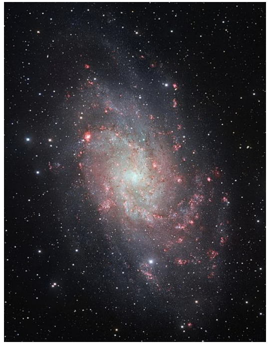
Classifying the Evolutionary States of Giant Molecular Clouds in M33



by

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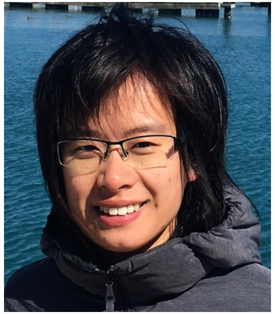

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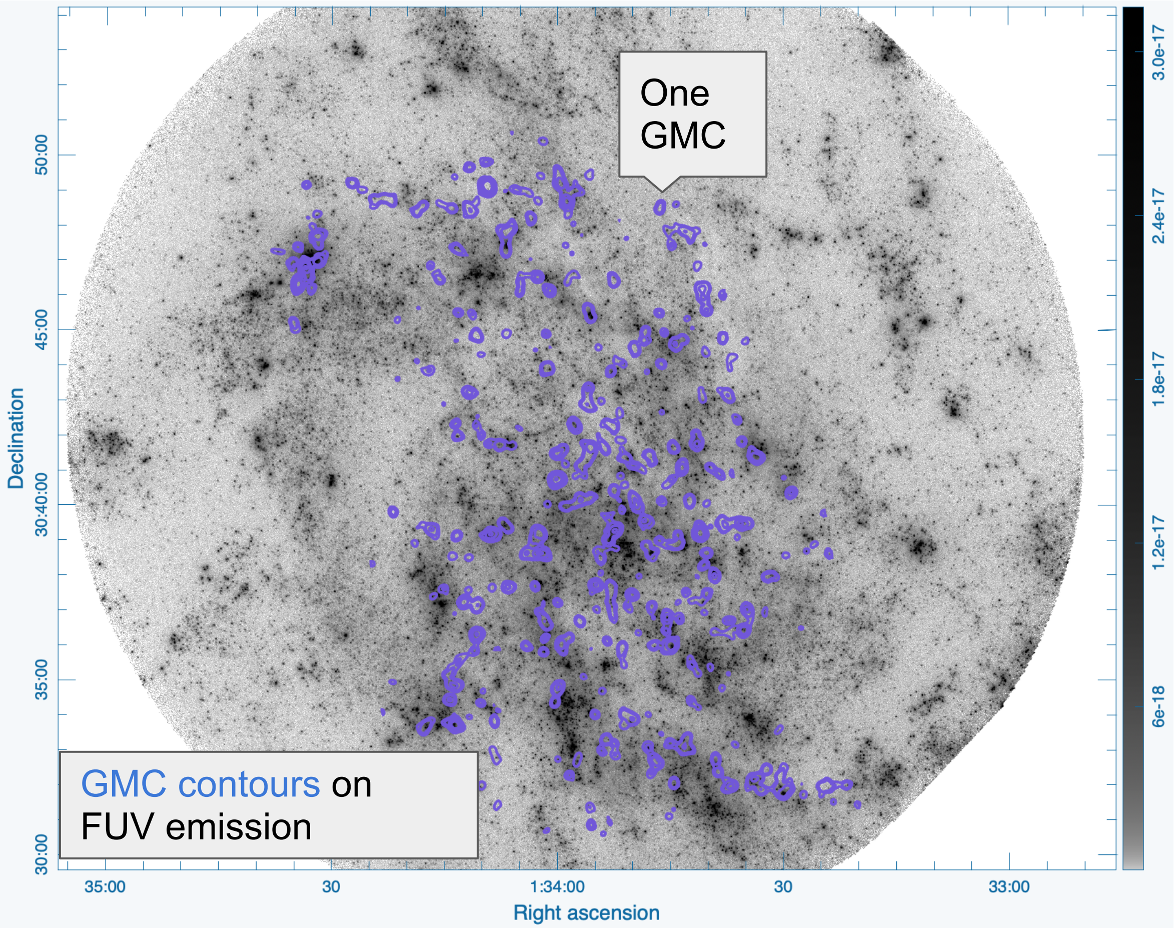
Motivations & Significance (why do we care?)

- **Studying the evolution of molecular clouds in galaxies is crucial for understanding the mechanisms behind star formation**
  - How does the mass function evolve with SF stages? What does it indicate about GMC accretion?
  - Does the evolutionary state of clouds affect the size-linewidth relationship in M33?

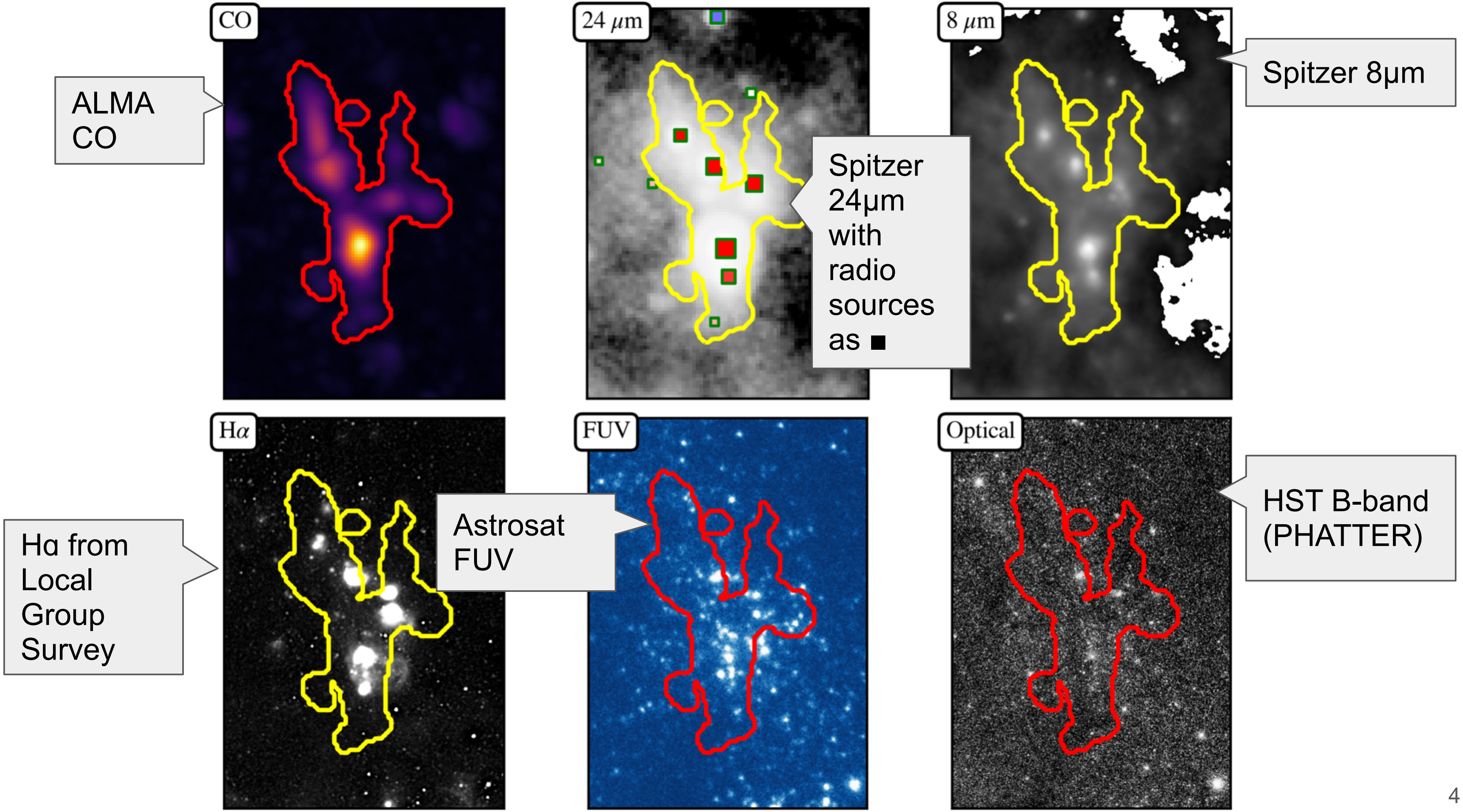
- **Environment/morphology may be an indicator of the GMC's evolutionary stage**
  - Can the galactocentric radius of a cloud inform its morphology and star formation activity?
  - Can the morphology of clouds tell us about their star formation activity?
  - Can properties like the virial mass and CO-traced luminosity of clouds shed light on the validity of the α_{CO} factor?

- **Why M33?**
  - M33 is nearby, close to face-on, and data are available in various bands
  - New ALMA data on M33!

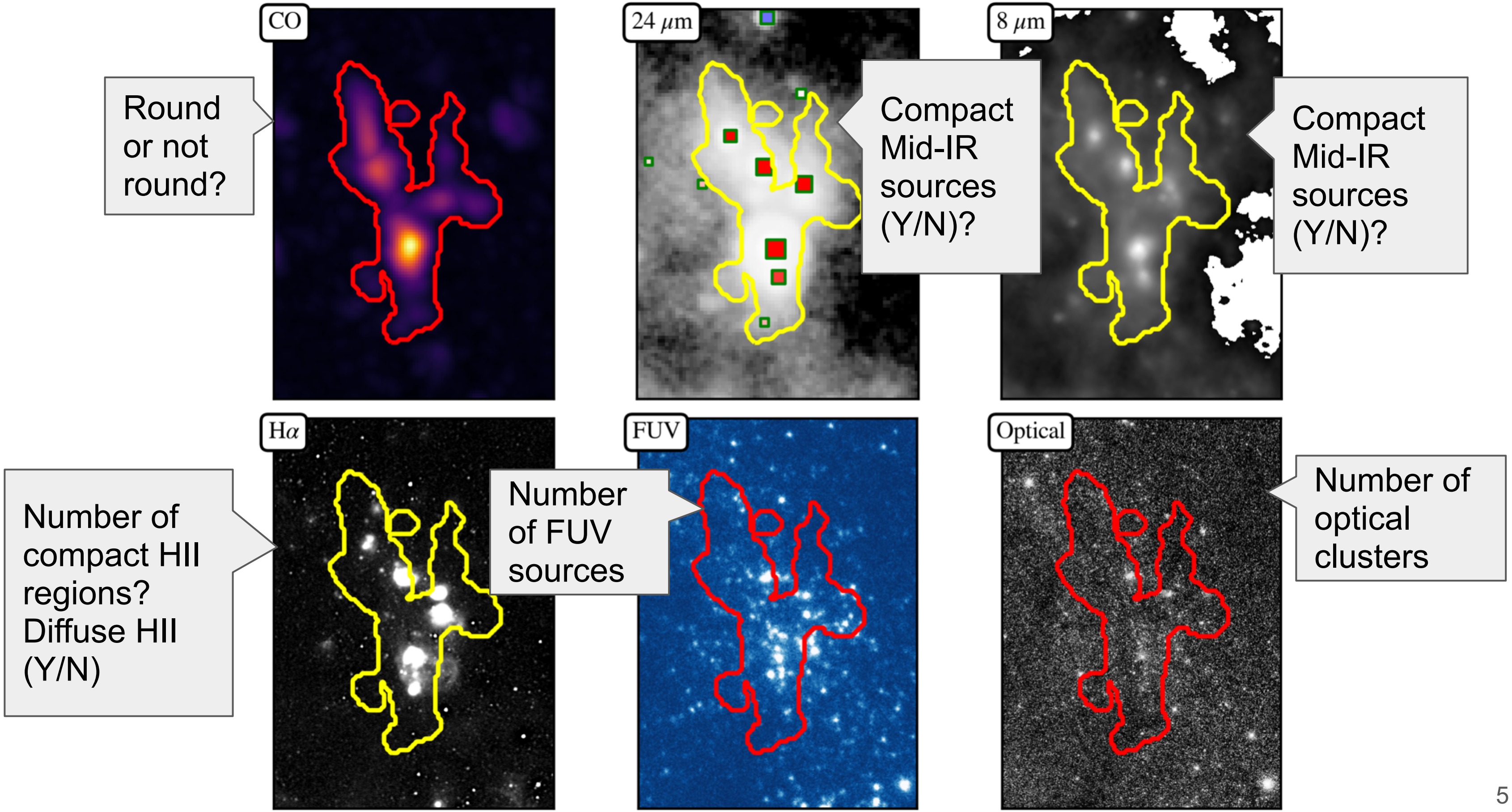


Observational Data & Methodology

- New ALMA-ACA mapping of CO(2-1) emission from M33 (d=840 kpc)
- Spatial resolution = 30 pc
- Use SCIMES to identify 442 GMCs ($M=10^4 M_\odot$ to $10^6 M_\odot$)
- Examine and compare each GMC to archival data to assess star formation activity.


CO
24 μm
8 μm
ALMA CO
Spitzer 24μm with radio sources as ■
Spitzer 8μm
Hα
FUV
Optical
Hα from Local Group Survey
Astrosat FUV
HST B-band (PHATTER)

We visually checked each GMC region using a classification scheme



Results

- Bigger and more complex shaped clouds have a higher star formation activity (more diverse content)
- Dark GMCs (no SF or w/ only embedded SF) tend to be less massive
- GMCs located in the inner part have a more complex morphology and a higher star formation activity than GMCs located in the outer part of M33
- Both M_{vir} and M_{lum} show weak evidence for decreasing outward suggesting more massive GMCs are located in the inner part; α_{CO} increases with R (with decreasing metallicity)
- At first look, the evolutionary state of the cloud doesn’t seem to affect size-linewidth relation

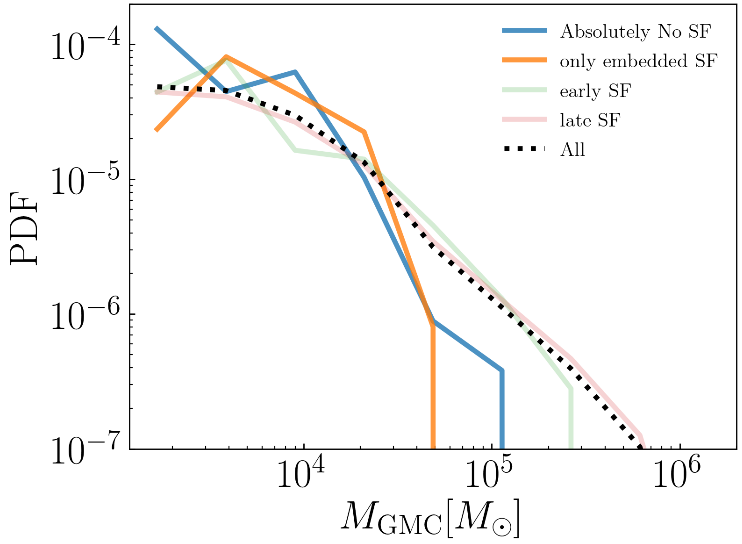
APPENDIX

Significant Differences in GMC Mass Function b/w Different SF Stages:

We classify the GMCs into four categories:

Absolutely No SF, only embedded SF, early SF, late SF

(no srcs) (MIR only) (no clusters&diffused HII) (has clusters/diffused HII)



We performed K-S test to these samples, and p-value=
No SF vs. All : 0.00007
embedded vs. All: 0.002

GMCs without exposed SF have significantly lower mass

There is a hint that the lower end of the mass function is slightly higher in embedded subsample than the NoSF subsample, but it is not very significant p-value=0.09

Morphology vs content and star formation indicators

Morphology : 2 criteria

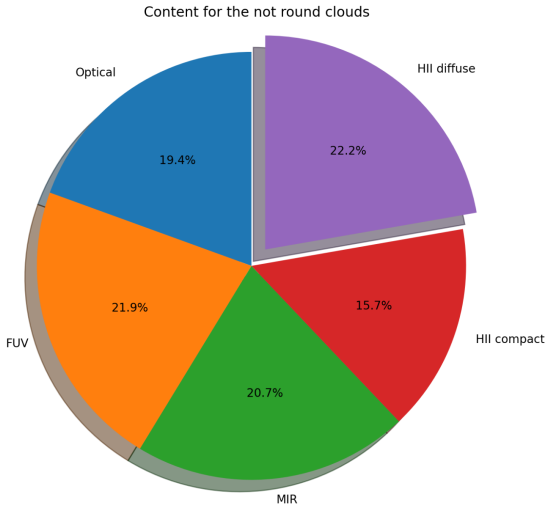
- the shape : from round to more complex structures such as filaments or multipeaked clouds
- size : small to more extended

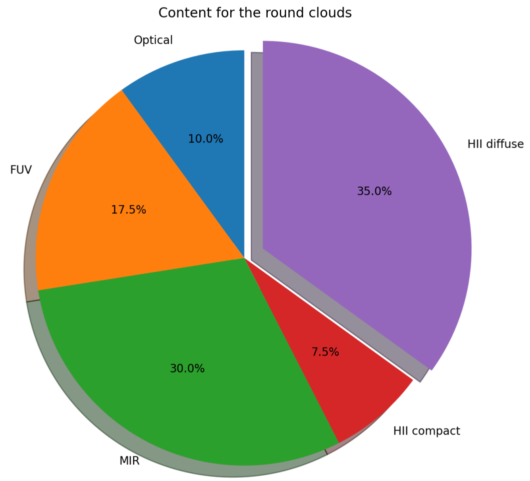
Content :

- type of the sources : far UV or medium IR or optical compact sources, HII compact regions or diffuse HII regions …
- number of each type of source inside the cloud
- connection between types : finding the same source in more than one map (UV, IR, optical, ..)

Analysis :
content vs morphology
kind + number of sources inside the cloud vs round/not round

Morphology vs content and star formation indicators





As the cloud gets more complex in shape (round to multipeaked, …) it increase his content as the type of sources and the number of each type of source
Same trend as you grow in size

→ Impact on the size and morphology of the cloud on star formation

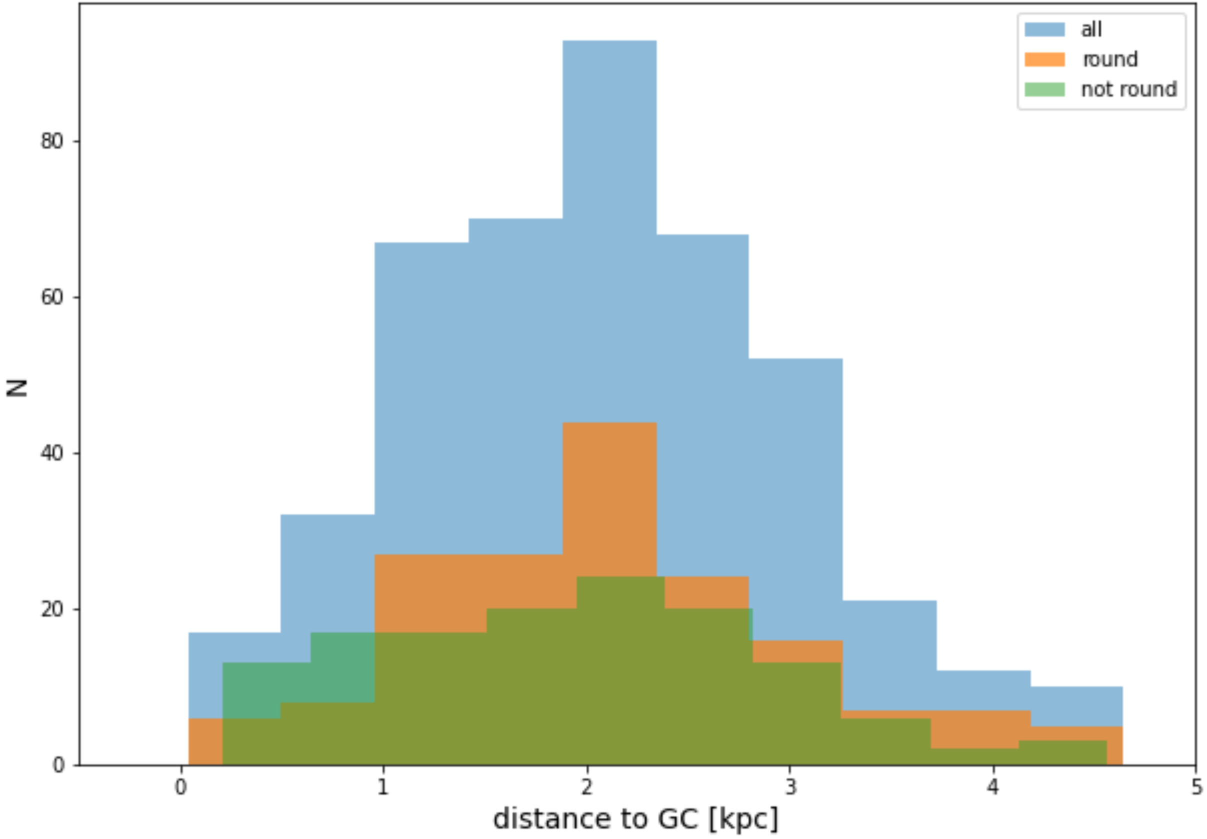
Morphology and star forming cloud populations vary with their distance to the center of the galaxy

Ratio of SF tracers inner/outer -- all clouds

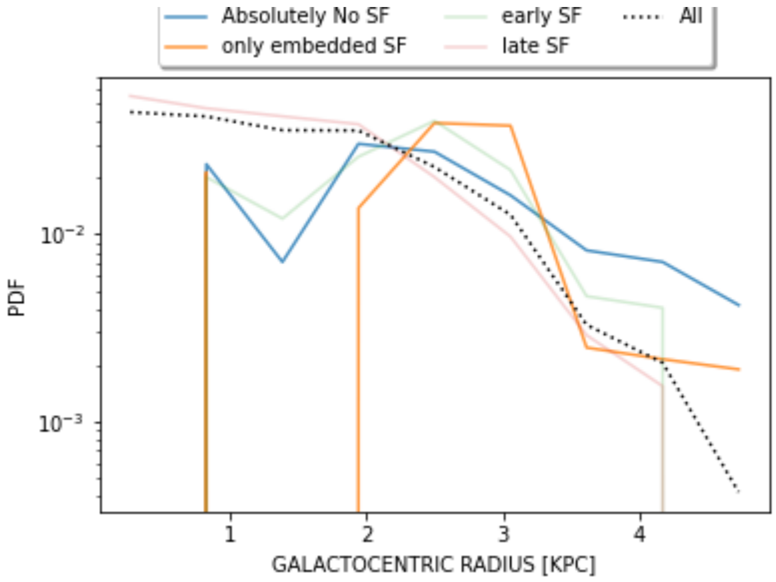
[1.68028005 1.57333333 1.26650321]

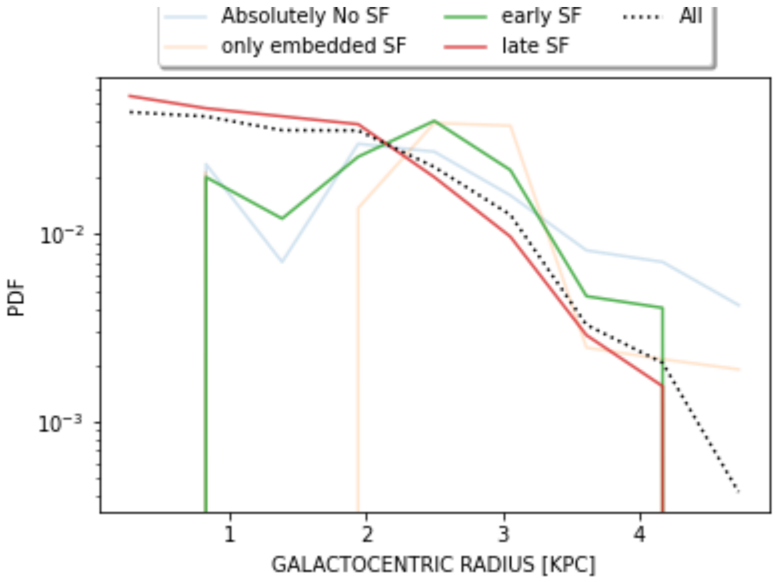
properties of GMCs are different in inner / outer galaxy and SF indicators are different —> galactic environment influences GMC properties and GMC properties themselves control SF process

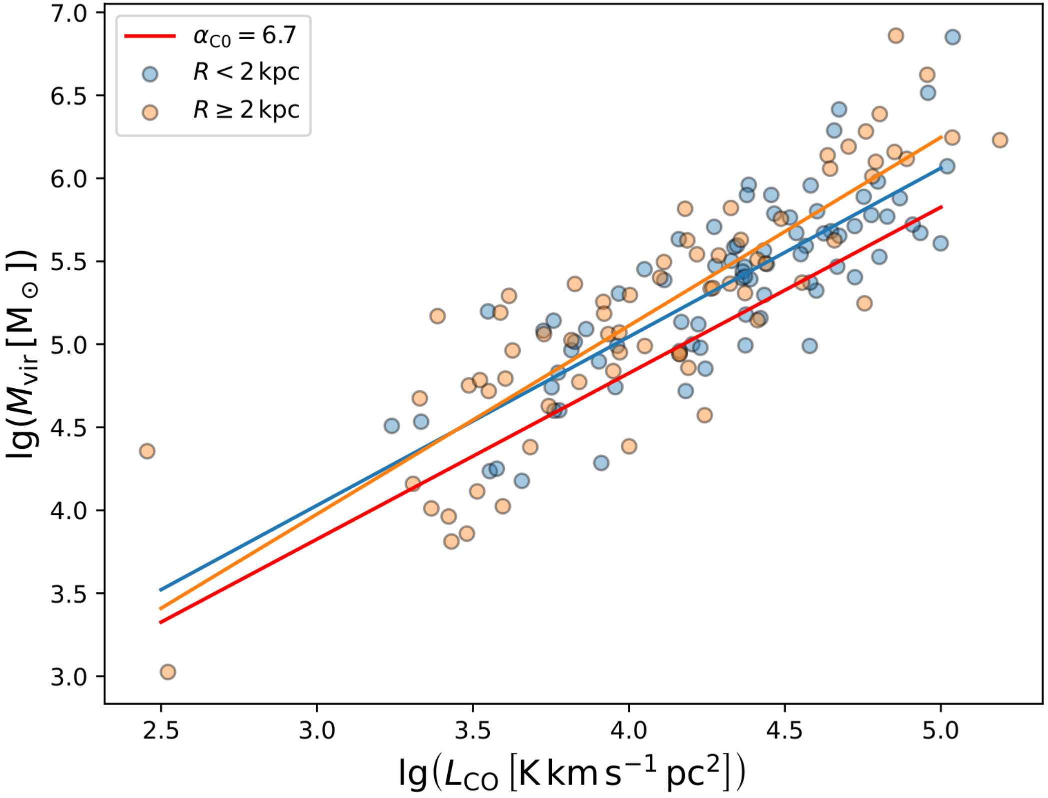
Morphology and star forming cloud populations vary with their distance to the center of the galaxy: we distinguish two areas, inner part of M33 (R < 2 kpc) with turbulent medium and outer part (R > 2 kpc) which corresponds to the spirals arms.



Morphology and star forming cloud populations vary with their distance to the center of the galaxy



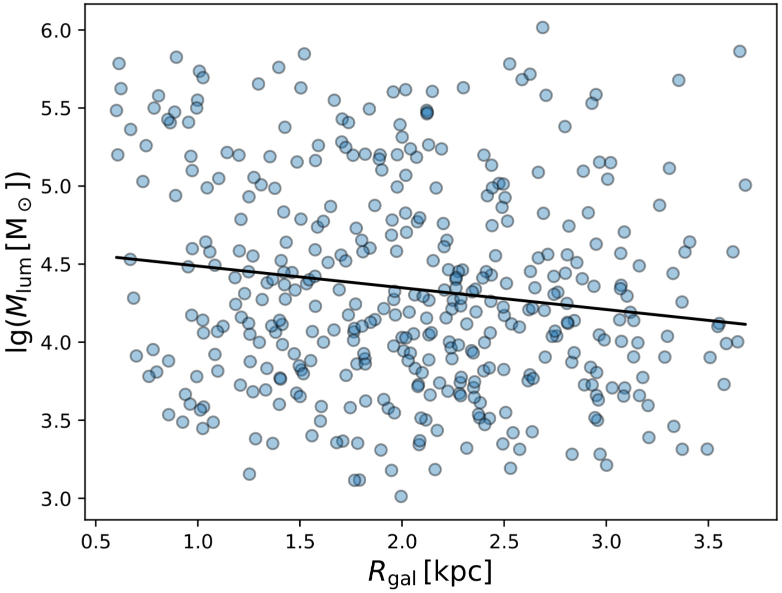




M_{vir} and M_{lum} ↘ outwards

α_{CO} ↗ with R (with ↘ Z)

$\Sigma_{gas} = \Sigma_{HI} + \Sigma_{H2} = \Sigma_{HI} + \alpha_{CO} I_{CO}$



$\alpha_{CO} = M_{vir} / L_{CO}$

Relation between normalised turbulent linewidth coefficient and virial parameter in sub-sample of 73 clouds at 3 evolutionary states (Type I, Type II, Type III)