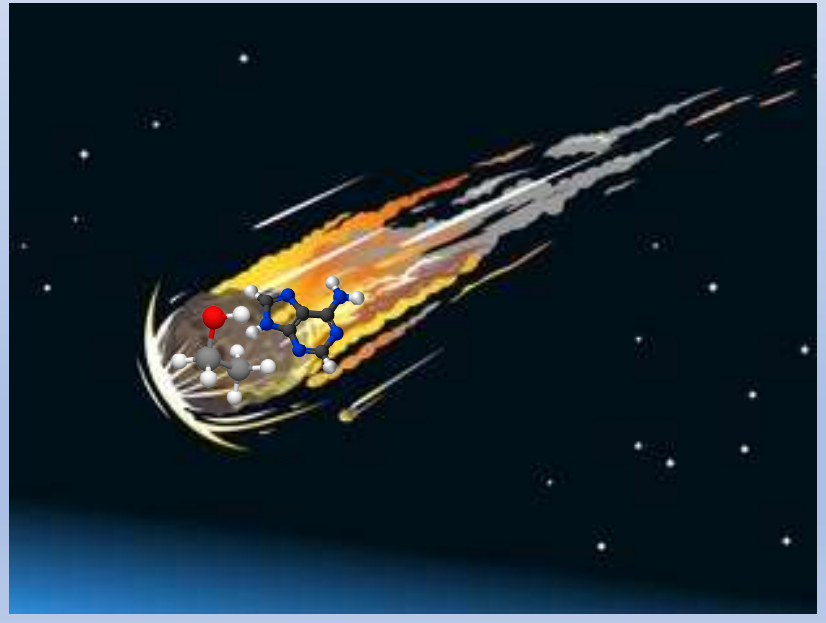
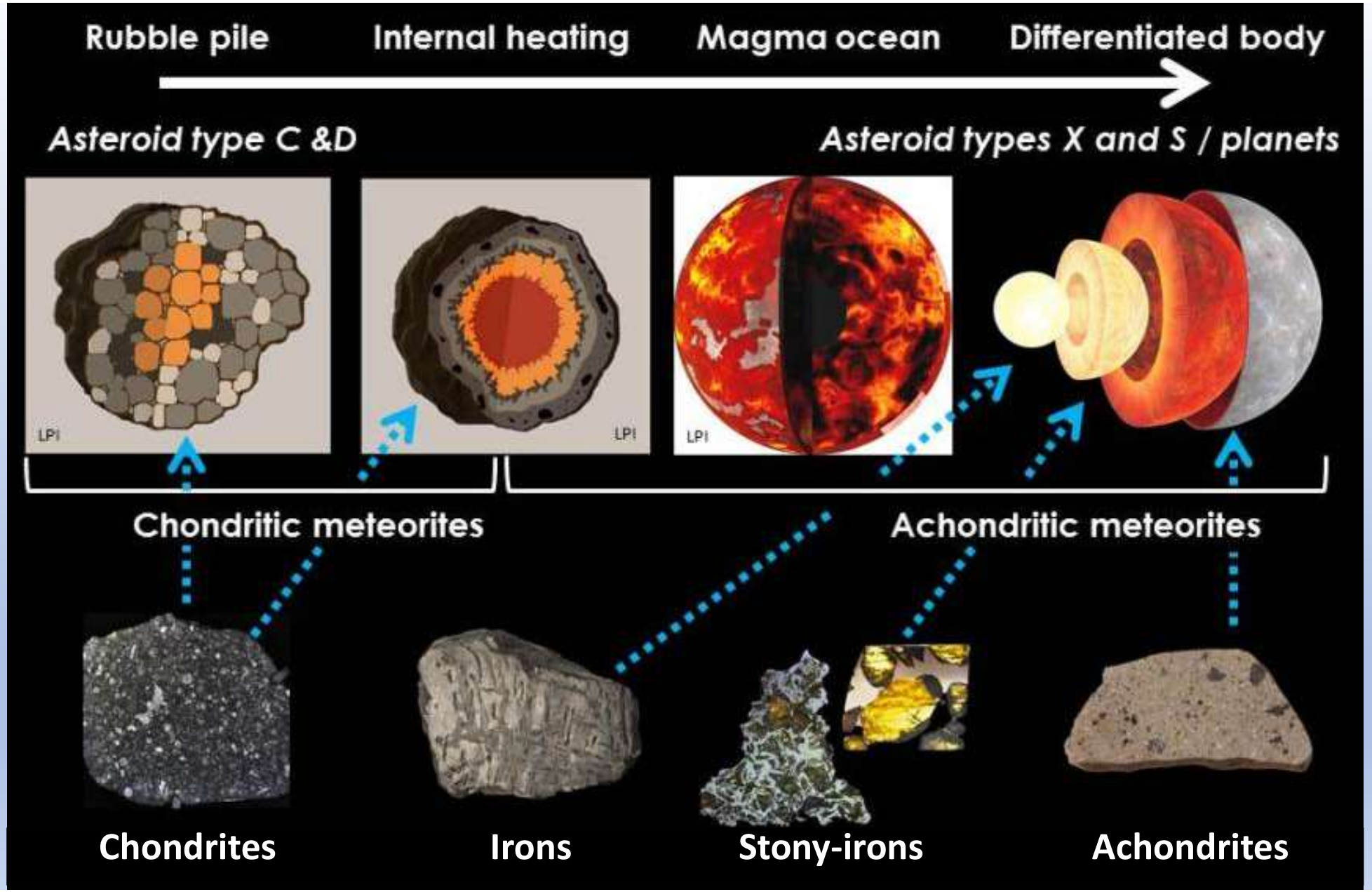
Is catalysis in meteorites relevant to the origin of life?

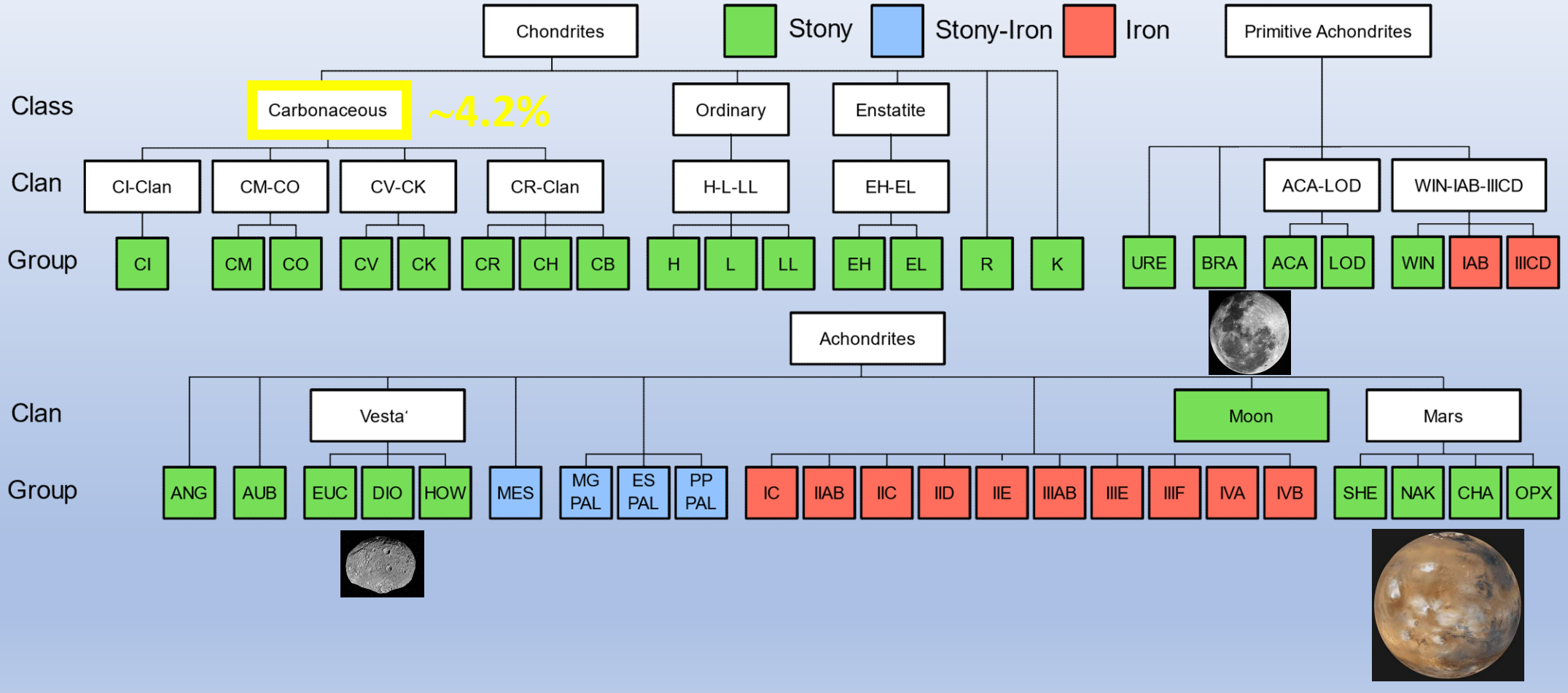
Jordi Llorca

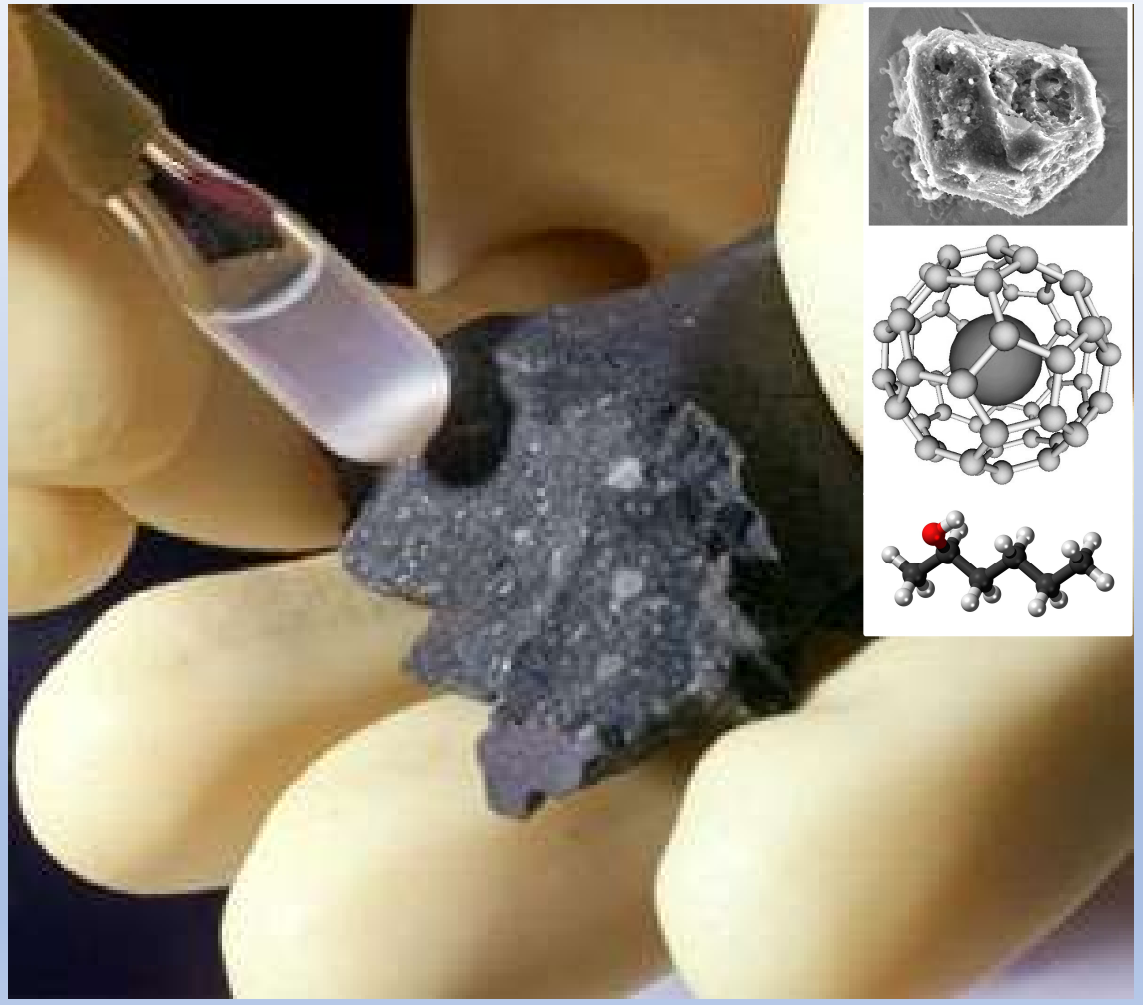
Why meteorites? Because we know some of them contain organic molecules

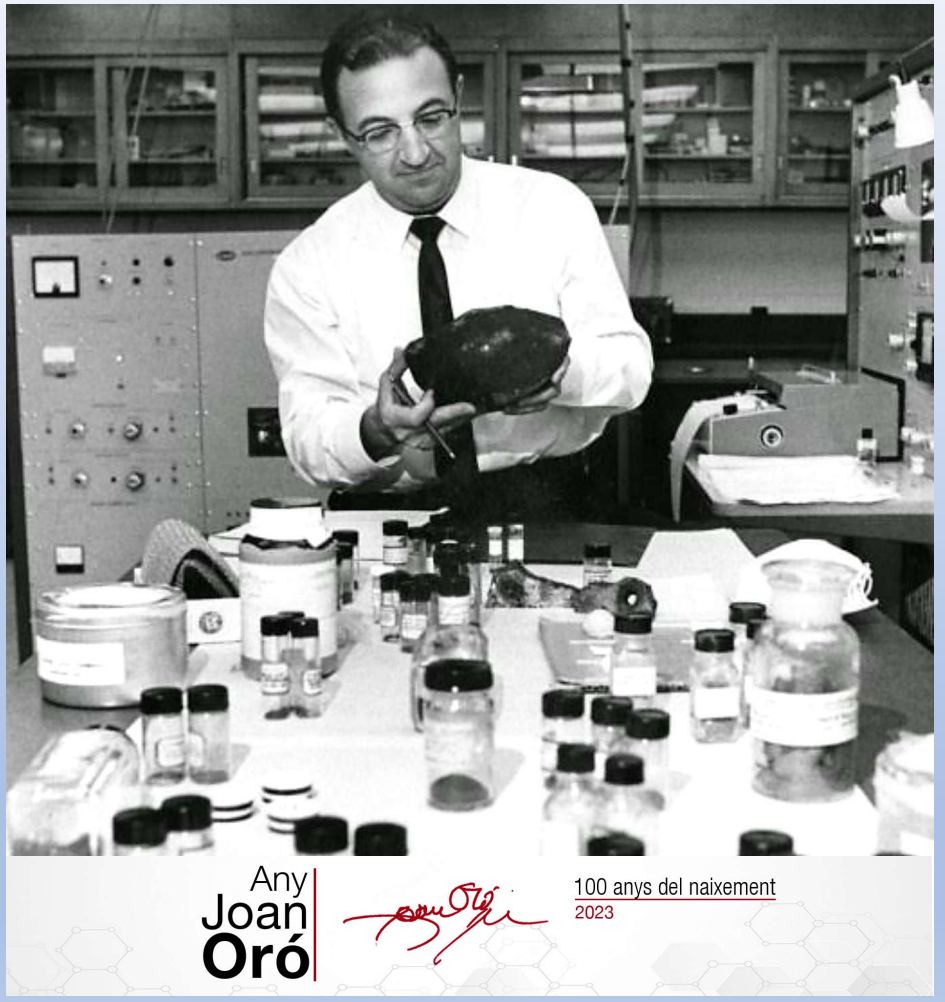



YouTube.com/Tuvix72


Rubble pile
Internal heating
Magma ocean
Differentiated body
Asteroid type C &D
Asteroid types X and S / planets
LPI
LPI
LPI
Chondritic meteorites
Achondritic meteorites
Chondrites
Irons
Stony-irons
Achondrites

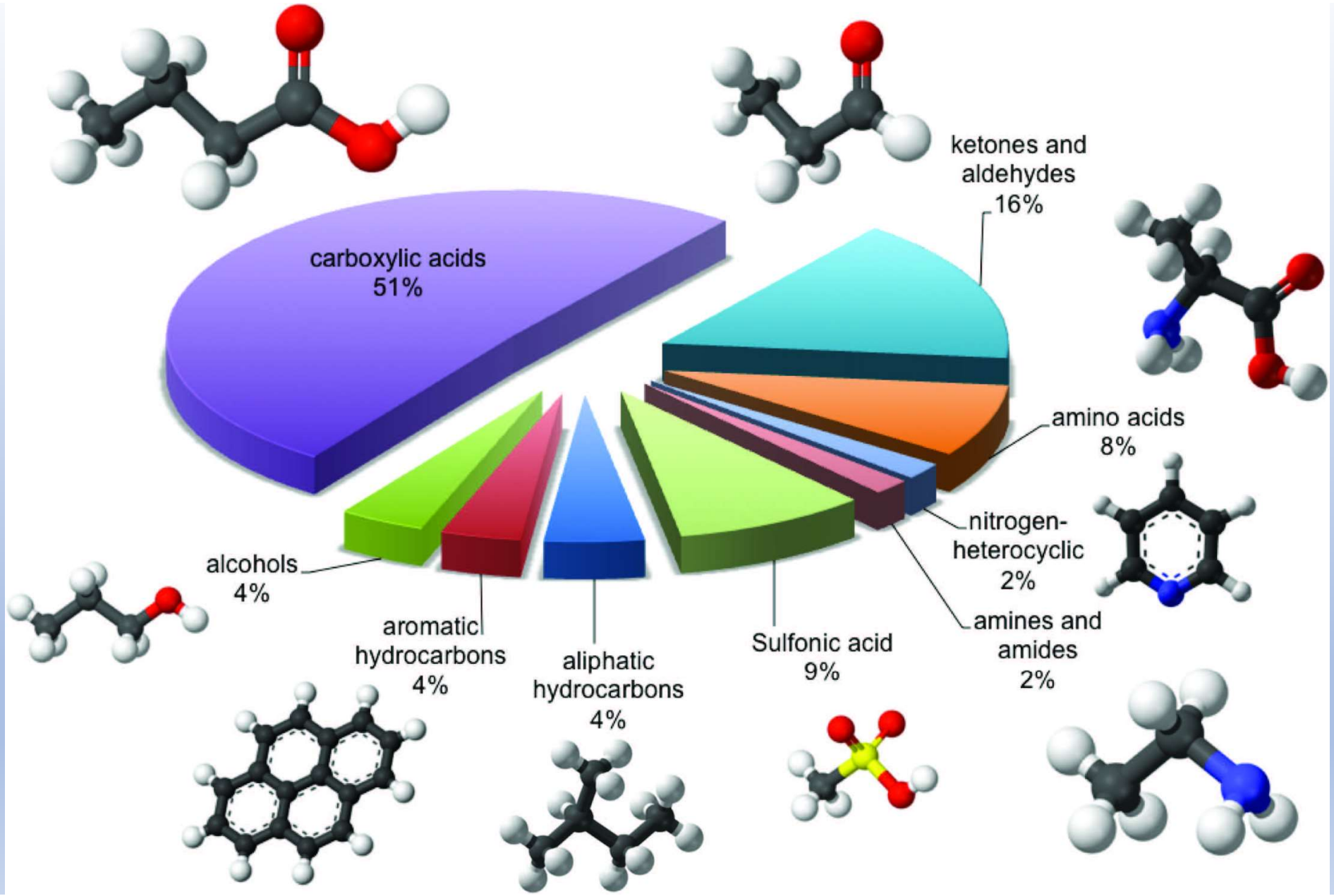

Chondrites
Stony
Stony-Iron
Iron
Primitive Achondrites
Class
Carbonaceous
~4.2%
Ordinary
Enstatite
Clan
CI-Clan
CM-CO
CV-CK
CR-Clan
H-L-LL
EH-EL
ACA-LOD
WIN-IAB-IIICD
Group
CI
CM
CO
CV
CK
CR
CH
CB
H
L
LL
EH
EL
R
K
URE
BRA
ACA
LOD
WIN
IAB
IIICD
Achondrites
Clan
Vesta'
Moon
Mars
Group
ANG
AUB
EUC
DIO
HOW
MES
MG PAL
ES PAL
PP PAL
IC
IIAB
IIC
IID
IIE
IIIAB
IIIE
IIIF
IVA
IVB
SHE
NAK
CHA
OPX



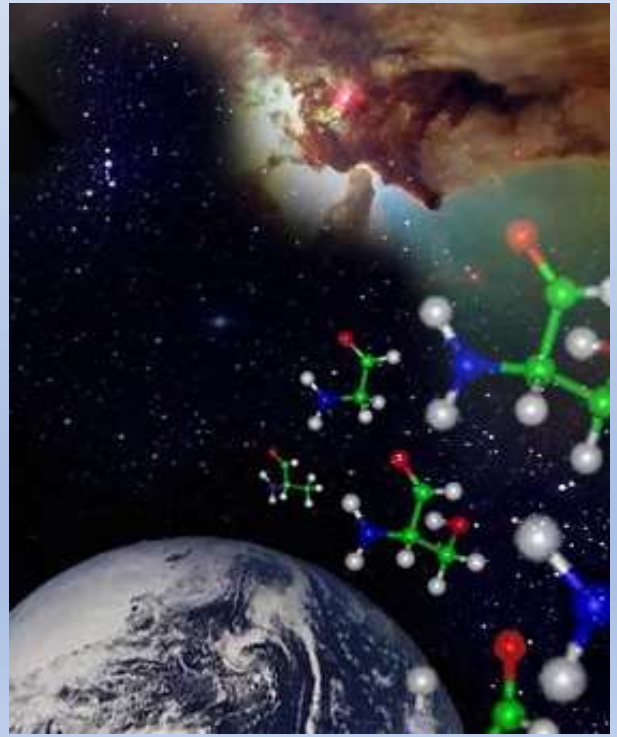


Murchison

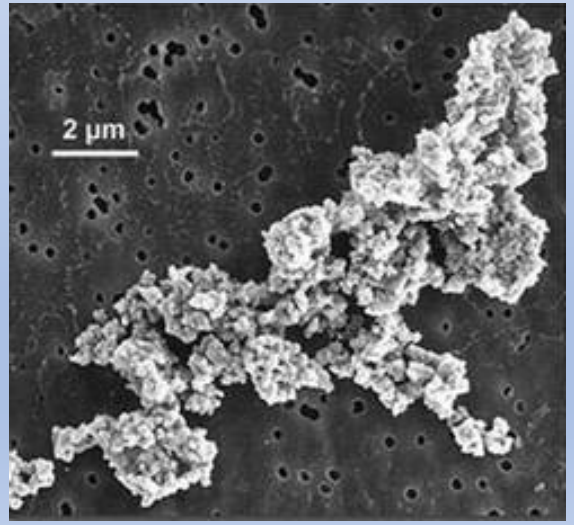
Compound type	Concentration (ppm)	Identified compounds	Carbon chain length	Examples of molecules
Aliphatic hydrocarbons	35	210	C_1-C_{30}	Propane, isobutane, hexane
Aromatic hydrocarbons	25	87	C_6-C_{20}	Pyrene, phenantrene, benzene, toluene
Alcohols	11	8	C_1-C_4	Ethanol, methanol, propanol
Aldehydes and ketones	27	9	C_1-C_5	Dimethylketone, acetaldehyde, formaldehyde
Carboxylic acids	350	63	C_1-C_{12}	Acetic acid, propionic acid, valeric acid
Hydrocarboxylic acids	15	101	C_2-C_8	Lactic acid, α-hydroxy glutaric acid
Amines	8	10	C_1-C_4	Methylamine, propilamine
Amides	62	4	C_1-C_3	Urea, guanylurea, phenylurea
Amino acids	60	78	C_2-C_9	Glycine, α-aminoisobutyric acid, isovaline
Purines and pyrimidines	2	5	C_4-C_5	Adenine, xanthine, guanine, uracil
Other heterocycles	7	38	C_5-C_{10}	Dibenzothiophene, quinoline
Sugar-related	60	27	C_3-C_6	Glycerol, tartaric acid, glucitol, erythritol
Sulfonic and phosphonic acids	65	12	C_1-C_4	Methyl sulfonic acid, ethyl phosphonic acid
Polymer	>14300	–	$C_{>100}$	$C_{100}H_{48\text{-}71}N_{1.8\text{-}3}O_{12}S_2$ (Murchison)
Total	>15000	652		


carboxylic acids
51%
ketones and
aldehydes
16%
amino acids
8%
nitrogen-
heterocyclic
2%
amines and
amides
2%
Sulfonic acid
9%
aliphatic
hydrocarbons
4%
aromatic
hydrocarbons
4%
alcohols
4%

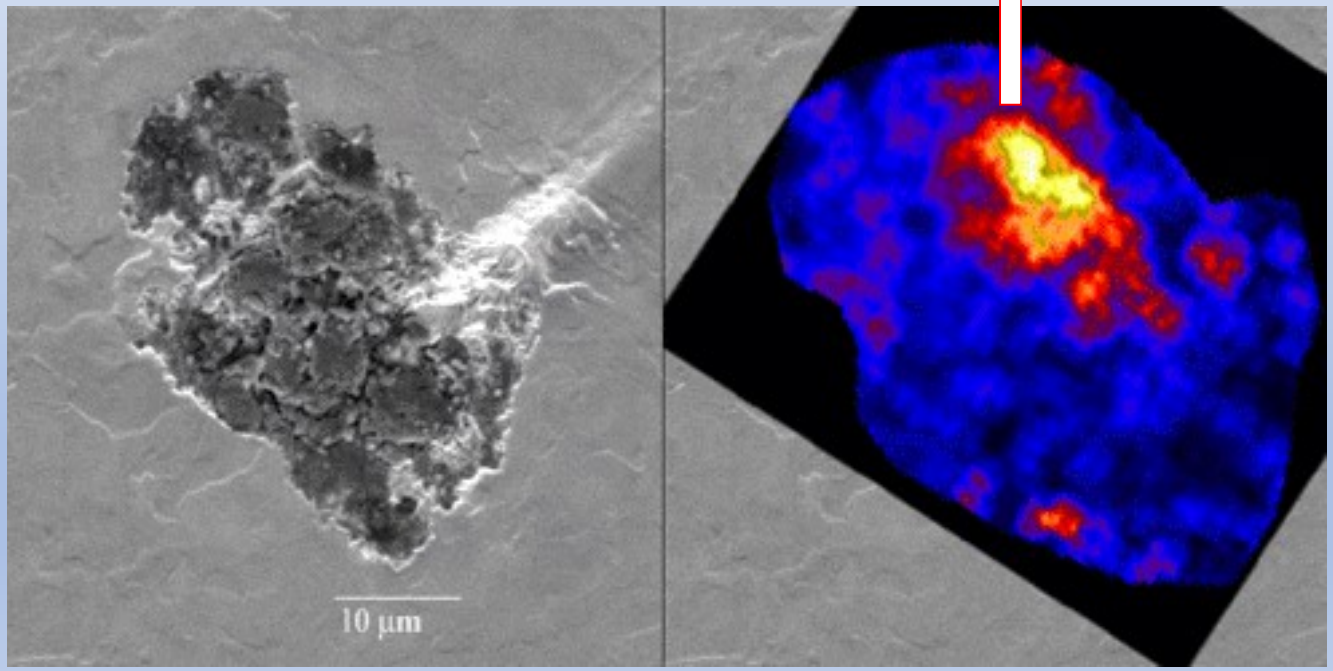
Any other input of organic molecules from space?



Yes, interplanetary dust particles

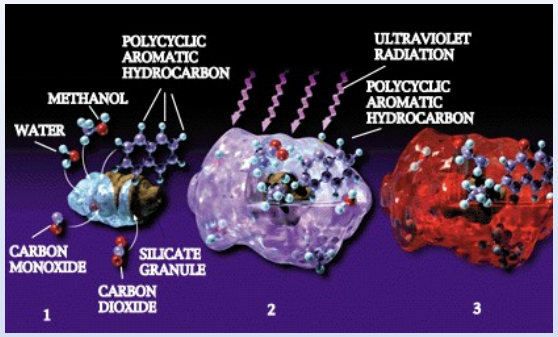


Organics



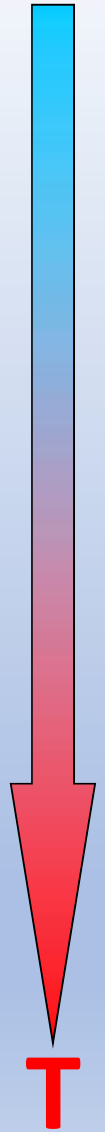
Where and how were all these organic molecules formed?

➡ Interstellar medium



➡ Nebular gas-solid reactions
(Fischer-Tropsch-type)

➡ Parent body *in situ* alteration



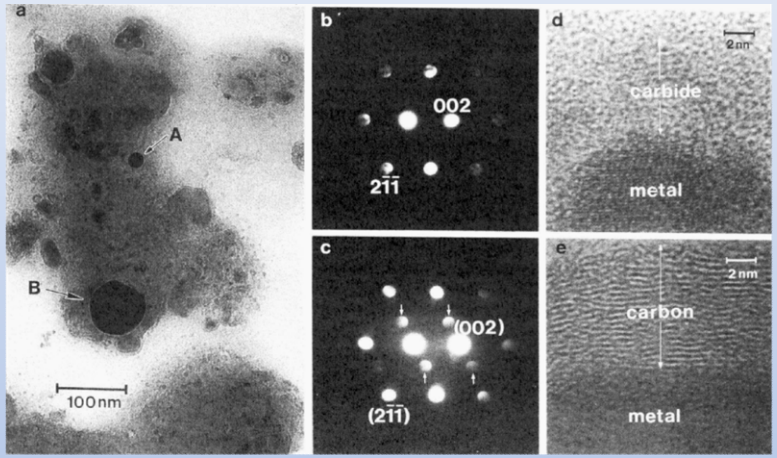
Experimental evidences: working in the laboratory

I. “Reproducing” the solar nebula

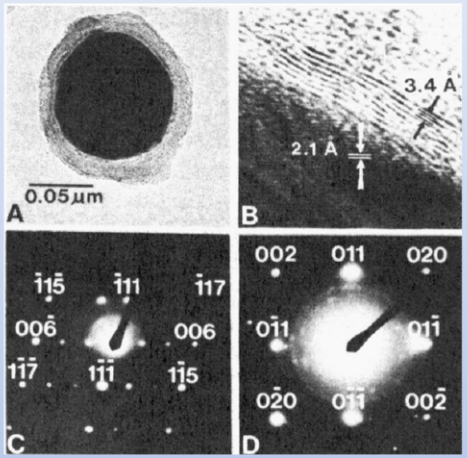
II. Using meteorite samples

III. Clays in carbonaceous chondrites

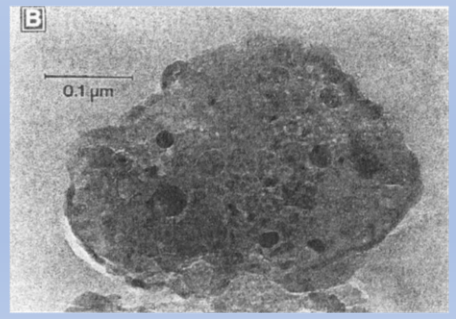
I. “Reproducing” the solar nebula



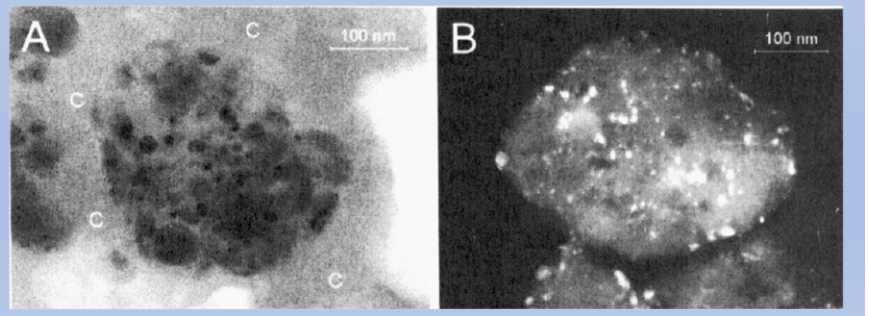
Bradley, J.P. *GCA* (1994) 58, 2123



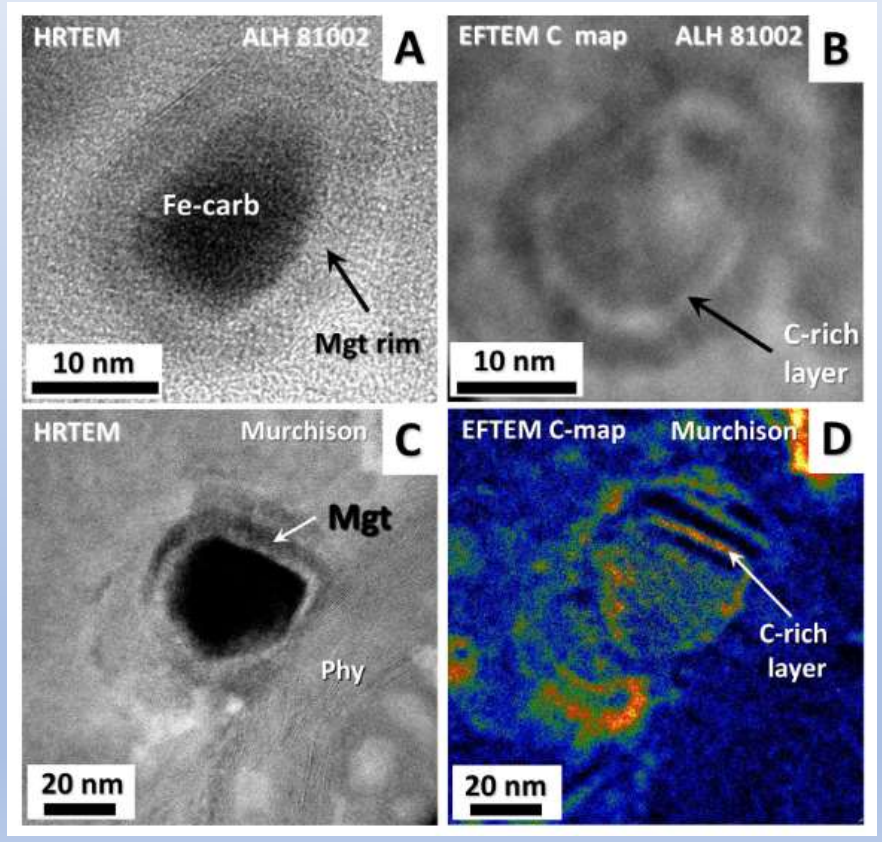
Bradley, J.P. et al., *Science* (1984) 223, 56



Bradley, J.P. *Science* (1994) 265, 925

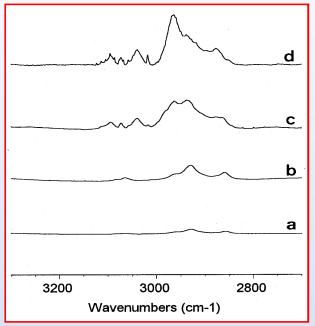


Bradley, J.P. et al. *Science* (1999) 285, 1716



Brearley, MAPS (2021) 56, 108

$H_2/CO=250$, $5x10^{-4}$ atm, 473 K



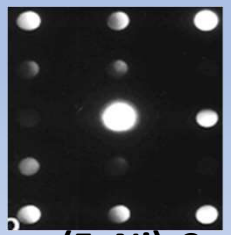
hydrocarbons, thiols

FeNi + { H_2S, H_2, CO }

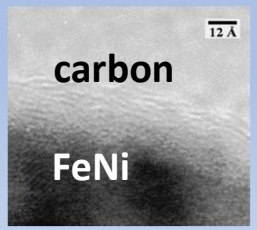
Gas phase

Solid phase

carbides, sulfides, carbon deposition

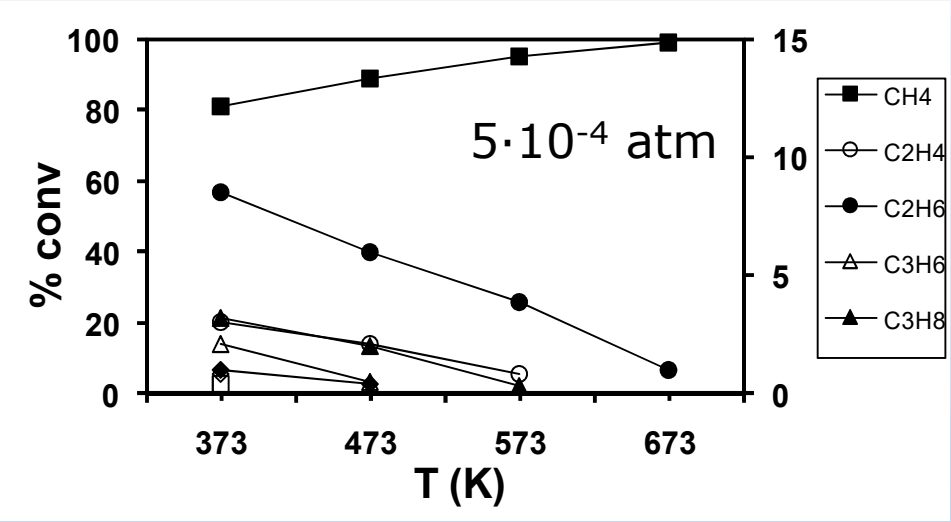


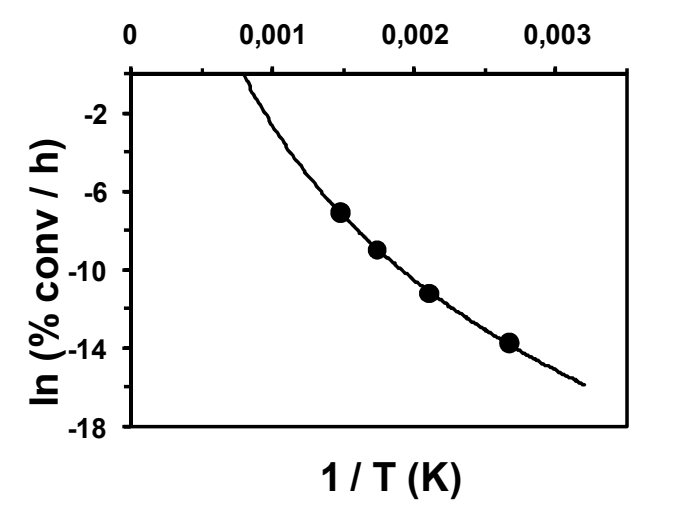
ε-$(FeNi)_xC$

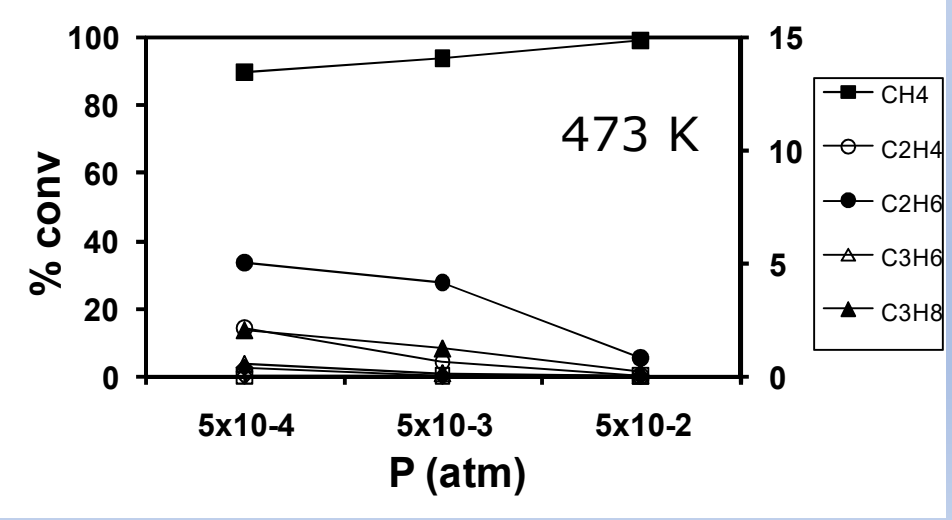


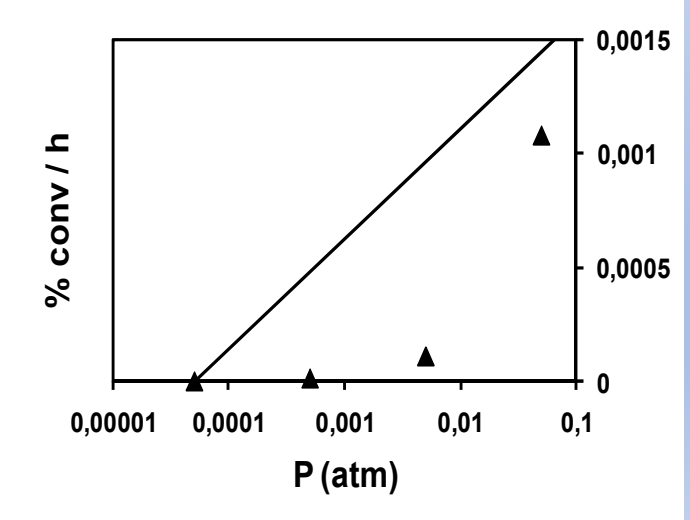
	H_2+CO	H_2+CO+H_2S
Conv.	$1.3x10^{-2}$	$4.8x10^{-2}$
CH_4	90	84
C_2H_4	2.1	2.8
C_2H_6	5.0	8.1
C_3H_6	0.5	0.8
C_3H_8	2.0	3.0
C_4H_8	-	0.1
C_4H_{10}	0.4	0.6
C_5H_{12}	-	0.2
CH_3SH	-	0.3
C_2H_5SH	-	0.1

Llorca and Casanova, MAPS, 1998, 2000

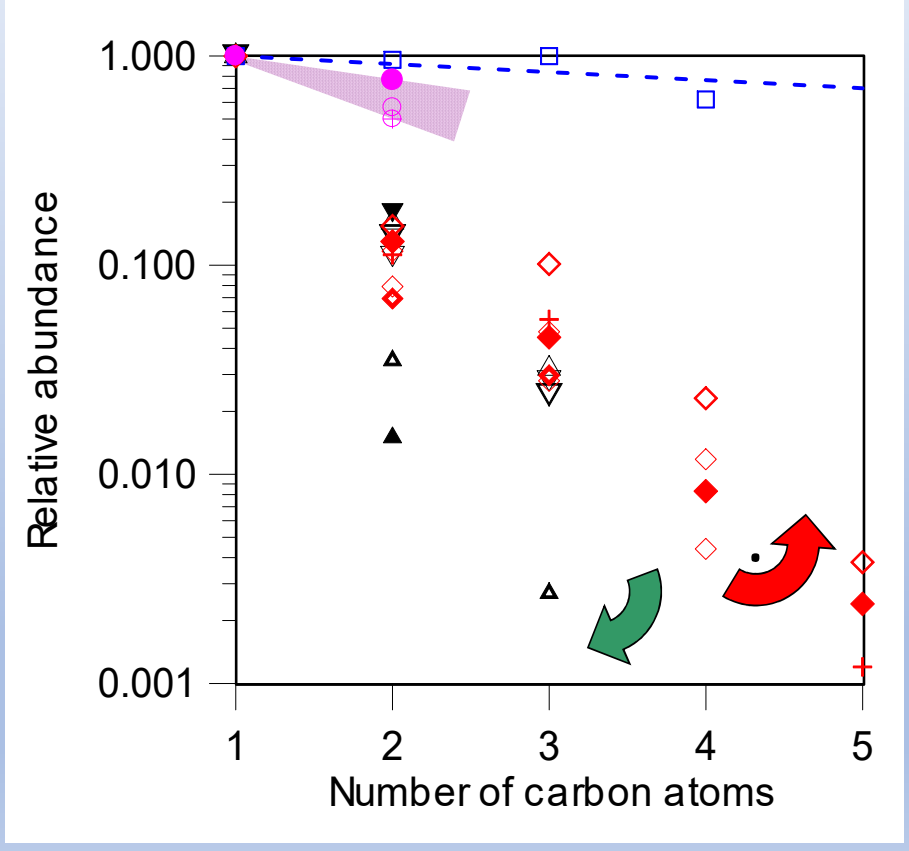

100
80
60
40
20
0
% conv
15
10
5
0
5·10-4 atm
CH4
C2H4
C2H6
C3H6
C3H8
373
473
573
673
T (K)


0
0,001
0,002
0,003
-2
-6
-10
-14
-18
ln (% conv / h)
1 / T (K)


100
80
60
40
20
0
% conv
15
10
5
0
473 K
CH4
C2H4
C2H6
C3H6
C3H8
5x10-4
5x10-3
5x10-2
P (atm)


0,0015
0,001
0,0005
0
% conv / h
0,00001
0,0001
0,001
0,01
0,1
P (atm)

Relative abundances of C_1-C_5 hydrocarbons



Llorca, Phys. Chem. Earth 1999

Murchison
(Yuen et al.)

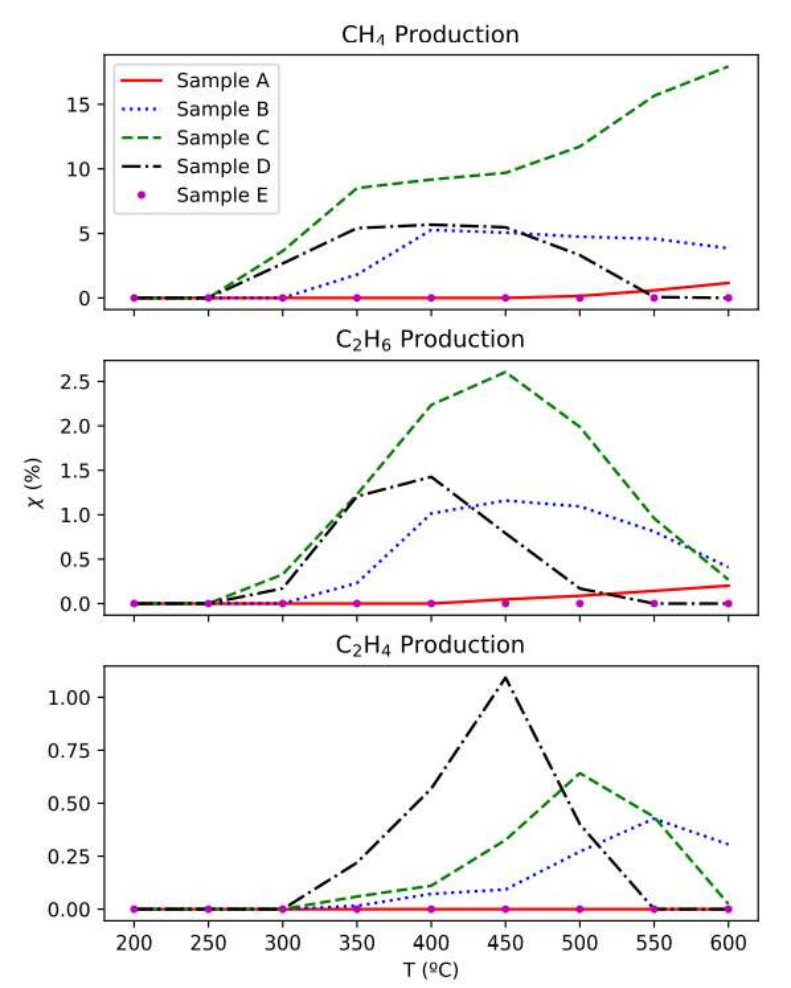
Hyakutake, Hale-Bopp
(Mumma et al.; Weaver et al.; Campins et al.)

Irradiated ices
(Moore and Hudson; Gerakines et al.)

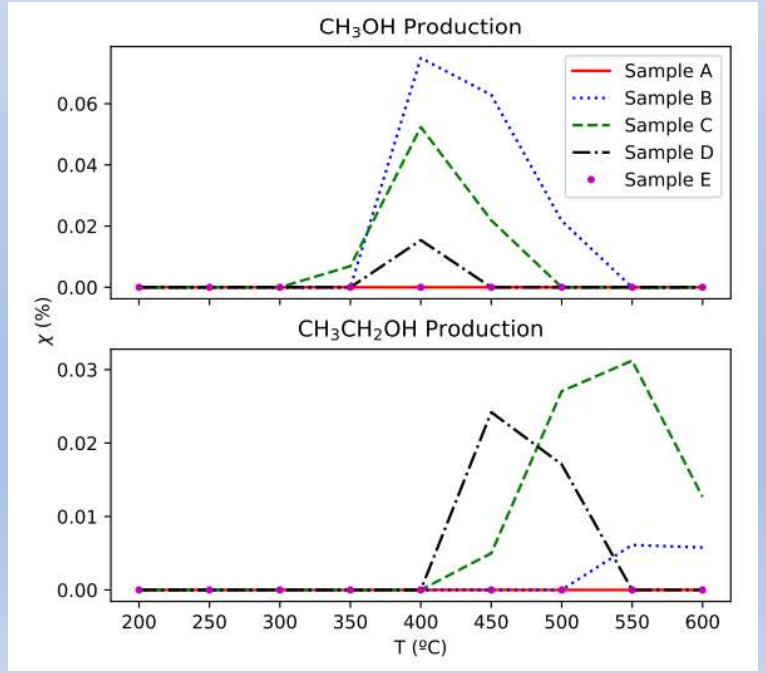
FTT
(Llorca et al.)

II. Using meteorite samples

H_2/CO=4, 1 atm



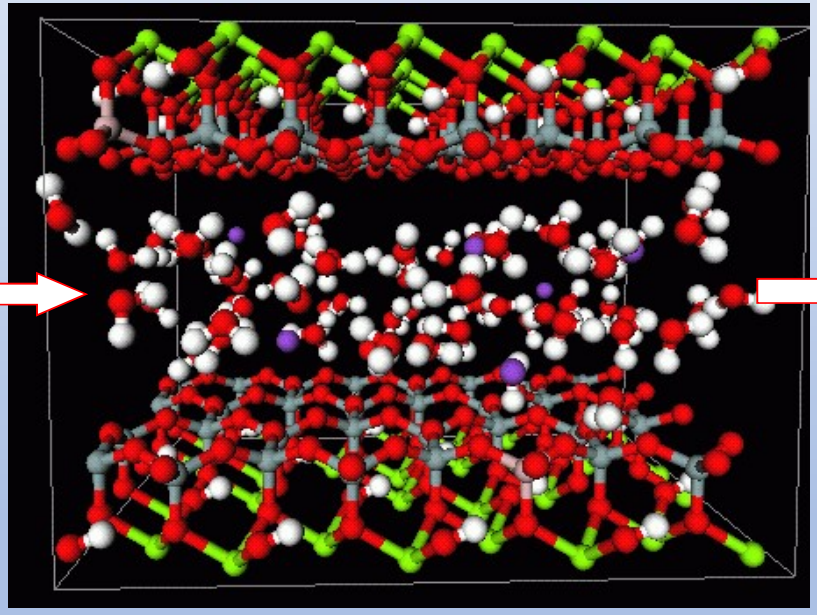
Sample	Meteorite	Type	Subtype	Weight (g)	SiC weight (g)	Total weight (g)	Gas flow
A	–	–	–	–	3.0027	3.0027	H_2/CO
B	KG007	OC	H6	0.5012	2.4996	3.0008	H_2/CO
C	KG007 (magnetic phase)	OC	H6	0.5158	2.4929	3.0087	H_2/CO
D	NWA 801	CC	CR2	0.5256	2.4814	3.0070	H_2/CO



Cabedo et al., A&A 2021

III. Clays in carbonaceous chondrites

Simple molecules



Complexity

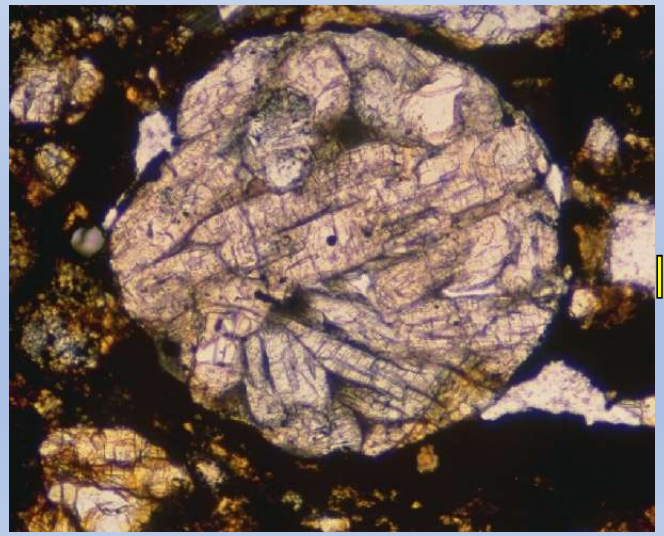
Organic molecules

Aqueous alteration

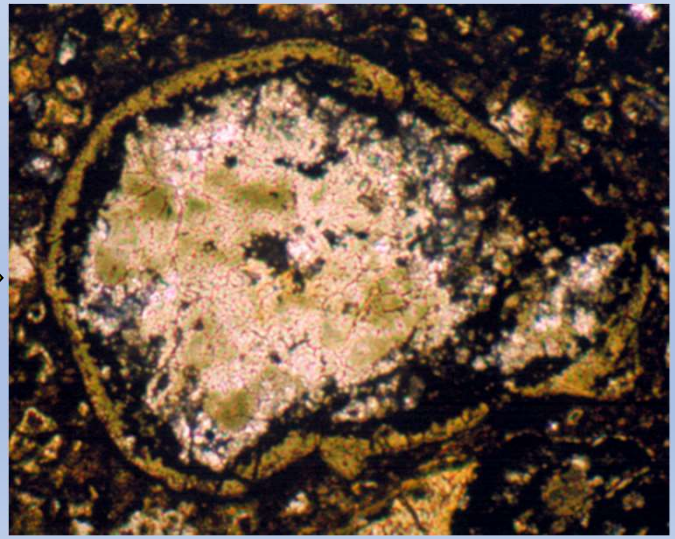
Carbonaceous chondrites

CI, CM

CO, CV, ...

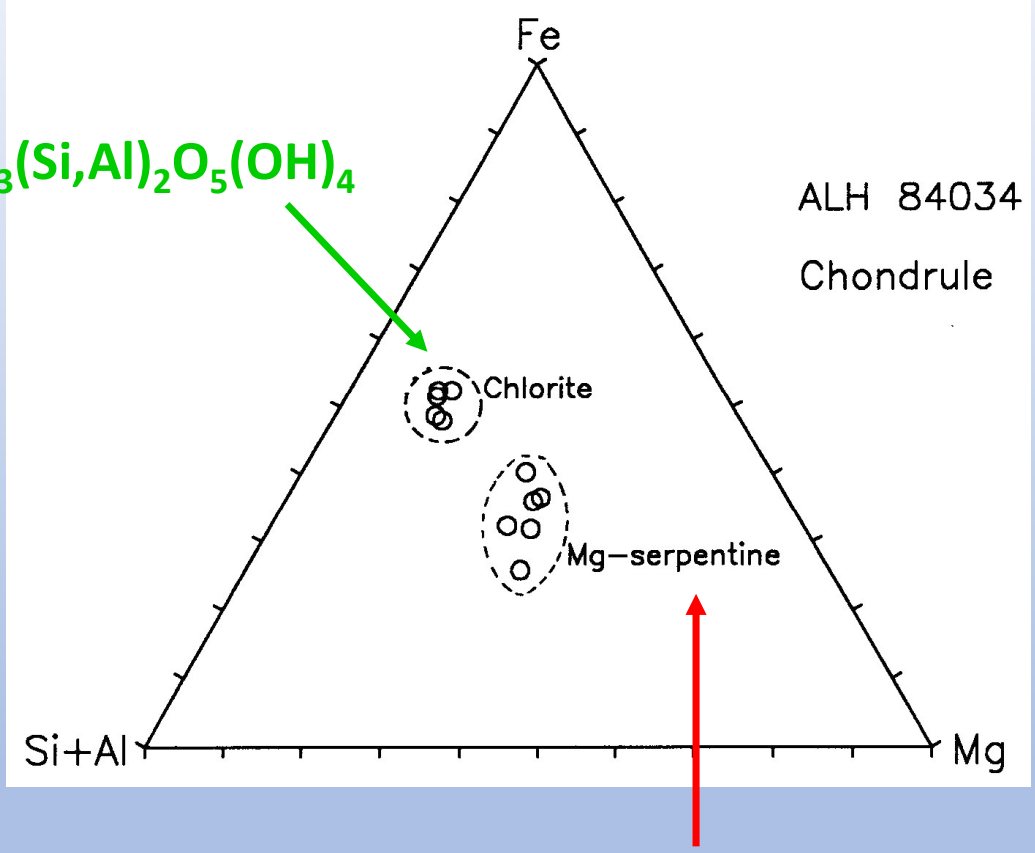


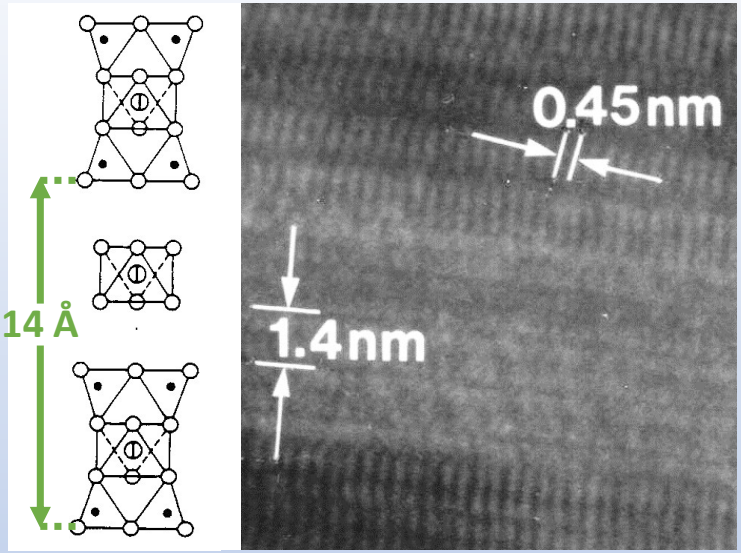
Allende CV3

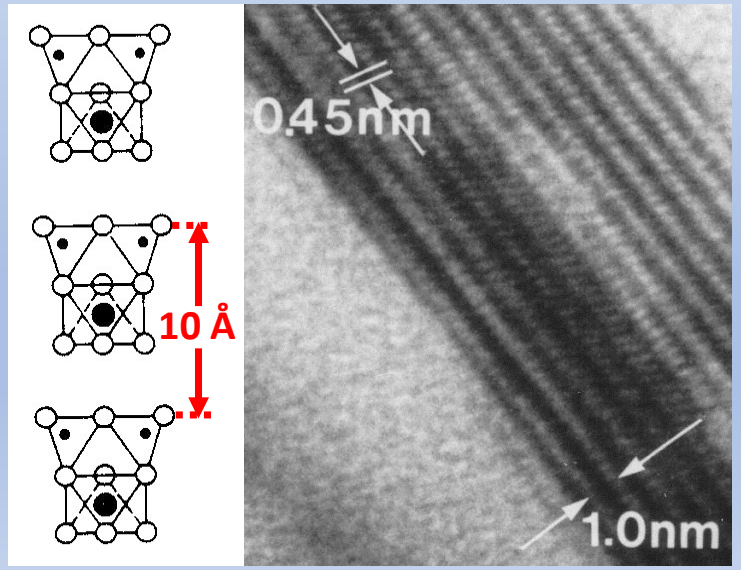


ALH84034 CM2

$(Fe,Mg)_3(Si,Al)_2O_5(OH)_4$



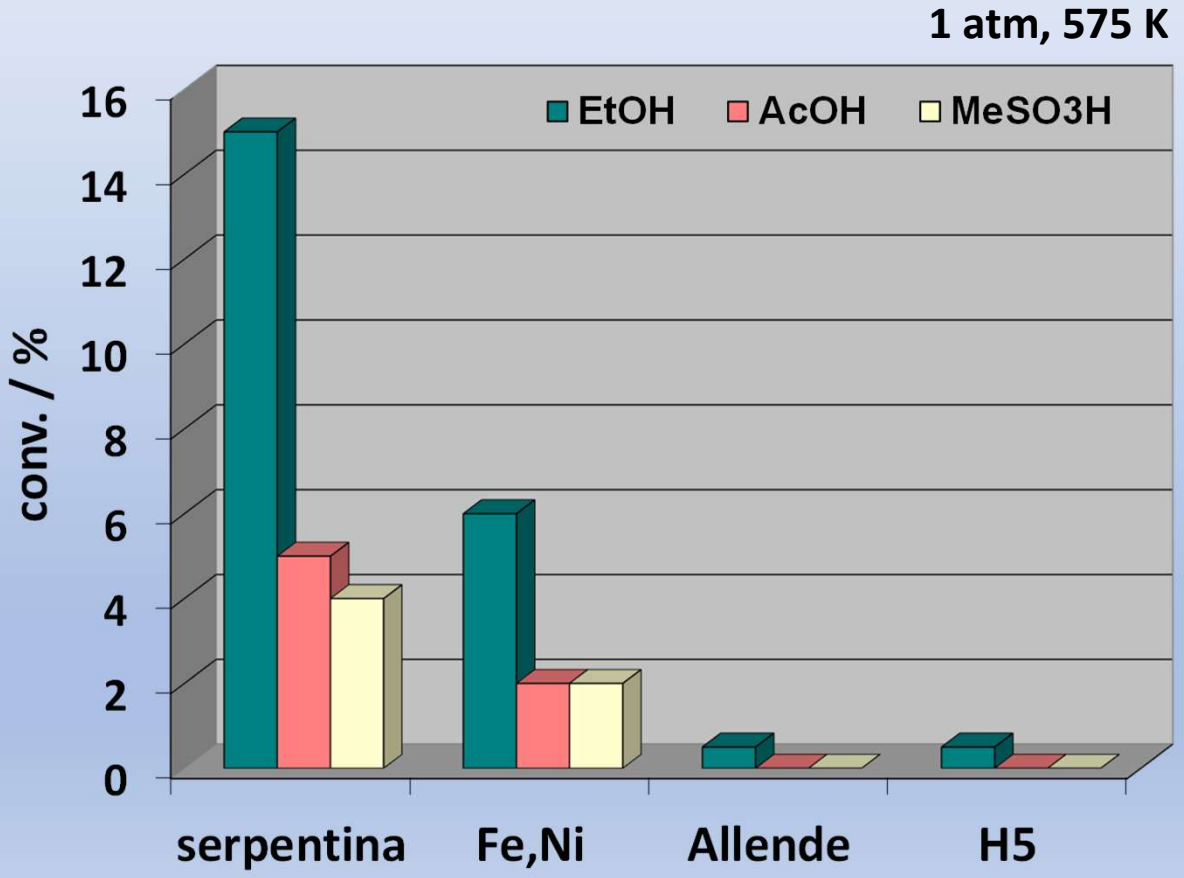




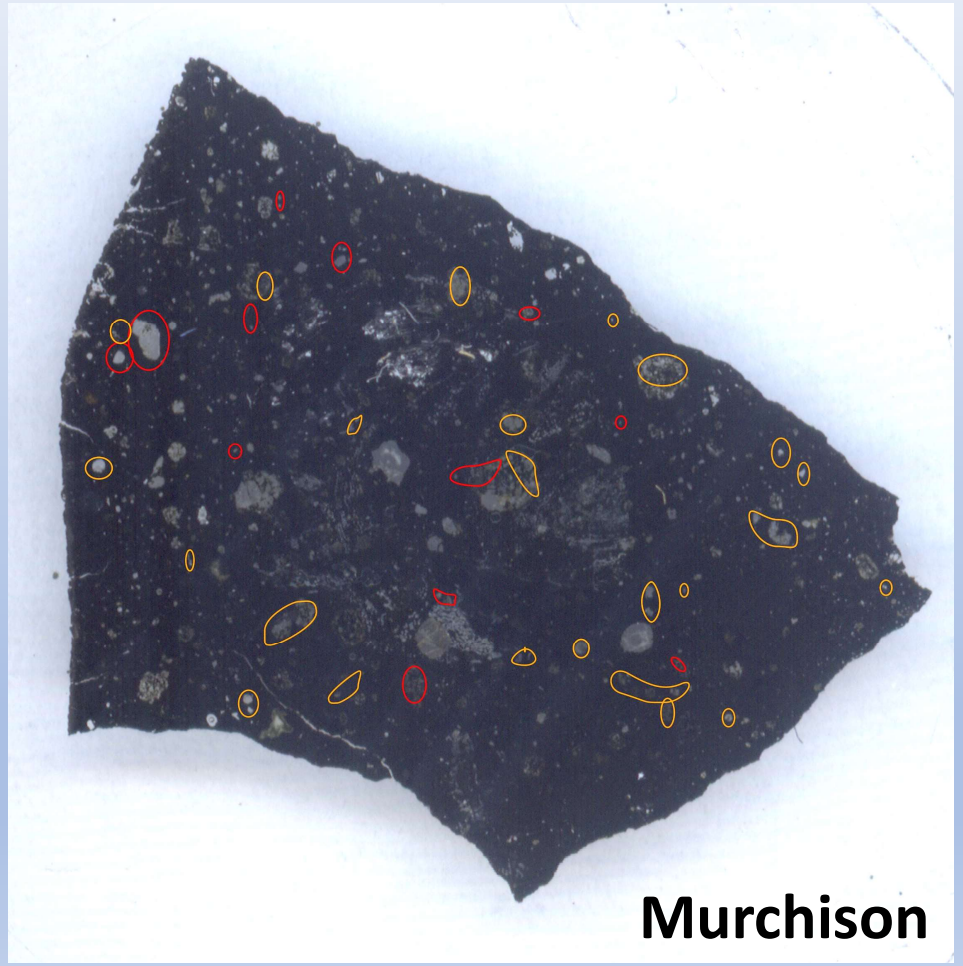
$2\ Mg_2SiO_4 + 3\ H_2O \longrightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$

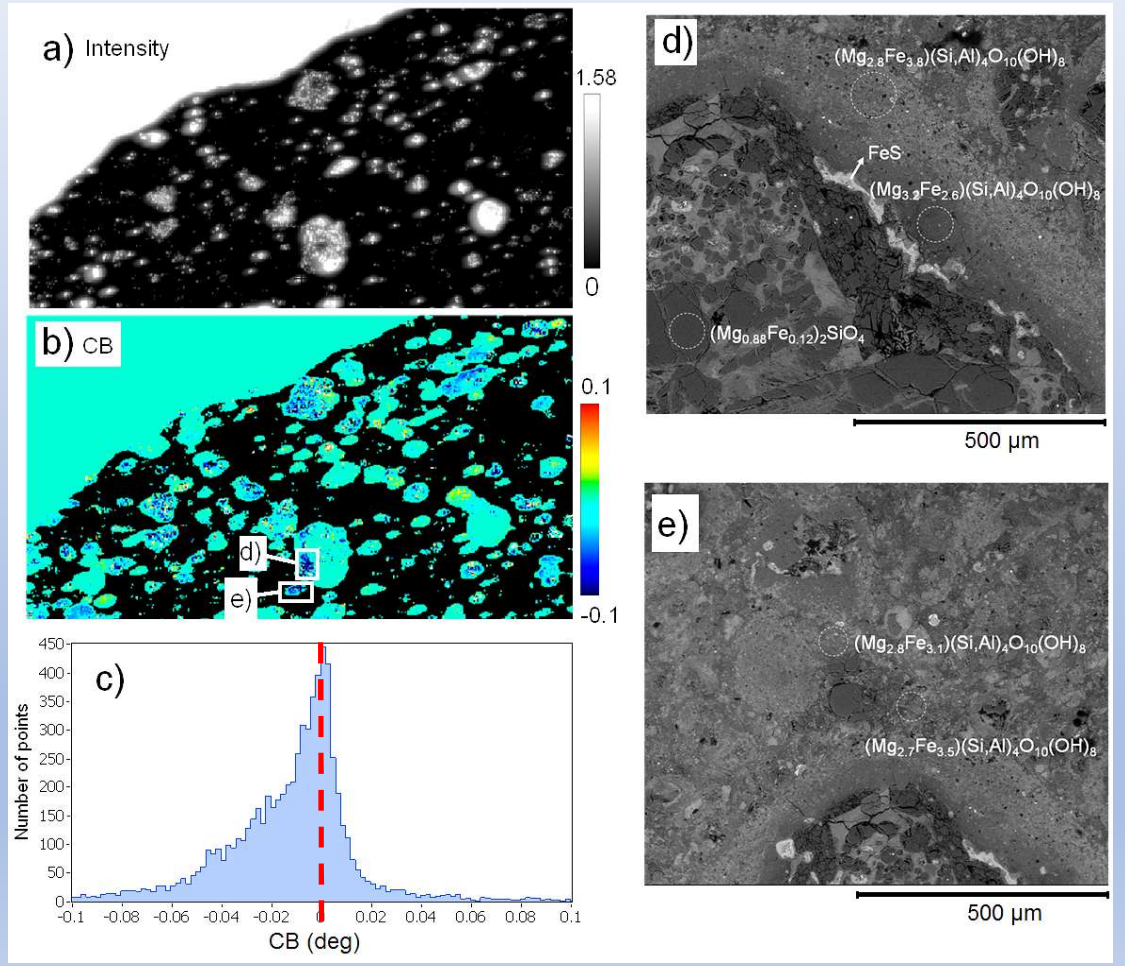
$$CH_2{=}CH_2 \xrightarrow{H_2O} CH_3CH_2OH \xrightarrow{H_2O} CH_3COOH$$

$$CH_3SH \xrightarrow{H_2O} CH_3SO_3H$$



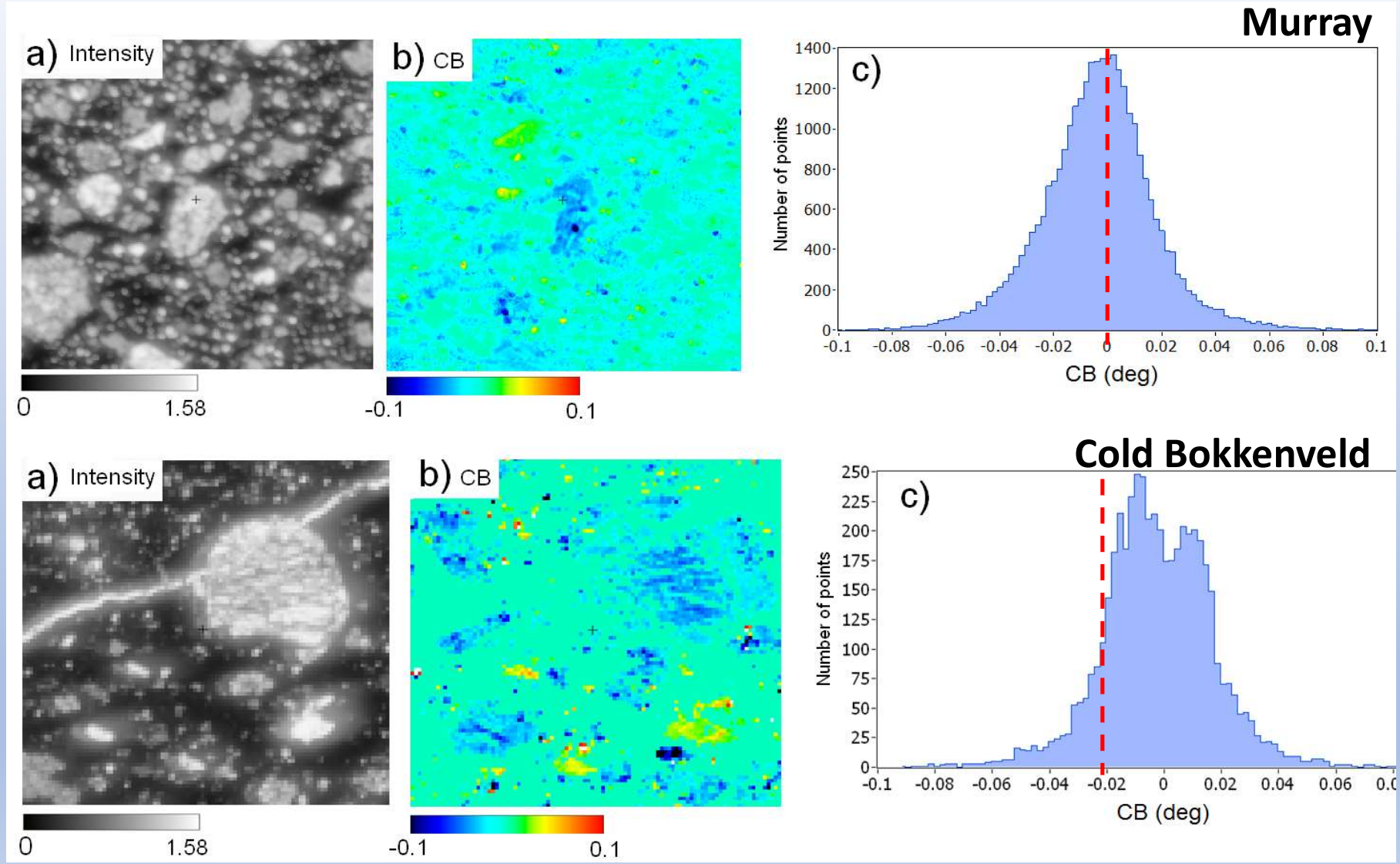
But are the organics really within clays?





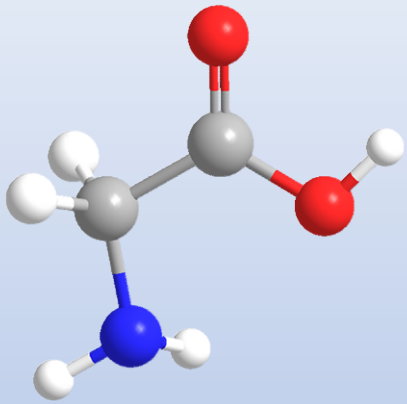
circular birefringence

Arteaga et al., OLEB 2009

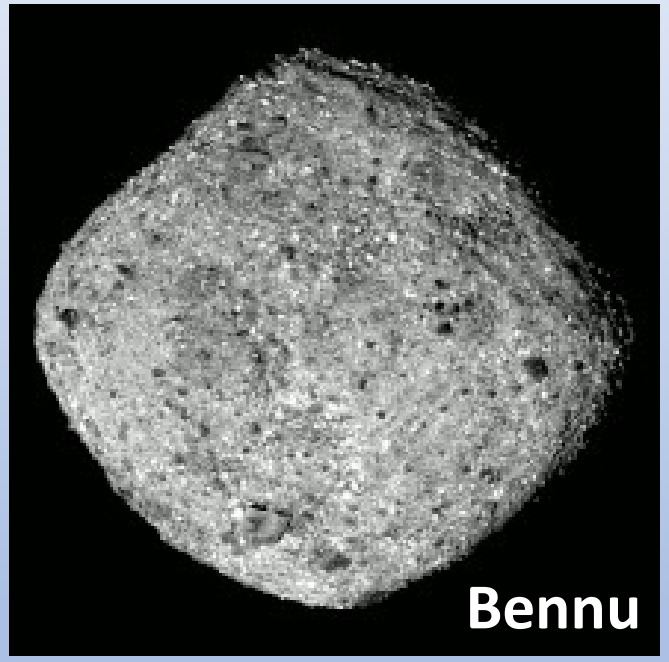


Arteaga et al., OLEB 2009

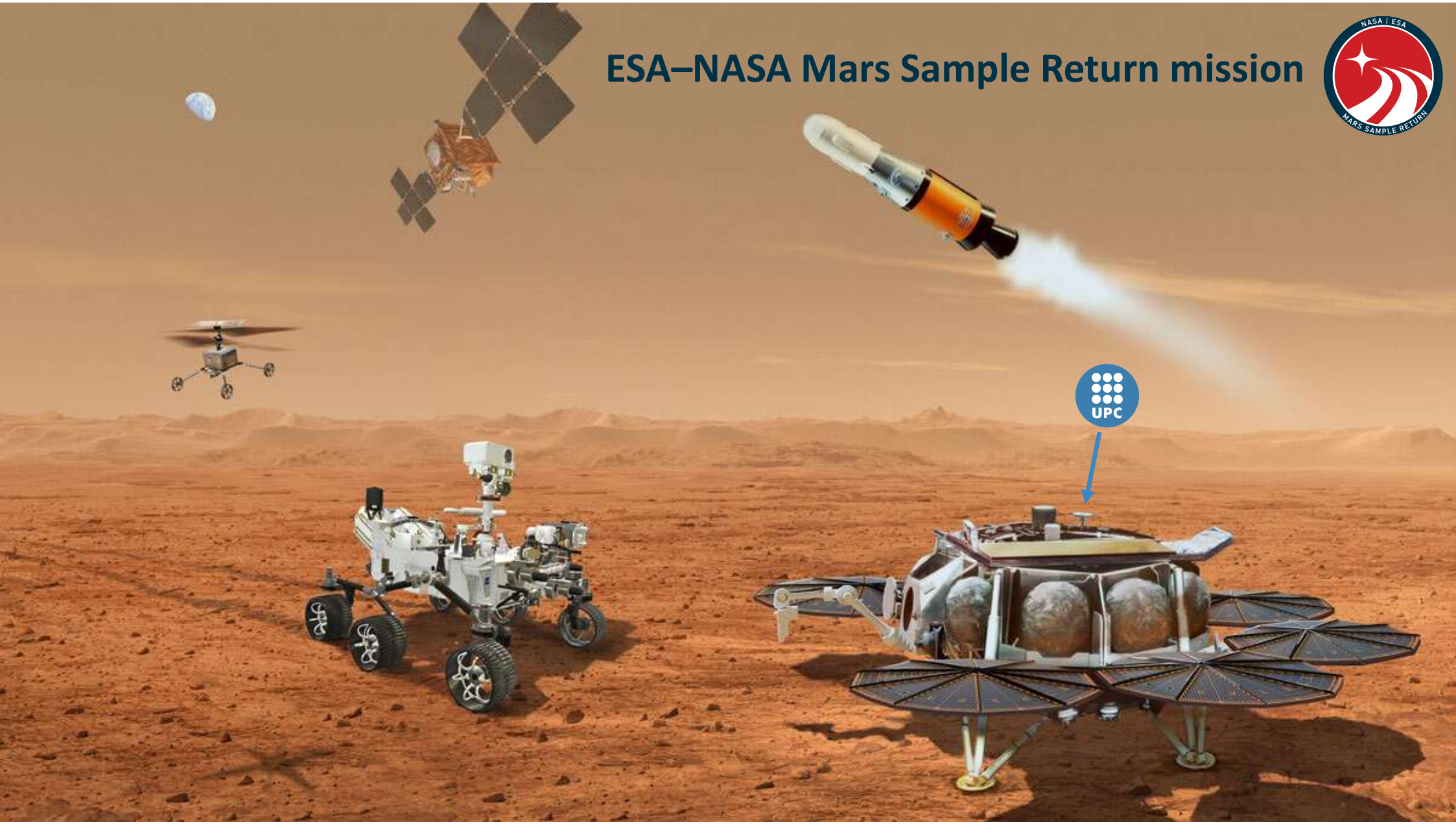
Final thoughts:



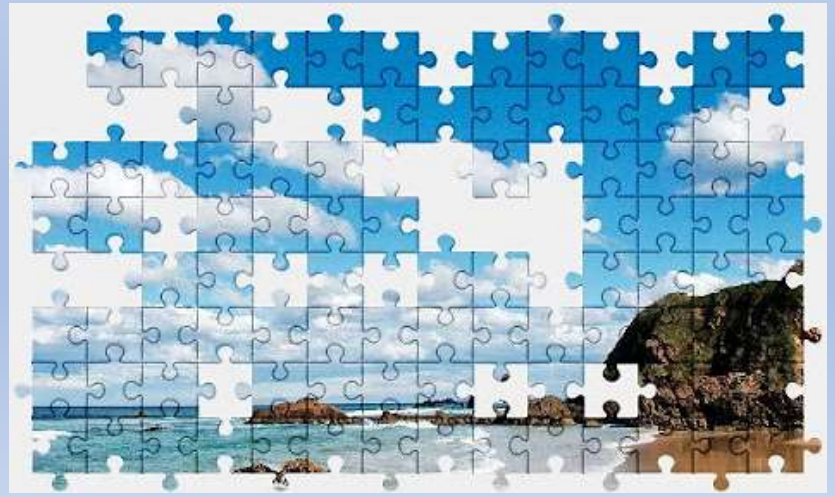
New surprises?



OSIRIS-Rex (NASA)
24 September 2023


ESA–NASA Mars Sample Return mission
NASA | ESA
MARS SAMPLE RETURN
UPC

Meteorites might be important from the origin of life perspective (among others), so we need to recover them:



>500 meteorites recovered!