

THE DAWN OF ORGANIC CHEMISTRY IN SPACE

ERC-Advanced Project

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E. Bianchi, A. Jaber Al-Edhari, **F. Vazart**,
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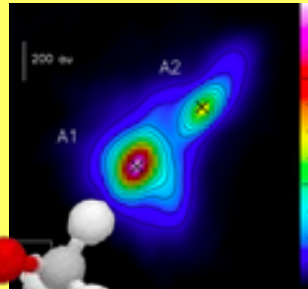
Institut de Planétologie et d'Astrophysique de Grenoble

FROM A DIFFUSE CLOUD TO THE SOLAR SYSTEM FROM ATOMS & SIMPLE MOLECULES TO LIFE

(adapted from Caselli & Ceccarelli 2012, A&A Rev)

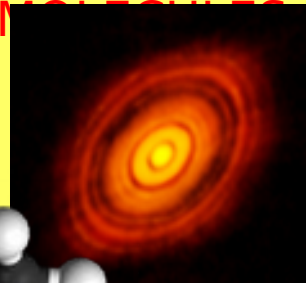
1- PRE-STELLAR PHASE: cold and dense gas

FORMATION OF SIMPLE/COMPLEX



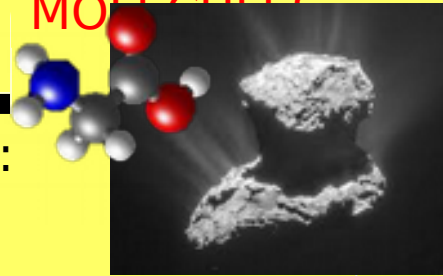
2- PROTOSTELLAR PHASE: collapsing, warm dense gas

SUBLIMATION/FORMATION OF COMPLEX MOLECULES



3- PROTOPLANETARY DISK PHASE: cold and warm dense gas

SIMPLE & COMPLEX MOLECULES



4- PEBBLES/PLANETESIMAL FORMATION : grains coagulation

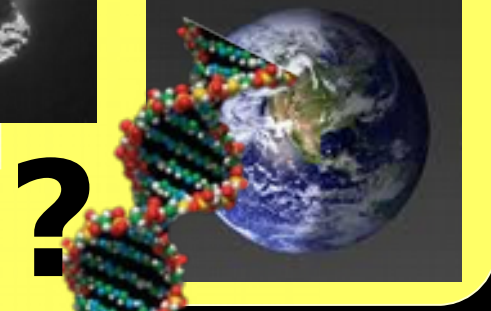
STORAGE/REPROCESSING OF GRAIN

MANTLE ICE

5- PLANET FORMATION AND THE "COMET/ASTEROID RAIN":

planet migration, small bodies scattering; **Earth**

oceans formation



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HOW MUCH REPROCESSING?

PRE-STELLAR PHASE: cold and dense

FORMATION OF SIMPLE/COMPLEX

PROTOSTELLAR PHASE: collapsing, warm

gas

FORMATION OF COMPLEX

3- PROTOPLANETARY DISK

PHASE: cold and warm dense

COMPLEX

MO

4- PE
grains

ST

MAINT

5- PL
RAIN'

pla

ocea

**NOT ALL IS LOST,
SOME MEMORY
REMAINS
(e.g. WATER ON
EARTH)**

?

COOLING

Organic chemistry in space & life



Organic chemistry in space & life



C. DE DUVE

The building blocks of life form naturally in our Galaxy and, most likely, also elsewhere in the Cosmos.

The chemical seeds of life are universal.

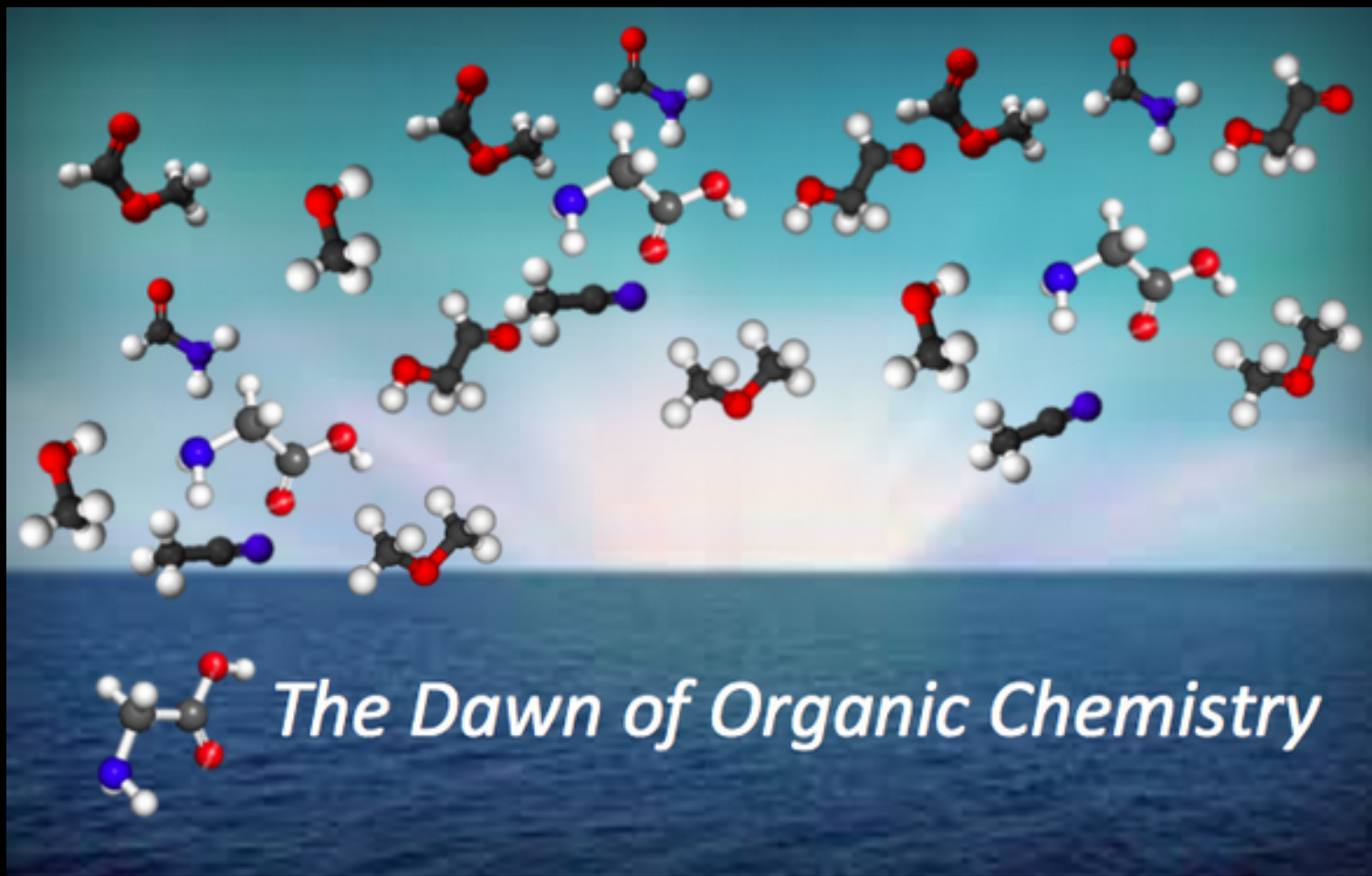
("Singularities. Landmarks on the Pathways of life", Cambridge University Press 2005)



ASTROCHEMISTS' JOB:

1. SEARCH FOR THE SEEDS
2. UNDERSTAND THE PROCESSES AND WHAT KIND OF MOLECULAR COMPLEXITY CAN GROW IN SPACE

In this context, let me introduce the ERC-Ad project



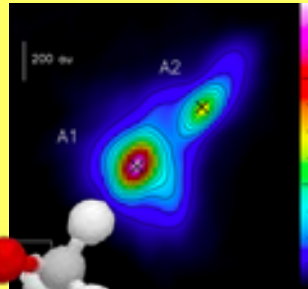
The Dawn of Organic Chemistry

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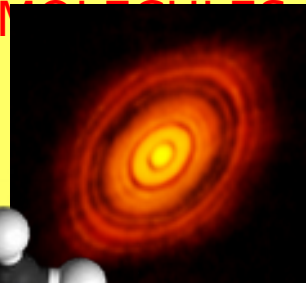
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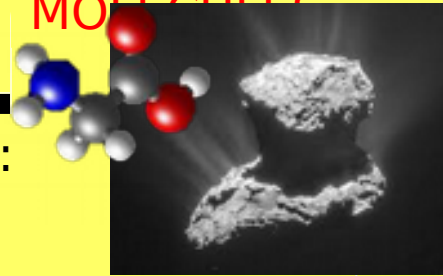
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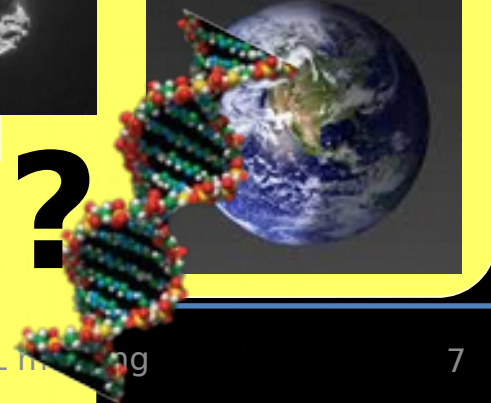
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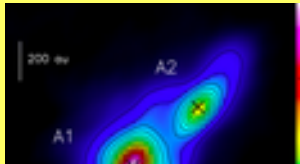


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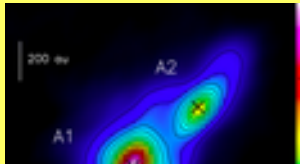
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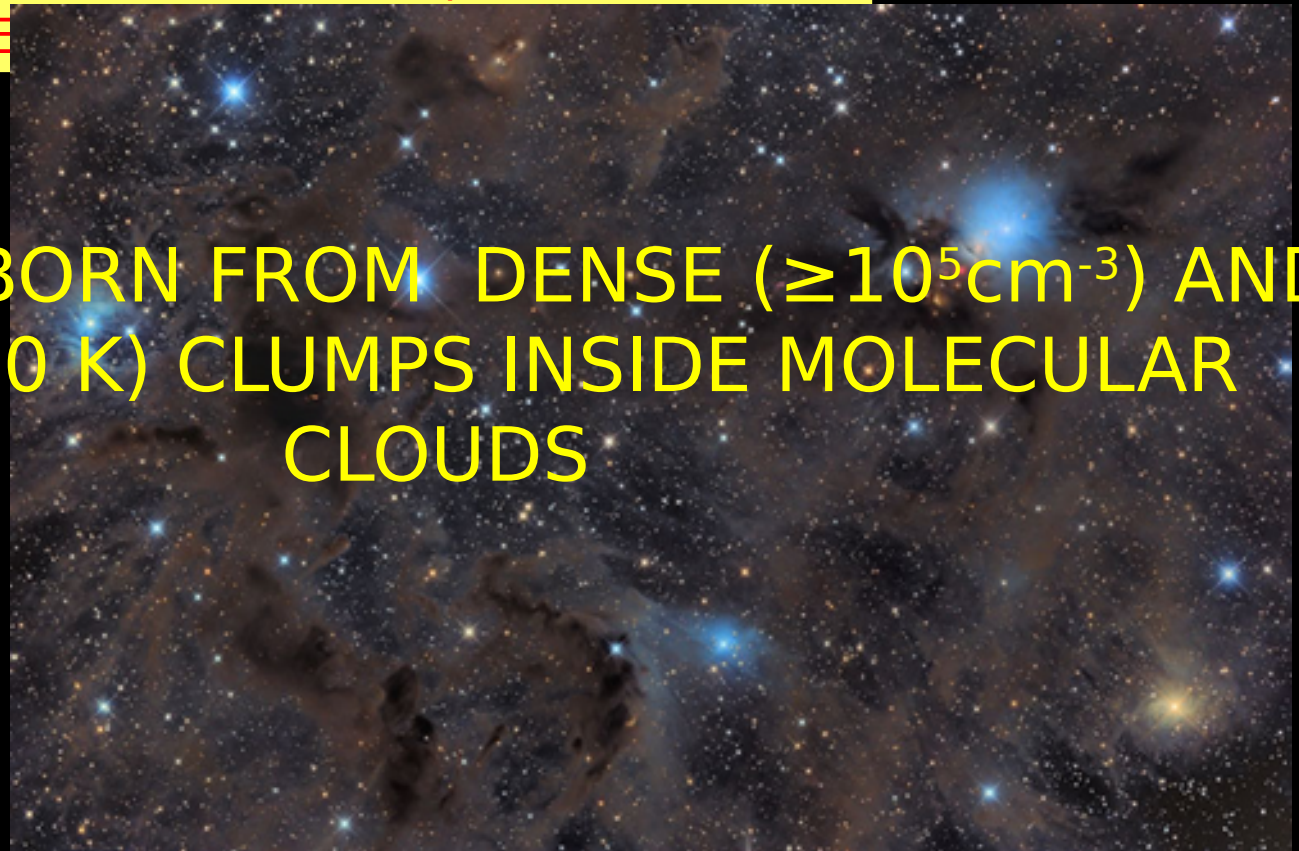
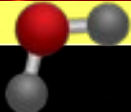
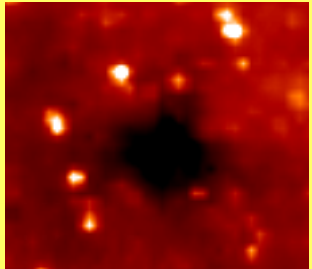
**THE FIRST TWO STEPS ARE
CRUCIAL
TO UNDERSTAND
THE CHEMICAL COMPLEXITY
REACHABLE DURING THE
FORMATION OF A SOLAR-LIKE**

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FORMATION OF SIMPLE/COMPLEX
MOLE



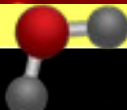
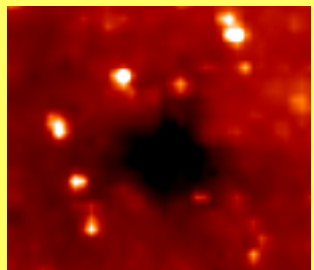
STARS ARE BORN FROM DENSE ($\geq 10^5 \text{cm}^{-3}$) AND
COLD ($\leq 10 \text{K}$) CLUMPS INSIDE MOLECULAR
CLOUDS

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1- PRE-STELLAR PHASE: cold and dense gas

FORMATION OF SIMPLE/COMPLEX MOLE



STARS ARE BORN FROM DENSE ($\geq 10^5 \text{cm}^{-3}$) AND COLD ($\leq 10 \text{K}$) CLUMPS INSIDE MOLECULAR CLOUDS



→ DUST GRAINS ARE COVERED BY ICE

→ WHAT MOLECULES ARE

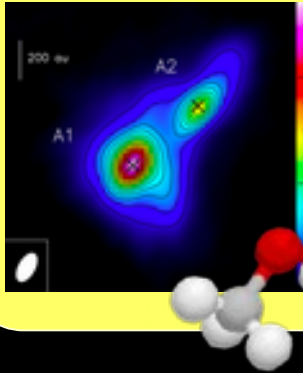
SYNTHESISED ON THE GRAIN SURFACES?

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GRAVITATIONAL ENERGY RELEASED BY THE
INFALLING MATERIAL HEATS THE GAS

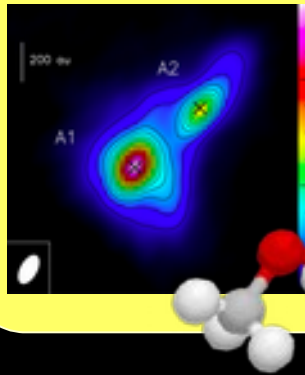


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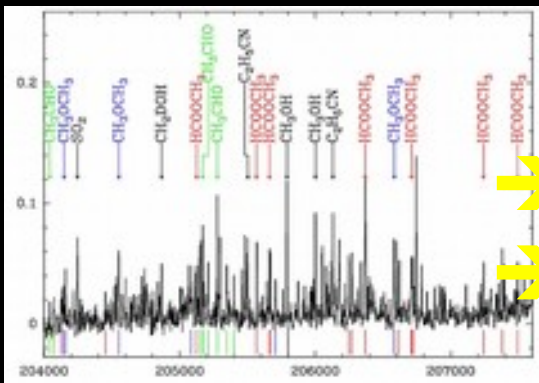
SUBLIMATION/FORMATION OF COMPLEX MOLEC



GRAVITATIONAL ENERGY RELEASED BY THE INFALLING MATERIAL HEATS THE GAS
APPEARANCE OF **HOT CORINOS**, RICH IN ORGANIC SPECIES

→ GRAIN ICES SUBLIMATE

→ WHAT MOLECULES ARE SYNTHESISED ON THE GAS



iCOMs IN HOT CORINOS

(iCOMs = interstellar Complex Organic Molecules)

SPECIES

O-BEARING

propyne (CH_3CCH)

methanol (CH_3OH)

methyl formate
(HCOOCH_3)

dimethyl ether (CH_3OCH_3)

ethylene glycol ($\text{CH}_2\text{OH})_2$)

acetaldehyde (CH_3CHO)

glycol aldehyde
($\text{HCO}(\text{CH}_2)\text{OH}$)

acetone (CH_3COCH_3)

ethanol ($\text{CH}_3\text{CH}_2\text{OH}$)

S N-BEARING

propanal ($\text{CH}_3\text{CH}_2\text{CHO}$)

ethylene oxide (c- $\text{C}_2\text{H}_4\text{O}$)

formamide (NH_2CHO)

methyl isocyanate
(CH_3NCO)

acetic acid (CH_3COOH)

methyl cyanide (CH_3CN)

ethyl cyanide ($\text{CH}_3\text{CH}_2\text{CN}$)

cyanoacetylene (HC_5N)

iCOMs IN HOT CORINOS

(iCOMs = interstellar Complex Organic Molecules)

SPECIES

BEARING

propyne (CH_3CCH)	
methanol (CH_3OH)	acetaldehyde (CH_3CHO)
methyl formate (H_3COCHO)	glycol aldehyde (HOCH_2CHO)

IF WE UNDERSTAND HOW THESE SPECIES ARE FORMED WE CAN THEN TO PREDICT WHAT OTHER MOLECULES CAN BE SYNTHESIZED

⇨ THE ULTIMATE REACHABLE COMPLEXITY

(CH_3NCO)	
cyanoacetylene (HC_5N)	




TO UNDERSTAND:

- the start of organic chemistry in systems similar to the progenitor of the Solar System;
- how organic chemistry builds up and evolves in these systems;
- how universal the chemical seeds of life are.

GOAL of (2/2)

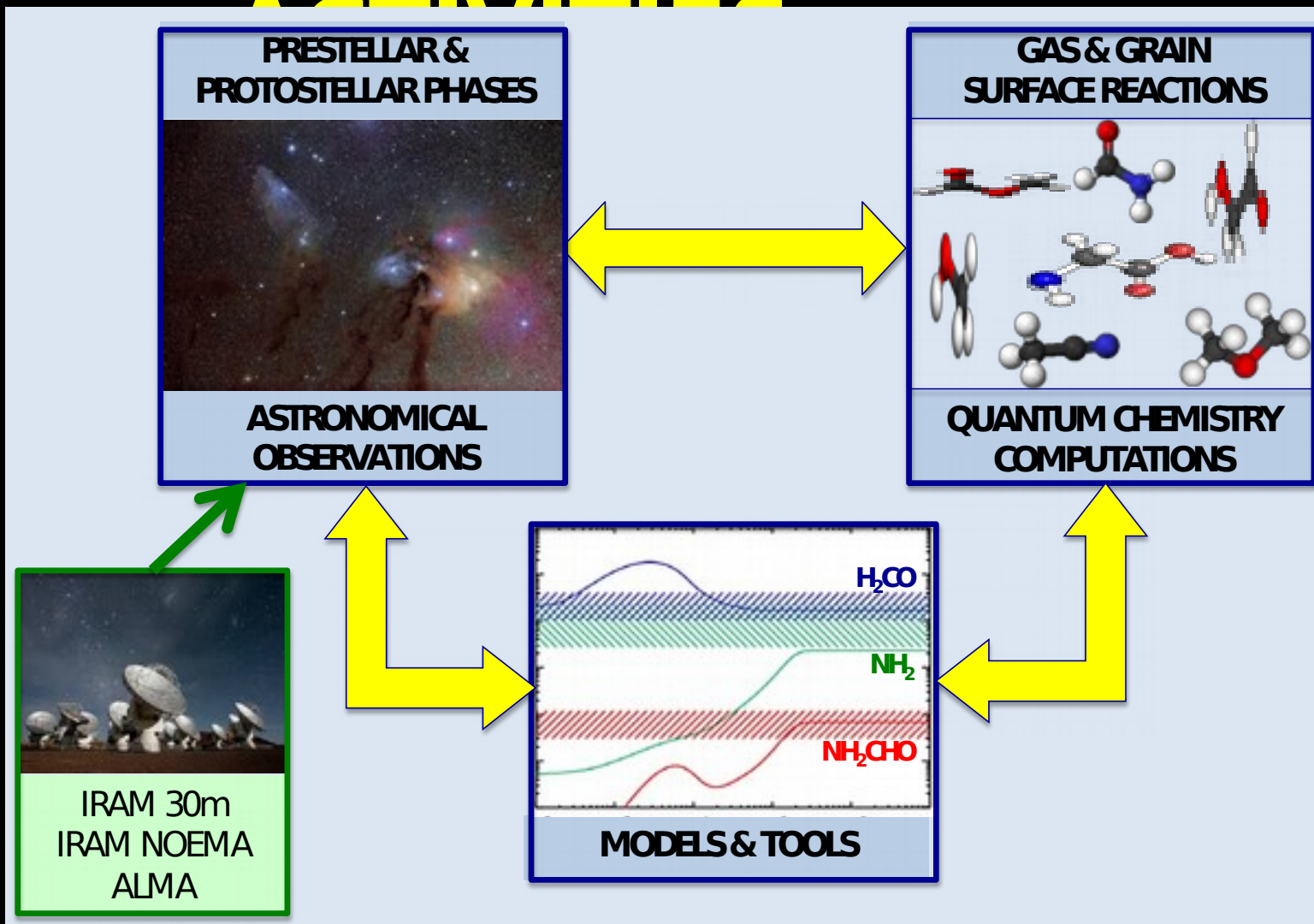
Move from a “stamp collection” phase to a “quantitative and predictive” phase of organic electrochemistry



The goal  is to build a reliable theory for the organic chemistry in



STRUCTURE & ACTIVITIES



CONCLUSIONS

ORGANIC CHEMISTRY IS ALREADY RICH AT THE VERY BEGINNING OF A SOLAR-LIKE FORMING SYSTEM

WHAT IS THE ULTIMATE REACHED COMPLEXITY ?

→ NEED TO UNDERSTAND BETTER THE *i*COMS FORMATION PROCESS: OBS + THEORY

ARE iCOMS PASSED TO THE FORMING PLANETS, COMETS AND ASTEROIDES ?

→ NEED TO UNDERSTAND BETTER THE PLANETARY SYSTEM FORMATION PROCESS:

THE TEAM



C. Ceccarelli



C. Kahane



B. Lefloch



A. López-Sepulcre



E. Bianchi



A. Jaber Al-Edhari



F. Vazart



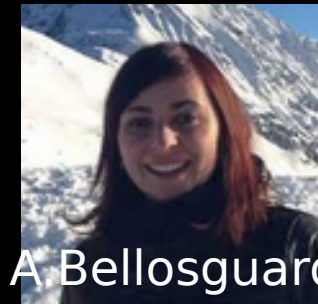
J. Enrique-Romero



J. Ospina-Zamudio



J. Dupré



A. Bellosguardo