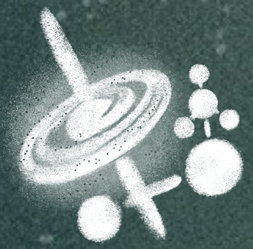
Ministero dell'Università e della Ricerca

FIS

iSEEDs

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Dalla Nascita dei Pianeti ai Mattoni della Vita



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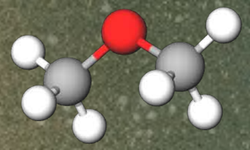

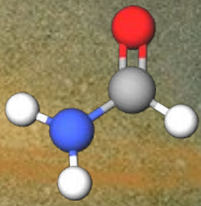

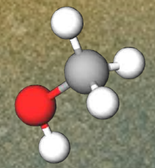

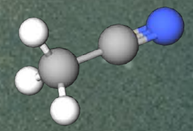

Eleonora Bianchi
INAF - Osservatorio Astrofisico di Arcetri
eleonora.bianchi@inaf.it

Perché c'è vita sulla Terra?

1. Come si è formato il nostro pianeta?
2. Da dove vengono gli atomi che ci compongono?
3. Come è nata la vita sulla Terra?

Come si è formato il nostro pianeta?

Credits: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

Circa 100 000 anni luce (30 kpc)

Come si è formato il nostro pianeta?

Credits: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

Circa 100 anni luce (30 pc)

Credits: NASA, ESA, CSA, and STScI

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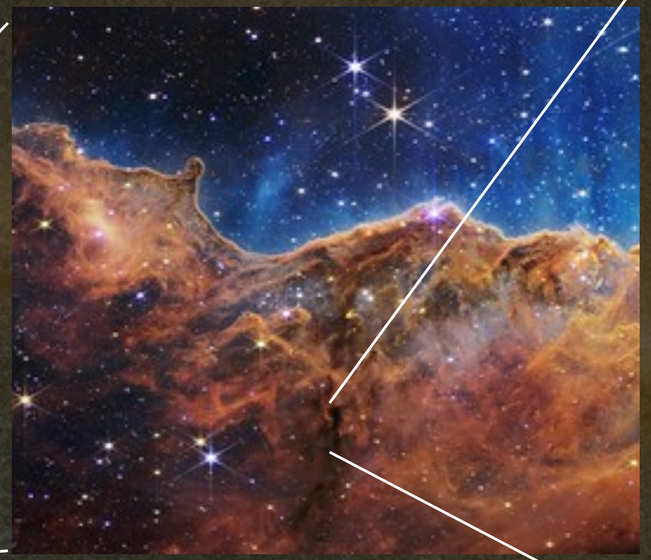
Come si è formato il nostro pianeta?

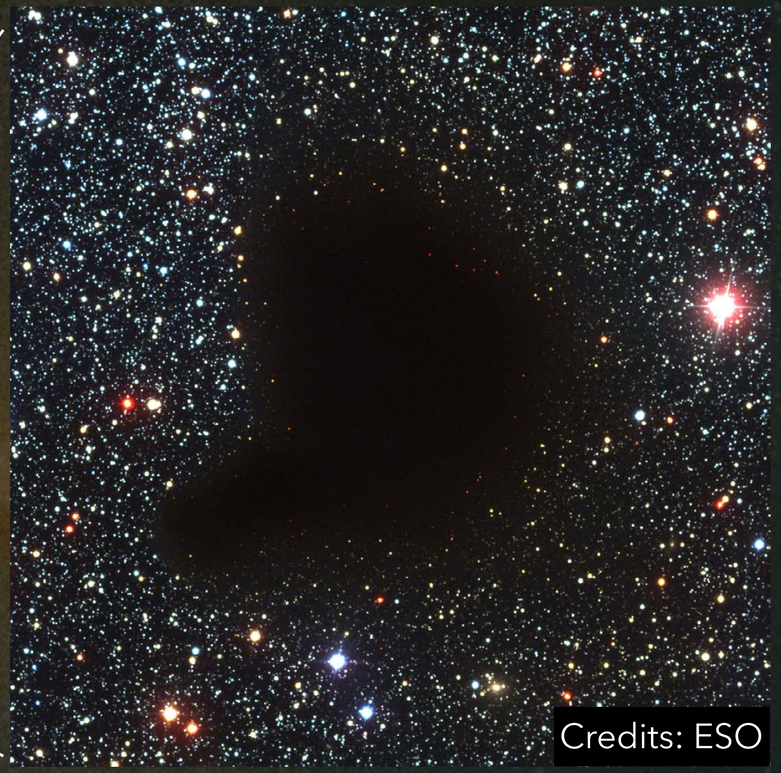
Credits: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)



Credits: NASA, ESA, CSA, and STScI

In questa stanza
10^{19} mol/cm^{-3}

Circa 0.5 anni luce (0.2 pc)

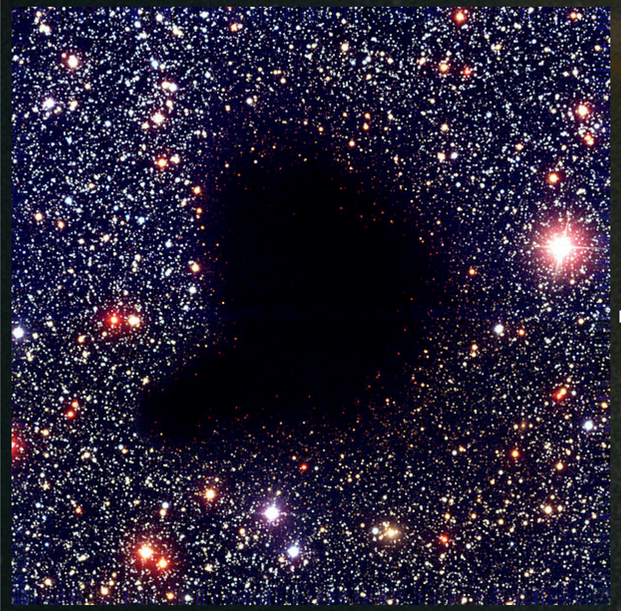


Credits: ESO

Temperatura -263 °C
Densità 10^{4} mol/cm^{-3}

Come si è formato il nostro pianeta?

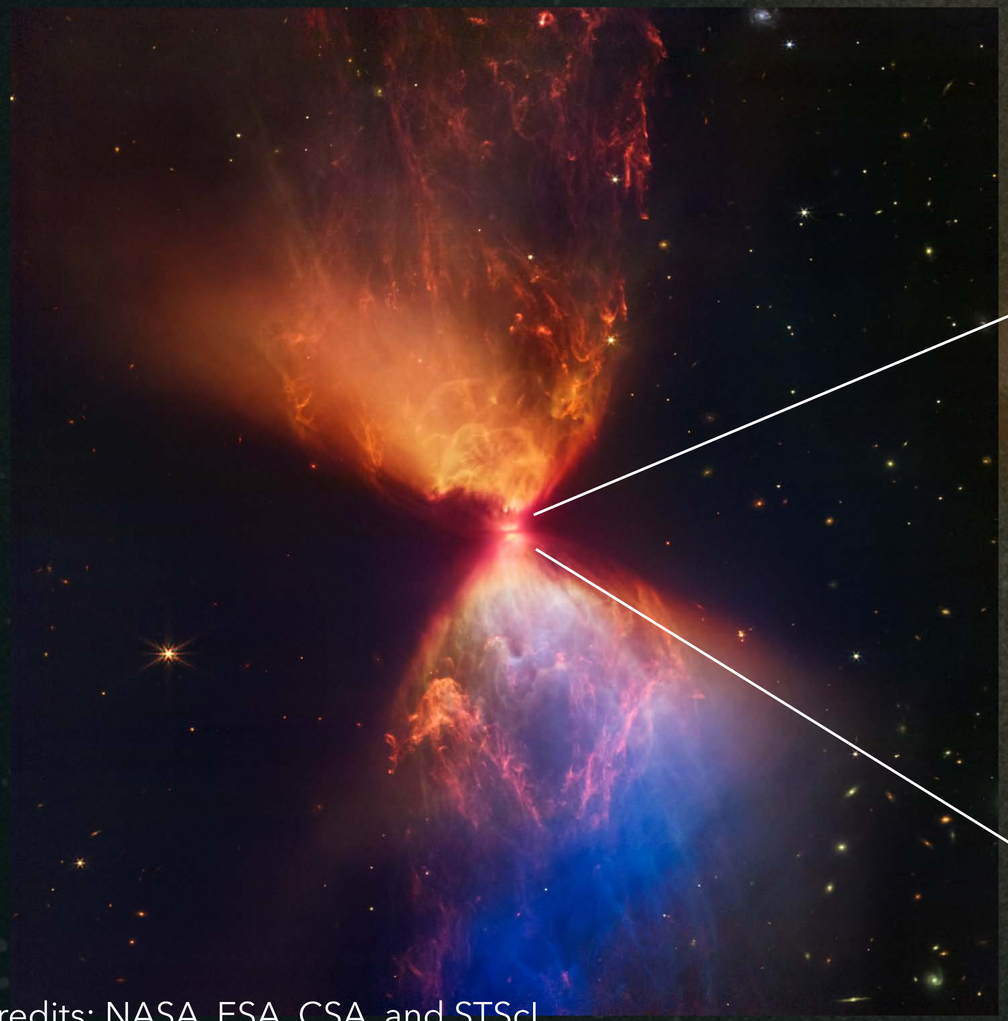
Dopo 10 mila anni..



Credits: NASA, ESA, CSA, and STScI

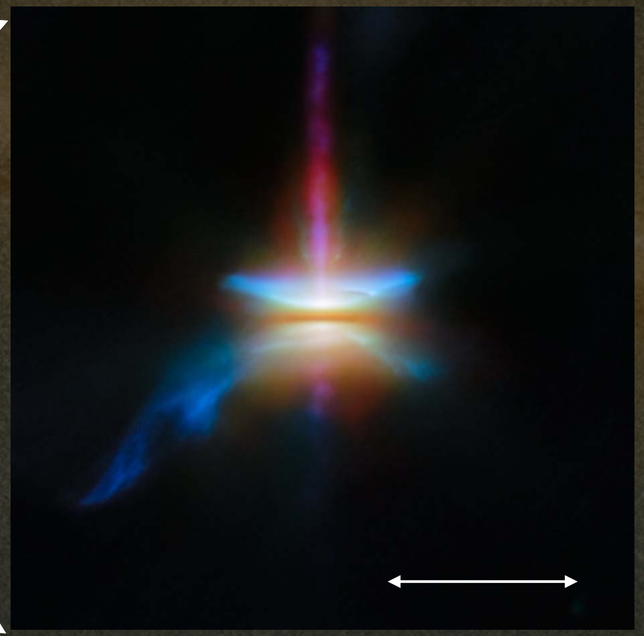
È nata una stella simile al Sole!

Come si è formato il nostro pianeta?

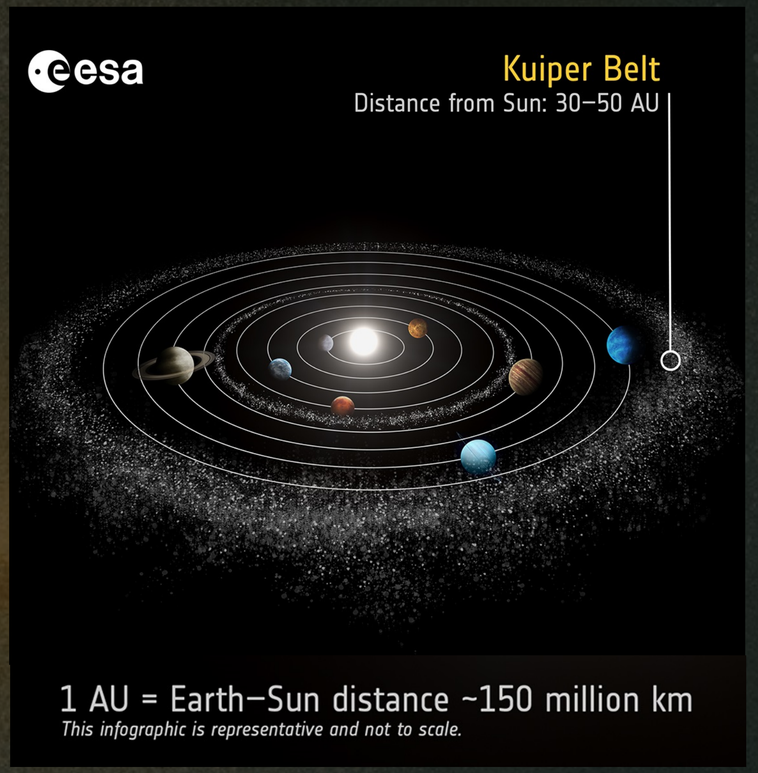


Credits: NASA, ESA, CSA, and STScI

È nata una stella!

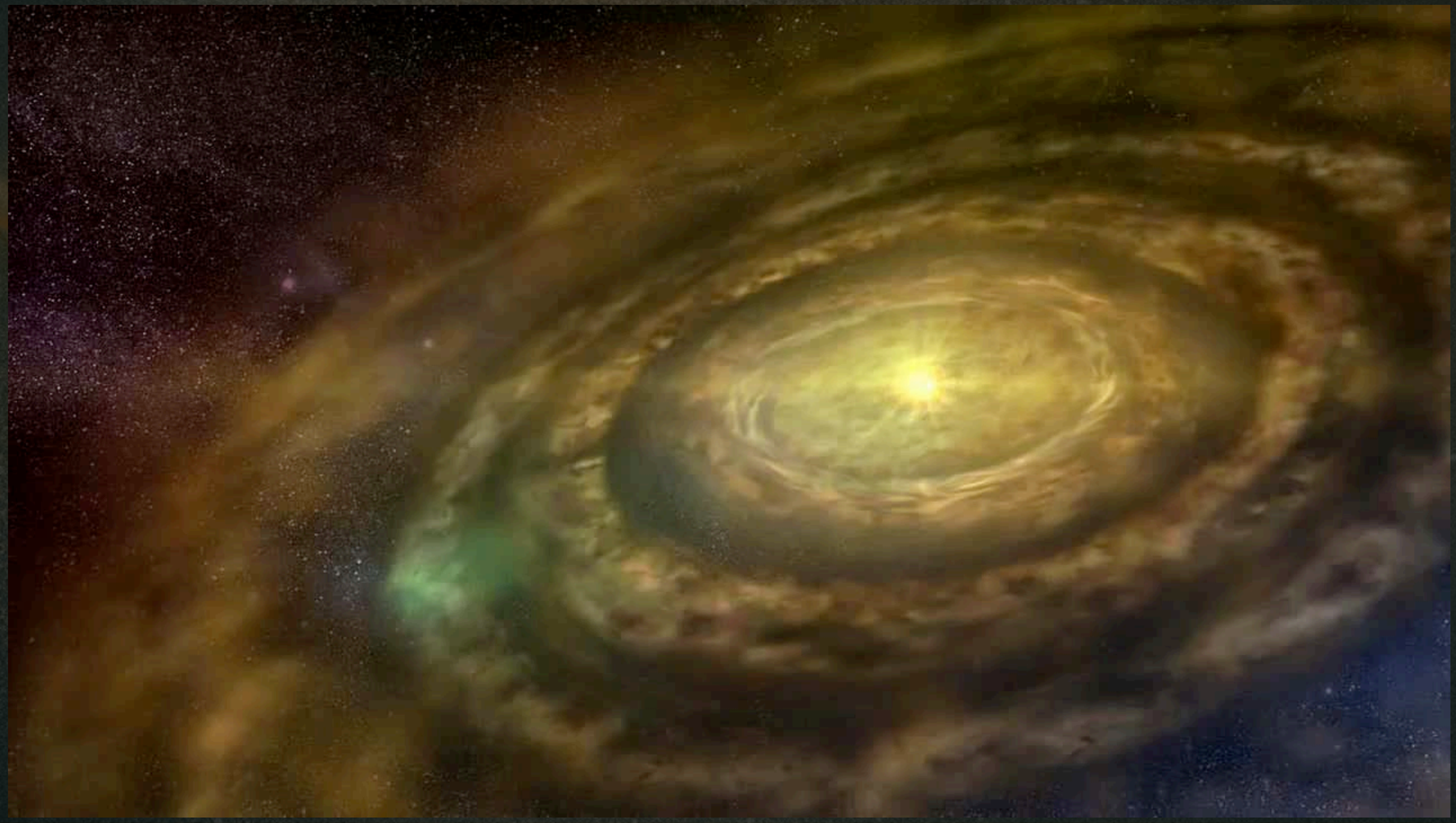


Circa100 unità astronomiche

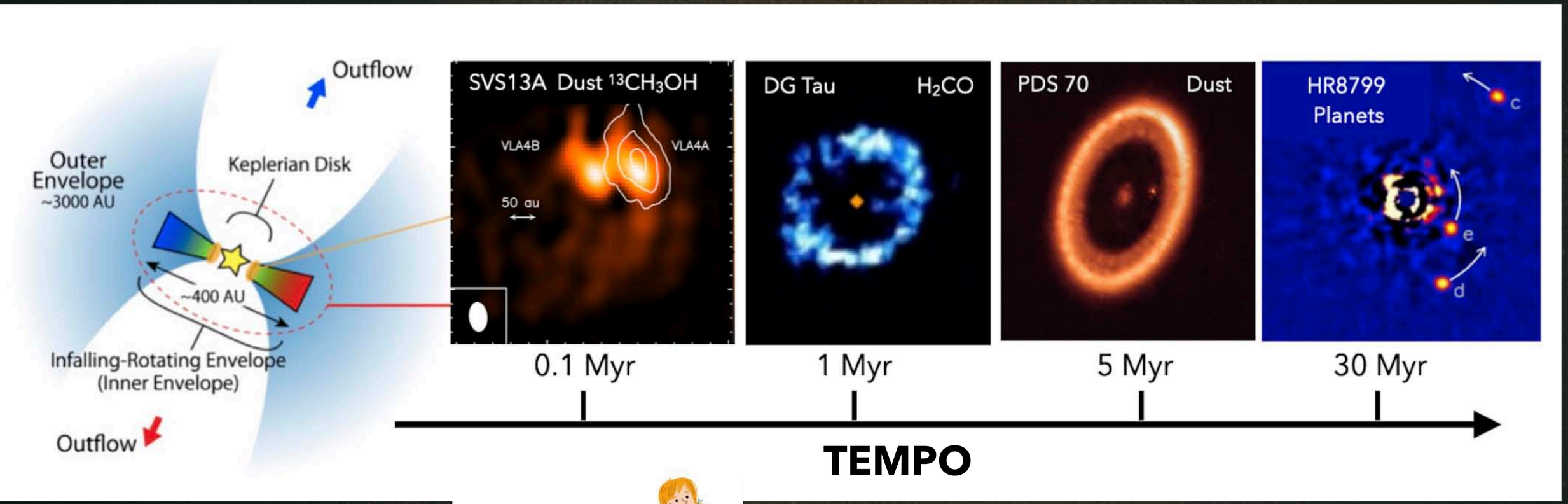


Scale del Sistema Solare!

Come si è formato il nostro pianeta?



Come si è formato il nostro pianeta?



Dischi protoplanetari

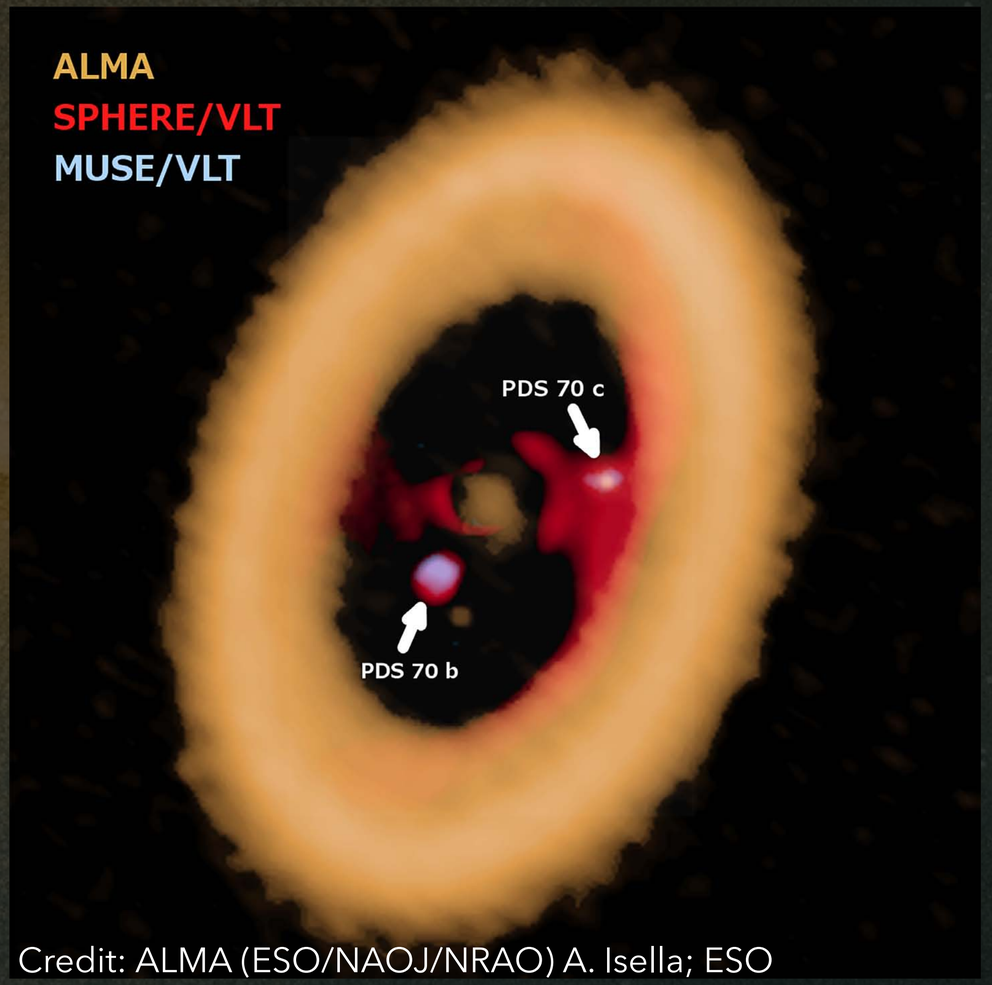
Come si è formato il nostro pianeta?

PDS 70 età 5 milioni di anni

Due pianeti neonati e le loro lune

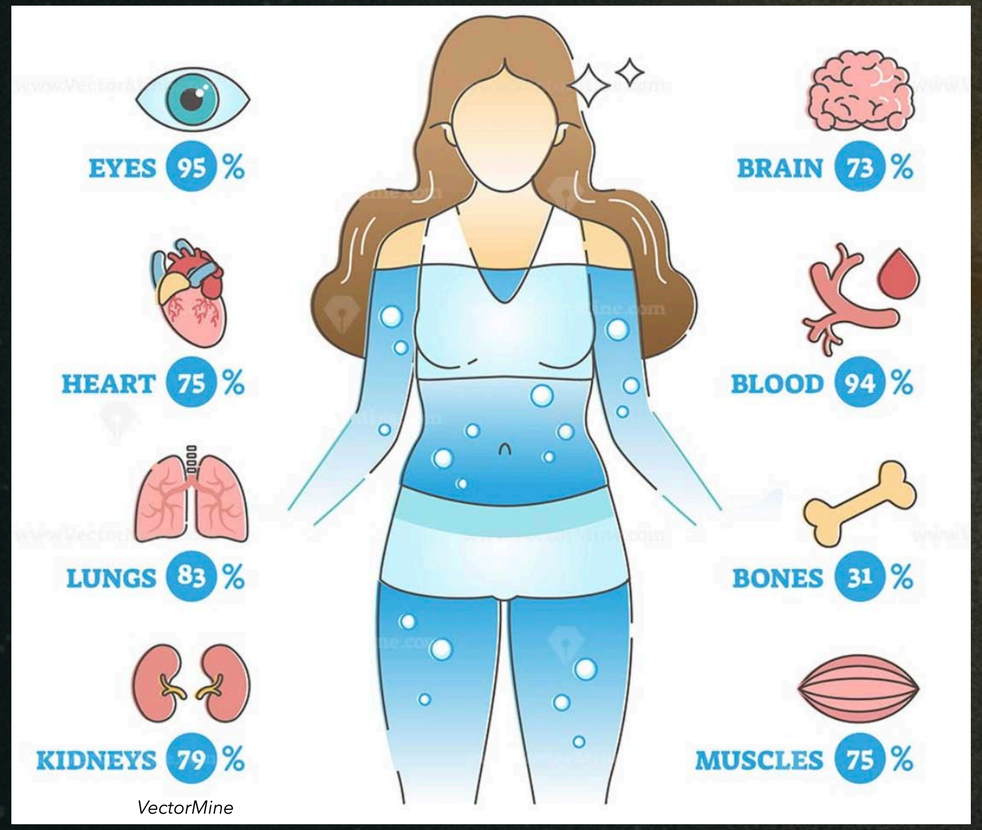
VLT, Paranal

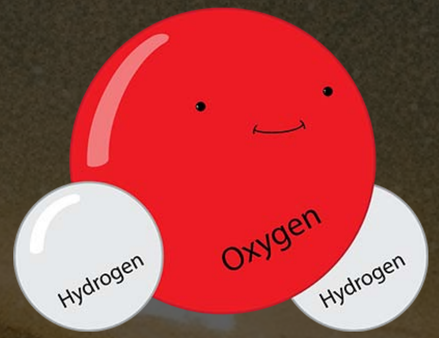
ALMA, Atacama



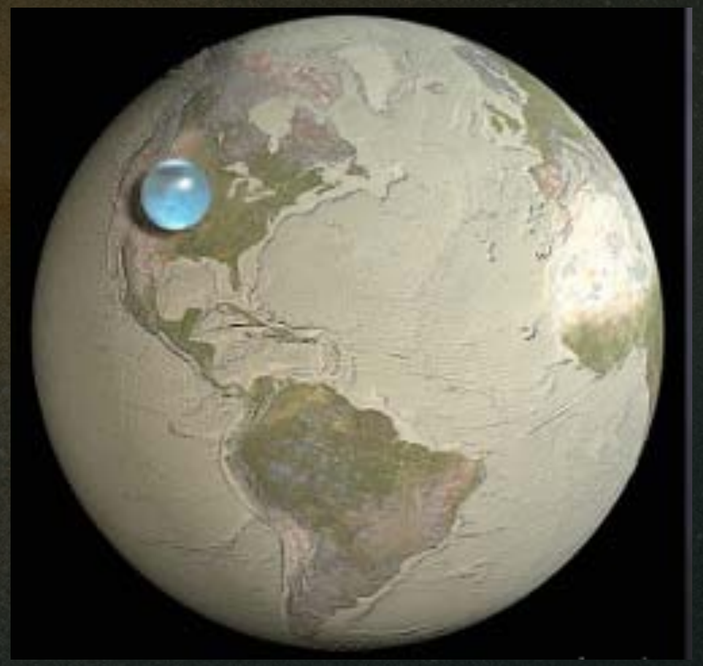
Credit: ALMA (ESO/NAOJ/NRAO) A. Isella; ESO

Di cosa siamo fatti ?



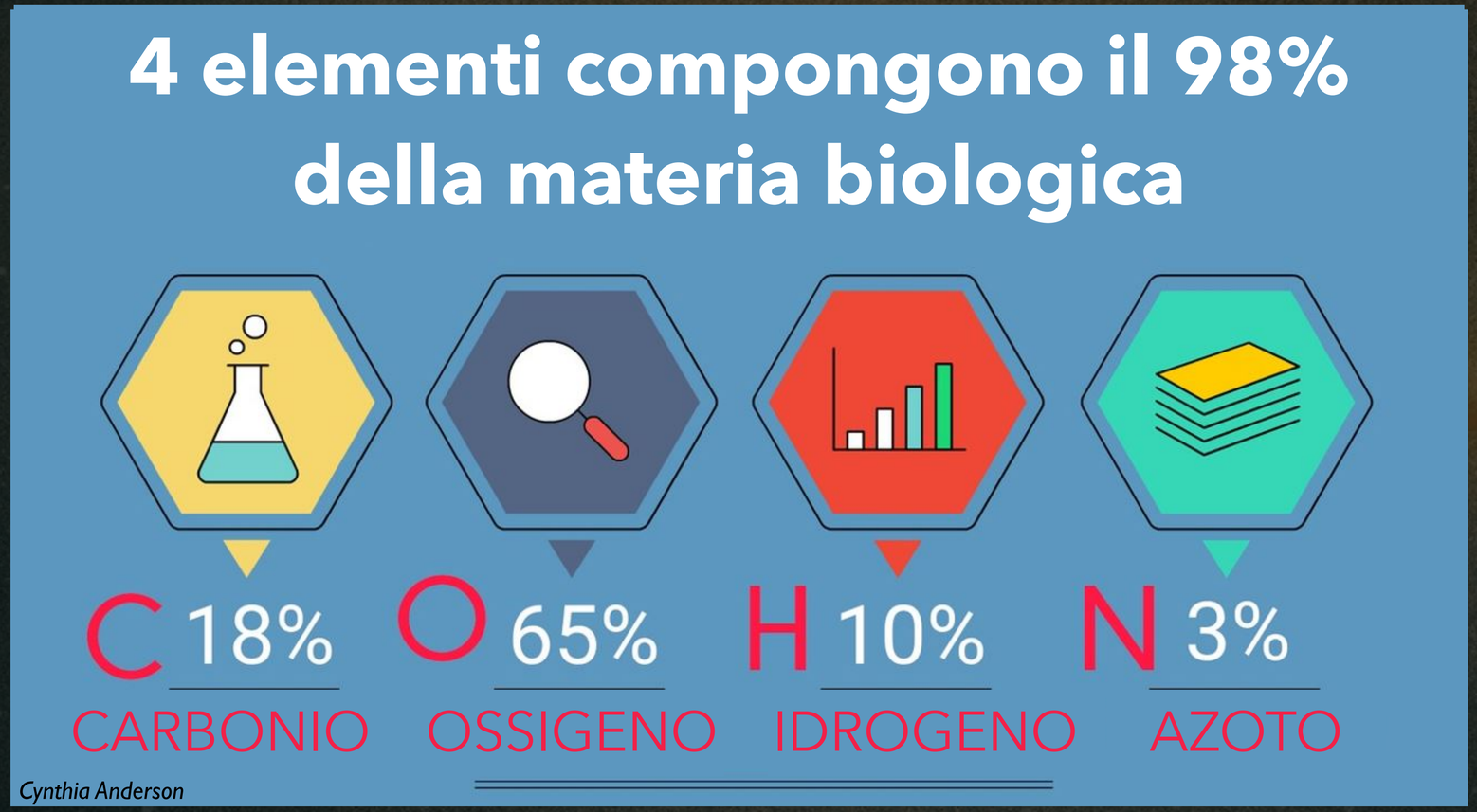


Acqua



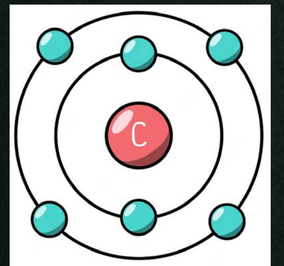
Di cosa siamo fatti ?

Carbonio, Ossigeno, Idrogeno e Azoto + altri elementi

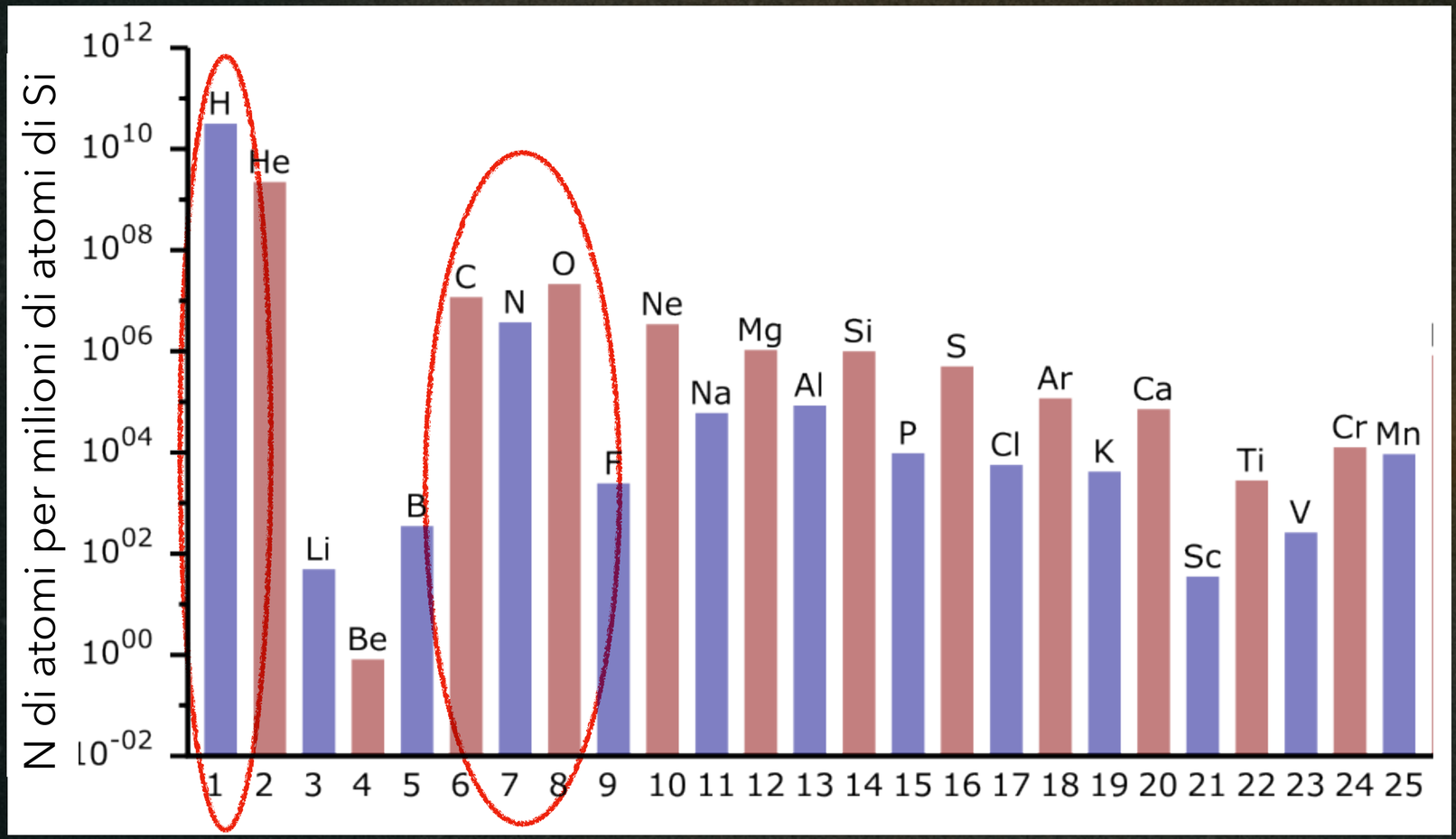


Quali sono gli elementi più abbondanti nell'Universo?

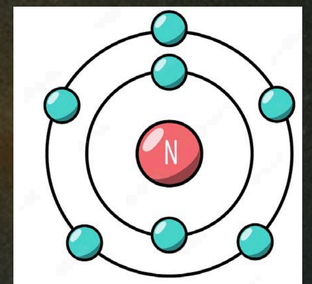
IDROGENO



CARBONIO

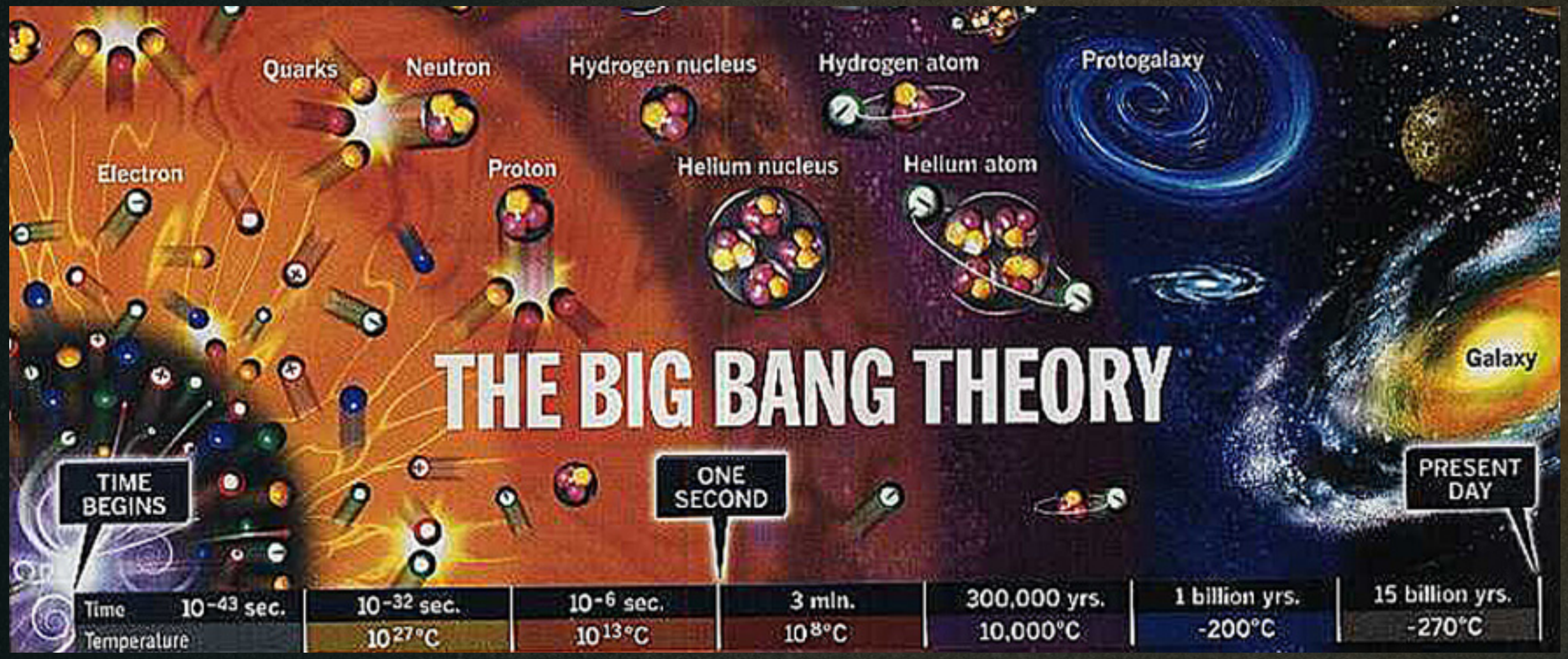


OSSIGENO



AZOTO

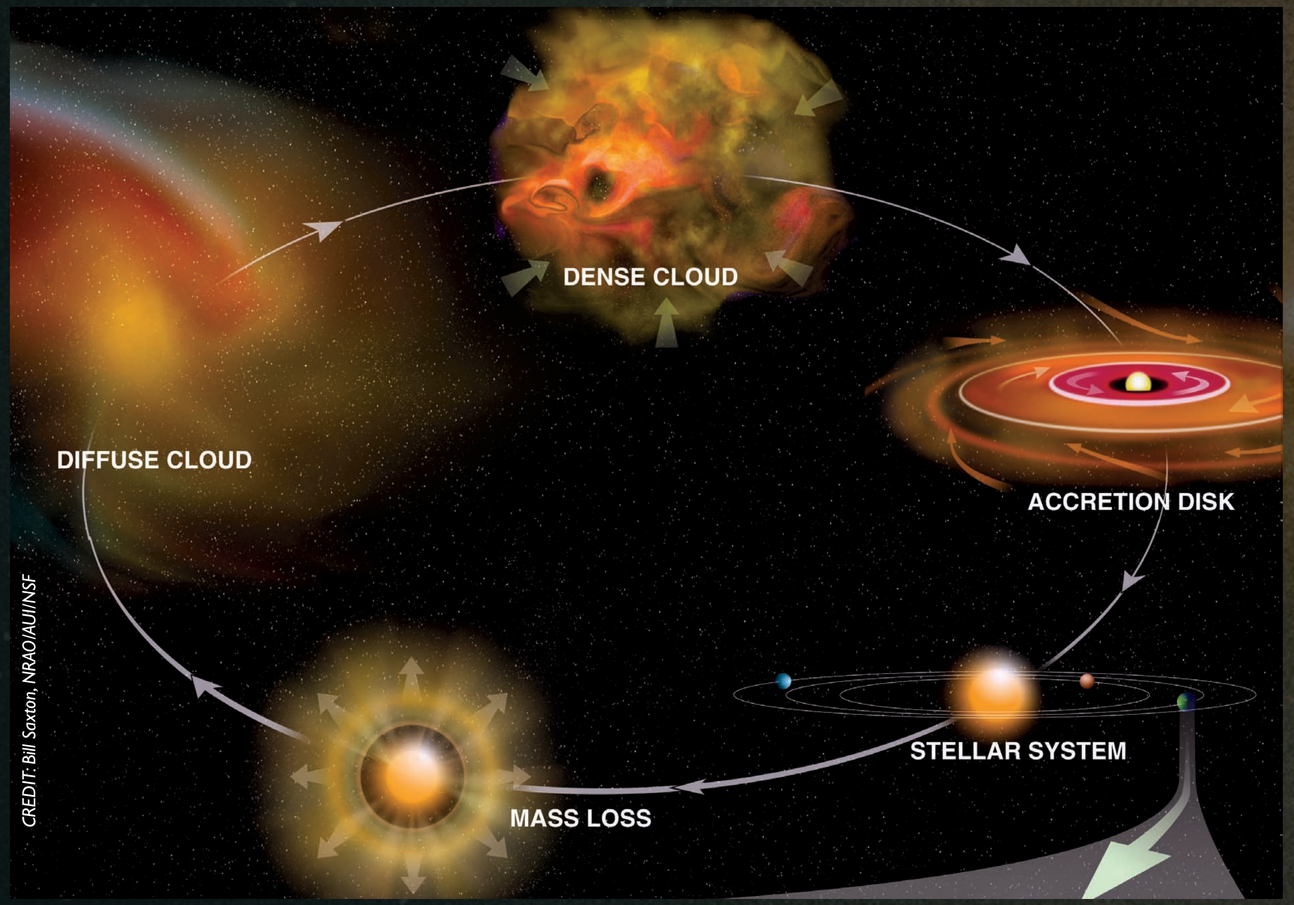
Da dove vengono gli atomi che ci compongono?



Idrogeno ed elio si formano ~ 3 minuti dopo il Big Bang

Source: The Kingfisher book of the Universe

Da dove vengono gli atomi che ci compongono?

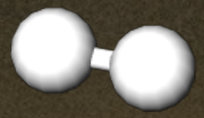


Carbonio ed Ossigeno si formano nelle stelle e vengono espulsi nel mezzo interstellare quando le stelle muoiono

(Ri-)ciclo cosmico!

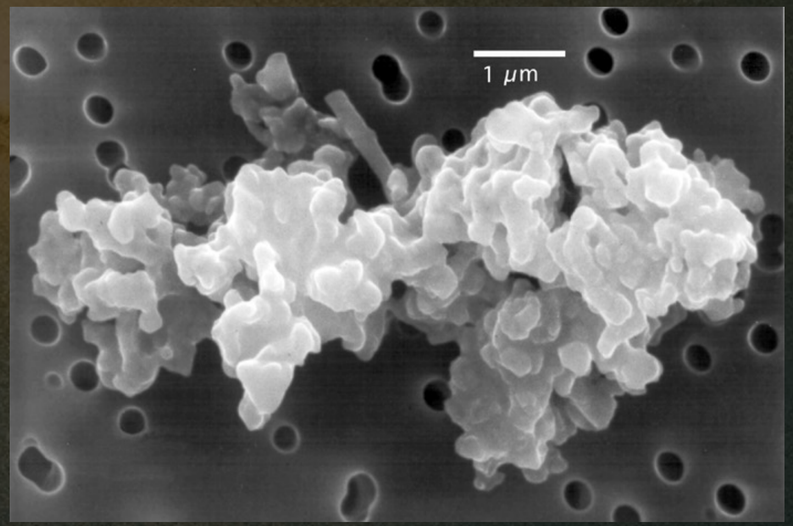
Come si formano le molecole?

Credits: NASA, ESA, CSA, and STScI



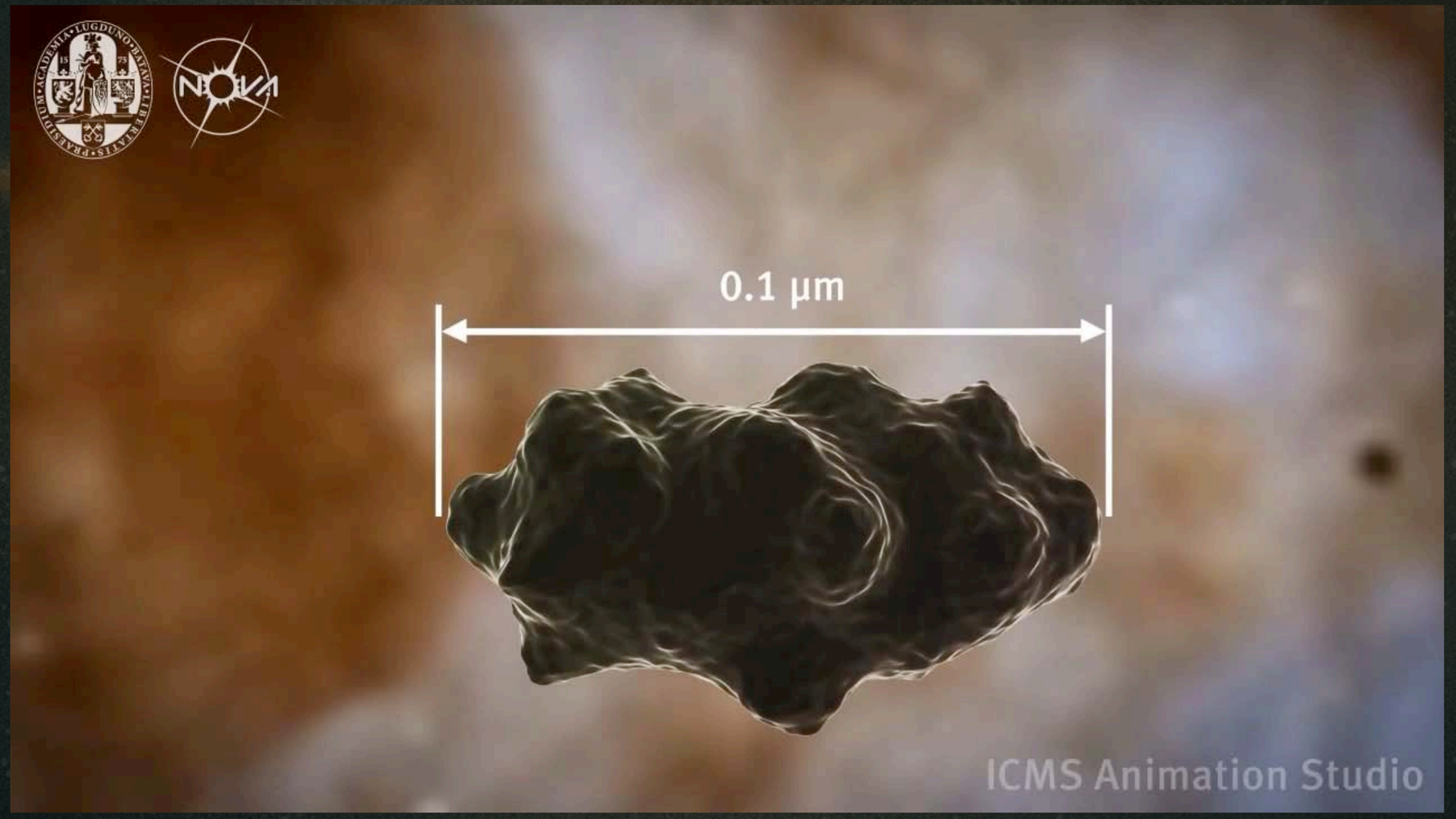
99% di gas, principalmente H_2

1% di grani di polvere



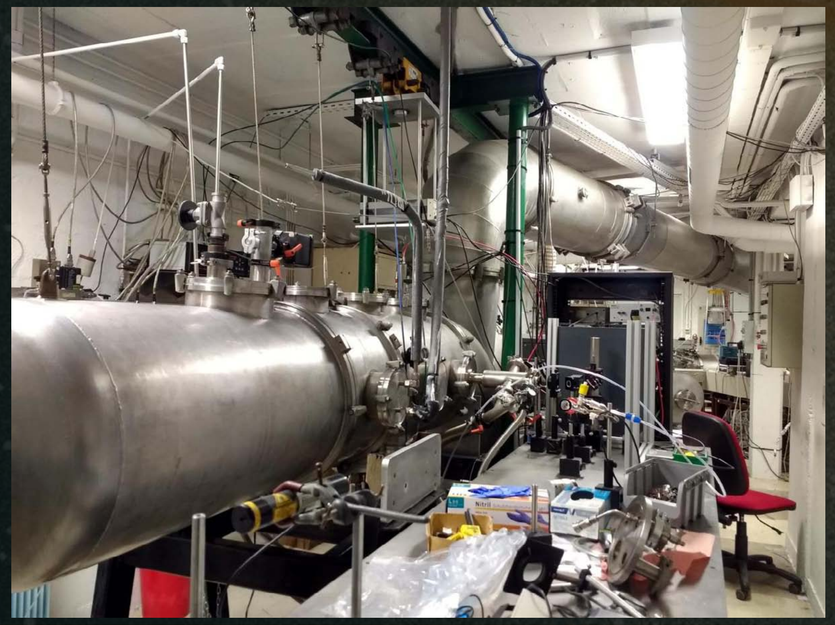
Credits: Credits: Wikipedia, Donald E. Brownlee, University of Washington, Seattle, and Elmar Jessberger, Institut für Planetologie, Münster, Germany

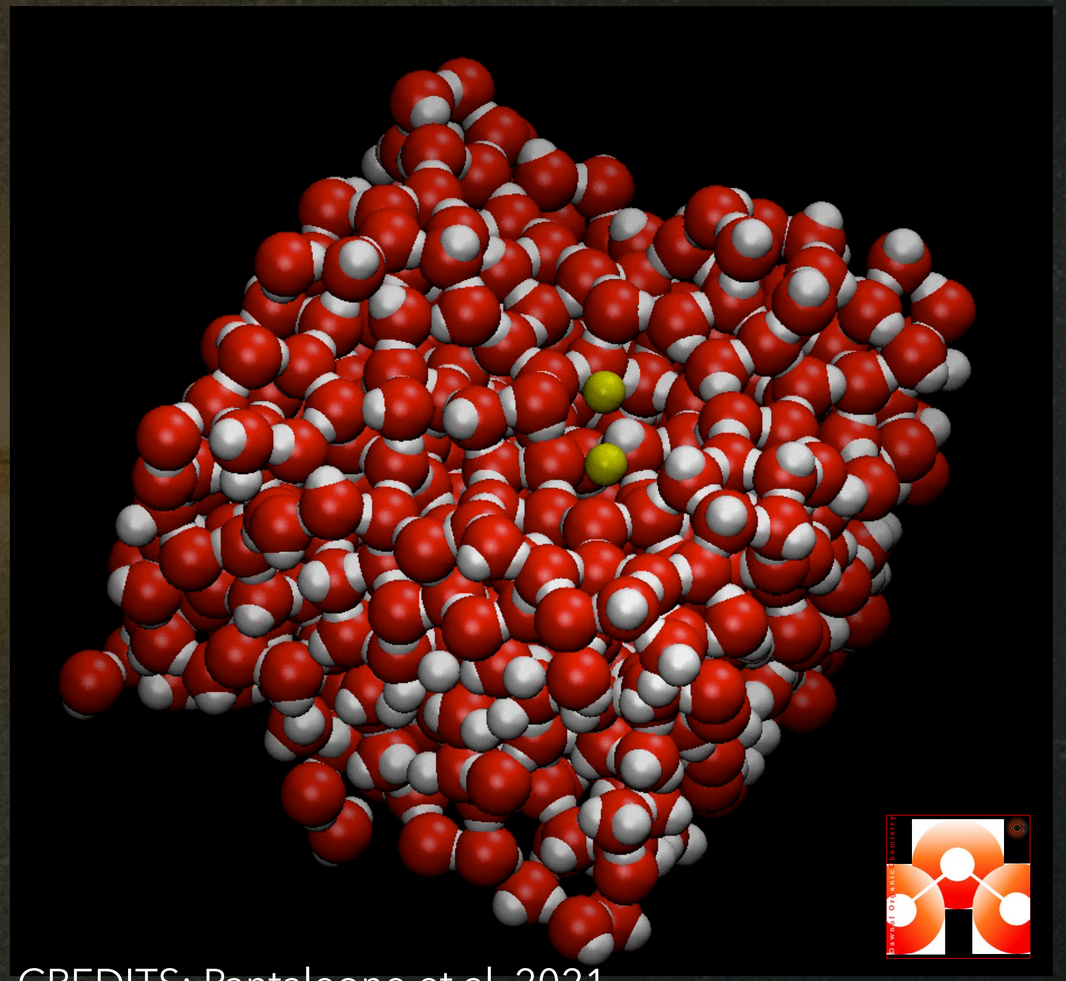
Come si formano le molecole?



Come si formano le molecole?

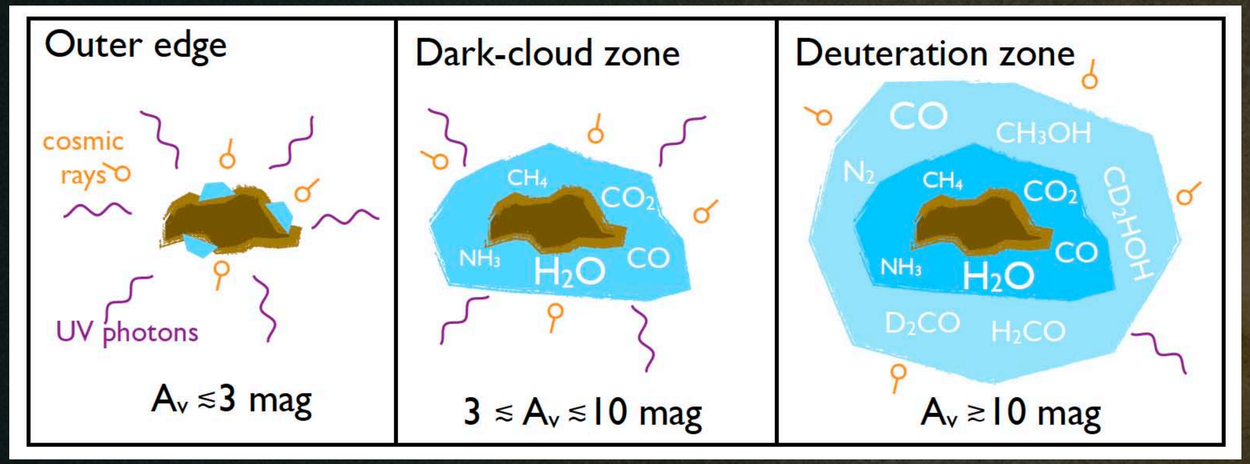
Possiamo studiare la formazione delle molecole in laboratorio o tramite simulazioni di chimica quantistica

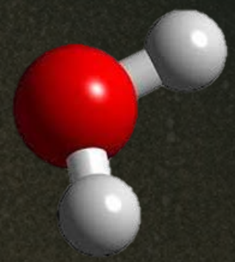




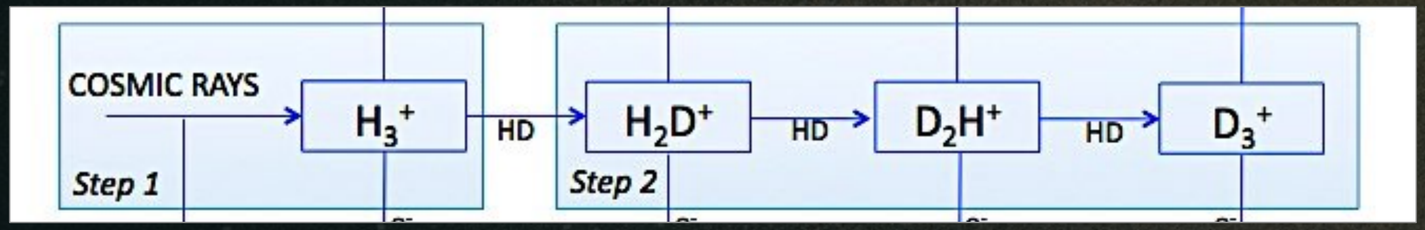
CREDITS: Pantaleone et al. 2021

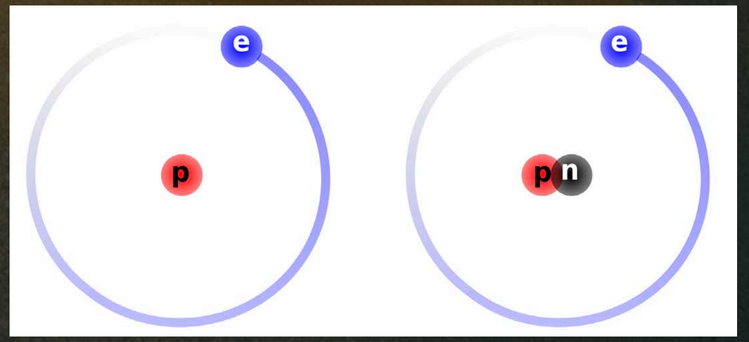
Come si formano le molecole?





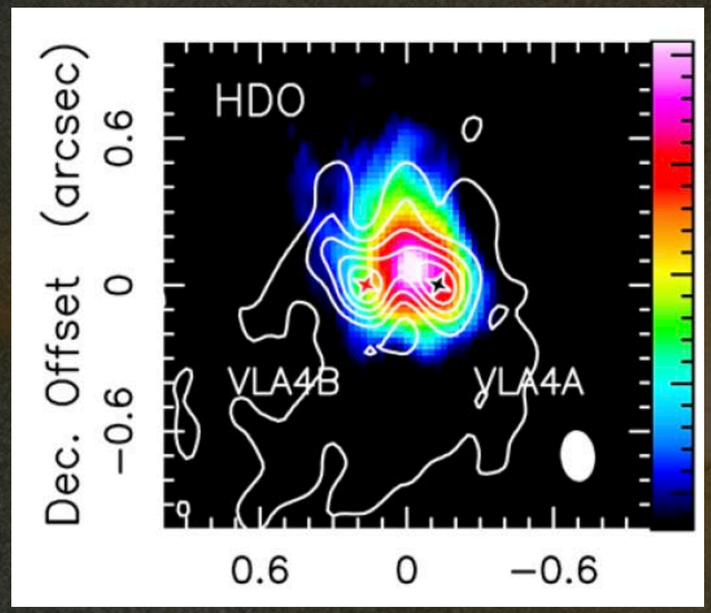
I mantelli dei grani di polvere contengono H_2O, HDO, D_2O e molecole deuterate

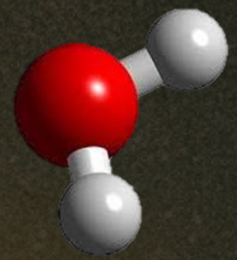




Idrogeno Deuterio

Cosa sono le molecole deuterate?





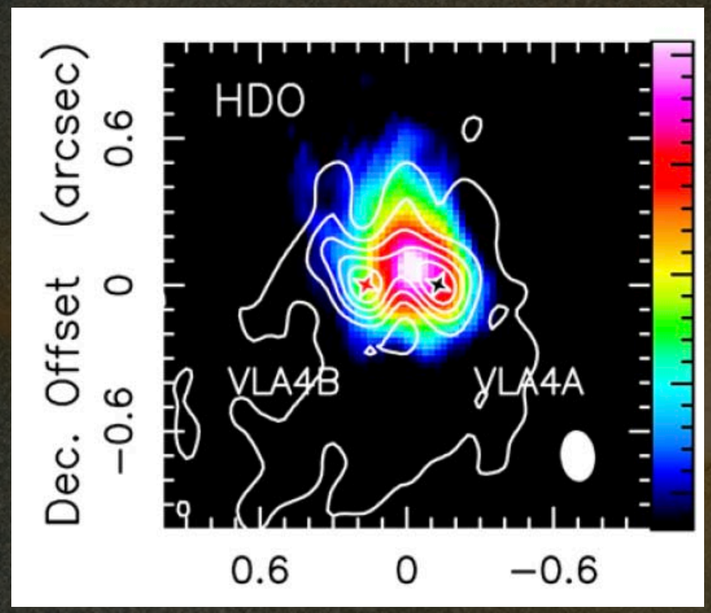
A. Molecole noiose

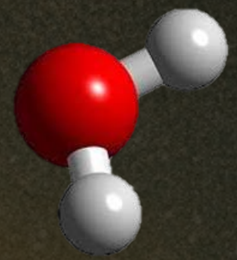
B. Isotopologhi

C. Isomeri

D. Molecole ionizzate

Cosa sono le molecole deuterate?





A. Molecole noiose

B. Isotopologhi

C. Isomeri

D. Molecole ionizzate

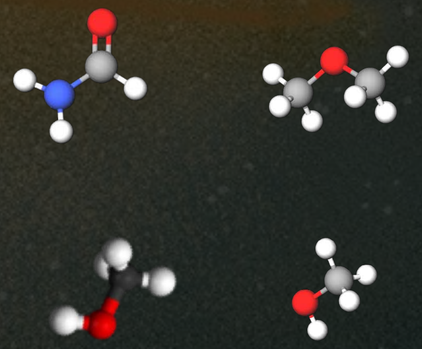
Quali molecole osserviamo nello spazio?

Molecules in the Interstellar Medium or Circumstellar Shells (as of 03/2026)

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
CH^+	H_2O	NH_3	HC_3N	CH_3OH	CH_3CHO	$HC(O)OCH_3$	$(CH_3)_2O$	$(CH_3)_2CO$	HC_9N	c-C_6H_6*	C_{60}*
CH	HCO^+	H_2CO	HCOOH	CH_3CN	CH_3C_2H	CH_3C_3N	CH_3CH_2OH	$(CH_2OH)_2$	CH_3C_6H	n-C_3H_7CN	C_{70}*
CN	HCN	HNCO	H_2CNH	NH_2CHO	CH_3NH_2	C_7H	CH_3CH_2CN	CH_3CH_2CHO	C_2H_5OCHO	i-C_3H_7CN	C_{60}^{+*}
OH	OCS	H_2CS	H_2NCN	CH_3SH	CH_2CHCN	CH_3COOH	HC_7N	CH_3C_5N	$CH_3OC(O)CH_3$	$C_2H_5OCH_3$	c-C_6H_5CN
CO	HNC	C_2H_2*	H_2C_2O	C_2H_4*	HC_5N	C_6H_2	CH_3C_4H	CH_3CHCH_2O	$CH_3C(O)CH_2OH$	1-c-C_5H_5CN	$HC_{11}N$
H_2	H_2S	C_3N	C_4H	C_5H	C_6H	CH_2OHCHO	C_8H	CH_3OCH_2OH	c-C_5H_6	2-c-C_5H_5CN	1-$C_{10}H_7CN$
SiO	N_2H^+	HNCS	SiH_4*	CH_3NC	c-C_2H_4O	l-HC_6H*	$CH_3C(O)NH_2$	c-C_6H_4	$HOCH_2CH_2NH_2$	CH_3C_7N (?)	2-$C_{10}H_7CN$
CS	C_2H	$HOCO^+$	c-C_3H_2	HCCCHO	H_2CCHOH	CH_2CHCHO	C_8H^-	H_2CCCHC_3N	H_2CCCHC_4H	n-C_3H_7OH	c-C_9H_8
SO	SO_2	C_3O	H_2CCN	l-C_4H_2	C_6H^-	CH_2CCHCN	C_3H_6	C_2H_5NCO	$C_{10}H^-$	i-C_3H_7OH	1-c-C_5H_5CCH
SiS	HCO	l-C_3H	C_5*	HC_3NH^+	CH_3NCO	H_2NCH_2CN	CH_3CH_2SH	$C_2H_5NH_2$ (?)	$H_2C(CH)_3CN$?	$(CH_3)_2C=CH_2$	2-c-C_5H_5CCH
NS	HNO	$HCNH^+$	SiC_4	C_5N	HC_5O	CH_3CHNH	CH_3NHCHO	HC_7NH^+	$CH_3CH(OH)CHO$ (2026)		c-$C_5H_4CCH_2$
C_2^{**}	HCS^+	H_3O^+	l-C_3H_2	l-HC_4H*	$HOCH_2CN$	CH_3SiH_3	HC_7O	E-$CH_3CHCHCN$	CH_3OCH_2CHO (2026)		2-C_9H_7CN
NO	HOC^+	C_3S	CH_4*	l-HC_4N	HCCCHNH	$H_2NC(O)NH_2$	HCCCHCHCN	Z-$CH_3CHCHCN$			C_6H_5CCH
HCl	c-SiC_2	c-C_3H	HCCNC	c-H_2C_3O	HC_4NC	$HCCCH_2CN$	H_2CCHC_3N	$CH_3C(CN)CH_2$			$CH_3OCH_2CH_2OH$ (2

~ 350 molecole osservate nello spazio

> 74 in altre galassie



https://cdms.astro.uni-koeln.de/classic/molecules

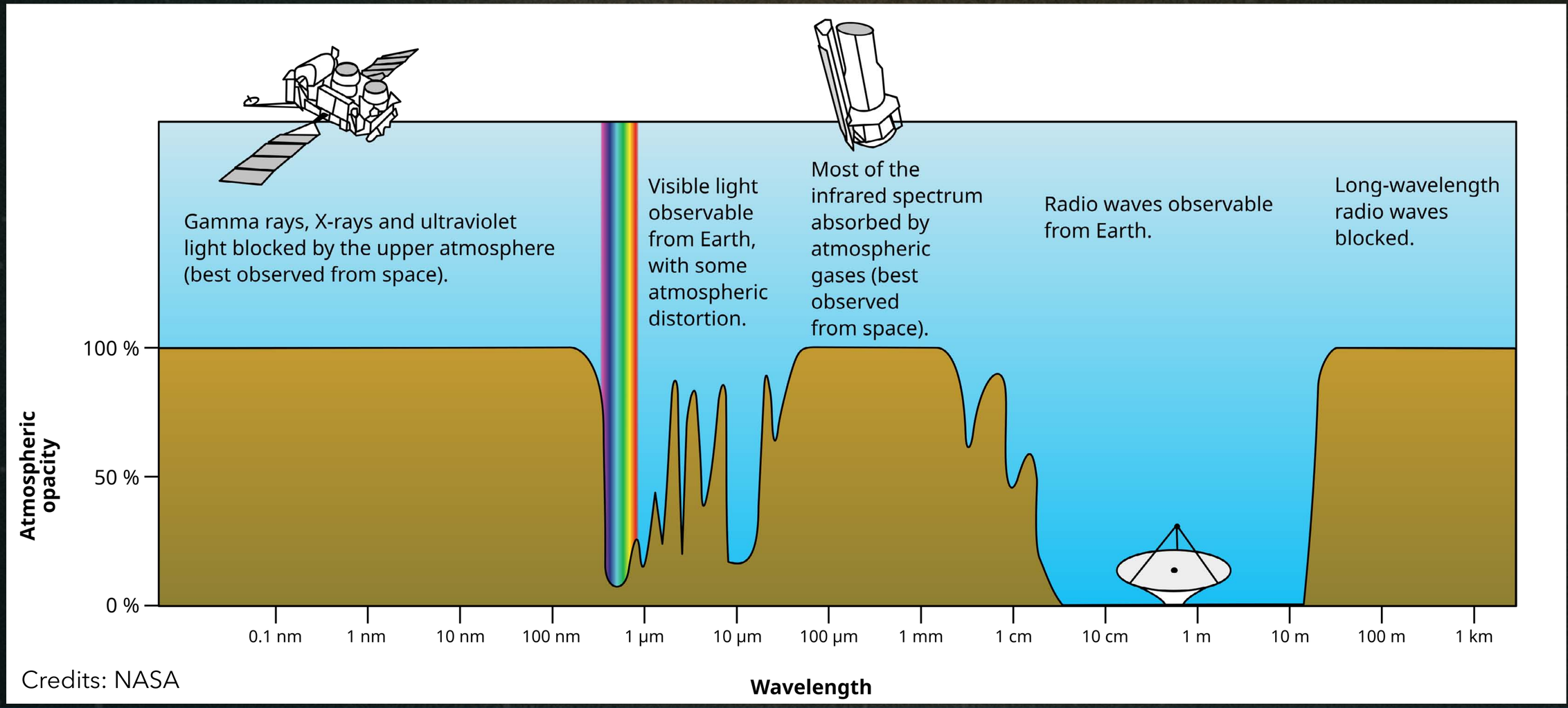
Come osserviamo le molecole?

Credits: INAF-Osservatorio di Arcetri

Regioni estinte
(oscure) nel visibile

Credits: ESO/S. Guisard

Come osserviamo le molecole?



Credits: NASA

Come osserviamo le molecole?

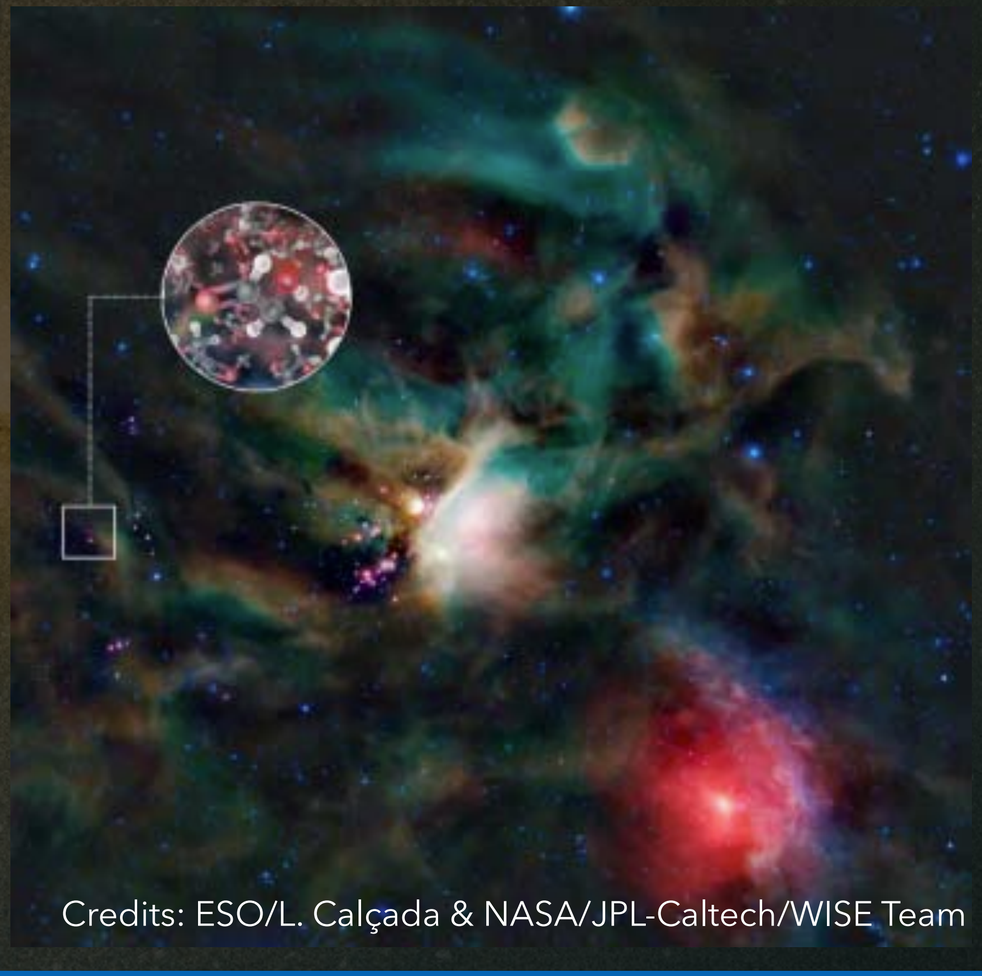
21 paesi
54 antenne 12m + 12 antenne 7m
5000m altitudine
1 TB dati ogni giorno
(~1000-1500 film)

Atacama Large Millimeter/submillimeter Array (ALMA)

https://www.eso.org/public/italy/products/virtualtours/chajnantor/

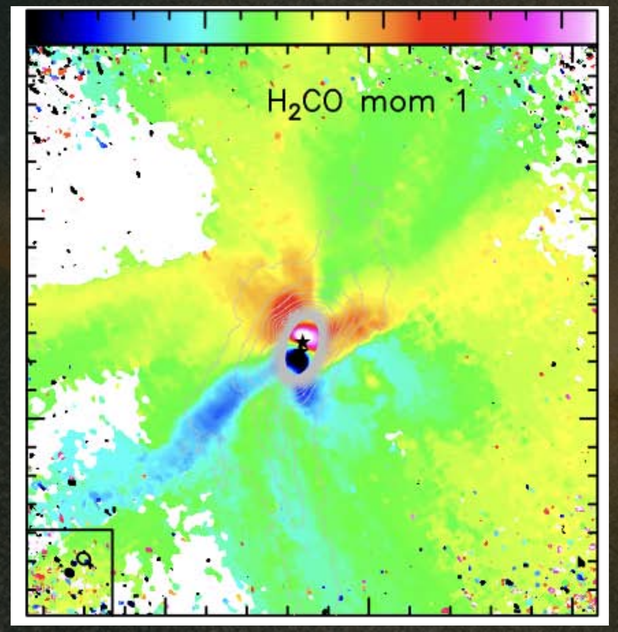
Come osserviamo le molecole?

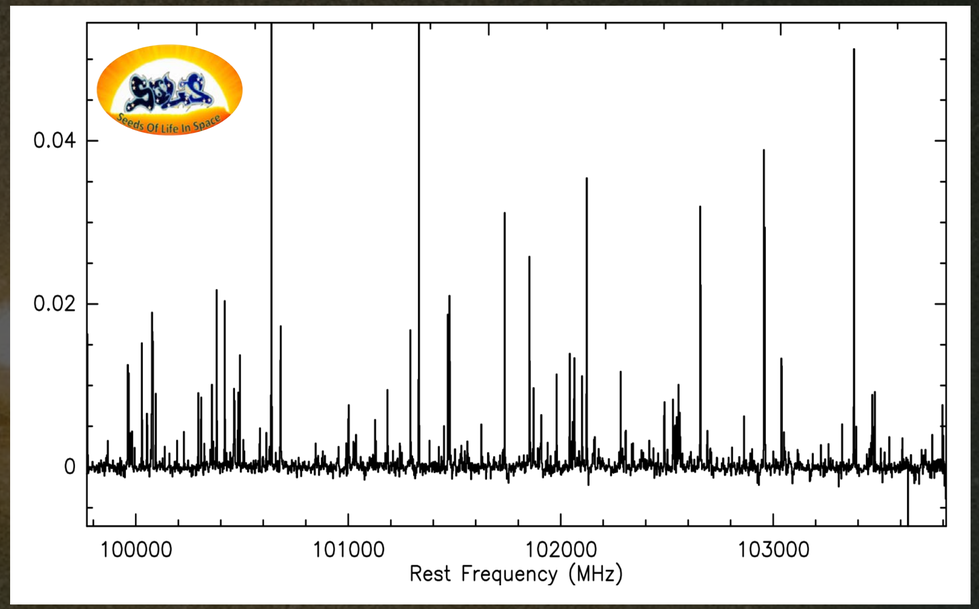
Credits: NRAO/AUI/NSF



Credits: ESO/L. Calçada & NASA/JPL-Caltech/WISE Team

Come osserviamo le molecole?





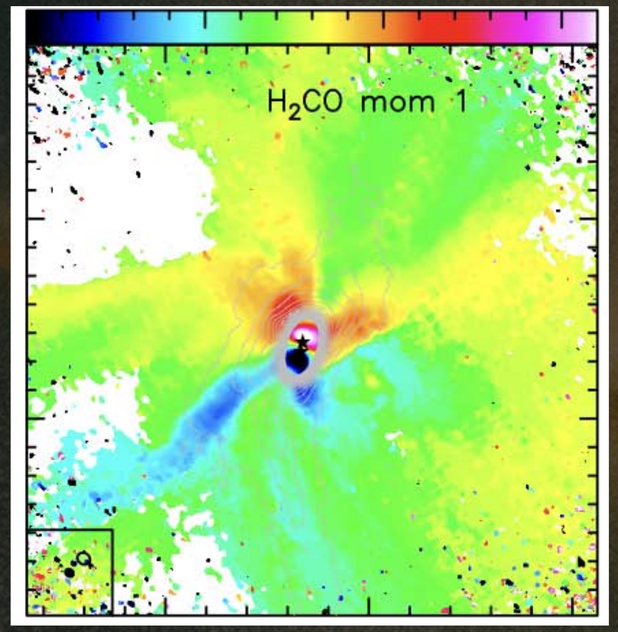
A. Usiamo le camere a nebbia

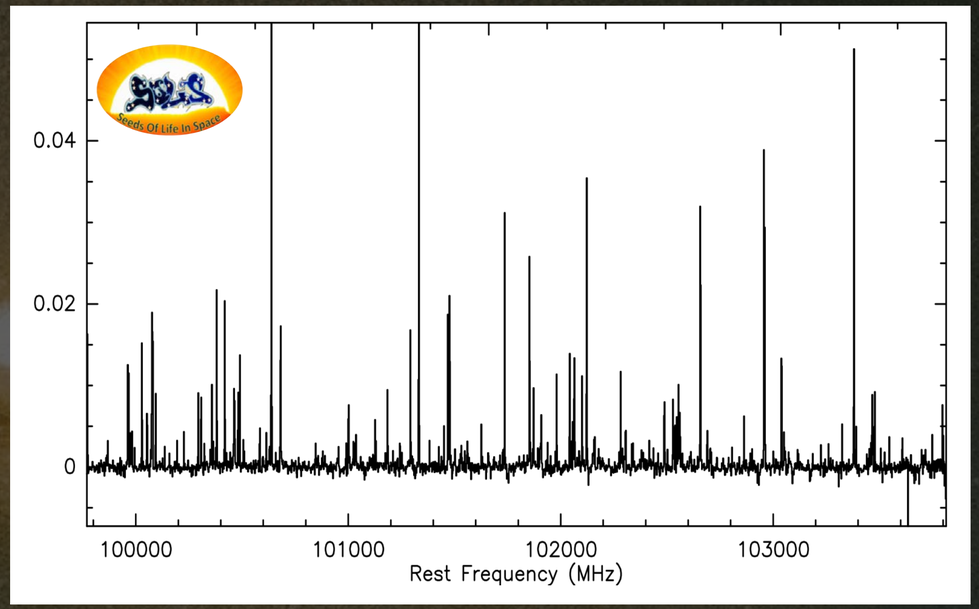
B. Usiamo la spettroscopia

C. Usiamo il microscopio

D. Le annusiamo

Come osserviamo le molecole?





A. Usiamo le camere a nebbia

C. Usiamo la spettroscopia

C. Usiamo il microscopio

D. Le annusiamo

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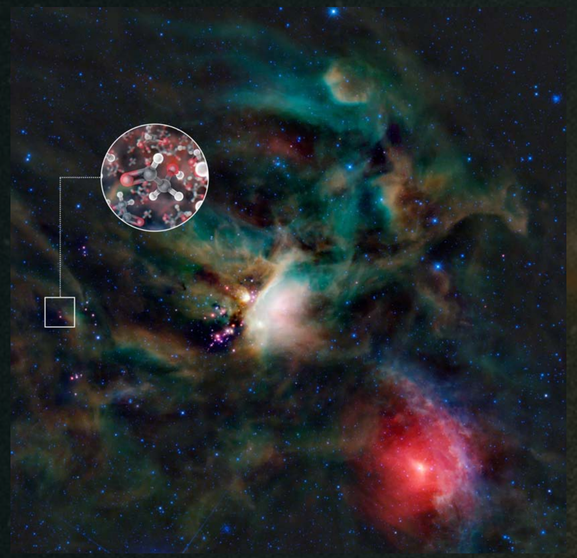
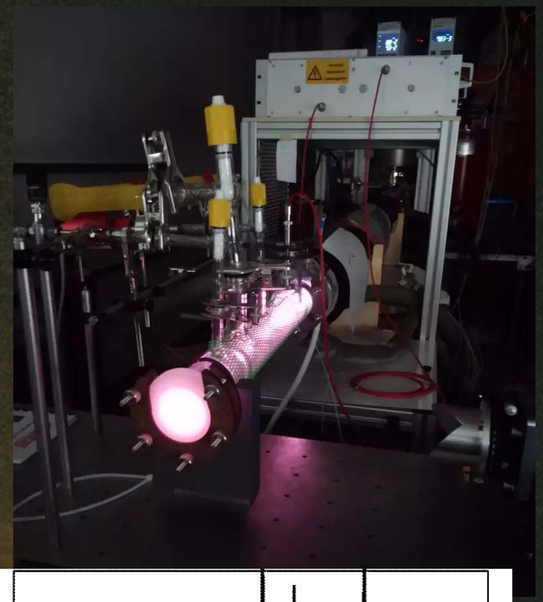
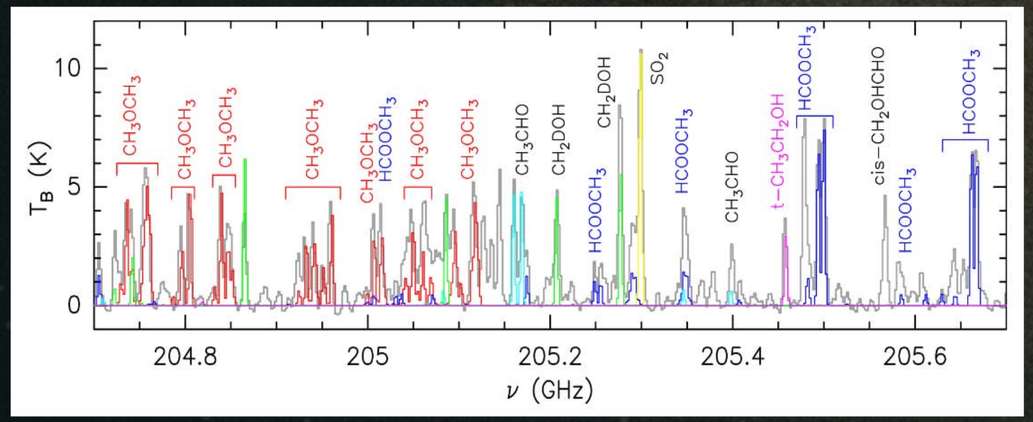
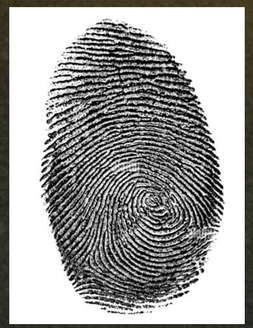
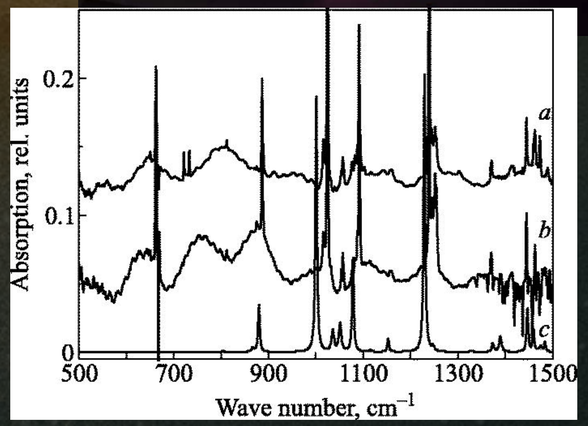
Con l'astrochimica!





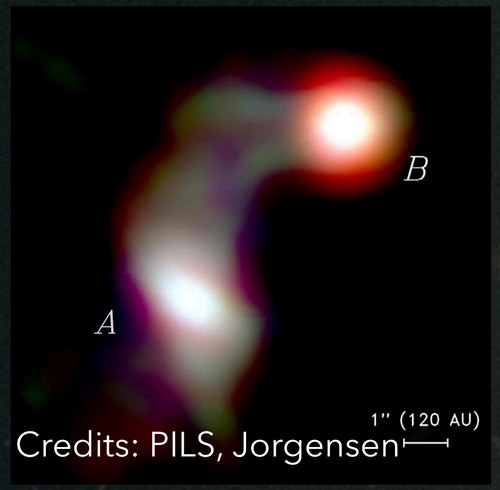




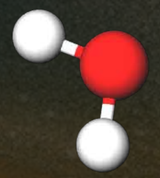


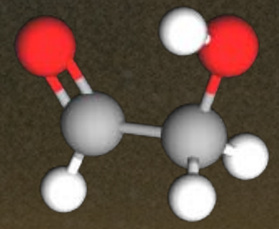
CREDITS: MPE/Pitsevich et al. 2013

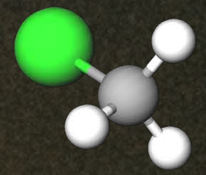
I mattoni della vita!

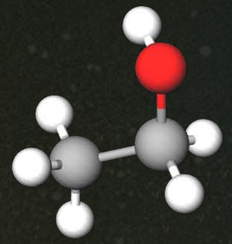


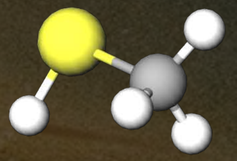
Credits: PILS, Jorgensen

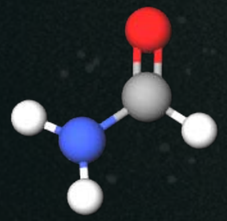

Acqua

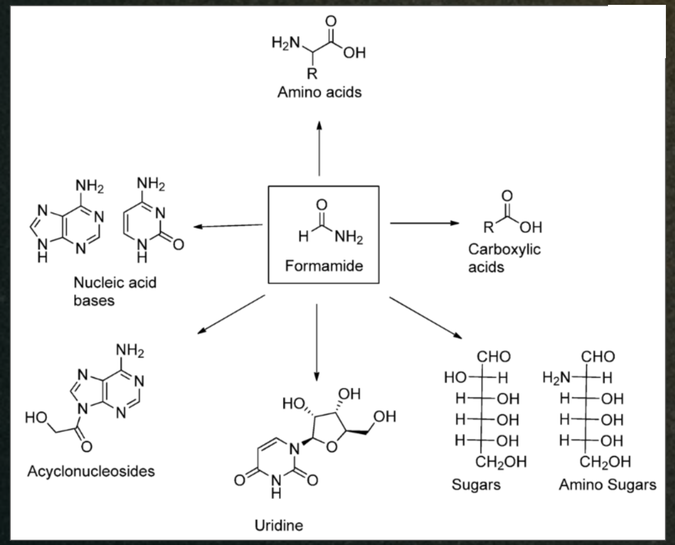

Glicolaldeide, Zucchero!

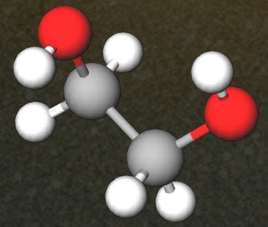

Cloro metano

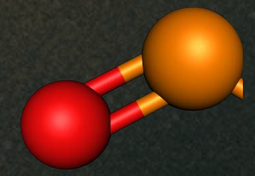

Etanolo

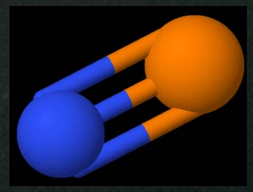

Metilmercaptano


Formamide




Glicole etilenico


PN, PO, fosforo!



Quali molecole sono state davvero osservate nello spazio?

1. Caffeina

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO

Quali molecole sono state davvero osservate nello spazio?

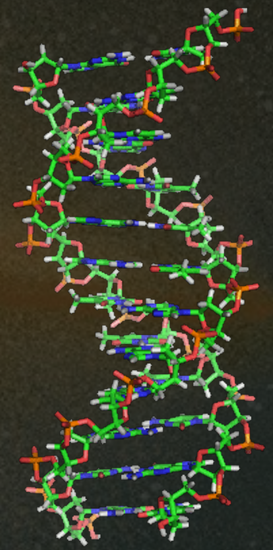
1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO

Quali molecole sono state davvero osservate nello spazio?

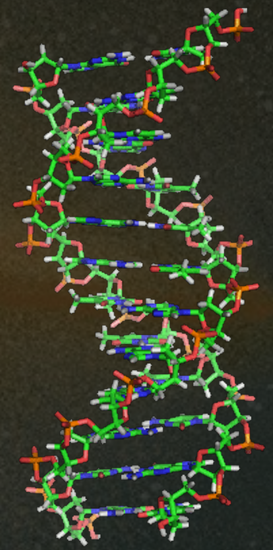
1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA



Credits: Wikipedia, adapted by Richard Wheeler (Zephyris)

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA FALSO



Credits: Wikipedia, adapted by Richard Wheeler (Zephyris)

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene

Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene VERO

Quali molecole sono state davvero osservate nello spazio?

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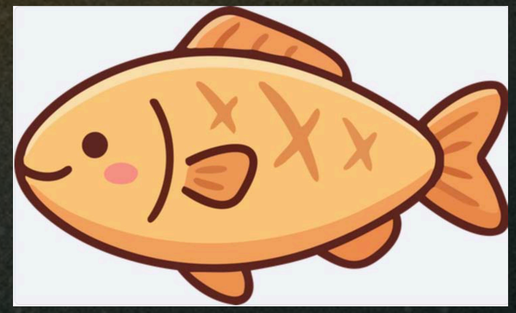
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene VERO
7. Fosforo



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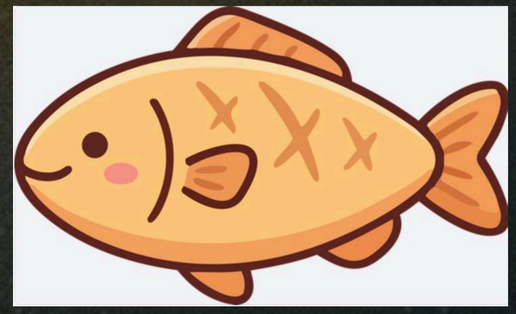
6. Benzene VERO
7. Fosforo VERO



Quali molecole sono state davvero osservate nello spazio?

1. Caffeina FALSO
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene VERO
7. Fosforo VERO
8. Clorofilla

Quali molecole sono state davvero osservate nello spazio?

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3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene VERO
7. Fosforo VERO
8. Clorofilla FALSO

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3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene VERO
7. Fosforo VERO
8. Clorofilla FALSO
9. Zucchero

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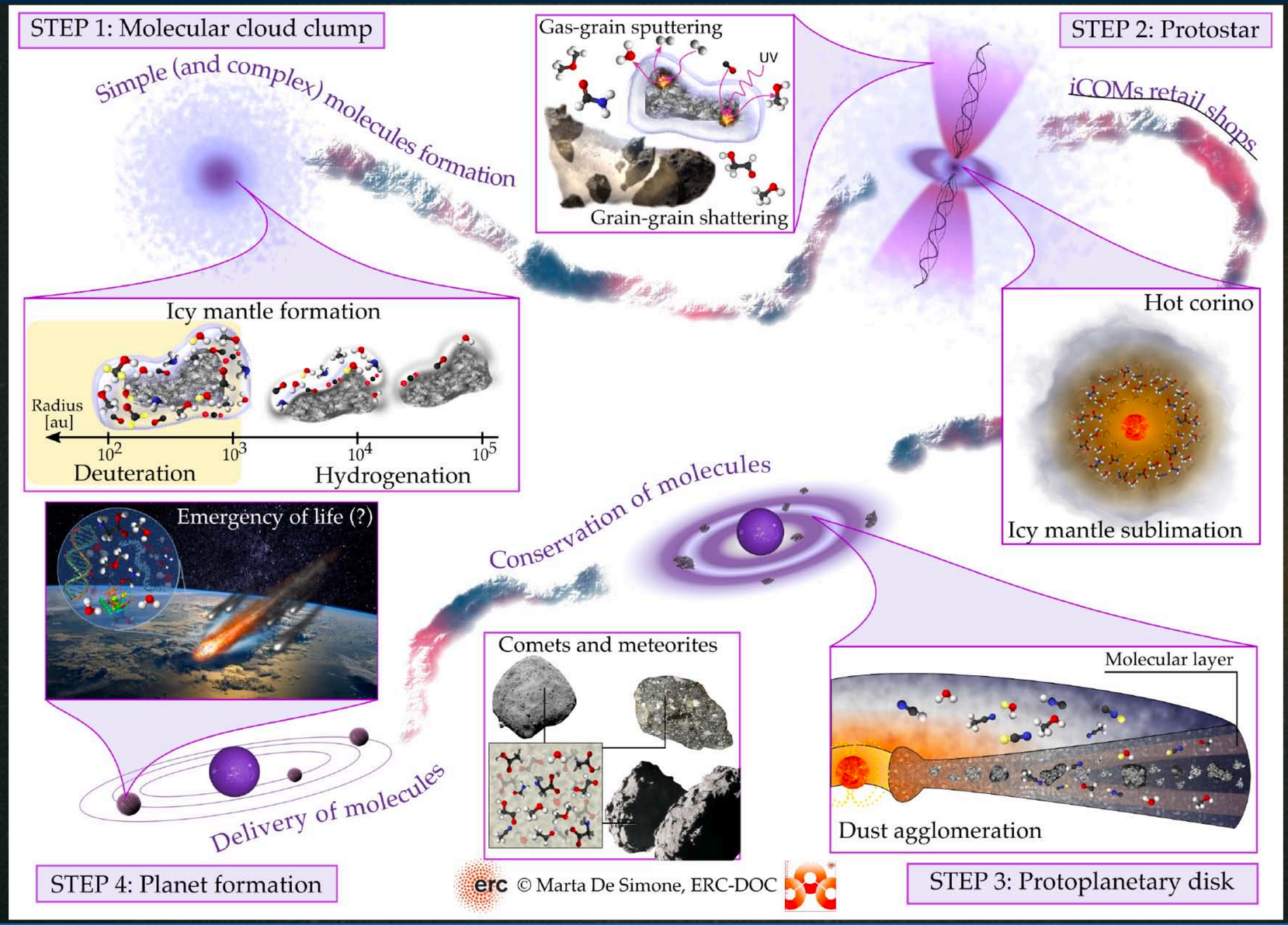
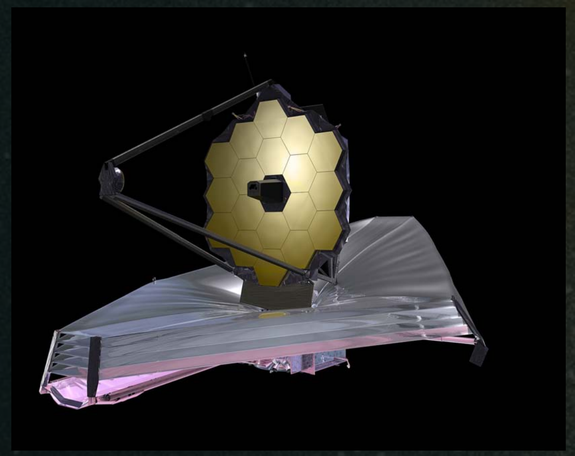
2. Zolfo VERO
3. Etanolo VERO
4. Urea VERO
5. DNA FALSO
6. Benzene VERO
7. Fosforo VERO
8. Clorofilla FALSO
9. Zucchero VERO

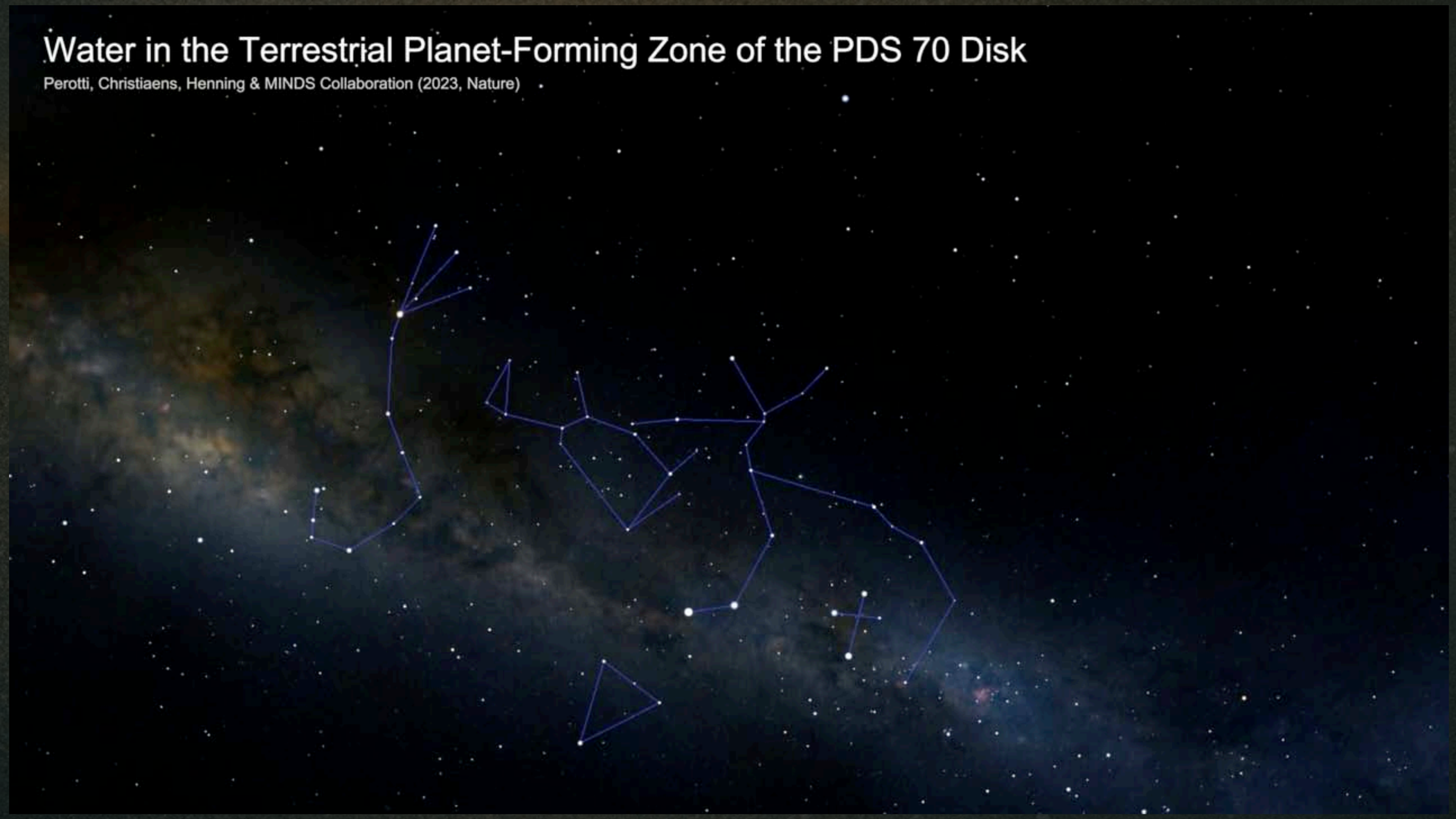

STEP 1: Molecular cloud clump
Simple (and complex) molecules formation
Gas-grain sputtering
UV
Grain-grain shattering
STEP 2: Protostar
iCOMs retail shops
Icy mantle formation
Radius [au]
10^2
10^3
10^4
10^5
Deuteration
Hydrogenation
Hot corino
Icy mantle sublimation
Emergency of life (?)
Conservation of molecules
Comets and meteorites
Molecular layer
Dust agglomeration
Delivery of molecules
STEP 4: Planet formation
erc © Marta De Simone, ERC-DOC
STEP 3: Protoplanetary disk

Acqua in un sistema solare in formazione

James Webb
Space Telescope



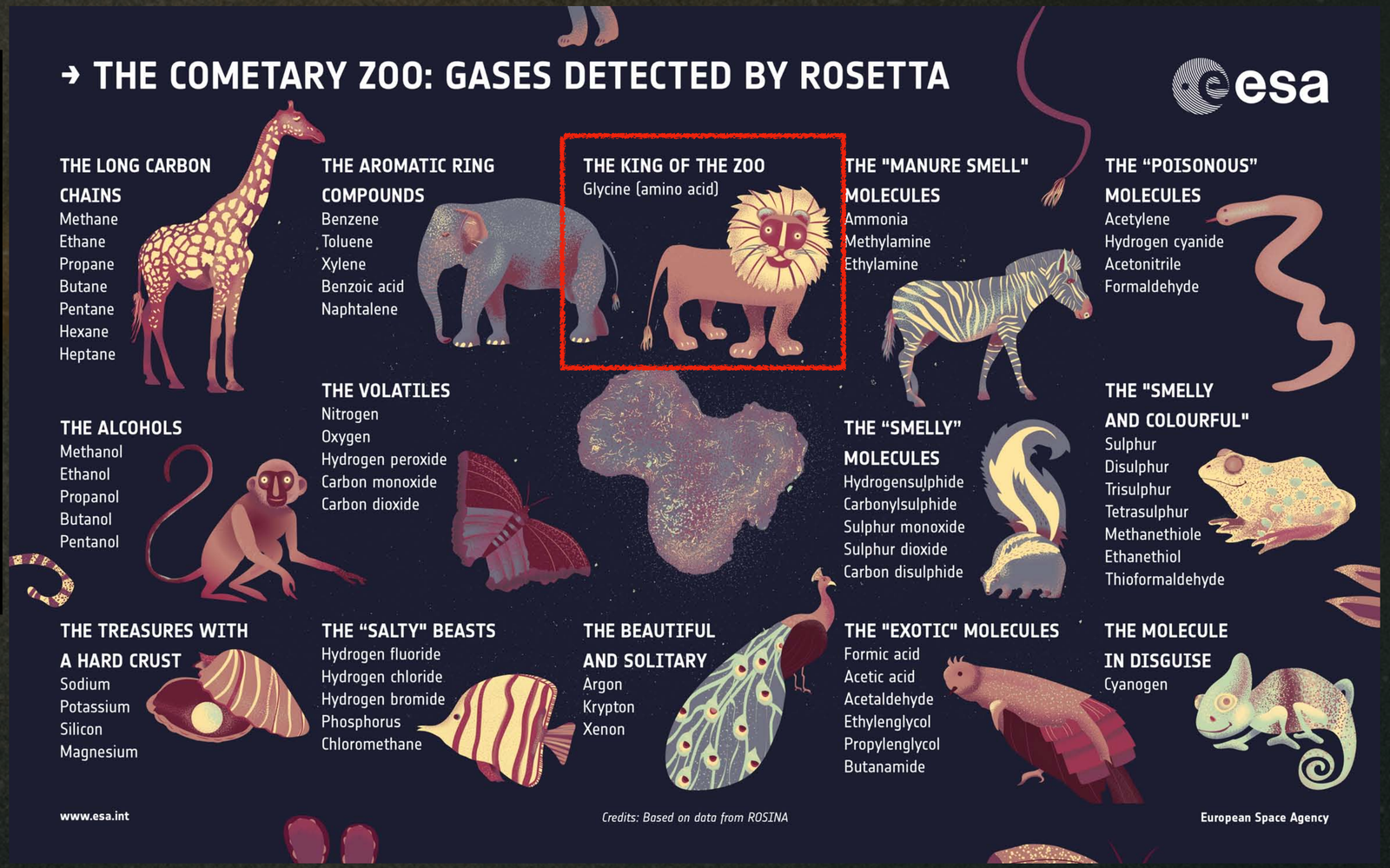
Credits: NASA



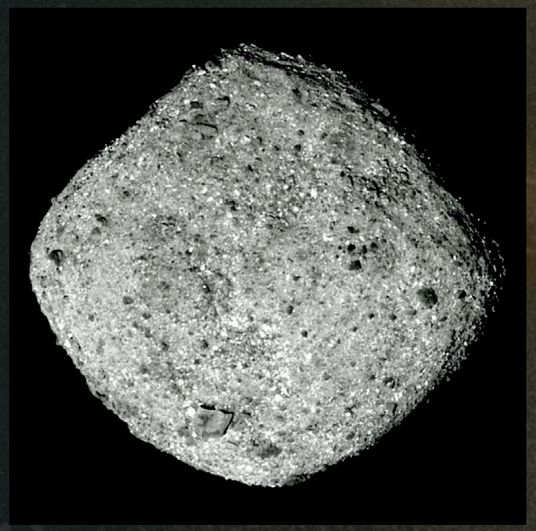
Come è nata la vita sulla Terra?

CREDITS: ESA/Rosetta/NavCam

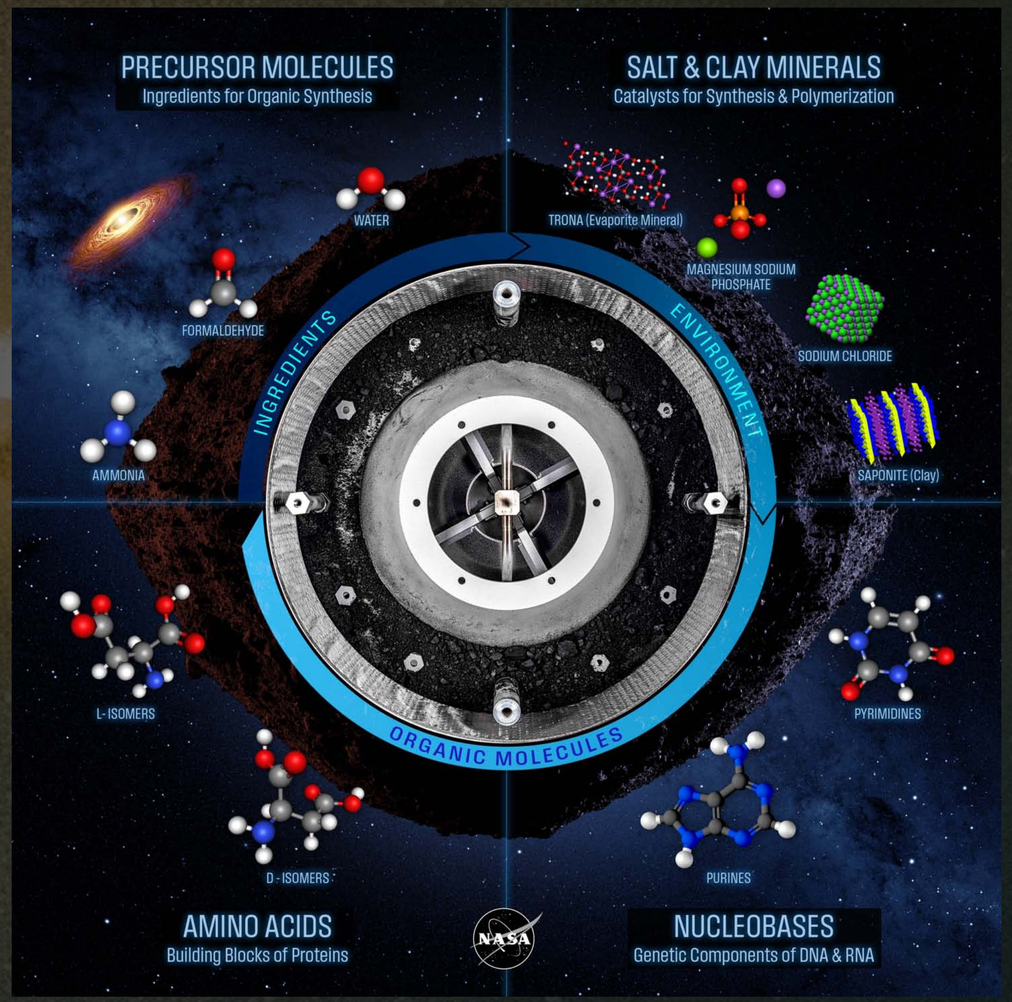
Missione ROSETTA
2004-2016 Cometa 67P/
Churyumov-Gerasimenko



Come è nata la vita sulla Terra?

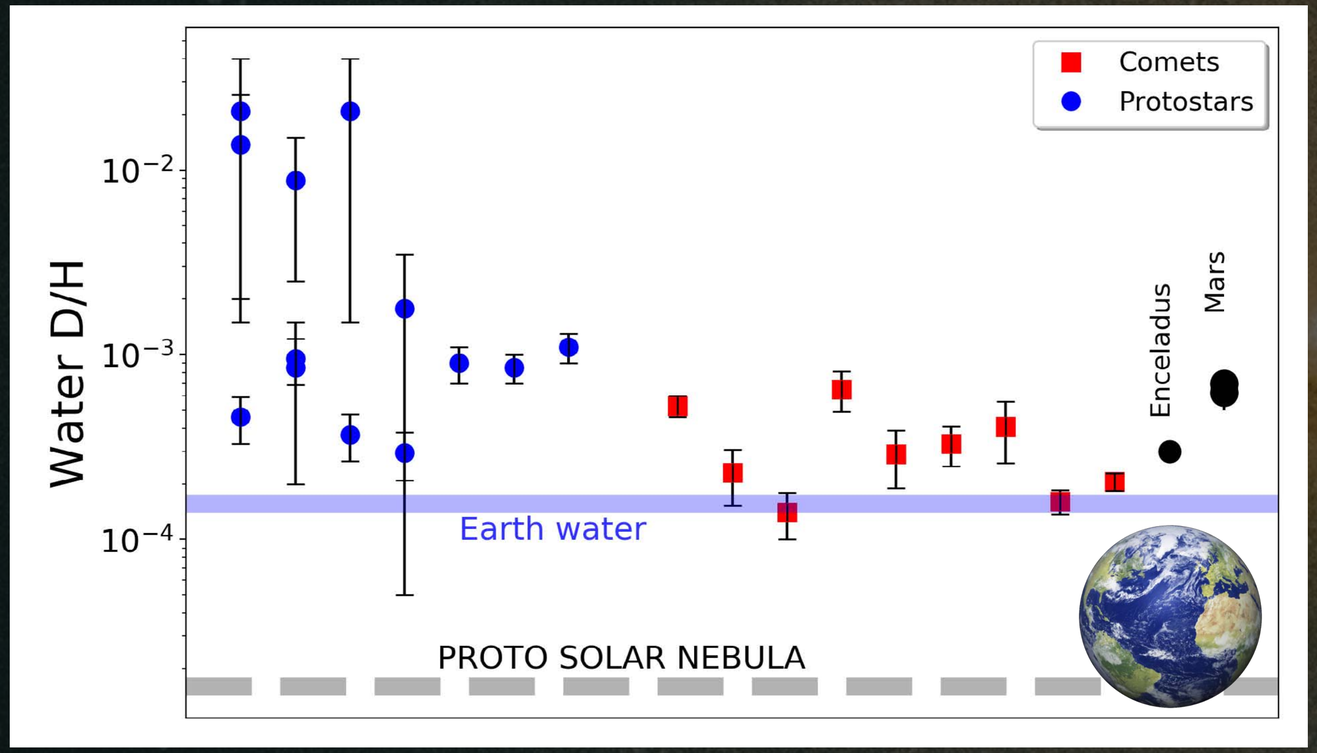


OSIRIX-Rex
2016-2023 Bennu



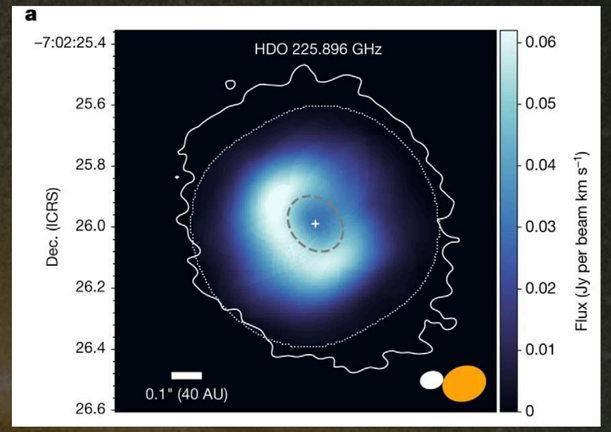
CREDITS: Nasa Goddard/Osiris-Rex/Dan Gallagher

Le nostre origini astrochimiche



Comets from Altwegg et al. 2019

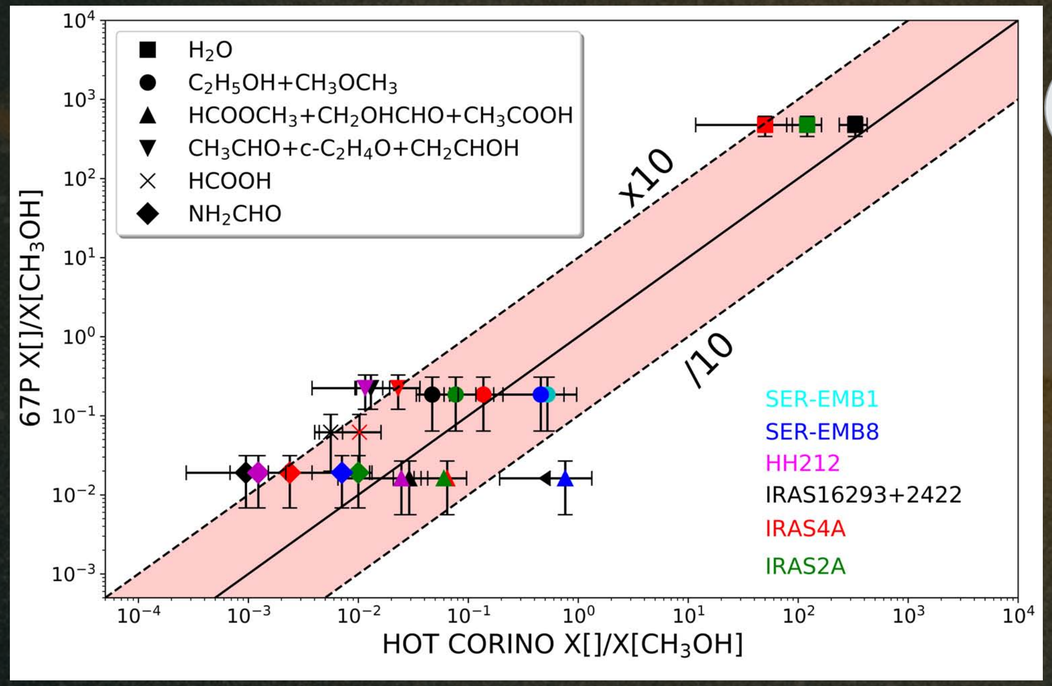
Tobin et al. 2023

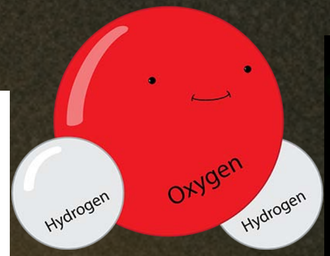


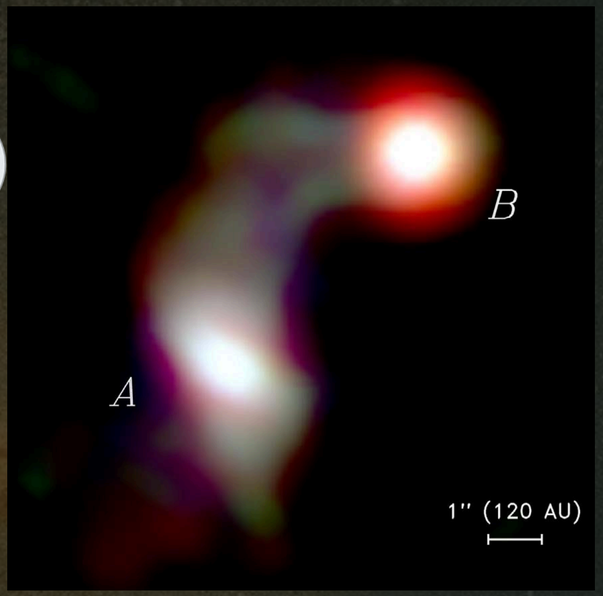
L'acqua sulla Terra è un'eredità della fase "fredda" del Sistema Solare. Beviamo acqua vecchia di 4,5 miliardi di anni!

Le nostre origini astrochimiche

CREDITS: ESA/ Rosetta/NavCam







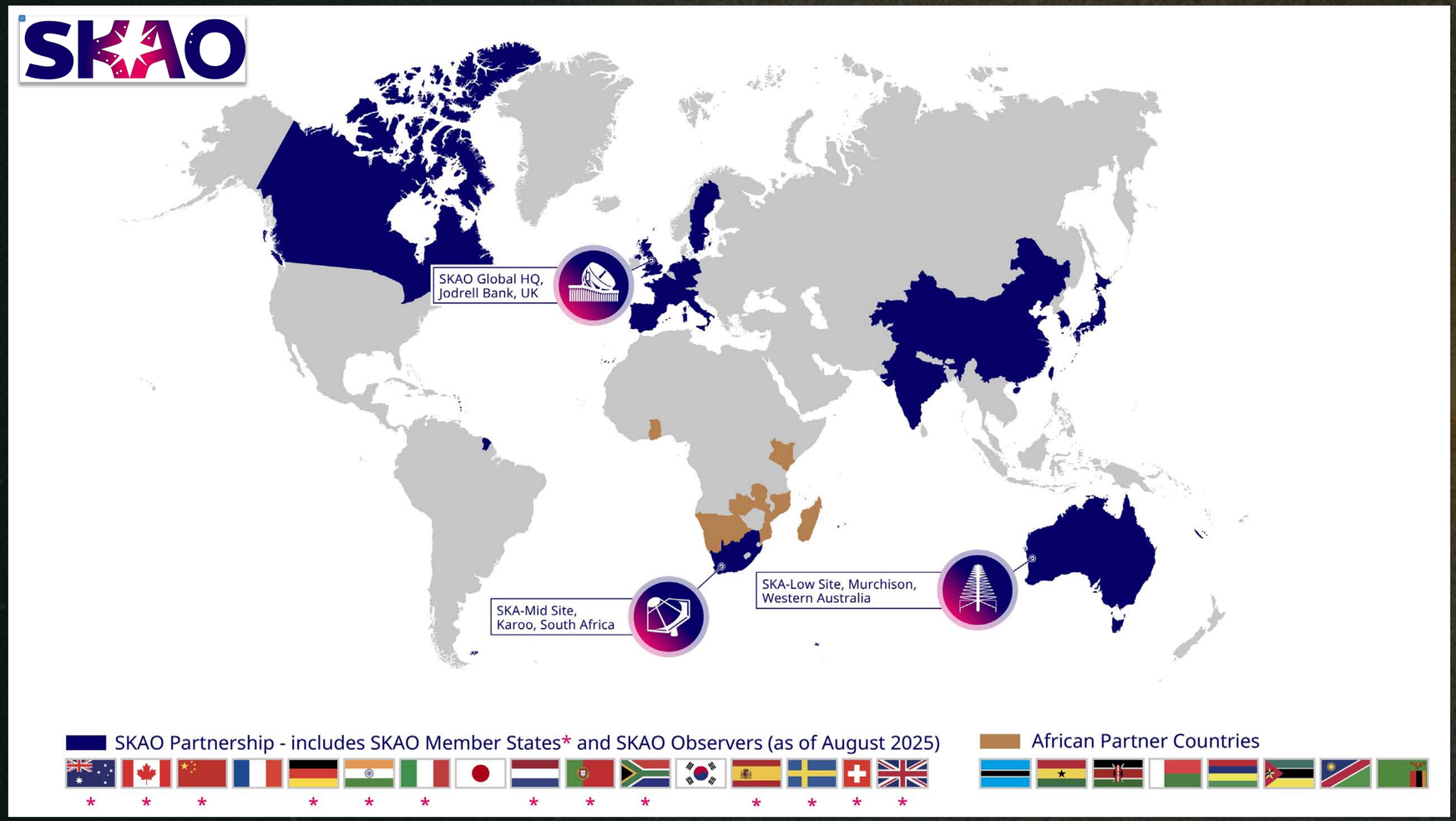
Credits: PILS, Jorgensen

Nelle comete ritroviamo i mattoncini della vita che osserviamo nelle protostelle e nei dischi protoplanetari..

Dalla nascita dei pianeti ai mattoni della vita

- Il nostro Sistema Solare e gli altri sistemi planetari sono nati dal collasso di una nube di gas e polvere
- Gli elementi utilizzati dalla vita sono il risultato del Big Bang e della sintesi all'interno delle stelle
- L'acqua che beviamo risale alla formazione del Sistema Solare; con essa, potremmo aver ereditato anche i precursori organici necessari alla chimica della vita
- I mattoni della vita si formano naturalmente nella nostra galassia e, probabilmente, anche altrove nel cosmo. I semi della vita sono universali

Square Kilometre Array



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SKAO

Square Kilometre Array

Eleonora Bianchi

Associazione Astronomica del Rubicone

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Astrochemical Study of Early Embedded Disks

2025-2028 1.2M€

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Studiare la struttura fisica e chimica dei dischi protoplanetari

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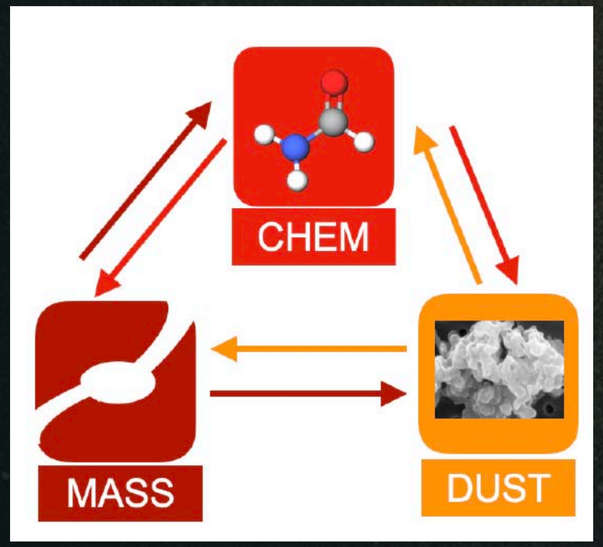


PI + 5 Ricercatori

Sviluppare tecniche di machine learning per l'astrochimica

Eleonora Bianchi

Associazione Astronomica del Rubicone

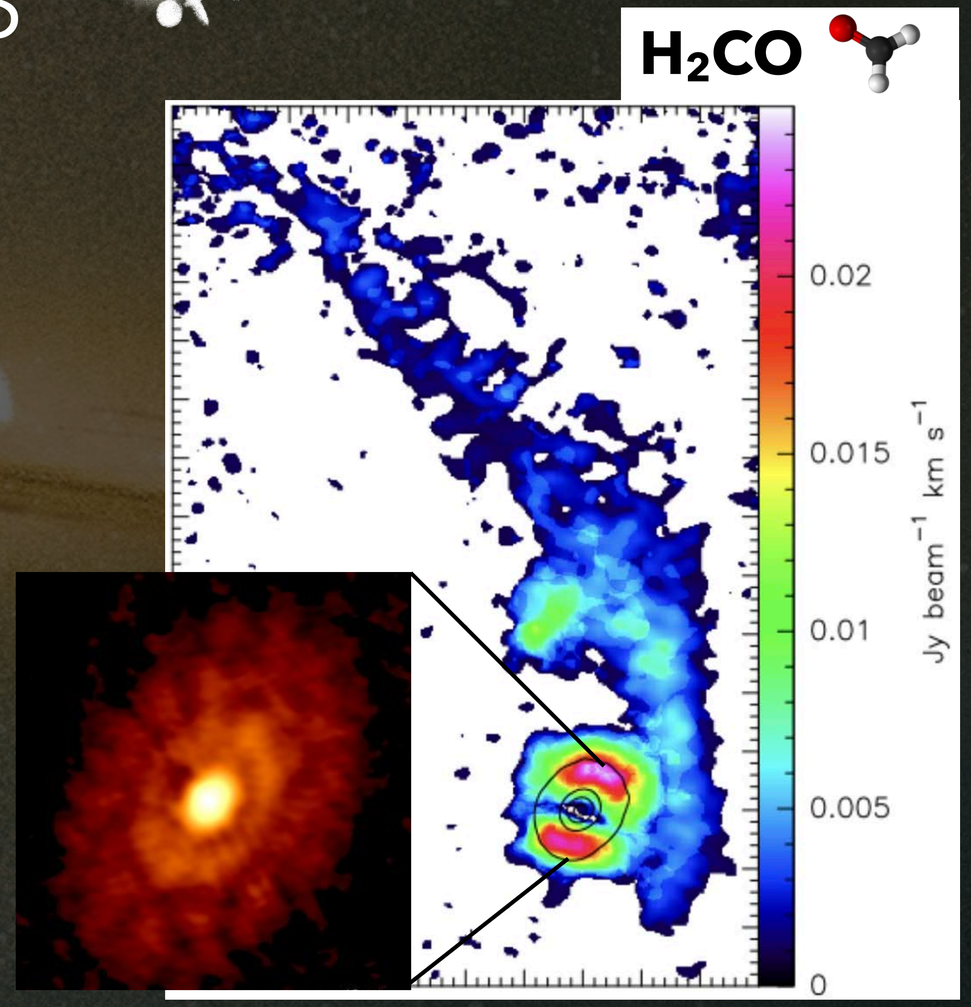
MASS

Linea di ricerca MASS

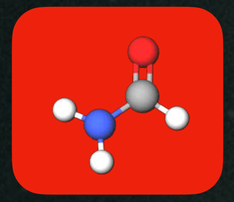
iSEEDs

1. Quanta massa è disponibile nei dischi per formare pianeti?

Massa di gas + polvere

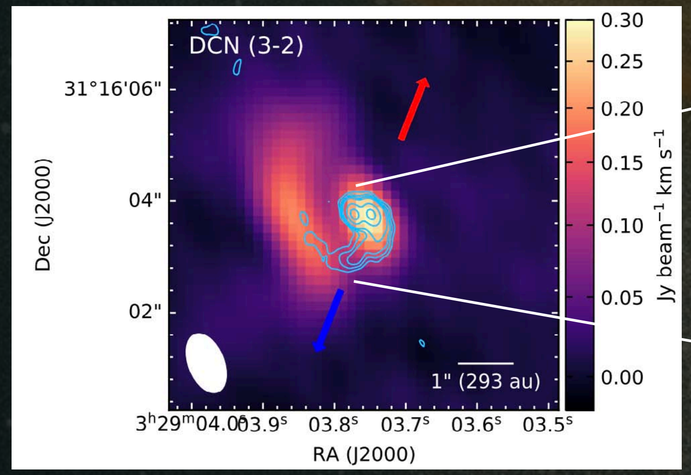


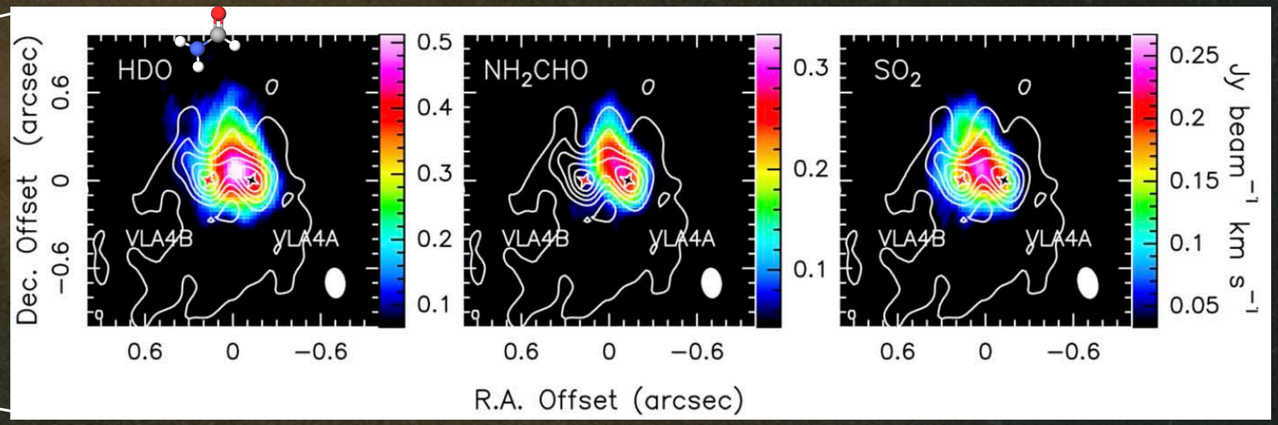
Linea di ricerca CHEM



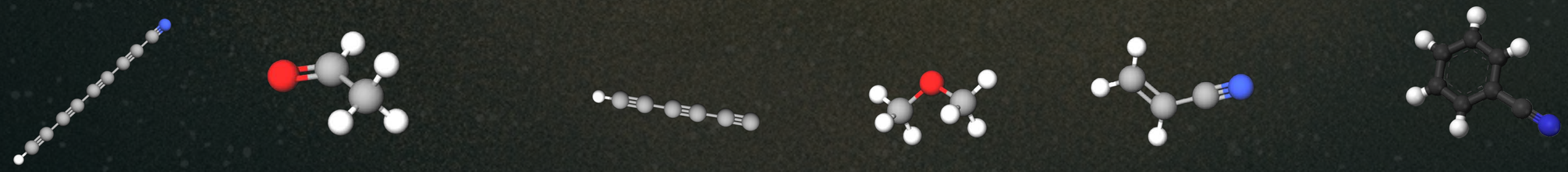
CHEM

2. Qual è la composizione chimica dei dischi, che sarà ereditata dai pianeti?





Bianchi et al. 2023

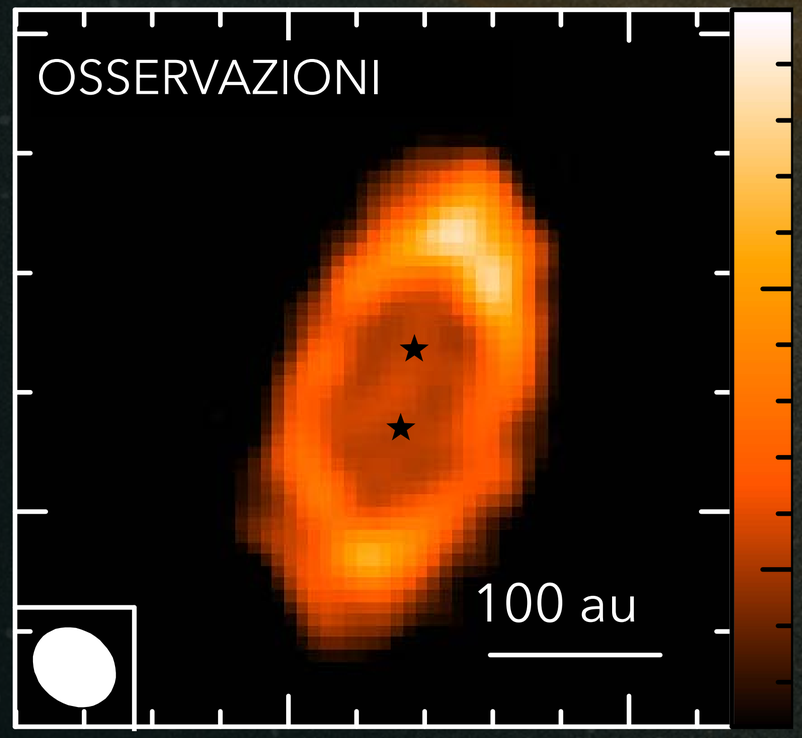


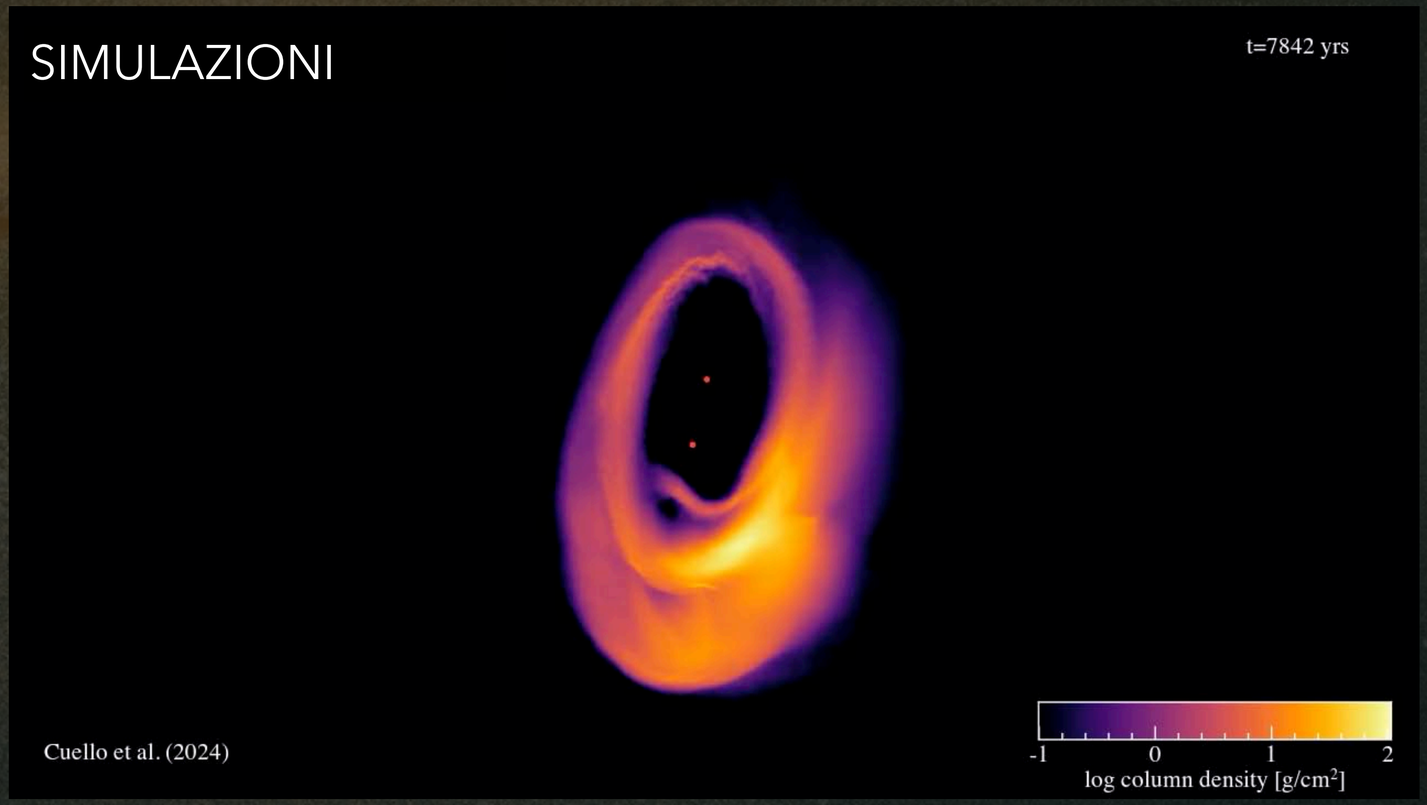
DUST

Linea di ricerca DUST

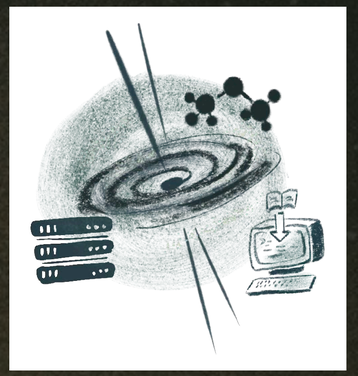
iSEEDs

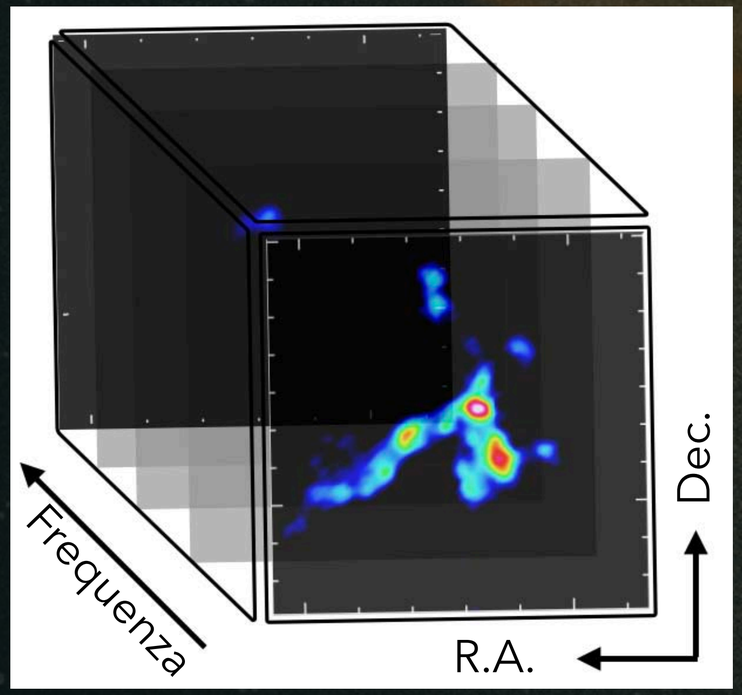
3. Quando e come i grani di polvere crescono fino a formare i pianeti?

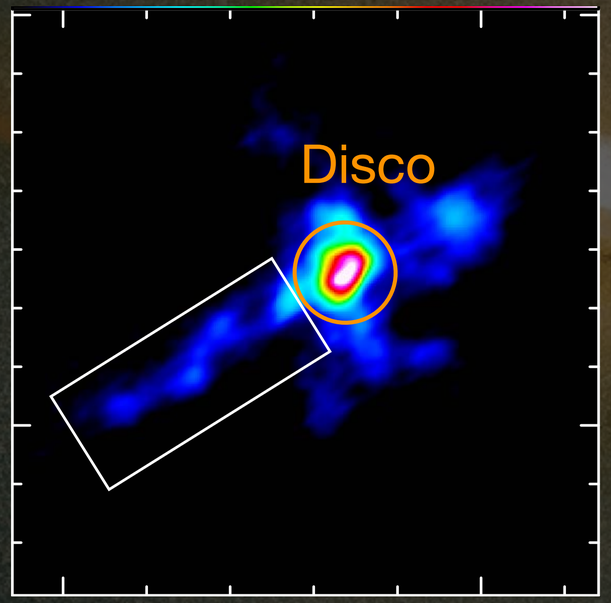


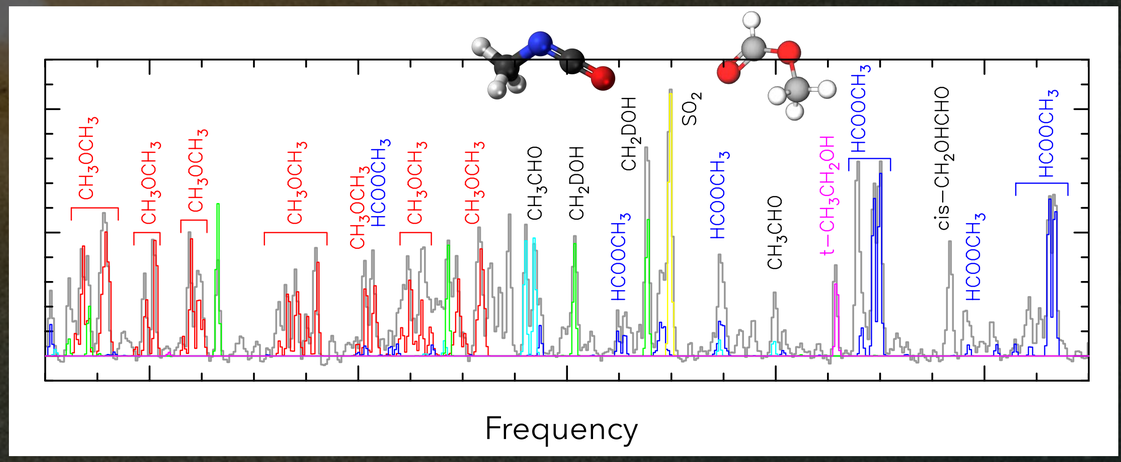


Machine Learning per l'astrochimica







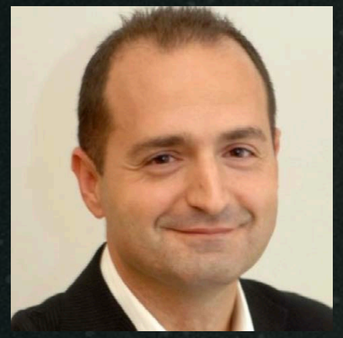


Identificazione automatica di strutture e molecole

Eleonora Bianchi

Associazione Astronomica del Rubicone

Team di iSEEDs



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SPH+radiative transfer

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Grazie!!

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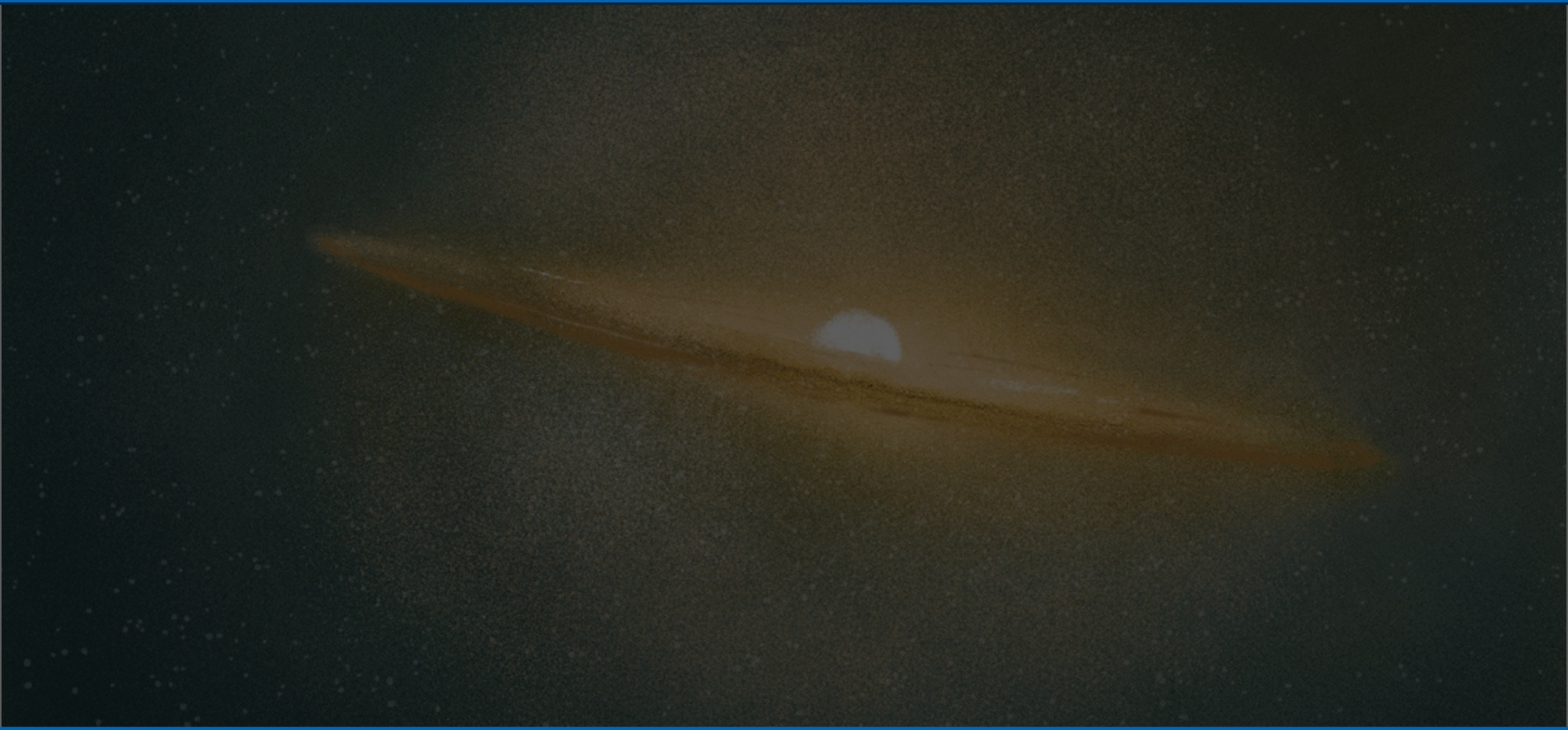

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