The Mopra Southern Galactic Plane CO Survey

Catherine Braiding, Michael Burton

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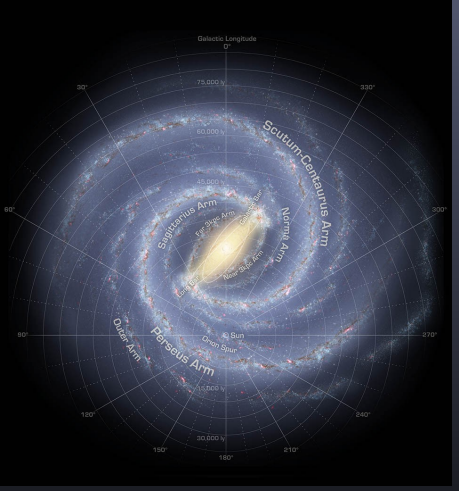
D. Romano, J. Lau, S. Pointon, E. Istiqomah, M. Freeman

and probably even more people that I have missed out by accident

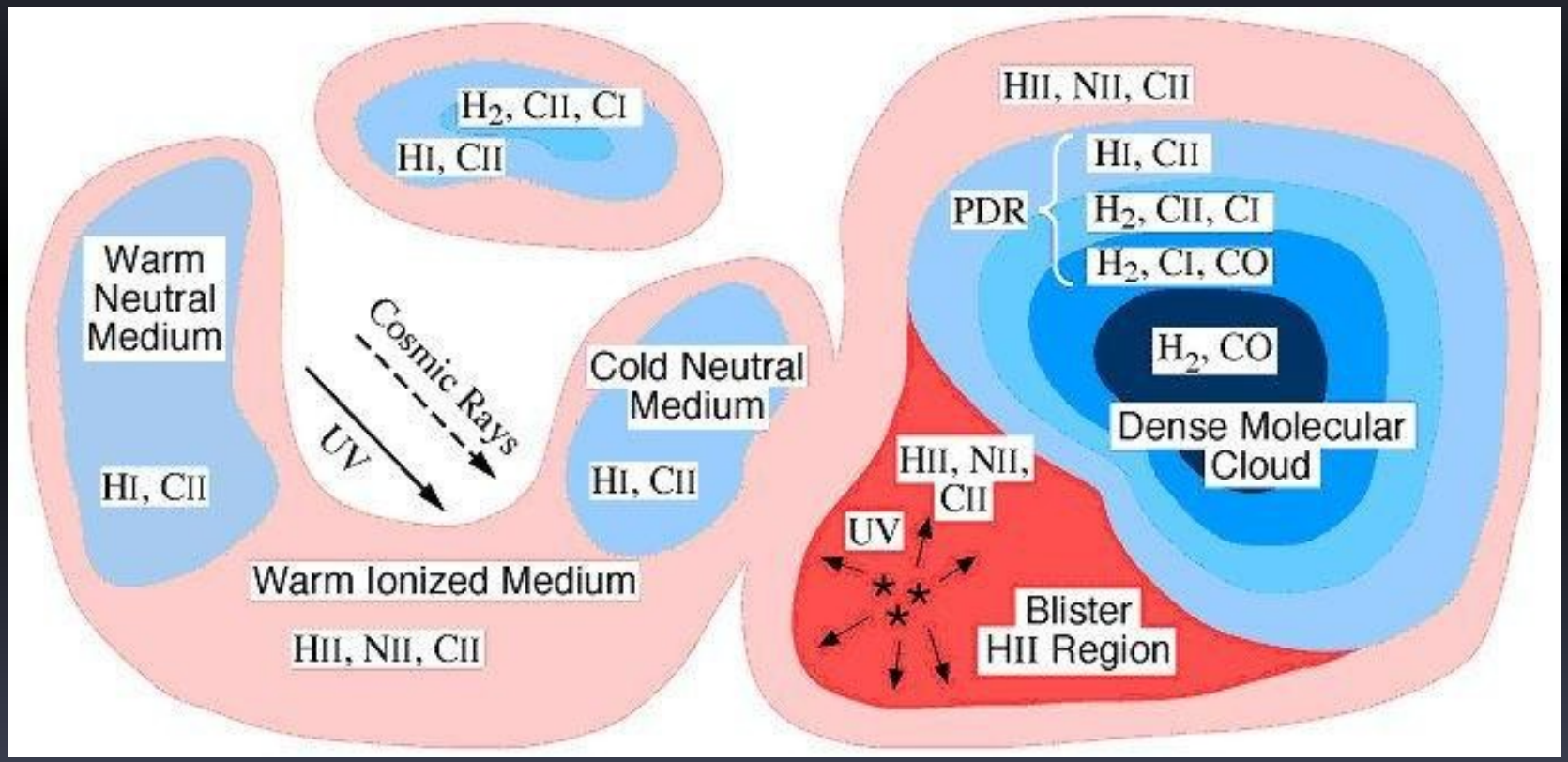
UNSW, University of Adelaide, and others.



Outline

1. Probing the multi-phase ISM of the Milky Way
   - Following the Galactic Carbon Trail
2. Mopra Southern Galactic Plane CO Survey (Mopra CO for short)
3. Multiwavelength study of G328

Schematic of the multi-phase ISM
and its diagnostic tracers



Follow the Carbon Trail: C^+ → C → CO

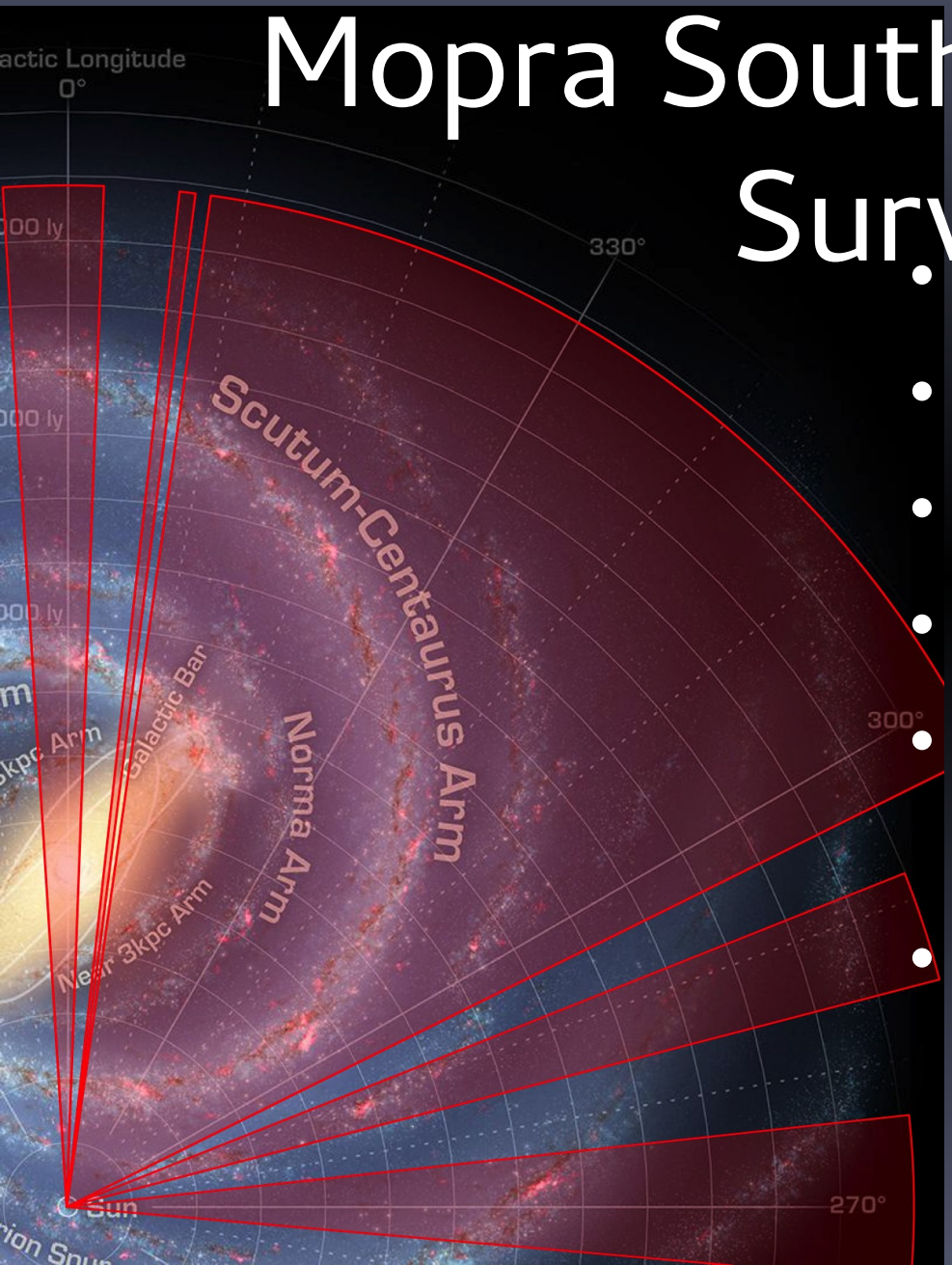
Spectral Tracers

Species	Lines	Frequency	Facilities
H	HI 21cm S=1-0	1.42 GHz	SGPS (Parkes + ATCA)
CO	^{12}CO J=1-0 ^{13}CO J=1-0	115 GHz 110 GHz	Mopra
C	[CI] J=1-0 [CI] J=2-1	0.49 THz 0.81 THz	Nanten2 HEAT / STO2
C^+	[CII] J=3/2-1/2	1.90 THz	HEAT / STO2

Mopra!

- 22m telescope for long-wave mm astronomy
  - 3mm + 7mm + 12mm
- +2 dish of fire resistance.
- 77–116 GHz MMIC receiver (2.5-4 mm)
  - T_{sys} ~ 150K (@85GHz) – 600K (@115GHz)
  - 35” beam
  - ηmb (86 GHz) = 0.49, ηmb (115 GHz) = 0.42
  - ηxb (86 GHz) = 0.65, ηxb (115 GHz) = 0.55
- Bandwidth: 8 GHz UNSW-MOPS correlator.
  - Broadband 32,000 channels, 0.8 km/s res$^{n.}$
  - 16 zoom modes over 137 MHz
  - 4 per band, 4096 channels/zoom, 0.1 km/s@3mm
- 2 Polarizations (i.e. 64,000 channels)

Mopra Southern GP CO Survey



- 12CO, 13CO, C18O and C17O J = 1-0
- l = 270 – 360o, $|b|$ < 0.5o
- 0.6’ Beam @ 0.1 km/s resolution
- Fast mapping = 1 sq deg every 4 nights.
- Including: CMZ, Carina, and a few other (gamma ray) objects of interest.
- www.phys.unsw.edu.au/MopraCO/ (data publicly available as published.)

Fast Mapping with Mopra

- Binning mode in 2.048s cycles
  - 8 x 256ms samples
- i.e. 8 x faster for 1/3rd the sensitivity
  - Only suitable for CO lines
- Scan at 35"/s = 9" cell size
- 15" row spacing
- 30 hours/sq. deg. c.f. 350 hours
- 8 zoom modes, not 16
  - 12CO, 13CO, C18O, C17O

Thanks also to Warwick Wilson, Dick Ferris, Balt Indermuehle

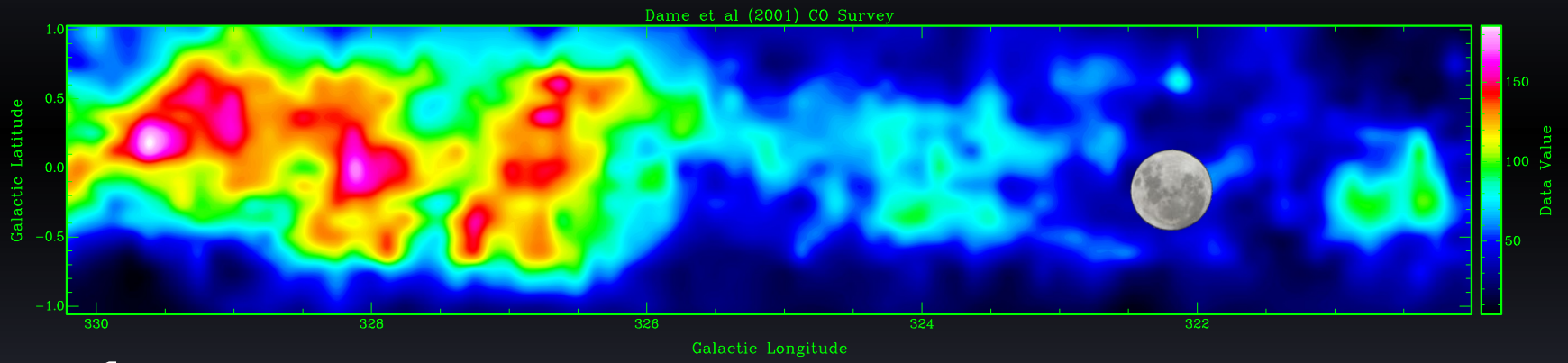
Line Parameters for CO Survey

IF	Frequency (GHz)	Isotopologue	V_{low} (km/s)	V_{high} (km/s)
1+2	110.1	^{13}CO 1-0	-475	+270
3+4	109.7	C^{18}O 1-0	-495	+255
5	112.3	C^{17}O 1-0	-235	+130
6+7+8	115.2	^{12}CO 1-0	-550	+525

0.6’ Beam @ 0.1 km/s resolution

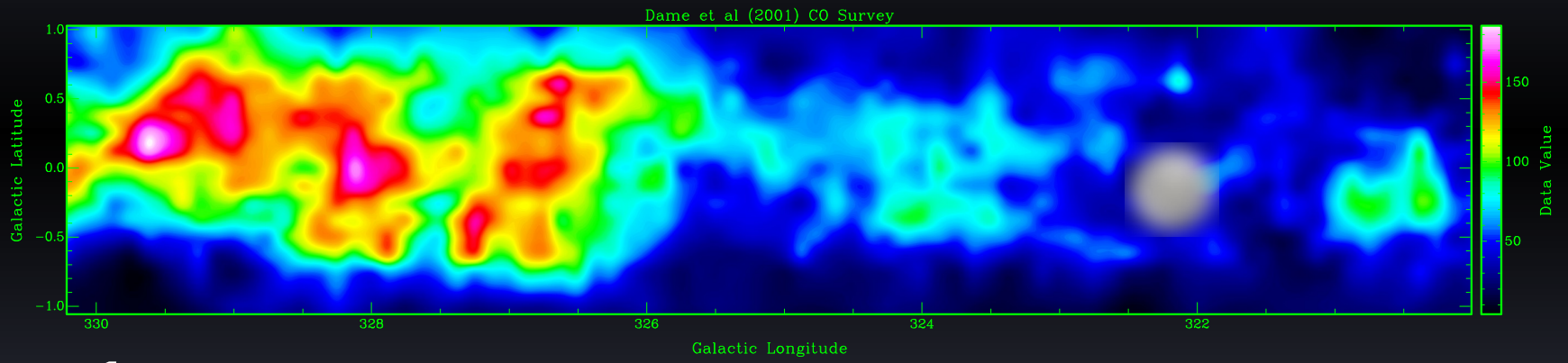
~4 transits per 1°x1° block (|b|<0.5°)

Carbon Monoxide Surveys



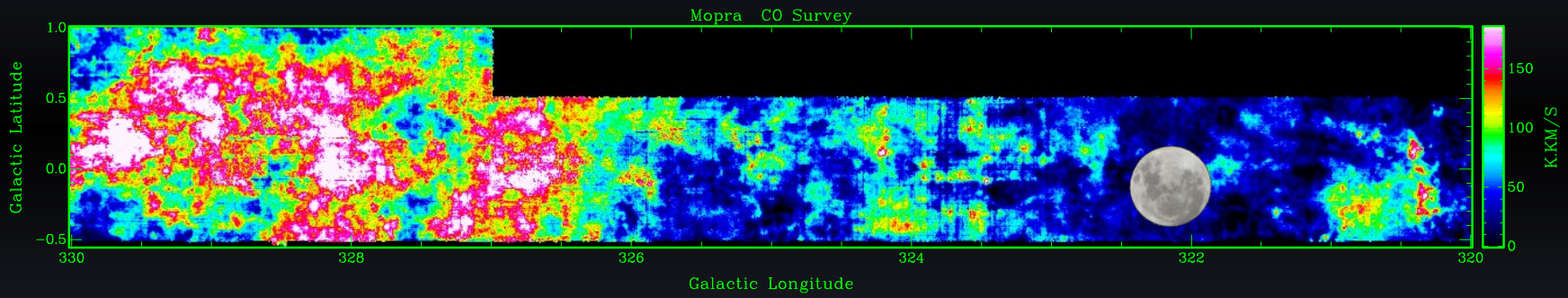
- 1 metre telescope

Carbon Monoxide Surveys



- 1 metre telescope

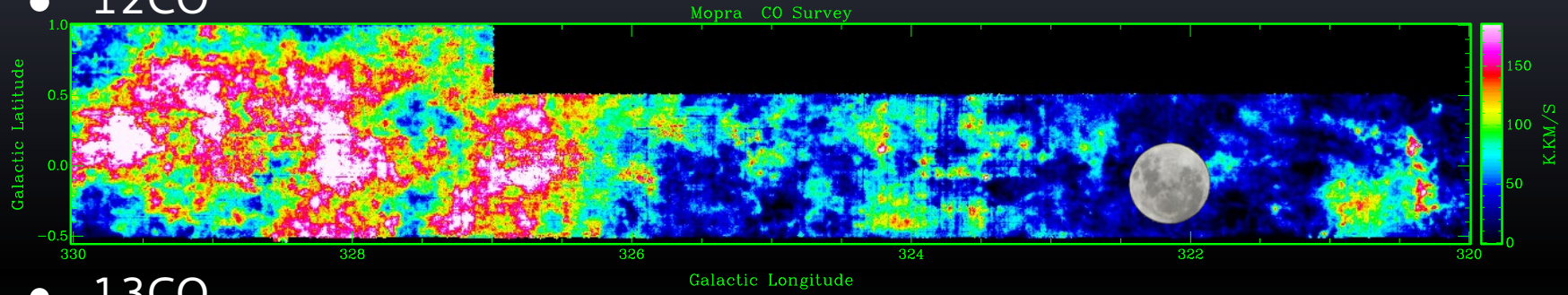
Carbon Monoxide Surveys



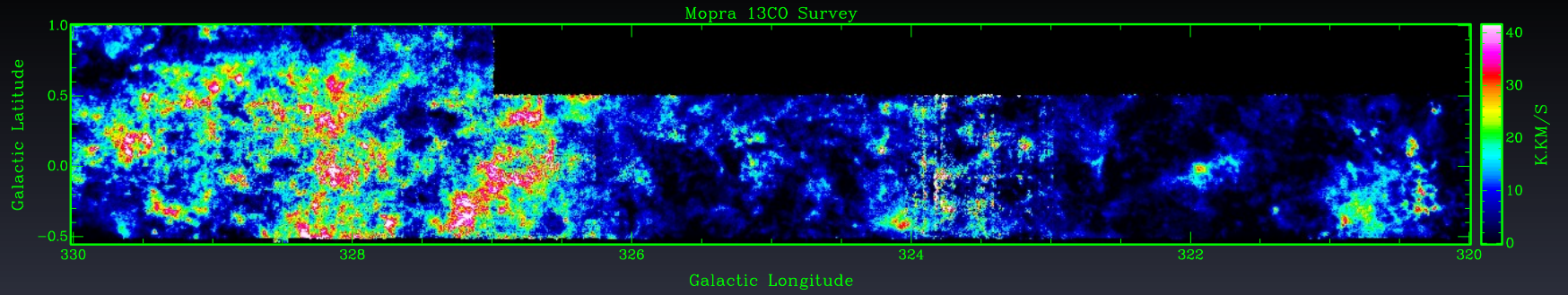
- 22 metre Mopra telescope

Carbon Monoxide Surveys

- 12CO



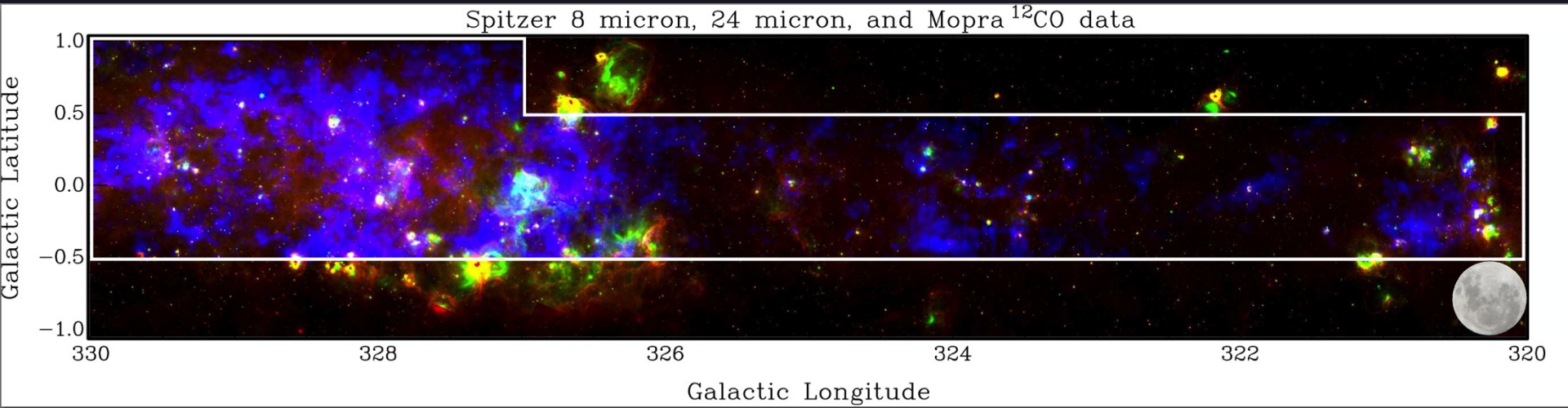
- 13CO



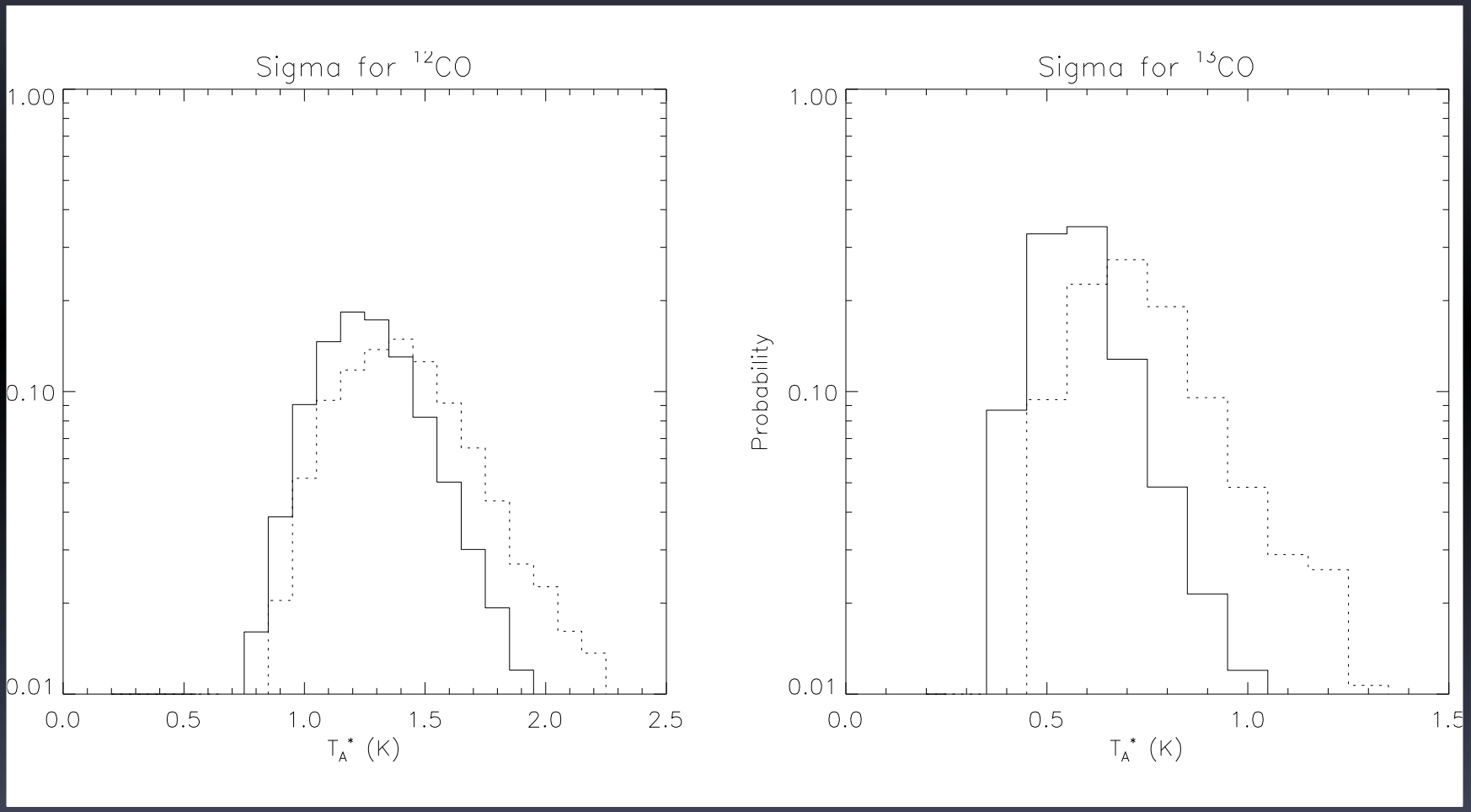
- Also C18O and C17O

Data Release 1 (DR1)

- l = 320-330o, |b| < 0.5o; l = 327-330o, 0.5o < b < 1.0o
- Clouds found with velocities -130 < v < +40 km/s
- Total mass in 10 square degrees ~ 4 x 107 M_{sun}
- Paper: Braiding et al. 2015, PASA, 32, e20

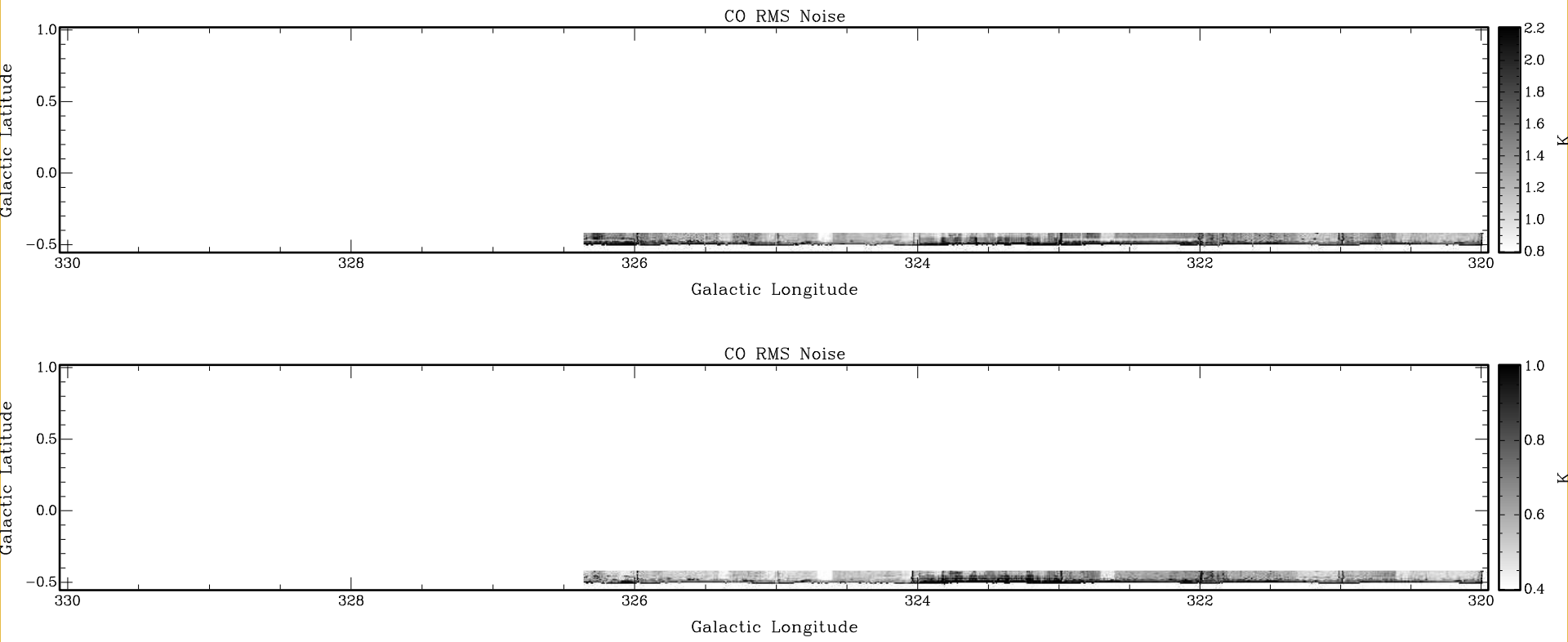


Noise Distribution (DR1)

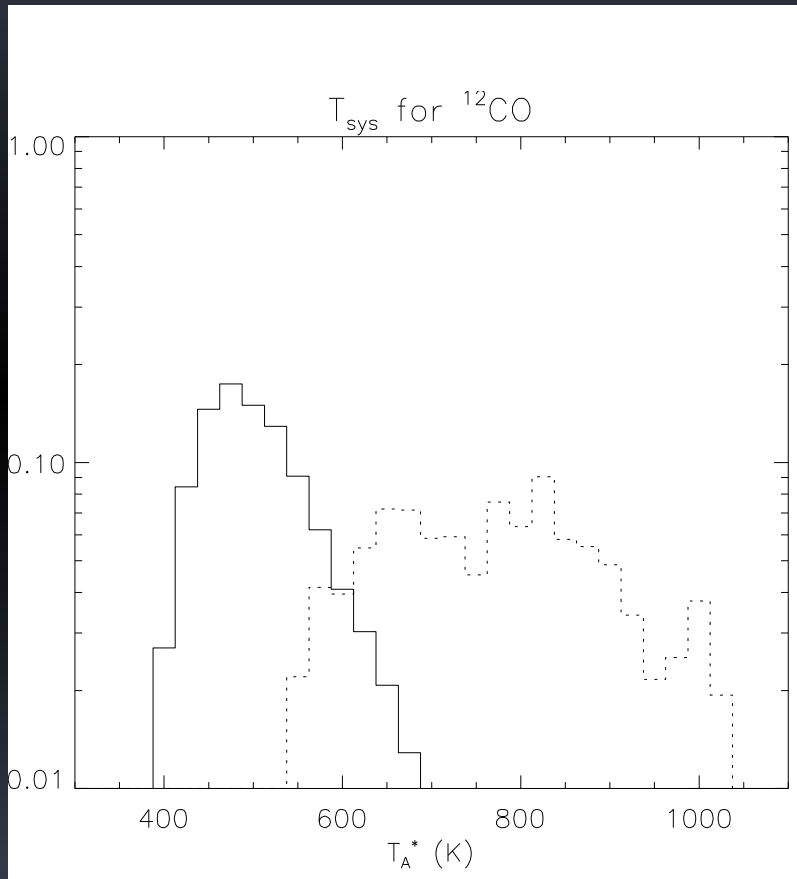


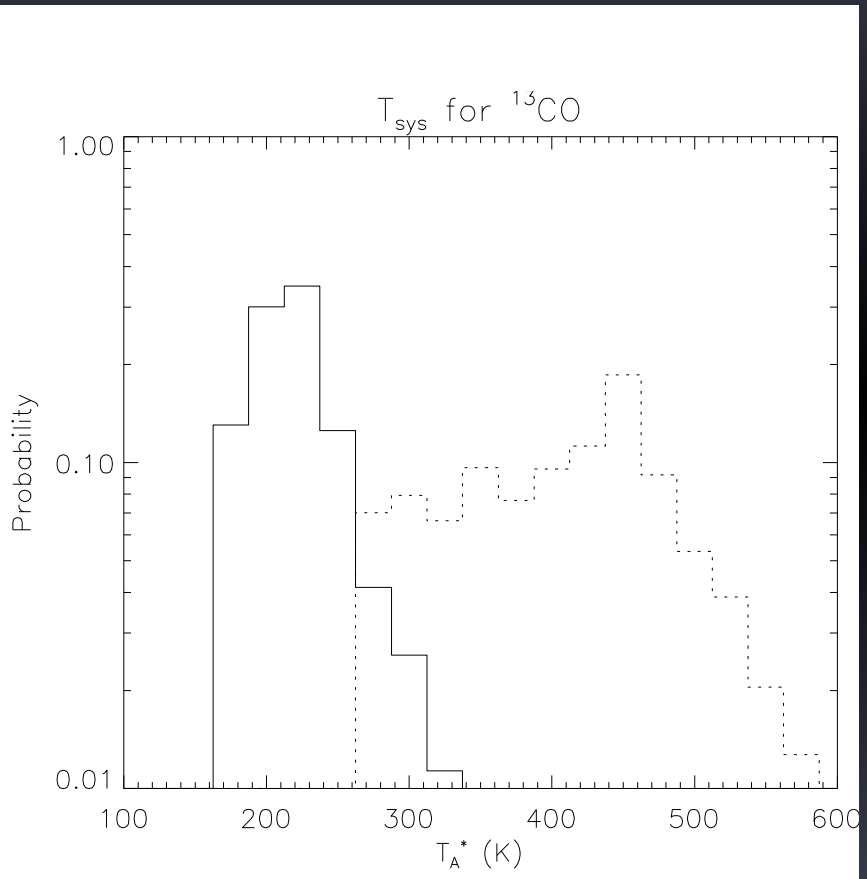
Dotted Distribution is G323 (Summer) Data

Sigma Noise (DR1)



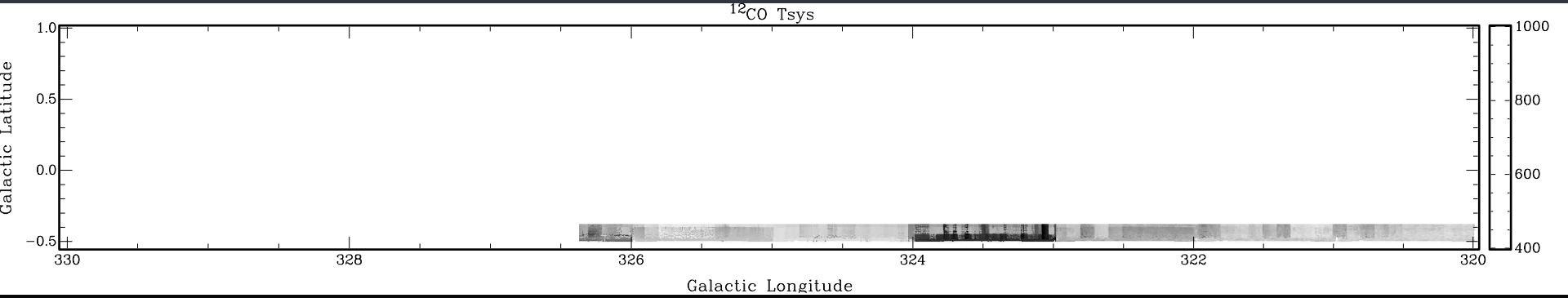
Tsys (DR1)

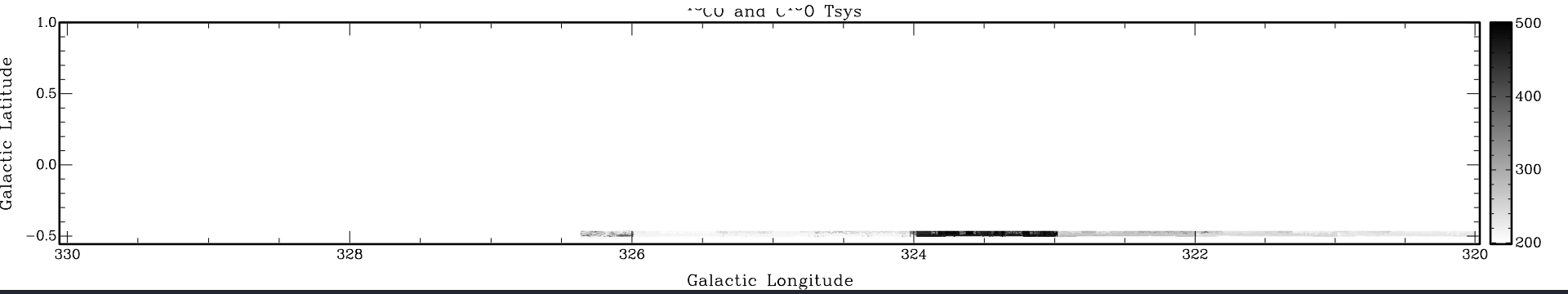


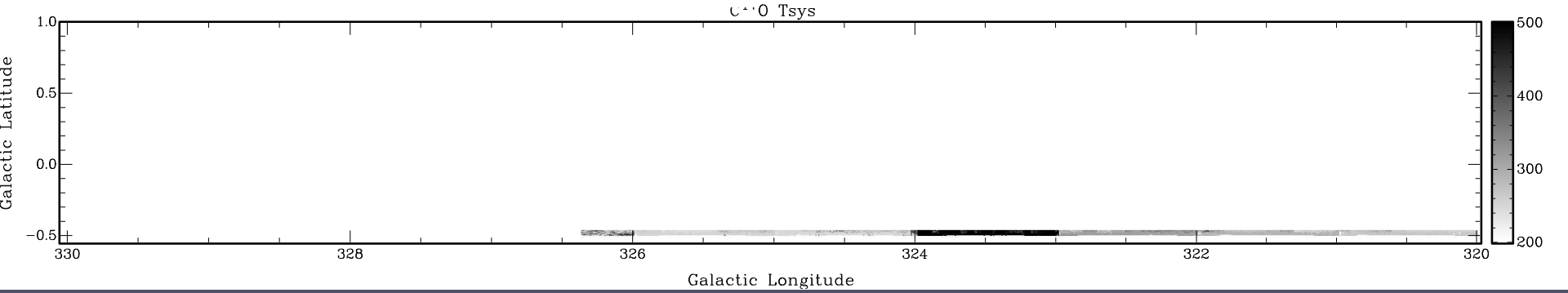


Dotted Distribution is G323 (Summer) Data

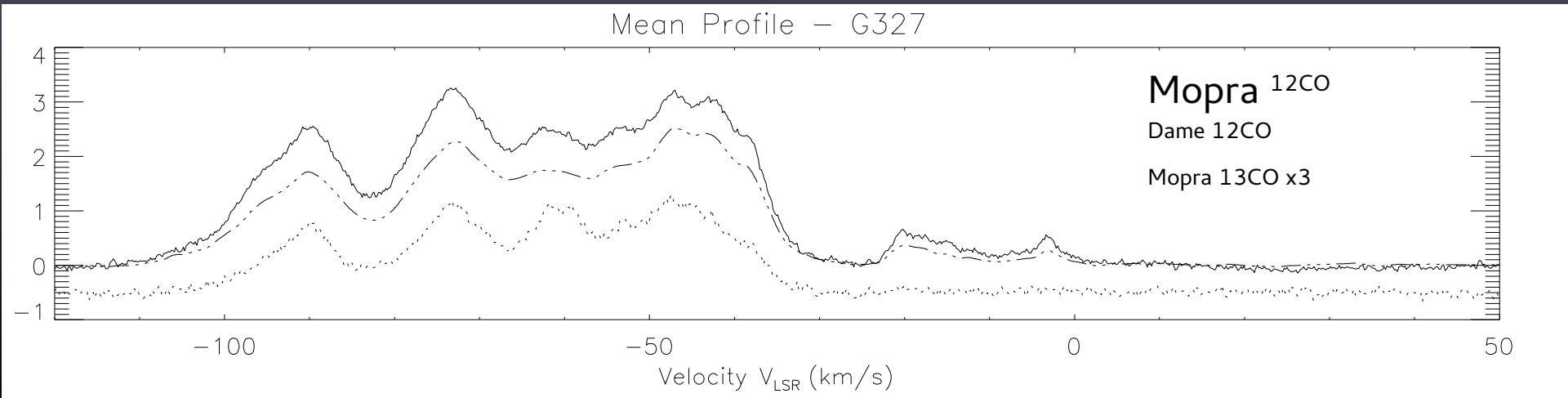
Tsys (DR1)

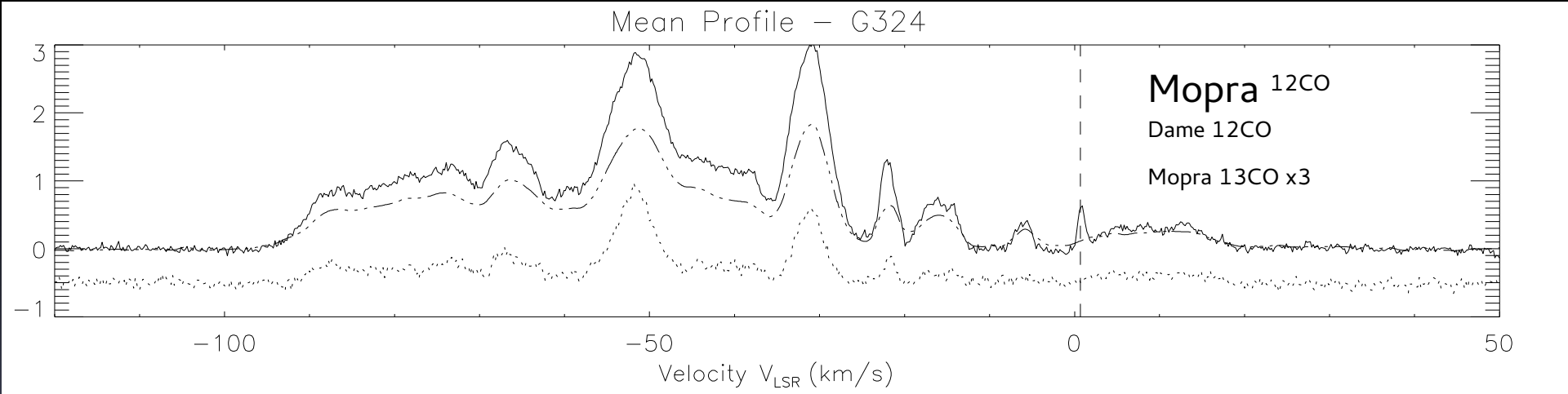

^{12}CO Tsys
Galactic Latitude
Galactic Longitude
1.0
0.5
0.0
−0.5
330
328
326
324
322
320
1000
800
600
400


Galactic Latitude
Galactic Longitude
1.0
0.5
0.0
−0.5
330
328
326
324
322
320
500
400
300
200


Galactic Latitude
Galactic Longitude
1.0
0.5
0.0
−0.5
330
328
326
324
322
320
500
400
300
200

1o Spectra (DR1)

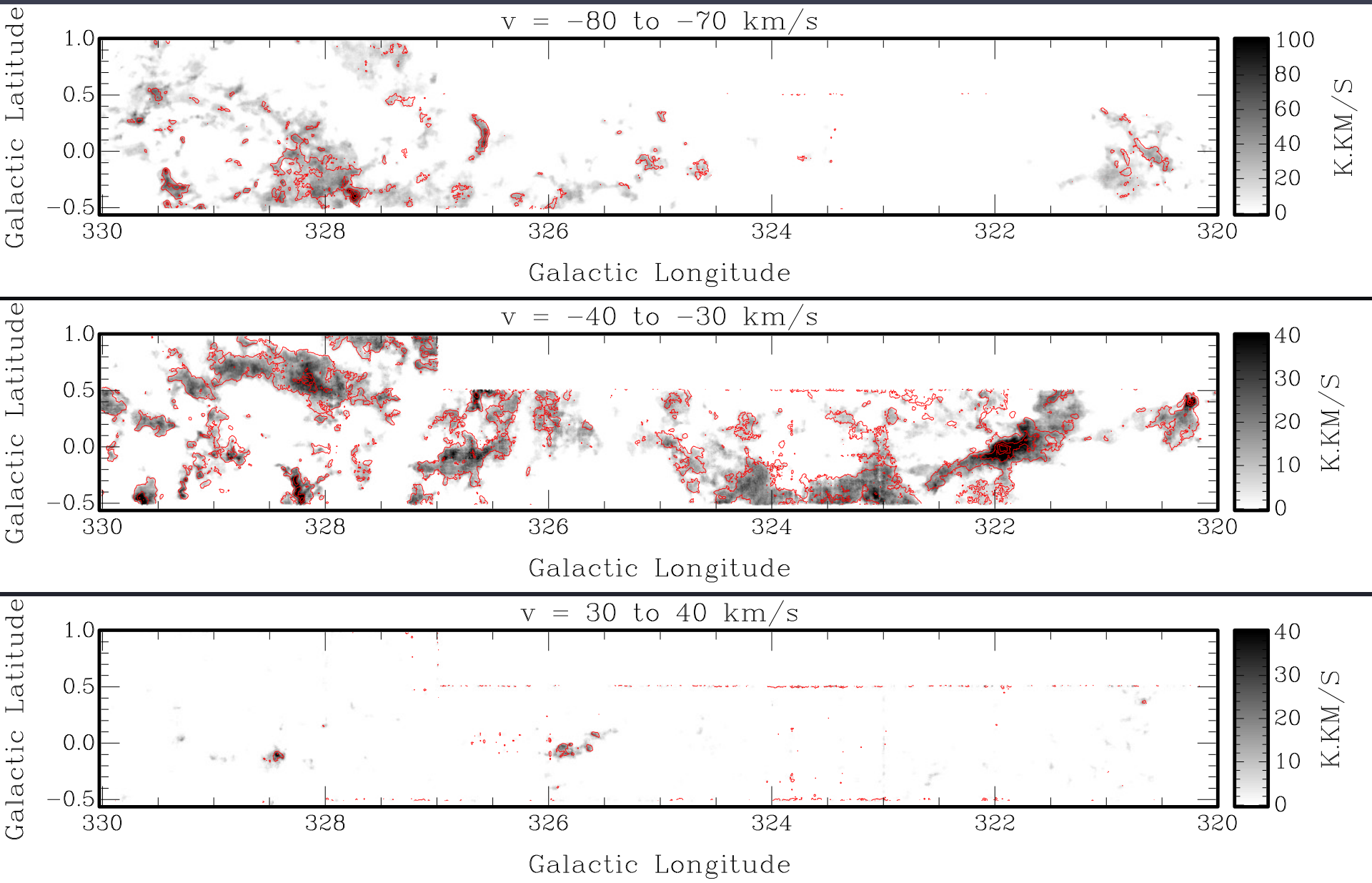


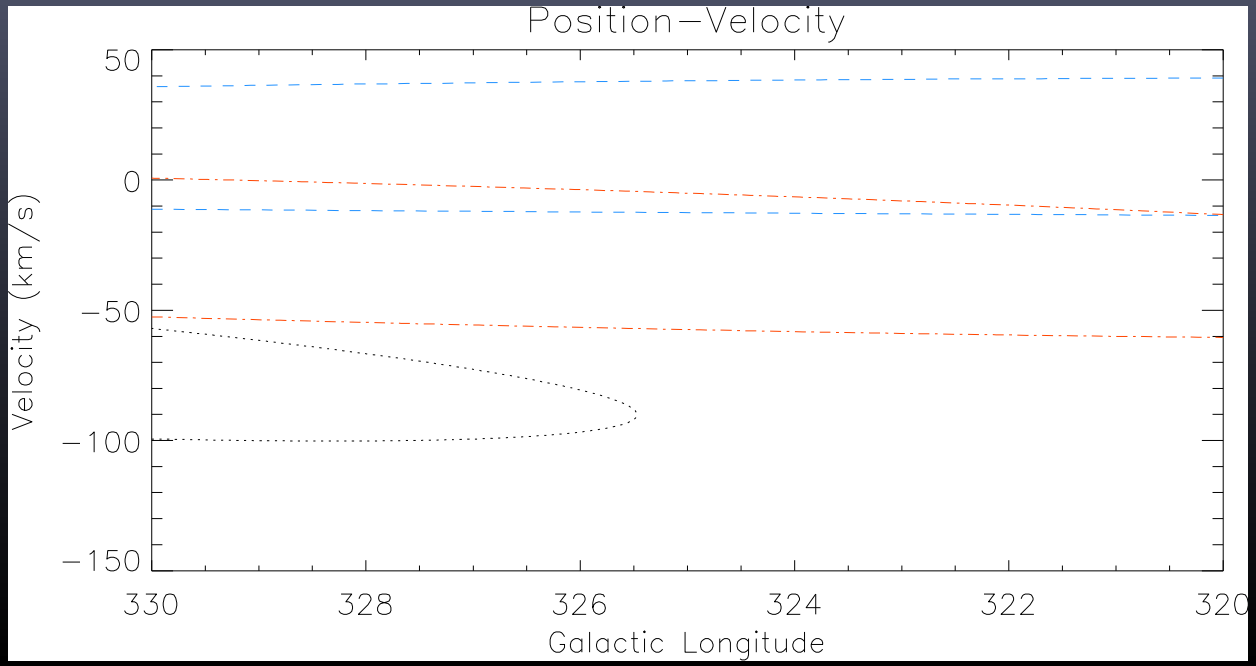


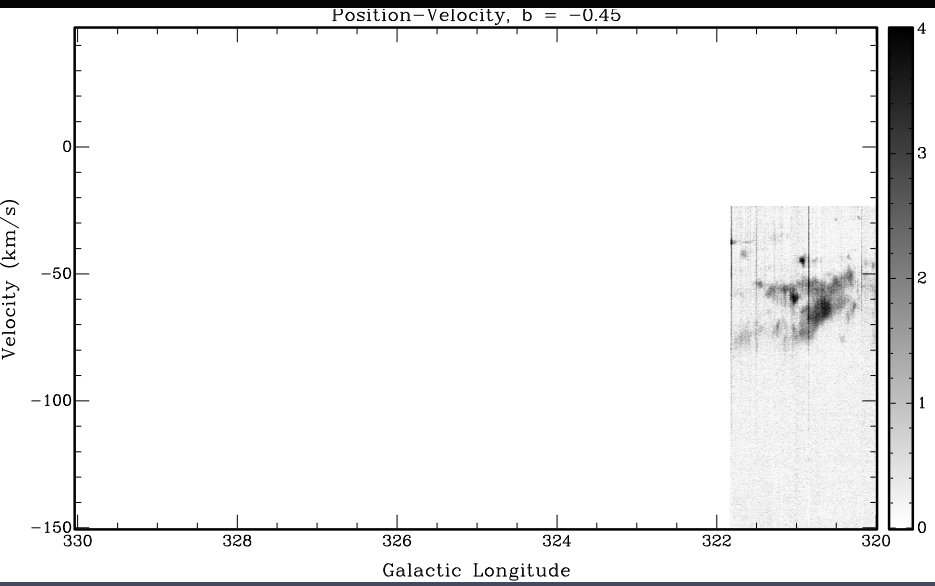
Data Release 1

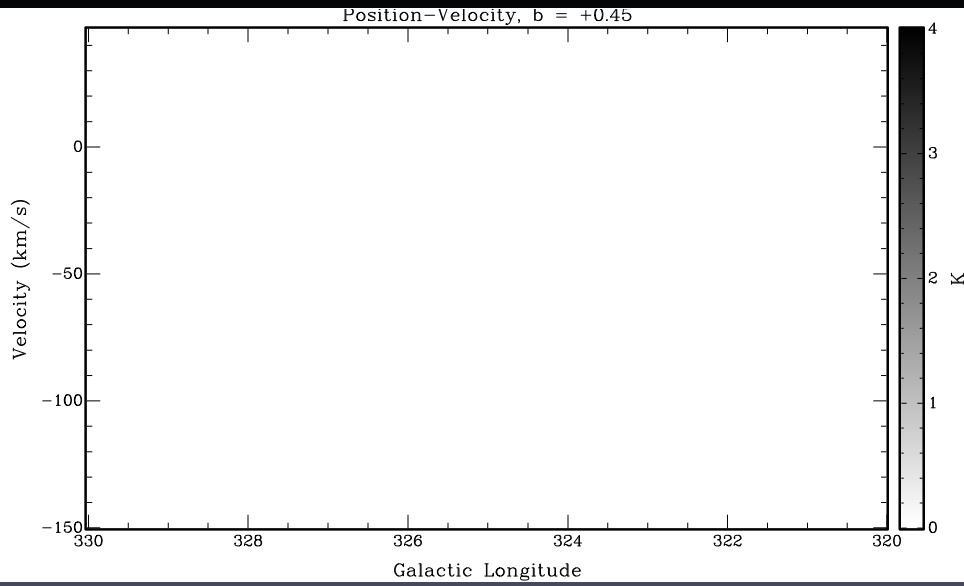
www.youtube.com/watch?v=W973X-mYFQQ

In case of no movie... (DR1)

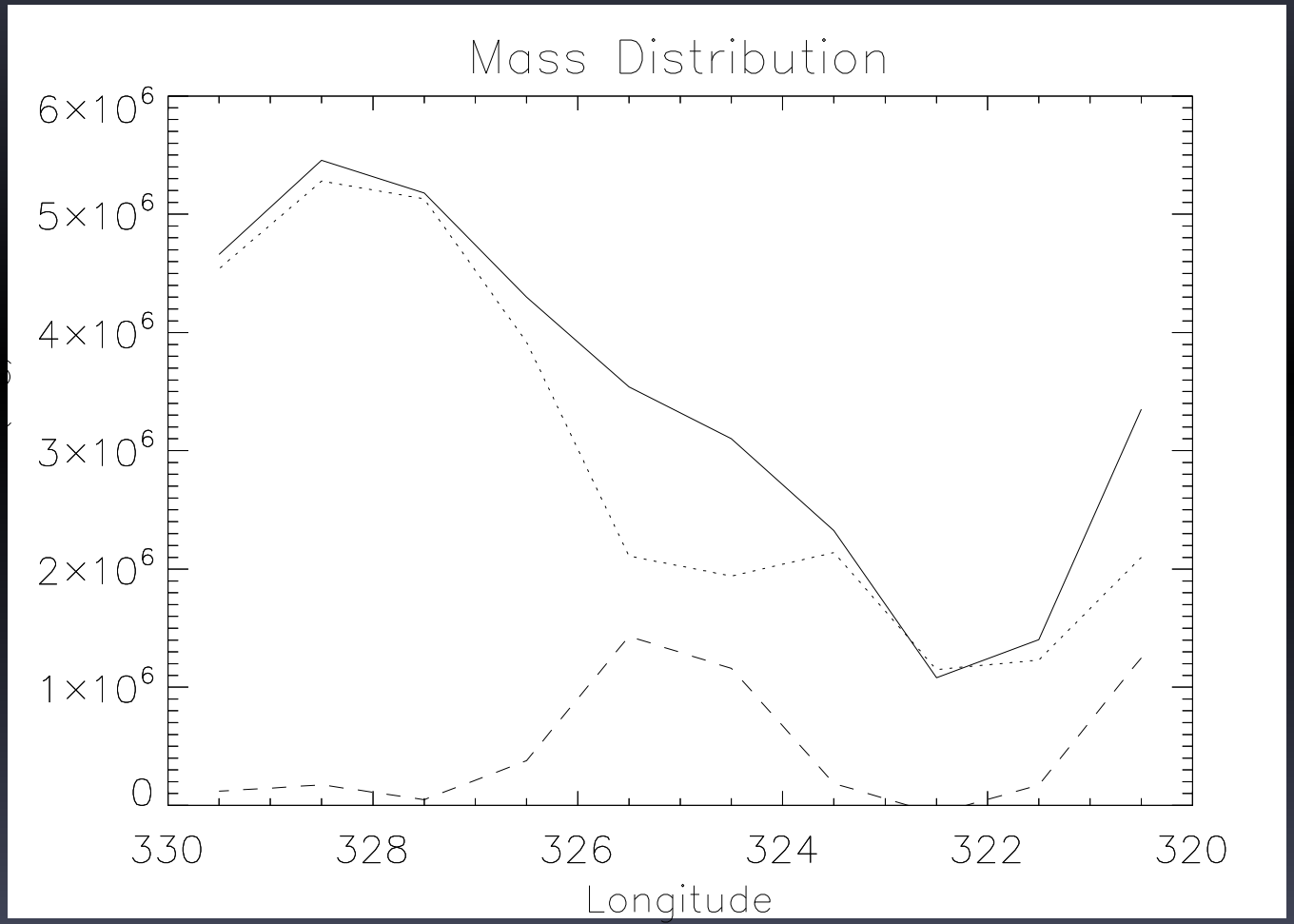



Position−Velocity
50
0
−50
−100
−150
Velocity (km/s)
330
328
326
324
322
320
Galactic Longitude


Position−Velocity, b = −0.45
0
−50
−100
−150
Velocity (km/s)
330
328
326
324
322
320
Galactic Longitude
4
3
2
1
0
K


Position−Velocity, b = +0.45
0
−50
−100
−150
Velocity (km/s)
330
328
326
324
322
320
Galactic Longitude
4
3
2
1
0
K

Mass Distribution (DR1)



Data Release 1

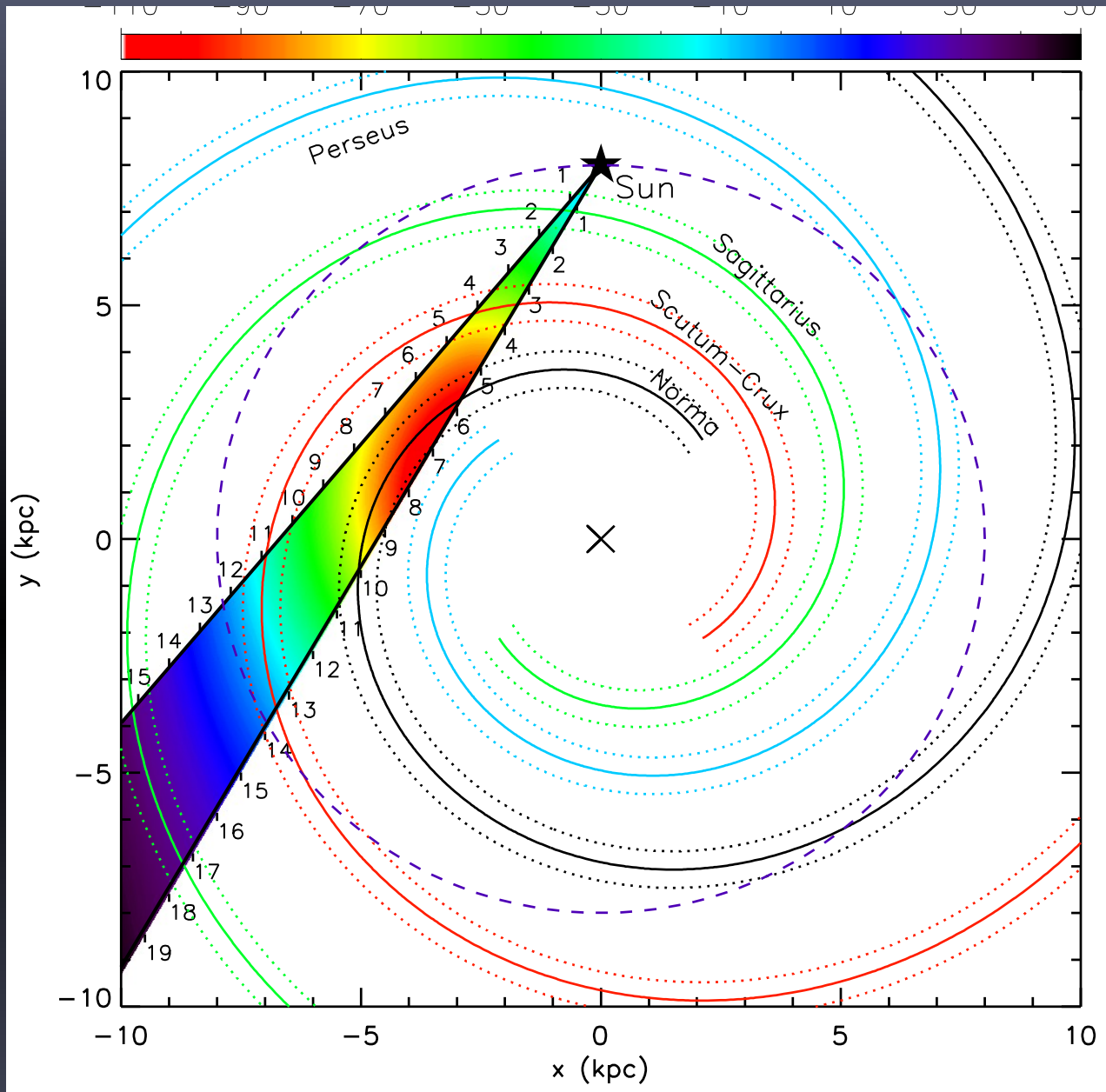
- ATNF Data Server: atoa.antf.csiro.au/CO

  and www.phys.unsw.edu.au/mopraCO/
- 1 sq degree ~ 200-300 Mb per line, V cropped
- 1 sq degree ~ 1 Gb for 12CO, full V range
- Cubes for every 0.5^{o} along the plane.
- l = 320-3300
- Now Available!

CO is awesome, but...

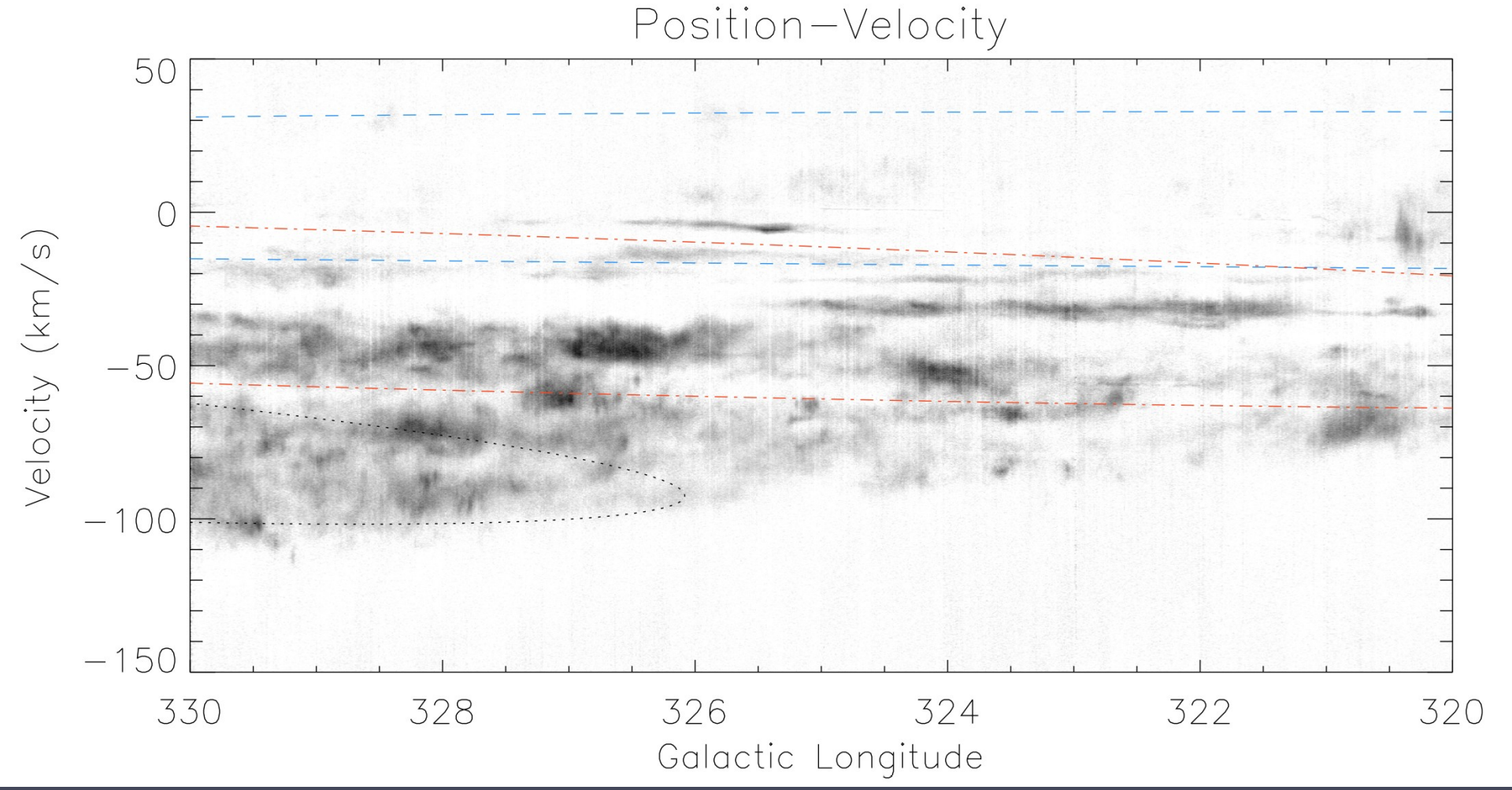
- ...there's a lot it can't tell us.

- We tend to use constant X_{CO} factor to find masses.
- And it misses "CO-dark" H2.
- Solution: Multiple scalpels for sharper dissection!



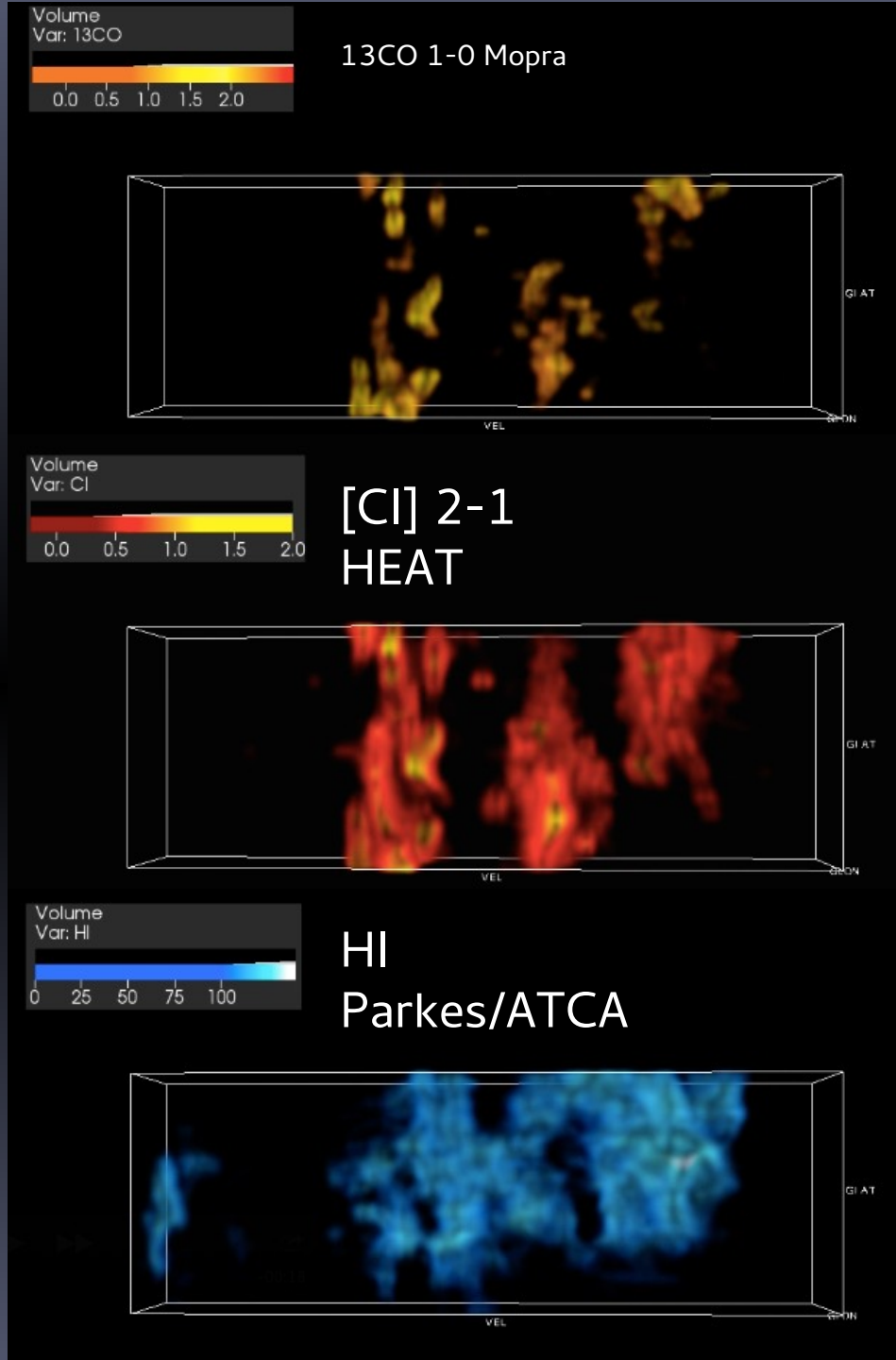
- Is MW typical?
- We don't know.
- Model MW (parameters from Vallee, 2014).
- Colour field is radial velocity in DR1.

Position – Velocity (DR1)



Radio & THz

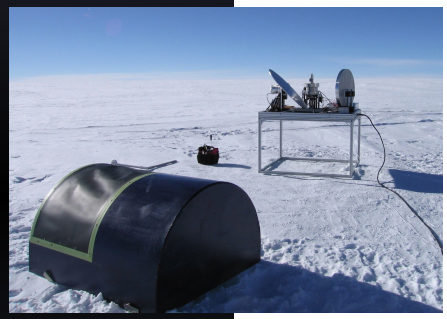
- 3D renderings of ^{13}CO from Mopra, [CI] from HEAT and HI from Parkes/ATCA SGPS.
- 1o x 0.5o x 150 km/s
- Atomic Carbon is more extended than CO – some is "dark" molecular gas.
- Galactic H_2 can be faint in CO but recovered in [CI] and [CII].

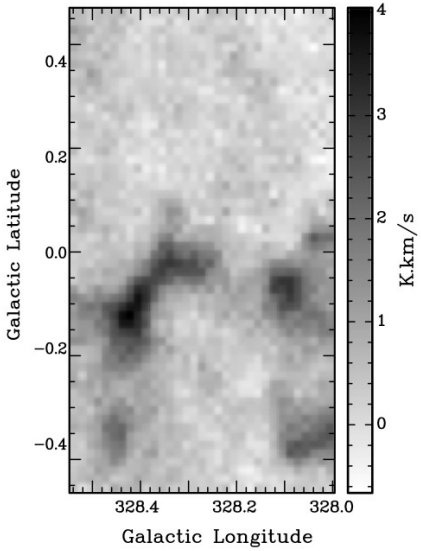


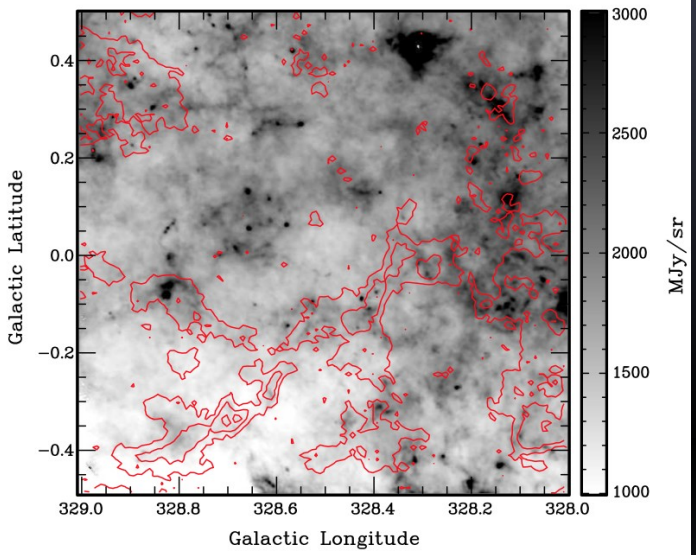
G328: From atomic to molecular

Narrow, Quiescent (4 km/s wide: -80 to -76 km/s) filament

[C I]
HEAT
0.8 THz

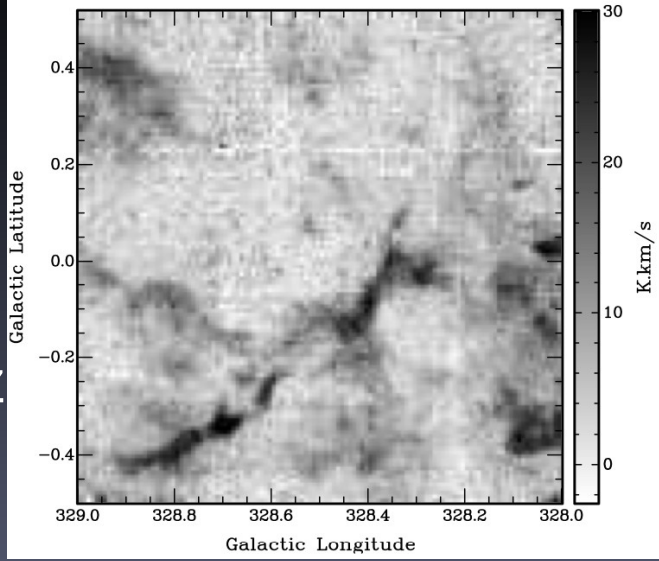


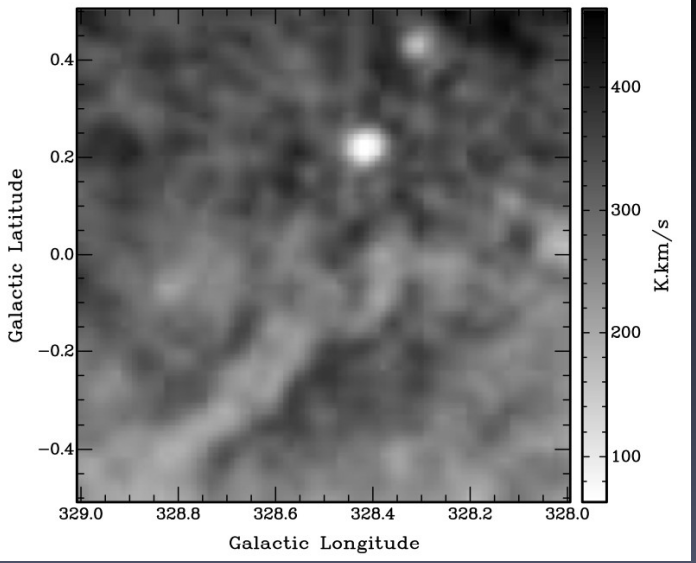




No dust!
Herschel
1.2 THz

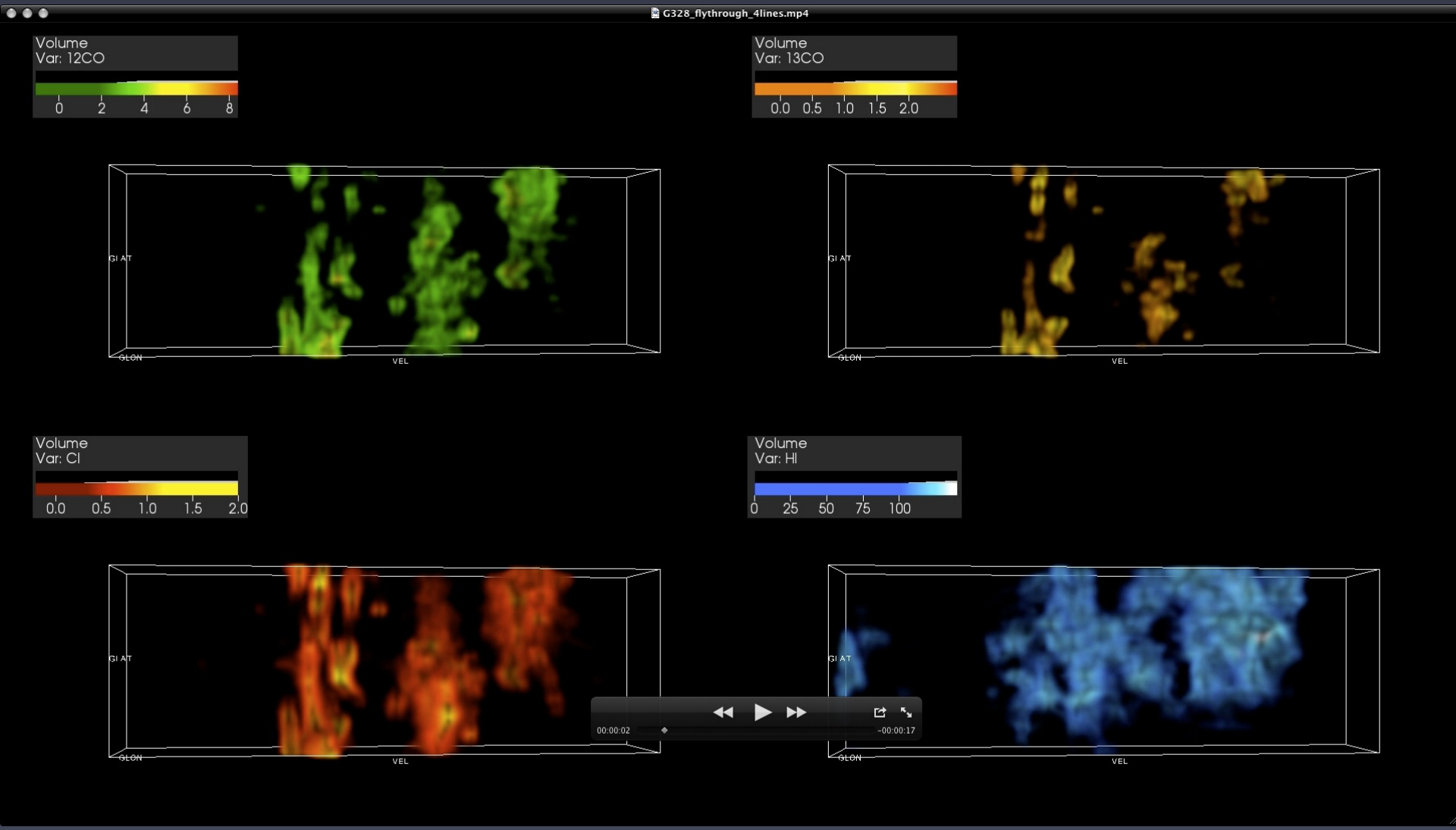
CO
Mopra
115 GHz





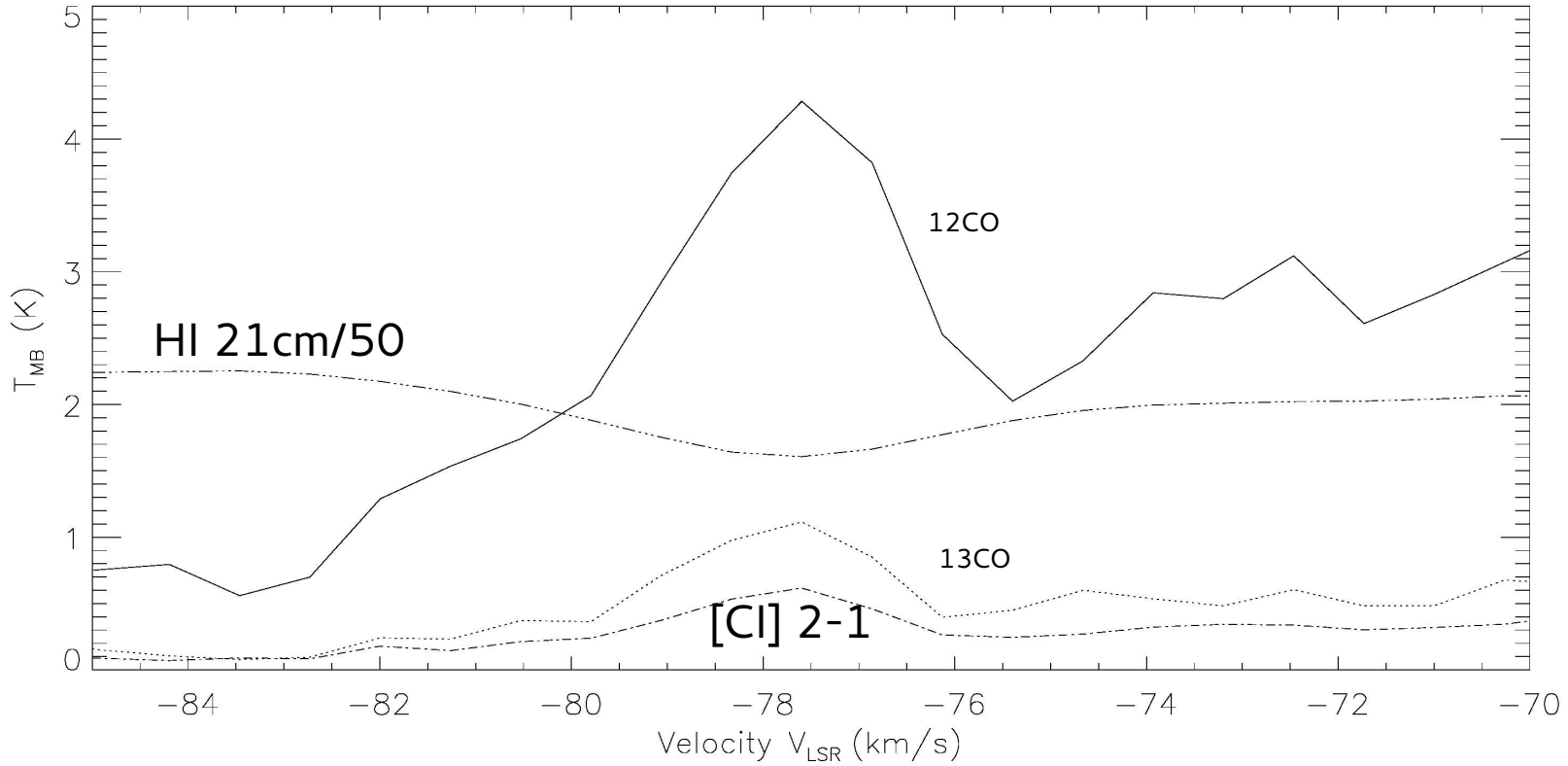
HISA
SGPS
1.4 GHz

G328 Flythrough



http:/www.phys.unsw.edu.au/mopraco/images.html

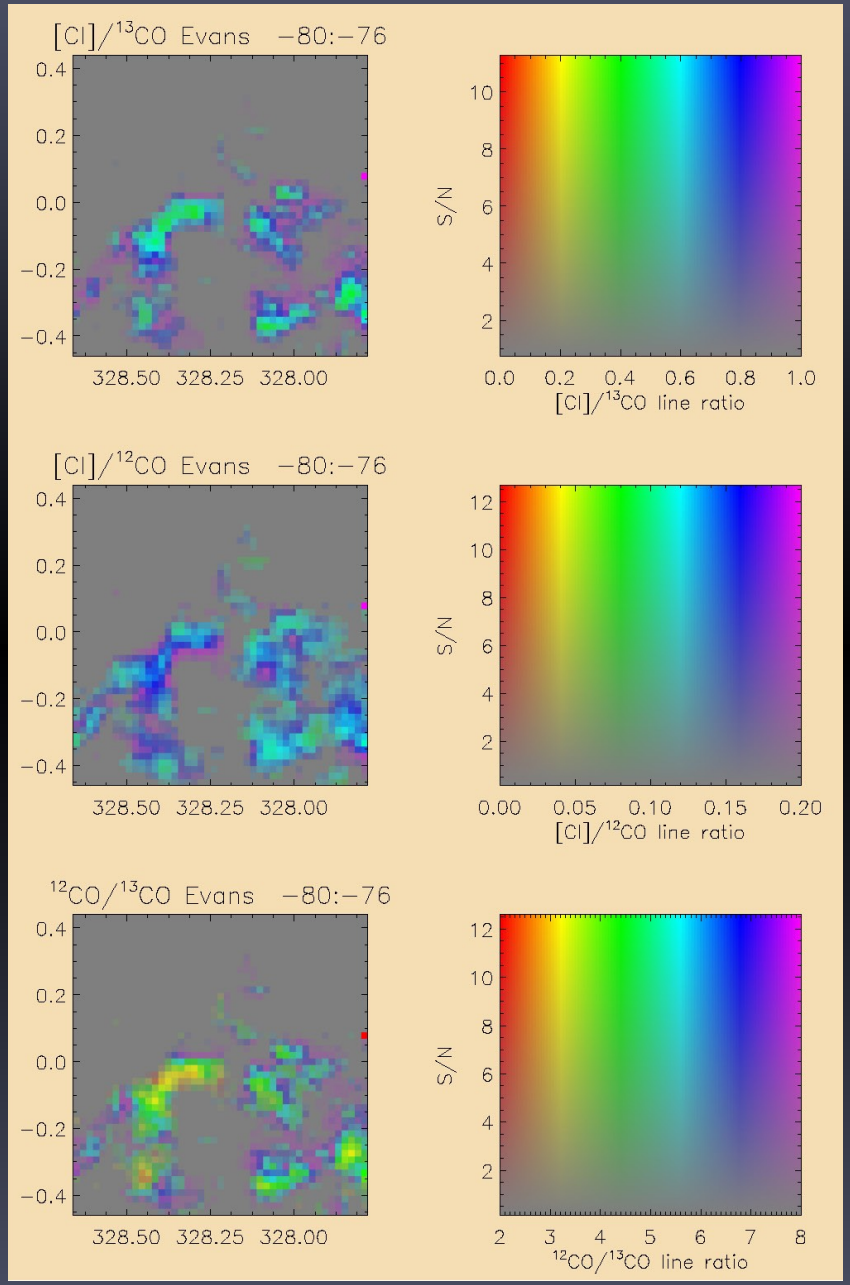
G328 Line Profiles



Burton et al. 2014, ApJ, 782, 72

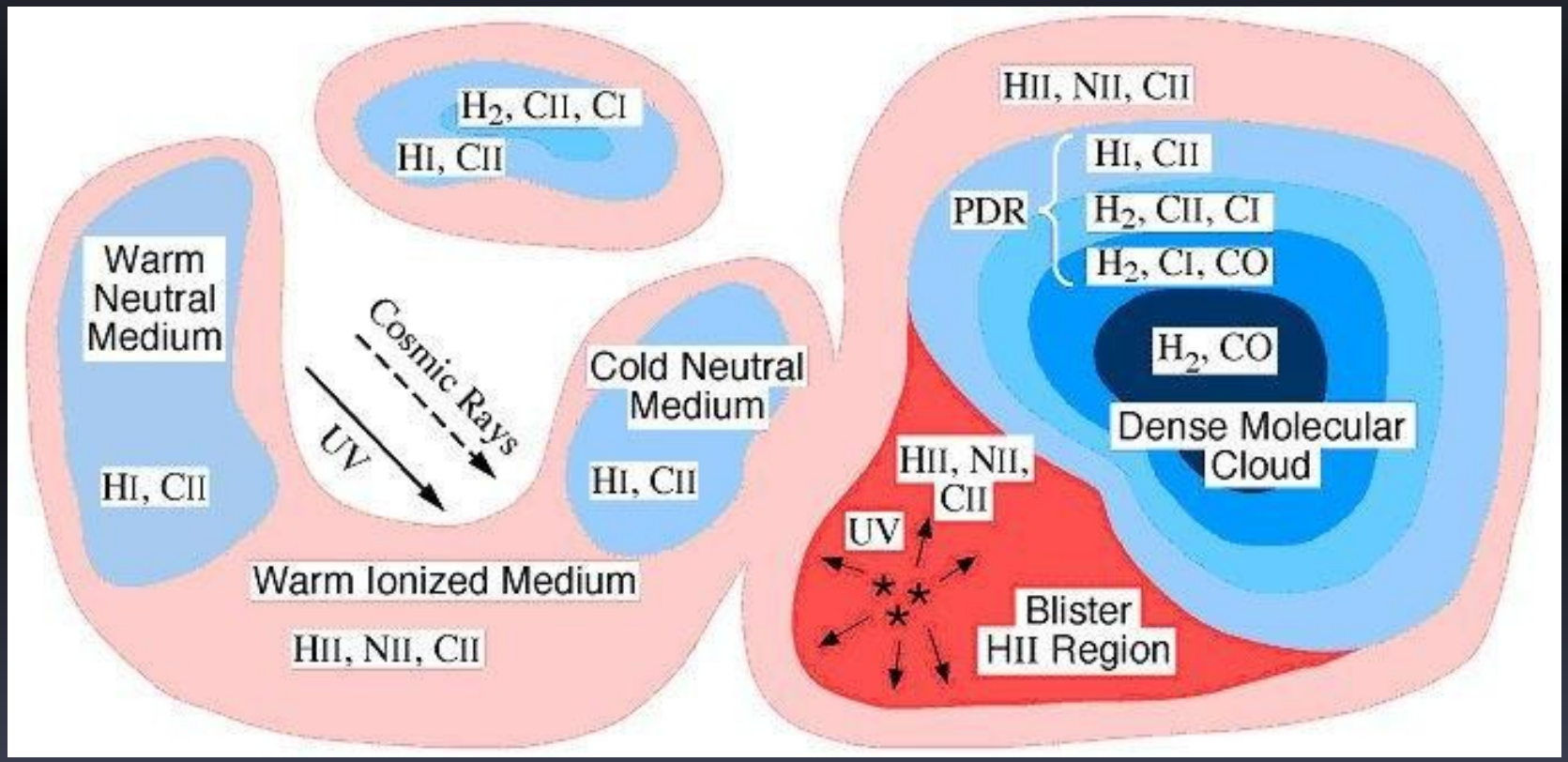
Line Ratios

- Evans plots: Colour is value; saturation is S/N (significance).
- There is clearly more [CI] around the edges of the filament.
- Column densities and optical depths match PDR models of Wolfire et al. (2010).
- All of this suggests a cloud in formation (without stars yet).



Burton et al. 2015, ApJ, 811, 13

Schematic of the multi-phase ISM and its diagnostic tracers



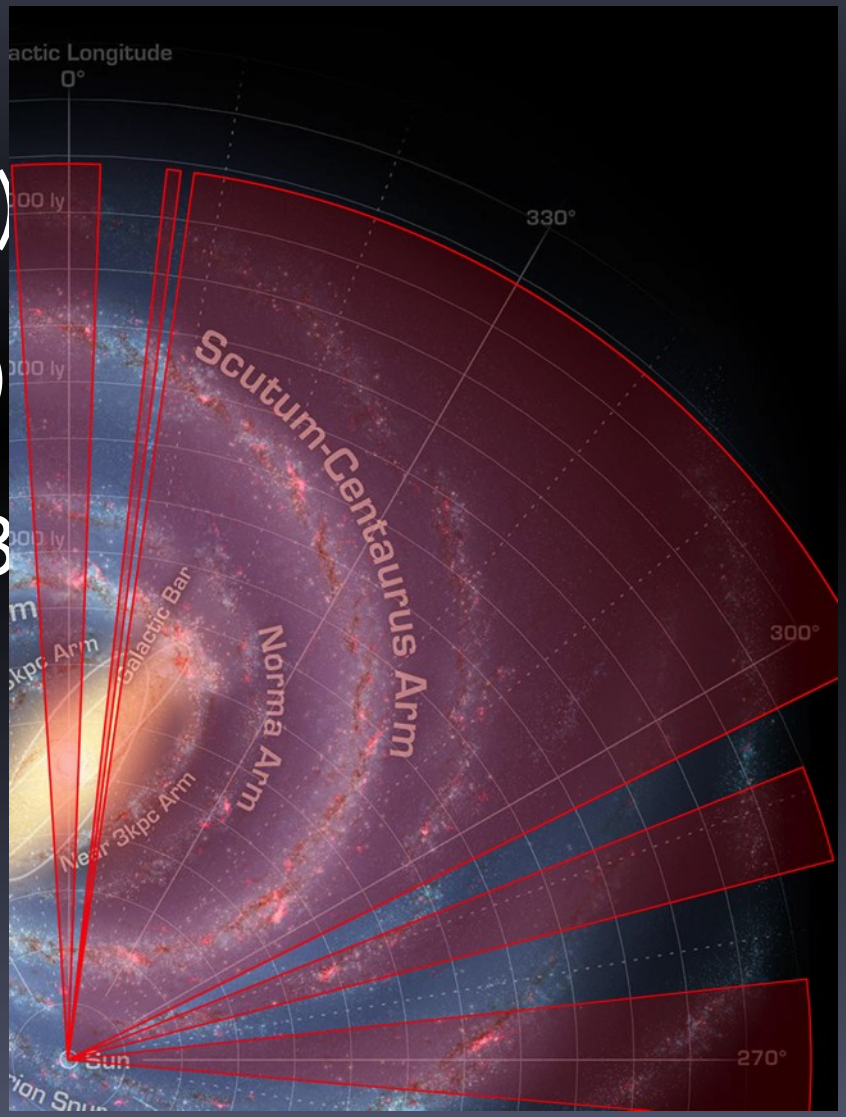
Follow the Carbon Trail: C^+ → C → CO

Circinus X-1

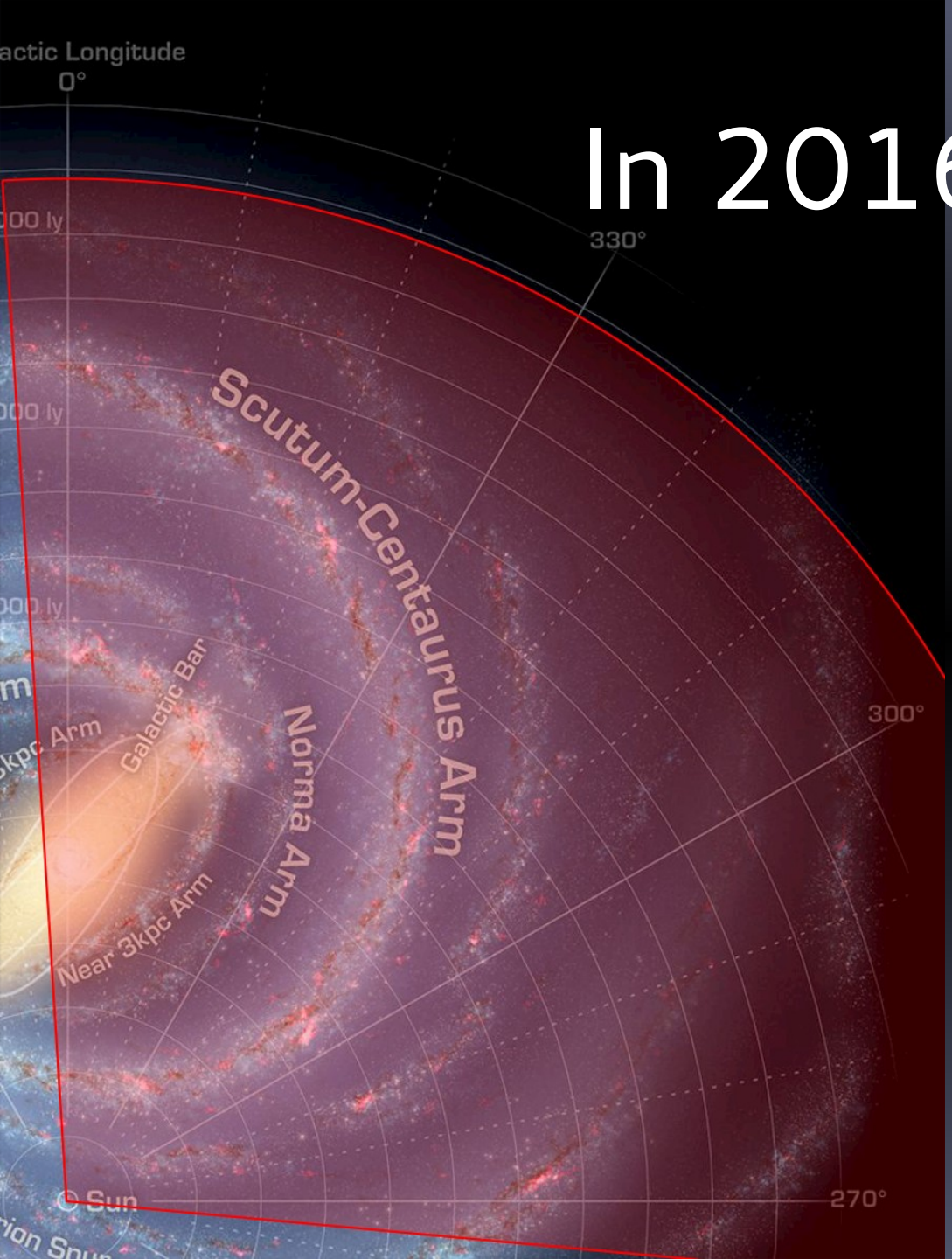
Heinz et al 2015, ApJ, 806, 265H

Mopra CO Survey – Coverage

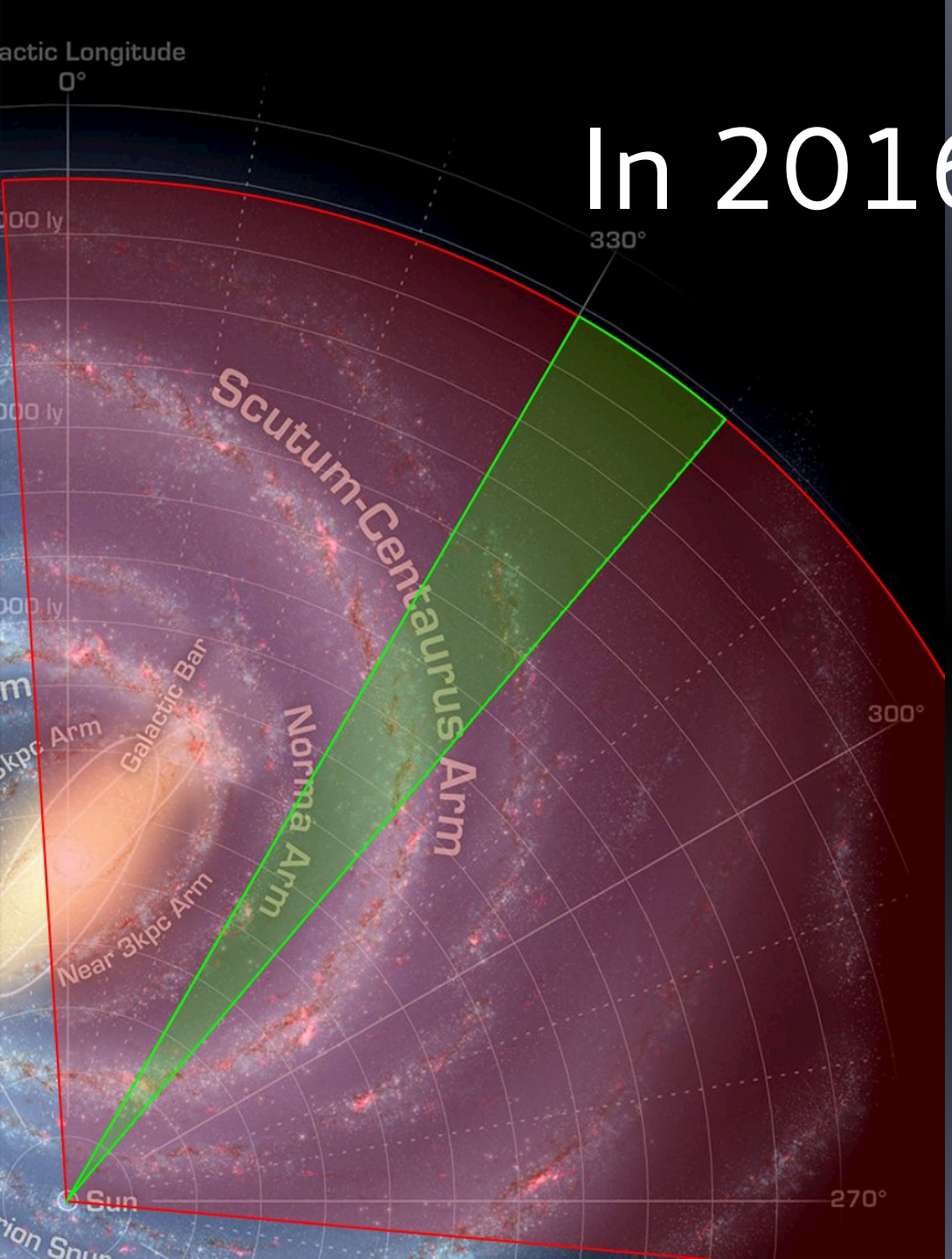
- Vela Jnr (l=265-274)
- Carina (l = 287-291)
- Mopra CO (l = 297-3
- HESSJ1731 (l = 353
- CMZ (l = 358-003)

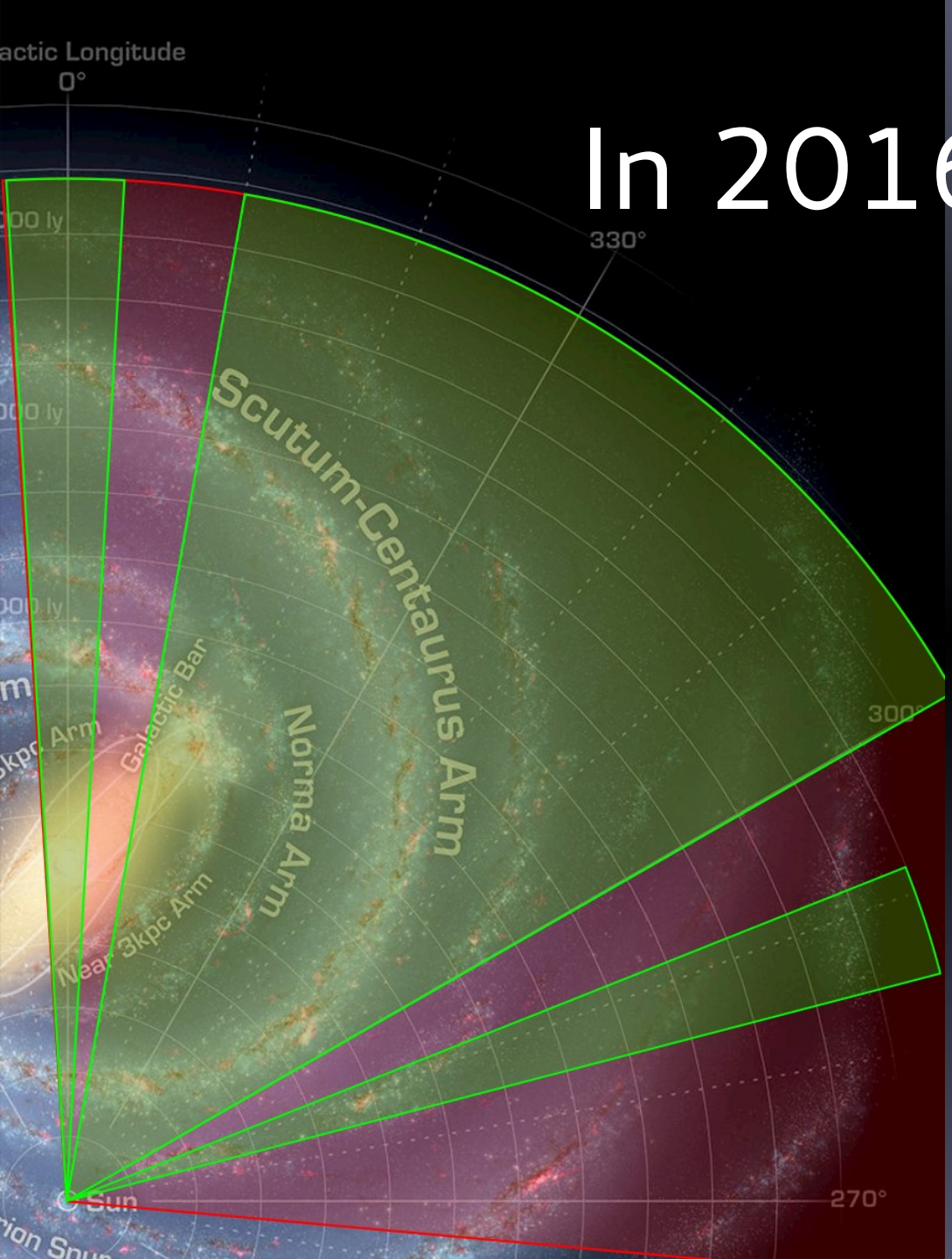


In 2016...


actic Longitude
0°
330°
300°
270°
Sun
Scutum-Centaurus Arm
Norma Arm
Galactic Bar
Near 3kpc Arm

In 2016...


actic Longitude
0°
330°
300°
270°
Sun
Scutum-Centaurus Arm
Norma Arm
Galactic Bar
Near 3kpc Arm



In 2016…

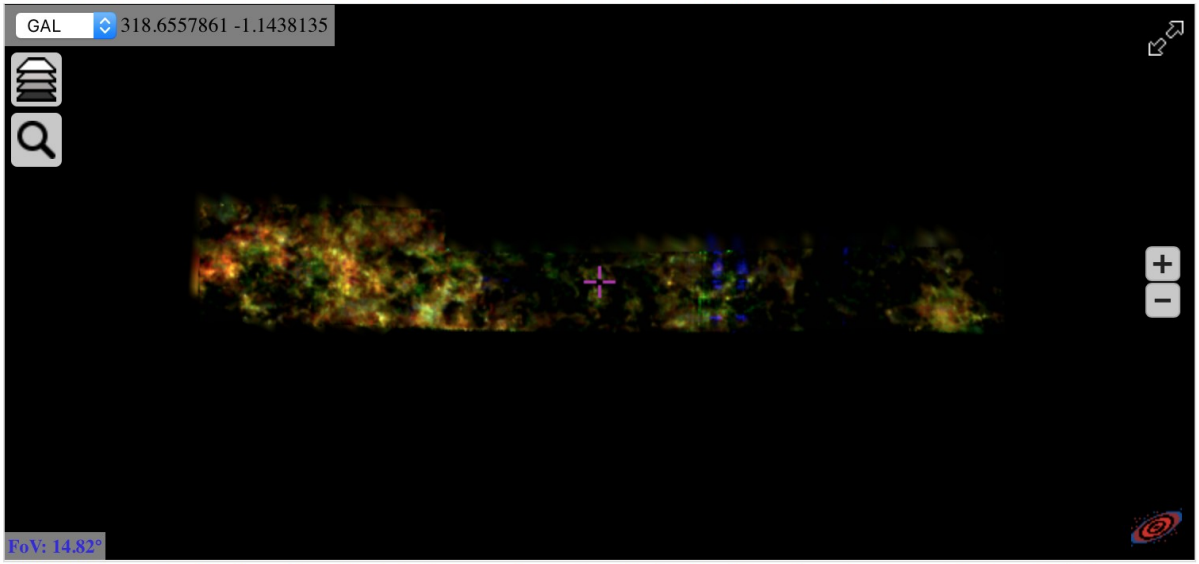
- Data Release 2: Carina (see David's Talk)
- Data Release 3/4: l = 300-350
- Data Release 3/4: CMZ (see Rebecca's Talk)
- Moment maps available via Aladin/VO

Aladin Lite

Google Maps-style multiwavelength astronomy.

"ID1447106541" progressive survey

This Web resource contains HiPS(*) components for **ID1447106541** progressive survey.



This survey can be displayed by Aladin Lite (see above), by Aladin Desktop client (just open the base URL) or any other HiPS aware clients .

- **Label:** ID1447106541
- **Type:** HiPS image
- **Best pixel angular resolution:** 25.77"
- **Max tile order:** 4 (NSIDE=16)
- **Available encoding tiles:** png fits
- **Tile size:** 512x512
- **FITS tile BITPIX:** -32
- **Processing date:** 2015-11-09T22:02Z
- **HiPS builder:** Aladin/HipsGen v8.177
- **Coordinate frame:** equatorial
- **Sky area:** 0.228% of sky => 94¡^2
- **Associated coverage map:** MOC
- **Original data access template:** metadata.xml
- **Raw property file:** properties
- **Base URL:**

  http://localhost:8000

http://aladin.u-strasbg.fr/AladinLite/

The Latest Data!

- (Catherine produced this in the hour before her talk. ‘scuse any errors.)
- http://youtu.be/KKiyd-CrsYM

Observations in 2016?

- Hope to start in April / May.
- Plan to move to b = +/- 1°
- In select regions only, so talk to me!

(Tweetable) Summary

- To find 'dark' gas in the Milky Way, we need to follow the Carbon trail. Require CO, [CI] and C+ to get the 'full' picture. #Mopra15

- Mopra CO: www.phys.unsw.edu.au/mopraCO
- DR2: @TeamMopra for updates.
- DR1 paper: Braiding et al. 2015, PASA, 32, e
- For pre-release data: Email, or @AstroCate!