Herschel observations of interstellar hydrogen fluoride

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Outline

- Introduction: the unique thermochemistry of fluorine
- Herschel/HIFI observations of interstellar hydrogen fluoride
- Future prospects: HF as a surrogate for molecular hydrogen

Dissociation energy of the diatomic hydrides (eV)

H_2 4.48							
LiH 2.41	BeH 2.24	BH 3.44	CH 3.49	NH 3.22	OH 4.39	HF 5.87	
NaH 2.04	MgH 1.99	AlH 2.95	SiH 2.98	PH 2.87	SH 3.65	HCl 4.43	
KH 1.87	CaH 1.77	GaH 2.78	GeH 2.73	AsH 2.66	SeH 3.11	HBr 3.76	

ScH 2.09	TiH 2.08	VH 1.67	CrH 2.27	MnH 1.27	FeH 1.59	CoH 1.97	NiH 2.57	CuH 2.64	ZnH 0.83

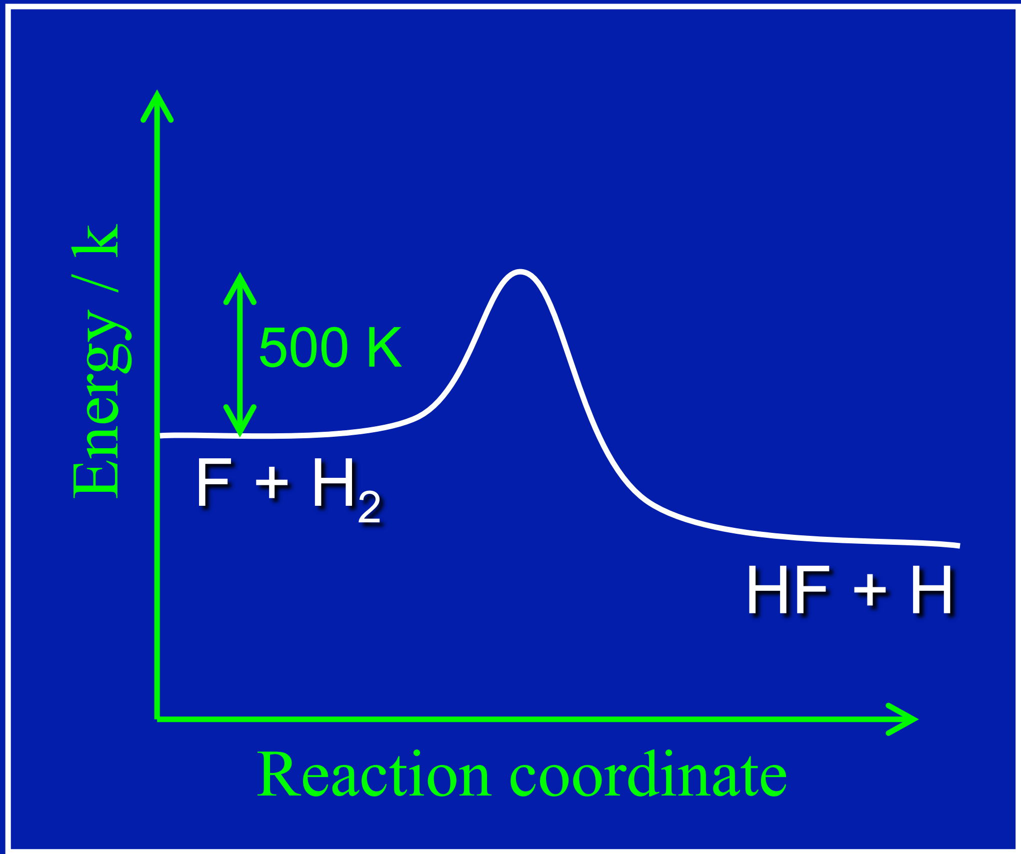
Neufeld and Wolfire 2009, ApJ

Reaction of H_2 with F

One of the most extensively studied bimolecular chemical reactions

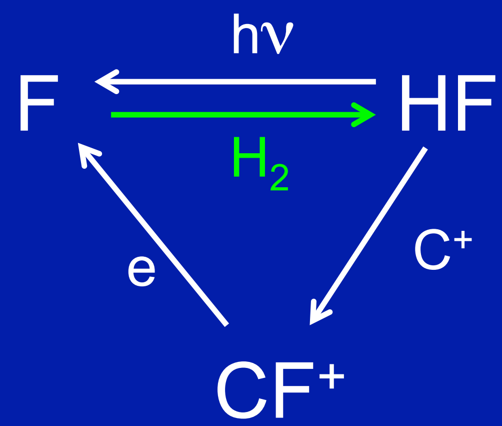
Room temperature experiments suggest a barrier, $E_A/k \sim 500$ K

Theory suggests a substantial tunneling probability at low T



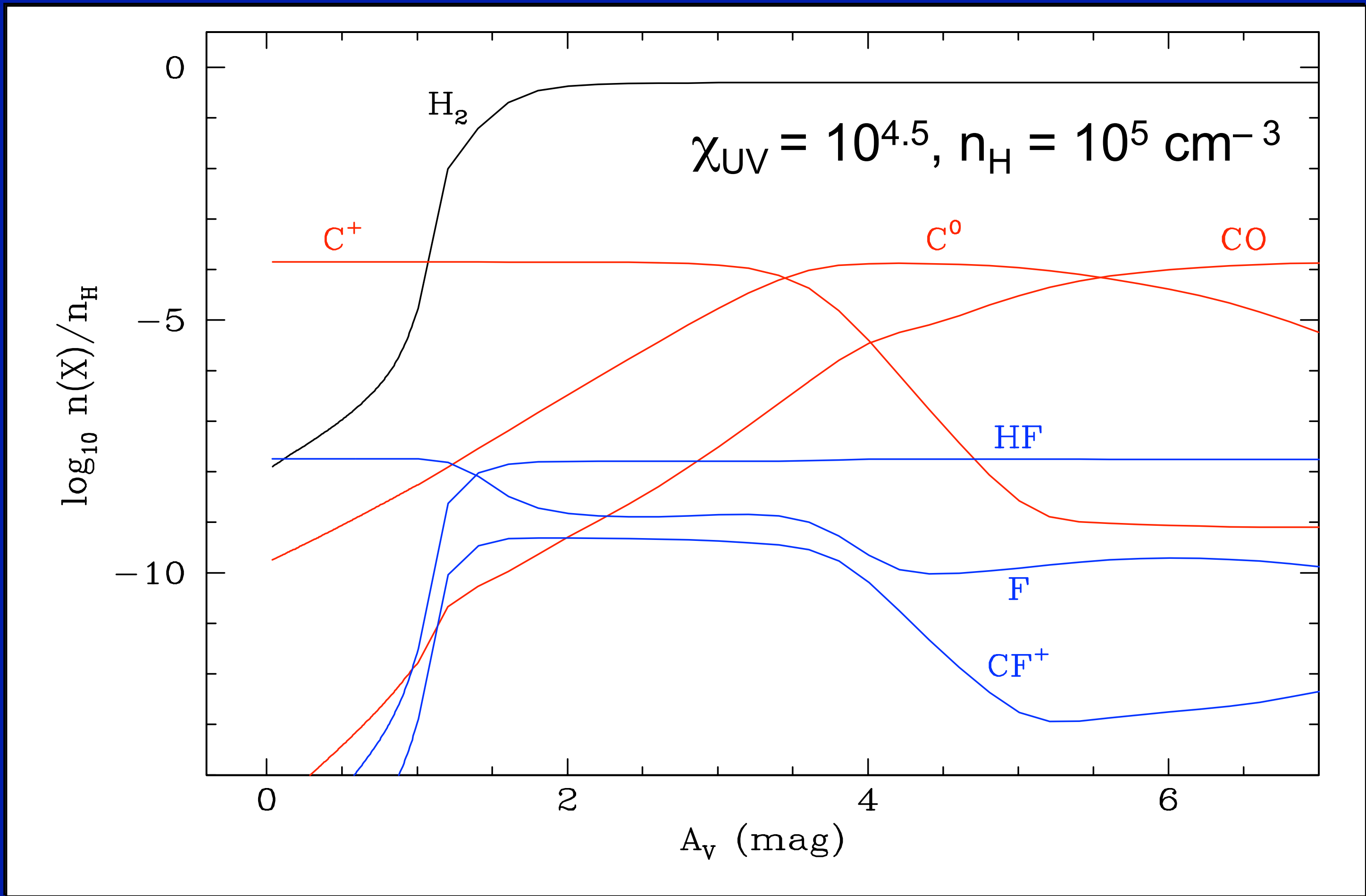
Chemistry of interstellar fluorine

- Fluorine chemistry is very simple



Predicted abundance profiles
(Neufeld, Wolfire & Schilke 1995)

UV



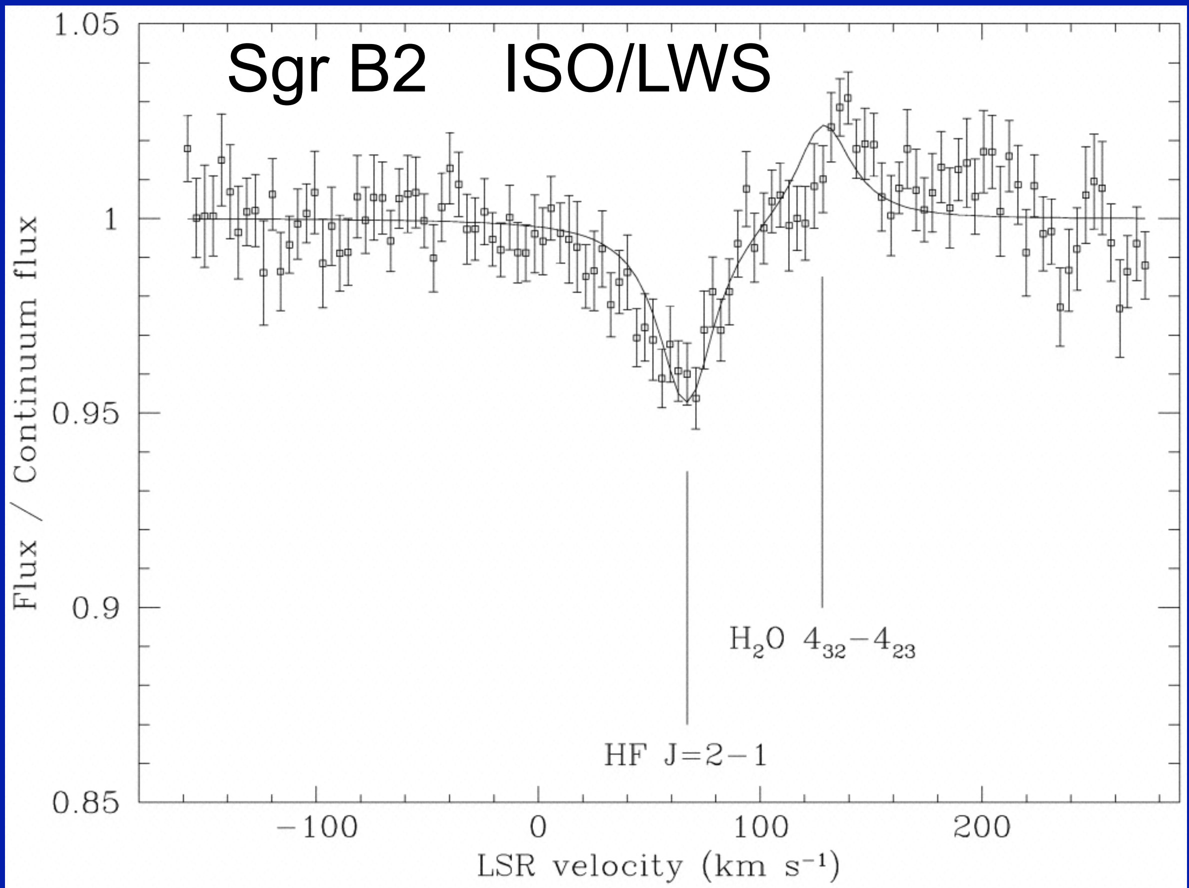
Chemistry of interstellar fluorine

- Once H_2 becomes abundant, HF is produced rapidly
- HF is destroyed slowly by photodissociation and reaction with C^+
- HF becomes the dominant reservoir of fluorine:
  - Unobservable from the ground, however: the $J = 1 – 0$ transition is at 1.232 THz

Discovery of interstellar HF

J = 2 – 1 transition discovered by ISO

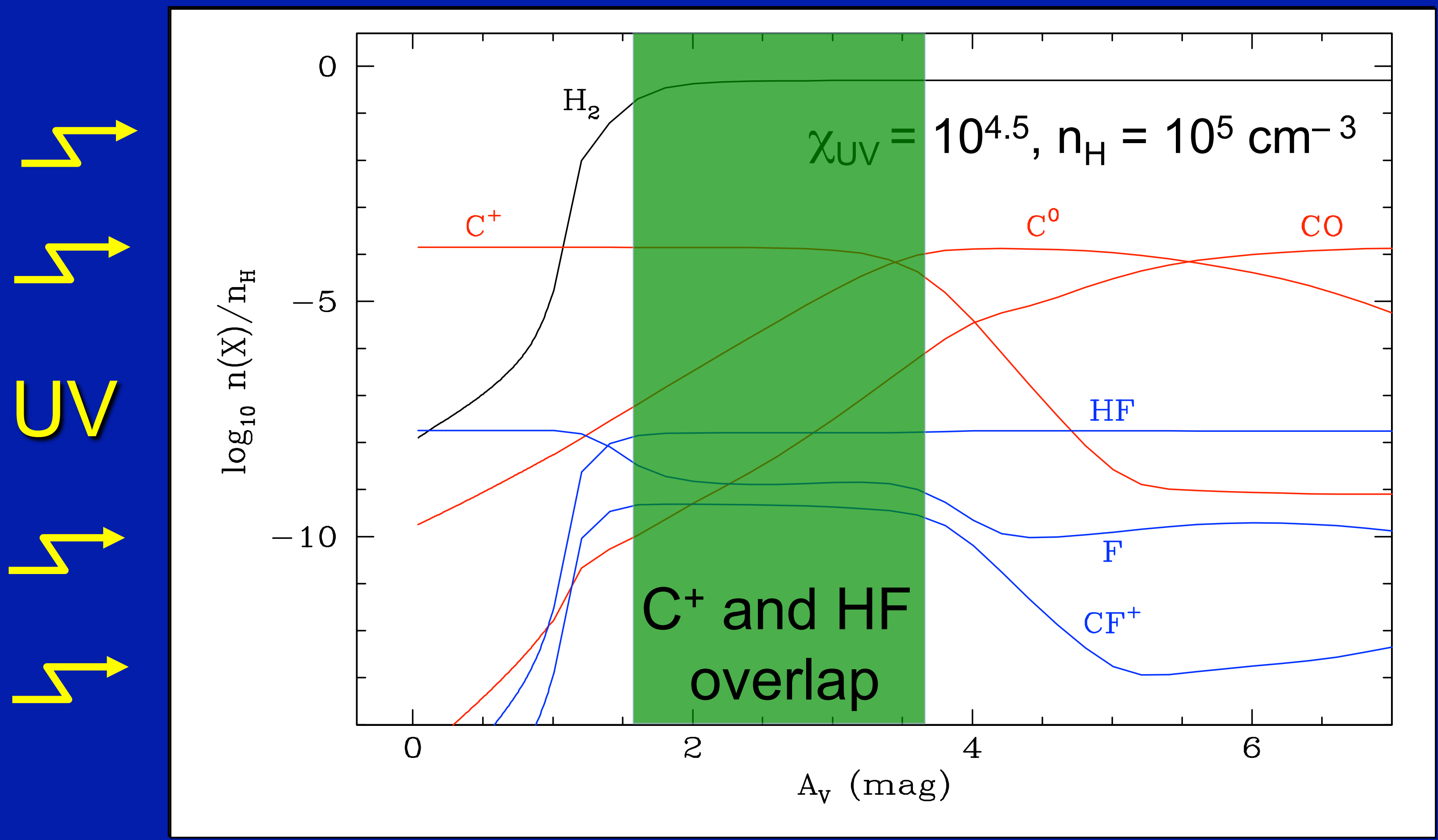
(Neufeld, Zmuidzinas, Schilke and Phillips 1997)



Lacking access to the J = 1 – 0 transition, ISO was unable to probe HF in any source other than Sgr B2

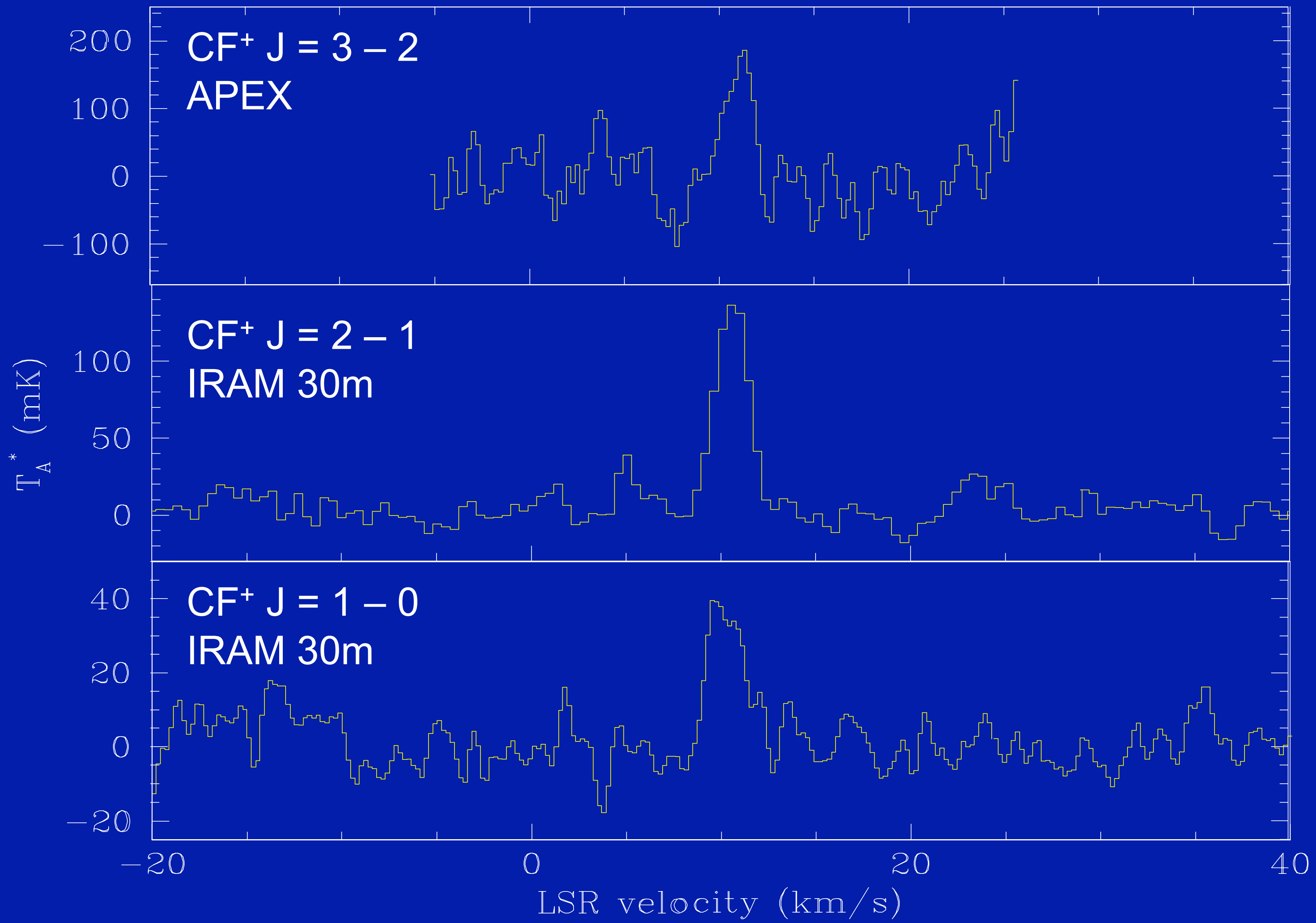
Predicted abundance profiles

(Neufeld, Wolfire & Schilke 1995)



CF^+ spectra toward the Orion Bar

(Neufeld et al. 2006, A&A)

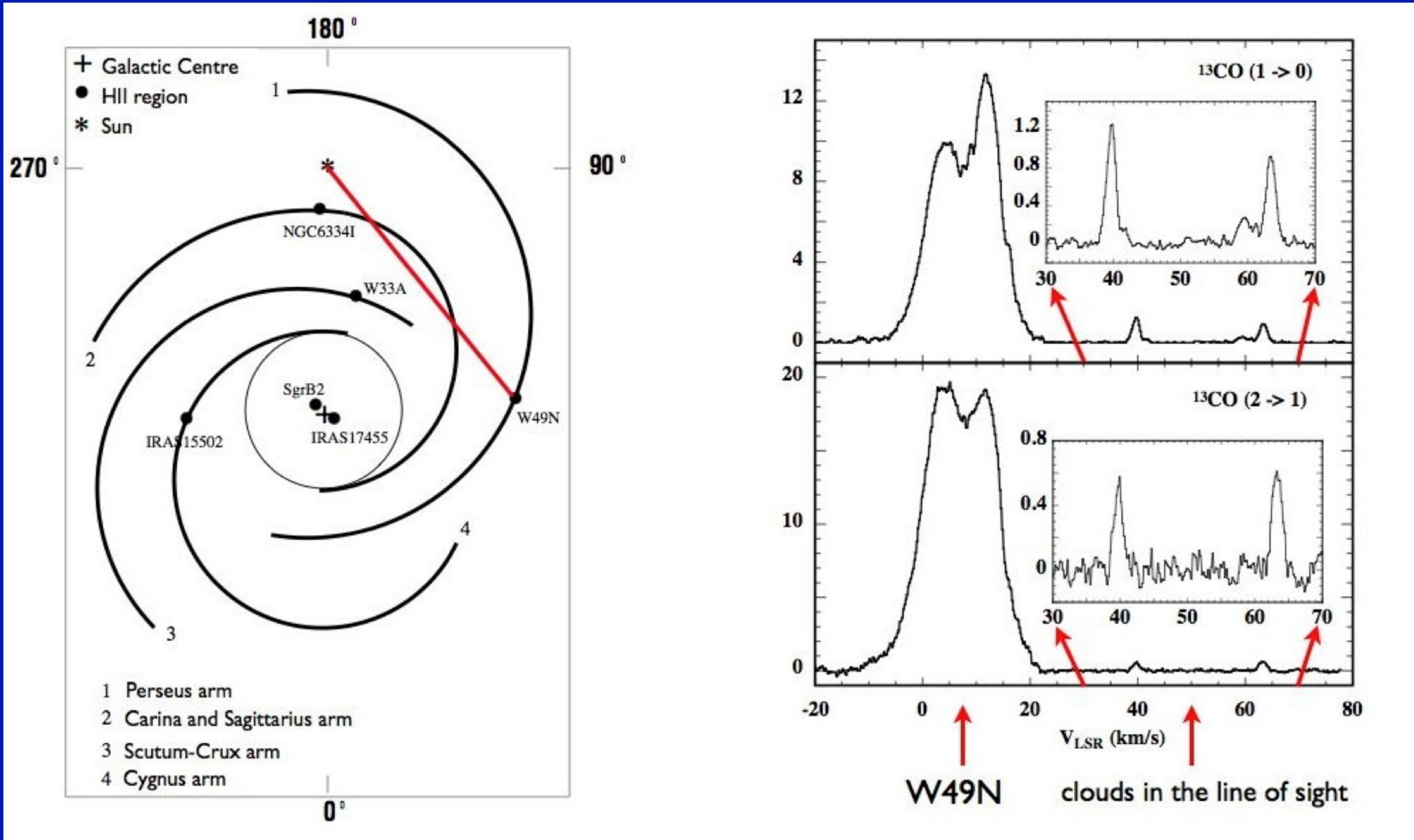


Herschel/HIFI observations of HF J = 1 – 0

- As part of the “PRobing InterStellar Molecules with Absorption line Studies (PRISMAS)” Key Program, we have observed the HF J = 1 – 0 transition toward three strong continuum sources with sight-lines that are intersected by foreground clouds:

G10.6 – 0.4 (W31C), W49, W51

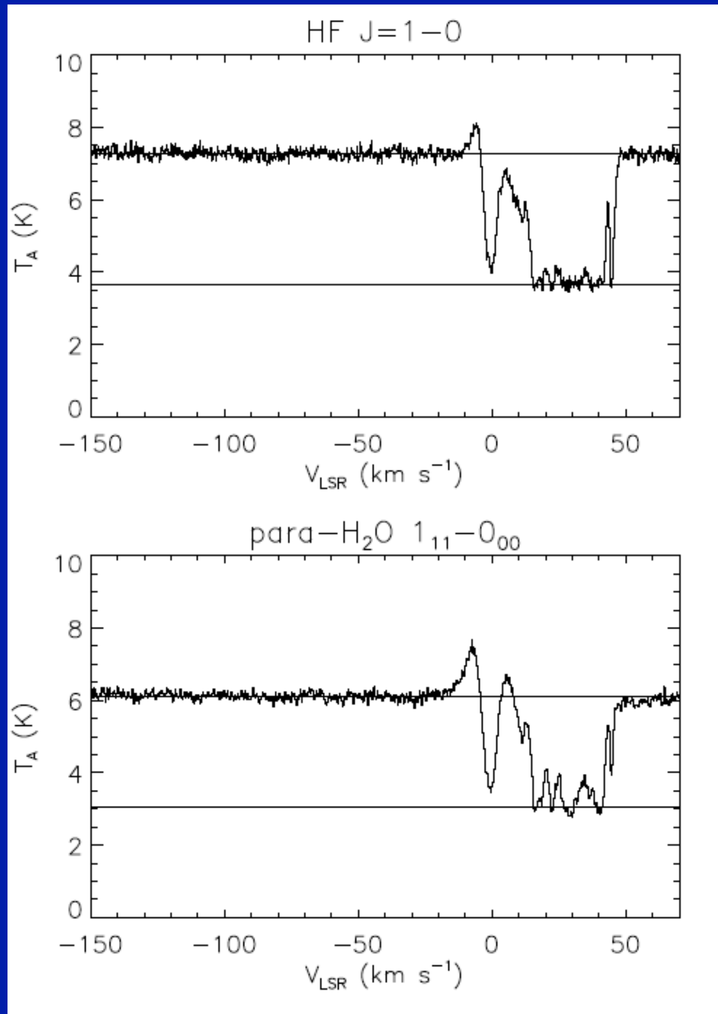
Observing geometry



http://astro.ens.fr/index.cgi?exe=217263

Strong HF absorption observed toward G10.6 – 0.4 (W31C)

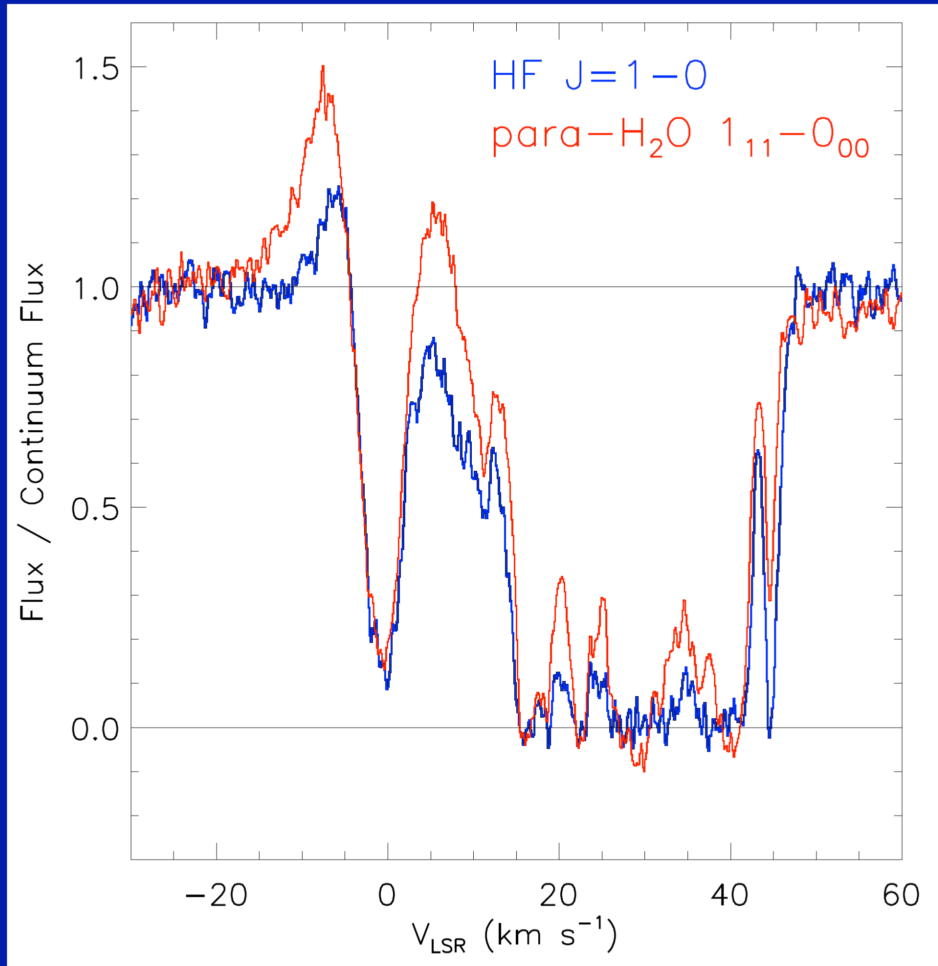
- We observed the HF J = 1 – 0 and para-H_2O $1_{11} – 0_{00}$ transitions in mixer band 5a
- The on-source integration times were 225 s and 117 s, respectively
- The spectra are double-sideband spectra ➔ the complete absorption of radiation reduces the apparent antenna temperature by one-half (for a sideband gain ratio of unity)



Neufeld et al. 2010, A&A, accepted

Strong HF absorption observed toward G10.6 – 0.4 (W31C)

Remarkably, the optical depth for HF is larger than that for para-H_2O, even though the elemental abundance of fluorine is 10^4 times smaller than that of oxygen



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$\tau(HF) / \tau(p\text{–}H_2O) \sim 2 – 3$

→ $N(HF) / N(H_2O) \sim 1$
for an assumed H_2O ortho-to-para ratio of 3

Strong HF absorption observed toward G10.6 – 0.4 (W31C)

- Inferred column density and abundance

$N(HF) > 1.6 \times 10^{14}$ cm^{-2} (lower limit, because the optical depth is large)

Along this sight-line, $N_H = N(H) + 2\,N(H_2) \sim 2.7 \times 10^{22}$ cm^{-2} (based on extinction estimates)

$N(HF)/N_H > 6 \times 10^{-9}$

➔ HF accounts for 30 – 100% of fluorine in the gas phase

HF also detected in absorption toward the Orion hot core

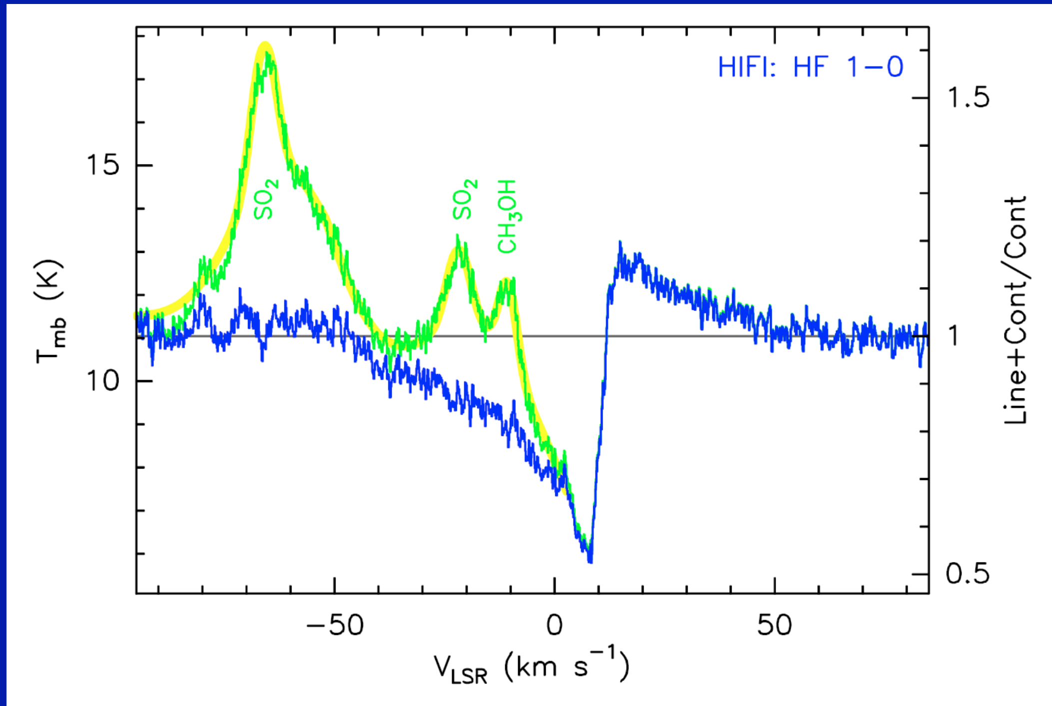
A complete HIFI spectral scan is being carried out toward the Orion hot core in the Herschel observations of EXtra-Ordinary Sources (HEXOS) Key Program

This is a classic “emission line source”, but HF appears in absorption toward the hot core

HF also detected in absorption toward the Orion hot core

Three components are detected:

1) Narrow absorption at the systemic velocity of the hot core (+9 km/s)
2) Broad blueshifted absorption associated with the “Low Velocity Flow”
3) Redshifted emission , most likely scattered radiation



Phillips, Bergin, Lis et al. 2010, A&A, accepted

HF also detected in absorption toward the Orion hot core

Gas responsible for the broad absorption component is well characterized by observations of CO rotational emission and CO v = 1– 0 absorption (e.g. Beuther et al. 2010, astro-ph)

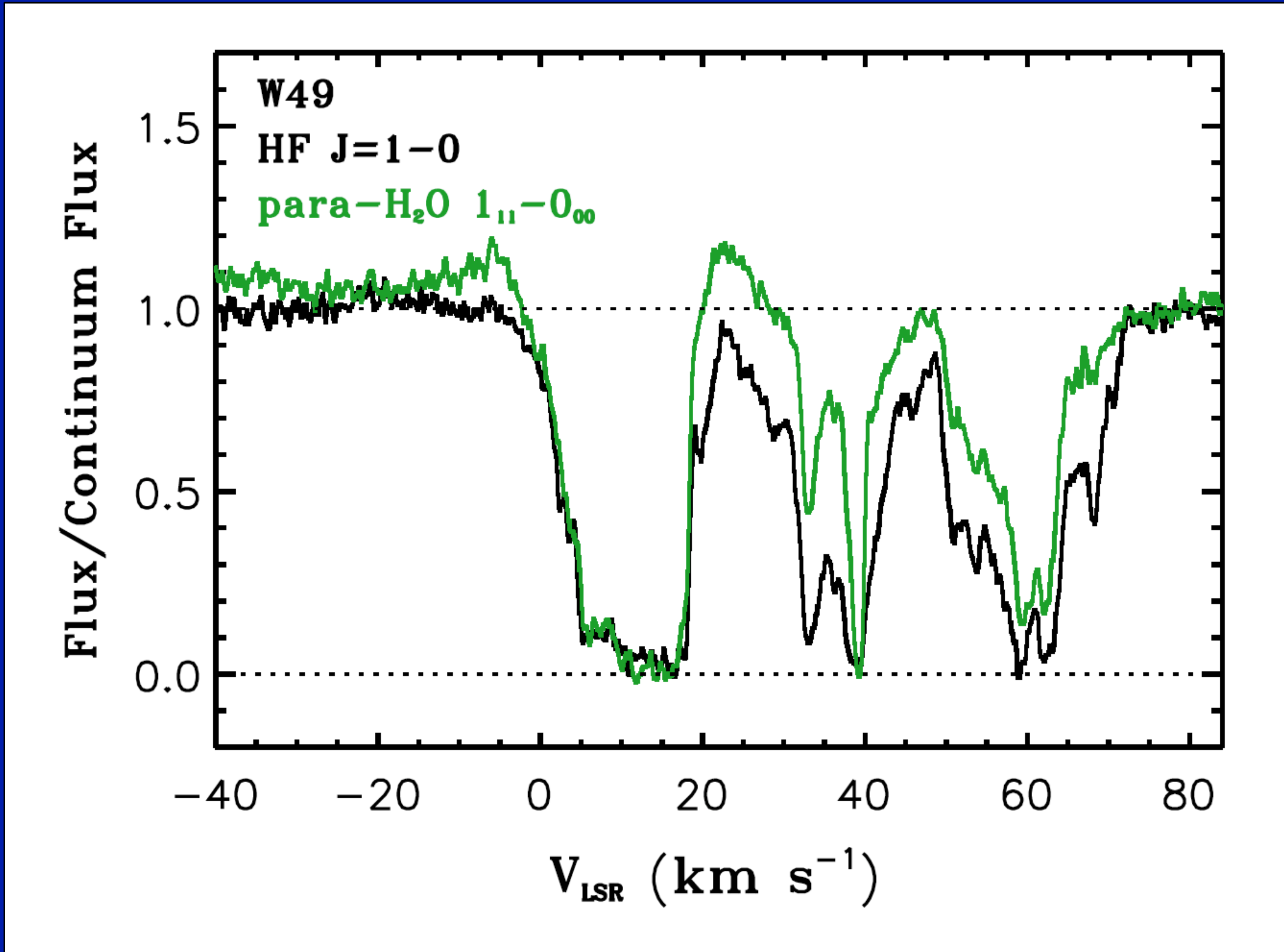
Gas density ~ 10^5 cm^{-3}

N(HF) ~ 3 x 10^{13} cm^{-2}

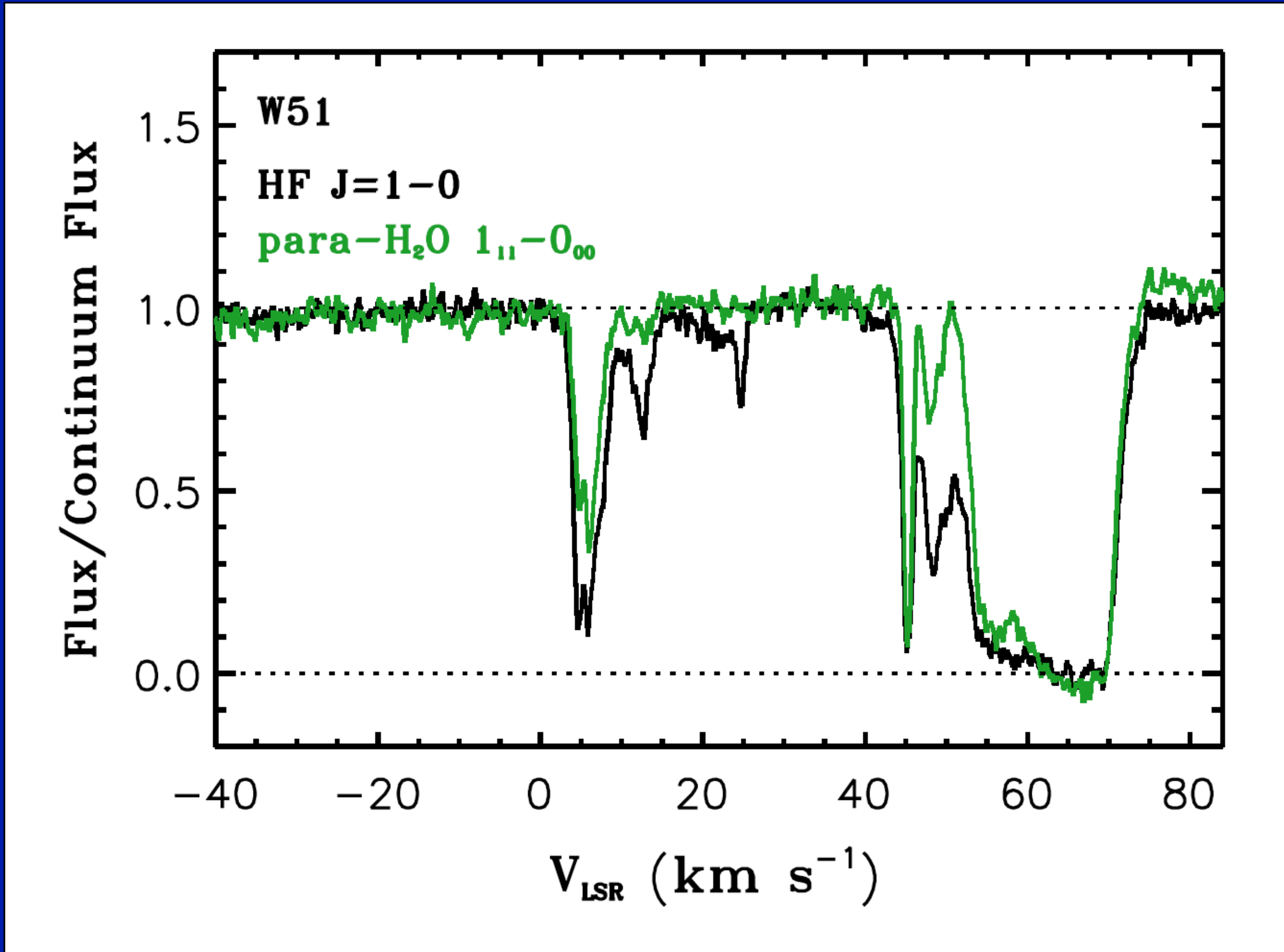
N(HF)/N(H_2) ~ 3 x 10^{-10}, corresponding to ~ 0.6 % of the solar abundance

This behavior likely reflects the effects of depletion in dense clouds

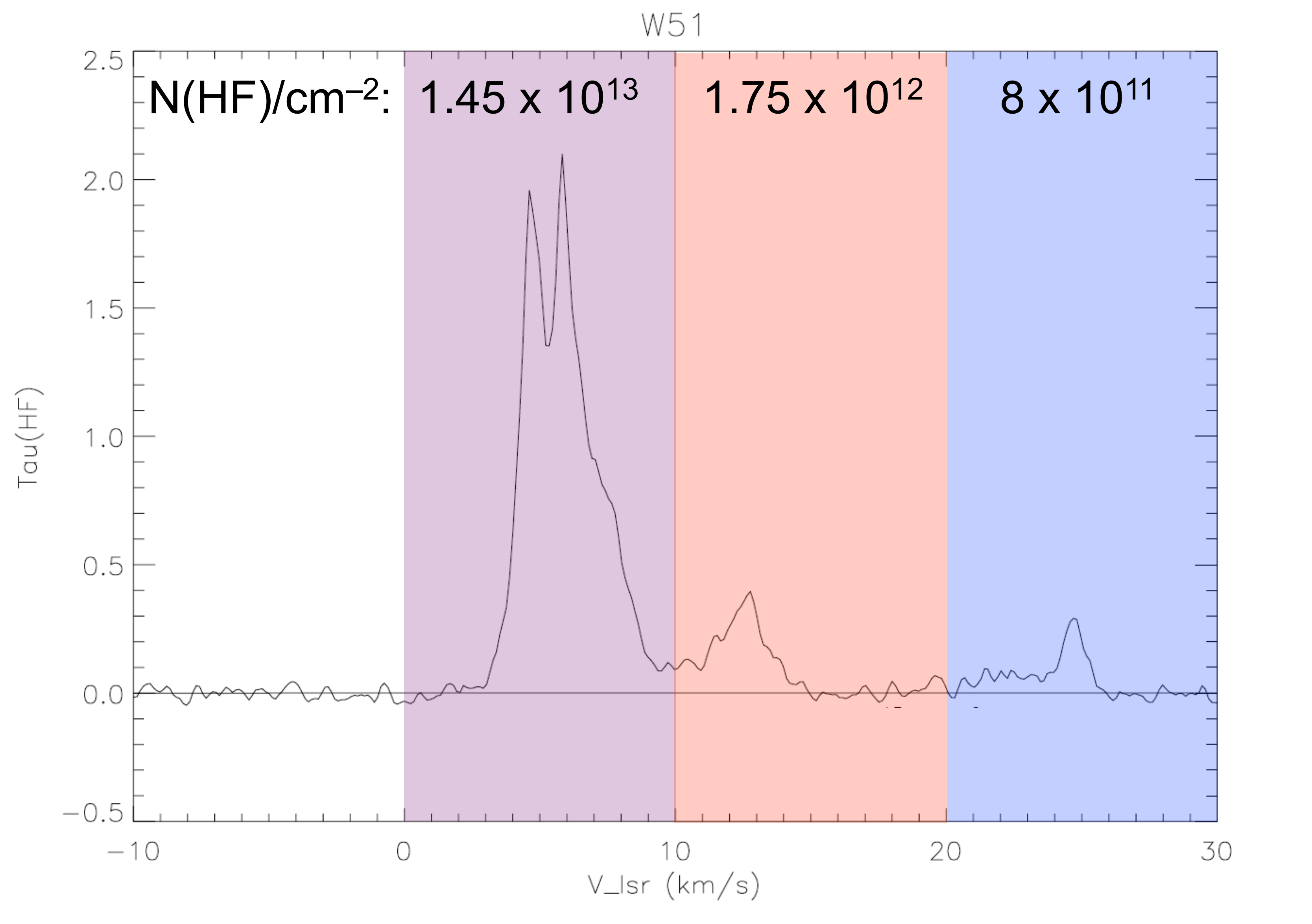
HF absorption also detected toward W49



…….and toward W51



W51 exhibits some *optically-thin* absorption clouds



W51 absorption

Total HF column density at LSR velocities between 3 and 27 km s^{-1}: 1.7×10^{13} cm^{-2}

(a *measurement*, not a lower limit)

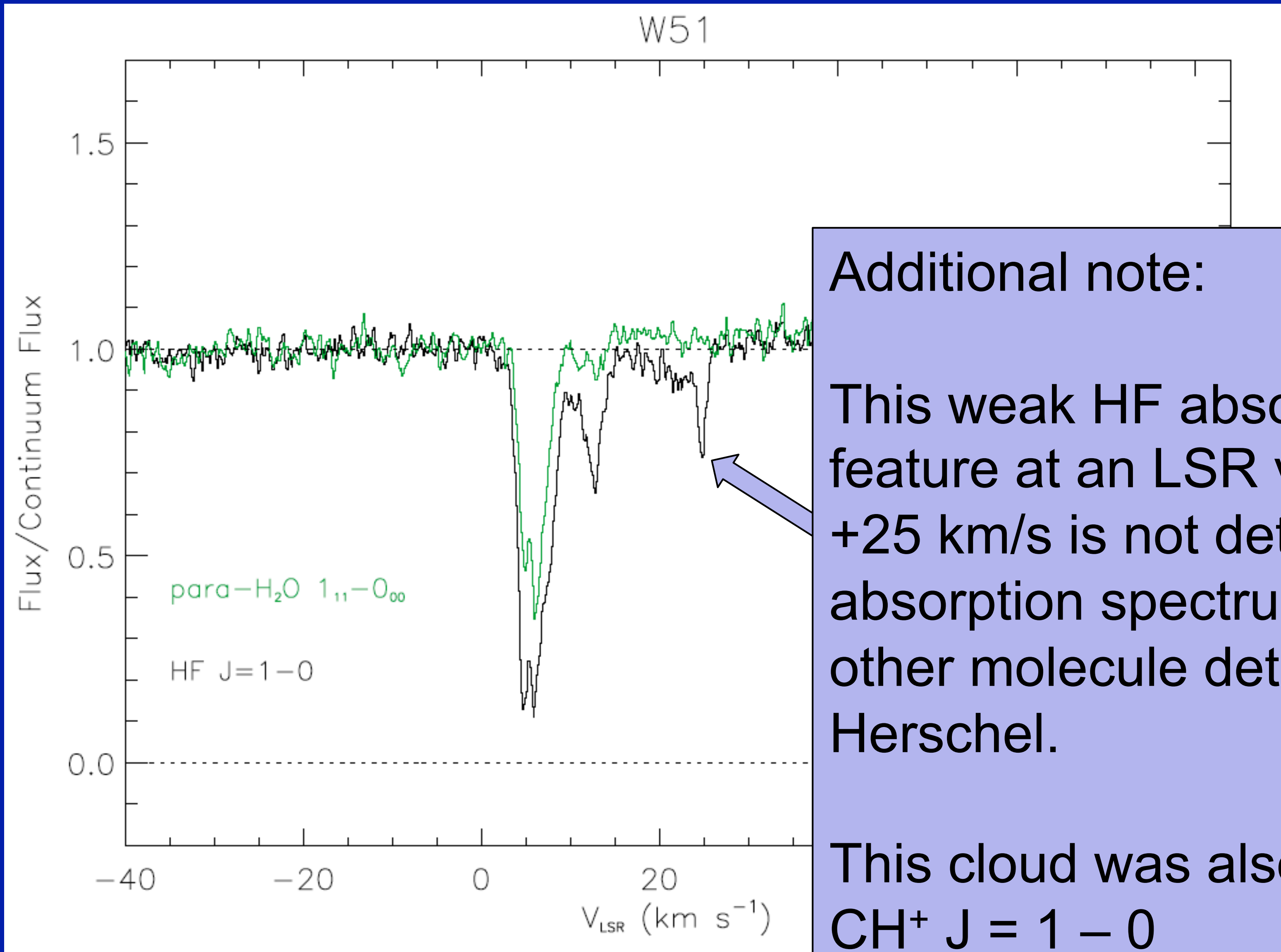
Corresponding H_2 column density ~ 6×10^{20} cm^{-2}

(based upon observations of CH by Gerin et al. 2010, and assuming $CH/H_2 = 3.5 \times 10^{-8}$)

$N(HF)/N(H_2) \sim 3 \times 10^{-8}$

By comparison: average $N_F/N_H = 1.8 \times 10^{-8}$ in diffuse atomic clouds (Snow et al. 2007)

W51 absorption



Additional note:

This weak HF absorption feature at an LSR velocity of +25 km/s is not detected in the absorption spectrum of any other molecule detected before Herschel.

This cloud was also detected in CH^+ J = 1 – 0 (Falgarone et al., Poster P1.02)

Future prospects

Hydrogen fluoride could prove to be a valuable surrogate for H_2

- Initial observations of diffuse clouds confirm the theoretical prediction that $N(HF)/2N(H_2)$ = gas phase elemental F/H ratio
- HF J = 1 – 0 can trace clouds of very small H_2 column density ($< 10^{20}$ cm $^{-2}$) that are difficult to detect by other means
- In the observations presented here, the on-source integration time was only 4 minutes

  ➔ substantial sensitivity improvement will be achievable in longer integrations

Future prospects

In dense regions, HF abundances will reflect the effects of depletion

If we accept that all gas-phase fluorine is in the form of HF, then hydrogen fluoride observations reveal the extent to which volatile species are bound up in icy grain mantles

Future prospects

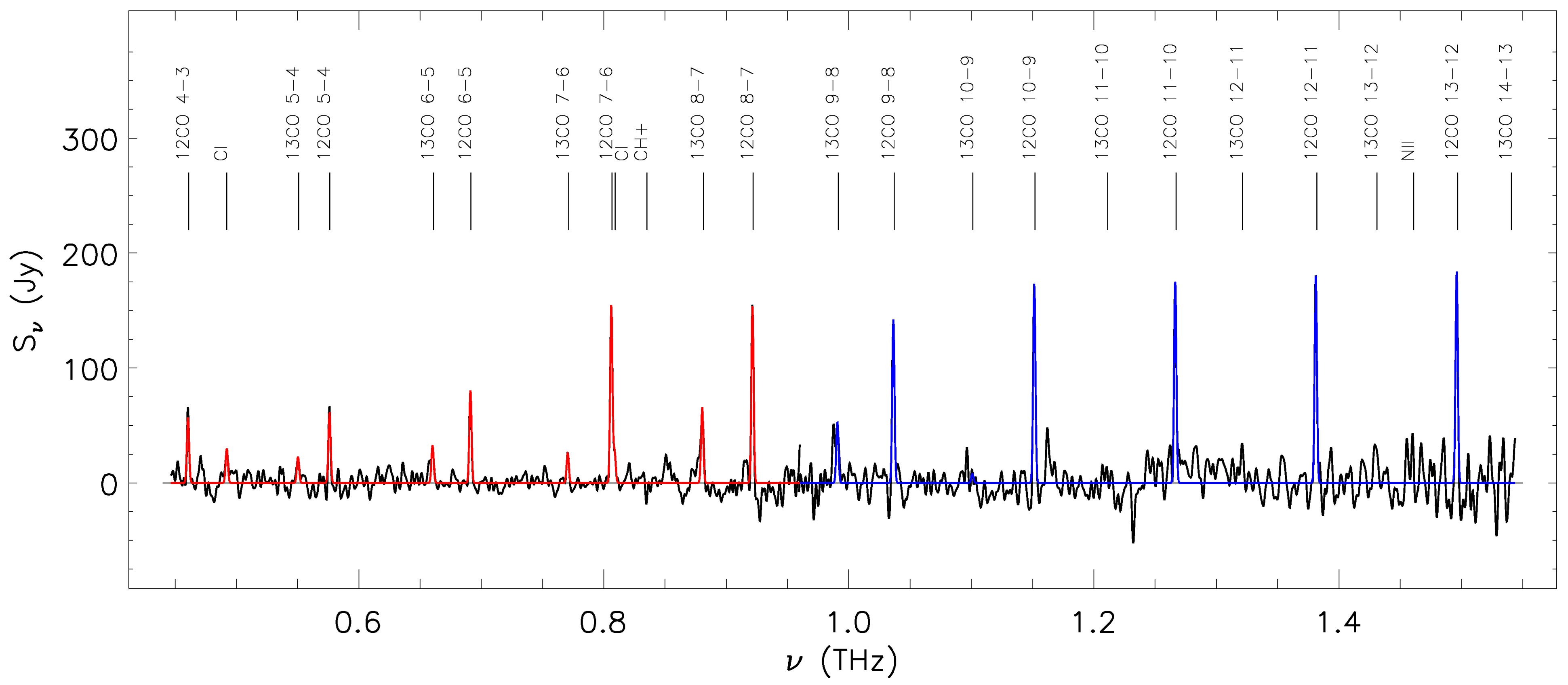
HF absorption should be detectable by SPIRE:

At the highest resolution (1.2 GHz), the SPIRE resolution element corresponds to ~ 300 km/s

HF J = 1 - 0 in G10.6–0.4, W49 and W51 will lead to absorption features of depth ~ 10% of the continuum

Future prospects

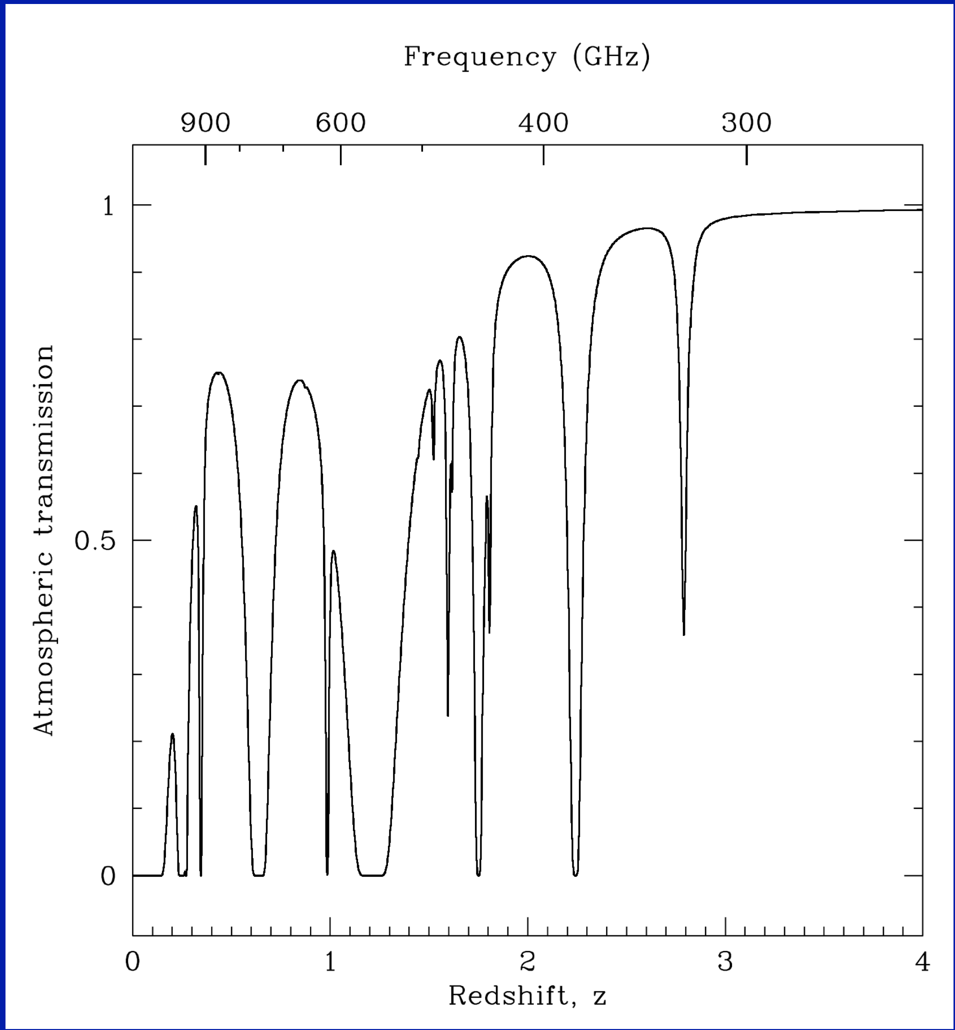
An example may be evident in the SPIRE spectrum of G29.96-0.02, presented yesterday in poster P1.18 by Jason Kirk et al. (and A&A, submitted)



Future prospects

Observations of HF J = 1 – 0 absorption might prove valuable in probing molecular hydrogen at high redshifts (e.g. in absorption toward a quasar)

Atmospheric windows appear at redshifts > 0.2



Neufeld, Wolfire & Schilke 2005