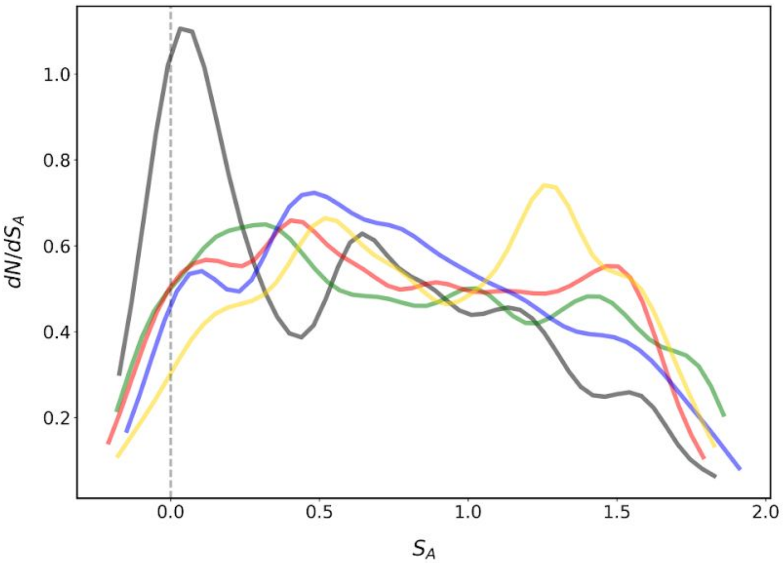


spherical
prolate
filamentary
oblate
1.0
0.8
0.6
0.4
0.2
0.0
γ
0.0
0.2
0.4
0.6
0.8
1.0
β

Morphology



2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8
1.0
dN/dA_3
A_3



1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
dN/dS_A
S_A

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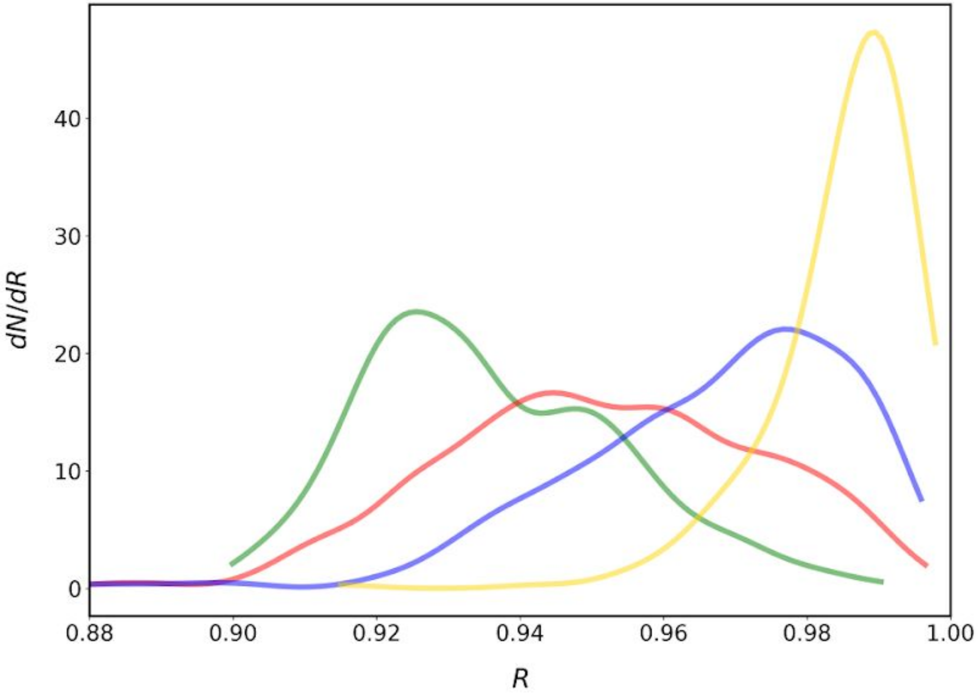
Relative alignments



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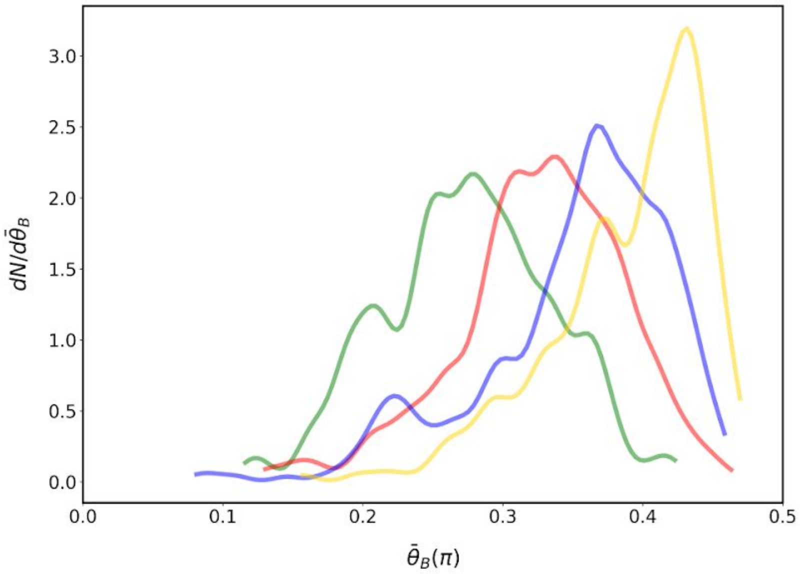
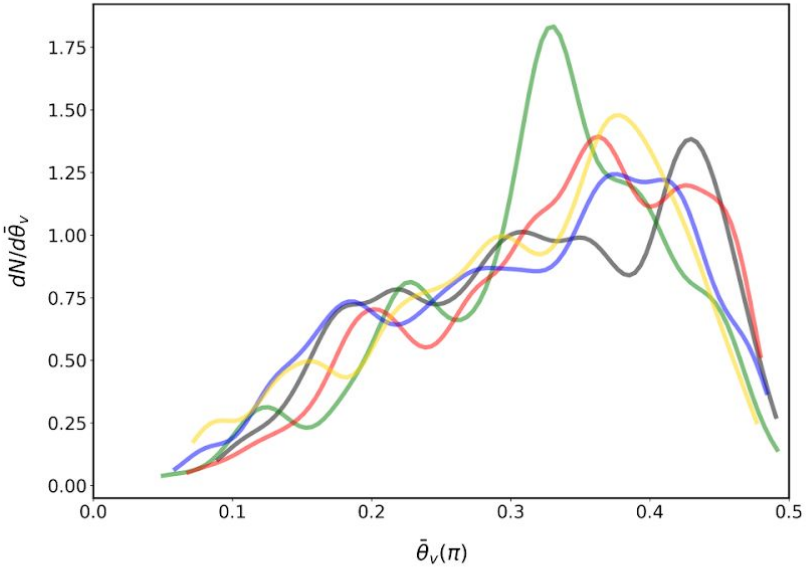
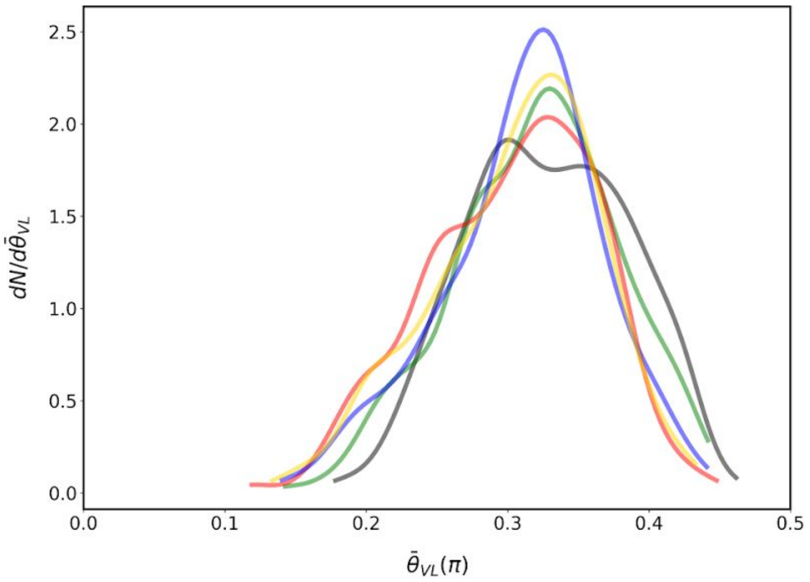


θB: largest principal axis of the clump and magnetic field

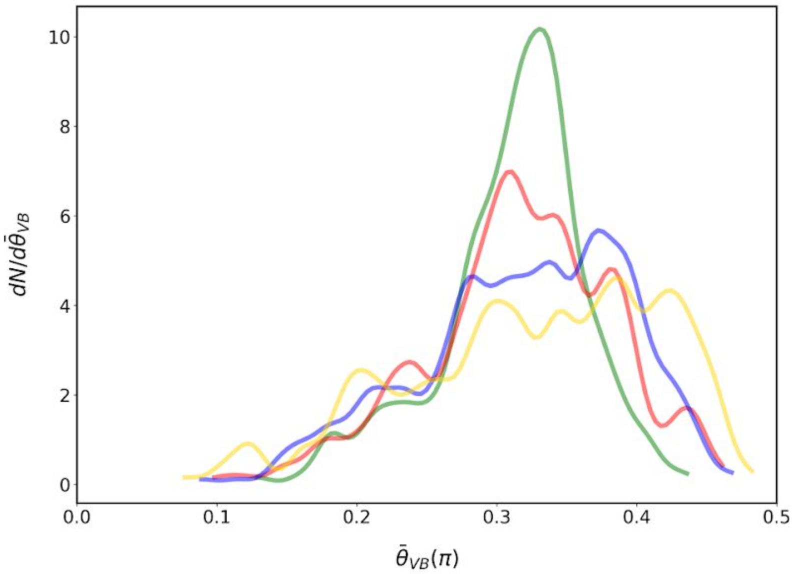


θV: largest principal axis of the clump and velocity

Relative alignments



θ_{VL}: largest principal axis of the clump and internal velocity



θ_{VB}: velocity and magnetic field

Discussion

1. Internal motions and magnetic field intensity
2. Pressure balance
3. Effects of the magnetic field on morphology
4. Magnetic field alignments

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Clumps as a whole move supersonically while their internally movements are barely transonic

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↓

Accordance with previous numerical works (e.g. Heitsch et al. 2005; Hennebelle et al. 2007; Saury et al. 2014)

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- Observations consistent with the distributions including only internal motions

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- Large difference between magnetized and non-magnetized clumps $\longrightarrow$ magnetic fields are heavily relevant to the structure of the neutral clumps of the ISM
- Accordance with previous works (Hennebelle 2013; Xu et al. 2019)

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- HI filaments $\longrightarrow$ edge-on shells or sheets originated by shock-waves resulting from supernova explosions (Kalberla et al. 2016, 2017a)

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- HI filaments $\longrightarrow$ edge-on shells or sheets originated by shock-waves resulting from supernova explosions (Kalberla et al. 2016, 2017a)
- These models cannot evaluate the presence of CNM sheets

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- As B_0 increases the clumps are preferentially perpendicular to magnetic field.
- $\bar{\theta}_{VL} \longrightarrow$ π/2 : compression facilitates the accumulation of material in directions almost perpendicular to the flow
- $\bar{\theta}_{VB}$ wider as B_0 increases: the internal motions in the clumps of this sample are not preferentially along the magnetic field lines

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- The morphology of HD is different to MHD
- Predominantly filament-like structures and tendency to prolate structures for MHD with respect to HD
- Preferred angles for $\theta_B : [\pi/4, \pi/2]$
- Asphericity and prolatness: a different way to characterize the morphological properties of density structures

Thank you for your attention!