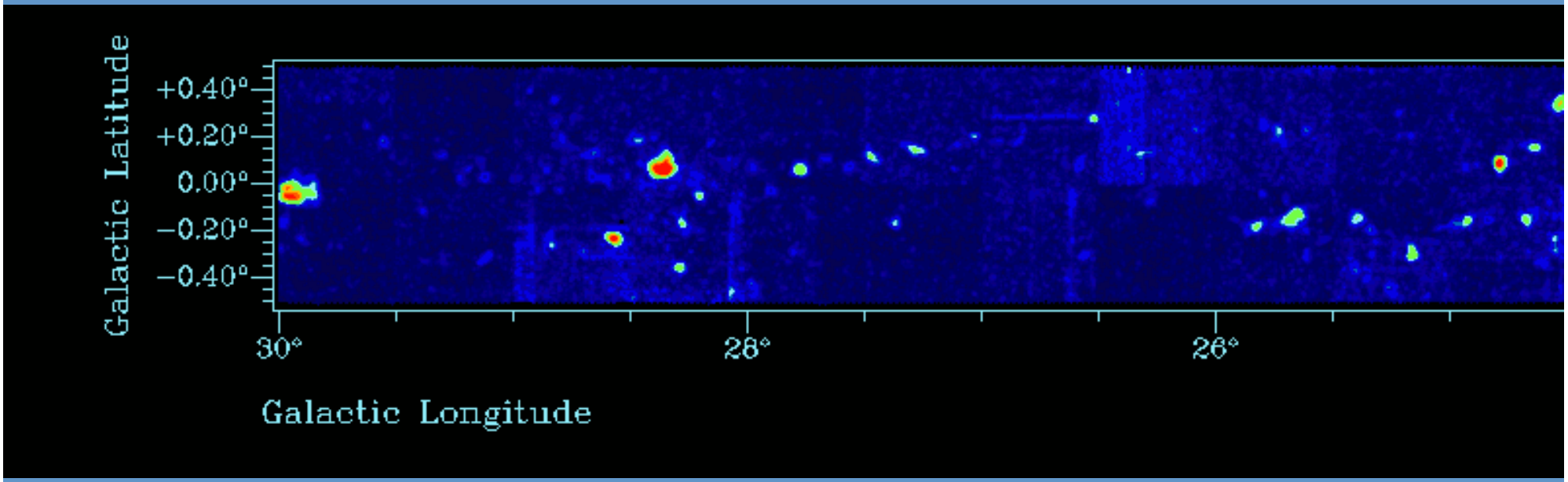
New Flavours in Galactic Surveys: HOPS and MALT



Andrew Walsh,
Centre for Astronomy
James Cook University

Centre for Astronomy JCU JAMES COOK UNIVERSITY

Outline

- Basic data collected for HOPS
- Some interesting first results from HOPS
  * The CMZ and star formation
  * An extreme young high mass cluster
  * Followup of water masers at high resolution
- MALT-45 Pilot survey
  * Survey design
  * CS (1-0) autocorrelation data
  * New CH_3OH and SiO masers

HOPS – The H_2O southern Galactic Plane Survey

Andrew (Is it beer time yet?) Walsh, JCU
Steven (Hoots Man!) Longmore, ESO
Cormac (MopraBoy) Purcell, Leeds
Michael (The Bloodnut) Burton, UNSW
Nadia (Lo-Lo) Lo, U Chile
Kate (El Presidente) Brooks, ATNF
Chris (VLBIBoy) Phillips, ATNF
Shari (Shazaaaahh) Breen, ATNF
Lyshia (The Teacher) Quinn, Manchester
Maxim (PlaneBoy) Voronkov, ATNF
Maria (QuietGirl) Cunningham, UNSW

Paul (NoisyBoy) Jones, UNSW
James (Hames) Urquhart, ATNF
Melvin (Pommie Bastard) Hoare, U. Leeds
Mark (Pommie Bastard) Thompson, U. Hertfordshire
Lisa (Pommie Bastard) Harvey-Smith, ATNF
Tui (Kiwi Bastard) Britton, Macquarie/ATNF
Luke (Pommie Bastard) Hindson, Hertfordshire/ATNF
Jimi (WorldBeer) Green, ATNF
Vicki (GeeThreeThreeThree) Lowe, UNSW/ATNF
Balt (Baltipoos) Indemuehle, ATNF

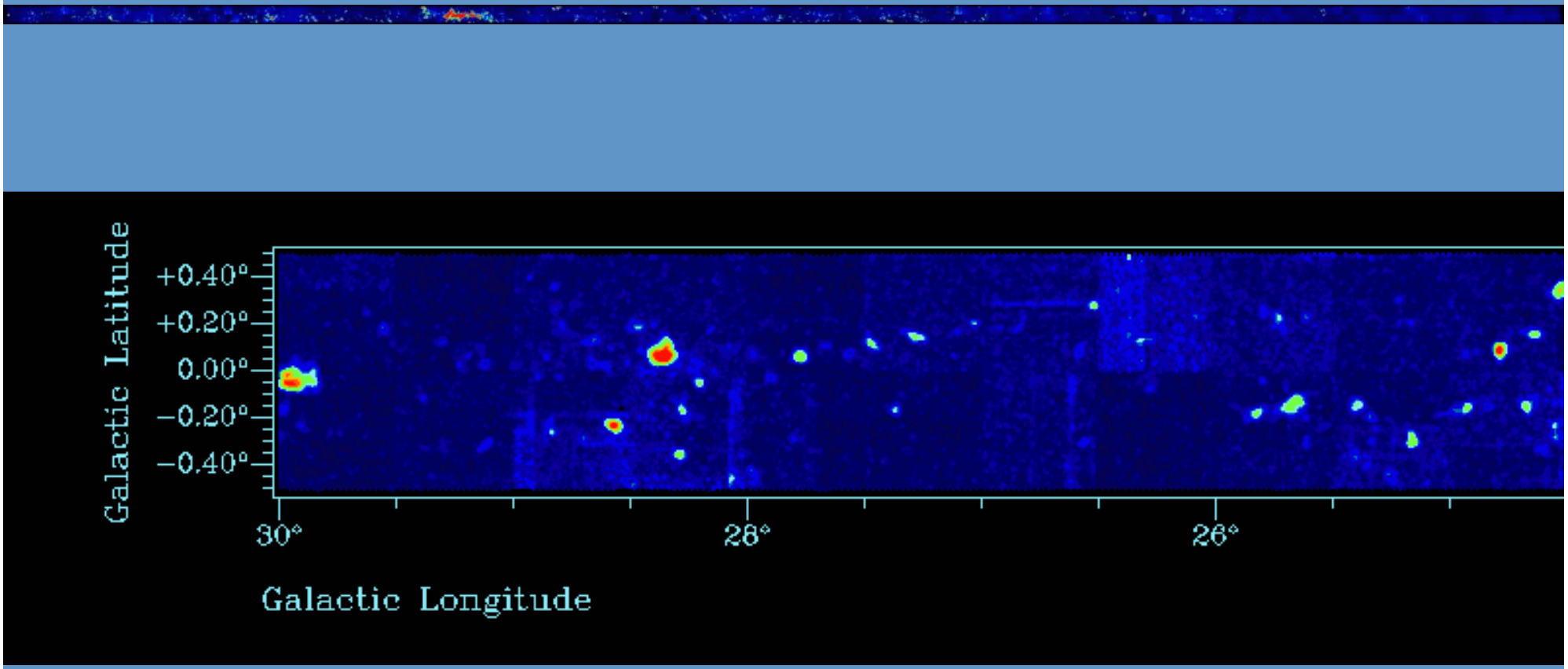
AIMS

- Survey the southern Galaxy with Mopra at 12mm
- Use MOPS zo
- 100 square d
- l=290° - 30°;

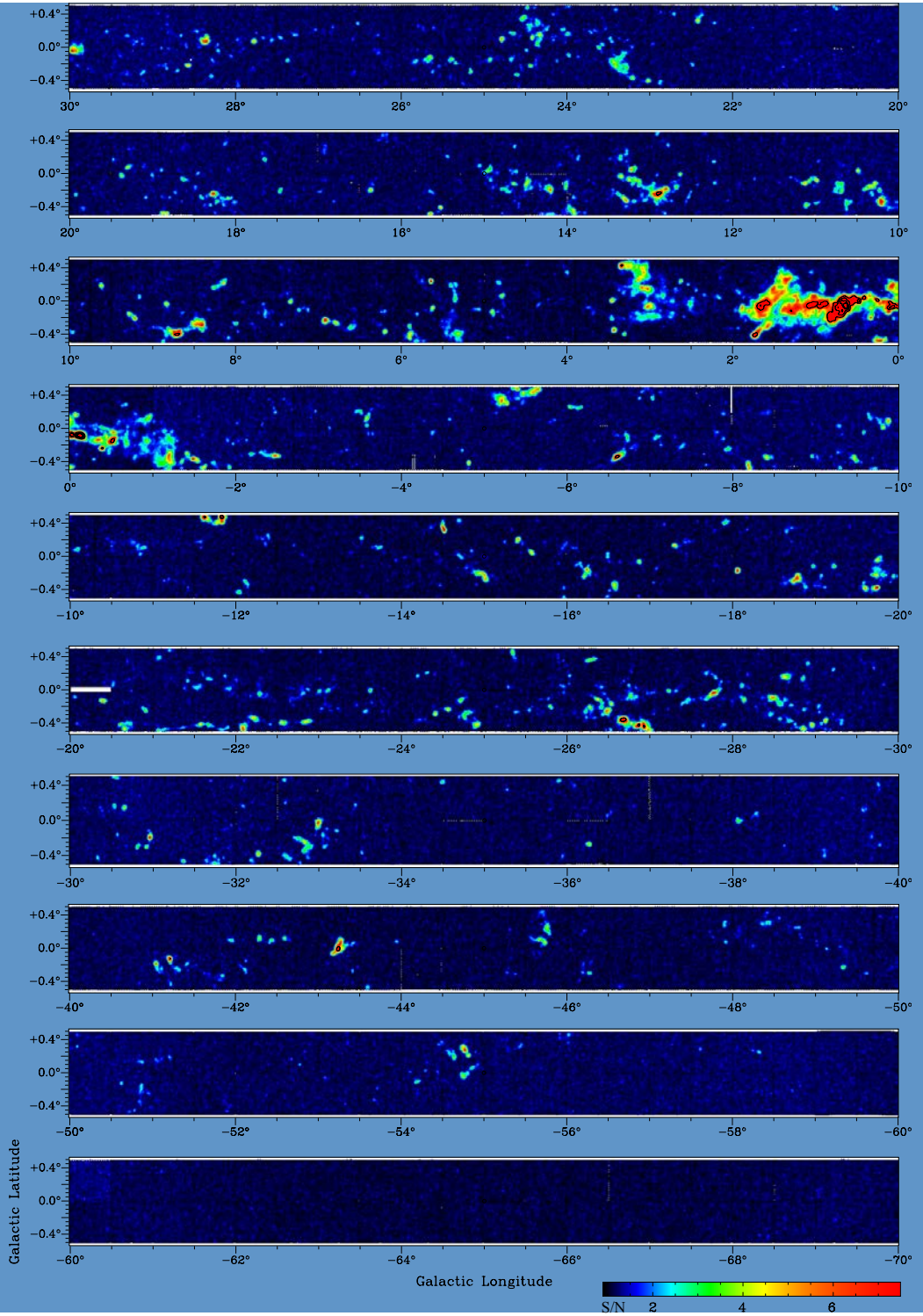
Main lines surveyed

- H_2O maser
- NH_3 (1,1), (2,2), (3,3), (6,6), (9,9)
- HC_3N (3-2)
- H69α radio recombination line
- Many CH_3OH lines
- Many others including H62α, H64α, H65α, NH_3 (non-metastable), CCS, HC_5N

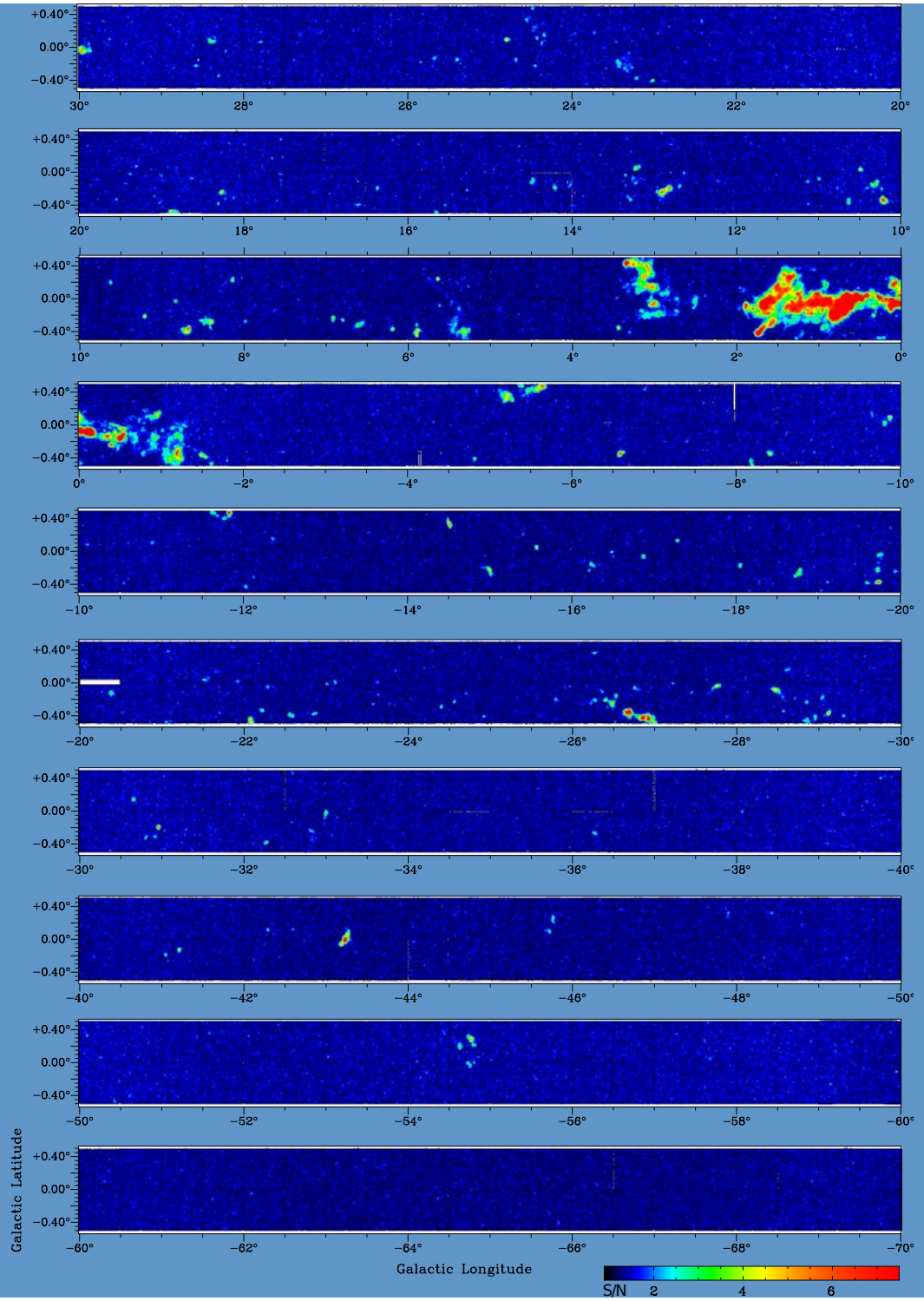
NH_3 (1,1) Emission Peak Temperature Maps

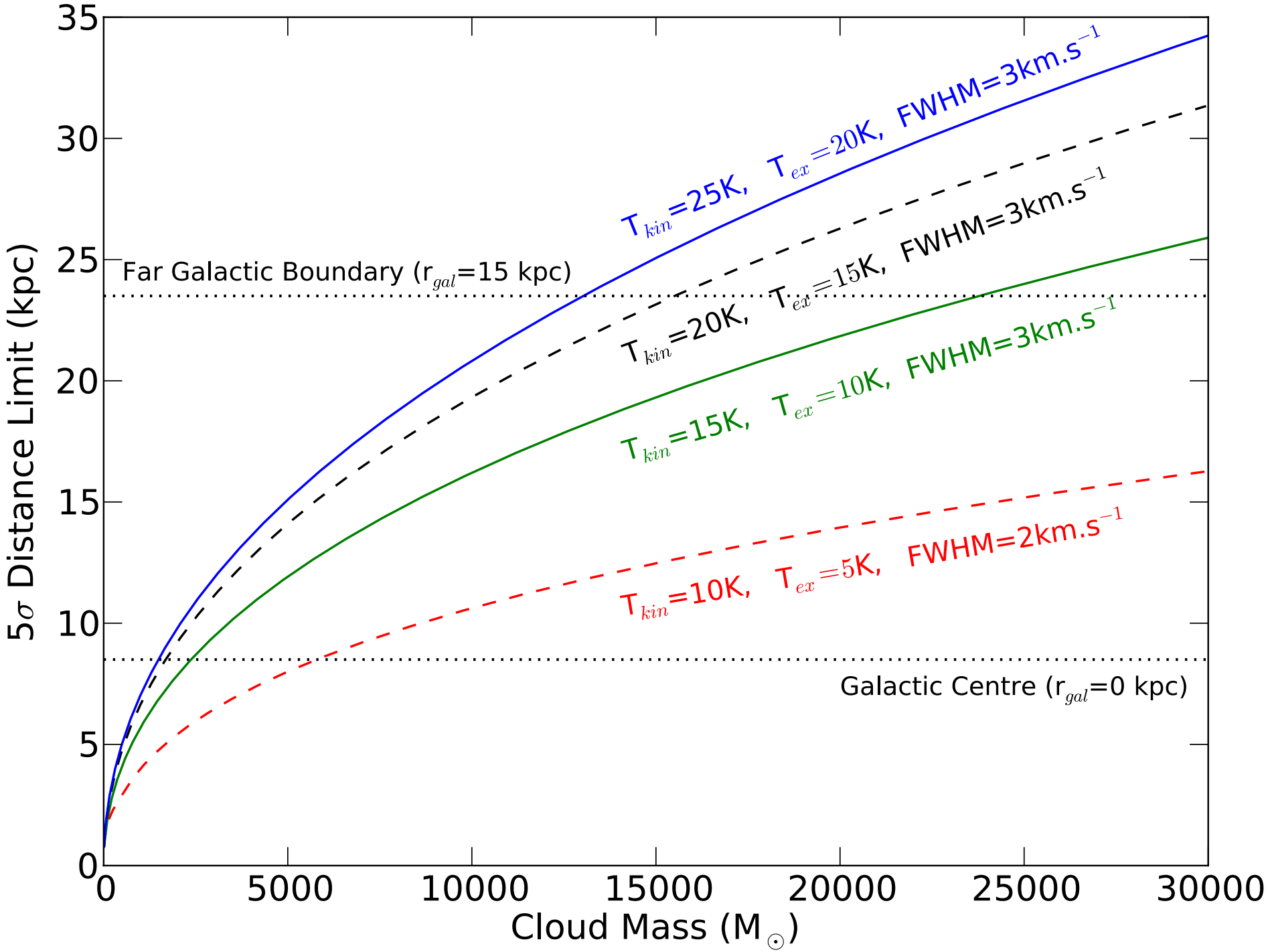


NH_3 (1,1)

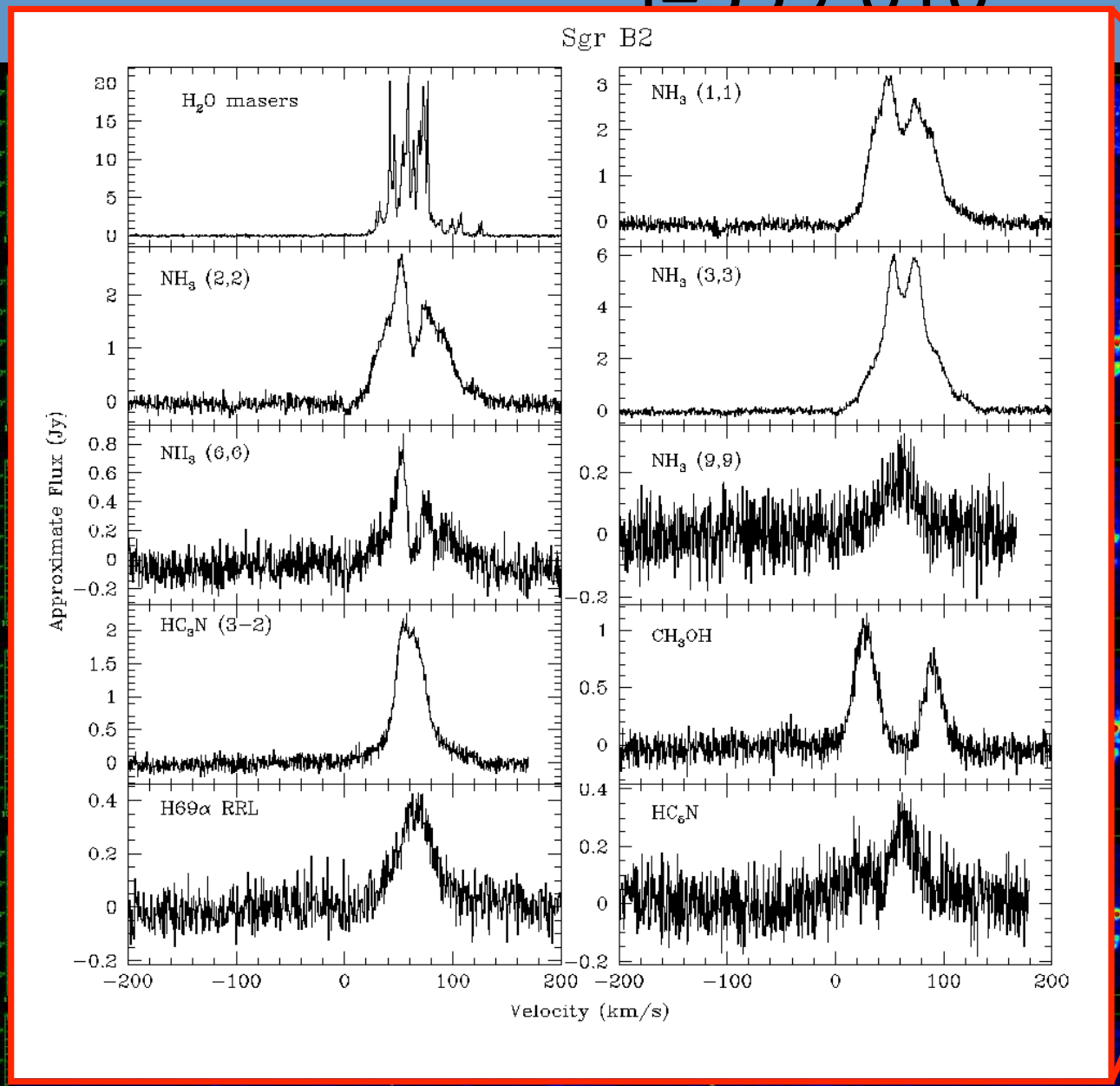

+0.4°
0.0°
−0.4°
30° 28° 26° 24° 22° 20°
20° 18° 16° 14° 12° 10°
10° 8° 6° 4° 2° 0°
0° −2° −4° −6° −8° −10°
−10° −12° −14° −16° −18° −20°
−20° −22° −24° −26° −28° −30°
−30° −32° −34° −36° −38° −40°
−40° −42° −44° −46° −48° −50°
−50° −52° −54° −56° −58° −60°
−60° −62° −64° −66° −68° −70°
Galactic Latitude
Galactic Longitude
S/N 2 4 6

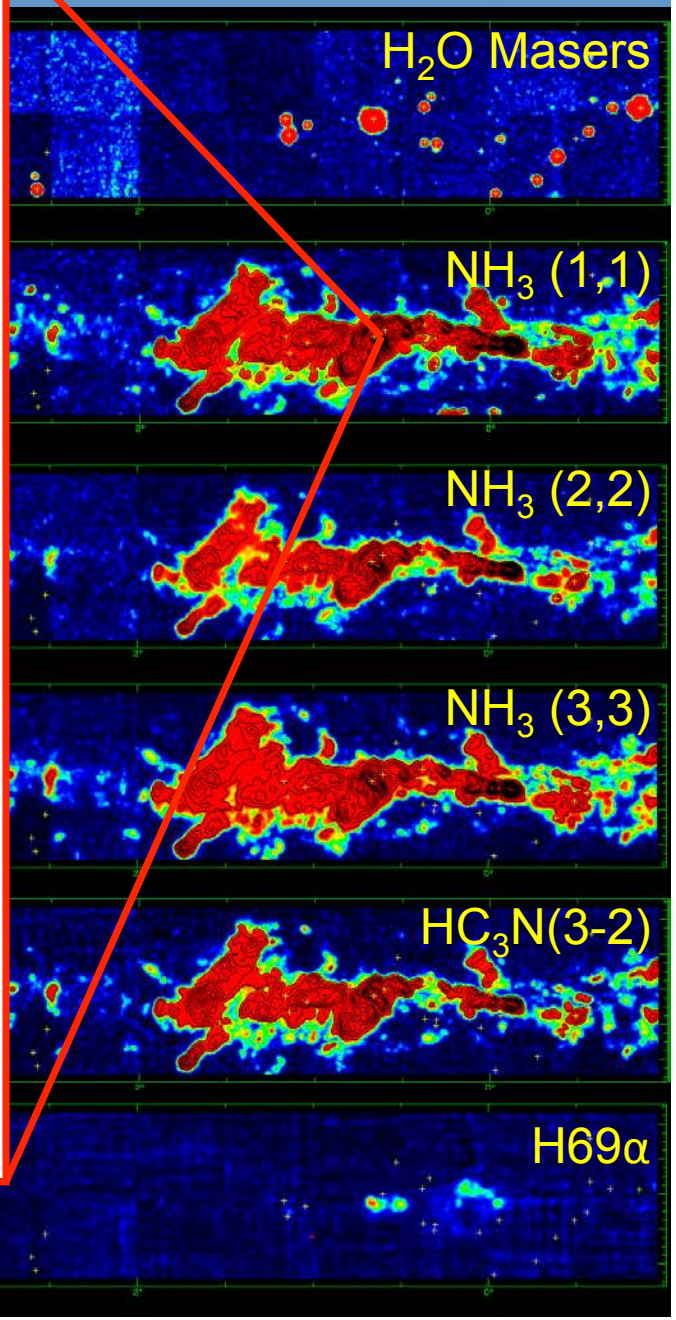
NH_3 (2,2)


+0.40°
0.00°
−0.40°
30° 28° 26° 24° 22° 20°
20° 18° 16° 14° 12° 10°
10° 8° 6° 4° 2° 0°
0° −2° −4° −6° −8° −10°
−10° −12° −14° −16° −18° −20°
−20° −22° −24° −26° −28° −30°
−30° −32° −34° −36° −38° −40°
−40° −42° −44° −46° −48° −50°
−50° −52° −54° −56° −58° −60°
−60° −62° −64° −66° −68° −70°
Galactic Latitude
Galactic Longitude
S/N 2 4 6


35
30
25
20
15
10
5
0
0
5000
10000
15000
20000
25000
30000
5σ Distance Limit (kpc)
Cloud Mass (M⊙)
Far Galactic Boundary (r_gal=15 kpc)
Galactic Centre (r_gal=0 kpc)
T_kin=25K, T_ex=20K, FWHM=3km.s^-1
T_kin=20K, T_ex=15K, FWHM=3km.s^-1
T_kin=15K, T_ex=10K, FWHM=3km.s^-1
T_kin=10K, T_ex=5K, FWHM=2km.s^-1

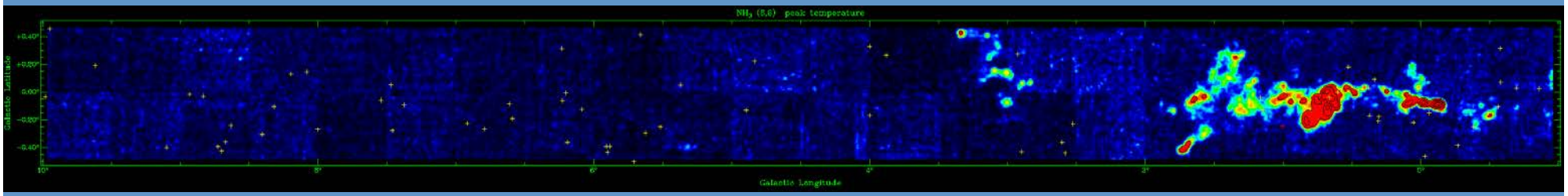
l=359-010°


Sgr B2
H2O masers
NH3 (1,1)
NH3 (2,2)
NH3 (3,3)
NII3 (6,6)
NH3 (9,9)
HC3N (3–2)
CH3OH
H69α RRL
HC6N
Approximate Flux (Jy)
Velocity (km/s)

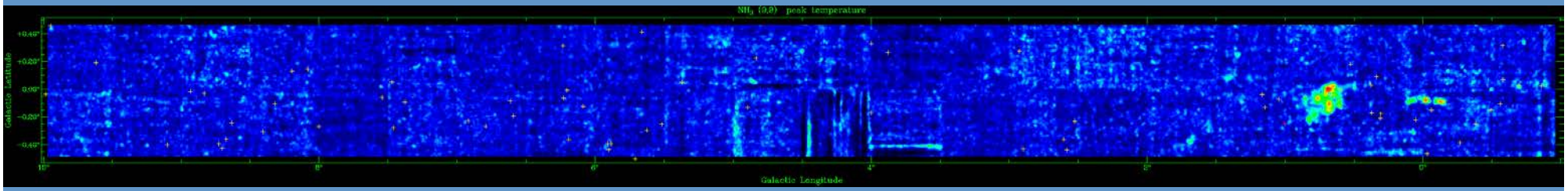

H2O Masers
NH3 (1,1)
NH3 (2,2)
NH3 (3,3)
HC3N(3-2)
H69α

Hot gas emission in the CMZ

NH_3 (6,6)

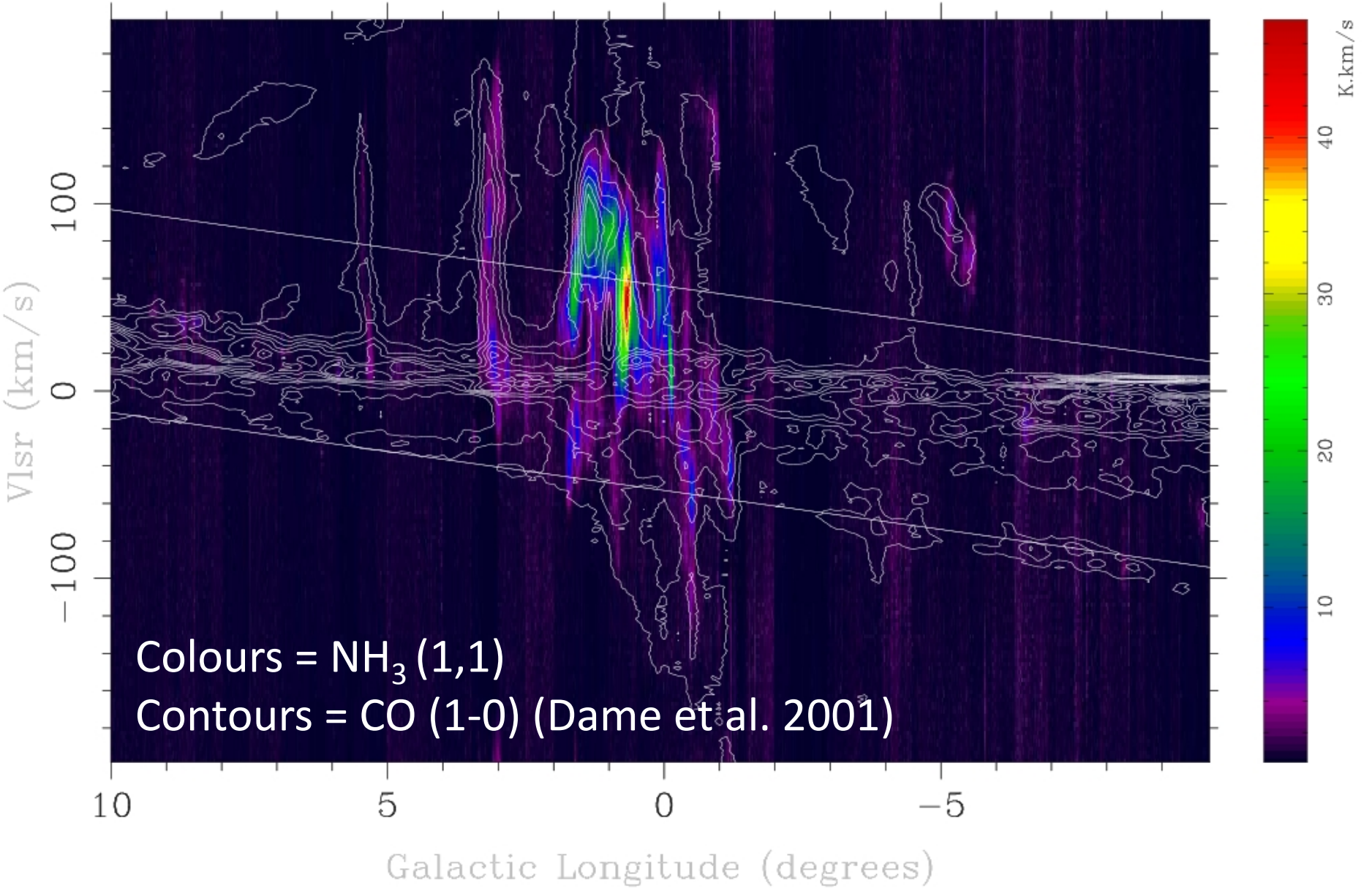


NH_3 (9,9)

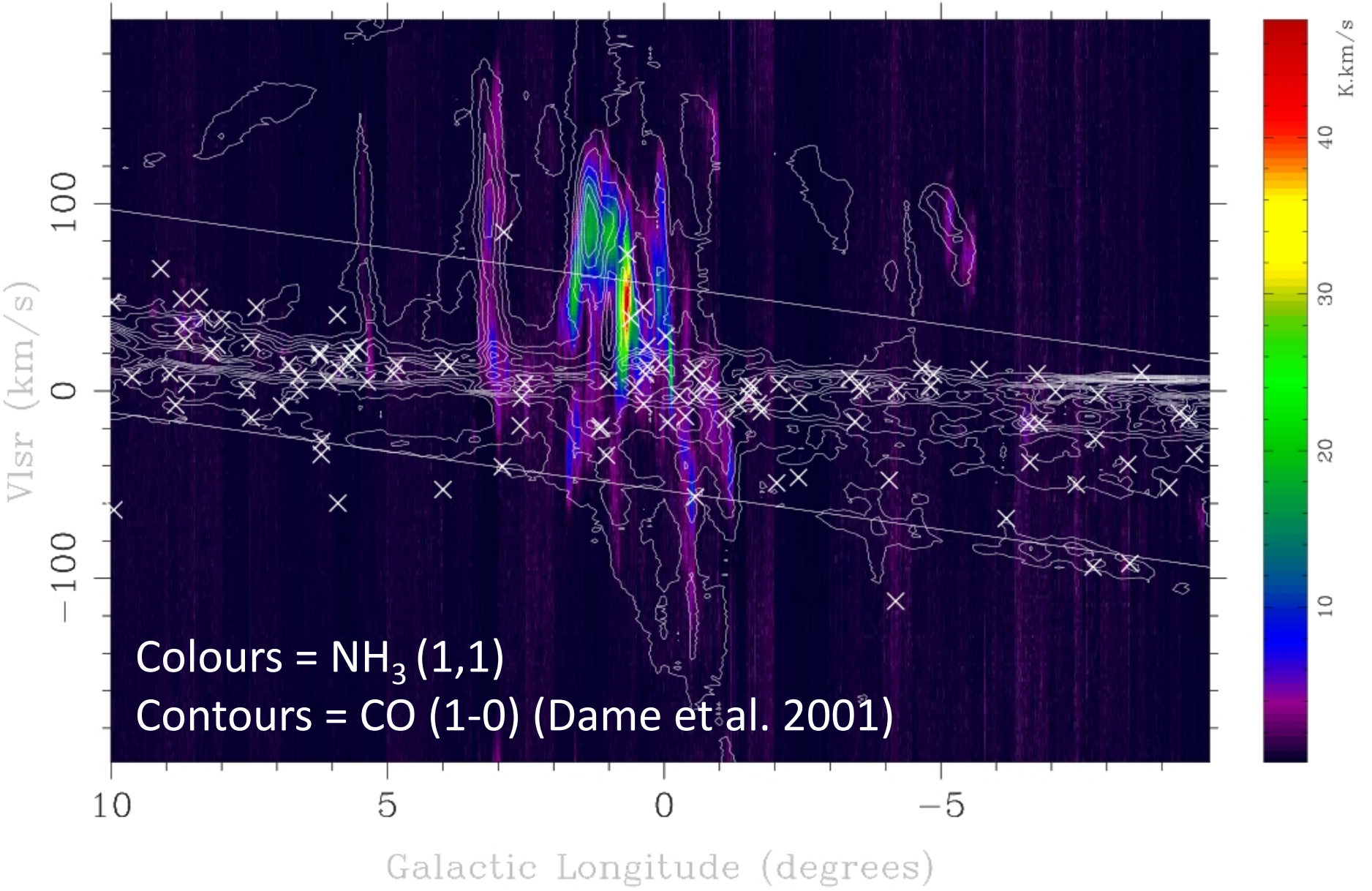


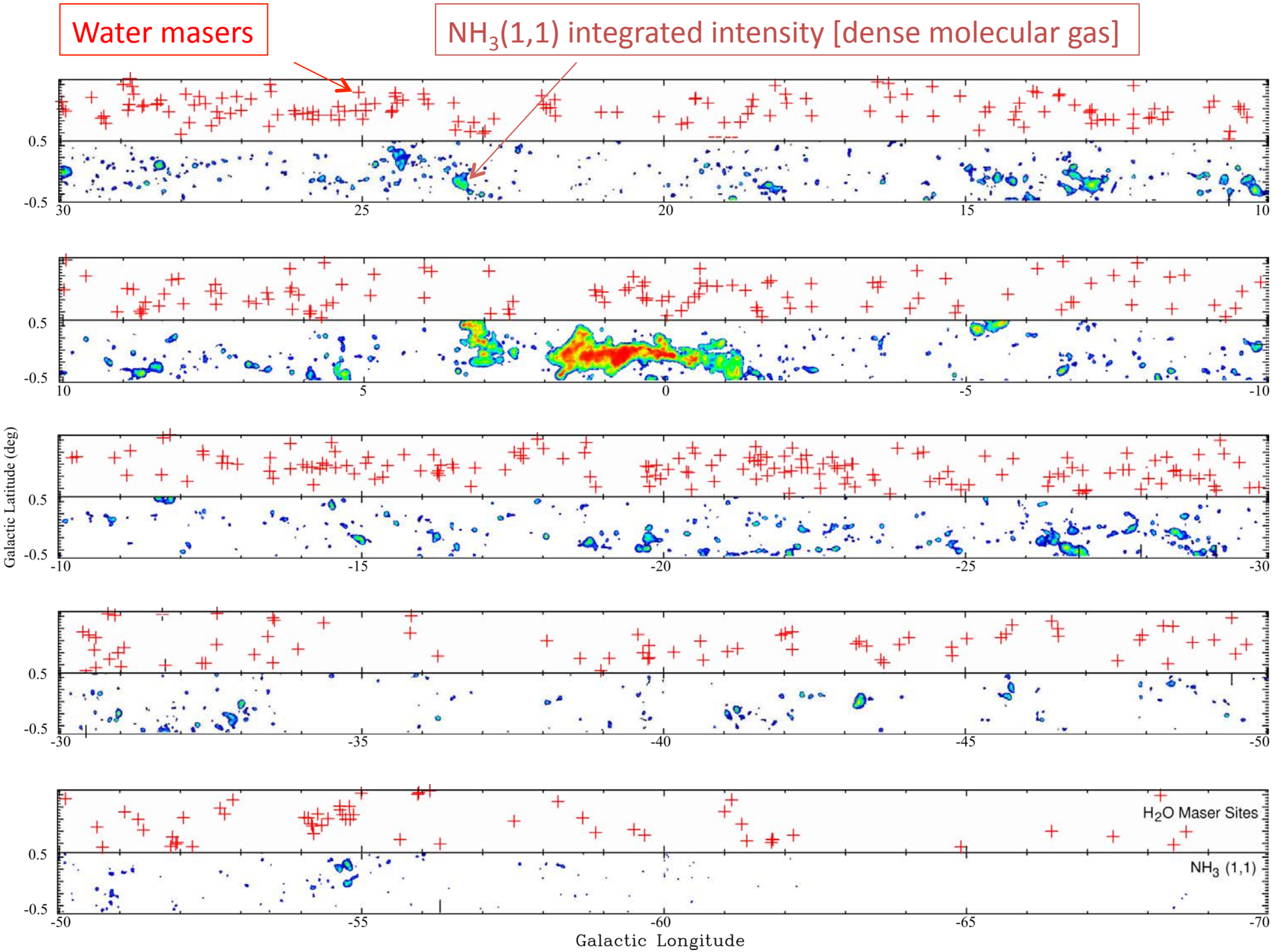
50pc

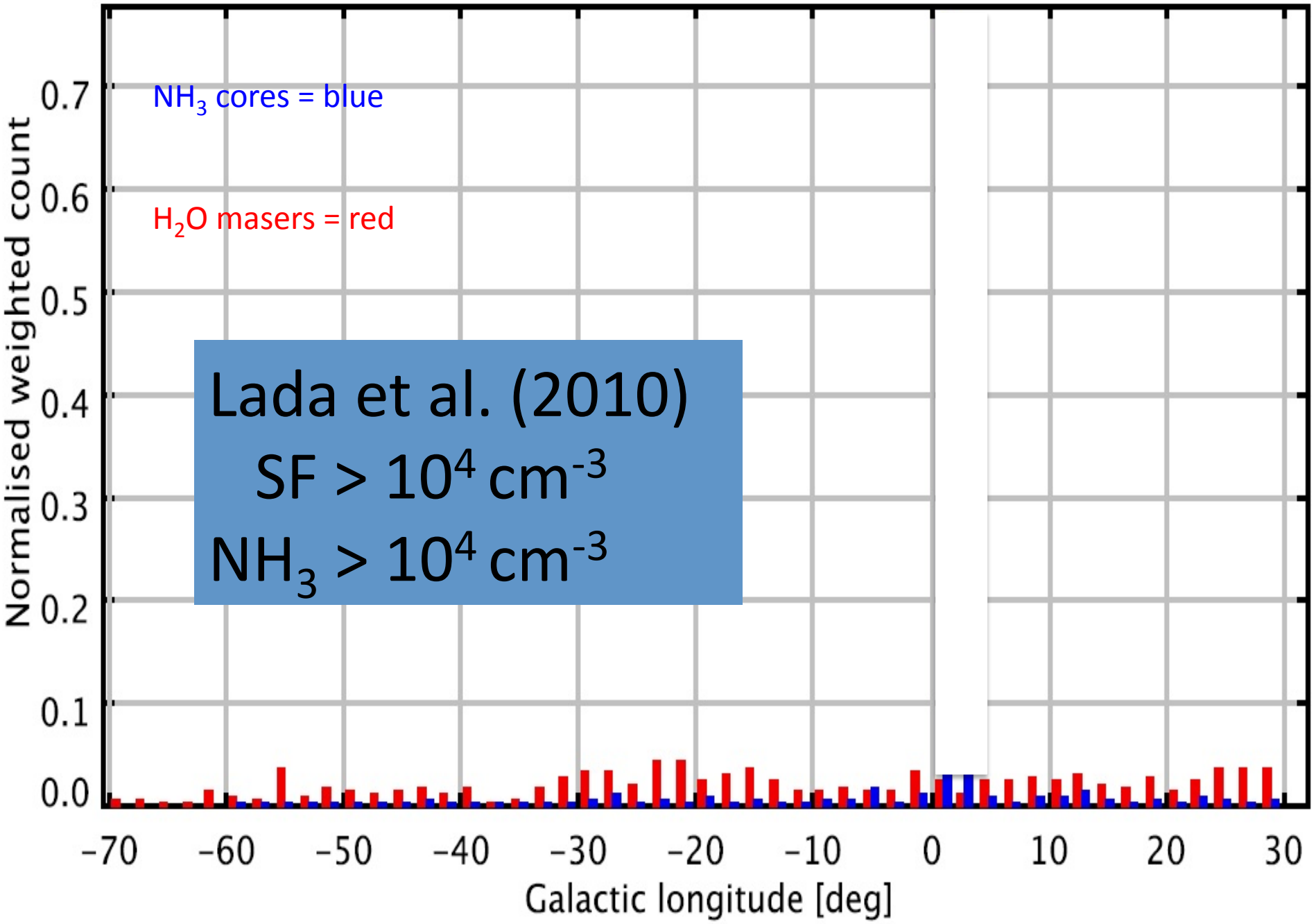
Kinematics of the Inner Galaxy with NH_3



Kinematics of the Inner Galaxy with NH_3

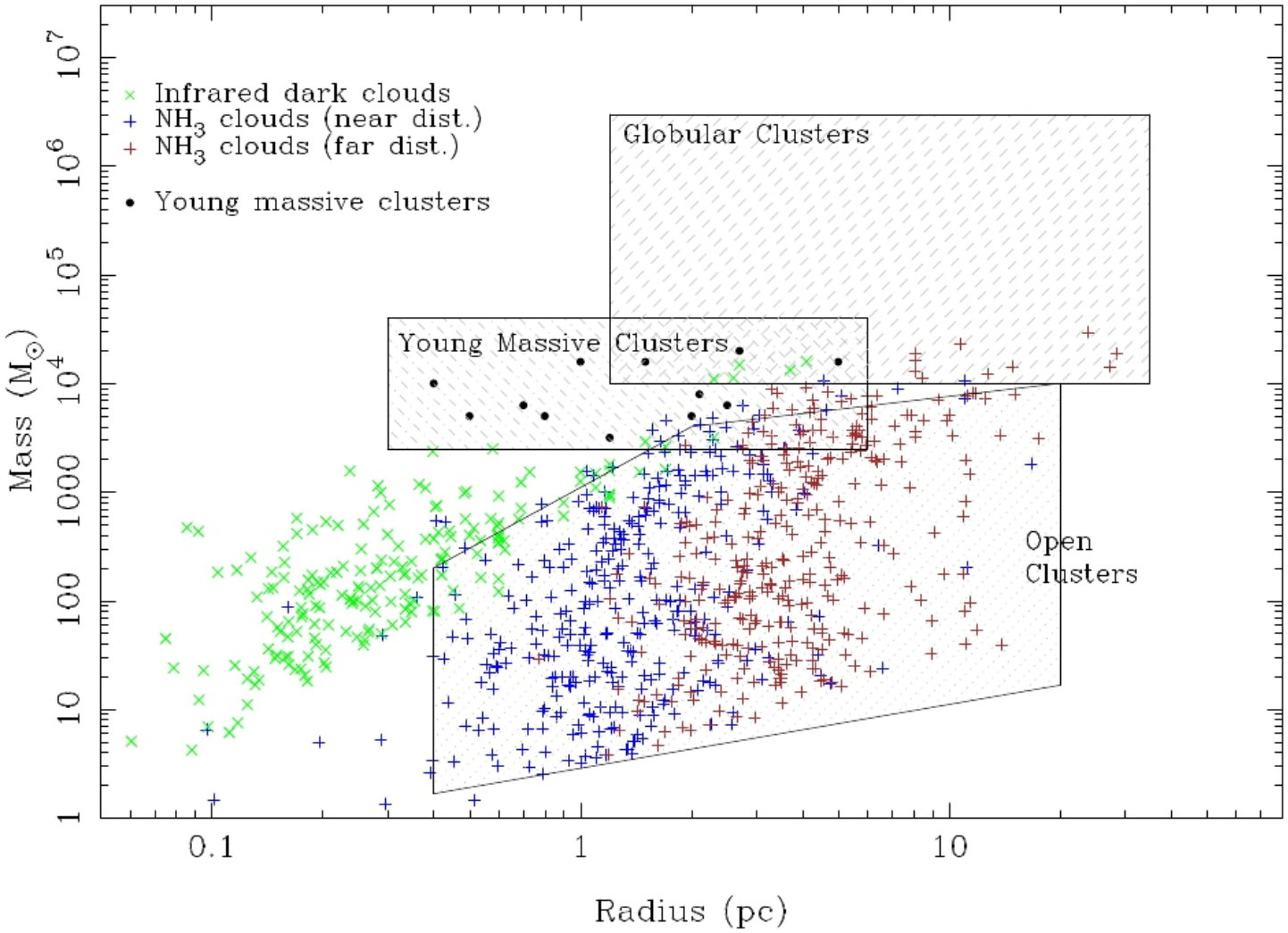



Water masers
NH3(1,1) integrated intensity [dense molecular gas]
Galactic Latitude (deg)
Galactic Longitude
H2O Maser Sites
NH3 (1,1)
0.5
-0.5
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70

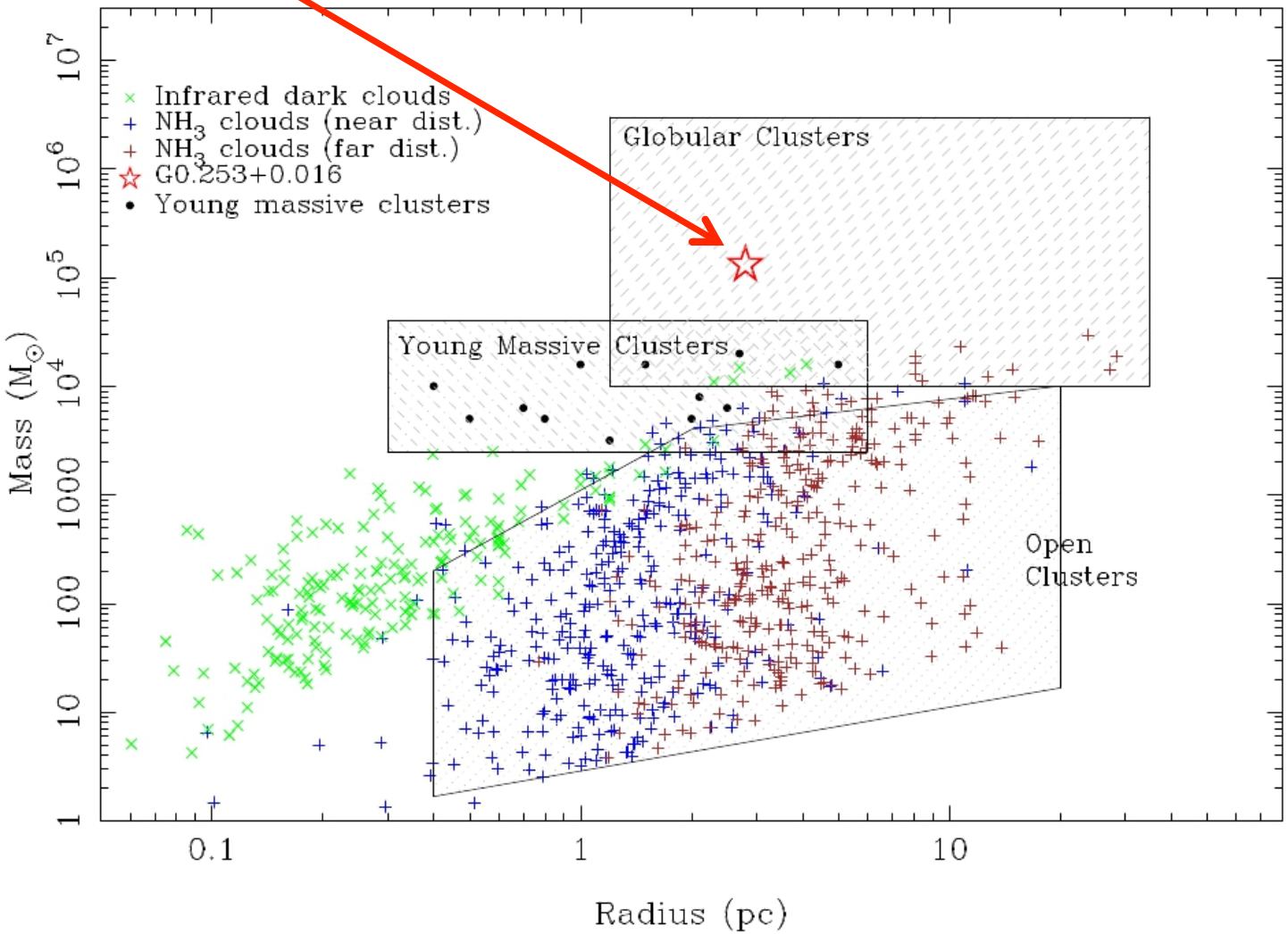

NH3 cores = blue
H2O masers = red
Lada et al. (2010)
SF > 10^4 cm^-3
NH3 > 10^4 cm^-3
Normalised weighted count
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
Galactic longitude [deg]

Large number of surveys in recent years searching for high mass protoclusters

Based on measured gas density these seem destined to predominantly form Open clusters



G0.253+0.016 – the initial conditions of a young high mass cluster?
(aka “The Brick”, “The Lima Bean”, “M0.25”, “Mr Hankey”)



Longmore et al 2011 submitted

G0.25

- 1.4×10^5 M_{sun}
- Radius 2.8pc
- Almost no signs of current star formation
- Gravitationally-bound so likely to form stars

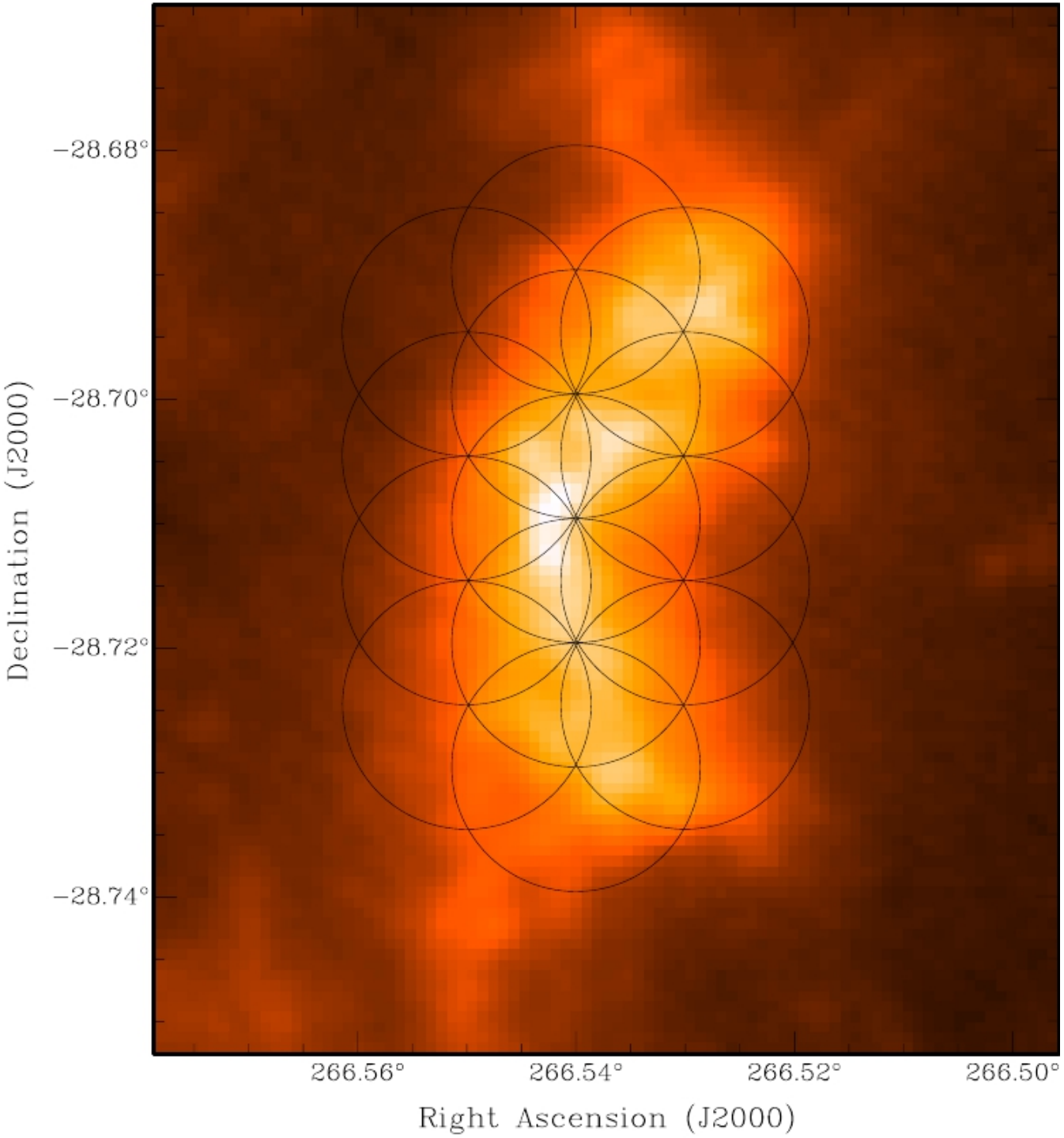
- Potentially unique in Galaxy?

Initial conditions of a precursor to a YMC

Detailed study can reveal important information about YMC formation and help test theoretical models

ALMA Follow UP

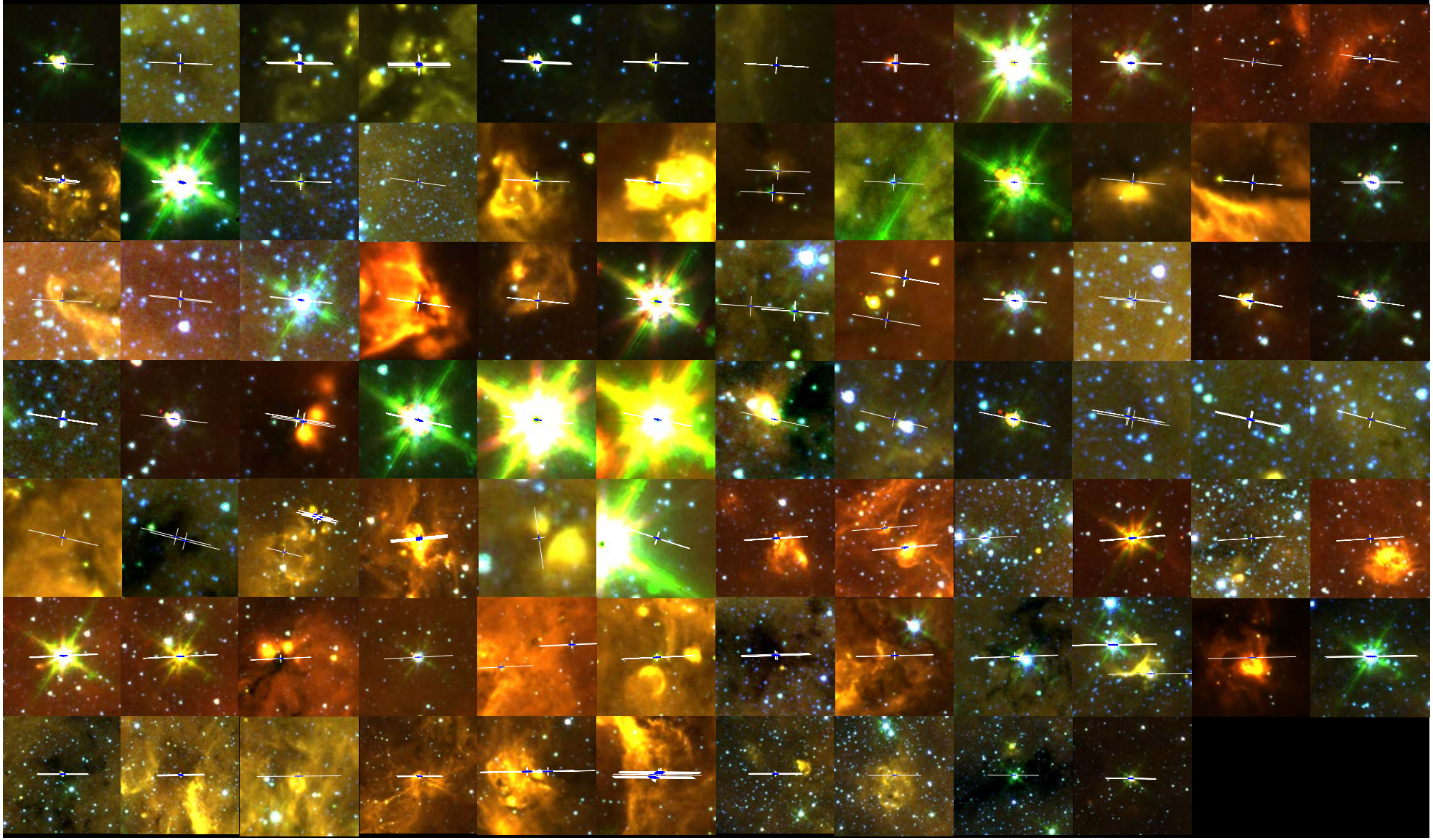
- Awarded 6 hours of ALMA Early Science time to map G0.25 at 90GHz



Accurate positions of water masers using ATCA

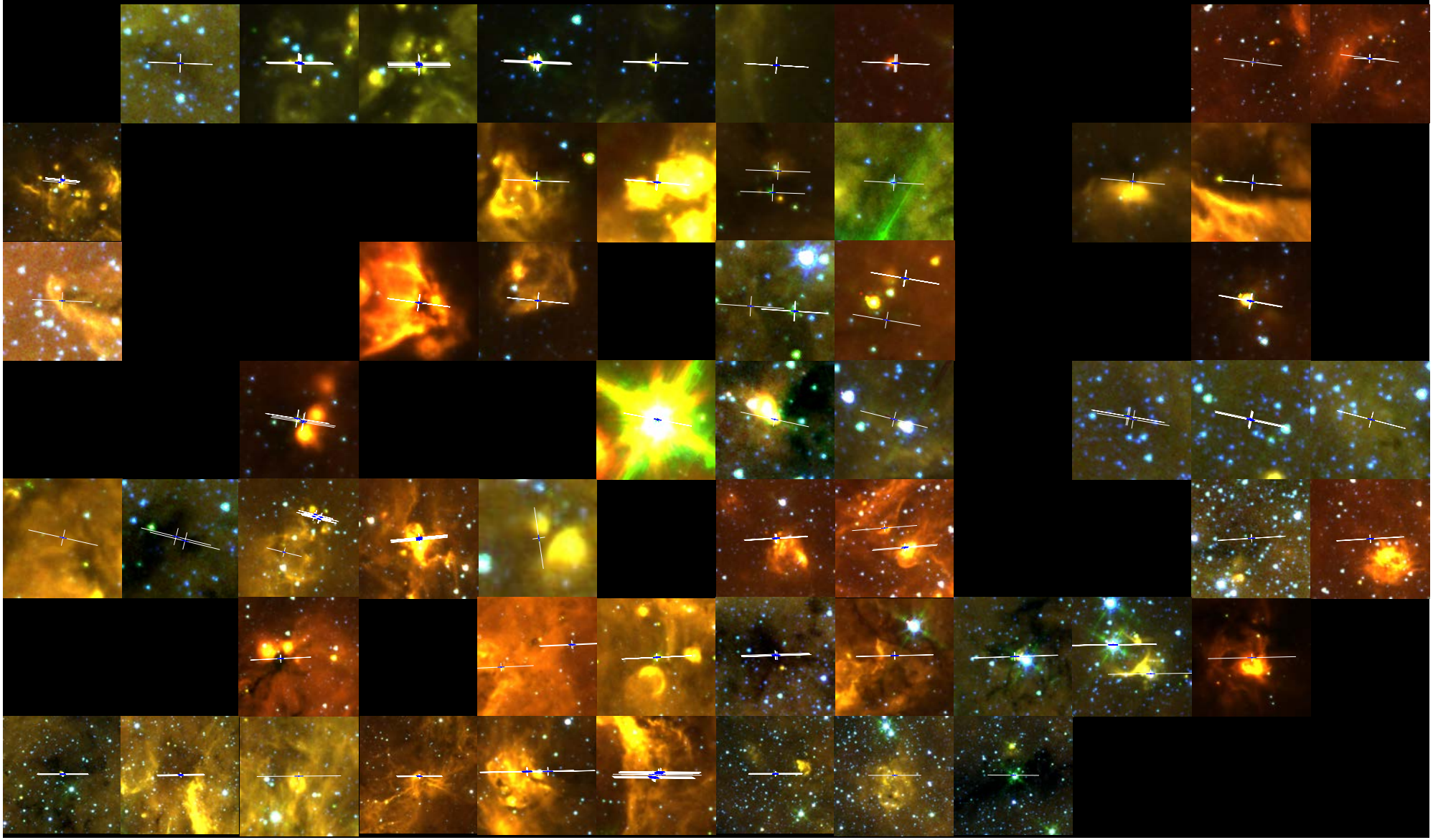
Processed data from l=10 to l=25, including 90 water masers

Mosaic of GLIMPSE infrared around water maser positions



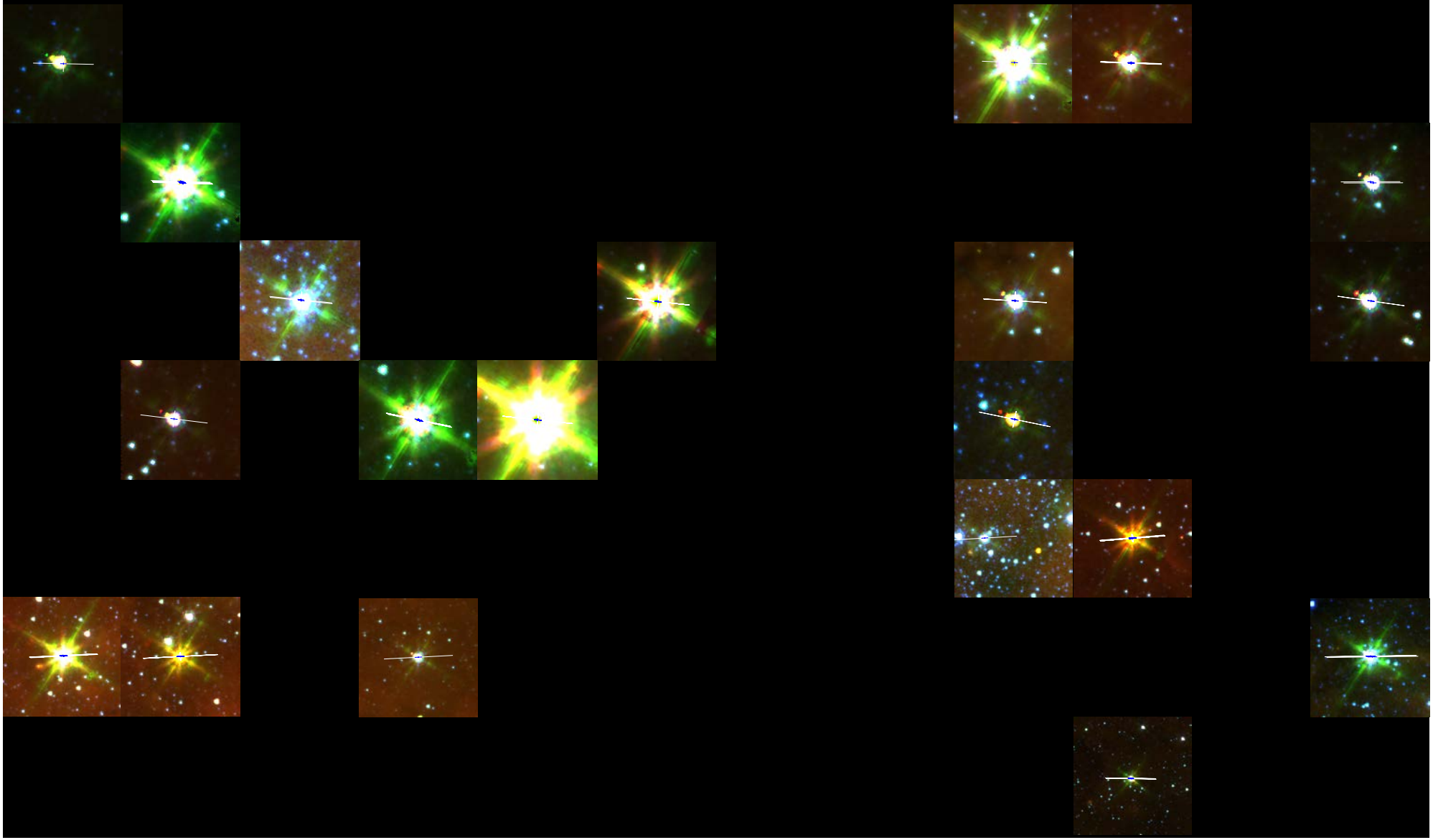
Mosaic of GLIMPSE infrared around water maser positions

Star formation associations



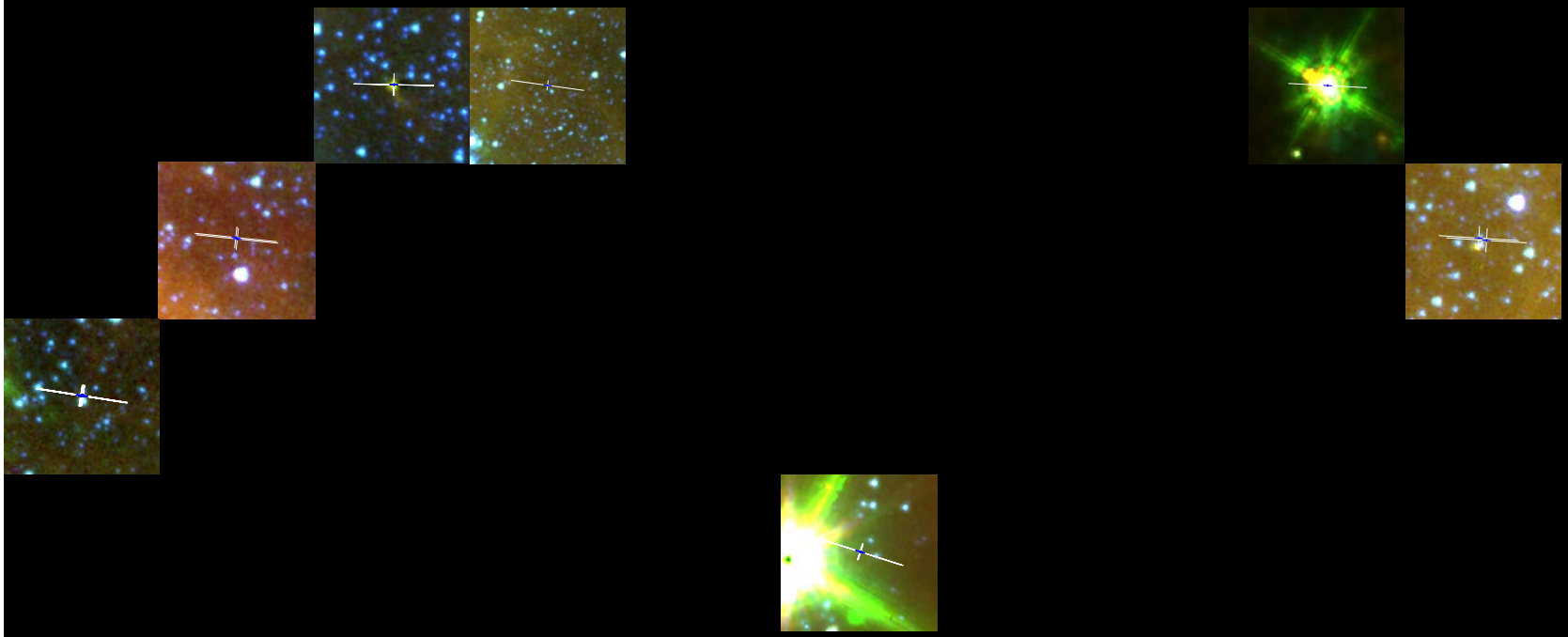
Mosaic of GLIMPSE infrared around water maser positions

Evolved star associations

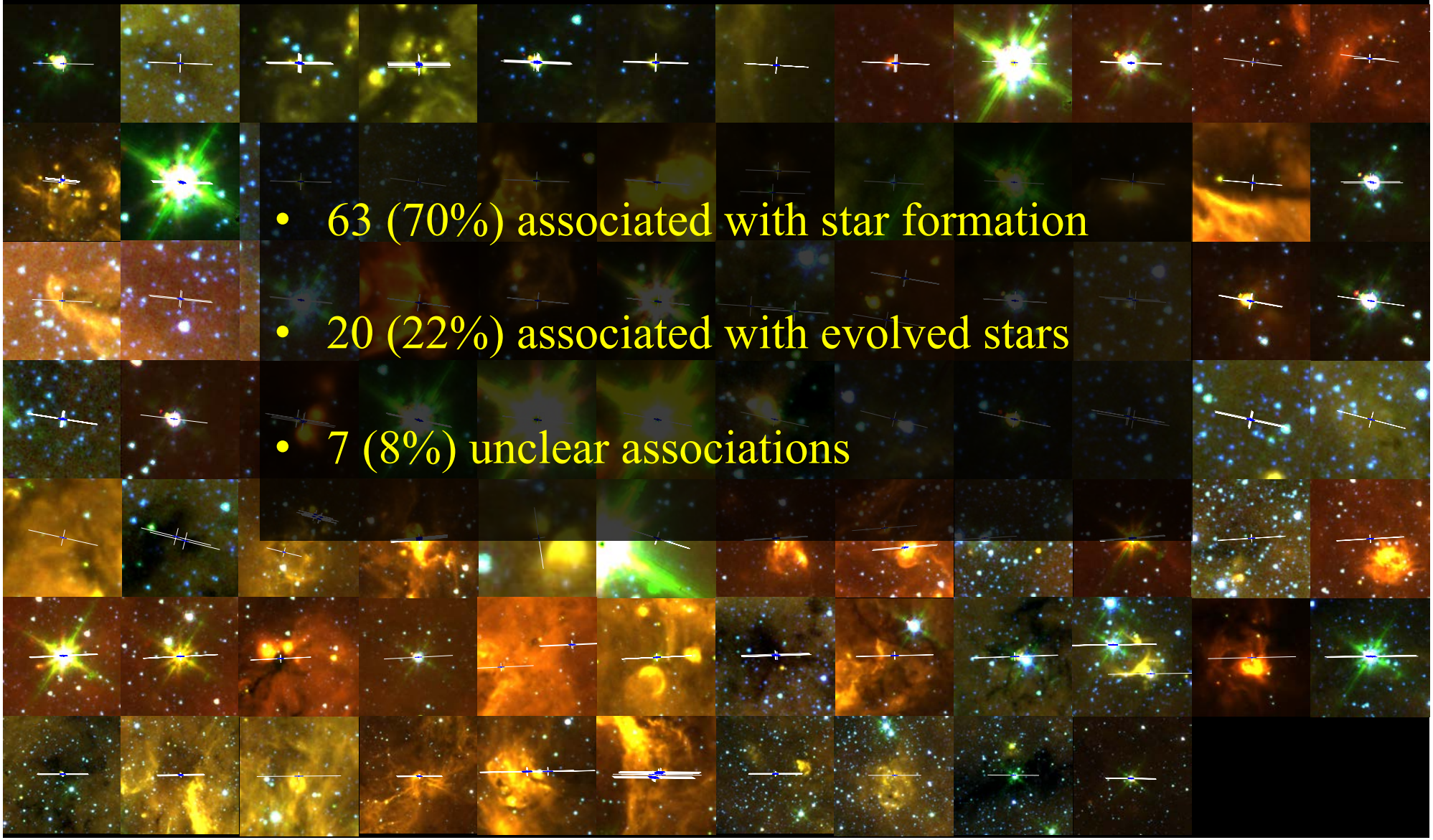


Mosaic of GLIMPSE infrared around water maser positions

Unknown associations



Mosaic of GLIMPSE infrared around water maser positions



- 63 (70%) associated with star formation
- 20 (22%) associated with evolved stars
- 7 (8%) unclear associations

HOPS Summary

- Mopra observations of 100 square degrees finished
- 540 water masers (64% new)
- 568 NH_3 (1,1) detections
- ~ 30% of NH_3 (1,1) sources also show NH_3 (2,2) and NH_3 (3,3)
- Occasional detections: HC_3N (3-2), RRLs, multiple Class I methanol masers, HC_5N, NH_3 (6,6) and (9,9)
- Lack of star formation in the CMZ?
- High mass precursor for cluster
- ATCA followup complete; 90 masers processed (70% SF, 22% ES, 8% ?)

MALT – The Millimetre Astronomy Legacy Team

Three Galactic Plane Surveys

- A 3mm spectral line survey at 90GHz – MALT-90
- A 3mm spectral line survey at 115GHz – MALT-115
- A 7mm spectral line survey at 45GHz – MALT-45

MALT – The Millimetre Astronomy Legacy Team

A 3mm spectral line survey at 90GHz – MALT-90

- Focusses on emission from many strong spectral lines: N_2H^+, ^{13}CS, H41α, CH_3CN, HC_3N, $^{13}C^{34}S$, HNC, $HC^{13}CCN$, HCO^+, HCN, HNCO, C_2H, SiO, $H^{13}CO^+$ and $H^{13}CN$

- 3000 cores throughout the Galaxy based on ATLASGAL continuum sources

MALT – The Millimetre Astronomy Legacy Team

A 3mm spectral line survey at 115GHz – MALT-115

- Focuses on emission from CO isotopologues: ^{12}CO, ^{13}CO, $C^{18}O$
- Survey requires some sort of fast mapping, which can be accomplished by sampling very quickly or spacing observations over many beams.

MALT – The Millimetre Astronomy Legacy Team

A 7mm spectral line survey at 45GHz – MALT-45

Use the ATCA rather than Mopra:

- Increase sensitivity/speed
- Use cross-correlation data to position masers
- Use auto-correlation data to map extended emission

MALT-45 Pilot Survey

Thanks to:
Chris Jordan (JCU/ATNF)
Vicki Lowe (UNSW/ATNF)
Maxim Voronkov (ATNF)
Cormac Purcell (U. Leeds)

MALT-45 Pilot Survey

Observations in March 2010 over 3×12-hour tracks on ATCA

- Map a one-square-degree patch of the Galactic Plane
- Fast mosaicing mode (6 seconds per pointing)
- Observe multiple spectral lines (42.2-44.2GHz & 47.2-49.2GHz)

MALT-45 Pilot Survey

Multiple spectral lines

- CS and $C^{34}S$ (1-0) high density gas tracer. Also enhanced in outflows (compare to NH_3 from HOPS)
- CH_3OH Class I maser – strongest Class I transition at 44.069GHz. Typically shows up in shocked gas/outflows, but occasionally found close to Class II masers.
- SiO (1-0) masers: multiple vibrationally excited masing transitions – star formation + evolved stars.

MALT-45 Pilot Survey

Continuum

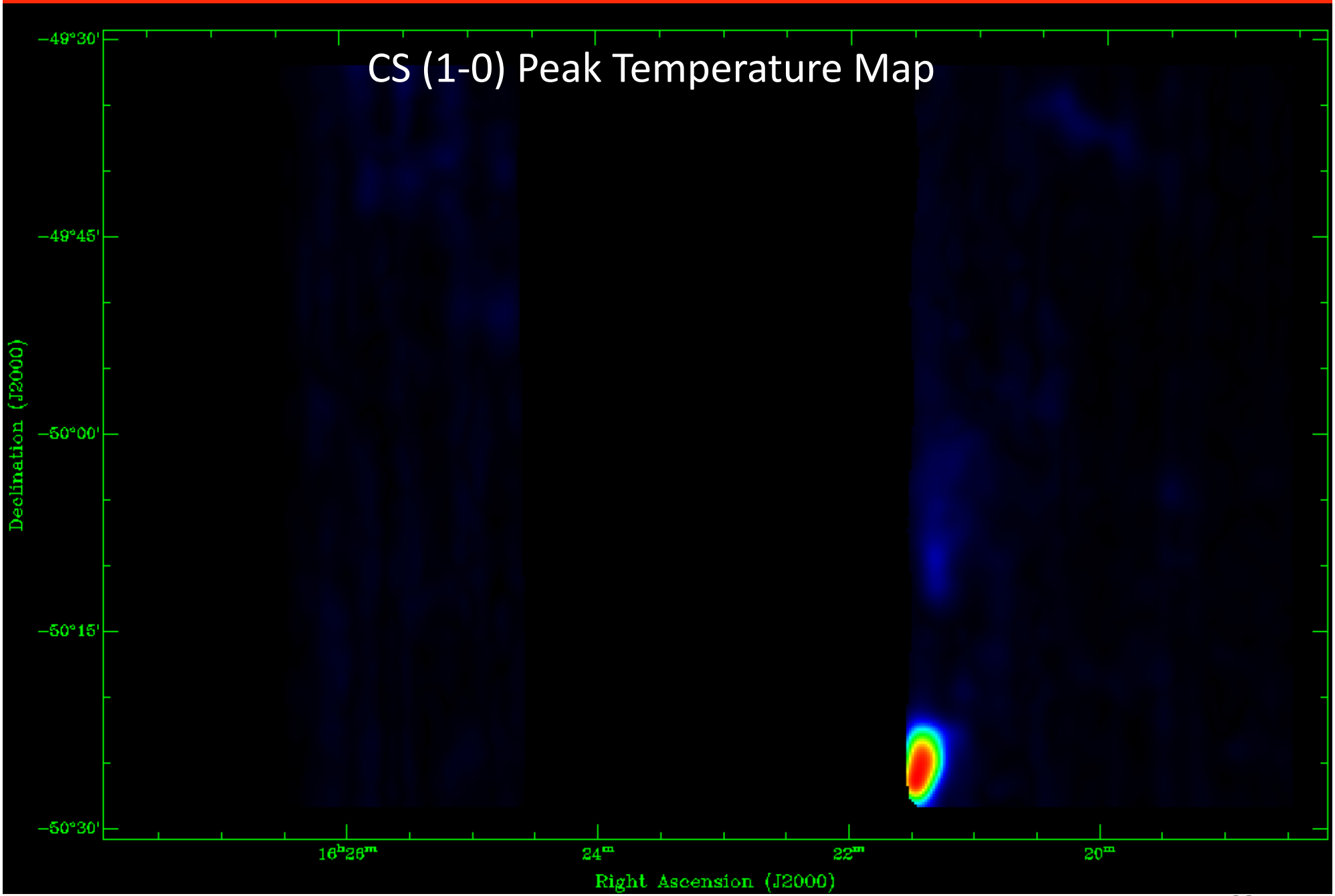
- Identify hypercompact HII regions: very small signatures of HMSF seen only at high frequencies.
- Use CABB: can get spectral index from 42.2 – 49.2GHz

MALT-45 Pilot Survey

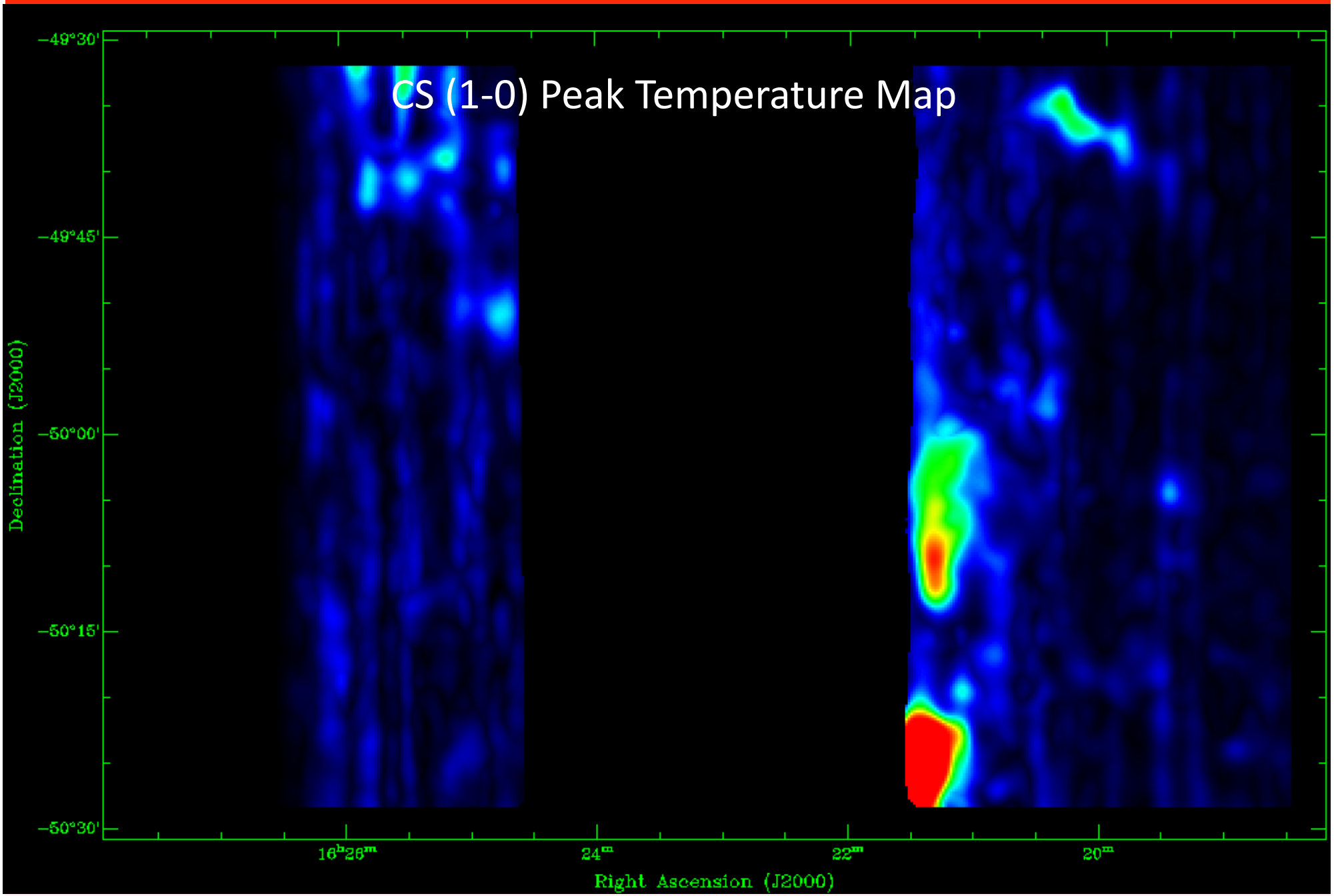
Results

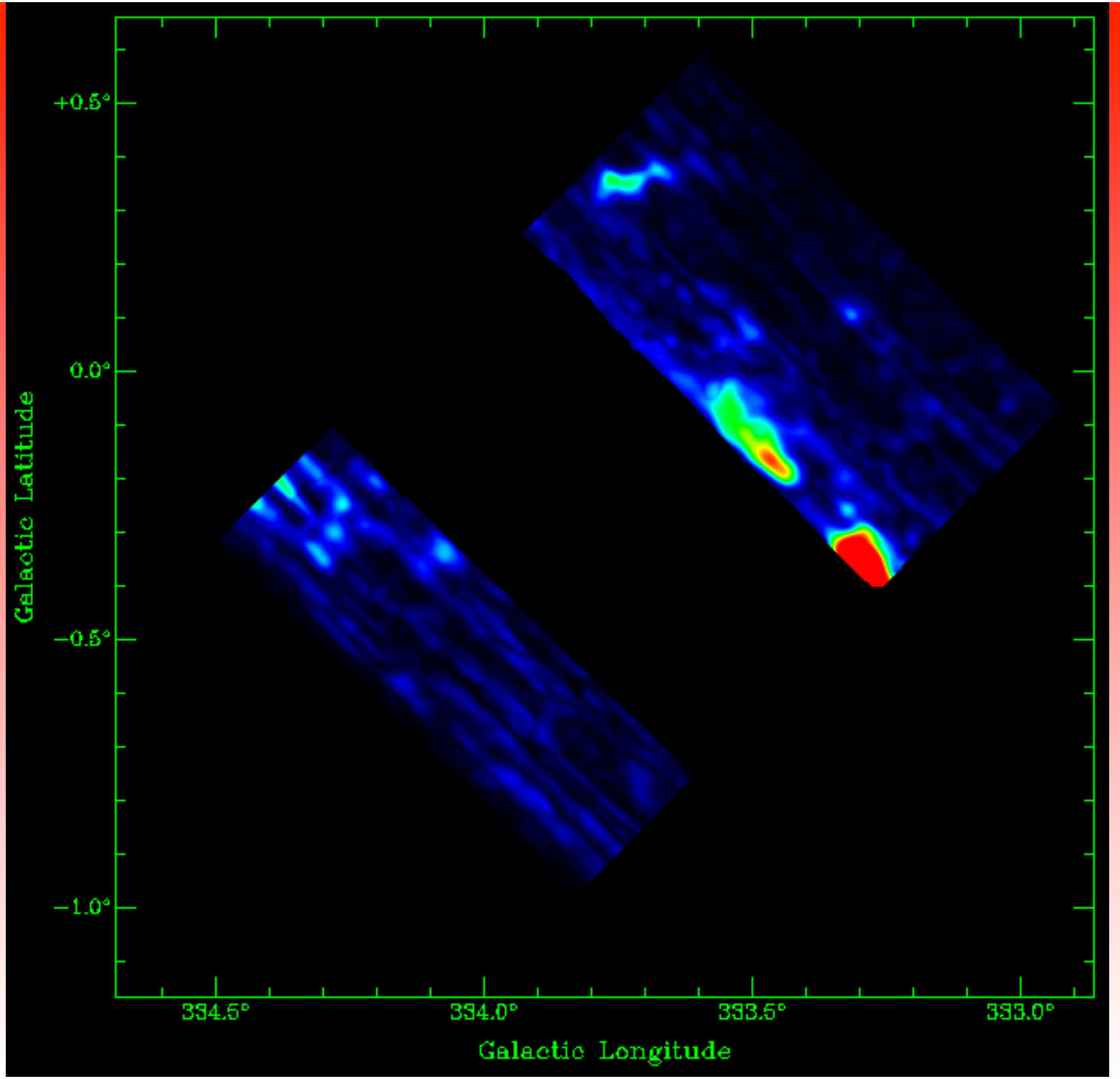
- **CS(1-0) maps**
- **Comparison with HOPS NH_3 (1,1)**
- **Comparison with GLIMPSE infrared**
- **Class I CH_3OH masers**
- **SiO (1-0) v=1,2 masers**

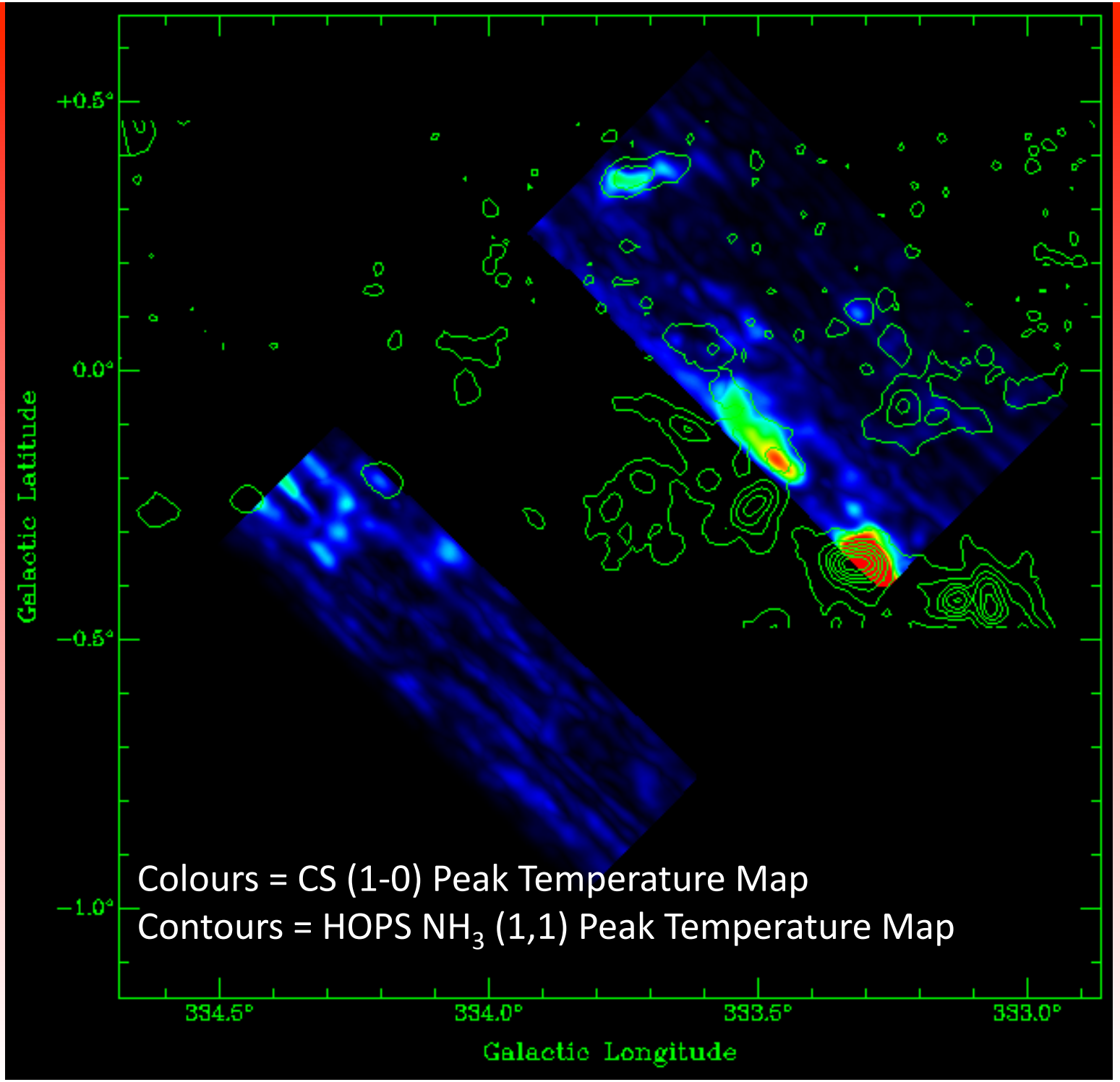
CS (1-0) Peak Temperature Map

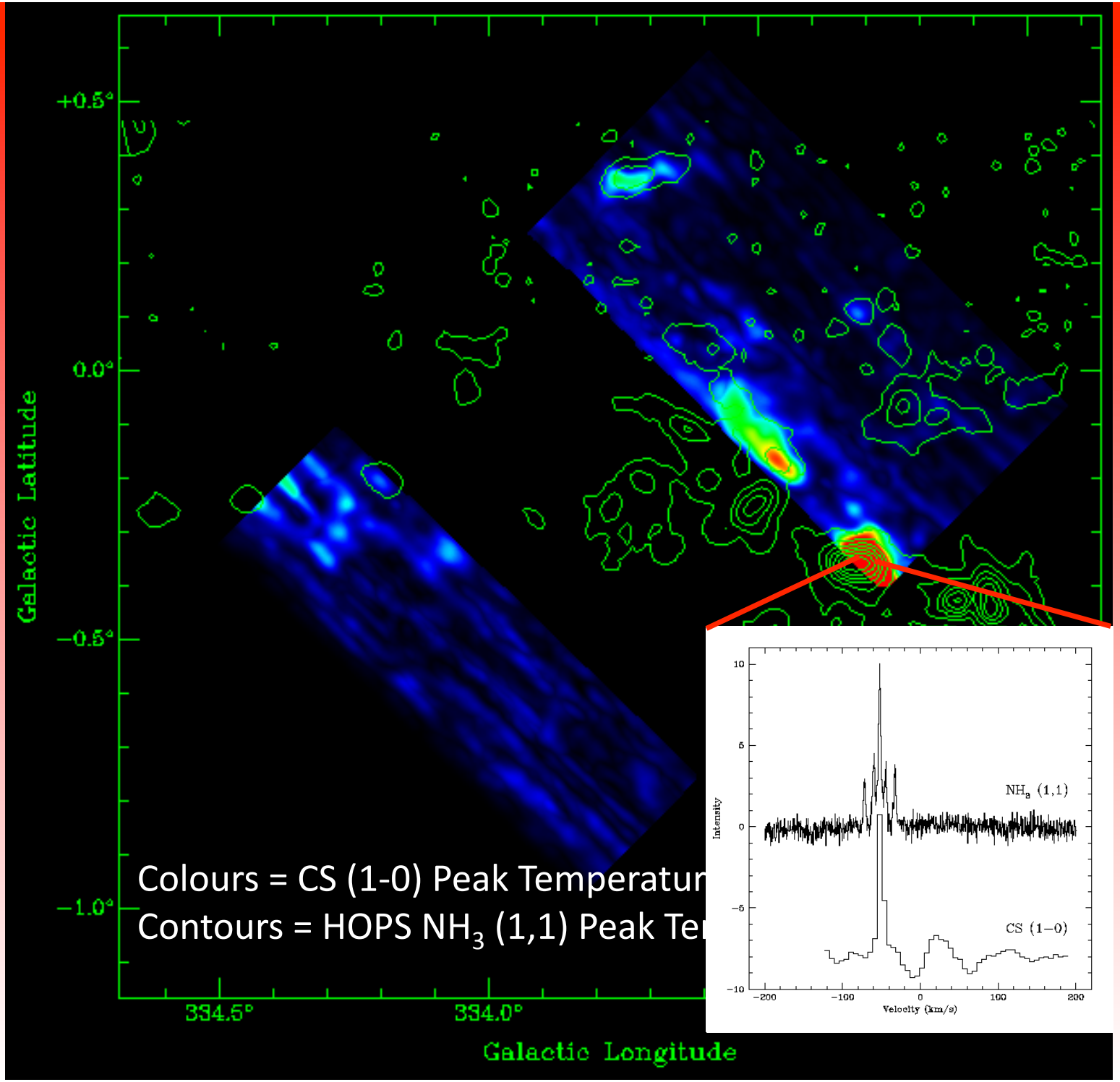


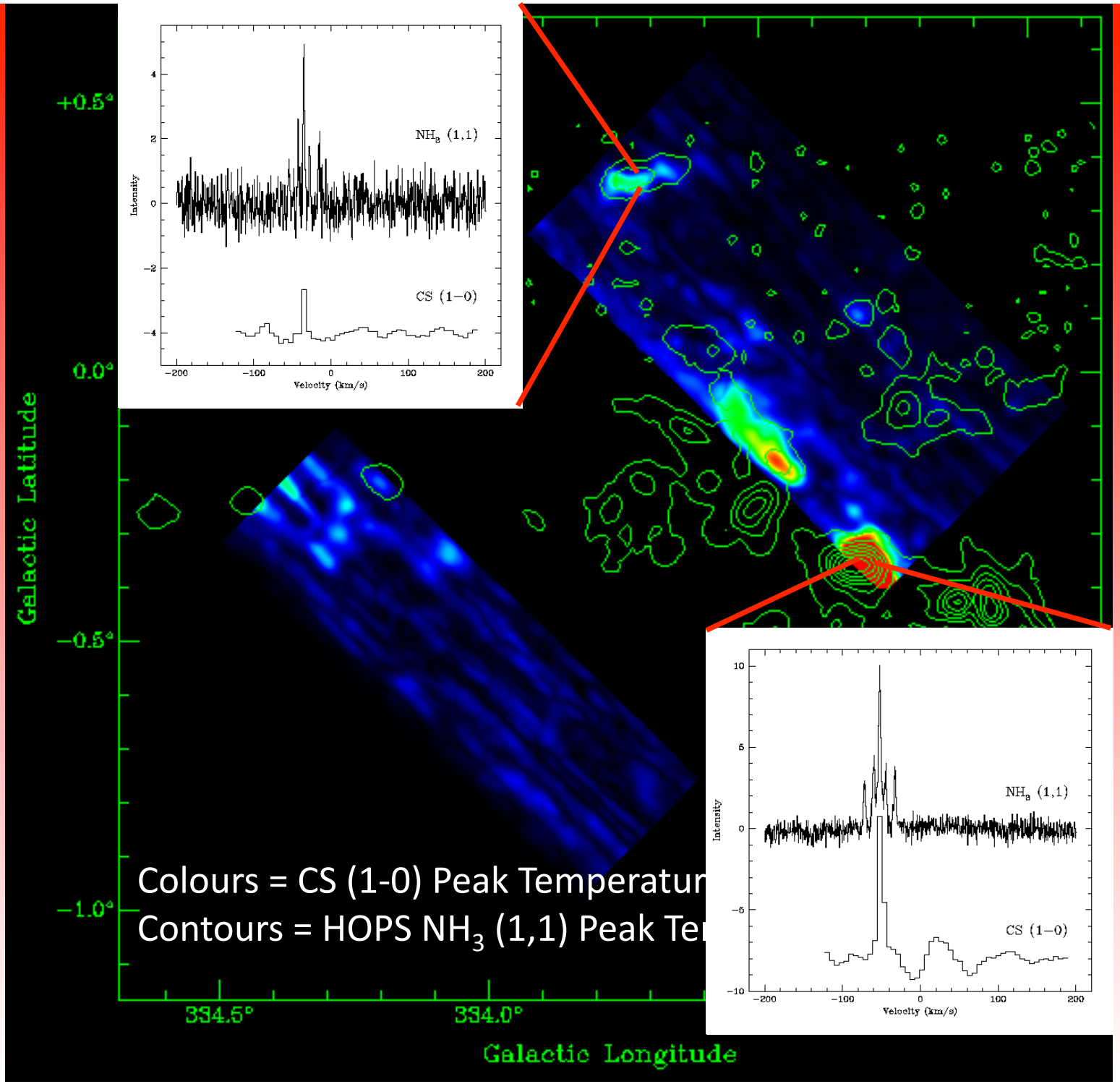
CS (1-0) Peak Temperature Map

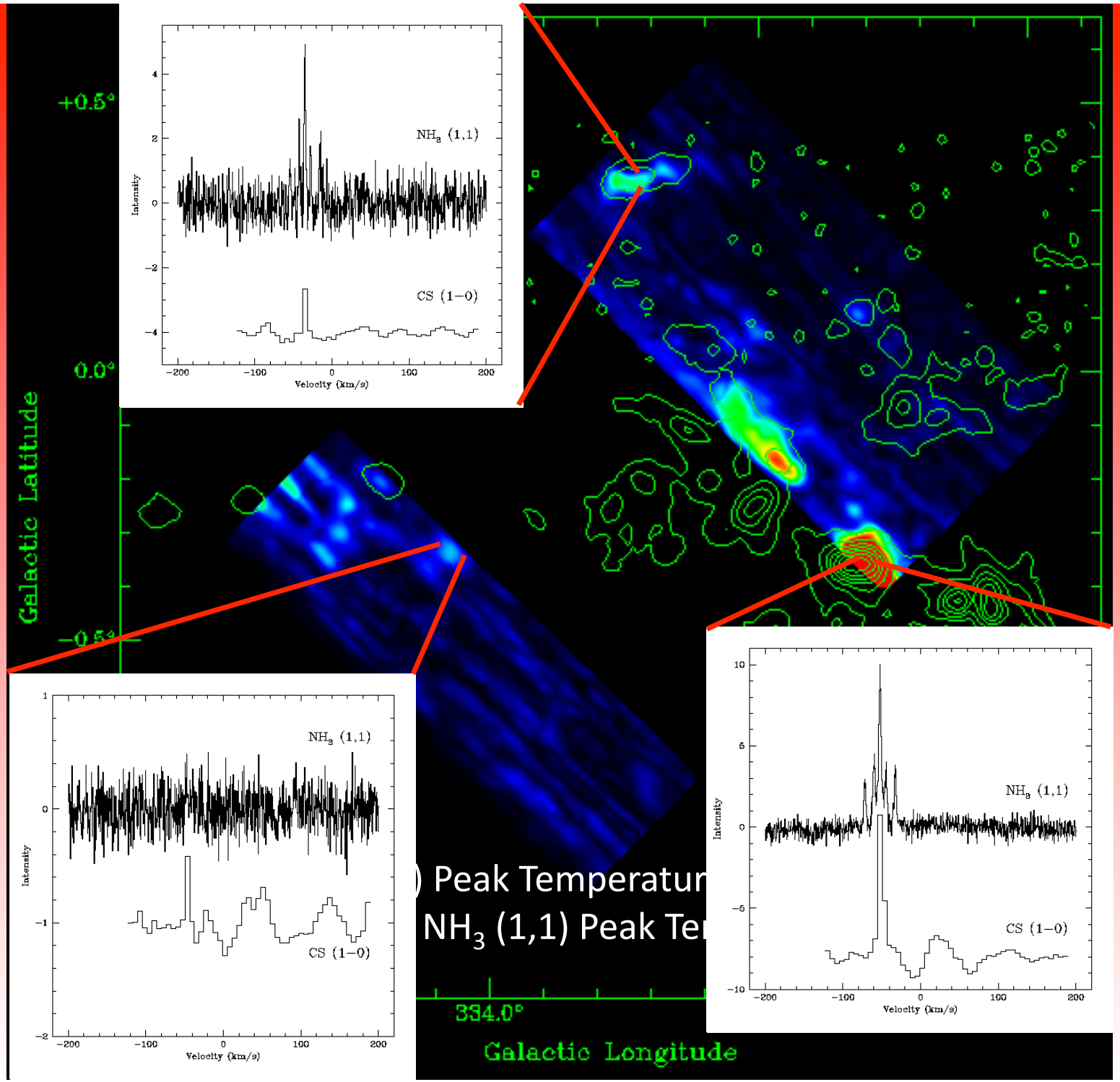


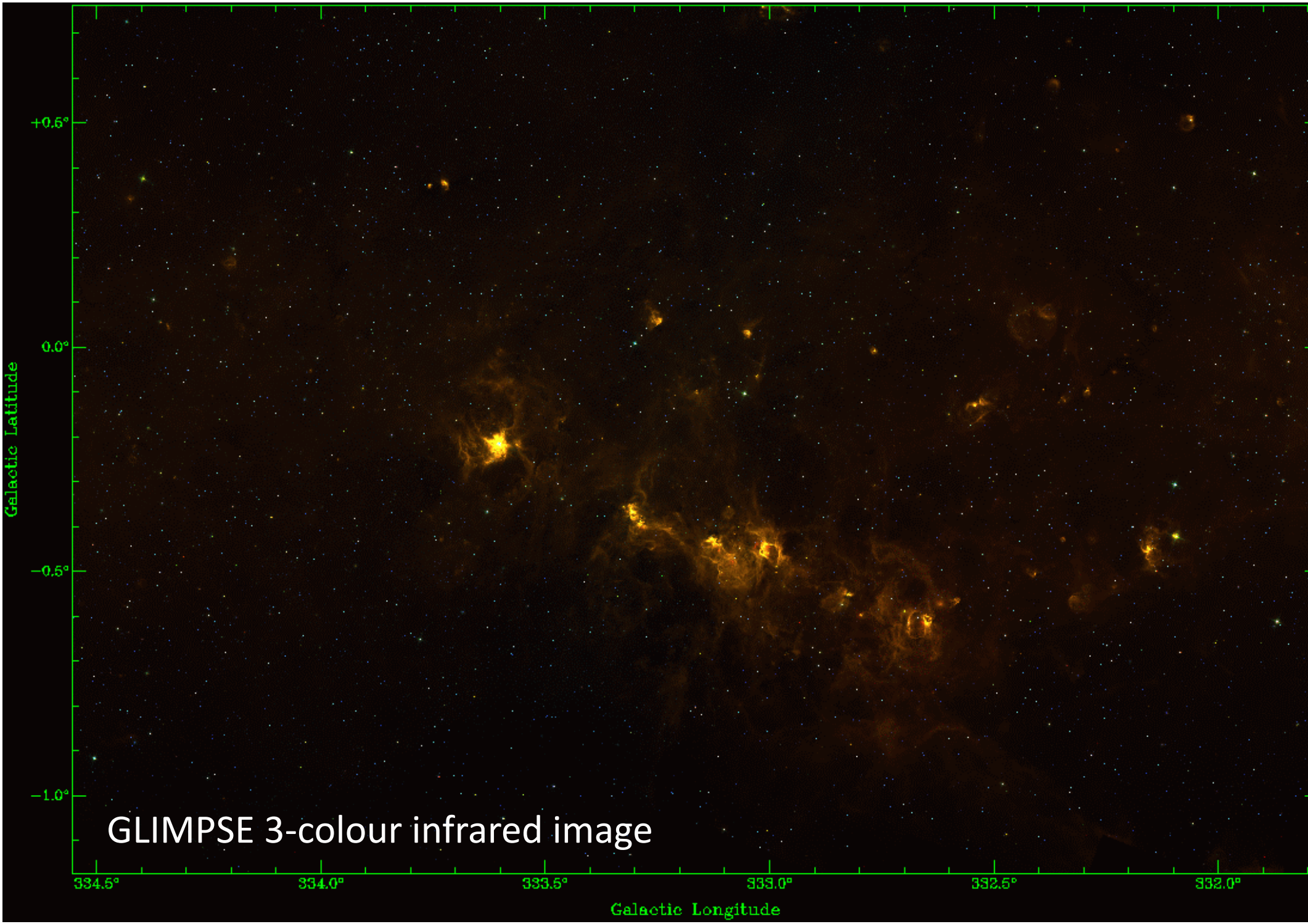

+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
Galactic Longitude


+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
Galactic Longitude
Colours = CS (1-0) Peak Temperature Map
Contours = HOPS NH3 (1,1) Peak Temperature Map

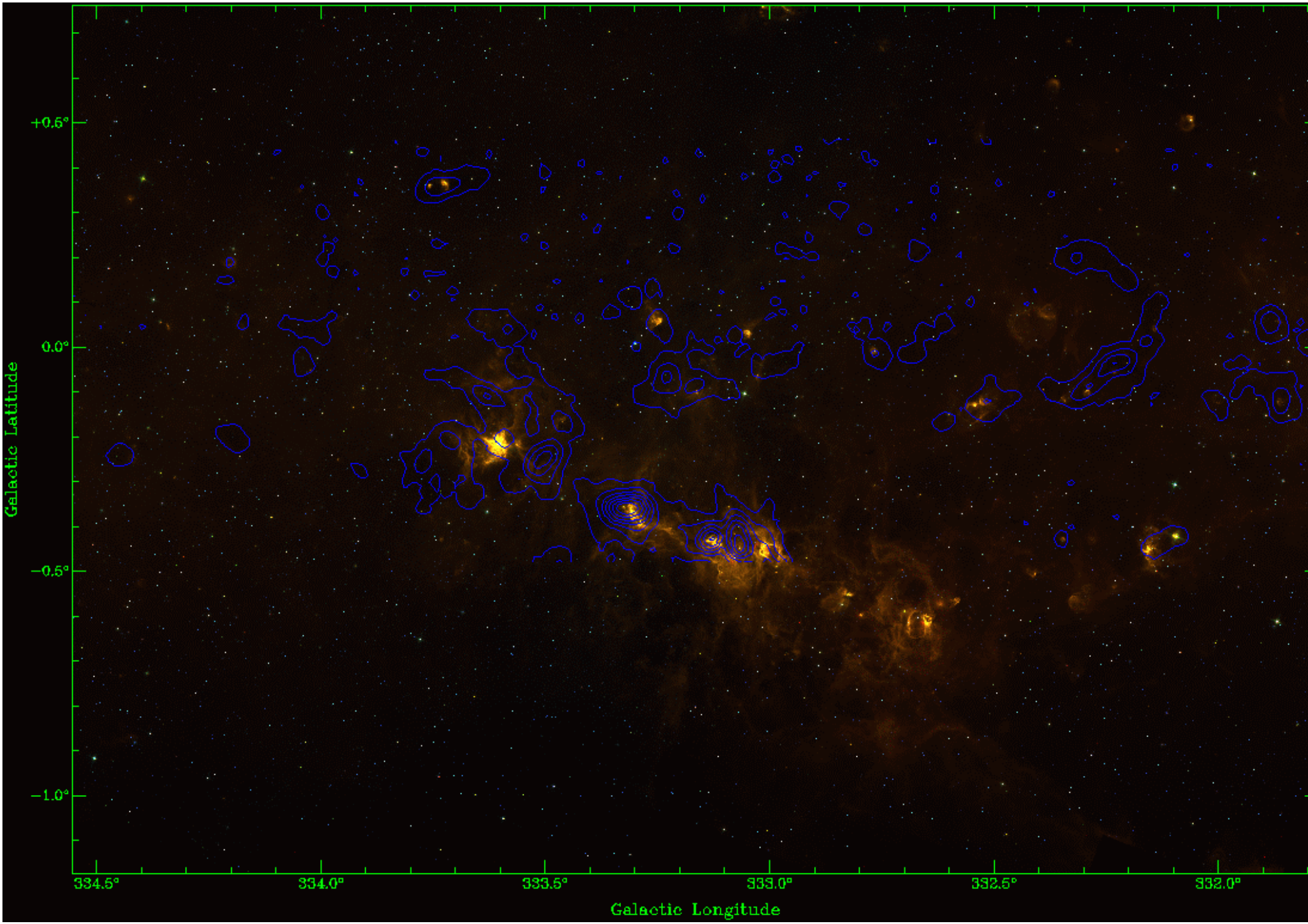

+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
Galactic Longitude
Colours = CS (1-0) Peak Temperatur
Contours = HOPS NH3 (1,1) Peak Te
NH3 (1,1)
CS (1−0)
Intensity
Velocity (km/s)
10
5
0
−5
−10
−200
−100
0
100
200

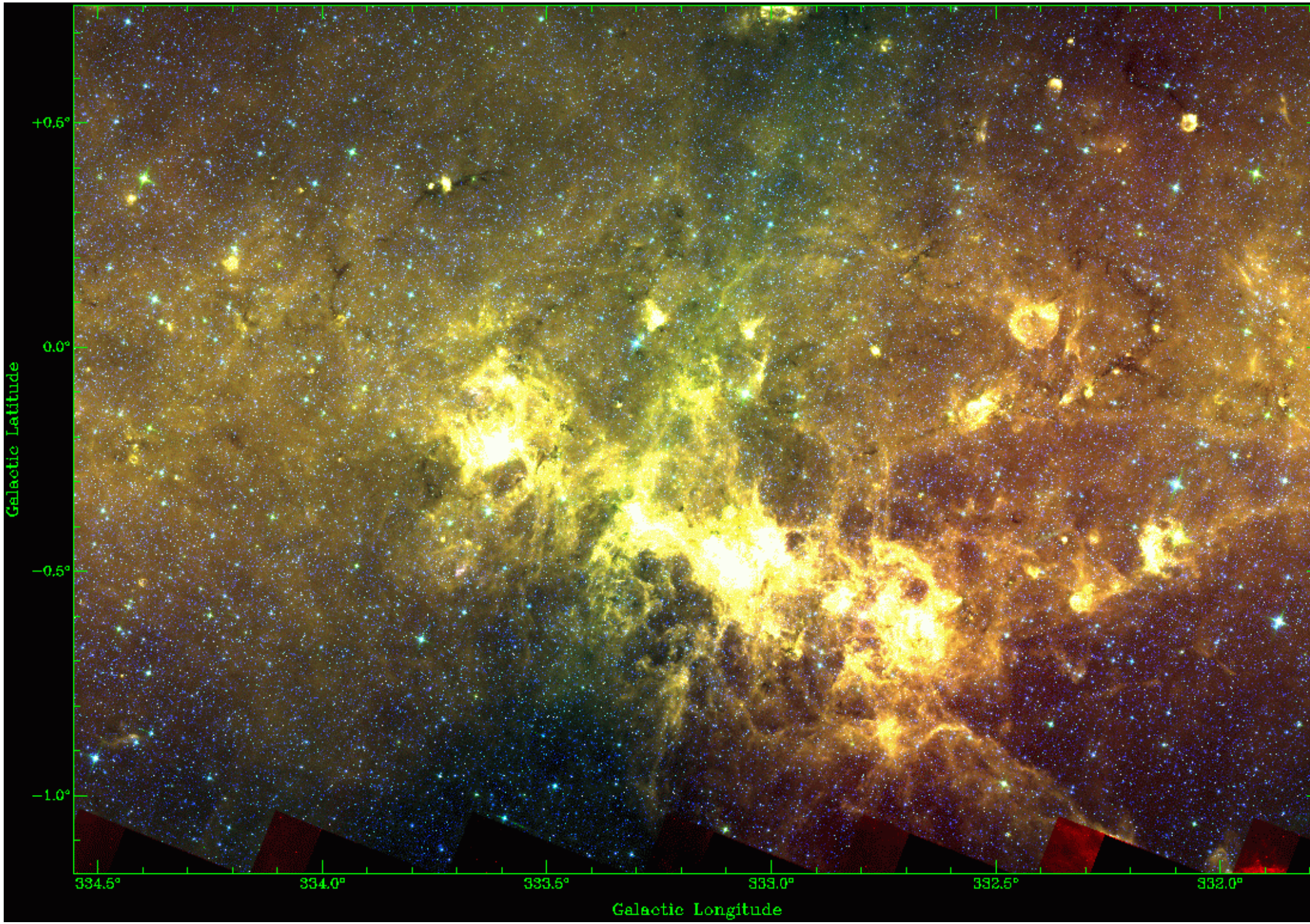

+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
Galactic Longitude
Colours = CS (1-0) Peak Temperatur
Contours = HOPS NH3 (1,1) Peak Te
NH3 (1,1)
CS (1−0)
Intensity
Velocity (km/s)

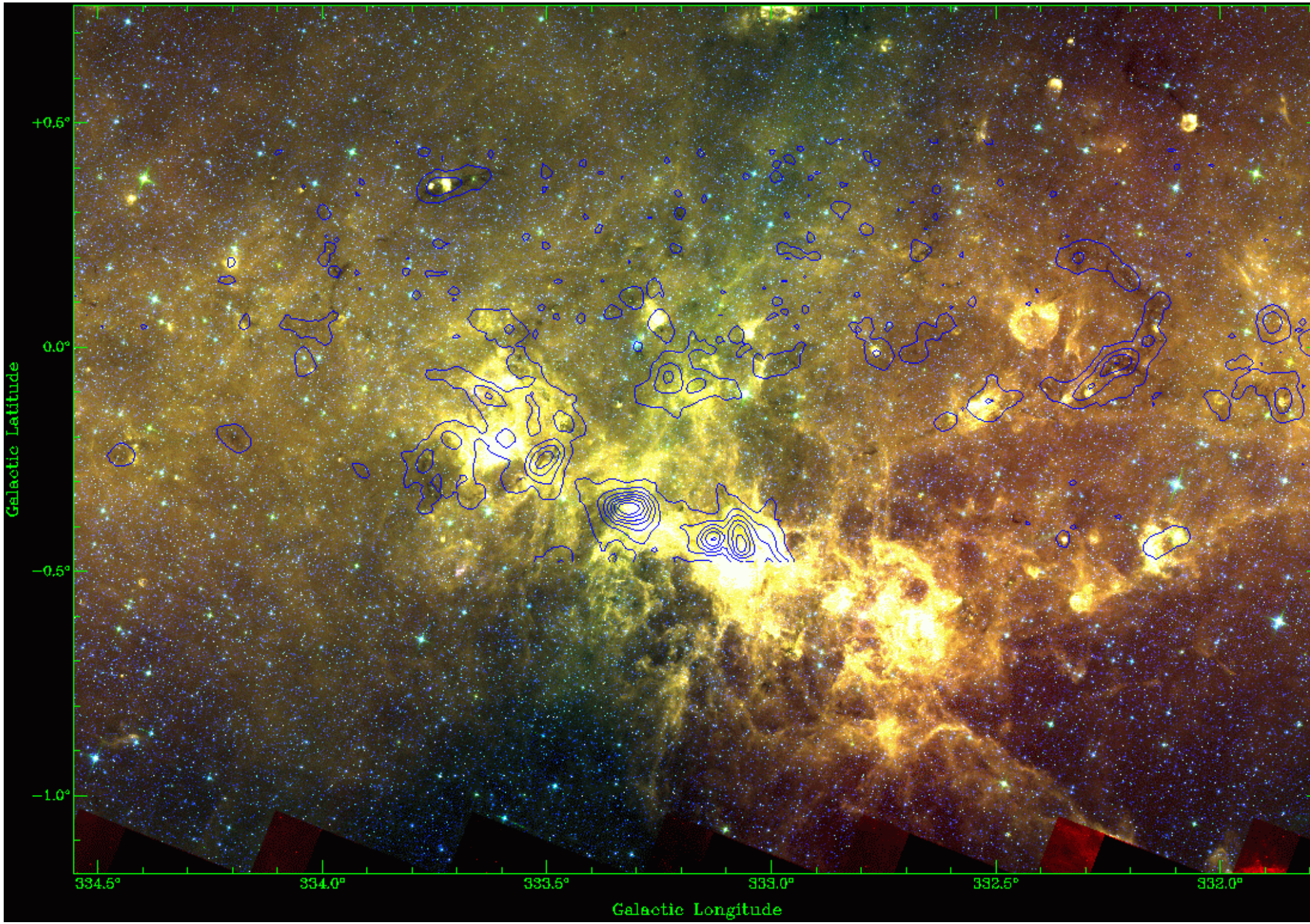

+0.5°
0.0°
−0.5°
Galactic Latitude
NH3 (1,1)
CS (1−0)
Intensity
Velocity (km/s)
NH3 (1,1)
CS (1−0)
Intensity
Velocity (km/s)
NH3 (1,1)
CS (1−0)
Intensity
Velocity (km/s)
) Peak Temperatur
NH3 (1,1) Peak Te
334.0°
Galactic Longitude

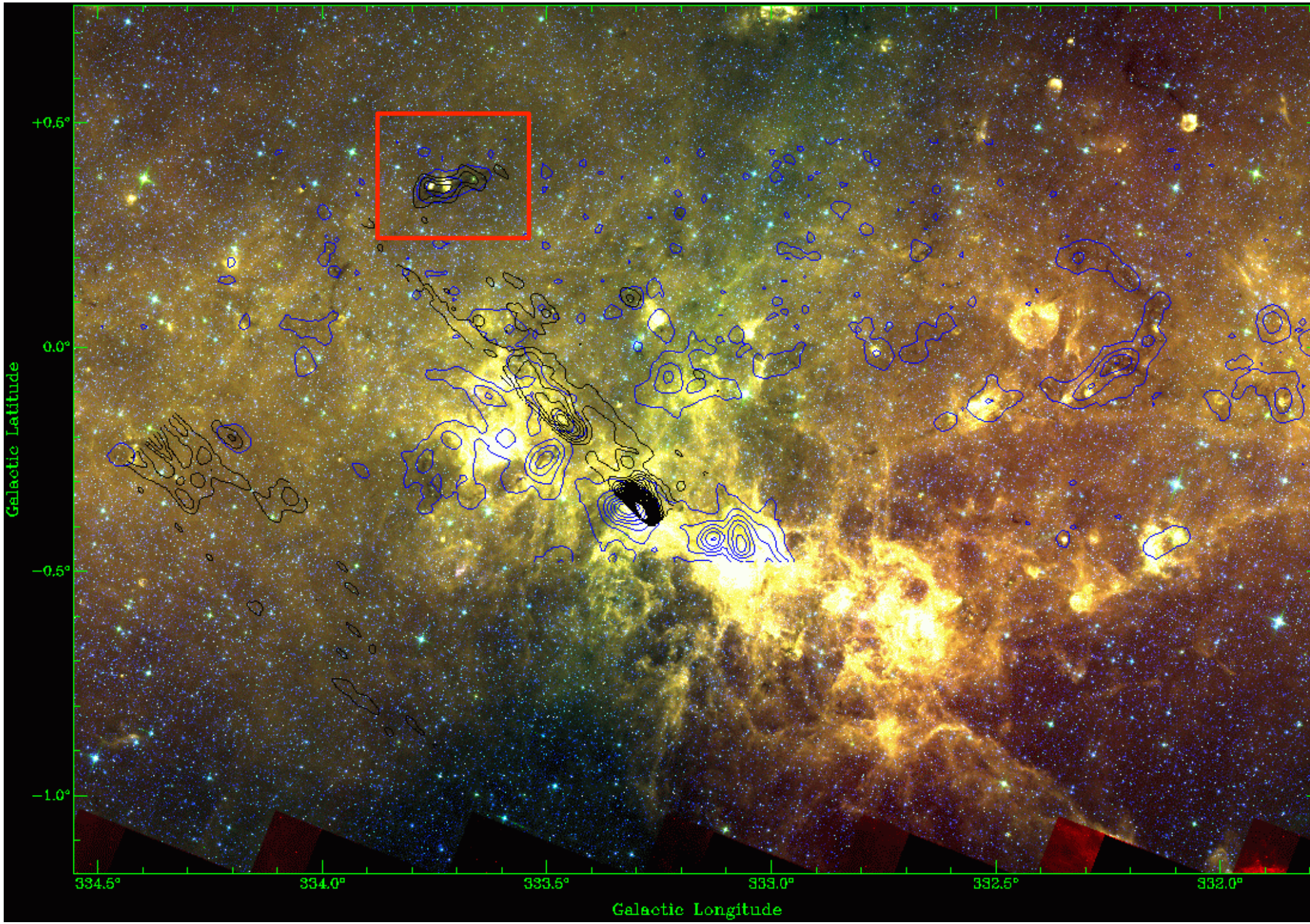


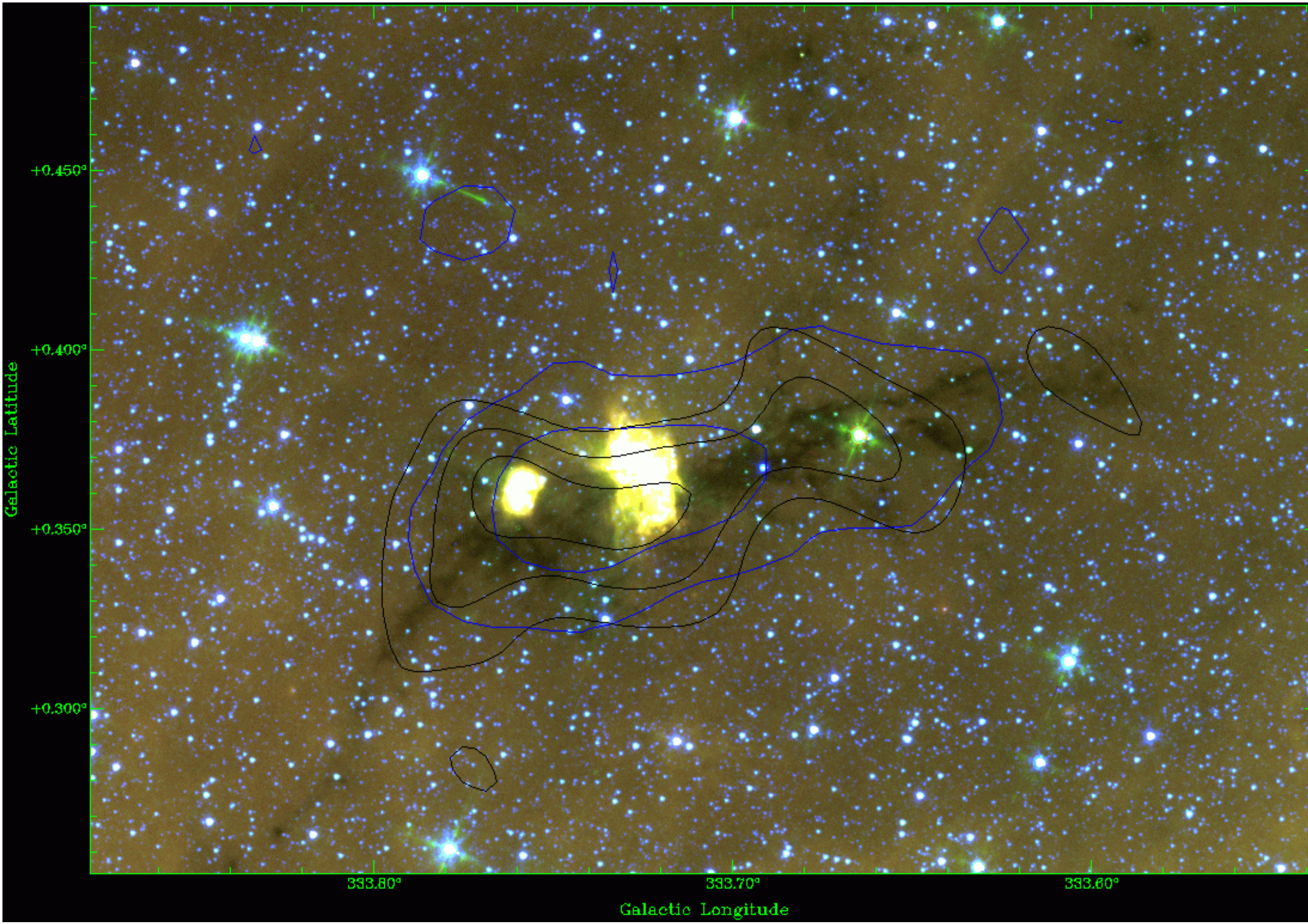
GLIMPSE 3-colour infrared image

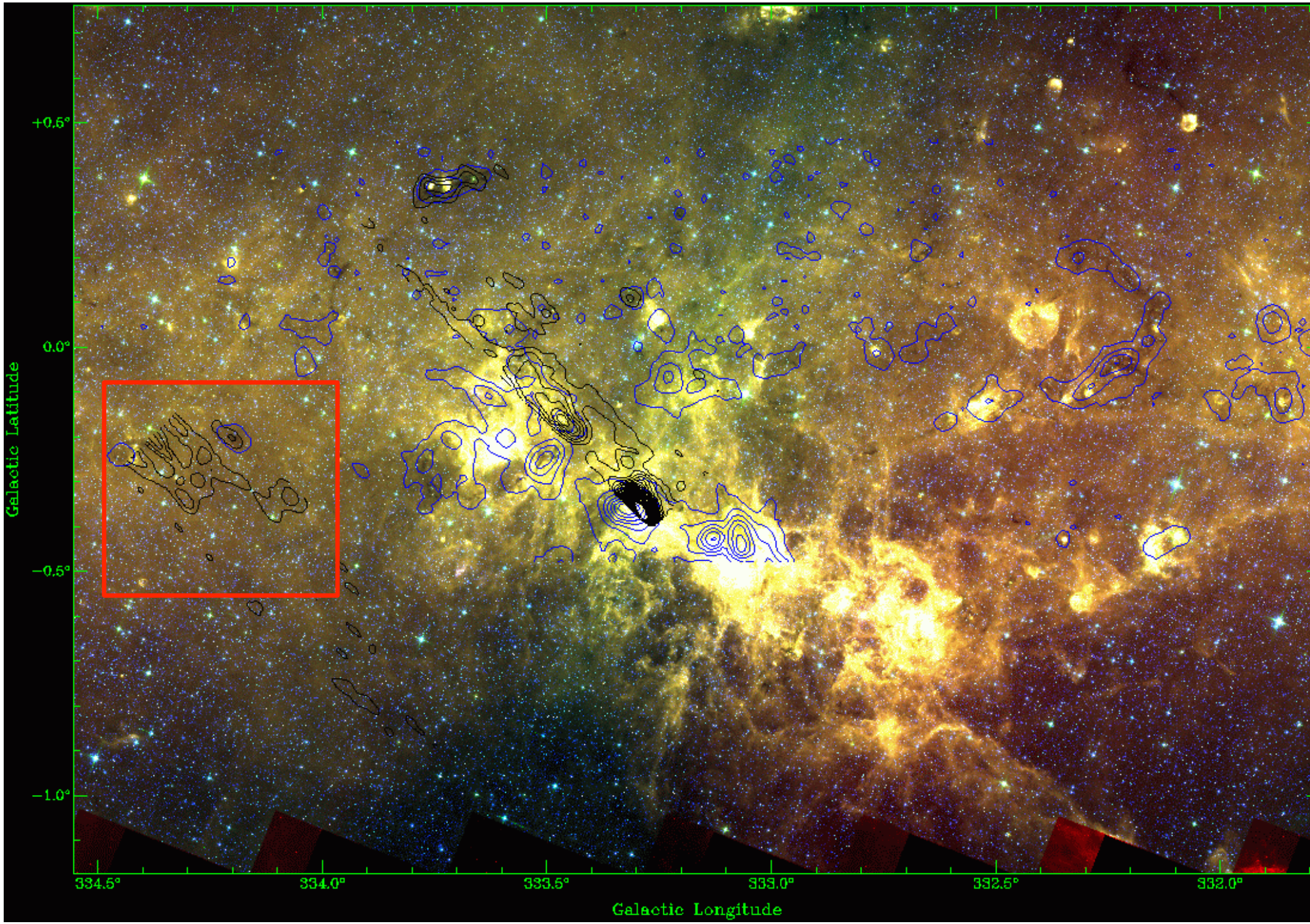

+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
332.5°
332.0°
Galactic Longitude

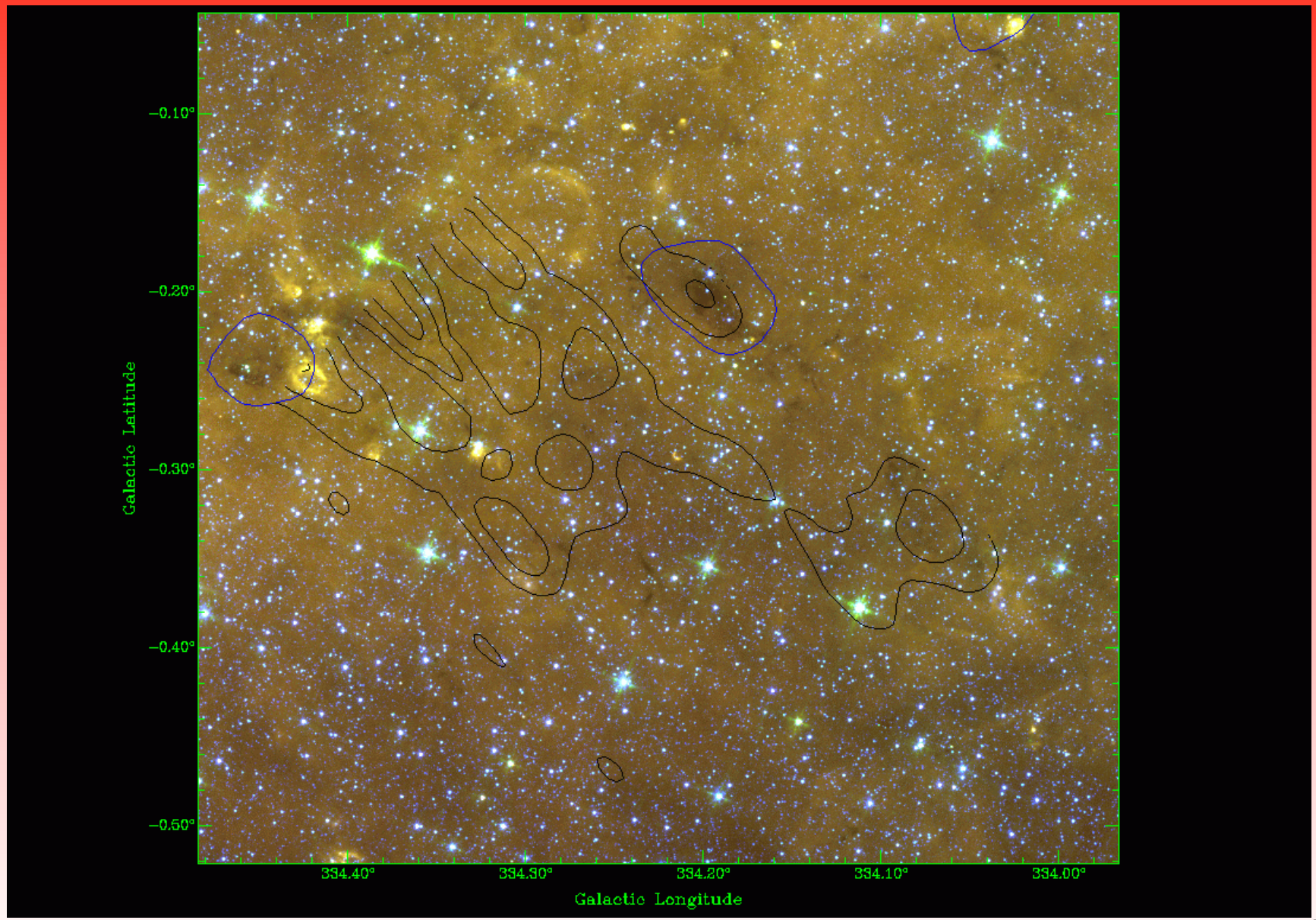

+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
332.5°
332.0°
Galactic Longitude


+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
332.5°
332.0°
Galactic Longitude


+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
332.5°
332.0°
Galactic Longitude


+0.450°
+0.400°
+0.350°
+0.300°
Galactic Latitude
333.80°
333.70°
333.60°
Galactic Longitude


+0.5°
0.0°
−0.5°
−1.0°
Galactic Latitude
334.5°
334.0°
333.5°
333.0°
332.5°
332.0°
Galactic Longitude

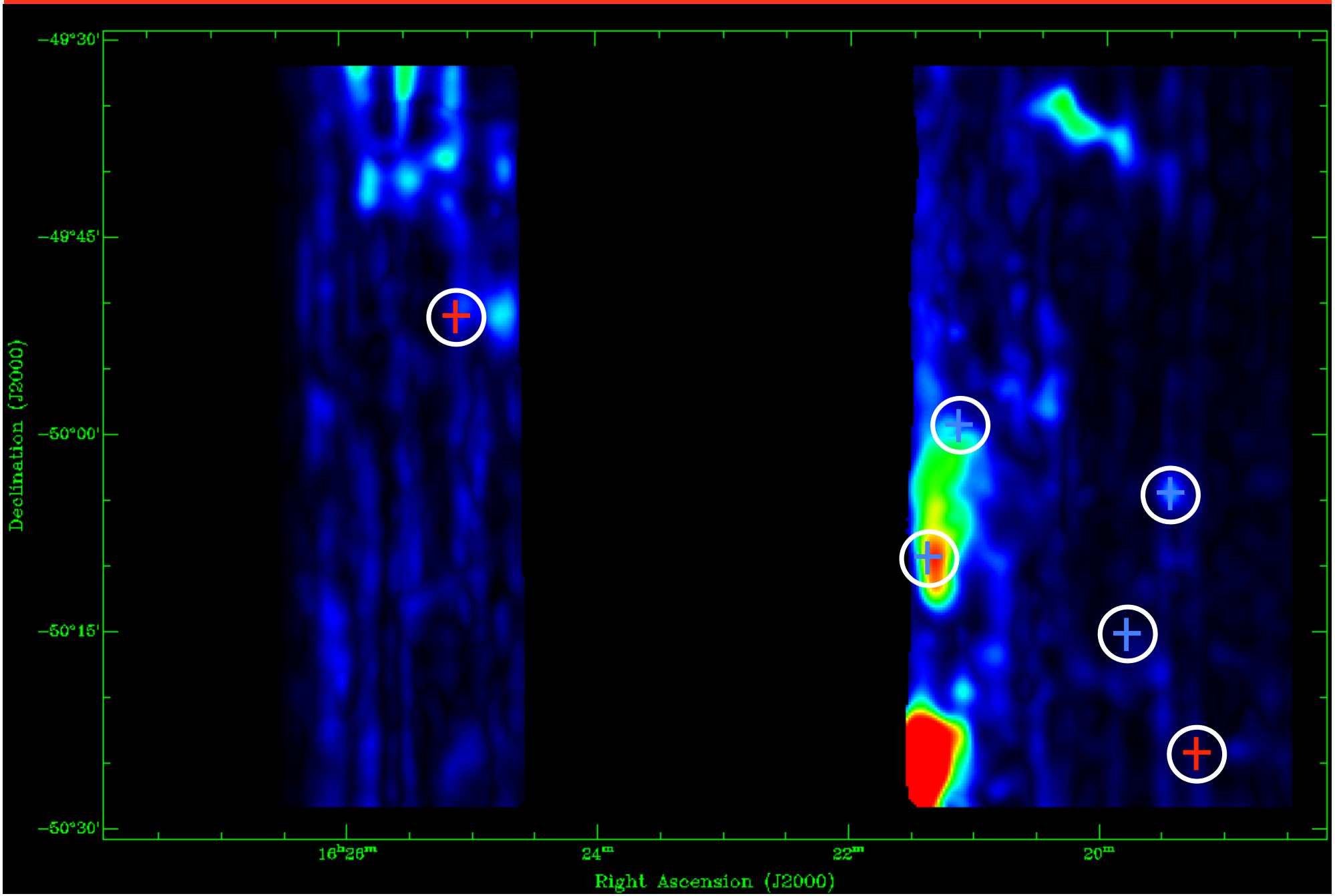

−0.10°
−0.20°
−0.30°
−0.40°
−0.50°
Galactic Latitude
334.40°
334.30°
334.20°
334.10°
334.00°
Galactic Longitude

Close correspondence:

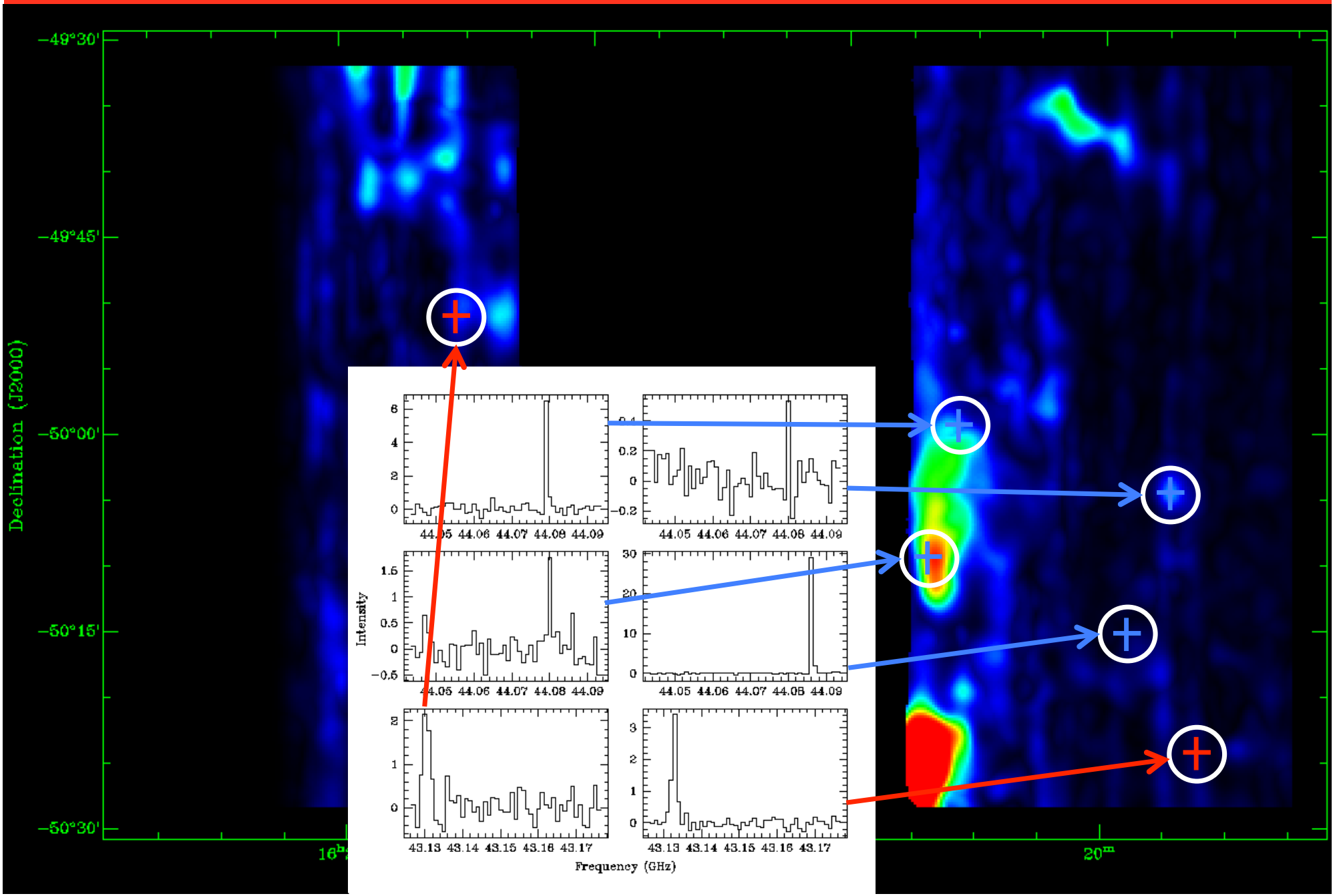
- CS (1-0) from MALT-45 Pilot
- NH_3 (1,1) from HOPS
- IRDCs from GLIMPSE

Possible differences in CS and NH_3

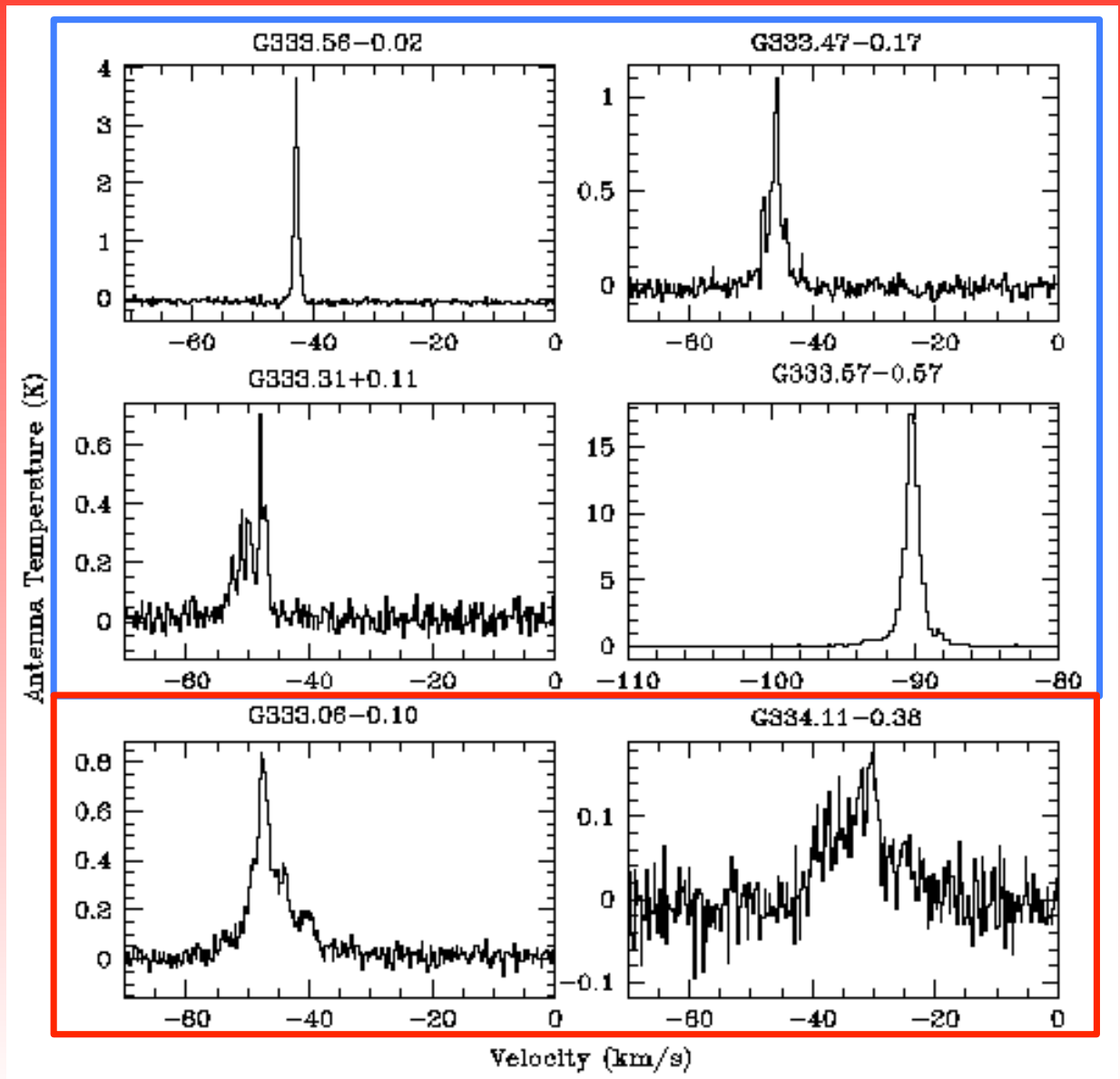
CH_3OH and SiO Masers



CH_3OH and SiO Masers



CH_3OH and SiO Masers
Mopra spectra



MALT-45 Pilot Summary

7mm ATCA observations successful in March 2010

Autocorrelation works on the ATCA

Things to do:

- Better baseline subtraction
- Extract continuum data
- More OTF mapping tests
- How will zoom modes improve the data?

MALT-45 Pilot Summary

Full MALT-45 survey will be 45 square degrees:

$l=330° - 0° - 15°$ $|b|<0.5°$

CS (1-0), Class I CH_3OH masers, SiO (1-0) masers,
RRLs and continuum

CCAT Synergies

CCAT Synergies

- CCAT is ideally suited to sensitive Galactic plane surveys relevant to star formation

- High density tracers to map the structure of star

- gas (CH_3CN) and ionised gas (RRLs)

CCAT needs a multi-element (~100), multi-spectral line instrument to do this