Synergies between SOFIA and ALMA

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Overview

- Diffuse ISM
- Extragalactic objects
- Star Formation

Diffuse ISM

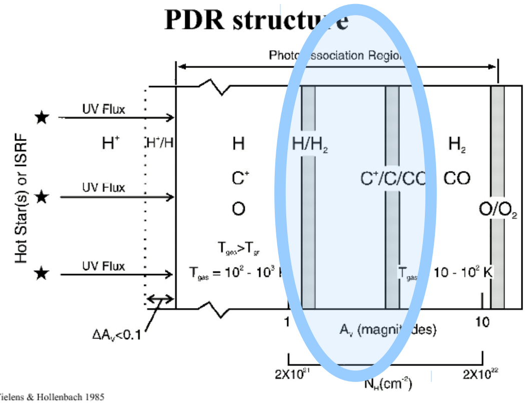
Science, 2005

Molecular, but no CO

Unveiling Extensive Clouds of Dark Gas in the Solar Neighborhood

Isabelle A. Grenier,[1*] Jean-Marc Casandjian,[1,2] Régis Terrier[3]

From the comparison of interstellar gas tracers in the solar neighborhood (HI and CO lines from the atomic and molecular gas, dust thermal emission, and γ rays from cosmic-ray interactions with gas), we unveil vast clouds of cold dust and dark gas, invisible in HI and CO but detected in γ rays. They surround all the nearby CO clouds and bridge the dense cores to broader atomic clouds, thus providing a key link in the evolution of interstellar clouds. The relation between the masses in the molecular, dark, and atomic phases in the local clouds implies a dark gas mass in the Milky Way comparable to the molecular one.



Tielens & Hollenbach 1985

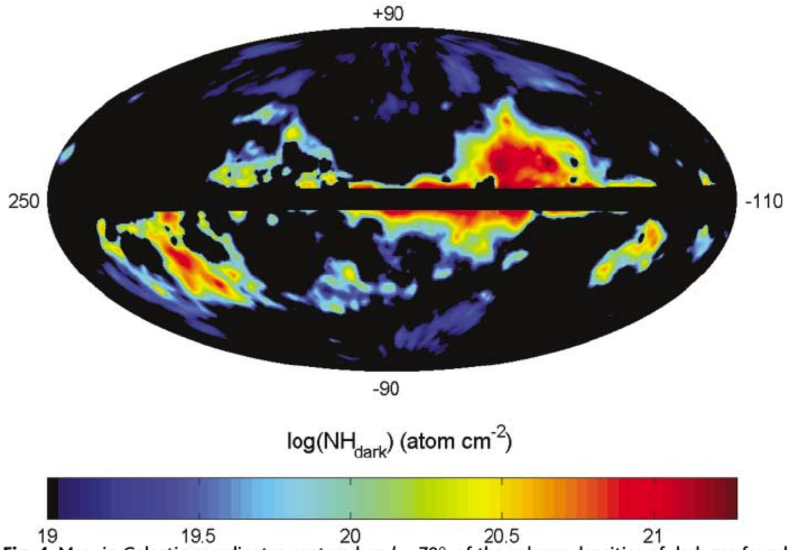


Fig. 4. Map, in Galactic coordinates centered on $l = 70°$, of the column densities of dark gas found in the dust halos, as measured from their γ-ray intensity with the reddening map. This gas complements that visible in HI and CO. The two dust tracers [E(B-V) and 94-GHz emission] yield consistent values within 30% over most regions.

Science, 2005

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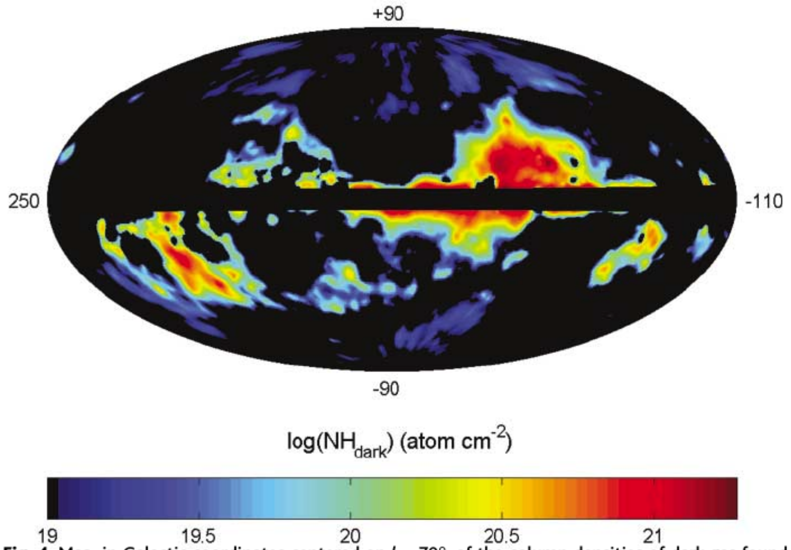
Talks by

Simon Glover
Paola Caselli
Karl Menten
David Neufeld

CO-dark gas



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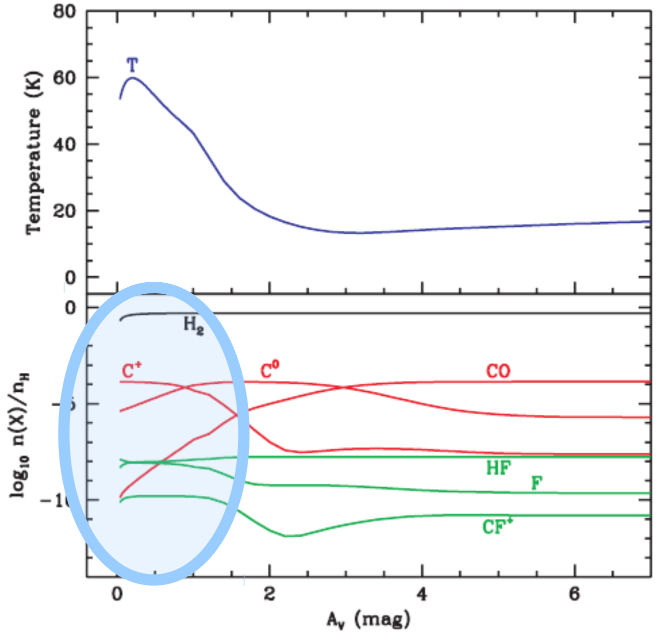
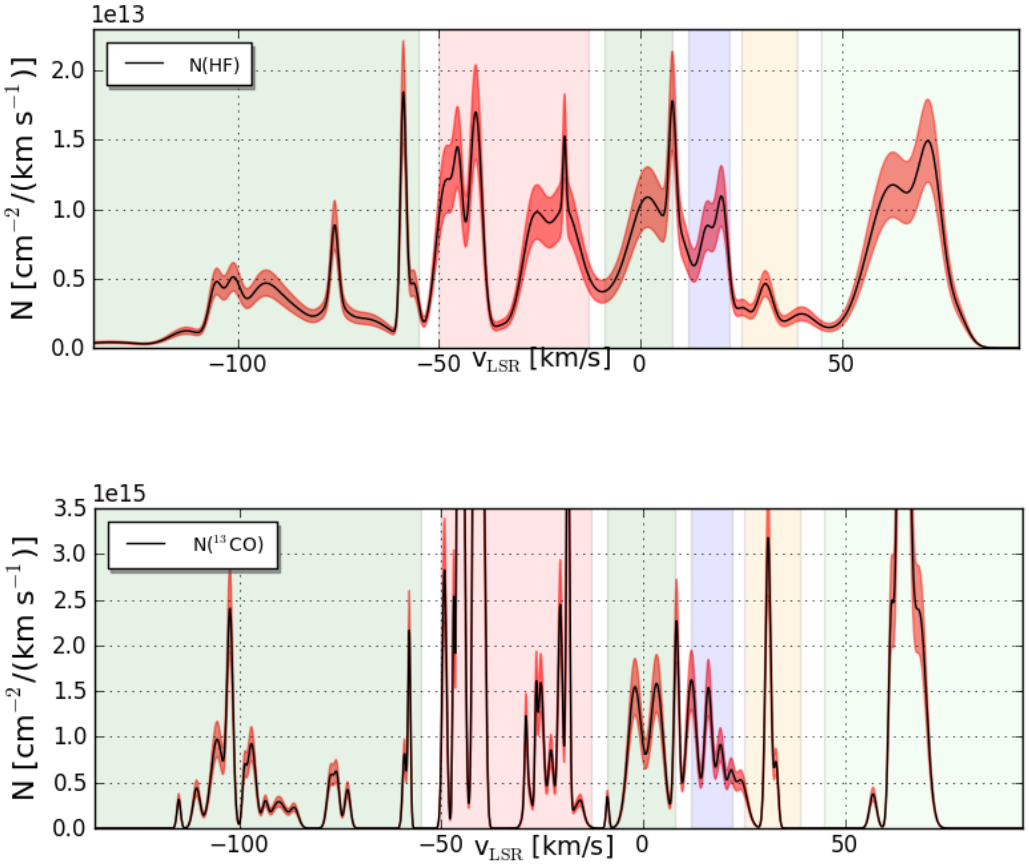
Tracers other than C^+ – the Herschel legacy



Neufeld, Wolfire & Schilke 2005

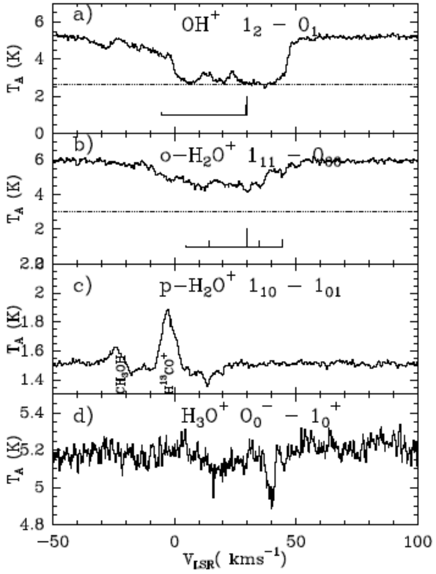


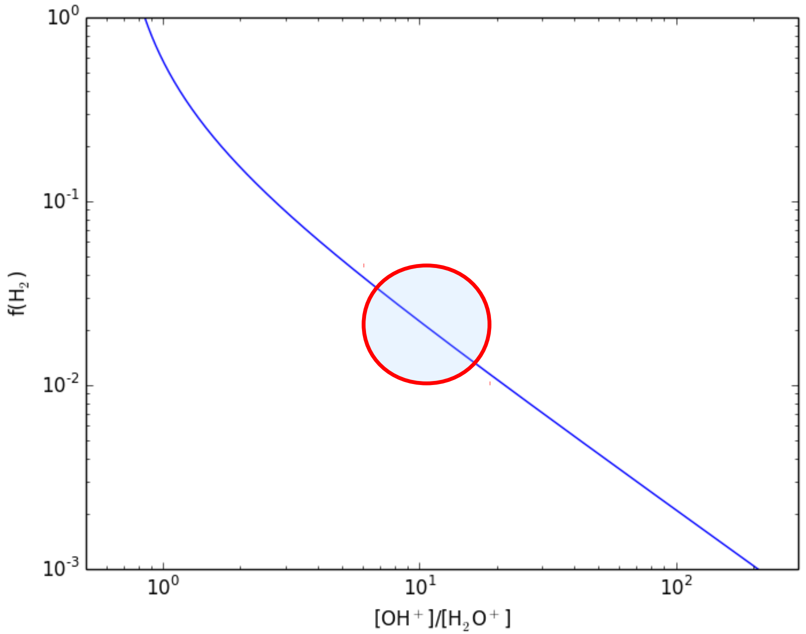
SgrB2(M) HEXOS (HF), SMA, PdB (CO)

$$\frac{k(\mathrm{H_2}|\mathrm{OH^+})}{k(\mathrm{H_2}|\mathrm{H_2O^+})} + \frac{n(\mathrm{e})k(\mathrm{e}|\mathrm{H^+})}{n(\mathrm{H_2})k(\mathrm{H_2}|\mathrm{H_2O^+})} = 0.64 + 1490\,\frac{x_\mathrm{e} T_2^{-0.5}}{f(\mathrm{H_2})}, \qquad (1)$$

G10.6-0.4
Gerin et al. 2010

$OH^+ > H_2O^+ > H_3O^+$



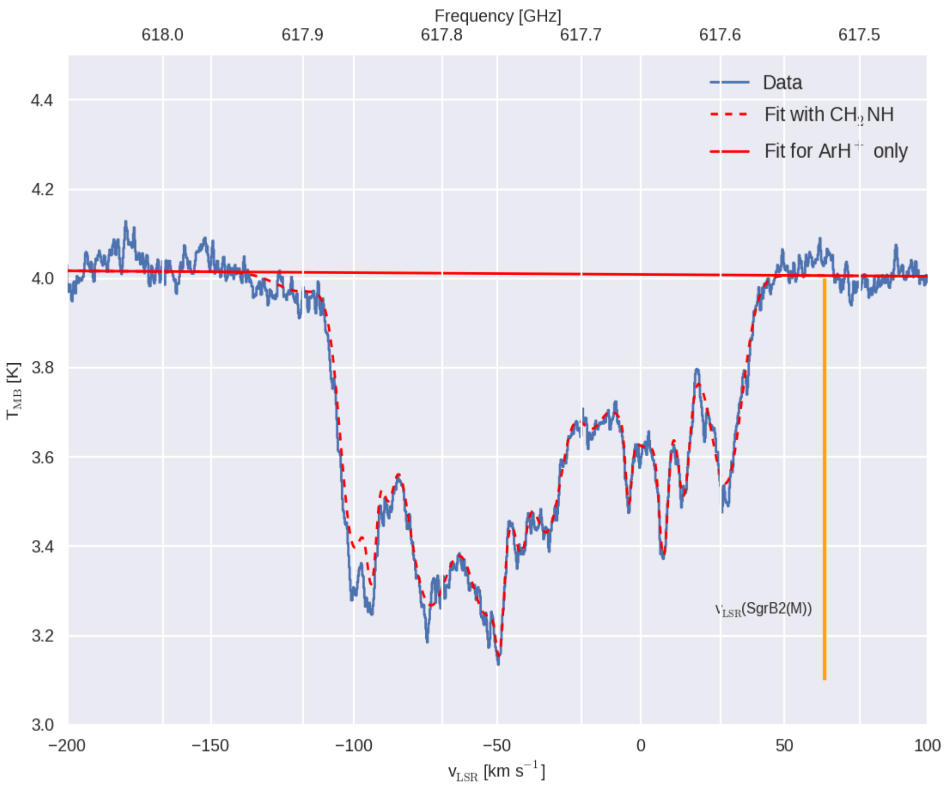


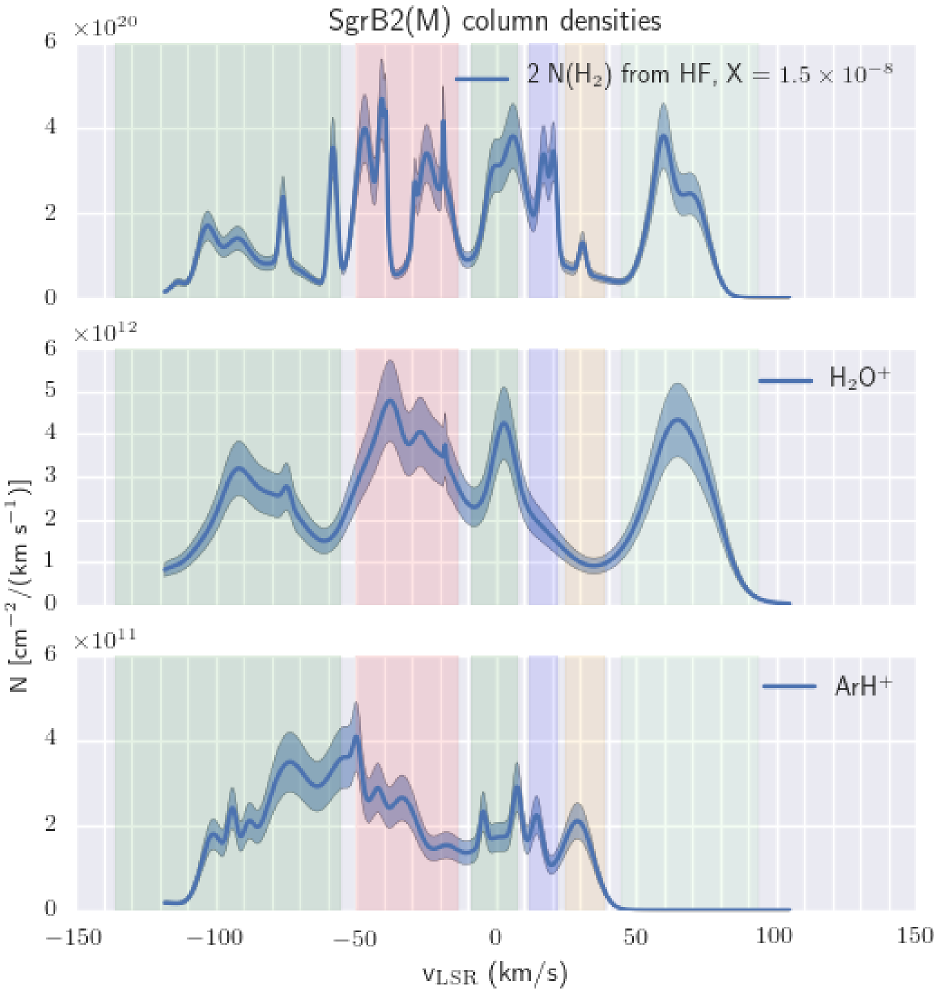
$f\,(H_2) = 2n(H_2)/[2n(H_2) + n(H)]$

OH^+/H_2O^+ trace $f(H_2)$ about 2-8%

OH^+/H_2O^+ tracer of transition zone between atomic and molecular gas

Neufeld et al. 2010



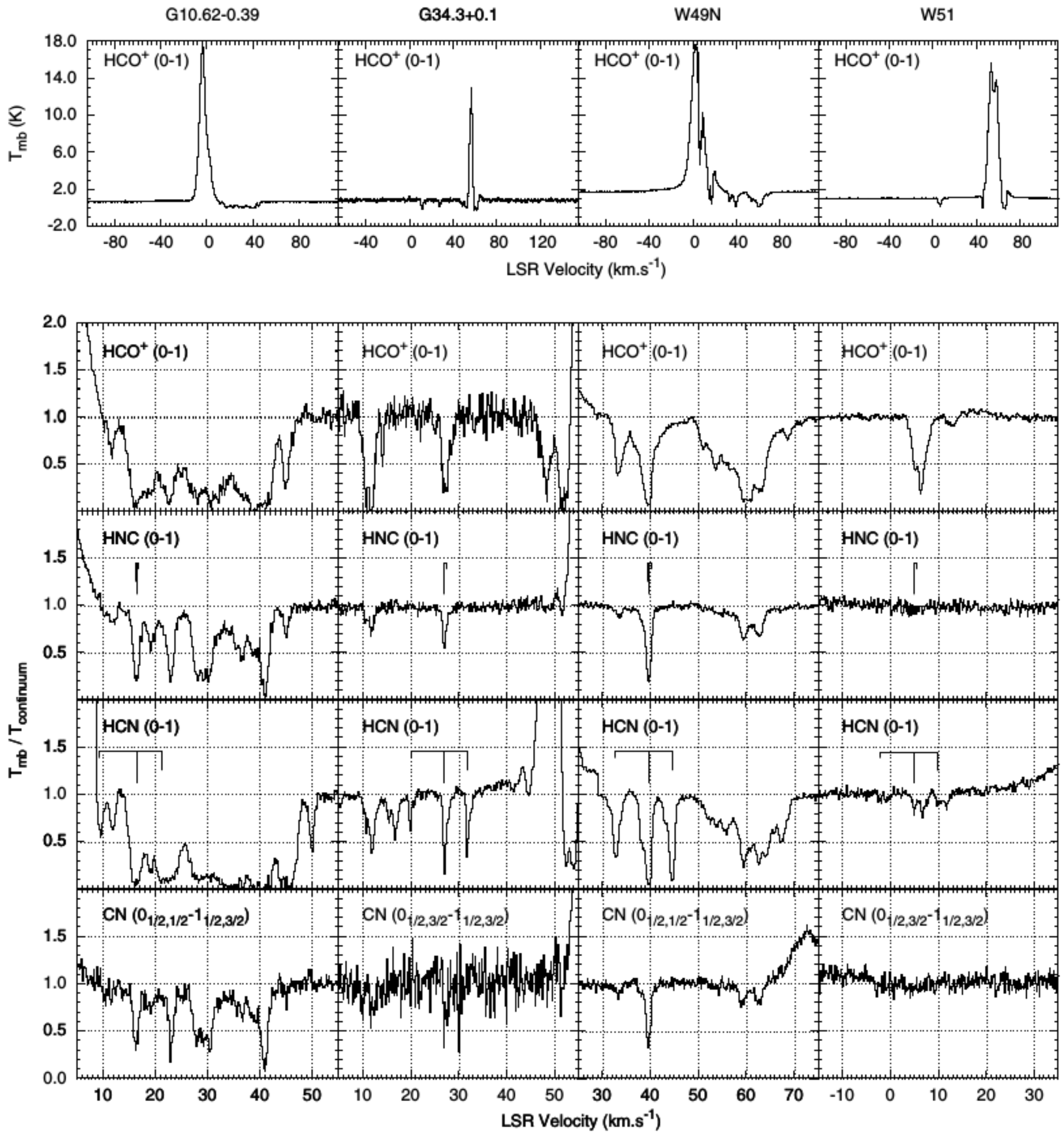


ArH$^+$ resides in gas with $f(H_2) = 10^{-4}$-10^{-3}

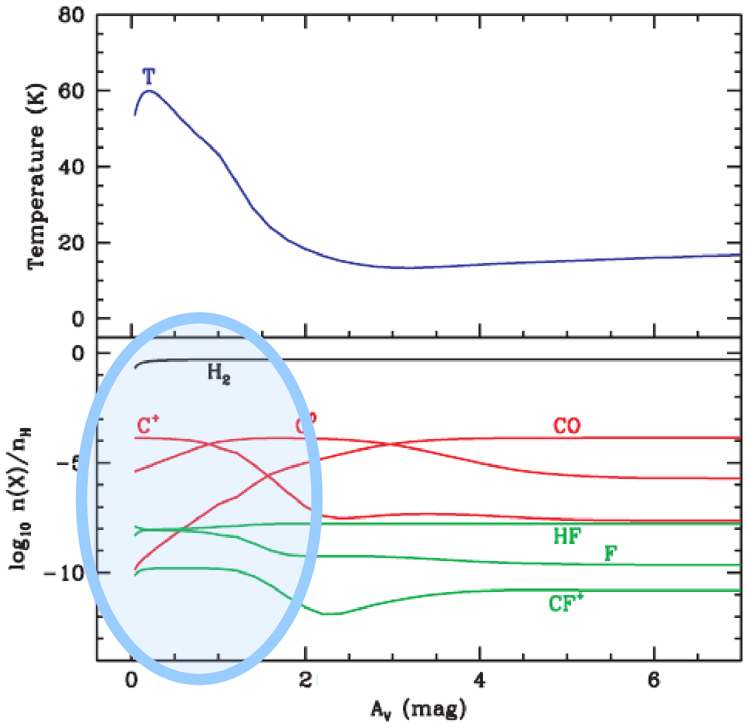
Schilke et al. 2014

Tracers of denser gas at millimeter wavelengths

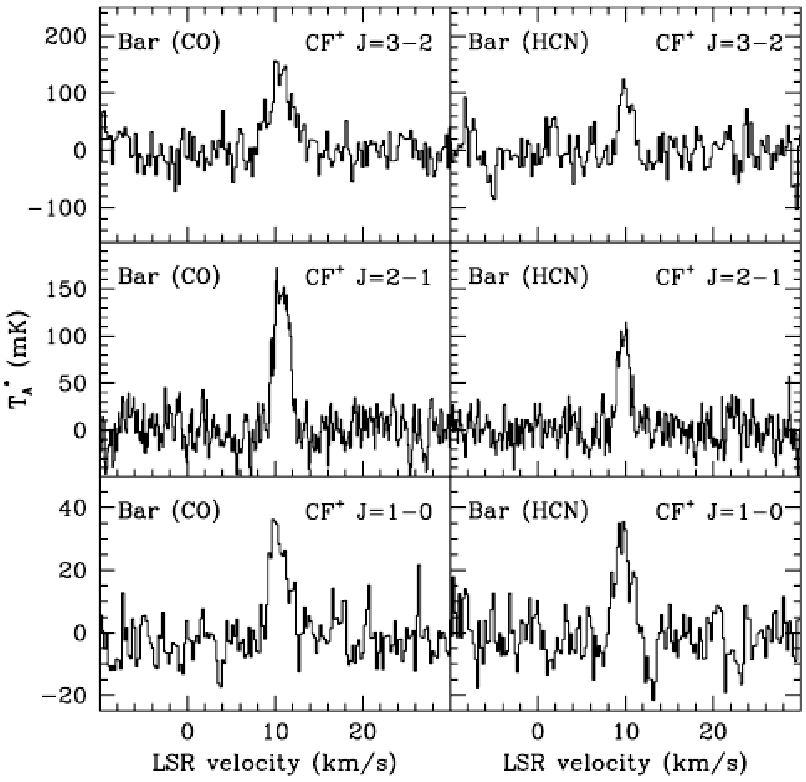
Godard et al. 2010



Hybrid tracers: C^+ *and* H_2: CF^+



Neufeld, Wolfire & Schilke 2005



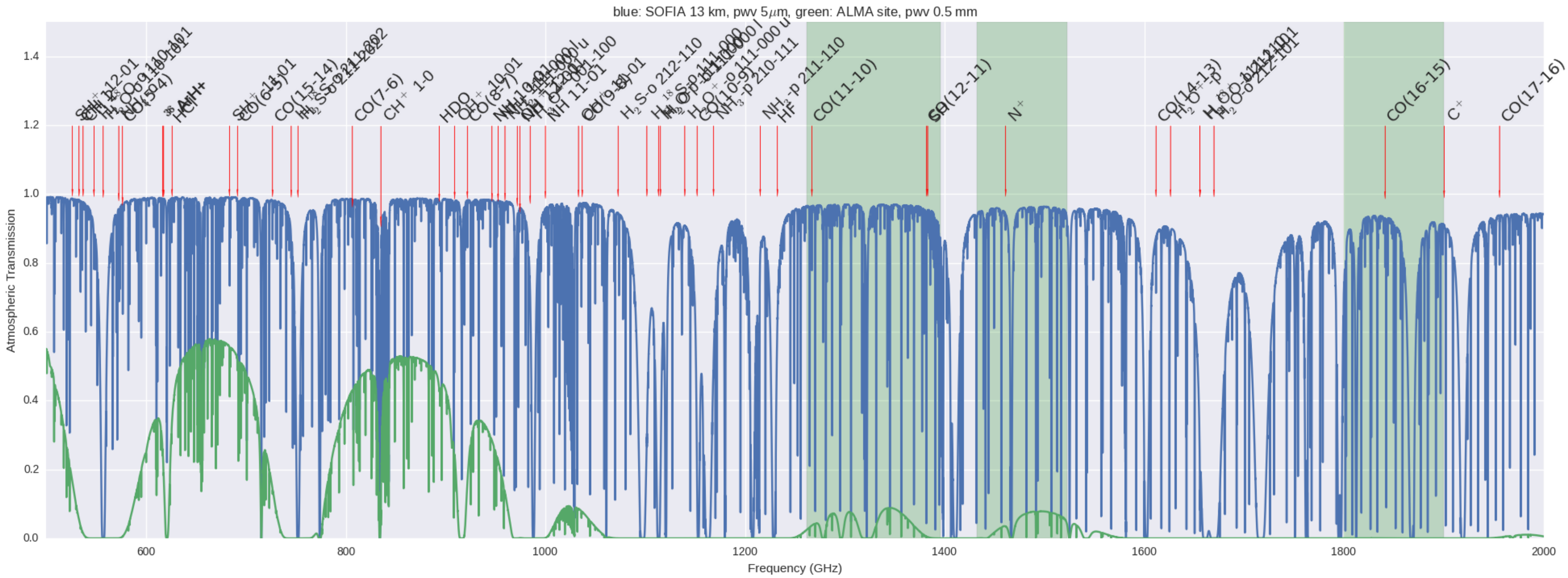
Neufeld et al. 2006

Diffuse ISM

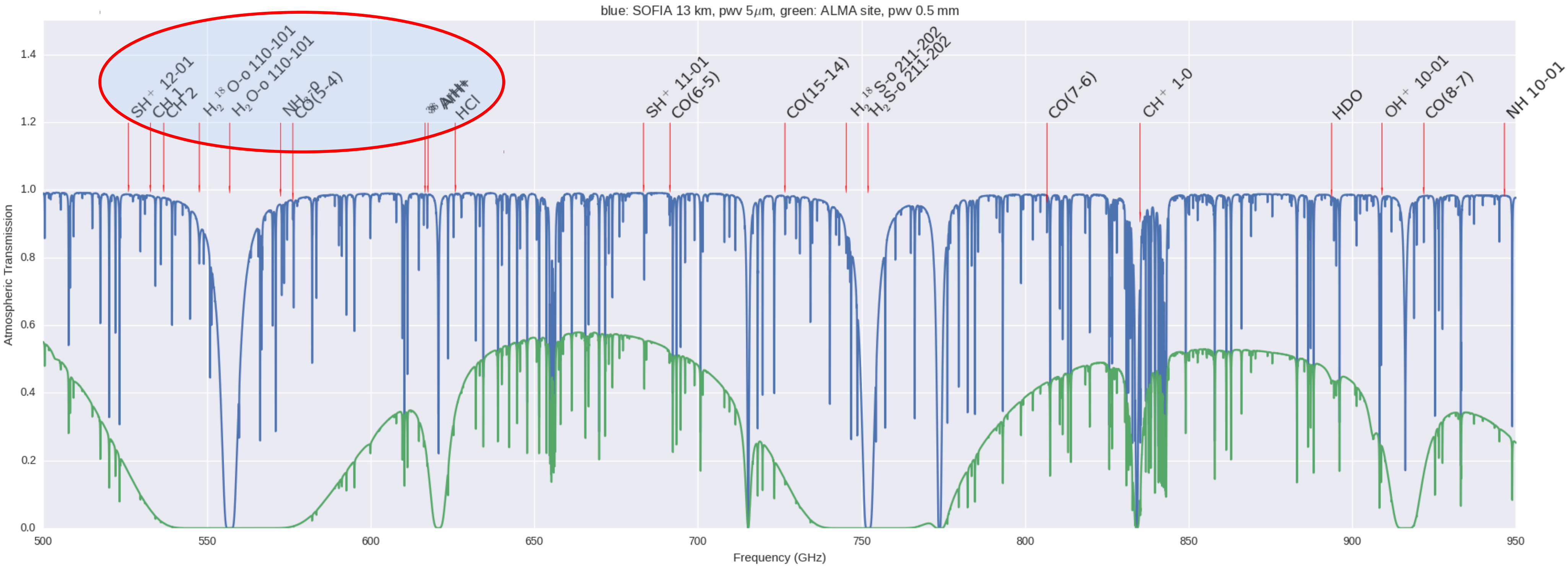
- Is more complicated than previously thought
- Tracers of CO bright, denser gas – mostly ALMA* land
- Tracers of CO dark, diffuse gas – mostly SOFIA land
- Complete picture only by combining both

*And NOEMA, but not IRAM 30m or APEX, because there would be contamination by emission

SOFIA



Lots of interesting hydride lines are accessible by SOFIA

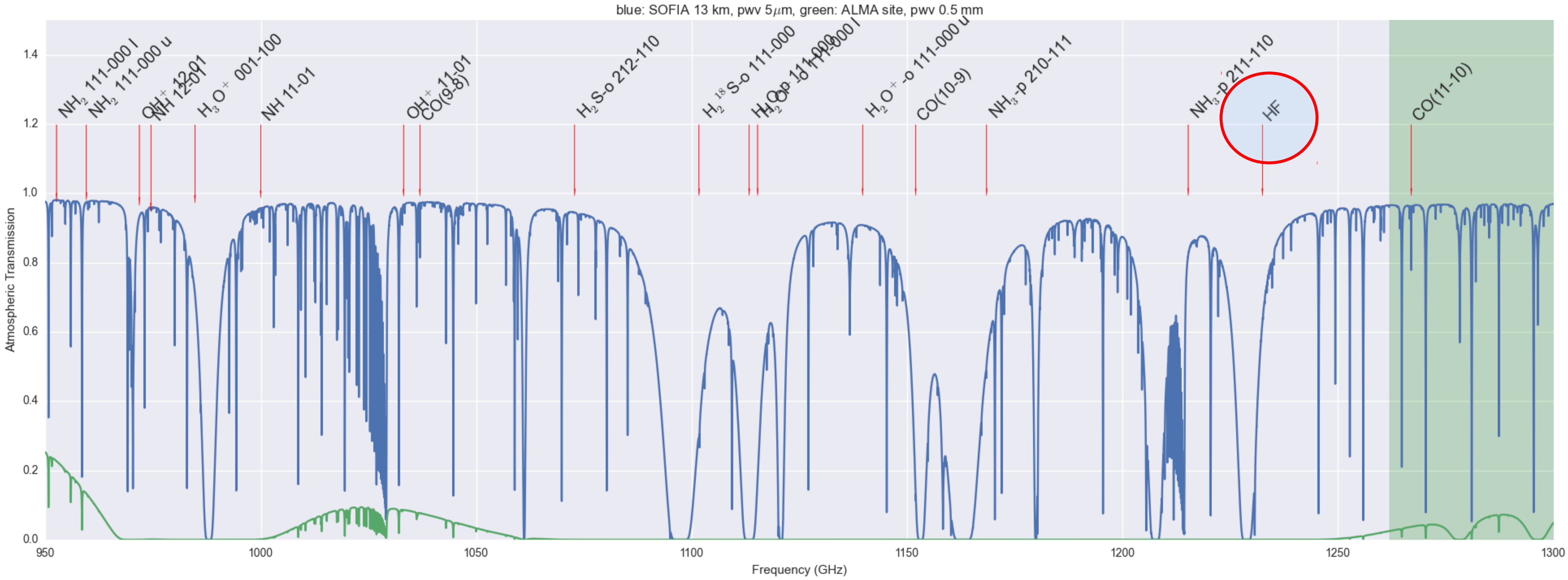


would be

Lots of interesting hydride lines ~~are~~ accessible by SOFIA – if we had the receivers

- downGREAT!

and very few by ALMA – but some: SH^+, OH^+, H_3O^+, HCO^+, HCl, HDO, (ArH^+), ...



would be

Lots of interesting hydride lines ~~are~~ accessible by SOFIA – if we had the receivers - downGREAT!

Intermediate conclusion I

- Full characterization of the ISM needs both SOFIA and ALMA
- Much could be learned by extending the SOFIA frequency coverage – as already mentioned by Jürgen, Karl, David...

Extragalactic Objects

Extragalactic: size

- SOFIA beam @ 1.3 THz = 23”

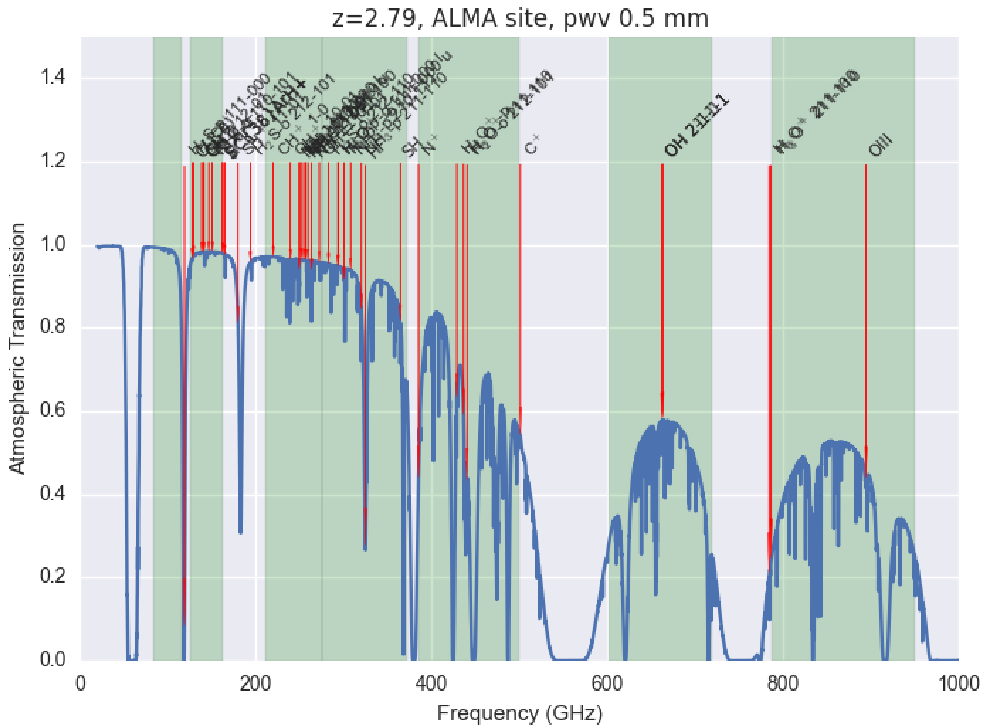
  = 0.2 pc @ 2 kpc

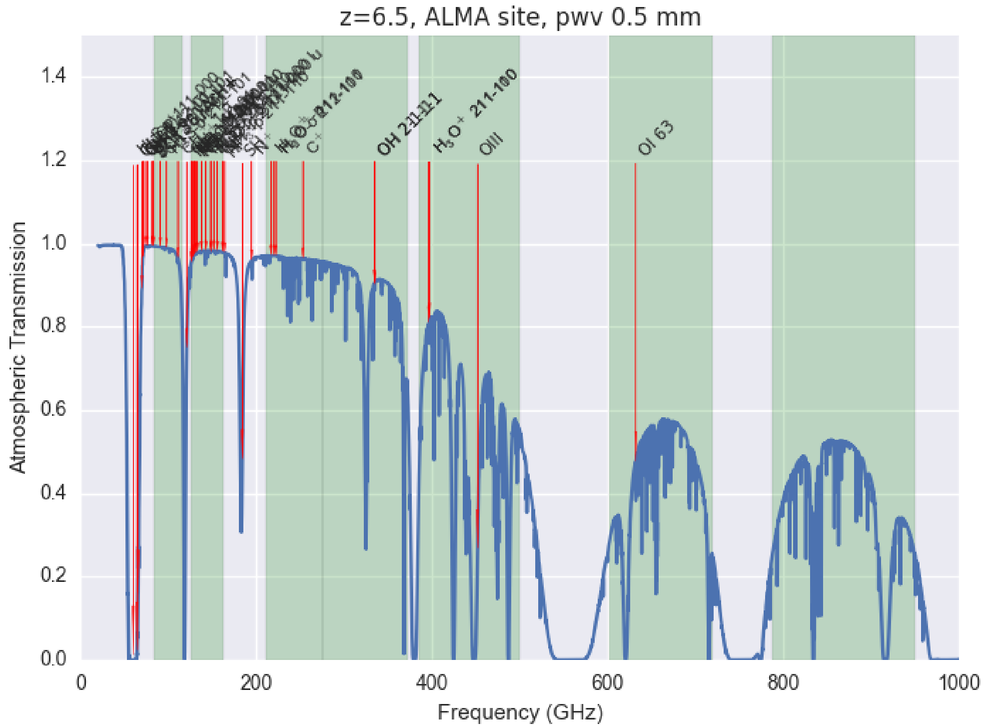
- ALMA beam of 0.01” @ 345 GHz

  = 0.2 pc @ 4.6 Mpc

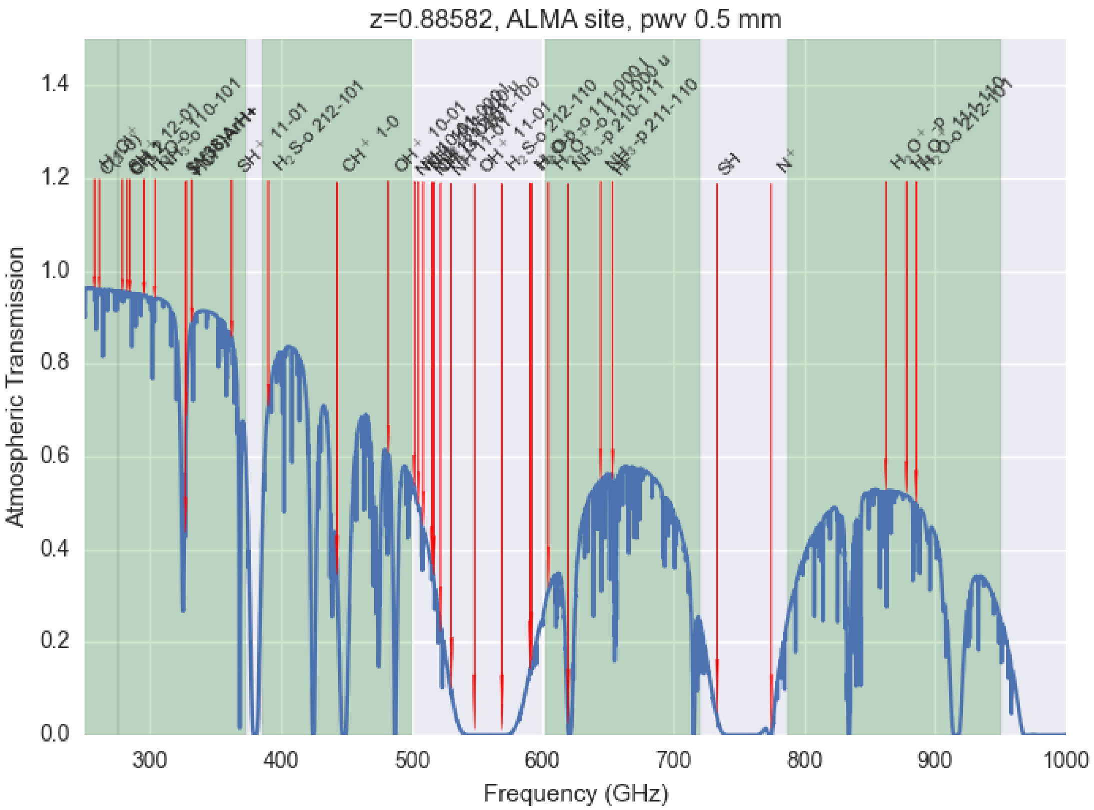
  (> d(M82, NGC253))

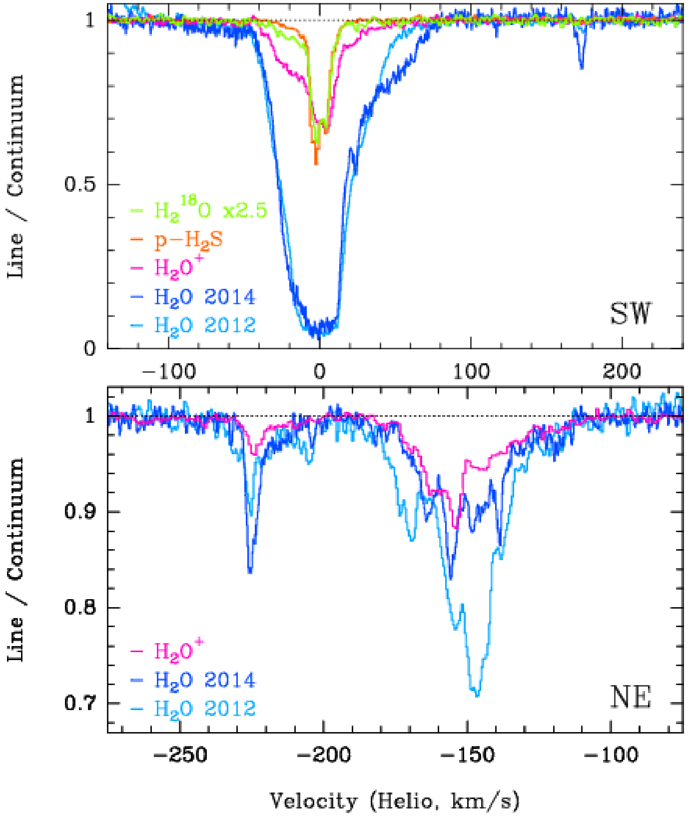
Extragalactic: redshift





Extragalactic: redshift
Example: PKS 1830 at z=0.88582 with ALMA





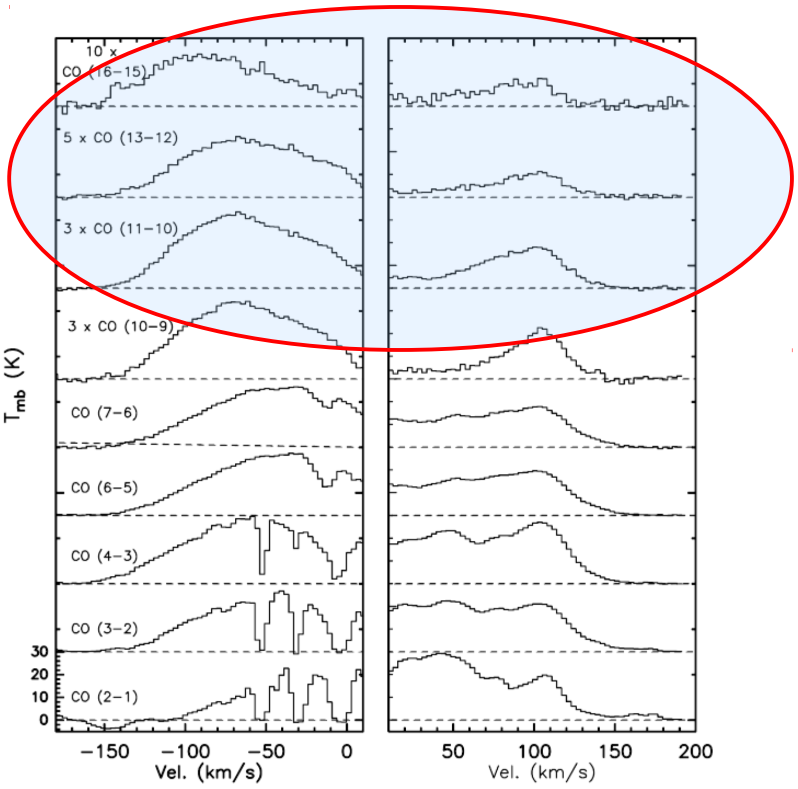
Muller et al. , in prep

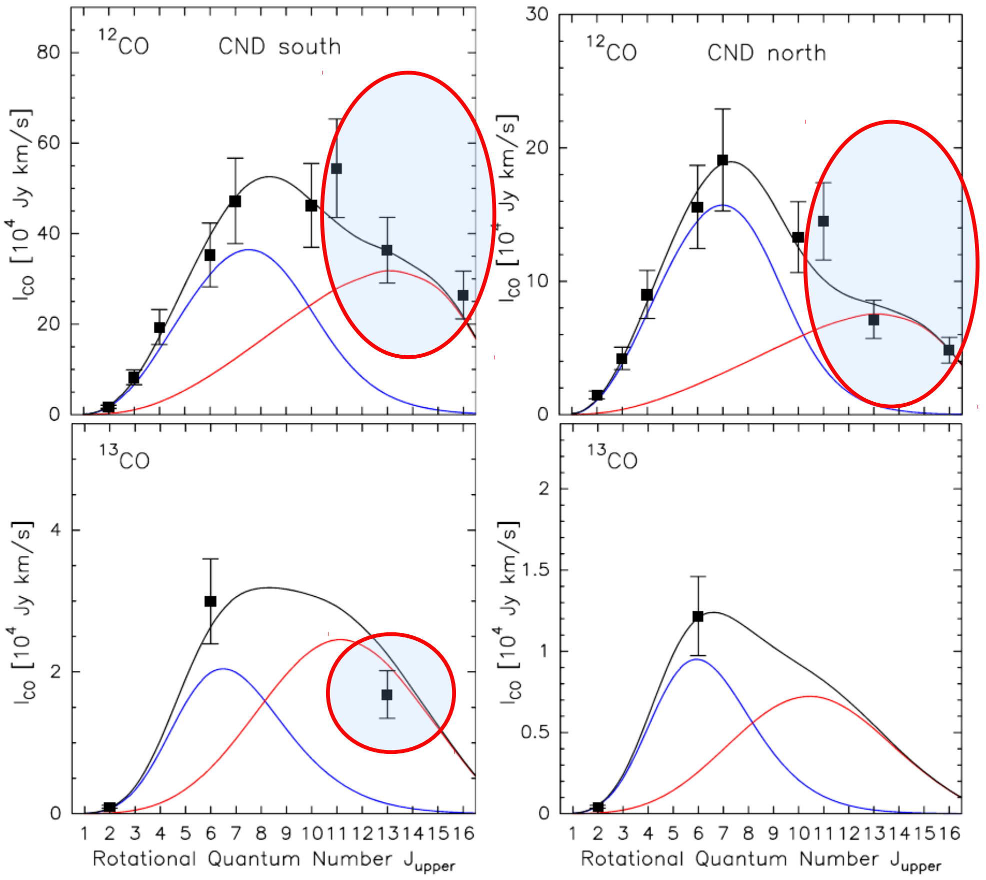
Intermediate conclusion II

- SOFIA and ALMA are complementary for studies of extragalactic objects in spatial scale
- SOFIA provides Galactic templates for ALMA studies of redshifted objects

Star Formation

Requena-Torres et al. 2012



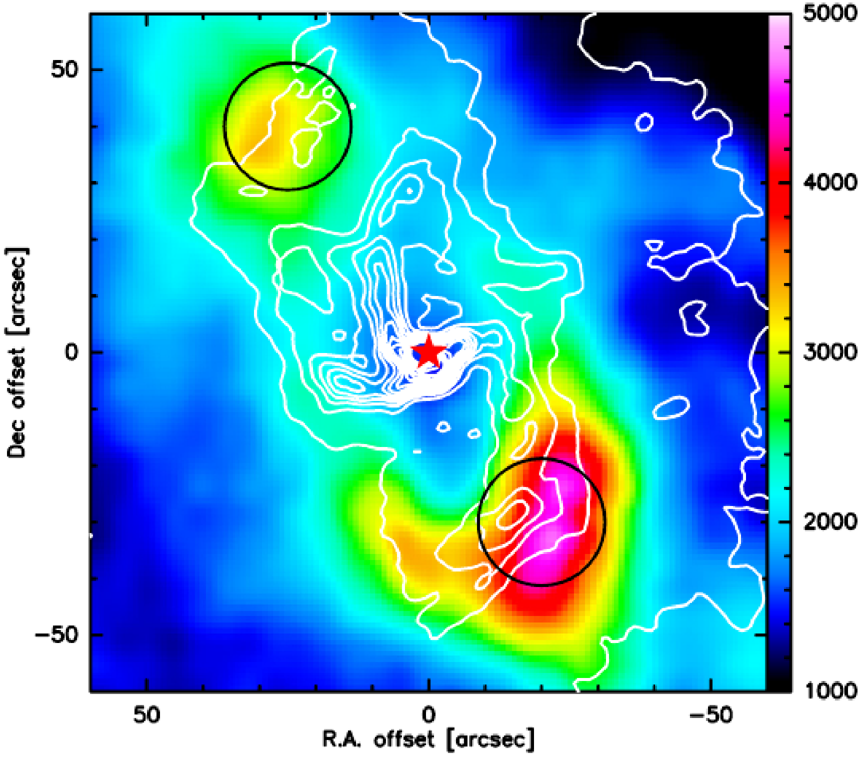


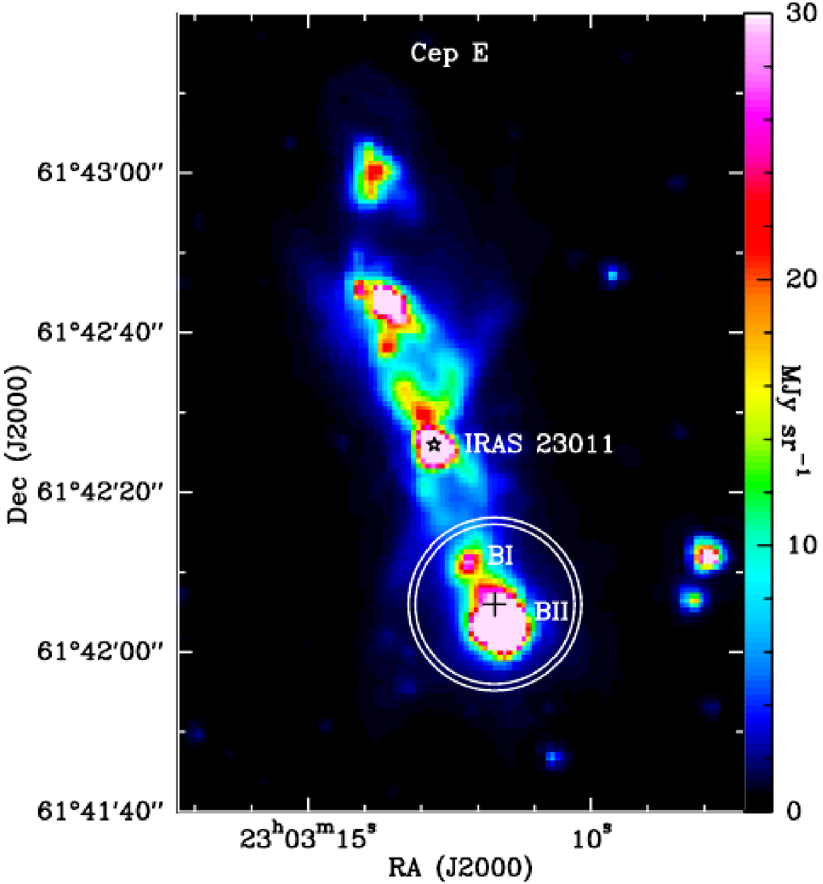
(discussed by Jesús Martín-Pintado)

SOFIA extends the energy range considerably and puts important constraints on models

Eislöffel et al. 2012

Requena-Torres et al. 2012





...but SOFIA does not resolve the typical structure sizes

Star Formation regions

- SOFIA data give access to important excitation regimes

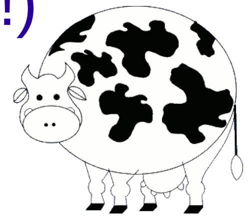
  ...but are hard to interpret because of the unresolved underlying complex geometry

- ALMA provides access to underlying complex geometry in lower excitation lines (most clouds are **not** spherical!)

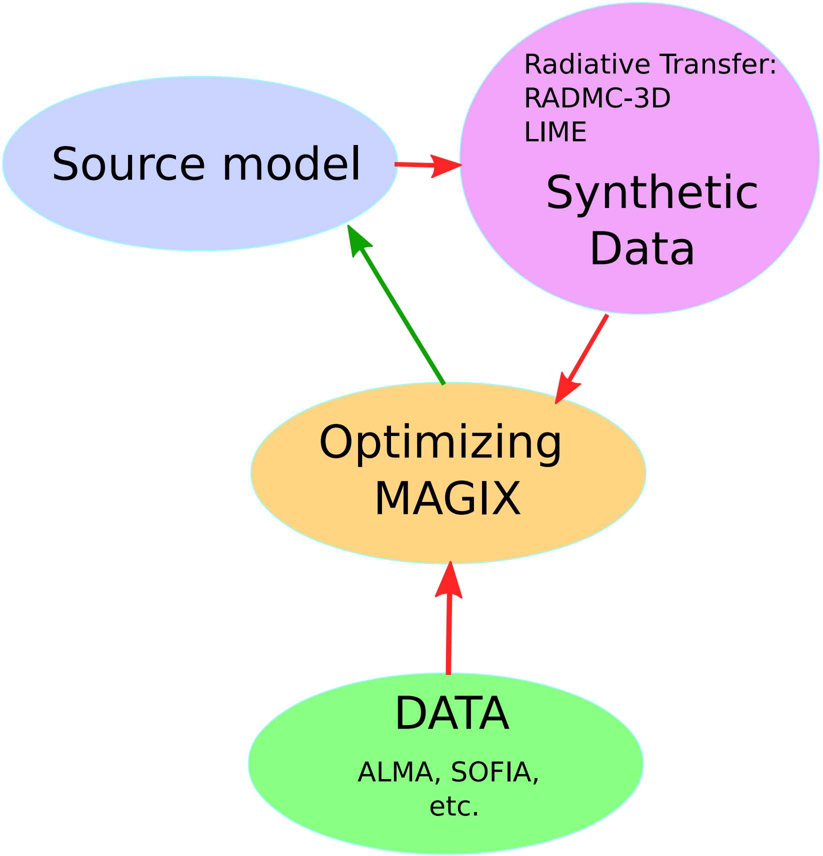
- ...but do not trace the complete excitation regime

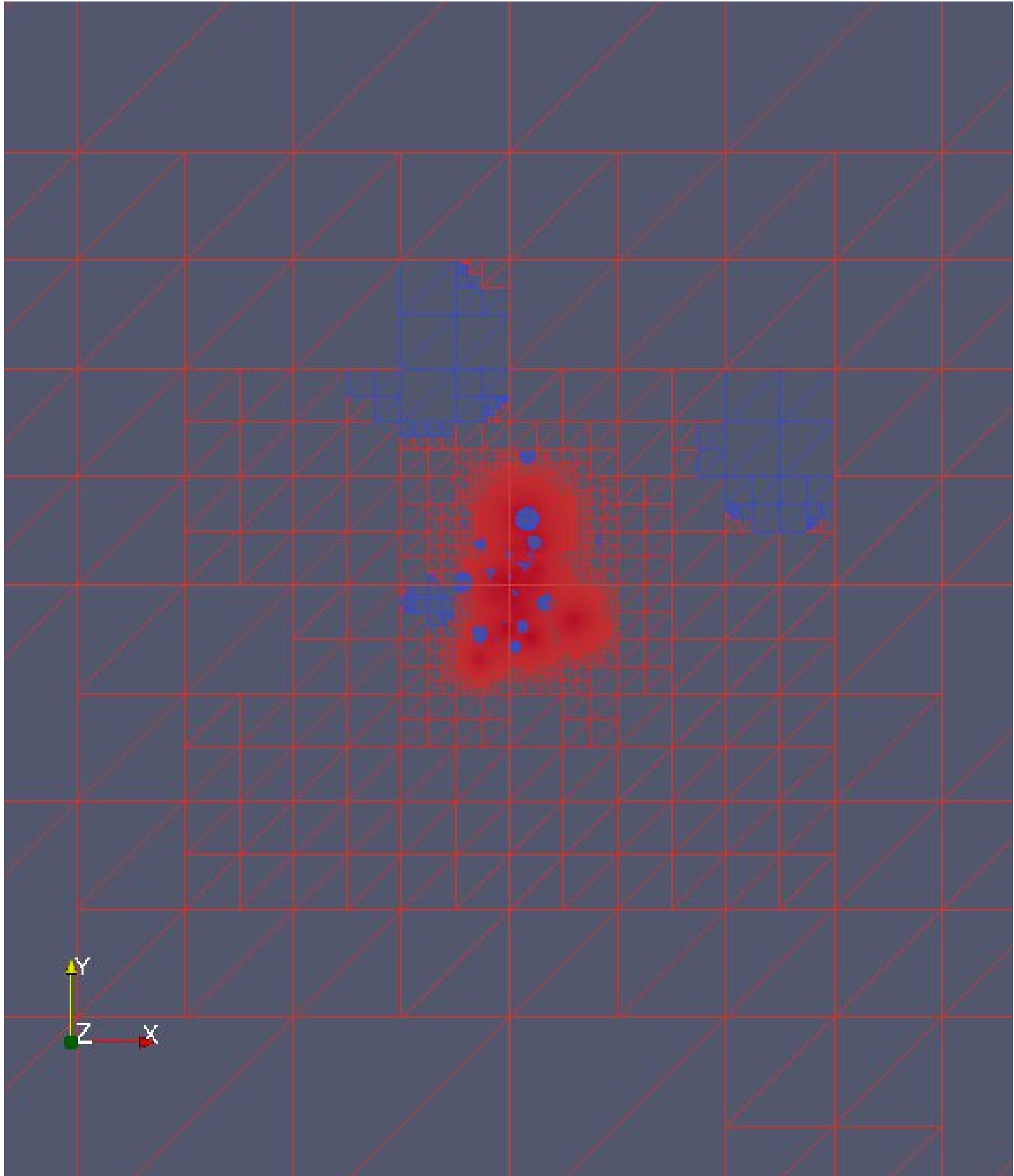
  (also Friedrich Wyrowski's talk)

  ⇒ combine both!

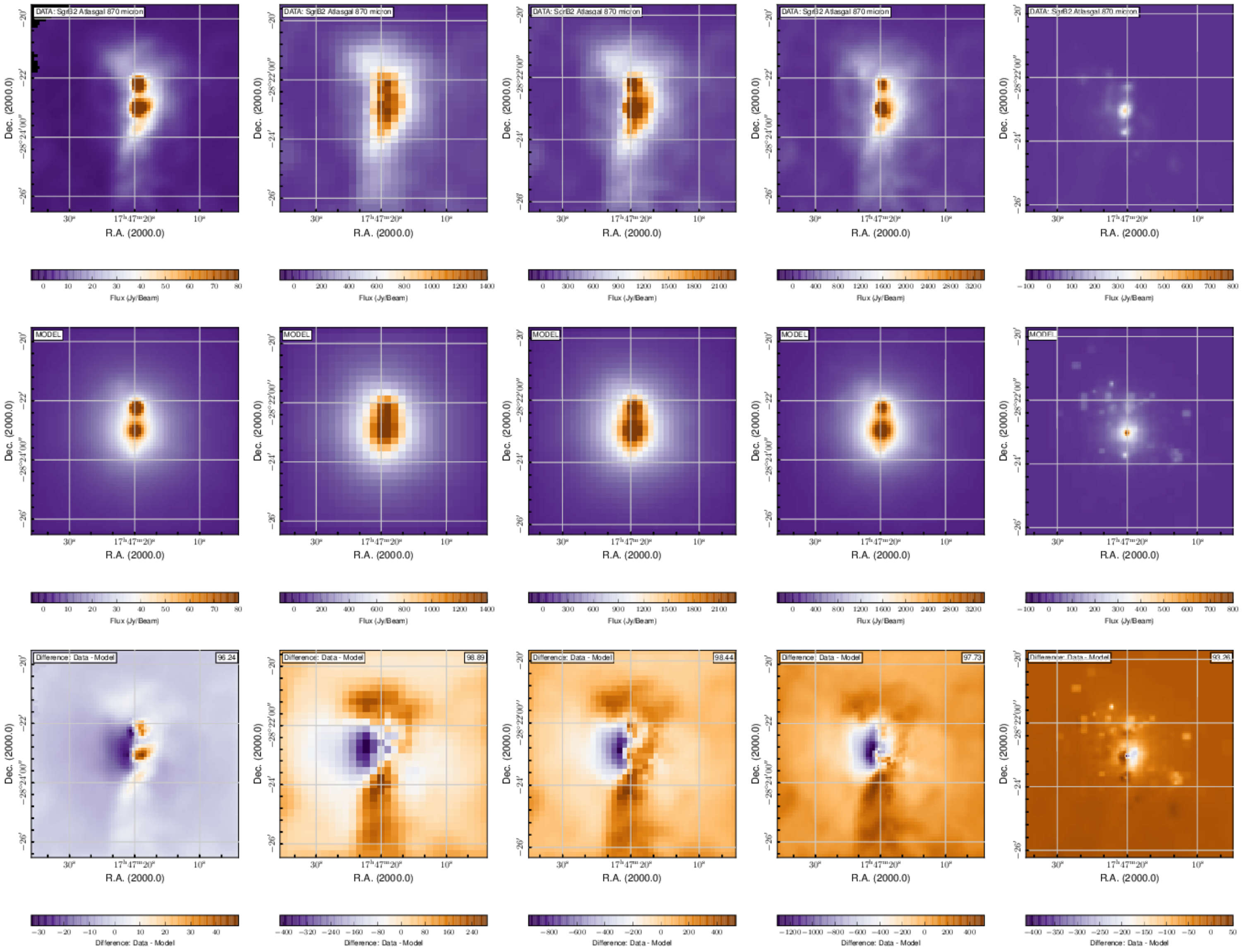


pandora by Anika Schmiedeke (PhD thesis)
Example: 3-d continuum



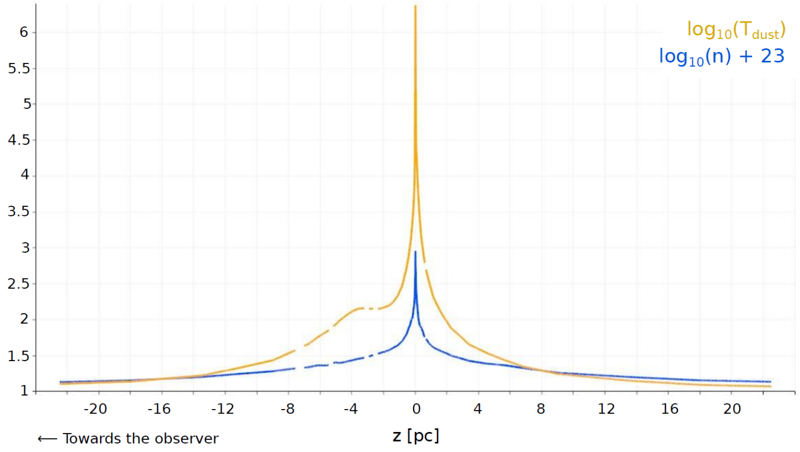


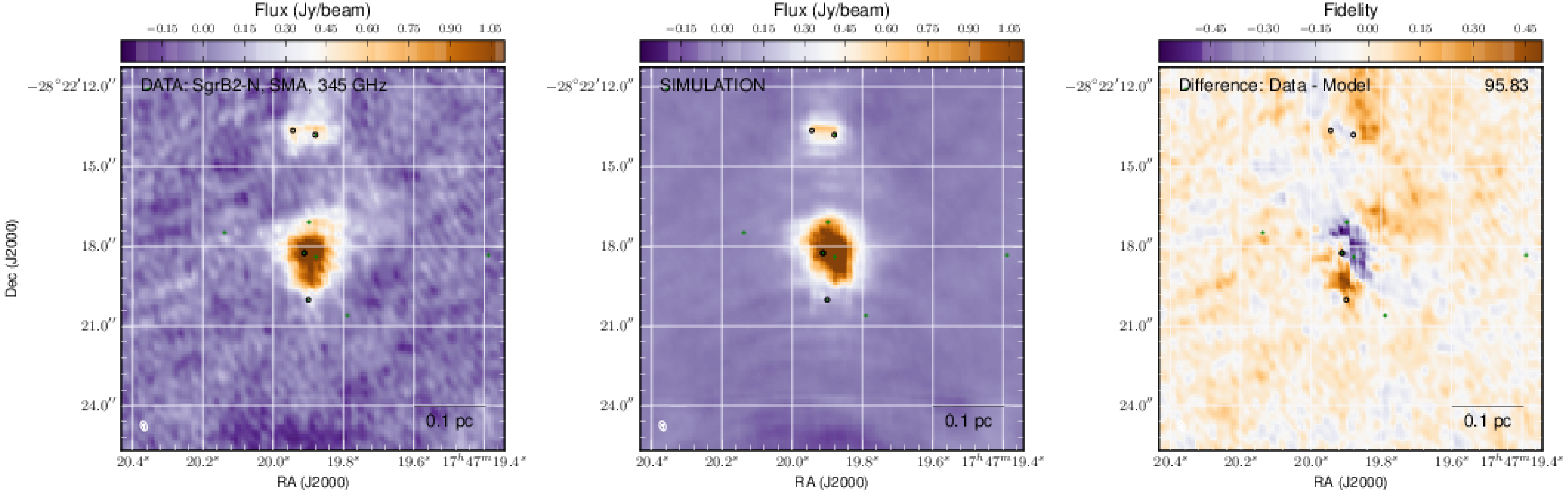
SOFIA scales: 5'
and wavelengths 250-70µm



ALMA scales: 0.3” and wavelengths: 870 µm

spatial dynamical range of current model:
0.3” (SMA resolution): 5' (Herschel map size)
= 1:1000
for ALMA (0.01”) can achieve 1:30000





Final conclusions

SOFIA and ALMA are complementary in many respects

- ISM studies (extended wavelength range desirable!)
- extragalactic/high redshift studies
- star formation studies