PRISMAS

PRobing InterStellar Molecules with Absorption line Studies

Absorption spectroscopy with Herschel/HIFI and IRAM-PdBI : Promises for ALMA

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Why Absorption Spectroscopy ?

- Sensitivity limited to continuum sensitivity, access to weak features
- Background sources : from stars/star forming regions to QSOs/distant galaxies

- Direct probe of line opacity => easier analysis of molecule column density
- Comparison over a broad spectral range if the background source structure is understood (eg from cm to IR for star forming regions)

- Less information on spatial structure => need for extended continuum sources.

Molecules detected by absorption spectroscopy

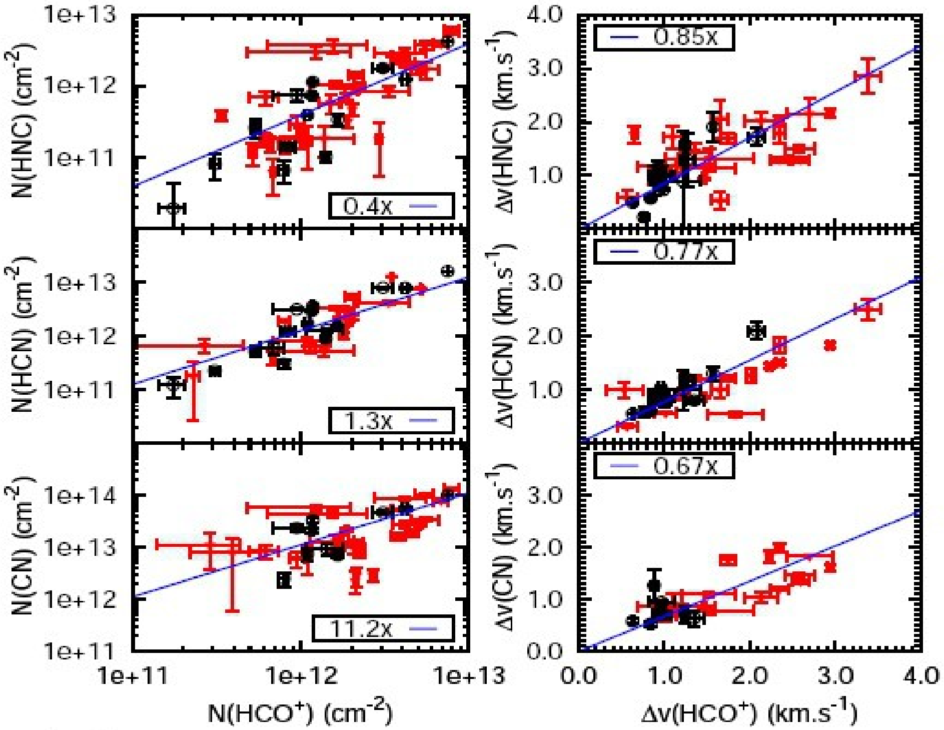
- First detections : CH, CN, CH^+ (1937 – 1940)
- **UV / Visible/IR absorption**

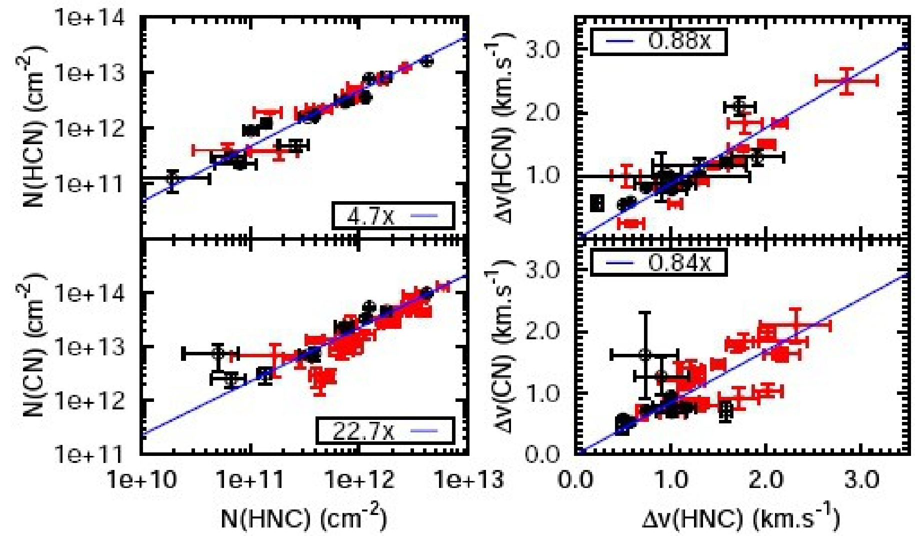
- H, H_2, C^+, C, CO, CH, C_2, C_3, CN, OH, NH, H_3^+...
- relatively simple molecules + atoms/ions (Na,Ca..)
- DIBs ...,? PAH ?

- **Radio absorption :**

- HI, OH, CO, CN, H_2O, H_2S, HCO^+, CCH, HCN, HNC, CS, NH_3, H_2CO, c-C_3H_2, ...

- From simple to ~ complex species
- Little overlap between radio and visible spectral domains
- Potential tracers of H2, cosmic ray ionization rate, dissipation of turbulence ...





Godard et al, 2010

HCN/HCO$^+$ ~ 1.3 HNC/HCO$^+$ ~ 0.4 CN/HCO$^+$ ~ 11.2

HCN/HNC ~ 4.7, CN/HNC ~ 22.7 CCH/c-C_3H_2 ~ 28

Similar properties as the diffuse matter probed towards high latitude sources (Liszt , Lucas et al.)

Molecules in the diffuse ISM
(Liszt, Lucas, Pety)

Table 3. Relative abundances $10^8 \times N()/N(H_2)$.

Species	ζ Oph[1]	Our Work[2]	TMC-1[3]	BD-G[4]
OH	10	10	30	10
CO	480	300	8000	41
HCO^+		0.2-0.3	0.8	0.009
C^+	26 100			89 100
C	700			720
C_2	3.3			3.7
C_3	0.35			10^{-5}
CH	5.4		2	3.9
CH^+	6.3			0.006
C_2H		2.9	5–10	0.4
C_3H_2		0.14	1	
CN	0.54	2.0	3	0.30
HCN	(0.079)	0.30	2	0.007
HNC	(0.016)	0.06	2	
CS		0.25	1	
SO		0.15	0.5	
H_2CO		0.40	2	
NH	0.19			0.10
NH_3		0.20	2	

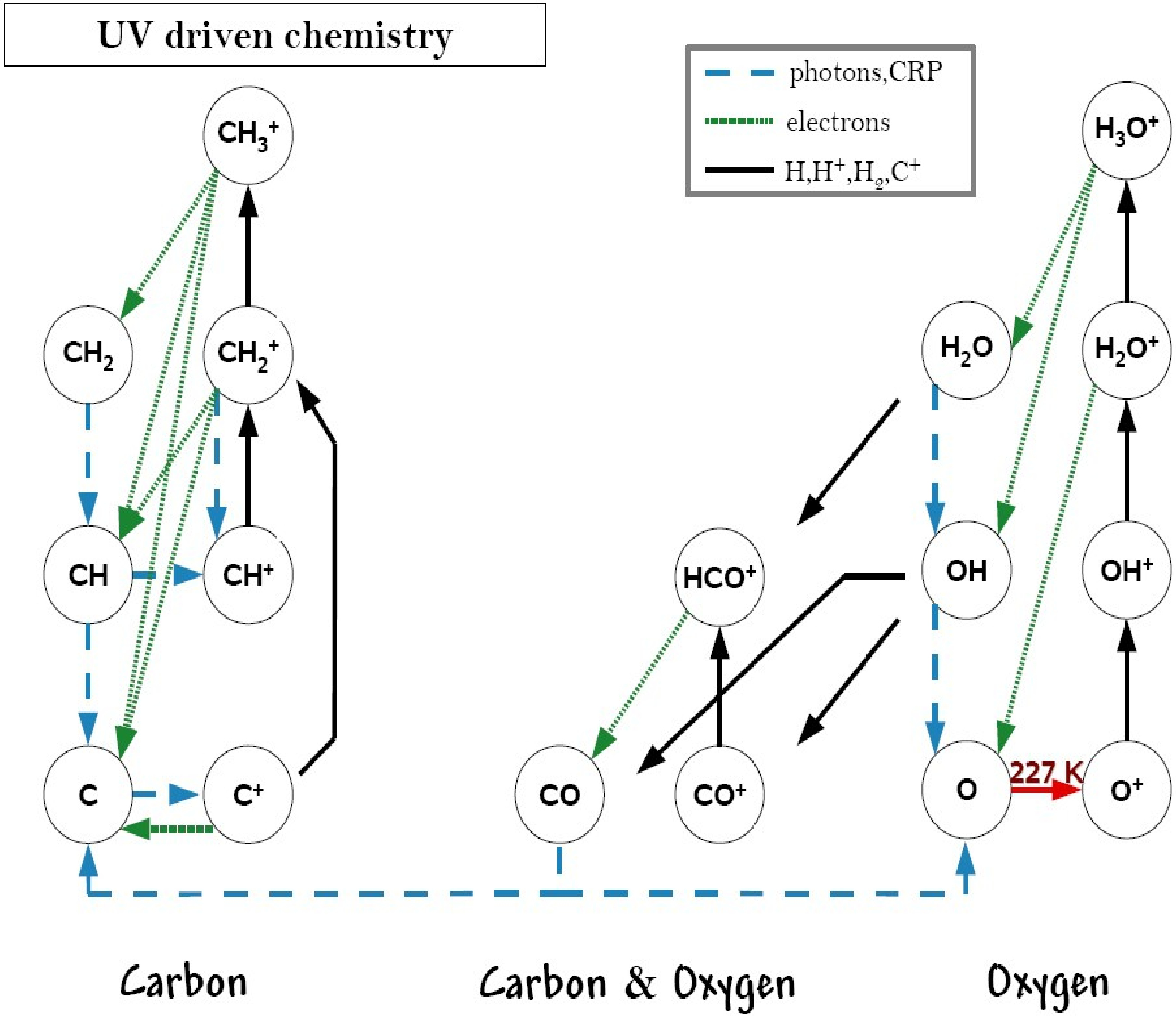
Lower or Comparable abundances in diffuse and dense gas

HCO^+ & CCH (c-C_3H_2 ?) tracers of H_2 in diffuse gas (ubiquitous absorption)

PRISMAS programme: Absorption spectroscopy

- Hydride ground state lines in the submm spectral range
- 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.
- 8 sources, 25 Species

- 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^+



Godard et al. 2009

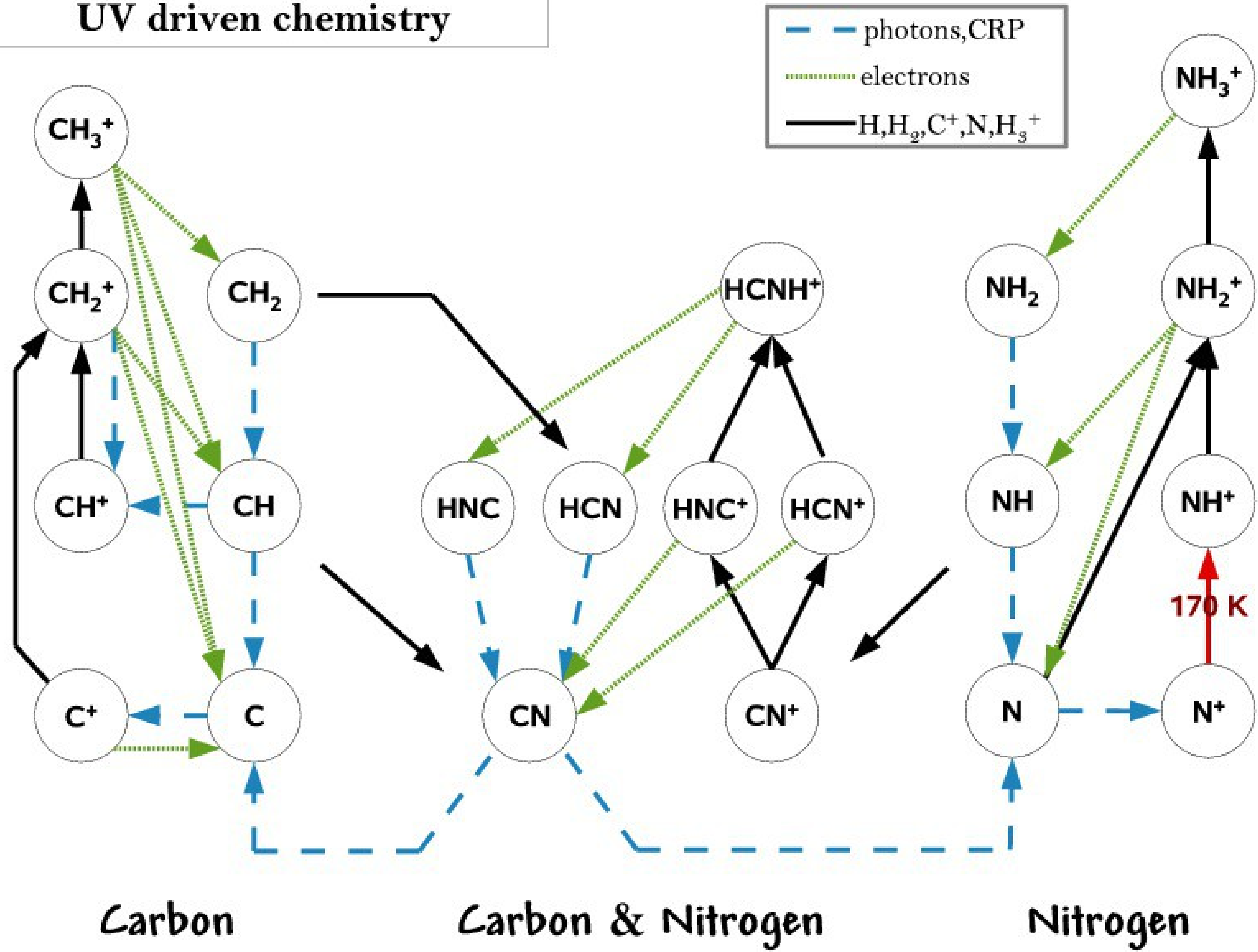
Hydrides

- built in the first chemical steps starting from atomic gas

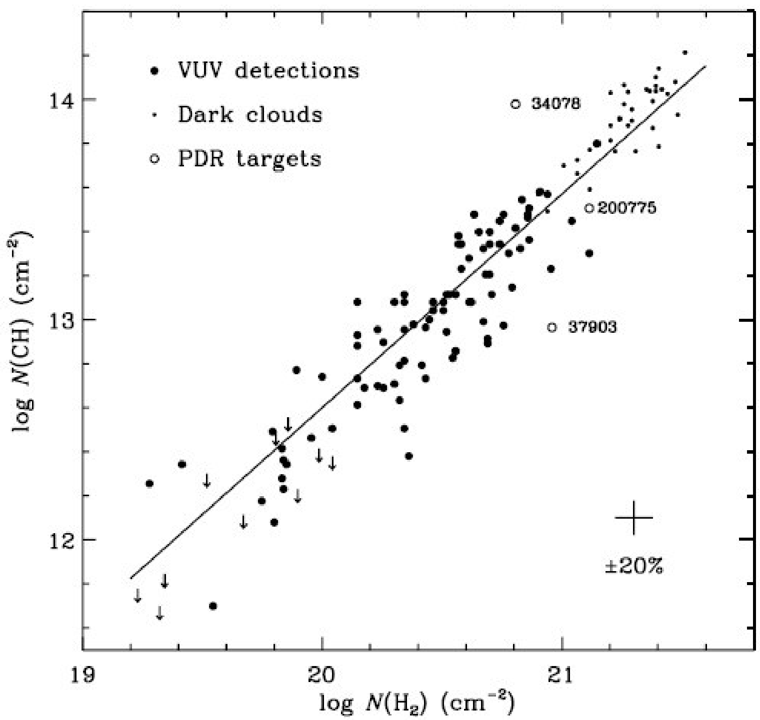
- at the root of interstellar chemistry

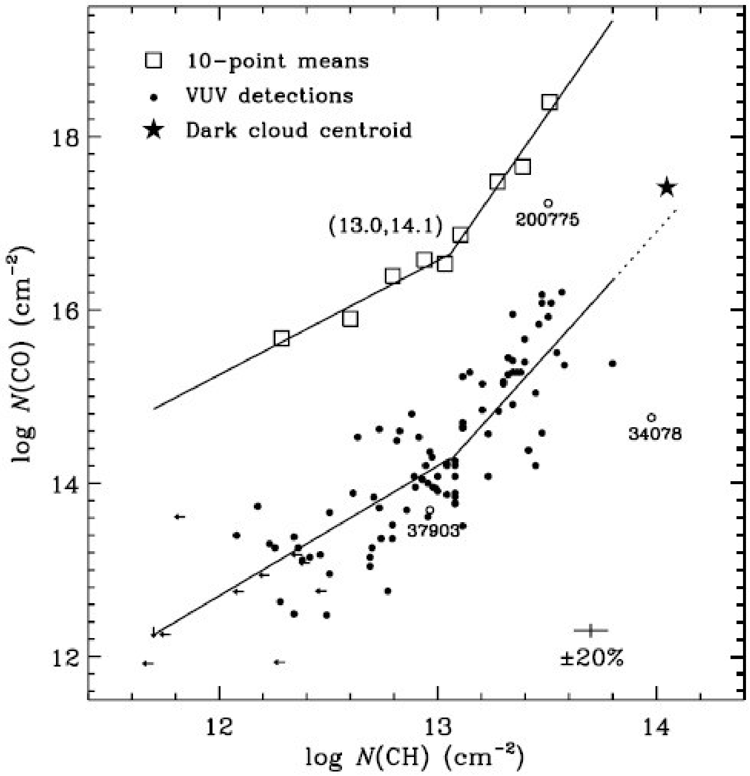
- Diagnostics of physical / chemical processes

UV driven chemistry



Molecular hydrogen tracers





Visible/UV spectra

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

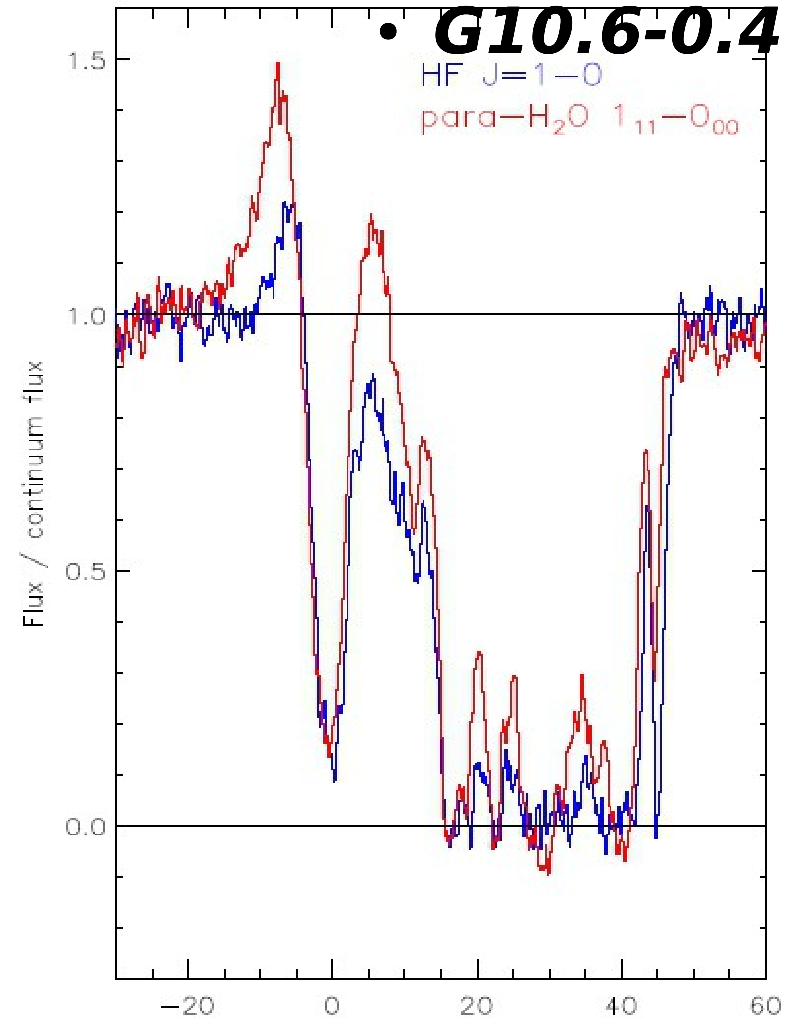
Sheffer et al 2008

New tracers of H_2 in the submillimeter : Hydrogen fluoride (HF) & CH

- 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.
- => $\tau(HF) > \tau(p\text{-}H_2O)$
- => $\tau(HF) \sim N(H_2)/10^{20} cm^{-2}$

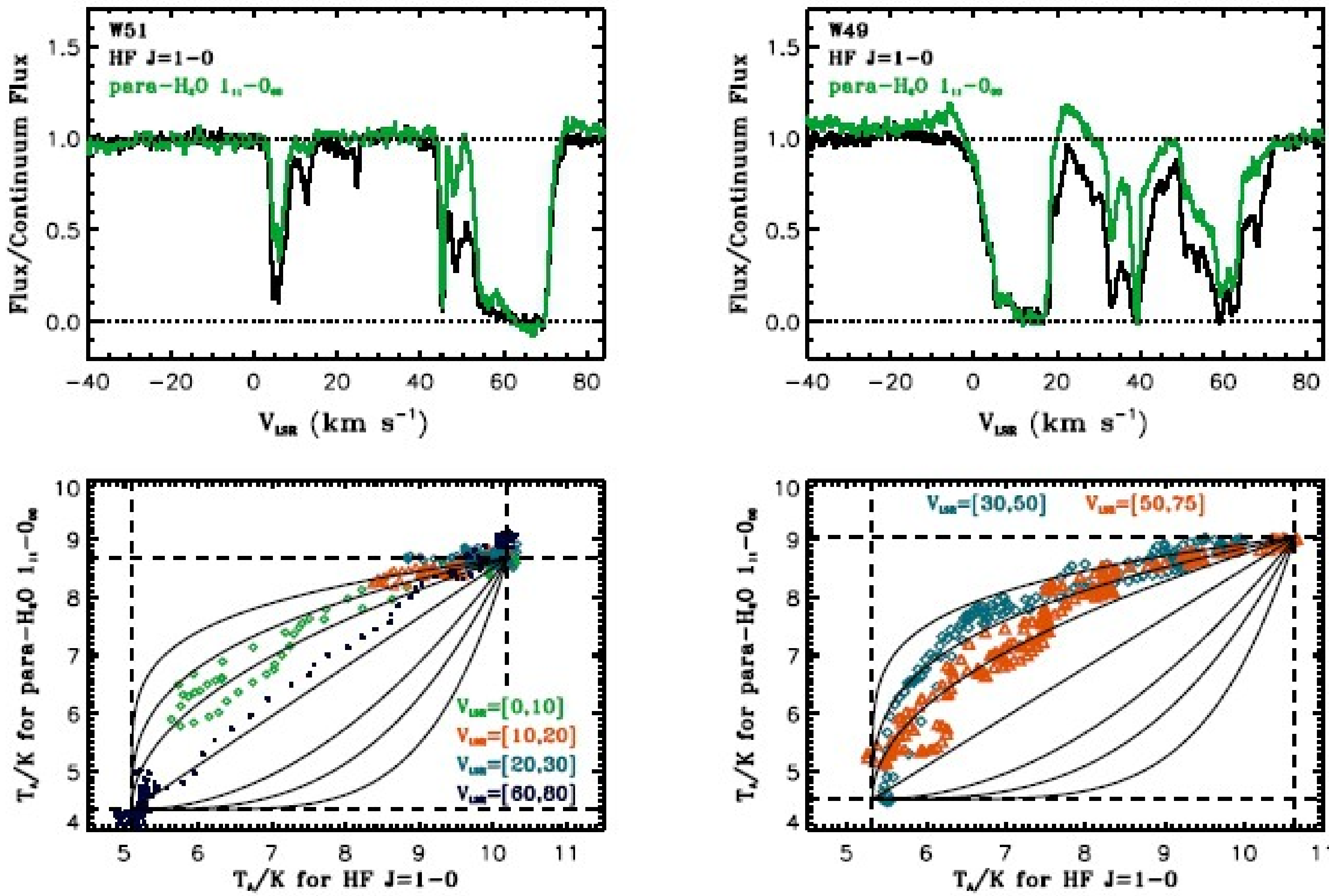
(dv = 1 km/s)

- **G10.6-0.4**



Neufeld et al 2010a A&A 518

Sonnentrucker et al, and poster

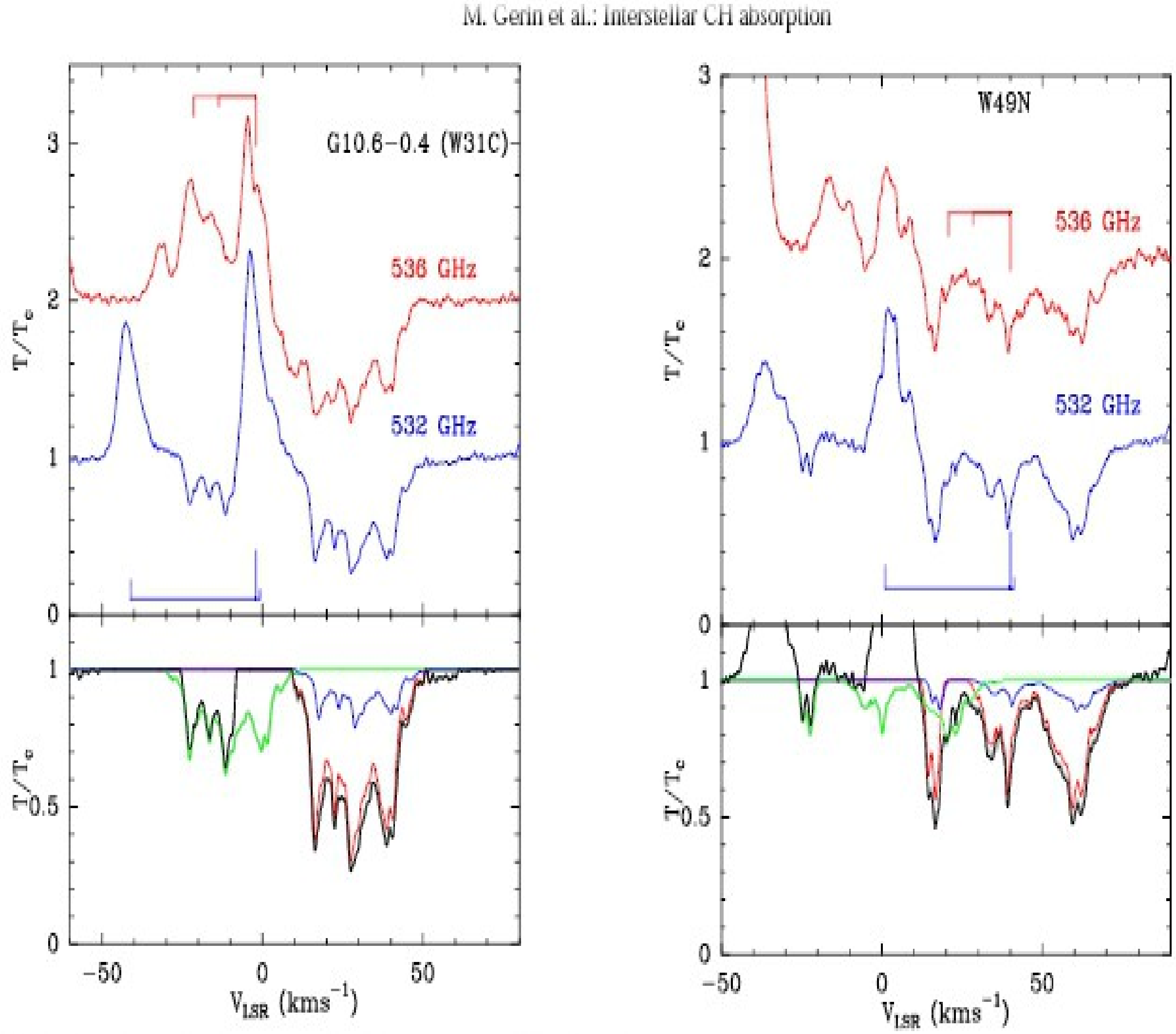


- $HF/H_2 \sim 1 - 3 \times 10^{-8}$ ($F/H = 1.8 \times 10^{-8}$)
- $N(HF)$: $1 - 70 \times 10^{12}$ cm^{-2}

Sonnentrucker, Neufeld et al (A&A 521

CH

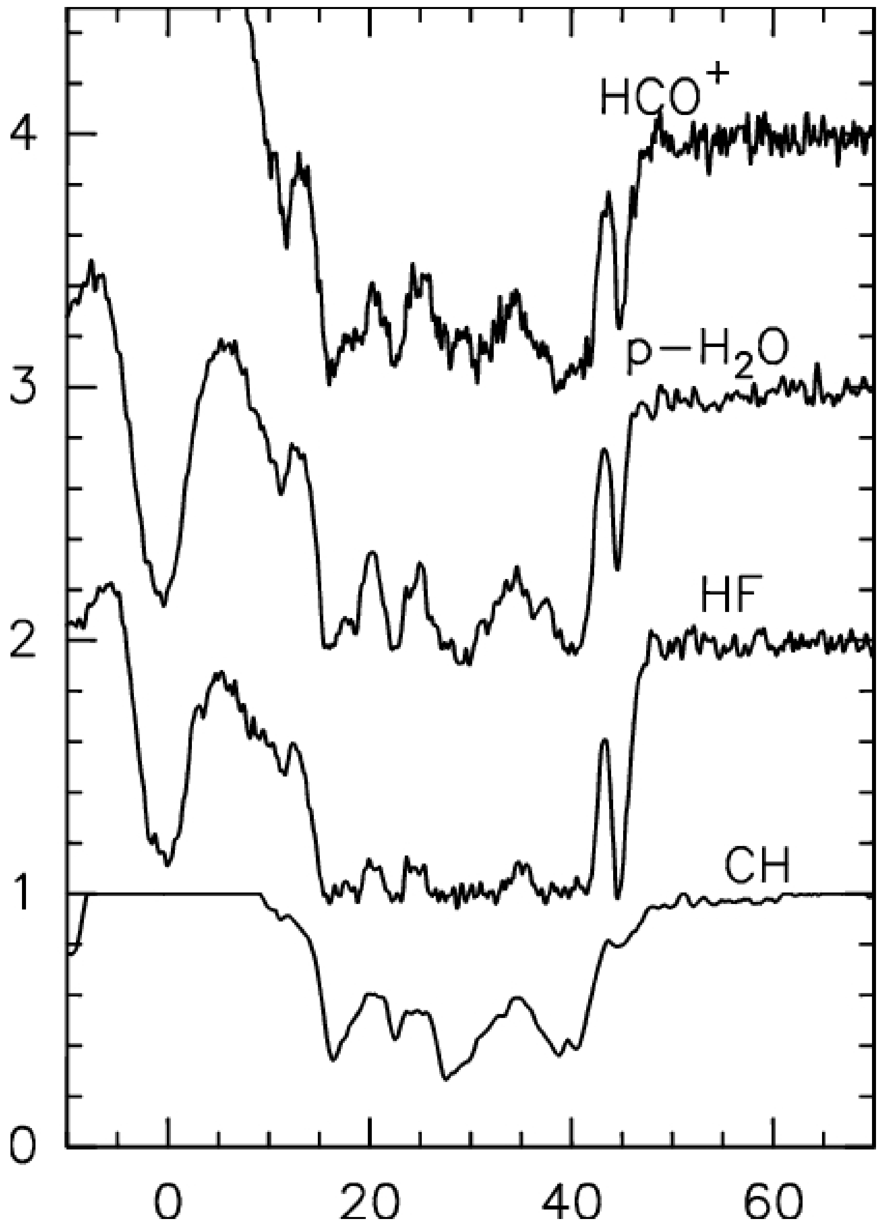
- CH ground state triplet at 532 & 536 GHz.
- Lines not saturated but complex profiles
- Combination of emission & absorption
- N(CH) ~ few 10^{14} cm^{-2}
- **CH & HF consistent with CH/H_2 ~ 3.5 10^{-8} derived from UV/visible**
- $\tau(CH)$ ~ $N(H_2)/10^{21}cm^{-2}$

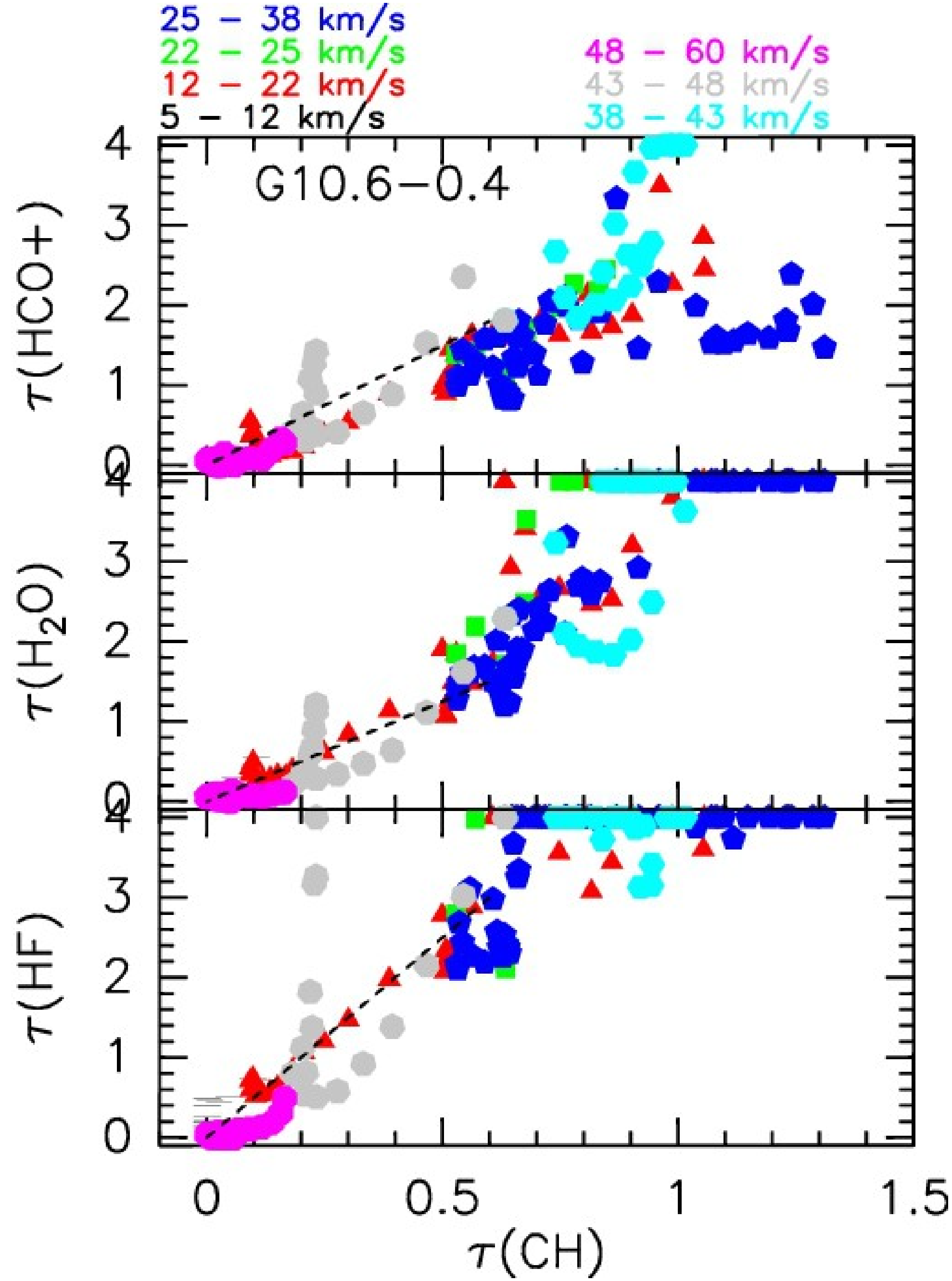


Gerin et al 2010 A&A 521

CH : relation with other molecules :

linear scaling => constant abundance ratio





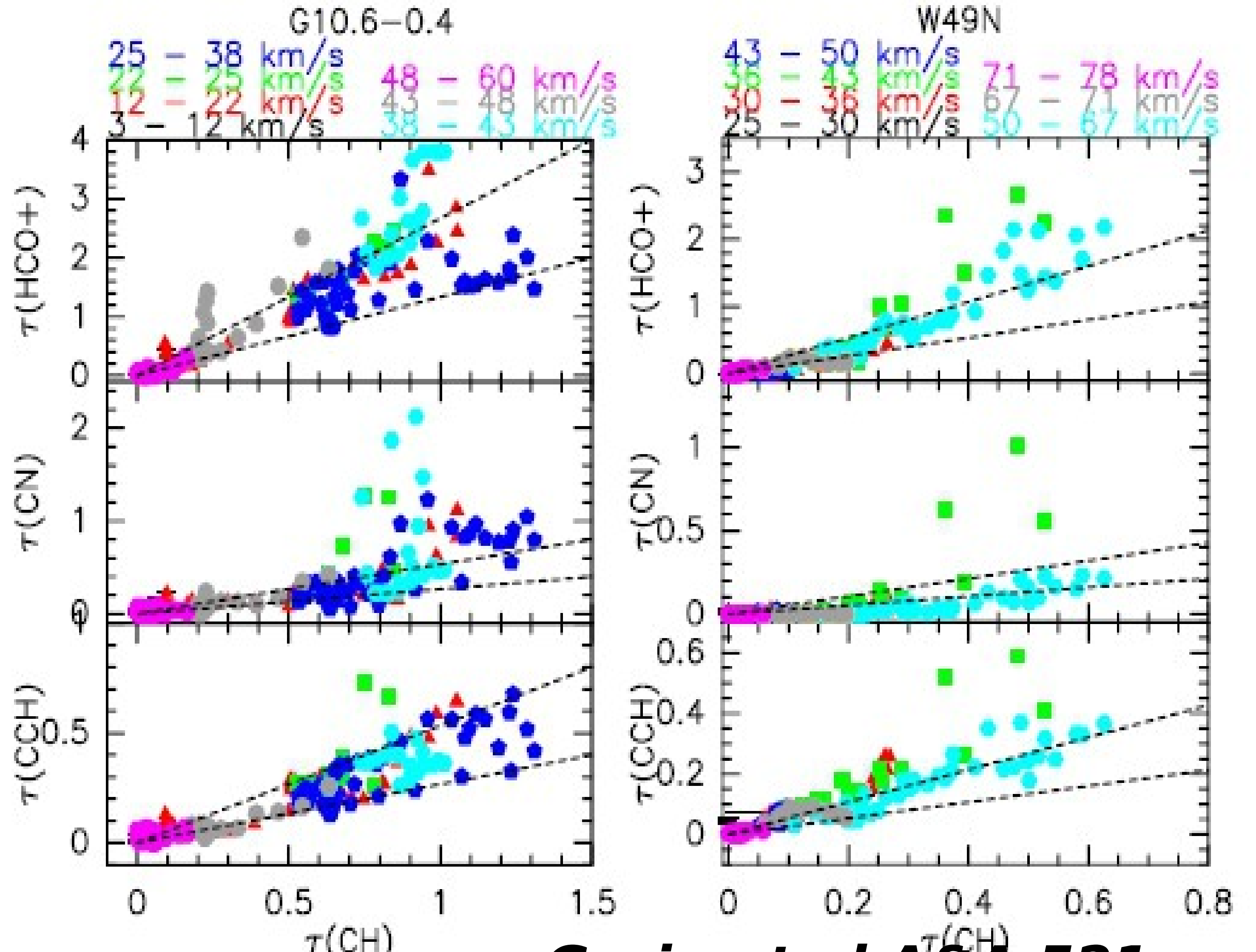
CH : relation with other molecules

- Well defined trends & deviations in narrow velocity intervals

- CCH/CH ~ 0.6 – 1.2

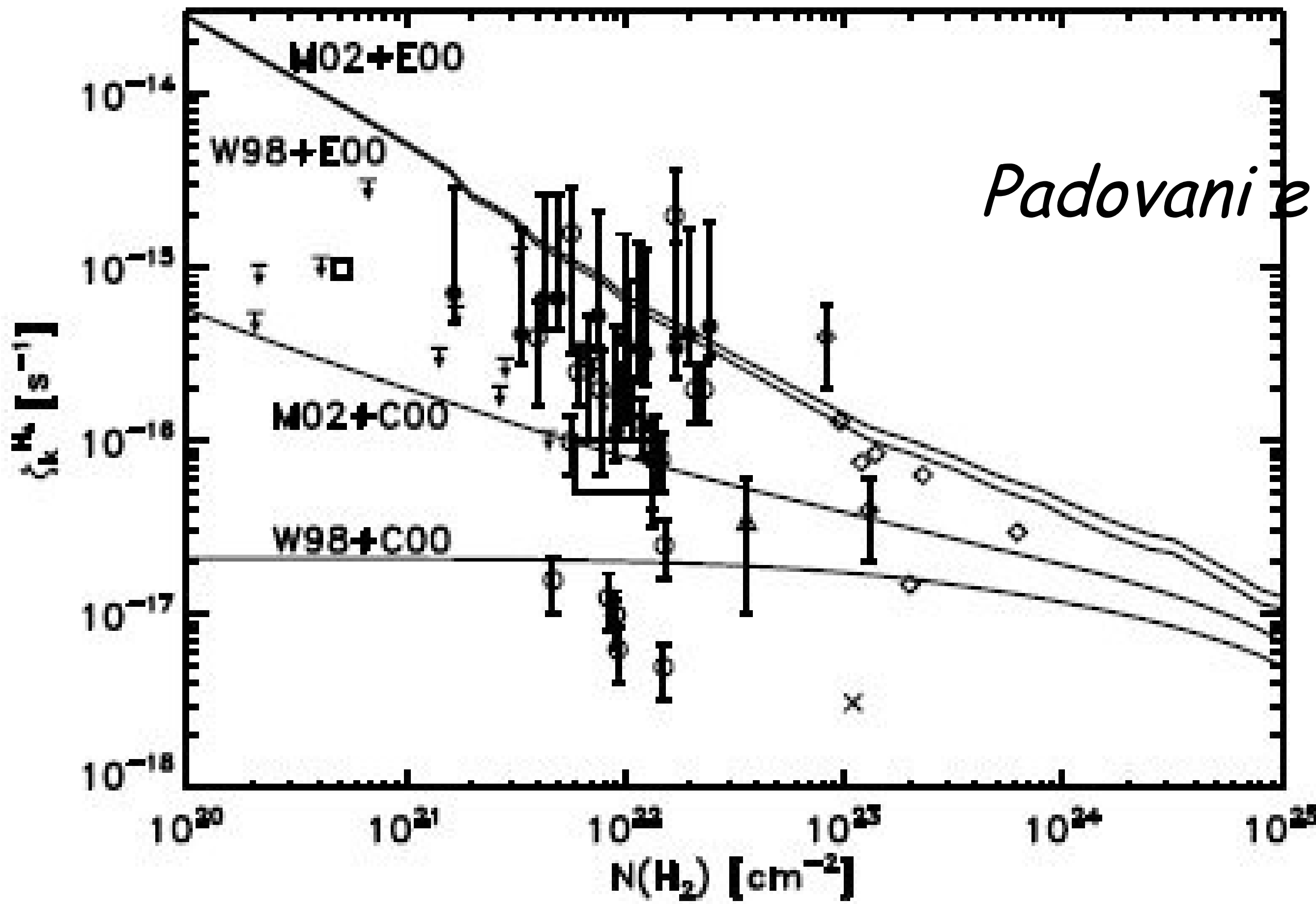
- CN/CH ~ 0.5 – 1

- HCO^{+}/CH ~ 0.04 - 0.08



- ***Gerin et al A&A 521***

Cosmic rays ionization rate

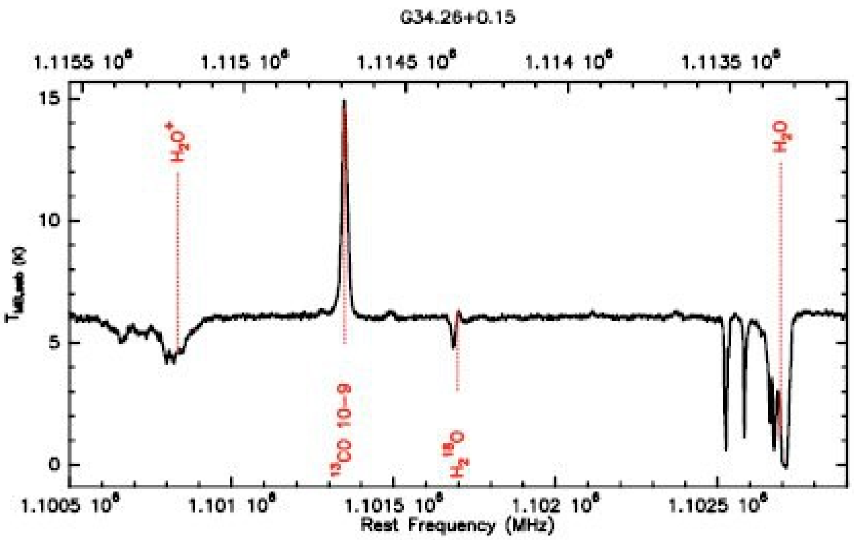


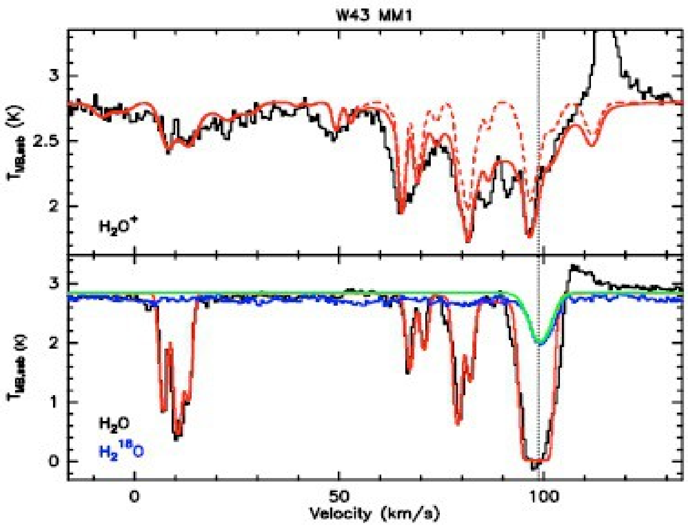
Padovani et al (2009)

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 ?

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



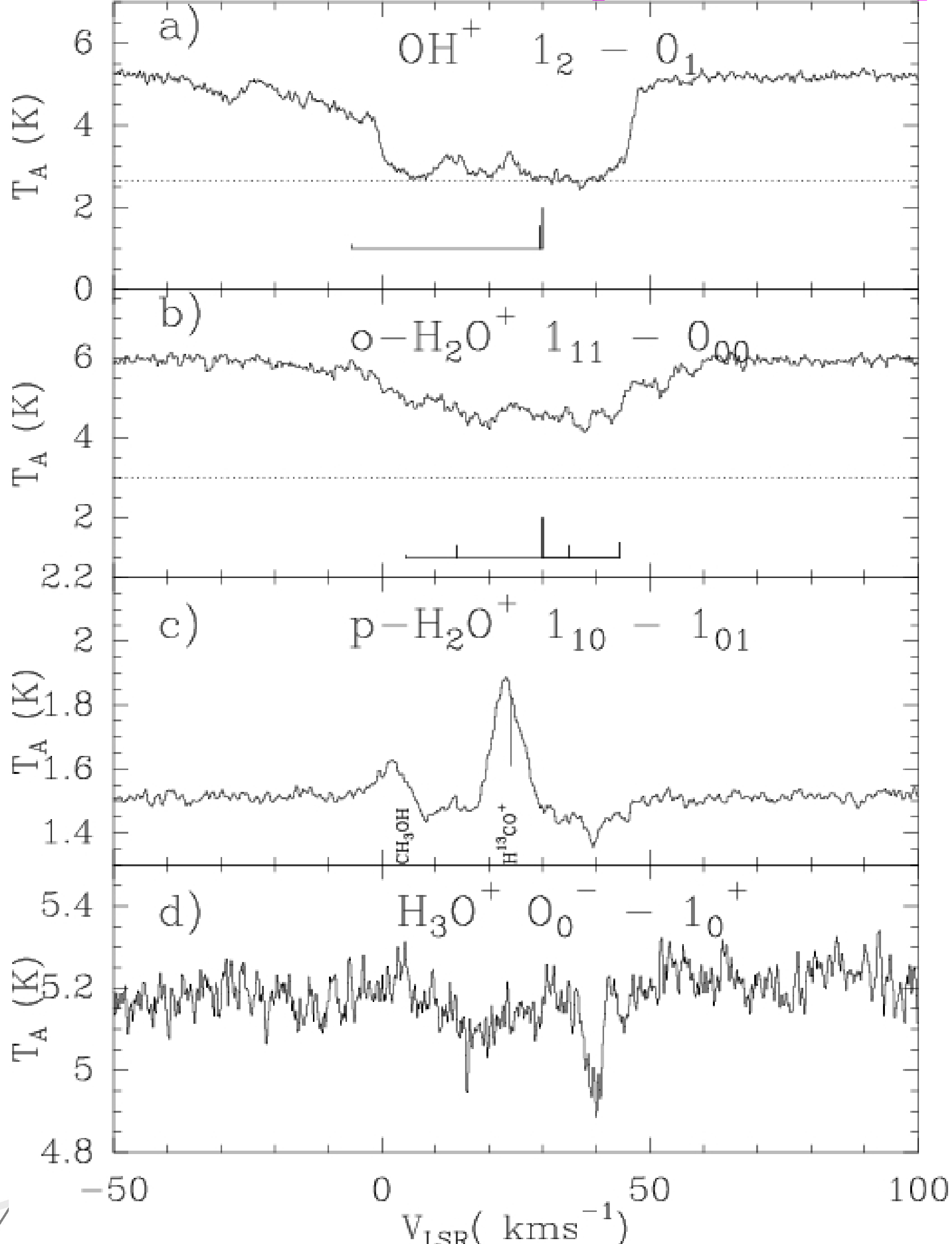


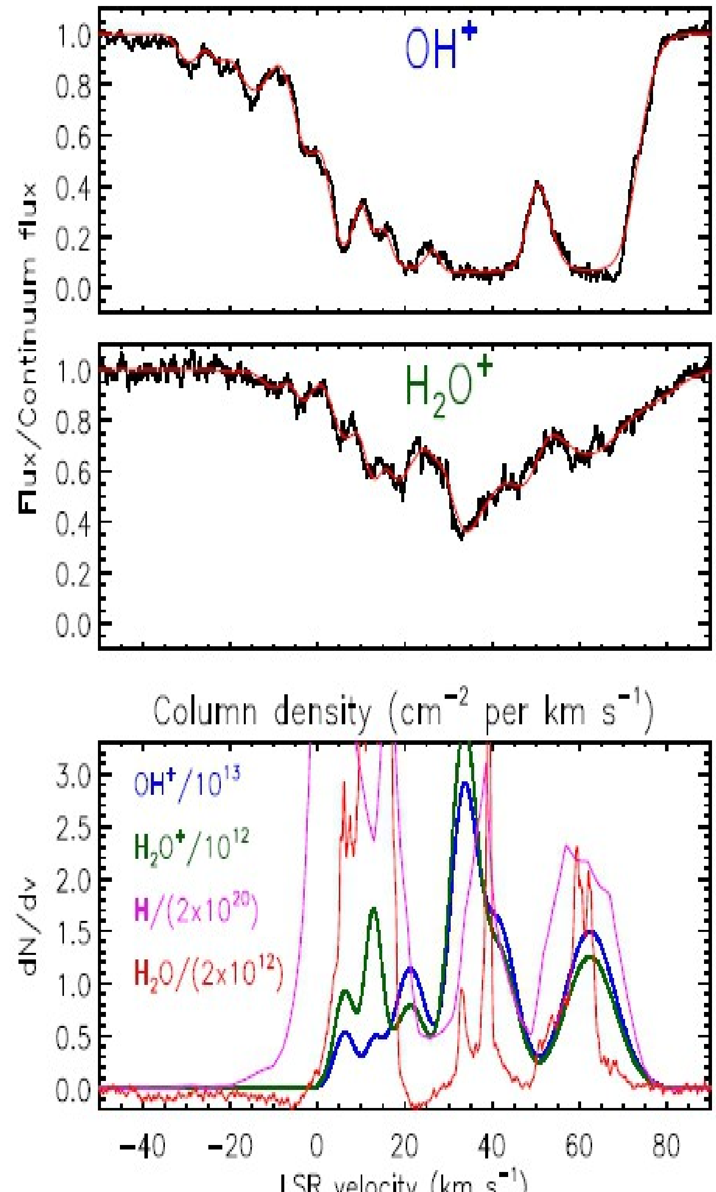
- o-H_2O^+ at 1.115 THz => Strong absorption in diffuse ISM and in outflows associated with massive YSO
- p-H_2O^+ : weaker lines 607, 633 GHz

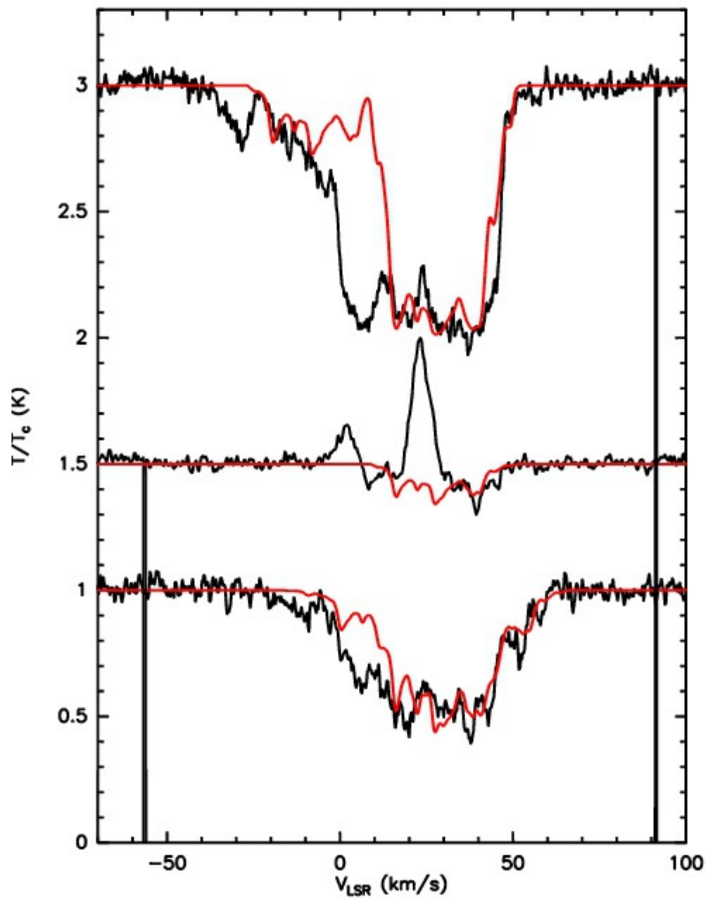
Gerin et al, Neufeld et al, Ossenkopf et al , Wyrowski et al , Benz et al ...

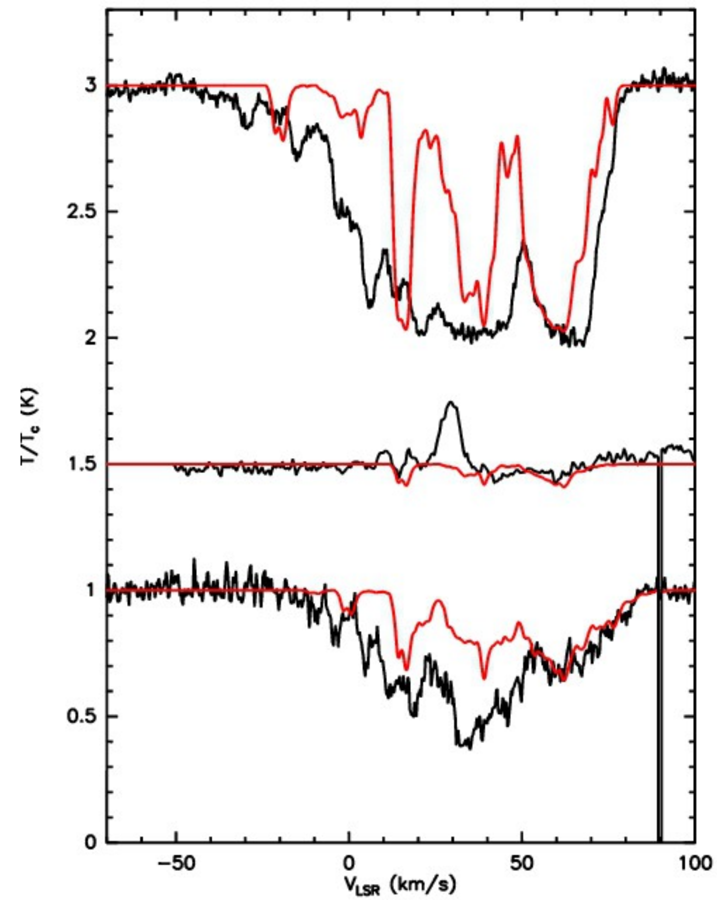
OH^+ 971 GHz

(also 909, 1033 GHz)









- 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

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

- **$OH^+/H_2O^+ > 4$**
- **=> OH^+ mostly in atomic gas with a small fraction of H_2 (< 10%)**

=> Analytic expression

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

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

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

=> OH^+ & H_2O^+ sensitive to ζ , the ionization rate due to cosmic rays $\zeta(H) = 0.6 - 2.4\ 10^{-16}\ s^{-1}$

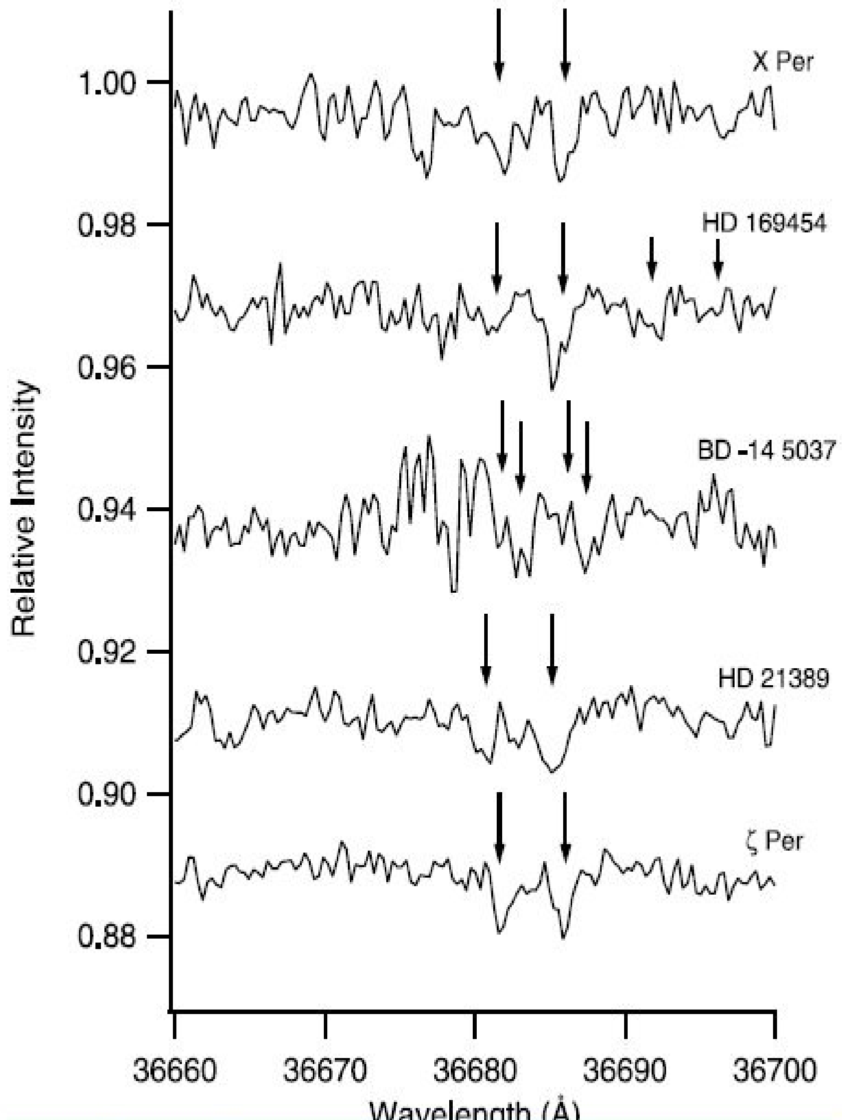
Comparison with H_3^+

H_3^+ absorption from diffuse gas

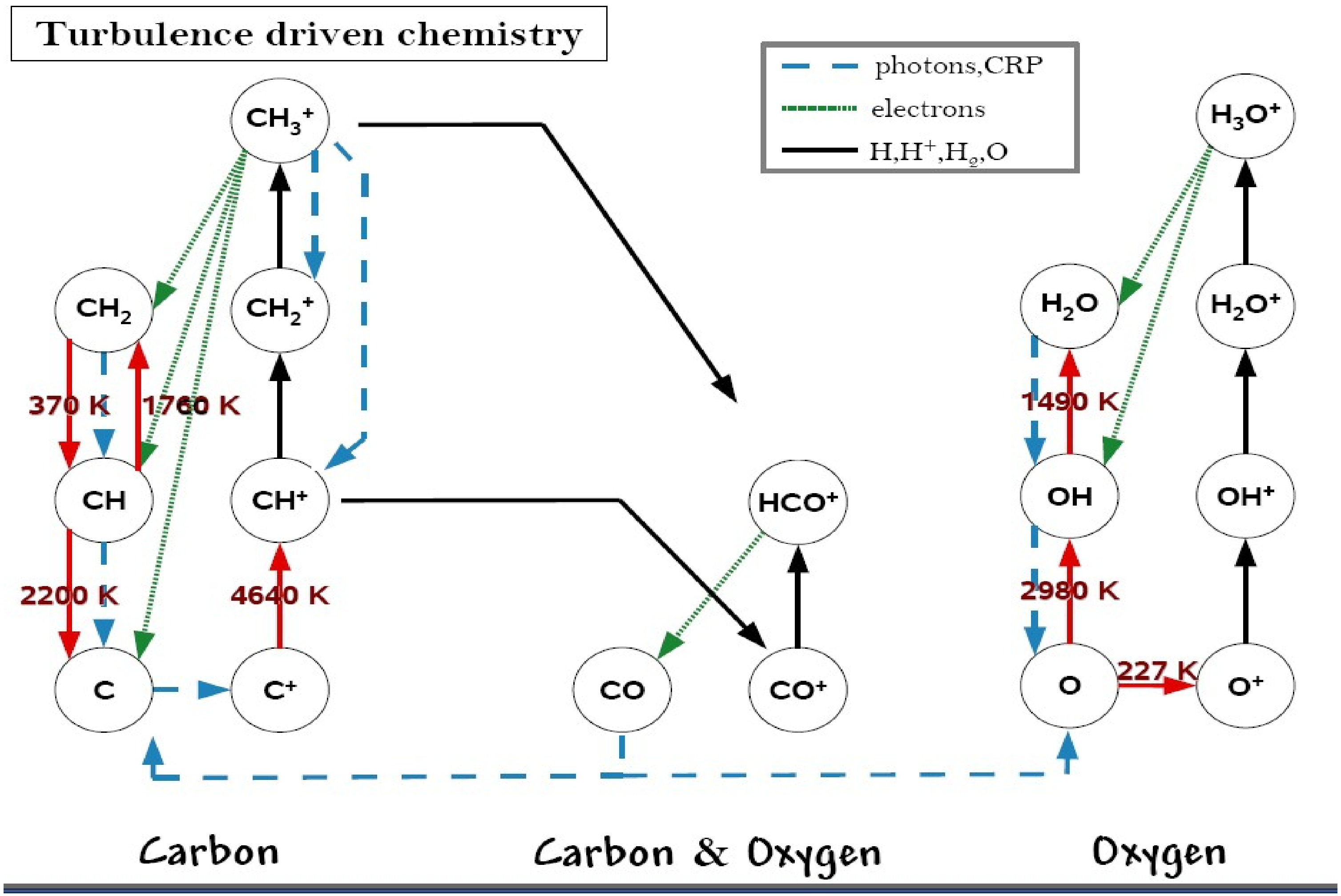
High ionization rate

ζ > 10(-16) s-1

(Indriolo et al 2007, 2009)



CH+ : a probe of energetic events dissipation of turbulence

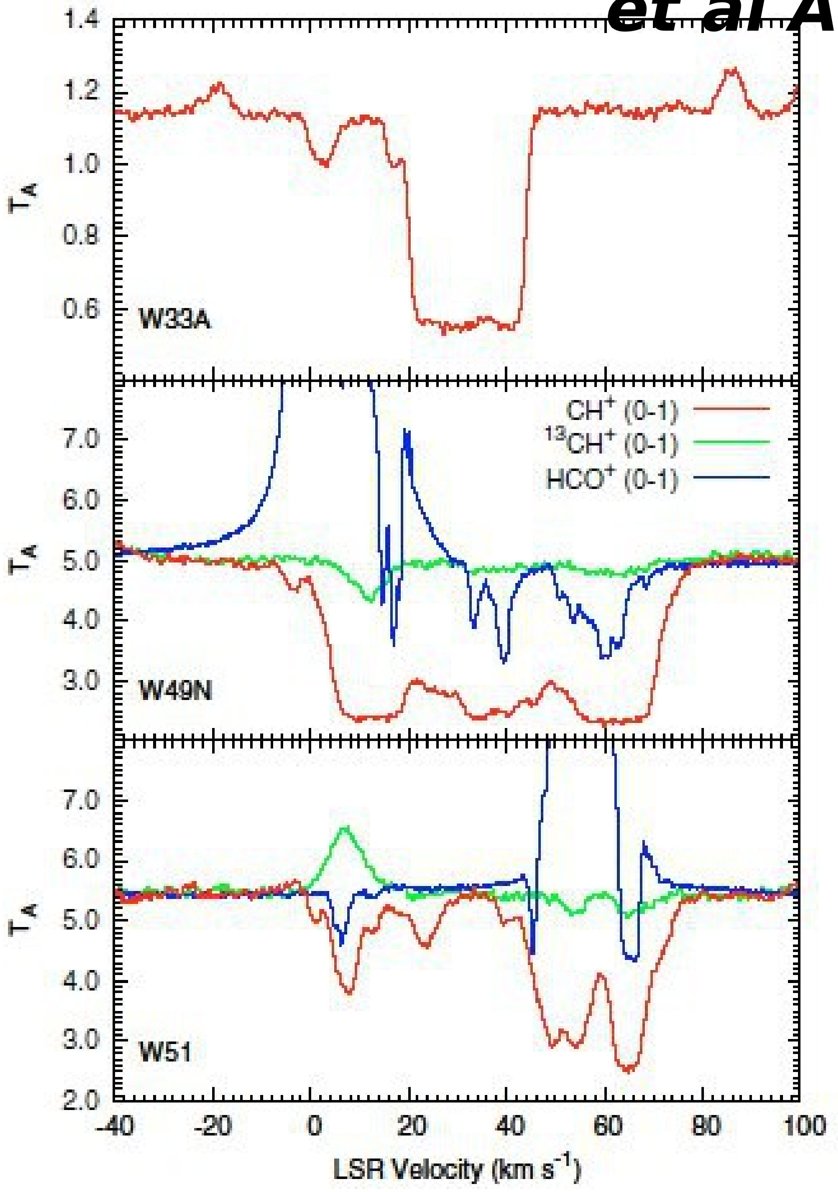


Godard et al 2009,2010

CH^+ 835 / 831 GHz

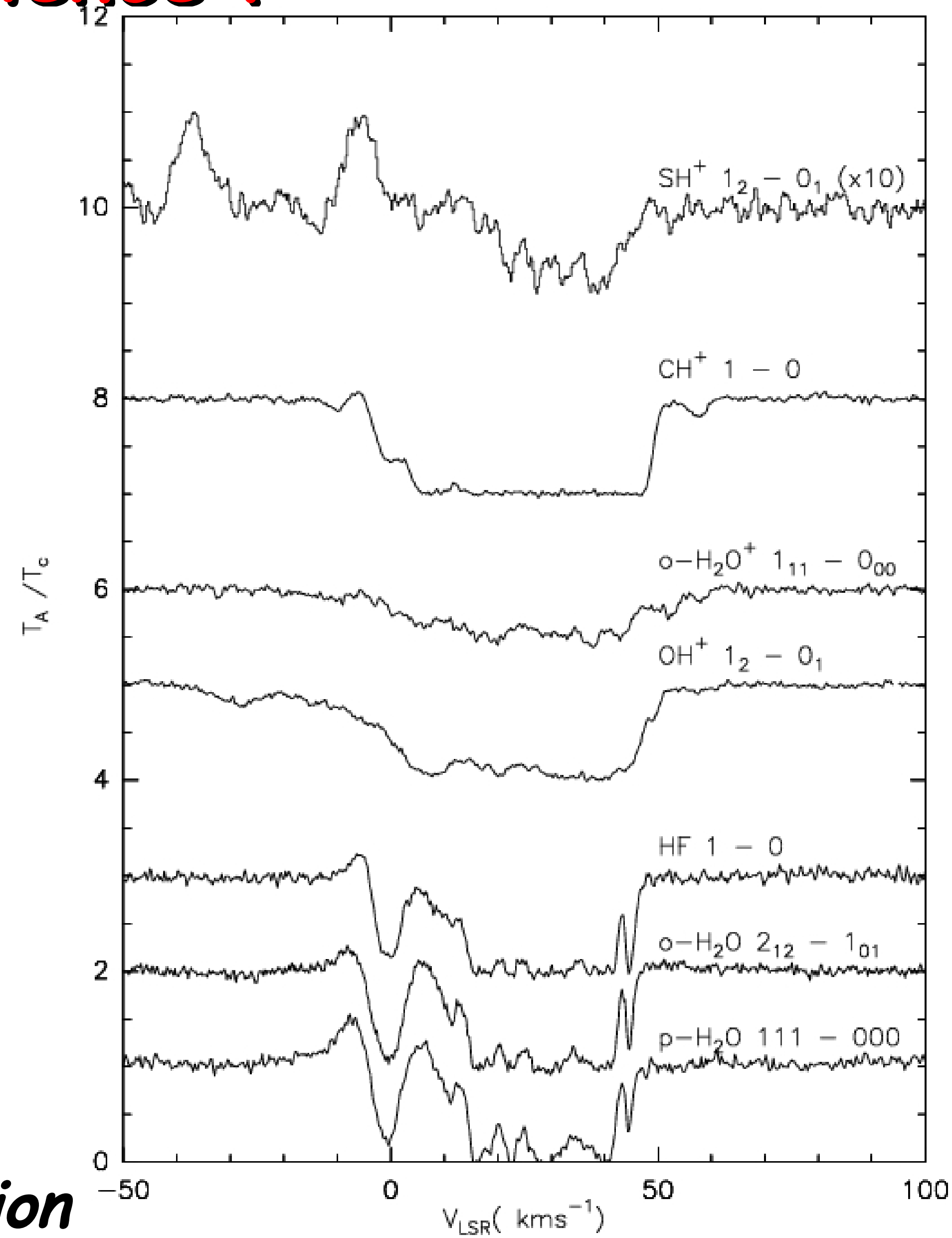
Falgarone et al A&A

- 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
- $N(CH^+) > 3 \times 10^{14}$ cm^{-2}



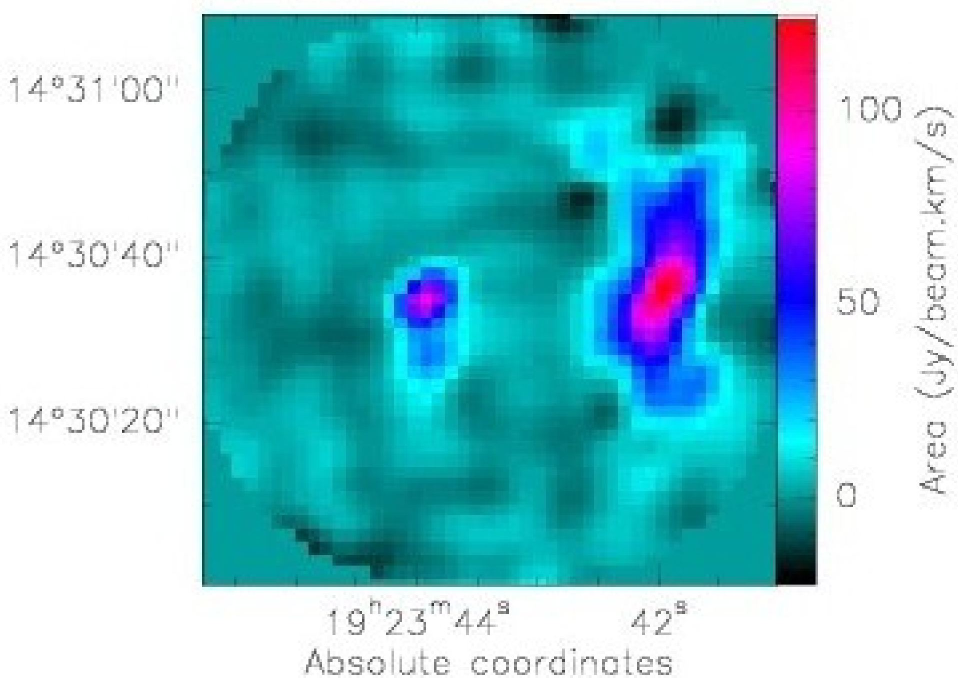
SH^+ another tracer of the dissipation of turbulence !

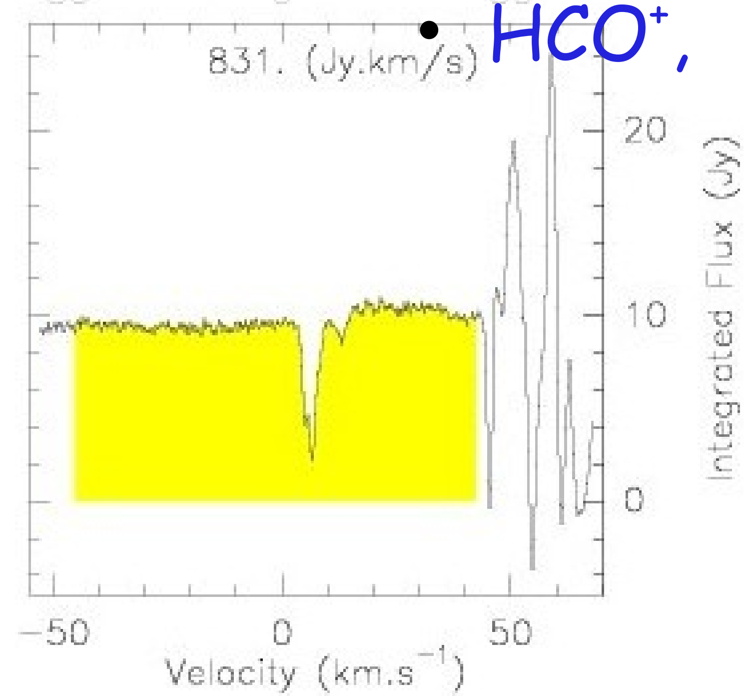
- Detection in the SgrB2 l.o.s with APEX (Menten et al)
- SH^+ produced by the reaction $S^+ + H_2$ that has E > 4000K
- CH^+ & SH^+ complementary diagnostics



Godard, Falgarone in preparation

ISM Structure : IRAM-PdBI observations





- HCO^+,

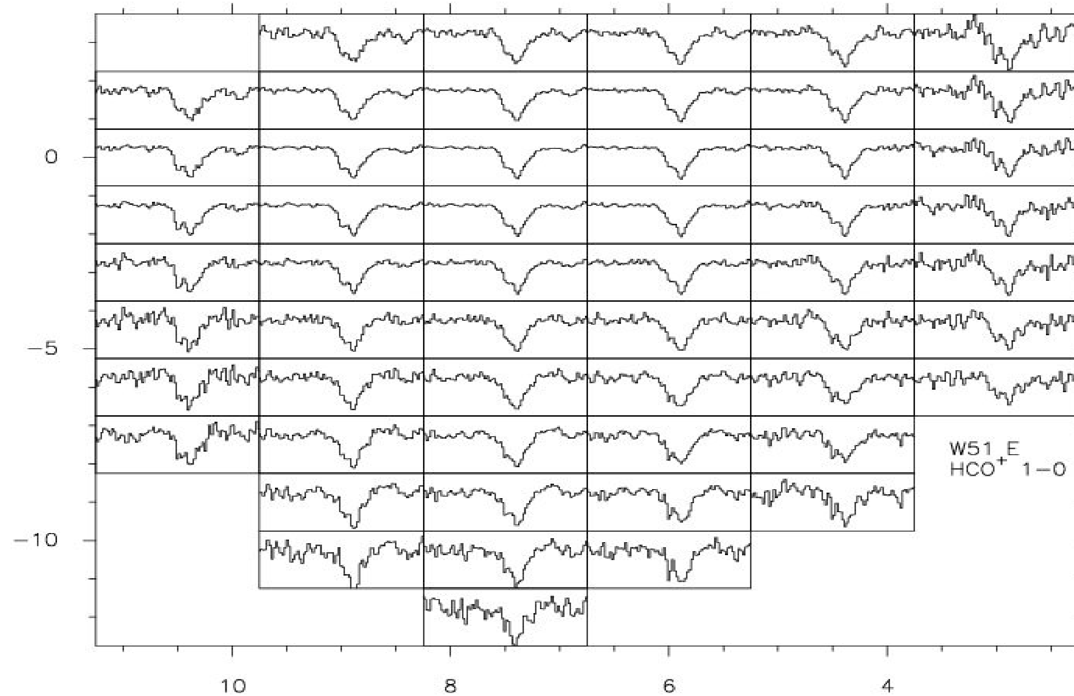
- Set-up with HCO^+, $H^{13}CO^+$, CCH, HCN, SiO & HCO simultaneously, 40 kHz .
- W51, conf D, 2 field mosaic : ~ 5" beam

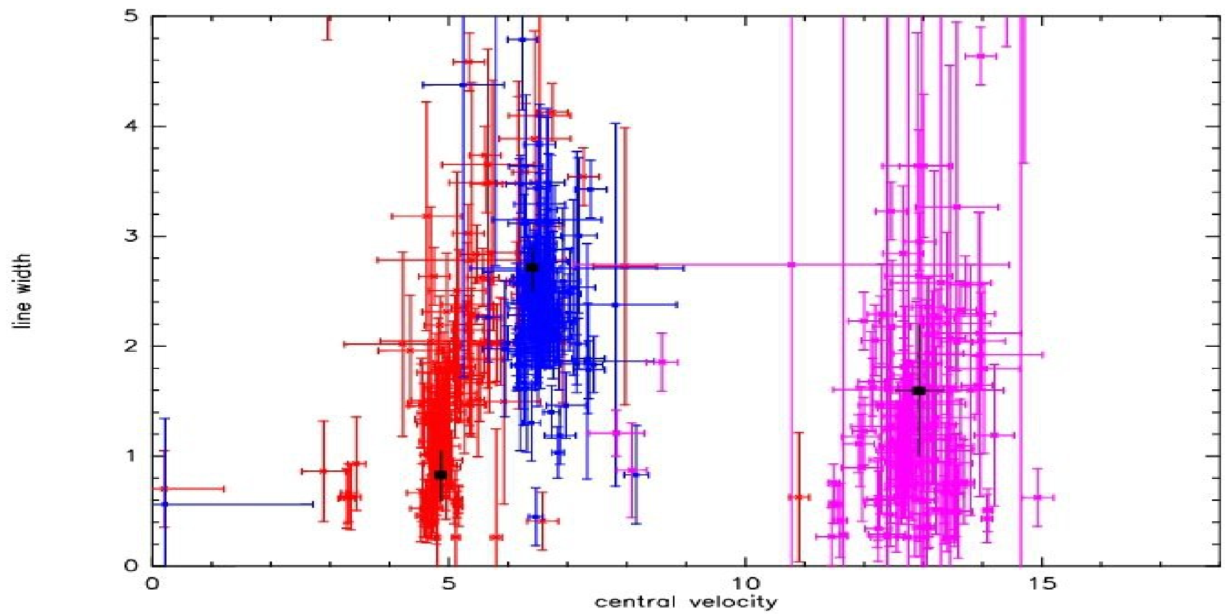
Velocity structure

3 velocity components at 5, 6 & 13 km/s

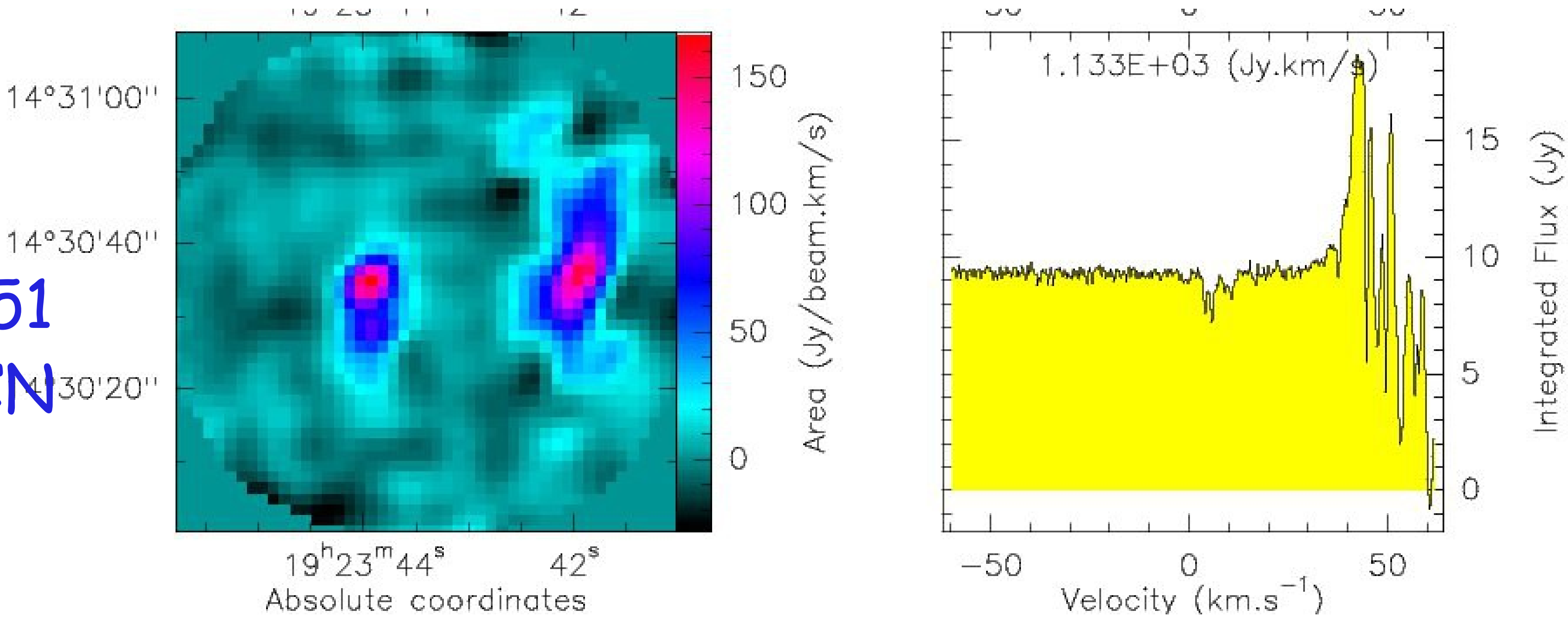
Similar profiles over the mapped area

Comparison with ≠ beams ~ OK



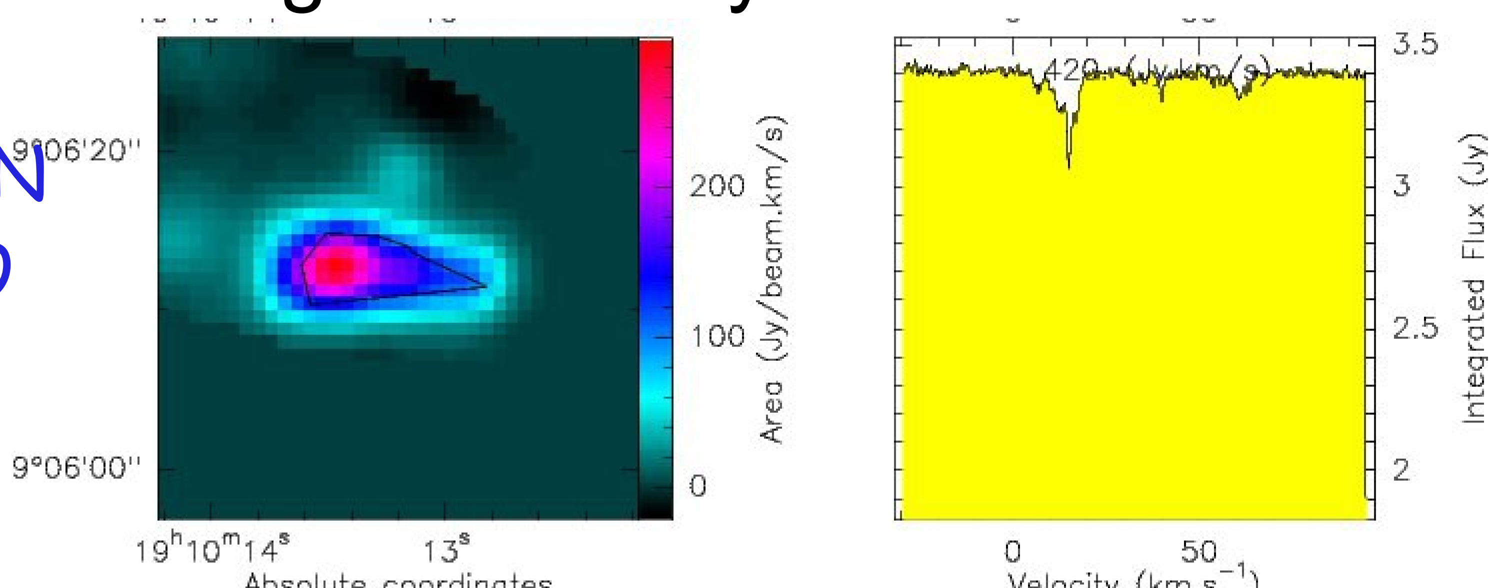


W51
HCN



High sensitivity => weak lines

W49N
HCO



Perspectives for ALMA : local universe

- Imaging of background sources => spatial structure, down to small scales
- Systematic surveys of background sources => characterization of the diffuse ISM (mass, H2 content, energetics, dynamics)
- Very weak lines/ Isotopologues
  - 1/ abundance gradients and metallicity
  - 2/ test of chemical routes : eg origin of CCH by comparison of C13CH and 13CCH ? (asymmetry in TMC1 - Sakai et al)

Perspectives for ALMA : distant universe

- Molecular lines offer sensitive probes of ISM content : gas mass, gas density, energetics, ionization rate, ionization fraction, etc.
- Molecule excitation → CMB if diffuse gas

- new spectral lines => new possibilities of testing possible drifts of fundamental constants
 (eg comparison of NH_3 rotational and inversion lines is sensitive to me/mp Henkel et al 2010)

PRISMAS

Interesting lines for absorption

Z = 0

Hydrides : H_2S, p-NH_2, p-H_2O^+, HCl, SH^+, $13CH^+$, HDO, OH^+

Other interesting absorption

HCO^+, HOC^+ CN, CCH, c-C_3H_2,HCN, HNC, H_2CO , CS, SO, etc

High redshift (z >0.4)

More hydride lines : CH, H2O,NH3, HCl, CH+, NH, NH2,OH+, H2O+, H3O+, HF

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