Turbulence, feedback and star formation in the G333 molecular cloud complex

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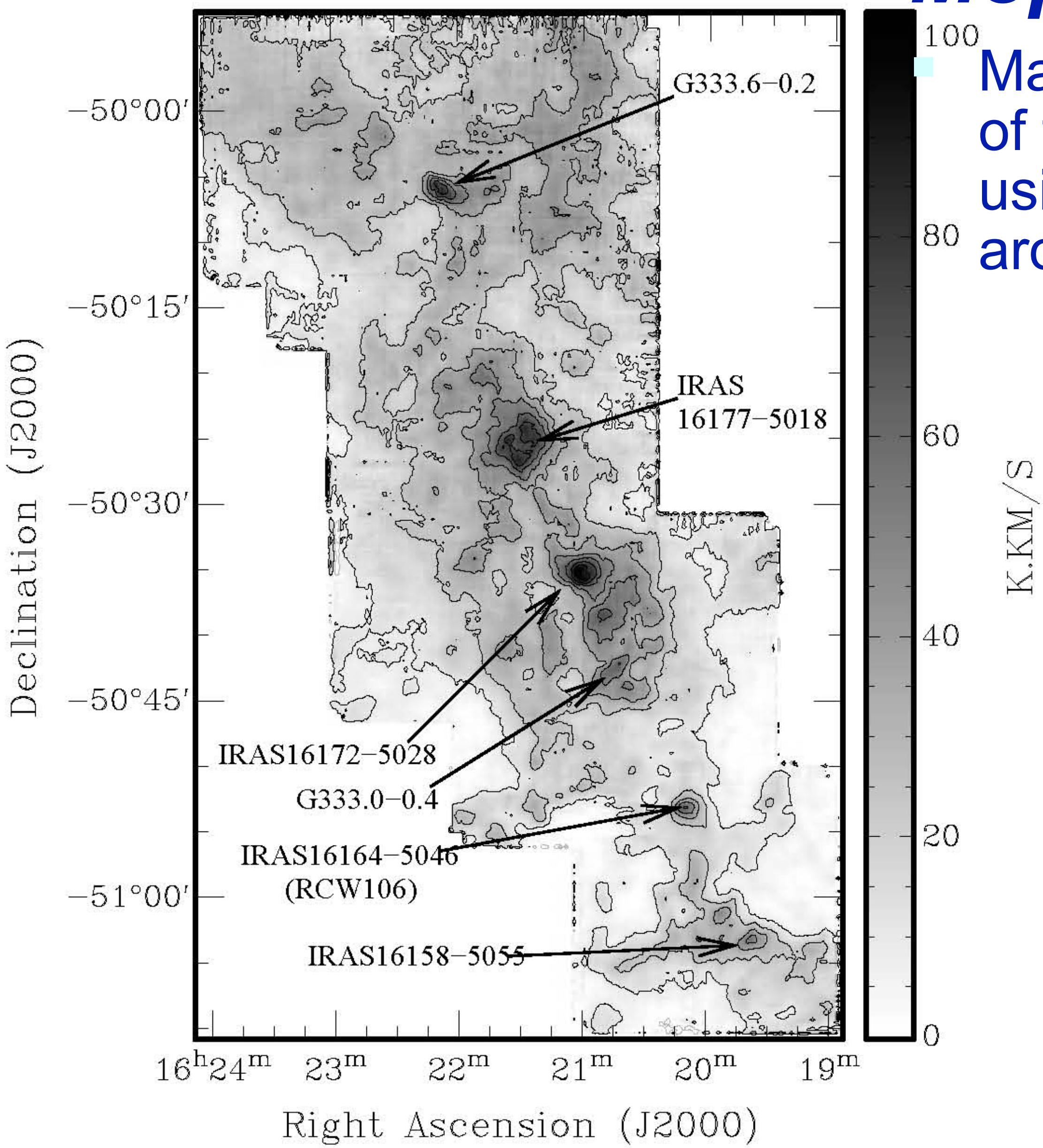
The G333 Region



Mopra G333 survey

- Mapping of ~0.6 x 1.2° region of the southern Galactic plane using the Mopra telescope, in around twenty 3-mm transitions

Integrated Mopra ^{13}CO emission (Bains et al. 2006 MNRAS 367 1609).

Velocity resolution 0.1 to 0.2 km/s

C180: Wong et al. 2008 MNRAS, 386, 1069.

Other Molecules: Lo et al., 2008 – hopefully!

G333: 4 kpc distant. Spatial resolution ~1 pc.

^{13}CO, C^{18}O data now publicly available on request: maria.cunningham@unsw.edu.au

Mopra

- **22-m Telescope**
  - λ of 3, 7, 12 mm,
  - 35” beam @ 100 GHz
- **78–116 GHz MMIC receiver**
  - 8-GHz bandwidth
- **DFB backend (“correlator”)**
  - 2 polarizations, 64,000 channels.
  - Broadband ~ 0.67 km/s resolution,
  - zoom mode ~0.1 km/s, 16 zoom bands, 137 MHz wide.
- **OTF Mapping**

Molecules

- 2004 ^{13}CO (64 MHz, 0.2 km/s)
- 2005 $C^{18}O$, CS (64 MHz, 0.2 km/s)
- 2006 (137 MHz bandwidth, 0.1 km/s resolution)
  - July, Aug, 84 to 90 GHz: HCN, HNC, HCO^+, HC_3N C_2H, SiO, CH_3OH, $H^{13}CN$, $H^{13}CO^+$
  - Sep, Oct, 93 to 100 GHz: CH_3OH, N_2H^+, OCS, SO, CS, HC_3N and optically thin isotopologues.
- 2007
  - 108 to 116 GHz: CH_3CN, CH_3OH, CN, $C^{17}O$, HC_3N

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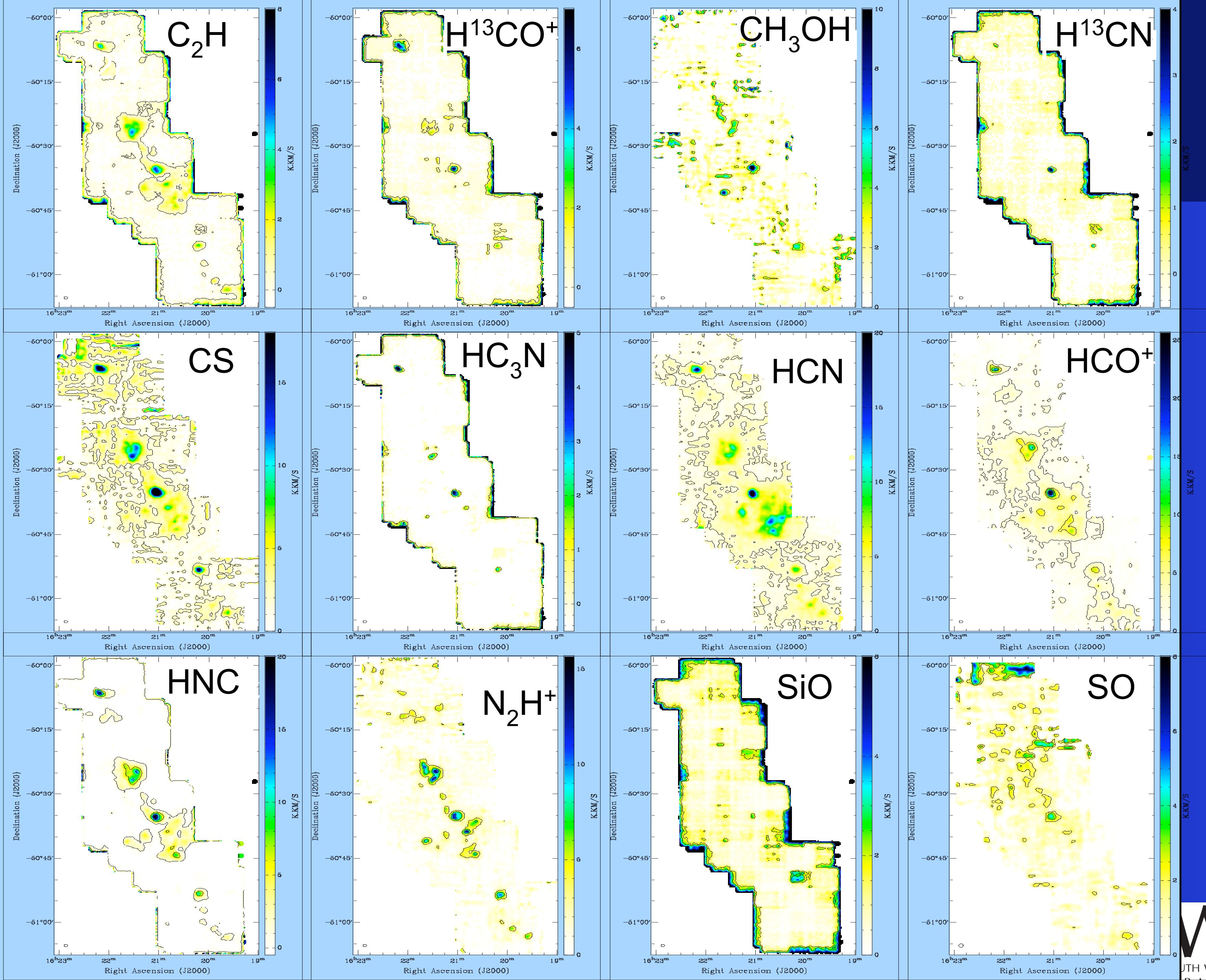

C_2H
$H^{13}CO^+$
CH_3OH
$H^{13}CN$
CS
HC_3N
HCN
HCO^+
HNC
N_2H^+
SiO
SO
Declination (J2000)
Right Ascension (J2000)
K.KM/S

Some Movies

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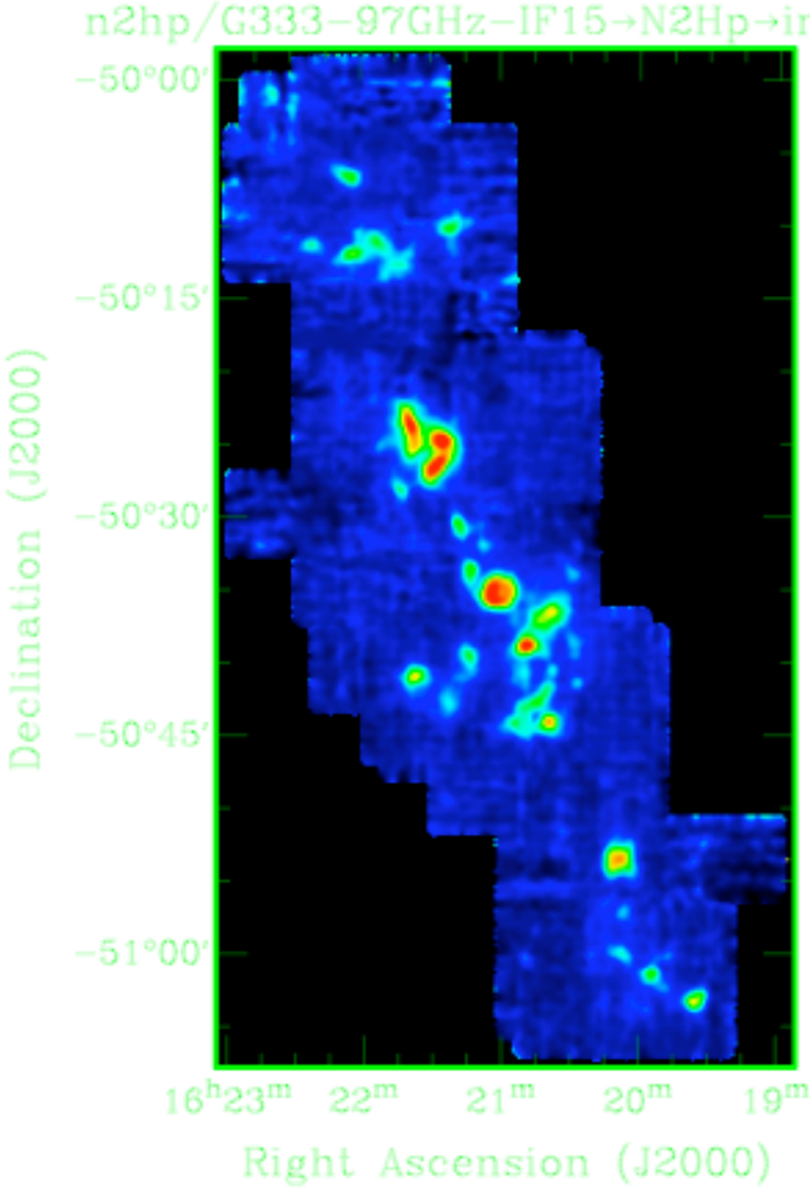
Turbulence, feedback and star formation

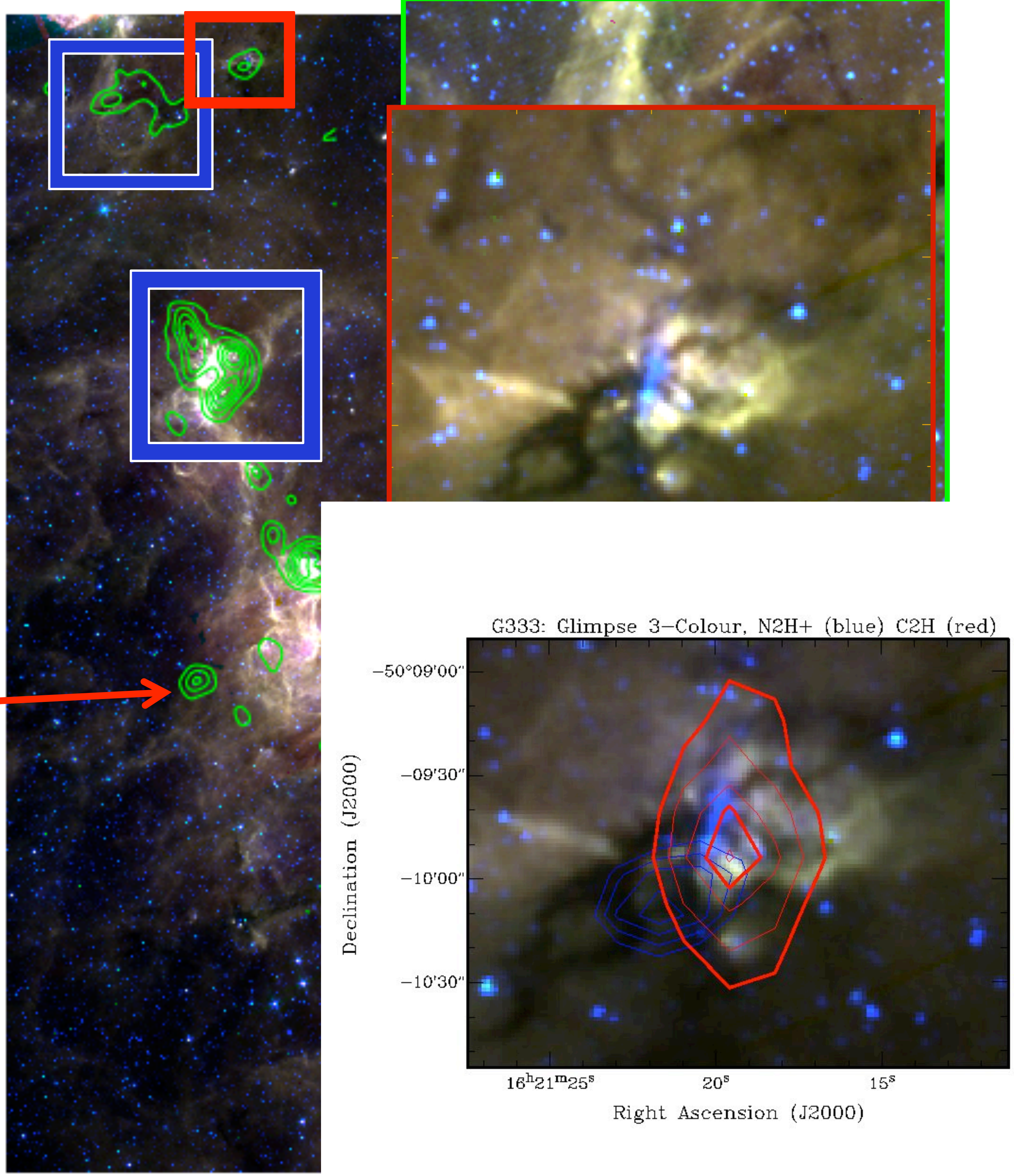
- Driving scales for turbulence: Galactic scale, stellar feedback? - Can we see them in this data?
- Do molecules with different critical densities trace regions with different turbulent properties?
- What effect does turbulence/ dynamics have on chemistry?
- Does feedback commonly trigger star formation?



N_2H^+ 1-0

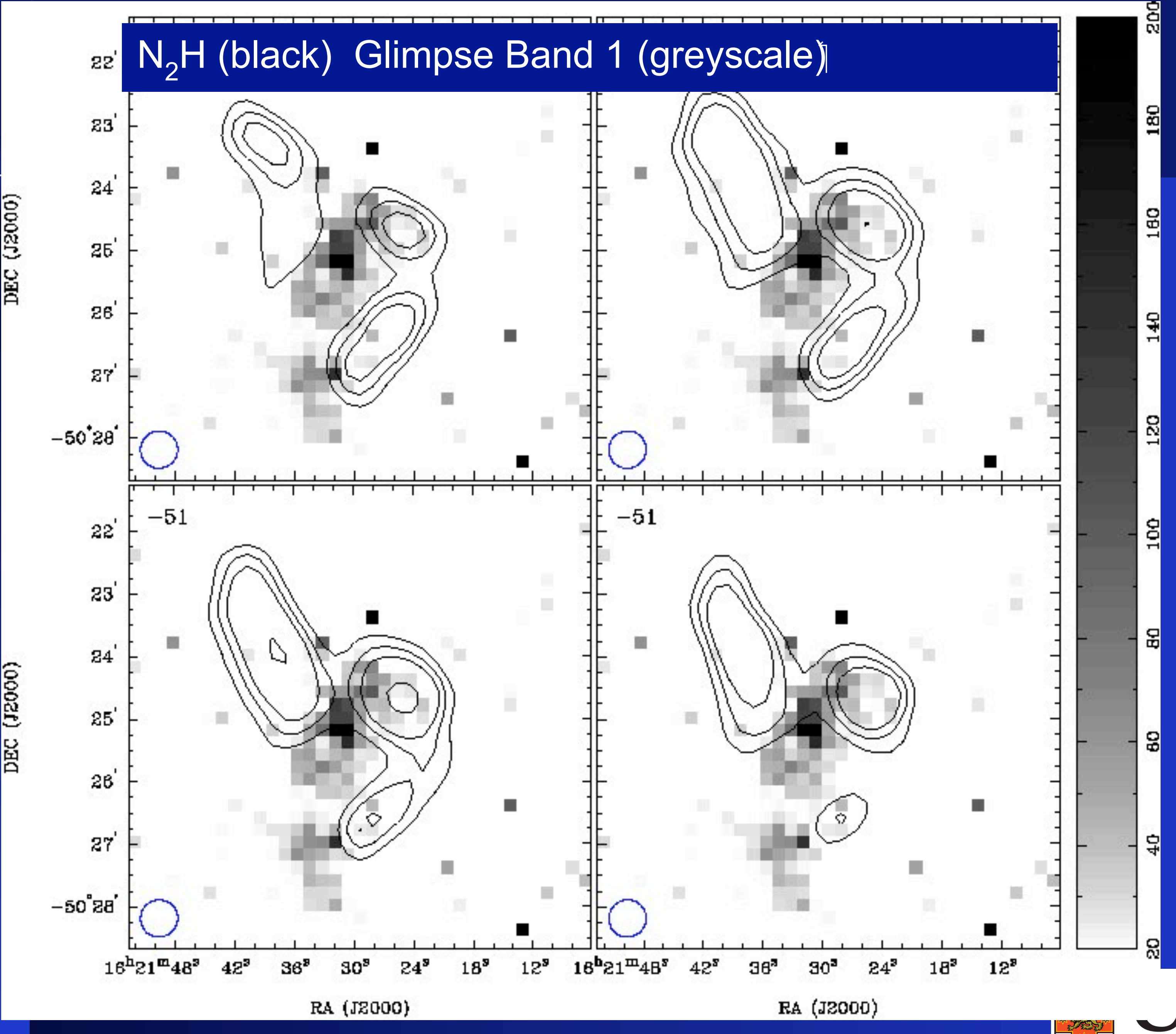
Tracing cool CO depleted gas?

Detection of Silicon Monoxide from a Massive Dense Cold Core (Lo et al., 2007, MNRAS, 381, L30)



GLIMPSE 3 colour (3.6, 4.5, 8.0 μm) overlaid with N2H+

N_2H (black) Glimpse Band 1 (greyscale)



Spatial Power Spectrum

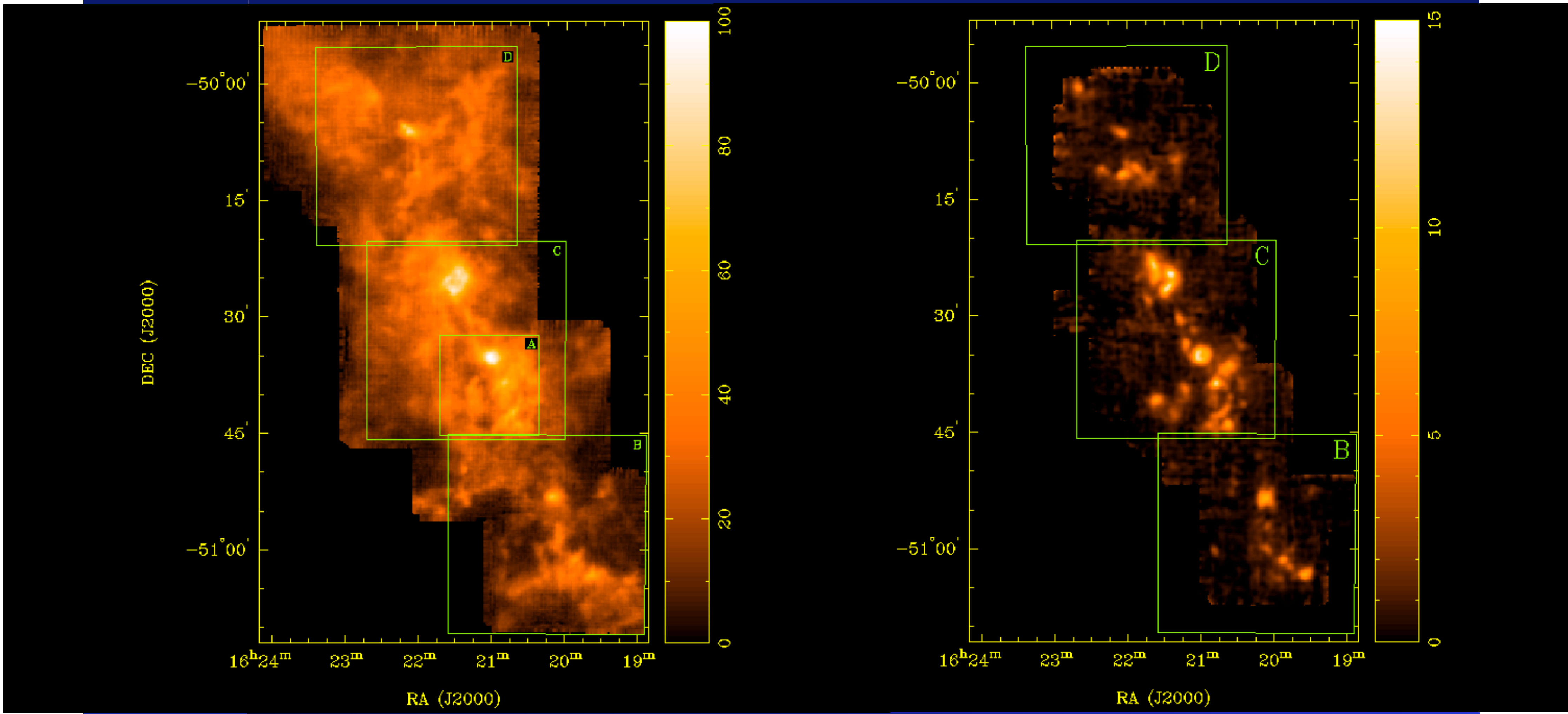
- Work by Paul Jones

- The Spatial Power Spectrum (SPS) is obtained as the power (P) in the image, as a function of spatial scale
- The power here, in the statistical sense, is the square of the amplitude of the Fourier Transform of the image, which we plot in the FT domain as a function of spatial frequency (k).

- The SPS algorithm is then:

- (Fast) Fourier Transform the 2-D image to get

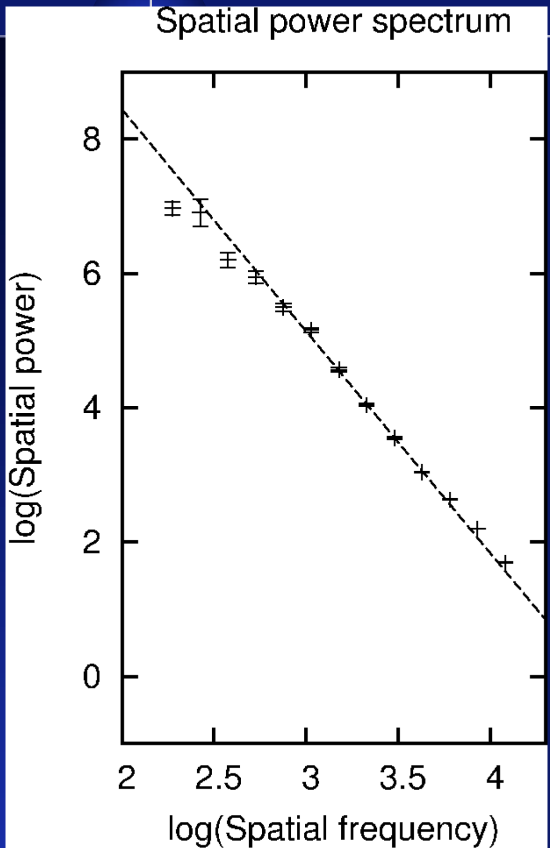
$$P = A^2 = (Re)^2 + (Im)^2$$

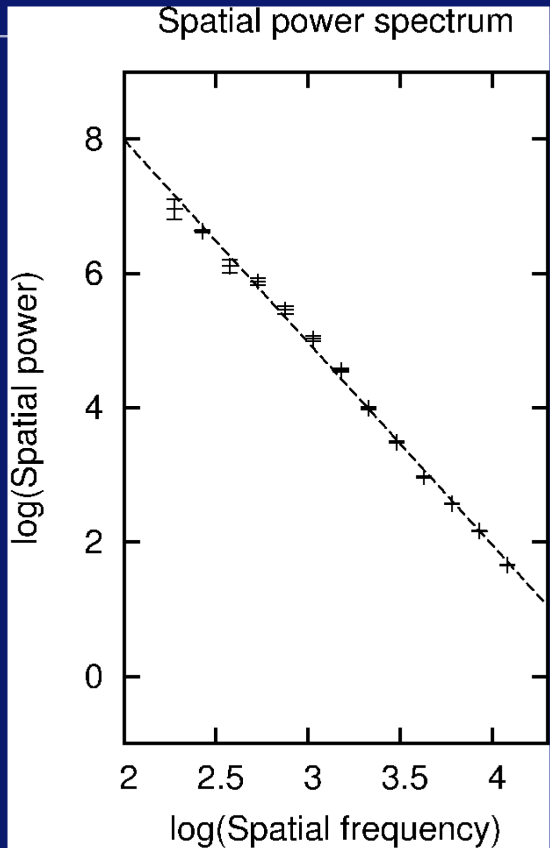

DEC (J2000)
−50°00′
15′
30′
45′
−51°00′
16h24m
23m
22m
21m
20m
19m
RA (J2000)
A
B
C
D
0
20
40
60
80
100
5
10
15

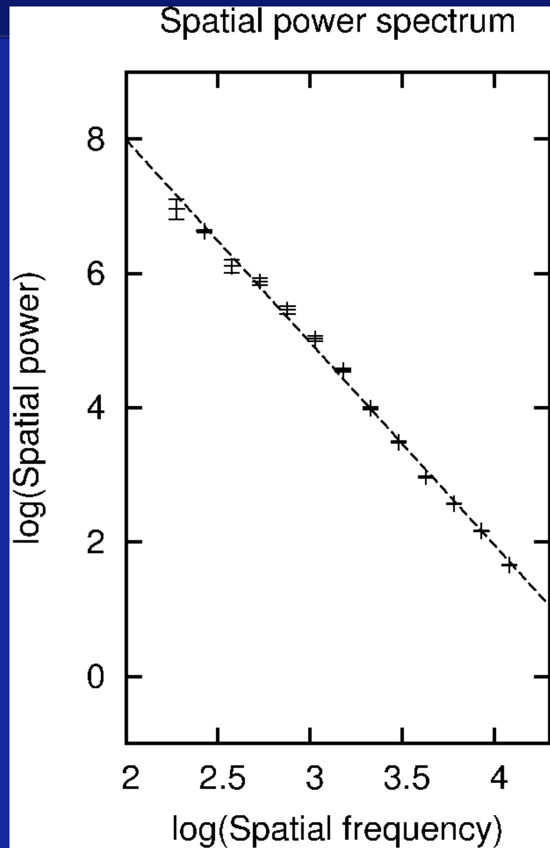
^{13}CO

N_2H^+

1) Power law SPS







B C D

^{13}CO mean for 64 channels (~ 1 -20 pc)

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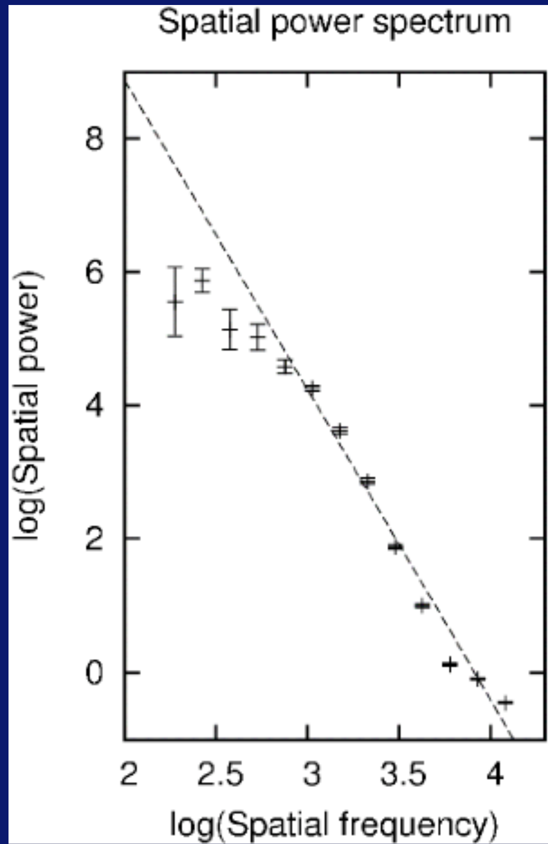
Different molecules

Slope
(mean for areas B, C and D,
integrated emission, noise corrected)

^{13}CO	-3.8
$C^{18}O$	-3.6
corrected ^{13}CO	-3.4
CS (MOPS)	-4.2 *
HNC	-3.9
HCO^{+}	-4.0
HCN	-4.1
N_2H^{+}	-3.4



Similar power law slopes, indicating 'fractal structure' , except some indication of deficit of large-scale power e.g. CS here (Area C), which may give poorer fit to power law, c.f 3-D Kolmogorov = -11/3 = -3.7

Jones et al. (in prep)   Uncertainty in slopes ~10%

Some Results

The data generally fit a good power law (scales ~1 to 20 pc)

Optical depth affects the slope for ^{13}CO (flattens slope)

The slope depends on the velocity smoothing (2D -> 3D Kolmogorov)

The slope depends on the area within the G333 complex

The slope does NOT change much for the different molecules (perhaps surprisingly)

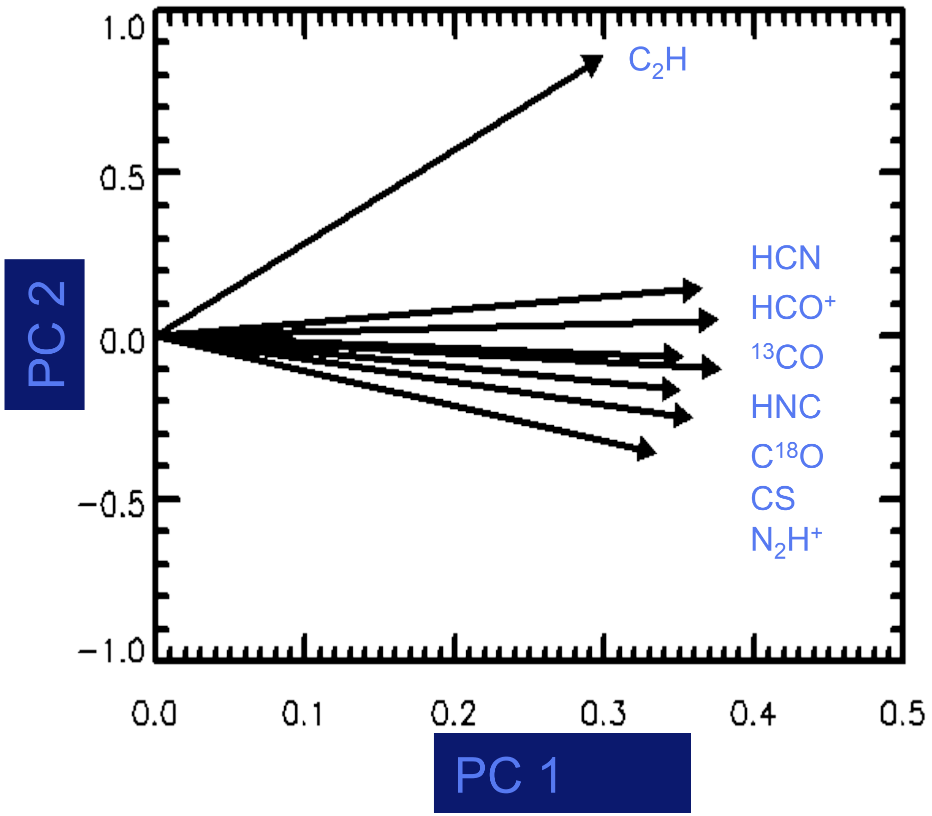
BUT there is a deficit of large-scale power for molecules other than CO

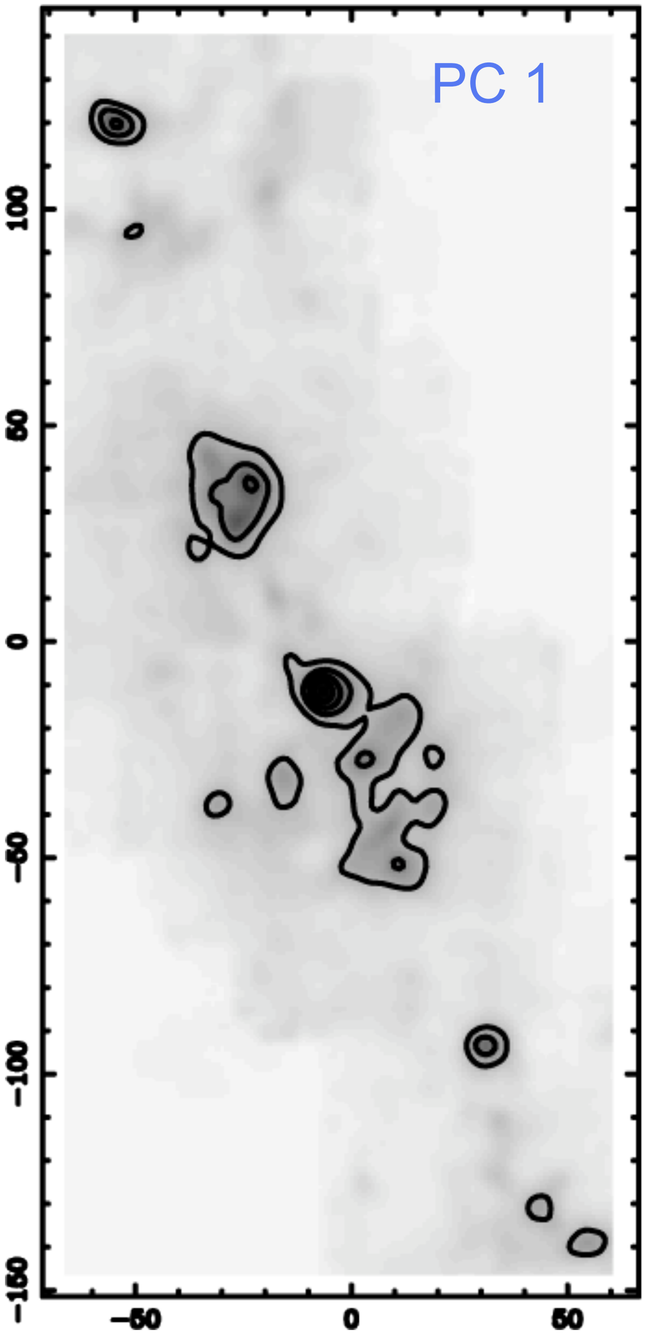
Principal Component Analysis

Correlation matrix (Work by Nadia Lo)

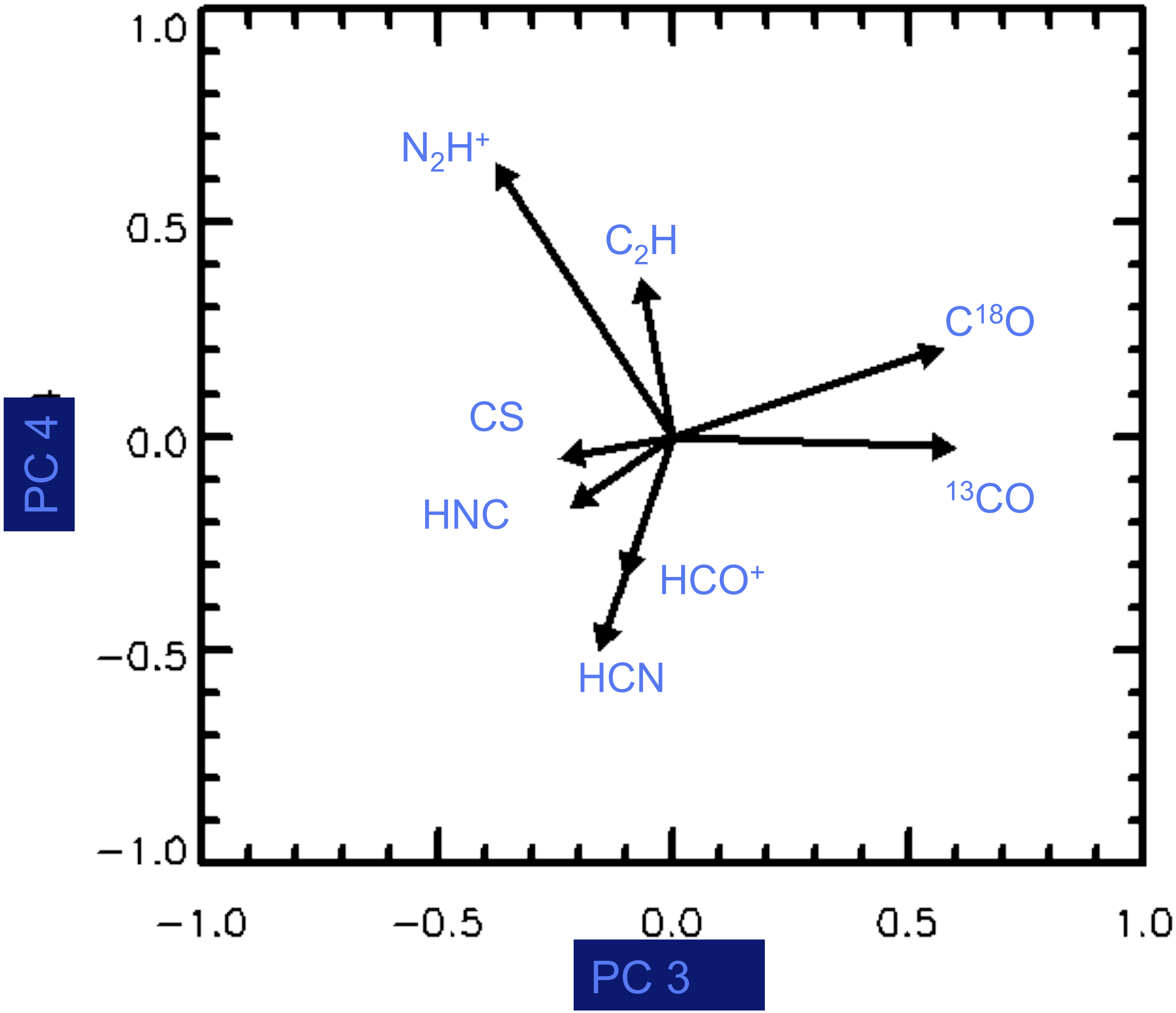
	CS	HCO^+	HNC	$C^{18}O$	C_2H	HCN	N_2H^+	^{13}CO
CS	1.00							
HCO^+	0.85	1.00						
HNC	0.90	0.92	1.00					
$C^{18}O$	0.77	0.80	0.81	1.00				
C_2H	0.60	0.70	0.67	0.61	1.00			
HCN	0.81	0.94	0.90	0.75	0.70	1.00		
N_2H^+	0.80	0.76	0.82	0.73	0.56	0.71	1.00	
^{13}CO	0.77	0.82	0.81	0.88	0.63	0.79	0.69	1.00

Results [I]


1.0
0.5
0.0
−0.5
−1.0
0.0
0.1
0.2
0.3
0.4
0.5
PC 2
PC 1
C$_2$H
HCN
HCO$^+$
^{13}CO
HNC
C^{18}O
CS
N$_2$H$^+$

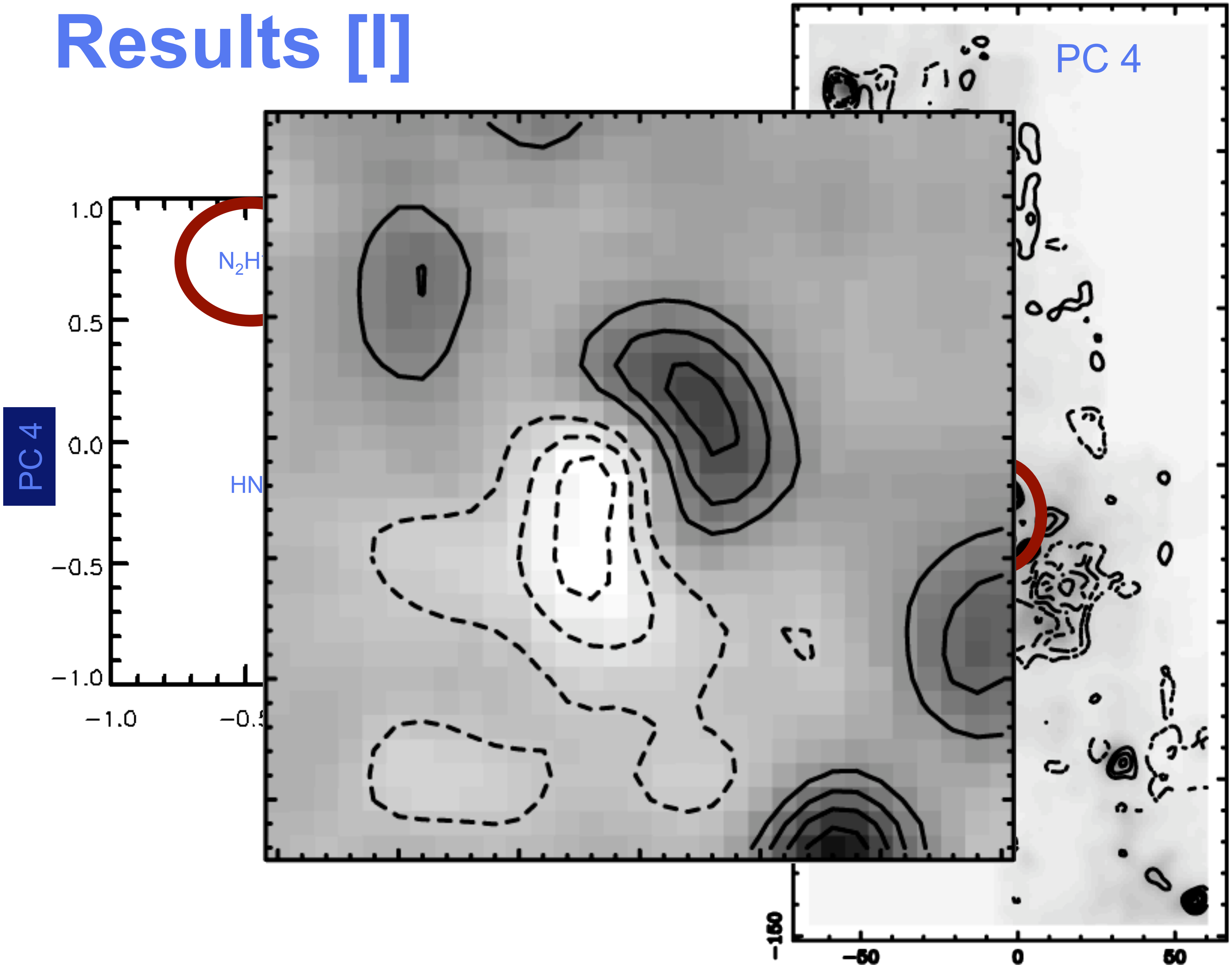

PC 1
100
50
0
−50
−100
−150
−50
0
50

Results [I]



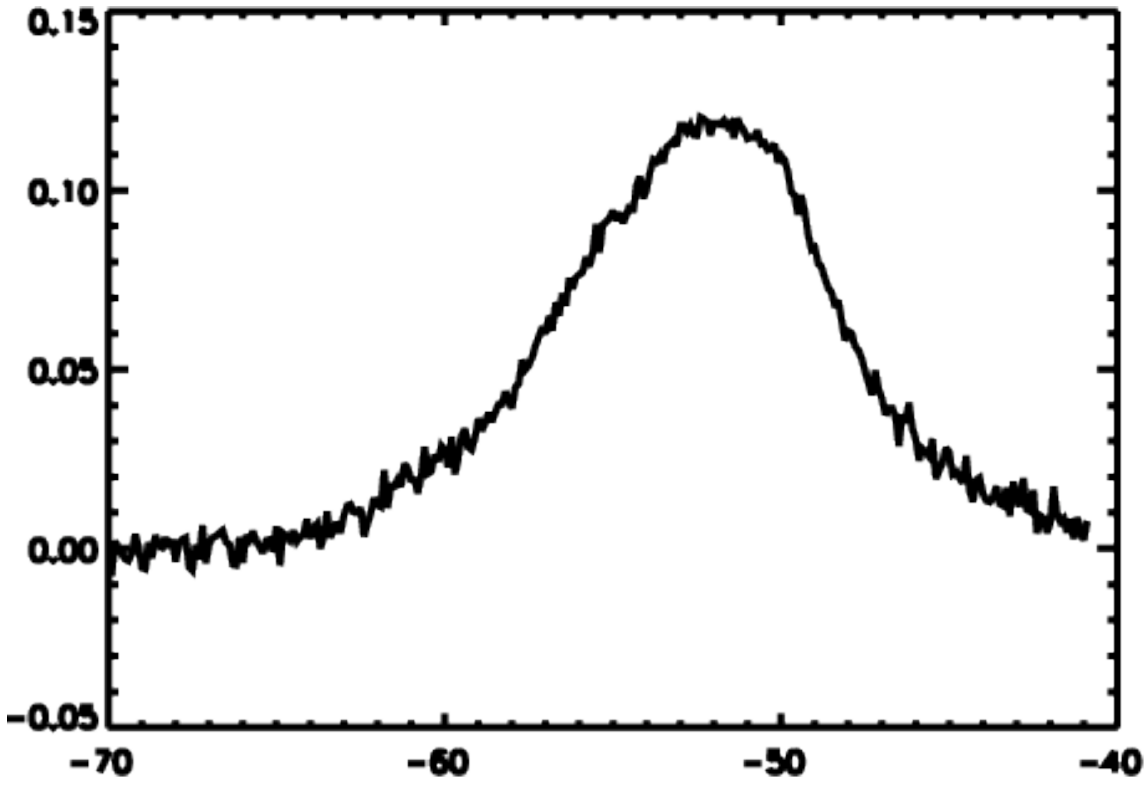
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
PC 4
PC 3
N_2H^+
C_2H
$C^{18}O$
CS
^{13}CO
HNC
HCO^+
HCN

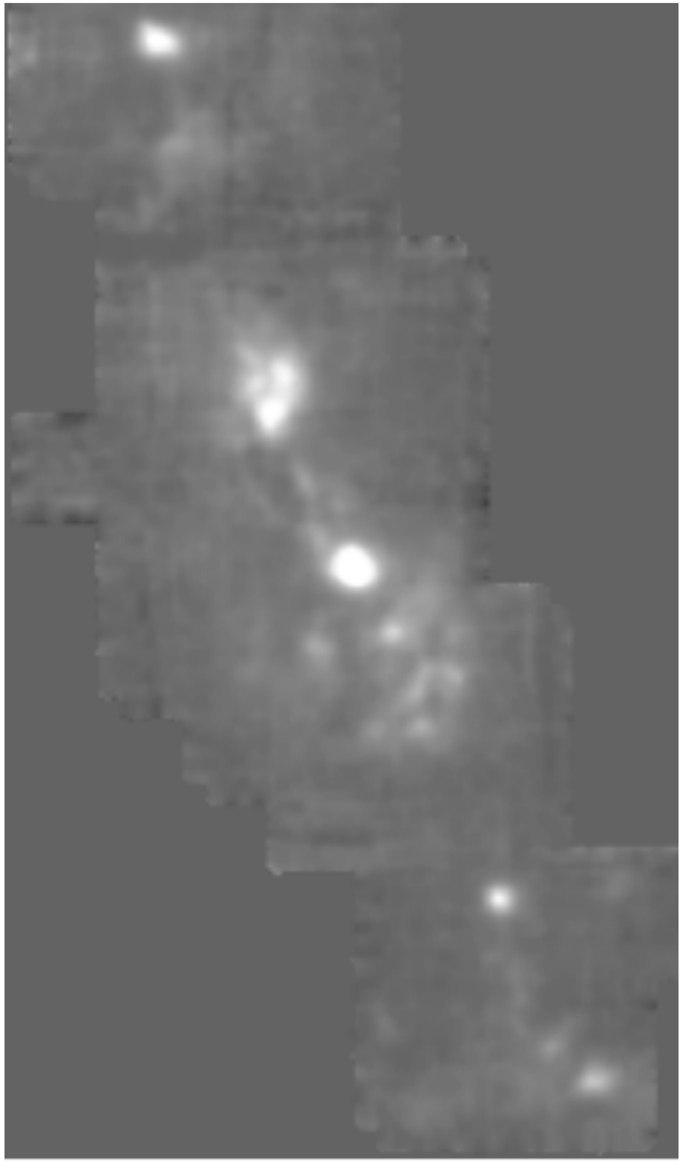
Results [I]



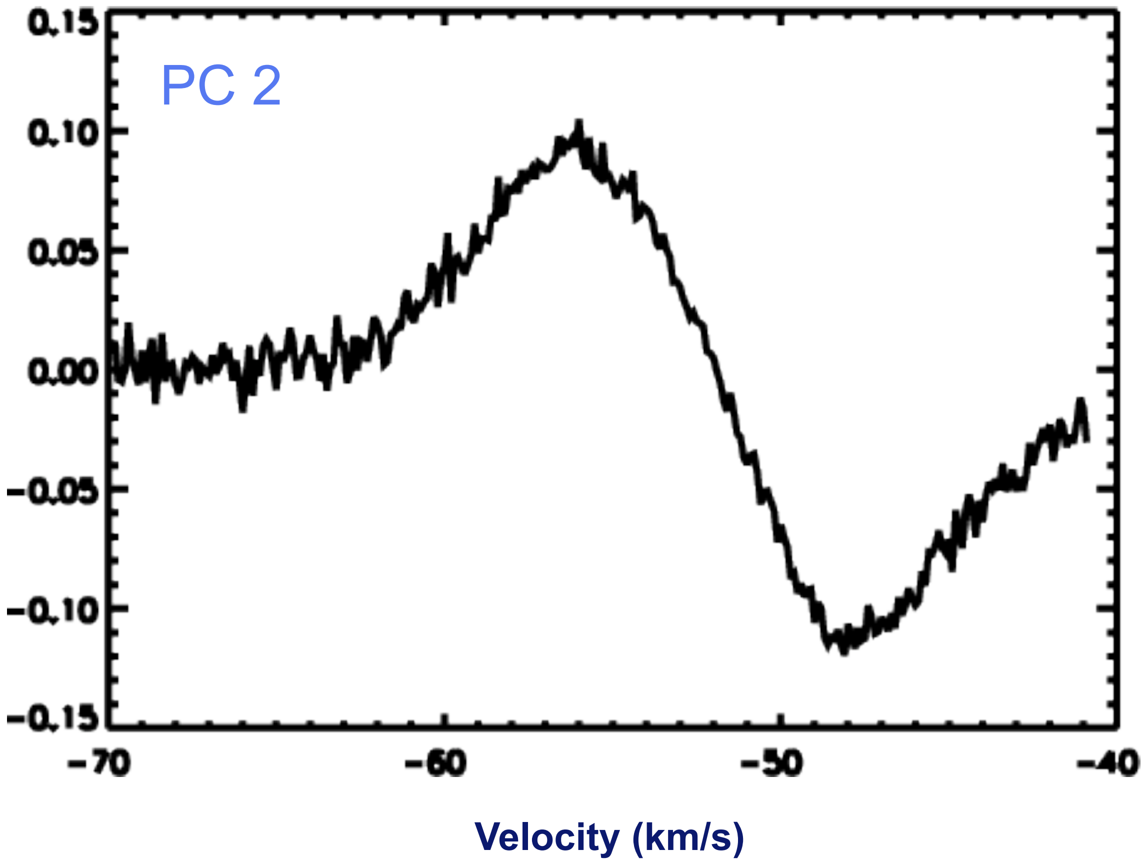
Results [II] - CS

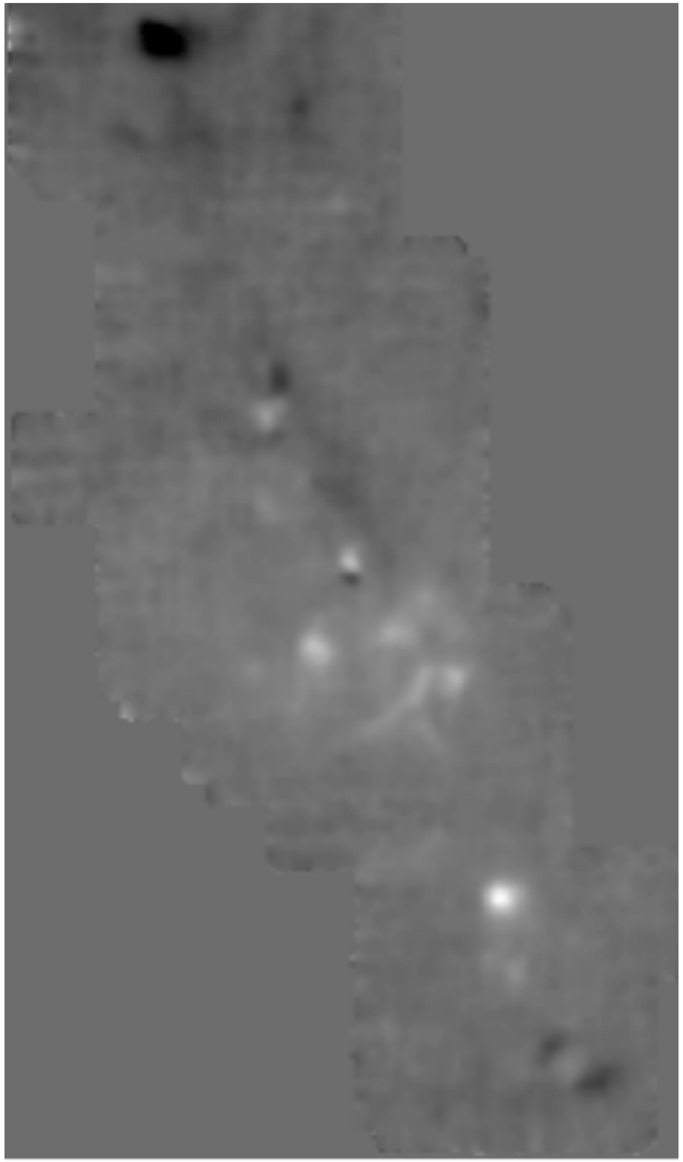
As per Heyer & Schloerb, 1977, ApJ, 475, 173





Results [II] - CS





How Can ALMA Help?

- The largest scales of molecular emission are defined by the spatial extent of the molecular cloud complex.
- The smallest scales available are defined by the resolution of the telescope
- ALMA will be able to probe smaller spatial scales and different gas tracers to find how energy flows through/ enters/ is dissipated in different parts of the ISM.
- The ACA will provide the zero spacing

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