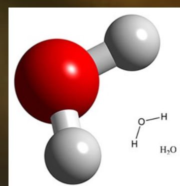
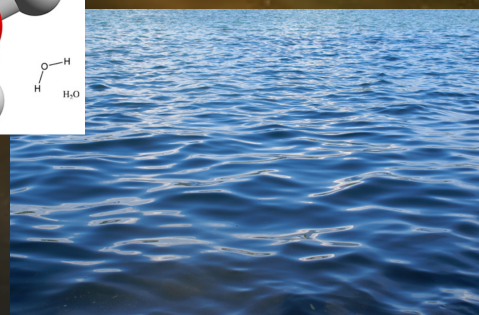
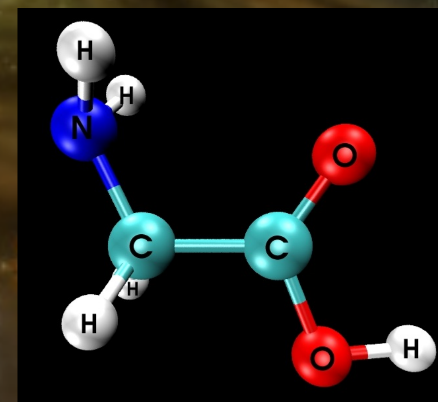
CHEMISTRY of Protoplanetary DISKS: searching for the building blocks of LIFE



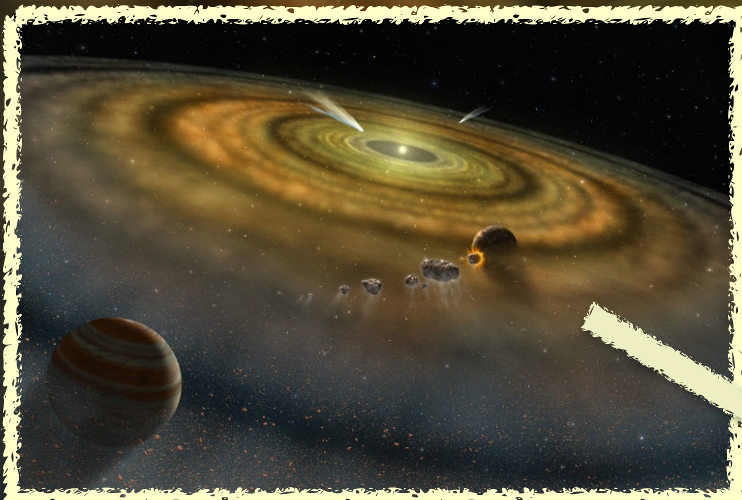




Linda Podio
AstroFIt Marie Curie Fellow, INAF-Arcetri Observatory

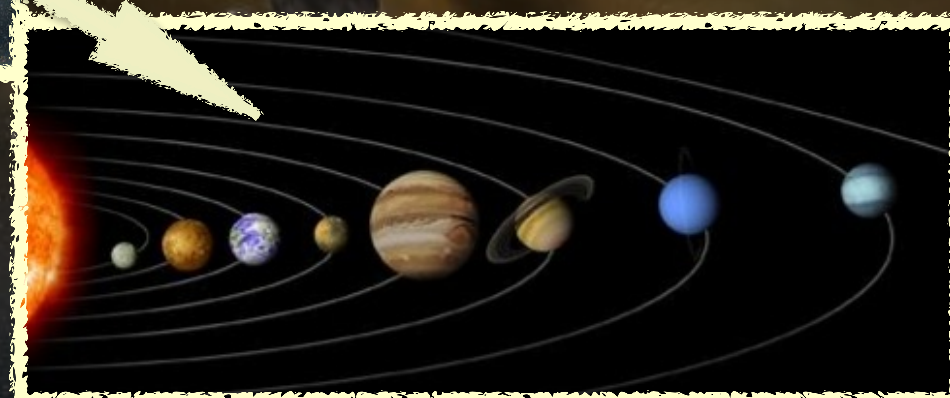
C. Codella (INAF-Arcetri, Italy), I. Kamp (Kapteyn, NL),
C. Ceccarelli, B. Lefloch (IPAG, France),
F. Gueth (IRAM, France), S. Cabrit (Obs Paris, France),
R. Bachiller, M. Tafalla (OAN, Madrid), B. Nisini (INAF-Rome, Italy),
P. Caselli (MPE, Germany), L. Testi (ESO, Germany)

Protoplanetary disks are the birthplace of planets



the study of the disk physical & chemical structure
is fundamental to comprehend
the formation of our own solar system
& extra-solar planetary systems

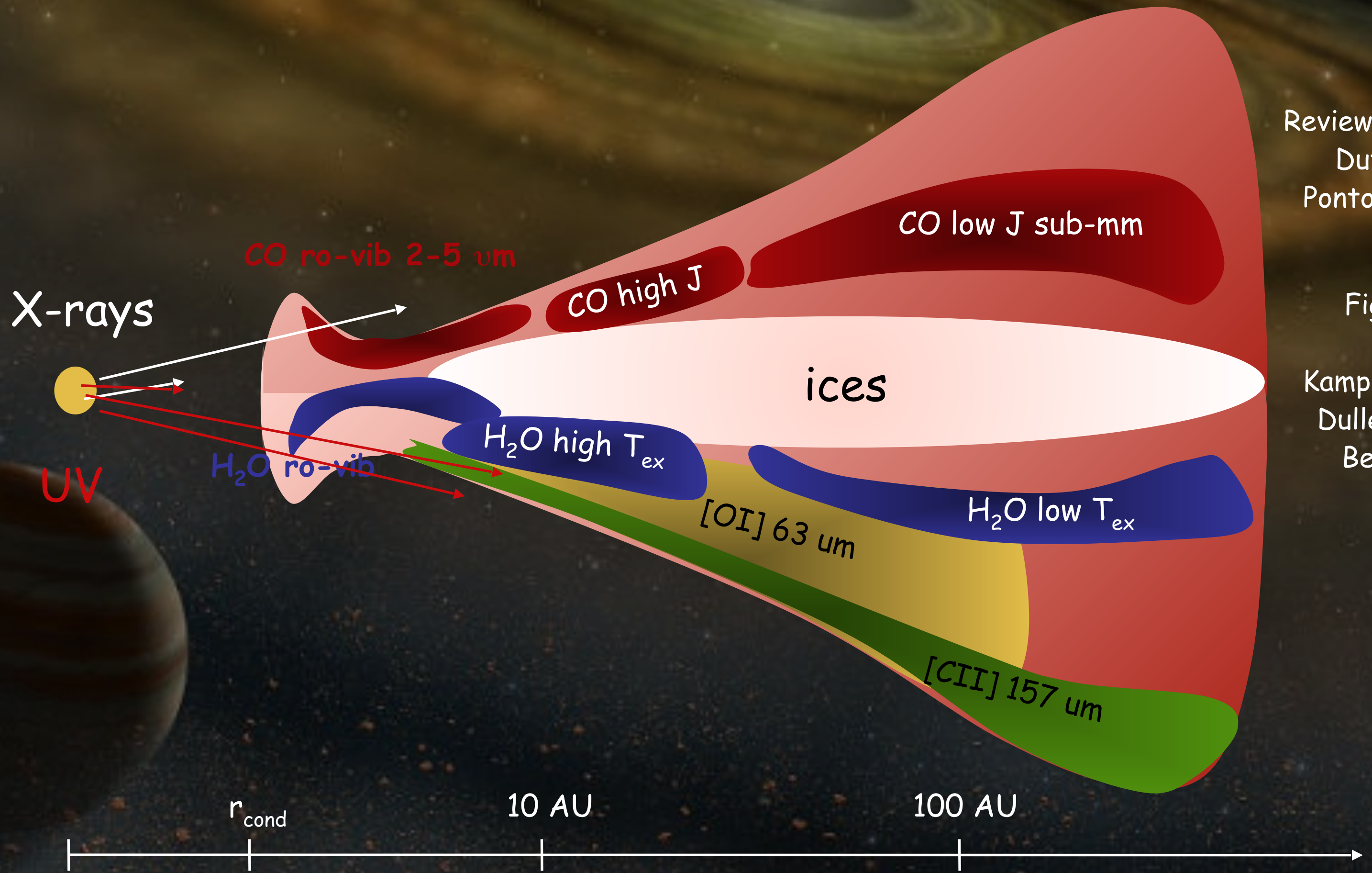
the forming planetesimal & planets
inherit the disk chemical complexity



Disks physical & chemical structure

disks have a stratified structure —> strong gradients in density & temperature

different lines probes the physical/chemical conditions of the gas located in different regions of the disk

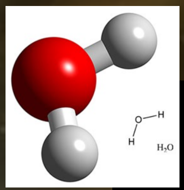


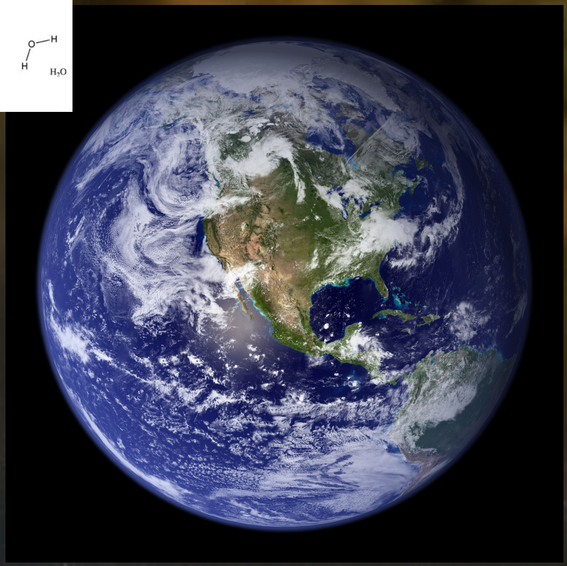
Reviews on disk chemistry
Dutrey et al. 2014
Pontoppidan et al. 2014

Figure by I. Kamp
based on
Kamp & Dullemond 2004
Dullemond et al. 2007
Bergin et al. 2007

The building blocks of LIFE

WATER





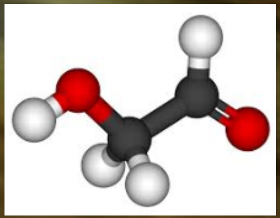
1 earth ocean = 1.5e24 g = 2.5e-4 $M_{\oplus}$

H_2O on earth: 10x — 50x

efficient solvant (liquid on large T range)
—> facilitates formation of COMs

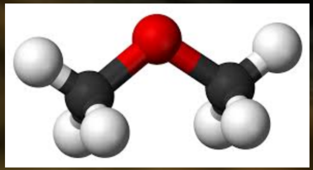
COMs & pre-biotic molecules

CH_2OHCHO



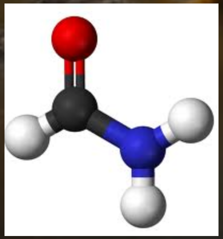
glycoaldehyde

CH_3OCH_3



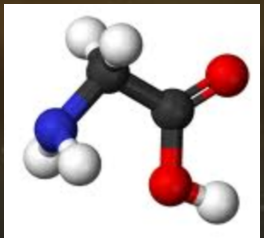
dimethyl ether

NH_2CHO



formamide

NH_2CH_2COOH



glycine

terrestrial life is based
on CARBON chemistry

H_2O in protoplanetary disks: vapour vs ices

$R < R_{snow}$
H_2O is in gas-phase

SNOW LINE (T_{dust} = 150 K)

R_{snow} ~ 2-3 AU in young solar analogs

(Lecar+ 2006)

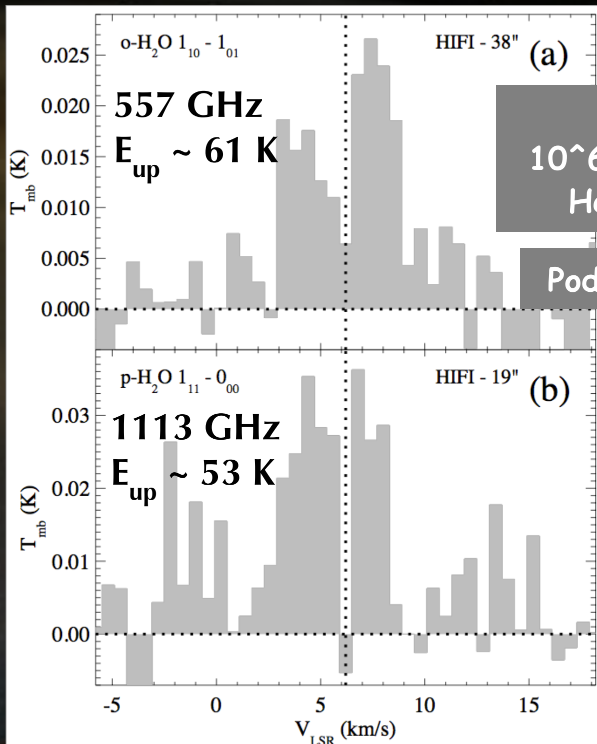
$R > R_{snow}$
H_2O frozen on dust grains

In the outer disk upper layers
H_2O is partially released in gas-phase
by non thermal processes
(Dominik+ 2005, Ceccarelli+ 2005, Kamp+ 2013)

planetesimal with H_2O form in the outer disk (water ice reservoir)

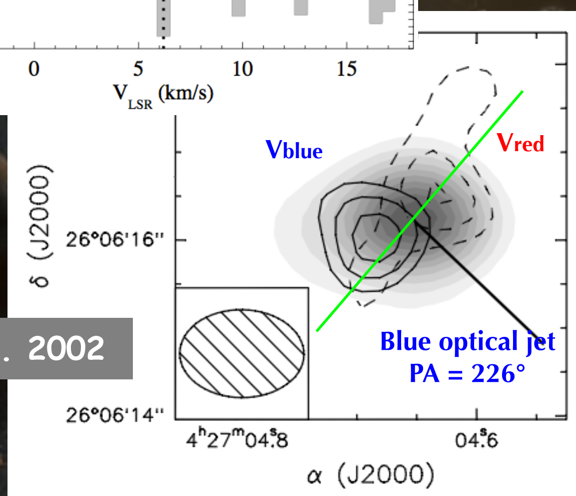
H_2O in the outer disk is difficult to observe
because H_2O_{gas} << H_2O_{ice} and low H_2O transitions in the FIR

WATER in the OUTER DISK : the revolution with HERSCHEL !

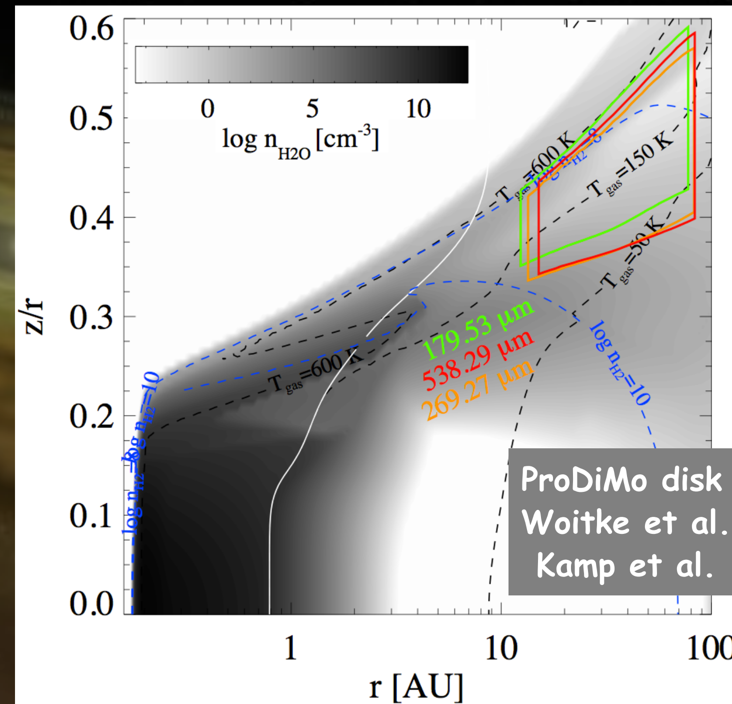


DG Tau
10^6 years, 140 pc
Herschel/HIFI

Podio et al. 2013



Testi et al. 2002



ProDiMo disk model
Woitke et al. 2009
Kamp et al. 2010

Mdisk = 0.01 – 0.1 $M_\odot$
≥ Minimum Mass of the Solar Nebula before planets formation (MMSN)

H2O gas ~ 1/100 H2O ice

M(H2O) ~ 7–100 M⊕ ~ 1e4–1e5 earth oceans

see also Hogerheijde et al. 2011
PPVI review by Van Dishoeck et al. 2014

COMs in disks

surface layers —> molecules destroyed due to photodissociation by UV

outer disk/mid-plane (T <100 K) —> molecules freeze out onto dust grains
COMs are efficiently produced by surface grain chemistry: $X_{\#} \sim 10^{-6} - 10^{-4}$
BUT only a few percent released in gas-phase by non-thermal processes: $X_{gas} \sim 10^{-11} - 10^{-7}$

The chemical composition of disks is hidden in ices !!!

Modica & Palumbo 2010
Walsh et al. 2014

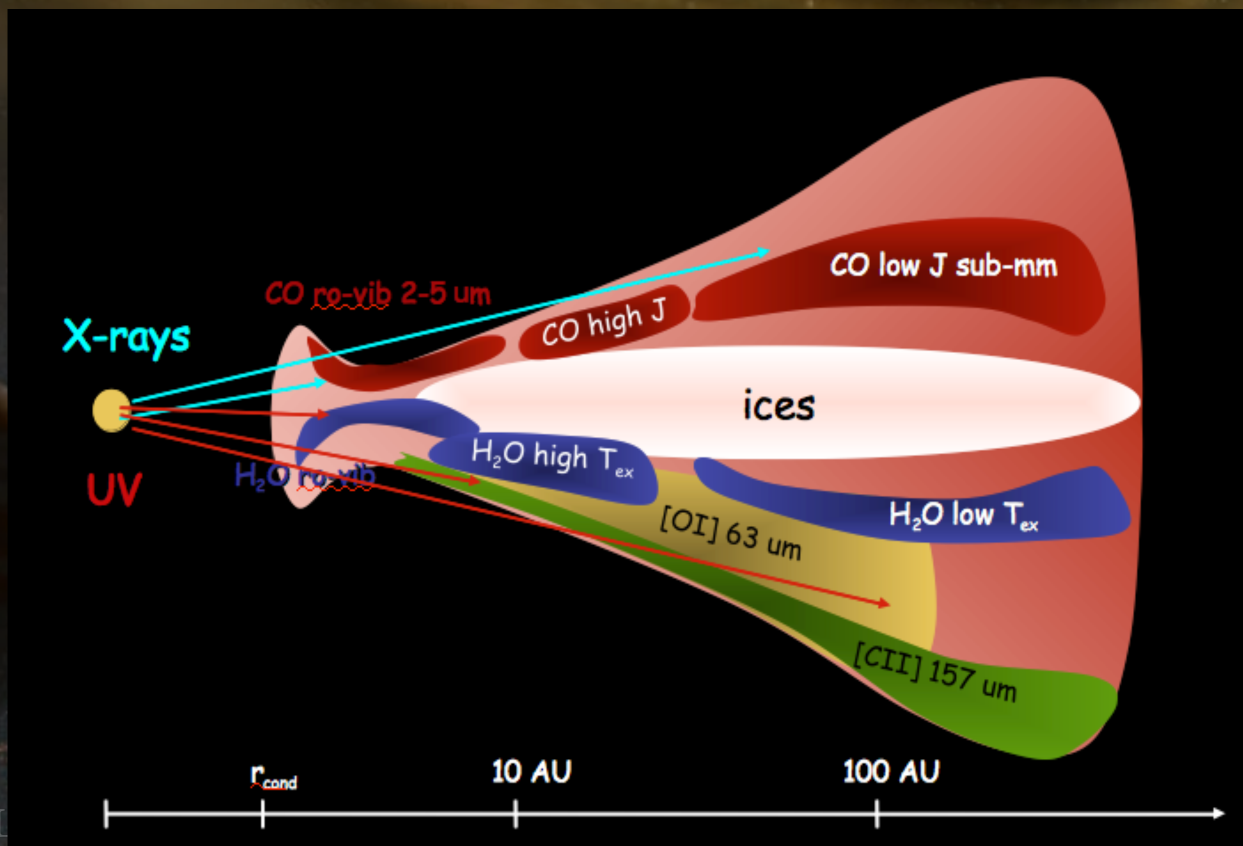
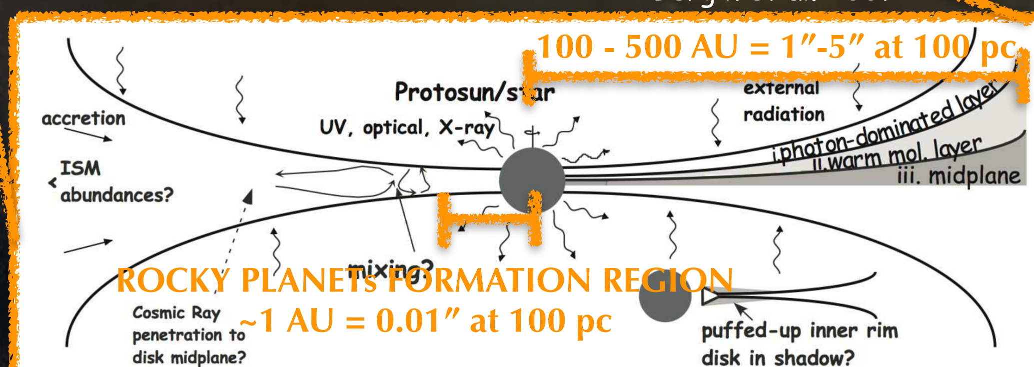


Figure by I. Kamp
based on
Kamp & Dullemond 2004
Dullemond et al. 2007
Bergin et al. 2007

We need mm interferometry
high sensitivity & resolution to observe COMs in disks

Bergin et al. 2007



Searching for COMs
unbiased + high angular res spectral surveys

ASAI
IRAM-30m Large Program
PI: B. Lefloch, R. Bachiller

CALYPSO
PdBI Large Program
PI: P. Andre'

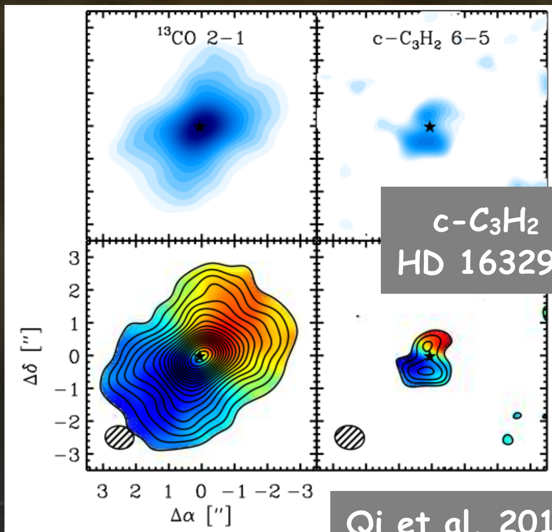
Premiale INAF iALMA
PI: L. Testi

iALMA

SOLIS
NOEMA Large Program
PI: C. Ceccarelli, P. Caselli

Seeds Of Life In Space

first detections of COMs in evolved disks with ALMA !



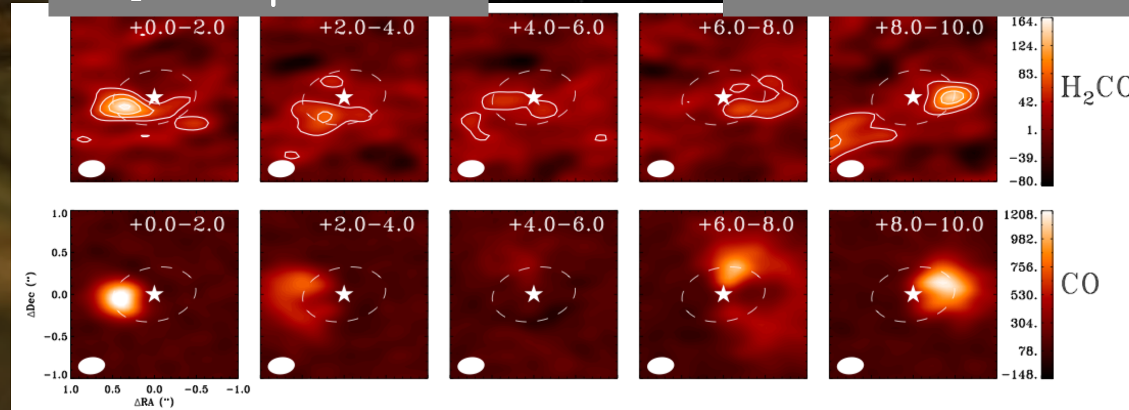
c-C_3H_2
HD 163296

Qi et al. 2013

ring=30-165 AU

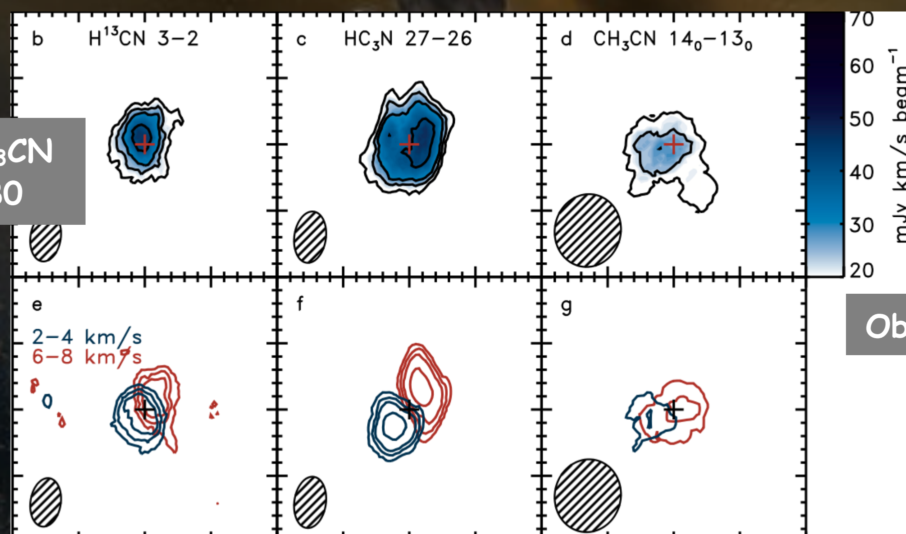
H₂CO — Oph IRS 48

Van der Marel et al. 2014



CH_3OH/H_2CO < 0.3 —> H_2CO partially formed in gas-phase

HC₃N, CH₃CN
MWC 480



Oberg et al. 2015

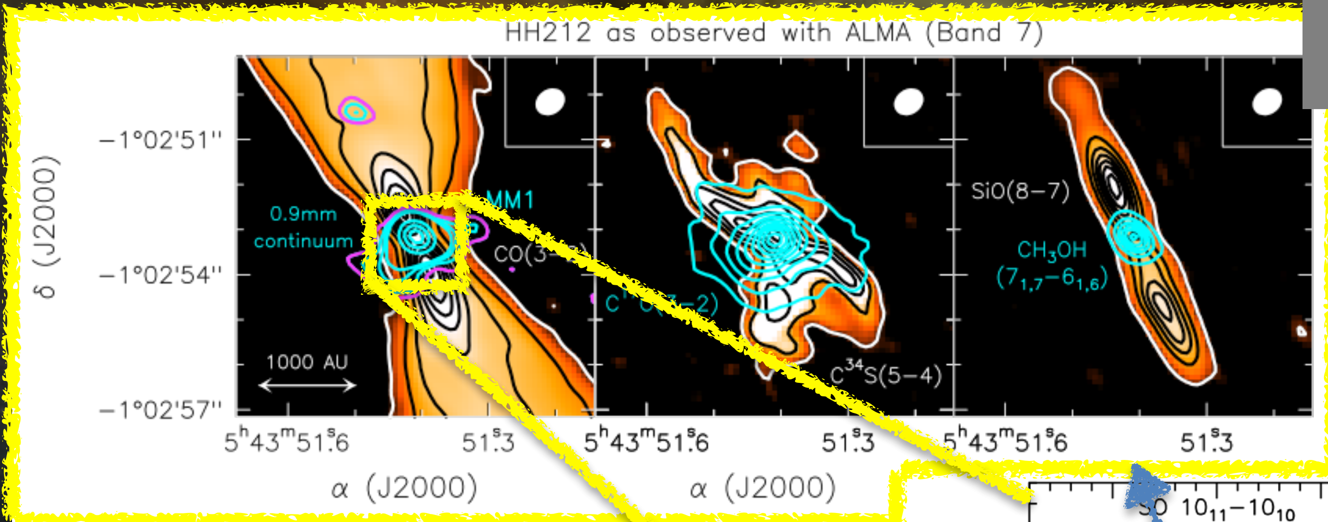
abundance of N-bearing COMs
similar to comets

DISKS chemistry in PROTOSTARS: the revolution with ALMA !

iALMA

JEDI

outflow + rotating cavities + molecular JET !

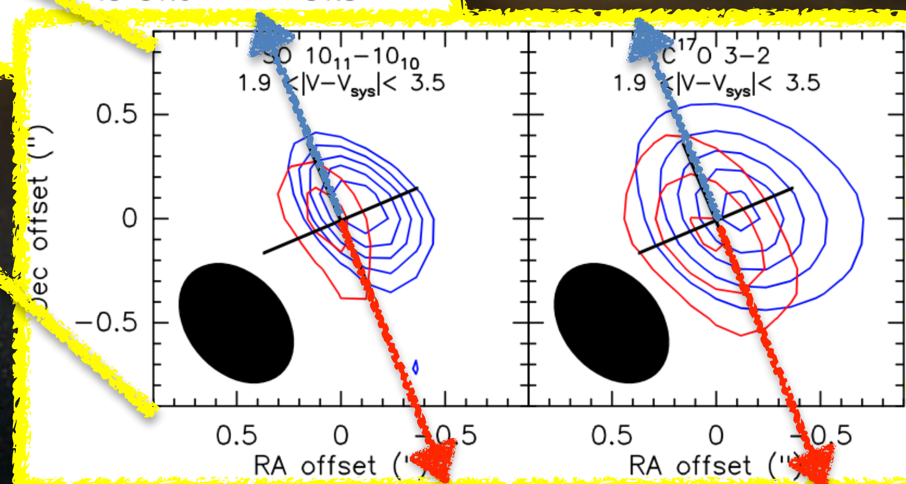


HH 212
10^4 years
d = 450 pc

Codella et al. 2014

Podio et al 2015

The compact rotating DISK !



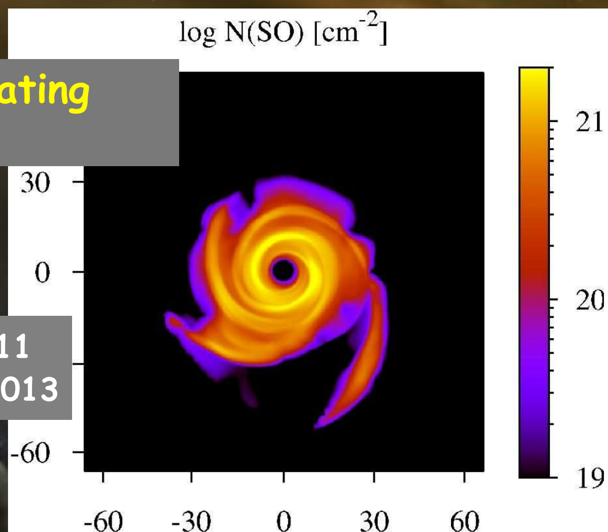
Fuente et al. 2010
Dutrey et al. 2011

Class II disks (passively heated) —> $X(SO) \sim 10^{-11}$
Class 0 disk (HH 212) —> $X(SO) \sim 10^{-8}$-10^{-7}

Podio et al 2015

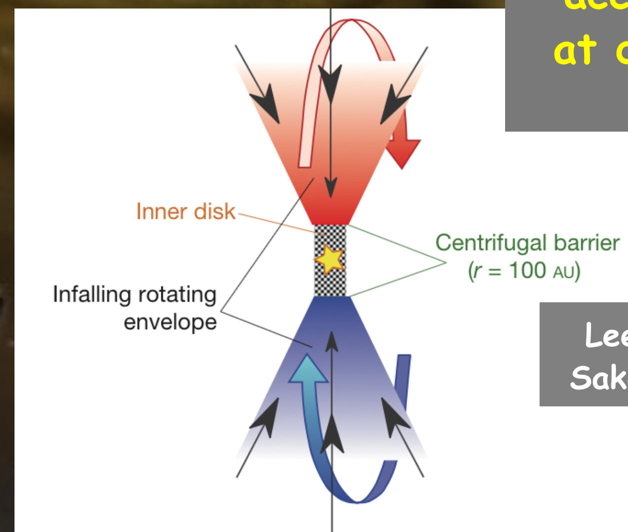
is SO enhanced in protostellar disks ?

self-gravitating disk



Ilee et al. 2011
Douglas et al. 2013

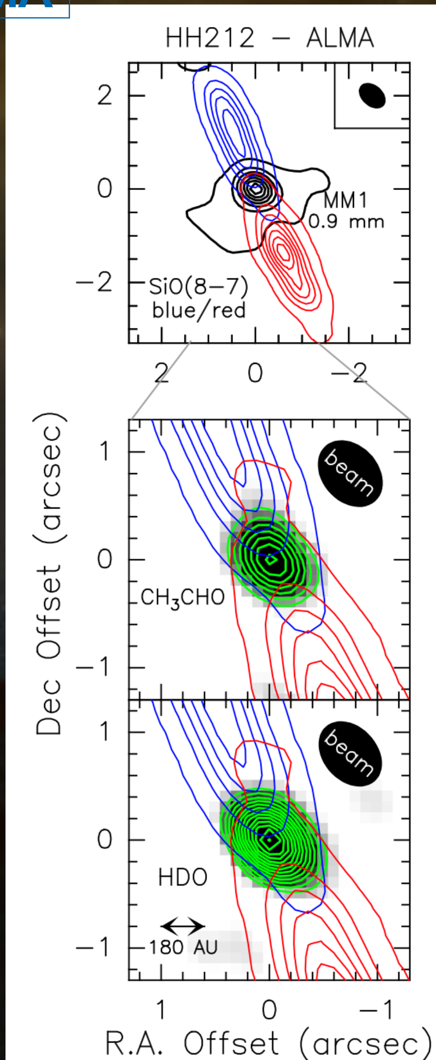
accretion shock at disk-envelope interface

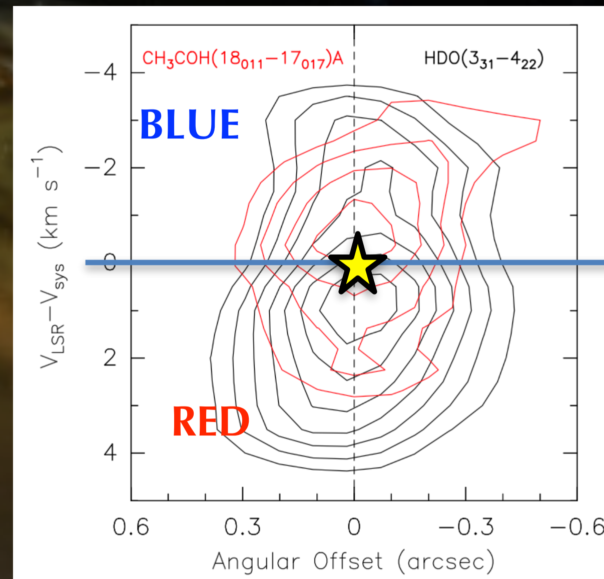


Lee et al. 2014
Sakai et al. 2014

… and COMs ???

HDO & CH_3CHO in the HH 212 protostar





Codella et al 2015

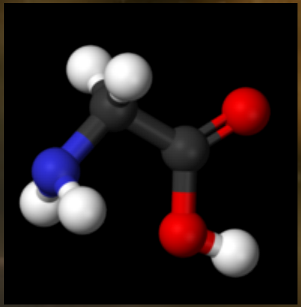
distance from source
along the disk

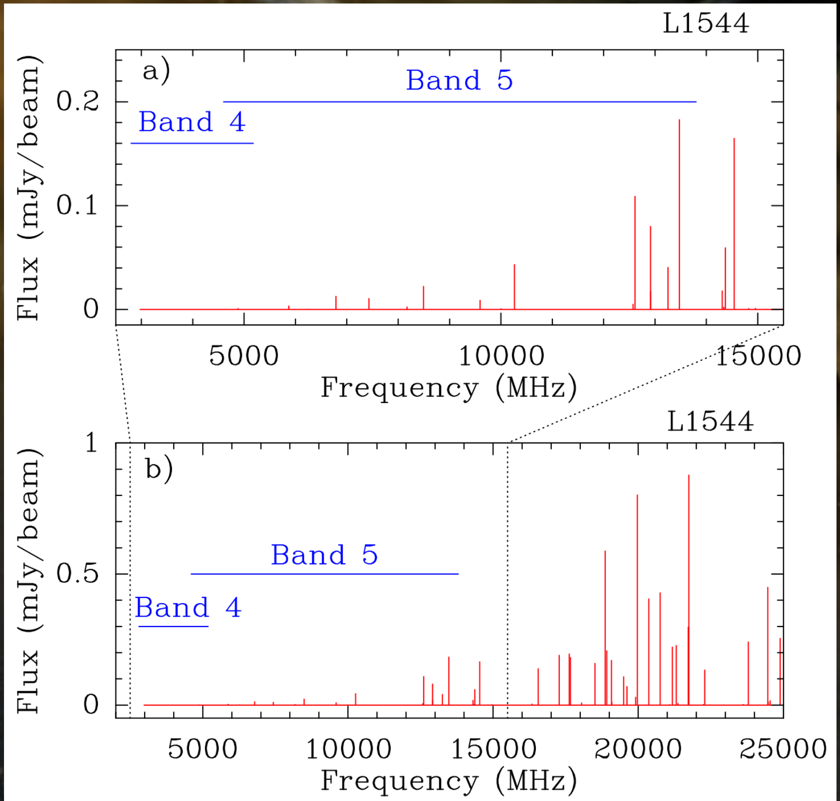
higher angular resolution is needed
to disentangle disk emission !

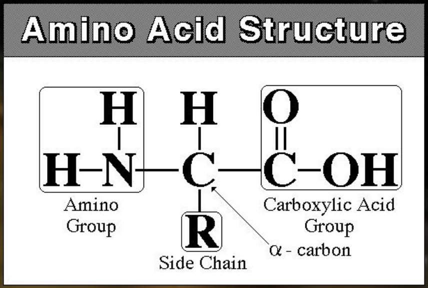
H/D ratio → diagnostic of the isotopic composition
of the planetesimal that delivered H_2O to Earth

Earth --> (D/H) = (1.558 ± 0.001) 1e-4
~ D/H in Carbonaceus chondrites (ASTEROIDS) and Jupiter-family COMETS

The future with SKA:
Glycine in prestellar cores & protoplanetary disks ?







Jimenez-Serra et al. 2014, Codella et al. 2014, Testi et al. 2014

iALMA

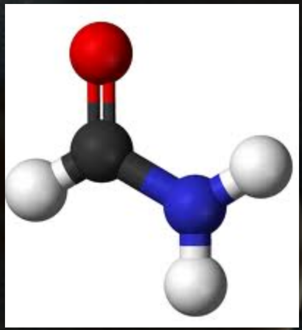
1st Italian Workshop on Astrochemistry

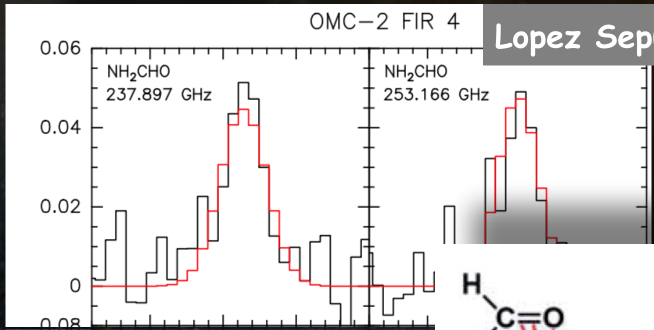
PREBIOTIC CHEMISTRY IN SPACE

Firenze, Palazzo Strozzi, March 10-11 2016

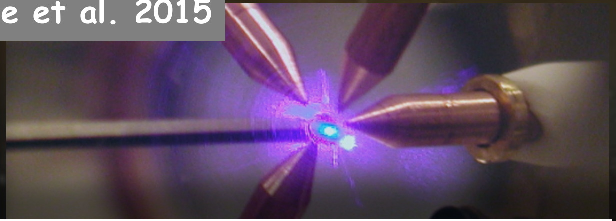
sponsored by SNS & INAF-iALMA

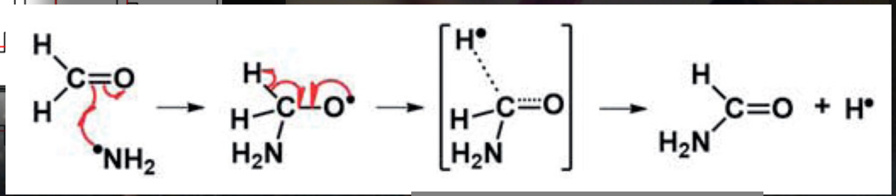
building up the link between astronomers & chemists





Lopez Sepulcre et al. 2015





Barone et al. 2015

for info: lpodio@arcetri.astro.it
dimitrios.skouteris@sns.it