The Mopra Southern Galactic Plane CO Survey

www.phys.unsw.edu.au/mopraco

PASA (Publications of the Astronomical Society of Australia), 2013, 30, e044 (Burton et al.) + 2015, in-press (Braiding et al.)

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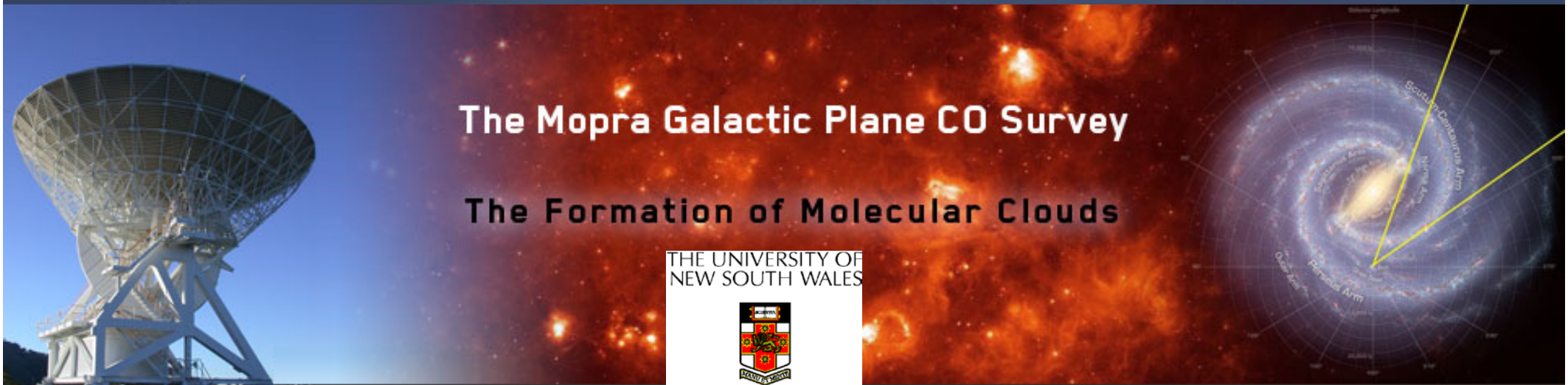
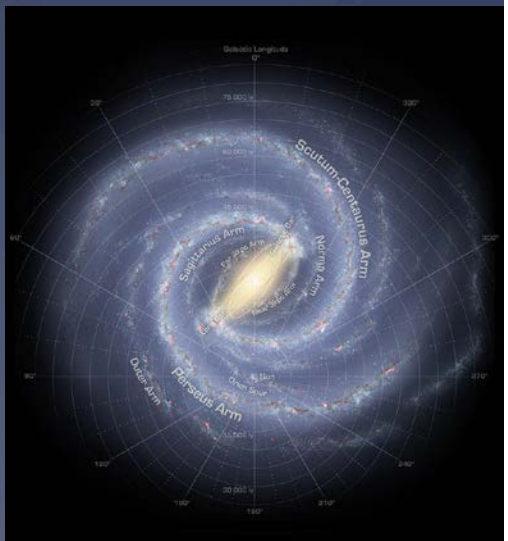
Jürgen Stutzki, Robert Simon, Christian Glück, James Urquhart (Germany)
+ more Adelaide and UNSW students to come....

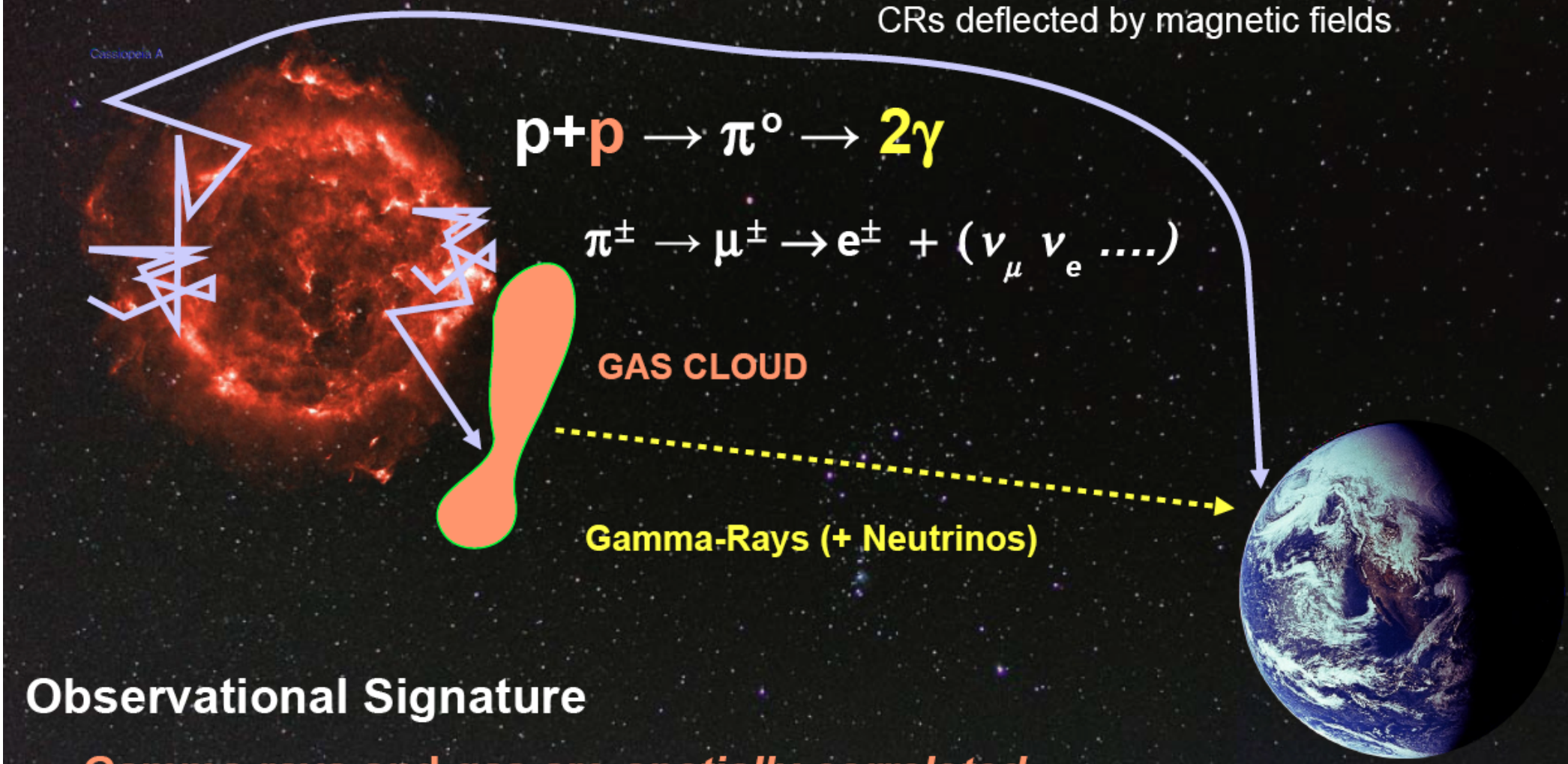


Outline

1. Molecules and TeV Gamma-rays
   - What's the connection?!
2. Radio telescopes and interstellar gas
   - Mopra + Nanten2 + Parkes + ATCA + ASKAP + HEAT ...
3. The Mopra Southern Galactic Plane CO Survey
4. The future of Mopra?



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

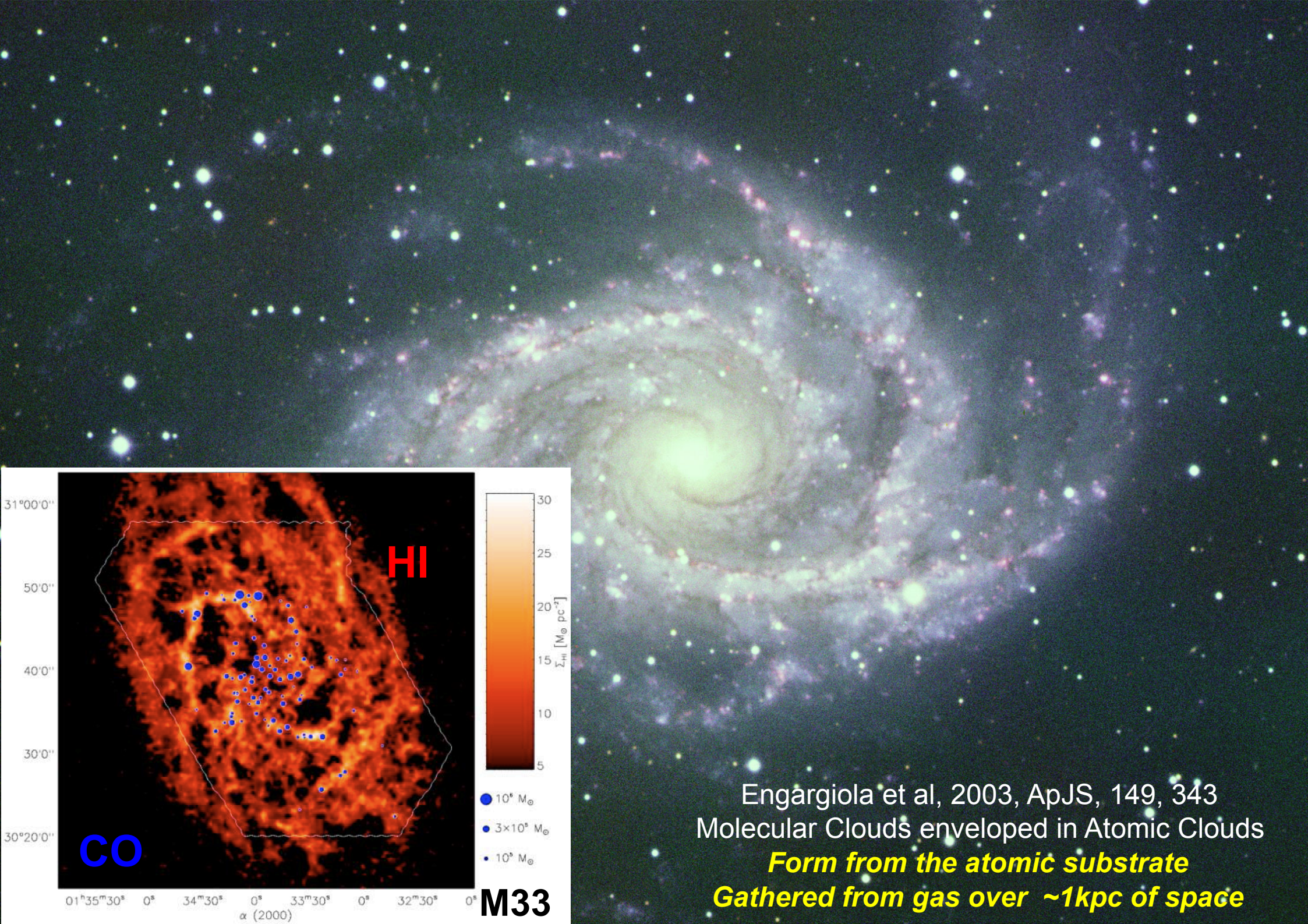


Observational Signature

→ Gamma-rays and gas are *spatially correlated*

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

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



Engargiola et al, 2003, ApJS, 149, 343

Molecular Clouds enveloped in Atomic Clouds

Form from the atomic substrate

Gathered from gas over ~1kpc of space

H

Parkes + ATCA
SGPS – **HI 21cm**
McClure-Griffiths et al. 2005

GASKAP
Dickey et al.

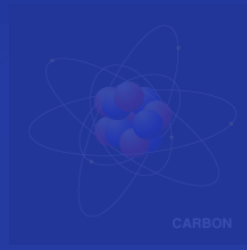
H_2 → CO

1.2m Columbia
New York + Chile
Dame et al 2001.
CO J=1-0 2.6mm

22m Mopra

4m Nanten2 (Fukui)

Dark Gas → C



60cm HEAT
Ridge A, Antarctica
[CI] 2-1 0.37mm
(Ashley)

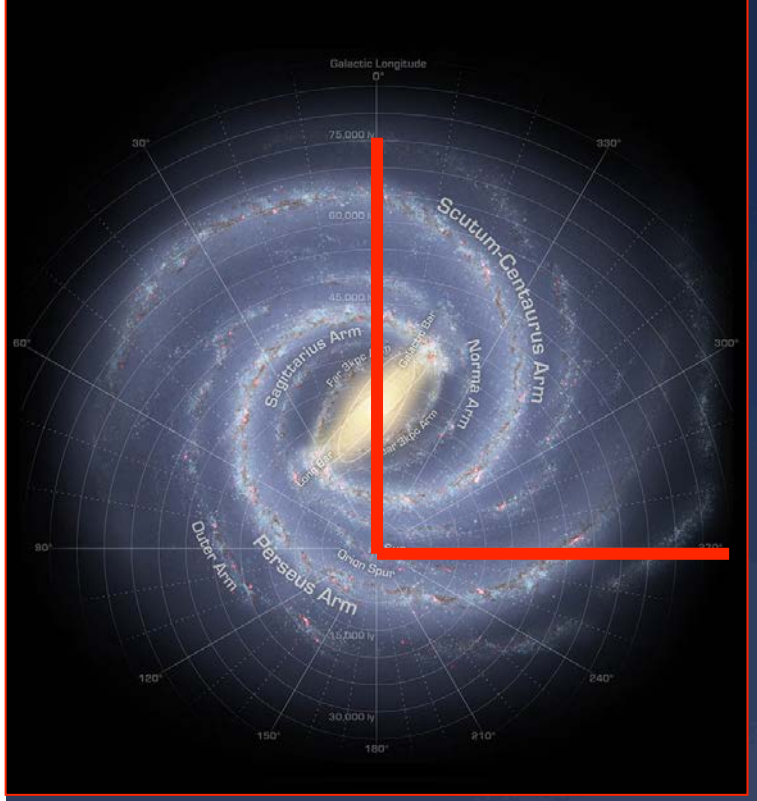
60cm STO-2

5m DATE5

Mopra Telescope MM Capabilities

- 22-m Telescope for long-wave mm astronomy
  - 3mm + 7mm + 12mm
- 77–116 GHz MMIC receiver (2.5-4 mm)
- 30-50 GHz receiver (5-10mm)
- 16-25 GHz receiver (12-18mm)
- Bandwidth 8 GHz: UNSW-MOPS correlator
  - Broad Band 32,000 channels, 0.8 km/s resn.
  - 16 Zooms modes over 137 MHz
    4096 channels/zoom, 0.1 km/s@3mm
- 2 Polarizations (i.e. 64,000 channels)
- "Fast-On-the-Fly" (FOTF) Mapping

- User-pays operation:
  - UNSW/Adelaide + NAOJ 3-year contract
  - Due to close at end of 2015!

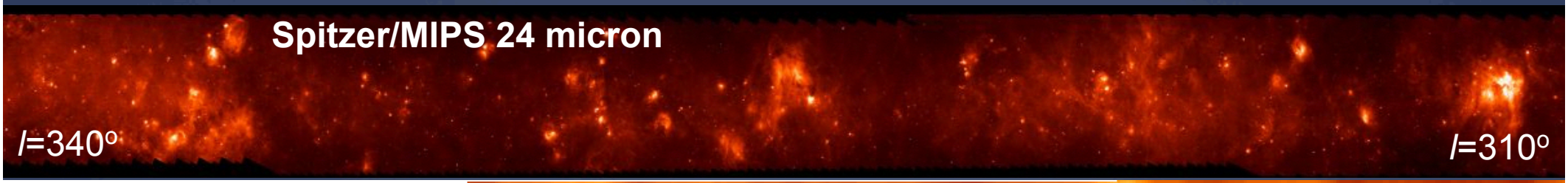


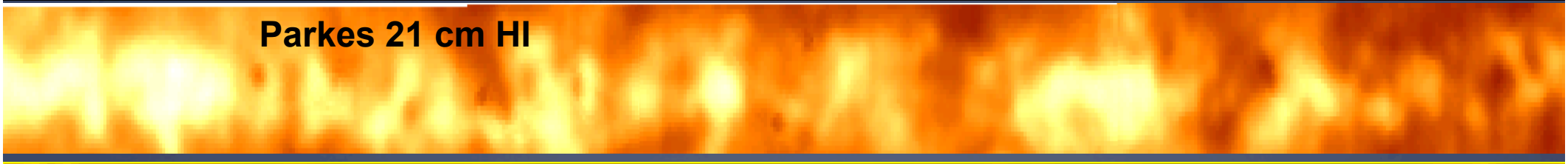
The Mopra CO Survey

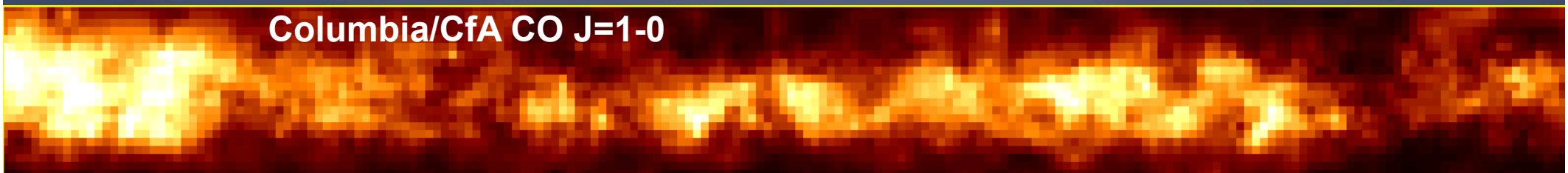
The 4th Quadrant

l=270º – 360º, |*b*|<0.5°

Includes three spiral arms and the Central Molecular Zone

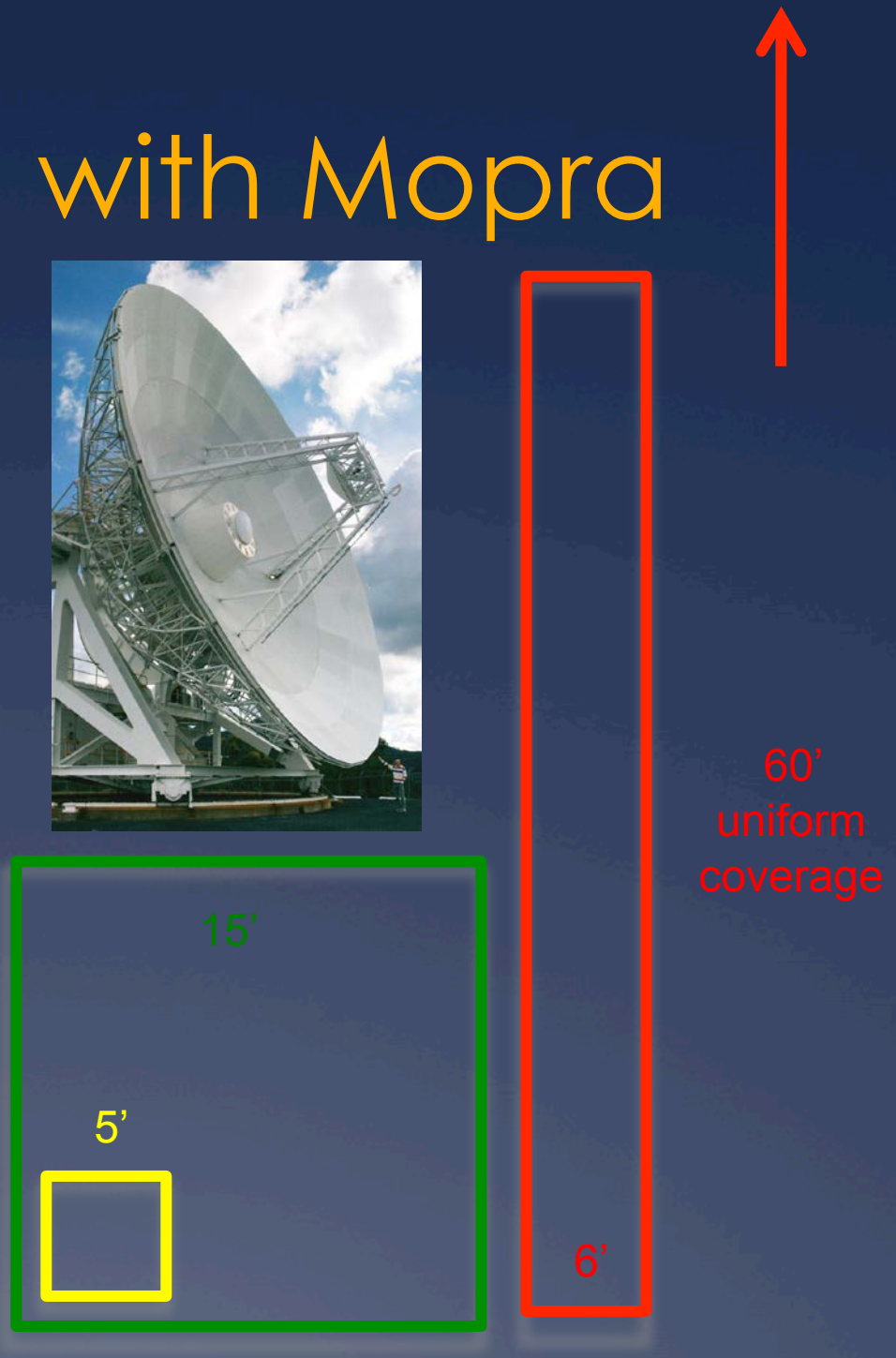






Fast Mapping with Mopra

- 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

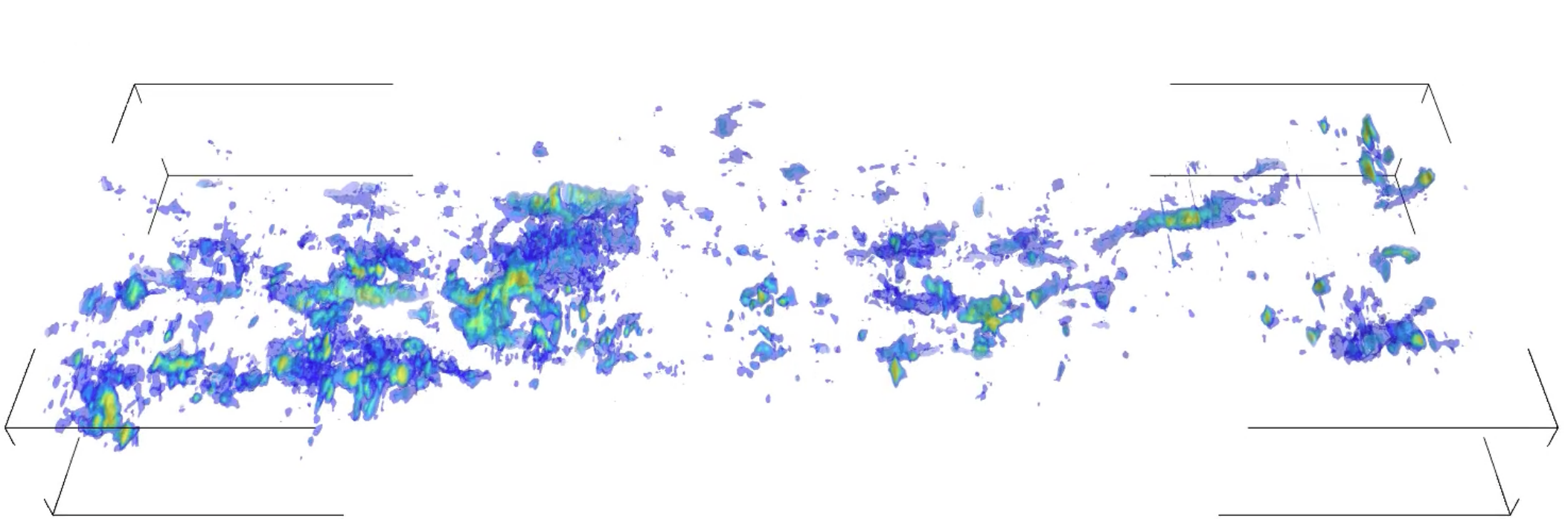
0.6’ Beam @ 0.1 km/s resolution

~4 shifts per 1°x1° block (|b|<0.5°)

An order of magnitude improvement in <u>both</u> spatial and spectral resolution than previous generation survey, and in three key lines, not one!

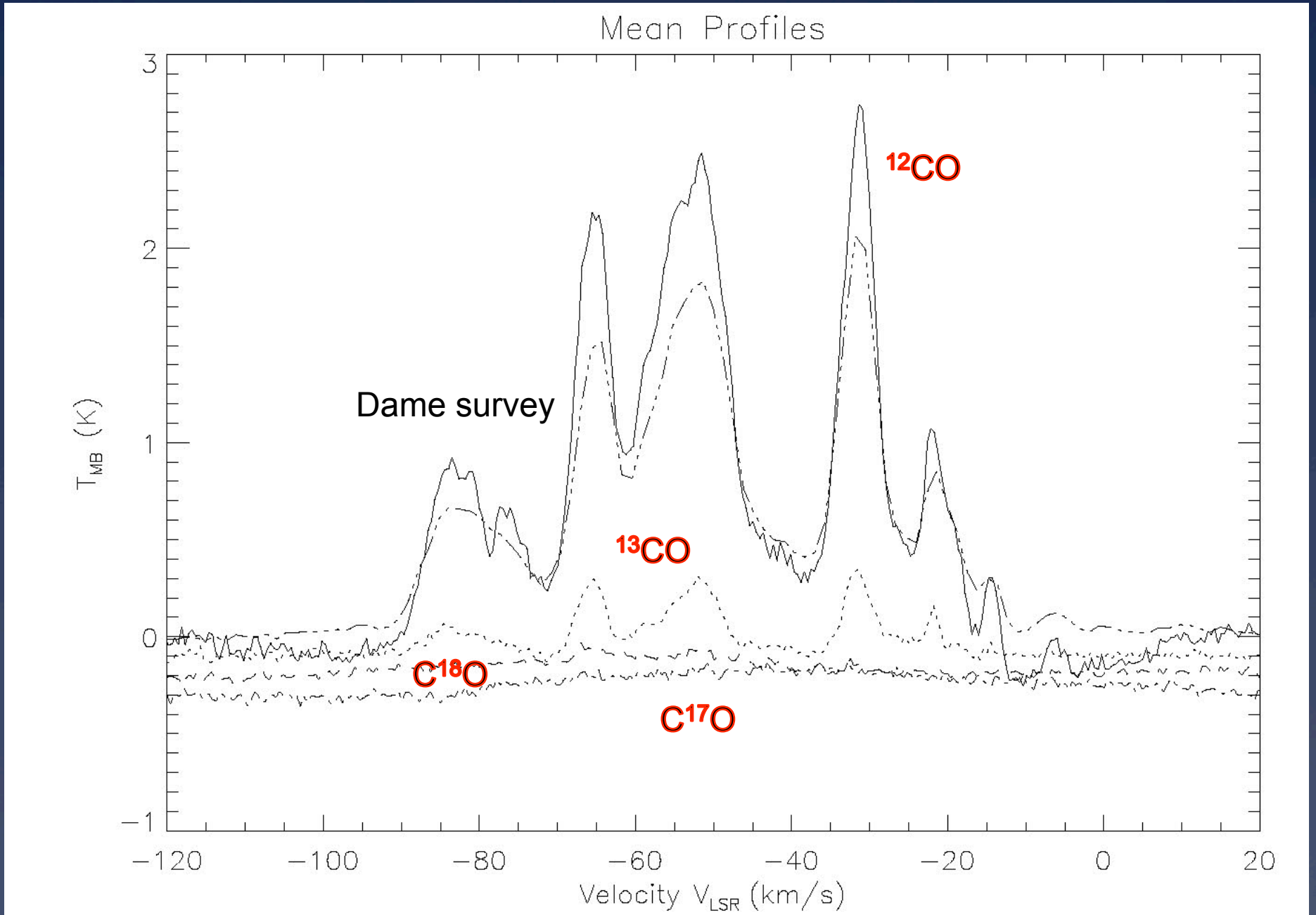
G320-330 ^{12}CO Rendering

longitude-latitude-velocity

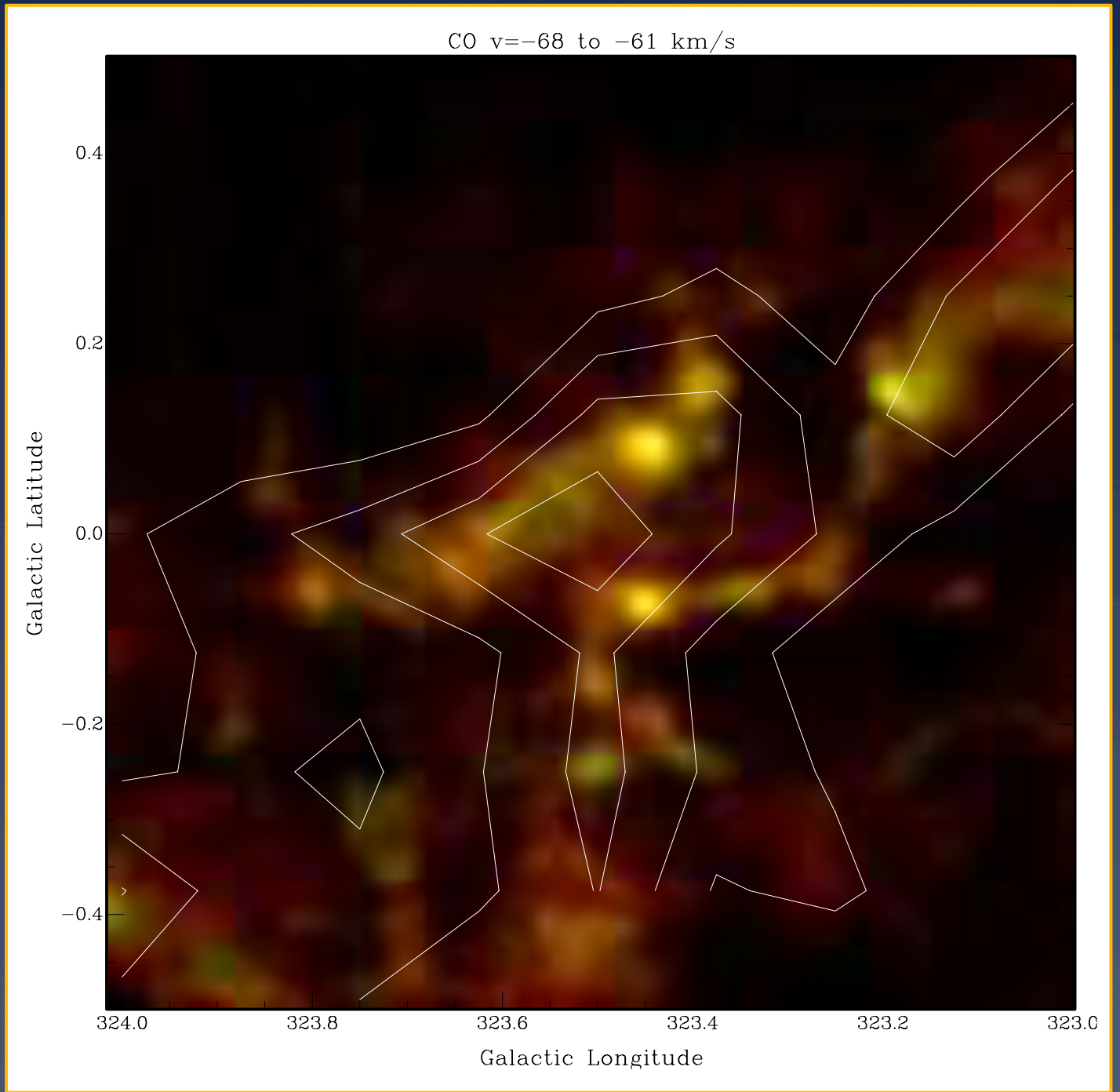


Thanks to Matthew Freeman

G323: Mean CO Profiles: 1°x1°

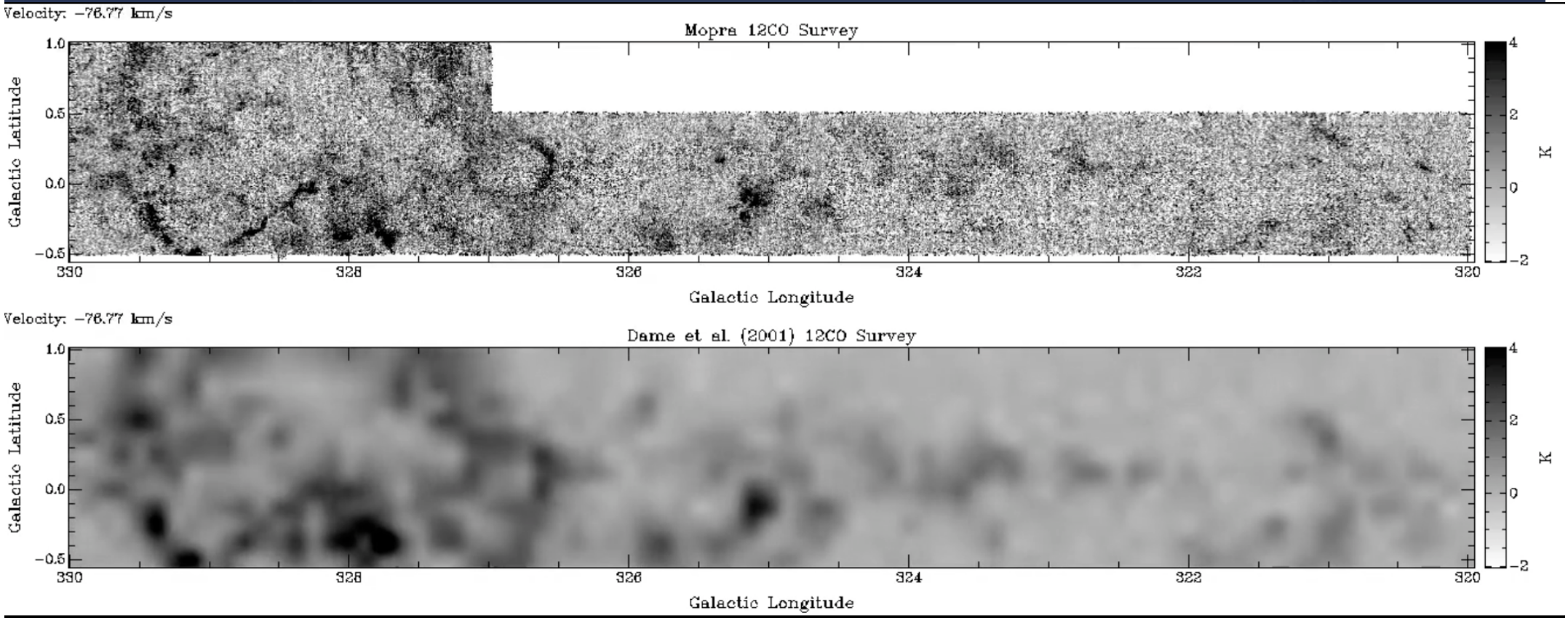


G323: ^{12}CO vs. ^{13}CO vs. Dame et al



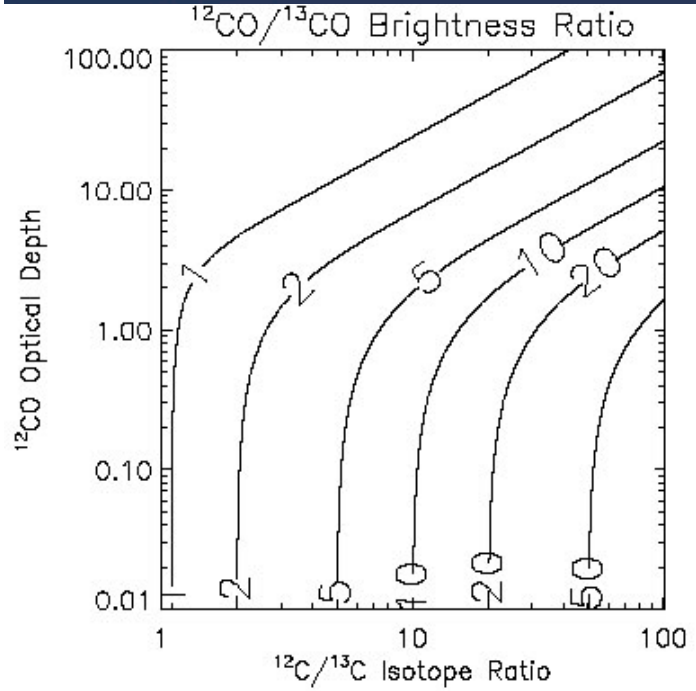
^{12}CO Mopra vs Columbia

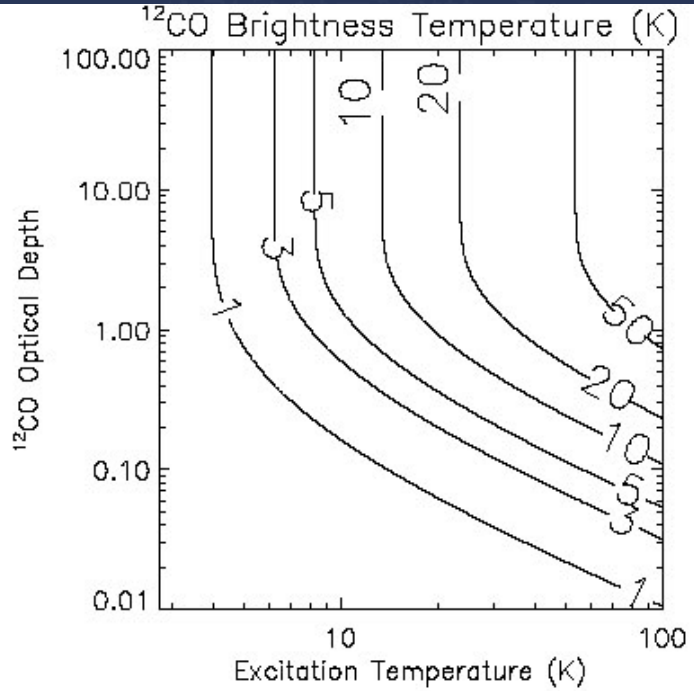
www.phys.unw.edu.au/mopraco

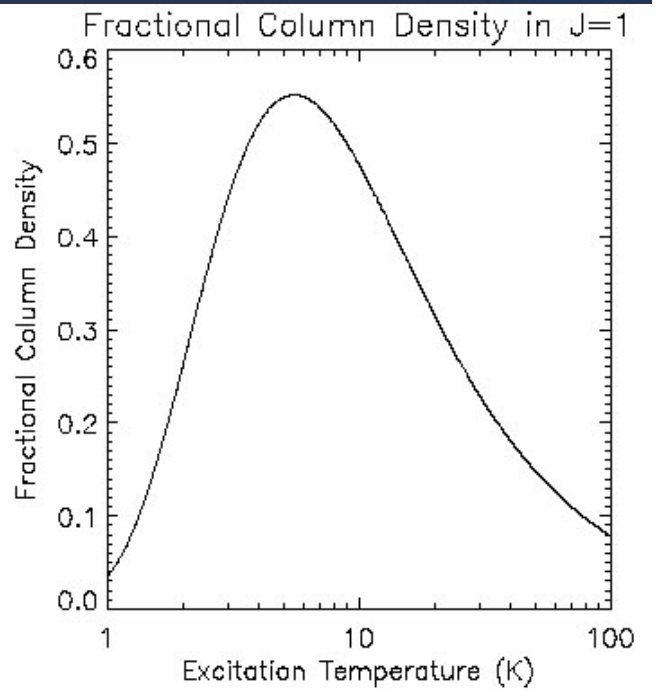


Interpreting CO Fluxes
i.e. why this is useful for CTA

Column Density





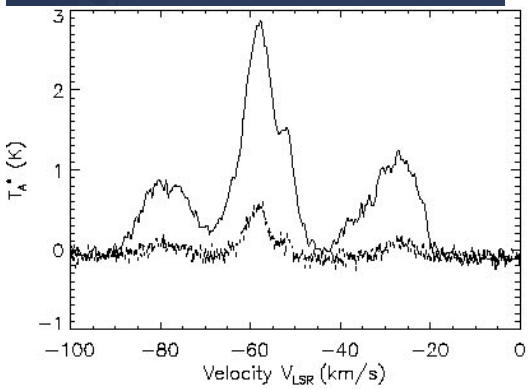


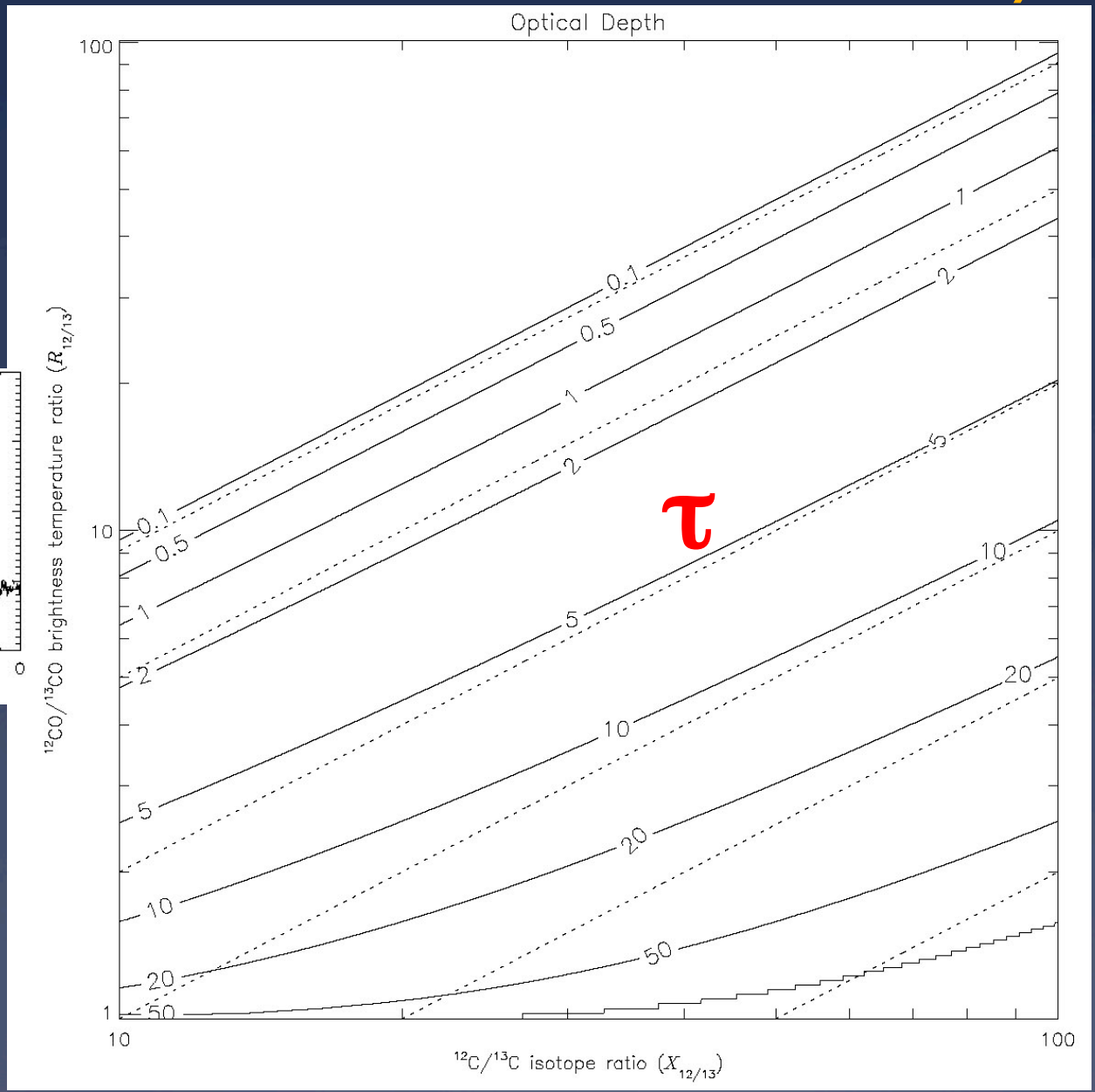
Need to know the optical depth and the isotopologue ratio to yield column densities

CO Optical Depth

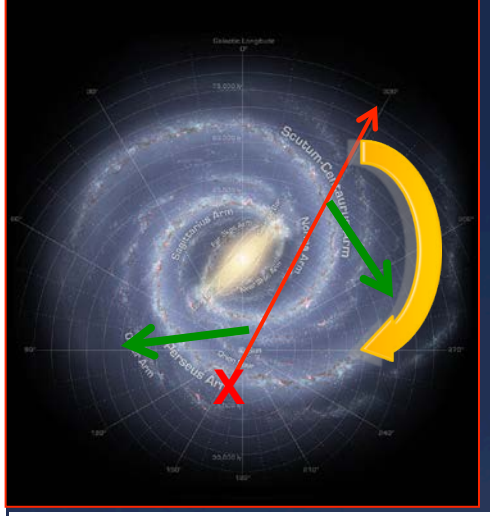
➔*Yields Column Density*

$^{12}CO/^{13}CO$ Observed Line Ratio





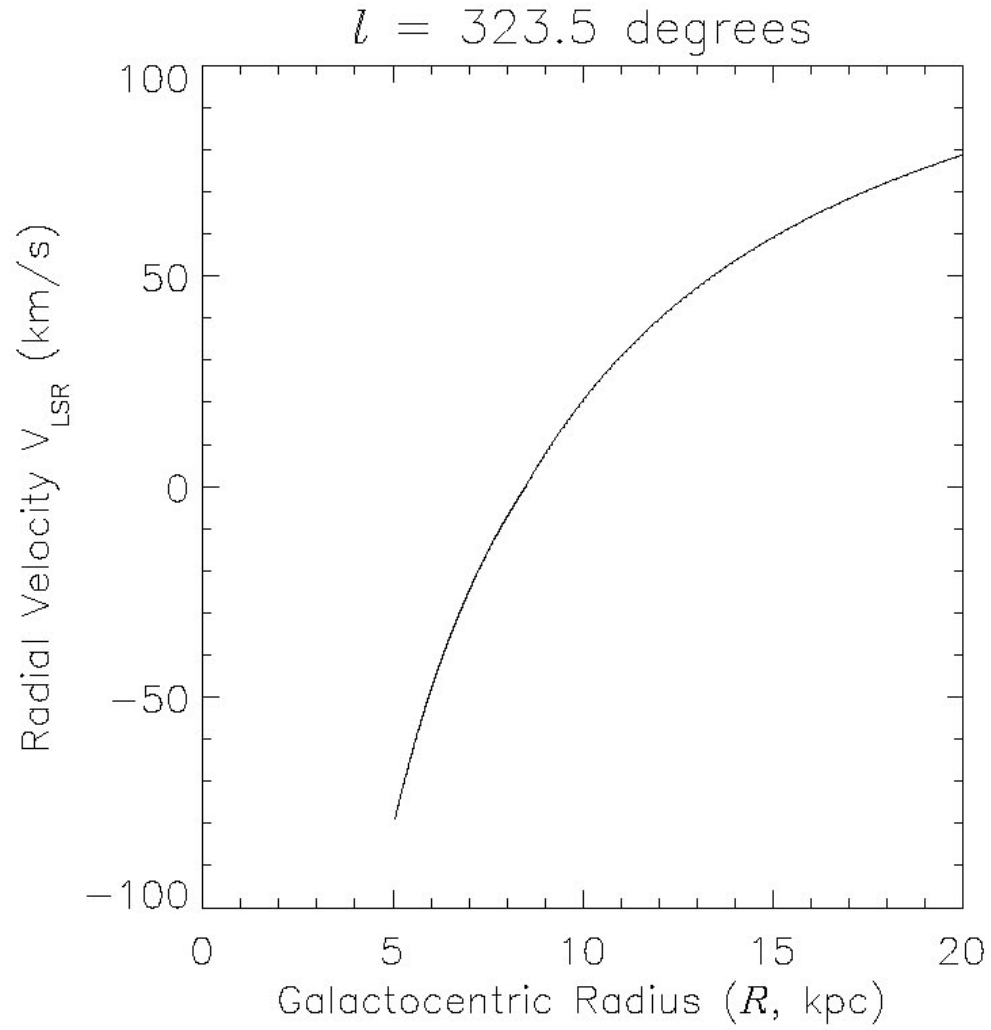
$[^{12}C/^{13}C]$ Intrinsic Isotope Ratio

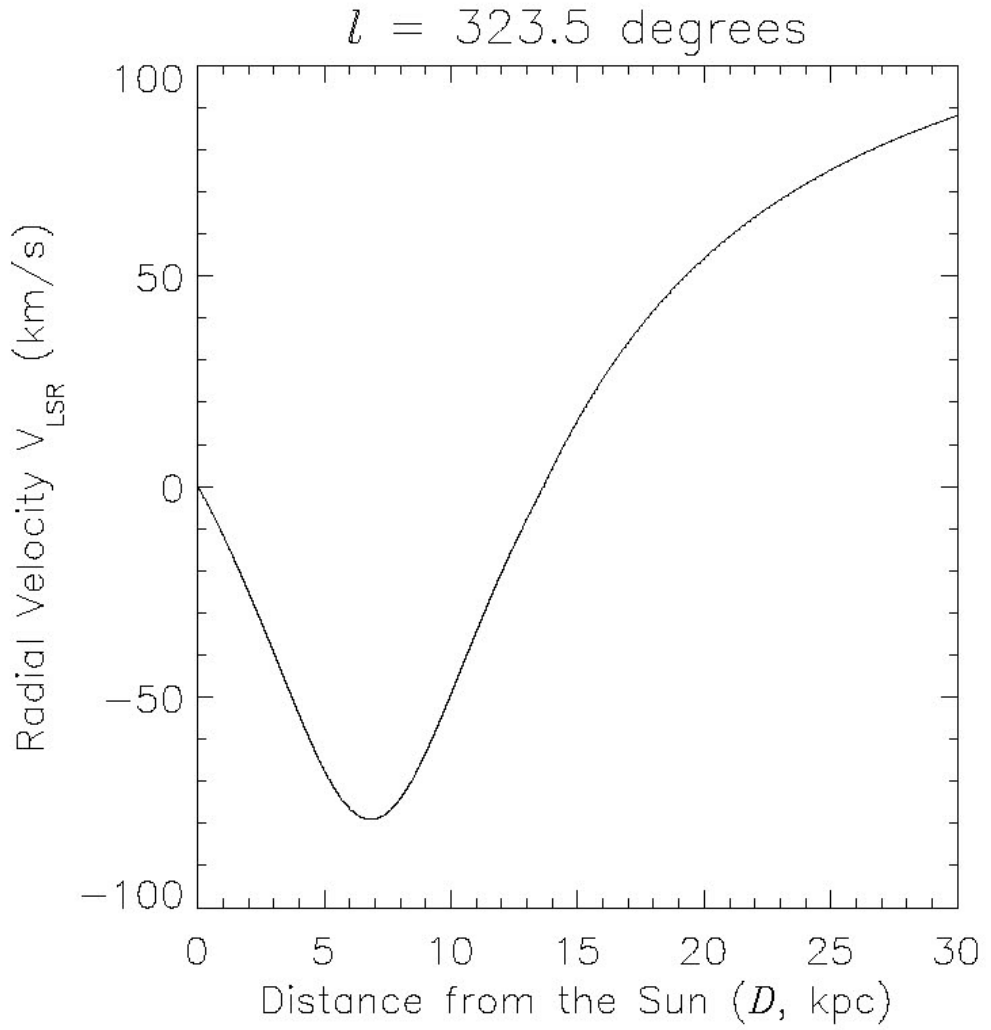


orbital motion

Galactic Rotation

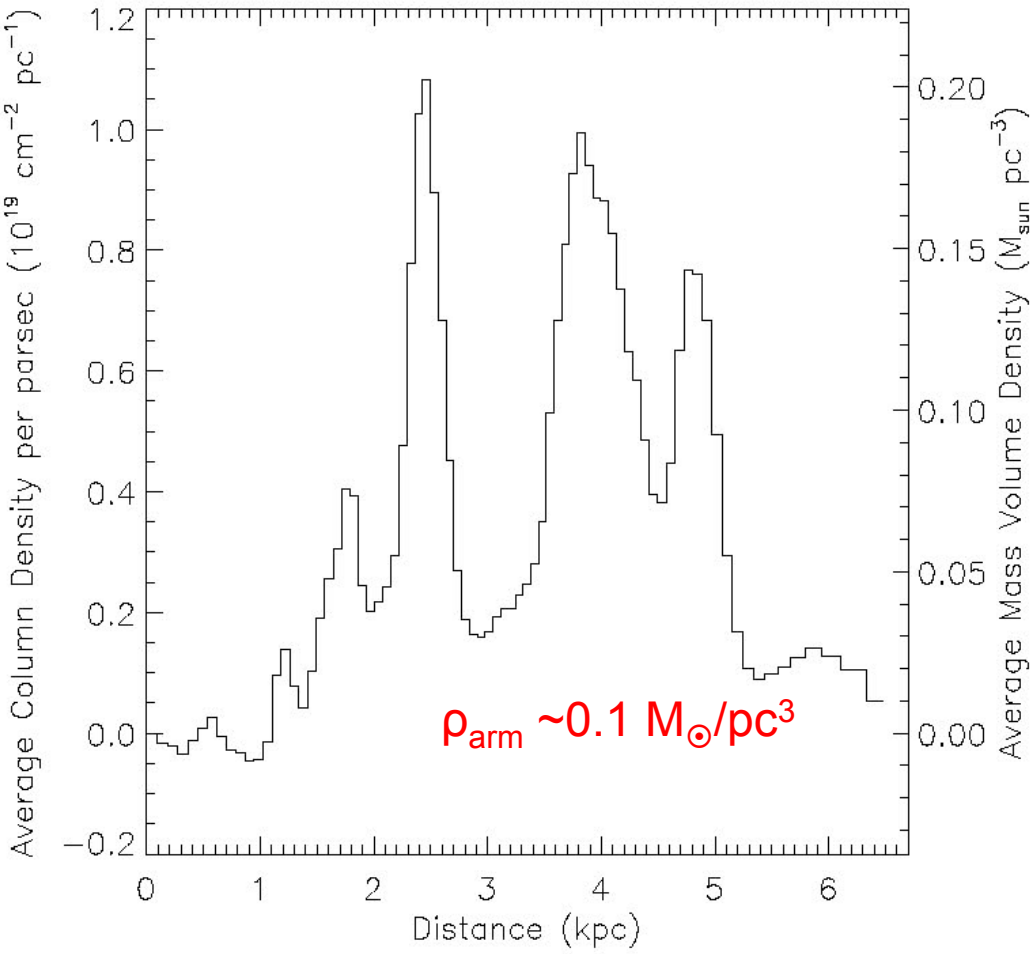
➔ *Yields Distance*

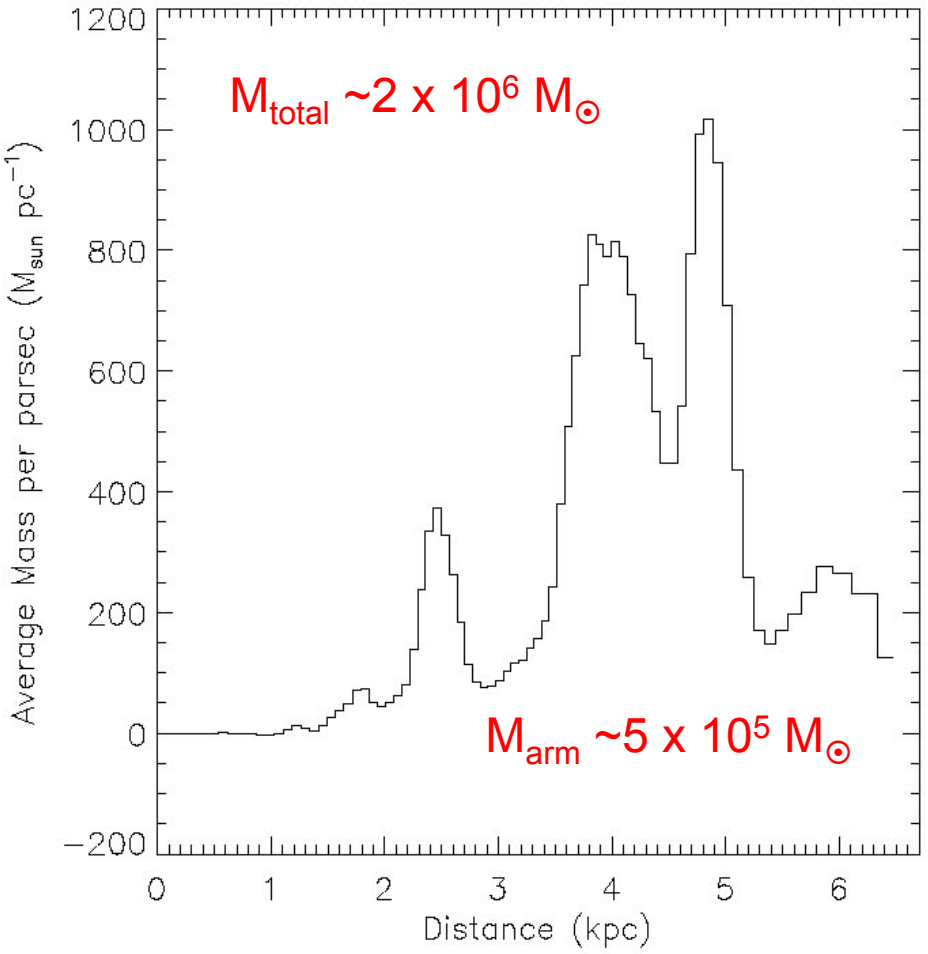




Molecular Mass Distribution at *l*=323°

Aim to produce a 3D galactic molecular mass distribution





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

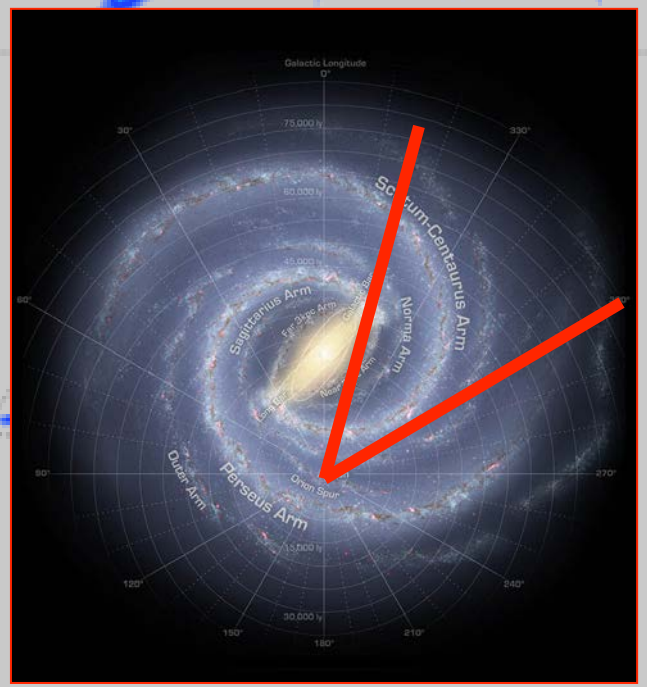
Nanten2

End of 2015? Mopra Consortium ➔ CTA

CMZ

Fourth Quadrant

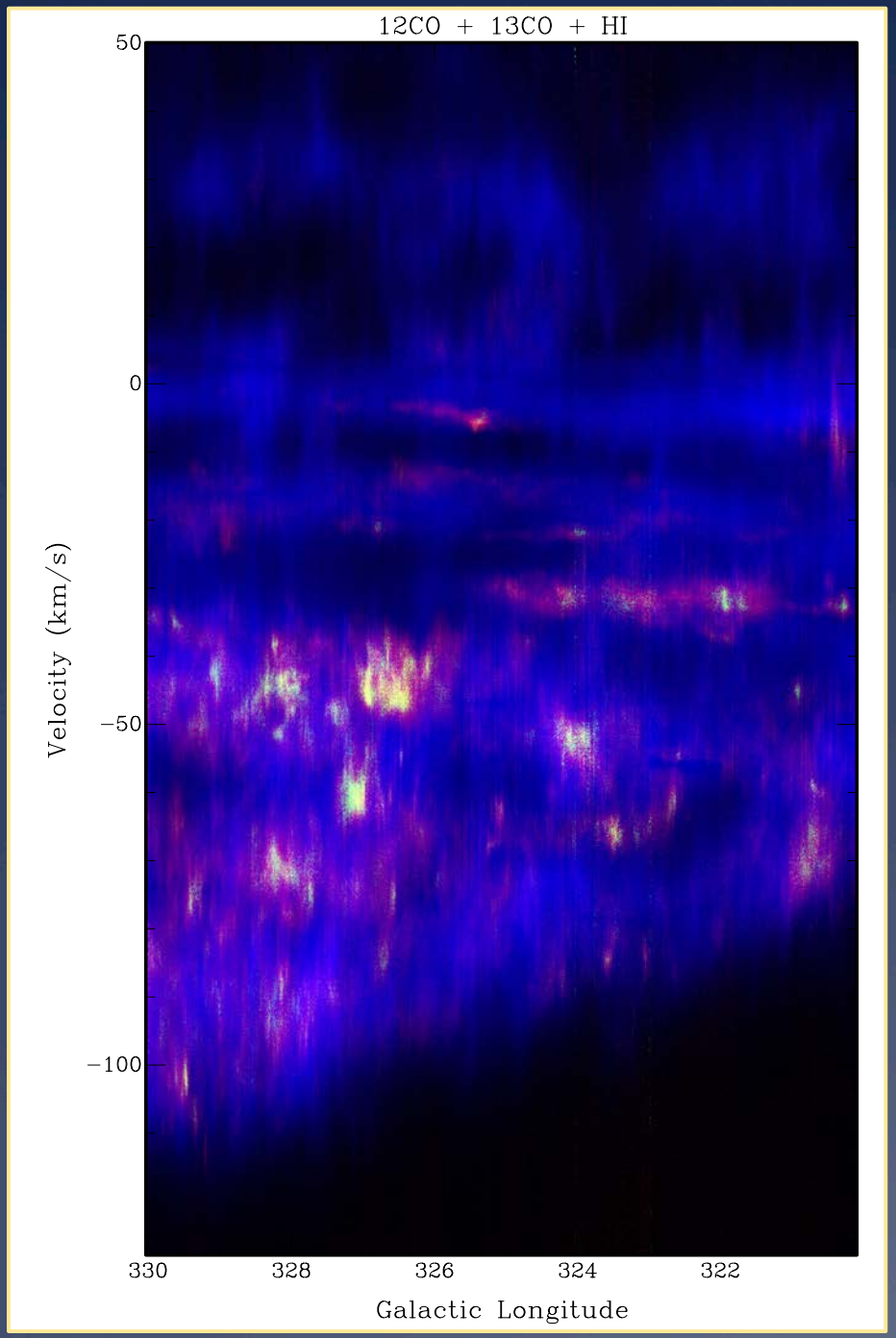
Carina



Status and Plans for Mopra Survey

0° 350° 340° 330° 320° 310° 300° 290° 280°

G320 - 330



12CO, 13CO, HI

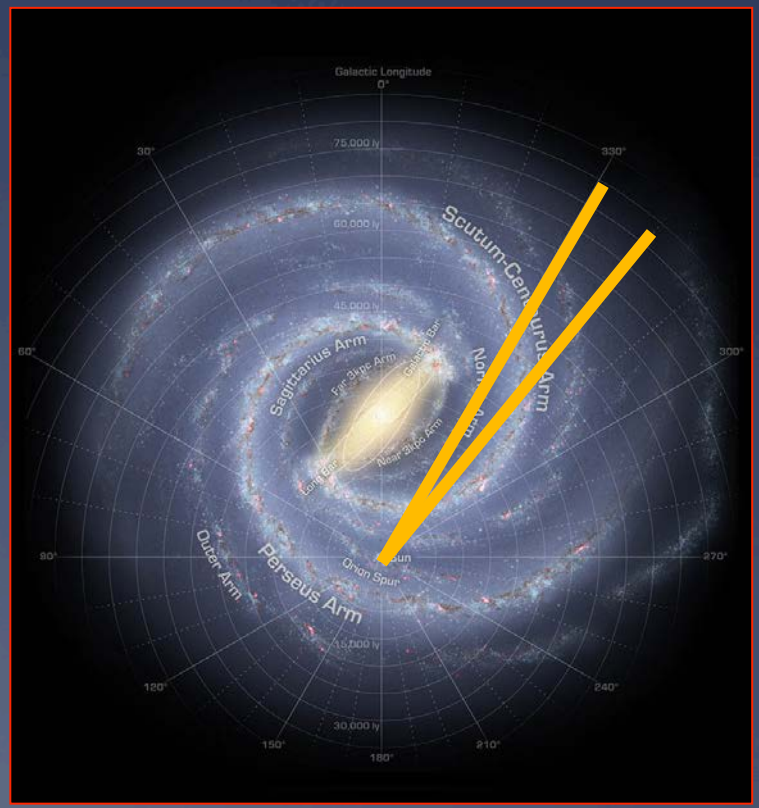
Spiral arms clearly evident

[Scutum - Crux]

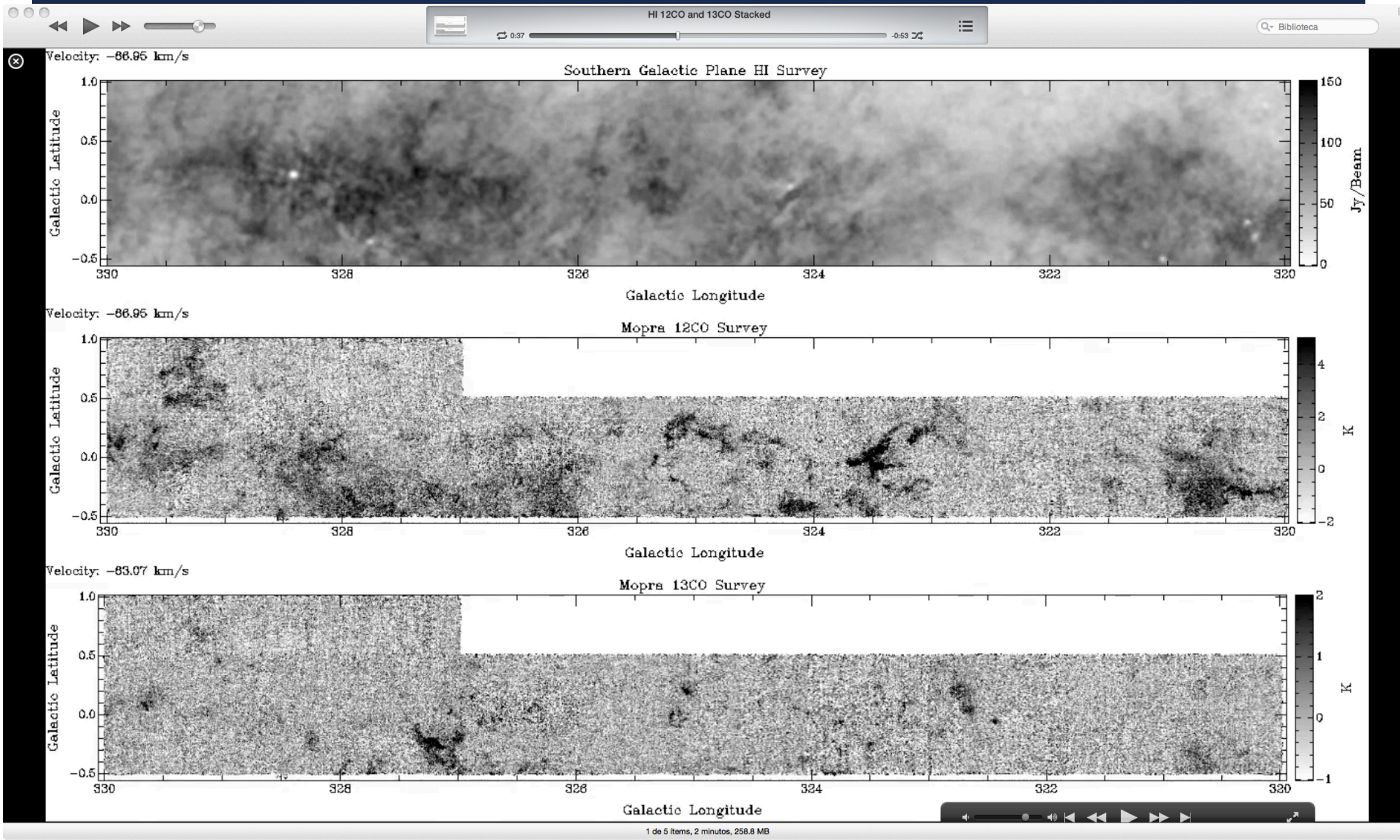
Sag - Carina

Scutum - Crux

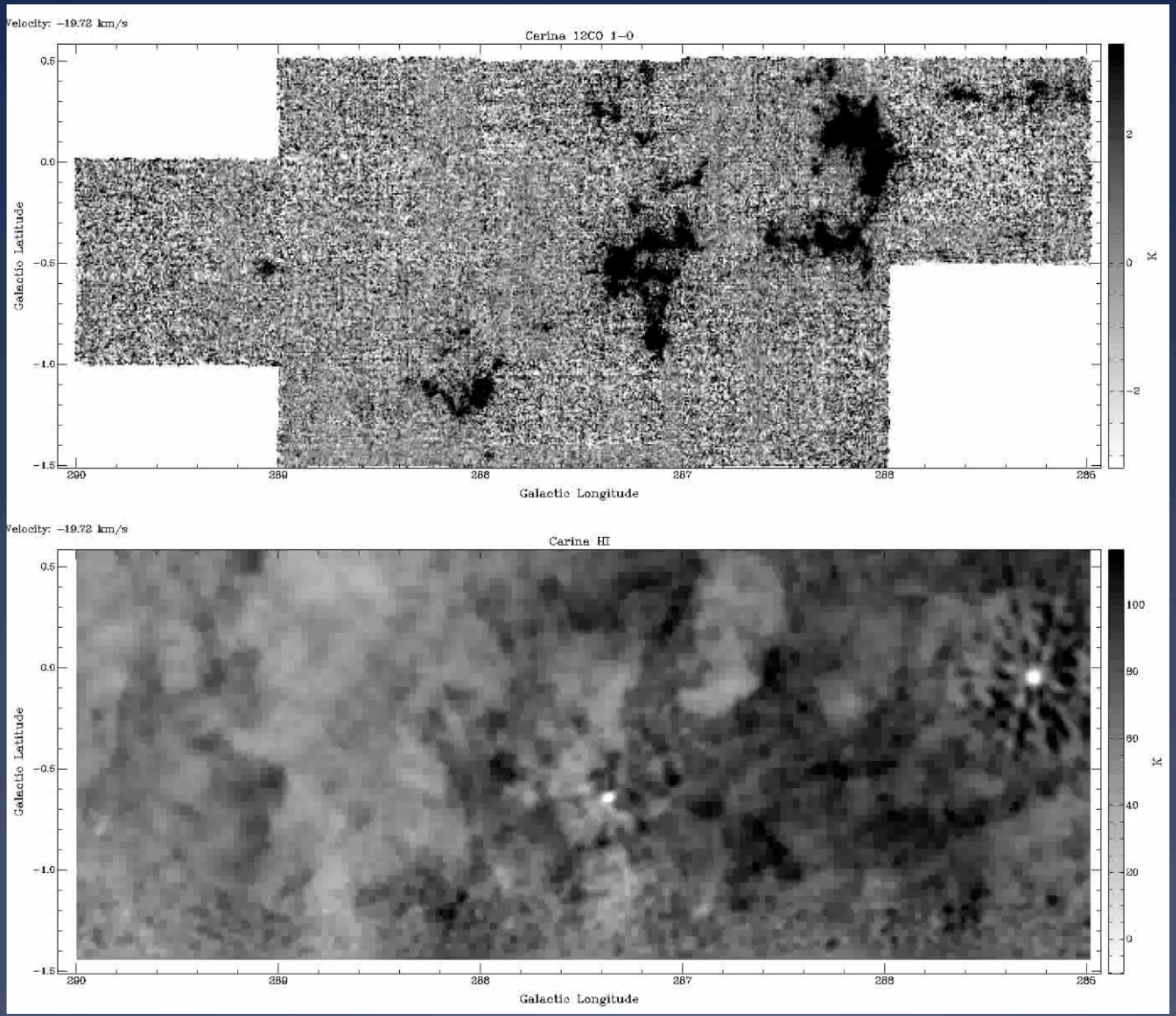
Norma - Cygnus



HI (SGPS), ^{12}CO & ^{13}CO (Mopra)



Carina: Mopra ^{12}CO + SGPS HI



The Future of Mopra?

CTA needs a sub-arcminute CO & HI survey of the southern galactic plane to maximise its scientific return

- CSIRO will not operate Mopra after the end of this year
  - 2013-15 Mopra operations have been funded by Adelaide, UNSW & NAOJ contributions (for both mm and VLBI)
- 3-year LIEF proposal submitted for 2016-18 funding @$0.5m/yr
  - 6 Australian universities: UNSW, Adelaide, Macquarie, Sydney, Tasmania, UWS
  - 3 Overseas institutions: MPIfR, MPIK (Germany) + Nagoya (Japan)
  - One-third requested from the ARC, two-thirds from the partners
- Mopra will be transferred from CSIRO to SSO (ANU)
  - Support both mm and VLBI
  - Will offer 1 month of community access
  - Will contract CSIRO to continue the maintenance
- We still need to do more!
  - Mopra Kickstarter?
- Mopra Workshop in Sydney in December
  - Celebration or a Wake?!