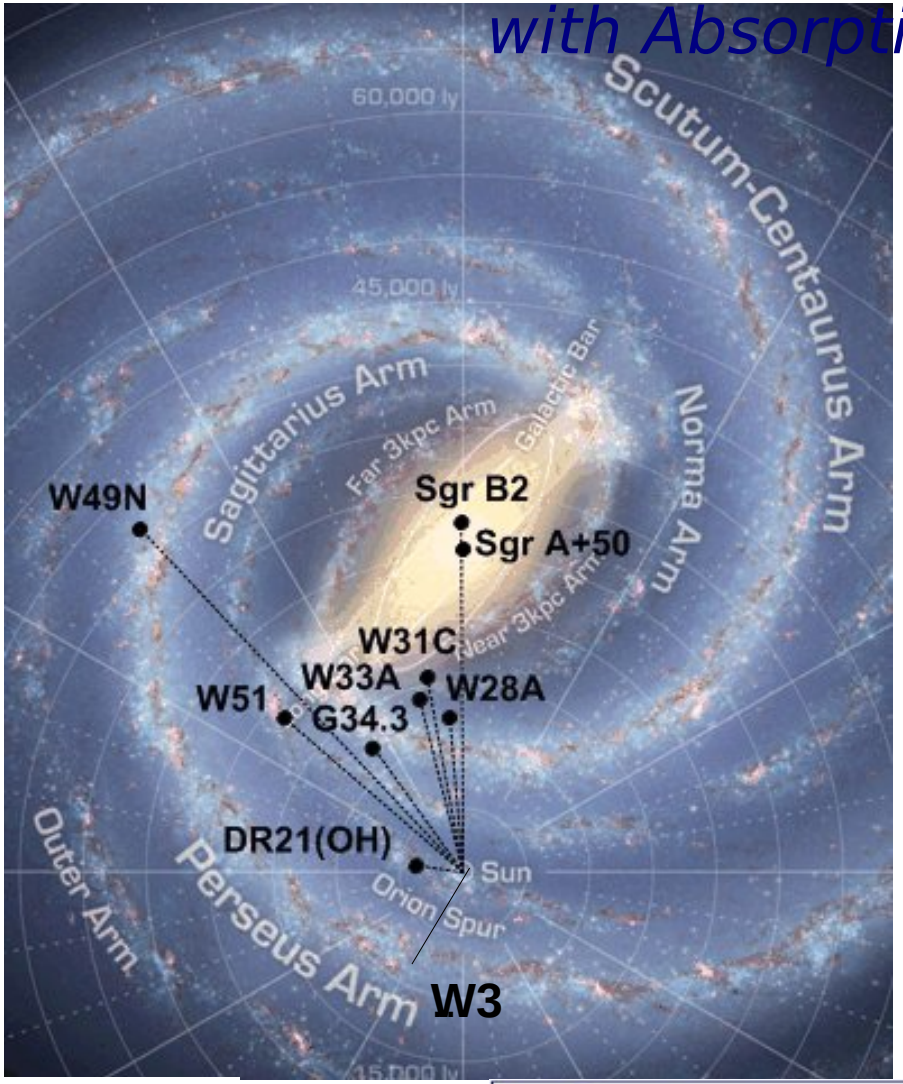
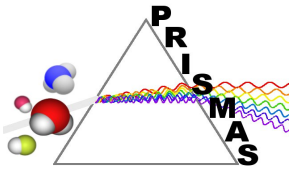
PRISMAS

PRobing InterStellar Molecules with Absorption line Studies



Sounding the diffuse ISM with Herschel/HIFI

Maryvonne Gerin on behalf of the PRISMAS team



PRISMAS

PRobing InterStellar Molecules with Absorption line Studies

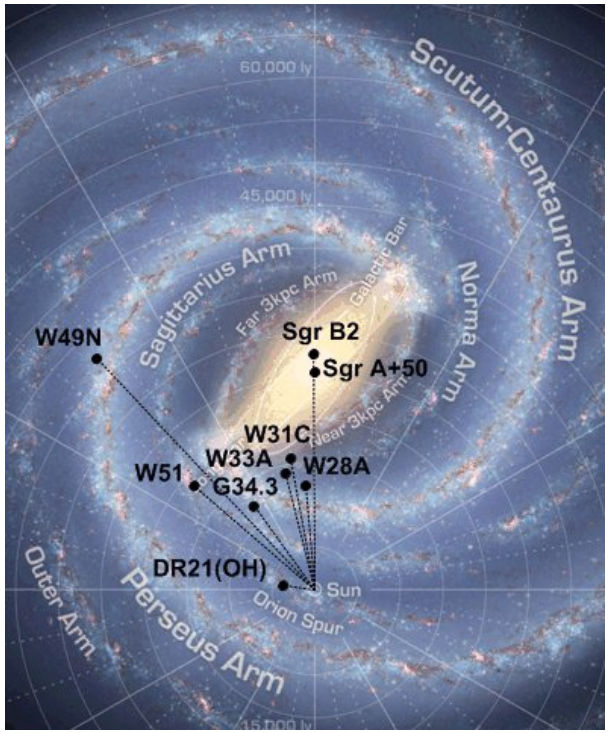
- Absorption spectroscopy : Direct probe of line opacity. easier analysis of molecule column density
- Excellent sensitivity : reach the same range of column density as visible spectroscopy for molecules accessible both ways (eg CH and CH^+) => probe diffuse and translucent gas with Av few mag in the FIR spectral range.
- 11 background sources (massive star forming regions)

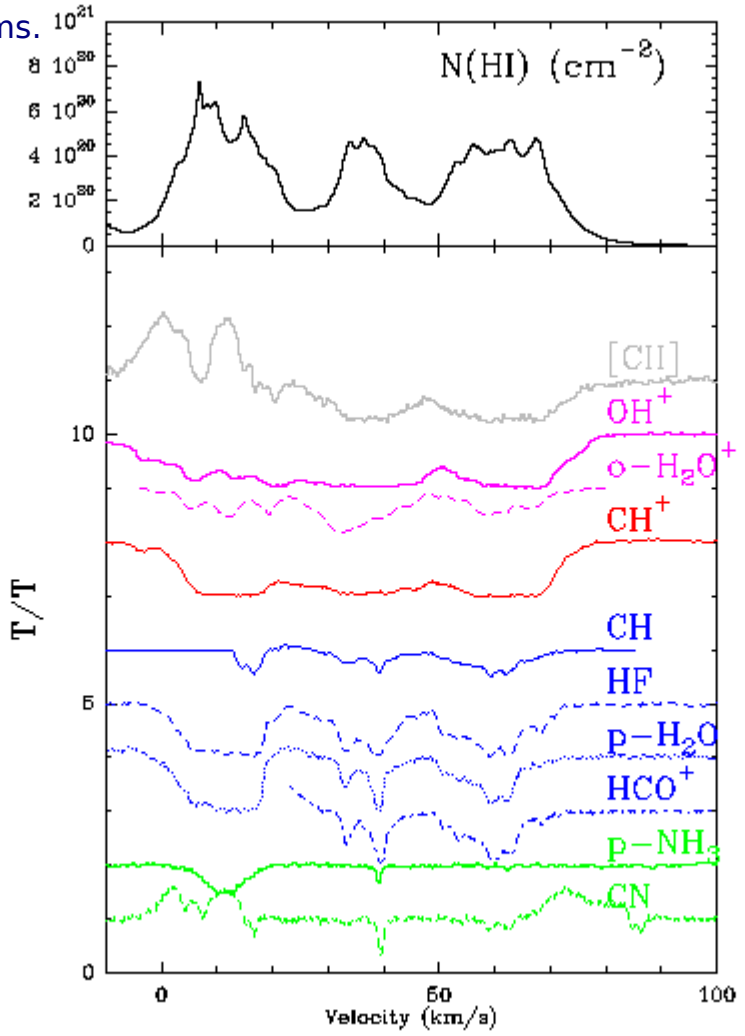
Targeted species for absorption

- C CH, ^{13}CH, CH^+, $^{13}CH^+$, CH_2 , C_3
- N NH, NH_2, NH_3 (o & p), $^{15}NH_3$, ND, NH_2D, NH^+
- O **OH^+,H_2O^+ (o & p)**,H_3O^+, H_2O (o & p), $H_2{}^{18}O$, HDO, D_2O
- F HF, DF
- Cl HCl, **HCl^+ , H_2Cl^+**
- S **SH^+**
- & one U line !

An example : the line of sight towards W49N

The line of sight crosses two spirals arms.
V → position in the MW
Similar line ratios →
Similar properties of the diffuse ISM across the Galactic plane





New Diagnostics

OH^+, H_2O^+, H_3O^+ : CR ionization rate

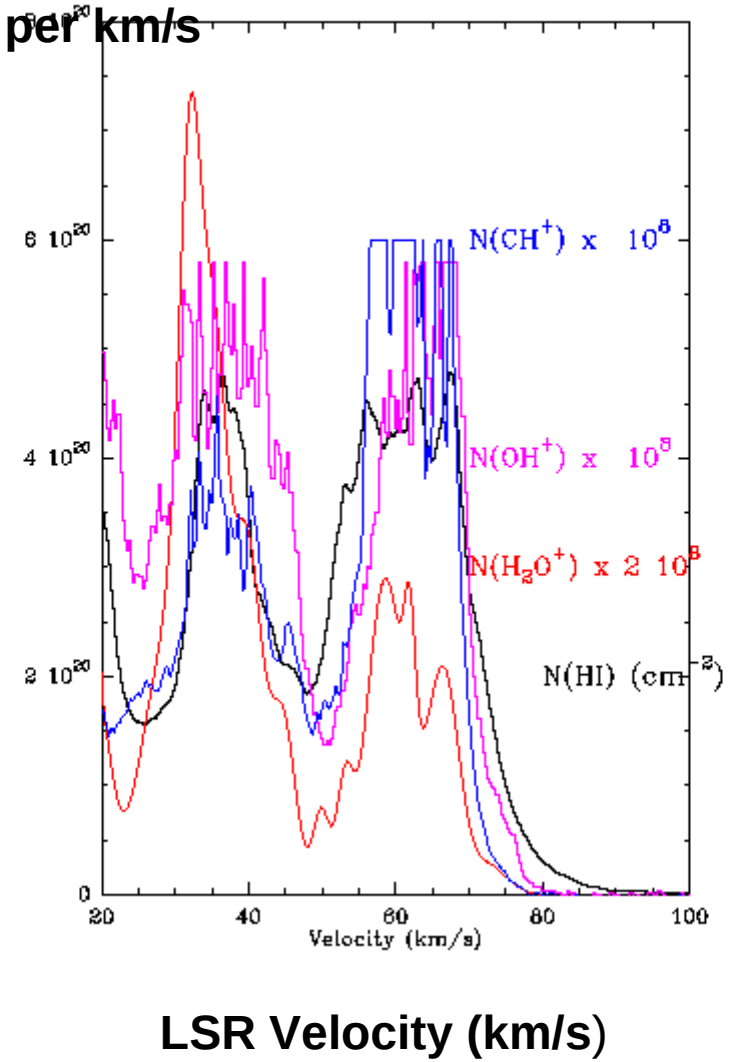
CH^+, SH^+ : Dissipation of turbulence

CH, HF (H_2O, HCO^+) → H_2

C^+ , C & HI → n,T

NH_3 (NH_2, NH, CN) → higher density

Molecules in (nearly) atomic gas



$$O^+ + H_2 \rightarrow OH^+ + H$$
$$OH^+ + H_2 \rightarrow H_2O^+ + H$$
$$H_2O^+ + H_2 \rightarrow H_3O^+ + H$$

High OH^+/H_2O^+ ratio → low fraction of H_2 (< 10%)

See talk by Indriolo

(Neufeld et al 2010, Indriolo et al 2012)

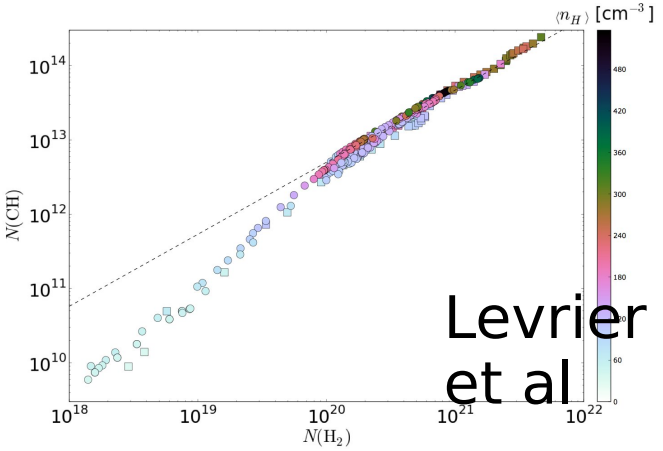
$$C^+ + H_2 \rightarrow CH^+ + H$$

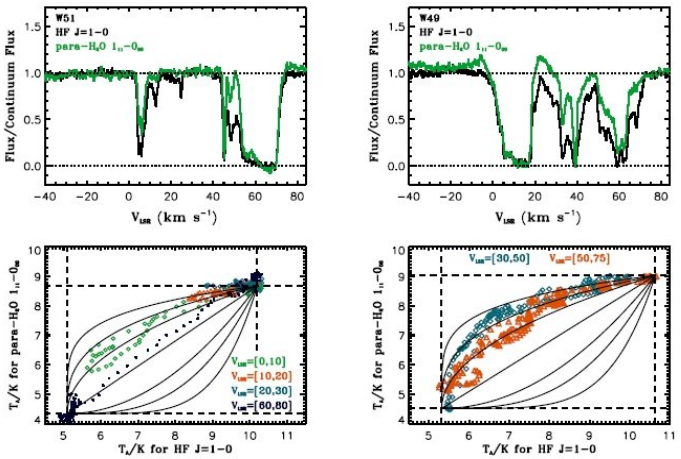
(endothermicity ~ 4000K)

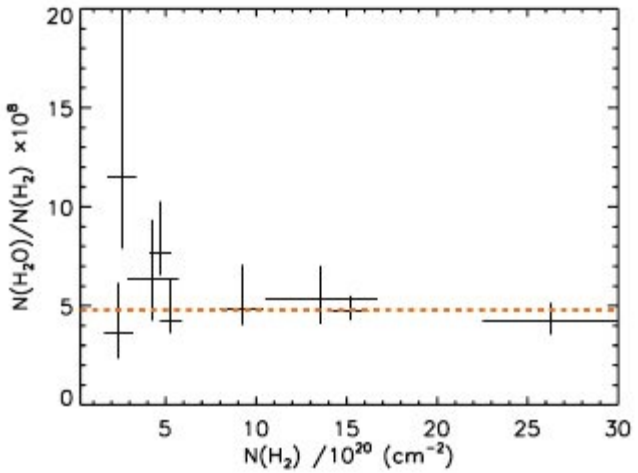
Also true for SH^+

See talk by Falgarone & Godard

(Falgarone et al 2010, Godard et al 2012)







Molecules as tracers of H_2

Molecular species with nearly constant abundance relative to H_2.

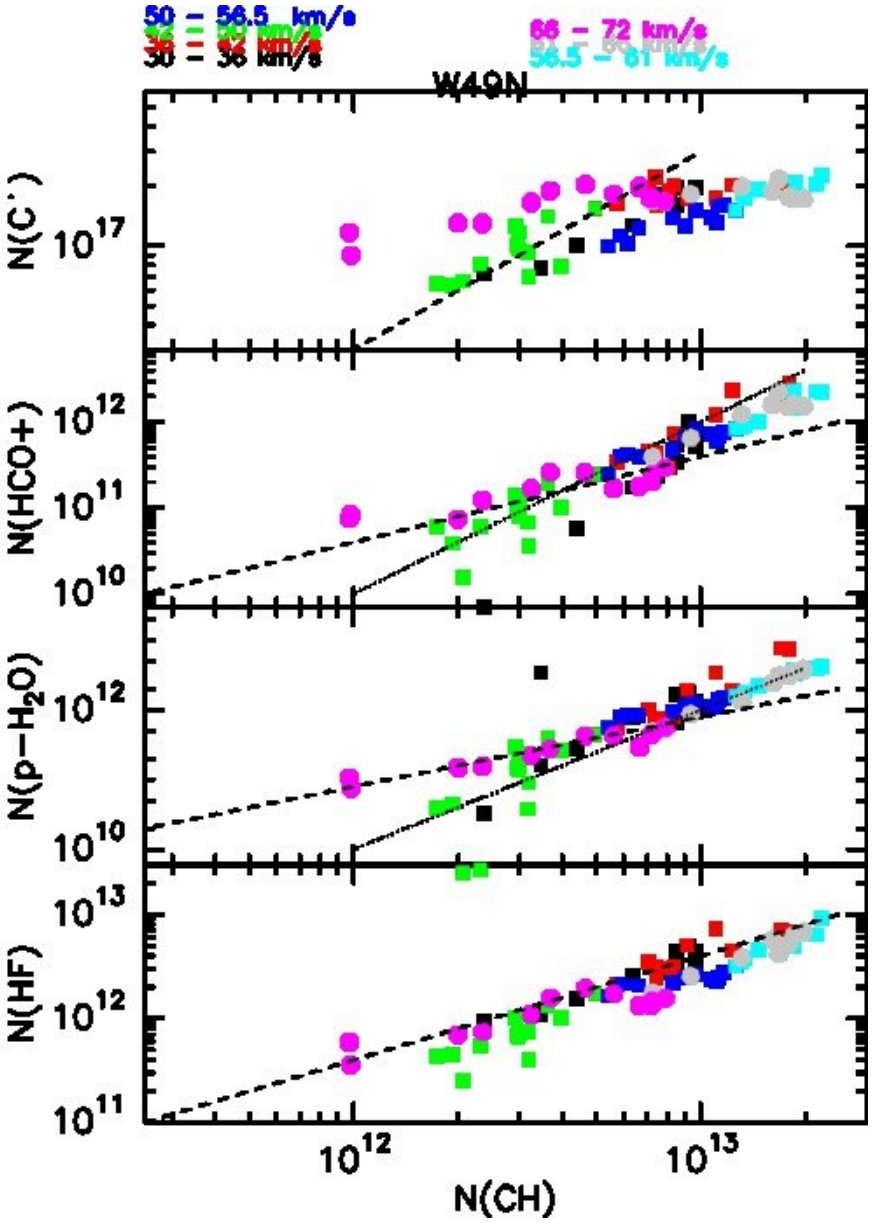
CH *(Sheffer et al)*

HF *(Neufeld et al, Sonnentrucker et al, Monje et al)*

H_2O (Lis et al, Flagey et al)

What about other species like HCO^+ , CCH ?

Comparison of H_2 tracers



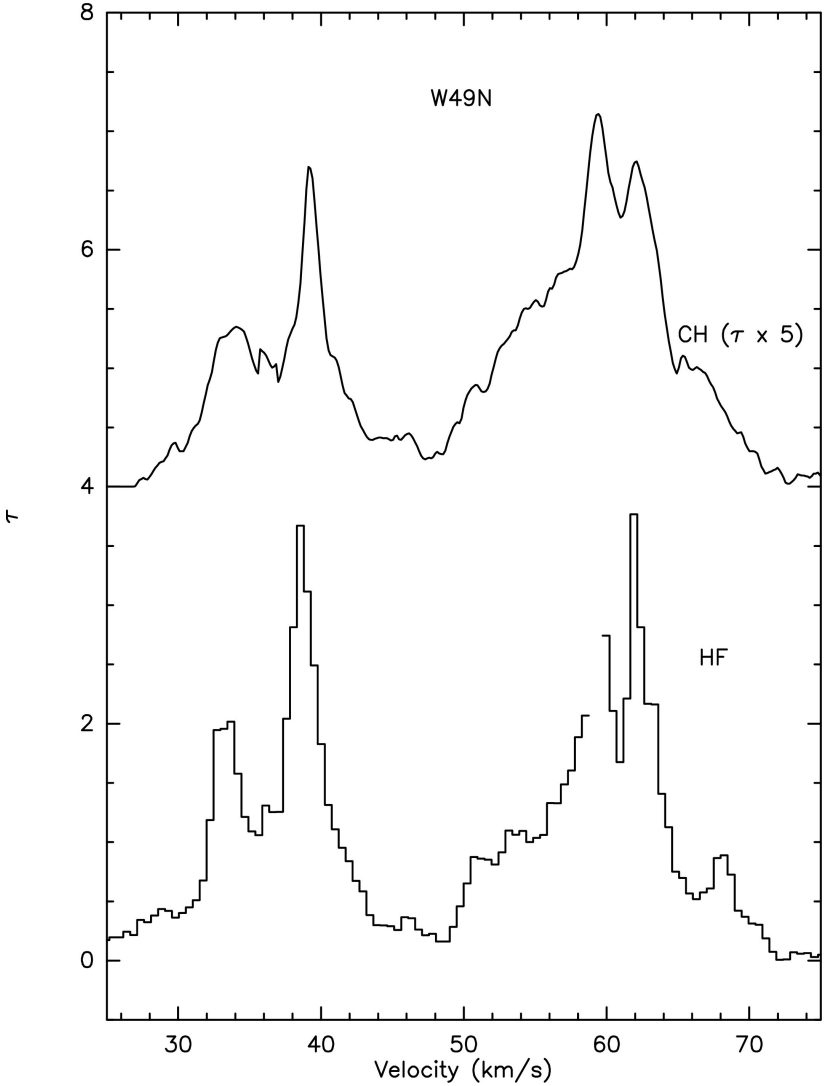
CH & HF are good tracers of molecular hydrogen in diffuse interstellar gas.

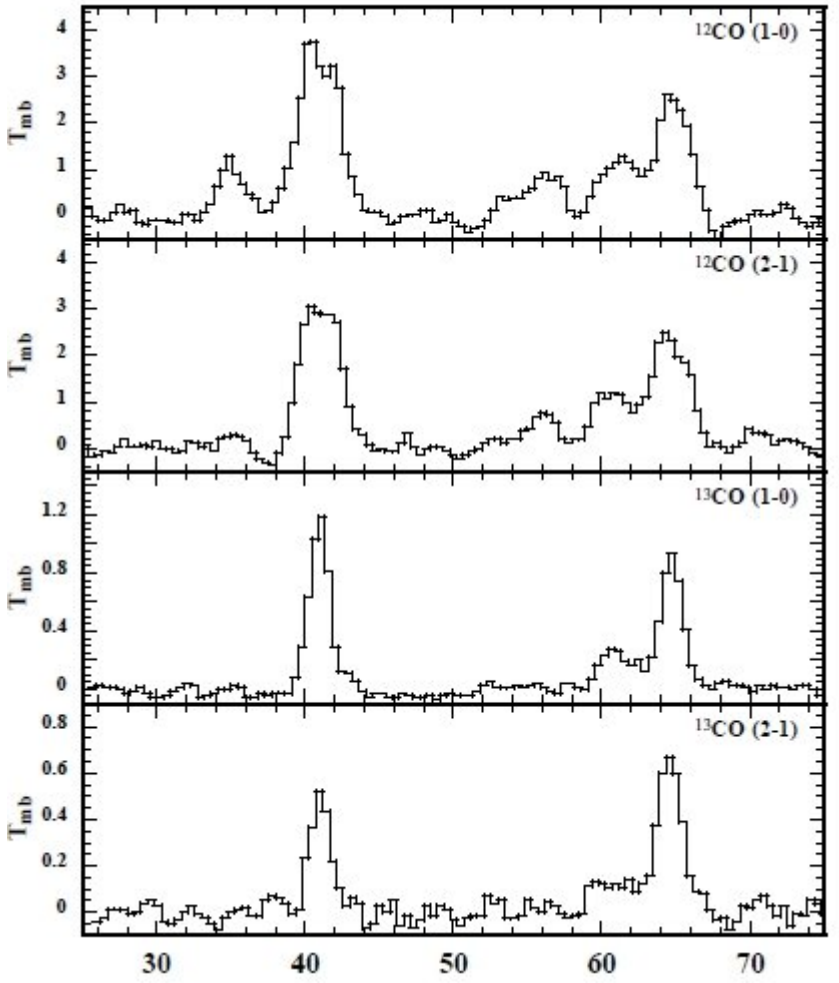
Mean HF/CH ~ 0.4 → F/H ~ 10-8 rather than 1.8 10-8 ? (see also Indriolo et al 2013 for a direct measurement)

CH is well correlated with CCH and c-C_3H_2 → possible tracers of H_3 accessible from the ground.

CH is correlated with HCO^+ and H_2O but with a slope > 1

H_2 tracers vs CO along the W49N line of sight

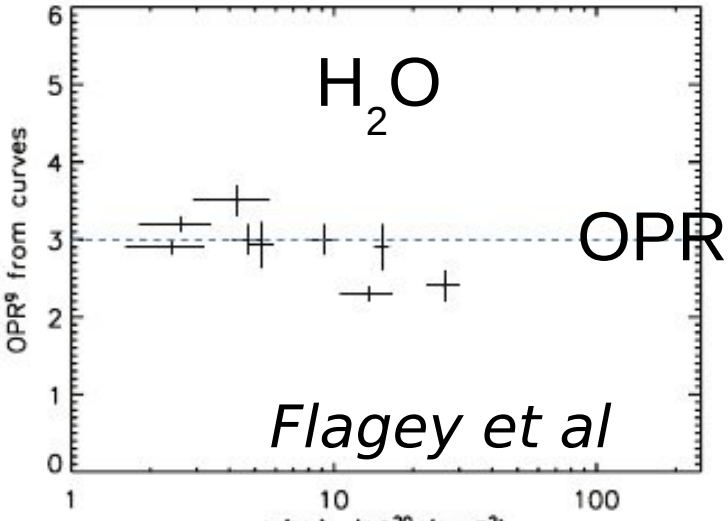


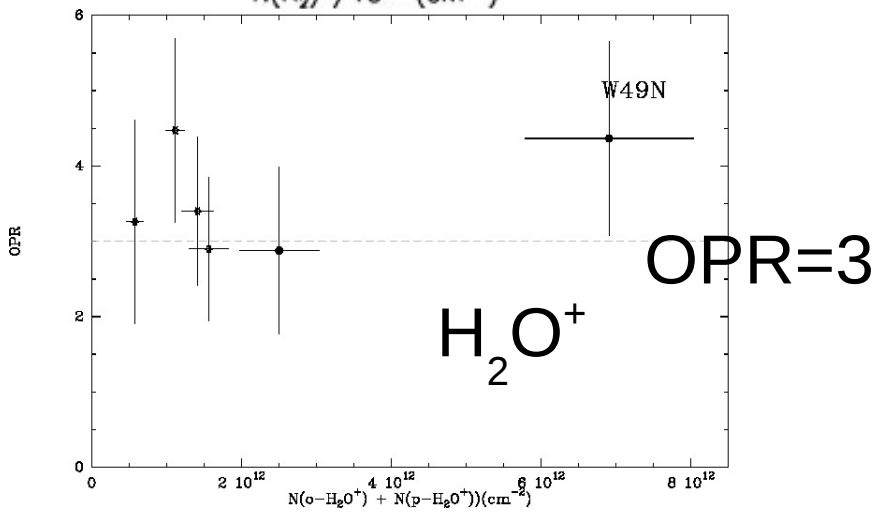


CH, HF (Herschel) CO (Vastel 2000)

Broader velocity distribution of CH & HF opacity than CO emission

Spin symmetry states





Gerin et al

Many species with different spin symmetry states accessible for the first time.

Ortho to para ratio (OPR)

H_2O

H_2O^+

H_3O^+

NH_3

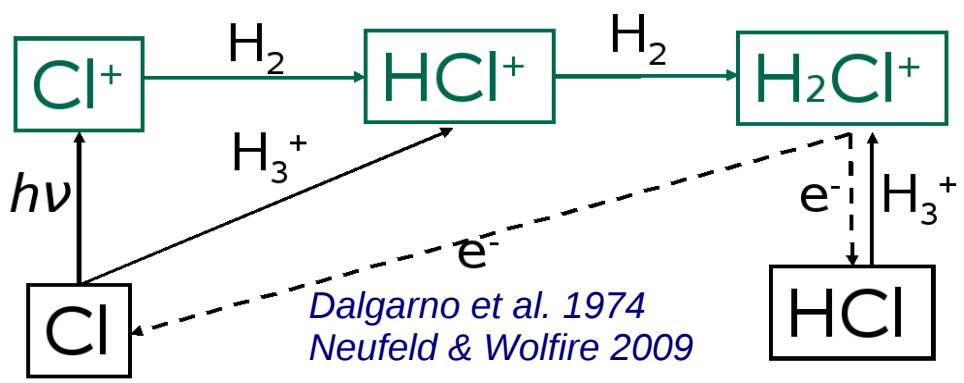
NH_2

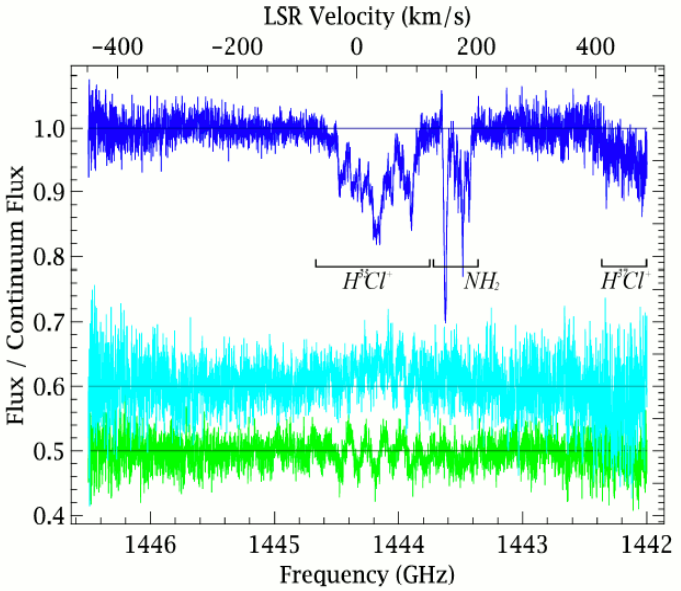
H_2Cl^+,

Clues to formation pathway ?

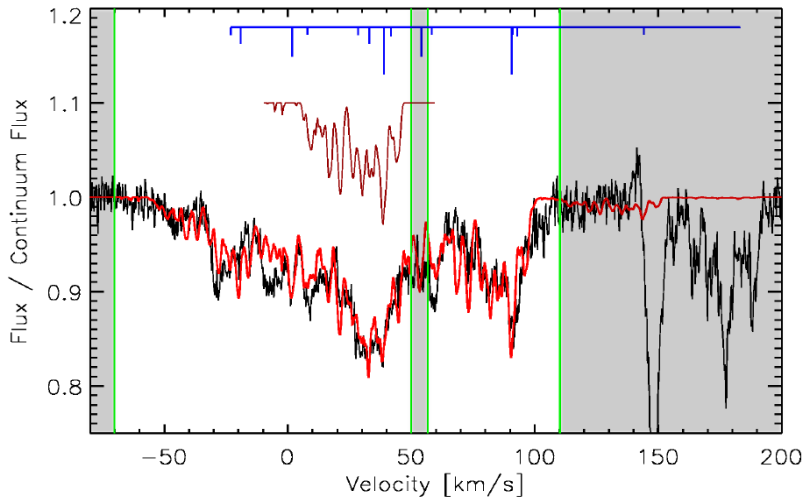
See talk on H_3O^+ (D. Lis)

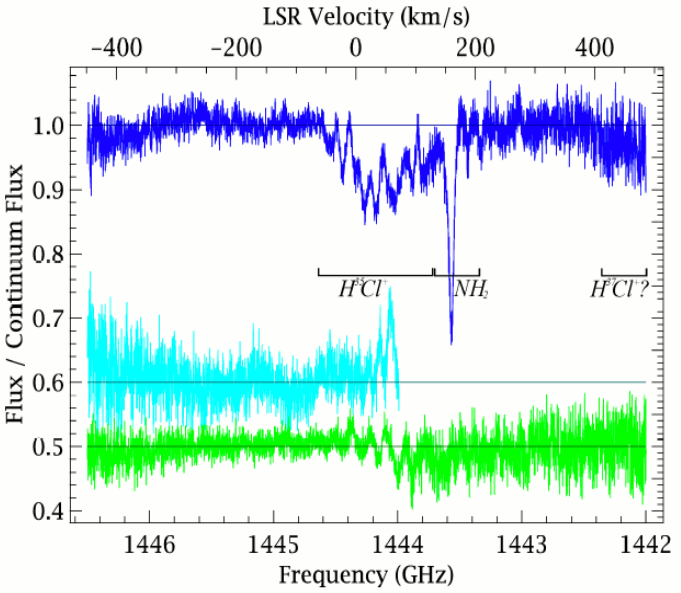
A revised view of the Chlorine chemistry in the ISM



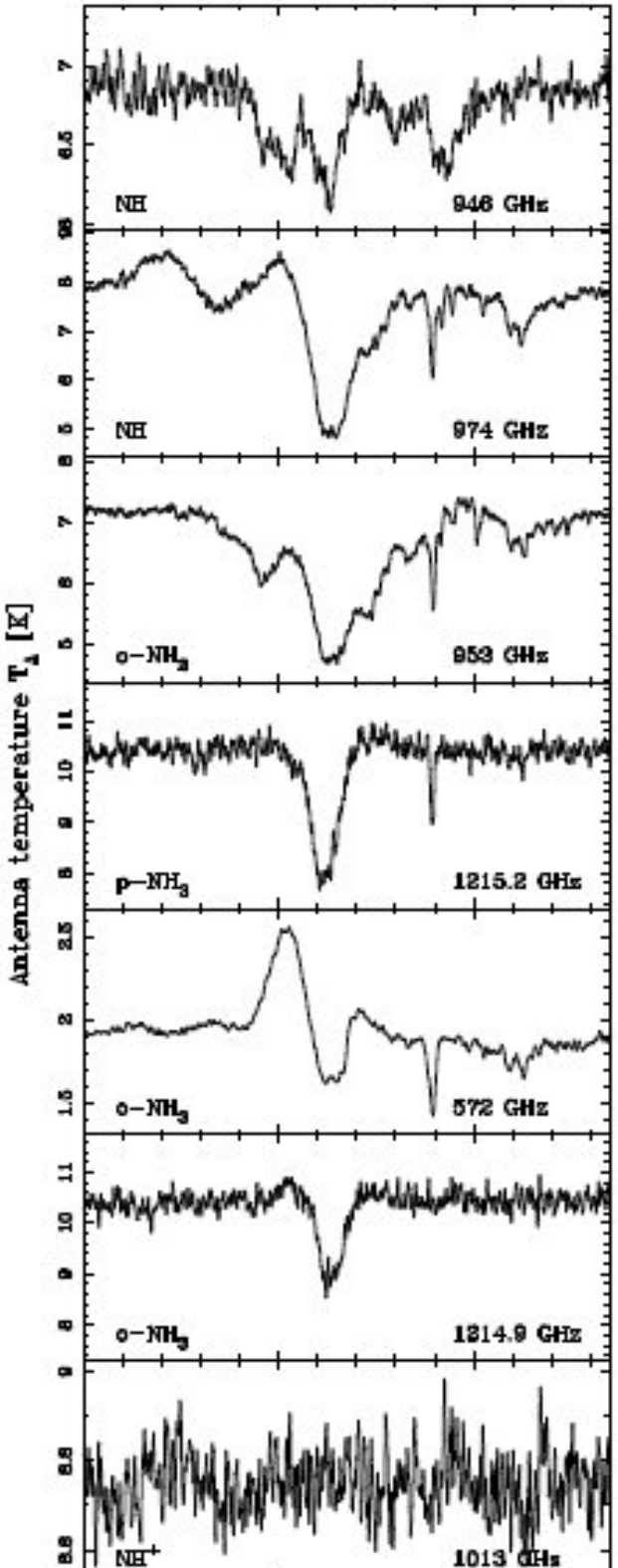


HCl in the ISM discovered in 1985 *(Blake et al 1985)*
New *Herschel/HIFI* data (Monje et al 2012)
Herschel/HIFI discovery of **H_2Cl^+** *(Lis et al. 2010, Neufeld et al 2012)* and **HCl^+** *(De Luca et al. 2012)*





(De Luca et al 2012)

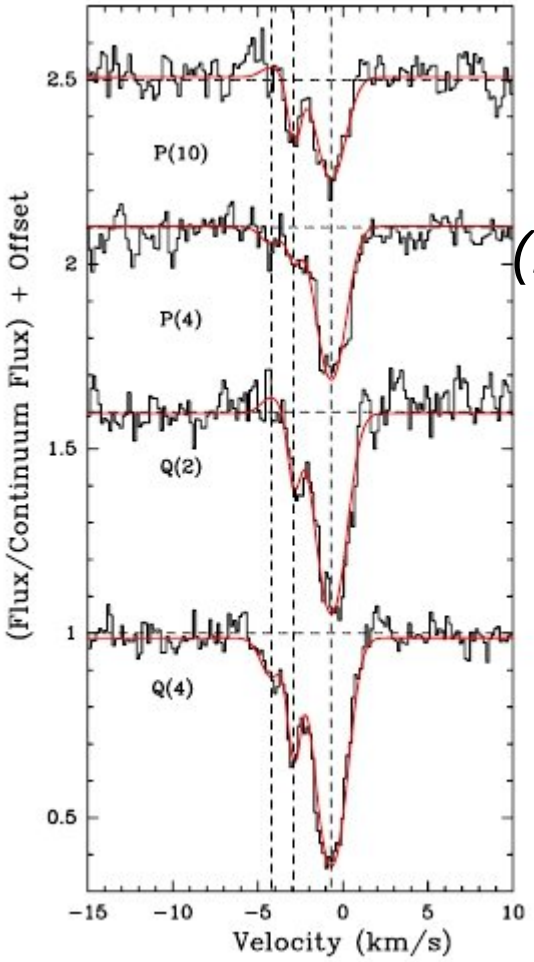


The building blocks of N-chemistry

- Full chain of neutral species in the NH3 network.
- Numerous hyperfine components for NH & NH_2 => Complex line profiles
- No NH^+ detection
- Restricted number of velocity components compared to CH or HF
- Close similarity with nitriles (CN, HCN, HNC).

See talk by C. Persson *(Persson et al)*

The special case of C_3



DR21(OH)

(Mookerjea et al 2010, 2012) **+ talk**

on W51 sight-line

Table 2. Spectroscopic parameters for the C_3 and CCH transitions observed with *Herschel*/HIFI.

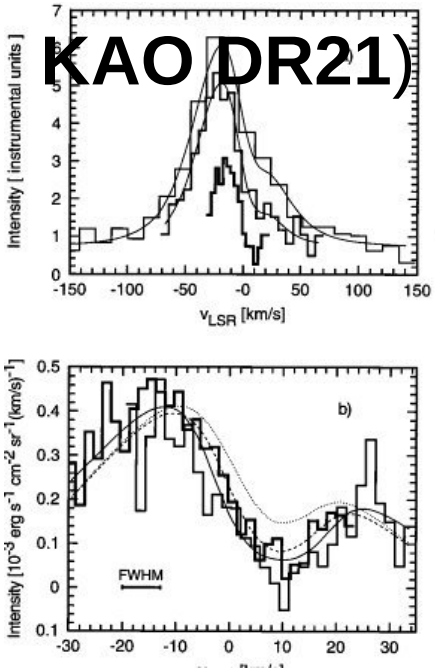
Species	Transition	Frequency (MHz)	A-coeff (s^{-1})	E_l (cm^{-1})	Beam size
C_3, (J, v)	(9, 1)–(10, 0) P(10)	1 654 081.66	2.38×10^{-3}	47.3	13″
	(3, 1)–(4, 0) P(4)	1 787 890.57	2.72×10^{-3}	8.6	12″
	(2, 1)–(2, 0) Q(2)	1 890 558.06	7.51×10^{-3}	2.6	11″
	(4, 1)–(4, 0) Q(4)	1 896 706.56	7.58×10^{-3}	8.6	11″

FIR Vibrational bands → Frequencies ~ OK.
Could be improved with Herschel data.
2 dense cores MM1 & MM2 with different abundances.
Qualitatively consistent with scenario with ice warm up.
Ongoing search for ^{13}CCC and $C^{13}CC$ (T. Giesen)

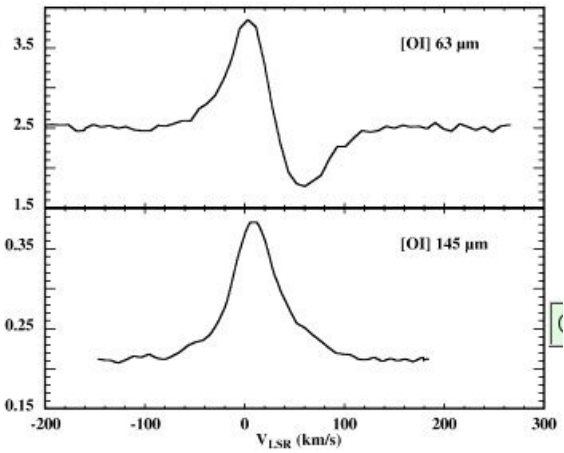
Fine structure line : [CII], [OI], [CI], [NII]

- Some Previous studies :
  - OI in DR21(Poglitsch et al)
  - Sgrb2, W49 with ISO high spectral resolution (FP) : Absorption in CII and OI-63, limited velocity resolution. Difficulty in accounting the absorption by HI/CNM + H2/CO. Contribution from warm phases ? (Baluteau, Vastel, Keene ...)

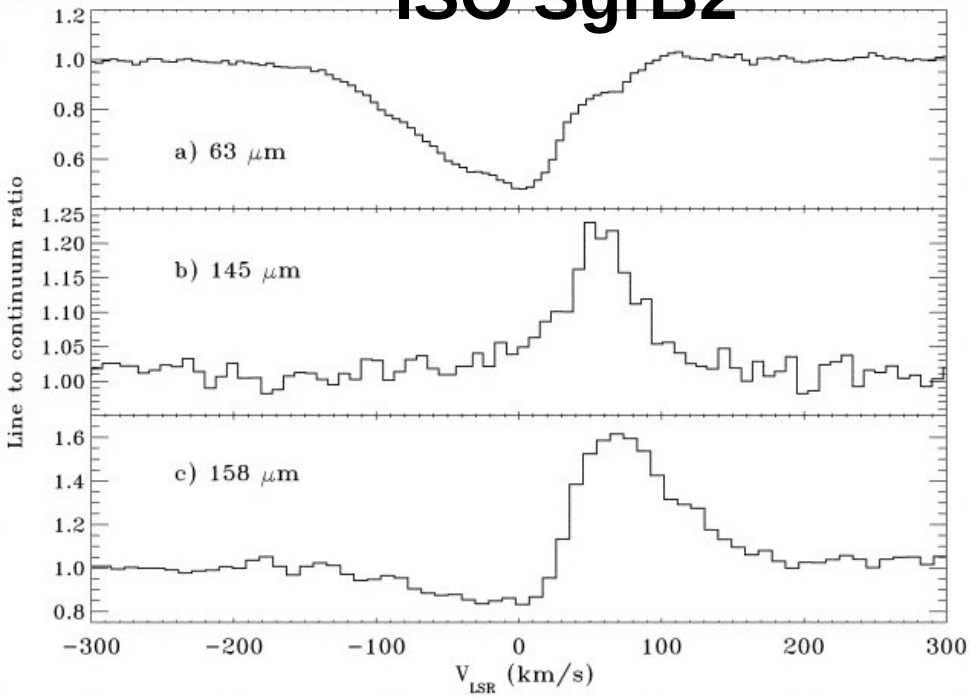
KAO DR21)



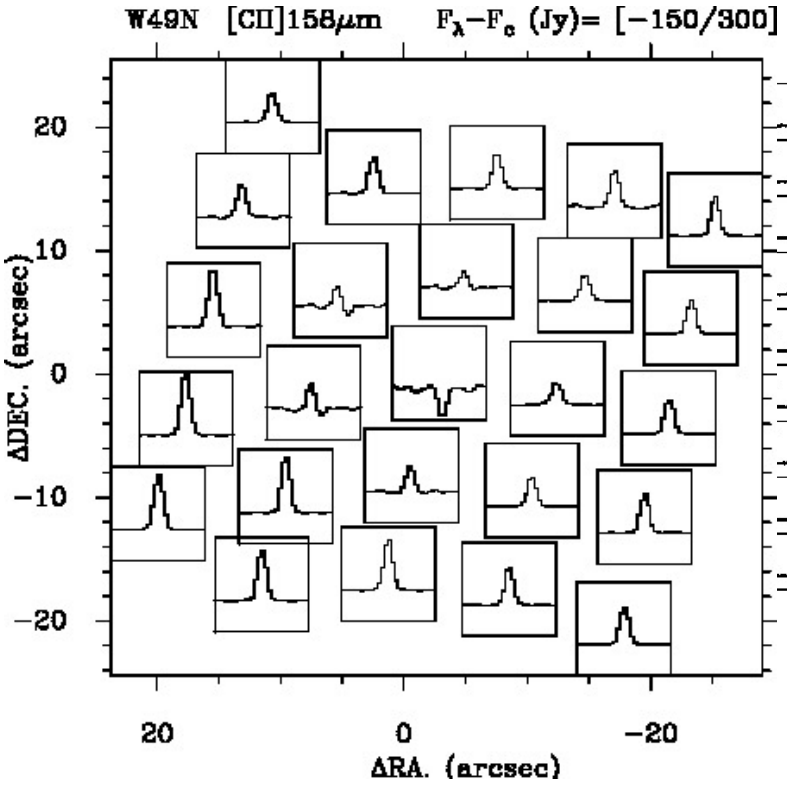
ISO W49N



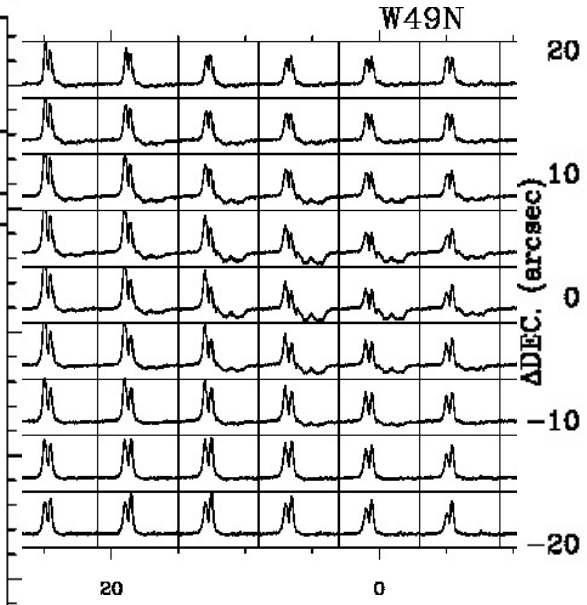
ISO SgrB2



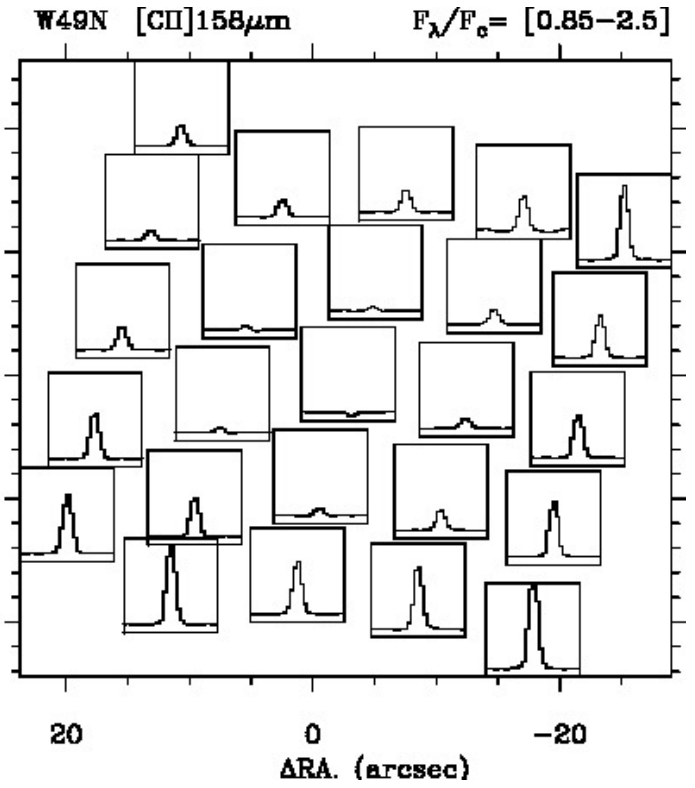
[CII] (1.9 THz – HIFI/PACS)



Line Flux



HIFI

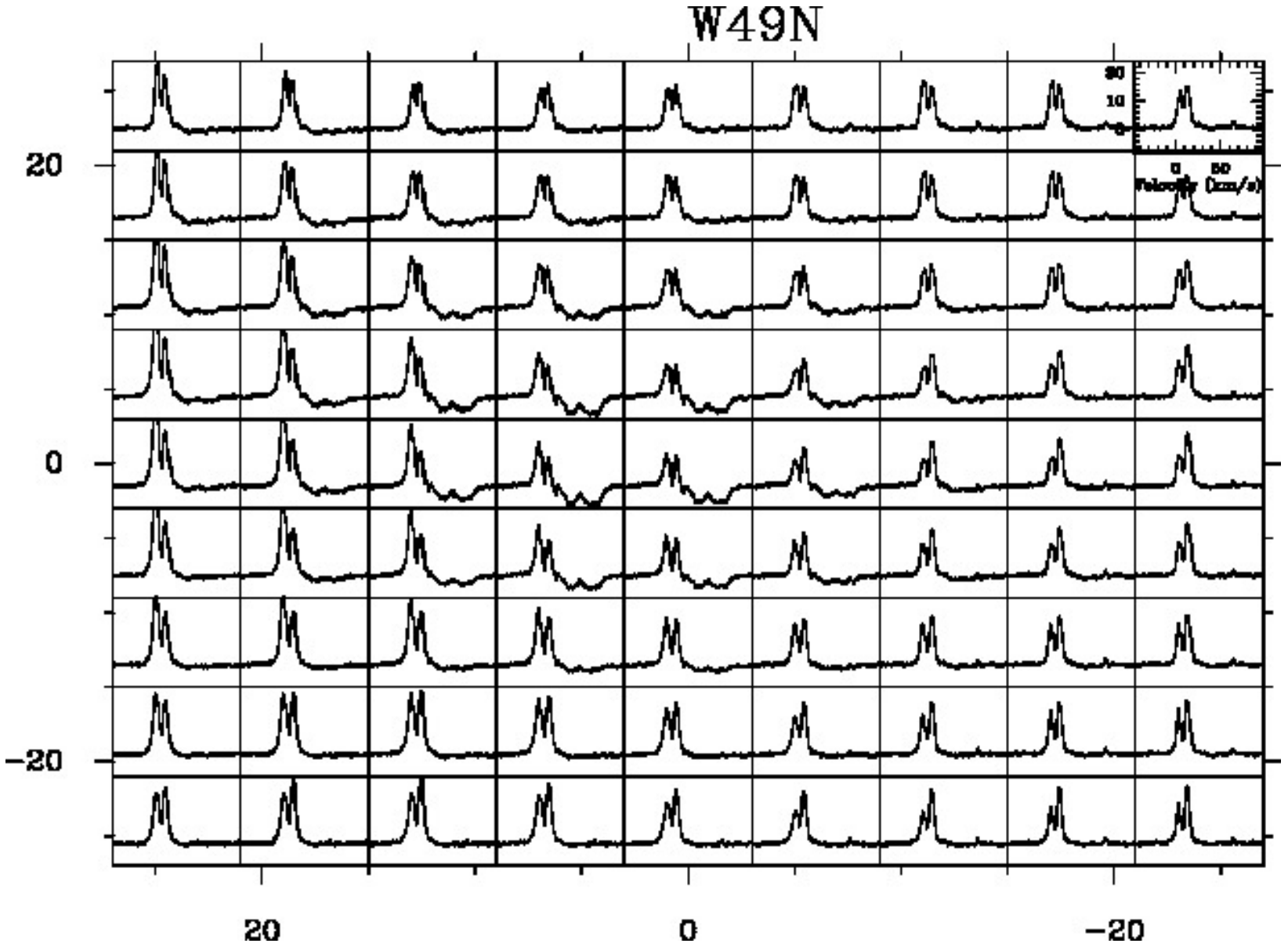


Line/continuum ratio

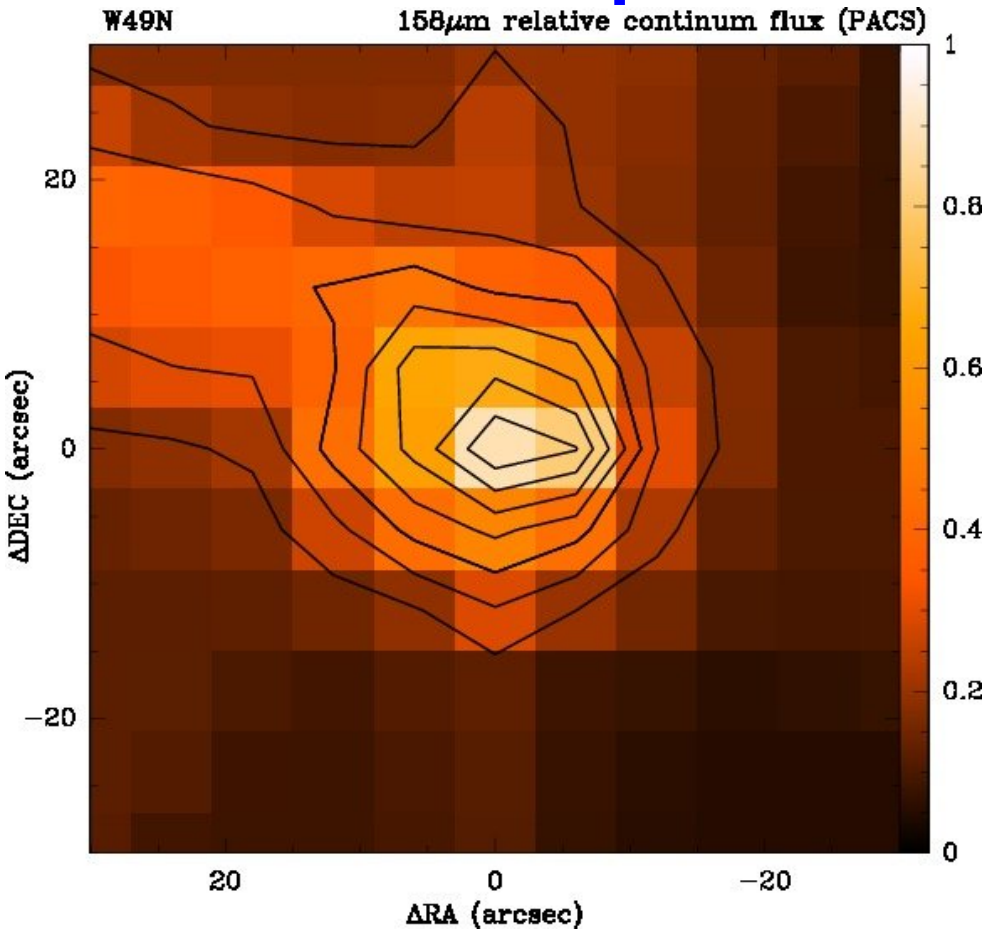
- Strong absorption from foreground gas
- Complex profiles towards the star forming regions (outflows, self-absorption)
- Interpretation of the PACS spectral map difficult when foreground gas
- Low Line/continuum for bright continuum sources → CII deficit ?

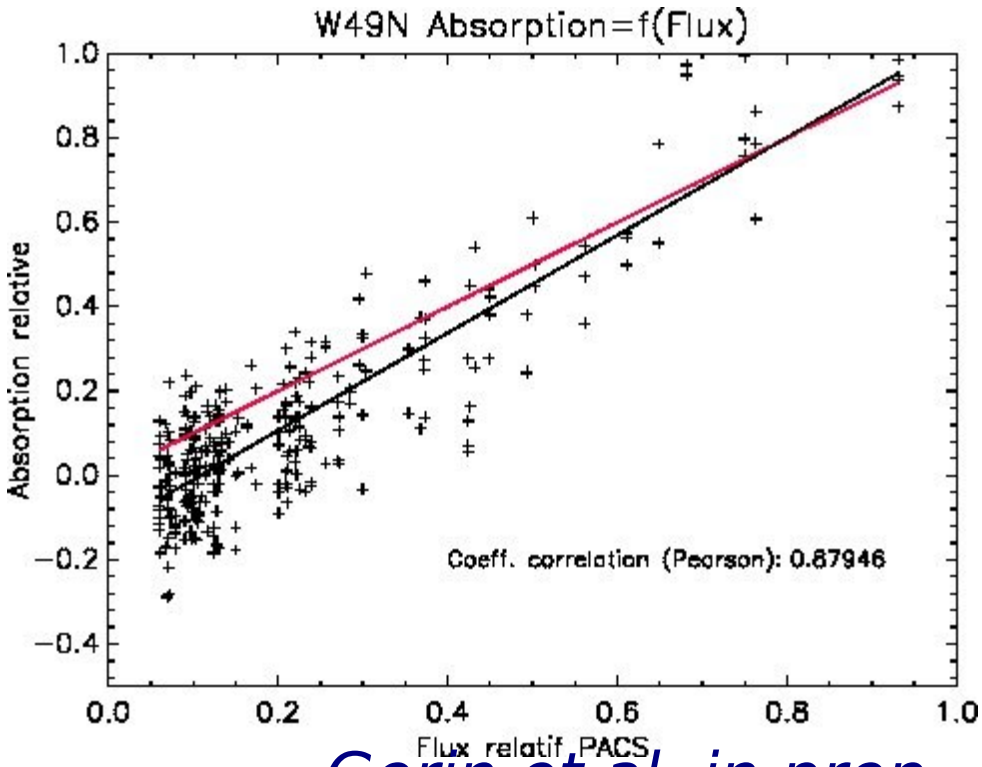
CII maps

- Strong absorption from foreground gas
- Complex profiles towards the star forming regions (outflows, self-absorption)



[CII] absorption – structure

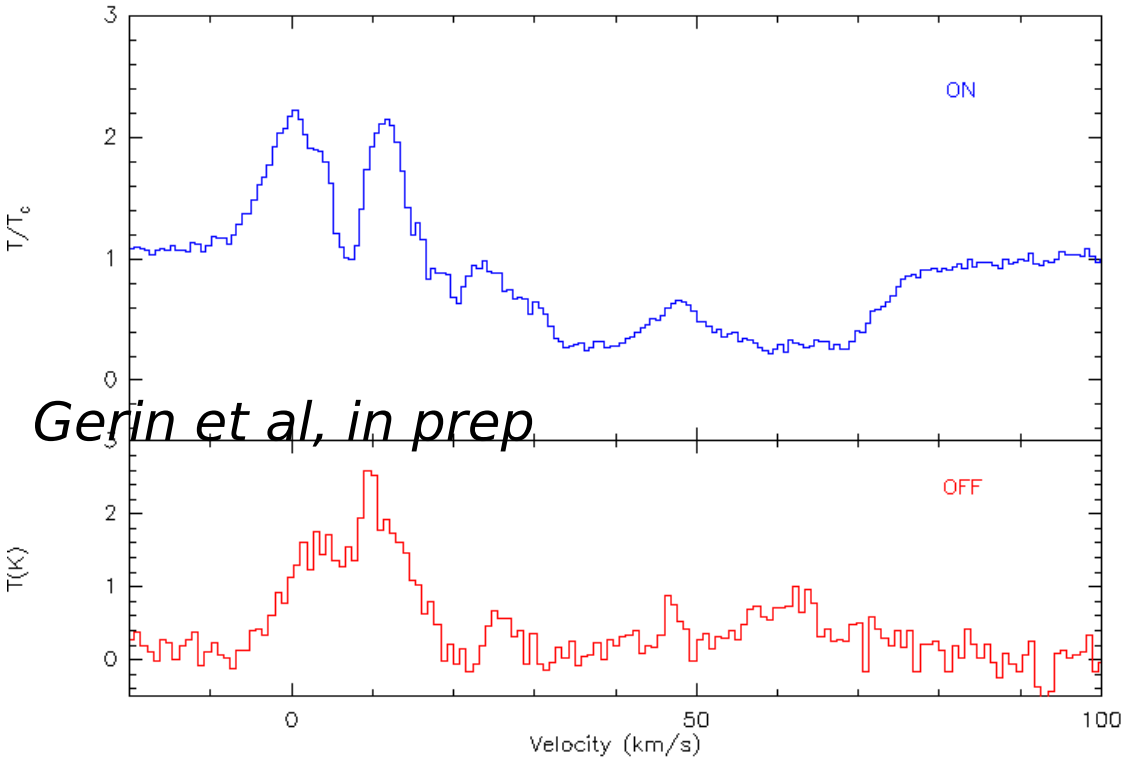




Gerin et al, in prep

Comparison with PACS continuum “map” : Extended absorption from the foreground gas. The depth of the absorption scales with the continuum → ~ constant opacity.

Nearly uniform foreground



Gerin et al, in prep

[CII] Excitation

- Typical level of the diffuse CII emission ~ 0.5K & opacity from absorption : $\tau \sim 1$ → **Tex ~ 20.5K**
- Most of the C^+ ions are in the ground state (~ 98%) → Absorption

- Excitation conditions consistent with diffuse gas

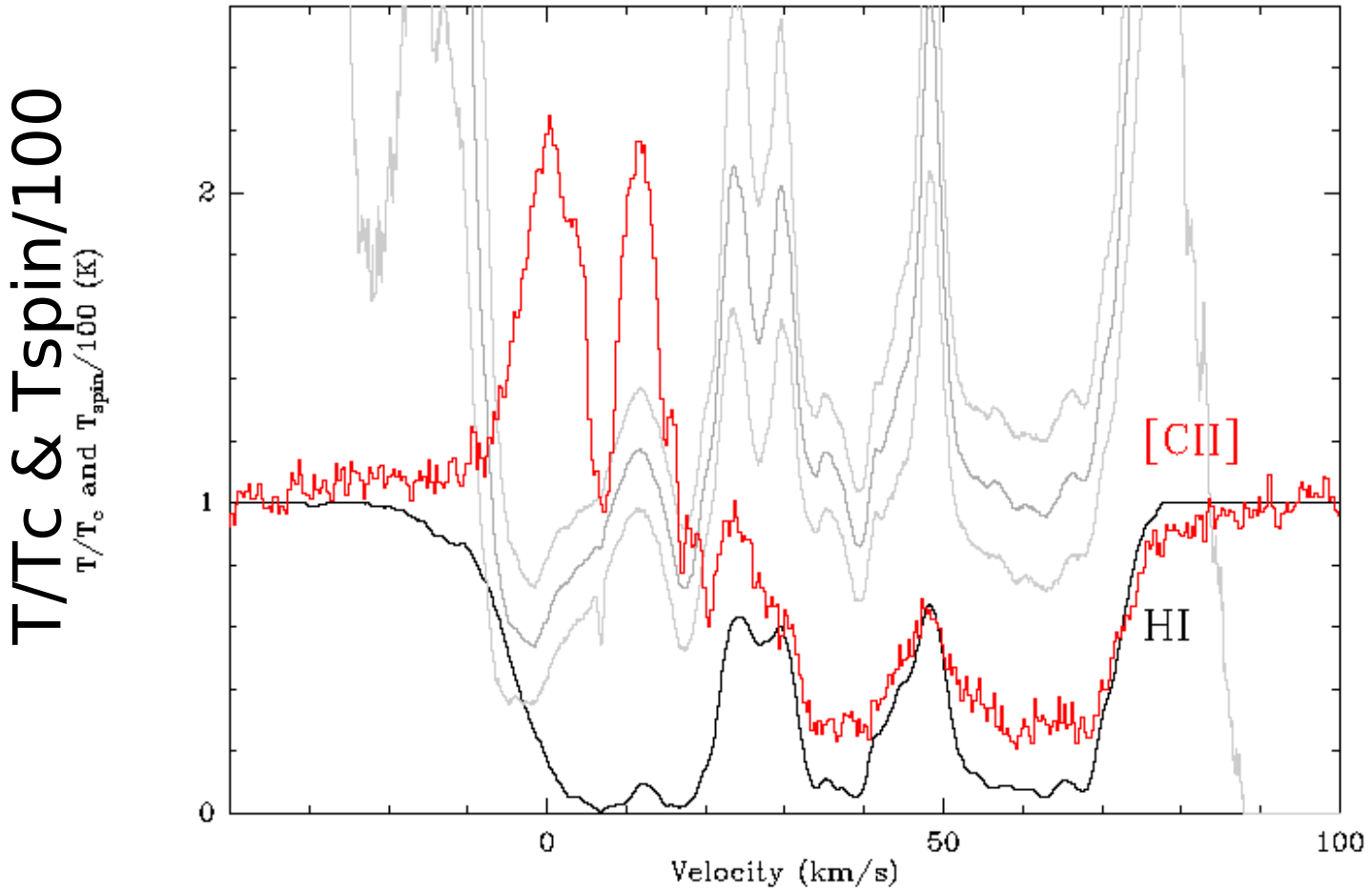
  T ~ 100 K (from HI), n ~ 40 – 80 cm^{-3} and p ~ 6500 Kcm^{-3}

- Same conclusions from the diffuse [CI] emission

The gas detected in absorption is the CNM with f(H_2) ~ 0.5

The filling factor of CNM along the line of sight is 2 – 10%

Warm phases

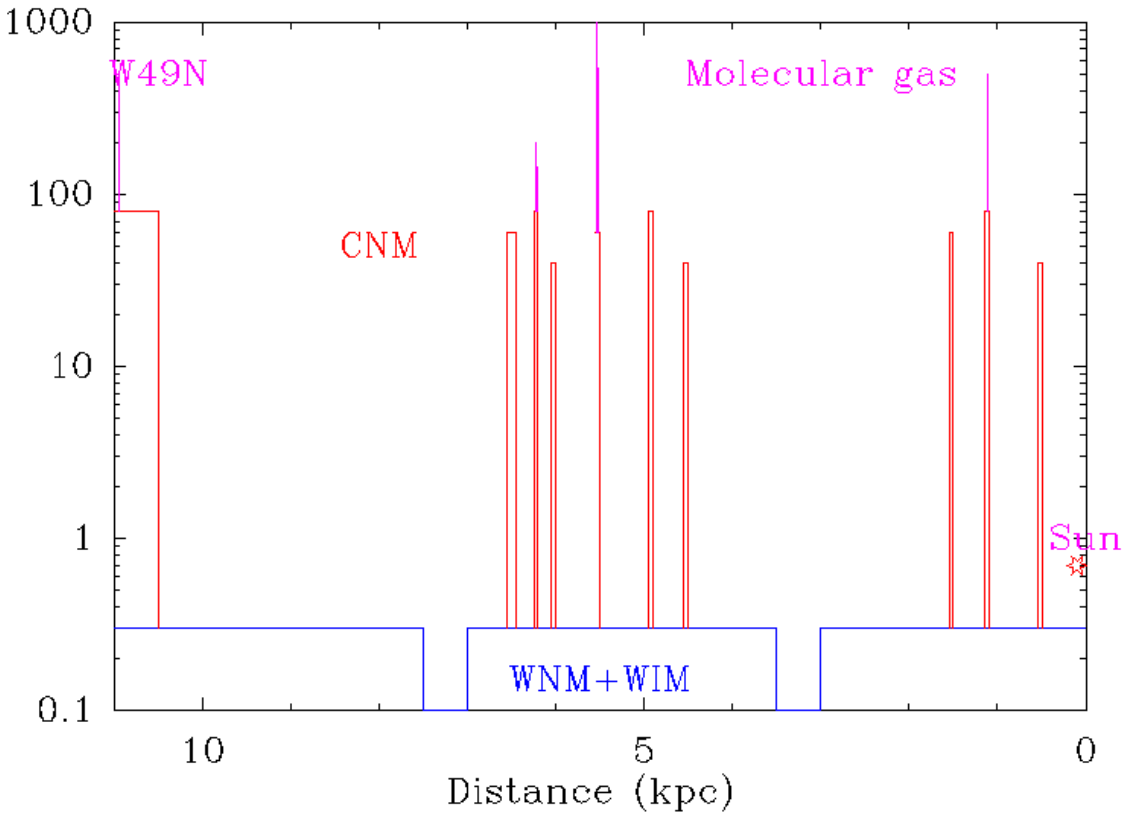


CII emission from the WIM (Velusamy et al) → CII absorption from WIM / WNM ?

- Excess absorption in high Tspin regions (JVLA data Winkel & Menten in prep)
- Excess C^+ column density from the combination of HI (CNM) and H_2 (from CH)
- Consistent with ~10% of the total C^+ and a filling factor of the warm phases ~ 1

Tomography along the line of sight to W49N

Thanks to Herschel, we have good tracers of the total gas column density :
HI abs → CNM; CH & HF → H_2, CII → H_tot
We can determine the fraction of H in H_2 the gas density & pressure (using T from HI) & connect CNM and molecular gas.



- CNM contribution to the column density > 85%
- CNM pressure ~ 6500 Kcm^{-3}
- CNM Filling factor along the line of sight ~ 10%
- Higher density regions from NH_3 , CN , (300 – 1000cm^{-3})
- OH^+ trace the CNM interfaces with low H_2 fraction

- Most of the volume is filled by the warm phases (> 50%)

Conclusions

The diffuse ISM is present everywhere in the Galaxy and is an important segment of the ISM life cycle

Absorption spectroscopy is the most sensitive method to detect species in the diffuse ISM

Big improvement thanks to Herschel/HIFI spectroscopy :
Fine structure lines & Hydride lines are excellent & complementary diagnostics of physical and chemical processes.
Confirmation of the phase structure, Fraction of gas in H2, cosmic ray ionization rate, role of turbulence ...

Key information is still lacking for modeling (reaction rates, collisional rates, branching rations, spectroscopy)
- dissociative recombination of ionized hydrides incl H3+
- charge exchange reaction with H+ (Cl, O, ...)
- reactions with H
- state to state chemistry can be important