Pre-biotic Molecules in the Sub-mm Regime

Robin Garrod
Cornell University

Cornell University

Pre-biotic Molecules in the Sub-mm Regime

- Interstellar pre-biotic & complex molecules
- How detected and where
- Some current theory & experiment
- Unsolved problems
- Potential for CCAT

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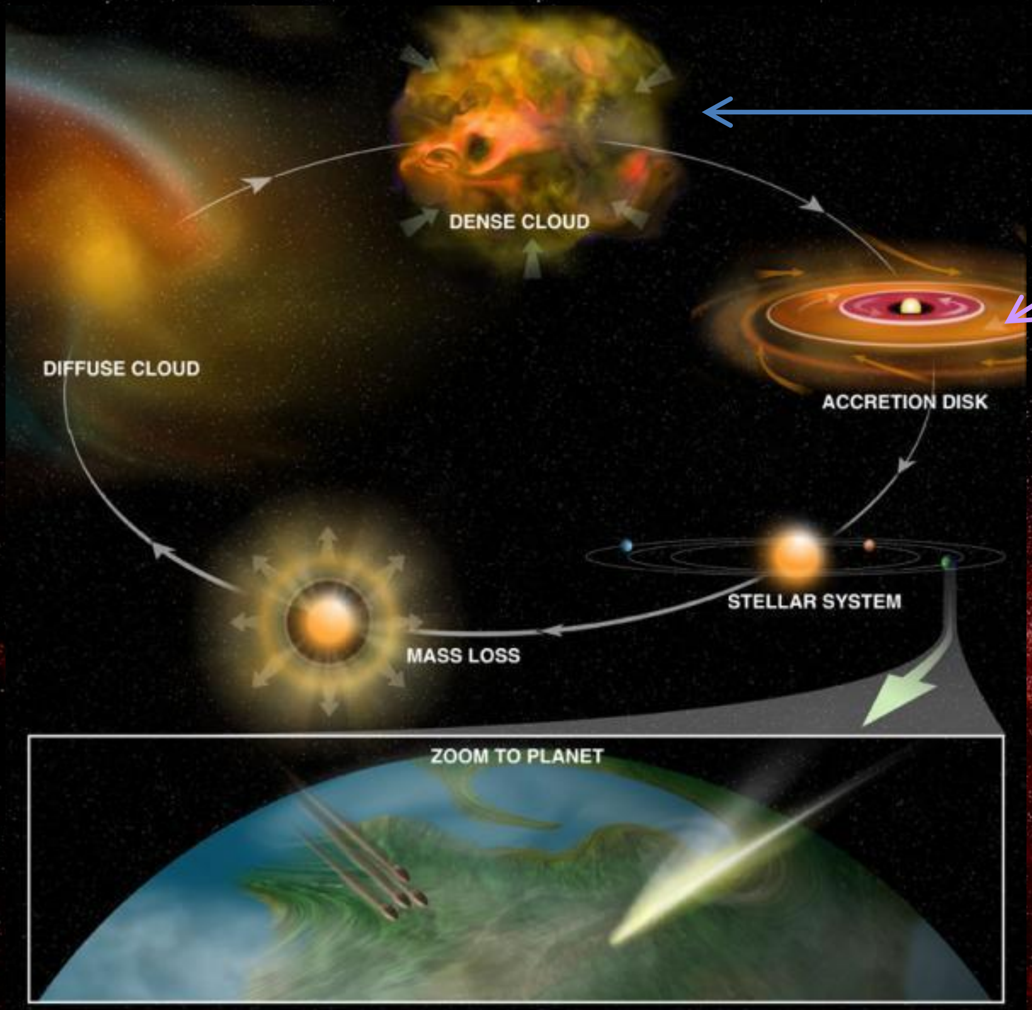

The Cosmic Chemistry Cycle
CREDIT: Bill Saxton, NRAO/AUI/NSF

How do we get from here to here?

How does the physics evolve?

How does the chemistry evolve?

How are the two related?

Does dense cloud chemistry have a strong effect on much later (i.e. biotic) chemistry?

Detected Interstellar Molecules

Number of Atoms										
2	3	4	5	6	7	8	9	10	11	12+
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_6H_6
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		$HC_{11}N$
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH?	$(CH_3)_2O$	NH_2CH_2COOH?		PAHs
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			C_{60}^+?
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	H_2C_6	HC_7N			
CH^+	HCN	C_2H_2	CH_2CN	CH_3OH	NH_2CH_3	$HOCH_2CHO$	C_8H			
CN	HCO	CH_2D^+?	CH_4	CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+						
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN	CH_3								
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF	H_2D^+									

~150 molecules

Largely organic; some very complex

Biologically significant:

e.g. Glycolaldehyde, $HCOCH_2OH$ (Hollis+, 2000)

or acetamide, CH_3CONH_2 (Hollis+, 2006) – peptide bond

Largest saturated organics associated with star-forming regions

Pre-biotics(?)

Simple ices – H_2O, CH_4, NH_3, H_2CO, CH_3OH, CO, CO_2

Simple gas-phase species – e.g. as above

Carbon chains, cyanopolyynes – $HC_{11}N$ is largest yet

Complex (>5 atoms), highly-saturated organics
– alcohols, carboxylic acids, esters, sugars …

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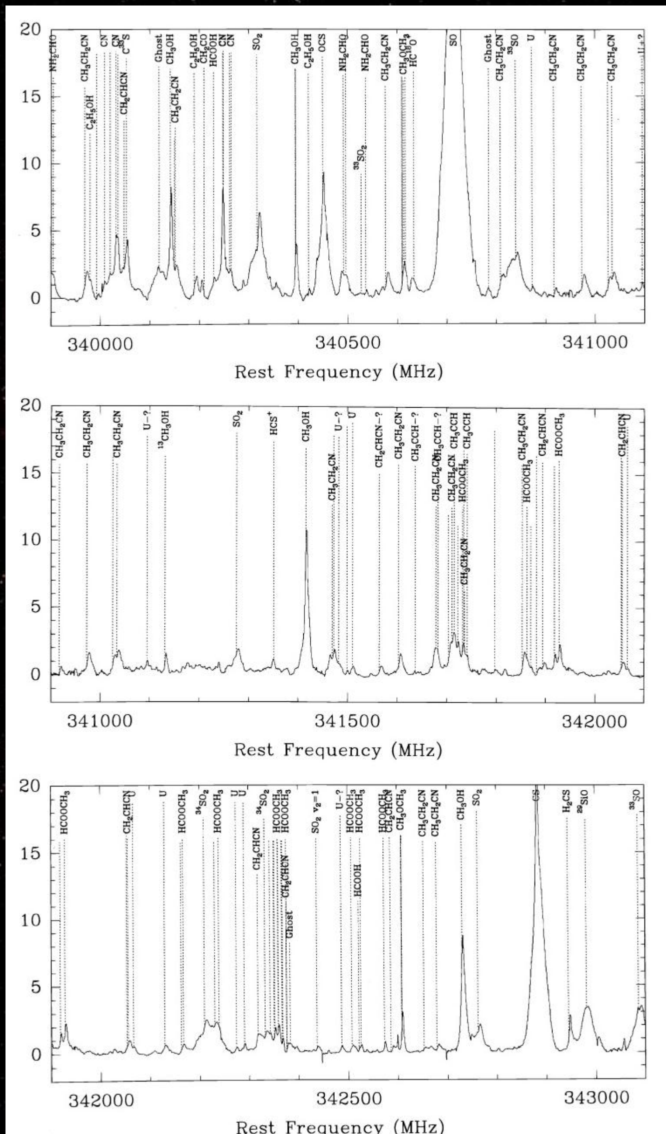
Sub-mm molecular (rotation) spectra:

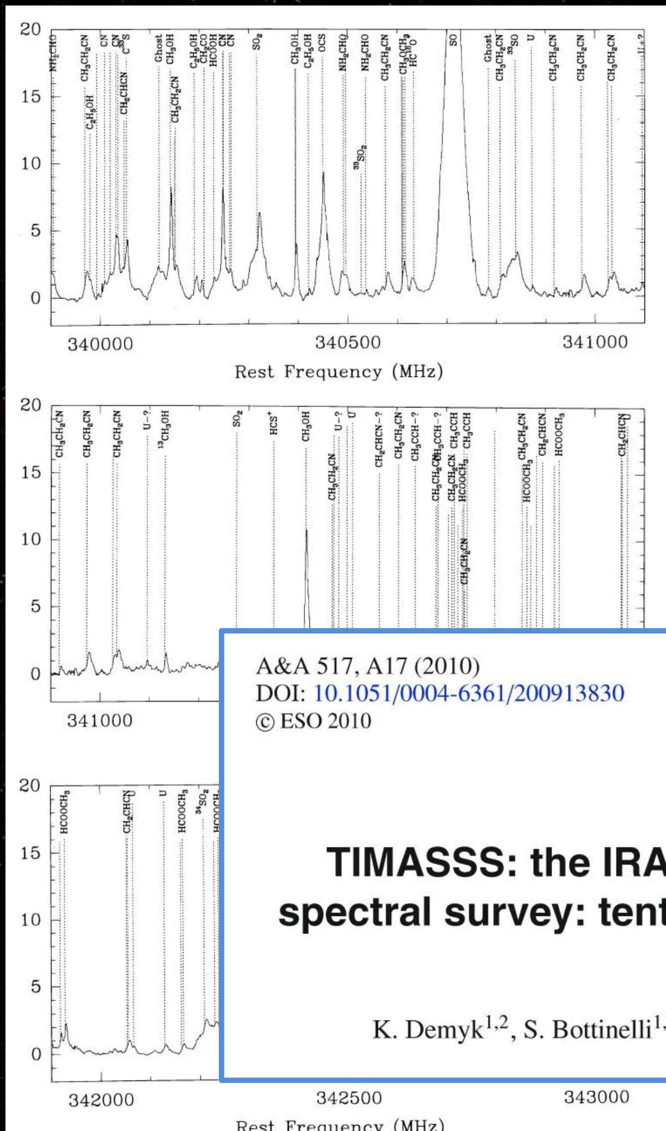
- Spectral-line strengths:
  - $\rightarrow$ Indicates column density, excitation temp of molecule
  - $\rightarrow$ Under certain assumptions, indicates gas kinetic temps
- Molecular line emission also tells us:
  - Information on gas dynamics (via red/blueshift)
  - Spatial information
  - Density info, via critical (minimum) densities for line excitation
- Chemistry responds to, and records, changing physical conditions
  - $\rightarrow$ Chemical abundances indicate the HISTORY of the gas/dust (via chemical modeling)

Schilke et al. (1997) spectra of Orion KL



- “Hot core” spectrum – high mass SF
  (but cf. Zapata et al. 2010)
- 1000’s of lines – many saturated complex organics
- Methanol (CH_3OH), methyl formate ($HCOOCH_3$) are very prominent
- Full of weeds
- Full spectroscopic surveys required
- Only ~50 % of lines are identified
- Many isotopically-substituted molecules may be present
- Require good spectroscopic assignments

Schilke et al. (1997) spectra of Orion KL



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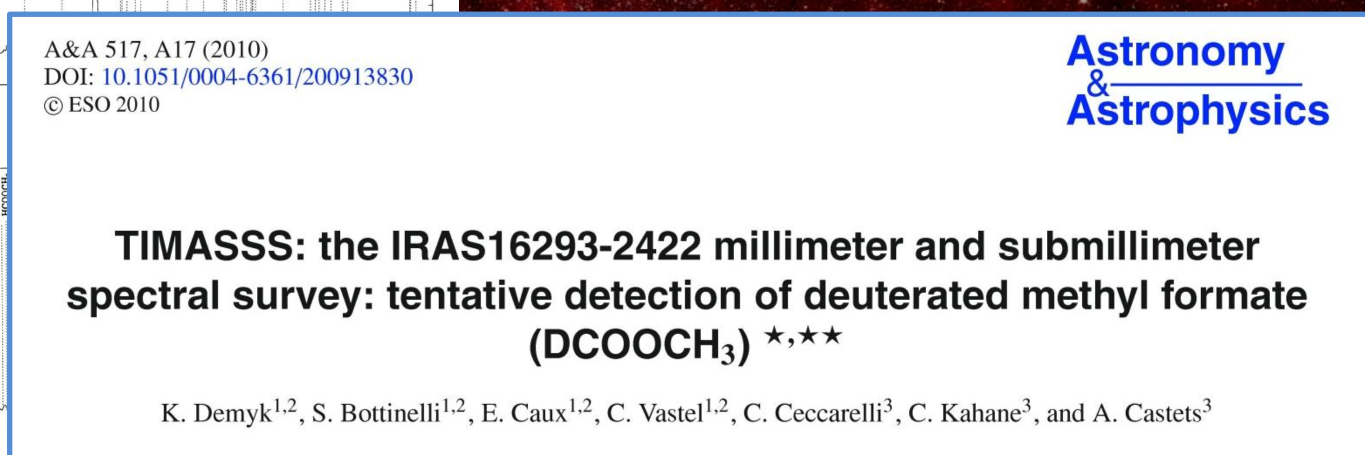


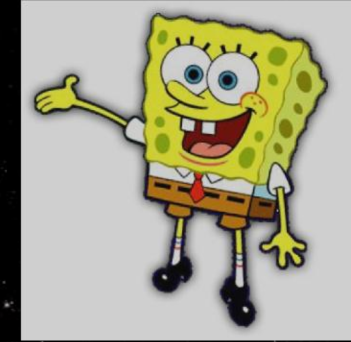
A&A 517, A17 (2010)
DOI: 10.1051/0004-6361/200913830

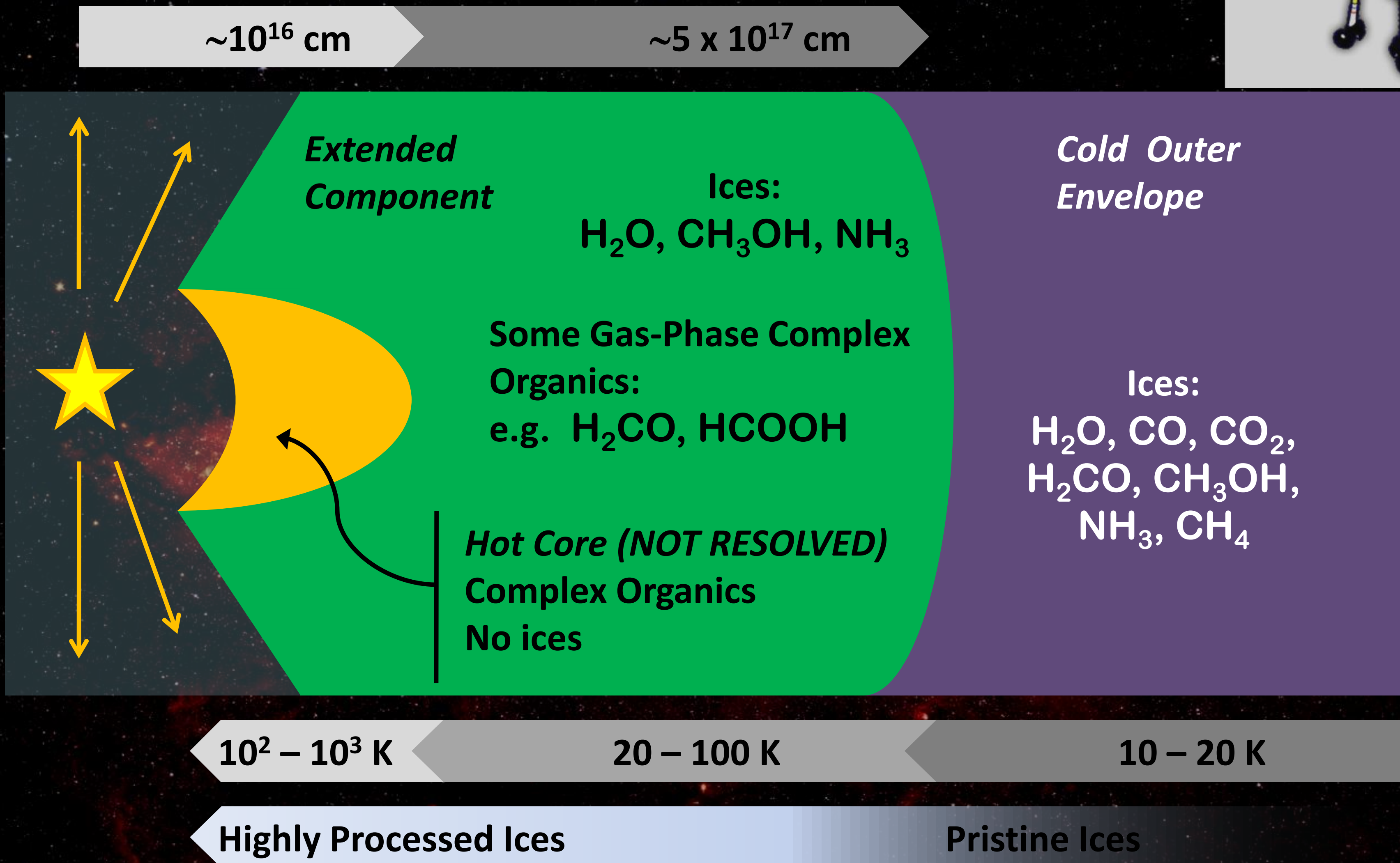
Astronomy & Astrophysics

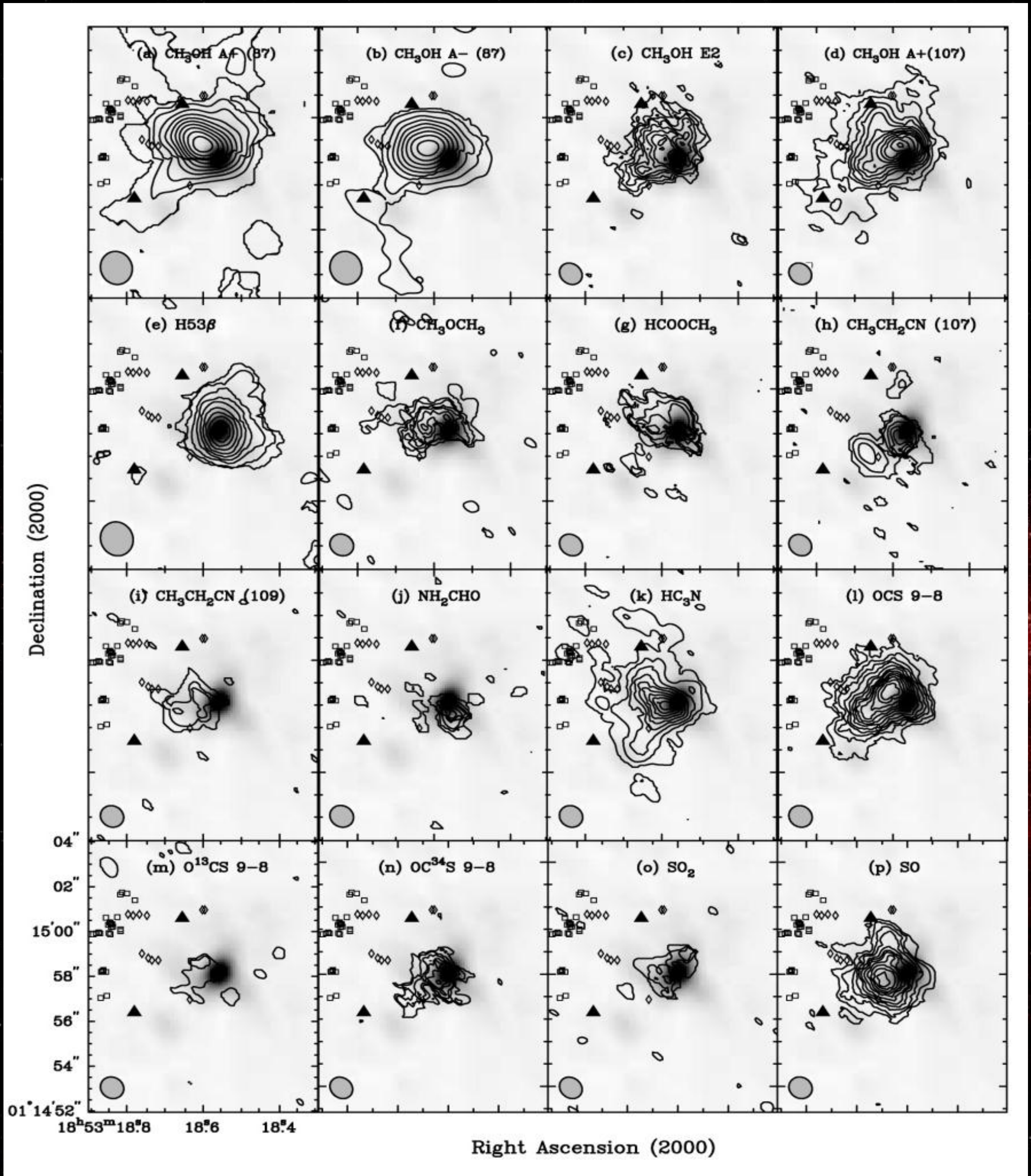
TIMASSS: the IRAS16293-2422 millimeter and submillimeter spectral survey: tentative detection of deuterated methyl formate ($DCOOCH_3$) ⋆,⋆⋆

K. Demyk[1,2], S. Bottinelli[1,2], E. Caux[1,2], C. Vastel[1,2], C. Ceccarelli[3], C. Kahane[3], and A. Castets[3]

Hot Core Structure







Hot Core G34.26+0.15

At 2.8mm

w/ BIMA (now CARMA) interferometer

Mookerjea et al. 2007

Complex molecule production in star-forming regions

(Garrod et al. 2008)

1) Ices: Formed during **cold** collapse phase - hydrogenation of atoms (H_2O, CH_3OH, CH_4, NH_3)

2) Cosmic-Ray-induced photodissociation

→ functional-group radicals

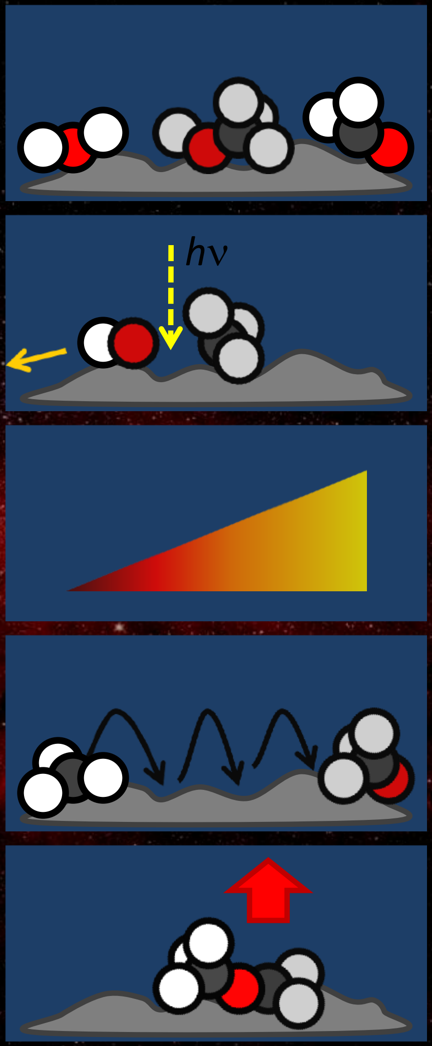
... And at the same time ...

3) Gradual warm-up of gas & dust (10 - 200K)

4) Increased mobility

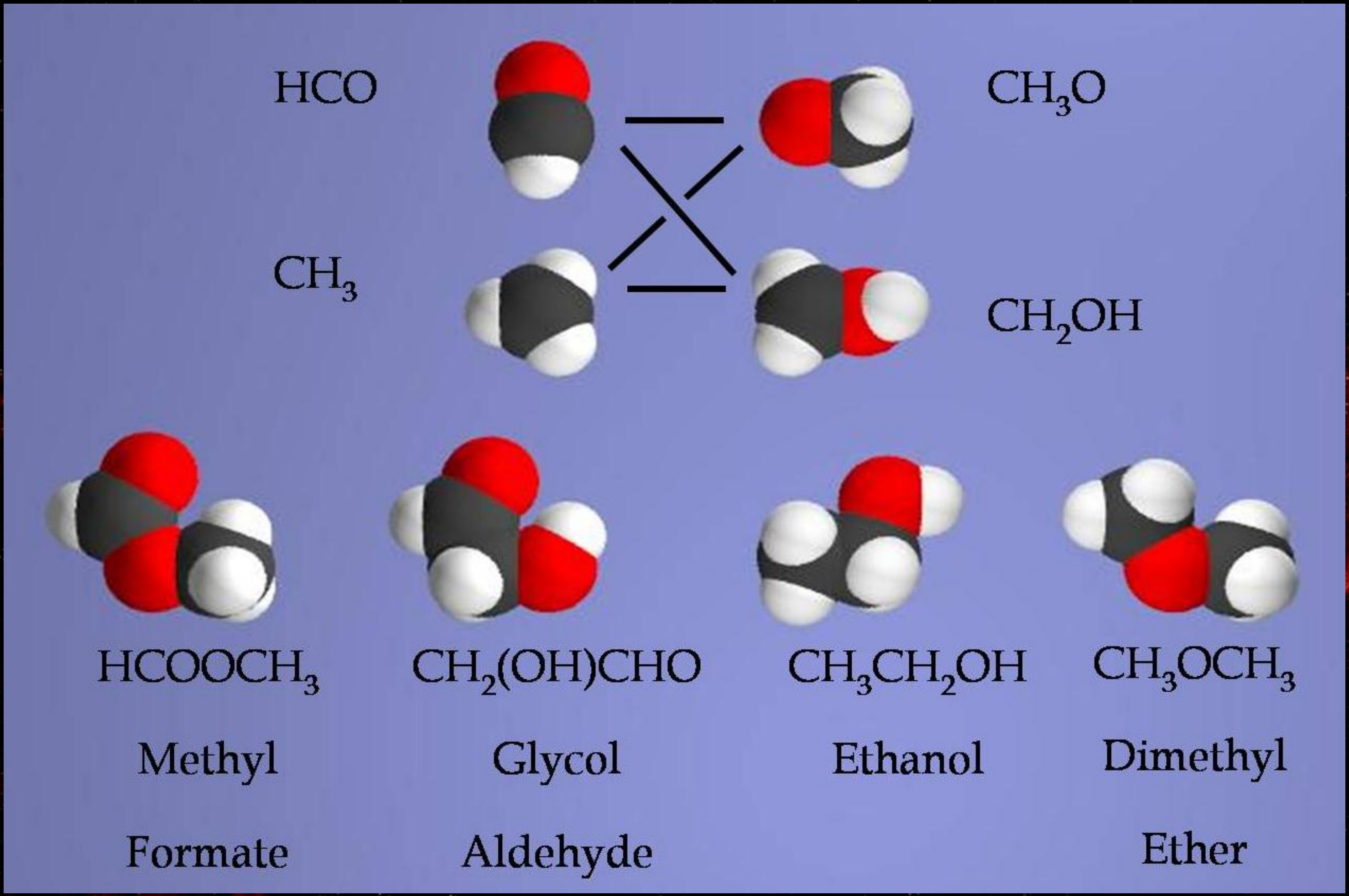
→ addition of radicals on surfaces, and within ice mantles

5) Evaporation at higher temps



UV ice photolysis $\rightarrow$ complex molecules

(Garrod & Herbst 2006; Garrod et al. 2008)



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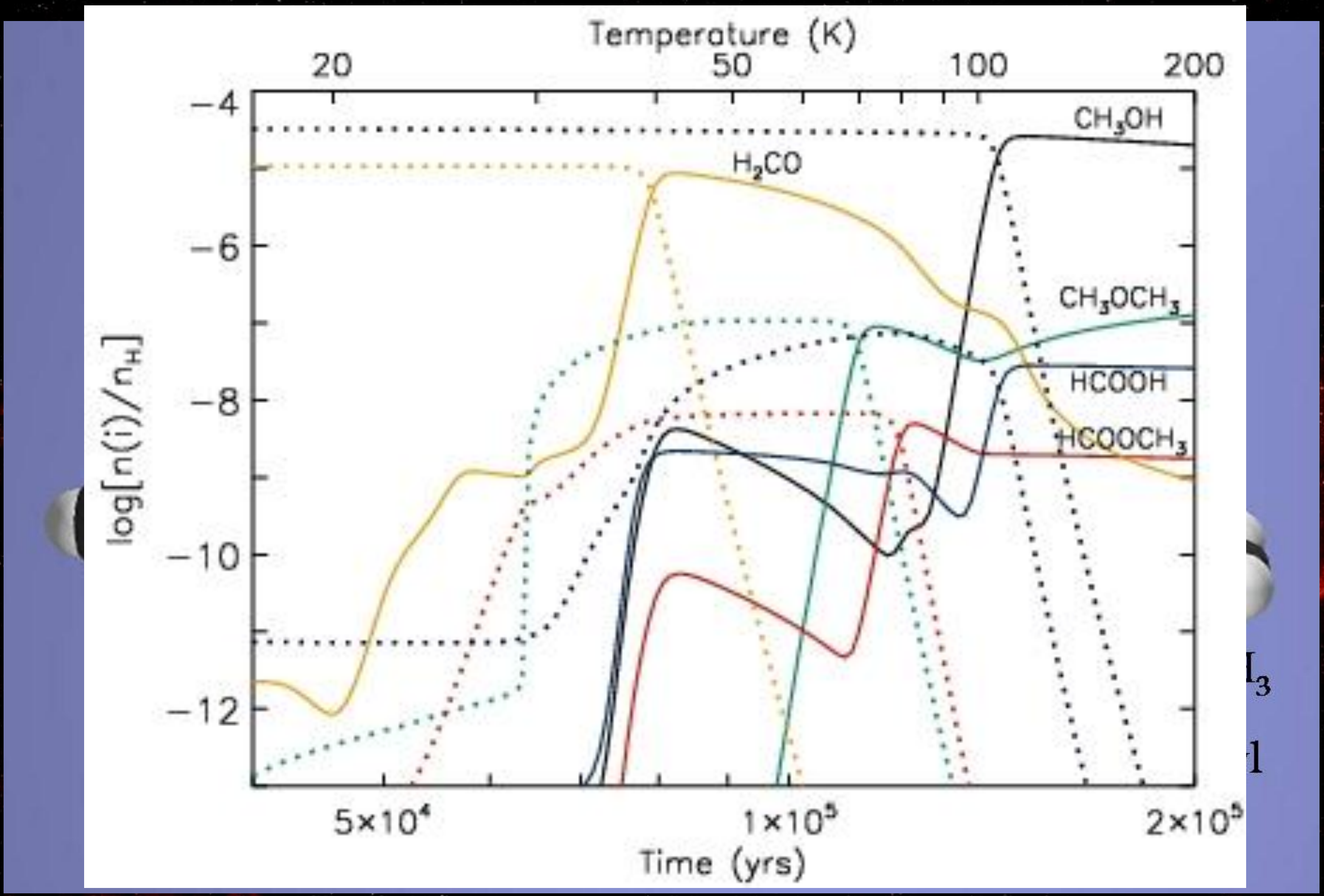
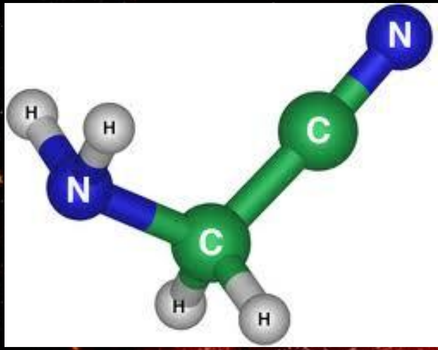
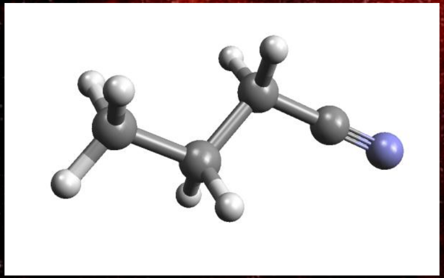
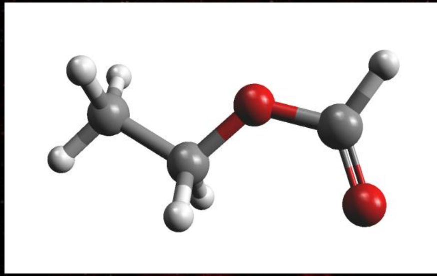


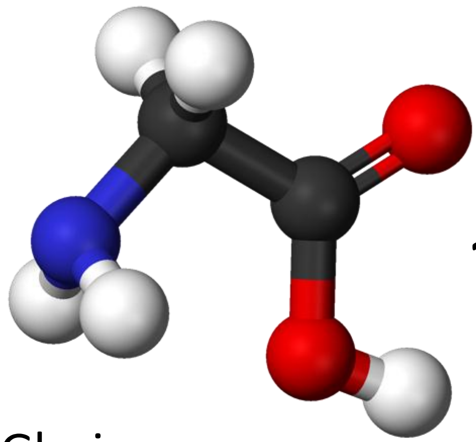
How complex?

Belloche et al.
2008, 2009









?

Glycine

DETECTION OF INTERSTELLAR UREA WITH CARMA

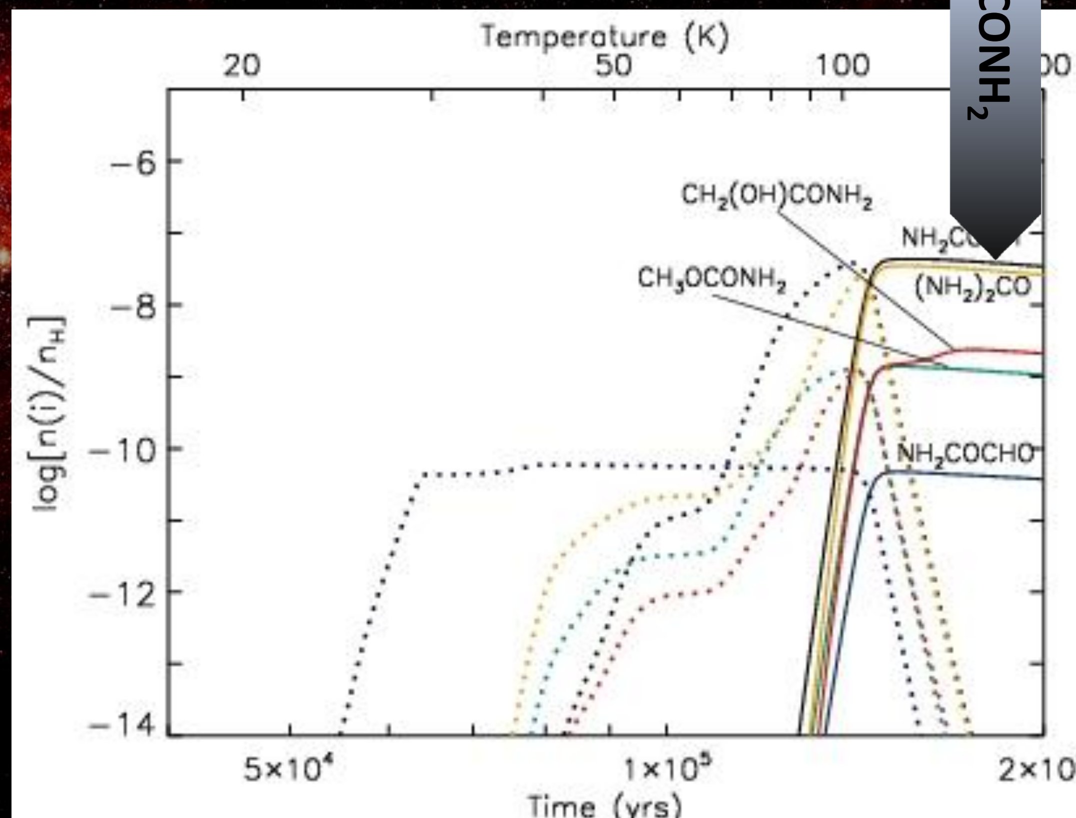
H.-L. KUO, L. E. SNYDER, D. N. FRIEDEL, L. W. LOONEY, *Department of Astronomy, University of Illinois at Urbana-Champaign*; B. J. McCALL, *Departments of Chemistry and Astronomy, University of Illinois at Urbana-Champaign, Urbana IL 61801*; A. J. REMIJAN, *NRAO, Charlottesville VA 22903*; F.J. LOVAS, *Optical Technology Division, NIST, Gaithersburg MD 20899-8441*; J. M. HOLLIS, *NASA/GSFC, Code 606, Greenbelt MD 20771*.

Urea - NH_2CONH_2

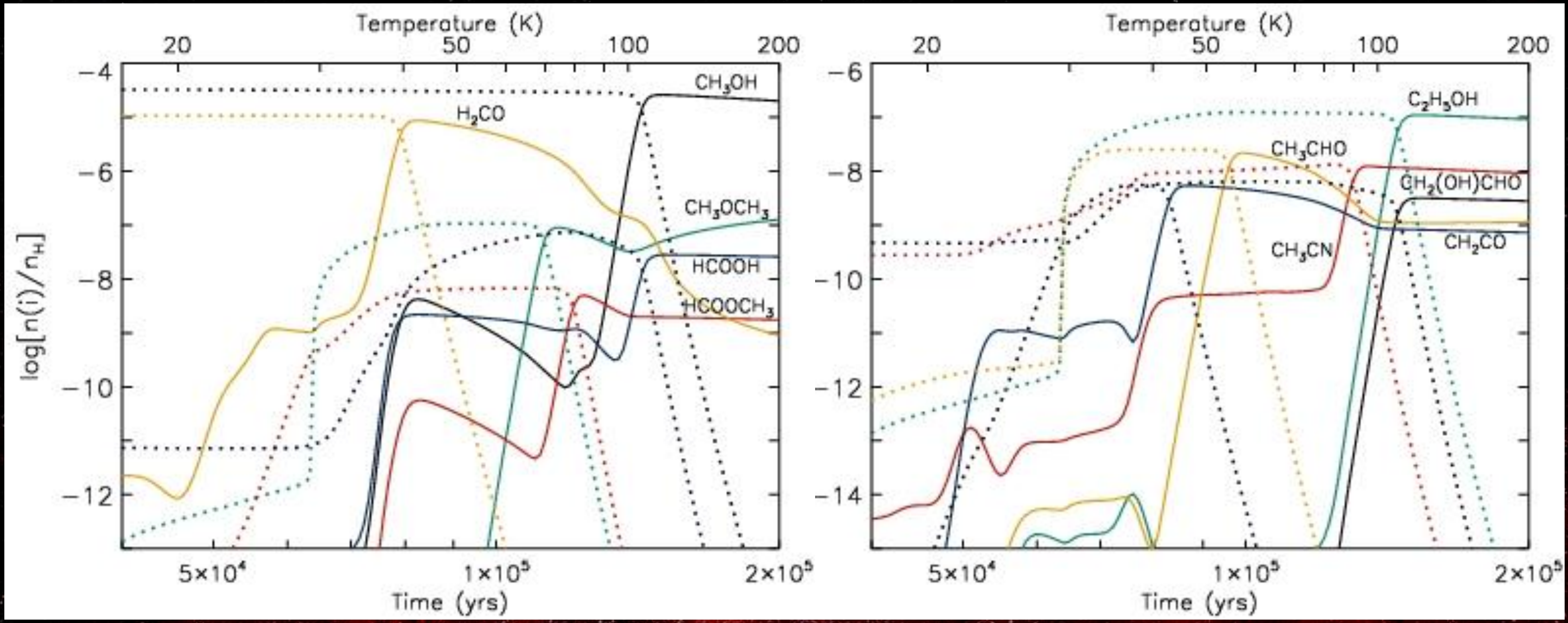
Urea tentatively detected in Sgr B2(N)

Predicted by Garrod et al. (2008) model

Chemical models can play unique role in forming observing strategies



Warm, extended molecules



Garrod et al. 2008

- Observations: low rotational temps (<<100 K) for H_2CO, HCOOH, CH_3CHO, … (e.g. Bisschop et al. 2006)
- Models: caused by differential evaporation – various binding energies
- How extended are these molecules?
- Gas-grain interactions are complex…

Heterodyne array observations with CCAT

- 16, 32, … element arrays are available or being developed
- Multiple, broadband spectra in a single ‘stamp’
- Characterize chemistry over wide range of wavelengths
  - necessary for chemically complex sources with many lines
- Catch the flux that ALMA misses
- Take spectra from multiple and/or extended sources
- Broad, deep searches for new molecules more likely to be successful

Mysteriously cold, extended molecules

- Glycolaldehyde – $HCOCH_2OH$
  (Sgr B2N, Hollis et al. 2004)
- Ethylene glycol – $(CH_2OH)_2$
  (Sgr B2N, Hollis et al. 2002)
- Methyl formate – $HCOOCH_3$
  (Low-mass Protostar B1-b, Öberg et al. 2010)

$T_{rot} \sim 10$ K?

How are they formed at low temps?
How do they get off grains?
Why are some so extended? (~1 arcmin in Sgr B2)

Broad deep searches with new arrays of wideband spectrometers…

Galactic Center molecular clouds

M. A. Requena-Torres et al.: Organic molecules in the GC

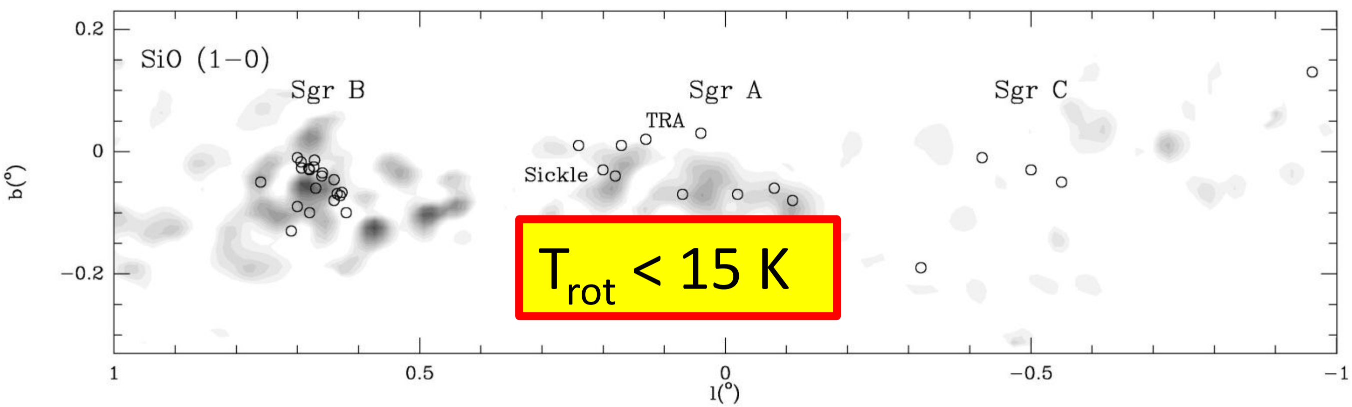
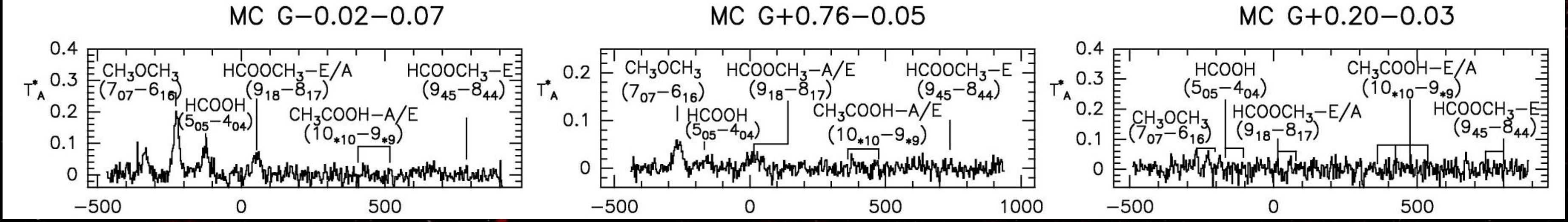


Fig. 1. Position of the observed sources superimposed on the SiO $J = 1 \rightarrow 0$ maps from the GC region by (Martín-Pintado et al. 1997).

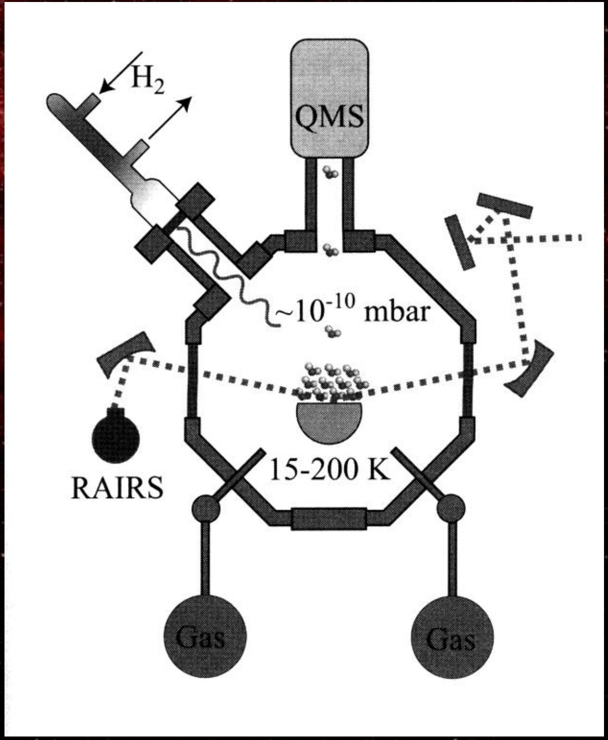
Requena-Torres et al., 2006



Laboratory ice photochemistry experiments
(Öberg, Garrod, van Dishoeck & Linnartz, 2009)

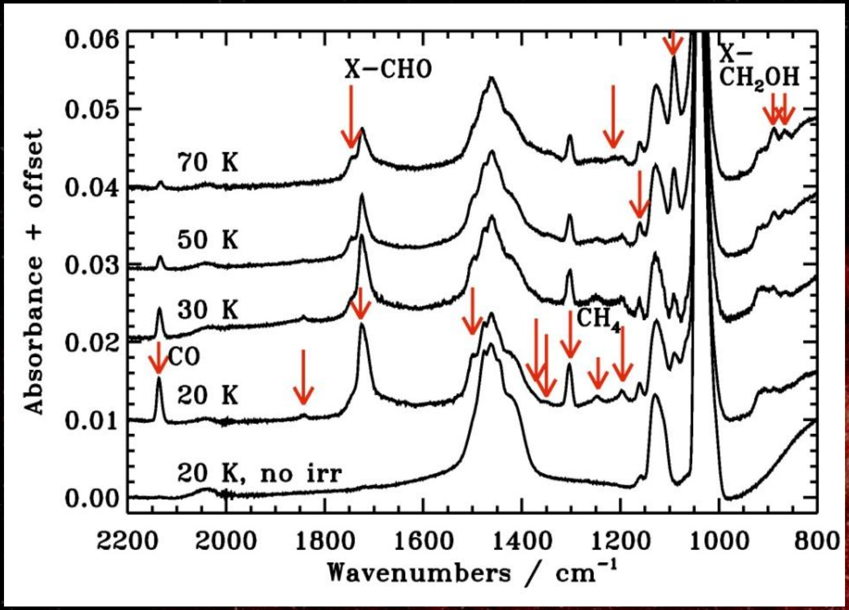
- Deposit ~20 monolayers of CH_3OH onto gold substrate, under UHV
- Range of temperatures 20 – 70 K
- Irradiate with UV lamp (7 – 10.5 eV) to produce photolysis, for ~5 hrs
- UV flux is ~10^5 x ISRF
- Conduct RAIRS spectroscopy throughout process
- Identify unique bands with molecules:

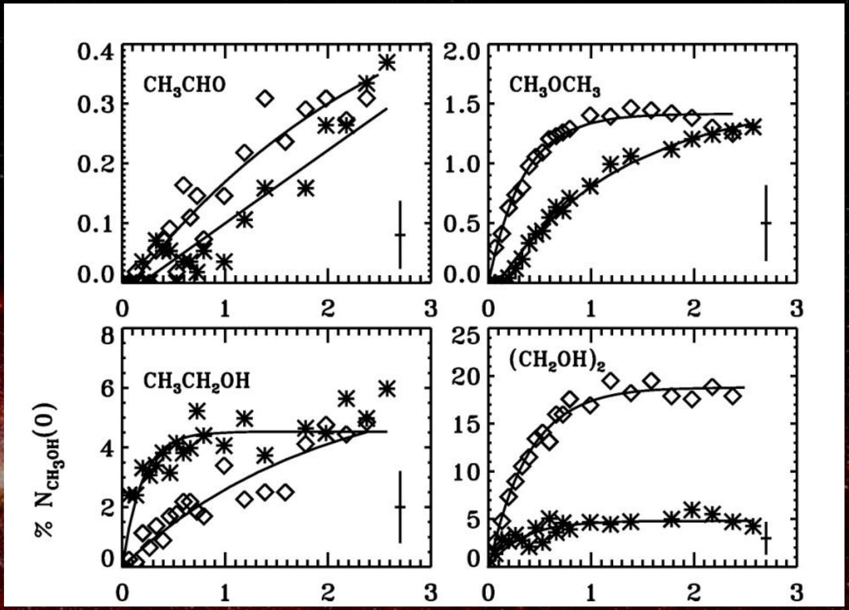
CH_3OH, H_2O, CO, HCO, H_2CO, CH_2OH, CO_2, CH_4, C_2H_6, CH_3CHO, CH_3OCH_3, CH_3CH_2OH, $HCOOCH_3$, HCOOH, CH_3COOH, $HCOCH_2OH$, $HOCH_2CH_2OH$



CRYOPAD setup, Leiden (courtesy K. Öberg)

Experimental ice spectra + models





Stars = 20 K
Diamonds = 70 K

Model fits IN PROGRESS!!!
(Garrod & Öberg, in prep.)

Use models to:

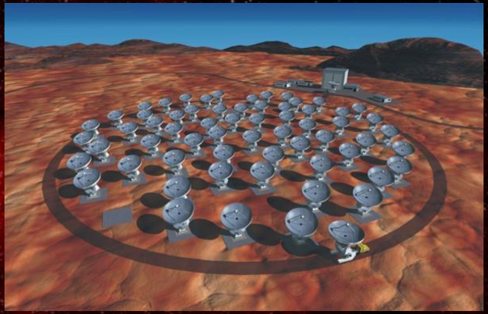
- Derive physical/chemical parameters of ice
- Directly extrapolate to ISM
- Make predictions for new detections

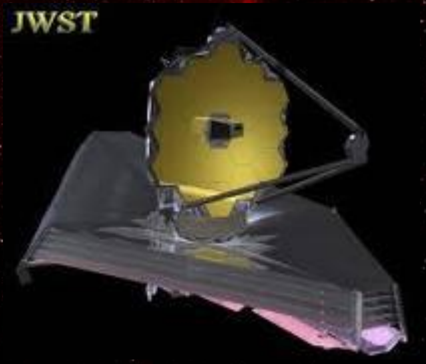
Synergies with ALMA, JWST

- ALMA for hot, compact species
- CCAT for extended spatial structure of hot core molecules
- Spectra from multiple sources
- Explore molecular evolution in molecular clouds during earlier stages of star-formation
- Chemical models being developed to take more comprehensive approach to gas-grain interactions

  $\rightarrow$ Guide spectroscopy & observational searches
- Chemical models can tie together infrared ice observations and sub-mm/mm gas-phase spectra

  - synergies between CCAT, ALMA, JWST, …





Summary of pre-biotic possibilities with CCAT

- Search for new molecules
- Characterize physical conditions in extended regions – Galactic Center
- Characterize gas-grain interactions
- Examine mysterious "cold" complex molecules
- Understand deuteration of complex molecules
- Build picture of star formation on multiple spatial scales
- Use chemical models to create synergies between CCAT, ALMA, JWST
- Build picture of the lifecycle of interstellar molecules and dust-grain ices