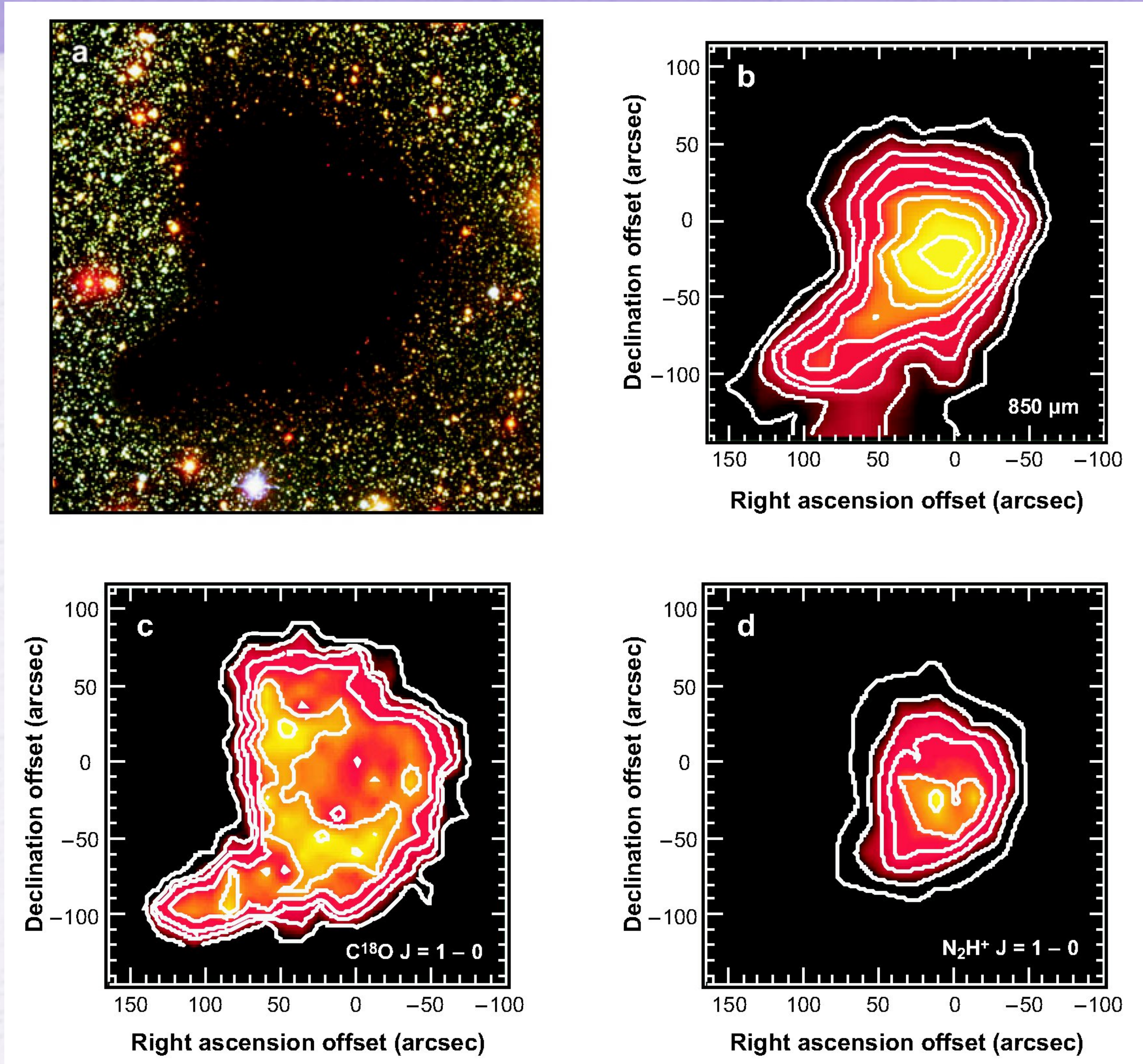
The chemical inventory of pre/proto-stellar cores

Nuria Marcelino
INAF – IRA / Italian ARC node

EUROPEAN ARC
ALMA Regional Centre || Italian

Dark clouds



- ★ Dense (≥10^4 cm^{-3}), cold (~10 K) cores
- ★ Sites of low-mass star formation
- ★ Simple to model (lack of a central heating source, outflows, etc.)

→ $\Delta v \leq 1$ km/s

Bergin & Tafalla (2007)

Chemistry in dark clouds

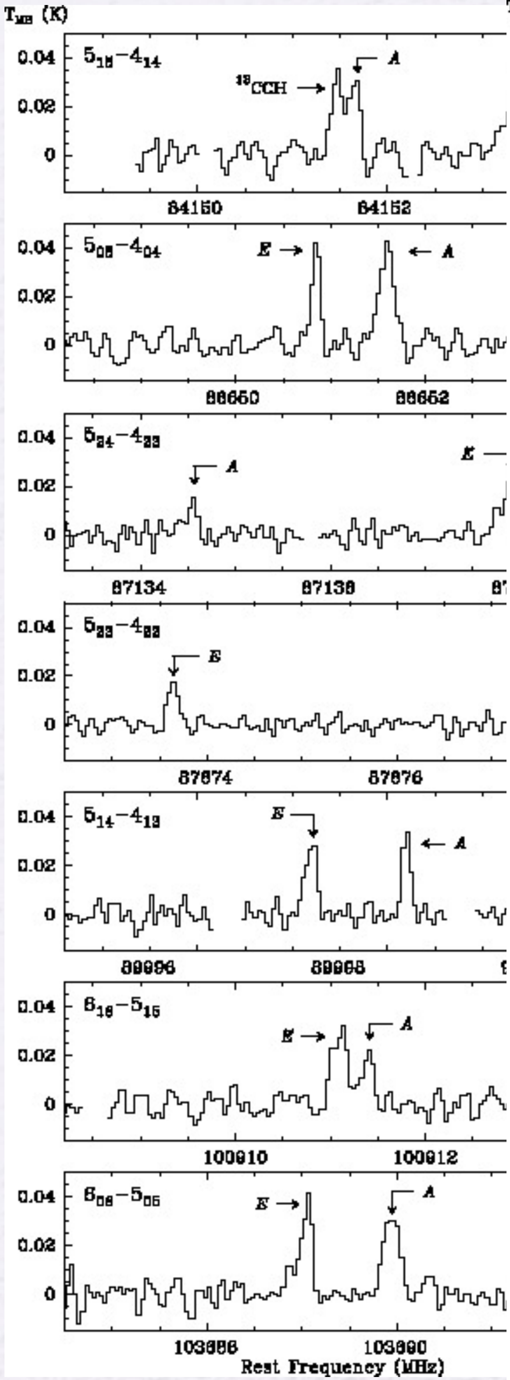
→ Important laboratories for astrochemistry !

- ★ Gas-phase chemistry: *exothermic* reactions, neutral-neutral and ion-molecule

- ★ Production on grain mantles… return to gas-phase:
  - thermal evaporation not effective at T_d = 10 K
  - non-thermal evaporation mechanisms (cosmic rays, secondary photons, etc.)

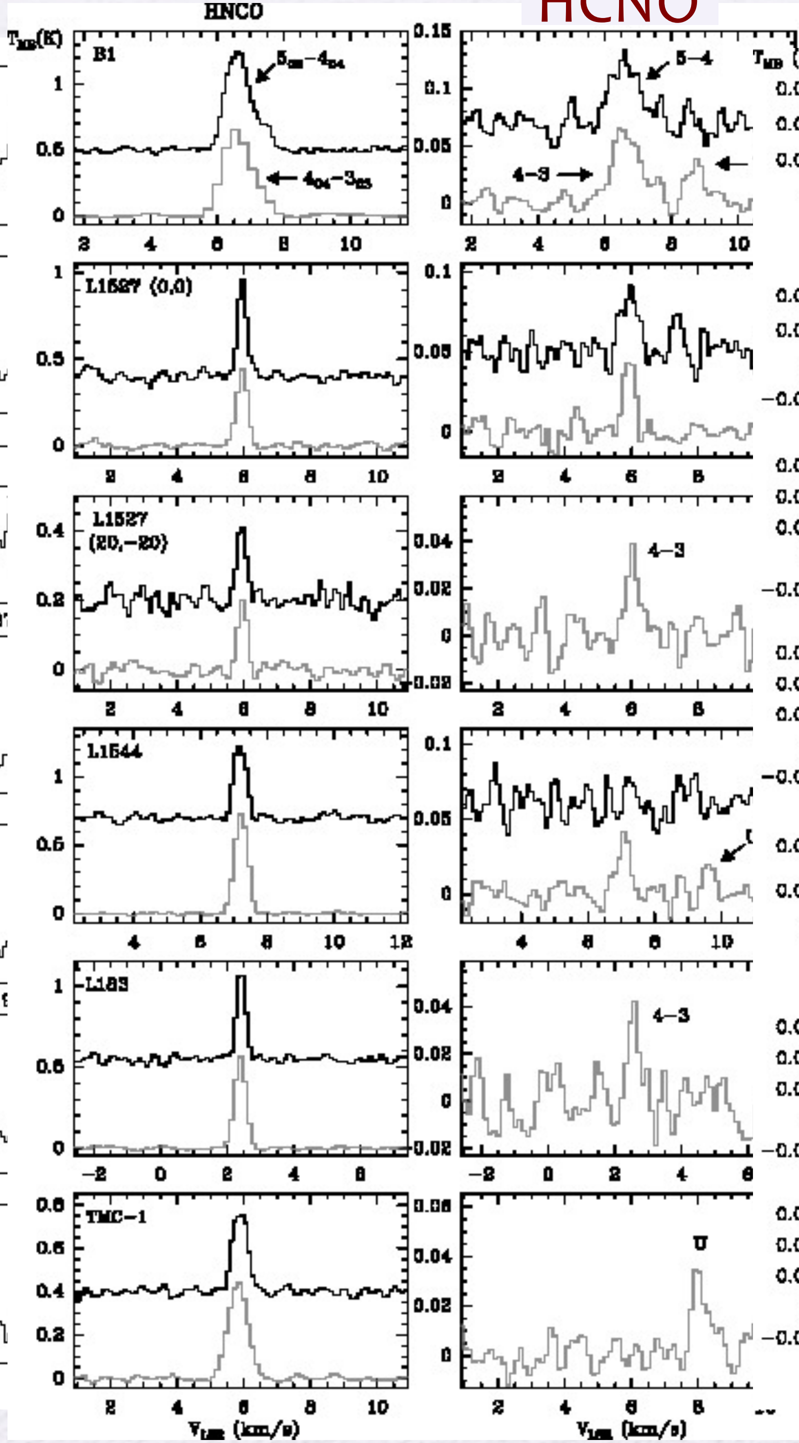
- ★ But they are more chemically rich and complex than previously thought…

CH_2CHCH_3



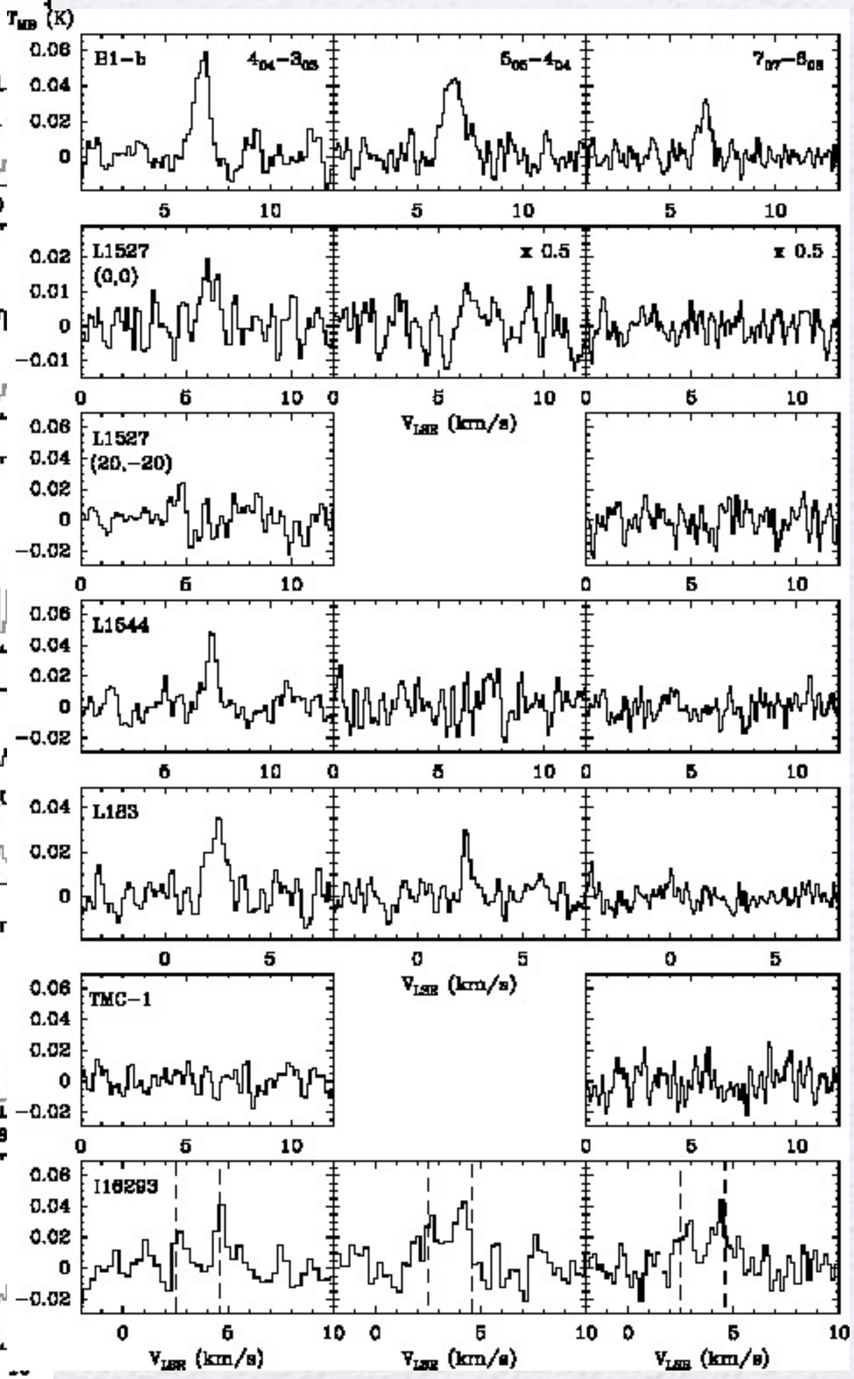
Marcelino ea (2007)

HCNO



Marcelino ea (2009)

HOCN



Marcelino ea (2010)

Spectral line surveys… the best tool to obtain the molecular content of interstellar clouds !

However… surveys in dark clouds need:

- High sensitivity receivers
- Backends providing large bandwidth coverage with high spectral resolution

→ Pioneering 3mm scan between 86–93 GHz of 4 cores used 50 hrs per source to reach rms~8-10 mK (2 hrs per setting covering 315 MHz each!)

New generation of receivers and backends…

- EMIR receivers at 3mm (83-117 GHz, 2x4 GHz of bandwidth, dual sideband)

- 24 FFT Spectrometers

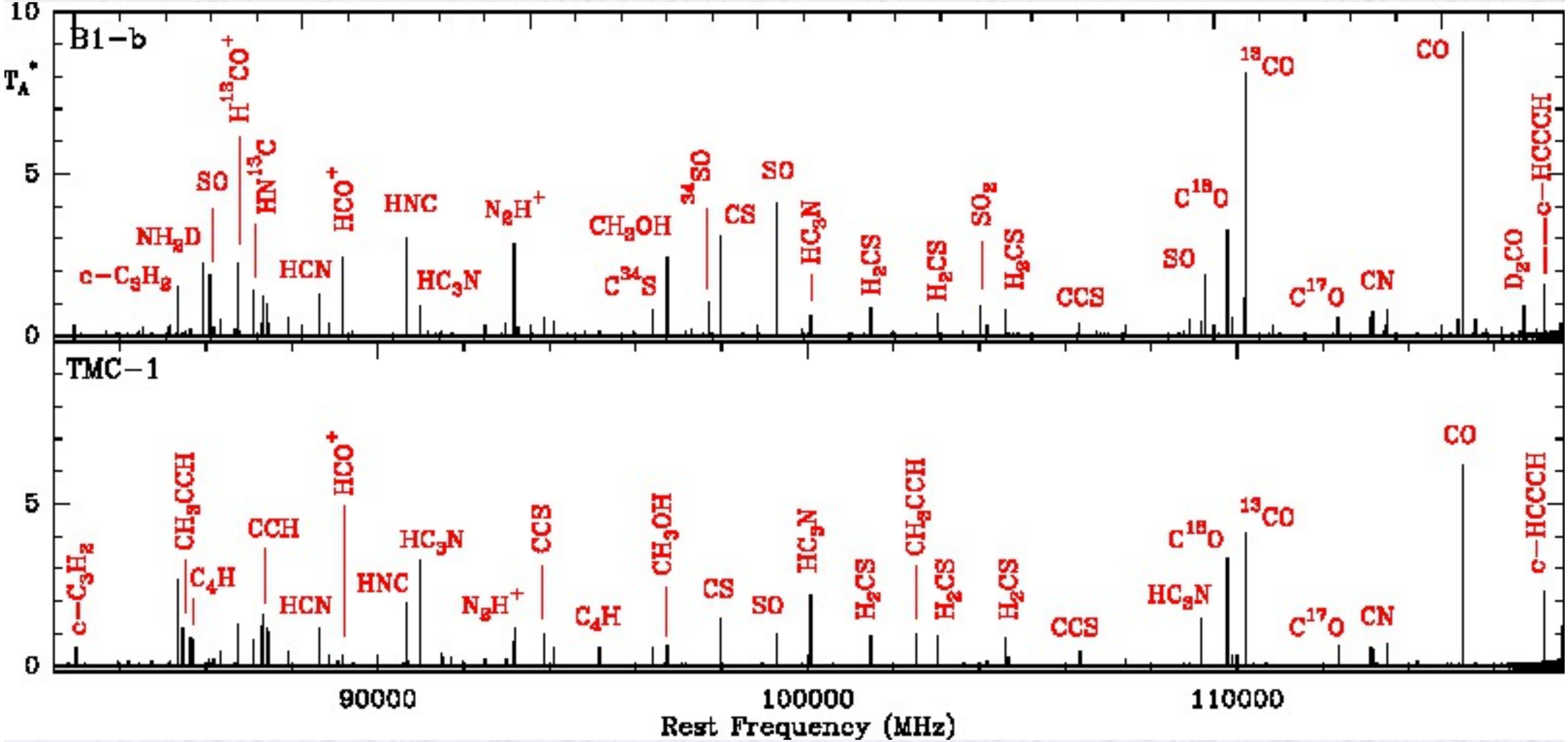
  - resolution = 50 kHz (0.13-0.17 km/s)

  - bandwidth = 7.2 GHz (4x1.8 GHz)

→ 82.5 – 117.5 GHz (35 GHz)

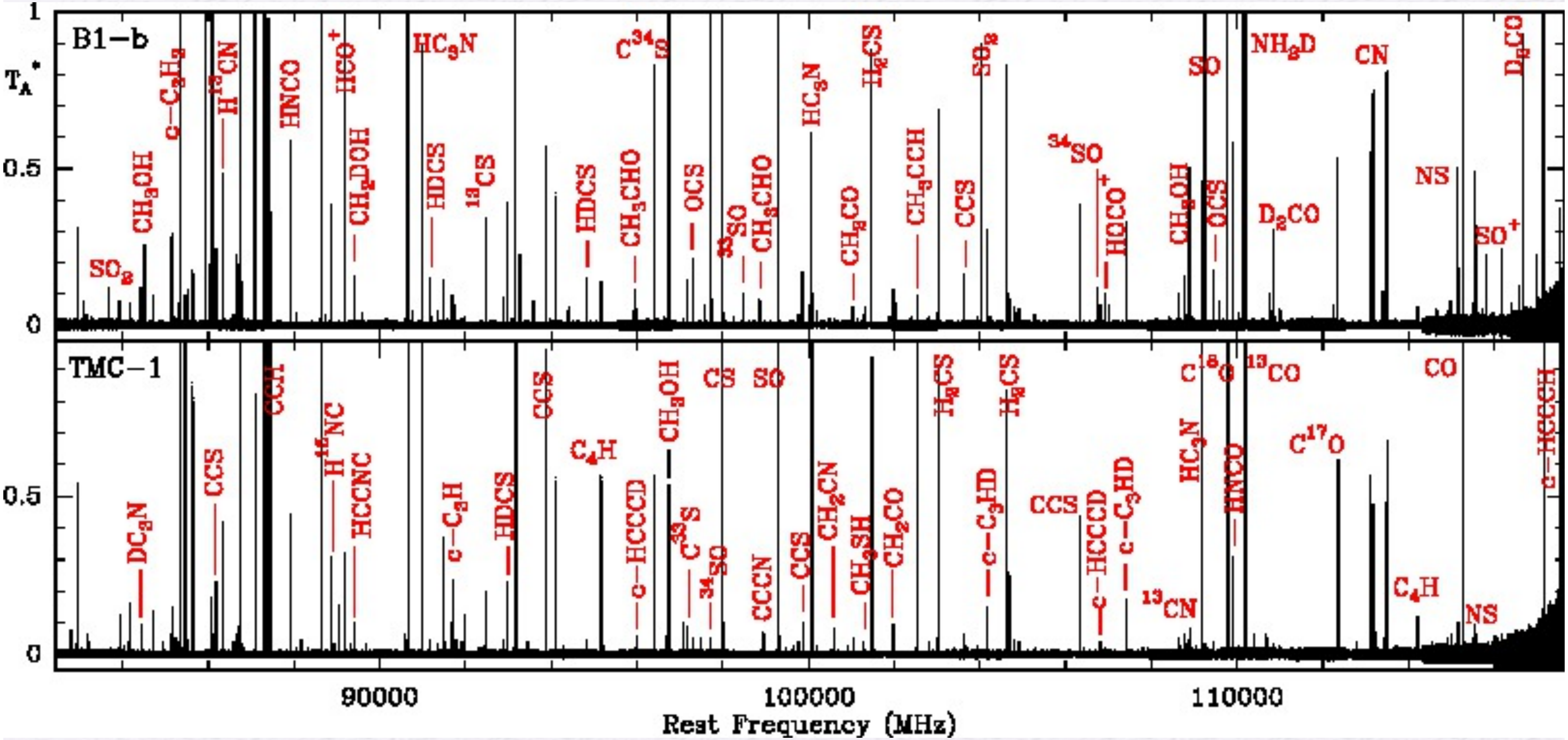
→ rms ~ 4-6 mK in 2 hours per setting = 15 hours (per source)

82.5-117.5 GHz scan



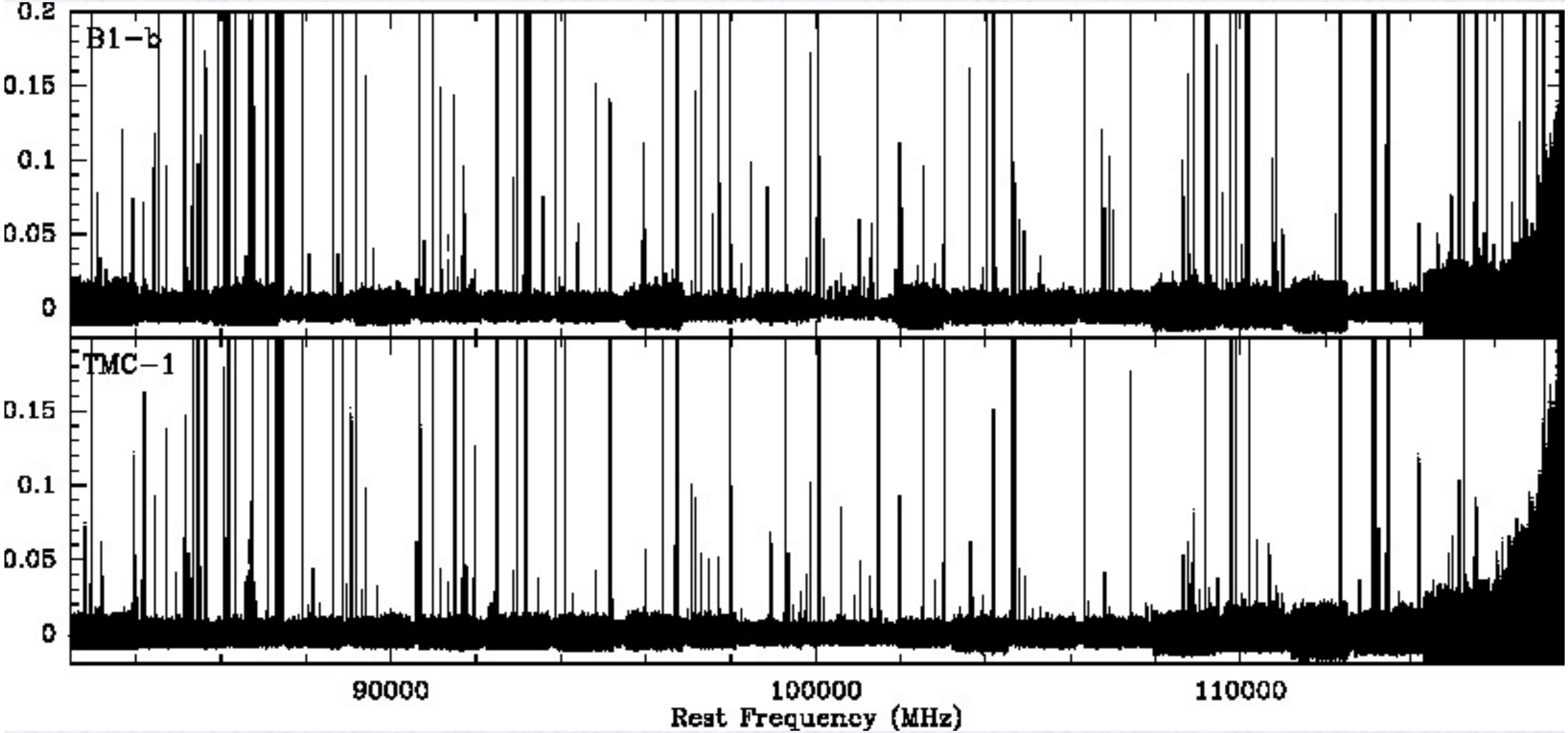
Marcelino ea (in prep)

82.5-117.5 GHz scan



Marcelino ea (in prep)

82.5-117.5 GHz scan



Marcelino ea (in prep)

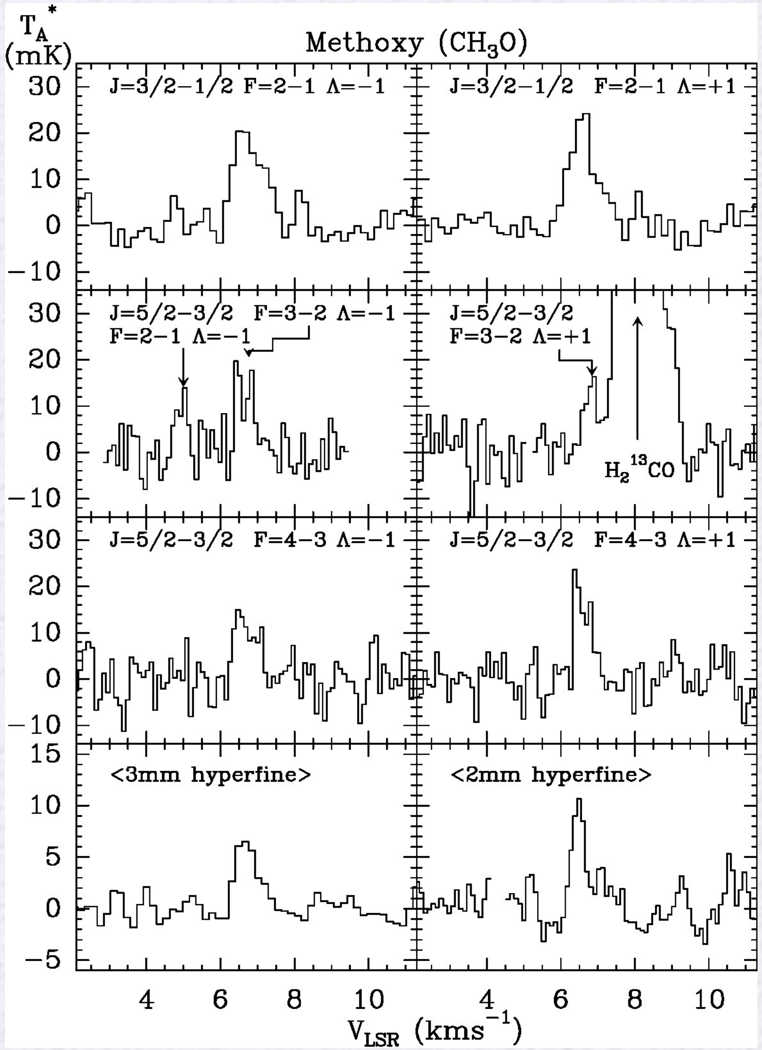
B1-b: 325 lines from 110 species (including isotopomers)

TMC-1: 281 lines from 77 species

2 atom	3 atom	4 atom	5 atom	6 atom	7 atom	8 atom	9 atom
CN	CCH	CCCN	C4H	HC3NH+	CH3CCH	CH3OCOH	CH2CHCH3
CO	HCN	CCCO	CH2CN	CH3CN	CH2DCCH		CH3OCH3
CS	HNC	CCCS	HC3N	H2CCCC	CH3CCD		
NS	N2H+	NH2D	HCCNC	HCCCHO	CH3CHO		
SO	HCO	HNCO	DC3N	CH3OH	CH2CHCN		
SO+	HCO+	HCNO	c-C3H2	CH2DOH	CH2OCH2		
SiO	HCS+	HOCN	c-C3HD	CHD2OH			
	CCO	DNCO	l-C3H2	CH3OD			
	CCS	D2CO	H2CCO	CH3SH			
	SO2	H2CS	HDCCO				
	OCS	HDCS	HCOOH				
		D2CS	CH3O				
		c-C3H					
		l-C3H					
		HOCO+					

CH3O and COMs in B1-b

- Discovery of CH_3O in space. It is the precursor of COMs, such as CH_3OH, CH_3OCOH and CH_3OCH_3

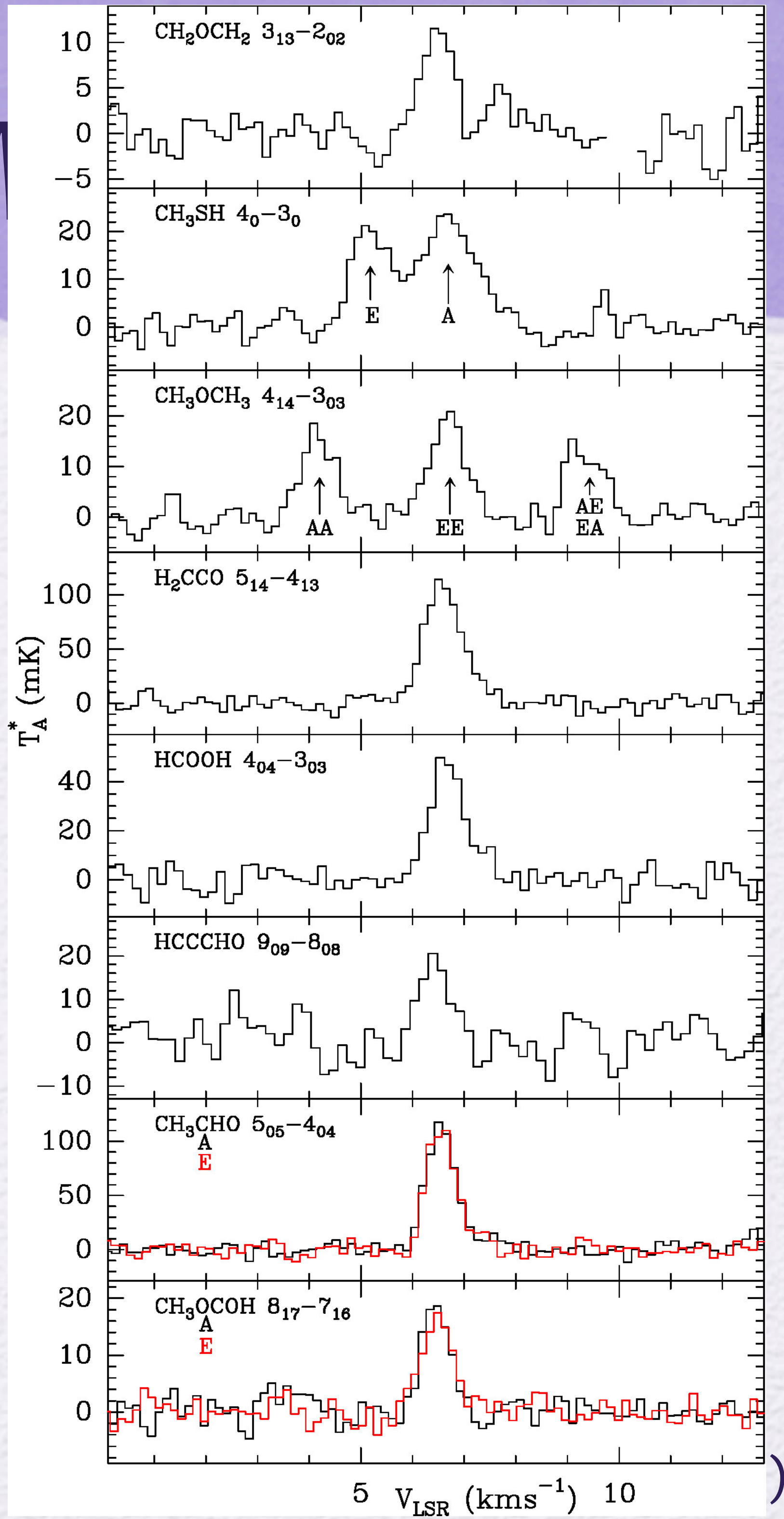


Cernicharo, Marcelino ea (2012)

CH3O and COM

- Discovery of CH_3O in space. It is the precursor of COMs, such as CH_3OH, CH_3OCOH and CH_3OCH_3
- COMs only detected in B1-b: CH_3O, CH_2OCH_2, CH_3OCH_3, HCOOH, and CH_3OCOH
- First detection of CH_3SH outside the GC
- Observed abundances ~ 10^{-11}

  → common origin ?



COMs in dark clouds

- Gas-grain chemistry models (Garrod & Herbst 2006) suggest formation of COMs on grain mantles during warm-up phase, when radicals become mobile at >30 K, followed by (thermal and non-thermal) evaporation

  However: diffusion of radicals not effective below 25 K !

- Gas-phase possible formation after *reactive desorption* of precursor species (CH_3O, CH_3OH and H_2CO), but CH_3O is overestimated by models (Vasyunin & Herbst 2013)

COMs in dark clouds

- L1689B: CH_3CHO, CH_3OCH_3, CH_3OCHO, H_2CCO

Bacmann ea (2012) suggest radical mobility and molecular desorption could be driven by UV photons, cosmic rays or released energy from exothermic reactions

- L1544: C_3O, CH_3OH, CH_3CHO, HCOOH, H_2CCO, CH_3CCH

Vastel ea (2014) locate the emission at an outer layer rather than the core, where H_2O (Caselli ea 2012) and deuterated methanol have also been observed (Bizzocchi ea 2014)

After photodesorption of H_2O, CH_3OH and C_2H_4, gas-phase reactions would lead to production of COMs

COMs in dark clouds

Still COM abundances not fully reproduced by current chemical models in prestellar cores…

Need of high angular resolution observations to constrain the emitting region !

Or could they be related with very early star formation stages?

→ B1-b harbors 2 very young protostellar objects, one FHSC candidate, with slow outflows (Gerin ea 2015)

→ COMs as tracers of FHSCs (Furuya ea 2012) ?

Summary ~ Future

- Spectral line surveys are the best tool to obtain the molecular inventory of prestellar cores. Current sensitive and large bandwidth receivers make these studies much more efficient.
- New detections (of know and unknown species) provide new diagnostics and probe chemical models.
- Many lines remain unidentified in our 3mm survey.
- Extend to other frequencies: e.g. 4mm Band at GBT (ALMA B2).
- Extend to other sources to probe all stages in low-mass star formation: starless, protostellar, hot corinos and outflows (IRAM LP *Astrochemical Surveys At Iram –PI Lefloch & Bachiller*).
- Potential for follow-up projects at high angular resolution.