Molecular Complexity in Space: What Astrochemistry Produces

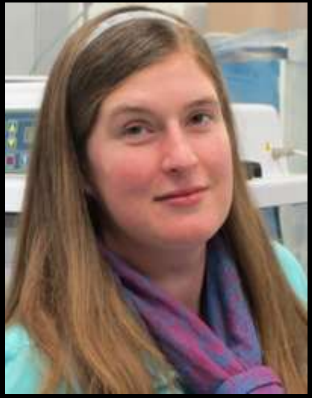
José Carlos Aponte

VI AstrobiON
Escola de Astrobiologia do Observatório Nacional, Rio de Janeiro, Brazil
September 14th, 2026


Danny Glavin


Angel Mojarro


Denise Buckner


Hannah McLain


Eric Parker

GSFC ASTROBIOLOGY ANALYTICAL LAB http://science.gsfc.nasa.gov/691/analytical/

Hi, I am José Carlos Aponte

Born in Lima, Perú, but grown up in the countryside

Hi, I am José Carlos Aponte

Went to public schools

Hi, I am José Carlos Aponte

Studied Chemistry in college:

1- Study something that can be done everywhere

2- Study something that will give you time for yourself

3- Leverage your strengths, don't compare yourself to others

Hi, I am José Carlos Aponte, PhD

Left home to pursue a doctorate degree in Organic Chemistry at the University of Louisville in Kentucky, USA

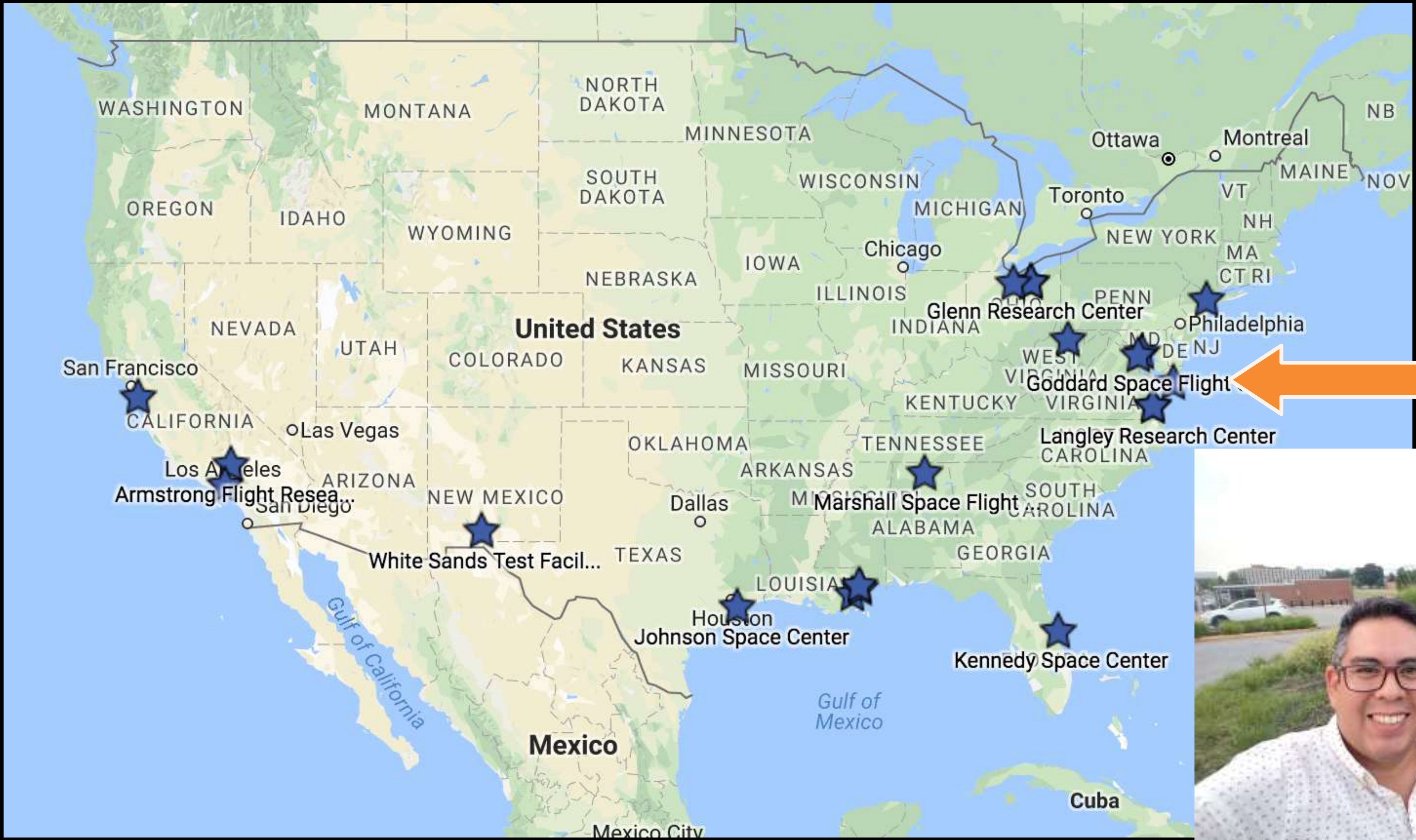
Hola, soy José Carlos Aponte, PhD

Went to work at Brown University

There I learnt about astrobiology and astrochemistry

In 2012 moved to MD to work at NASA Goddard

Where is NASA?



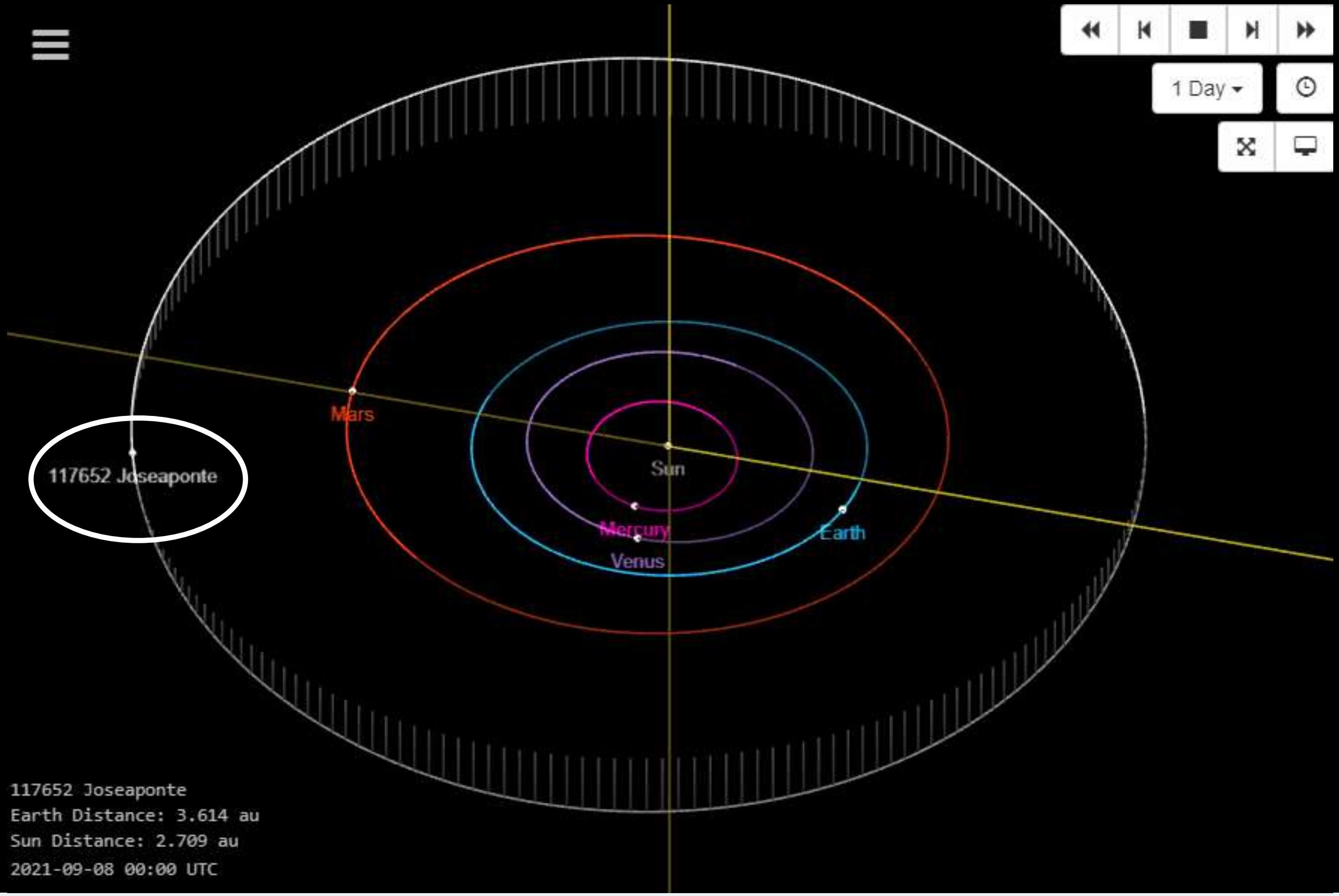
Here is where I work

"My" Asteroid

In 2017 asteroid 2005 EY161 was renamed after myself:

117652 Joséaponte

For my work as astrochemist and as part of the OSIRIS-REx mission.



Physical Parameter Table

Parameter	Symbol	Value	Units	Sigma	Reference	Notes
absolute magnitude	H	16.1		n/a	MPO453647	
diameter	diameter	3.006	km	0.132	urn:nasa:pds:neowise_diameters_albedos::2.0[mainbelt] (http://adsabs.harvard.edu/abs/2011ApJ...741...68M)	
geometric albedo	albedo	0.078		0.014	urn:nasa:pds:neowise_diameters_albedos::2.0[mainbelt] (http://adsabs.harvard.edu/abs/2011ApJ...741...68M)	

117652 Joséaponte Discovered 2005 Mar. 9 by Mt. Lemmon Survey at Mount Lemmon.

José Aponte (b. 1981) is an astrobiologist at the Goddard Space Flight Center for the OSIRIS-REx Mission. His research emphasis is in organic chemistry in meteorites.

Reference: MPC batch dated 2017-10-05 **Last Updated:** 2017-10-09

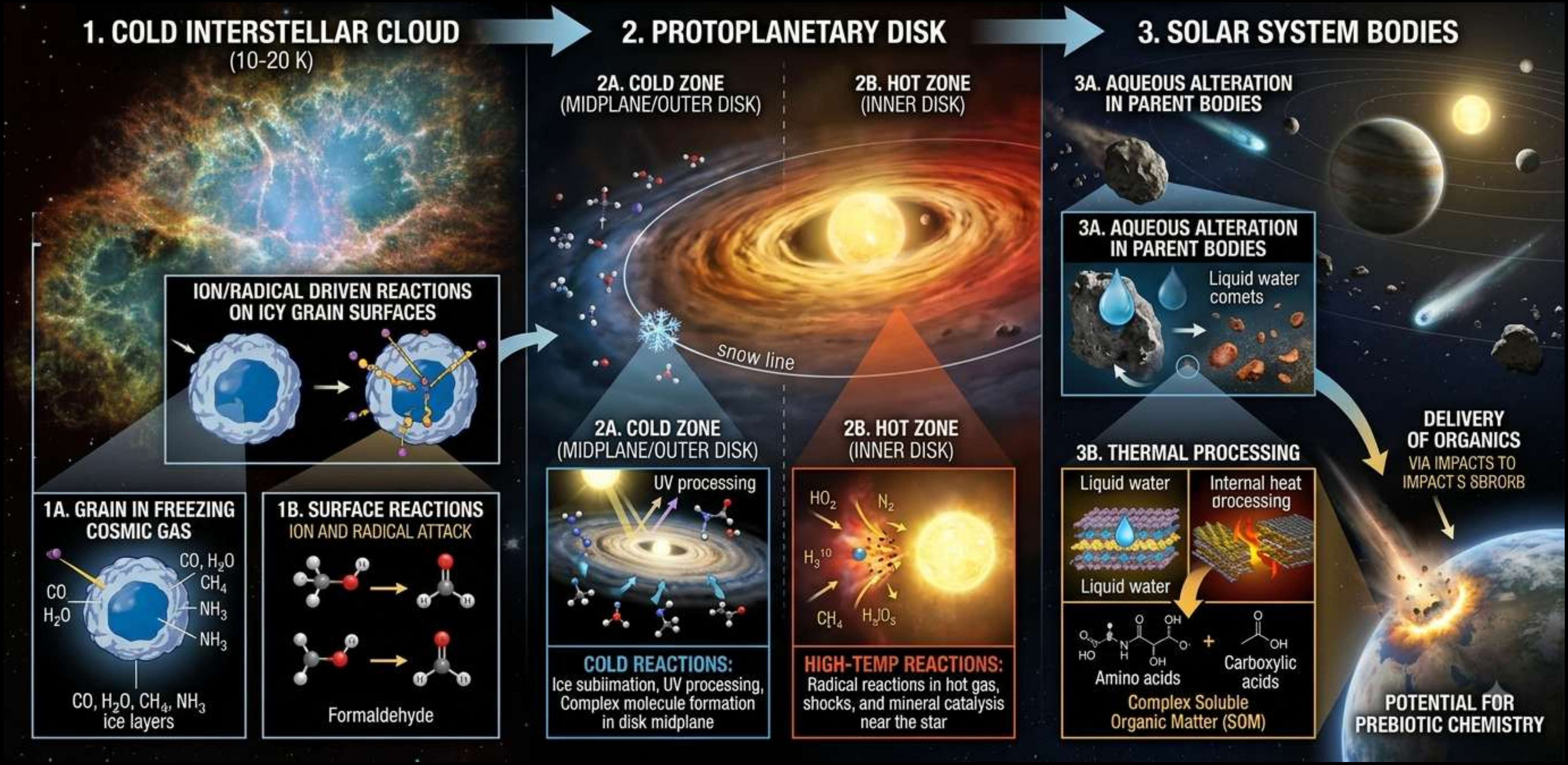
Easy Take-Homes for a Successful Career

Adapted from Dr. Stephanie Getty, Deputy Director of Solar System Exploration Division at NASA GSFC

- Be yourself
- Admit to what you don't know – and don't be afraid to contribute what you do know
- Have an open mind about where your career will take you
- Set a work-life balance that is right for you – there is no one-size-fits-all
- If one path doesn't suit you, look for opportunities that really interest you to bring out your best

> Don't chase or follow your dreams, focus on your reality and how that can take you to fulfill your dreams.
>
> -Christopher Nolan?

Where do Astrochemistry Happen?



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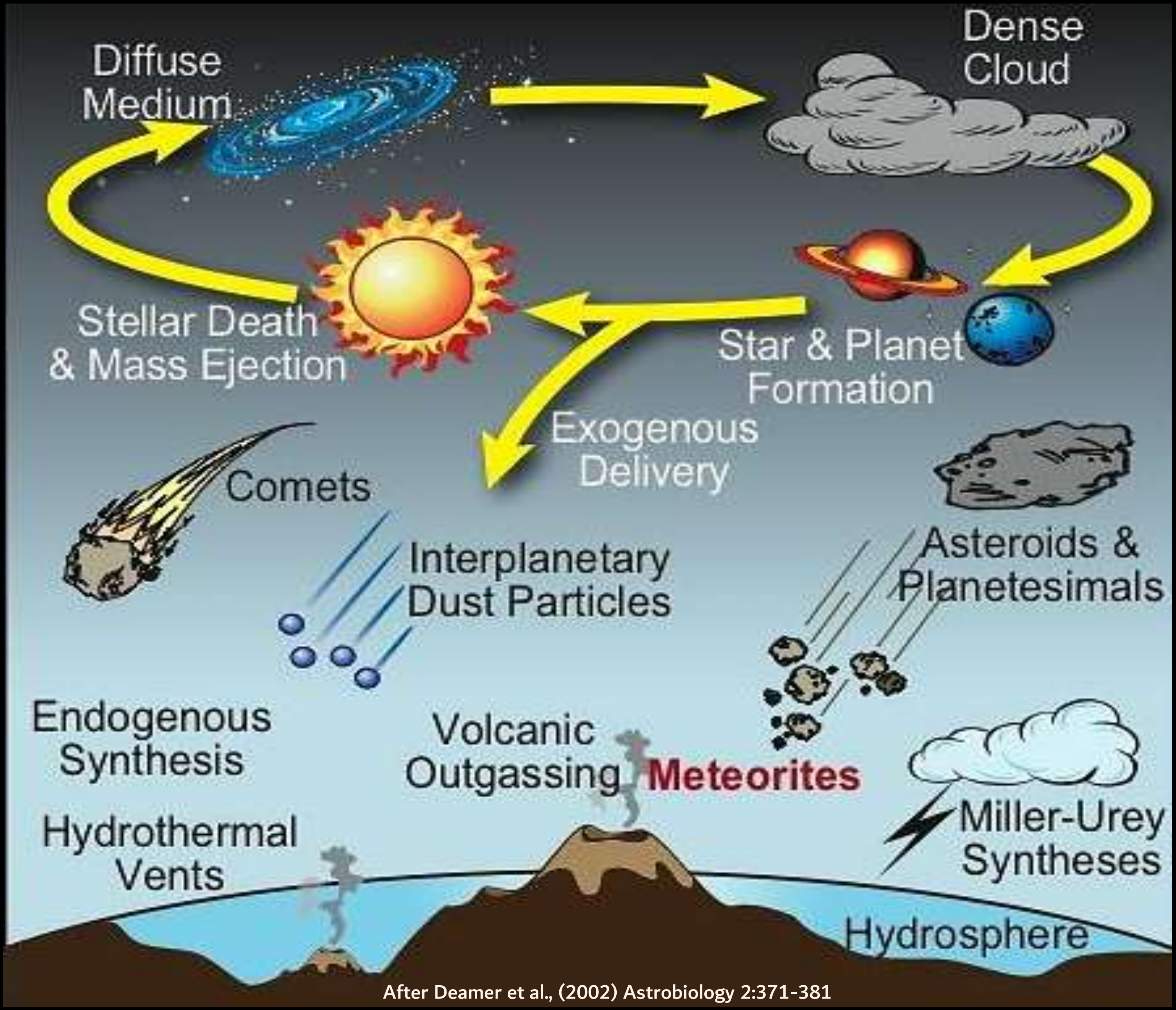
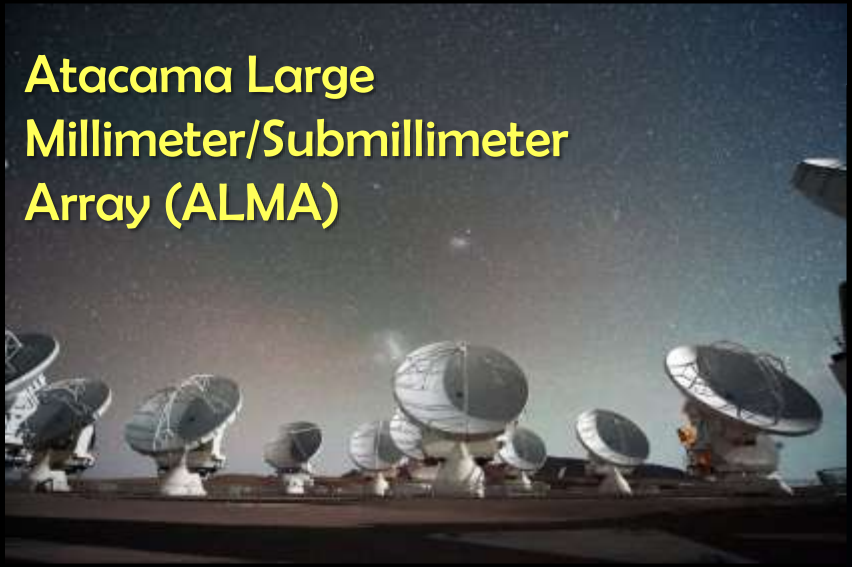
Approaches to Study Prebiotic Chemistry

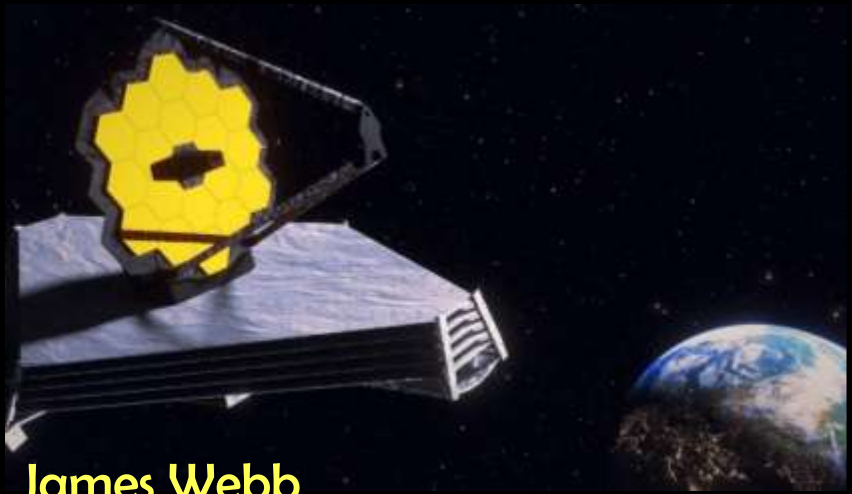


After Deamer et al., (2002) Astrobiology 2:371-381

Remote Observations & Simulations

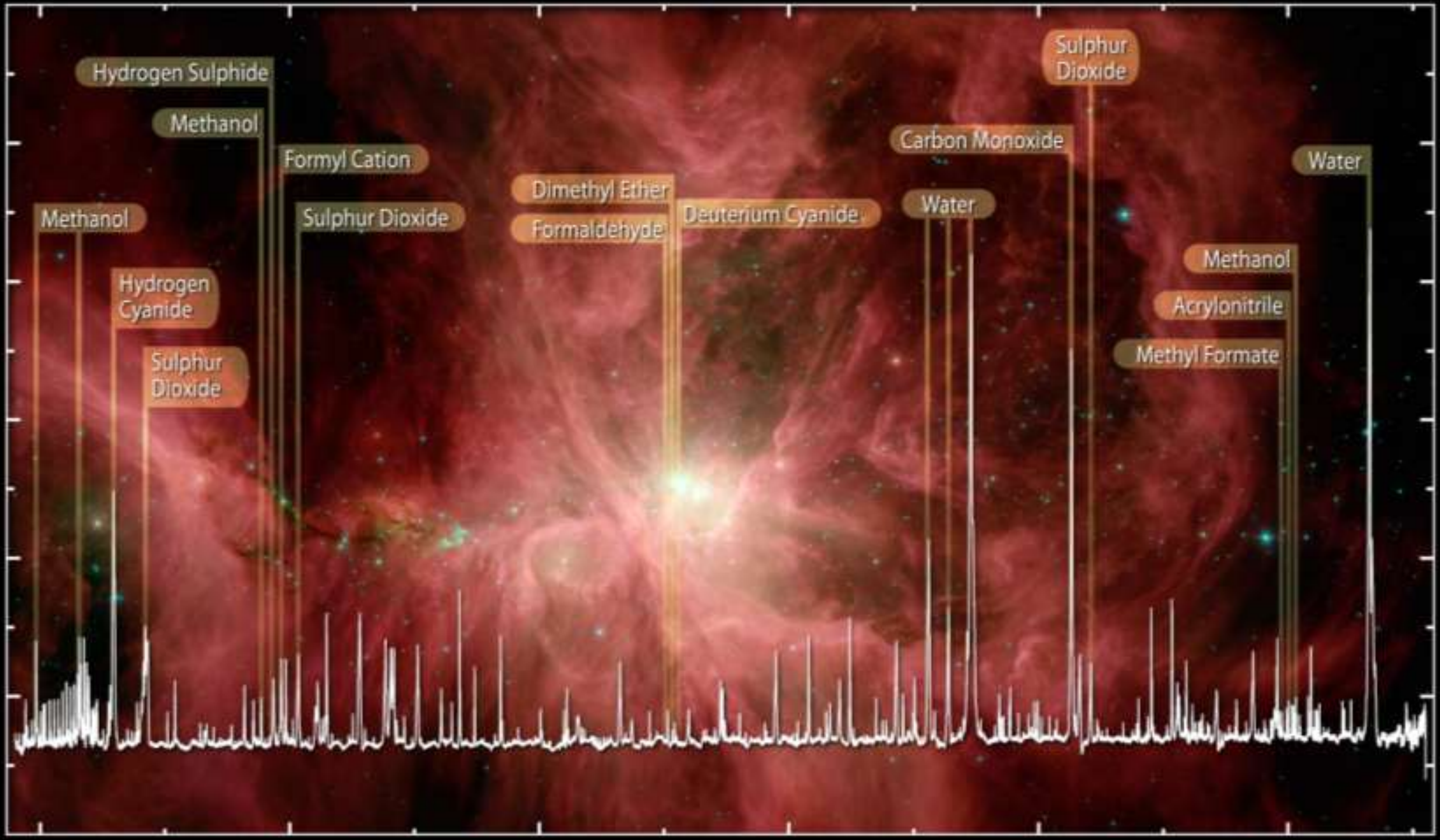
Spectroscopy for Remote Observations





James Webb
Space Telescope

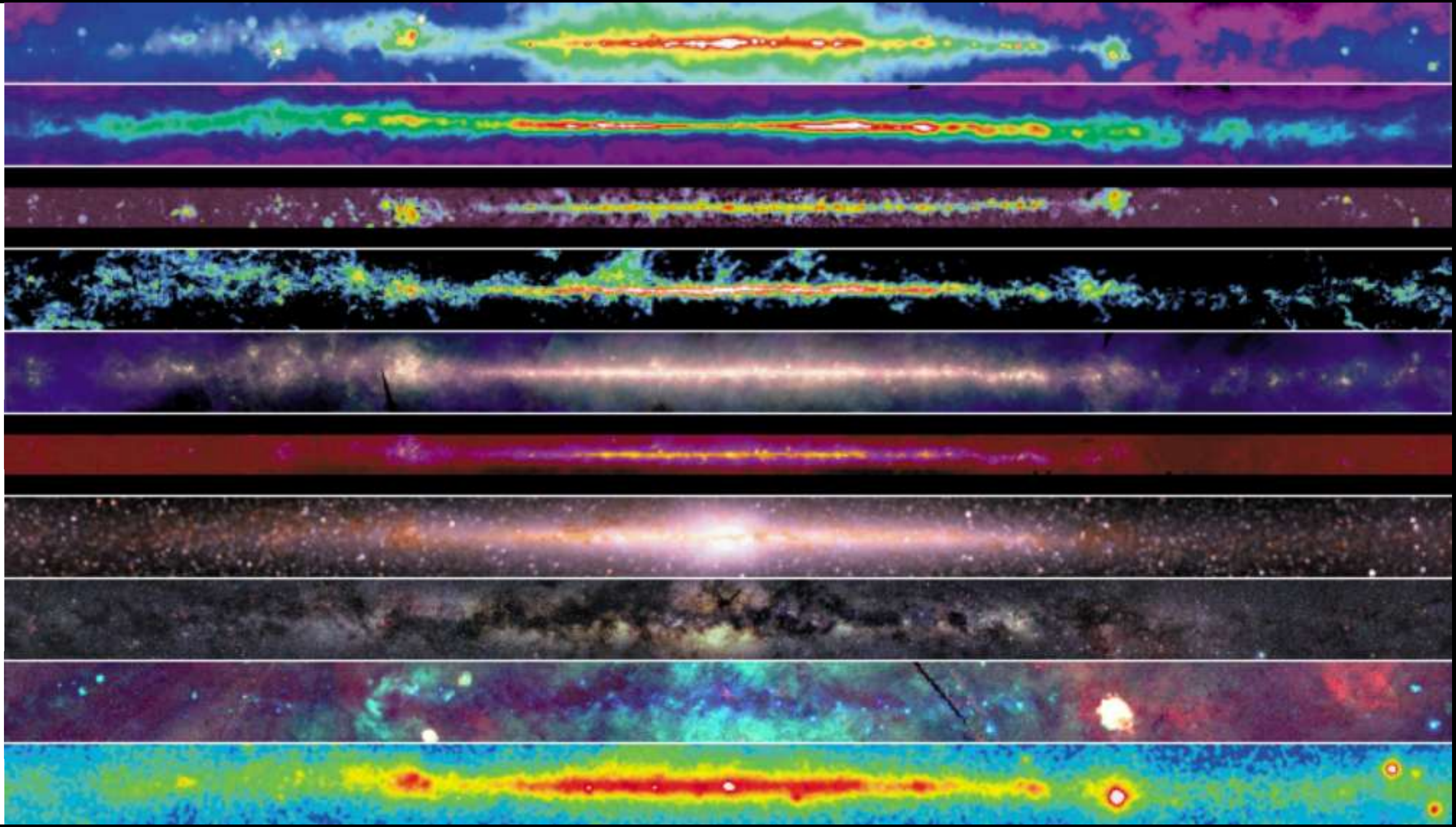
>100 organic molecules have been identified interstellar locations



Heterodyne Instrument for the Far-Infrared (HIFI) Spectrum of Water and Organics in the Orion Nebula

Milky Way Galaxy at Ten Wavelength Regions

Radio Continuum (408 MHz)
Atomic Hydrogen
Radio Continuum (2.4 - 2.7 GHz)
Molecular Hydrogen
Infrared
Mid Infrared
Near Infrared
Optical
X-Ray
Gamma Ray



https://asd.gsfc.nasa.gov/archive/mwmw/mmw_product.html

Some of the Known Interstellar Molecules

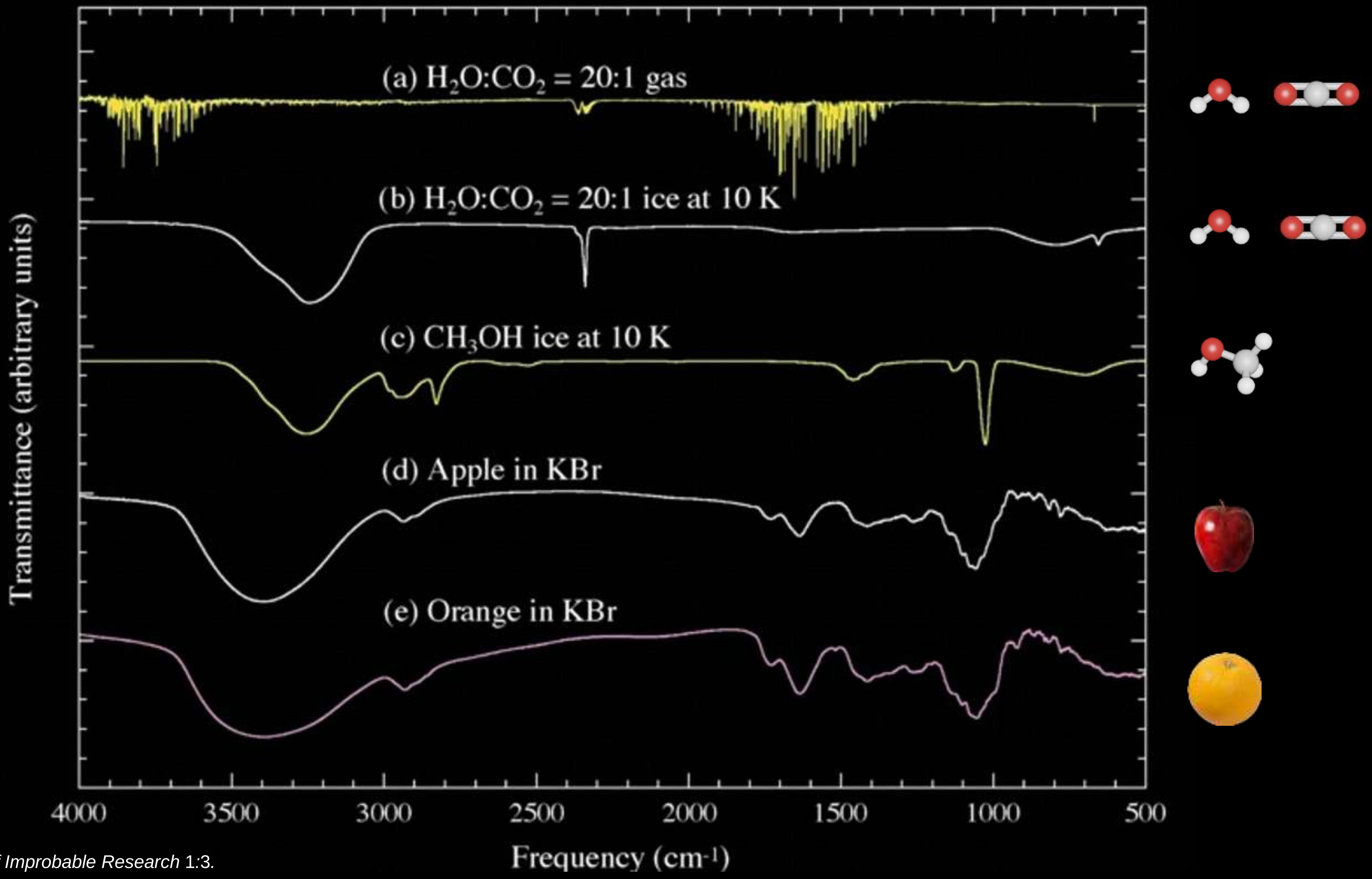
Molecules in the Interstellar Medium or Circumstellar Shells (as of 08/2026)

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	$CH_3C(CN)CH_2$			$CH_3OCH_2CH_2OH$
$NaCl$	C_2S	$HCCN$	HNC_3	H_2CCNH	c-C_3HCCH	HC_5NH^+	$H_2CCCHCCH$	CH_2CHCH_2CN			1-$C_{12}H_7CN$ (2024)
KCl	C_3^{*}	H_2CN	H_2COH^+	C_5N^-	l-H_2C_5	CH_2CHCCH	$HOCHCHCHO$	$HOCH_2C(O)NH_2$			5-$C_{12}H_7CN$
$AlCl$	CO_2^{*}	c-SiC_3	C_4H^-	$HNCHCN$	MgC_5N	MgC_6H	HC_7N^+	CH_3CH_2CCH			1-$C_{16}H_9CN$
AlF	CH_2	CH_3^{*}	$HC(O)CN$	SiH_3CN	CH_2C_3N	$C_2H_3NH_2$	$CH_2(CCH)_2$	$CH_3OC(O)N_2$ (2026)			2-$C_{16}H_9CN$ (2025)
PN	C_2O	C_3N^-	$HNCNH$	C_5S	NC_4NH^+	$(CHOH)_2$	$(CH_3)_2S$ (2025)				4-$C_{16}H_9CN$ (2025)
SiC	$MgNC$	PH_3	CH_3O	MgC_4H	MgC_5N^+	$HC_3(H)C_4$					$C_{24}H_{11}CN$ (2025)
CP	NH_2	$HCNO$	NH_4^+	CH_3CO^+	HC_5N^+ (2024)	C_7N^-					$C_{13}H_{10}$ (2025)
NH	$NaCN$	$HOCN$	H_2NCO^+	C_3H_3	HNC_5	CH_3CHCO					3-$C_{12}H_7CN$ (2026)
SiN	N_2O	$HSCN$	$NCCNH^+$	H_2C_3S	$CH_2(CN)_2$	MgC_6H^+					4-$C_{12}H_7CN$ (2026)
SO^+	$MgCN$	H_2O_2	CH_3Cl	$HCCCHS$	$HCCCHCN$ (2025)	Z-$(CH)_2(CN)_2$					c-$C_{11}H_8$ (2026)
CO^+	$H_3^{+(*)}$	C_3H^+	MgC_3N	C_5O	CH_3CHS (2025)	CH_2CHCHS (2025)					2,5-c-C_6H_6S (2026)
HF	$SiCN$	$HMgNC$	NH_2OH	C_5H^+	SiC_6 (2025)						
SiH?	$AlNC$	$HCCO$	HC_3O^+	$HCCNCH^+$							
FeO?	$SiNC$	$CNCN$	HC_3S^+	c-C_3C_2H							
O_2	HCP	$HONO$	H_2C_2S	HC_4S							
CF^+	CCP	MgC_2H	C_4S	$HMgC_3N$							
PO	$AlOH$	$HCCS$	$HC(O)SH$	MgC_4H^+							
AlO	H_2O^+	$HNCN$	$HC(S)CN$	$H_2C_3H^+$							
OH^+	H_2Cl^+	H_2NC	$HCCCO$	H_2C_3N							
CN^-	KCN	$HCCS^+$	$NaCCCN$	$(HO)_2CO$							
SH^+	$FeCN$	CH_3^+	MgC_3N^+	H_2CNCN (2024)							
SH	HO_2	$HCNS$	HC_3N^+	$NCHCCS$							

About 350 molecules have been detected in the **interstellar medium or circumstellar shells**

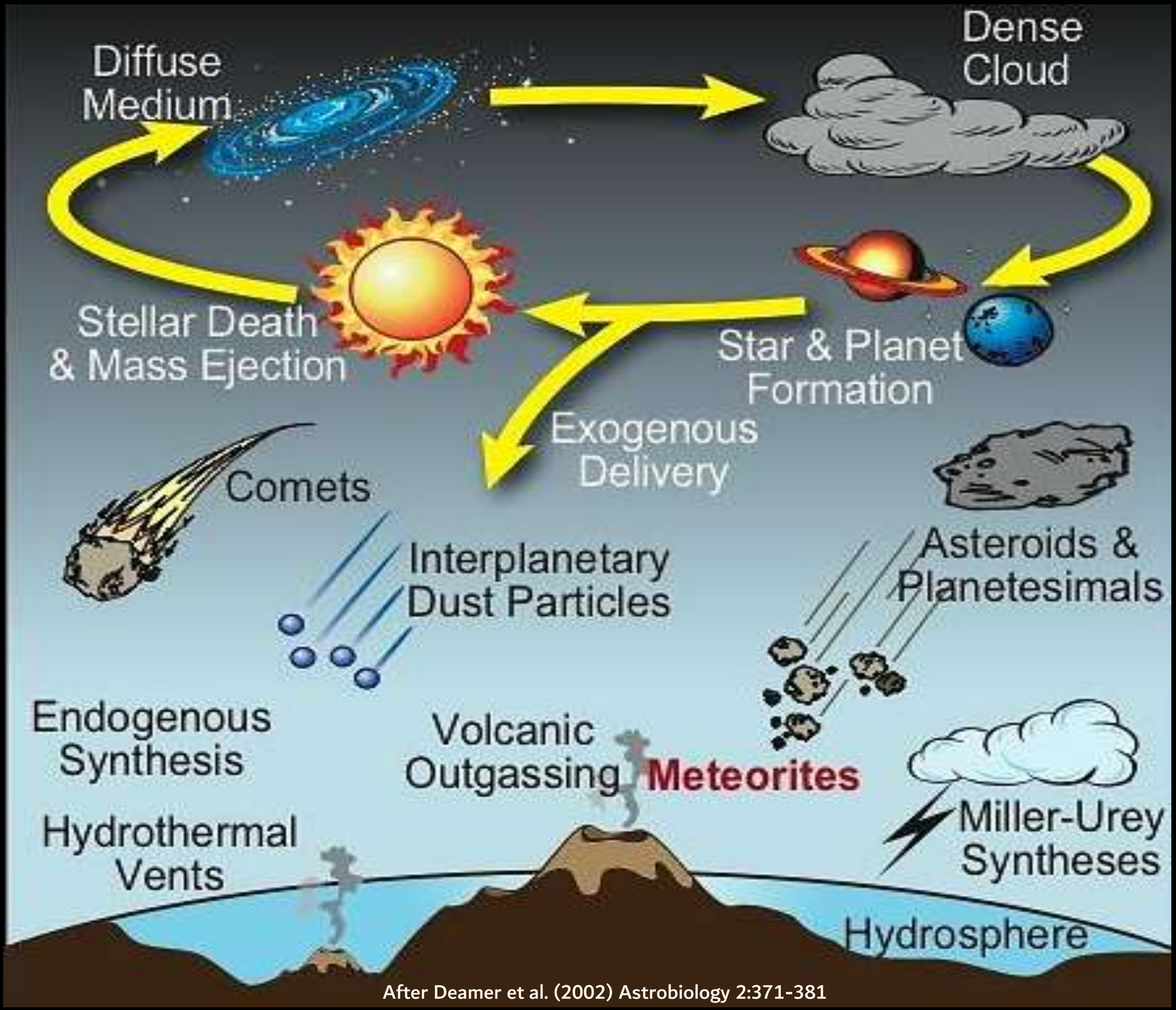
https://cdms.astro.uni-koeln.de/classic/molecules

Remote Observations… Not Always Easy



After Sandford (1995) *Annals of Improbable Research* 1:3.

Approaches to Study Prebiotic Chemistry



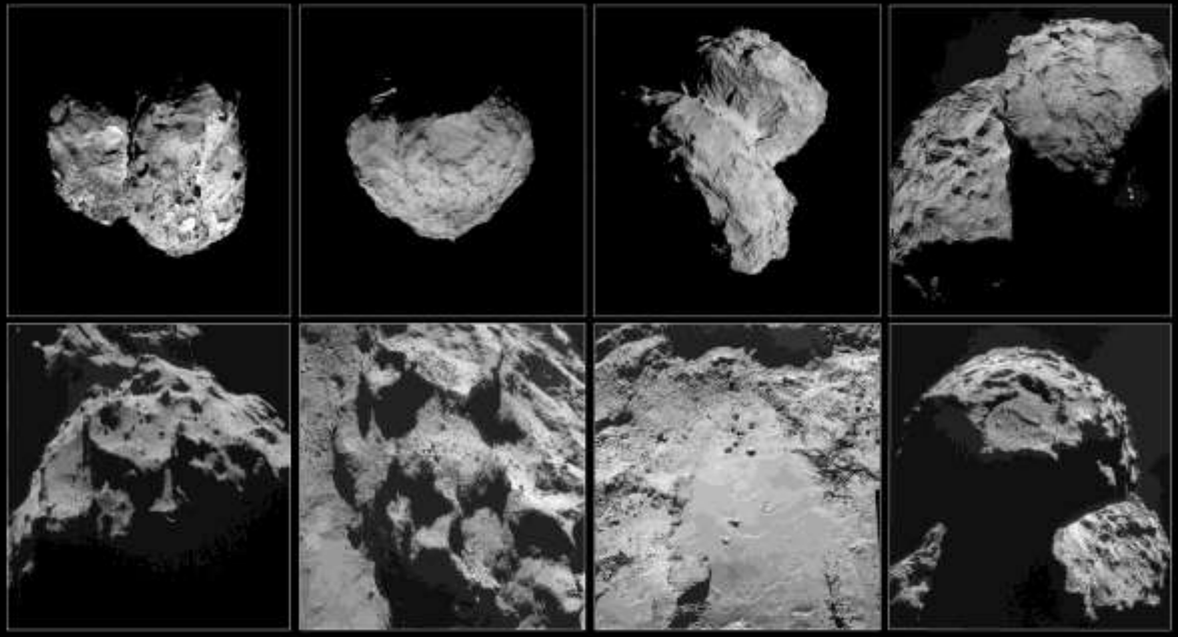
After Deamer et al. (2002) Astrobiology 2:371-381

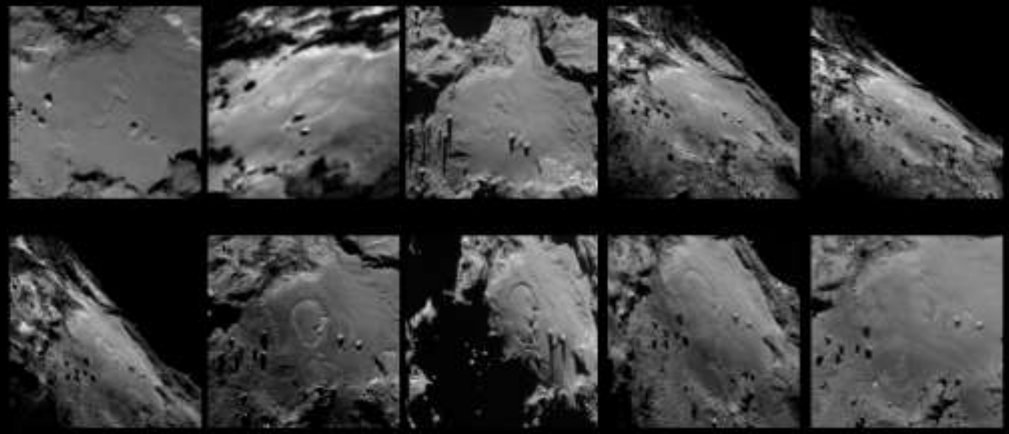
Remote Observations & Simulations

In situ measurements
Sample return missions

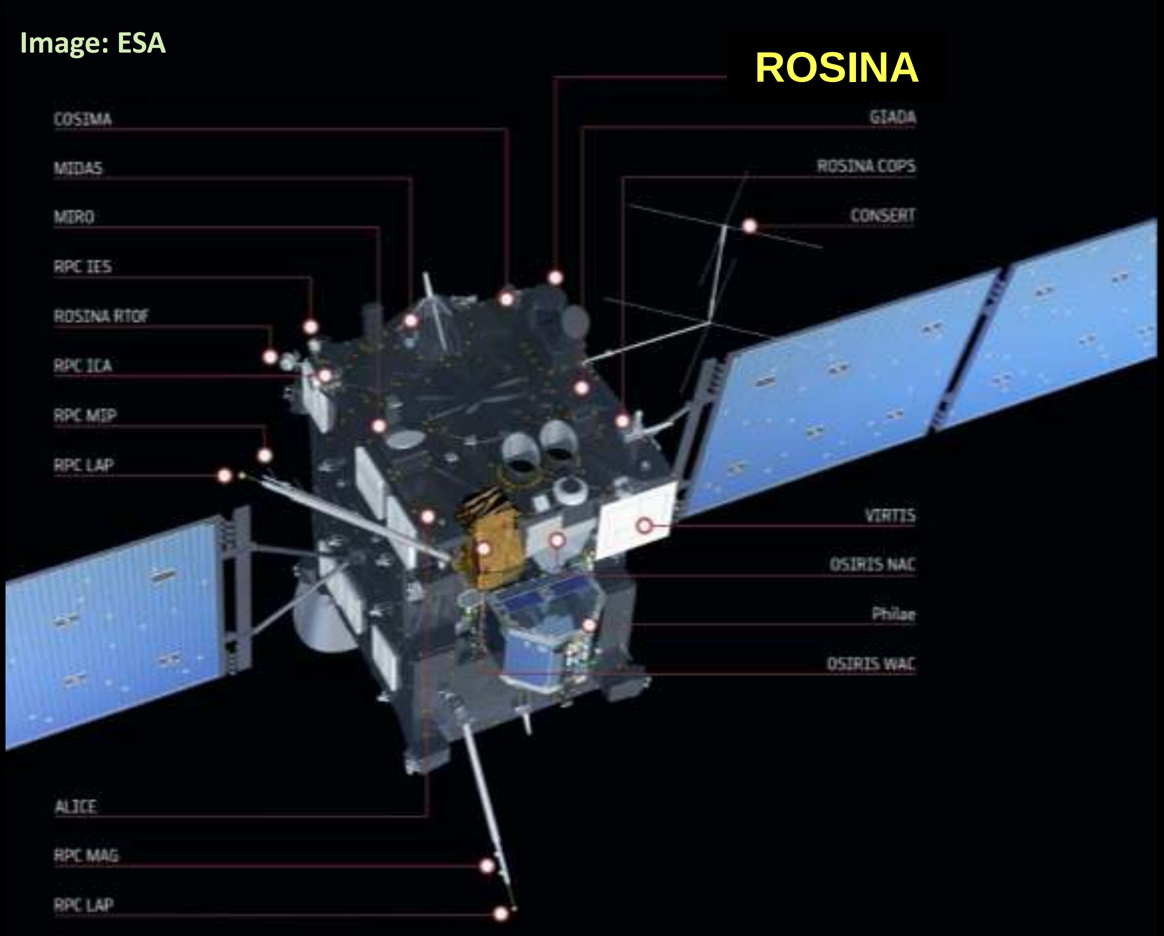
ESA's Rosetta Mission

Studied Comet 67P/Churyumov-Gerasimenko from 2014 to 2016

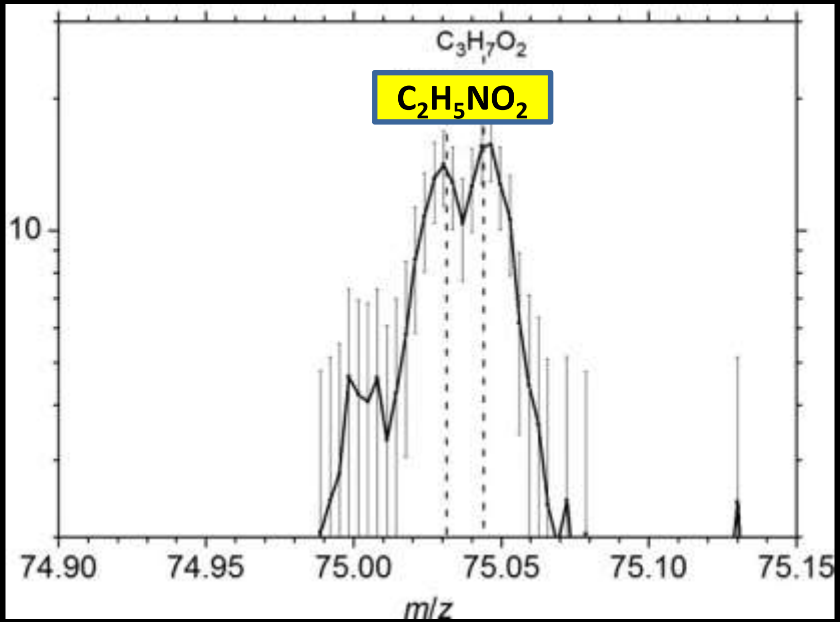




Rosetta's Glycine Detection



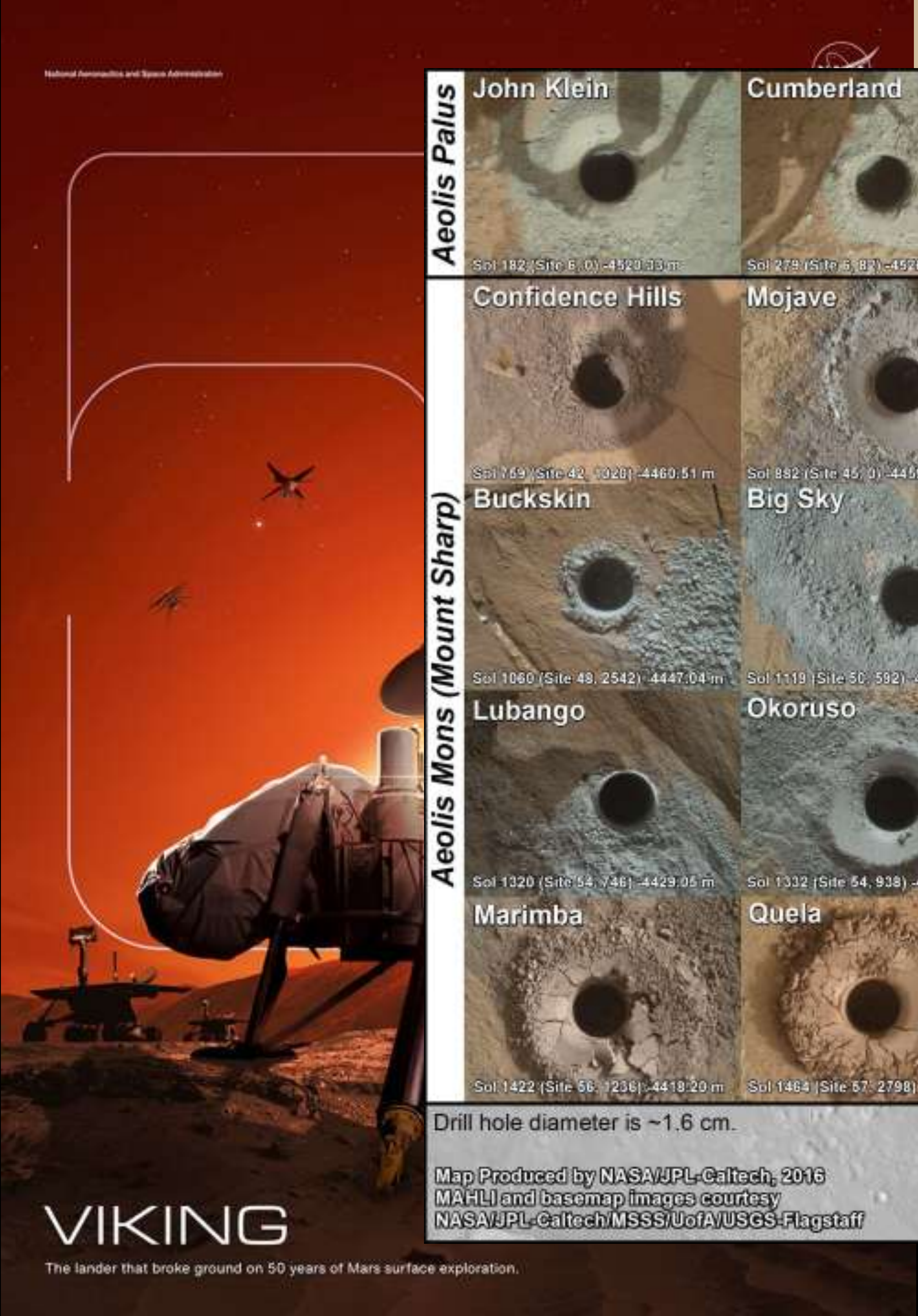
- Glycine detections made based on mass and fragmentation pattern
- Glycine detected ~10% of the time, with abundances from 0% to 0.16% of water

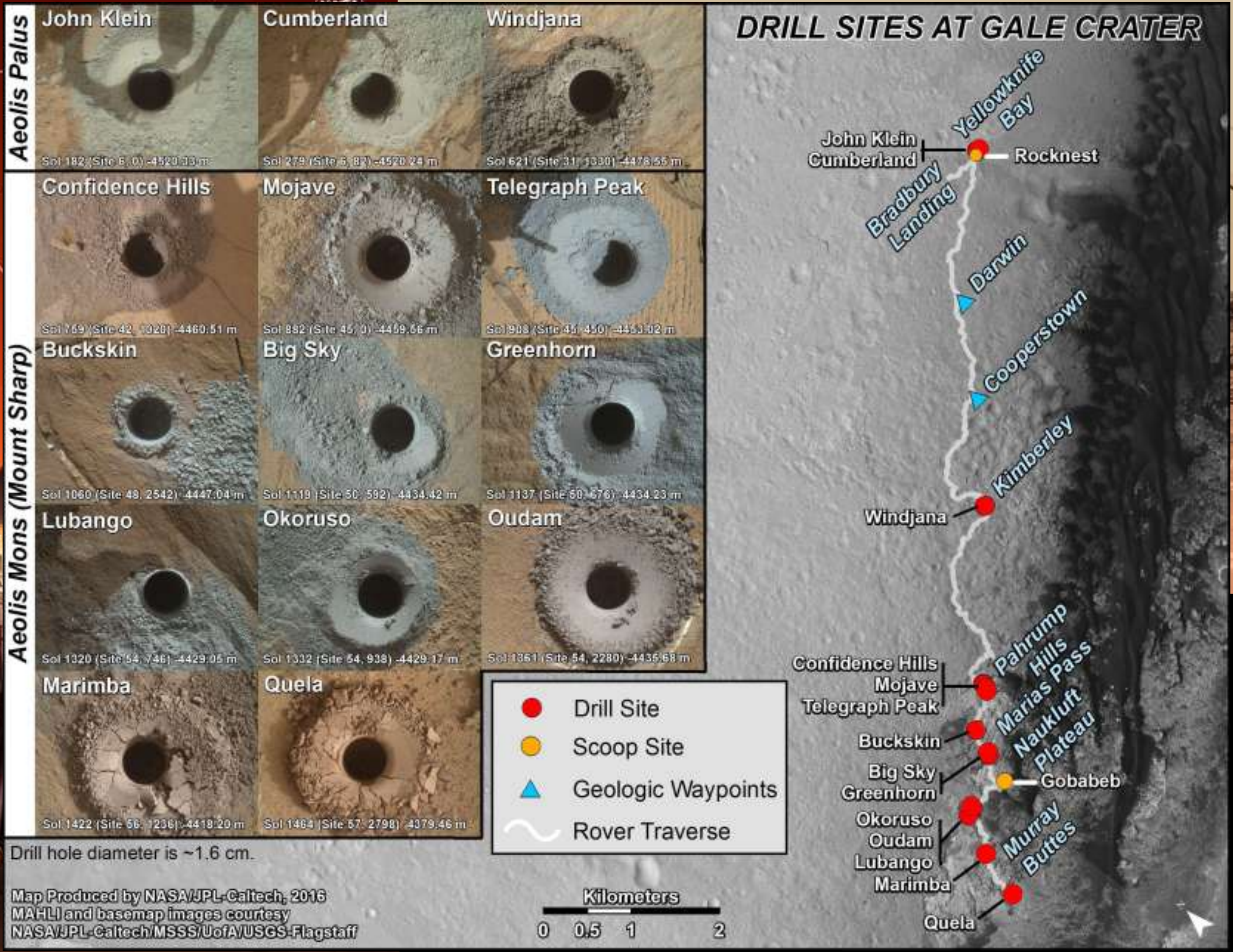


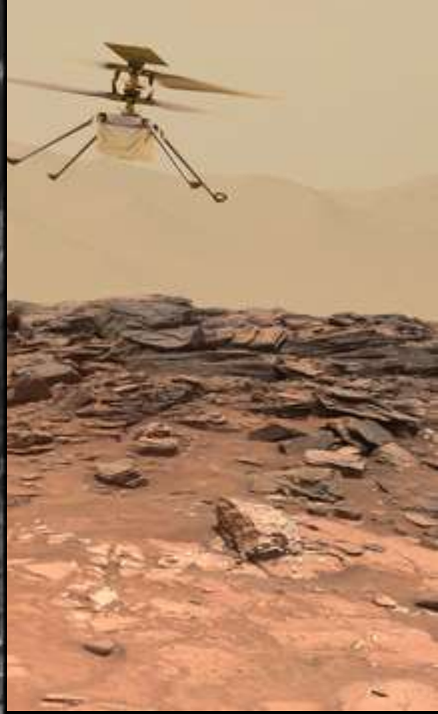
- Methylamine and ethylamine also detected concurrent with glycine

Altwegg et al.(**2016**) Sci. Adv. *2,* e1600285

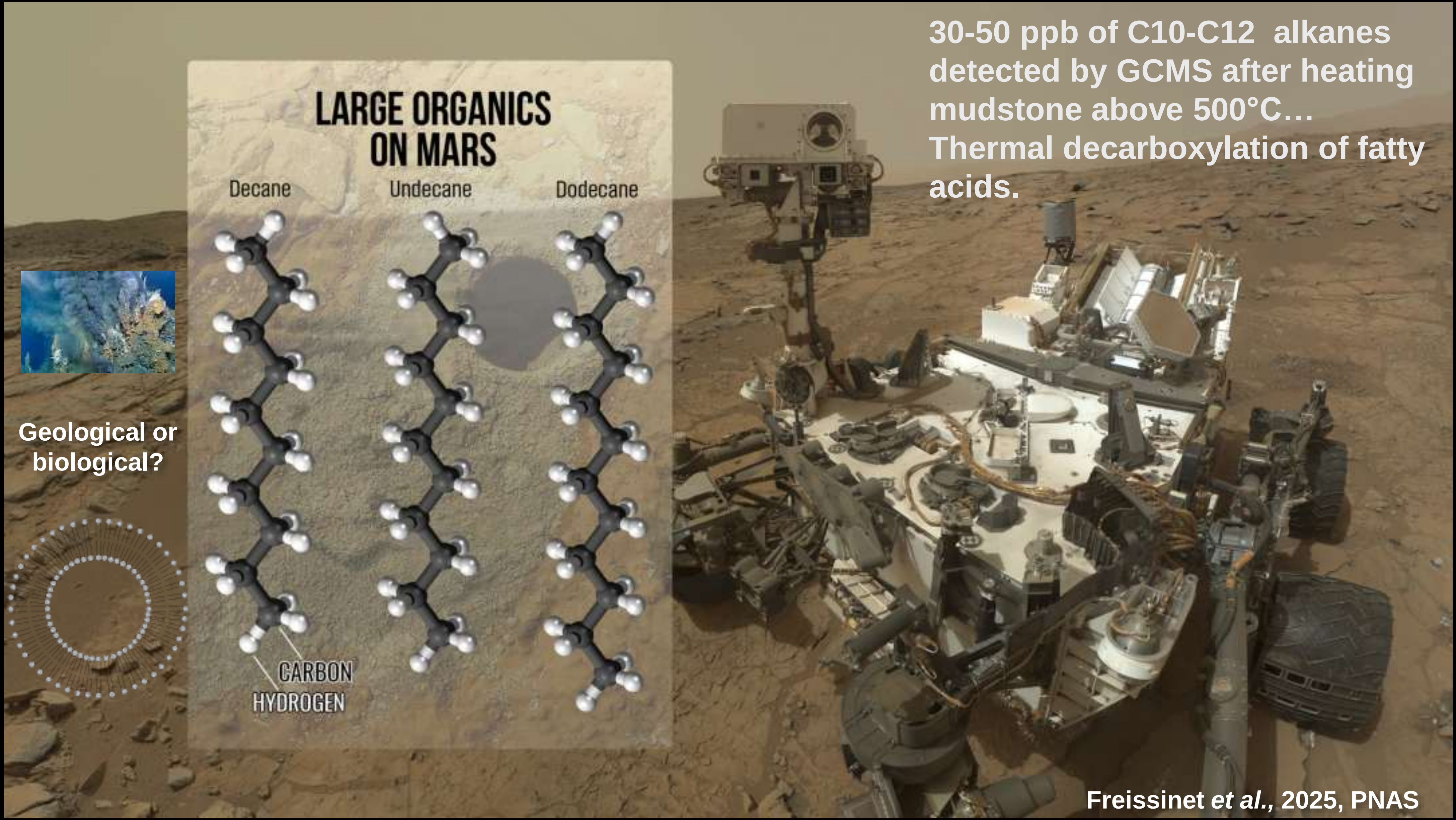
Ingenuity


National Aeronautics and Space Administration
VIKING
The lander that broke ground on 50 years of Mars surface exploration.


DRILL SITES AT GALE CRATER
Aeolis Palus
John Klein
Sol 182 (Site 6, 0) -4520.33 m
Cumberland
Sol 279 (Site 6, 87) -4520.24 m
Windjana
Sol 621 (Site 31, 1330) -4478.56 m
Aeolis Mons (Mount Sharp)
Confidence Hills
Sol 759 (Site 42, 1028) -4460.51 m
Mojave
Sol 882 (Site 45, 0) -4459.66 m
Telegraph Peak
Sol 908 (Site 45, 450) -4453.02 m
Buckskin
Sol 1060 (Site 48, 2542) -4447.04 m
Big Sky
Sol 1119 (Site 50, 592) -4434.42 m
Greenhorn
Sol 1137 (Site 50, 676) -4434.23 m
Lubango
Sol 1320 (Site 54, 746) -4429.05 m
Okoruso
Sol 1332 (Site 54, 938) -4429.17 m
Oudam
Sol 1361 (Site 54, 2280) -4435.68 m
Marimba
Sol 1422 (Site 56, 1236) -4418.20 m
Quela
Sol 1464 (Site 57, 2798) -4379.46 m
Drill hole diameter is ~1.6 cm.
Drill Site
Scoop Site
Geologic Waypoints
Rover Traverse
Map Produced by NASA/JPL-Caltech, 2016
MAHLI and basemap images courtesy
NASA/JPL-Caltech/MSSS/UofA/USGS-Flagstaff
Kilometers
0 0.5 1 2
Yellowknife Bay
John Klein
Cumberland
Rocknest
Bradbury Landing
Darwin
Cooperstown
Kimberley
Windjana
Pahrump Hills
Confidence Hills
Mojave
Telegraph Peak
Marias Pass
Naukluft Plateau
Buckskin
Big Sky
Greenhorn
Gobabeb
Okoruso
Oudam
Lubango
Marimba
Murray Buttes
Quela



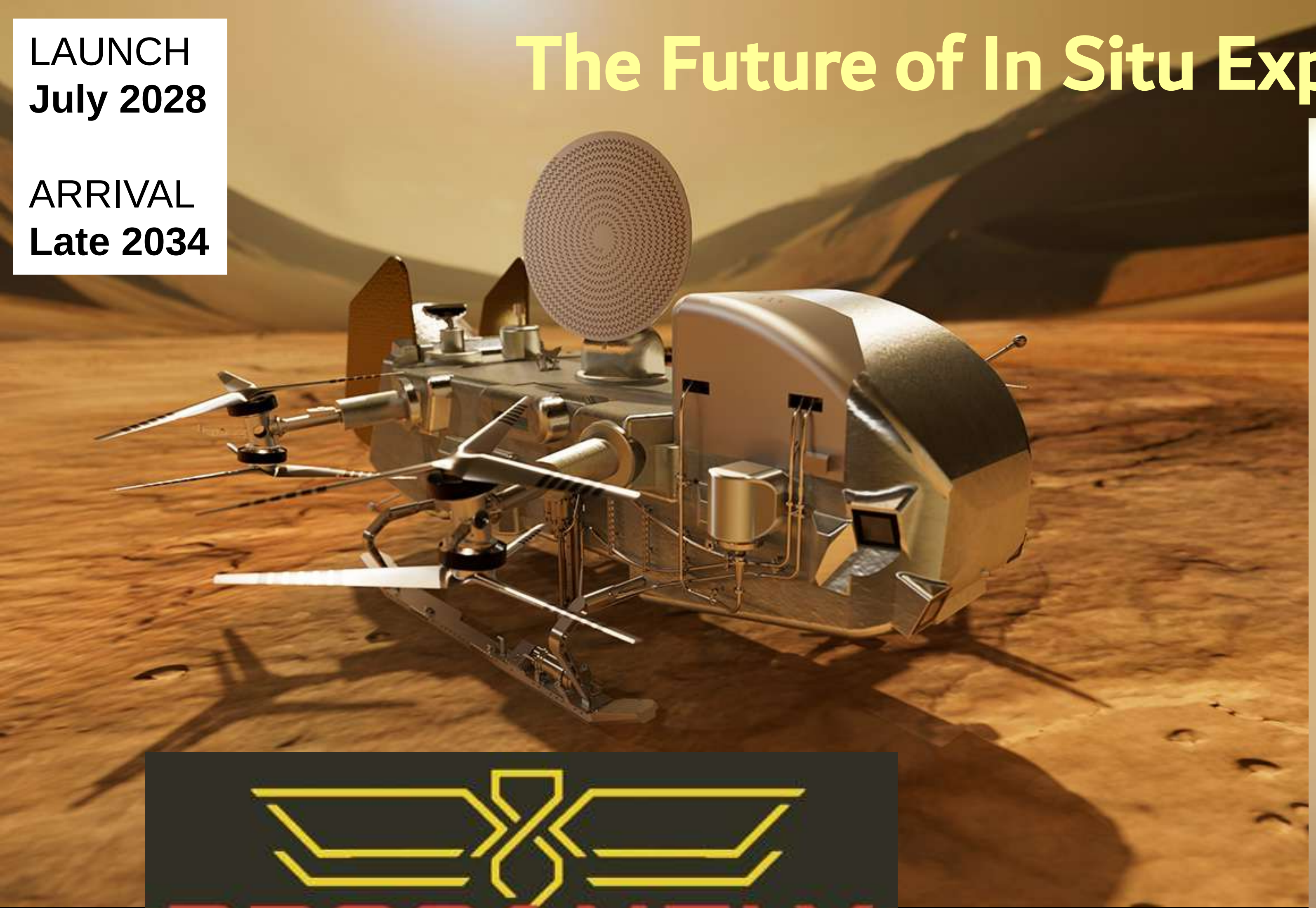
Curiosity Rover Fatty Acids Detection



The Future of In Situ Exploration

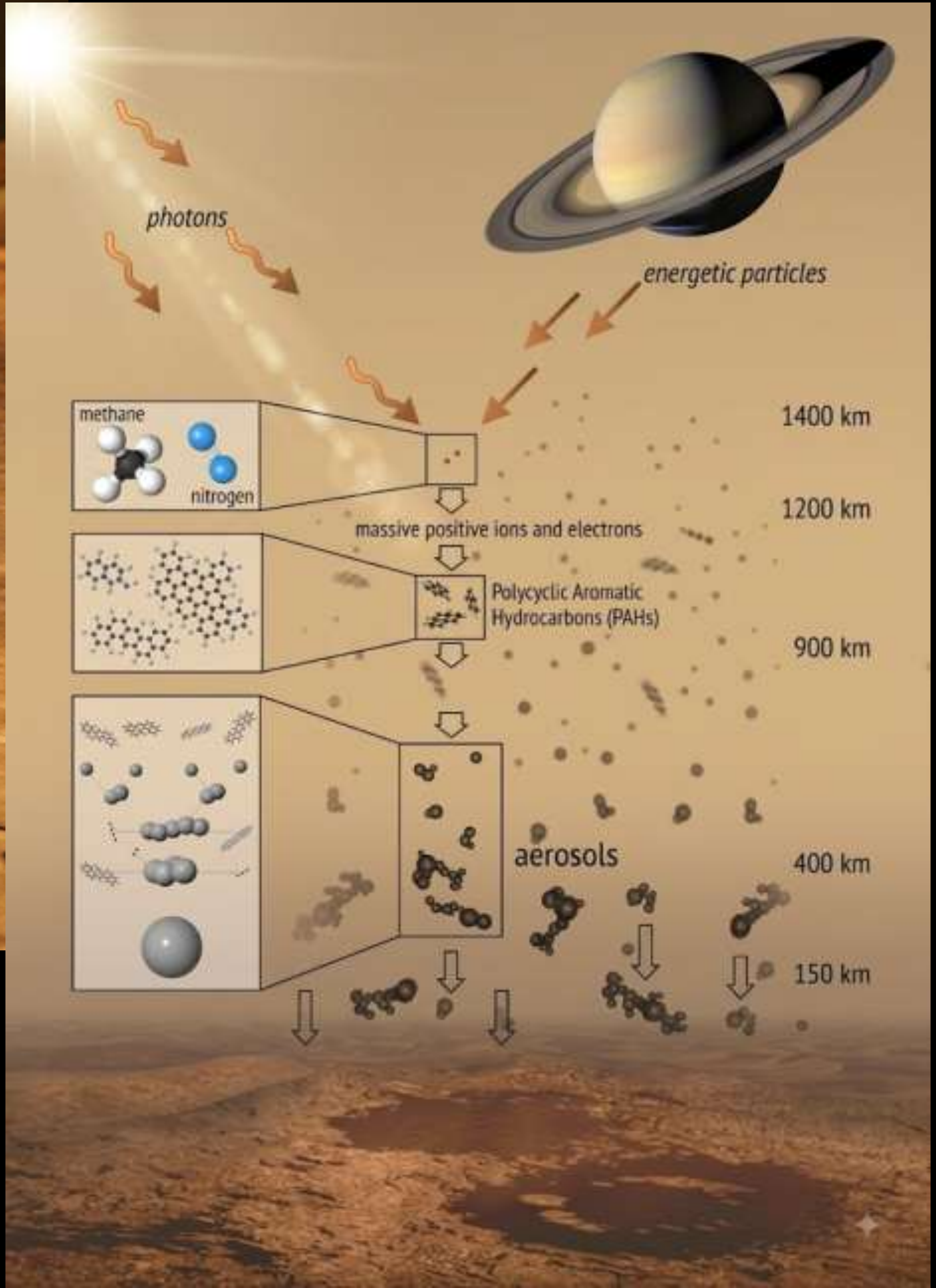
LAUNCH
July 2028

ARRIVAL
Late 2034



DRAGONFLY

FLIGHTS OF EXPLORATION
ACROSS SATURN'S MOON TITAN



Sample Return Missions

Moon

NASA *Apollo* 11, 12, 14, 15, 16, and 17 (1969, 1971, 1972)
Soviet Luna 16, 20, and 24 (1970, 1972, 1976)
CSNA Chang'e 5, 6 (2020, 2024)
NASA *Artemis IV, etc.* (in development)

Solar wind

NASA Genesis (returned 2004)

Comet tail

NASA Stardust (returned 2006)

Stony Asteroid

JAXA Hayabusa (returned 2010)
CSNA Tianwen-2 (launched 2025)

Carbonaceous Asteroid

JAXA Hayabusa2 (returned 2020)
NASA OSIRIS-REx (returned 2023)

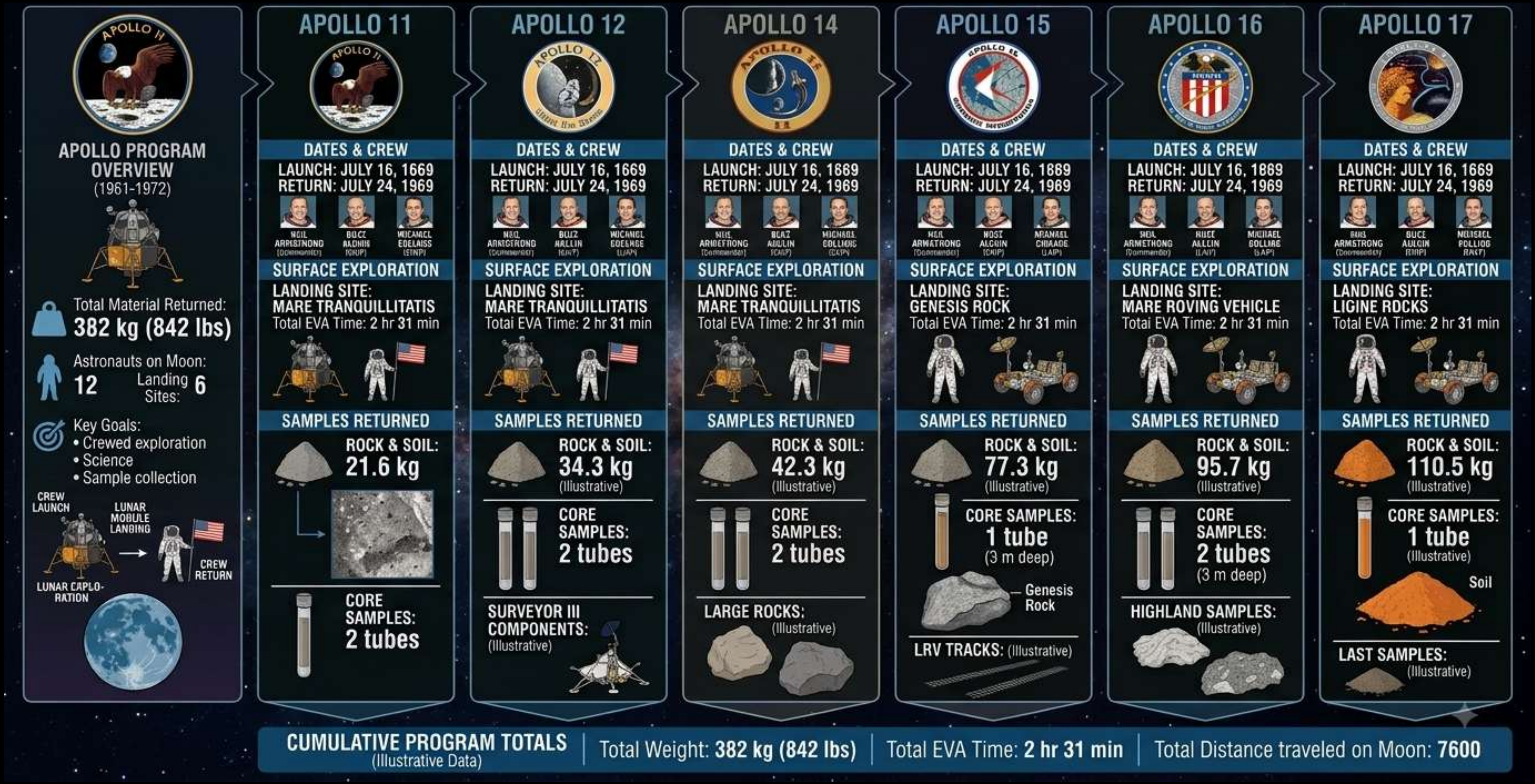
Phobos

JAXA MMX (in development)

Mars

NASA/ESA MSR (cancelled)
CSNA Tianwen-3 (in development)

Apollo Missions



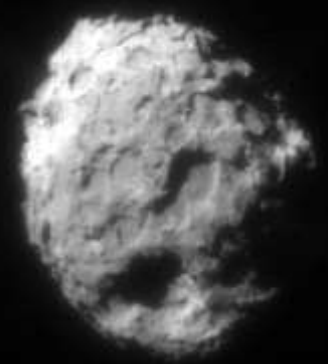
AI generated image

Genesis Mission

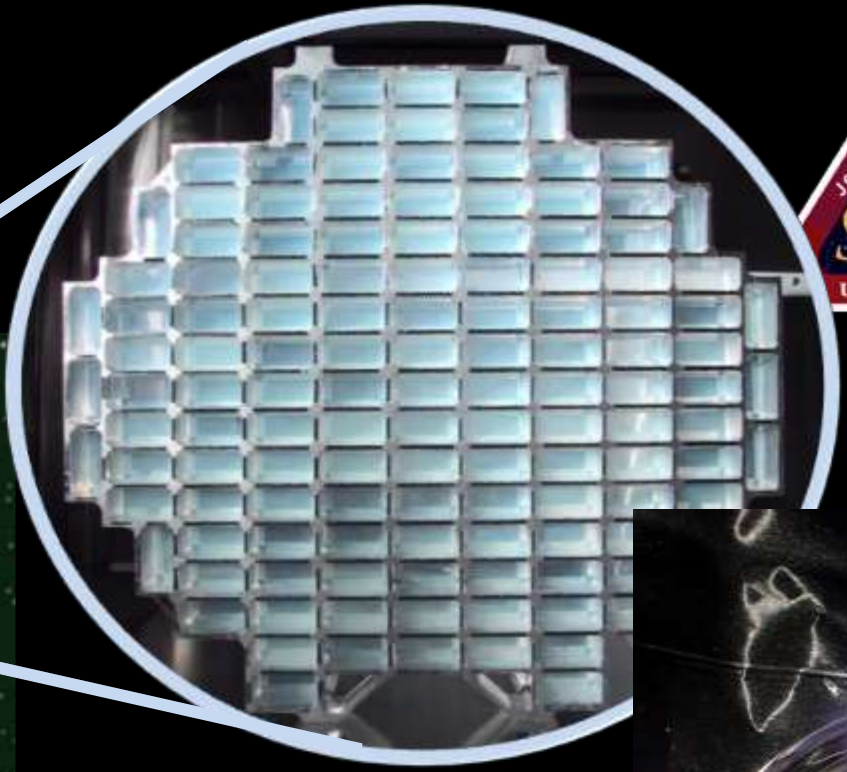
Genesis was designed to capture pristine <u>**solar wind particles**</u> and return them to Earth for analysis.

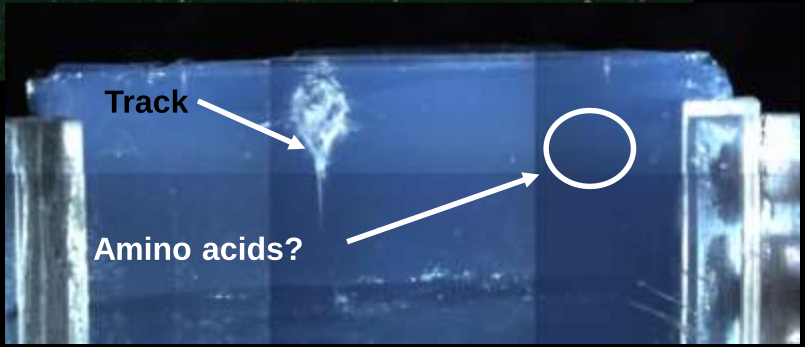
It successfully gathered solar material, but its return capsule suffered a hard crash in the Utah desert in September 2004 due to a deployed parachute design error.

Stardust Mission

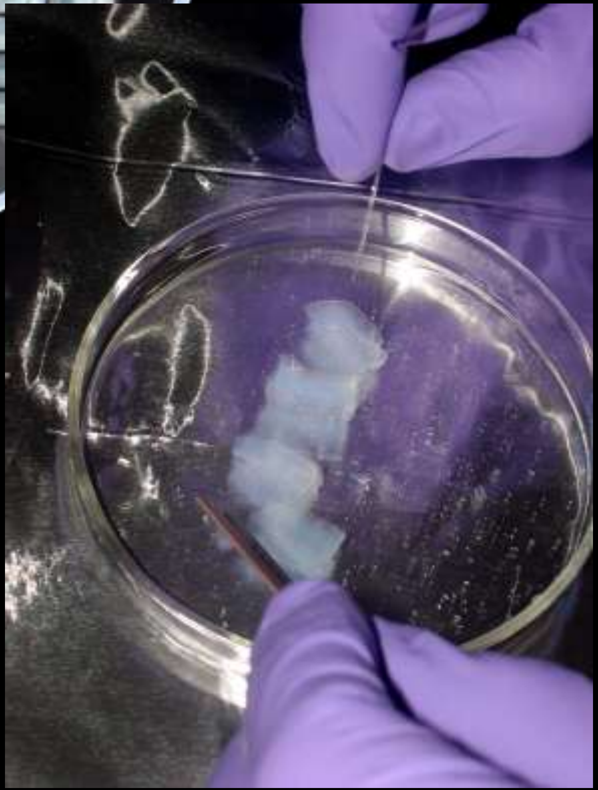


Comet Wild 2

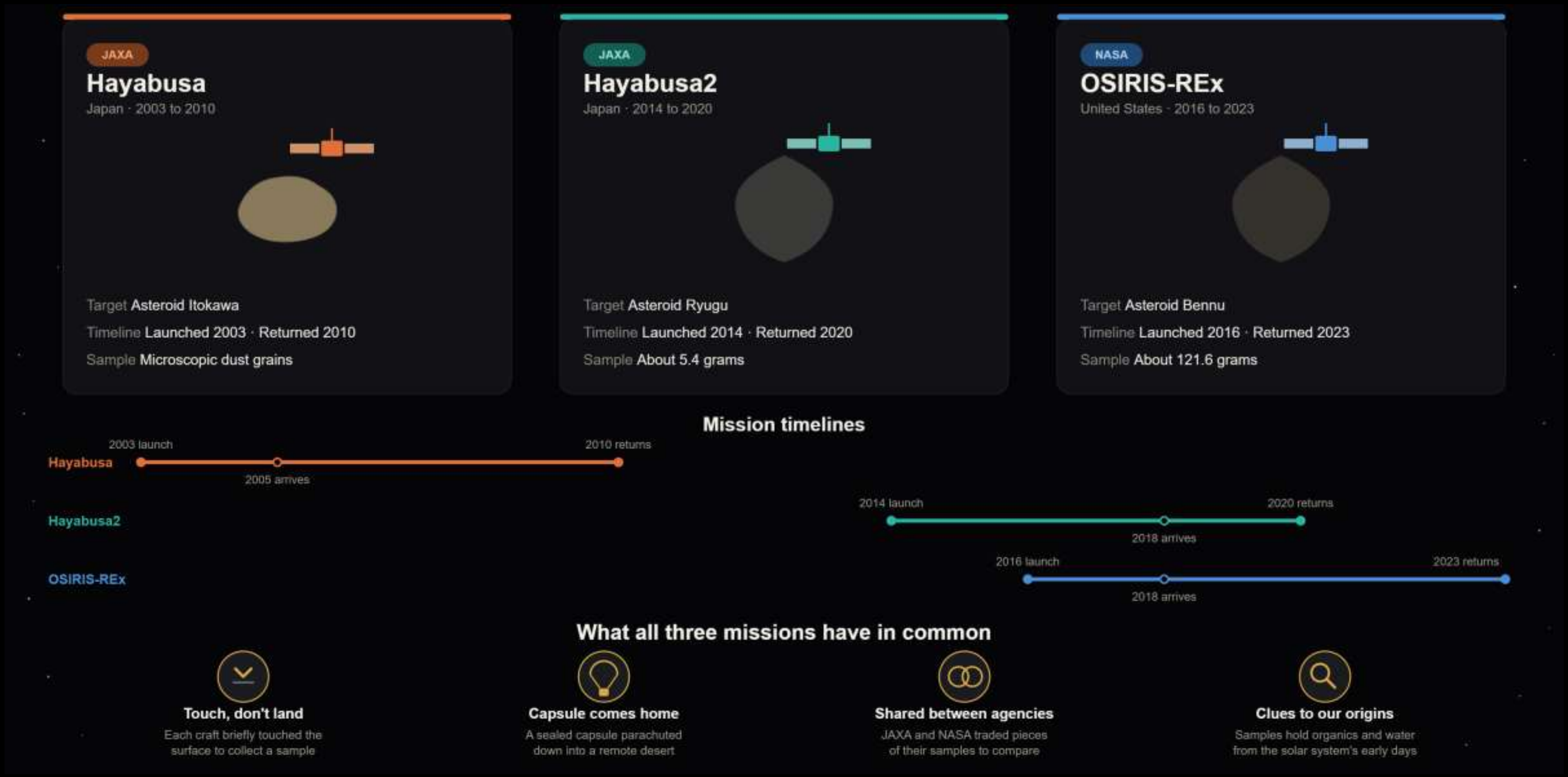




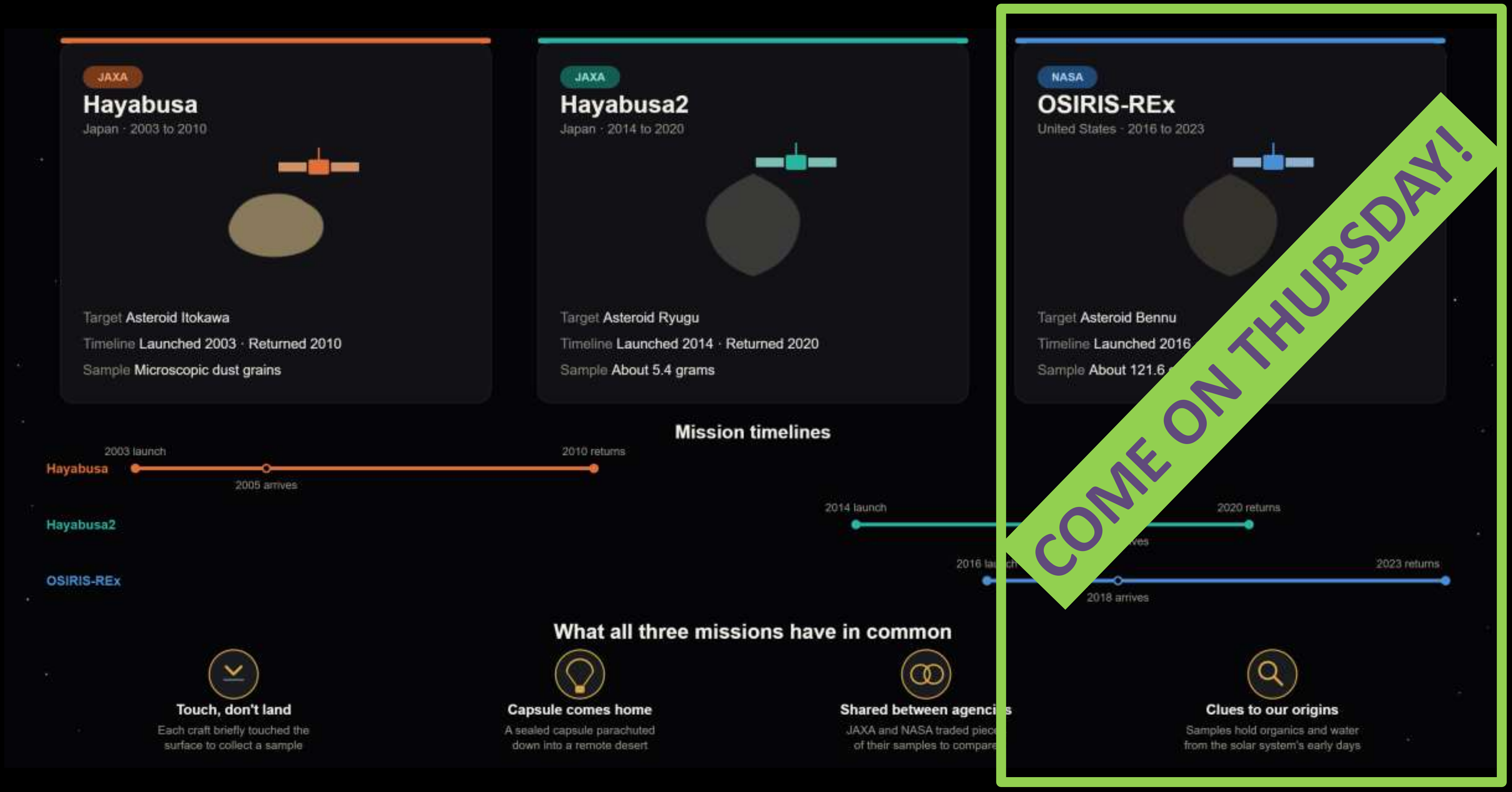
We detected ammonia, amines, and amino acids.
Elsila et al. 2009



Hayabusa, Hayabusa2, and OSIRIS-REx



Hayabusa, Hayabusa2, and OSIRIS-REx



JAXA's Hayabusa2 Mission

Asteroid **Ryugu**

("Dragon palace")

~1 km wide (0.62 mi)

Launched in December 2014

Arrived at Ryugu on June 27, 2018

Hayabusa2 touched down on July 11, 2019

JAXA’s Hayabusa2 Mission

Hayabusa2 touched down on July 11, 2019

Landed in the Australian Outback on December 6, 2020

Over 5 g of material was collected

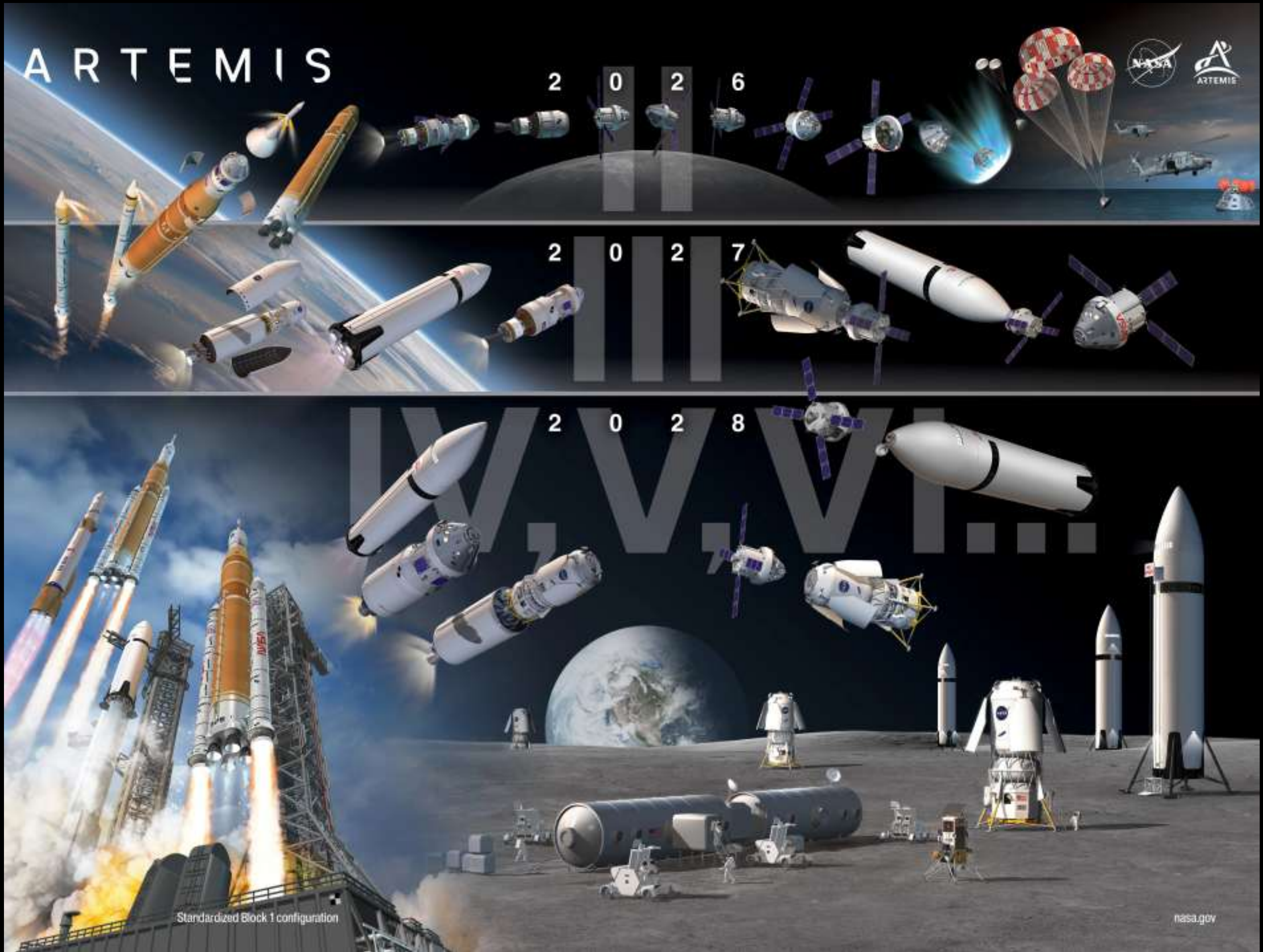
Hayabusa2 Initial Analysis SOM Team

Over 20 analysis subteams based in Japan, Germany, France, and USA, among them:

Volatile components
Organic macromolecules
Raman characterization
X-ray nanotomography
CNHOS isotopic compositions

&

Soluble organic matter (SOM)

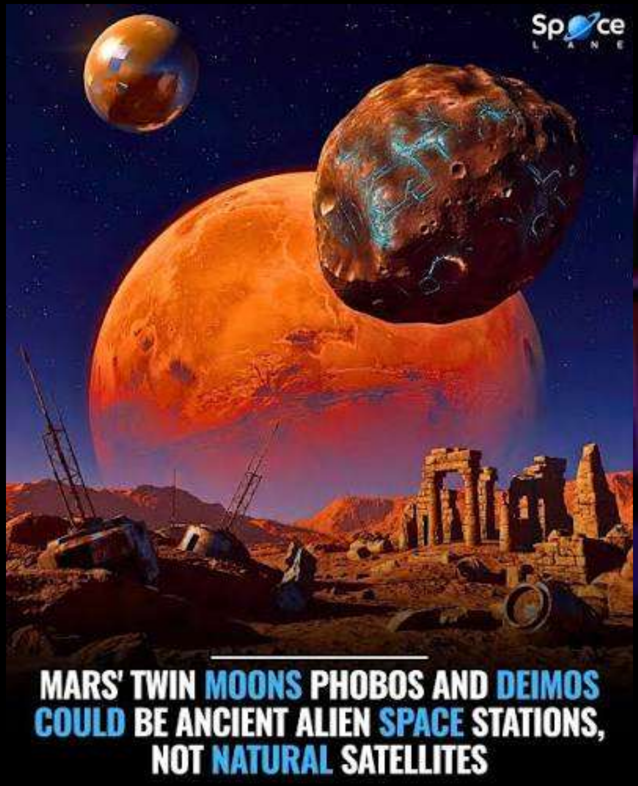


Artemis Missions Going back to the Moon and the Future of Sample Return Missions

Artemis Missions Going back to the Moon and the Future of Sample Return Missions

Martian Moons eXploration (MMX) Mission

- Launch late 2026 (Tanegashima Space Center, Japan)
- Orbit around Mars in 2027 and map Phobos and Deimos
- Land on Phobos in 2029 and collect ≥10 grams
- Return samples to Earth in 2031



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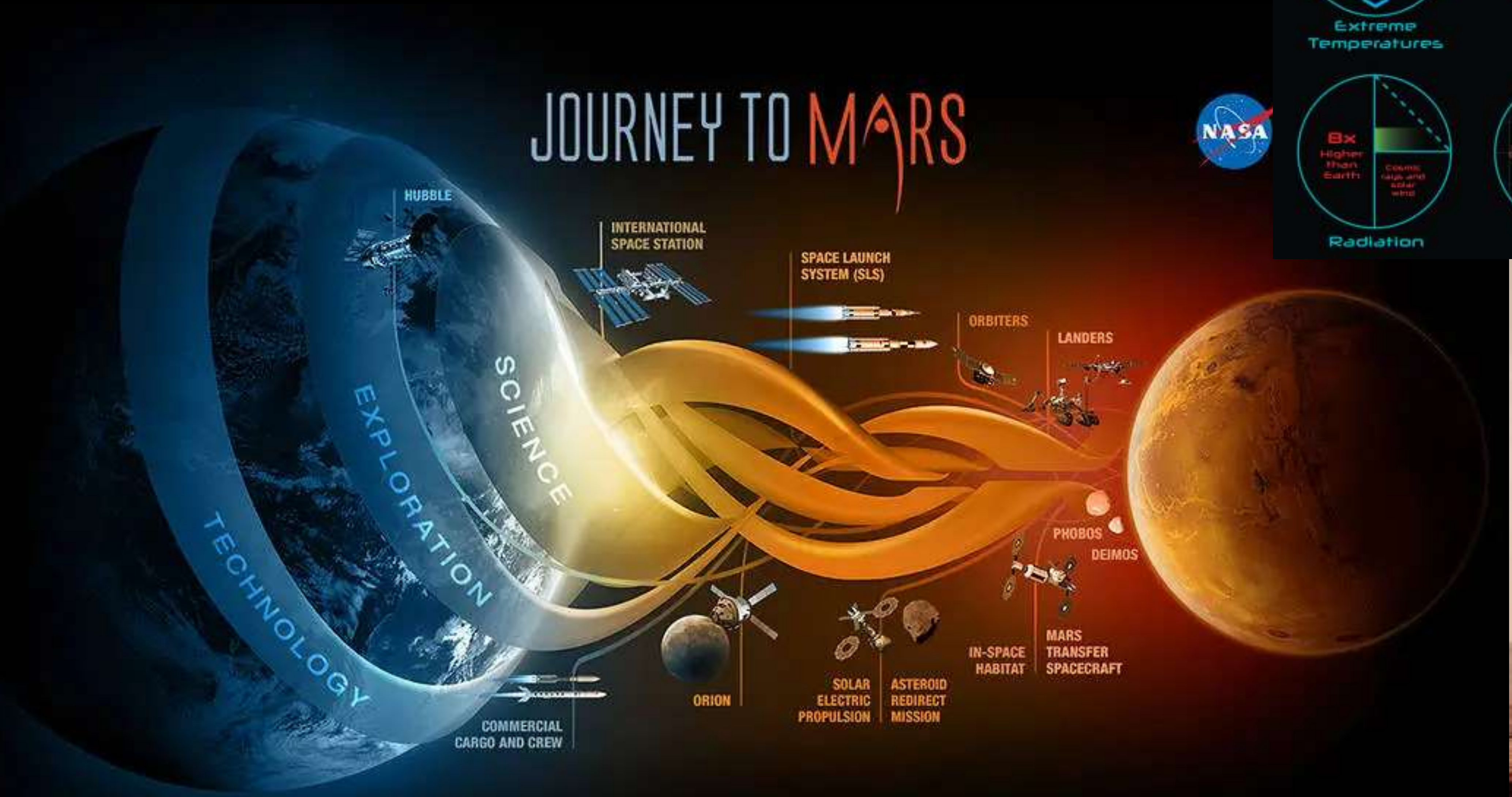
- Orbit around Mars in 2027 and map Phobos and Deimos
- Land on Phobos in 2029 and collect ≥10 grams
- Return samples to Earth in 2031
- **Science objective**: Determine the origin of the martian moons: captured asteroids or giant impact on Mars

MMX Science Team Meeting at APL
November 2024

Can Artemis and MMX missions help us on our journey to Mars?



CAESAR

Comet Astrobiology Exploration SAmple Return

Alexander Hayes (PI, Cornell U.)

Jessica Barnes (Deputy PI, U. Arizona)

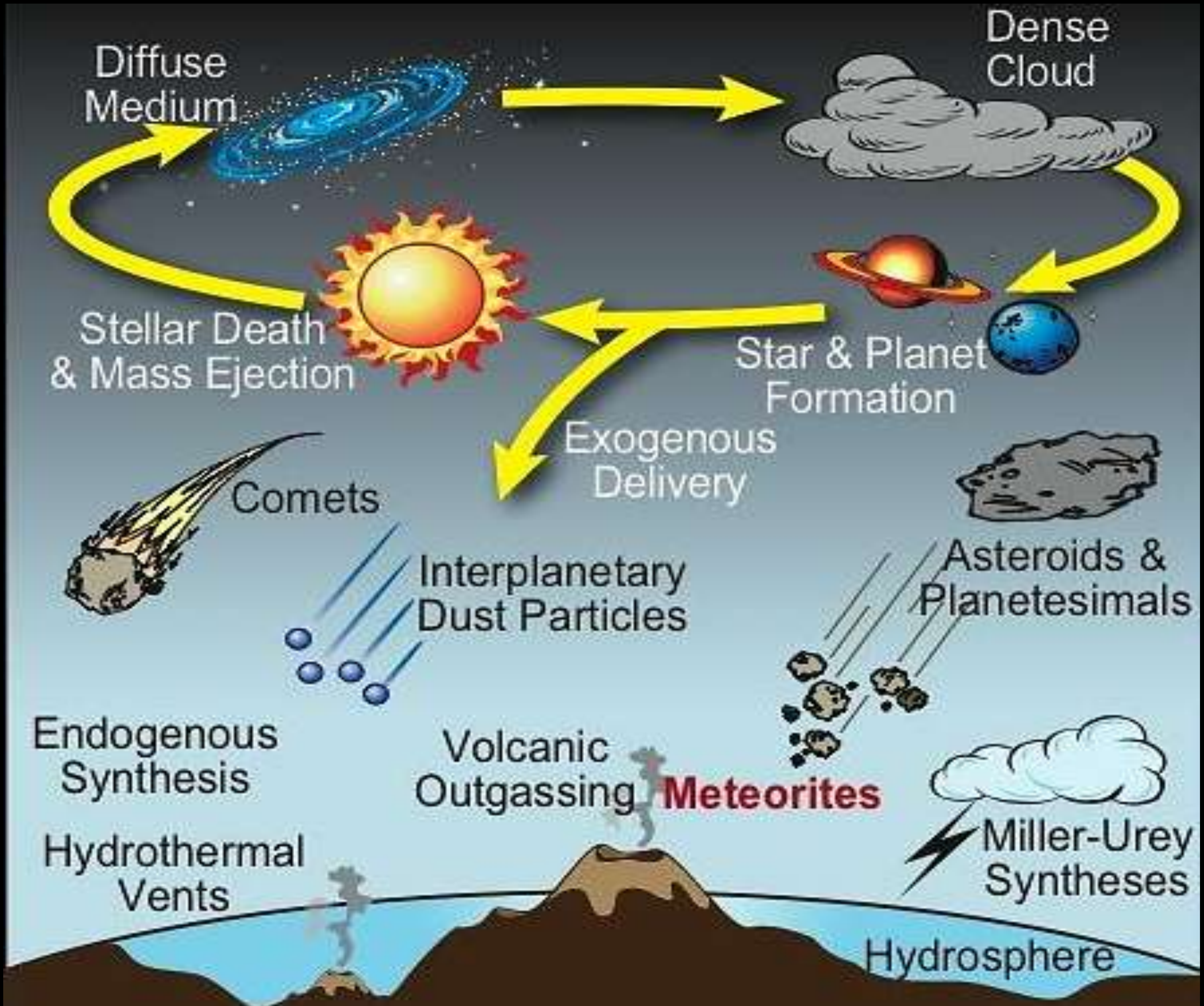
Danny Glavin (Project Scientist, GSFC)

Perry Gerakines, Stefanie Milam (DPS, GSFC)

Unraveling the Mystery of How Star Stuff Became Us

NASA Goddard SPACE FLIGHT CENTER arianeGROUP JAXA NORTHROP GRUMMAN

Approaches to Study Prebiotic Chemistry



After Deamer et al., (2002) Astrobiology 2:371-381

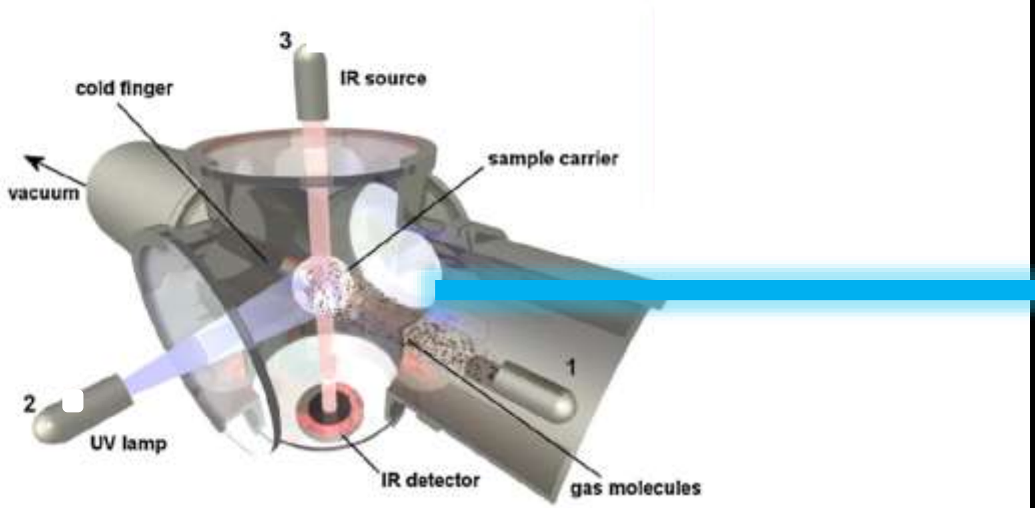
Remote Observations & Simulations

In situ measurements
Sample return missions

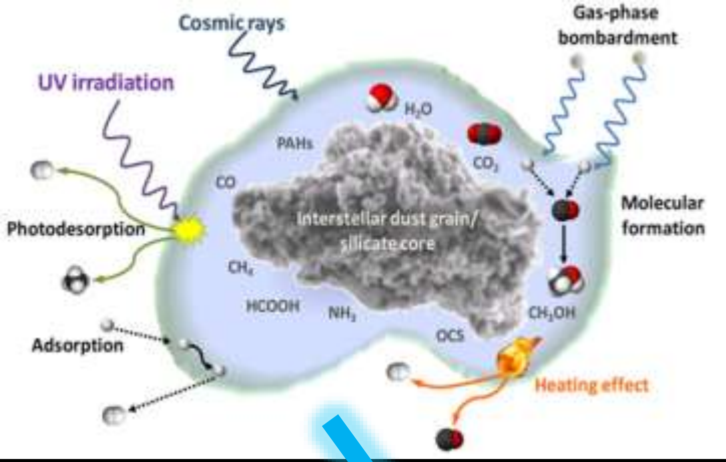
Lab Analyses

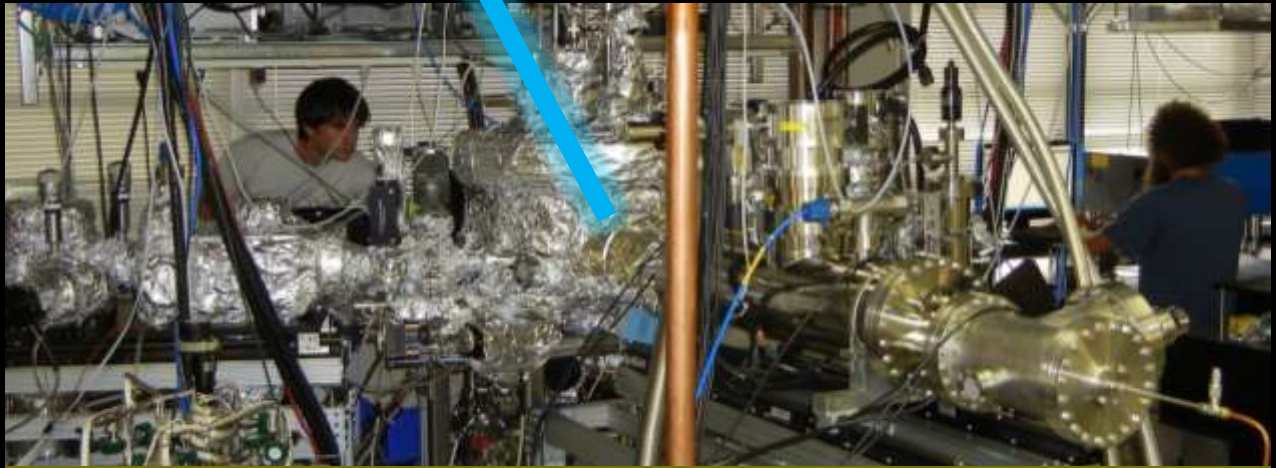
Simulations

Synthesis of Interstellar Ice Analogs



Meinert et al. (2011) *Physics of Life Reviews* 8: 307-330

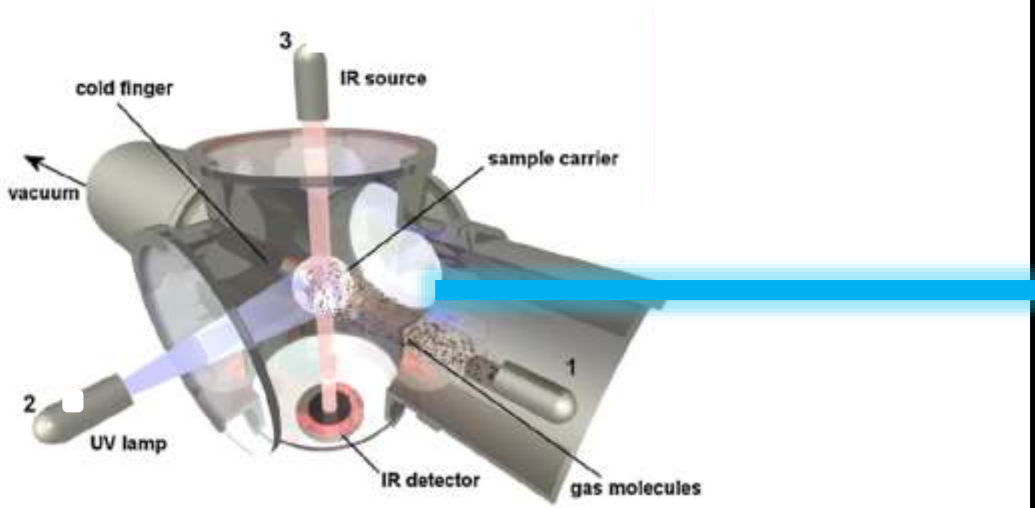




W. M. Keck Research Laboratory in Astrochemistry, Univ. of Hawaii at Manoa campus

d’Hendecourt et al. (2019) arXiv:1902.04575

Synthesis of Interstellar Ice Analogs



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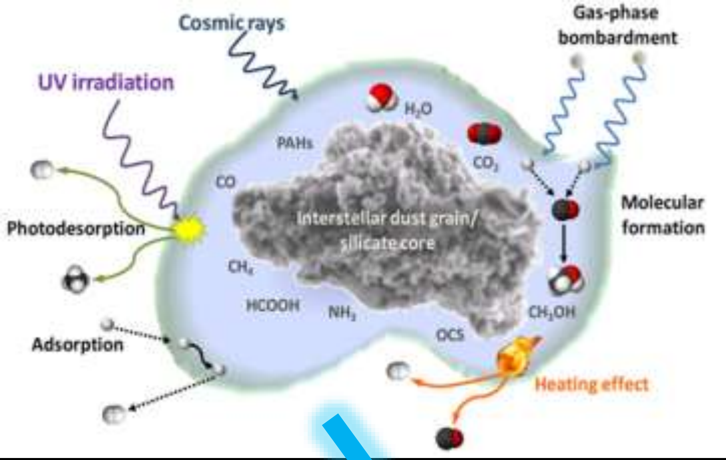
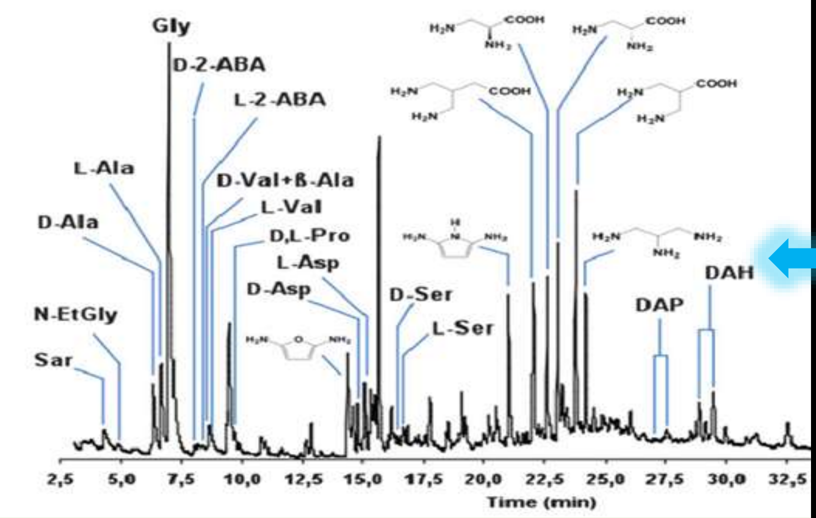


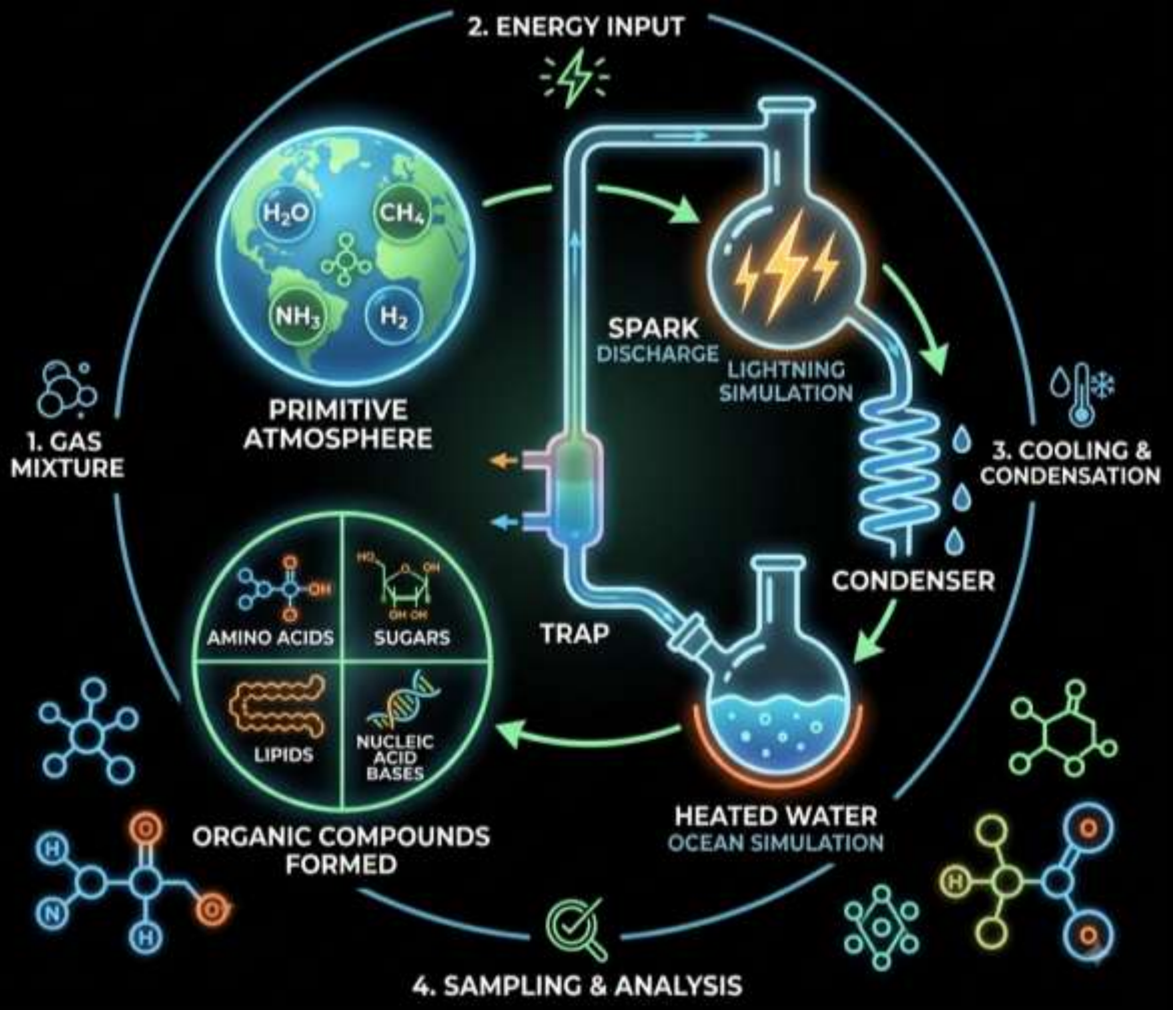
d'Hendecourt et al. (2019) arXiv:1902.04575



Muñoz Caro et al. (2002) *Nature* 416: 403-406

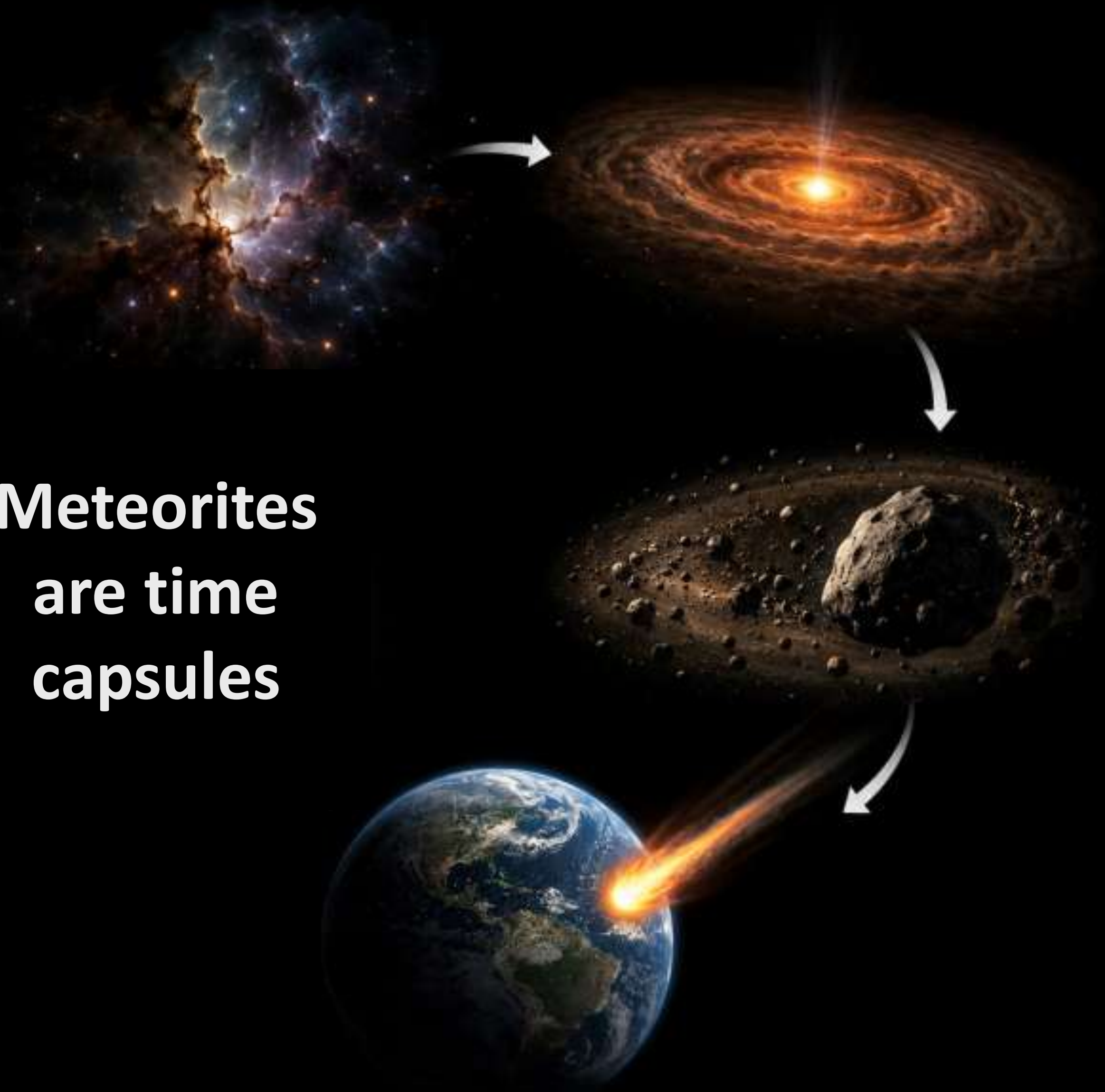
Prebiotic Chemistry: Miller-Urey Experiments

Stanley Miller (1953)



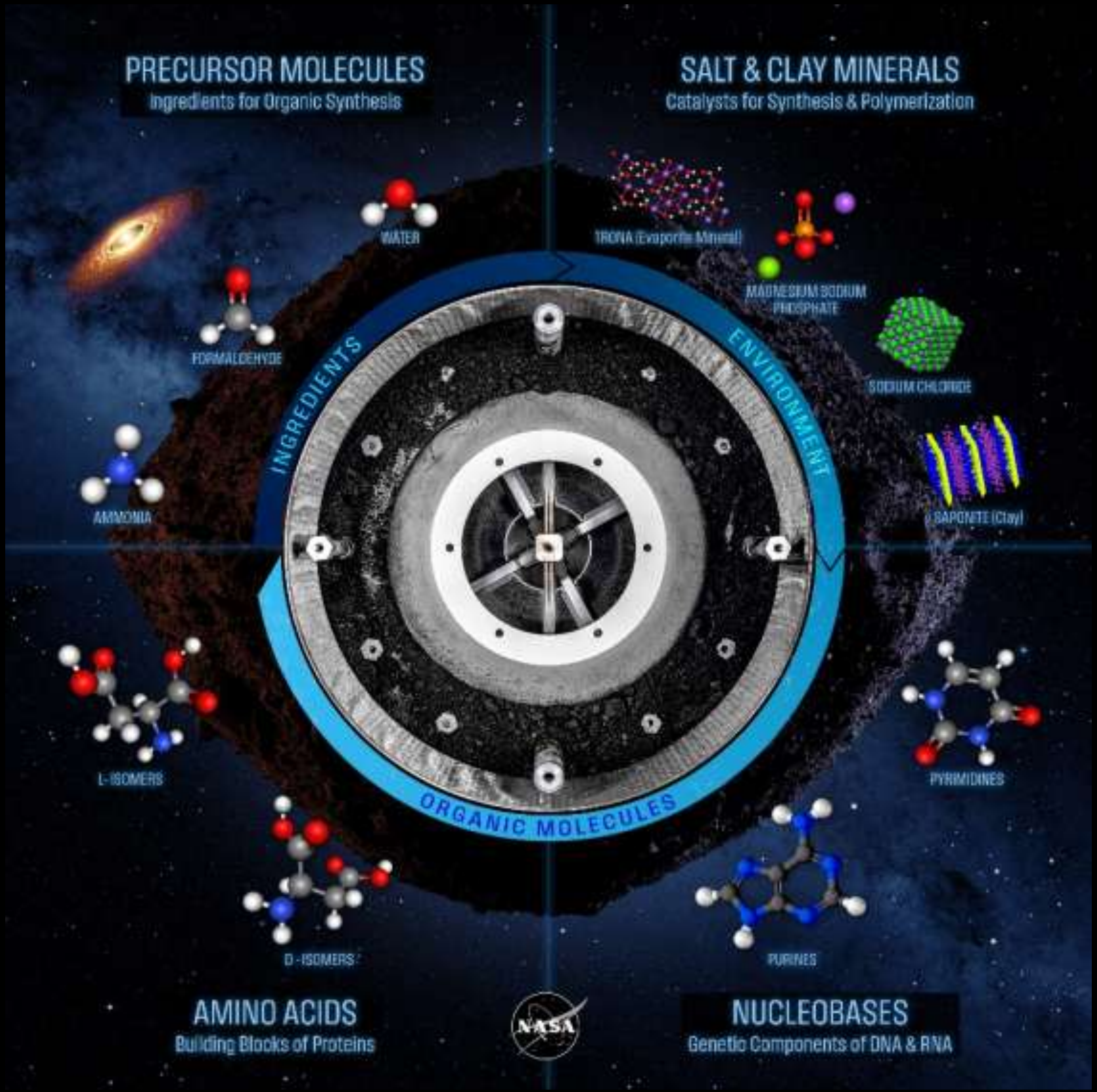
AI generated image

The Real Deal: Meteorites

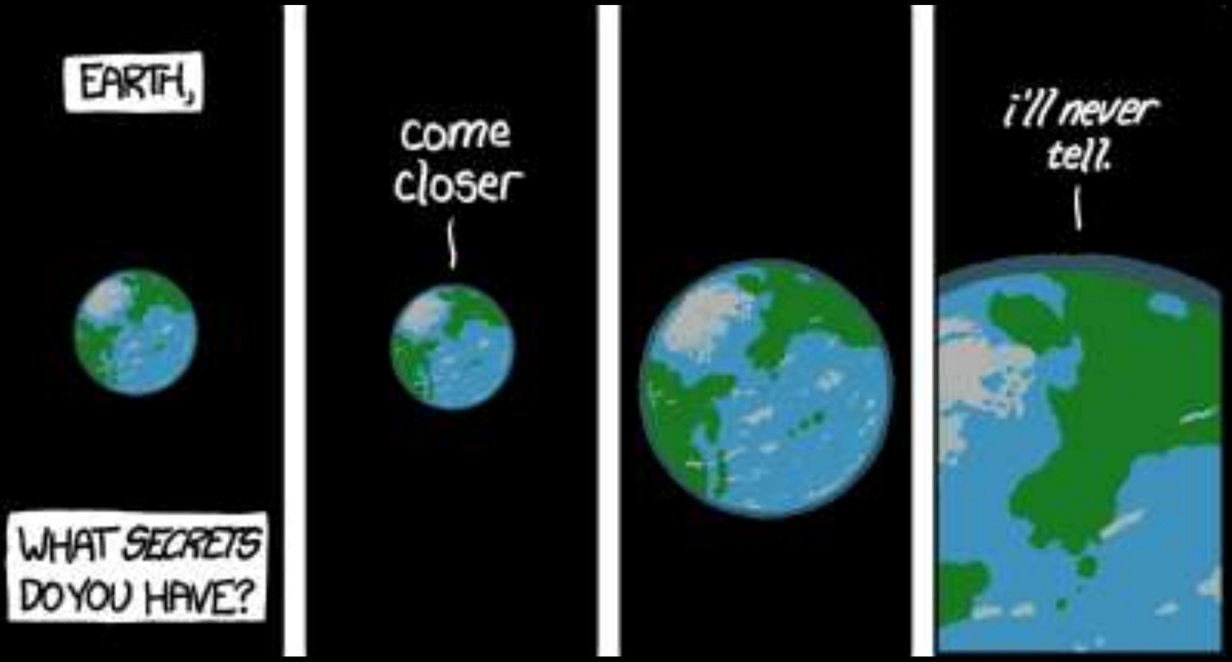


AI generated image

Meteorites are time capsules



NASA Goddard/Dan Gallagher



https://xkcd.com/1194/

The record of the origin of the Earth and of the origin of life,

has been

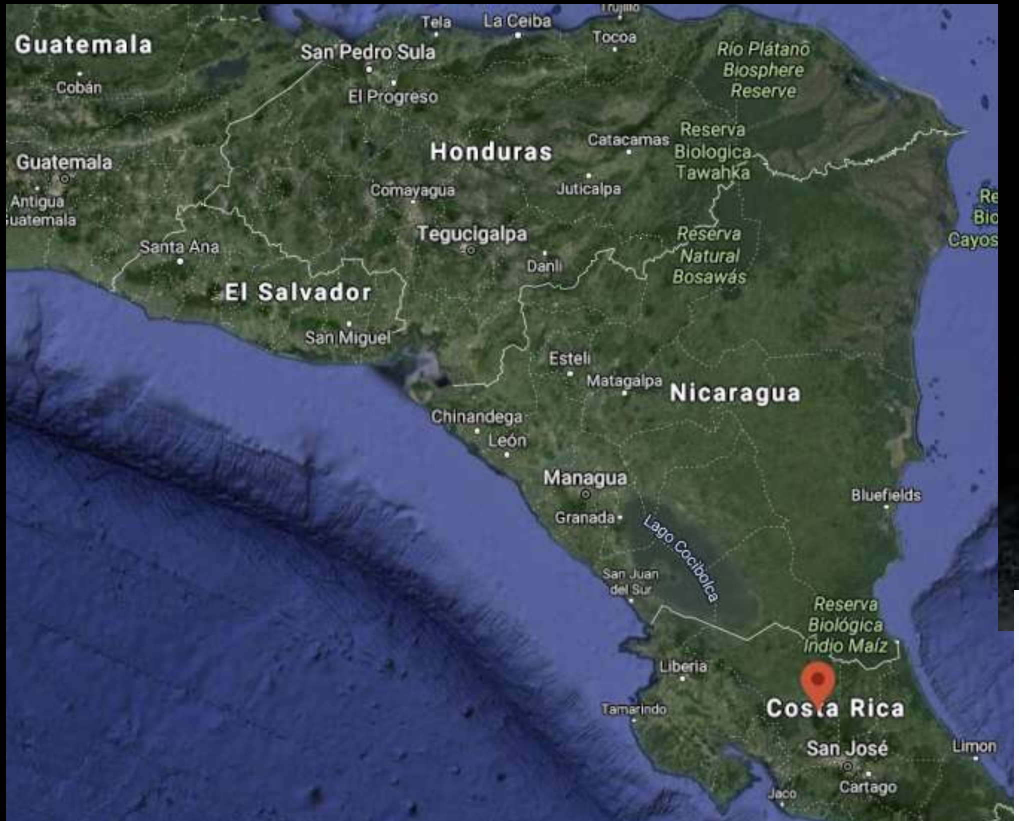
destroyed

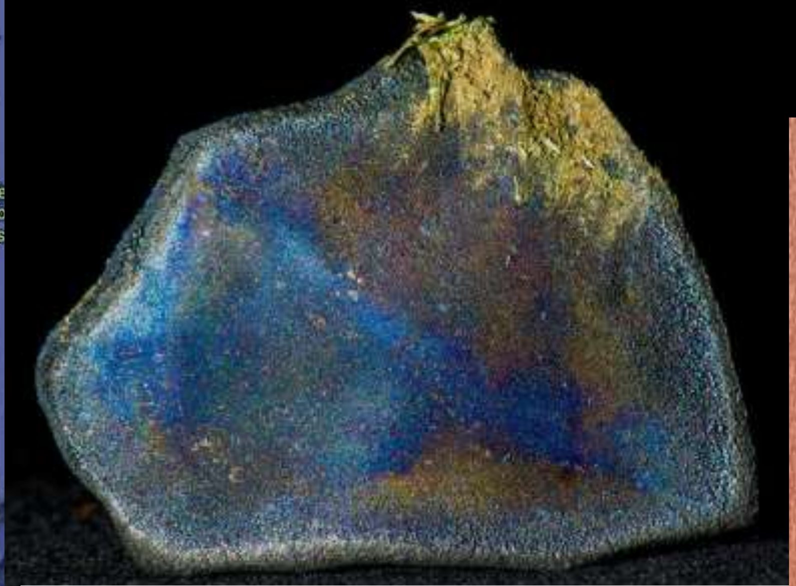
courtesy of…

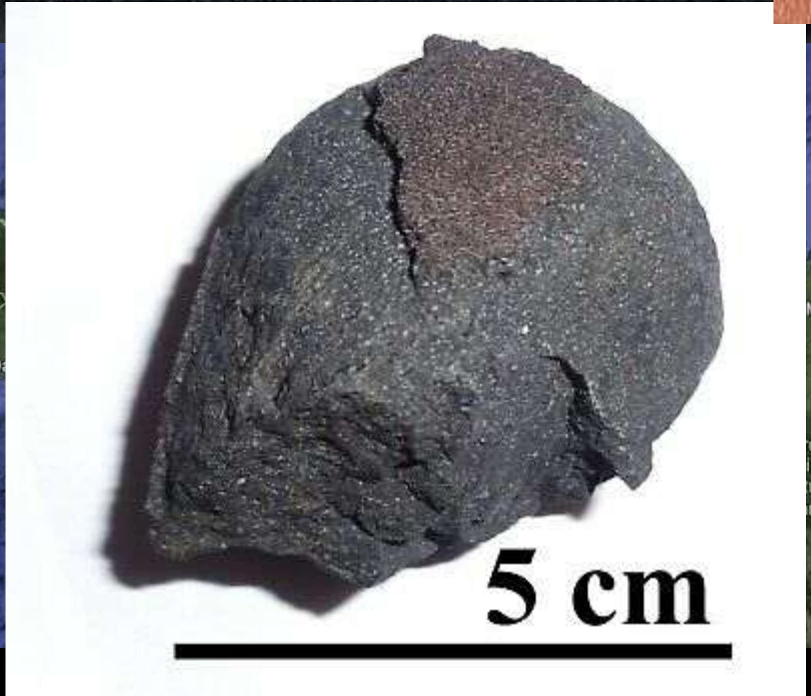
geologic processes and biology

Geologists have
a saying –
rocks remember.

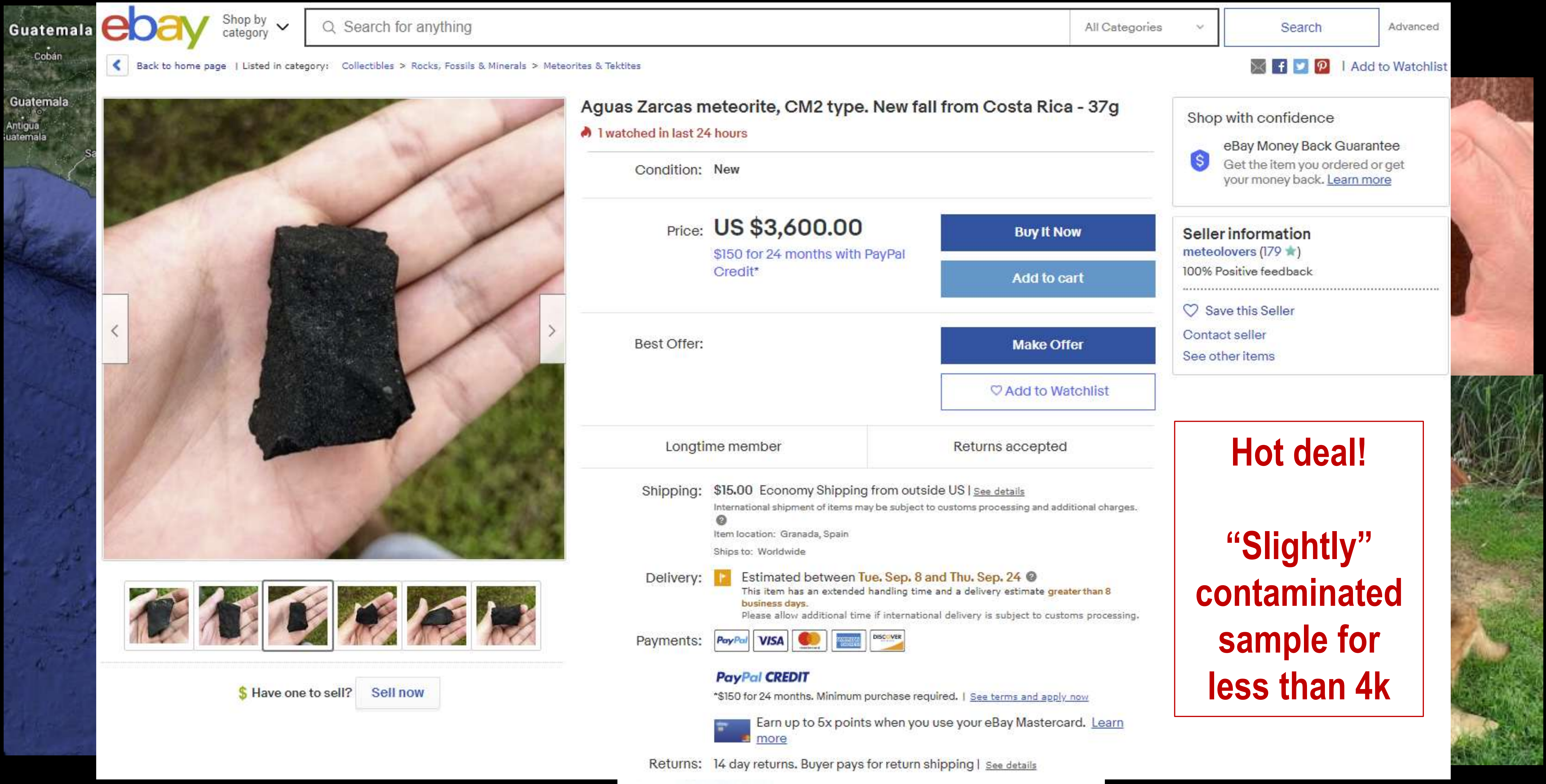
The Aguas Zarcas Meteorite (CM2)







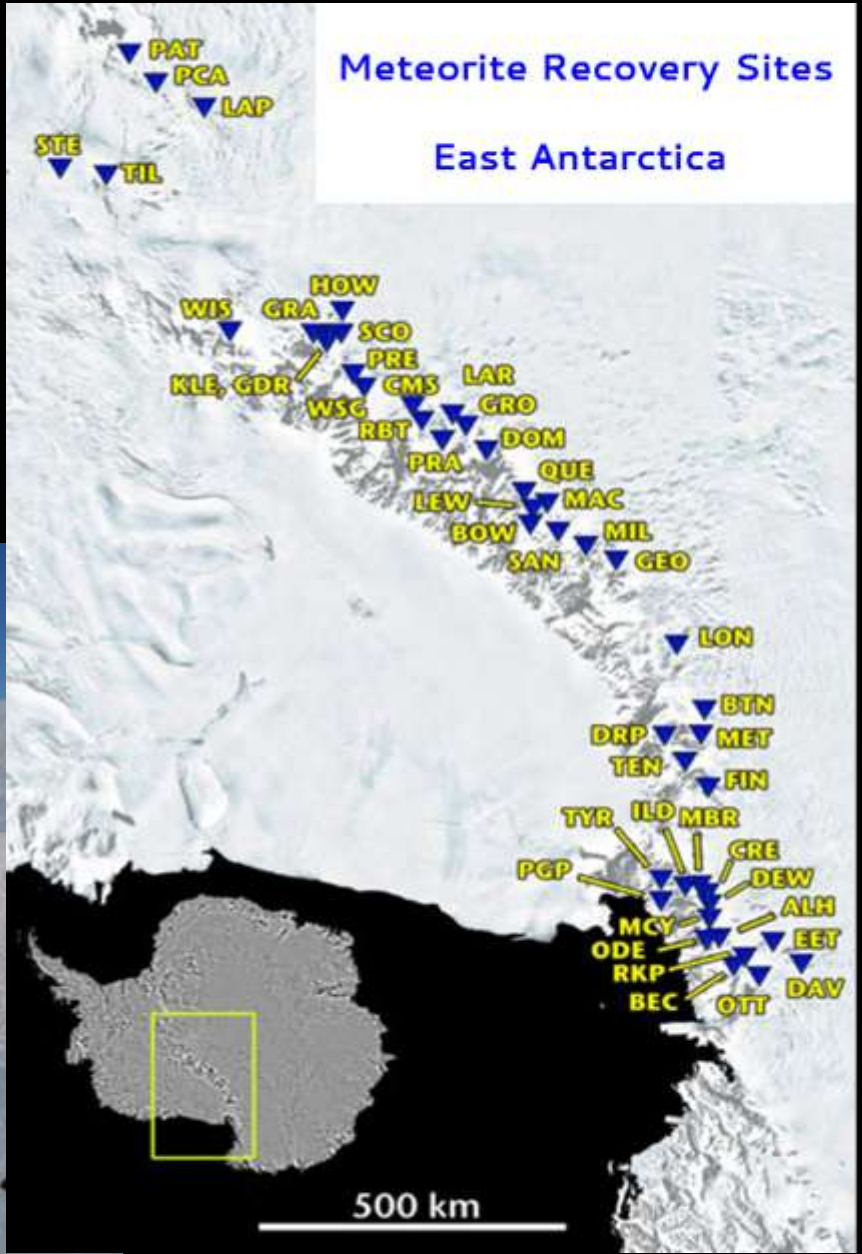
The Aguas Zarcas Meteorite (CM2)



Hot deal!

"Slightly" contaminated sample for less than 4k

Extraterrestrial Samples



Frozen in Time: Hunting Meteorites in Antarctica for Signs of Life
By: D. Glavin & E. Jarrell (2019; ISBN-10 : 1788303075)

Meteorite Classification

- **Irons** (~ 5% falls)
- **Stony Meteorites** (> 90% falls)
- **Stony-Irons** (~ 1% falls)

Stony Meteorites:

- **Chondrites** (with chondrules)
- **Achondrites** (lack chondrules)

Chondrites:

- **Ordinary** (~ 75% falls)
- **Carbonaceous** (~ 4% falls)
- **Enstatite** (~ 2% falls)
- **Other** (K and R type)

Carbonaceous:

CI	CM	CR	CO	CV	CK	CB	CH
Ivuna	Mighei	Renazzo	Ornans	Vigarano	Karoonda	Bencubbin	High Iron

Petrographic Type (Carbonaceous Chondrites)

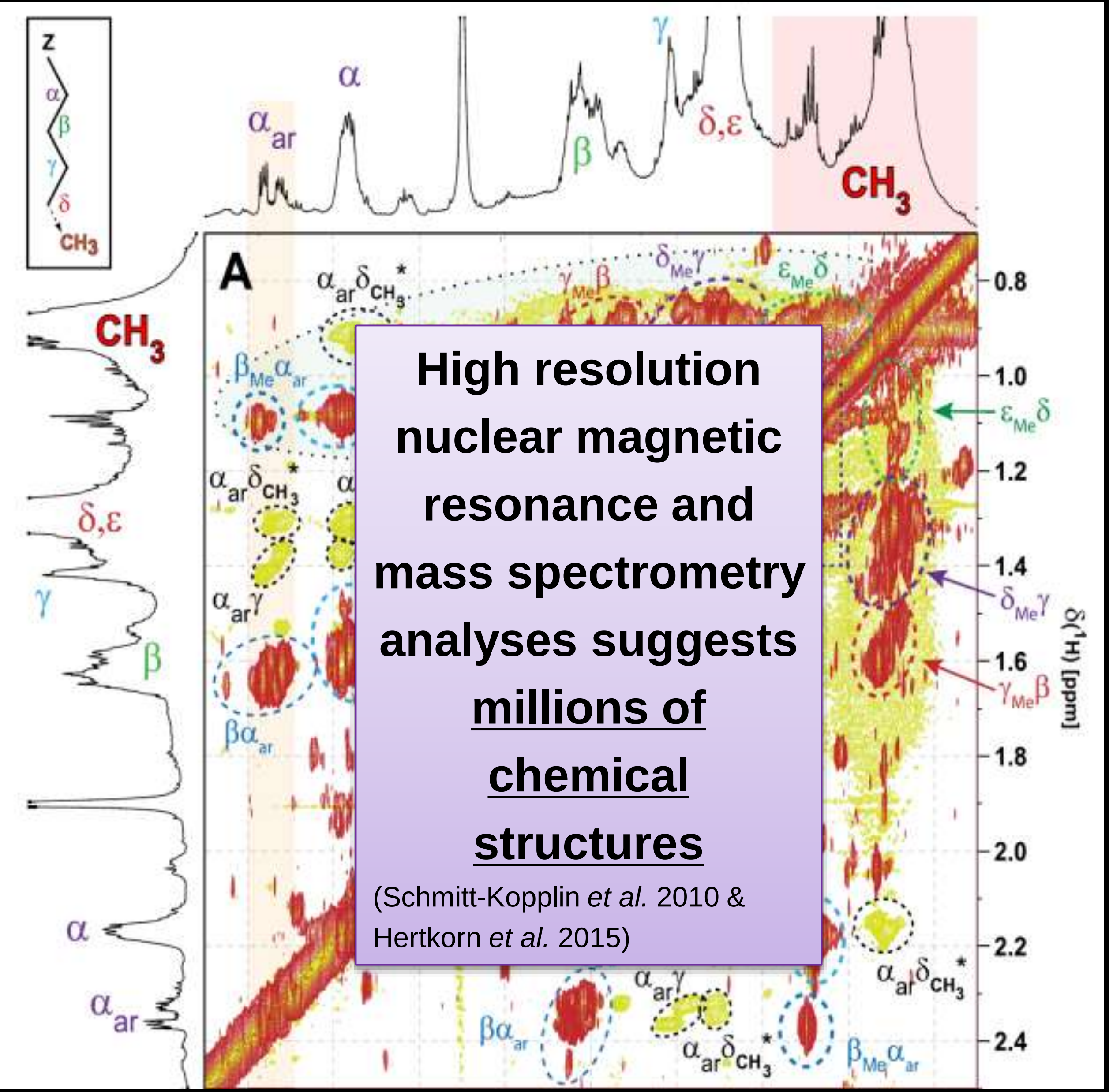
More AQUEOUS Alteration ← 1 2 3 4 5 6 → More THERMAL Metamorphism

Murchison (CM Type 2) is Organics Rich

Insoluble Organic Matter (IOM)	Abundance
Macromolecular material ($C_{100}H_{70}N_3O_{12}S_2$)	70-99% total organic carbon

Soluble Organic Matter (SOM)	Concentration (ppm)
Carboxylic acids	**100-700**
Polar hydrocarbons	<120
Sulfonic acids	68
Amino acids (92 named)	**70**
Dicarboxyimides	>50
Aliphatic hydrocarbons	>35
Dicarboxylic acids	>30
Polyols	30
Aromatic hydrocarbons	**15-28**
Hydroxy acids	**15**
Amines	**4-20**
Pyridine carboxylic acids	>7
N-heterocycles	**7**
Phosphonic acids	2
Purines and pyrimidines	**1**

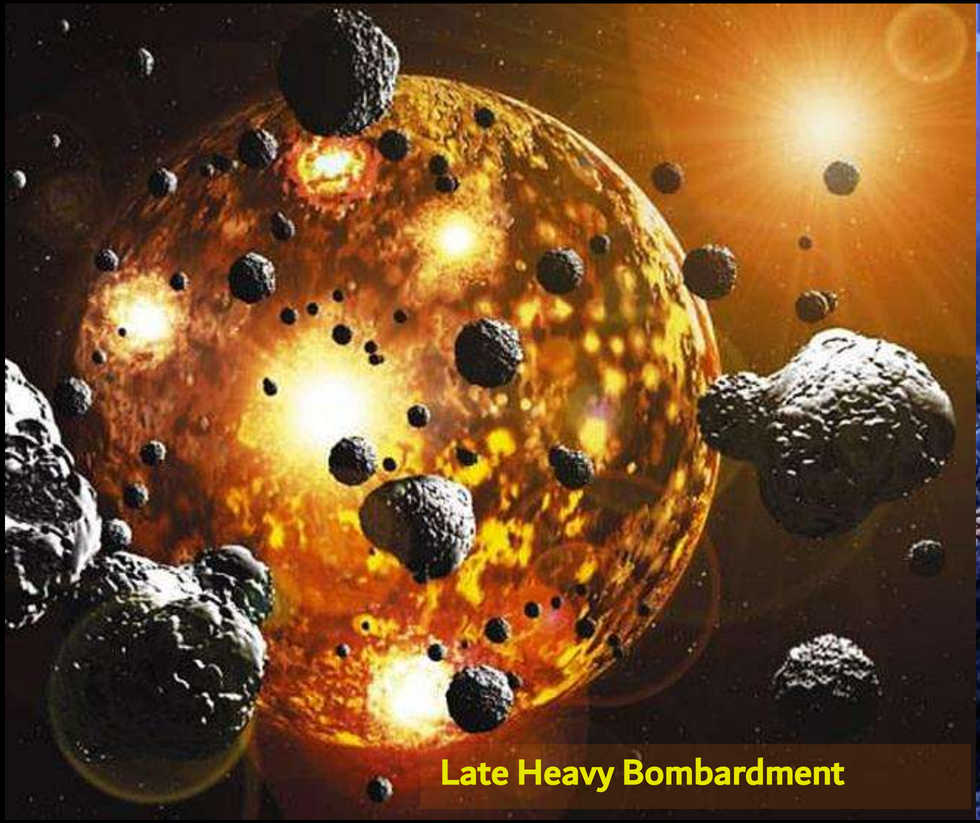
After *Primitive Meteorites and Asteroid* (2018) Glavin et al., pp. 205-271, ed. N. M. Abreu.



Origins of Life on Earth

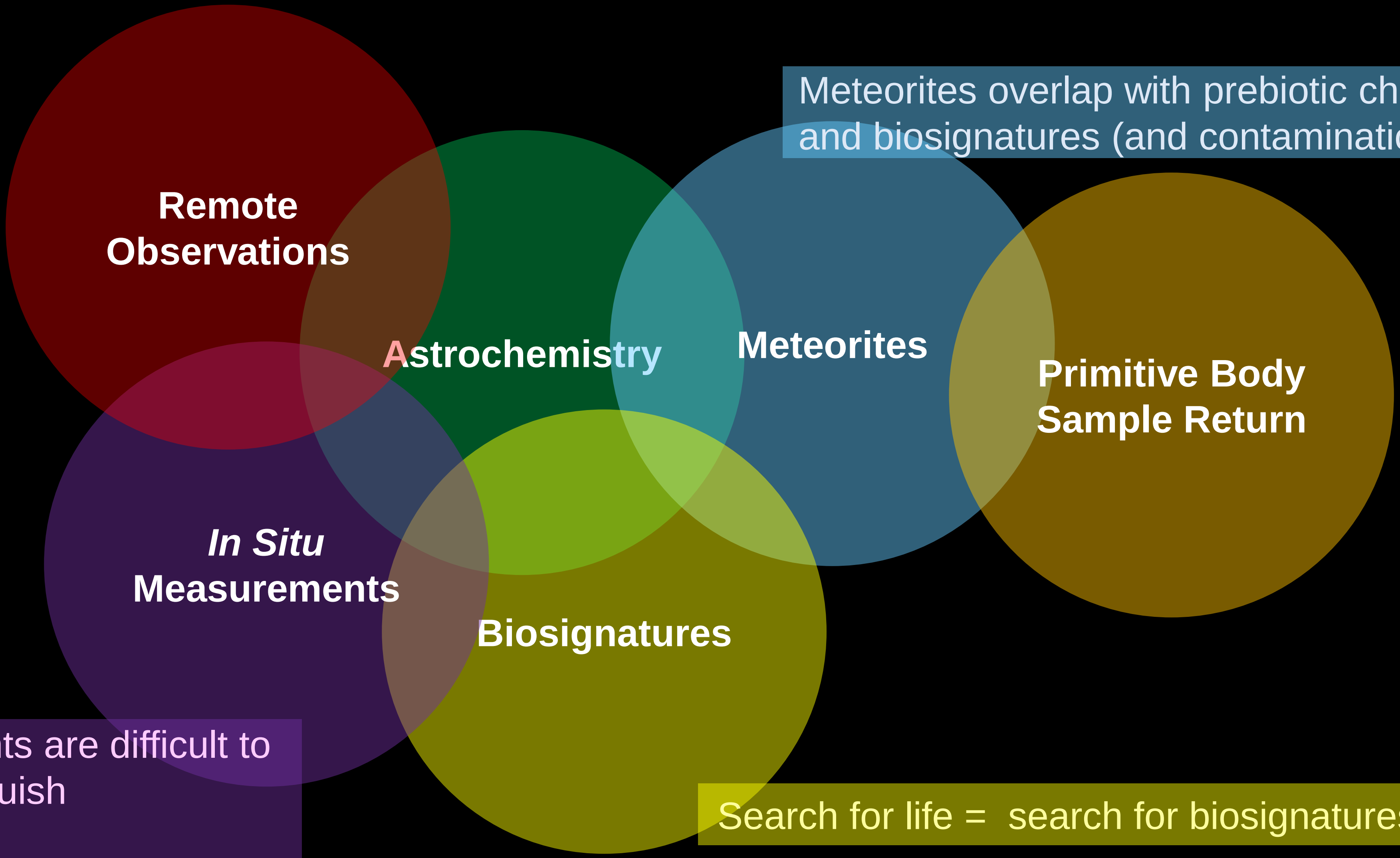
- ✓ Today, 30,000 tons of cosmic dust fall to Earth each year
- ✓ 3.8 billion years ago, this amount was 1000 times larger

A hell of a delivering water and organic


Late Heavy Bombardment


Early Earth

Connecting Some Dots in Astrochemistry



Meteorites overlap with prebiotic chemistry and biosignatures (and contamination)

In situ measurements are difficult to convincingly distinguish biosignatures

Search for life = search for biosignatures