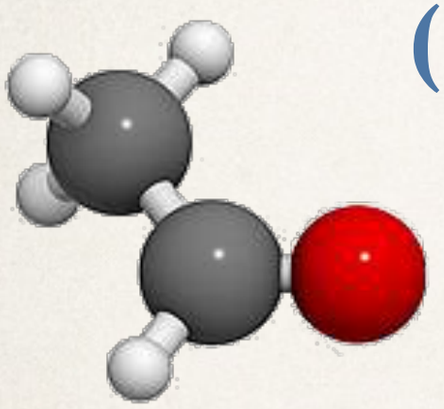
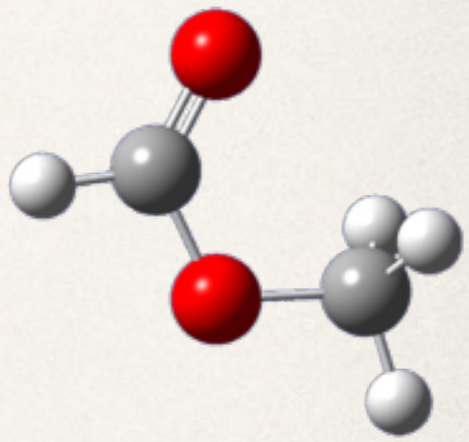
PhD Dissertation

TRACING OUR CHEMICAL ORIGIN:

Interstellar Complex Organic Molecules (iCOMs) in Sun-like protostars





E. Bianchi

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INAF-Osservatorio Astrofisico di Arcetri

Supervisor: Claudio Codella

OUTLINE:

1. Scientific context

- The formation of a Sun-like star
- Our tools: Interstellar Complex Organic Molecules (iCOMs) and deuterated molecules
- How we can observe iCOMs and what they can tell us

2. How do iCOMs form in protostars?

- ALMA Cycle 1 data of the Class 0 protostar HH212

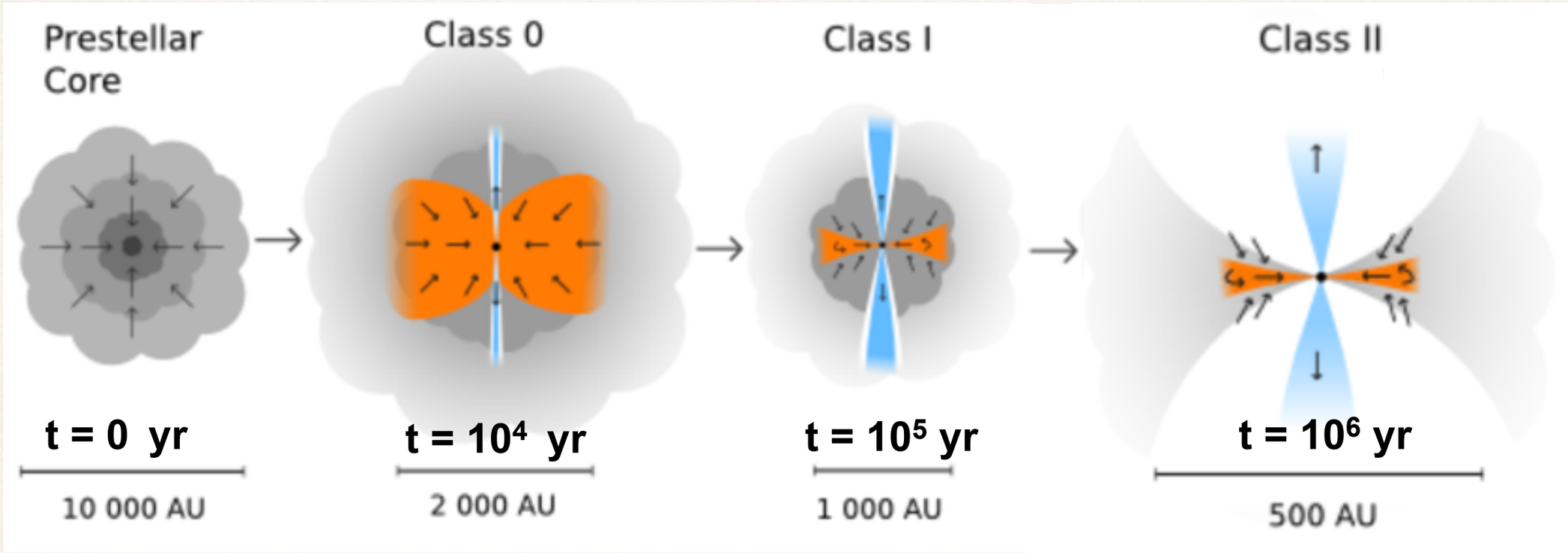
3. How do the chemical content evolve?

- Chemical complexity and deuteration in SVS13-A

4. Future perspectives

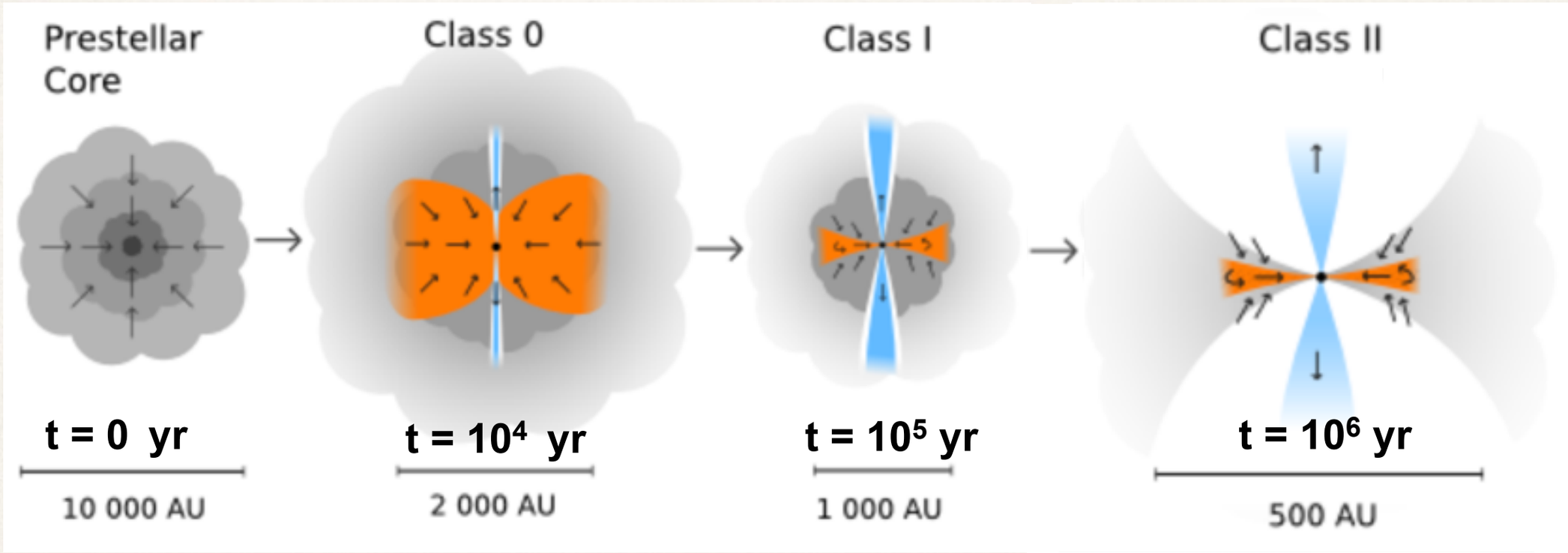
- Large programs for NOEMA and ALMA

THE FORMATION OF A SUN-LIKE STAR

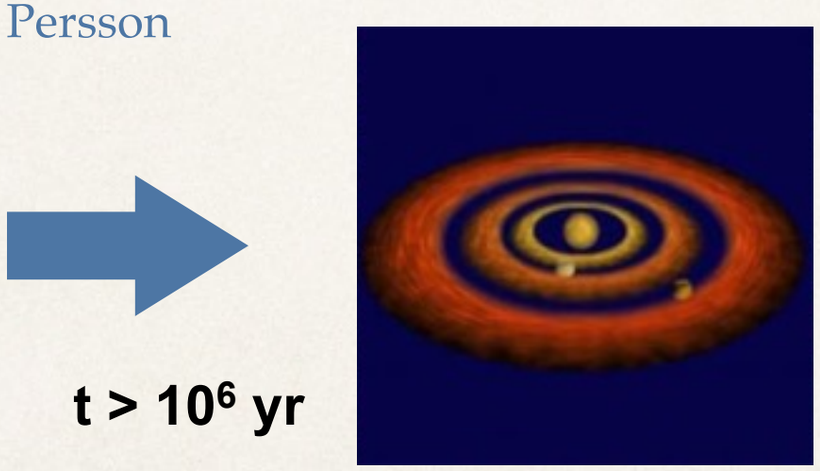


Adapting Persson

THE FORMATION OF A SUN-LIKE STAR



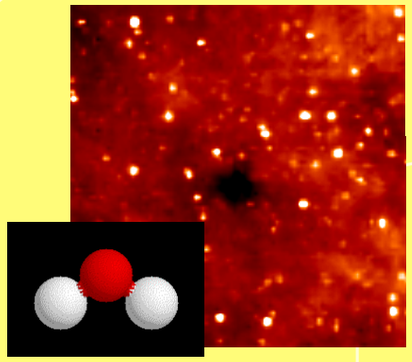
Adapting Persson



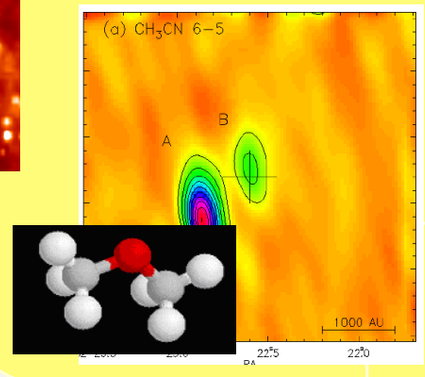
$t > 10^6$ yr

PLANETARY SYSTEM AND LIFE…

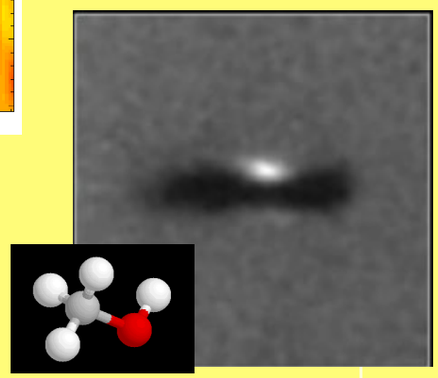
THE FORMATION OF A SUN-LIKE STAR



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

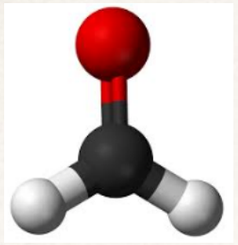
Adapted from
Caselli & Ceccarelli 2012

4- PLANETESIMALS FORMATION : grains agglomeration

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

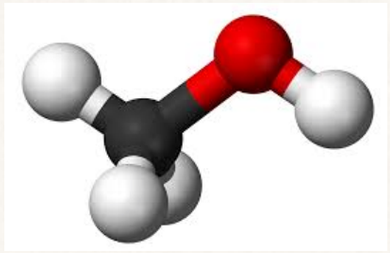
THE iCOMs ZOO

H_2CO



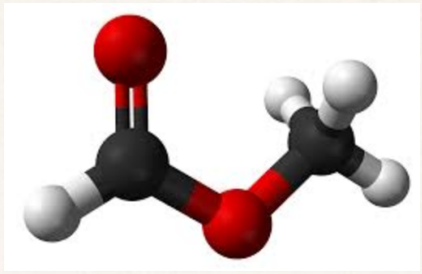
formaldehyde

CH_3OH



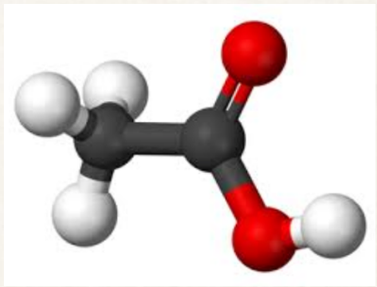
methanol

CH_3OCHO



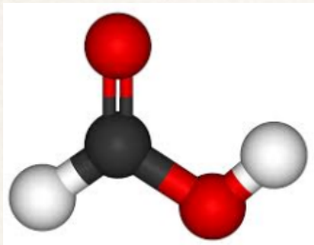
methyl formate

CH_3COOH



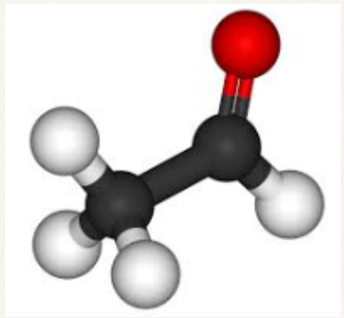
acetic acid

HCOOH



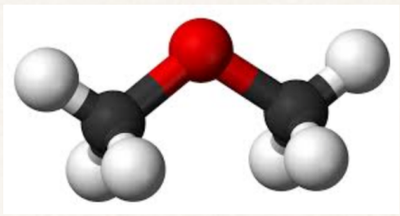
formic acid

CH_3CHO



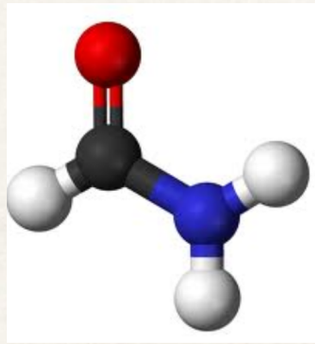
acetaldehyde

CH_3OCH_3

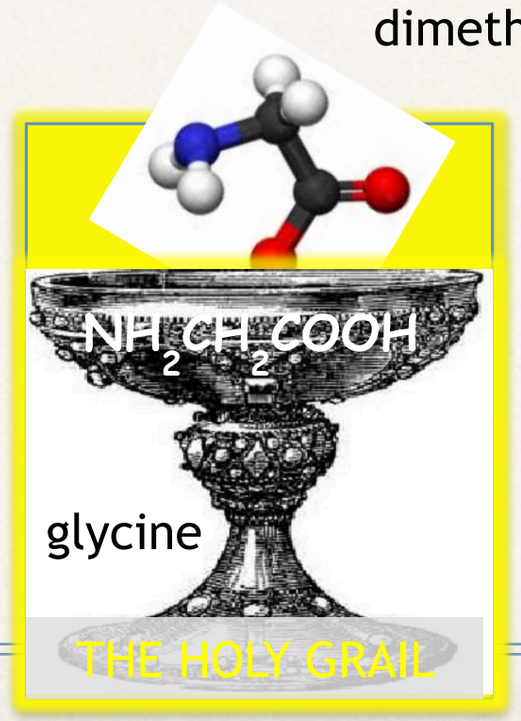


dimethyl ether

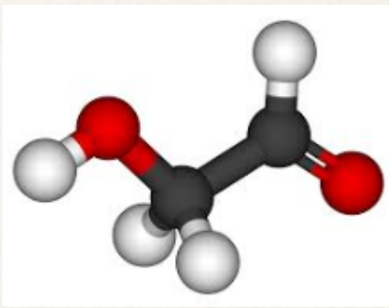
NH_2CHO



formamide



$HCOCH_2OH$



glycoaldehyde

DEUTERATED MOLECULES

Deuterium is formed during the Big Bang, and destroyed into stars

Deuteration = abundance ratio between a molecule and its deuterated form, e.g. HDO/H_2O

GAS

Roberts & Millar 89; Gerlich+02; Asvany+04; Gerlich & Schlemmer 02; Flower+06

If T is low

$$H_3^+ + HD \rightarrow H_2D^+ + H_2 + 230\ K$$

If $n(H_2)$ is high $H_2D^+ + CO \rightarrow DCO^+$

$H_2D^+ + N_2 \rightarrow N_2D^+$

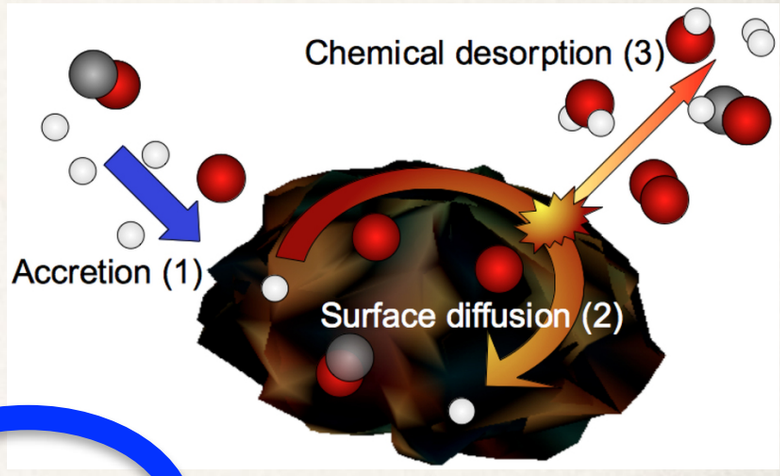
$H_2D^+ + CN \rightarrow \ldots \rightarrow$ **DNC**

$H_2D^+ + NH_3 \rightarrow \ldots \rightarrow NH_2D$

$H_2D^+ + H_2CO \rightarrow \ldots \rightarrow$ **HDCO**

GRAINS

Hasegawa et al. 1992; Roueff et al. 2007; Caselli & Ceccarelli 2012; Ceccarelli et al. 2012, PPVI



$O \rightarrow OH/OD \rightarrow H_2O/HDO$

$CO \rightarrow HCO/DCO \rightarrow H_2CO/HDCO \rightarrow \ldots \rightarrow CH_3OH/CH_2DOH$

$CN \rightarrow HNC/DNC$

Grains only!

DEUTERATED MOLECULES

Deuterium [illegible] yed into stars

Deuteration = abundar [illegible] **rated form**, e.g. HDO/H_2O

GAS

Roberts & Millar 89; Gerlich+02; Asv

If T is low $H_3^+ + H$ [illegible]

$^+ + N_2 \rightarrow N_2D^+$

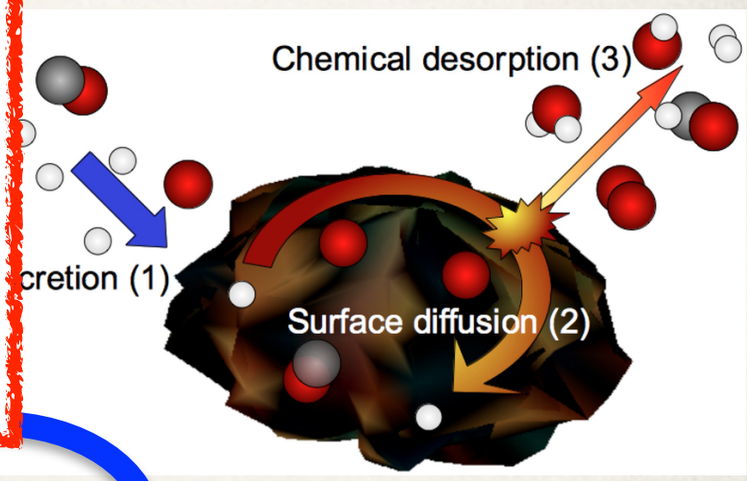
$^+ + CN \rightarrow \ldots \rightarrow$ DNC

$^+ + NH_3 \rightarrow \ldots \rightarrow NH_2D$

If $n(H_2)$ is high H_2I [illegible] $H_2CO \rightarrow \ldots \rightarrow$ HDCO

GRAINS

Hasegawa et al. 1992; Roueff et al. 2[illegible]



O → OH/OD →

CO → HCO/DCO → H_2CO/HDCO → … → CH_3OH/CH_2DOH

CN → HNC/DNC

Grains only!

In the Local ISM

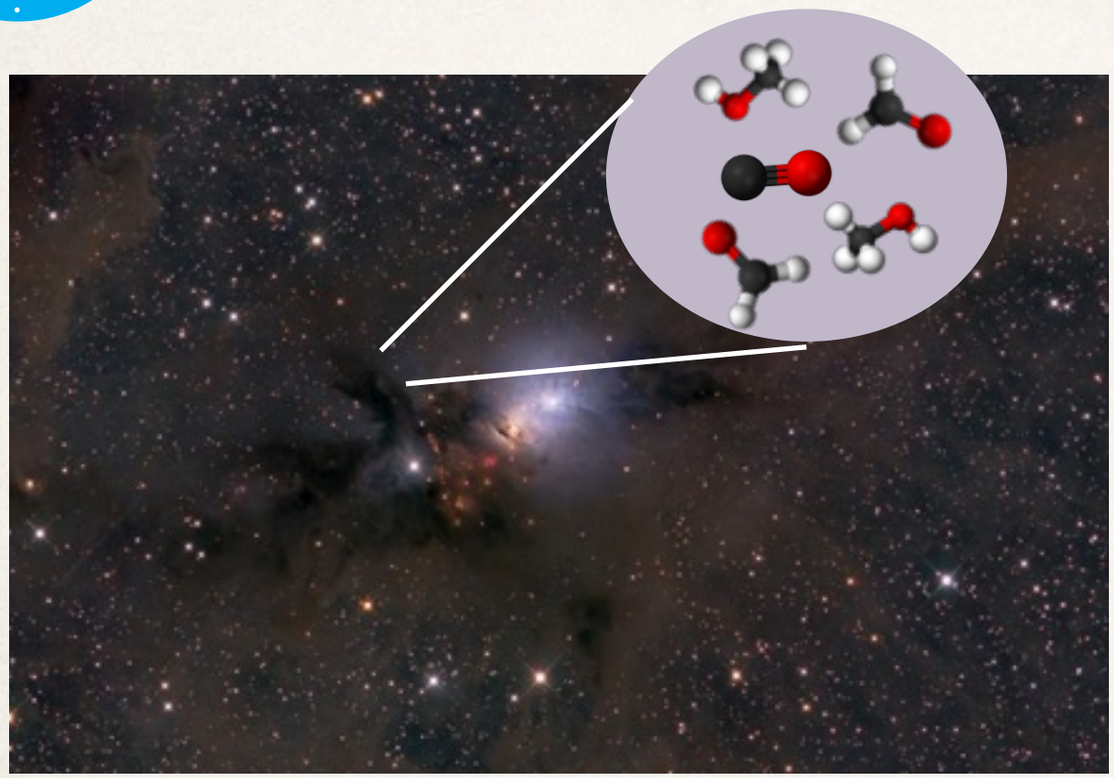
D/H ~ 1.5 10^{-5}

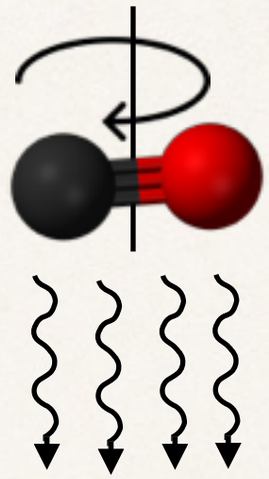
(Oliveira+03; Linsky+06)

Different from Terrestrial Standards by a factor 10!

We can use D/H as a tool!

HOW DO WE OBSERVE iCOMs ?



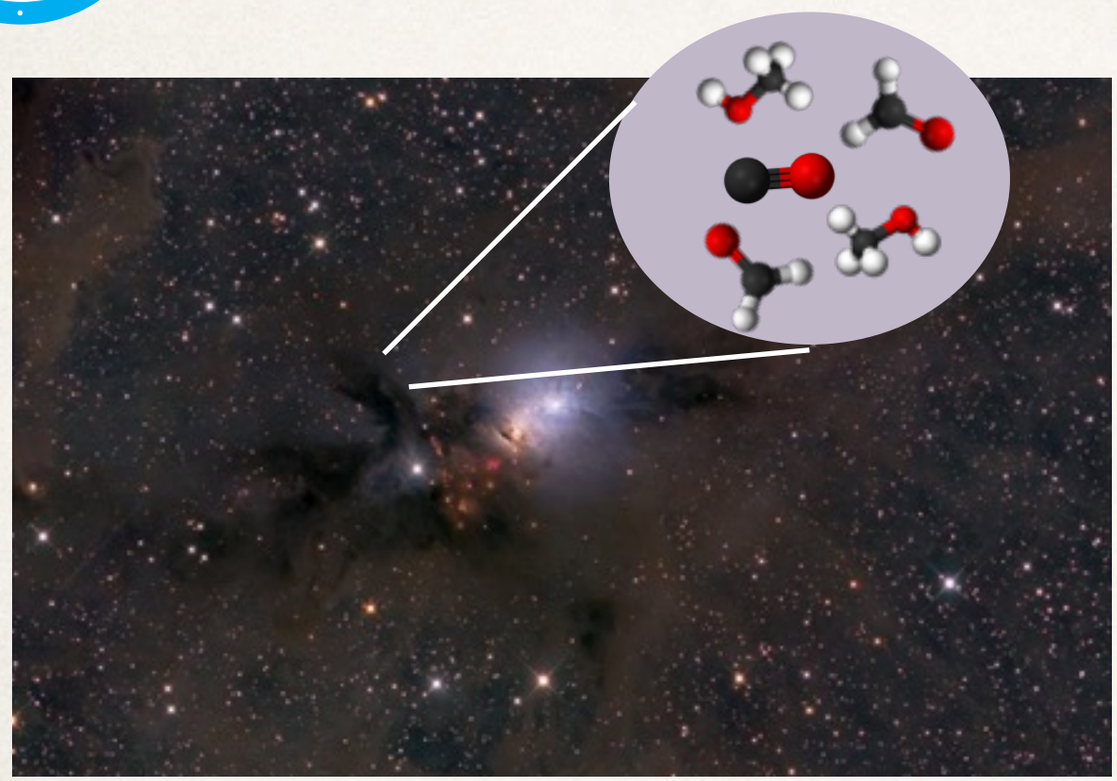


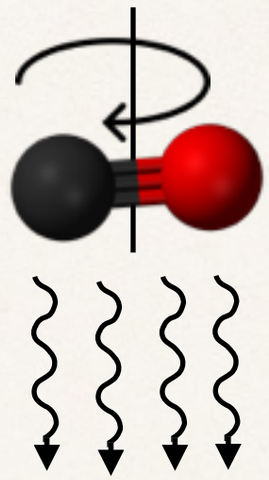
Observations in (sub)mm wavelenghts using

SINGLE DISH (IRAM 30m)
or

INTERFEROMETER (ALMA, NOEMA)

HOW DO WE OBSERVE iCOMs





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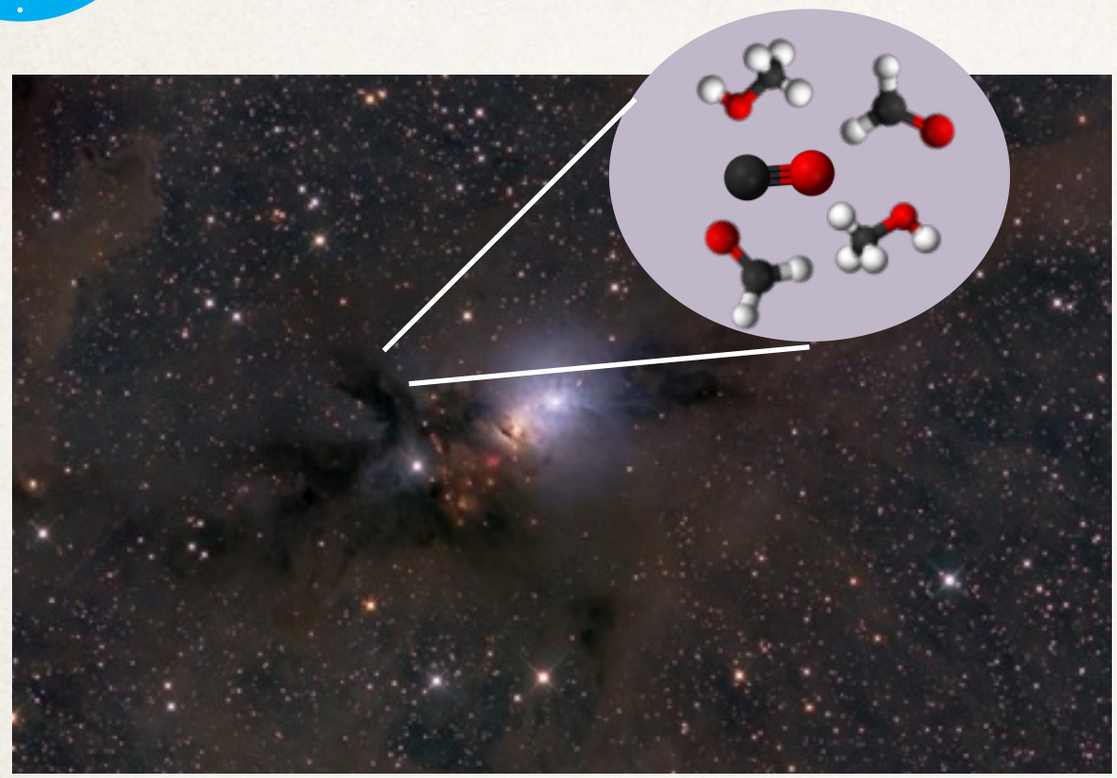

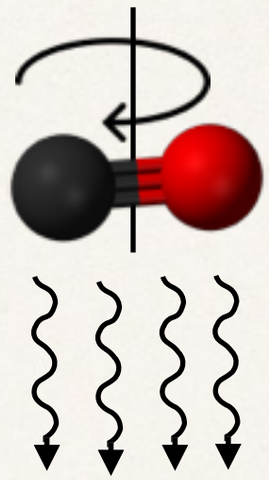

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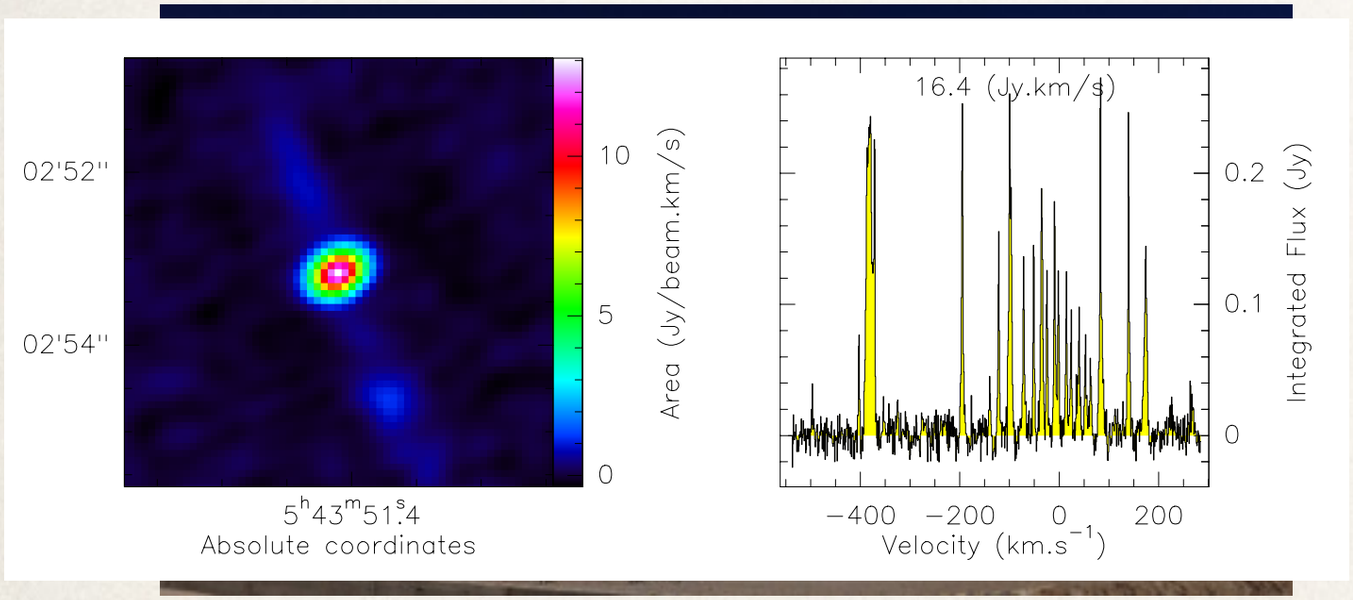

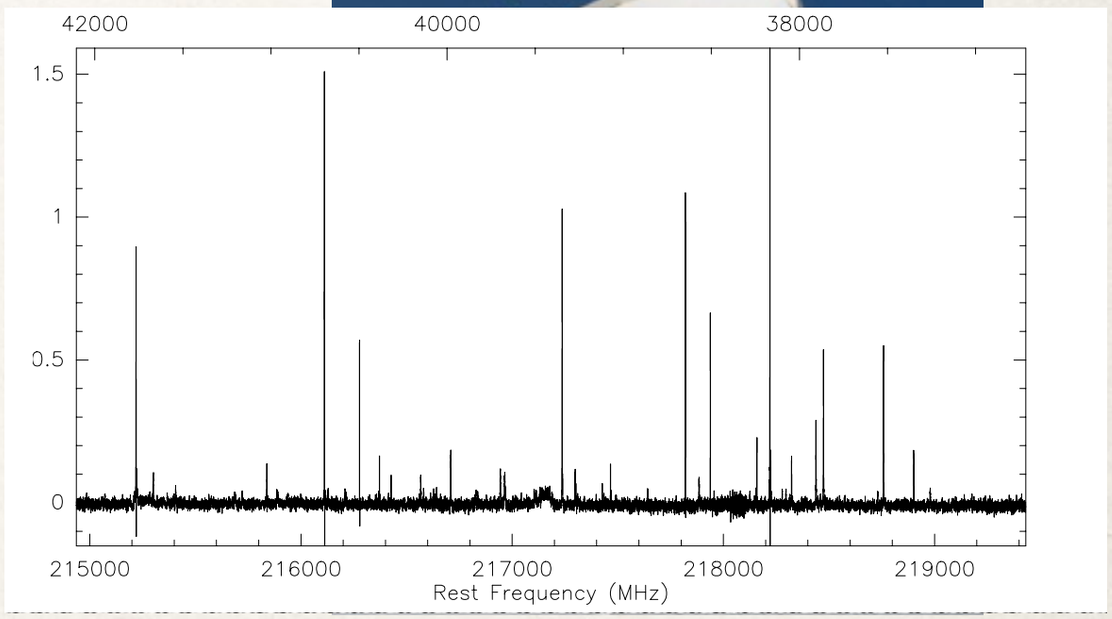

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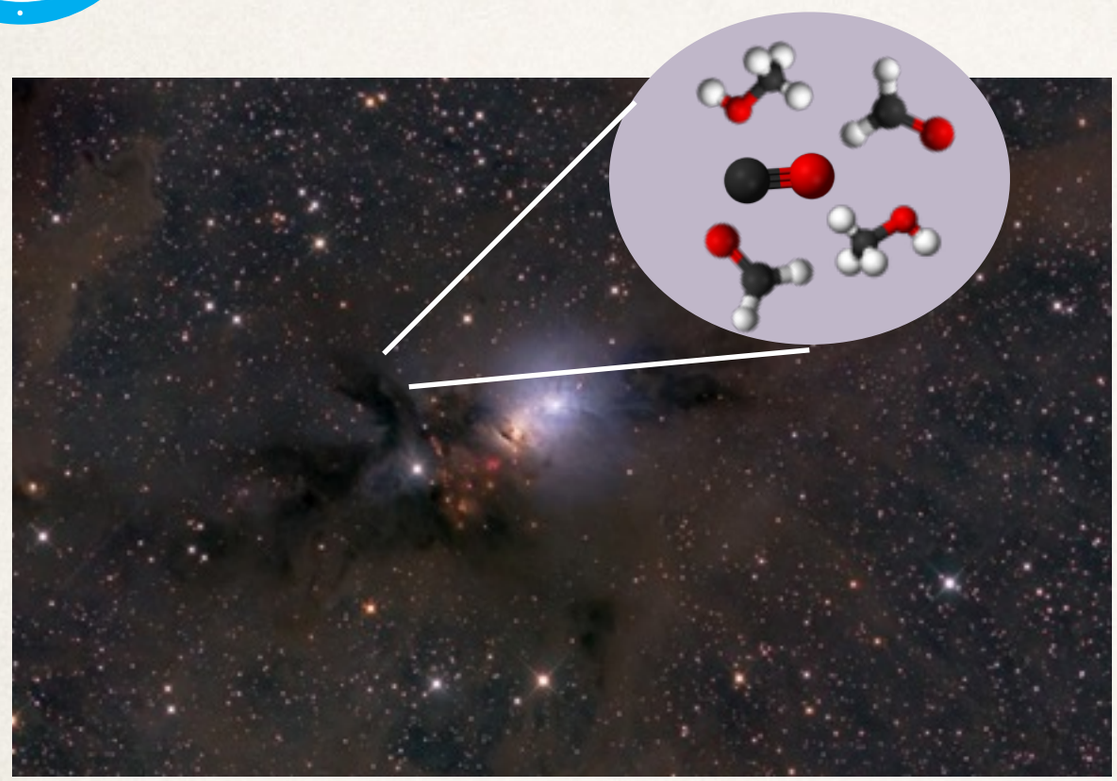

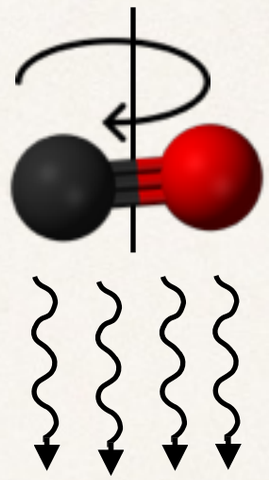

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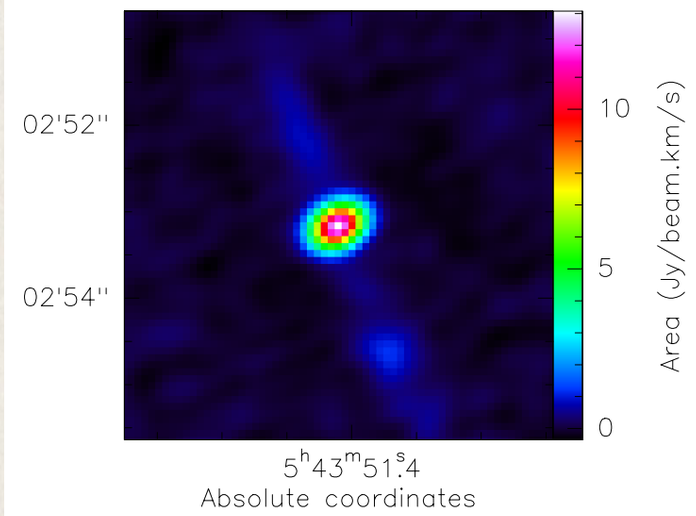
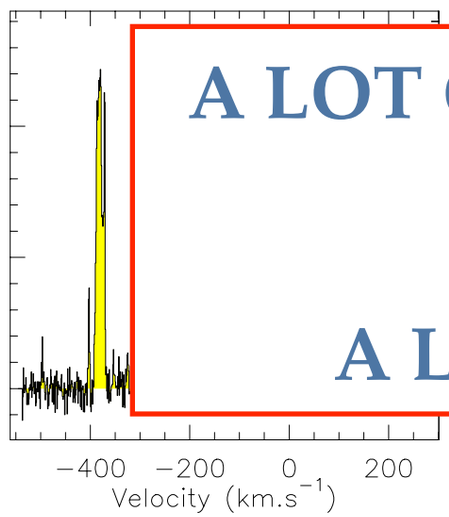
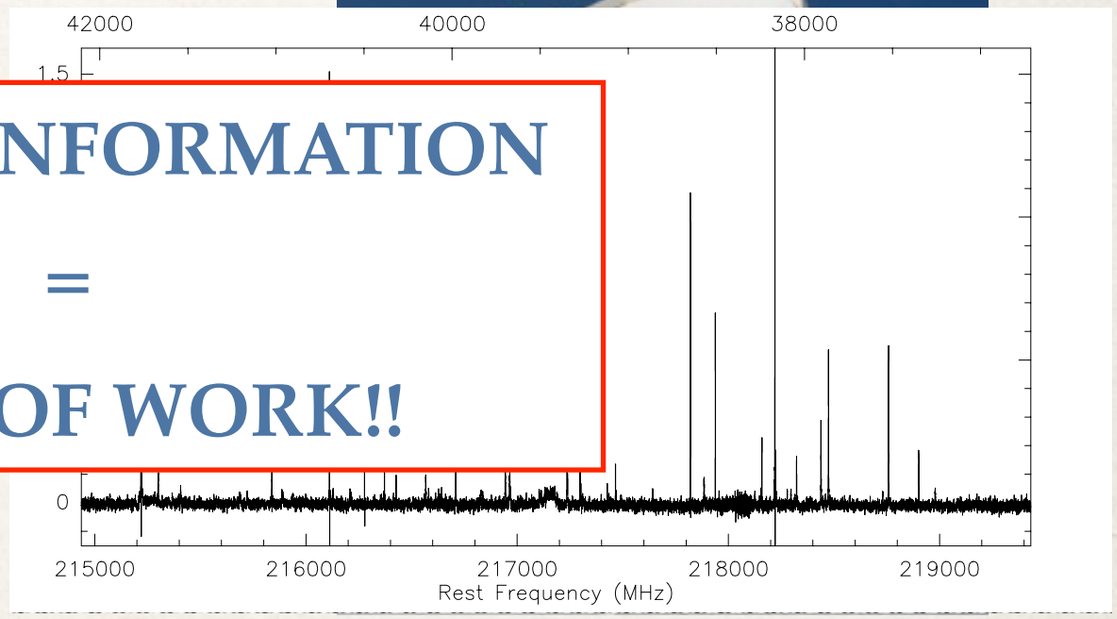




A LOT OF INFORMATION

=

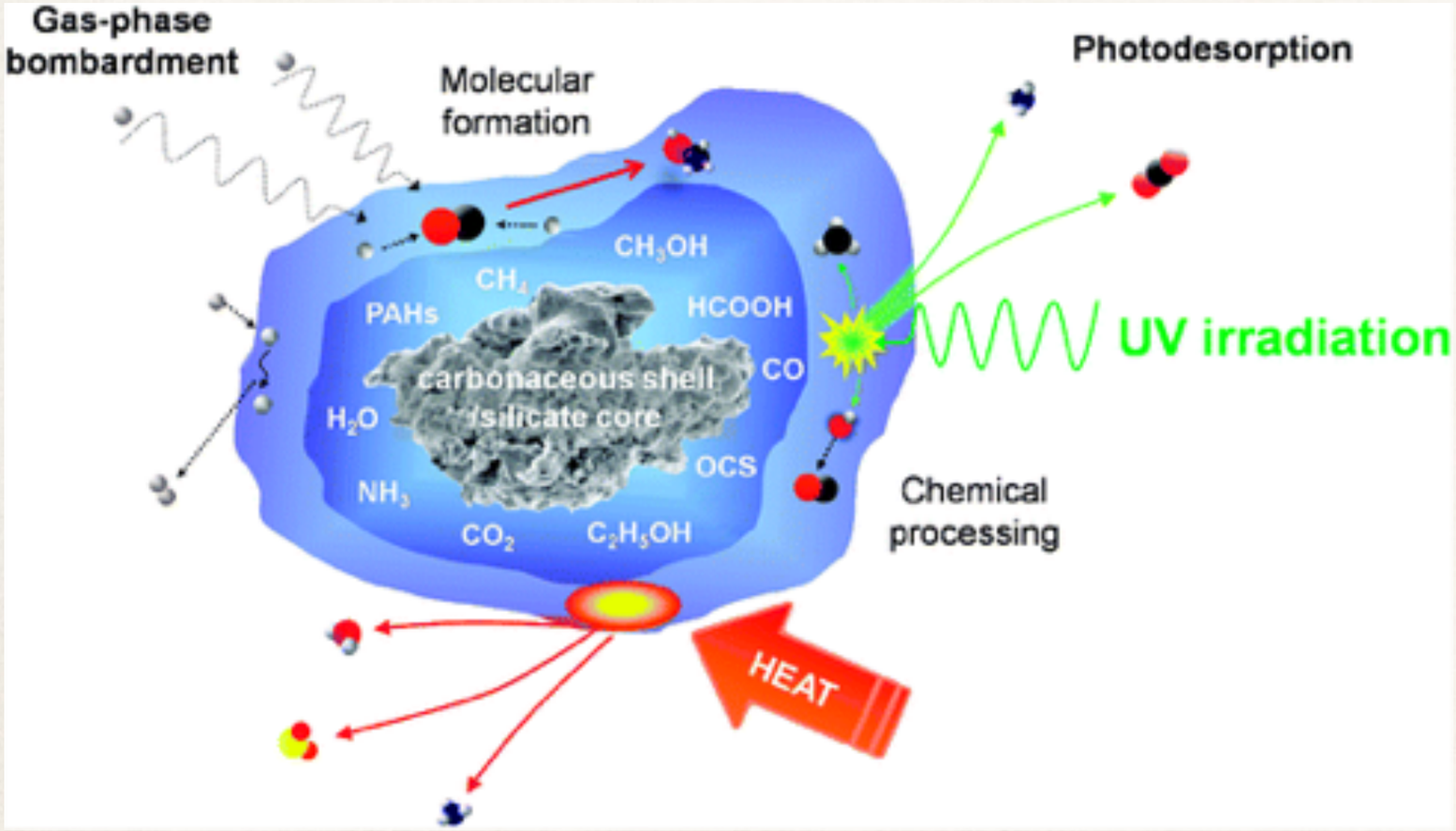
A LOT OF WORK!!



OPEN QUESTION 1 : How do iCOMs form?

GAS or GRAINS ?

Caselli & Ceccarelli 2012; Herbst and van Dishoeck 2009



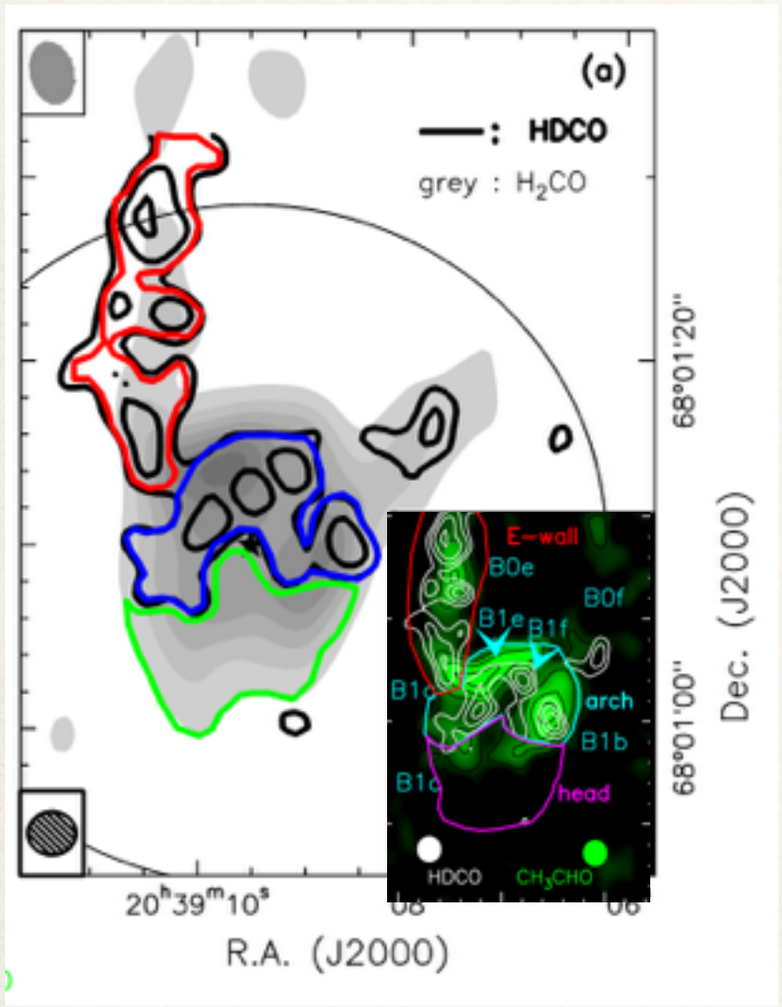
Are they directly formed on grain mantles?
Or are daughter species, i.e. are formed in gas phase following the release of parent species such as methanol and formaldehyde?

OPEN QUESTION 1 : How do iCOMs form?

Some evidences..

Fast and weak shocks in Class 0

L1157-B1 Fontani+14



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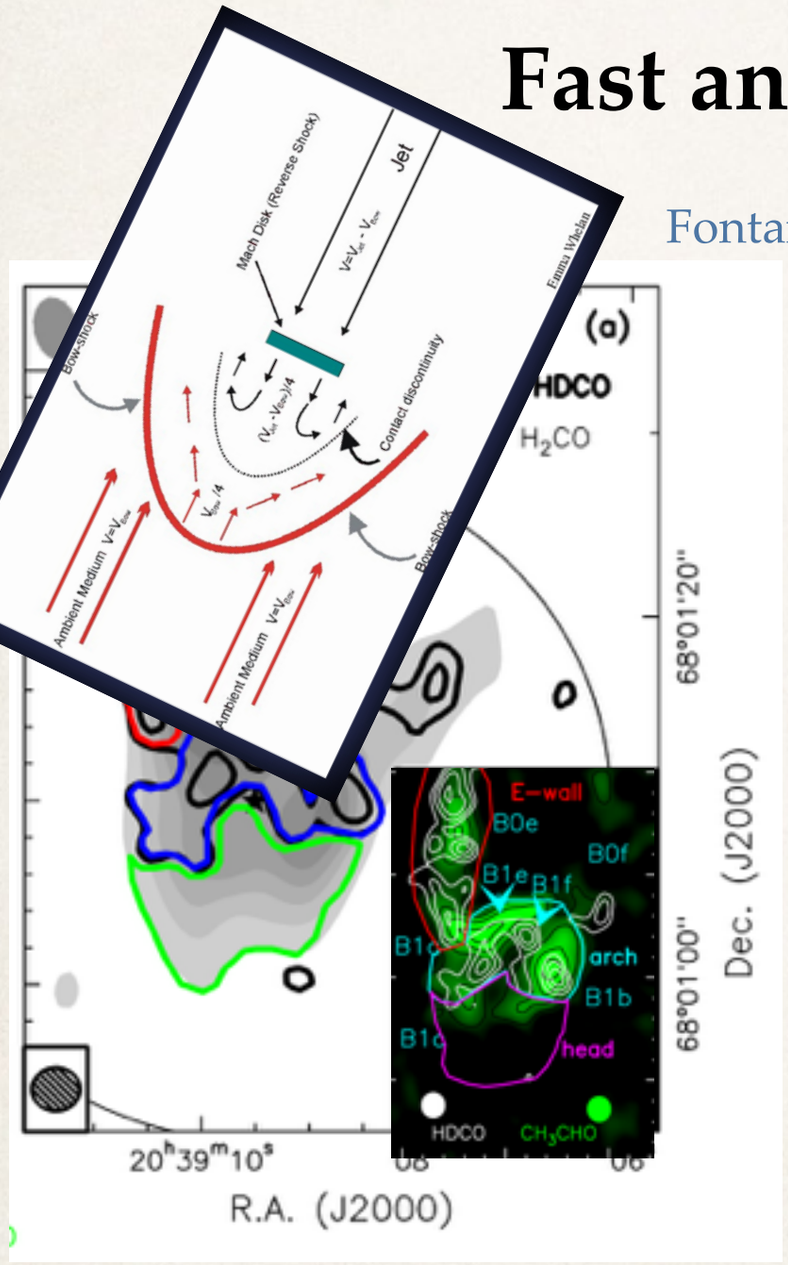

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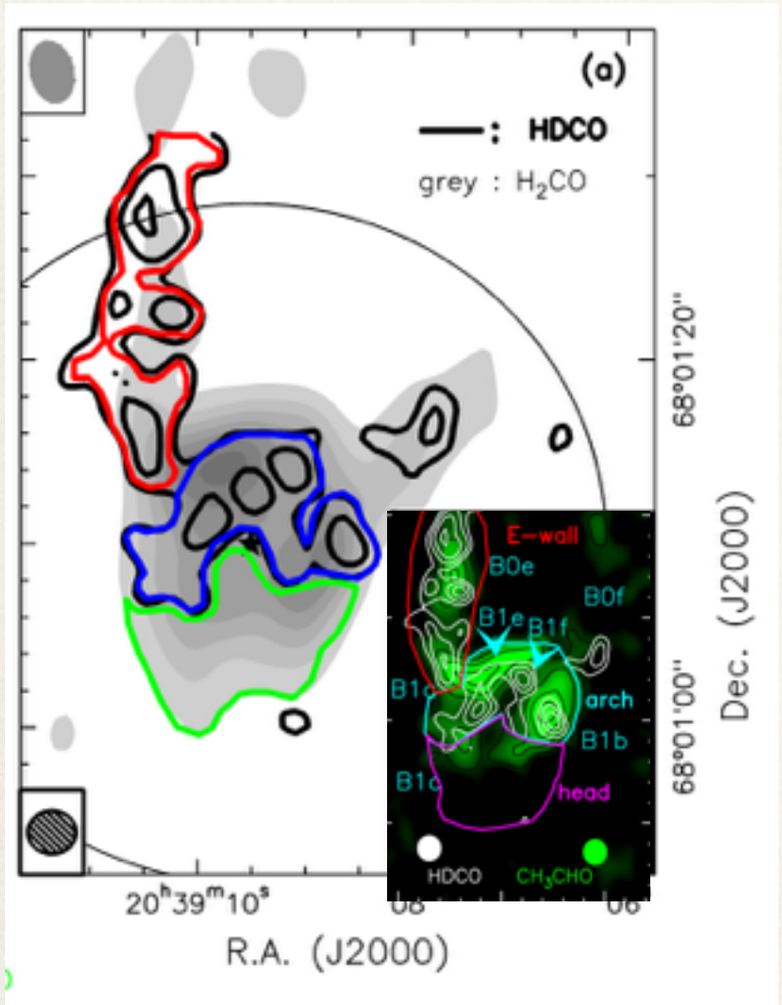
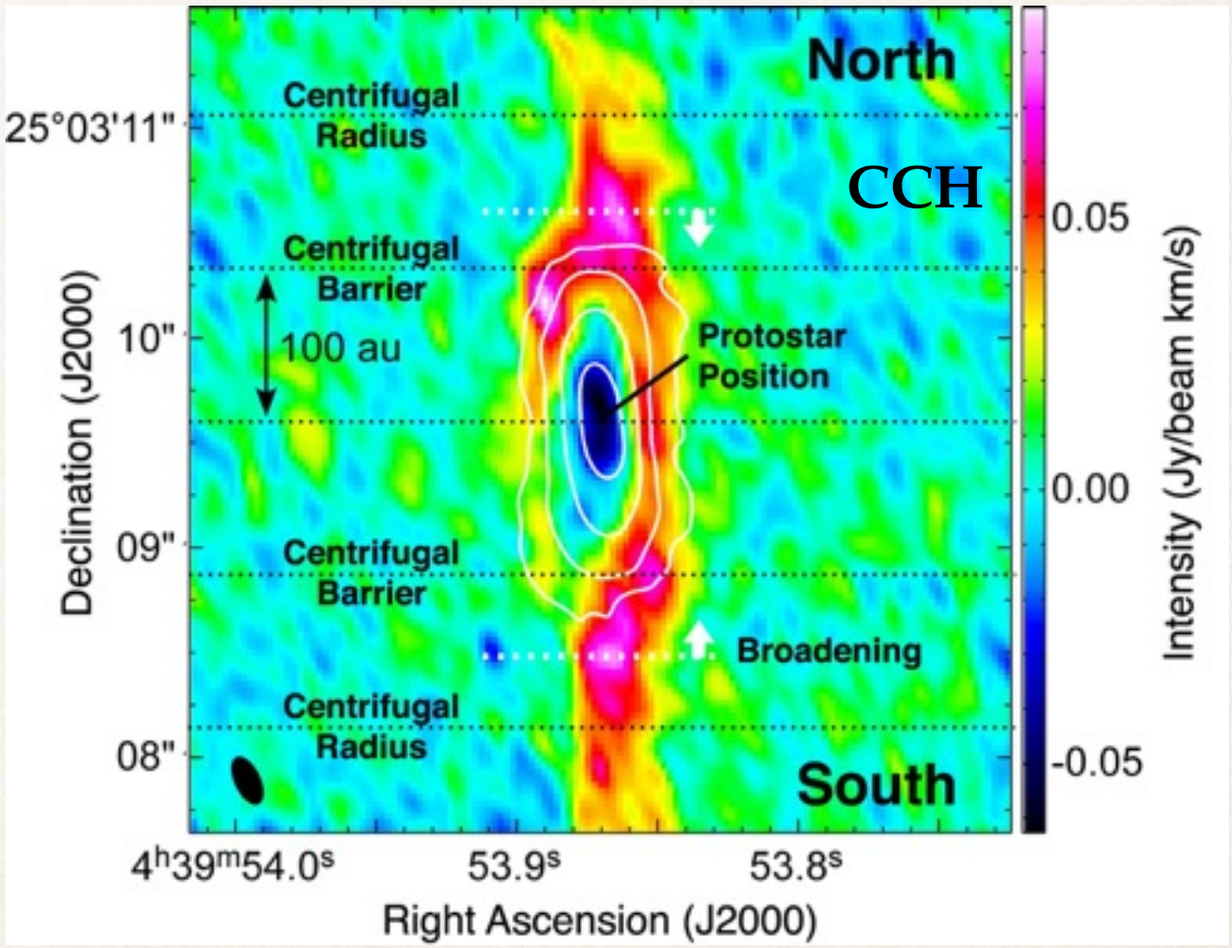
L1157-B1 Fontani+14 Codella+14



L1527 Sakai+17



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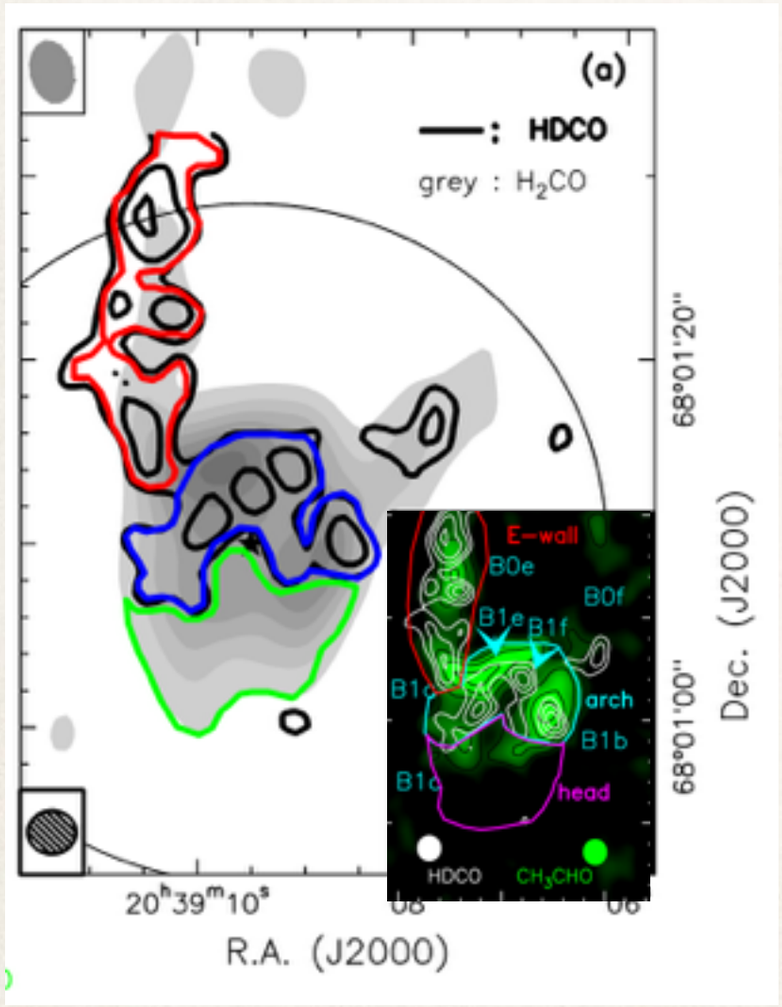
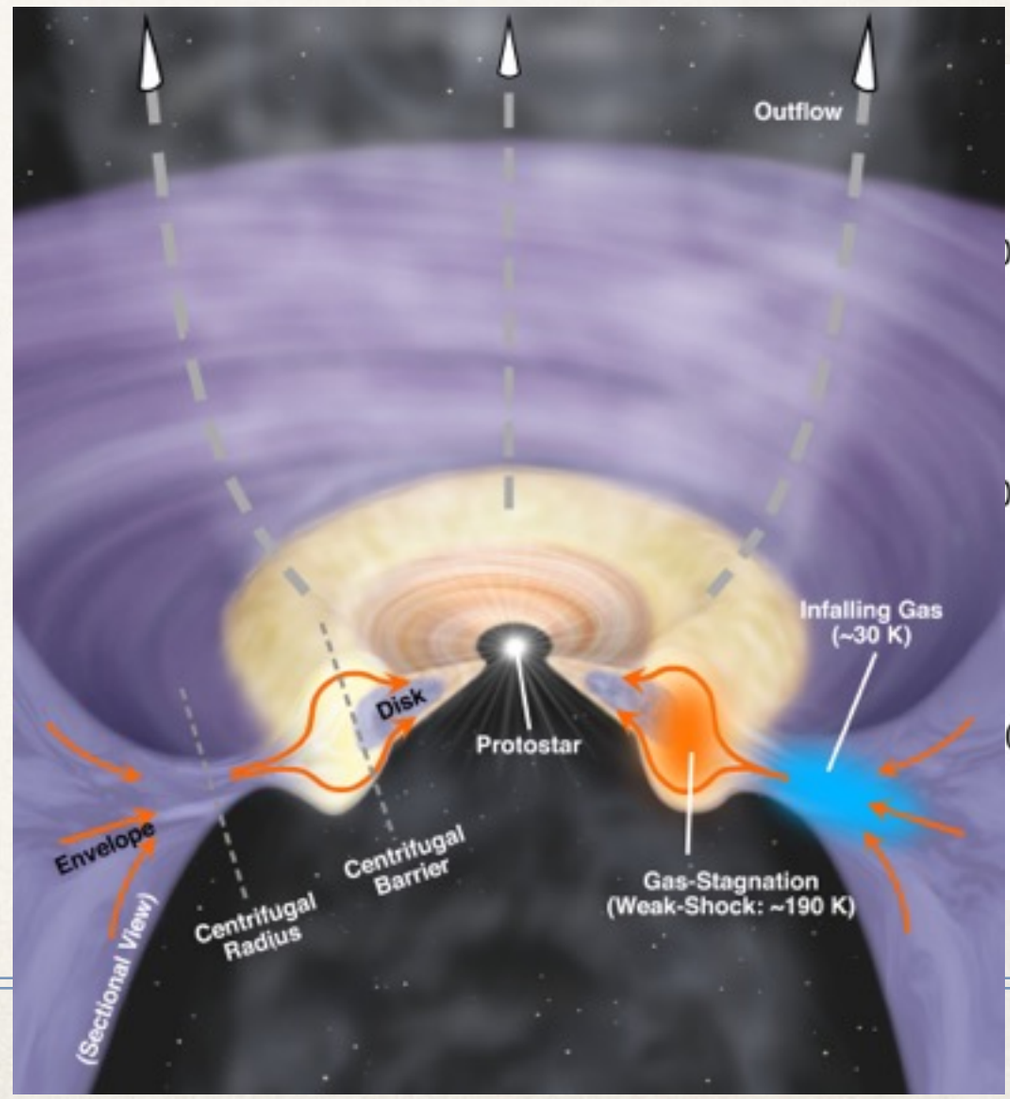
L1157-B1

Fontani+14



L1527

Sakai+16

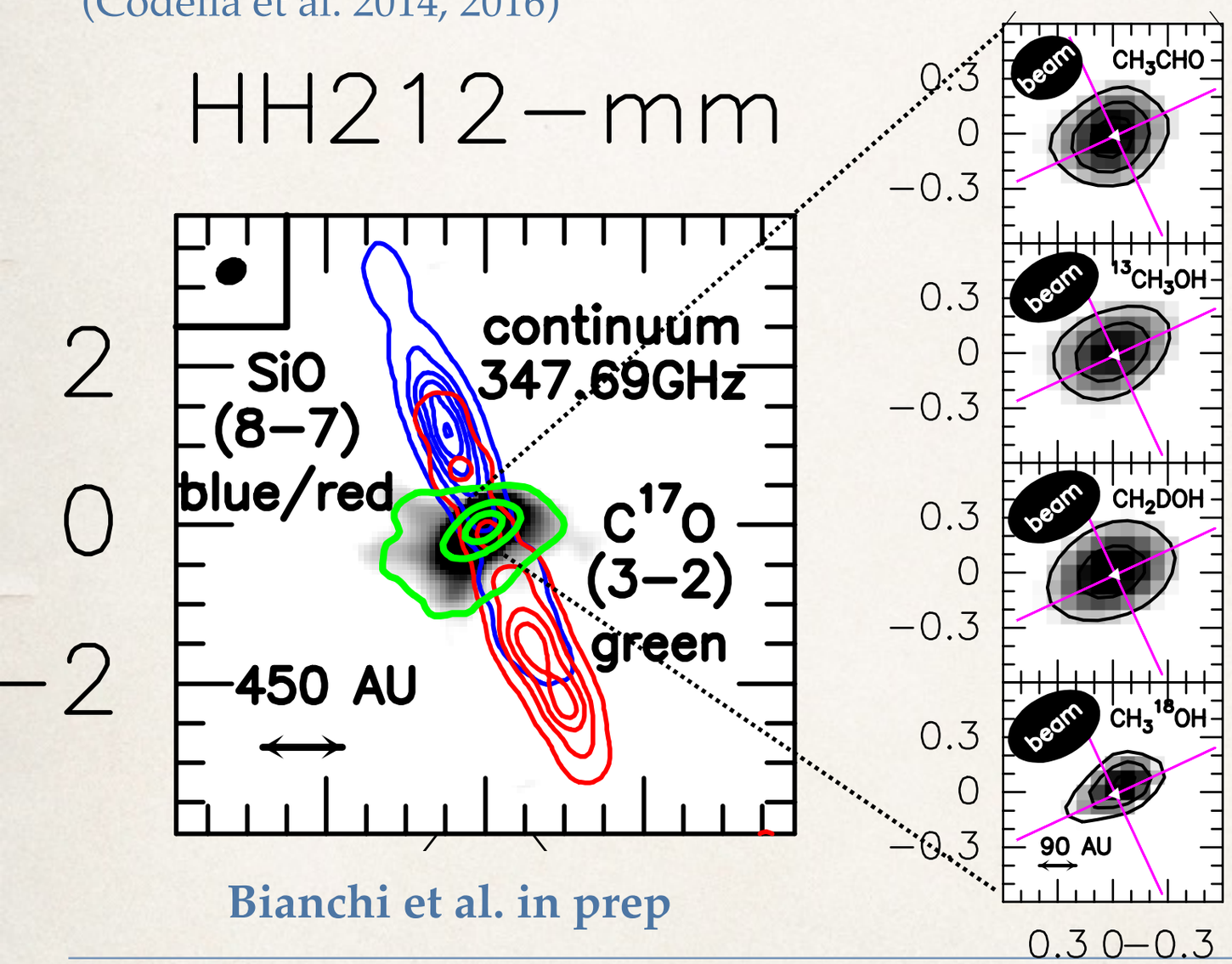


OPEN QUESTION 1 : How do iCOMs form?

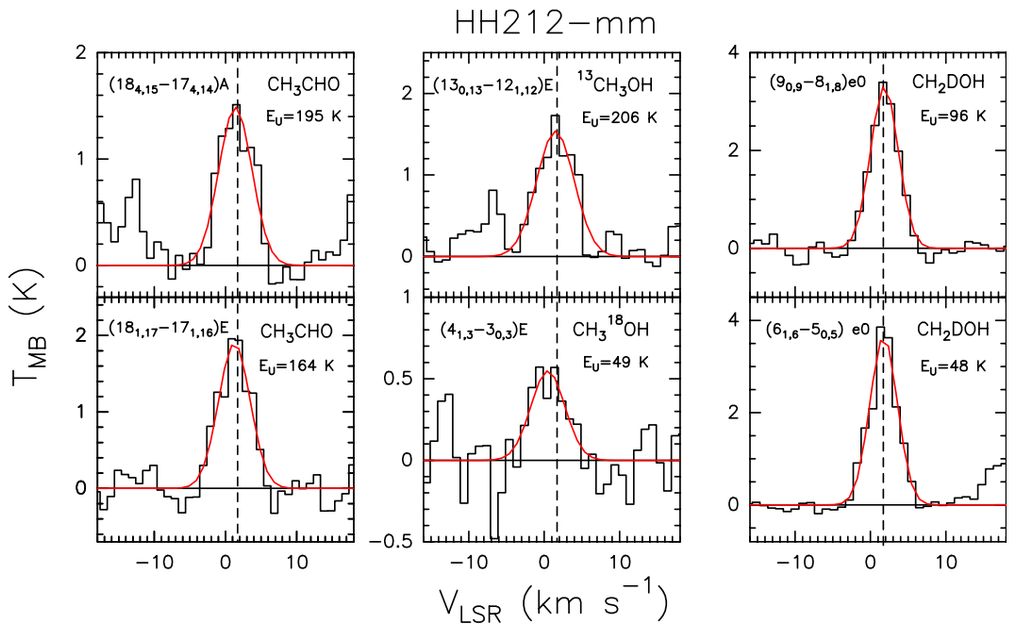
HH212 in Orion

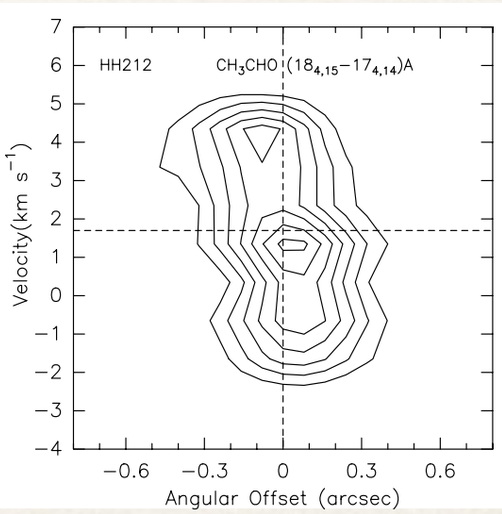
ALMA Band 7 observations of HH212

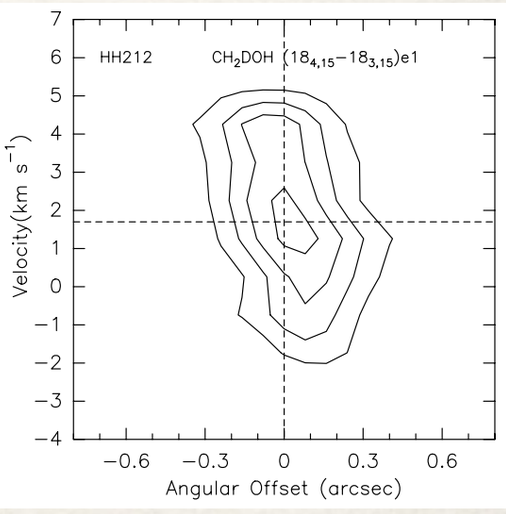
(Codella et al. 2014, 2016)



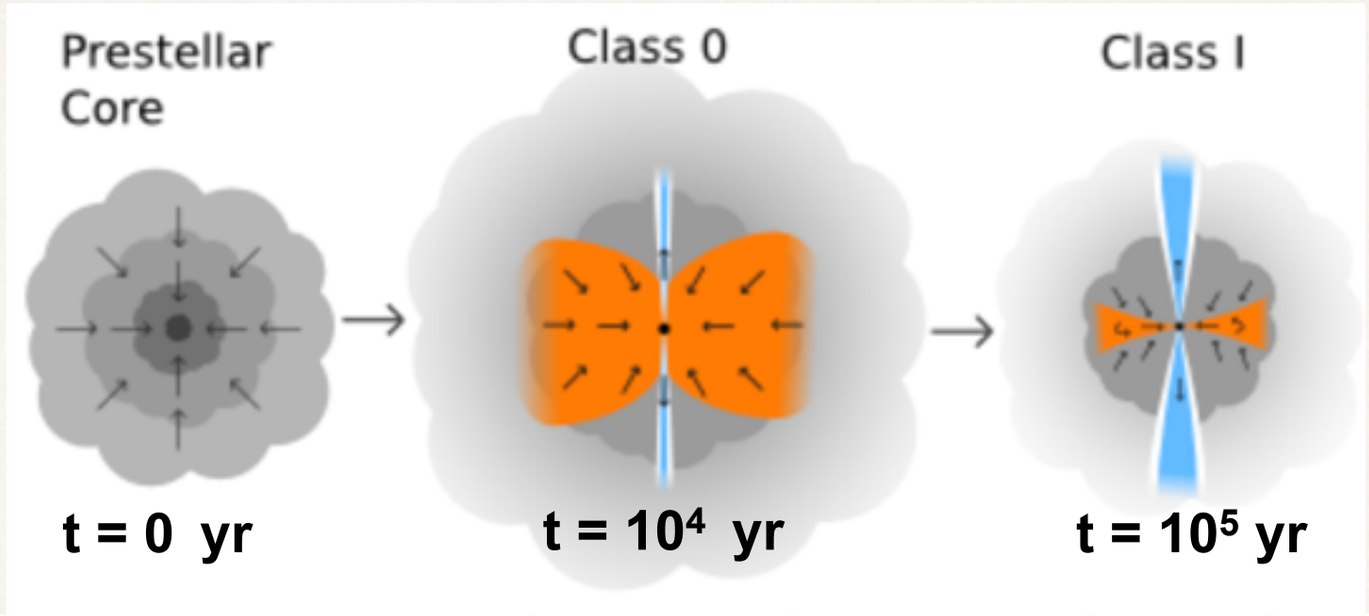
Bianchi et al. in prep



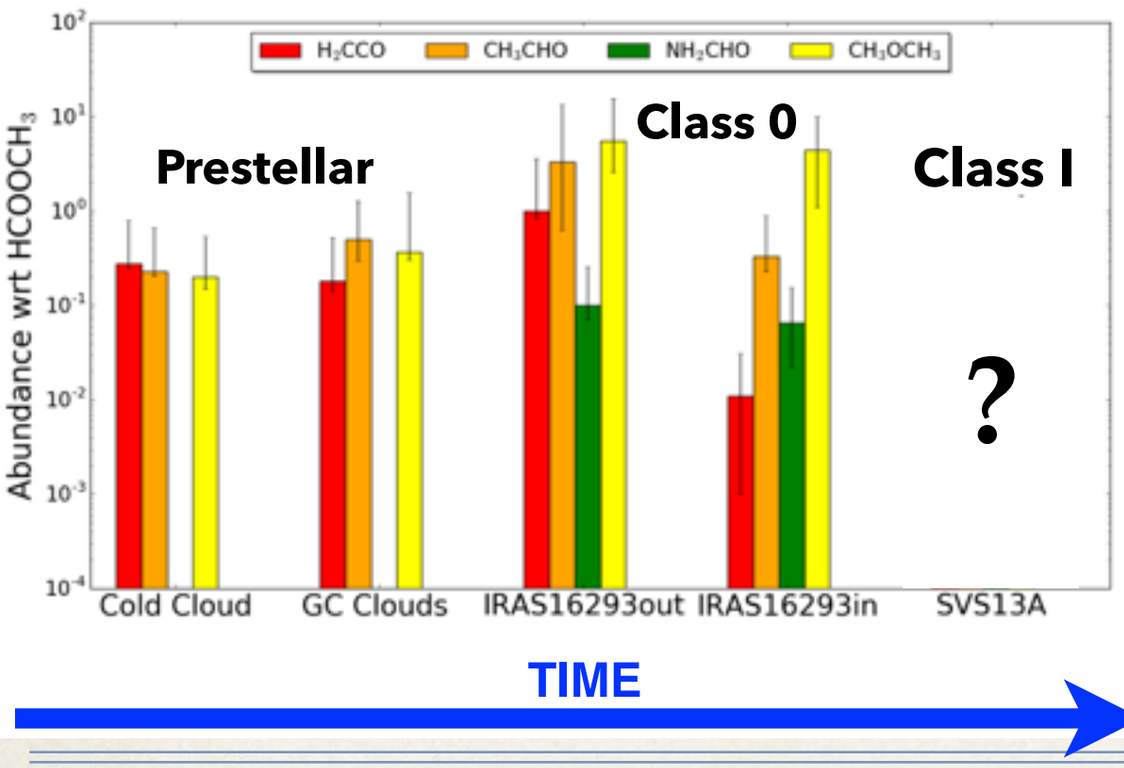




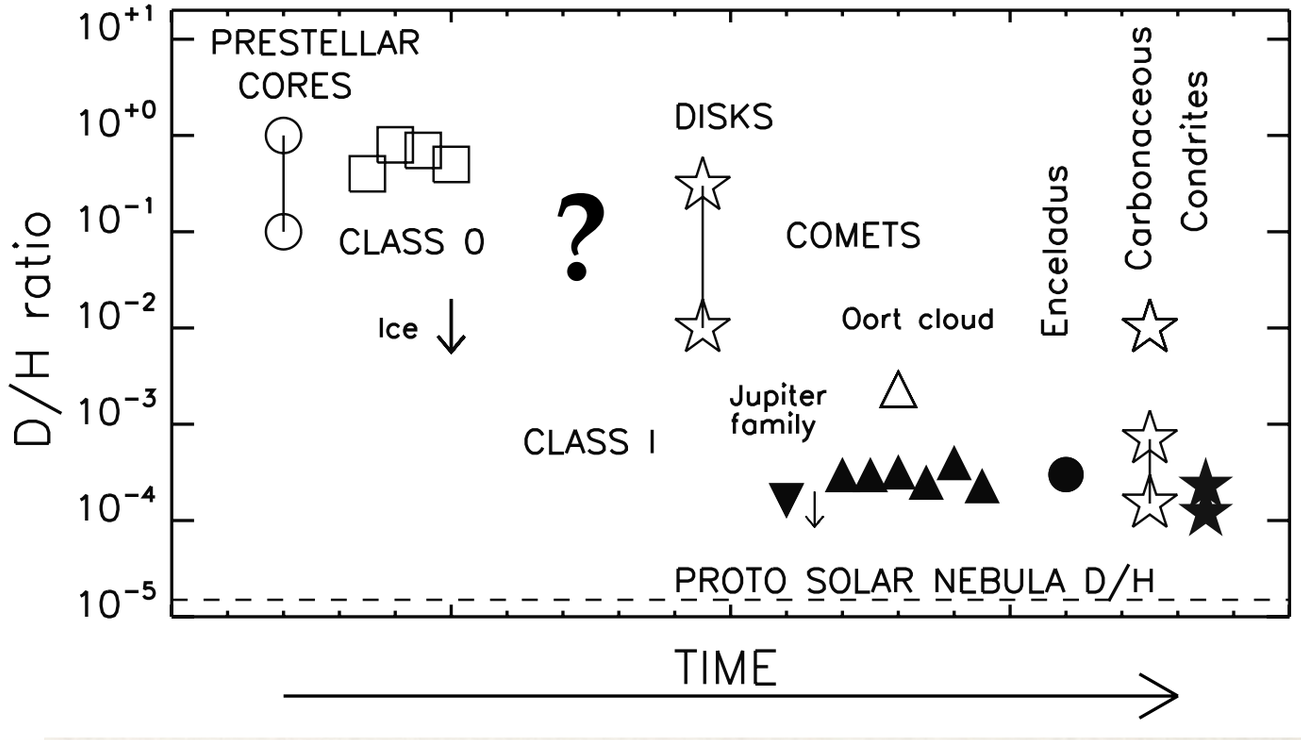
OPEN QUESTION 2 : How do chemical content evolve?



iCOMs



D/H



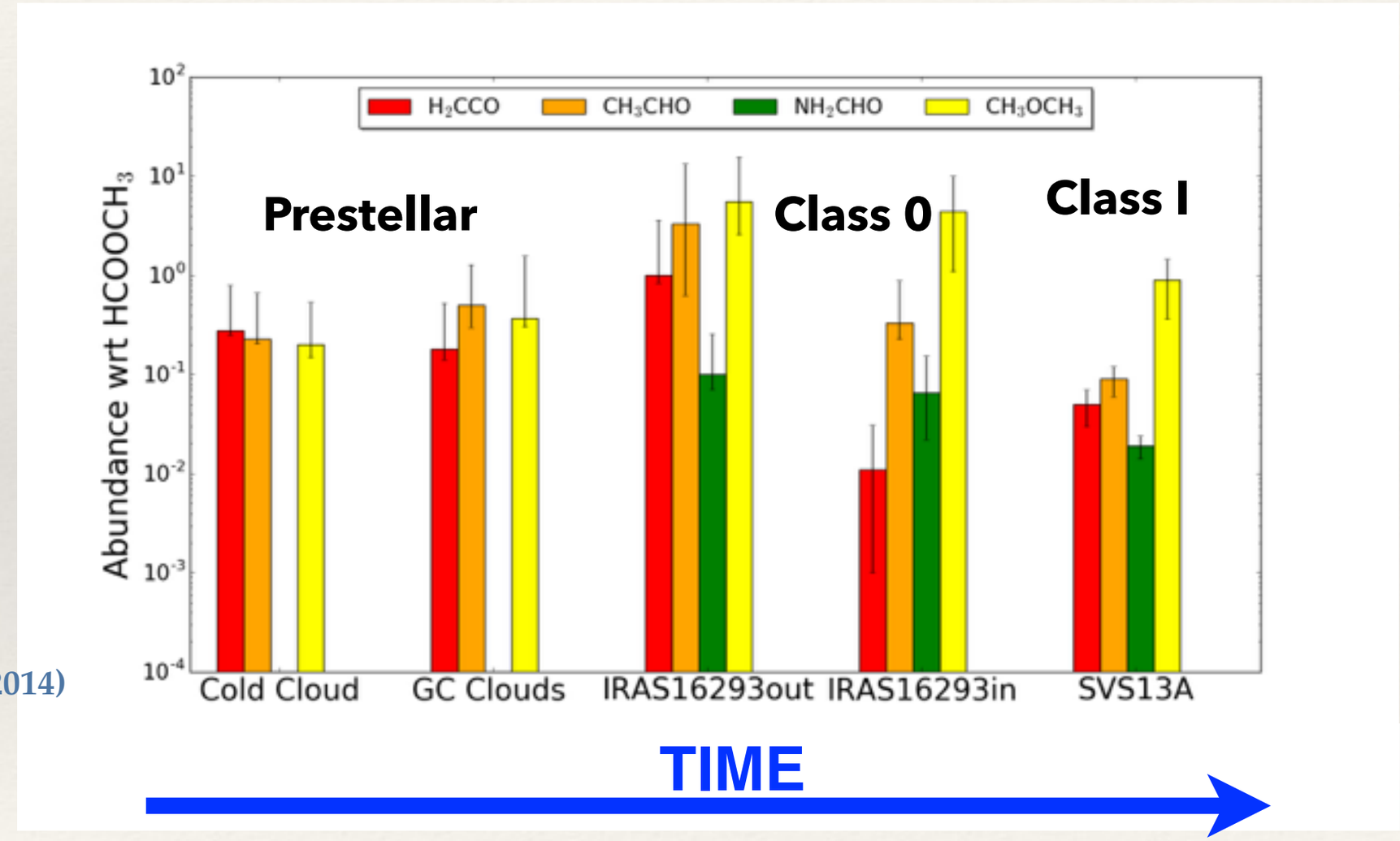
CHEMICAL COMPLEXITY IN SVS13-A

iCOMs abundances seems to be the same from Class 0 to Class I
Paving the way for the investigation of more evolved sources…

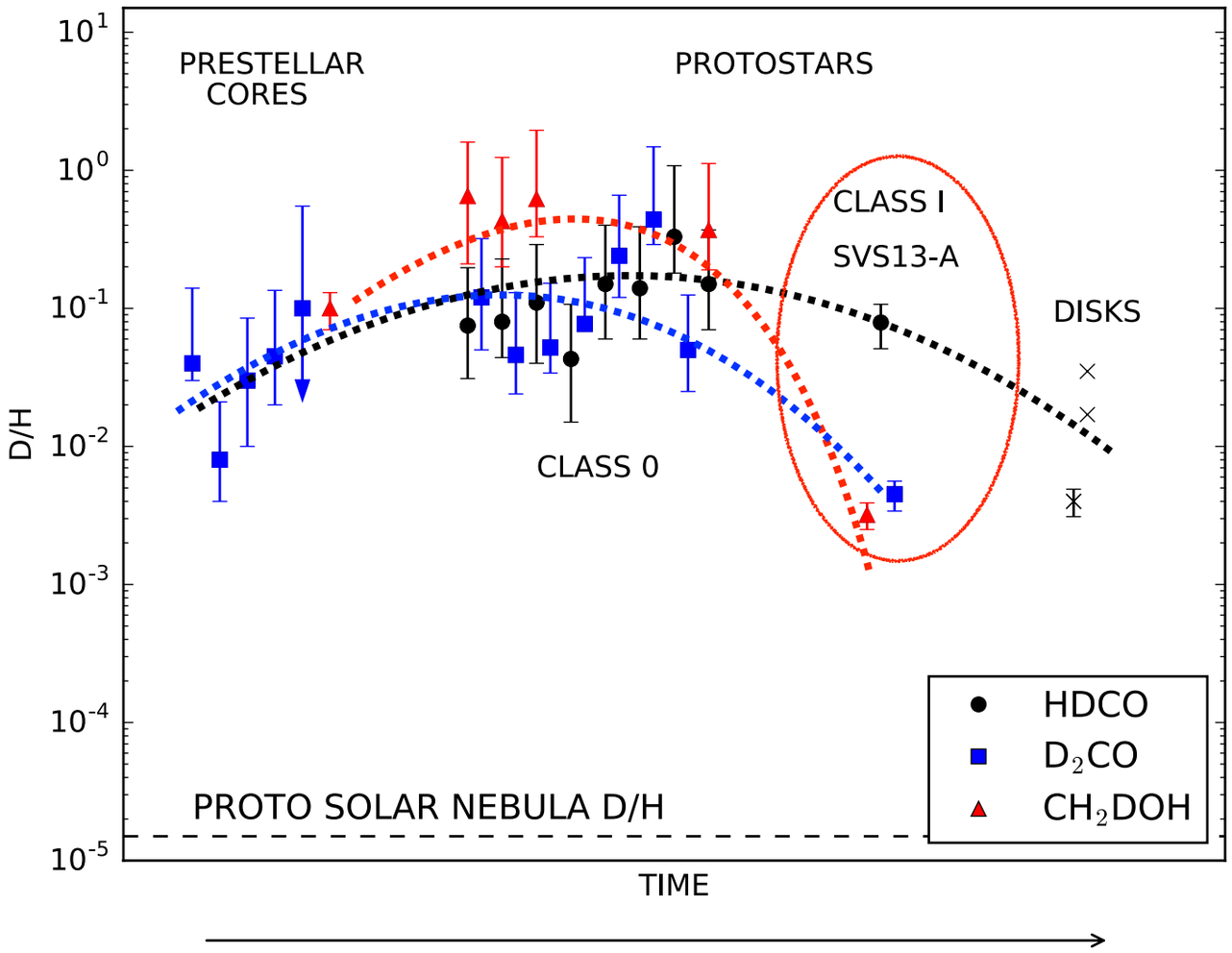
[$H_2CCO/HCOOCH_3$] ~ 0.05(0.02) **[$CH_3CHO/HCOOCH_3$] ~ 0.09(0.03)** **[$CH_3OCH_3/HCOOCH_3$] ~ 0.91(0.55)**

Bianchi et al.
in preparation

(Adapting Jaber et al. 2014)



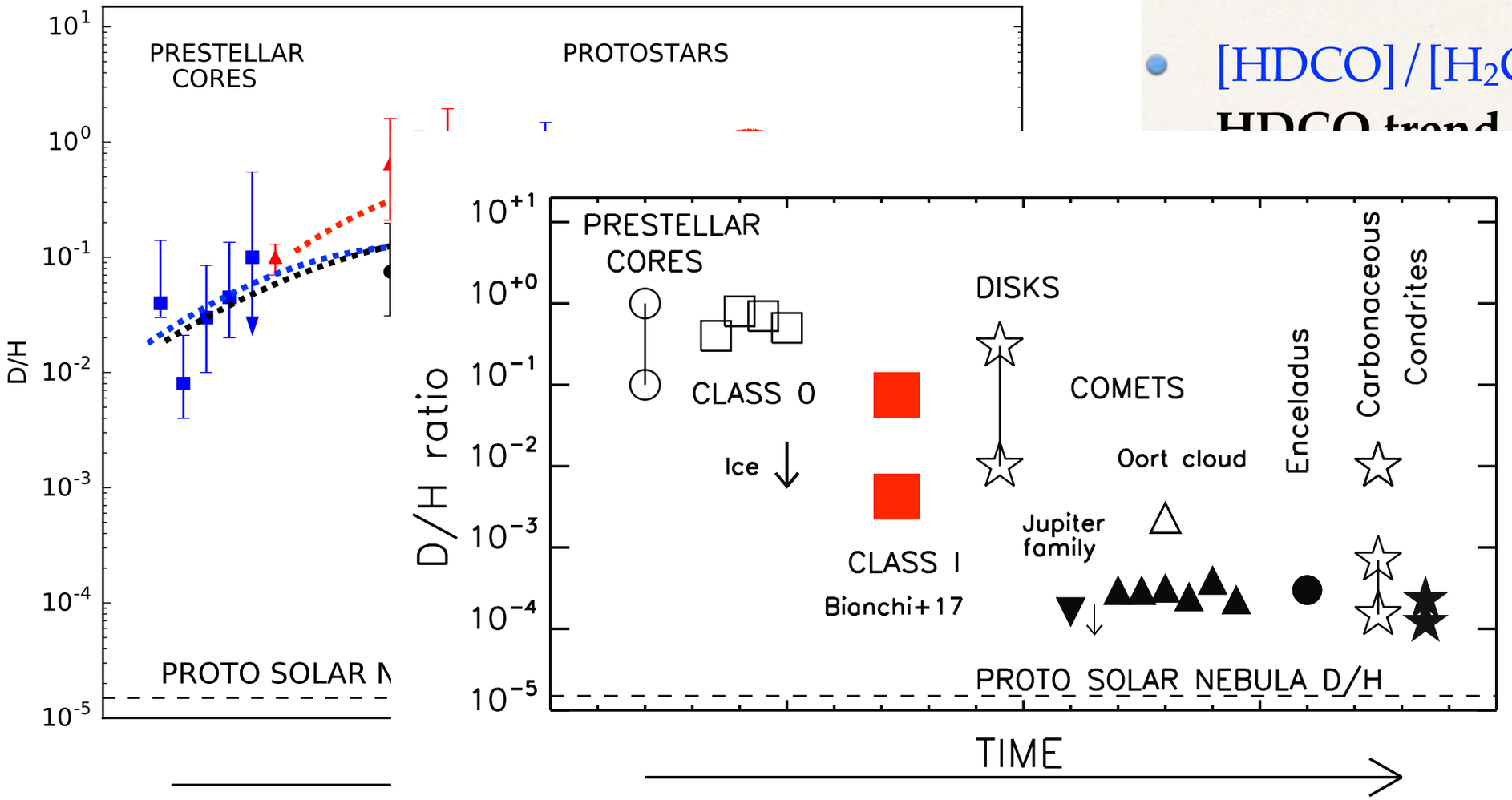
DECREASE OF THE ORGANICS DEUTERATION



- $[HDCO]/[H_2CO] \sim (7.9 \pm 0.80)\ 10^{-2}$
  HDCO trend not clear
- $[D_2CO/H_2CO] \sim (4.5 \pm 1.1)\ 10^{-3}$
  D_2CO deuteration decreases of 1 order of magnitude for Class I
- $[CH_2DOH/CH_3OH] \sim (3.2 \pm 0.7)\ 10^{-3}$
  CH_3OH deuteration decreases by 2 orders of magnitude!

Bianchi et al. 2017

DECREASE OF THE ORGANICS DEUTERATION



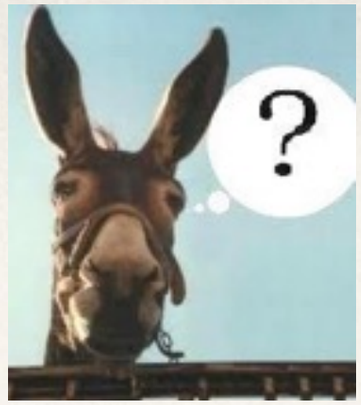
- [HDCO]/[H_2CO] ~ (7.9 ± 0.80) 10^{-2}
  HDCO trend not clear

(4.5 ± 1.1) 10^{-3}
n decreases of 1
de for Class I

OH] ~ (3.2 ± 0.7) 10^{-3}
ion decreases by 2
ude!

Bianchi et al. 2017

TAKE HOME MESSAGES

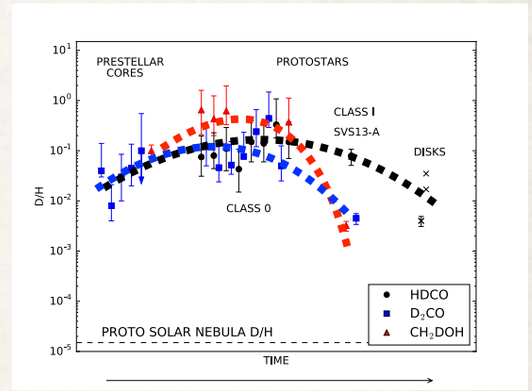


1. iCOMs and D/H are powerful tools

- observed in all the stages of the Sun-like star formation
- used to disentangle the physical emitting components of protostars and to investigate their formation

2. Chemical evolution

- iCOMs abundances look the same from Class 0 to Class I
- D/H decrease from Class 0 to Class I



PRESENT AND FUTURE PROJECTS

1. IRAM NOEMA Large program

SOLIS: Seeds Of Life In Space

PIs: C.Ceccarelli & P.Caselli

380 hr observations

SYSTEMATIC OBSERVATIONS OF 5 COMs IN DIFFERENT SOURCES REPRESENTATIVES OF SUN-LIKE STAR FORMATION

2. ALMA Cycle 5 Proposal for Large Program

FAUST: Fifty AU STudy of the chemistry and physics of proto-Sun analogues

PIs: S. Yamamoto, C. Ceccarelli, C. Chandler, C. Codella, N. Sakai

110 hr observations

SYSTEMATIC OBSERVATIONS OF 14 SOURCES IN DIFFERENT EVOLUTIONARY STAGES ON SCALES OF 50 AU

PRESENT AND FUTURE PROJECTS

+ ALMA Cycle 4 proposal

Accepted with grade C

"HOT WATER FROM THE INNER 25AUS OF THE CLASS I SOURCE SVS13-A"

PI: E. Bianchi

angular resolution ~ 70 mas

HDO @ 226 GHz

HDO @ 242 GHz

$H_2{}^{18}O$ @ 322 GHz

2.

FAUST: Fifty A

PIs: S. Y

110 hr observations

SYSTEMATIC OBSERVATIONS OF 14 SOURCES IN DIFFERENT EVOLUTIONARY STAGES ON SCALES OF 50 AU

am

e

ERENT SOURCES

RMATION

un analogues

ai

THANK YOU!!