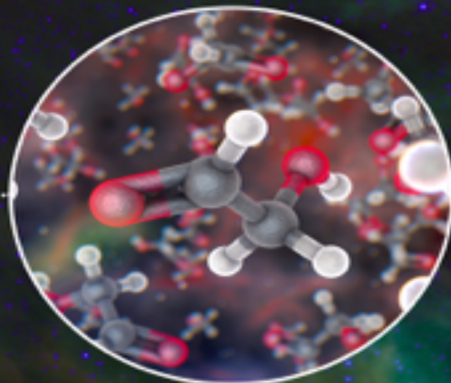

Understanding the formation of astrobiological molecules in star-forming regions

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September 15 2015, “Life in a cosmic context”, Trieste, Italy

Maite Beltrán, Riccardo Cesaroni, Claudio Codella, Francesco Fontani, Paul Woods, Serena Viti, Paola Caselli, Anton Vasyunin, Hannah Calcutt

Image credit: ALMA (ESO/NAOJ/NRAO)/L. Calçada (ESO) & NASA/JPL-Caltech/WISE Team

A new science:

ASTRO-BIOLOGY

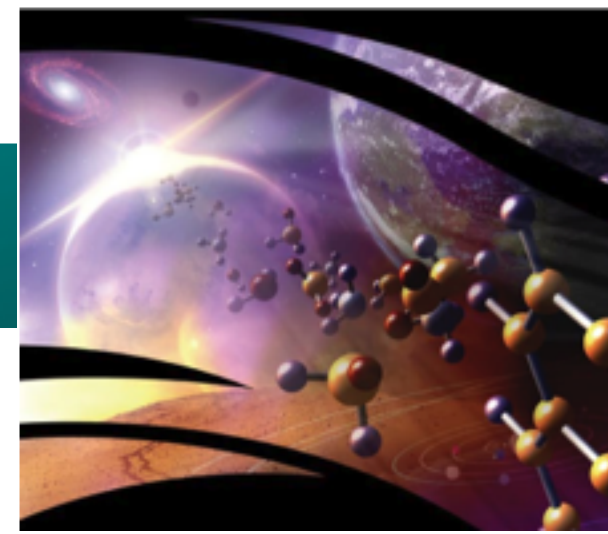
The science of LIFE

- **Origin of life on Earth?**
- **Is the life we know a unique event in the universe?**

5th Workshop of the Italian Astrobiology Society

Life in a Cosmic Context

15-17 September 2015, Trieste, Italy



ASTRONOMY

- Astrophysics & Astrochemistry

+ geology, ecology, planetary science…

Origin of life?

Spontaneous generation on Early Earth?

Delivery of extraterrestrial material through e.g. meteorites?

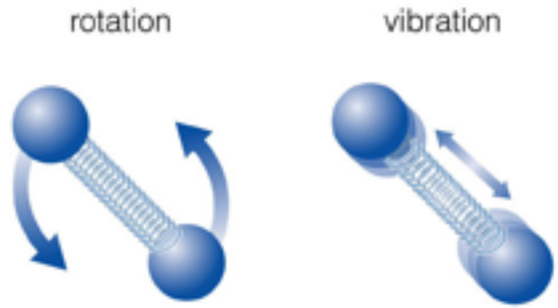
Search for organic molecules in space

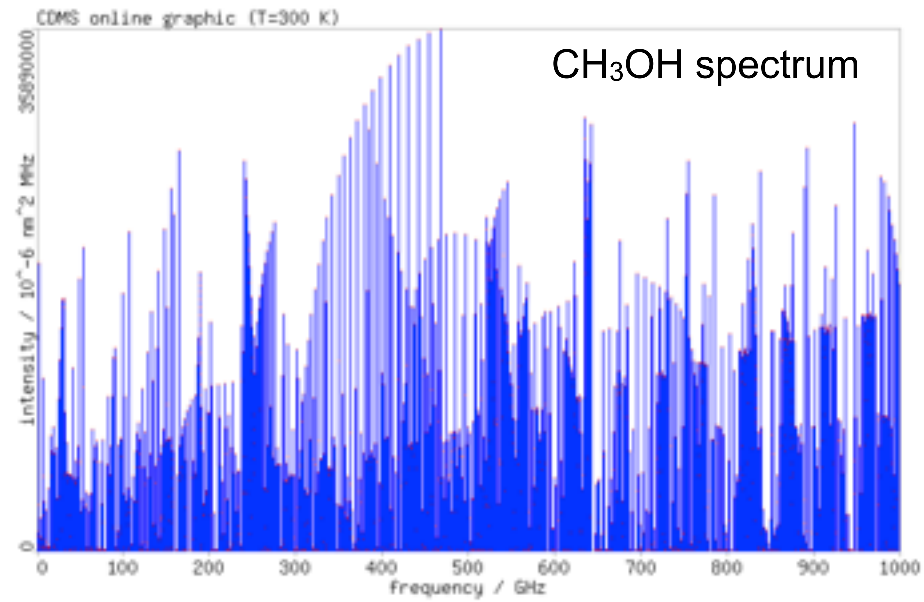
The building blocks of life

How do we detect molecules?

The fingerprints of interstellar molecules

• When molecules vibrate and rotate emit photons in the radio and (sub)millimeter spectrum.





• Each molecule produce a unique spectrum.


ALMA radiotelescopes (Chile)

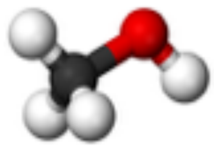
• Ground based and space telescopes are able to detect these photons.

IDENTIFICATION OF COMPLEX ORGANIC MOLECULES IN THE SPACE

Detection of "complex" organic molecules (COMs)

Species	Name	Source	Species	Name
Hydrocarbons			**N-Containing**	
C_2H_4	Ethene	circ	CH_3CN	Acetonitrile
HC_4H	Butadiyne	circ	CH_3NC	Methylisocyanide
H_2C_4	Butatrienylidene	circ, cc, lc	CH_2CNH	Keteneimine
C_5H	Pentadiynyl	circ, cc	HC_3NH^+	Prot. cyanoacetylene
CH_3C_2H	Propyne	cc, lc	C_5N	Cyanobutadiynyl
C_6H	Hexatriynyl	circ, cc, lc	HC_4N	Cyanopropynylidene
C_6H^-	Hexatriynyl ion	circ, cc, lc	CH_3NH_2	Methylamine
H_2C_6	Hexapentaenylidene	circ, cc, lc	C_2H_3CN	Vinylcyanide
HC_6H	Triacetylene	circ	HC_5N	Cyanodiacetylene
C_7H	Heptatriynyl	circ, cc	CH_3C_3N	Methylcyanoacetylene
CH_3C_4H	Methyldiacetylene	cc	CH_2CCHCN	Cyanoallene
CH_3CHCH_2	Propylene	cc	NH_2CH_2CN	Aminoacetonitrile
C_8H	Octatetraynyl	circ, cc	HC_7N	Cyanotriacetylene
C_8H^-	Octatetraynyl ion	circ, cc	C_2H_5CN	Propionitrile
CH_3C_6H	Methyltriacetylene	cc	CH_3C_5N	Methylcyanodiacetylene
C_6H_6	Benzene	circ	HC_9N	Cyanotetraacetylene
O-Containing			C_3H_7CN	N-propyl cyanide
CH_3OH	Methanol	cc, hc, gc, of	$HC_{11}N$	Cyanopentaacetylene
HC_2CHO	Propynal	hc, gc	**S-Containing**	
c-C_3H_2O	Cyclopropenone	gc	CH_3SH	Methyl mercaptan
CH_3CHO	Acetaldehyde	cc, hc, gc	**N,O-Containing**	
C_2H_3OH	Vinyl alcohol	hc	NH_2CHO	Formamide
c-CH_2OCH_2	Ethylene oxide	hc, gc	CH_3CONH_2	Acetamide
$HCOOCH_3$	Methyl formate	hc, gc, of		
CH_3COOH	Acetic acid	hc, gc		
$HOCH_2CHO$	Glycolaldehyde	hc, gc		
C_2H_3CHO	Propenal	hc, gc		
C_2H_5OH	Ethanol	hc, of		
CH_3OCH_3	Methyl ether	hc, gc		
CH_3COCH_3	Acetone	hc		
$HOCH_2CH_2OH$	Ethylene glycol	hc, gc		
C_2H_5CHO	Propanal	hc, gc		
$HCOOC_2H_5$	Ethyl formate	hc		

First detections of "COMs" in space (1970):



CH_3OH (Methanol)

> 150 molecules detected
> 50 with 6 or more atoms

Herbst & van Dishoeck (2009)

Where do we look?

Cold molecular clouds
(without star formation)

Star-forming regions
- **Galactic Center (extreme conditions)**
- **Hot cores (massive stars)**
- **Hot corinos (sun-like stars)**

Viti´s & Ceccarellis´s talks

Circumstellar disks and molecular outflows

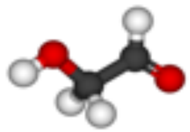
Podio´s & Codella´s talks


Comets and meteorites ("in situ")

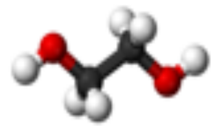
OPEN QUESTIONS:

- Do they share the same molecular abundances?
- Is the chemistry similar despite of the different environments?

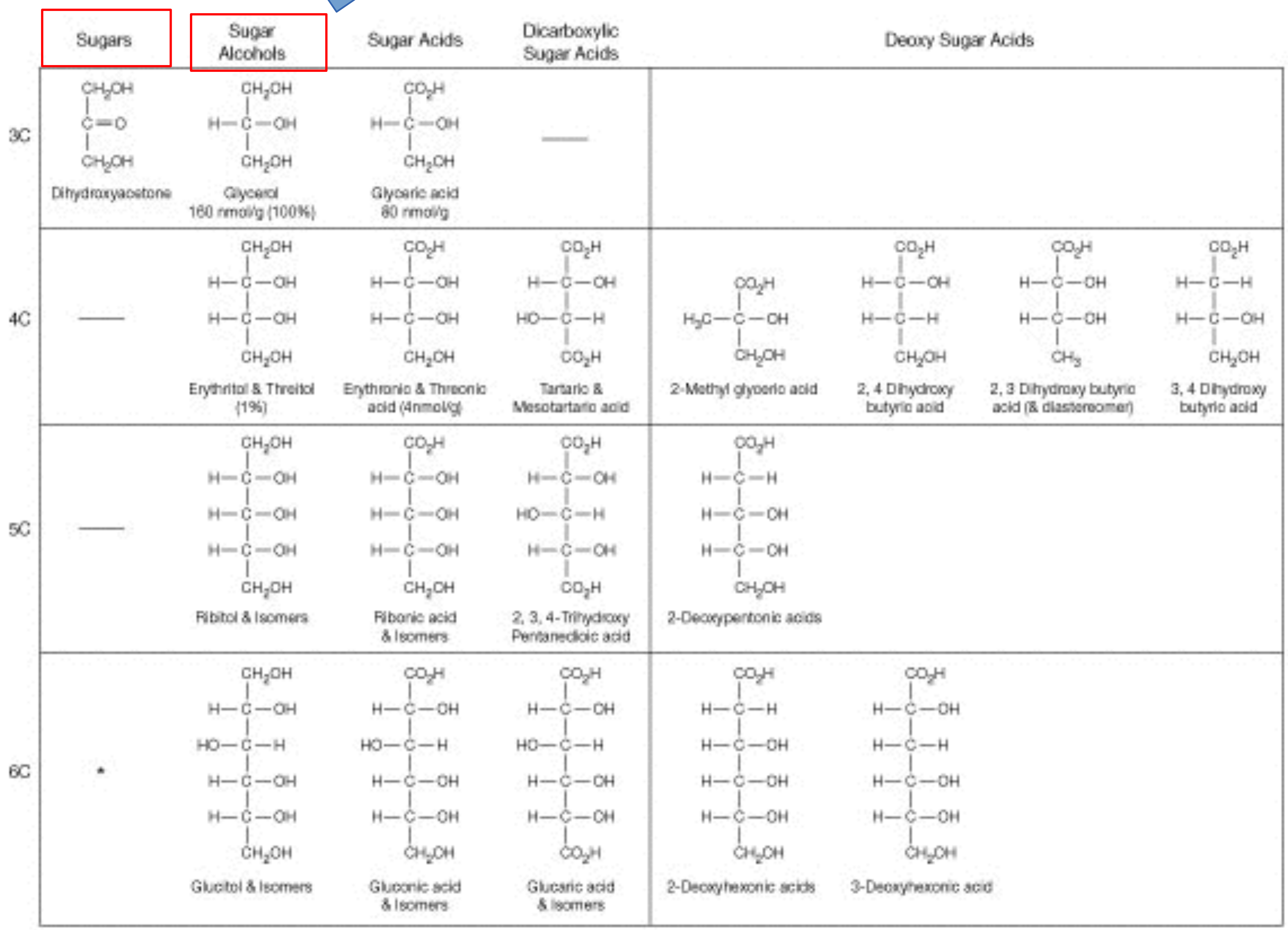
Let´s start by “the simplest complex”…



Glycolaldehyde (CH_2OHCHO)



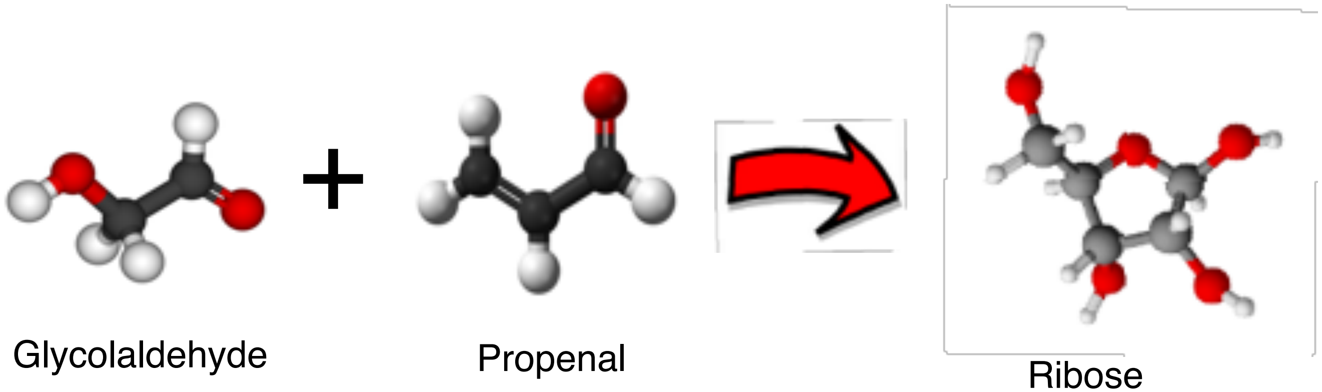
Ethylene glycol $(CH_2OH)_2$



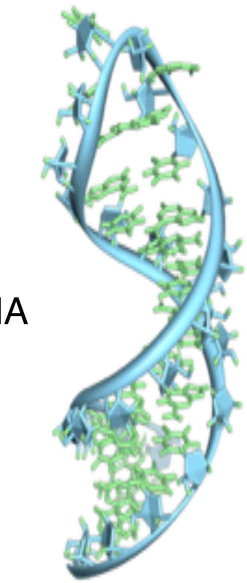
Complex organic molecules detected in the Murchinson meteorite “in situ” (Cooper+01, Nature)

Glycolaldehyde (GA) (CH_2OHCHO)

- It is the simplest *sugar*.
- It can react with propenal (3-carbon sugar) to produce ribose, the central constituent of RNA.

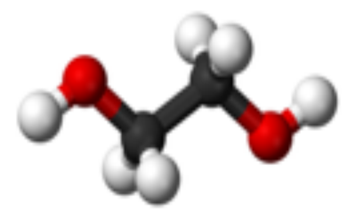


RNA



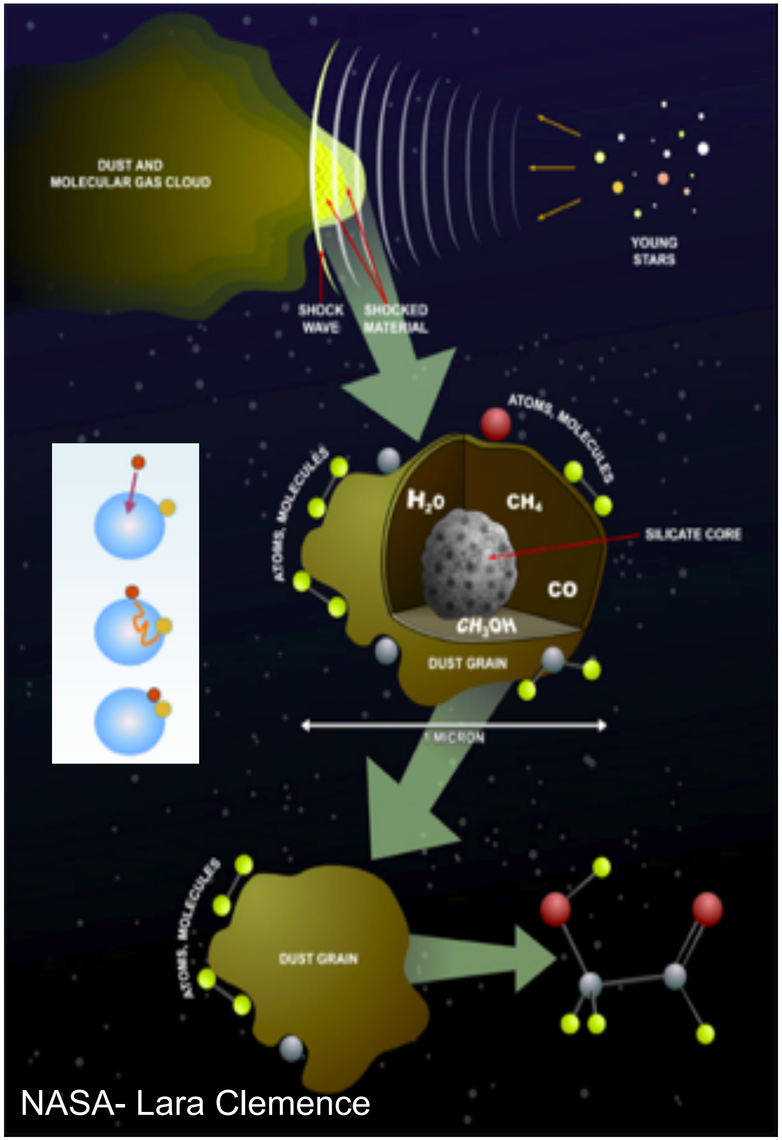
Ethylene glycol (EG) ($(CH_2OH)_2$)

- It is the simplest *sugar alcohol* (sugar + hydrogen atoms)
- It is the reduced alcohol of glycolaldehyde



Important role in interstellar prebiotic chemistry associated with sugar synthesis

Hot molecular cores: a perfect laboratory for astrochemistry



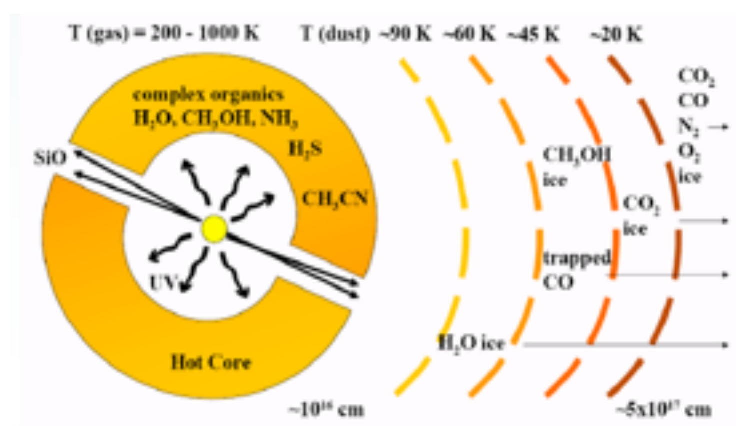
NASA- Lara Clemence

- Molecular environment surrounding massive stars ($M > 8\ M_{sun}$)
- The radiation from the star evaporates the complex molecules molecules from the grain mantles.
- Very rich chemistry.

OUR TARGET: G31.41+0.31 HOT CORE

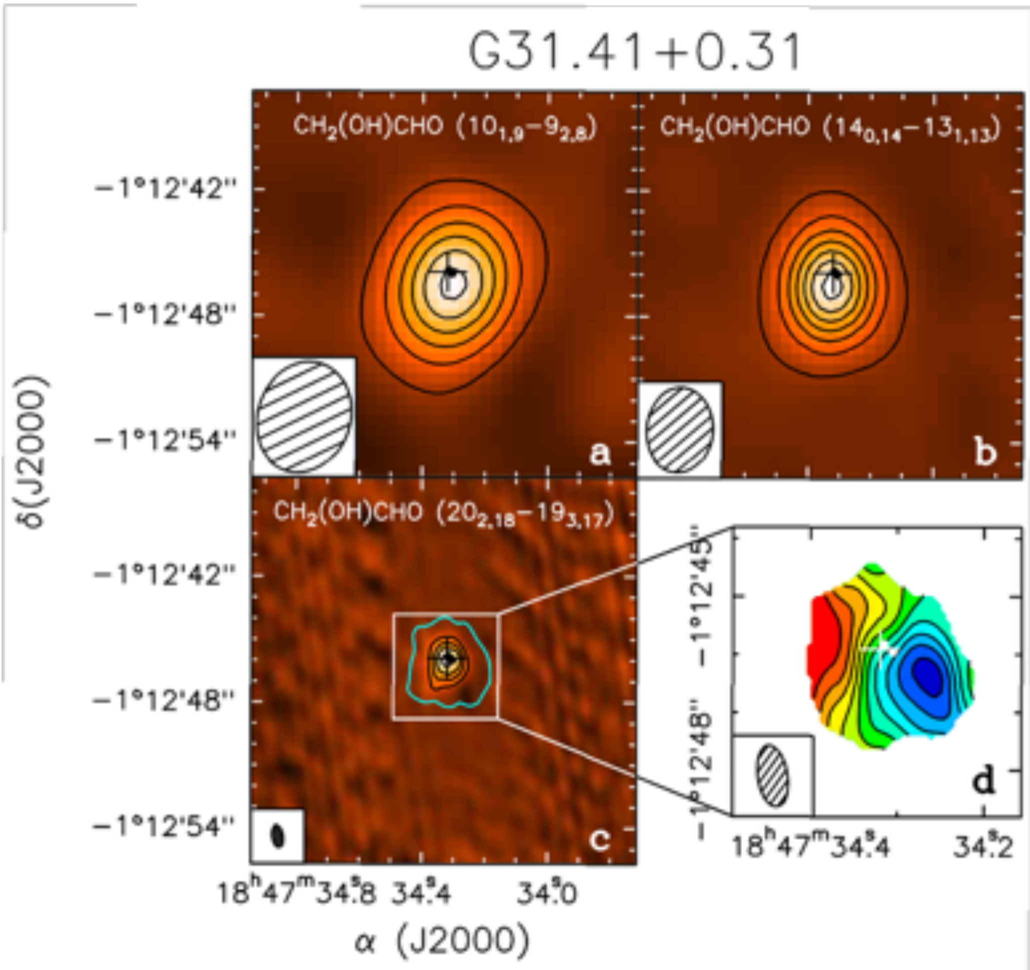
Complex molecules already detected:
CH_3OH, CH_3CN, CH_3CHO, C_2H_5OH, C_2H_5CN, $HCOOCH_3$, CH_3OCHO, CH_3COCH_3... (e.g. Fontani+07, Beltrán+09)

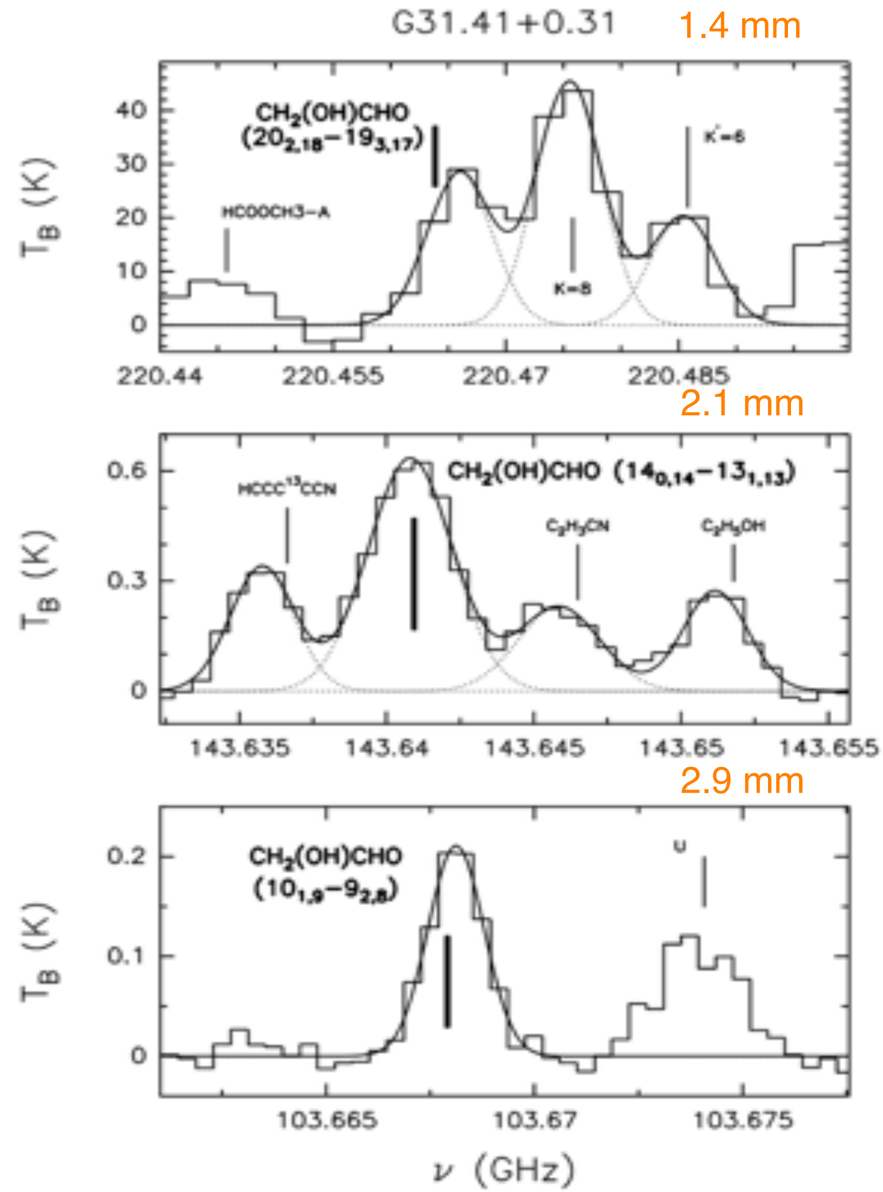
Good candidate for the detection of GA and EG



Detection of glycolaldehyde in G31

- First detection outside the Galactic Center by Beltrán et al. (2009)

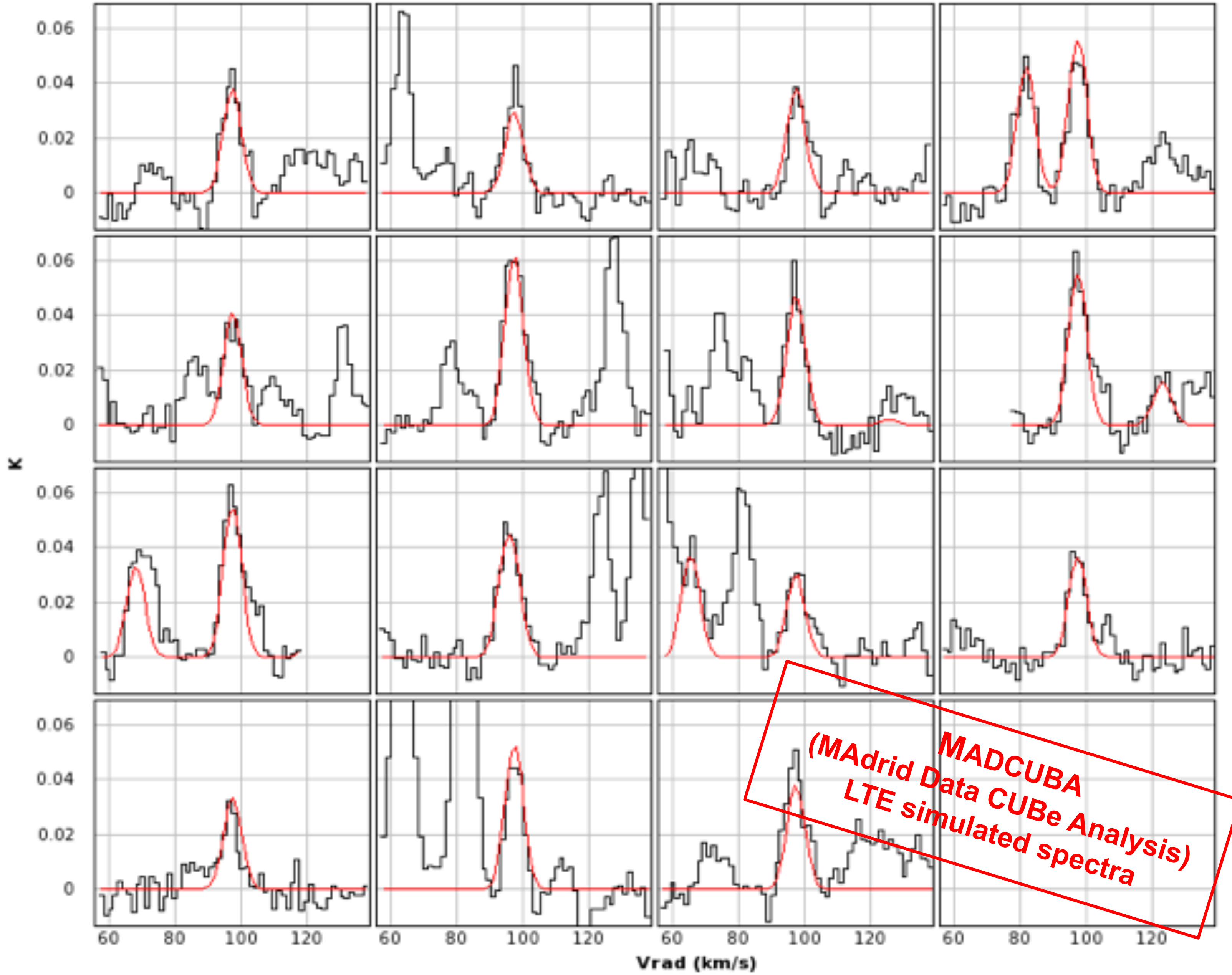




Beltrán+09

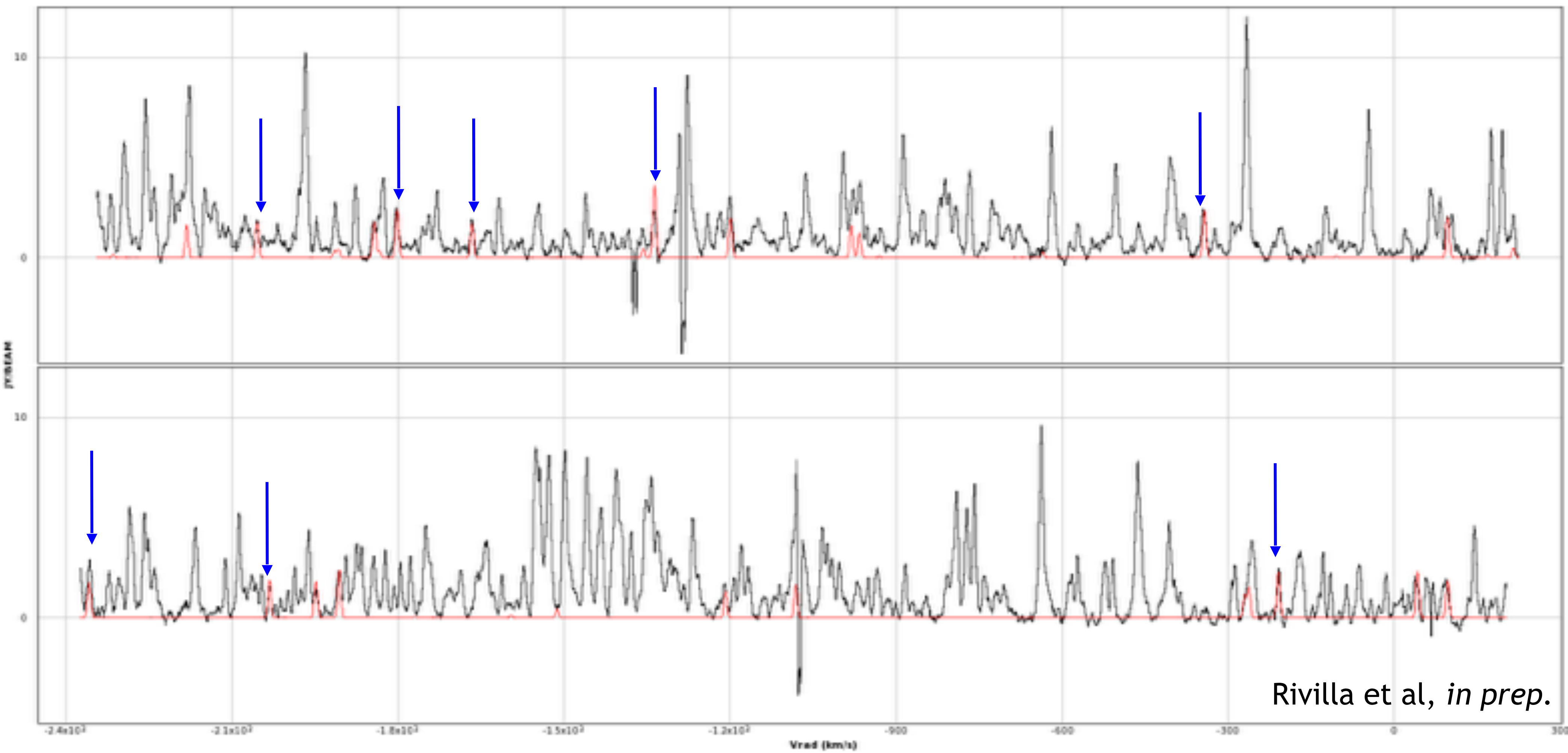
Detection of ethylene glycol in G31

Up to 30 “clean” (not blended) lines



Rivilla et al, *in prep.*

Detection of ethylene glycol in G31



Rivilla et al, *in prep*.

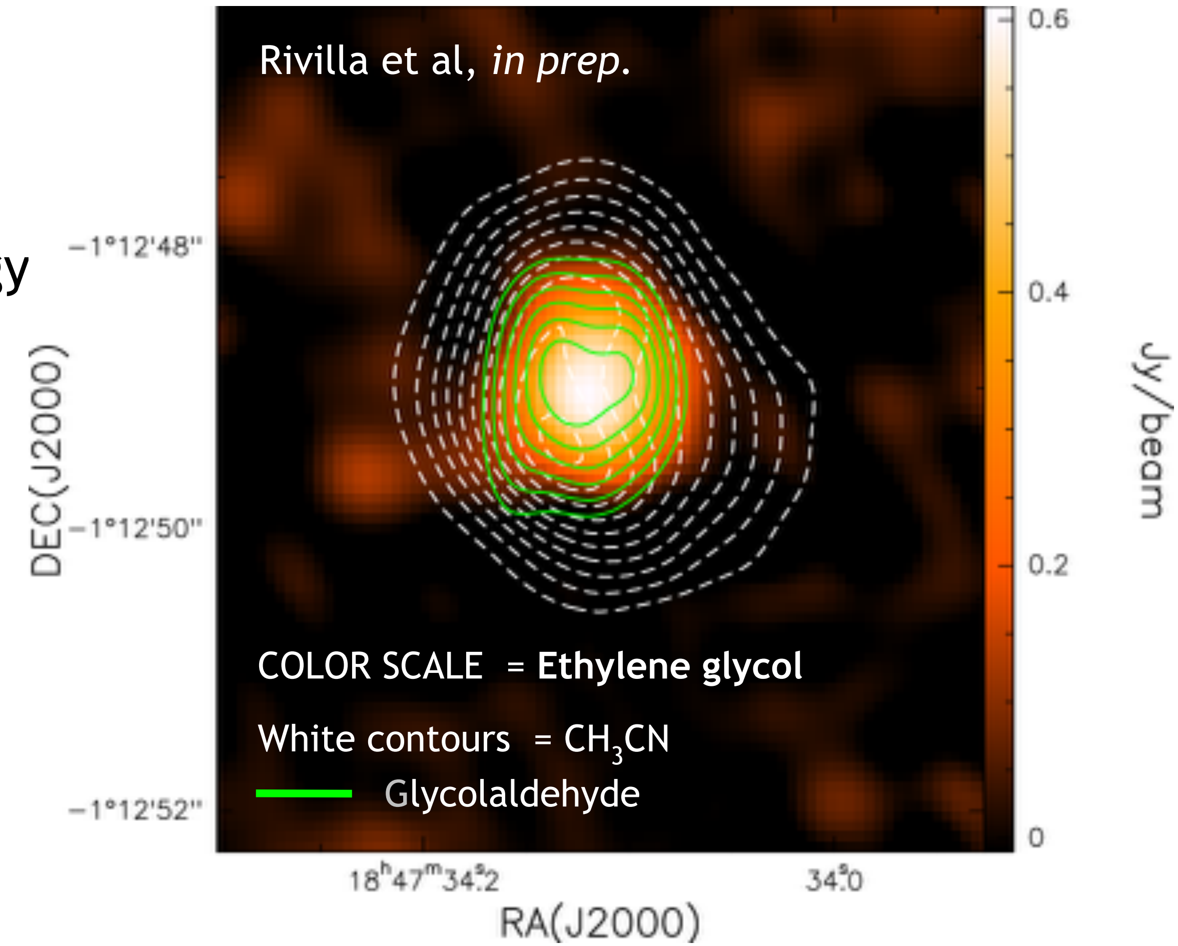
Spatial distribution of GA and EG

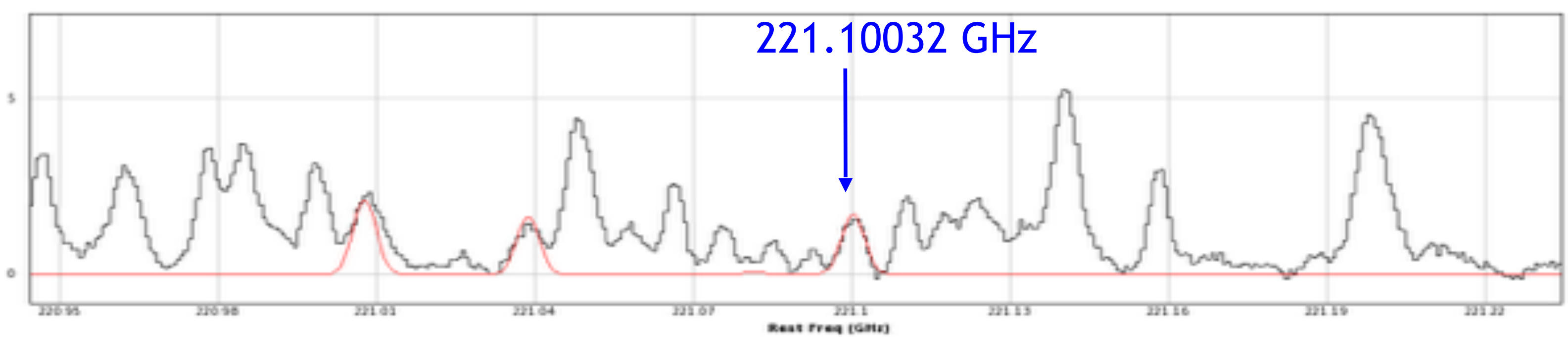
- Compact spatial distribution
- EG & GA: very similar morphology

↓

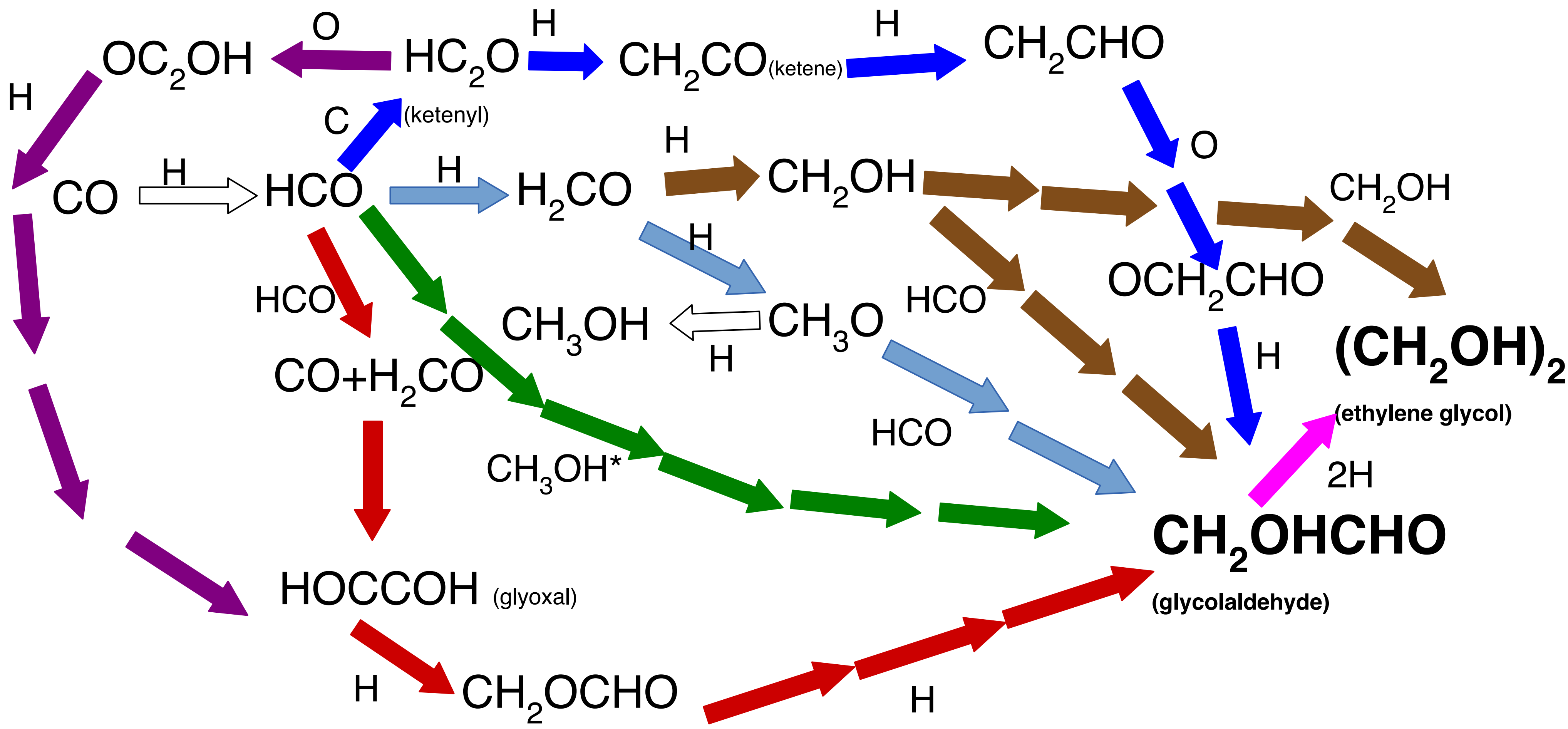
Hint of common synthesis pathway
(species chemically related)

HOW GA & EG WERE FORMED?





GAME OF REACTIONS



(F) Woods+13, Fedoseev+15

(A) Sorrell+01, Woods+12

(E) Charnley&Rogers+05

Fedoseev+15

(D) Beltrán+09,Woods+12

Charnley&Rogers+05

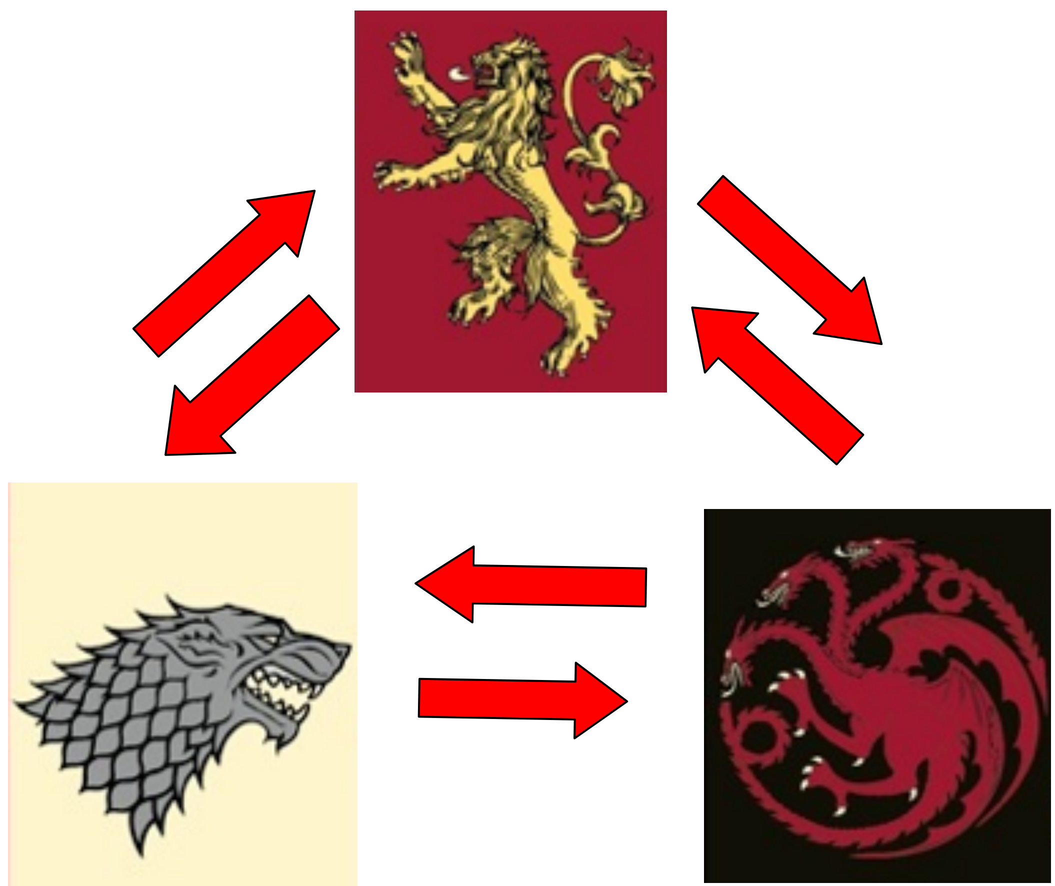
(B) Bennett&Kaisser07, Garrod+08, Butscher+15

ISTITUTO NAZIONALE DI ASTROFISICA INAF

GAME OF REACTIONS

Joint study is the only way to really understand how COMs are formed in the space

Chemical (+ physical) models



Observations

Laboratory experiments

Observations: EG/GA ratio

Source	[EG/GA]
Hale-Bopp (comet)	**>6**
Lemmon (comet)	**>3**
Lovejov (comet)	**>5**
IRAS 16293-2422	**1**
NGC 1333 IRAS2A	**5**
NGC7129 FIRS2	**2**
SgrB2N	**1.3**
G31.41+0.31	**3-5**
Orion hot core	**>10**
W51e2	**>16**
G34.3+0.2	**>6**
G-0.02, G-0.11,G+0.693	**1.2-1.6**

EG/GA is rather different between sources

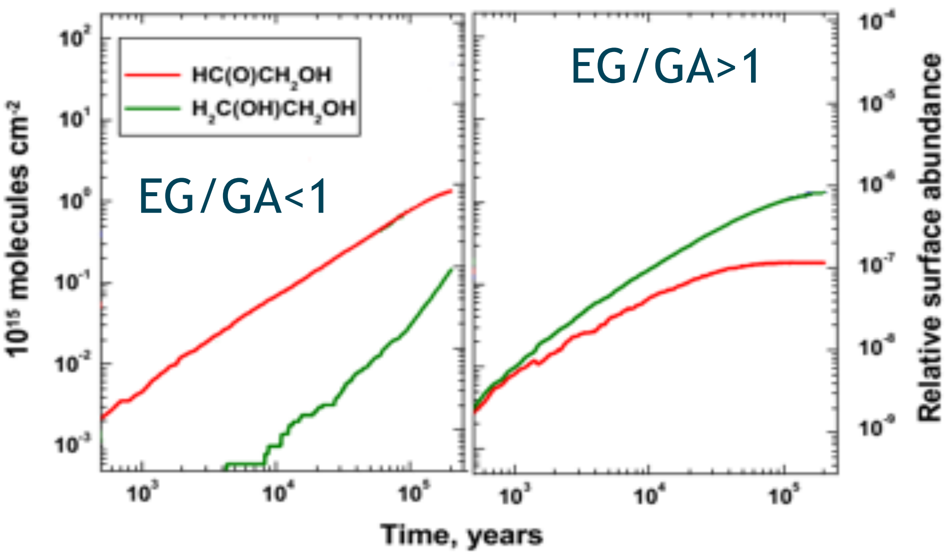
EG/GA > 1

Do the differences arise from the **origin** (the grains) or are a consequence of **subsequent evolution**?

Chemical models and laboratory: EG/GA ratio

Fedoseev+15

Different initial atom H density



Oberg+09

Different compositions of the ices

CH_3OH:CO	EG/GA
Pure CH_3OH	>10
1:10	< 0.25

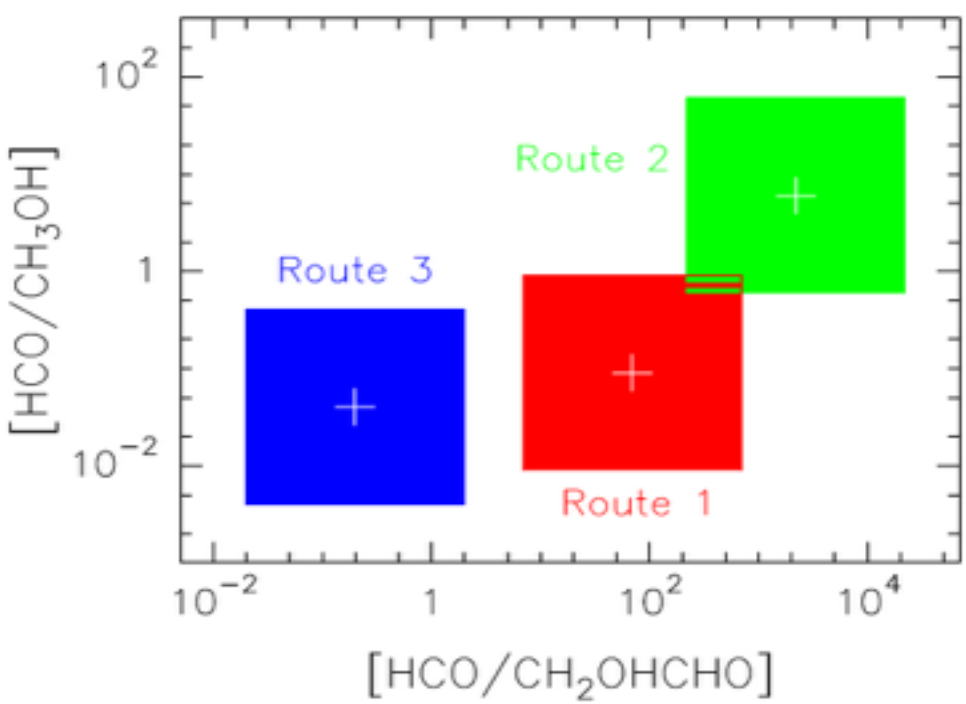
OTHER EXPLANATIONS:
- Different destruction efficiency in the gas phase?
- **Different timescales** produce different ratios (Garrod+08).

Observations & chemical models

Predictions from chemical models for the formation of glycolaldehyde (Woods+12,13):

ROUTE 1)	$CH_3OH + HCO$	$\longrightarrow$	$CH_2OHCHO + H$
ROUTE 2)	$H_2CO + HCO + H$	$\longrightarrow$	CH_2OHCHO
ROUTE 3)	$2HCO + 2H$	$\longrightarrow$	CH_2OHCHO

DIAGNOSTIC DIAGRAM (from Woods+12,13 models)



- The 3 proposed routes predict different ratios of abundances

Determination of multiple abundances ratios involving all the molecules in a complete sample of regions

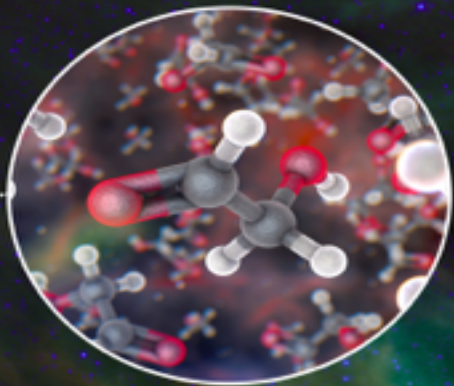


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Image credit: ALMA (ESO/NAOJ/NRAO)/L. Calçada (ESO) & NASA/JPL-Caltech/WISE Team