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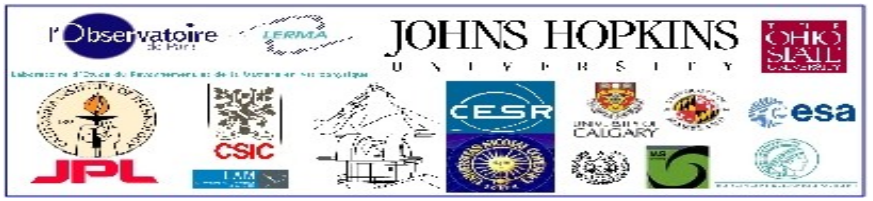
PRobing InterStellar Molecules with Absorption line Studies

Herschel brings new light on molecule formation in the ISM

Maryvonne Gerin



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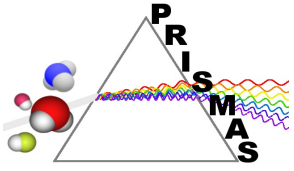
PRISMAS – Scientific Goals

How are interstellar molecules formed ?

What is the role of high temperature reactions in the formation of interstellar molecules and how are such reactions driven ?

How do grain surface reactions & solid phase processes affect the abundance of gas phase molecules ? Vice-versa how do small molecules participate in grain growth in the ISM ?



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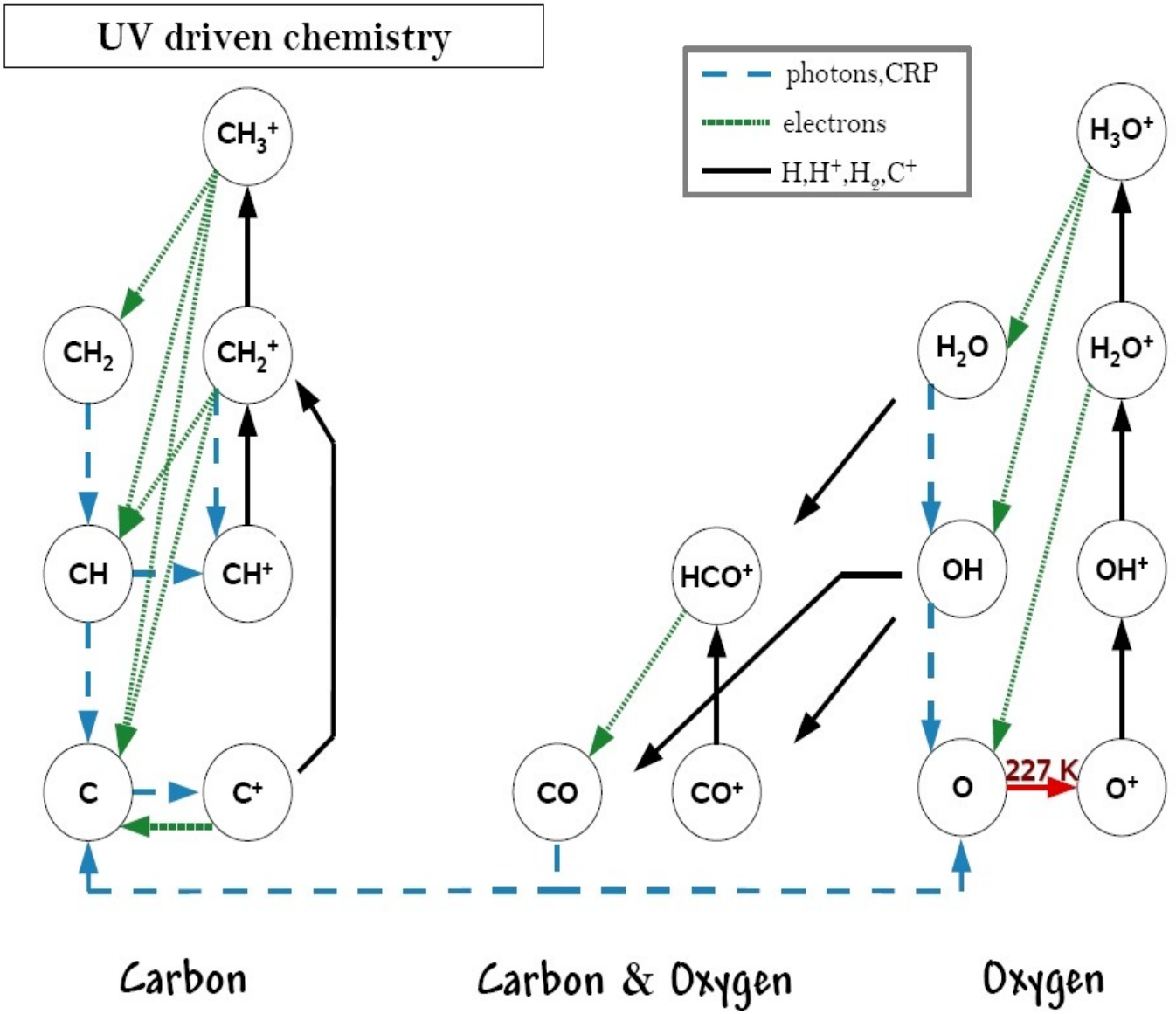
Hydrides

Scientific Goals - 1

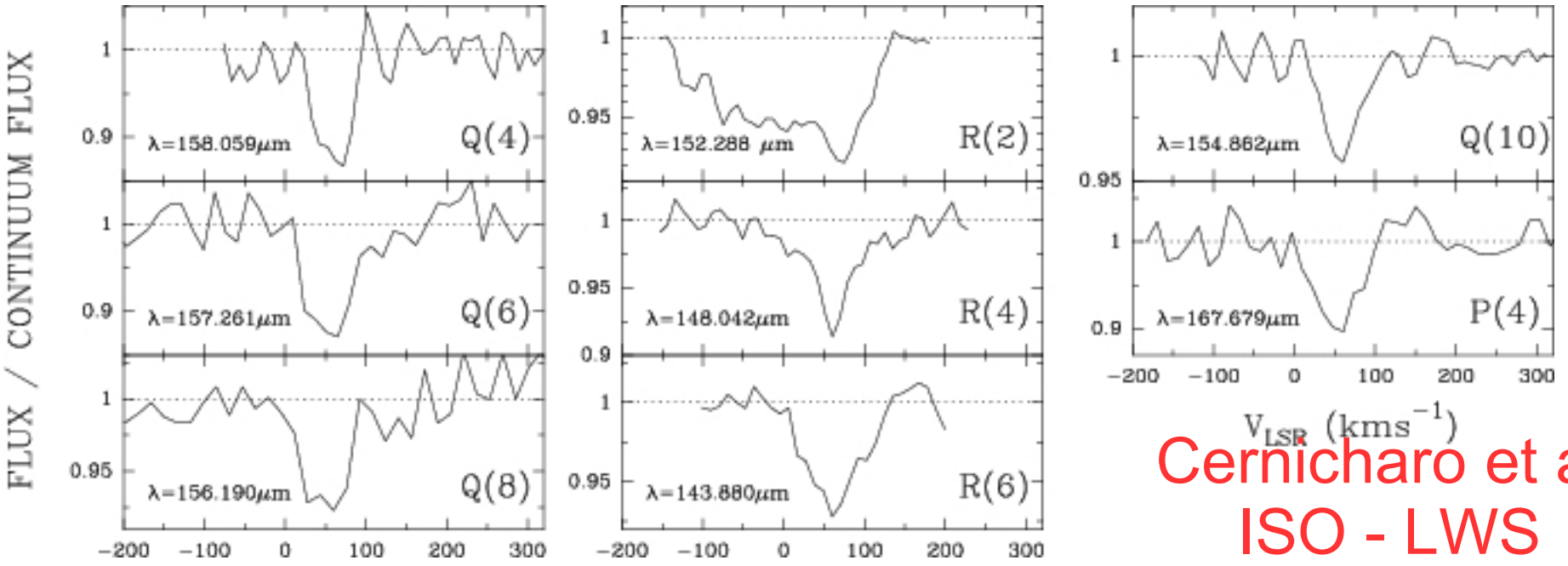
- built in the first chemical steps starting from atomic gas

- at the root of interstellar chemistry

- Diagnostics of physical / chemical processes



Scientific Goals - 2



Cernicharo et al
ISO - LWS

Carbon clusters (C_2,C_3) are detected in the diffuse ISM with visible and (for C_3) FIR spectroscopy

How are they formed ? Gas phase processes ?
Fragmentation of PAHs or carbonaceous grains ?
What about heavier clusters (C_n with n >4 ?)?

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Herschel Observations

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 transluscent gas with Av few mag in the FIR spectral range.
- targeted species

C CH, ^{13}CH, CH^+, $^{13}CH^+$, CH_2

N NH, NH_2, NH_3 (o & p), $^{15}NH_3$, ND, NH_2D, NH^+

O OH^+,H_2O^+ (o & p), H_2O (o & p), $H_2{}^{18}O$, HDO, D_2O

F HF, DF

Cl HCl, HCl^+

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Observation strategy

- Selection of 8 massive star forming regions with known interstellar clouds along the line of sight
- **HIFI** observations of ground state (+ few excited) transitions in DBS mode, single pointing
  - 3 LO tunings for each line, $\Delta v \sim 15$ km/s
    - Enable sideband assignment
    - Relatively safe in cases of spectral confusion
  - 1 'continuum' AOR for each band:
    - Fast chop, continuum stabilization
    - Strong absorption features
  - PSP1: observe all target lines in one source (W31C = G10.62-0.4)
- **PACS** scans for complete coverage of FIR spectrum

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First results

- HIFI observations obtained in March and April 2010
  - G10.6-0.4 (W31C) plus W49N, W51
  - Excellent quality : sensitivity and stability
  - Most ground state hydride lines are detected with strong absorption
  - complex profiles with mixed emission and absorption : high spectral resolution adds valuable information

=> Hydrides shape the submillimeter spectrum of the ISM

- PACS observations of W51
  - Excellent quality : strong spectral features OI, OH, CII, CO, H_2O, ...

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Oxygen hydrides G10.6-0.4

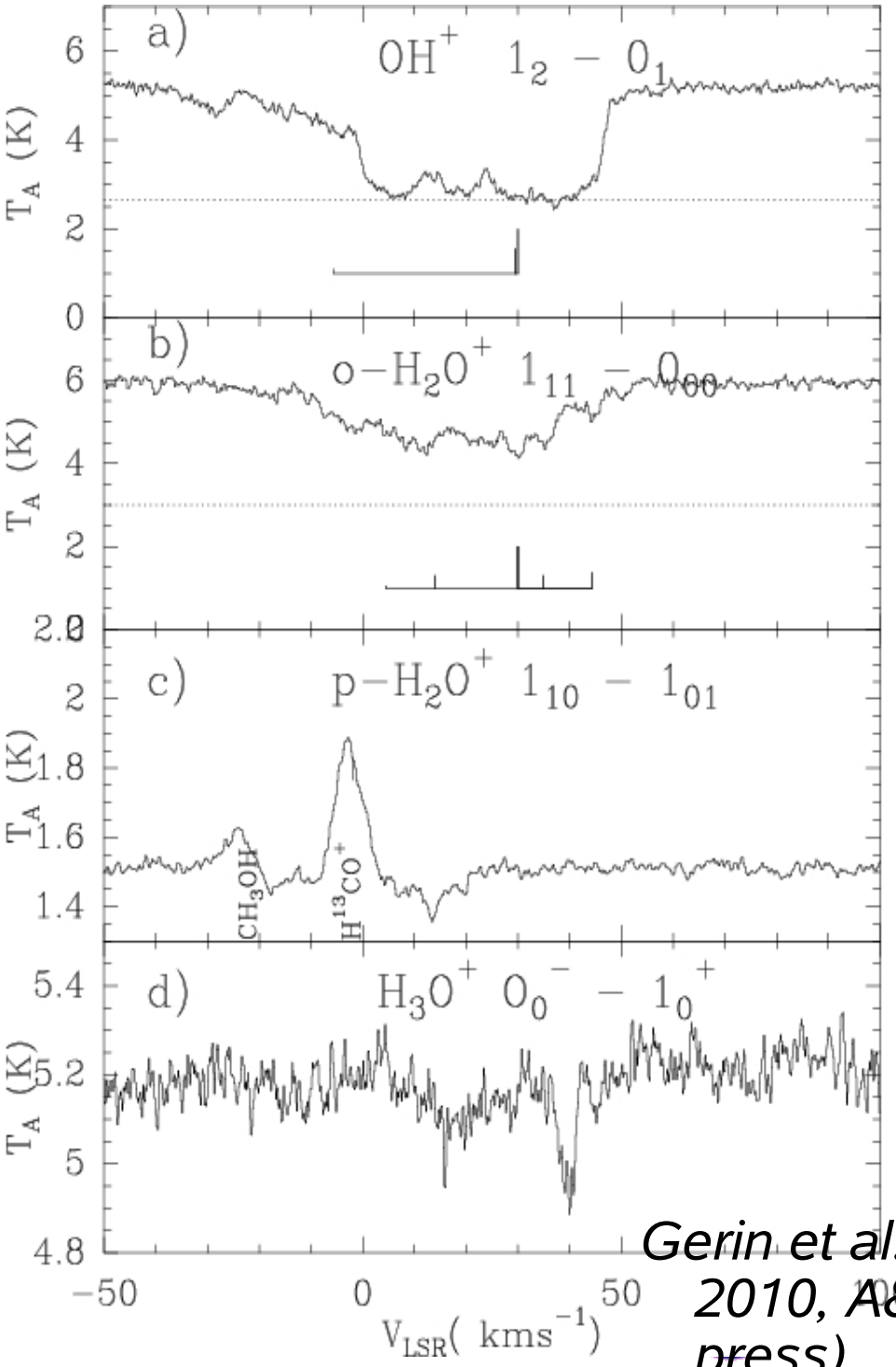
- OH^+, H_2O^+,H_3O^+: the gas phase route to H_2O

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

- Absorption from the gas along the line of sight : diffuse and transluscent matter.
- OH^+,/H_2O^+, > 4

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

- [OH+]/(H] > 10().



Gerin et al. 2010, A&A in press)

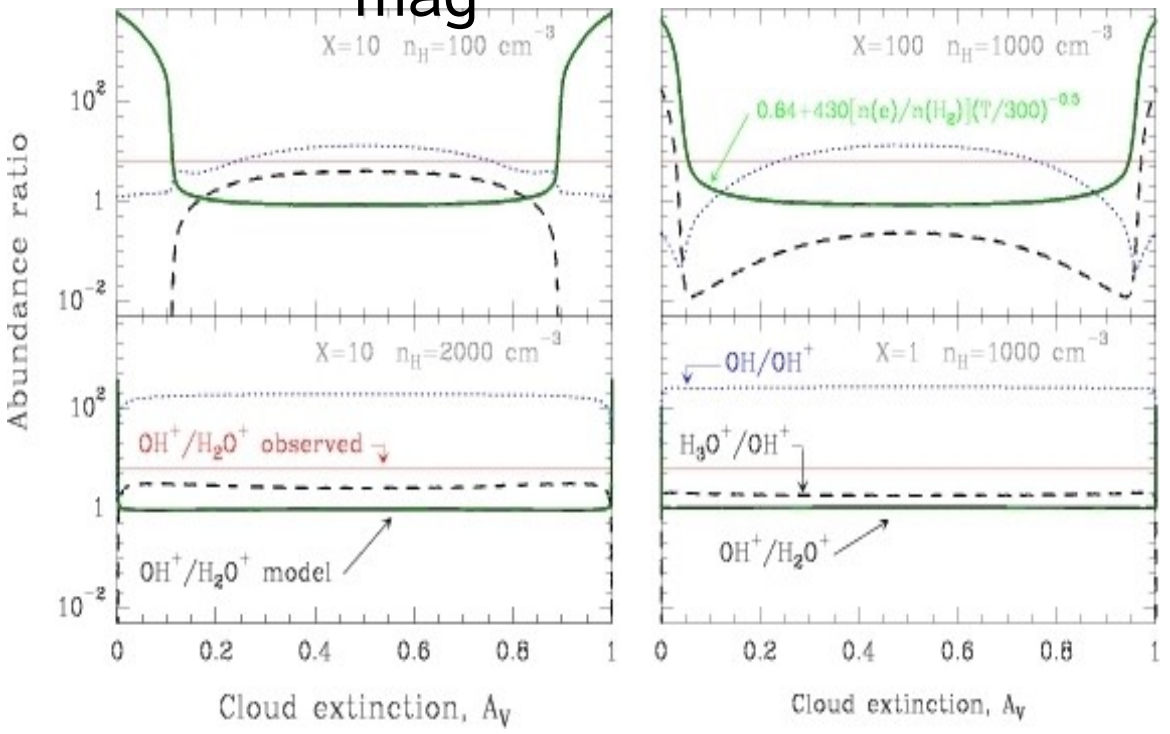
G10.6-0.4

$N(OH^+) > 2.5 \times 10^{14}\ cm^{-2}$

$N(H_2O^+) \sim 6 \times 10^{13}\ cm^{-2}$

$N(H_3O^+) \sim 4 \times 10^{13}\ cm^{-2}$

Meudon PDR model, Av = 1 mag



– Small number of reactions involved, all well known

=> Analytic expression

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

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

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

Hydrogen fluoride HF

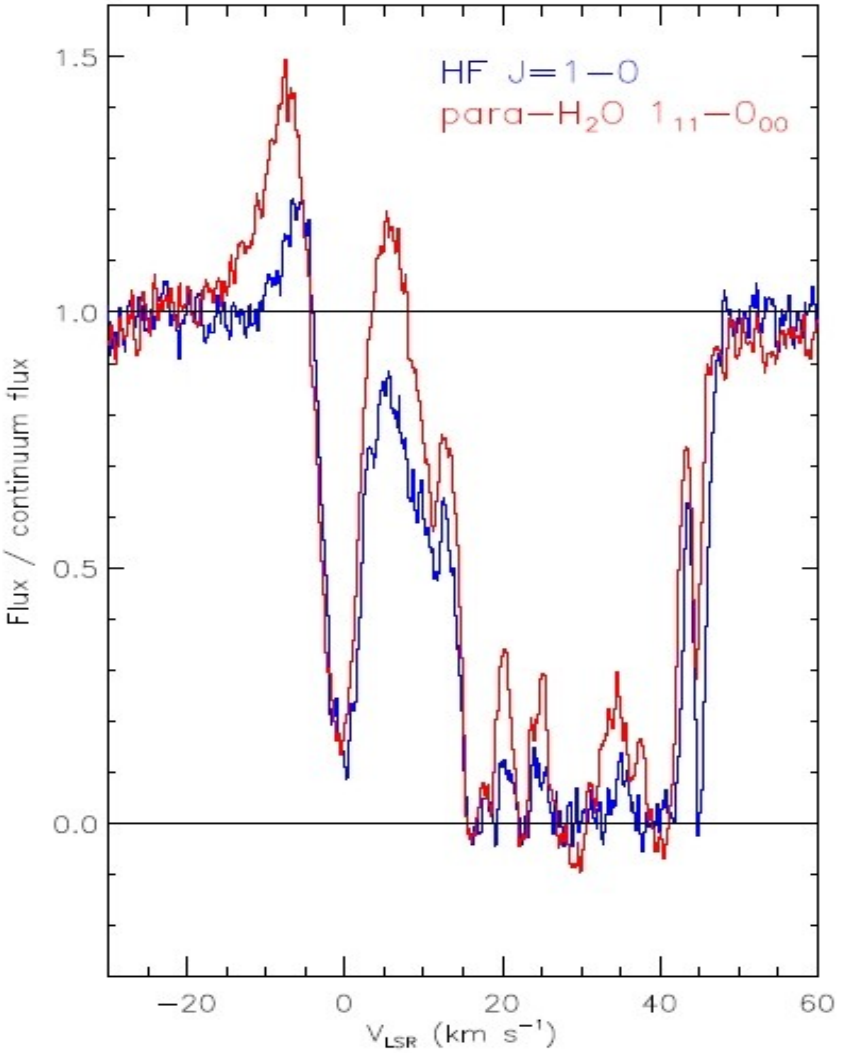
Fluorine reacts with H_2, making HF

= > 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.

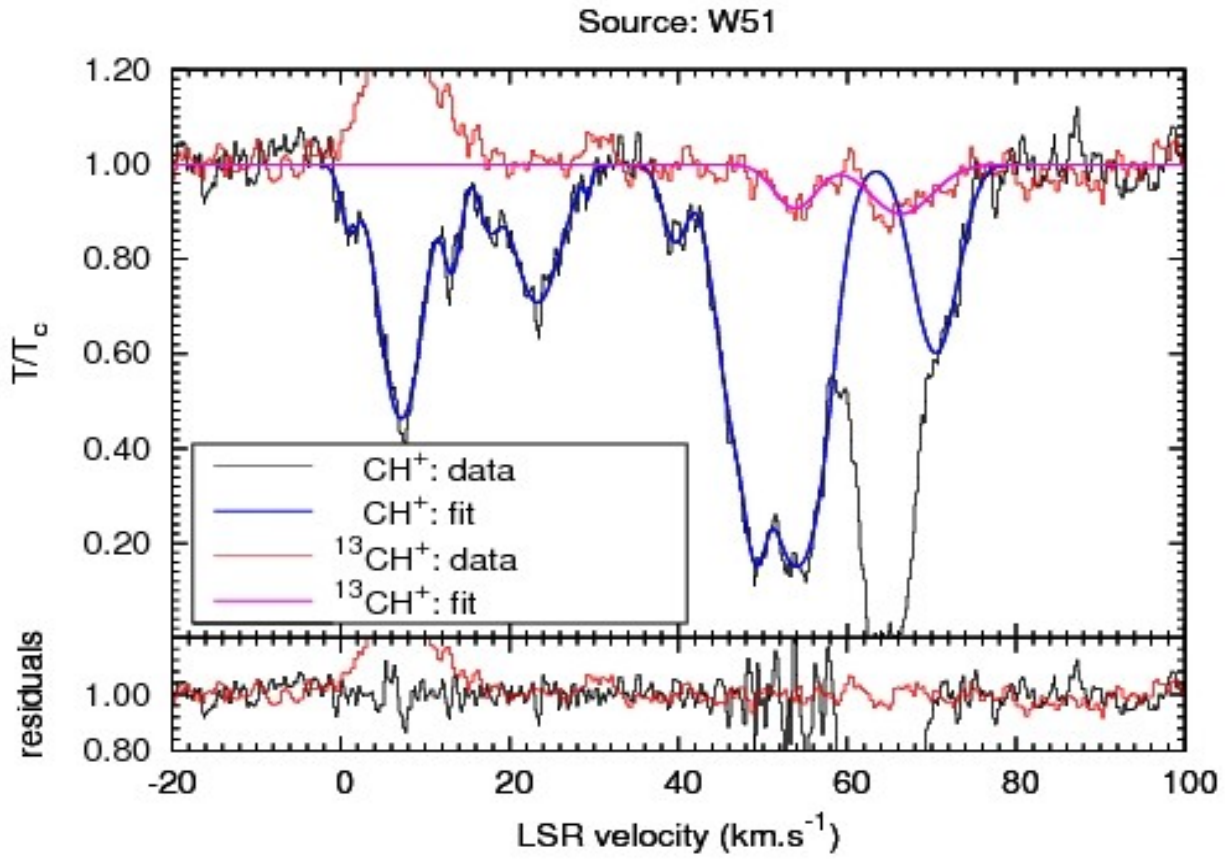
(see talk by D. Neufeld)



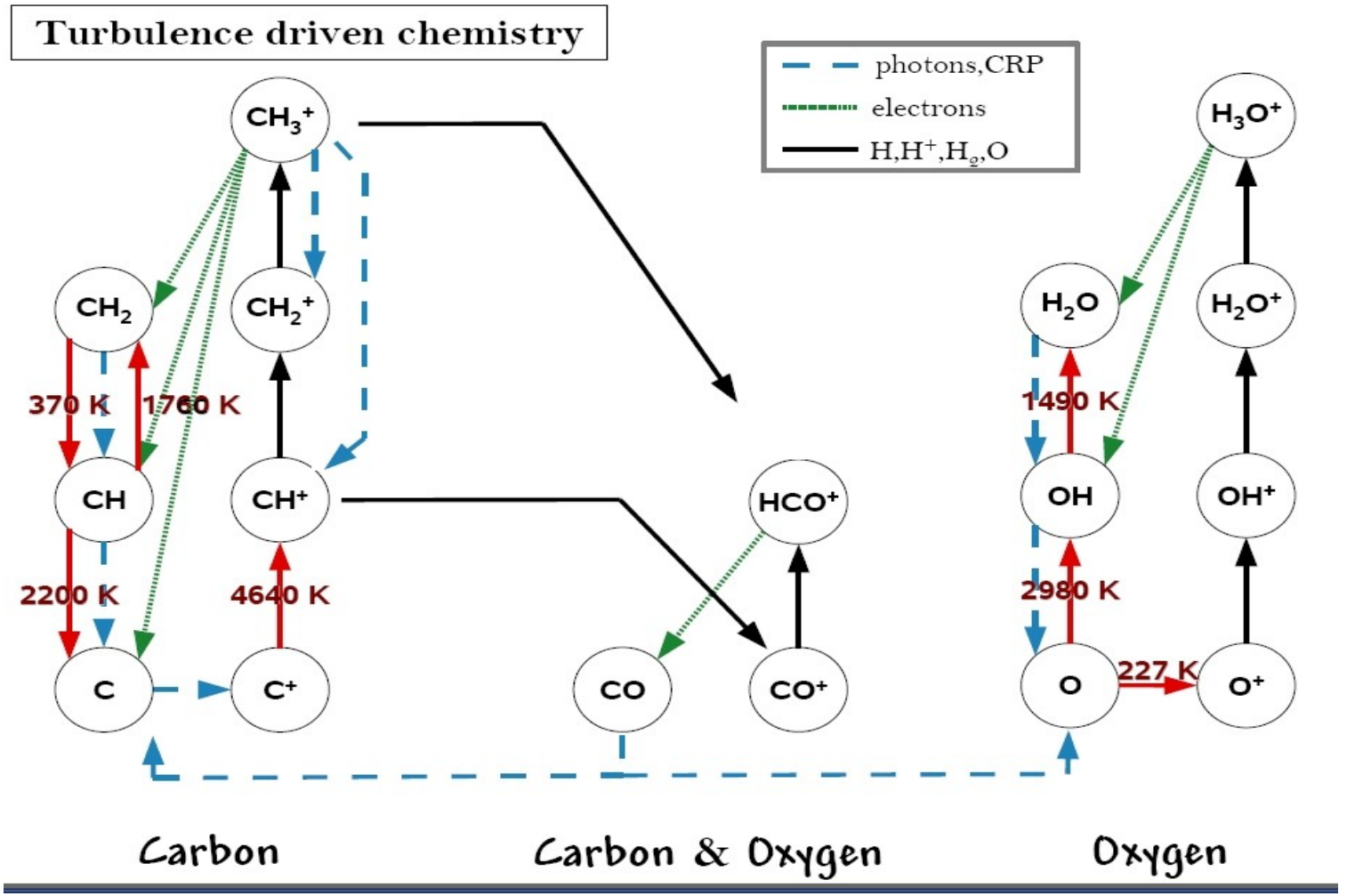
Neufeld et al 2010

Carbon hydrides : CH, CH^+

- CH^+ shows strong absorption, reaching saturation profiles, use $^{13}CH^+$ (see poster by E. Falgarone)
- Agreement with $^{13}CH^+$ data from CSO (Falgarone in prep).
- N(CH+) >3 x 10^{14} cm^{-2}



CH+ : a product of turbulence driven chemistry !



Godard et al 2009,2010

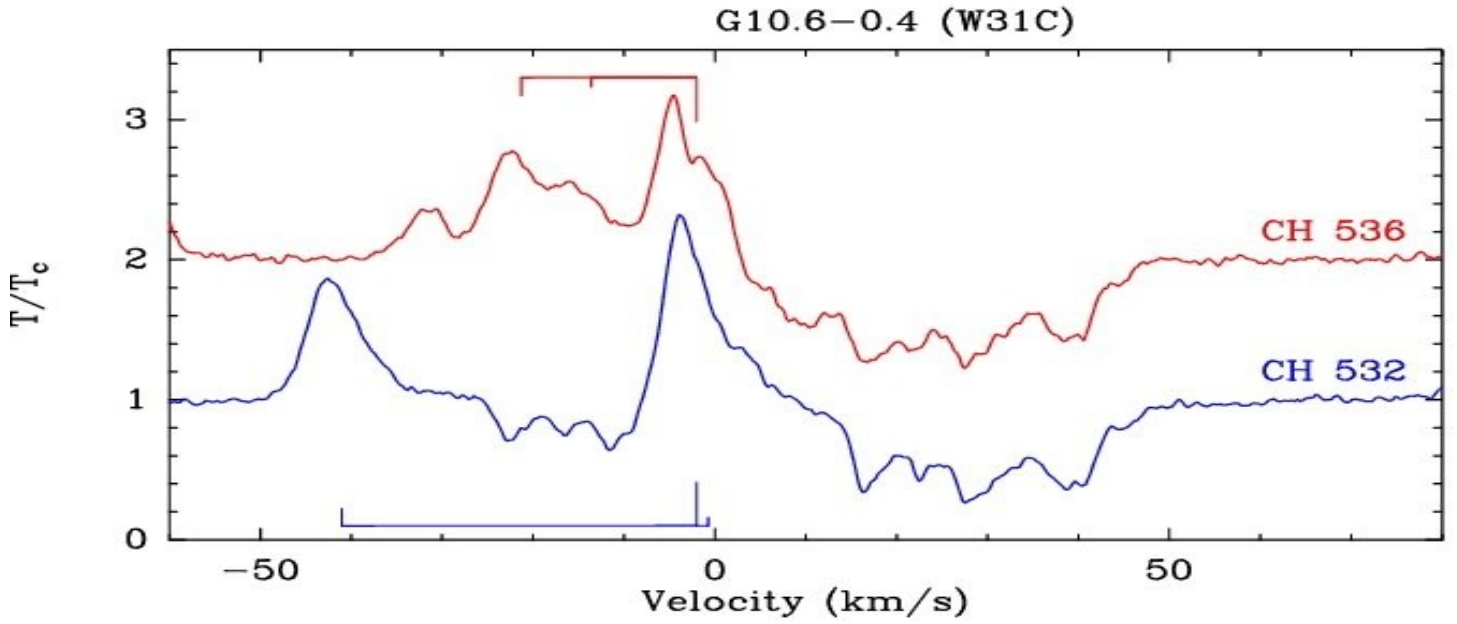
CH : complex profiles

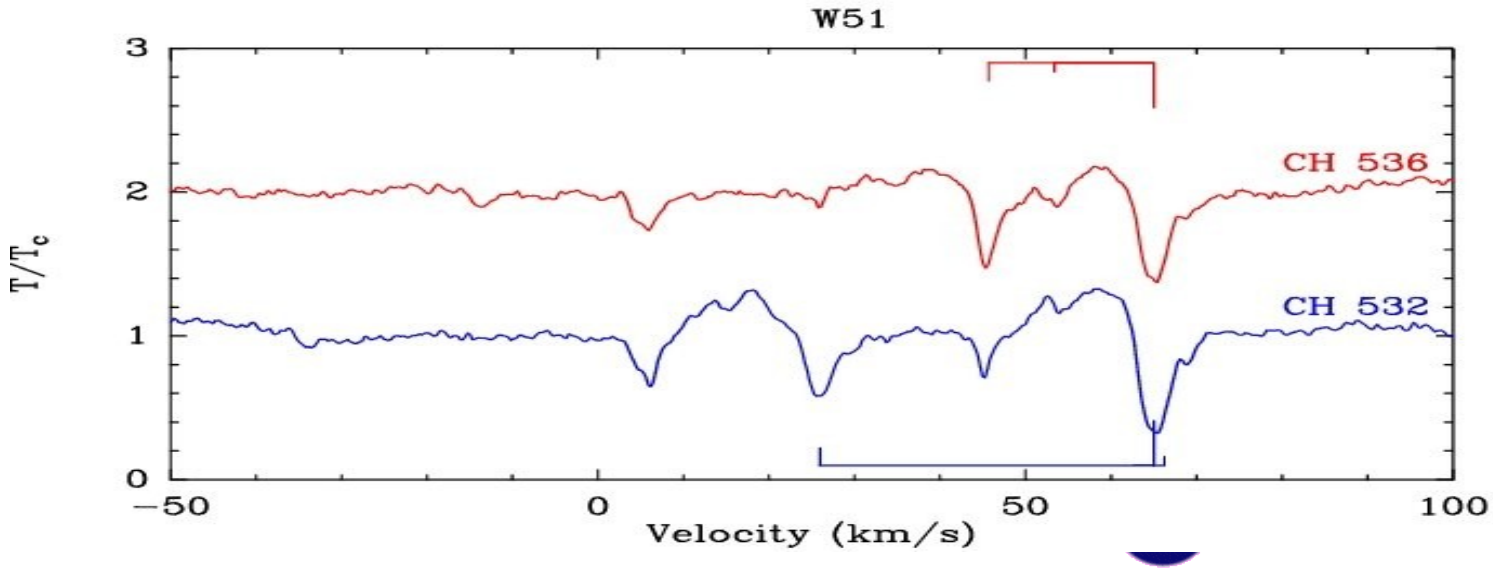
CH ground state triplet at 532 & 536 GHz.

lines not saturated

combination of emission & absorption

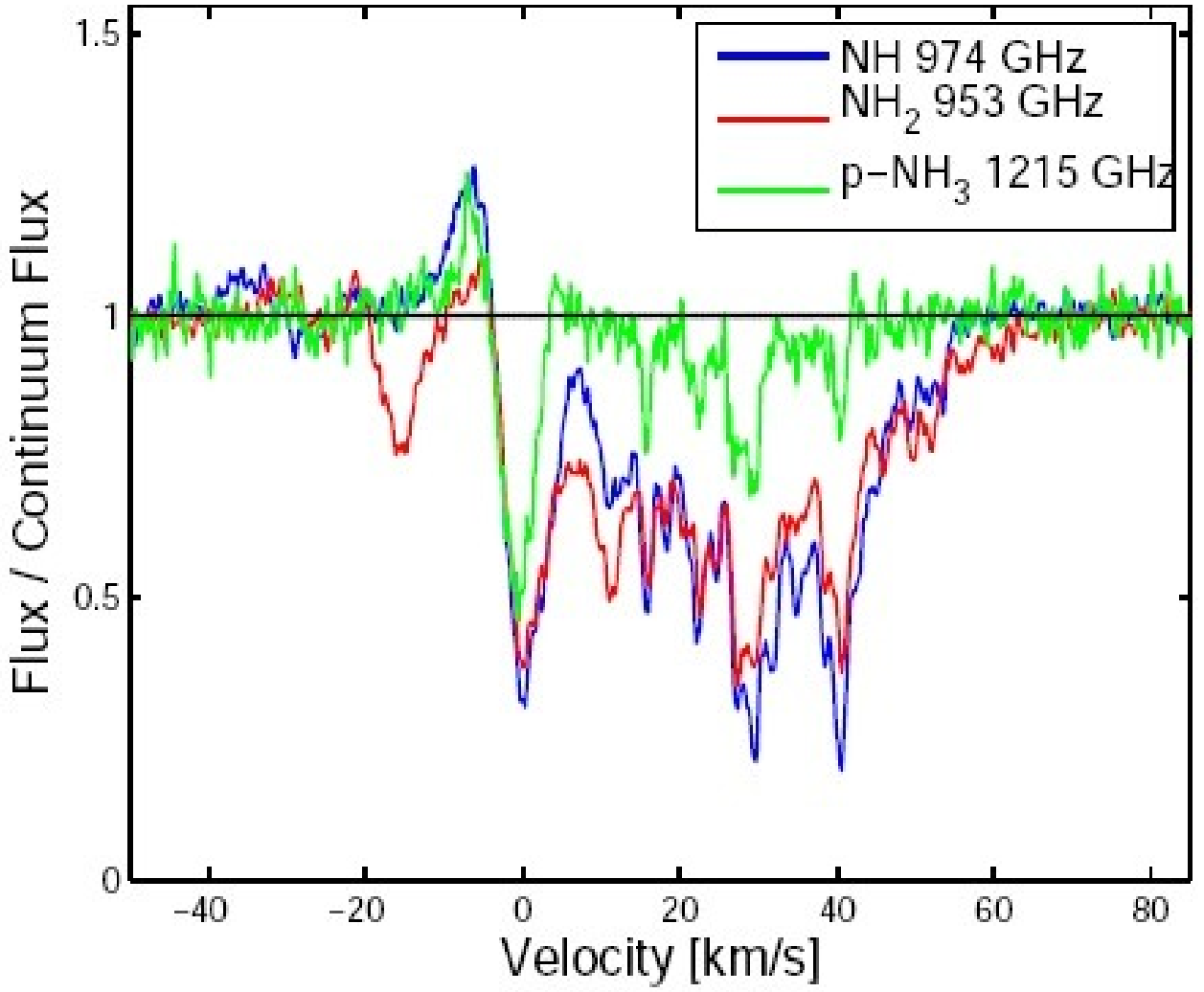
N(CH) ~ few 10^{14} cm^{-2}





Nitrogen Hydrides NH, NH_2, NH_3, NH^+

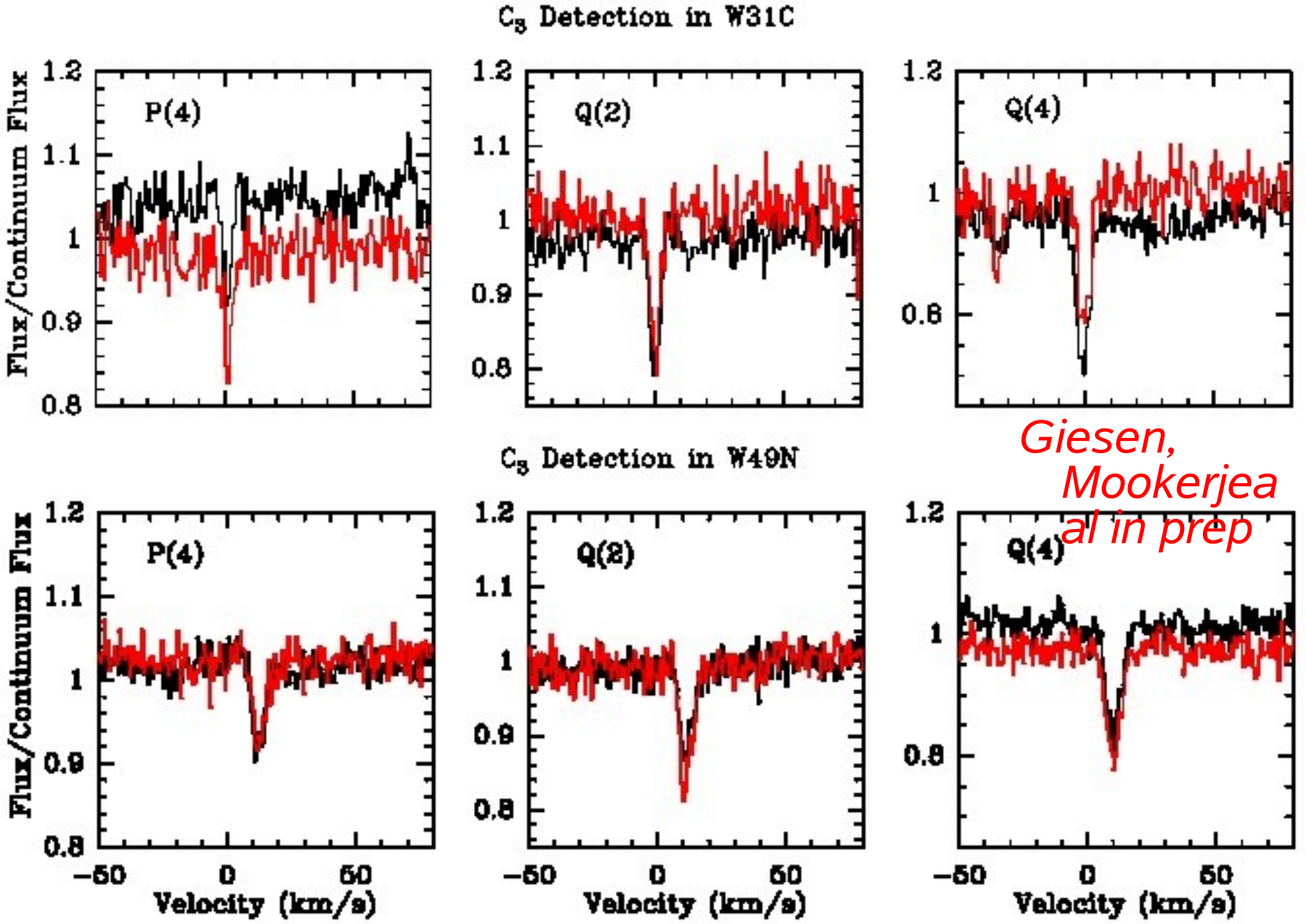
- Complex profil with multiple hyperfine components
- NH & NH_2 hav similar opacitie
- N(NH) ~ 1.5 $N(NH_2)$
- NH^+ : no detection so fa



Persson, Black et al in prep

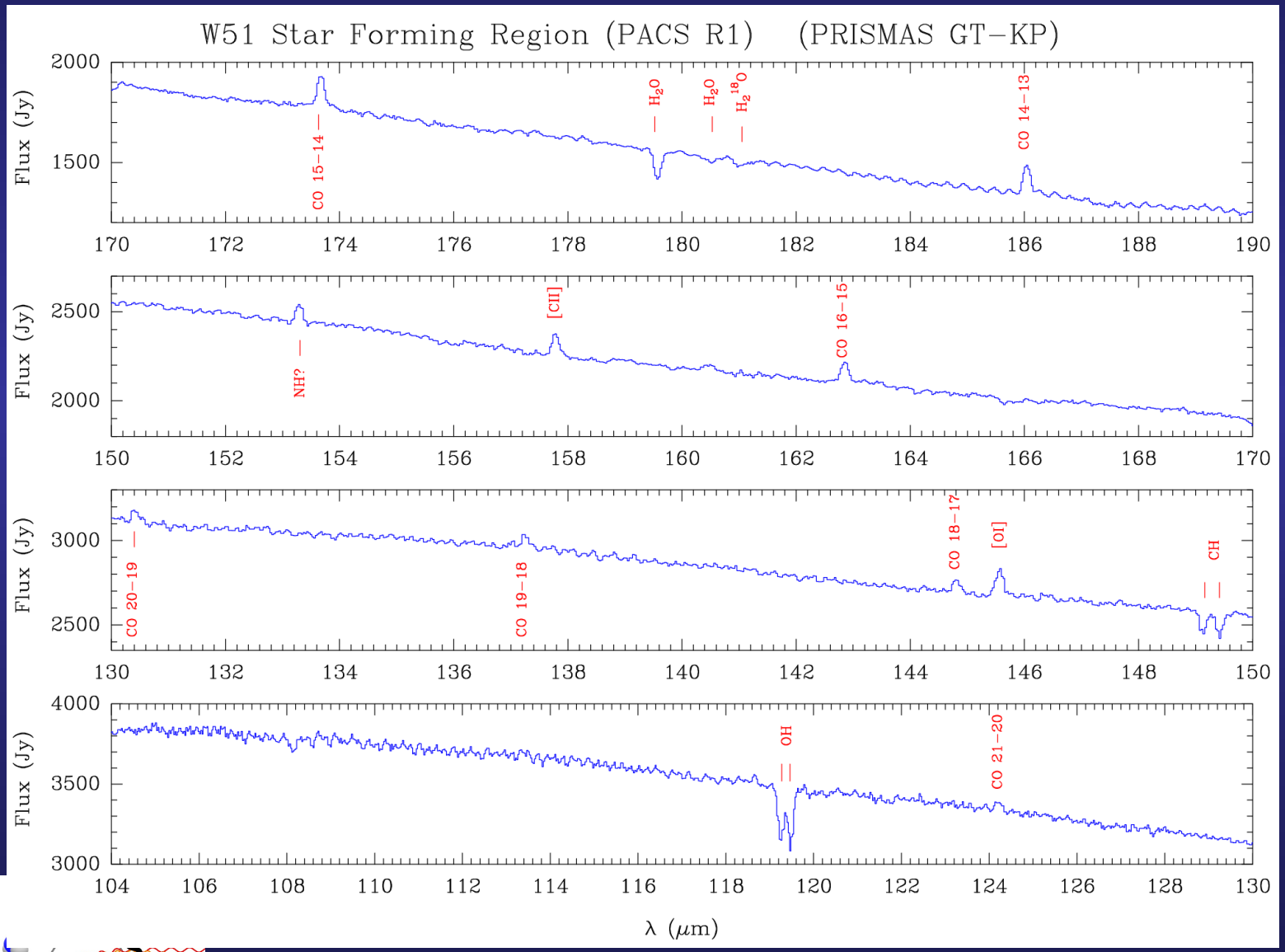
Carbon clusters

C3 ro-vibratoinal band at 1.8 THz. 3 lines



Giesen, Mookerjea et al in prep

Complementary PACS Range Scans (~57-190 μm)



Dust:
continuum

CO:
from *J*=14-13
to 21-20

H_2O:
absorption
(several)

OH:
absorption
(several)

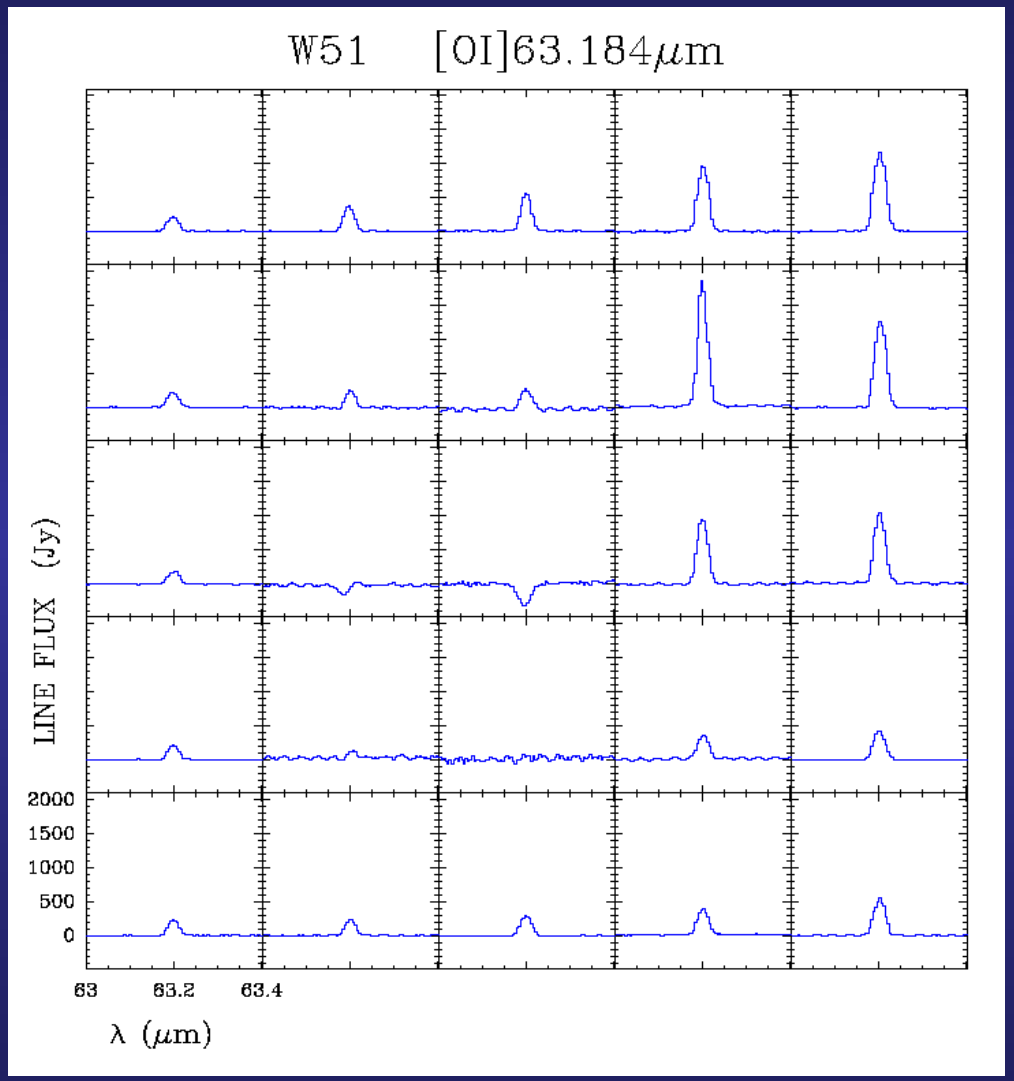
CH:
absorption

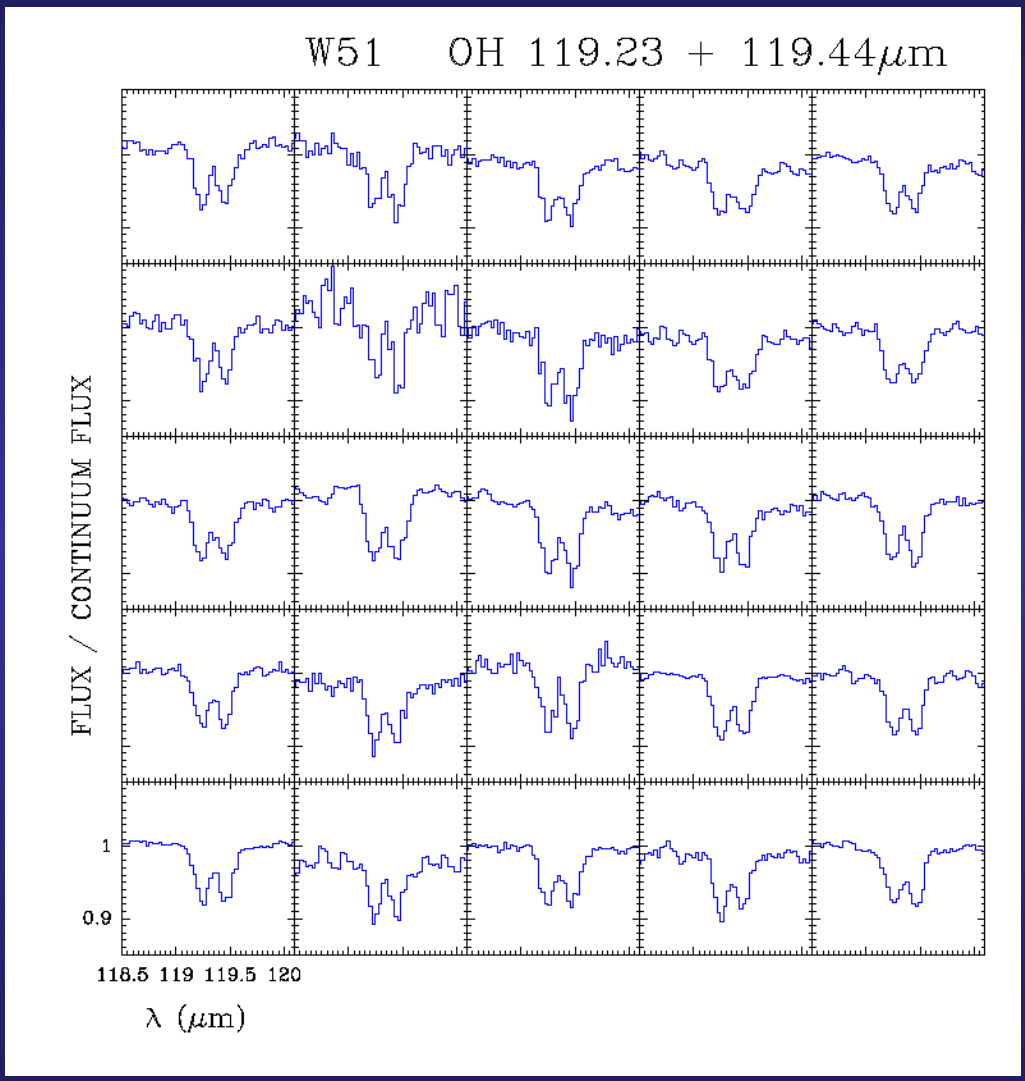
OI:
Abs/emi

CII, OIII, NII, NIII…

Example:

OI and OH line absorption/emission toward W51 IRS1





SEE POSTER P1.20

Goicoechea, Cernicharo et al. (2010, in prep.)

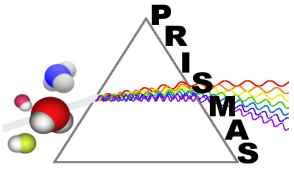
Future perspectives

Herschel gives access to new probes of interstellar medium and processes :

- Gas with small fraction of H_2 : HF, OH^+, CH^+
- Cosmic ray ionization rate : OH^+, H_2O^+
- Dissipation of turbulence CH^+, H_2O^+, H_3O^+,
- ...

Valid for local ISM and throughout the Galactic plane

=> Strong spectral features in external galaxies including high redshift objects ?



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