Feeding the Central Molecular Zone

Andy Nilipour

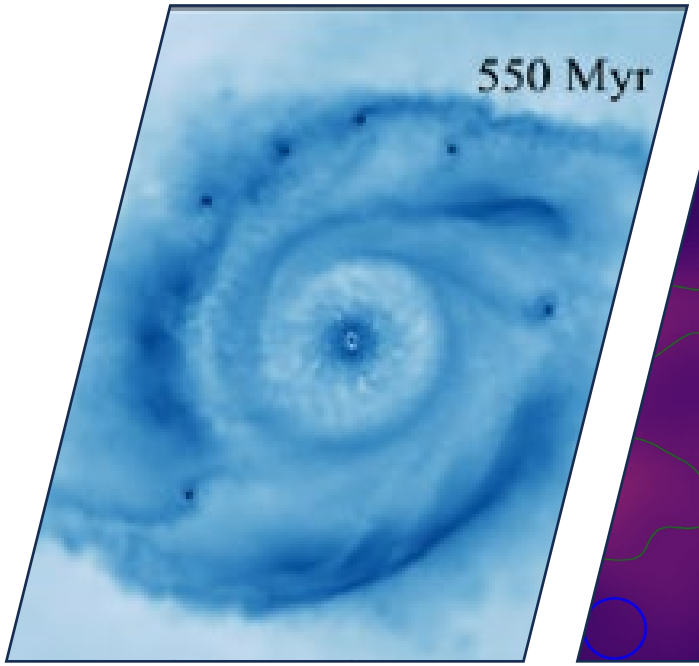
Mentors: Juergen Ott, Brian Svoboda, David Meier

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

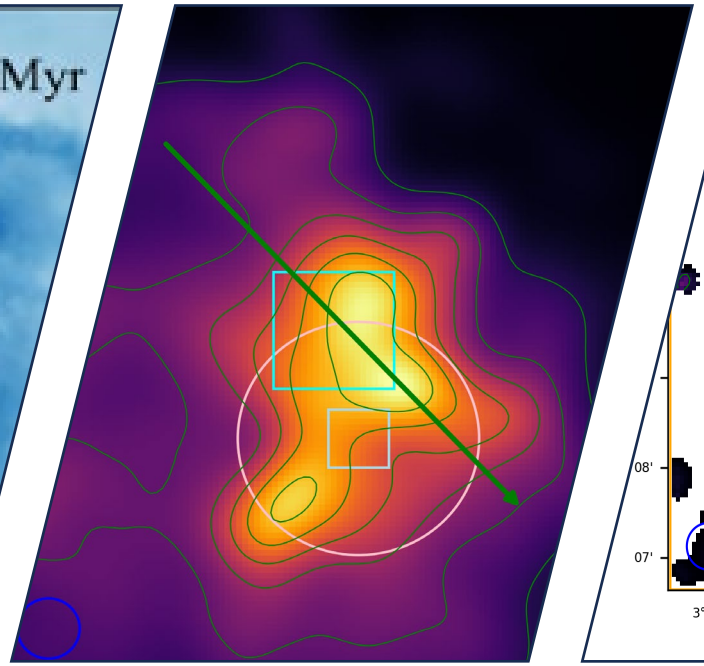
Yale

NRAO National Radio Astronomy Observatory

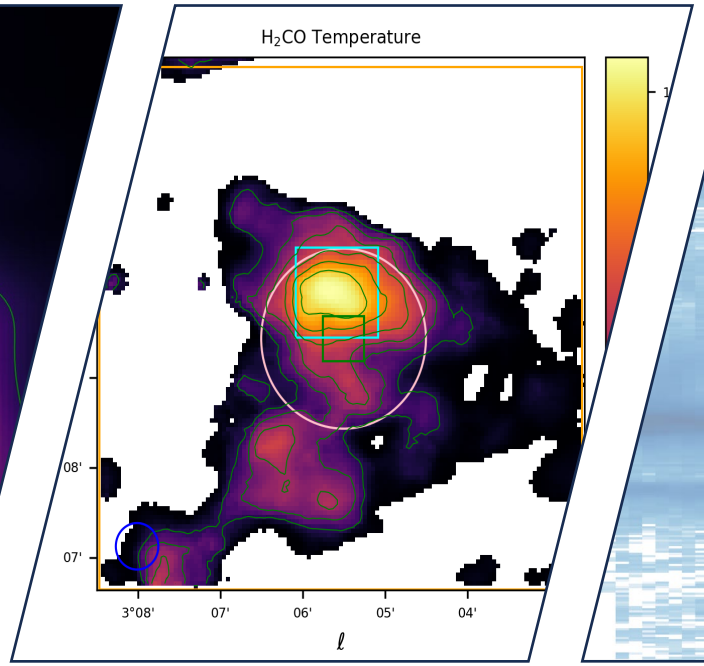
Outline



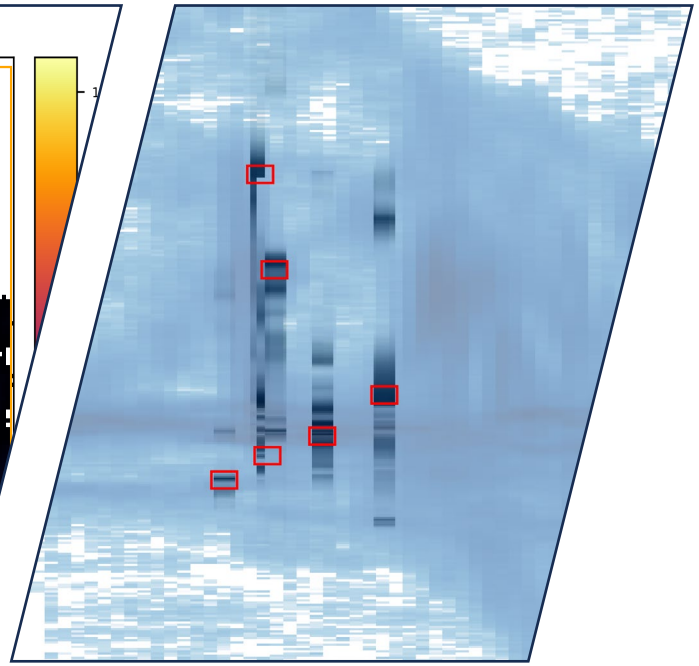
Background



Data

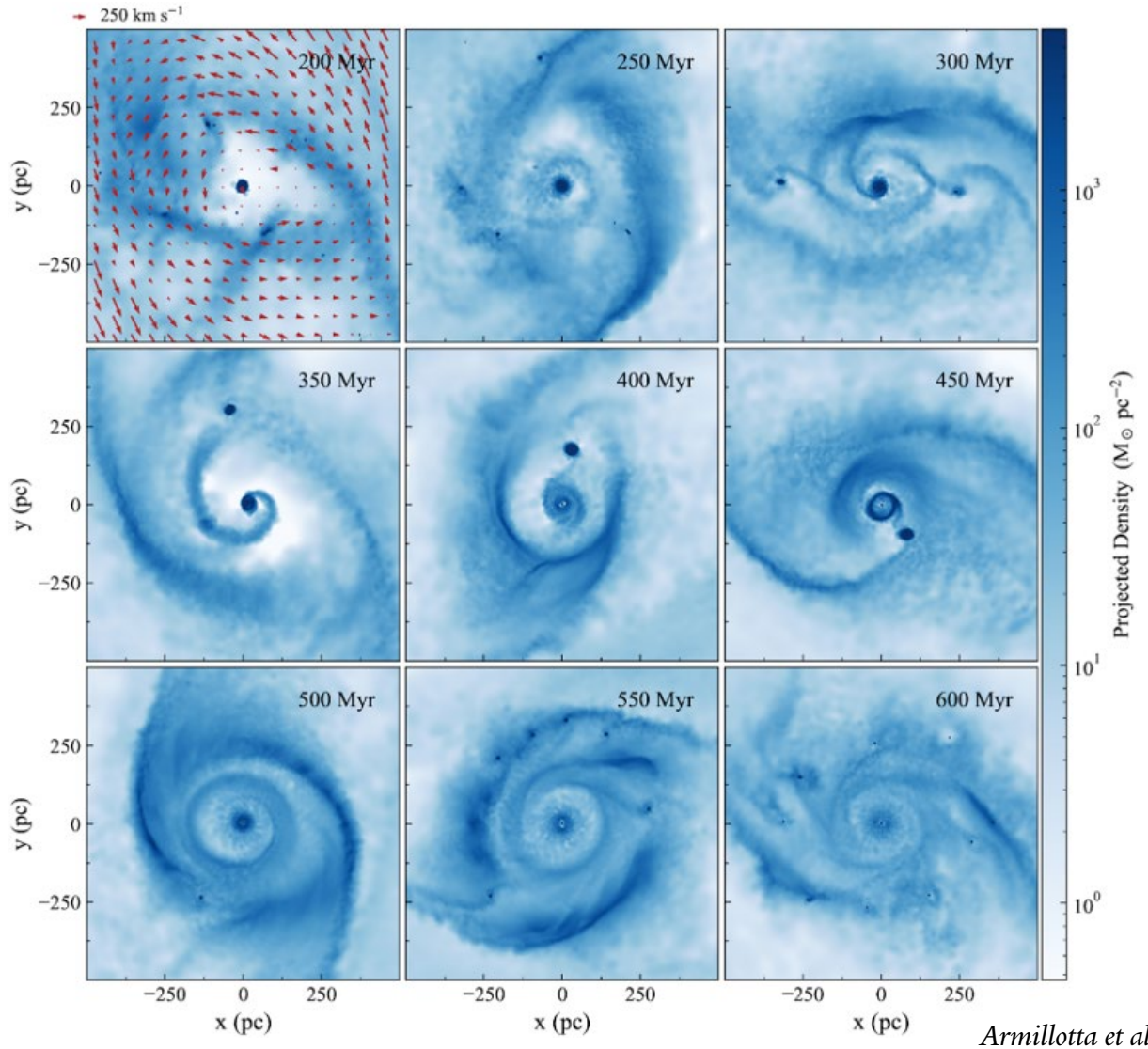


Properties



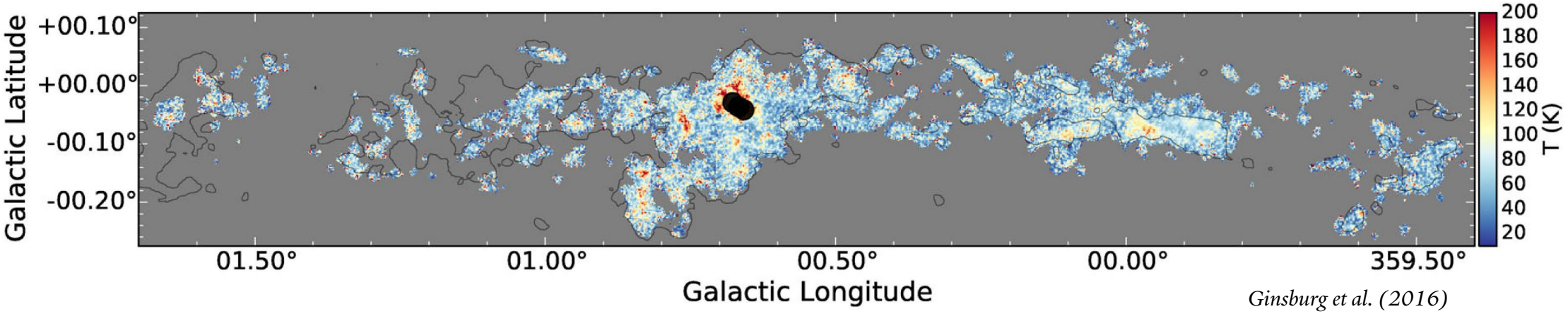
Discussion

Central Molecular Zone (CMZ)



Armillotta et al. (2019)

Central Molecular Zone (CMZ)

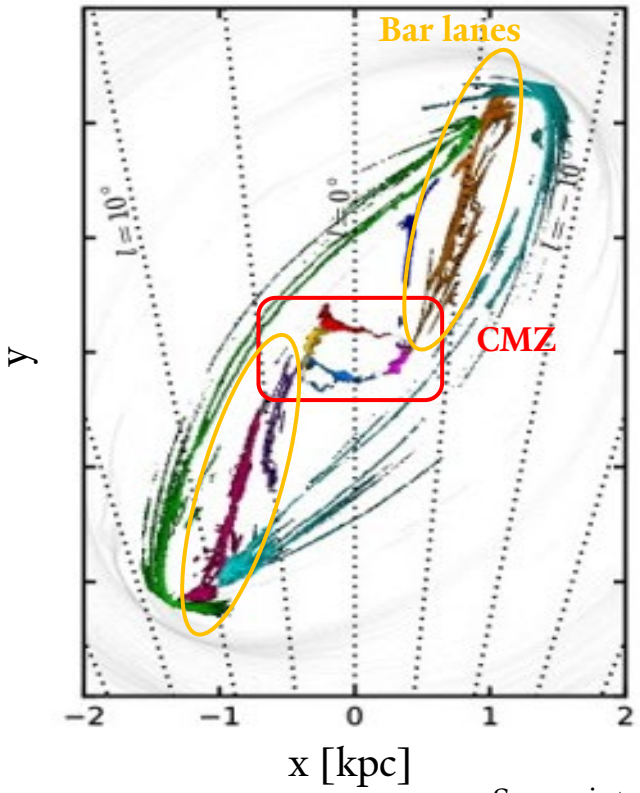


Ginsburg et al. (2016)

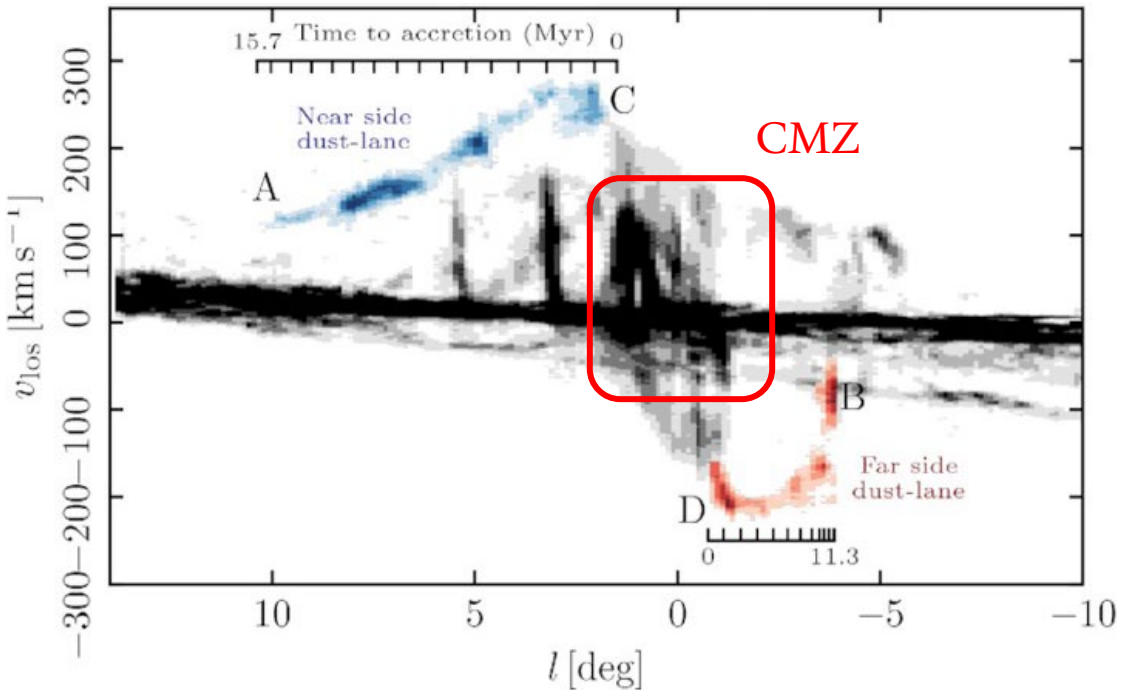
Dense, warm, and turbulent

CMZ Inflows

Bar potential drives inflows towards the CMZ



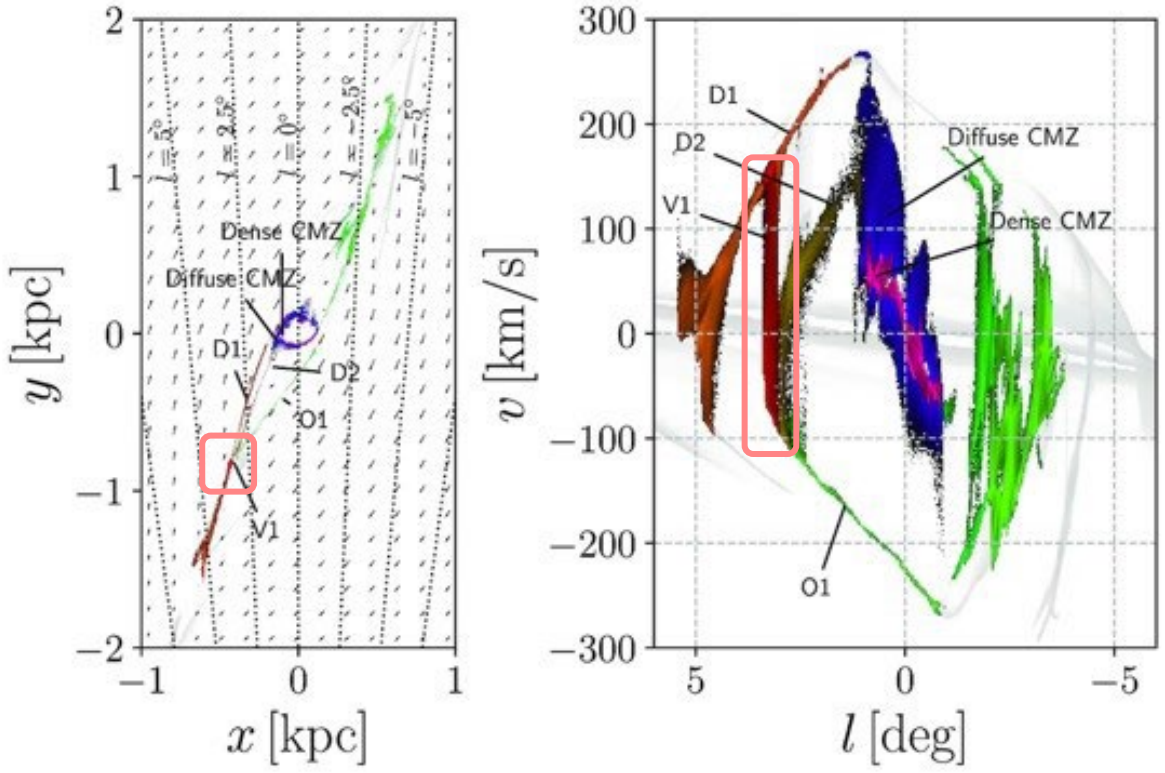
Sormani et al. (2018)



Sormani & Barnes (2019)

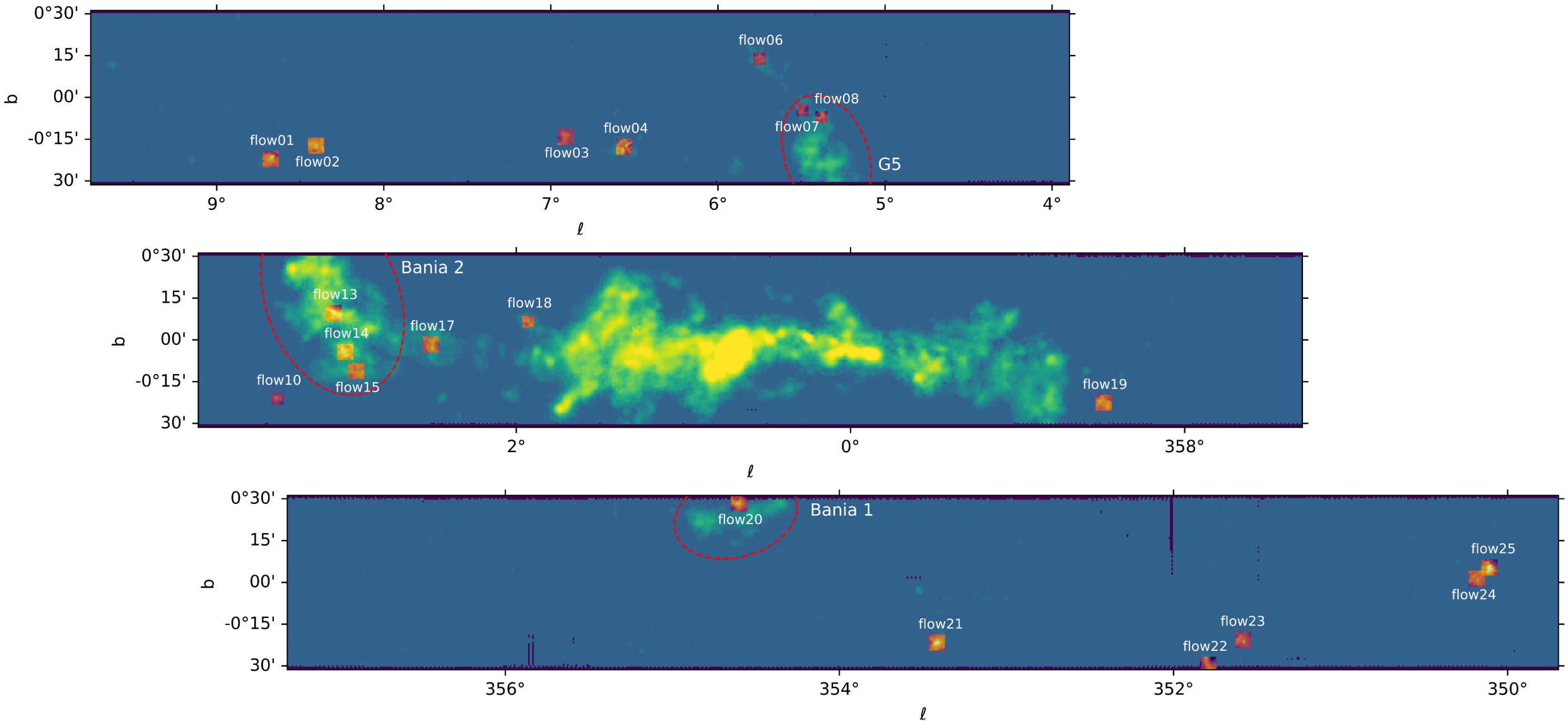
CMZ Inflows

Overshooting gas and collision sites



Sormani et al. (2019)

Selected 25 warm, broad-lined clouds outside the CMZ



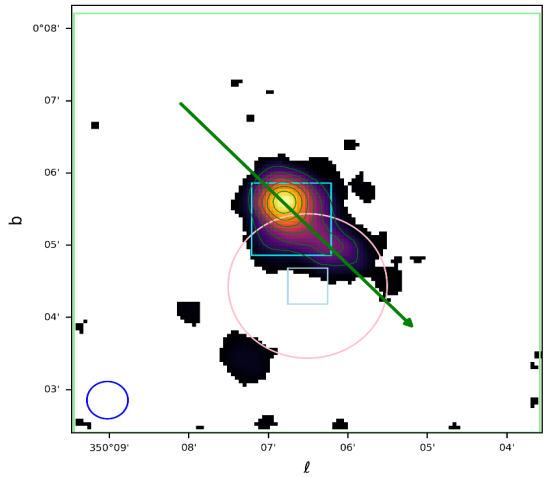
Atacama Compact Array

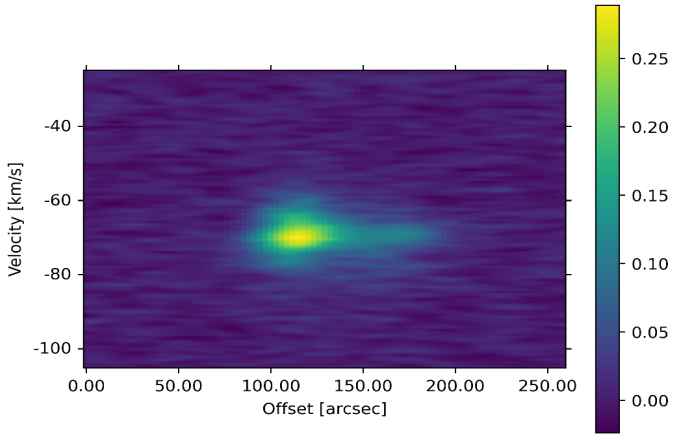
ALMA (ESO/NAOJ/NRAO)

Shortest baselines of ALMA

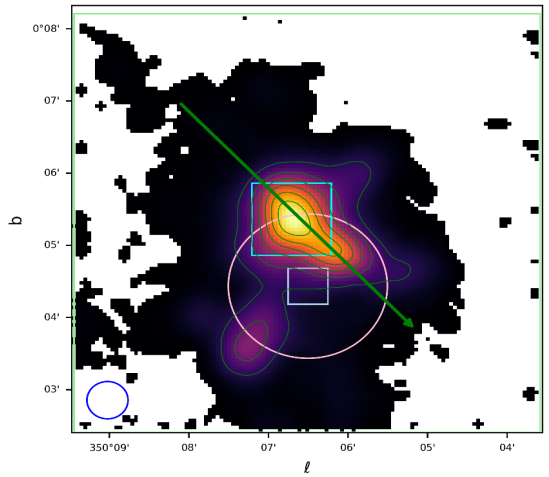
Data

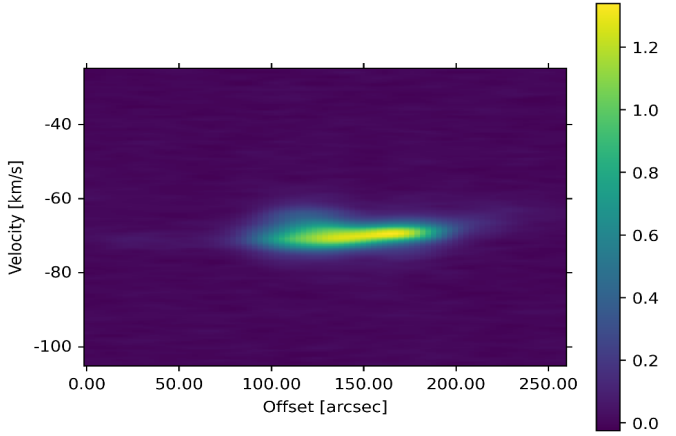
Cloud 25 SiO *5-4*



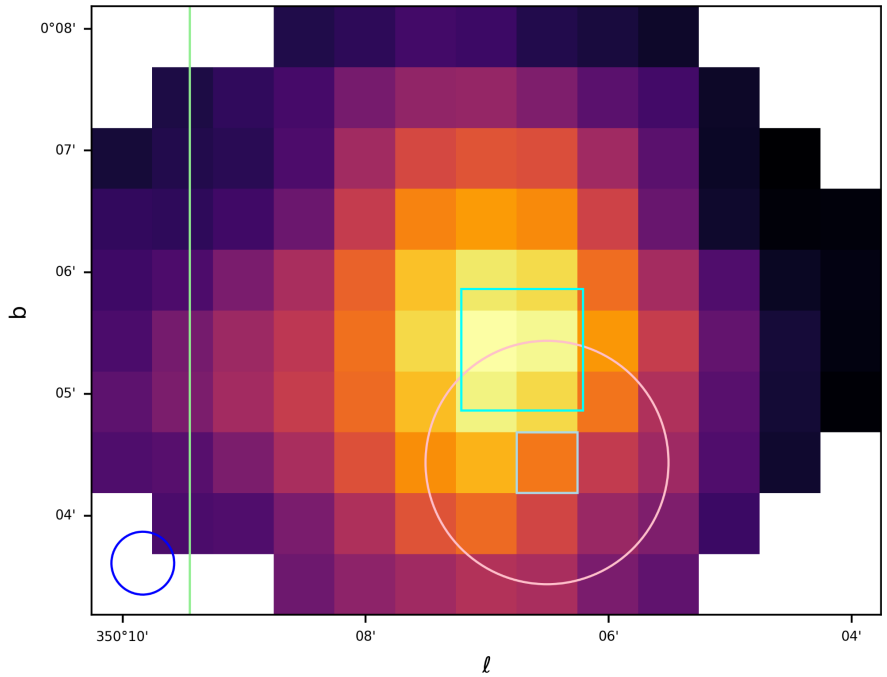


Cloud 25 H_2CO 3_{03}-2_{02}





Cloud 25 NH_3 (1,1)



ALMA (30" beam) Band 6:

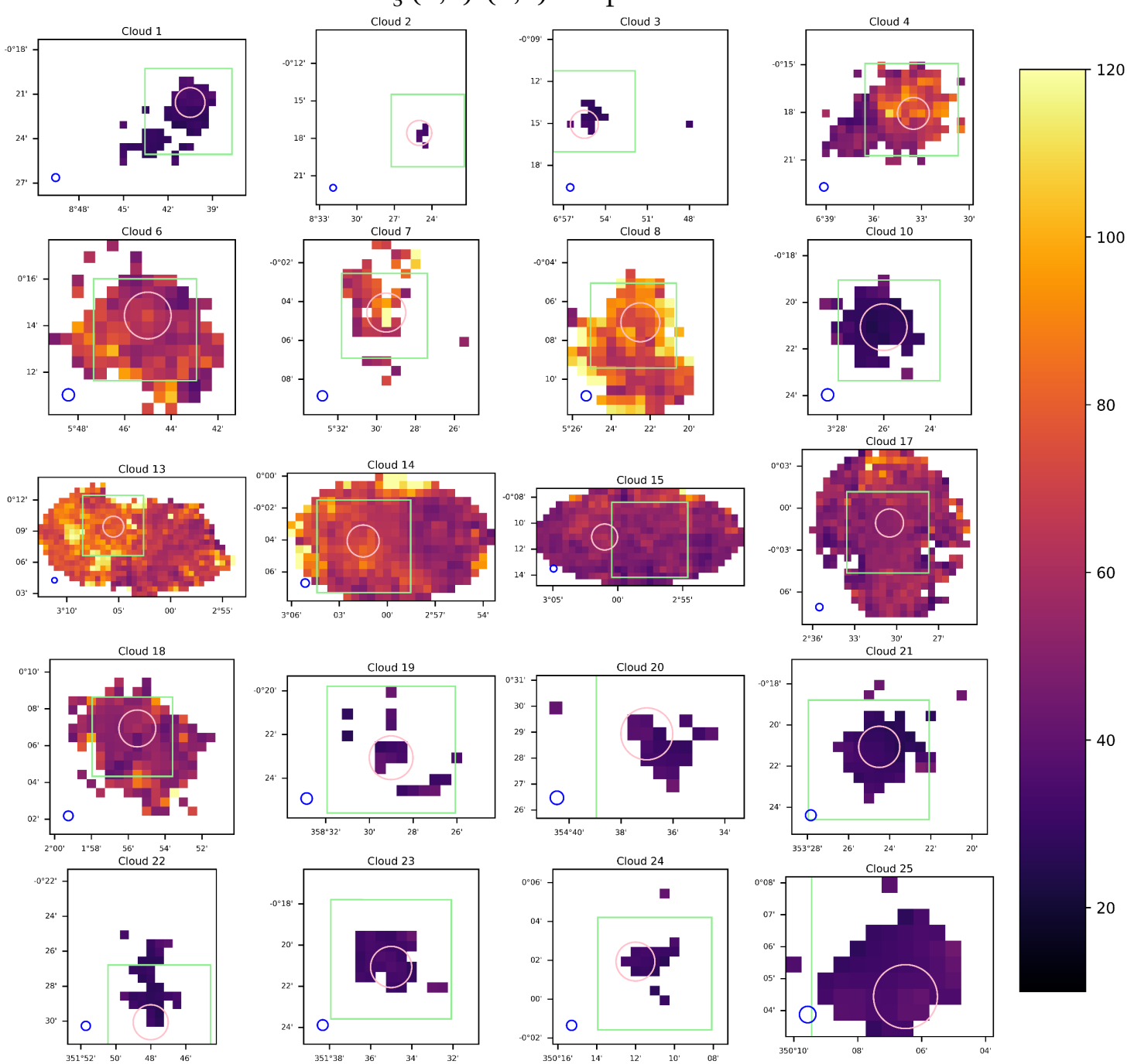
- SiO $J = 5 \rightarrow 4$
- H_2CO $J = 3_{21} \rightarrow 2_{20}$, $J = 3_{03} \rightarrow 2_{02}$
- HC_3N $J = 24 \rightarrow 23$
- CH_3OH $J = 4_{22} \rightarrow 3_{12}$
- $C^{18}O$, ^{13}CO, ^{12}CO $J = 2 \rightarrow 1$
- H30α

Mopra (2' beam) HOPS (H_2O southern Galactic Plane Survey):

- NH_3 (1,1), (2,2), (3,3), (6,6)

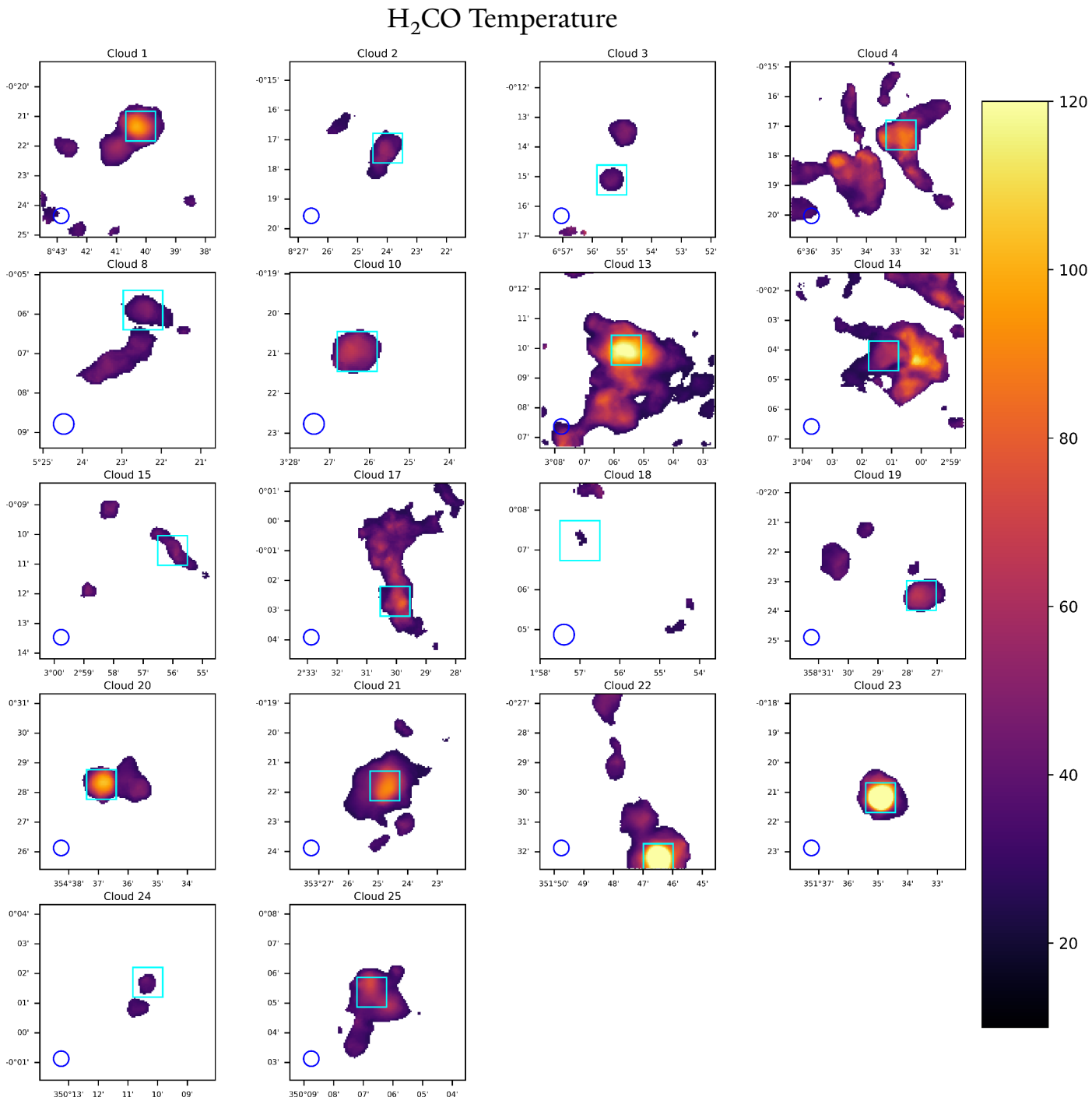
Ammonia Temperature

Clouds closer to the Galactic center seem to be warmer



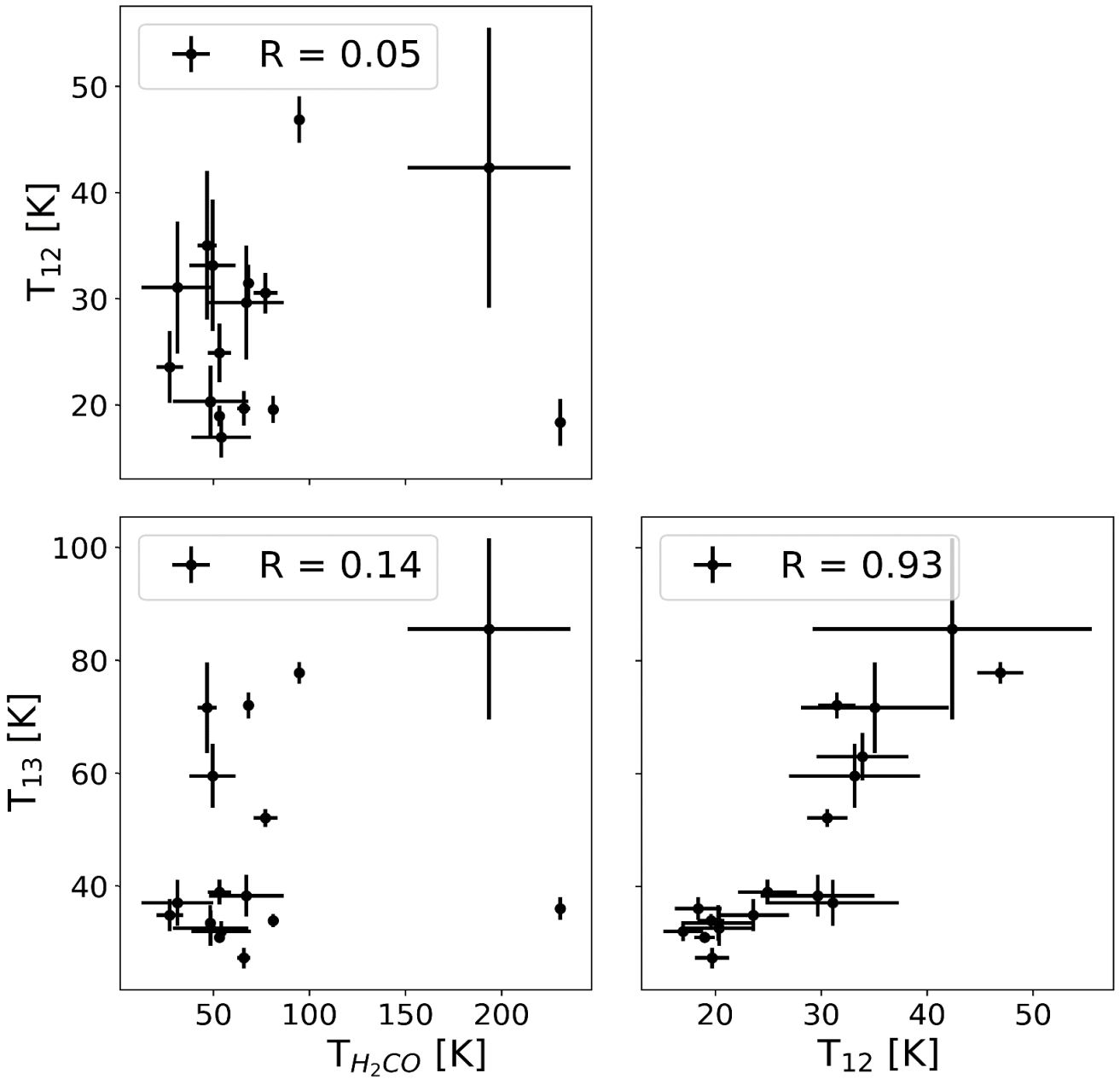
Formaldehyde Temperature

Presence of hot molecular cores not seen in ammonia



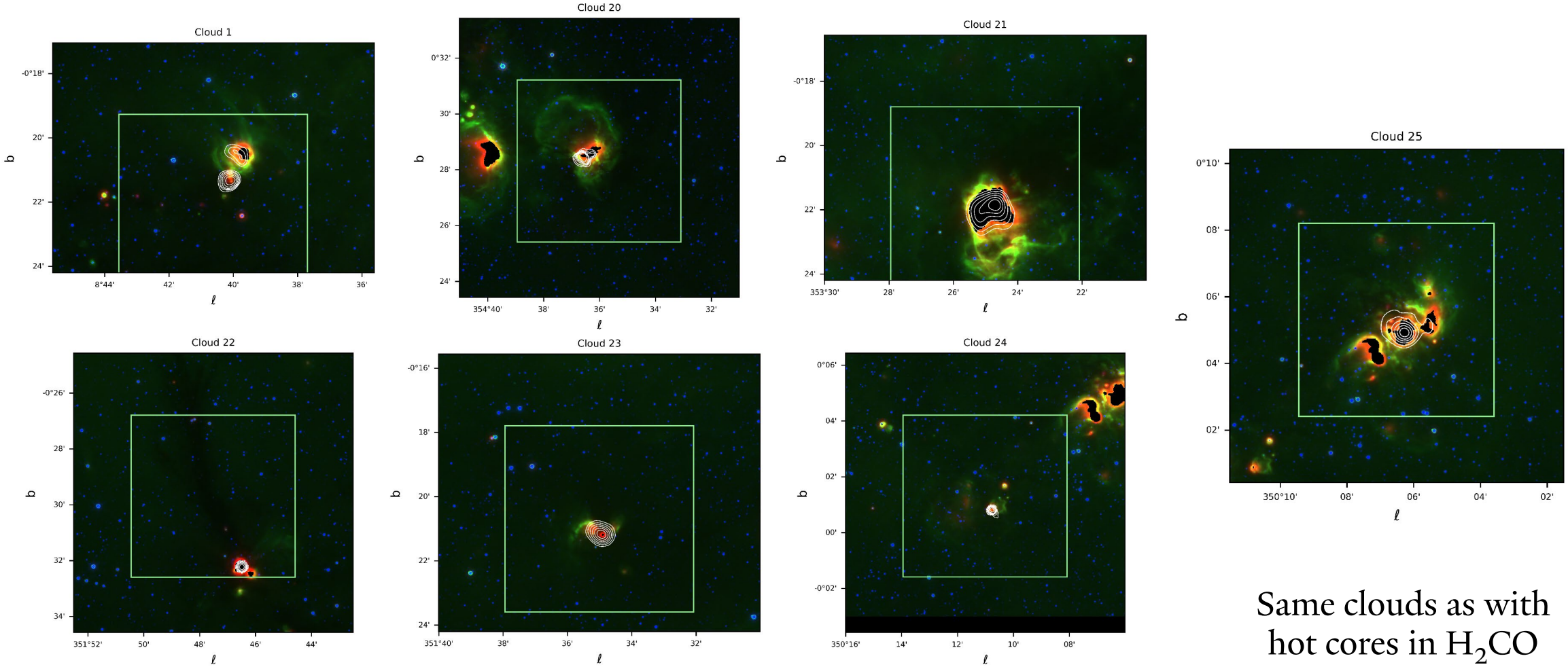
Temperature Comparisons

Ammonia and formaldehyde seem to trace different gas



Star Formation from *Spitzer*

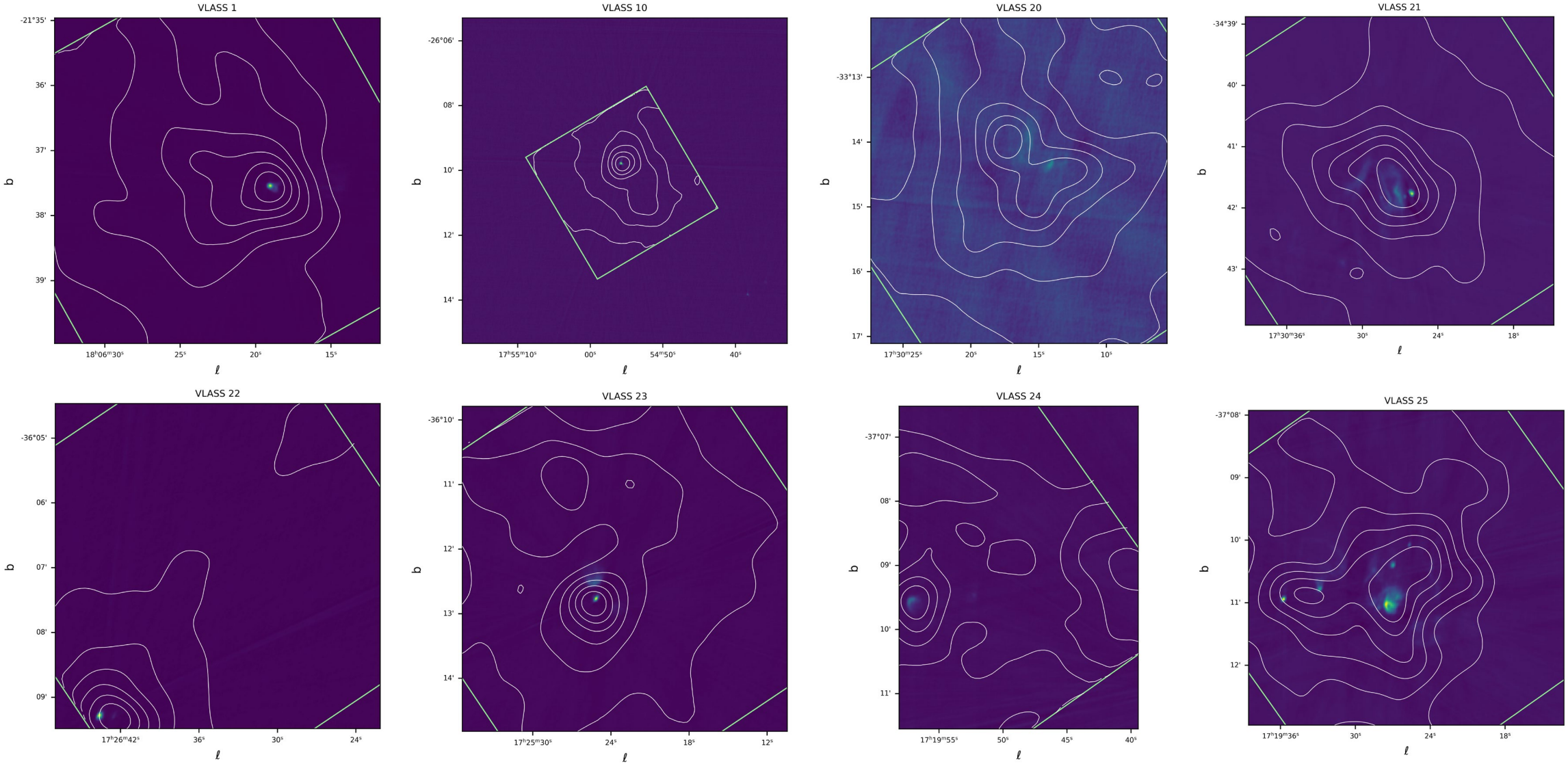
Three-color *Spitzer* images (4.5, 8, and 24 micron) with H30α contours



Same clouds as with hot cores in H_2CO

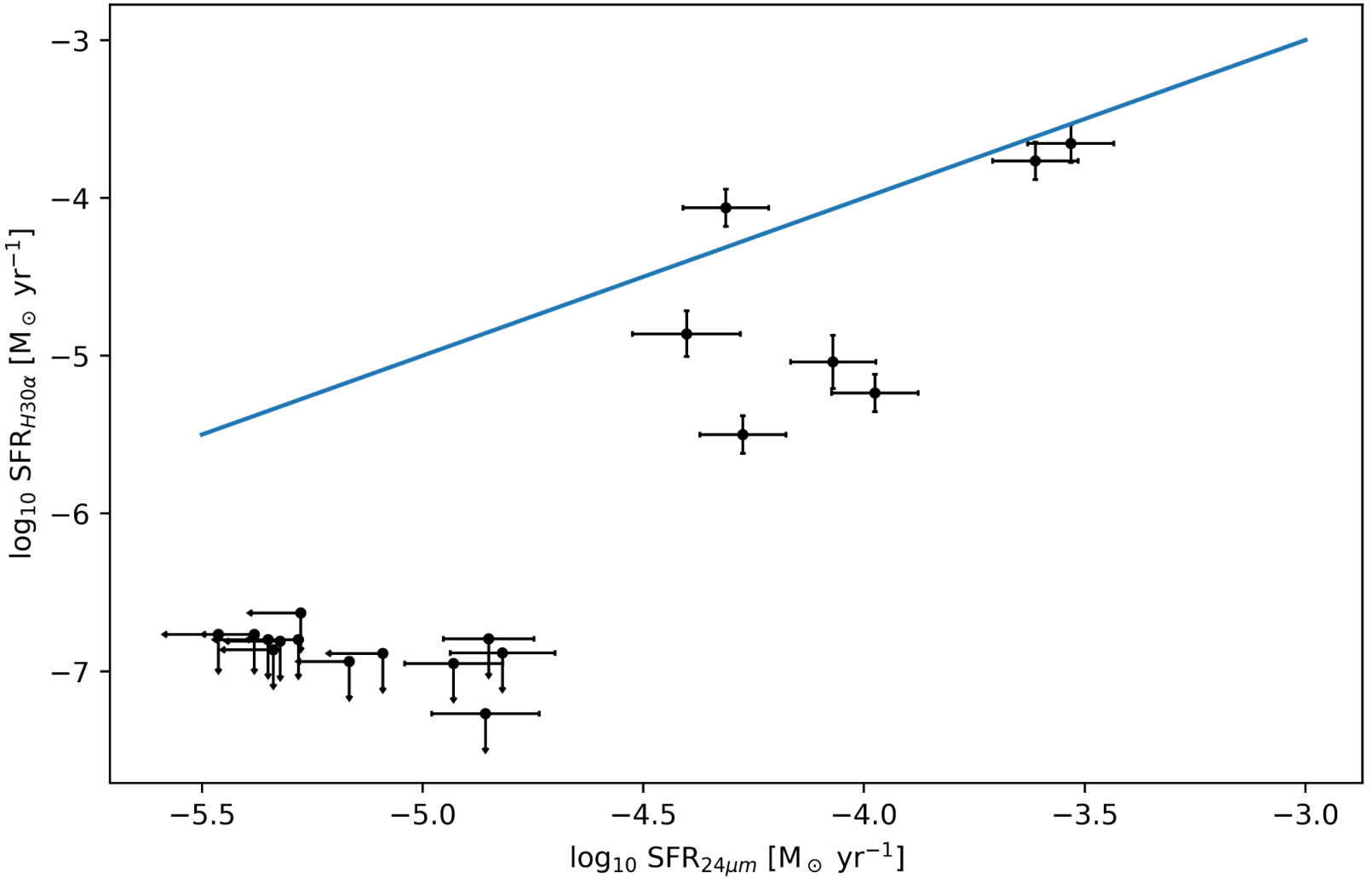
VLASS Detections

VLASS cutouts with ^{13}CO contours



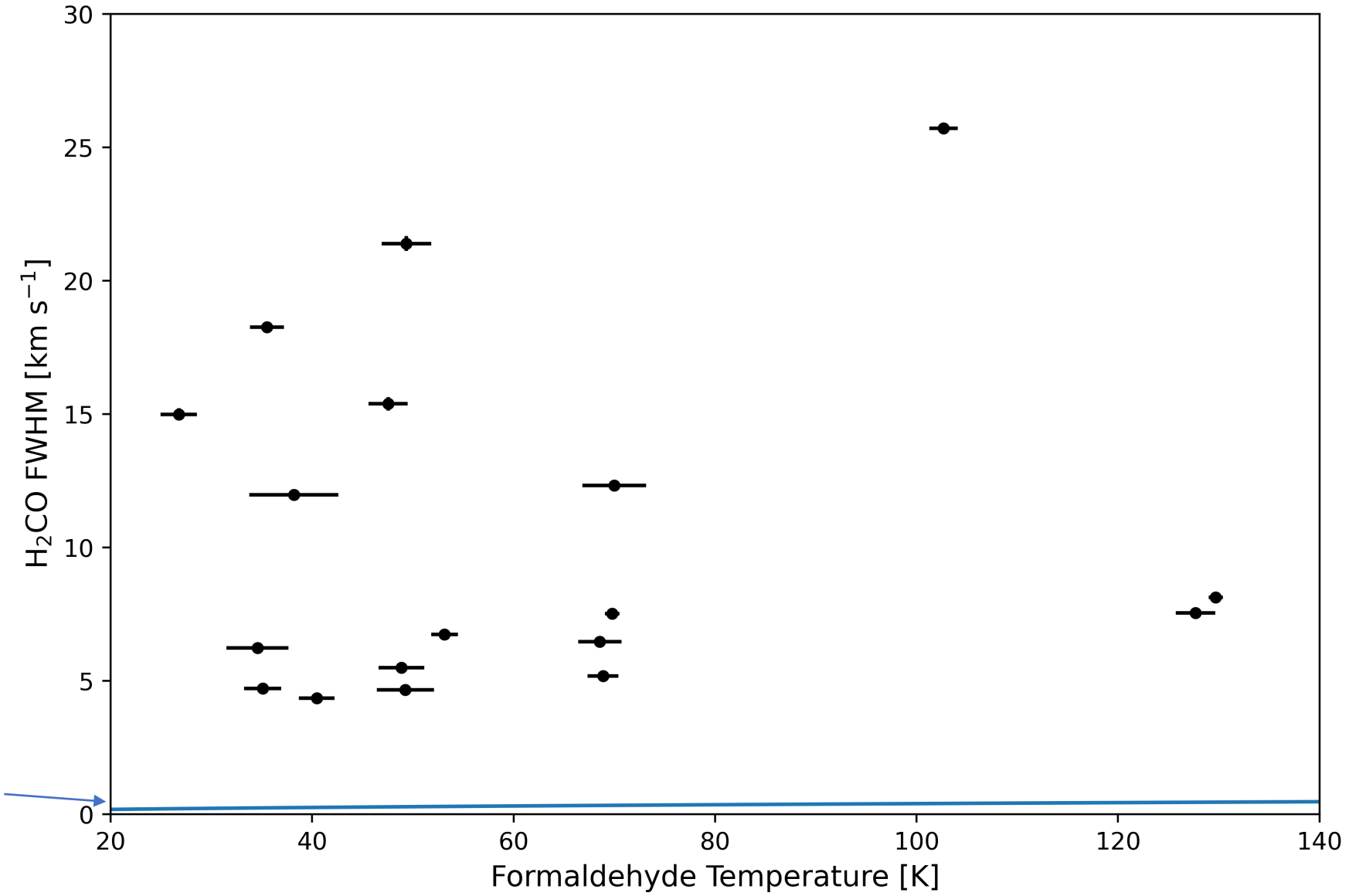
Star Formation Comparison

These conversions generally apply to larger spatial scales, so may not hold here



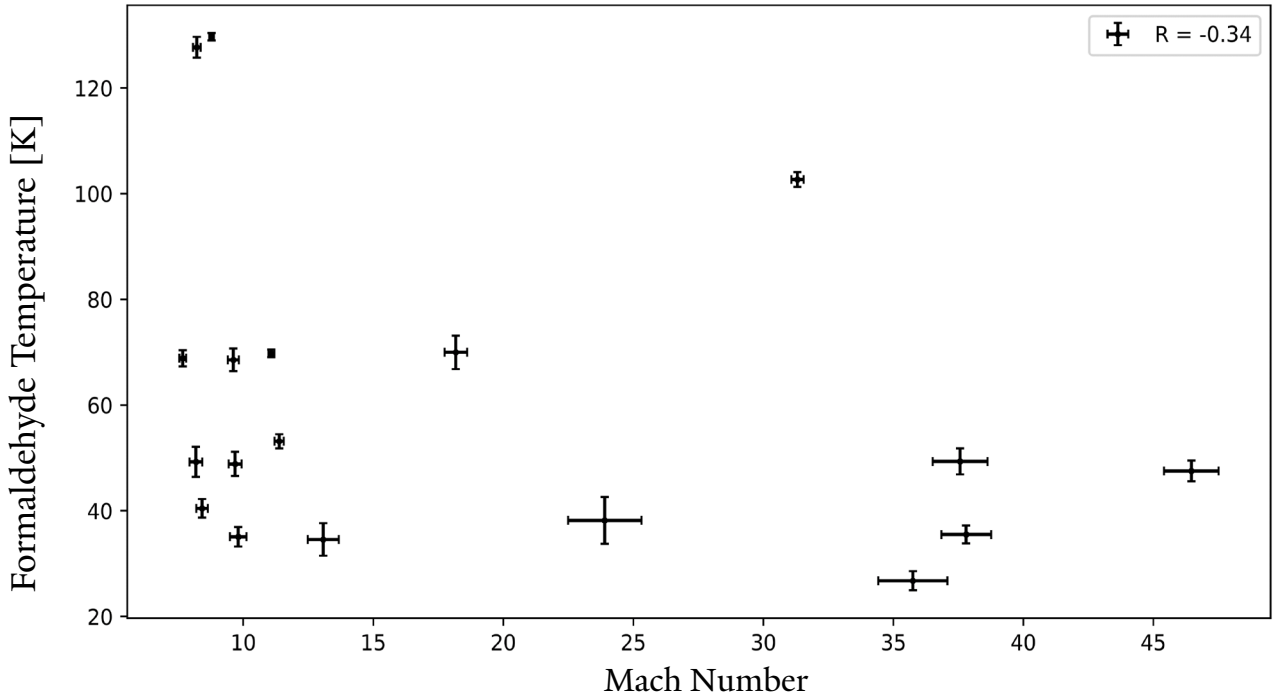
Turbulence

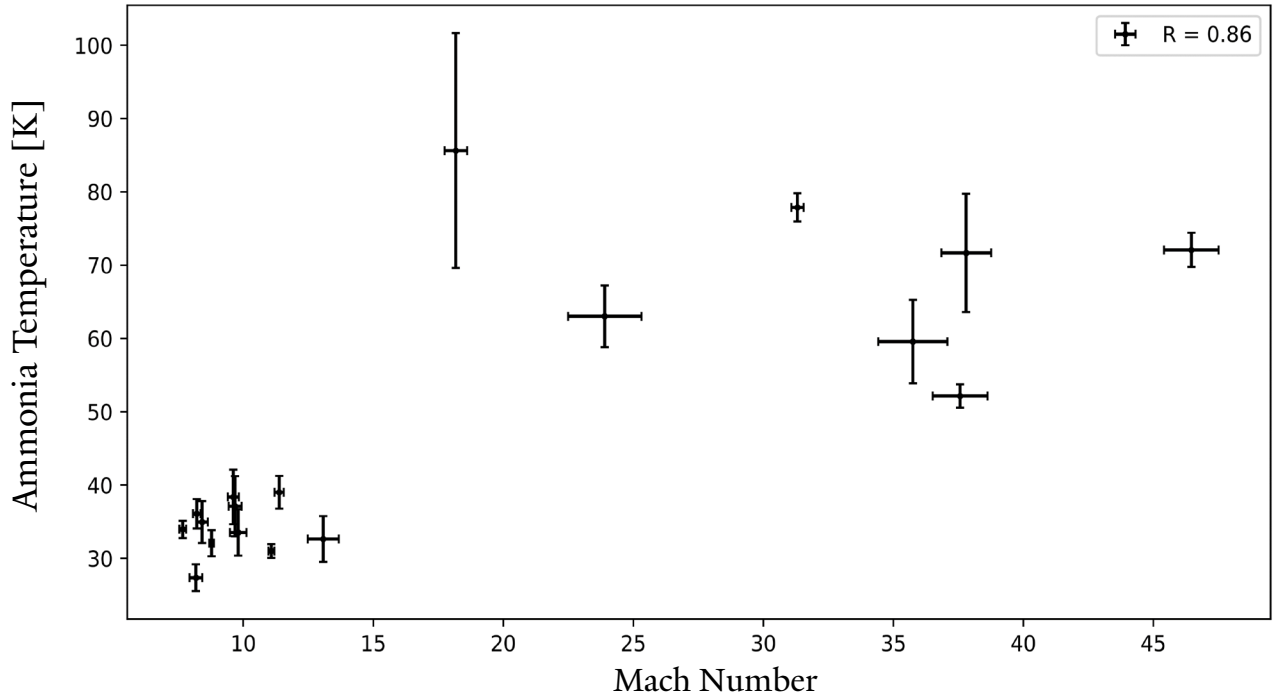
Non-thermal contributions (e.g. turbulence) dominate



Turbulent Heating

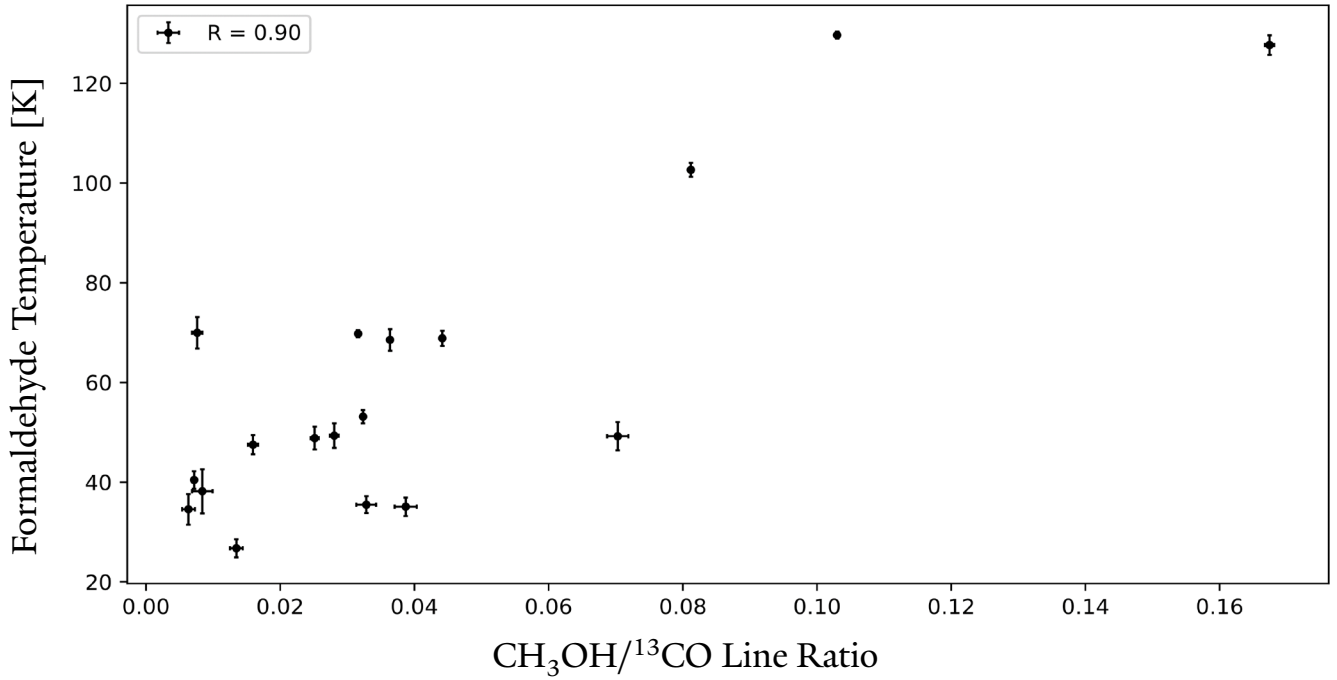
Formaldehyde thermometer appears to be less sensitive to turbulent heating

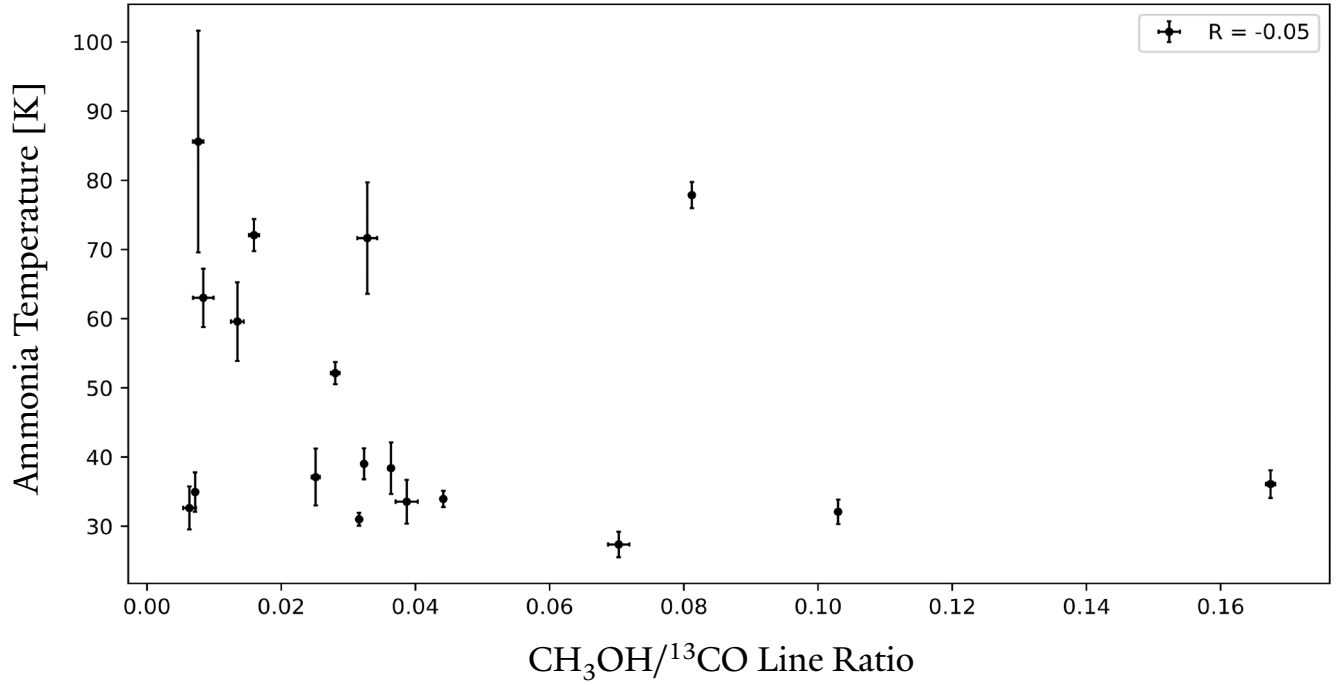




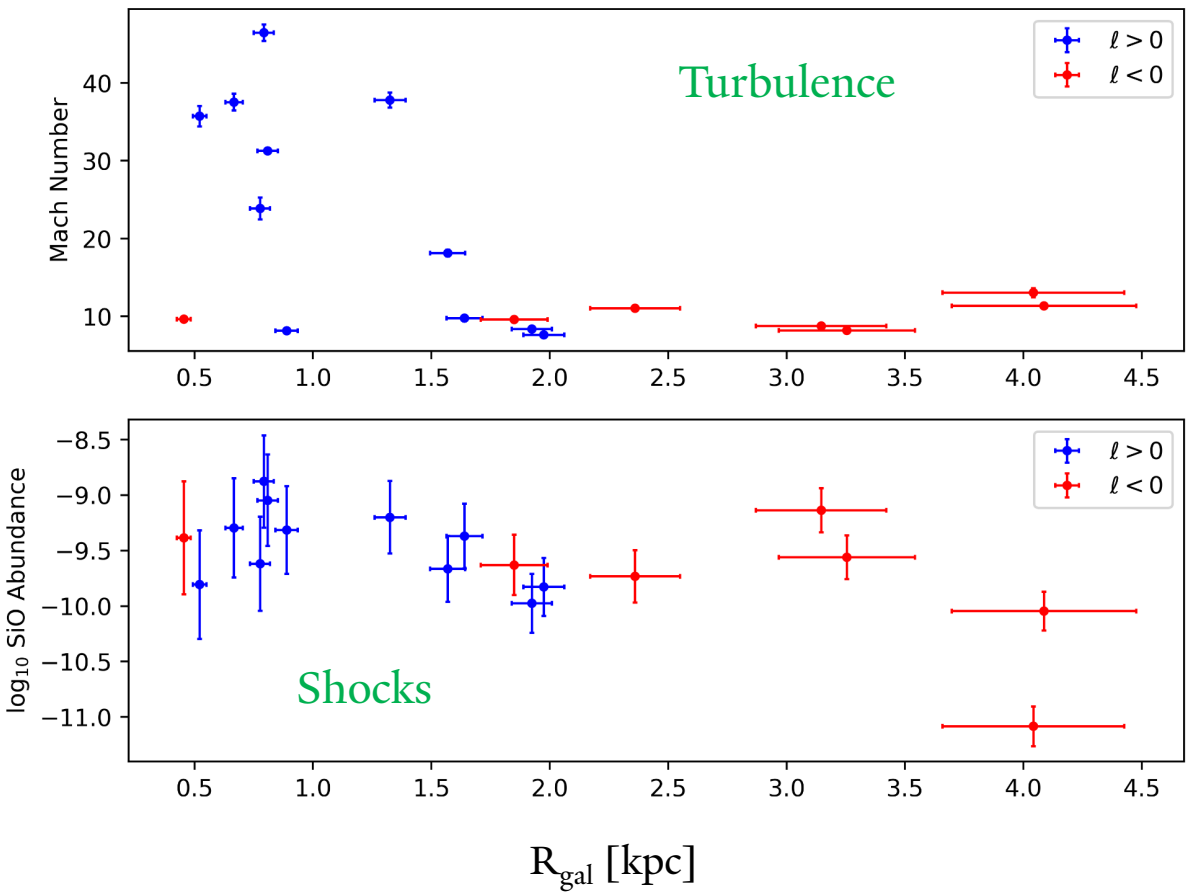
Shock Heating

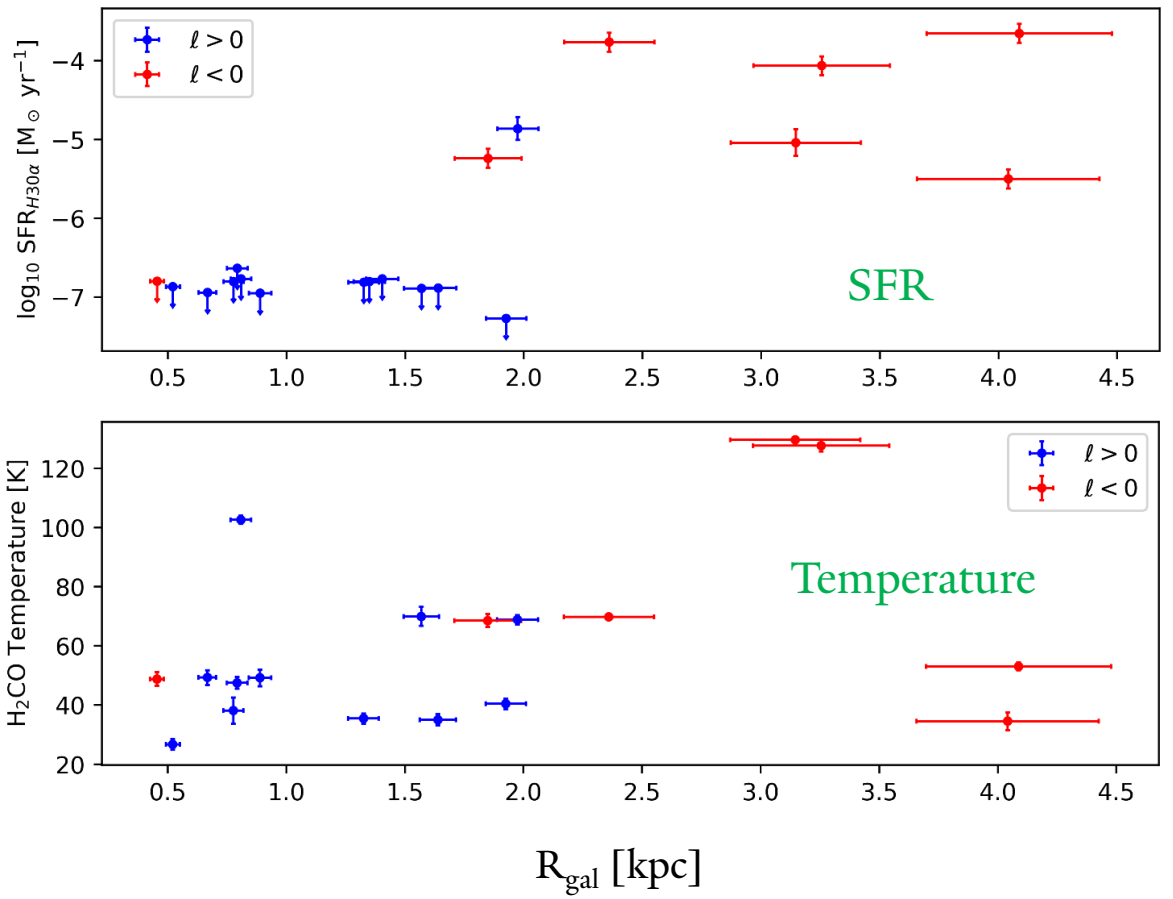
Formaldehyde thermometer appears to be more sensitive to shock heating. Or, SF enhances methanol more than turbulent shocks



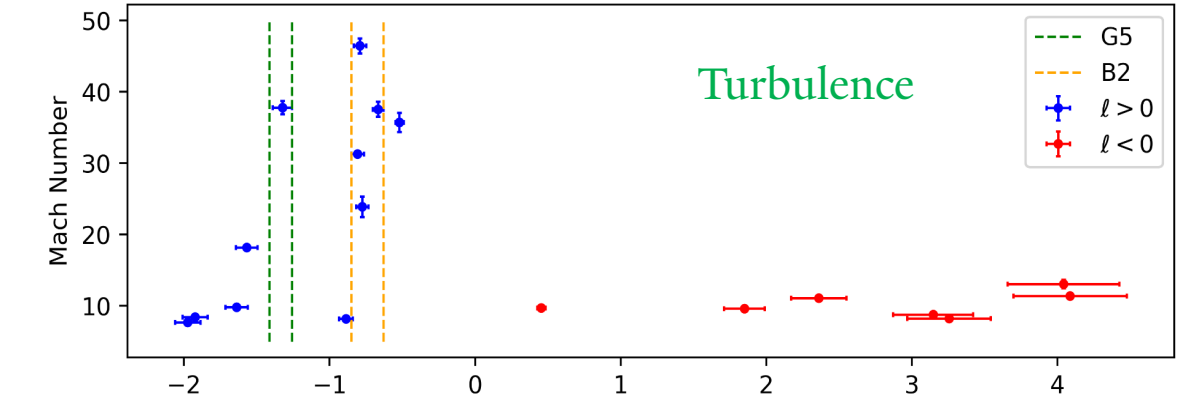


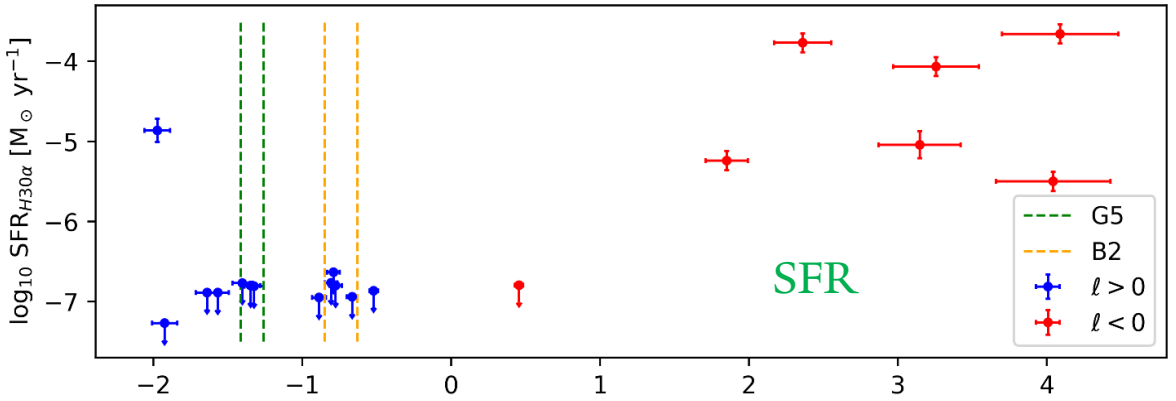
Distribution of Cloud Properties

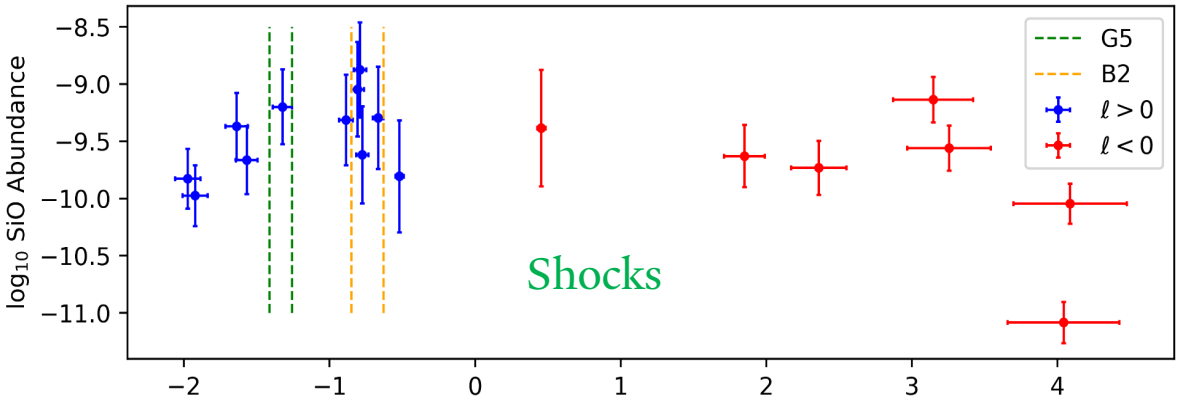


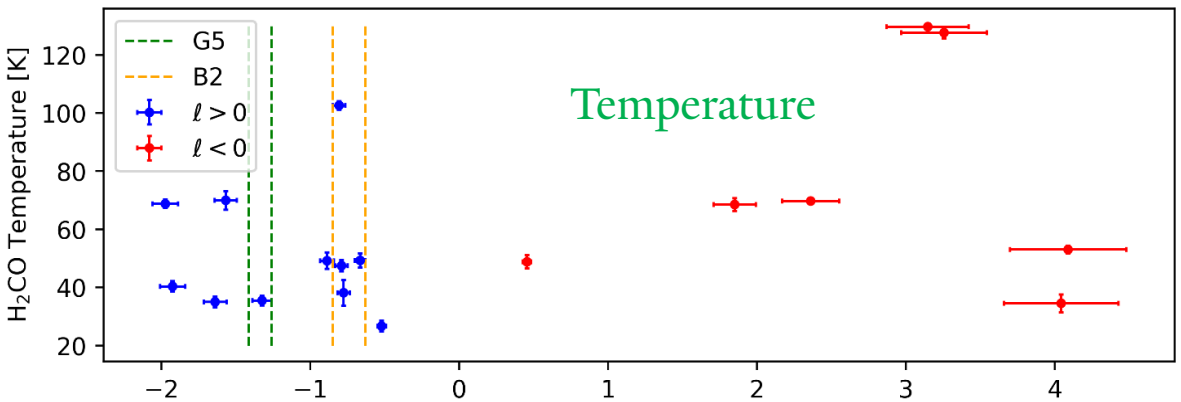


Distribution of Cloud Properties





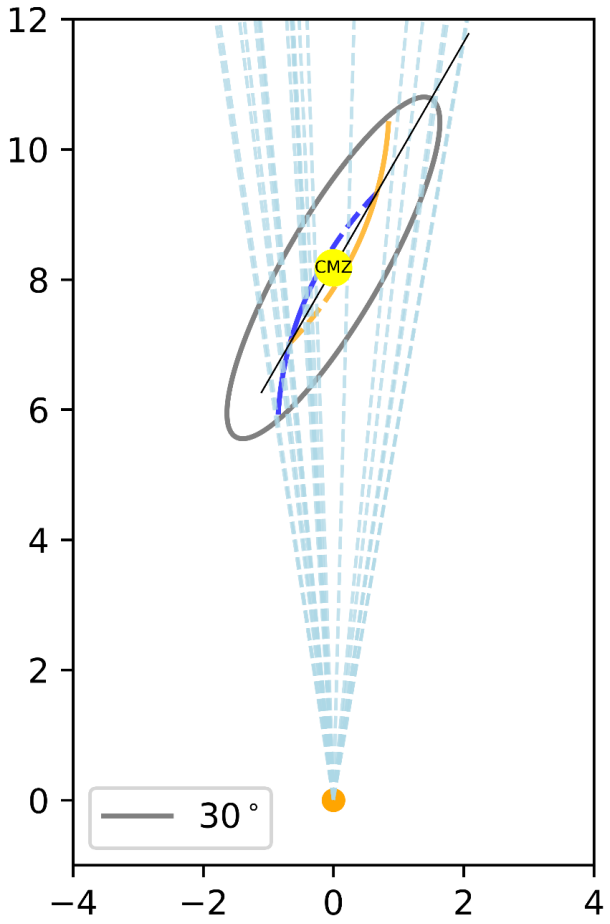


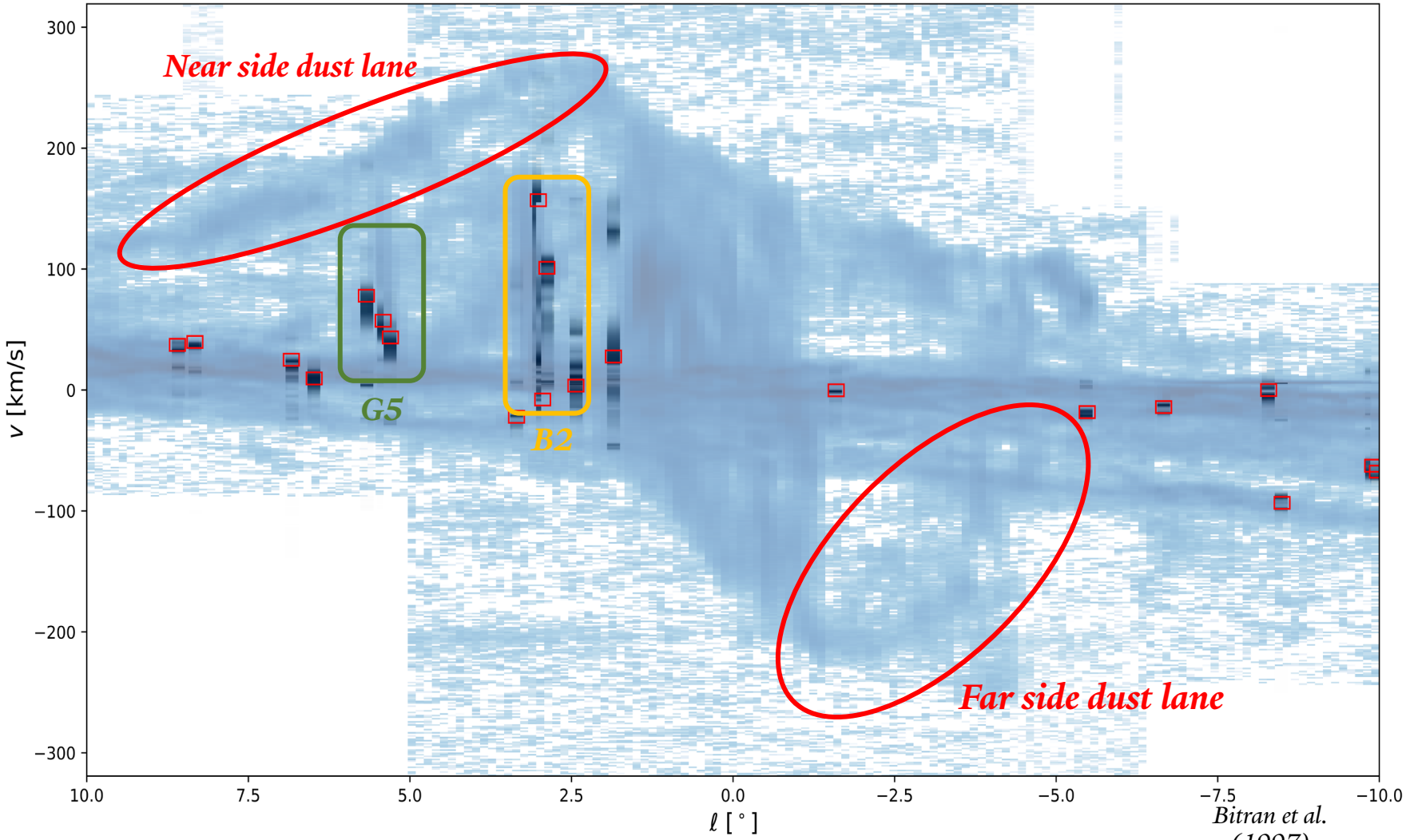


Position Along Bar [kpc]

Position Along Bar [kpc]

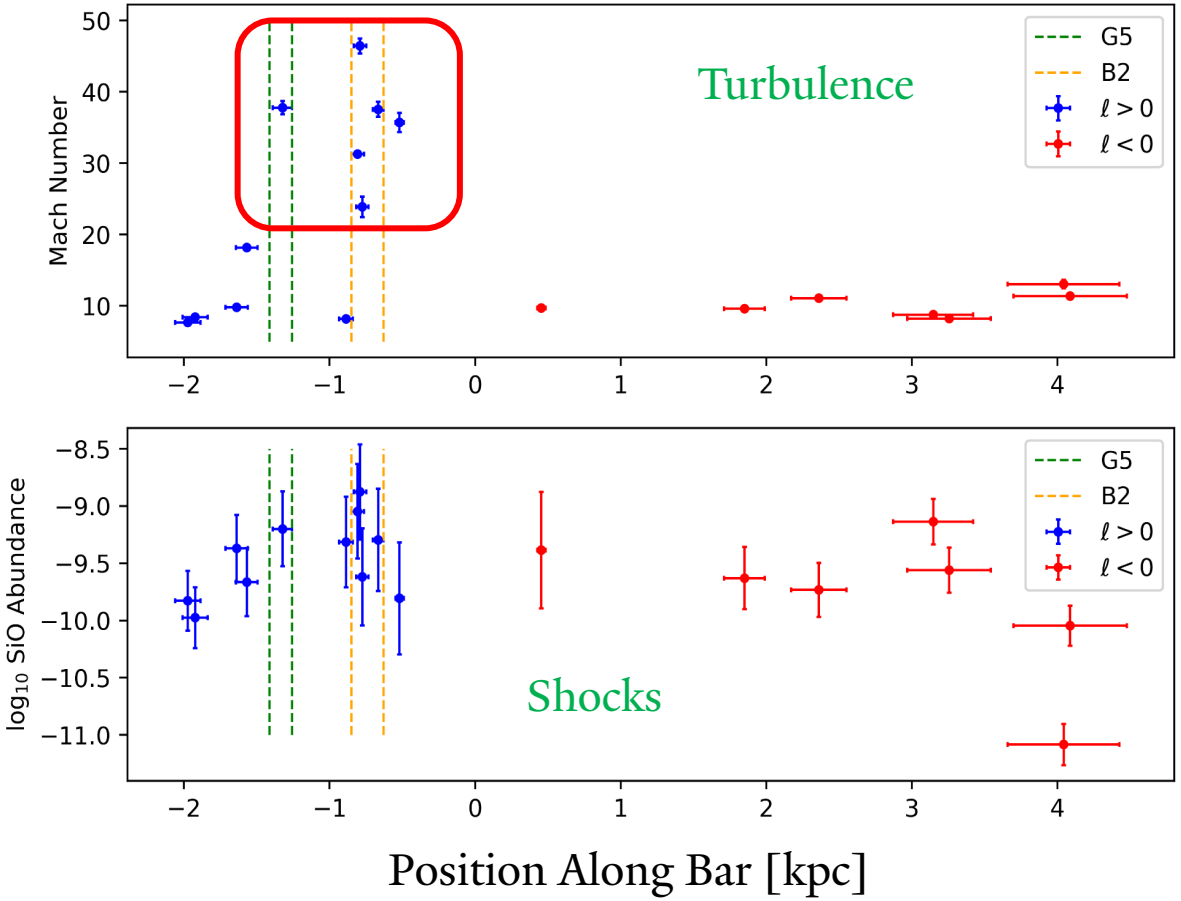
Are our clouds on the Galactic bar?

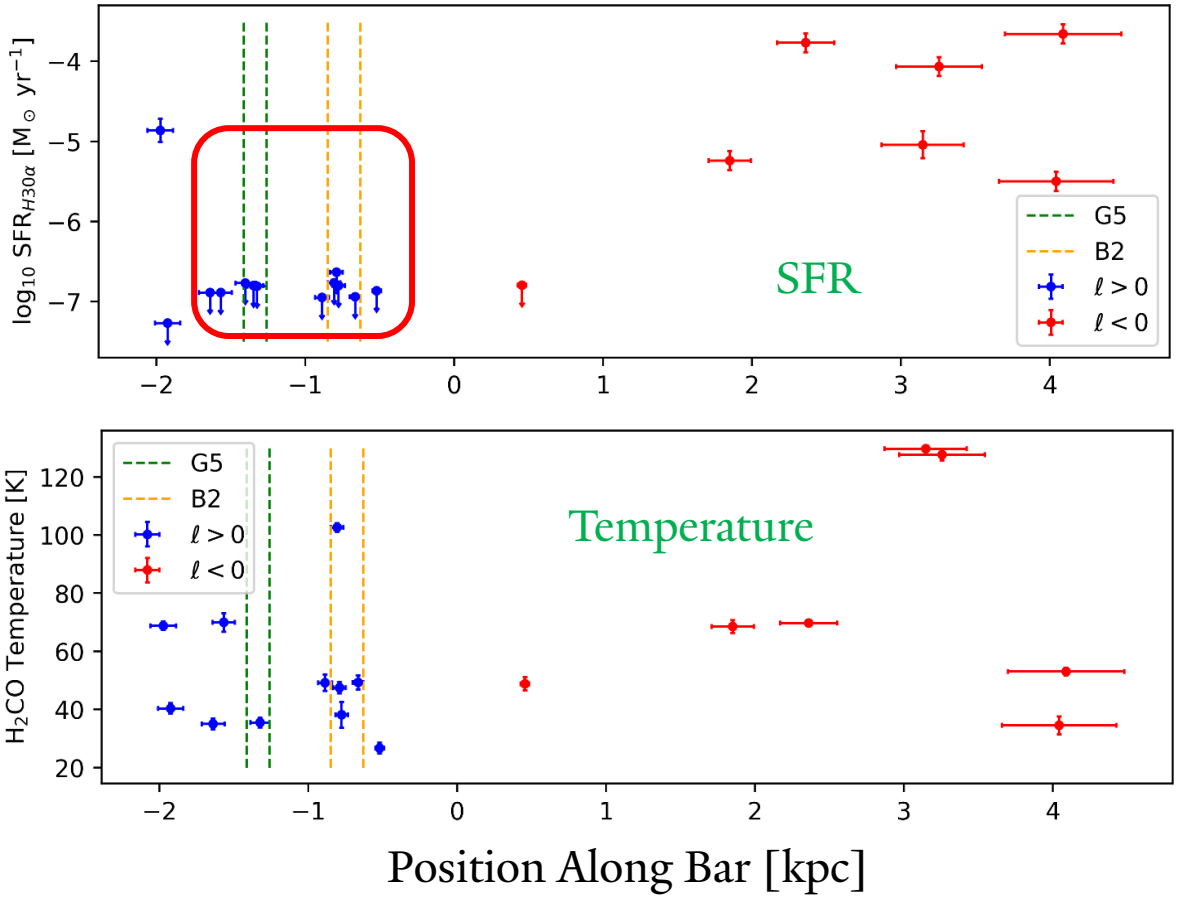




Bitran et al. (1997)

Distribution of Cloud Properties

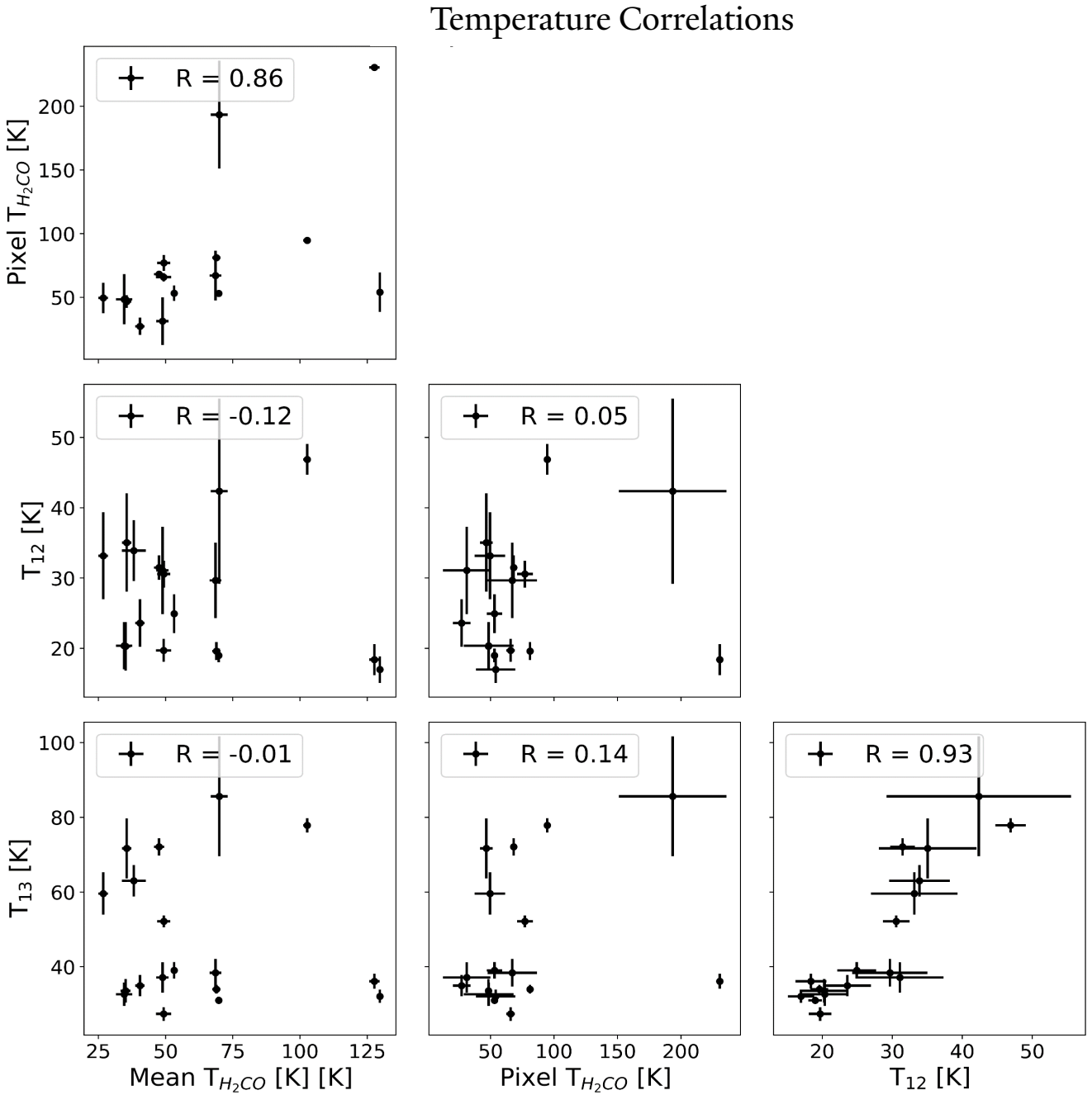


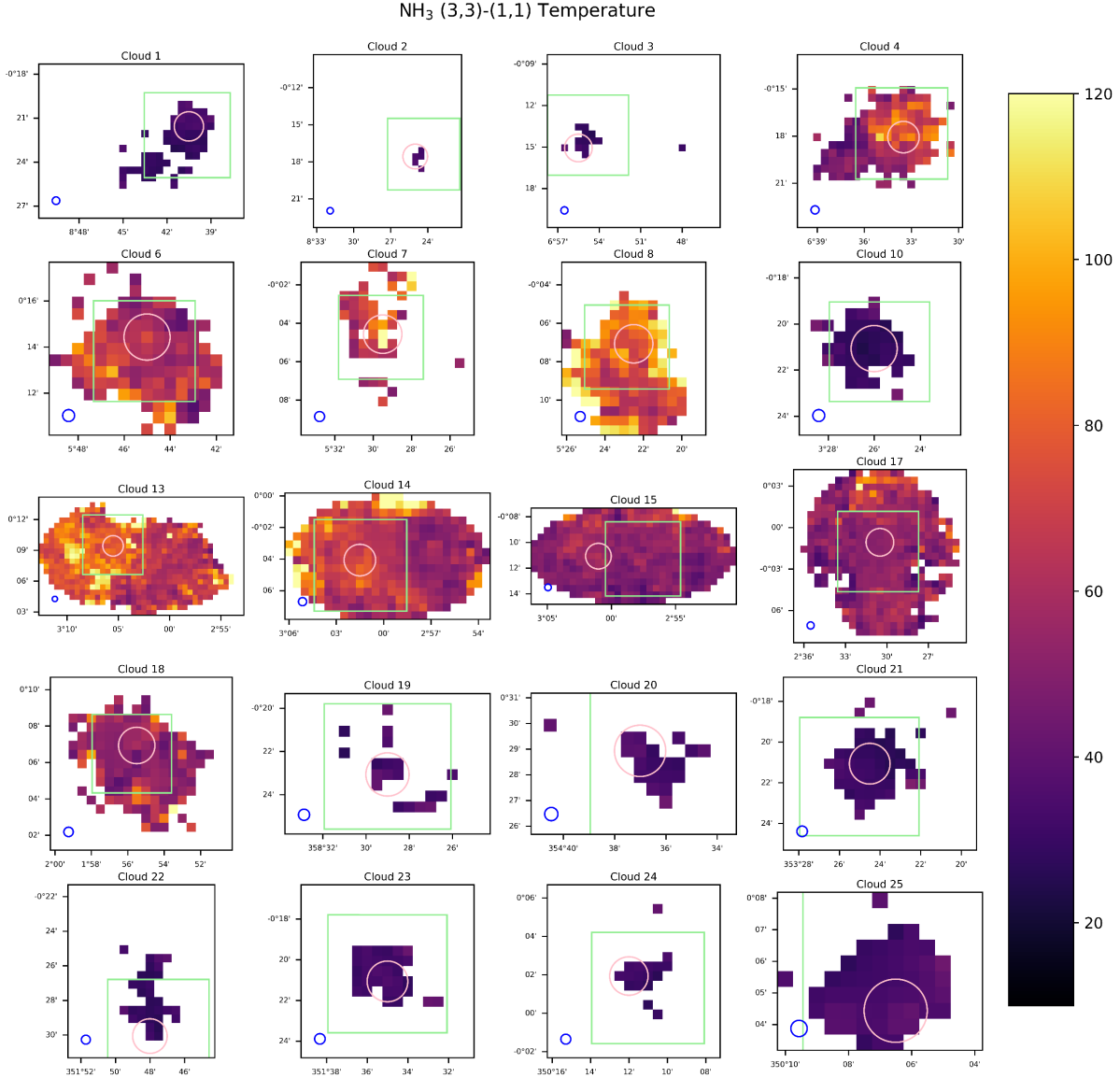


Conclusions

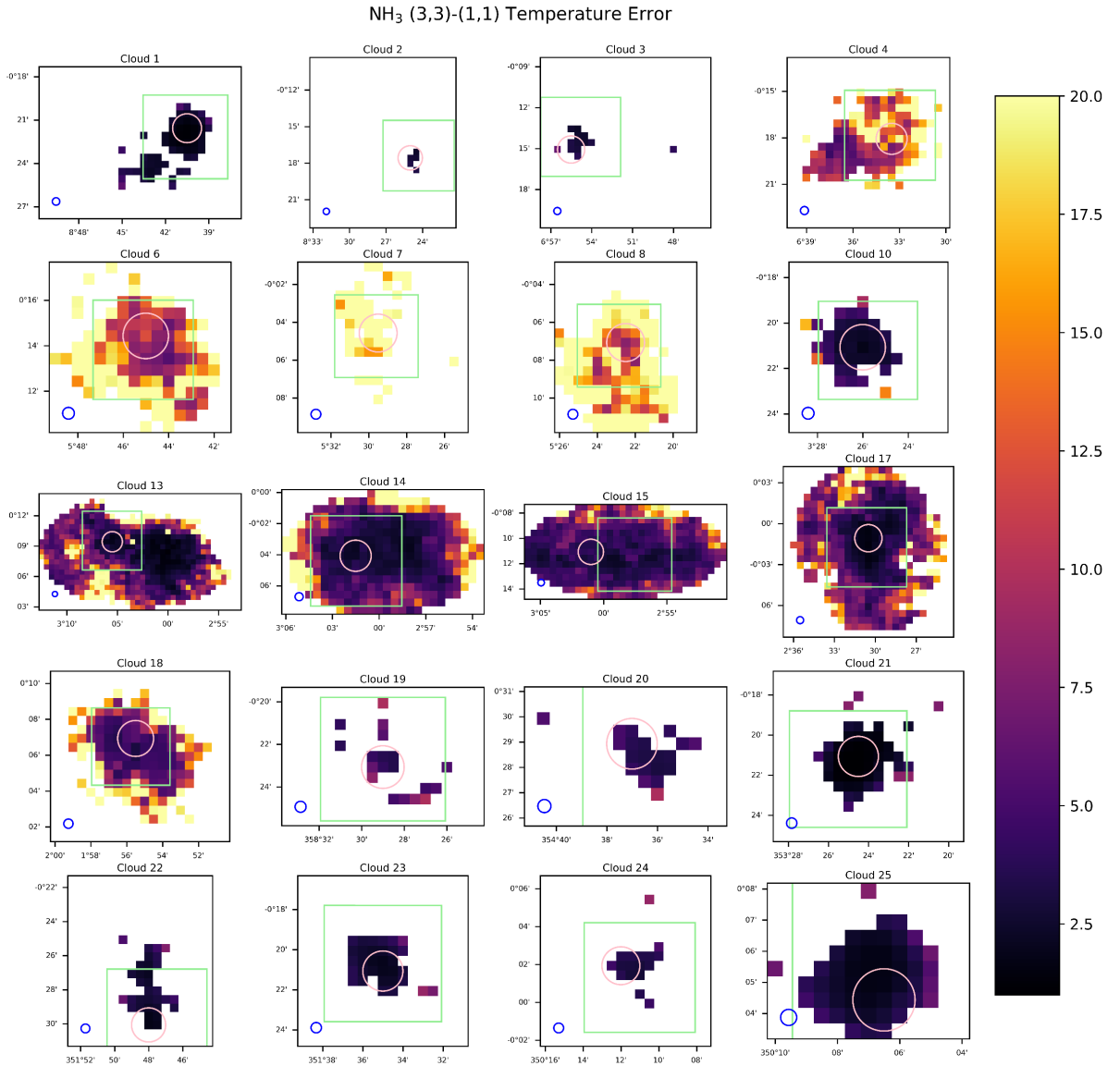
- Observed 20 clouds on the Galactic plane
- Measured various properties
  - Temperature, turbulence, star formation, and shocks
- Still more work needed to determine locations of clouds
  - Asymmetric bar
  - A few clouds are at collision sites between inflowing gas, overshooting gas, and the CMZ

Temperature Comparisons

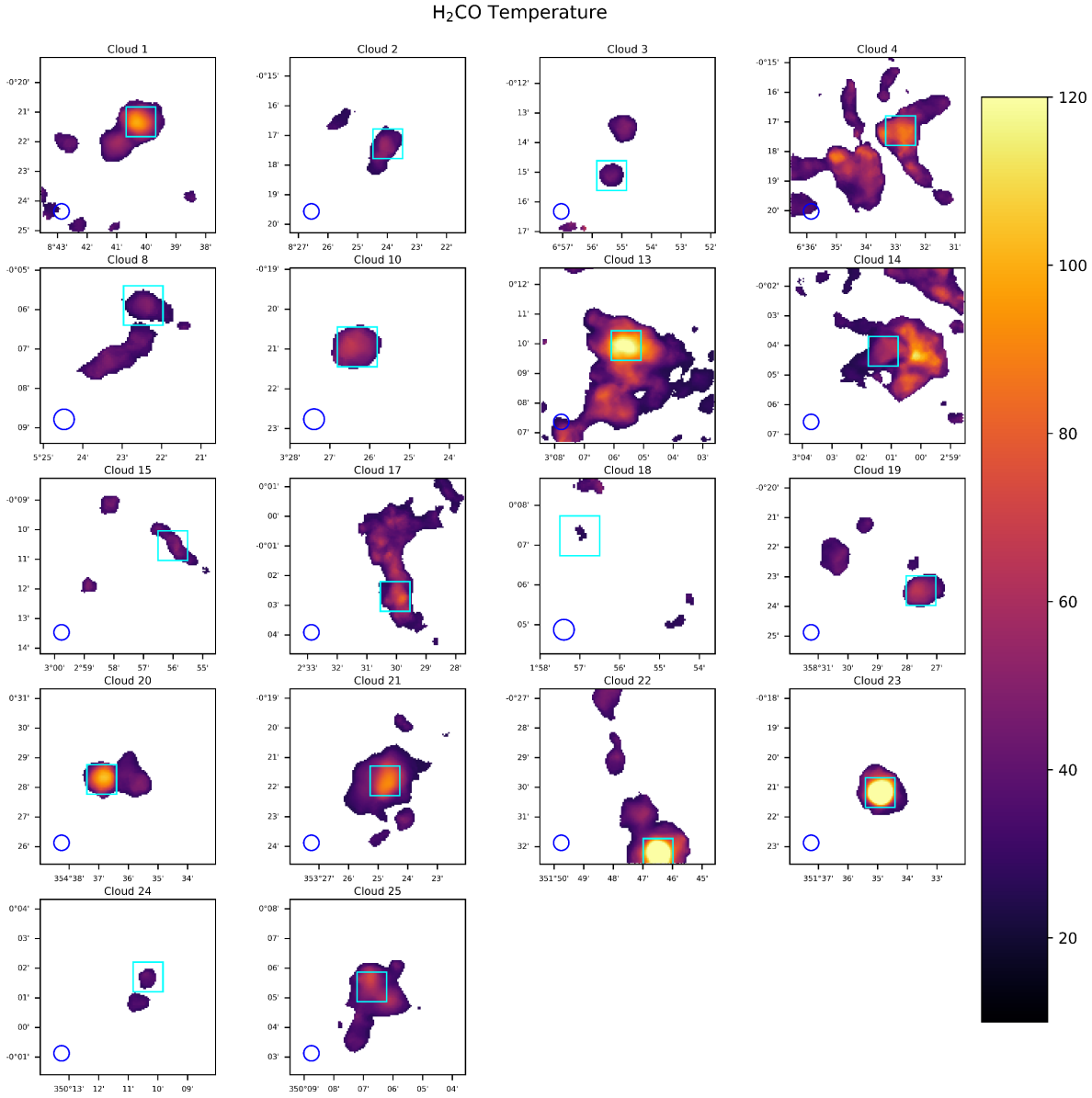



NH3 (3,3)-(1,1) Temperature
Cloud 1
Cloud 2
Cloud 3
Cloud 4
Cloud 6
Cloud 7
Cloud 8
Cloud 10
Cloud 13
Cloud 14
Cloud 15
Cloud 17
Cloud 18
Cloud 19
Cloud 20
Cloud 21
Cloud 22
Cloud 23
Cloud 24
Cloud 25
120
100
80
60
40
20

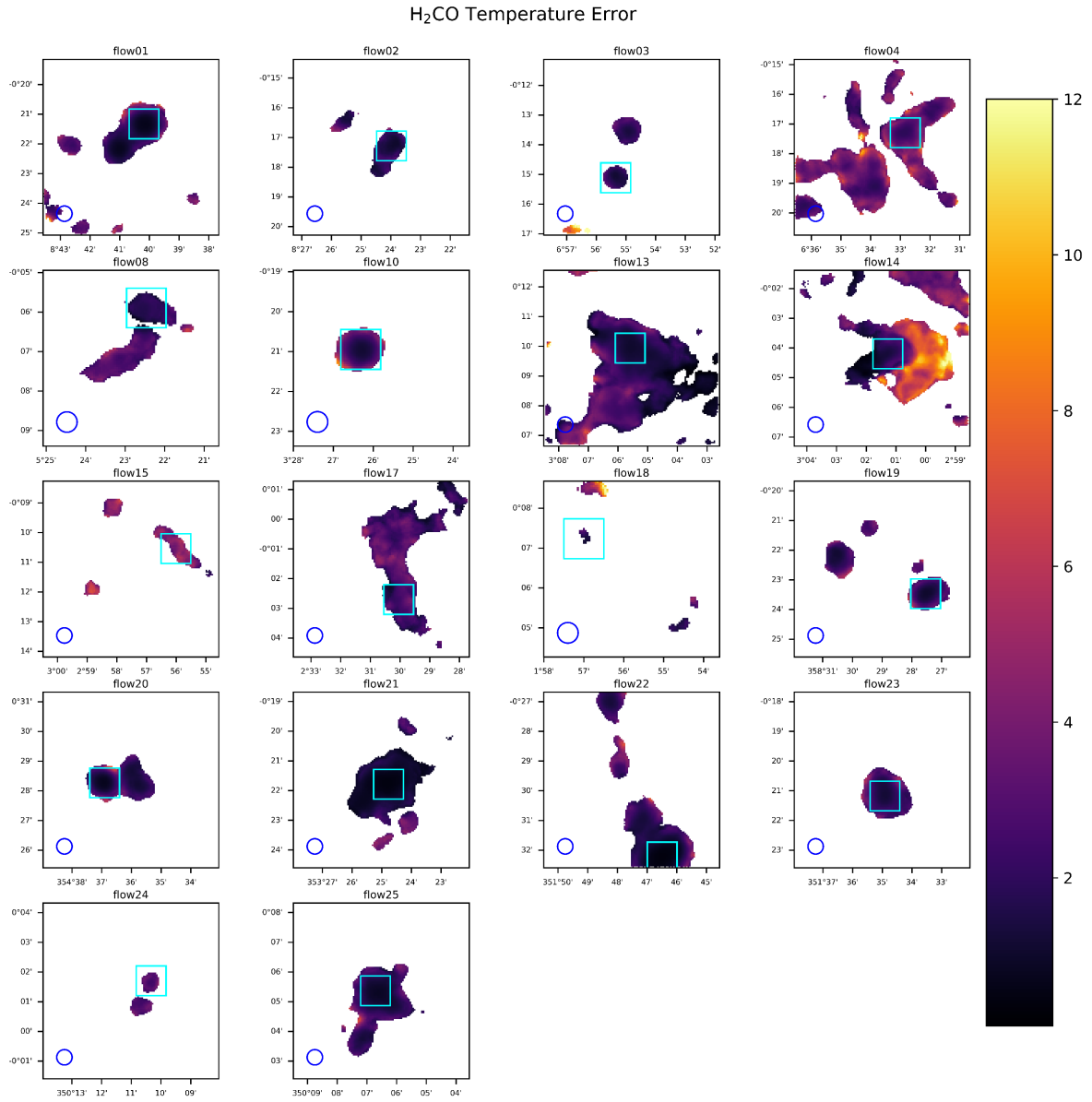
(a)


NH3 (3,3)-(1,1) Temperature Error
Cloud 1
Cloud 2
Cloud 3
Cloud 4
Cloud 6
Cloud 7
Cloud 8
Cloud 10
Cloud 13
Cloud 14
Cloud 15
Cloud 17
Cloud 18
Cloud 19
Cloud 20
Cloud 21
Cloud 22
Cloud 23
Cloud 24
Cloud 25
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5

(b)


H2CO Temperature
Cloud 1
Cloud 2
Cloud 3
Cloud 4
Cloud 8
Cloud 10
Cloud 13
Cloud 14
Cloud 15
Cloud 17
Cloud 18
Cloud 19
Cloud 20
Cloud 21
Cloud 22
Cloud 23
Cloud 24
Cloud 25
120
100
80
60
40
20

(a)


H2CO Temperature Error
flow01
flow02
flow03
flow04
flow08
flow10
flow13
flow14
flow15
flow17
flow18
flow19
flow20
flow21
flow22
flow23
flow24
flow25
12
10
8
6
4
2

(b)