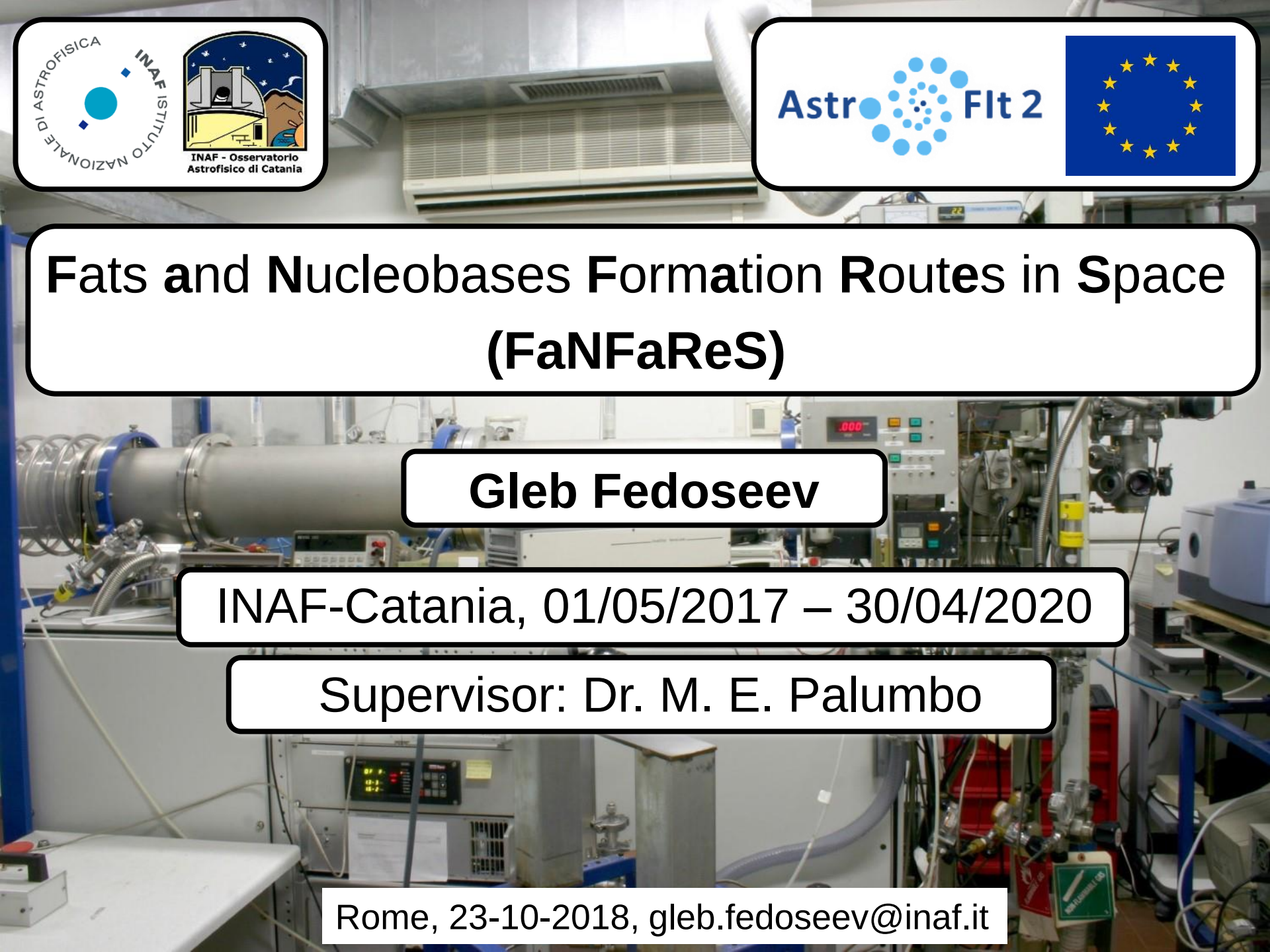


Fats **a**nd **N**ucleobases **F**orm**a**tion **R**out**e**s in **S**pace **(FaNFaReS)**

Gleb Fedoseev

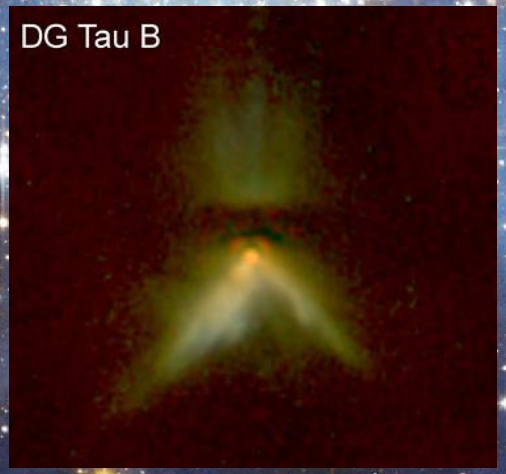
INAF-Catania, 01/05/2017 – 30/04/2020

Supervisor: Dr. M. E. Palumbo

Rome, 23-10-2018, gleb.fedoseev@inaf.it

Different Stages of Star Formation

10^5-10^6 Years



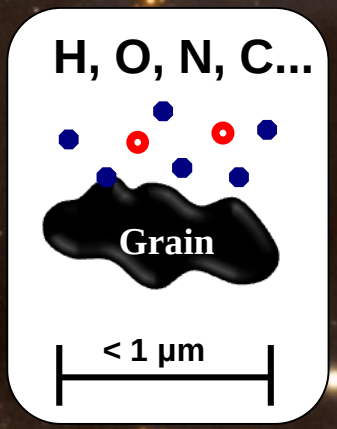
~10^7 Years

~10^9 Years

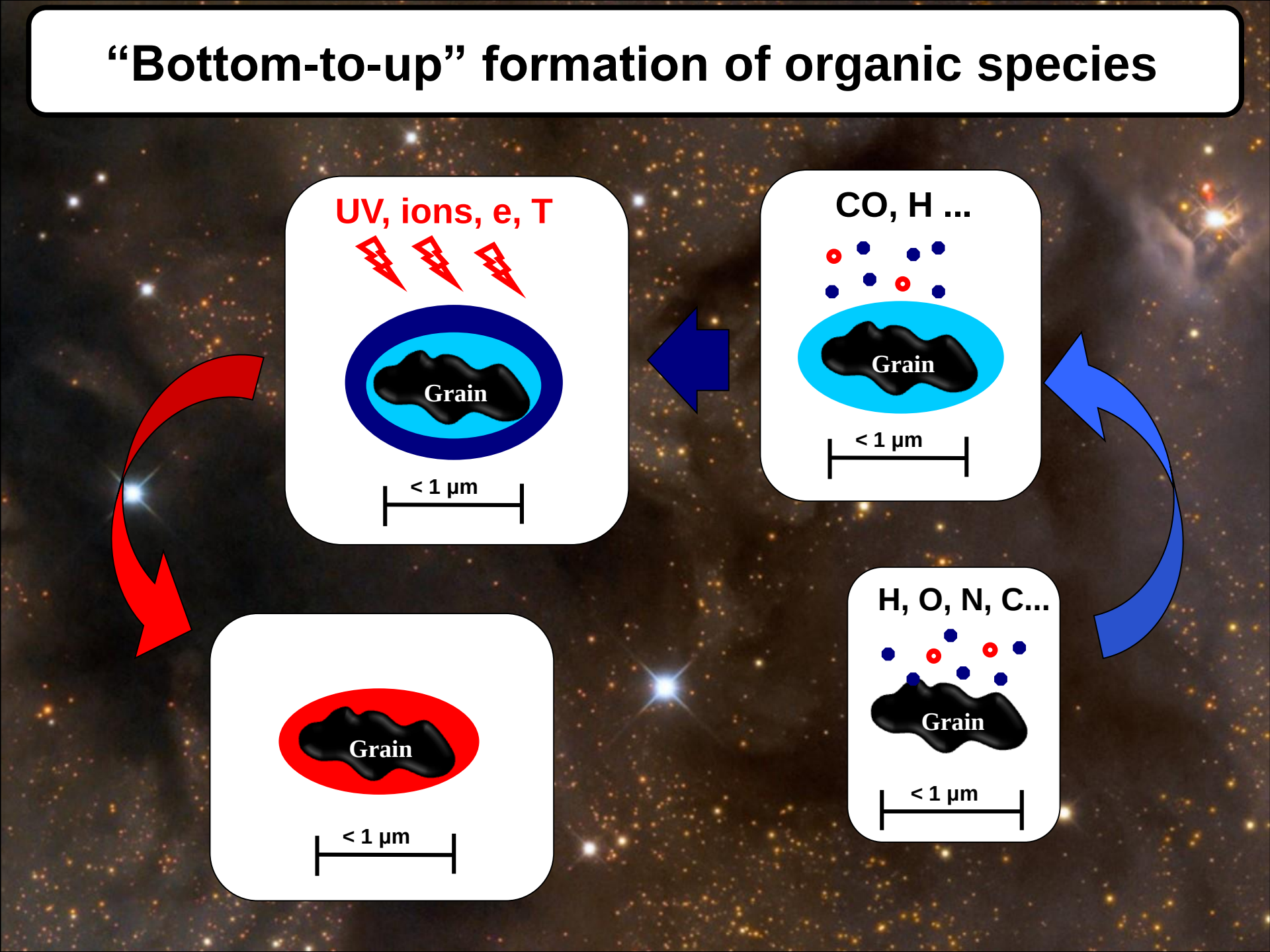
~10^{10} Years

>10^{10} Years

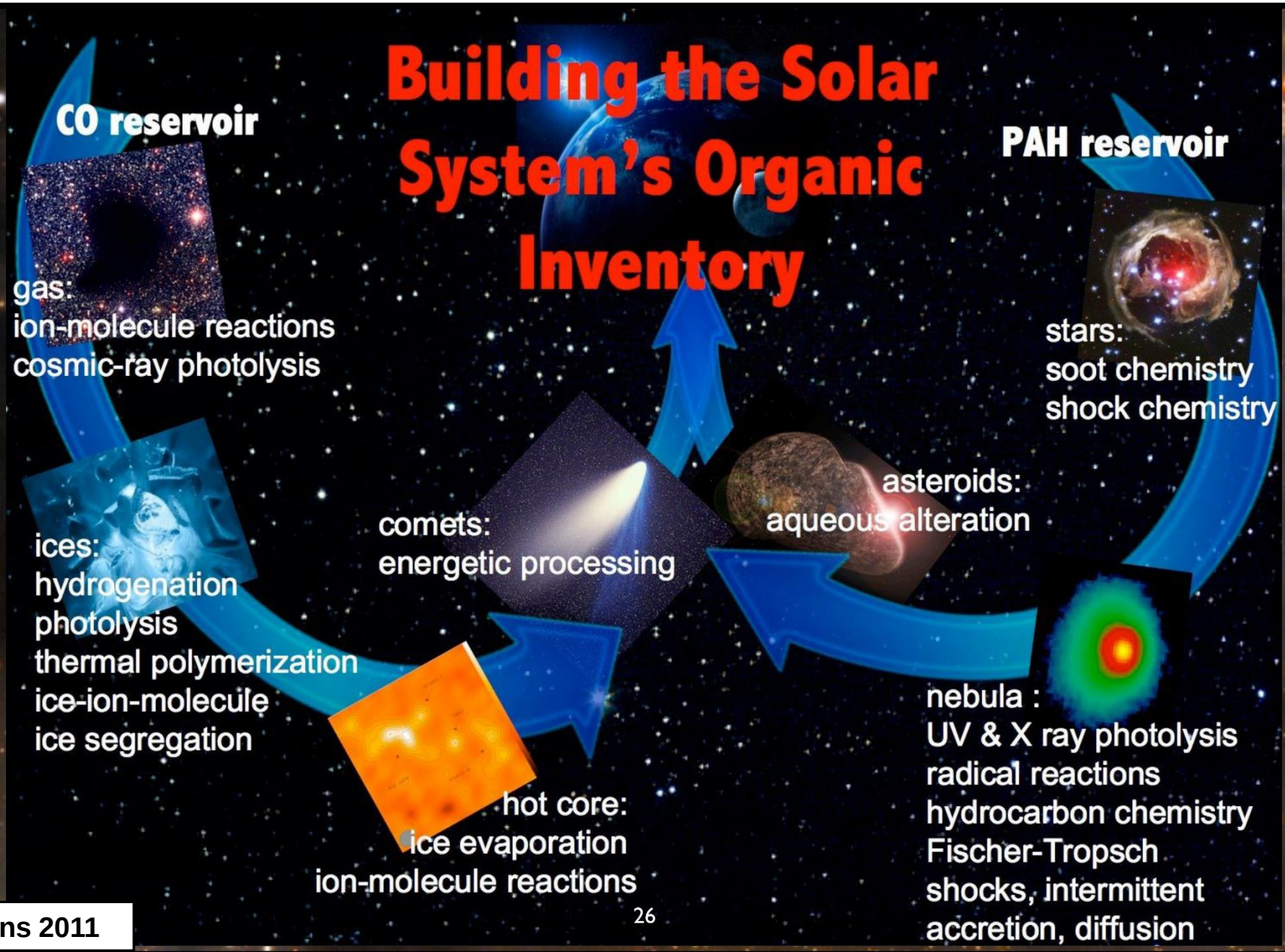
“Bottom-to-up” Formation of Organic Species



“Bottom-to-up” formation of organic species

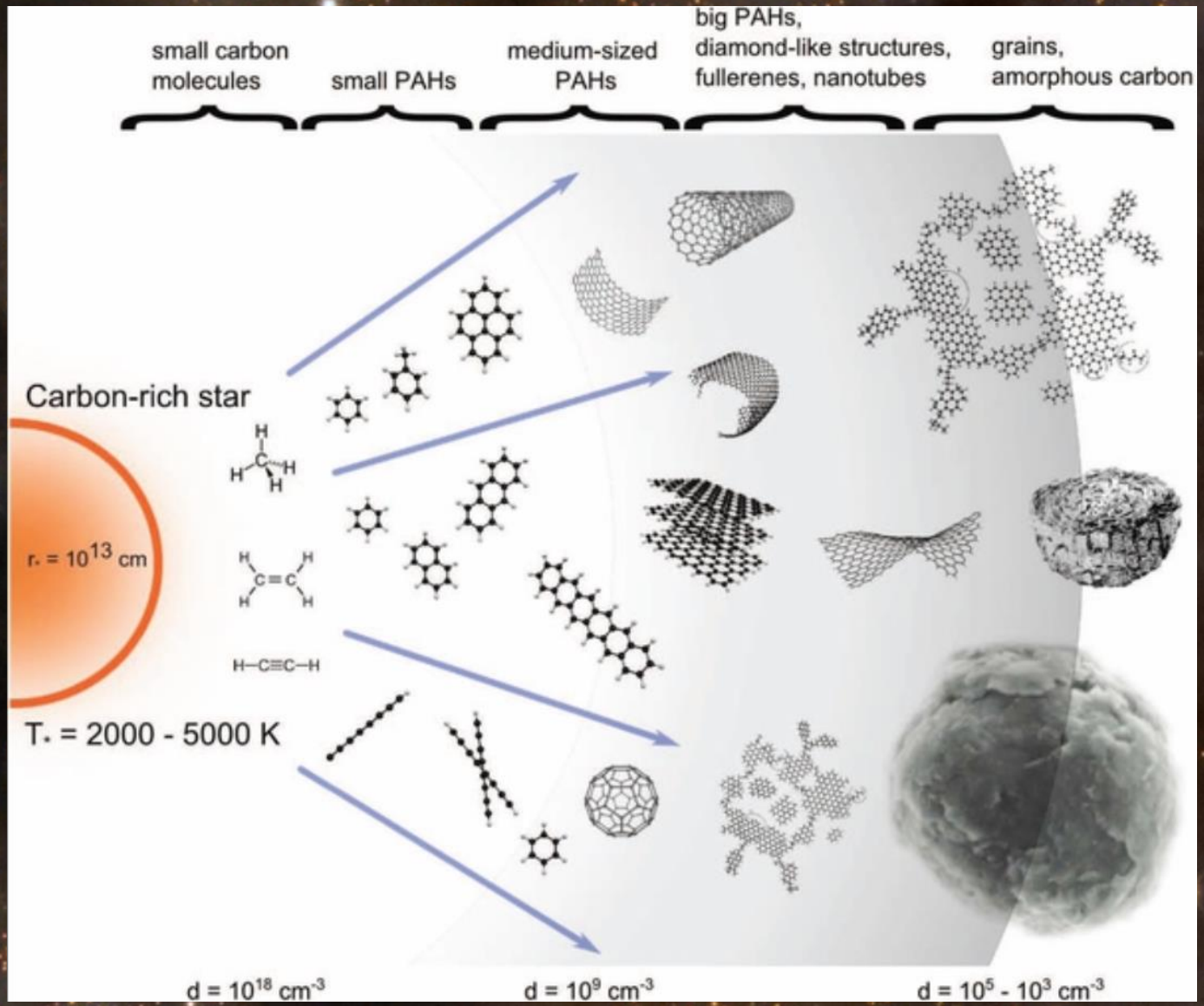


Two Sources of Organic Carbon in the ISM



Tielens 2011

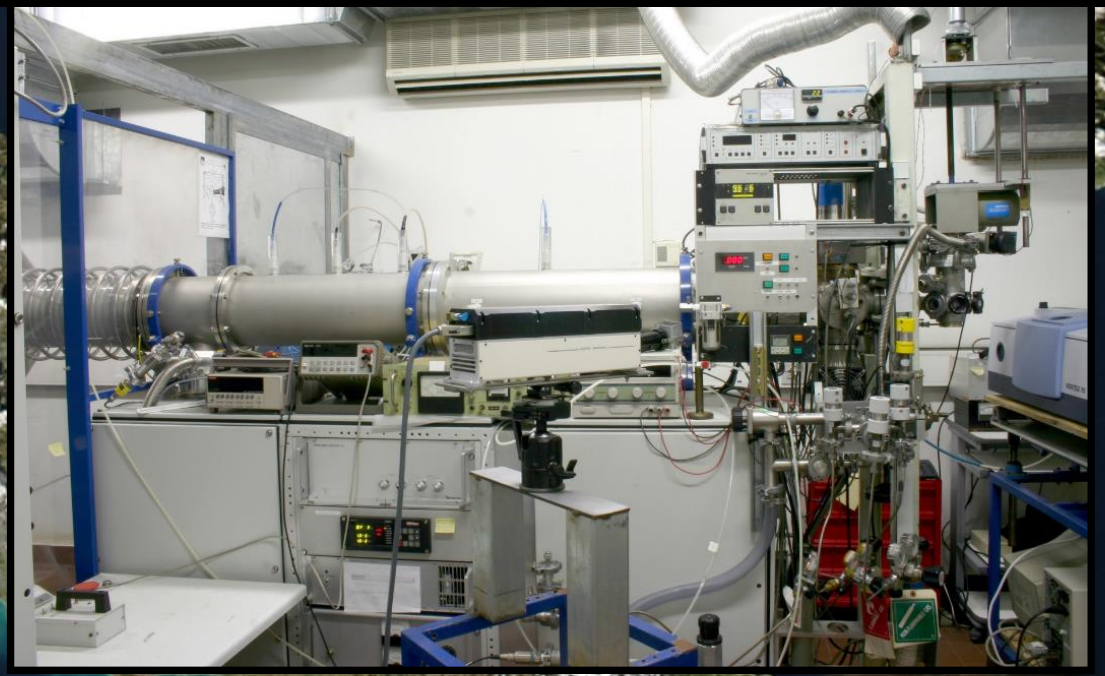
‘Up-to-bottom’ formation of COMs



Contreras & Salama, 2013

Can We Address Dark Cloud Chemistry in the Lab?

Experimental Astrophysics Laboratory (LASP)

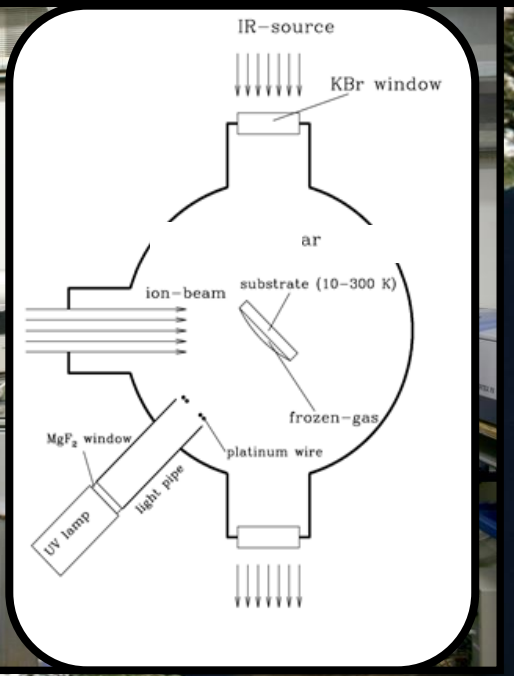


Addressing the extreme conditions of dark clouds:
Pressure: ~10^{-12} atmosphere; Temperature: as low as 15 K (-258ºC)

Strazzulla et al. 2001, Baratta et al. 2015

Can We Address Dark Cloud Chemistry in the Lab?

Experimental Astrophysics Laboratory (LASP)



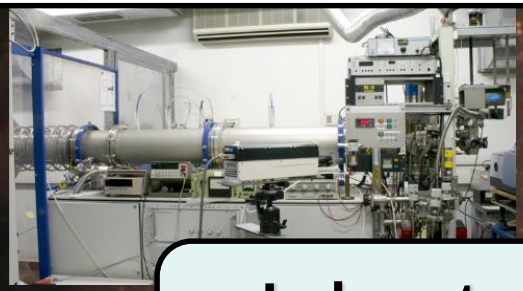
Addressing the extreme conditions of dark clouds:
Pressure: ~10^{-12} atmosphere; Temperature: as low as 15 K (-258ºC)

Utilized Analytical Techniques:
***In-situ* IR spectroscopy; Raman spectroscopy**

Strazzulla et al. 2001, Baratta et al. 2015

Fats and Nucleobases Formation Routes in Space

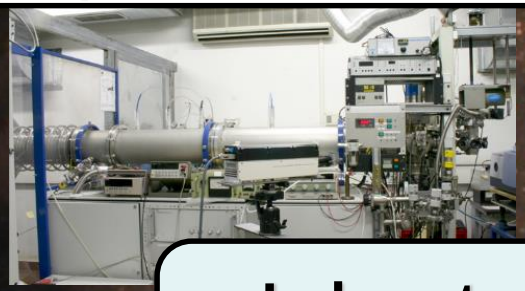
LASp, INAF – Catania, IT



Laboratory Astrophysics

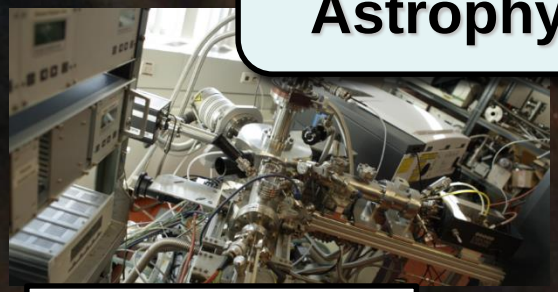
Fats **a**nd **N**ucleobases **F**orm**a**tion **R**out**e**s in **S**pace **(FaNFaReS)**

LASp, INAF – Catania, IT



LASSIE FP7 ITN

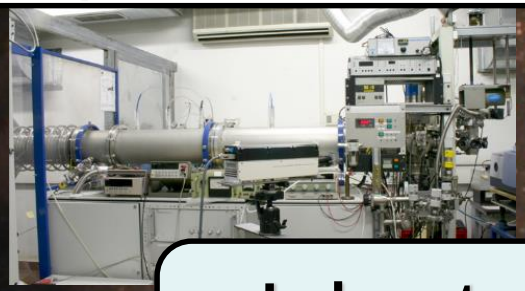
Laboratory Astrophysics



Sackler Lab, NL

Fats **a**nd **N**ucleobases **F**orm**a**tion **R**out**e**s in **S**pace **(FaNFaReS)**

LASp, INAF – Catania, IT

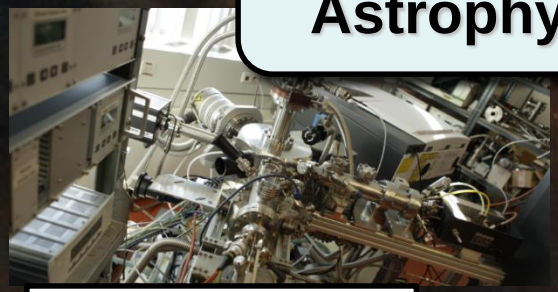


LASSIE FP7 ITN

Astrochemistry Group, Leiden Observatory, NL

Laboratory Astrophysics

Astronomical Observations

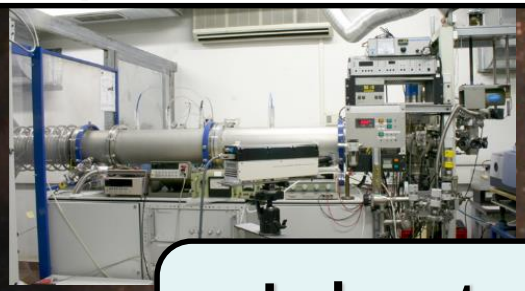


Sackler Lab, NL

Dr. Vianney Taquet, INAF – Arcetri, IT

Fats **a**nd **N**ucleobases **F**orm**a**tion **R**out**e**s in **S**pace **(FaNFaReS)**

LASp, INAF – Catania, IT

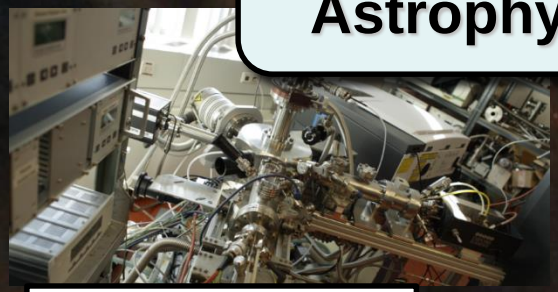


LASSIE FP7 ITN

Astrochemistry Group, Leiden Observatory, NL

Laboratory Astrophysics

Astronomical Observations



Sackler Lab, NL

Dr. Vianney Taquet, INAF – Arcetri, IT

Numerical Simulations

Dr. Thanja Lamberts, Universität Stuttgart, DE Leiden University, NL

Dr. Herma Cuppen, Radboud Univeisty, Nijmegen, NL

What is the simplest unit of life?

Oxford Dictionaries

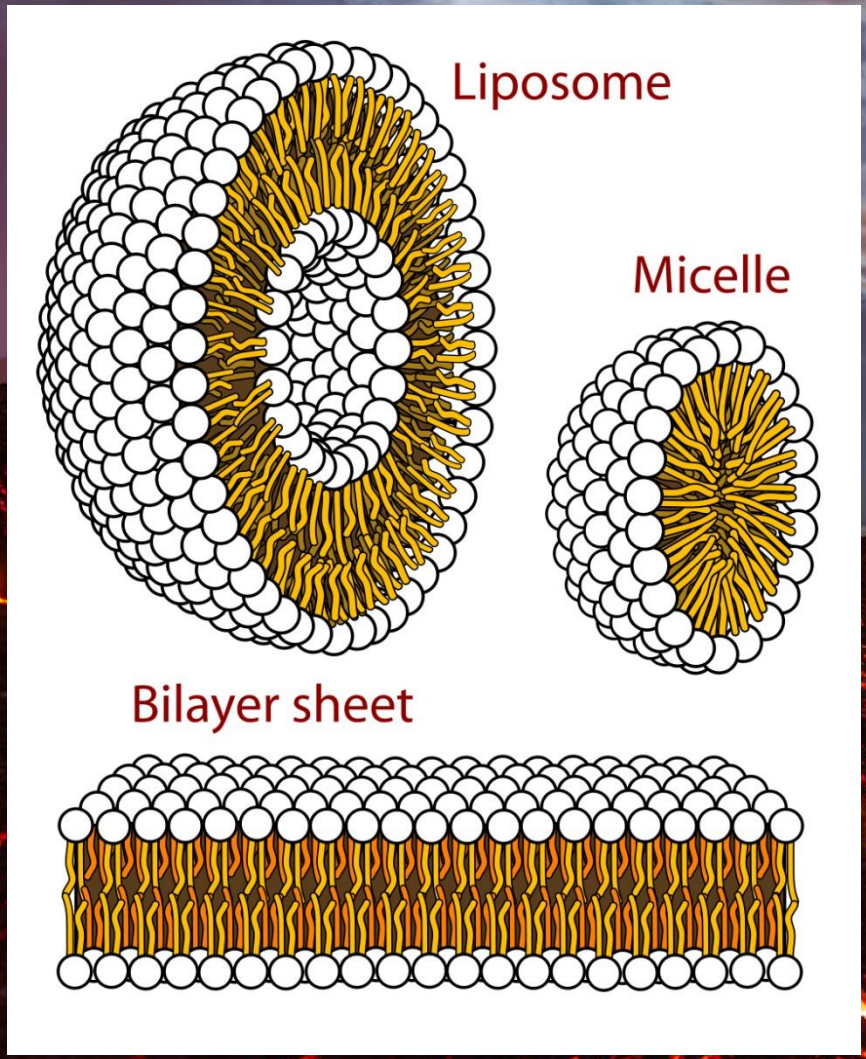
Powered by OXFORD

Cell *- The smallest structural and functional unit of an organism, which is typically microscopic and consists of cytoplasm and a nucleus enclosed in a membrane.*

ENCYCLOPÆDIA Britannica®

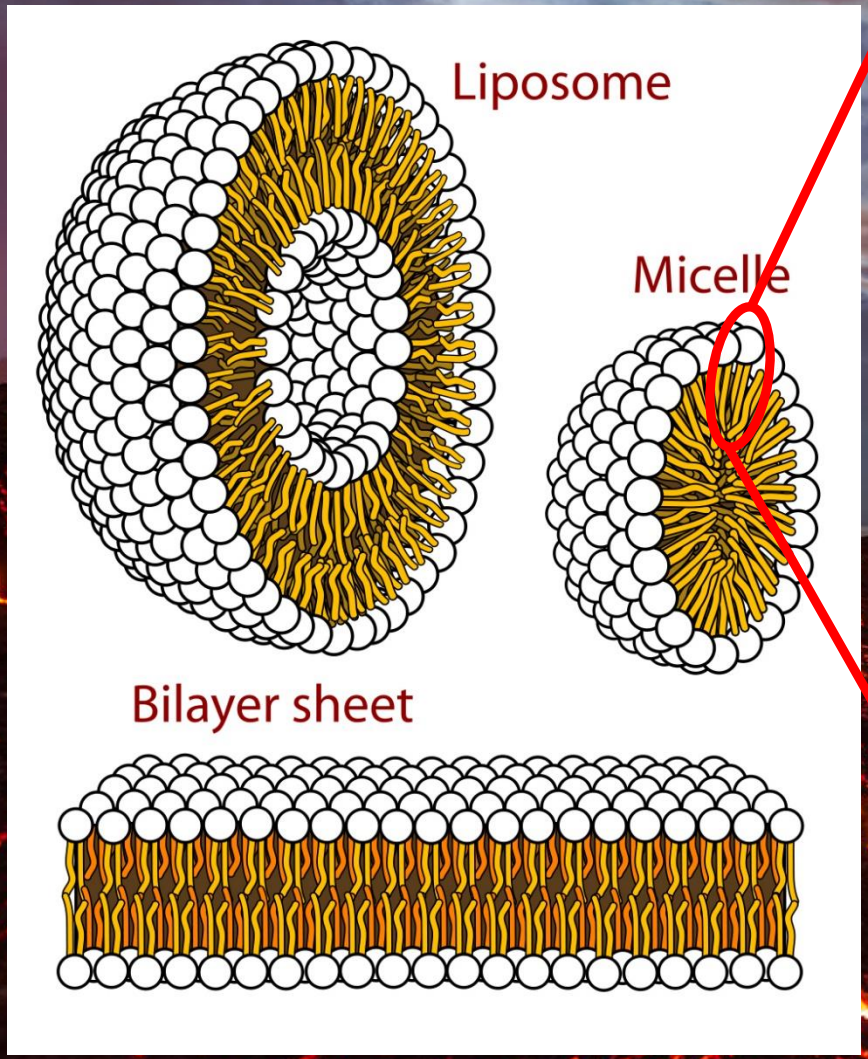
Cell*, in biology, the basic membrane-bound unit that contains the fundamental molecules of life and of which all living things are composed.*

What is the simplest unit of life?

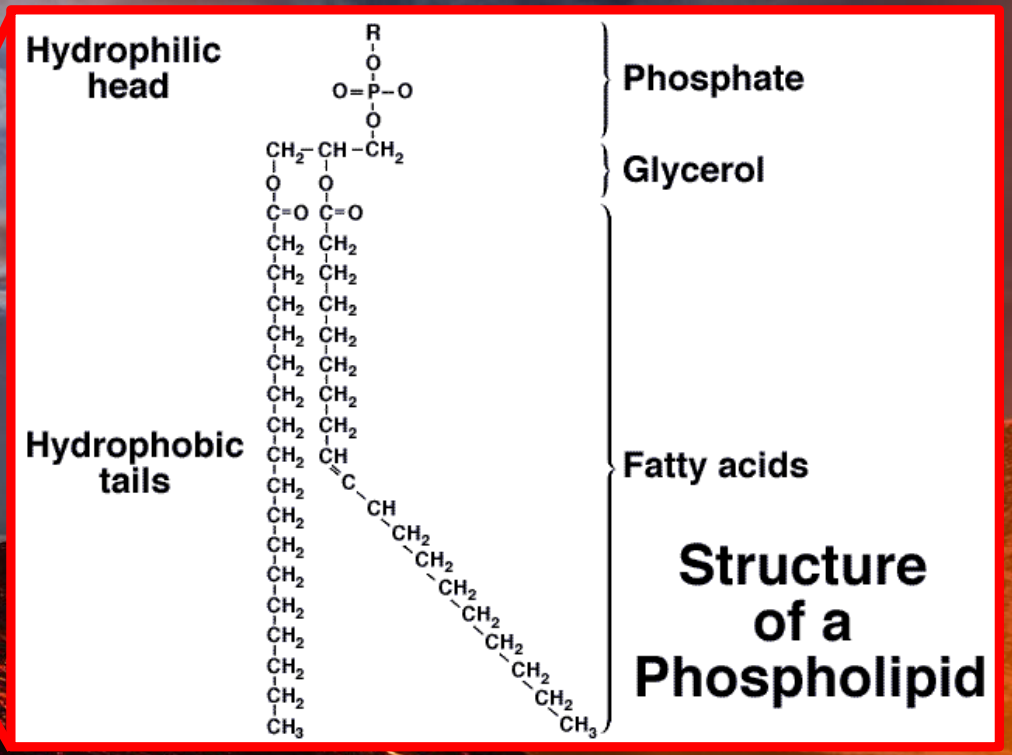


Mariana Ruiz Villarreal

What is the simplest unit of life?



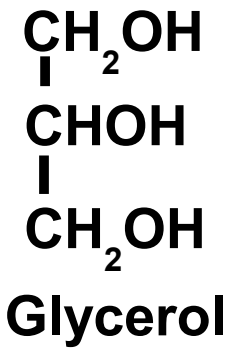
Mariana Ruiz Villarreal



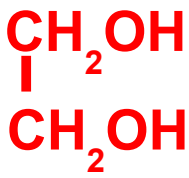
Randy Moore, Dennis Clark, and Darell Vodopich,
Botany Visual Resource Library (c) 1998
The McGraw-Hill Companies, Inc.

Why Glycolaldehyde and Ethylene Glycol?

SUGAR ALCOHOLS:

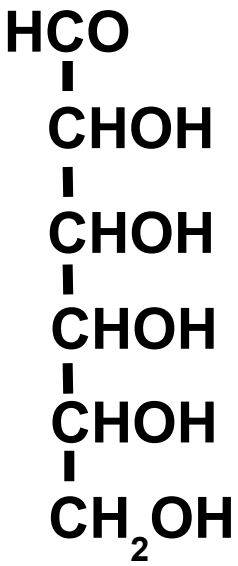


Glycerol

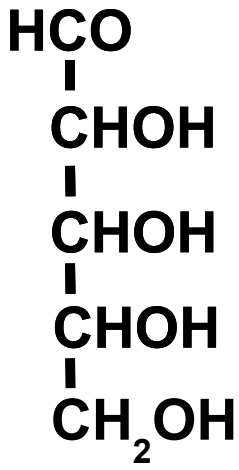


Ethylene Glycol

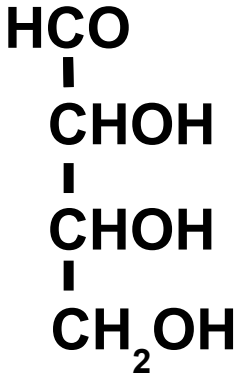
SUGARS



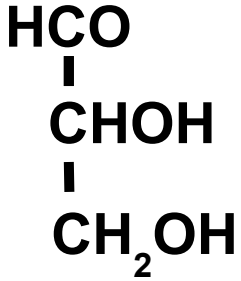
Glucose



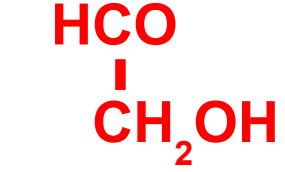
Ribose



Erythrose

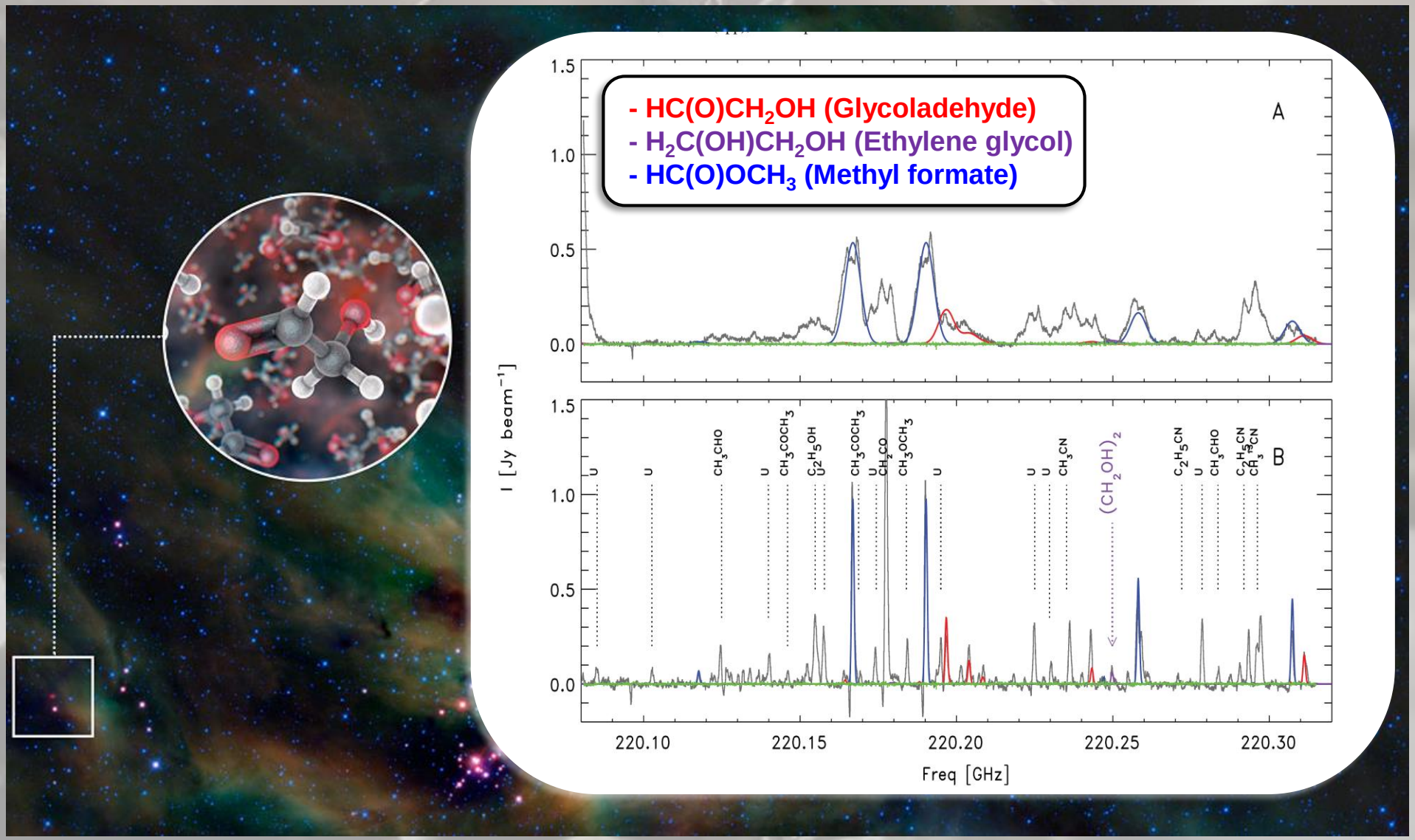


Glyceraldehyde



Glycolaldehyde

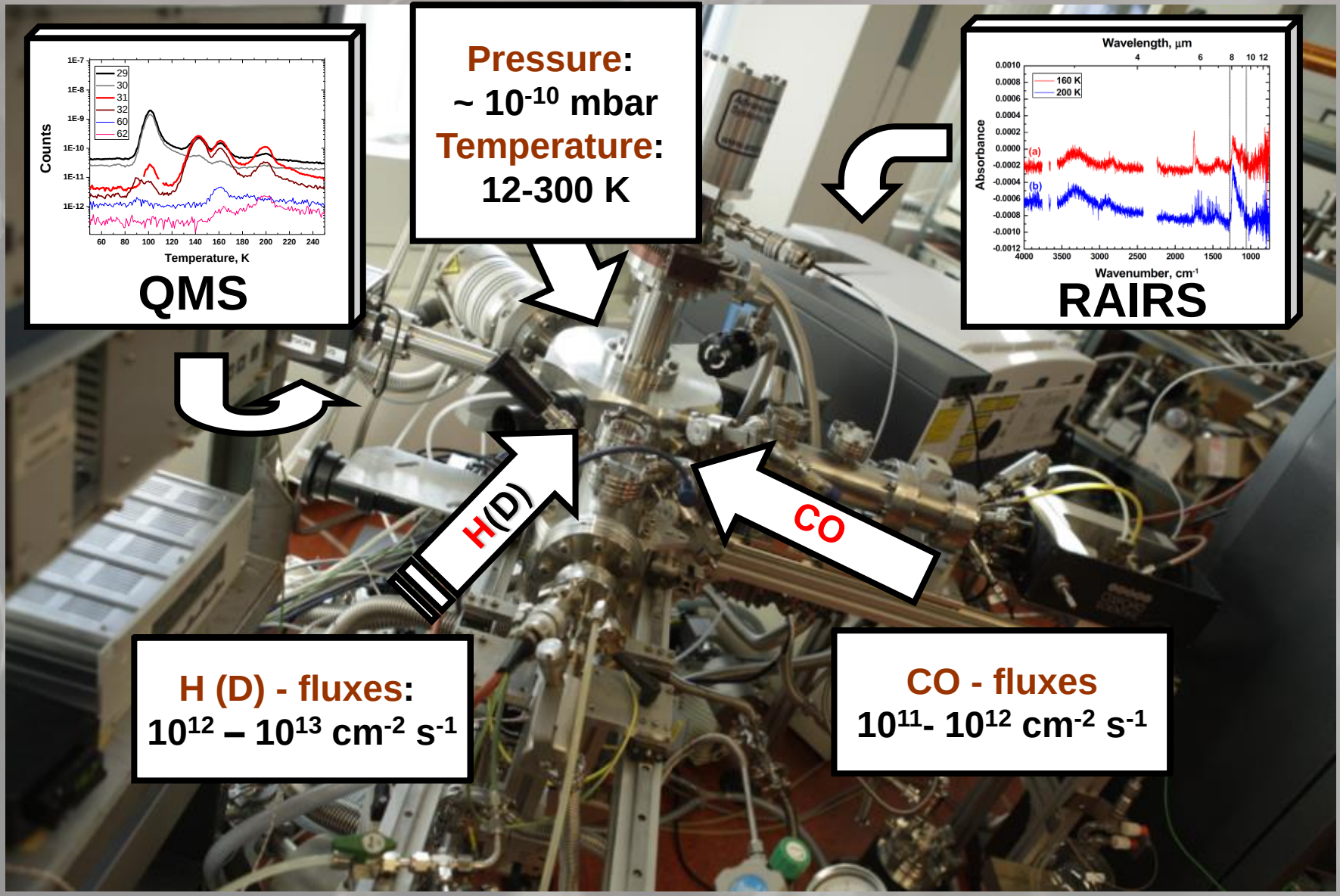
“Sweet Result from ALMA”



Jørgensen et al. 2012, 2016, Beltran et al. 2009, Taquet et al. 2015, 2017, Rivilla et al. 2016

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

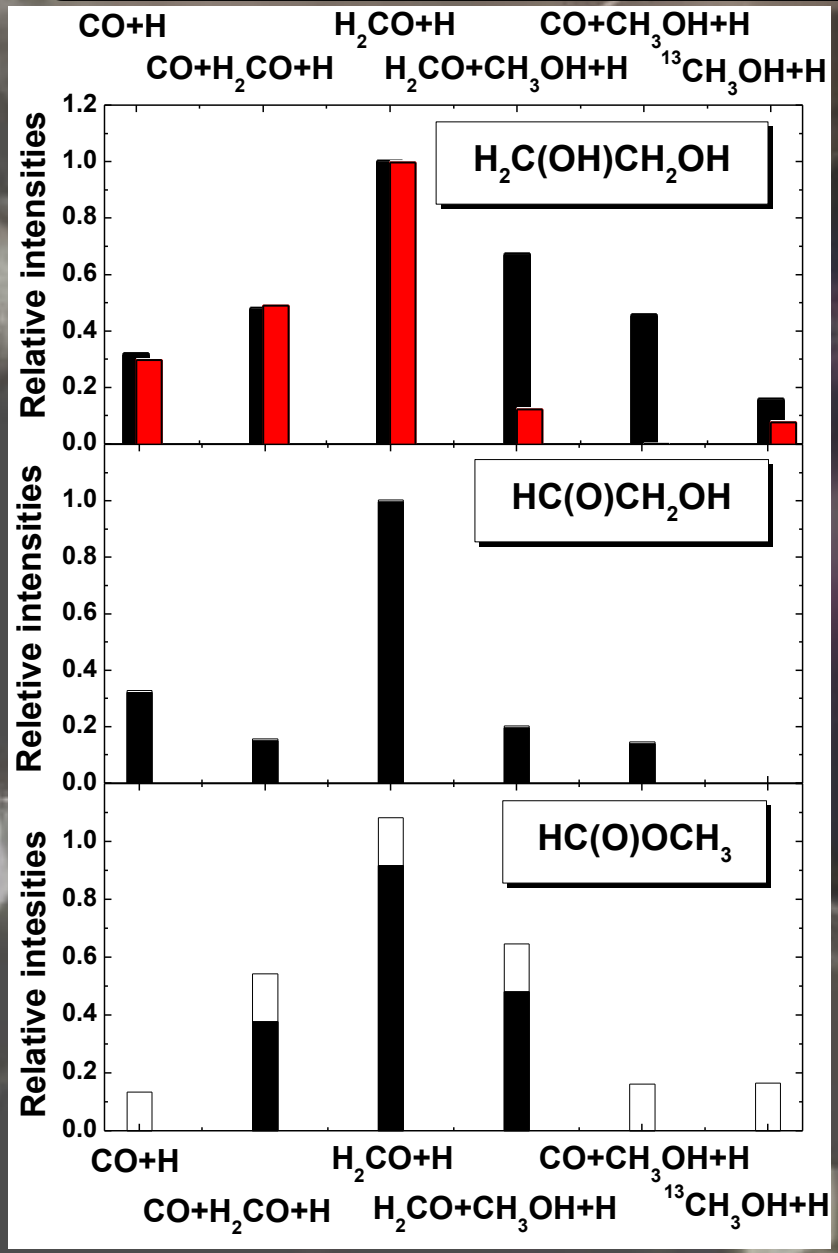
Analysis and Method

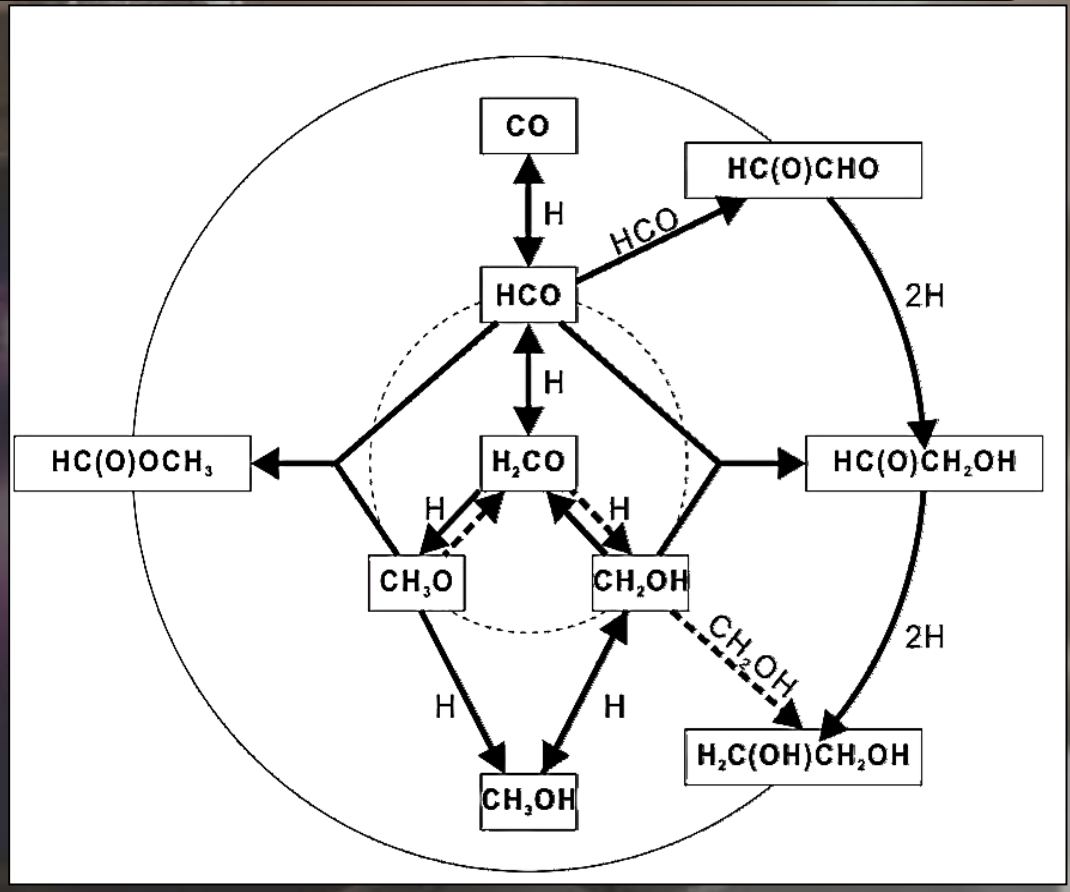


Ioppolo et al. 2013, Fedoseev et al. 2016

Sackler Laboratory for Astrochemistry

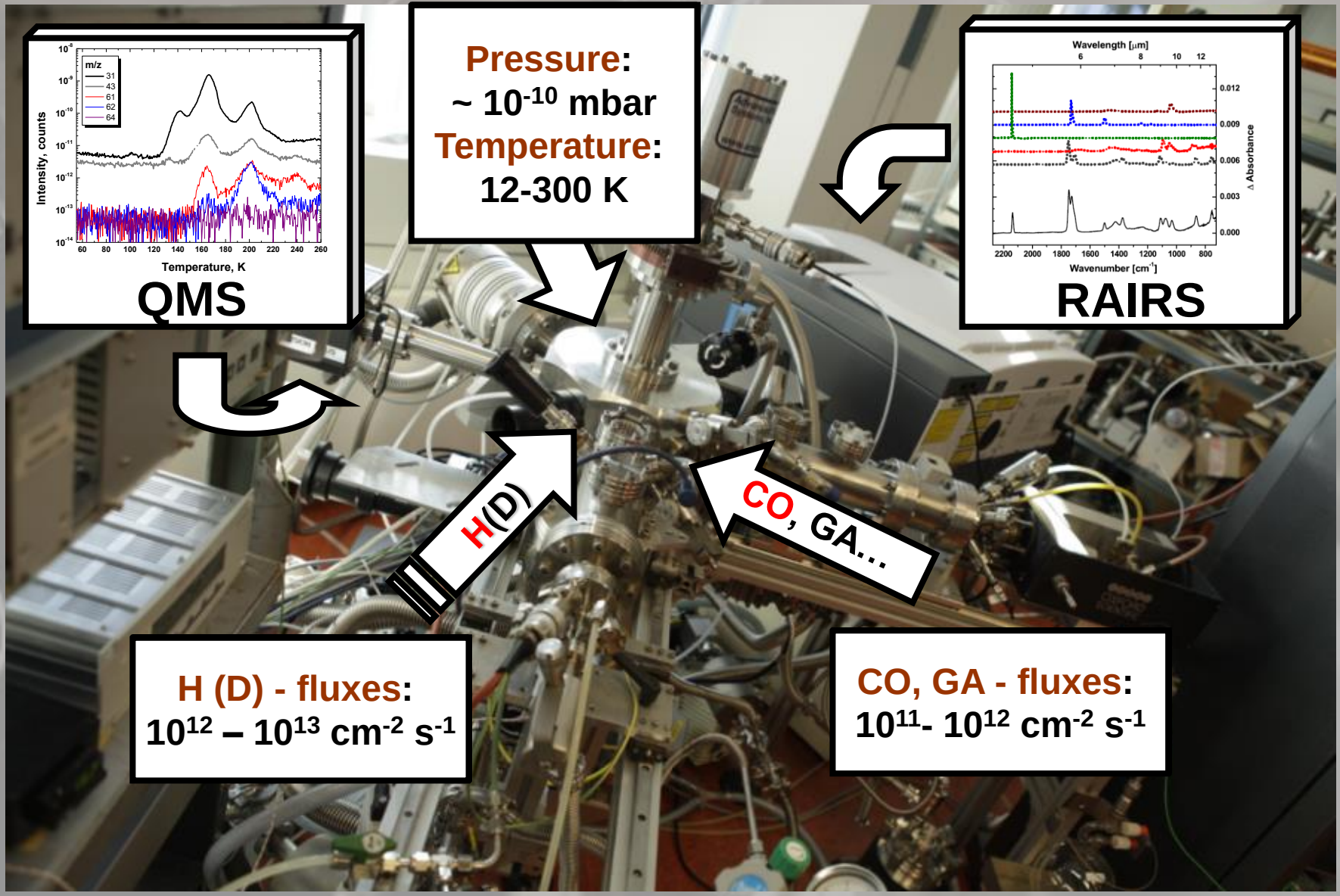
Constructing the Full Reaction Network





Fedoseev et al. 2015, Chuang et al. 2016
Hidaka et al. 2009,
Butscher et al. 2015, Minissale et al. 2016

Analysis and Method

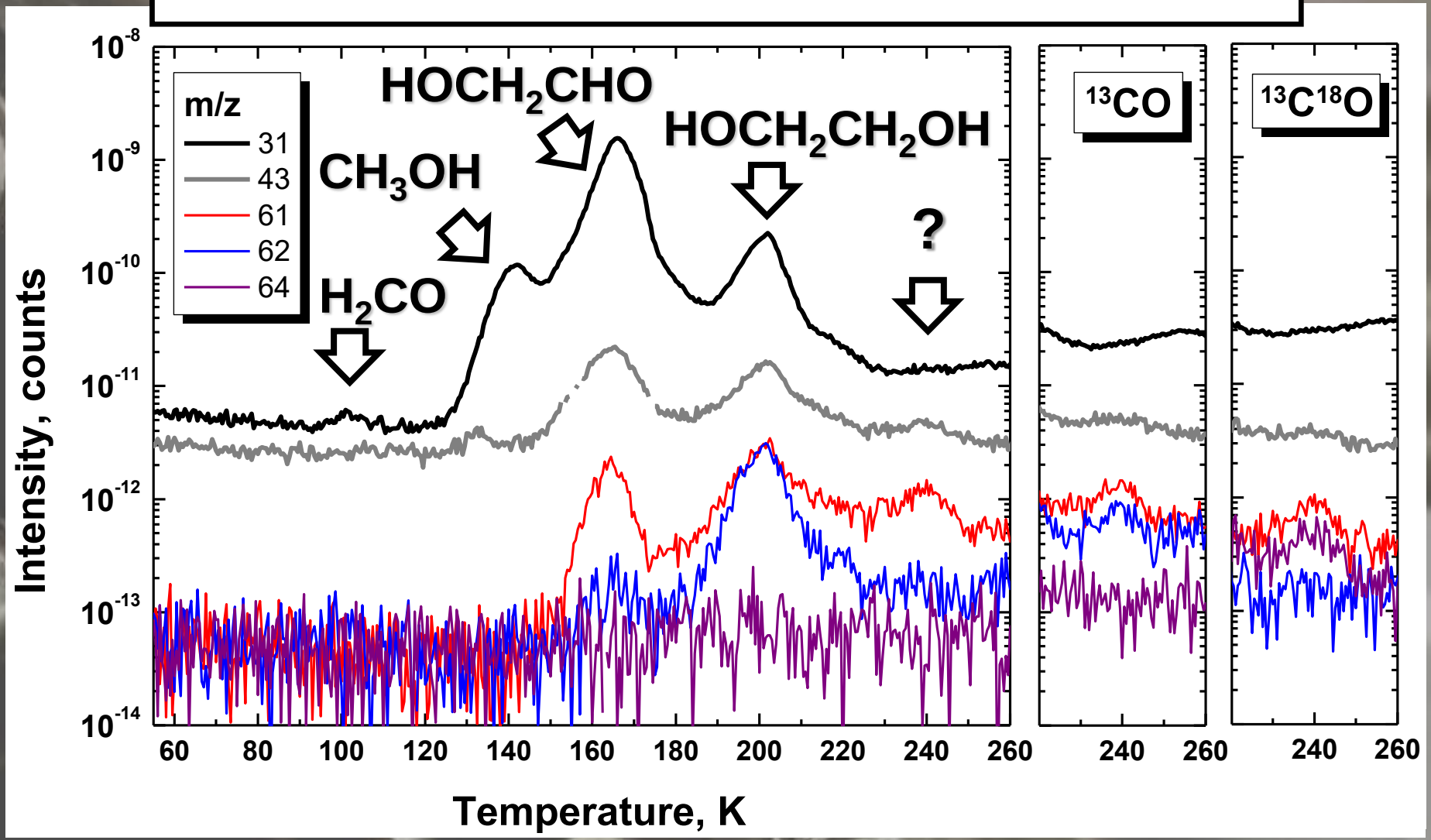


Ioppolo et al 2013, Fedoseev et al. 2016

Sackler Laboratory for Astrochemistry

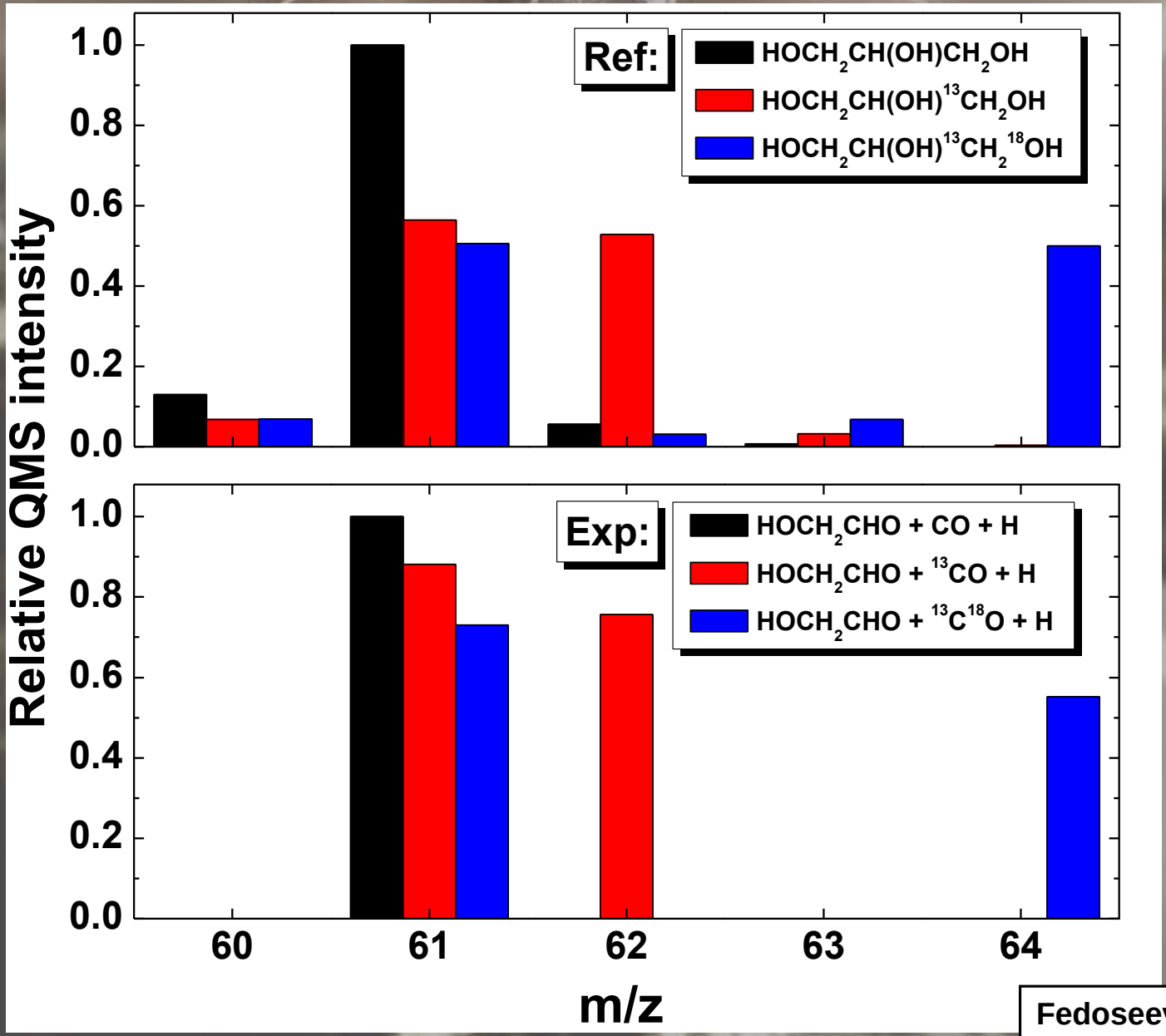
Hydrogenation of CO with Glycolaldehyde (1:1)

Co-deposition of H-atoms with CO:GA (1:1) at 15 K



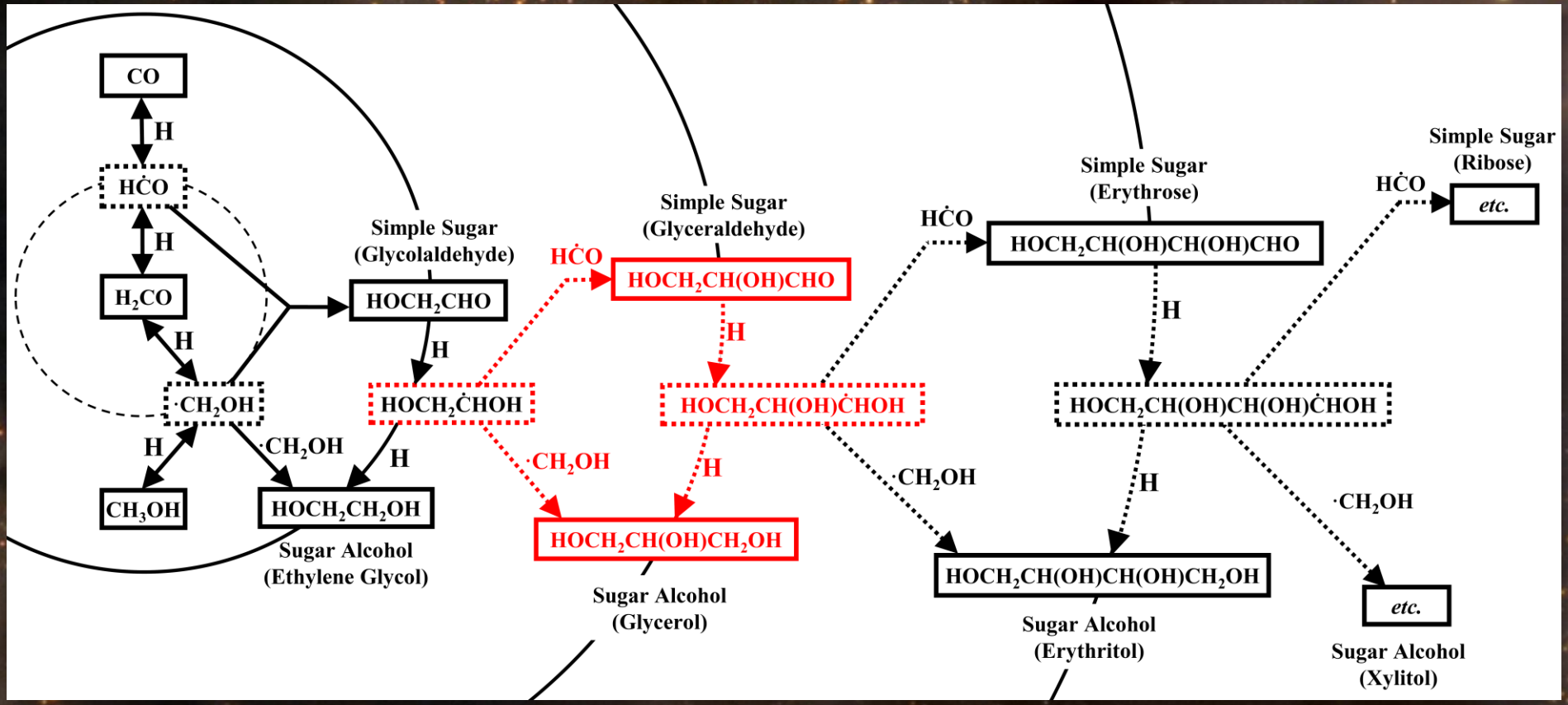
Fedoseev et al. 2017

Hydrogenation of CO with Glycolaldehyde (1:1)



Fedoseev et al. 2017

Chemistry on the Surface of Interstellar Grains

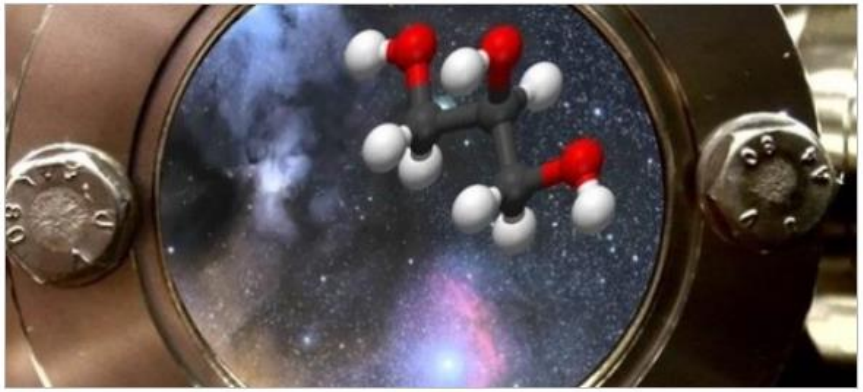


Fedoseev et al. 2017

Butlerov's Synthesis in the Interstellar Medium

Dutch astronomers discover recipe to make cosmic glycerol

donderdag 22 juni 2017, 12:31

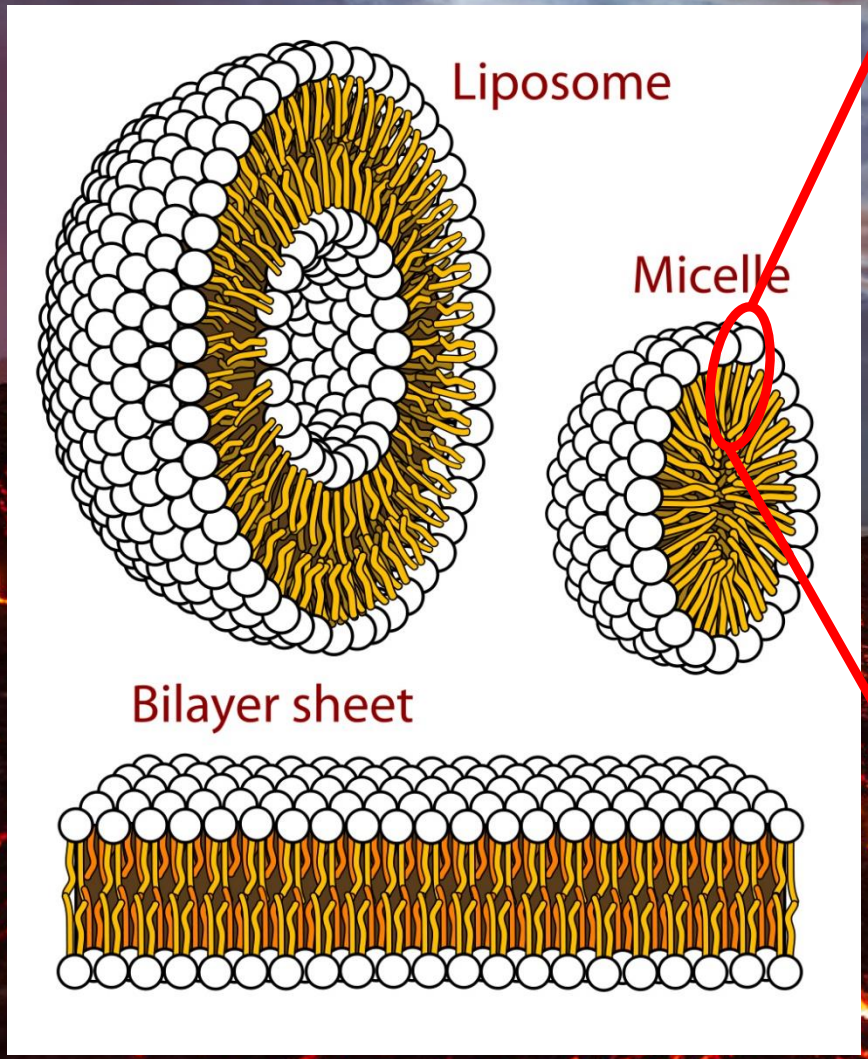


Dutch astronomers from Leiden University created the biologically important molecule of glycerol at minus 250 degrees Celsius out of only carbon monoxide and hydrogen. The photo shows a close up of the ice cold vacuum chamber containing an artist impression of glycerol and the star forming area IRAS 16293-2422. *(c) Harold Linnartz*

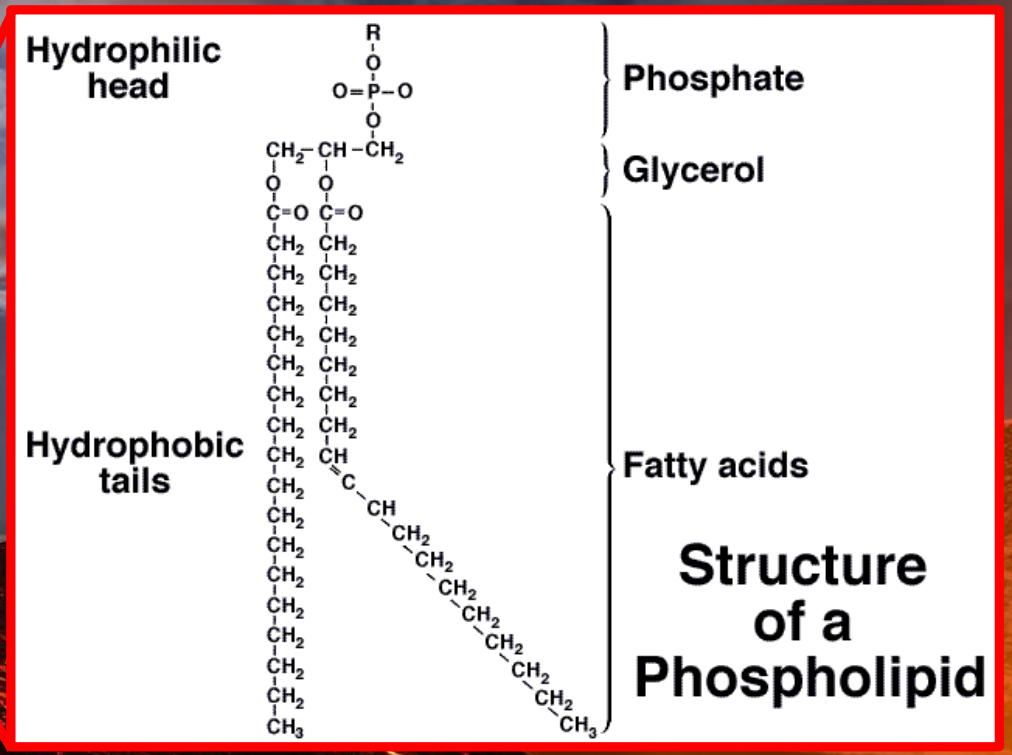
A team of laboratory astrophysicists from Leiden University (the Netherlands) managed to make glycerol under conditions comparable to those in dark interstellar clouds. They allowed carbon monoxide ice to react with hydrogen atoms at minus 250 degrees Celsius. The researchers publish their findings in the *Astrophysical Journal*.

In recent years more and more complex molecules have been identified in space. Their formation schemes are still under debate. Gleb Fedoseev, now a postdoc at the Osservatorio Astrofisico di Catania in Italy and the first author of the article: "The density of particles in space is extremely low and carbon monoxide is highly volatile. However, it freezes out on small dust particles at temperatures below minus 250 degrees Celsius where it acts as the seed for larger

What is the simplest unit of life?

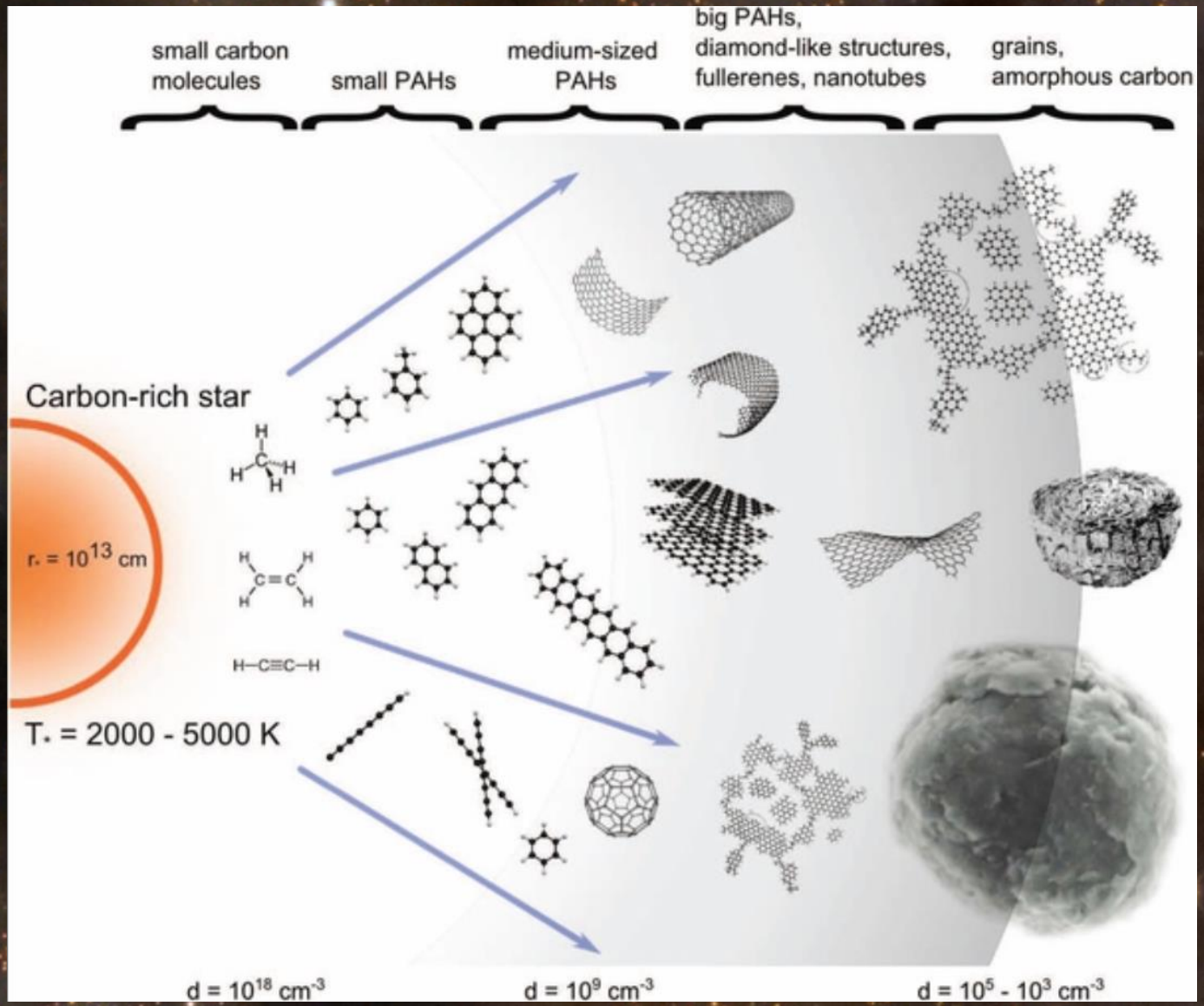


Mariana Ruiz Villarreal



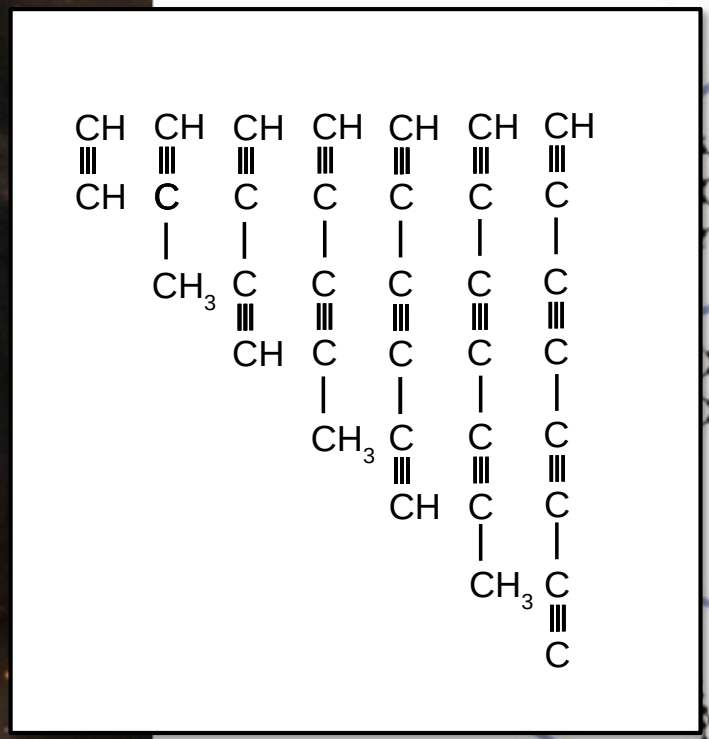
Randy Moore, Dennis Clark, and Darell Vodopich,
Botany Visual Resource Library (c) 1998
The McGraw-Hill Companies, Inc.

‘Up-to-bottom’ formation of COMs



Contreras & Salama, 2013

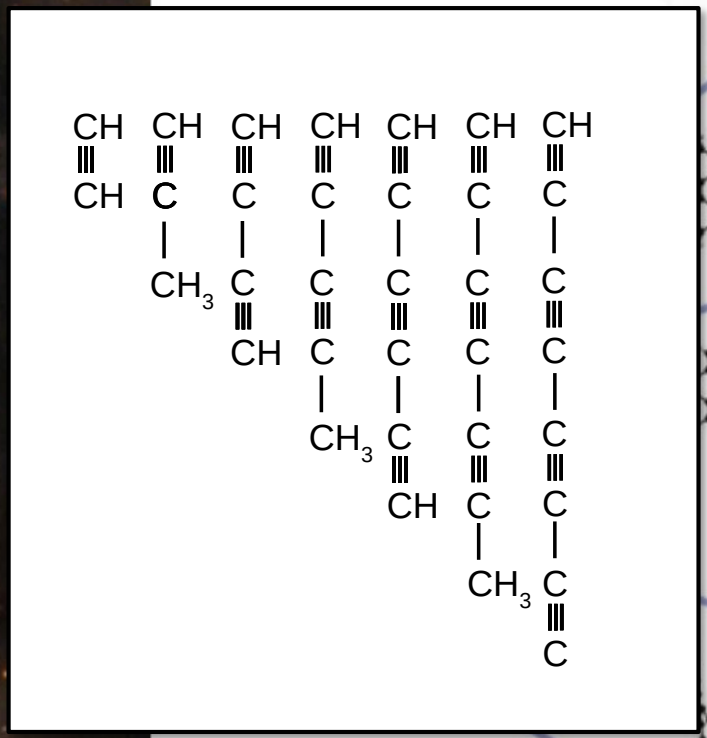
‘Up-to-bottom’ formation of COMs

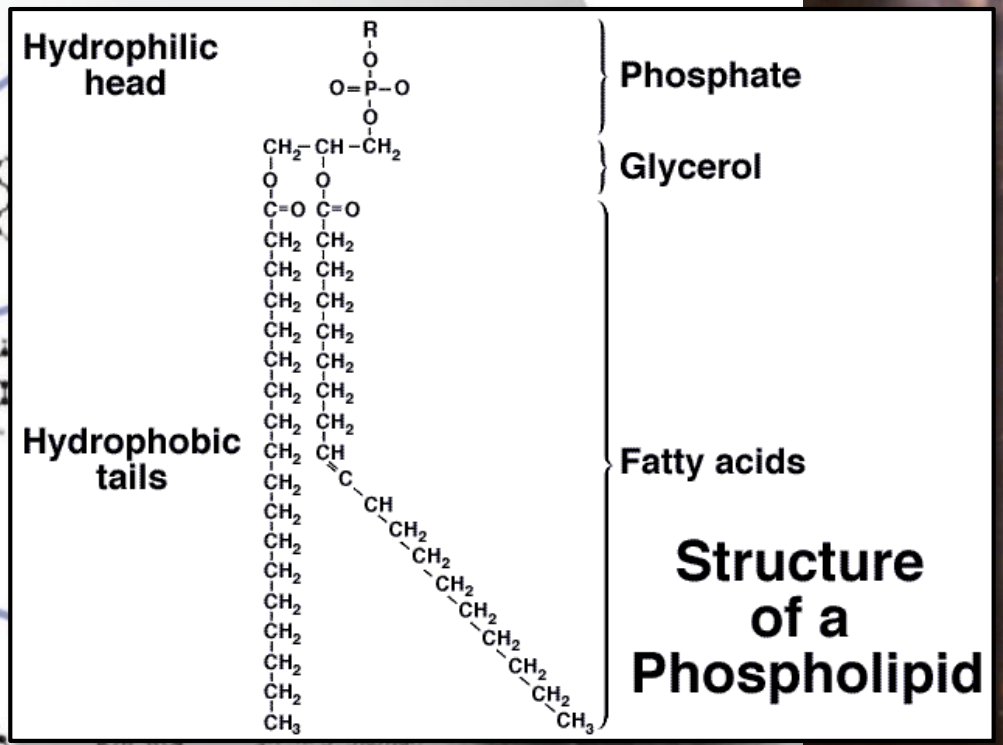


Contreras & Salama, 2013

‘Up-to-bottom’ formation of COMs

small carbon molecules | small PAHs | medium-sized PAHs | big PAHs, diamond-like structures, fullerenes, nanotubes | grains, amorphous carbon





Structure of a Phospholipid

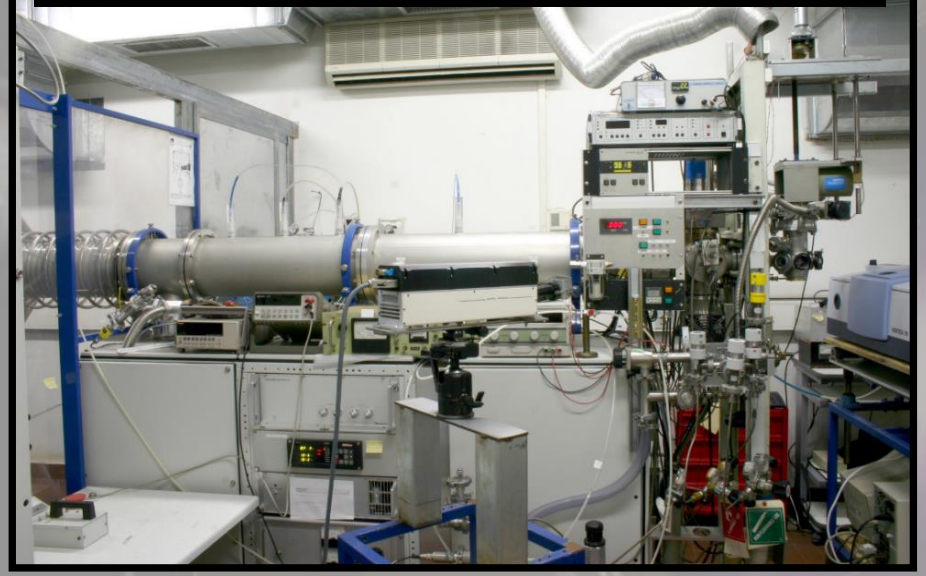
Randy Moore, Dennis Clark, and Darell Vodopich, Botany Visual Resource Library (c) 1998
The McGraw-Hill Companies, Inc.

$d = 10^{18}$ cm^{-3} | $d = 10^{9}$ cm^{-3} | $d = 10^{5} - 10^{3}$ cm^{-3}

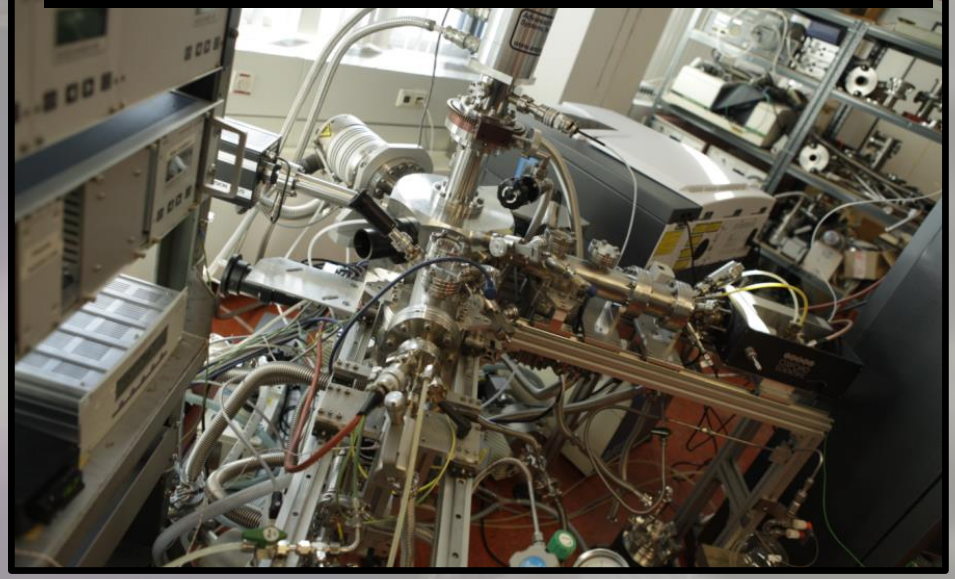
Contreras & Salama, 2013

Analysis and Method

Experimental Astrophysics Laboratory (LASP)



Sackler Laboratory for Astrophysics (SLA)

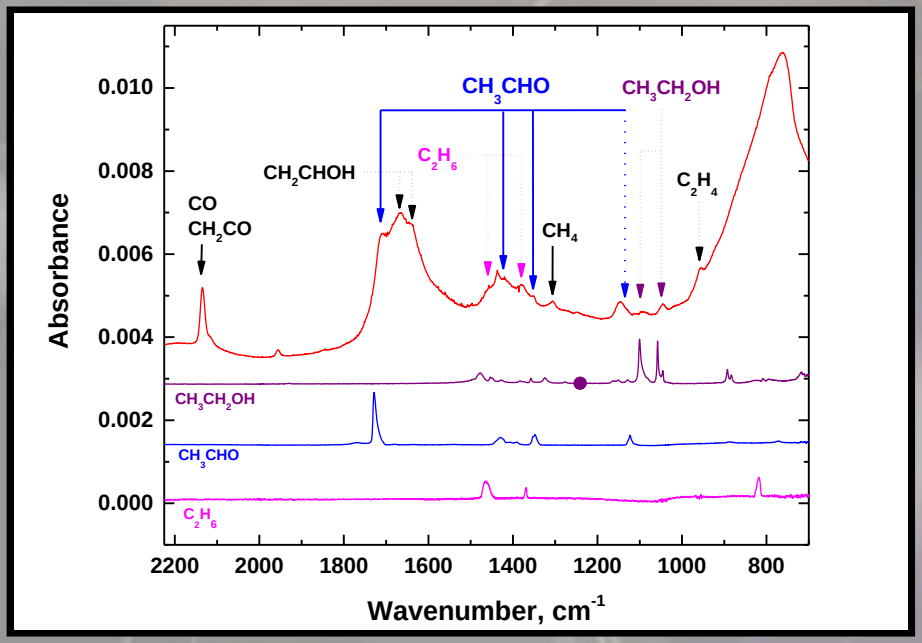


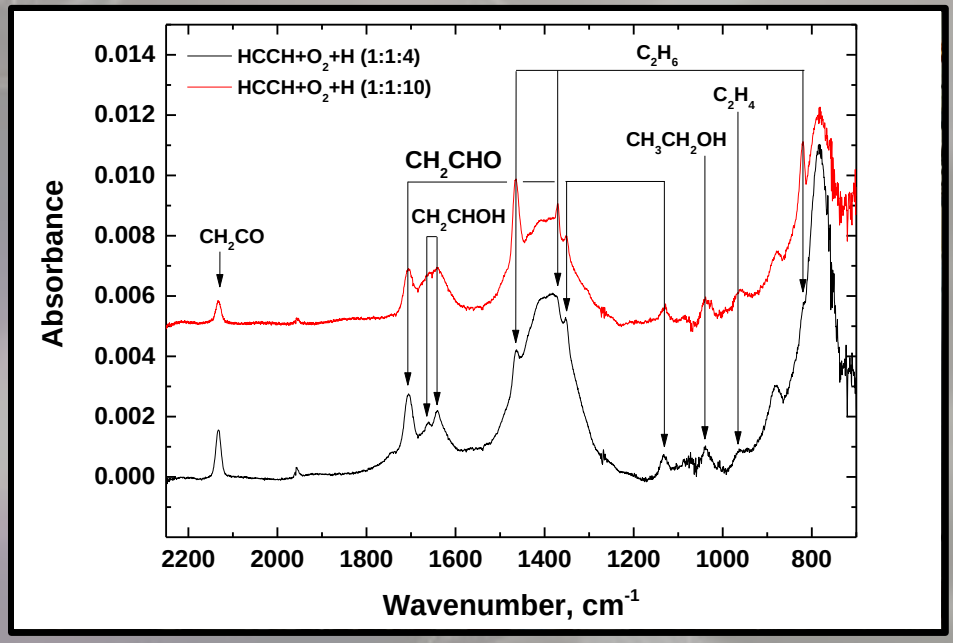
$HC{\equiv}CH{:}H_2O$ ice + H^+ (200 keV)

$HC{\equiv}CH{:}O_2$ ice + H (atoms)

Fedoseev at al. 2018 (in preparation), Chuang et al. 2018 (in preparation)

Analysis and Method





HC≡CH:H_2O ice + H^+ (200 keV)

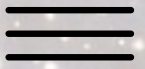
HC≡CH + O_2 + H (atoms)

Detections of various single oxygen bearing species:

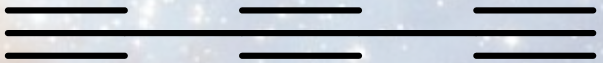
- CH_3CH_2OH (Alcohol), CH_3CHO (Aldehyde), CH_2=CHOH (Enol)
- Tentative detection of two oxygen-bearing CH_3COOH (Carboxylic Acid) in hydrogenation experiments

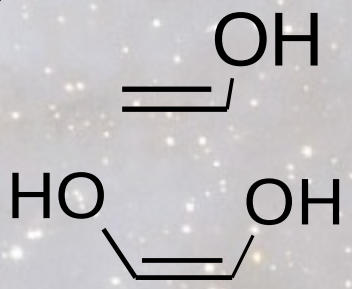
Fedoseev at al. 2018 (in preparation), Chuang et al. 2018 (in preparation)

Overall suggested mechanism:



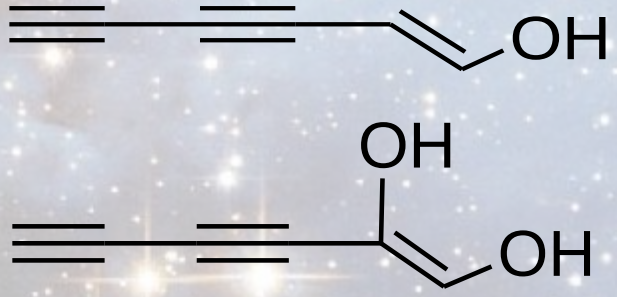
Linear carbon chain observed in the ISM

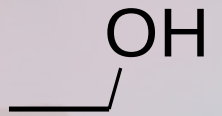


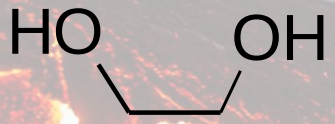


Hydroxylation

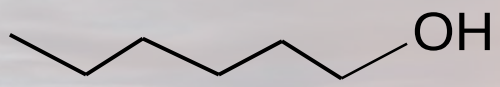
(Aim of this research)

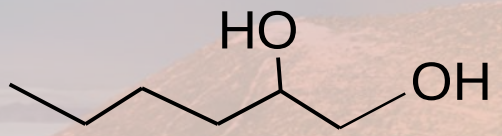






Further hydrogenation to yield various primary and secondary alcohols or polyols





List of publications:

(1) Qasim D., **Fedoseev G.**, et al., *"Formation of interstellar propanal and 1-propanol ice starting from solid-state CO hydrogenation"*, submitted to MNRAS

(2) Accolla, M., Pellegrino, G., Baratta, G. A., Condorelli, G. G., **Fedoseev, G.**, et al., *"Combined IR and XPS characterization of organic refractory residues obtained by ion irradiation of simple icy mixtures"*, A&A, in press.

(3) Chuang, K.-J., **Fedoseev, G.**, et al.,*"H_2 chemistry in interstellar ices: the case of CO ice hydrogenation in UV irradiated CO:H_2 ice mixtures"*, 2018, A&A, 617, A87.

(4) **Fedoseev G**., et al., *"Cosmic ray processing of N_2-containing interstellar ice analogues at dark cloud conditions"*, 2018, MNRAS, 475, 1819.

(5) Chuang, K.-J., **Fedoseev, G.,** et al., *"Reactive desorption of CO hydrogenation products under cold pre-stellar core conditions*", 2018, ApJ, 853, 102.

(6) Qasim, D., Chuang, K.-J., **Fedoseev, G.**, et al., *"Formation of interstellar methanol ice prior to the heavy CO freeze-out stage"*, 2018, A&A, 612, A83.

(7) **Fedoseev, G.,** et al., *"Formation of Glycerol through Hydrogenation of CO Ice under Prestellar Core Conditions"*, 2017, ApJ, 842, 52.

List of cotributions on (inter)national events:

(1) 10/2018: Oral. *“Solid-state formation of lipid precursors under dense molecular cloud conditions”*. SIAW 2018, Cosmos within us: life on Earth as a way to study its origin and distribution in the universe. Naples, Italy

(2) 05/2018: Oral. “*Laboratory simulations of cosmic-ray processing of N_2-containing ices at dark cloud conditions*”. Cosmic Rays: the salt of the star formation recipe. Florence, Italy.

(3) 03/2018: Poster. “Solid-state formation of aldoses and polyols by CO hydrogenation under prestellar core conditions”. WE-Heraeus-Seminar on prebiotic molecules in Space and origin of life on Earth. Bad Honnef, Germany.

(4) 09/2017: Oral. *“Formation of Complex Organic Molecules under Prestellar Core Conditions”.* LXI Congresso della Società Astronomica Italiana. Padova, Italy

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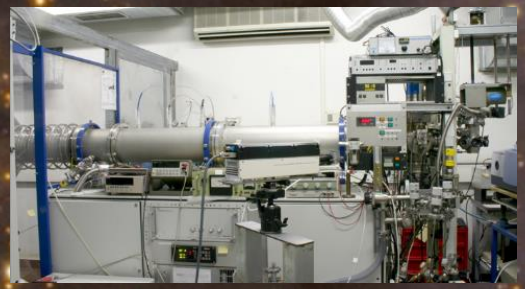
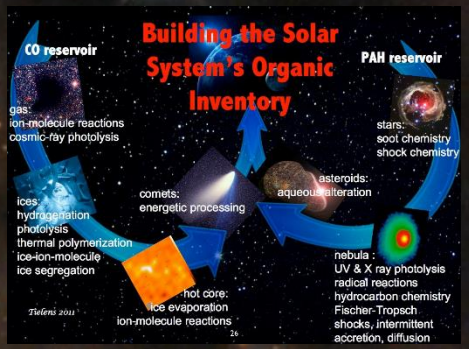
Take to home message:

- Pioneering formation of **prebiotics** in **Dark clouds**

- A detailed **laboratory based research**
- Mimicking **cosmic ray processing**





- Up-to-bottom approach
- Utilizing interstellar **carbon chains** and **PAHs** as the source of carbon

- Pioneering formation of **membrane precursors**
- Supporting the **'Lipid World'** scenario