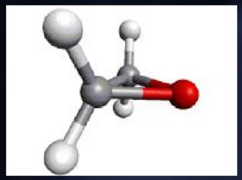
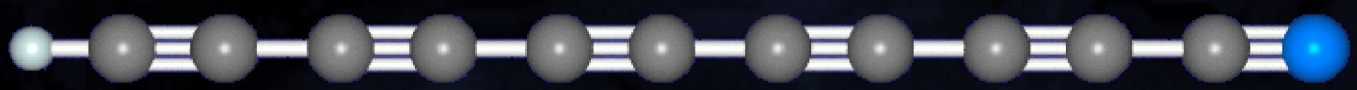
Molecular Spectroscopy with SKA





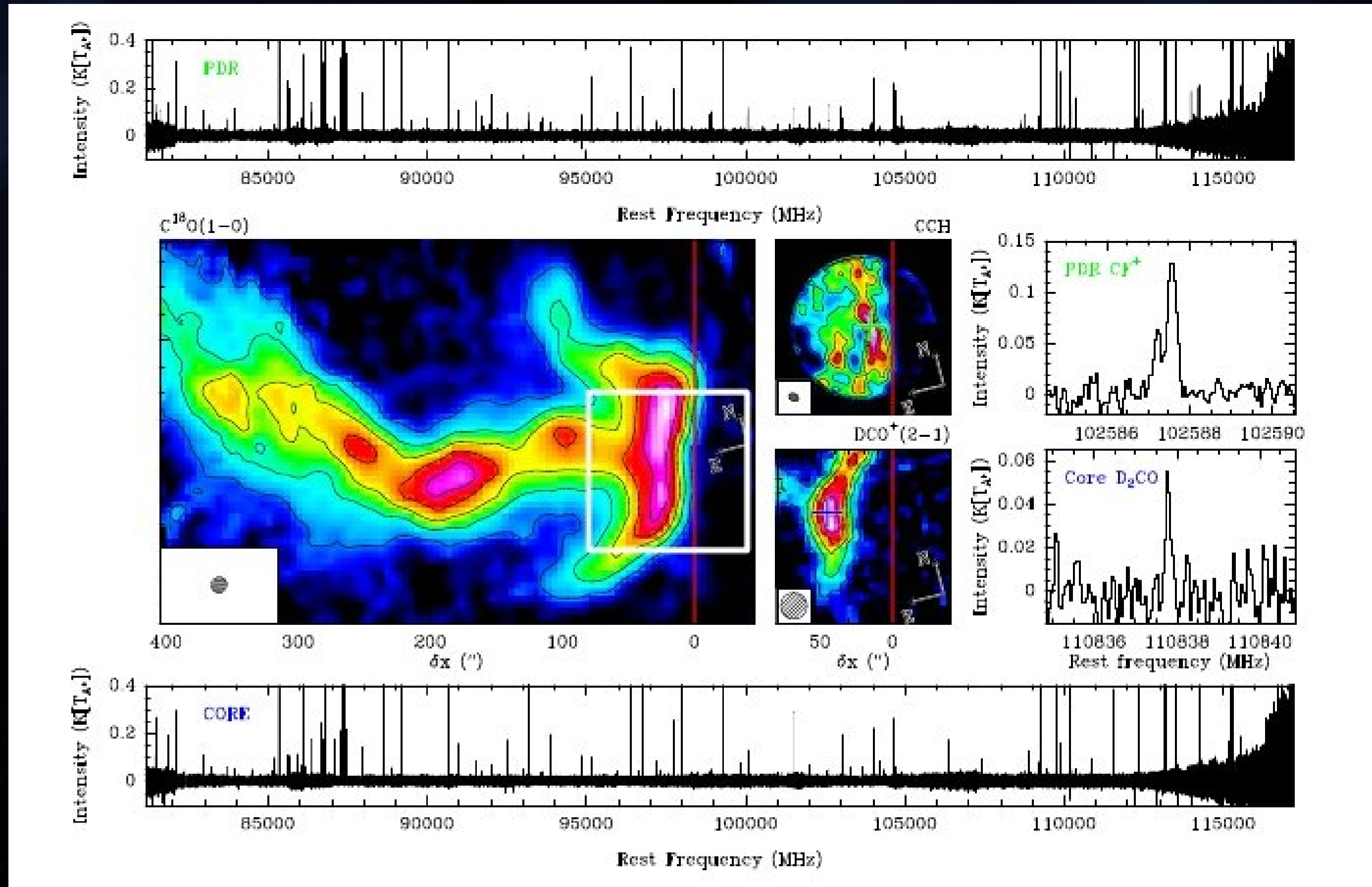




What are the pathways from atoms to simple diatomics to complex species ?

What is the interplay between gas phase and solid phase synthesis ?

What is the origin of organic matter in solar system and how is it related to the ISM ?
(meteorites, comets, planets & satellites)



Pety et al, 2013, IRAM-30m & PdBI

- Over 170 species, most detected in the radio (cm to submm) domain ; not including isotopologues

- Molecular line spectra depend on the environment : molecular abundances vary depending on the source properties & history

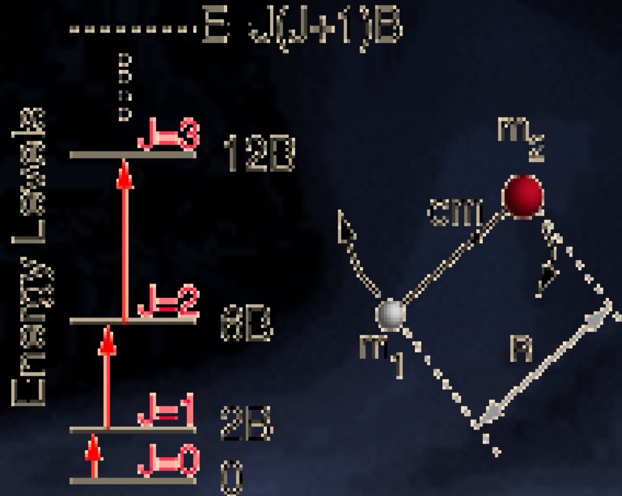
Molecules in the Interstellar Medium or Circumstellar Shells (as of 11/2012)

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
H_2	C_3 *	c-C_3H	C_5 *	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N	HC_9N	c-C_6H_6 *	$HC_{11}N$
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	HC(O)OCH_3	CH_3CH_2CN	$(CH_3)_2CO$	CH_3C_6H	$C_2H_5OCH_3$?	C_{60} * 2012
AlCl	C_2O	C_3N	C_4Si	C_2H_4*	CH_3C_2H	CH_3COOH	$(CH_3)_2O$	$(CH_2OH)_2$	C_2H_5OCHO	n-C_3H_7CN	C_{70} *
C_2**	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH	CH_3CH_2CHO			
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	CH_3CHO	C_6H_2	HC_7N				
CH^+	HCN	C_2H_2*	H_2CCN	CH_3OH	CH_3NH_2	CH_2OHCHO	C_8H				
CN	HCO	NH_3	CH_4 *	CH_3SH	c-C_2H_4O	l-HC_6H *	$CH_3C(O)NH_2$				
CO	HCO^+	HCCN	HC_3N	HC_3NH^+	H_2CCHOH	CH_2CHCHO (?)	C_8H^-				
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO	C_6H^-	CH_2CCHCN	C_3H_6				
CP	HOC^+	HNCO	HCOOH	NH_2CHO		H_2NCH_2CN					
SiC	H_2O	HNCS	H_2CNH	C_5N							
HCl	H_2S	$HOCO^+$	H_2C_2O	l-HC_4H *							
KCl	HNC	H_2CO	H_2NCN	l-HC_4N							
NH	HNO	H_2CN	HNC_3	c-H_2C_3O							
NO	MgCN	H_2CS	SiH_4 *	H_2CCNH (?)							
NS	MgNC	H_3O^+	H_2COH^+	C_5N^-							

Molecular Spectroscopy with SKA

A few basic numbers :

Rotational lines → The line frequencies scale with the rotational constant B α h/I (α 1/μ for a diatomic species) where I the the inertia momentum and μ is the reduced mass



CO : B = 57 GHz

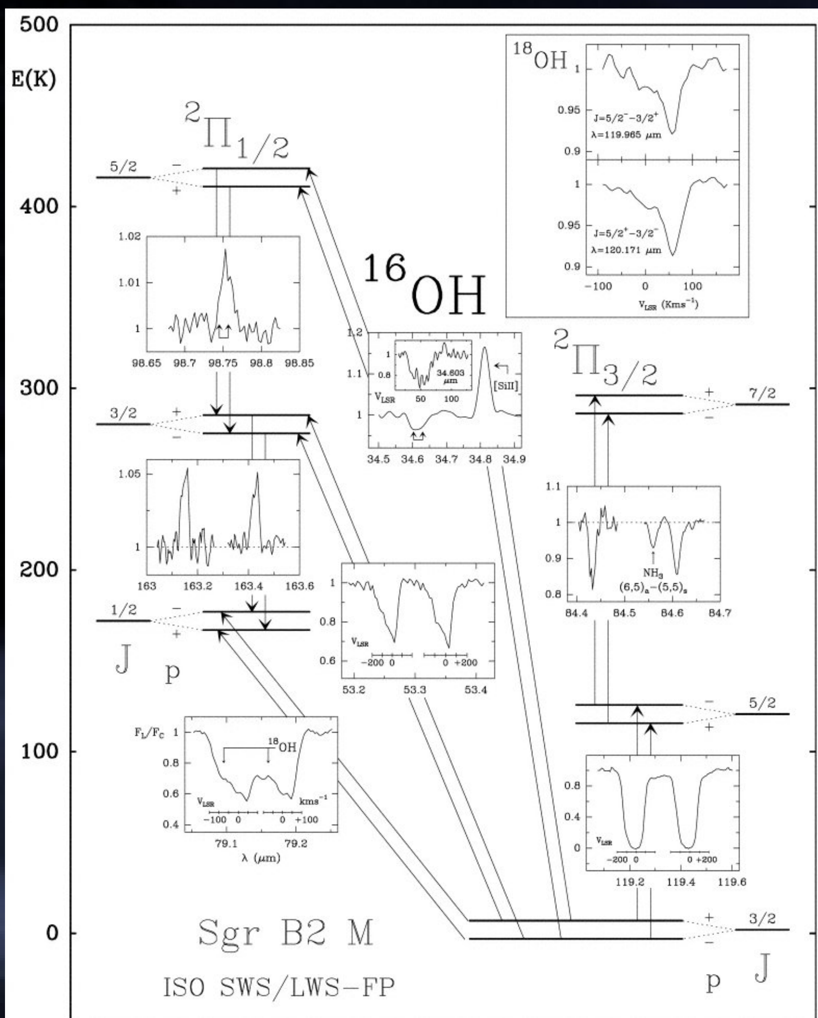
HC_3N : B = 4.5 GHz

$HC_{11}N$: B = 0.17 GHz

Rotational transitions in the SKA baseline domain → « heavy molecules » with B ~ few GHz

Molecular Spectroscopy with SKA :

Other types of molecular transitions



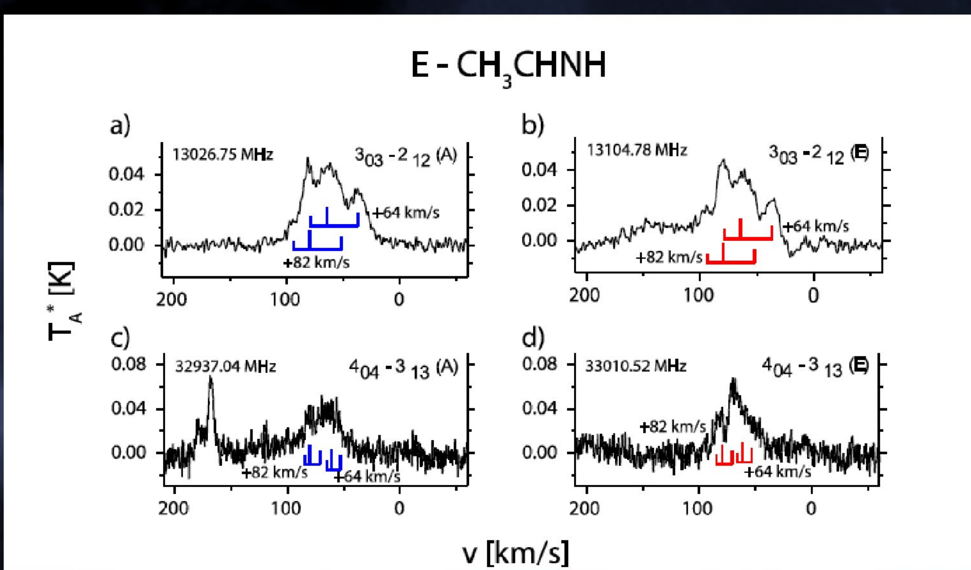
- Rotational level splitting due to couplings of rotation with other properties (eg fine, hyperfine structure, Λ doubling, etc.)

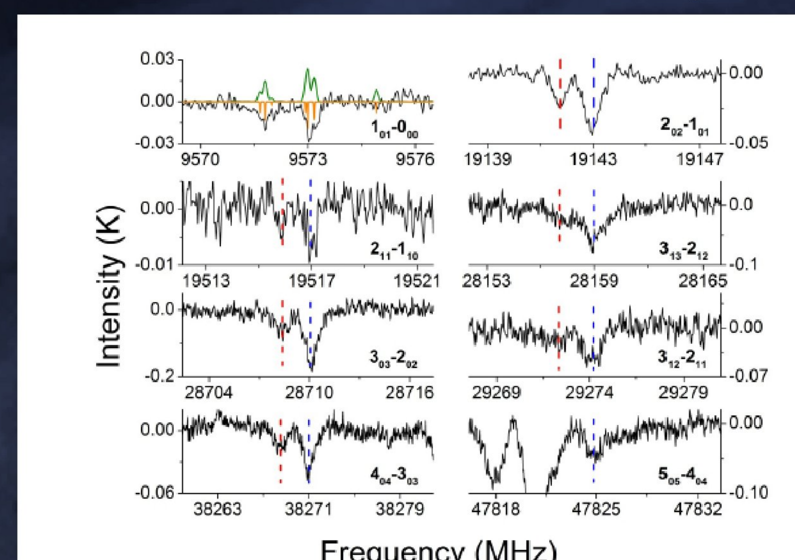
- Relatively low energies → transitions at GHz frequencies

Examples : OH , CH , NH_3

Lessons from spectral surveys

- Arecibo 4-6 GHz & 8-10 GHz (Kalenskii et al 2004)
  - needs <5mK sensitivity.
  - The line density is higher in the 8 - 10 GHz window and above.
- GBT PRIMOS (A. Remijan et al) 0.5 – 50 GHz
  - Several detections of new species towards SgrB2 (ethanimine, E-cyanomethanimine E-NHCHCN)



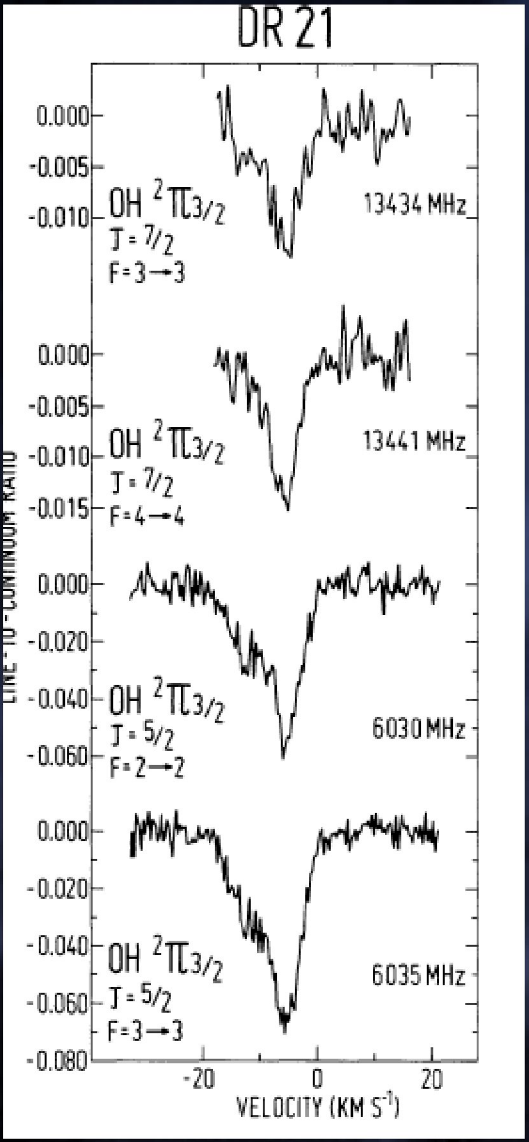


Sensitivity issues

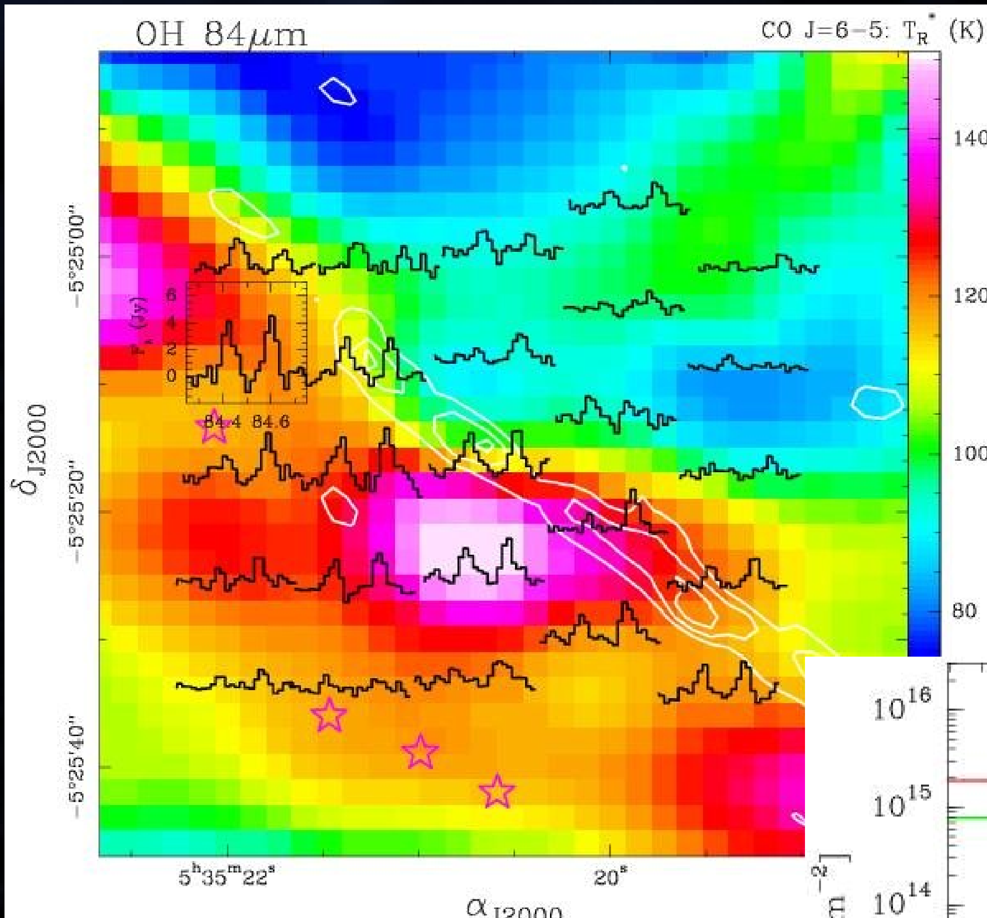
- Thermal emission & line strengths
  - Brightness temperature limited by the kinetic/excitation temperature : 5 - 300 K
  - Small source sizes for complex molecules & warm regions : few arcsec
  - Line width : few km/s → high spectral resolution
  - Non LTE effects, masers
- Most suitable windows for complex species above 10 GHz
- NB : Even with the VLA imaging NH3 at high spatial resolution is not easy (Conf C with 0.9'' 2mJy or 6 K rms at 0.2 km/s resolution in |5 hr)

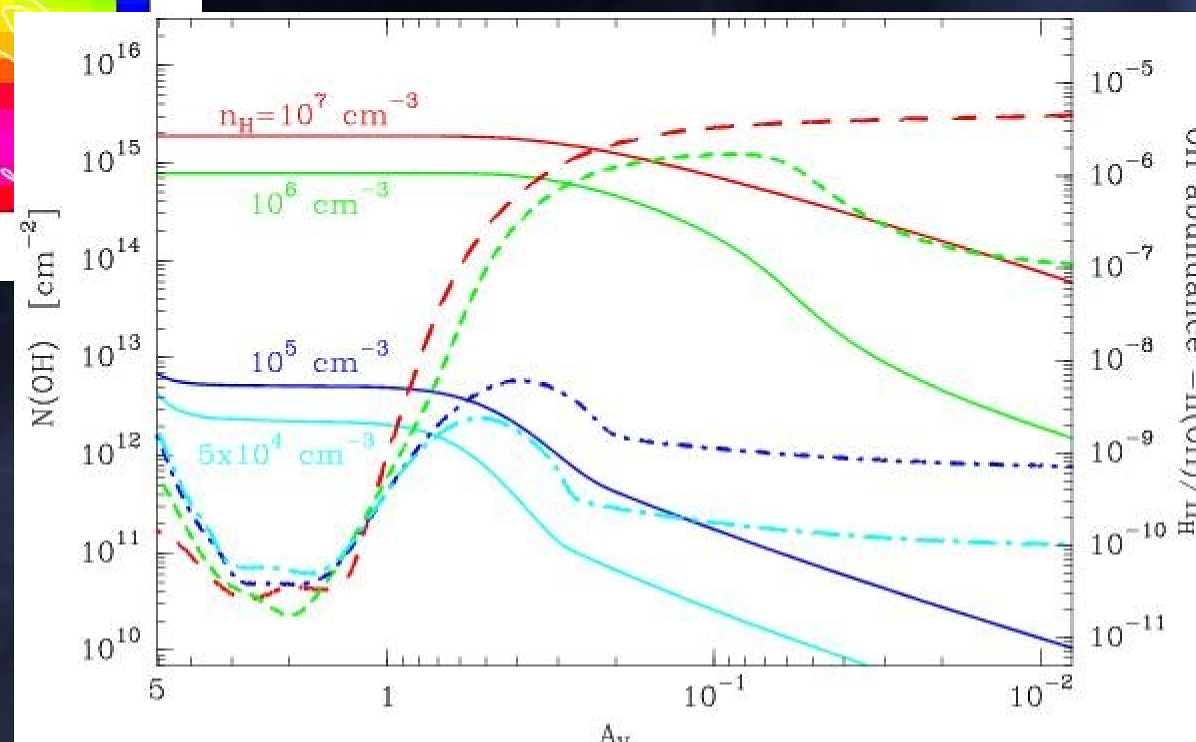
A few important spectral diagnostics below 8 GHz

- OH 1.7 GHz (ground state) + excited lines (6 GHz, 13 GHz)
  - From diffuse to dense molecular gas + Masers & mega-masers
  - A good probe of H_2O desorption (e.g. PDRs, comets)
- CH 3.3 GHz
  - A good probe of diffuse molecular gas with a constant abundance relative to H_2
  - Non LTE Excitation (weak maser)



OH FIR emission in the Orion Bar





Goicoechea et al 2011
Herschel PACS with ~ 10'' resolution

CH in molcular gas

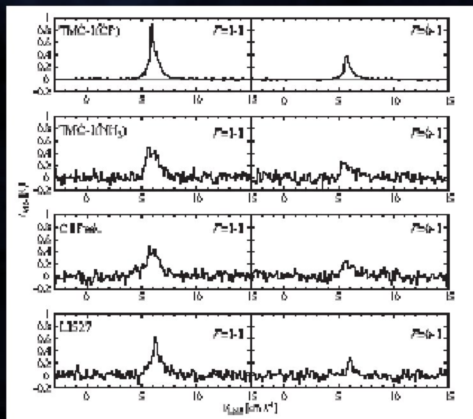
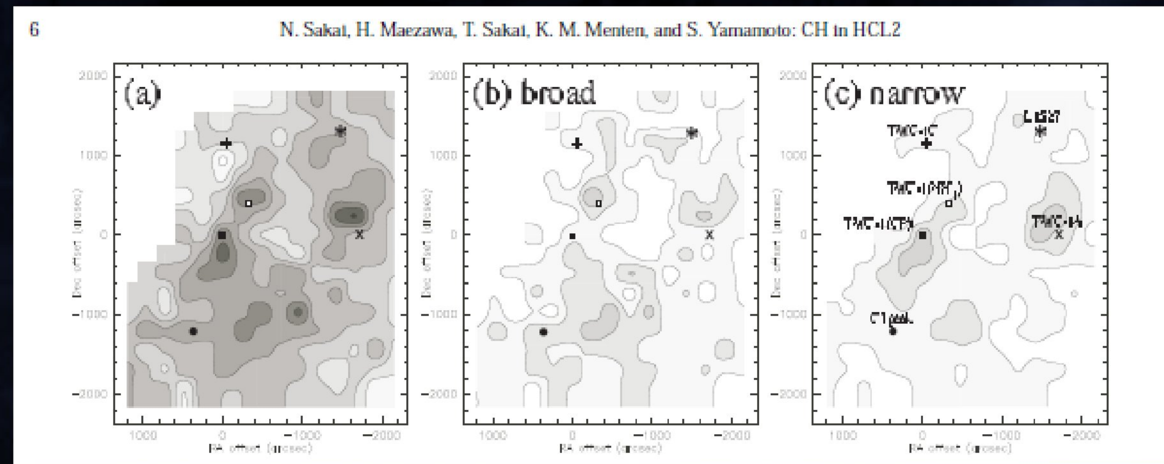
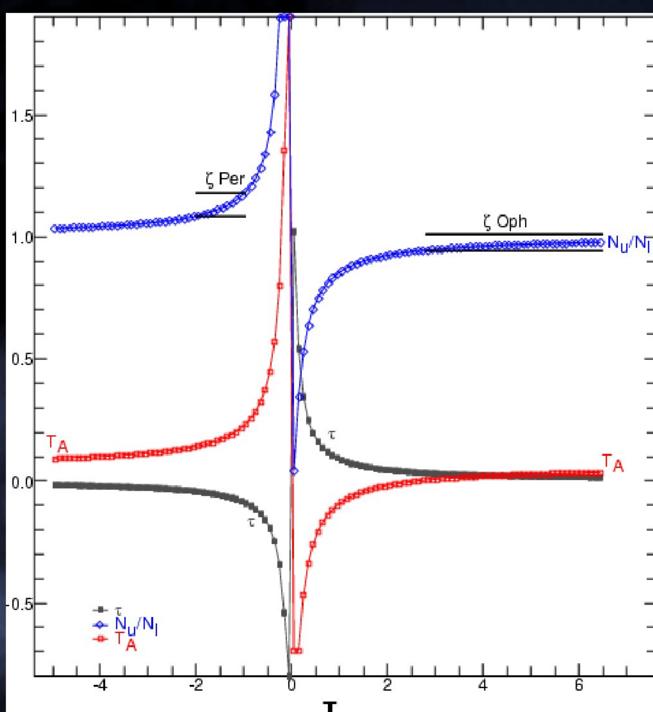
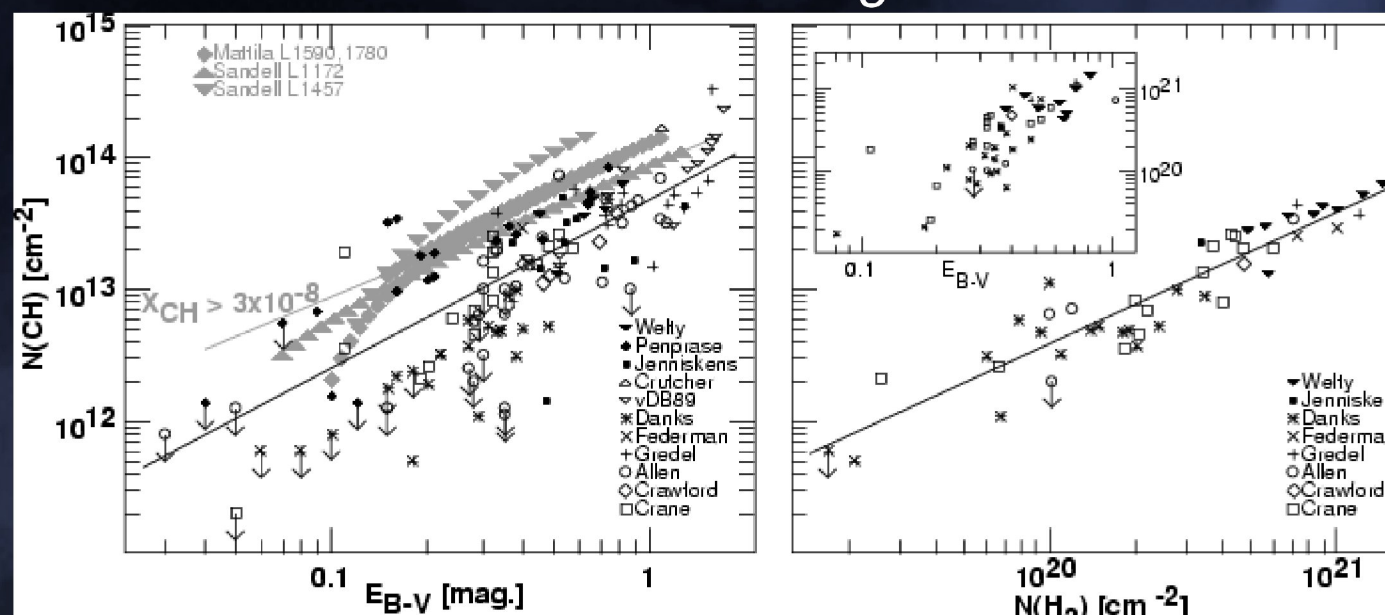


Fig. 1. Line profiles of CH toward four representative positions in HCL2.



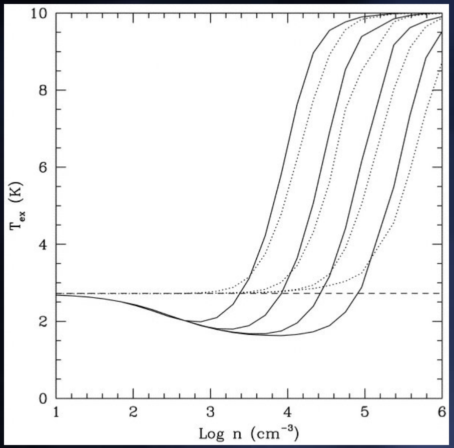
Nakai et al 2013, Effelsberg





Liszt & Lucas ; comparison visible & radio data

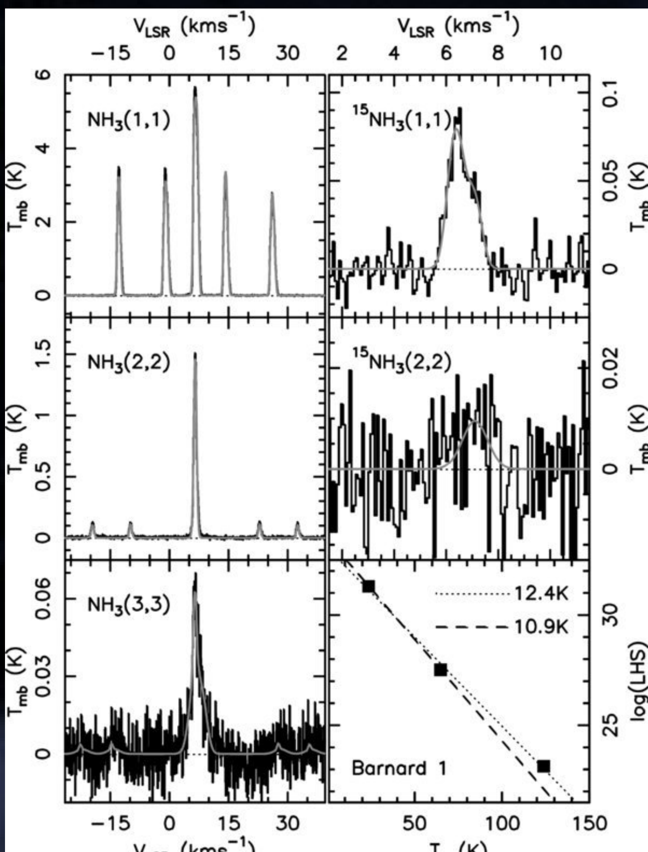
A few important spectral diagnostics below 8 GHz

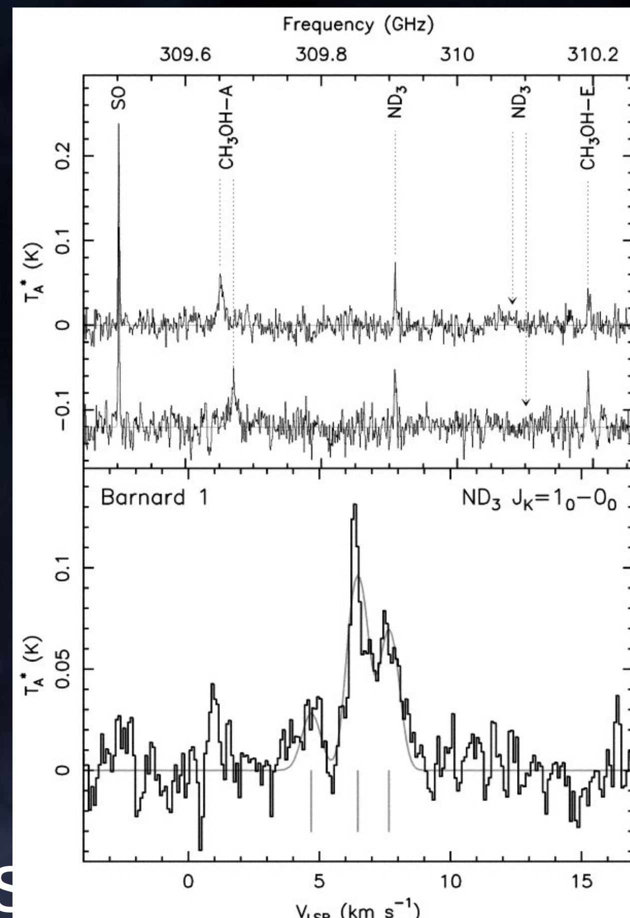


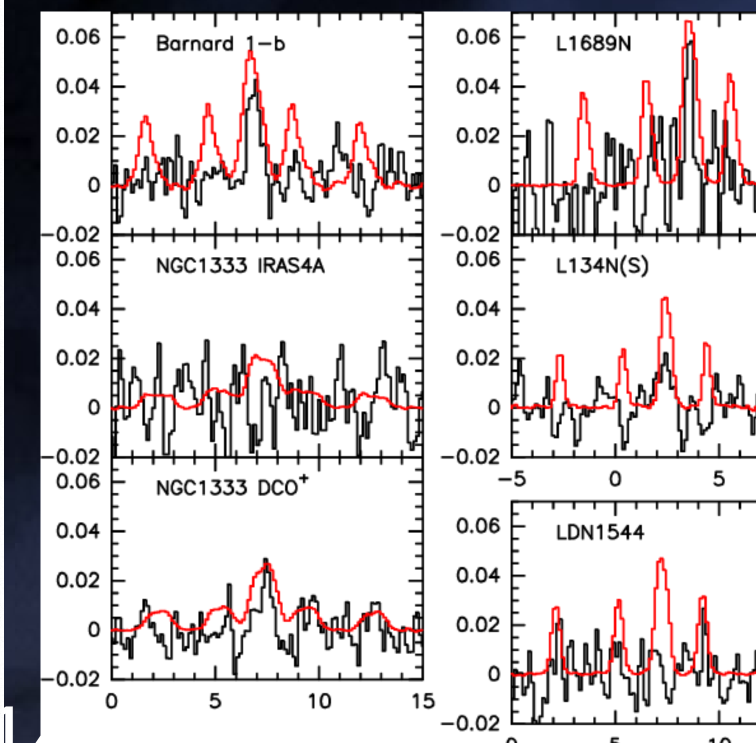
- H_2CO 1_{11}-1_{10} 4.8 GHz
  - Sensitive probe of molecular cores

    (absorption of the CMB)
  - Maser in star forming regions
- CH_3OH 6.7 GHz
  - Maser in high mass star forming region : high angular resolution probe , proper motions
- Carbon chains (C_8H, C_8H-) and cyanopolyynes ($HC_{11}N$)
  - Building molecular complexity
- Recombination lines (H, C, S,...)
  - Interfaces of ionized and neutral gas

Understanding the connection from ISM to the solar system







Us … 14N

NH_3,NH_2D,ND_2H,ND_3,$^{15}NH_3$,$^{15}NH_2D$

Inversion lines in the cm regime for ND_3

Magnetic Field probes (Zeeman effect)

OH :

well demonstrated for ground state lines (~1.7 GHz) ;

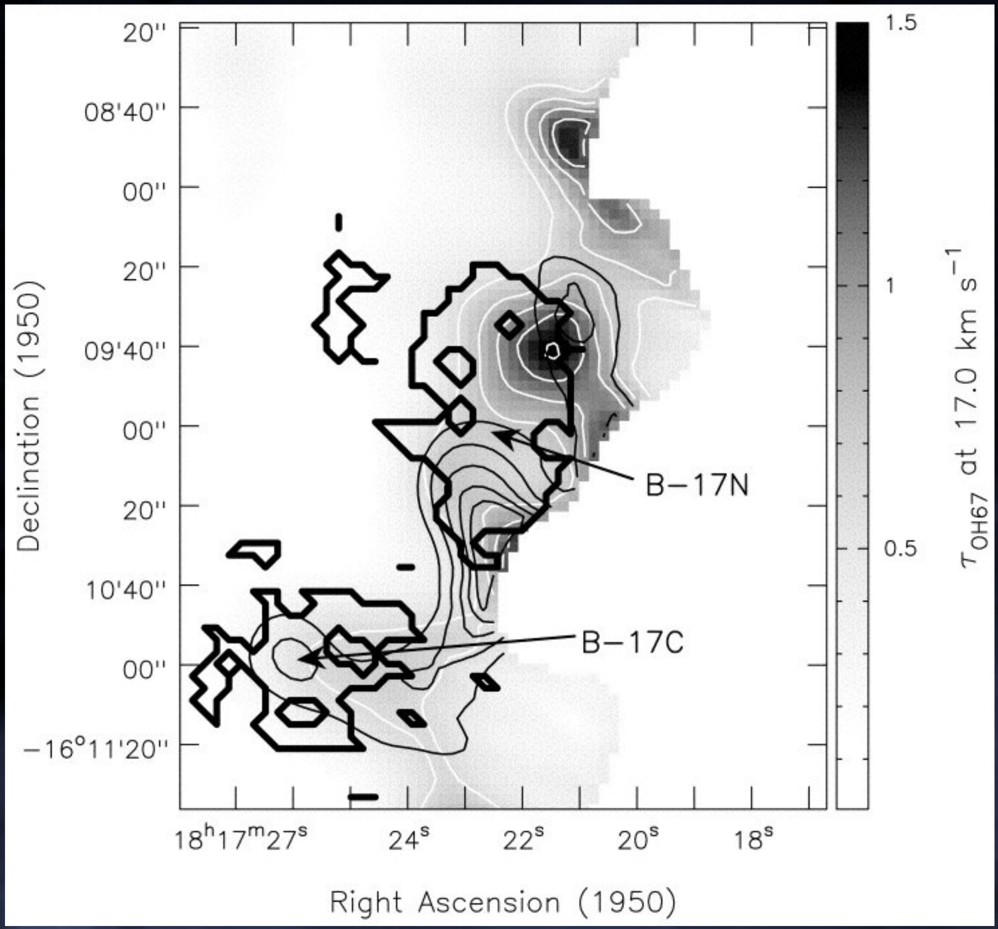
can use the excited levels at eg 6GHz for probing high densities in star forming regions ?

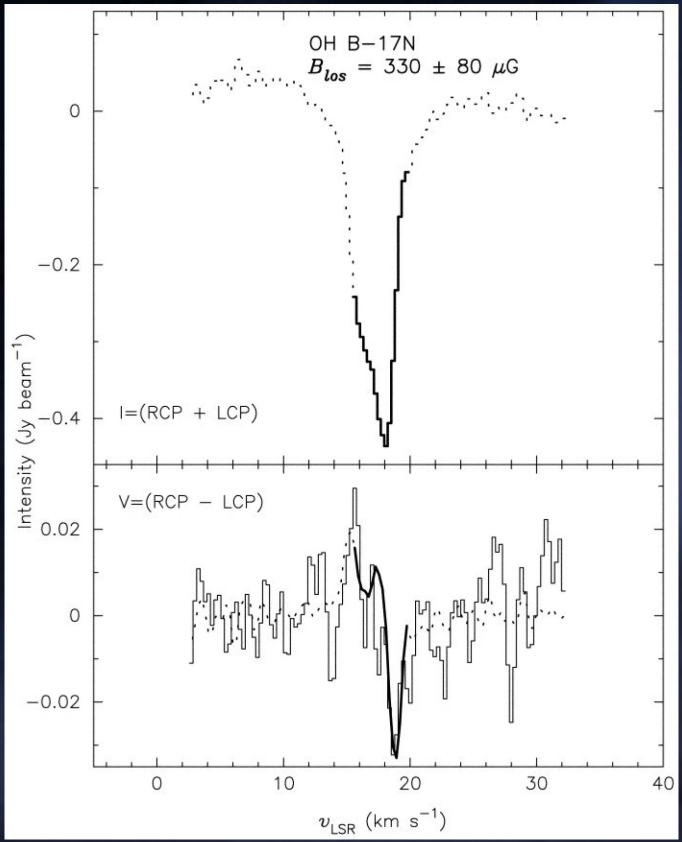
CH & Carbon chains (eg C_4H Turner & Heiles) :

Similar sensitivity than OH but weaker lines. Not demonstrated yet : can provide complementary probes for different density or ionization fraction regimes.

Requires a very high S/N

OH in M17 (Brogan & Troland 2001)





VLA, 26'', ~ 12 hrs, 10mJy/beam