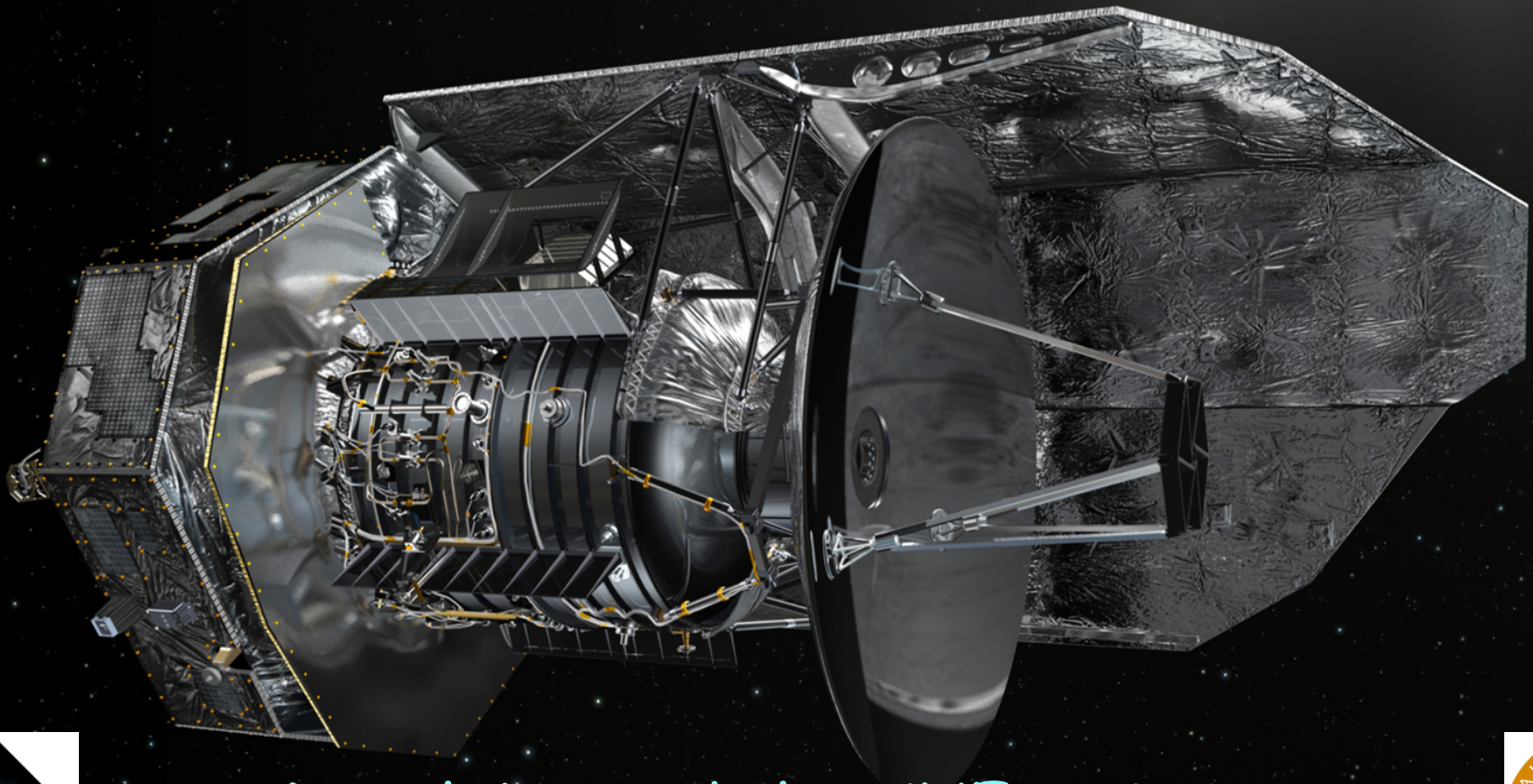


# Early Results from the Spectral Line Survey of NGC 6634I

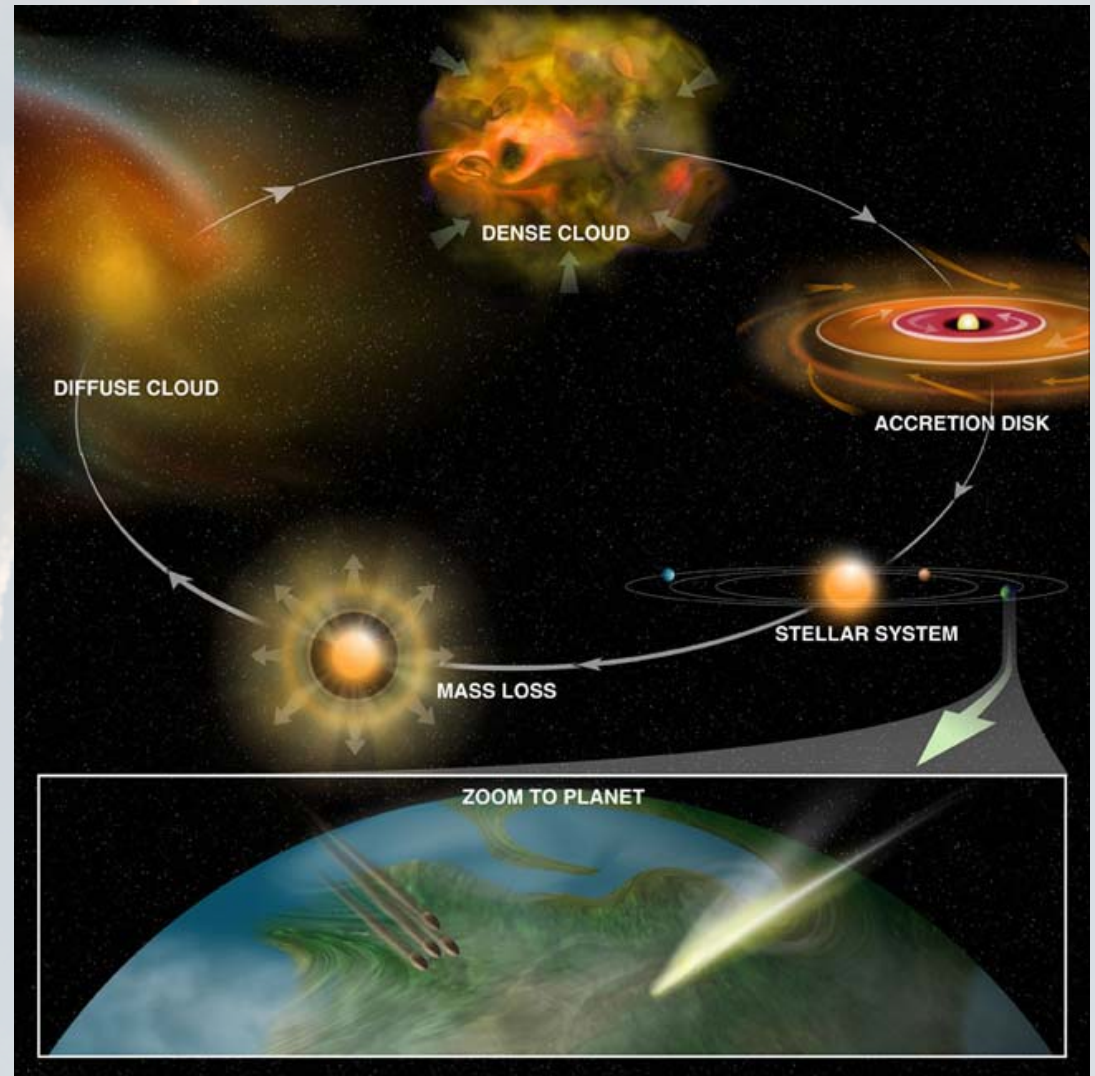


Darek Lis and the CHESSTeam  
*Noordwijk, May 6, 2010*



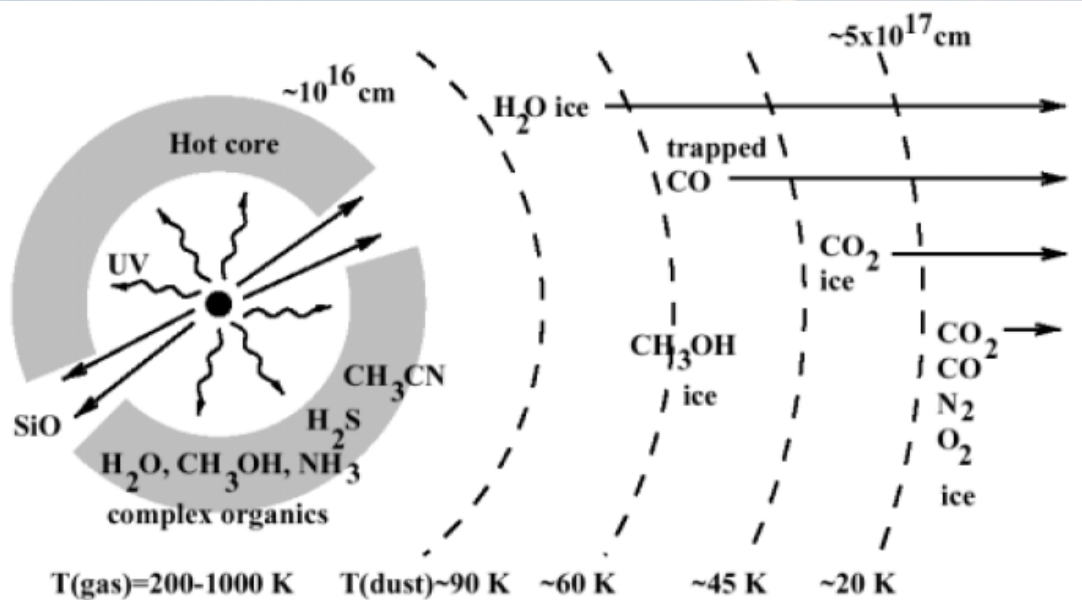
# Molecular Universe

- Submillimeter Astrophysics is a study of the *life cycle* of the molecular universe
- Heavy elements produced in stars
- Incorporated into diffuse interstellar gas
- Processed into molecular material in dense clouds
- Incorporated into planet-forming bodies in disks, and eventually into life itself



# Spectral Line Surveys

- Complete census of molecules in CNM; in regions with high line confusion essential for identification
- Submm  $\lambda$ s give access to high-energy transitions, excited only in the immediate vicinity of the newly formed stars
- Complex, high-T chemistry driven by molecules evaporating from grain mantles (e.g., methanol)

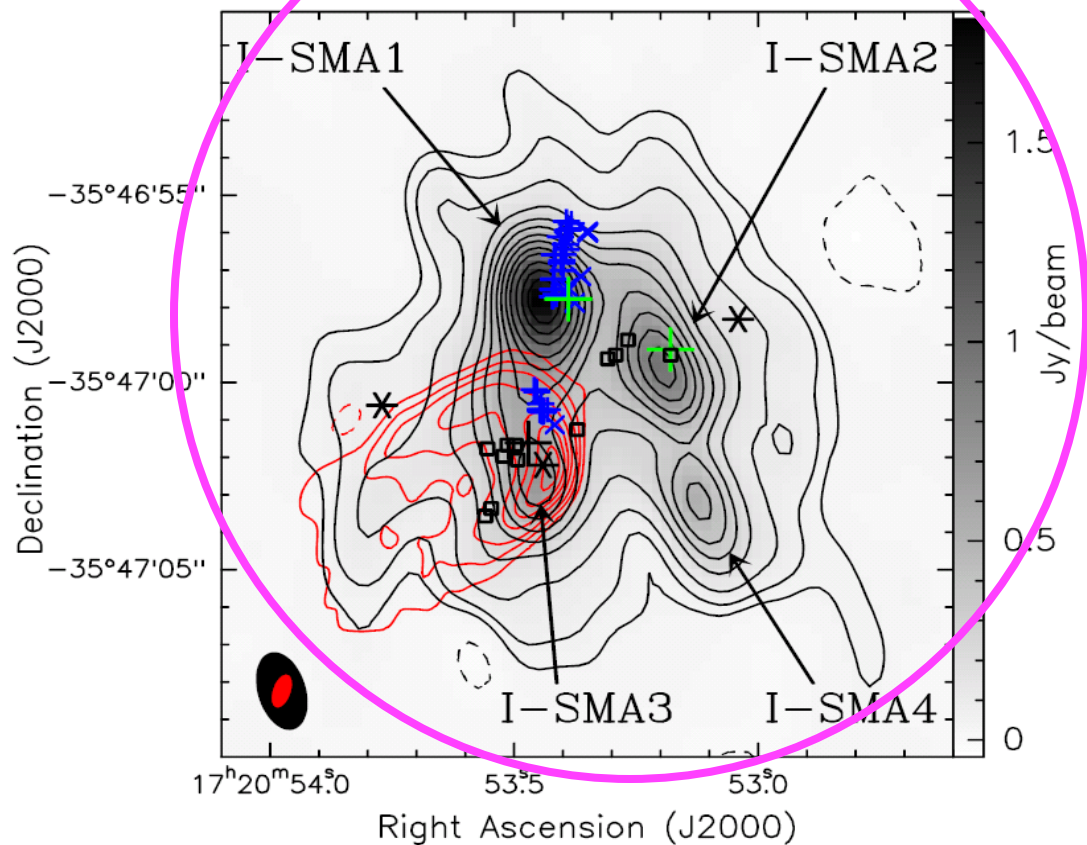


*van Dishoeck et al. 1998*

## Fundamental questions:

- Grain-surface vs. gas-phase processes
- Formation of large organic molecules → small grains (PAHs)
- Time scales (molecular clocks)
- Dependence on mass, luminosity etc.

# NGC 6334

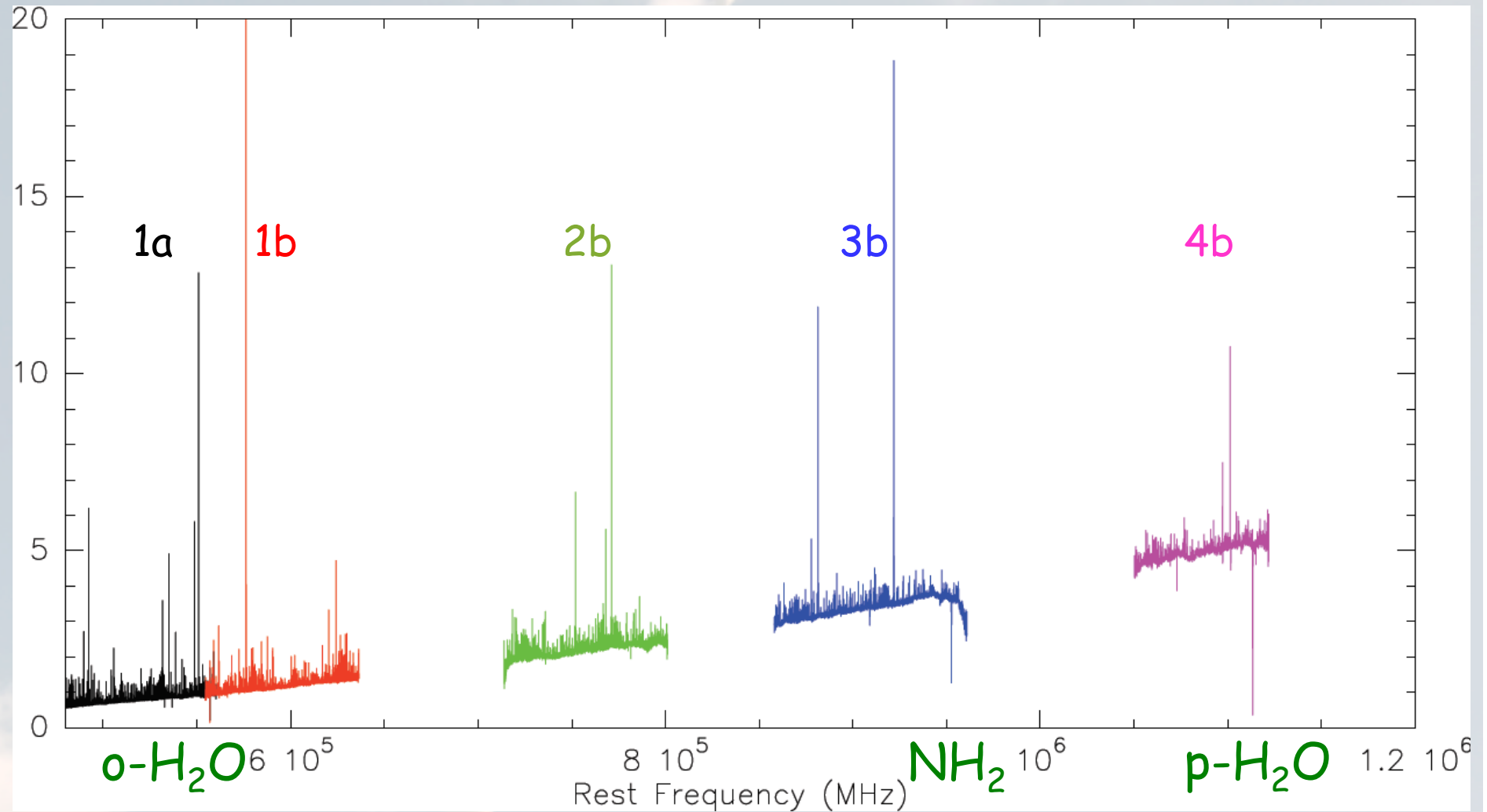


- Nearby molecular cloud/HII region complex (1.7 kpc)
- Infrared source "I"  
 $\sim 2.6 \times 10^5 L_{\text{sun}}$ ,  $200 M_{\text{sun}}$
- Four compact submm continuum sources located near the center of the NIR cluster
- Similar to the more evolved Orion Nebula
- Several cold foreground absorption components seen in OH, NH<sub>3</sub>, CH<sub>3</sub>OH
- Complete unbiased spectral line survey across all HIFI bands in CHESS

HIFI band 3 beam  $\sim 26''$  FWHM

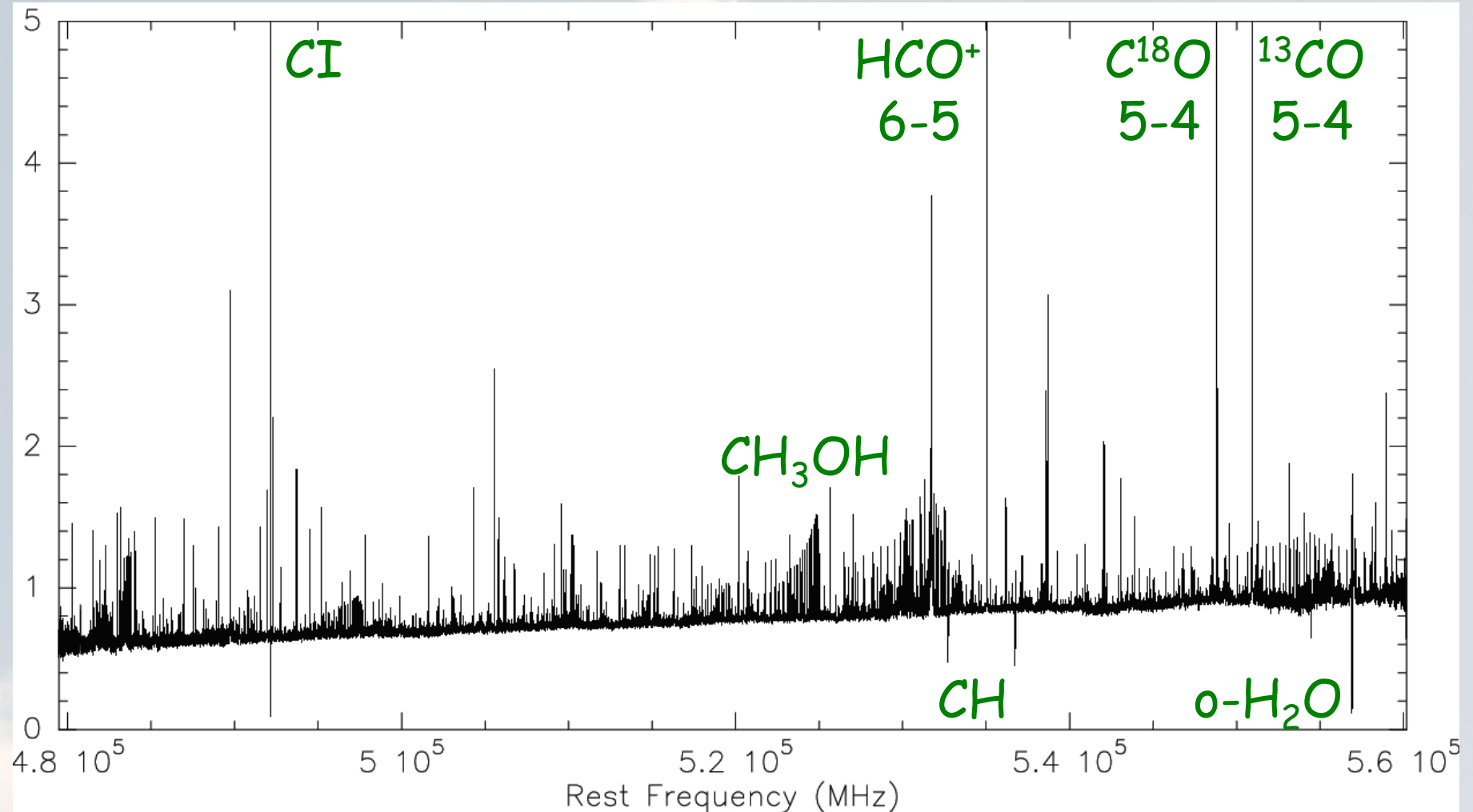
*SMA 1.3 mm; Hunter et al. 2006*

# NGC 6334I: SDP/PSP



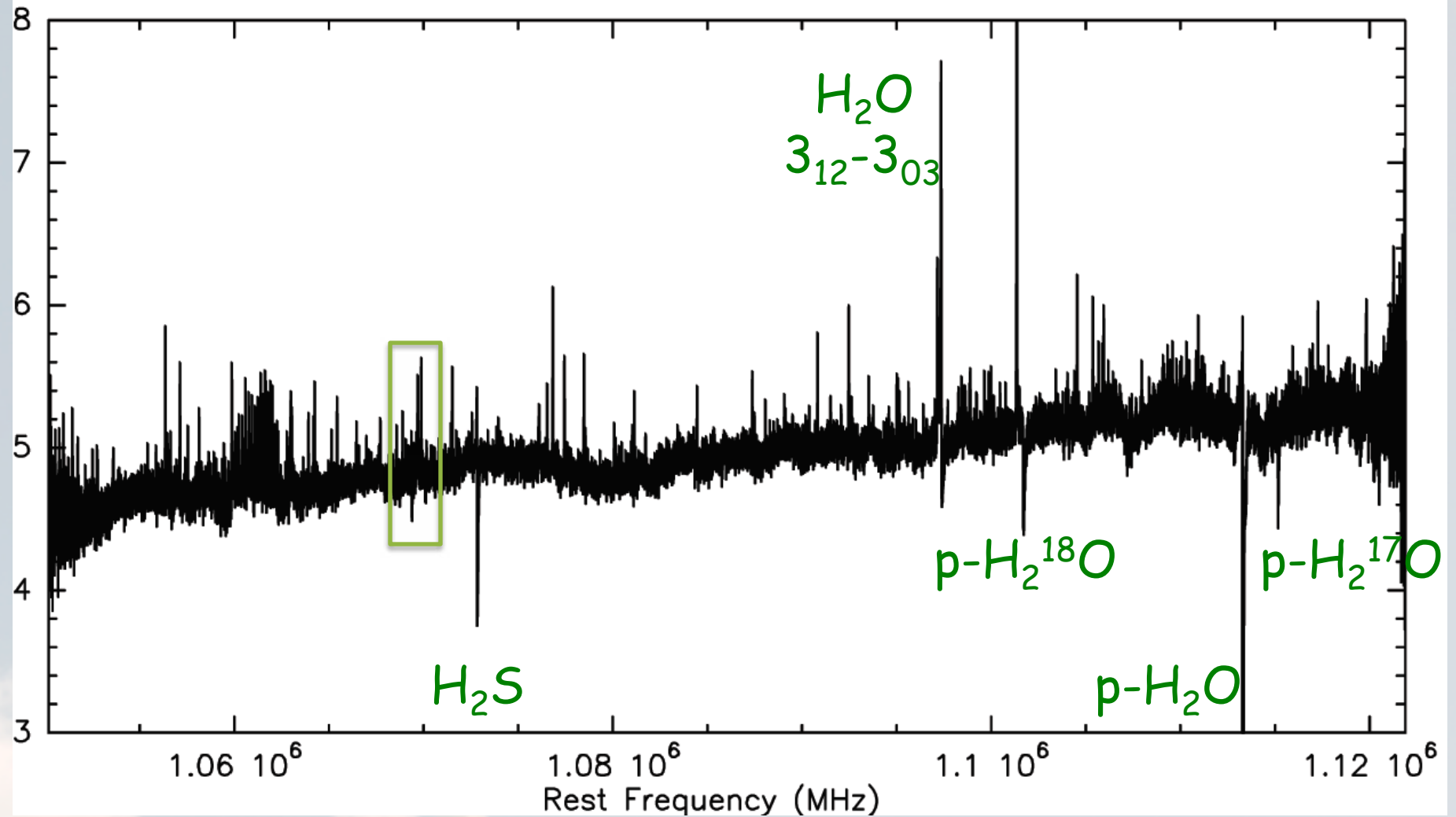
- Good continuum stability even without continuum optimization!

# NGC 6334I: Band 1a (SDP)



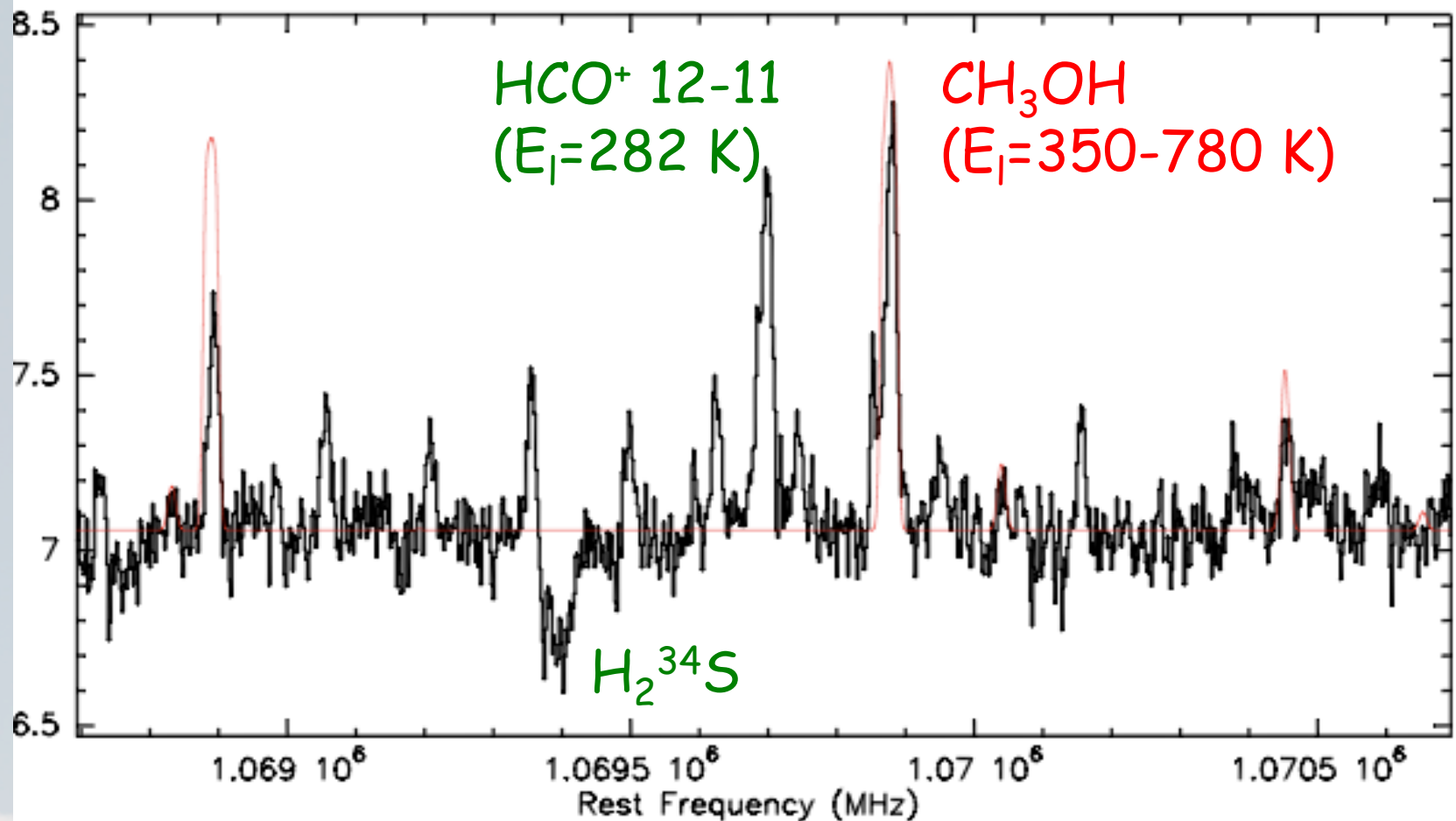
- Rich line spectrum—a forest of lines at 0.5–1 K level
- Fantastic data quality—kudos to the HIFI Instrument Team!

# NGC 6334I: Band 4b



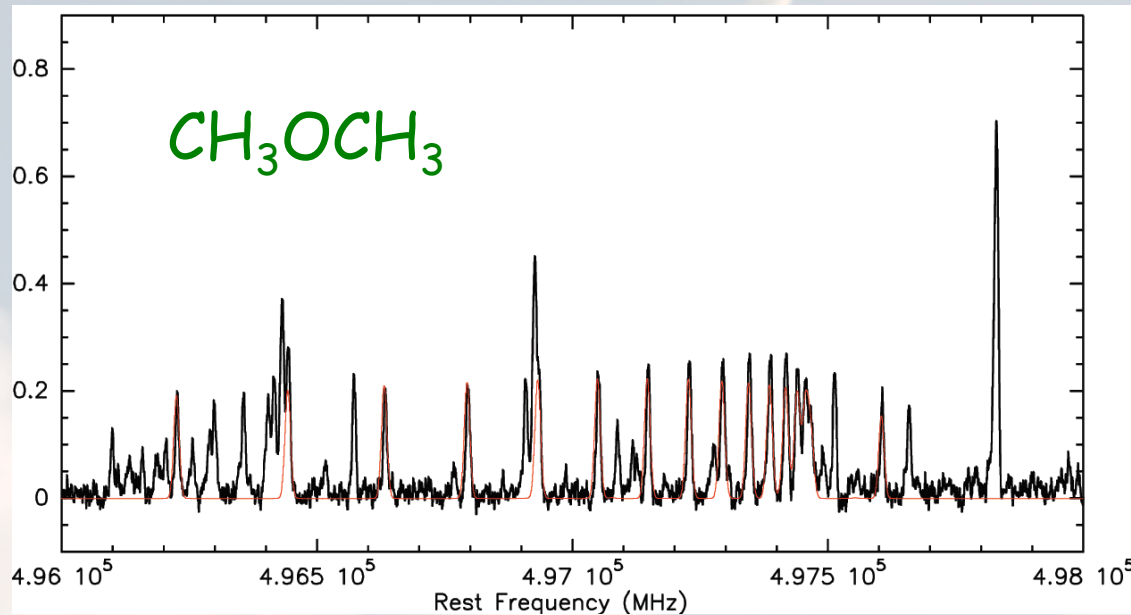
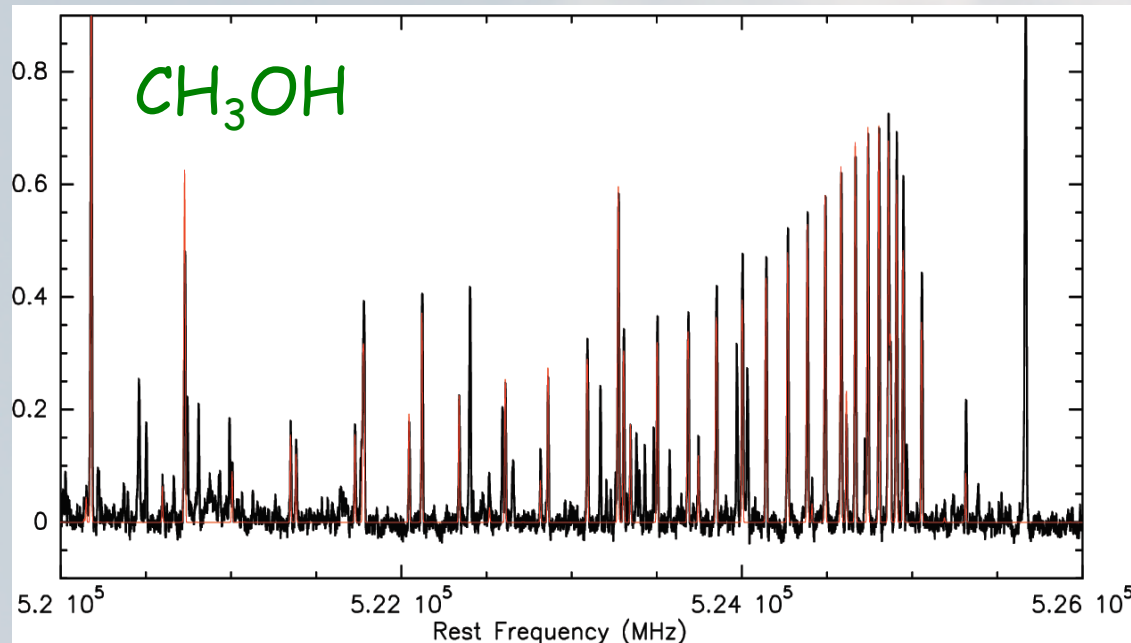
- Still many emission lines, prominent absorption features

# NGC 6334I: Band 4b—Zoom



- Impossible to identify lines without a source model
- Can be simple LTE to identify most abundant “weeds”
- Lab frequencies often not available above a few hundred GHz





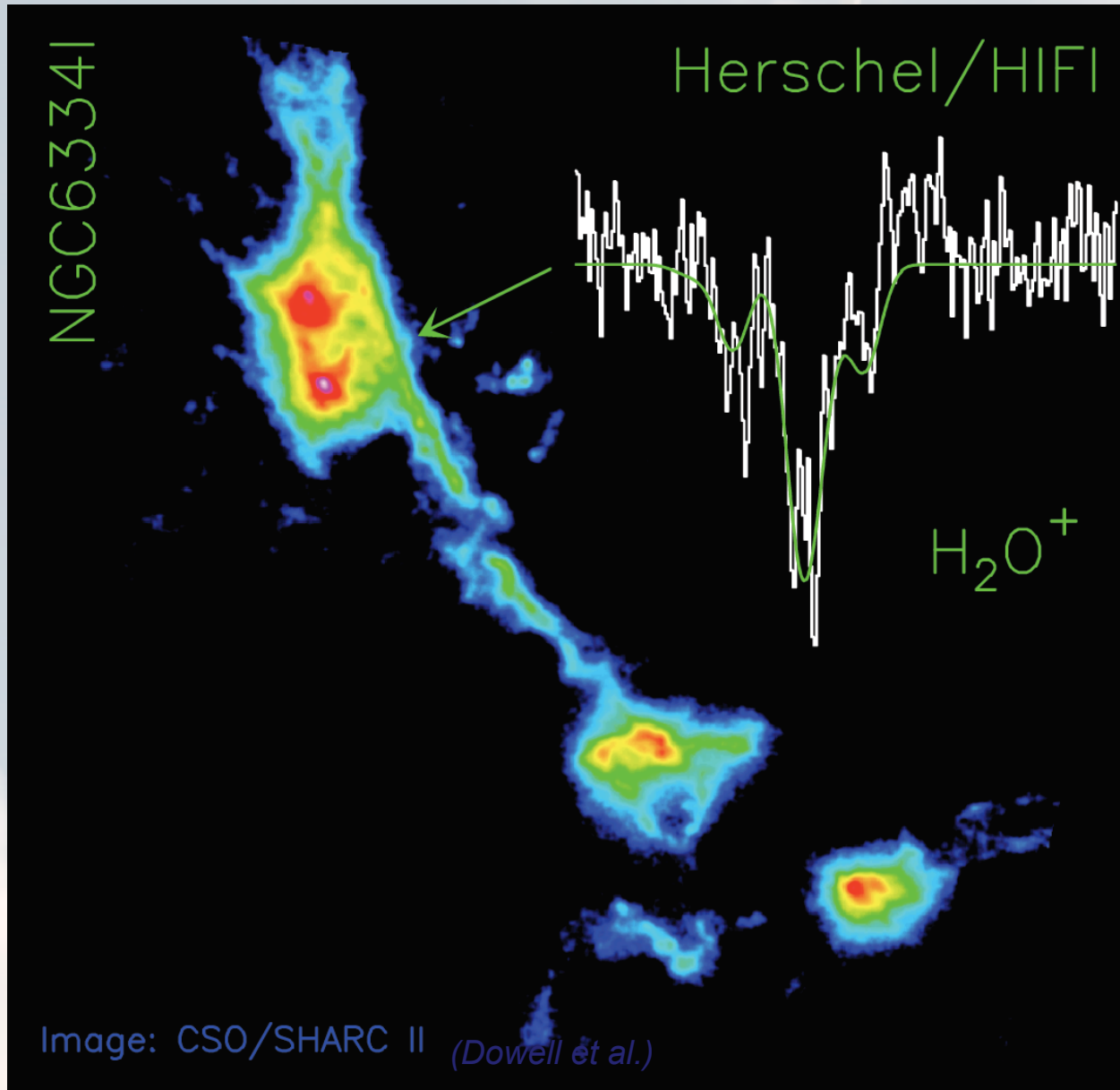
## "Weeds" and "Flowers"

- Spectral line confusion
- "Weeds": molecular species with extremely numerous, strong transitions across the submillimeter band
- Methanol ( $\text{CH}_3\text{OH}$ ), methyl formate ( $\text{HCOOCH}_3$ ), dimethyl ether ( $\text{CH}_3\text{OCH}_3$ ), ethyl cyanide ( $\text{CH}_3\text{CH}_2\text{CN}$ )
- Have to model the spectrum to identify any new species of astrophysical interest



Keukenhof Garden,  
April 29, 2010

# Detection of $\text{H}_2\text{O}^+$



- Reactive water cation plays a key role in the initial steps of the oxygen chemical network in UV irradiated parts of molecular clouds
- Talks by M. Gerin, V. Ossenkopf, C. Ceccarelli...

# Chlorine Chemistry in PDRs

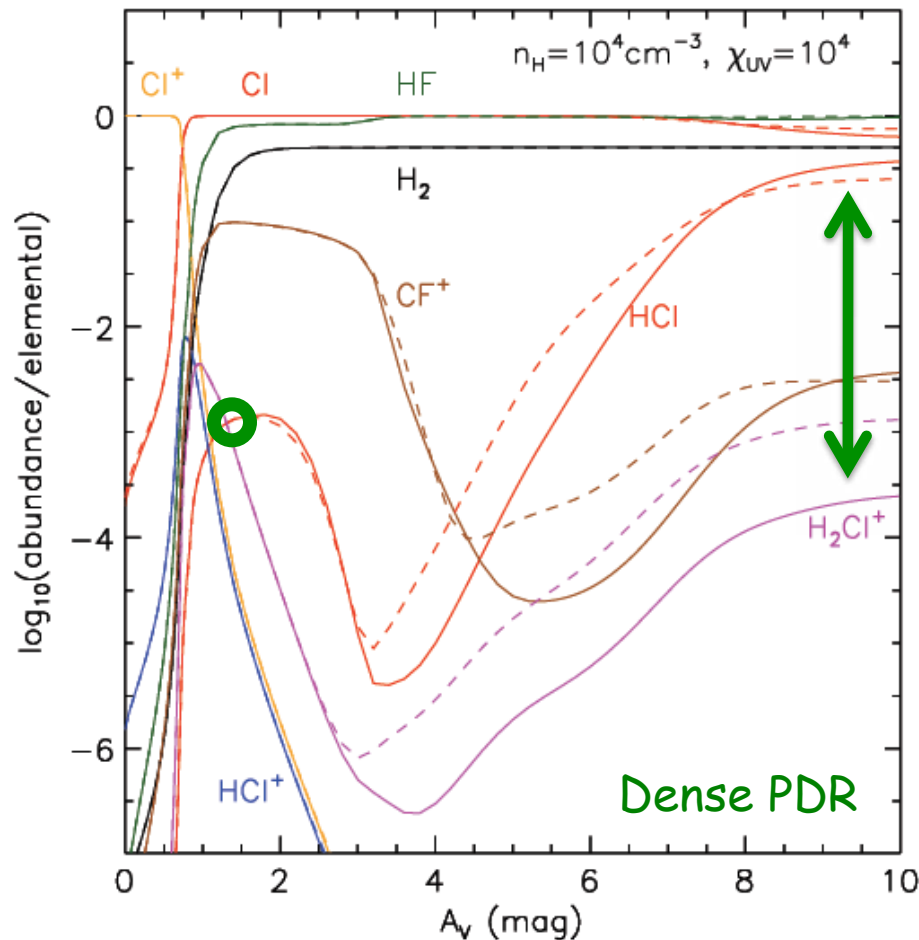
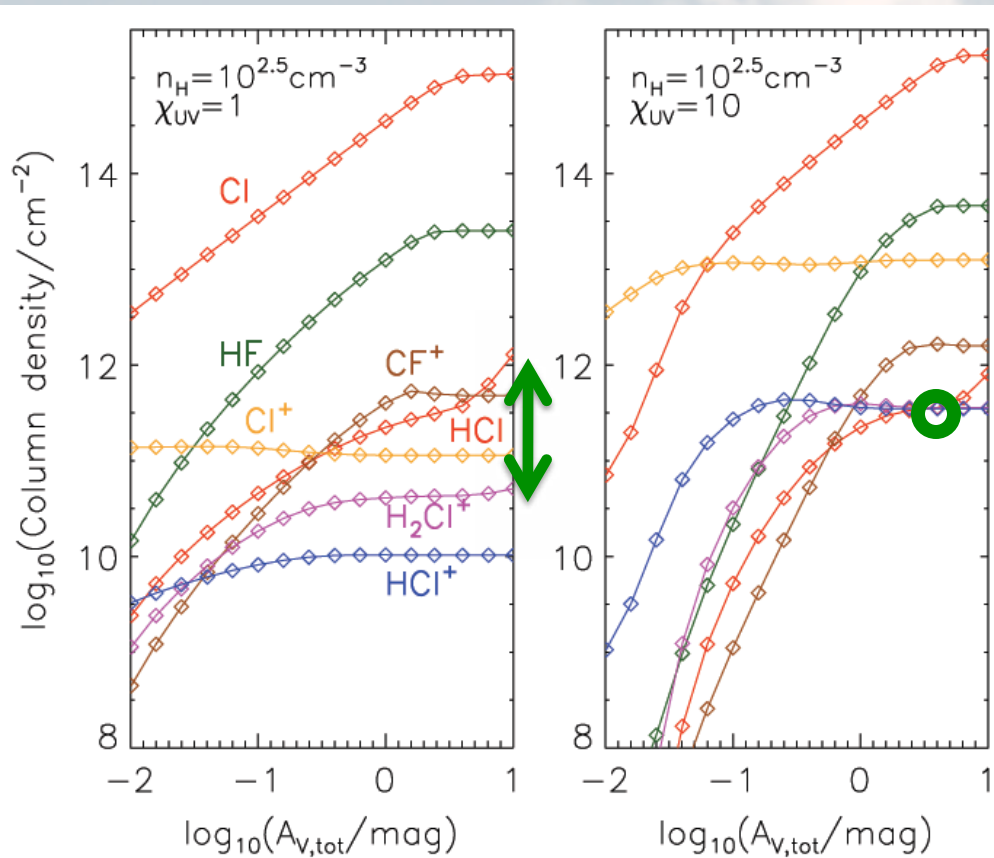


Figure 3. Abundance profiles for a one-sided slab model with  $n_{\text{H}} = 10^4 \text{ cm}^{-3}$  and  $\chi_{\text{UV}} = 10^4$ . Solid lines show the results for an assumed primary cosmic ray ionization rate of  $1.8 \times 10^{-17} \text{ s}^{-1}$  per H nucleus (standard case). Dashed lines show the results for an assumed primary cosmic ray ionization rate of  $1.8 \times 10^{-16} \text{ s}^{-1}$  per H nucleus.

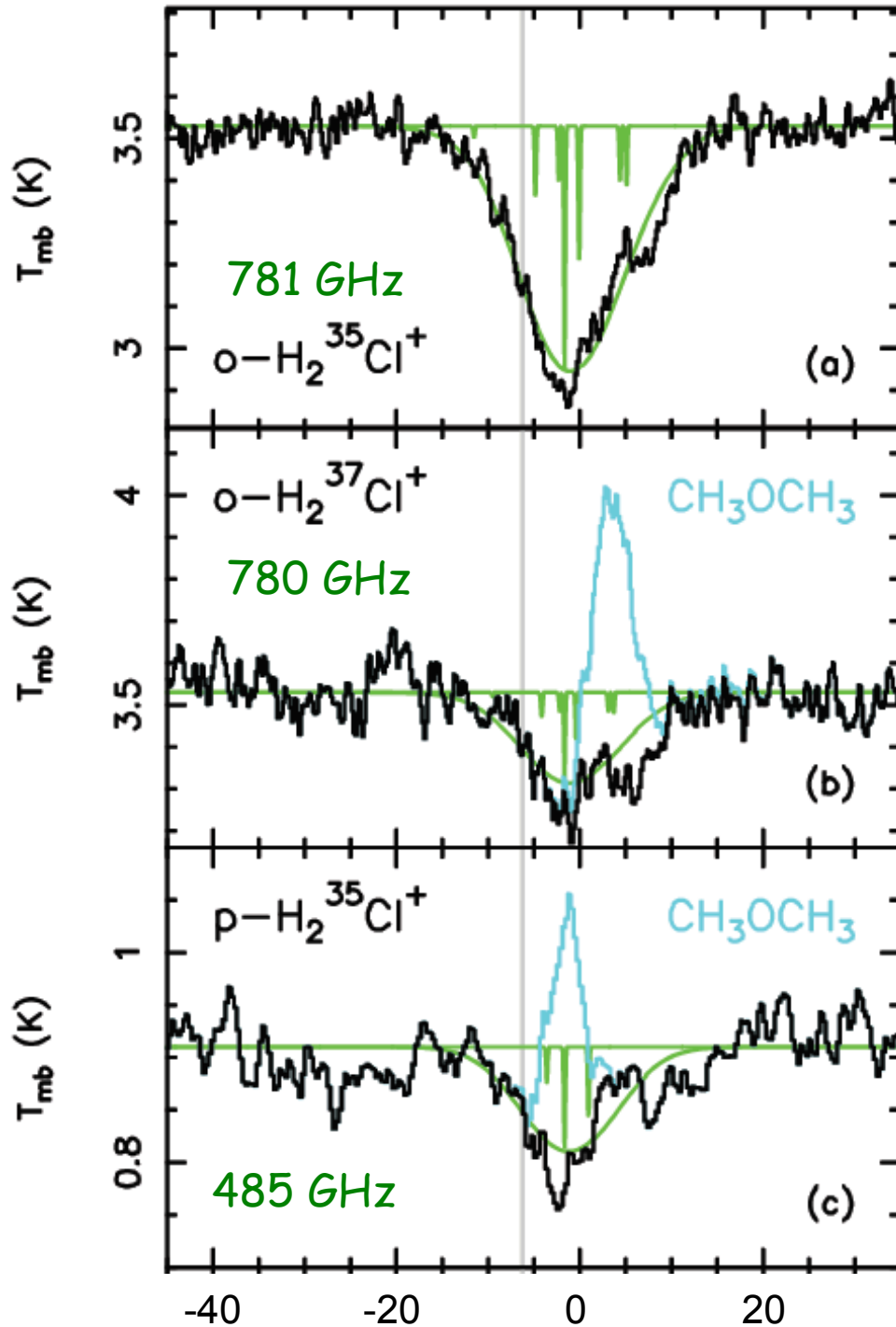
- Prior to Herschel, HCl and  $\text{H}^{37}\text{Cl}$  were the only Cl-bearing molecules detected in the ISM
- Metal halides NaCl, KCl, AlCl detected in IRC+10216
- Chloronium,  $\text{H}_2\text{Cl}^+$ , predicted to be abundant in PDRs (Neufeld & Wolfire 2009) and targeted in HOP  $\text{O}_2$  observations at 487 GHz
- Predicted maximum column densities:  $N(\text{H}_2\text{Cl}^+) \sim \text{a few} \times 10^{11} \text{ cm}^{-2}$

# Diffuse PDR Models



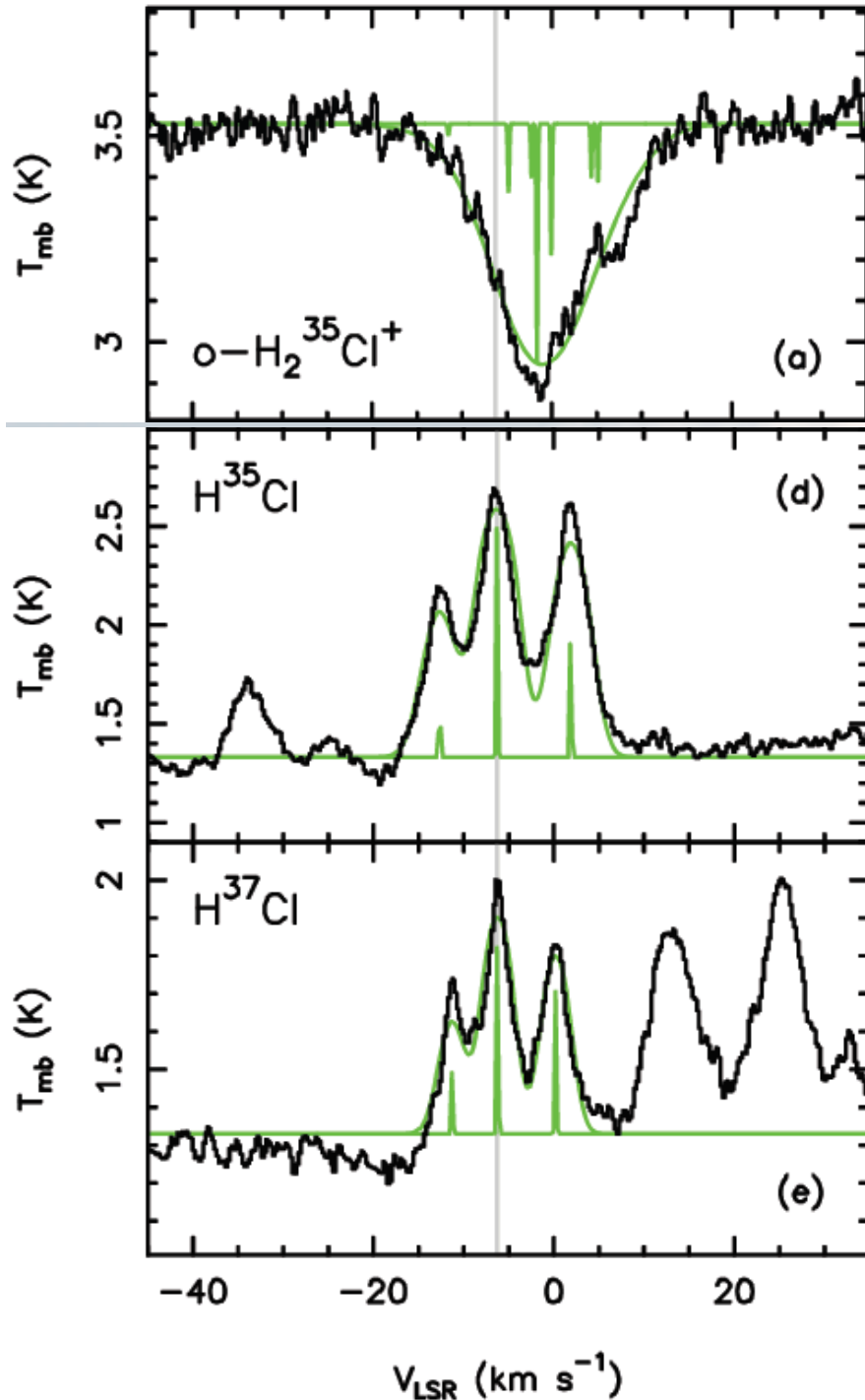
- In *dense* PDRs the HCl/H<sub>2</sub>Cl<sup>+</sup> ratio can exceed 100 for densities above  $10^6 \text{ cm}^{-3}$
- In *diffuse* clouds the HCl/H<sub>2</sub>Cl<sup>+</sup> column density ratio of order 1–10 for  $A_V \leq 3$ , depending on  $\chi_{UV}$

# Detection of Chloronium



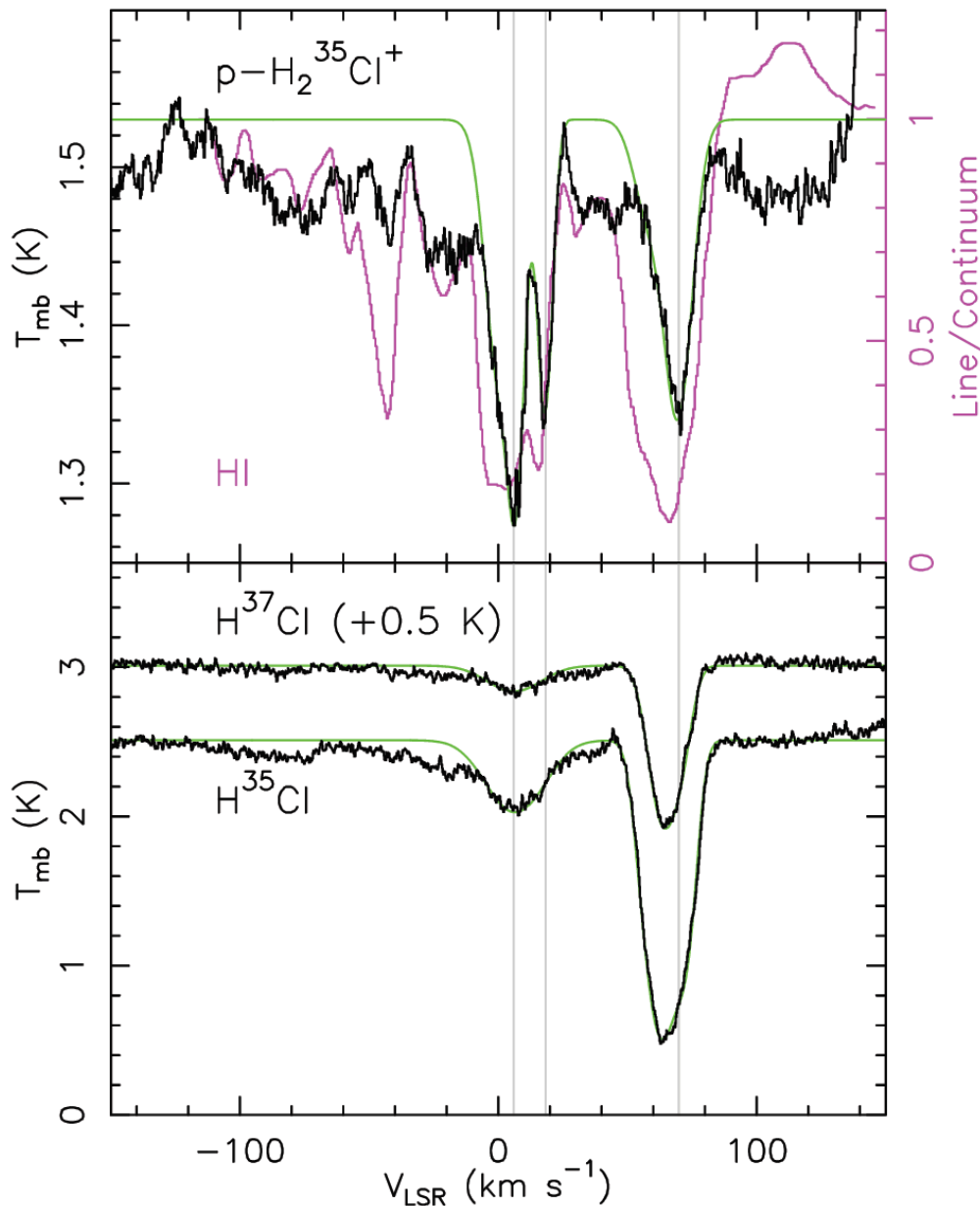
- Strong absorption at 781 GHz in the Band 2b spectral scan of NGC6334 identified as  $o\text{-H}_2\text{Cl}^+$
- Equivalent lines of  $o\text{-H}_2\text{}^{37}\text{Cl}^+$  line at 780 GHz and a  $p\text{-H}_2\text{Cl}^+$  line at 485 GHz also identified, blended with  $\text{CH}_3\text{OCH}_3$  emission
- Other lines of  $\text{CH}_3\text{OCH}_3$  in the same band, with *similar upper level energies* used to subtract the contamination

# $H_2Cl^+$ vs. HCl



- HCl is a chemically related species
- HCl and  $H^{37}Cl$  seen *in emission* at the hot core velocity,  $-6.3\ km\ s^{-1}$ ; narrow line widths  $4.1/3.3\ km\ s^{-1}$
- HCl lines moderately optically thick—can determine excitation temperature and column density
- $H_2Cl^+$  absorption in NGC 6334I centered at  $-1.7\ km\ s^{-1}$  with a line width of  $11.6\ km\ s^{-1}$
- $H_2Cl^+$  absorption originates in a physically different region than HCl emission
- Diffuse, UV-irradiated foreground gas (same as  $H_2O^+$ ?)

# Sgr B2(S)

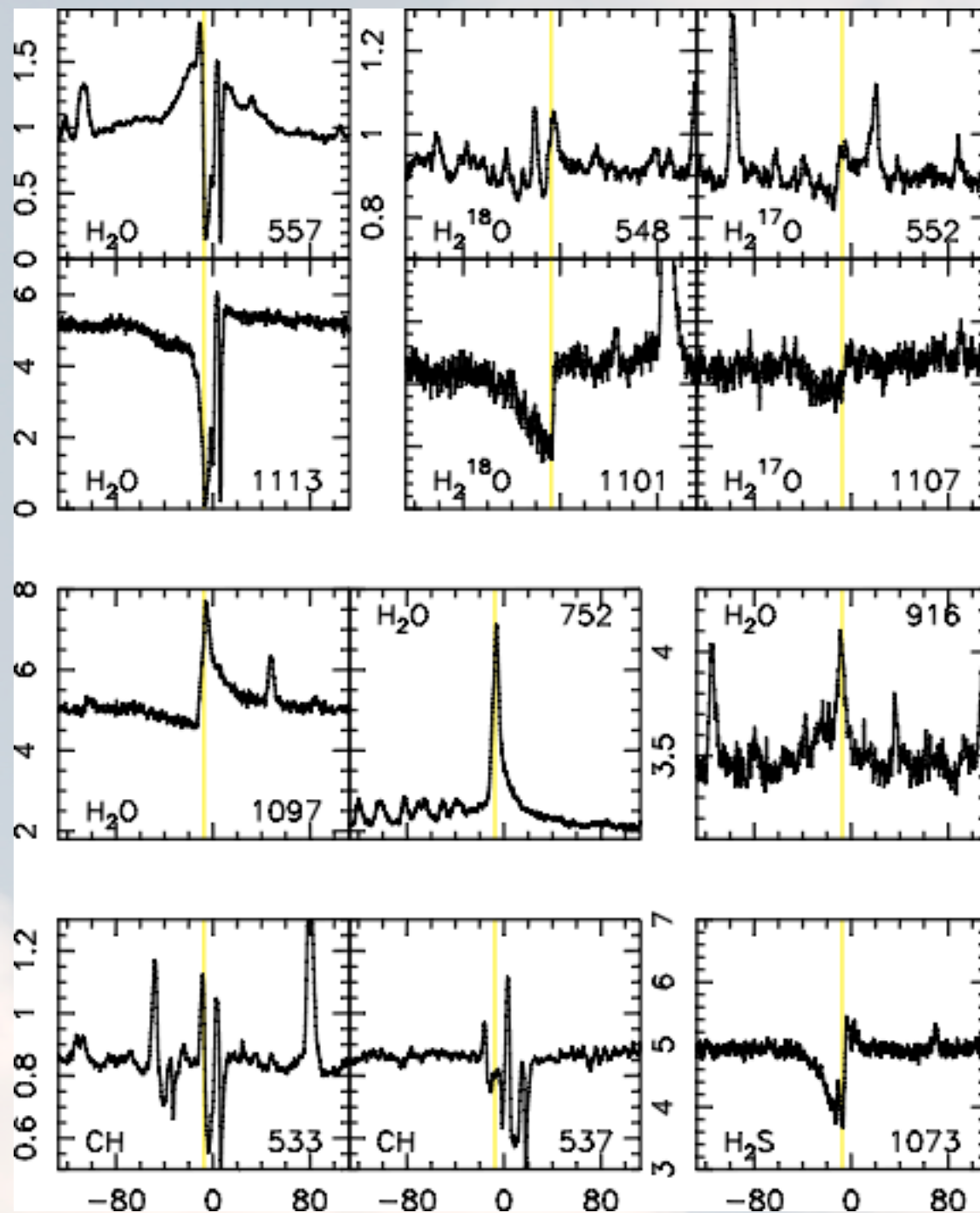


*HOP and HEXOS Data*

- Observed  $\text{H}_2\text{Cl}^+$  column densities: a few  $\times 10^{13} \text{ cm}^{-2}$
- Two orders of magnitude higher than model predictions for normal incidence
- Limb brightening? Multiple PDRs on the line of sight?
- Measured  $\text{HCl}/\text{H}_2\text{Cl}^+$  column density ratio in a pencil beam  $\sim 10$  in NGC 6334I and Sgr B2(S) envelope; within the range predicted for dense PDRs
- Measured  $\text{HCl}/\text{H}_2\text{Cl}^+$  column density ratio in the foreground gas near  $0 \text{ km s}^{-1}$  toward Sgr B2(S)  $\sim 1$ ; consistent with predictions for diffuse clouds



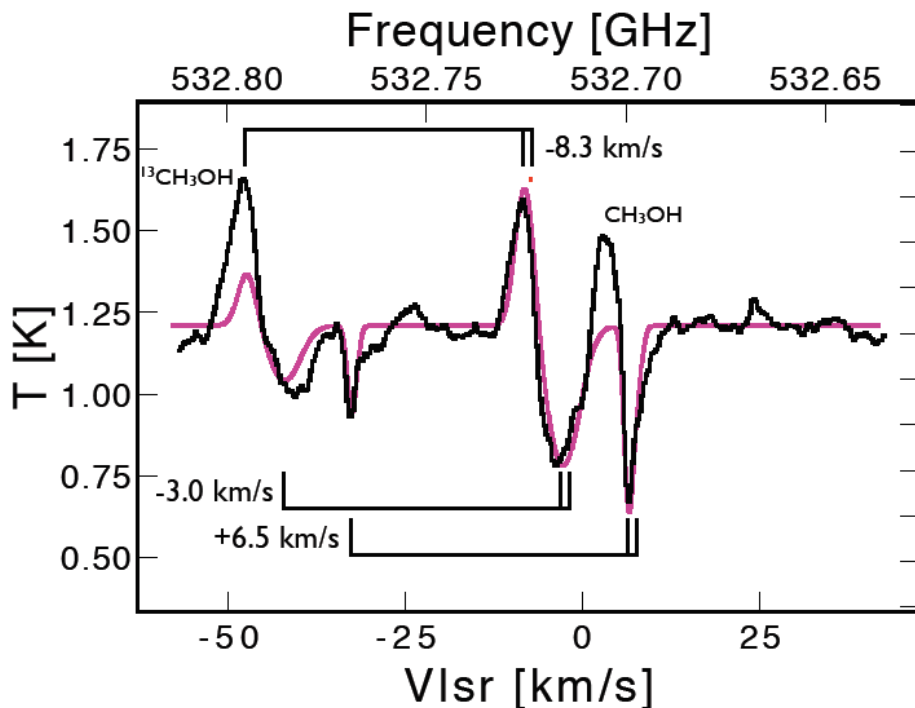
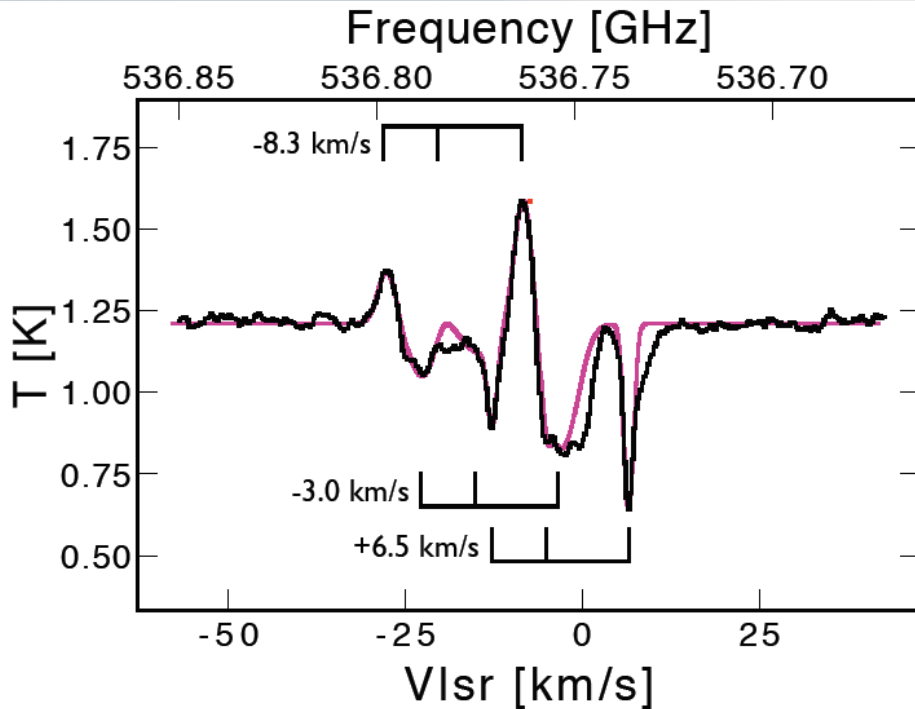
# NGC 6334I: Foreground Absorption and Outflow



- Preliminary analysis indicates low water o/p ratio in the foreground gas
- Prominent absorption in the blue lobe of the outflow (e.g.,  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{S}$ )
- Warm outflow:  $3_{12}-3_{03}$  absorption ( $E_l=197$  K)
- Water emission from the hot core gas

*Emprechtinger et al.*

# NGC 6334I: CH



- Another hydride showing prominent absorption is CH
- Two lines at 537 and 533 GHz detected in the Band 1a survey
- Emission at the hot core velocity
- Several foreground absorption components with low excitation temperature ( $6.5 \text{ km s}^{-1}$ ,  $-3 \text{ km s}^{-1}$ ; different from  $\text{H}_2\text{Cl}^+$ , but similar to ground state water lines)
- Both cold and warm, UV irradiated foreground gas components seen in absorption toward NGC 6334I

*van der Wiel, van der Tak et al.*

# Summary

- HIFI is providing a comprehensive view of the Molecular Universe, not obscured by the Earth's atmosphere
- Unbiased spectral line surveys are the key for investigations of the chemical complexity of ISM sources (new species, e.g.,  $\text{H}_2\text{O}^+$ ,  $\text{H}_2\text{Cl}^+$ )
- Absorption spectroscopy allows observations of light hydrides and deuterides in the foreground gas (e.g.  $\text{CH}$ ,  $\text{H}_2\text{O}$ )
- With good understanding of the *chemistry* we can select proper tracers of the underlying *physics*
- NGC6334 line survey: We have only scratched the surface
- Thank you HIFI Team!