Molecular Gas Accretion in the Galactic Center

SWAG
Survey of Water and Ammonia in the Galactic Center

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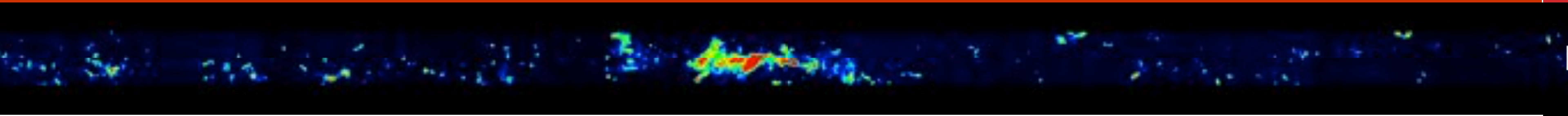
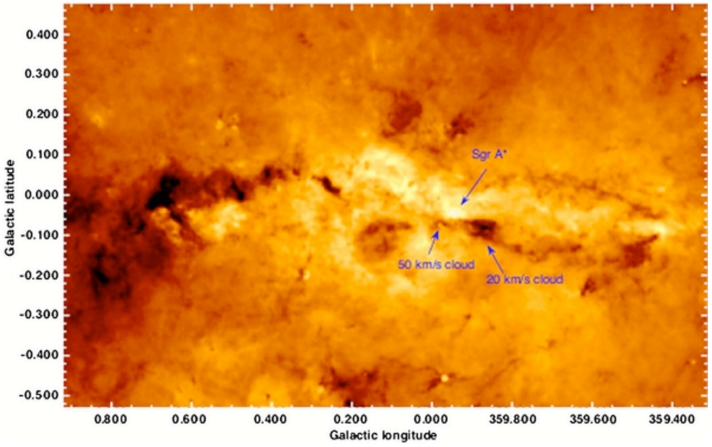
NRAO

NM Symp 2019

Central Molecular Zone



Molecular gas in the Central Molecular Zone (CMZ), the inner ~500pc
- abundant: 10% of all MW gas in 0.1% of the volume
- wide lines: ~20 km/s vs few km/s in the disk
- higher gas temperatures (~60K) than the disk (~10K)
- substantial diffuse component
- appears to move on a 100pc nuclear ring
- appears to be **inefficient** in forming stars



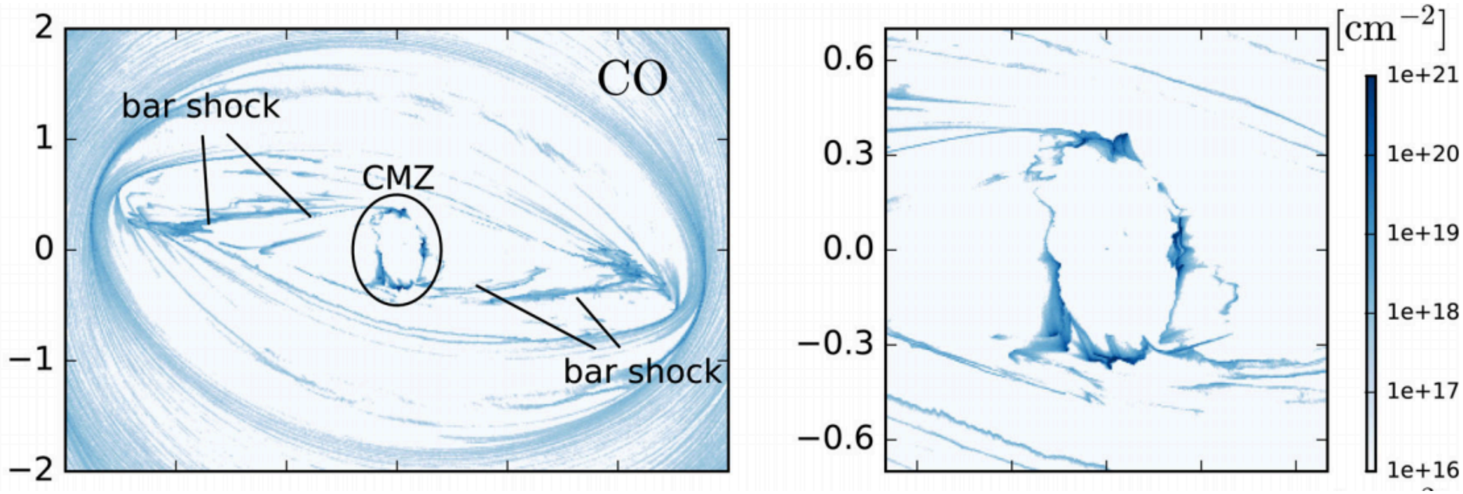
- How does the gas get there?
- Where is the gas energized?
- Does the energy input happen as a sequence of single events or is it a continuous energy input?

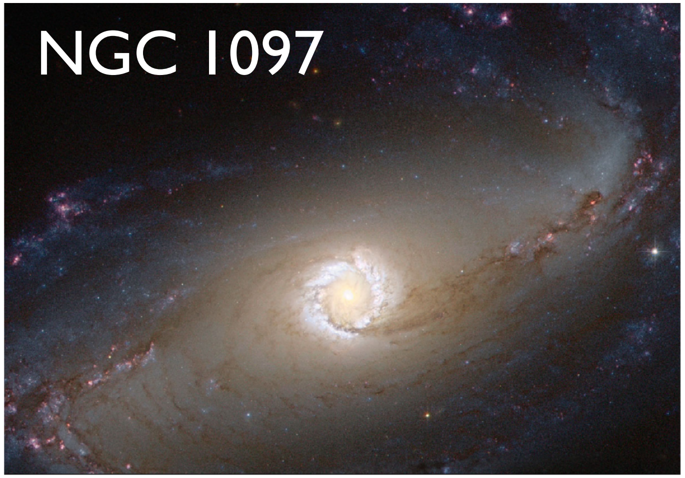
Energy injection sources: Bar potential dynamical forces, shocks from cloud-cloud collisions, embedded in high pressure regions, feedback from compact objects, (HII regions, AGB stars, SNRs, BHs, XRBs, NSs, …), magnetic fields, cosmic rays, large photon field (PDR, XDR), winds, … the CMZ hosts a plethora of energized components

For this talk, the focus will be on the inflowing gas

Gas Flows in Bar Potentials

Bar potential x_1 orbits, start self-intersecting → cloud-cloud collisions → loss of angular momentum → infall of gas → formation of dust lanes ('bar shocks') → instabilities form inner 100pc radius ring close to x_2 orbits (Sormani+ 2018)

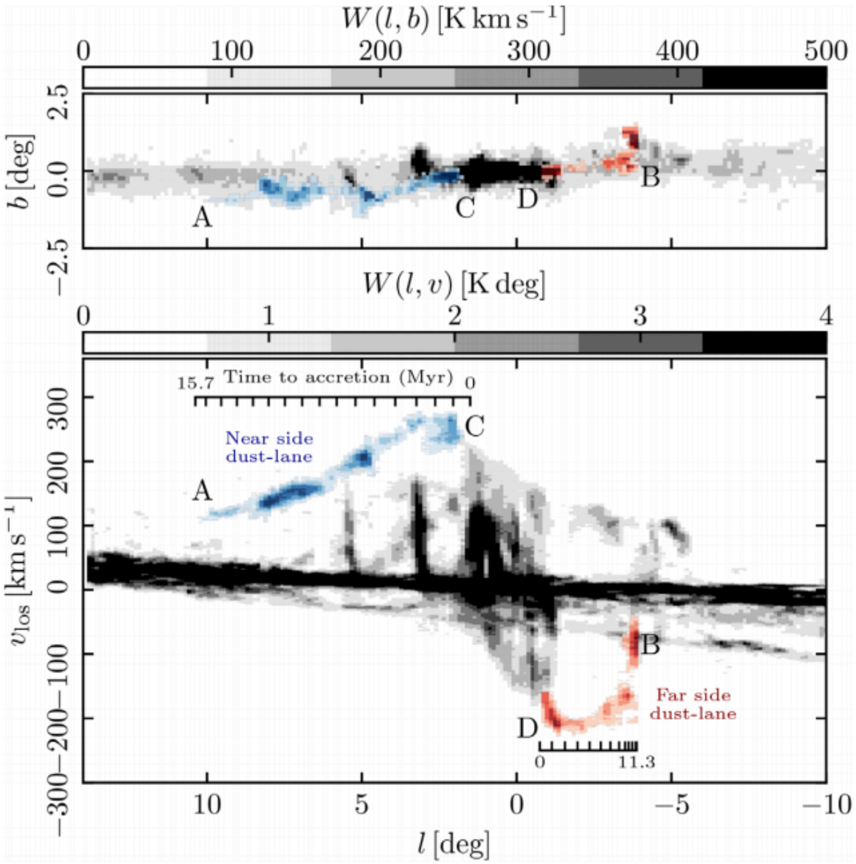


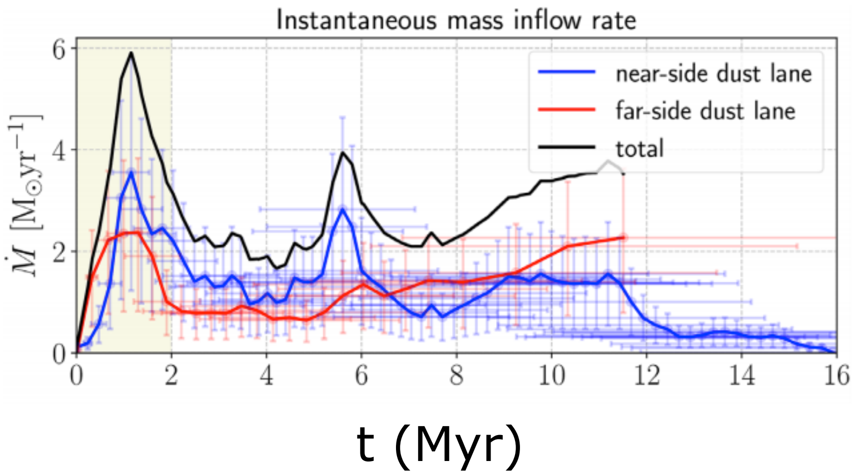


Observed in nearby face-on barred galaxies; difficult to confirm and detail this scenario in the edge-on Milky Way

Gas Flows from the disk to the CMZ

Gas flows from disk to CMZ: Based on CO, ~2.7M$_\odot$/yr, fairly symmetric from both sides, but episodic (Sormani & Barnes 2018) – dynamical approach



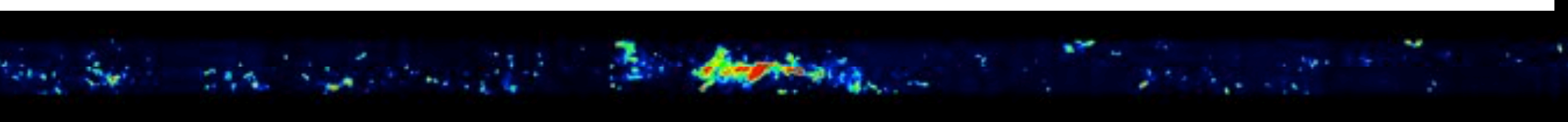


Gas Flows from the disk to the CMZ

HOPS data: Mopra Single dish survey in H_2O, NH_3 and other molecular lines (Walsh et al. 2011)

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



Gas Flows from the disk to the CMZ

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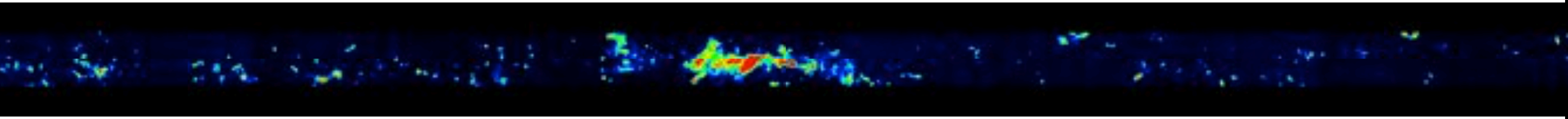
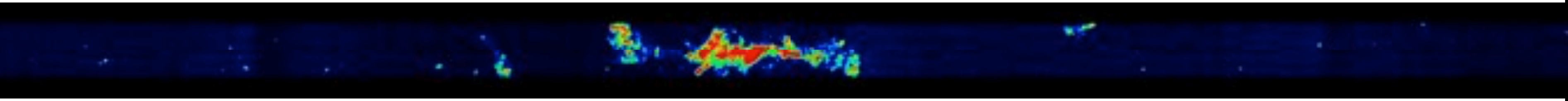


What gas is in the flow and what gas is in the MW disk across the line of sight?
→ “missing link”

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



B1 and G5

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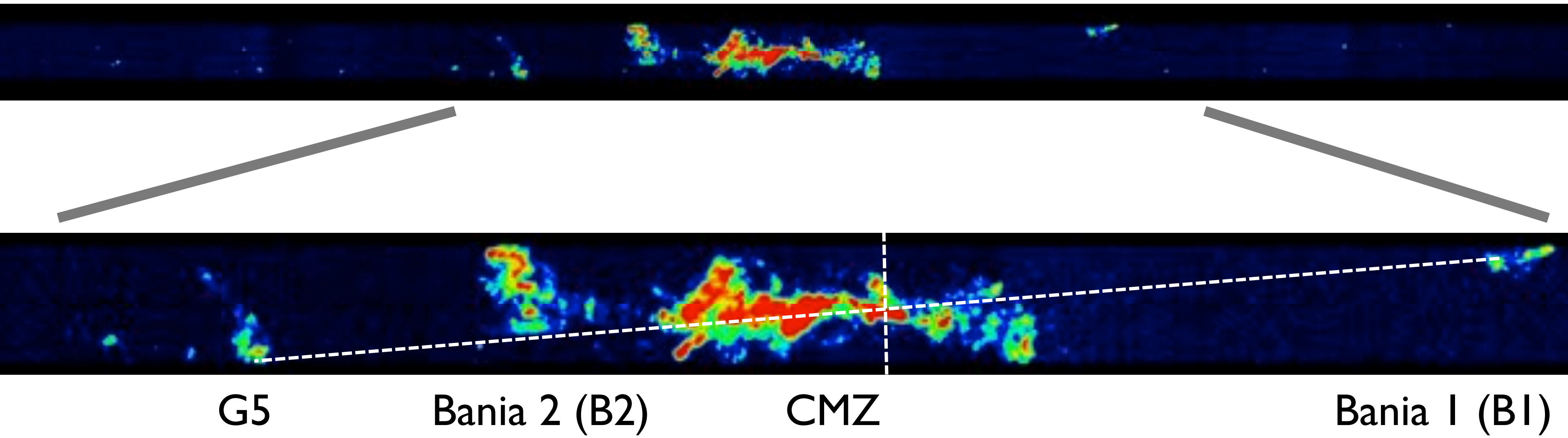

Most prominent gas that is likely in the flow: G5, B2, B1

G5 (+5.5, -0.2) and B1 (-5.5,+0.2) are perfectly symmetric in position!

Are these specific spots in the Bar potential?
Other mechanisms possible, like outflow from CMZ/Sgr B2, molecular loops, etc. …
→ ALMA ACA Band 6 multi-line data on G5 and B1 to check for similarities other than position, like temperature, optical depth, shocks, … (Savannah Gramze REU)

B1 and G5

(S. Gramze REU project)

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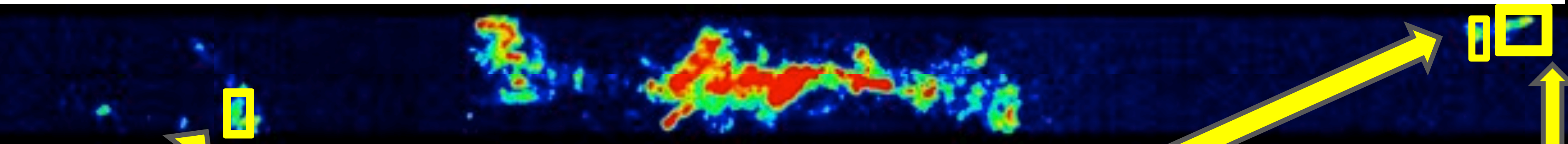
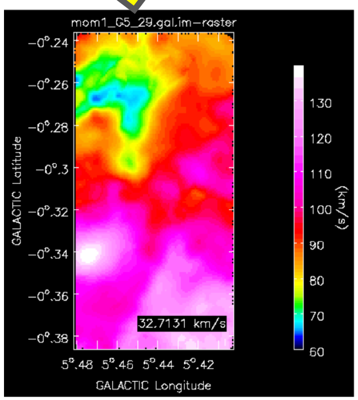
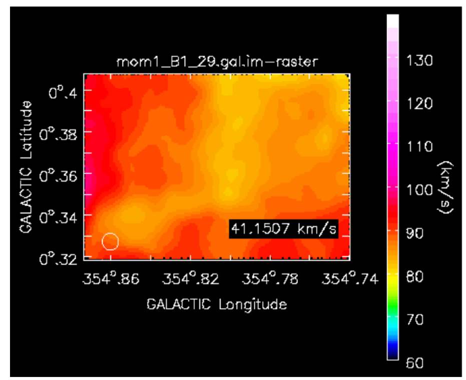
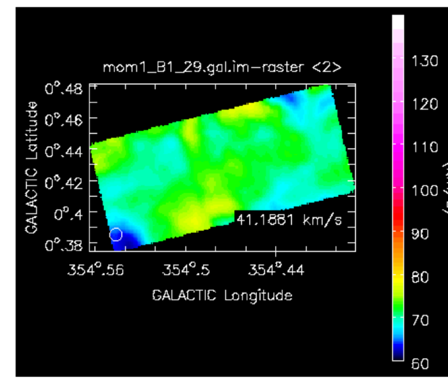


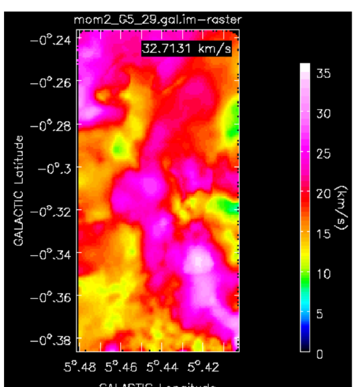
G5 Bania 2 (B2) CMZ Bania 1 (B1)



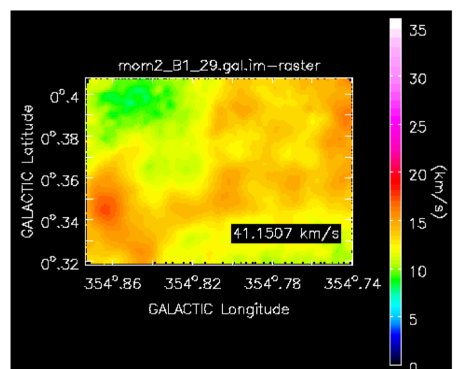
^{13}CO(2-1)
Velocity Field
(not symmetric around 0, all positive)

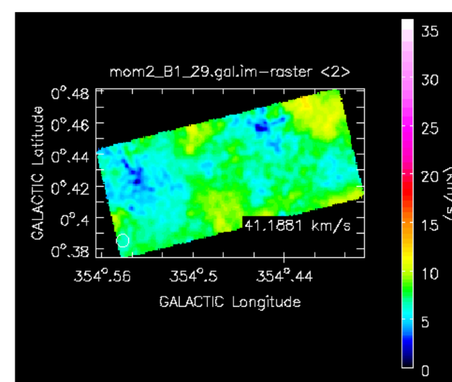






^{13}CO(2-1)
Velocity Dispersion
(25 – 15 – 8 km/s)
G5 larger Δv





B1 and G5

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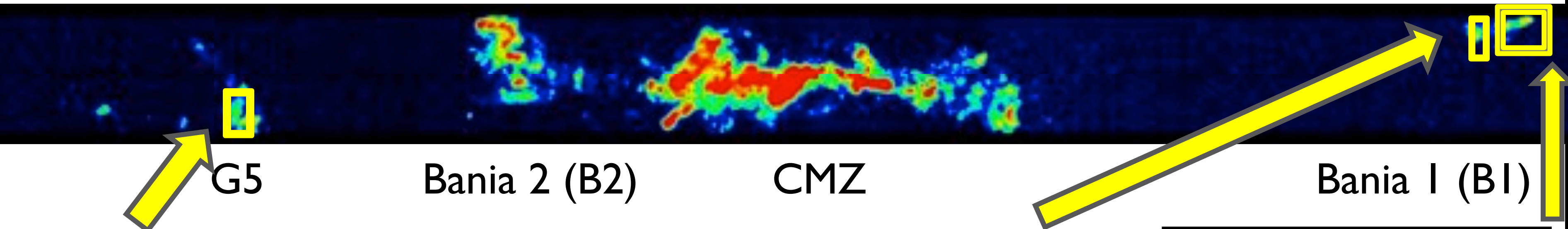

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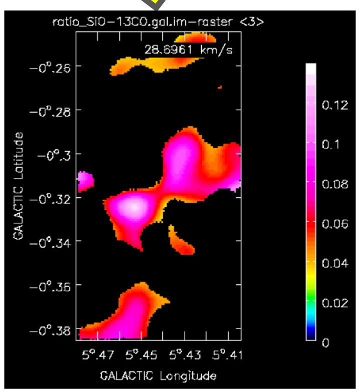
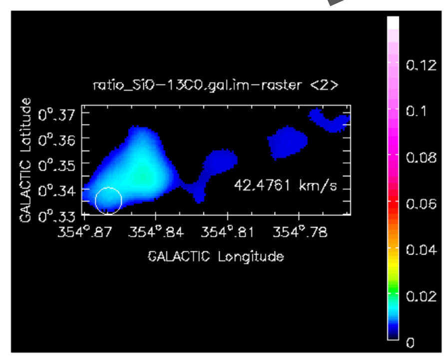
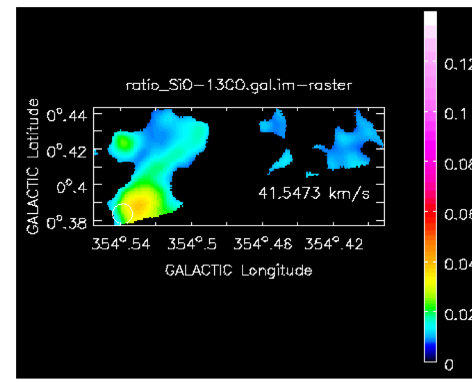
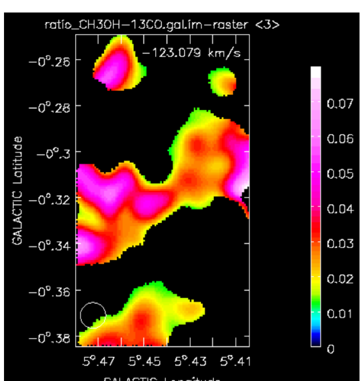


$SiO(5\text{-}4)/^{13}CO(2\text{-}1)$

G5 shows brighter **strong shock tracers**

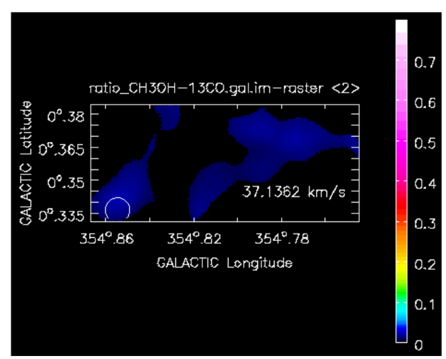


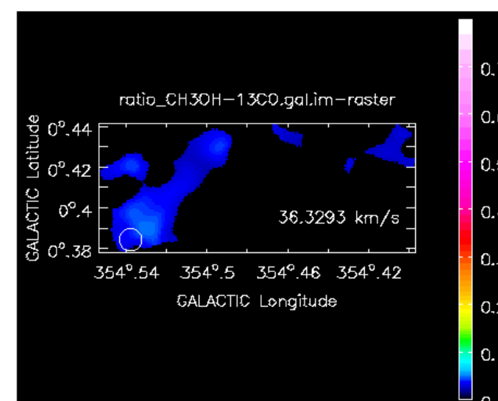




$CH_3OH/^{13}CO(2\text{-}1)$

…and G5 also brighter in **weak shock tracers**





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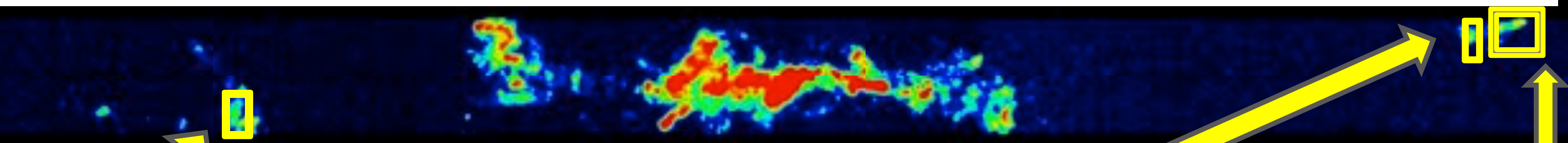
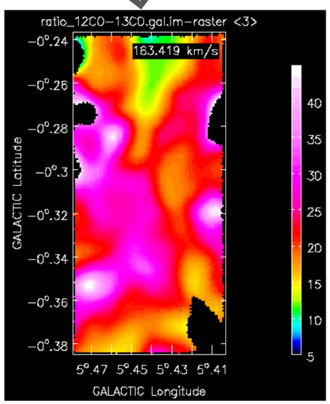
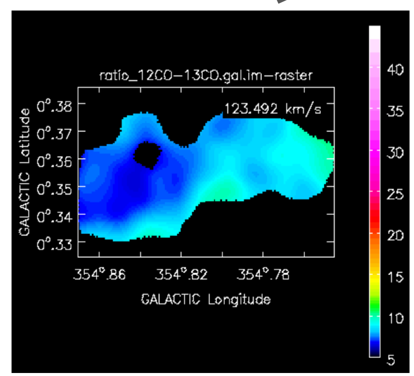
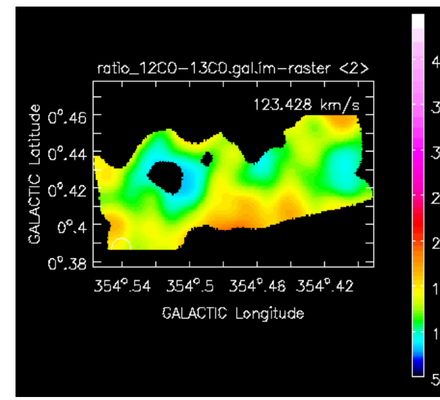


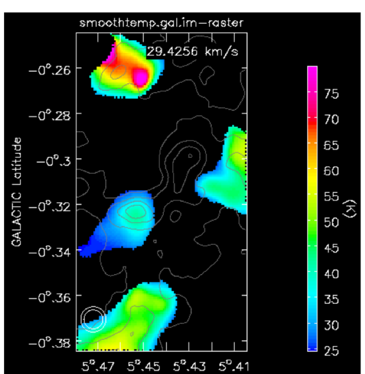


$^{12}CO(2\text{-}1)/^{13}CO(2\text{-}1)$

Higher **optical depth** in G5

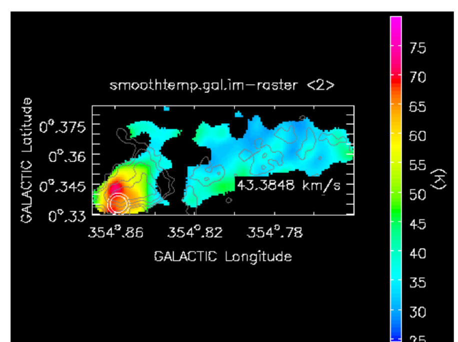


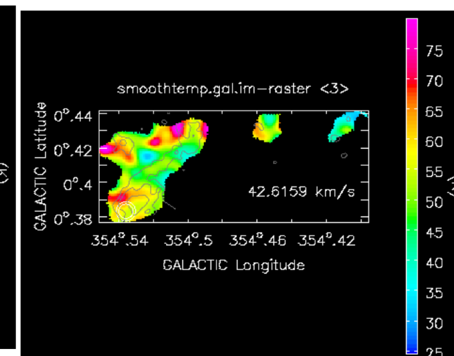




H$_2$CO temperature

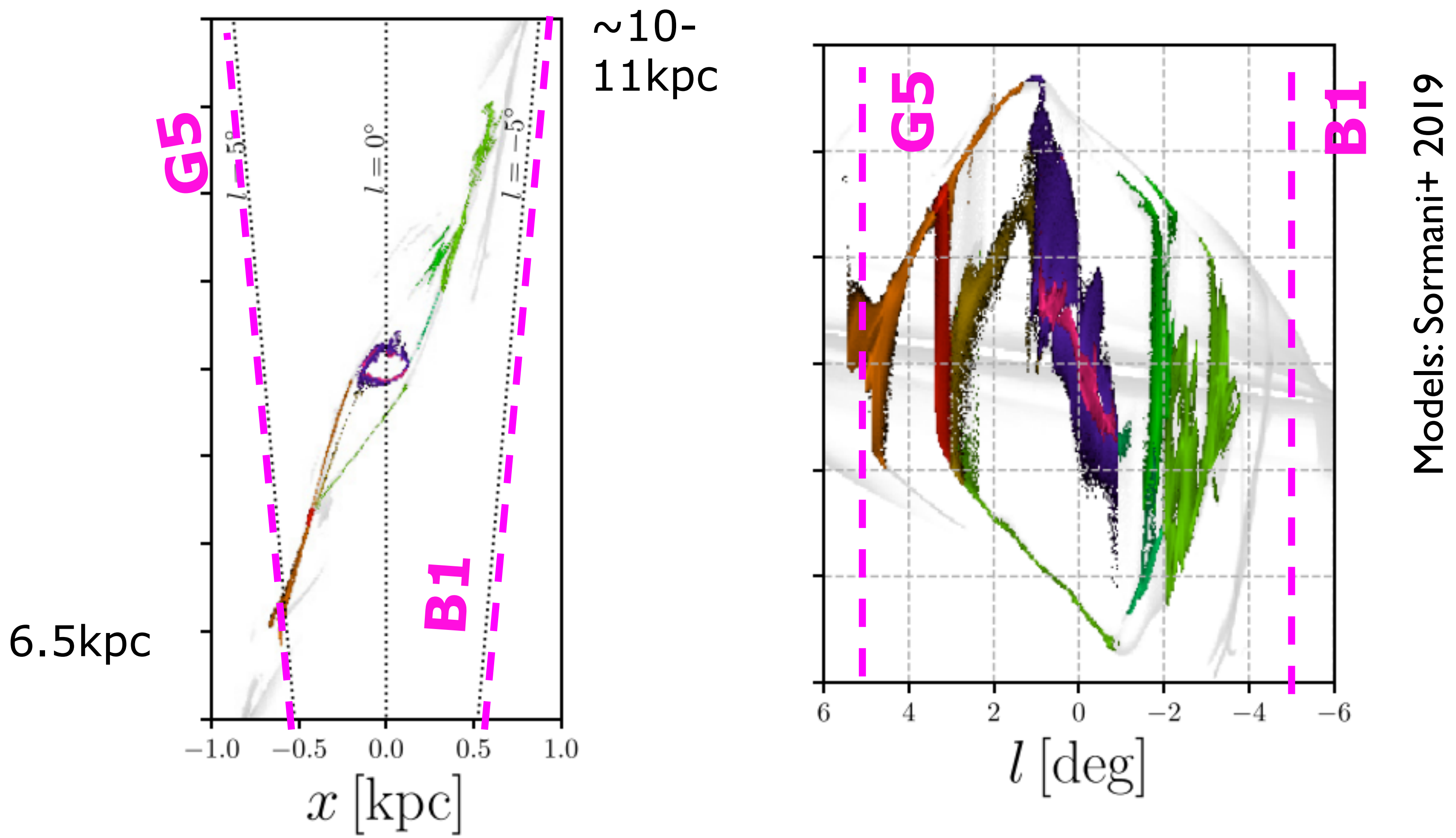
Warm gas overall, similar to CMZ





Bar Dynamics/Dust lane models

G5: more turbulent, more shocks, higher optical depth than B1
→ Sormani models show very different locations along G5 and B1:



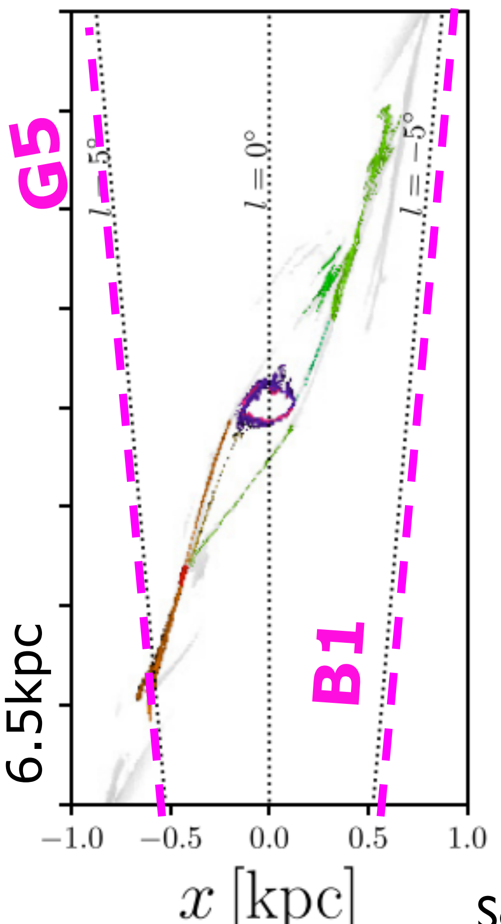
Bar Dynamics/Dust lane models

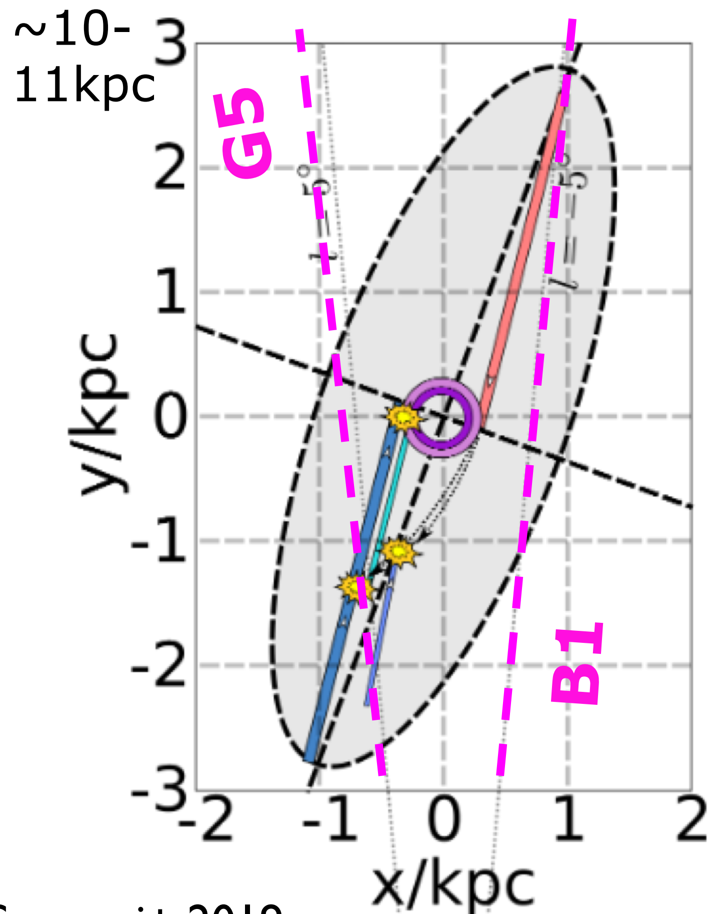
G5: more turbulent, more shocks, higher optical depth than B1

→ Sormani models show very different locations along G5 and B1:

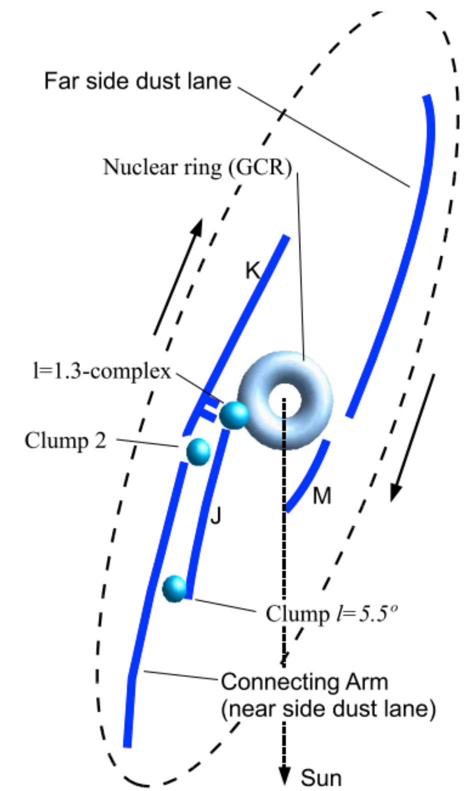
→ B1: line of sight along dust lane, on the far side

→ G5: dust lane overshooting CMZ accretion zone, collision with dust lane on other side





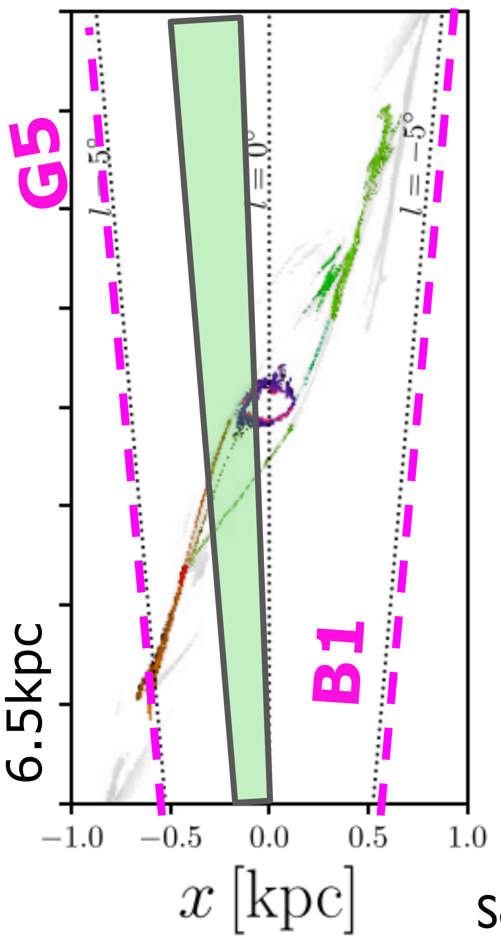
Sormani+ 2019

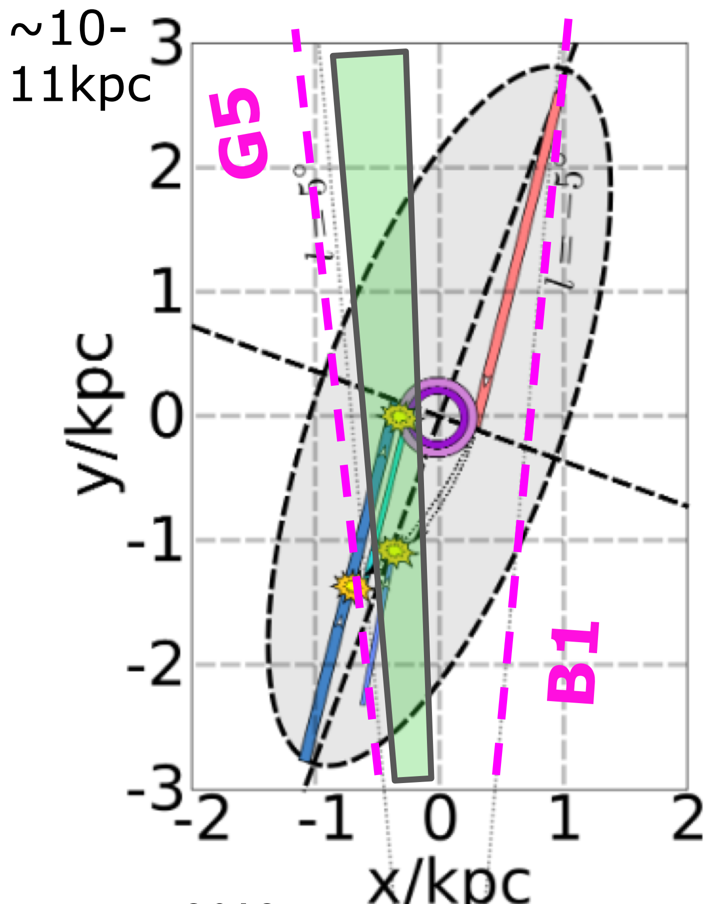


Rodriguez-Fernandez+ 2006

Accretion Zone

Accretion Zone on the Molecular ring at about 100pc from the center, or ~0.1 degree radius





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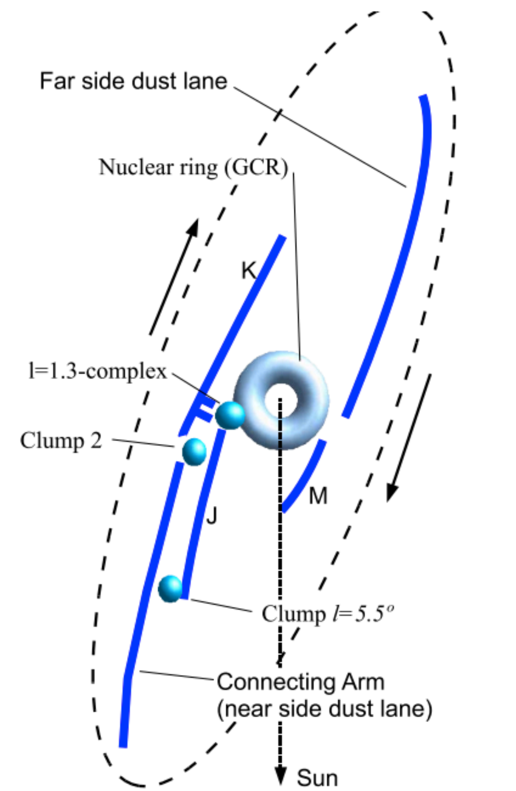
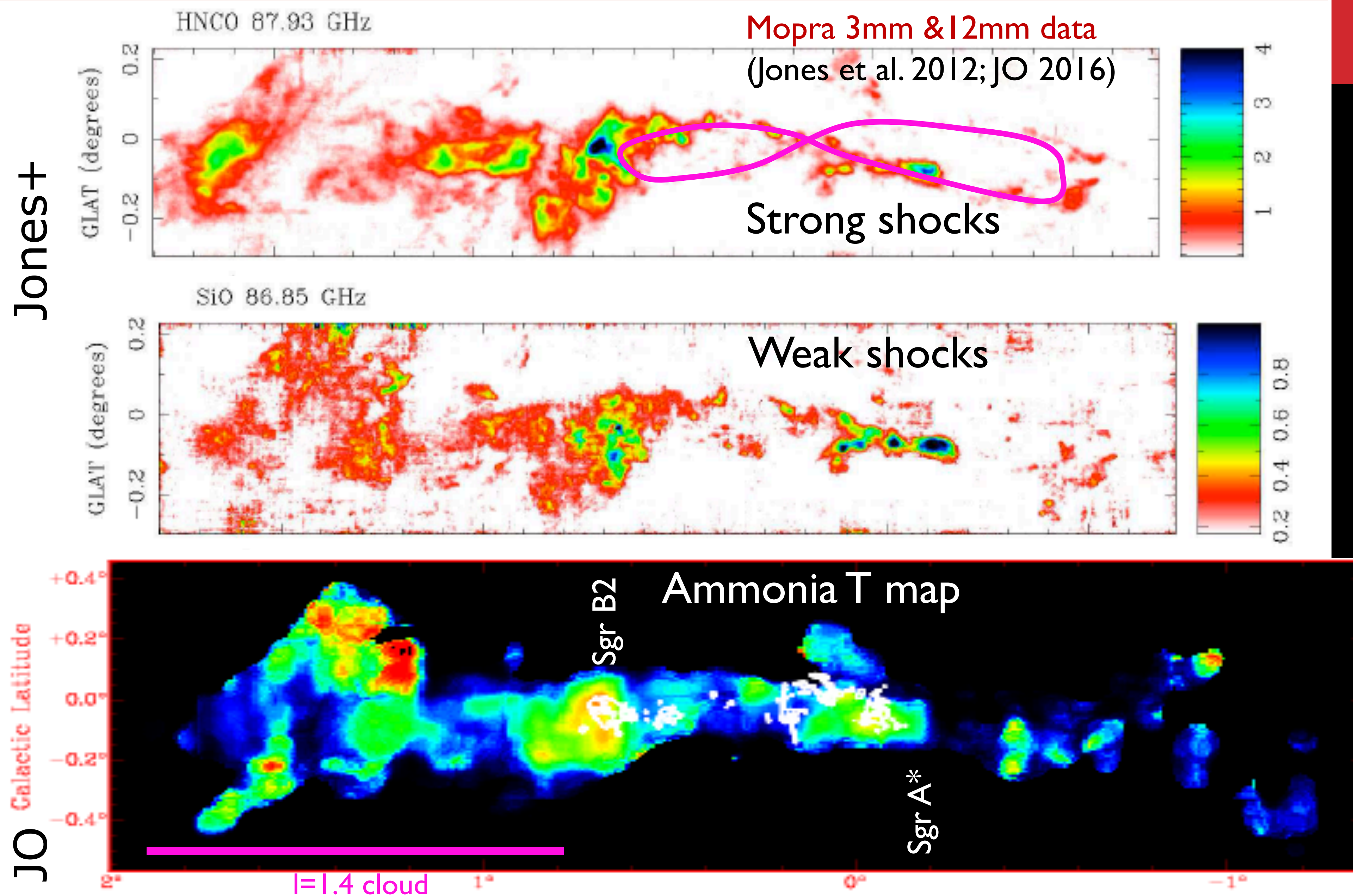


Rodriguez-Fernandez+ 2006

Dust Lane – Nuclear Ring Interface: l=1.4 Cloud



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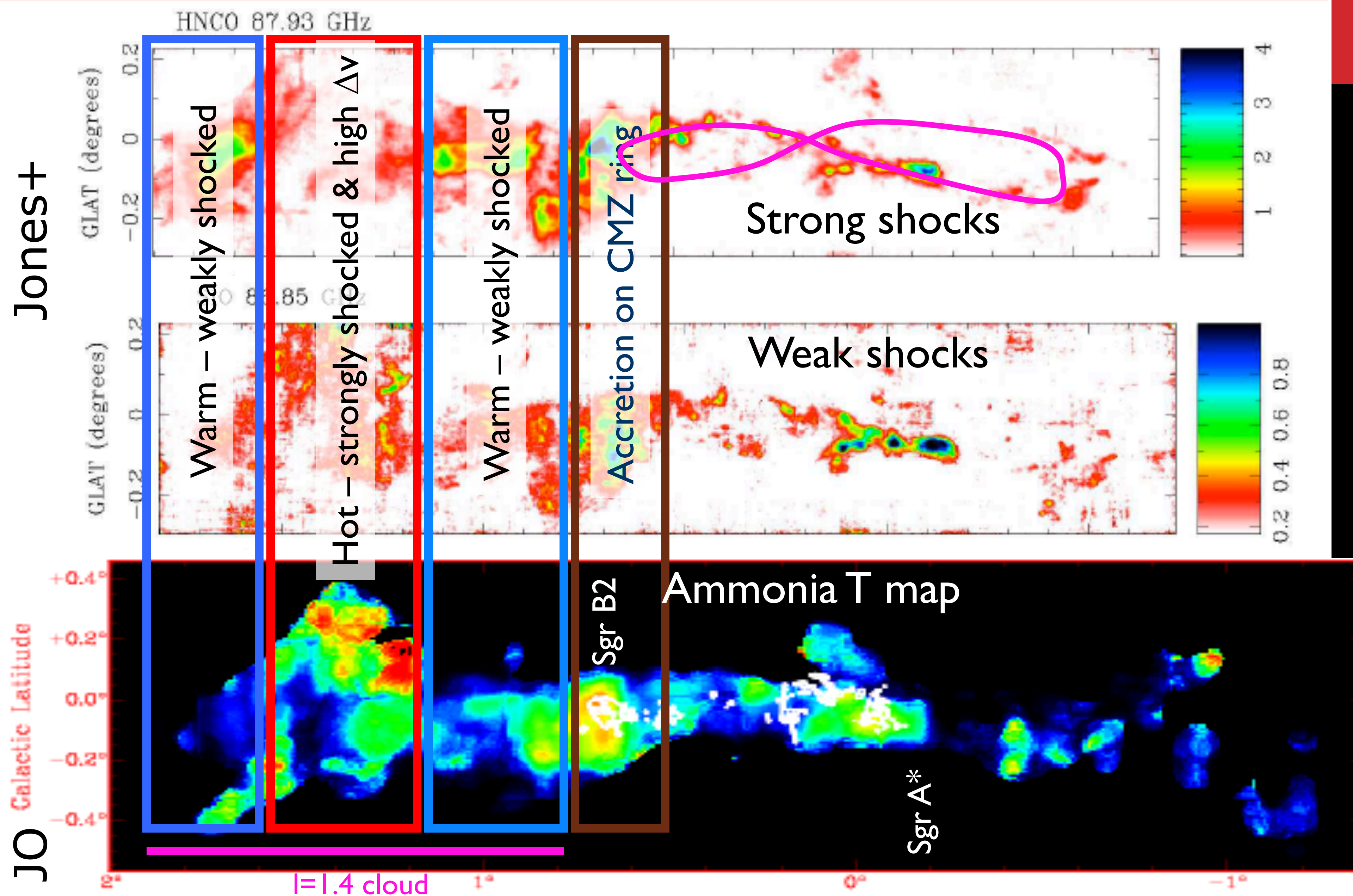

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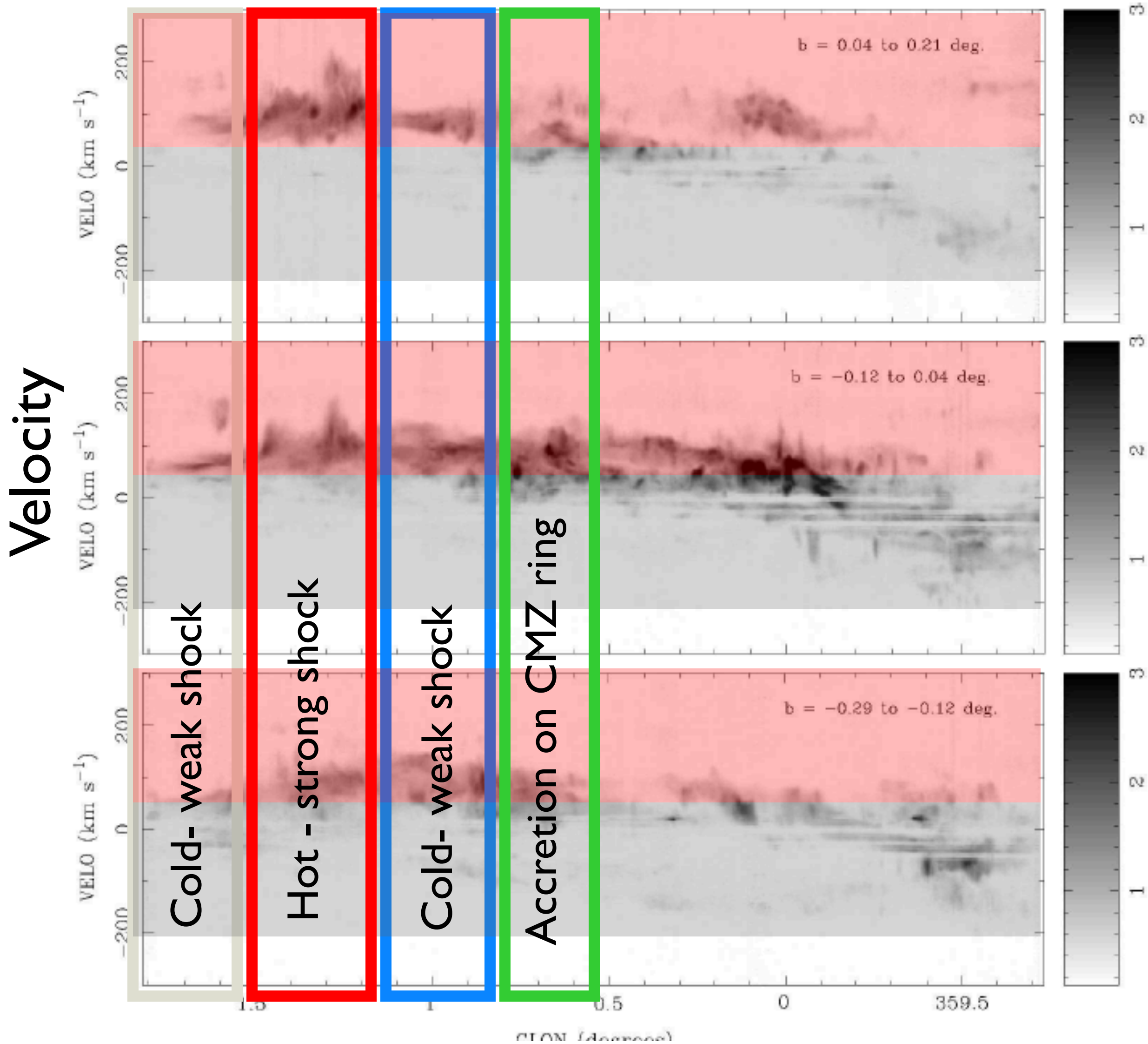
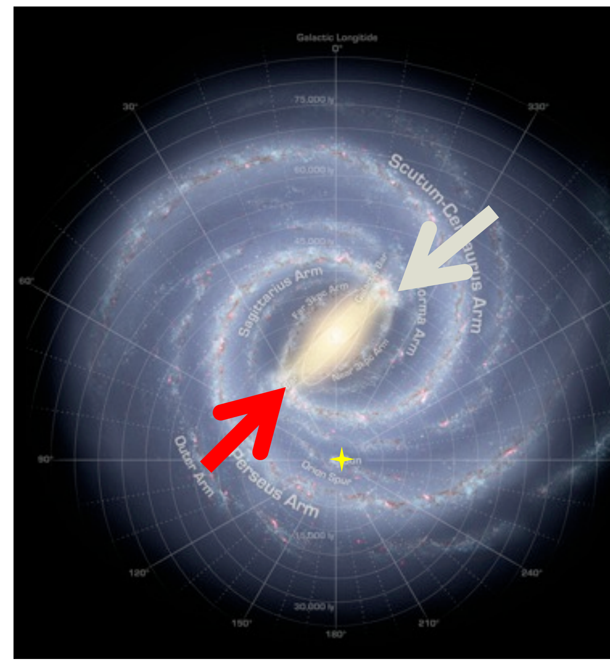


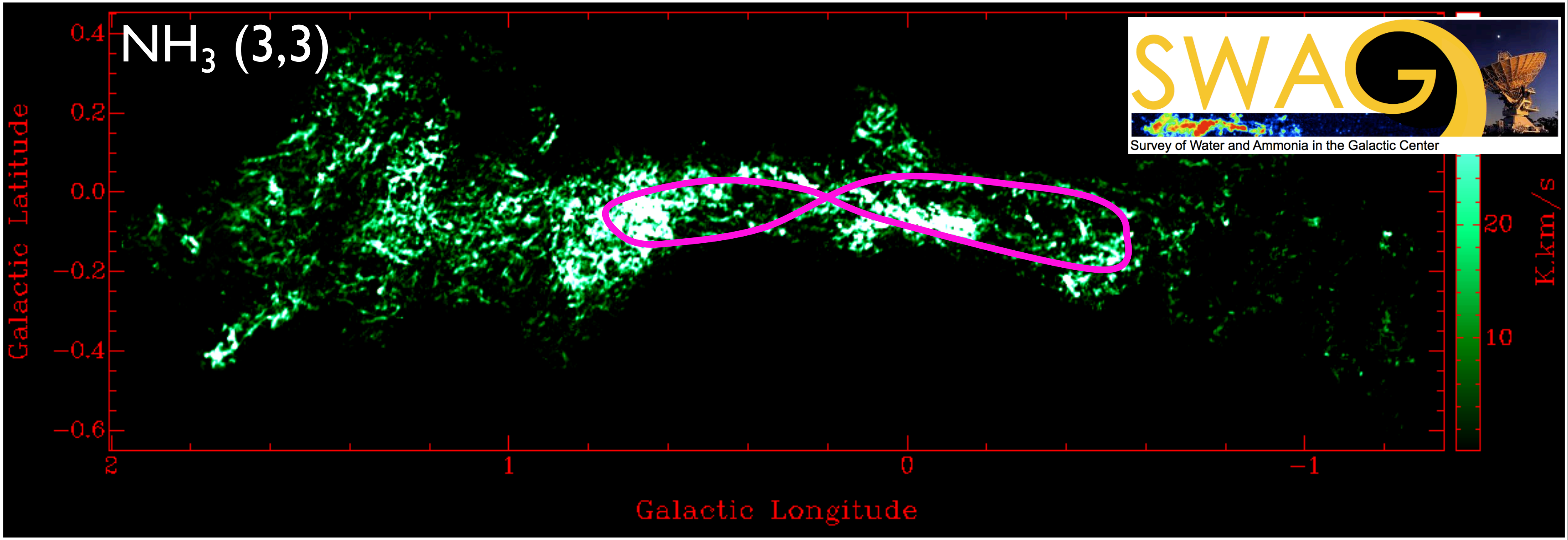
Gas more turbulent
Where the shock is
strong and the gas is
hotter



Dust Lane – 100pc Ring Interface: l=1.4 Cloud

There are a sequence of shocks in the dust lane as the gas moves to the CMZ 100pc ring accretion point. Some of the shocks may be due to shear and cloud-cloud collision within the dust lane, other regions may be gas from the other side that overshoots.

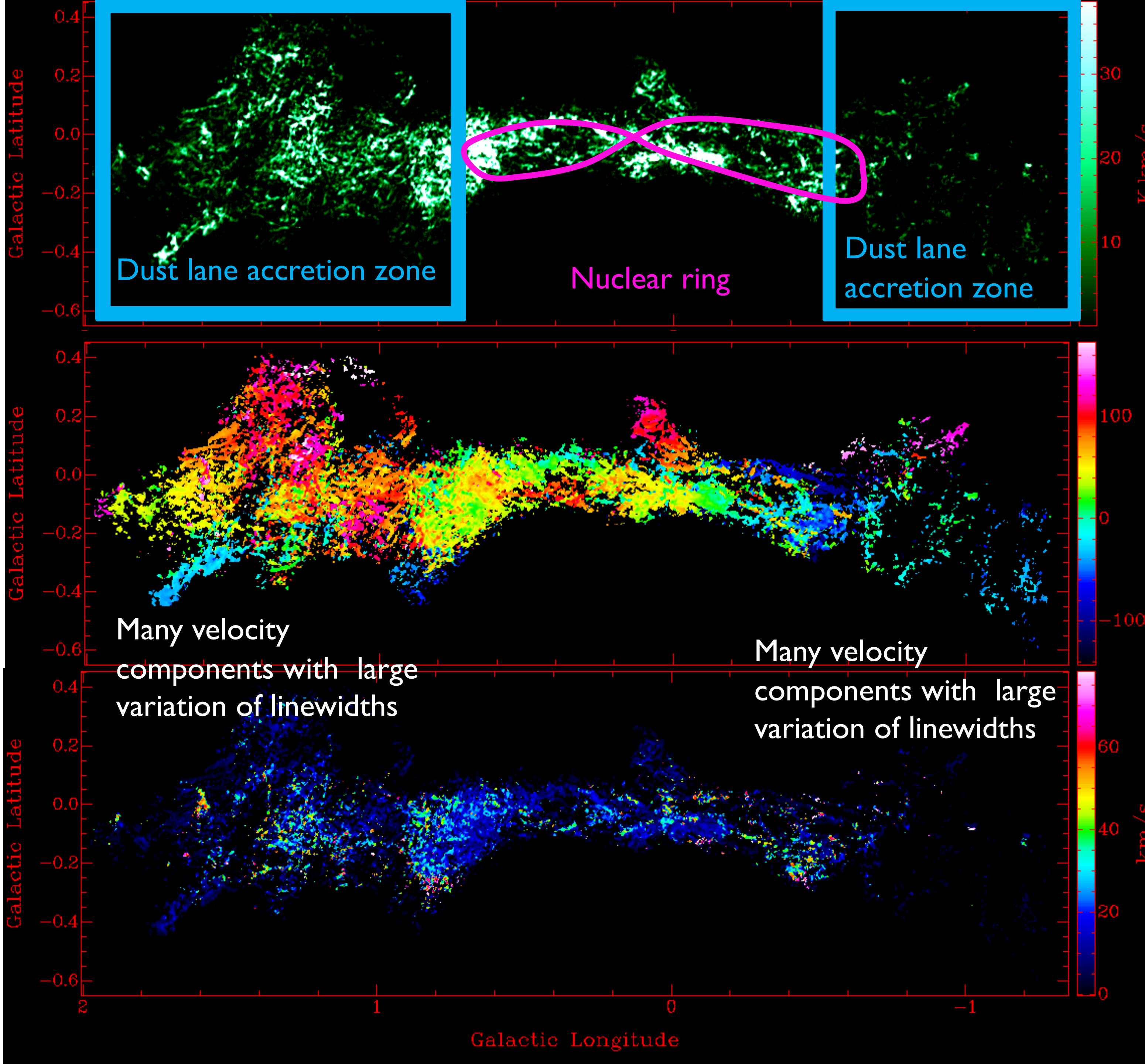
High resolution: SWAG "Survey of Water and Ammonia in the Galactic center"
Tens of lines in radio K (1.3cm) band, Large Australia Telescope Compact Array project, ~30"/1pc resolution 6000 pointings across CMZ, 750h



$NH_3(3,3)$ Intensity (m0)

Velocity field (m1)

Velocity dispersion (m2)



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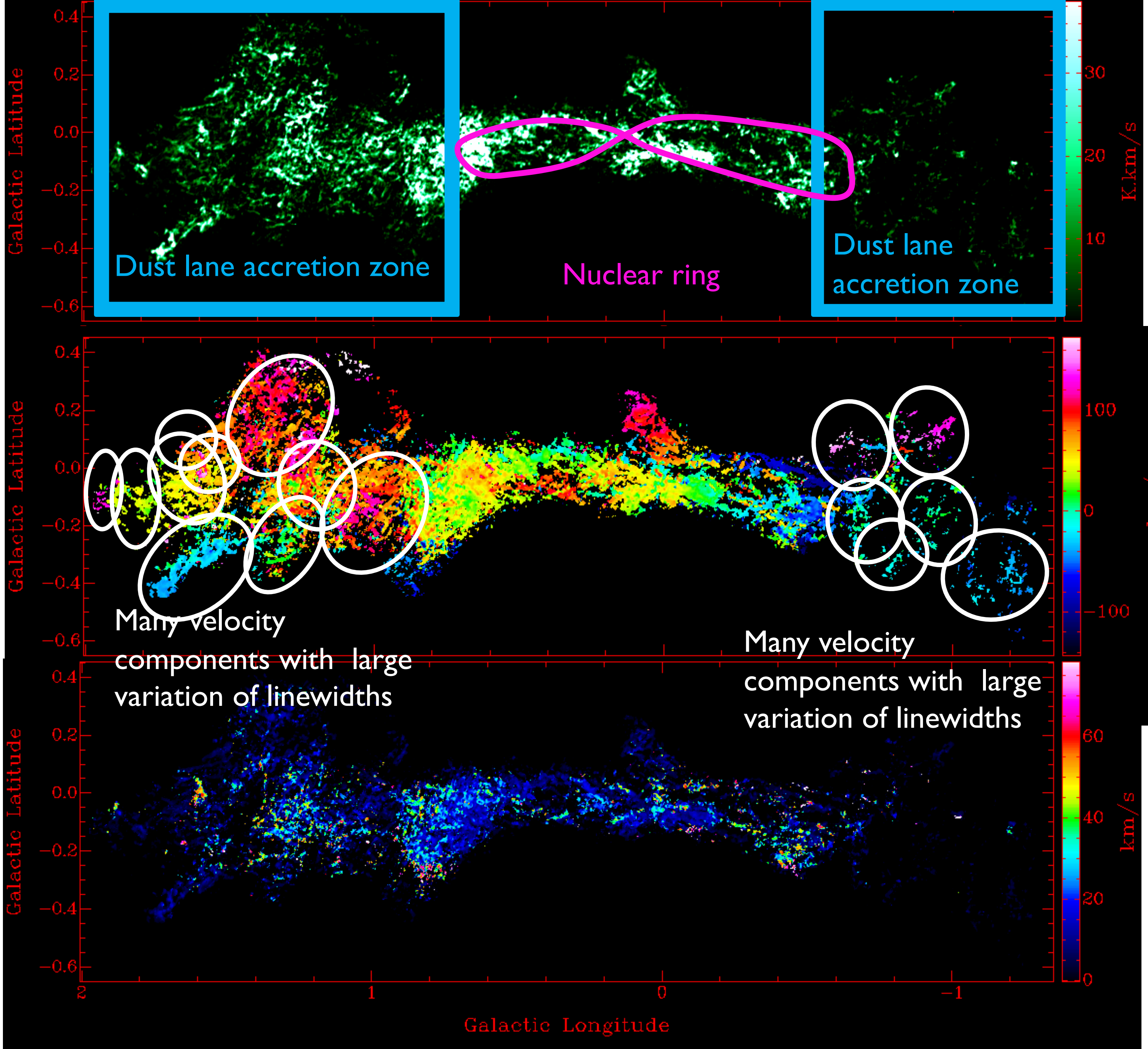
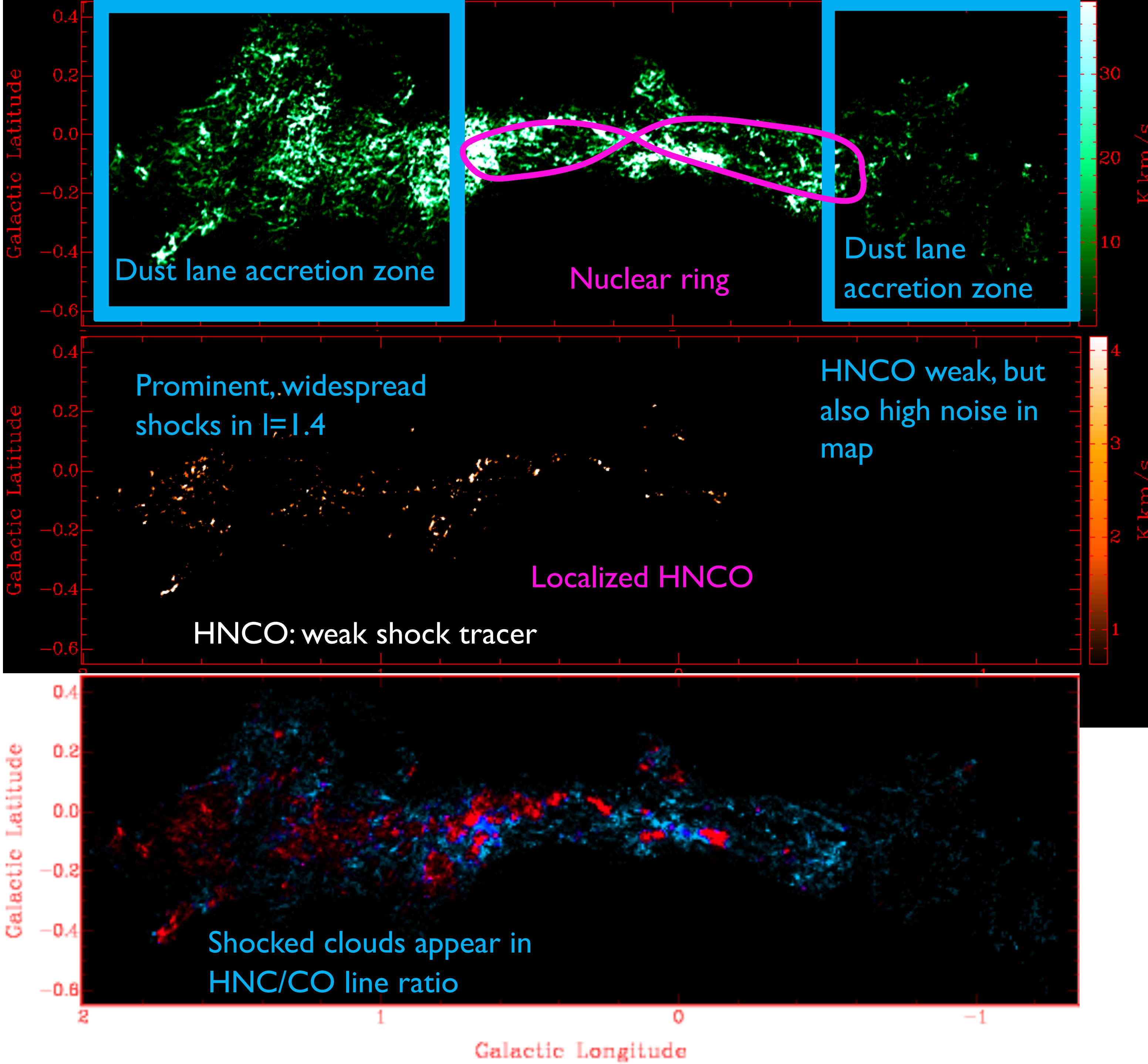


NH_3(3,3) Intensity (m0)

HNCO Intensity (m0)

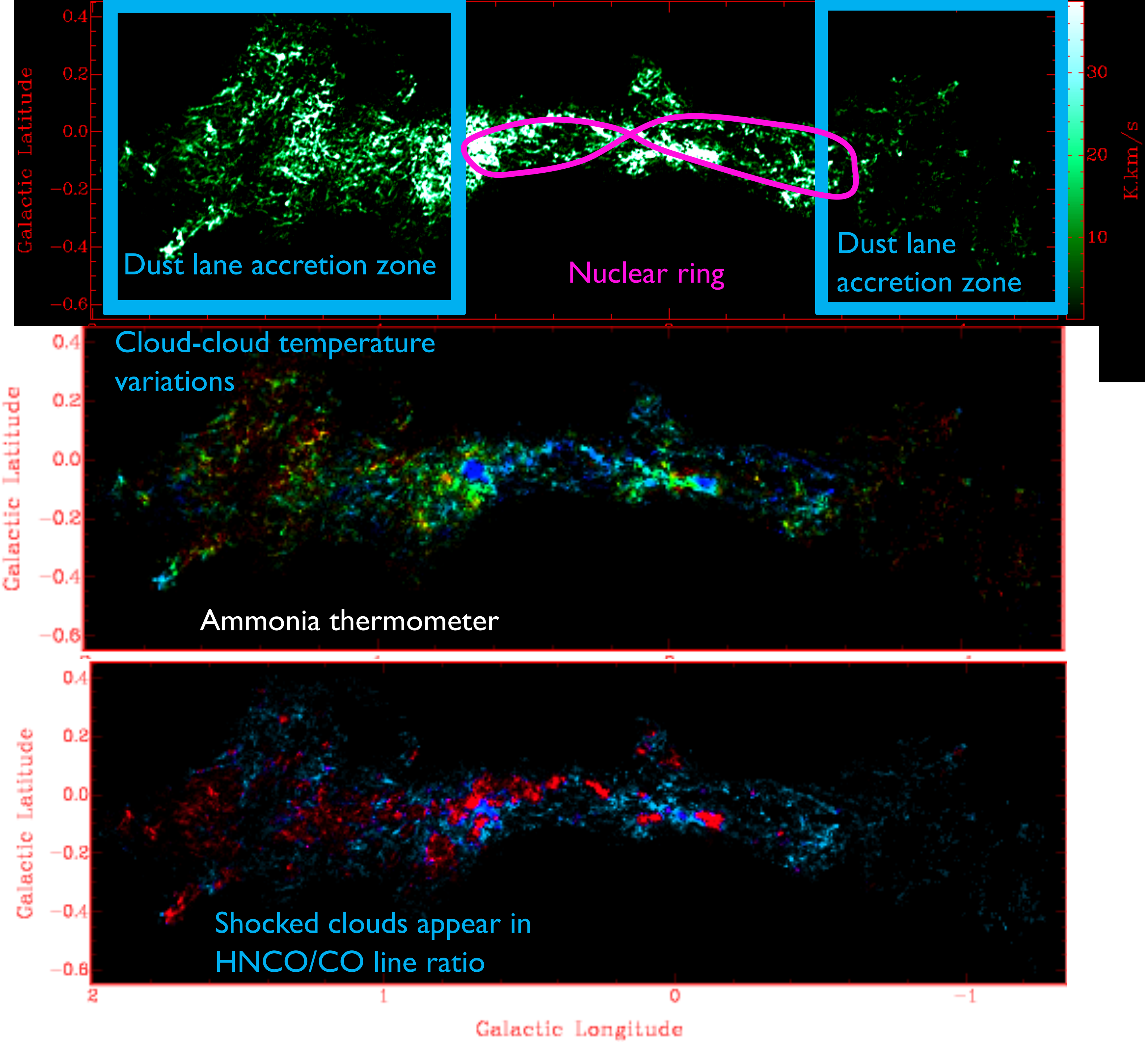
HNCO/ NH_3 (3,3) *weak shocks*

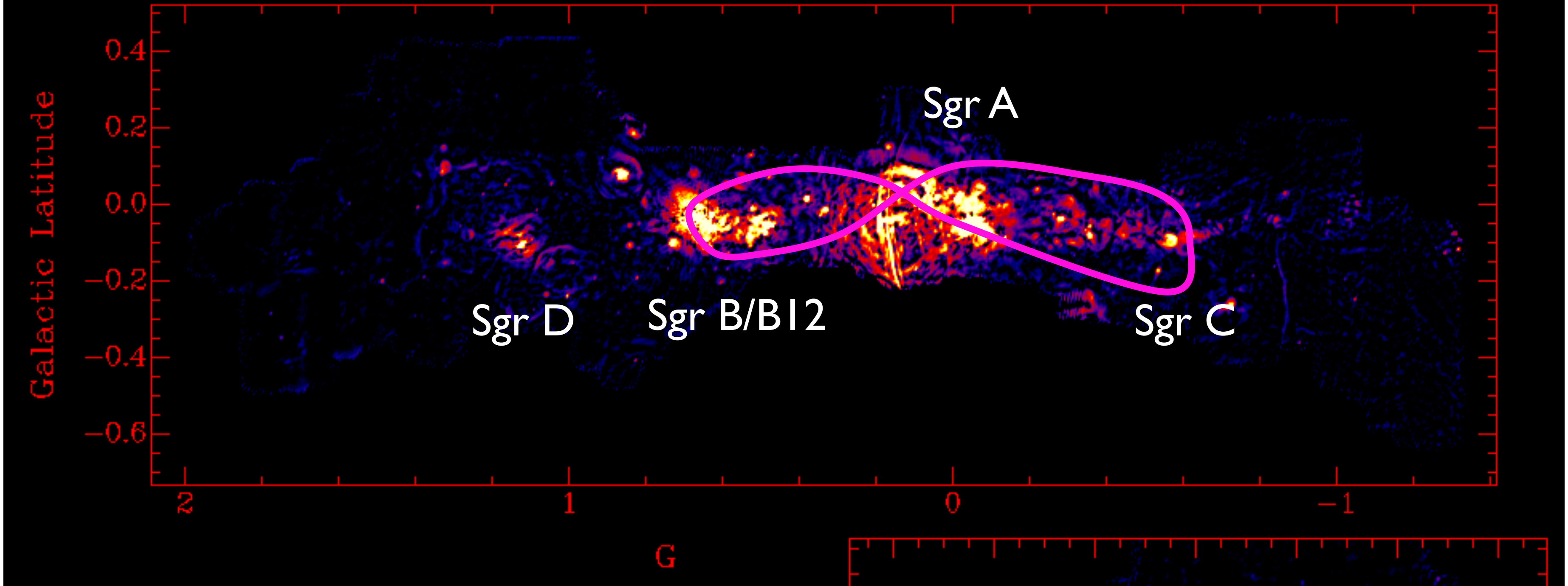


$NH_3(3,3)$
Intensity
(m0)

$NH_3(3,3)$/
$NH_3(1,1)$
temperature

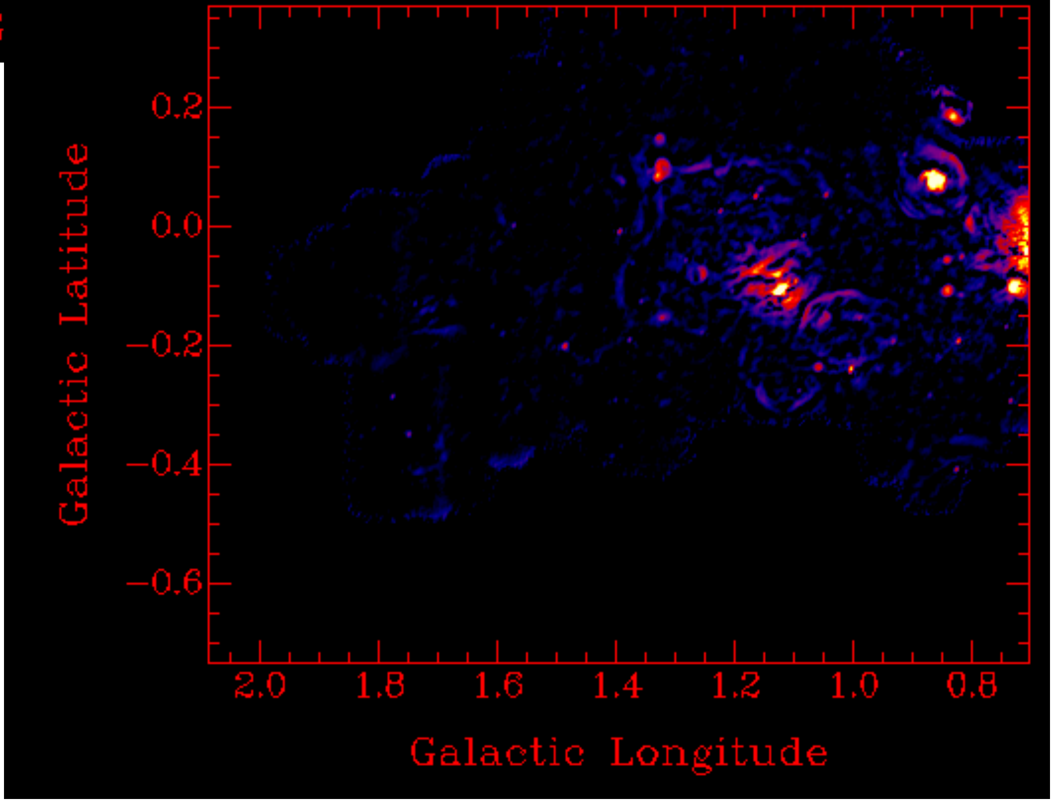
HNCO/
NH_3 (3,3)
weak shocks

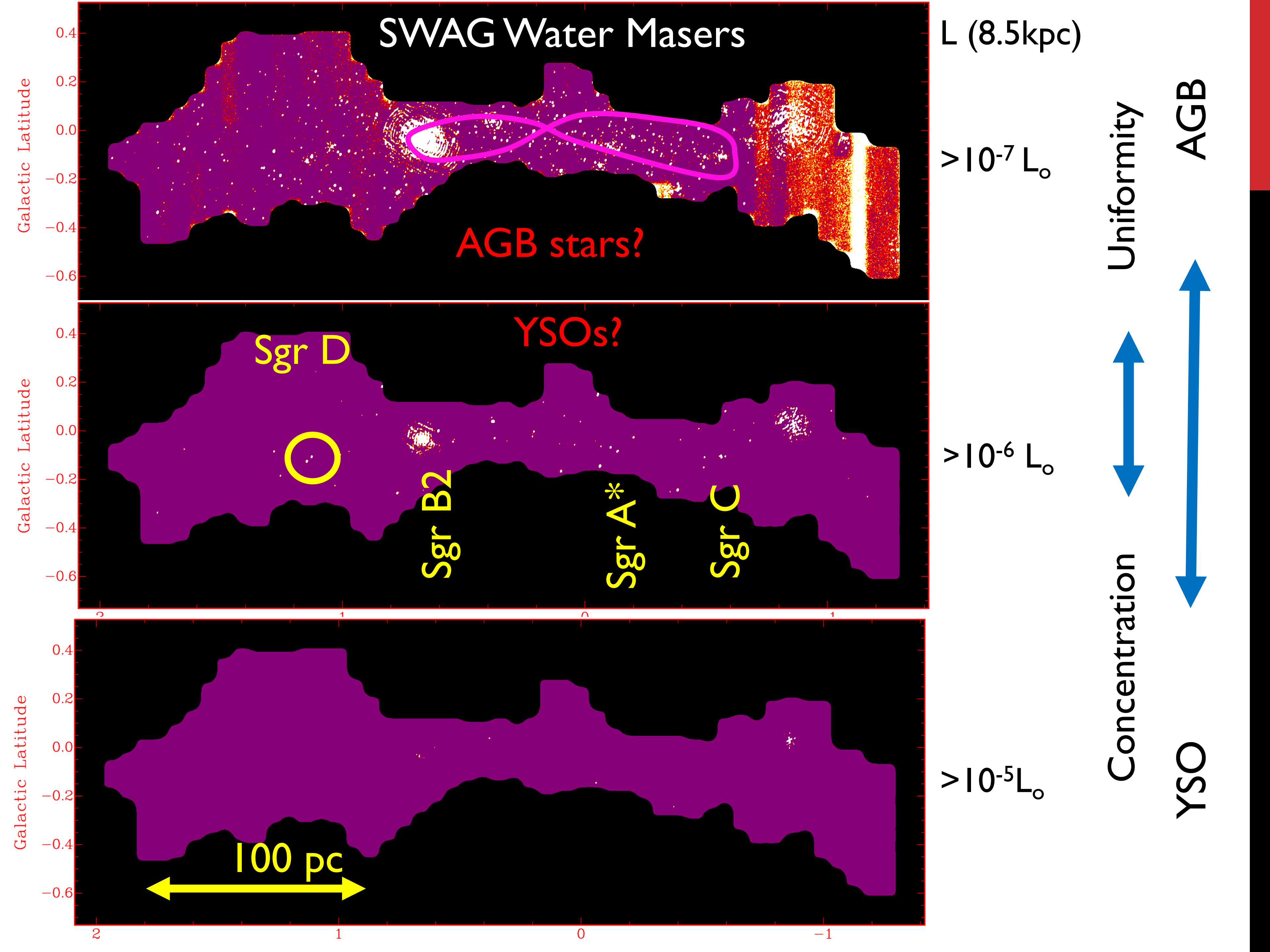




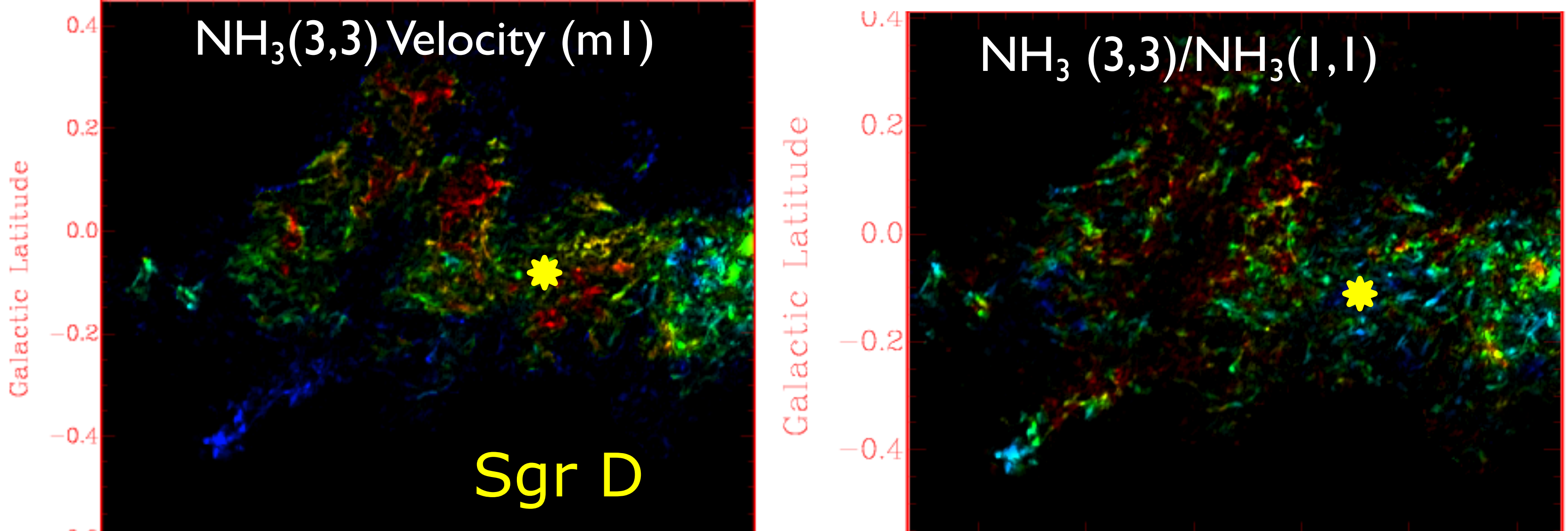
1.3cm SWAG radio continuum:

Few HII regions, most notably Sgr D; almost no star formation at l>1.3deg

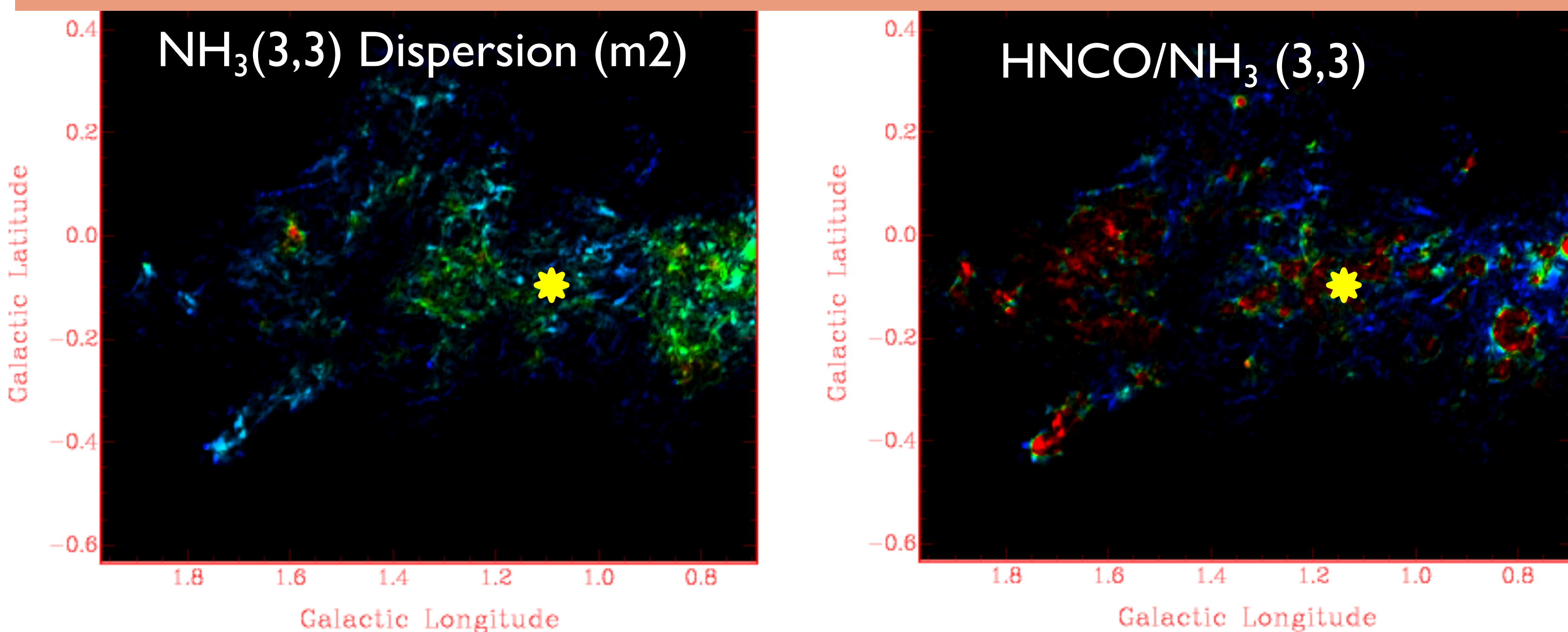


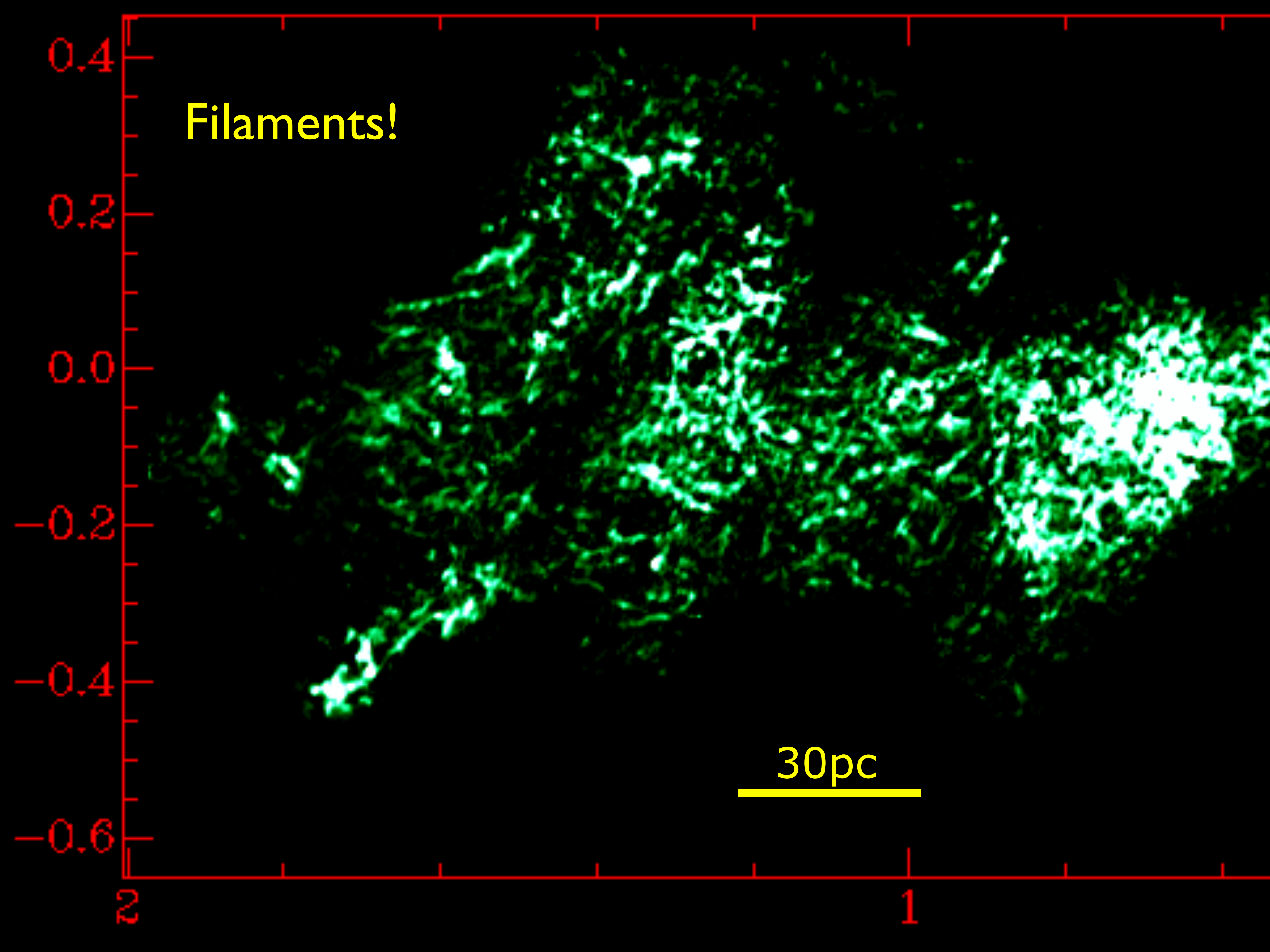


SWAG Water Masers
L (8.5kpc)
AGB stars?
YSOs?
Sgr D
Sgr B2
Sgr A*
Sgr C
100 pc
>10-7 Lo
>10-6 Lo
>10-5Lo
Uniformity
Concentration
AGB
YSO
Galactic Latitude
0.4
0.2
0.0
−0.2
−0.4
−0.6
2
1
0
−1



Sgr D has little influence on the gas outside the immediate environment → gas arrives in clouds with their individual but overall energized properties





Filaments!
30pc
0.4
0.2
0.0
−0.2
−0.4
−0.6
2
1

Conclusions

- There is a sequence of warm, high velocity dispersion clouds on both sides of the CMZ, similar to CMZ gas properties
- The clouds are likely in the gas flow within the bar potential, along the dust lanes
- **(some) inflowing gas is energized along dust lanes, it already arrives at the CMZ in this state, before it is accreted on the 100pc ring**
- Gas is likely shocked by cloud-cloud interactions, the shocks can differ significantly between individual regions
- G5 and B1 may have very different causes despite their exact point symmetric locations: G5 may be the region where overshooting gas from western dust lane hits the eastern dust lane (similar to B2); B1 could be the line of sight aligned with the western dust lane,
- The l=1.4 cloud consists of a sequence of clouds at very different velocities, velocity dispersions, shock degrees, and temperatures
- SF increases close to accretion point
- The high resolution SWAG maps show very filamentary gas in l=1.4, independent of energy content or shock state

Ongoing: Accepted ALMA/ACA project to map all the incoming warm clouds in the dust lane that will likely be accreted on the CMZ