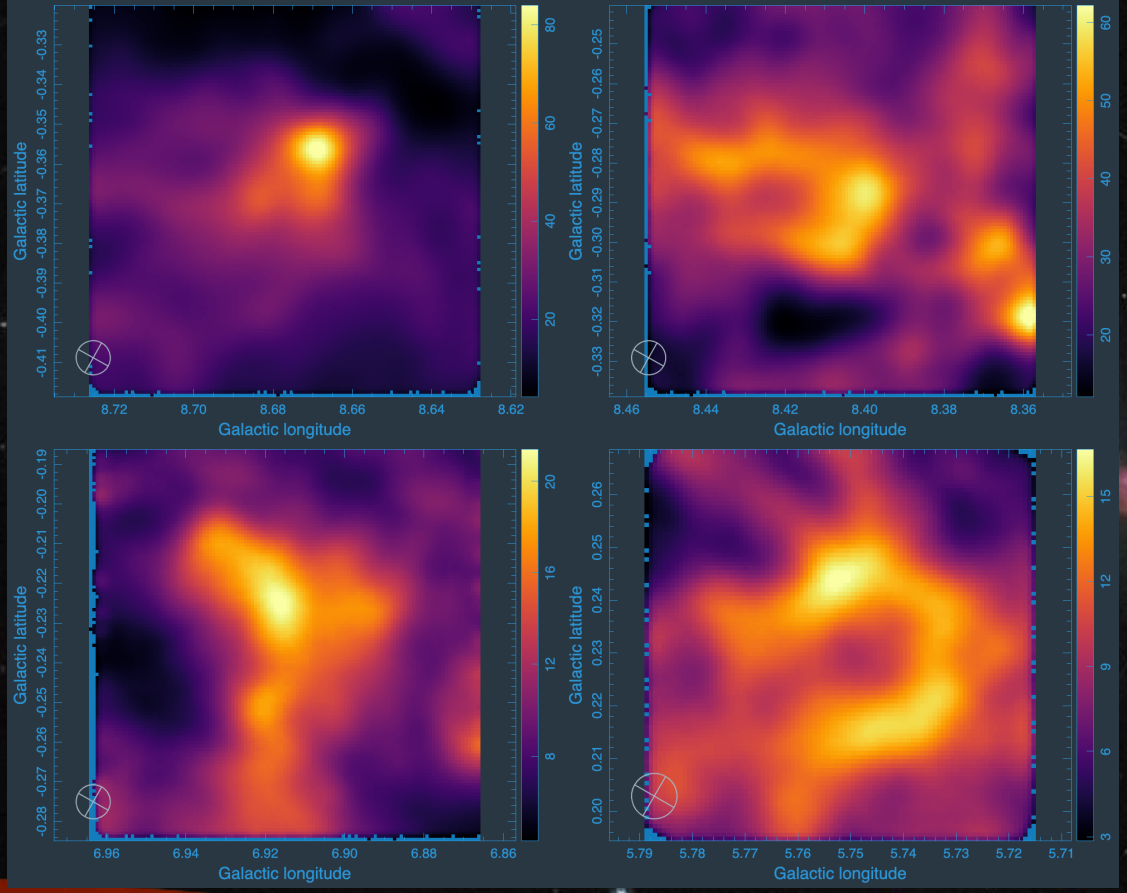
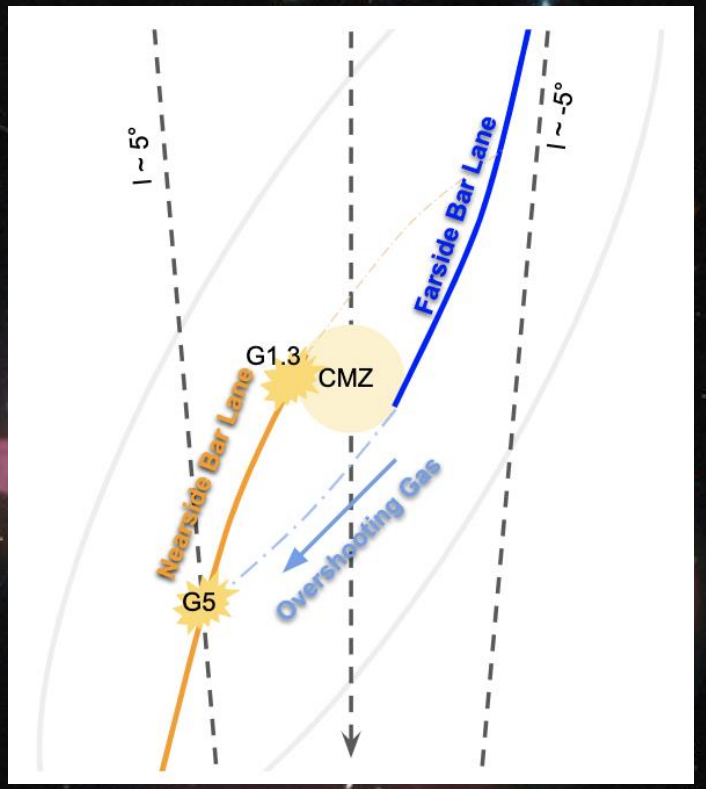




Energized Clouds in the Milky Way Bar: Overshooting, Colliding, and Accreting Gas

Juergen Ott

John Bally's Fundamental Galactic Center Work; also linking Galaxy to extragalactic universe, and the disk to the Center

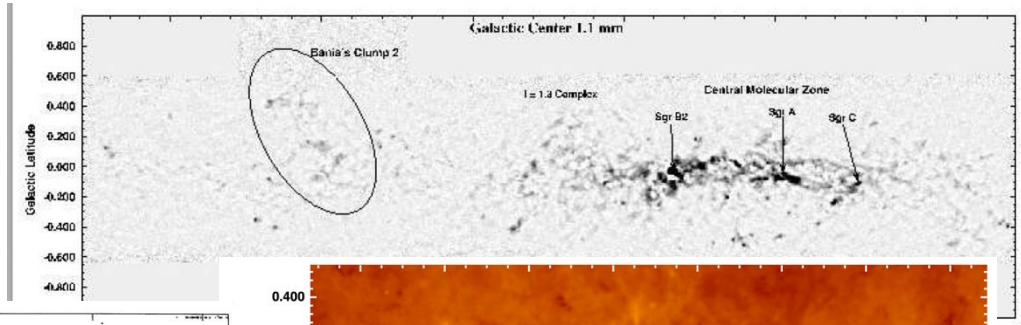
gas + dust content

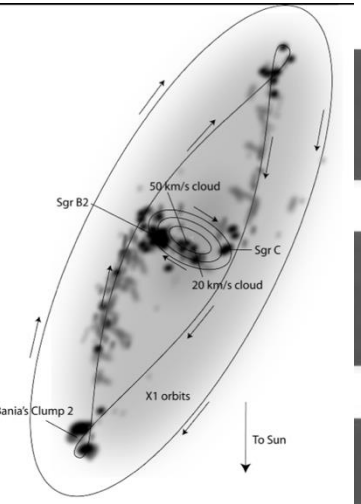
Temperature distribution

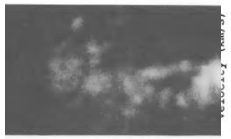
Energetic sources; feedback

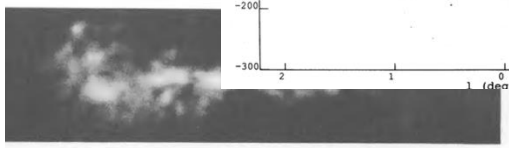
Star formation properties

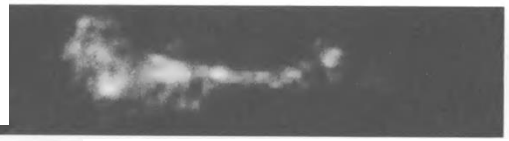
3D models

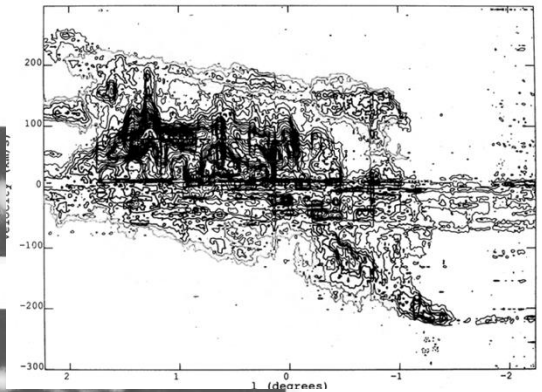


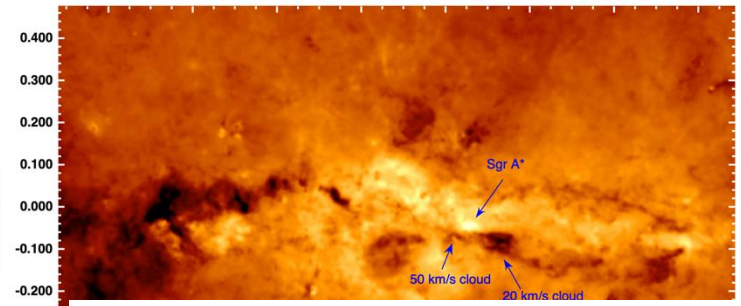


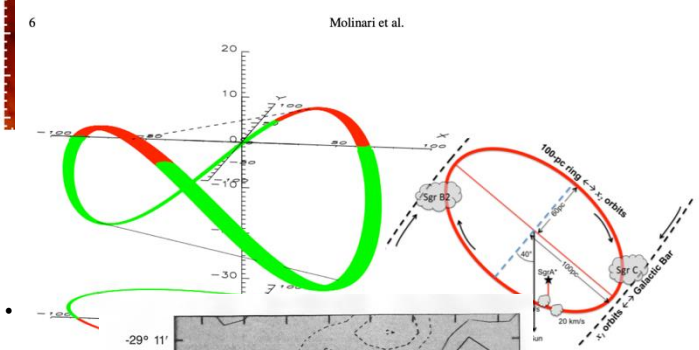




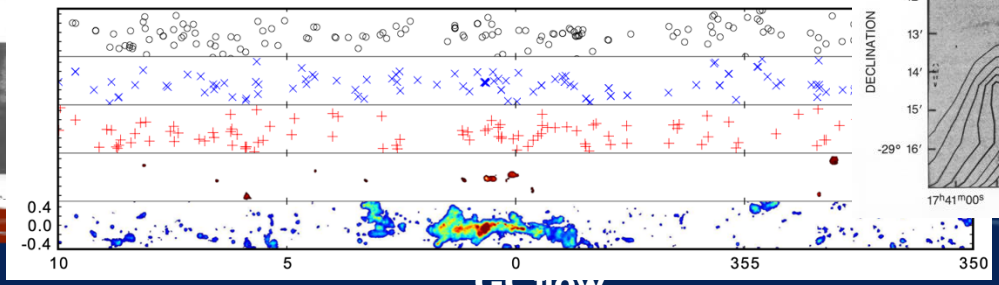


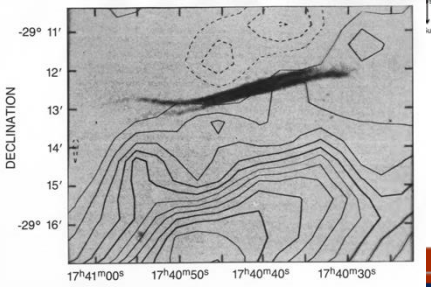






.. and much much more…



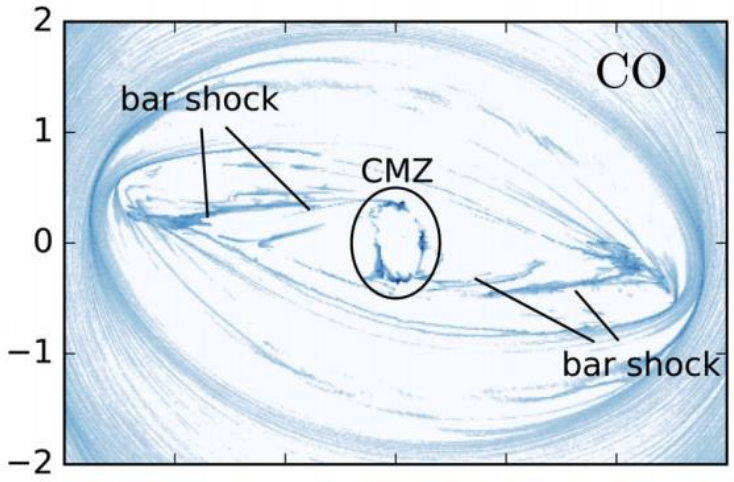


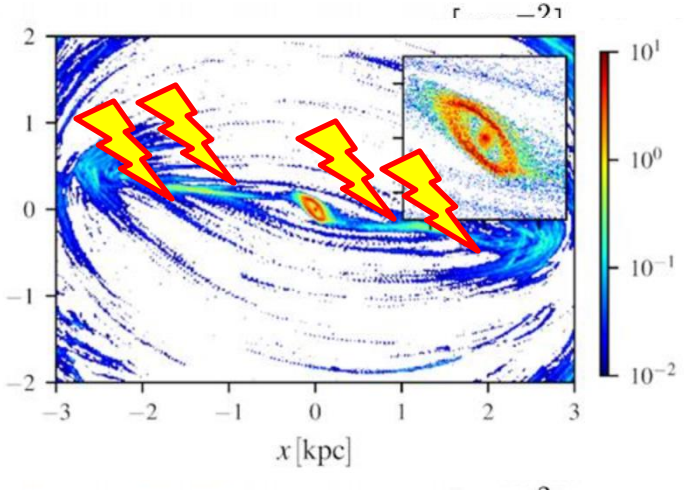
GCflow

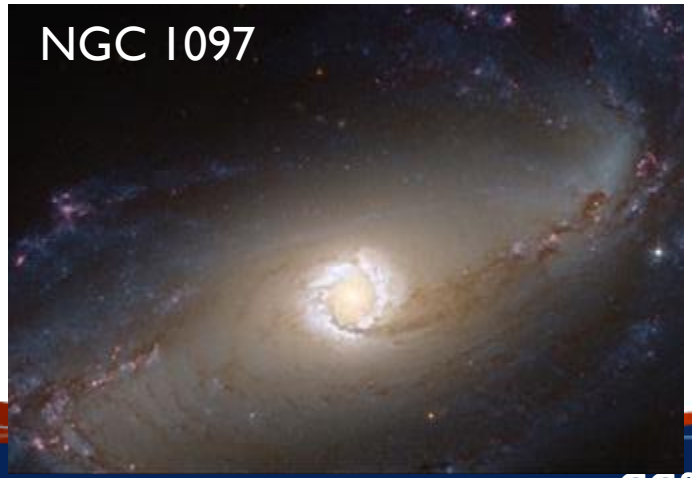
Gas Flows in Bar Potentials

Bar potential x_1 orbits, start self-intersecting → cloud-cloud collisions → formation of dust lanes ('bar shocks') → instability form inner ring close to x_2 orbits (Sormani+ 2018, Tress+ 2020, 2022, Hatchfield+ 2021…)

~50%(?) of accreting material overshoots … and eventually re-accretes..



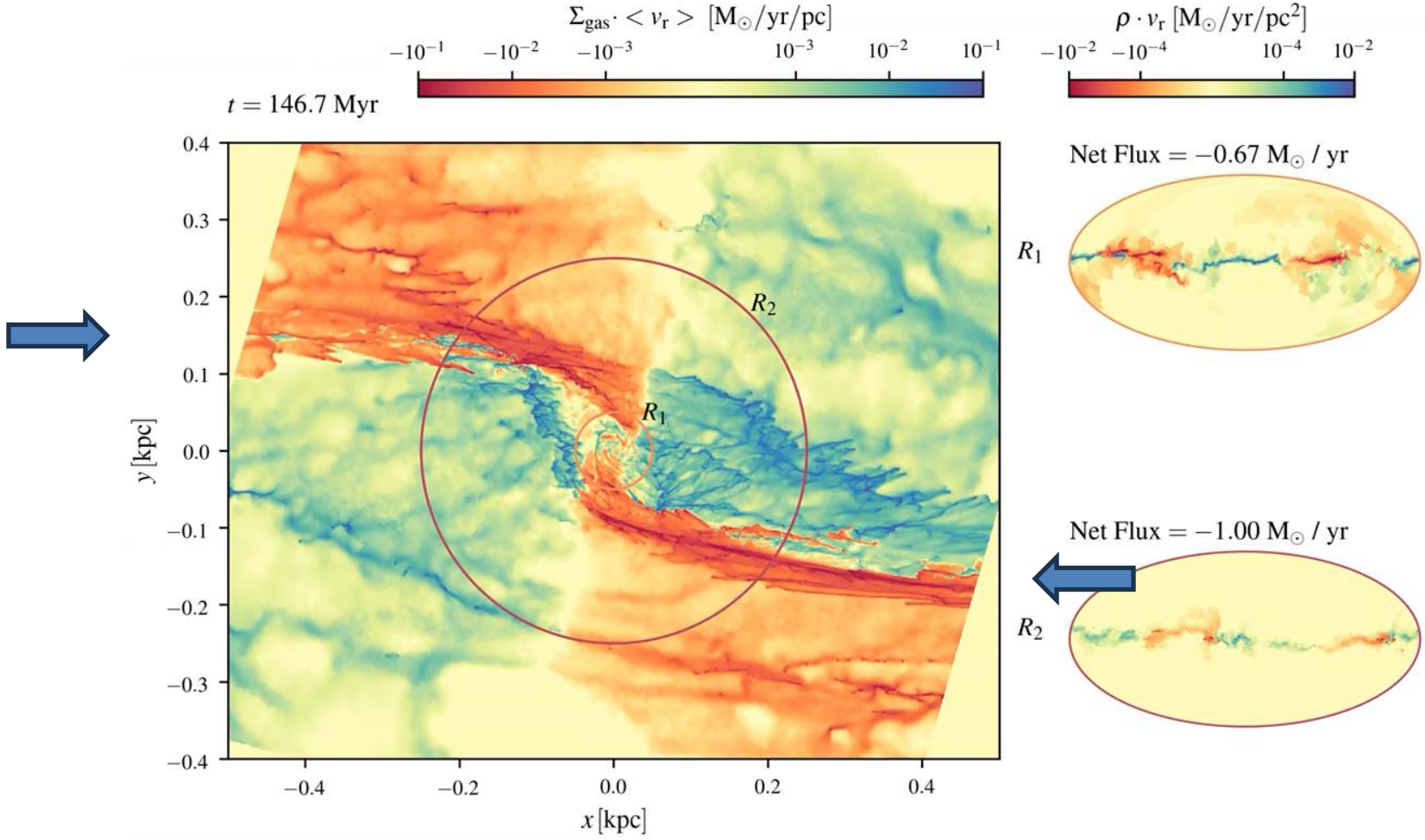




Observed in nearby face-on barred galaxies; difficult to confirm and detail this scenario in the edge-on Milky Way

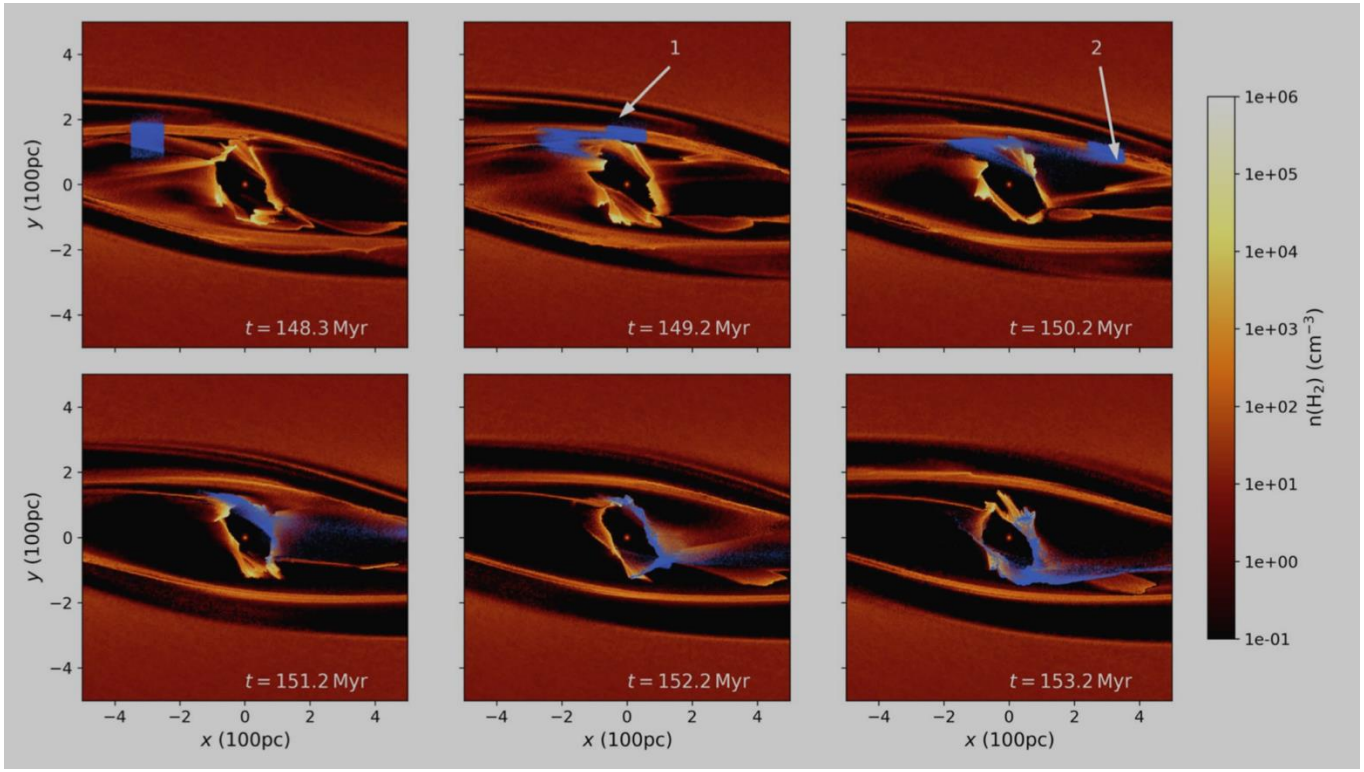
Gas Flows from the disk to the CMZ

Simulation: Tress, Sormani+; Sormani, Tress+ 2020



Gas Flows in Bar Potentials

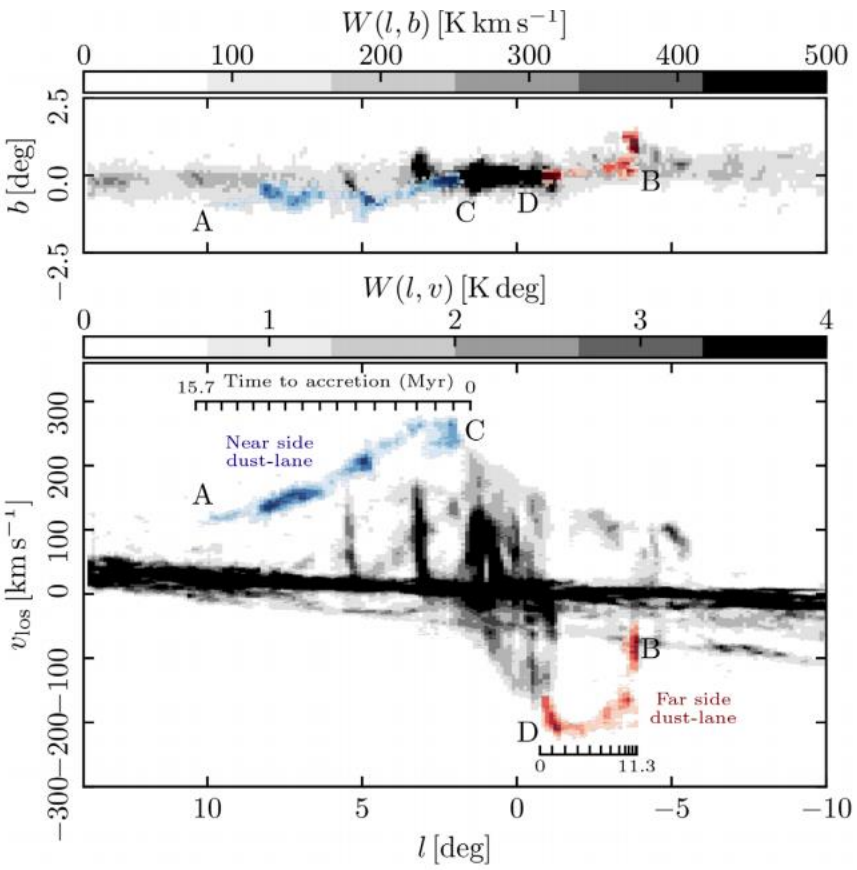
Hatchfield+ 2021

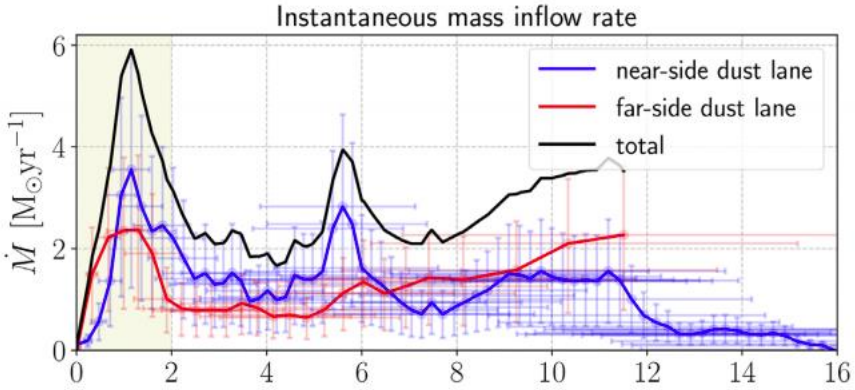


Violent accretion on the CMZ, but also by the overshooting material along the bar.
Does the gas there resemble the CMZ gas before it accretes?
Temperature, Mach number, shock states, …
What are the star formation properties?
→ We are looking for non-dustlane velocities, and gas that has higher linewidths and temperatures.

Gas Flows from the disk to the CMZ

Gas flows from disk to CMZ: Based on CO, ~2.7M_o/yr, fairly symmetric from both sides, but episodic (Sormani & Barnes 2018)





t (Myr)

Some broad line regions are also visible that seem to connect the dust lanes and lower velocity gas

Gas Flows from the disk to the CMZ

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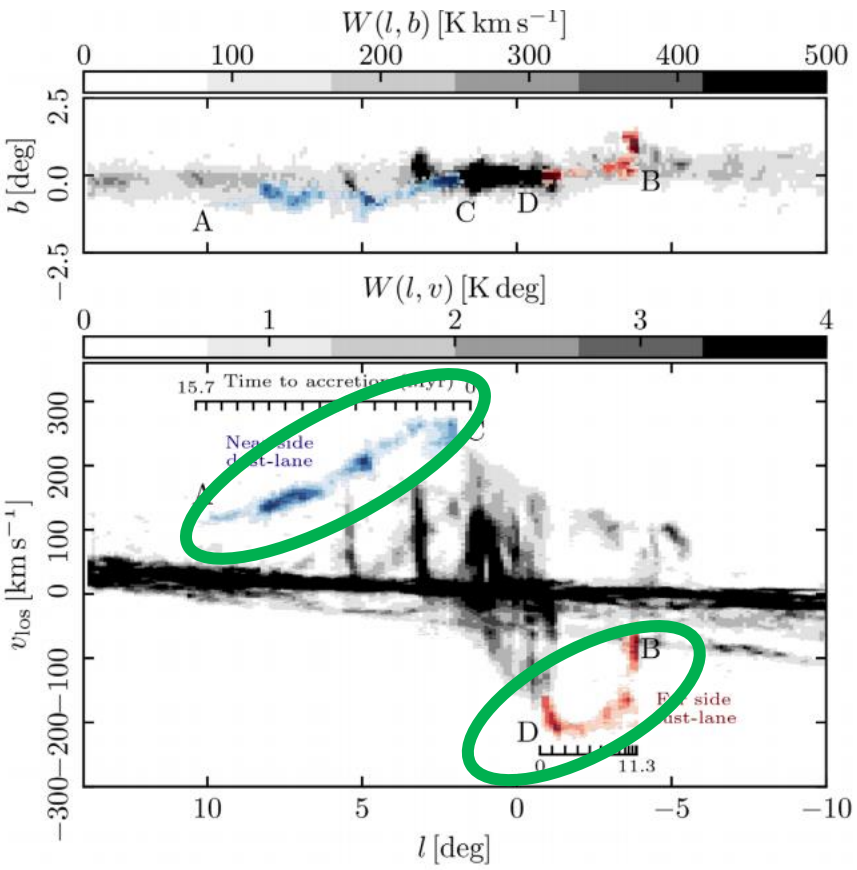

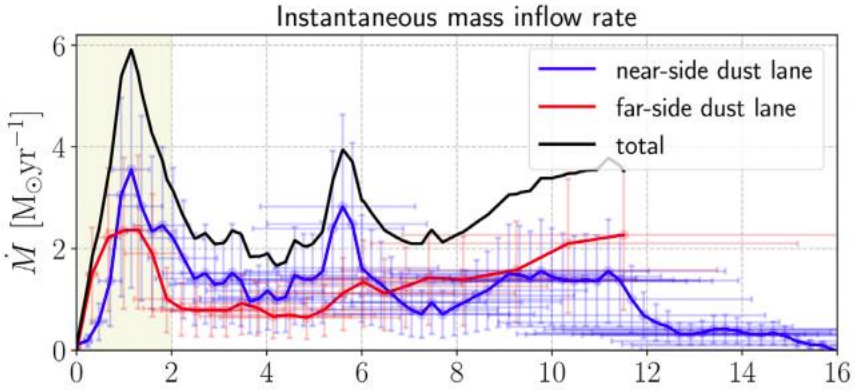

t (Myr)

Dust Lanes: BARFLY GBT survey
Butterfield et al.

Gas Flows from the disk to the CMZ

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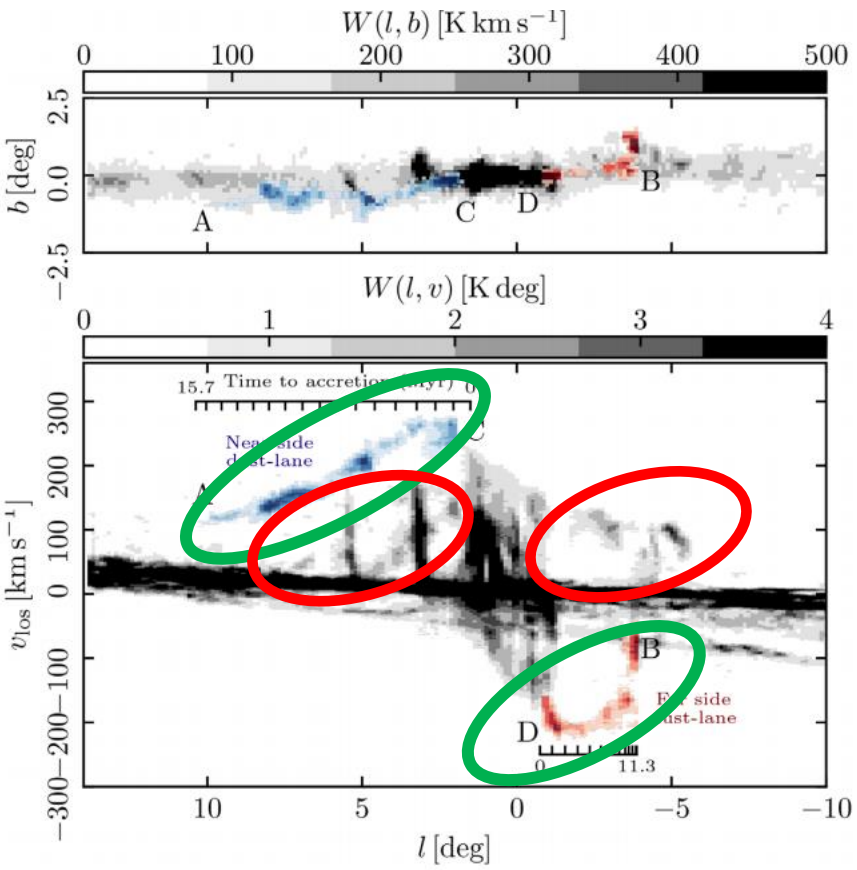
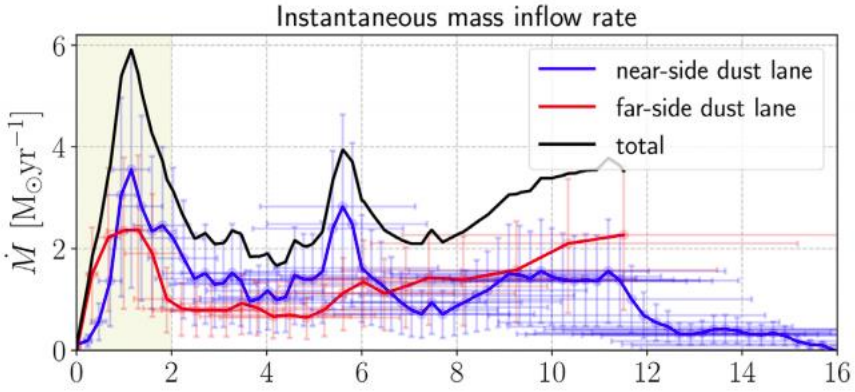




Dust Lanes: BARFLY GBT survey
Butterfield et al.

High Velocity/Non-Dust Lane Clouds:
This work

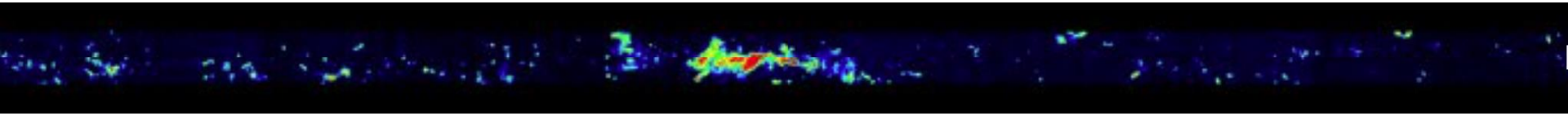
Gas Flows from the disk to the CMZ

Our approach: if the gas is on non-dustlane orbits, it should have experienced shocks → larger linewidths, higher temperatures, shock tracer (liberation of molecules and destruction of grains)

Search for warm, hot and turbulent gas with HOPS ("The H_2O Southern Galactic Plane Survey") data: Mopra Single dish survey in H_2O, NH_3 and other molecular lines (Walsh et al. 2011; Purcell et al. 2012; Longmore et al. 2017)

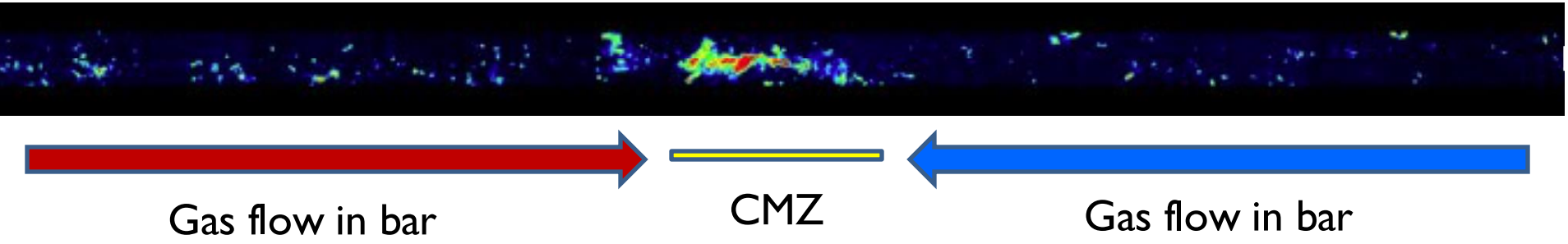
H_2O: relatively uniform distribution, YSOs and AGB stars in the CMZ but also across the entire MW disk

NH_3 (1,1): accumulation of (dense) molecular gas in the CMZ, scattered clouds



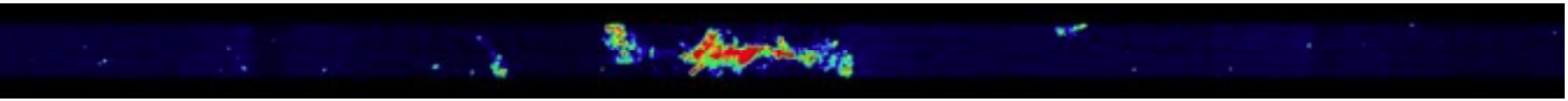
Gas Flows from the disk to the CMZ

NH_3 (1,1): accumulation of (dense) molecular gas in the CMZ

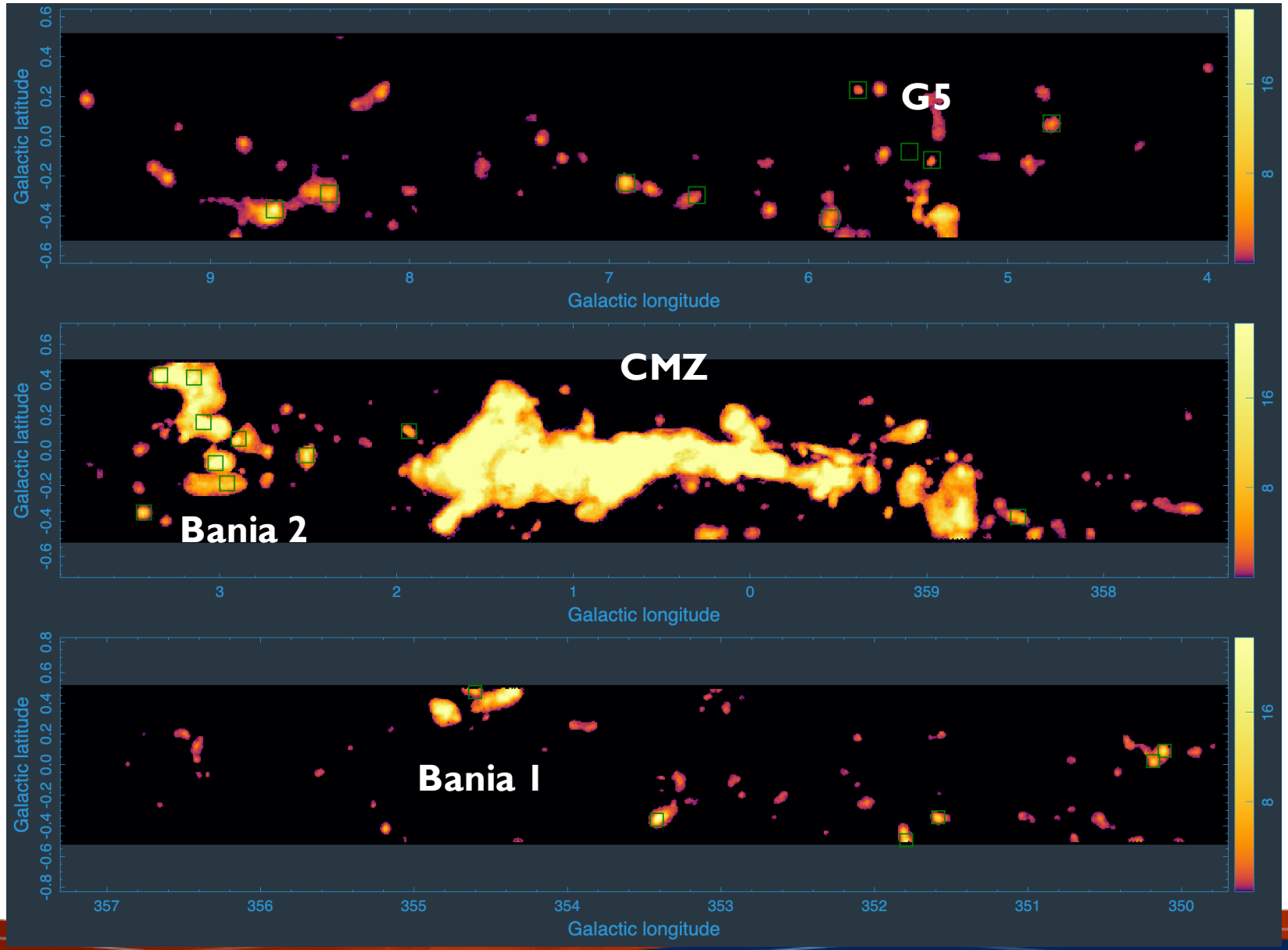


What gas is in the non-dustlane bar and what gas is in the MW disk across the line of sight?

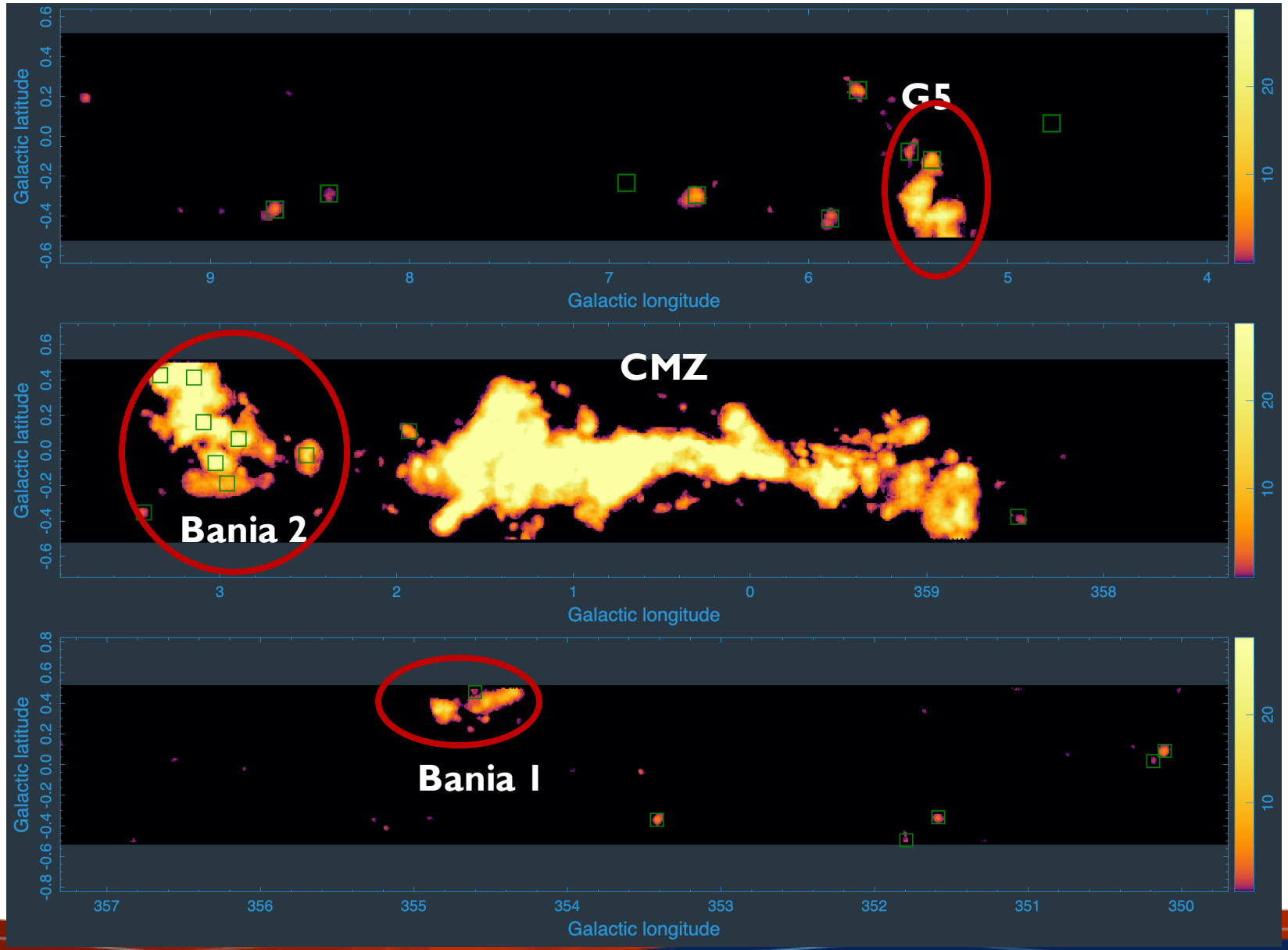
NH_3 (3,3): tracer of warm gas; (3,3) line also almost perfect correlation with large line widths: → gas properties similar to the CMZ, likely energized clouds in the gas flow



$NH_3(1,1)$: E=16K (para)



$NH_3(3,3)$: E=85K (ortho)



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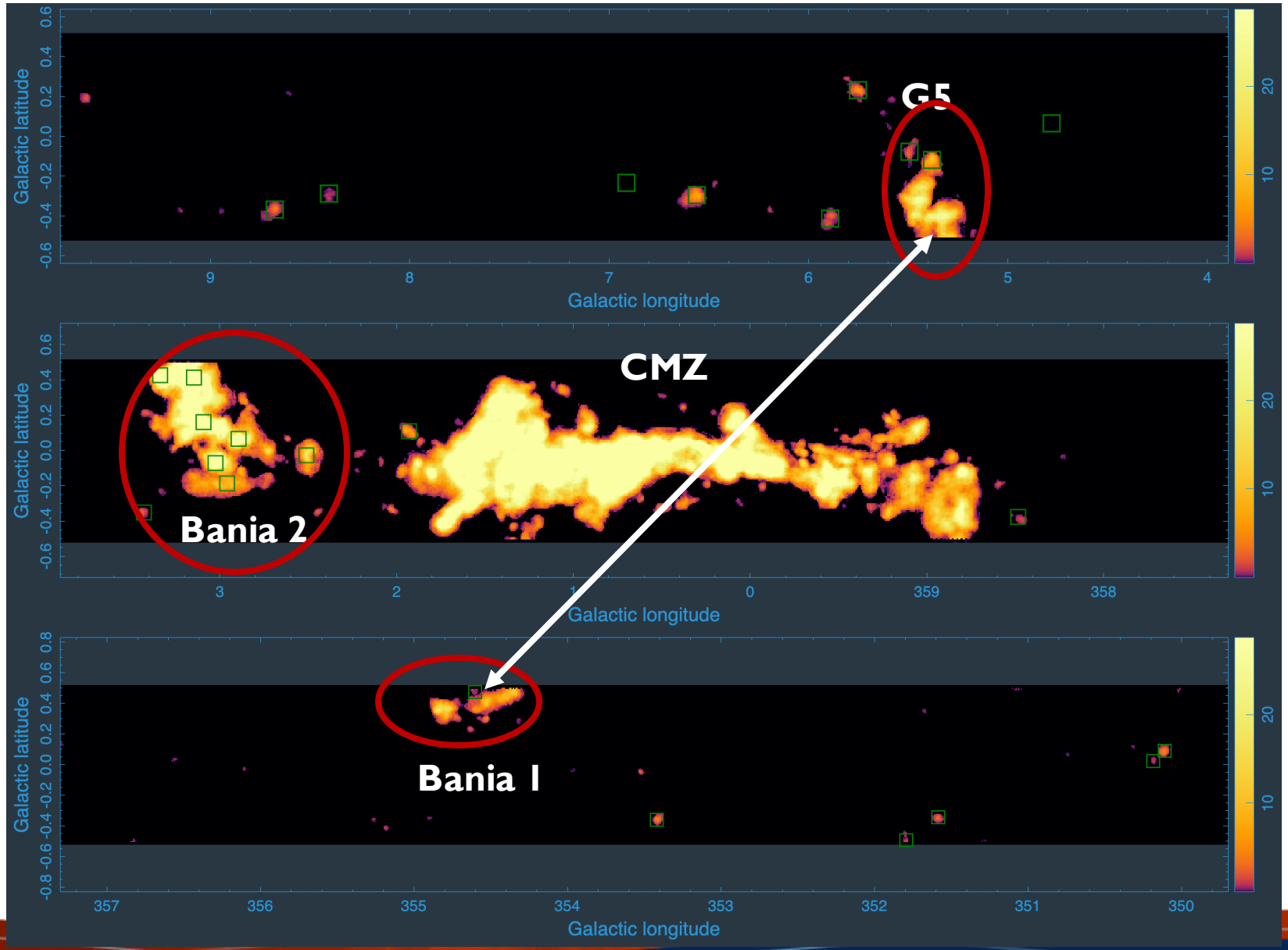
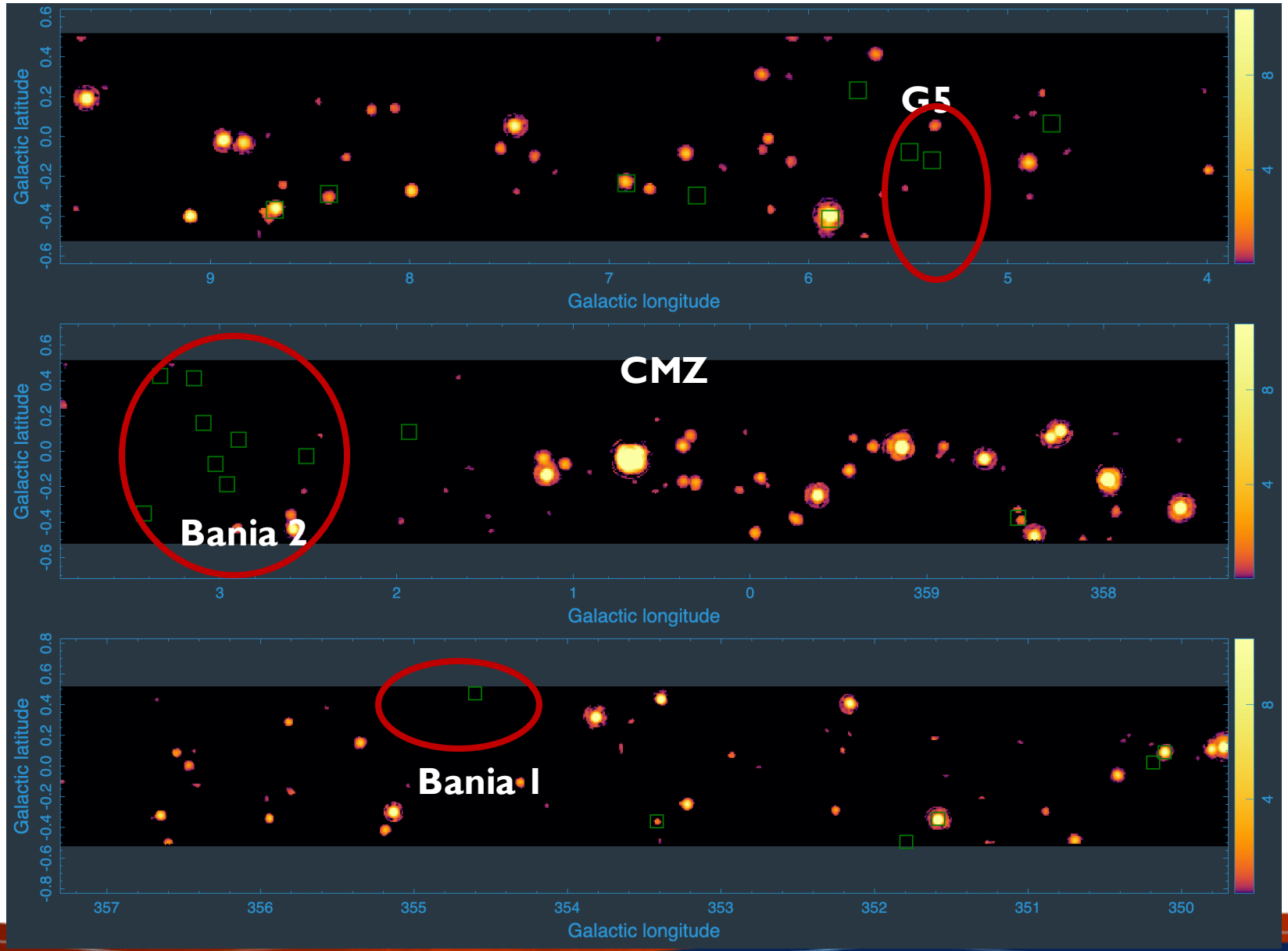


H_2O 22GHz maser: typically not correlated with these clouds (but mix of AGB and YSO)



Galactic Flow

ALMA ACA: TP+7m data

G5 and B1
25 5x5arcmin maps (some 3.5x3.5arcmin)

Band 6, 1mm

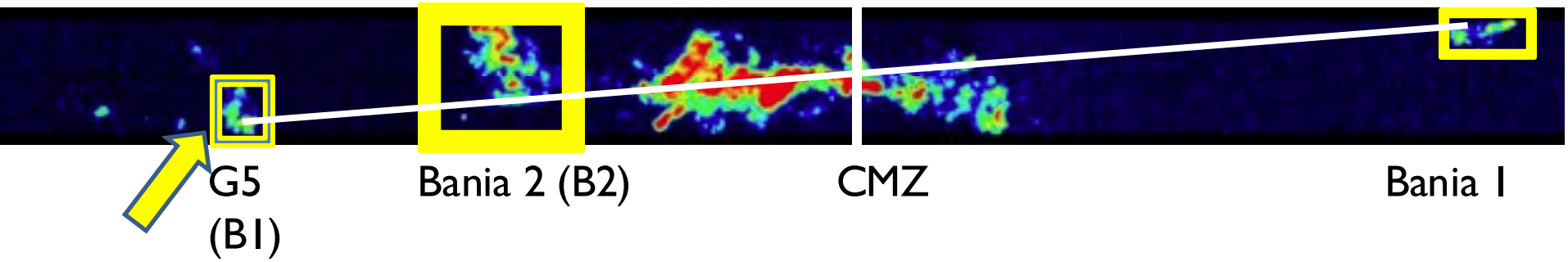
CO + isotopes → opacity tracers
Various H_2CO lines → Temperature tracer
HC_3N → excitation tracer
SiO → shock tracer
Methanol → weak shocks
H30a → SF /HII region
Continuum (dust)

ESO

G5

(Gramze, JO, D. Meier, A. Ginsburg, + 2023)

G5 and Bania1 are almost point symmetric +/-5.5° GLON +/-0.5° GLAT, but seem to have different properties. G5 shows a cloud-cloud collision



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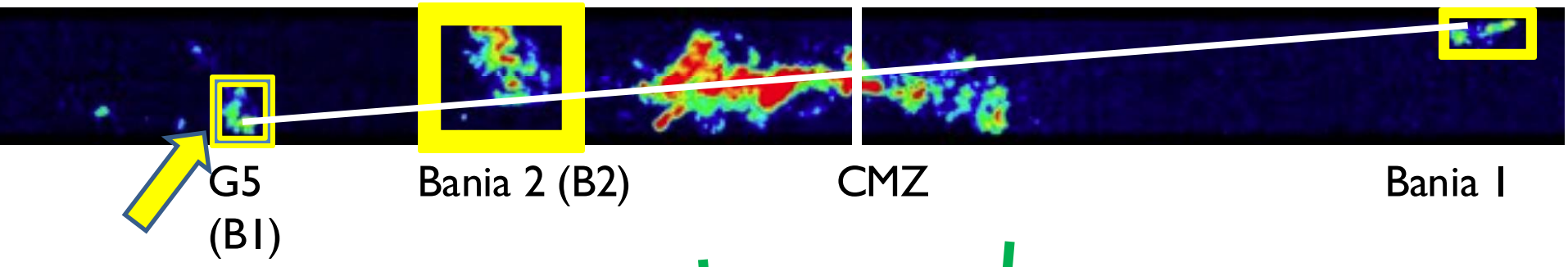
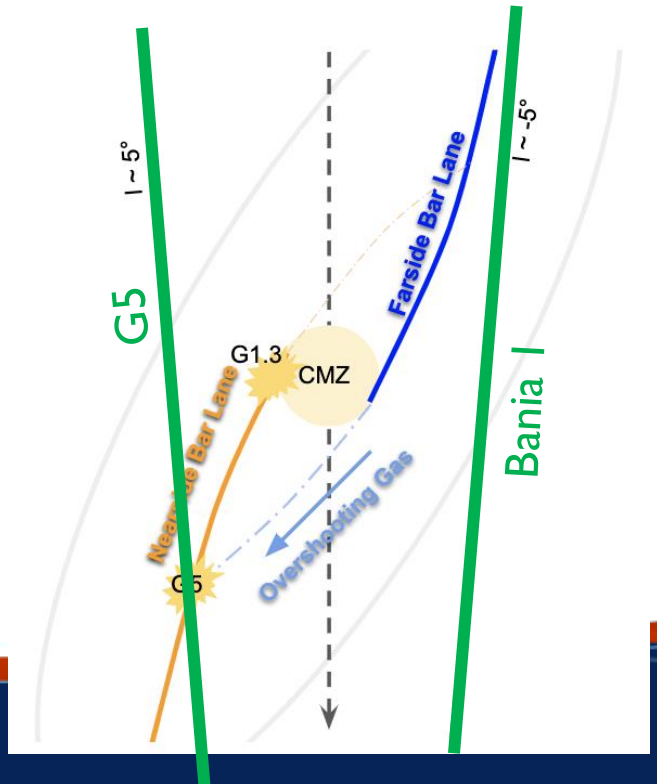


Point symmetry is still unexplained, maybe just a coincidence?



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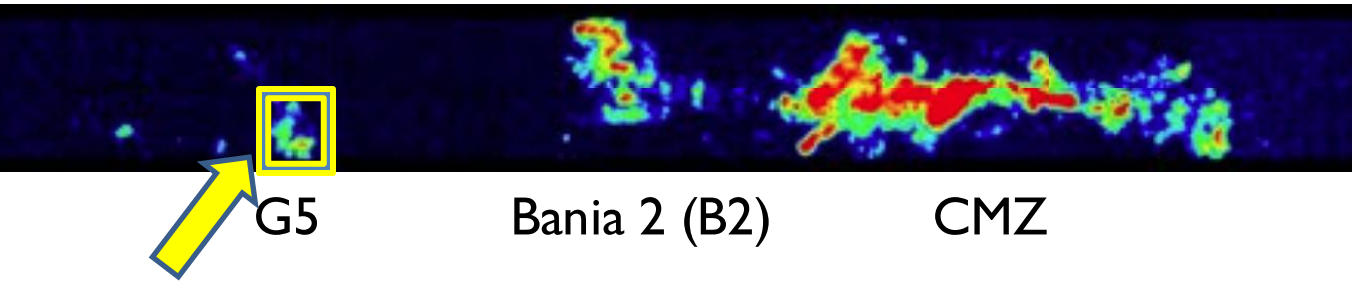
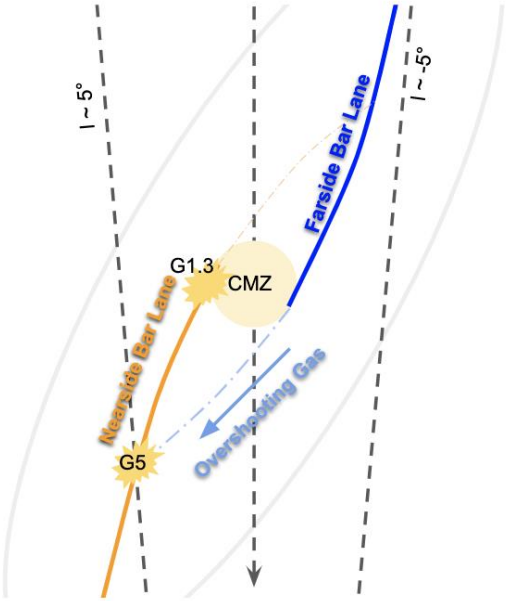
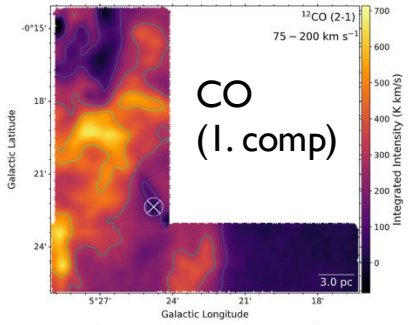
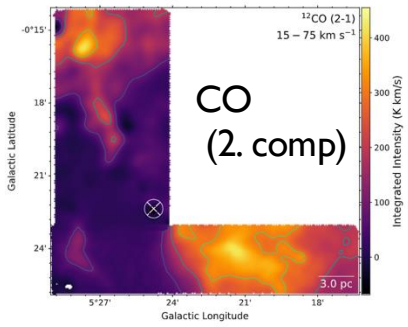






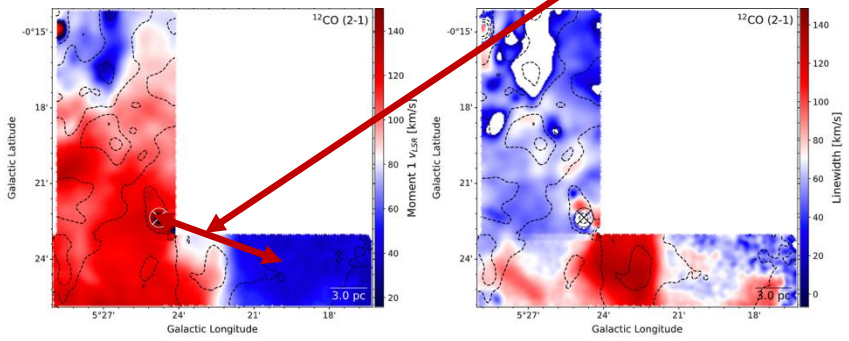


G5: high opacity, elevated T, shock tracer
Velocity gradient with bridge

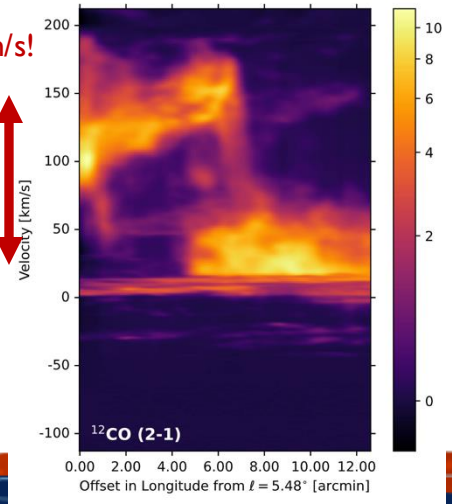
Δv=100km/s!

CO velocity field

CO velocity dispersion



CO position-velocity



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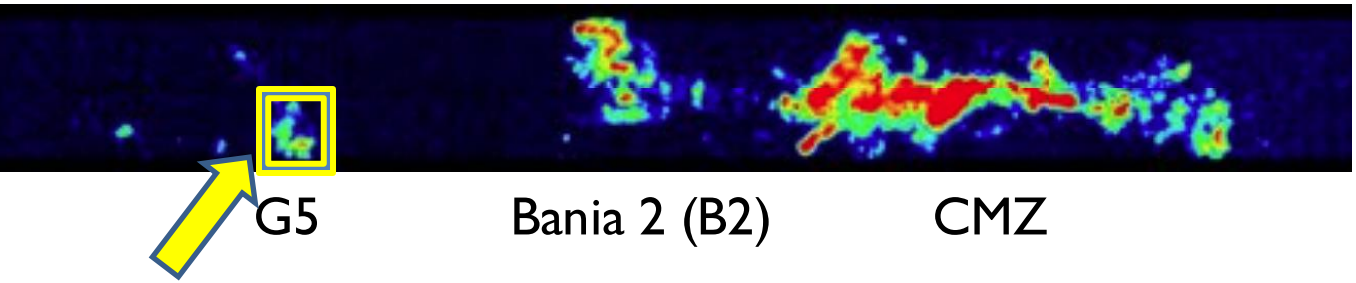
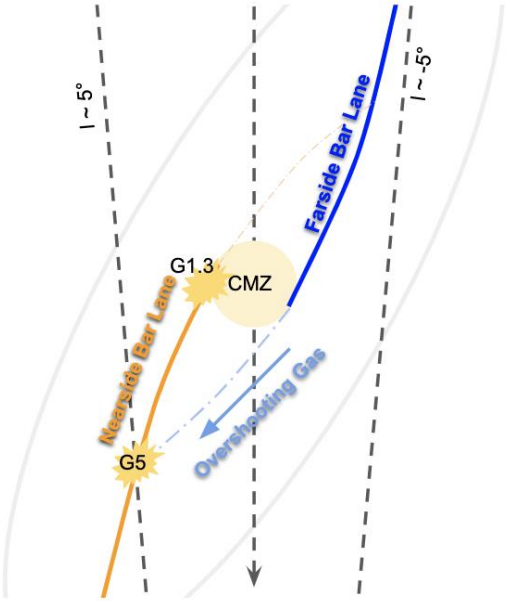
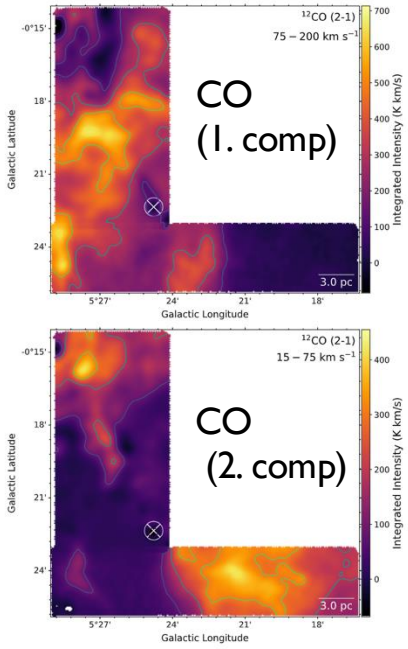


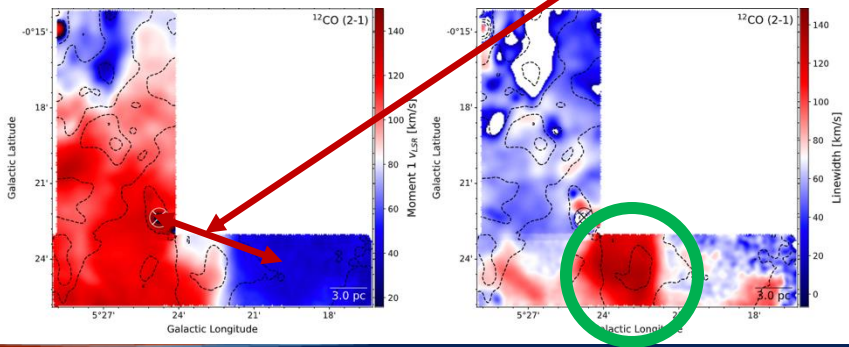




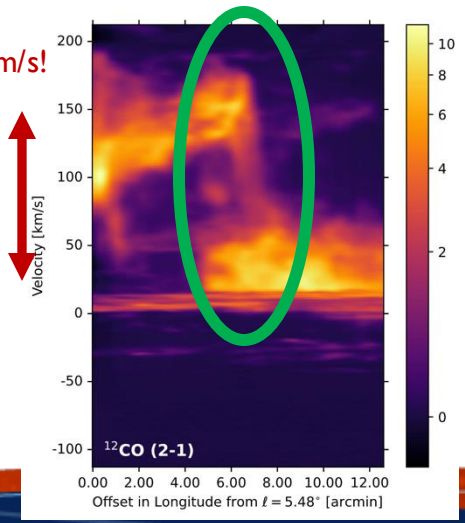
G5: high opacity, elevated T, shock tracer
Velocity gradient with bridge

CO velocity field

CO velocity dispersion



CO position-velocity



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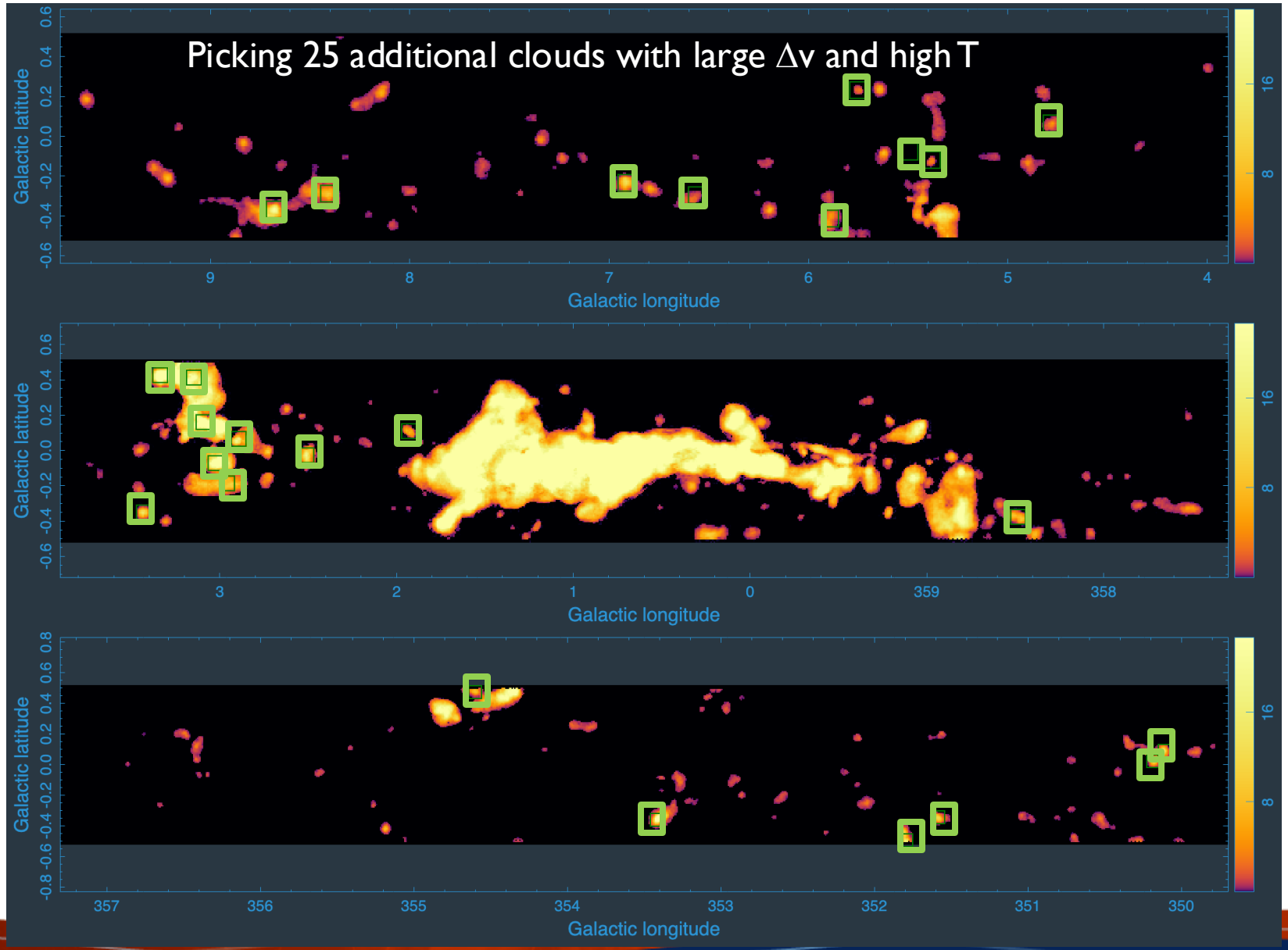

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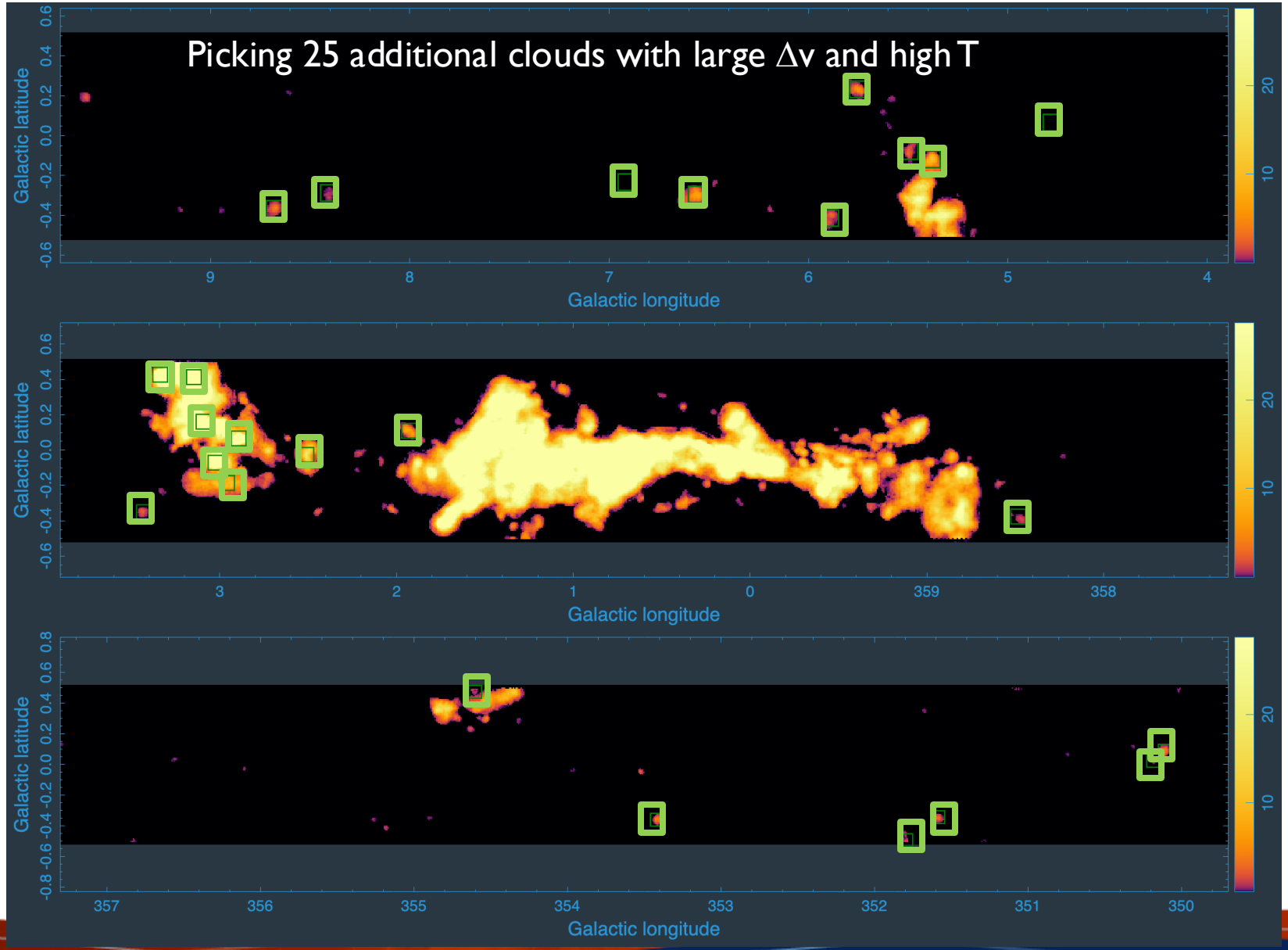
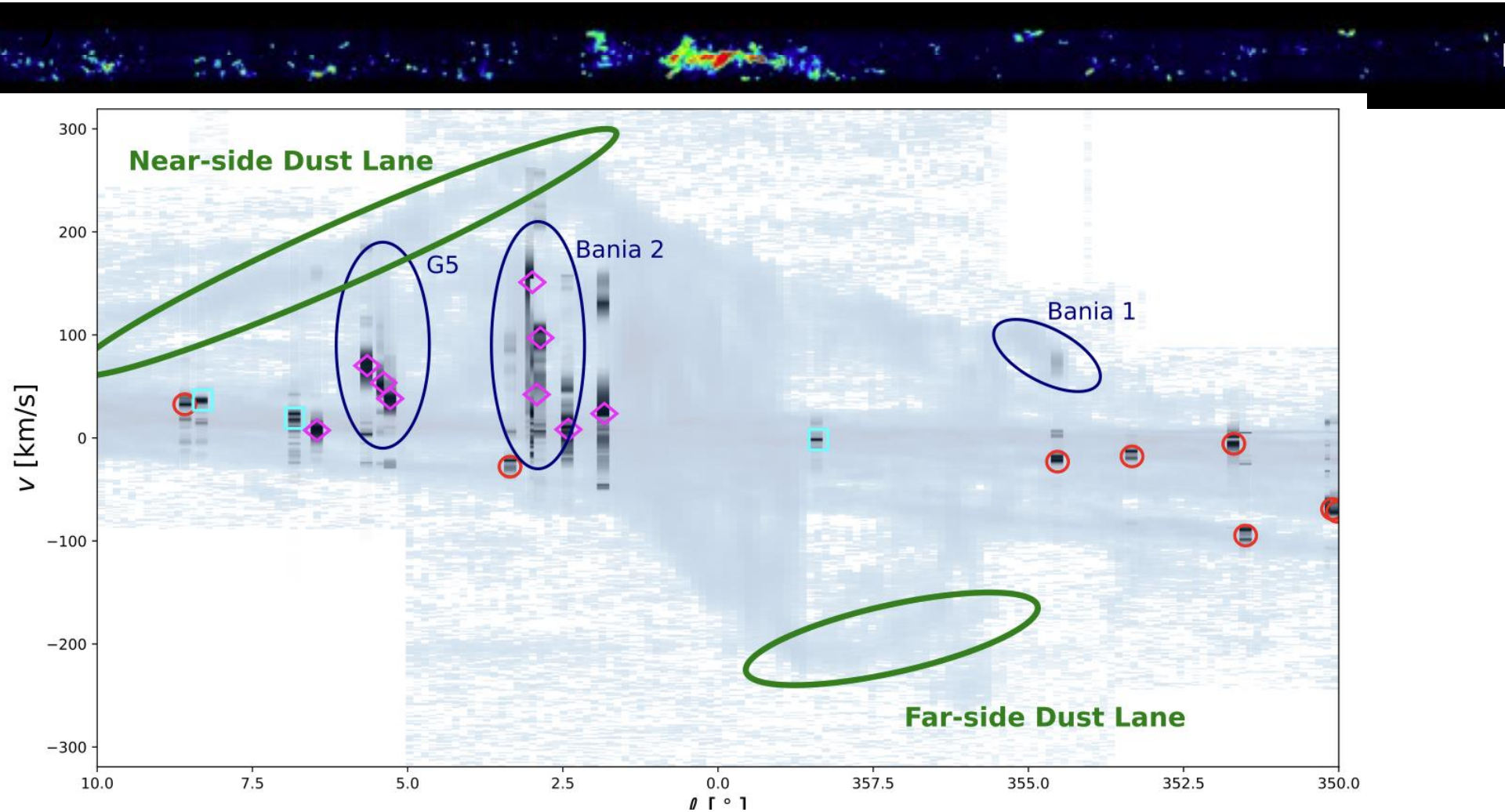


Clump gas properties (A. Nilipour, JO, D. Meier, + et al. 2024)

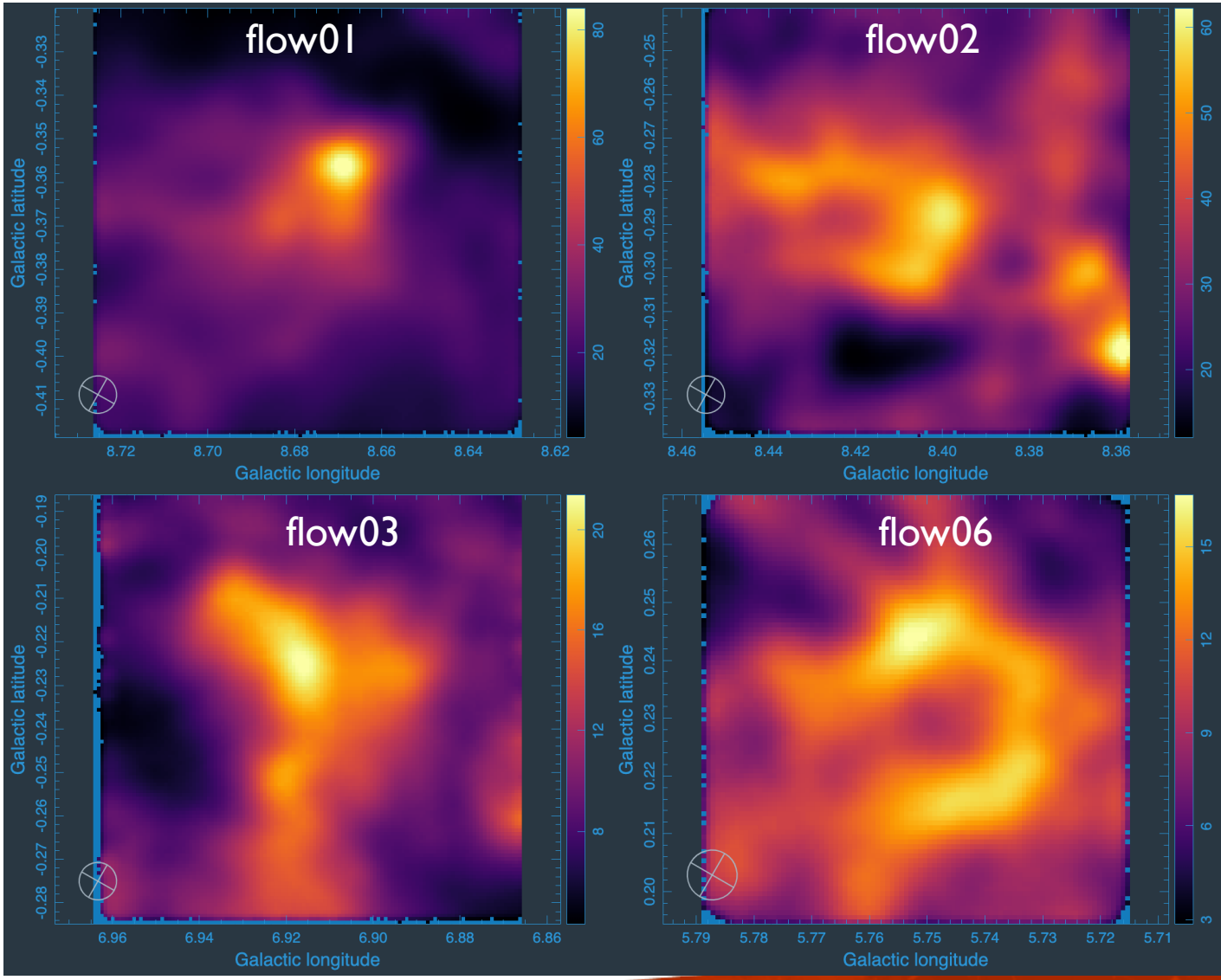


Galactic Flow

Different Structures:

Compact clumps
Ridges

Rings seem to be abundant in various tracers: indication of colissions?



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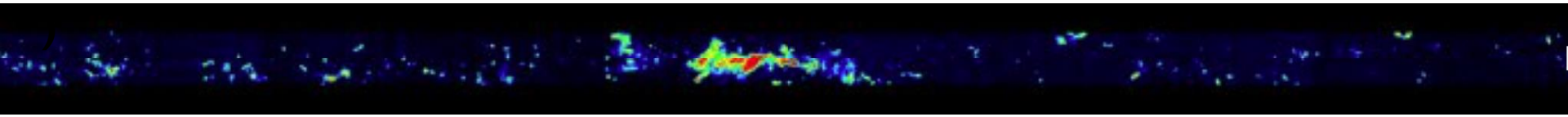
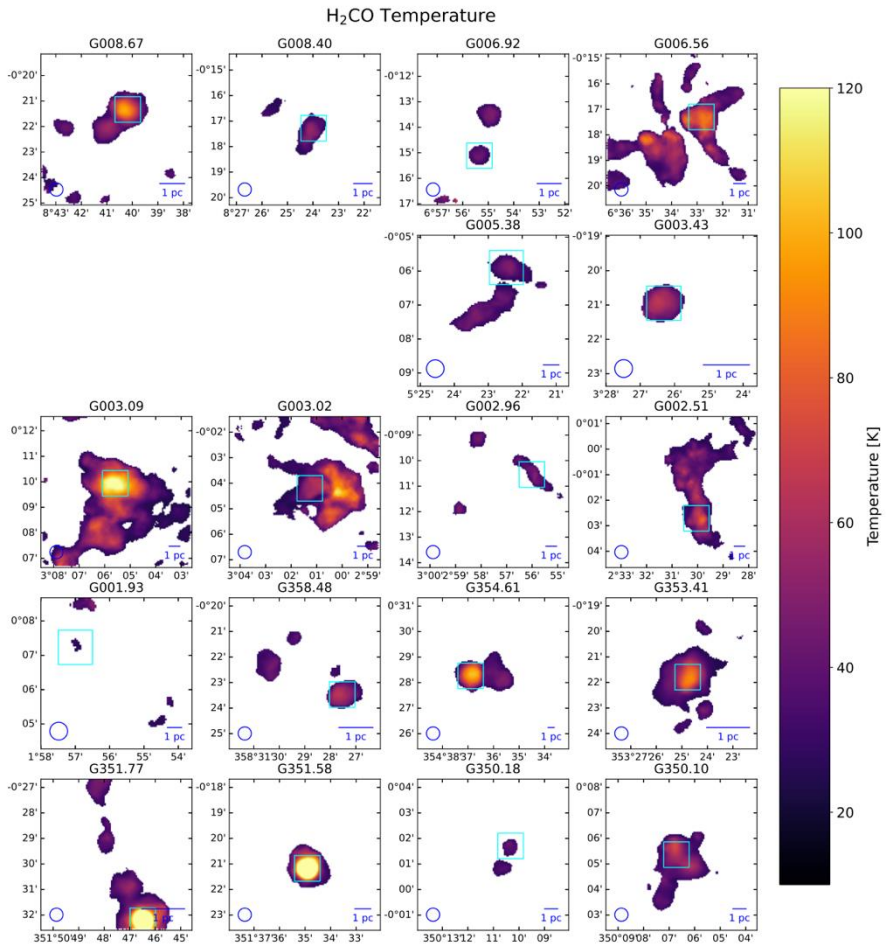
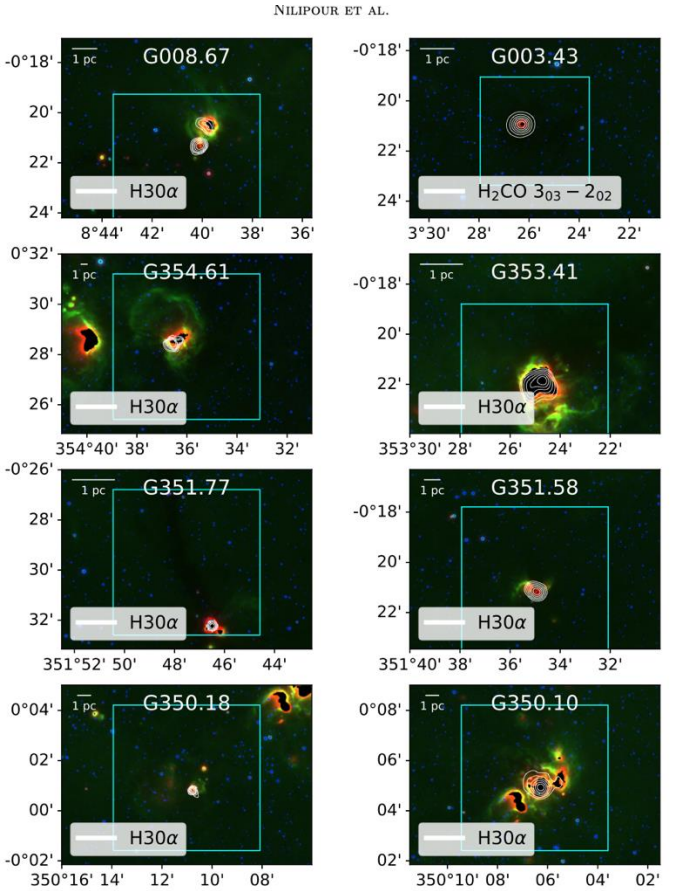
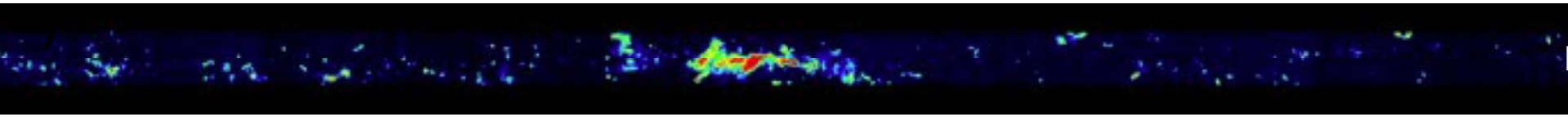


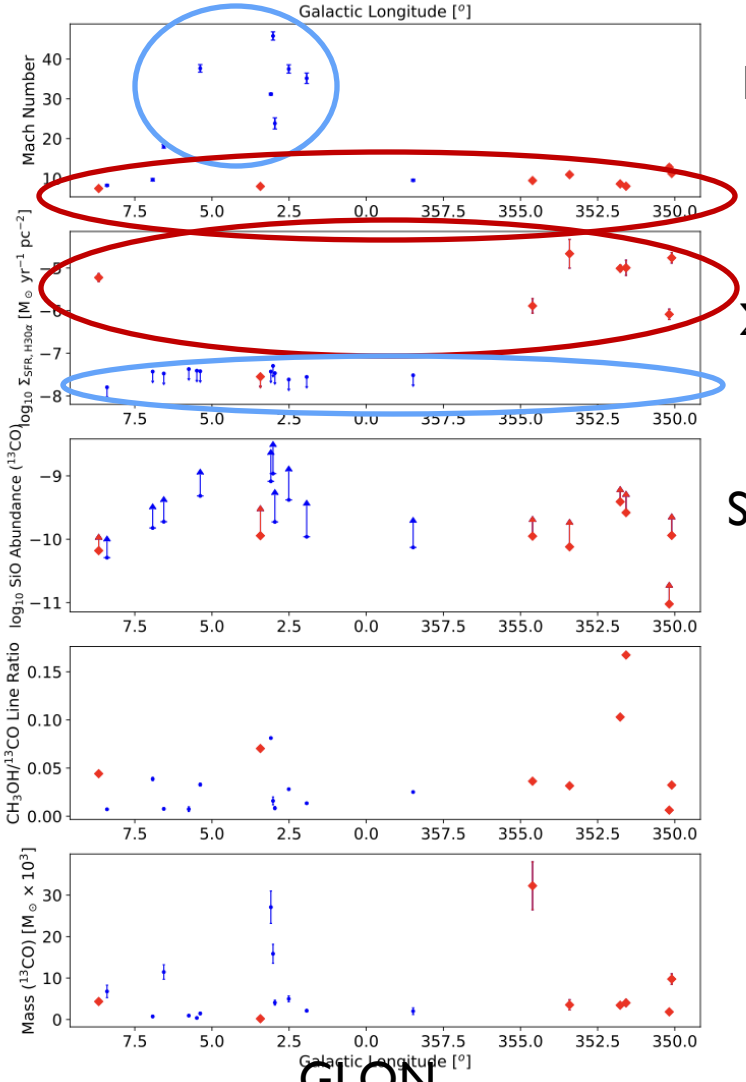


H30α and 24μm associated with some sources, but not all



Clump gas properties (A. Nilipour, JO, D. Meier, + et al. 2024)





Mach no

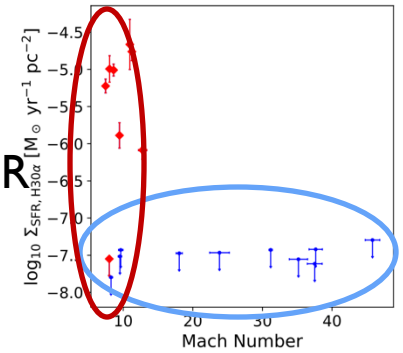
ΣSFR

SiO

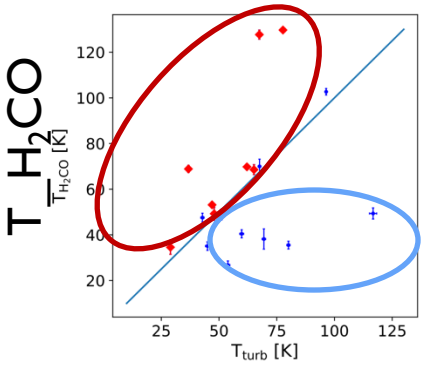
Methanol/CO

Mol. Mass

GLON



Mach no



T_turb

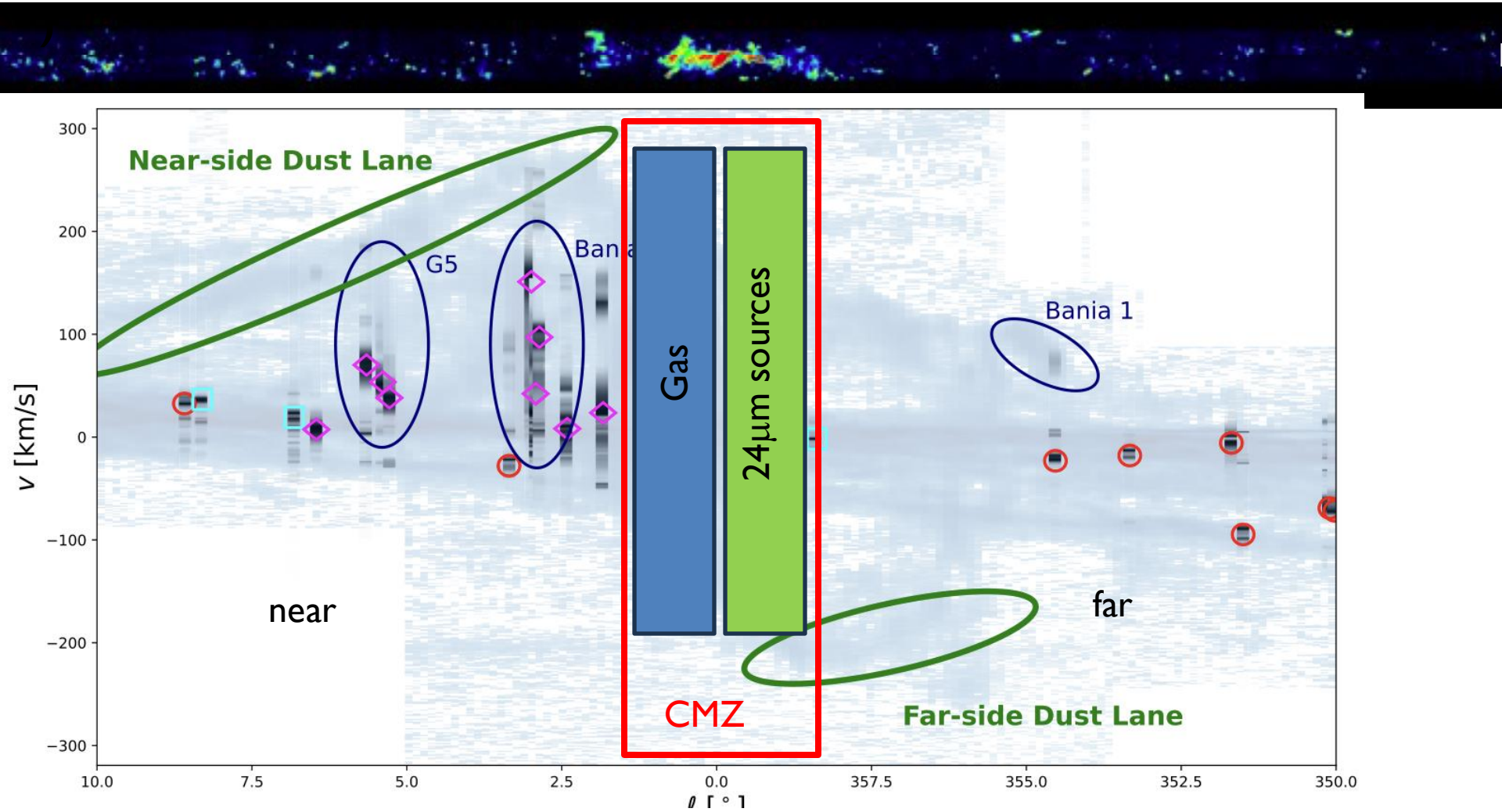
Red: star forming clouds (24μm)

- lower Mach numbers
- warmer in formaldehyde

Blue: non-star forming

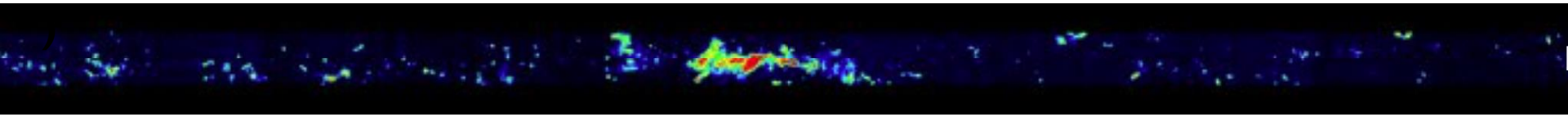
- higher Mach numbers
- warmer in turbulent temperature
- Lower X(CO) factor!

Clump gas properties (A. Nilipour, JO, D. Meier, + et al. 2024)



Is the CMZ asymmetry also reflected in the Galactic bar and accretion properties?

Clump gas properties (A. Nilipour, JO, D. Meier, + et al. 2024)

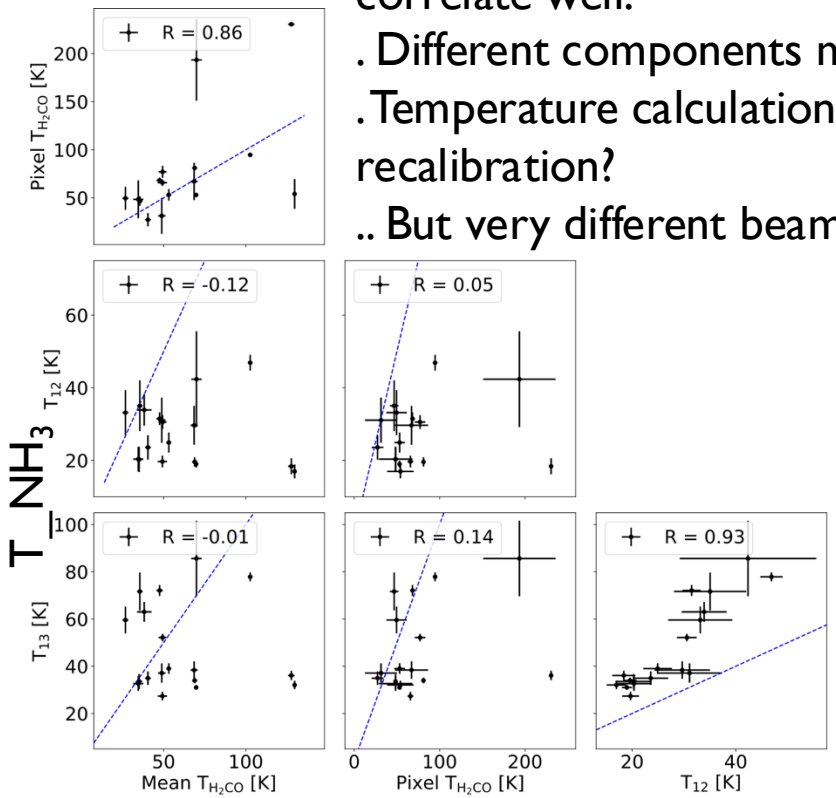


The ammonia (HOPS) vs H_2CO (ALMA) temperatures do not correlate well:

. Different components measured?

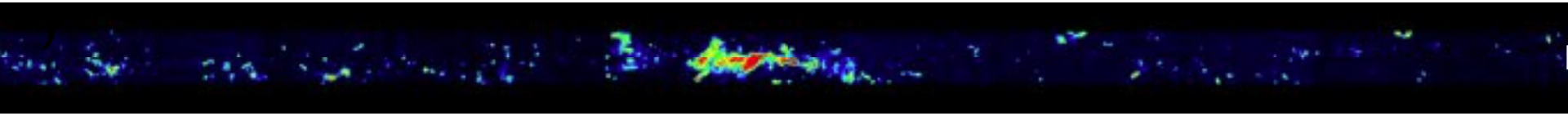
. Temperature calculations need recalibration?

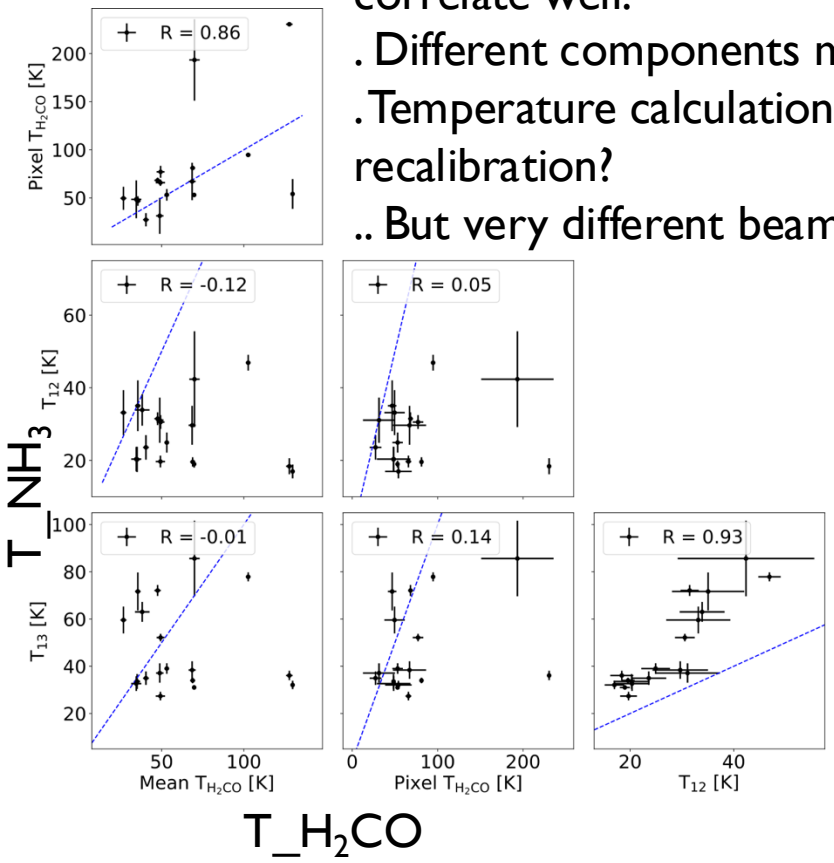
.. But very different beams



GLON

Clump gas properties (A. Nilipour, JO, D. Meier, + et al. 2024)





The ammonia (HOPS) vs H_2CO (ALMA) temperatures do not correlate well:

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.. But very different beams

~100h VLA imaging of the 25 clouds + B1, B2, G5 completely (total about 4000 pointings)

Ammonia, water, and other shock, Turbulence, ionization tracers, RC (K + C bands)

Resolution compatible with ALMA ACA

GLON

Galactic Flow/Bar/Overshoot Clouds

Results:

- Based on HOPS data, we find clouds near the positive and negative side of the CMZ that seem to be energized: they have a higher temperature than other clouds in the vicinity and wider linewidths, they resemble CMZ gas, only very few have obvious star formation tracers
- Clouds are +/- 100 km/s, which is not aligned with the dust lanes

→ Some of it is likely overshooting, interacting gas

ALMA ACA data reveals

- At least one cloud, G5, is likely energized by a very strong ~100km/s collision with gas likely from the other side of the CMZ
- The energized clouds show very different morphologies in different gas tracers, some have apparent shell structure, some show compact areas, many ring-like structures, also some chemically very rich areas
- A small fraction shows active star formation tracers, mostly at low GLON: energized disk clouds?
- SiO abundance not always enhanced
- In the high velocity features: Gas have mostly no SF but high Mach numbers, turbulent heating; Sub-disk X(CO), similar to CMZ
- H_2CO and NH_3 temperature differ (gas phases?) but also have been observed with very different beams.
- VLA has finished observing all of the cloud two weeks ago. → high resolution NH_3, H_2O and additional shock and gas tracers will be available

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