New facets of the cold ISM

Edith Falgarone

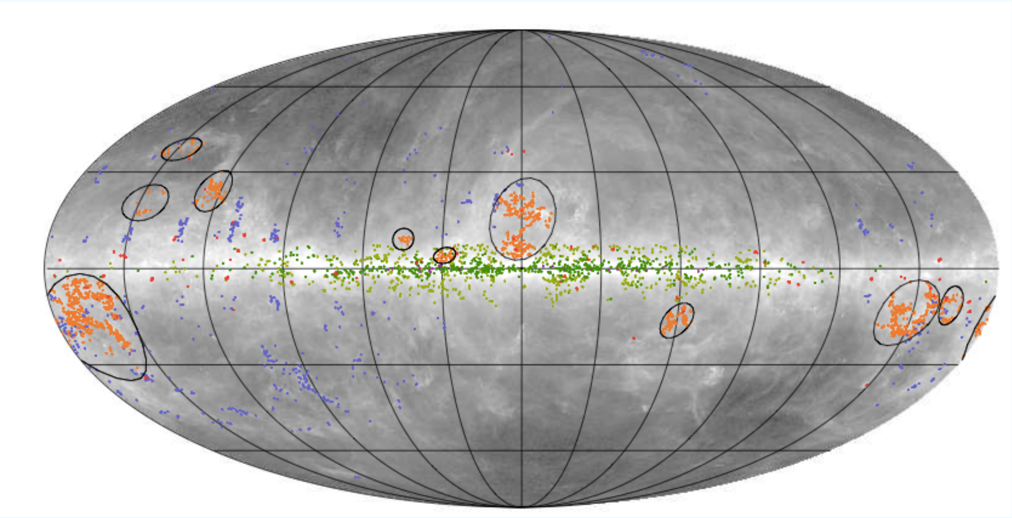
on behalf of the *Planck* collaboration

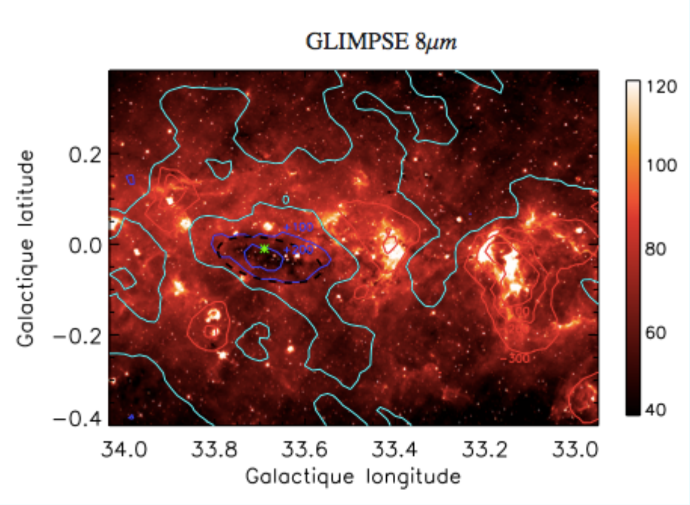
- *Planck* Cold clumps
- All-sky CO survey
- CO-dark gas

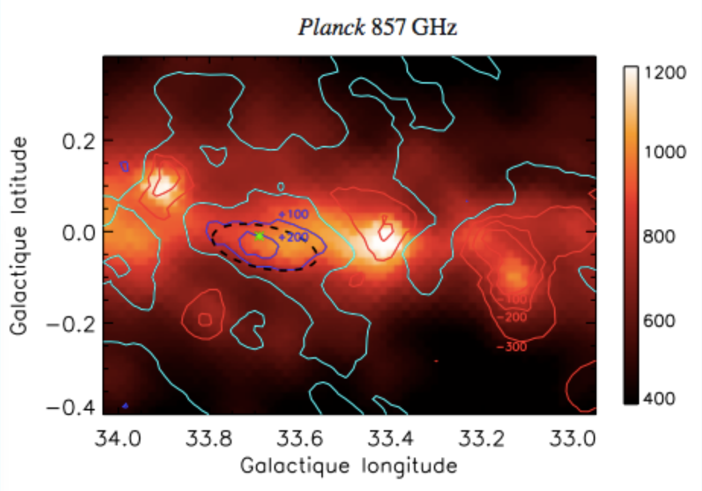
planck

l'Observatoire de Paris

The *Planck* Galactic Cold Clumps







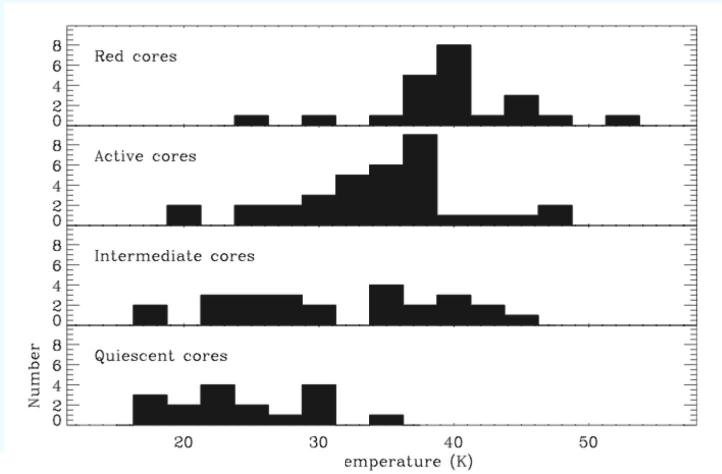
IRDC MSXDC G033.69−00.01

11262 Galactic sources, 3040 with reliable distance estimates

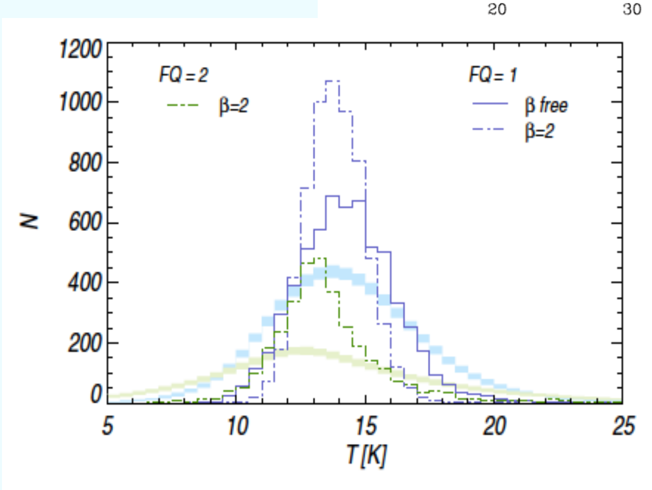
Spanning most galactic environments : arm/interarm, distance to GC, distance to plane

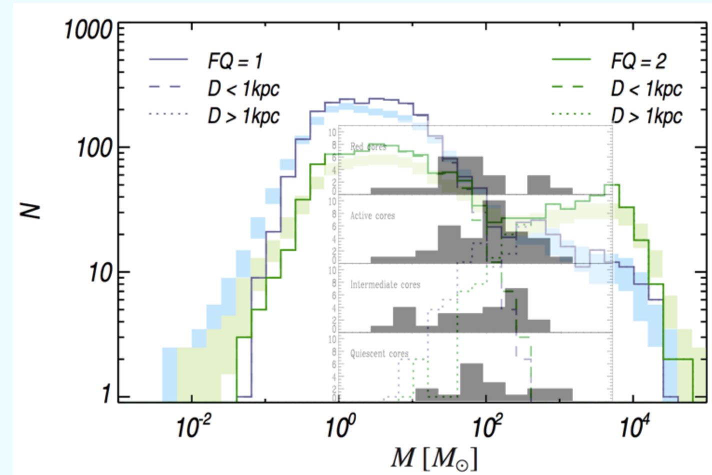
➔ enables unique statistical studies of the earliest phases of SF

Comparison PGCC and IRDC distributions



Rathborne + 2010

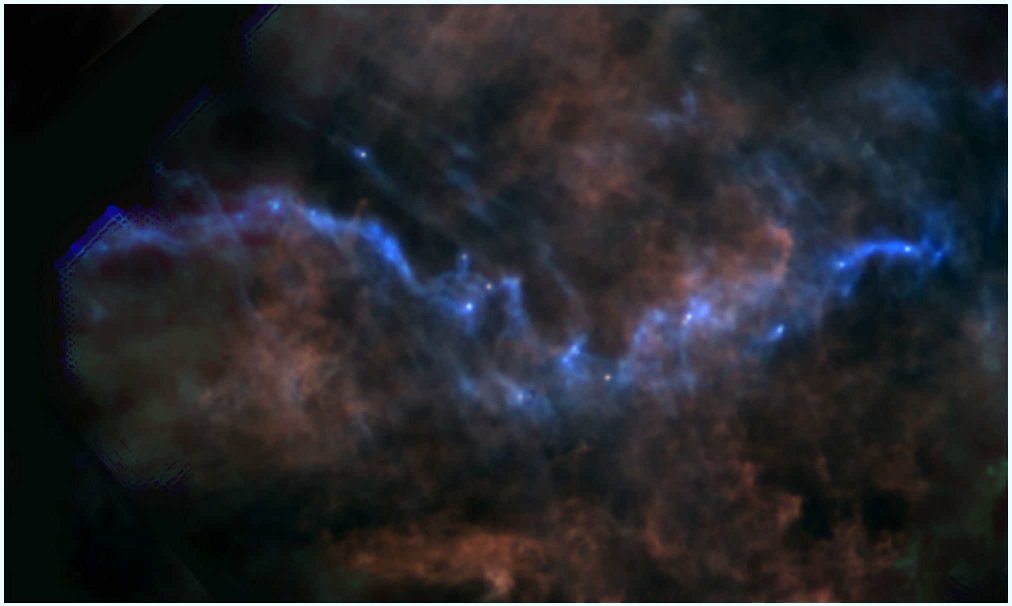




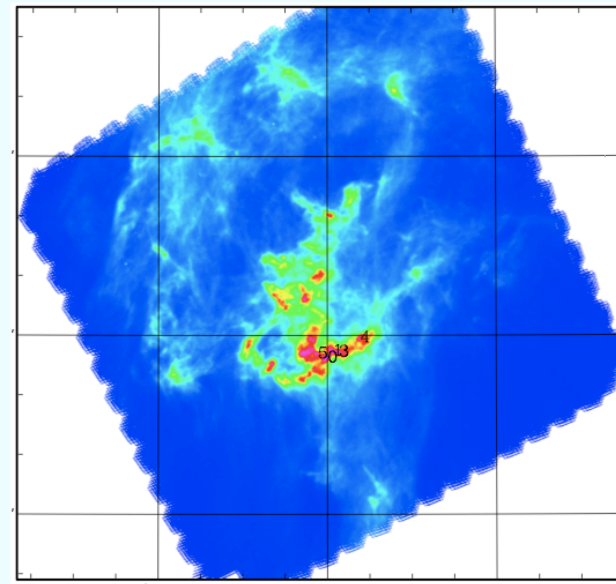
Broader mass distribution

Coldest structures
➔ very early stages
of core/clump evolution

Herschel/SPIRE follow-up at 160, 250 and 500 µm



G82.65-2.00 : very cold filaments undetected at 250 µm



Star forming
high Latitude Cloud
MBM12

Juvela + 2010, 2011, 2012,

G049+11.38

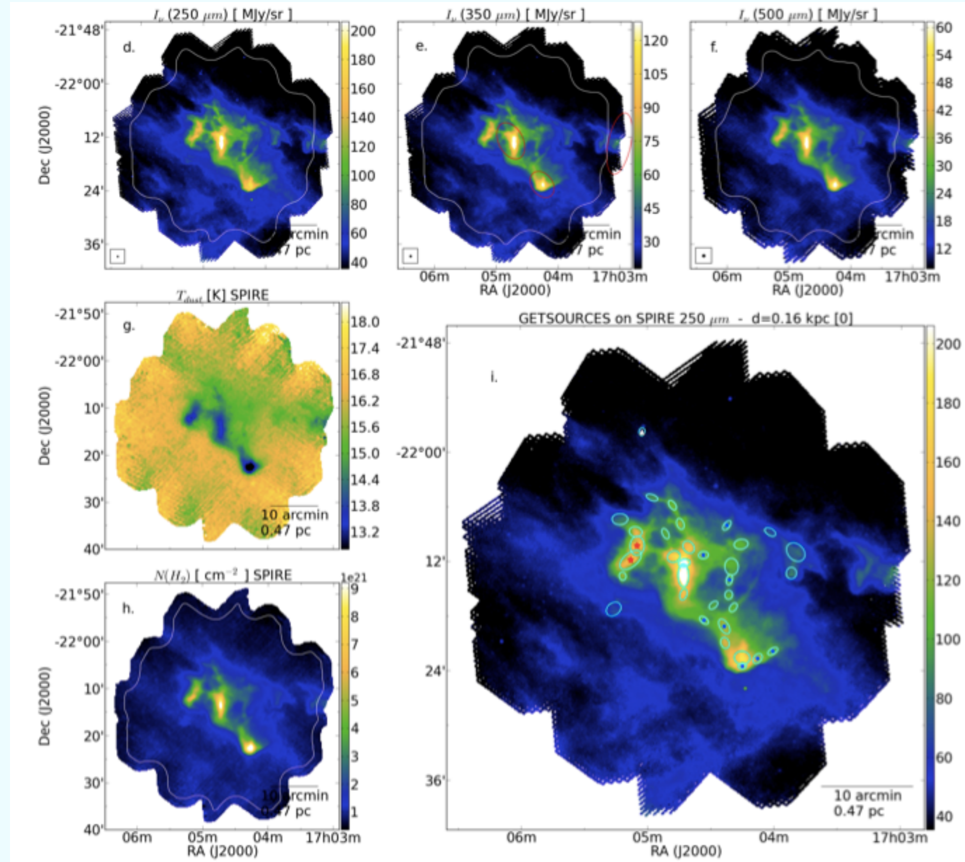
3 cold substructures,
Only one with 2 YSOs

YSOs from
AKARi and WISE IR data

$$N(\mathrm{H_2}) = \frac{I_\nu}{B_\nu(T_{dust})\kappa_\nu \mu_{\mathrm{H_2}} m_{\mathrm{H}}}$$

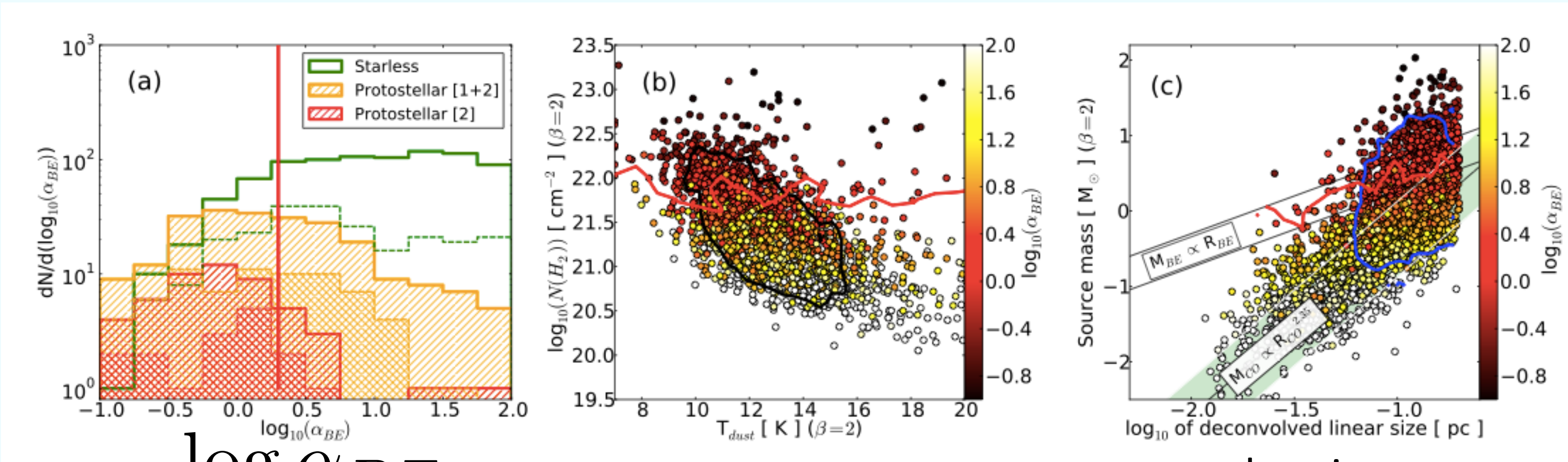
with the dust emissivity $\kappa_\nu \propto \nu^\beta$

➔ degeneracy N_{H2}, T_{dust} and the dust emissivity properties (β index)



Montillaud + 2015

Gravitational binding and stability



$\log \alpha_{BE}$ log size

Isolated clump : $M_{\rm BE}^{crit} \approx 2.4 R a^2 / G$ *a* = isothermal sound speed

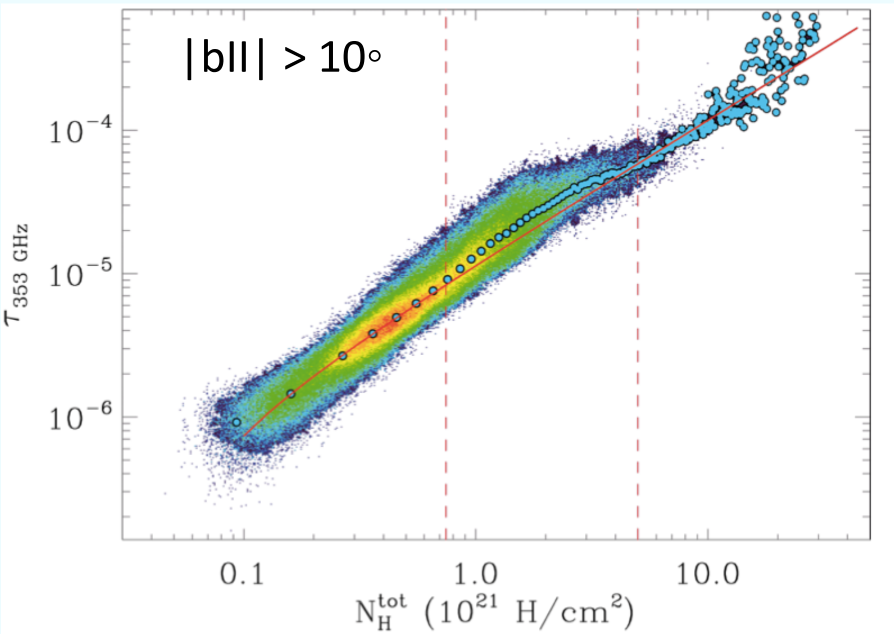
Pressure-bounded clump : $M_{\rm BE}^{crit} \approx 1.18 a^4 G^{-3/2} P_{ext}^{-1/2}$

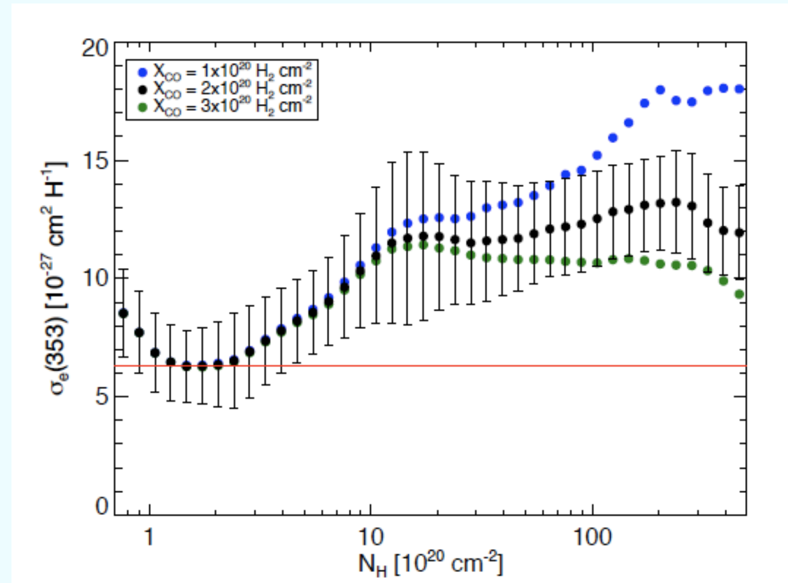
where $P_{ext} \approx 0.88 G \Sigma_{cl}$

$$\alpha_{BE} = max\left(M_{\rm BE}^{crit}(R), M_{\rm BE}^{crit}(\Sigma_{cl})\right)/M$$

➔ Dynamical analysis warranted : supra-thermal contributions to internal energy, role of environment in gravitational statibility, outflow feedback see Tie Liu's talk

CO-dark gas in Solar Neighbourhood





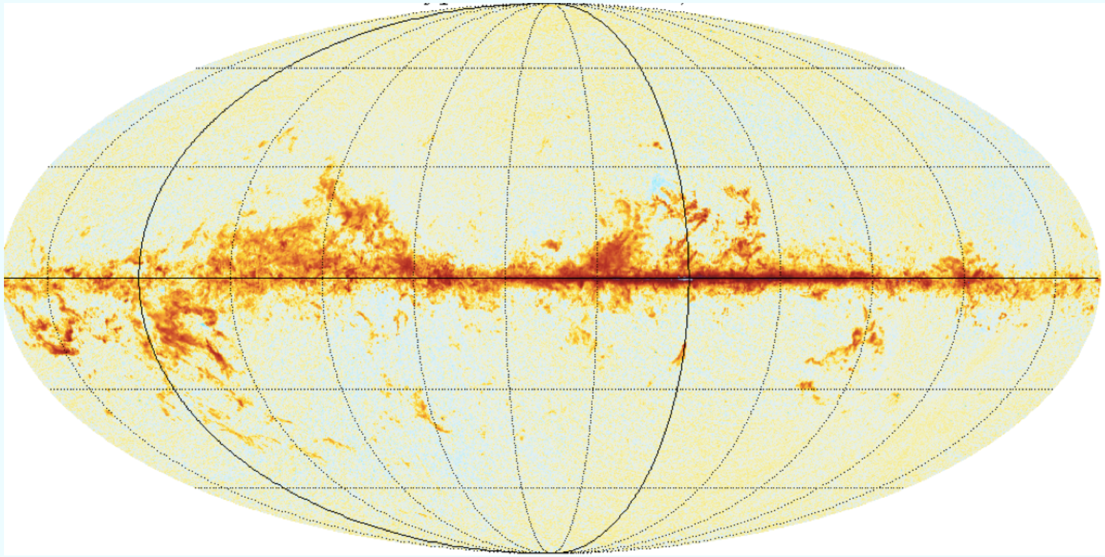
N_H^{tot} – dust optical depth correlation at 353 GHz
Red line: best linear correlation derived at low N_H^{tot}

Assumption: the dust opacity per unit gas column is the same in atomic and molecular phases

Degeneracy : dust properties, HI optical depth

Planck Early Results 2011:
Dark Gas: 28% of atomic component
118% of CO emitting gas

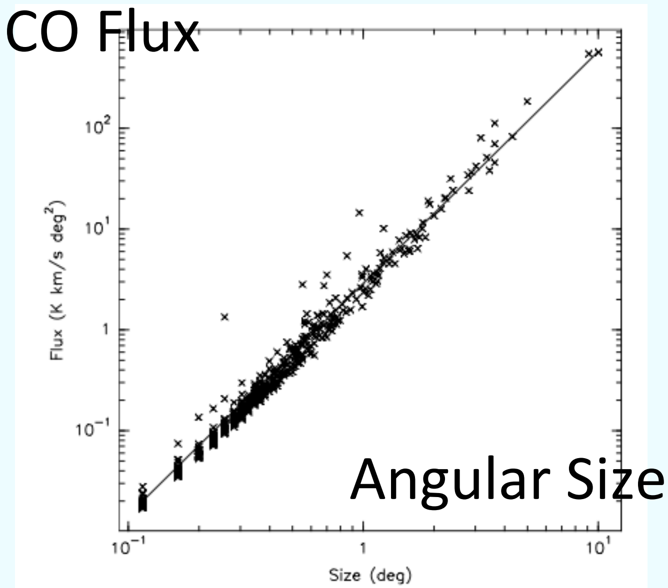
Planck : all-sky CO



CO at high galactic latitude:
power law distributions of size and flux of hundreds of « patches »

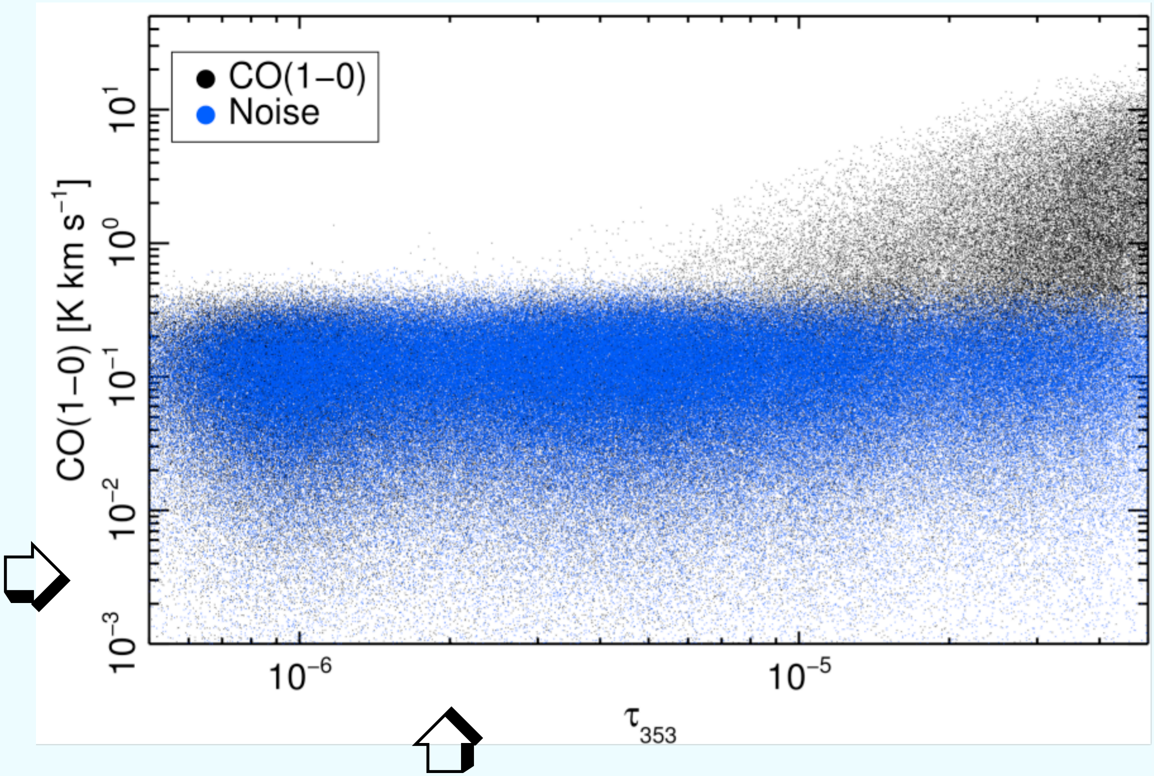
flux = CO brightness x $(\text{size})^2 \sim (\text{size})^{1.9 \text{ to } 2.5}$

➔ CO brightness ~ $(\text{size})^{-0.1 \text{ to } 0.5}$
➔ Weak extended emission expected below the detection level



Planck collaboration, in preparation

Noise-limited threshold for CO emergence

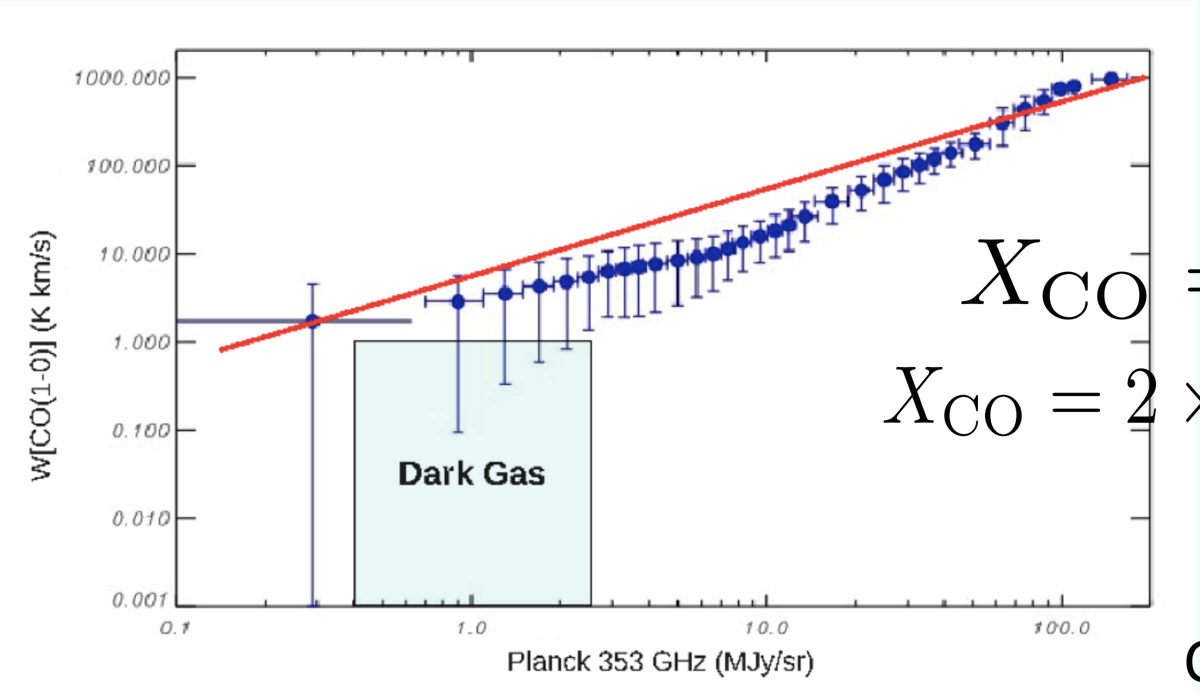


Expected threshold: $N_{CO} = 3 \times 10^{12}$ cm^{-2} (HST visible absorption)

⇨ $W(CO_{1\text{-}0}) = 3$ mK km s^{-1} (low density gas)

at $N_H = 2 \times 10^{20}$ cm^{-2} (threshold for H_2 emergence) ⇨ $\tau_{353} = 2 \times 10^{-6}$

CO reliable gas mass tracer



Average X_{CO} factor :

$$X_{\rm CO} = N({\rm H_2})/W({\rm CO})$$

$$X_{\rm CO} = 2 \times 10^{20} {\rm cm}^{-2}/{\rm K\,km\,s}^{-1}$$

$$f_{\rm H_2} = 1$$

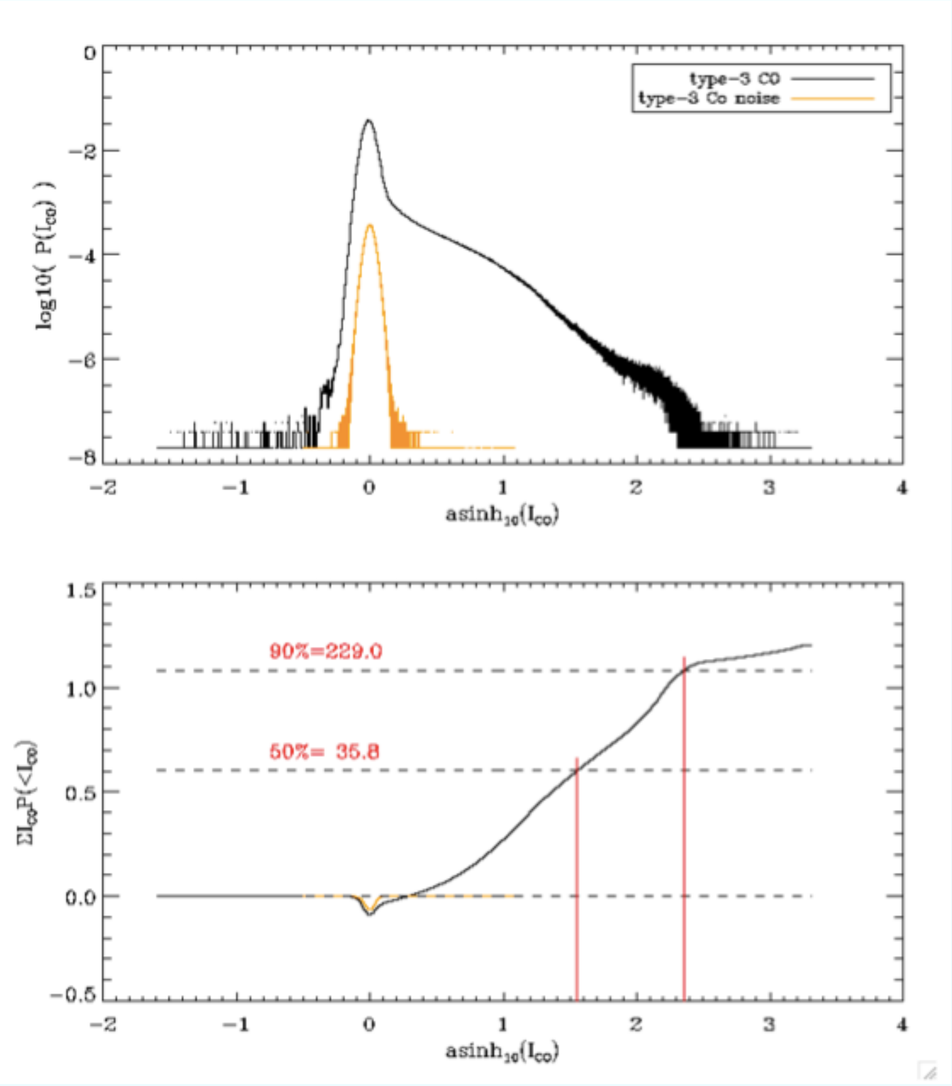
Mean and standard deviation of CO emission in bins of 353 GHz emission = proxy for N_H

1 MJy sr^{-1} @ 353 GHz ➔ 2 x 10^{21} cm^{-2} or ≈1 mag

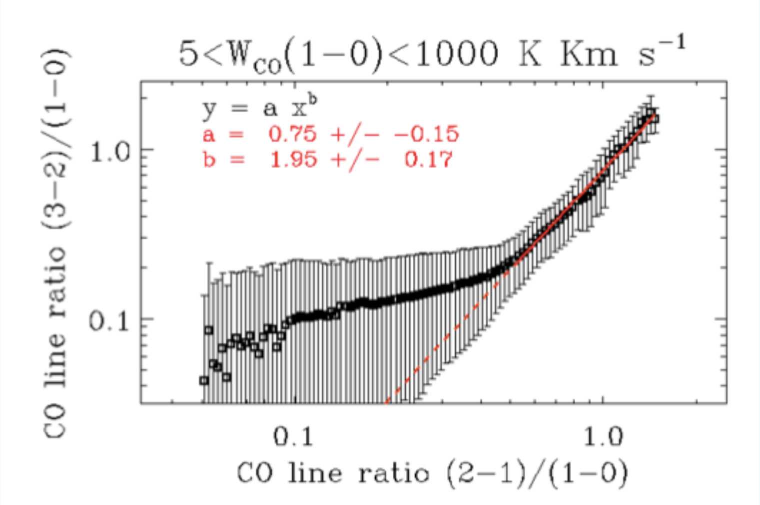
CO is a reliable gas mass tracer within a factor of a few over 3 orders of magnitude of column densities

see Bolatto + 2013

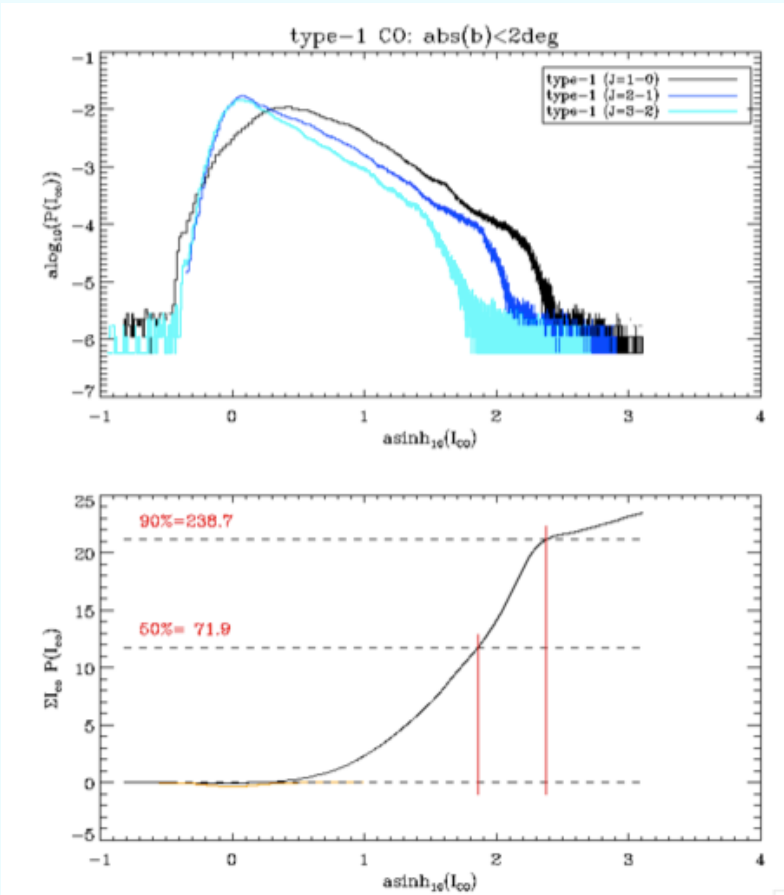
CO all-sky distribution



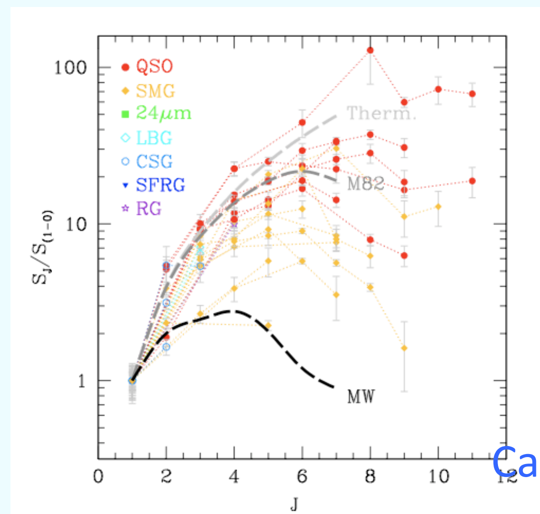
90% of the cumulative flux reached at W(CO)=229 K km s^{-1}



Bulk molecular mass of the Milky Way
H_2 density < 600 cm^{-3} and T_k > 20K



$$R_{2-1/1-0} = 0.5 \pm 0.1$$
$$R_{3-2/1-0} = 0.23 \pm 0.05$$

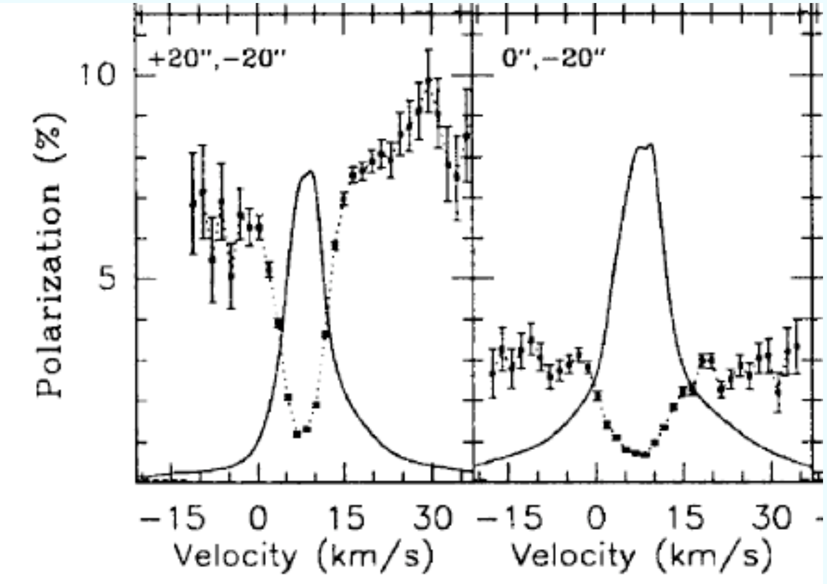


SLEDs of galaxies
Milky Way model

Carilli & Walter 2013

Non-LTE analysis: density, temperature degeneracy
➔ H_2 density < 600 cm^{-3} and T_k > 20K

Linear polarization of CO lines



CO(2-1) Stokes I and polarization fraction vs velocity in Orion
Girart + 2004, Crutcher 2012 ARAA

Golreich-Kylafis effect

B field splits the energy levels into magnetic sub-levels (π and σ_{+-})

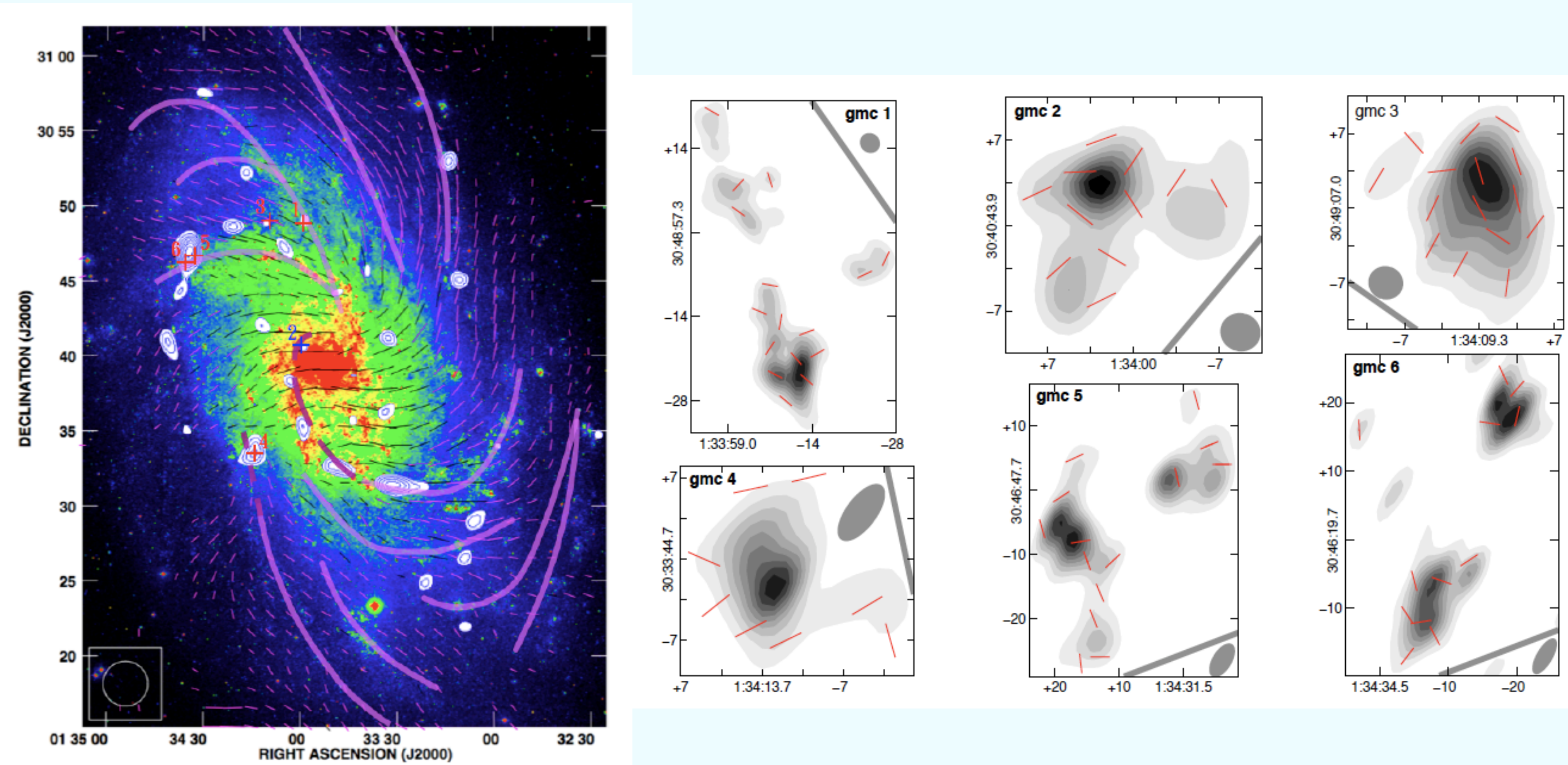
Non-thermal populations of magnetic sub-levels enhanced in

- ➪ low gas density (levels populated by radiation, not by collisions)
- ➪ anisotropic mm/submm radiation (optical depth ~ 1, little scattering)
- ➪ linewings (low opacity)

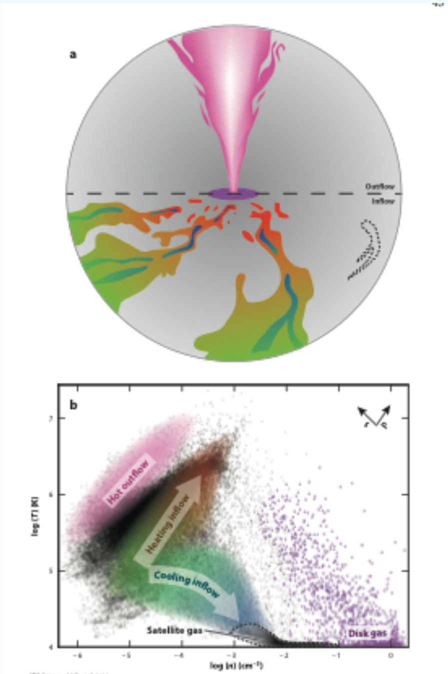
Up to 10% in edges of star forming regions

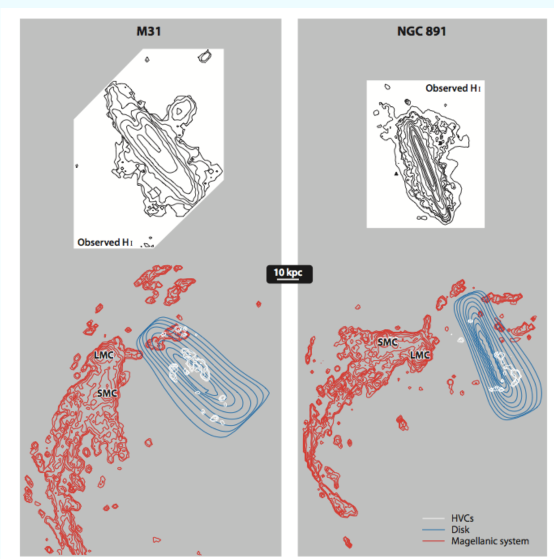
Never measured in diffuse gas.

CO line polarization: tracer of magnetic field direction independent of dust properties



M33: synchrotron polarization vs CO line polarization in GMCs
Li et al 2011





Perspectives

- High latitude CO and PCCs open a new window on Galactic halo physics: disk-halo multi-phase interaction
- Statistics of PCCs dynamics in a variety of Galactic environments will broaden SF approach
- CO polarization for B field studies independently of dust properties
- Dark gas origin and mass content: dust properties, HI line opacity

Putman + 2012