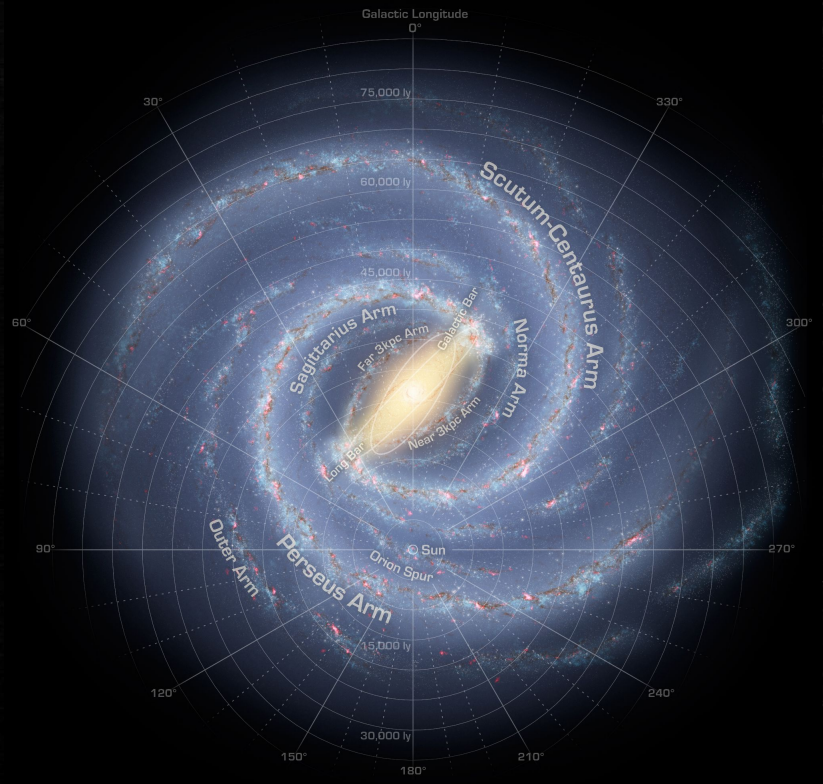
-ACES-

Mass Flows

Savannah Gramze - 2026
PhD Student - University of Florida

Manchester, UK

Background



NASA - R. Hurt

The Milky Way Galaxy

- ★ Barred spiral galaxy
- ★ The Galaxy has several spiral arms
- ★ At its center is the Central Molecular Zone (CMZ)

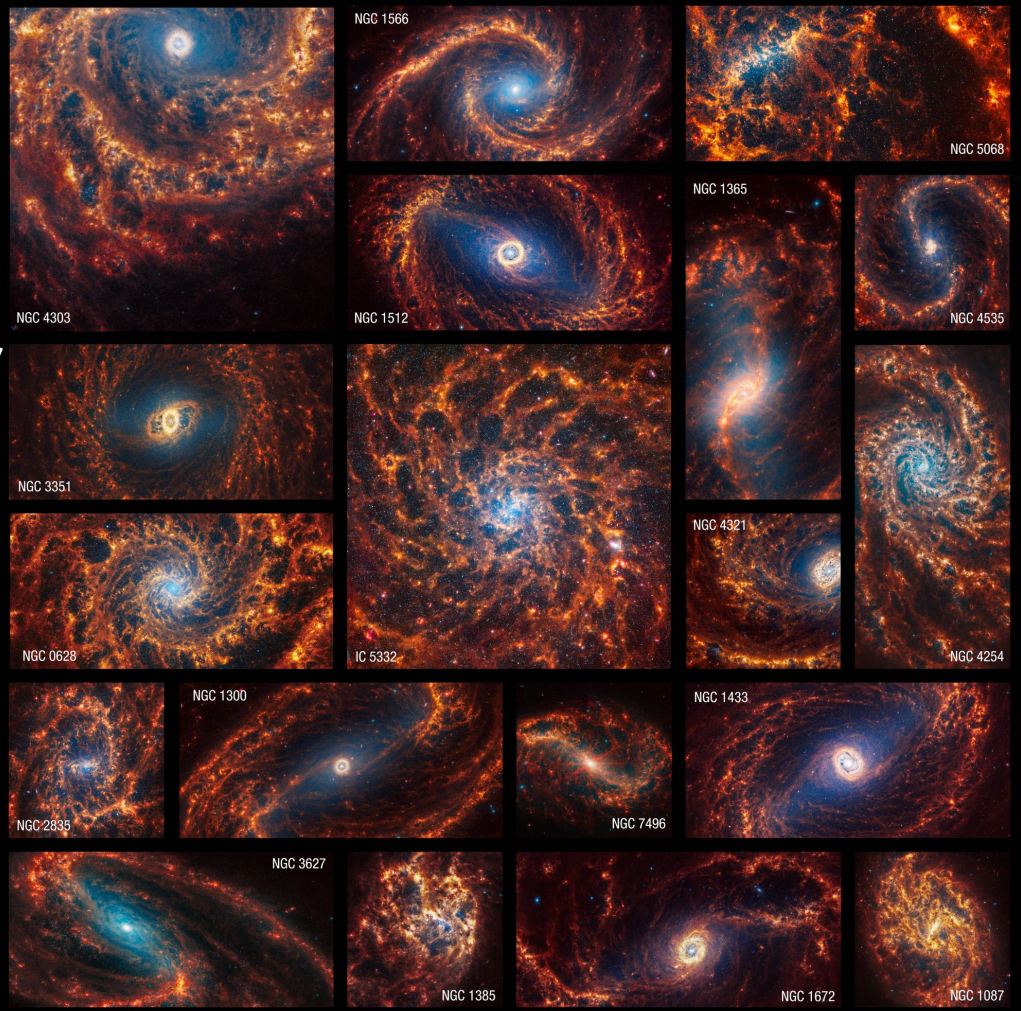
NGC 4394

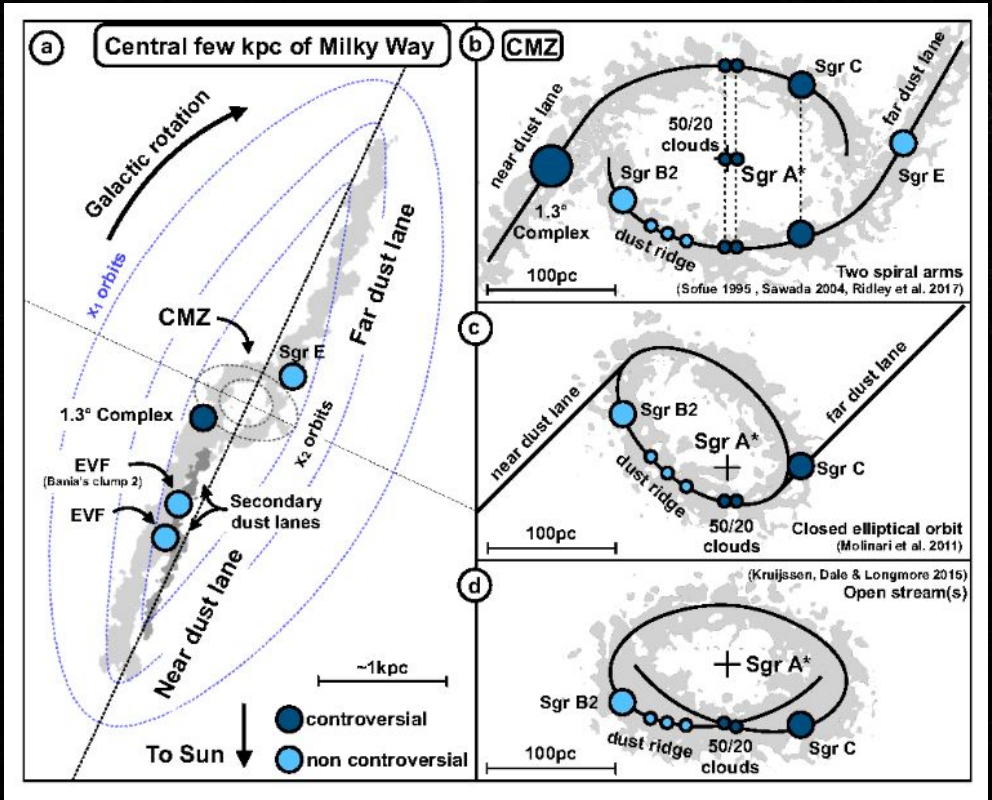
Barred Spiral Galaxies

- ★ Instead of a spherical gravitational potential (ie. the Sun), barred galaxies have a central bar-shaped potential.
- ★ This causes exotic, non-elliptical orbits along the length and perpendicular to the bar.

The Centers of Other Galaxies

NASA, ESA, CSA, STScI, PHANGS Team, Janice Lee (STScI), Thomas Williams (Oxford); Designer: Elizabeth Wheatley (STScI)



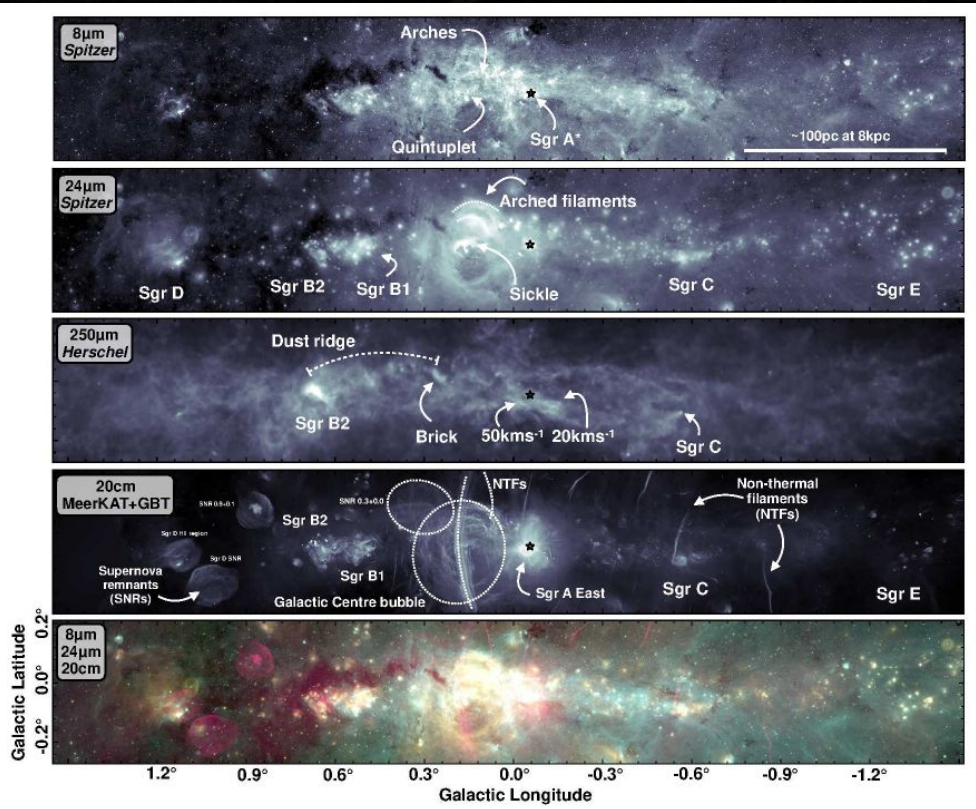


Henshaw et al 2023

The Central Molecular Zone

- ★ Gas and dust orbiting the Galactic Center, Sgr A*
- ★ Gas is warm (~50 K) and turbulent
- ★ Extreme environment
- ★ Exact structure unknown

The Central Molecular Zone



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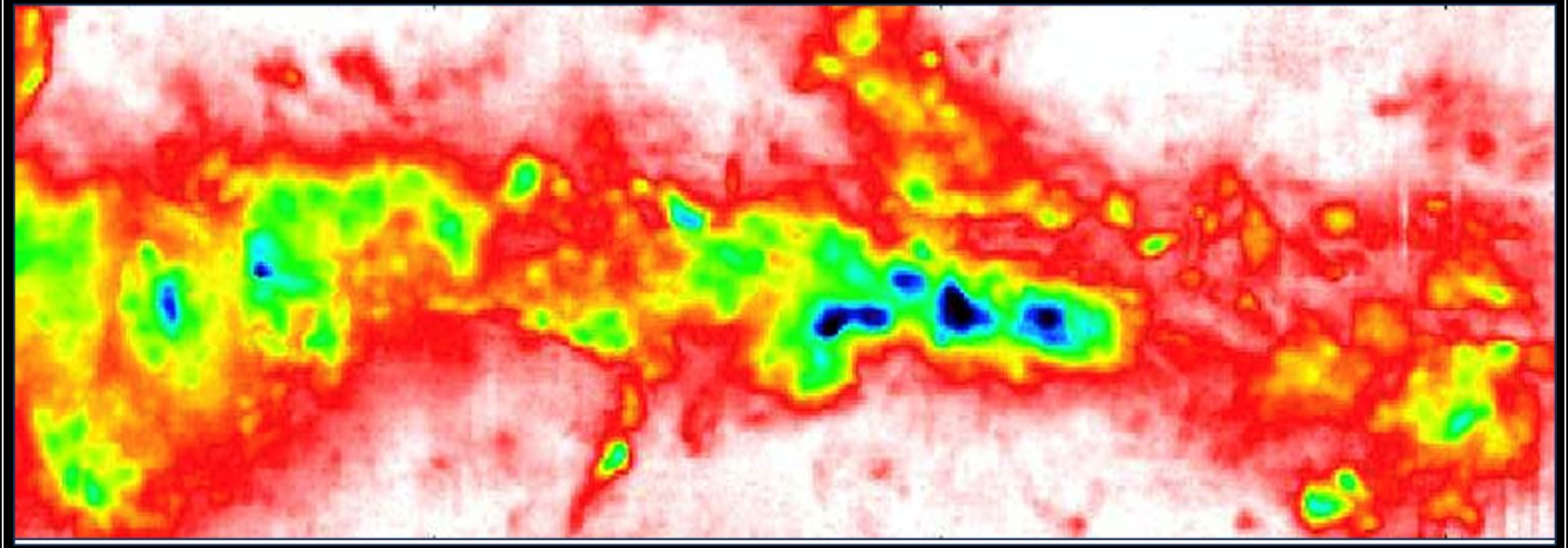
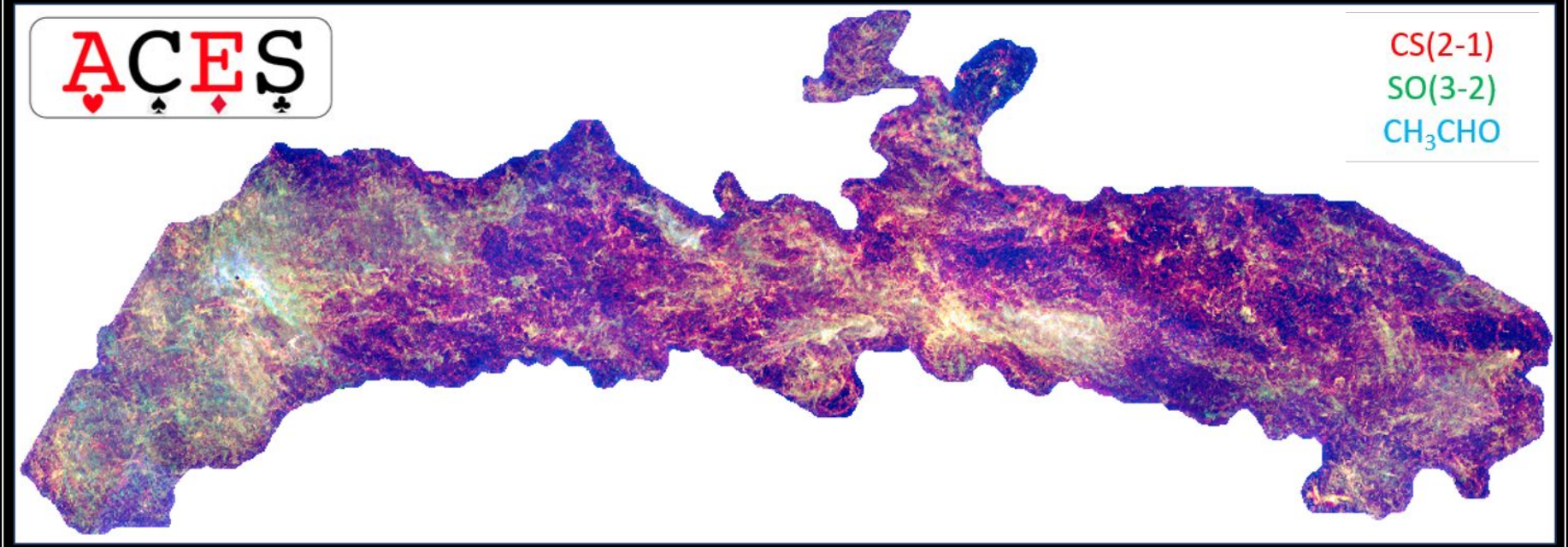
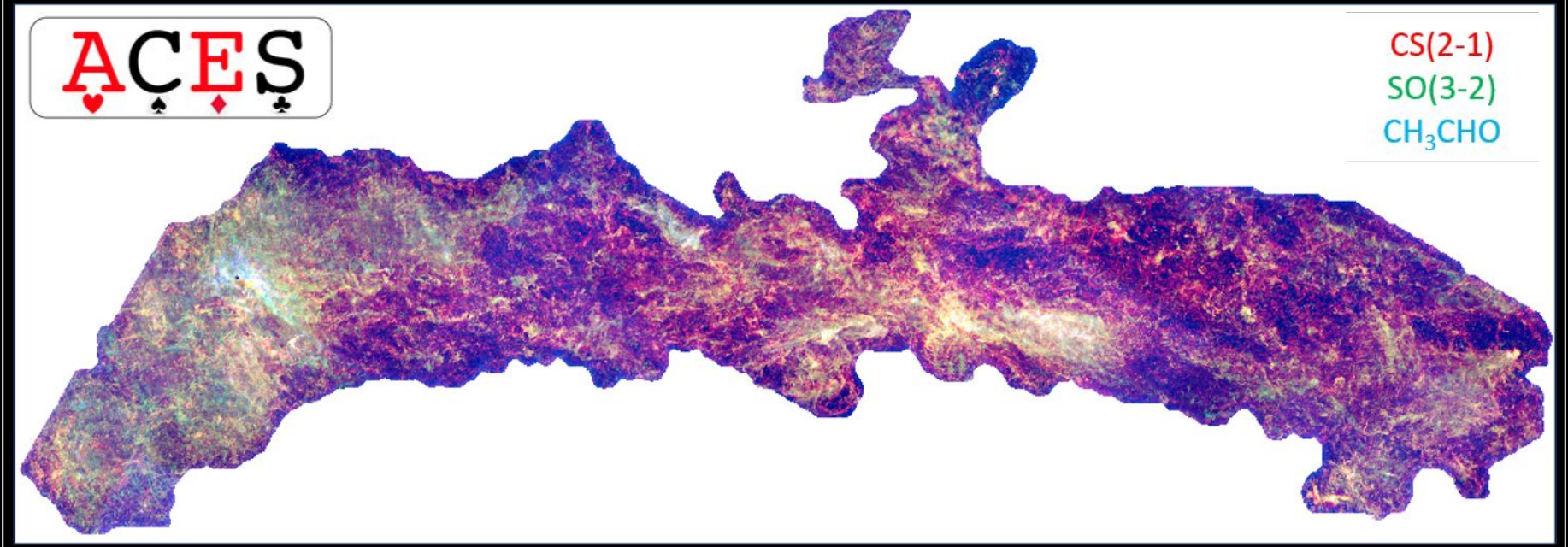


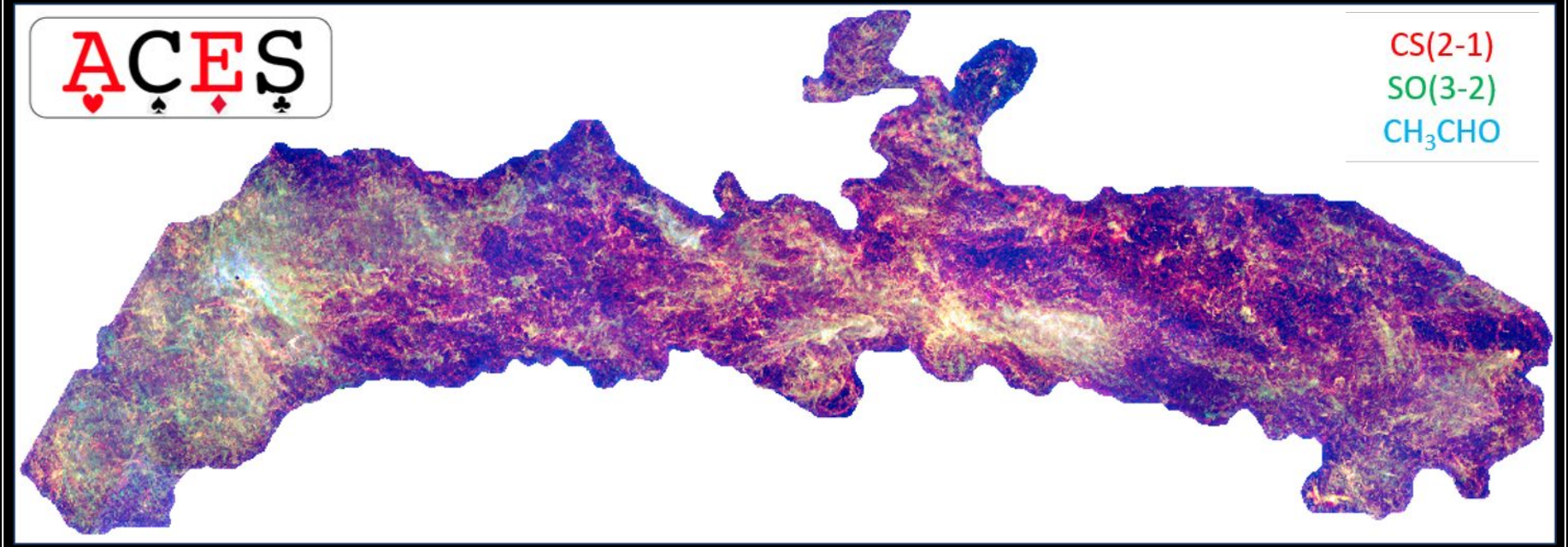
HCN (1-0) Mopra single-dish (Jones+09)



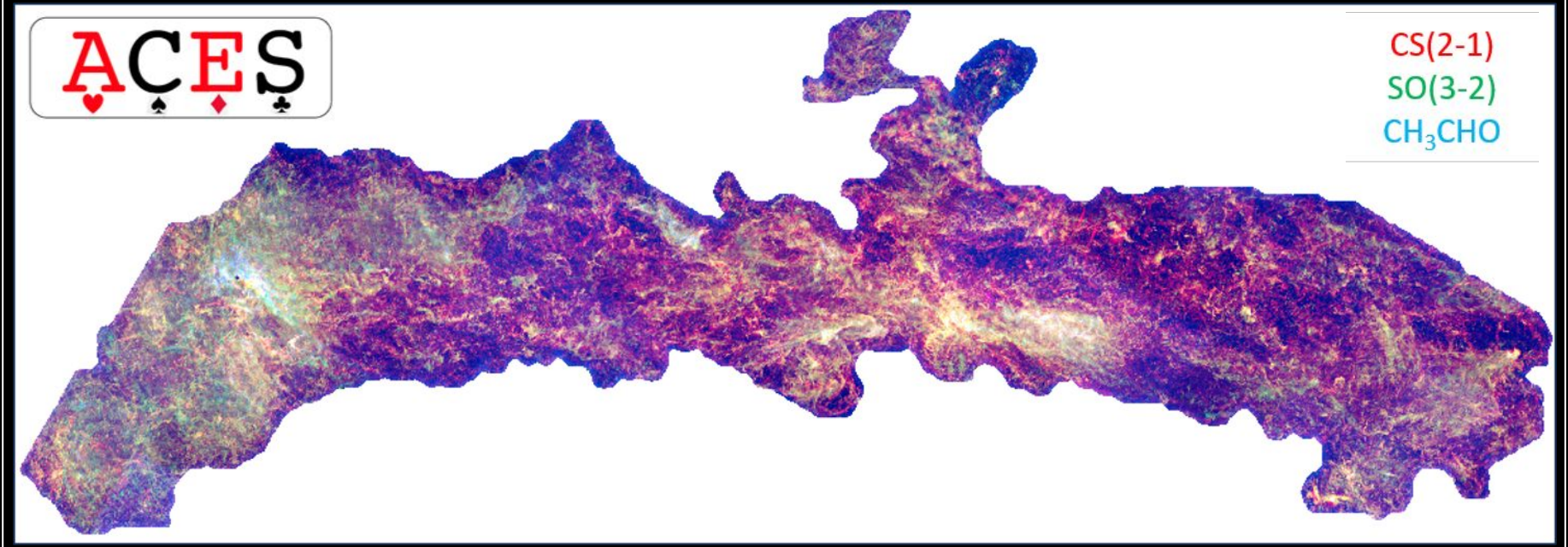
ACES - ALMA CMZ Exploration Survey



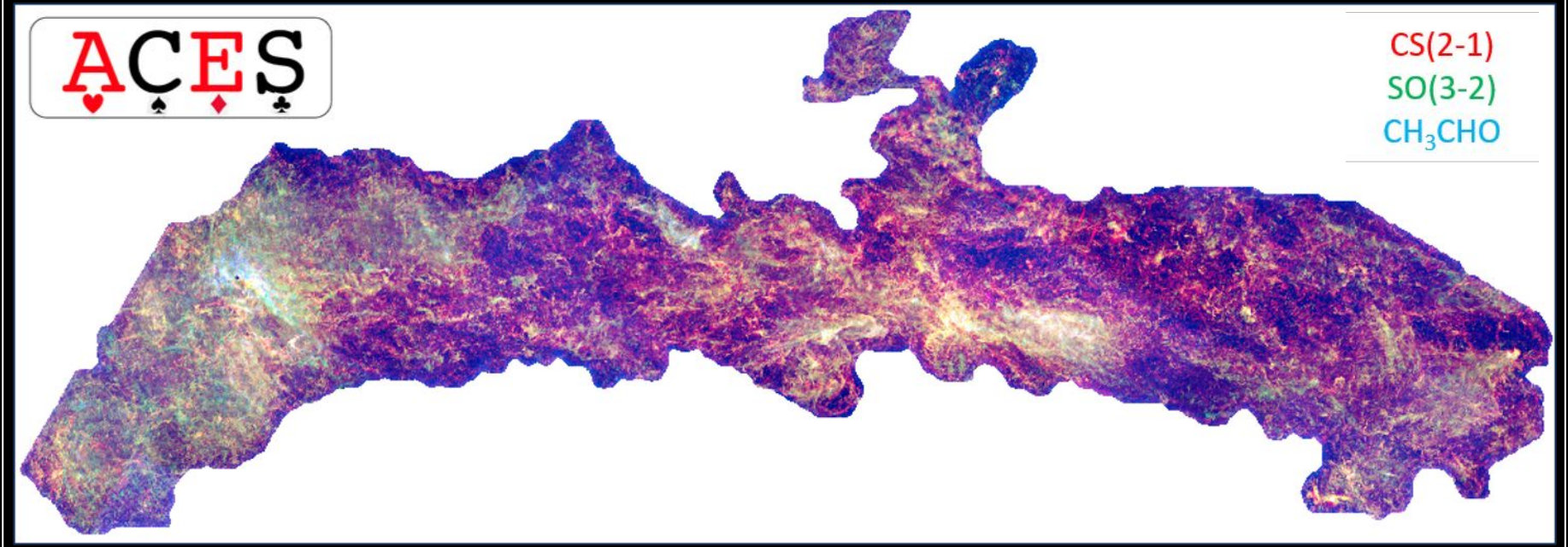
ACES : > 50x sensitivity, > 10x angular resolution, > 10x velocity resolution,
20+ simultaneous spectral lines



Uniform, homogeneous coverage of all potentially star forming gas in the inner 100pc radius of the Galaxy (CMZ) from 100 - 0.05 pc scales

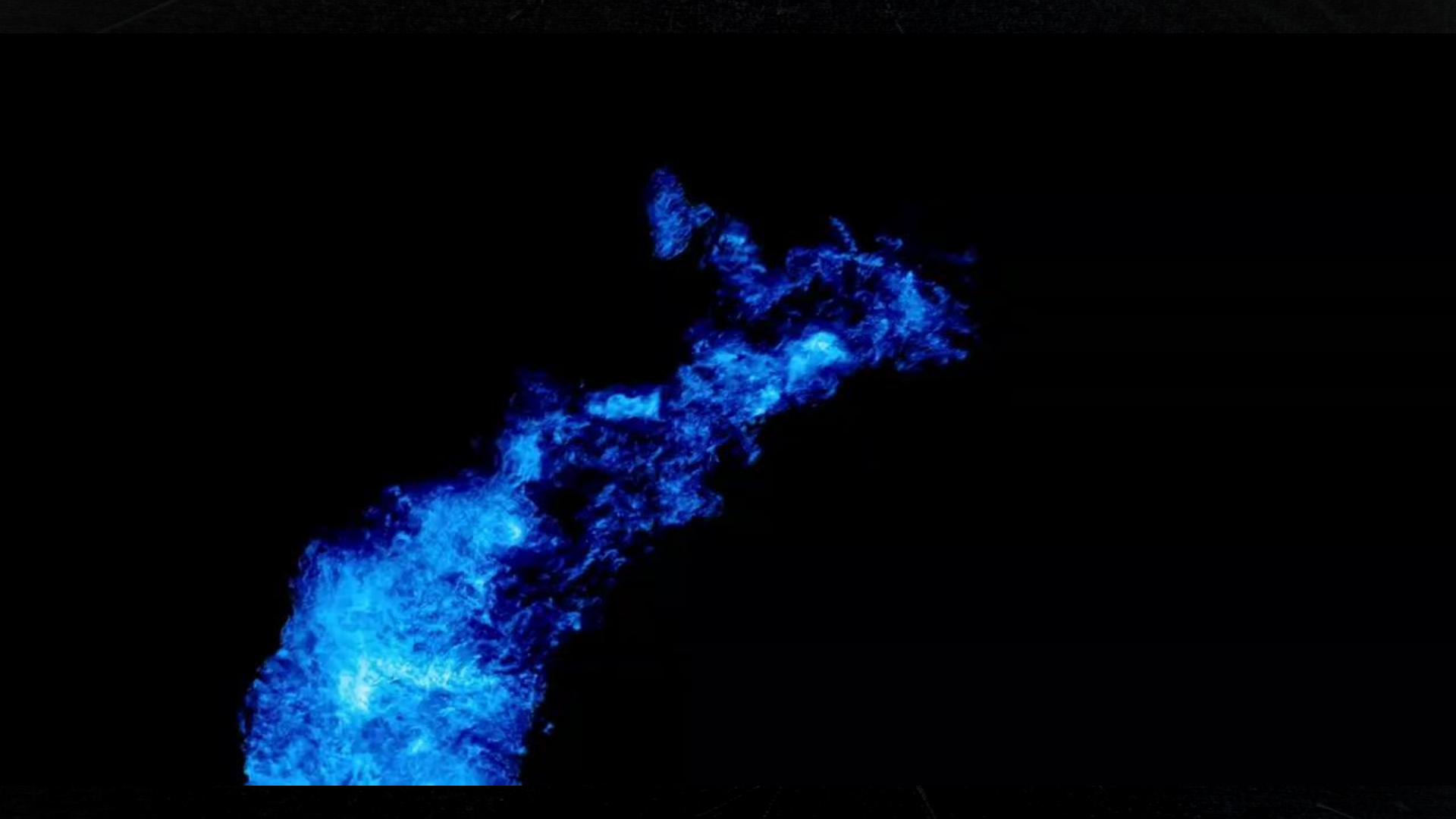


Linking the large-scale processes that shape the gas structure (shear, infall, etc.) with the sites of star formation and feedback.



The largest ALMA mosaic > 5,000 12m pointings
120 hr (12m), 360 hr (7m), 700 hr (TP)

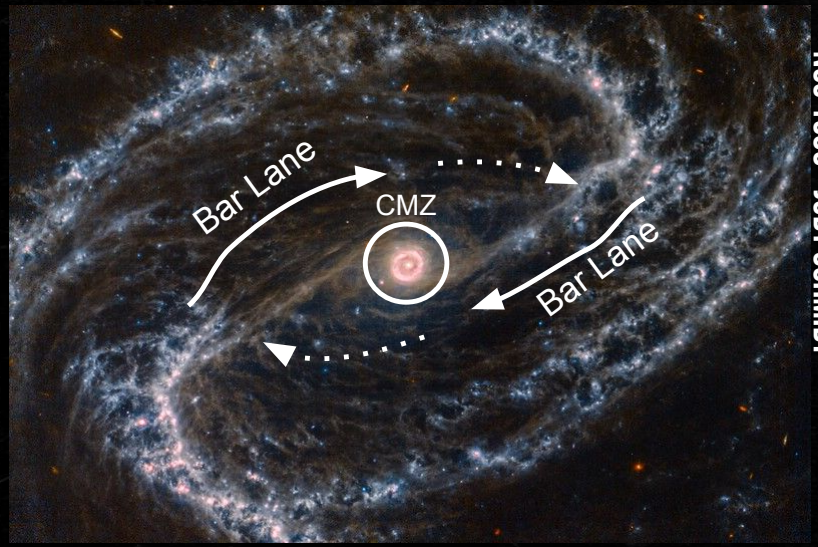
ACES Videos



Clouds with High Velocity Dispersions

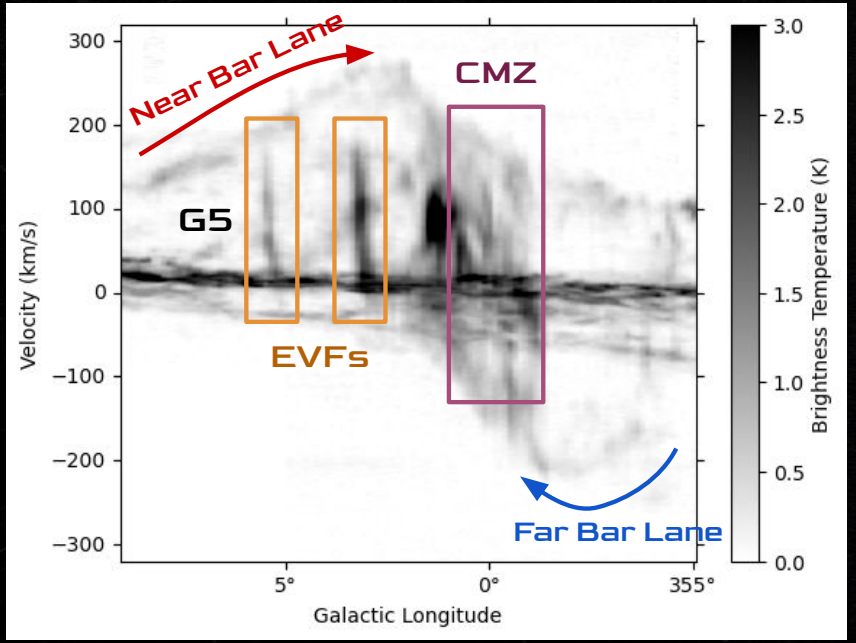
Galactic Center Environment

- ★ The CMZ is fed material via the dust or “bar” lanes
- ★ Gas and dust on the bar lanes either accretes onto the CMZ
- ★ … or misses, eventually colliding with gas on the other side of the Galaxy

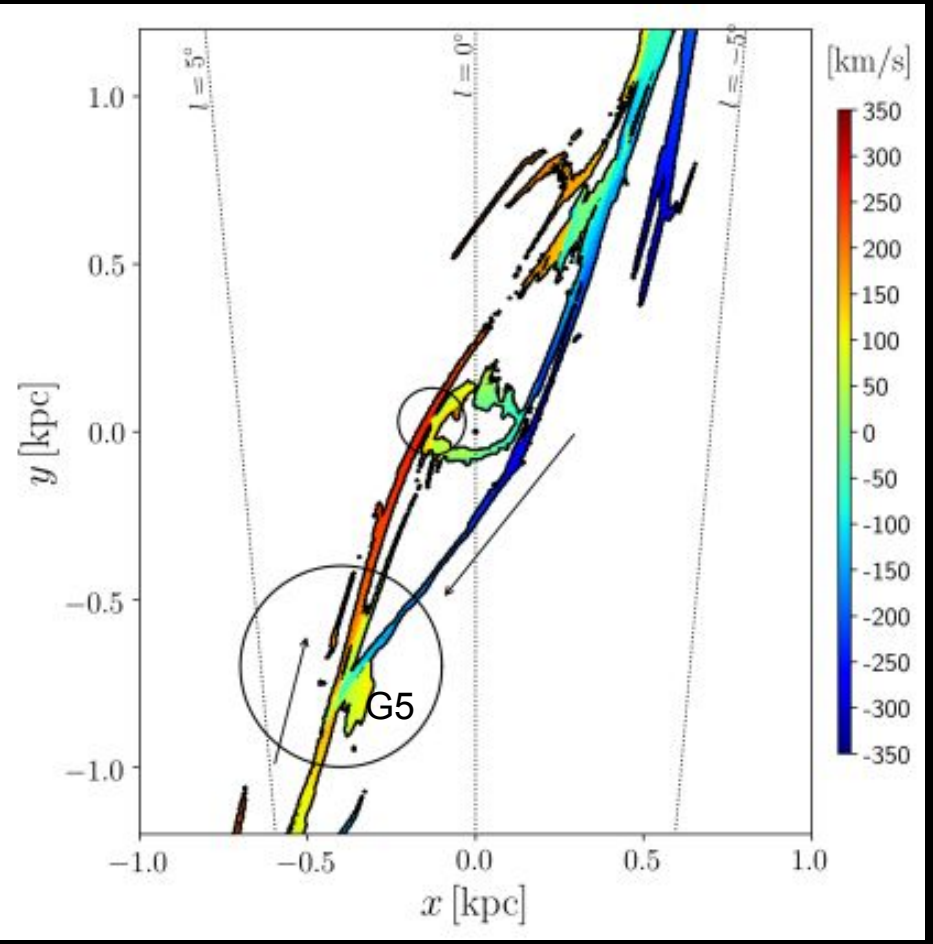


What is an EVF?

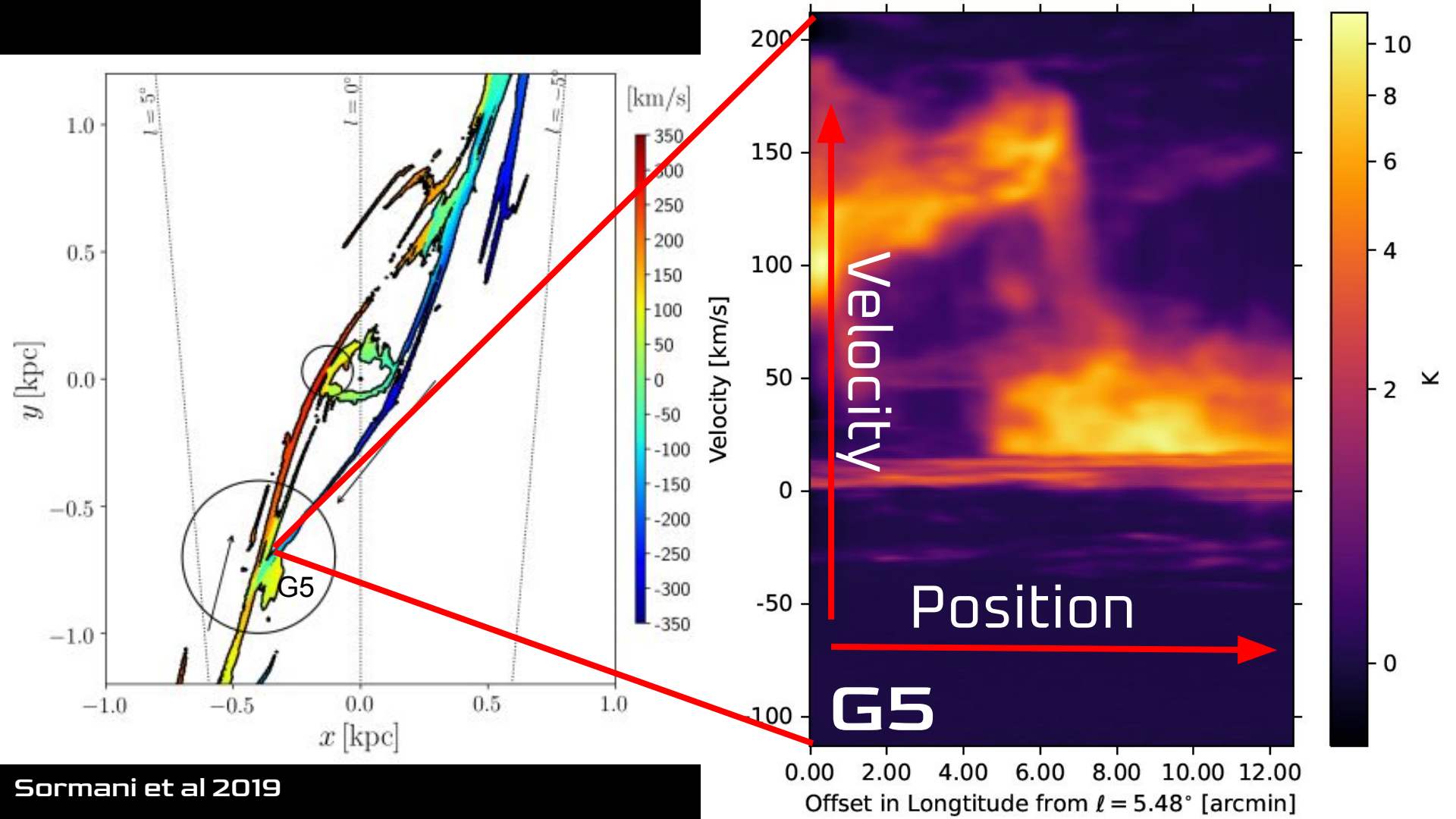
- When overshooting gas hits the bar lane on the other side of the Galaxy...
- It collides with that gas at $\Delta v > 100$ km/s
  - Maybe up to 200 km/s?
- Extended Velocity Features (EVFs)
  - Signatures of the collision



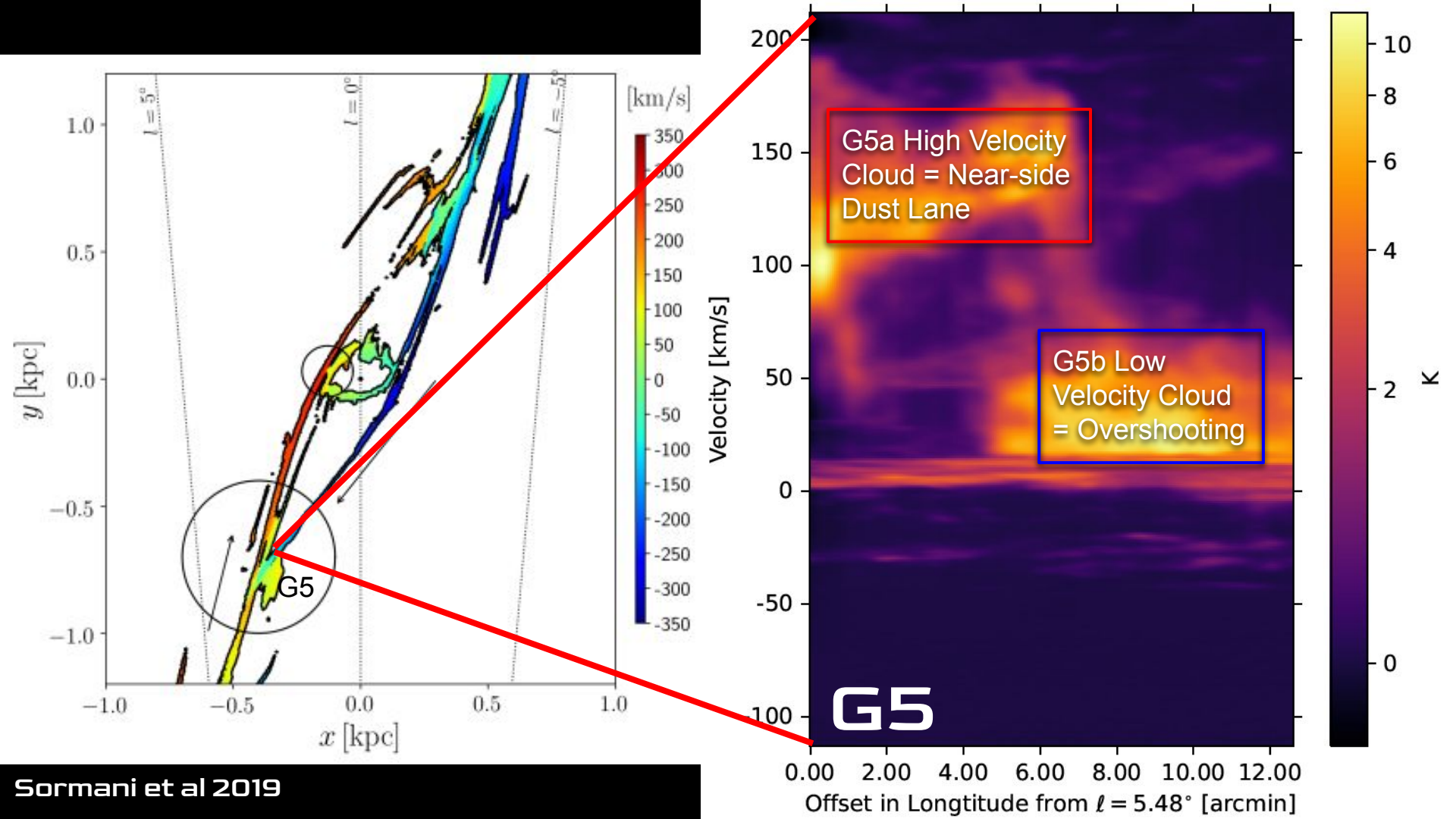
DAME ET AL 2001 CO 1-0



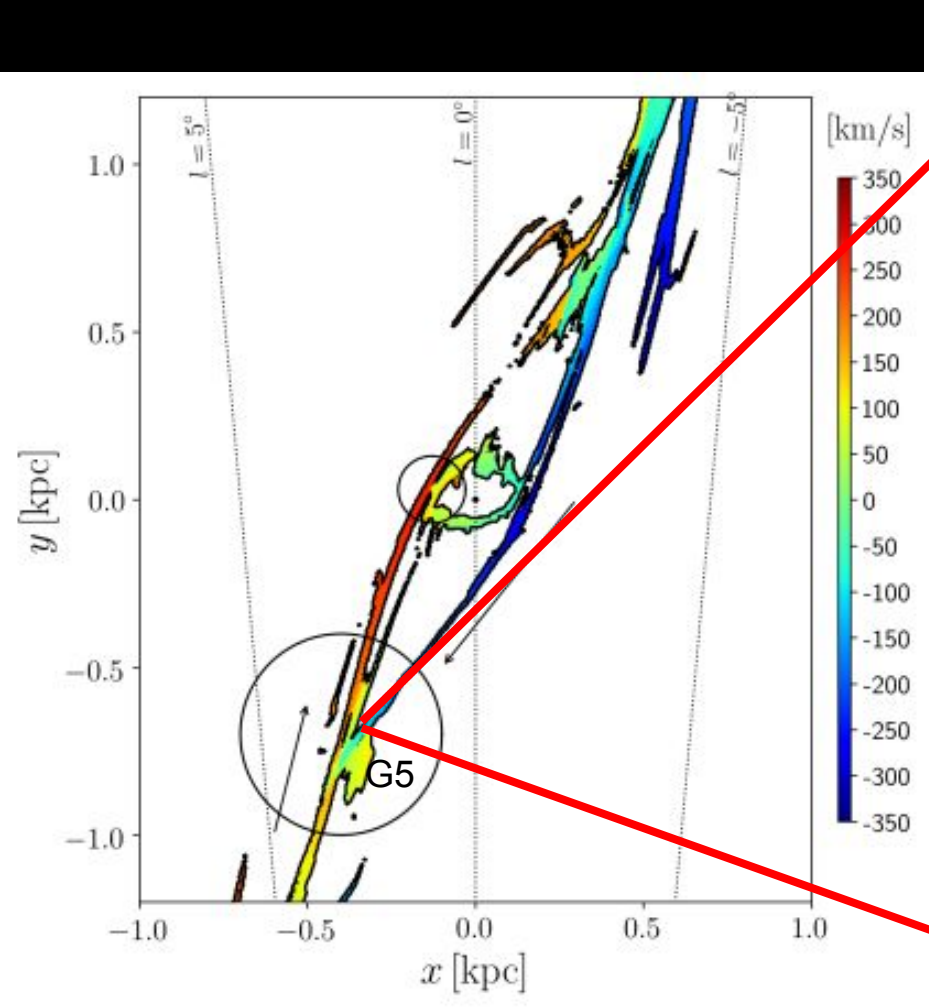
Sormani et al 2019



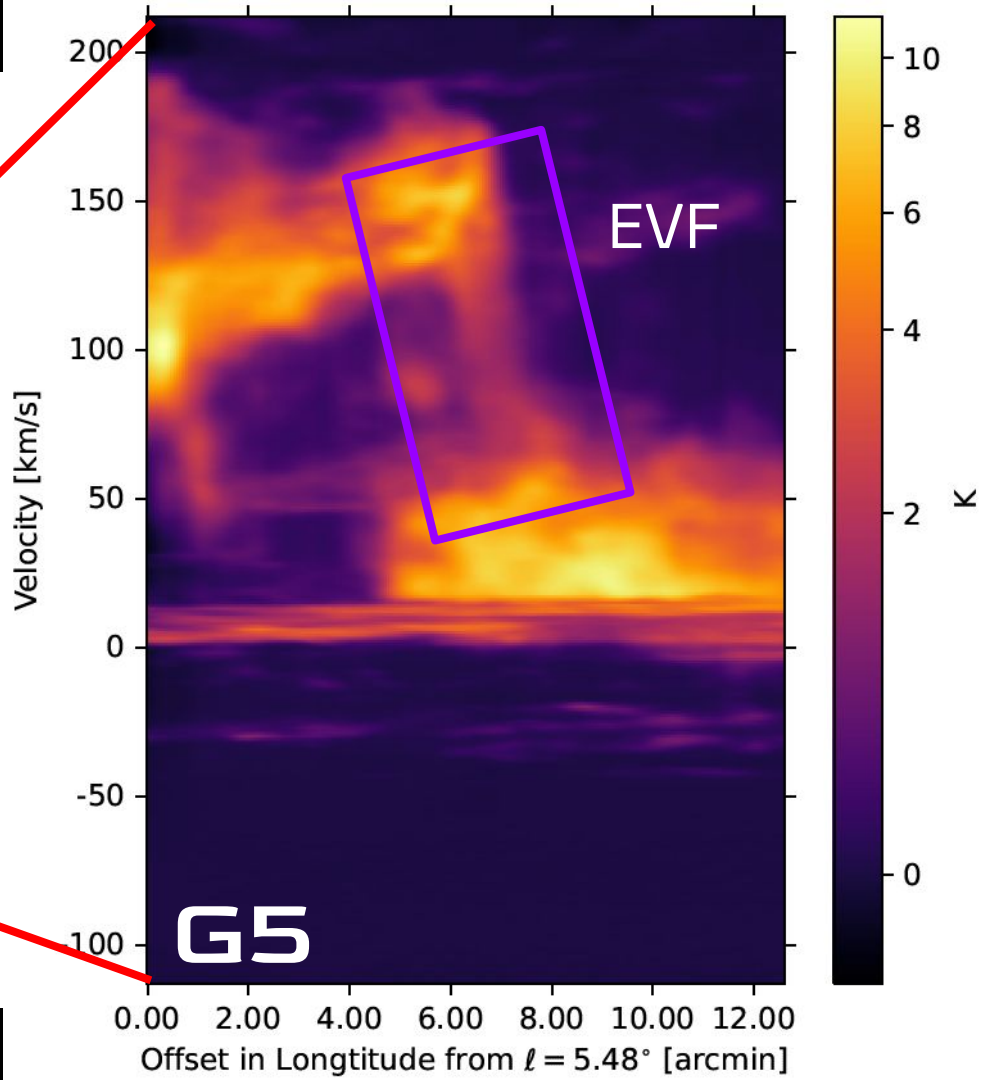
Sormani et al 2019

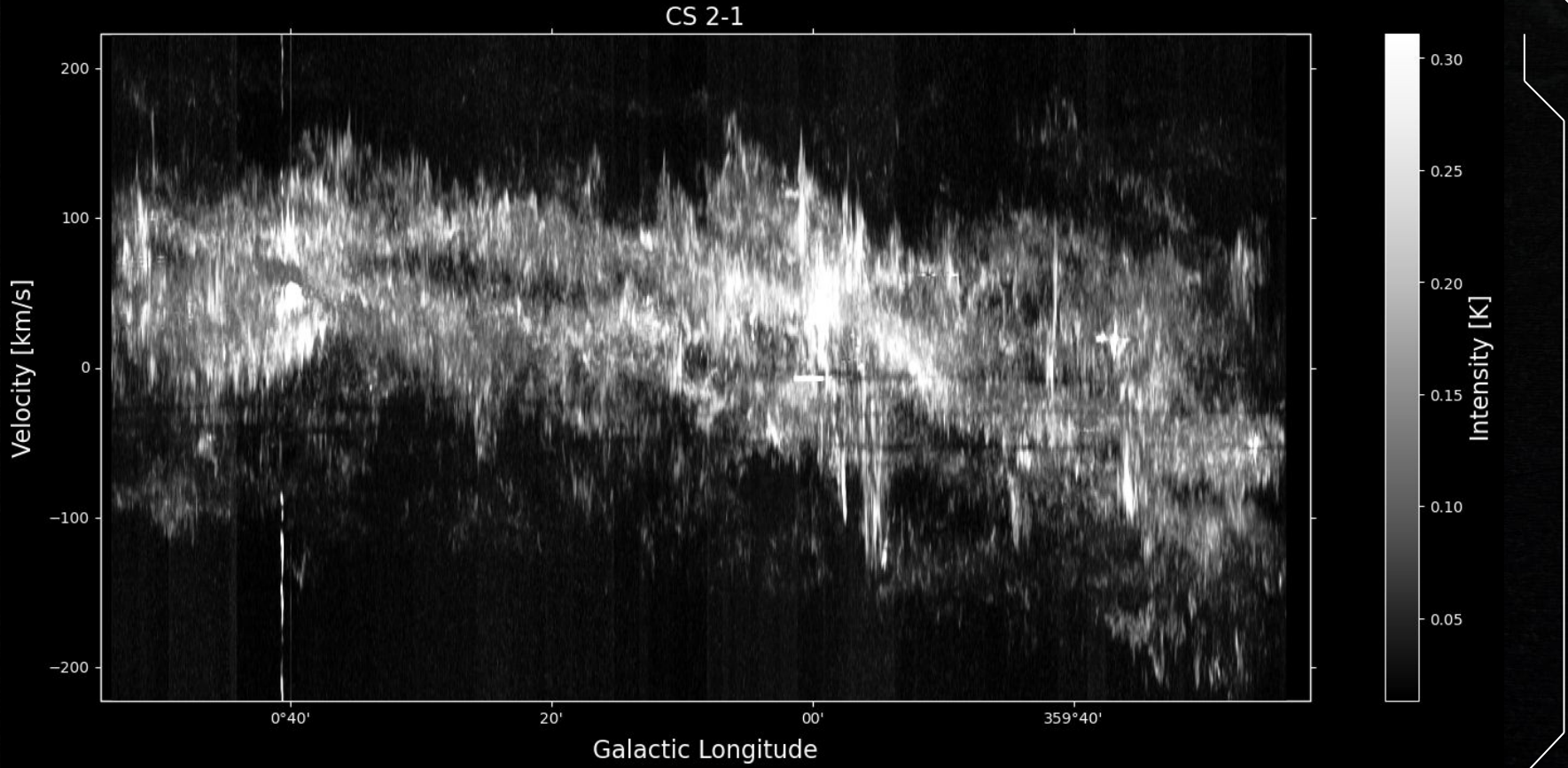


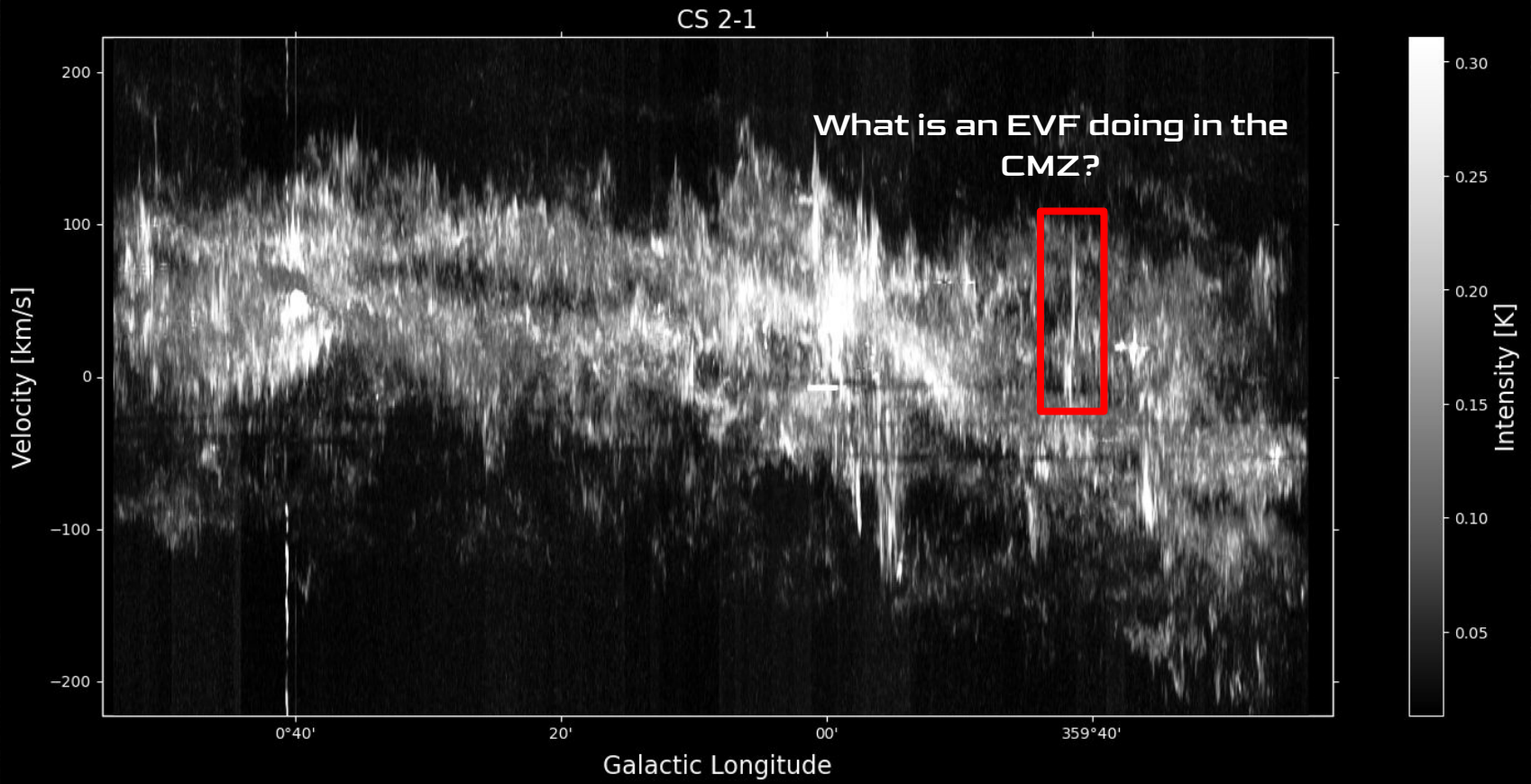
Sormani et al 2019



Sormani et al 2019

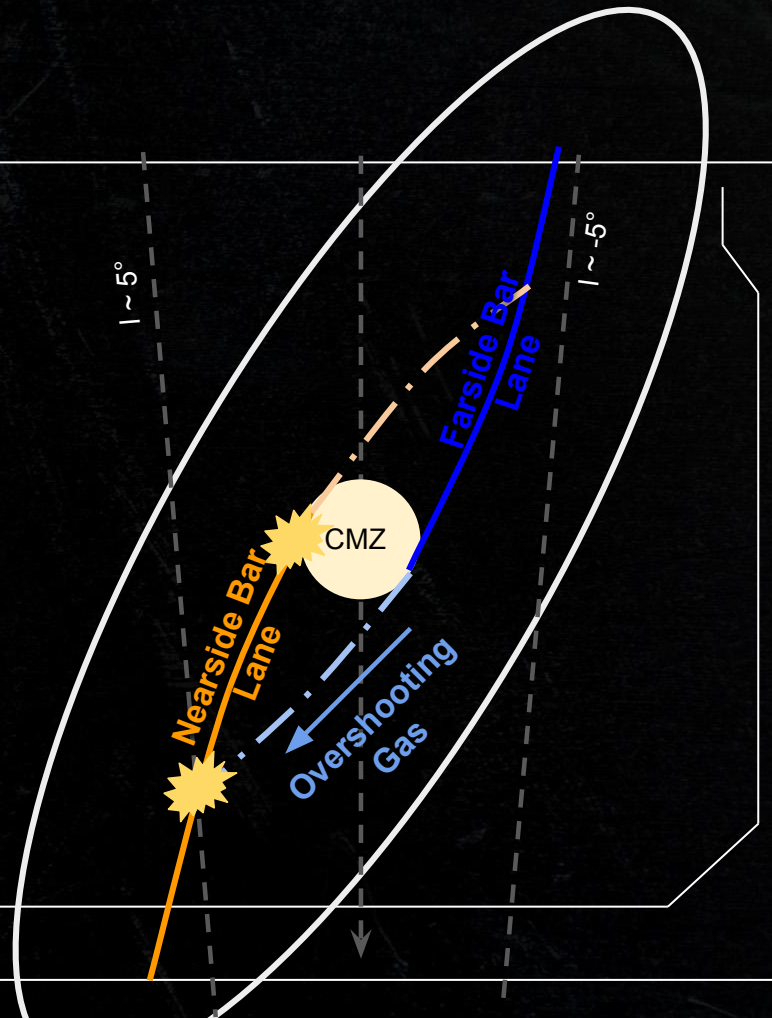



CS 2-1
Velocity [km/s]
200
100
0
−100
−200
0°40'
20'
00'
359°40'
Galactic Longitude
Intensity [K]
0.30
0.25
0.20
0.15
0.10
0.05


CS 2-1
What is an EVF doing in the CMZ?
Velocity [km/s]
200
100
0
−100
−200
0°40'
20'
00'
359°40'
Galactic Longitude
Intensity [K]
0.30
0.25
0.20
0.15
0.10
0.05

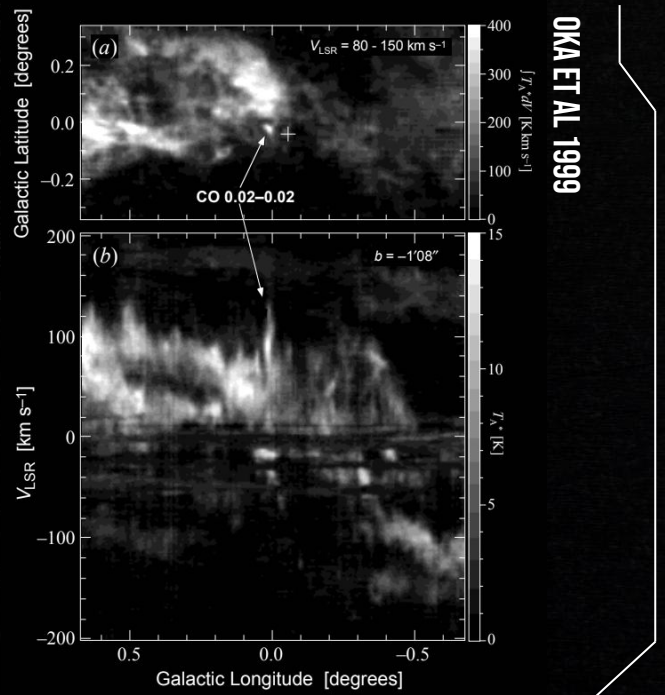
What is an EVF?

- What about EVFs within the CMZ?
  - Are they due to bar lane material accretion?
  - Dynamic flows within the CMZ?
  - Accretion onto the circumnuclear disk / minispiral?
  - Something else?



What is an HVCC?

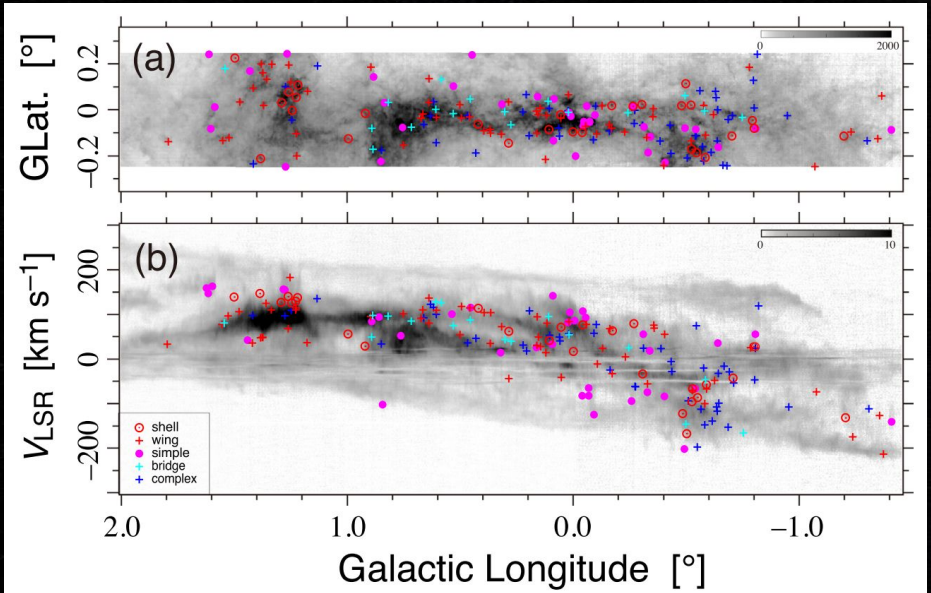
- ★ High Velocity dispersion Compact Cloud (HVCC)
  - Small cloud with an unusually high velocity dispersion
- ★ Variety of potential origins
  - SNR interacting with molecular gas
  - Cloud-cloud collision
  - Molecular outflow
  - Gas stream inflowing to Sgr A*
  - Intermediate mass black hole disk



EVFs and HVCCs

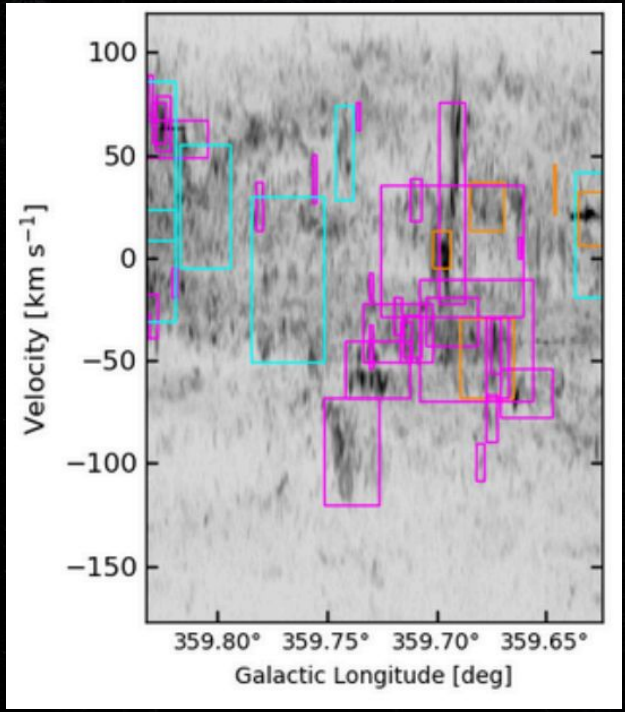
- ★ Do EVFs and HVCCs trace similar phenomena?
  - Both have larger velocity dispersions than expected from their size
- ★ EVFs have a more obvious connection to bar lanes
- ★ HVCCs likely have a variety of origins
- ★ EVFs and HVCCs have different size scales(?)
- ★ What can we find using ACES?

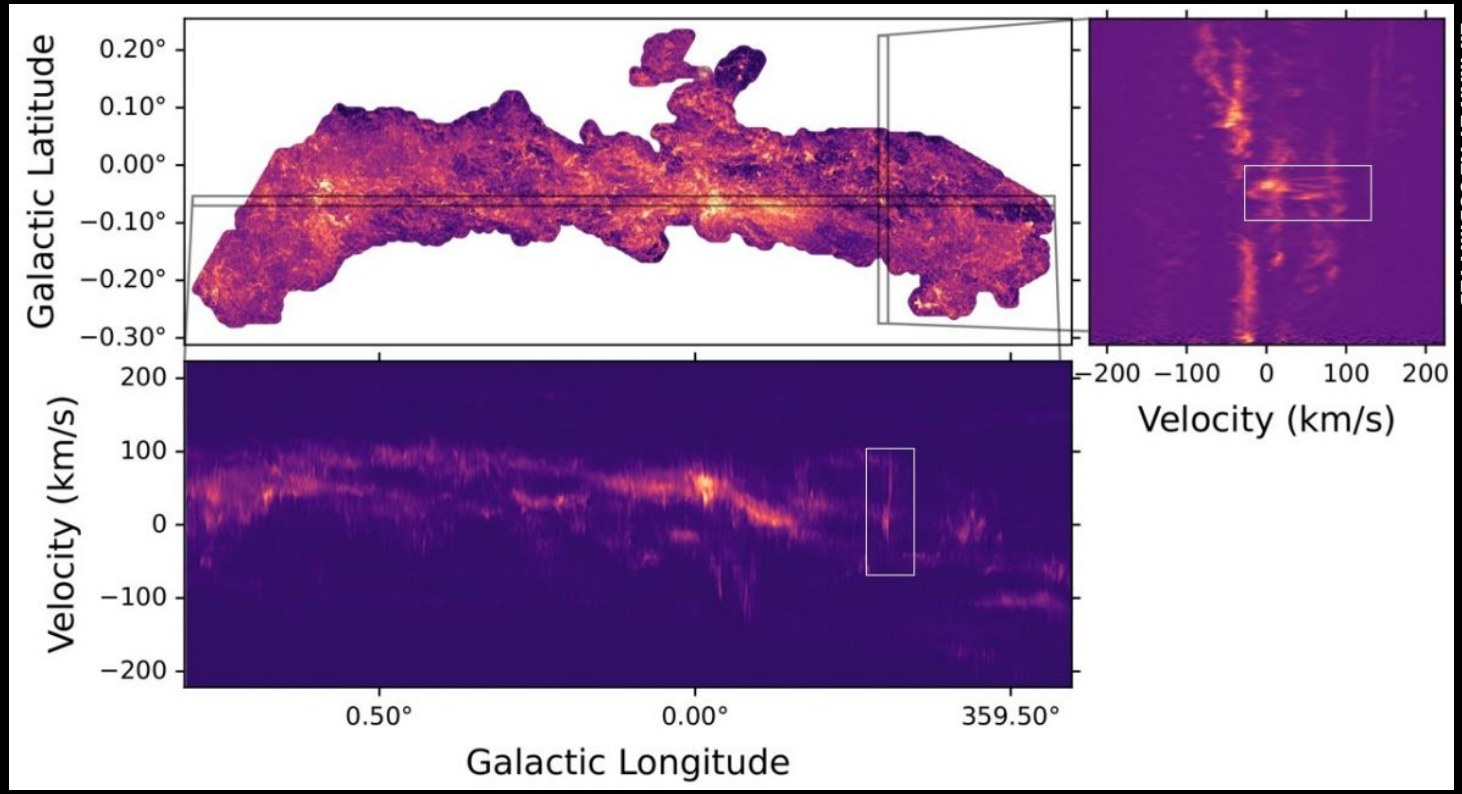
OKA ET AL 2022



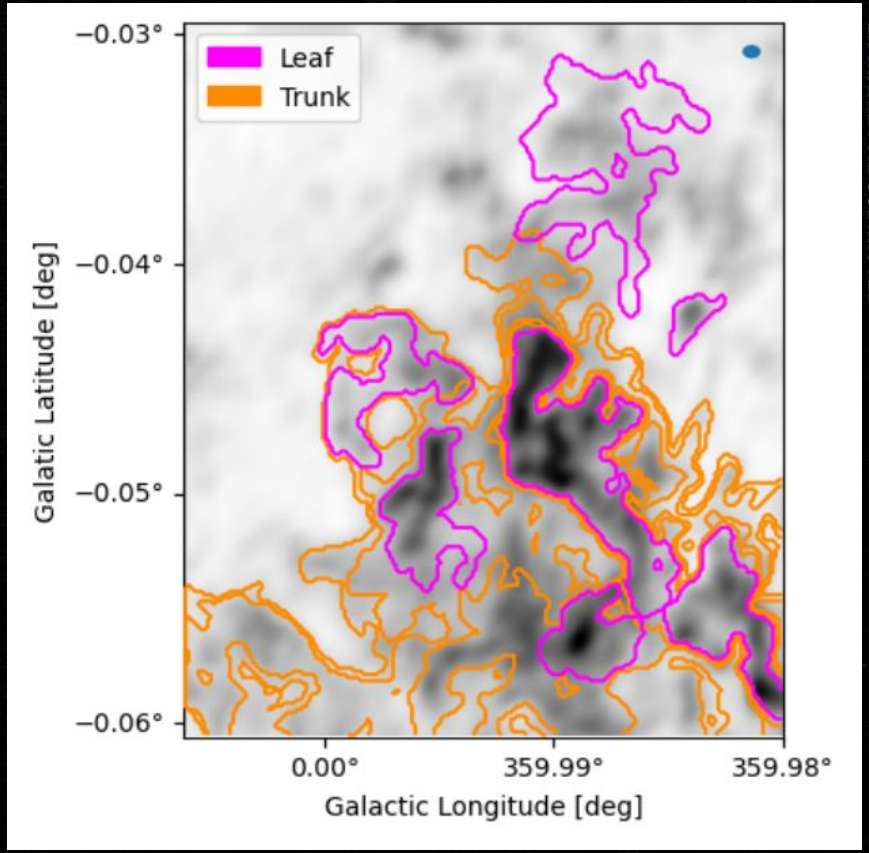
Searching for HVCCs in ACES

- ★ Searching the ACES CS 2-1 data
  - Target: regions with unusually high velocity dispersions
- ★ EVFs => HVCCs
- ★ Do HVCCs trace bar lane accretion?
  - Inflow toward Sgr A*?
- ★ Shock properties with line ratios





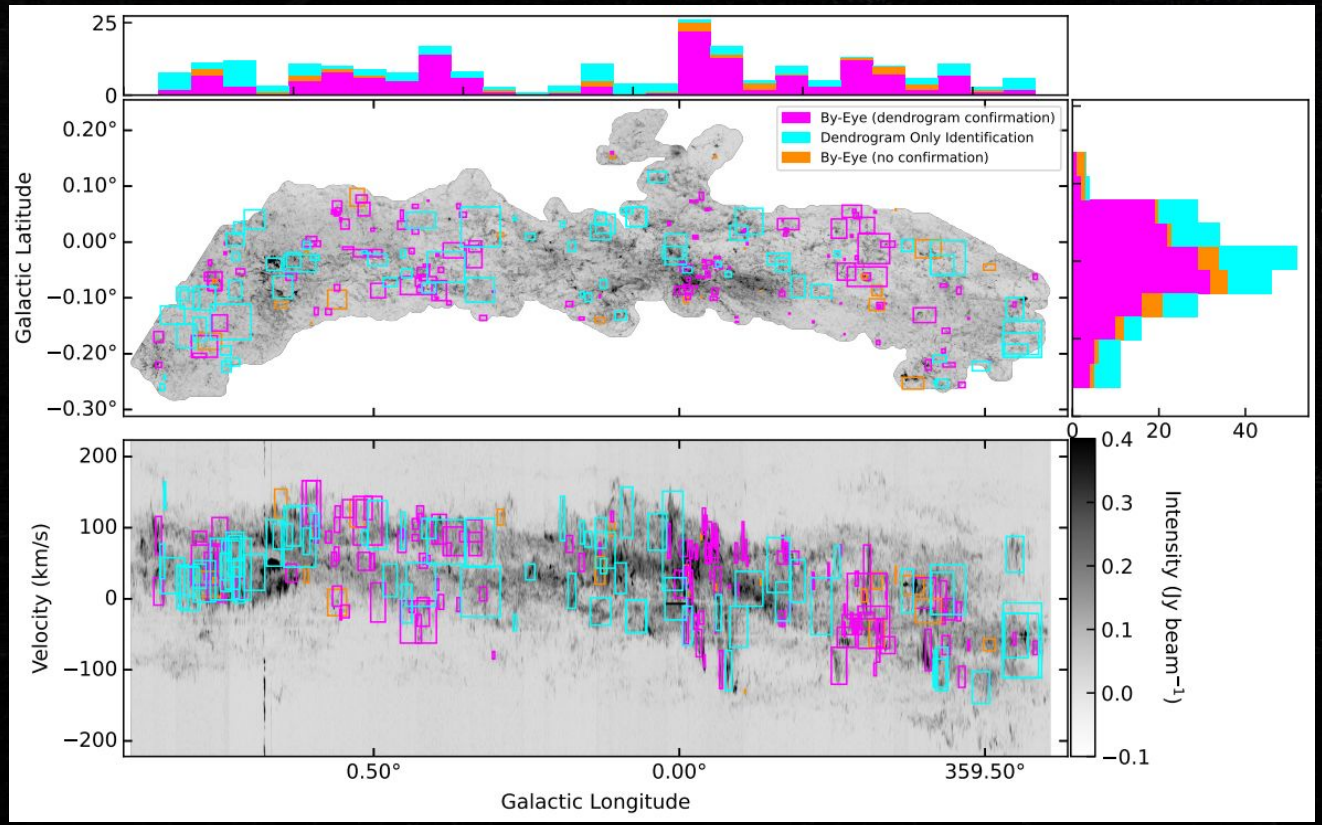
HVCC Identification - By Eye



LIPMAN ET AL SUBMITTED

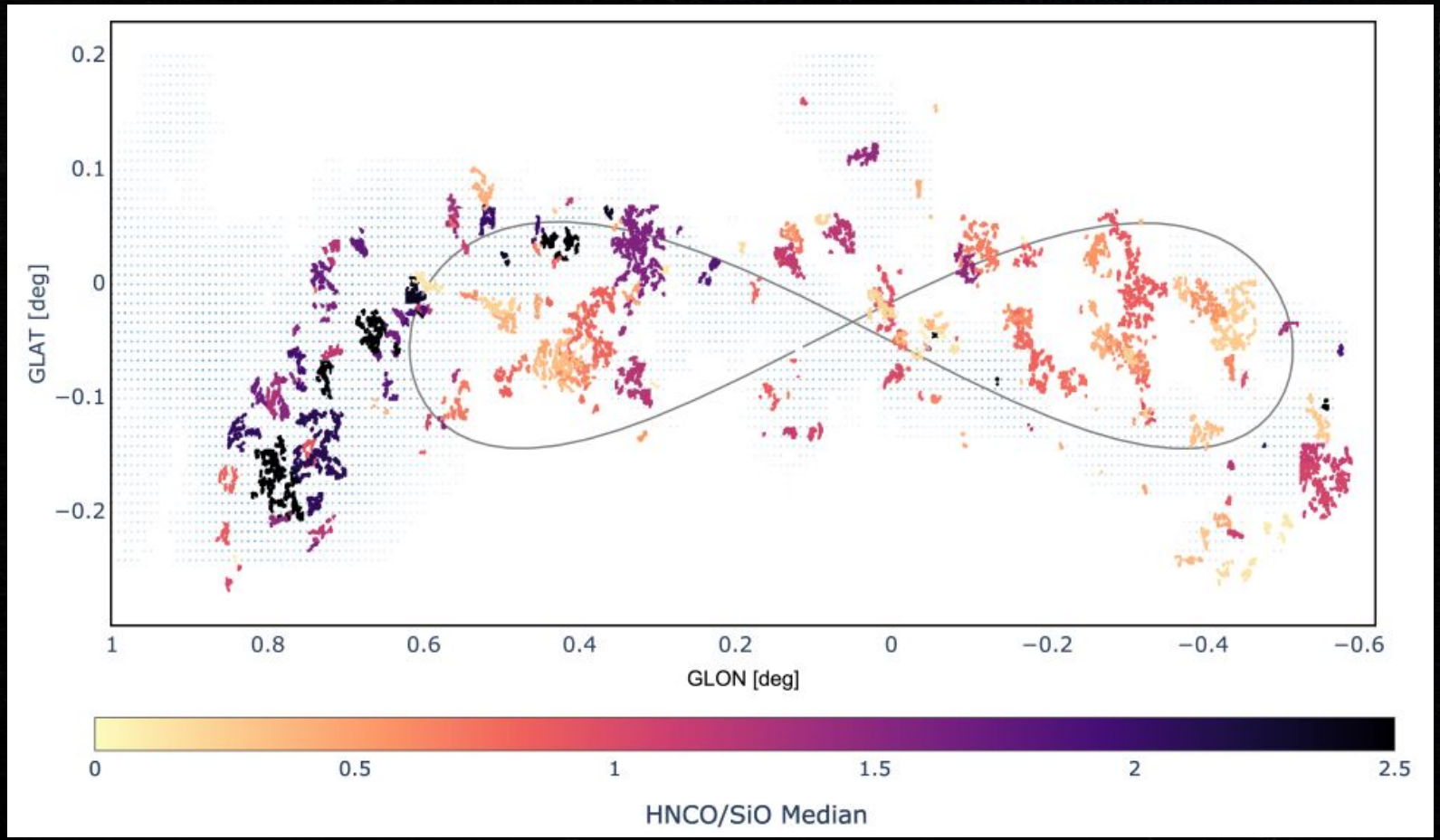
HVCC Identification - Dendrogram

Results - 235 identified sources



235 Identified Sources

- ★ Velocity width/dispersion $\Delta v > 50$ km/s
- ★ Size $d < 10$ pc
- ★ Verticality > 1,000 km/s/deg



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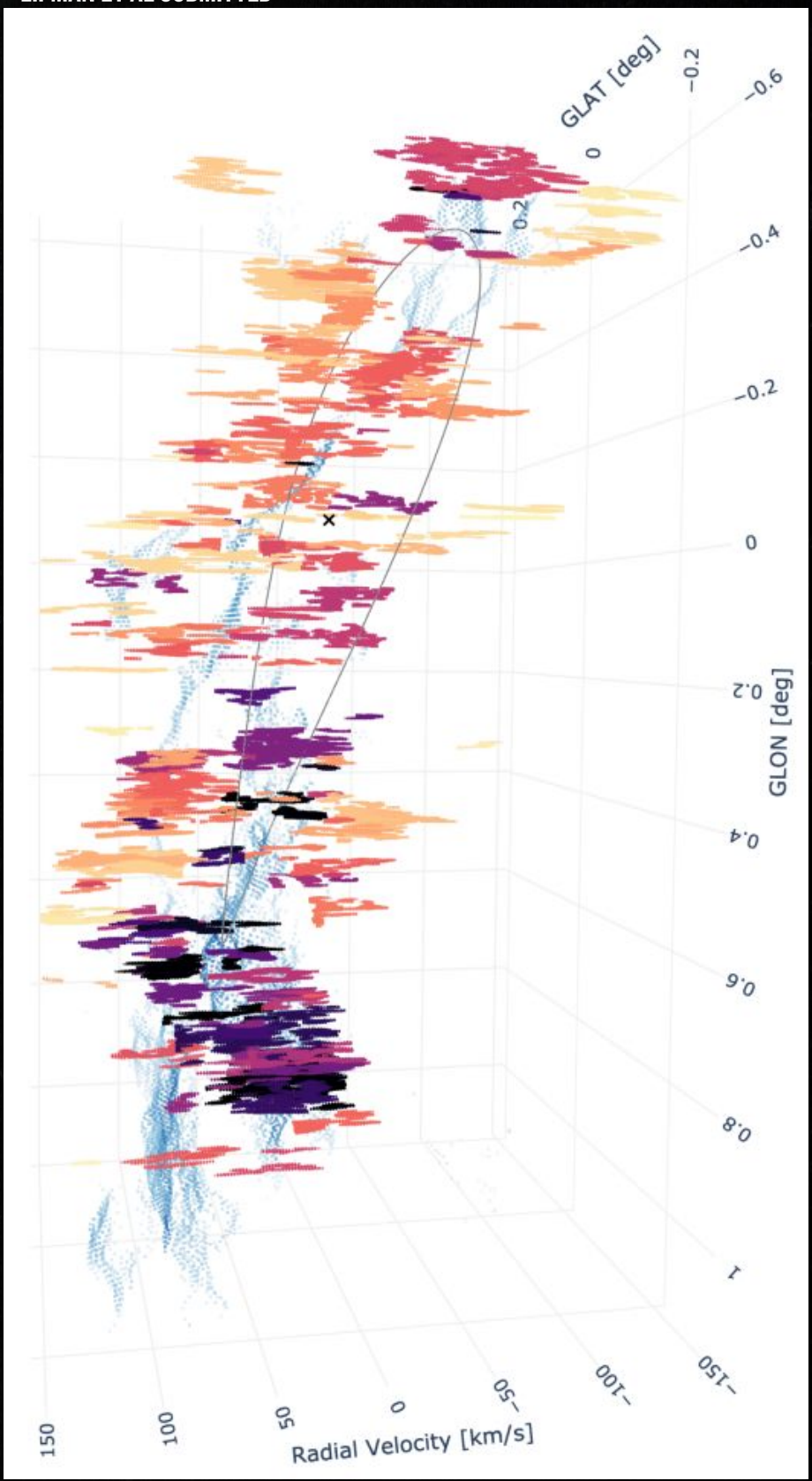
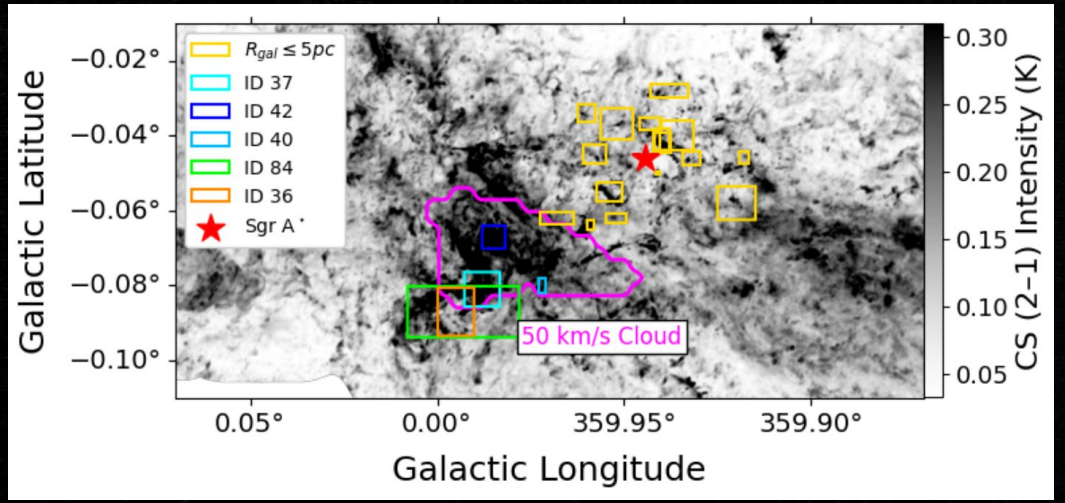


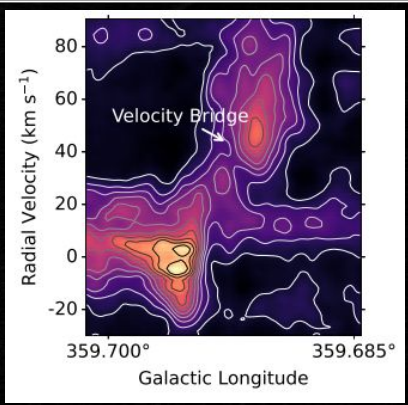
HVCCs near Sgr A*

- ★ Yellow = HVCCs within 5 pc on the plane of the sky from Sgr A*
- ★ Other HVCCs associated with the 50 km/s cloud
- ★ Potentially tracing mass flows toward or away from Sgr A*?

LIPMAN ET AL SUBMITTED

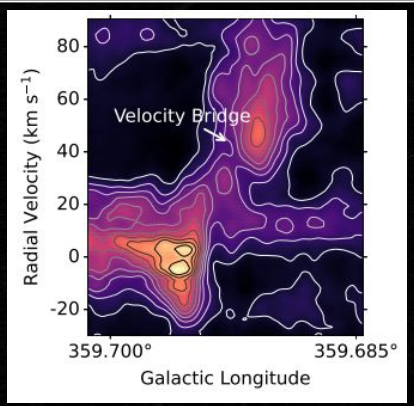


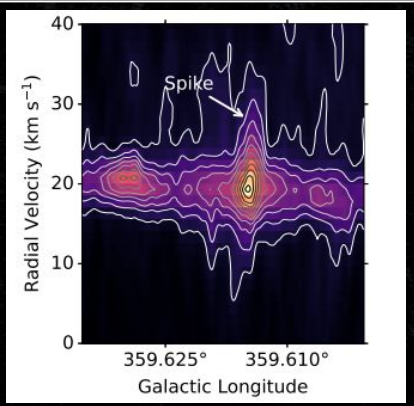
Position-Velocity Morphologies



Cloud-Cloud
Collision
Signature

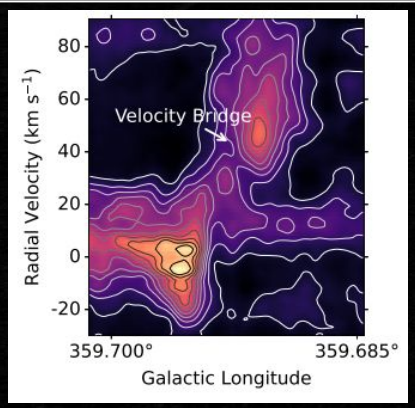
Position-Velocity Morphologies

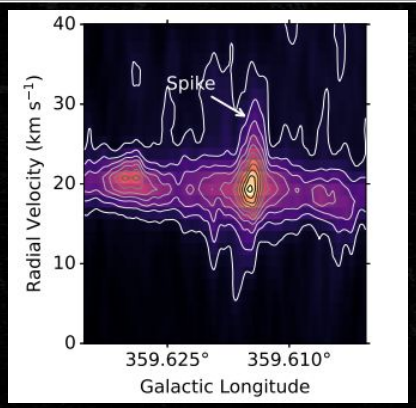


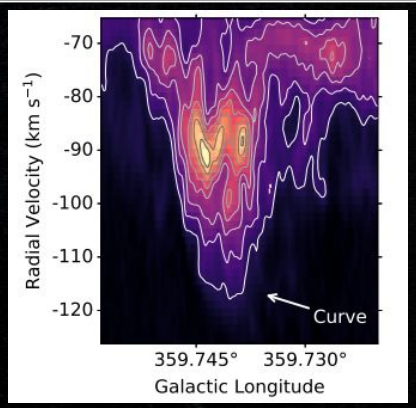


Unresolved, complex kinematics

Position-Velocity Morphologies

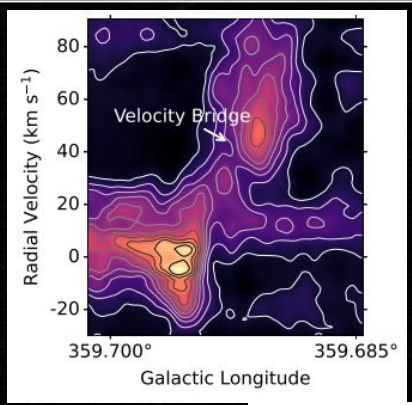


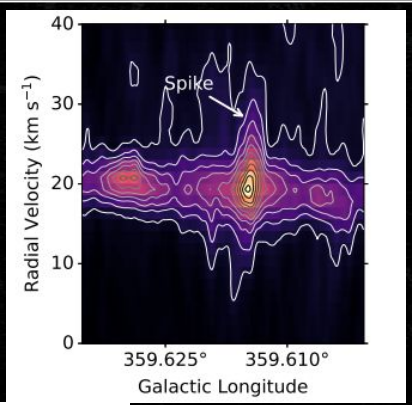


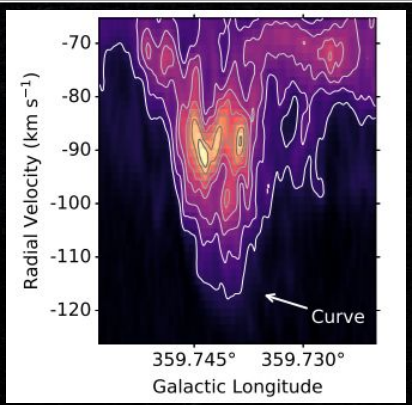


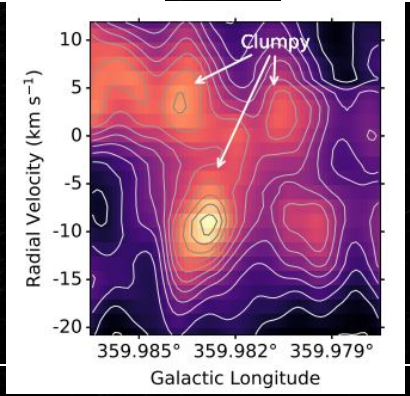
Cloud-Cloud Collision Signature

Position-Velocity Morphologies



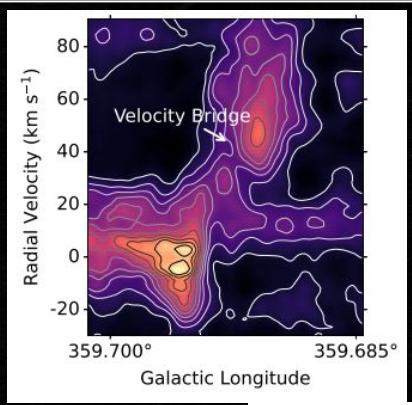


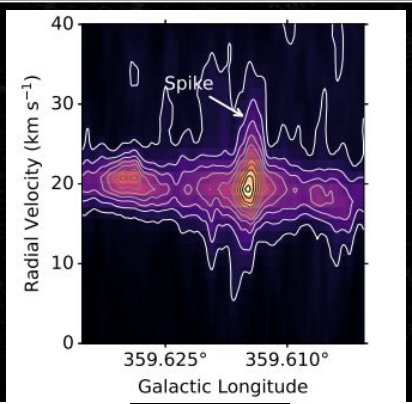


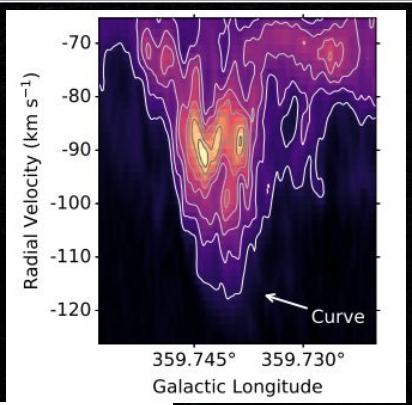


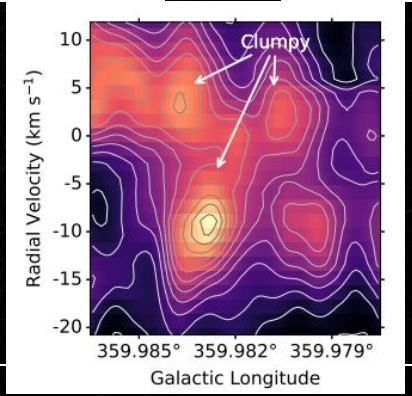
Multiple Velocity Components, Complex Structure

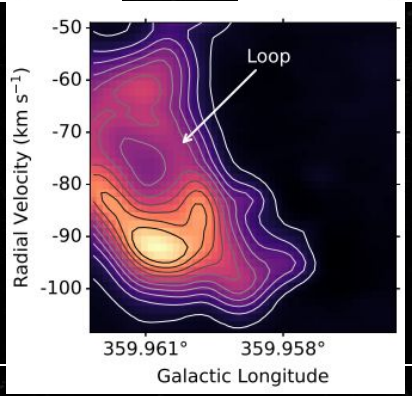
Position-Velocity Morphologies







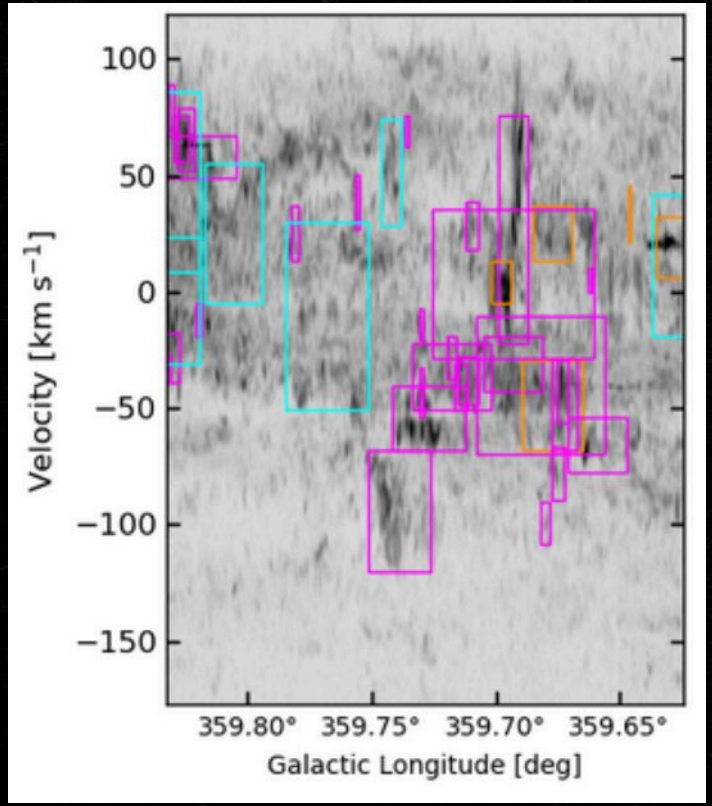




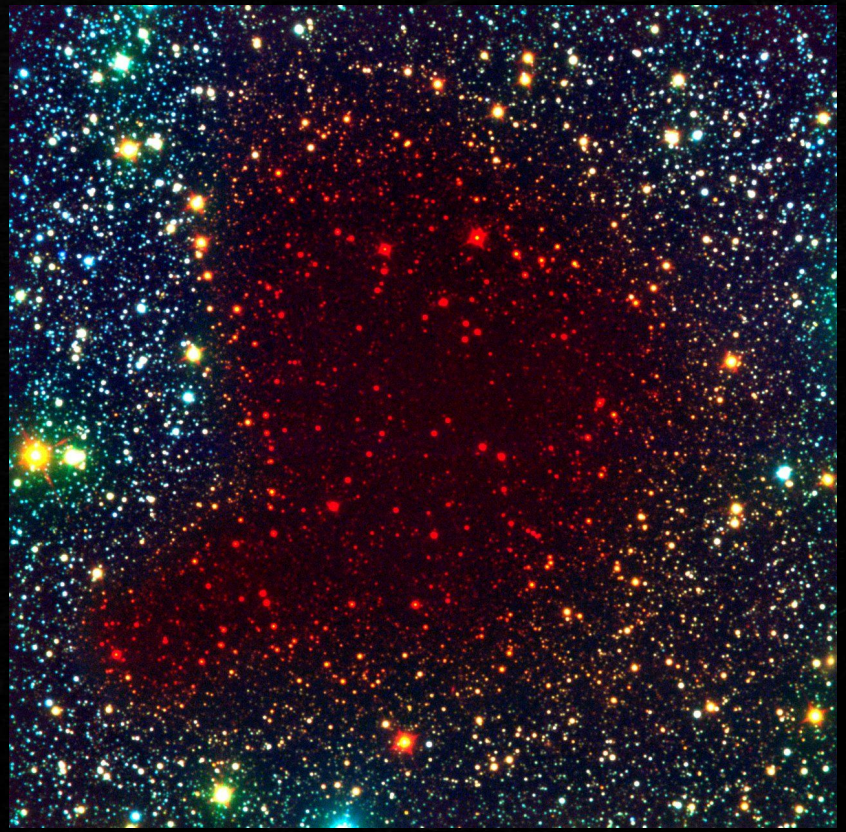
Expanding Bubble, Feedback

What are HVCCs?

- ★ Cloud-cloud collisions
- ★ Feedback
- ★ Complex CMZ kinematics
- ★ Inflow toward Sgr A*



Does Accretion onto the CMZ Change its Chemistry?



Dust Reddens Stars

Dust blocks shorter wavelengths of light.
Only redder light gets through.

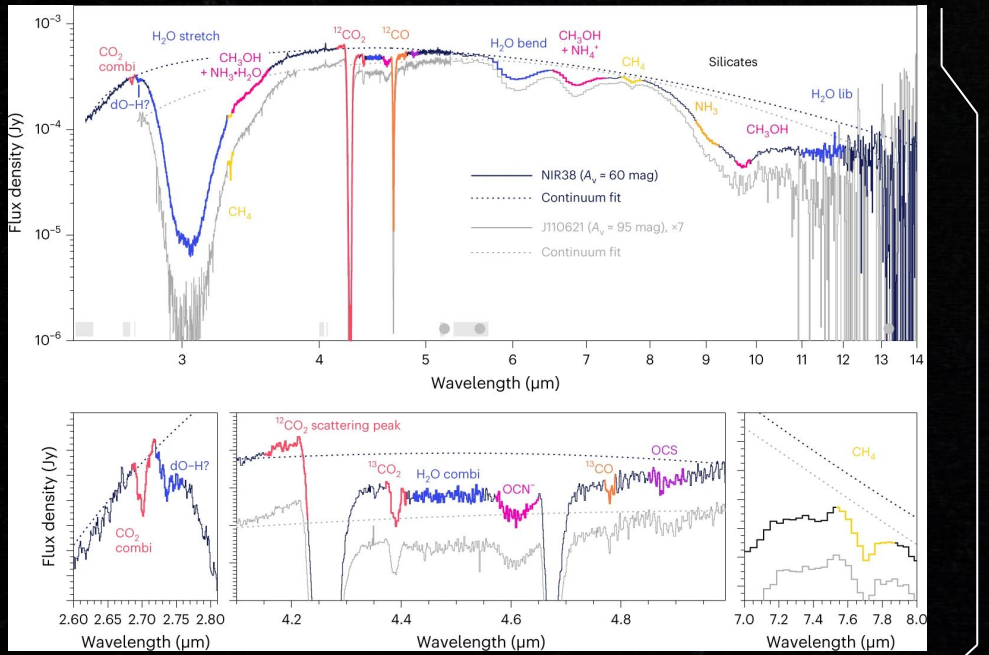
ESO

Why are the stars behind these clouds blue, not red?

JWST NIRCam - Gramze et al 2025

Interstellar Ices

- ★ In the interiors of cold, dark infrared dark clouds, molecules freeze out onto dust grains
- ★ Near infrared ice absorption features
- ★ CO ice absorbs light in F466N



MCCLURE ET AL 2023

Blue = F405N, Red = F466N

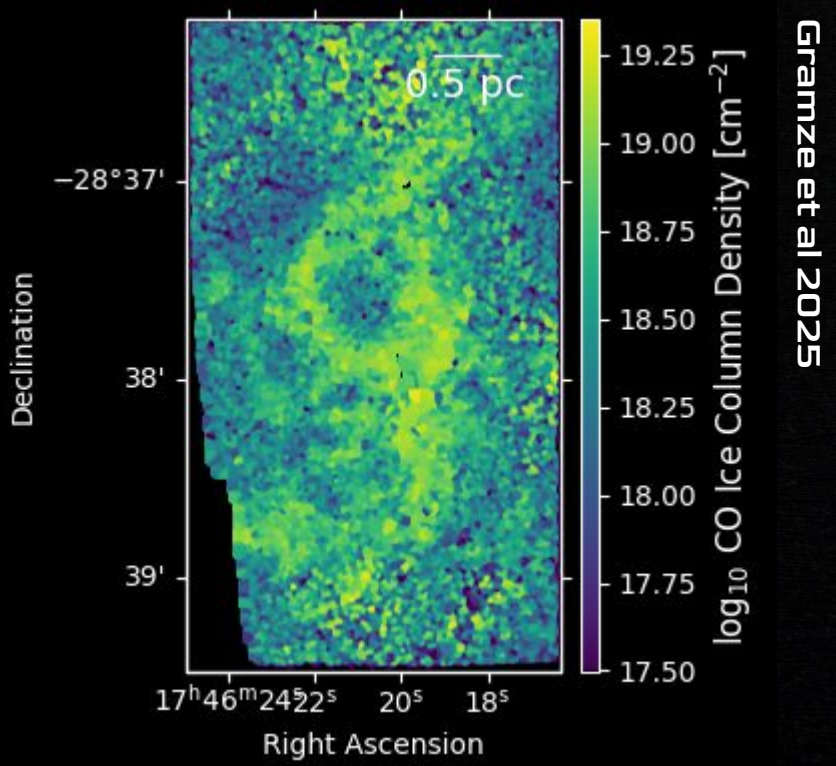
JWST NIRCam - Gramze et al 2025

F466N is heavily impacted by ice, F405N is not

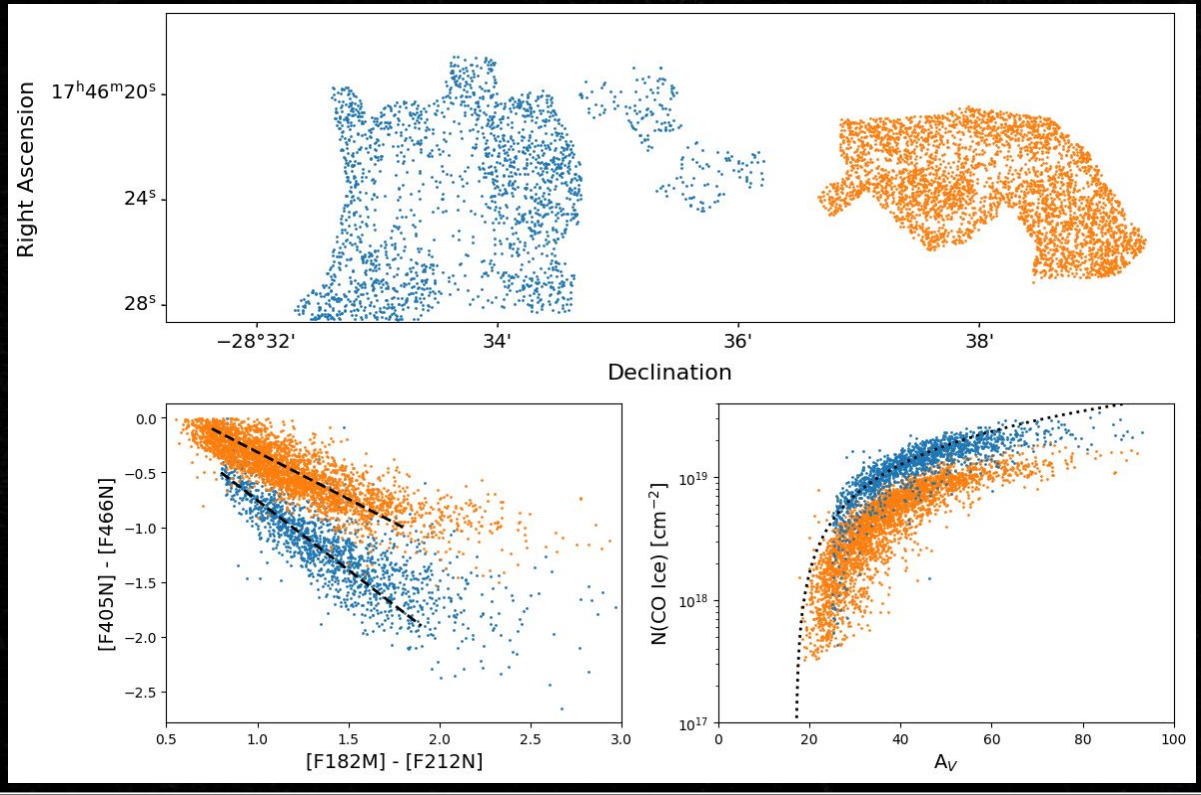
JWST NIRCam - Gramze et al 2025

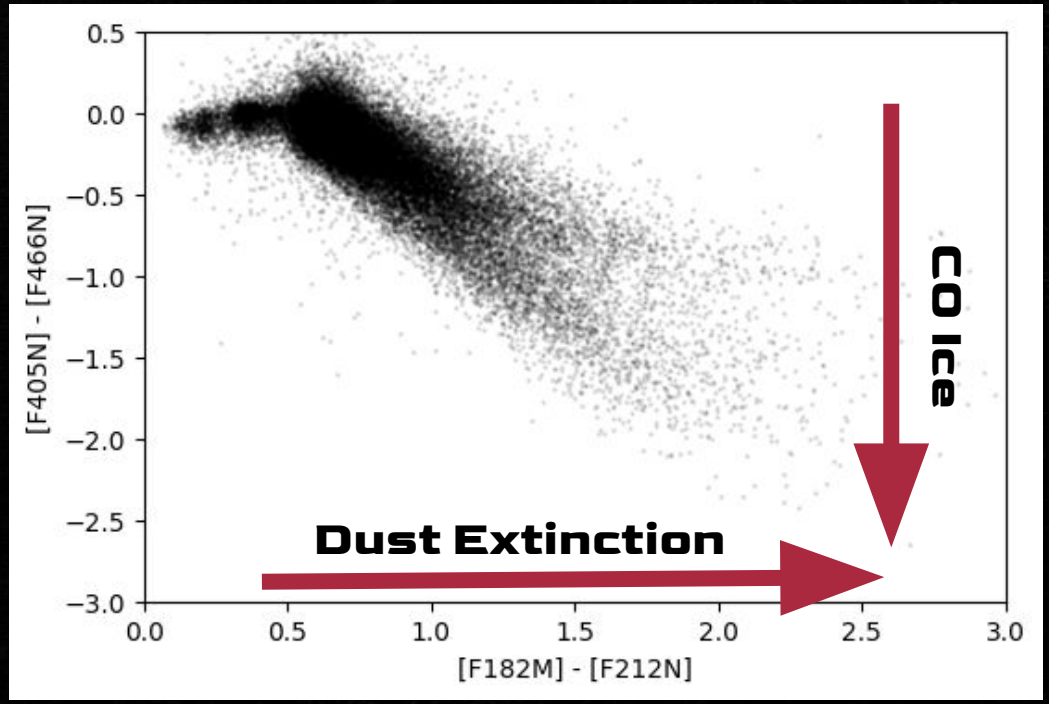
Map CO Ice Column Density

- ★ Using colors with F466N
- ★ Measure N(CO Ice)
- ★ Interpolate between each star



CMZ Clouds Icier than Disk Clouds

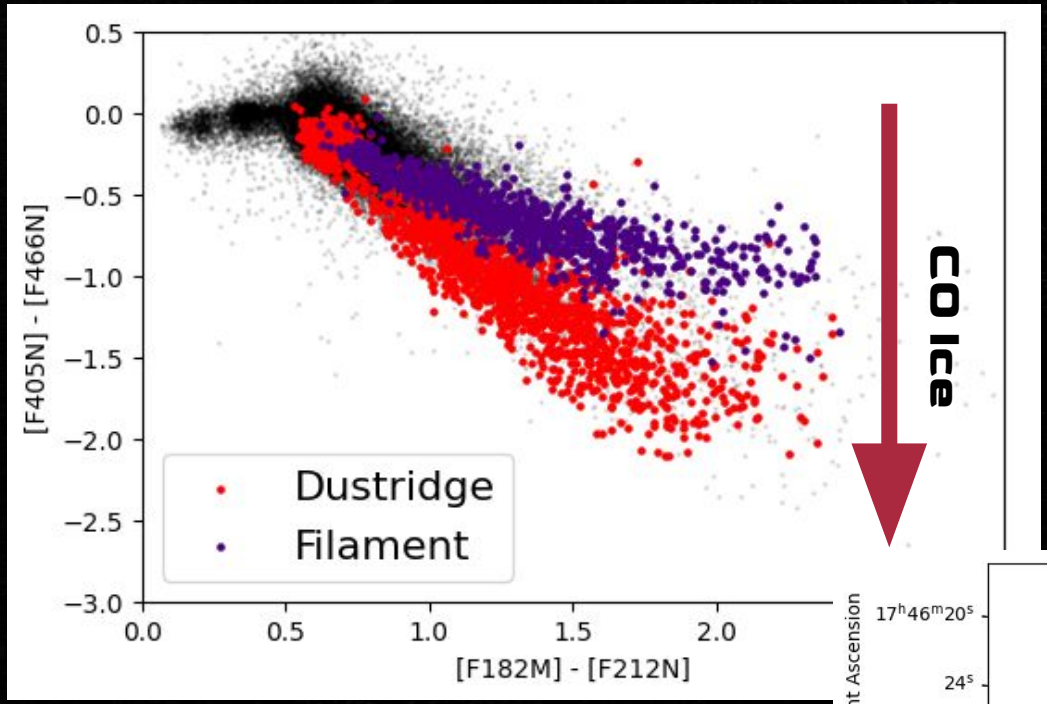


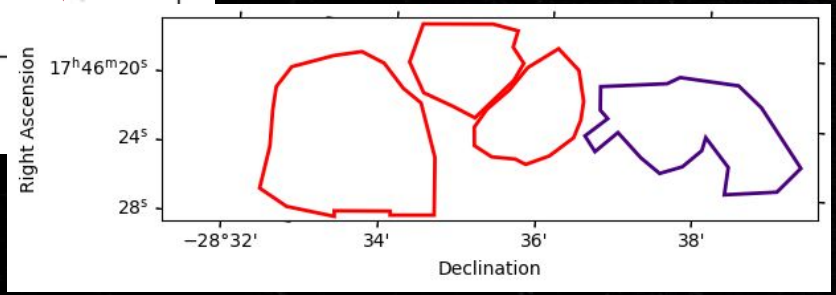


Color-Color Diagram

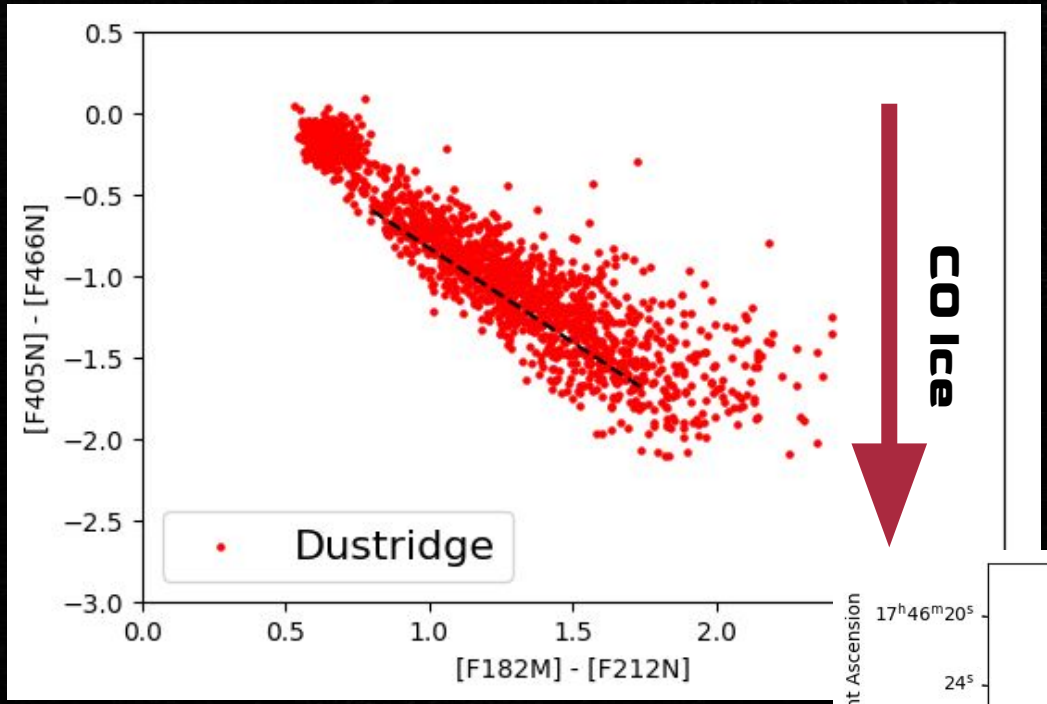
- ★ Shorthand for dust extinction and CO ice ratio
- ★ [F466N] becomes fainter as N(CO ice) increases

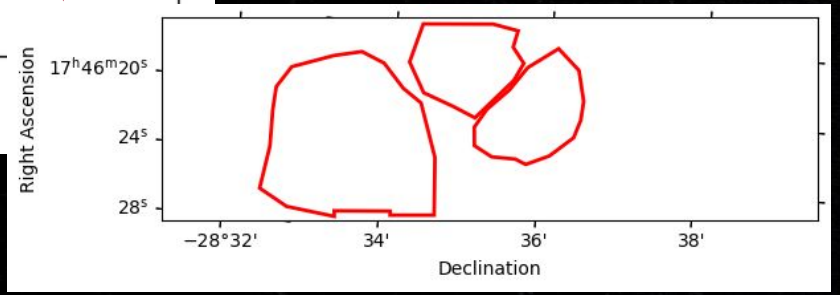
Different Slopes = Differences in Ice



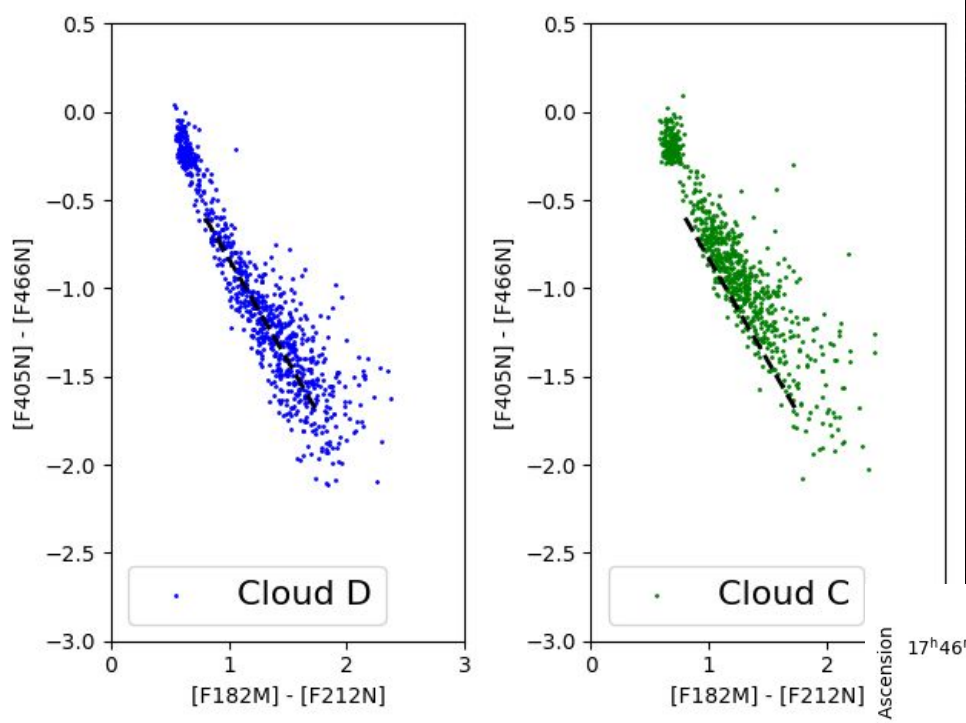


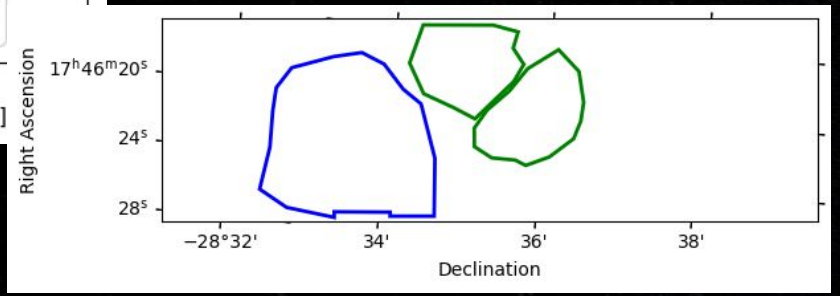
Dust Ridge

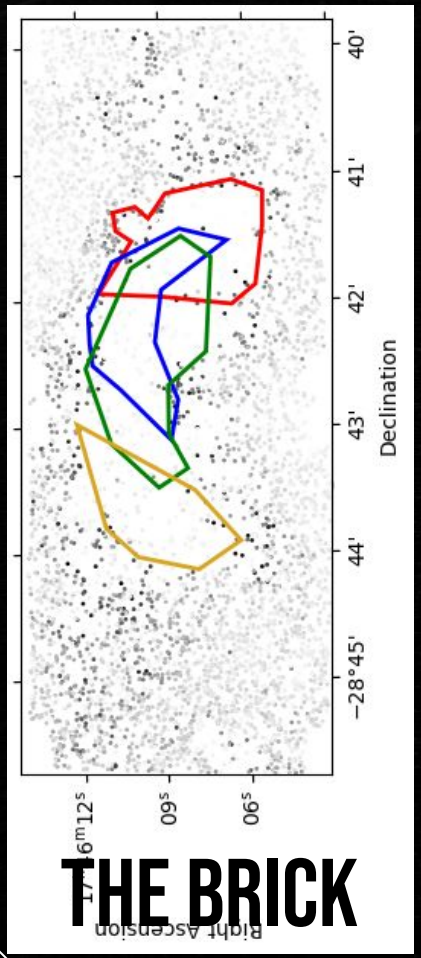

0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
[F405N] - [F466N]
0.0
0.5
1.0
1.5
2.0
[F182M] - [F212N]
Dustridge
CO Ice


Right Ascension
17h46m20s
24s
28s
−28°32'
34'
36'
38'
Declination

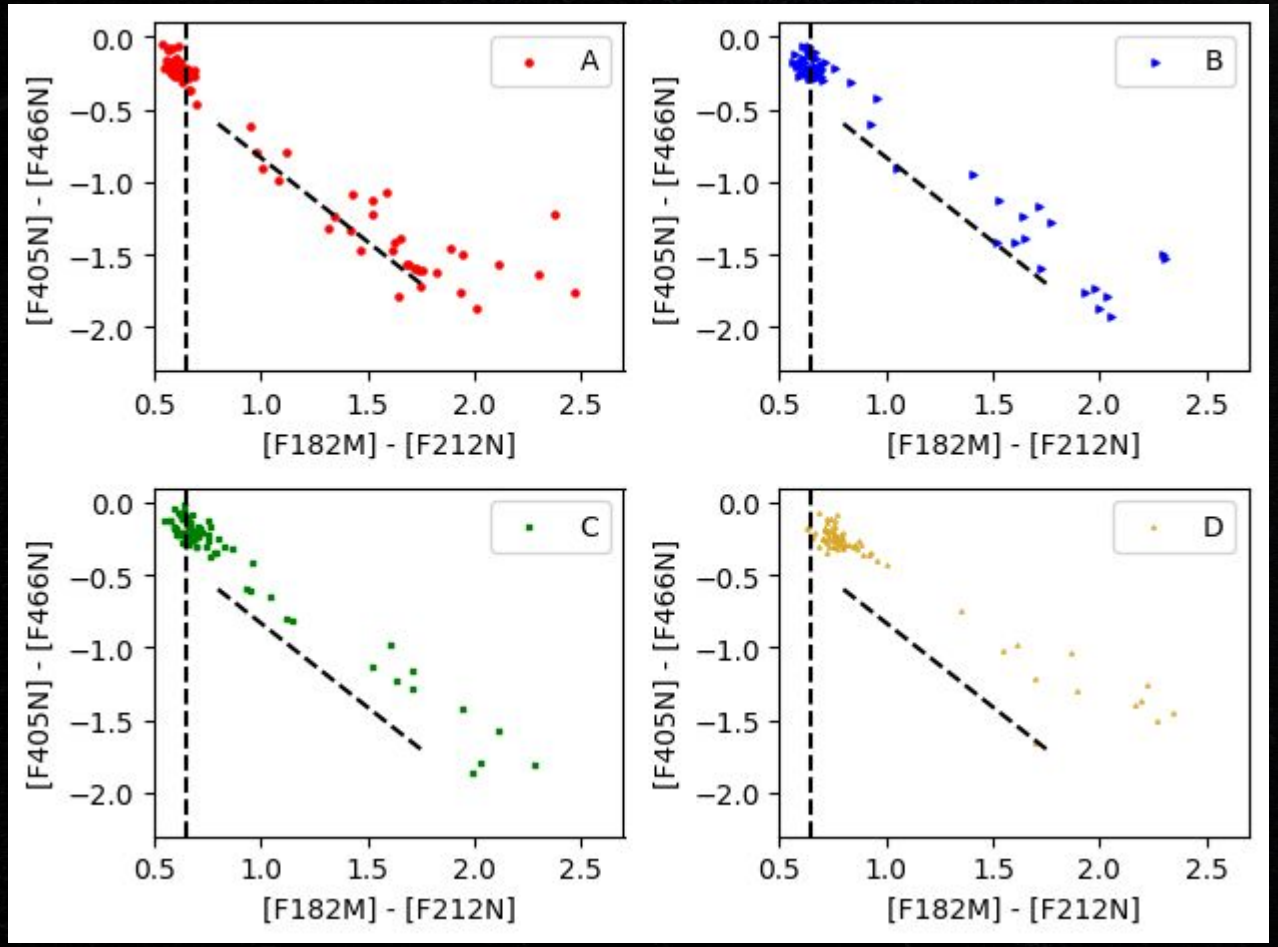
Comparing Dust Ridge Clouds



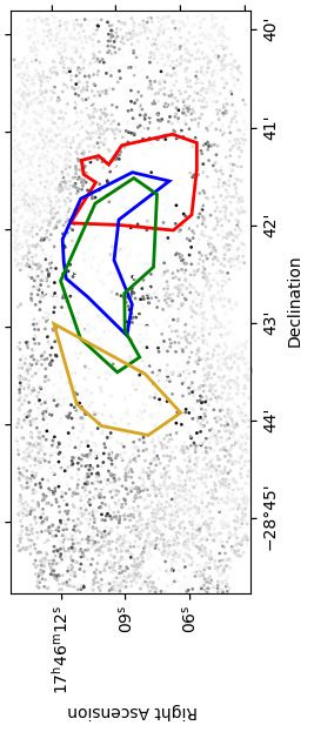


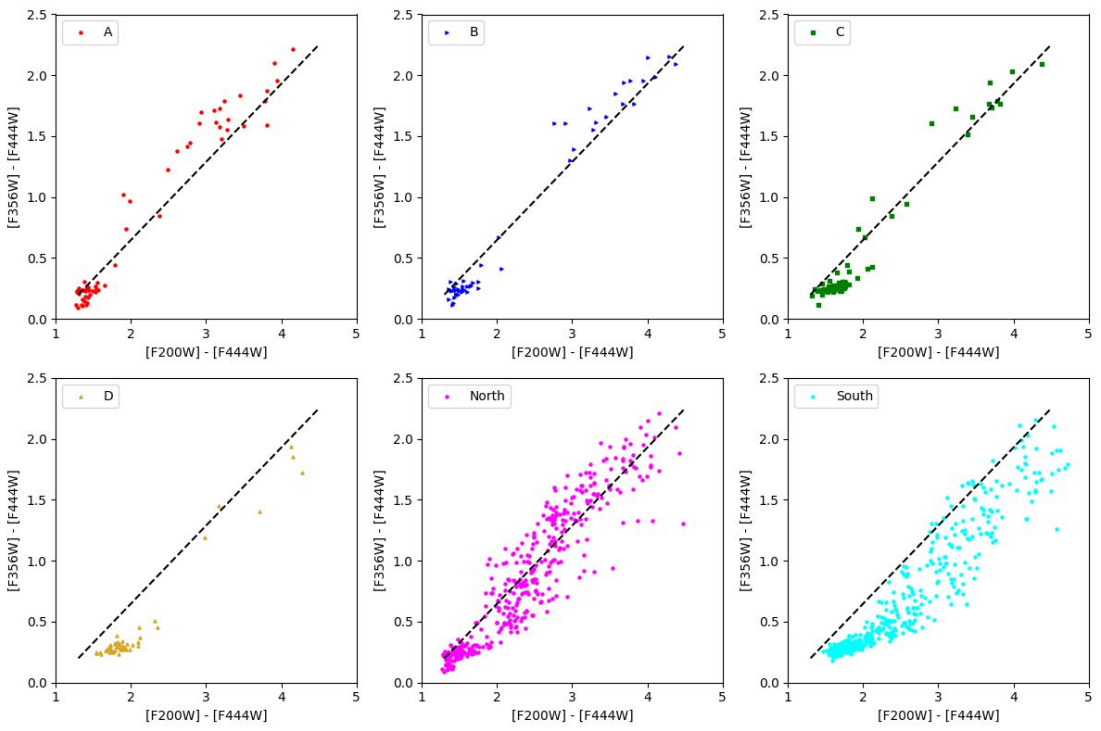

40'
41'
42'
43'
44'
−28°45'
Declination
17h46m12s
09s
06s
Right Ascension

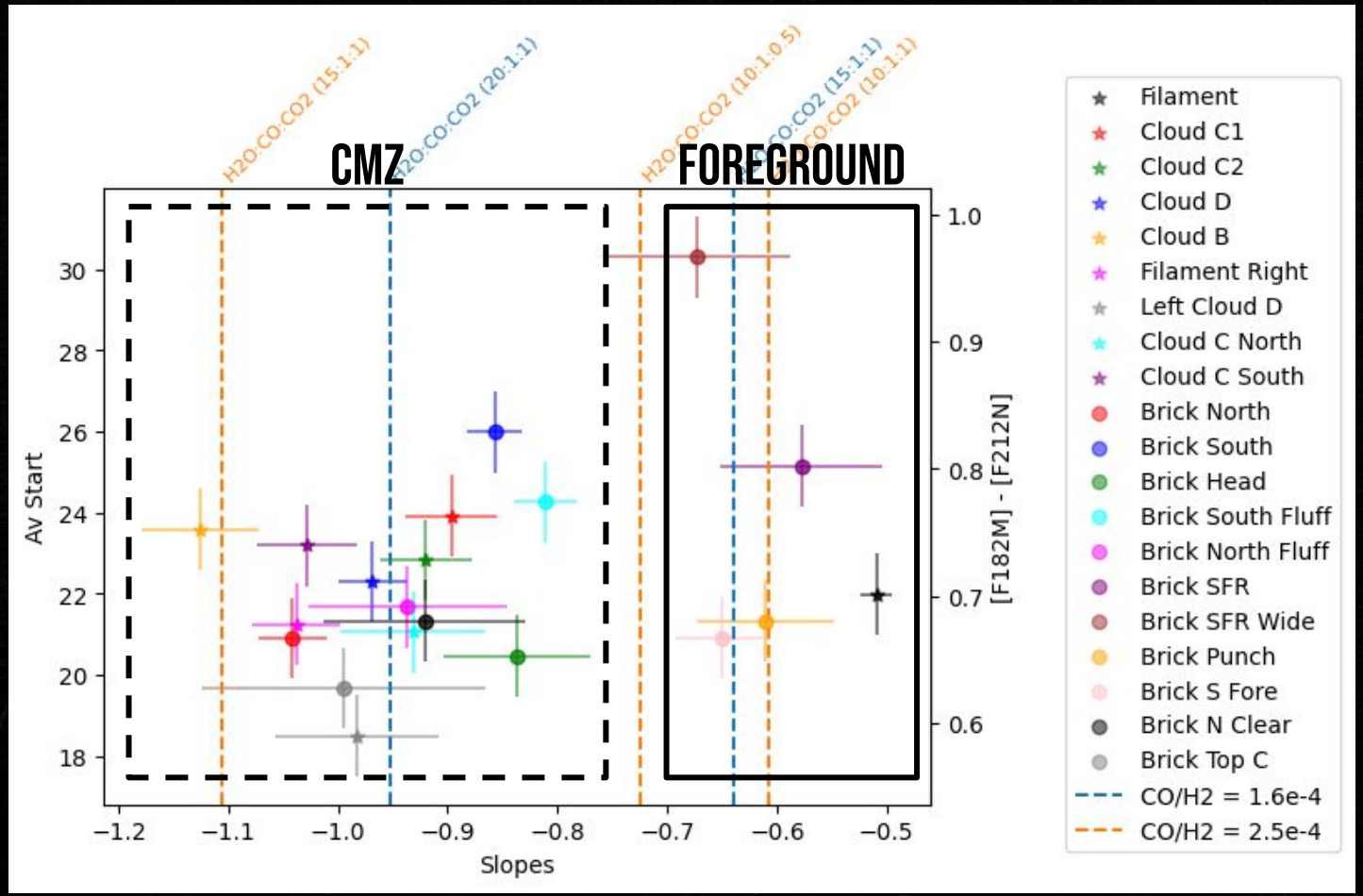
THE BRICK


A
B
C
D
[F405N] - [F466N]
[F182M] - [F212N]
0.0
−0.5
−1.0
−1.5
−2.0
0.5
1.0
1.5
2.0
2.5

CH_3OH Ice Variation






CMZ
FOREGROUND
H2O:CO:CO2 (15:1:1)
H2O:CO:CO2 (20:1:1)
H2O:CO:CO2 (10:1:0.5)
H2O:CO:CO2 (15:1:1)
H2O:CO:CO2 (10:1:1)
Av Start
Slopes
[F182M] - [F212N]
Filament
Cloud C1
Cloud C2
Cloud D
Cloud B
Filament Right
Left Cloud D
Cloud C North
Cloud C South
Brick North
Brick South
Brick Head
Brick South Fluff
Brick North Fluff
Brick SFR
Brick SFR Wide
Brick Punch
Brick S Fore
Brick N Clear
Brick Top C
CO/H2 = 1.6e-4
CO/H2 = 2.5e-4

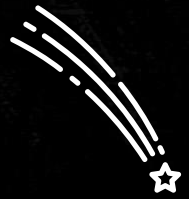
What Causes Ice Variation?

Gas Metallicity

But clouds in the same region of the Galaxy should have the same metallicity, right?

Ice Composition

But why would the ice composition change from cloud to cloud?



Chemical History

Could some clouds be chemically altered or “older” relative to other CMZ clouds?

Bar Lane Material Accreting onto the CMZ?

Conclusions

- ★ The CMZ is fed material from the bar.
- ★ Ice properties differ between CMZ clouds.
- ★ Could this variation be explained by sporadic accretion of bar lane gas?