PRISMAS

PRobing InterStellar Molecules with Absorption line Studies

Herschel observations of molecules in the diffuse ISM

Maryvonne Gerin

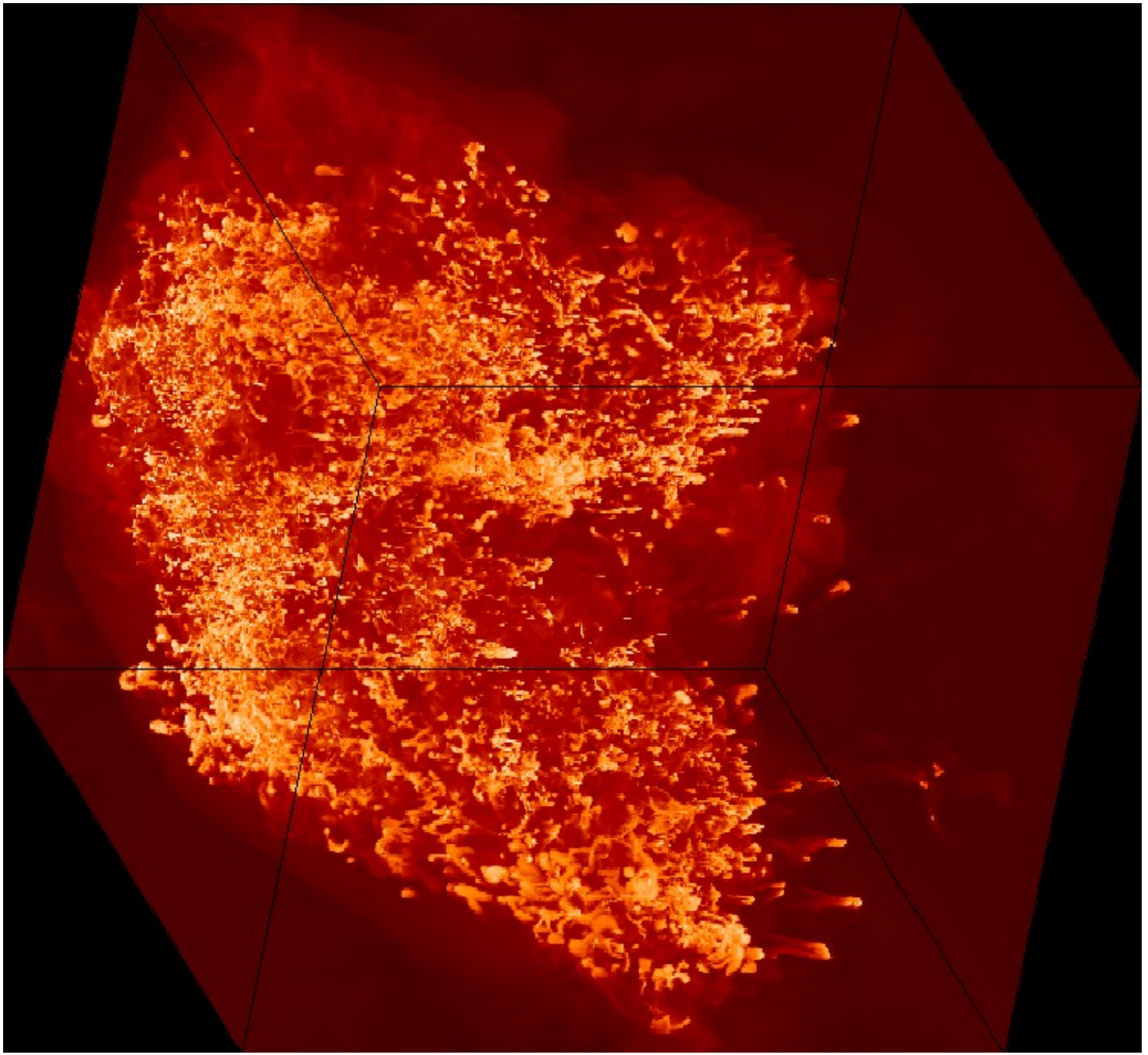
l'Observatoire de Paris | LERMA

Planck image of the Milky Way

- The diffuse ISM is present everywhere in the Galaxy
- Important segment of the ISM life cycle.
- Neutral gas : HI + H2 => which molecules?

PRISMAS

l'Observatoire de Paris LERMA



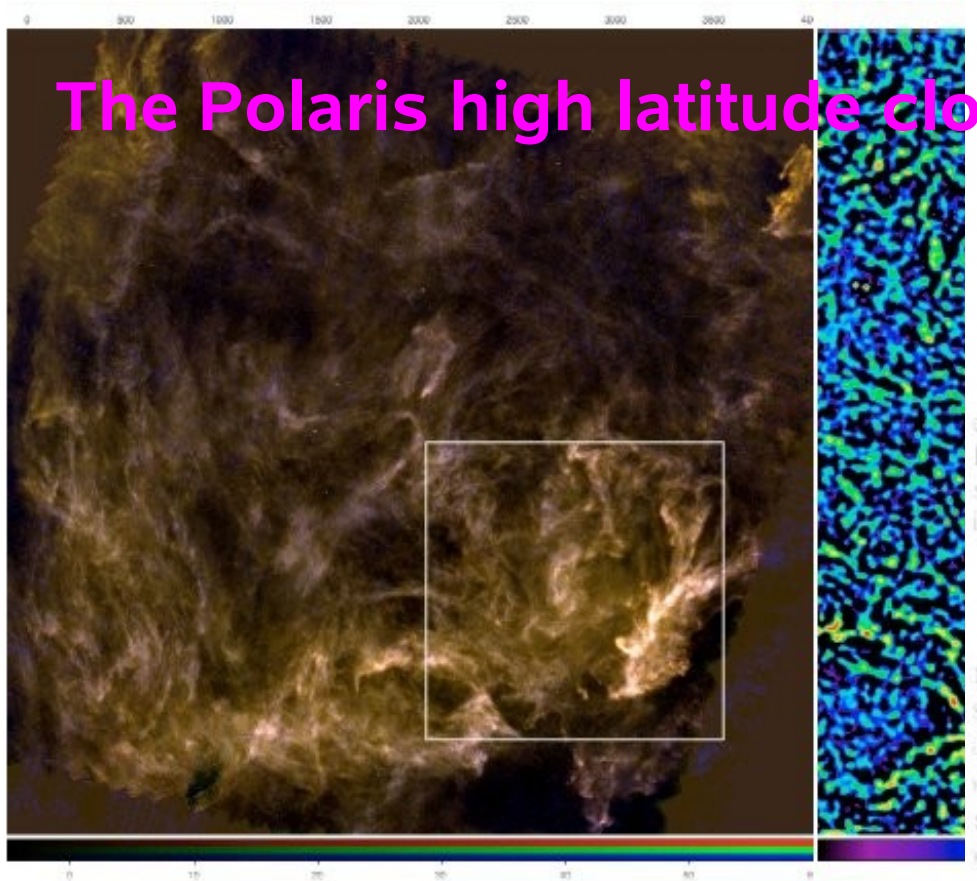
Audit &
Henebelle,

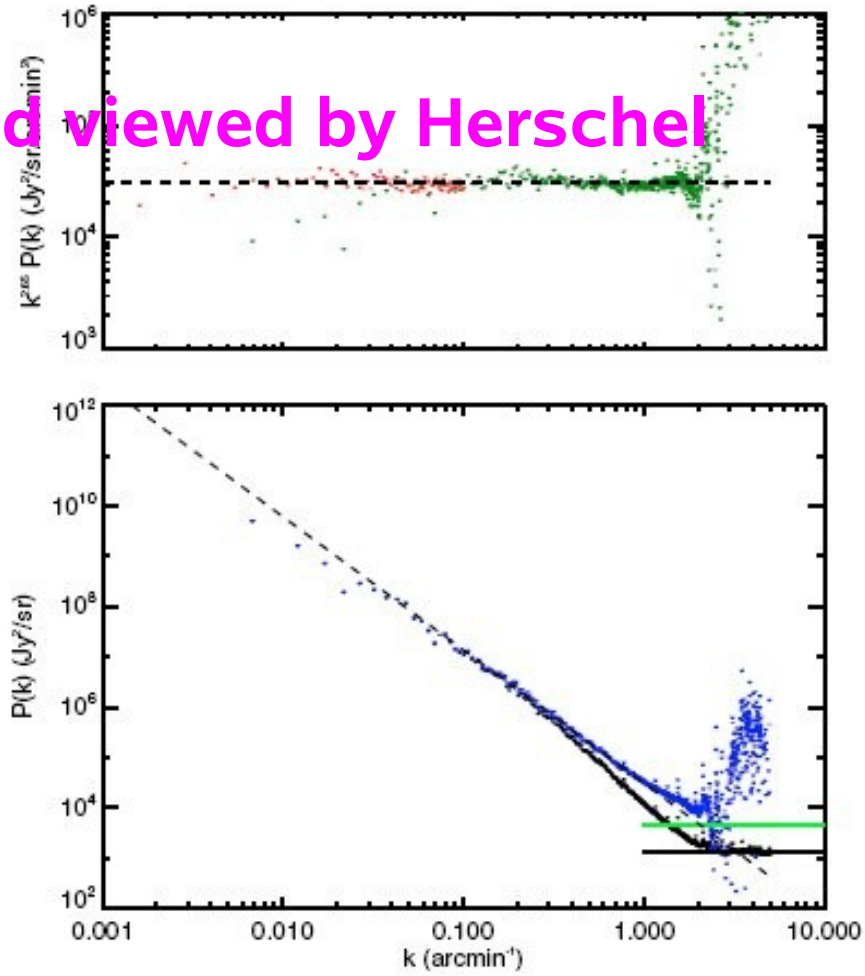
Max density
n>100 cm-3
min density
n ~ few cm-3

PRISMAS

l'Observatoire de Paris | LERMA

The Polaris high latitude cloud viewed by Herschel





Self-similar structure with a single power law (Miville-Deschênes et al 2010)

Low to moderate visual extinction 0.5 – 3 mag

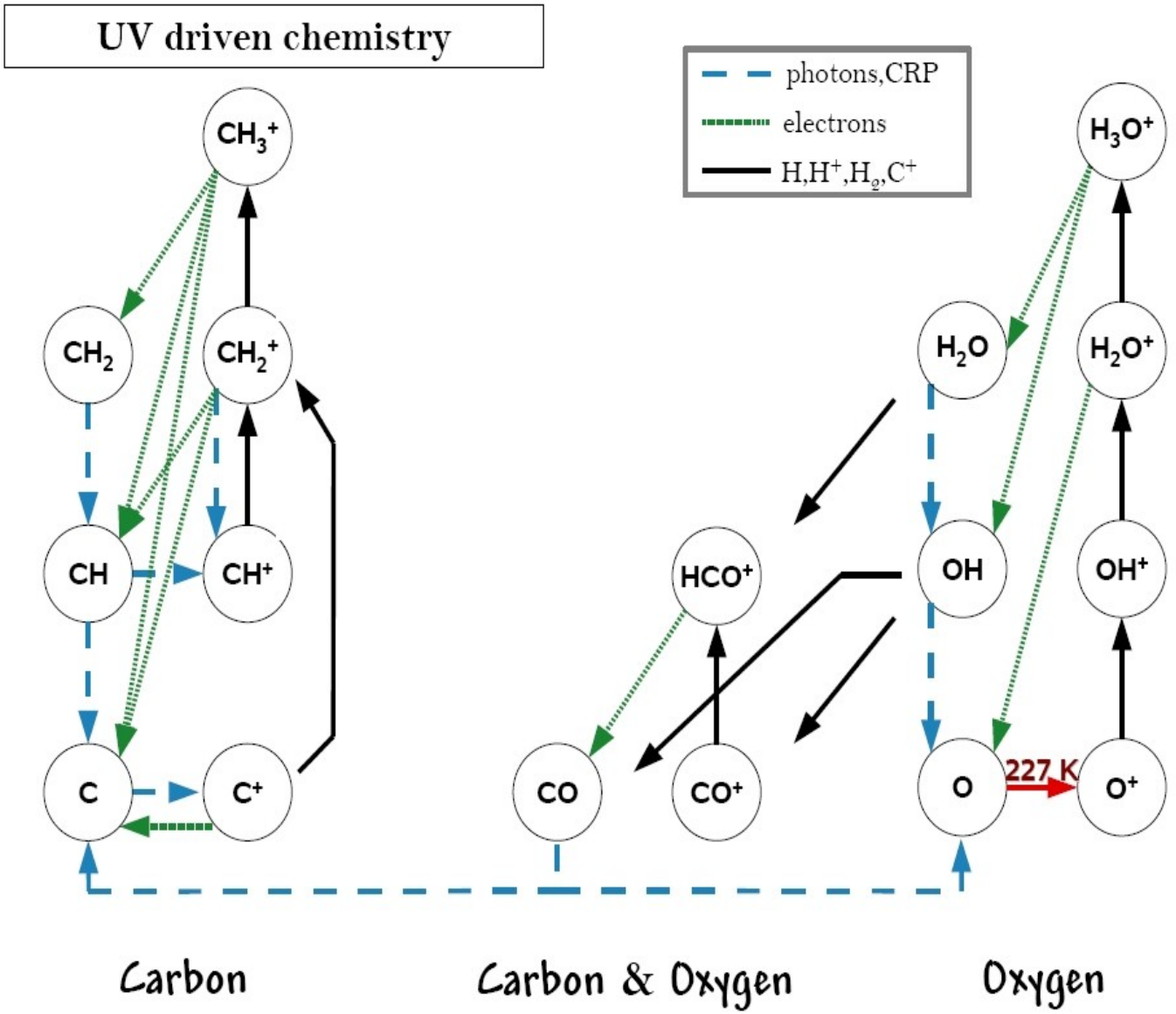
Low to moderate densities. FUV radiation

Hydrides

- built in the first chemical steps starting from atomic gas

- at the root of interstellar chemistry

- Diagnostics of physical / chemical processes



Molecules in the diffuse ISM : absorption spectroscopy

UV / Visible/IR absorption

First detections : CH, CN, CH+ (1937 – 1940)

- H,H2, C+,C, CO, CH, C2, C3, CN, OH, NH, H3+...
- relatively simple molecules
- n ~ 50 – 1000 cm-3, T ~ 30 – 100 K
- DIBs ? HC4H+ , PAHs ?
-

cm/mm/submm/FIR absorption :

- HI, OH, CO, CN, HCN, HNC, HCO+, CCH, c-C3H2, NH3, H2CO, CS, H2O, OI ...
- more complex species
- little overlap with visible studies

Origin of molecules ?

PRISMAS

l'Observatoire de Paris LERMA

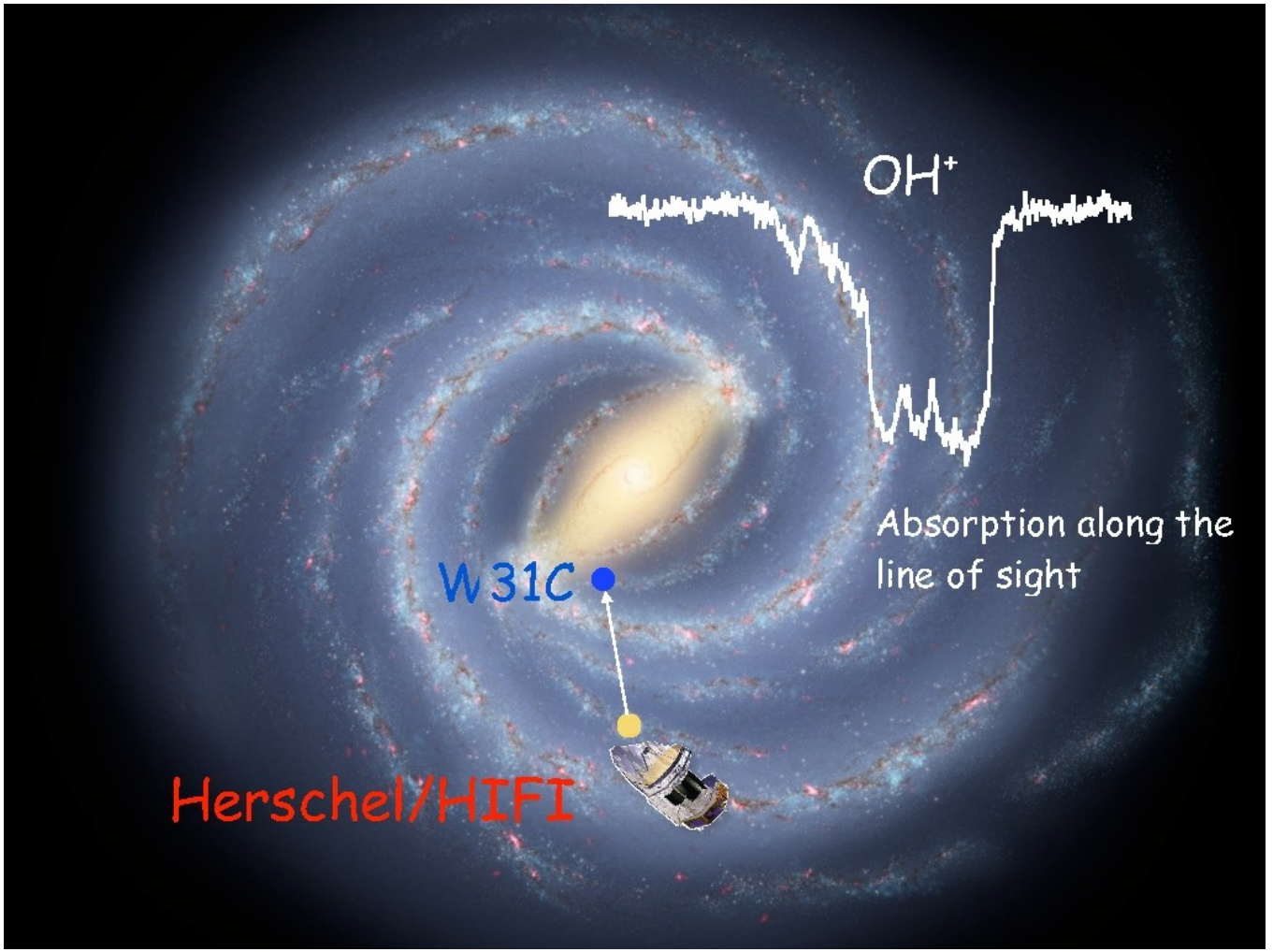
Absorption spectroscopy with HIFI

480 – 1250 GHz with 5 SIS receivers

1430 – 1900 GHz with 2 HEB receivers

2 polarizations

2 spectrometers (from 0.14 to 1.1 MHz)



C Vastel

Far IR absorption
⇒ massive star forming regions in distant spiral arms

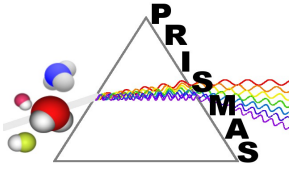
PRISMAS

l'Observatoire de Paris LERMA

PRISMAS programme: Absorption spectroscopy

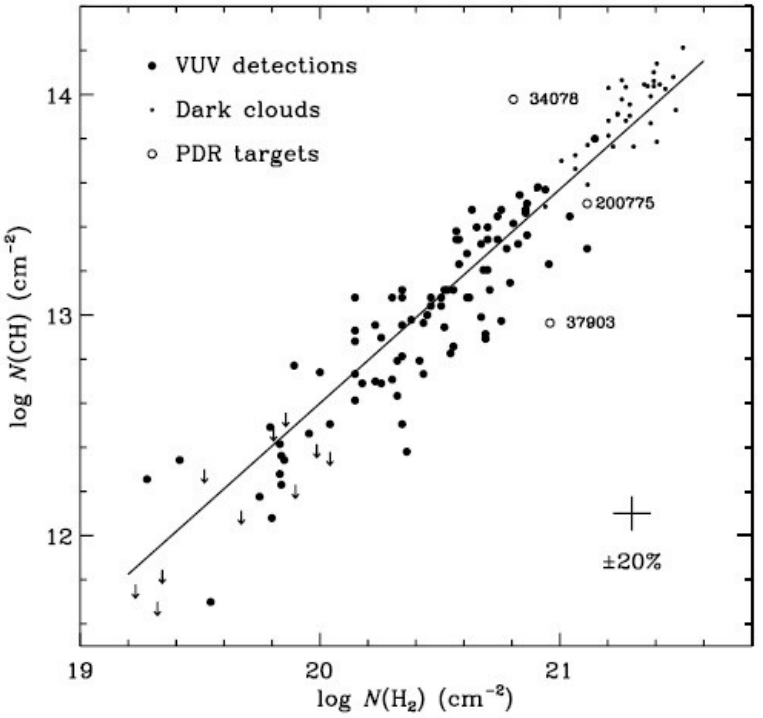
- Direct probe of line opacity. easier analysis of molecule column density
- Excellent sensitivity : reach the same range of column density as visible spectroscopy for molecules in common (eg CH and CH^+) => probe diffuse and translucent gas with Av few mag in the FIR spectral range.
- targeted species, 8 background sources

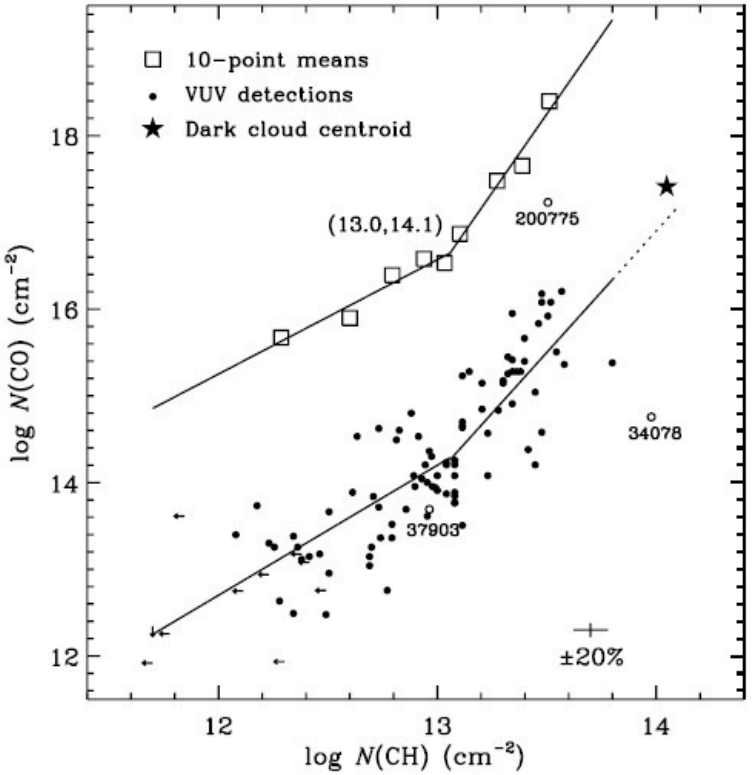
C	CH, ^{13}CH, CH^+, $^{13}CH^+$, CH_2 C_3
N	NH, NH_2, NH_3 (o & p), $^{15}NH_3$, ND, NH_2D, NH^+
O	OH^+,H_2O^+ (o & p),H_3O^+, H_2O (o & p), $H_2{}^{18}O$, HDO, D_2O
F	HF, DF
Cl	HCl, Hcl^+
S	SH^+



l'Observatoire de Paris | LERMA

Molecular hydrogen tracers





CH scales with H_2 ($CH/H_2 \sim 3.5\ 10^{-8}$)

Sheffer et al 2008

Hydrogen fluoride HF a new tracer of molecular gas

Fluorine reacts with H_2, making HF

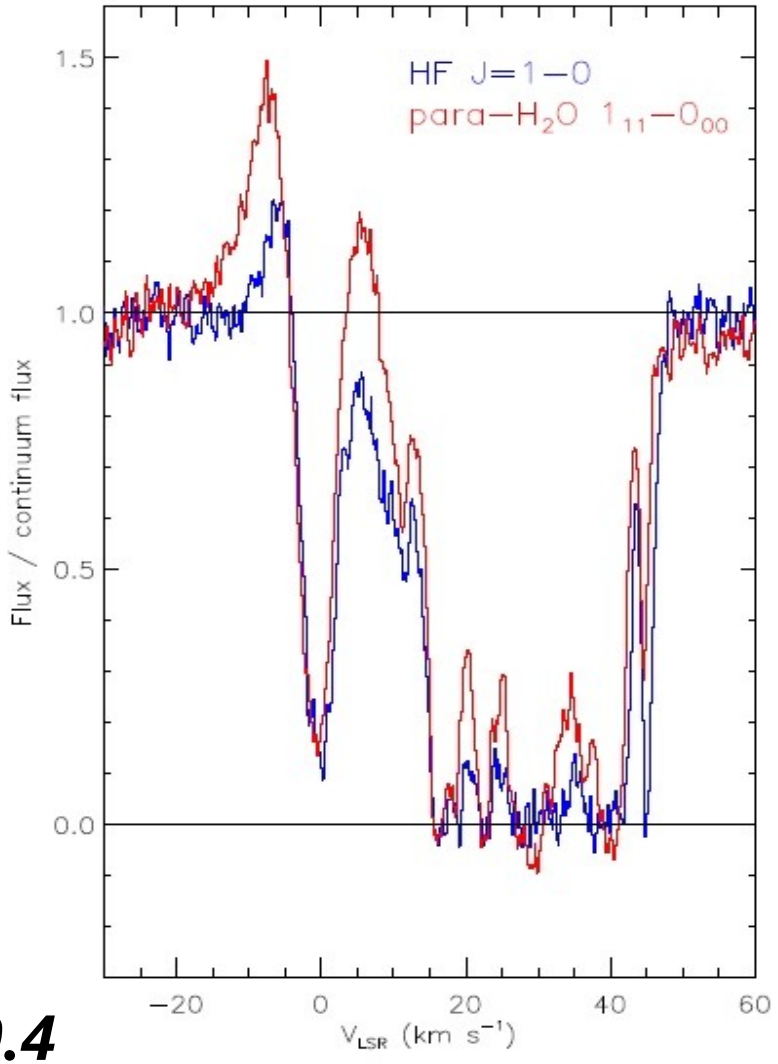
(Neufeld et al)

= > HF uses all the gas phase F

=> HF reveals H_2

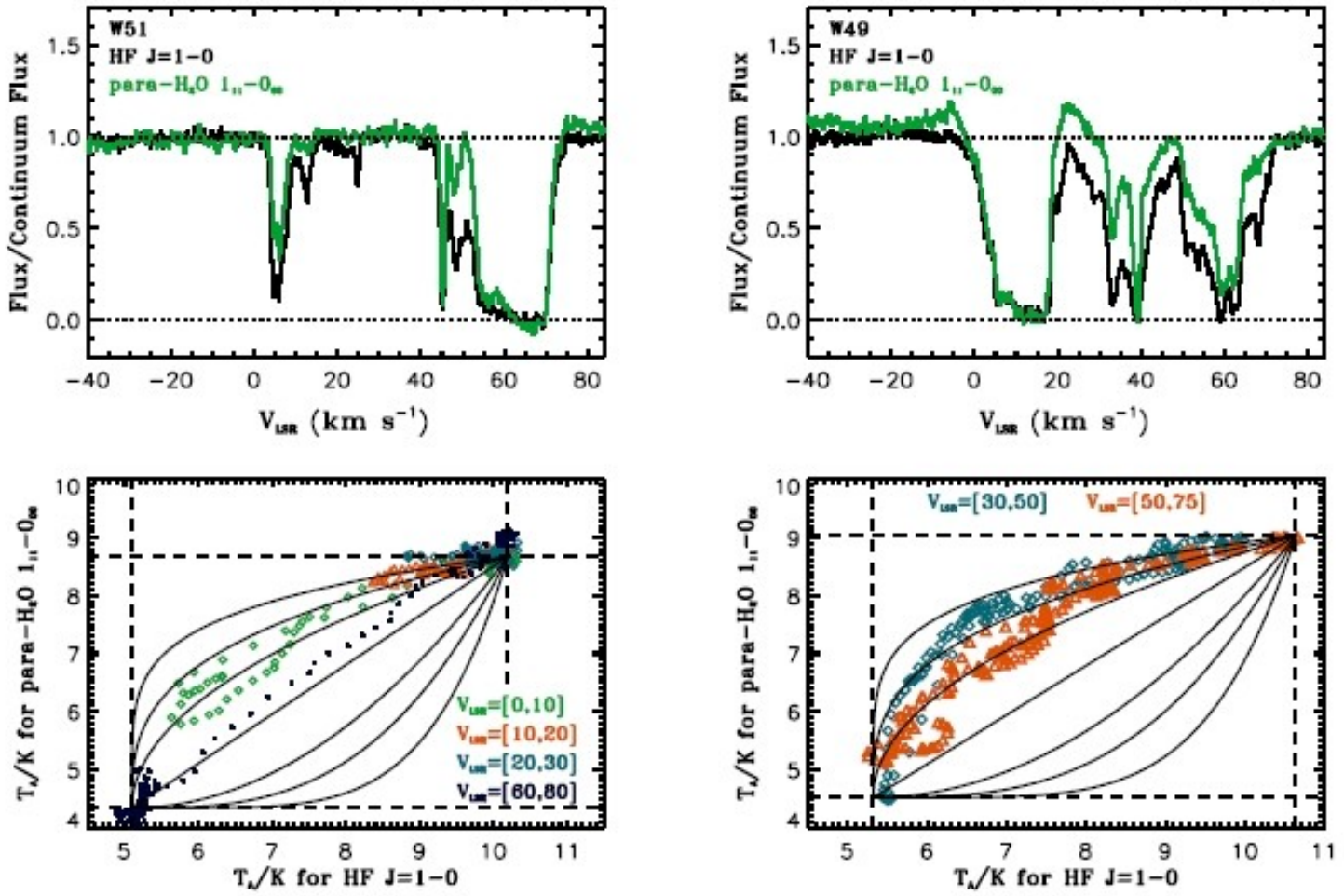
=> HF is present as soon as H_2 is present, even in clouds with no detectable CO or H_2O.

=> $\tau(HF) > \tau(p\text{-}H_2O)$



G10.6-0.4

Neufeld et al 2010a A&A 518



Sonnentrucker, Neufeld et al (A&A 521

$HF/H_2 \sim 1 - 3 \times 10^{-8}$ ($F/H = 1.8 \times 10^{-8}$)

$N(HF) : 1 - 70 \times 10^{12}$ cm^{-2}

$\Rightarrow \tau(HF) \sim N(H_2)/10^{20}$ (dv = 1 km/s)

CH

CH ground state triplet at 532 & 536 GHz.

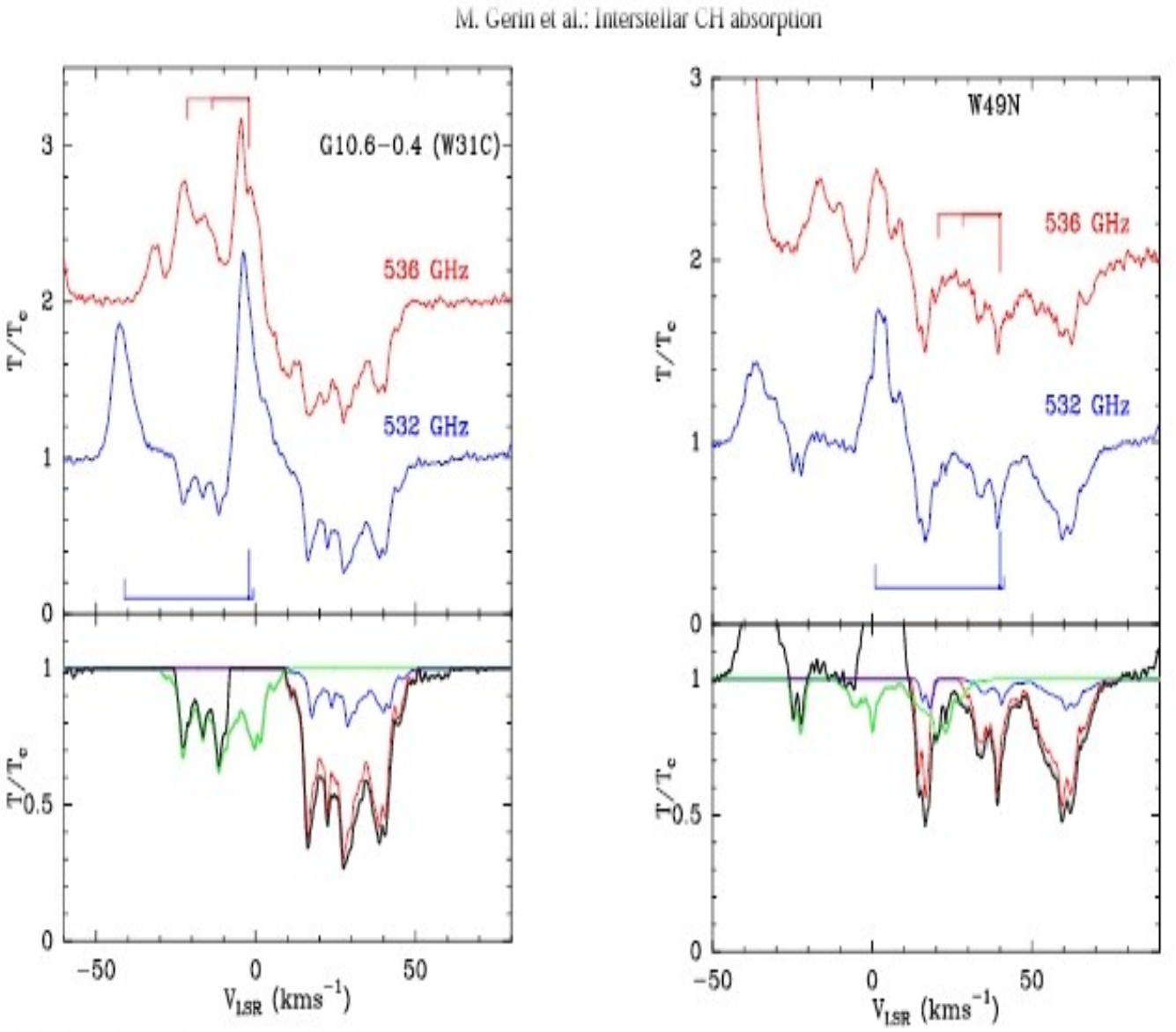
Lines not saturated but complex profiles

Combination of emission & absorption

N(CH) ~ few 10^{14} cm^{-2}

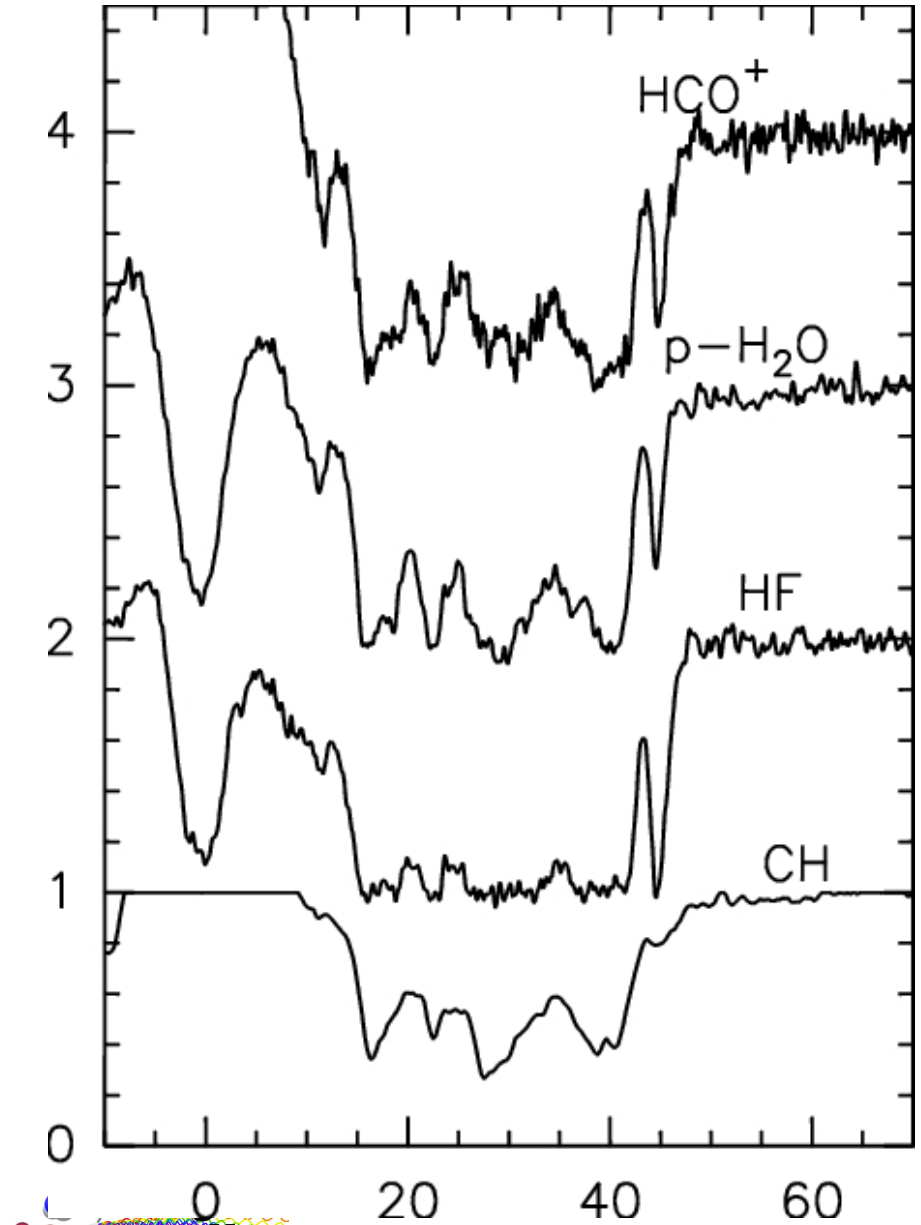
$\tau(CH) \sim N(H_2)/10^{21}$

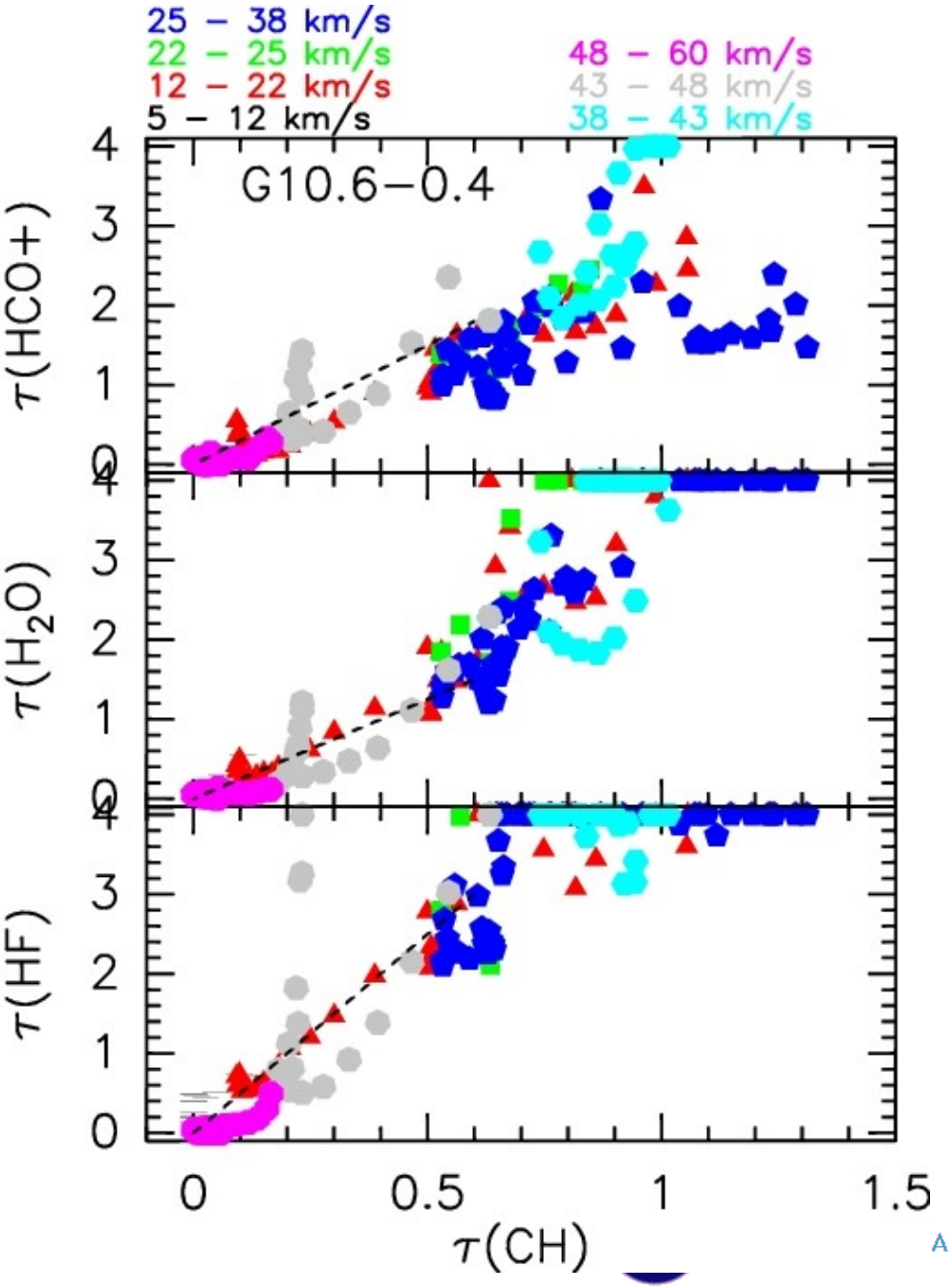
CH & HF consistent with $CH/H_2 \sim 3.5\ 10^{-8}$ derived from UV/visible



Gerin et al A&A 521

CH : relation with other molecules : linear scaling => constant abundance ratio





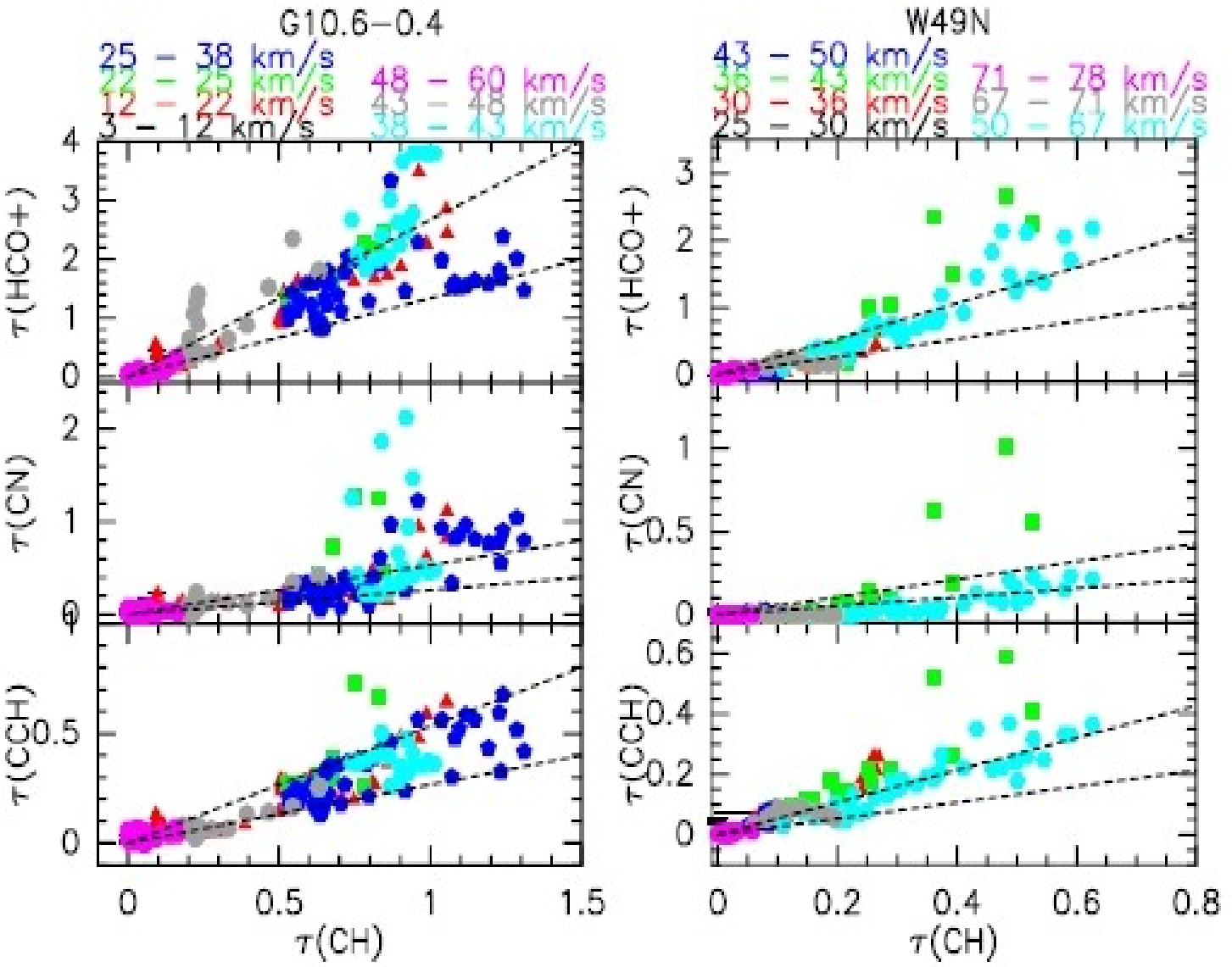
CH : relation with other molecules

Well defined trends & deviations in narrow velocity intervals

CCH/CH ~ 0.6 - 1.2

CN/CH ~ 0.5 - 1

HCO^+/CH ~ 0.04 - 0.08



Gerin et al A&A 521

Nitrogen Hydrides NH, NH_2, NH_3, NH^+

- Complex profile w multiple hyperfine components
- NH & NH_2 have similar opacities
- o-NH_3 and p-NH_3

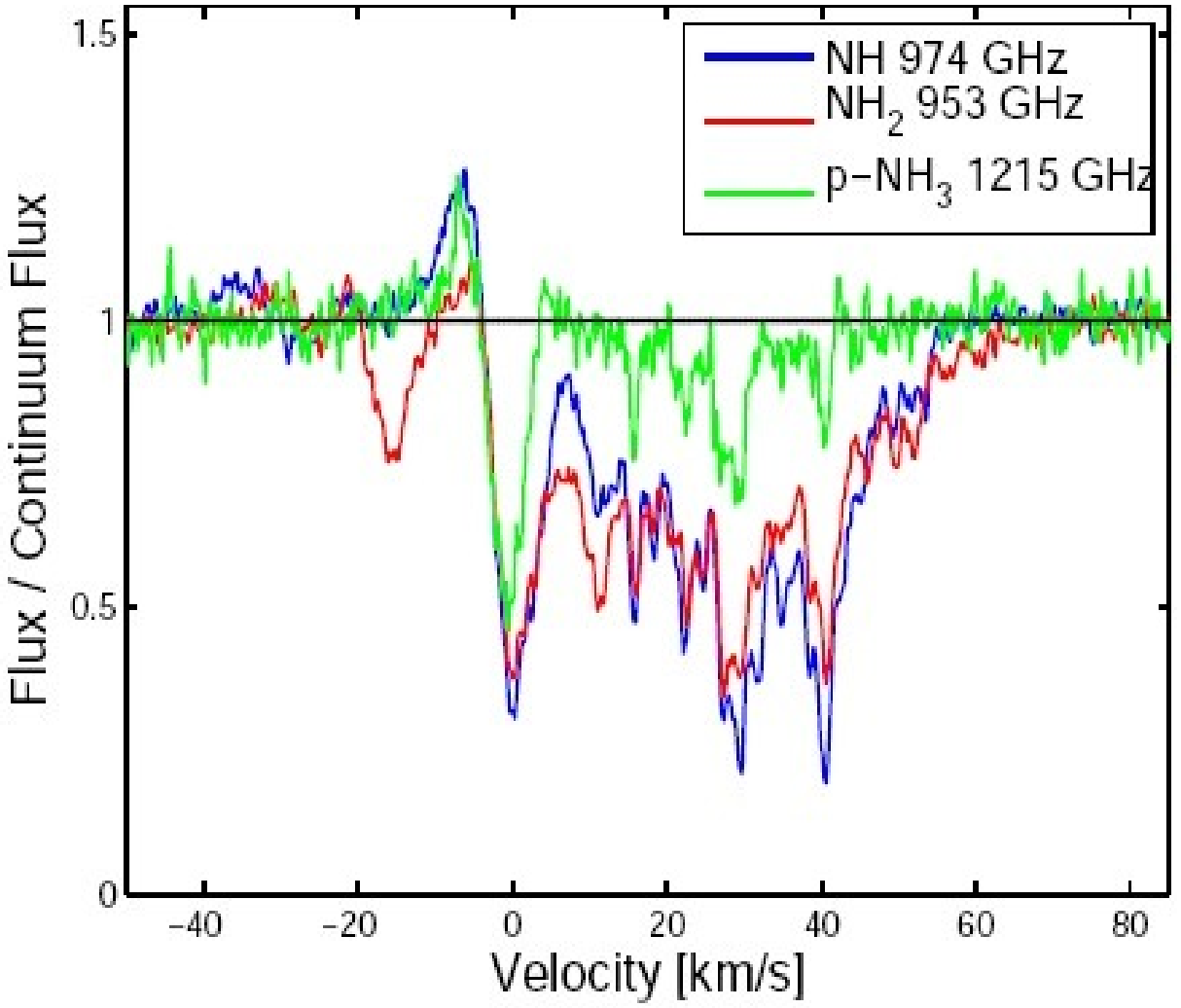
NH = 1.5×10^{14} cm^{-2}

NH_2 = 8×10^{13} cm^{-2}

NH_3 = 8.7×10^{13} cm^{-2} (ortho + para)

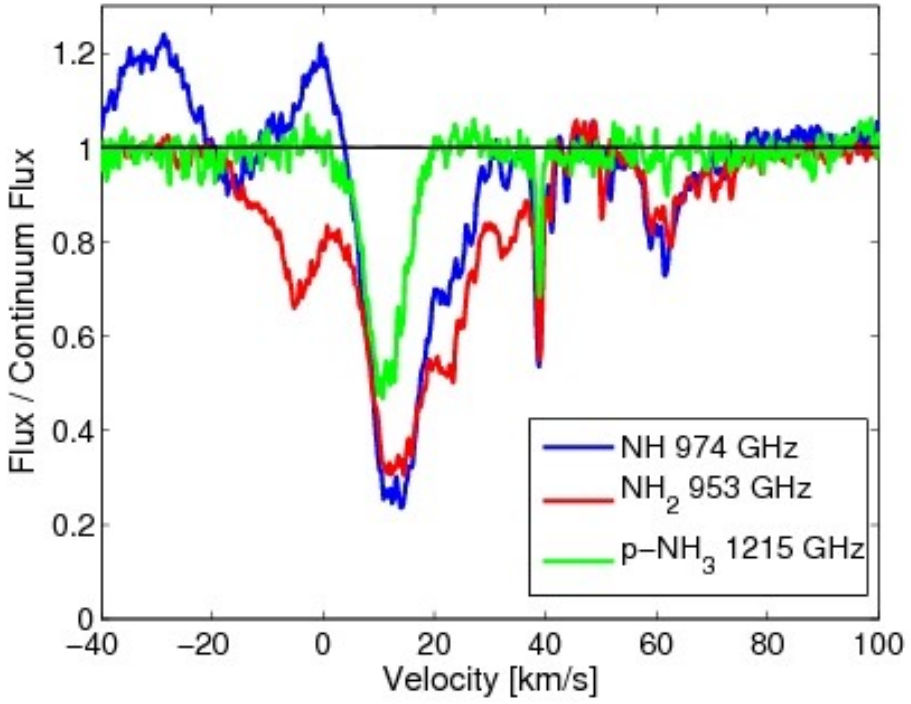
- NH^+ : no detection

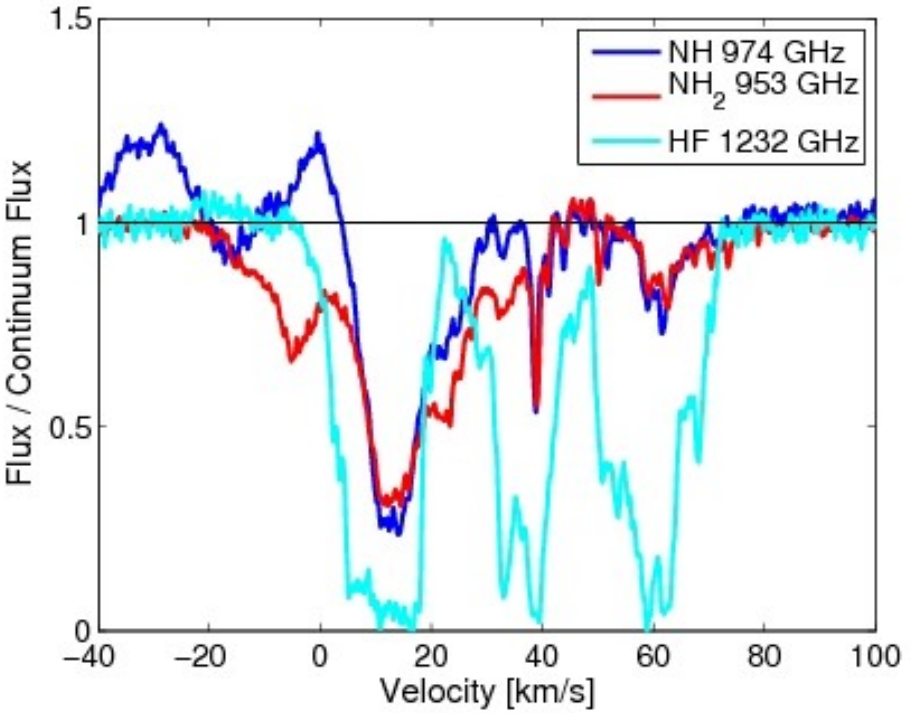
$NH^+ < 2 \times 10^{13}$ cm^{-2}



Persson, Black et al A&A 521

Nitrogen Hydrides NH, NH_2, NH_3, NH^+





W49N : NH ~ NH2 ~ NH3~ 2.x 10^{13} $cm^{-2,}$

Good correlation with p-H2O.

See also Hily-Blant et al 2010 for the envelope of IRAS16293

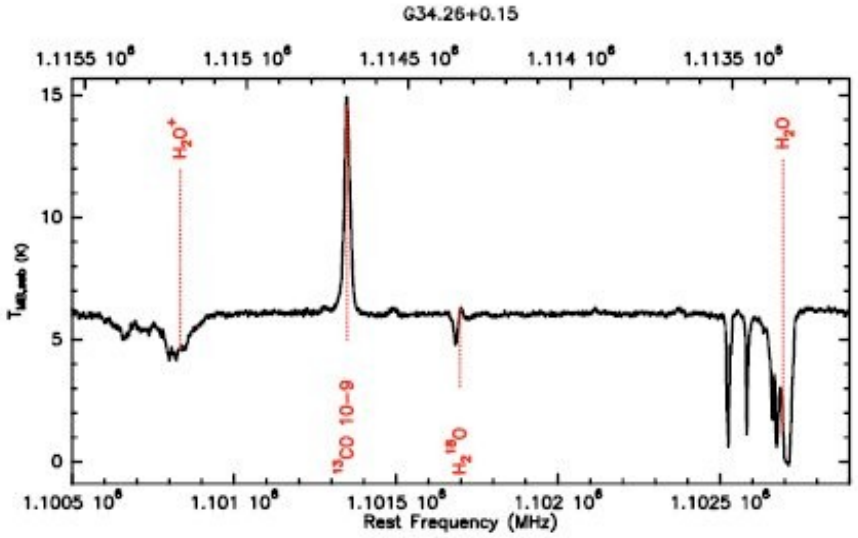
No good explanation with state of the art models

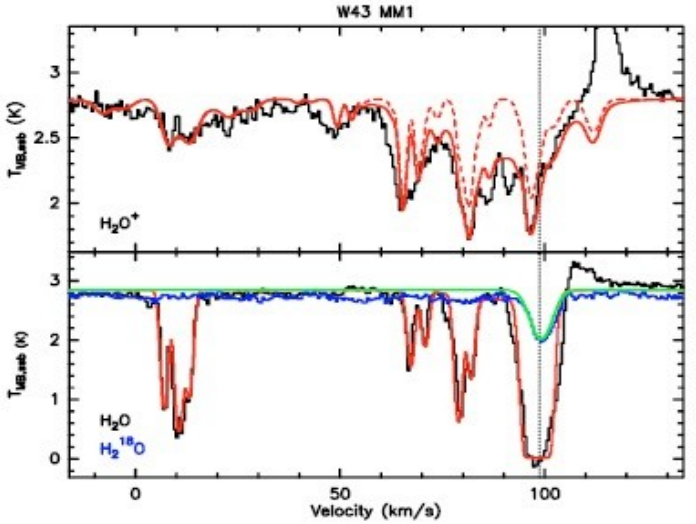
=>the N chemistry needs to be revised !

PRISMAS

l'Observatoire de Paris LERMA

Oxygen hydrides :OH^+, H_2O^+, H_3O^+





o-H_2O^+ at 1.115THz => Strong absorption in diffuse ISM and in outflows associated with massive YSO

Gerin et al, Neufeld et al, Ossenkopf et al , Wyrowski et al , Benz et al ...

PRISMAS

l'Observatoire de Paris LERMA

Oxygen hydrides OH^+, H_2O^+, H_3O^+

- Absorption from the gas along the line of sight : diffuse and translucent matter.
- OH^+, H_2O^+,H_3O^+: the gas phase route to H_2O

=>**Strong confirmation of the validity of the chemical network**

- Small number of reactions involved, all well known

=> Analytic expression

$n(OH^+)/n(H_2O^+) = 0.64 + 0.12\ (T/300K)^{-0.5}/f(H_2)$

-

– **$OH^+/H_2O^+ > 4$**

=> **OH^+ mostly in atomic gas with a small fraction of H_2 (< 10%)** .

$OH^+/H \sim 3 \times 10^{-8}$
$H_2O^+/H \sim 3 \times 10^{-9}$

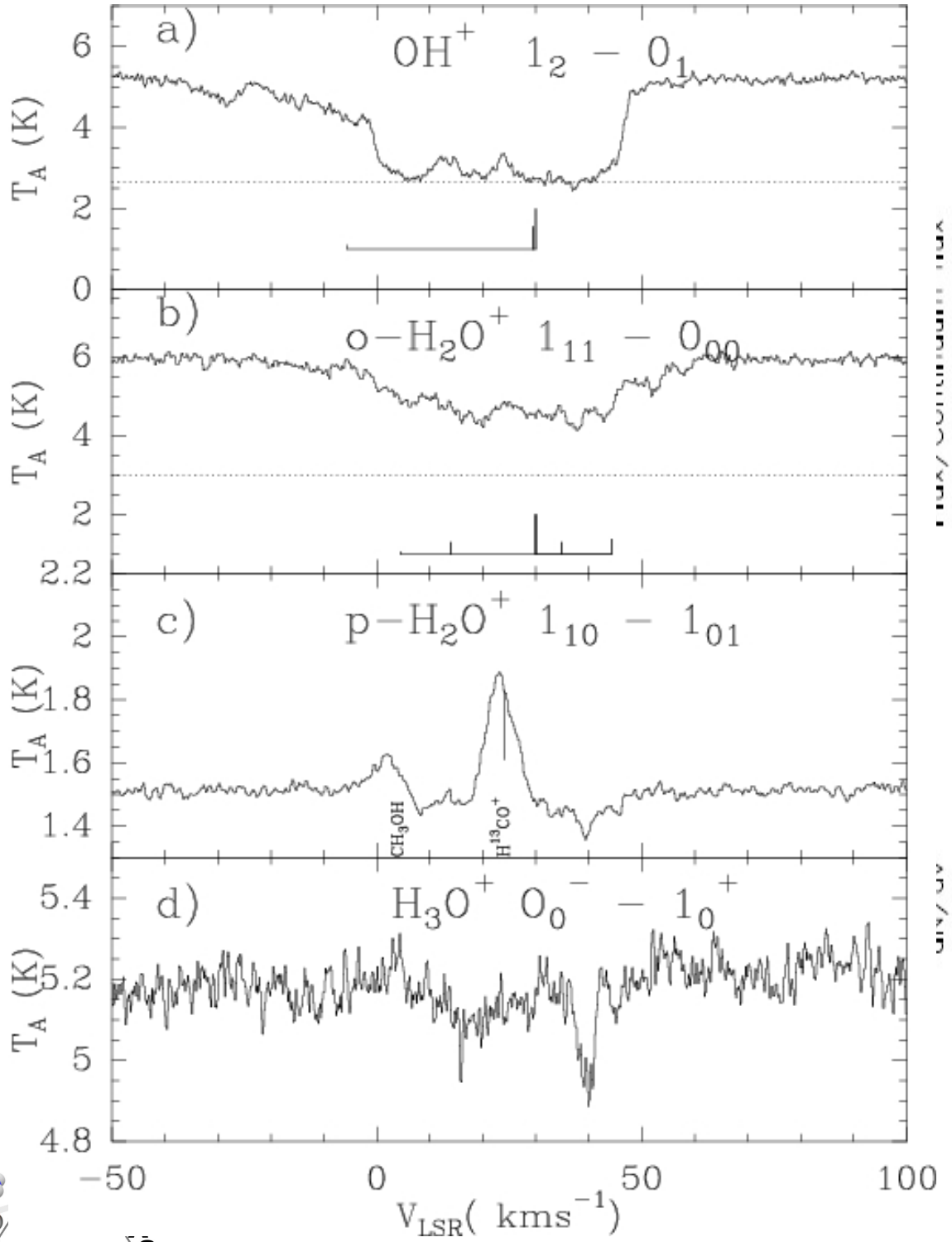
- O+ formed by charge transfer between O and H^+

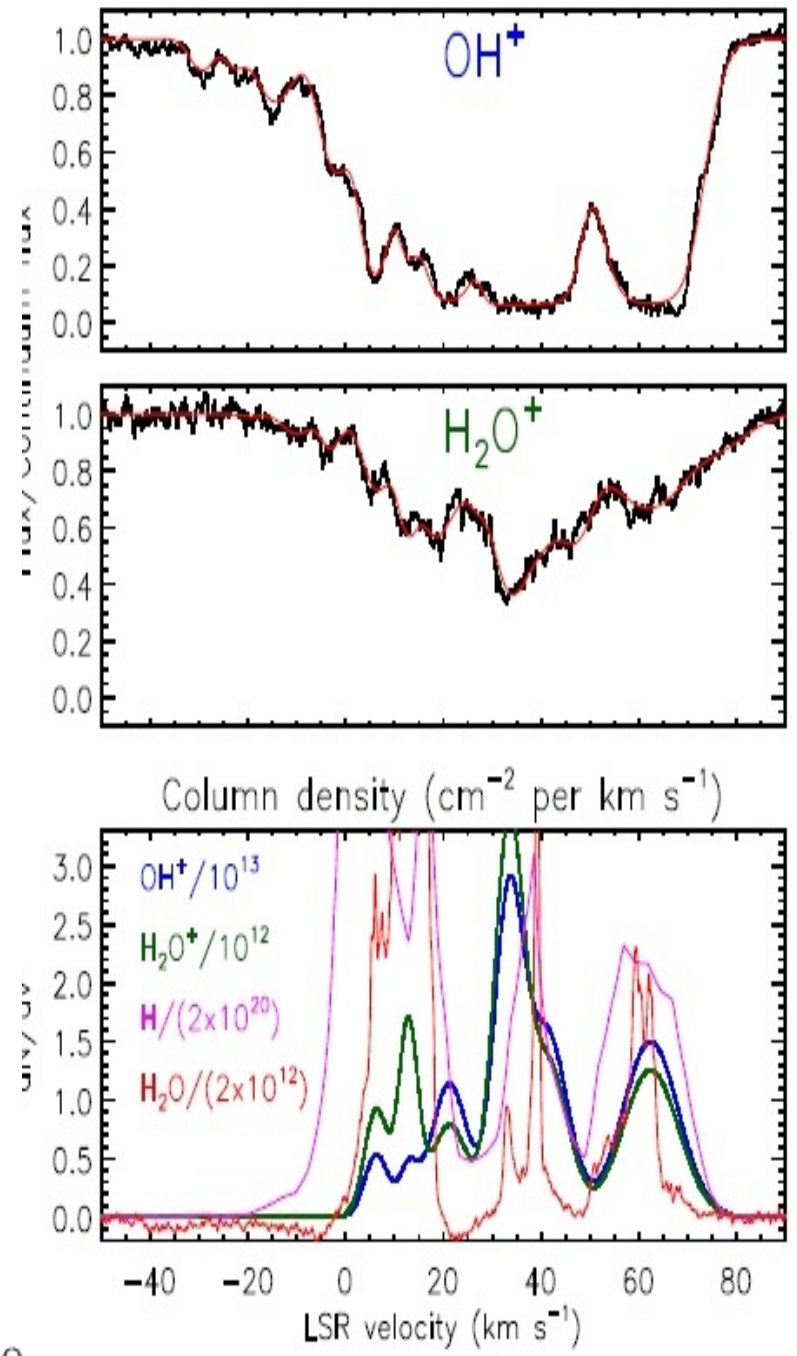
=> **OH^+ & H_2O^+ sensitive to ζ , the ionization rate due to cosmic rays**

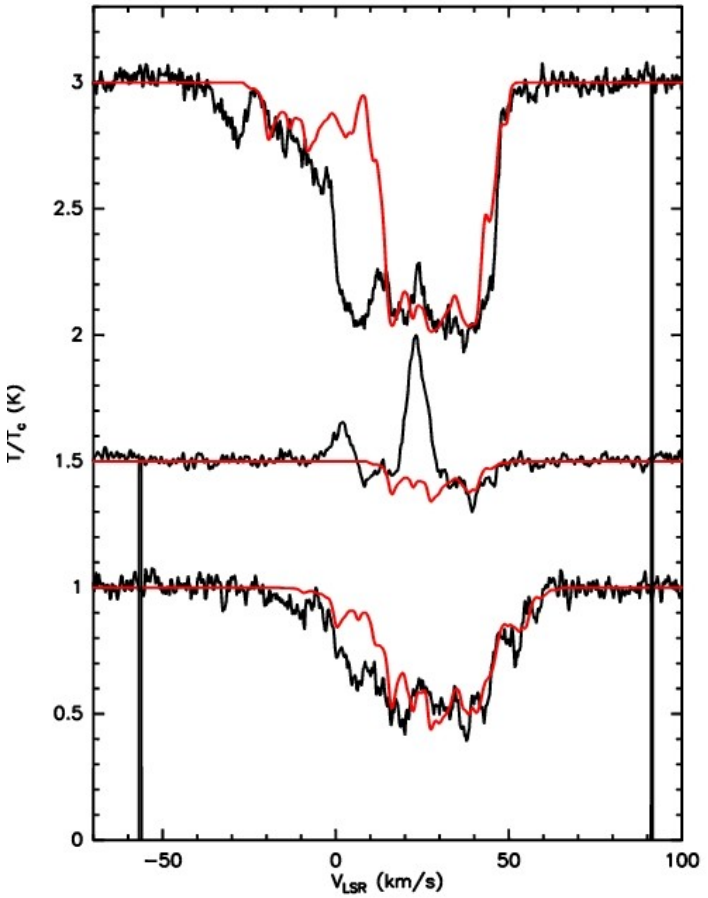
$\zeta(H) = 0.6 – 2.4\ 10^{-16}\ s^{-1}$

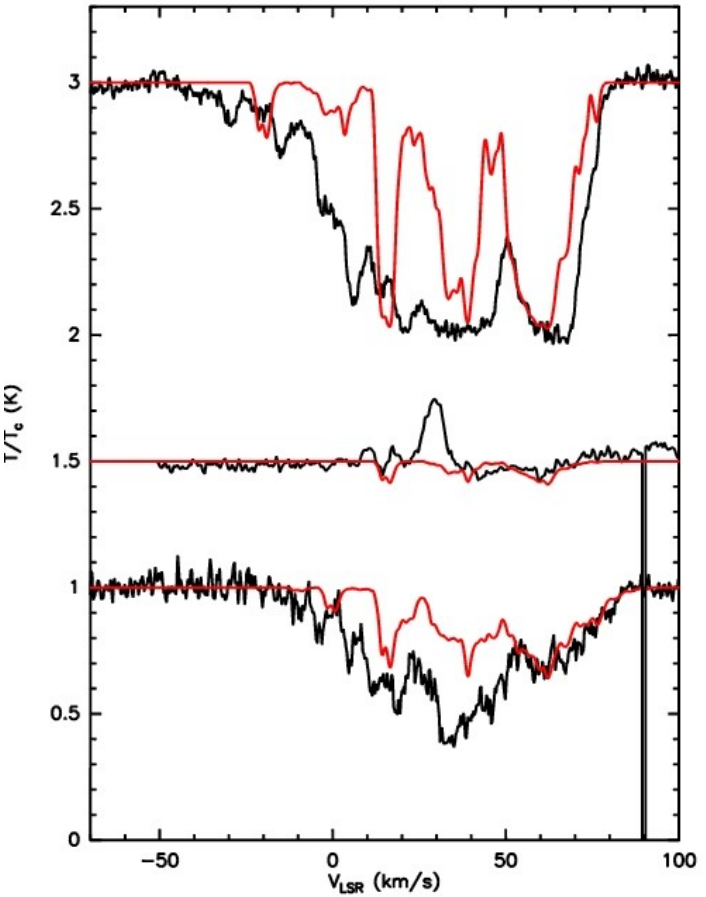
PRISMAS

l'Observatoire de Paris | LERMA


a) OH^+ $1_2 - 0_1$
b) o−H_2O^+ $1_{11} - 0_{00}$
c) p−H_2O^+ $1_{10} - 1_{01}$
d) H_3O^+ $O_0^- - 1_0^+$
T_A (K)
CH_3OH
$H^{13}CO^+$
V_{LSR}(kms^{-1})


OH^+
H_2O^+
Column density (cm^{-2} per km s^{-1})
$OH^+/10^{13}$
$H_2O^+/10^{12}$
$H/(2x10^{20})$
$H_2O/(2x10^{12})$
LSR velocity (km s^{-1})





OH^+ and H_2O^+ are not well correlated with CH.

OH^+ and H_2O^+ trace a phase with a small fraction of H in H_2

PRISMAS

l'Observatoire de Paris LERMA

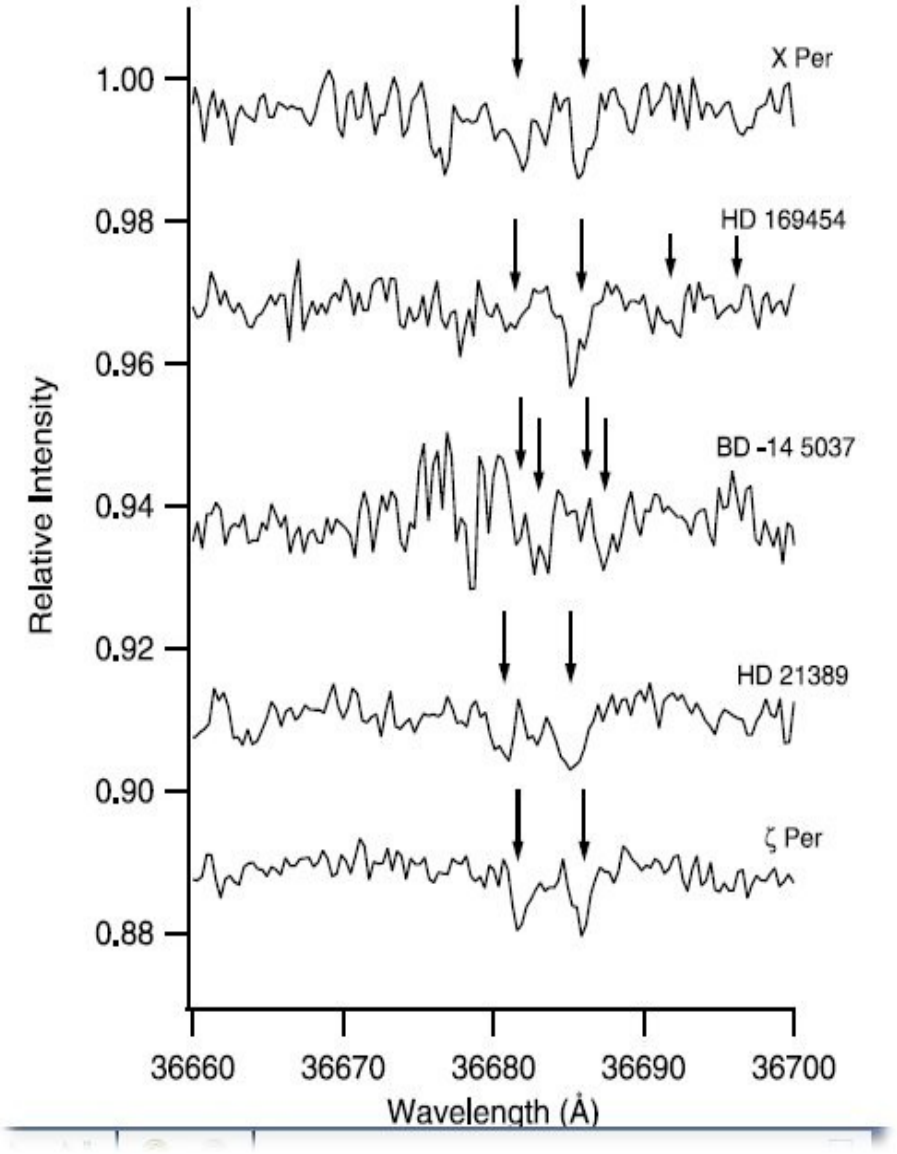
Comparison with H_3^+

H_3^+ absorption from diffuse gas

High ionization rate

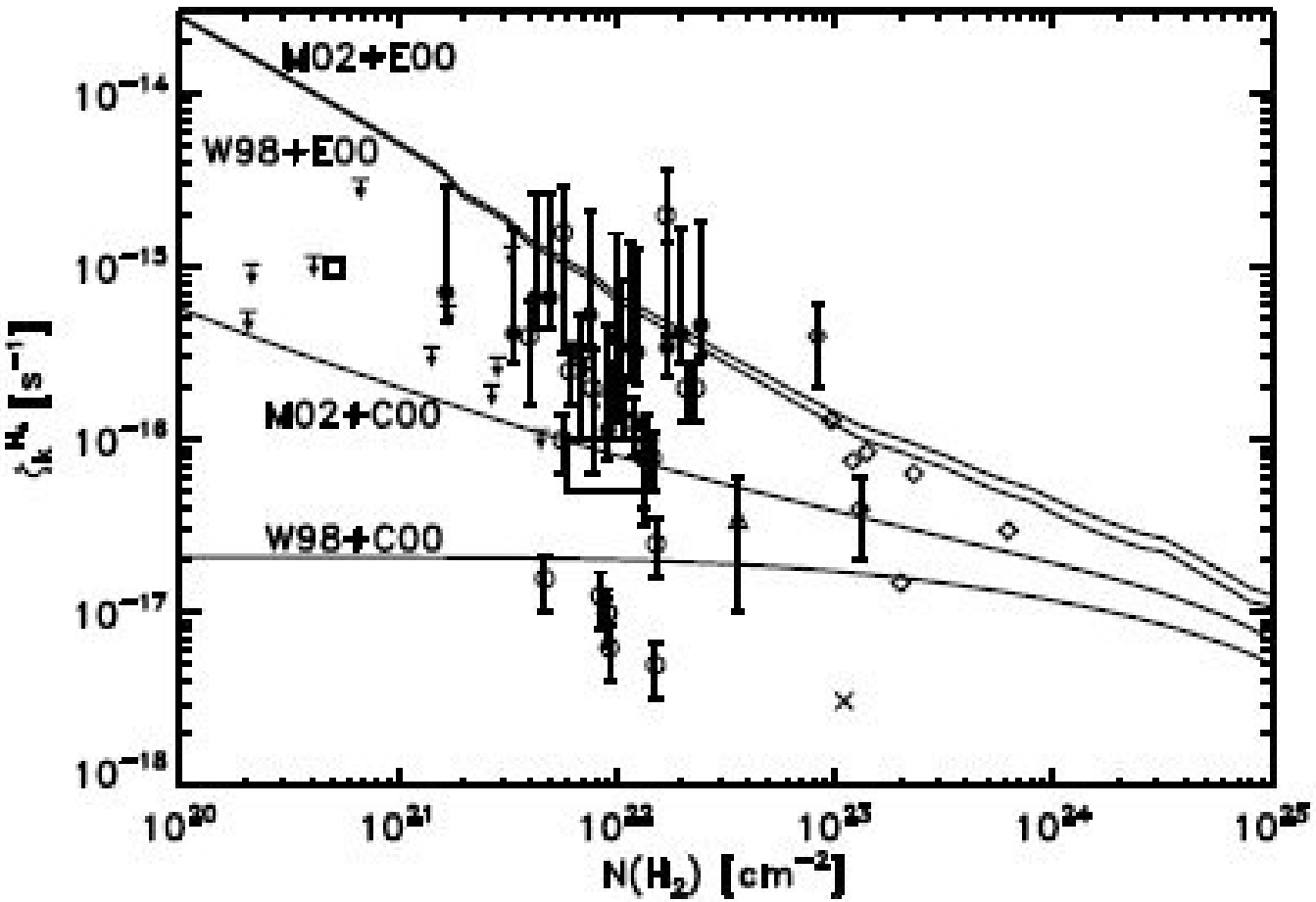
$\zeta > 10(-16)\ s^{-1}$

(Indriolo et al 2007, 2009)



PRISMAS

l'Observatoire de Paris LERMA



Padovani et al (2009)

Different models for the propagation of cosmic rays and for their energy spectrum.

ζ is expected to decrease with increasing column density of matter. Local variations ?

PRISMAS

l'Observatoire de Paris LERMA

H_2Cl^+

Precursor of HCl in gas phase chemistry

$Cl^+ + H_2 \rightarrow HCl^+$

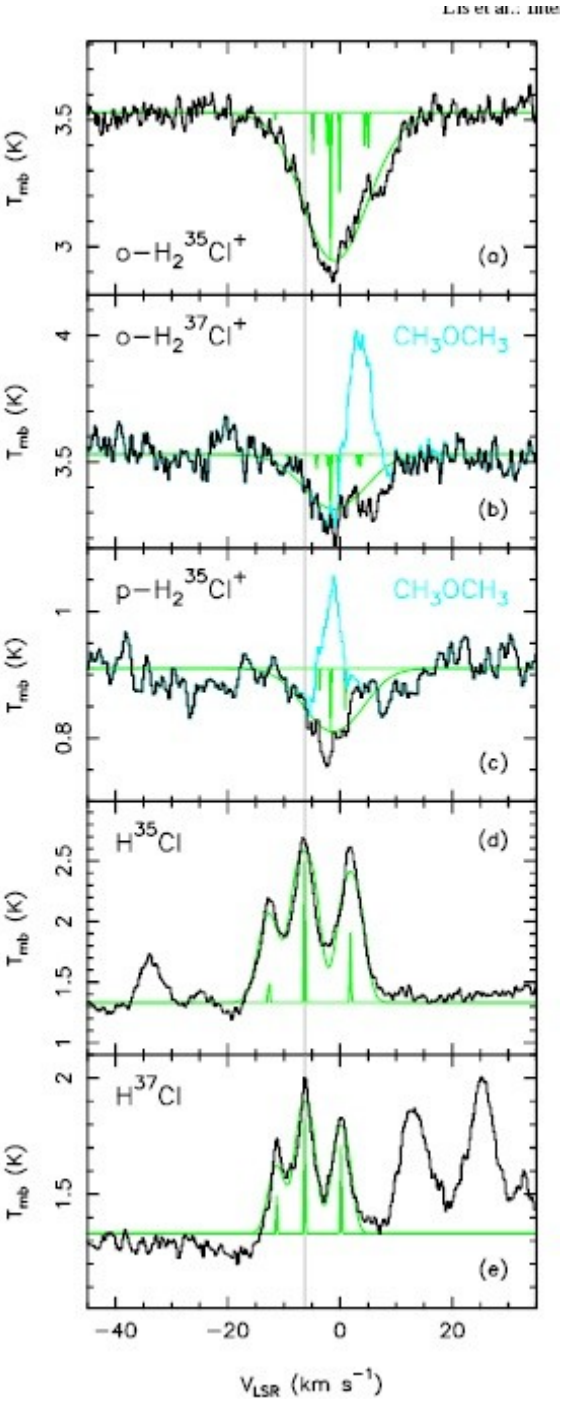
$HCl^+ + H_2 \rightarrow H2Cl^+$

$H_2Cl^+ + e \rightarrow HCl + H$

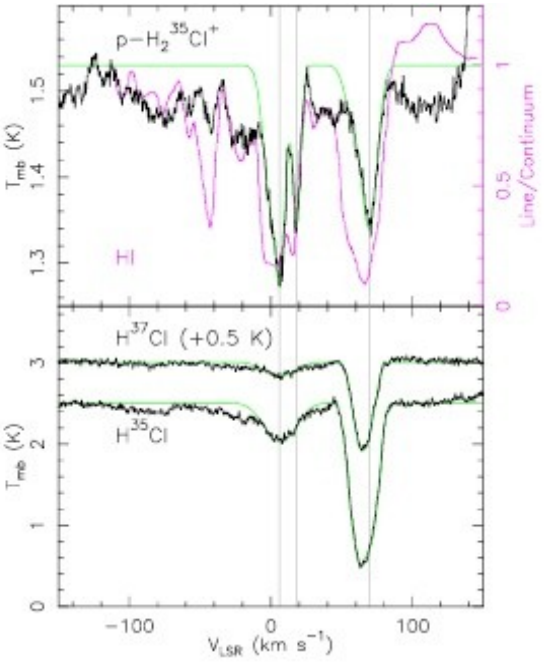
=> Present in dense & diffuse gas

=> $H_2Cl^+/HCl \sim 0.1 - 1$

=> $35Cl/37Cl \sim 3$



SgrB2



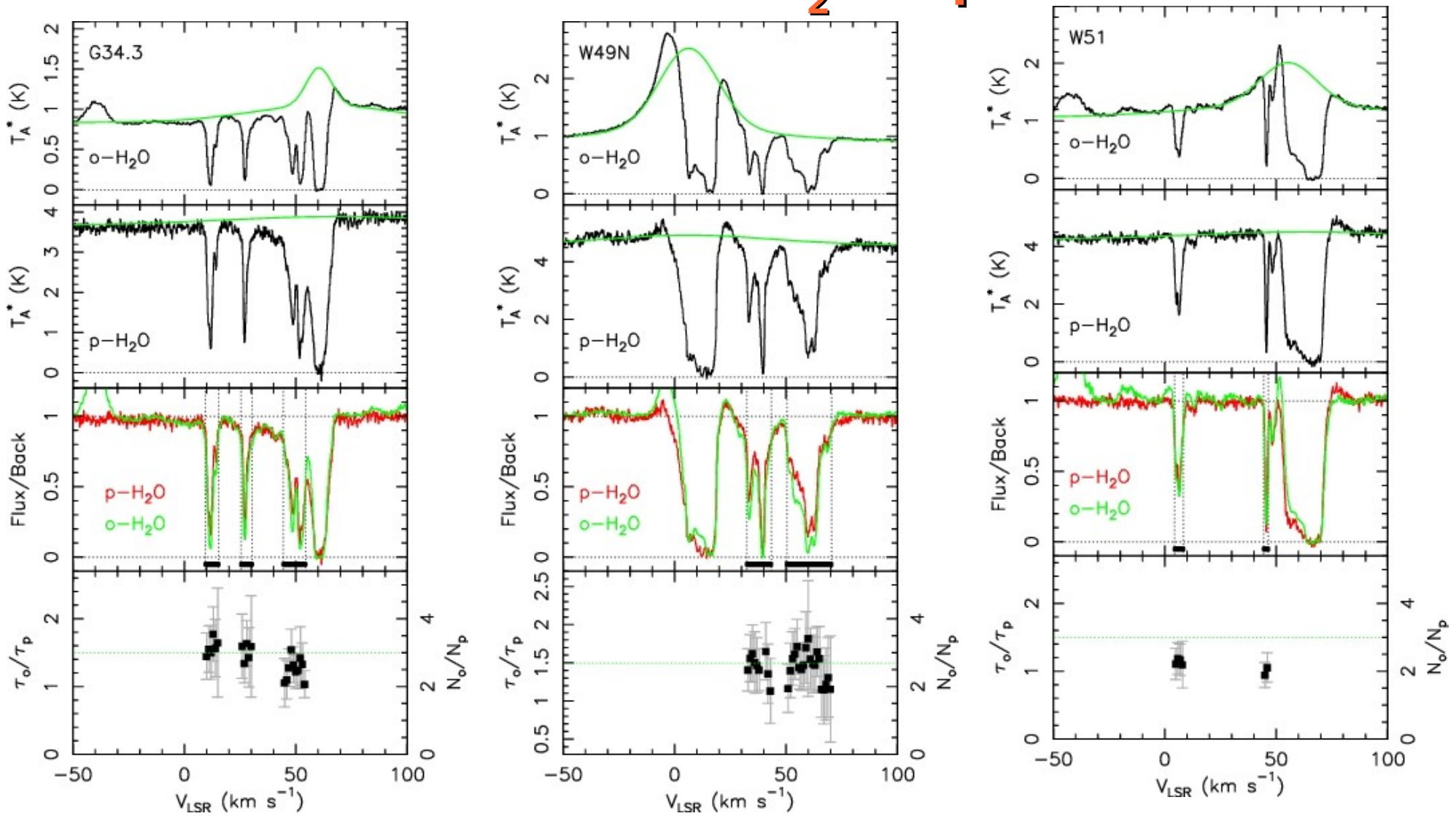
NGC6334I

Lis et al 2010

PRISMAS

l'Observatoire de Paris LERMA

H_2O o/p ratio



o/p ~ 3 for most velocities
o/p ~ 2 – 2.5

Lis et al 2010,

Goldsmith, Lis, Gerin, in preparation

PRISMAS

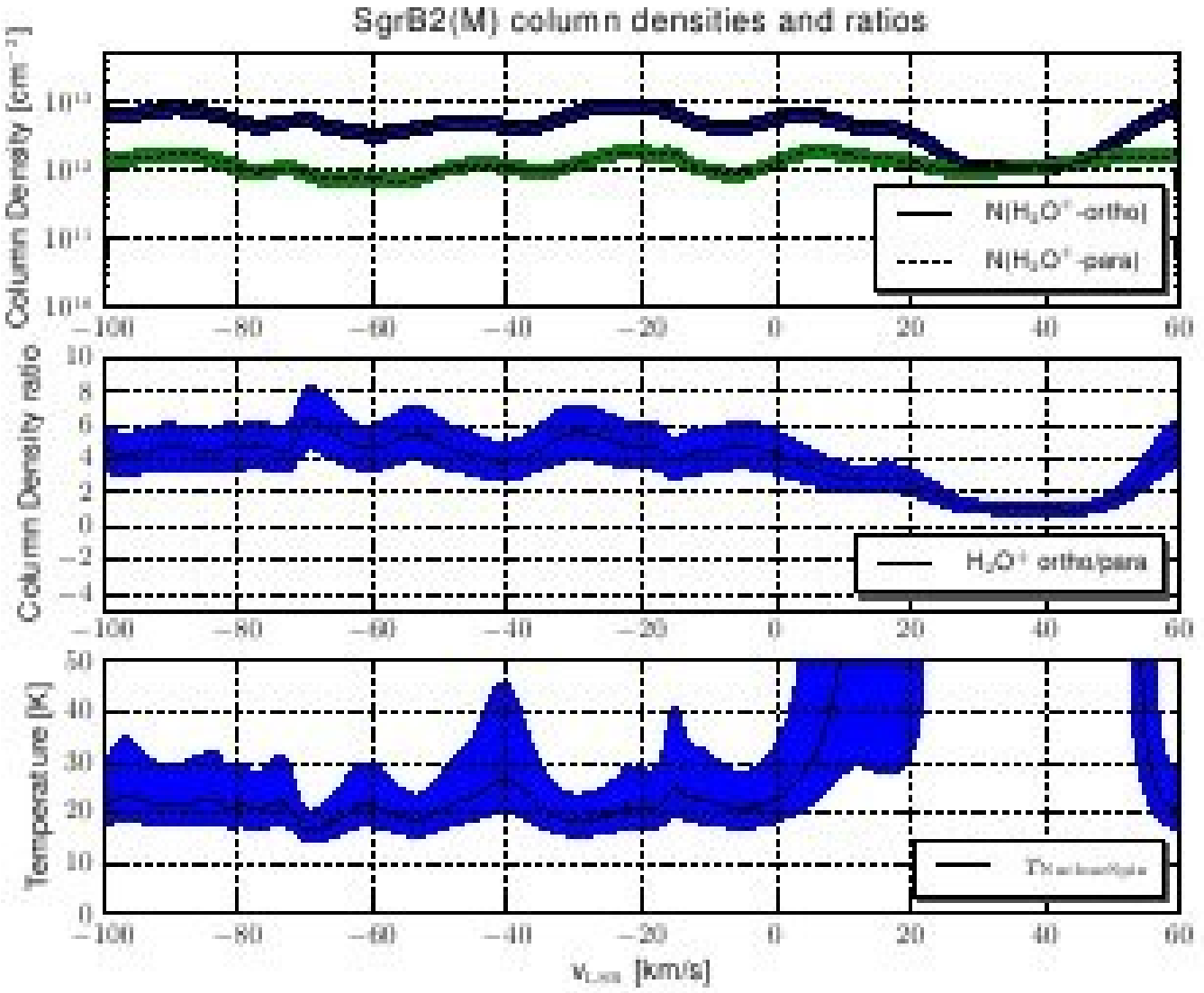
l'Observatoire de Paris LERMA

H_2O^+ o/p ratio

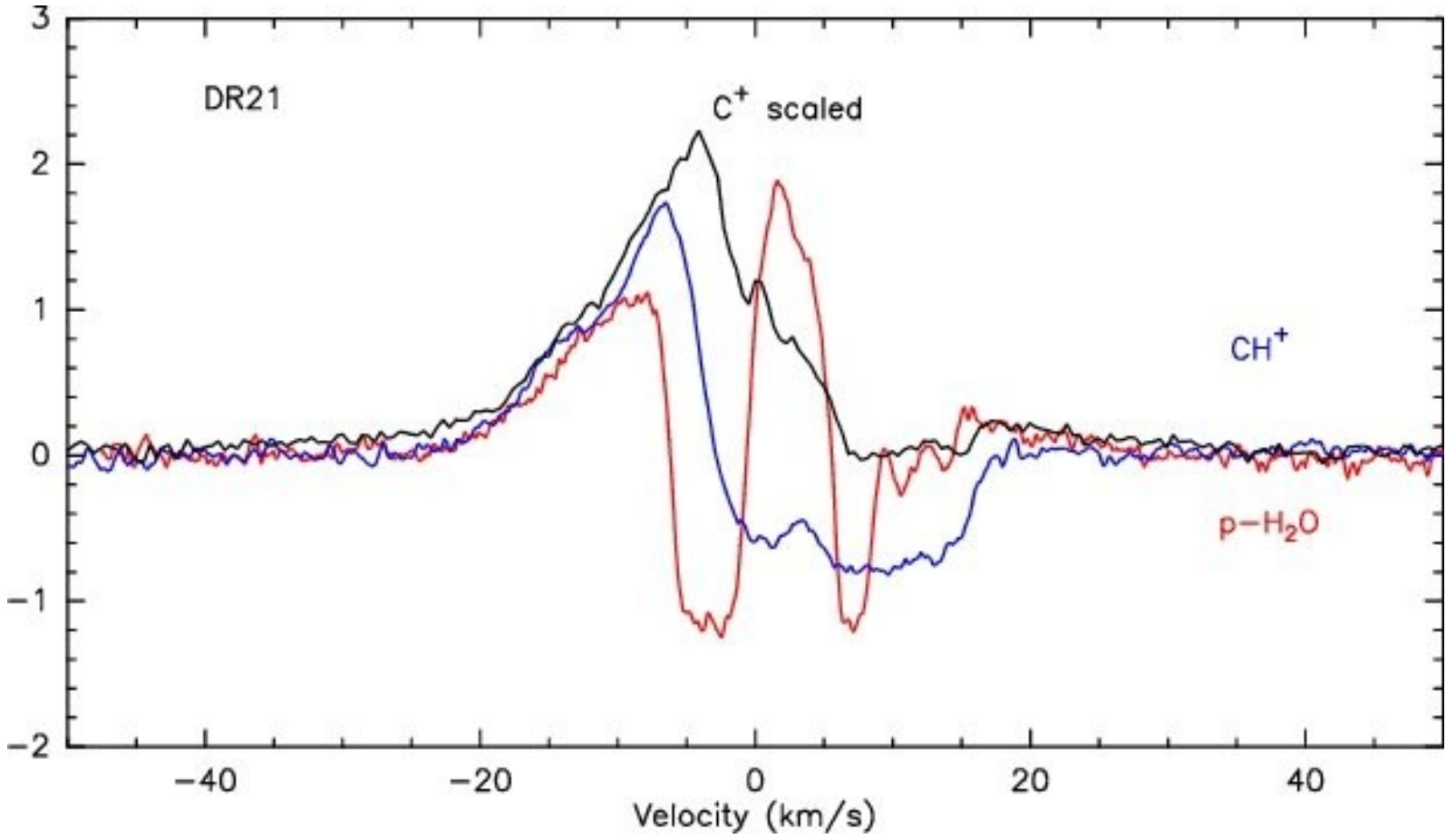
H_2O^+

o/p ~ 4

(Schilke et al 2010)



CH+ in a massive star forming region : DR21



Broad wings : CH+ in irradiated shock (C shock + FUV photons to dissociate CO)
+ Foreground absorption

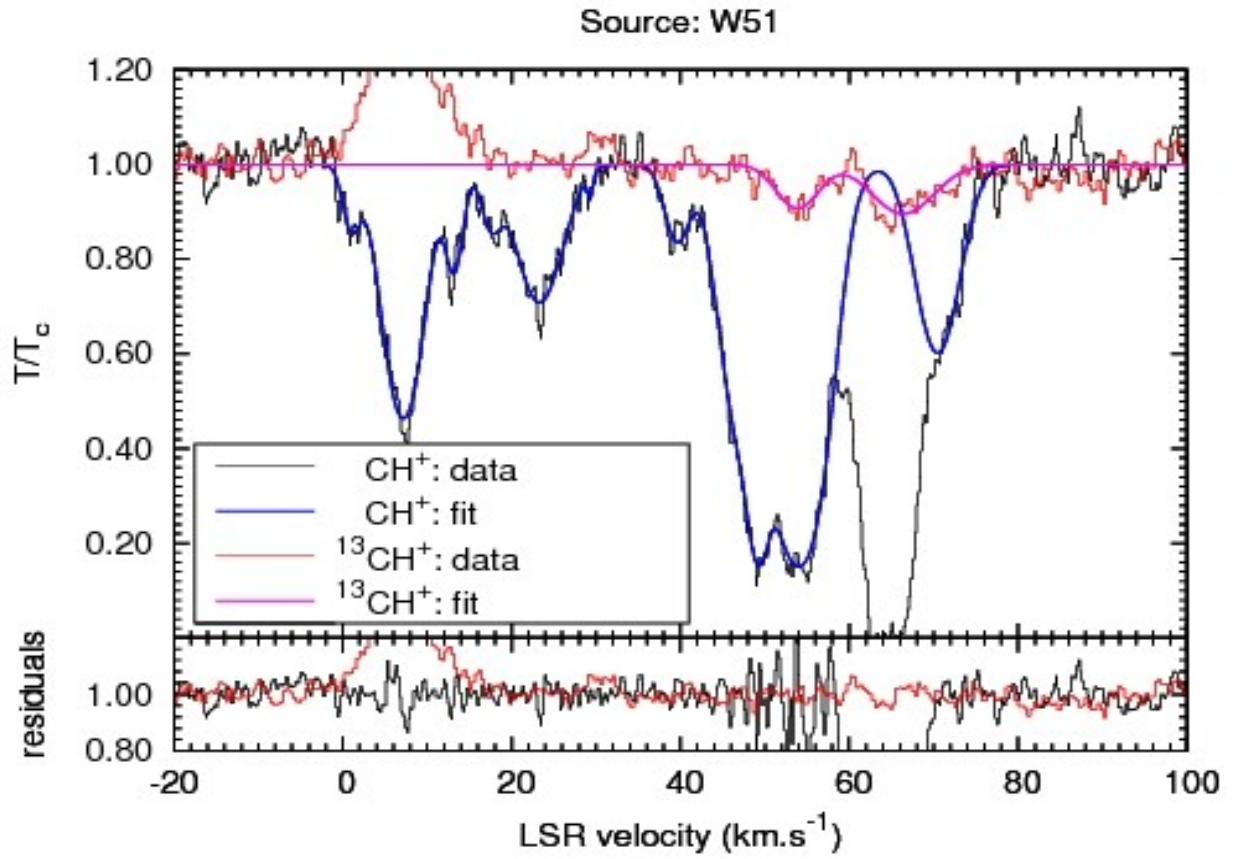
Falgarone et al 2010

PRISMAS

l'Observatoire de Paris LERMA

CH^+ in diffuse gas

- CH^+ shows strong absorption, reaching saturation
- use $^{13}CH^+$
- Agreement with $^{13}CH^+$ data from CSO (Falgarone in prep).
- Absorption with no CH, no HCO+ counterpart
- N(CH+) >3 x 10^{14} cm^{-2}

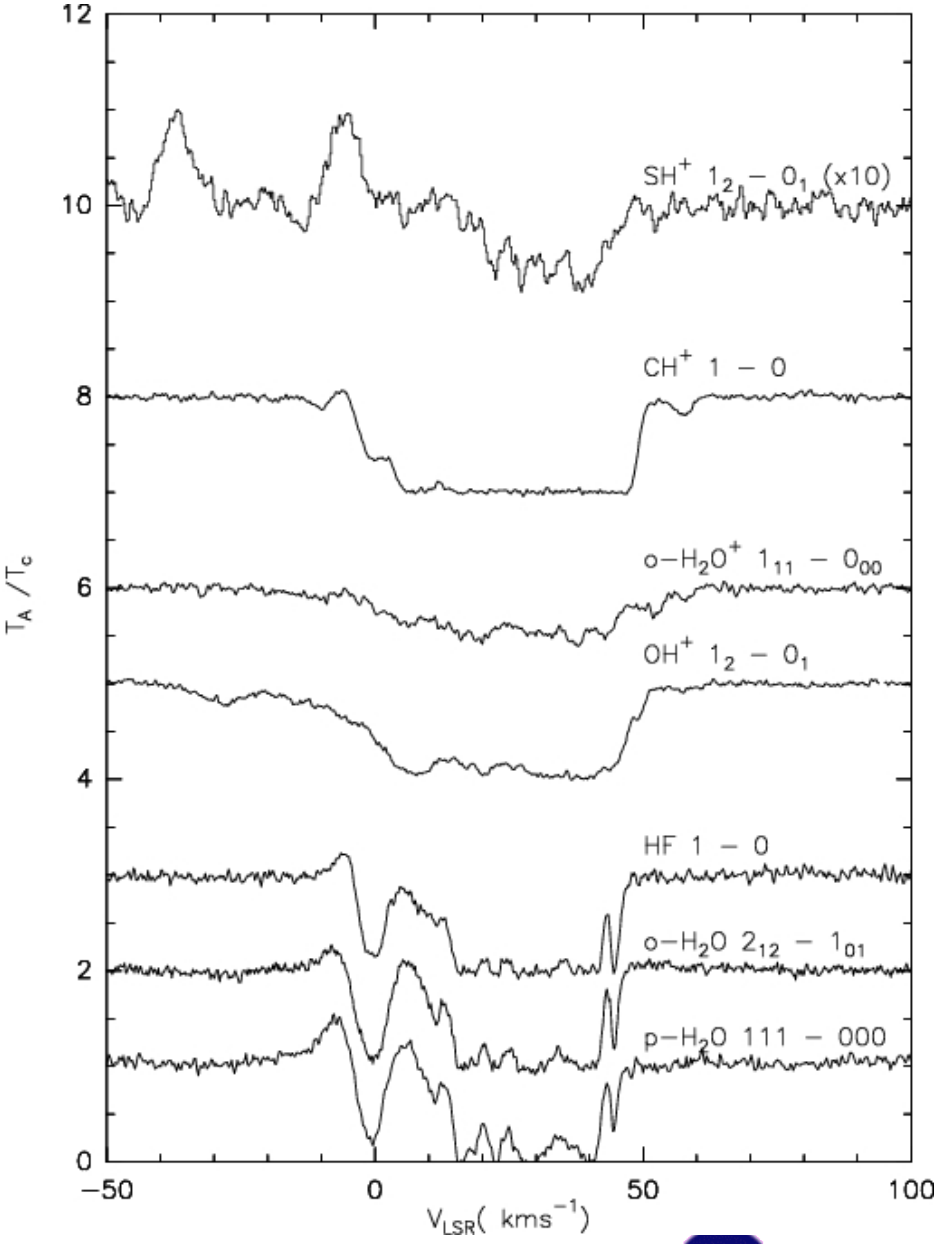


PRIMAS

l'Observatoire de Paris LERMA

SH^+ another tracer of the dissipation of turbulence !

- SH^+ produced by the reaction $S^+ + H_2$ that has $E > 4000K$
- CH^+ & SH^+ complementary diagnostics
- Godard, Falgarone in preparation



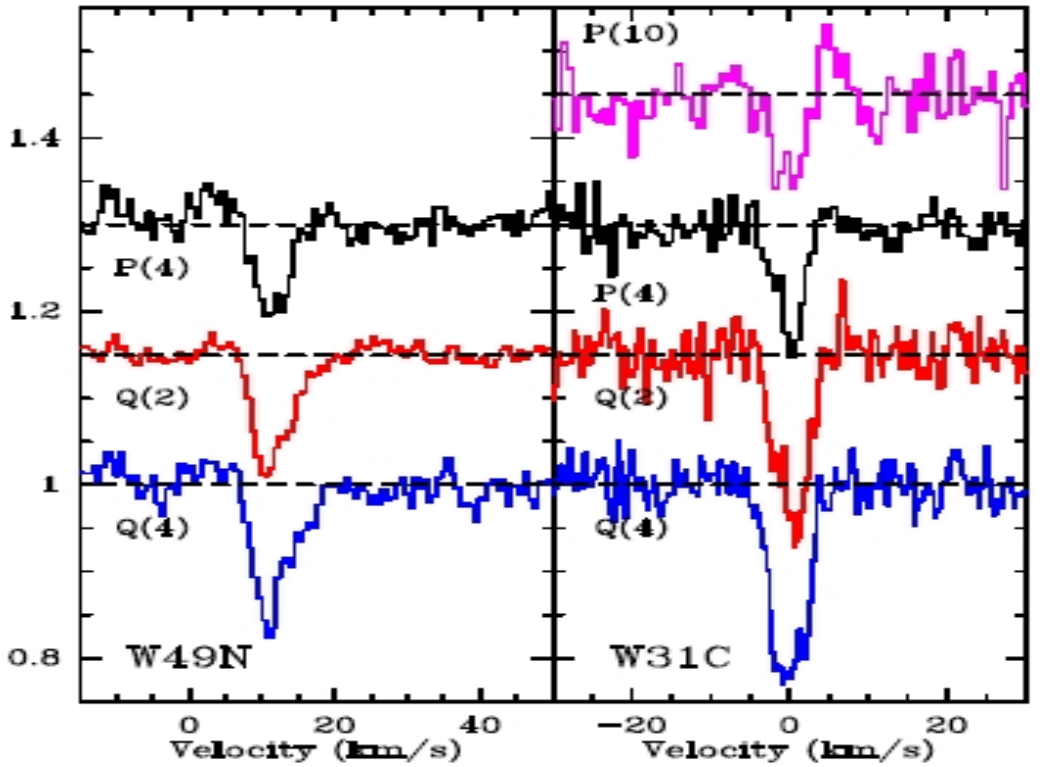
PRISMAS

l'Observatoire de Paris LERMA

Carbon clusters : C_3
ro-vibratoinal band at 1.8 THz, 4 lines

- C_3 detected in the envelope of the massive star form regions
- $N(C_3) \sim 1x10^{15} cm^{-2}$
- $T_{ex} \sim$ Tdust
- Abundance $\sim 10^{-8}$
- combined line and dust emission & absorption

=>needs more sophisticated modelling



Mookerjea, Giesen et al, A&A

Summary and Future perspectives

Herschel gives access to new probes of interstellar processes :

- H_2 tracers : HF, CH, ...
- Gas with a small fraction of H_2 : HF, OH^+, CH^+
- Cosmic ray ionization rate : OH^+, H_2O^+,
- Dissipation of turbulence CH^+, SH^+ OH^+, H_2O^+, H_3O^+, NH
- Elemental abundances HF, HC35Cl, H37Cl, ...
- Photoionization HCl/H_2Cl^+

Need for a revision of chemical models and networks

N chemistry

Coupling chemistry with dynamics (shocks, turbulence, mixing ...)

PRISMAS

l'Observatoire de Paris LERMA

Acknowledgements

The PRISMAS team is grateful to

the Herschel project team

the HIFI consortium

the PACS consortium

for the excellent performances of the satellite, telescope and instruments