

# FRACTIONATION IN YOUNG PROTOSTARS

where past and present merge

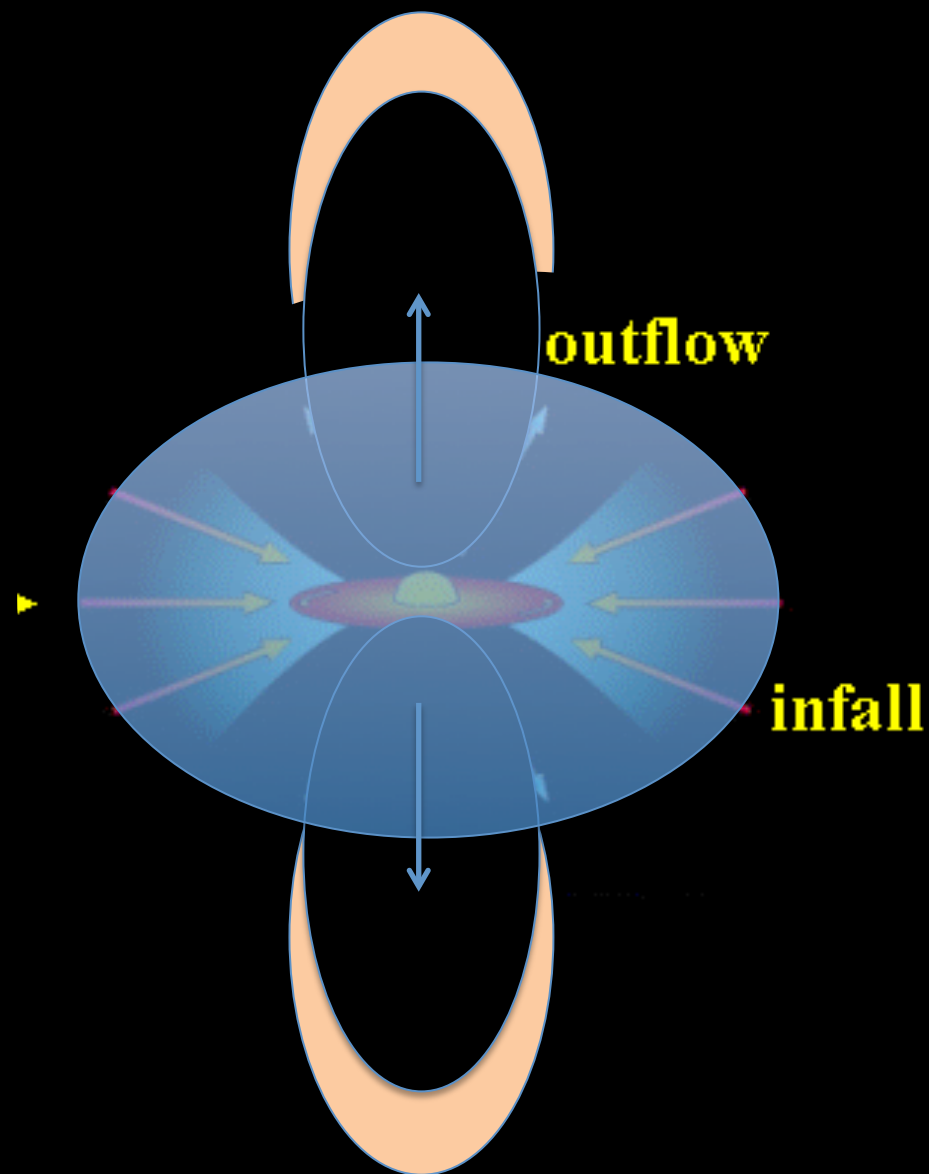
**C. Ceccarelli**

*Université Grenoble Alpes/CNRS-INSU*

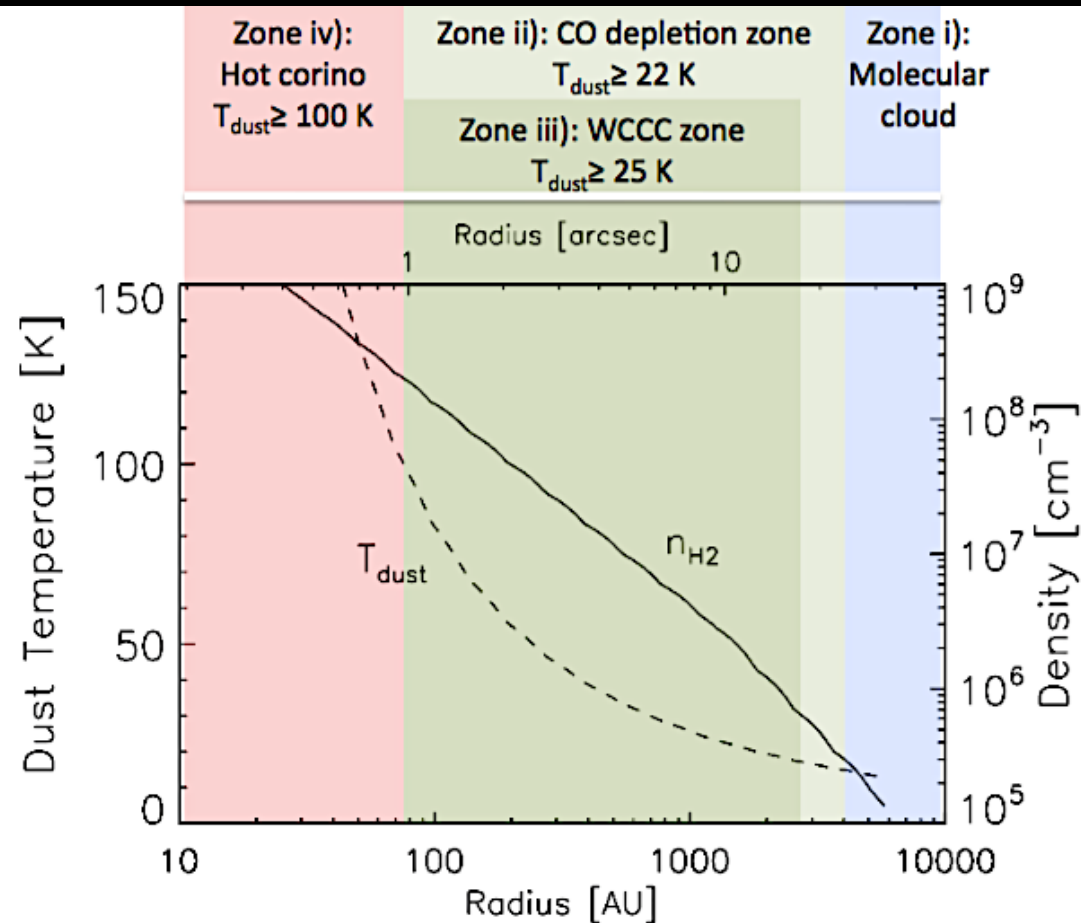
*Institut de Planétologie et d'Astrophysique de Grenoble (IPAG)*



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Florence  
Fractionation  
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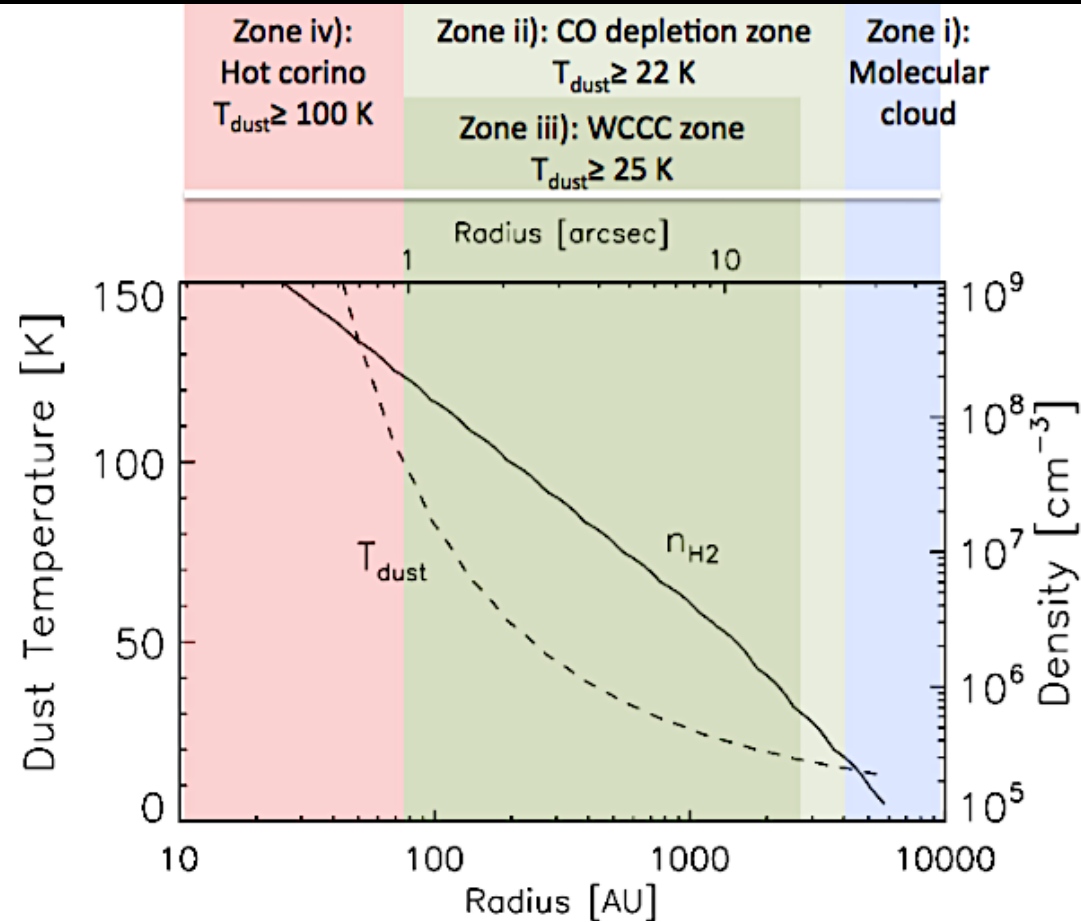
# YSOs: approximate chemical structure



**ICED MANTLE SUBLIMATION ZONE (e.g. hot core/corino)**

**CO DEPLETION ZONE (e.g. the cold outer envelope)**

# YSOs: approximate fractionation zone



**ICED MANTLE SUBLIMATION ZONE (e.g. hot core/corino)**

**DOMINATED BY THE ICE COMPOSITION → PAST**

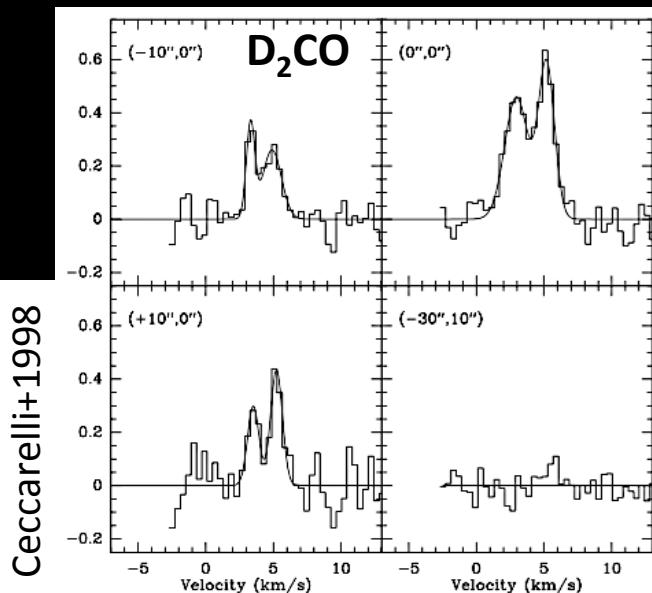
**CO DEPLETION ZONE (e.g. the cold outer envelope)**

**DOMINATED BY PRESENT GAS COMPOSITION → PRESENT**

# SUBLIMATION ZONE: fossils from the past

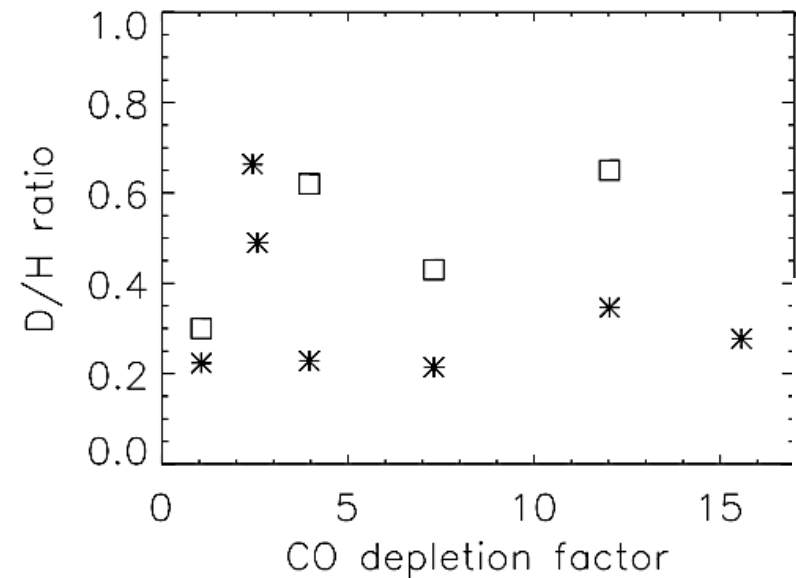
## THE SINGLE-DISH OBS ERA

- Bianchi, Codella, Trevino-Morlaes, & Podio TALKS
- Zahorecz's POSTER



**SUPER-DEUTERATED  
MOLECULES IN LOW-MASS  
YSOs DETECTED FOR  
ALMOST TWO DECADES**

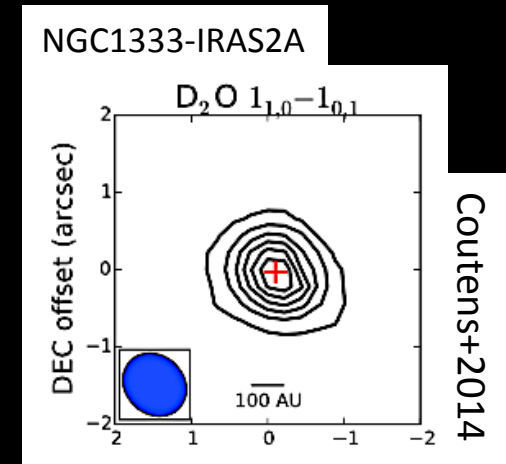
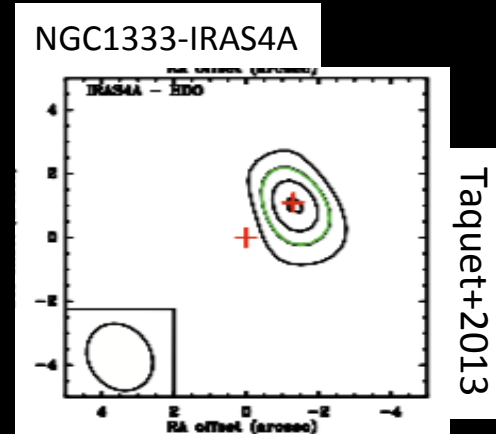
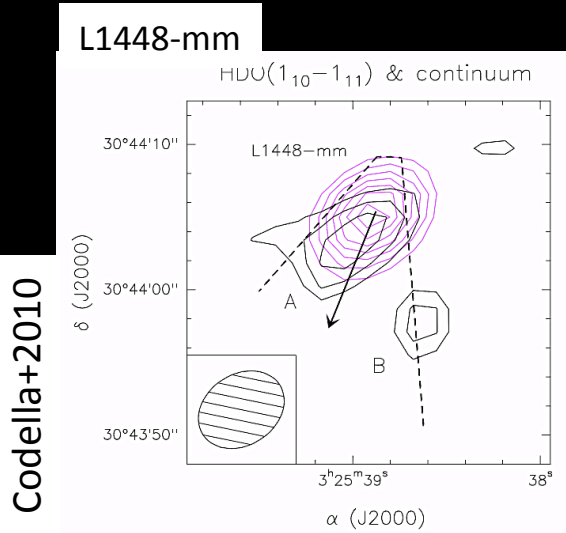
**LACK OF CORRELATION  
WITH CO DEPLETION  
+  
WARM GAS  
=  
SUBLIMATED ICES**



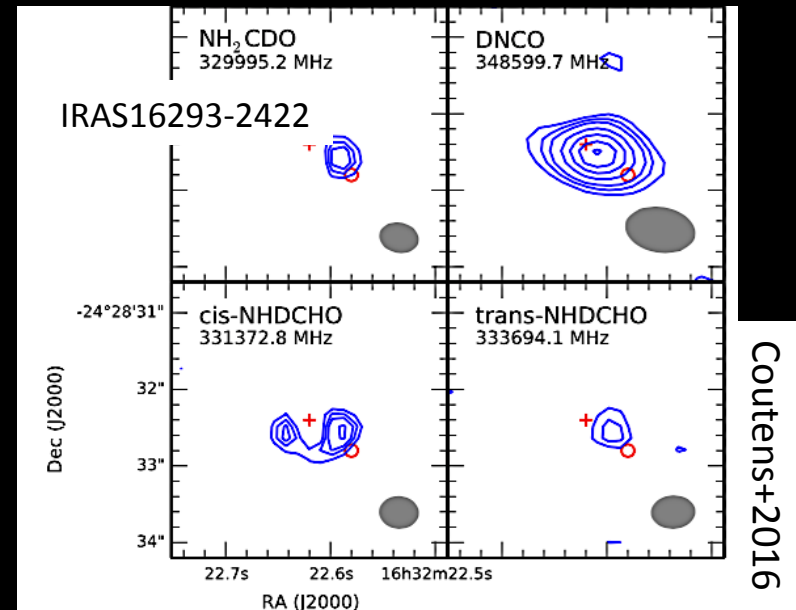
# SUBLIMATION ZONE: fossils from the past

## THE INTERFEROMETER OBS ERA

→ Codella, Coutens & Kento's talks

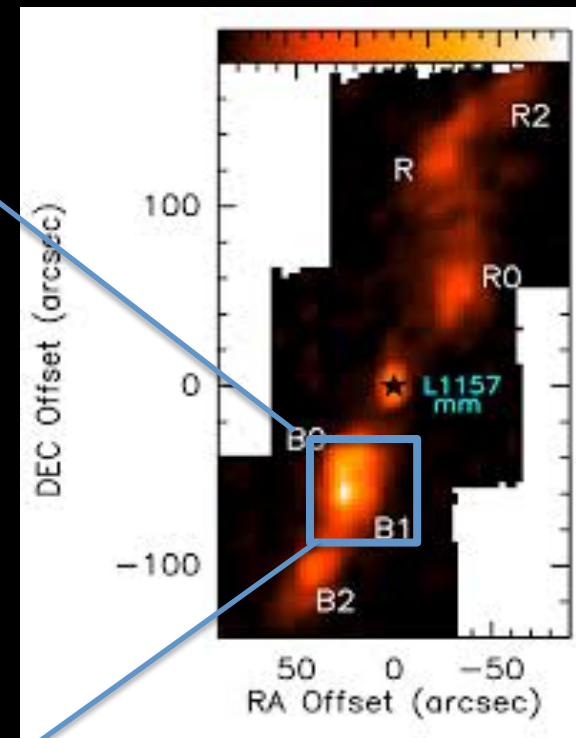
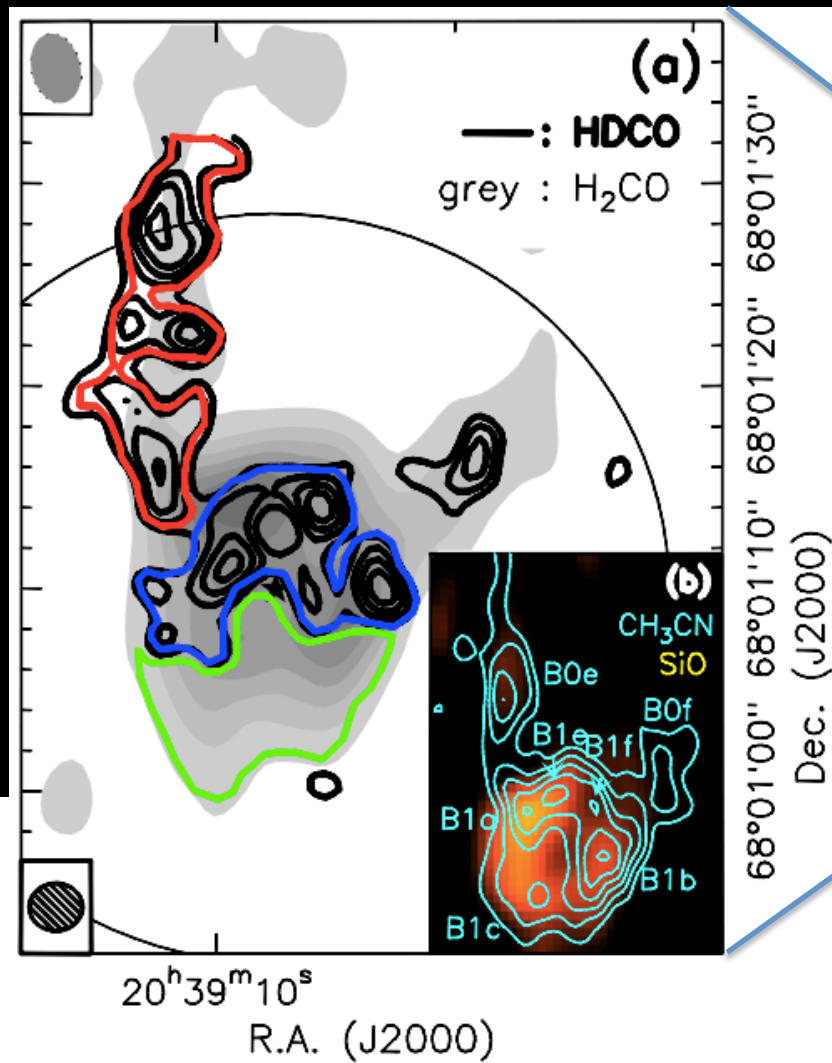


EMISSION FROM THE  
CENTRAL WARM  
REGION  
=  
SUBLIMATED ICES



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# SUBLIMATION ZONE: fossils from the past



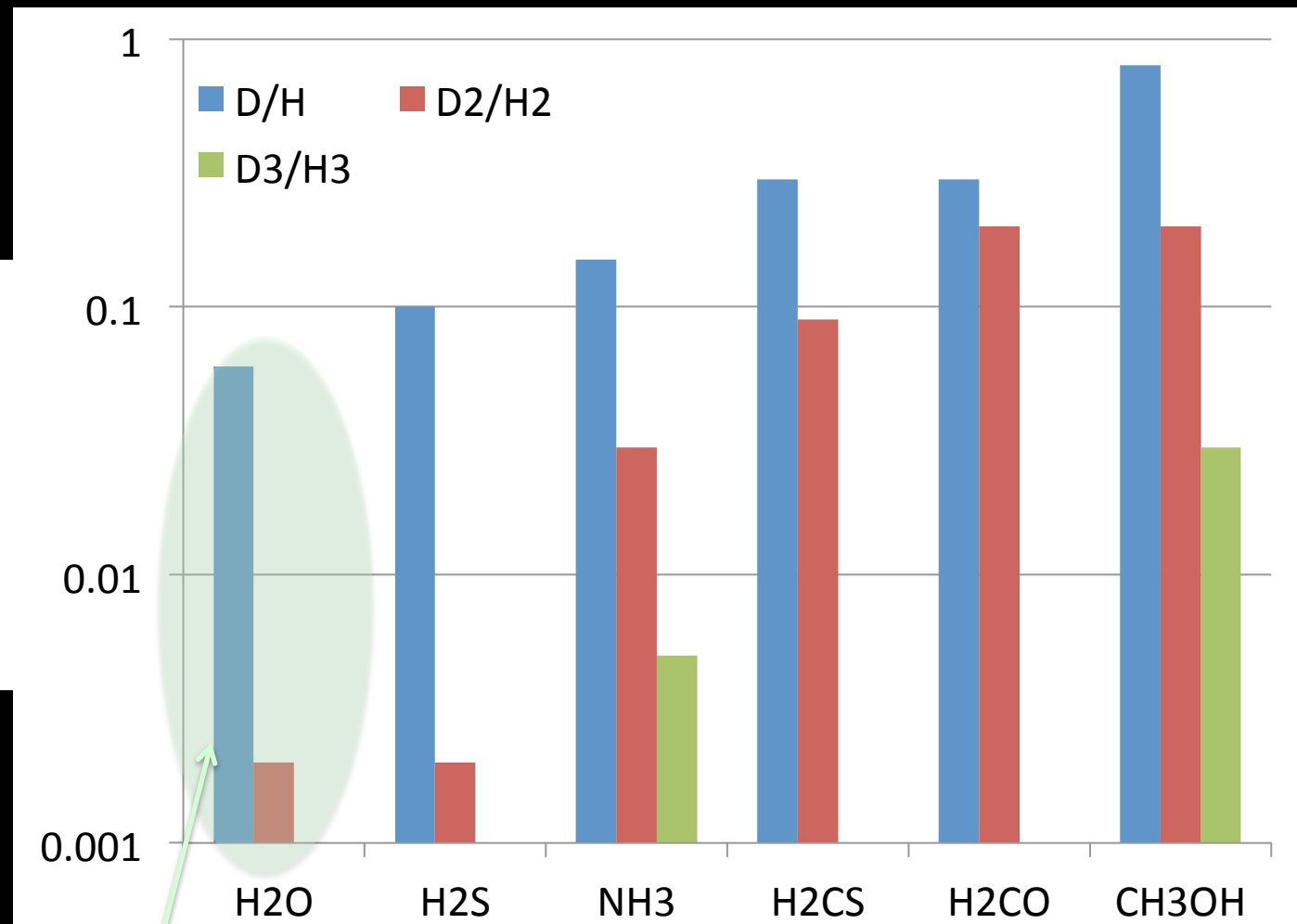
HDCO MAP  
L1157-B1 SHOCK

→ Busquet & Podio talks

DEUTERATED H<sub>2</sub>CO FRESHLY SPUTTERED FROM ICES

# SUBLIMATION ZONE: fossils from the past

INFERRED ICE FORMATION TIME →



Caselli & Ceccarelli 2012

Values still under debate



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# COLD ENVELOPE ZONE: echoes from the present

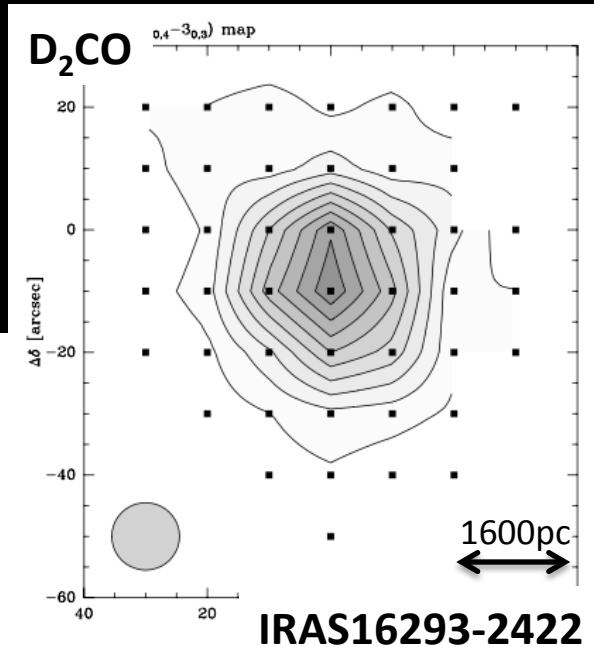
EXTENDED EMISSION MAPS

CONDITIONS SIMILAR TO  
THOSE IN PRESTELLAR  
CORES



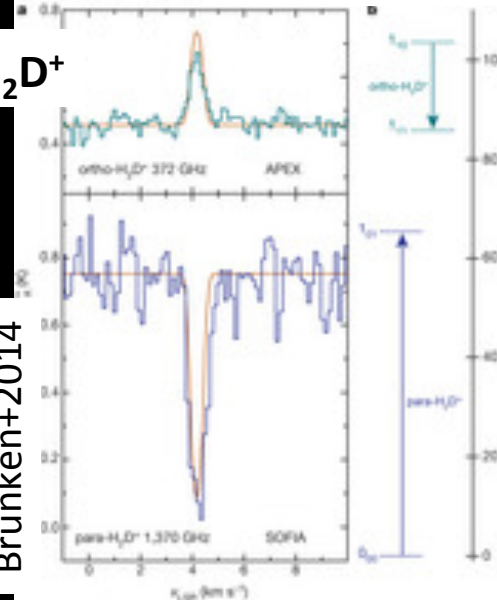
PRESENT DAY DEUTERATION  
IN THE GAS PHASE

Ceccarelli+2001



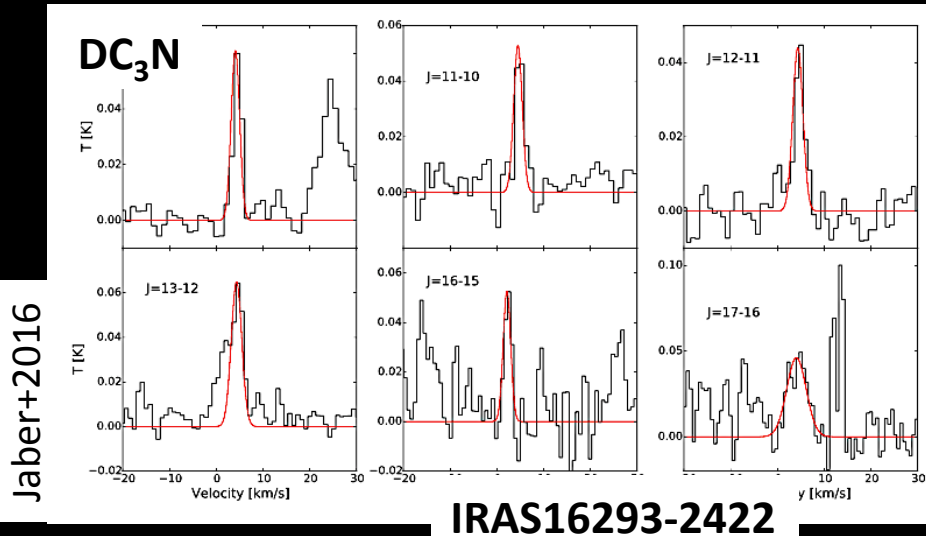
H<sub>2</sub>D<sup>+</sup>

Brunken+2014



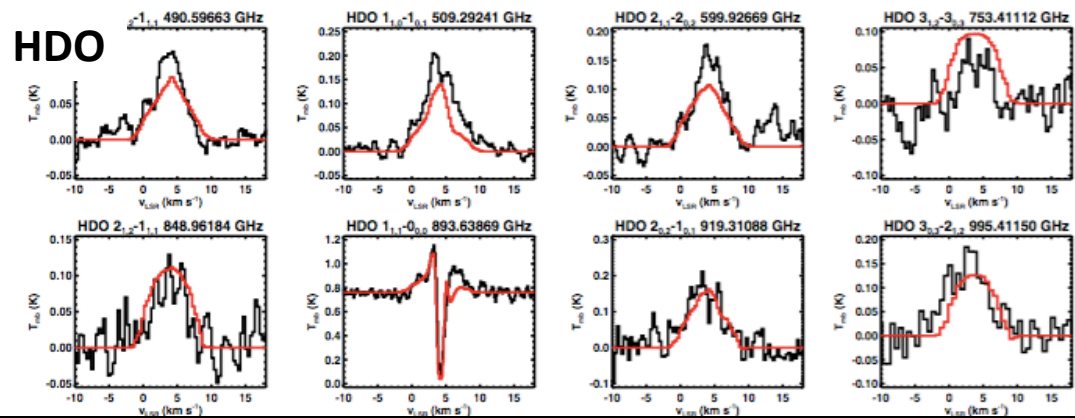
# COLD ENVELOPE ZONE: echoes from the present

## MULTI-FREQUENCY LINE ANALYSIS



Jaber+2016

DC<sub>3</sub>N/HC<sub>3</sub>N  
Hot corino < 50%  
Envelope ~ 5%



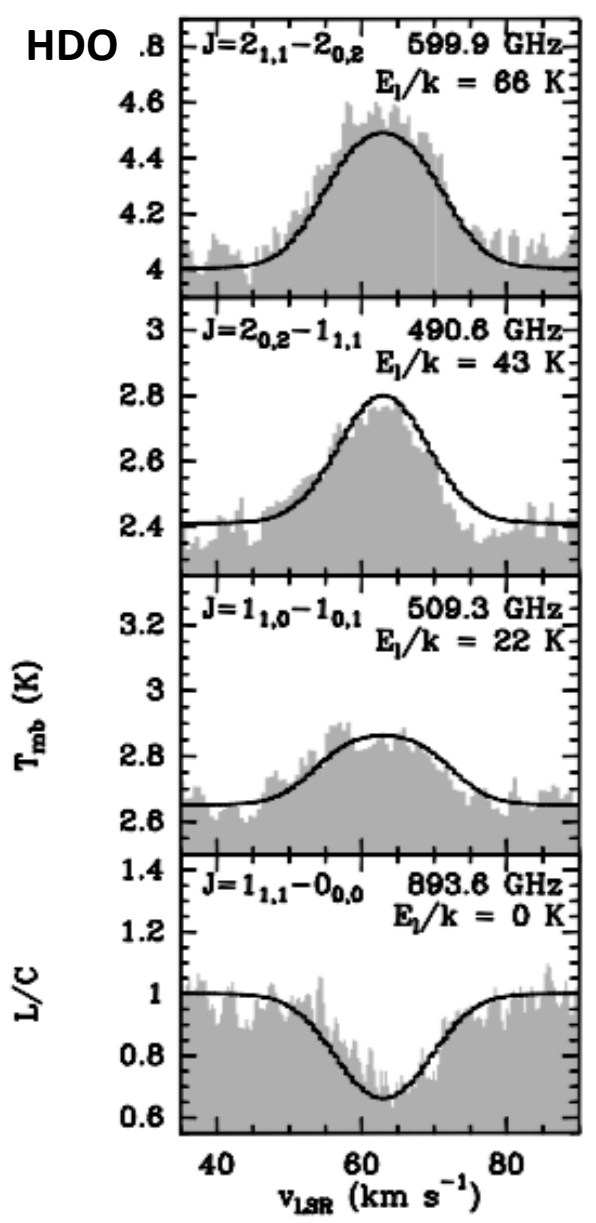
HDO/H<sub>2</sub>O  
Hot corino ~ 3%  
Envelope ~ 0.5%



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# SgrB2 : echoes from the Galactic Center

Comito+2003, 2010



HDO/H<sub>2</sub>

Warm/Hot core  $\sim 1.5-3.5 \times 10^{-11}$

Envelope  $\sim 2.5 \times 10^{-11}$

**HDO/H<sub>2</sub>O  $\sim 0.06\%$**

much lower than in low-mass YSOs : WHY ???

→ Warmer conditions?

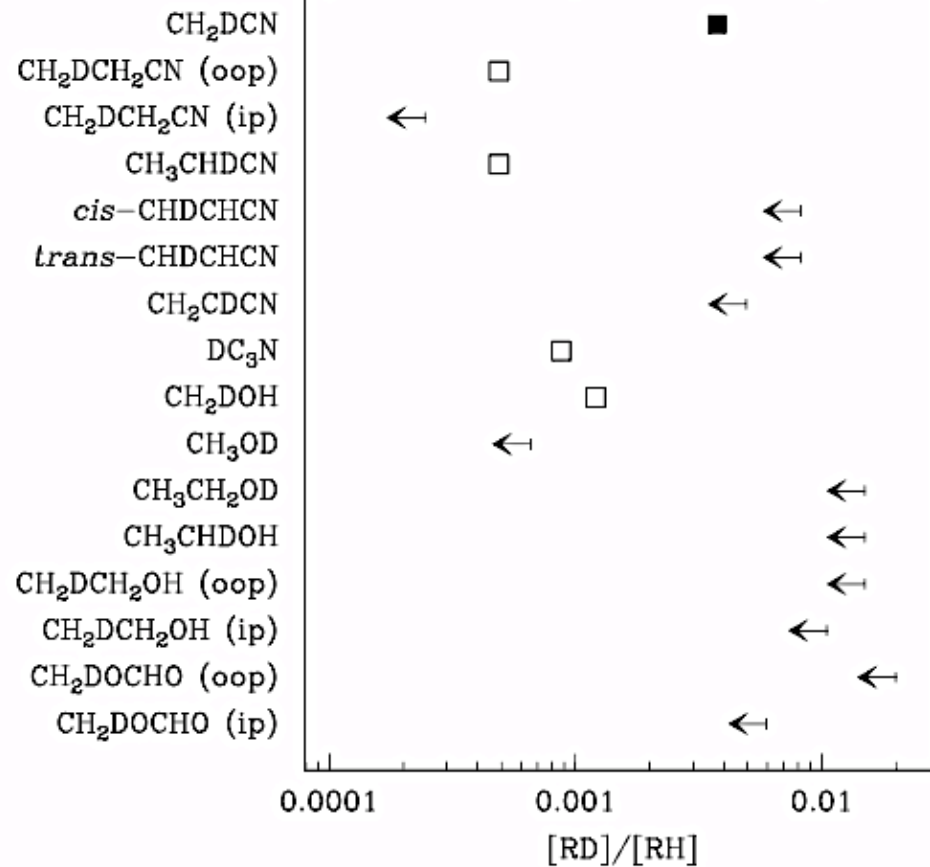
→ Lower elemental D/H?  
(see Lubowich+2000)

→ Comito's talk

# SgrB2 : echoes from the Galactic Center

→ Look also at Martin-Pintado's poster

## ORGANIC MOLECULES

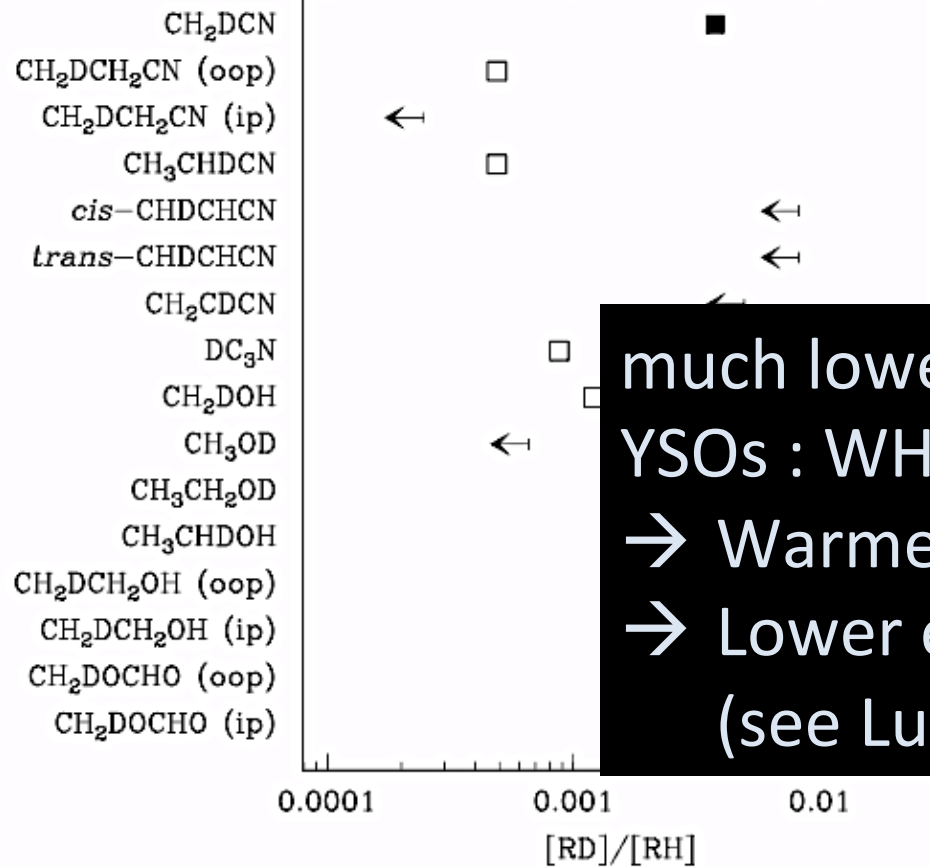


Belloche+ 2016

TO COMPARE WITH HDO/H<sub>2</sub>O~0.06%

# SgrB2 : echoes from the Galactic Center

## ORGANIC MOLECULES



much lower than in low-mass YSOs : WHY ???

→ Warmer conditions?

→ Lower elemental D/H?  
(see Lubowich+2000)

Belloch+ 2016

TO COMPARE WITH LOW-MASS PROTOSTARS

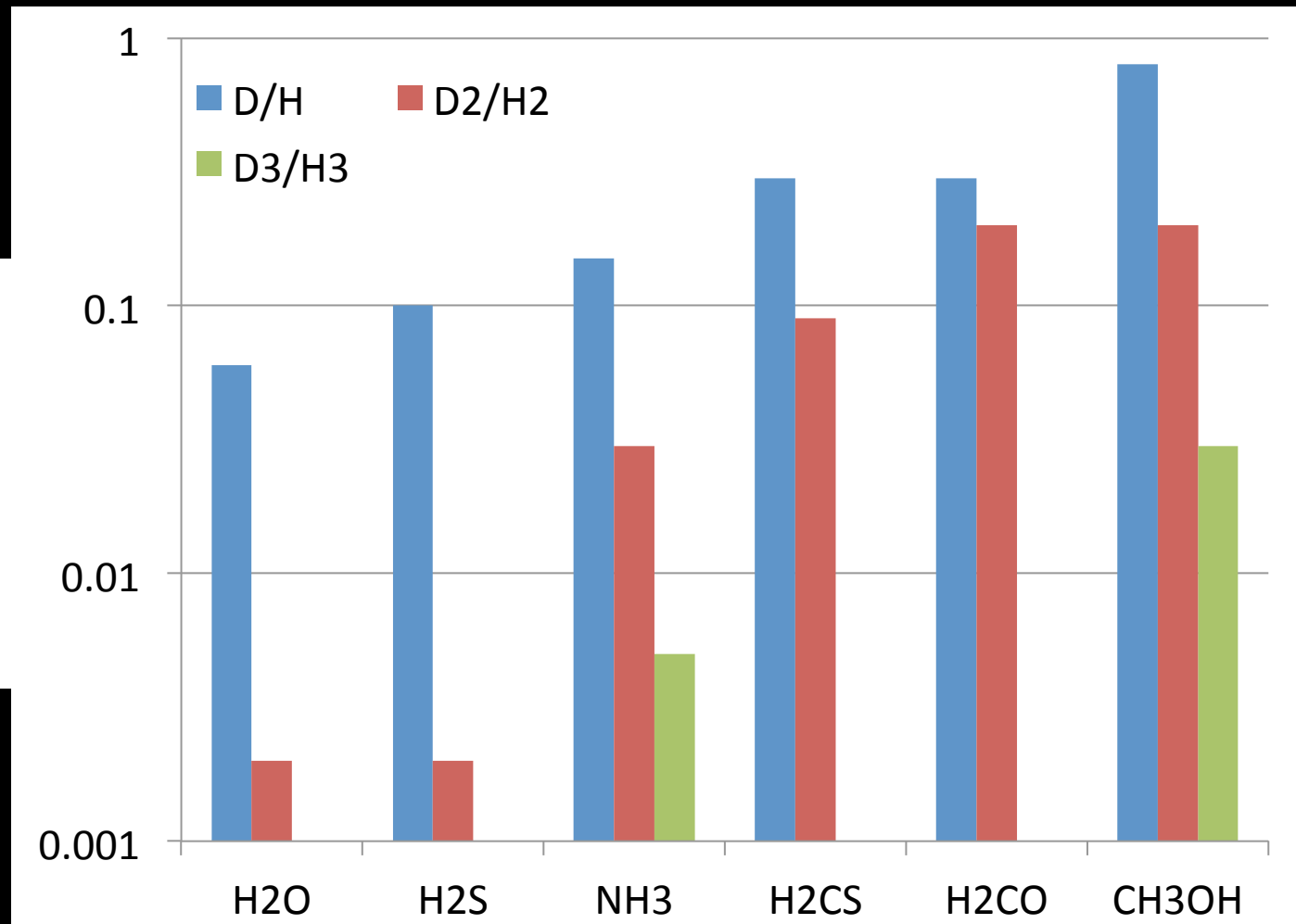
# WHAT INFORMATION ?



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# D FRACTIONATION: the history of ices

INFERRED ICE FORMATION TIME 



Caselli & Ceccarelli 2012

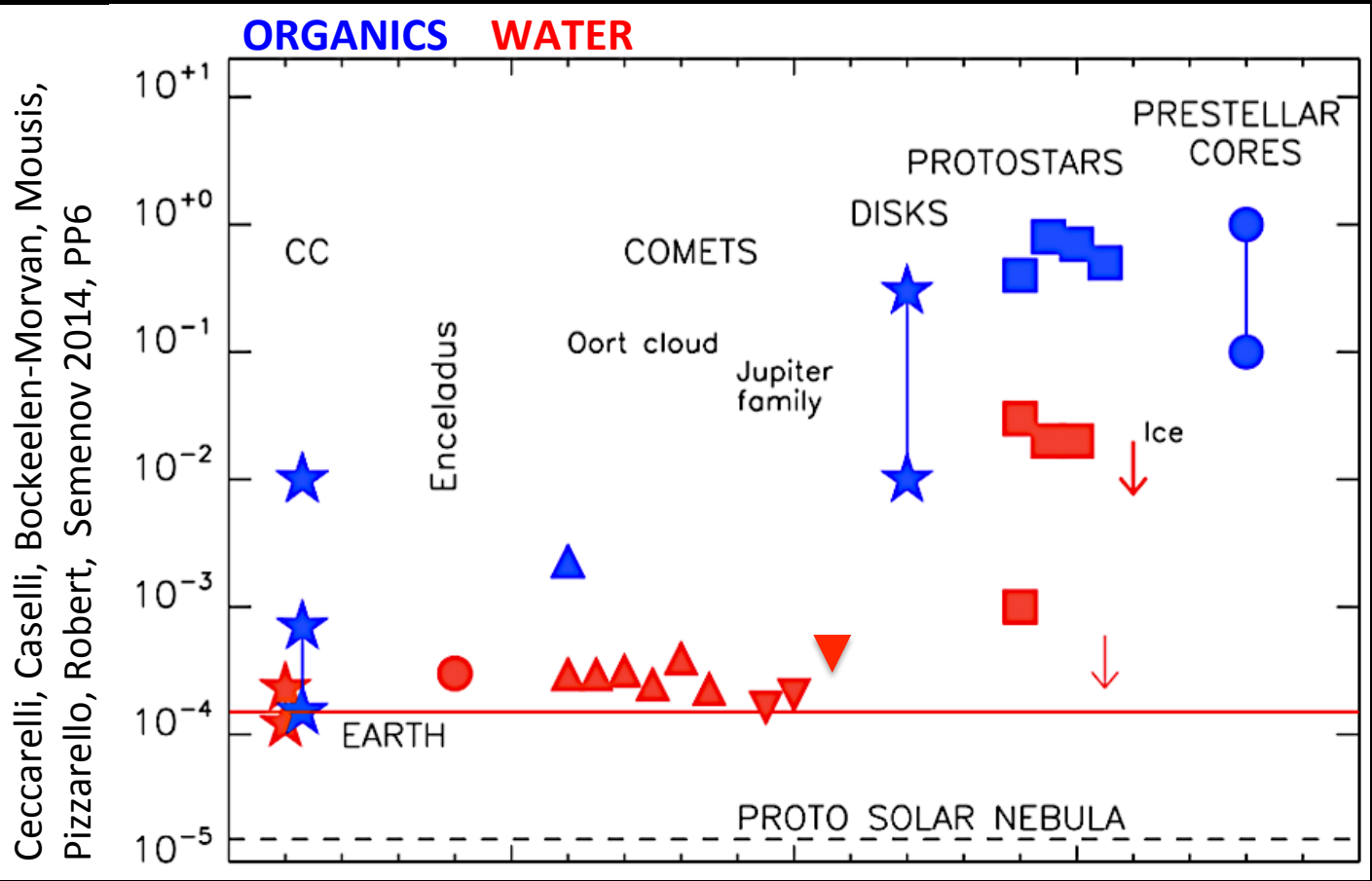
→ Taquet's talk



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# D FRACTIONATION: the Ariadne's thread

← EVOLUTION ?



Ceccarelli, Caselli, Bockeelen-Morvan, Mousis,  
 Pizzarello, Robert, Semenov 2014, PP6



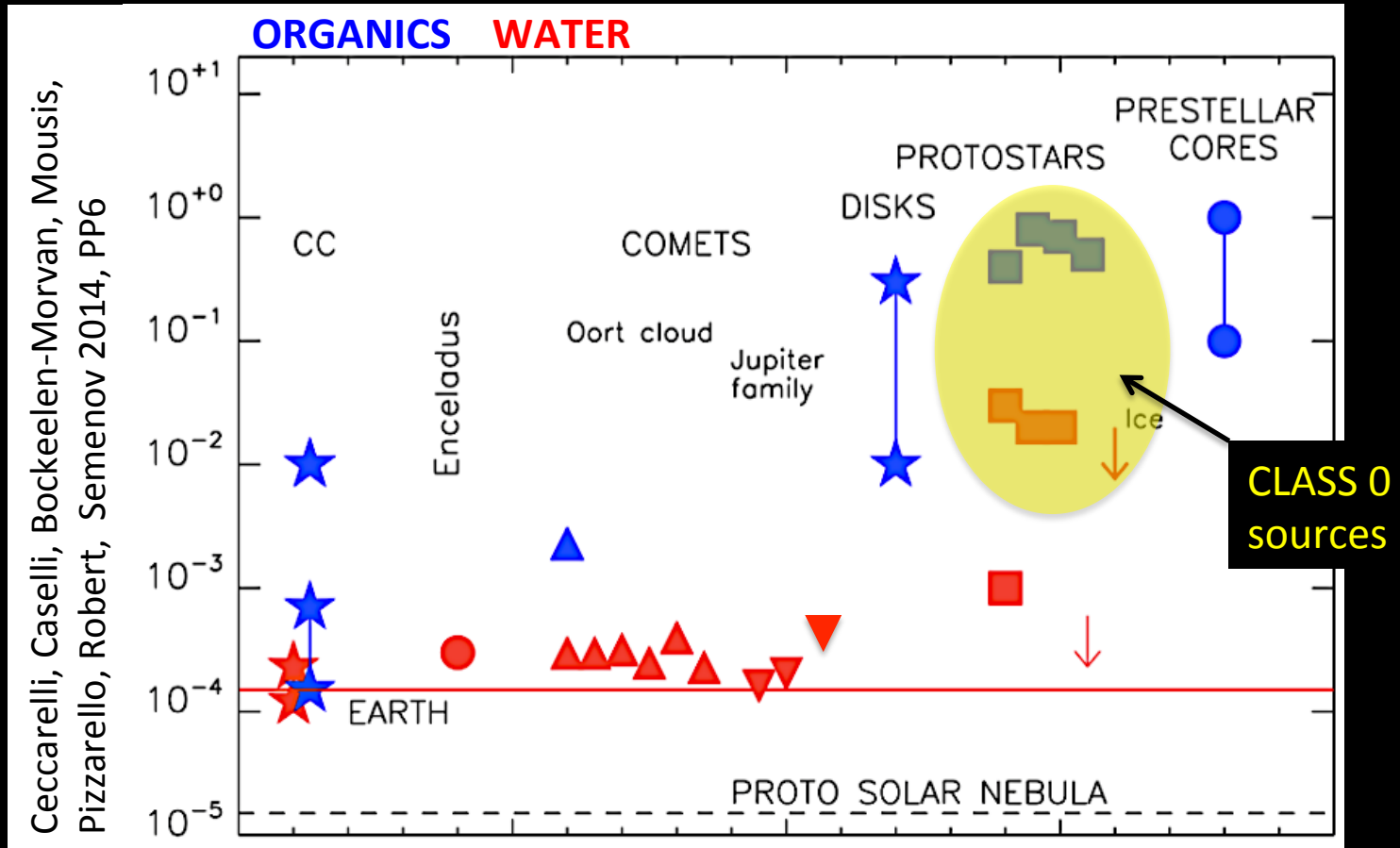
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 Workshop

→ LARGER LINEAR SCALES & COLDER REGIONS



# D FRACTIONATION: the Ariadne's thread

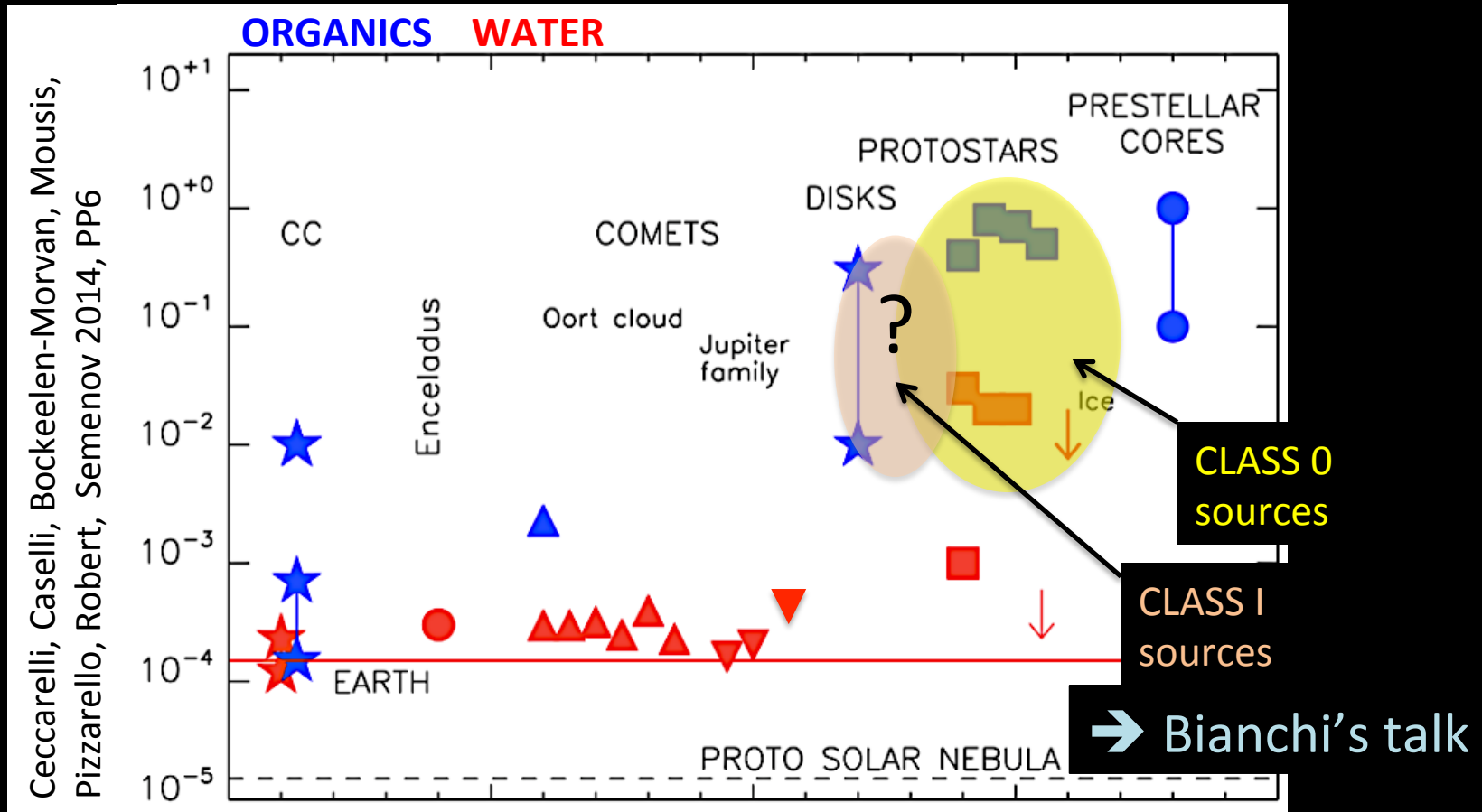
← EVOLUTION ?



**BUT... IS THE DEUTERATION REALLY DECREASING WITH THE PROTOSTAR EVOLUTION ?**

# D FRACTIONATION: the Ariadne's thread

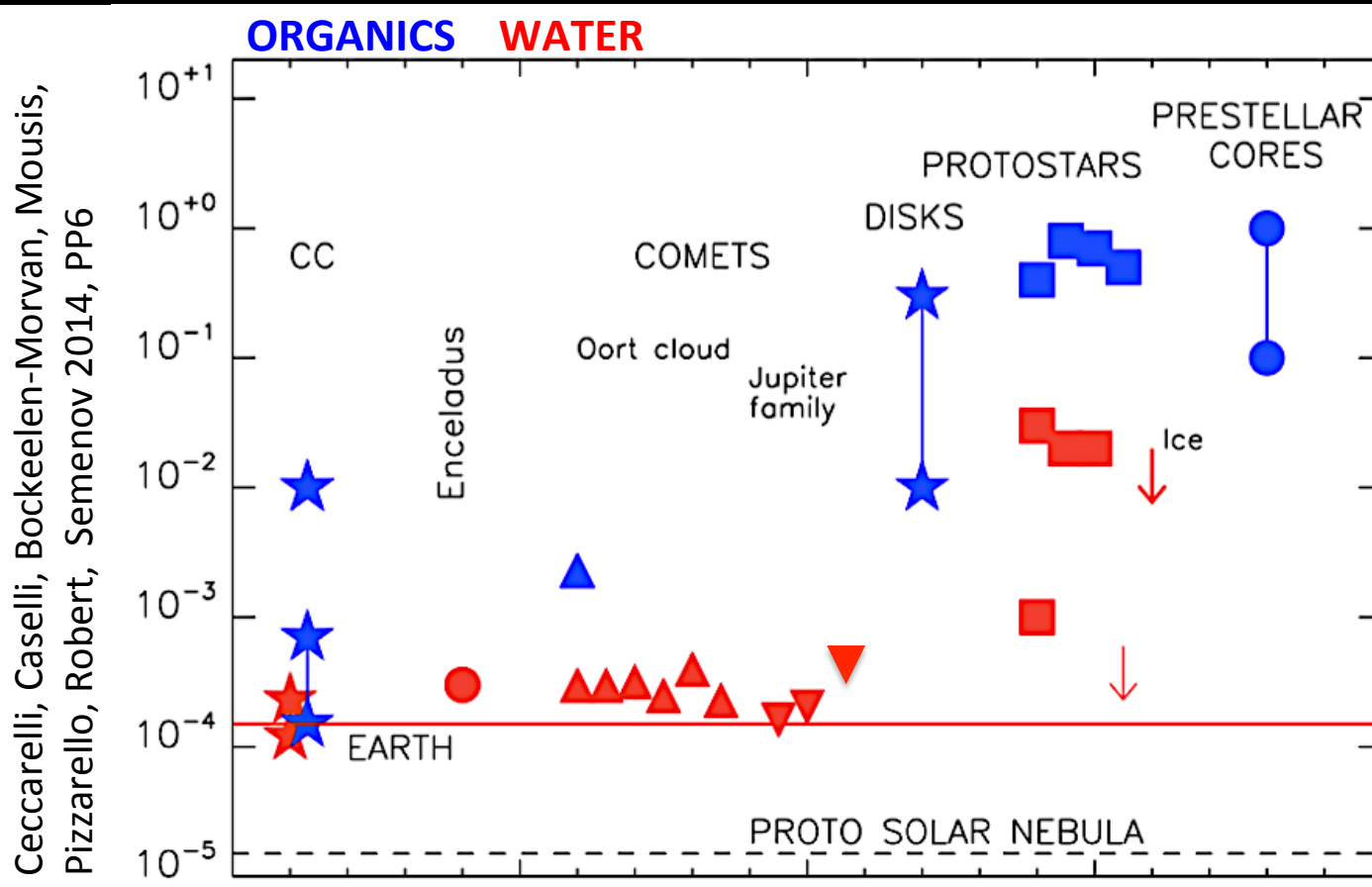
← EVOLUTION ?



**BUT... IS THE DEUTERATION REALLY DECREASING WITH THE PROTOSTAR EVOLUTION ? WHAT ABOUT CLASS I SOURCES ?**

# D FRACTIONATION: the Ariadne's thread

LARGER LINEAR SCALES & COLDER REGIONS



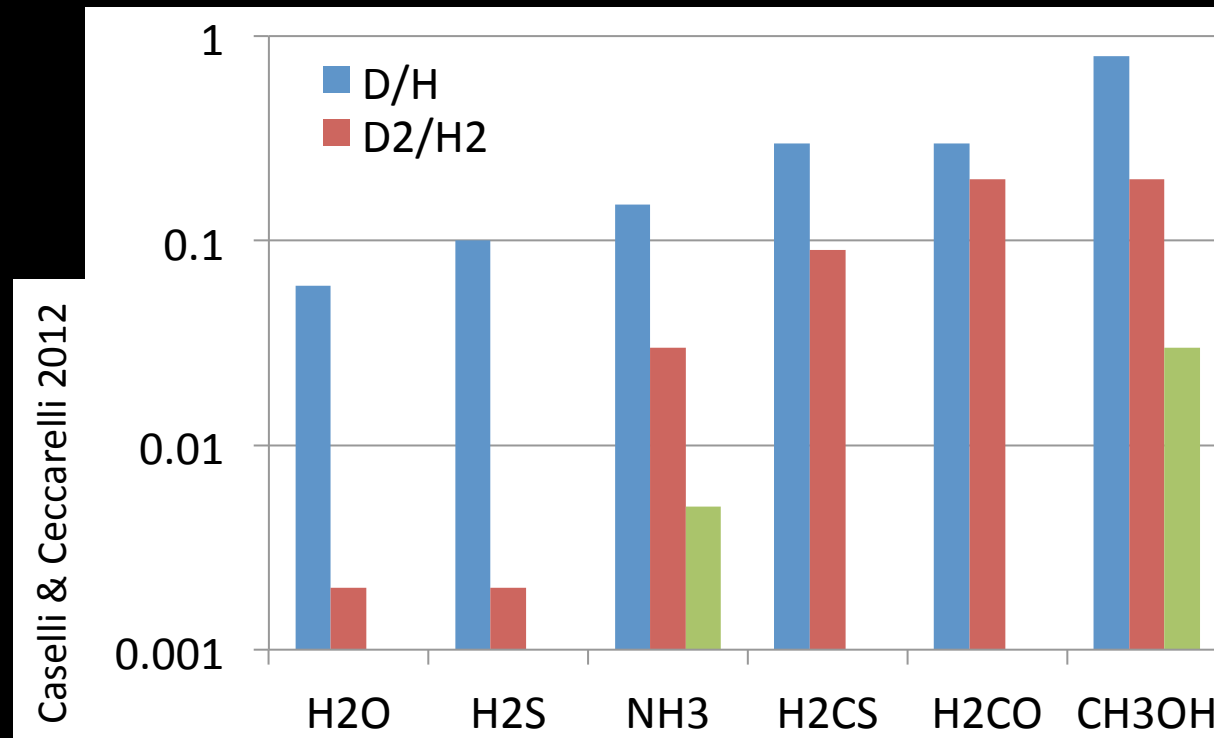
Ceccarelli, Caselli, Bockeleen-Morvan, Mousis,  
Pizzarello, Robert, Semenov 2014, PP6



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**WHAT IS THE ORIGIN OF THIS SYSTEMATIC DIFFERENCE ?  
FORMATION HISTORY as IN YSOs ?**

# HINTS ON FORMATION ROUTES



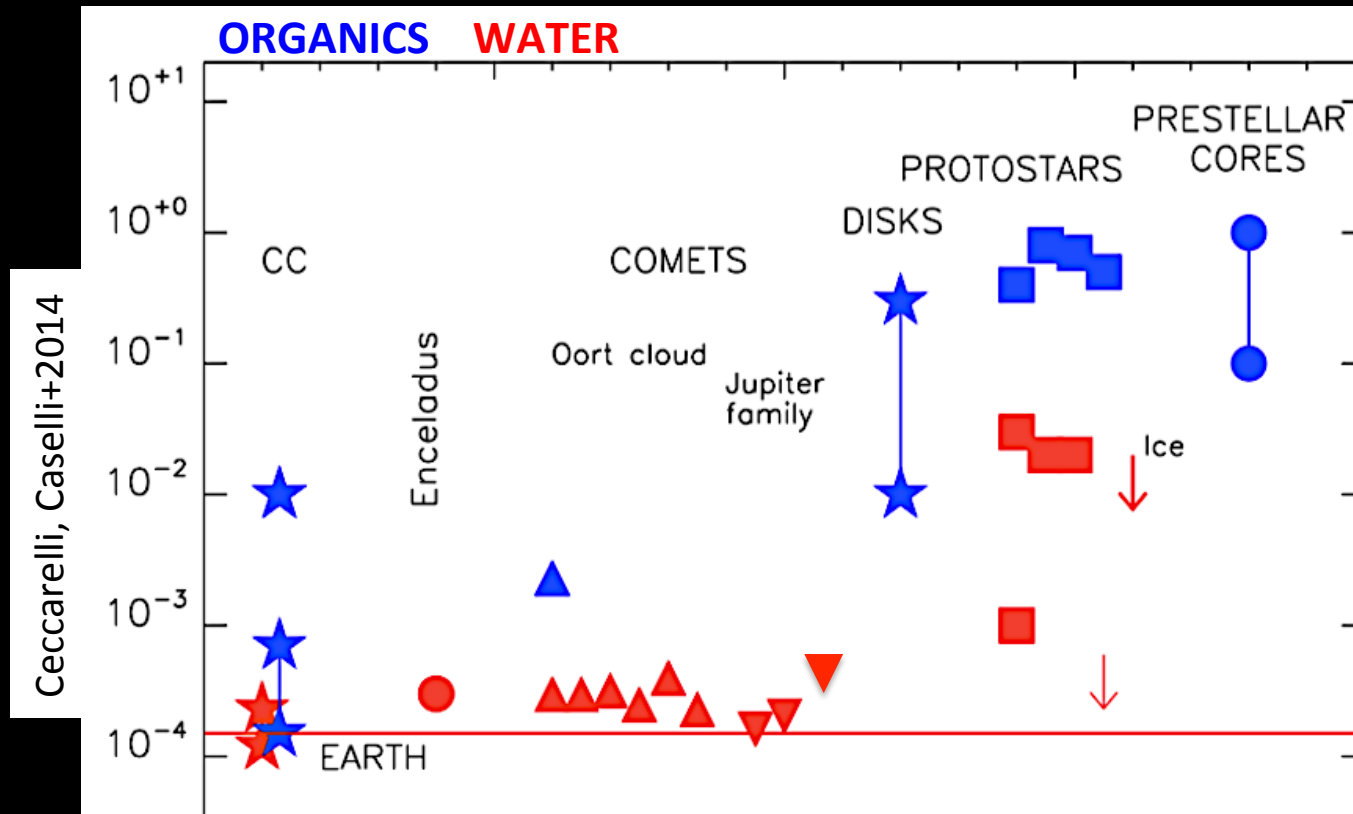
FORMATION VIA HYDROGENATION/DEUTERATION  
ON THE GRAINS SURFACES

**WATER FIRST (low D/H), ORGANICS LATER (high D/H)**  
**LOW D/H WATER, HIGH D/H ORGANICS**

→ Taquet's talk

# D FRACTIONATION: the Ariadne's thread

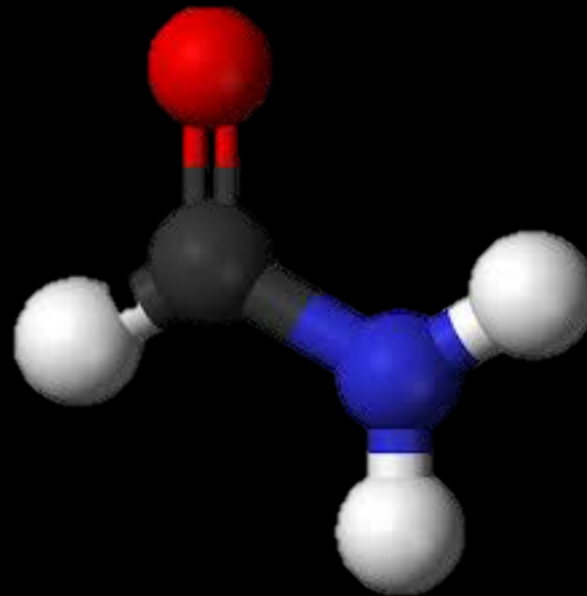
LARGER LINEAR SCALES & COLDER REGIONS



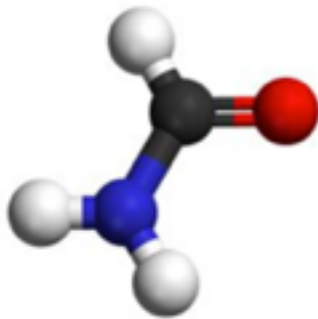
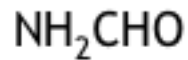
**WATER FIRST (low D/H), ORGANICS LATER (high D/H)**  
**LOW D/H WATER, HIGH D/H ORGANICS**

# D FRACTIONATION: hints on formation routes

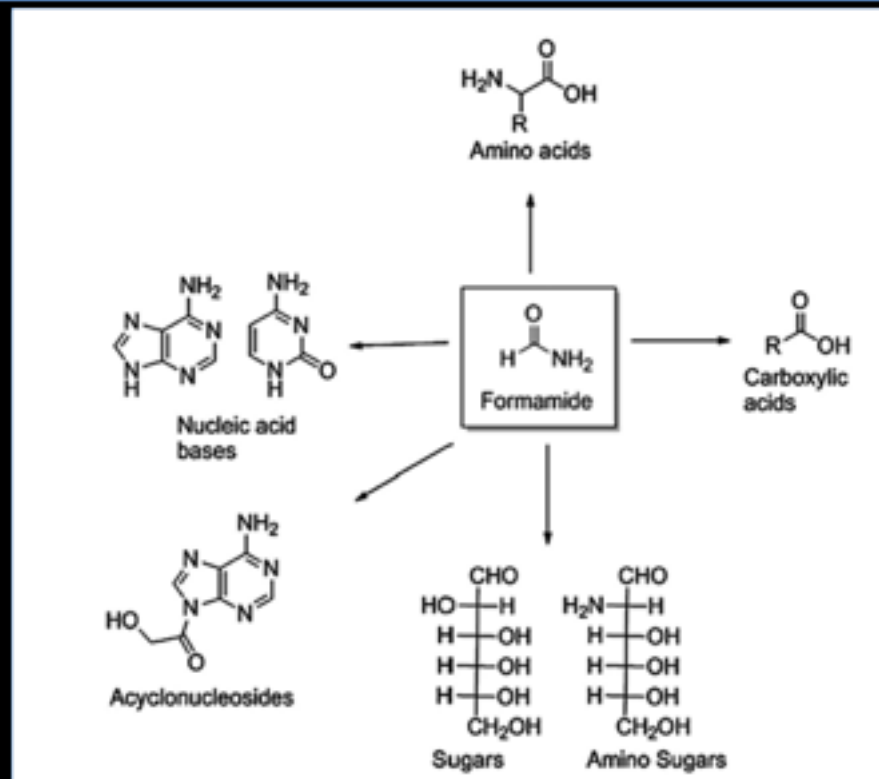
## FORMAMIDE



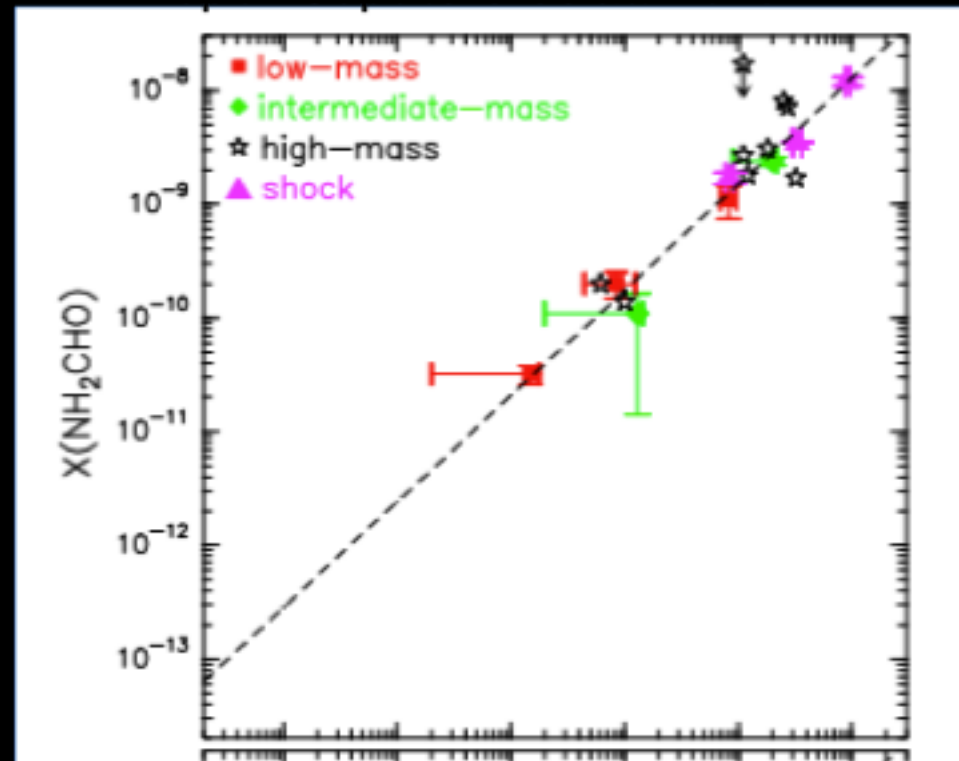
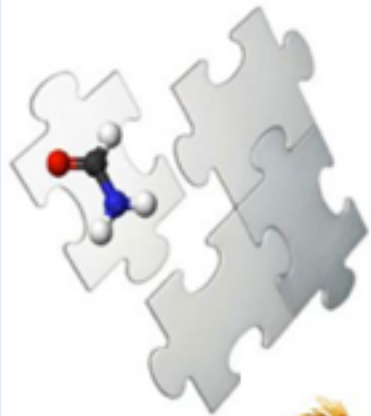
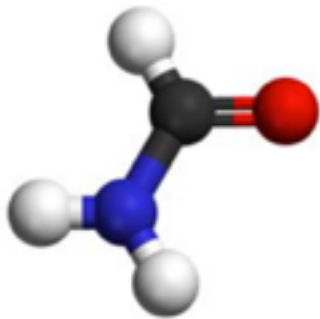
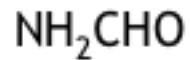
# METABOLISM OR GENETIC FIRST? THE POSSIBLE KEY ROLE OF FORMAMIDE



= starting point for the prebiotic synthesis of both metabolic and genetic species: amino acids, nucleic acid bases, acyclonucleosides, sugars, amino sugars and carboxylic acids.  
(Saladino et al. 2012, Ferus et al. 2015.)



# METABOLISM OR GENETIC FIRST? THE POSSIBLE KEY ROLE OF FORMAMIDE



FORMAMIDE IS ABUNDANT,  $>10^{-11}$  wrt  $\text{H}_2$ , IN STAR FORMING REGIONS



# HINTS ON FORMATION ROUTES

## POSSIBLE FORMATION ROUTES:

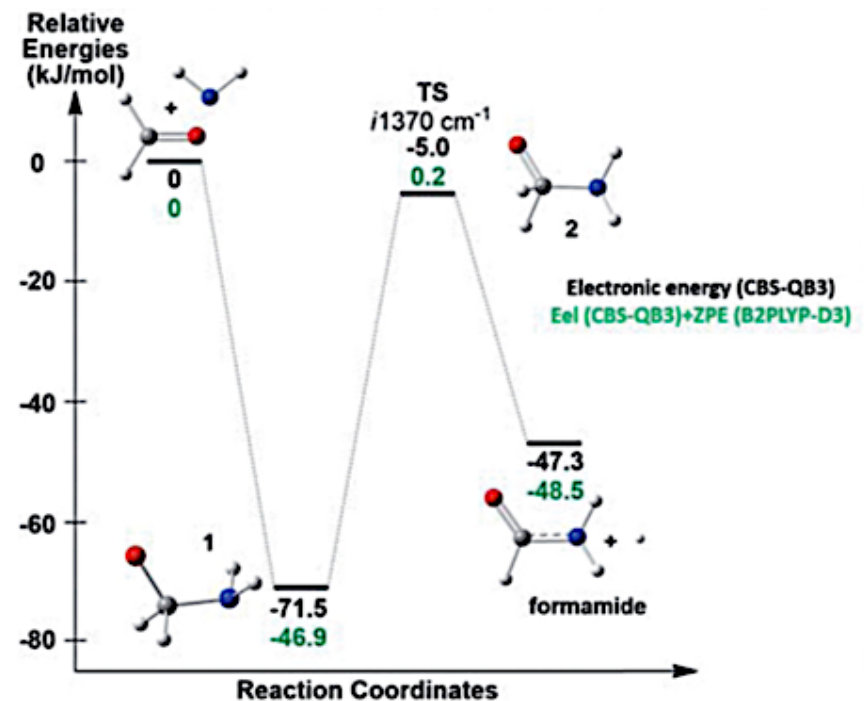
1- grain surface: HCNO + H

claimed by Lopez-Sepulcre+2015

excluded by Noble+2015

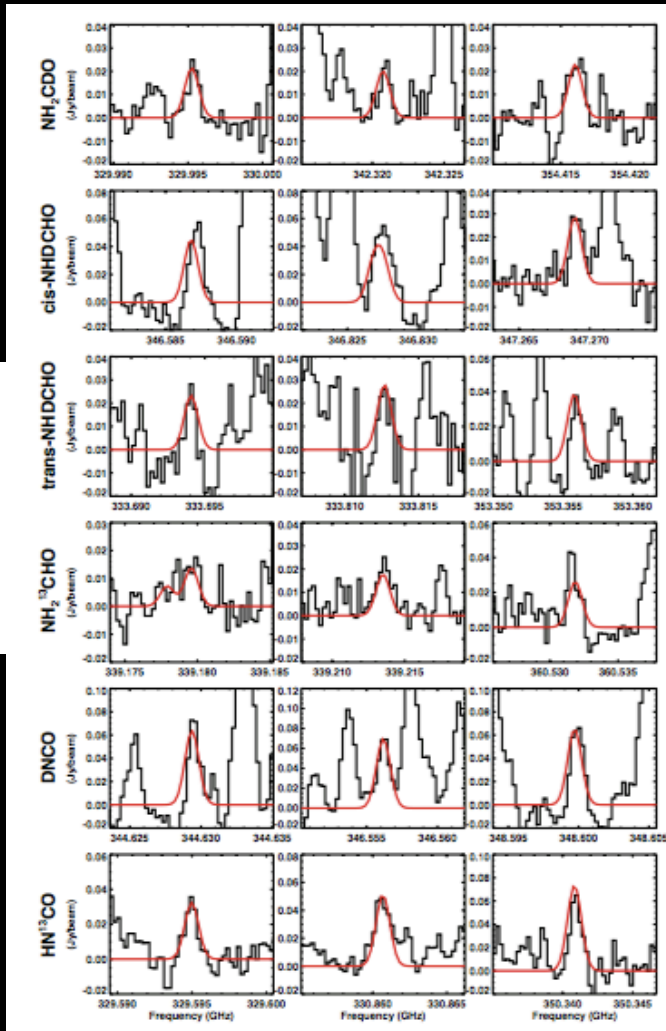
2- gas phase:  $\text{NH}_2 + \text{H}_2\text{CO}$

claimed by Barone+2015



# HINTS ON FORMATION ROUTES

Coutens+2016



FORMAMIDE  
 trans-NHDCHO/NH<sub>2</sub>CHO ~ 2-5 %  
 cis-NHDCHO/NH<sub>2</sub>CHO ~ 2-5 %  
 NH<sub>2</sub>CDO/NH<sub>2</sub>CHO ~ 2-5 %

POSSIBLE FORMATION ROUTES:

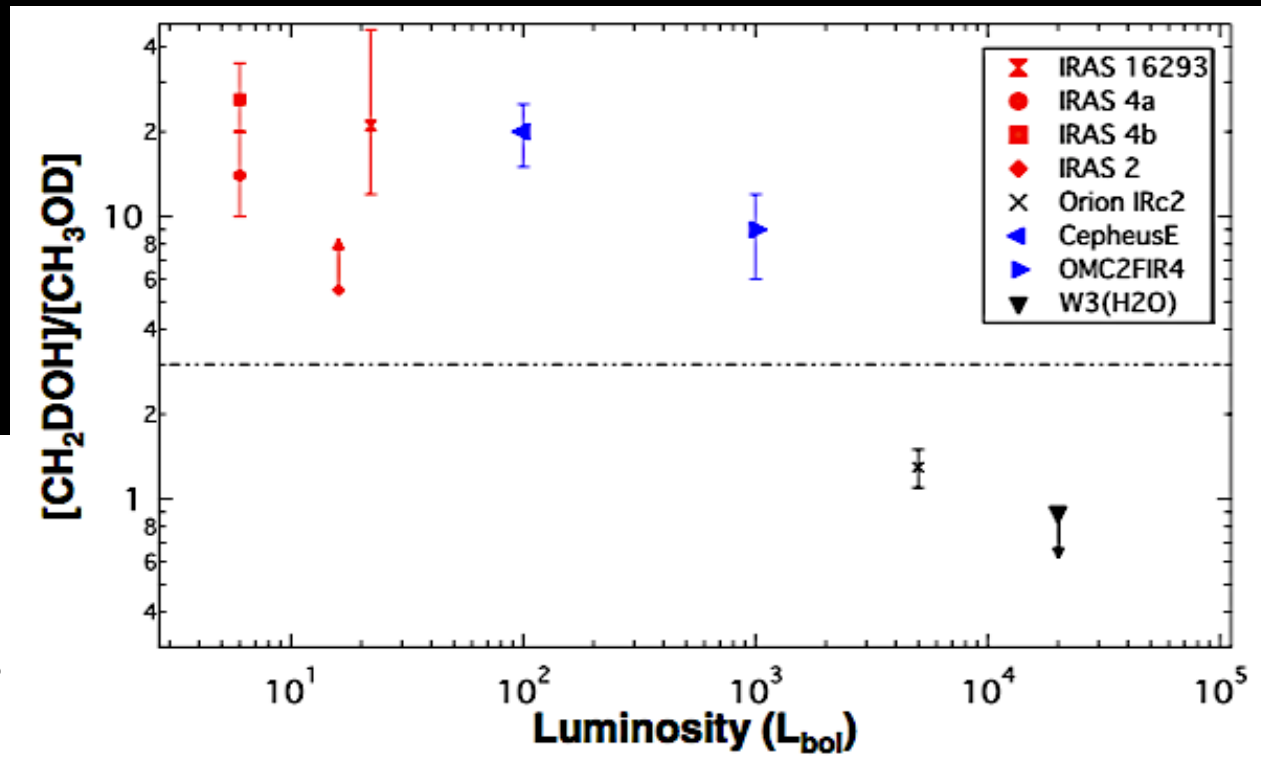
1- grain surface: HCNO + H  
 claimed by Lopez-Sepulcre+2015  
 excluded by Noble+2015

2- gas phase: NH<sub>2</sub> + H<sub>2</sub>CO  
 claimed by Barone+2015  
 challenged by Coutens+2016

→ Coutens's talk

trans & cis NHDCHO/NH<sub>2</sub>CHO ~ NHD/NH<sub>2</sub>  
 NH<sub>2</sub>CHO/NH<sub>2</sub>CHO ~ HDCO/H<sub>2</sub>CO

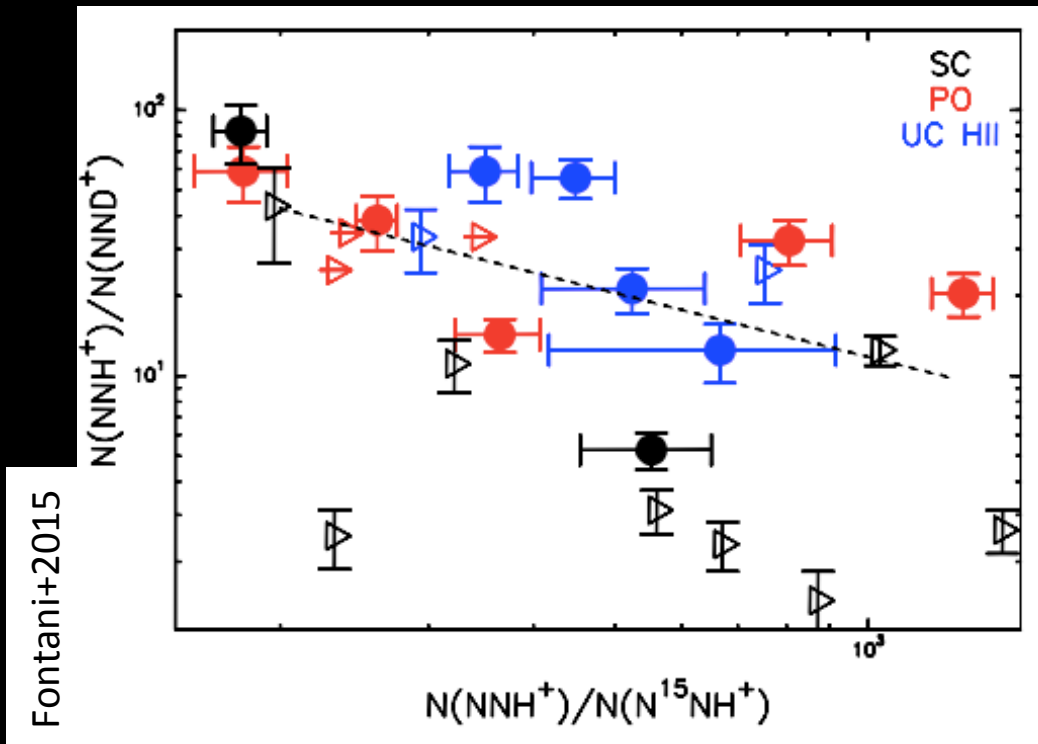
# HINTS ON FORMATION ROUTES



Ratajczak+2011

→ Faure's talk

# $^{15}\text{N}/^{14}\text{N}$ and D/H relationship in massive protostars



ANTICORRELATION ?

→ PLEASE LOOK AT THE LAURA COLZI'S POSTER

# $^{15}\text{N}/^{14}\text{N}$ & $^{12}\text{C}/^{13}\text{C}$ FRACTIONATION



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# $^{15}\text{N}/^{14}\text{N}$ & $^{12}\text{C}/^{13}\text{C}$ FRACTIONATION



Talks by Wamplfler & Yoshida



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# CONCLUSIONS

DEUTERIUM FRACTIONATION IS AN EXTREMELY POWERFUL TOOL TO

- RECONSTRUCT OUR PAST HISTORY
- INFER THE ICE FORMATION SEQUENCE
- UNDERSTAND THE PRESENT CONDITIONS
- MEASURE THE STAR FORMATION HISTORY
- CONSTRAIN THE CHEMICAL FORMATION AND DESTRUCTION ROUTES

**MORE TO COME IN THE NEAR FUTURE WITH THE NEW POWERFUL FACILITIES → ALMA & NOEMA**

