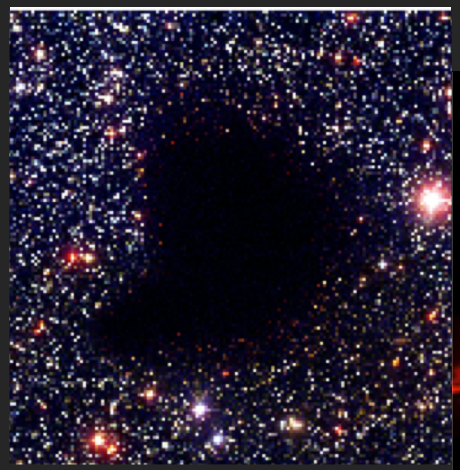
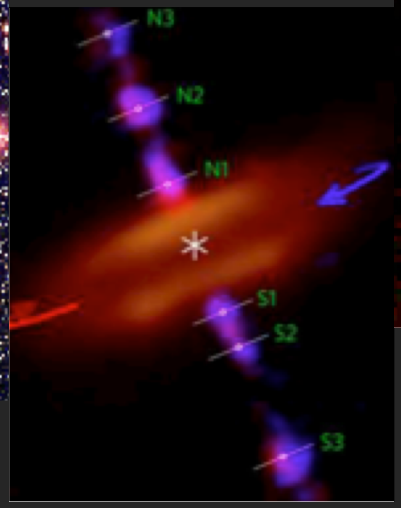
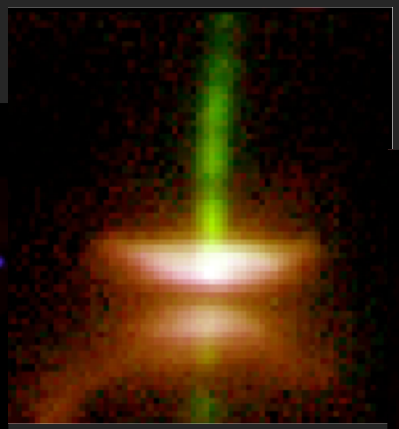
Jet-driven and accretion shocks as factories of interstellar complex organic molecules around Sun-like precursors

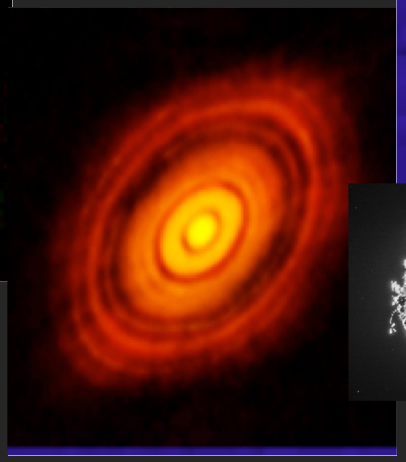
C. Codella (INAF, OA Arcetri)

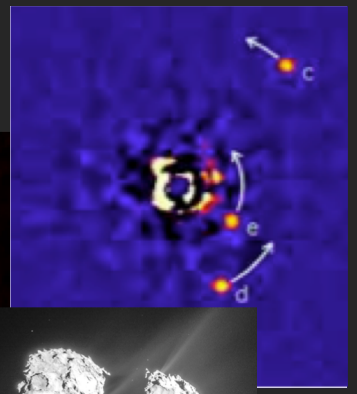
The formation of a Sun-like star

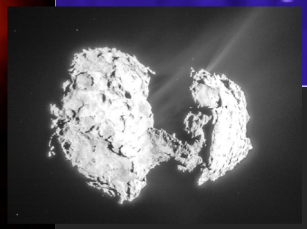




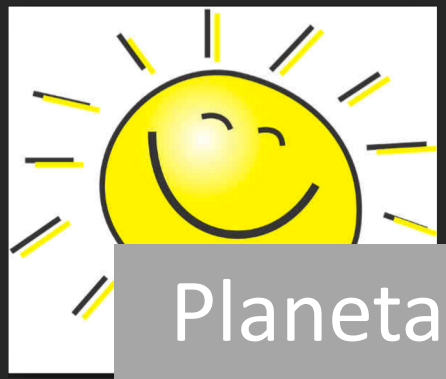






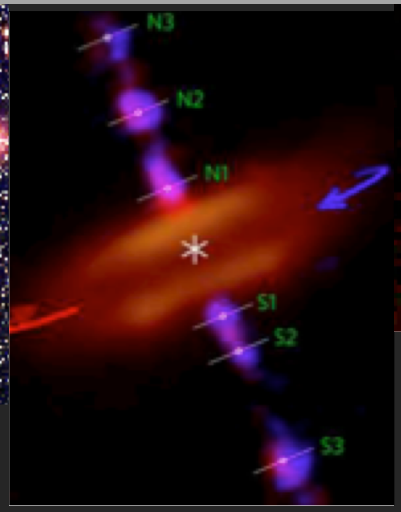


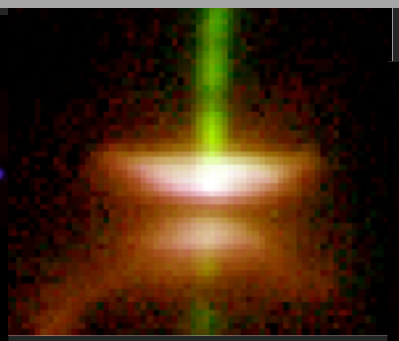
Time

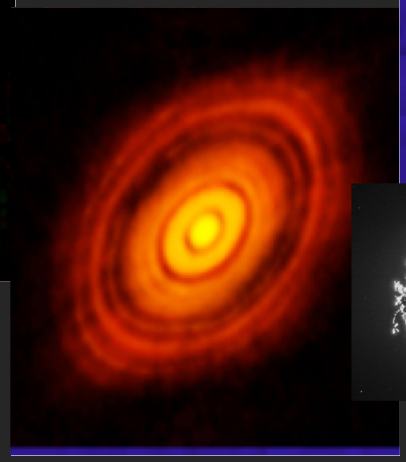


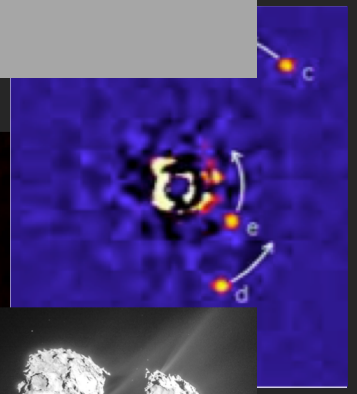
The formation of a Sun-like star
The formation of a Solar System
The emergency of life

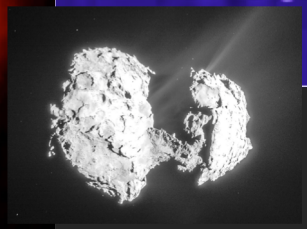
Planetary composition: disk chemical **reset** or **inheritance** ?



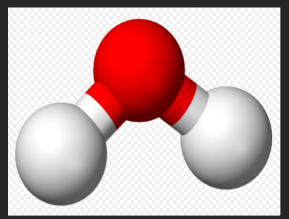


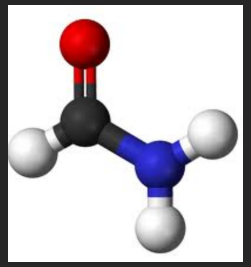


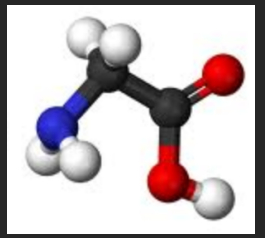


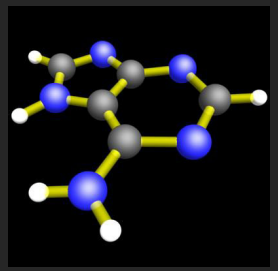


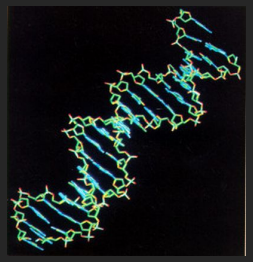
Time





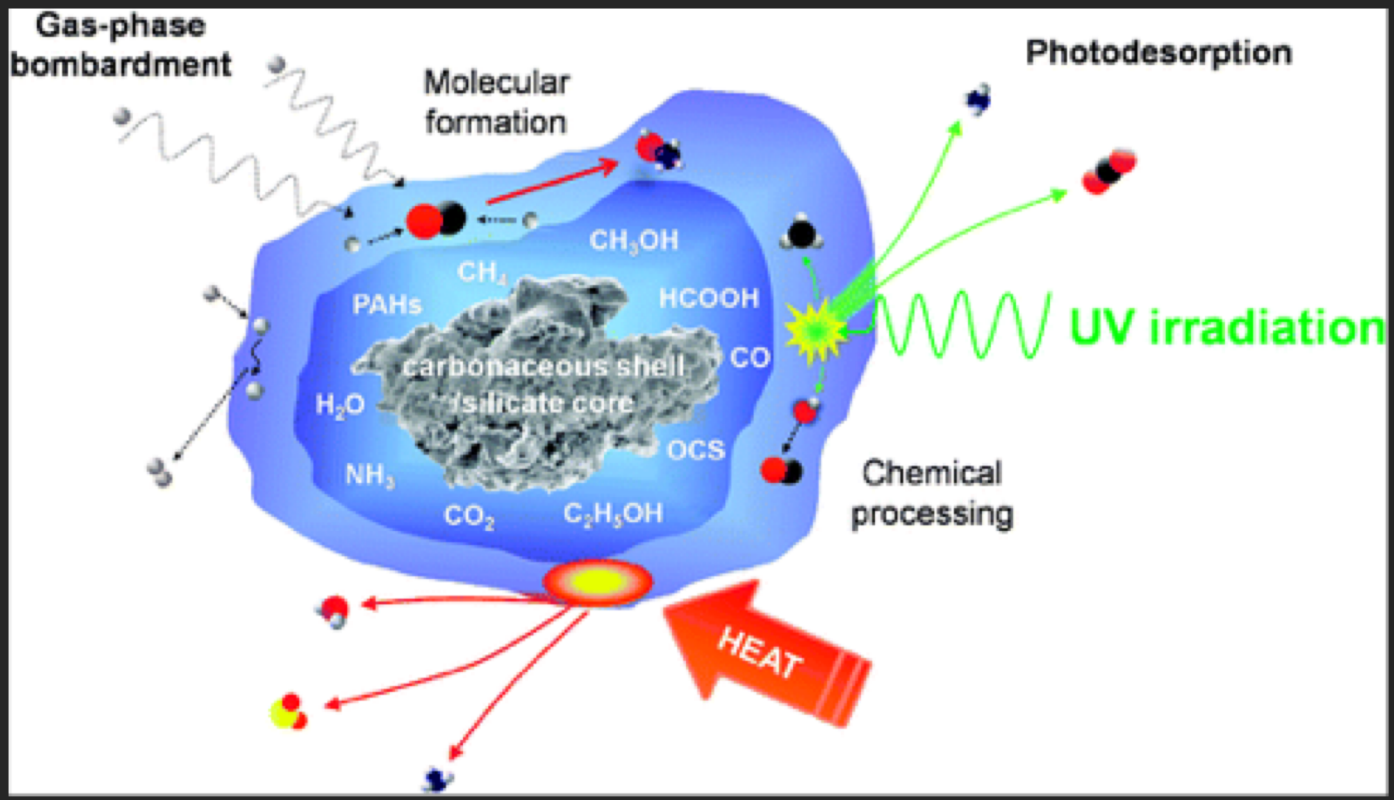






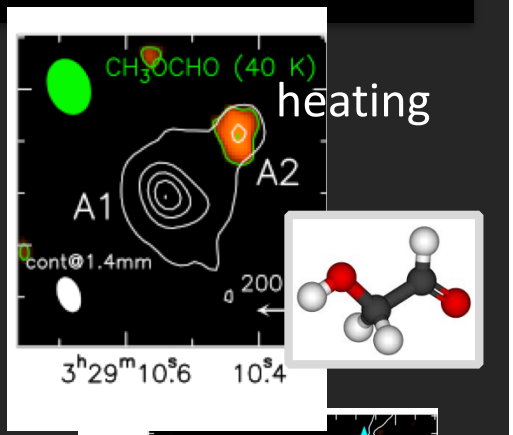
The formation of iCOMs (interstellar Complex Organic Molecules)

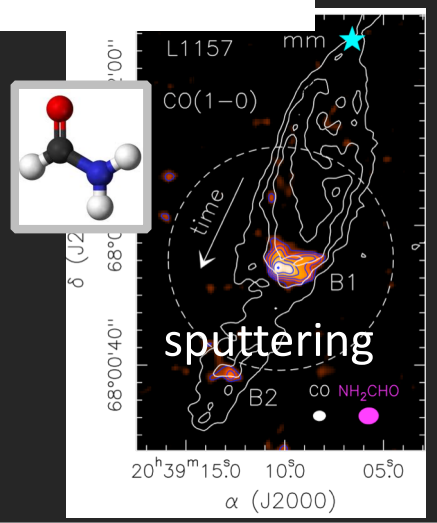
iCOMs are formed on ices and then released into the gas phase?



Or are daughter species, i.e. are formed in gas phase following the release of parent species such as methanol?

and C-chains.....

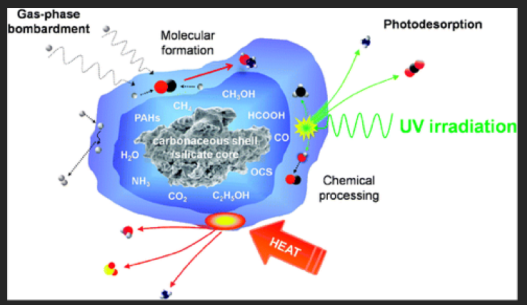




De Simone+ 2017
Codella+ 2017

PROTOSTELLAR SHOCKS !

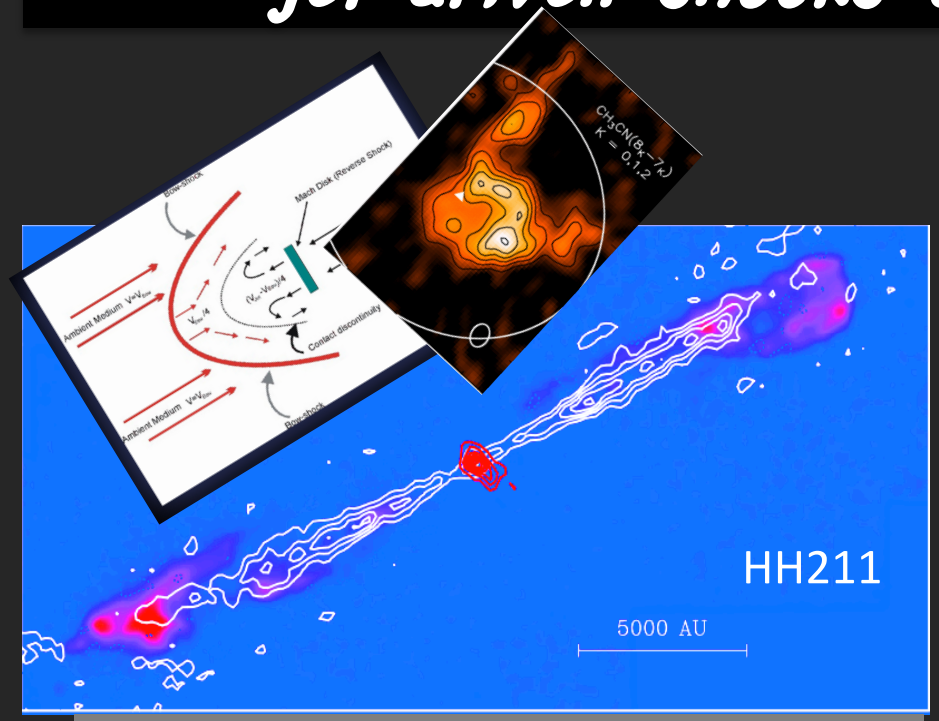
iCOMS factories



Plus:
Si-, S-, P-, Cl-bearing
D/H, Ions, ….

Why?
Because shocks sputter/shutter dust grains

Two main shock families: jet-driven shocks and accretion shocks



Gueth & Guilloteau (1992), Codella et al. (2009)

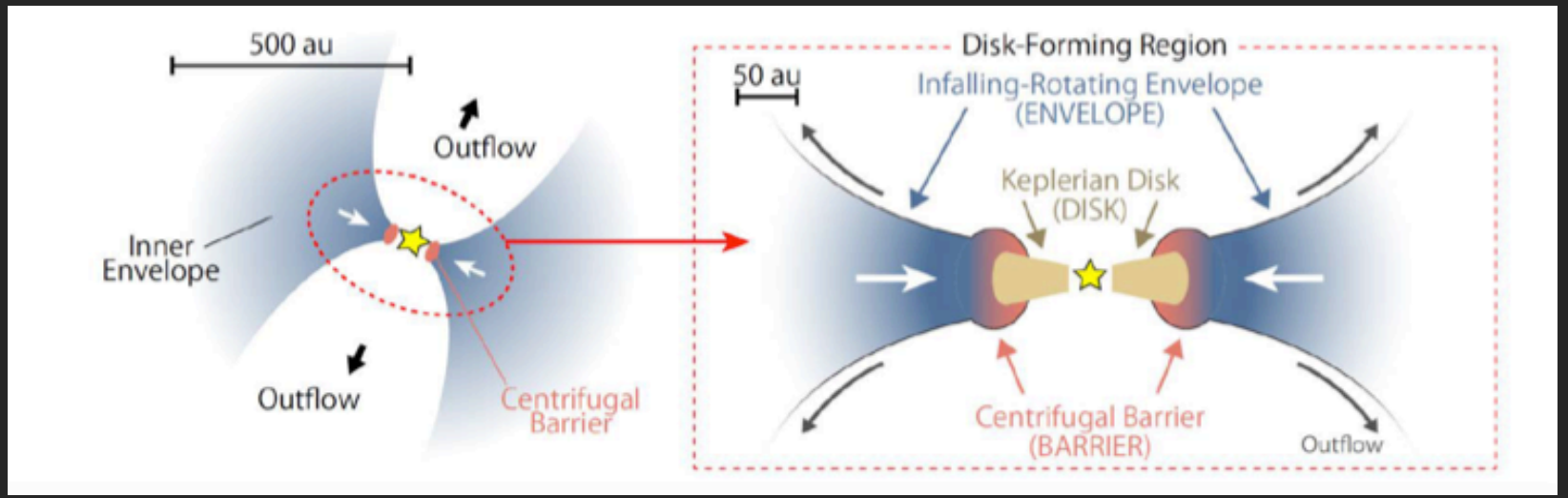
Rapid heating (from ~10 K to a few 1000 K) and compression of the gas → "Shock chemistry"

High-T chemistry: endothermic reactions

Ice sublimation & grain disruption

The gas acquires a chemical composition distinct from that of the unperturbed medium

e.g. Sakai et al. (2014ab; 2017)



Tracing our chemical origins: Astrochemistry of forming Sun-like star

Genesis - SKA

iALMA

CHESS

Herschel

2009

A S A I

IRAM 30-m

IRAM PdBI

CALYPSO

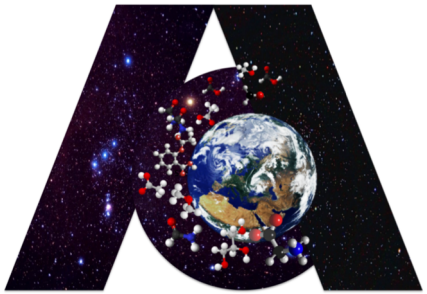
In 10 years:
1 Premiale INAF
5 Large Programs
1 Astrofit
1 PRIN-MIUR
1 PRIN-INAF
1 EU-ITN

Time

ALMA

FAUST

EU H2020 Innovative Training Network



Astro-Chemical Origins

x12 NOEMA

NOrthern Extended Millimeter Array

SOLIS

Seeds Of Life In Space

IRAM NOEMA

ALMA

2019

Volatiles evolution: Complex Organics as the building blocks of life

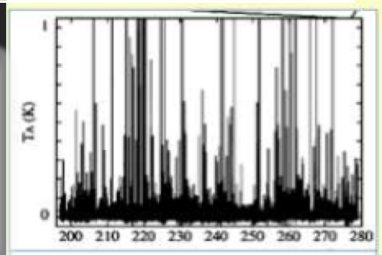
STARS IN THE CAOS

DREAMS

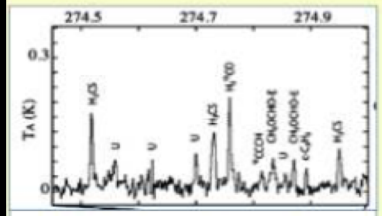
SCUOLA NORMALE SUPERIORE

Seeds Of Life In Space

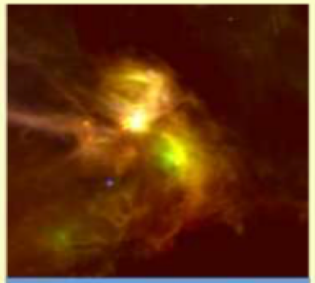
collaboration
SNS@Pisa - SOLIS@Arcetri, Bologna (Ciamician) and Perugia Universities
to model iCOMs in gas phase
PRIN-MIUR: STARS IN THE CHAOS
PRIN-INAF: GENESIS-SKA



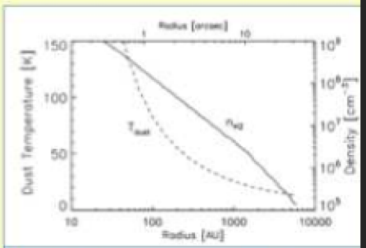
STEP 1: Observe the spectrum of the source.
Tool: telescope



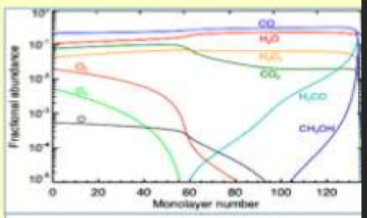
STEP 2: Identify the lines and species.
Tool: spectroscopic data



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

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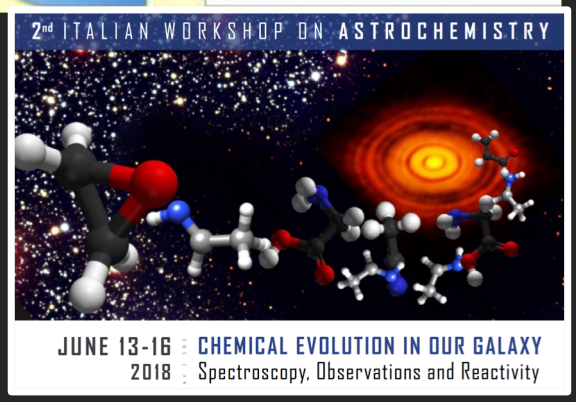
STUDIUM GENERALE CIVITATIS PERUSII A.D. MCCCVIII

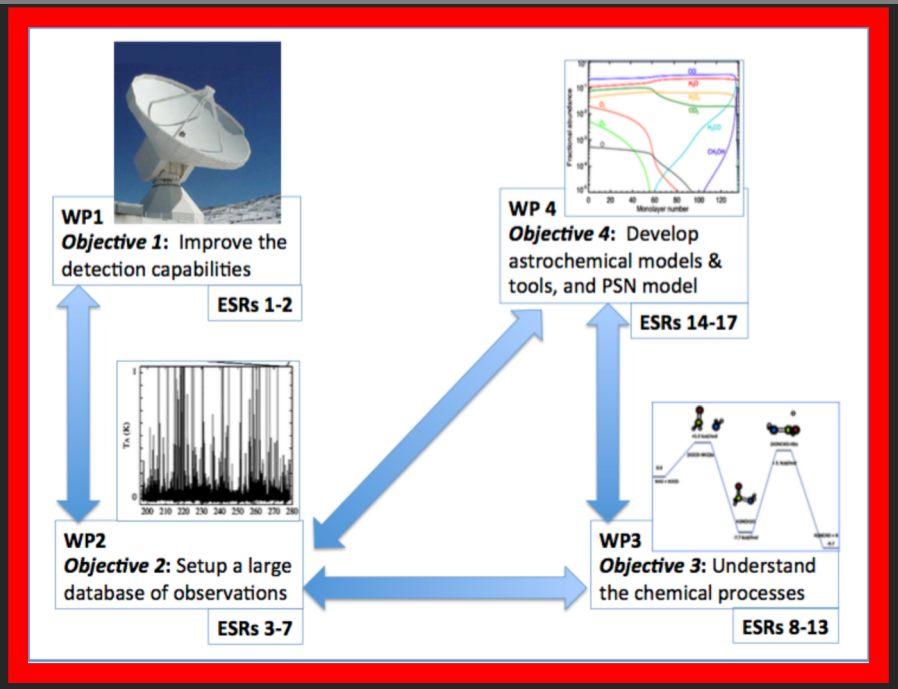


EU-ITN ACO: AstroChemical Origins

Marie Skłodowska-Curie Innovative Training Networks

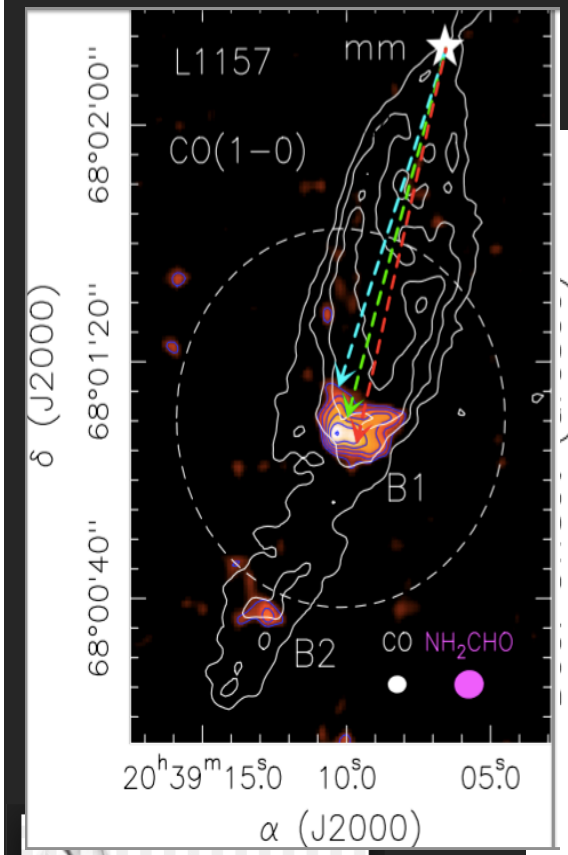
GOAL: **to unveil the early history of the Solar System by studying the chemical composition of young Solar analogs**

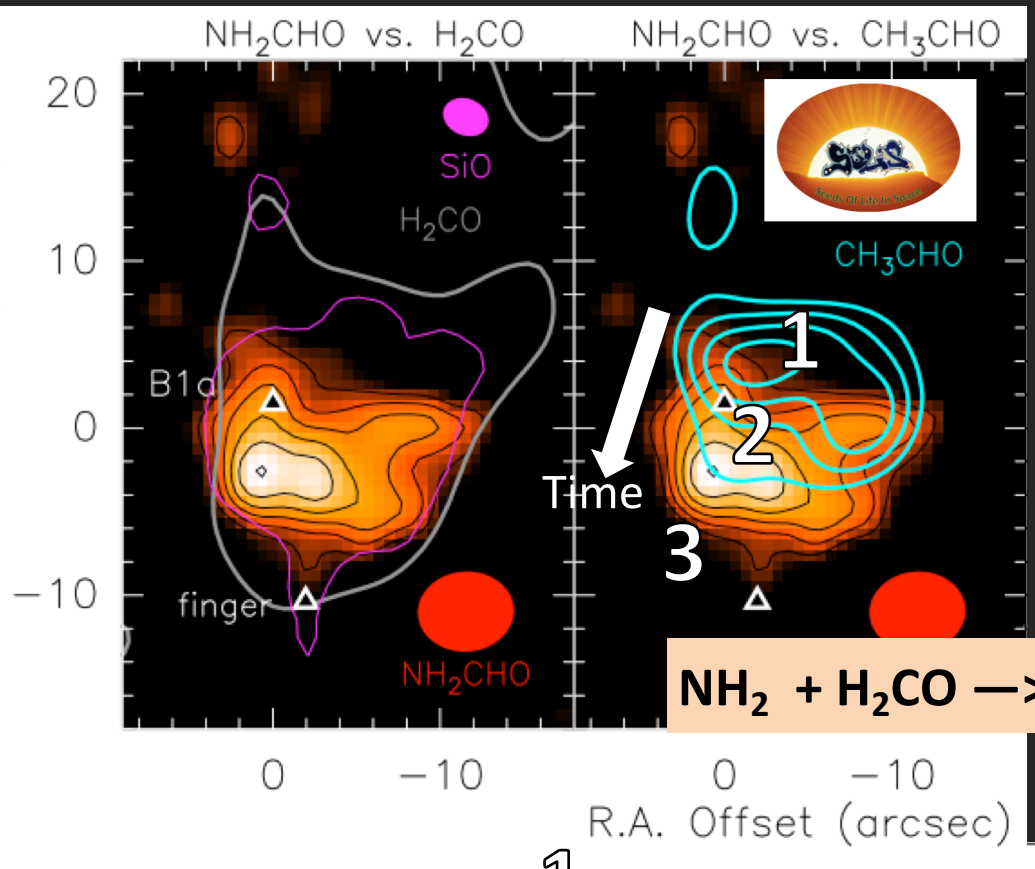
METHODOLOGY: **synergy between observers, chemists & laboratory experiments**



C. Ceccarelli (Université Grenoble)
C. Codella (INAF-Arcetri, I)
S. Viti (UCL, UK)
P. Ugliengo (UniTo, I)
A. Rimola (UBA, ES)
N. Balucani (UniPg, I)
L. Piccirillo (Manchester, UK)
C. Vastel (Touluse, FR)
P. Theulé (AMU, FR)
D. Ascenzi (UniTn, I)

NH_2CHO is anticorrelated wrt CH_3CHO



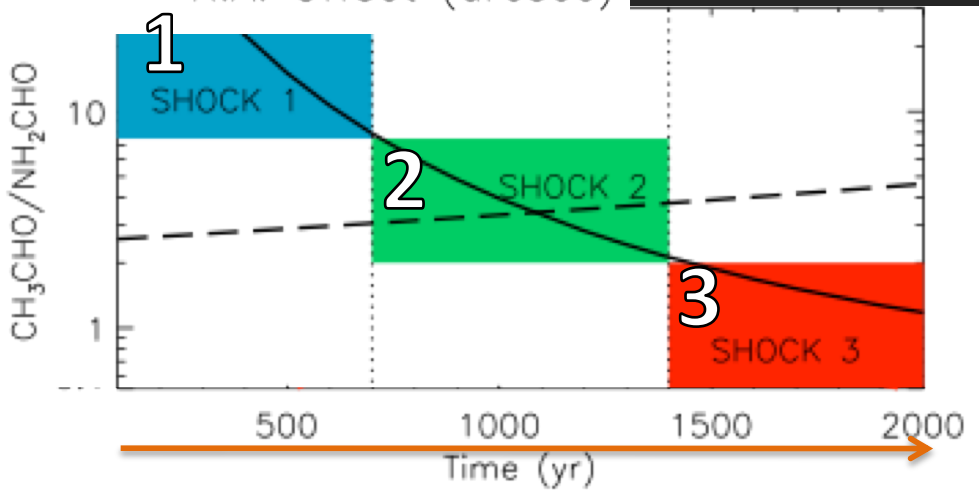


NH_2 + H_2CO —> NH_2CHO + H

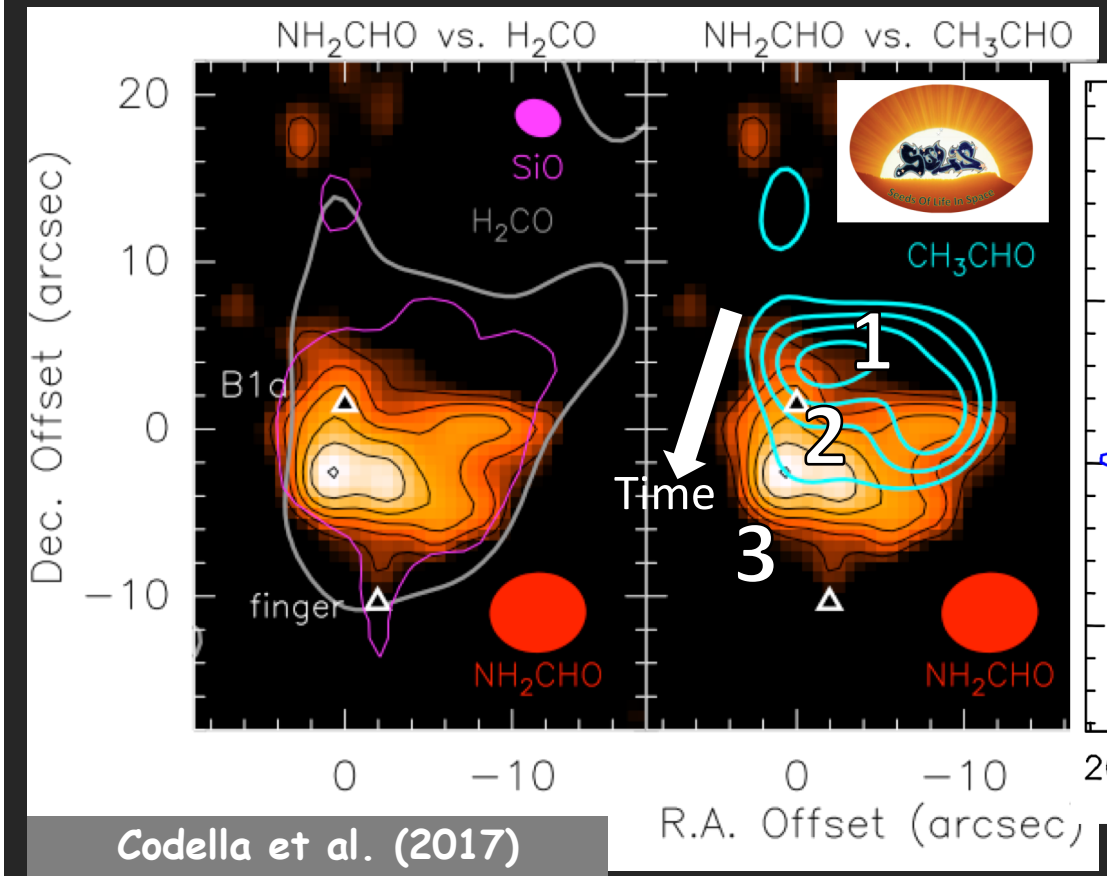
Codella et al. (2017)

The smoking gun of gas-phase at work (at least in L1157-B1)

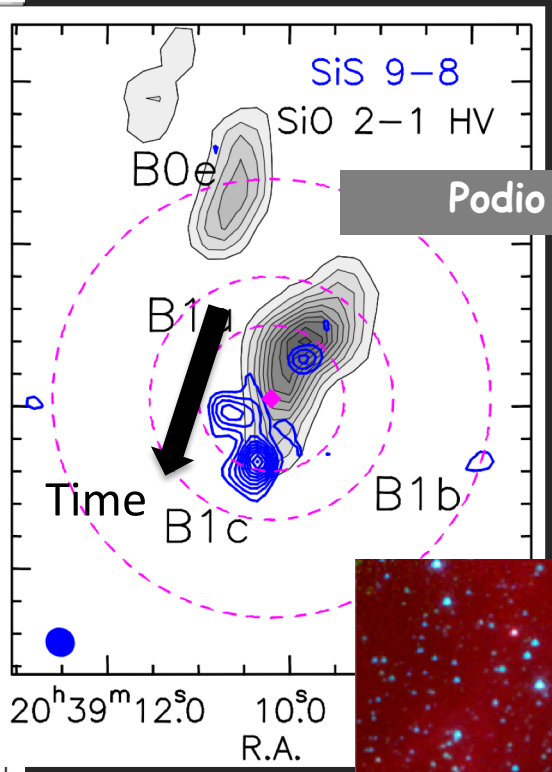
Barone et al. (2015)
Vazart et al. (2016)
Skouteris et al. (2017)



SiS is anticorrelated wrt SiO



Codella et al. (2017)

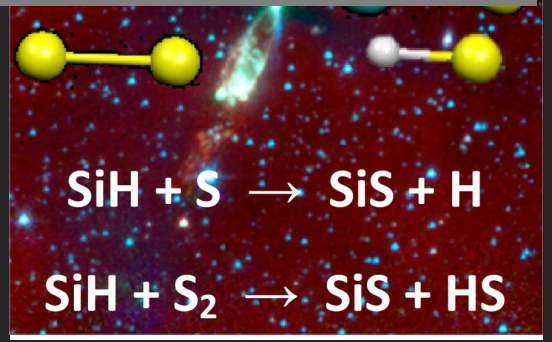


Podio et al. (2017)

Rosi et al. (2018)

1. more Si (wrt SiO) released in the B1c shock ?

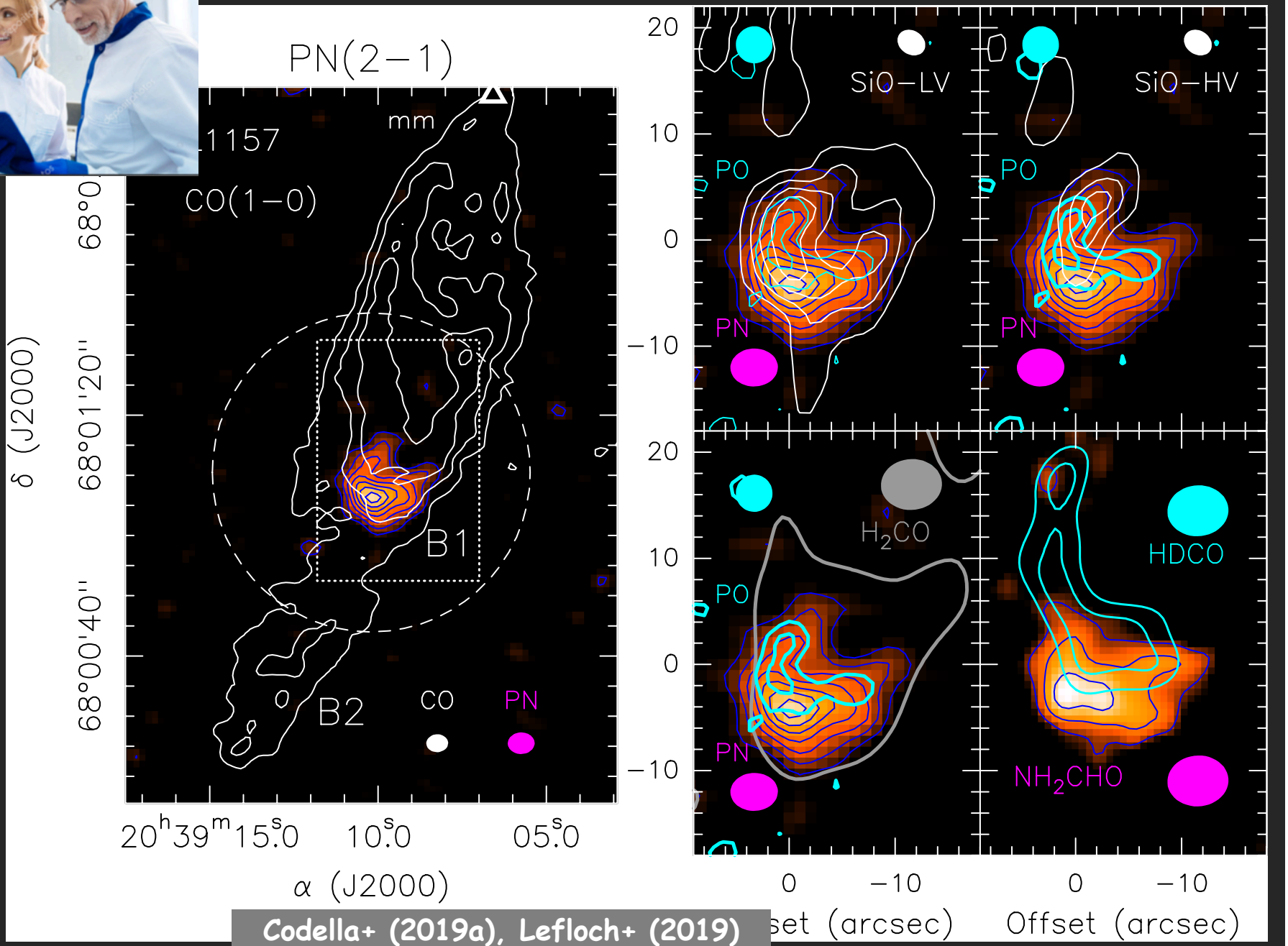
2. in B1c shock-generated CRs destroys SiO, releasing atomic Si, which then reacts with O/O_2 or S/S_2 ?



Si + SH —> SiS + H

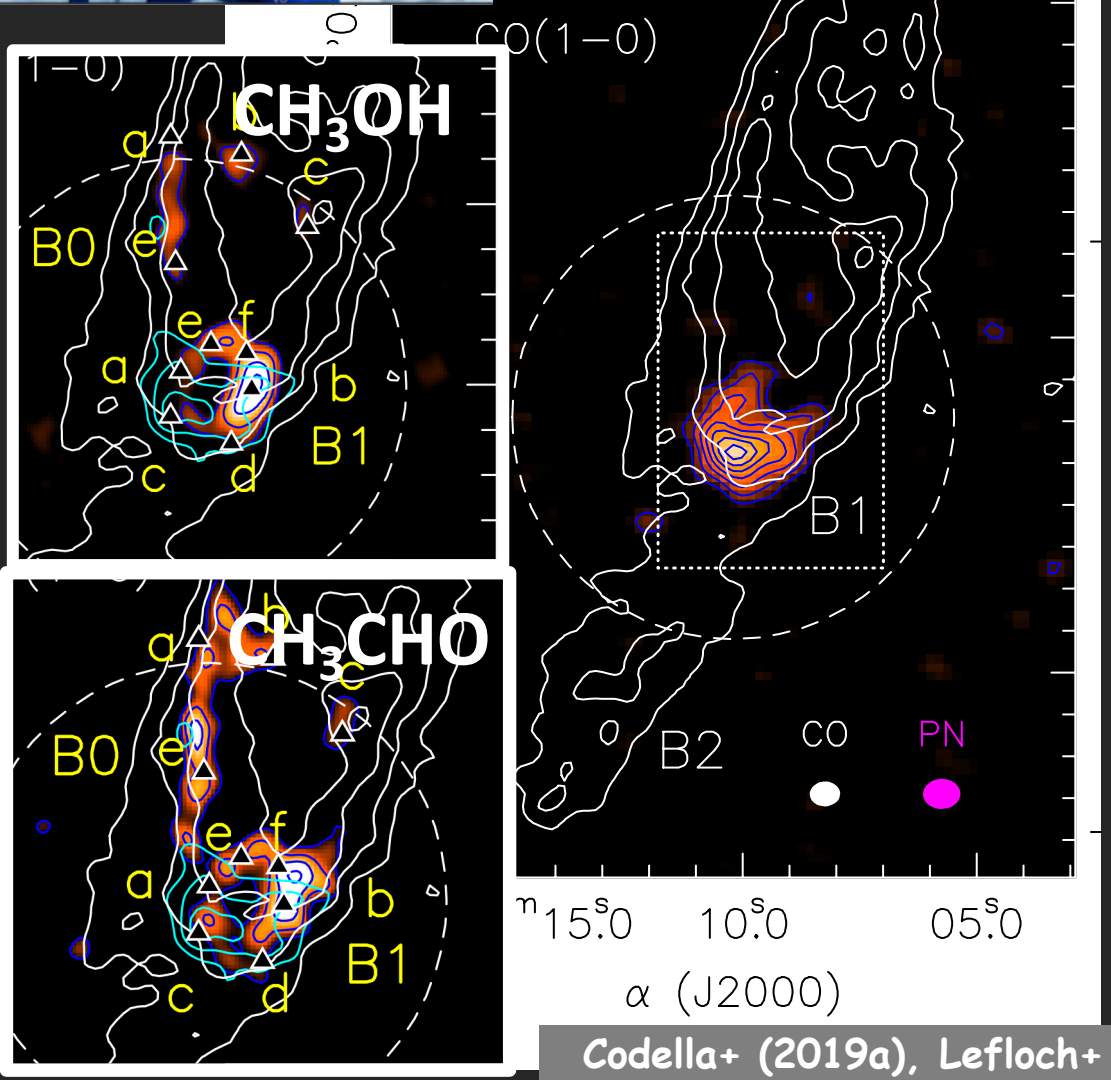
Rosi et al. (2019)

Our goal: make chemists happy!

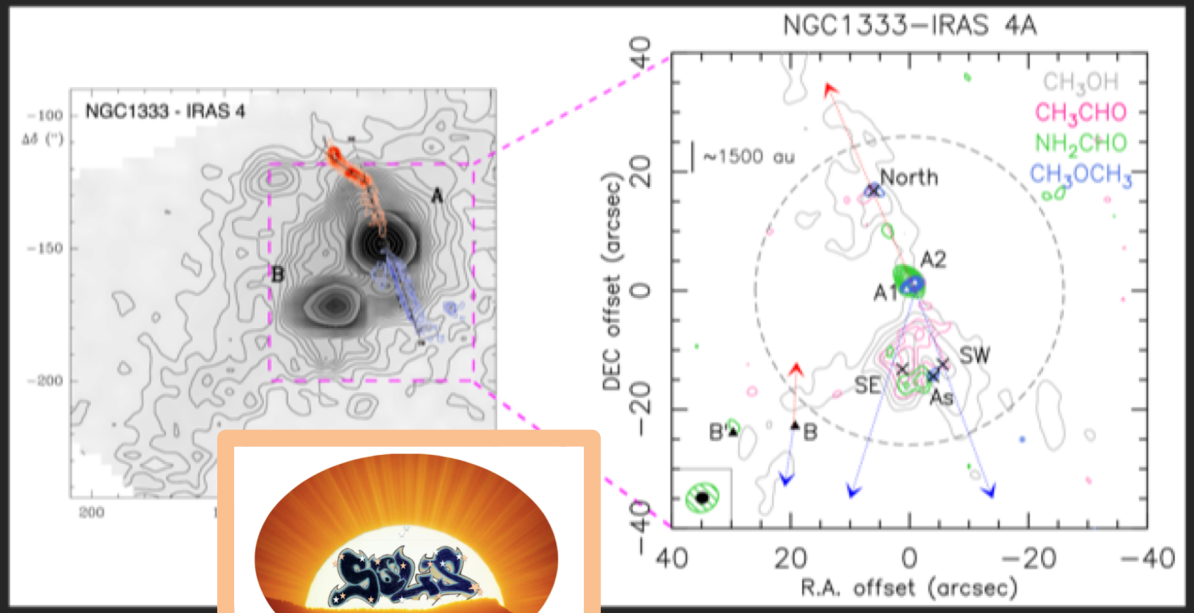


Codella+ (2019a), Lefloch+ (2019)

Our goal: make chemists happy!



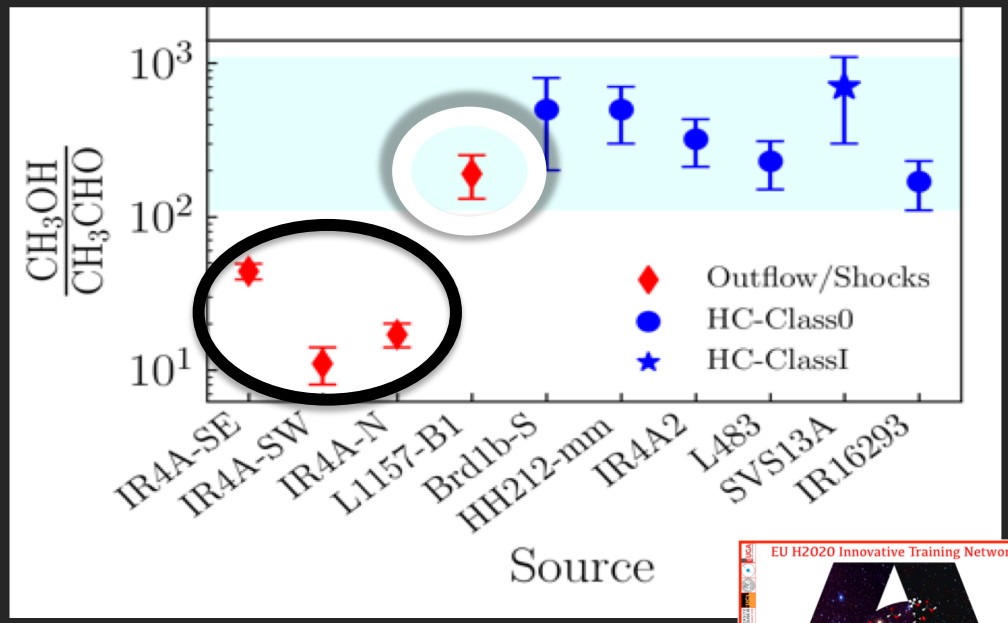
Codella+ (2019a), Lefloch+ (2019)



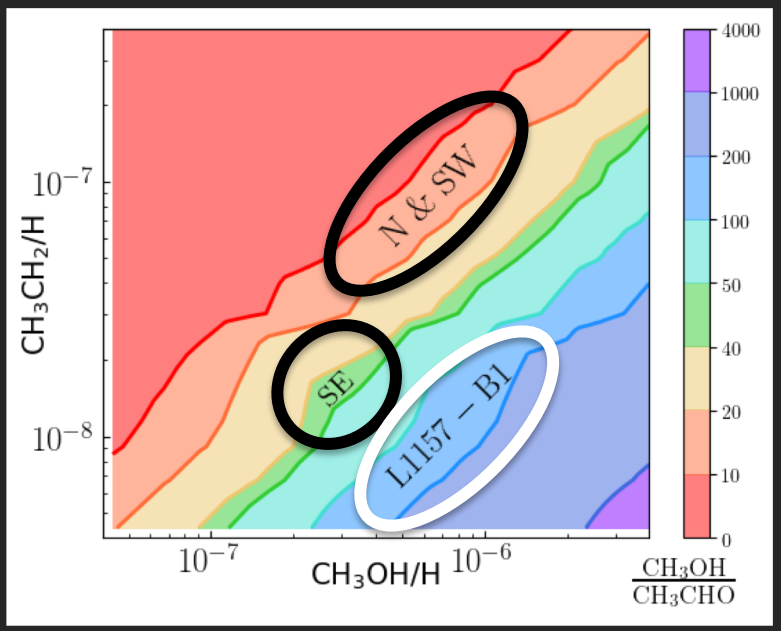
Opening new laboratories.....

De Simone et al. (submitted)

...and old questions: the CH_3CHO formation



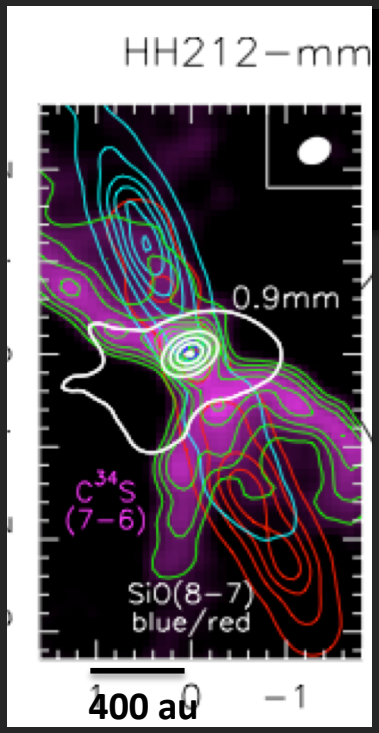
See also Bianchi et al. (2019)



CH_3CHO in the gas phase: the role of CH_3CH_2 (+ O) (Charnley+ 2004)

EU H2020 Innovative Training Network
Astro-Chemical Origins

The inner 50 AU of a Sun-like protostar: HDO & iCOMs



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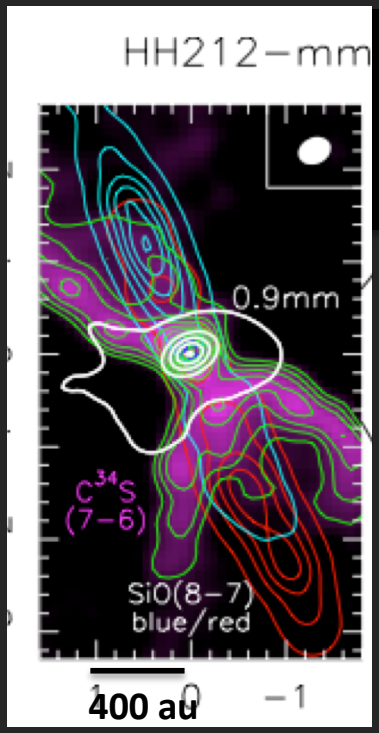
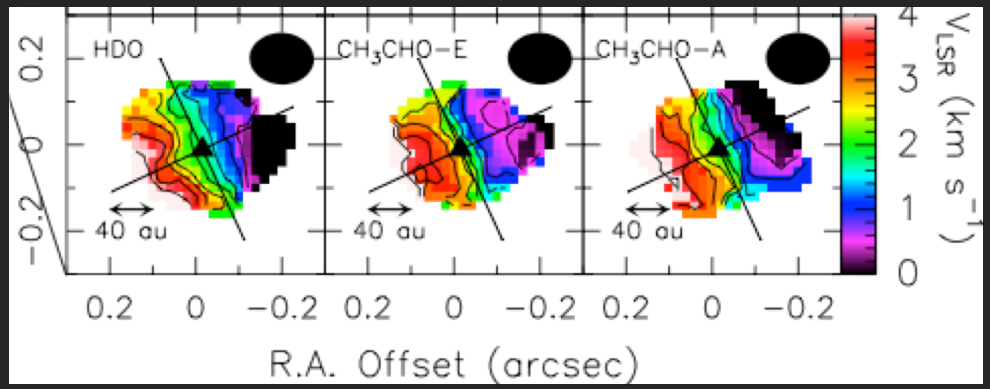
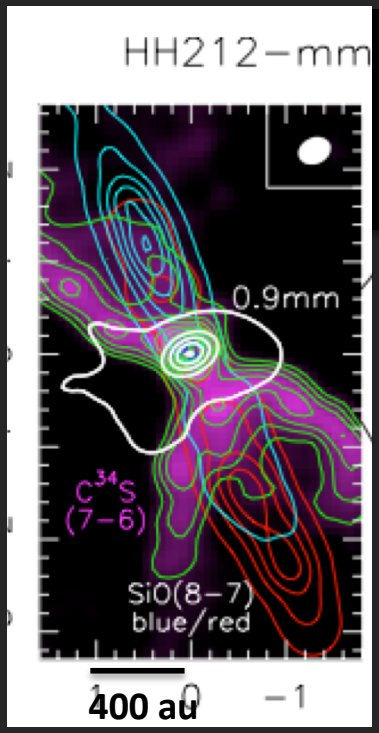
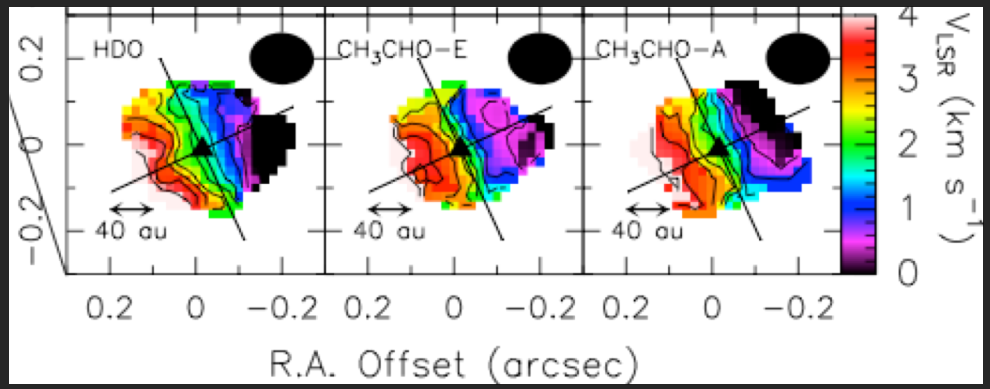
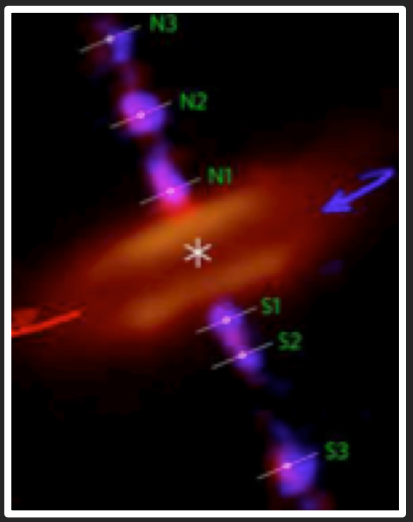




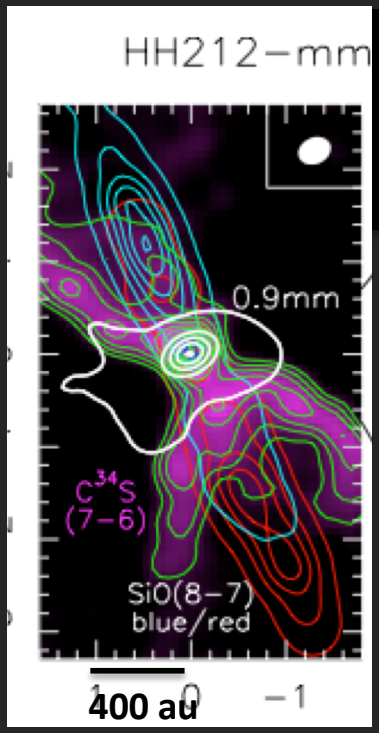
The inner 50 AU of a Sun-like protostar: HDO & iCOMs

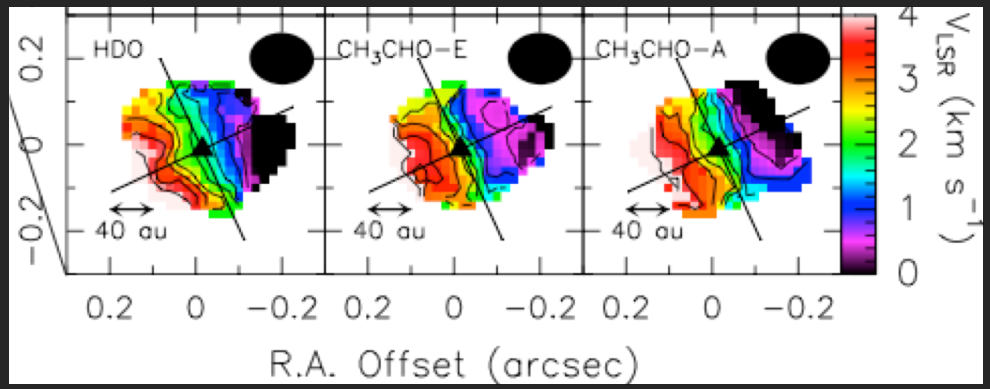


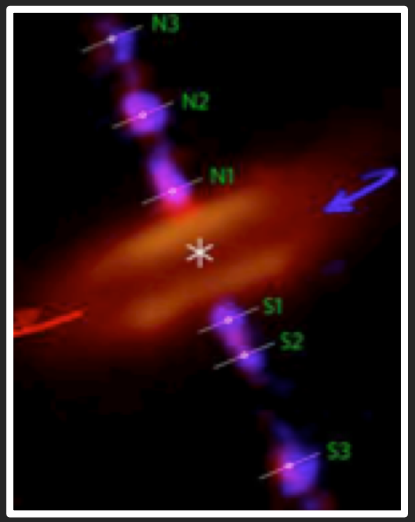




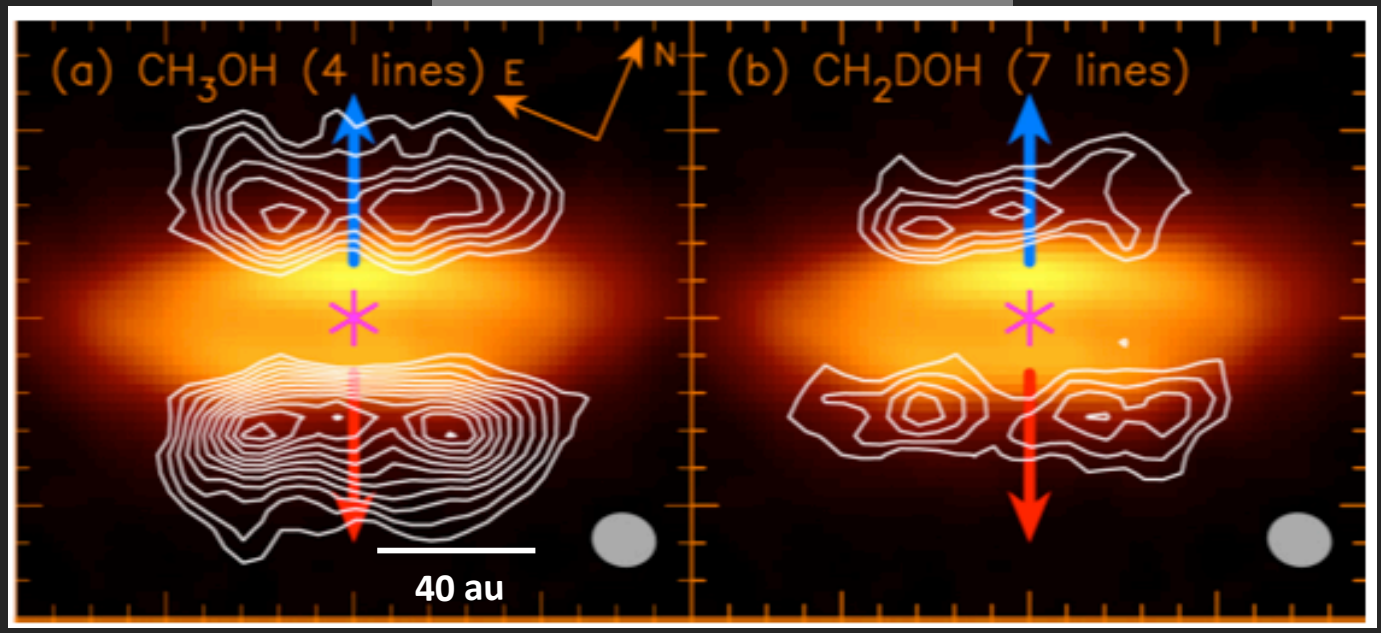
The inner 50 AU of a Sun-like protostar: HDO & iCOMs







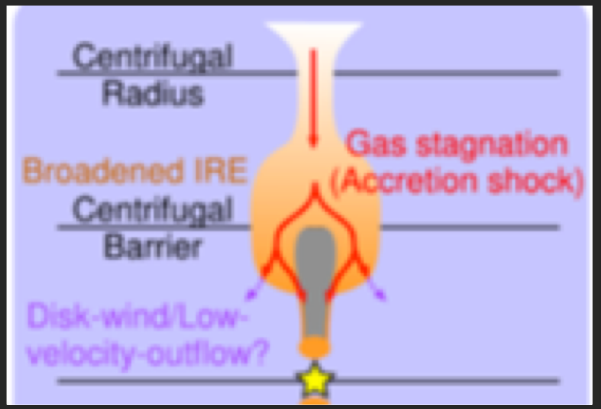
Lee et al. (2017, 2019)
Codella et al. (2018, 2019b)



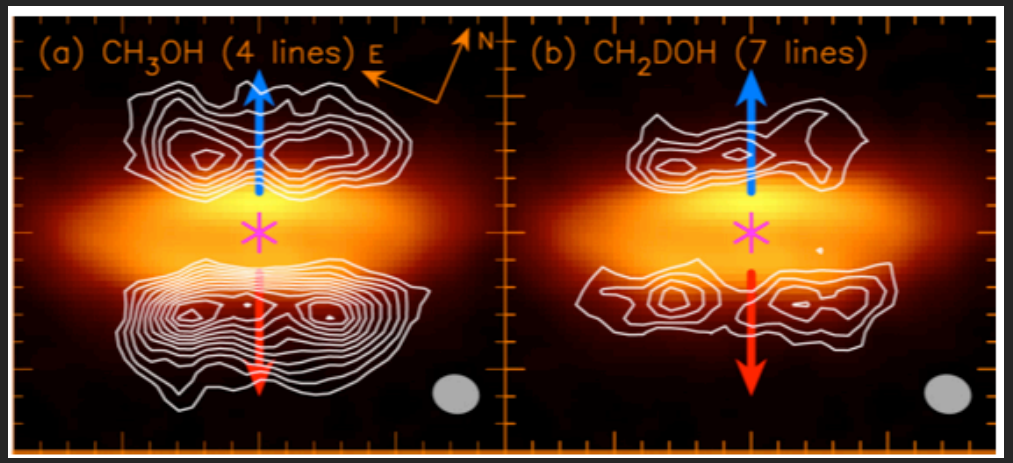
iCOMs associated with the disk

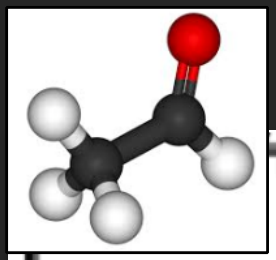
Emission related with the extended rotating disk

Gas launched by the centrifugal barrier ? (Sakai et al. 2017)

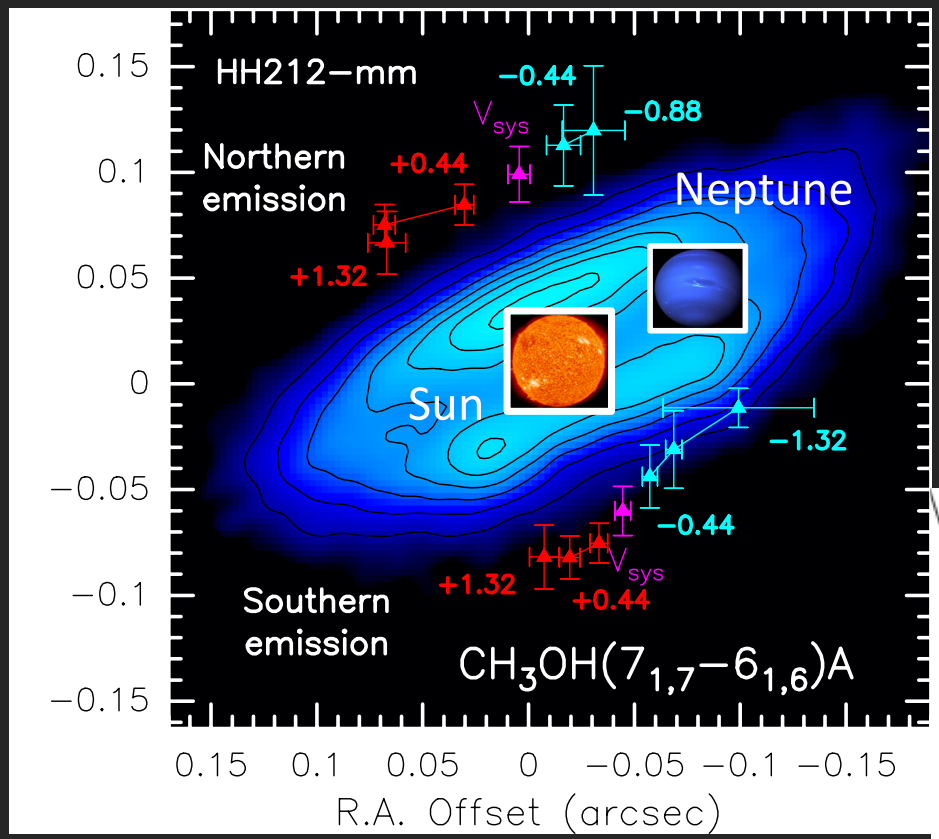


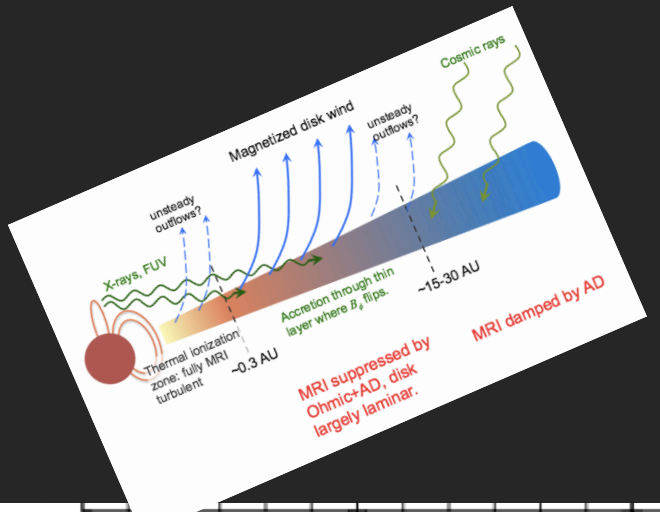
Disk atmosphere ?

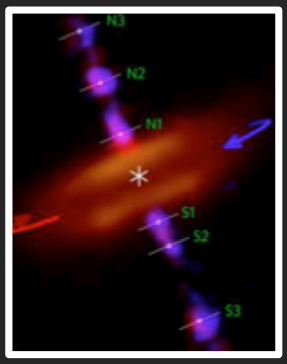


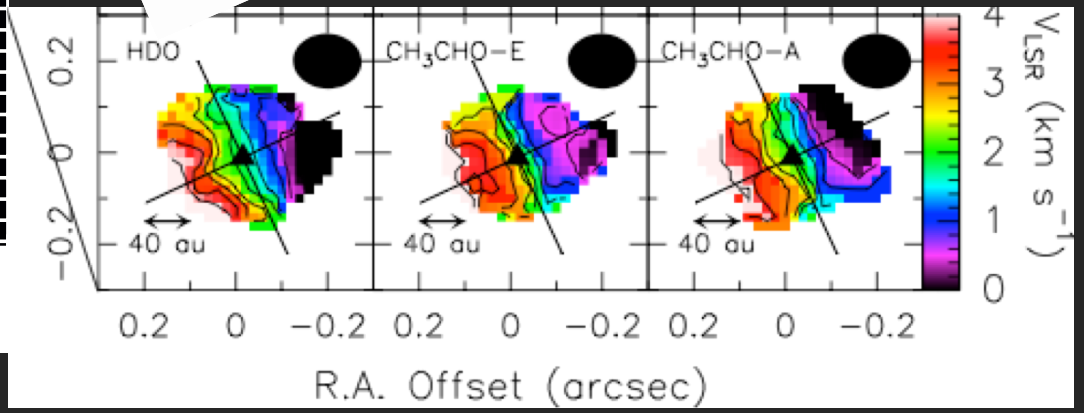


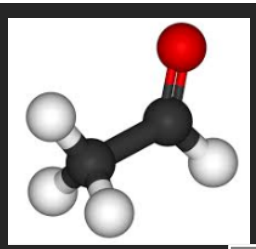
Bianchi et al. (2017)
Codella et al. (2018, 2019b)
Lee et al. (2017, 2019)











Codella et al. (2018, 2019b),
Lee et al. (2018, 2019)

Astrochemistry provides key tools to observe the fundamental processes (accretion, ejection) sculpting the cradle of a star (and its planetary system)

The first ALMA LP on Astrochemistry

The FAUST synergy
Fifty AU Study of Protosun Analogues
ALMA Large Program + 2 pilots @VLA and @GBT

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

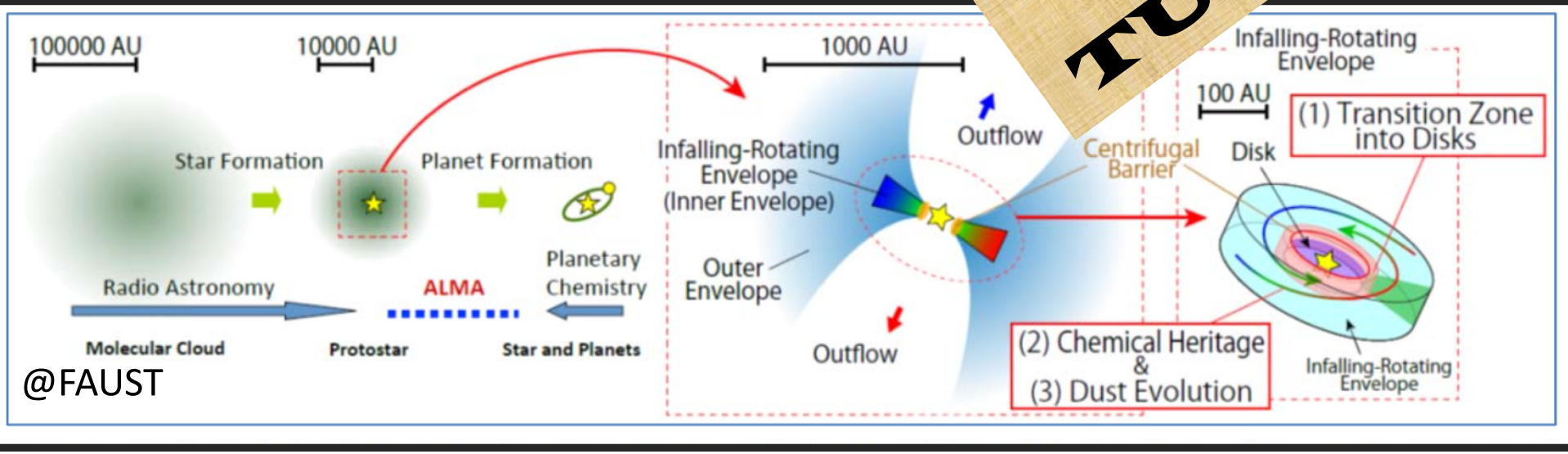
S. Yamamoto (Tokyo University)
N. Sakai (RIKEN)

C. Chandler (NRAO)

Is the chemical diversity at a 1000 au scale also present in the inner envelope/disk system (50 au) ?

What molecules are passed from the envelope to the disk in which planets, asteroids, and comets form

STAY TUNED !



Conclusions

Single-Dish

Interferometry

Wavelength