The Mopra Galactic Plane CO Survey

www.phys.unsw.edu.au/mopraco

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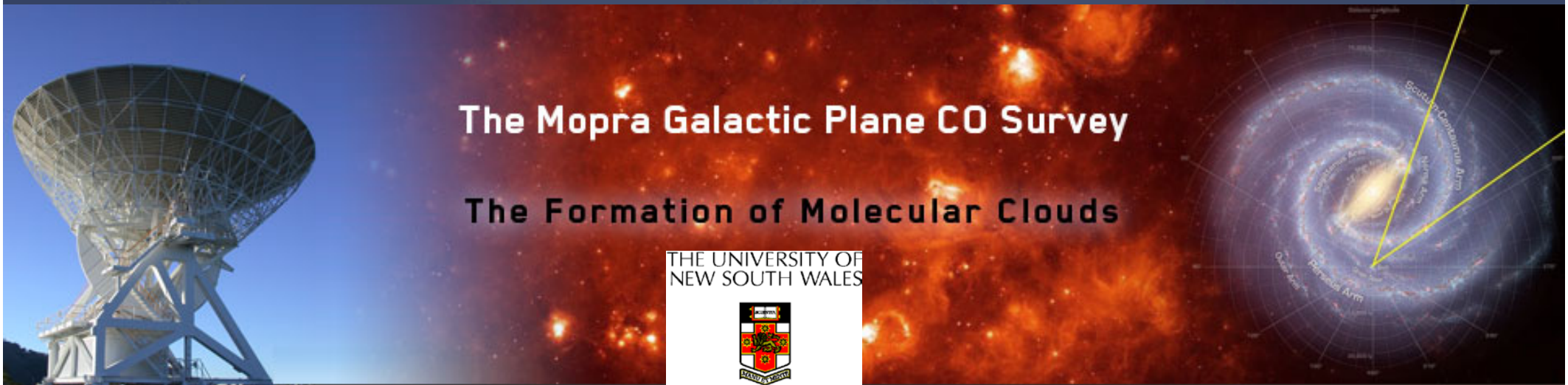
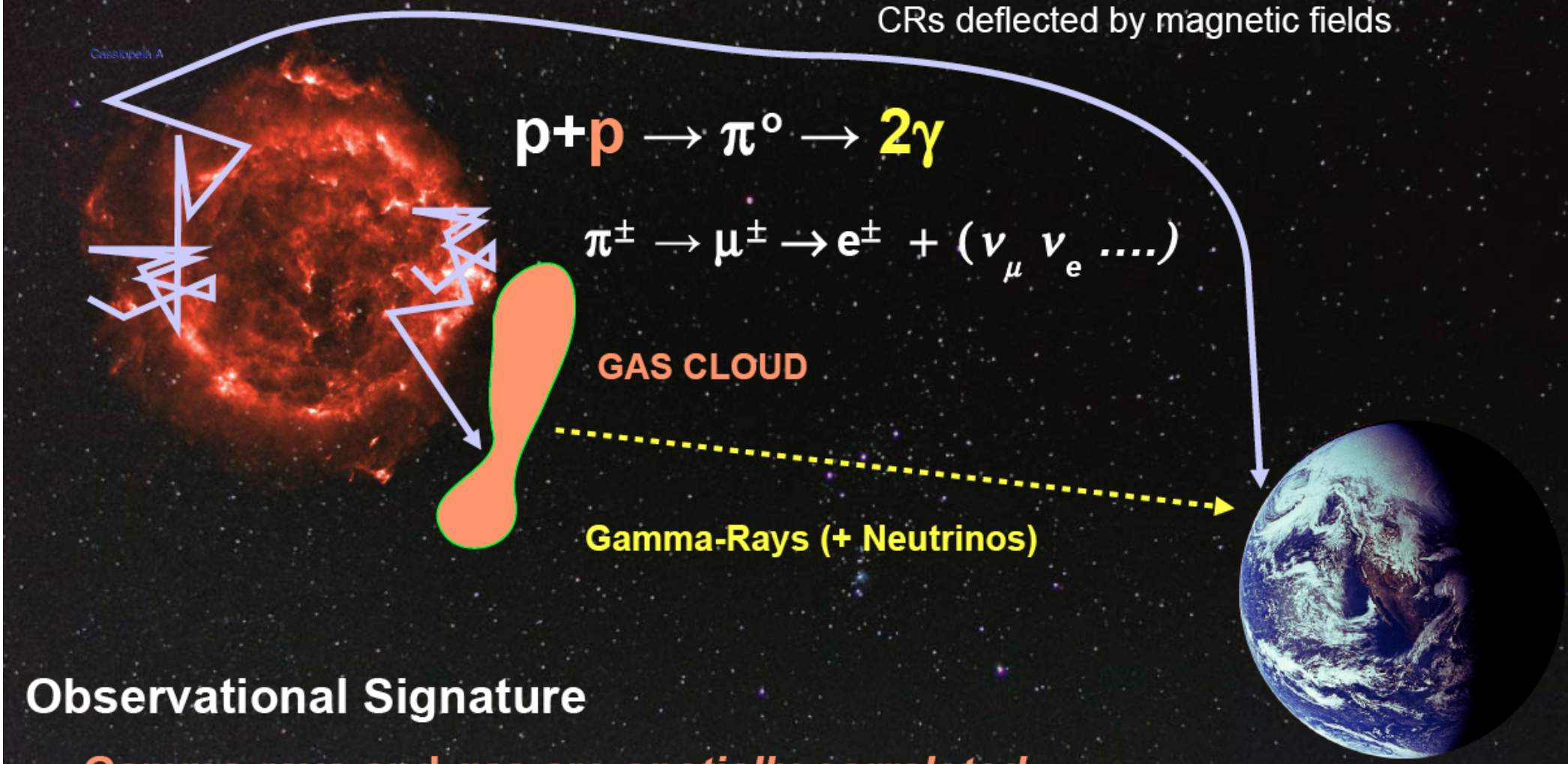
David Hollenbach, Craig Kulesa, Mark Wolfire, Paul Goldsmith, Chris Martin, Jorge Pineda, Tony Stark, Chris Walker (USA)
Jürgen Stutzki, Robert Simon, Christian Glück, James Urquhart (Germany)



Gamma Rays from multi-TeV Cosmic-Rays (p, He ...etc)



Observational Signature

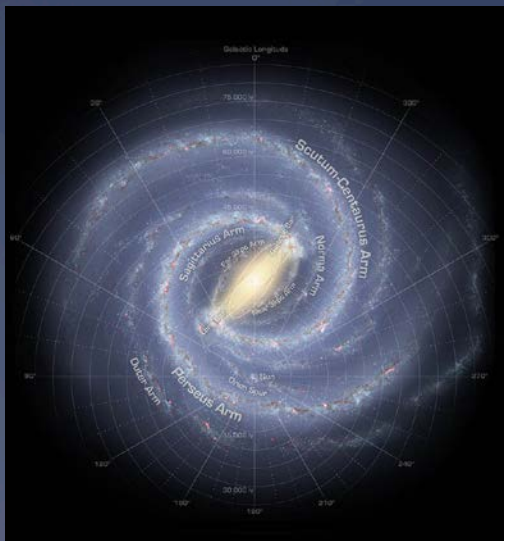
→ Gamma-rays and gas are *spatially correlated*

→ Intimate connection with mm- radio astronomy (tracing gas)

.....we expect gamma-ray flux $F_\gamma \sim k_{CR} M_{gas}$

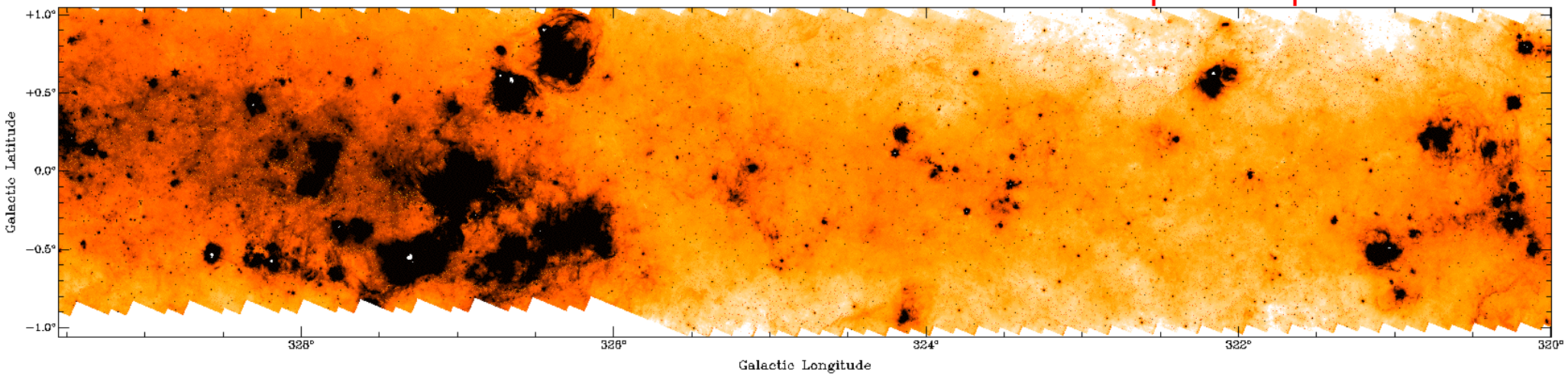
Outline

1. Two Science Problems:
   - Dark molecular gas
   - Following the Galactic Carbon Trail
2. A Suite of Telescopes:
   - Mopra + Nanten2 + STO-2 + HEAT + Parkes + ATCA
3. The Mopra Southern Galactic Plane CO Survey



4. HEAT at Ridge A, Antarctica
   - THz astronomy: the first Carbon survey

Spitzer 24μm



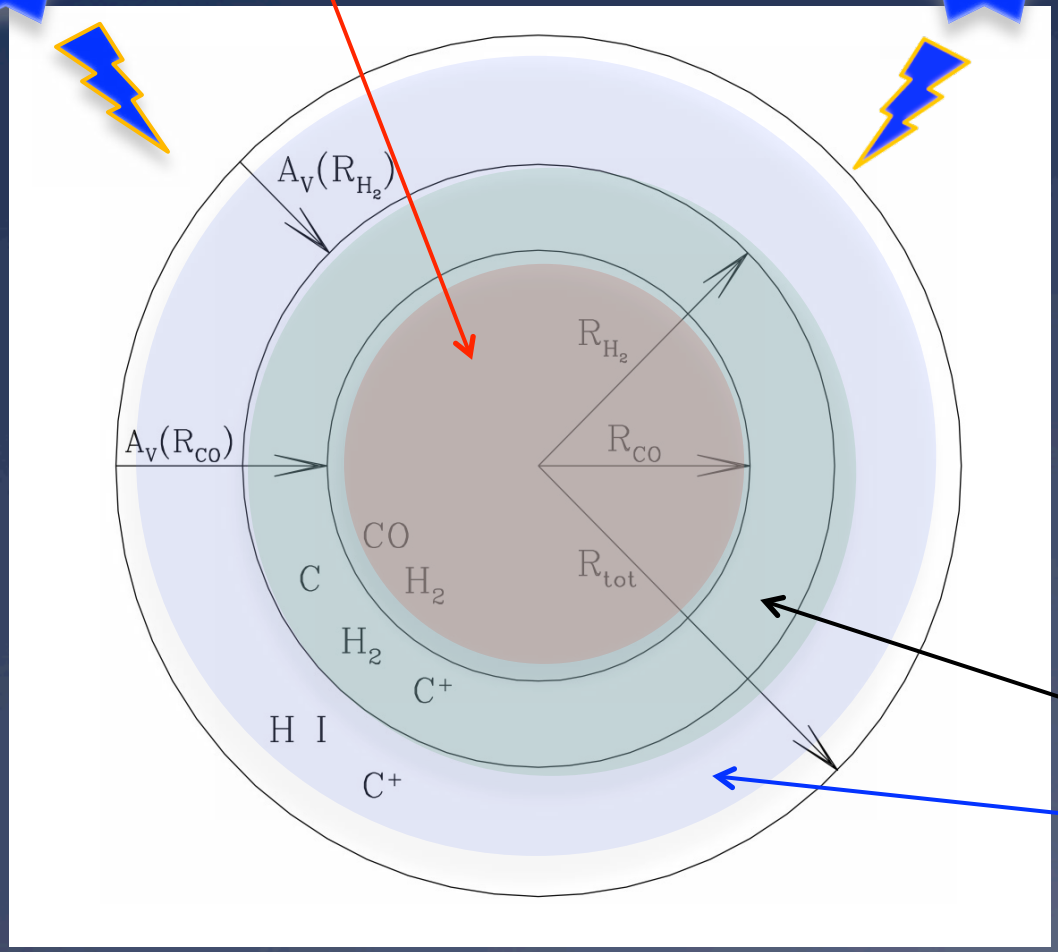
1. Science Problems

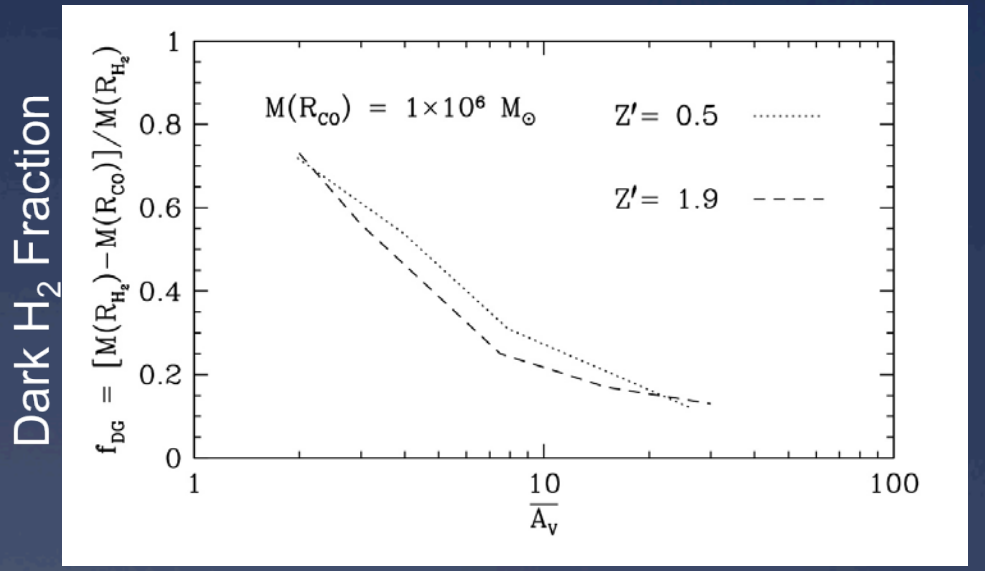
Where lyeth the dense ISM?

"Dark" H_2

'Normal' Molecular Gas

Perhaps one-third of the molecular gas is "dark"?!





Column Density of Cloud

Purely Molecular Hydrogen – Dark H_2

Atomic Gas

"The dark molecular gas", Wolfire, Hollenbach & McKee, 2010, Astrophysical Journal, 716, 1191

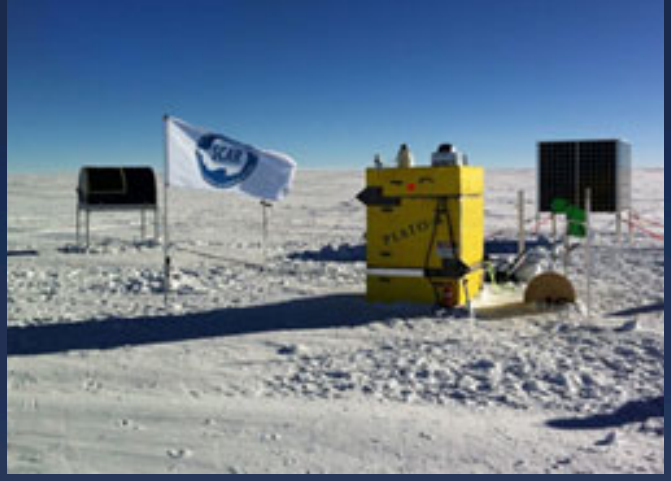
The Galactic Carbon Trail

H^+ Bright, Easy ✔✔
Broad-line
Limited column

2. The Telescopes

Mopra + Nanten2 + HEAT + STO-2 + Parkes + ATCA

Parkes + ATCA
SGPS – HI
McClure-Griffiths et al. 2005



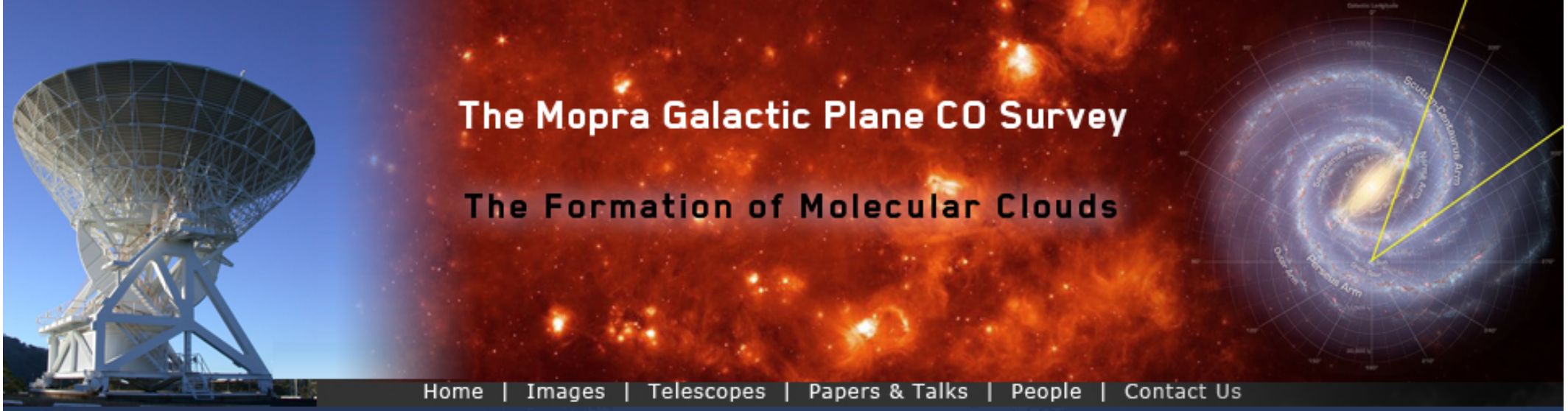
HEAT + STO-2: [CII] + [NII] + [CI] + CO 7-6

Mopra: ^{12}CO + ^{13}CO + $C^{18}O$ + $C^{17}O$ 1-0

Nanten2
[CI] + CO 4-3,7-6

Mopra Telescope MM Capabilities

- 22-m Telescope for long-wave mm astronomy
  - 3mm + 7mm + 12mm
- 77–116 GHz MMIC receiver (2.5-4 mm)
  - T_{sys} ~ 150K (@85GHz) – 400K (@115GHz)
  - 35" beam
  - η_{mb} (86 GHz) = 0.49, η_{mb} (115 GHz) = 0.42
  - η_{xb} (86 GHz) = 0.65, η_{xb} (115 GHz) = 0.55
- 30-50 GHz receiver (5-10mm)
  - T_{sys} ~ 65K, 75" beam
- 16-25 GHz receiver (12-18mm)
  - T_{sys} ~ 45K, η_{mb} ~ 0.7, 150" beam
- Bandwidth 8 GHz: UNSW-MOPS correlator
  - Broad Band 32,000 channels, 0.8 km/s resn.
  - 16 Zooms modes over 137 MHz
    4 per band, 4096 channels/zoom, 0.1 km/s@3mm
- 2 Polarizations (i.e. 64,000 channels)
- "Fast-On-the-Fly" (FOTF) Mapping



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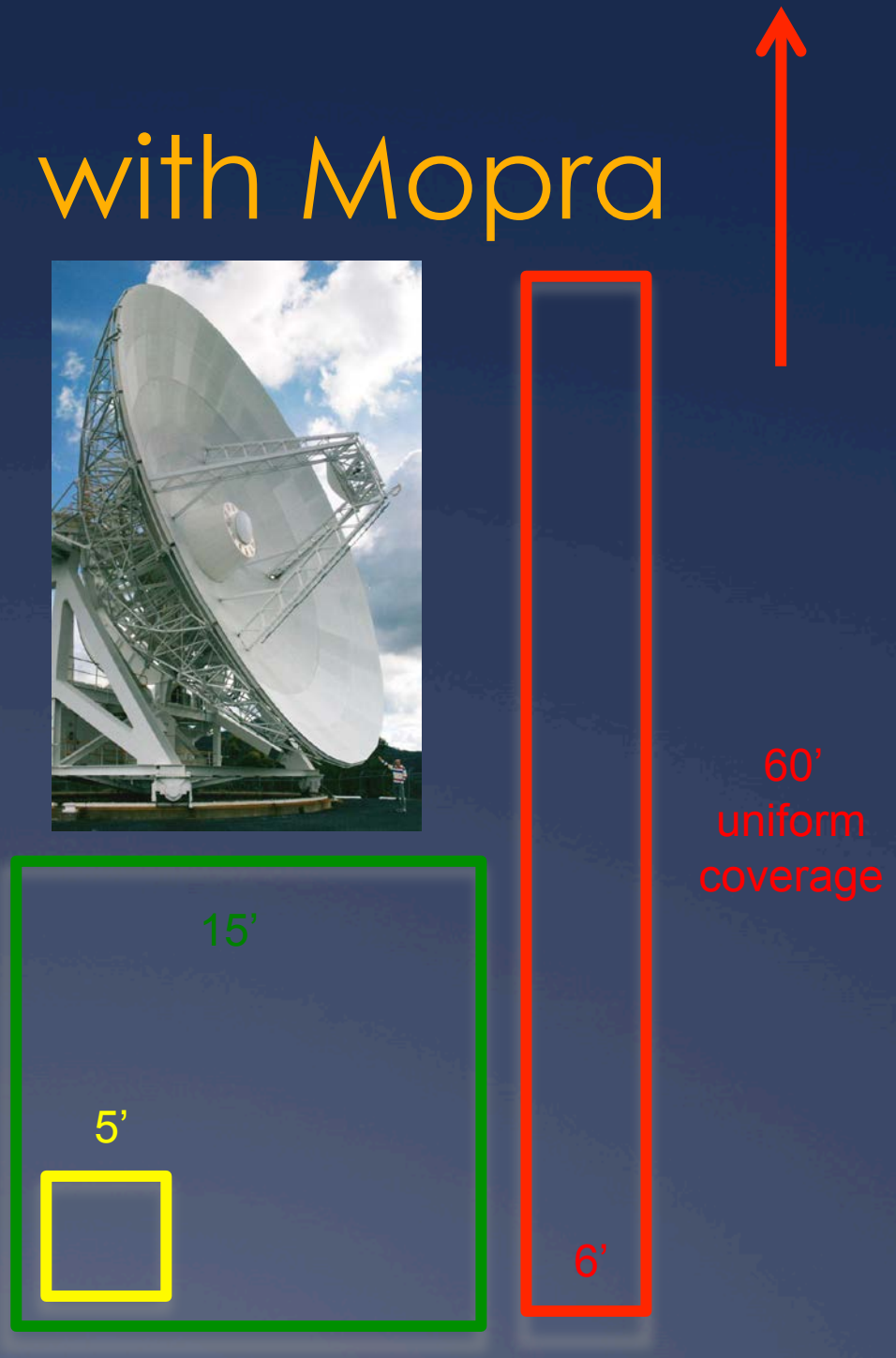
3. Molecular Gas in the Galaxy

The Mopra CO Survey of the Southern Galactic Plane

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
  - ^{12}CO, ^{13}CO, $C^{18}O$, $C^{17}O$



Thanks also to Warwick Wilson, Dick Ferris, Balt Indermuehle

Line Parameters for CO Survey

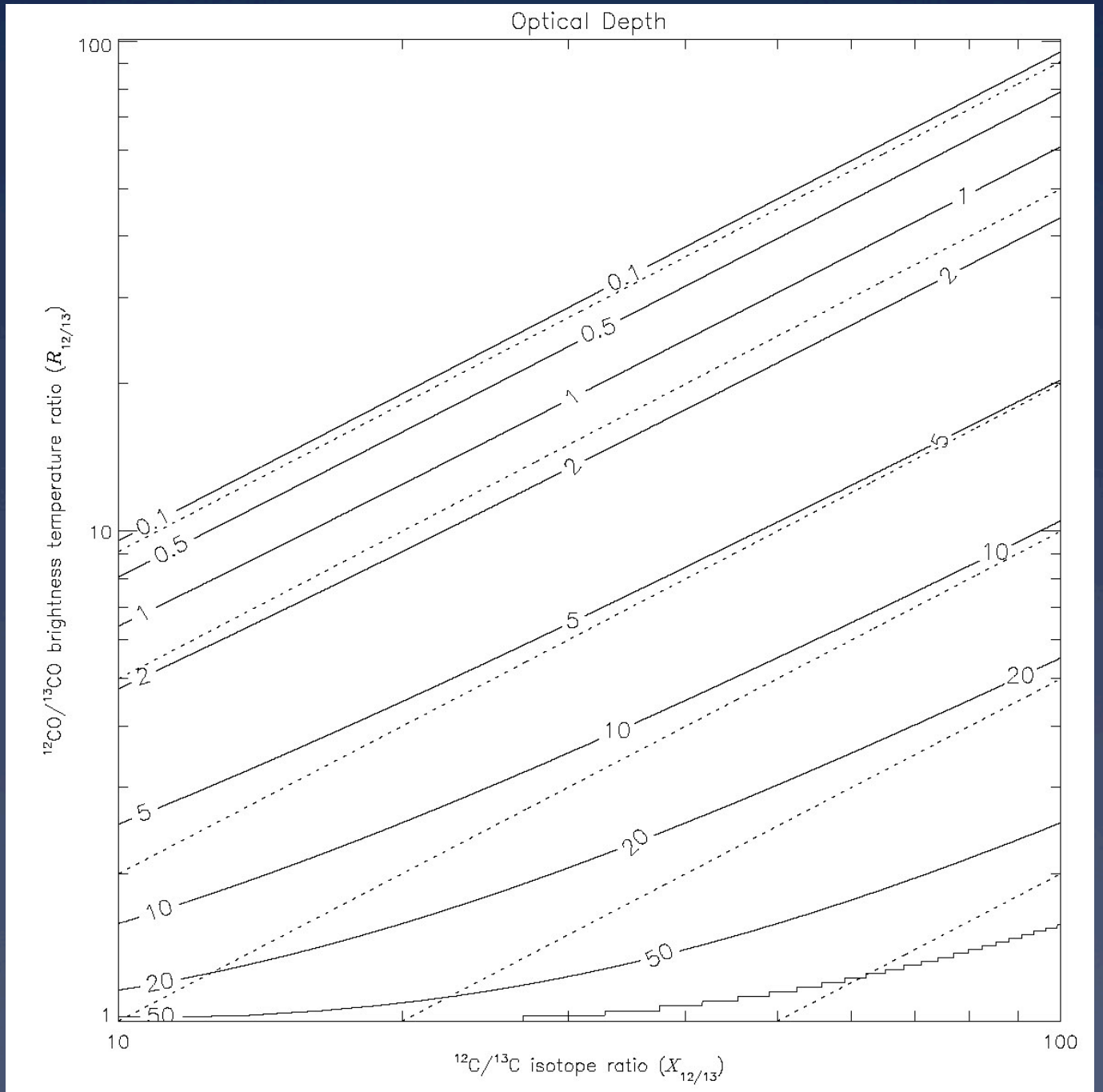
IF	Frequency (GHz)	Isotopologue	V_{low} (km/s)	V_{high} (km/s)
1+2	110.1	^{13}CO 1-0	-475	+270
3+4	109.7	$C^{18}O$ 1-0	-495	+255
5	112.3	$C^{17}O$ 1-0	-235	+130
6+7+8	115.2	^{12}CO 1-0	-550	+525

0.6’ Beam @ 0.1 km/s resolution

~4 shifts per 1°x1° block (|b|<0.5°)

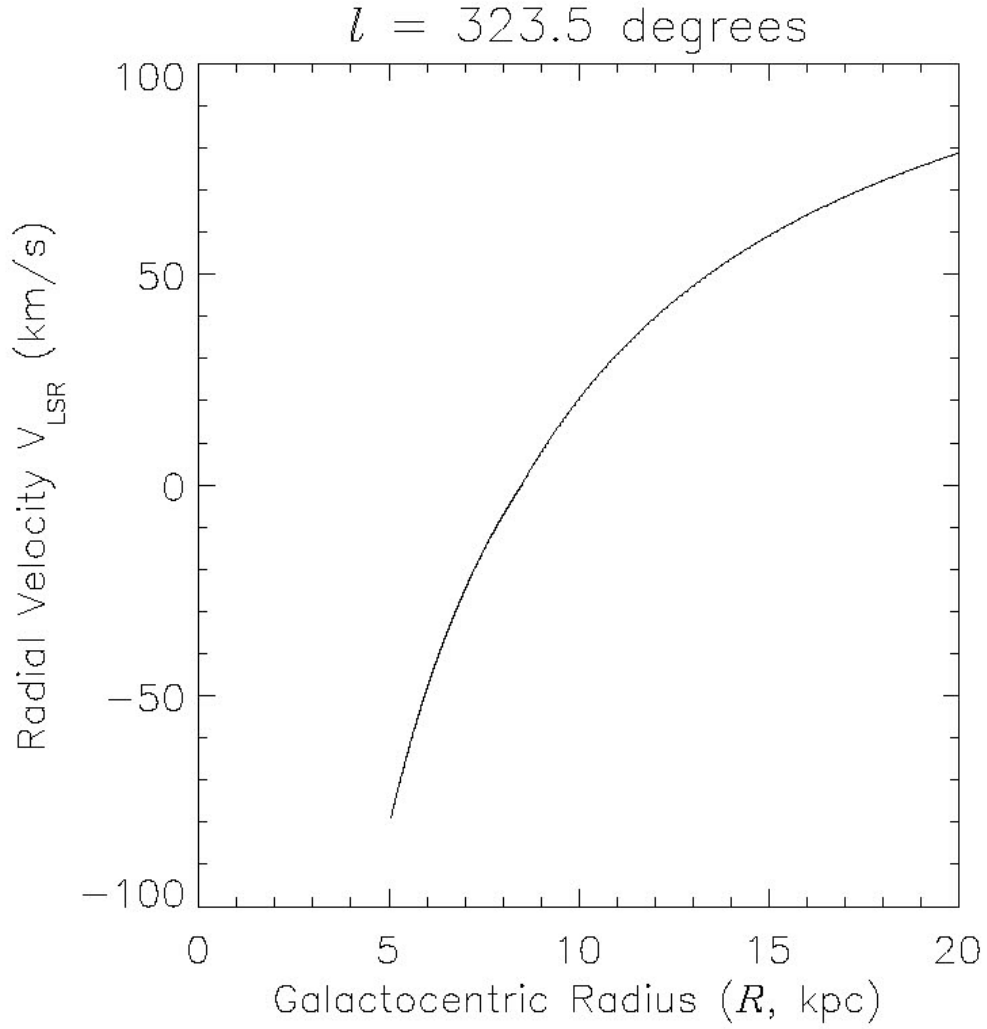
CO Optical Depth ➡ H_2 Column Density

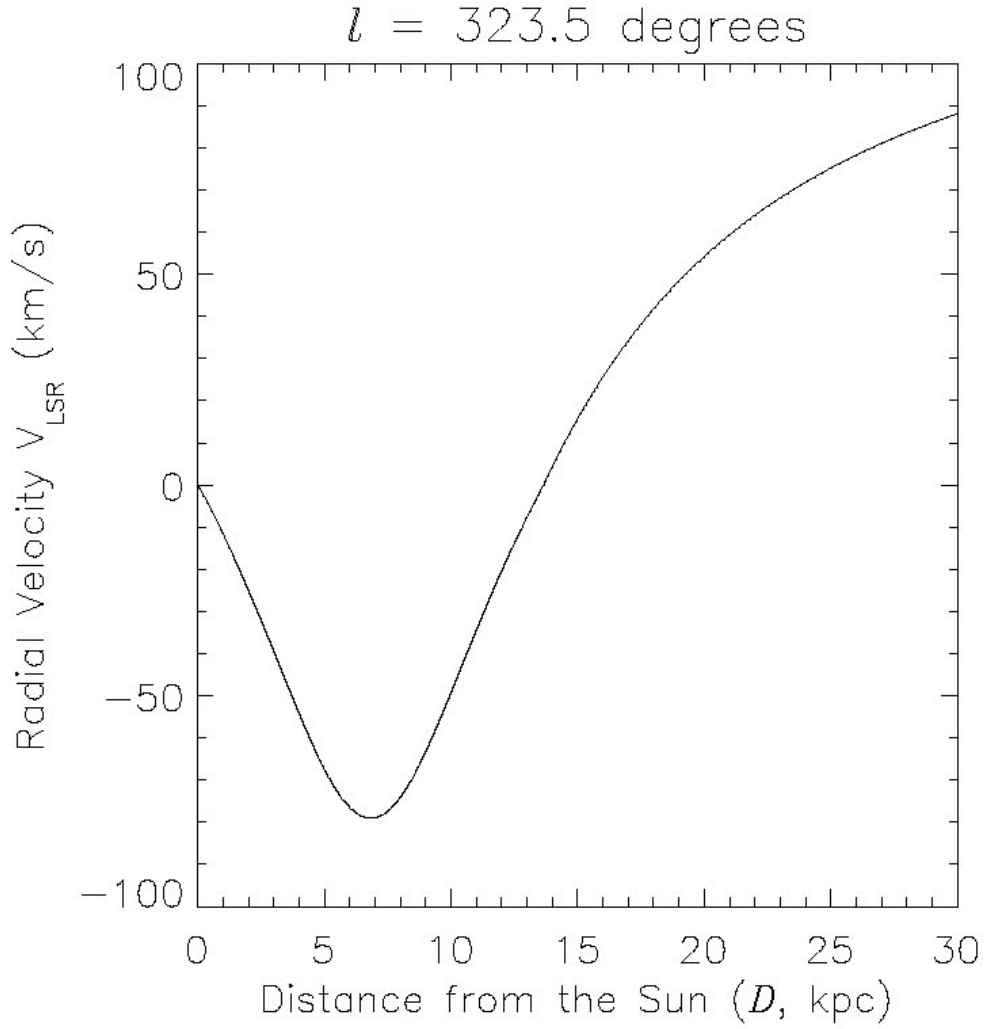
$^{12}CO/^{13}CO$



$[^{12}C/^{13}C]$

Galactic Rotation for G323
Velocity yields Distance





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doi:10.1017/pasa.2013.22

The Mopra Southern Galactic Plane CO Survey

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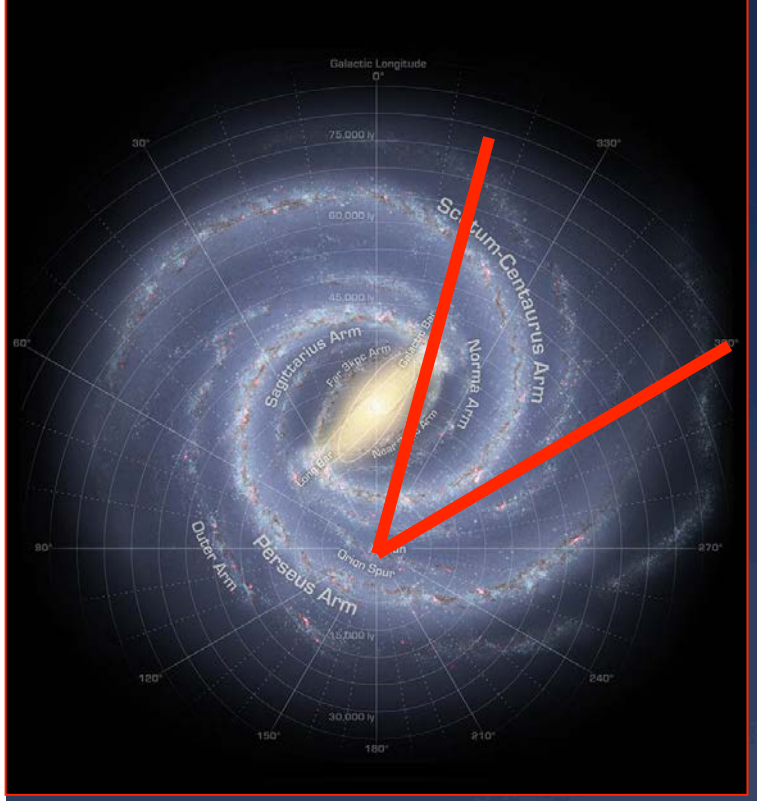
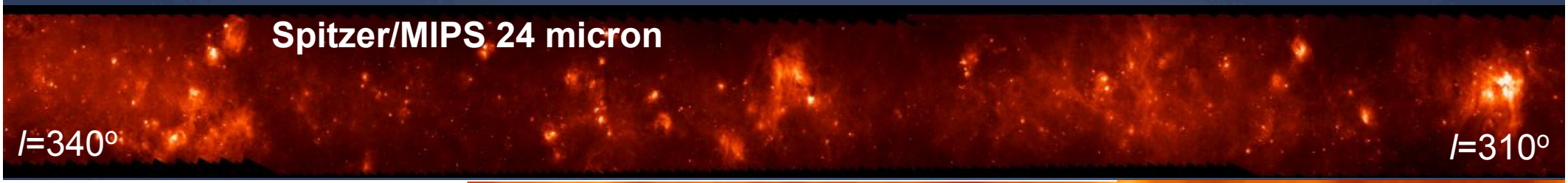
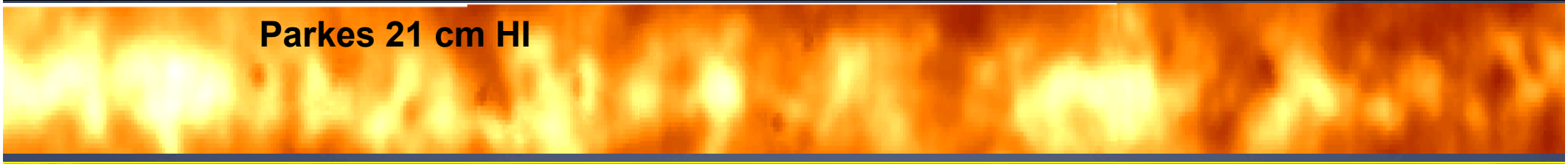
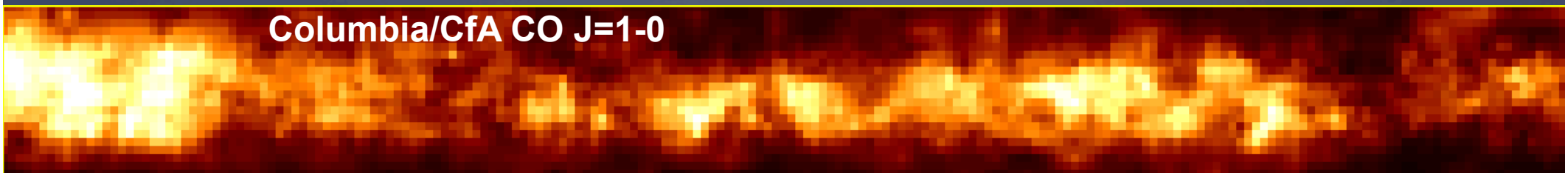


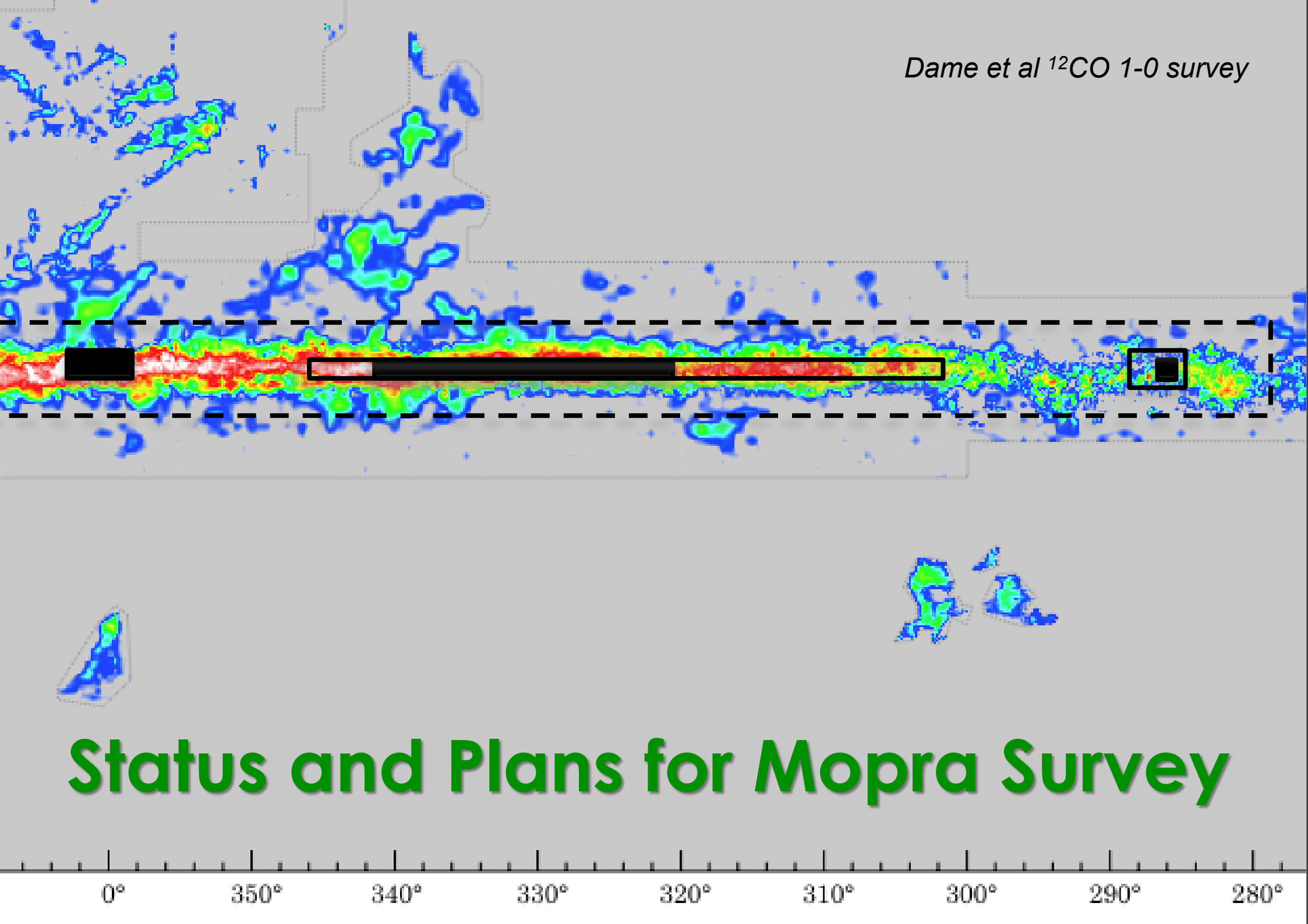
The Mopra CO Survey

l=305º – 345º, and |*b*|<0.5° spanning the Molecular Ring through the Scutum-Centaurus spiral arm and two inter-arm regions.

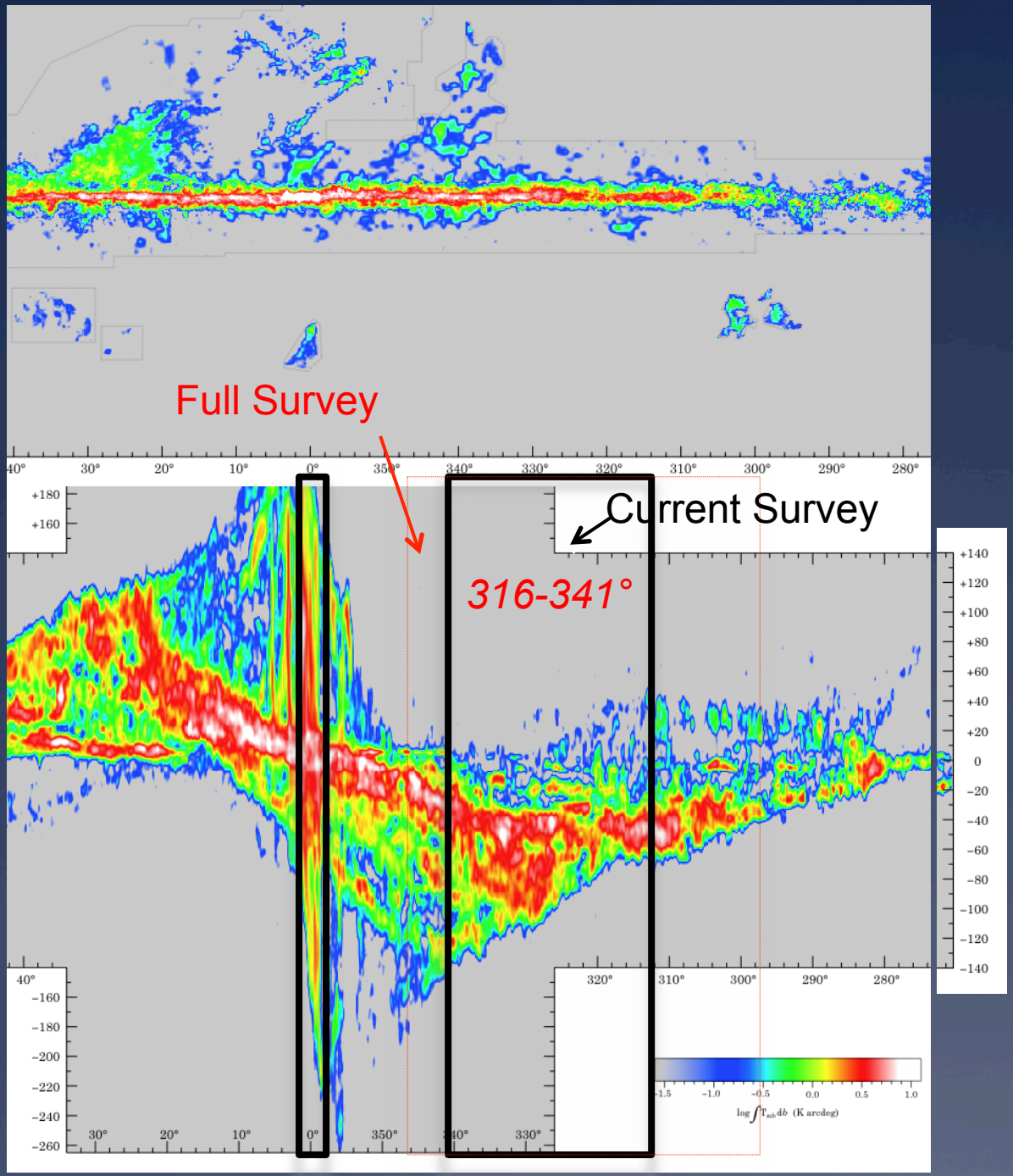






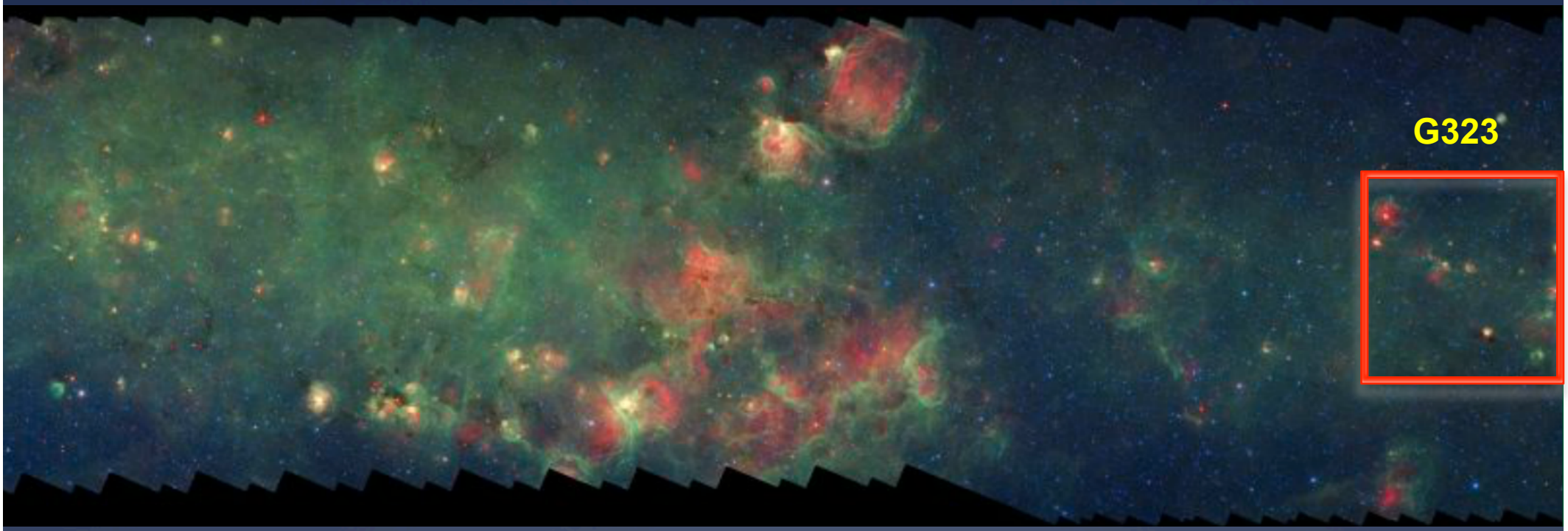


Status and Plans for Mopra Survey



Dame et al ^{12}CO 1-0 survey

Spitzer: 24μm (warm dust) + 8μm (FUV-fluoresced PAHs)

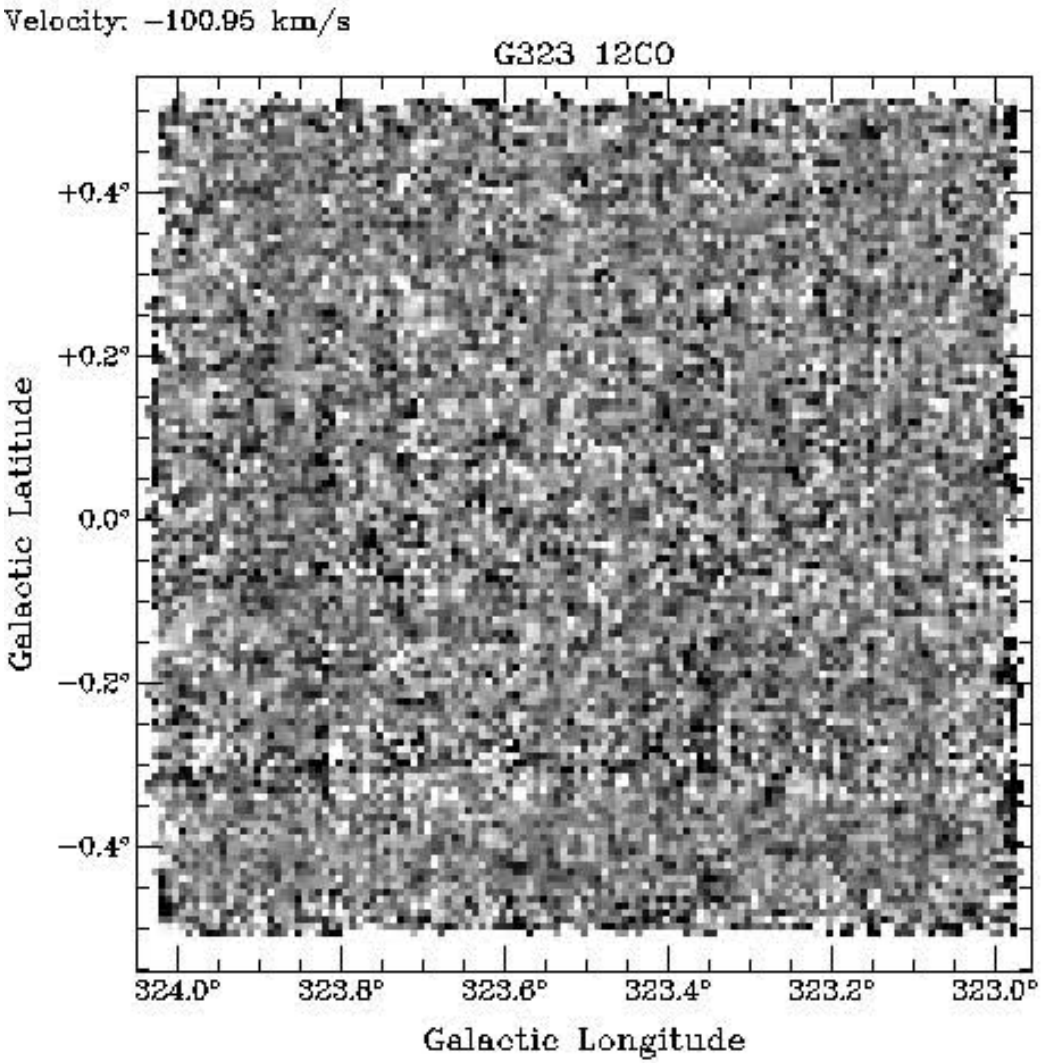


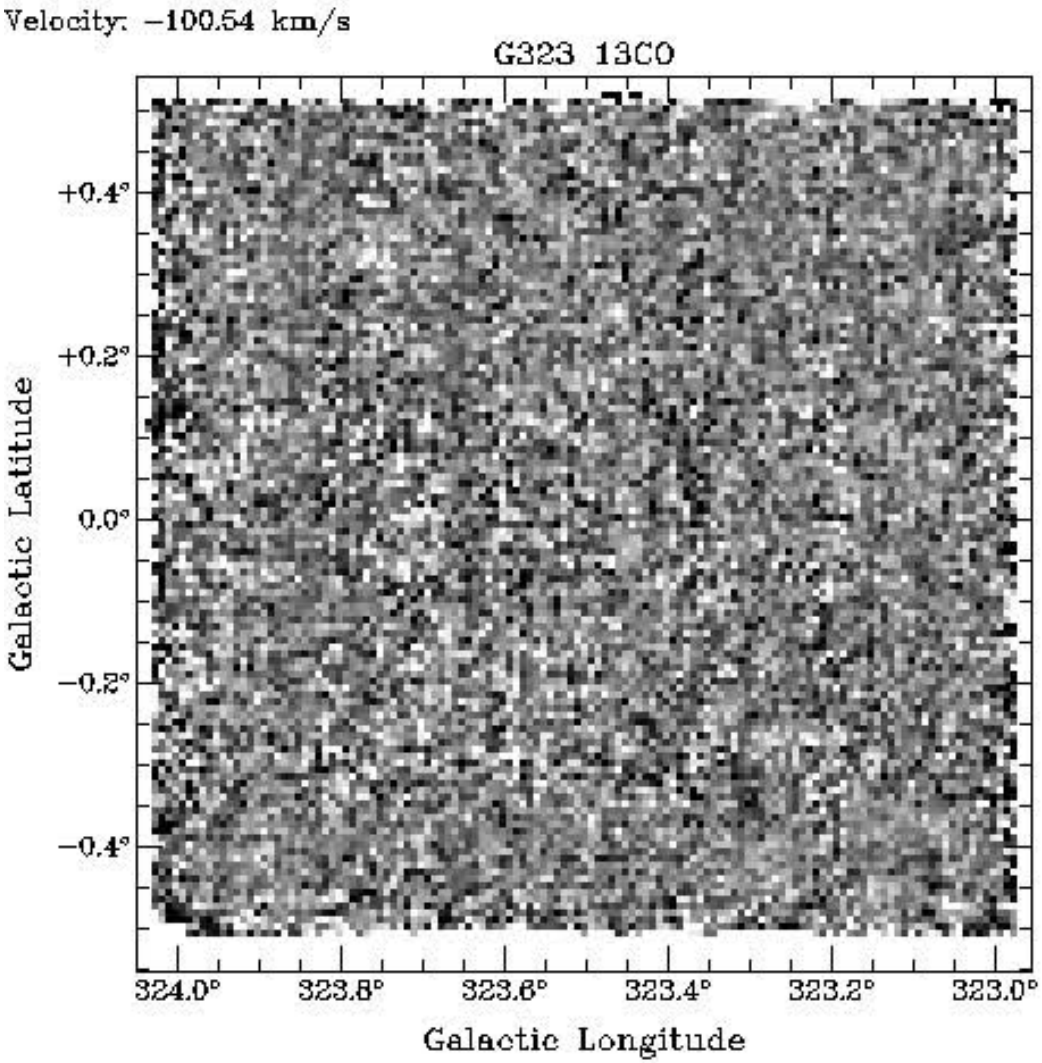
330°

323°

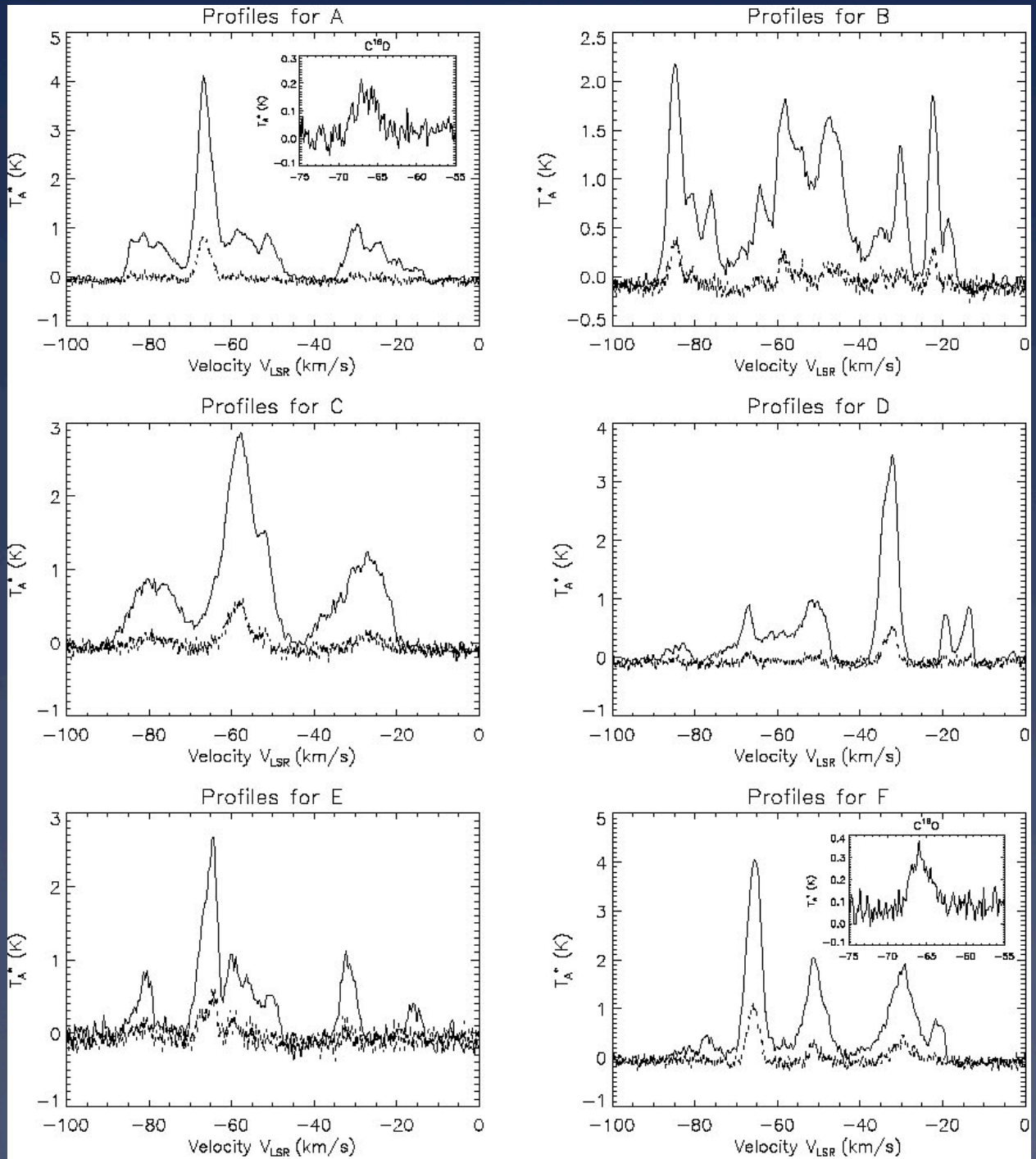
-100 km/s
to
0 km/s

G323 1°x1° ^{12}CO + ^{13}CO J=1-0





CO Lines Profiles



^{12}CO
^{13}CO
$C^{18}O$

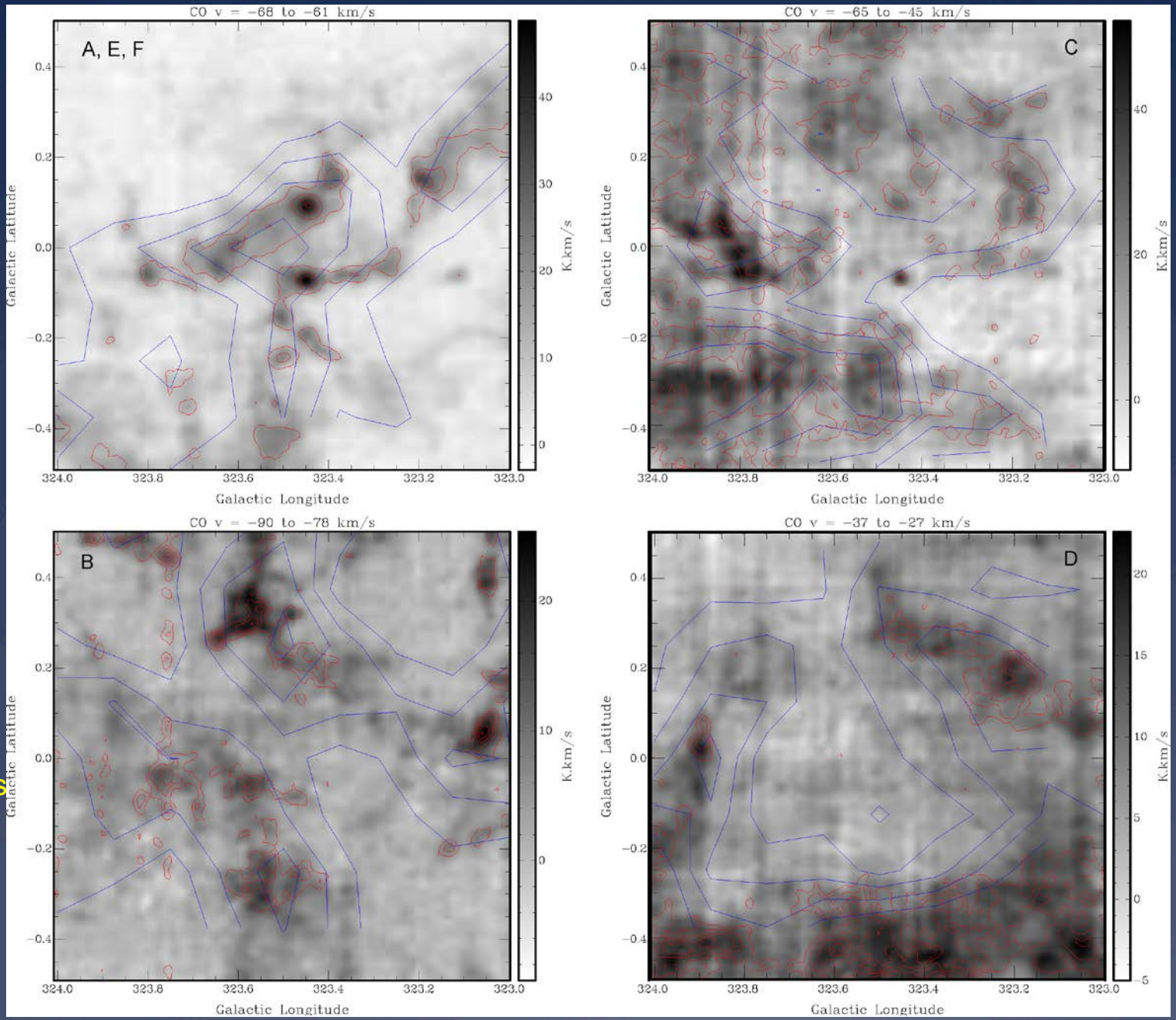
G323: Mopra CO *vs.* Dame et al.

-68 to -61 km/s

-65 to -40 km/s

-90 to -78 km/s

-37 to -27 km/s



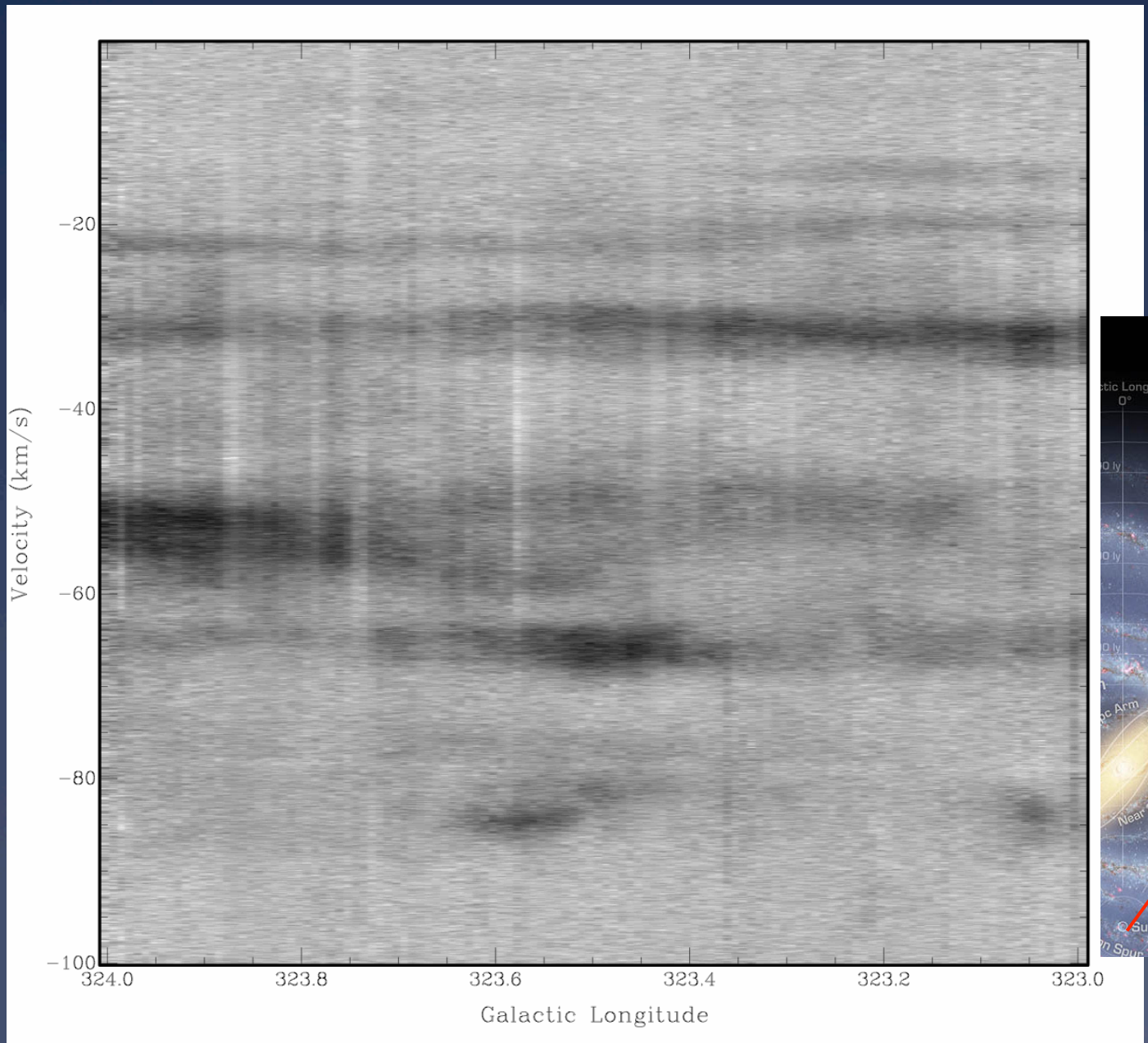
G323: Position – Velocity diagrams

Spiral Arms

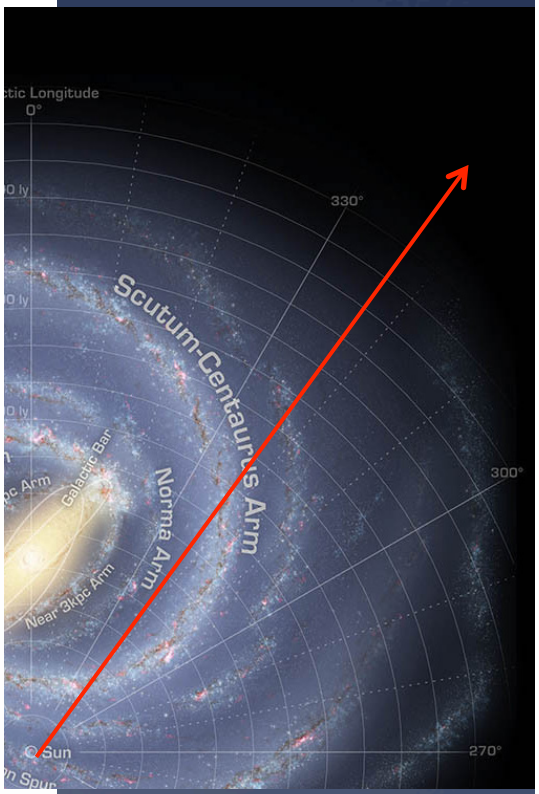
Sag - Carina

Scutum - Crux

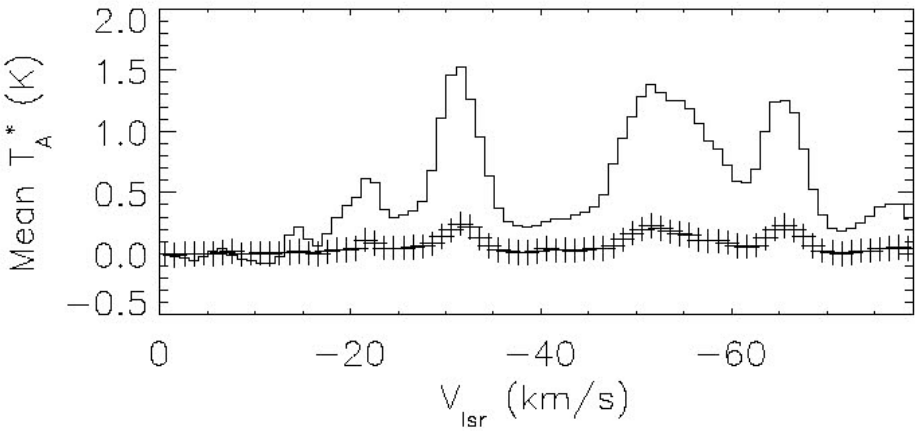
Norma - Cygnus

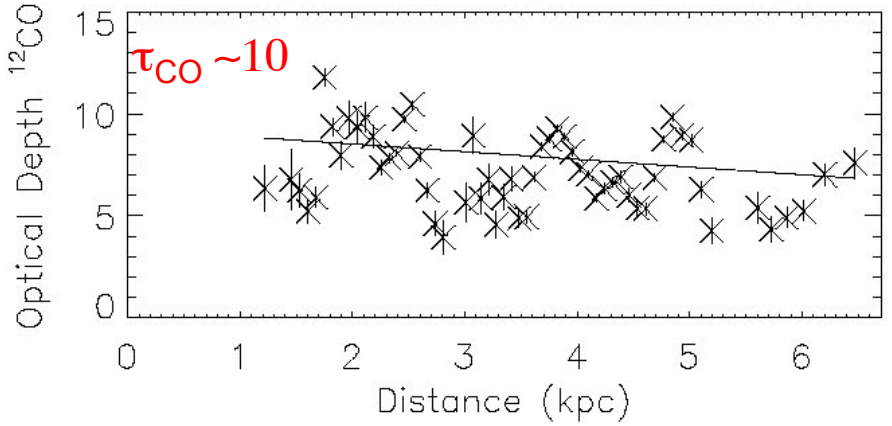


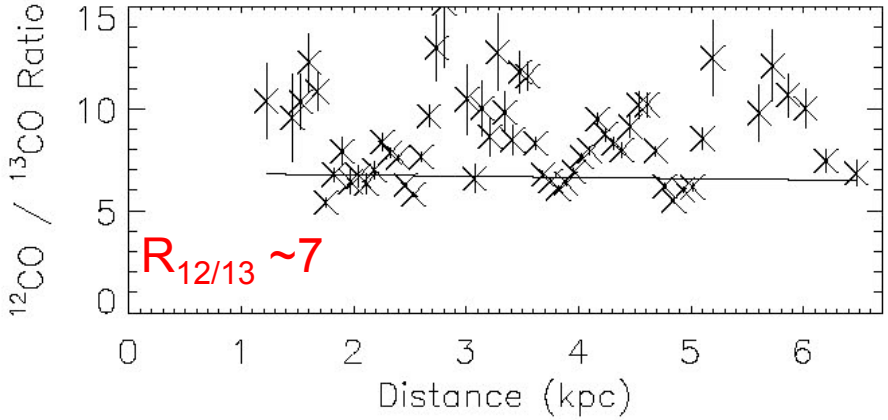
[Scutum - Crux]

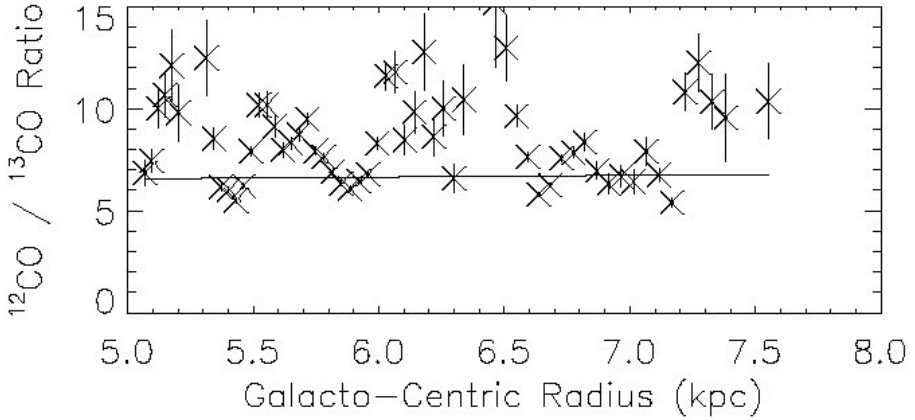


^{12}CO / ^{13}CO Line Ratios and Optical Depth

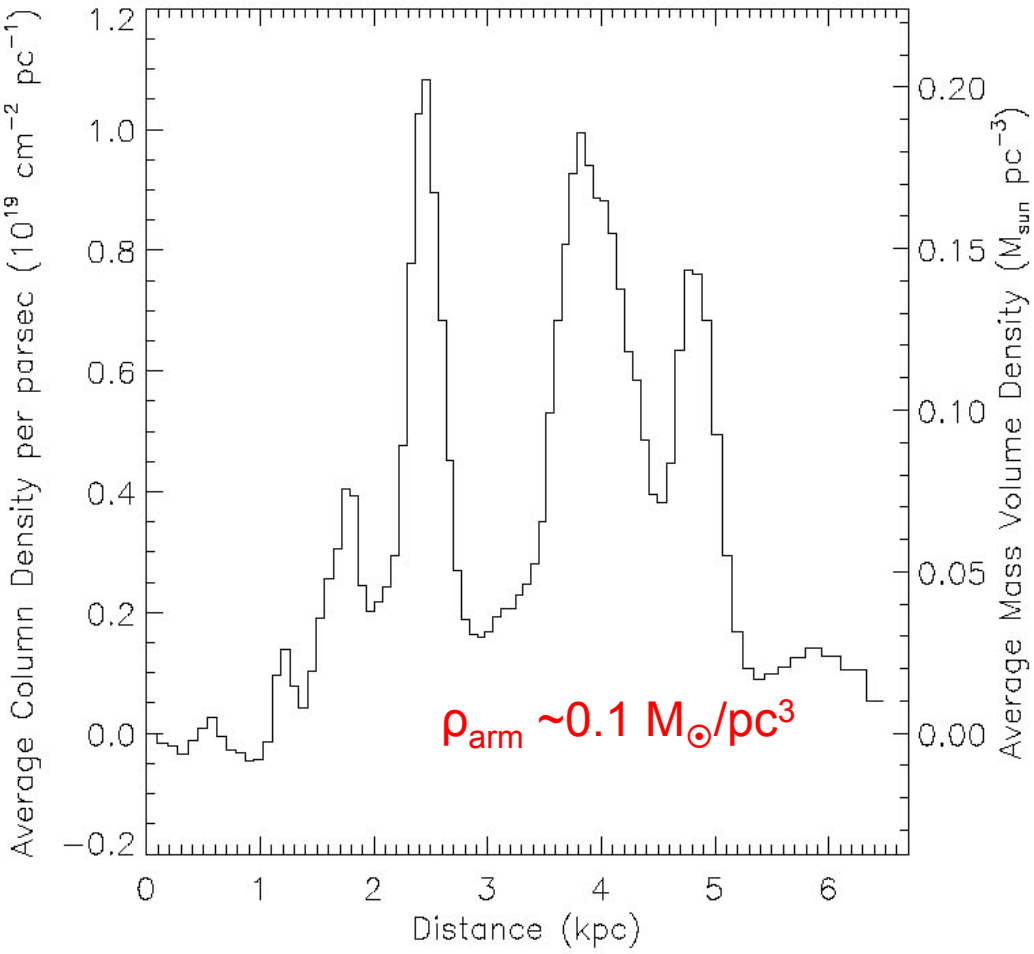


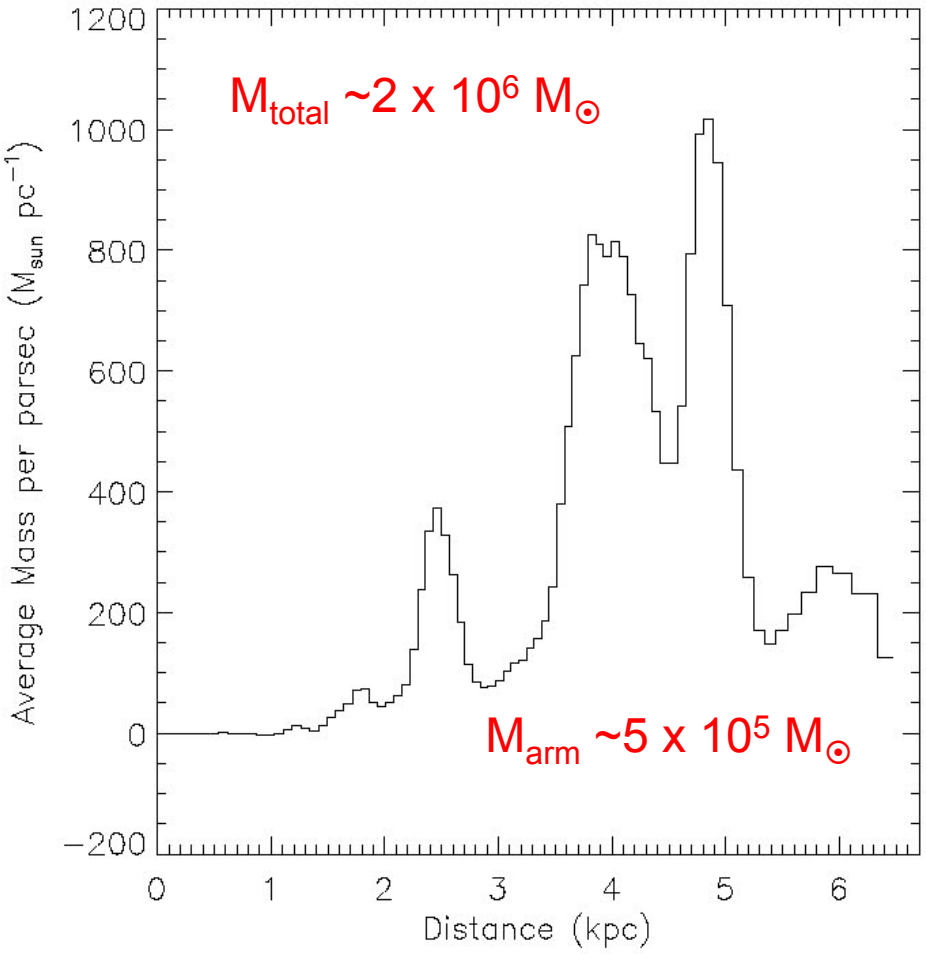


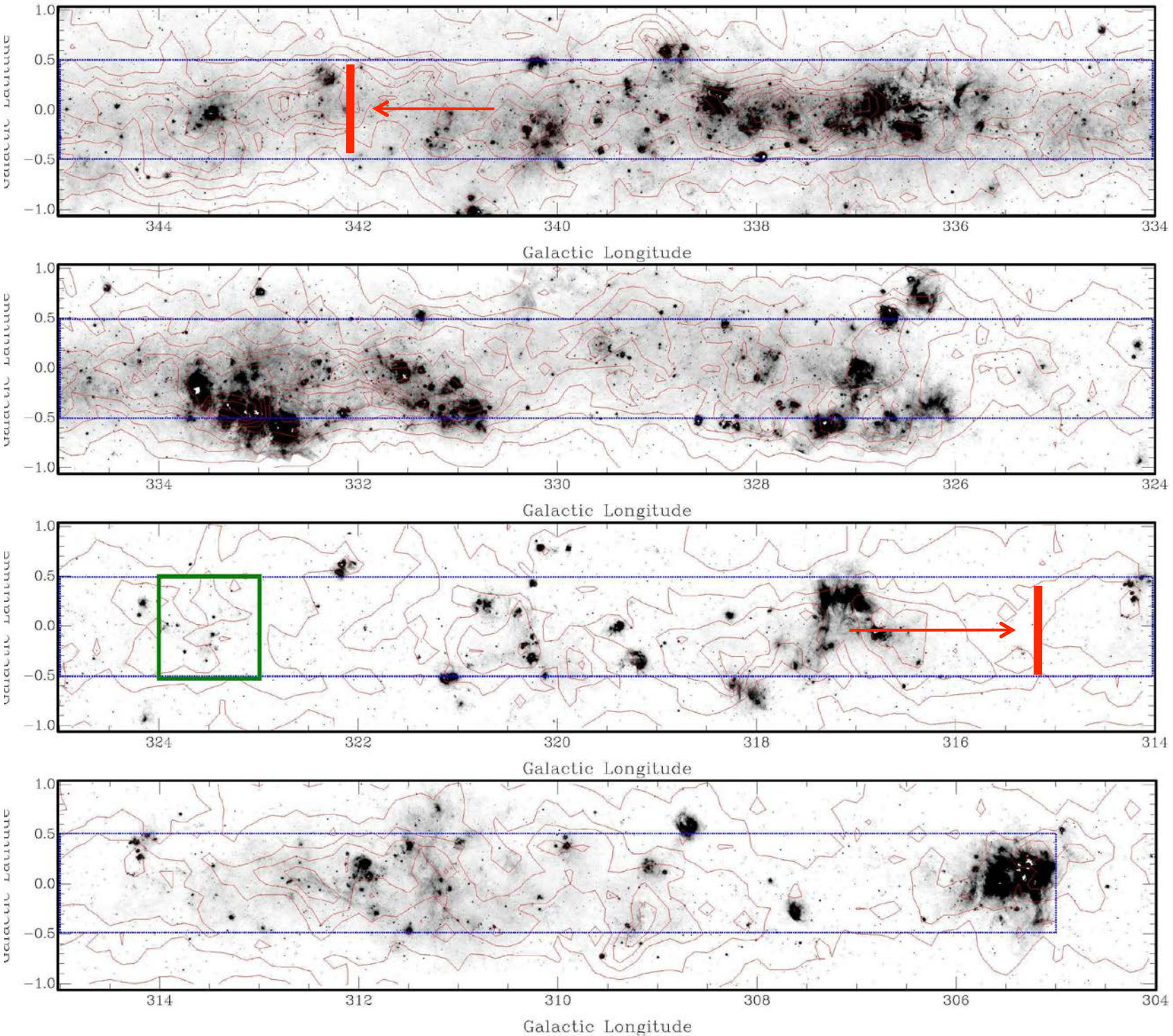




Molecular Mass Distribution at *l*=323°







Survey Region

Available on the ATNF online archive atoa.atnf.csiro.au

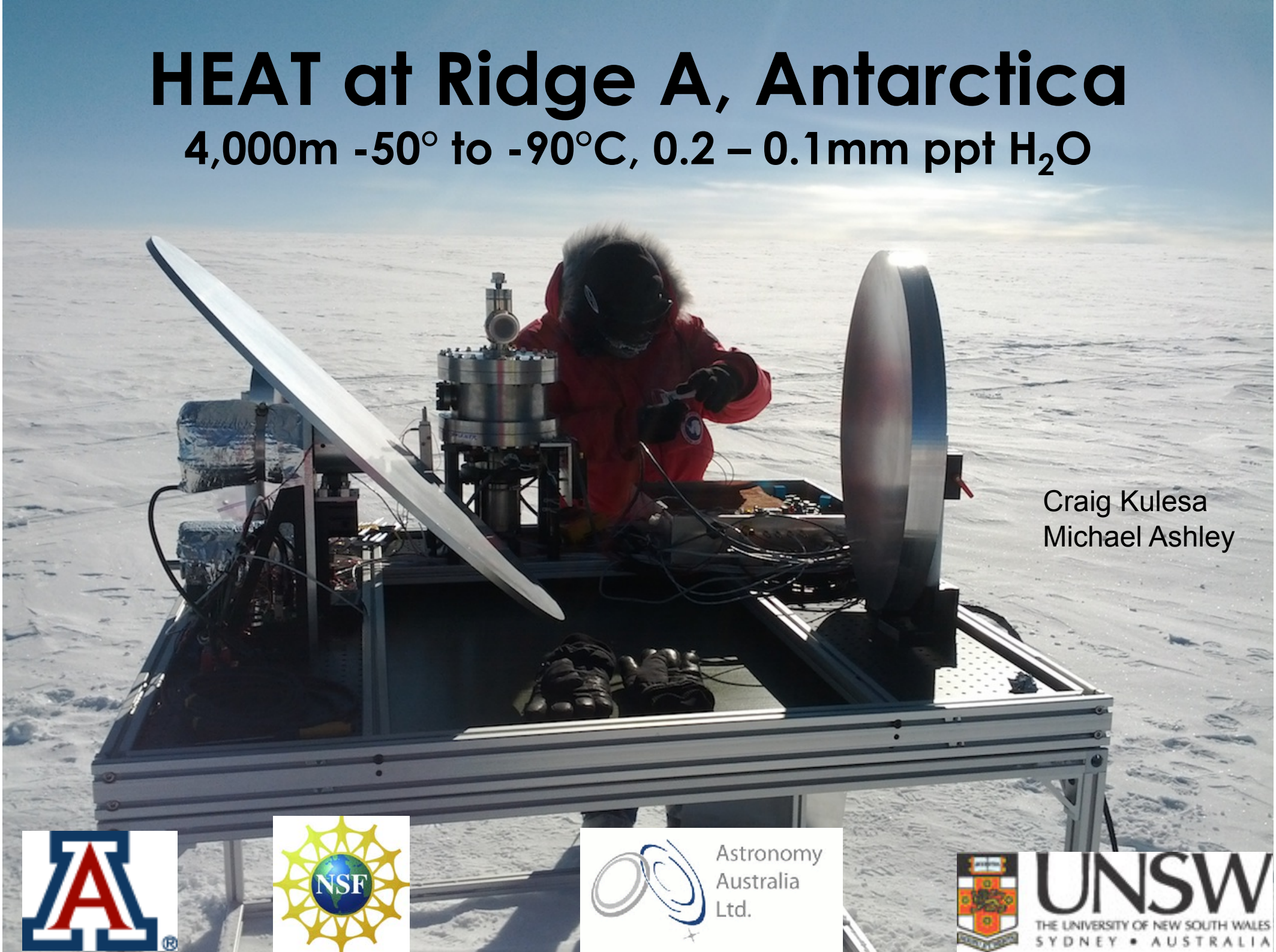
4. HEAT

THz Astronomy in Antarctica

with special thanks to Craig Kulesa and Michael Ashley

HEAT at Ridge A, Antarctica

4,000m -50° to -90°C, 0.2 – 0.1mm ppt H_2O

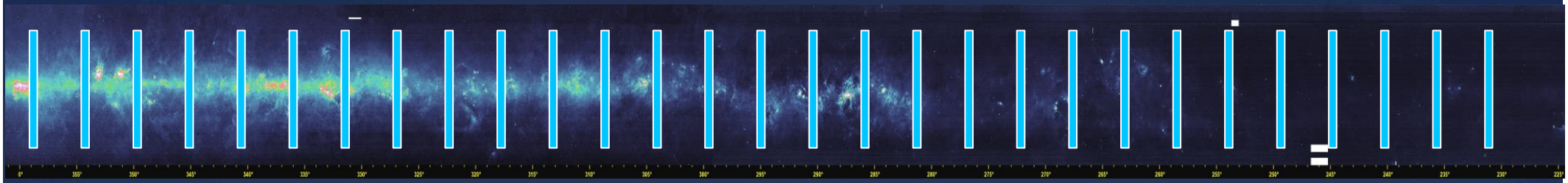


Craig Kulesa
Michael Ashley

Astronomy Australia Ltd.

UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY • AUSTRALIA

Galactic Plane [CI] Survey



61cm off-axis telescope, 492+810 GHz receiver, 1.5 GHz wide FFT spectrometer, inside thin-film radome, fully robotic – serviced yearly!

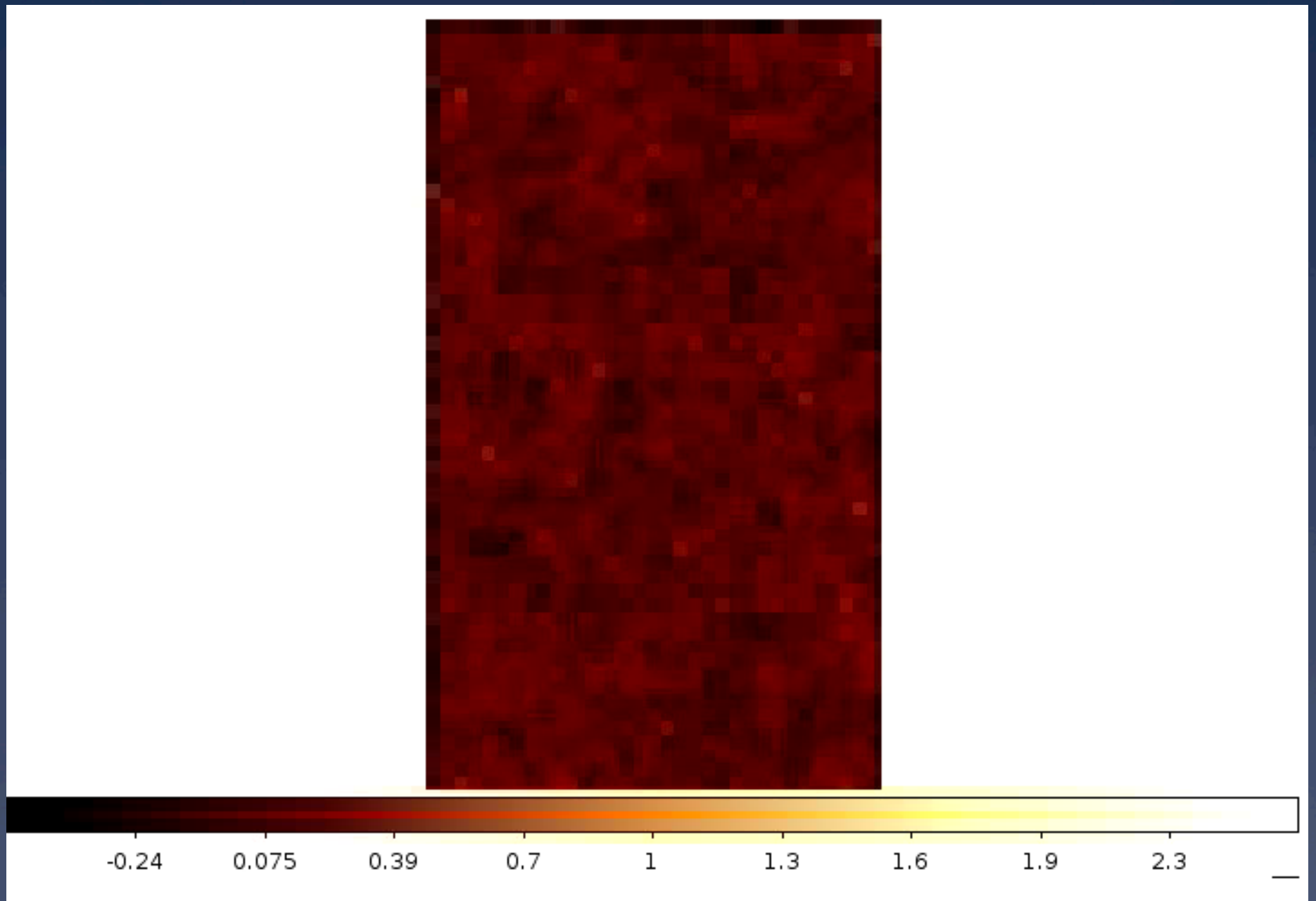
THz observatory operating with just 150W of power! 50K receivers.

Drift scanning: any point on the sky is seen for only 5-15 seconds per day, so tens of days of observations are needed to achieve desired SNR

Strip maps slicing through Galactic Plane from *l*=290^{o} to 330^{o}

2 arcmin spatial + 1 km/s spectral resolution.

G328 [CI] 809 GHz Movie



G328 Filament

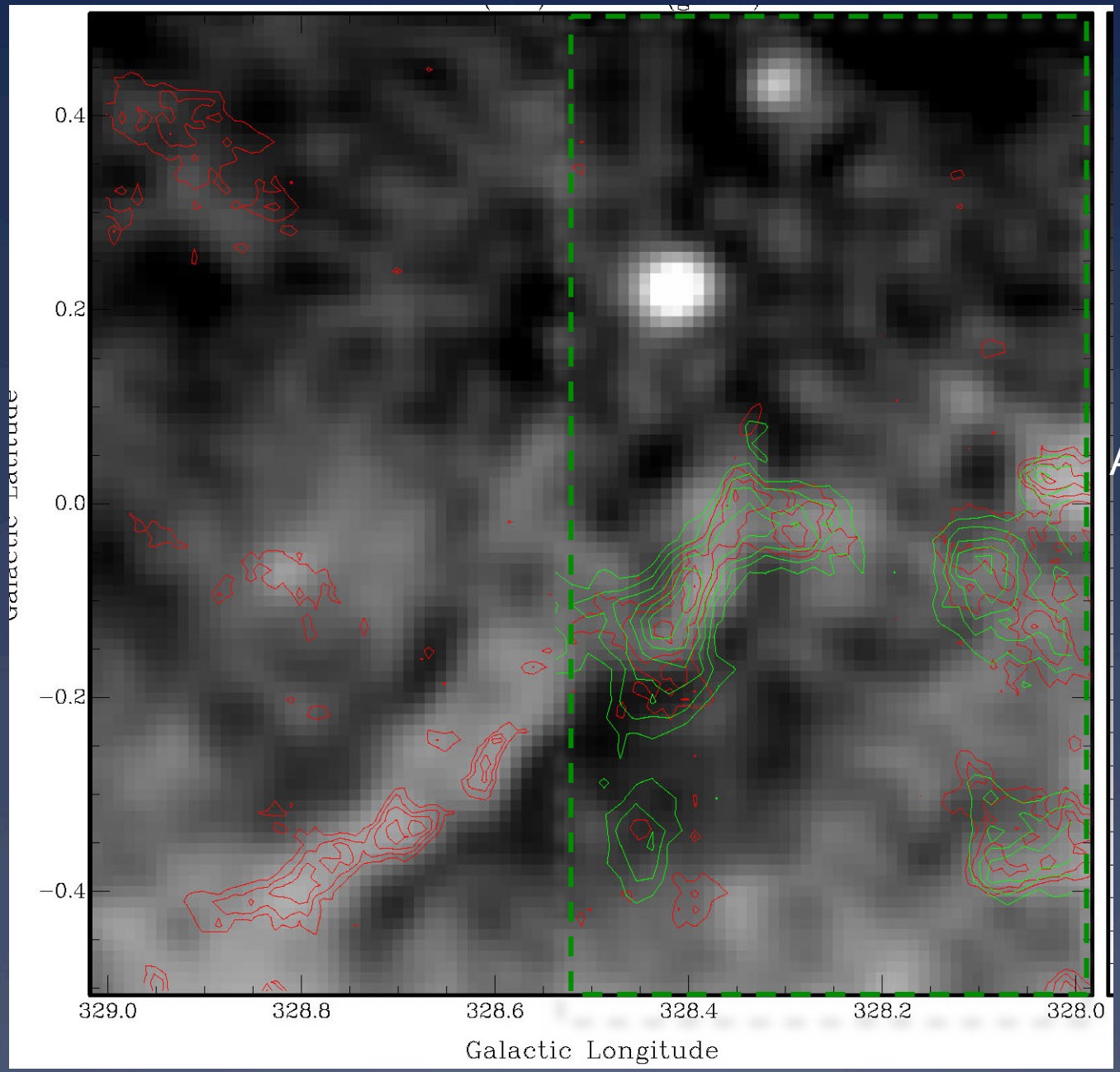
Quiescent:
v=-75 to -79 km/s

No far-IR dust

No Star Formation

[C/CO] ~ 1

HI Image
(HISA)



Burton et al
2013
ApJ submitted

4 x 10^4 $M_\odot$ 75pc-long CO + CI filament (red green contours) @ 5kpc within HI self-absorption?


Thank-you!