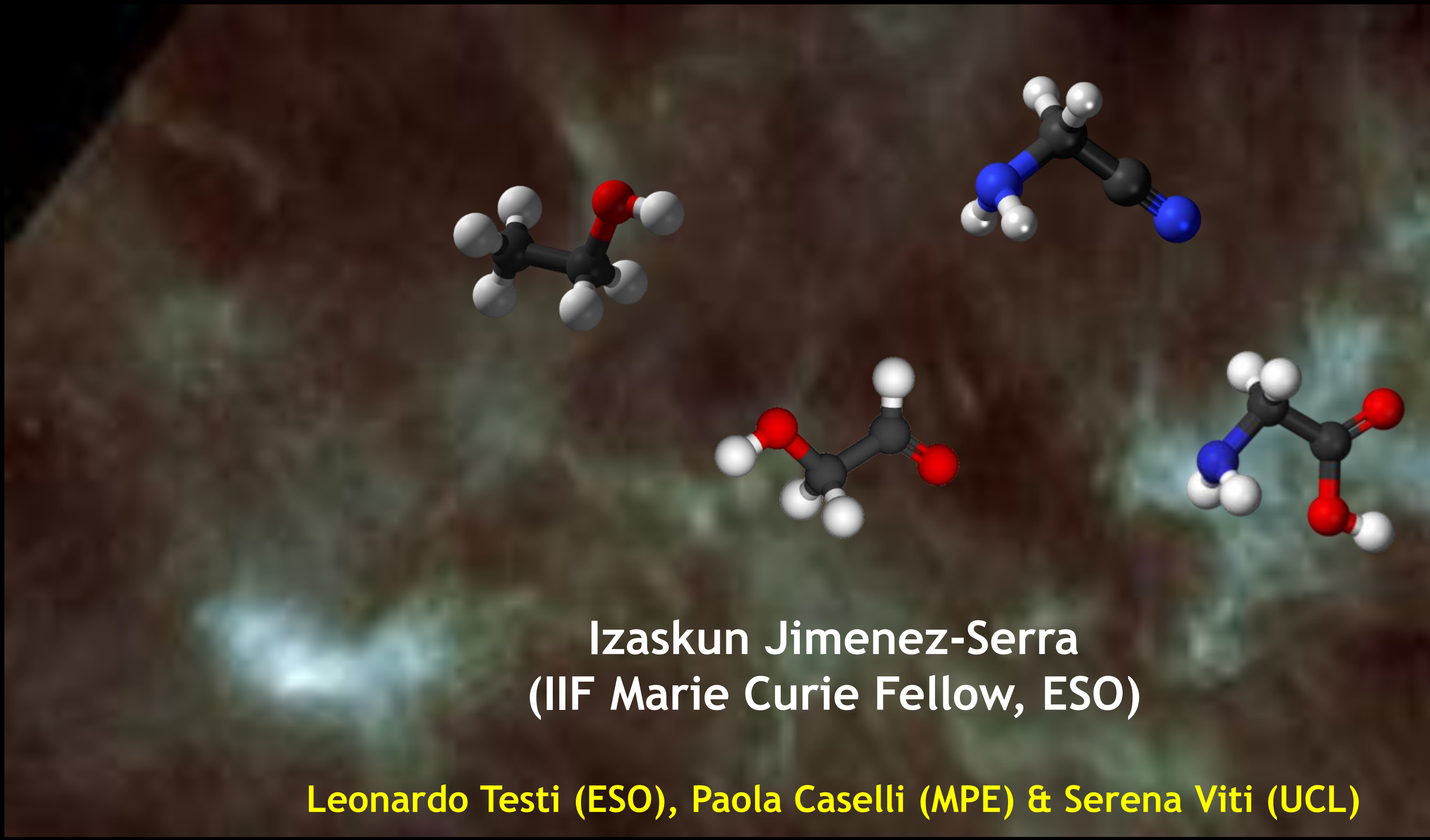
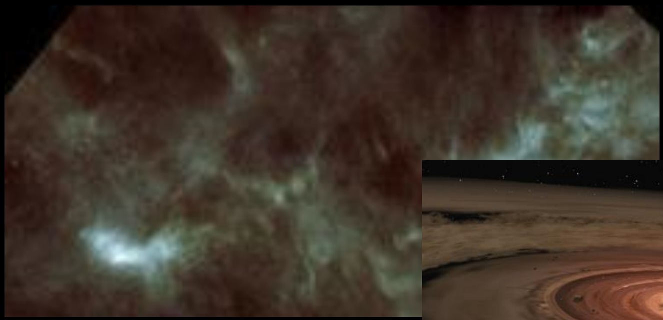
ESO in the 2020s: Astrobiology



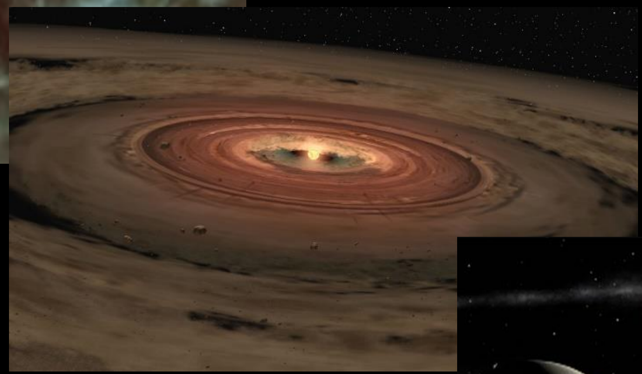
Izaskun Jimenez-Serra
(IIF Marie Curie Fellow, ESO)

Leonardo Testi (ESO), Paola Caselli (MPE) & Serena Viti (UCL)

From the ISM to the Origin of Life



Molecular clouds
(Pre-stellar Cores)

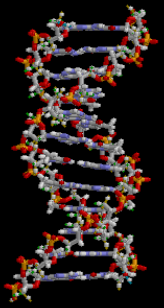


Circumstellar disks

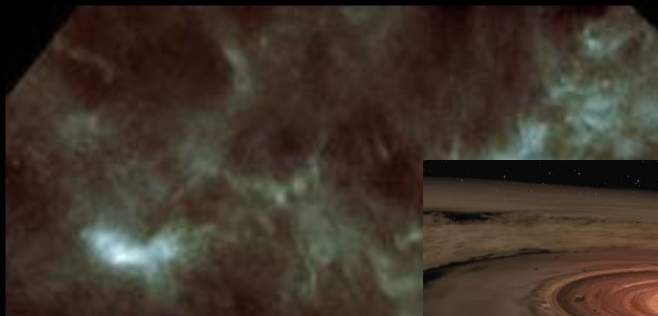
Solar-system

?

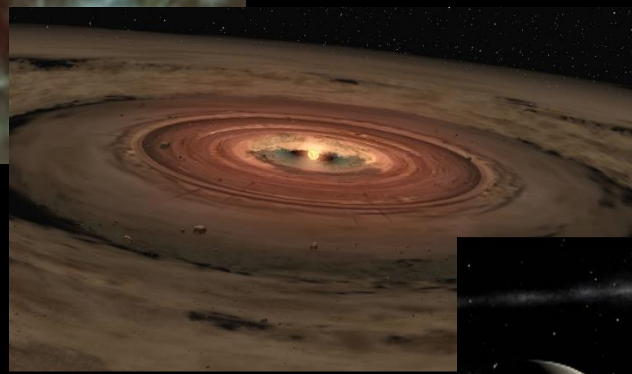
DNA



From the ISM to the Origin of Life

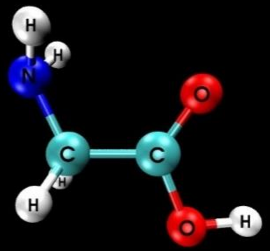


Molecular clouds
(Pre-stellar Cores)



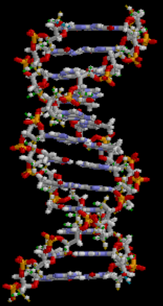
Circumstellar disks

Solar-system

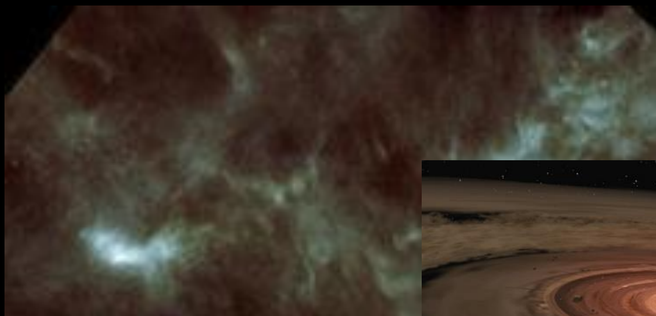


Complex Organics
(COMs)

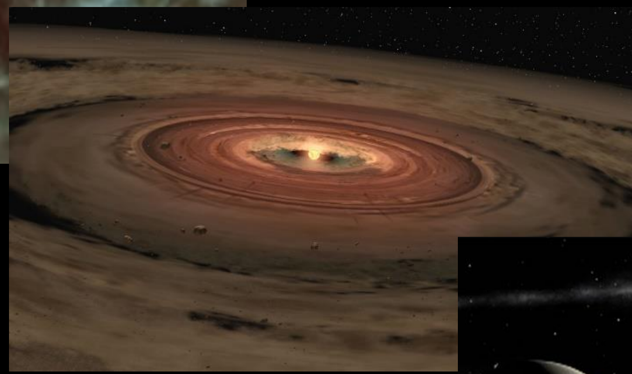
DNA



From the ISM to the Origin of Life

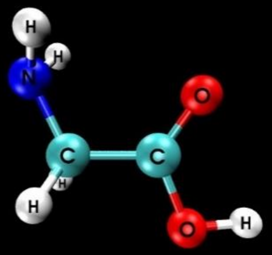


Molecular clouds
(Pre-stellar Cores)



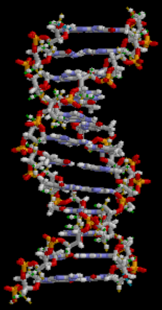
Circumstellar disks

Solar-system



Complex Organics
(COMs)

DNA



How complex can organic chemistry become in the ISM?

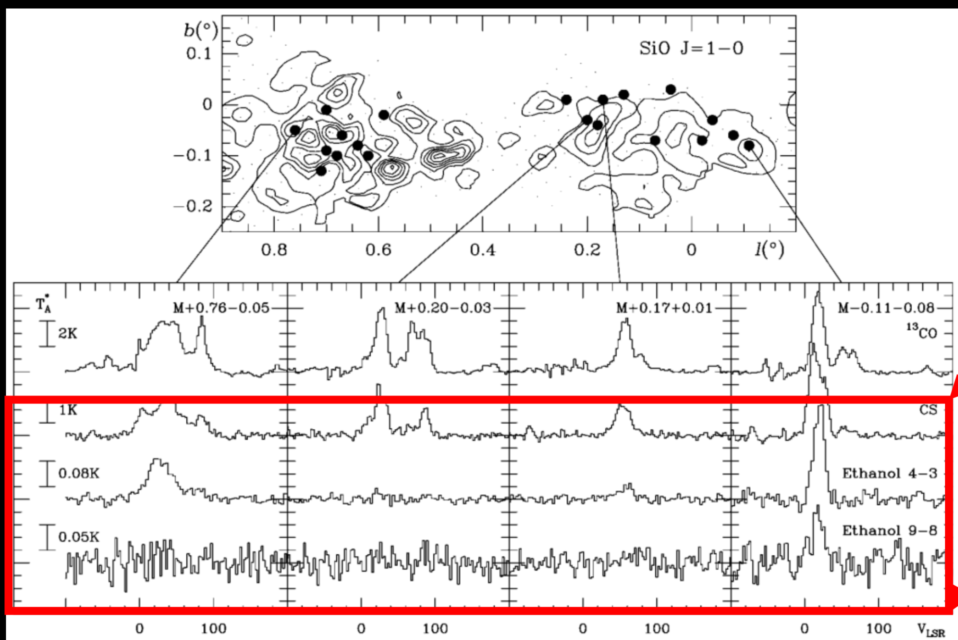
Pre-biotic species!!

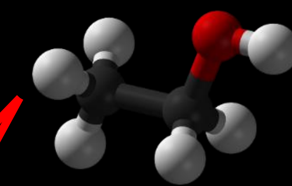
Complex Organic Molecules (COMs)

COMs detected in the ISM

- Galactic Center GMCs (Hollis+2000;Martin-Pintado+2001;Requena-Torres+2006,2008)

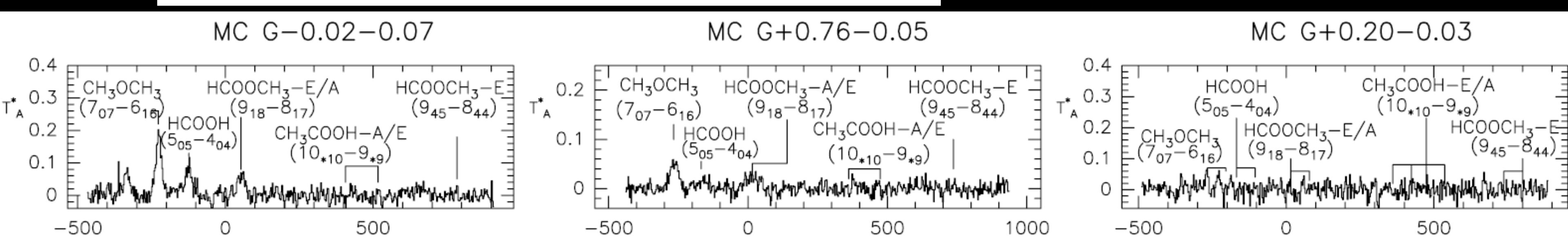
Martin-Pintado+2001





Ethanol
(C_2H_5OH)

Other species:
Formic Acid (HCOOH)
Methyl Formate ($HCOOCH_3$)
Acetic Acid (CH_3COOH)
Di-methyl ether (CH_3OCH_3)

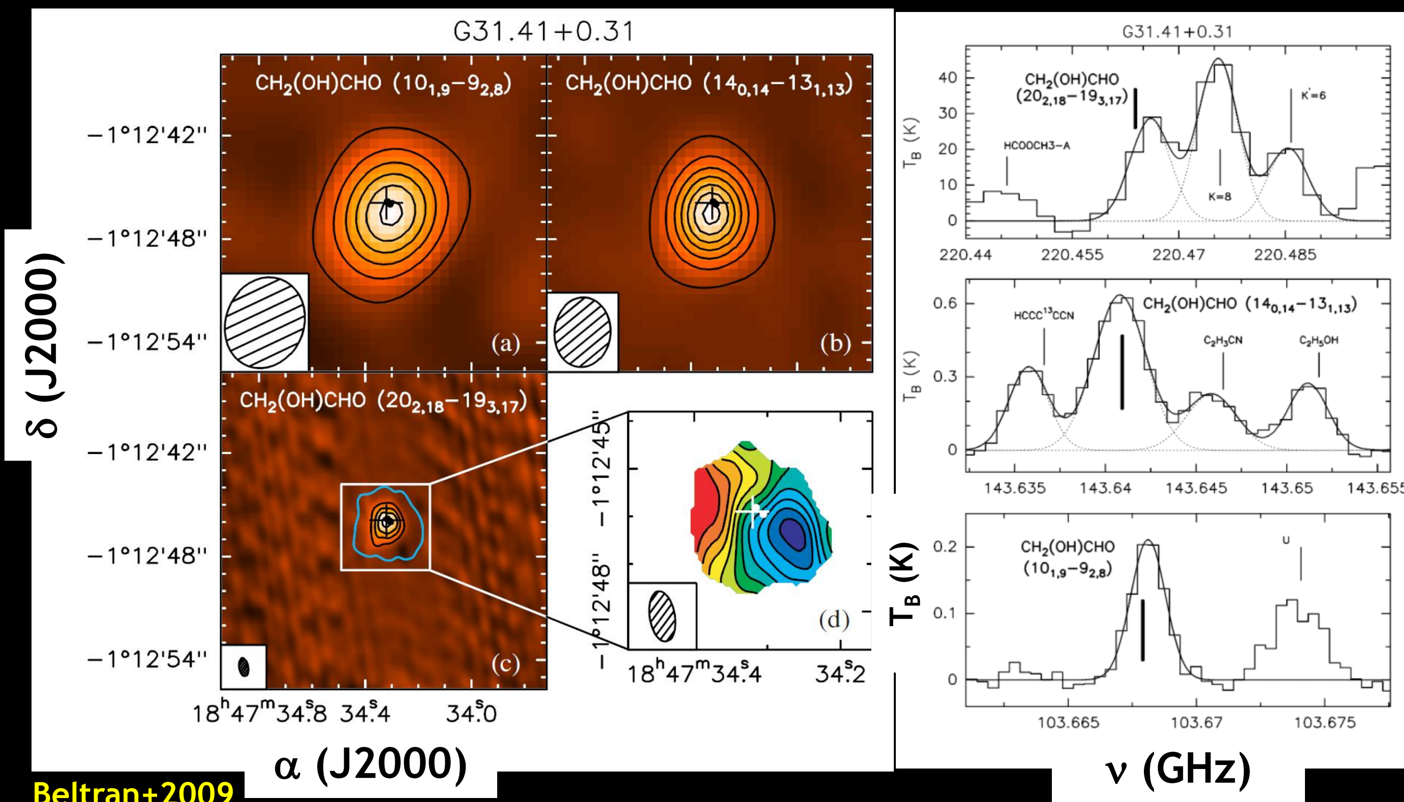


Requena-Torres+2006

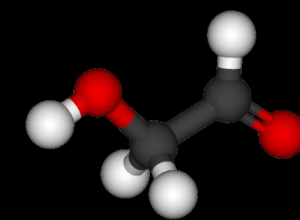
Complex Organic Molecules (COMs)

COMs detected in the ISM

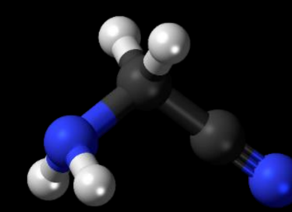
- Galactic Center GMCs (Hollis+2000;Martin-Pintado+2001;Requena-Torres+2006,2008)
- Star forming regions: Hot Cores and *Hot Corinos* (Beltran+2009; Belloche+2008,2013; Jorgensen+2012)



Beltran+2009



Glycolaldehyde (CH_2OHCHO)



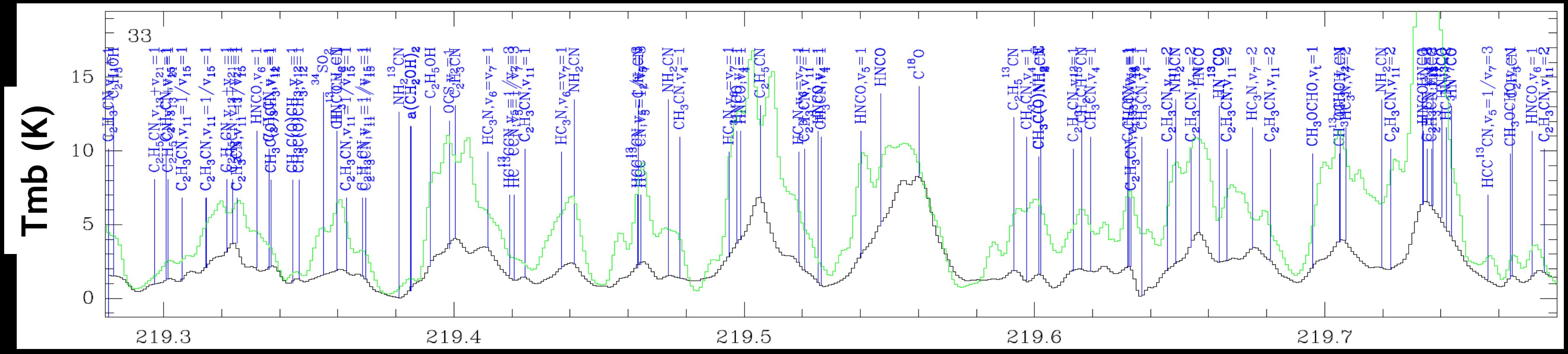
Amino Acetonitrile (H_2NCH_2CN)

Complex Organic Molecules (COMs)

COMs detected in the ISM

- Galactic Center GMCs (Hollis+2000;Martin-Pintado+2001;Requena-Torres+2006,2008)
- Star forming regions: Hot Cores and *Hot Corinos* (Beltran+2009; Belloche+2008,2013; Jorgensen+2012)

SgrB2(N) & SgrB2(M)



Rest Frequency (MHz)

Belloche+2013

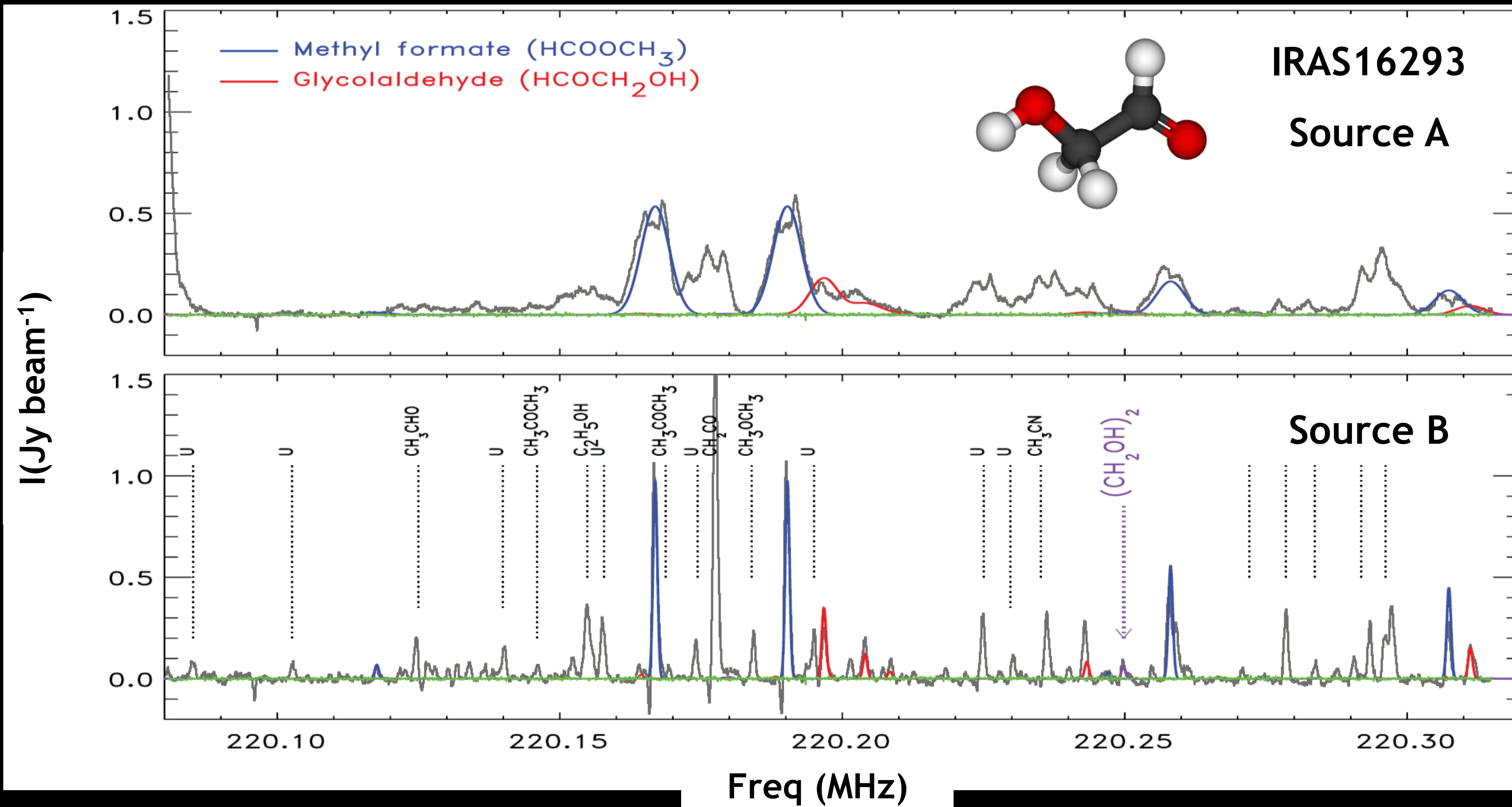
Challenges:

- High spectral line densities ⇒ Line blending and confusion!
- Broad linewidths ⇒ Line identification problematic

High-angular resolution key for COM detection

Jorgensen+2012

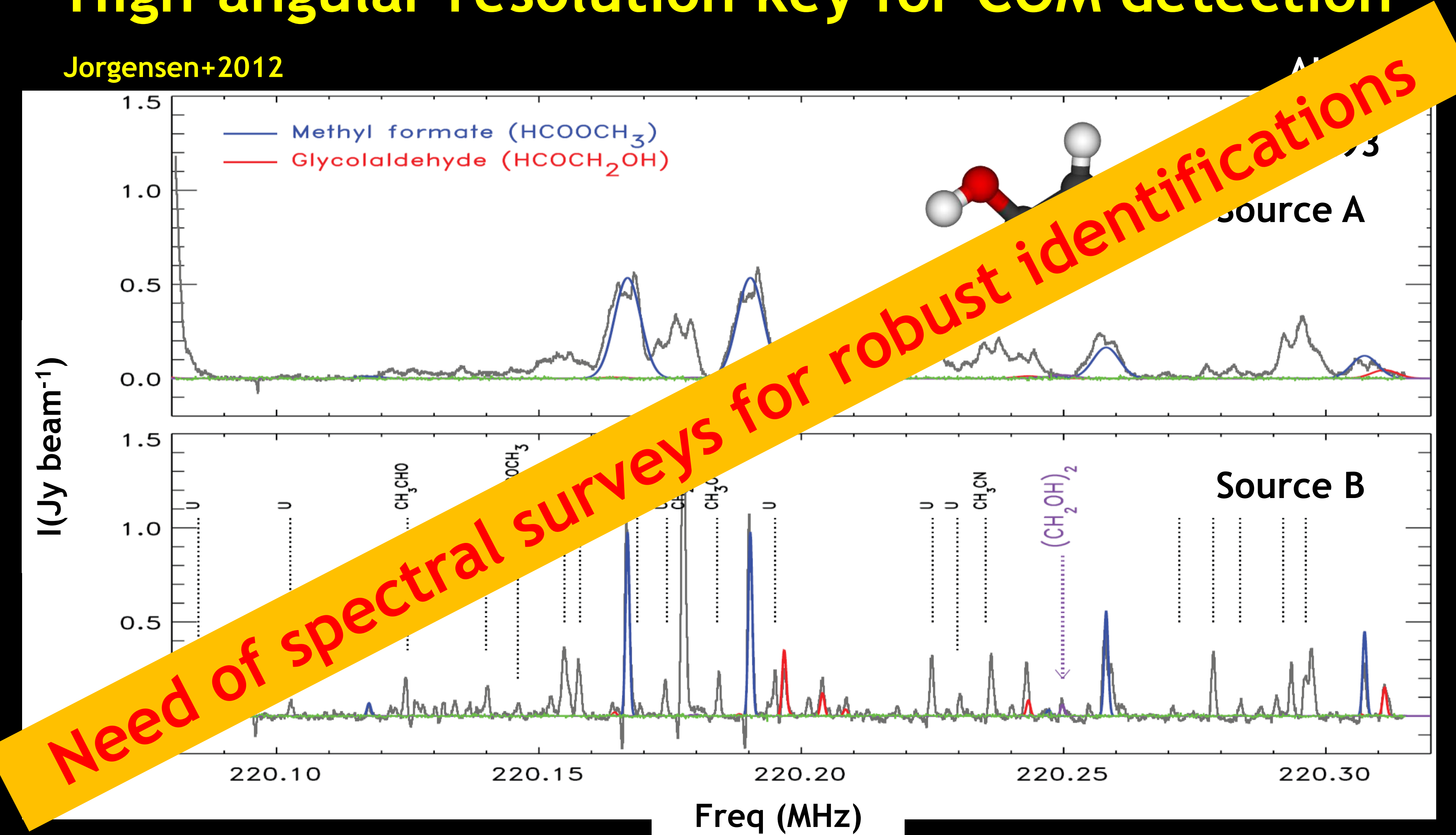
ALMA SV



detection of simplest sugar: Glycolaldehyde

High-angular resolution key for COM detection

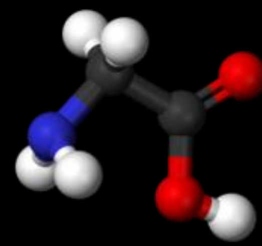
Jorgensen+2012

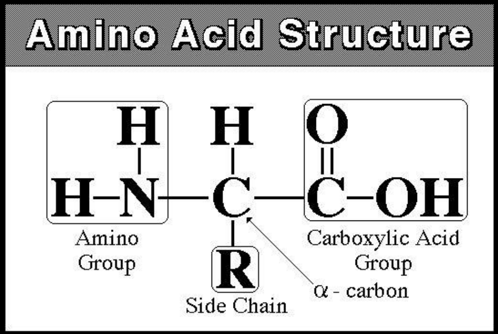


detection of simplest sugar: Glycolaldehyde

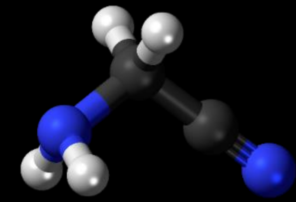
Amino acids and their precursors

Simplest Amino Acid:
Glycine (H_2NCH_2COOH)

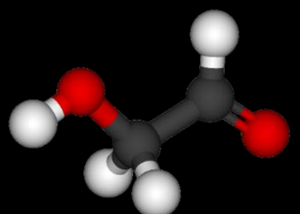




- Key molecule to understand the formation processes of pre-biotic molecules in the ISM
- Firm detection in meteorites (Ehrenfreund+2001) and possibly in comets (Elsila+2009)
- Possible precursors detected in hot cores and hot corinos (Belloche+2008; Jorgensen+2012)



Amino Acetonitrile (H_2NCH_2CN)



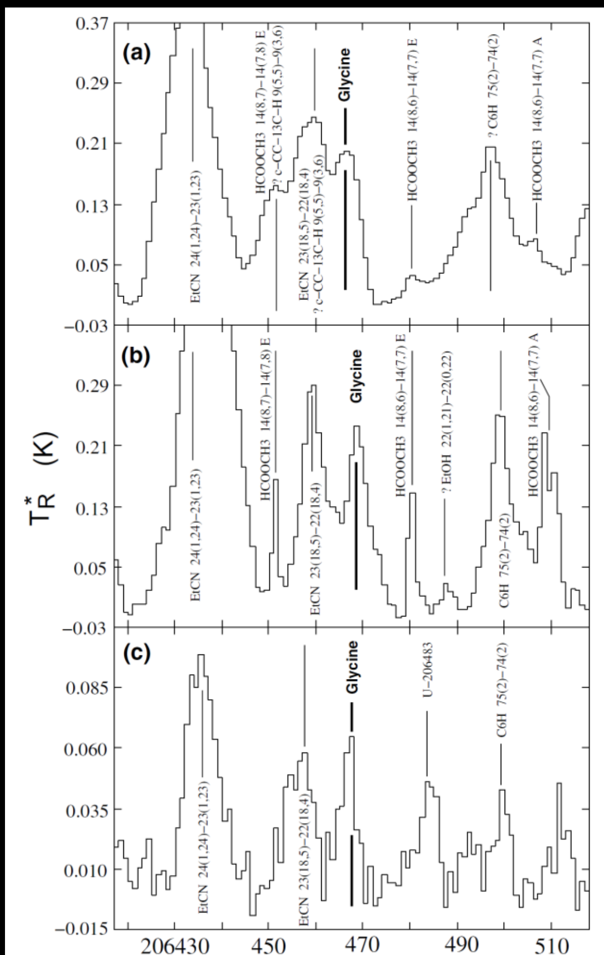
Glycolaldehyde (CH_2OHCHO)

- First detection of a branched COM (Belloche et al. 2014)

Search of Glycine in the ISM

Searches toward massive hot cores (e.g. SgrB2; Kuan+2003) have not yielded any firm detections (Snyder+2005; Cunningham+2007; Jones+2007)

Kuan+2003



Rest Frequency (MHz)

Snyder+2005

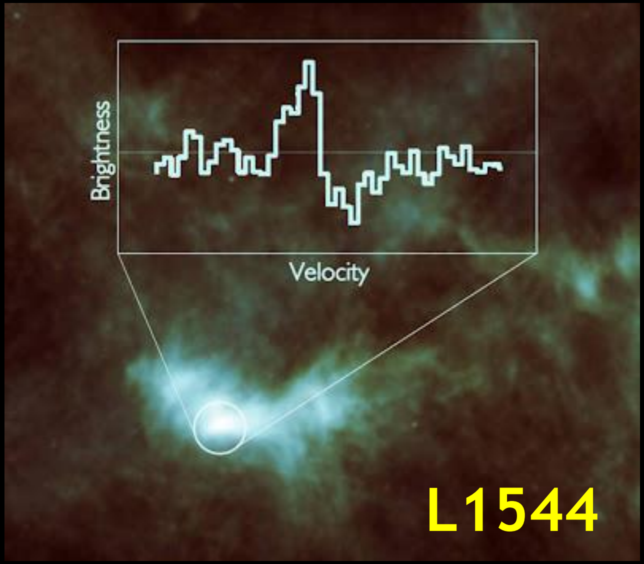
OTHER CANDIDATES FOR SOME OF THE REPORTED GLYCINE LINES

Search Frequency[a] (MHz)	Glycine Frequency[a] (MHz)	Possible Carrier	Transition
Lines Reported in Sgr B2(N-LMH), Orion KL, and W51 e1/e2			
206468.023(1694)	206468.453(17)	CH_3CH_2CN	$23_{6,18}-22_{6,17}$ A $\nu_b=1$
206468.023(1694)	206468.453(17)	CH_3CH_2CN	$23_{6,17}-22_{6,16}$ A $\nu_b=1$
228418.243(1100)	228419.435(104)	CH_2CHCN	$24_{11,13/14}-23_{11,12/13}$ $\nu_{15}=1$
228418.836(1100)	228420.029(104)		
228419.333(1100)	228420.526(104)		
228419.927(1100)	228421.120(104)		
240899.571(1908)	240900.647(76)	Compact source (see text)	

Putative glycine lines due to other molecular carriers (e.g. ethyl cyanide with $v \geq 1$).

A New Approach

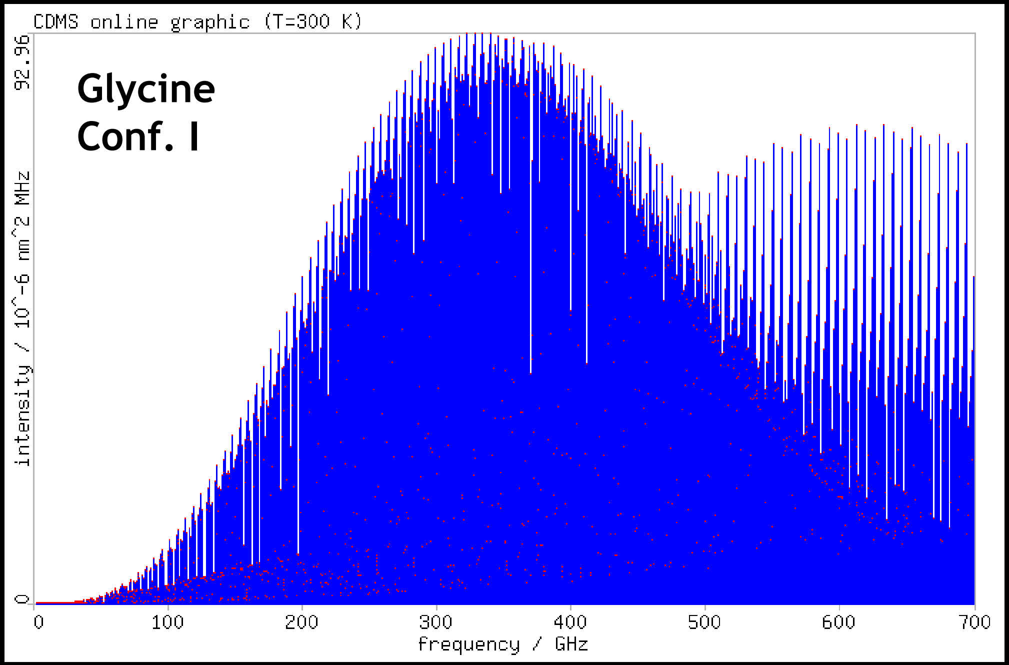
Glycine in Solar-system Precursors (Pre-stellar Cores)



Advantages:

- T_{gas}<10 K ⇒ lower level of line confusion!
- Linewidths <0.5 kms^{-1} ⇒ little line blending, easier line identification.
- Complex organic molecules detected in dark cloud cores and pre-stellar cores (Marcelino+2007; Bacmann+2012; Cernicharo+2013; Vastel+2014).
- High-sensitivity searches now possible ⇒ **Atacama Large Millimeter Array (ALMA)**

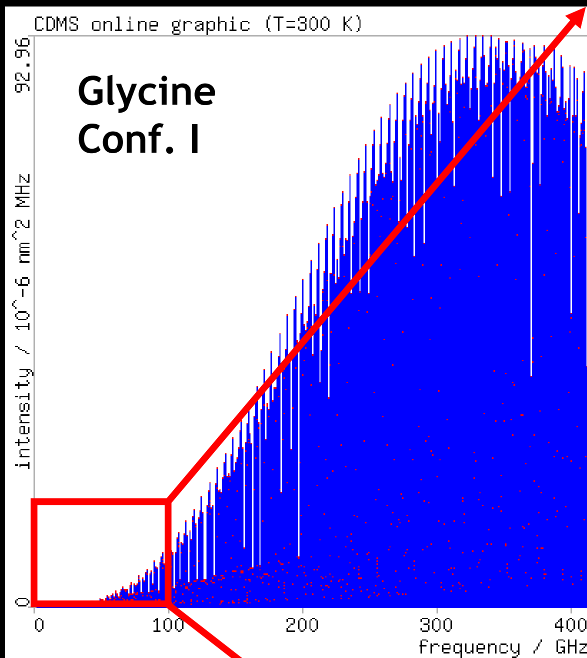
Glycine transitions with E_u< 30 K



CDMS
Müller+2005

Glycine transitions with $E_u < 30$ K

$A_{ul} > 10^{-6}$ s^{-1} $\Rightarrow$ 60 GHz $< \nu <$ 90 GHz



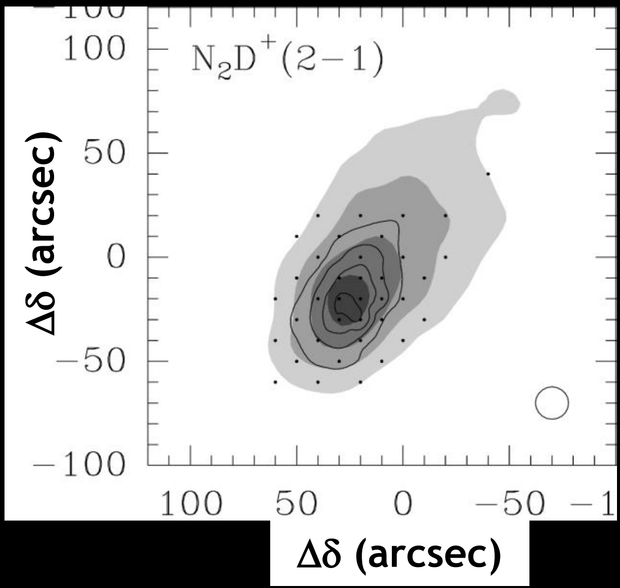
CDMS
Müller+2005

(For units and further details on the catalog entries see the General section.)

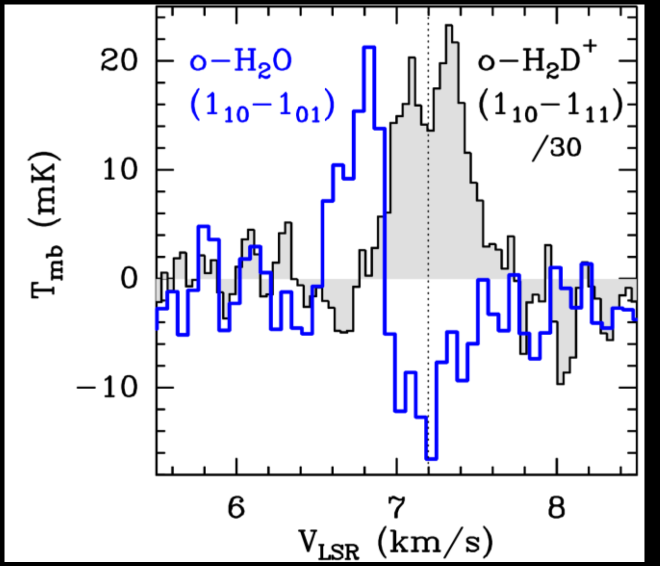
frequency	uncert.	Einst.A		E.lower		tag		quantum nos: up-low	molecule
60873.0340	0.0057	-5.9915	3	9.5212	63	75511	30310 110	9 1 9	Glycine, conf. I
61004.8405	0.0059	-5.9885	3	9.5112	63	75511	30310 010	9 0 9	Glycine, conf. I
61425.3468	0.0036	-5.9913	3	8.7553	57	75511	303 9 1 8	8 1 7	Glycine, conf. I
63866.8653	0.0074	-5.9741	3	10.3895	57	75511	303 9 3 6	8 3 5	Glycine, conf. I
65000.3333	0.0059	-5.9223	3	9.4662	57	75511	303 9 2 7	8 2 6	Glycine, conf. I
65565.2641	0.0038	-5.9093	3	10.9702	63	75511	30310 2 9	9 2 8	Glycine, conf. I
66721.6403	0.0061	-5.8694	3	11.5517	69	75511	30311 111	10 110	Glycine, conf. I
66796.6587	0.0063	-5.8678	3	11.5461	69	75511	30311 011	10 010	Glycine, conf. I
67189.1207	0.0042	-5.8726	3	10.8043	63	75511	30310 1 9	9 1 8	Glycine, conf. I
68323.7013	0.0042	-5.8757	3	12.3569	63	75511	30310 3 8	9 3 7	Glycine, conf. I
68736.2569	0.0048	-5.9502	3	16.0443	63	75511	30310 5 6	9 5 5	Glycine, conf. I
68769.0258	0.0049	-5.9495	3	16.0449	63	75511	30310 5 5	9 5 4	Glycine, conf. I
68941.6361	0.005	-5.8973	3	13.9849	63	75511	30310 4 7	9 4 6	Glycine, conf. I
69472.9012	0.0062	-5.8872	3	13.9991	63	75511	30310 4 6	9 4 5	Glycine, conf. I
71611.5610	0.0085	-5.8118	3	12.5199	63	75511	30310 3 7	9 3 6	Glycine, conf. I
71646.3858	0.0042	-5.7893	3	13.1572	69	75511	30311 210	10 2 9	Glycine, conf. I
71910.3034	0.0055	-5.7858	3	11.6344	63	75511	30310 2 8	9 2 7	Glycine, conf. I
72559.3531	0.0065	-5.7579	3	13.7773	75	75511	30312 112	11 111	Glycine, conf. I
72601.1067	0.0066	-5.7572	3	13.7742	75	75511	30312 012	11 011	Glycine, conf. I
72841.2492	0.0049	-5.7654	3	13.0455	69	75511	30311 110	10 1 9	Glycine, conf. I
74923.4420	0.0043	-5.7469	3	14.6359	69	75511	30311 3 9	10 3 8	Glycine, conf. I
75314.6060	0.0046	-5.9297	3	23.8534	69	75511	30311 7 5	10 7 4	Glycine, conf. I
75314.6868	0.0046	-5.9297	3	23.8534	69	75511	30311 7 4	10 7 3	Glycine, conf. I
75489.2932	0.0049	-5.8546	3	20.8597	69	75511	30311 6 6	10 6 5	Glycine, conf. I
75492.6159	0.0049	-5.8546	3	20.8598	69	75511	30311 6 5	10 6 4	Glycine, conf. I
75756.6272	0.0053	-5.7972	3	18.3371	69	75511	30311 5 7	10 5 6	Glycine, conf. I
75836.4964	0.0055	-5.7958	3	18.3387	69	75511	30311 5 6	10 5 5	Glycine, conf. I
75922.2340	0.0054	-5.7558	3	16.2846	69	75511	30311 4 8	10 4 7	Glycine, conf. I
76913.6995	0.0075	-5.7387	3	16.3165	69	75511	30311 4 7	10 4 6	Glycine, conf. I
77652.2918	0.0046	-5.681	3	15.5471	75	75511	30312 211	11 210	Glycine, conf. I
78390.5414	0.0069	-5.6554	3	16.1976	81	75511	30313 113	12 112	Glycine, conf. I
78413.3774	0.0069	-5.655	3	16.1960	81	75511	30313 013	12 012	Glycine, conf. I
78471.9442	0.0053	-5.6662	3	15.4752	75	75511	30312 111	11 110	Glycine, conf. I
78524.6322	0.0049	-5.6684	3	14.0330	69	75511	30311 2 9	10 2 8	Glycine, conf. I
79323.9346	0.0091	-5.6685	3	14.9086	69	75511	30311 3 8	10 3 7	Glycine, conf. I
81411.8819	0.0043	-5.6323	3	17.1351	75	75511	30312 310	11 3 9	Glycine, conf. I
82011.9030	0.05	-5.9506	3	33.7464	75	-75511	30312 9 3	11 9 2	Glycine, conf. I
82011.9030	0.05	-5.9506	3	33.7464	75	-75511	30312 9 4	11 9 3	Glycine, conf. I
82111.5190	0.05	-5.8454	3	29.8228	75	-75511	30312 8 5	11 8 4	Glycine, conf. I
82111.5190	0.05	-5.8454	3	29.8228	75	-75511	30312 8 4	11 8 3	Glycine, conf. I
82257.8420	0.05	-5.7684	3	26.3656	75	-75511	30312 7 6	11 7 5	Glycine, conf. I
82258.0440	0.05	-5.7684	3	26.3656	75	-75511	30312 7 5	11 7 4	Glycine, conf. I
82484.0560	0.05	-5.7091	3	23.3778	75	-75511	30312 6 7	11 6 6	Glycine, conf. I
82493.3050	0.05	-5.709	3	23.3779	75	-75511	30312 6 6	11 6 5	Glycine, conf. I

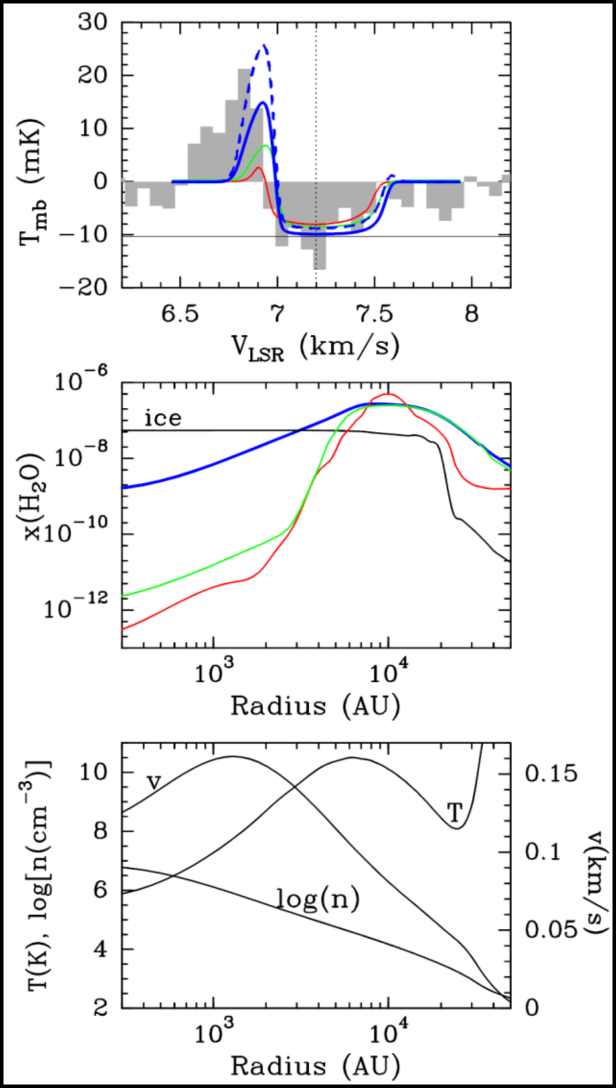
The L1544 Pre-stellar Core

Caselli+2002



Caselli+2012

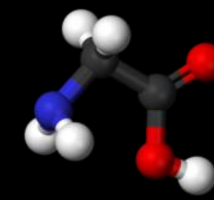




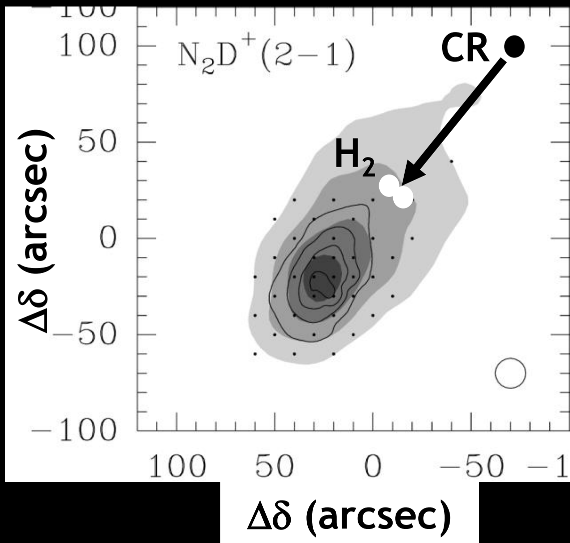
Simple and quiescent object ($\Delta v<0.5$ kms^{-1})

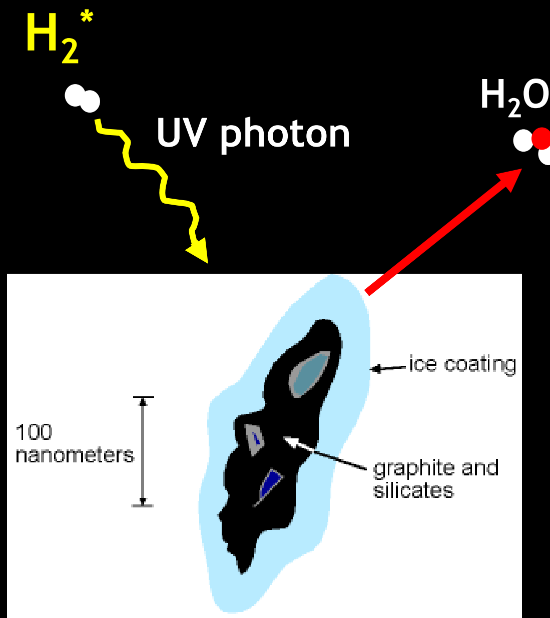
Gas-phase water in the central 5000 AU

UV photo-desorption of ices

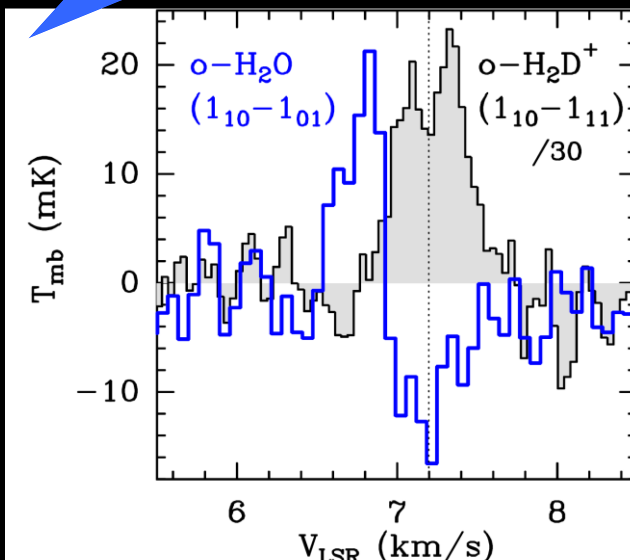


Caselli+2002



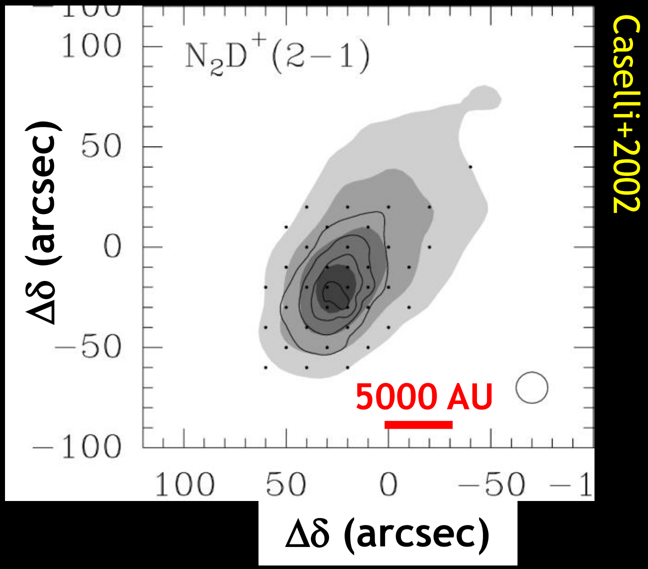


Caselli+2012

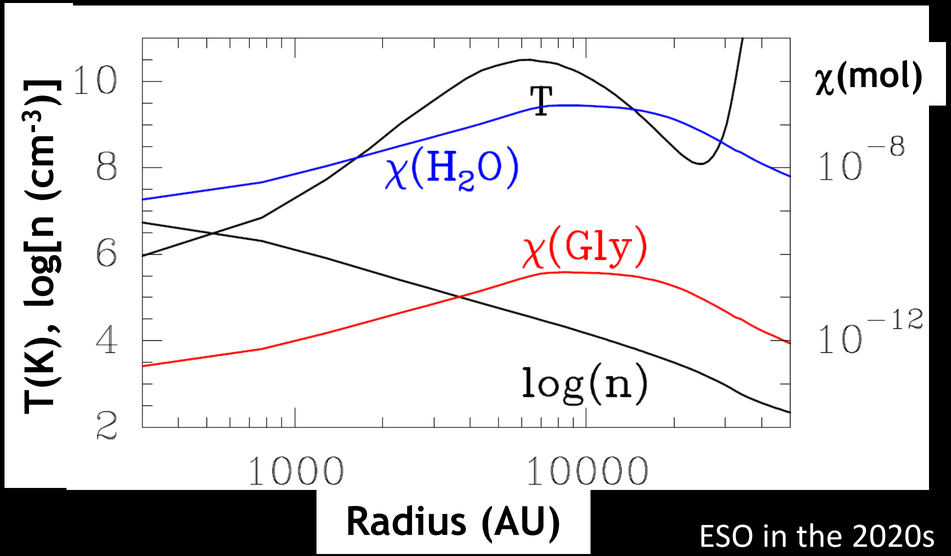


- Gas-phase water produced by cosmic ray induced UV photons (Caselli+2012)
- COMs released together with water
- Lines expected to be very narrow ⇒ high-spectral resolution needed!

Cold Glycine in Pre-stellar Cores: L1544

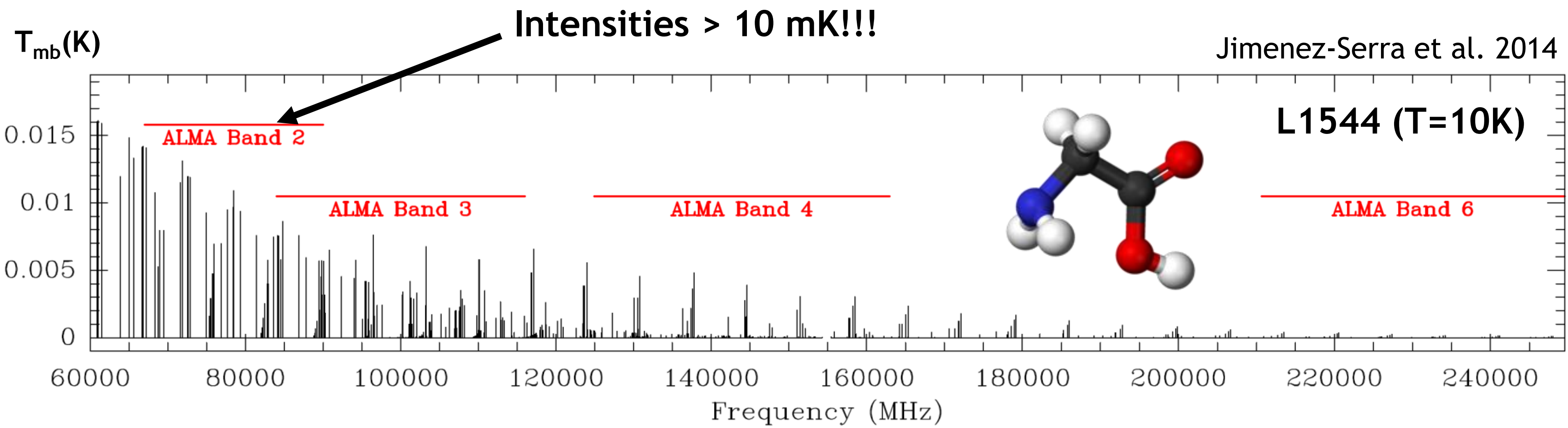


Jimenez-Serra et al. 2014

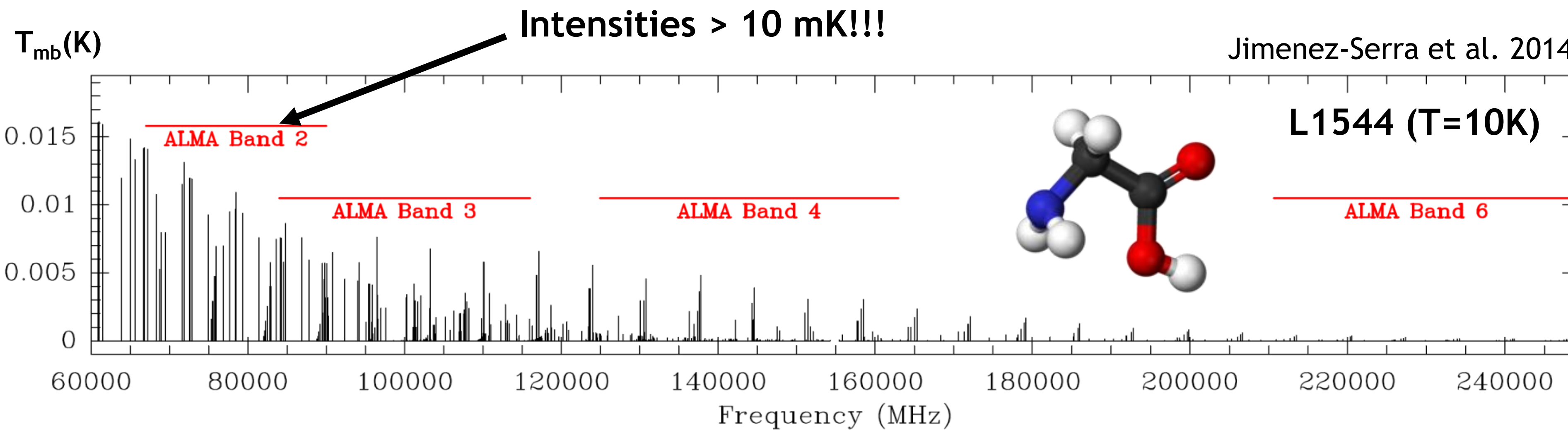


- Gas-phase H_2O found within r<5000 AU (Caselli+2012).
- Physical structure from Keto & Caselli (2010).
- Glycine abundance in ices ~0.01% wrt H_2O (Munoz-Caro+2002; Bernstein+2002).
- Glycine is photo-desorbed together with water.

Simulations of Glycine Lines in L1544



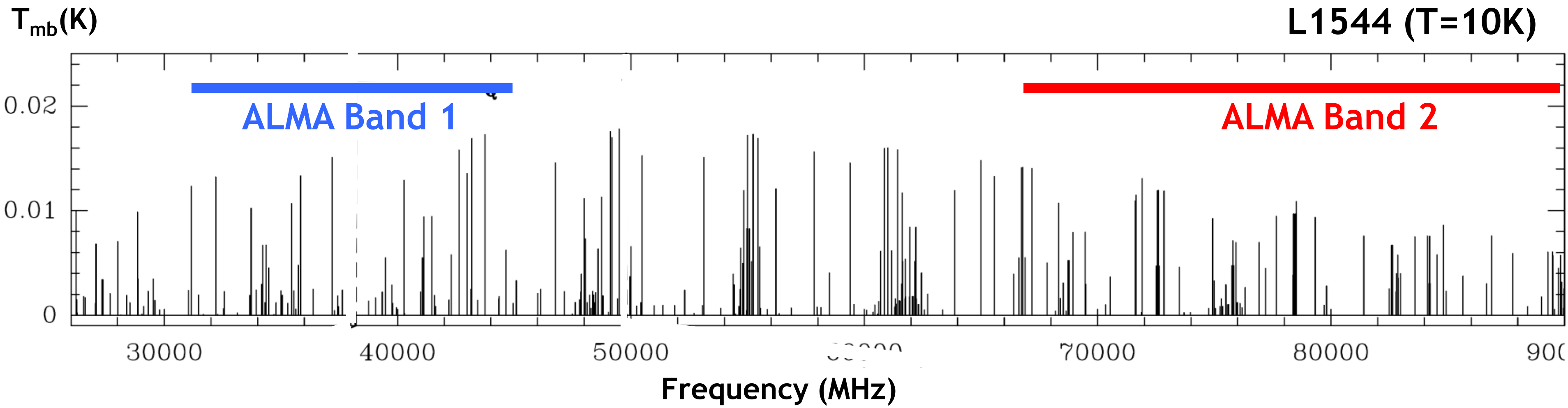
Simulations of Glycine Lines in L1544



- **Brightest lines between 67 GHz and 85 GHz.**
- **Excellent target for ALMA Band 2!!!!**

Line	Transition	Frequency[a] (MHz)	A_{ul} (s^{-1})	E_u (K)	g_u
1	$10_{1,9}\rightarrow 9_{1,8}$	67189.12	1.3×10^{-6}	18.8	63
2	$10_{3,8}\rightarrow 9_{3,7}$	68323.70	1.3×10^{-6}	21.1	63
3	$10_{3,7}\rightarrow 9_{3,6}$	71611.56	1.5×10^{-6}	21.5	63
4	$11_{2,10}\rightarrow 10_{2,9}$	71646.39	1.6×10^{-6}	22.4	69
5	$10_{2,8}\rightarrow 9_{2,7}$	71910.30	1.6×10^{-6}	20.2	63
6	$12_{1,12}\rightarrow 11_{1,11}$	72559.35	1.7×10^{-6}	23.3	75
7	$12_{0,12}\rightarrow 11_{0,11}$	72601.11	1.7×10^{-6}	23.3	75
8	$11_{1,10}\rightarrow 10_{1,9}$	72841.25	1.7×10^{-6}	22.3	69
9	$11_{2,9}\rightarrow 10_{2,8}$	78524.63	2.1×10^{-6}	24.0	69
10	$12_{2,10}\rightarrow 11_{2,9}$	84813.04	2.7×10^{-6}	28.0	75

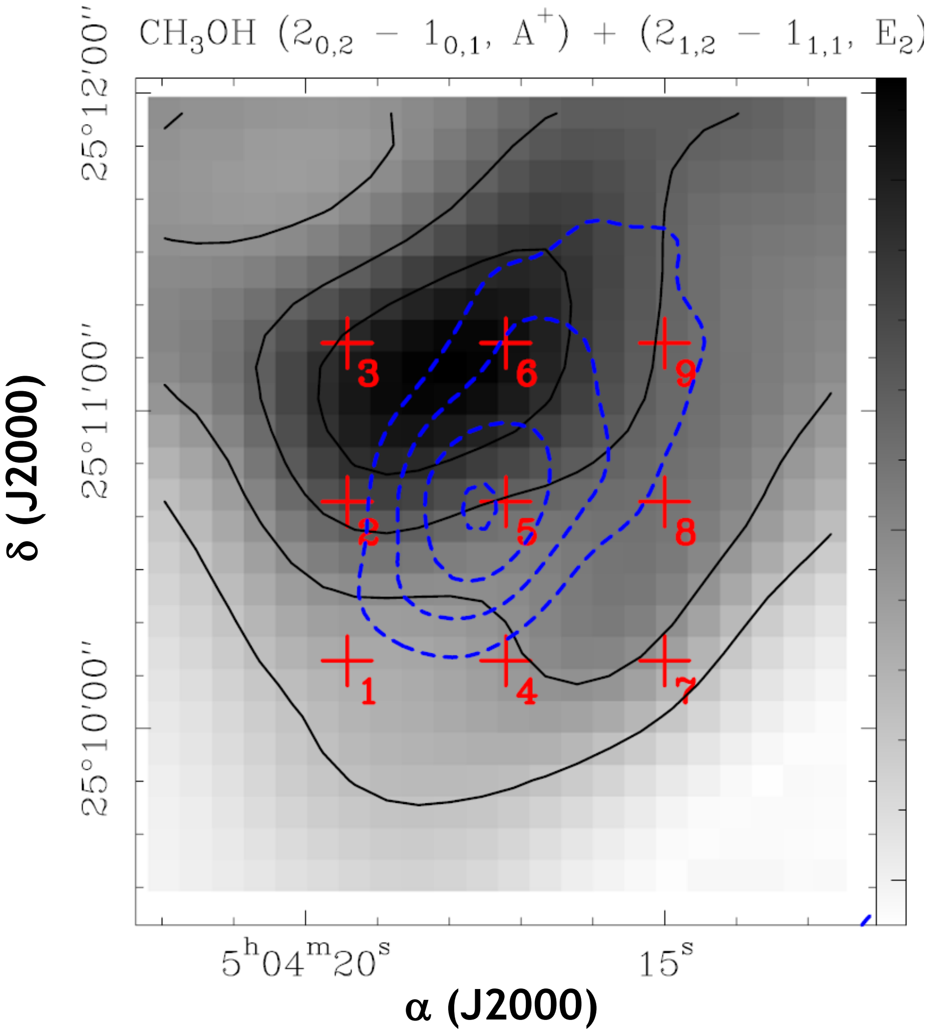
Simulations of Glycine for ALMA Band 1



Full Science Capabilities					Most Compact		Most Extended	
Band	Frequency (GHz)	Wavelength (mm)	Primary Beam (FOV; ")	Continuum Sensitivity (mJy/beam)	Angular Resolution (")	Spectral Sensitivity ΔT_{line} (K)	Angular Resolution (")	Spectral Sensitivity ΔT_{line} (K)
1	31.3-45	6.7-9.5	197-137	0.04	13-9	0.006	0.12-0.08	255
2	67-90	3.3-4.5	92-69	0.06	6-4.4	0.009	0.06-0.04	413
3	84-116	2.6-3.6	73-53	0.07	4.8-3.4	0.04	0.045-0.032	430
4	125-163	1.8-2.4	49-38	0.06	3.2-2.4	0.048	0.030-0.023	330
5	163-211	1.4-1.8	38-29	0.11	2.5-1.9	0.06	0.027-0.021	641
6	211-275	1.1-1.4	29-22	0.085	1.9-1.5	0.05	0.018-0.014	490
7	275-373	0.8-1.1	22-16	0.15	1.5-1.1	0.08	0.014-0.01	814
8	385-500	0.6-0.8	16-12	0.28	1.04-0.8	0.28	0.01-0.008	1900
9	602-720	0.4-0.5	10-8.6	1.1	0.66-0.55	0.9	0.006-0.005	8900
10	787-950	0.3-0.4	7.8-6.5	1.2	0.51-0.42	1.6	0.005-0.004	—

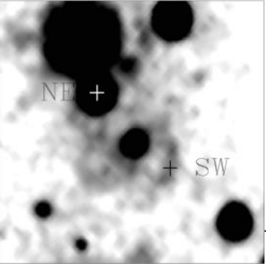
COM distribution in L1544

Bizzocchi et al. (2014)

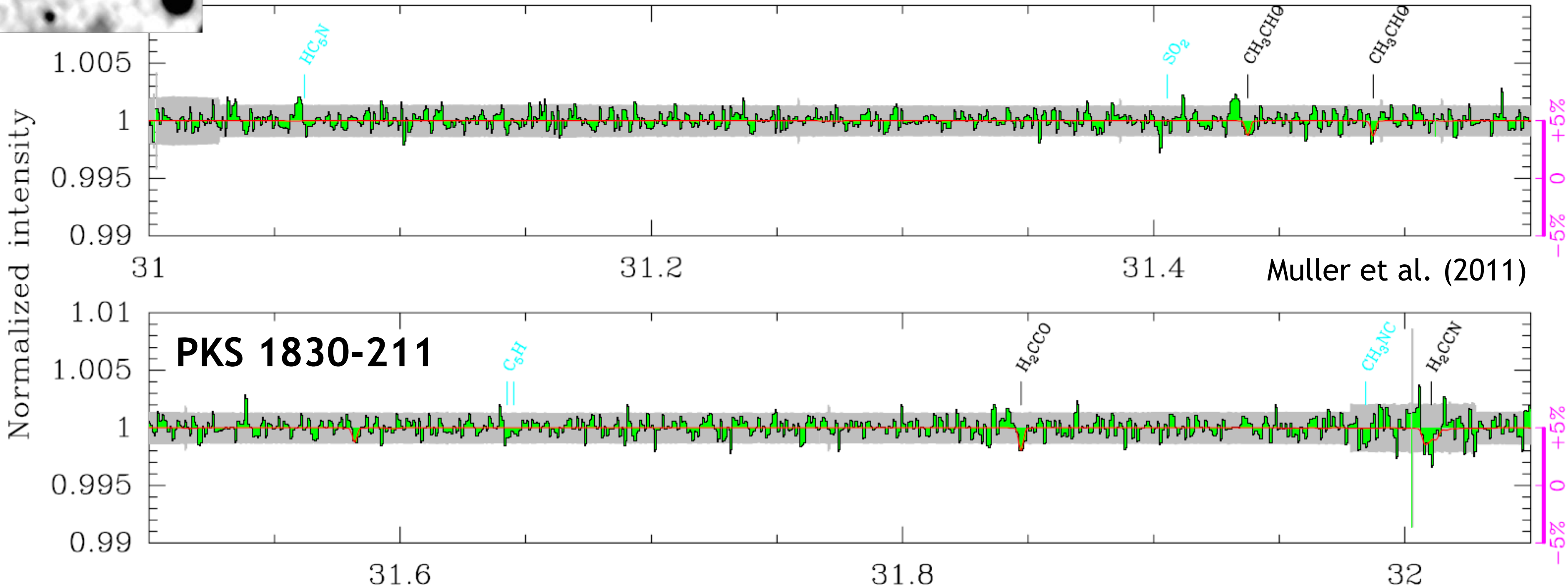


- ❑ **Extended nature of the COM emission.**
- ❑ **Matches FOV and θ_{beam} for Bands 1/2 in Compact (FOV~70"-200") (θ_{beam}~4.5"-13")**
- ❑ **ACA+TP needed to recover large-scale structure.**
- ❑ **Only sensitivity matters ⇒ ACA+TP could be used as stand-alone instrument.**

COMs in Extragalactic Sources

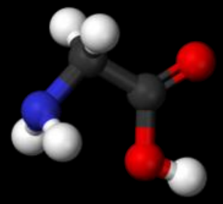


ATCA survey 30-50 GHz



- COMs (e.g. CH_3OH, CH_3CHO, H_2CCO) detected at z~0.89
- Water in starburst galaxies at z~5.7 (Vieira et al. 2013)
- Grain chemistry becomes active early on in the Universe

Conclusions



- High-angular resolution key for COM detection
- Broad bandwidth observations with high spectral resolution
  - currently limited by ALMA data rates
  - increase of simultaneous bandwidth desirable
- Detection of amino acids in cold sources
  - Development of low-frequency receivers
  - ALMA Bands 1 and 2 essential
- High-sensitivity needed but not limited by spatial resolution
  - ACA+TP could be used as stand-alone facility
- Increase of ALMA sensitivity for extragalactic studies
  - Detection of COMs at high-redshifts