Do Cores have Kinematic Memories of their Parent Cloud? - A Case Study of the Galactic Center Brick

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Overview

- Introduction
- Methods
- Results & Discussion
- Conclusion

Introduction - CMZ

- Region within $R \simeq 300\ pc$
- Complex & dynamic environment
- Massive young star clusters and dense molecular cloud

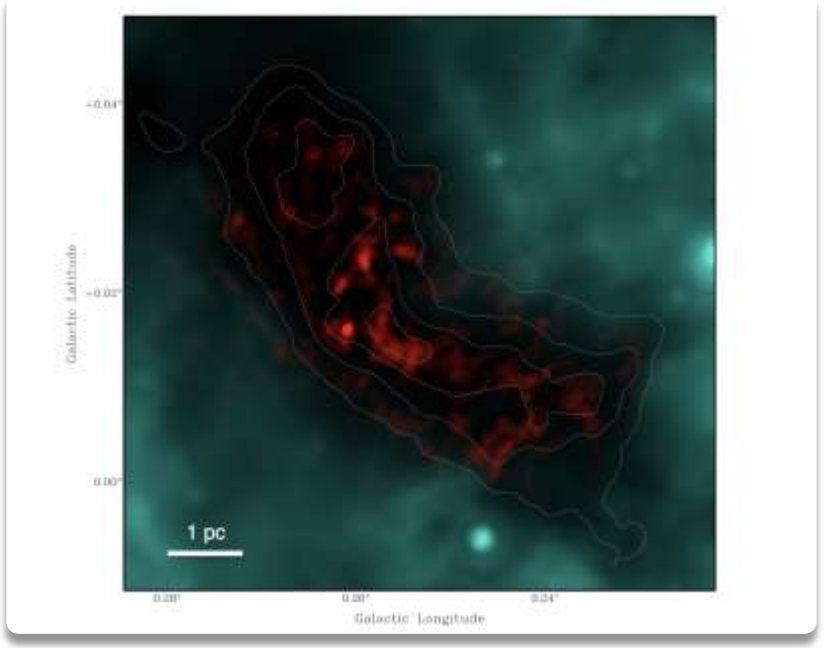

Near-Infrared (Spitzer)

Introduction – The Brick

- The focus cloud of the study
- A massive, dense and near-quiescent molecular cloud
  - $M \sim 10^5\ M_\odot$, $\rho \sim 10^4\ cm^{-3}$
- Potential candidate to host future high-mass stellar cluster

Introduction – The Brick (Observation)

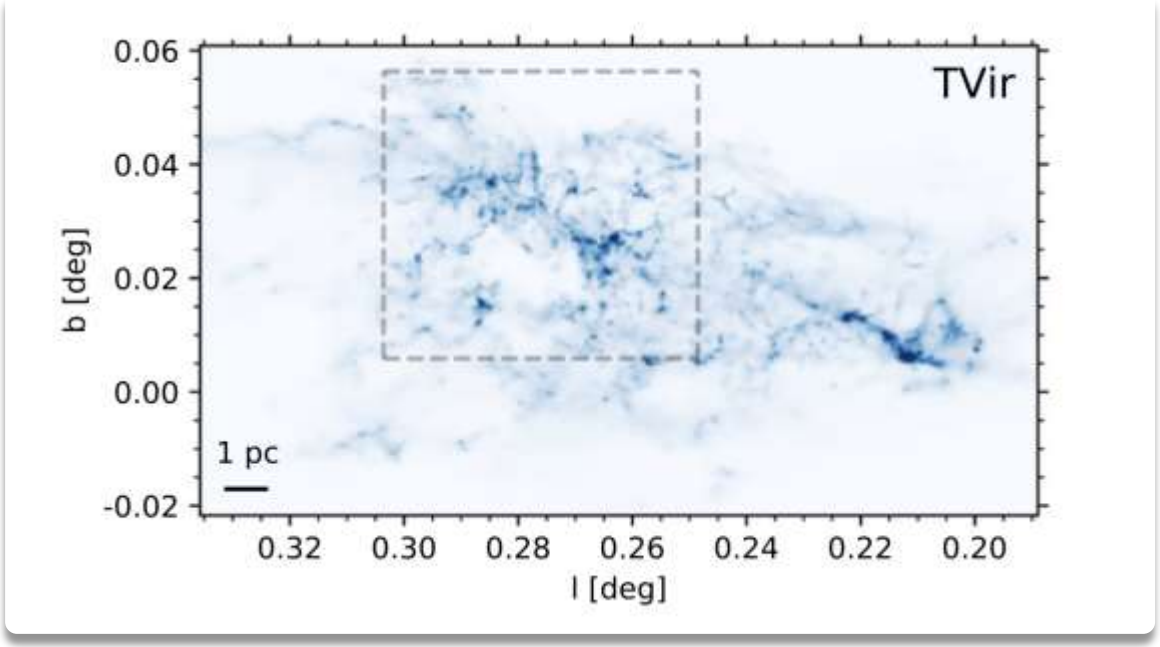
- We want to study the kinematic properties of the Brick
  - Specifically, **Angular Momentum**
- Not homogenous → potential dense core within the cloud
- Comparison between simulation data and observation data
- Observation: ALMA molecular line emission map



Rathborne et al. (2015)

Introduction – The Brick (Simulation)

- Simulation: Smoothed Particle Hydrodynamics method
- Cloud-scale, gravity and star formation, Galactic gravitational potential
- CMZ orbit



Dale et al. (2019); Kruijssen et al. (2019), Petkova et al. (2023)

Methods – PPV & PPP

- PPP: all three axes in position
  - Gas density, separate data for velocity
- PPV: 2 axes in position, 1 axis in velocity
  - Measured flux
- PPP gives us full 3D information; PPV gives us 2D projected information

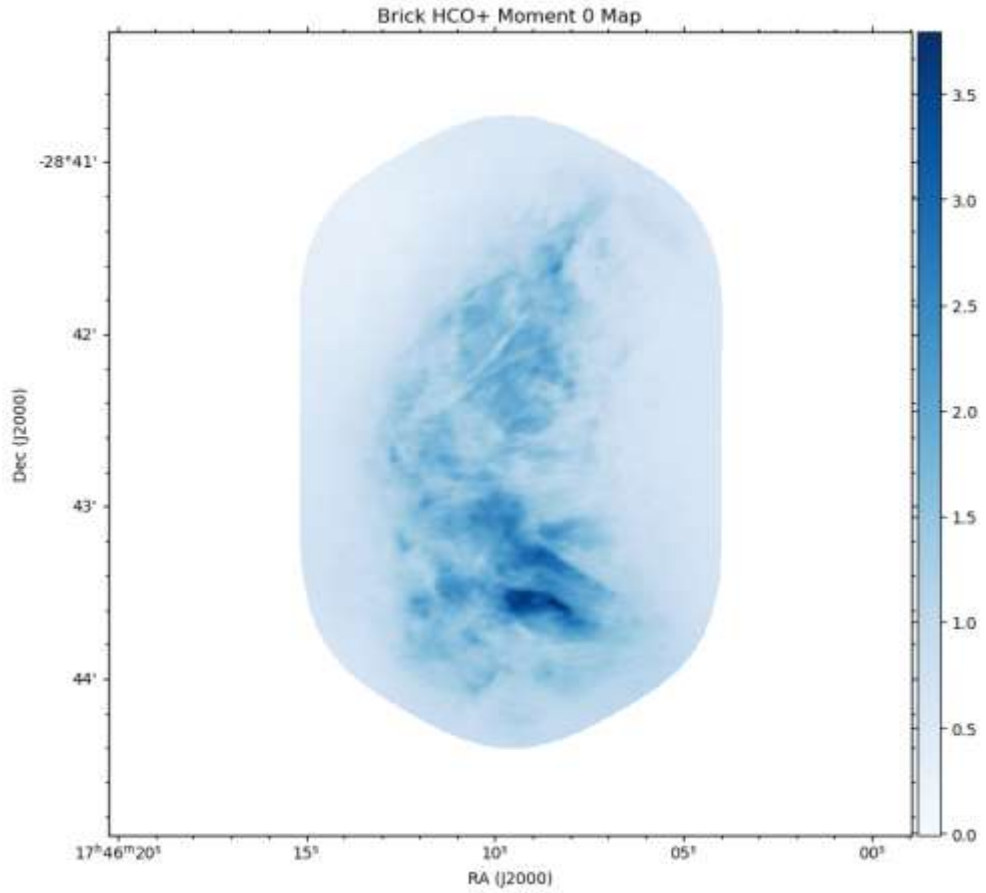
Methods – Moment Maps

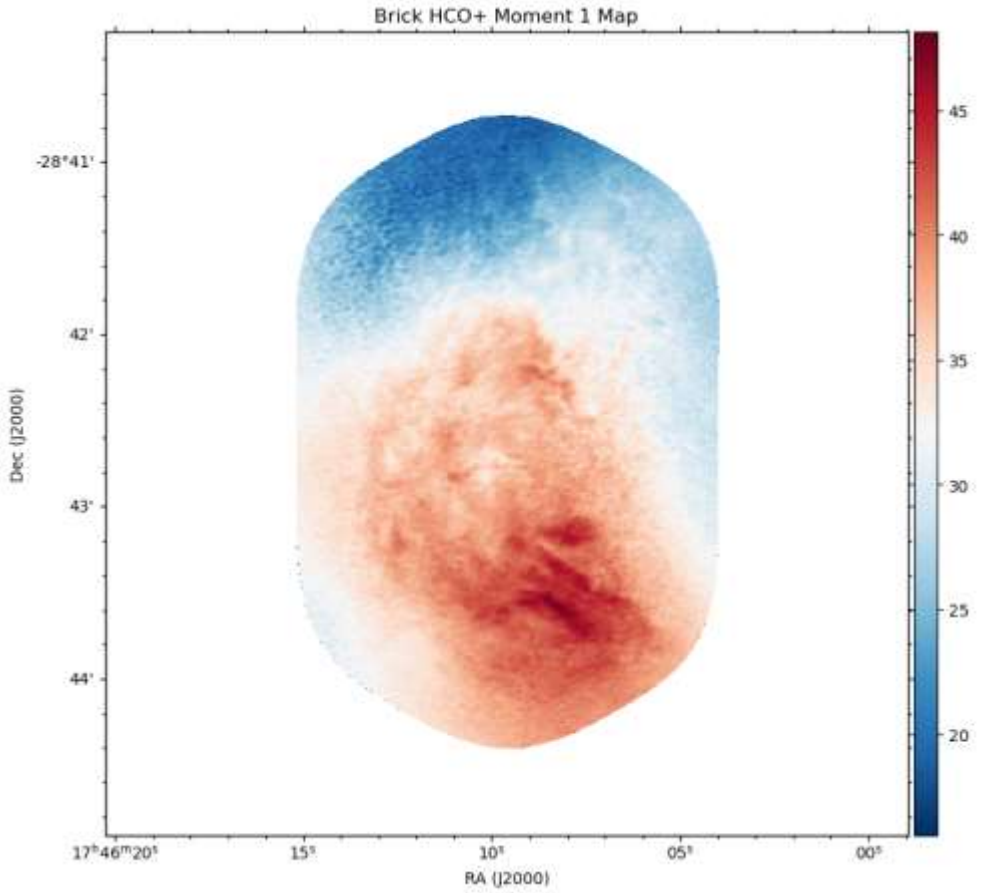
- Moment 0: Integrated intensity over the spectral line (column density)

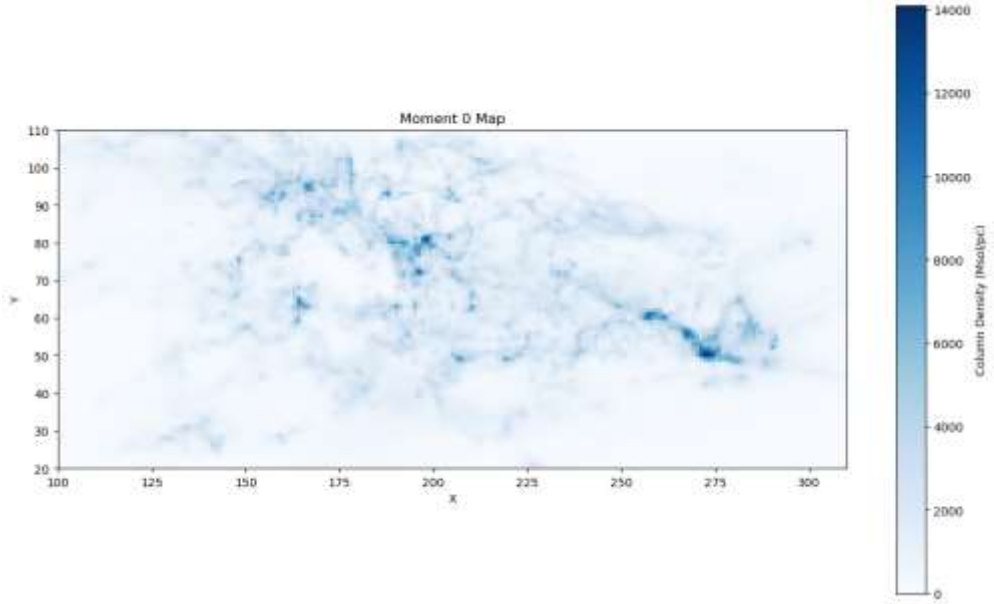
$$M_0 = \int I_v dv$$

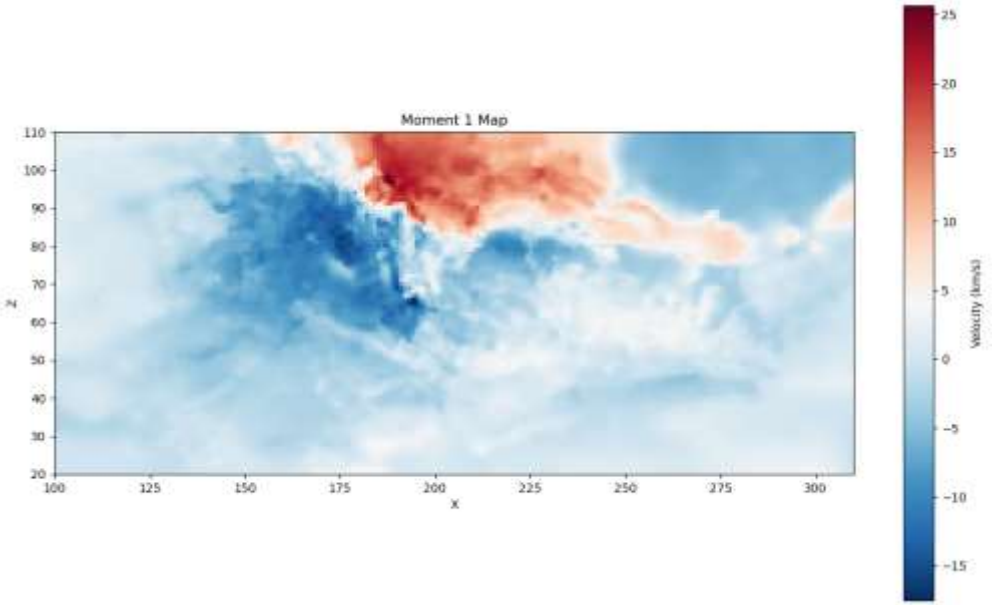
- Moment 1: Intensity-weighted velocity

$$M_1 = \frac{\int v I_v dv}{M_0}$$


Brick HCO+ Moment 0 Map
-28°41'
42'
43'
44'
Dec (J2000)
17h46m20s
15s
10s
05s
00s
RA (J2000)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0


Brick HCO+ Moment 1 Map
-28°41'
42'
43'
44'
Dec (J2000)
17h46m20s
15s
10s
05s
00s
RA (J2000)
45
40
35
30
25
20

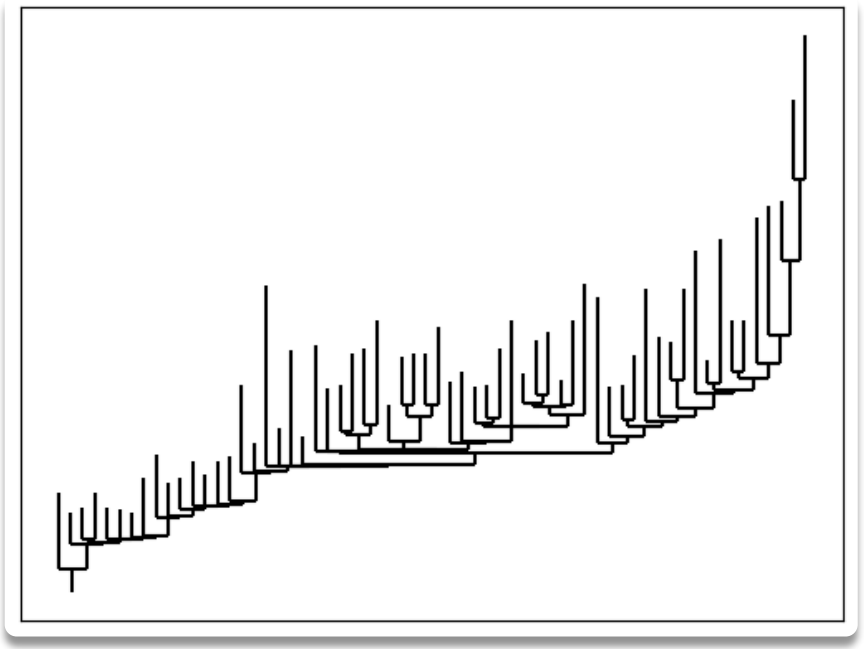

Moment 0 Map
Y
X
Column Density (Mso/pc)


Moment 1 Map
Z
X
Velocity (km/s)

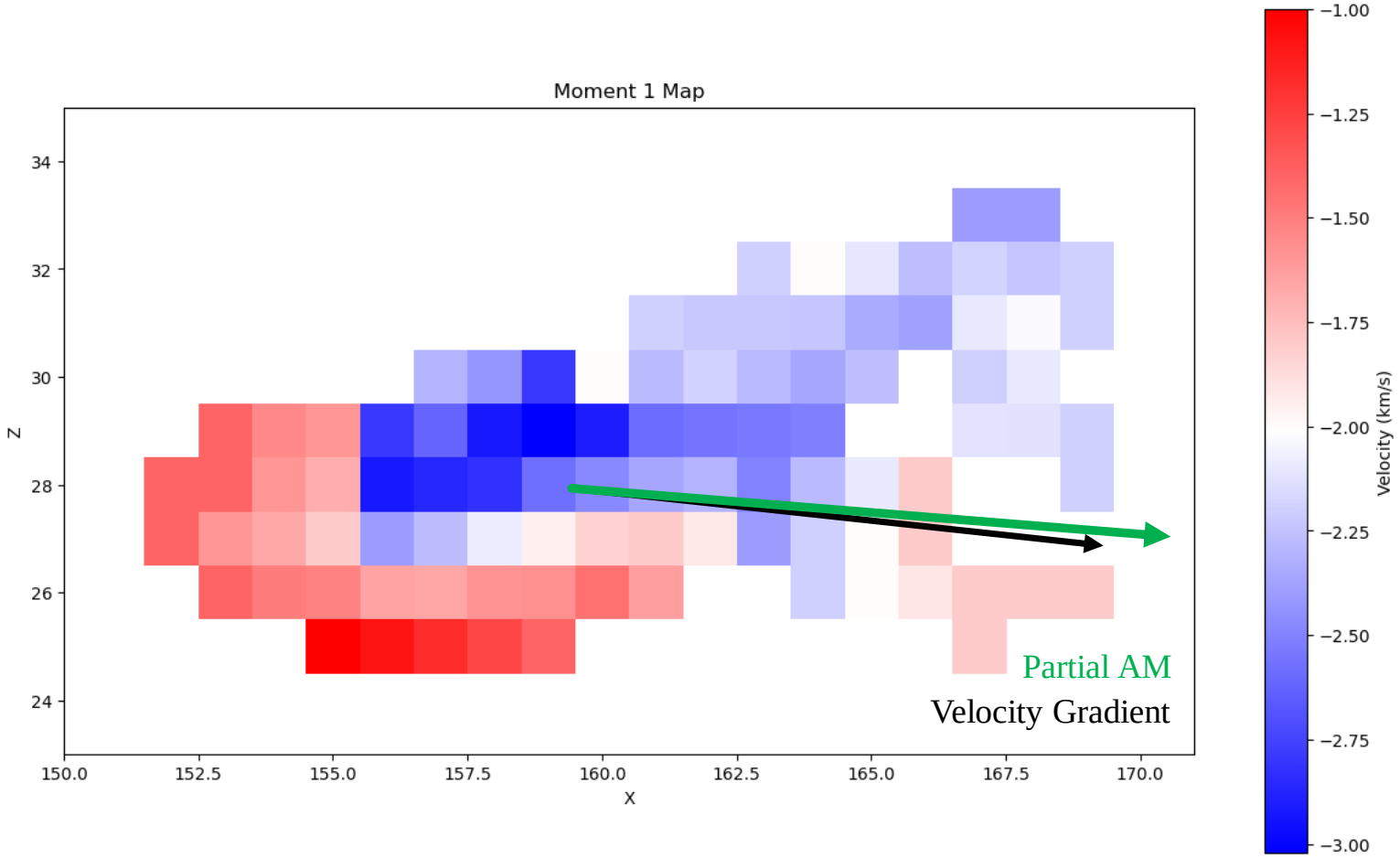
Do small structures also have the kinematic properties that we see in the parent cloud?

Methods - Dendrogram

- Need a way to identify structures from the data
- Dendrogram – view data with a hierarchical aspect
  - Leaf: independent structure
  - Branch: structures that can split into multiple sub-structures



Methods – Angular Momentum



$$\overrightarrow{L_{partial}} = m(\vec{r} \times \vec{v})$$

$$= m \begin{bmatrix} i & j & k \\ r_x & 0 & r_z \\ 0 & v_y & 0 \end{bmatrix}$$

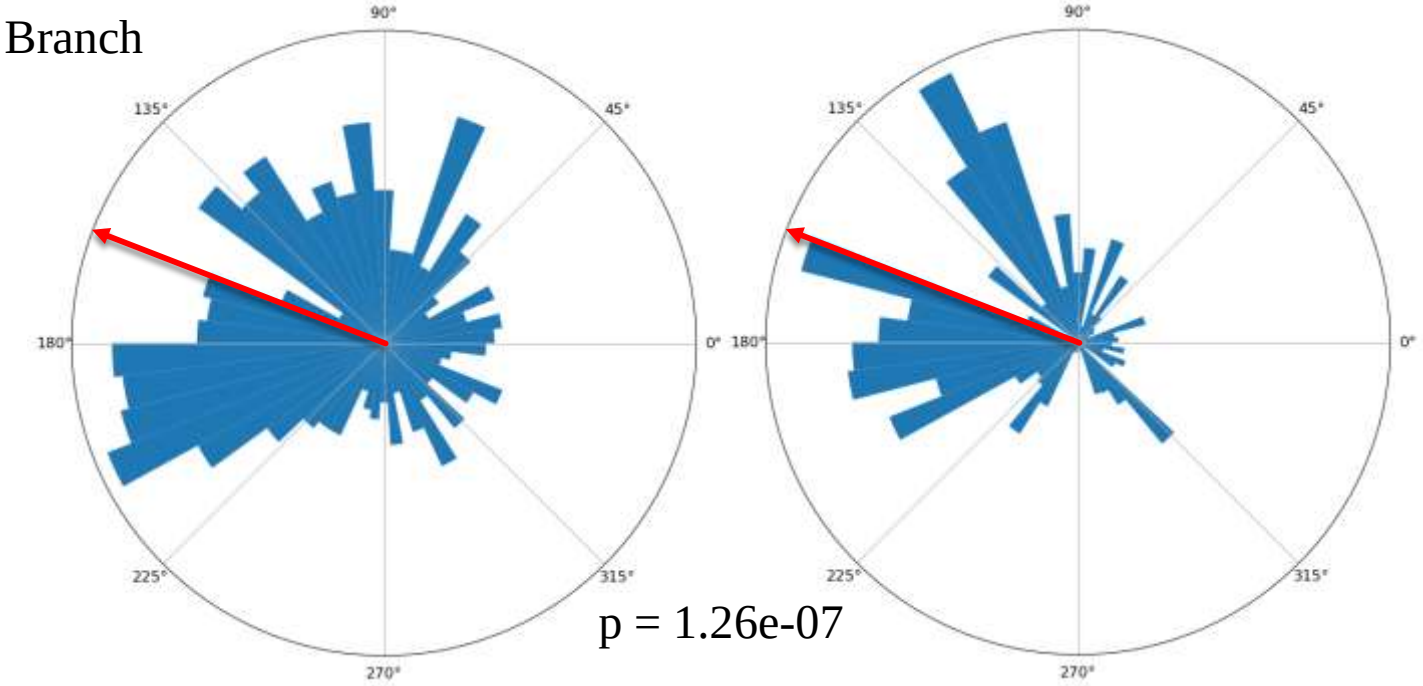
$$= m < -r_z v_y, 0, r_x v_y >$$

Results – Projected Angles and K-S test

- $\alpha = np.atan2(L_z, L_x)$, $\alpha \in [-\pi, +\pi]$
- Looking for preferred angle orientation and distribution
- Compared with uniform distribution using K-S test
  - P-value: reject the null hypothesis if < 0.05

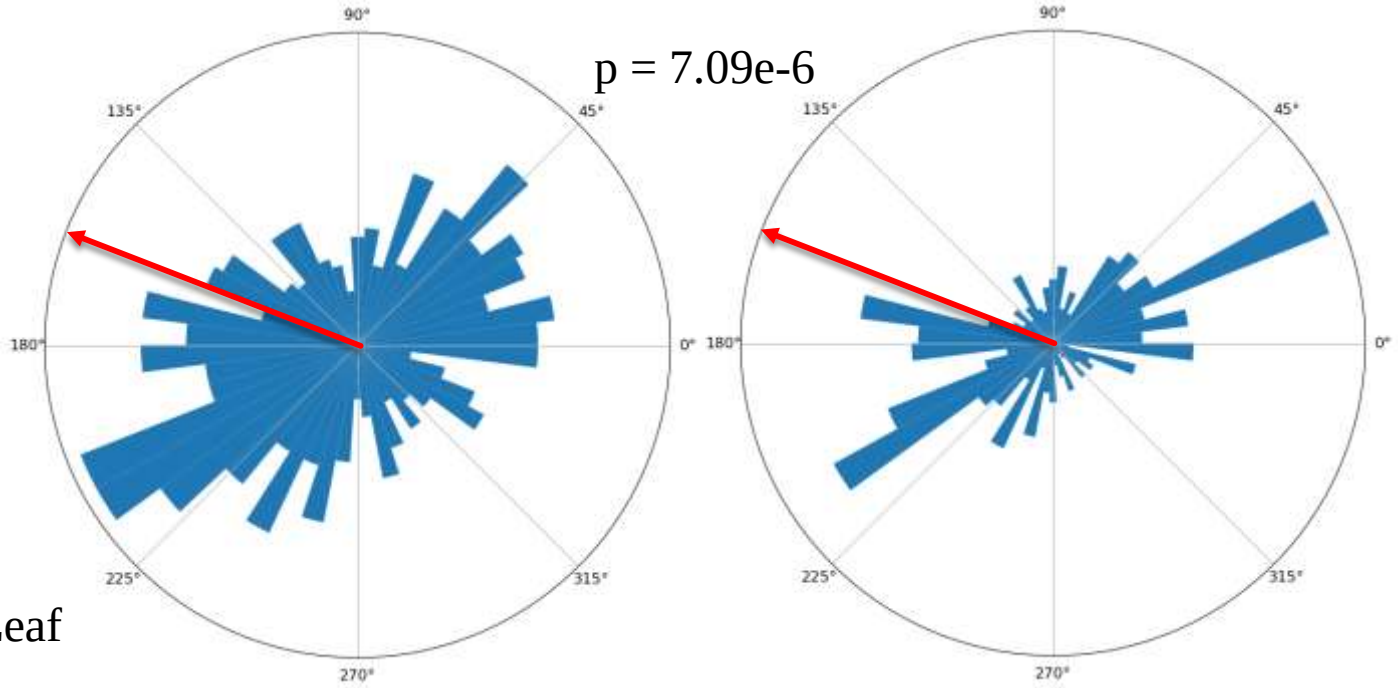
Results – PPP (Full Projected) : Leaf vs Branch

Branch



p = 1.26e-07

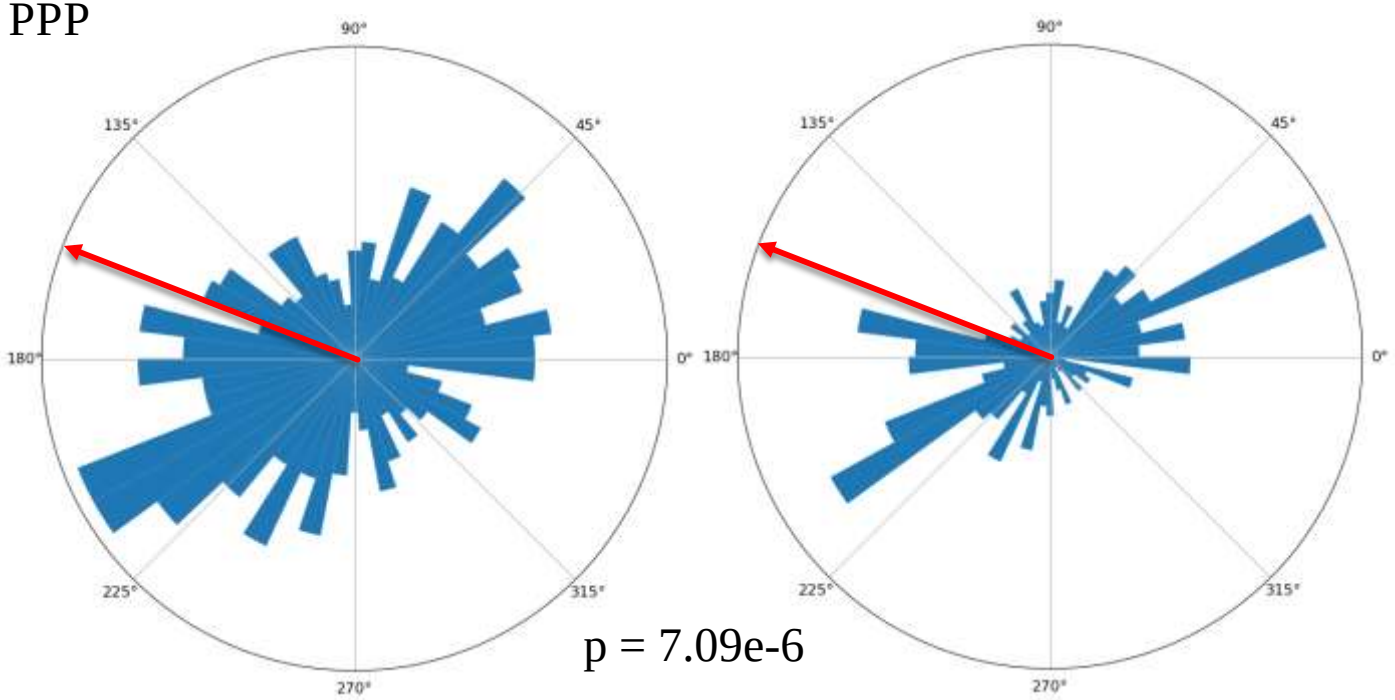
p = 7.09e-6



Leaf

Results – Simulation: PPP vs PPV

PPP



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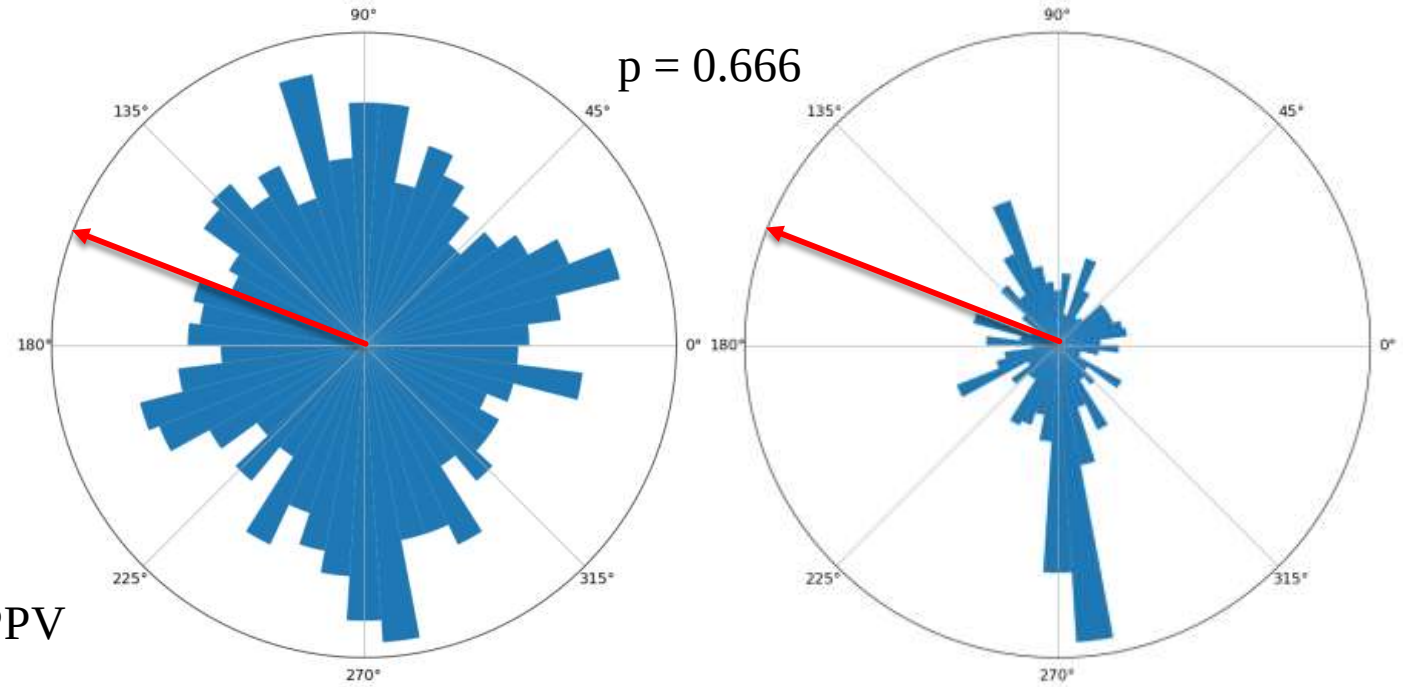
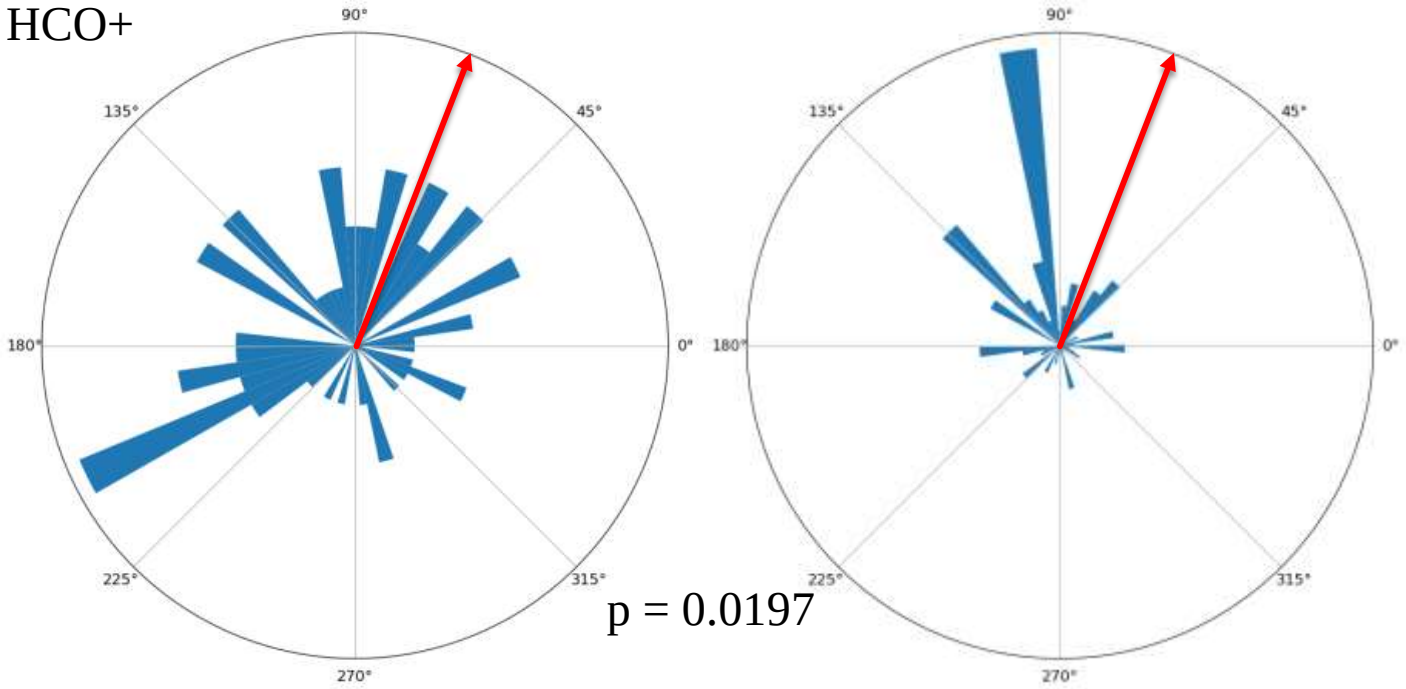
p = 0.666



PPV

Results - Observation

HCO+



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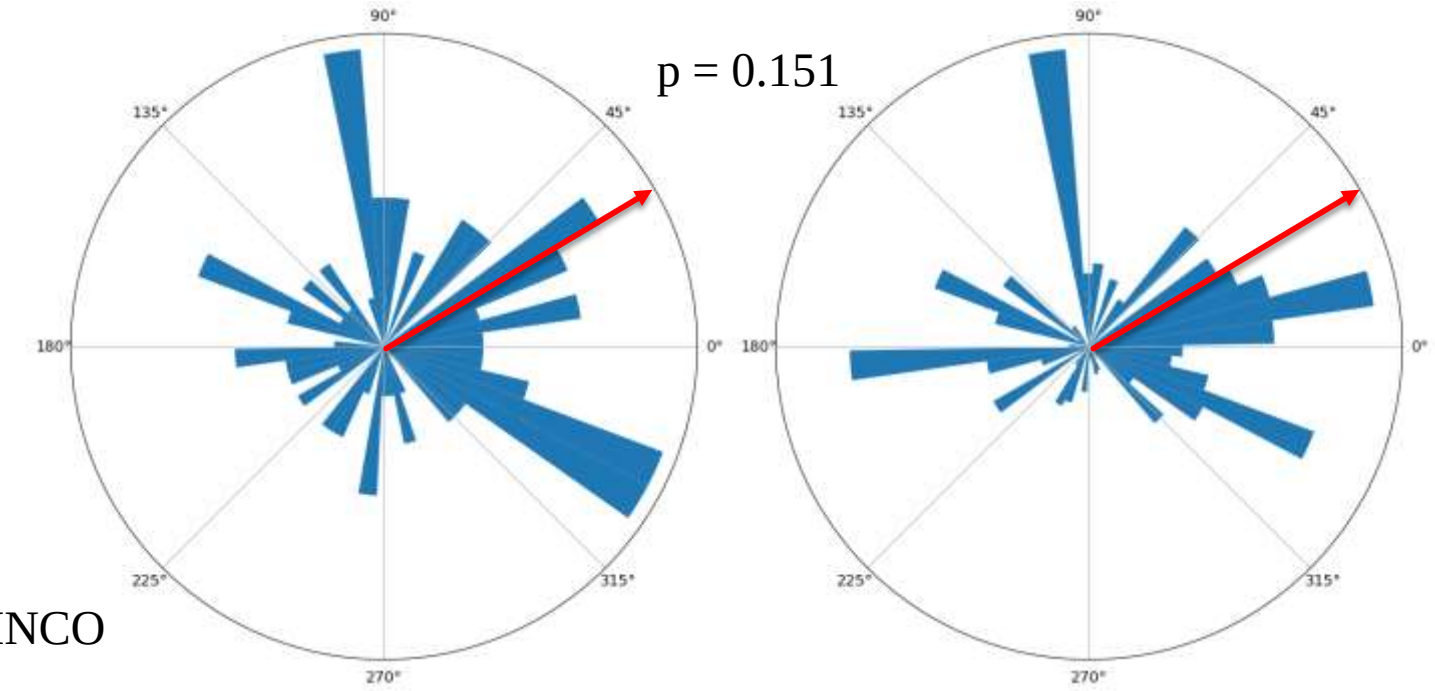


p = 0.151

HNCO

Conclusion

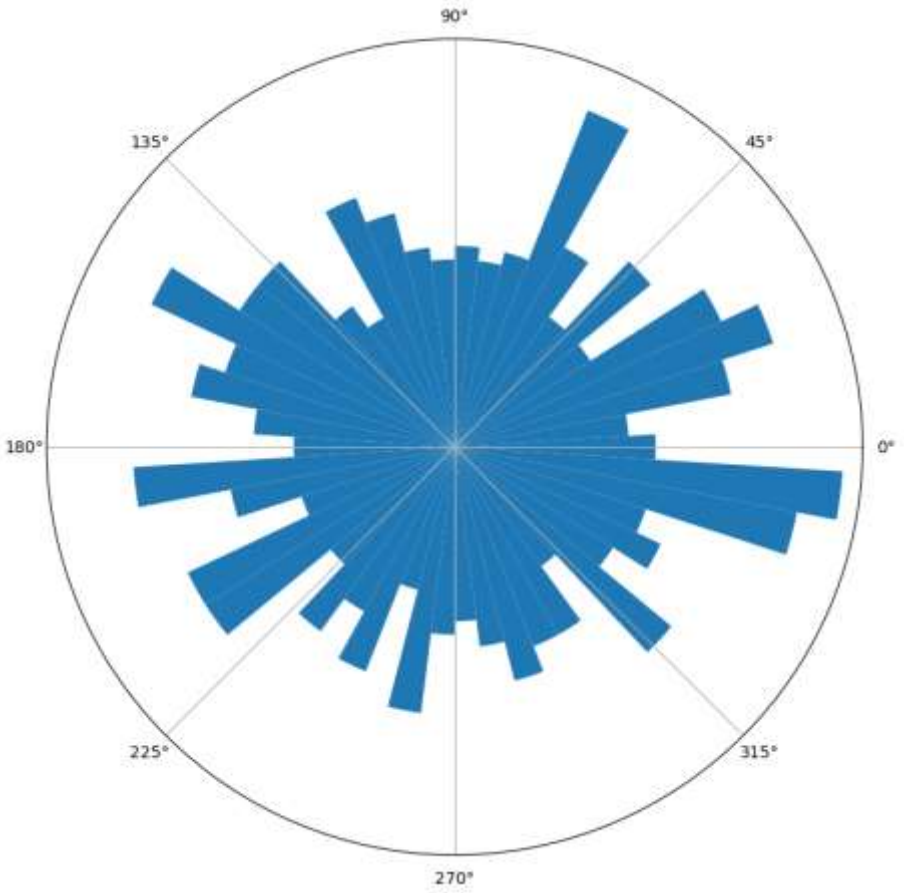
- Simulation:
  - Angle preference are noticed in 3D structures, but not in PPV space
  - Orientation can be due to the shear due to Galactic potential (no $\vec{B}$)
  - Simulation with magnetic field is needed to better compare with observation
- Observation:
  - Angle preference are not noticeable
  - Preferred orientation can be missed due to small dataset size
  - Expected results to be differ between different molecules (tracing different structures)

Reference / Credit

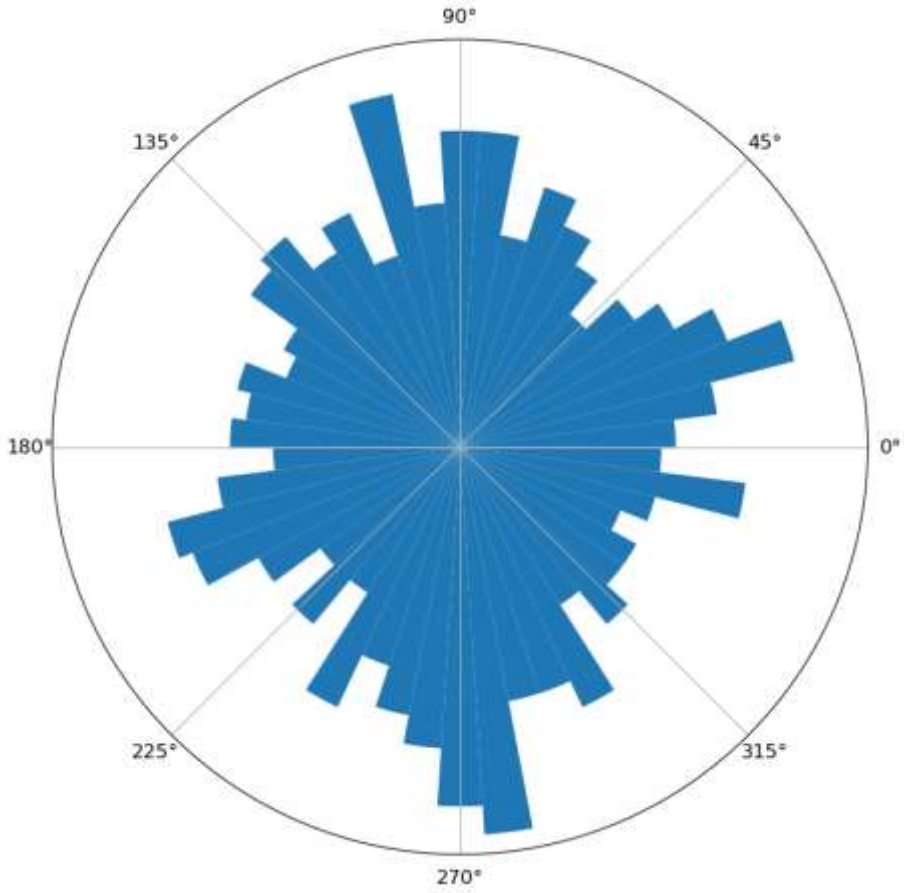
- Title background: *NASA/JPL-Caltech/S. Stolovy (Spitzer Science Center/Caltech)*
- Slide 4: *NASA, ESA, Greg T. Bacon (STScI)*
- Slide 6: Rathborne et. al 2015, **DOI**:10.1088/0004-637X/802/2/125
- Slide 7: Dale et al. (2019); Kruijssen et al. (2019), Petkova et al. (2023)

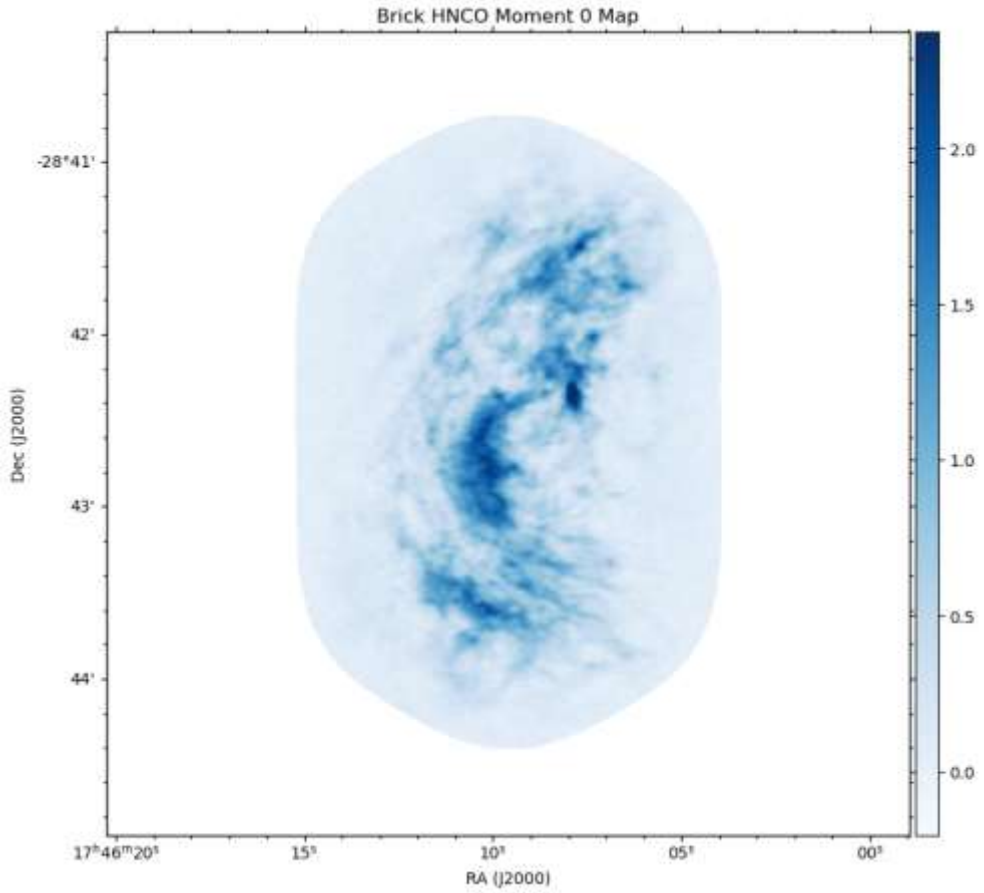
Backup Slides

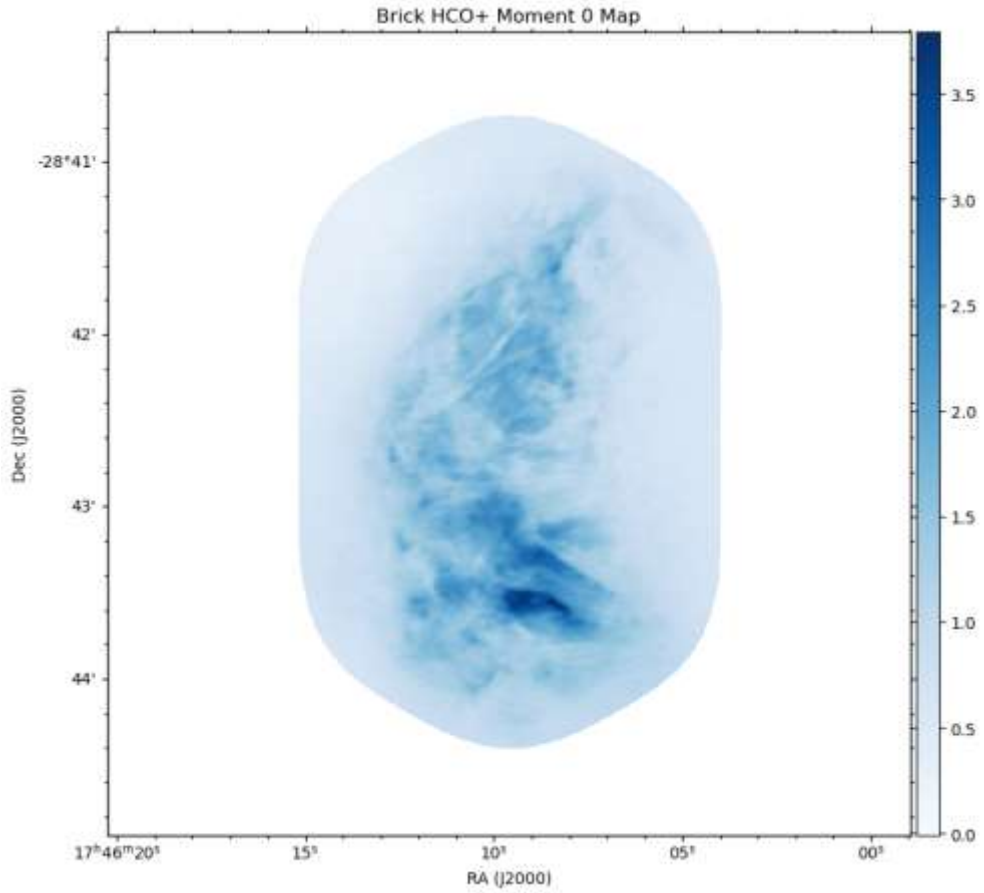
Gradient



Partial AM




Brick HNCO Moment 0 Map
-28°41'
42'
43'
44'
Dec (J2000)
17h46m20s
15s
10s
05s
00s
RA (J2000)
2.0
1.5
1.0
0.5
0.0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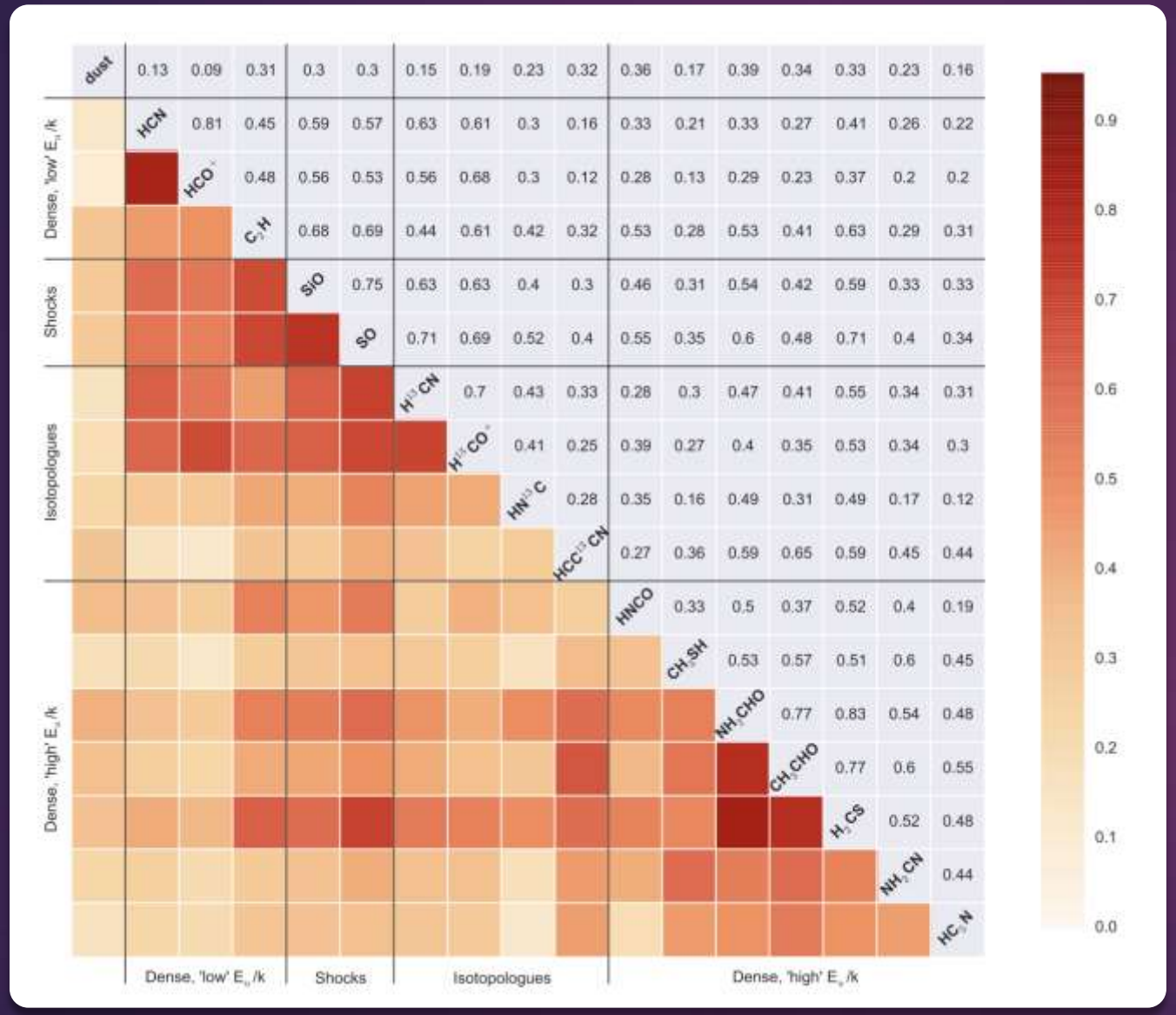
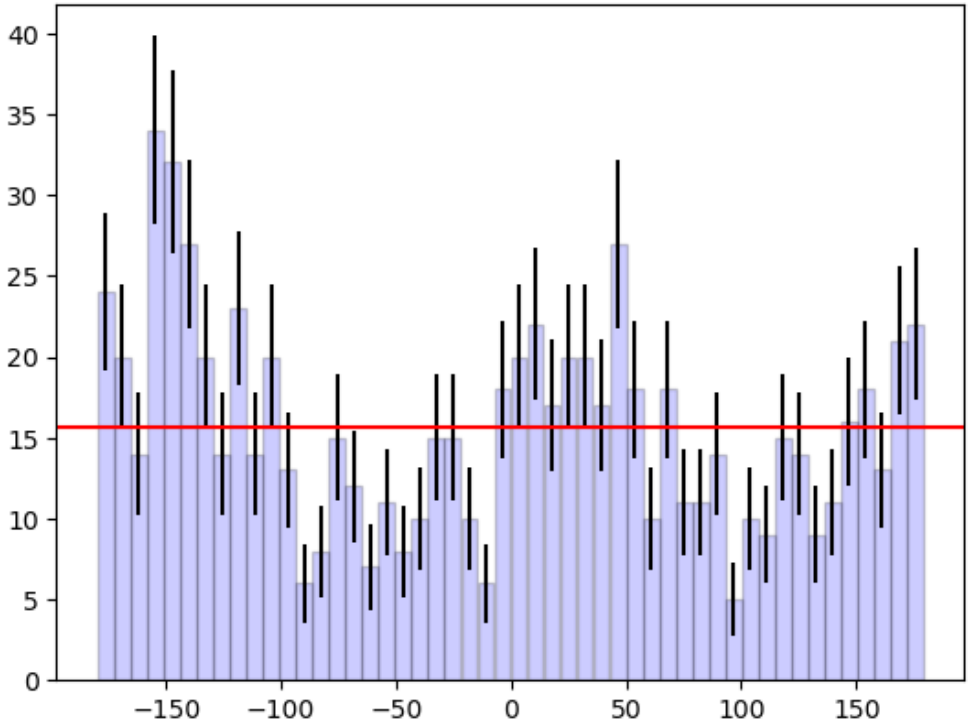


Cross-correlation Coefficient

Rathborne et al. (2015)



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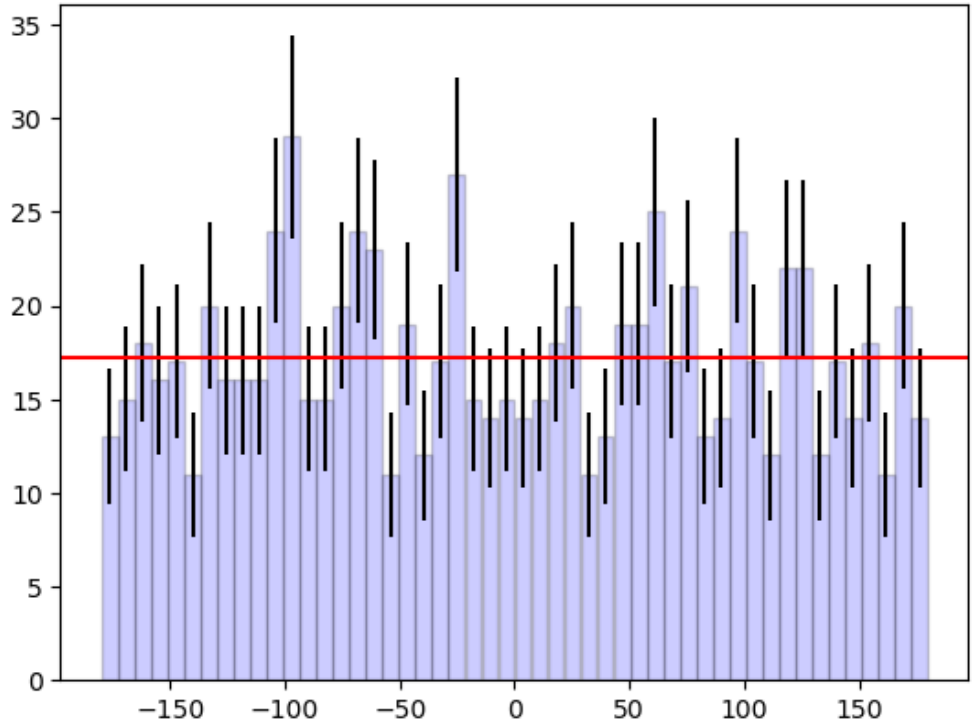
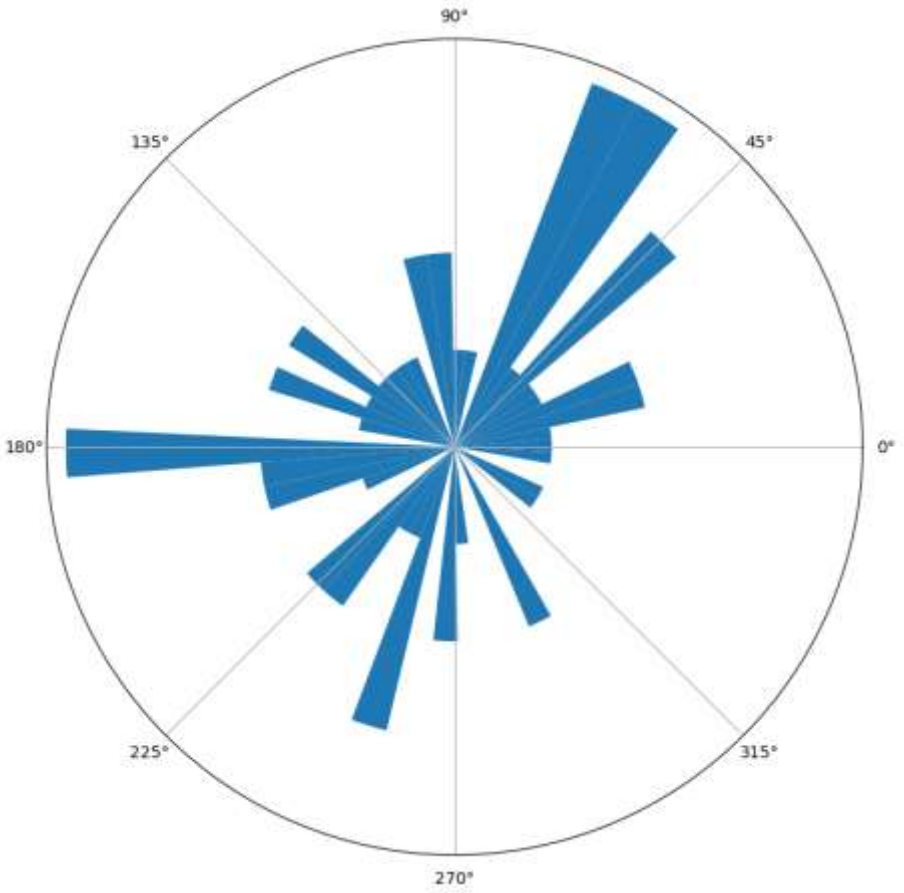
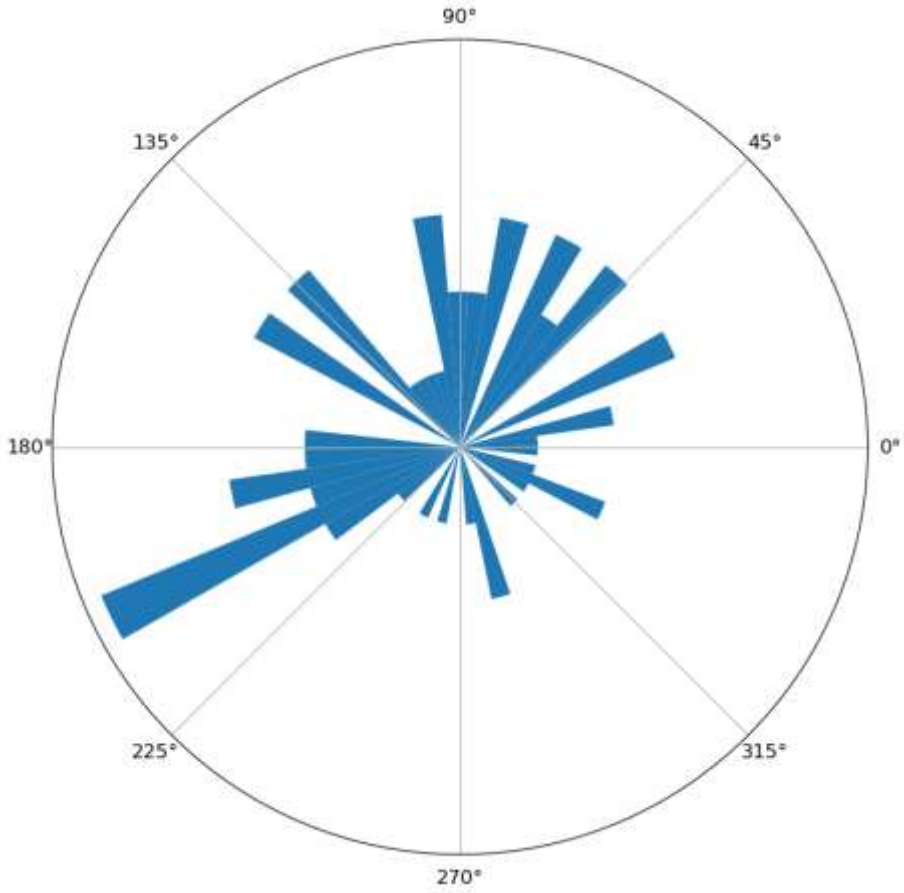


p = 0.845


90°
45°
135°
180°
0°
225°
315°
270°


90°
45°
135°
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225°
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