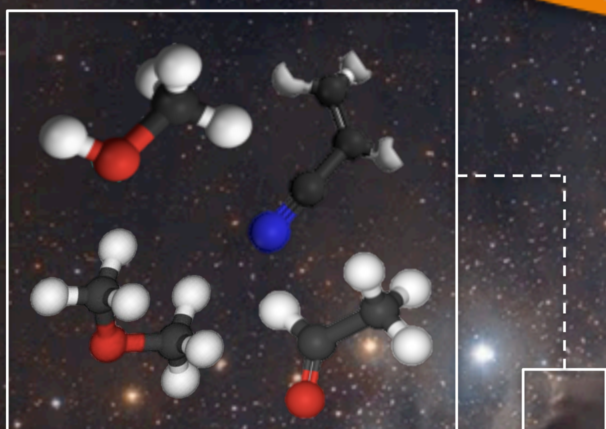
Prevalence of Complex Organic Molecules in Prestellar Cores Within the Taurus Star Forming Region



Samantha Scibelli

3rd year Graduate Student and NSF Fellow

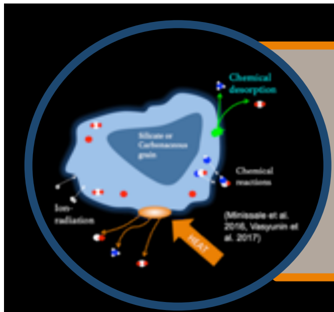
Advised by Dr. Yancy Shirley

Steward Observatory, University of Arizona

Arizona Radio Observatory

Celebrating The First 40 Years Of Alexander Tielens' Contribution To Science:
The Physics And Chemistry Of The ISM
Palais des Papes in Avignon, France. 2nd – 6th September 2019

NSF



Origins of Complex Molecules

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

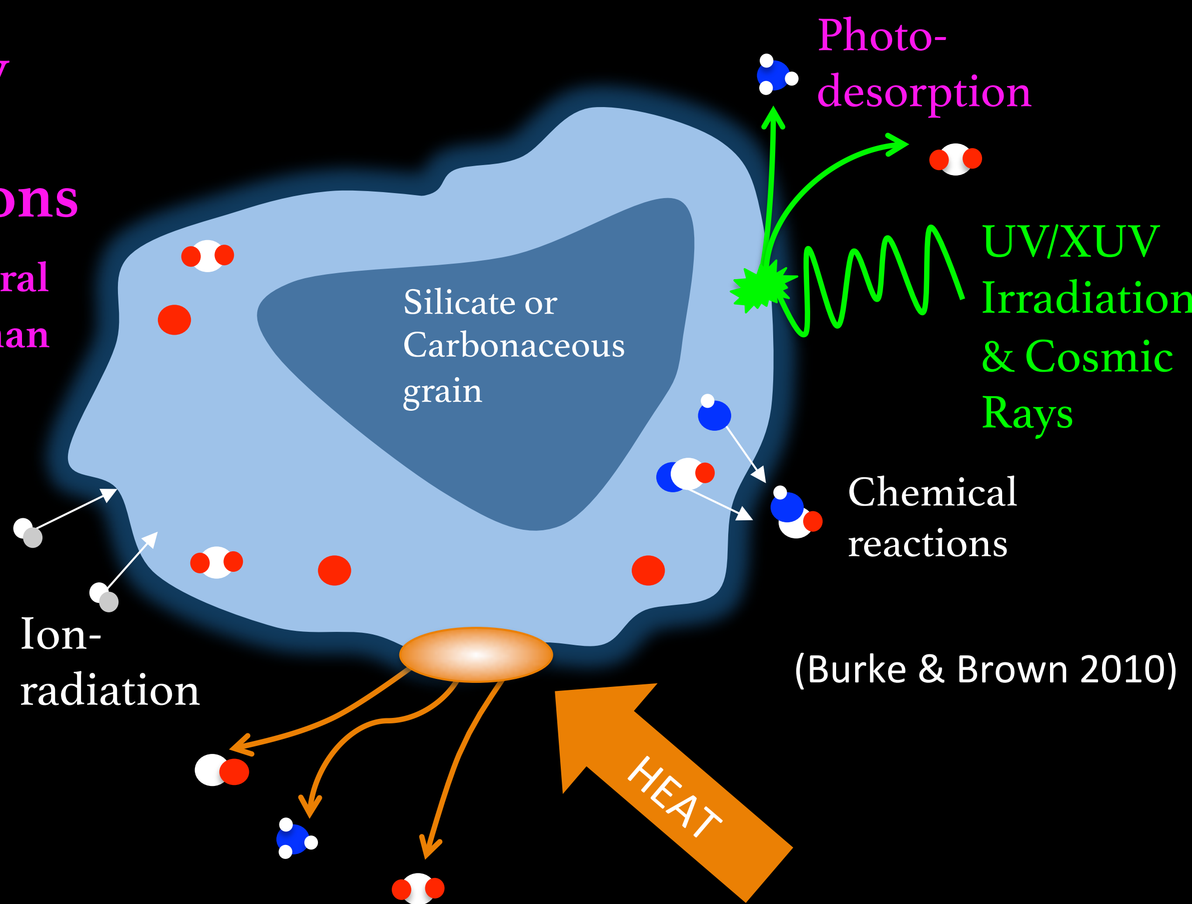
Gas-phase Chemistry

Ion-molecule Reactions

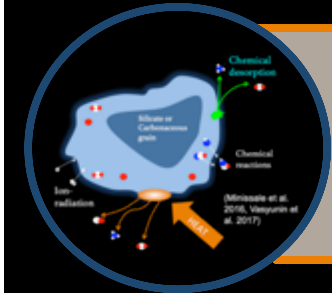
→ COM abundances several of orders of magnitude lower than observed

(Charnley & Tielens 1992)

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



(Burke & Brown 2010)



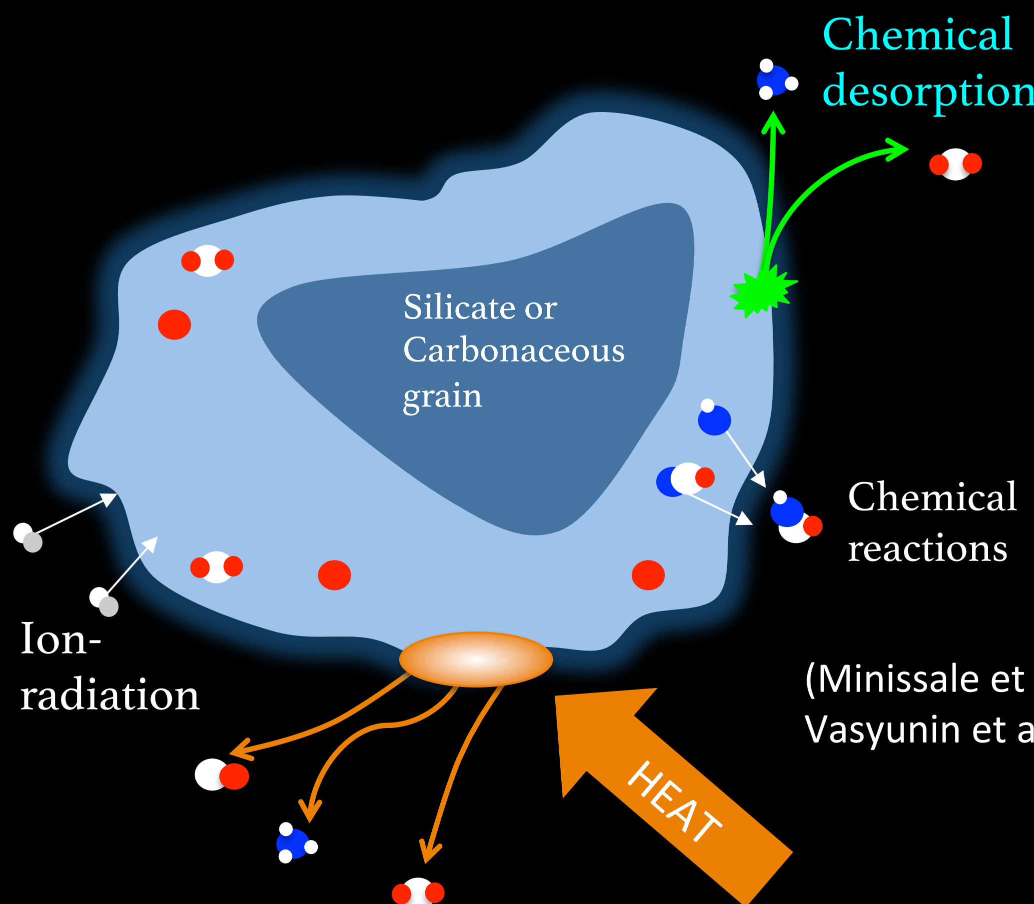
Origins of Complex Molecules

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

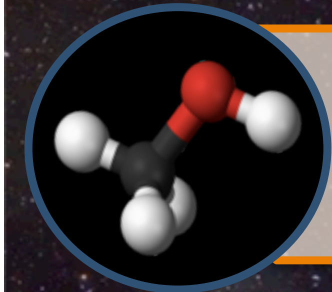
Chemical Reactive Desorption

Neutral-Neutral reactions of radicals

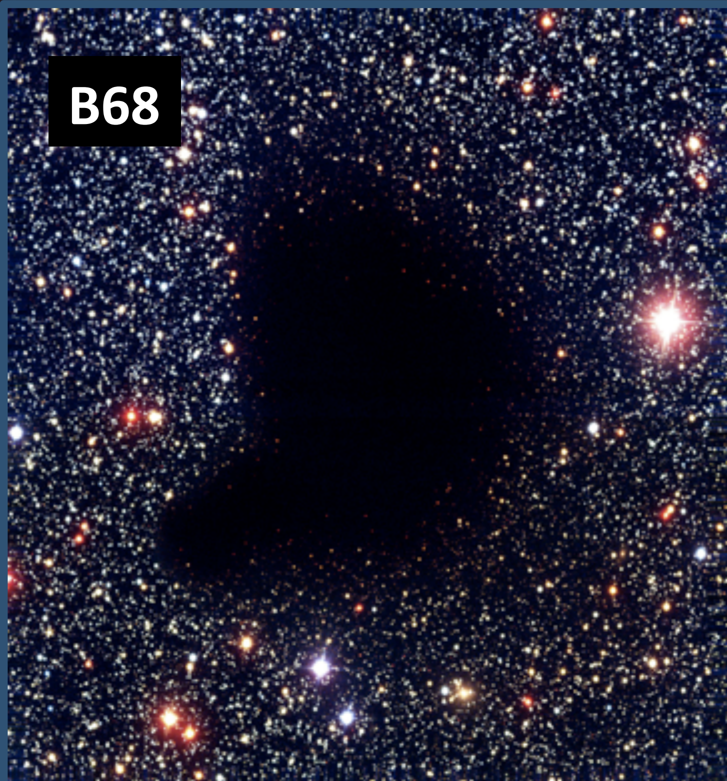
Models predict abundances which we can constrain!



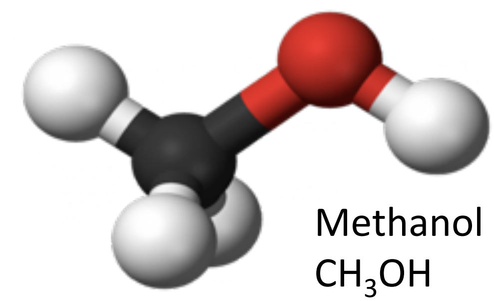
(Minissale et al. 2016, Vasyunin et al. 2017)



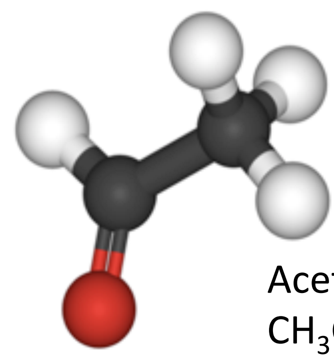
COMs in Prestellar Cores



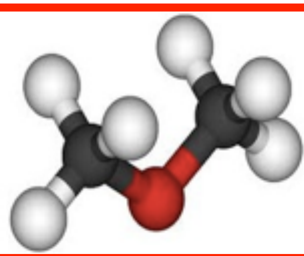
Birthplace of low-mass stars
($M \leq$ a few $M_{\odot}$)
Dense (10^4 - 10^5 cm^{-3}) & cold ($\leq$ 10K)



Methanol
CH_3OH

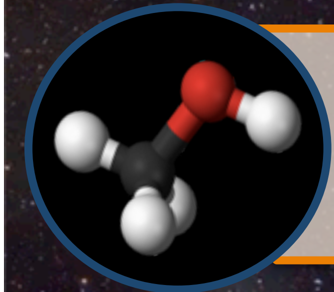


Acetaldehyde
CH_3CHO

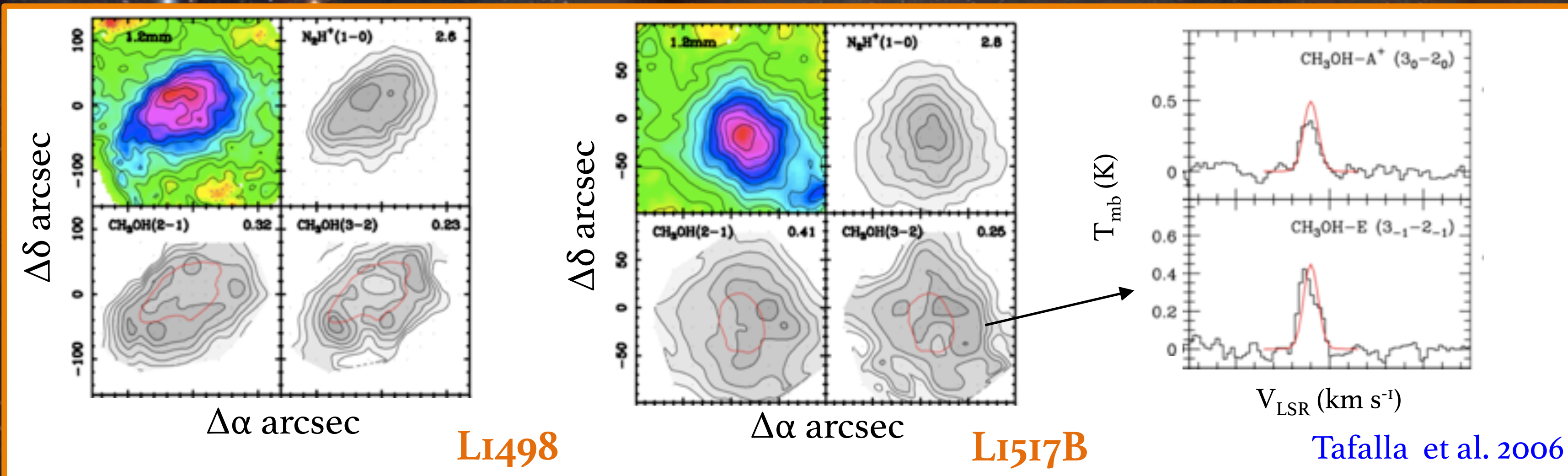


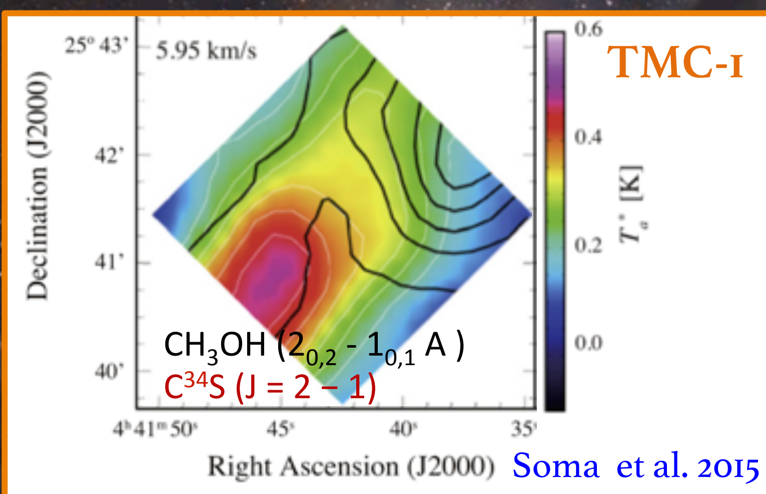
Dimethyl
Ether
CH_3OCH_3

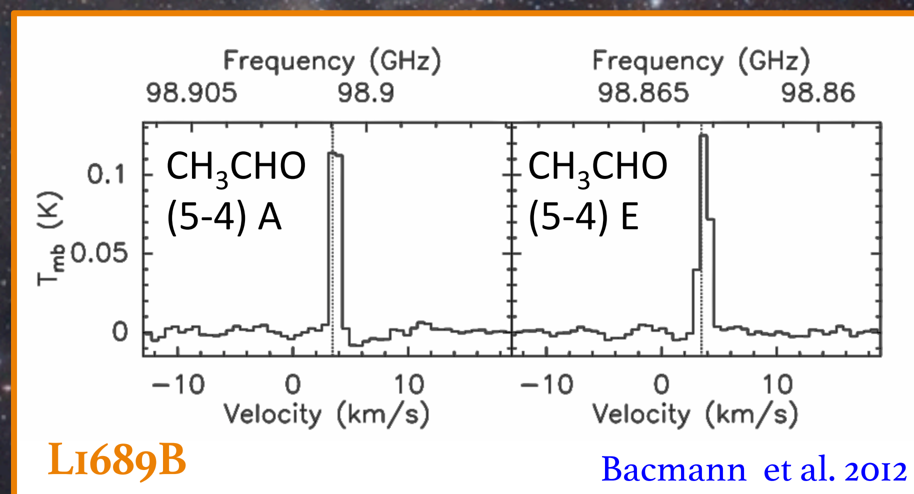
When, where and how are these molecules forming in prestellar cores?

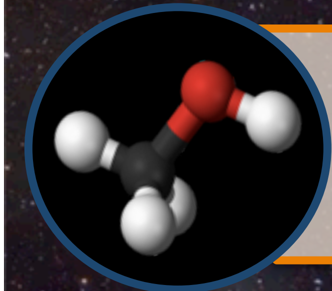


COMs in Prestellar Cores

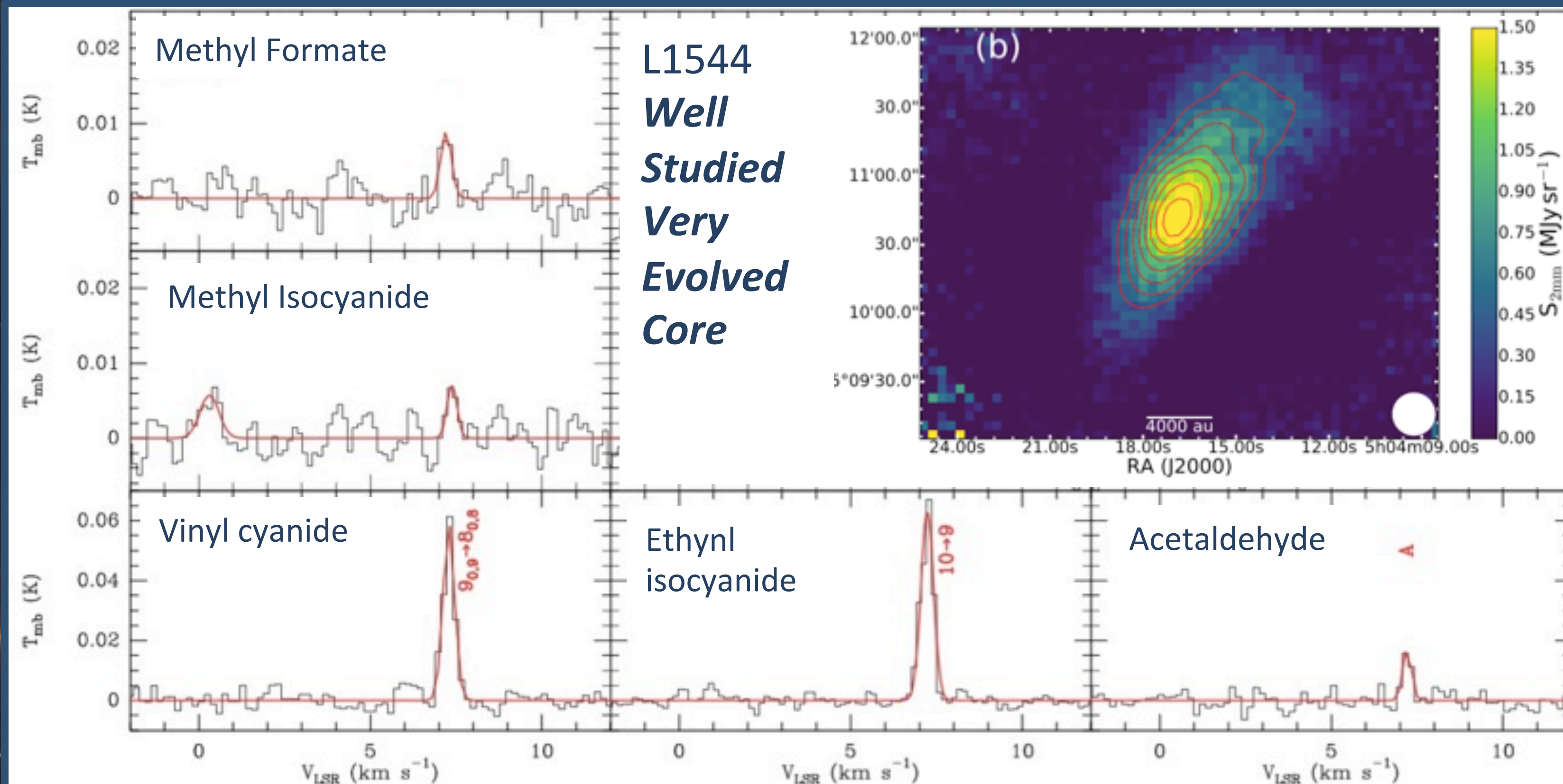






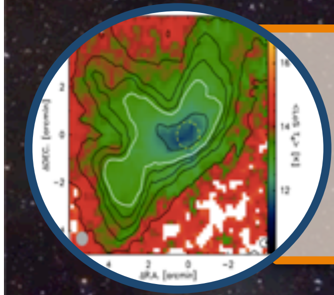


COMs in Prestellar Cores



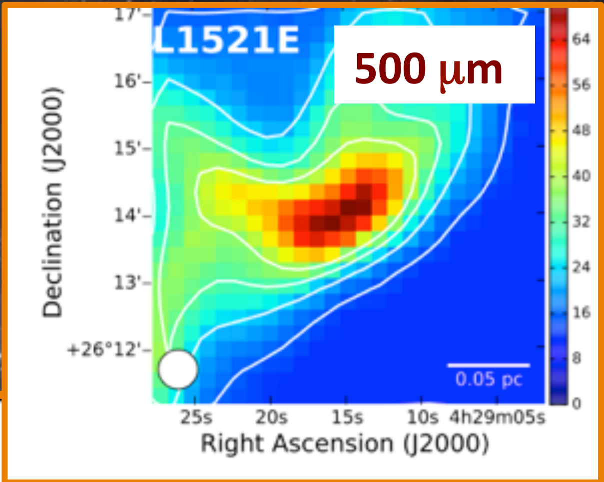
(Bizzocchi et al. 2014,
Jiménez-Serra et al. 2016,
Spezzano et al. 2017,
Chacón-Tanarro et al. 2017,
Chacón-Tanarro et al. 2019)

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

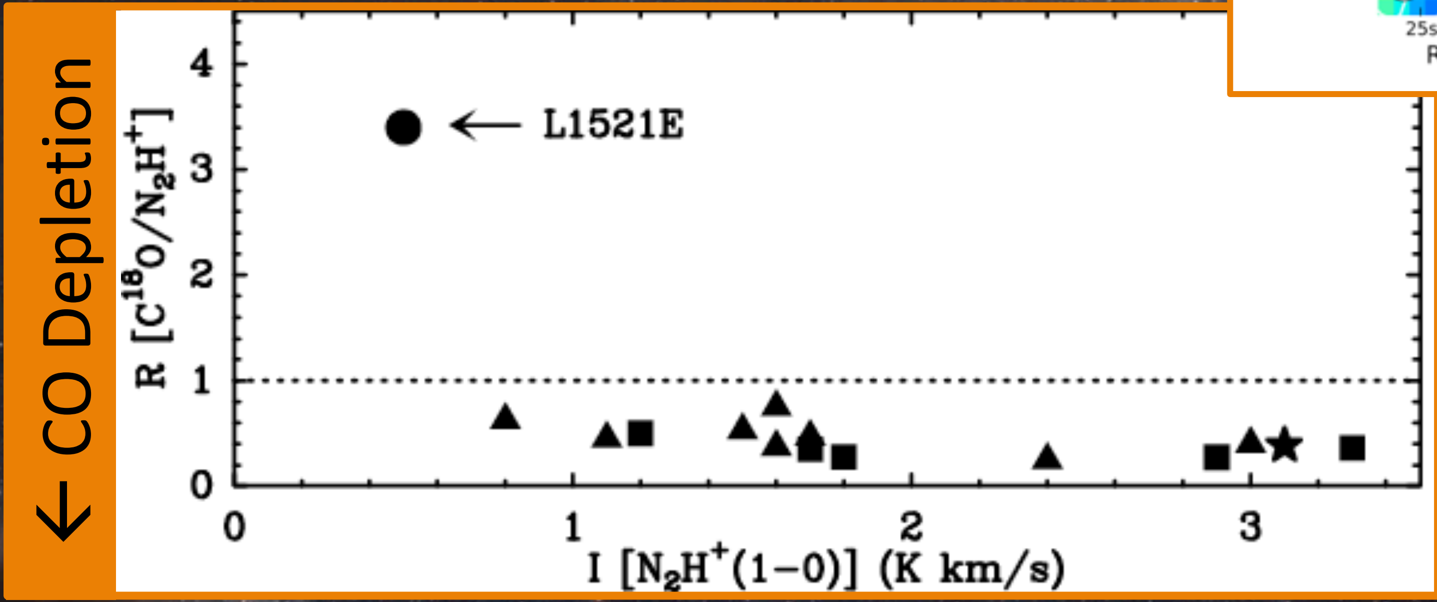


L1521E: A "Young" Core

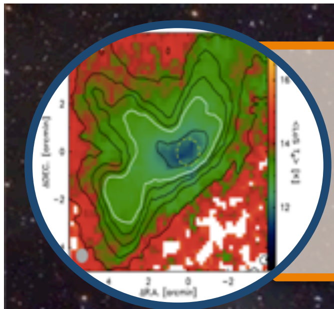
- Very low CO depletion
- No indication in kinematics of collapse
- "Early-time" molecules (CCS, etc.) peak on core
- "Late-time" molecules (NH_3, N_2H^+) very weak
- Weak deuteration (chemically young)



Makiwa et al. 2004



Tafalla et al. 2004



L1521E COM Line Survey

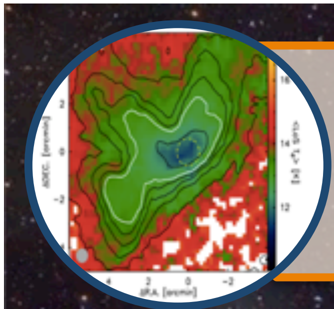
Arizona Radio Observatory (ARO) 12m dish
COM Line Survey

Table 1. Complex Organic Molecule Fit Results

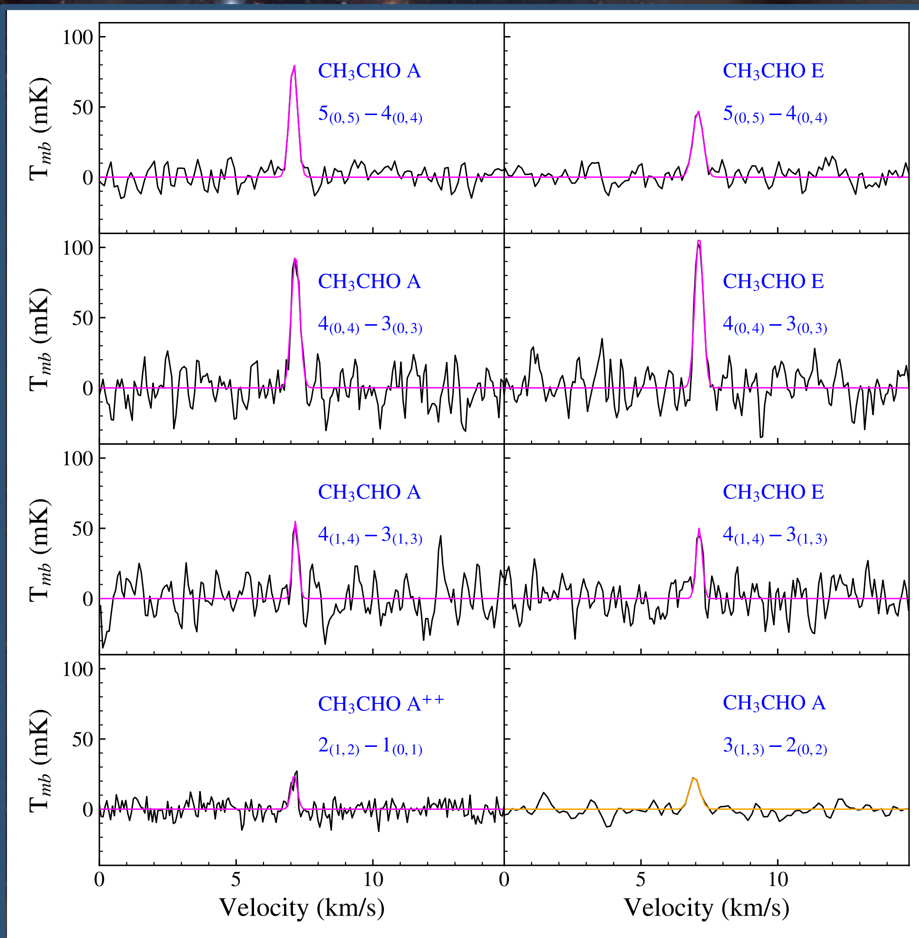
Molecule	Transition	ν (GHz)	E_u/k (mK)	A_{ul} (s^{-1})	T_{mb} (mK)	$\sigma(T_{mb})$ (mK)	$I(T_{mb})$ (mK km s^{-1})	$\sigma(I)$ (mK km s^{-1})
CH_3CHO	$3_{1,3}-2_{0,2}$ A*	101.892410	7.7	4.0E-06	23.1	3.8	10.7	1.3
	$5_{0,5}-4_{0,4}$ A	95.963465	13.8	3.0E-05	89.0	9.0	30.0	2.0
	$5_{0,5}-4_{0,4}$ E	95.947439	13.9	3.0E-05	50.7	8.0	22.76	2.0
	$2_{1,2}-1_{0,1}$ A^{++}	84.219750	5.0	2.4E-06	24.0	6.0	6.98	1.3
	$4_{0,4}-3_{0,3}$ A	76.8789525	9.2	1.5E-05	95.64	15.0	36.0	3.9
	$4_{0,4}-3_{0,3}$ E	76.8664357	9.3	1.5E-05	110.36	15.0	40.635	3.9
	$4_{1,4}-3_{1,3}$ E	74.9241336	11.33	1.3E-05	50.99	14.0	14.0	3.2
	$4_{1,4}-3_{1,3}$ A	74.8916770	11.26	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	5.53E-06	9.91	3.0	3.345	0.65
	$4_{1,4}-3_{0,3}$ EE	99.325217	10.2	5.53E-06	11.61	3.0	4.65	0.71
	$4_{1,4}-3_{0,3}$ AE+EA	99.324364	10.2	5.53E-06	5.465	3.0	7.81	1.3
CH_2CHCN	$8_{0,8}-7_{0,7}$	75.5856915	16.3	3.4E-05	58.6	7.0	16.71	1.6
	$9_{0,9}-8_{0,8}$ *	84.946000	20.4	4.9E-05	29.9	4.0	12.0	1.7
	$9_{1,8}-8_{1,7}$ *	87.312810	23.1	5.3E-05	24.3	4.7	9.9	1.9
o-H_2C_4	$10_{1,9}-9_{1,8}$ *	89.687050	23.3	6.7E-05	12.0	2.3	5.13	0.9
	$10_{1,10}-9_{1,9}$ *	88.940240	23.1	6.5E-05	23.8	2.85	8.2	1.1
o-H_2CCO	$5_{1,4}-4_{1,3}$ *	101.981390	13.7	1.1E-05	102.3	3.9	42.8	1.5
p-H_2CCO	$5_{0,5}-4_{0,4}$ *	101.036710	14.5	1.1E-05	67.3	6.4	32.0	2.5
trans-HCOOH	$4_{0,4}-3_{0,3}$ *	89.579170	10.8	7.2E-06	10.9	2.7	5.4	1.1
	$4_{1,4}-3_{1,3}$ *	86.546190	13.6	6.1E-06	13.1	3.0	5.8	1.3

NOTE— * Transitions detected using MAC backend.

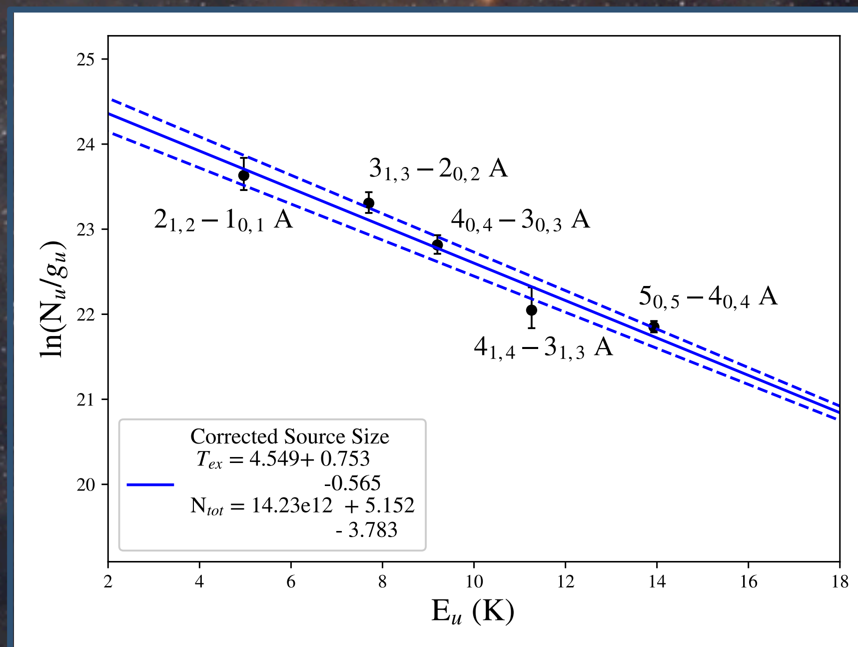
Scibelli et al., *in Prep*



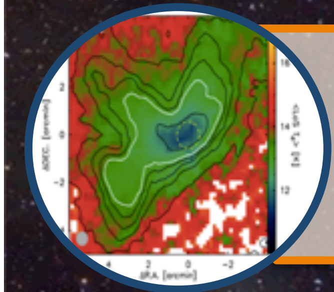
L1521E COM Line Survey



Acetaldehyde (CH_3CHO) Detections



Scibelli et al., *in Prep*

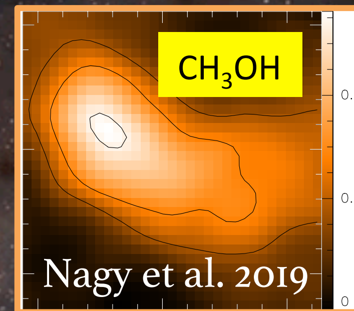


L1521E COM Line Survey

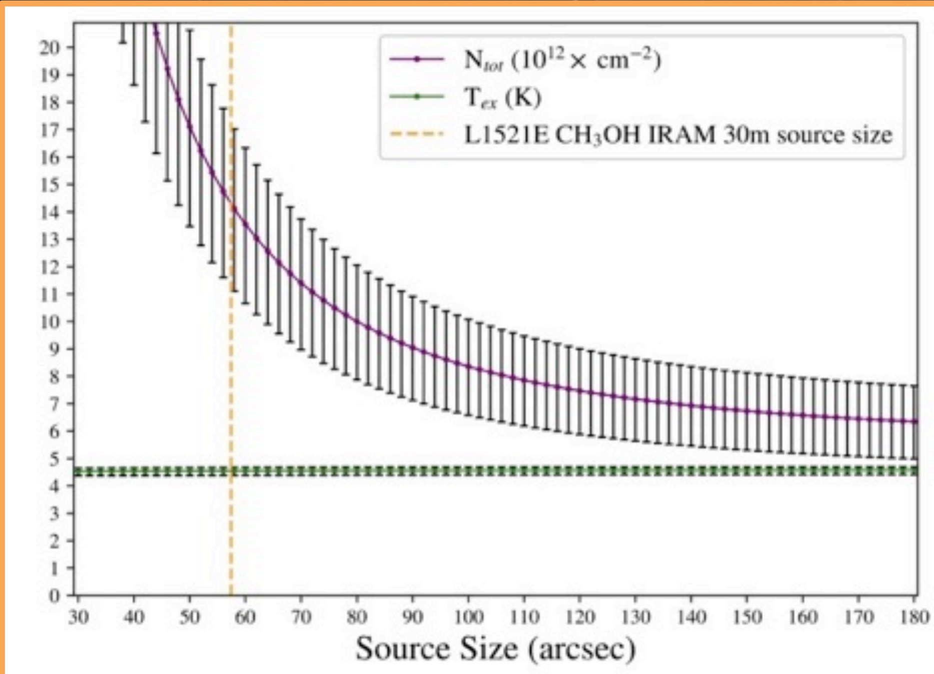
Estimating true column density from source size:

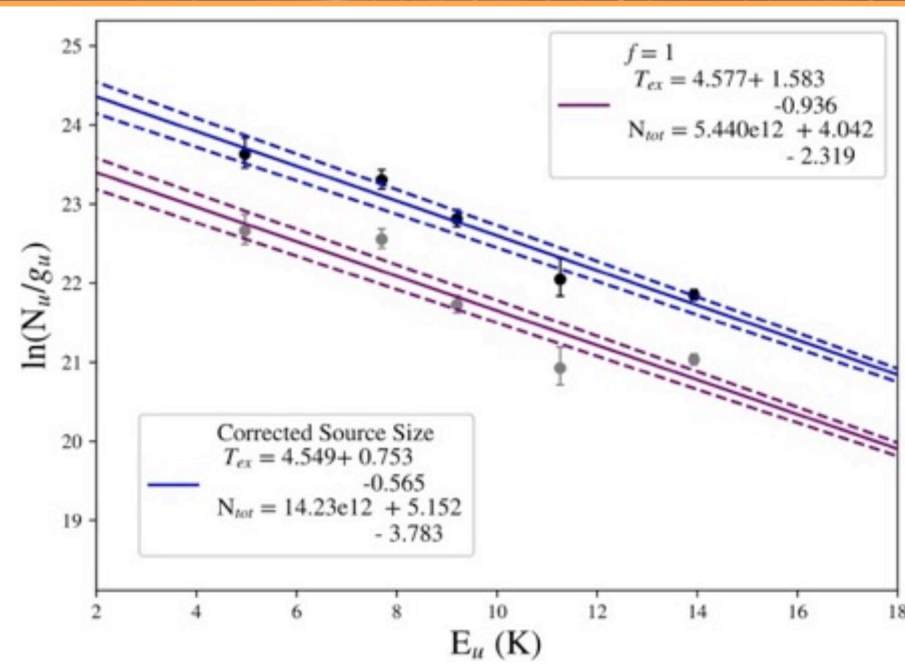
$$\theta_{IRAM\_beam}^2 + \theta_{source}^2 = \theta_{IRAM✪source}^2$$

Underestimates column density by factor of ~2.6

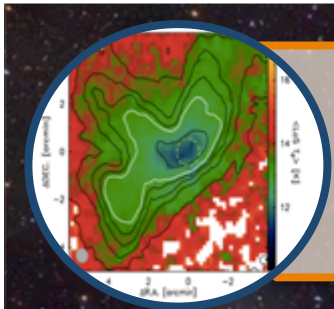


Nagy et al. 2019





Scibelli et al., *in Prep*



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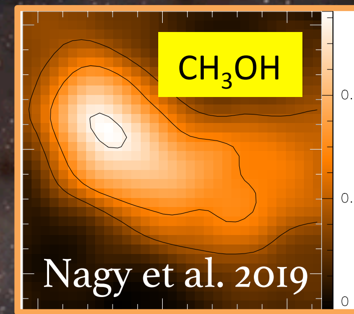
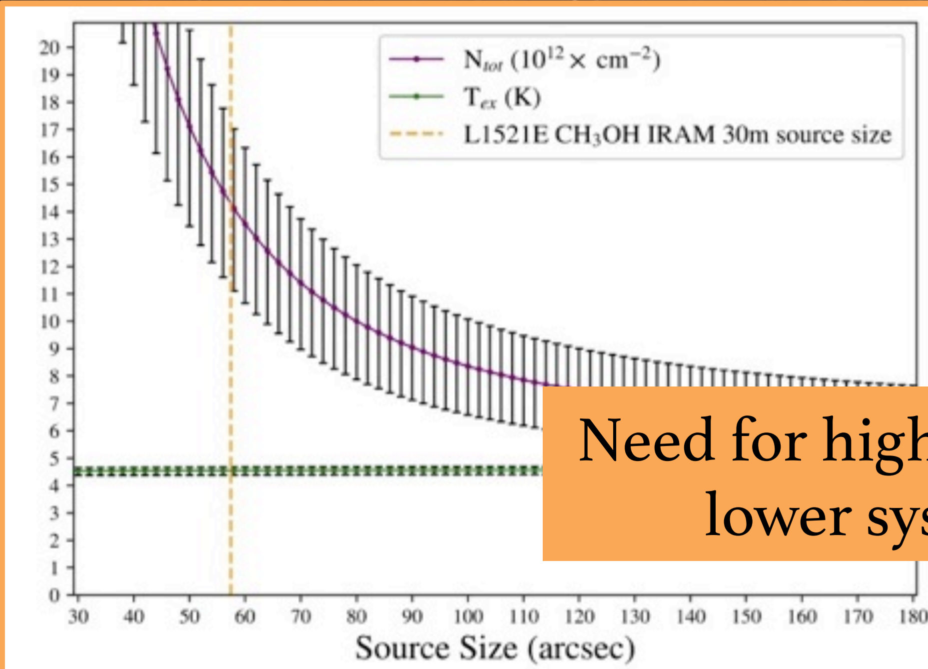
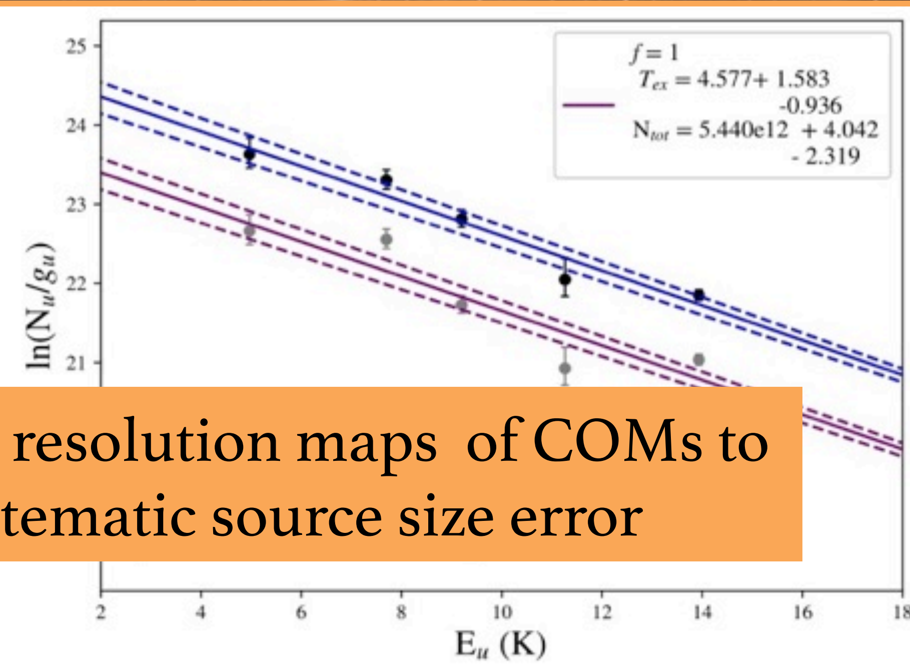
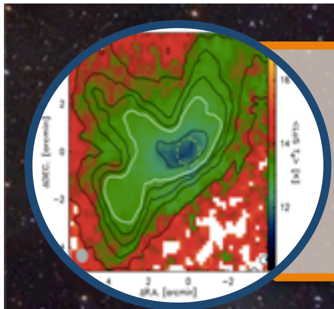






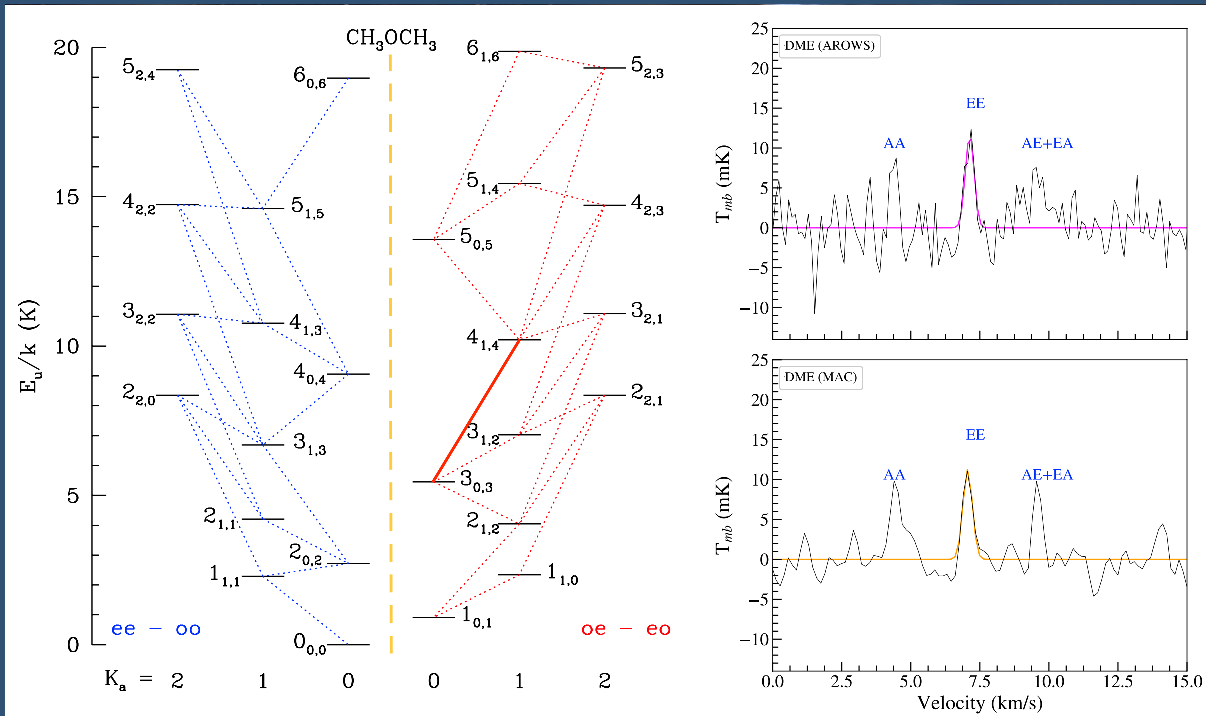
Need for high resolution maps of COMs to lower systematic source size error

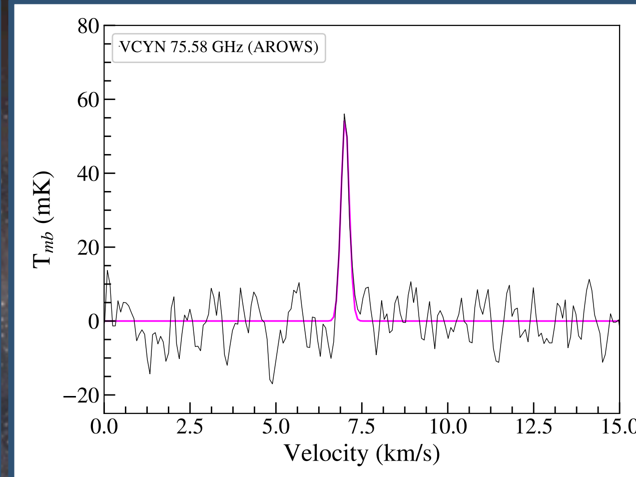
Scibelli et al., *in Prep*



L1521E COM Line Survey

Dimethyl ether (CH_3OCH_3) & Vinyl Cyanide (CH_2CHCN)



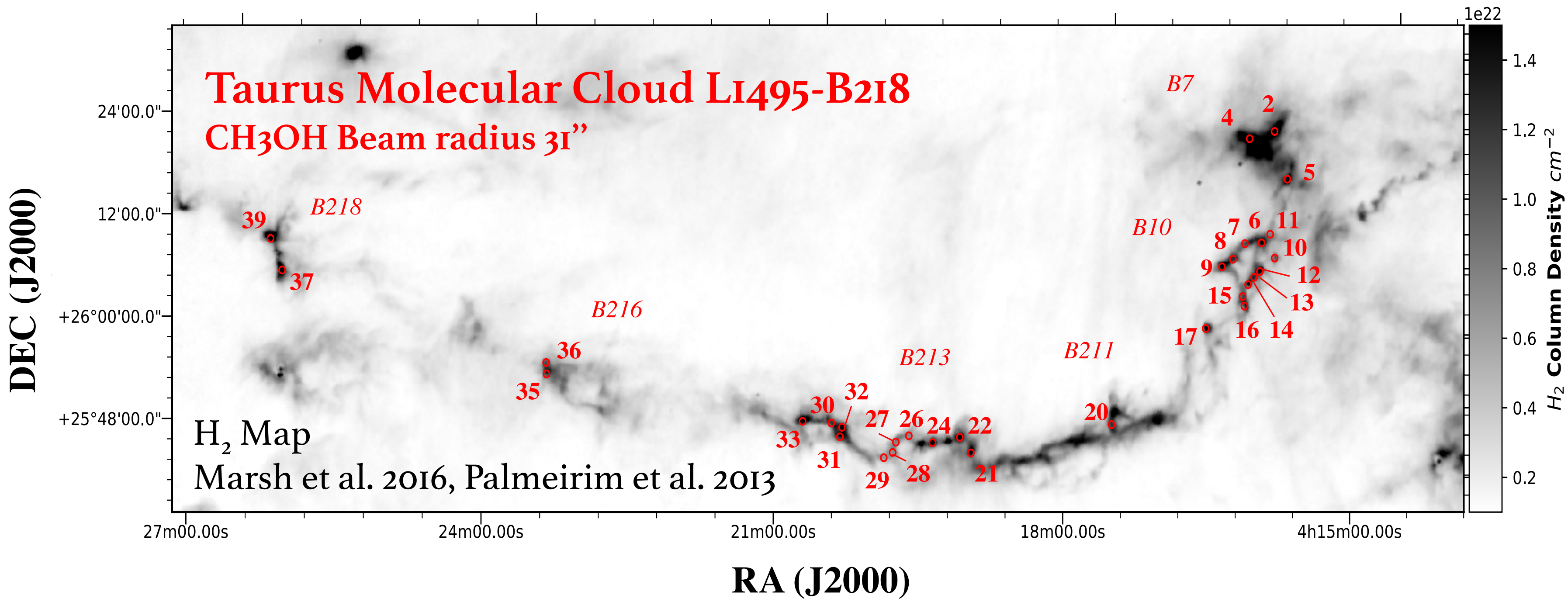


Organics Prevalent in L1521E!

What about in a more representative sample of cores?

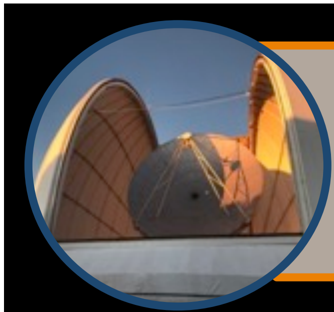
Scibelli et al., *in Prep*

Survey of Starless and Prestellar Cores in Taurus



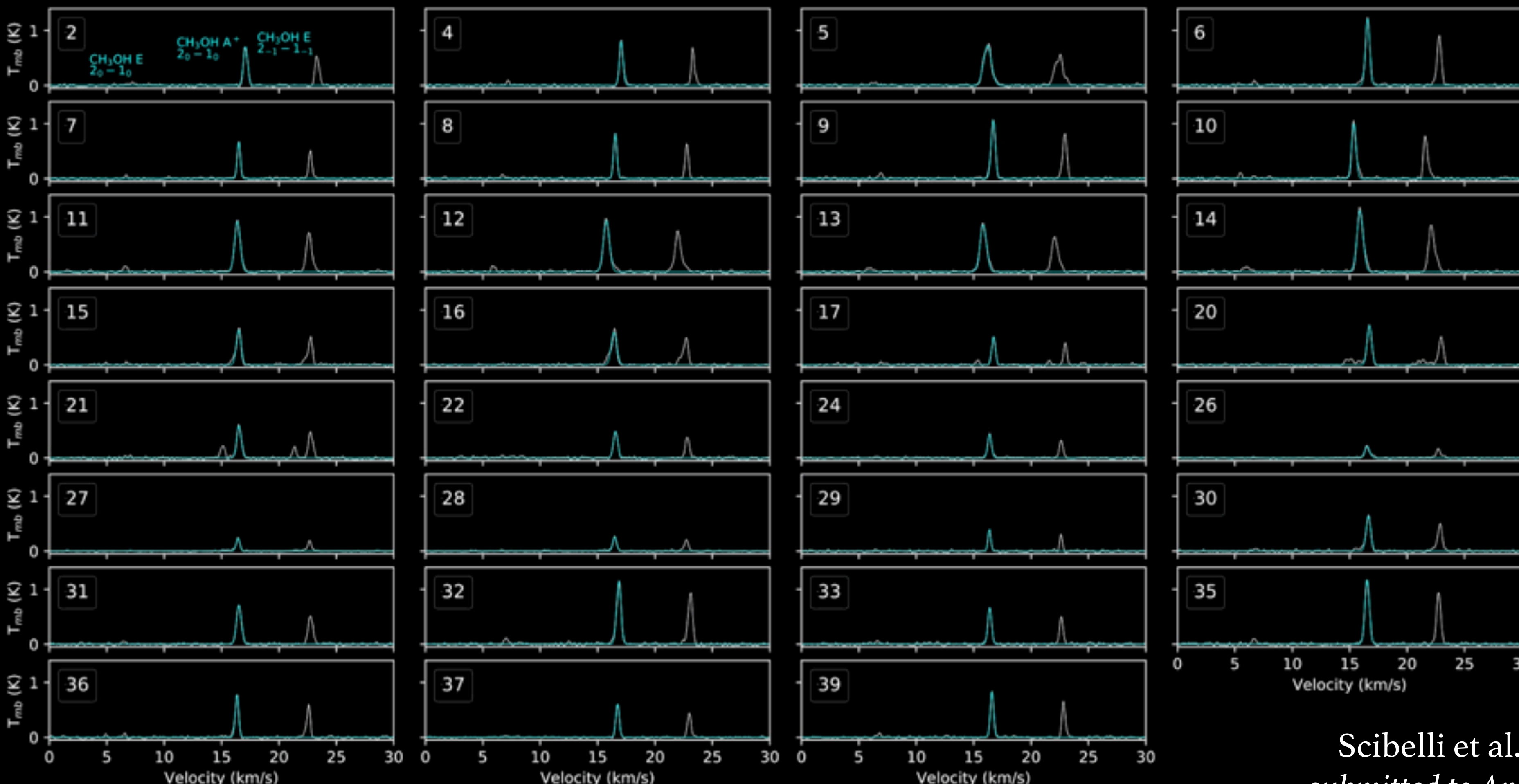
Conducted a large-sample systematic survey of 31 prestellar cores selected from NH_3 mapping results (Seo et al. 2015) in the Taurus Star Forming region

Scibelli et al., *submitted to ApJ*



ARO 12m Observing

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



Scibelli et al.,
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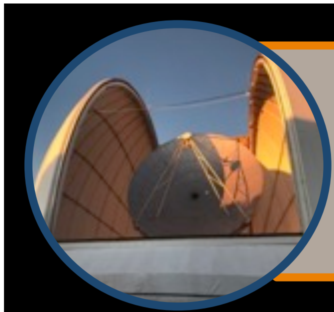

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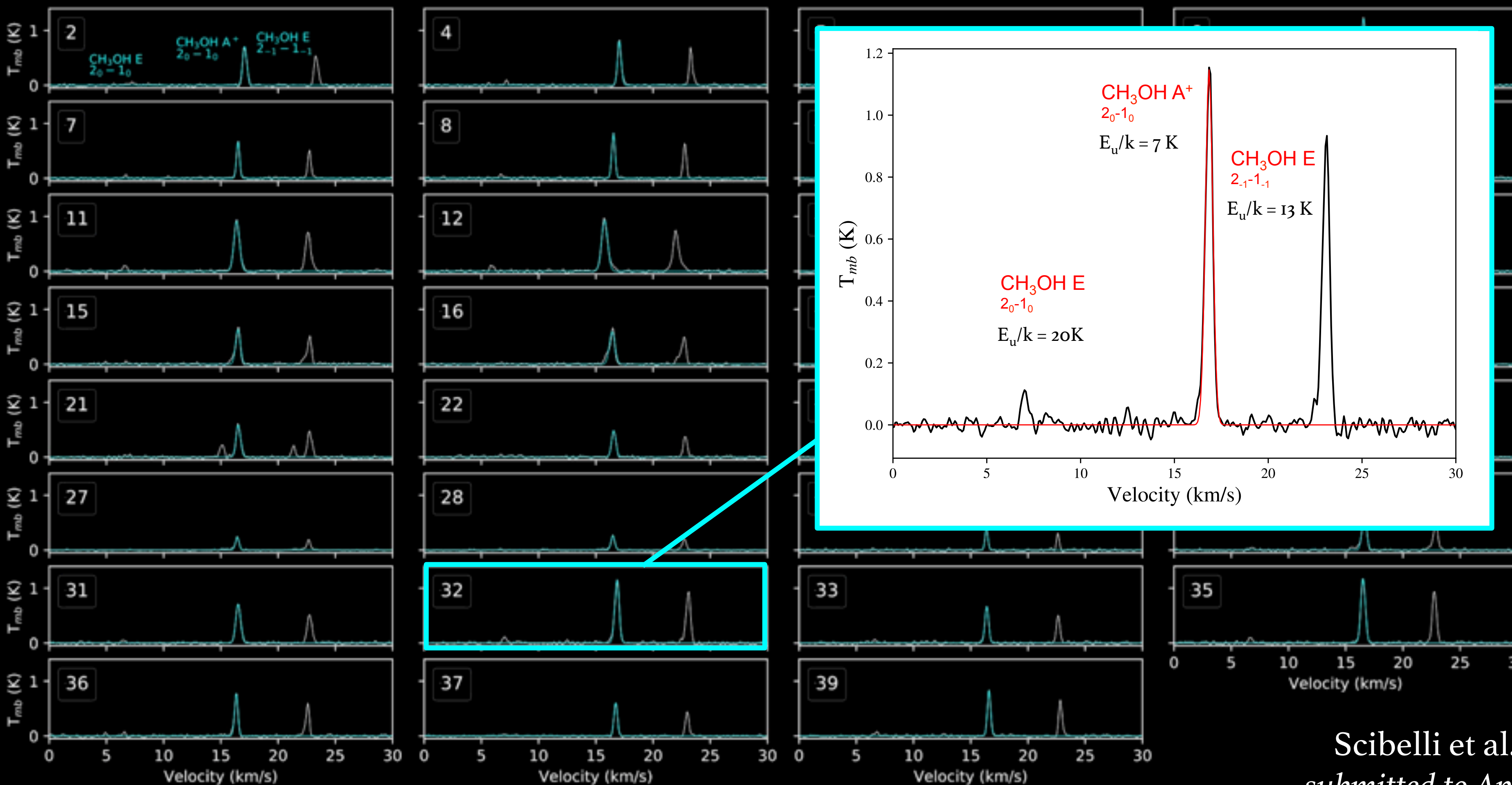

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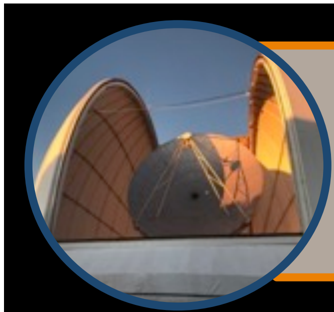

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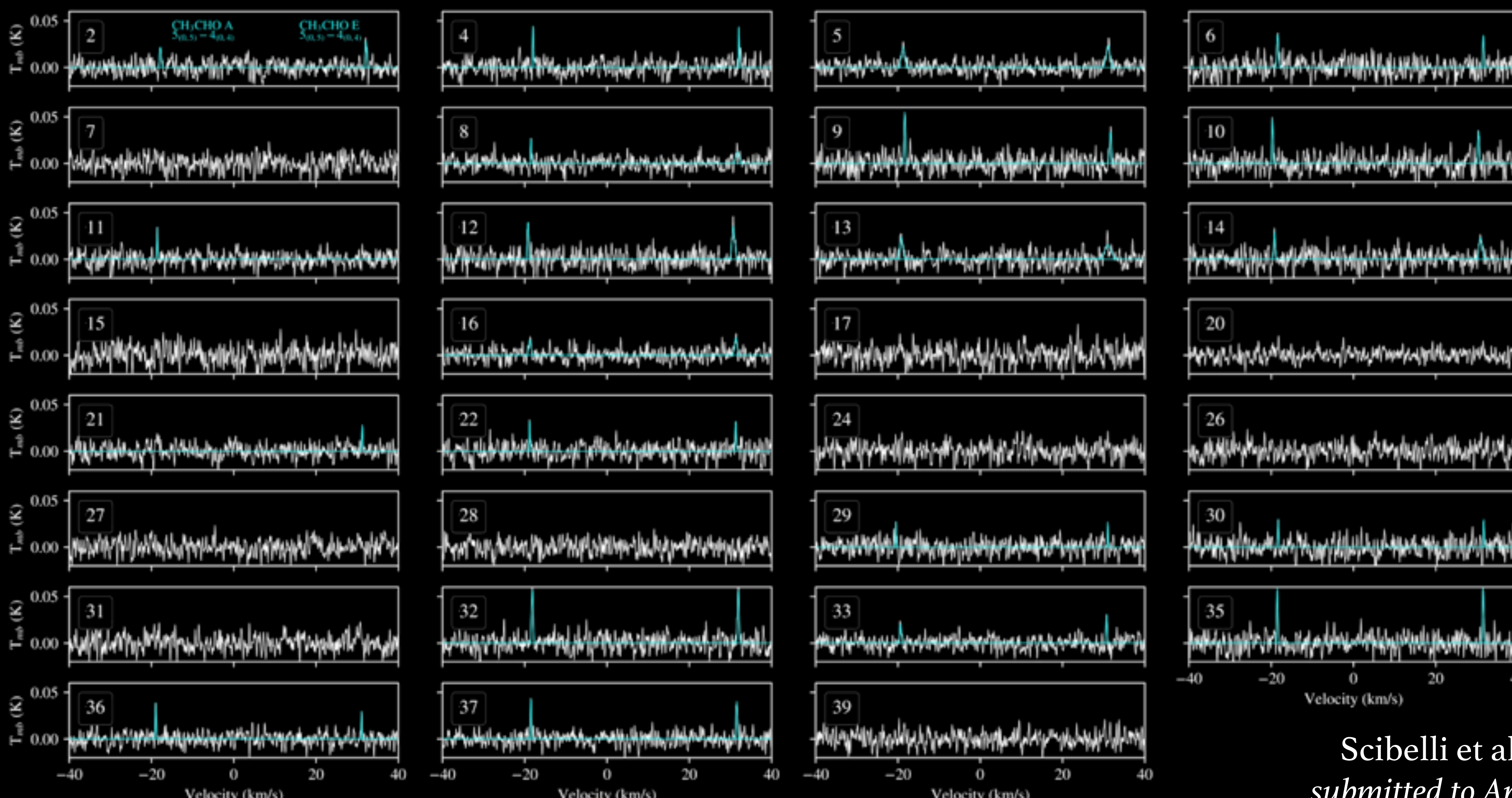
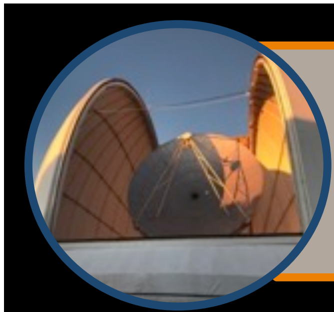
Detected acetaldehyde (CH_3CHO) in 68% of the cores targeted!



Scibelli et al., *submitted to ApJ*



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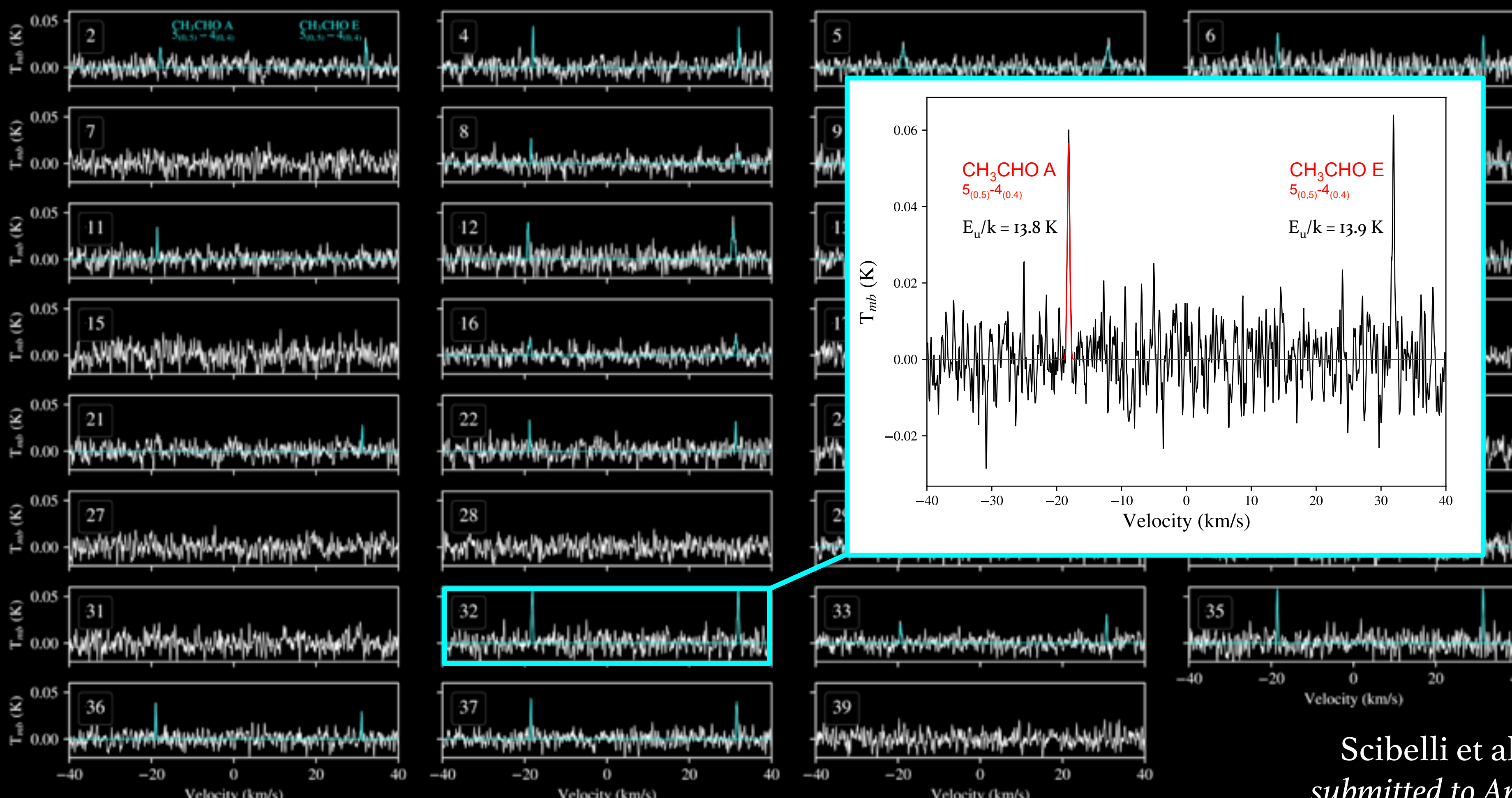
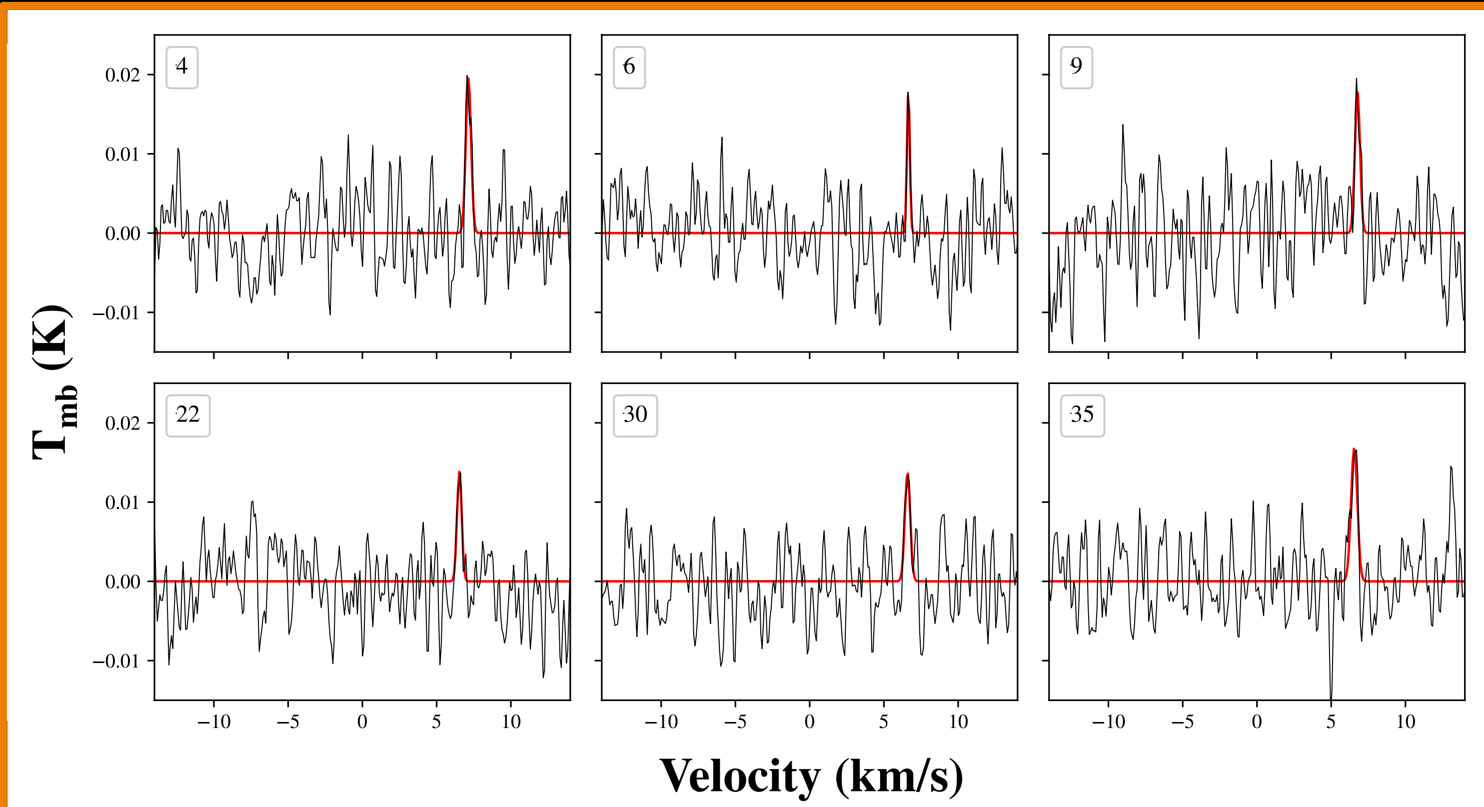


Scibelli et al.,
submitted to ApJ

ARO 12m Observing

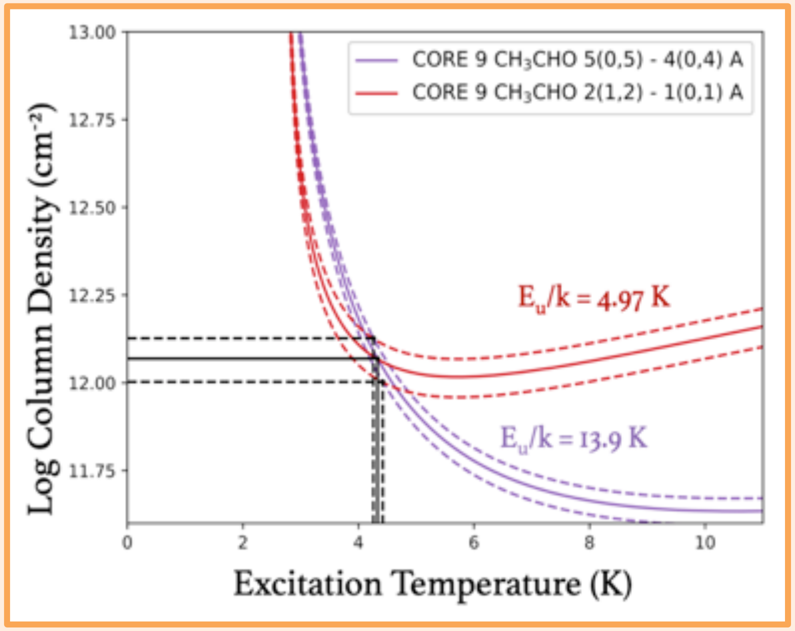
84 GHz CH_3CHO 2-1 transition (E_{up} = 5 K) detected in 6 of the 21 cores for which the 96 GHz CH_3CHO 5-4 transition was detected in



Scibelli et al., *submitted to ApJ*

Constraining Column Densities and Abundances

CH_3CHO: CTEX Method



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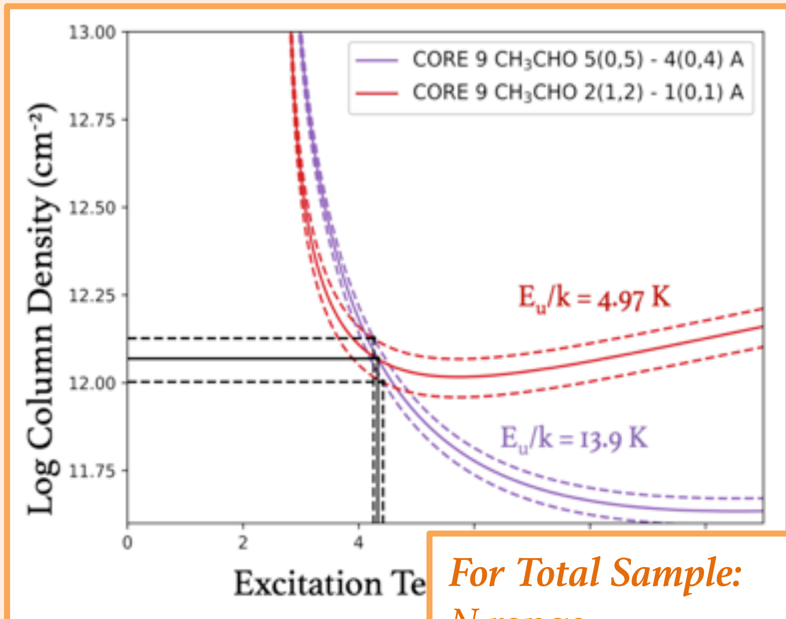

For Total Sample:

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 et al., *submitted to ApJ*

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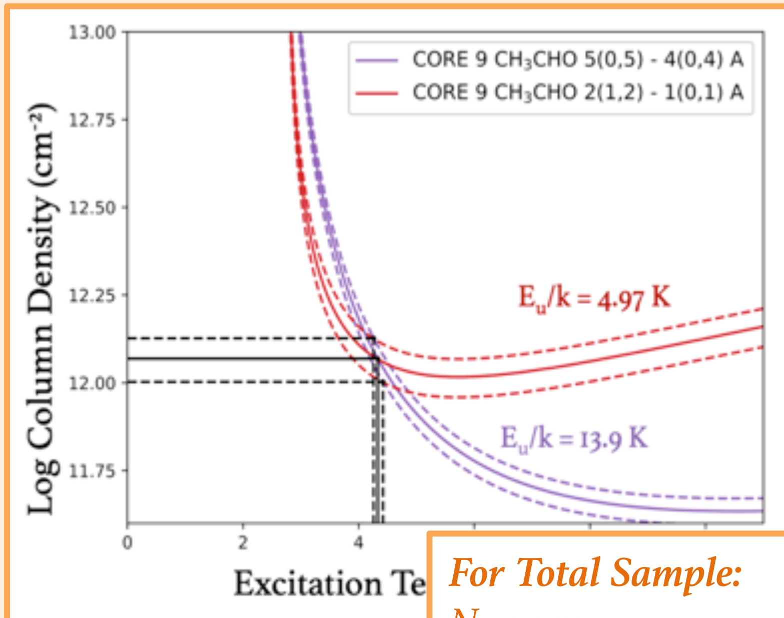

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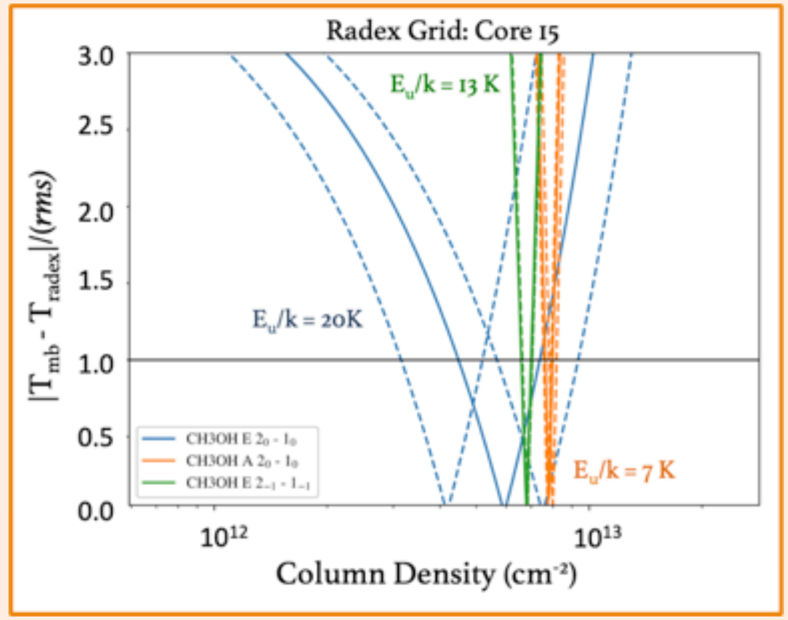
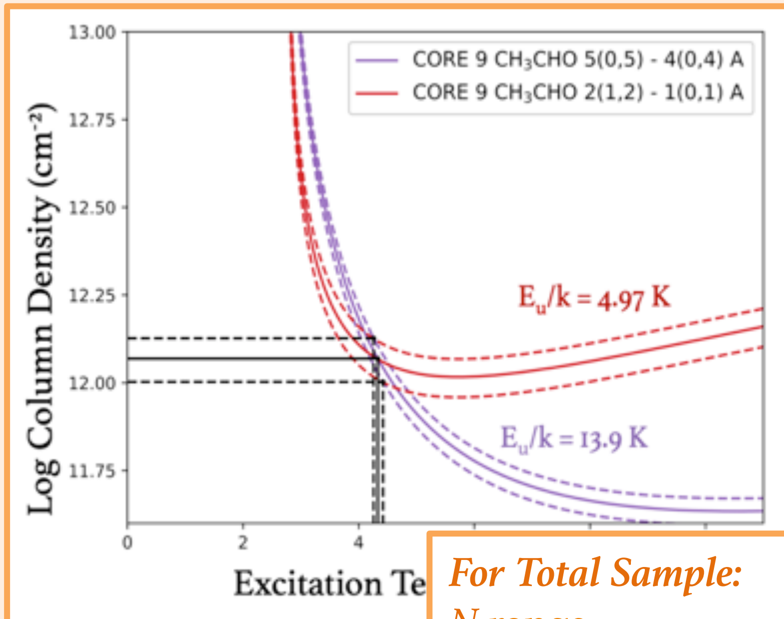
CH_3OH: RADEX Method



Scibelli et al., *submitted to ApJ*

Constraining Column Densities and Abundances

CH_3CHO: CTEX Method



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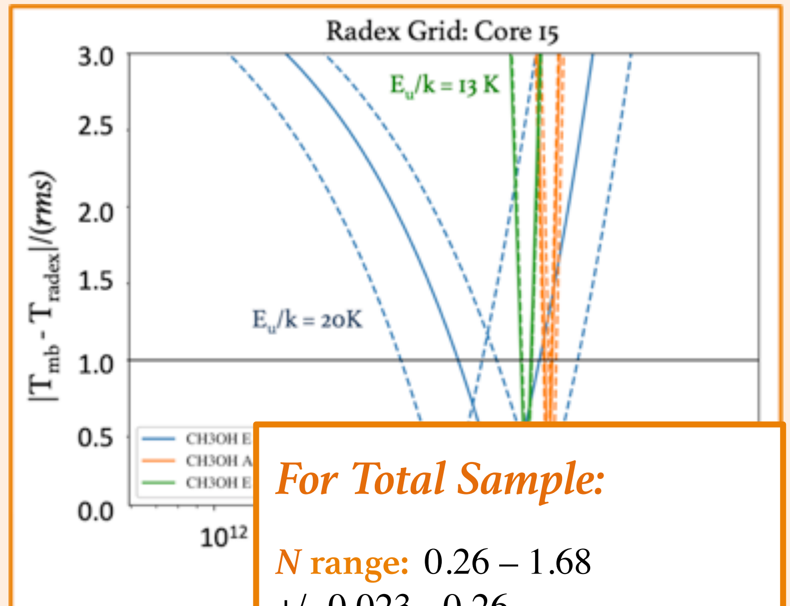


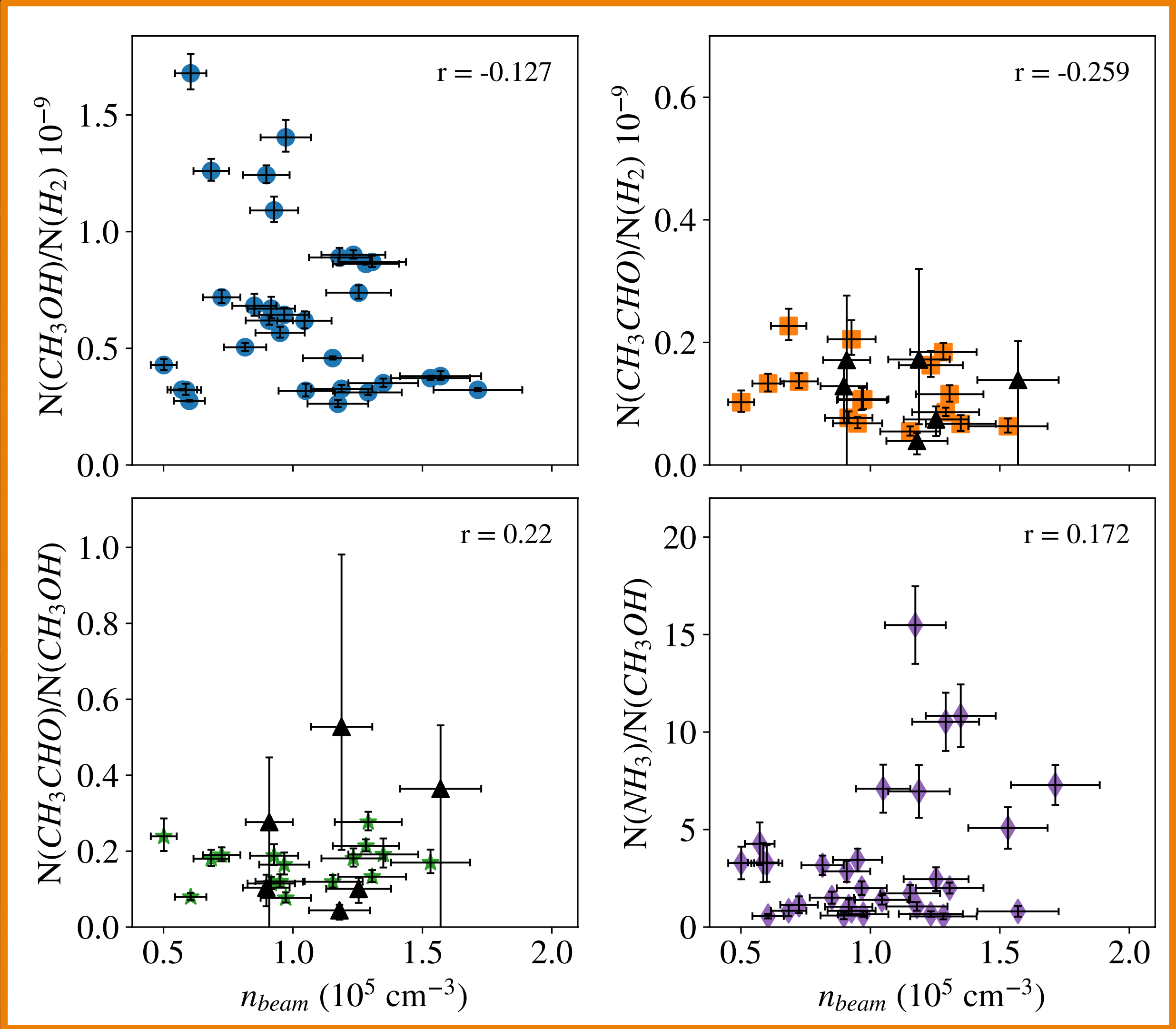
For Total Sample:

N range: 0.26 – 1.68
+/- 0.023 - 0.26
(10^{13} cm^{-2})

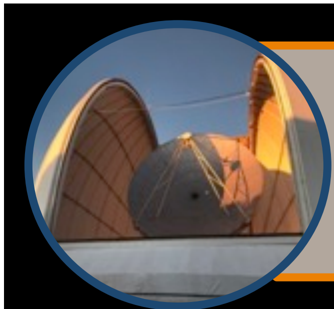
Tex range: 6.79 – 8.66
+/- 0.005 – 0.025 (K)

Scibelli et al., *submitted to ApJ*

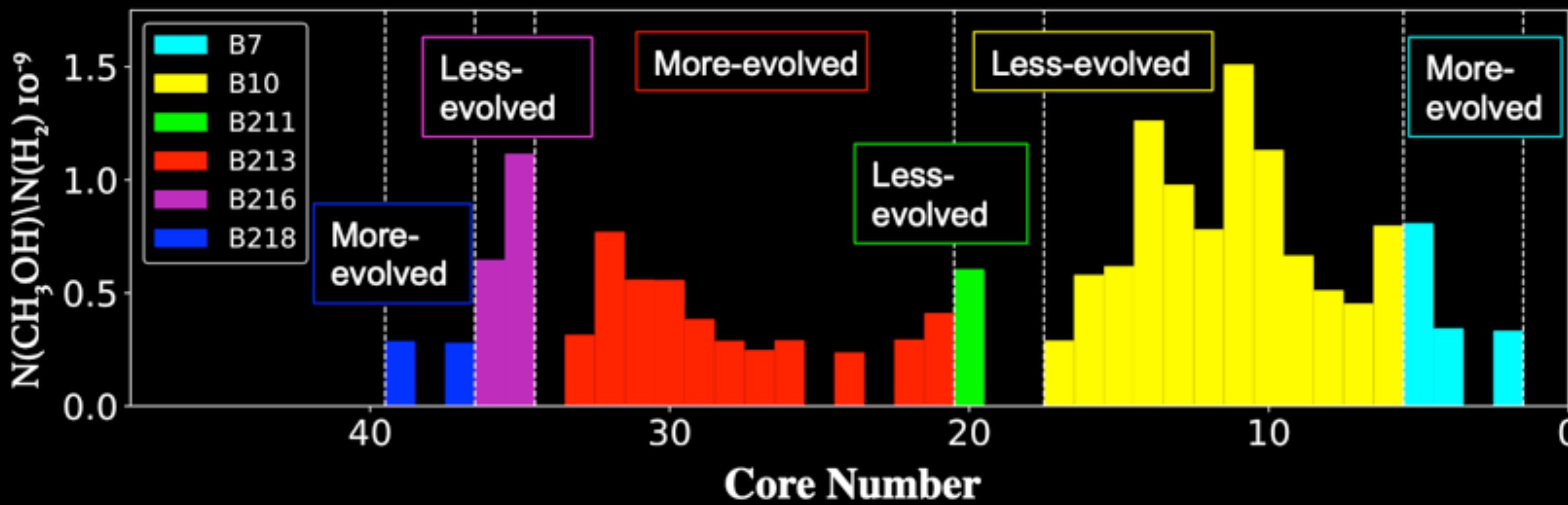
Core Abundances

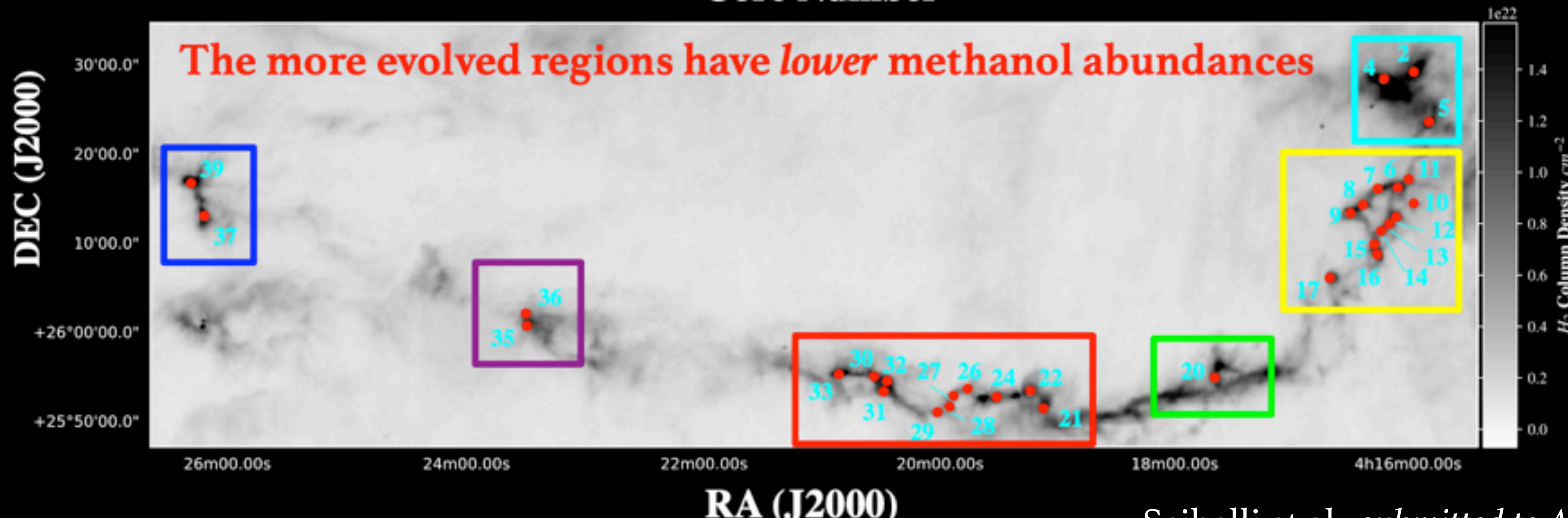


Scibelli et al.,
submitted to ApJ

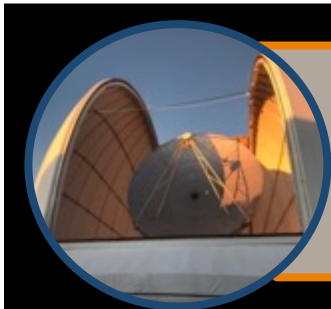


Methanol Abundances



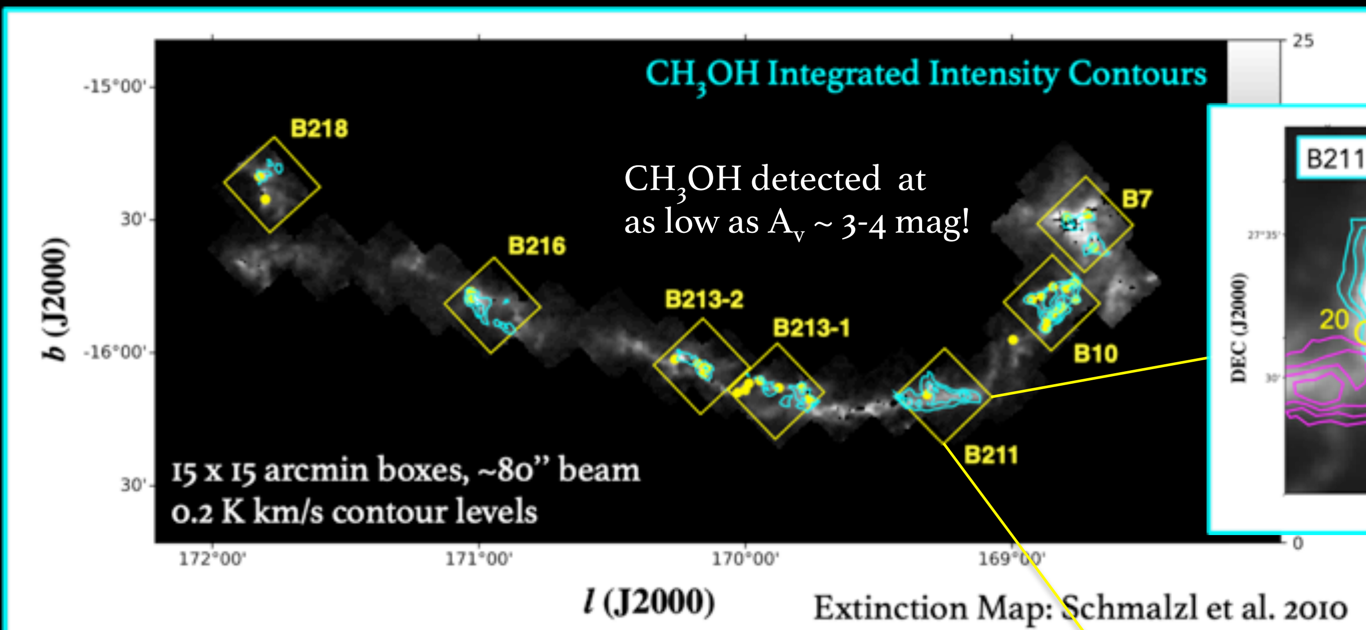


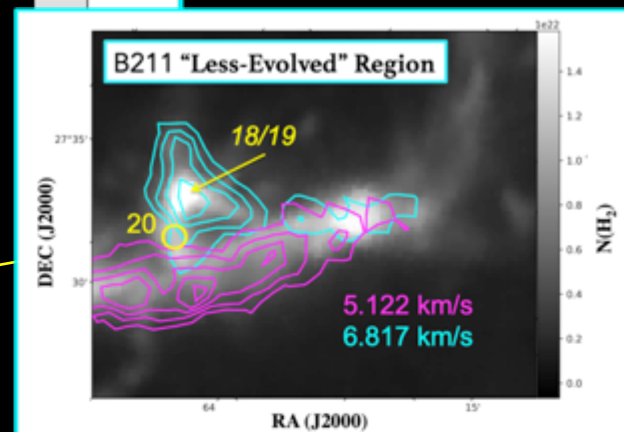
Scibelli et al., *submitted to ApJ*



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 et al., *submitted to ApJ*

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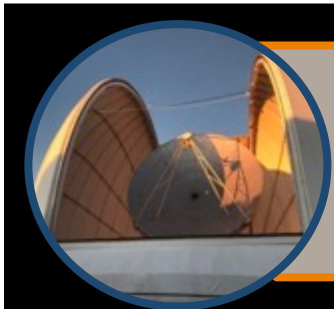

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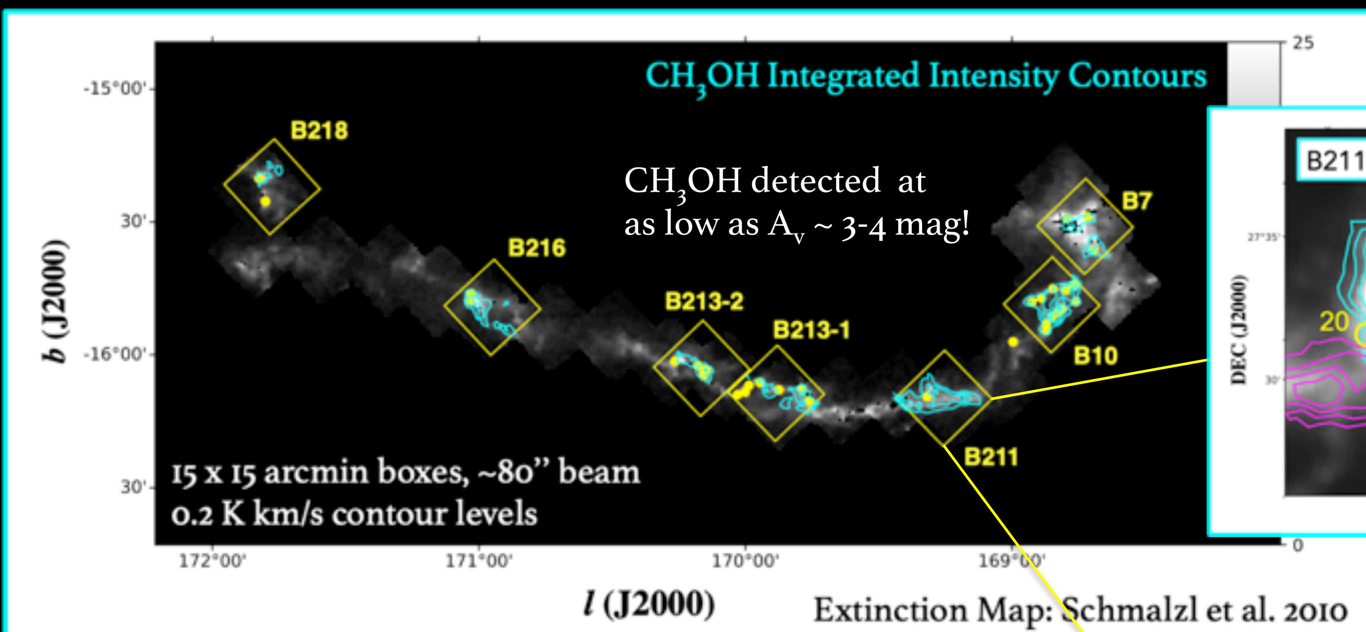

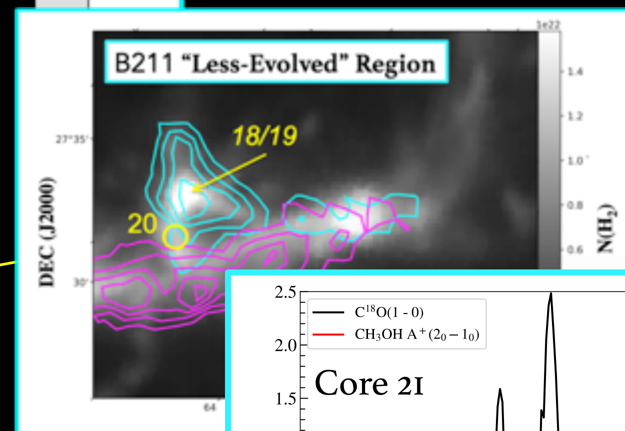

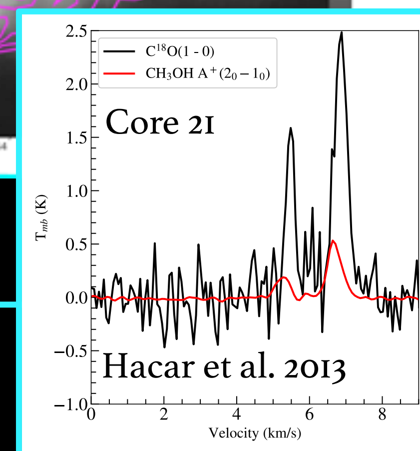

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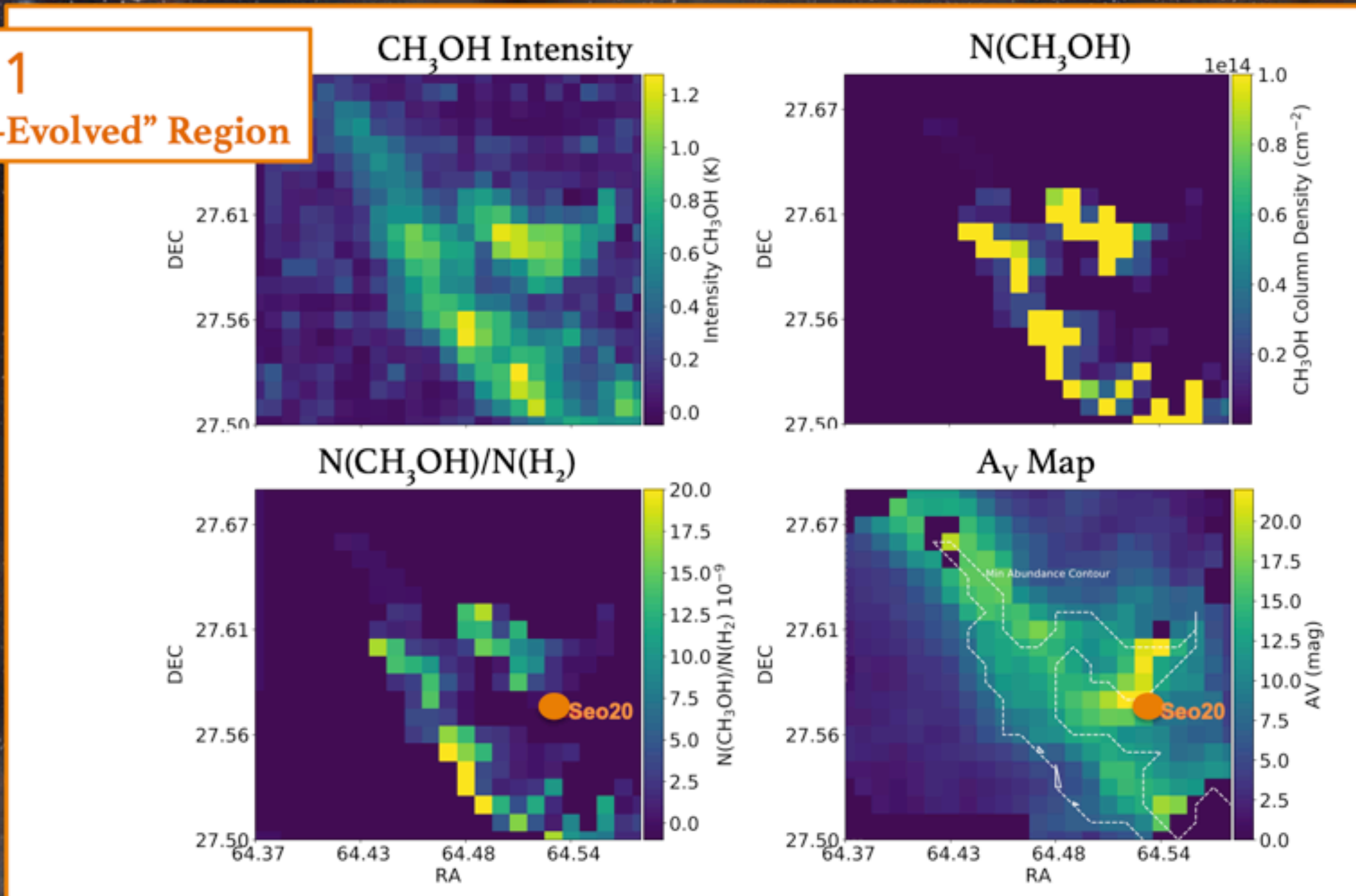
Methanol Abundance Maps

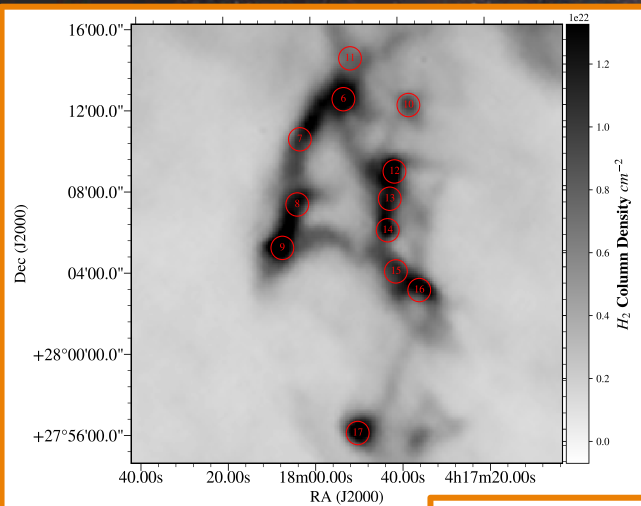
B211
“Less-Evolved” Region



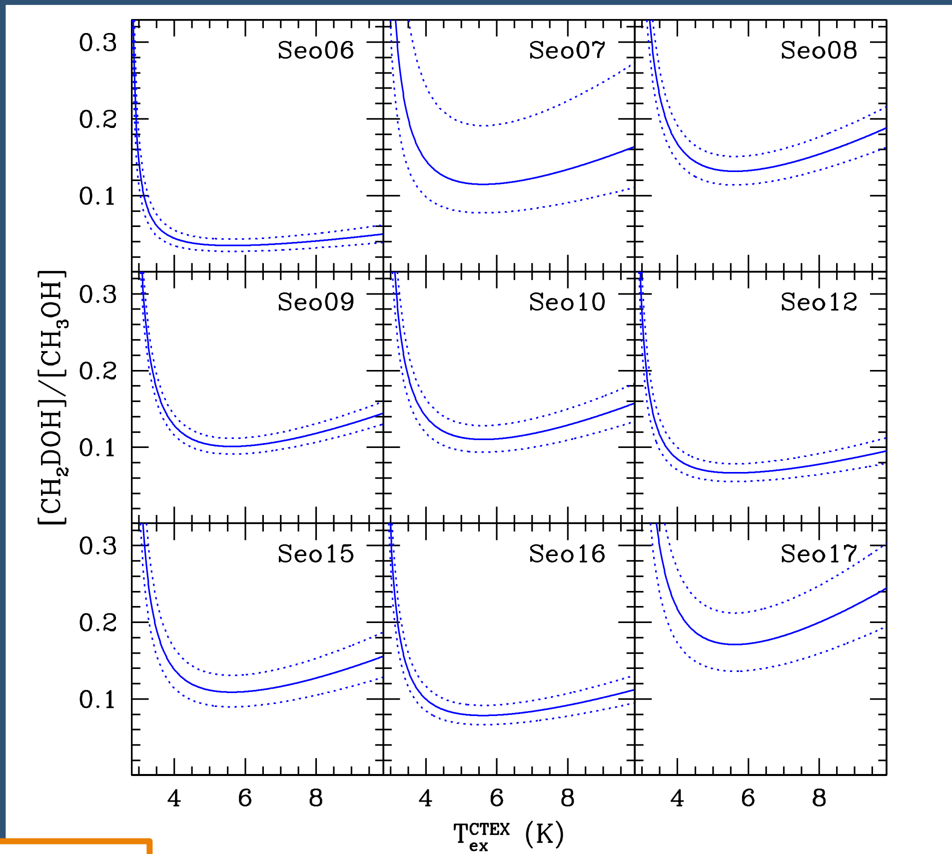
Scibelli et al., *submitted to ApJ*

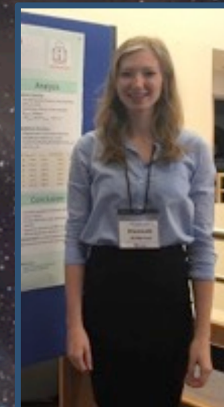
Deuterated Methanol: Survey of B10 Region

- 75 % Detection Rate!
- Deuteration fraction on average ~ 10% for reasonable excitation temperatures (> 4K)



B10 “Less-Evolved” Region

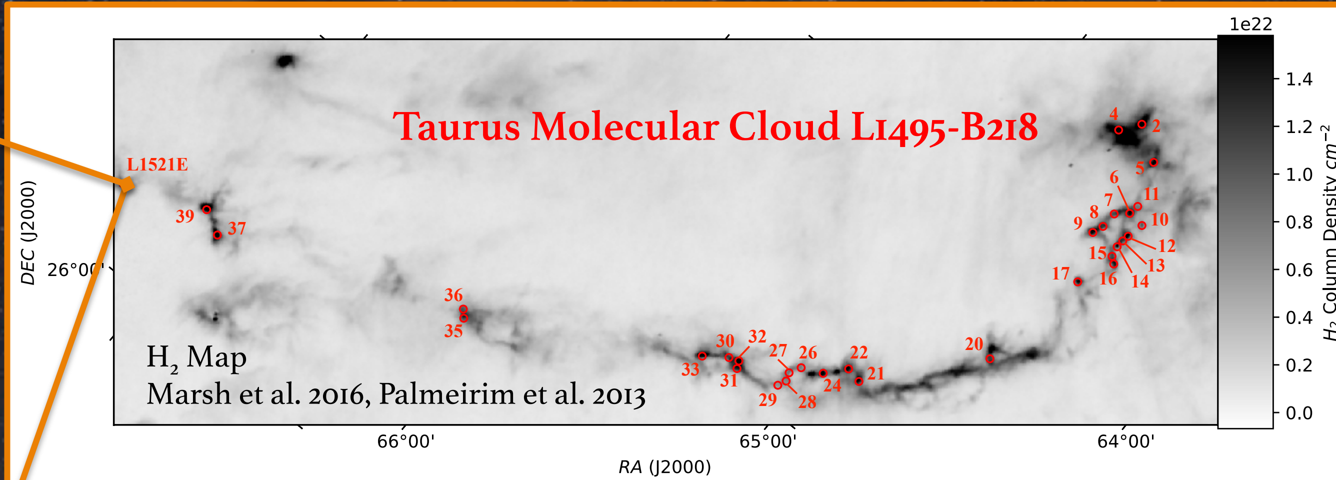


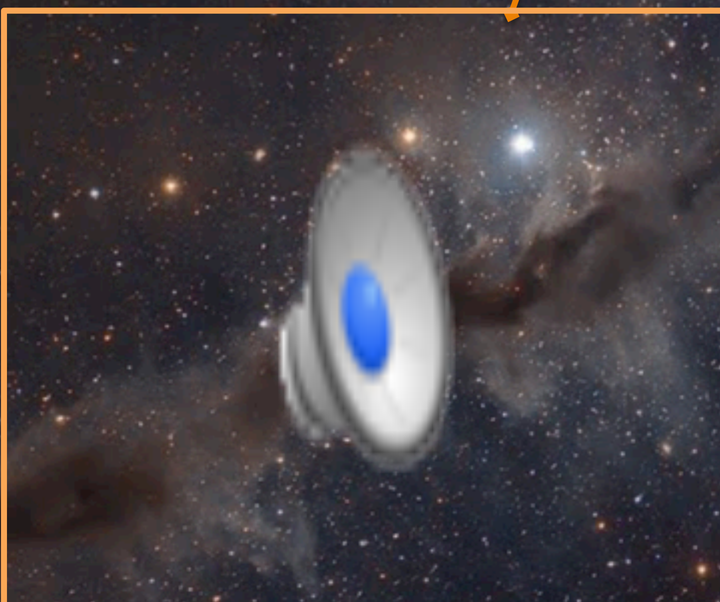


Ambrose et al. *in prep*

Next: Vinyl Cyanide Survey

Image: SDSS9





Lines Targeted (simultaneously):

Vinyl Cyanide: CH_2CHCN $8_{0,8} - 7_{0,7}$ (75.6 GHz)
Vinyl Cyanide: CH_2CHCN $8_{1,8} - 7_{1,7}$ (73.98 GHz)
Ethyl Cyanide: CH_3CH_2CN $8_{1,8} - 7_{1,7}$ (73.35 GHz)
Methyl Cyanide: CH_3CN $4_0 - 3_3$ (73.59 GHz)

Important Takeaways

1. The COMs acetaldehyde, dimethyl Ether and vinyl Cyanide have been detected in young core L1521E!
2. We have observed methanol in 100% of the 31 Taurus cores targeted and acetaldehyde in 68%!
   - ✧ One of the first survey's to target a large, homogenous sample of cores, warranting a robust comparison between cores of similar environmental conditions
3. Abundance measurements of COMs will provide constraints for astrochemical models

Complex Organics are forming early and often in prestellar cores!

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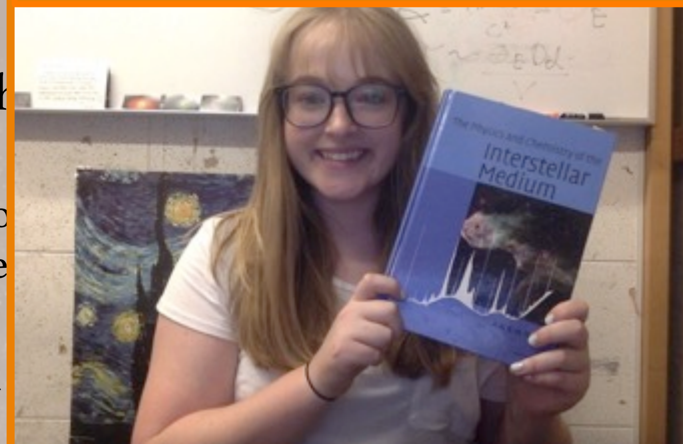
Thanks Xander!



Complex Organics are forming early and often in prestellar cores!