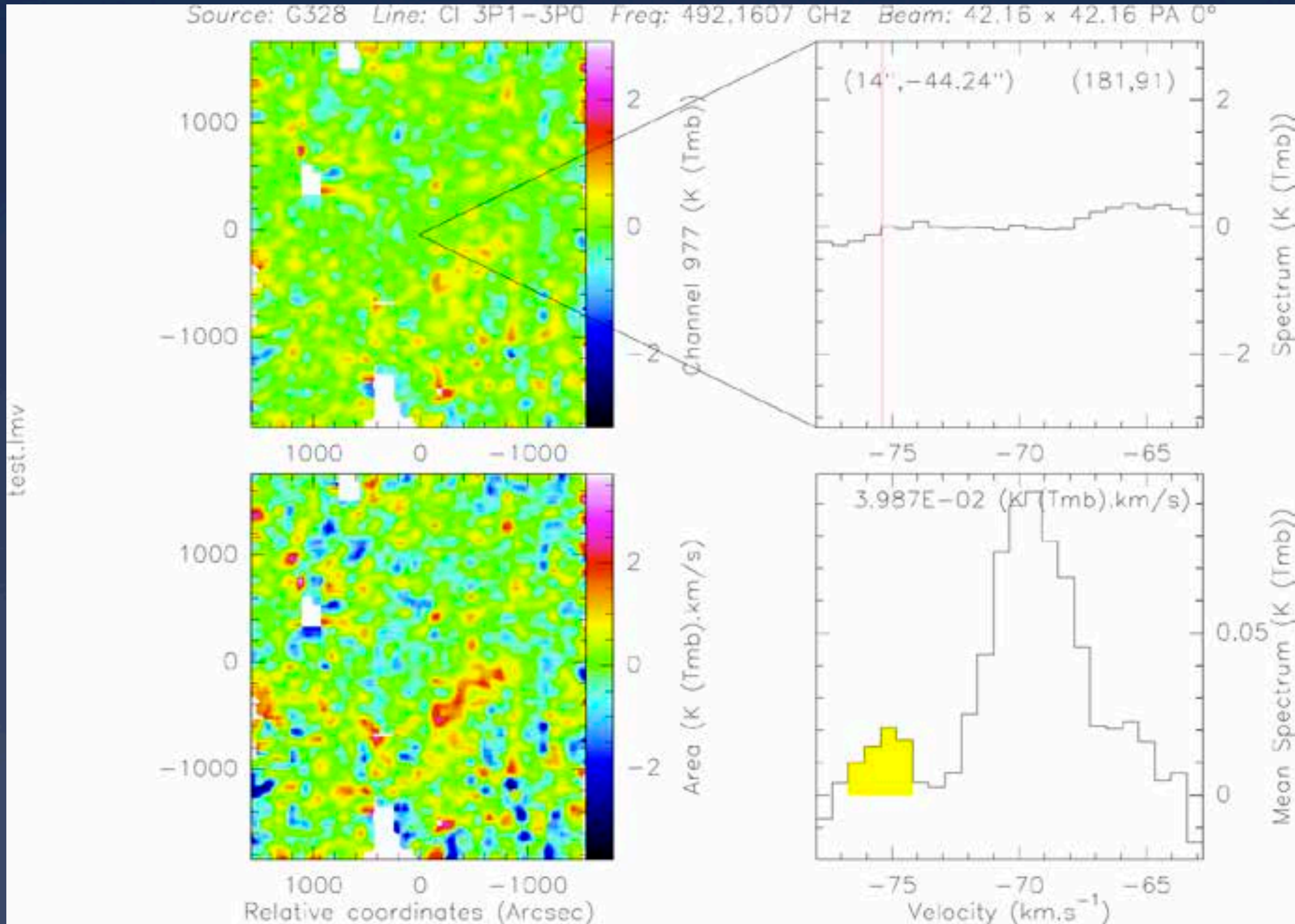
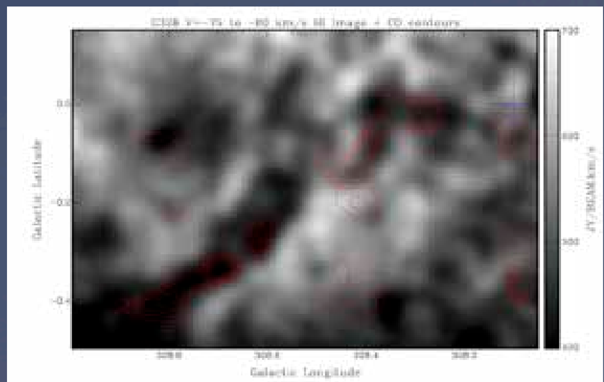
G328 [CI] 492 GHz @ -75 km/s





The Carbon Inventory in a Quiescent, Filamentary Molecular Cloud in G328

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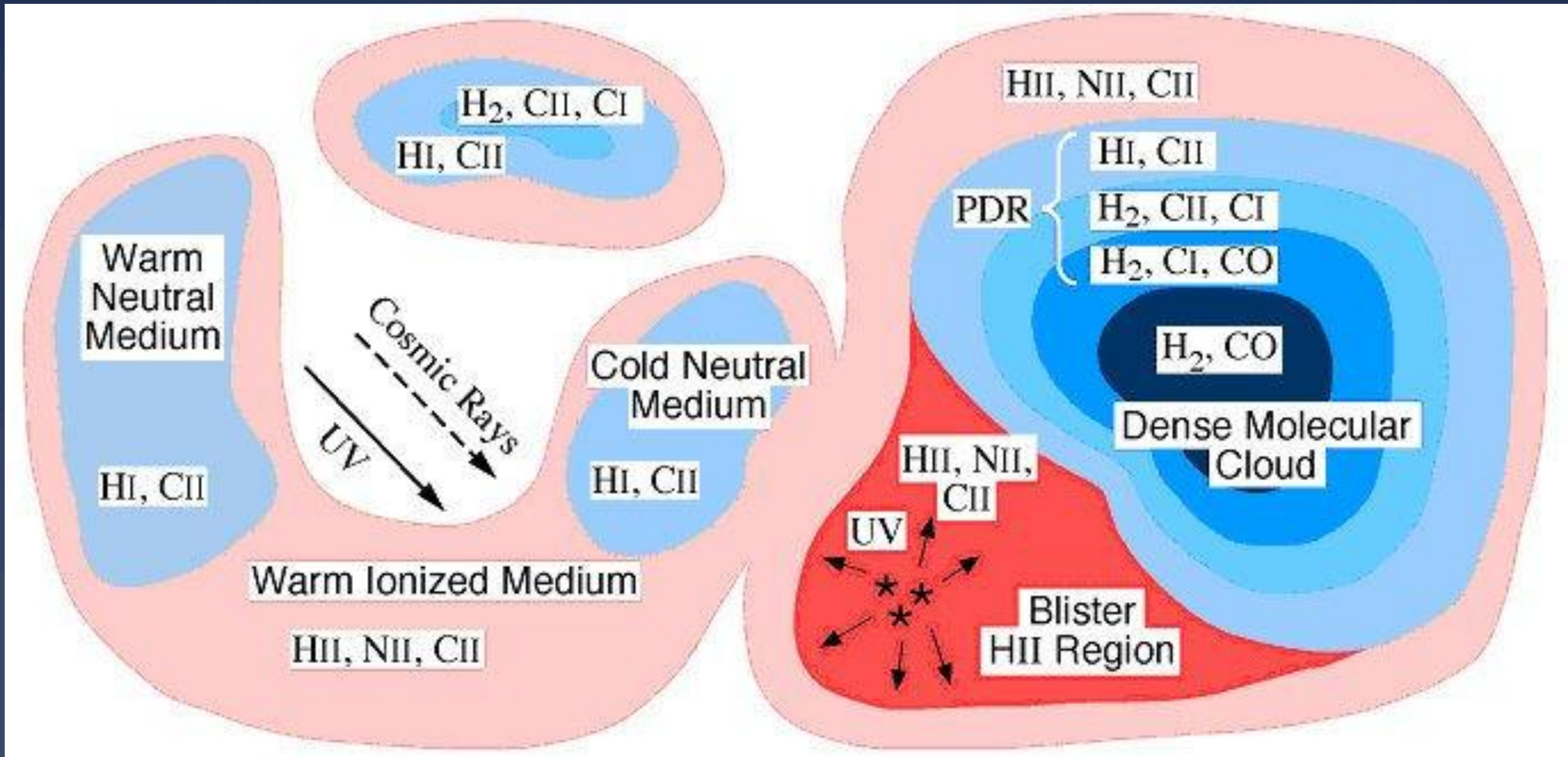
Astrophysical Journal, 2014, 782, 72 (Feb 20)

Outline

1. Probing the multi-phase ISM
   * Following the Galactic Carbon Trail

2. Southern Galactic Plane Carbon Surveys
   * Mopra CO
   * HEAT [CI]
3. The G328 Molecular Filament
   * Linking the atomic and molecular media

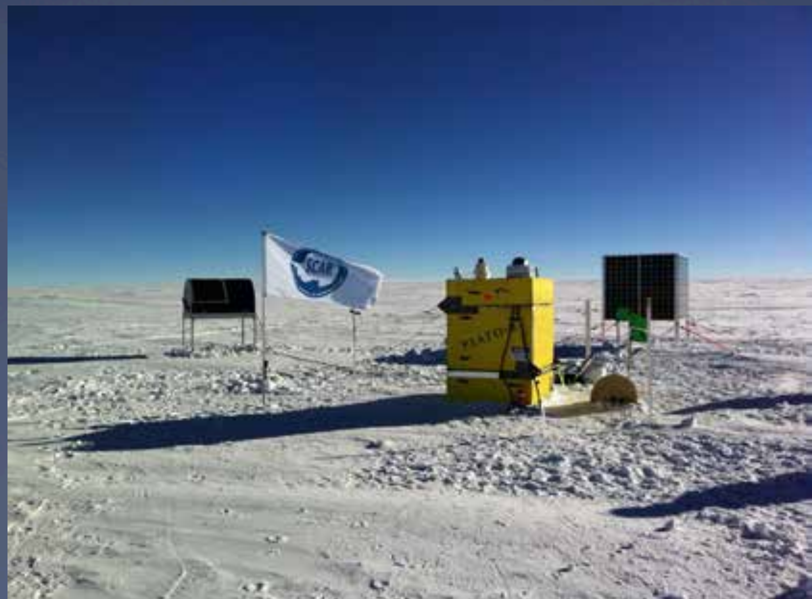
Schematic of the multi-phase ISM and its diagnostic tracers



Follow the Carbon Trail: C^+ → C → CO

Mopra:
115+110 GHz CO
Burton et al. 2013

Parkes + ATCA SGPS:
1.4 GHz HI
McClure-Griffiths et al. 2005



HEAT:
809 GHz [CI]

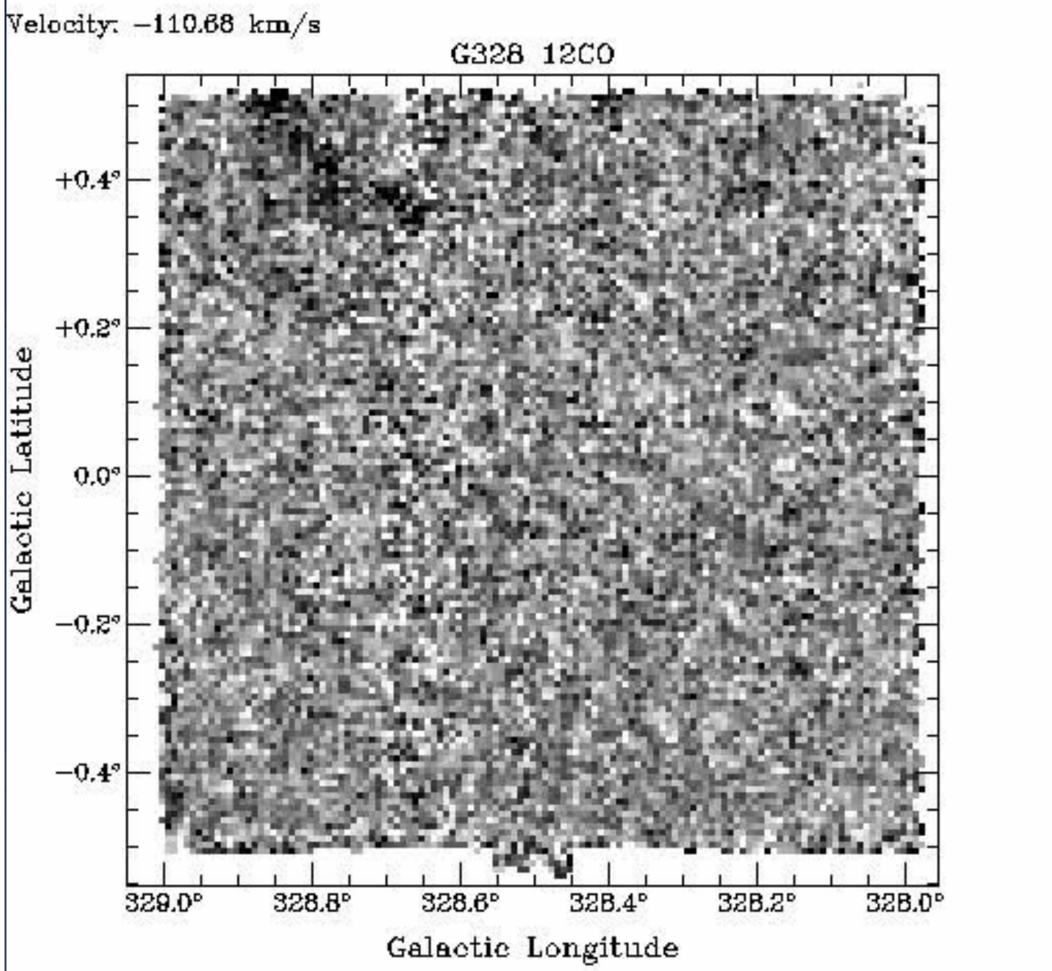
Kulesa et al. 2014

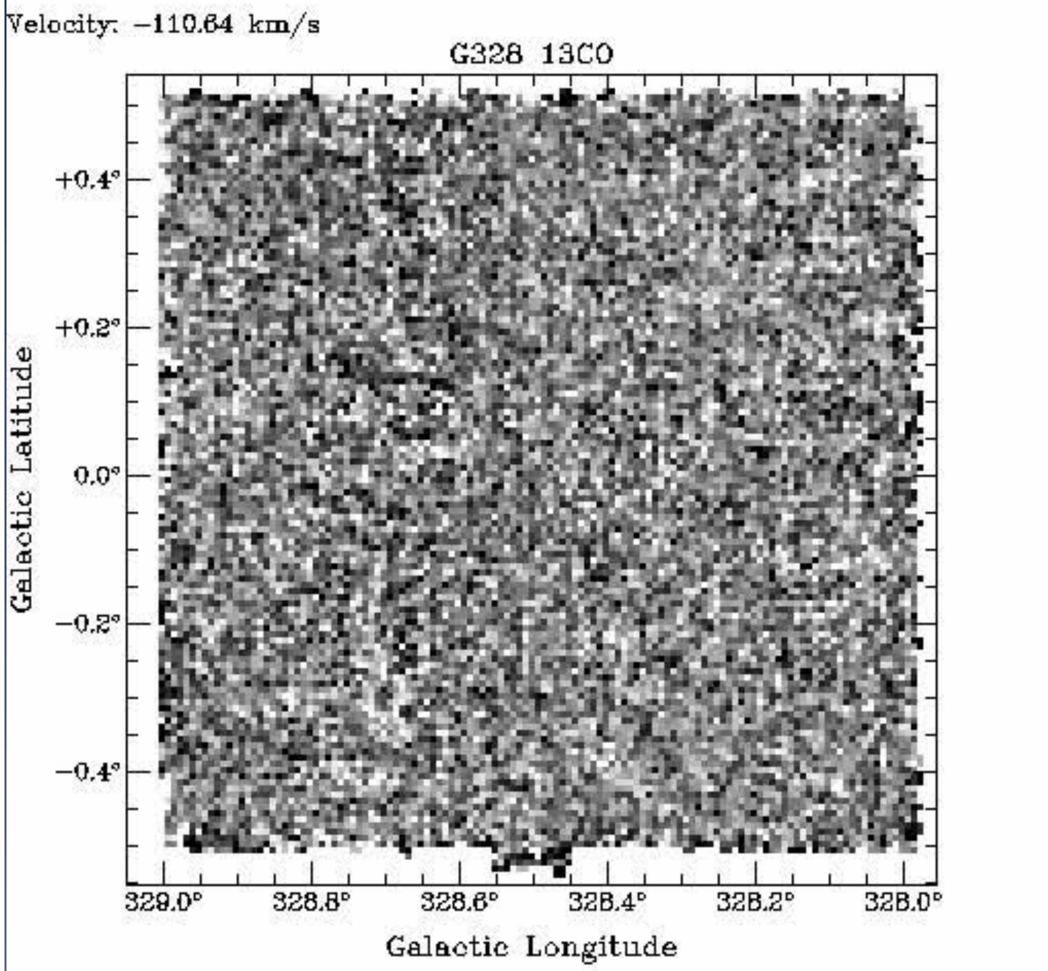
Spectral Tracers

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 / STO
C^+	[CII] J=3/2-1/2	1.90 THz	HEAT / STO

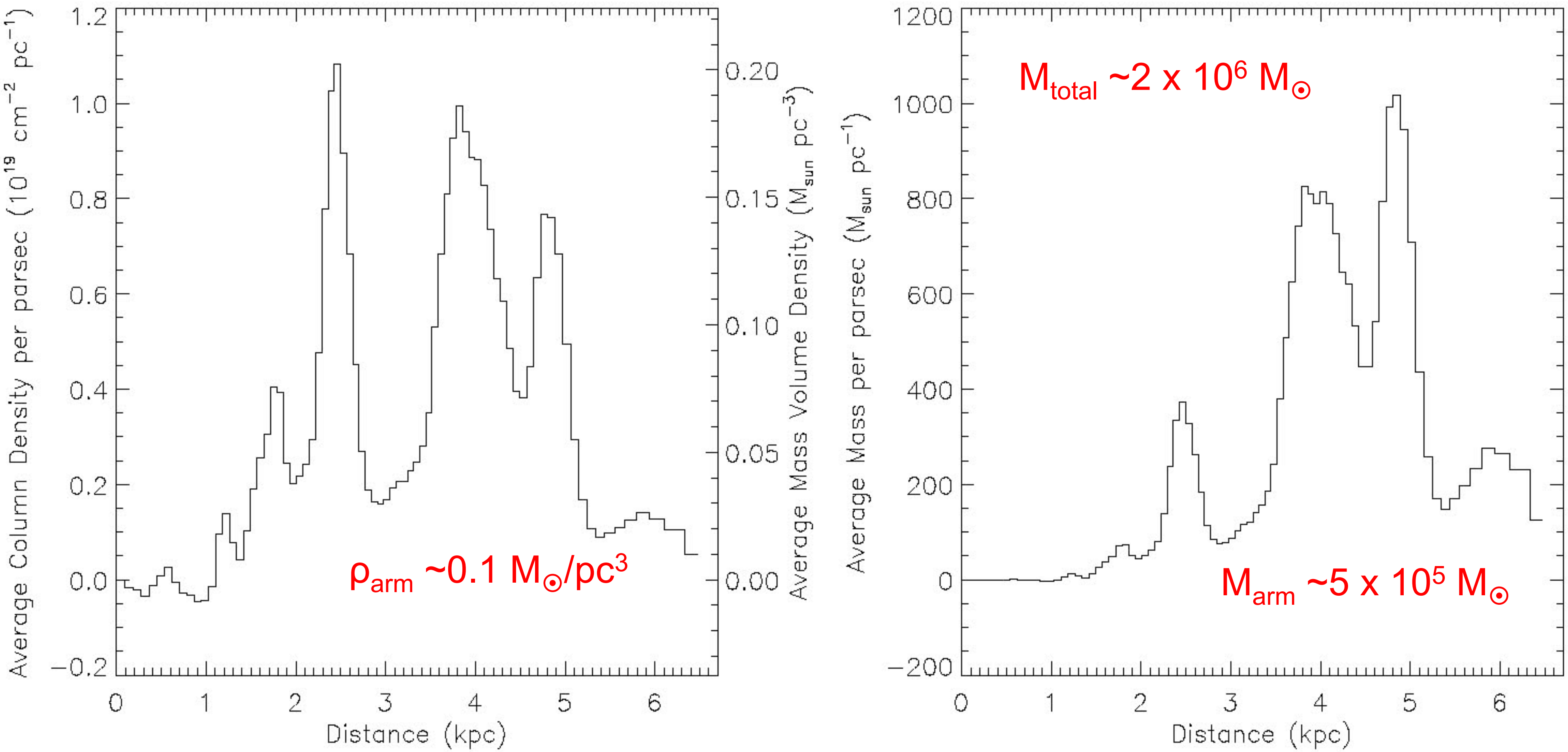
-110 km/s
to
+35 km/s

G328 1°x1° ^{12}CO + ^{13}CO J=1-0





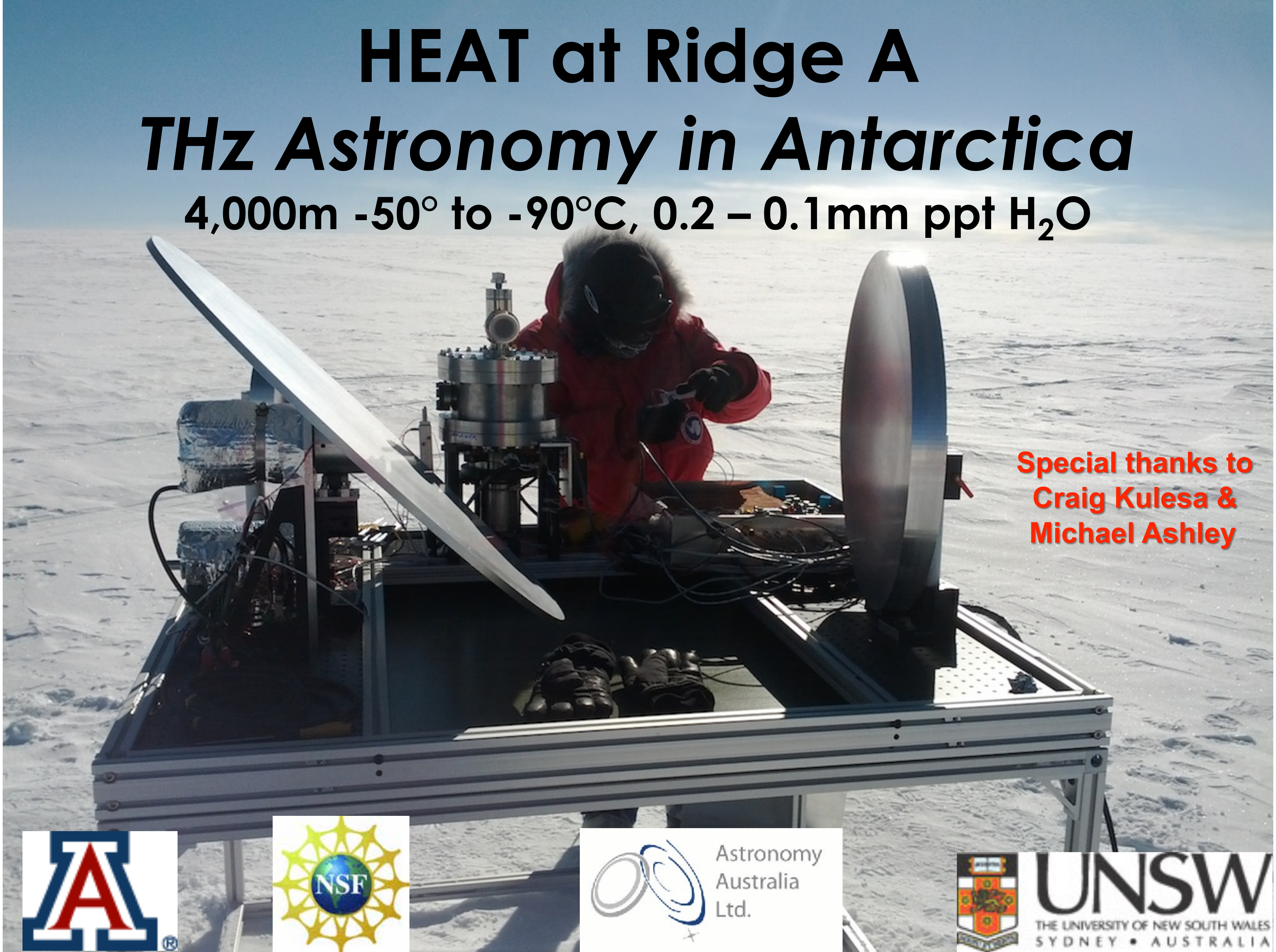
Molecular Mass Distribution at *l*=323°



HEAT at Ridge A

THz Astronomy in Antarctica

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



Special thanks to
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.

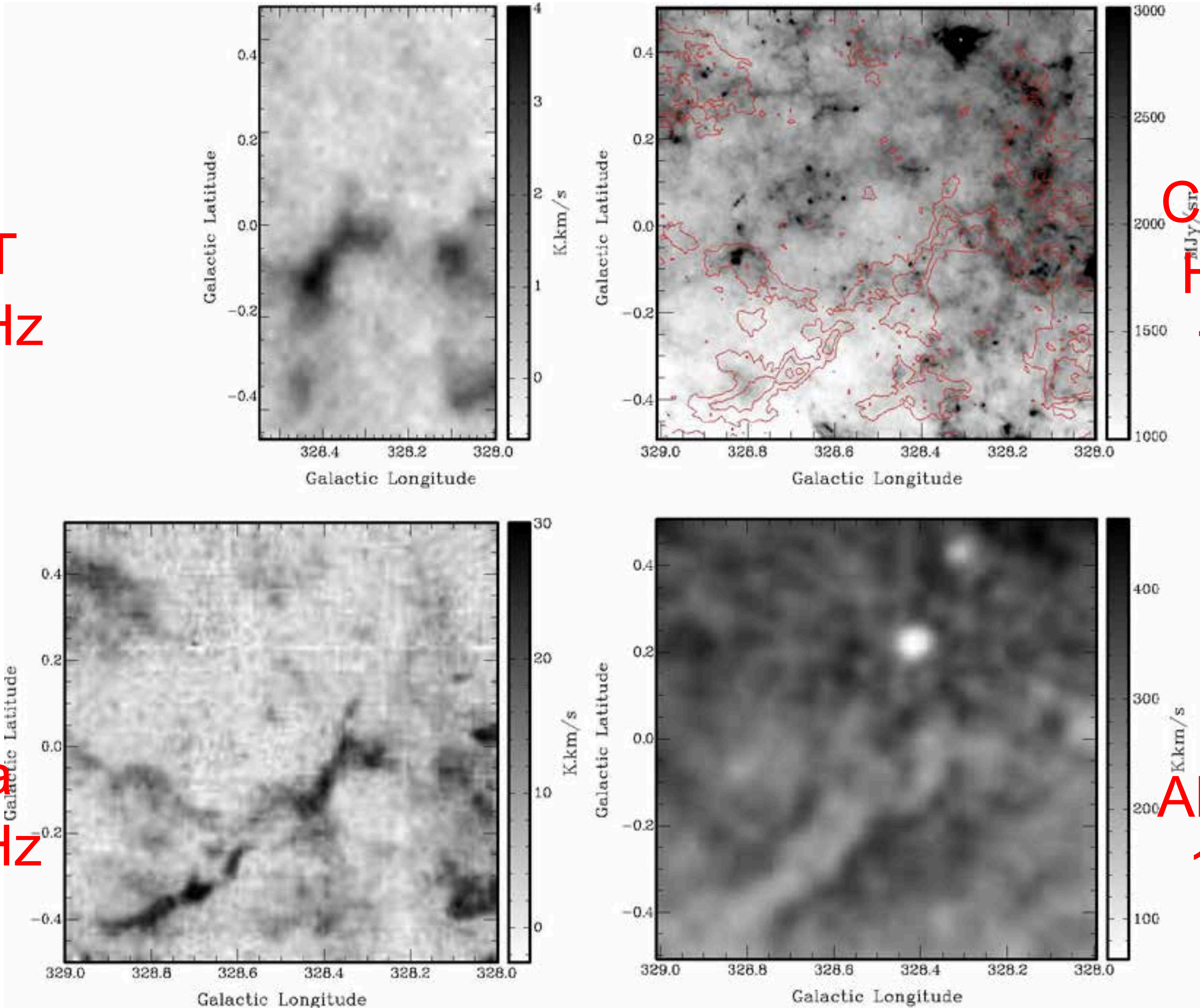
Drift scanning: any point on the sky is seen for only 5-15 seconds per day, so tens of days of observations are needed to achieve desired SNR

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

2 arcmin spatial + 1 km/s spectral resolution.

G328: From atomic to molecular

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



[CI]
HEAT
0.8 THz

No
Cold Dust!
Herschel
1.2 THz

CO
Mopra
115 GHz

HI, in
Self-
Absorption
1.4 GHz

G328 Filament

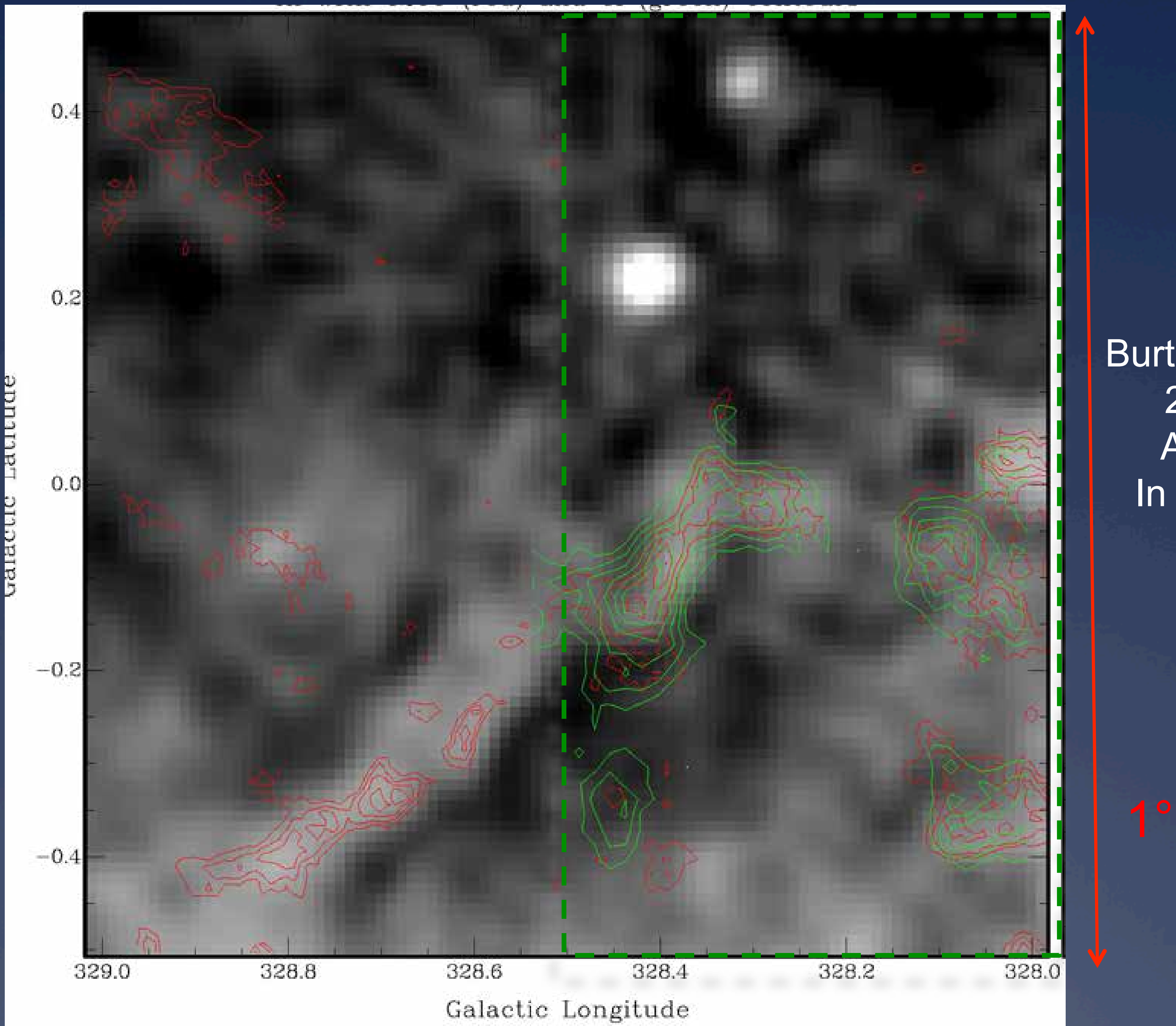
Quiescent:
v=-80 to -76 km/s

No far-IR dust

No Star Formation

[C/CO] ~ 1

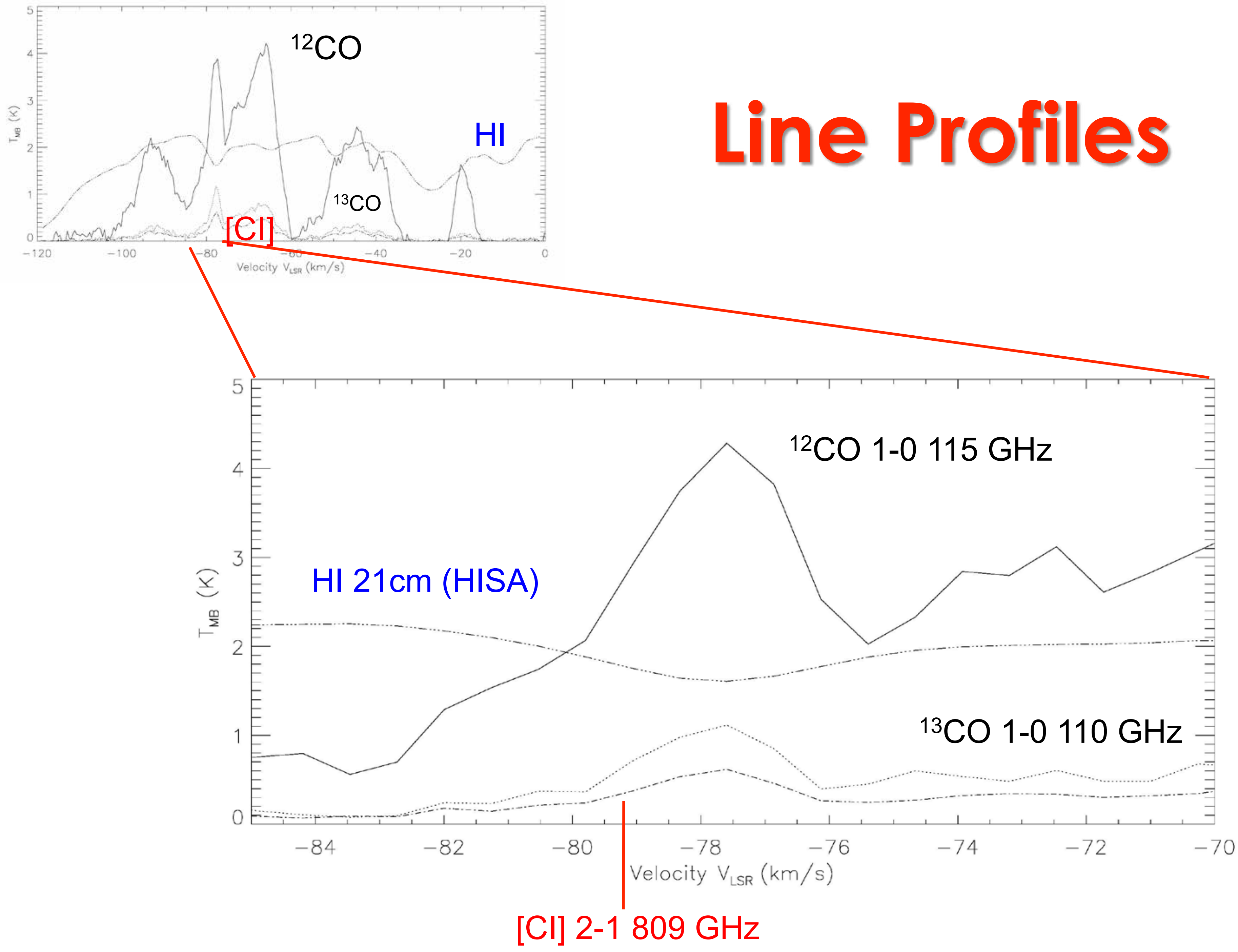
HI Image
(HISA)



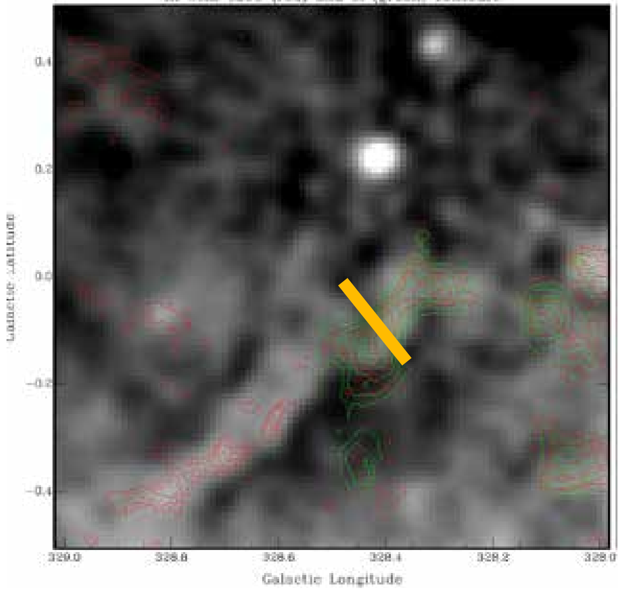
Burton et al. 2014 Ap. J. In press.

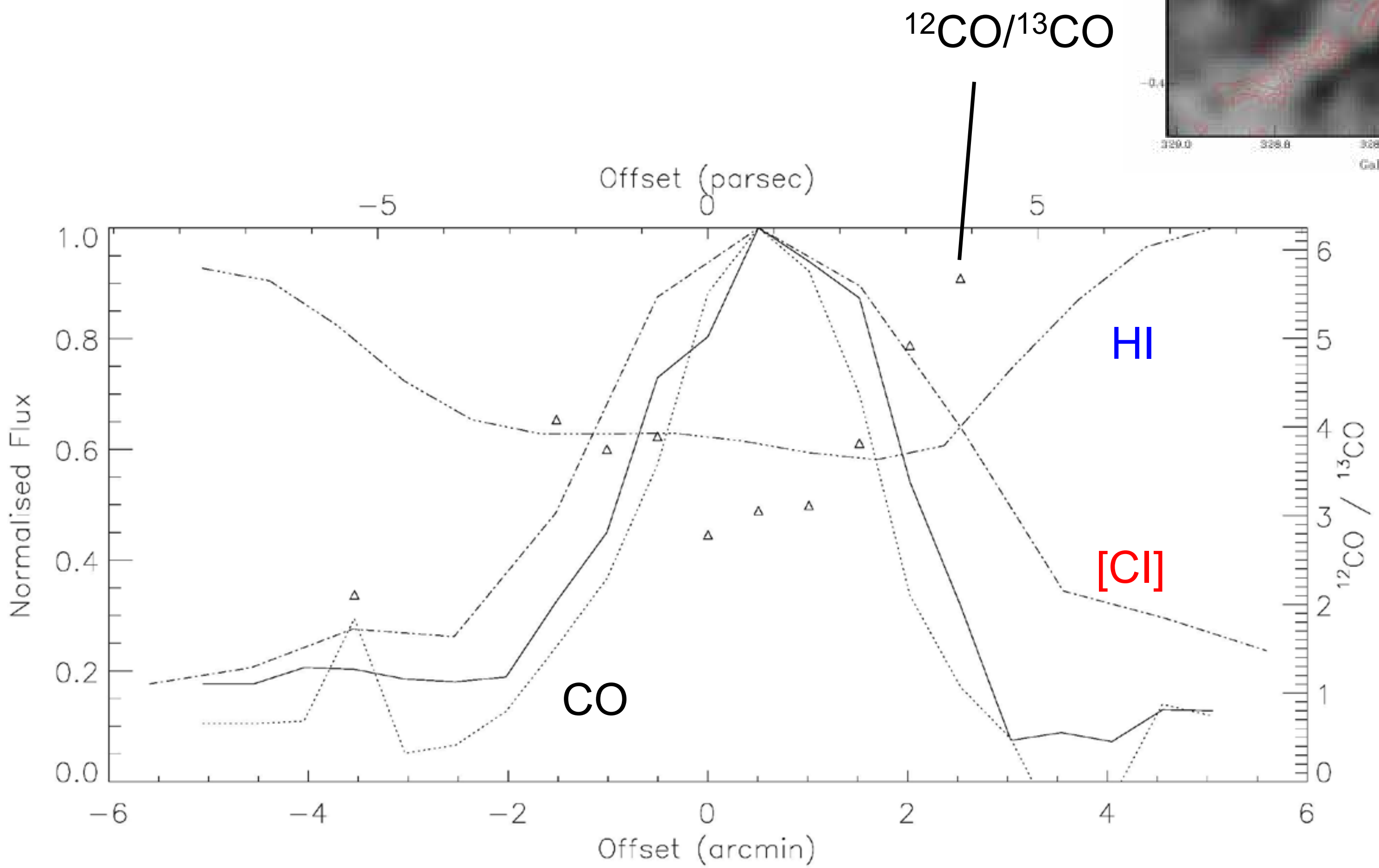
4 x 10^4 $M_\odot$ 75pc-long CO + CI filament (red green contours) @ 5kpc within HI self-absorption?

Line Profiles



Spatial Cut Across Filament





Is Carbon more extended than CO?

Calculating Column Densities

Upper Level: $$N_J = T_{MB}\Delta V \frac{8\pi k \nu_{JJ'}}{A_{JJ'}} \frac{\tau}{1-e^{-\tau}}$$

Total Column: $$N = \frac{N_J}{g_J} Q(T_{ex}) e^{T_J / T_{ex}} \text{ (Boltzmann)}$$

For HI emission: $$N_H = 1.8 \times 10^{18} T_{MB}\Delta V \ \text{cm}^{-2} \text{ (HI X-factor)}$$

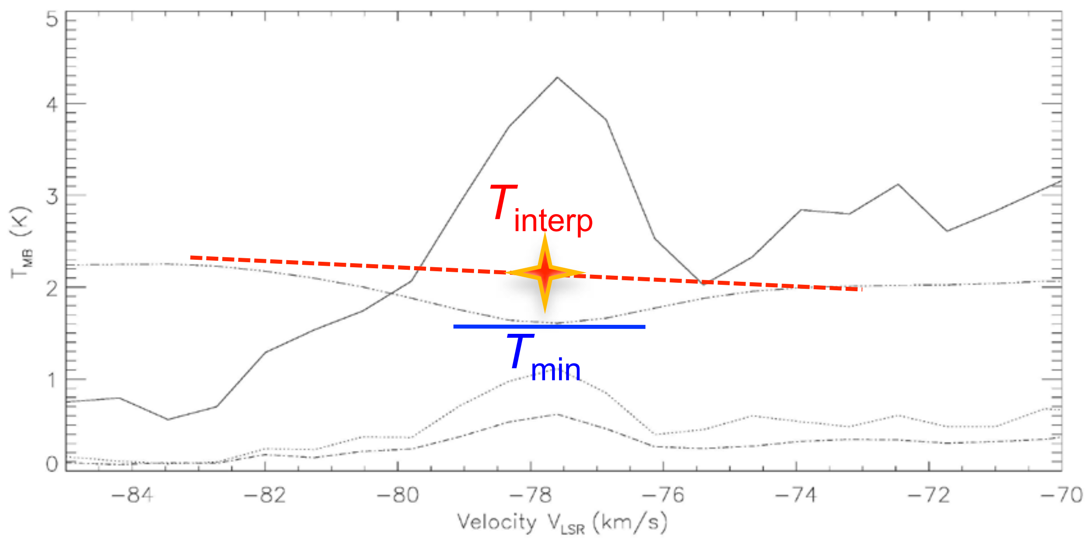
For HISA : $$N_H = 1.8 \times 10^{18} T_{Spin}\Delta V \, \tau_{\text{HISA}} \ \text{cm}^{-2}$$

HISA Column Densities

$$N_H = 1.8 \times 10^{18} T_{Spin} \quad \Delta V \, \tau_{\rm HISA} \ {\rm cm^{-2}}$$

$$\tau_{HISA} = \ln \frac{pT_{\rm interp} - T_{\rm Spin}}{T_{\rm min} + (p-1)T_{\rm interp} - T_{\rm Spin}}$$

Sato & Fukui 1978, Gibson et al. 2000
(with T_C=0K)



HI/50

Take T_{spin}=30K
For T_{spin}= [20K, 50K] multiply N_H by ~[0.5, 3] times

p is fraction of HI emission assumed to originate behind the filament
Take *p=1* ($p_{min}=1+(T_S-T_{min})/T_{interp} \sim 0.6$)
For *p=2/3* then multiply N_H by ~3 times

Column Densities and Abundances

τ_{CO}	ΔV (km/s)	HI_{min} (K)	HI_{Interp} (K)	τ_{HISA}
18	4	67	118	0.9

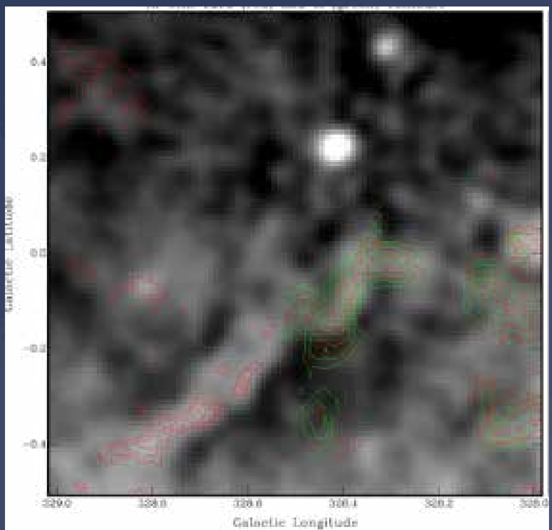
N(CO)	N(C)	$N(H_2)$ CO X-factor	N(HI) Emission	$N(H_{HISA})$ HISA	[C/CO]	[C/H]
10^{20} cm^{-2}	10^{20} cm^{-2}	10^{20} cm^{-2}	10^{20} cm^{-2}	10^{20} cm^{-2}	Integrated	From H_2 + CO X-factor
0.005	0.003	50	7	2	0.5	~$8x10^{-5}$

A PDR Model for the G328 Filament

Parameter	Value
A_V	7.2 mags.
Pressure / k	2.0×10^4 K cm^{-3}
G_0 (radiation field)	3 Habings
ΔV (Doppler Width)	2.4 km/s
ζ cosmic rays	2.0×10^{-16} s^{-1}
[C/H] abundance	1.6×10^{-4}

Parameter	Value
$T(\tau_{CO}=1)$	25 K
$n_{H2}(\tau_{CO}=1)$	650 cm^{-3}

~75x5pc, M~4×10^4 $M_\odot$, ΔV=4 km/s
T_{dust}<20K, L/M<0.5$L_\odot/M_\odot$
Quiescent, No (massive) star formation.
GMC in the process of formation?



➔ Beam filling factor of ~0.5

Quantity	Unit	Model	Observed
N(H)	x10^{20} cm^{-2}	7.5	7 or 2??
N(C^+)	x10^{17} cm^{-2}	2.4	???
N(C)	x10^{17} cm^{-2}	4.7	5
N(CO)	x10^{18} cm^{-2}	1.4	3
I (^{12}CO 1-0)	K km/s	51	26
I (^{13}CO 1-0)	K km/s	15	9
I ([CI] 1-0)	K km/s	21	???
I ([CI] 2-1)	K km/s	9	4
I ([CII])	K km/s	2.4	???

Testing the Hypothesis: “A cold, quiescent molecular cloud in the process of formation”

Question	Tool
Is there a “dark” molecular envelope to the molecular cloud?	[CI] 1-0 Nanten2 @ 30’’ c.f. Mopra CO
How cold is it?	[CI] 1-0 (Nanten2) / 2-1 (HEAT)
Where is all the carbon?	[CII] with HEAT or STO-2