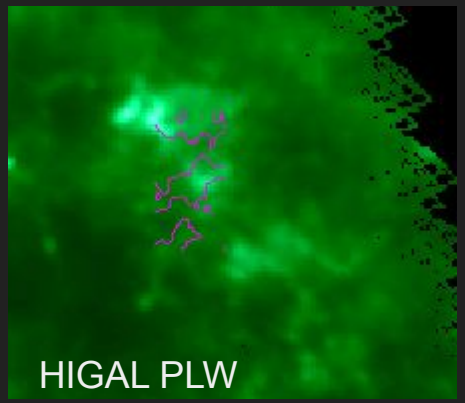
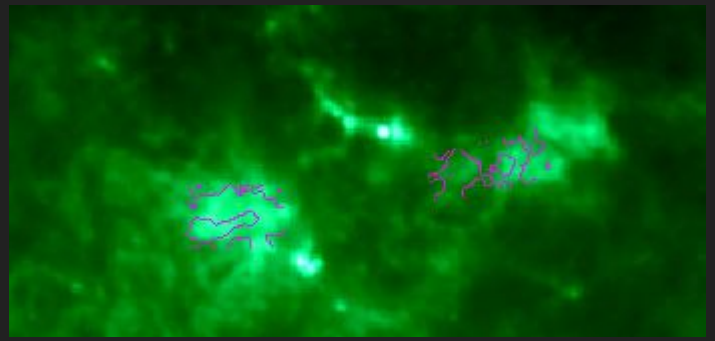
Point Symmetric Molecular Clouds Around the CMZ

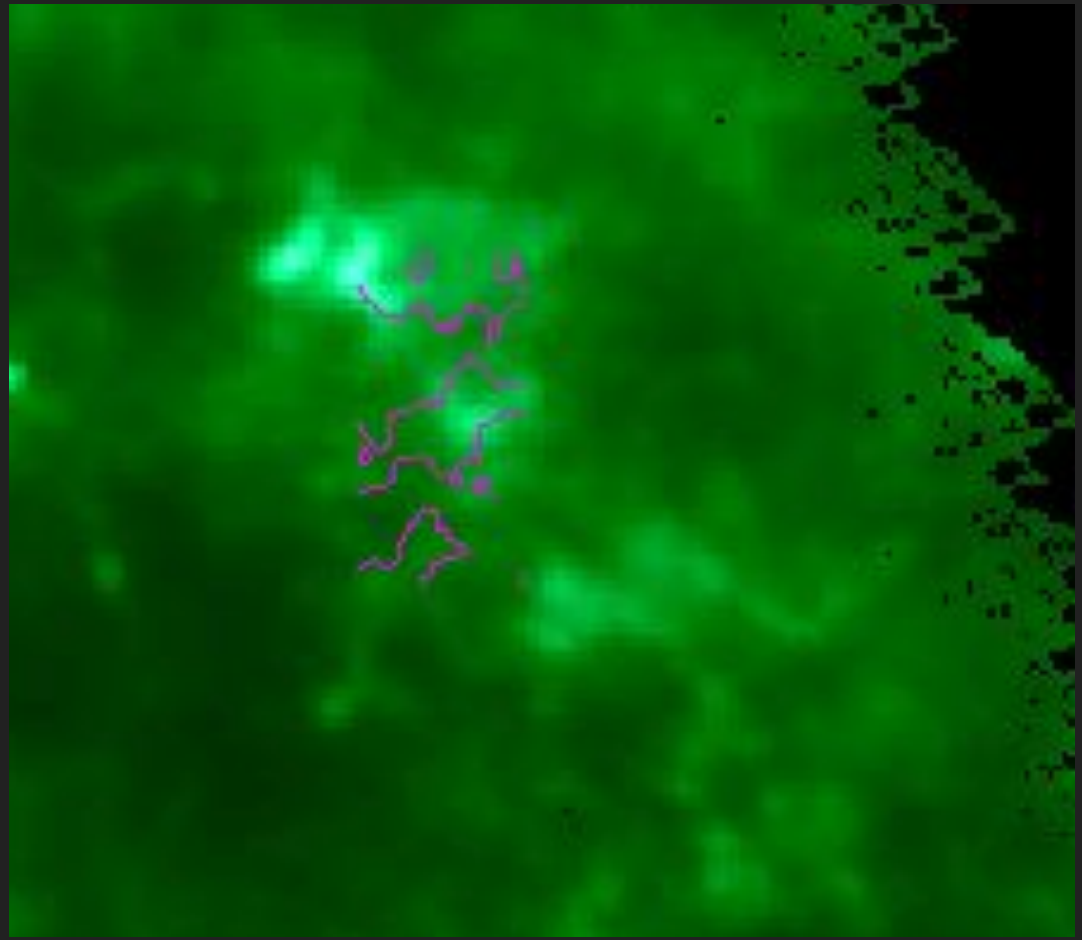
Savannah Gramze

August 9th, 2019

Juergen Ott
David Meier
Adam Ginsburg
Brian Svoboda

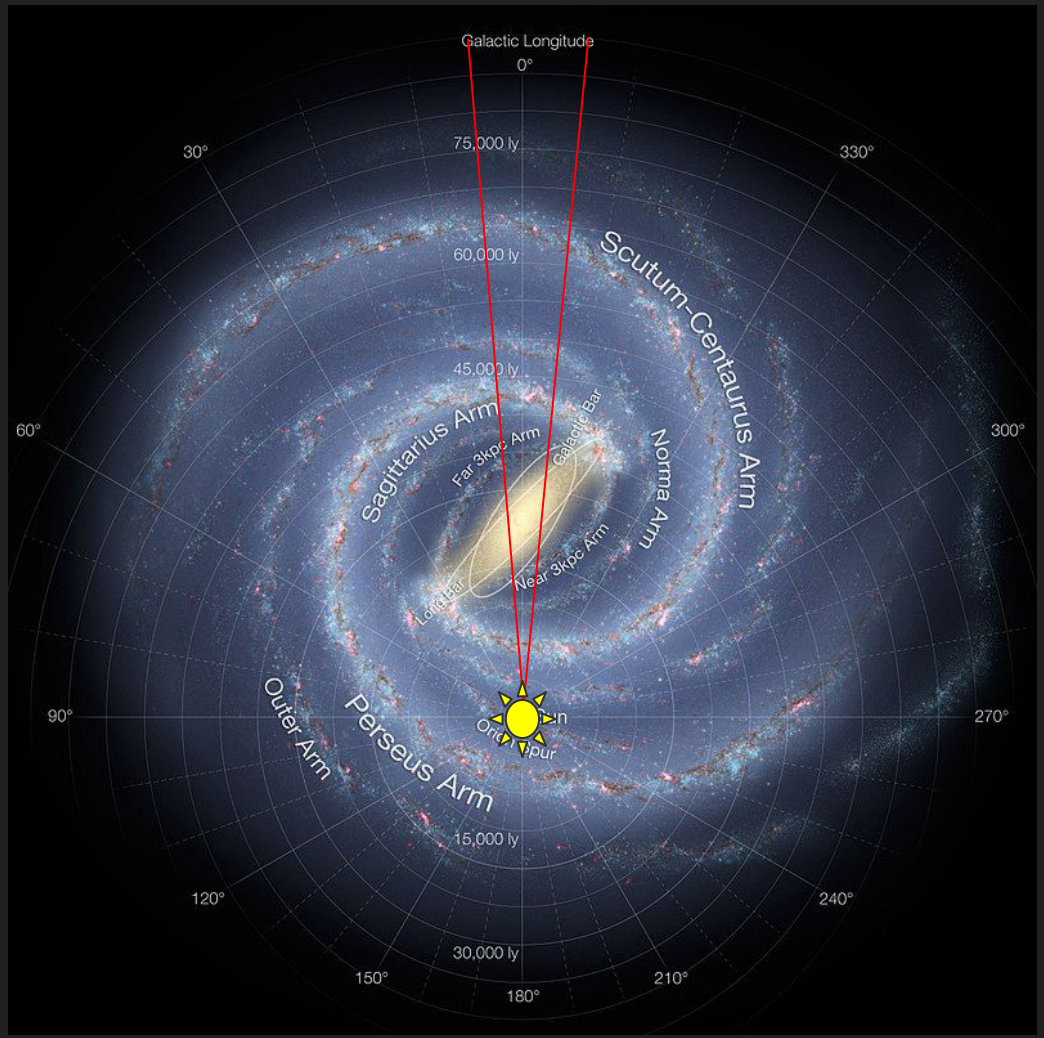


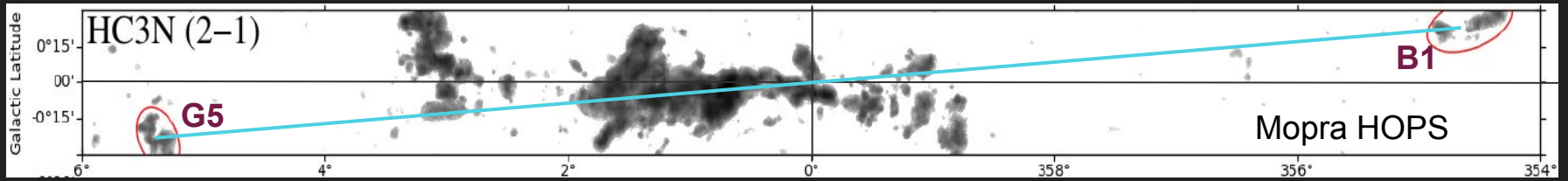


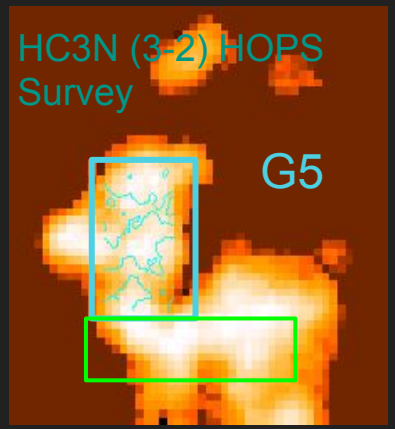


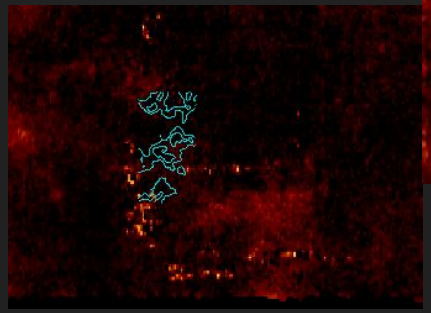
Introduction

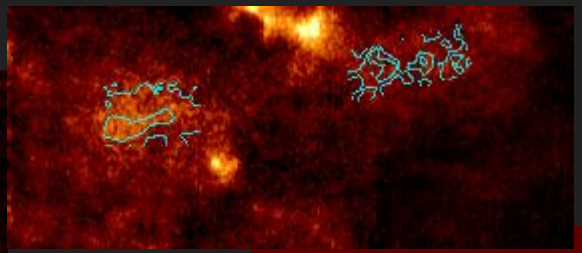
- The Galactic Center of the Milky Way Galaxy is the closest example we have of a galactic nucleus.
- It has unusual properties not found in the galactic disk, including very wide velocity widths, high temperatures, high densities, and inefficient star formation proportional to how much gas is there.
- It is a barred spiral galaxy, and the bar potential may control how and how much of the gas flows in from the spiral arms.



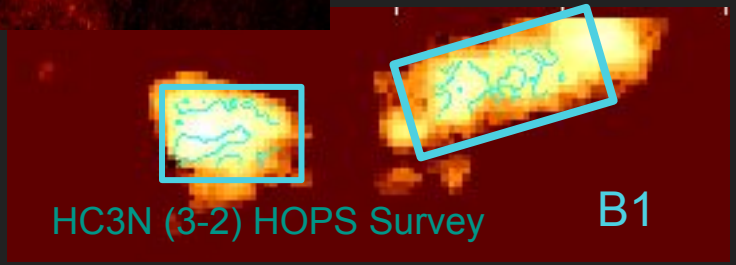








Slightly hotter and denser than the other gas.

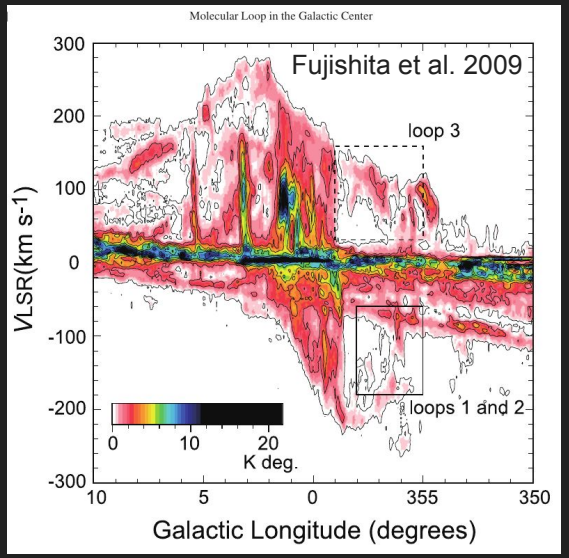


Three Possible Explanations

Barred Potential Response

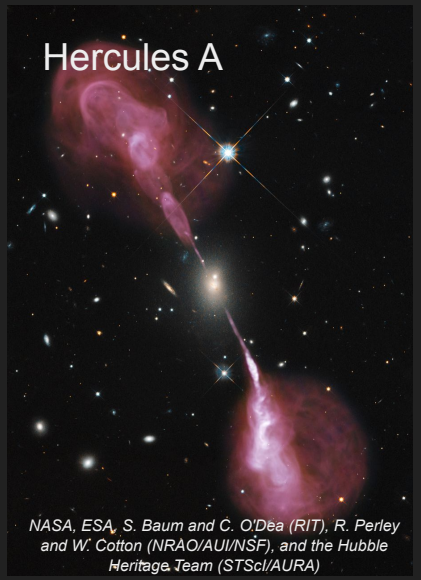
- Various orbits possible in a bar potential.
- Clouds may be evidence of some interaction between gas from these orbits, or inflow from spiral arms

Molecular Loops



- Loops made from the Galaxy's magnetic field.
- Much like sun spots.
- B1 may be the "foot point" of one of these loops.

Outflow from SgrA* ???



- Relation to SgrA* may be that they are evidence of previous outflow events.
- Side of clouds facing GC should be more excited than side further away.

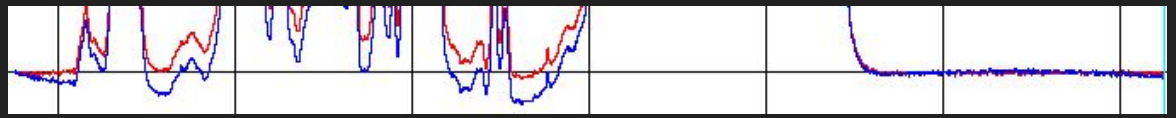
Observations

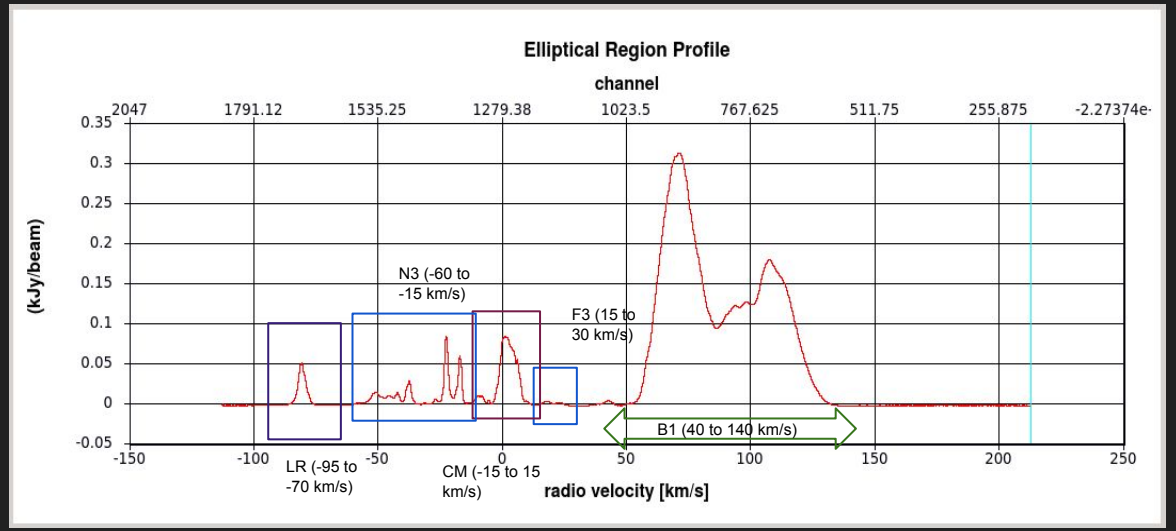
- ALMA, Atacama Compact Array
  - Took both 7m and TP observations.
- About 60 hours in total used to observe.
- Band 6, around 220 GHz. TP 12m resolution of 30” and structure size of 1.25pc.
  - Resolution ~6” with ACA, structure sizes of ~0.25pc at 8.2kpc away in the galactic center.
- Four regions in total, two at each cloud.
  - B1 (Bania 1) at (l,b) = (-5.4,+0.4), G5 at (+5.4, -0.4)
- Observed transitions of CO isotopologues, H30a, HC_3N, SiO, and two H_2CO transitions.

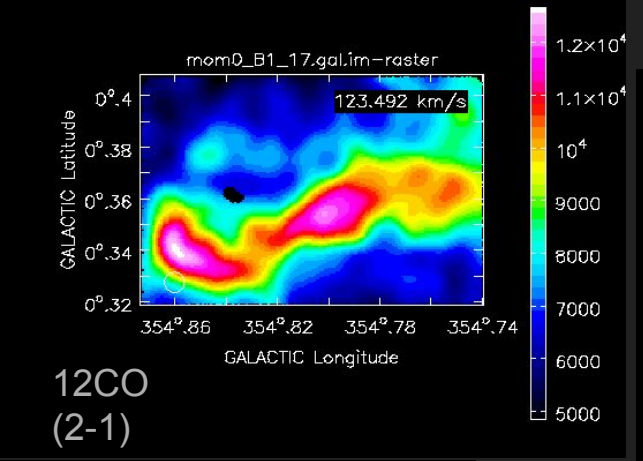
Data Reduction

- Used imcontsub to make a polynomial fit to fix poor baselining on cubes.
- Identified which channels and velocities contained spectral features from the clouds.
- Used immoments to make moment maps of just those channels.
- Discovered that there were no HC_3N spectral lines, but there are CH_3OH lines and two unidentified spectral lines.
- Various ratios were made of the moment 0 maps with immath.
- Excluded 7m and H30a for this portion of the research.

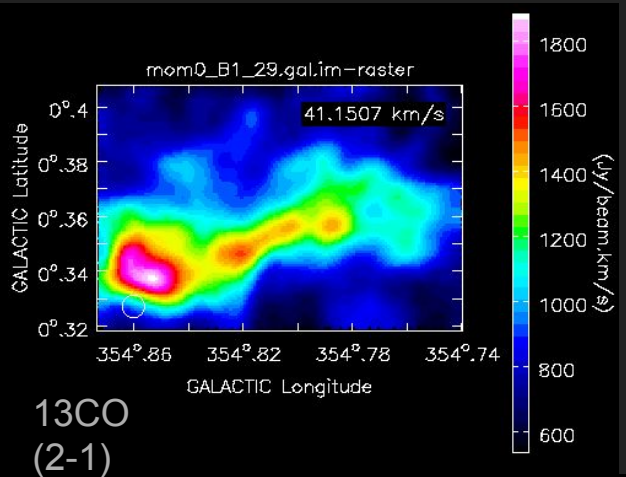
Uncorrected - Corrected



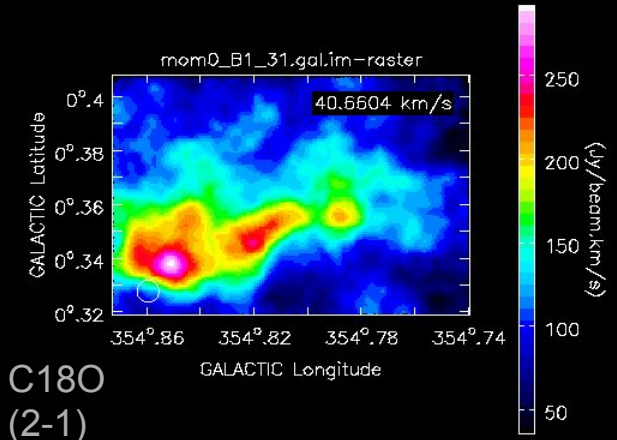




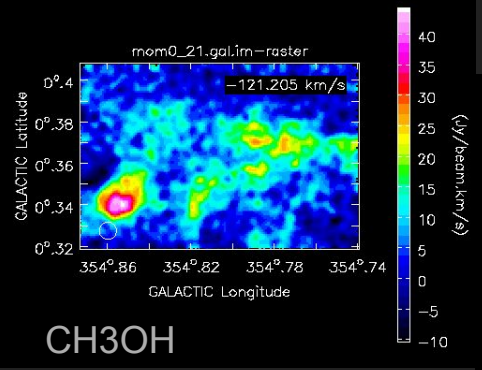
12CO
(2-1)



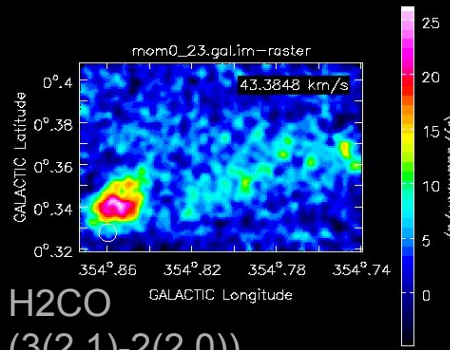
13CO
(2-1)



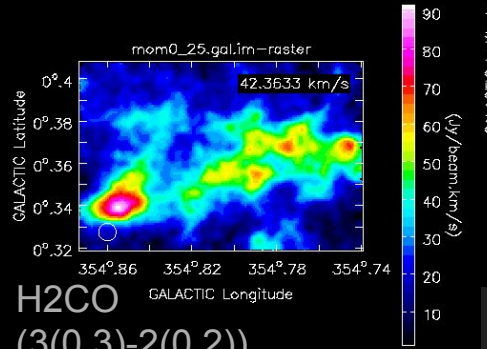
C18O
(2-1)



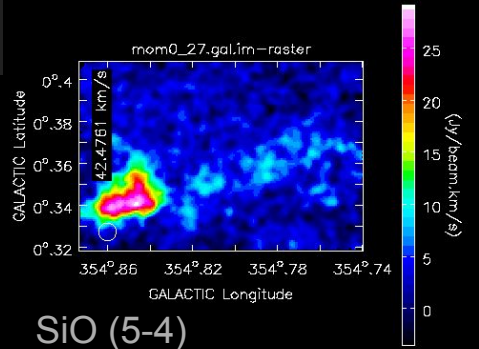
CH3OH
4(2,2)-3(1,2)



H2CO
(3(2,1)-2(2,0))



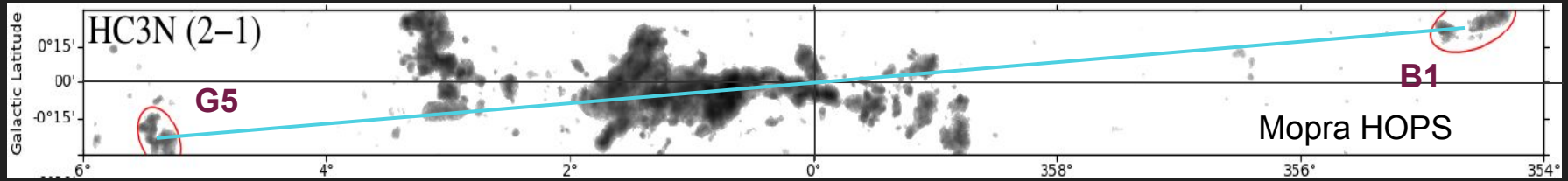
H2CO
(3(0,3)-2(0,2))

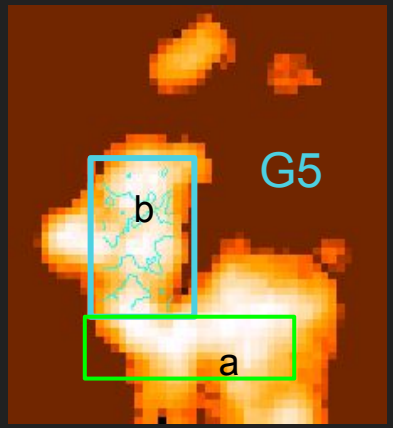


SiO (5-4)

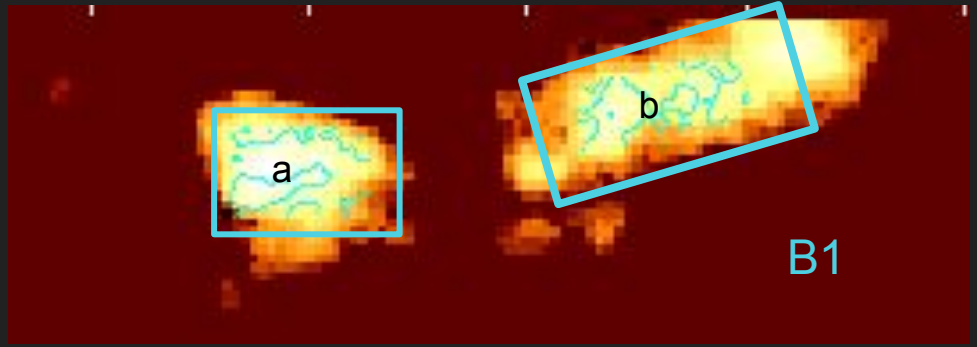
Moment 0 Maps of B1a - Area under curve of spectral feature, integrated intensity.

Results





HC3N (3-2) HOPS Survey

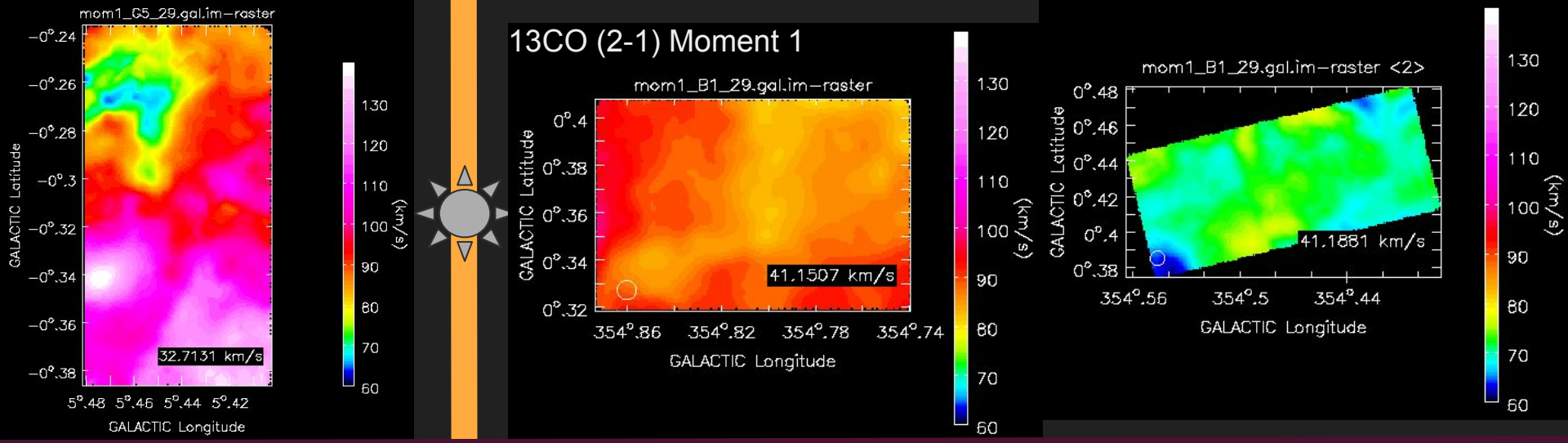


HC3N (3-2) HOPS Survey

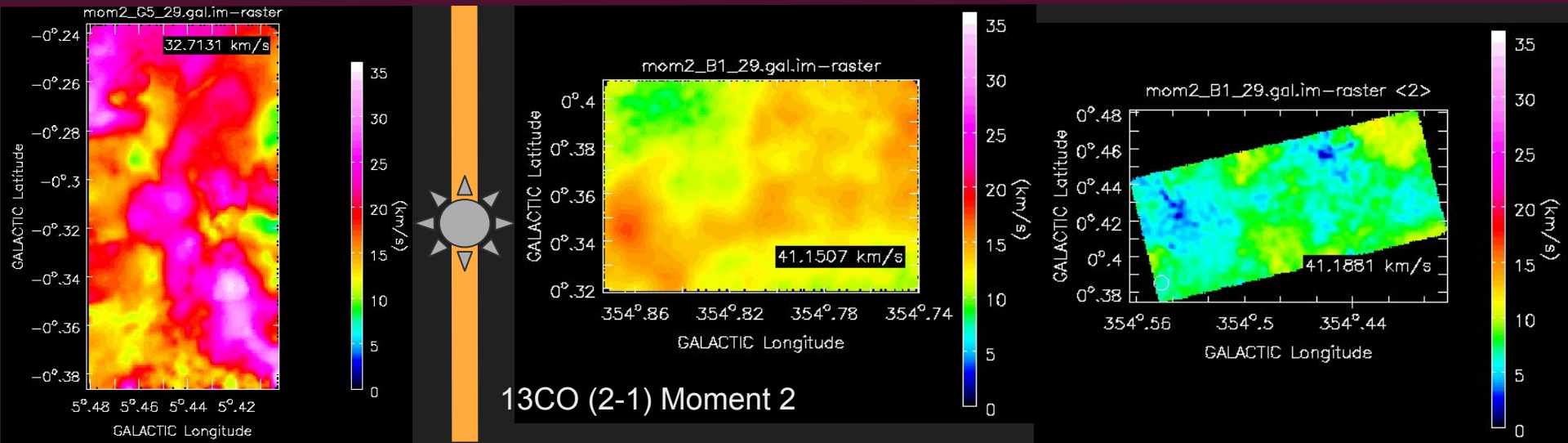
1. Kinematics Maps
2. CO Line Ratios and Gas Opacity
3. Formaldehyde Temperatures
4. Column Densities and Shock Tracers

Moment 1 and 2 Maps

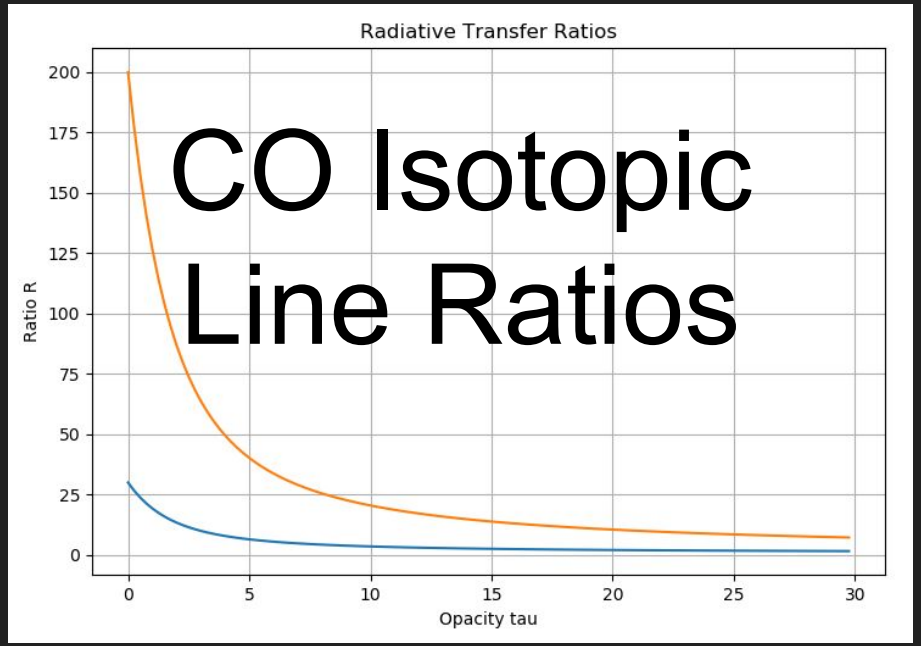
- Moment 1 shows the mean velocity of the spectrum selected, so it shows the velocity of that pixel.
- Moment 2 shows the velocity dispersion of the spectrum selected, so it shows how turbulent the gas is in that pixel.



13CO (2-1) Moment 1

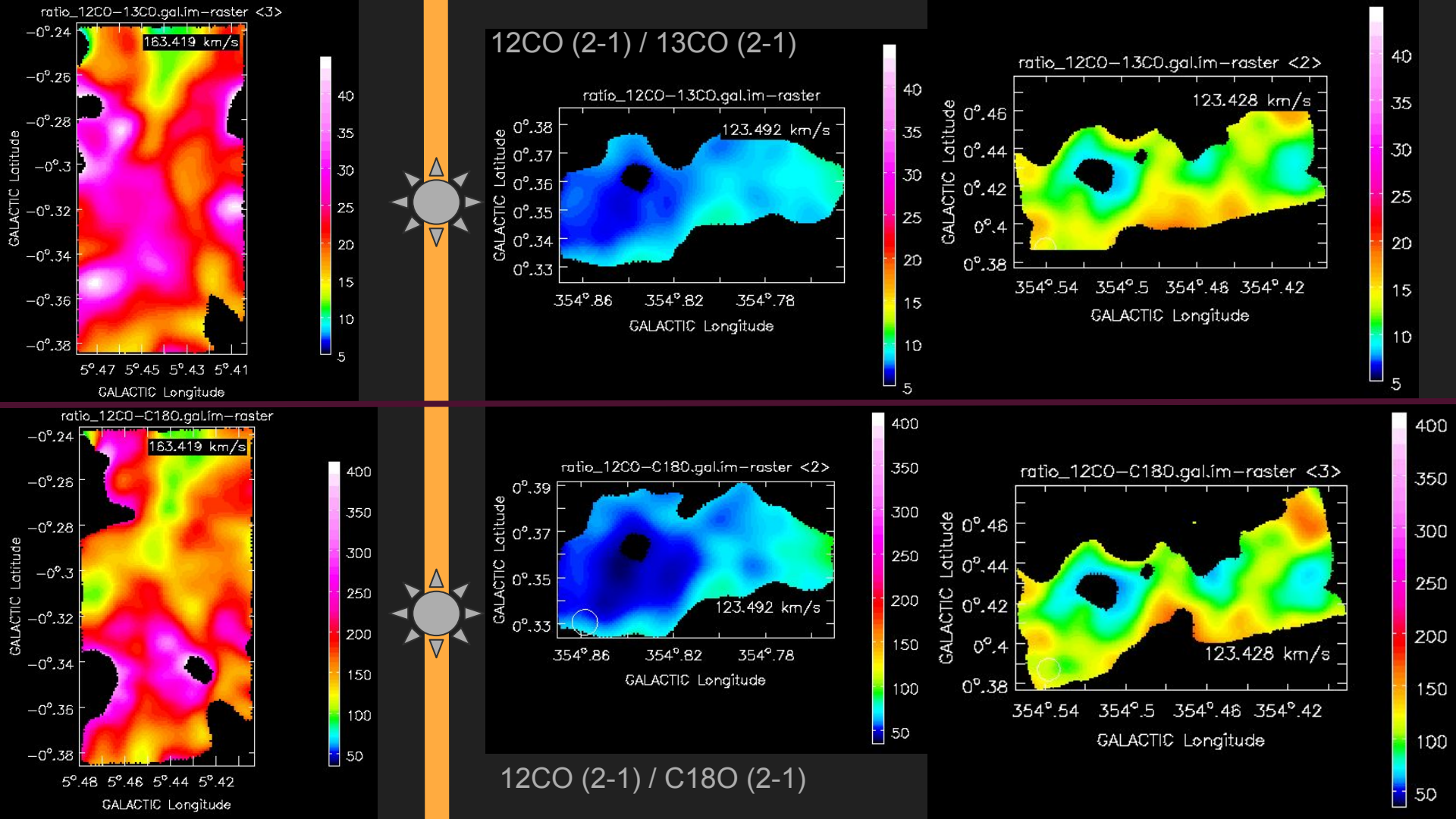


13CO (2-1) Moment 2

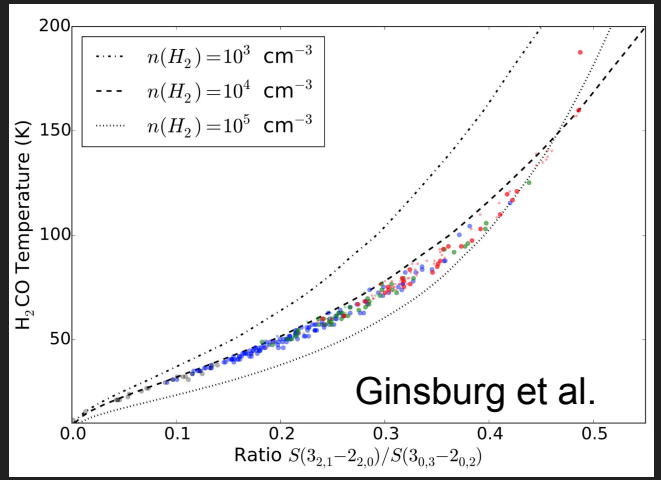


- Ratios of 12CO to its less abundant isotopologues ^{13}CO and $C^{18}O$.
- Help to calculate the opacity, “tau” value, of the clouds.

- Tau values for these clouds are about 1 to 4, translucent.
- Show how thick the clouds are and what should be expected from higher resolution observations.

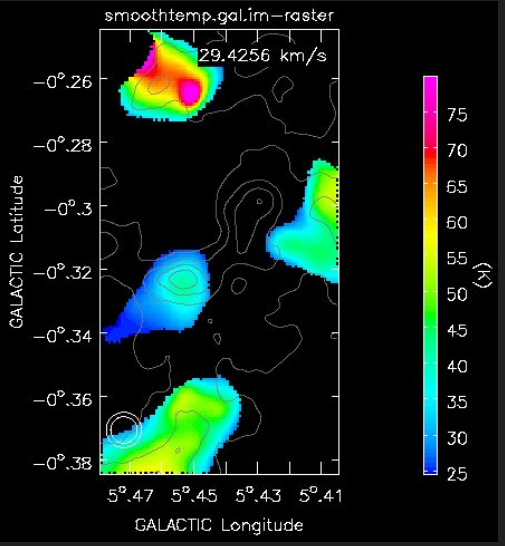

12CO (2-1) / 13CO (2-1)
ratio_12CO−13CO.gal.im−raster <3>
163.419 km/s
ratio_12CO−13CO.gal.im−raster
123.492 km/s
ratio_12CO−13CO.gal.im−raster <2>
123.428 km/s
GALACTIC Latitude
GALACTIC Longitude
ratio_12CO−C18O.gal.im−raster
ratio_12CO−C18O.gal.im−raster <2>
ratio_12CO−C18O.gal.im−raster <3>
12CO (2-1) / C18O (2-1)

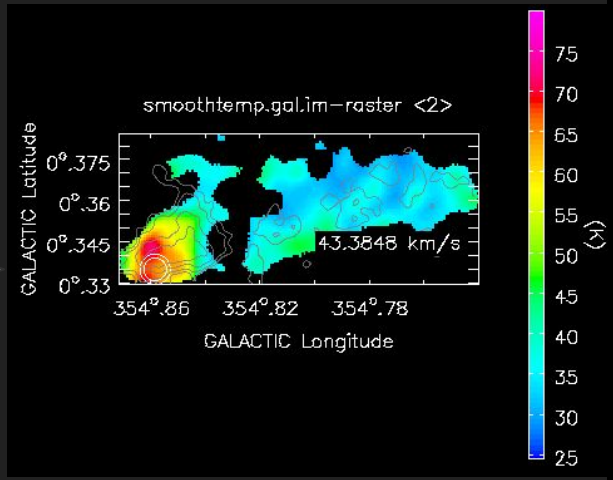
Formaldehyde Temperatures

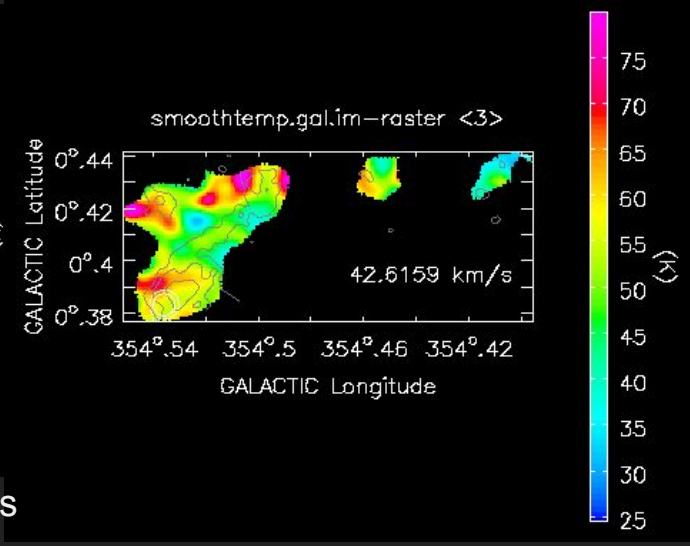


- Calculated based on ratio between two close formaldehyde spectral lines.
- Used a fit based on the relationship between the ratio and the temperature in Kelvin.

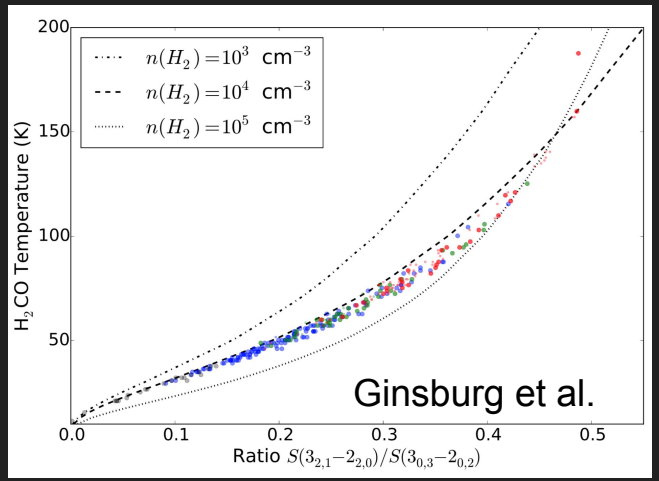
$T = 590 \times ratio^2 + 2.88 \times ratio + 23.4$







Kinetic Temperature with SiO contours



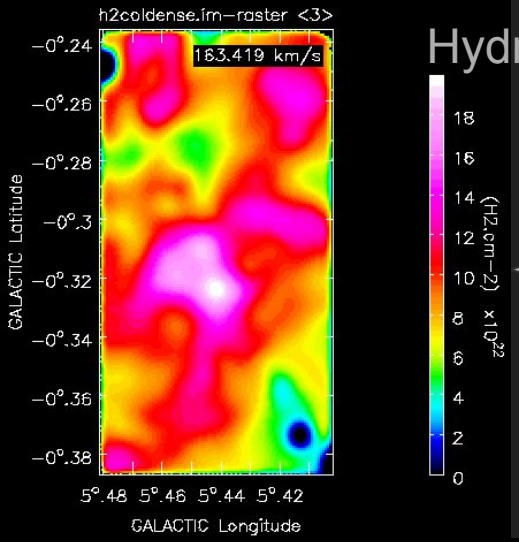
The temperatures of these clouds are around 35 to 80K, which are similar to the bulk of the galactic center.

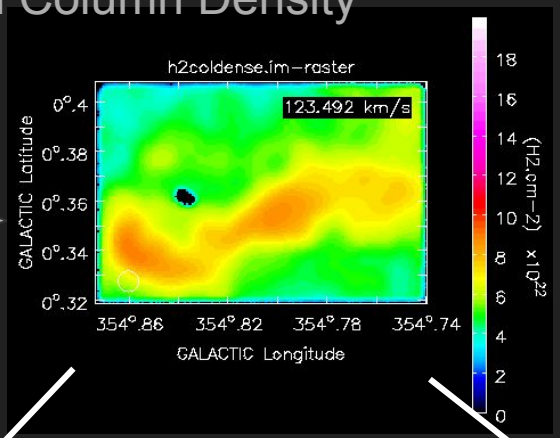
Column Densities

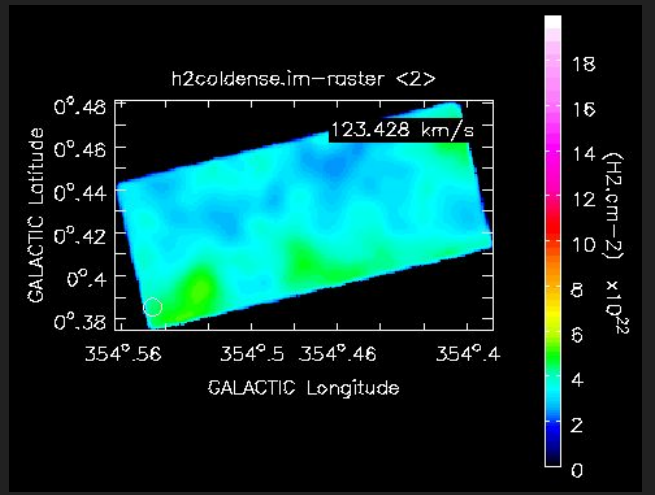
$N(H_2) = X * W_{CO}$
$X = 2e20$ (cm-2/(K*km/s))
N(H2) = 2e20 * M0 / 0.8
$W_{CO} = M0_{12CO(2-1)} / 0.8$

- Column Densities show how much gas there is.
- H_2 Column Density calculated from the Moment 0 Maps of ^{12}CO using the standard X-factor.
- SiO and CH_3OH column densities are based on the temperature of the gas, the intensity of the transition, and molecule specific constants.

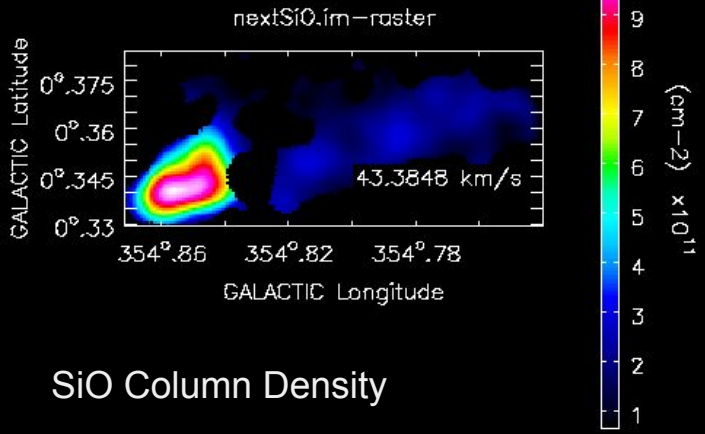
Hydrogen Column Density







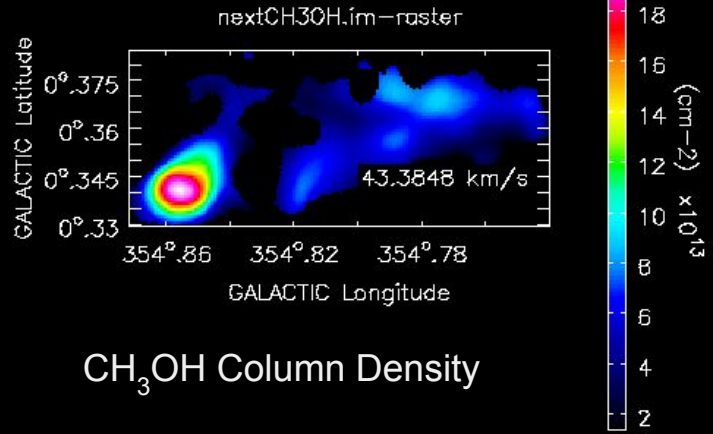
X_{SiO} ~ 10^-11



SiO Column Density

The shock tracers SiO and CH_3OH have high column densities, but their abundances relative to H_2 are only slightly elevated above zero, and overall not very high.

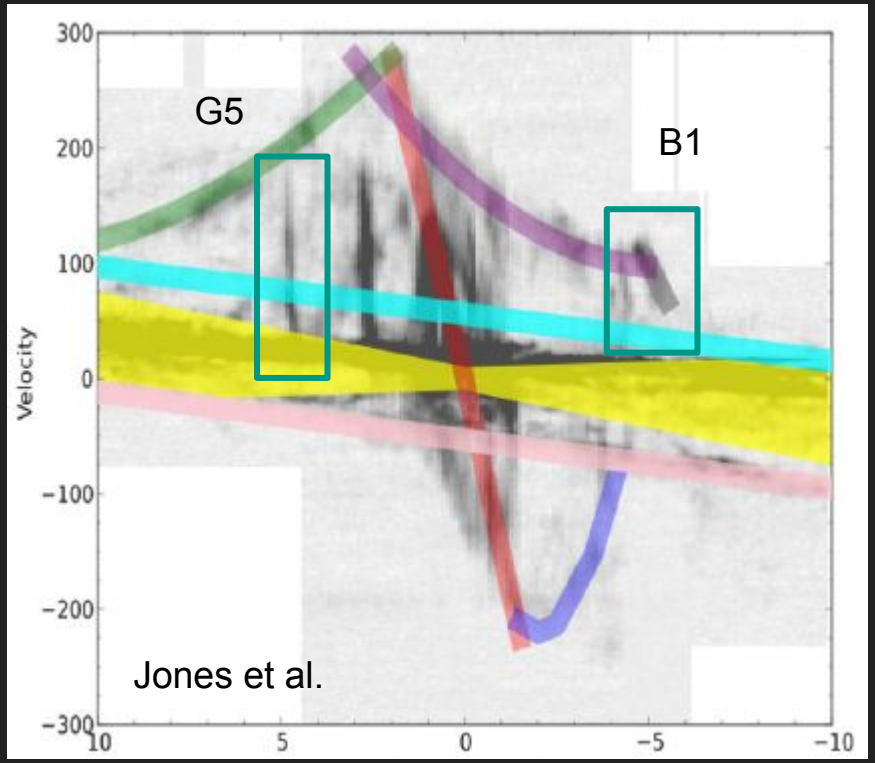
X_{CH3OH} ~10^-10

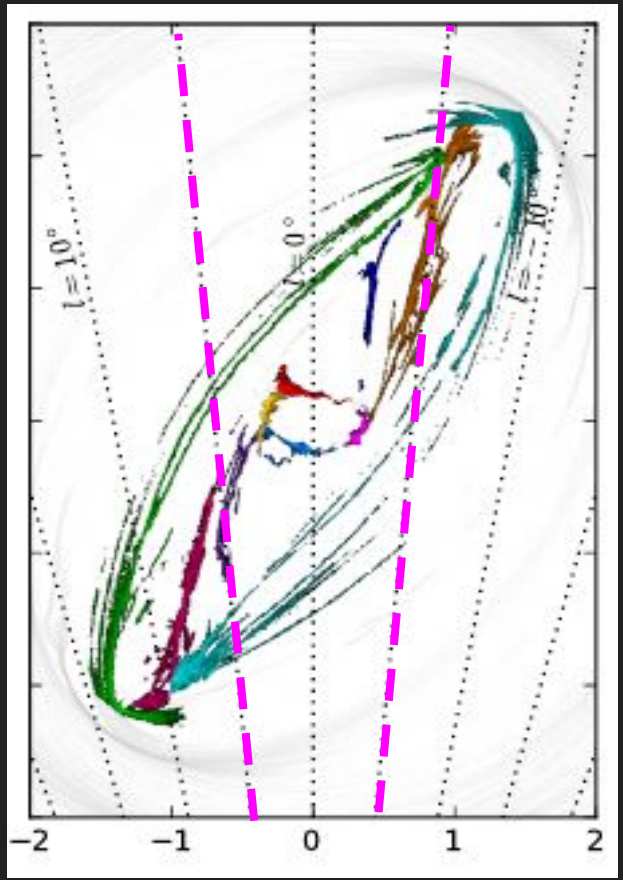


CH_3OH Column Density

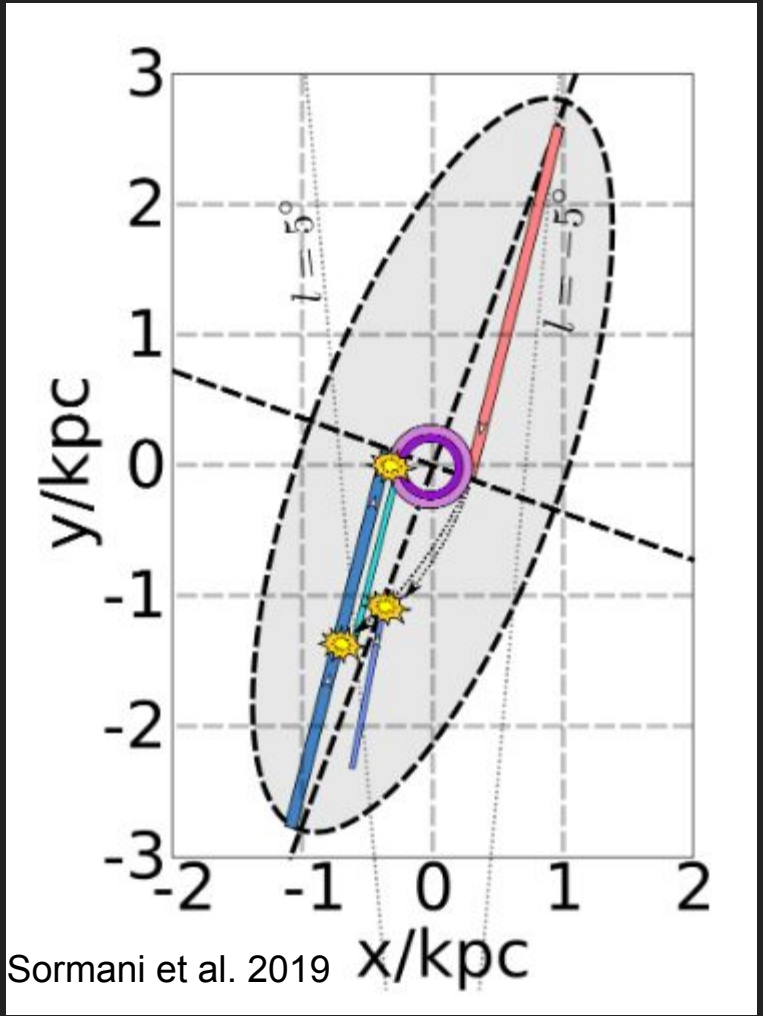
Discussion

- From the data, we can tell several things:
  - The line widths are extremely large and consistent with those found in the galactic center
  - The clouds are hot, with kinetic temperatures of around 50K.
  - From their tau values, they are not optically thick.
  - There are weak shocks.
  - They have high column densities, but they seem to be less dense in general.
- Consistent with bar model.





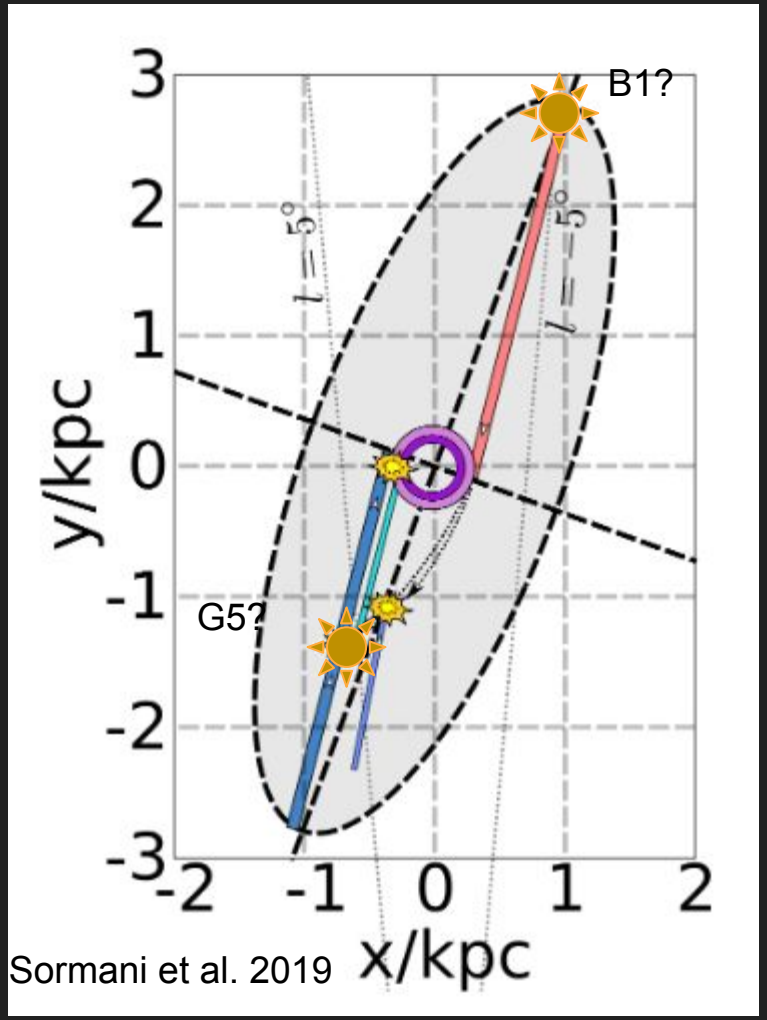
Sormani et al. 2018



Sormani et al. 2019

Conclusion

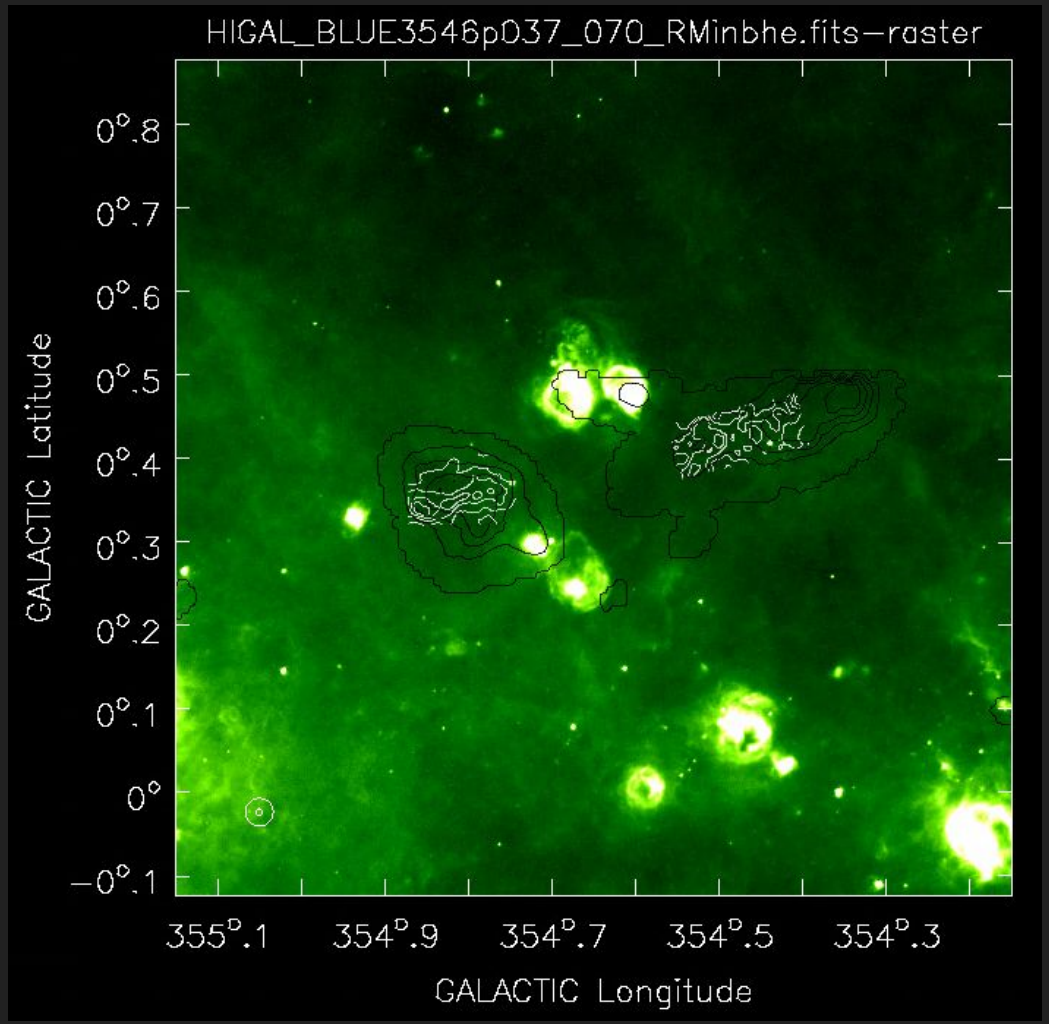
- These clouds are consistent with the bar model of the galaxy.
- They are not as similar as assumed.
- G5 is probably overshooting gas colliding with a dust lane.
- B1 is something else, perhaps a view down a dust lane or gas just entering the galactic center.

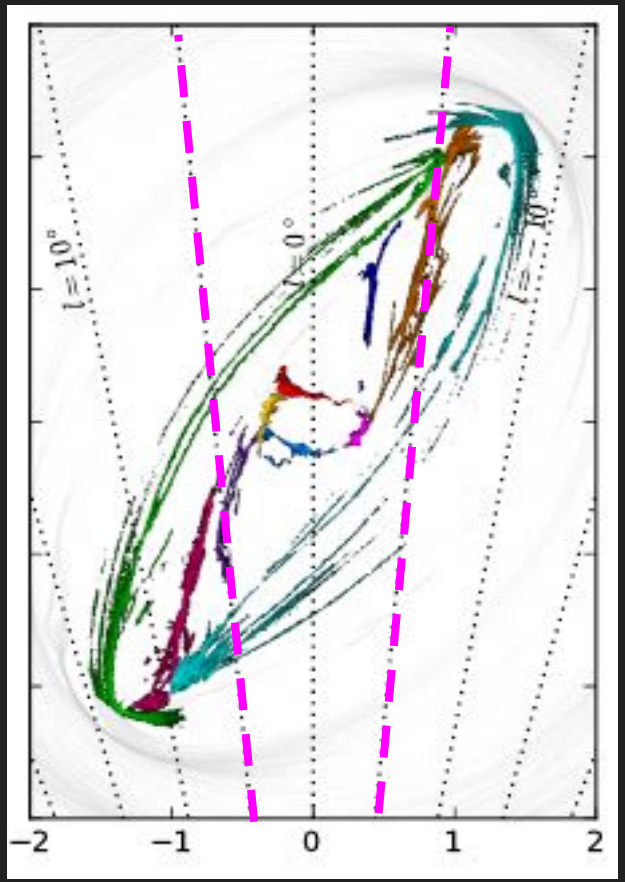


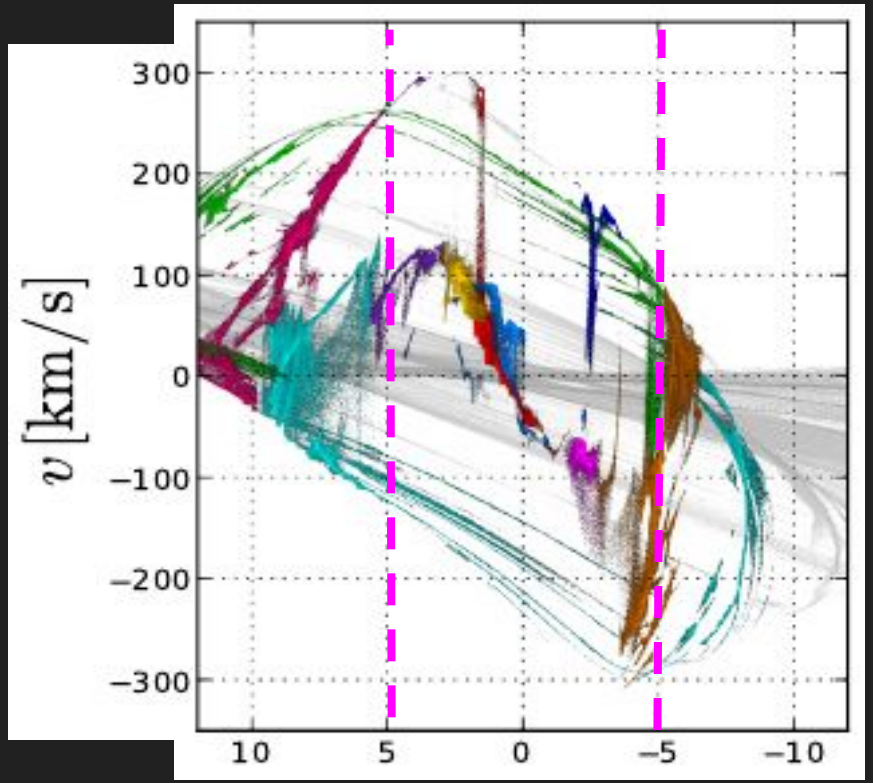
Sormani et al. 2019

Future Research

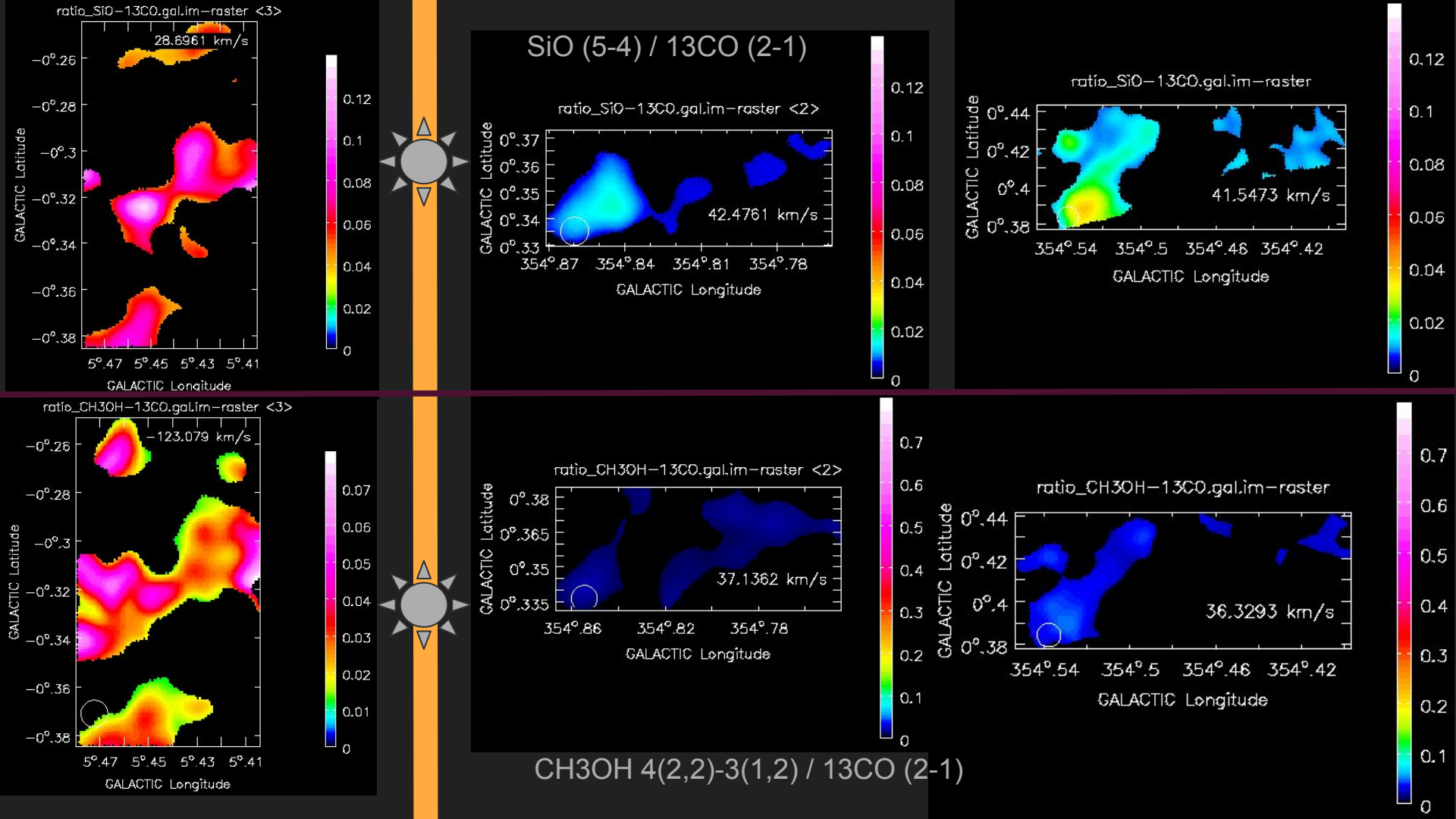
- Reduce 7m data and combine it with TP data to better understand the internal structure of the clouds better.
- Make TP observations of the entire clouds instead of just regions of them.
- Continue with more TP observations of other clouds along the bar in the galactic center which may be like G5 and B1.
- Compare the properties of these clouds with those of Bania 2.
- Make our own models of the galaxy/galactic center in collaboration with Sormani’s group.


HIGAL_BLUE3546p037_070_RMinbhe.fits−raster
0°.8
0°.7
0°.6
0°.5
0°.4
0°.3
0°.2
0°.1
0°
−0°.1
GALACTIC Latitude
355°.1
354°.9
354°.7
354°.5
354°.3
GALACTIC Longitude





Sormani et al. 2018


SiO (5-4) / 13CO (2-1)
ratio_SiO-13CO.gal.im-raster <3>
28.6961 km/s
ratio_SiO-13CO.gal.im-raster <2>
42.4761 km/s
ratio_SiO-13CO.gal.im-raster
41.5473 km/s
ratio_CH3OH-13CO.gal.im-raster <3>
-123.079 km/s
ratio_CH3OH-13CO.gal.im-raster <2>
37.1362 km/s
ratio_CH3OH-13CO.gal.im-raster
36.3293 km/s
GALACTIC Latitude
GALACTIC Longitude
CH3OH 4(2,2)-3(1,2) / 13CO (2-1)

H2CO (3(03)-2(02)) / 13CO