High-J CO lines in Nearby Galaxies with the Herschel FTS and ALMA Band 9

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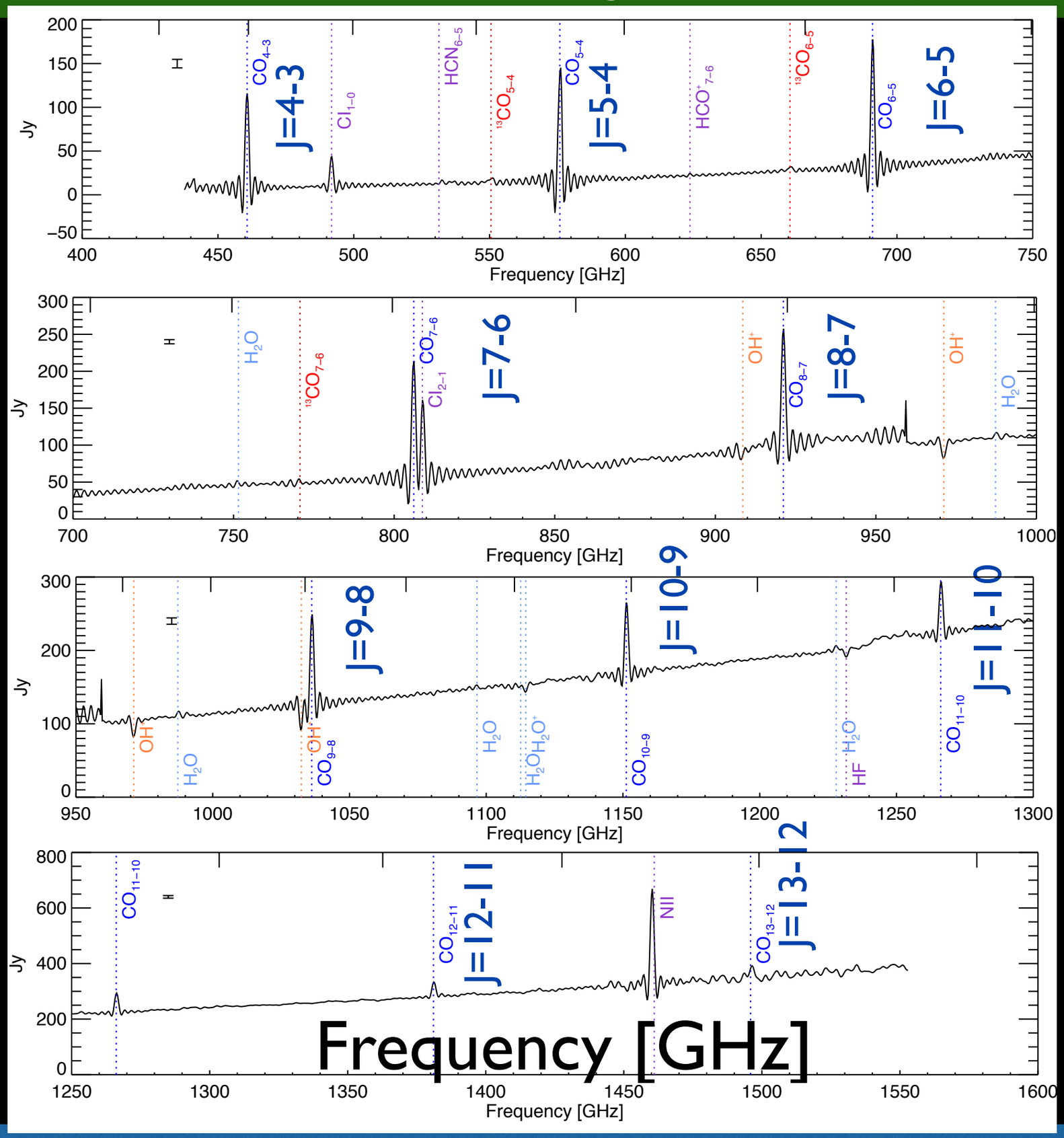
M82



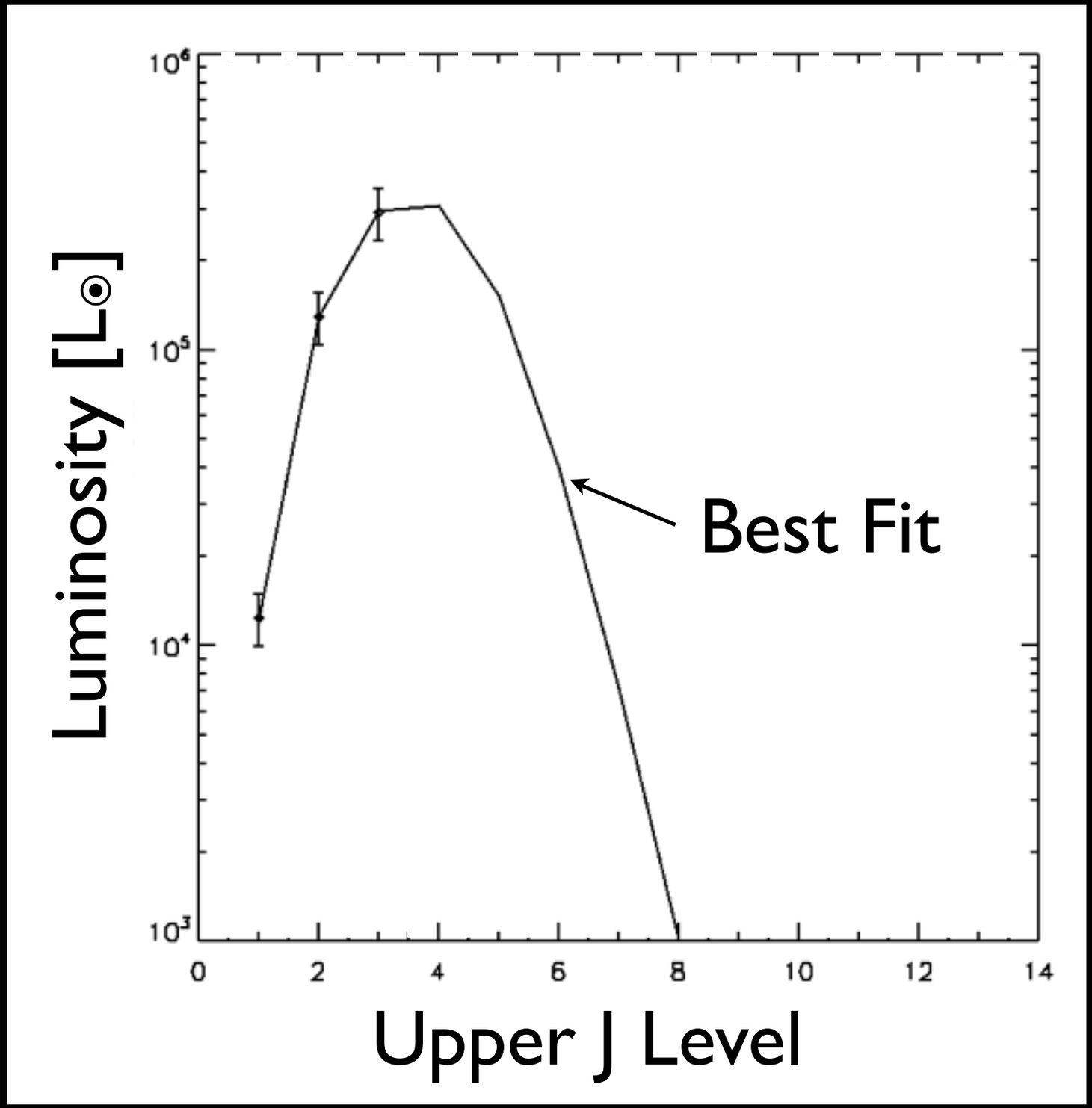
500 μm

350 μm

250 μm

Kamenetzky+ 2012

Spectral Line Energy Distribution = SLED

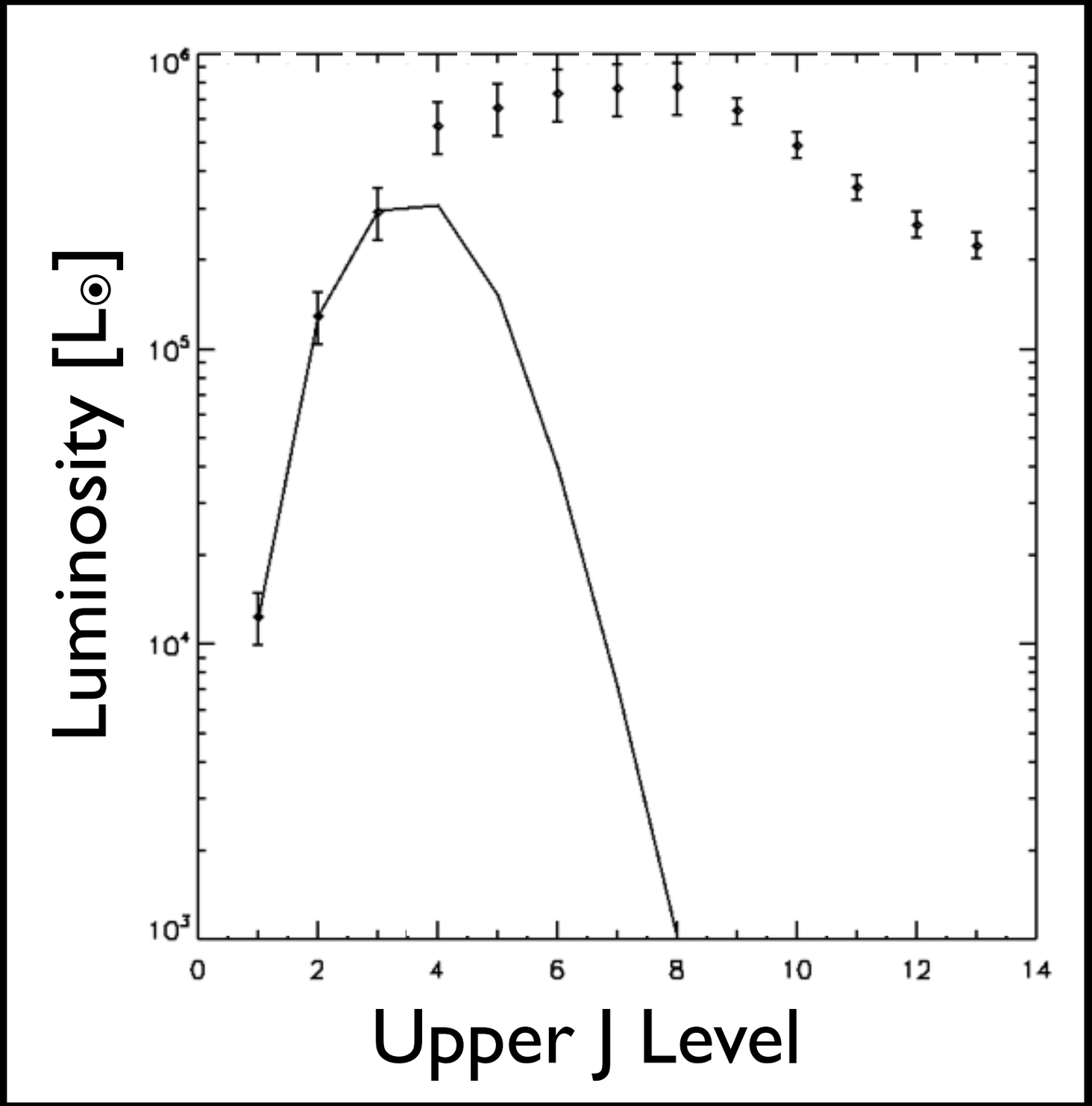


Kamenetzky+ 2012

Use the integrated CO line fluxes to understand the physical conditions of the ISM.

2 components required.

Spectral Line Energy Distribution = SLED



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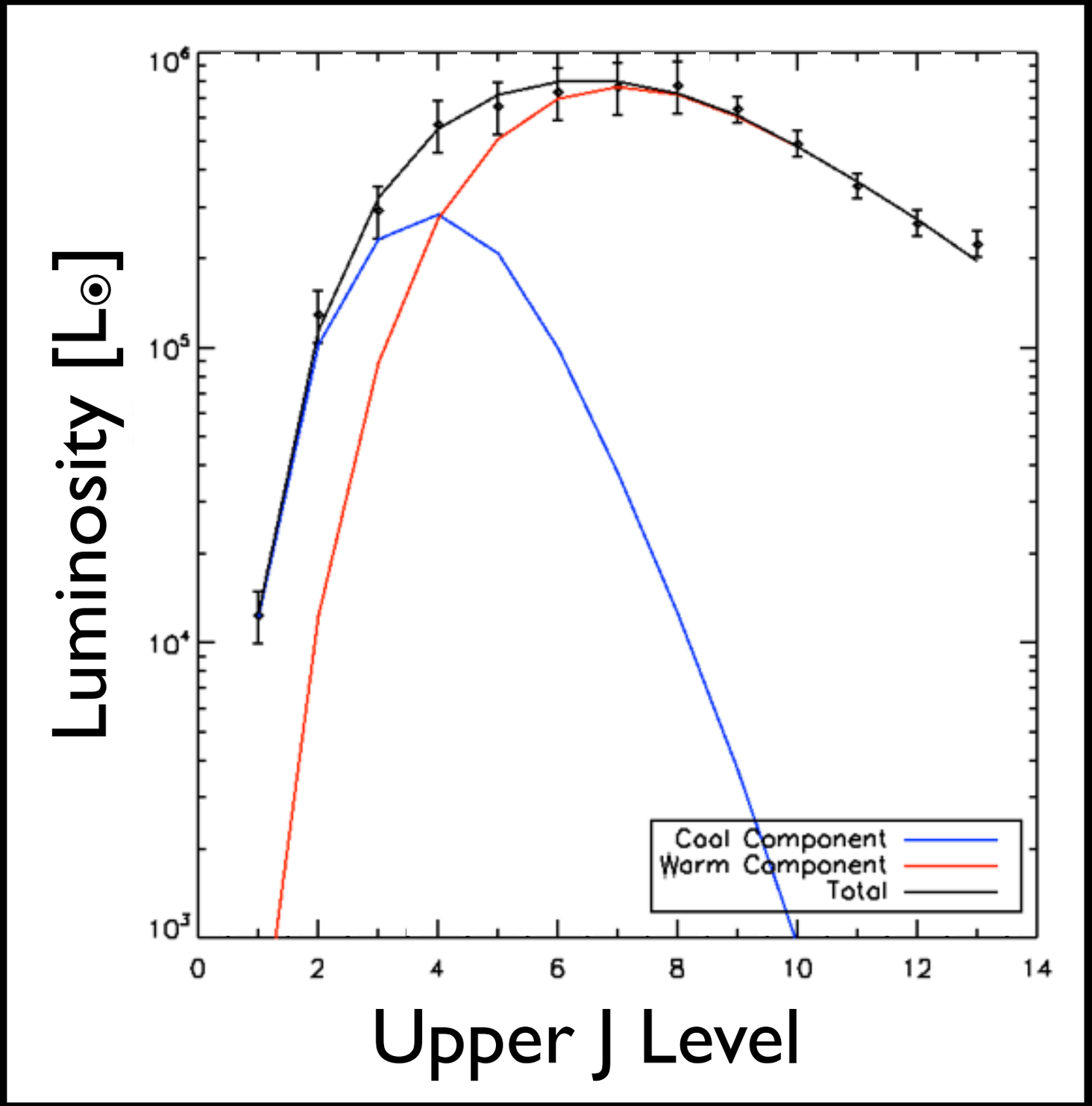

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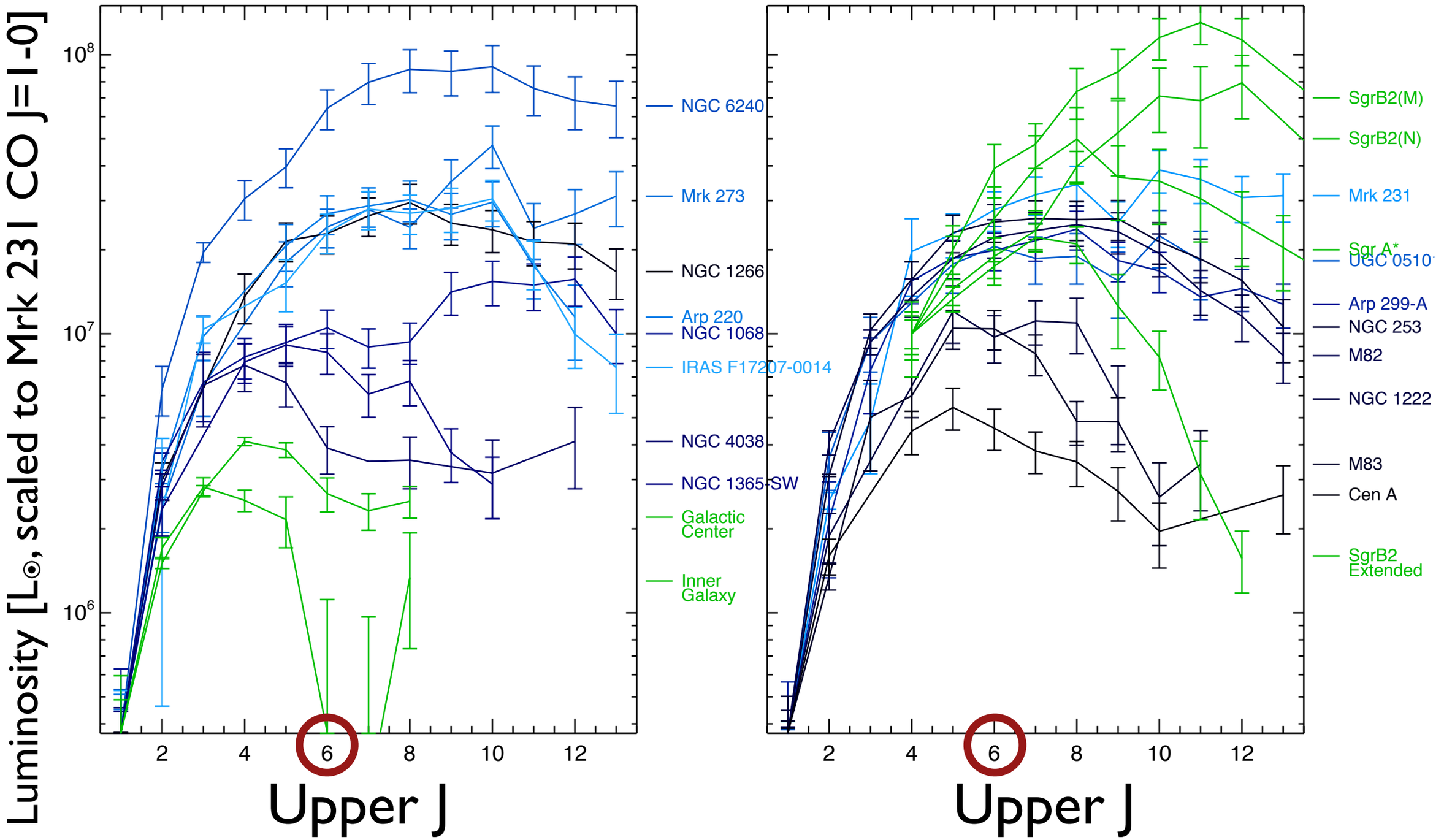
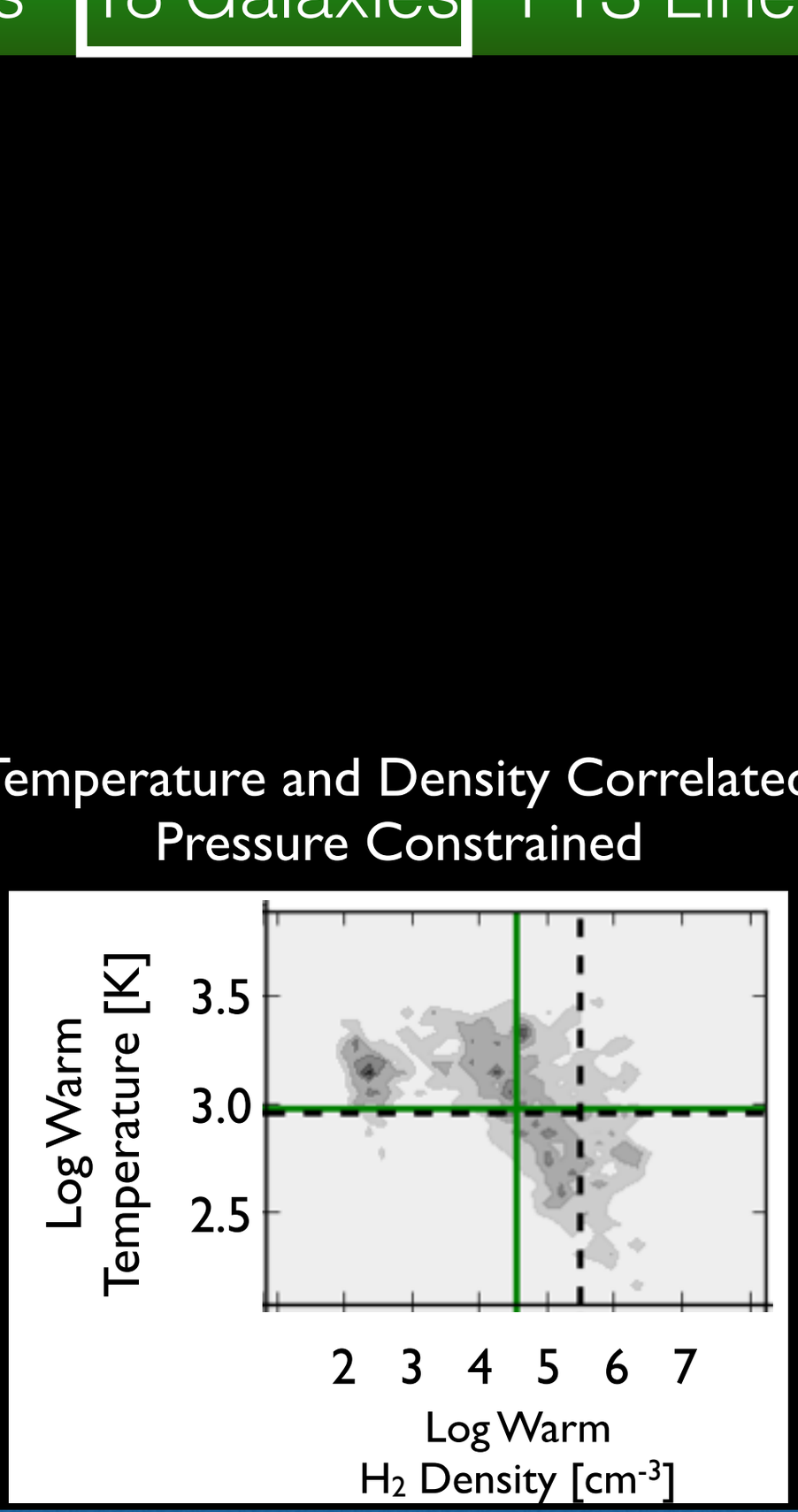
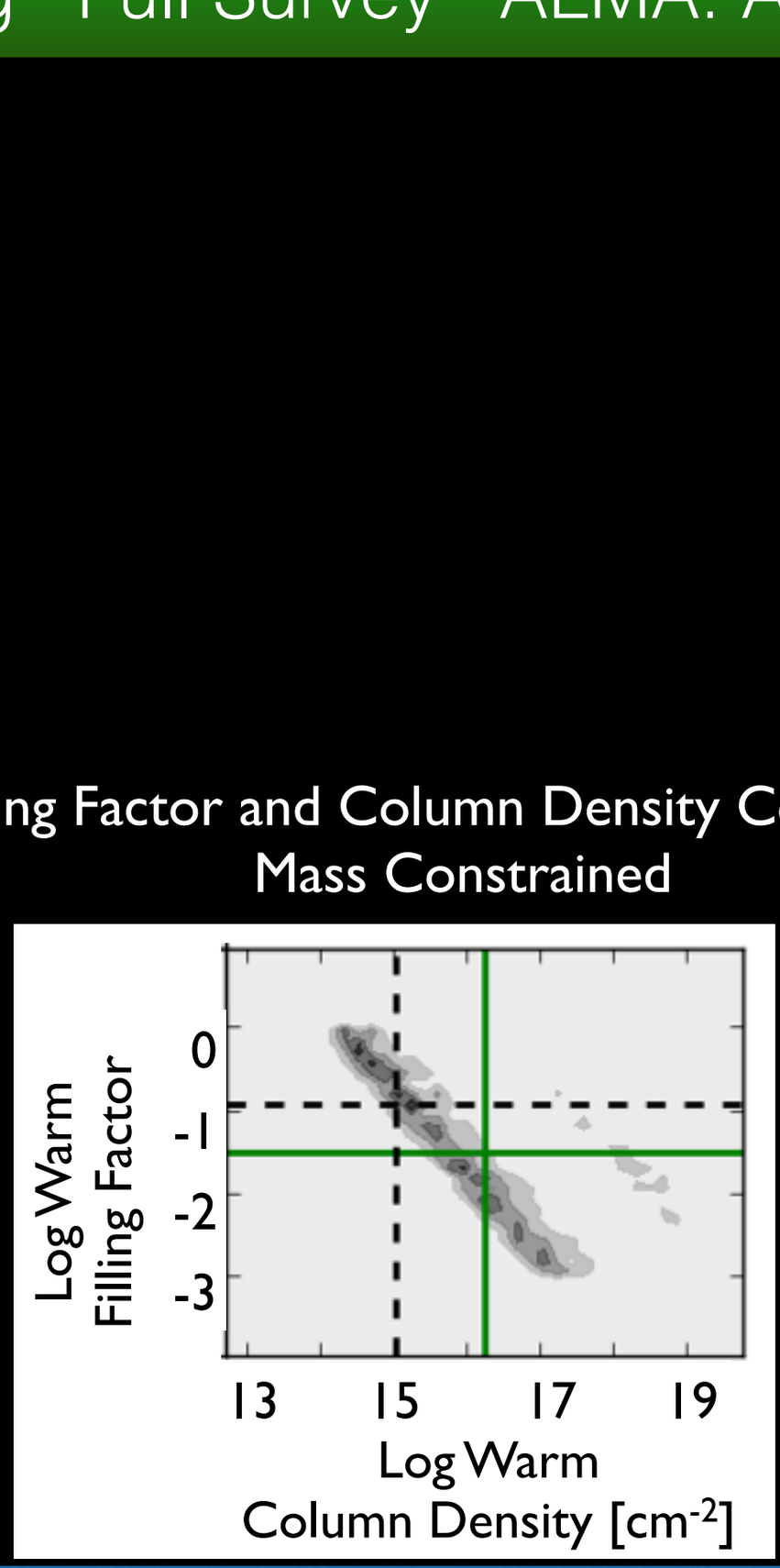

Luminosity [L⊙, scaled to Mrk 231 CO J=1-0]
10^8
10^7
10^6
2
4
6
8
10
12
Upper J
NGC 6240
Mrk 273
NGC 1266
Arp 220
NGC 1068
IRAS F17207-0014
NGC 4038
NGC 1365-SW
Galactic Center
Inner Galaxy
SgrB2(M)
SgrB2(N)
Mrk 231
Sgr A*
UGC 0510
Arp 299-A
NGC 253
M82
NGC 1222
M83
Cen A
SgrB2 Extended

github.com/jrk/PyRadexNest

Temperature and Density Correlated:
Pressure Constrained



Filling Factor and Column Density Correlated:
Mass Constrained



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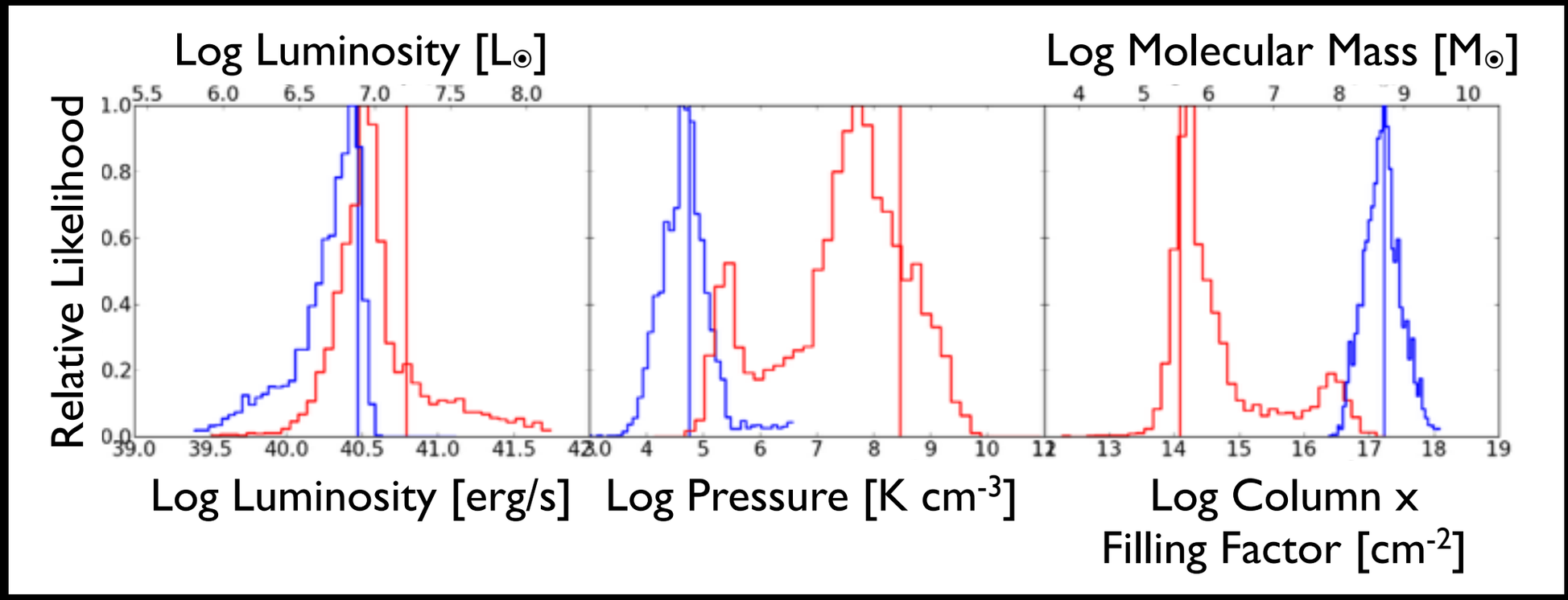

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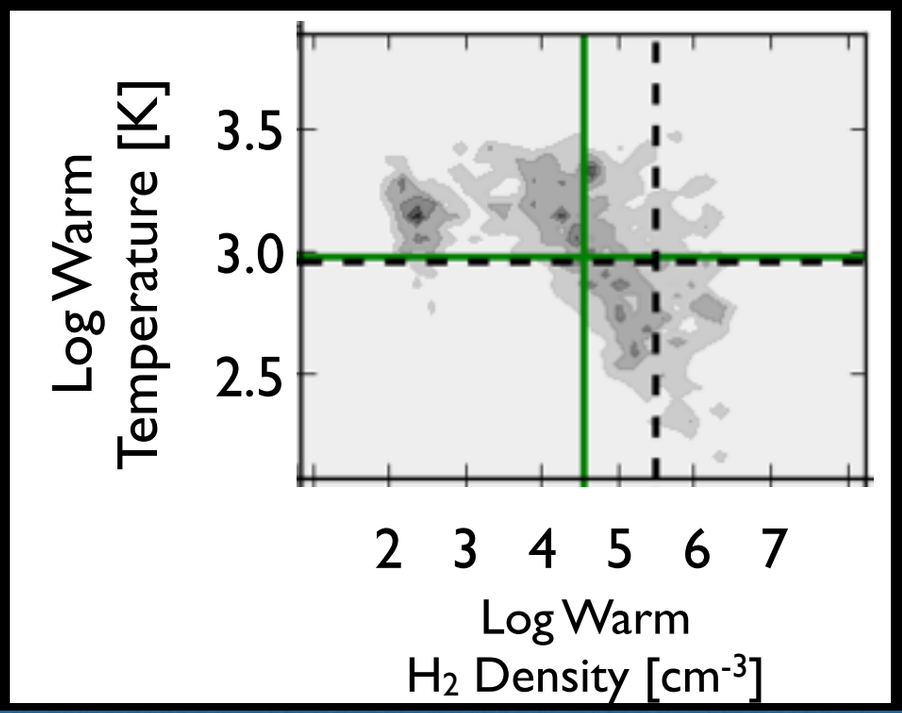

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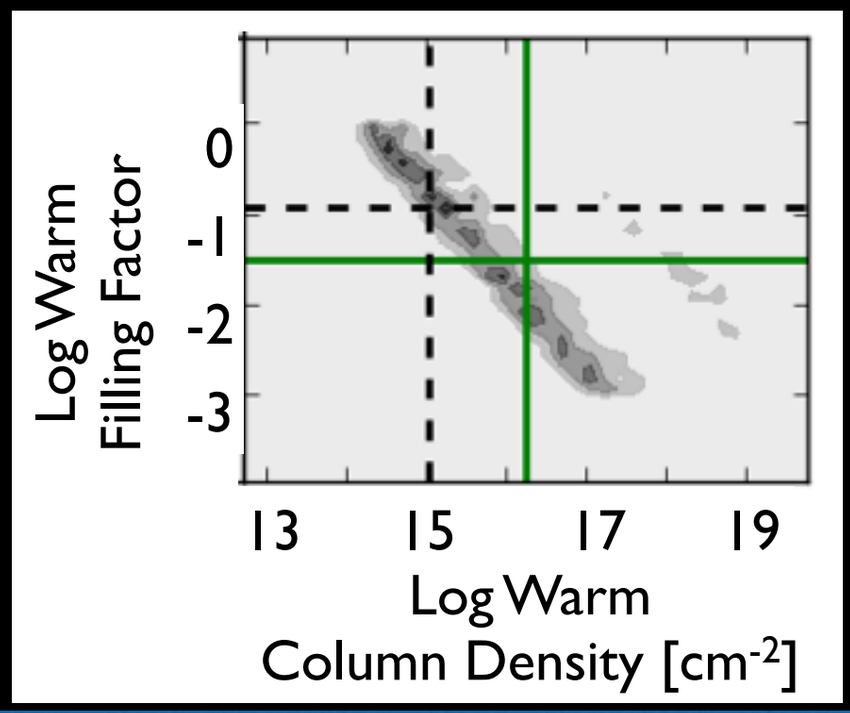
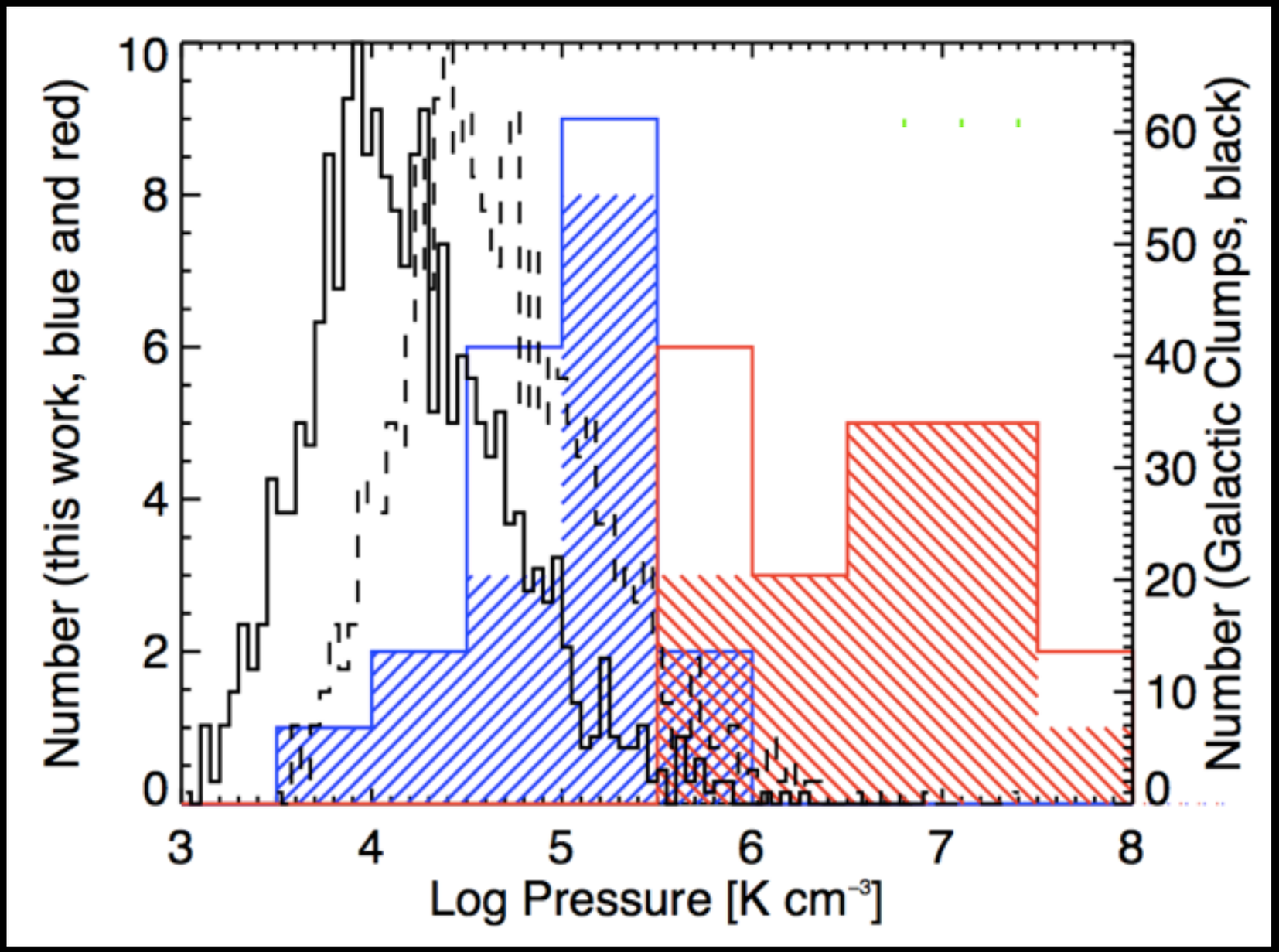
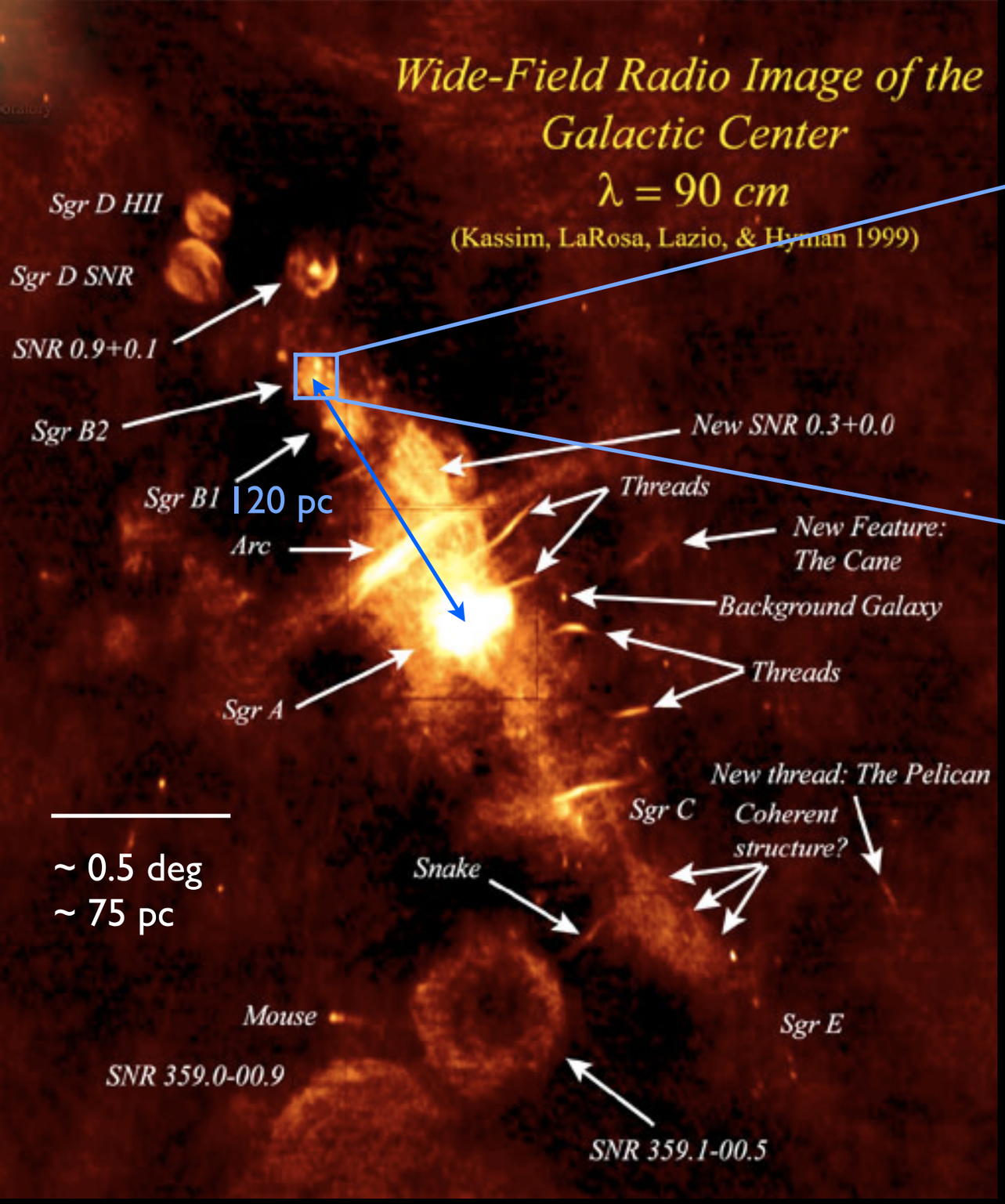


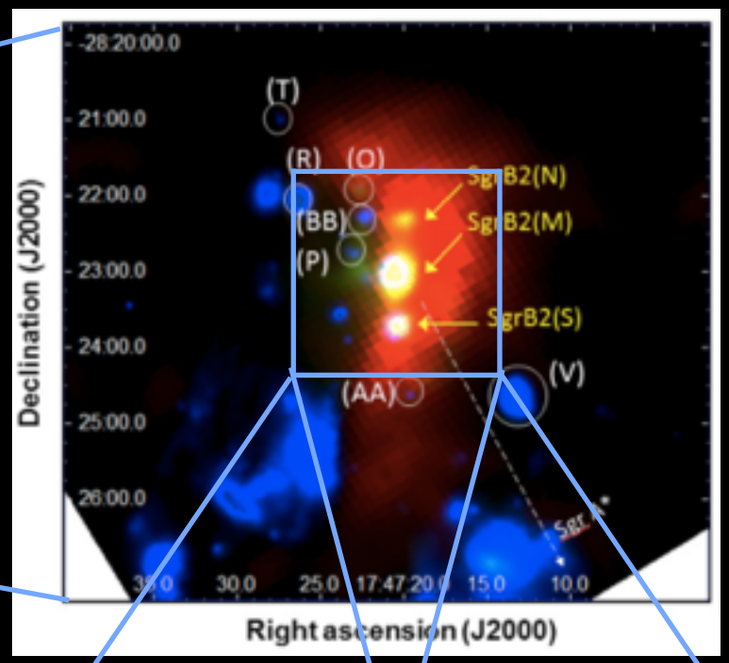
Pressure Comparison to Galaxy



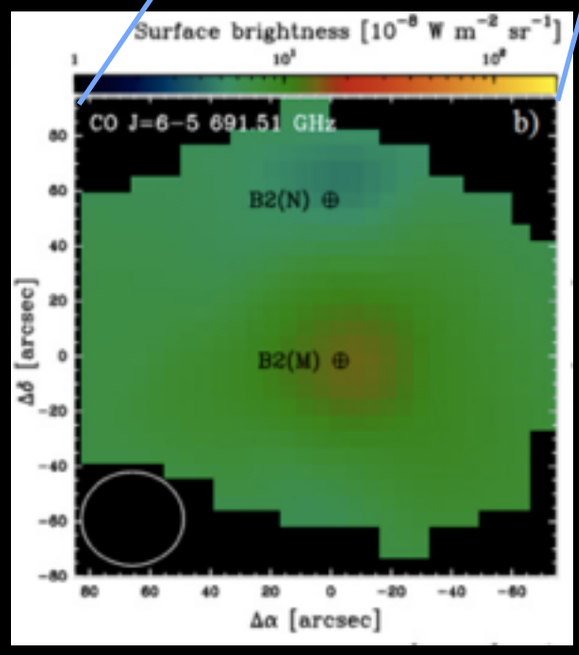


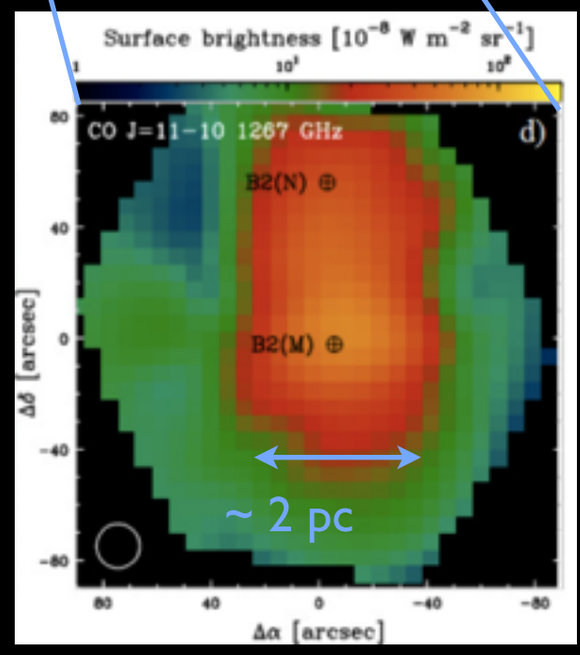
Galaxy	D	200 pc	20 pc	2 pc
NGC253	4	12”	1.2”	0.12”
IRAS 09022-3615	262	0.2”	0.02”	Dream On!

20 pc



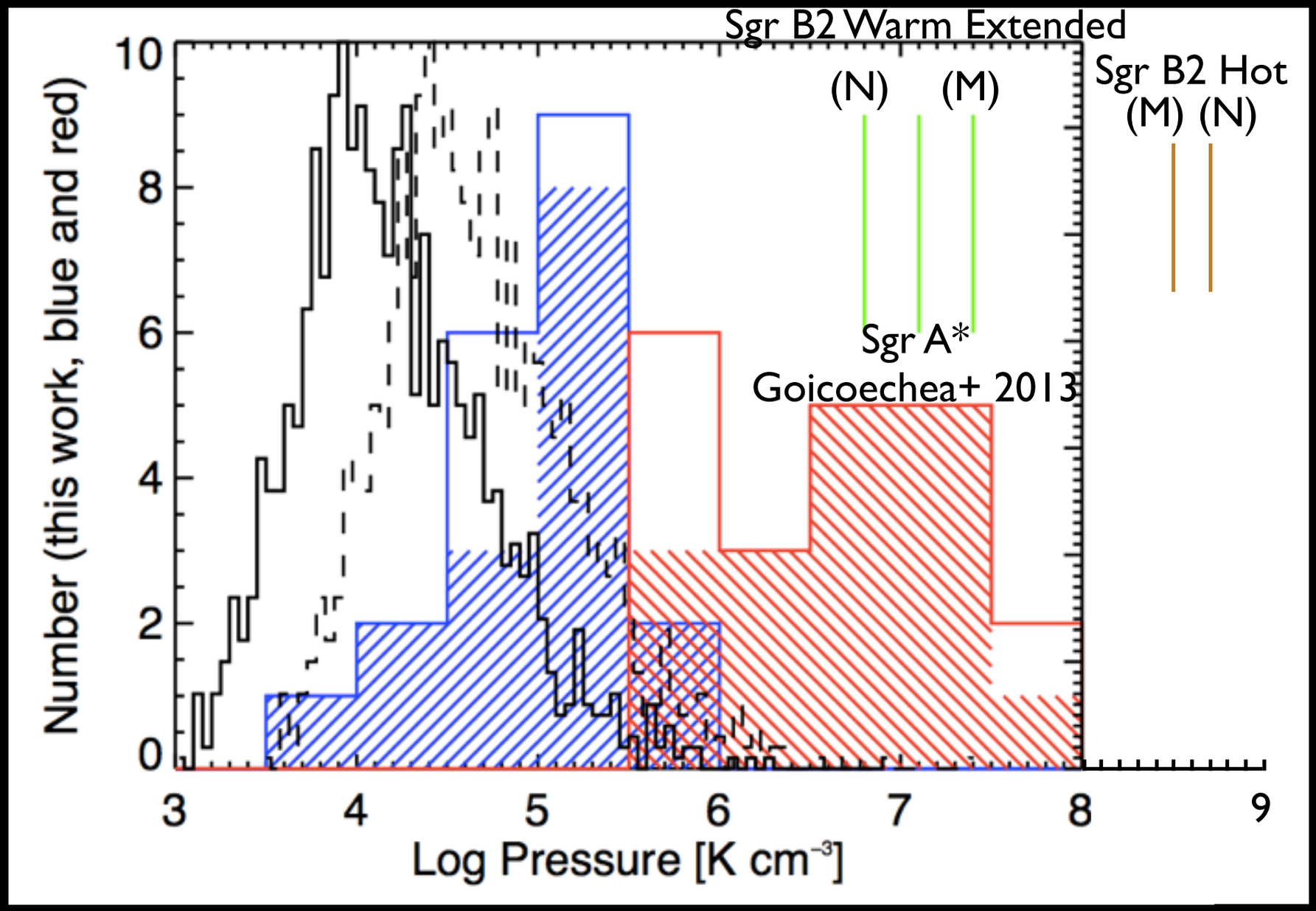
Etxaluze 2013
MIPS 24 μm (blue), PACS 70 μm (green), and SPIRE 350 μm (red).





Etxaluze 2013. CO J=6-5 (left) and CO J=11-10 (right).
Pixel size = 9.5”

Pressure Comparison to Galaxy

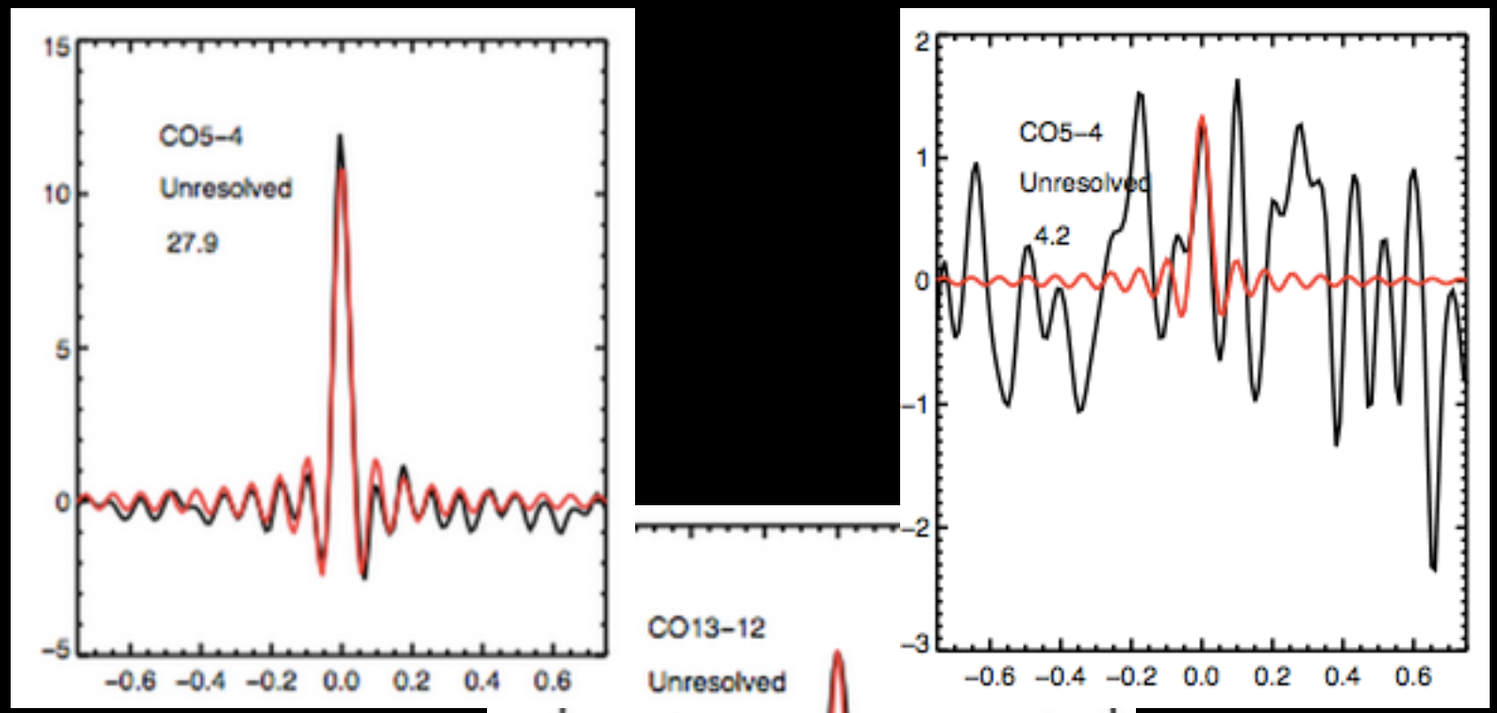


Warm Component Emission similar to Sgr B2 extended cloud molecular emission.

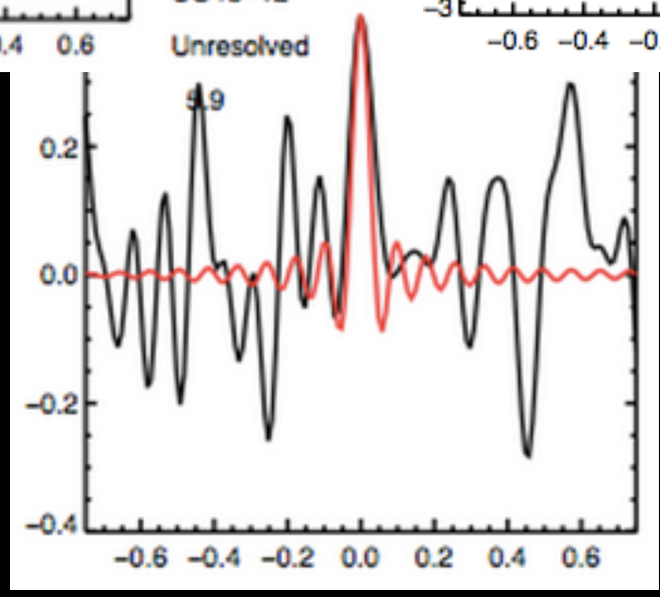
The hot core emission is too faint when galaxy integrated: imagine Sgr B2 observed as point source.

Line Flux Uncertainties

- Problems with least-squares fitting routines of sinc line profiles
  - Data not independent, highly correlated, not well understood
  - “Ringing” on approximately the size of the line profile can be “well fit”



NGC2146-SE



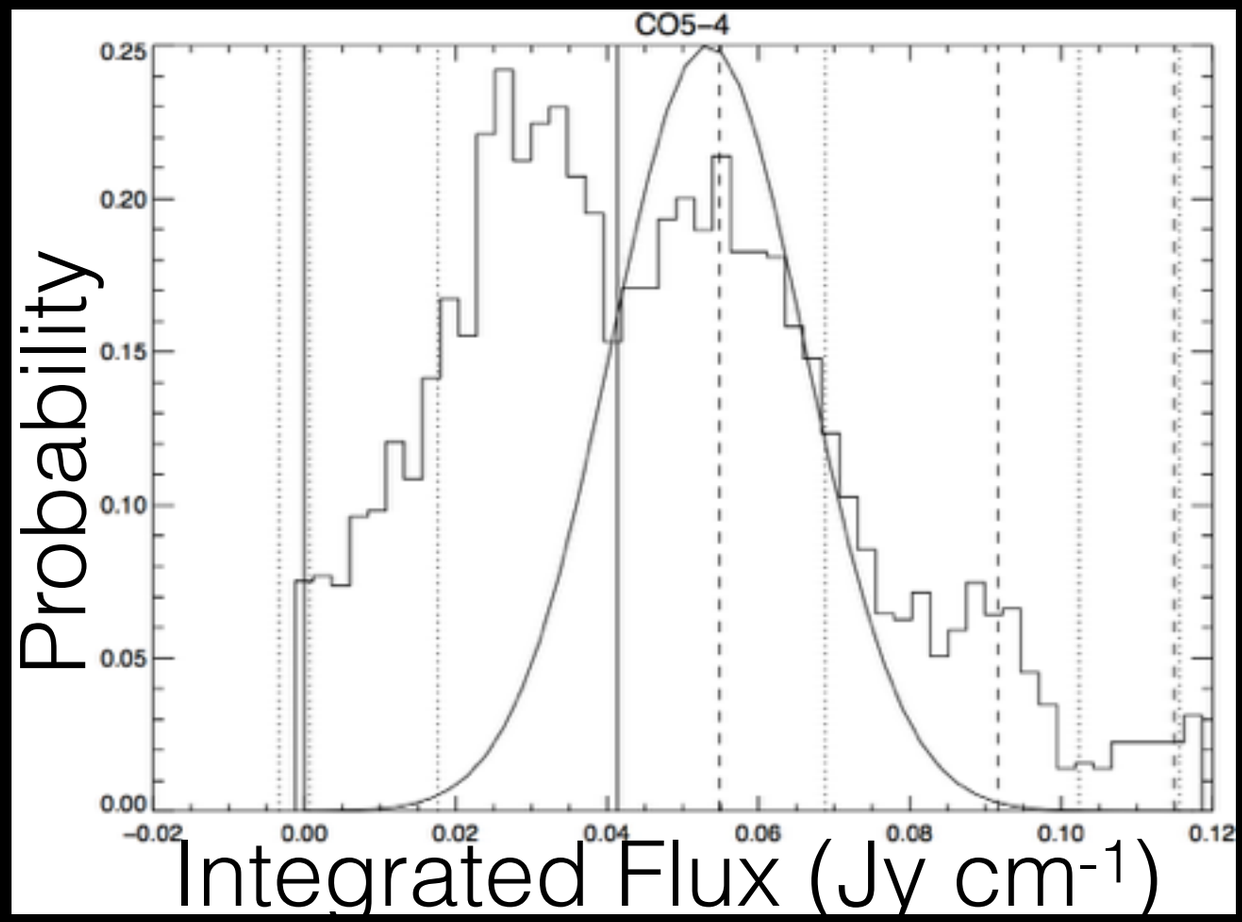
IRAS16090-0139

IRAS 05442 +1732

(FTFitter)

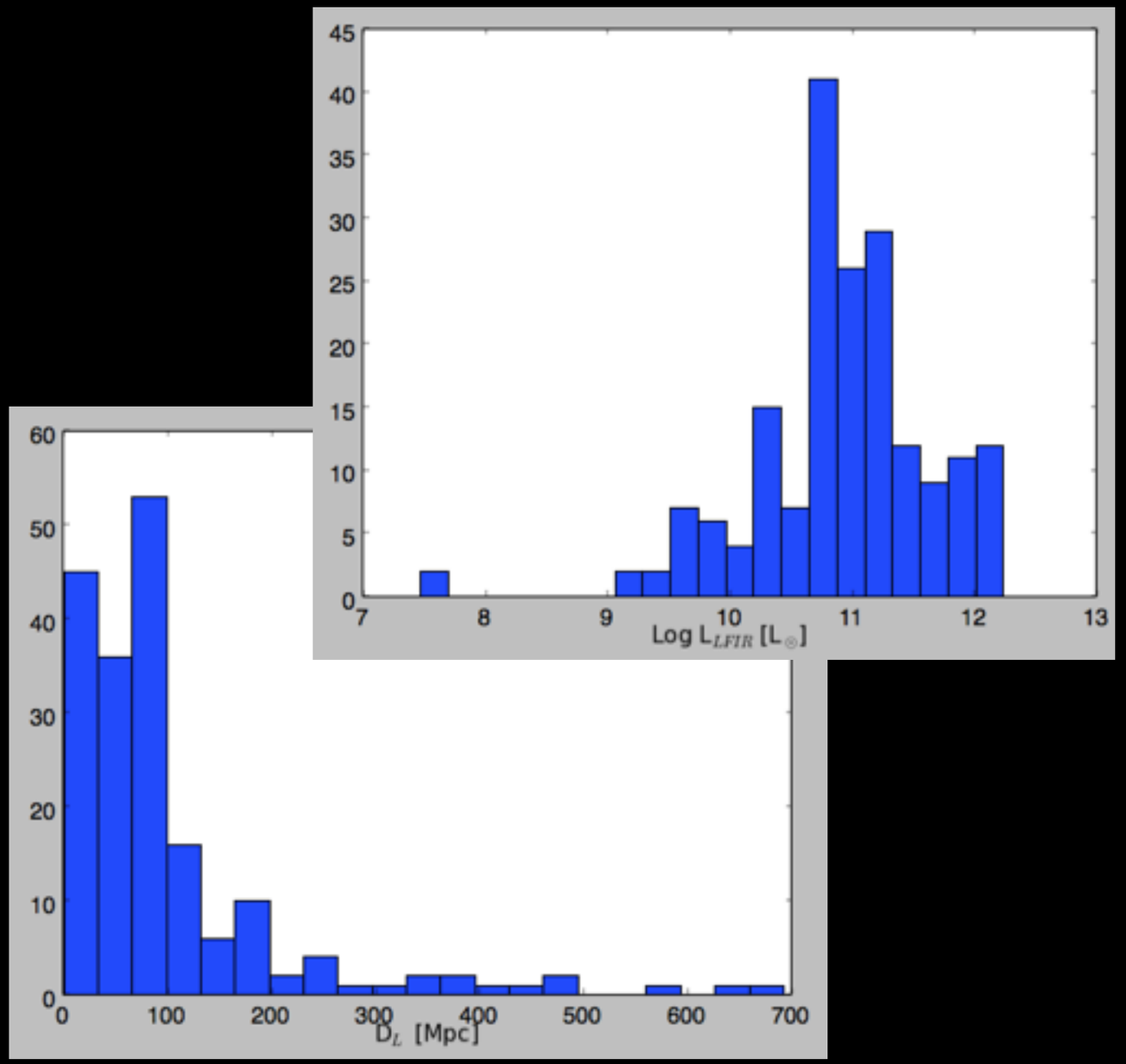
Bayesian Inference of $P(I_{true}|I_{observed})$

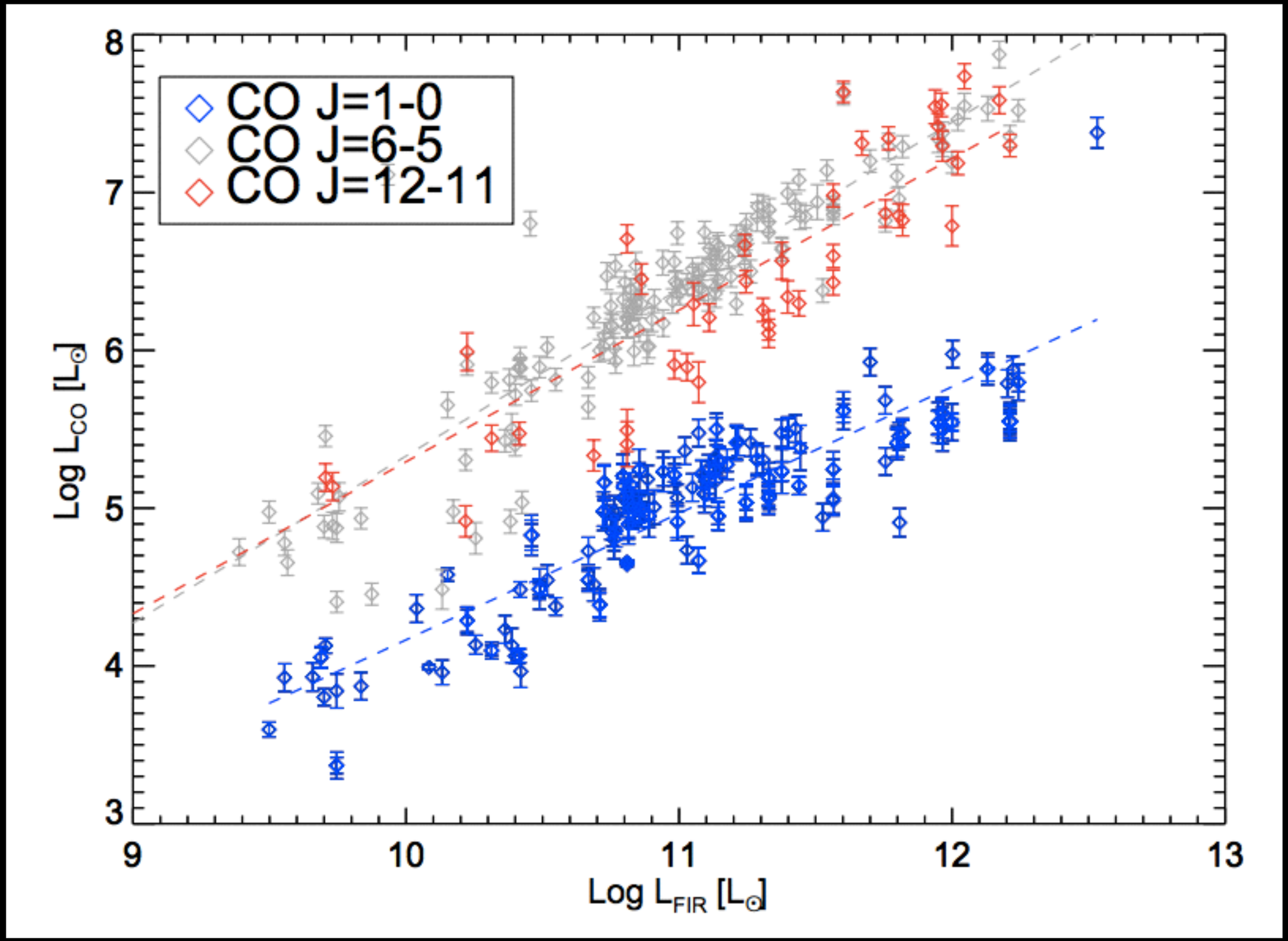
- Inject fake lines (of varying flux I_{true}) to the residual spectrum at intervals near the line
- Measure integrated flux ($I_{observed}$)
- A slice of the 2D surface at $I_{observed}$ gives the distribution of $P(I_{true}|I_{observed})$



Full Archival Survey

- 301 galaxies in successful Herschel proposals (FTS)
  - 232 known redshifts
  - Of 190 with CO 6-5 at S/N >3… (figures)
  - 109 have 8 or more CO lines from J=1-0 through J=13-12.
  - 62 include CO J=1-0.
- CO J=1-0, 2-1, 3-2 from literature, Arizona Radio Observatory




CO J=1-0
CO J=6-5
CO J=12-11
Log L_CO [L⊙]
Log L_FIR [L⊙]
8
7
6
5
4
3
9
10
11
12
13

Band 9 Observations of CO J=6-5

- *Warm* gas morphology, kinematics. Do we see features/excitation like we see in the galaxy?

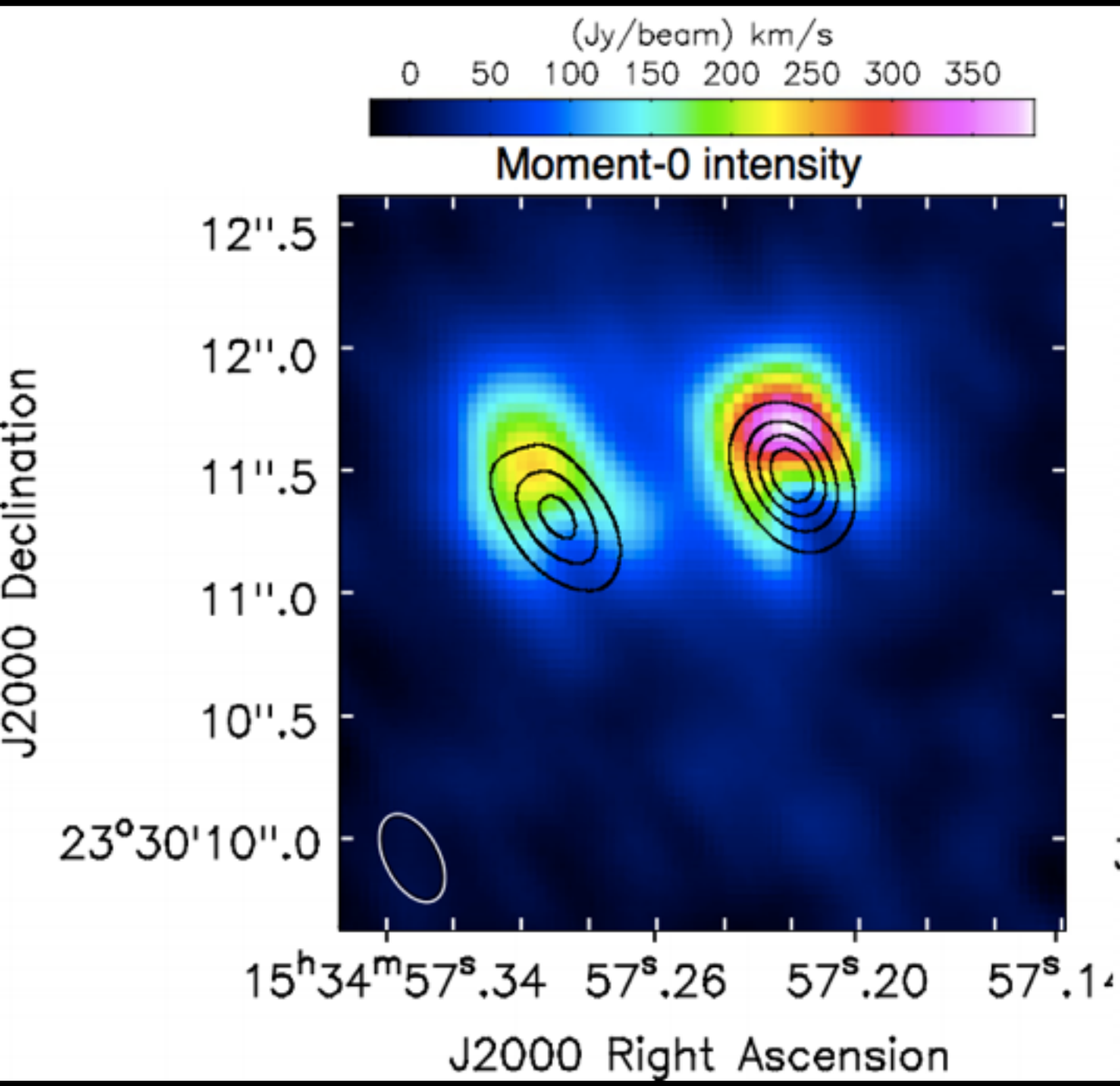
- ~ dozen galaxies so far

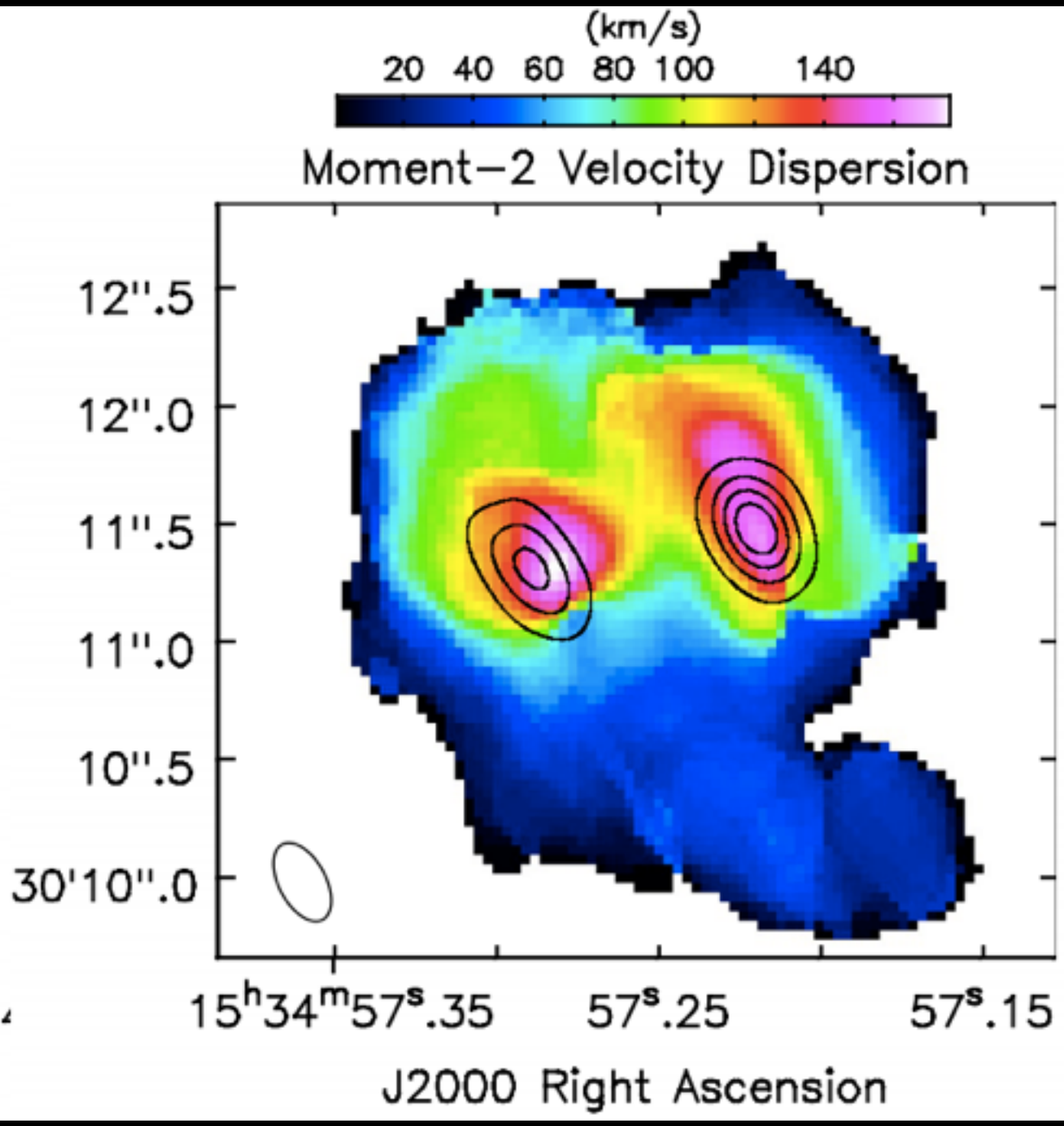
- The spatial and spectral resolution SPIRE did not have…

- … but only ONE line, not 10+, line ratios

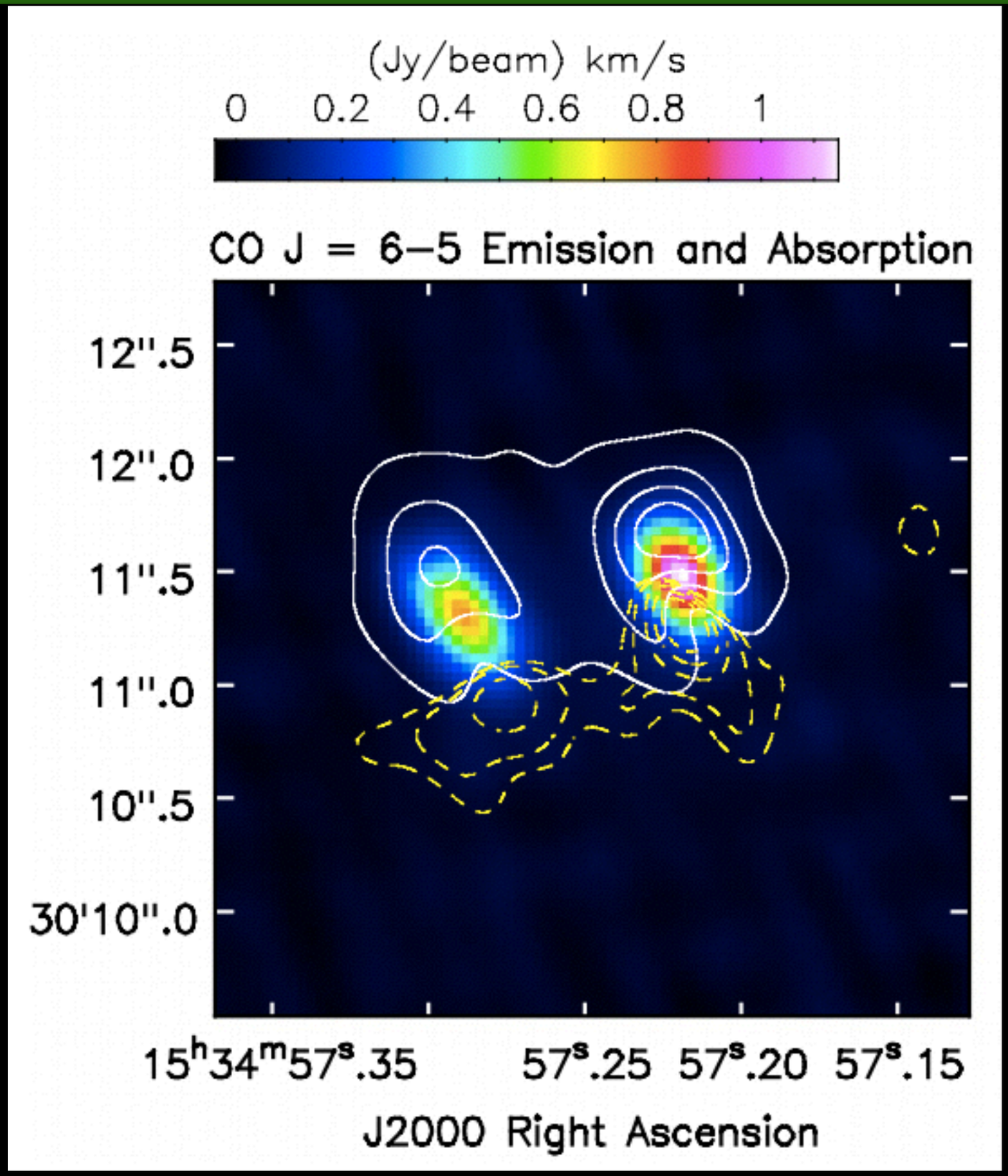
- Comparisons to low-J maps? Apples/Oranges

CO J=6-5 Intensity (offset from Continuum), and Velocity Dispersion





Rangwala et al. 2015, http://arxiv.org/abs/1504.01773



Redshifted CO Absorption

- Color = Continuum
- Solid = Line Emission
- Dashed = redshifted absorption
- Infalling molecular filament > 400 pc in length, > 150 km/s in velocity

Summary

- High-Excitation Molecular Gas is ubiquitous
  - Low-Pressure / High-Mass by low-J lines
  - High-Pressure / Low Mass by high-J lines
- Compact cores Sgr B2(N) and (M) more highly excited; not resolved by FTS CO SLEDs
- Conducting large survey of CO SLED modeling in all galaxies observed with Herschel FTS, Kamenetzky et al. in prep
- Take care with line flux estimates in marginal cases!
- ALMA Band 9 can be used to study warm molecular gas in CO J=6-5, Arp 220, Rangwala et al. 2015

Also see SN1987A Poster!