Morphology of Molecular Clouds

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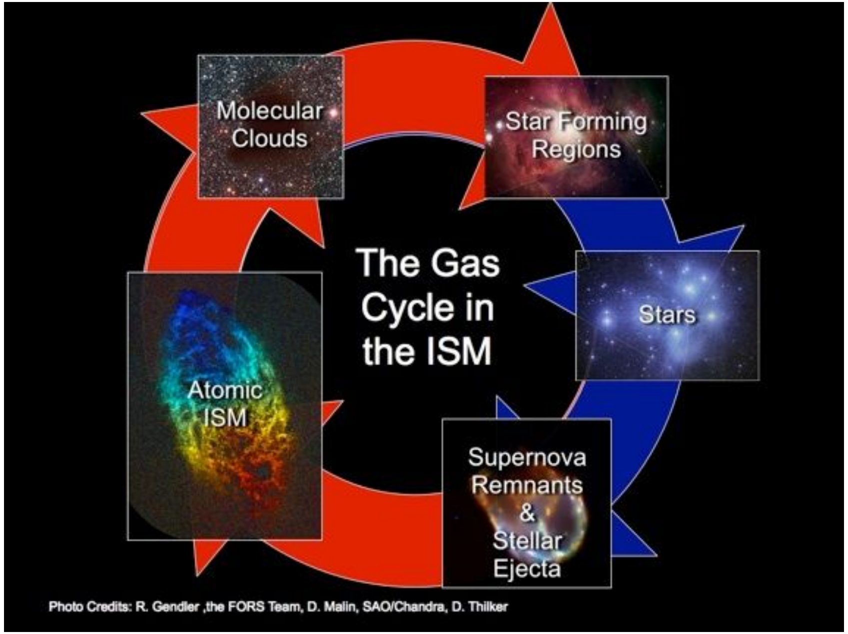
Molecular Clouds

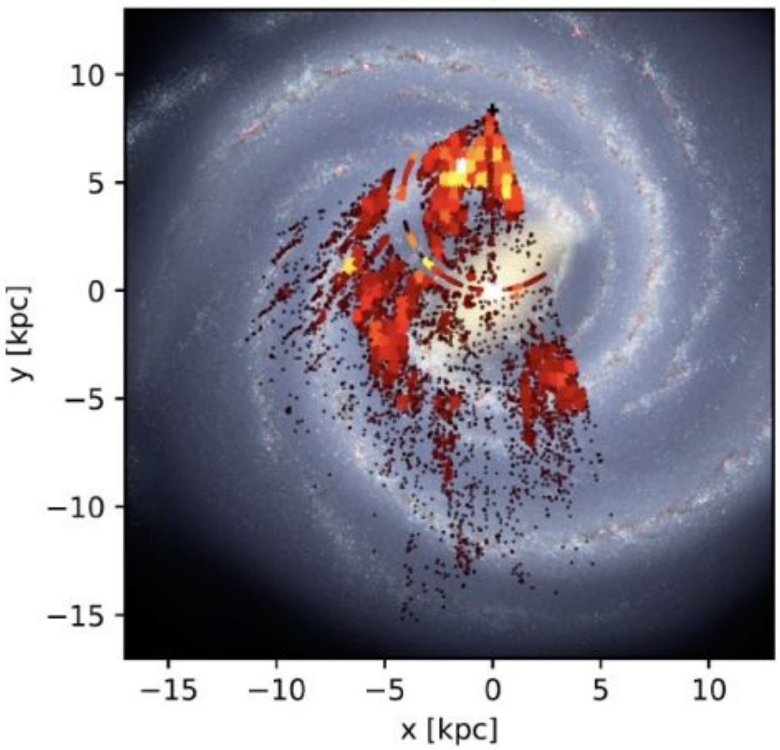
- Molecular clouds are dense and cold regions in ISM.
- They are sites of star formation.
- The formation theories include:
    - Local converging flows (Vazquez-Semadeni+ 2011).
    - Spiral arm cloud collision (Dobbs & Pringle 2012).
    - Gravitational and magneto-Jeans instability (Li+ 2005, Kim+ 2006).
    - Parker and thermal instability (Mouschovias+ 2009).



Dobbs et al. 2014, PPVI ; Heyer & Dame 2015, ARA&A, 53, 583

SEDIGISM Clouds (Duarte-Cabral et al. 2021)

- APEX observed 84 deg^2 of the inner Galaxy at 28”, using $^{13}CO(2\text{-}1)$ emission.
- **SCIMES** (Colombo et. al. 2015, 2019) algorithm used for identification of ~10000 clouds.
- A refined **SCIENCE sample** of well resolved molecular clouds with reliable distances contains **6664** clouds.



Source: Duarte-Cabral et al. (2021), MNRAS, 500, 3027

Morphological cloud classification

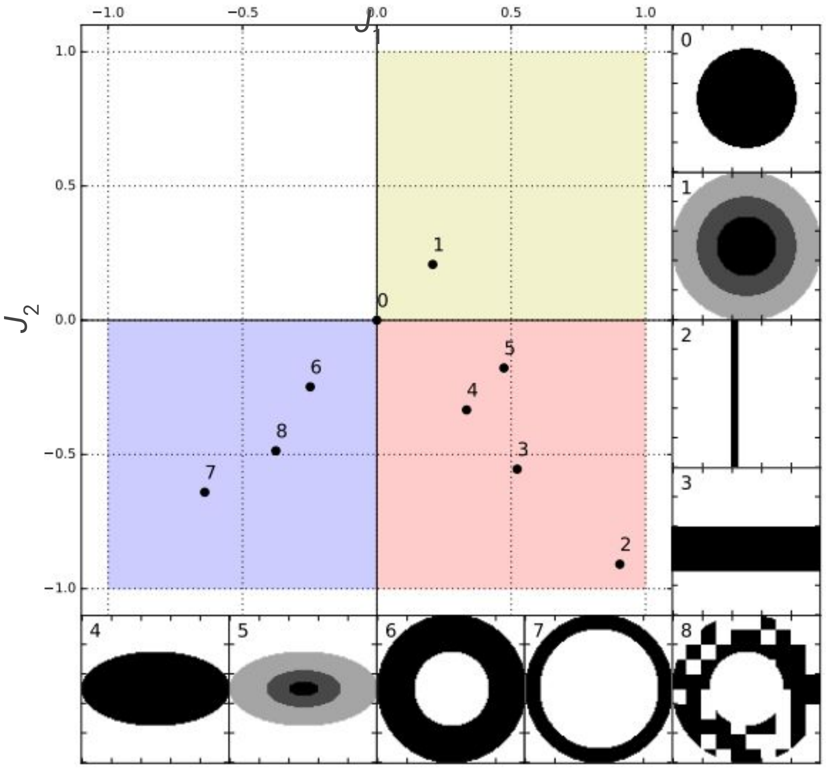
- *J* plot classification

$$J_i = \frac{I_0 - I_i}{I_0 + I_i} \quad , \quad i = 1, 2 ,$$

$$I_0 = \frac{AM}{4\pi}$$

- By-eye classification

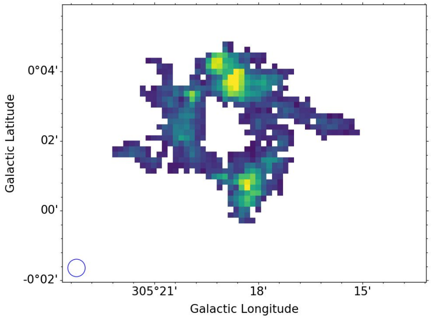
J Plots

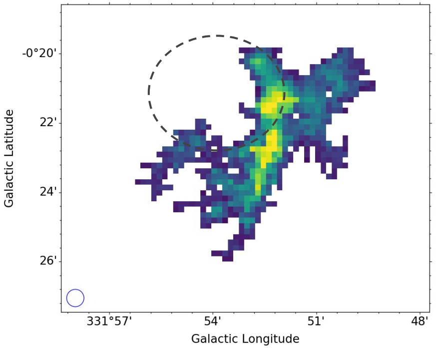


Source: S.Jaffa et. al. 2018

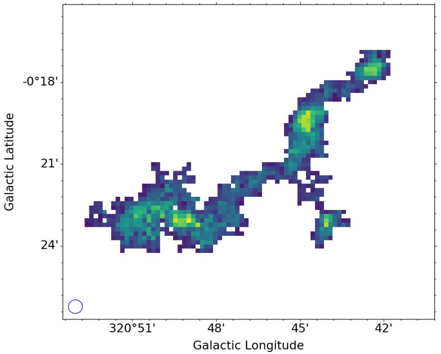
STRUCTURE	**PRINCIPAL MOMENTS**	J_1	J_2
Uniform surface density disc	$I_1 = I_2 = I_0 \equiv AM/4\pi$	0	0
Centrally concentrated disc (**Core**)	$I_1 = I_2 < I_0 \equiv AM/4\pi$	> 0	> 0
Limb-brightened ring (**Bubble**)	$I_1 = I_2 > I_0 \equiv AM/4\pi$	< 0	< 0
Elongated ellipse (**Filament**)	$I_1 < I_0 \equiv AM/4\pi < I_2$	> 0	< 0

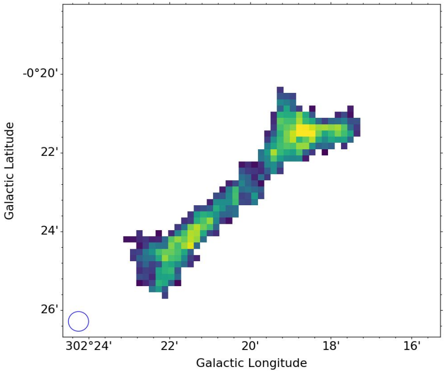
Cloud Morphologies (By-eye classification)



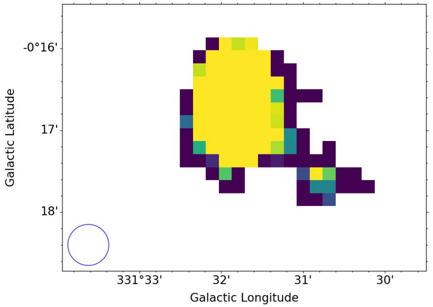


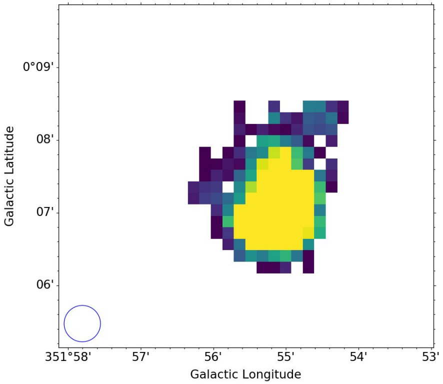
Ring-like clouds



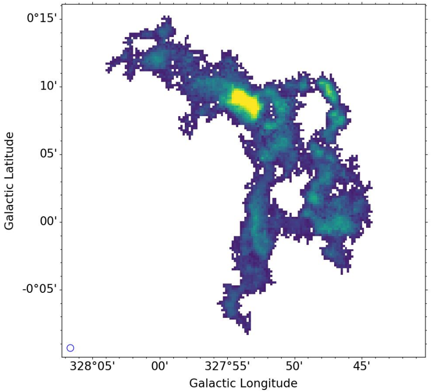


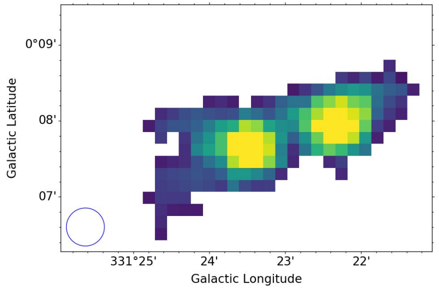
Elongated clouds





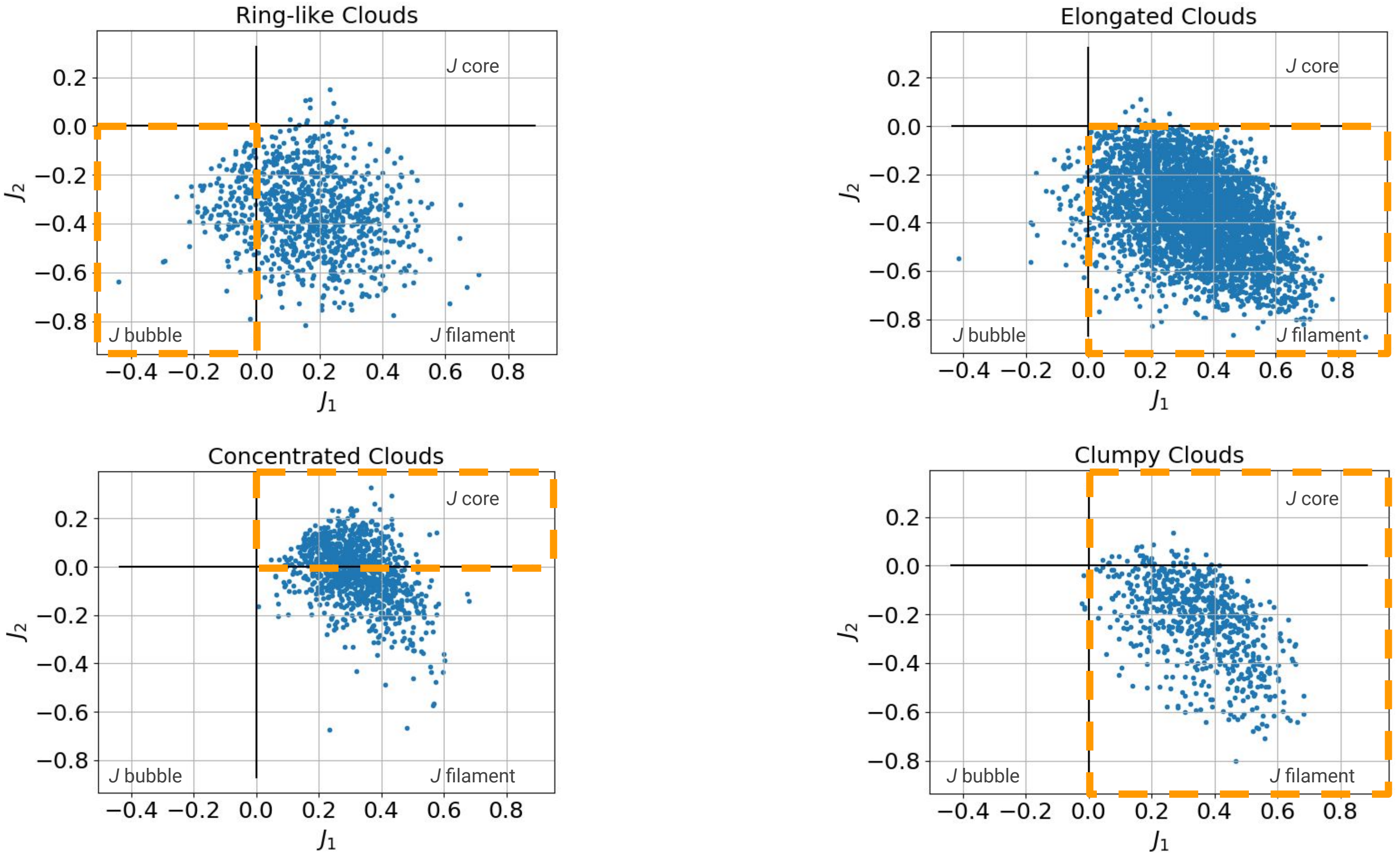
Concentrated clouds





Clumpy clouds

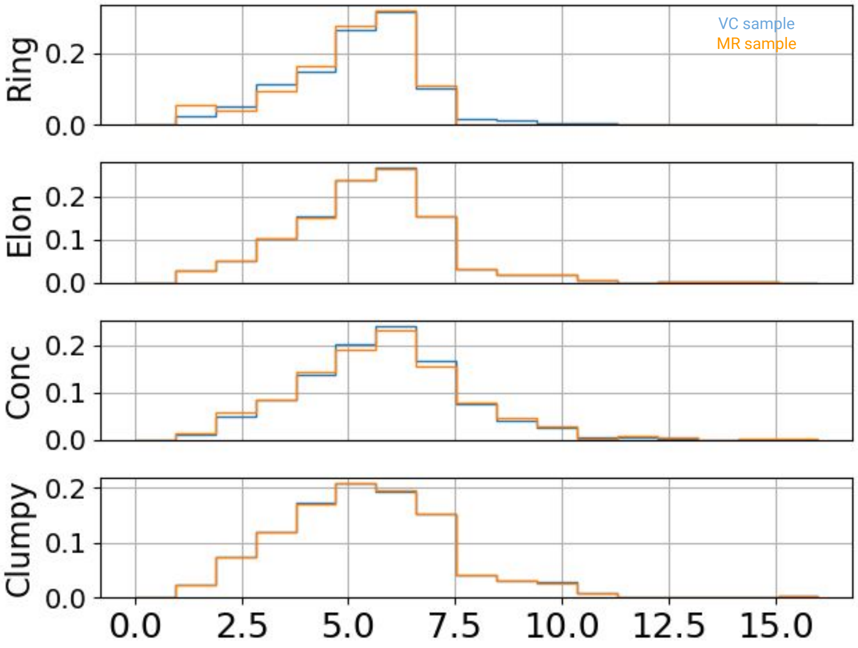
VC and MR samples



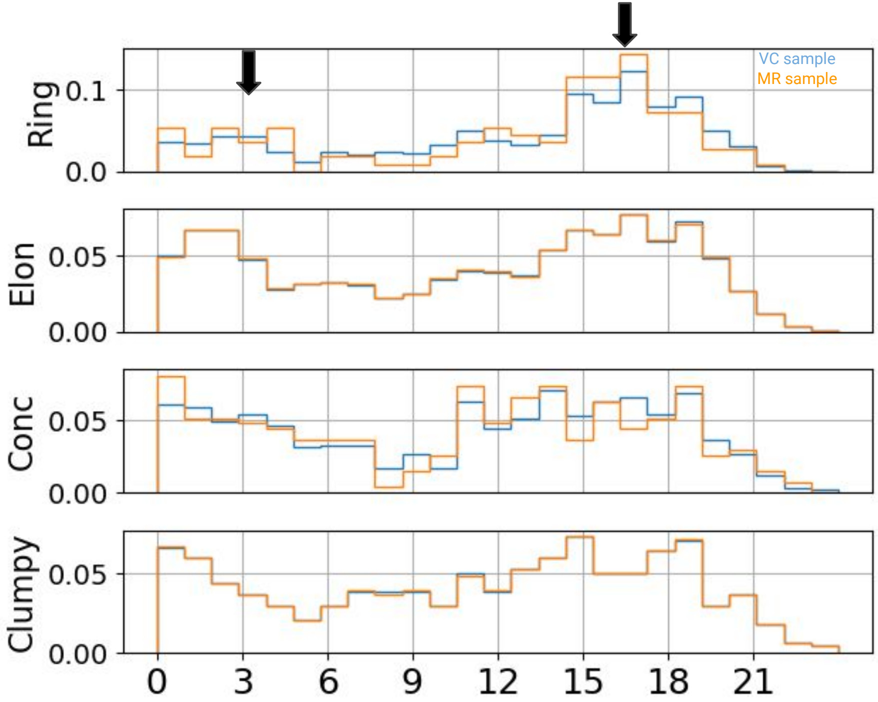
VC and MR samples

Structure		*J* - Classification			
		Bubble	Filament	Core	Total
Manual Classification	Ring-like cloud	156	791	14	961
	Elongated cloud	60	3607	9	3676
	Concentrated cloud	0	566	528	1094
	Clumpy cloud	4	688	41	733
	Total	220	5652	592	6464 (5020)

Environmental dependence of morphology

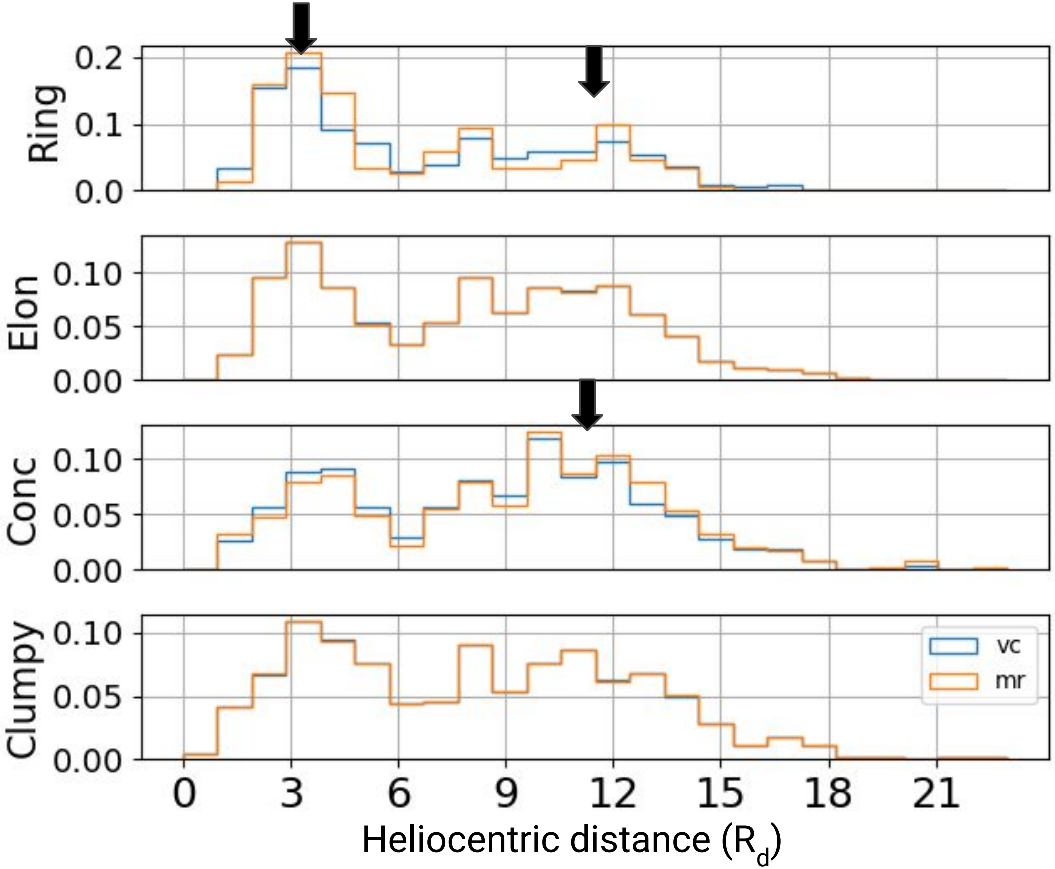


Galactocentric Radius (R_{gal})

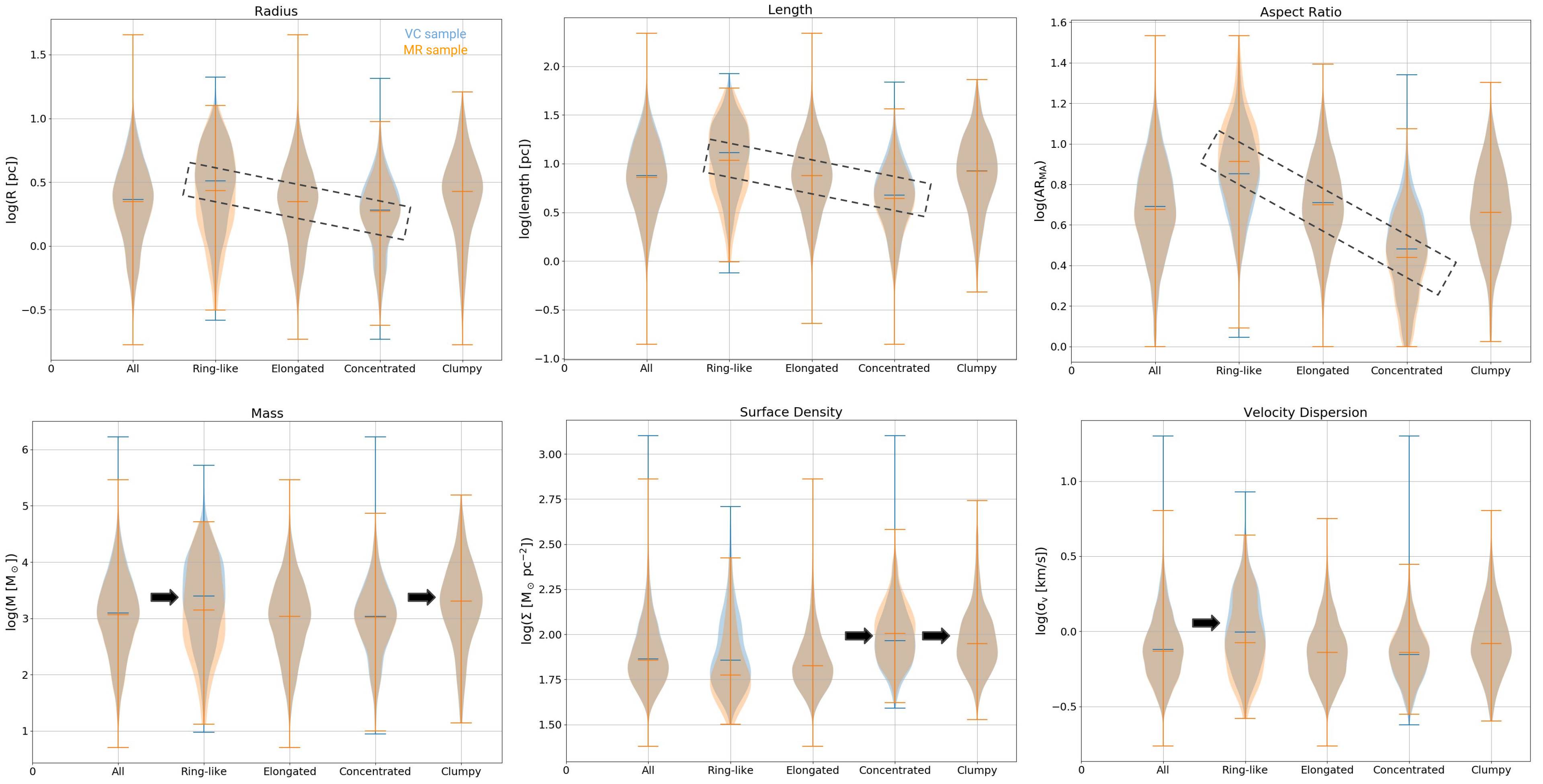


Galactic height (z_{gal})

Technical limitations



Integrated Properties (Duarte-Cabral et al. 2021)



Star formation properties

Urquhart et al. 2021

Cloud sample with SFE > 0 and DGF > 0
(1672 clouds)

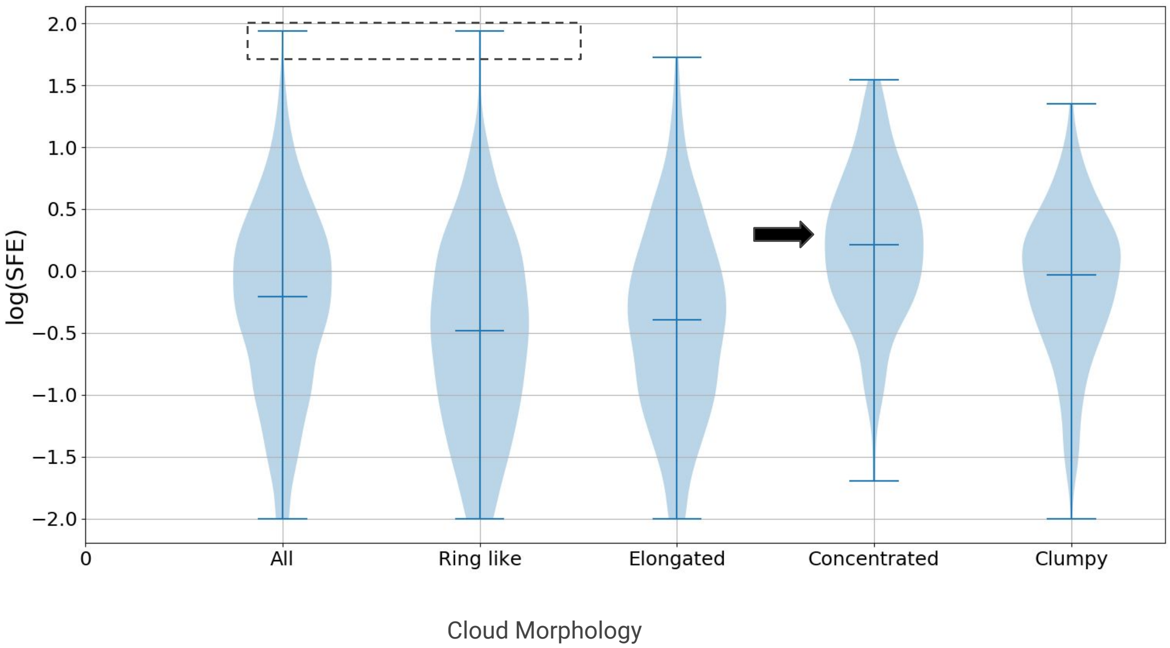
- Star Formation Efficiency

$$SFE = \frac{\sum L_{clump}}{M_{cloud}}$$

- Dense Gas Fraction

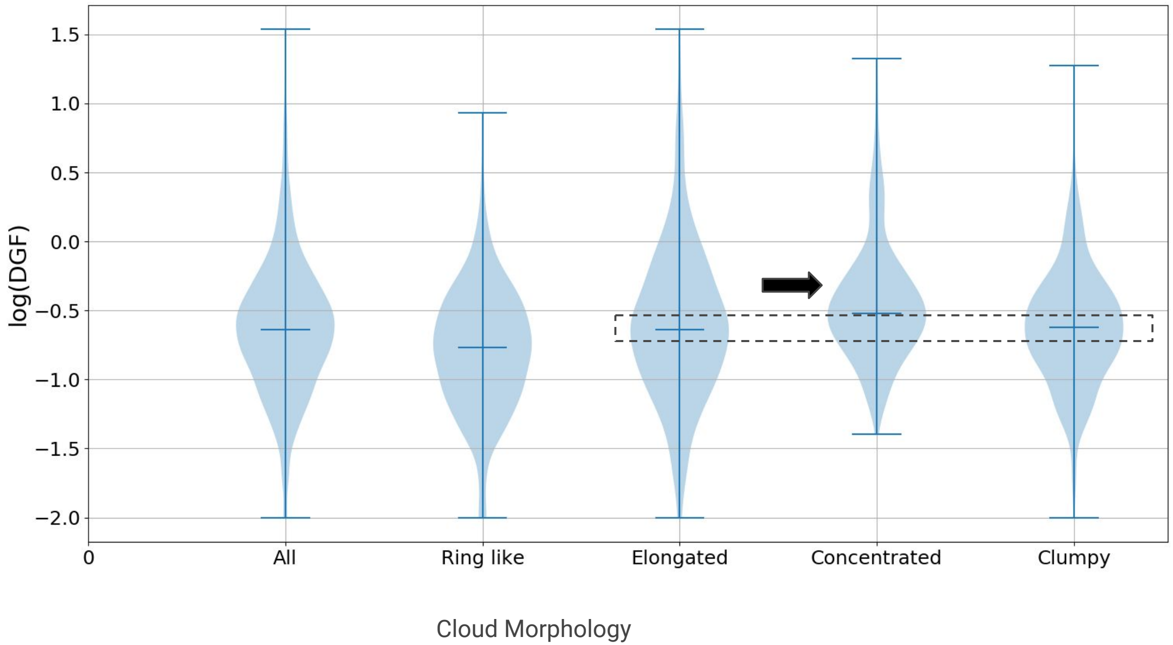
$$DGF = \frac{\sum M_{clump}}{M_{cloud}}$$

Star Formation Efficiency (SFE)



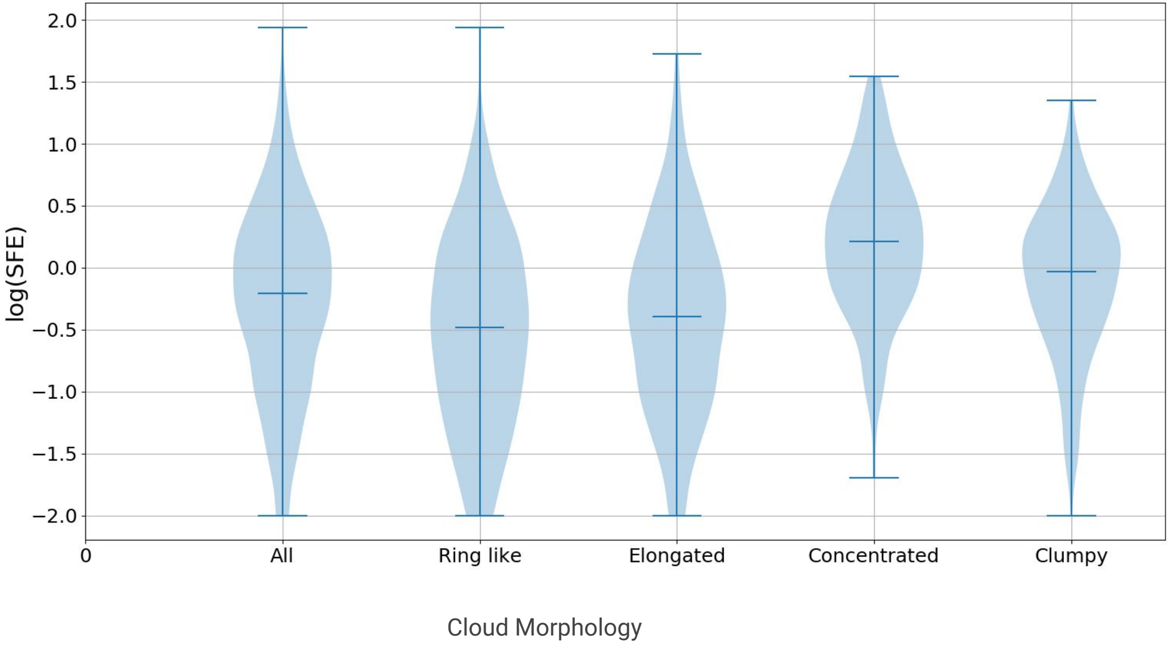
- Ring-like clouds show highest values but for a small sample.
- Concentrated clouds show overall higher distribution.

Dense Gas Fraction (DGF)



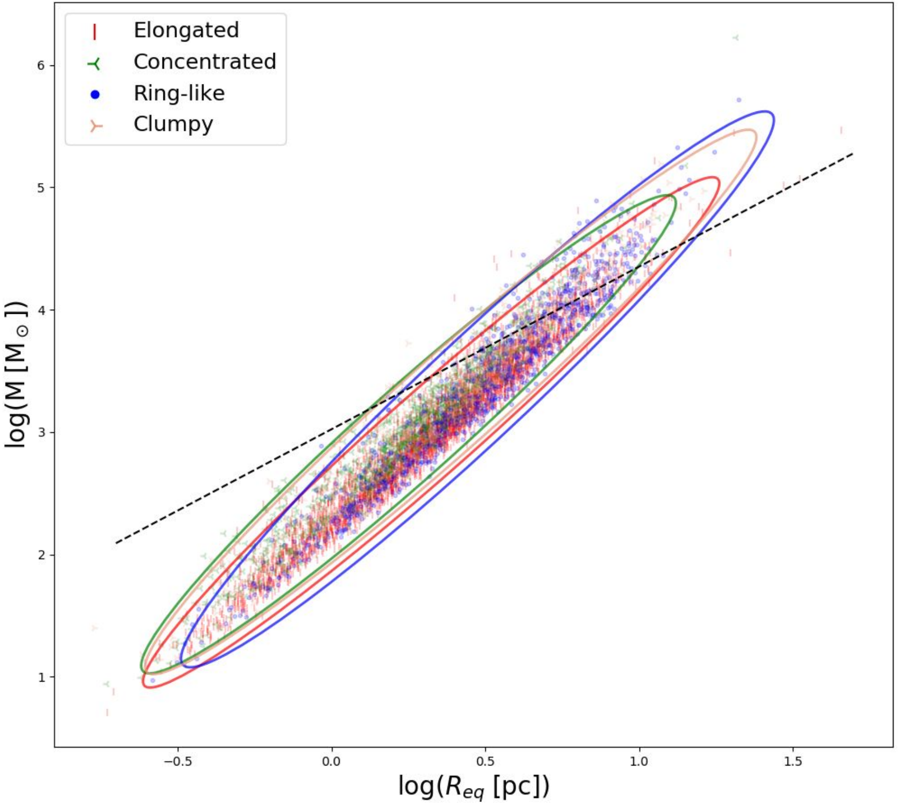
- Concentrated clouds show overall higher distribution.
- Elongated and clumpy clouds have similar distributions.

Star Formation Efficiency (SFE)



- Ring-like clouds show highest values but for lower sample.
- Concentrated clouds show overall higher distribution.
- Clumpy clouds have higher values than elongated clouds.

HMSF threshold (Kauffmann et al. 2010)



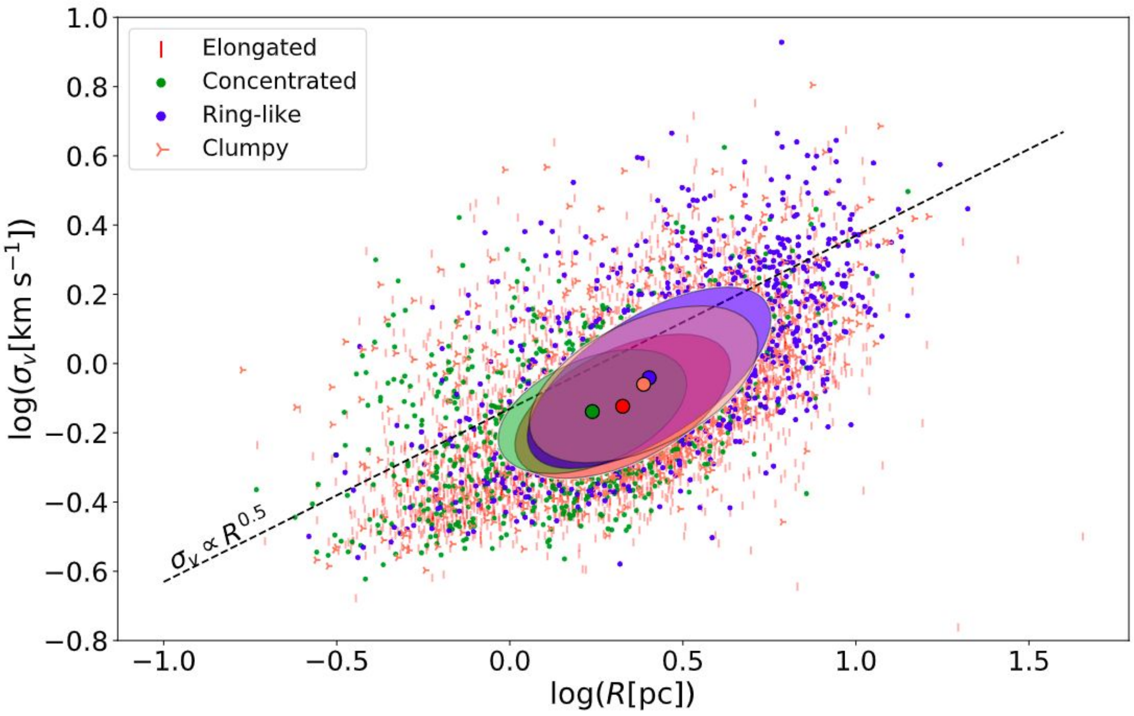
- The dashed line represents the mass-size threshold for high-mass star formation updated by Duarte Cabral et al. 2021.

$$M\ [M_\odot] = 1053 * (R\ [pc])^{1.33}$$

Sample	Ring-like	Elongated	Concentrated	Clumpy
VC	19.87	6.72	8.8	18
MR	16.67	6.68	9.88	17.96

Table : Percentage of clouds above HMSF threshold for each morphology.

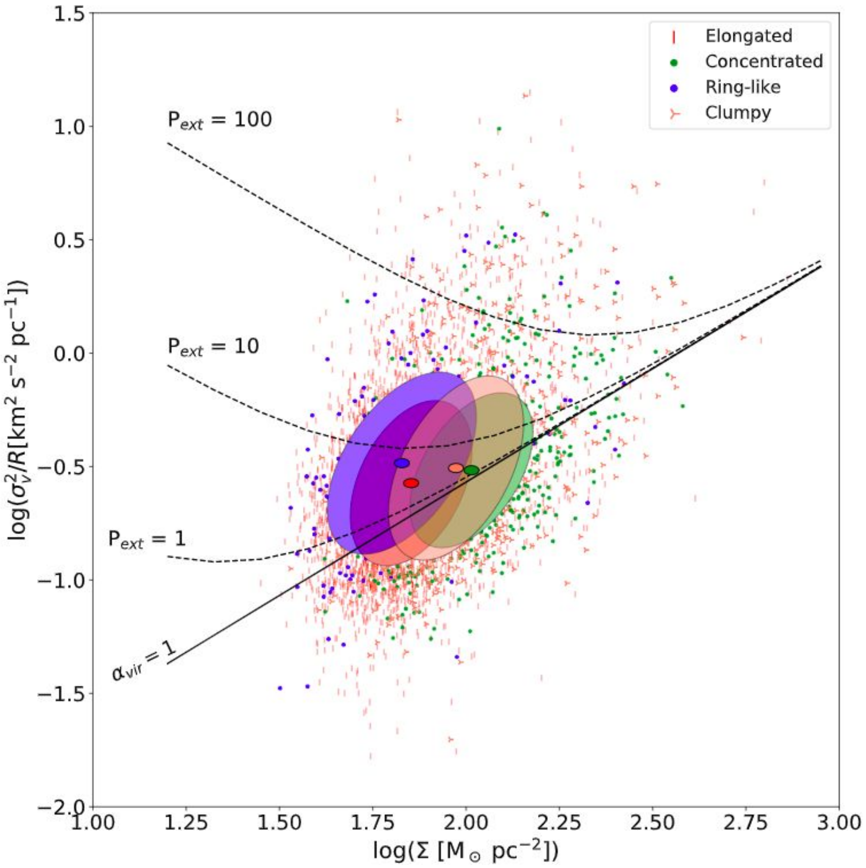
Size-linewidth relation (Larson 1981)



1-σ (68%) confidence ellipses obtained using Principal Component Analysis (PCA).

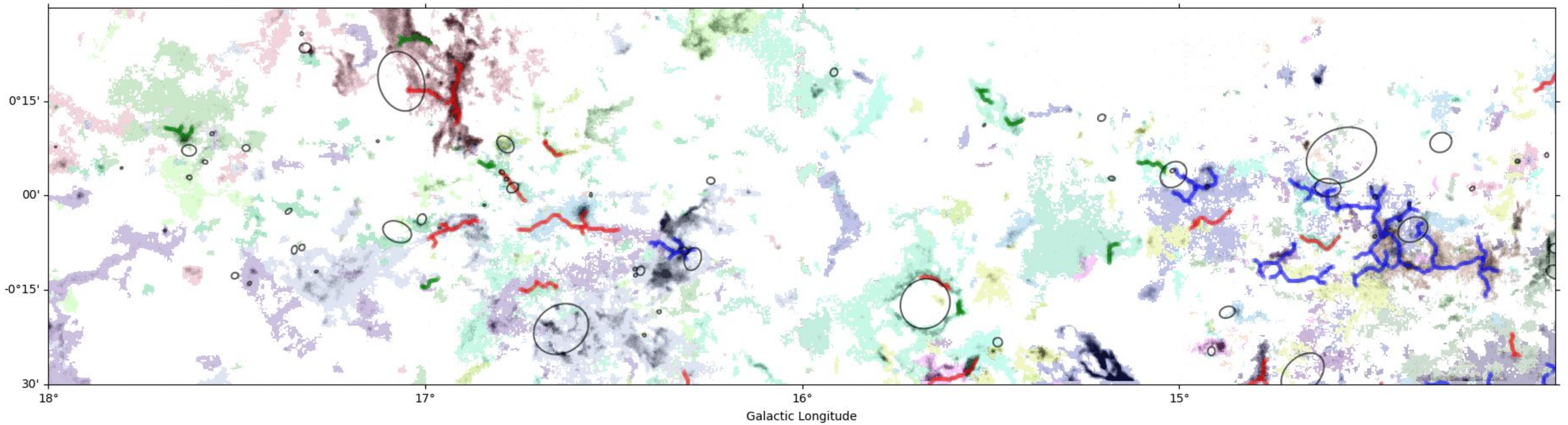
- The large scatter shows that not all clouds follow the relation.
- Ring-like clouds show higher velocity dispersion amongst similar sized structures.

Heyer Relation



- The progression of morphology in order of being gravitationally bound:
  - Ring-like clouds
  - Elongated clouds
  - Clumpy clouds
  - Concentrated clouds

Comparison to continuum surveys



ATLASGAL (Li et al. 2016)

- Filaments
- Network of filaments
- Resolved elongated structures

Milky Way Project
(Jayasinghe et al. 2019)

- Bubbles

Two Publications

Astronomy & Astrophysics manuscript no. output
September 7, 2021

The SEDIGISM survey: Morphological classification of molecular clouds

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ABSTRACT

We present one of the very first extensive classification of molecular clouds based on their morphology. This is achieved using a recently published catalogue of 10663 clouds obtained from the first data release of the SEDIGISM survey. The clouds are classified into four different morphologies using an automated algorithm – *J* plots – and by visual inspection. The visual inspection also serves as a test for the *J* plots algorithm, as this is the first time it has been used on molecular gas. The structure of molecular clouds is highly filamentary and our observations verify that most of our molecular clouds are elongated structures. Based on our visual classification of the 10663 SEDIGISM clouds, 15% are ring-like, 57% are elongated, 15% are concentrated and 10% are clumpy clouds. The remaining clouds do not belong to any of these morphologies and are termed unclassified. We compare the SEDIGISM molecular clouds with structures identified through other surveys, i.e. ATLASGAL elongated structures and the bubbles from MWP. We thus identify the velocity coherent ATLASGAL and MWP structures. ATLASGAL elongated structures overlap with ≈ 21% of the SEDIGISM elongated structures (elongated and clumpy clouds) and MWP bubbles overlap with ≈ 25% of the SEDIGISM ring-like clouds. We also analyse the star-formation associated with different cloud morphologies using two different techniques. The first technique employs star formation efficiency (SFE) and the dense gas fraction (DGF), obtained using SEDIGISM clouds and ATLASGAL clumps.The second techniques uses the high-mass star formation (HMSF) threshold for molecular clouds. The results indicate that two morphologies, i.e. ring-like and clumpy clouds show higher star formation.

Key words. ISM: clouds

Astronomy & Astrophysics manuscript no. output
September 7, 2021

The SEDIGISM survey: Connection between cloud morphology and integrated properties

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ABSTRACT

The high spatial and spectral resolution of the SEDIGISM survey has allowed us to investigate the physics of the molecular interstellar medium at an unprecedented level of detail. It has helped us identify integrated properties of molecular clouds as well as their morphology. In this paper, we use the morphological classification of clouds and study the relation between cloud morphology and their other properties such as size, mass, velocity dispersion, surface density, and virial parameter. We find evidences suggesting a connection between the morphology and properties, some of which can be related to the physical processes behind them. We also analyse the influence of the Galactic environment on the cloud morphology and find that only ring-like clouds are affected by changes in Galactic environment. These clouds also show the most peculiar properties compared to other morphologies and this might be related to their formation process. We plot the two well known scaling relations – Larson's and Heyer's relations – for the different cloud morphologies. The different morphologies show various trends for virial parameter supporting their different structures.

Key words. ISM: clouds

Future work

Detection of stellar feedback regions from large surveys like SEDIGISM, OGHReS & LASMAGAL using a combination of

- Machine learning techniques like dendrogram and clustering.
- Deep learning algorithm aided by magnetohydrodynamic simulations of molecular clouds (e.g. CASI).

Summary

- Identification of morphology for 10000+ clouds.
- Most of the clouds are elongated.
- Trends shown by cloud properties for different morphologies.
- Ring-like clouds show most peculiar behaviour.
- Star formation for different morphologies.