The Formation of Molecular Clouds in our Galaxy

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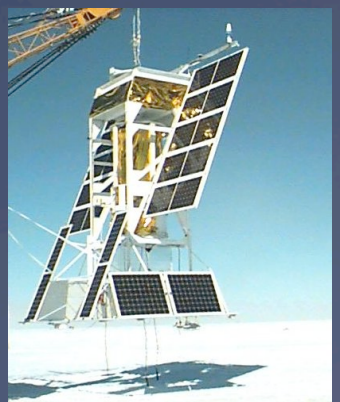
John Storey, Nick Tothill (UNSW)

David Hollenbach, Craig Kulesa, Chris Walker, Chris Martin (USA)

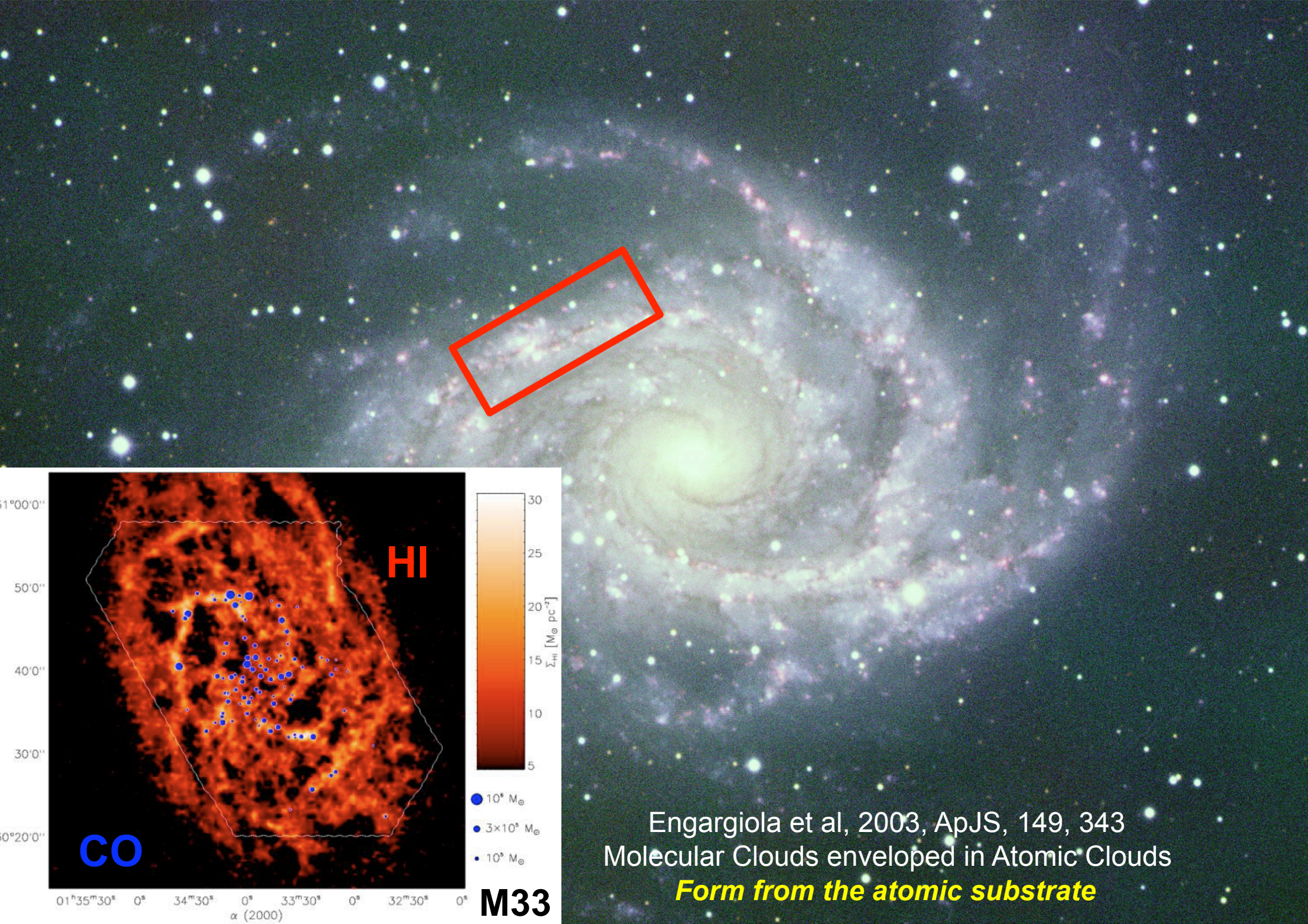
Jüergen Stutzki, Robert Simon (Germany) + many more….

STO, Antarctica
0.8m Terahertz



NANTEN2, Chile
4m Sub-millimetre

Mopra, Australia
22m Millimetre

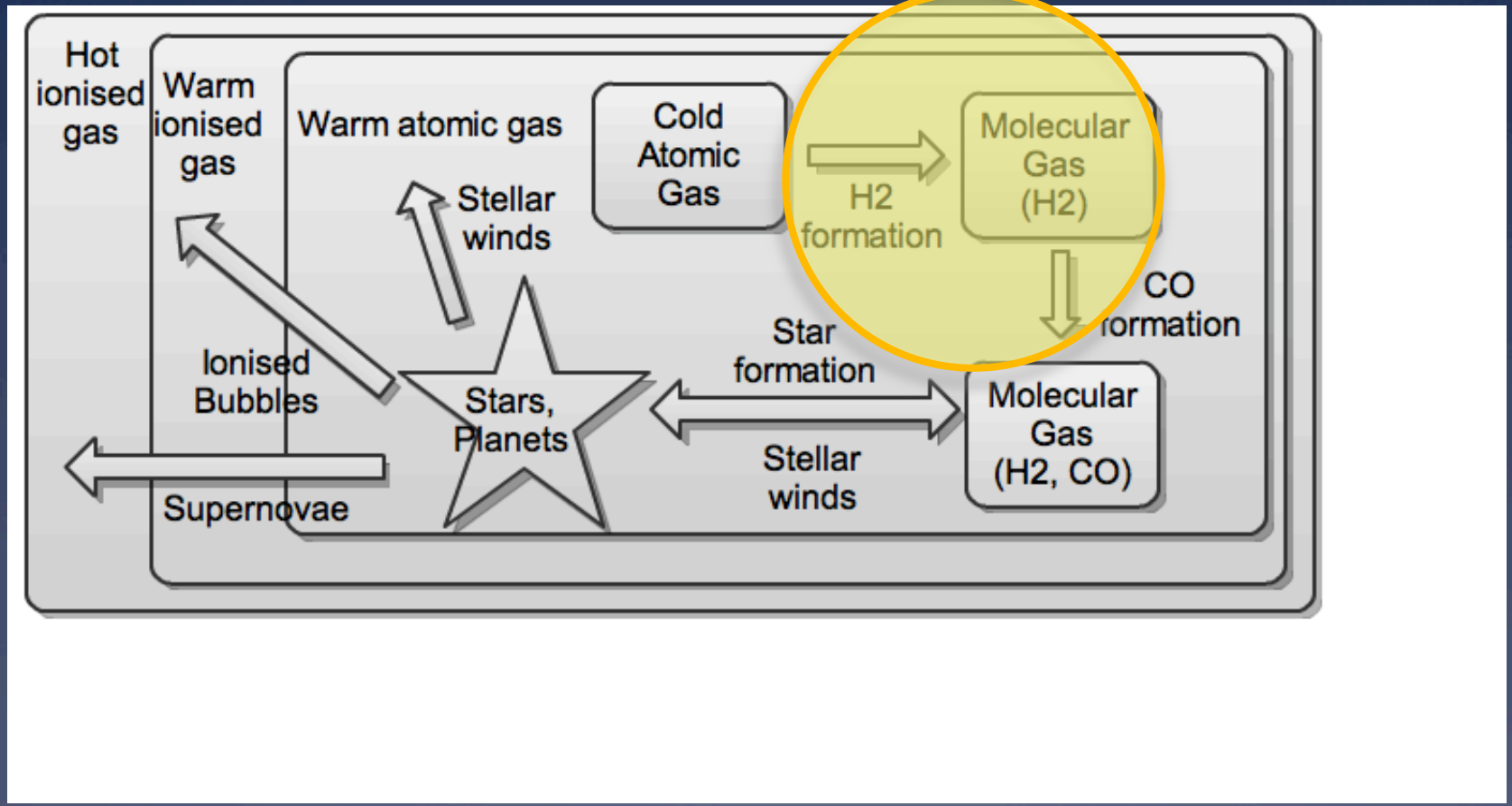


Engargiola et al, 2003, ApJS, 149, 343

Molecular Clouds enveloped in Atomic Clouds

Form from the atomic substrate

The Star-Gas Cycle

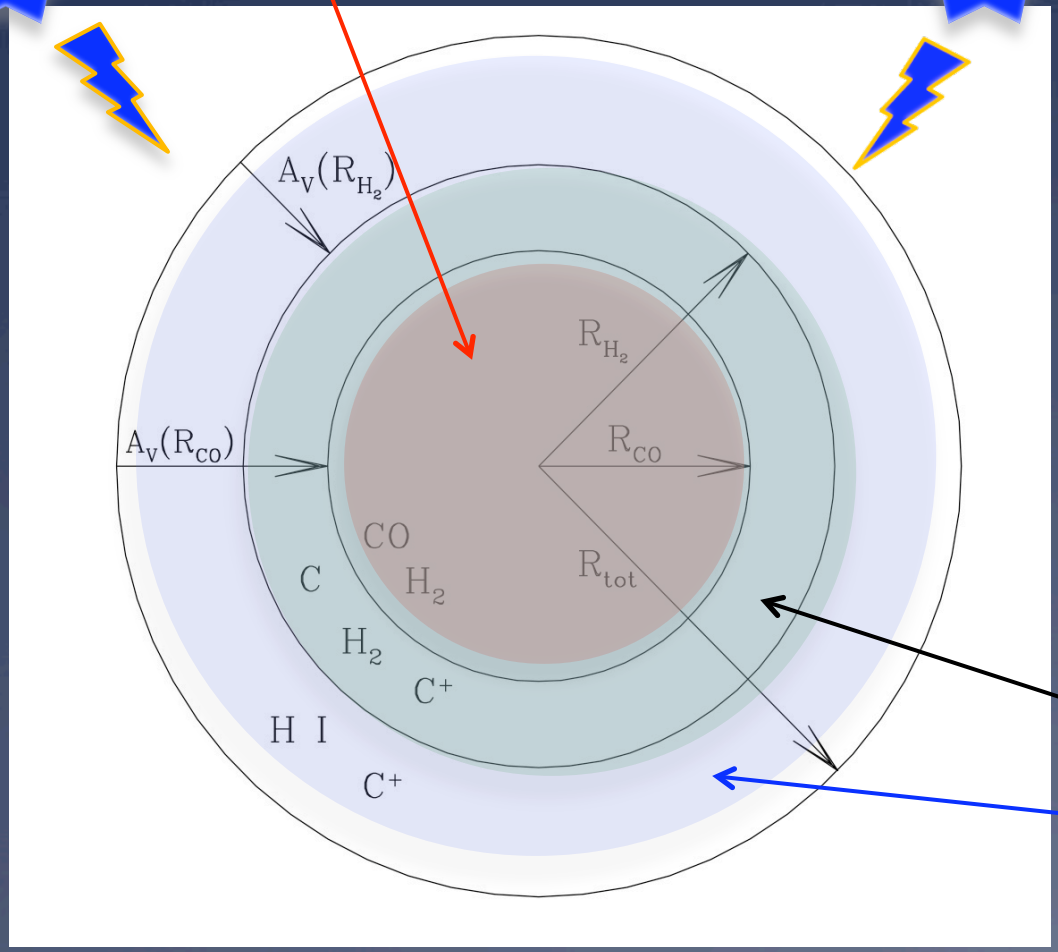


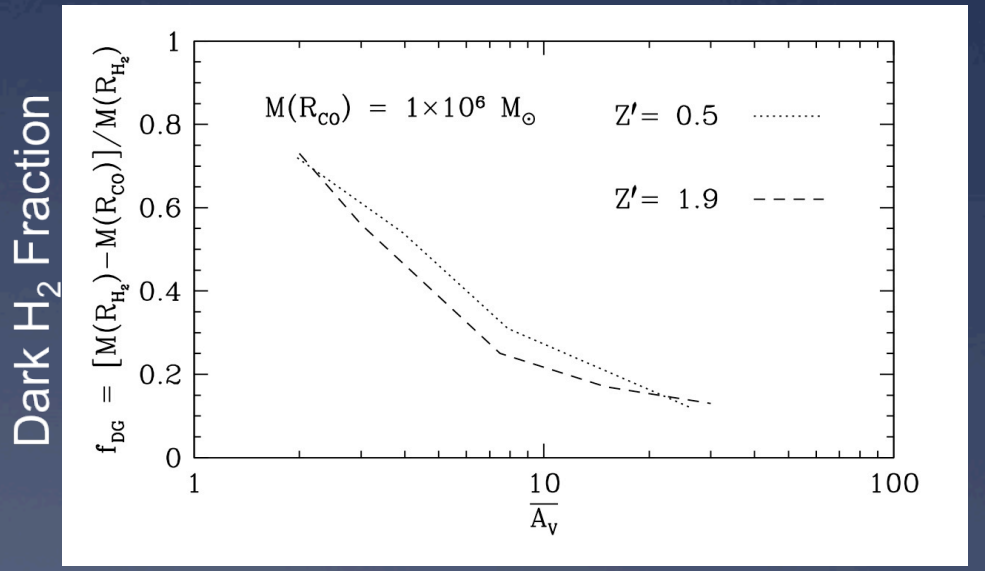
Stars form once molecular clouds form.
The formation of molecular clouds is its rate-determining step.

"Dark" H_2

'Normal' Molecular Gas

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





Column Density of Cloud

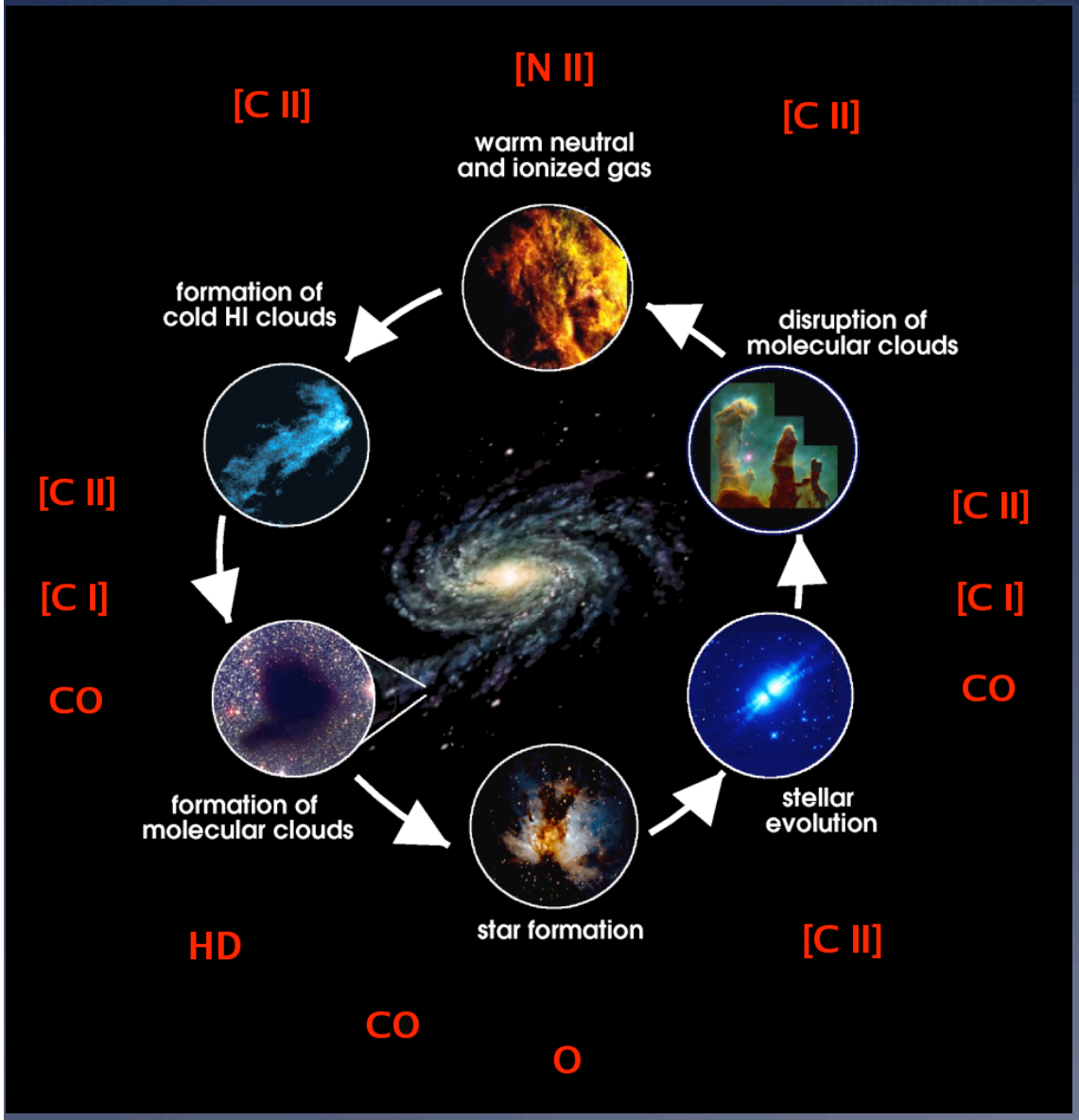
Purely Molecular Hydrogen – Dark H_2

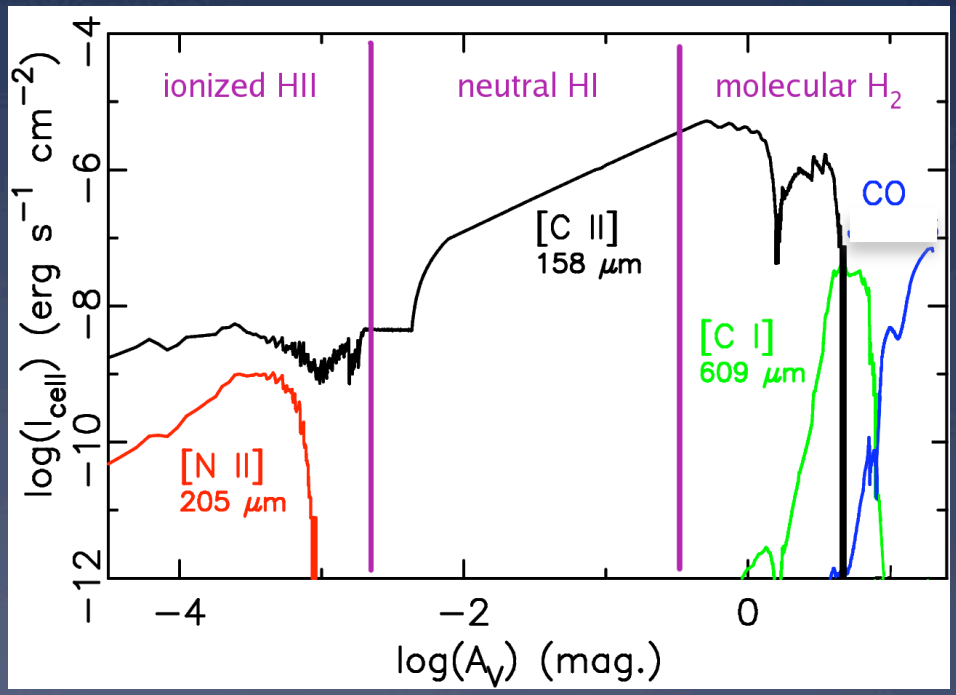
Atomic Gas

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

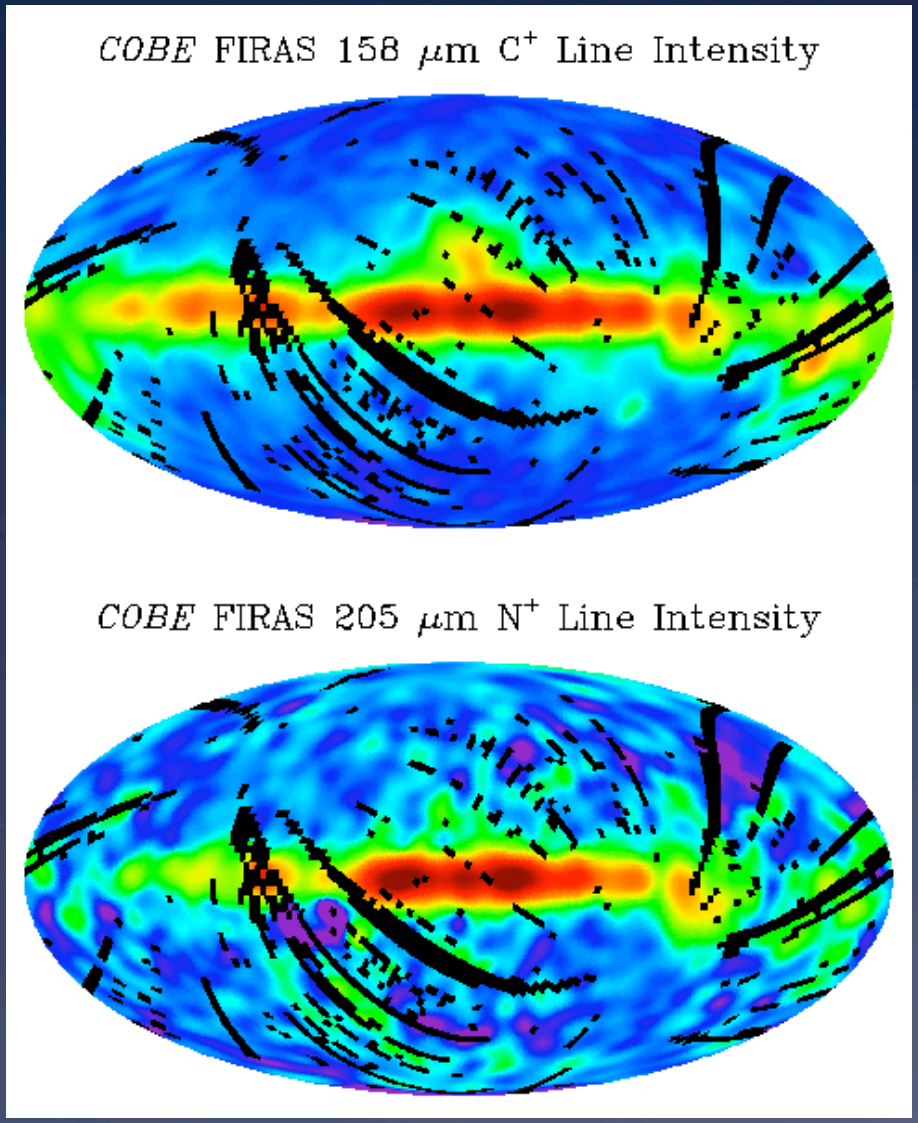
Emission Signatures
H_2 cannot be seen directly

Cut through surface of a molecular cloud





THz	[CII] [NII]	158μm 205μm
Sub-mm	[CI]	609μm
MM	CO	2.6mm
CM	HI	21cm

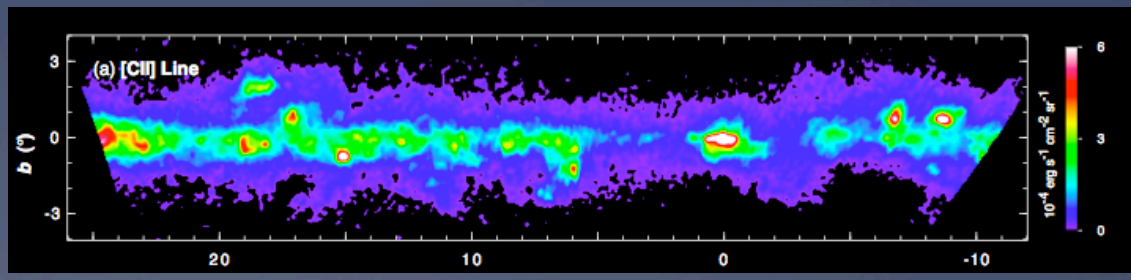


Only low resolution maps exist

Only Galactic Plane survey in [CII] and [NII] by FIRAS on COBE. 7° degree + R=100.

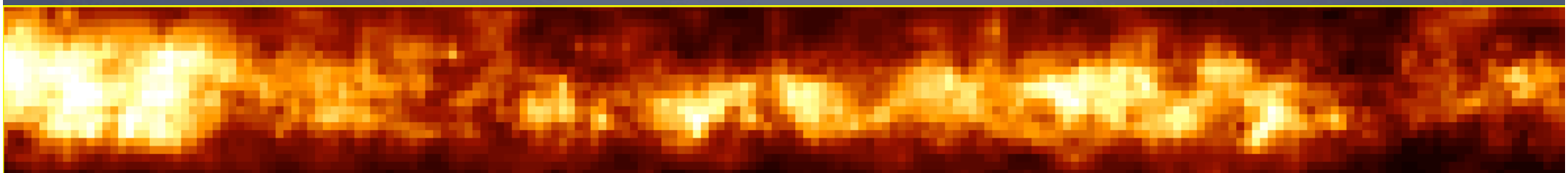
Balloon-borne BICE experiment measured [C II] over 200° with 15' resolution and R=1500.

In CO 1-0, the Colombia/CfA survey mapped the Galactic Plane at 8' resolution.



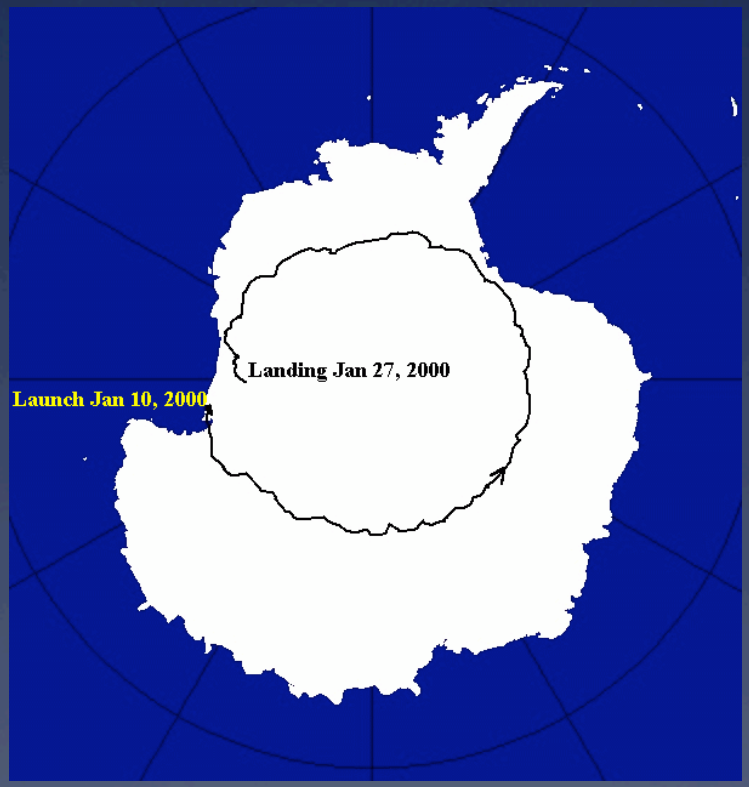
BICE [C II] balloon map

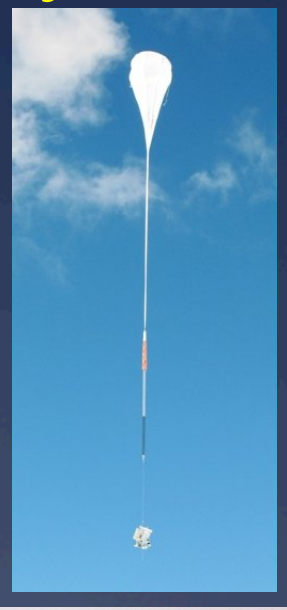
Columbia/CfA CO J=1-0



STO

Stratospheric Terahertz Observatory





- 80 cm telescope & gondola from Flare Genesis Experiment (solar)
- 2x4-pixel multibeam receiver
- 1.45 THz (NII) + 1.9 THz (CII)
- 0.2 km/s,1–1.5’ resolution

- Launched from McMurdo LDBF
- Long duration balloons
- 35 km altitude, 2 week mission
- Scheduled to fly Dec 2011
- 1 day US test flight in Sep 2009

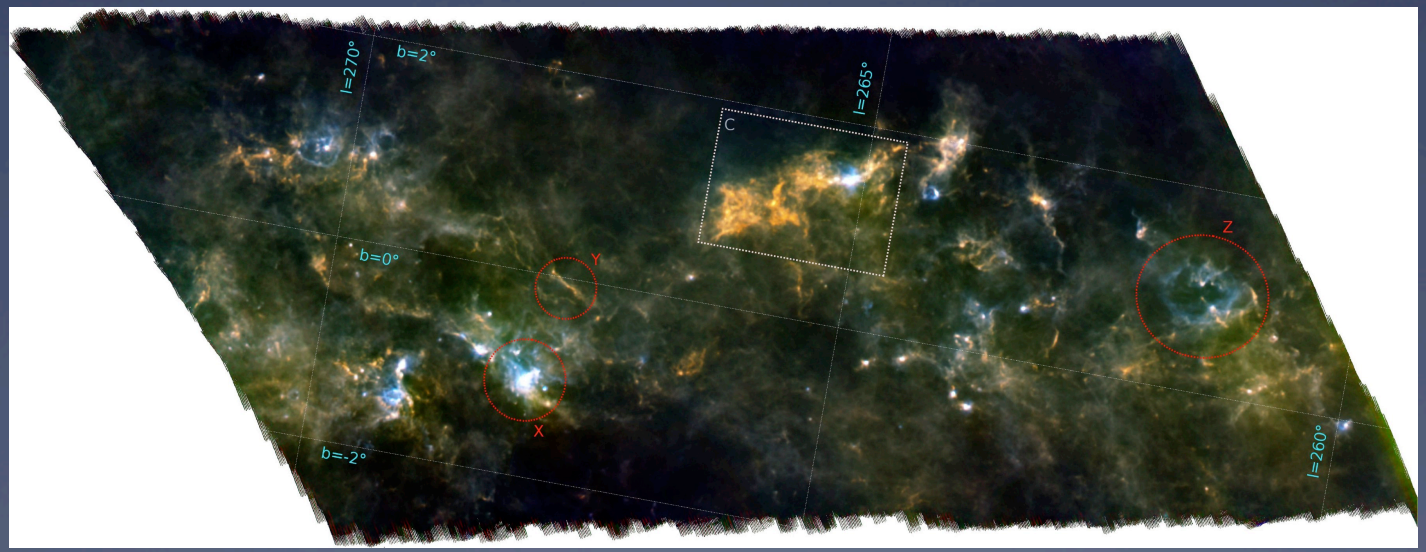
- Can be refurbished with new receivers and flown again
- Four missions planned.

BLAST

shows it can be done!

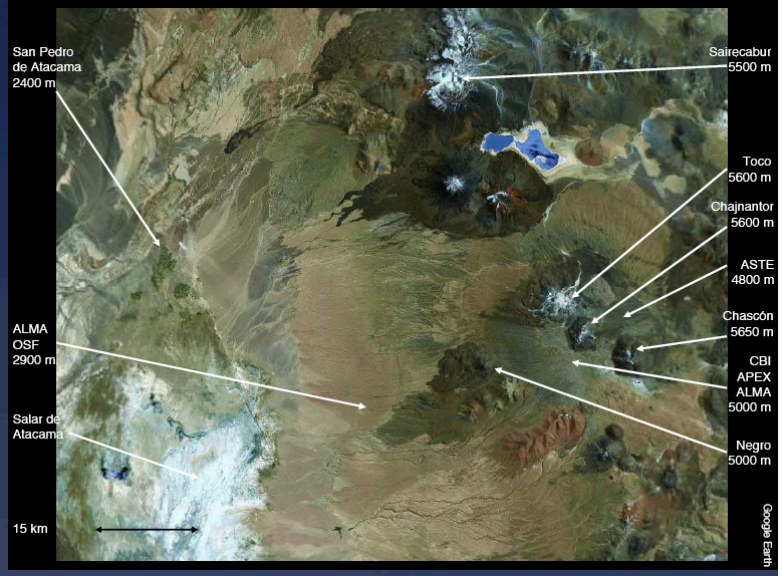
Balloon Large Aperture Sub-millimetre Telescope
2m Telescope, 11 day flight

10°x5° Vela Molecular Ridge
250μm, 350μm, 500μm

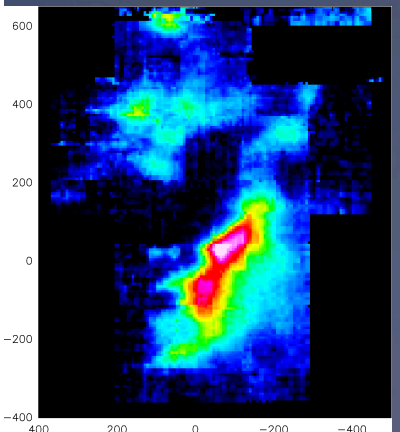


Netterfield CB *et al. (27 authors) (2009) BLAST: the mass function, lifetimes and properties of intermediate mass cores from a 50 square degree sub-millimetre galactic plane survey in Vela at l~265°.* ApJ 707, 1824

NANTEN2



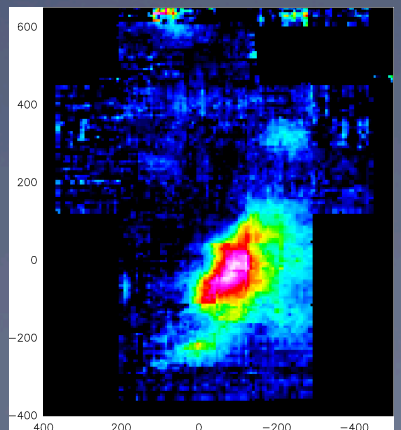
* 4m sub-mm Telescope
  * Pampa la Bola (4,800m; ALMA site)
  * 115/230/345 (Nagoya) + 460/810 (SMART) GHz receivers
* University of Nagoya (Japan) + Cologne (Germany)
* + Universities from Chile, Korea, Switzerland, Australia
  * UNSW, Sydney, Macquarie + Adelaide, JCU, Swinburne



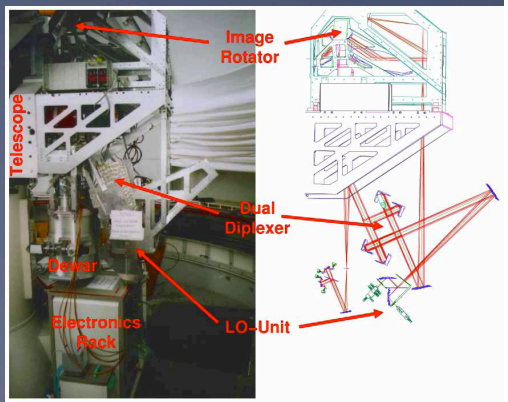
M17 @ 810GHz
~15'x20'

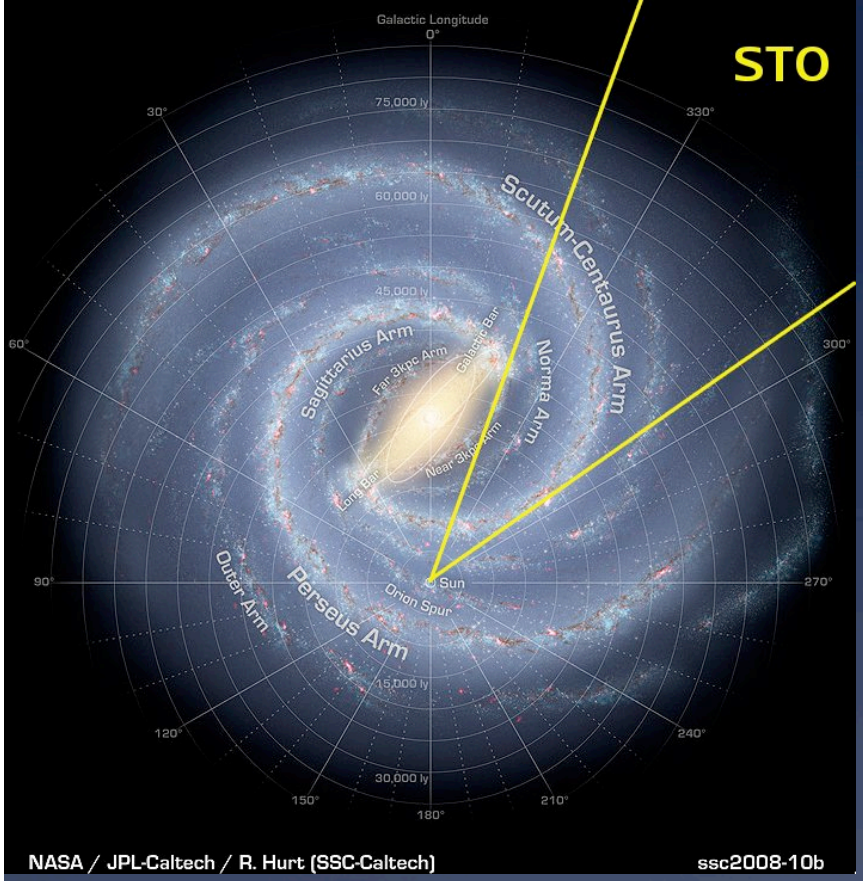
←CO 7-6

[CI] →



SMART
2x8 channel
multibeam
460 + 810 GHz

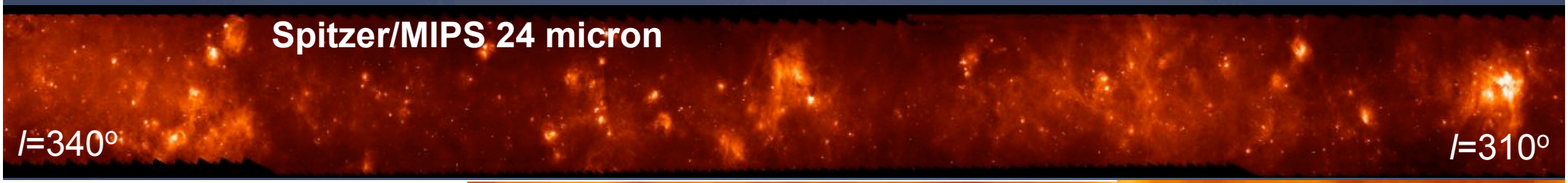


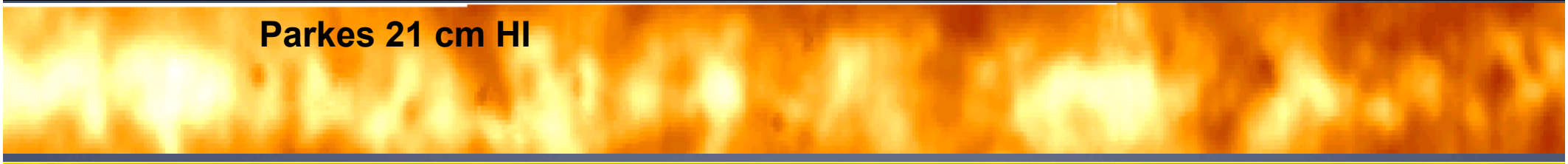


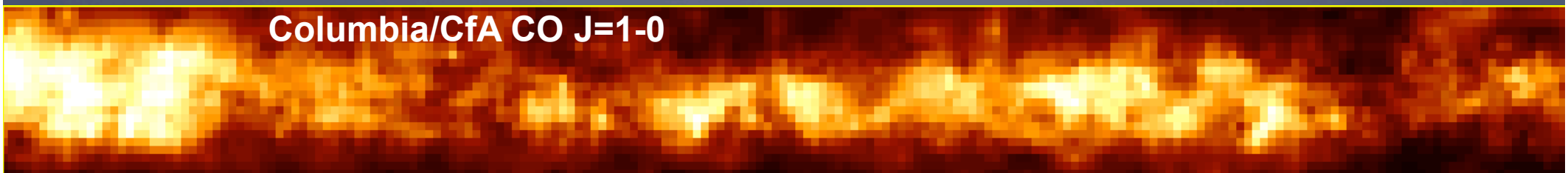
The STO Survey

Stratospheric Terahertz Observatory

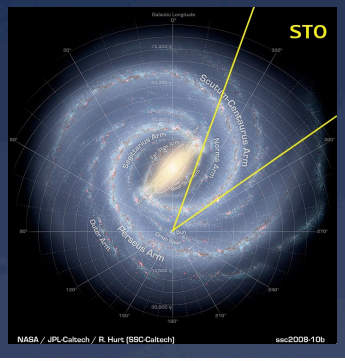
STO will perform a midplane Galactic survey from *l*=-20º to *l*=-55º, and |*b*|<1° spanning the Molecular Ring through the Scutum-Centaurus spiral arm and two inter-arm regions.

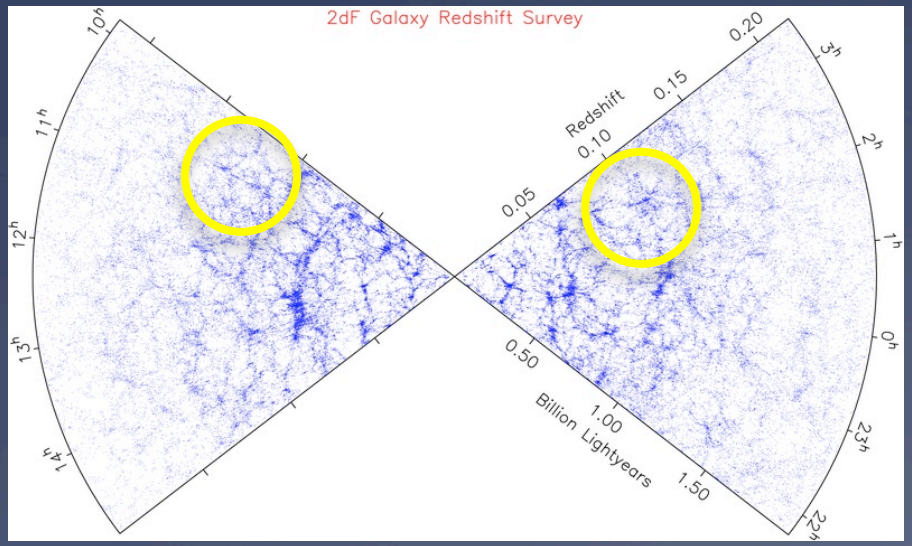


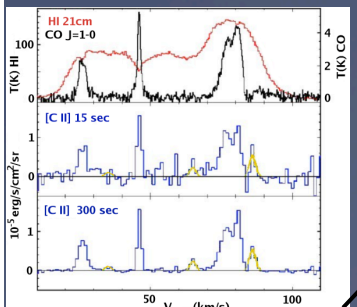


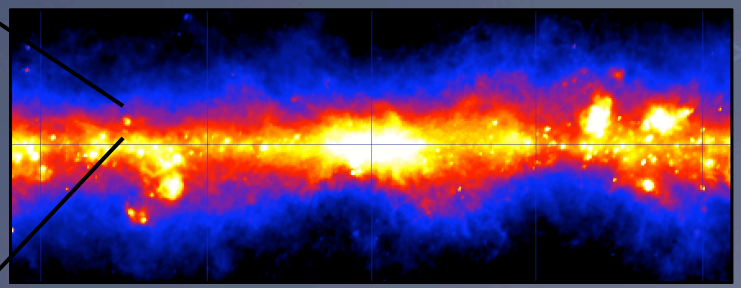


Identifying Forming Molecular Clouds from the Atomic Substrate









* Identify molecular, dark, atomic clouds from [CII], [CI], CO, [NII], HI emission
  * GMC initially spread over ~1 kpc
* Cover arm + inter-arm region
* Velocity structures akin to "fingers-of-God" in Galaxy redshift surveys, but on km/s scales.
* Galactic rotation curve for distance + "peculiar" velocities around a cloud complex
* Infall or Disruption?
  * Look for past tracers of SF; e.g. clusters, SN: disruption
  * If none: molecular cloud forming

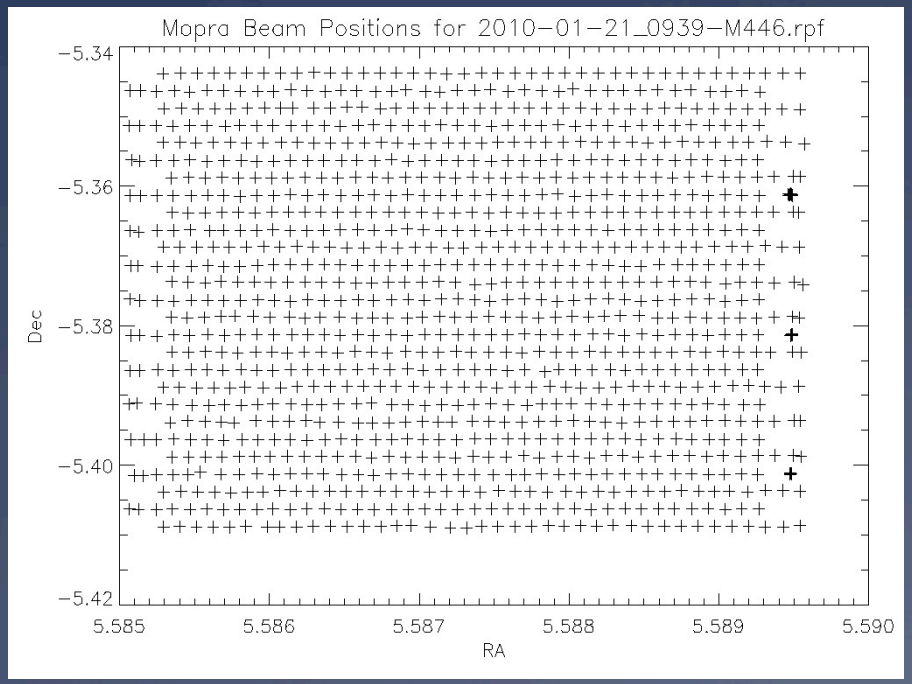
Fast Mapping with Mopra

- Binning mode in 2s cycles
  - 8 x 256ms samples
- i.e. 8 x faster for 1/3rd the sensitivity
  - Only suitable for CO lines
- Scan at 36"/s with 12" row spacing
  - c.f. 3"/s with 9" spacing
- 36 hours/sq deg c.f. 350 hours
- 4 zoom modes, not 16
  - ^{12}CO, ^{13}CO, $C^{18}O$, $C^{17}O$

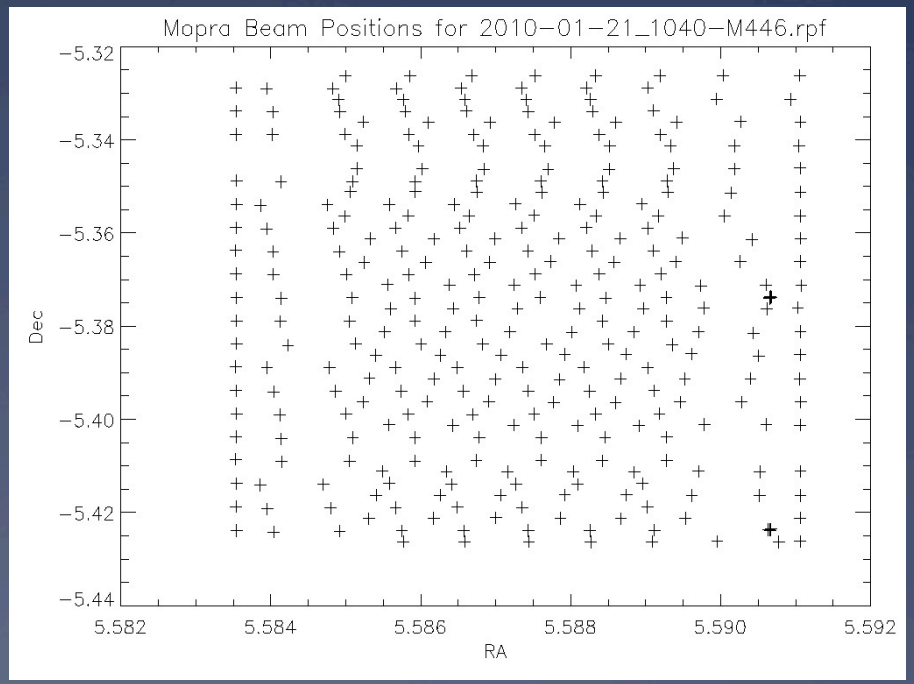
Thanks to Warwick Wilson, Dick Ferris, Balt Indermuehle, James Urquhart!

Beware uneven beam coverage with Fast OTF

Standard OTF

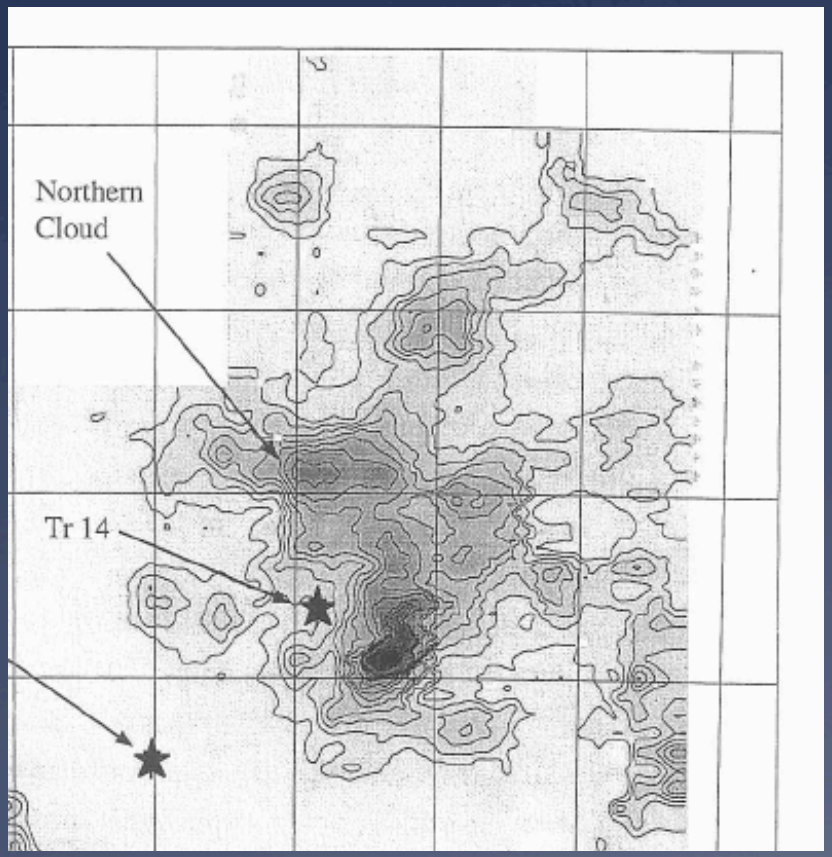


Fast OTF



Two Views of Carina in CO with Mopra

Point-by-Point

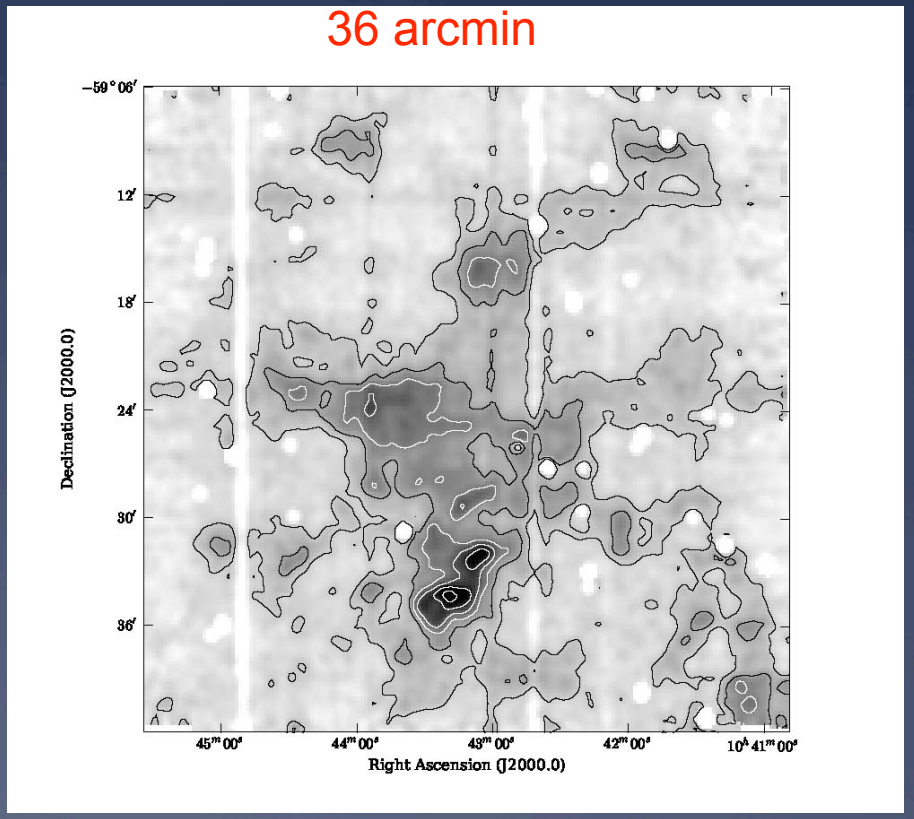


1996-7: Several months, at site.
45” beam, 1line, 1 poln, 64 MHz, 0.2 km/s
Clear skies!

Kate Brooks, PhD Thesis

Fast–OTF

36 arcmin

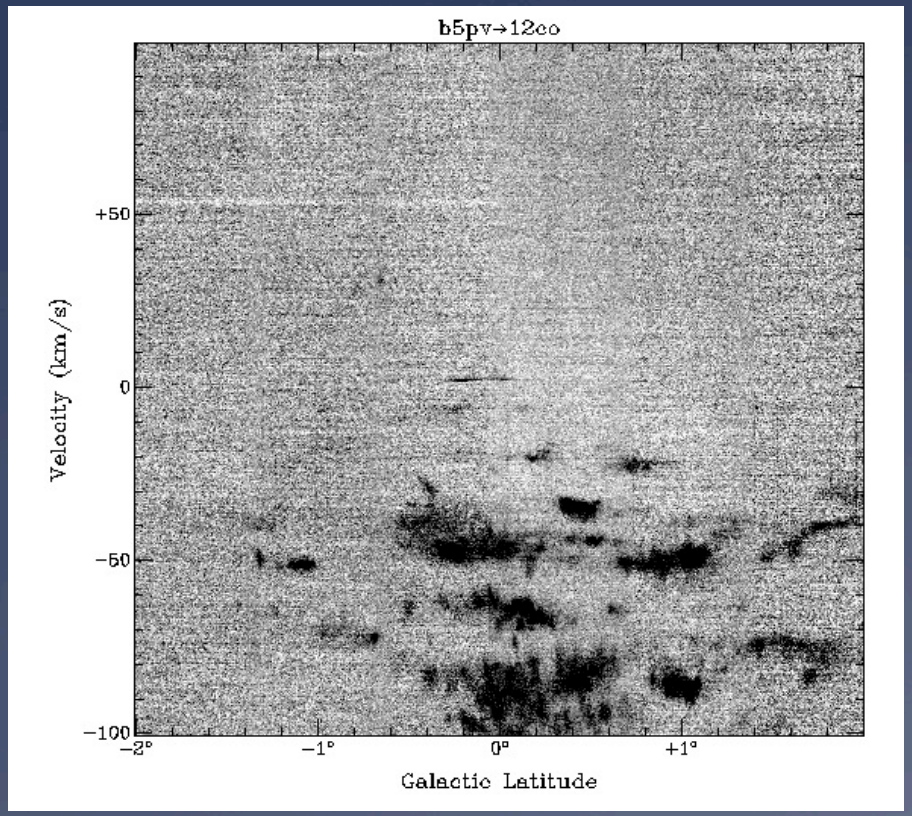


2010: 6 hours, in-between teaching from my office
30” beam, 4 lines, 2 poln, 137 MHz, 0.1 km/s
Extensive cloud!

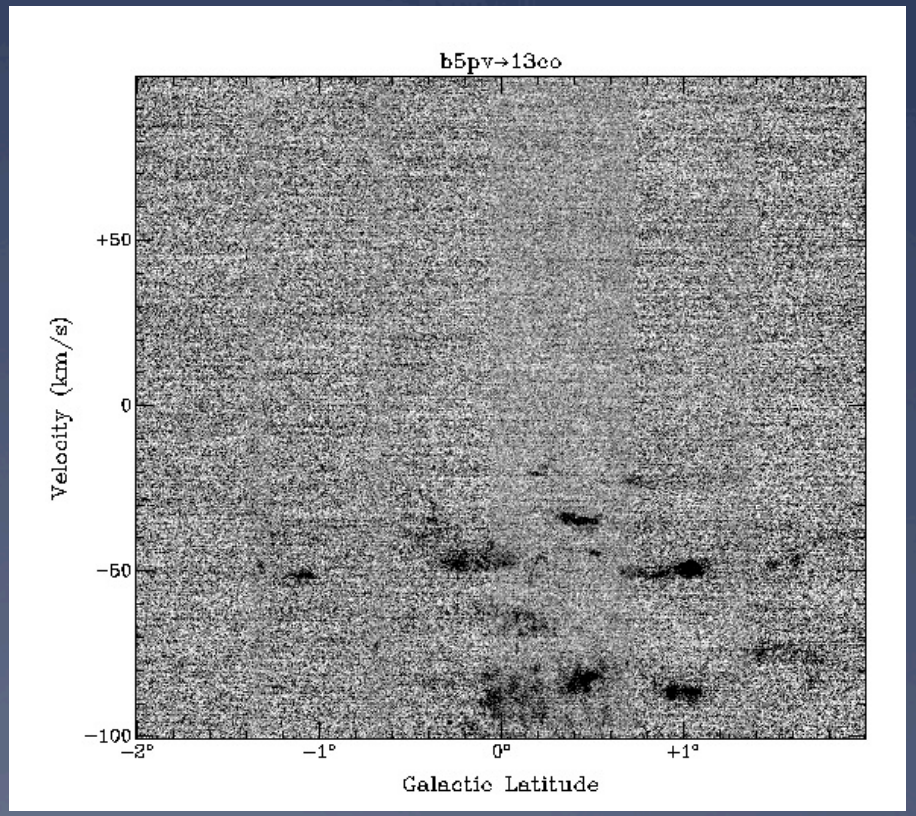
Fast Mapping Strip Scans

l=330° x 6', b=-2° – +2°, ΔV=+250 km/s

^{12}CO (115.3 GHz)



^{13}CO (110.2 GHz)



Velocity

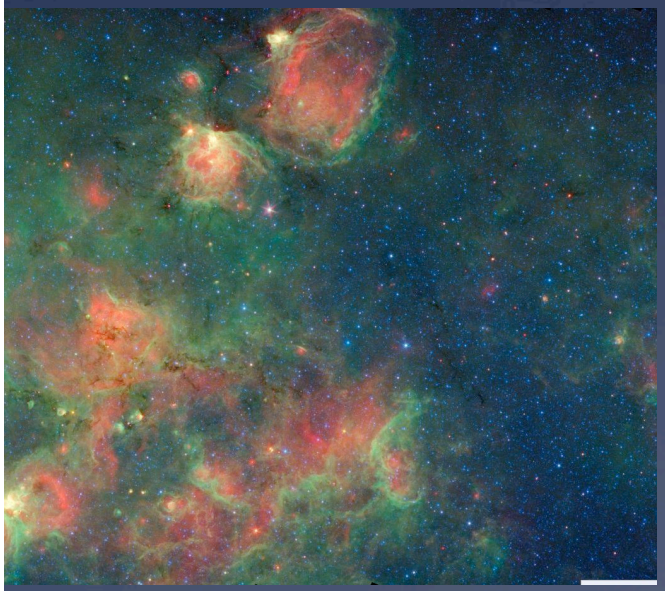
Latitude

The First Segment for Mopra

Edge of spiral arm to inter-arm region

l=325.25°–327.25°, b=+/-1°

2 x 2°



Spitzer / MIPSGAL
3.6μm+8μm+24μm

Parkes 21cm HI

We need Mopra!