HEXOS: Analysis of the HIFI 1.2 THz Wide Spectral Survey Toward Orion KL

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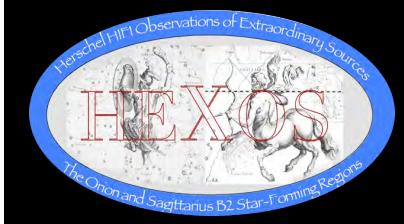
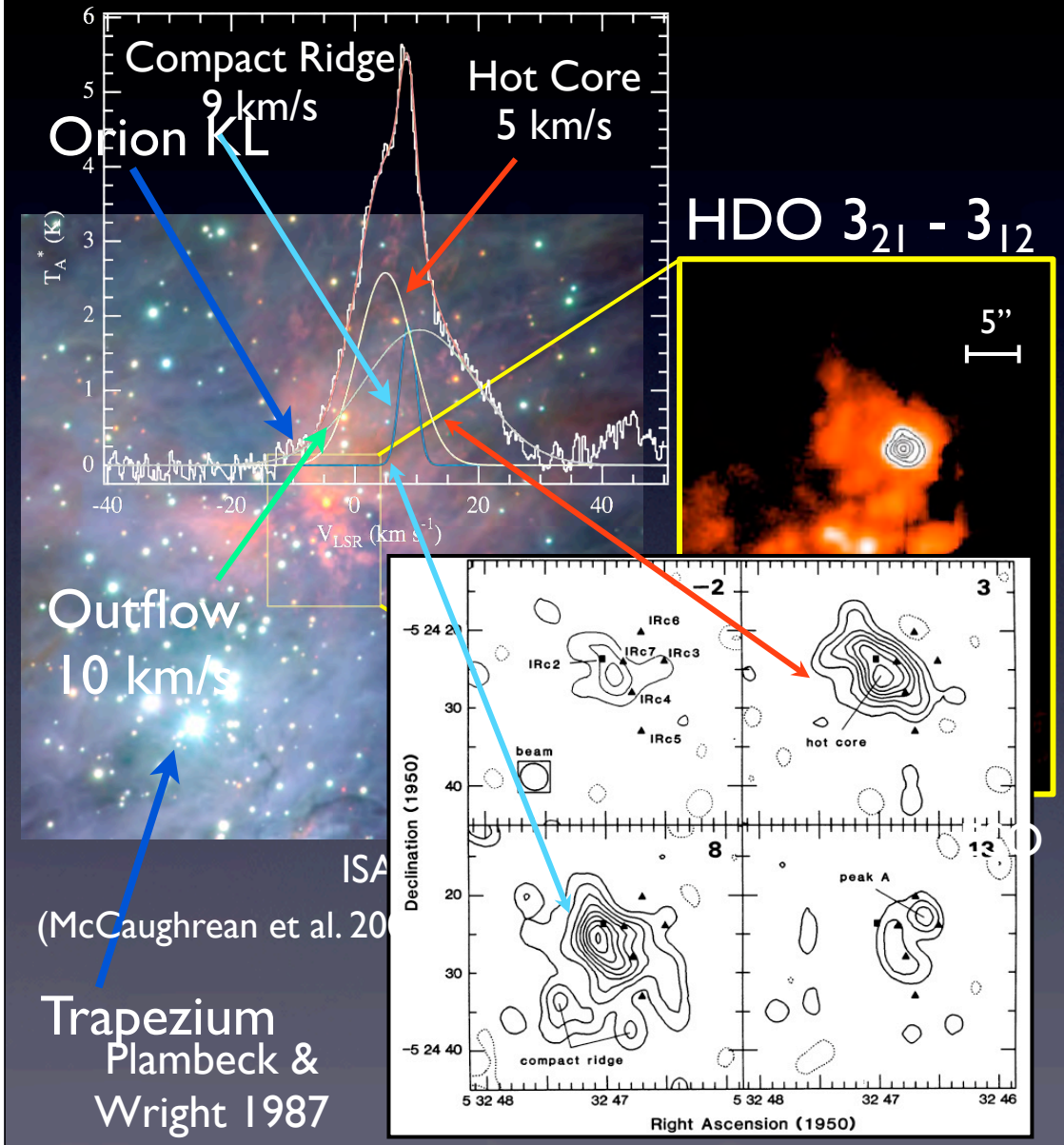


Herschel observations of EXtra-Ordinary Sources

- EXtra-Ordinary Sources: the Orion and Sagittarius B2 molecular clouds
- Main focus of HEXOS is to investigate the chemical and physical processes prevalent within the wide variety of environments found in star forming regions.
- As part of the HEXOS key program, a full HIFI spectral scan of Orion KL was obtained

Orion KL: A Brief Overview



- Massive star forming region located 2' NW of the Trapezium (Kleinmann & Low 1987)
- It is the brightest region within the OMC in the far IR
- Complex spatial/velocity structure
- One of the most chemically rich sources in the galaxy

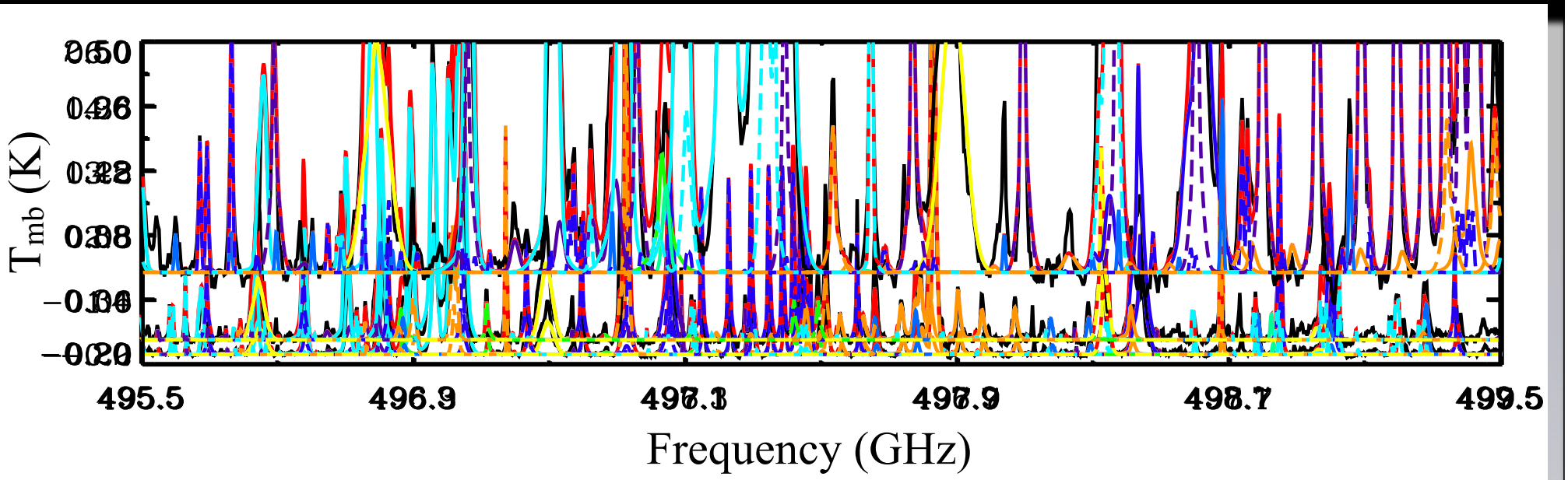
Analysis

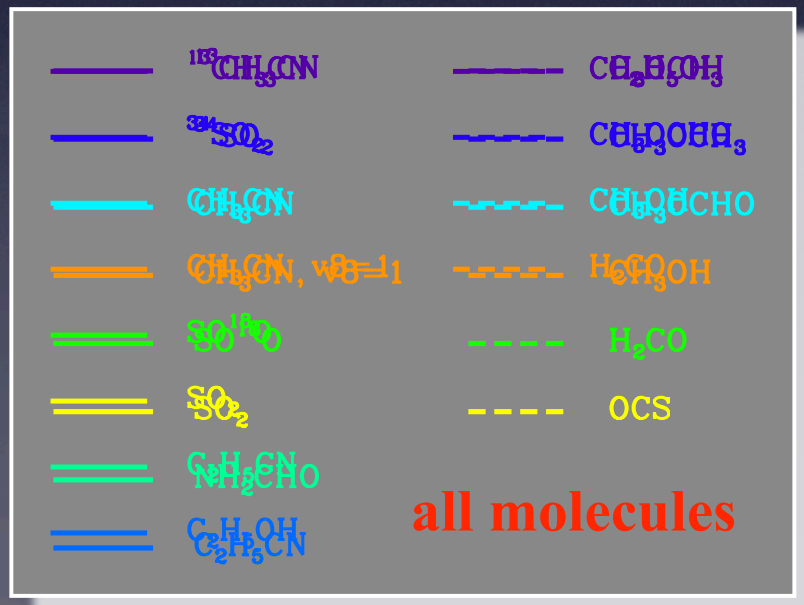
- Holistically characterize the HIFI spectrum of Orion KL
- Our analysis indicates ~$2x10^4$ spectral features present in the Orion KL HIFI spectrum from over 30 molecules
- Each detected molecule/isotopologue needs to be modeled/ analyzed one at a time
- Divided the labor (molecules) among ~15 people
  - Each person modeled several molecules
- Analysis tools:
  - XCLASS - LTE
  - MADEX or RADEX - LVG code

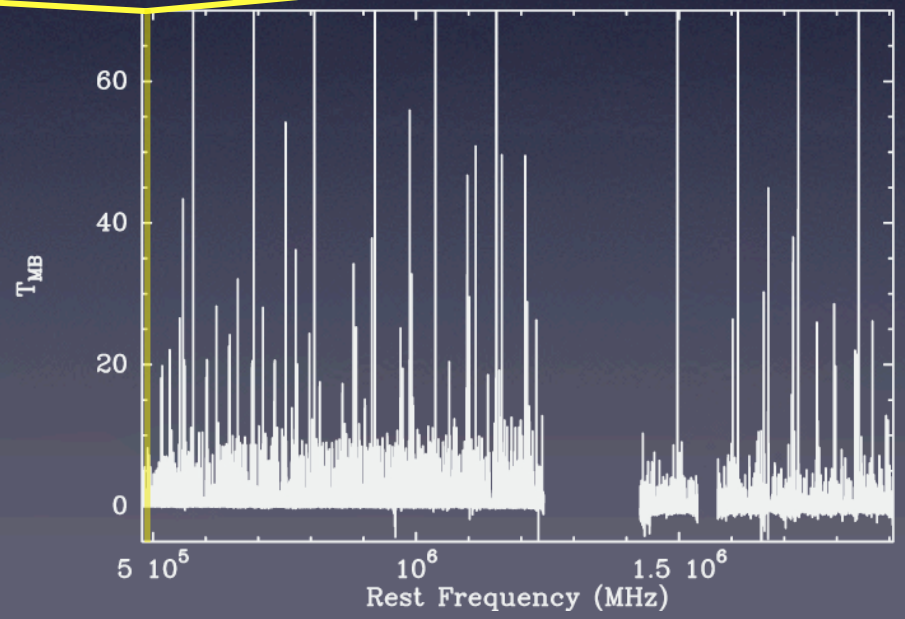
Currently Modeled Molecules

- NH_2CHO
- SiS
- C_2H_5OH
- H_2CS
- NO
- NS
- SO, ^{34}SO, ^{33}SO, $S^{18}O$
- SO_2, $^{34}SO_2$, $^{33}SO_2$
- HCN, $H^{13}CN$, $HC^{15}N$
- HNC, $H^{15}NC$, $HN^{13}C$
- SiO
- CH_3CN, $^{13}CH_3CN$, $CH_3{}^{13}CN$
- NH_3, $^{15}NH_3$, NH_2D
- HCl, $H^{37}Cl$
- H_2S, $H_2{}^{33}S$, $H_2{}^{34}S$
- H_2CO, $H_2{}^{13}CO$, HDCO
- $HCOOCH_3$
- CCH
- CN
- HC_3N
- H_2O, HDO, $HD^{18}O$, D_2O, $H_2{}^{18}O$, $H_2{}^{17}O$
- CH_3OH, $^{13}CH_3OH$, CH_3OD, CH_2DOH
- C_2H_5CN
- HNCO, $HN^{13}CO$
- HCS^+
- H_2CCO
- OCS
- CH_3OCH_3
- CS, $C^{34}S$, $C^{33}S$, ^{13}CS
- CO, ^{13}CO, $C^{17}O$, $C^{18}O$
- HCO^+

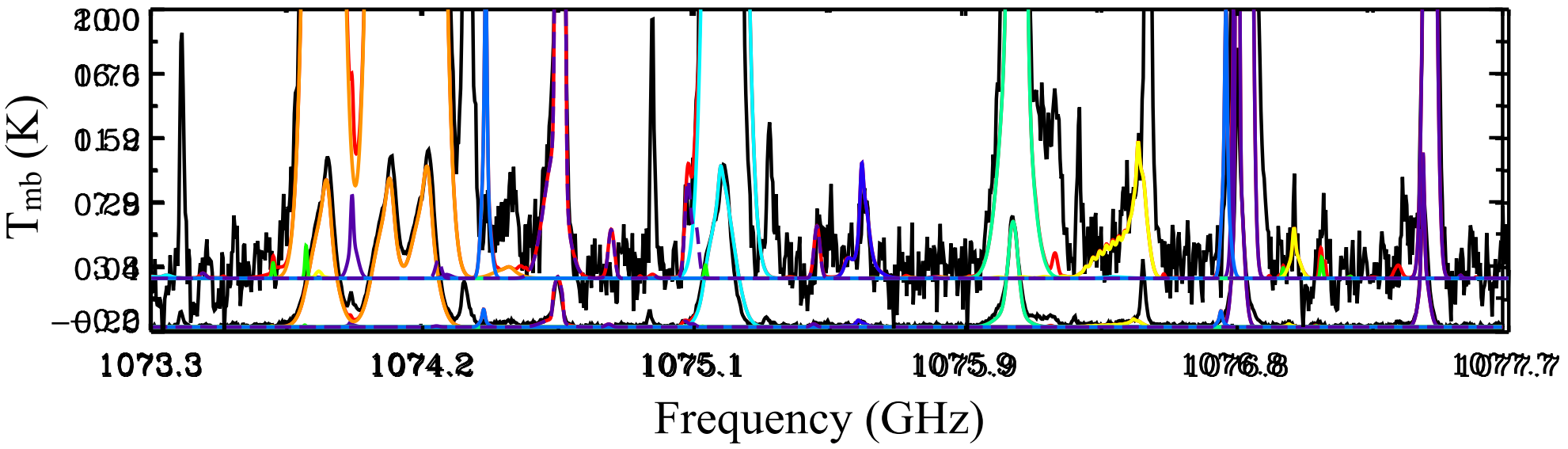
Full Band Model - Band 1a







Full Band Model - Band 4b



CH_3OH ---- HNCO

$^{33}SO_2$

SO_2

SO

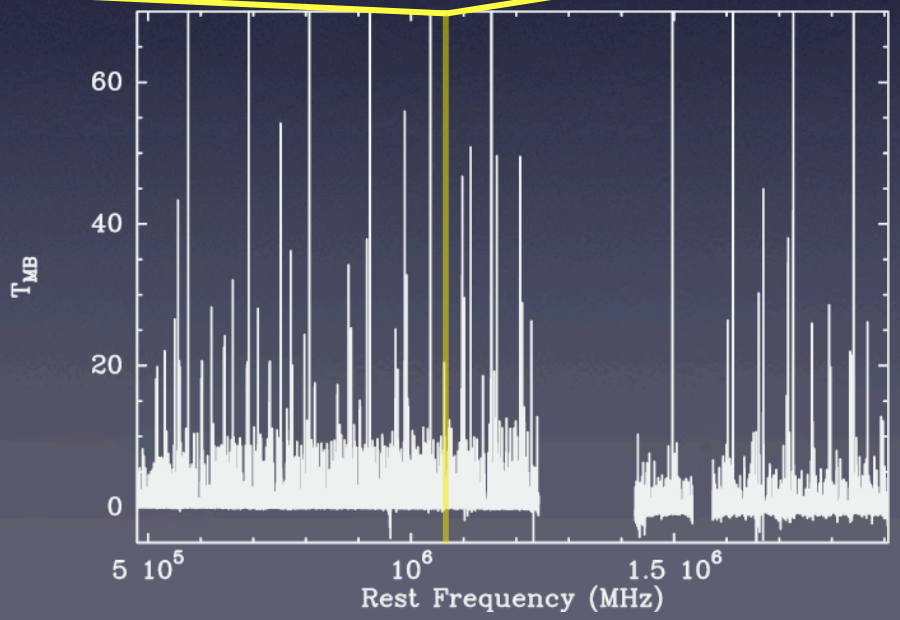
C_2H_5OH

CH_3OCH_3

CS

H_2CS

all molecules



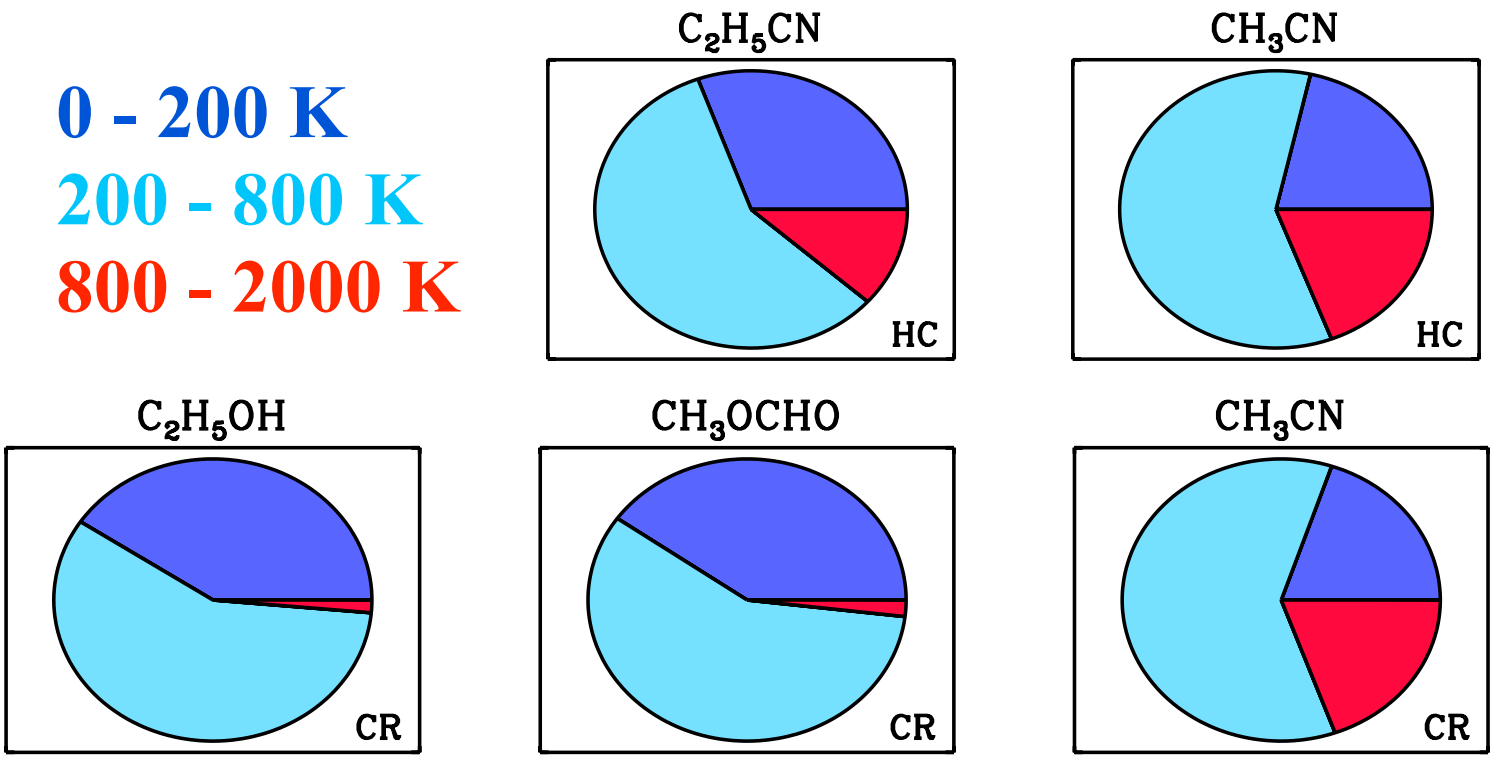
Hot Molecular Gas

- Constrained the emission over a large energy range
  - High energy transitions (E_{up}>800 K) - determine which molecules are emitting in the hottest gas.
- Complex organics emitting in hotter gas may represent molecules that are harder to evaporate off the grains.
- In order to identify those species, we computed the fractional emission emitted at different upper state energies.

Hot Molecular Gas

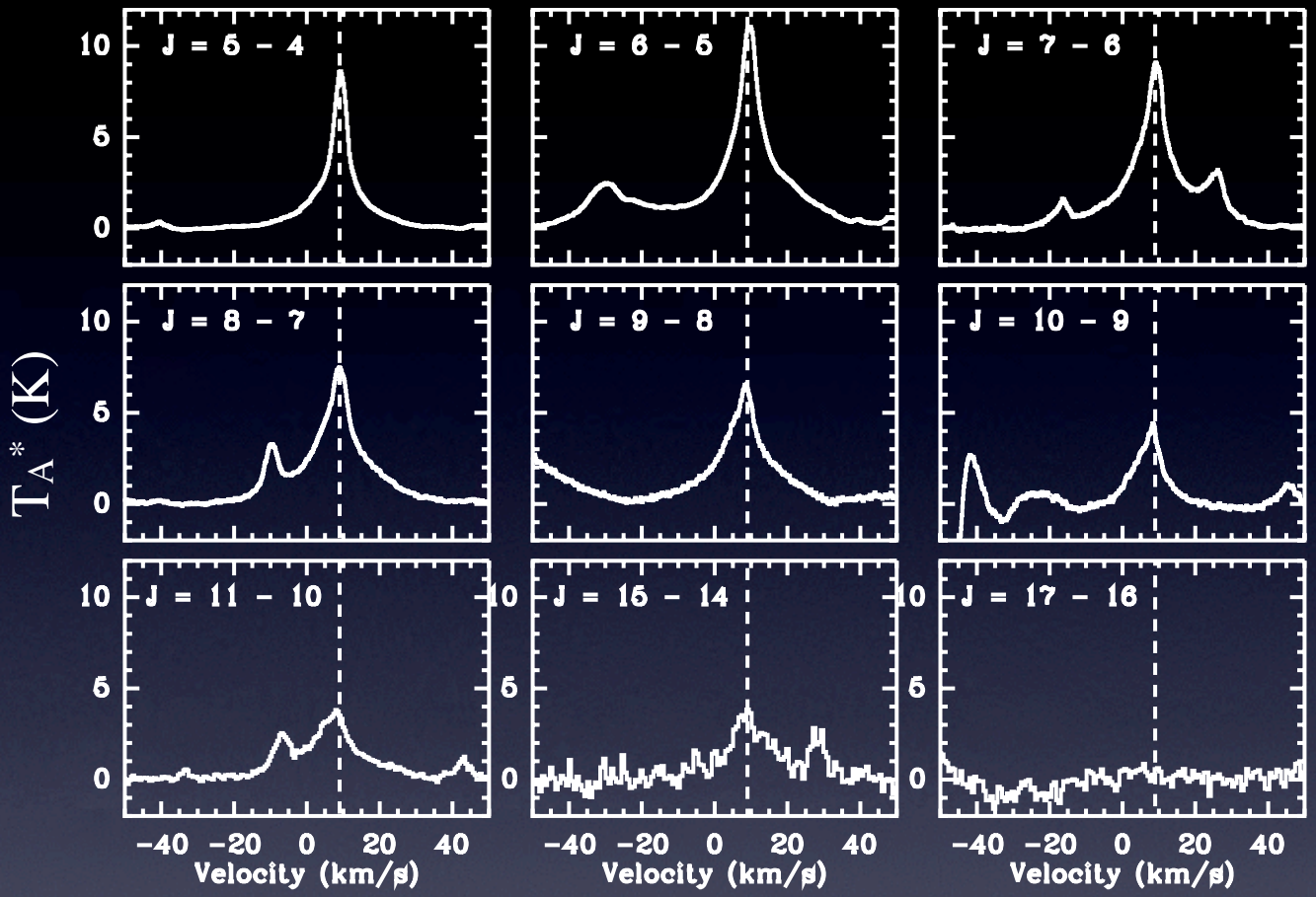
Hot Core

Compact Ridge



- C_2H_5CN and CH_3CN show significant emission from energy states > 800K indicating that it is probing the hottest gas
- C_2H_5OH and CH_3OCHO are probing cooler regions

$C^{18}O$ - Gas Column Density Probe



$N_u \propto \int T dv$

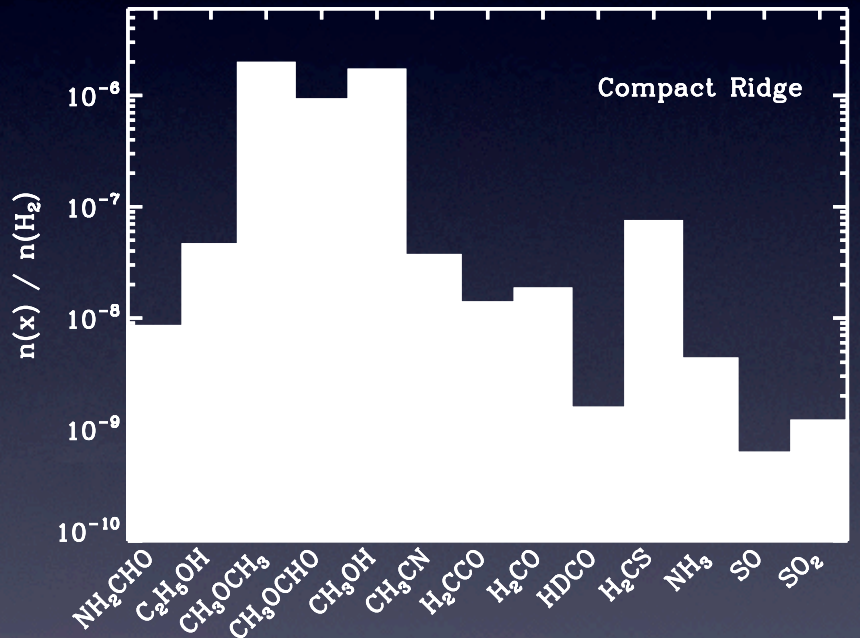
$N_{tot} = CF(T) \times \Sigma N_u(J)$

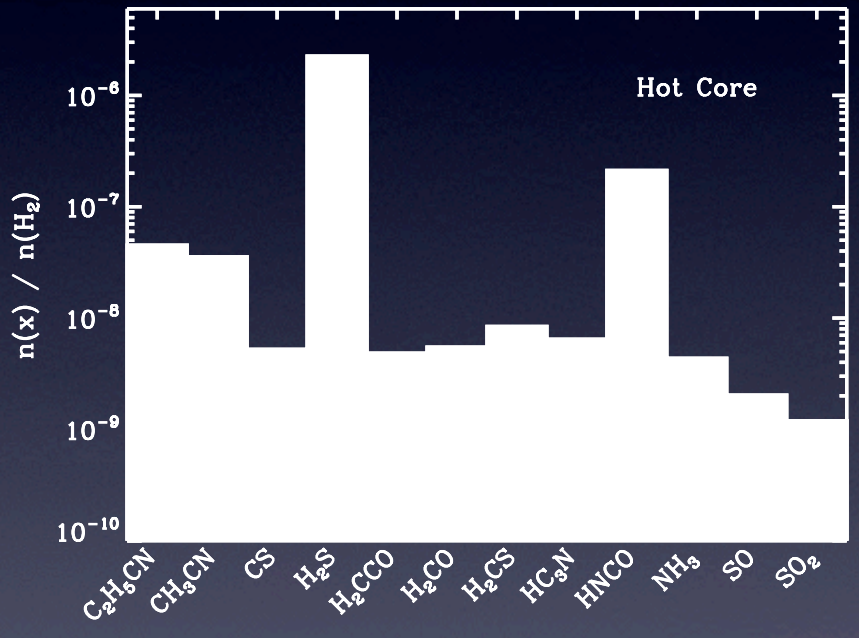
Use $N(C^{18}O)$ to derive $N(H_2)$ toward different compoents

Plume et al. (2012)

- Large frequency coverage - directly measure column density by summing upper state columns.
- e.g. $C^{18}O$ - 7 transitions from HIFI, combined with 3-2 and 2-1 transitions from the CSO.

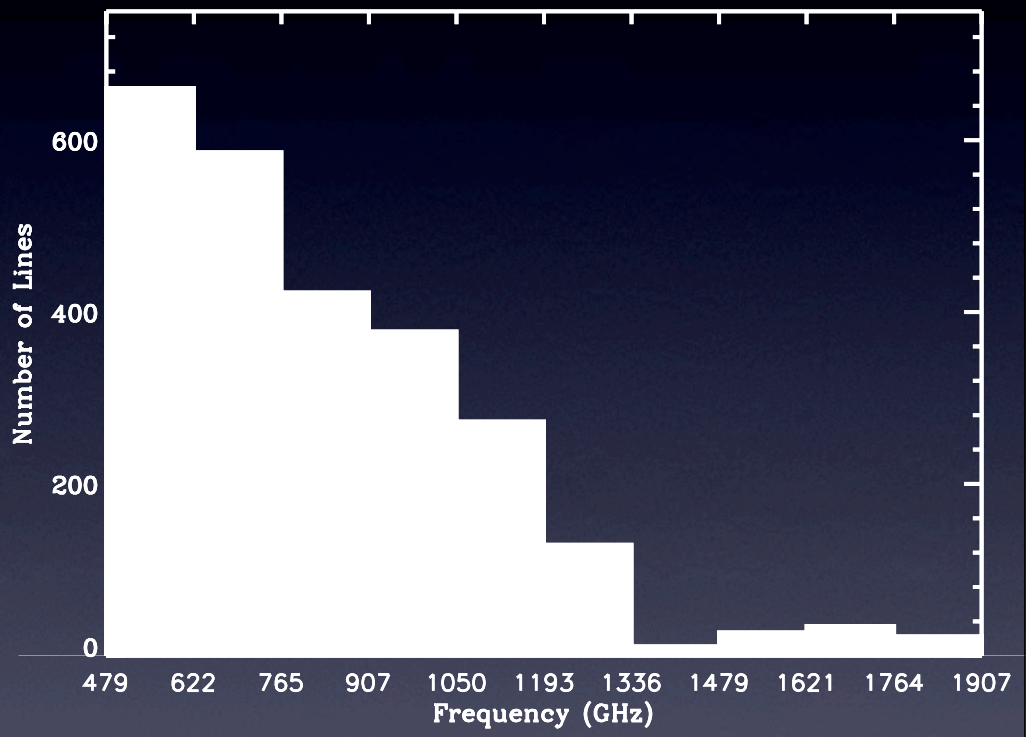
Orion KL Abundances





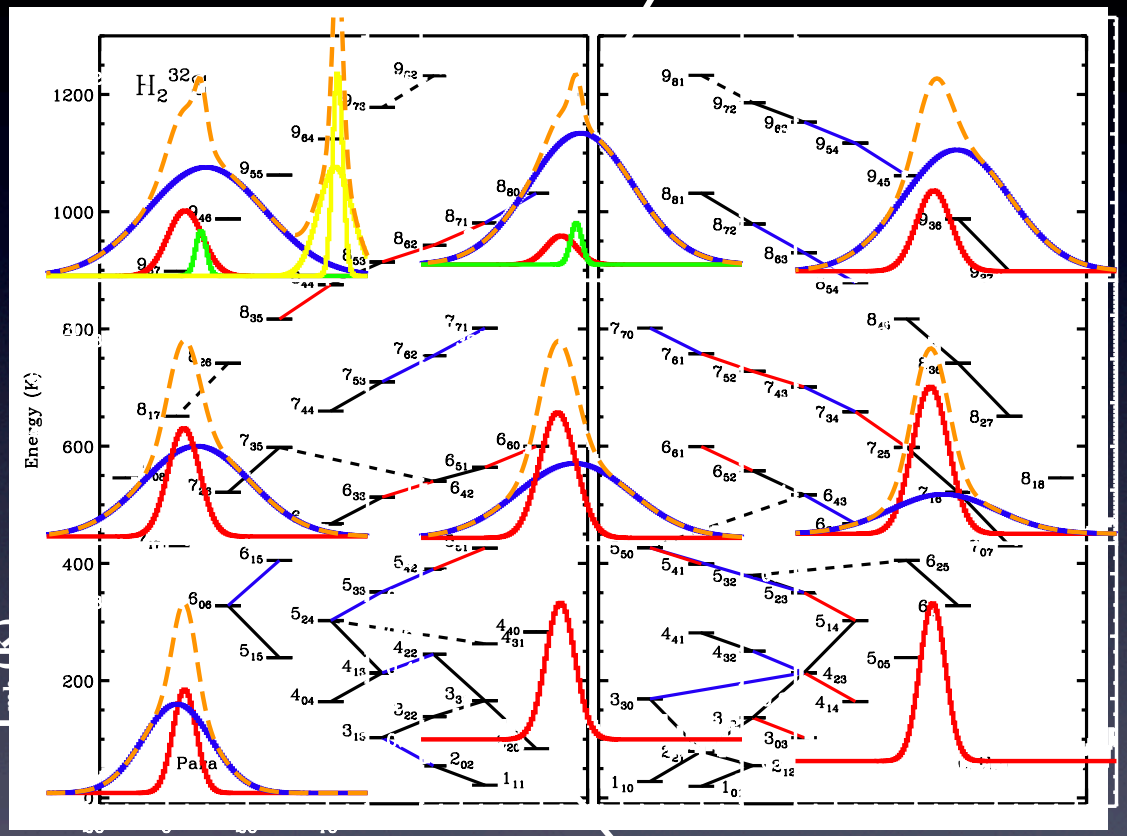
Unidentified Lines

- Residual of data and model provides a U Line spectrum
- We estimate ~12,700 channels in emission from U lines (>3x RMS noise level, data smoothed to ~1 km/s)
- Corresponds to ~2500 U lines (line width 5 km/s)
- Full band model: ~2×10^4 identified features
- U line fraction ~10%



H_2S, Probe of Dense Gas in the Hot Core

Gaussian Fits

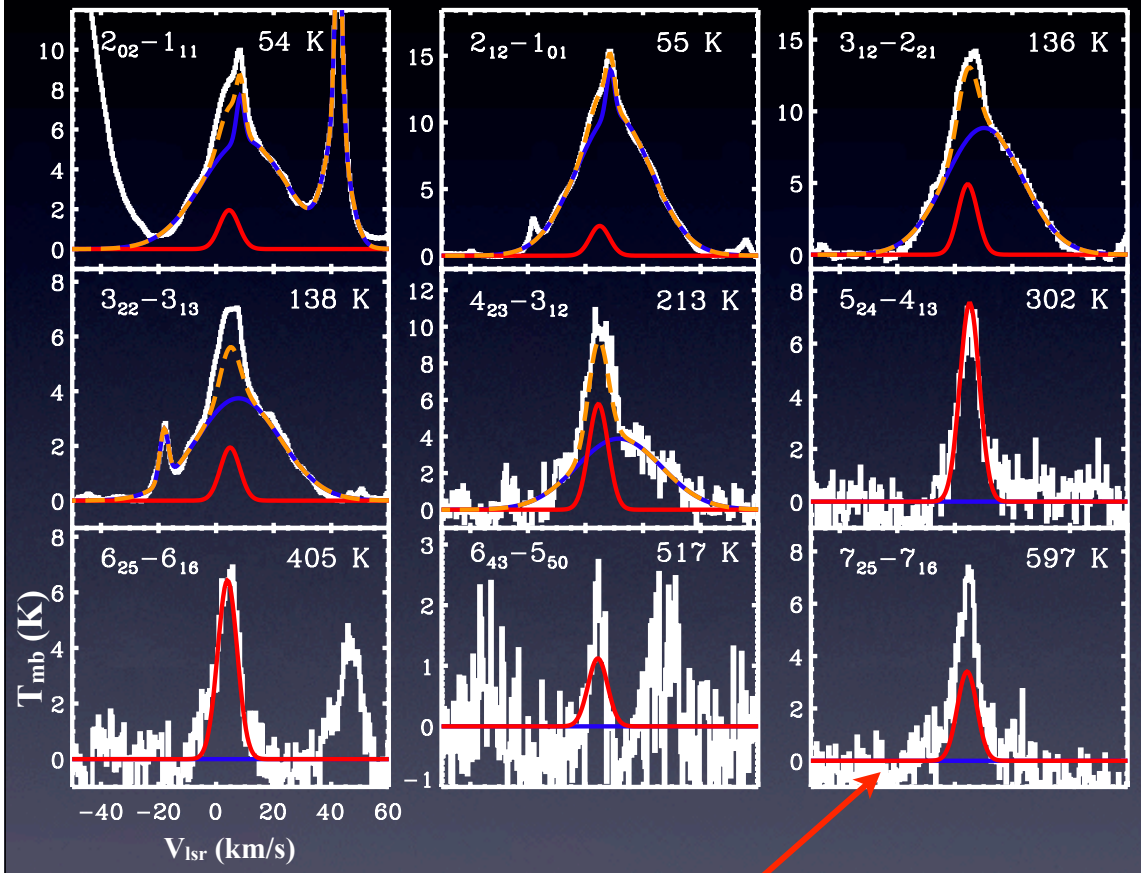


clean line
slightly blended
heavily blended
weak (dashed)

Hot Core
Outflow
Extended Ridge
Blending lines
Total fit

- H_2S is a light hydride that shows highly excited emission toward the hot core
- Probing very dense gas closest to a central protostar?
- We observe 70 transitions of $H_2{}^{32}S$ spanning E_{up} 50 - 1200 K
- Also observe $H_2{}^{34}S$ (40 lines) and $H_2{}^{33}S$ (19 lines)
- Directly constrain the column density, $N(H_2{}^{32}S)=7\times10^{17}$ cm^{-2} (9% of S available in ISM)

H_2S, Probe of Dense Gas in the Hot Core



- Use RADEX to model the hot core emission
- Estimate collision rates scaled from H_2O
- Highest energy levels (E_{up}>800K) are heavily coupled to the radiation field
- Simultaneously fit only lines with E_{up}<600K where collisions dominate
- Best fit: θ=5", $n(H_2)=1.3\times10^9 cm^{-2}$, T_{kin}=100K

Summary

- We've modeled over 60 molecular species in the HIFI spectral scan toward Orion KL
- Some complex organics probe very hot gas (e.g. C_2H_5CN and CH_3CN) while others probe cooler regions (e.g. C_2H_5OH and CH_3OCHO)
- We've derived preliminary abundances based on $N(H_2)$ estimates derived from the same data set
- U line fraction ~10%
- Detailed analysis of H_2S emission toward the hot core indicates that it is probing very dense gas (~10^9 cm^{-2})