Astrochemistry @ INAF

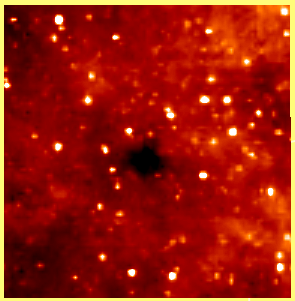
from ALMA to SKA

From Sun-like to high-mass star formation

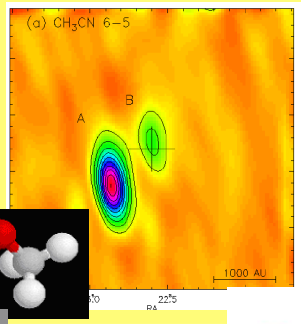
M. Beltrán, R. Cesaroni, V. Rivilla
C. Codella, L. Podio, E. Bianchi
F. Fontani, L. Testi

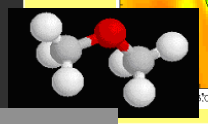
INAF, OA Arcetri

Tracing our chemical origins: pre-biotic molecules in forming Sun-like stars

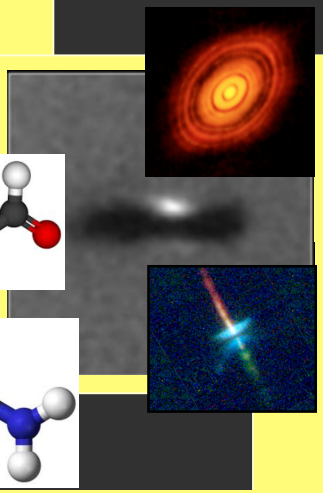


1- PRE-STELLAR PHASE: cold and dense gas
FORMATION OF SIMPLE MOLECULES



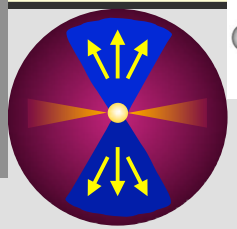


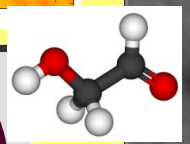
2- PROTOSTELLAR PHASE: collapsing, warm dense gas
FORMATION OF COMPLEX MOLECULES

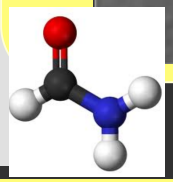


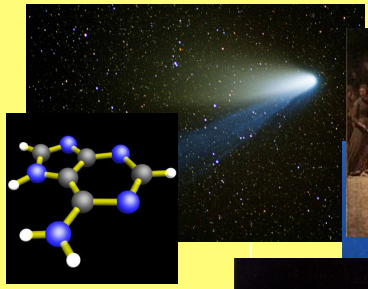
3- PROTOPLANETARY DISK PHASE:
cold and warm dense gas
SIMPLE & COMPLEX MOLECULES

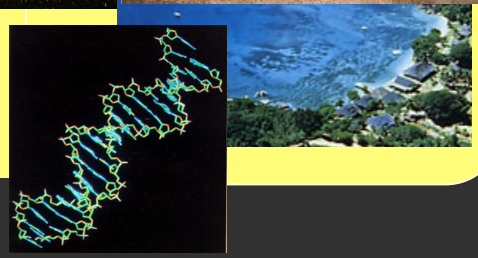
We need spatial resolutions of
< 50 AU:
350 mas @ Taurus;











4- PLANETESIMALS FORMATION : grains agglomeration

5- PLANETS FORMATION AND THE "COMETS/ASTEROIDES RAIN"
CONSERVATION AND DELIVERY OF OLD MOLECULES + LIFE

What is the role of the pre-solar chemistry in the present Solar System chemical composition?

Tracing our chemical origins: pre-biotic molecules in forming Sun-like stars

In the last years:
1 TD, 6 post-docs, 2 PhD students, 1 master student;
<u>Fundings:</u> AstroFIt, PRIN-INAF: JEDI; Premiale iALMA; ASI-Herschel

Need of subarcsec Large Programs as PIs
INAF should (keep) join(ing) international consortia managing the best facilities: ALMA-Band 2-3 & IRAM-NOEMA !

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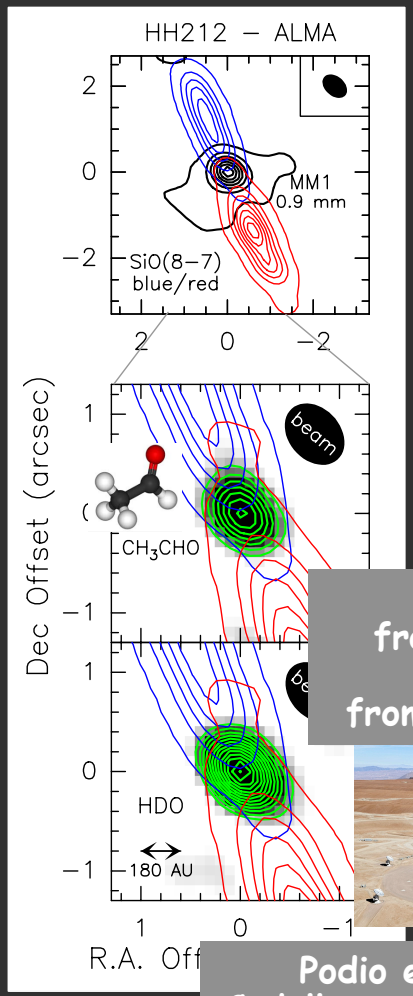
20 referred papers in the last 8 years on Astrochemistry @ Sun-like stars led by Arcetri

Pre-biotic molecules in forming Sun-like stars: Highlights !



Podio et al. (2015)
Codella et al. (2014, 2015)

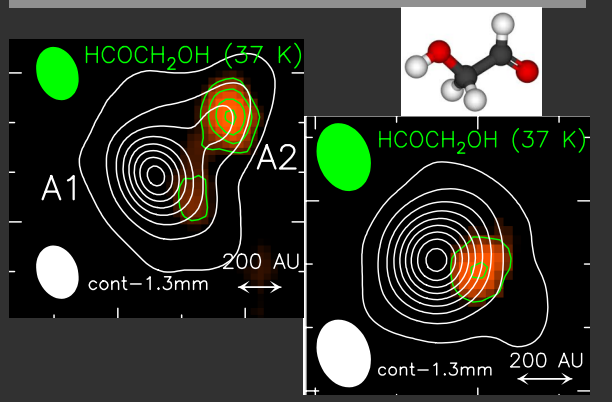
Water
from the disk wind
iCOMs
from the forming disk

iCOMs are key tools to observe the fundamental processes (accretion, ejection) sculpting the cradle where a star (and its planetary system) is going to form

….and viceversa….

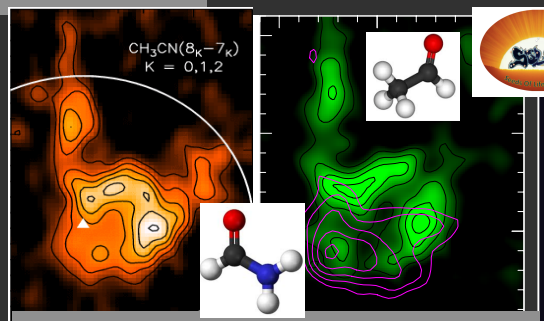
The jet/disk protostellar system is the ideal place to understand when the seeds of life form

Coeval sources; protostellar multiplicity

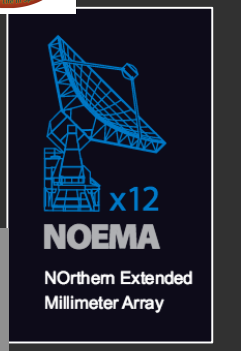


iCOMs chemical differentation on Solar System scales

Santangelo et al. (2015)
De Simone et al. (2016)



Fontani et al. (2014)
Bianchi et al. (2016)
Codella et al. (2016)



The future (I)

The FAUST synergy
Fifty AU Study of Protosun Analogues
ALMA Large Program (and more…)

S. Yamamoto (Tokyo University)
N. Sakai (RIKEN)

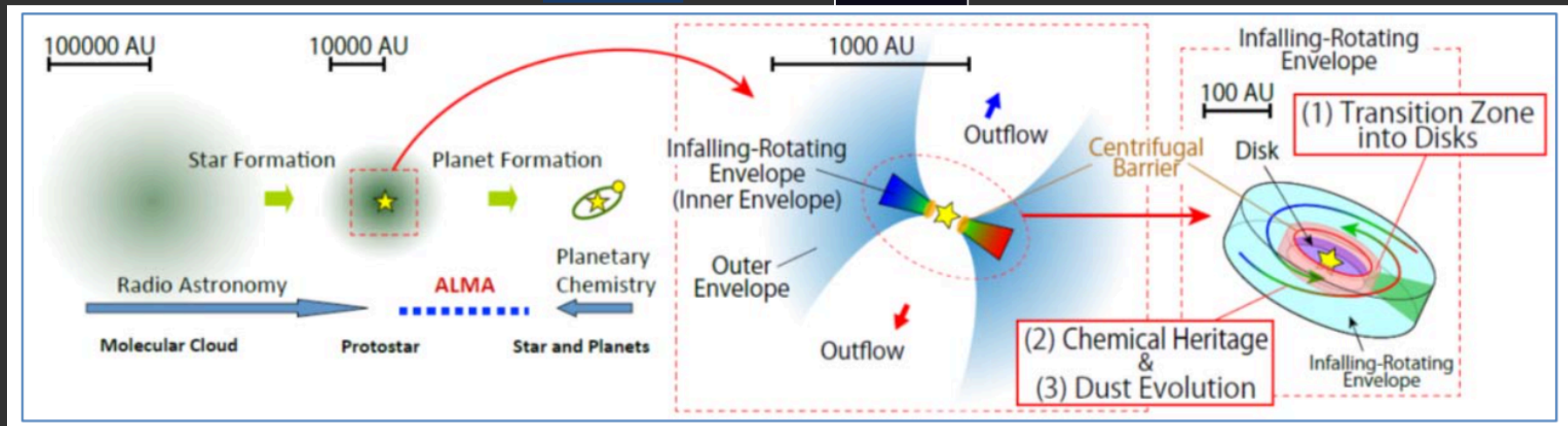
C. Codella (INAF-Arcetri)
C. Ceccarelli (IPAG, Grenoble)

C. Chandler (NRAO)

FAUST

ALMA

x12 NOEMA
NOrthern Extended Millimeter Array



The future (II)

Need to combine observations, chemical modelling, and laboratory measurements.

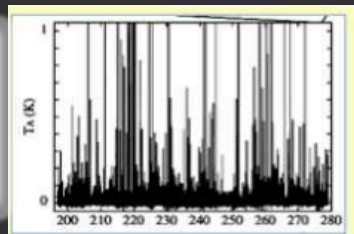
DREAMS

SCUOLA NORMALE SUPERIORE

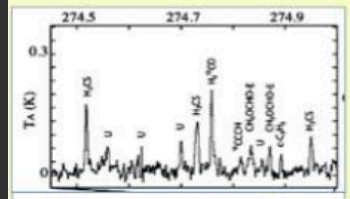
Seeds Of Life In Space

Active collaboration SNS@Pisa – SOLIS@Arcetri, plus the Bologna (Ciamician) and Perugia Universities to model COMs in gas phase

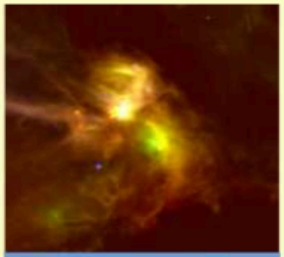
….and with the Catania Observatory for grain chemistry



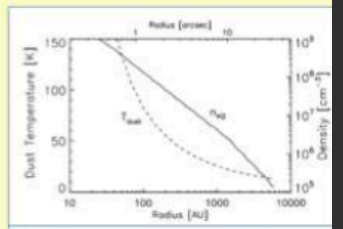
STEP 1: Observe the spectrum of the source.
Tool: telescope



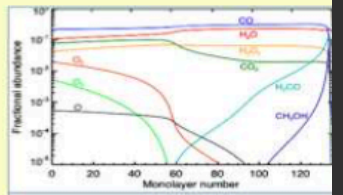
STEP 2: Identify the lines and species.
Tool: spectroscopic data



ASTROPHYSICAL OBJECT



STEP 3: Derive the physical and chemical structure.
Tool: collisional coefficients

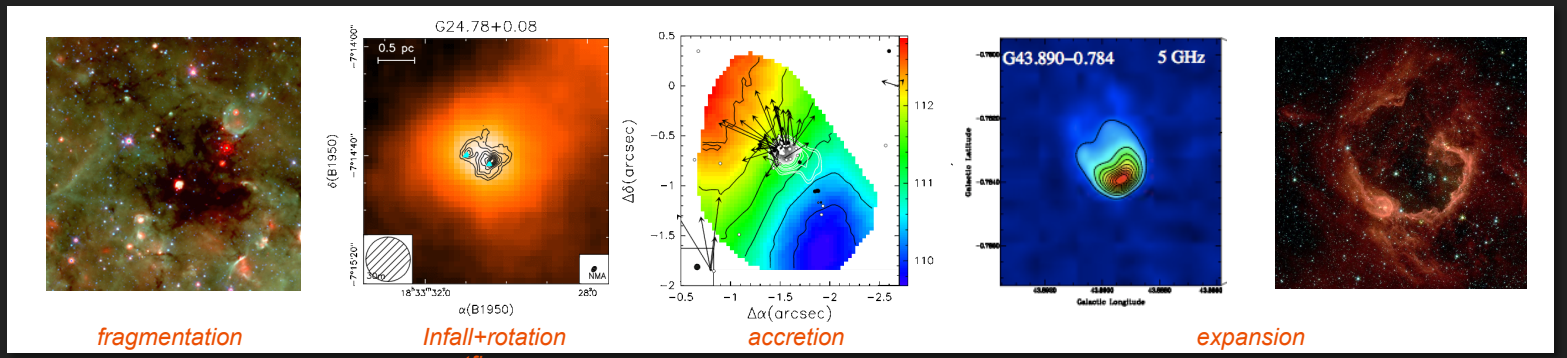


STEP 4: Understand the chemical structure.
Tool: reaction pathways and rate coefficients

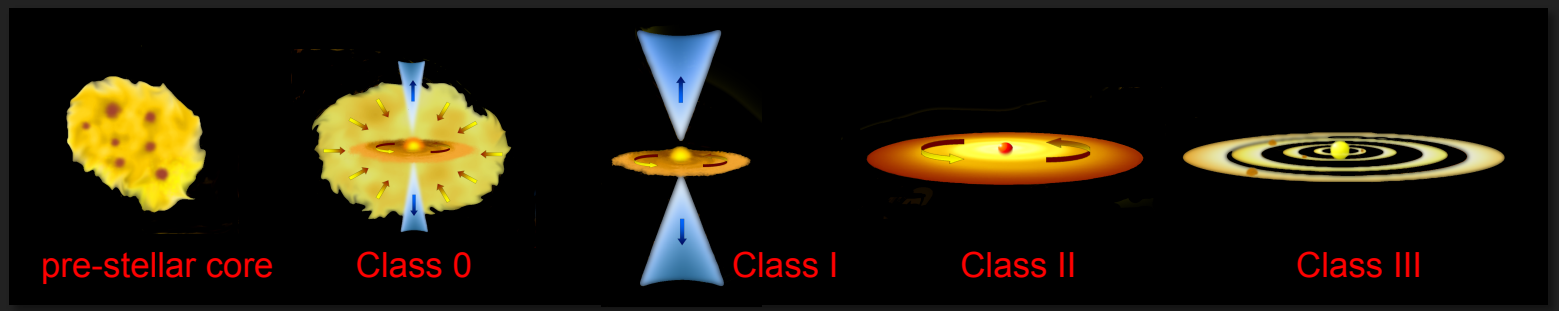
Barone et al. (2015)
Balucani et al. (2015)
Codella et al. (2016)
PRIN-MIUR

HIGH-MASS STAR FORMATION

IR-dark cloud → **Hot molecular core** → **HC HII** → **UC HII** → **Extended HII**

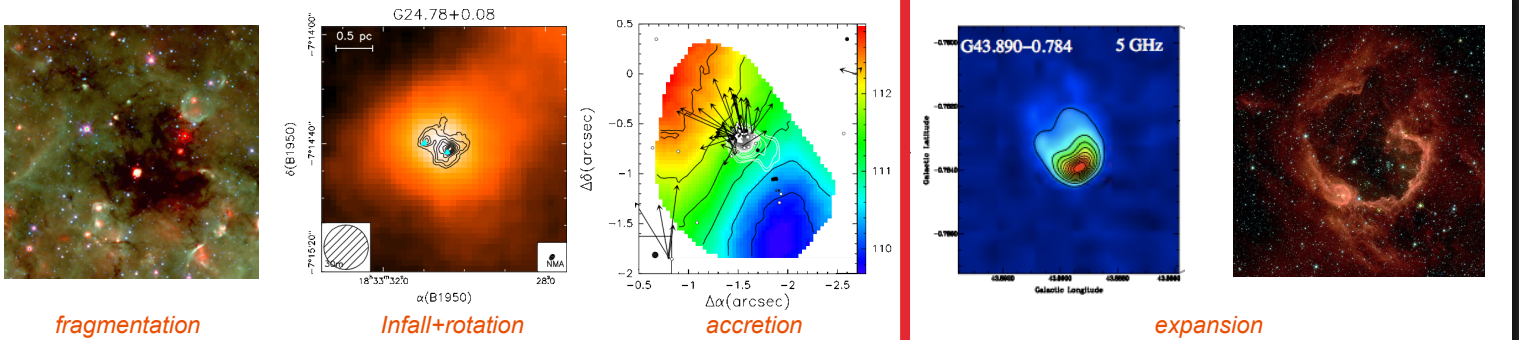


fragmentation — *Infall+rotation +outflow* — *accretion* — *expansion*



HIGH-MASS STAR FORMATION

IR-dark cloud | Hot molecular core | HC HII | UC HII | Extended HII



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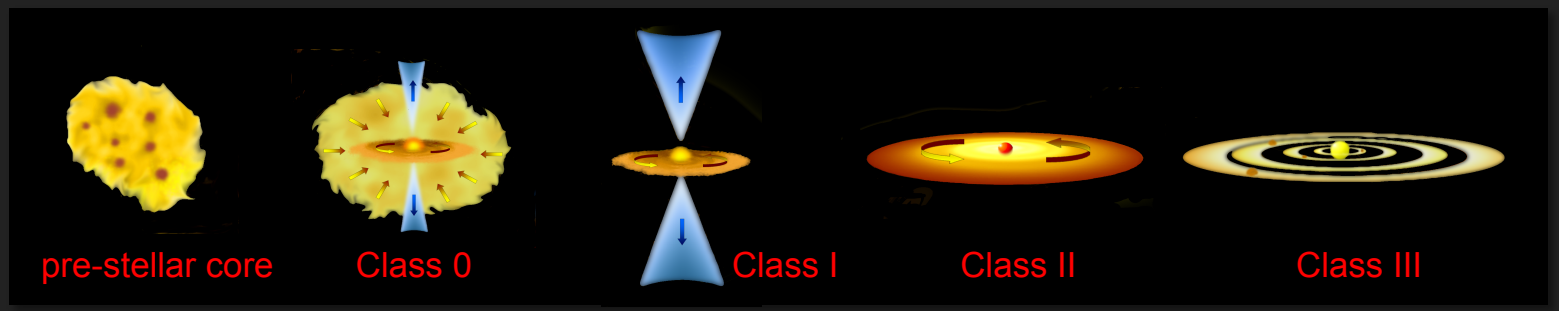
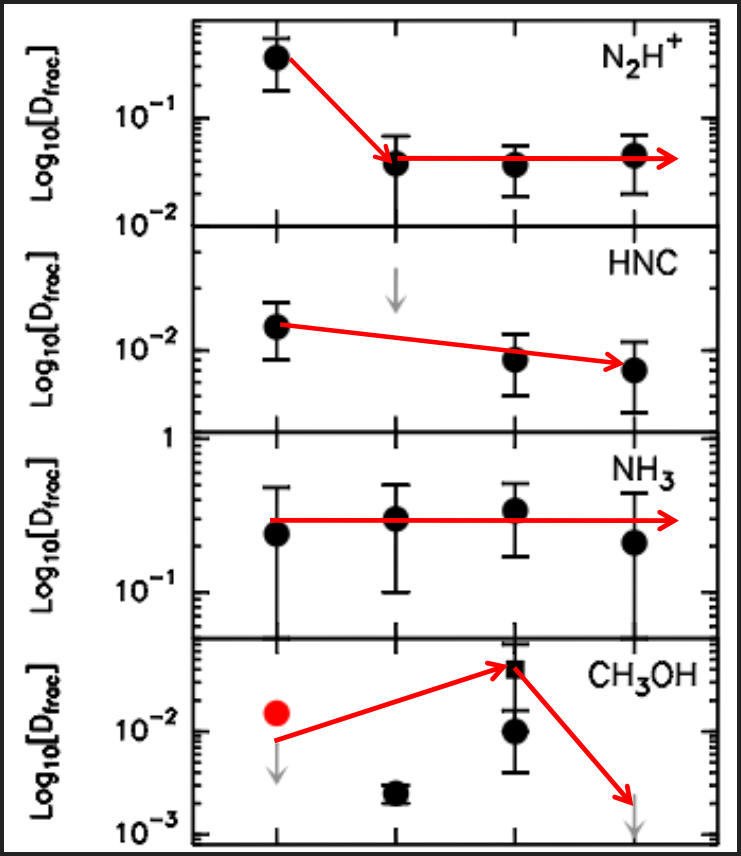


pre-stellar core | Class 0 | Class I | Class II | Class III

EVOLUTIONARY TRACERS?

HIGH-MASS CORES

time

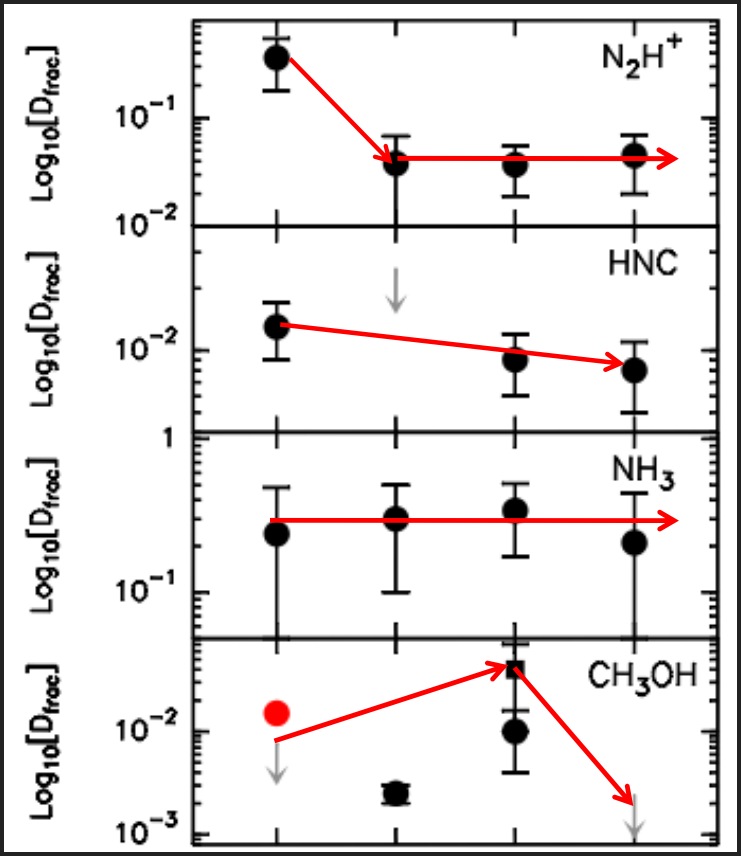


Fontani+ (2015)

EVOLUTIONARY TRACERS?

HIGH-MASS CORES → *time*

LOW-MASS CORES ← *time*



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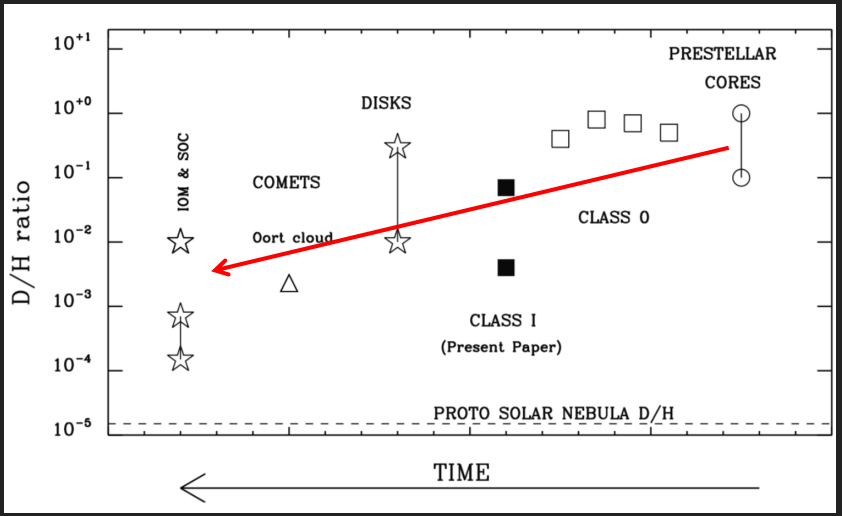
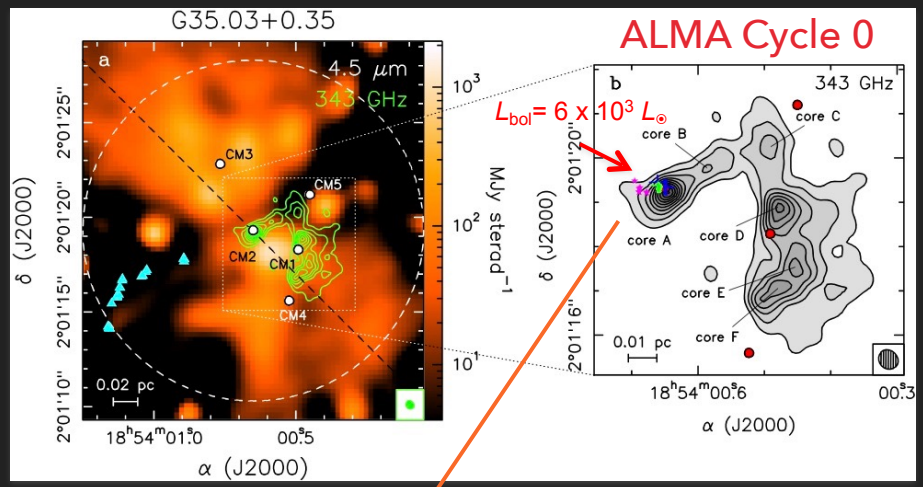


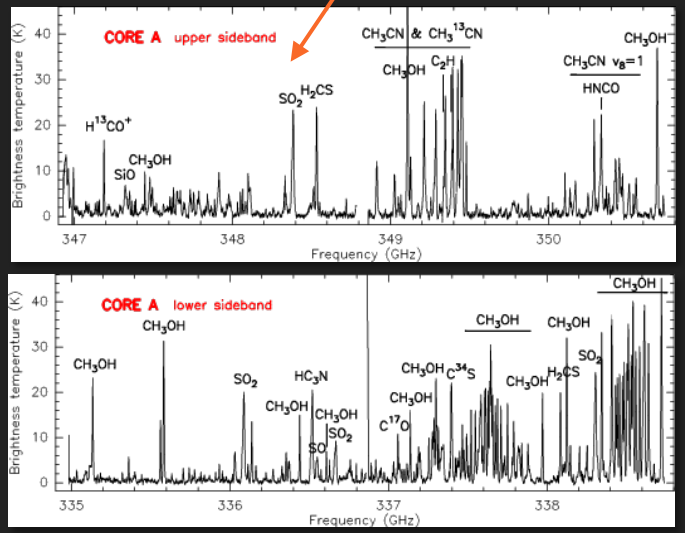
Bianchi+ (2015)

CHEMISTRY + KINEMATICS

G35.03+0.35



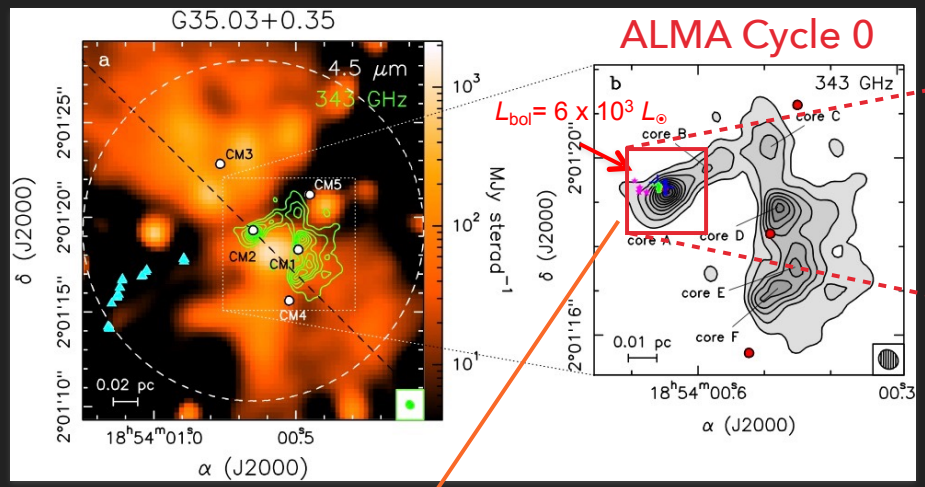
Beltrán+ (2014)



- 6 atoms
  - Methyl cyanide = CH_3CN
  - Methanol = CH_3OH
- 7 atoms
  - Acetaldehyde = CH_3CHO
  - Vinyl Cyanide = C_2H_3CN
- 8 atoms
  - Methyl formate = CH_3OCHO
  - Glycolaldehyde = $CH_2(OH)CHO$
- 9 atoms
  - Dimethyl ether = CH_3OCH_3
  - Ethanol = C_2H_5OH
  - Ethyl cyanide = C_2H_5CN
- 10 atoms
  - Ethylene glycol = $(CH_2OH)_2$
  - Acetone = CH_3COCH_3
- 11 atoms
  - Ethyl formate = CH_3CH_2OCHO

CHEMISTRY + KINEMATICS

G35.03+0.35



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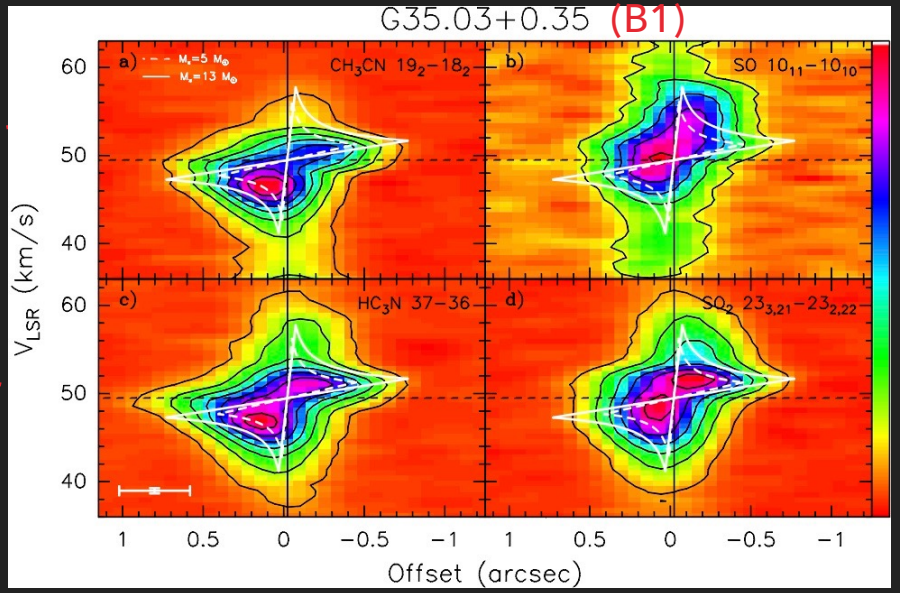
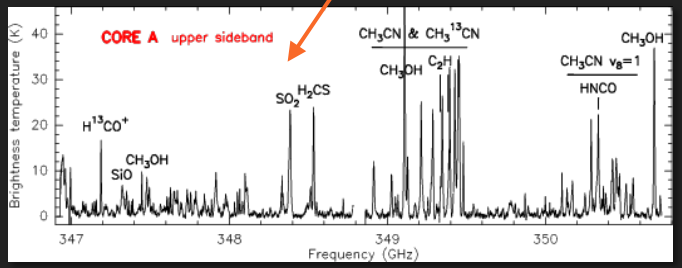
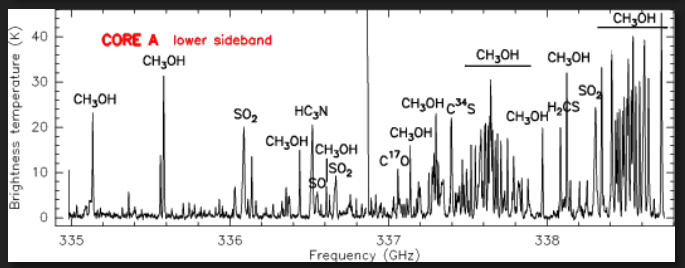
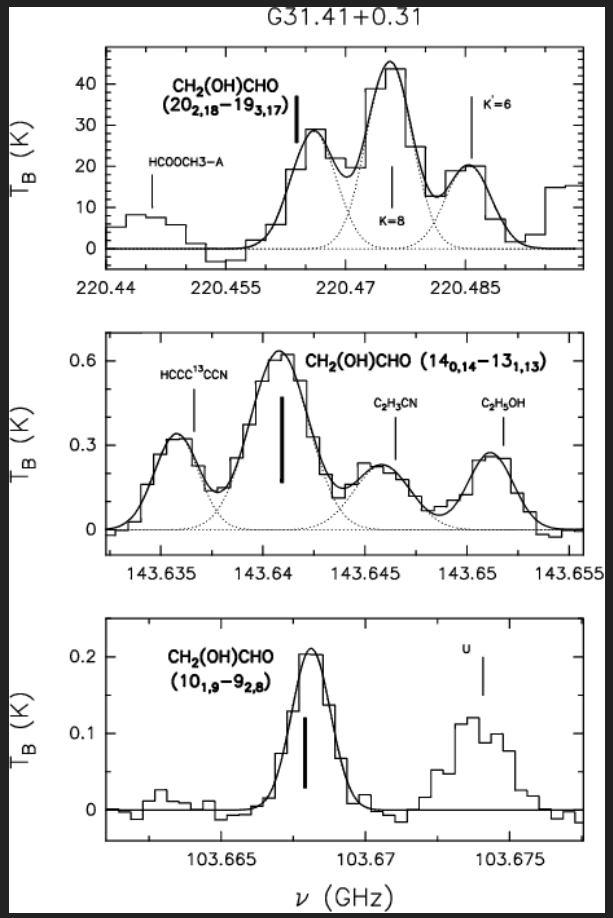


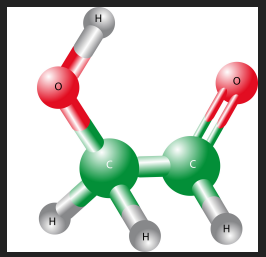




FIRST DETECTIONS

Glycolaldehyde: simplest monosaccharide sugar





Beltrán+ (2009)

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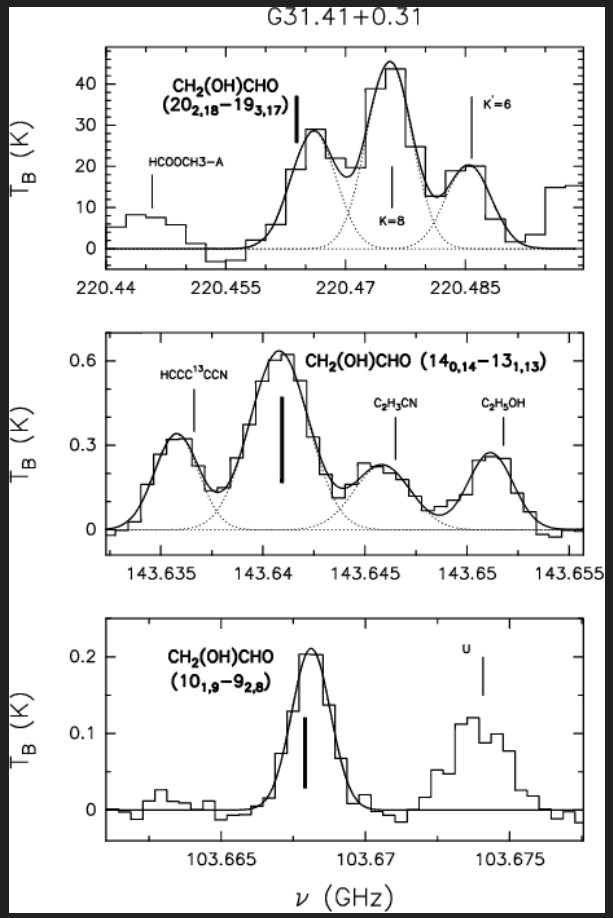
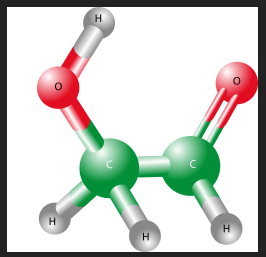
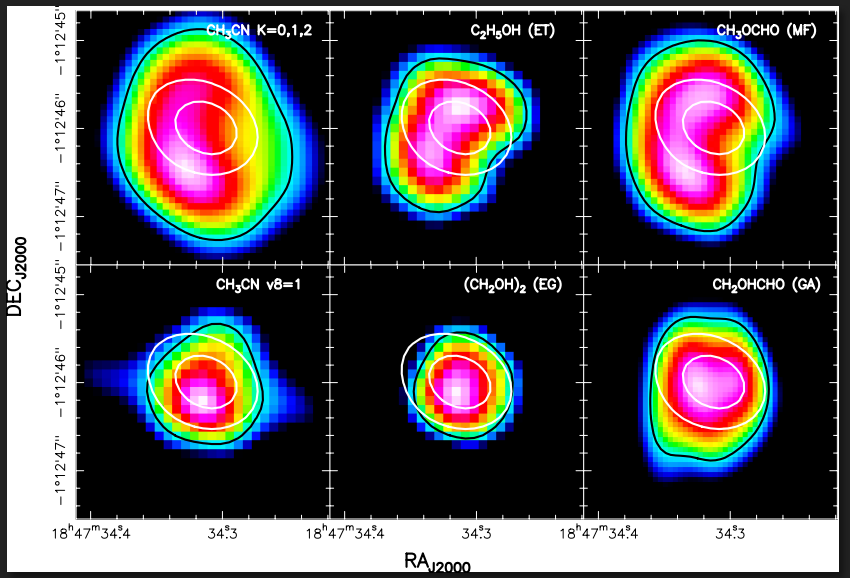
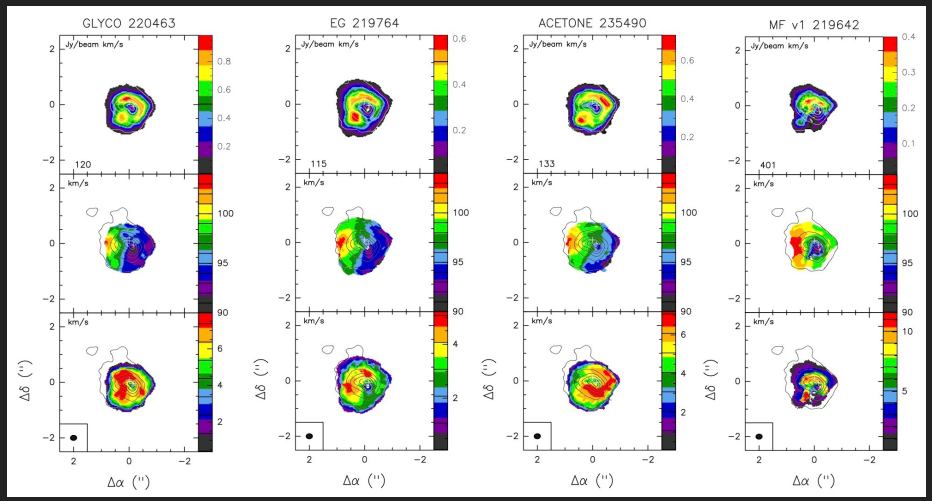




Beltrán+ (2009)



Rivilla, Beltrán+ (submitted)



Beltrán+ (in preparation)

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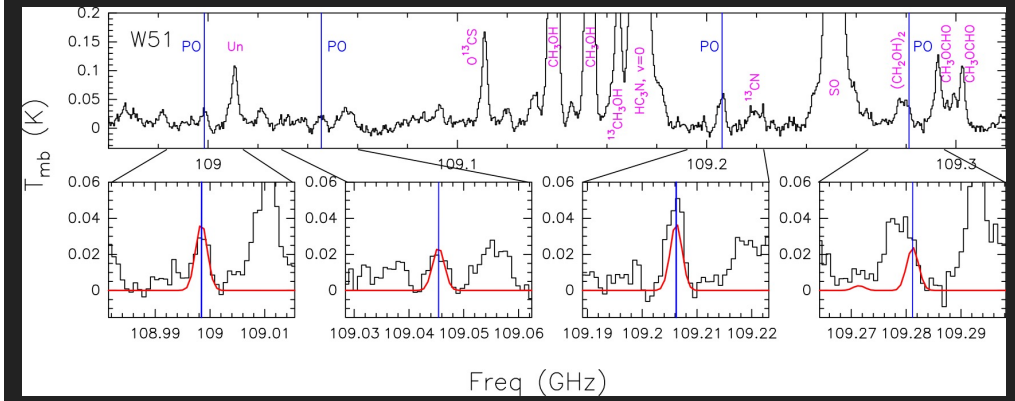
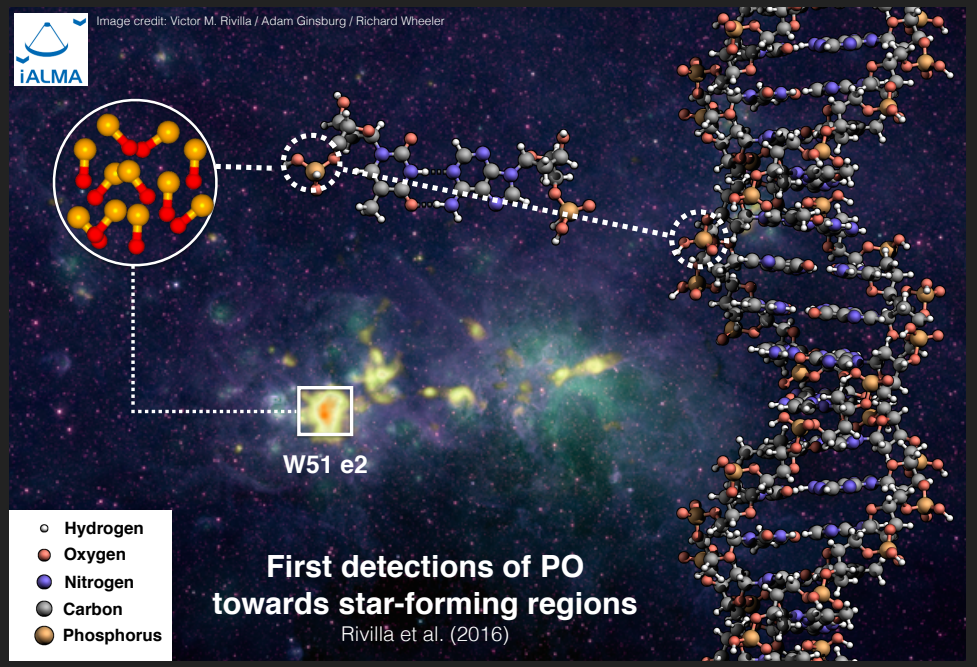


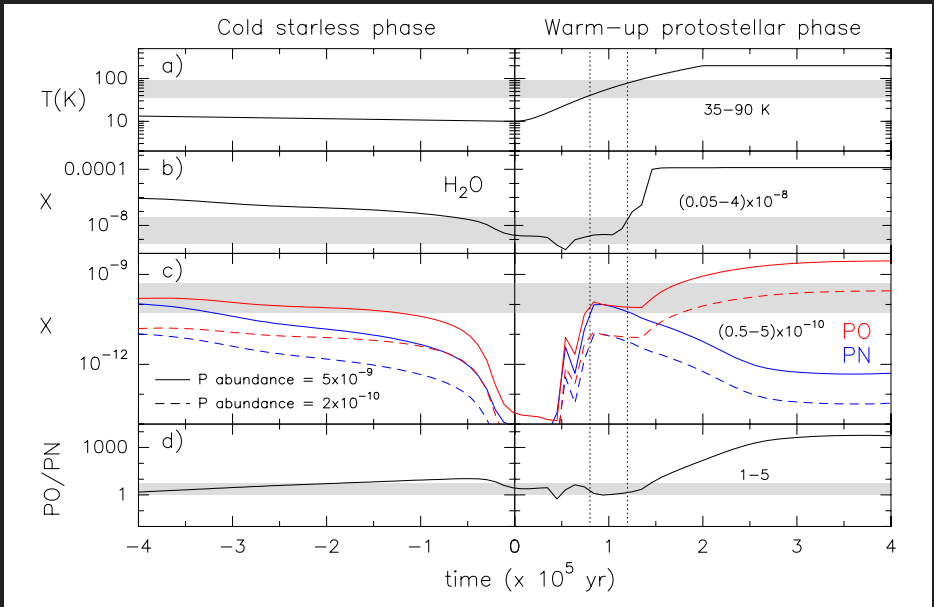
PO: structure and energy transfer in cells



Rivilla+ (2016)

P is one of the essential components of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), phospholipids (the structural components of all celullar membranes) and the adenosine triphosphate (ATP) molecule, from which all forms of life assume energy

FIRST DETECTIONS



Rivilla+ (2016)

PN detections: see also Fontani+ (2016)

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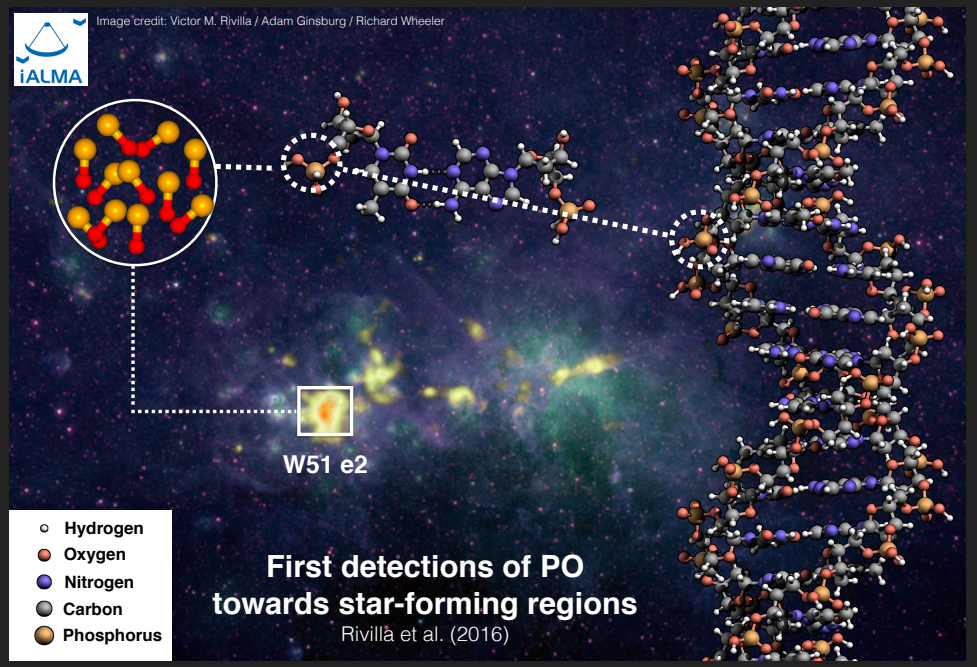

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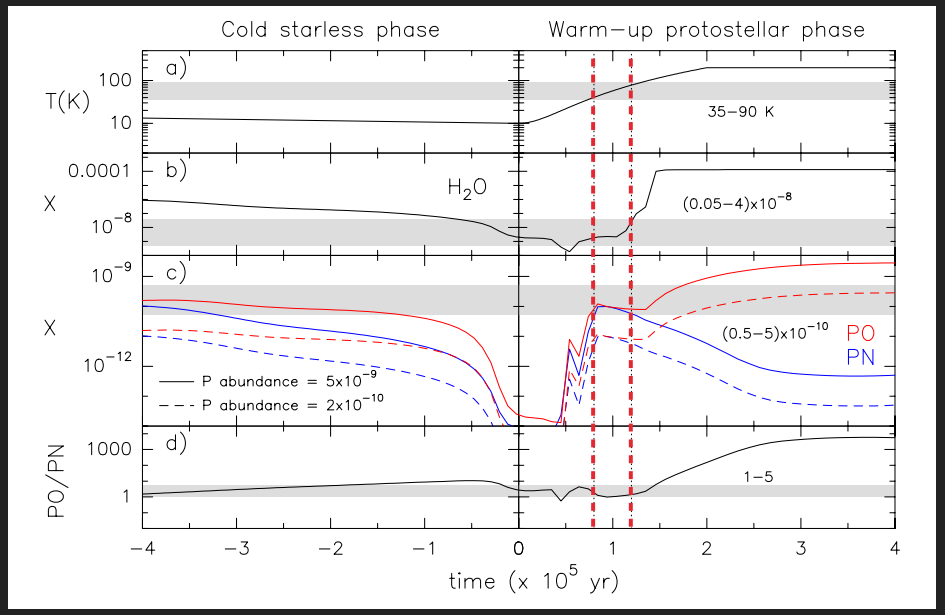

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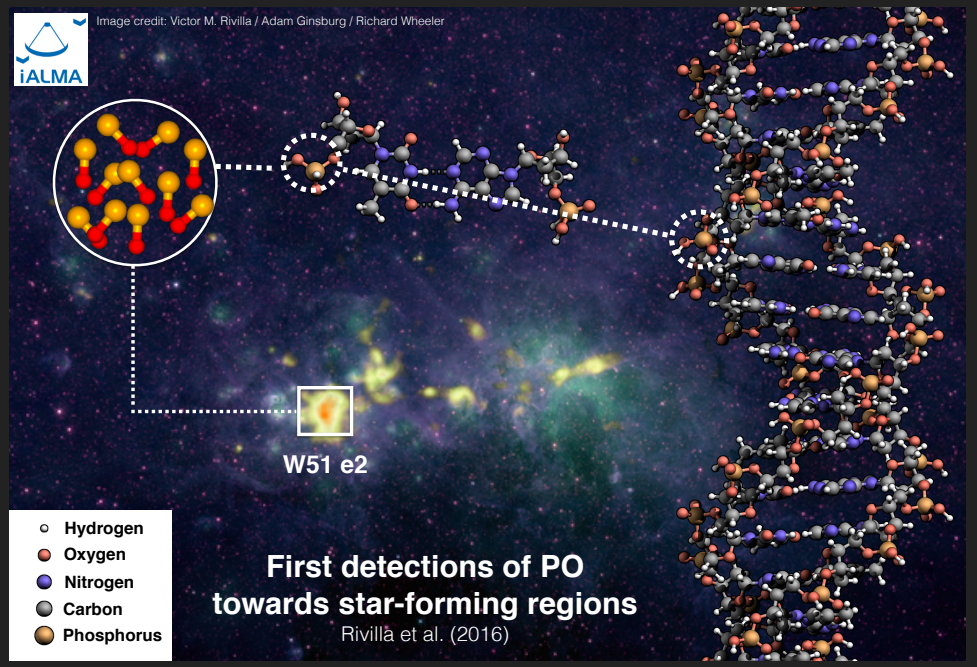

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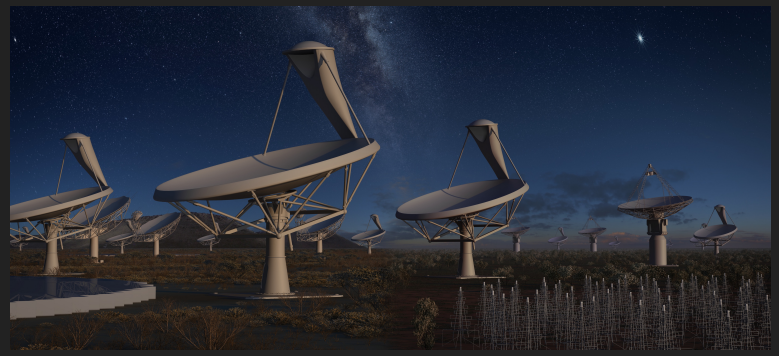
PRESENT AND FUTURE

Pre-biotic and deuterium chemistry in all star formation environments: from stars to planets

- Science case for ALMA Band 2 and Band 2+3 new receiver (67-116 GHz) 2020?
  - Italian level: Science Working Package Premiale iALMA; Beltrán+ (2015)
  - European level: Fuller+ (2016)

- Science Working Group The Cradle of Life: Next Generation Very Large Array (1-115 GHz with ten times the effective collecting area of the VLA + ALMA, with mas resolution)
  - Key Science Project "Complex organic molecules in Hot Molecular Cores" Isella+ (2015)

- Science case for SKA (50 MHz-14 GHz with 5 times the sensitivity of the VLA and 5 times its resolution) 2020
  - "Complex organic molecules in protostellar environments in the SKA era" Codella+ (2015)



Design: Jesús D. García Guijarro

Fractionation of isotopes in space: from the solar system to galaxies

10-13 October 2016
Arcetri, Florence, Italy
Department of Physics and Astronomy

SCIENTIFIC ORGANISING COMMITTEE

- **Maite Beltrán**
  INAF, Osservatorio di Arcetri (co-chair)
- **Francesco Fontani**
  INAF-Osservatorio di Arcetri (co-chair)
- **Ted Bergin**
  University of Michigan
- **Dominique Bockelée-Morvan**
  Observatoire de Paris
- **Paola Caselli**
  Max-Planck-Institute für extraterrestrische Physik
- **Claudio Codella**
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- **Sergio Martín**
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- **Thushara Pillai**
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- **Francesco Fontani**
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- **Patrizia Braschi**
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- **Víctor M. Rivilla**
  INAF-Osservatorio di Arcetri
- **Roberto Baglioni**
  Università degli Studi di Firenze

INVITED SPEAKERS

- **Sandra Brünken**
  Physikalisches Institut, Universitat zu Köln
- **Charlotte Vastel**
  Institut de Recherche en Astrophysique et Planétologie de Toulouse
- **Eva Wirström**
  Chalmers University of Technology
- **Cecilia Ceccarelli**
  Institute de Planétologie et d'Astrophysique de Grenoble
- **Vianney Taquet**
  Leiden University
- **Chunhua Qi**
  Harvard-Smithsonian CfA
- **Ilsedore Cleeves**
  Harvard-Smithsonian CfA
- **Nicolas Biver**
  Observatoire de Paris
- **Ursina Calmonte**
  Universität Bern
- **Steven Charnley**
  NASA Goddard Space Flight Center
- **Christian Henkel**
  Max-Planck-Institut für Radioastronomie
- **Serena Viti**
  University College London
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