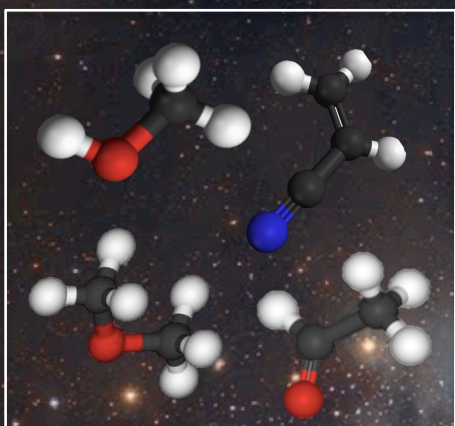
Detecting Complex Organic Molecules in Prestellar Cores in the Taurus Star Forming Region



Samantha Scibelli
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Advised by Dr. Yancy Shirley

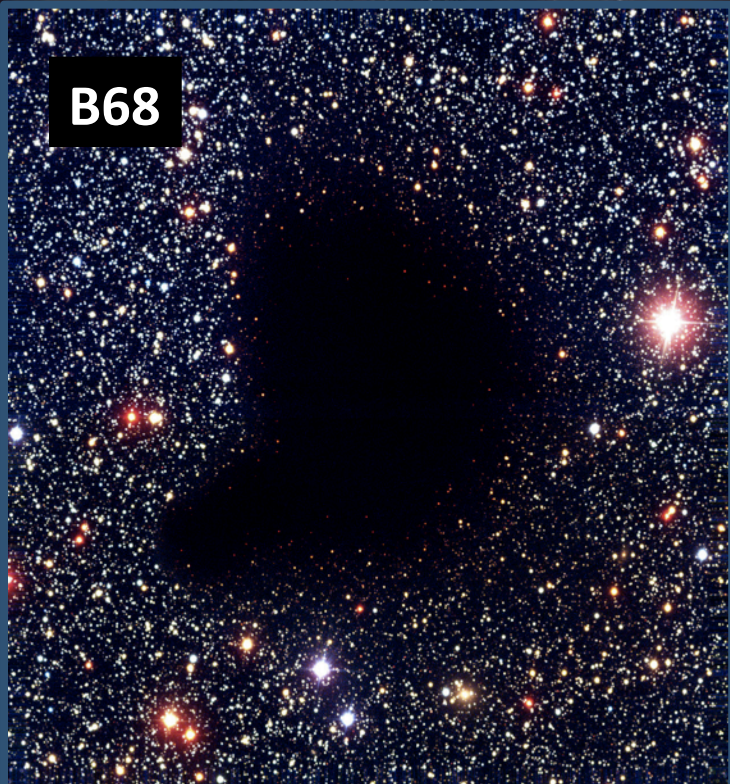
Steward Observatory, University of Arizona

Arizona Radio Observatory

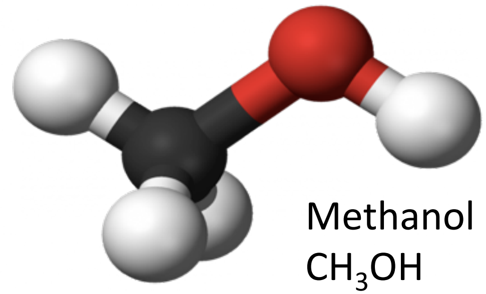
The 35th Annual New Mexico Symposium
21 February 2020 - National Radio Astronomy Observatory

NSF

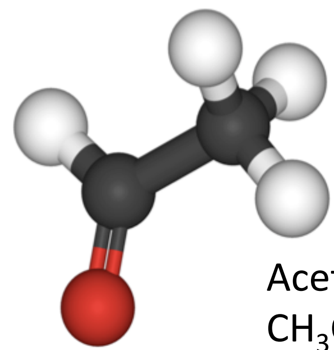
COMs in Prestellar Cores



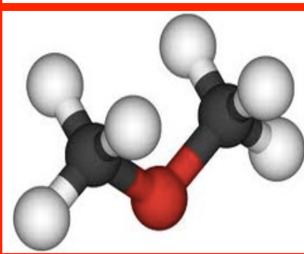
Birthplace of low-mass stars
($M \leq$ a few $M_{\odot}$)
Dense (10^4 - 10^5 cm^{-3}) & cold ($\leq$ 10K)



Methanol
CH_3OH

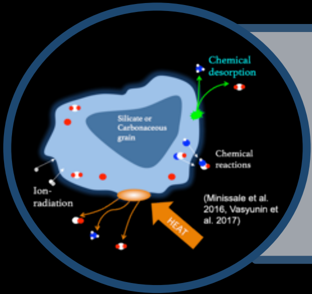


Acetaldehyde
CH_3CHO



Dimethyl Ether
CH_3OCH_3

When, where and how are these molecules forming in prestellar cores?



Origins of Complex Molecules

Gas: $CH_3OH_2^+ + e^- \rightarrow CH_3OH + H$ only 3% yield … ***too SLOW*** (Geppert et al. 2006)

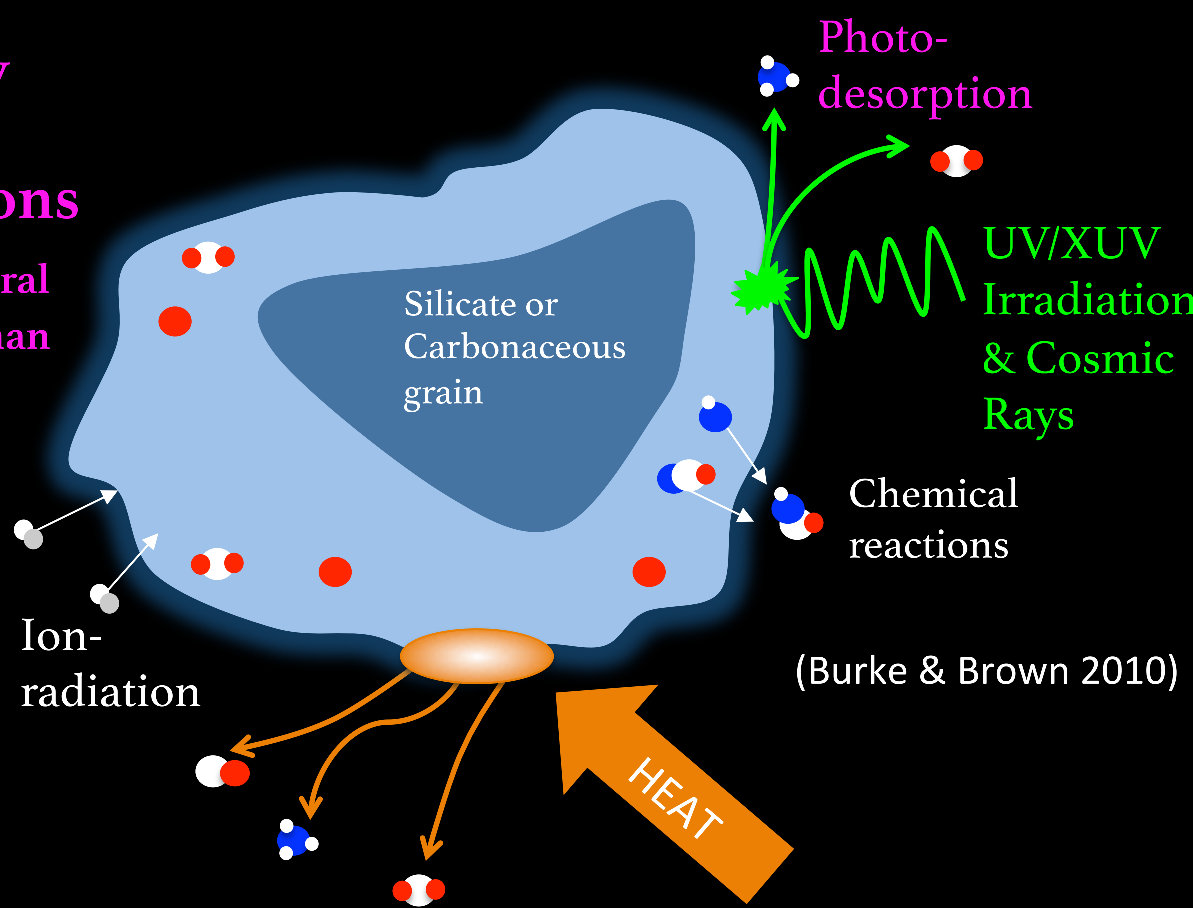
Gas-phase Chemistry

Ion-molecule Reactions

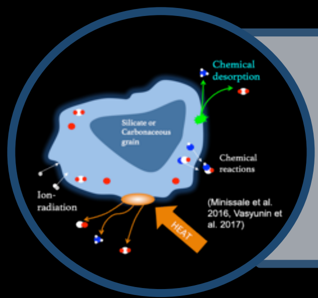
→ COM abundances several of orders of magnitude lower than observed

(Charnley & Tielens 1992)

How do complex organics form in cold (10 K), UV-shielded environments?



(Burke & Brown 2010)



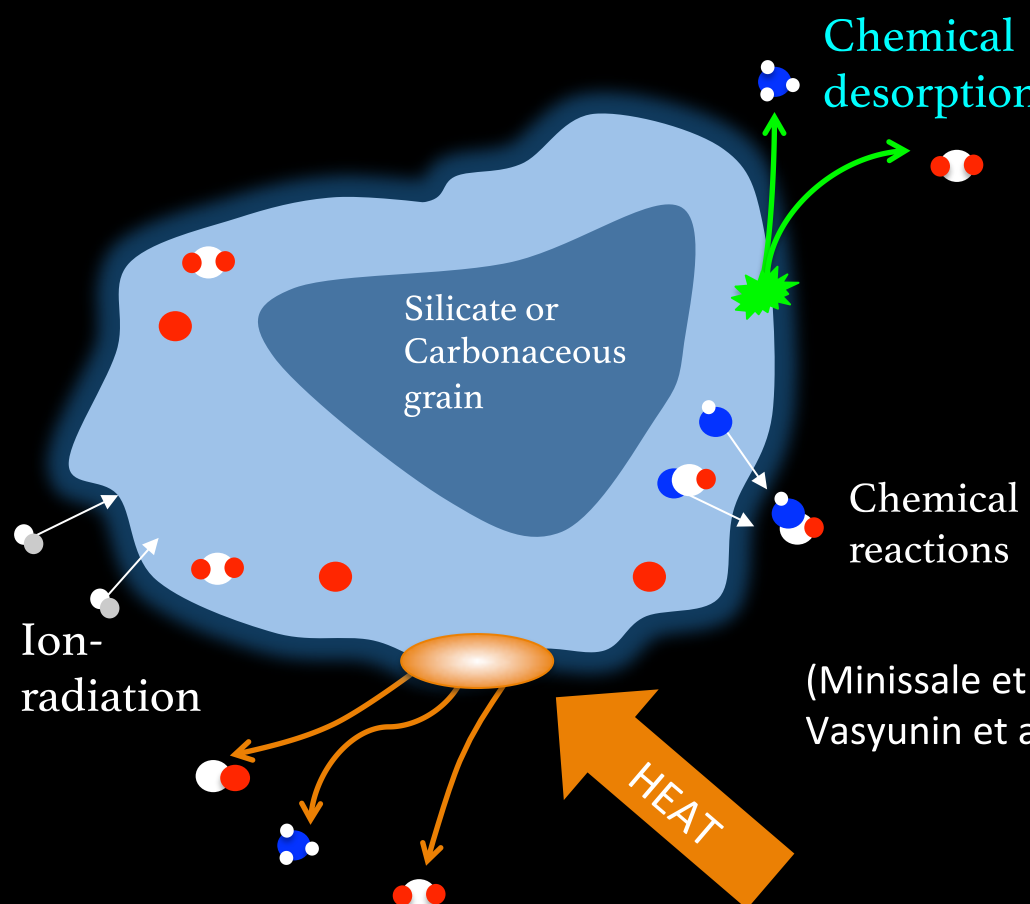
Origins of Complex Molecules

Solid: $CO + H \rightarrow HCO + H \rightarrow H_2CO + H \rightarrow CH_3O + H \rightarrow CH_3OH$

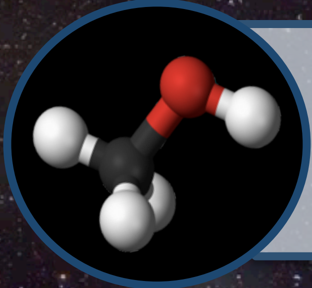
Chemical Reactive Desorption

Neutral-Neutral reactions of radicals

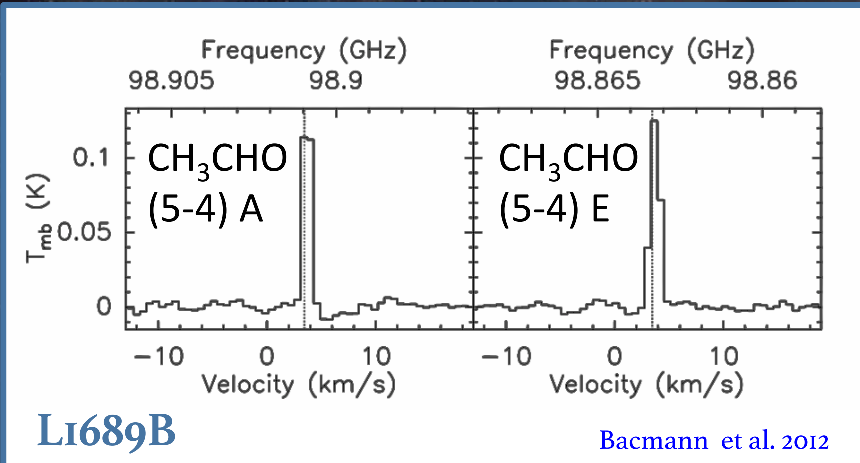
Models predict abundances which we can constrain!

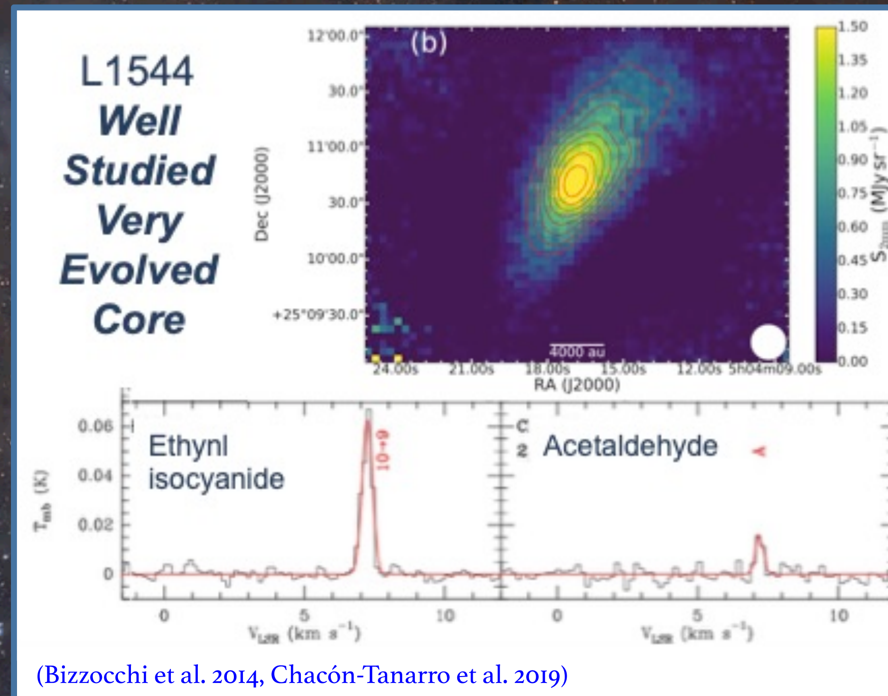


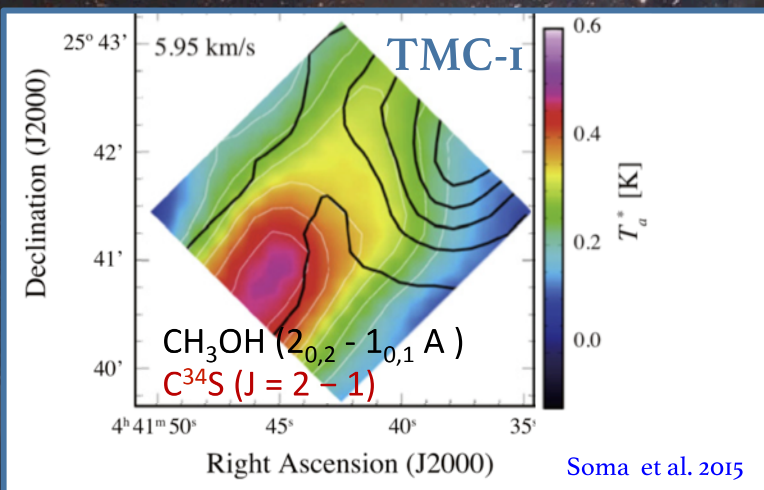
(Minissale et al. 2016, Vasyunin et al. 2017)



COMs in Prestellar Cores

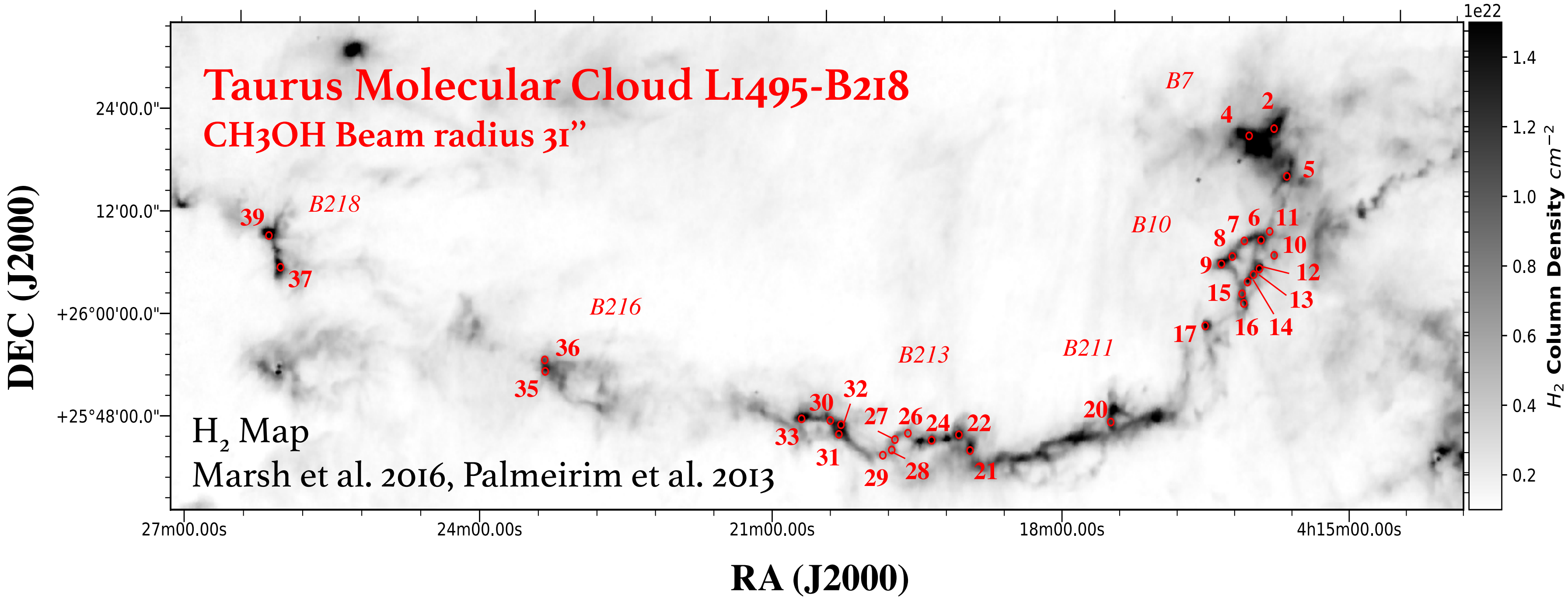






COMs observed **in only a few (< 10)** well-known dense and evolved prestellar cores

Survey of Starless and Prestellar Cores in Taurus



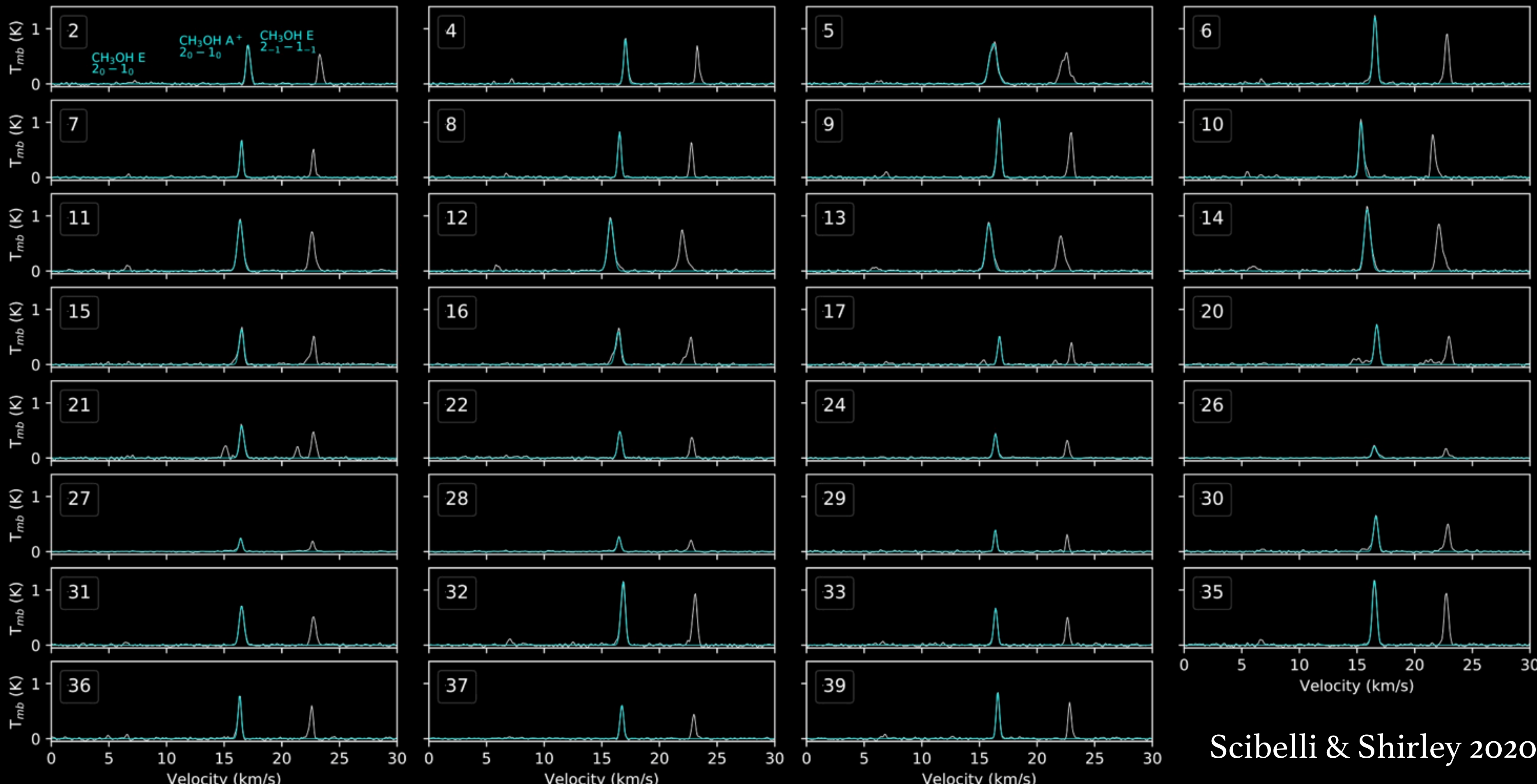
Conducted a large-sample systematic survey of 31 prestellar cores selected from NH_3 mapping results (Seo et al. 2015) in the Taurus Star Forming region

Scibelli & Shirley 2020

arxiv.org/abs/2002.02469

ARO 12m Observing

Detected methanol (CH_3OH) in 100% of the cores targeted!



Scibelli & Shirley 2020

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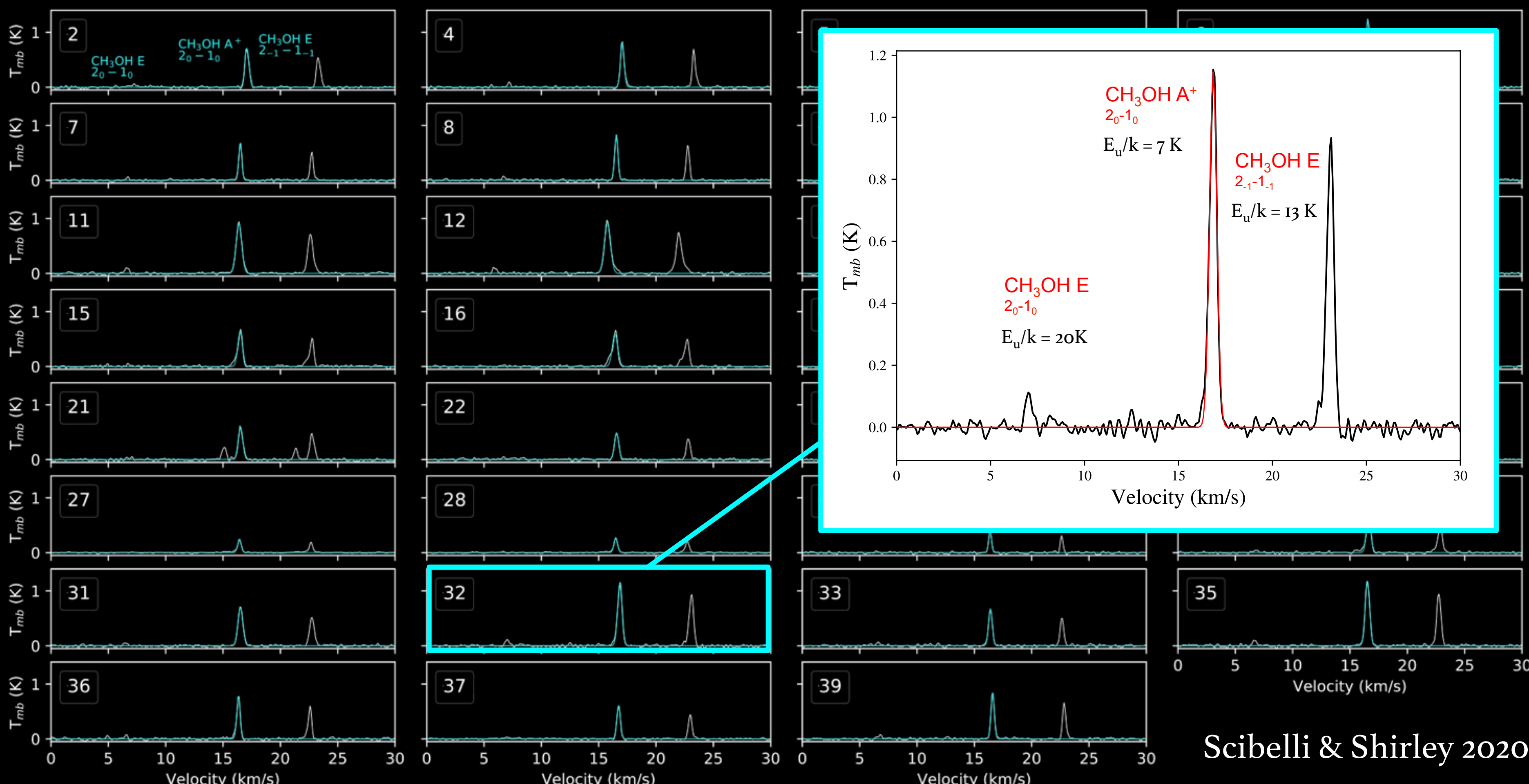

Scibelli & Shirley 2020

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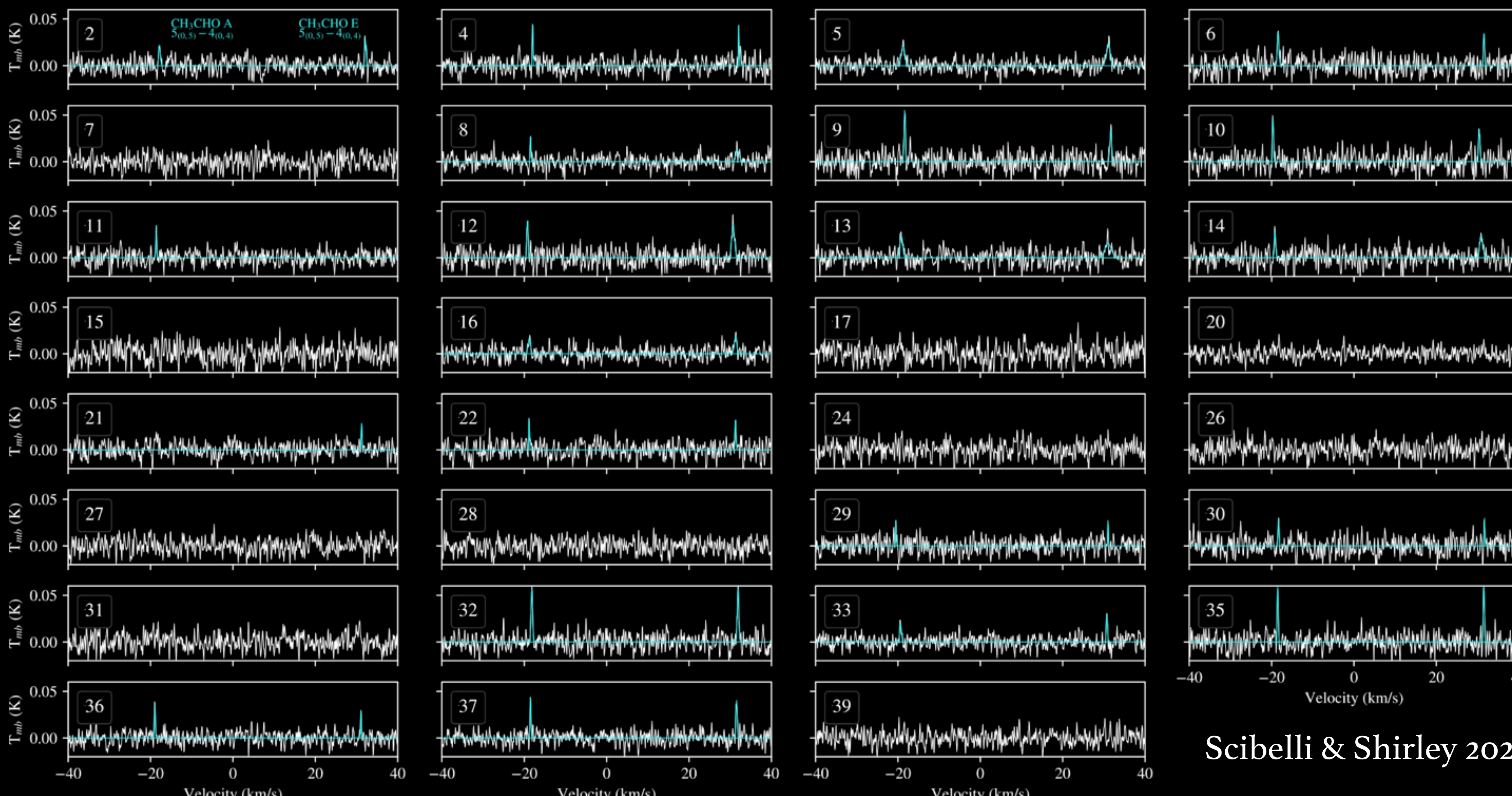
Detected acetaldehyde (CH_3CHO) in 70% of the cores targeted!



Scibelli & Shirley 2020

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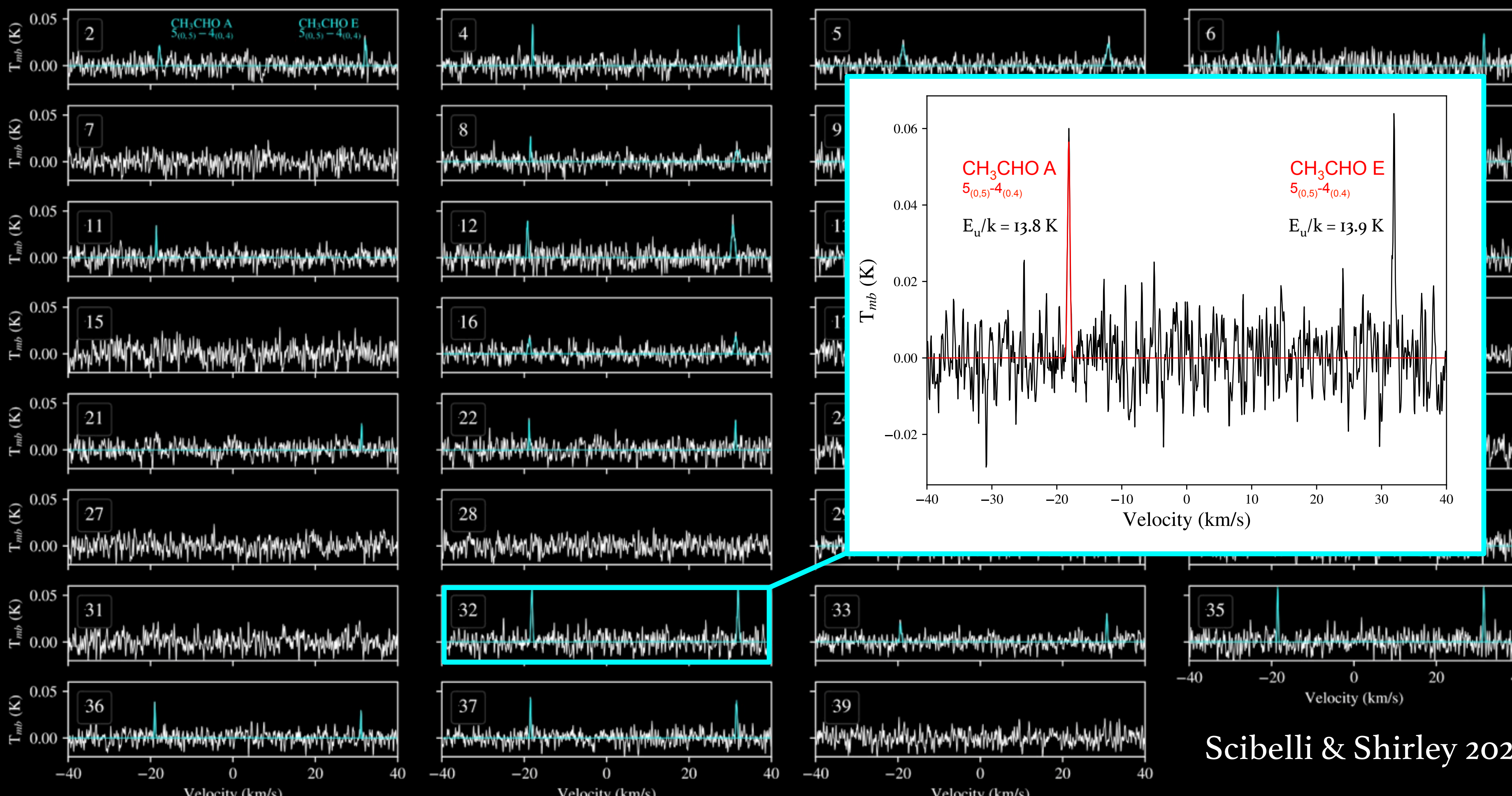

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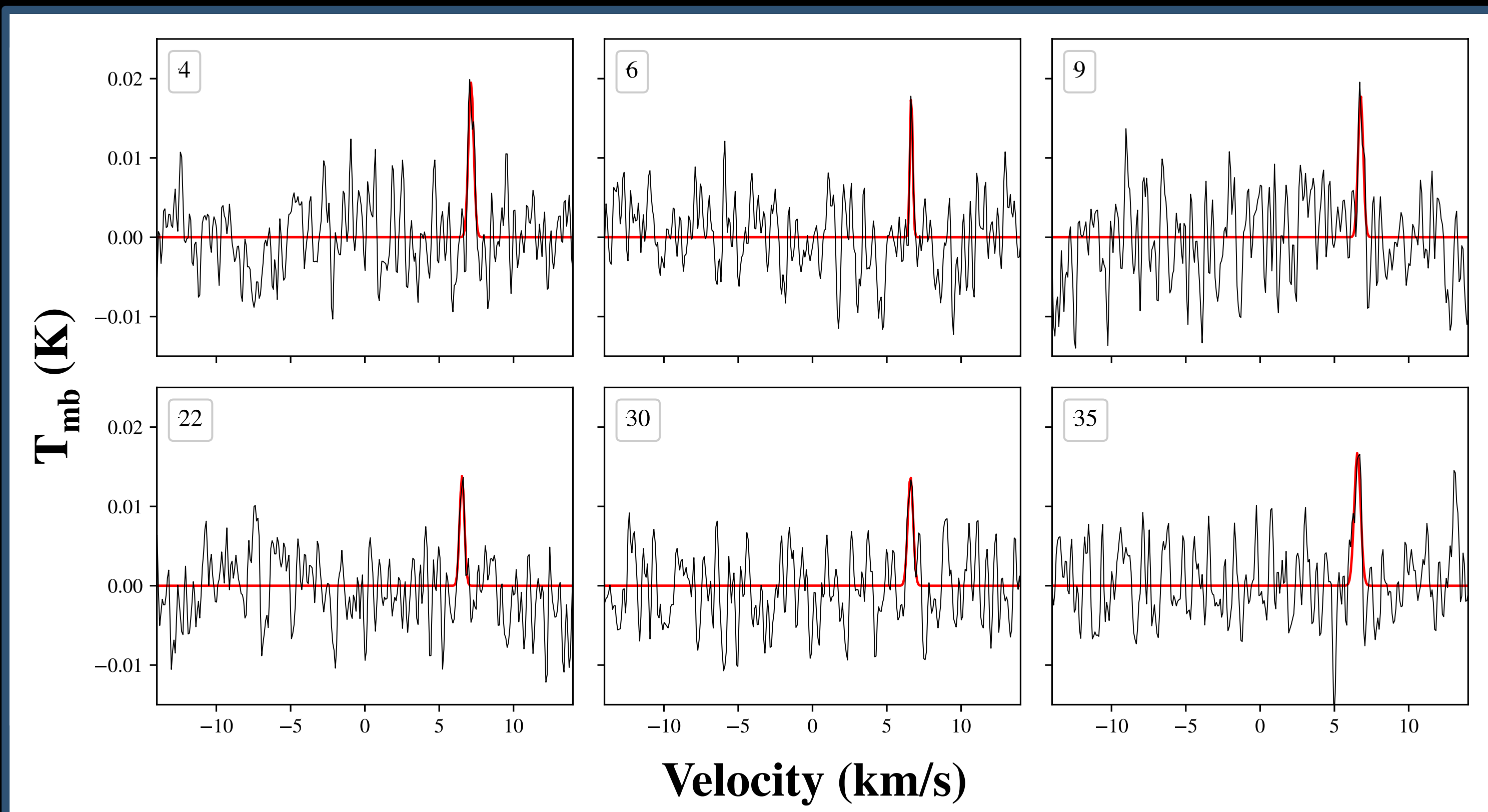
ARO 12m Observing

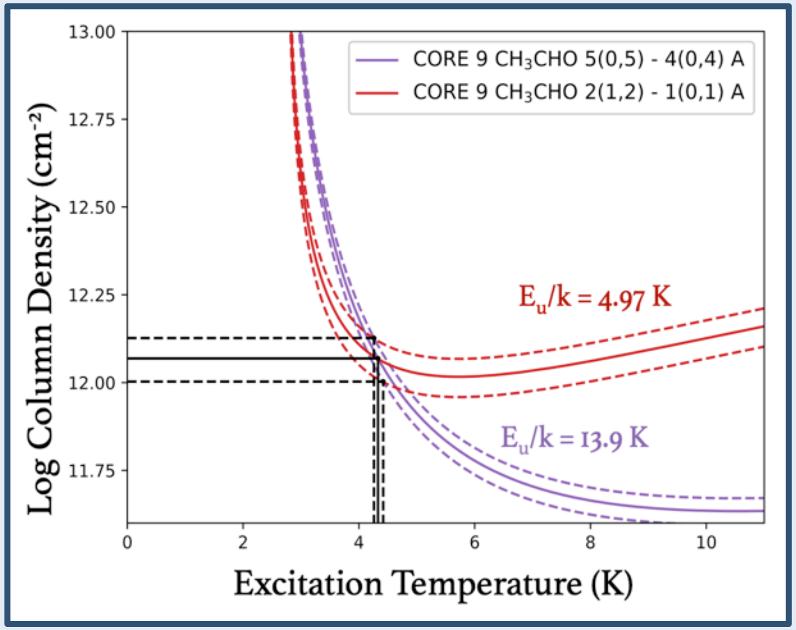
84 GHz CH_3CHO 2-1 transition (E_{up} = 5 K) detected in 6 of the 21 cores for which the 96 GHz CH_3CHO 5-4 transition was detected in



Scibelli & Shirley 2020

Constraining Column Densities and Abundances

CH_3CHO: CTEX Method



Scibelli & Shirley 2020

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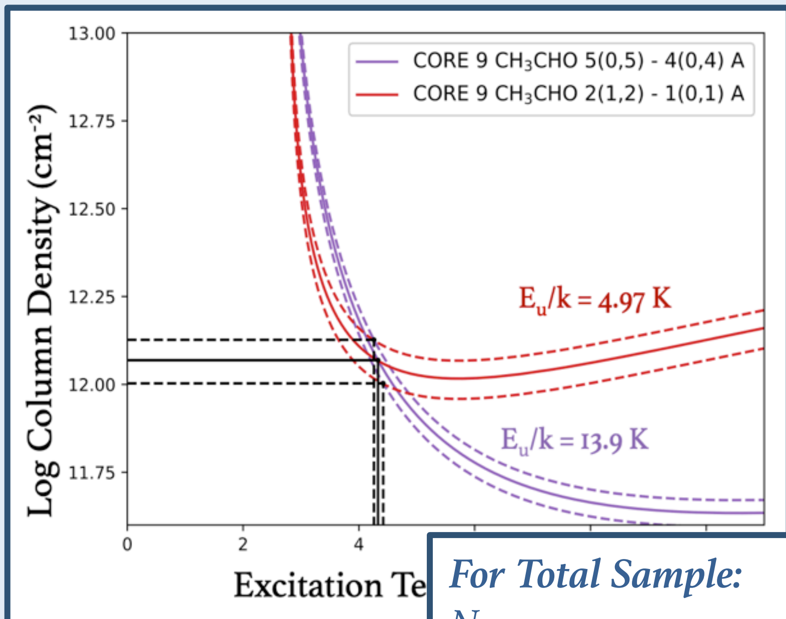

For Total Sample:

N range:

1.2-5.8

+/- 0.068 – 0.035

(10^{12} cm^{-2})

T_{ex} range: 3.06-5.39

-/+ 0.13 – 0.28 (K)

Scibelli & Shirley 2020

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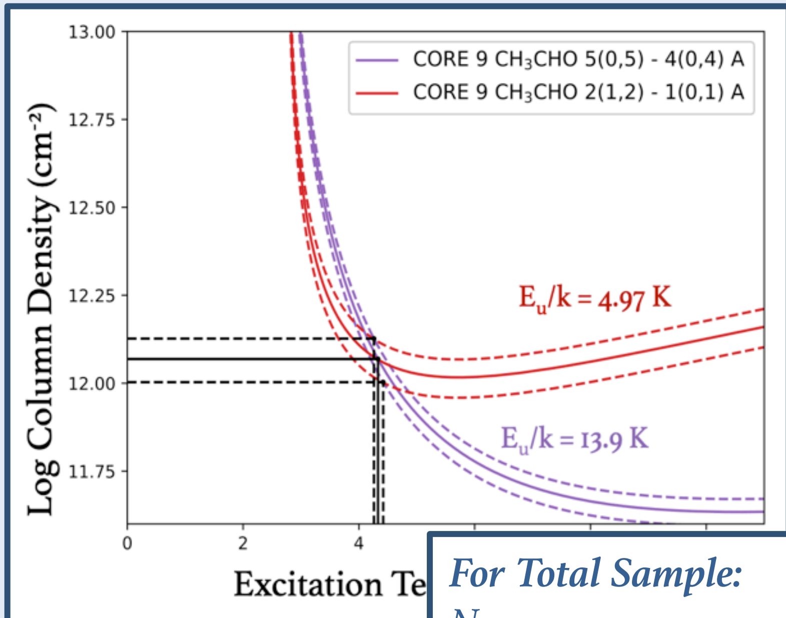

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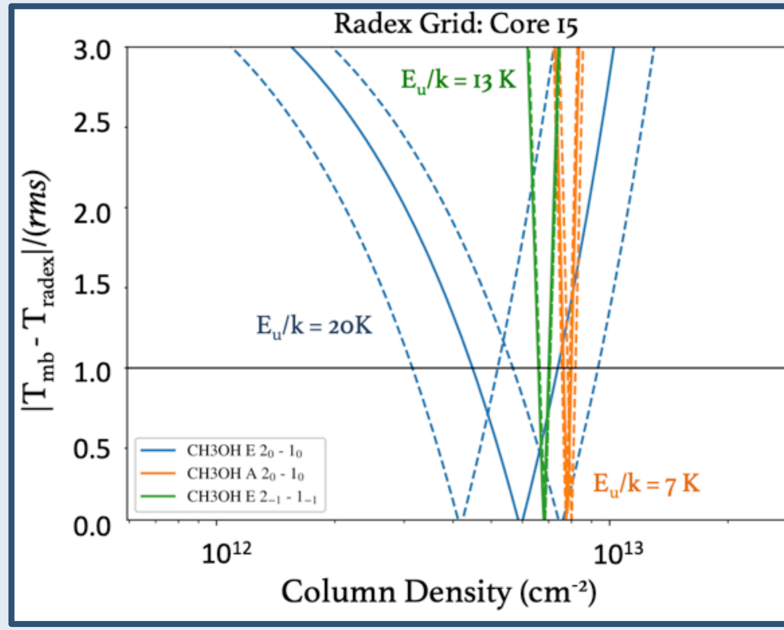
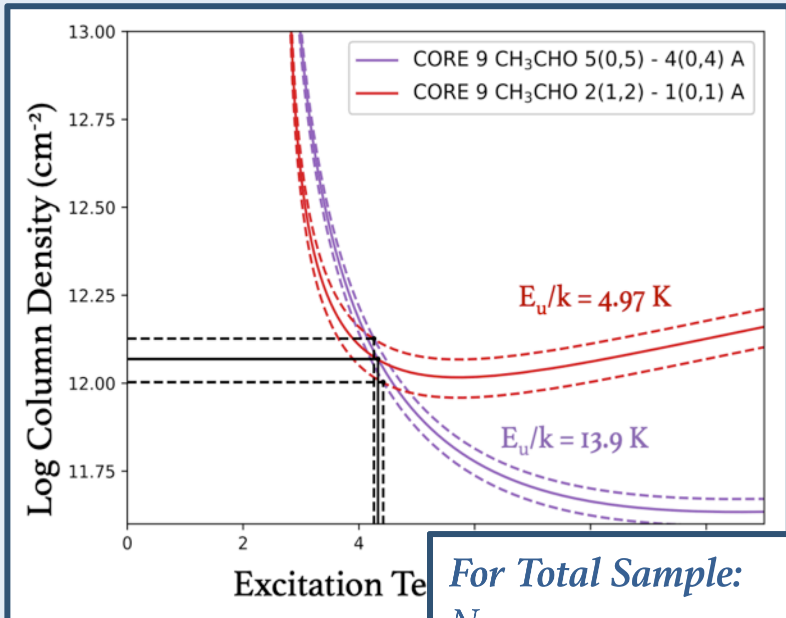
CH_3OH: RADEX Method



Scibelli & Shirley 2020

Constraining Column Densities and Abundances

CH_3CHO: CTEX Method



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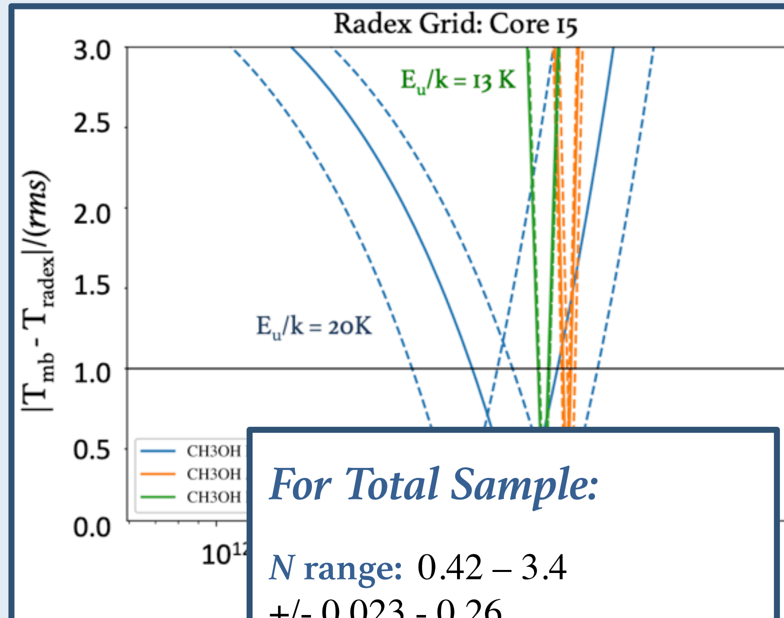

For Total Sample:

N range: 0.42 – 3.4

+/- 0.023 - 0.26

(10^{13} cm^{-2})

Tex range: 6.79 – 8.66

+/- 0.005 – 0.025 (K)

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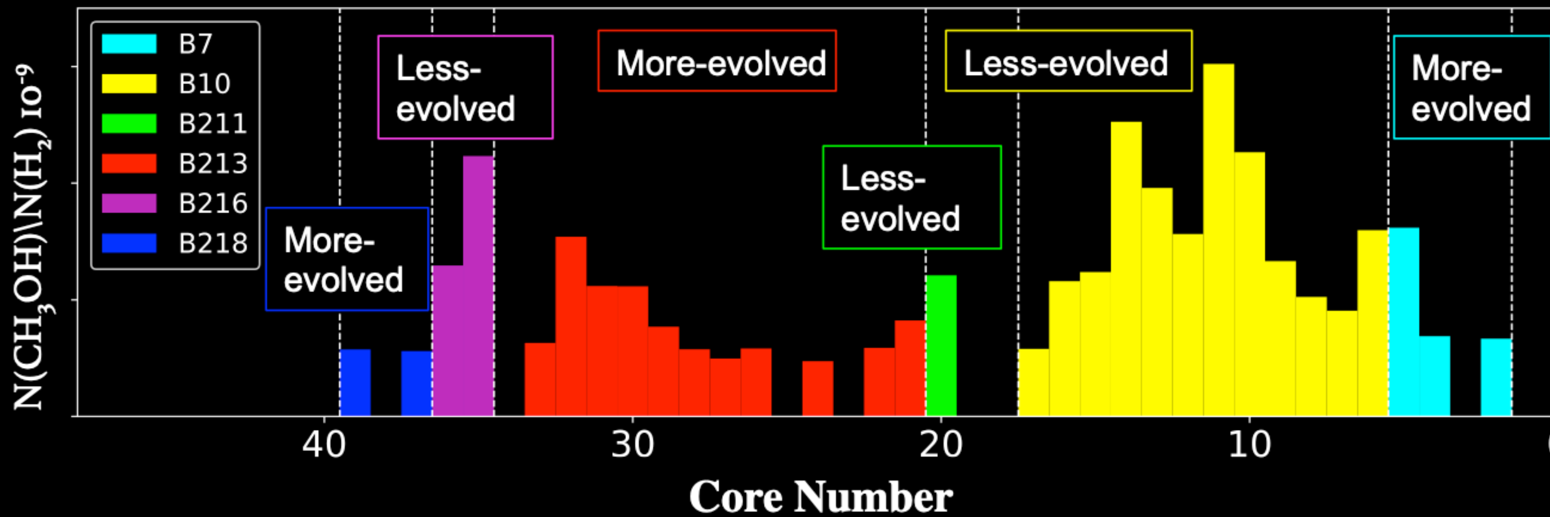
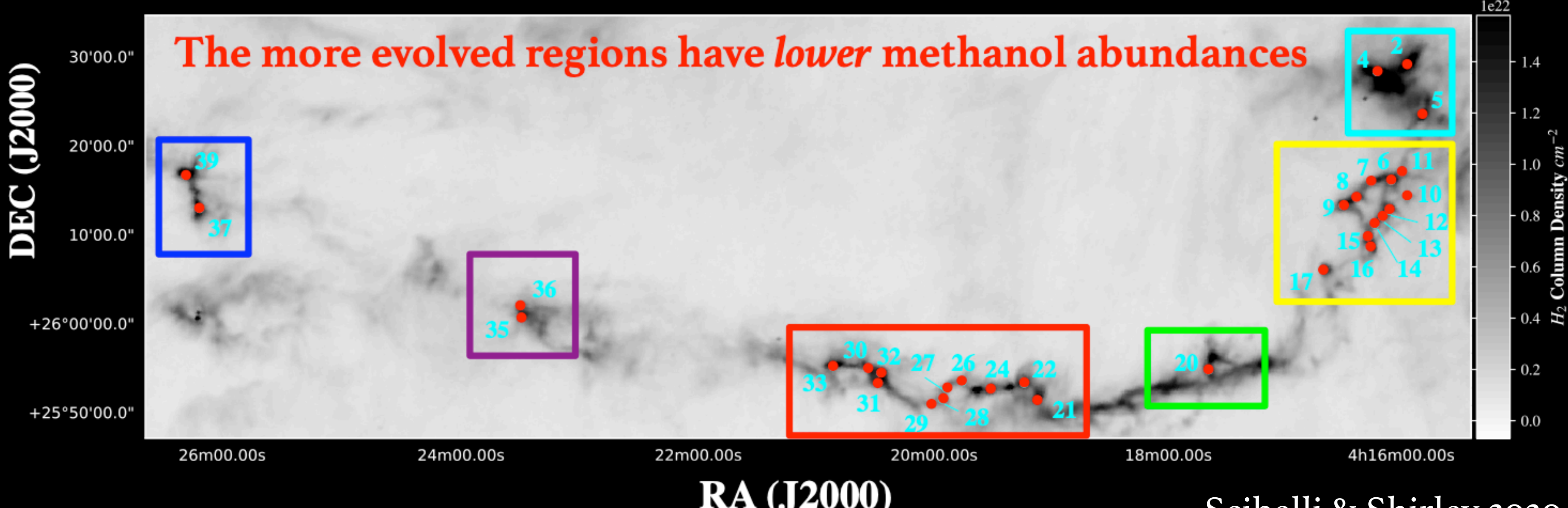
Methanol Abundances





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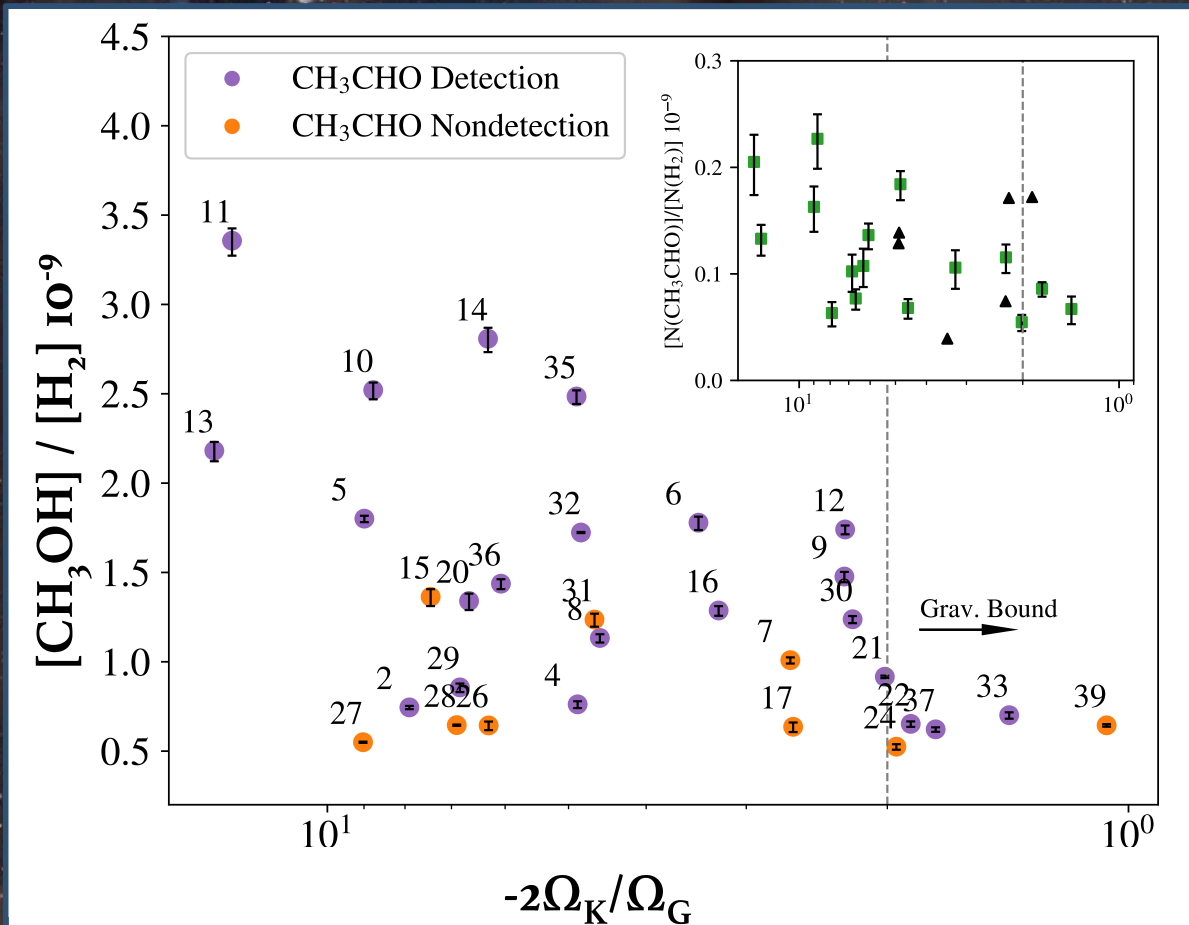
Virial Analysis



1) "More-evolved" cores show lower abundances of methanol and acetaldehyde
2) Could CH3OH and CH3CHO be chemically linked?

$$\Omega_K = \frac{3}{2} M \sigma_{nt}^2 \qquad \Omega_G = -\frac{3}{2}\frac{GM^2}{R}$$

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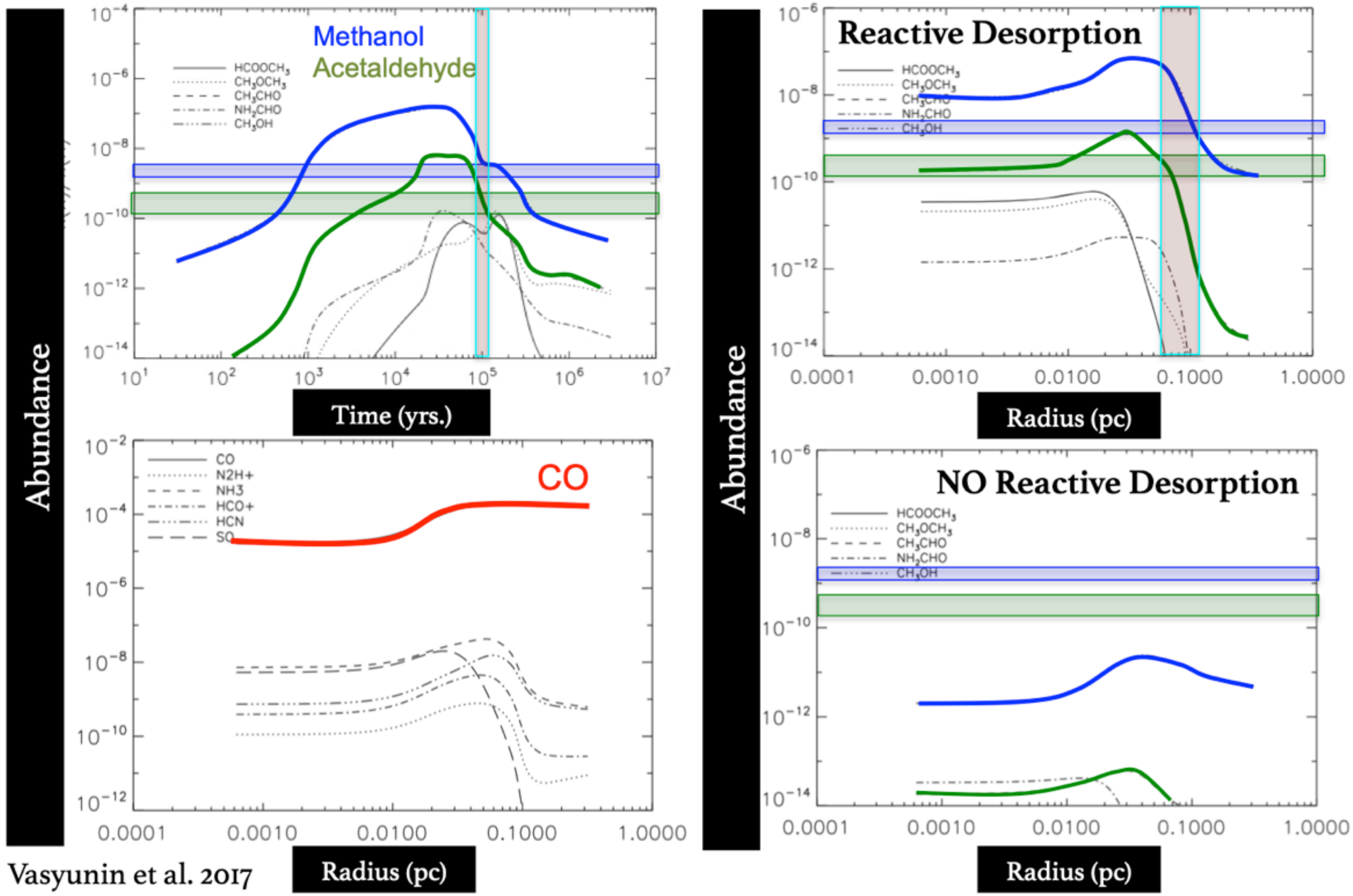
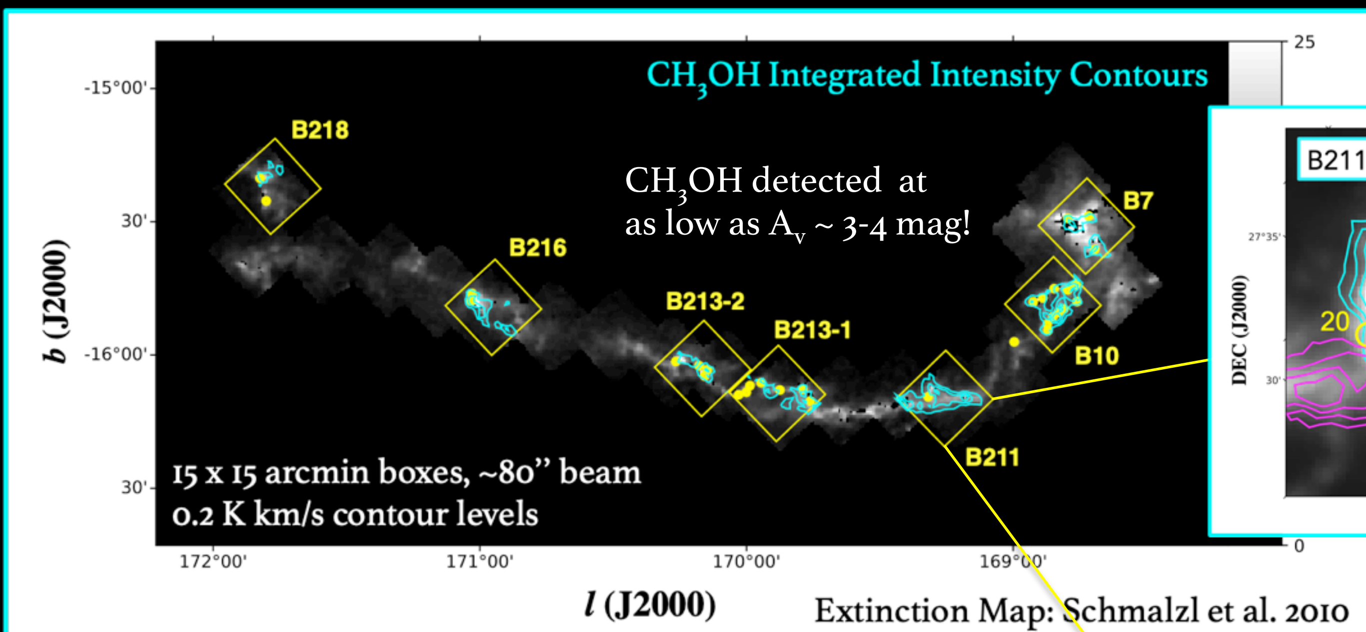
Evolutionary Models for L1544

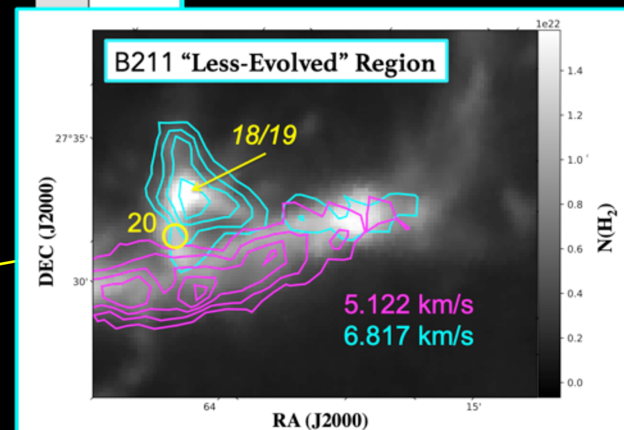


Vasyunin et al. 2017

ARO 12m OTF Mapping

Mapping helps us understand the distribution of methanol along the *filaments*





Uncovering velocity structure in CH_3OH which is tracing large-scale motions

Scibelli & Shirley 2020

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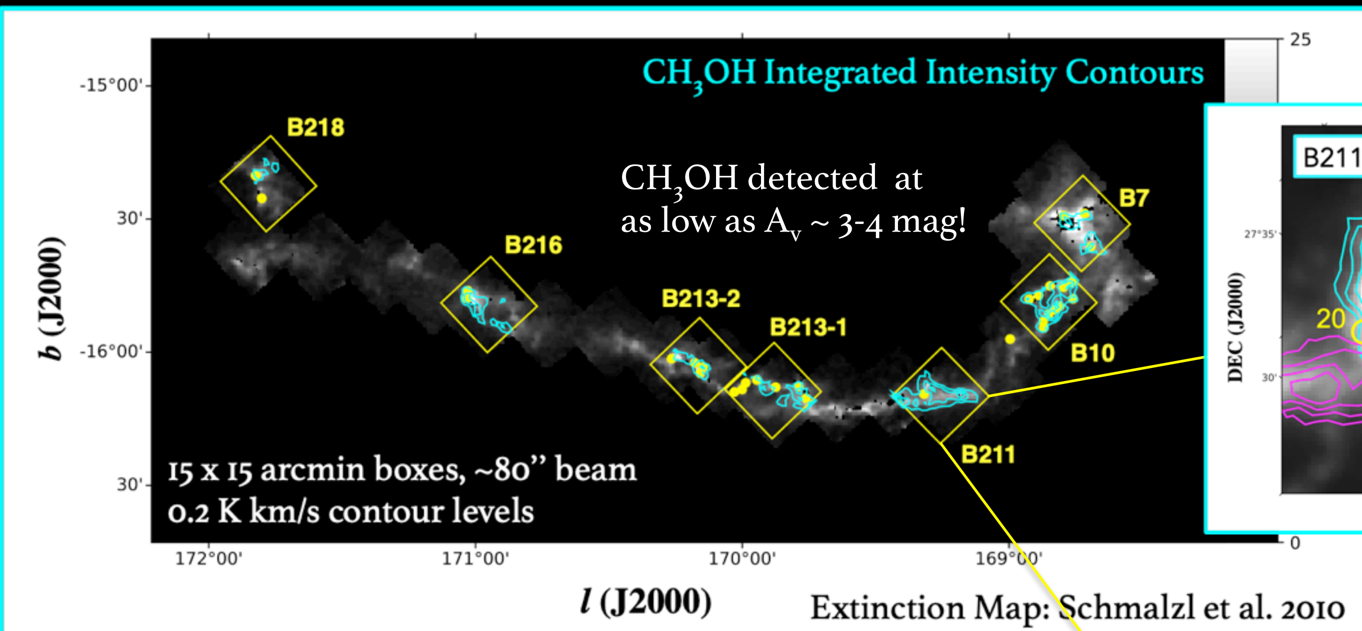

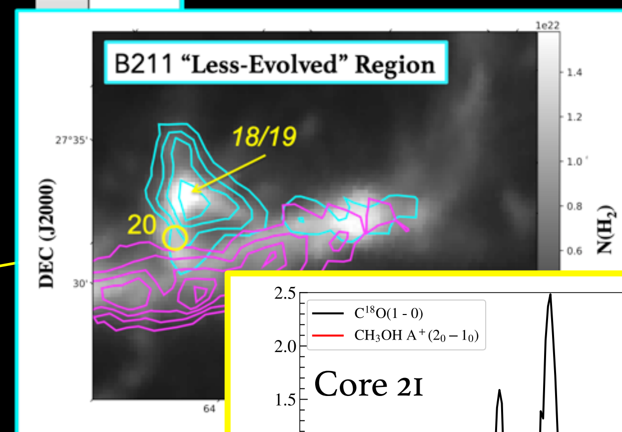

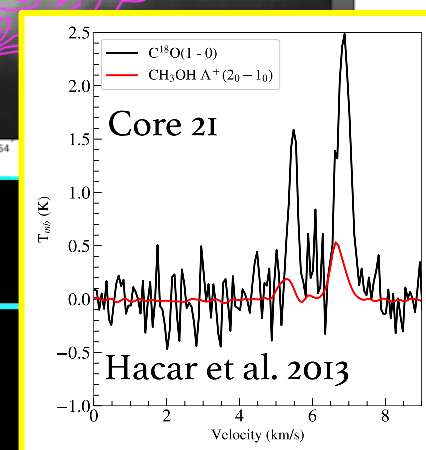

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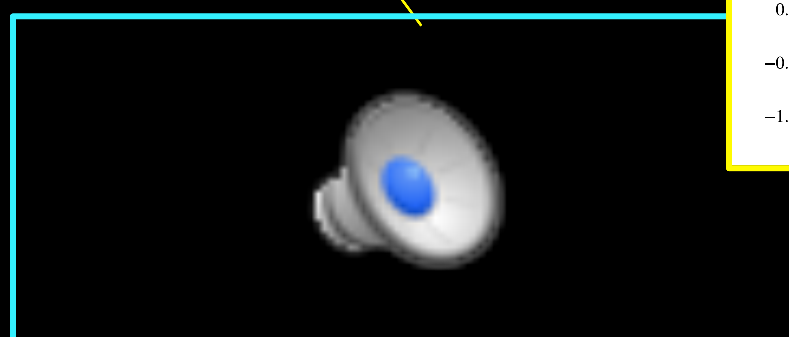

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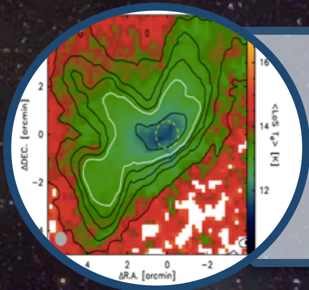
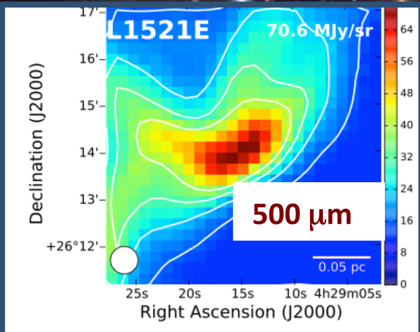
L1521E COM Line Survey





Makiwa et al. 2004

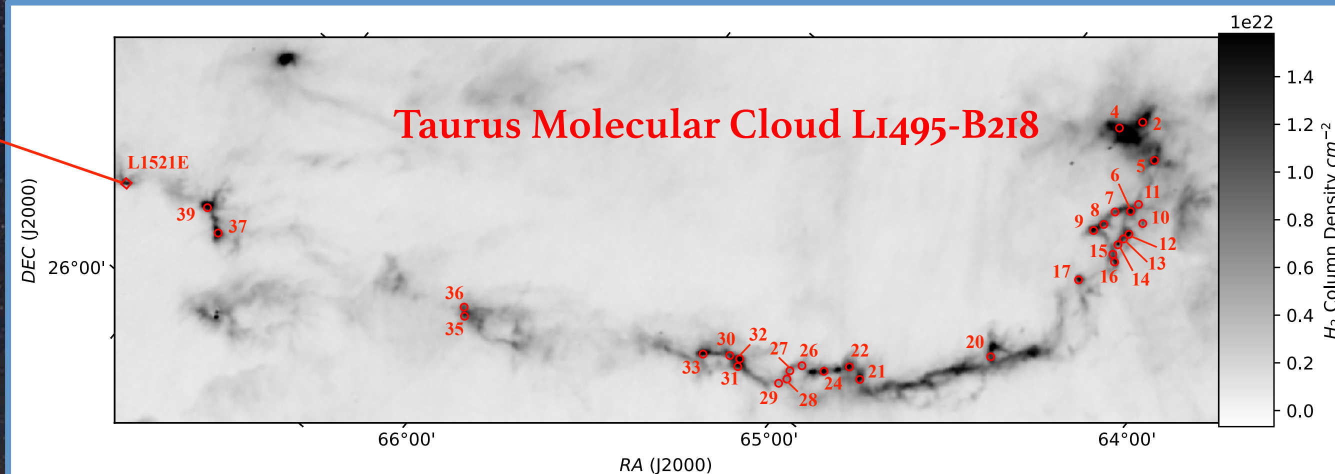
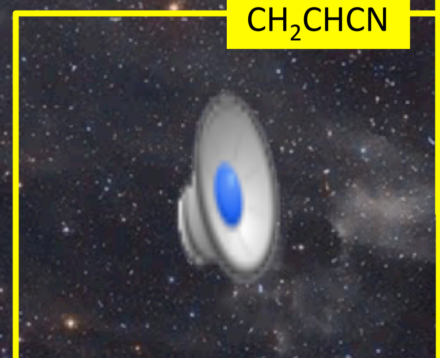


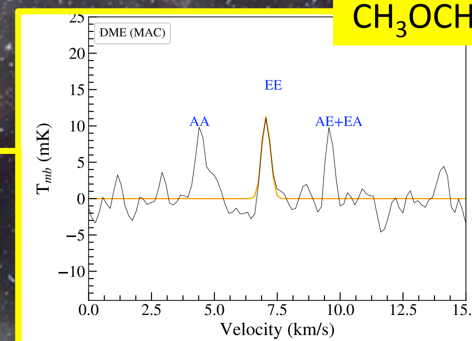
Table 1. Complex Organic Molecule Fit Results

Molecule	Transition	ν (GHz)	E_u/k (mK)	$^a g_u$	A_{ul} (s^{-1})	T_{mb} (mK)	$\sigma(T_{mb})$ (mK)	$I(T_{mb})$ (mK km s^{-1})	$\sigma(I)$ (mK km s^{-1})
CH_3CHO	$3_{1,3} - 2_{0,2}$ A*	101.892410	7.7	14	4.0E-06	23.1	3.8	10.7	1.3
	$5_{0,5} - 4_{0,4}$ A	95.963465	13.8	22	3.0E-05	89.0	9.0	30.0	2.0
	$5_{0,5} - 4_{0,4}$ E	95.947439	13.9	22	3.0E-05	50.7	8.0	22.76	2.0
	$2_{1,2} - 1_{0,1}$ A^{++}	84.219750	5.0	10	2.4E-06	24.0	6.0	6.98	1.3
	$4_{0,4} - 3_{0,3}$ A	76.8789525	9.2	18	1.5E-05	95.64	15.0	36.0	3.9
	$4_{0,4} - 3_{0,3}$ E	76.8664357	9.3	18	1.5E-05	110.36	15.0	40.635	3.9
	$4_{1,4} - 3_{1,3}$ E	74.9241336	11.33	18	1.3E-05	50.99	14.0	14.0	3.2
	$4_{1,4} - 3_{1,3}$ A	74.8916770	11.26	18	1.3E-05	58.83	16.0	14.658	3.5
CH_3OCH_3	$4_{1,4} - 3_{0,3}$ AA	99.326072	10.2	90	5.5E-06	9.91	3.0	3.345	0.65
	$4_{1,4} - 3_{0,3}$ EE	99.325217	10.2	44	5.5E-06	11.61	3.0	4.65	0.71
	$4_{1,4} - 3_{0,3}$ AE+EA	99.324364	10.2	54	5.5E-06	5.465	3.0	7.81	1.3
	$4_{2,3} - 4_{1,4}$ EE	93.857100	14.7	72	5.7E-05	⋯	2.2	⋯	0.8
	$2_{2,1} - 2_{1,2}$ EE	89.699810	8.4	40	3.7E-05	⋯	2.2	⋯	0.8
CH_2CHCN	$8_{0,8} - 7_{0,7}$	75.585692	16.3	51	3.4E-05	58.6	7.0	16.71	1.6
	$8_{1,7} - 7_{1,6}$	77.633835	18.9	51	3.6E-05	39.6	6.0	11.96	1.4
	$9_{0,9} - 8_{0,8}$ *	84.946000	20.4	57	4.9E-05	29.9	4.0	12.0	1.7
	$9_{1,8} - 8_{1,7}$ *	87.312810	23.1	57	5.3E-05	24.3	4.7	9.9	1.9
	$5_{1,5} - 4_{0,4}$ *	89.130910	8.8	33	1.8E-06	⋯	1.9	⋯	0.8
	$10_{1,10} - 9_{1,9}$	92.426257	26.6	63	6.8E-05	20.4	4.4	4.386	0.79
	$10_{0,10} - 9_{0,9}$	94.276641	24.9	63	6.2E-05	29.4	5.0	8.02	1.0
	$10_{1,9} - 9_{1,8}$	96.982446	27.8	63	7.2E-05	17.4	4.7	4.55	0.91
	$11_{0,11} - 10_{0,11}0$	103.5753916	29.9	69	8.8E-05	⋯	4.1	⋯	0.85

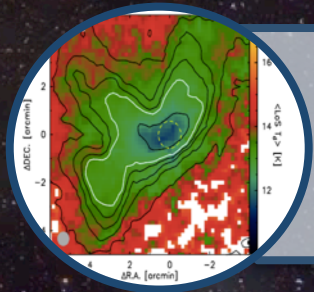
CH_2CHCN



CH_3OCH_3



Scibelli et al., *in Prep*

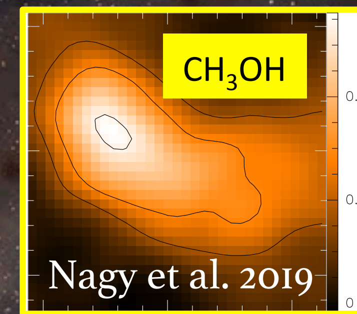


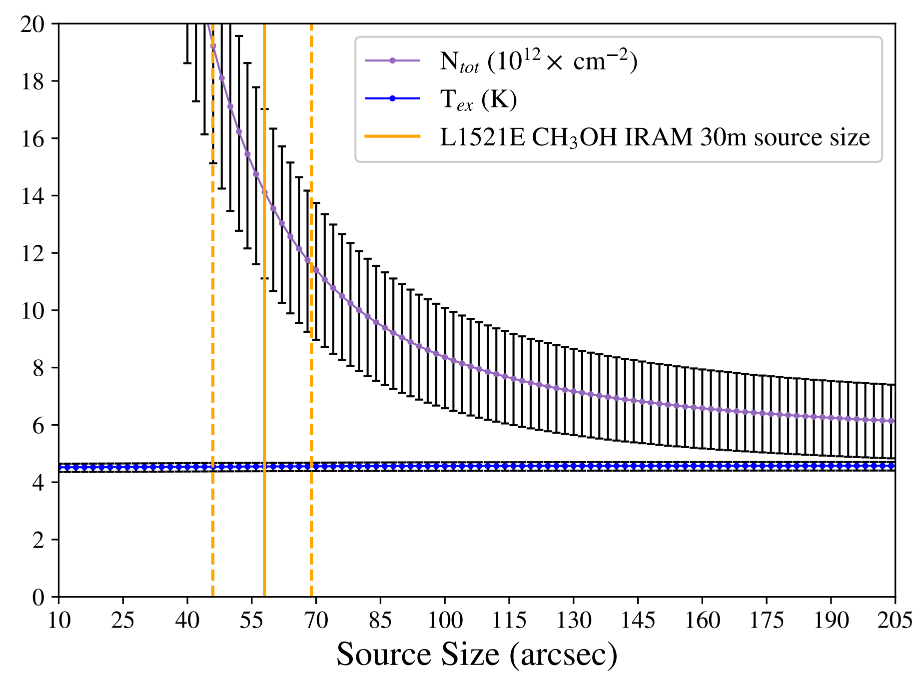
L1521E COM Line Survey

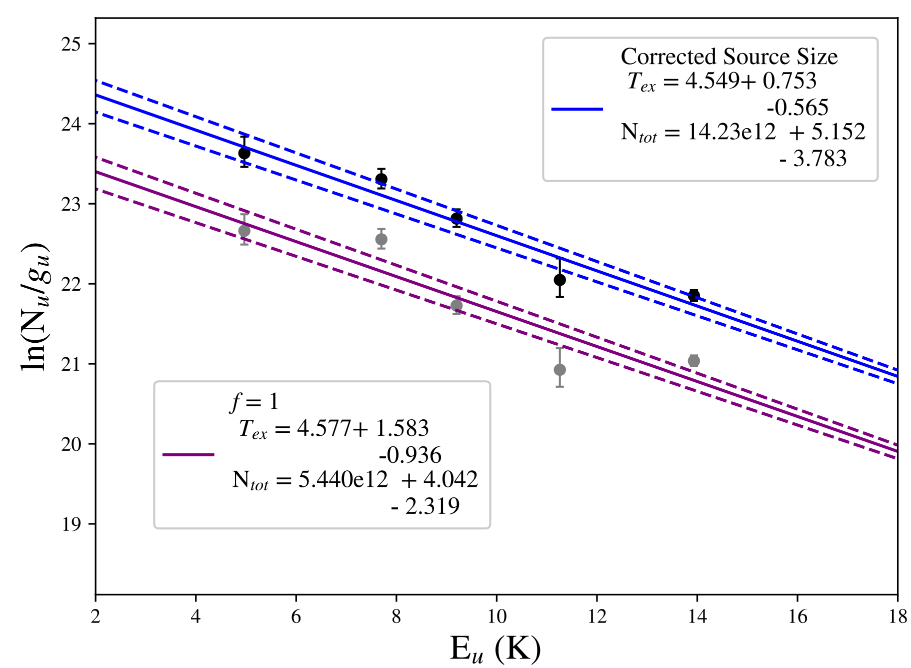
Estimating true column density from source size:

$$\theta_{IRAM\_beam}^{2} + \theta_{source}^{2} = \theta_{IRAM \star source}^{2}$$

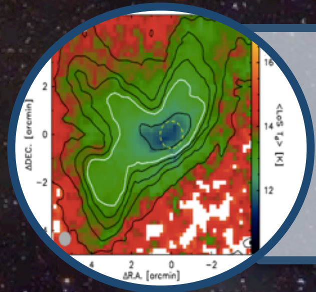
Underestimates column density by factor of ~2.6







Scibelli et al., *in Prep*



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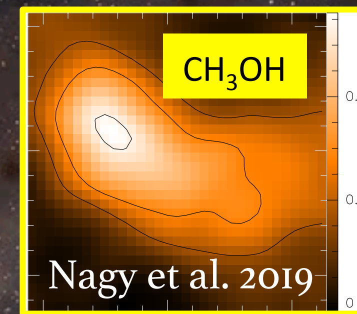
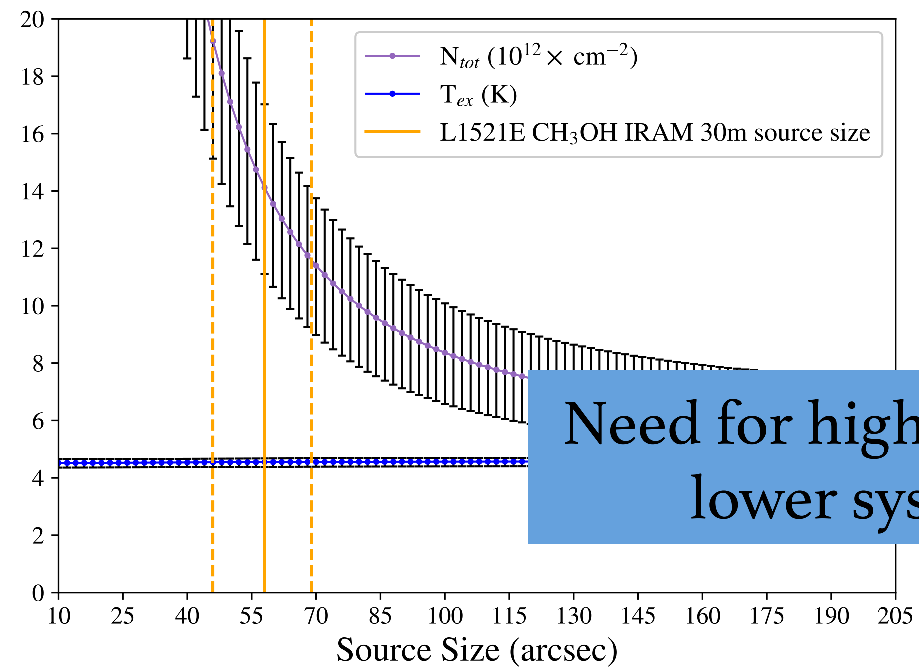
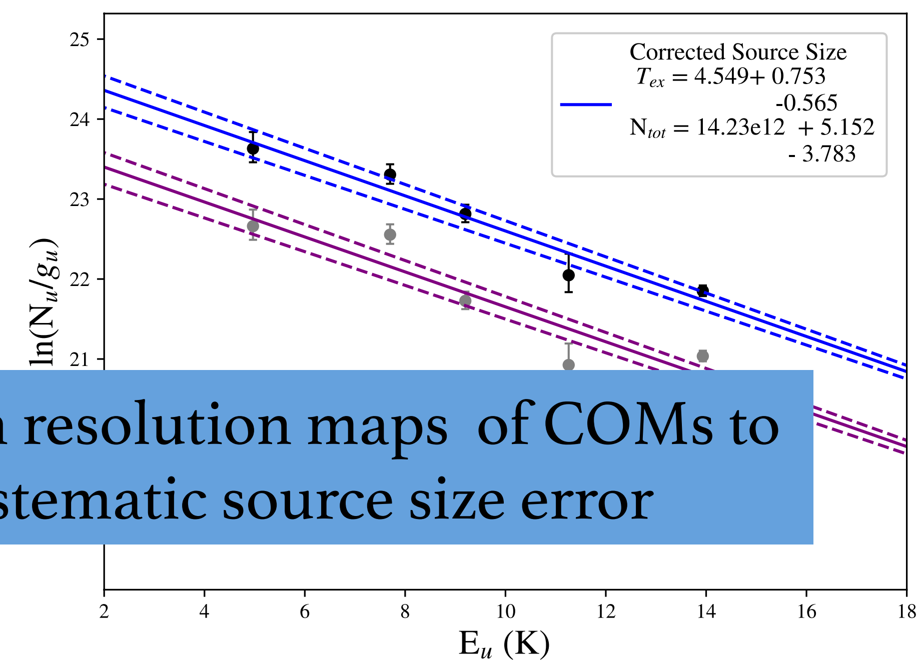


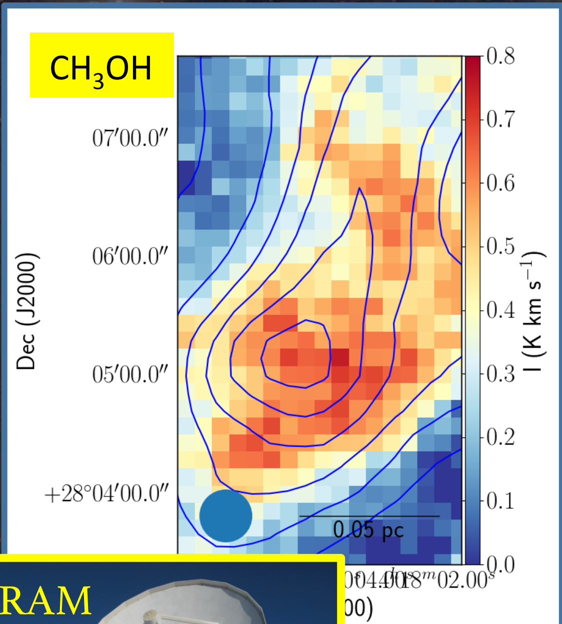




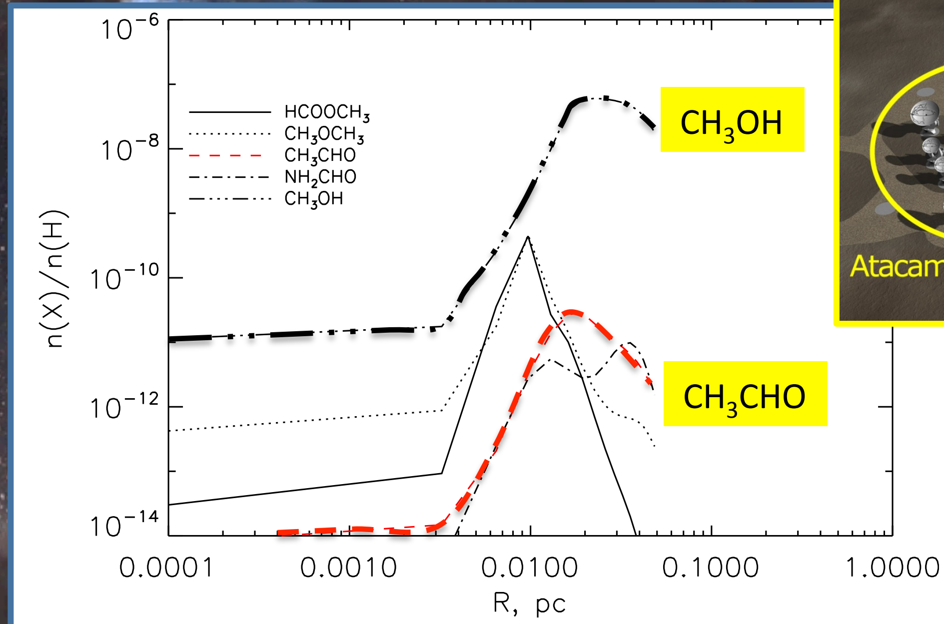
Need for high resolution maps of COMs to lower systematic source size error

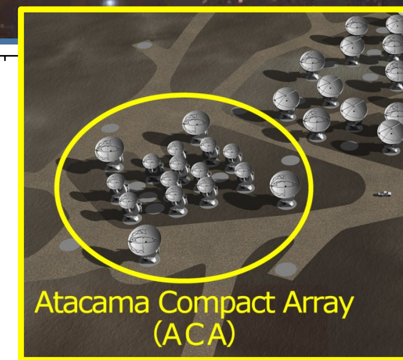
Scibelli et al., *in Prep*

Next: Understanding COM Spatial Distribution

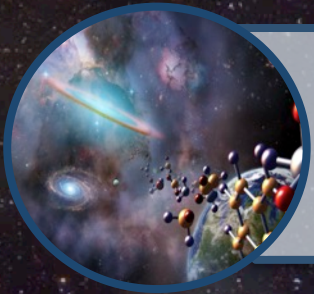


Punanova et al. *in prep*



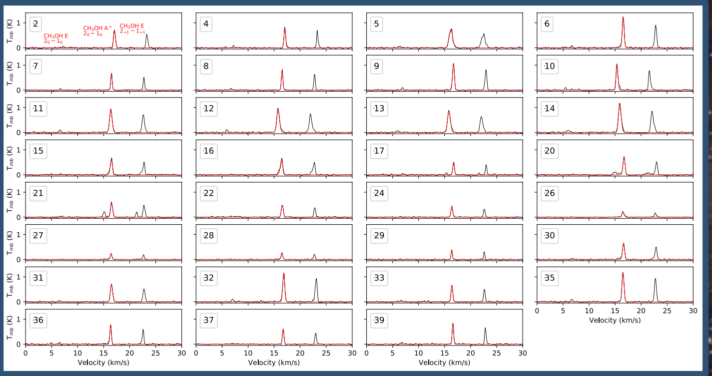


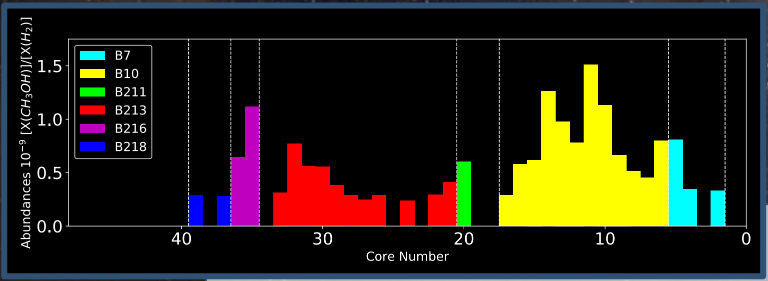
ALMA Cycle 7 ACA data at 16” resolution of both CH3OH and CH3CHO in prestellar core Se009 will allow us to test if these molecules do co-evolve



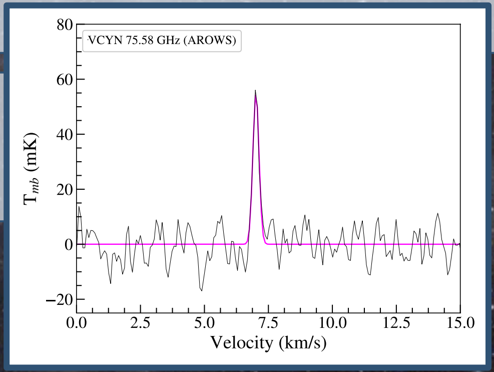
Important Takeaways

We observed methanol ***(CH_3OH) in 100%*** of the 31 cores targeted and acetaldehyde ***(CH_3CHO) in 70%***!

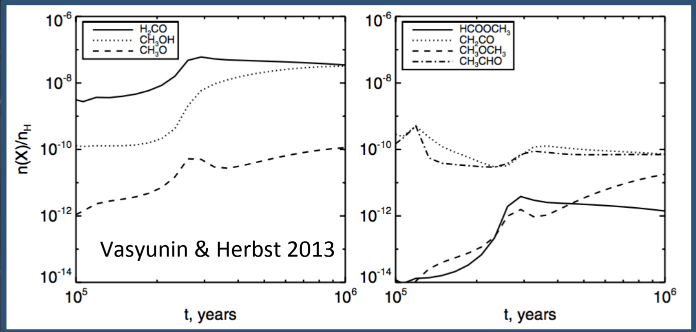




We conducted one of the first survey's to target a large, homogenous sample of cores, warranting a comparison between cores of similar environments



Acetaldehyde, dimethyl ether and vinyl cyanide have been detected in young core L1521E!



Our abundance measurements provide constraints for astrochemical models

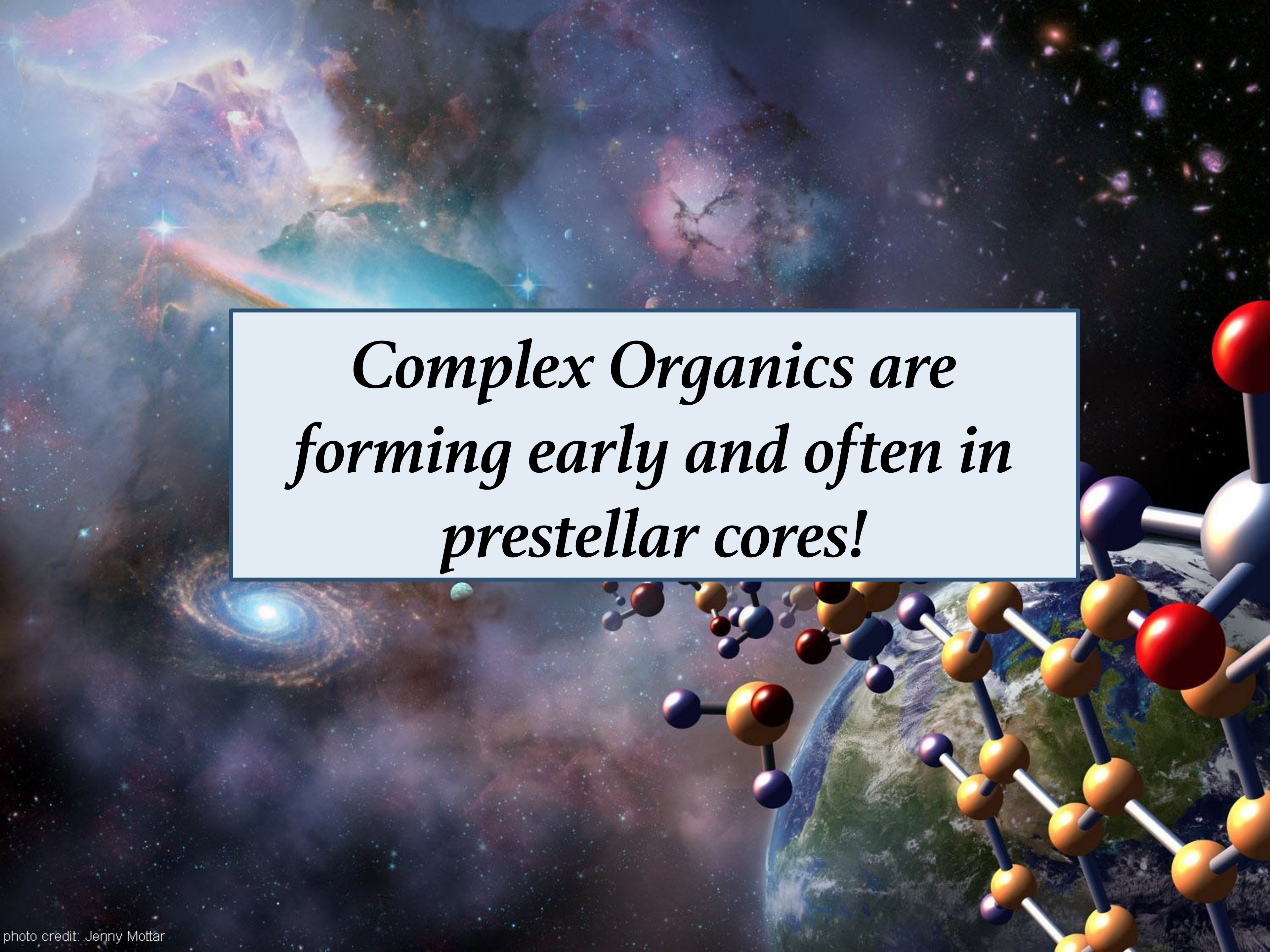


photo credit: Jenny Mottar