Sample Return Missions: OSIRIS-REx

José Carlos Aponte

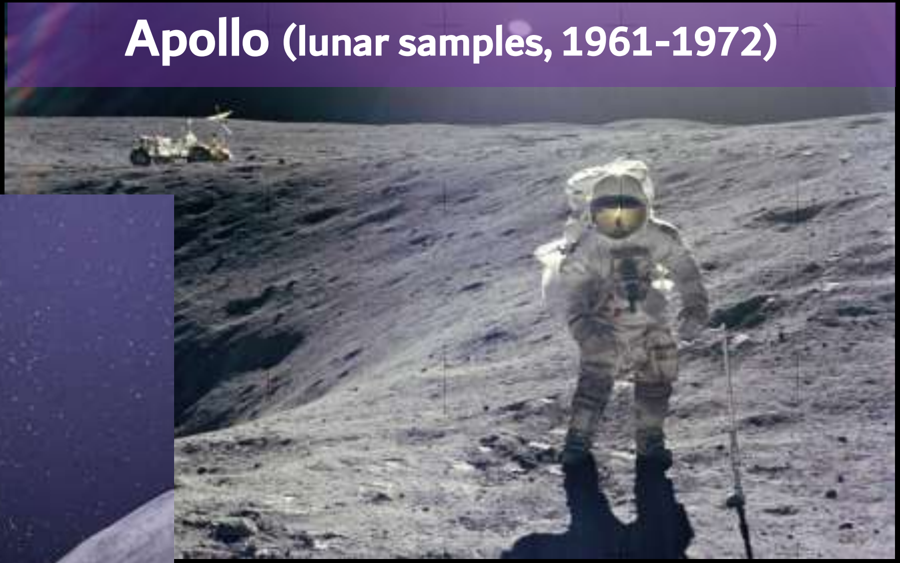
VI AstrobiON
Escola de Astrobiologia do Observatório Nacional, Rio de Janeiro, Brazil
September 17th, 2026

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

Beyond Meteorites: Sample Return Missions

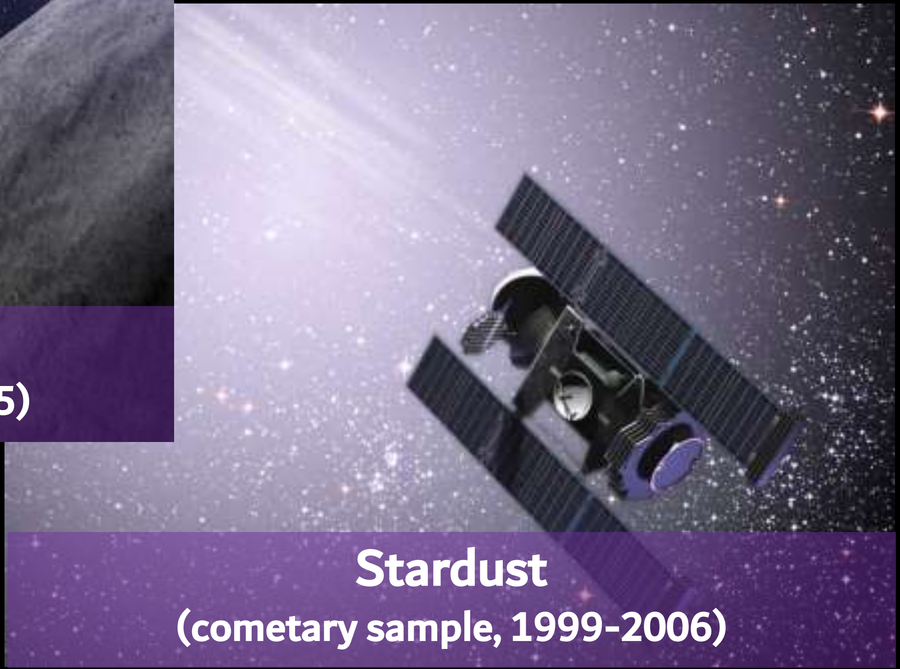
Analysis of meteorites is complicated by lack of context on their origin and potential contamination and weathering

Sample return missions offer new



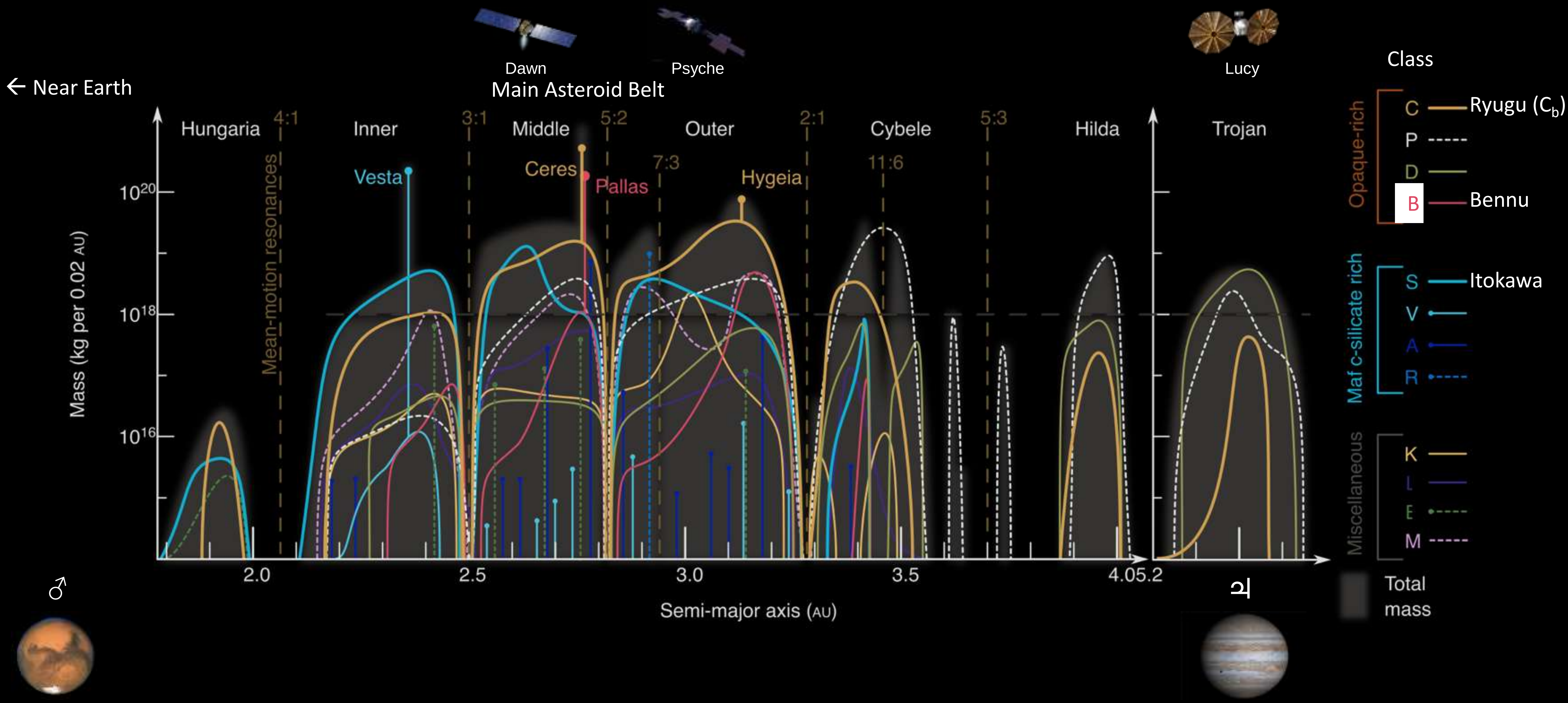
Apollo (lunar samples, 1961-1972)

OSIRIS-REx
(asteroid sample, 2016-2025)



Stardust
(cometary sample, 1999-2006)

Different Sources of Asteroids



DeMeo & Carry (2014) *Nature* 505:629

OSIRIS-REx

Origins

Return and analyze a sample of pristine carbonaceous asteroid regolith

Spectral Interpretation

Provide ground truth for telescopic data of the entire asteroid population

Resource Identification

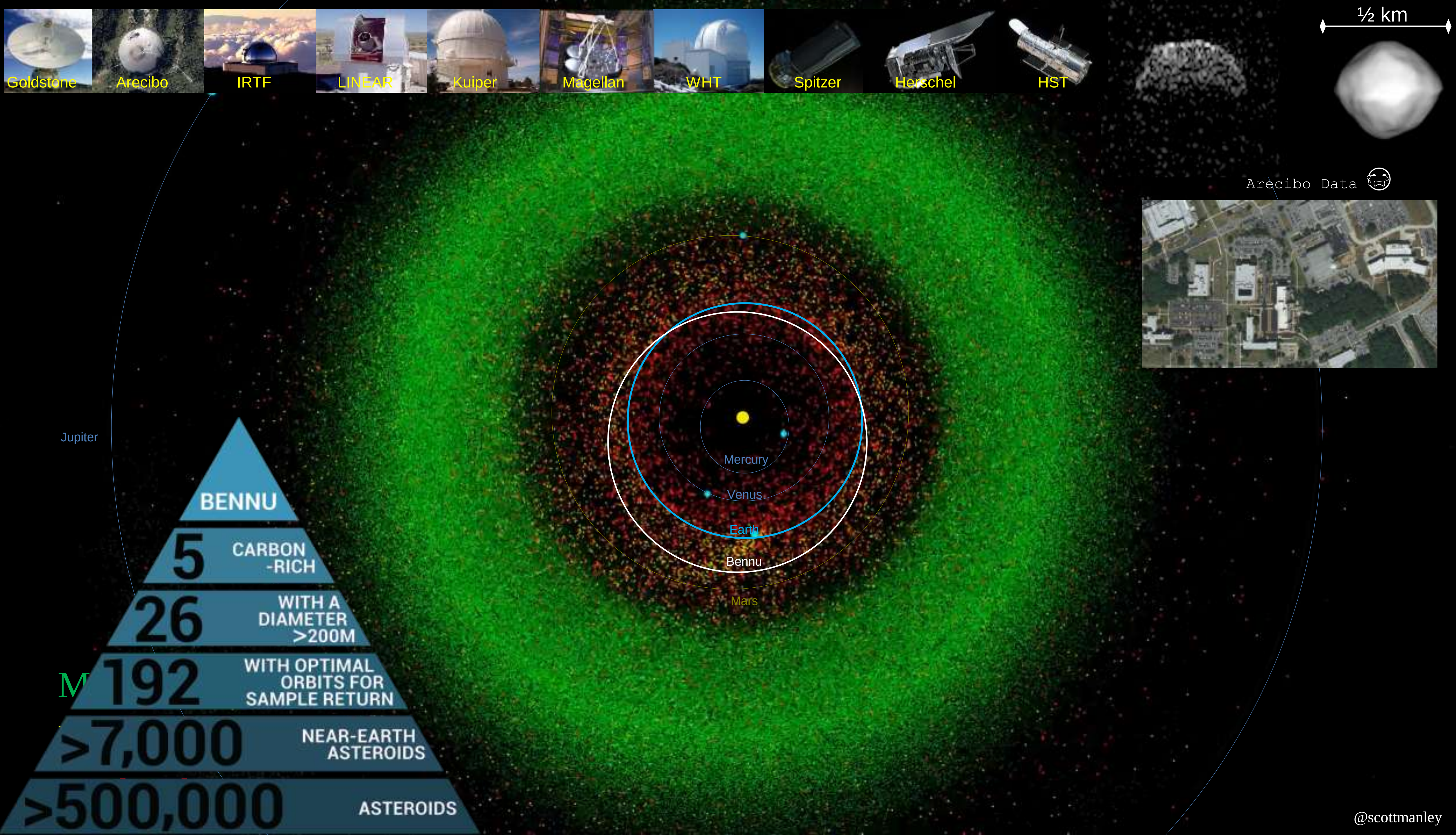
Map the chemistry and mineralogy of a primitive carbonaceous asteroid

Security

Measure the Yarkovsky effect on a potentially hazardous asteroid

Regolith Explorer

Document the regolith at the sampling site at scales down to the sub-cm



Goldstone
Arecibo
IRTF
LINEAR
Kuiper
Magellan
WHT
Spitzer
Herschel
HST
½ km
Arecibo Data
Jupiter
Mercury
Venus
Earth
Bennu
Mars
BENNU
5 CARBON -RICH
26 WITH A DIAMETER >200M
192 WITH OPTIMAL ORBITS FOR SAMPLE RETURN
>7,000 NEAR-EARTH ASTEROIDS
>500,000 ASTEROIDS

TAGSAM (LM)
Collects the sample

REXIS (MIT) Student Experiment maps the elemental abundances

SRC (LM) Returns the sample

OCAMS (UA) **PolyCam** >500K-km range, high-resolution imaging of the surface, **SamCam** images the sample site and TAG, **MapCam** provides landmark-tracking, filter photometry.

OLA (CSA) ranging to 7 km and maps the asteroid shape and surface topography

OTES (ASU) maps the thermal flux and spectra from 5 – 50 µm

NavCams (MSSS) navigates the surface of Bennu

OVIRS (GSFC) maps the reflectance albedo and spectra from 0.4 – 4.3 µm

Highly capable, nimble spacecraft

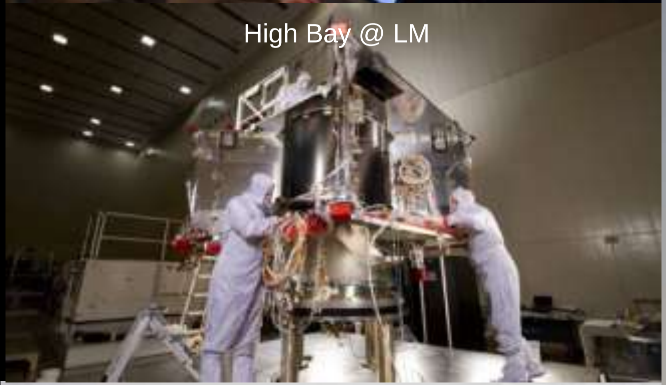
Path to Launch

Early Concept

Volume 2 of the Step 2 Proposal

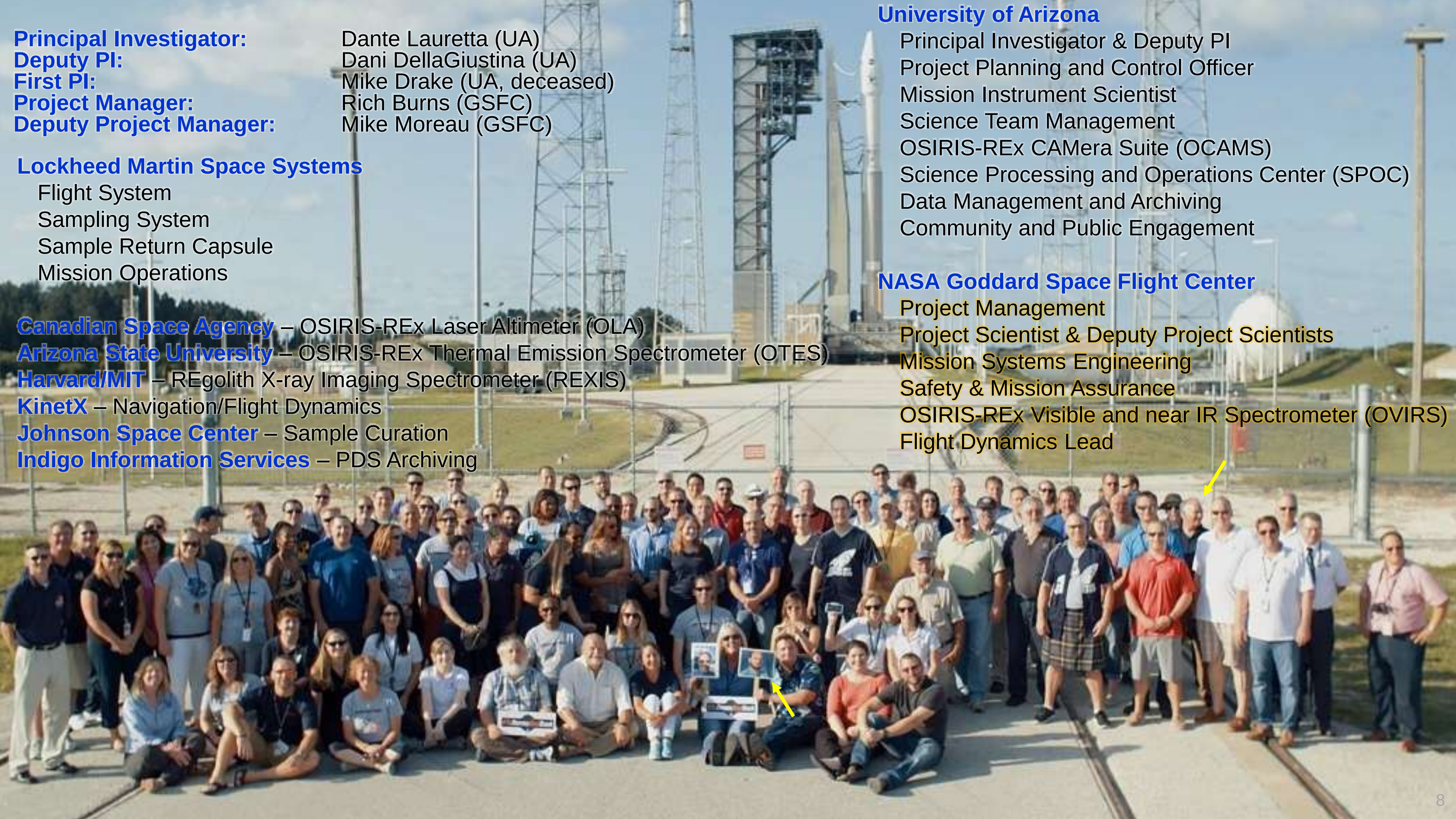
Discovery 11 Proposal	July 16, 2004
Non-selection	Feb 2, 2005
Discovery 12 Proposal	Mar 27, 2006
Down Select (KDP-A)	Oct 30, 2006
Step 2 Proposal	June 20, 2007
Site Visit	Aug 21, 2007
Non-selection	Dec 11, 2007
New Frontiers 3 Proposal	July 31, 2009
Down Select (KDP-A)	Dec 17, 2009
Step 2 Proposal	Jan 28, 2011
Site Visit	Apr 14, 2011
Selection (KDP-B)	May 25, 2011
MDR	May 8-10, 2012
PDR	Mar 4-8, 2013
Confirmation (KDP-C)	June 1, 2013
CDR (KDP-D)	Apr 1-9, 2014
Start of ATLO	March 23, 2015
PER	Oct 14-16, 2015
PSR	May 10-11, 2016
Ship to KSC	May 20, 2016
FOR / ORR	Jun 21-24, 2016
SMSR	Aug 9, 2016
MRB / KDP-E	Aug 18, 2016
FRR	Sep 1, 2016
LRR	Sep 6, 2016
Launch	Sep 8, 2016

Another Review @ LM



High Bay @ LM

PHSF @ KSC



Principal Investigator: Dante Lauretta (UA)
Deputy PI: Dani DellaGiustina (UA)
First PI: Mike Drake (UA, deceased)
Project Manager: Rich Burns (GSFC)
Deputy Project Manager: Mike Moreau (GSFC)

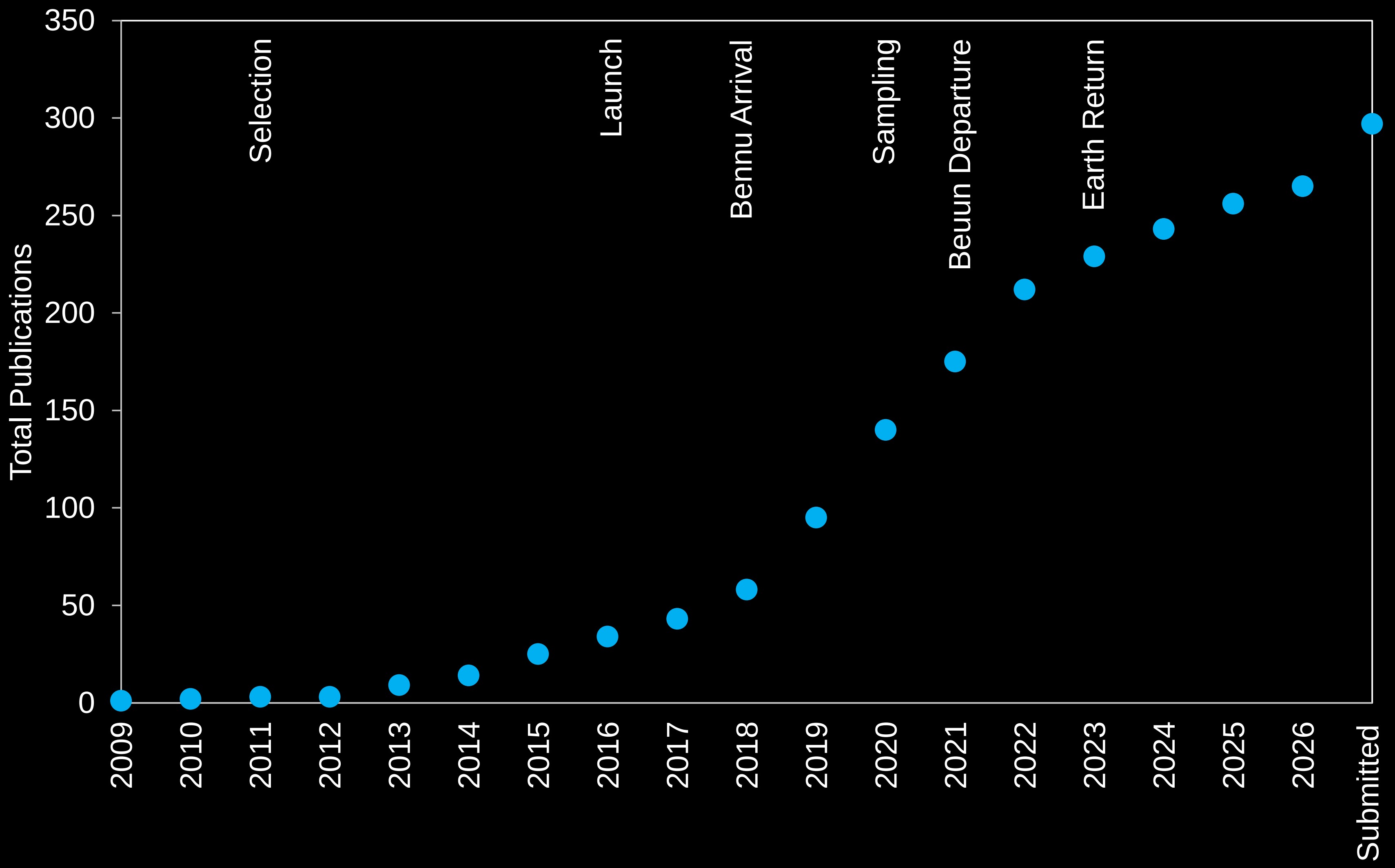
Lockheed Martin Space Systems
- Flight System
- Sampling System
- Sample Return Capsule
- Mission Operations

Canadian Space Agency – OSIRIS-REx Laser Altimeter (OLA)
Arizona State University – OSIRIS-REx Thermal Emission Spectrometer (OTES)
Harvard/MIT – REgolith X-ray Imaging Spectrometer (REXIS)
KinetX – Navigation/Flight Dynamics
Johnson Space Center – Sample Curation
Indigo Information Services – PDS Archiving

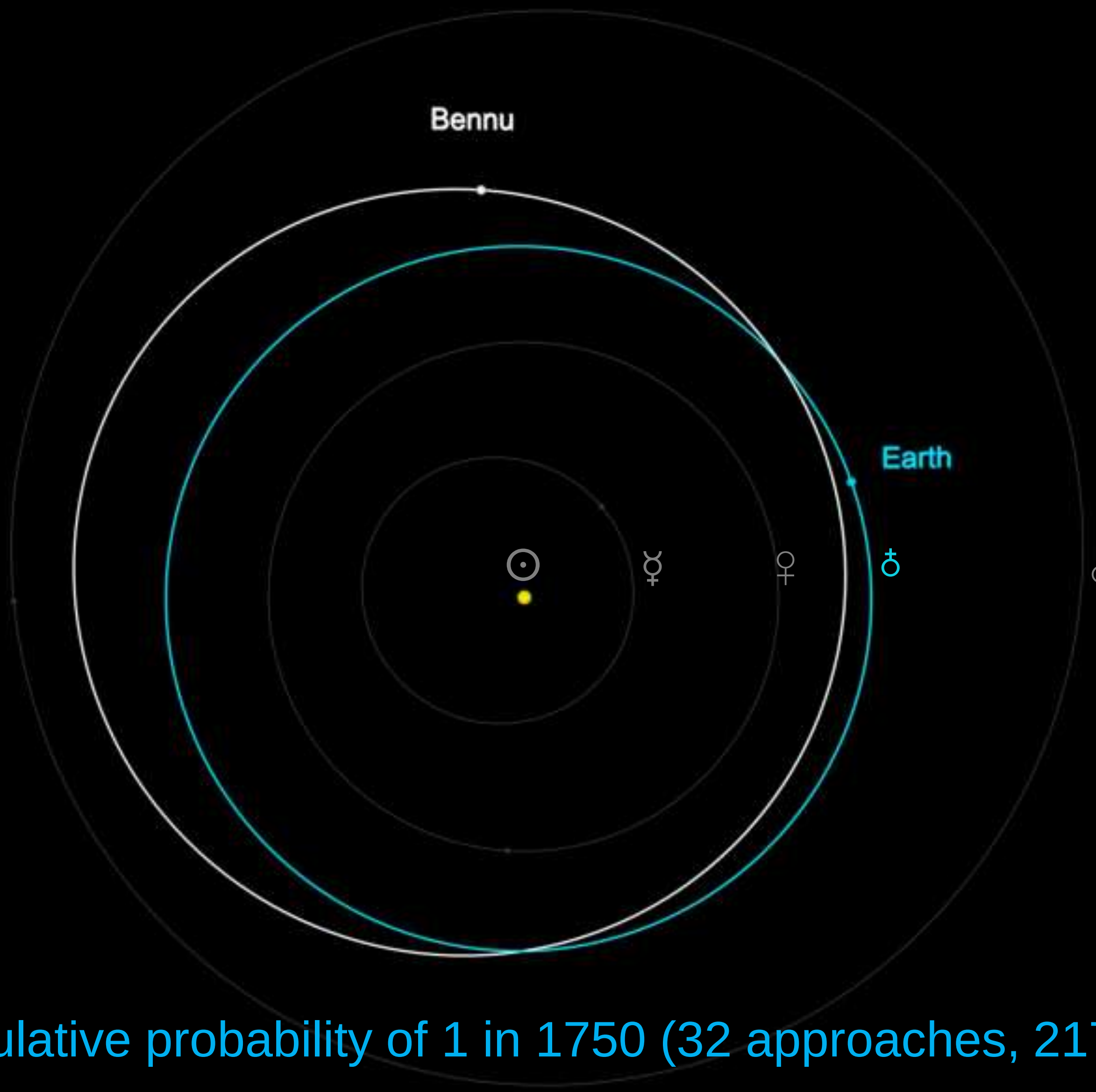
University of Arizona
- Principal Investigator & Deputy PI
- Project Planning and Control Officer
- Mission Instrument Scientist
- Science Team Management
- OSIRIS-REx CAMera Suite (OCAMS)
- Science Processing and Operations Center (SPOC)
- Data Management and Archiving
- Community and Public Engagement

NASA Goddard Space Flight Center
- Project Management
- Project Scientist & Deputy Project Scientists
- Mission Systems Engineering
- Safety & Mission Assurance
- OSIRIS-REx Visible and near IR Spectrometer (OVIRS)
- Flight Dynamics Lead

OSIRIS-REx Team Scientific Productivity



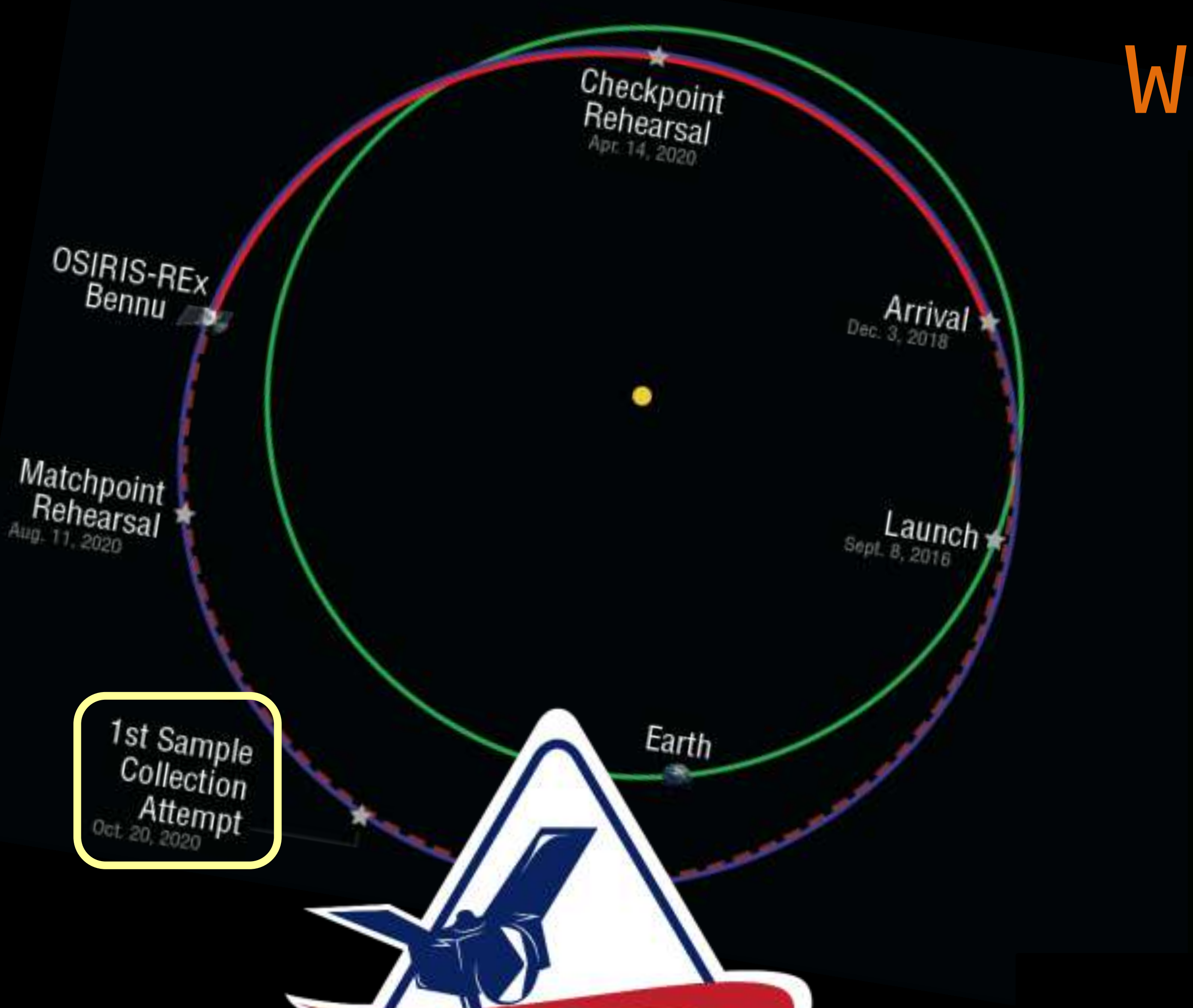
Refined Bennu Impact Probability



Jan 2135

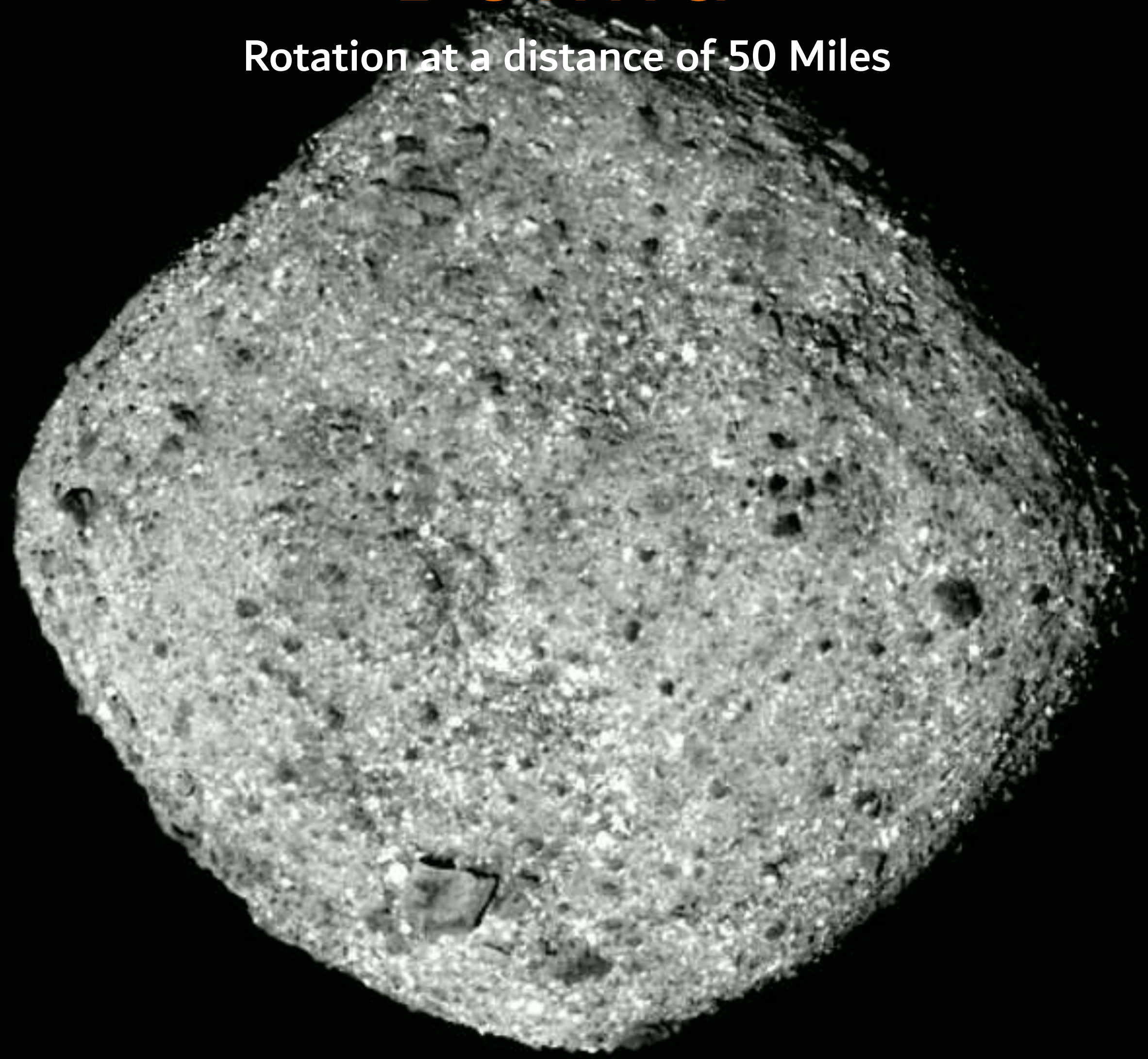
Cumulative probability of 1 in 1750 (32 approaches, 2179-2300)

Simulation



Welcome to asteroid Bennu

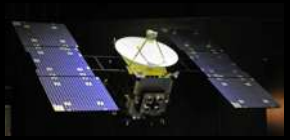
Rotation at a distance of 50 Miles



OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

https://www.asteroidmission.org

Comparing Asteroids



(25143) Itokawa
0.5 x 0.3 x 0.2 km
Hayabusa 2005

Bus: 1.5x1.5x1m
Wet mass: 530 kg

(162173) Ryugu
1 km
Hayabusa2 2018

Bus: 1.6x1.4x1m
Wet mass: 600 kg

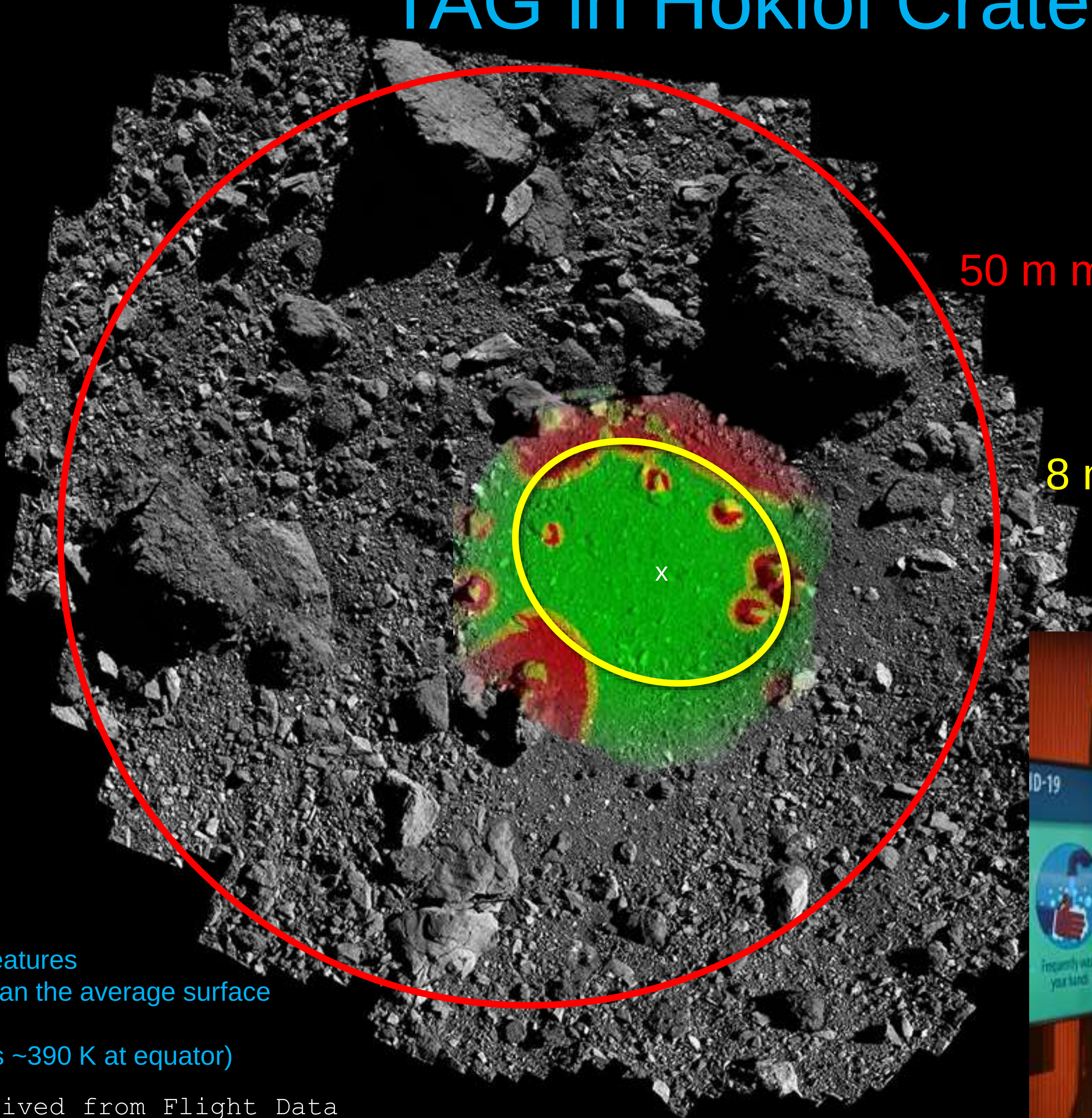
(101955) Bennu
0.5 km
OSIRIS-REx 2018

Bus: 3.1x3.1x2.7m
Wet mass: 1529 kg

½x¼x¼ km Rubble Pile, Bilobar, 2 Spin Axes	X	1 km Rubble Pile, Spinning Top, Retrograde	✓	½ km Rubble Pile, Spinning Top, Retrograde
Earth-Crossing, 1.32 AU Semimajor Axis	X	Earth-Crossing, 1.19 AU Semimajor Axis	✓	Earth-Crossing, 1.13 AU Semimajor Axis
Flora Dynamical Family	X	Eulalia or Polana Dynamical Family	✓	Eulalia or Nysa-Polana Dynamical Family
1.9 g/mL	X	1.19 g/mL	✓	1.19 g/mL
23% Albedo, Class S	X	4.4% Albedo, Class C_b	✓	4.6% Albedo, Class B
Dehydrated pyroxenes	X	Dehydrated phyllosilicates, carbonate	~	Hydrated phyllosilicates, carbonate, pyroxene xenoliths

After Oba, et al. (2023) *Nature Communications*, 14:3107

TAG in Hokioi Crater



50 m mission design TAG ellipse

8 m TAG ellipse at Nightingale site

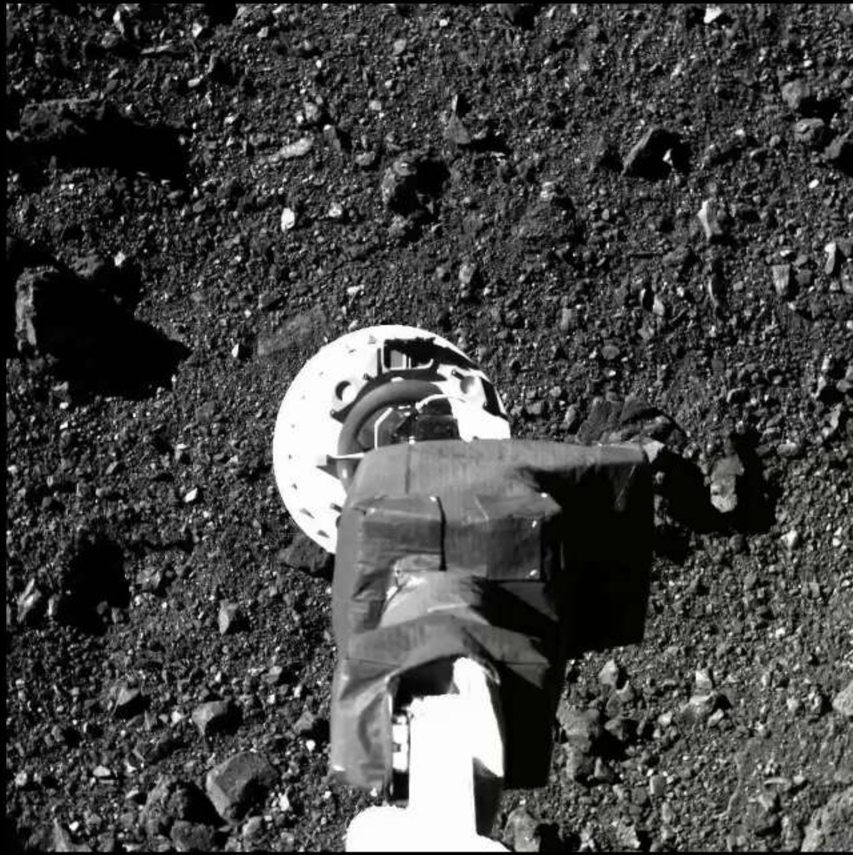
TAG 73 cm from center

20 October 2020

Among the youngest impact features
Spectrally redder in VISNIR than the average surface
Mid-latitude (56˚,43˚) location
Limited peak T ~360 K (versus ~390 K at equator)

Flight Imagery and Derived from Flight Data

TAG Crater

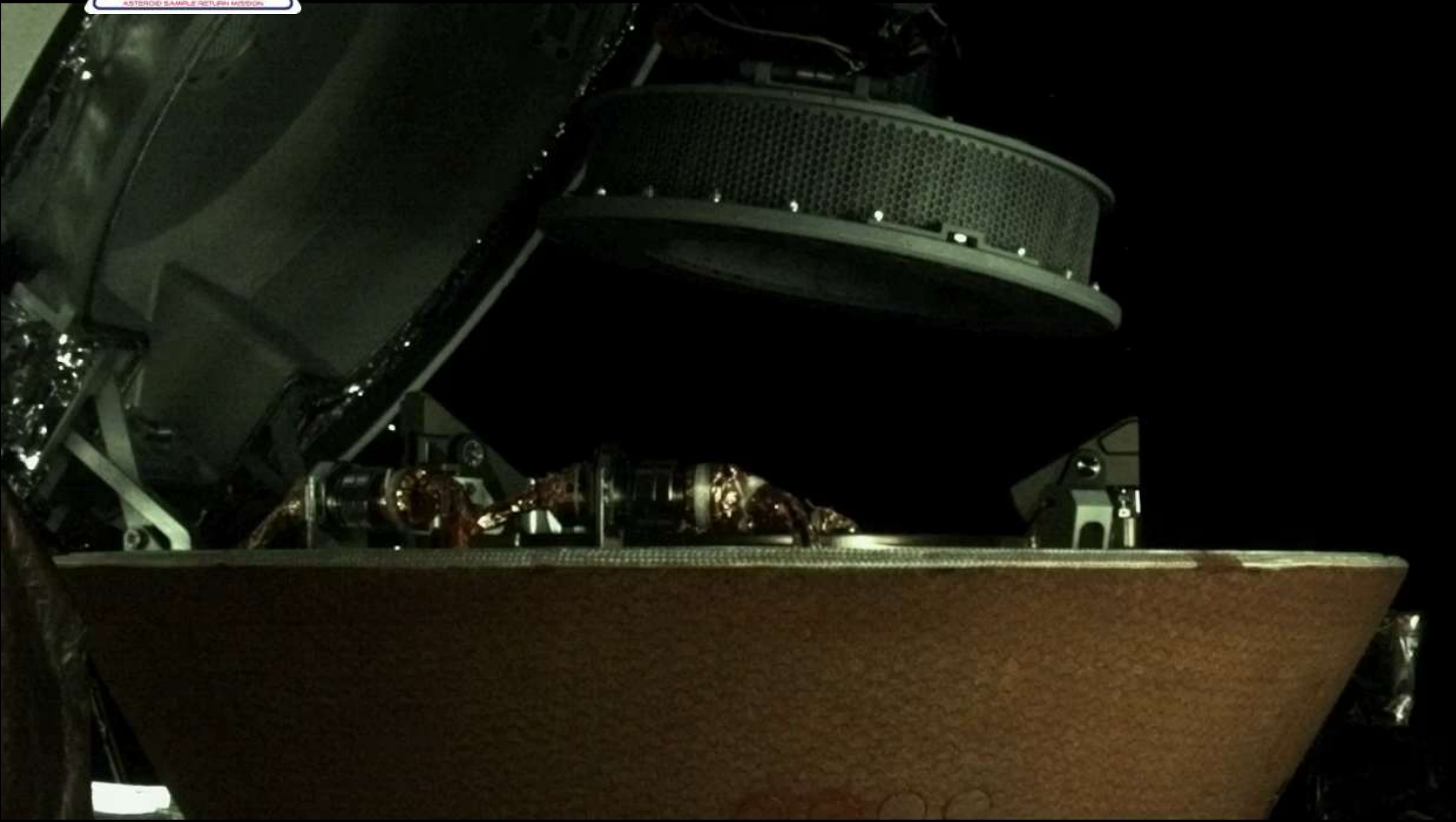


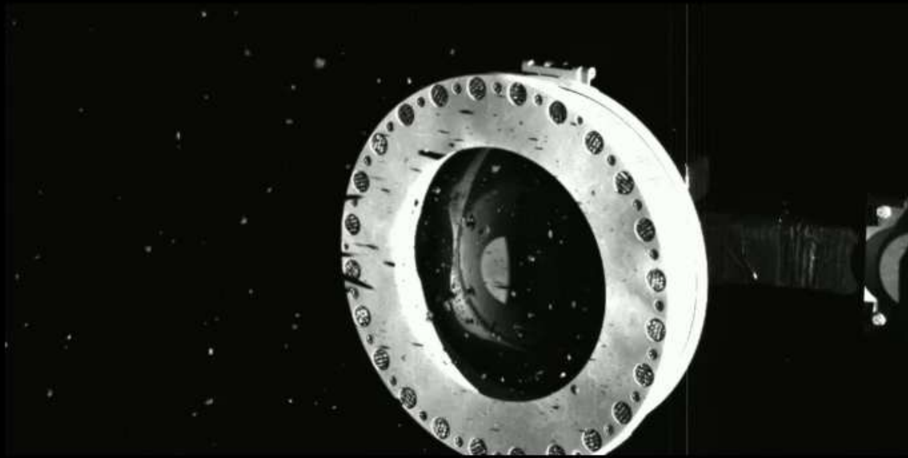
- Crater: 9.0 × 6.5 m
  0.68 ± 0.1 m deep
- Displaced volume is 12.2 ± 0.9 m^3

- Bulk density of 500 to 700 kg/m^3
- Nearly cohesionless (<0.001 Pa) granular material

Simulation

Flight Imagery





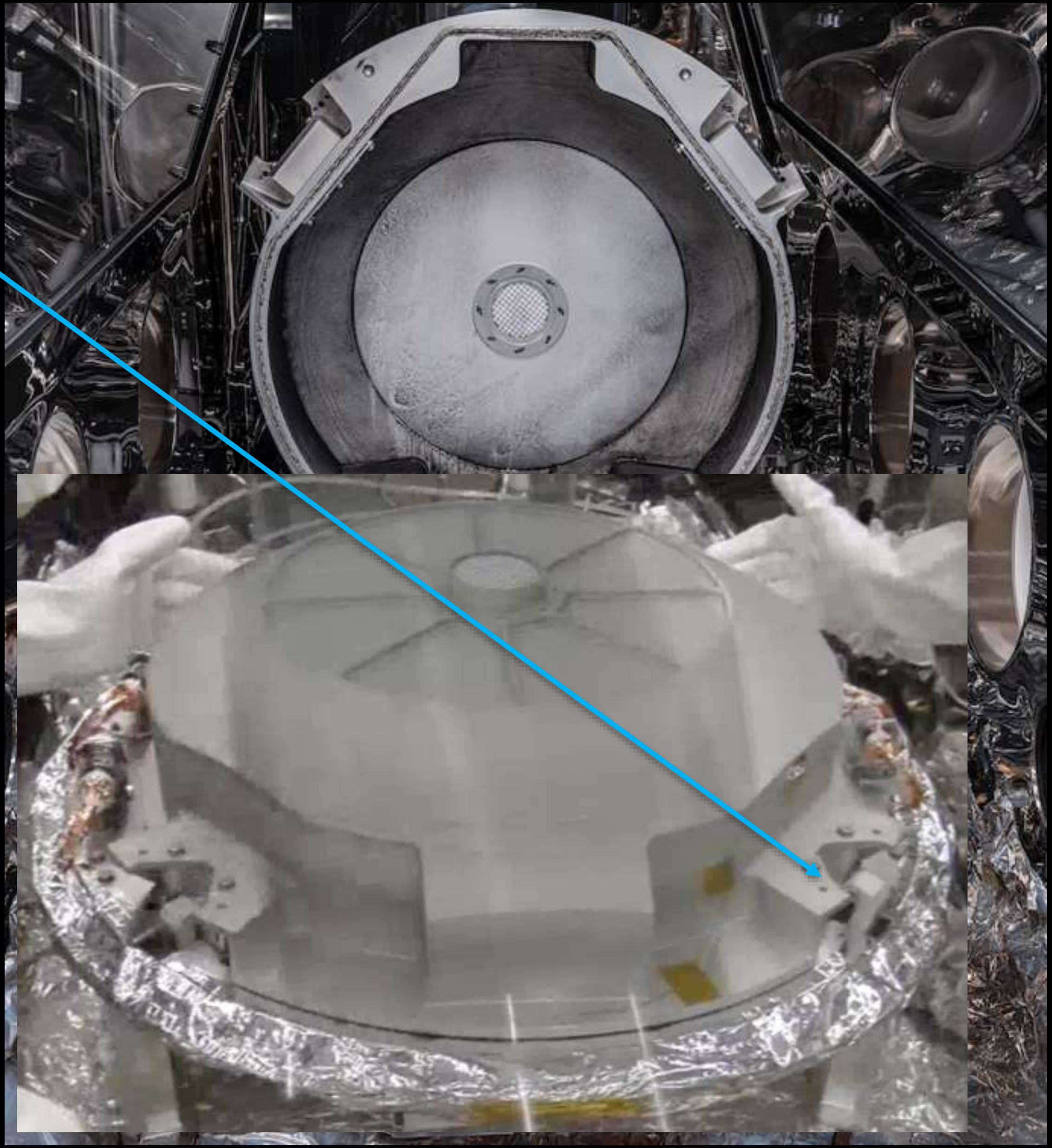
Flight Imagery

WB57 Imagery
Flight Imagery

Sample Return Capsule Landed on Earth on September 24, 2023

Bulk 121 g sample shows no evidence of terrestrial contamination.

Except, the closed canister lid trapped some SRC debris which had an opportunity to mix with 1.24% of bulk sample on the avionics deck during transportation, even under the closest supervision.



Dworkin et al. in prep

121.6g of Sample

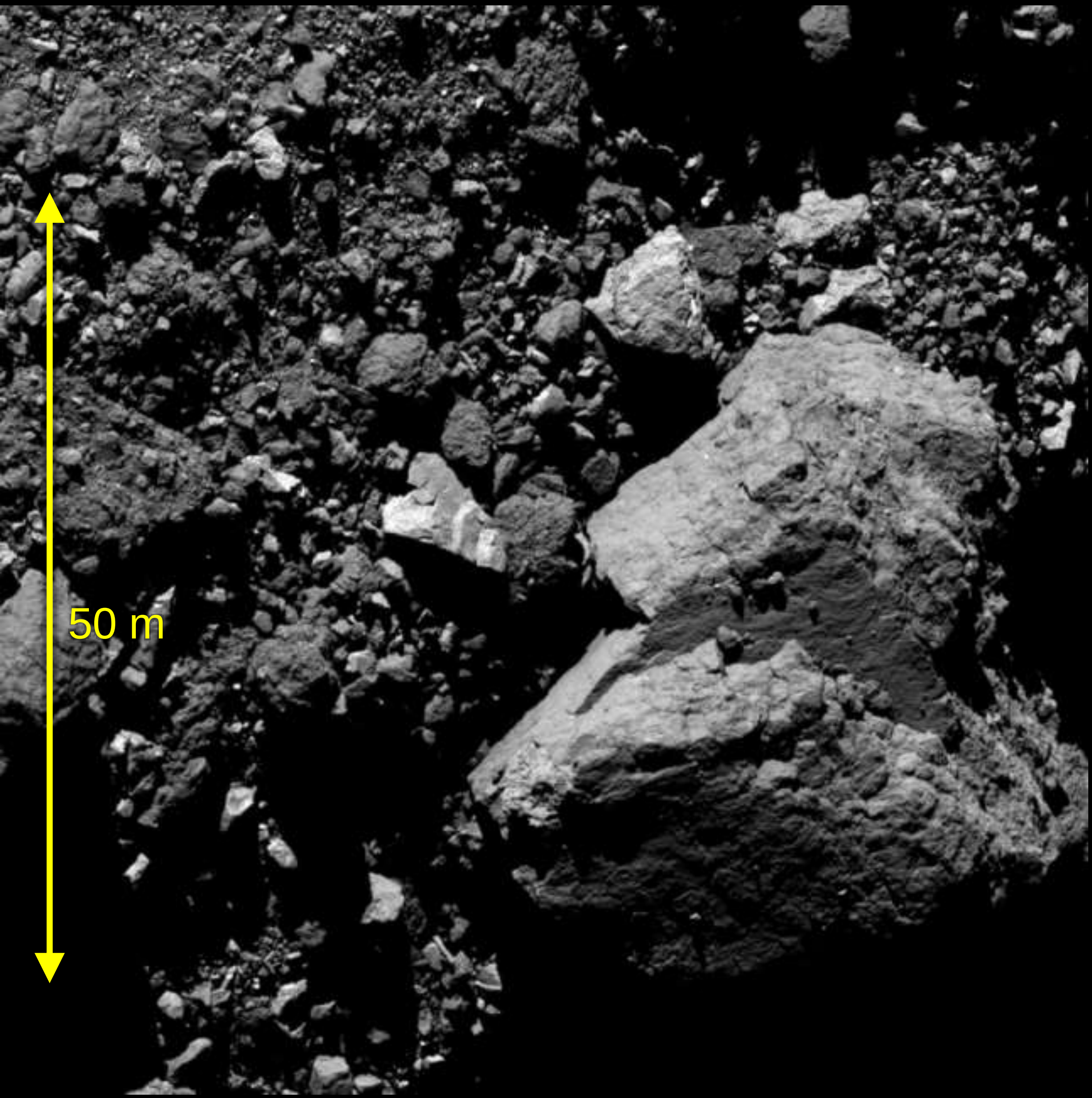
Requirement: Collect and return 60g from asteroid Bennu

Lauretta & Connolly, et al. (2024) *Meteoritics and Planetary Science* 59:2453

What is the Bennu sample like?

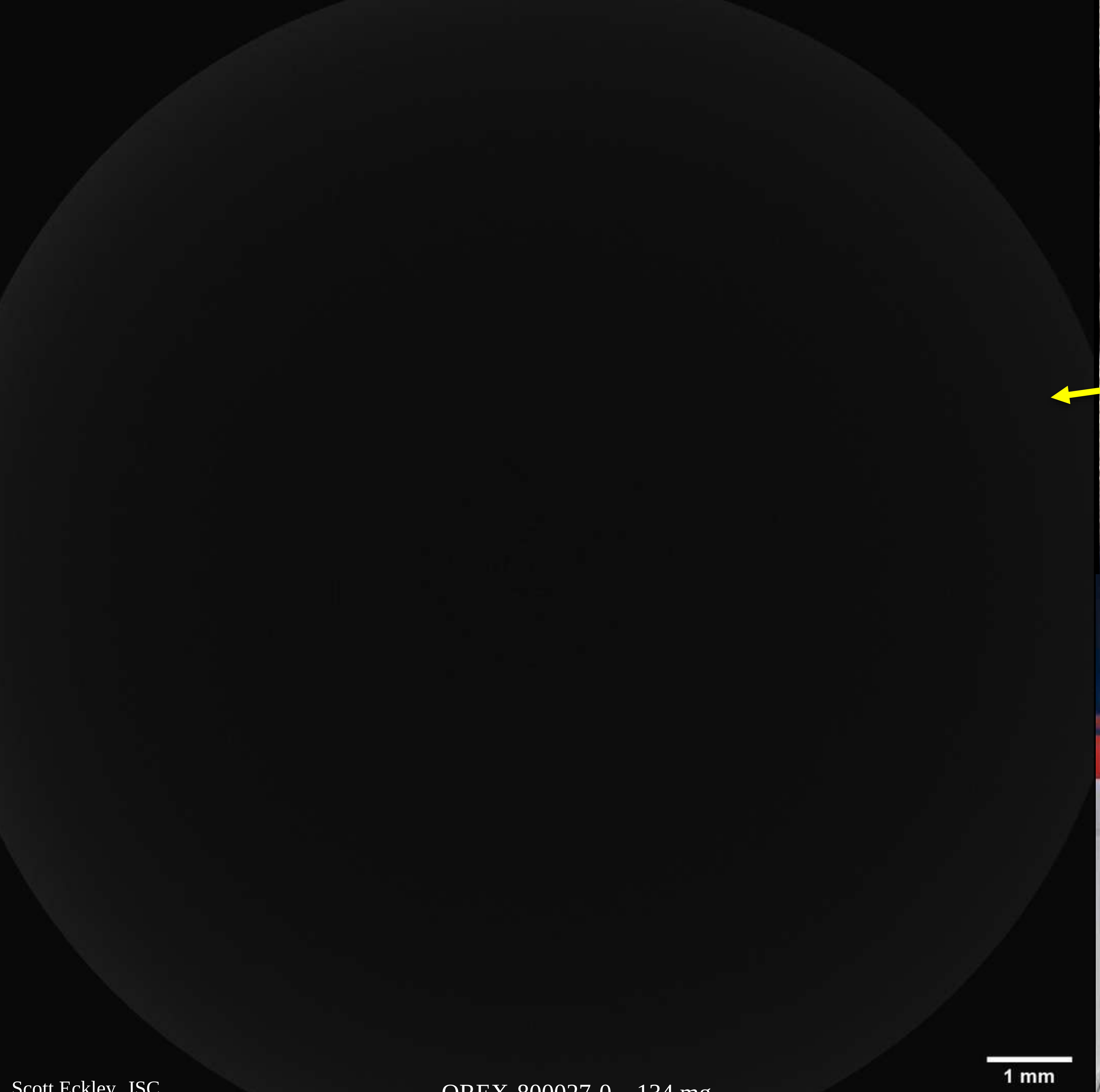
- Smell is very strong (sulfur, gun-powder and burned marshmallows)
- Dark black with some lighter/white particles throughout and shimmery particles (different lighting changes appearance)
- Very fine powders that stick to everything and are very challenging to remove from surfaces
- Some pieces are very angular, and some are very hummocky
- Density varies


Rachel Funk, JSC



Flight Imagery

Curation Image



Scott Eckley, JSC

OREX-800027-0 134 mg

Smithsonian Natural History Exhibit

Sample Distribution

121.6g &
24 contact pads

Up to 25%
(10.25% actual)

0.55% &
1 contact pad

JAXA

4% &
1 contact pad

Canadian Space Agency
Agence spatiale canadienne

>85%
(Remainder)

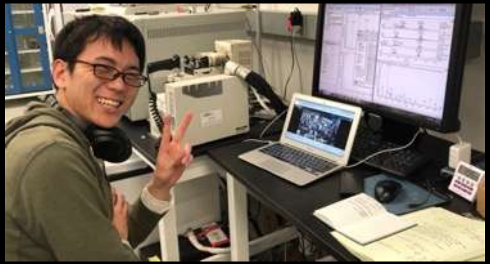
NASA

Sample Science

Fourier Transform Infrared Microscopy

2D Gas Chromatography High Resolution Mass Spectrometry

Liquid Chromatography Fourier Transform Mass Spectrometry



Gas Chromatography Mass Spectrometry

Compound Specific Isotopic Ratio Mass Spectrometry

Transmission Electron Microscopy

Electron Microprobe Analysis

Inductively Coupled Plasma Mass Spectrometry

Nanoscale Secondary Ion Mass Spectrometry

Visible Light Microscopy

Scanning-Electron Microscopy Energy-Dispersive X-ray Spectroscopy

X-ray Absorption Near-Edge Structure Spectroscopy

Accelerator Mass Spectrometry

>85% for the Future

curator.jsc.nasa.gov/osirisrex

Locations of Sample Analysis Facilities for the OSIRIS-REx Mission

1 Kyushi University
2 Ritsumeikan University
3 U of Tokyo / JAXA / JAMSTEC
4 Hokkaido University
5 Curtin University
6 Australian National University
7 University of Hawai'i
8 University of British Columbia
9 University of Calgary
10 University of Winnipeg
11 Utah Test and Training Range (SRC Landing)
12 Space Science Institute
13 Southwest Research Institute
14 NASA-Ames
15 Caltech-JPL
16 Arizona State University
17 Planetary Science Institute
18 University of Arizona
19 NASA-JSC
20 Perdue University
21 York University
22 Brown University
23 NMNH / CI
24 NASA-GSFC
25 University of Virginia
26 Open University
27 University of Oxford
28 NHM
29 Ghent University
30 German Aerospace Center (DLR)
31 Goethe University
32 CRPE
33 ETH Zurich
34 University of Turin
35 Cote d'Azur
36 University of Montpellier
37 Vatican Observatory
38 Science and Spirituality Research Institute

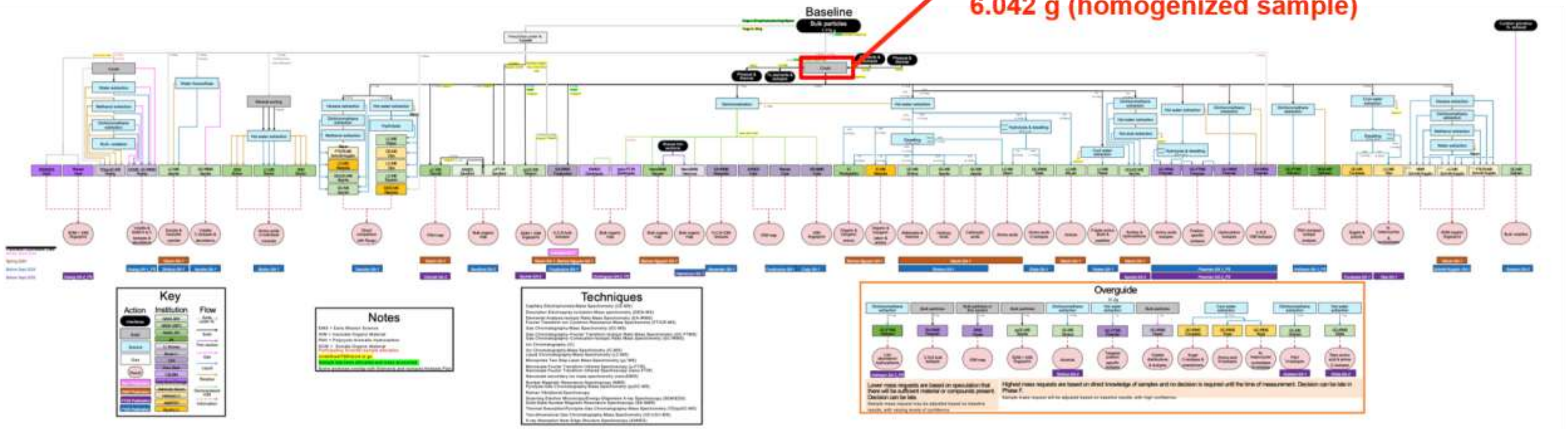
Sample Organics Analysis Working Group
(SOAWG)

66 Team Members from 30 Institutions

NASA Goddard Space Flight Center, USA
American Museum of Natural History, USA
Brown University, USA
Cal State San Marcos, USA
Caltech, USA
Carnegie Institution of Washington, USA
Chicago Field Museum of Natural History, USA
Helmholtz Zentrum Munich, Germany
Hokkaido University, Japan
JAMSTEC, Japan
Jet Propulsion Laboratory, USA
Keio University, Japan
Kyushu University, Japan
Lawrence Berkeley National Lab, USA
Max Planck Institute for Extraterrestrial Physics, Germany
NASA Ames Research Center, USA
NASA Johnson Space Center, USA
Pennsylvania State University, USA
Rowan University, USA
Smithsonian Natural History Museum, USA
Southwest Research Institute, USA
Stanford University, USA
Technical University Munich, Germany
Tohoku University, Japan
UC Berkeley, USA
University of Arizona, USA
University of Chicago, USA
University of Maryland, Baltimore County, USA
University of Rochester, USA
Washington University in St. Louis, USA

SOAWG Analysis Chart

6.137 g – 0.022 g (1st triage/QL) – 0.055 g (aggregate A4) – 0.018 g (aggregate Japan) = **6.042 g (homogenized sample)**



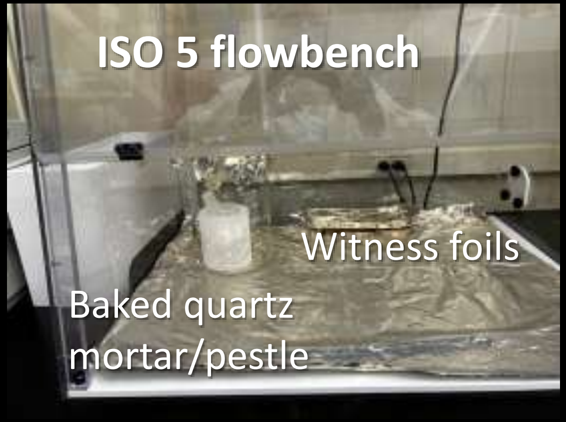
https://osiris-rex.atlassian.net/wiki/spaces/WG/pages/48103764/Data+Products+and+Publication+Plan

Processing Bennu Aggregate at JSC

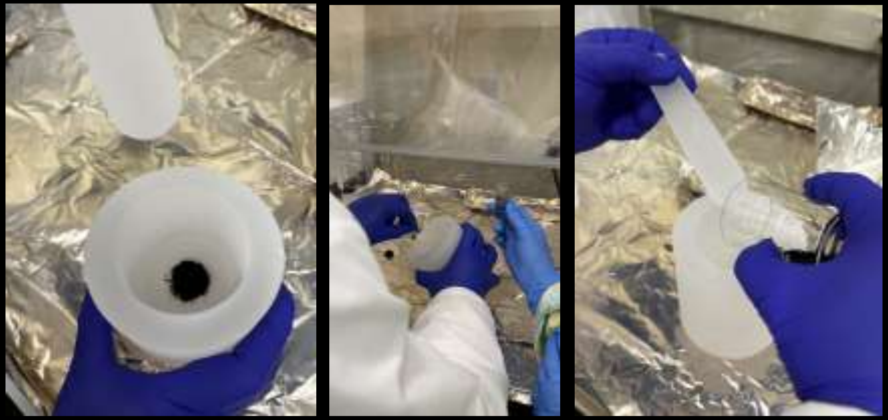
June 17-20, 2024

Official Handoff

Work Area

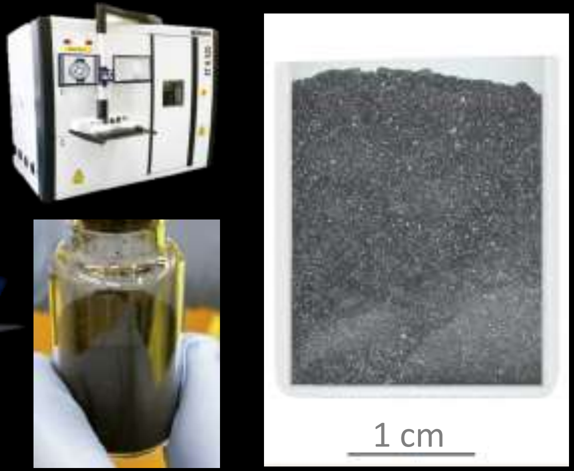


Hand Crush in Mortar (3 batches)



Diffusion of Responsibility

XCT Scan of Bennu Powder

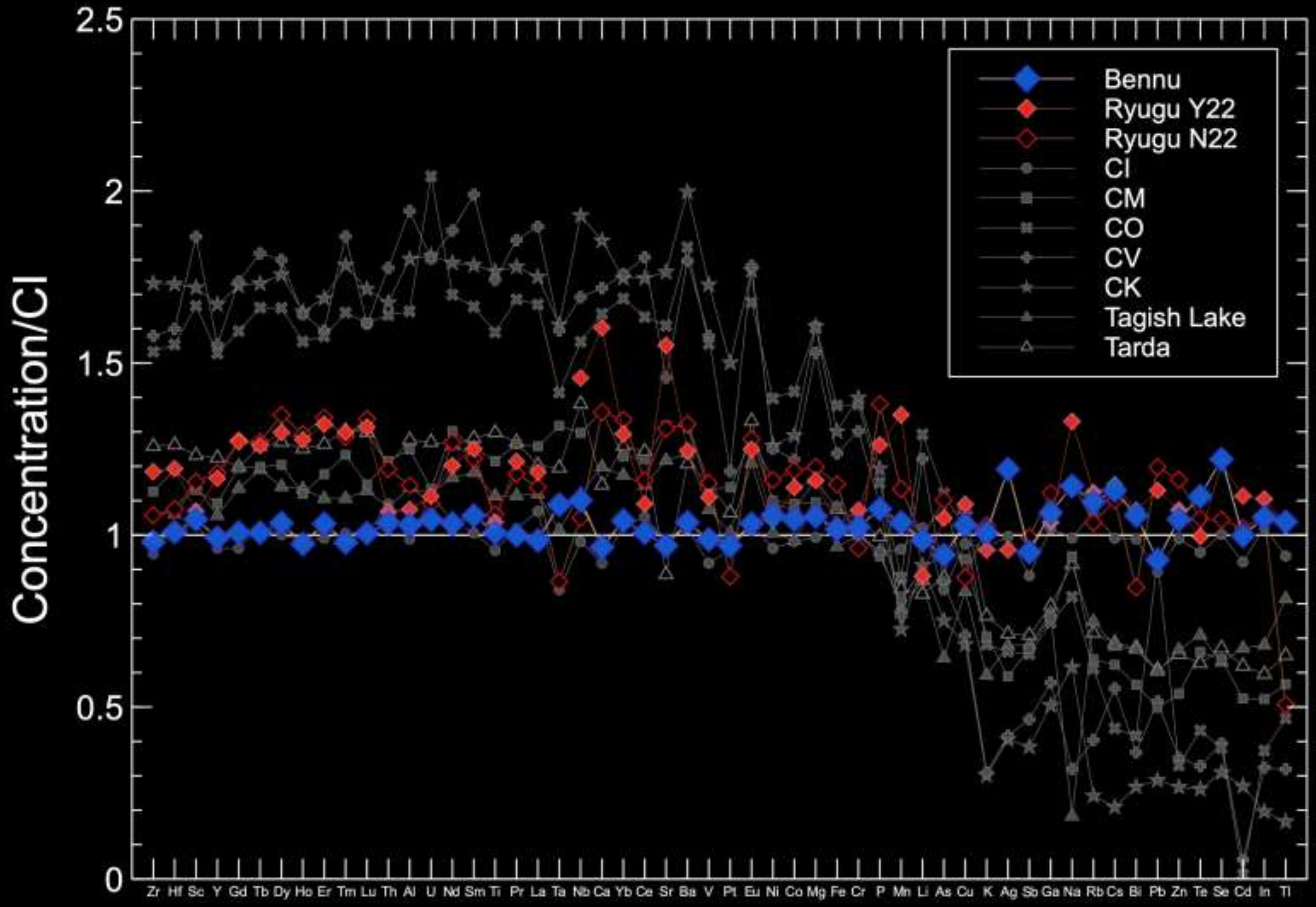


Hand Carry (JSC to GSFC)

Allocations of the Bennu Sample and Control

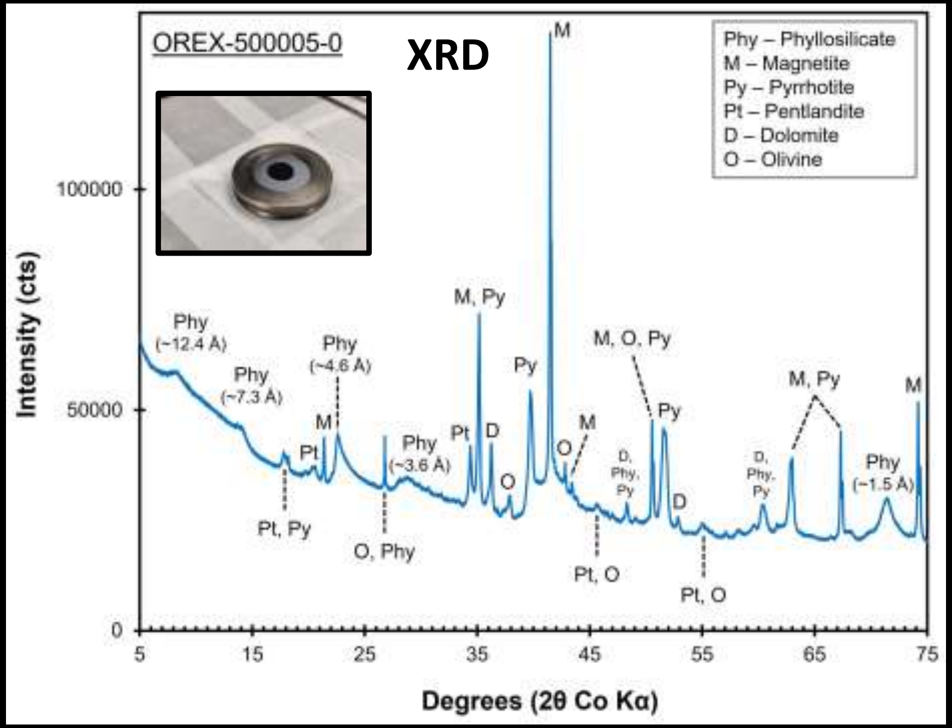
How does the sample compare with observations from the spacecraft at Bennu?

Bennu is elementally similar to a CI meteorite and Ryugu



Lauretta & Connolly, et al. (2024) *Meteoritics and Planetary Science* 59:2453

Mineralogy of the Bennu Samples

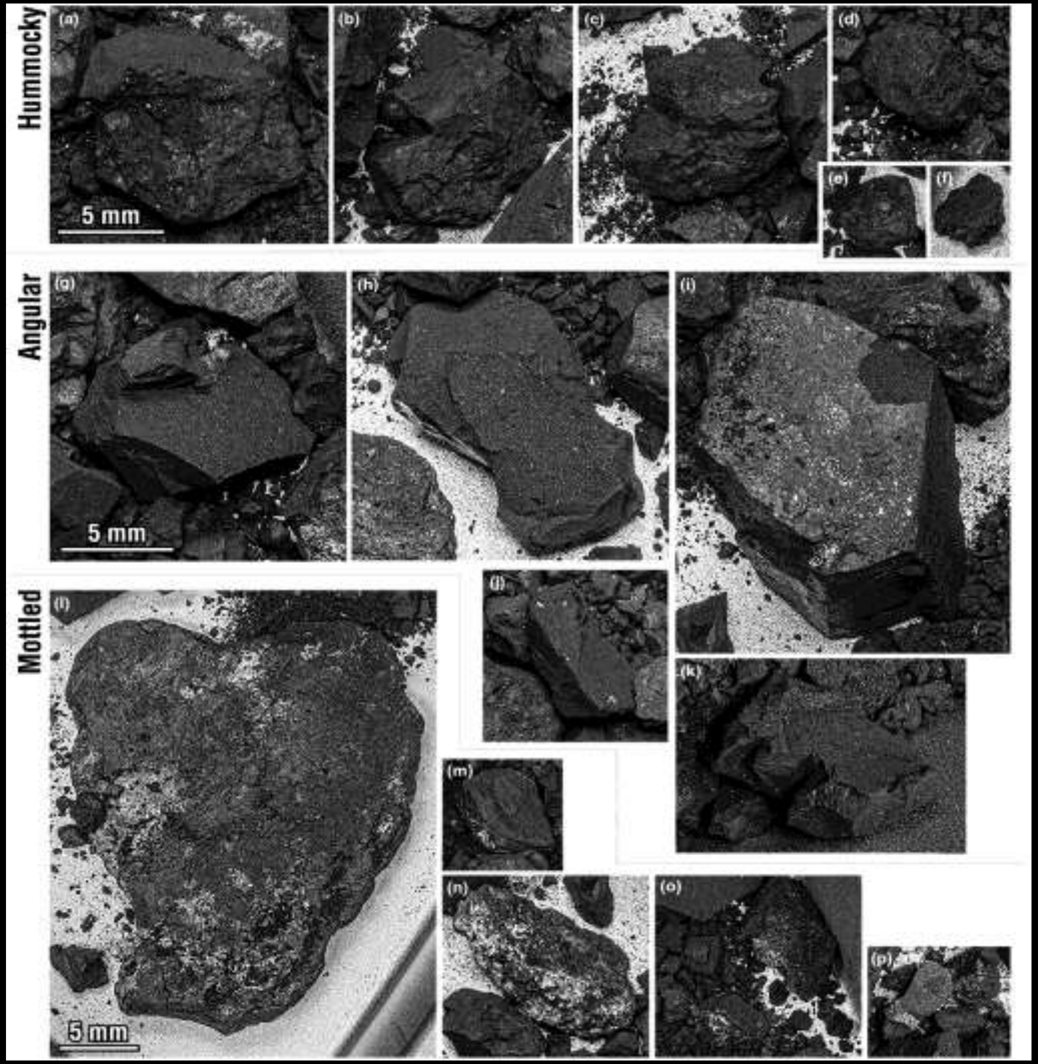


Bulk Mineralogy (vol. %)

80% Phyllosilicates (saponite and serpentinite)
9% Sulfides (primarily pyrrhotite and pentlandite)
5% Magnetite
3% Carbonates (calcite, dolomite, magnesite, bruennerite)
2% Olivine
<1% Phosphates, phosphides, chromite, ilmenite

Two Main Rock Types (Angular and Hummocky)

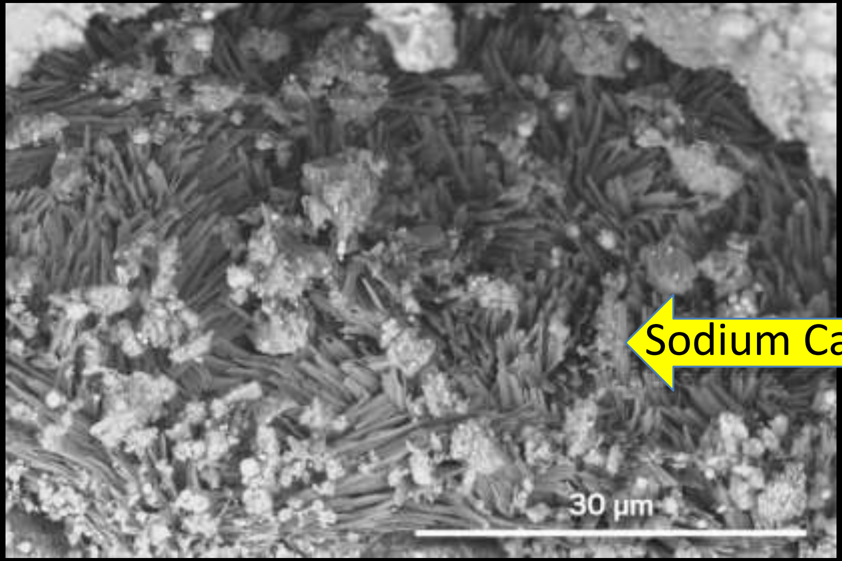
Mg,Na-phosphate rich materials (Mottled)



Lauretta & Connolly *et al.* (2024) *Meteorit. Planet. Sci.* **59**:2543
Zega *et al.* (2025) *Nature Geosci.* **18**:832

Evidence for Late-Stage Evaporation of Brine Fluids in Bennu Samples

Bennu evaporites formed from room temperature alkaline (pH ~8-9) fluids over several million years like those found on the surface of Ceres

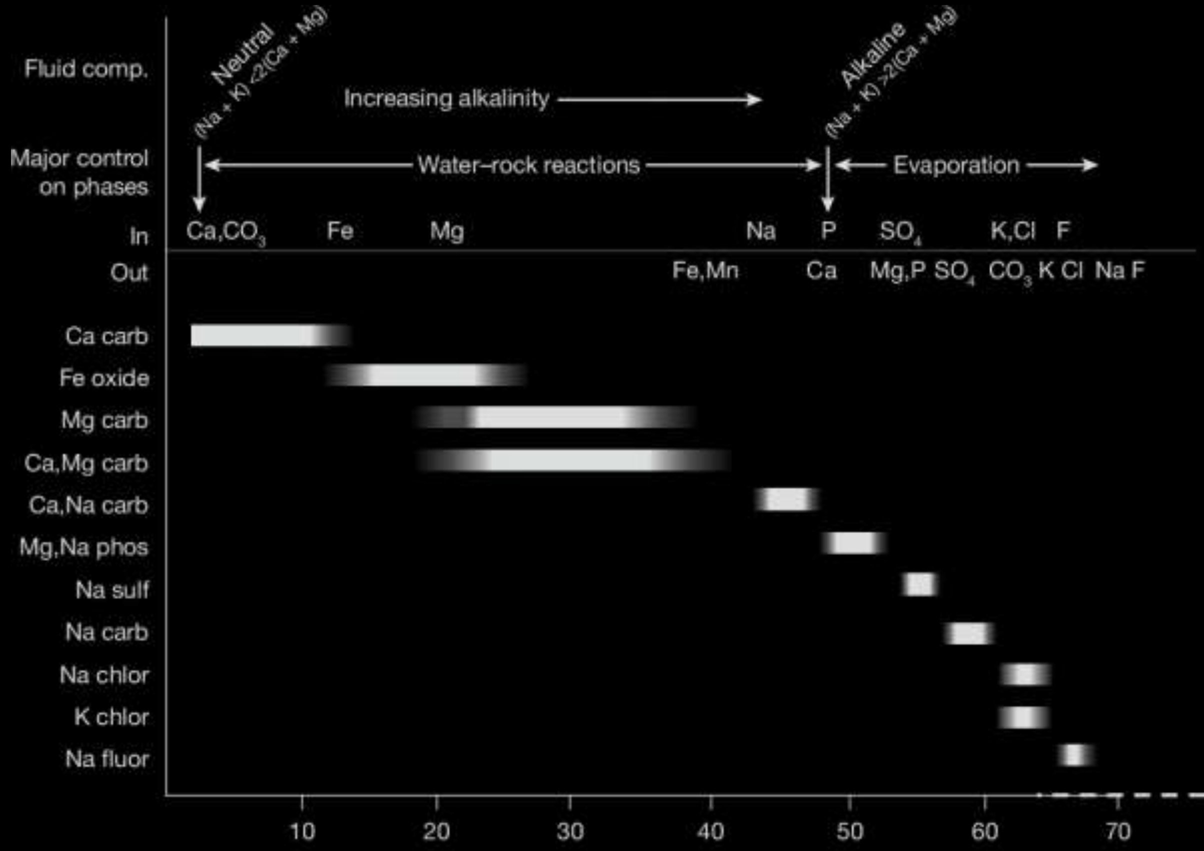


Bennu

Trona

$Na_3H(CO_3)2{\cdot}2H_2O$

(Searles Lake, California)

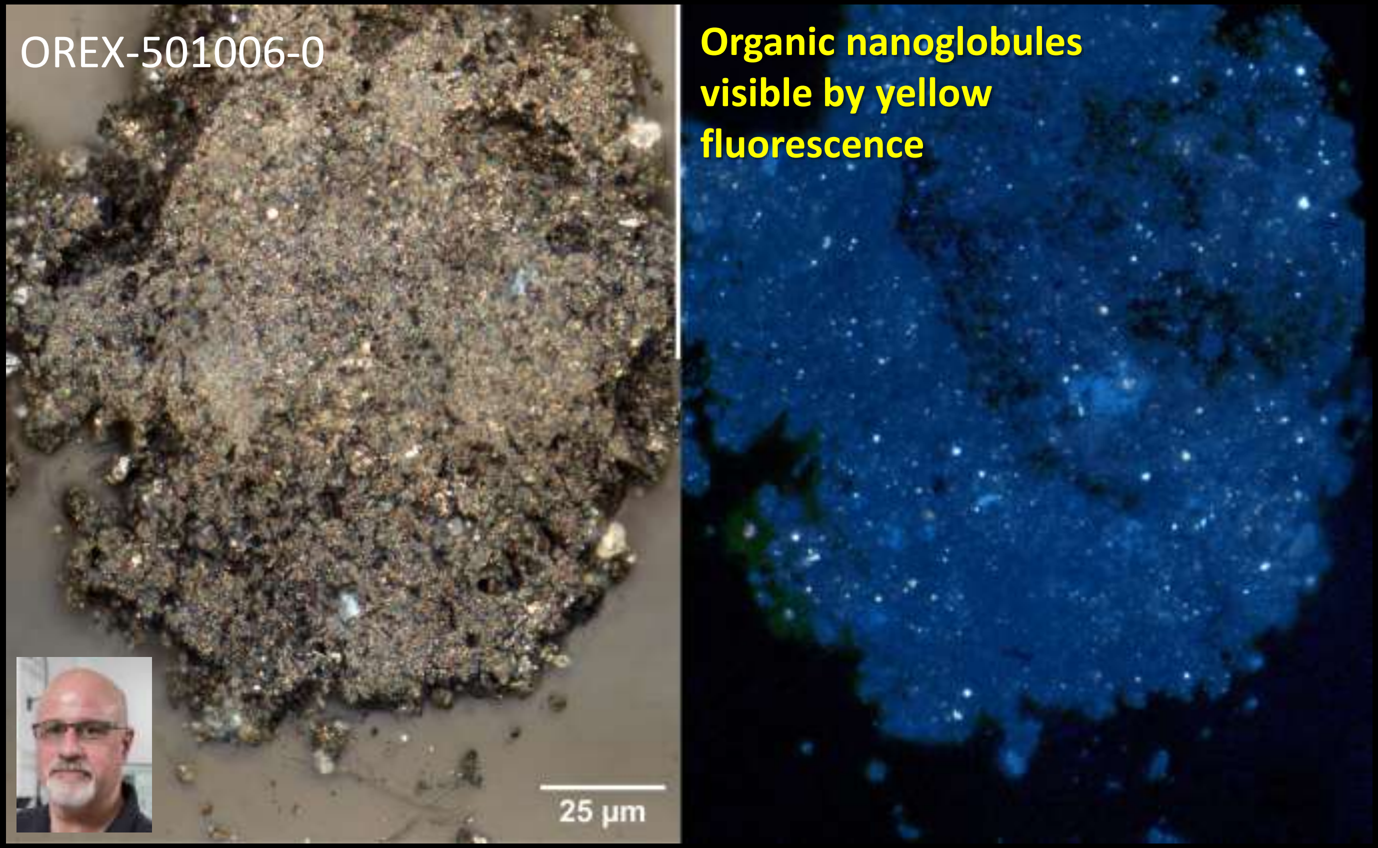


Sequentially precipitating evaporite minerals observed in Bennu implies alkaline pH, high concentrations of dissolved inorganic carbon and fluid temperatures < 55°C.

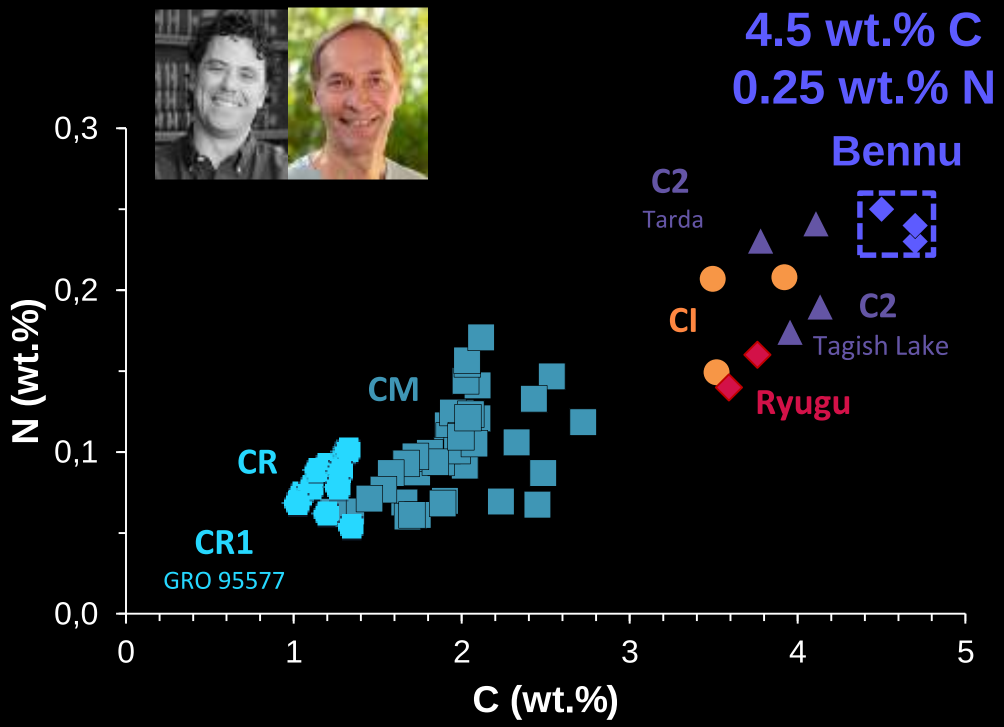
McCoy & Russell et al. (2025) *Nature* 637:1072

Asteroid Bennu is Rich in Organic C and N!

"An Astrobiologist's Dream"



Optical (left) and UV fluorescence imaging data (right) from S. Clemett (NASA JSC)



EA-IRMS data from D. Foustoukos and C. Alexander (Carnegie Institution for Science)

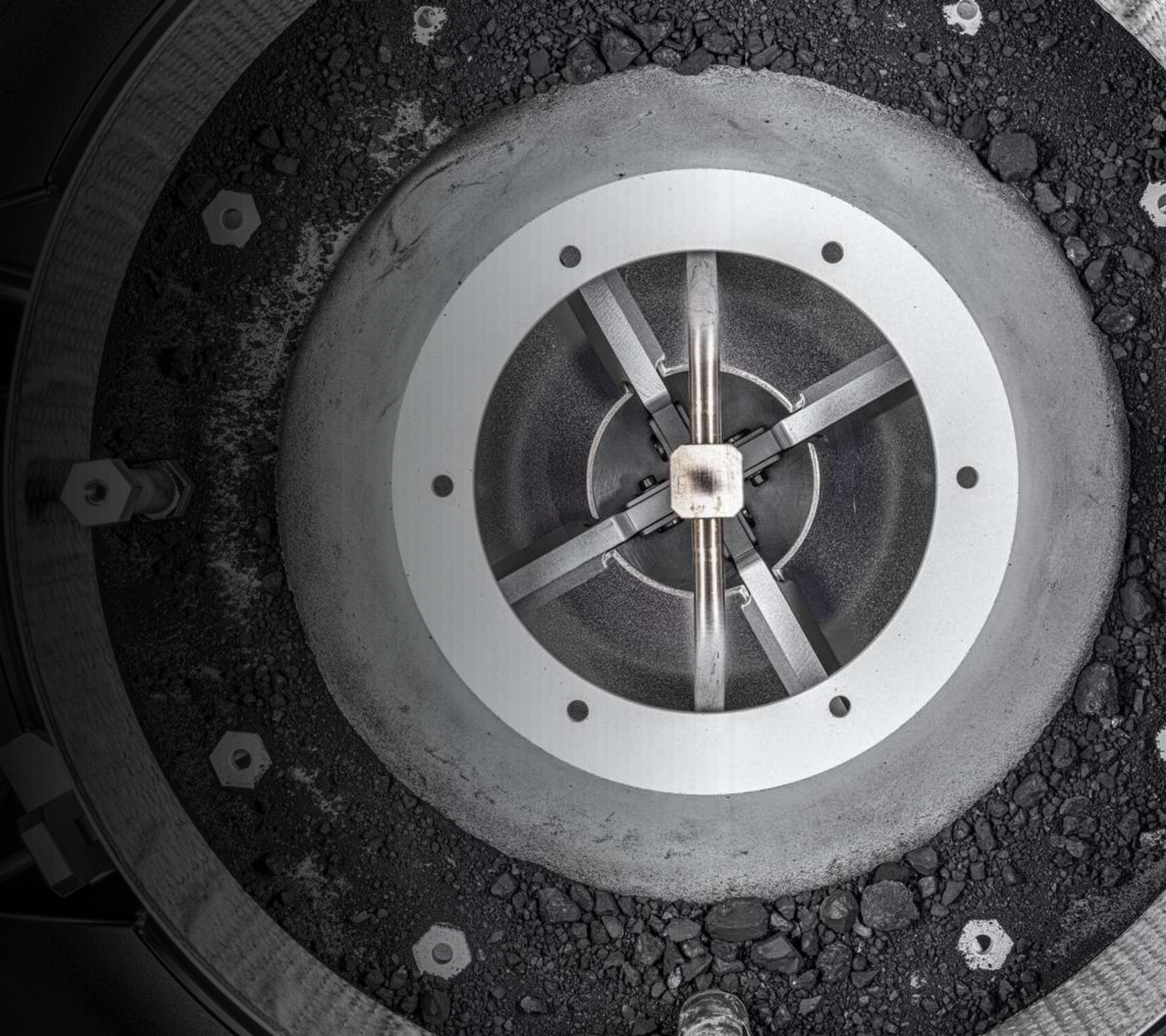
Lauretta & Connolly *et al.* (2024) *Meteoritics and Planetary Science* 59:2543

Glavin & Dworkin *et al.* (2025) *Nature Astronomy* 9:199

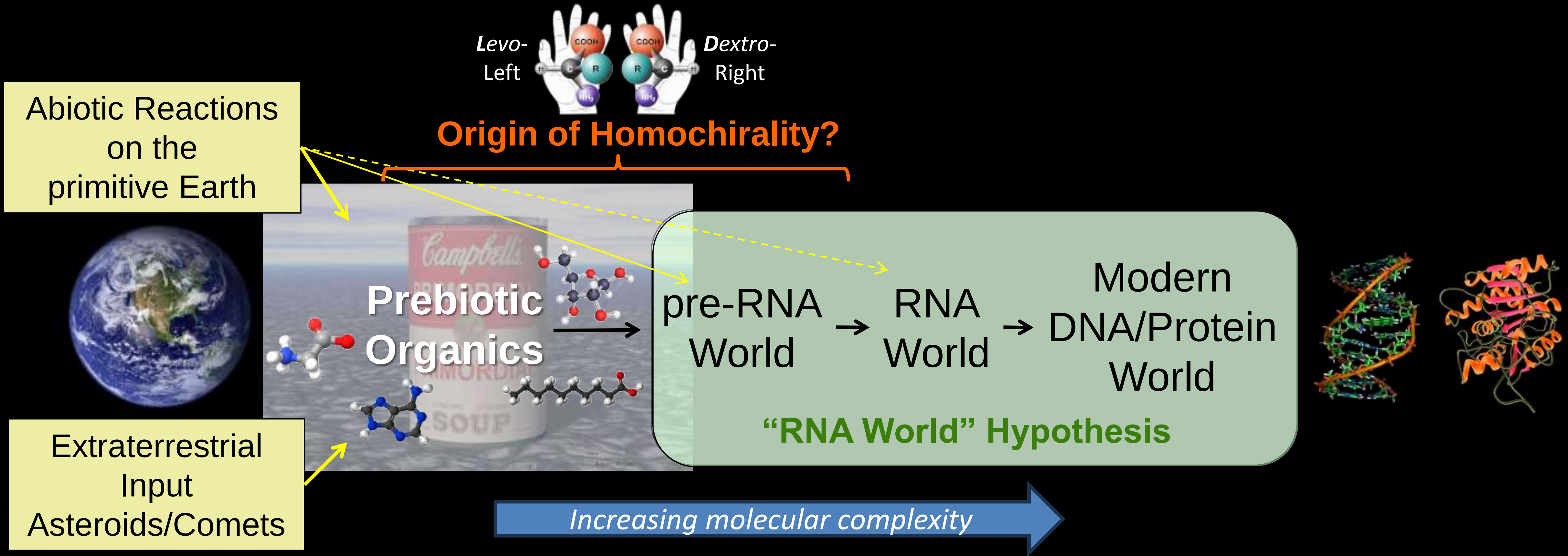
Clemett *et al.* (2026) *Geochim. Cosmochim Acta* , in review

Foustoukos *et al.* (2026) *Geochim. Cosmochim Acta* 424:113

Does the sample contain prebiotic organic molecules that could have influenced the origin of life?

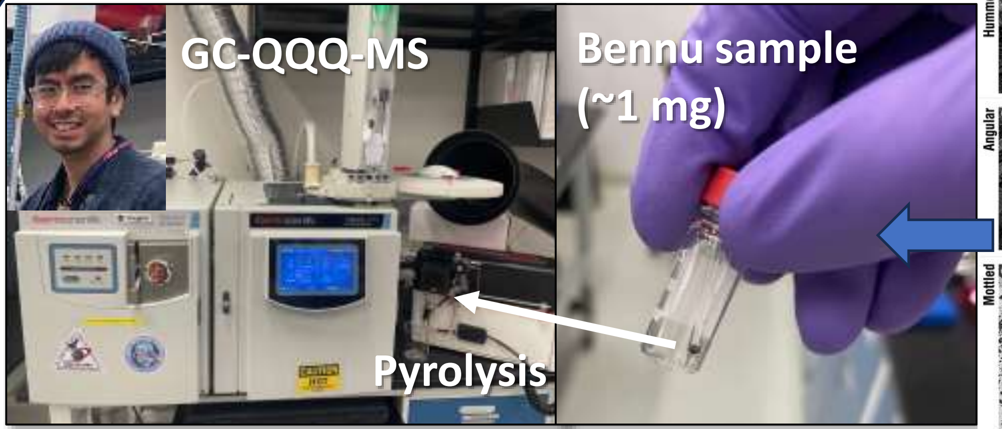


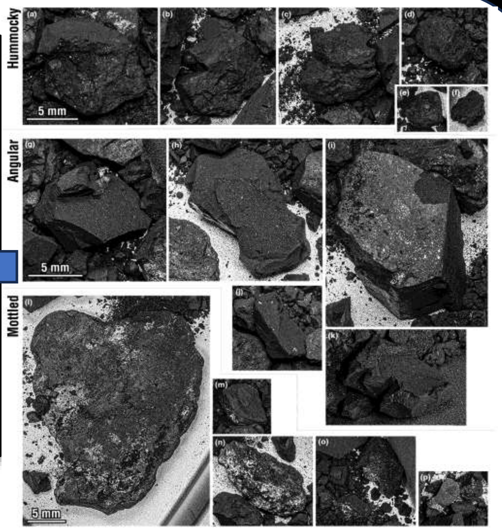
How did Life Emerge on the Earth ~4 Gya?



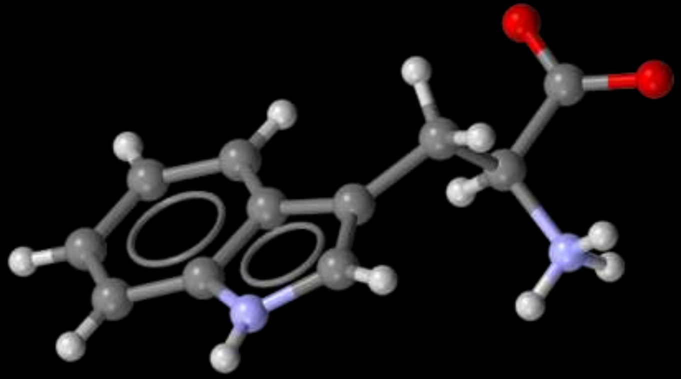
Laboratory analyses of prebiotic organics in pristine astromaterials will reveal more secrets about the pathway to life's chemistry

Evidence of Prebiotic Chemistry in the Bennu Samples





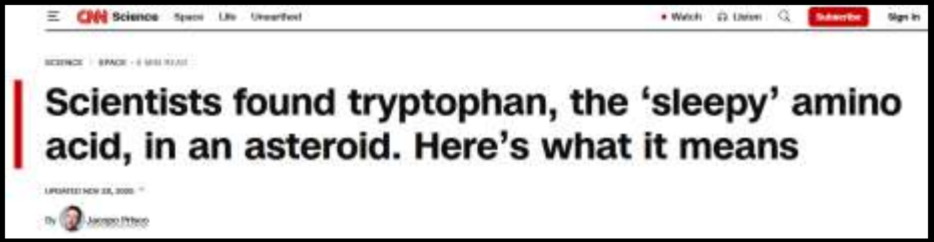
New wet chemistry pyrolysis GCMS developed by Angel Mojarro at Goddard used as a sample triage method.
← Derived from SAM instrument on Mars Curiosity Rover



Tryptophan is the most complex amino acid used in terrestrial biology. *Its presence in Bennu samples tells us that carbon-rich asteroids could create more complex organic molecules than previously thought.*

First confirmation of chemical building blocks of life in Bennu samples

- Bennu samples contain all canonical nucleobases (A, C, G, T, and U) found in life's genetic code.
- Bennu contains 15 of the 20 amino acids used to build proteins, including first detection of tryptophan in any extraterrestrial material.
- Missing 5 protein amino acids (Lys, Arg, Gln, Cys, His)



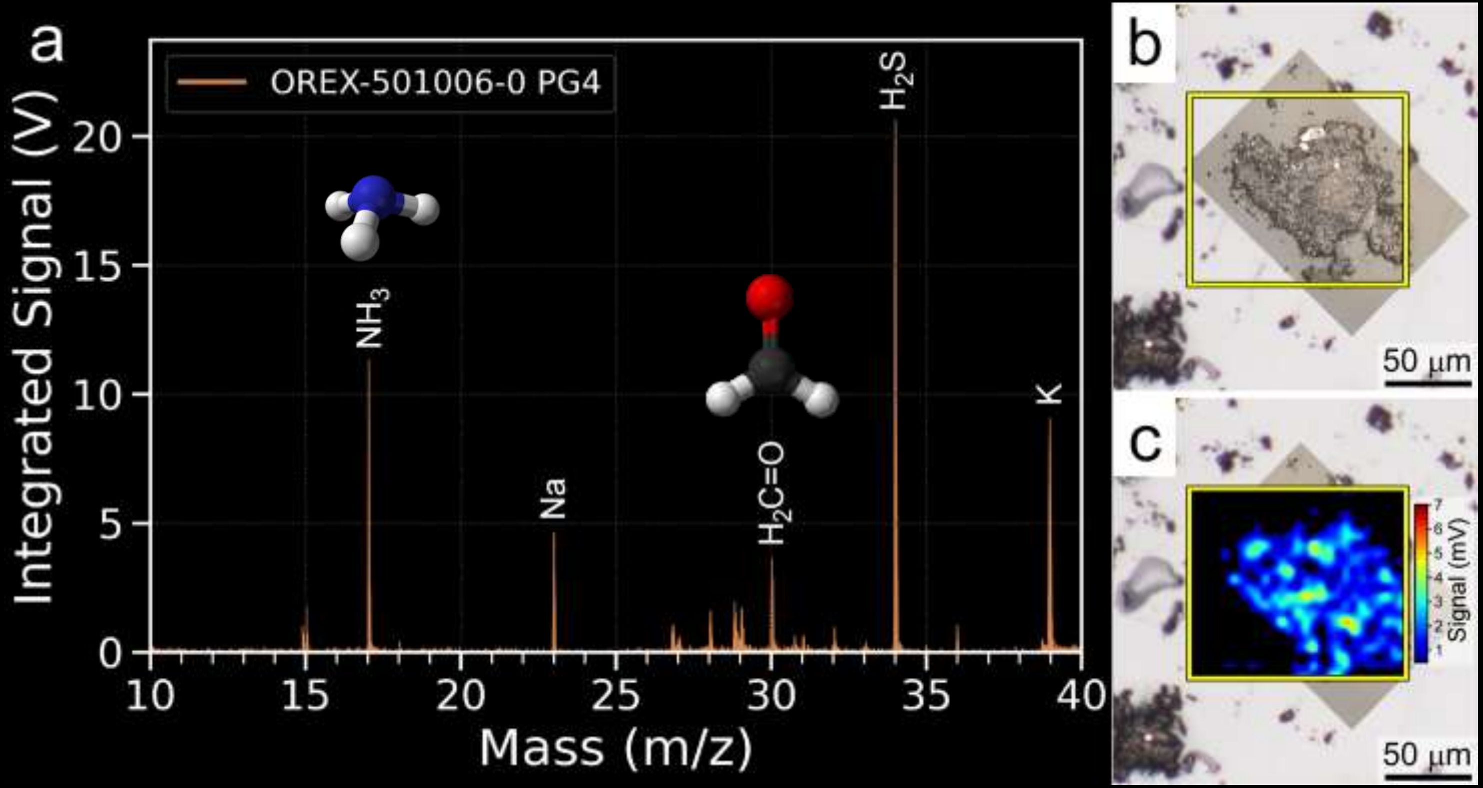
Scientists found tryptophan, the 'sleepy' amino acid, in an asteroid. Here's what it means

Mojarro, A. et al. (2025) *Proceedings of the National Academy of Science, USA* 122:e2512461122

https://www.cnn.com/2025/11/27/science/tryptophan-asteroid-bennu-nasa-sample

Ammonia & Formaldehyde Detected in Bennu Grains

Spectrum acquired by microprobe two-step laser desorption mass spectrometry (μ-L^{2}MS) of several 100 μm grains pressed into KBr window at JSC using vacuum UV photoionization at 118 nm

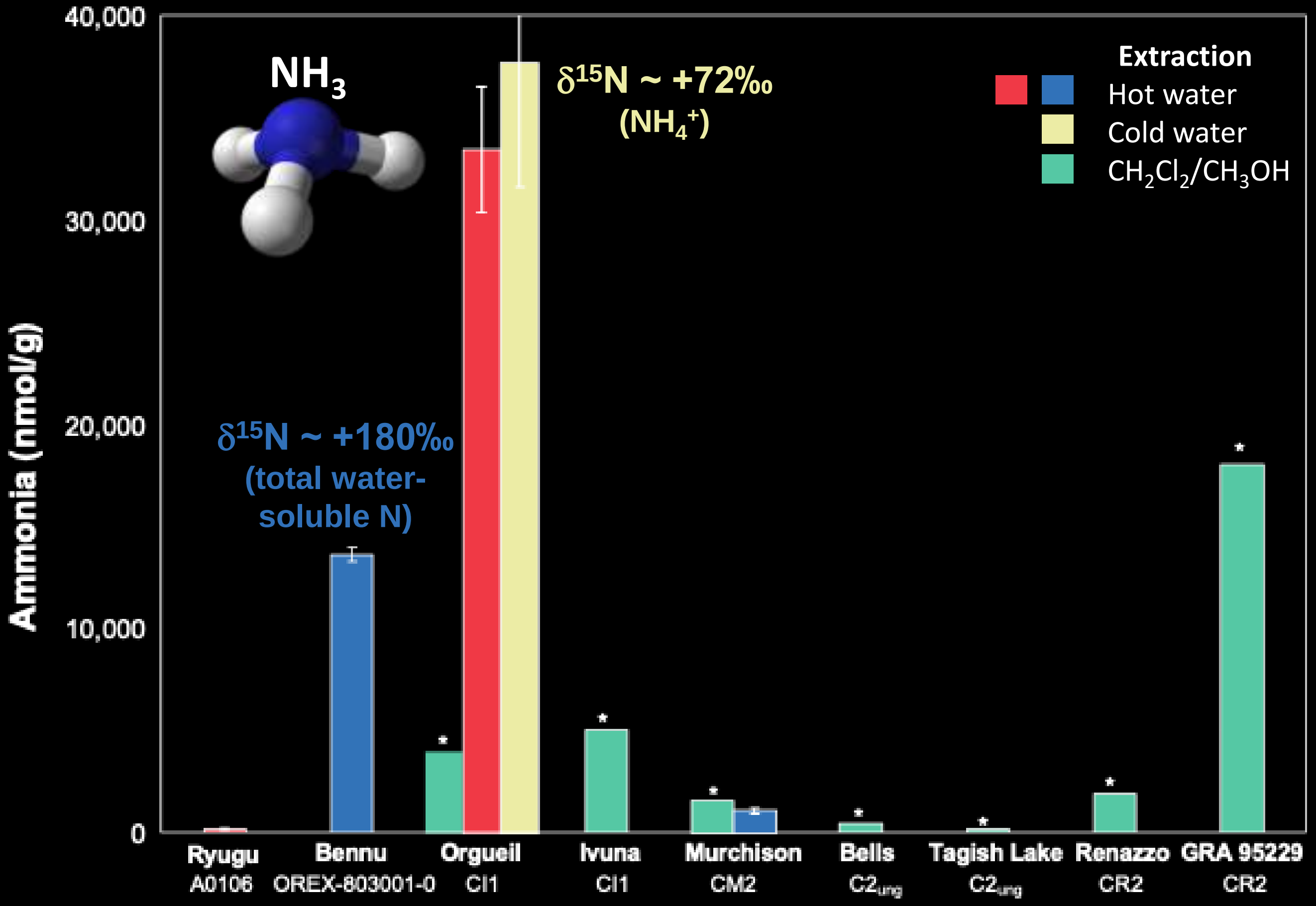


μ–L^{2}MS data from S. Clemett (JSC)

Ammonia and formaldehyde are important chemical precursors for the formation of amino acids, N-heterocycles and other soluble organic molecules. Ammonia was heterogeneously distributed across the Bennu particles on the 5 μm scale.

Glavin & Dworkin et al. (2025) *Nature Astronomy* 9:199

Abundant ^{15}N-rich Ammonia in Bennu Samples Suggests Icy Outer Solar System Origin



nature astronomy

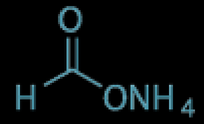
Glavin & Dworkin et al. (2025) *Nature Astronomy* 9:199

Article

https://doi.org/10.1038/s41550-024-02472-9

Abundant ammonia and nitrogen-rich soluble organic matter in samples from asteroid (101955) Bennu

Potential sources of Bennu ammonia:

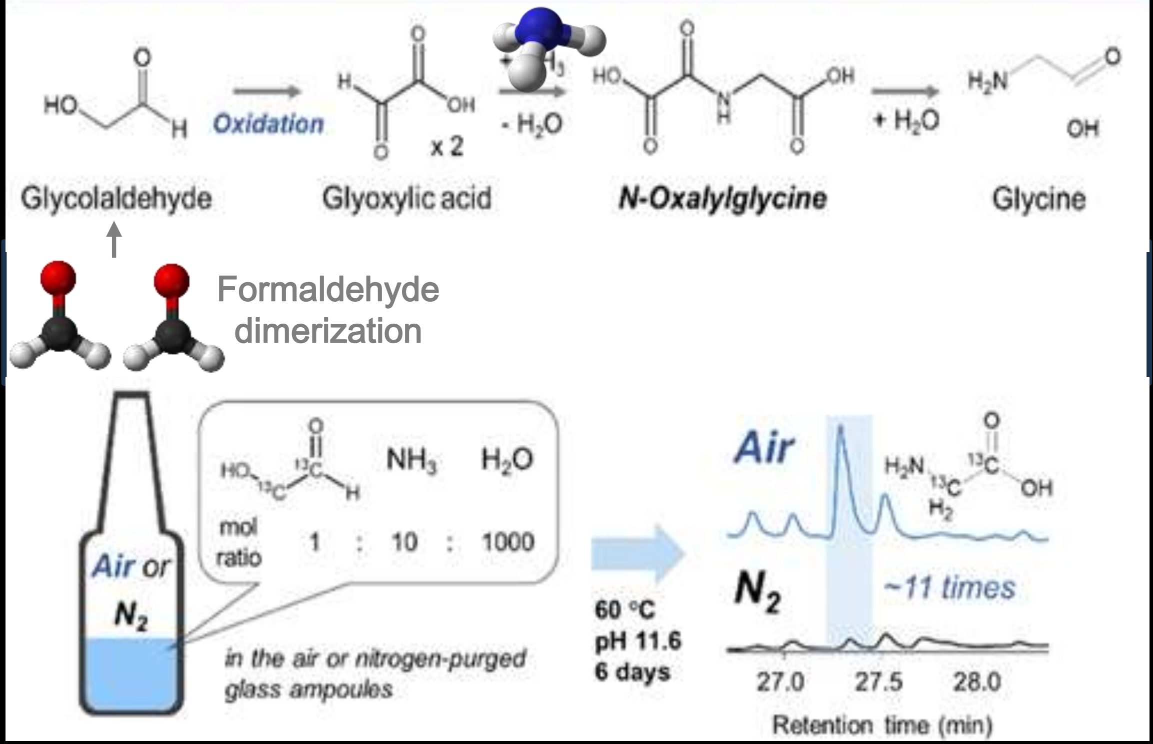


1) Ammonium salts
2) Ammoniated clays
3) N-rich insoluble organic matter
4) Hydrated Ammonium Mg-rich Phosphate (HAMP) grains
5) Mineral fluid inclusions (iron sulfide minerals)

Glavin & Dworkin *et al.* (2025) *Nature Astronomy* 9:199
Laize-Générat *et al.* (2024) *Geochimica et Geophysical Acta* 387:1
Yoshimura *et al.* (2023) *Nature Communications* 14:5284
*Estimated from Pizzarello and Williams (2012) *Astrophysical Journal* 749:161

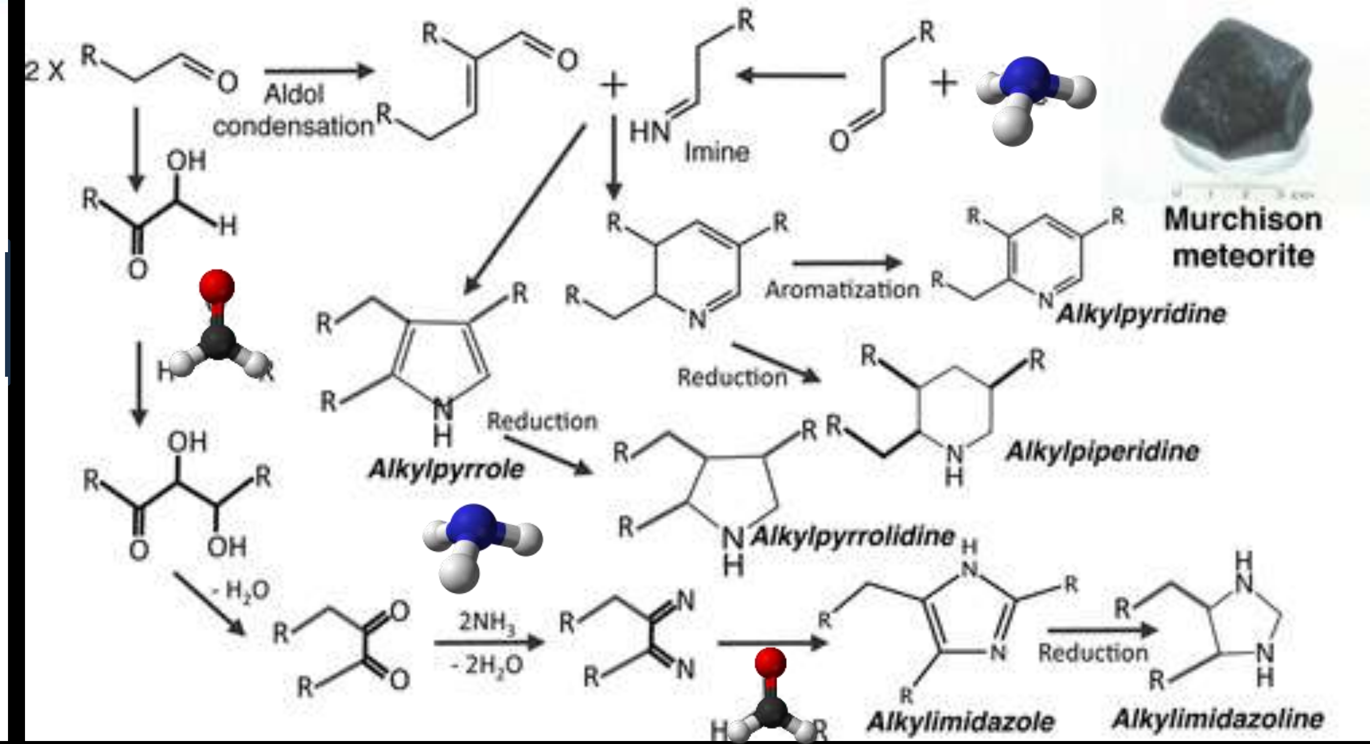
Formation of Amino Acids and N-Heterocycles in Alkaline Fluids with Ammonia and Aldehydes

Glycine formation pathway in the formose-like reaction



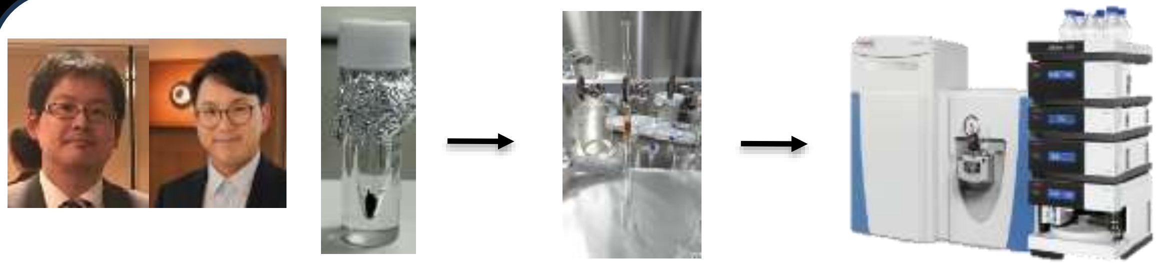
After Koga & Naraoka (2022) *ACS Earth and Space Chemistry* 6:1311

Aldol condensation and formose reaction with ammonia



After Naraoka et al. (2017) *ACS Earth and Space Chemistry* 1:540

Bennu Nucleobase Distribution Hints at Possible Cold Molecular Cloud Origin

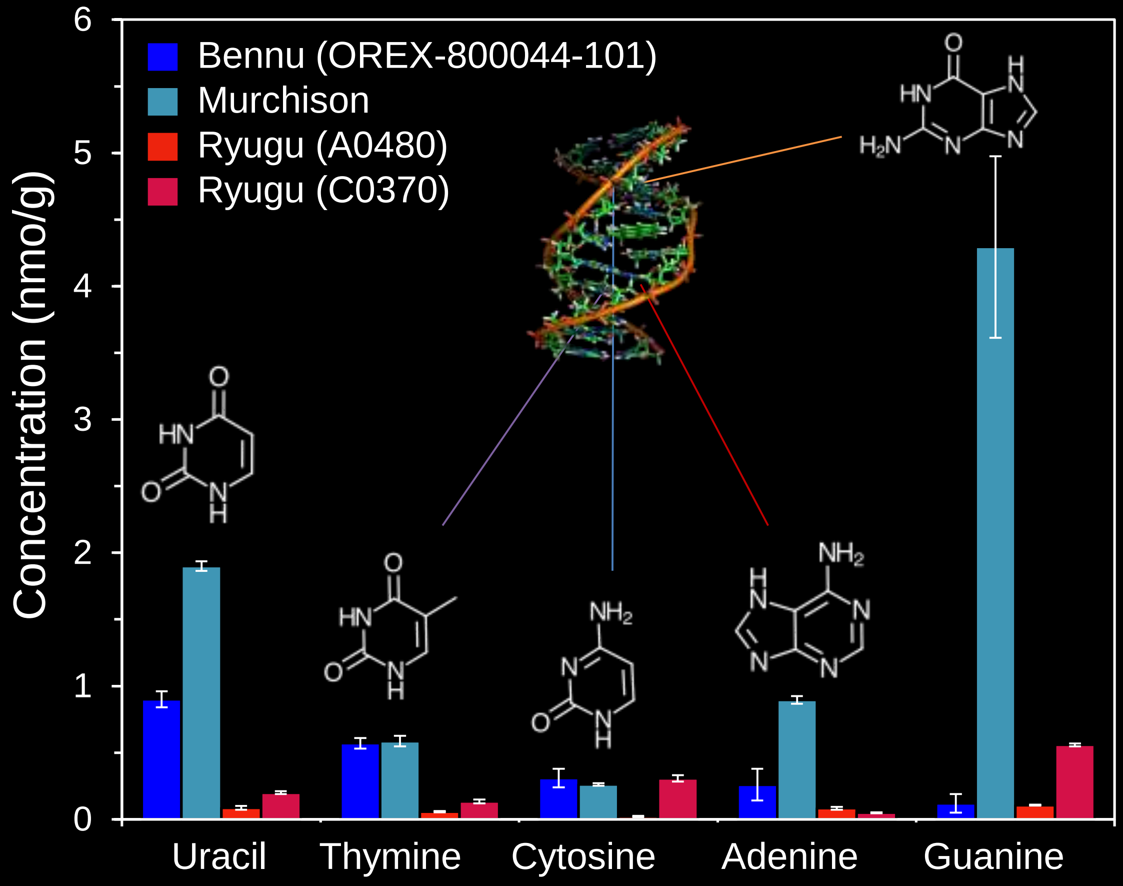


6M HCl extract 110ºC for 12 h (17.75 mg) → Cation-exchange chromatography (AG50W-X8) → **HPLC-Orbitrap MS** (Thermo Q Exactive)

>23 N-heterocycles (including all 5 biological nucleobases) found in Bennu. Violation of Chargaff's rules (1:1 ratio of purines to pyrimidine bases in DNA) and biologically rare N-heterocycles indicate a non-terrestrial origin.

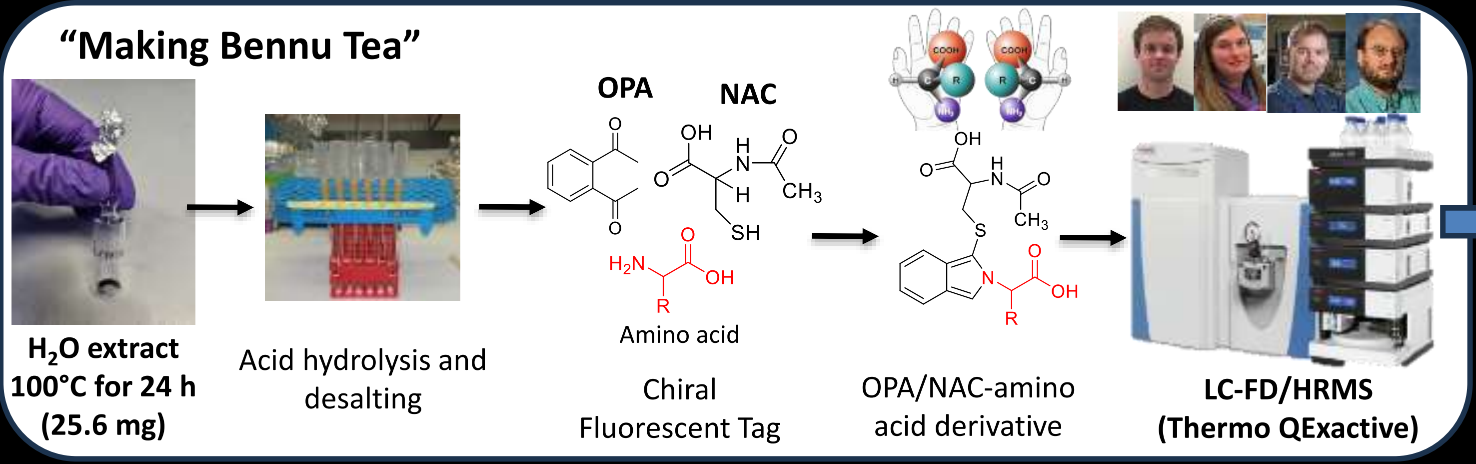
Single-ring pyrimidine bases more abundant than double-ring purines in Bennu (>2:1 ratio) suggesting preferential synthesis in ammonia-rich ices from the outer solar system.

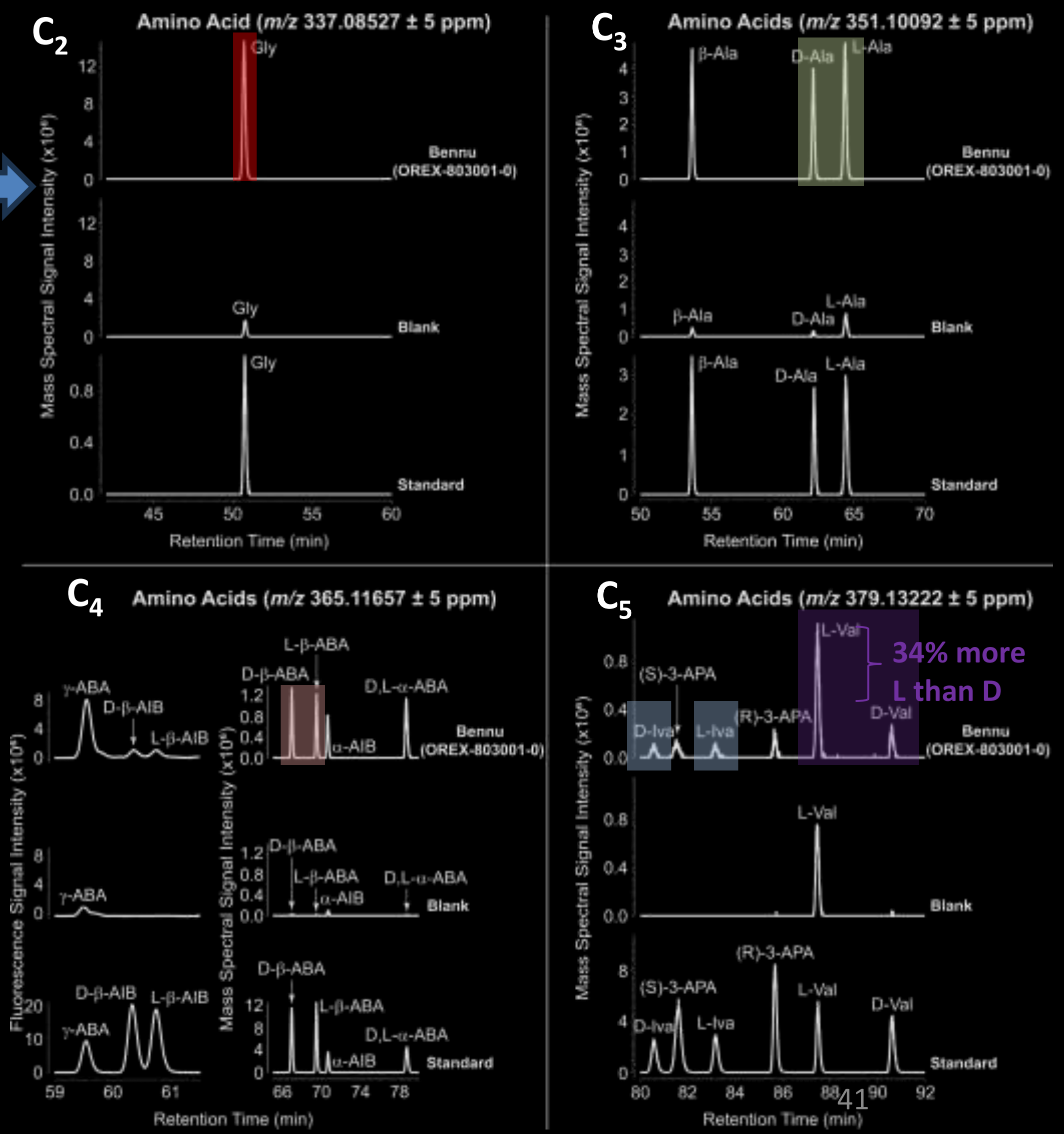
All 5 nucleobases in DNA/RNA in Bennu and Ryugu!



Glavin & Dworkin et al. (2025) *Nature Astronomy* 9:199
Oba & Koga *et al.* (2026) *Communications Chemistry* 9:132
Koga *et al.* (2024) *Geochimica et Cosmochimica Acta* 365:253
Koga *et al.* (2026) *Nature Astronomy* s41550-026-02791-z

Search for Extraterrestrial Amino Acids in Bennu

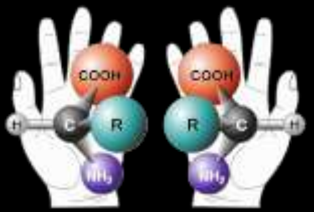


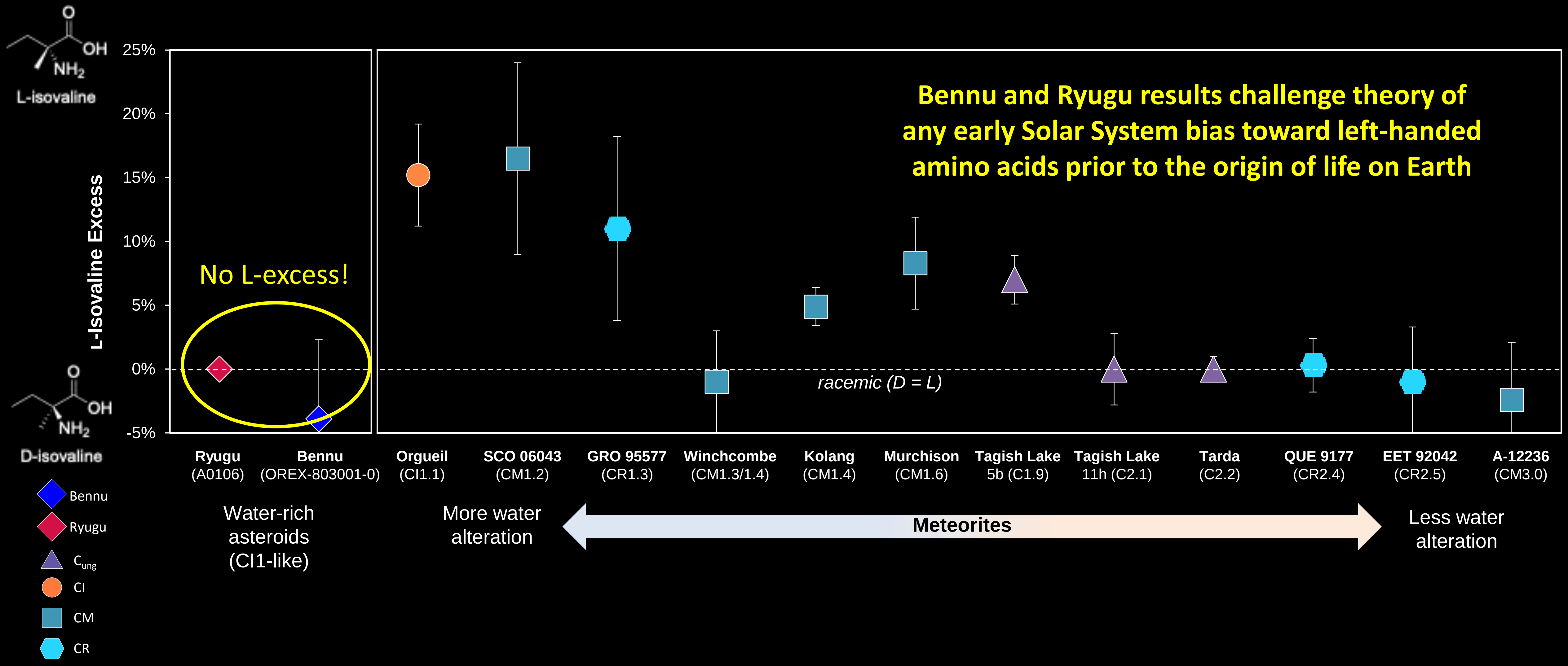


- **Glycine most abundant amino acid in Bennu samples**
  33 amino acids were found (including 15 of the 20 protein AAs)
- **Racemic (D = L) alanine indicates no terrestrial biological L-protein amino acid contamination**
- **All chiral non-protein amino acids in Bennu were racemic**
  β-ABA and isovaline → extraterrestrial origin.
- **Origin of L-valine excess in Bennu unclear.** Analyses underway to determine if the L-excess is from contamination or not.

Glavin & Dworkin et al. (2025) *Nature Astronomy* 9:199

Amino Acid Chirality “Handedness”

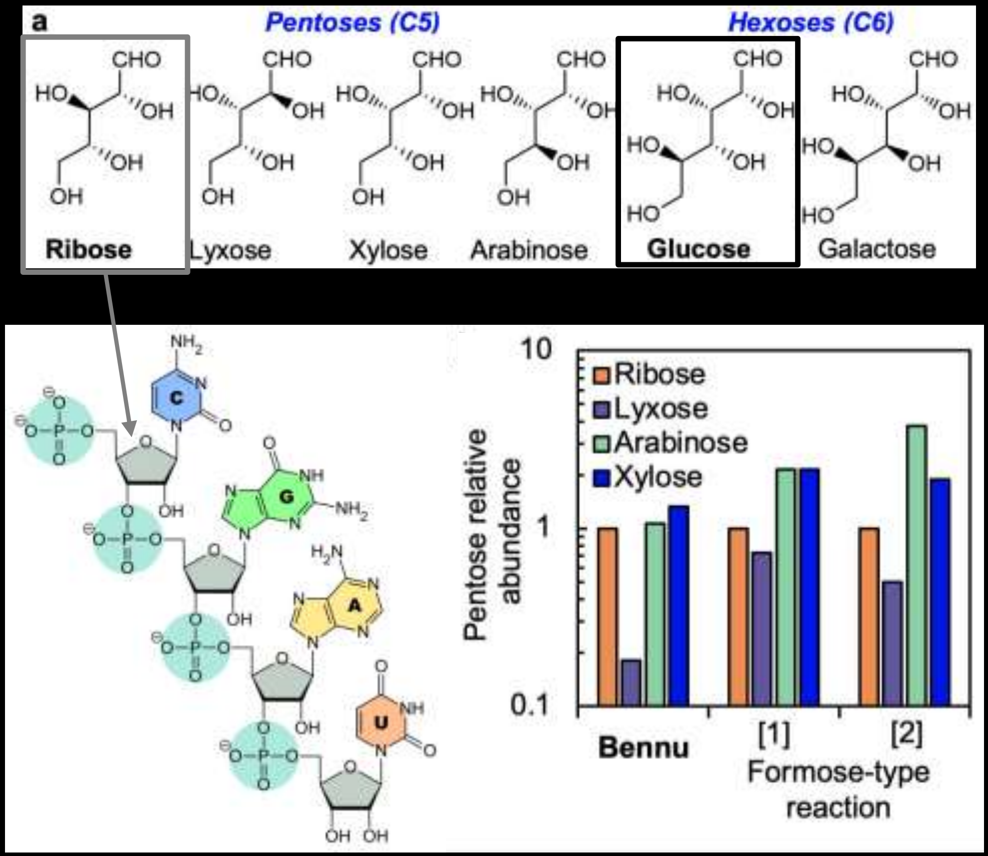




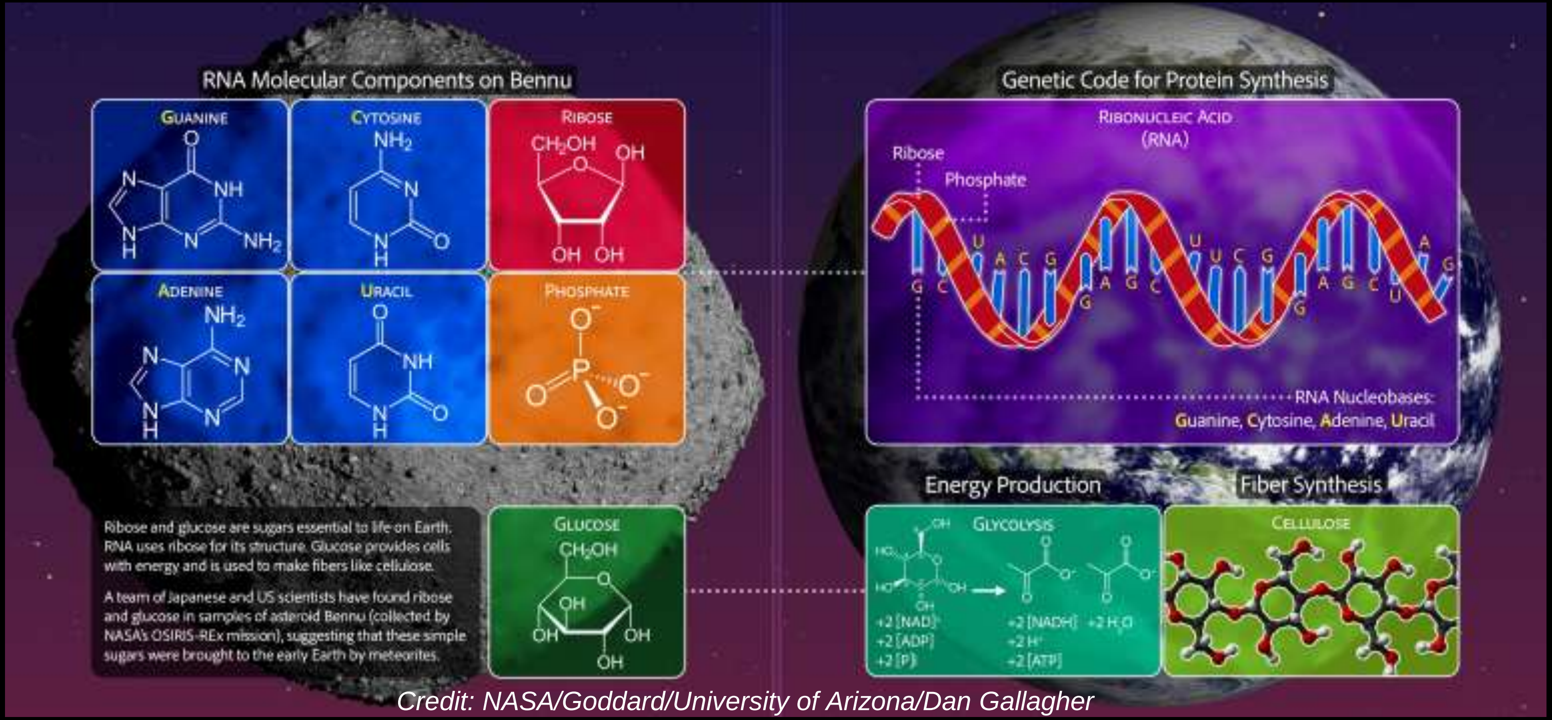
Glavin & Dworkin et al. (2025) *Nature Astronomy* 9:199

Bio-Essential Sugars Found in Bennu Samples

Bennu sample prepared at NASA, then extracted in 2% HCl and H_2O, derivatized and analyzed by GC-MS/MS at Tohoku University.



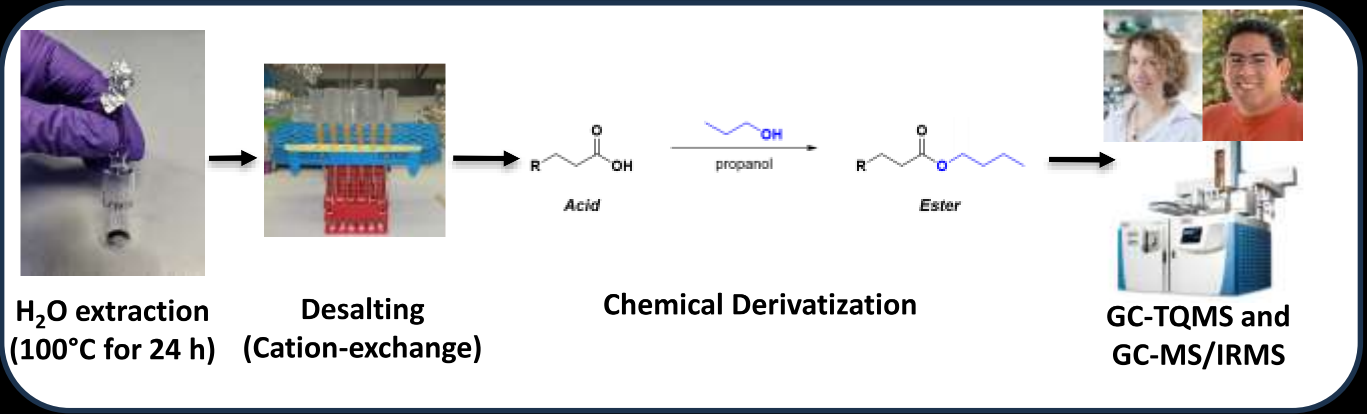
Furukawa *et al.* (2026) *Nature Geoscience* **19**:19

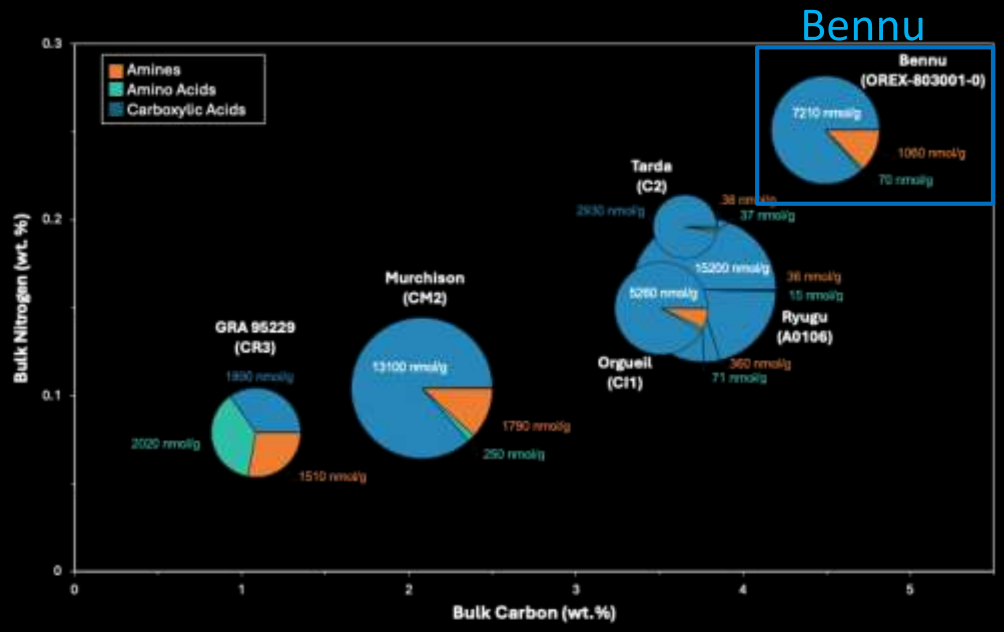


Credit: NASA/Goddard/University of Arizona/Dan Gallagher

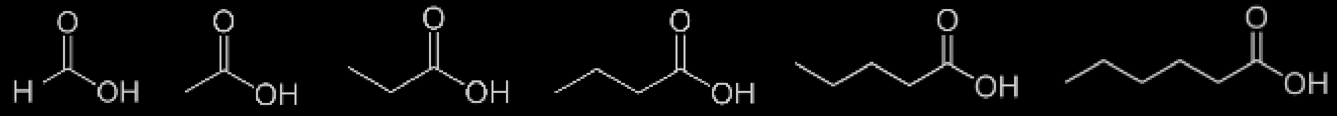
Detection of ribose (RNA sugar) but not 2-deoxyribose (DNA sugar), supports the RNA world hypothesis

Carboxylic Acids in Bennu Formed Through Interstellar and Parent Body Processes

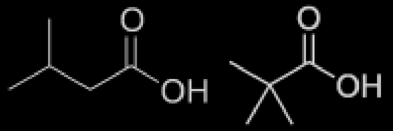




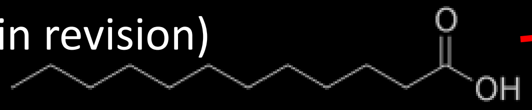
13 carboxylic acids C_1-C_6 (mostly straight-chained) identified in four different Bennu sample hot water extracts consistent with synthesis during parent body aqueous alteration (Buckner *et al.* 2026)



Branched carboxylic acids in Bennu aggregate may indicate some **interstellar contributions**

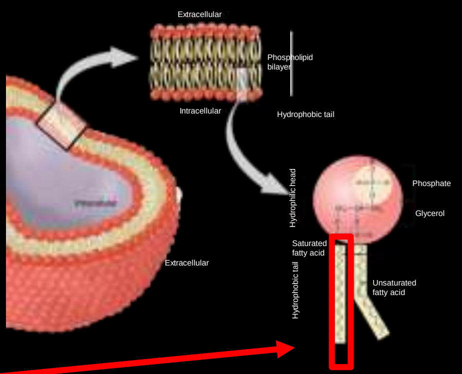


Long-chain carboxylic acids (up to C_{12}) identified in 0.1M NaOH extracts of Bennu (Huang *et al. Nat. Comm.* in revision)



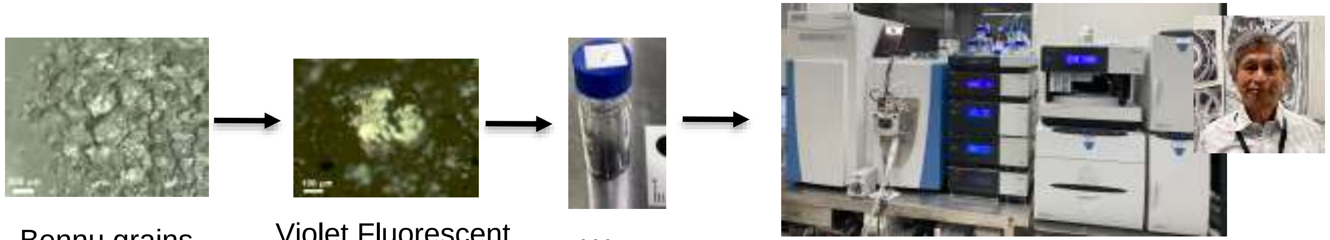
Prebiotic relevance:

Carboxylic acids are lipid membrane subcomponents and key for metabolism



Glavin & Dworkin *et al.* (2025) *Nature Astronomy* 9:199
Buckner *et al.*, (2026) Astrobiology Science Conference Abstract 409-04

Bennu Polyphosphates Could Provide Energy for Early Prebiotic Chemistry

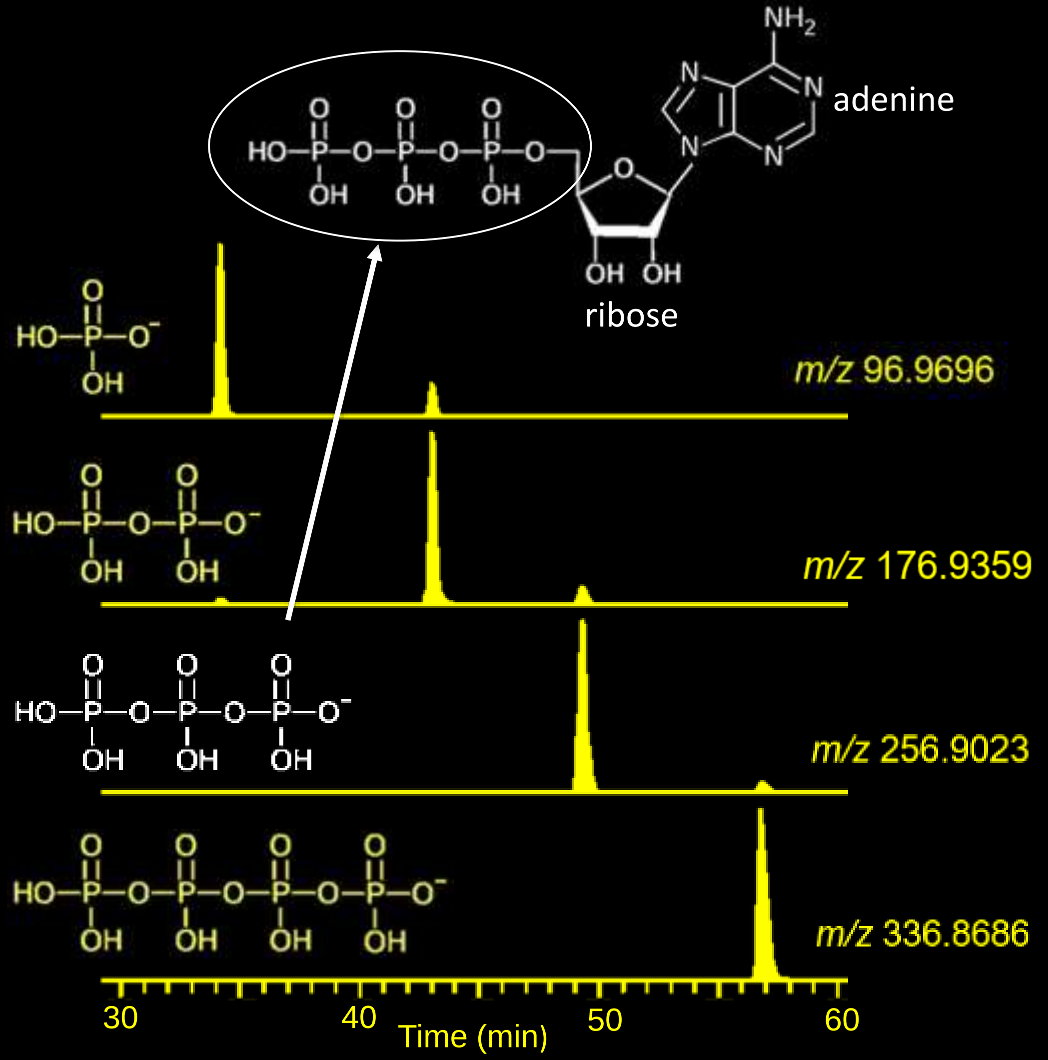


Bennu grains → Violet Fluorescent phosphate grain → Water extraction → **Ion Chromatograph-Orbitrap MS** (Thermo ICS-6000 & Q Exactive)

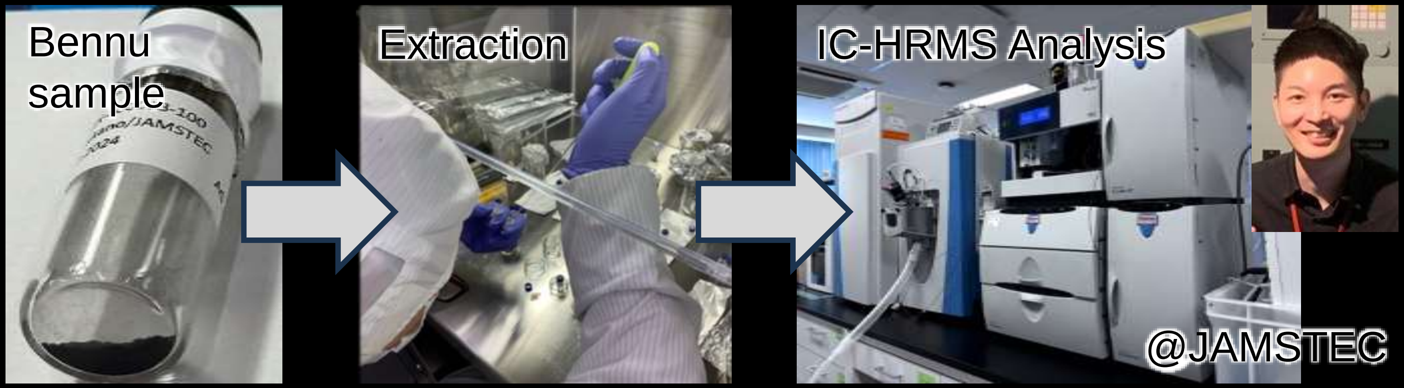
- **Polyphosphates including diphosphate and triphosphate, principal components in ADP and ATP respectively, were identified up to heptaphosphate (P_7) in the water extracts of Bennu samples using ultrahigh-resolution mass spectrometry.**
- **The polyphosphates were associated with the occurrence of Na-bearing Mg phosphate, which was likely formed in the brine of the parent body of Bennu.**
- **All components (adenine, ribose, triphosphate) were available to make an ATP molecule as energy currency for protometabolism on the early Earth.**

Naraoka *et al.* (2026)

ATP molecule for energy transfer in terrestrial biology



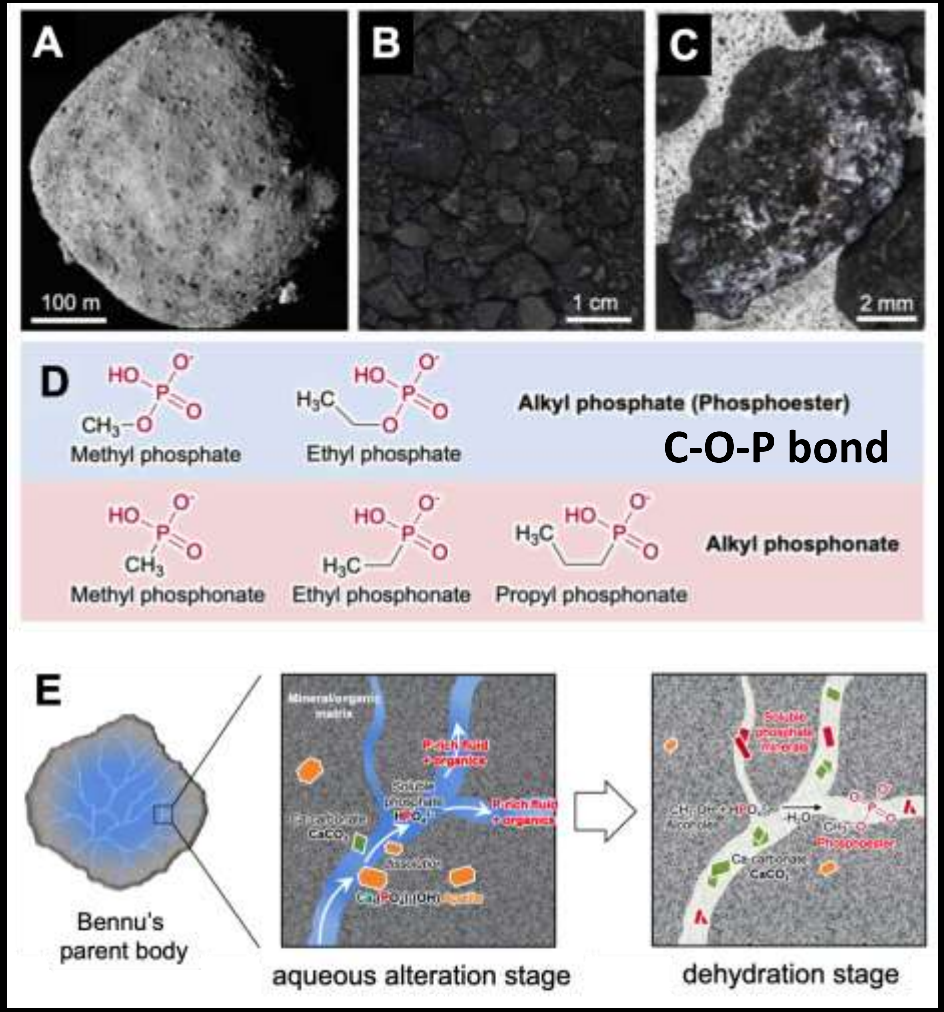
Phosphoesters in Bennu Provide Evidence of Abiotic Phosphorylation in Nature



- **Phosphoesters are key structures for all life on Earth, however they have not been previously detected in extraterrestrial samples.**

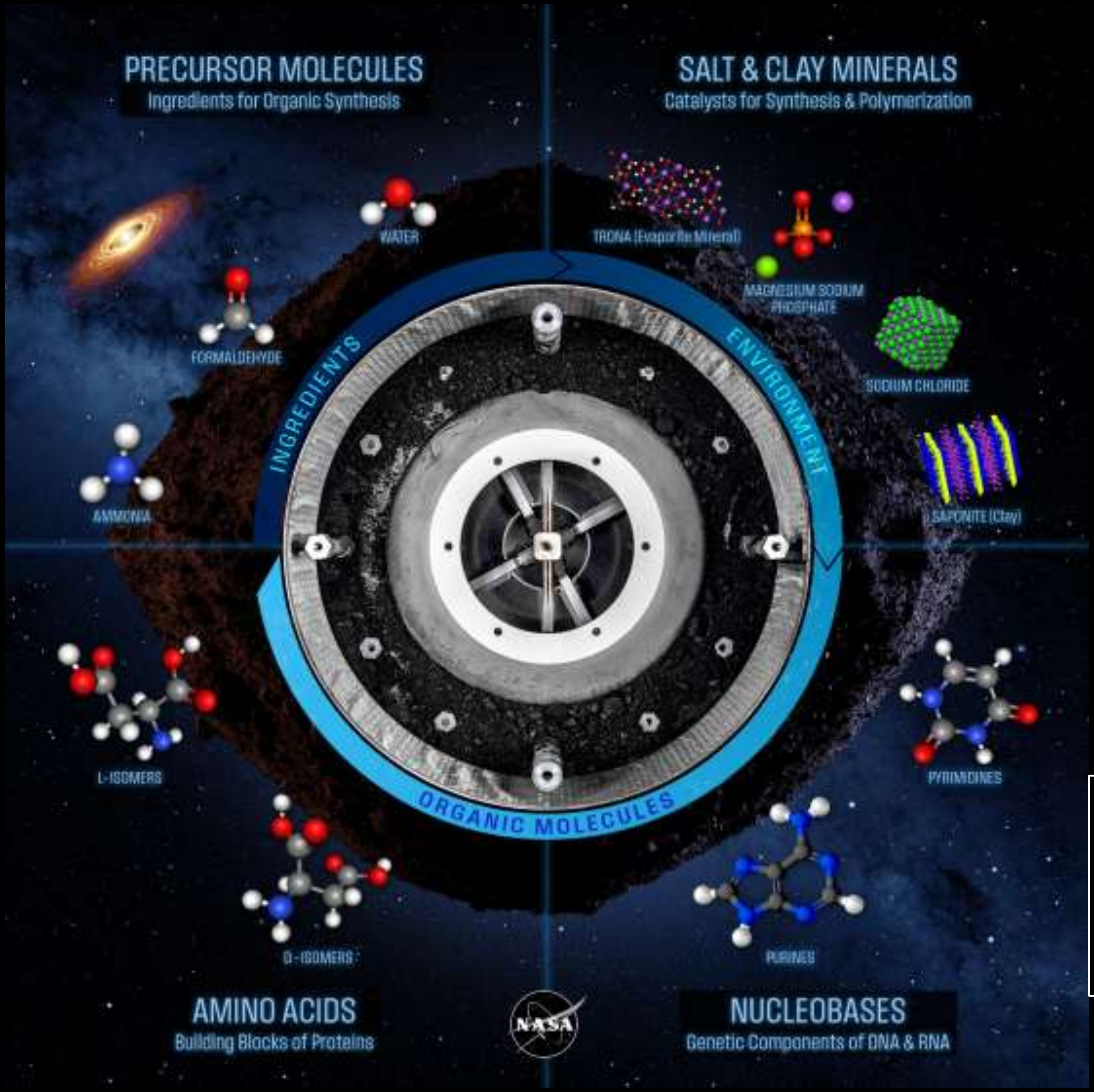
- **Several organophosphorus compounds, including alkyl phosphates with C-O-P bonds essential for energy transfer and nucleic acid structure in biology.**

- **The results provides evidence of <u>abiotic phosphorylation</u> in Bennu's parent body, likely during evaporation of phosphate-rich fluids and organics.**



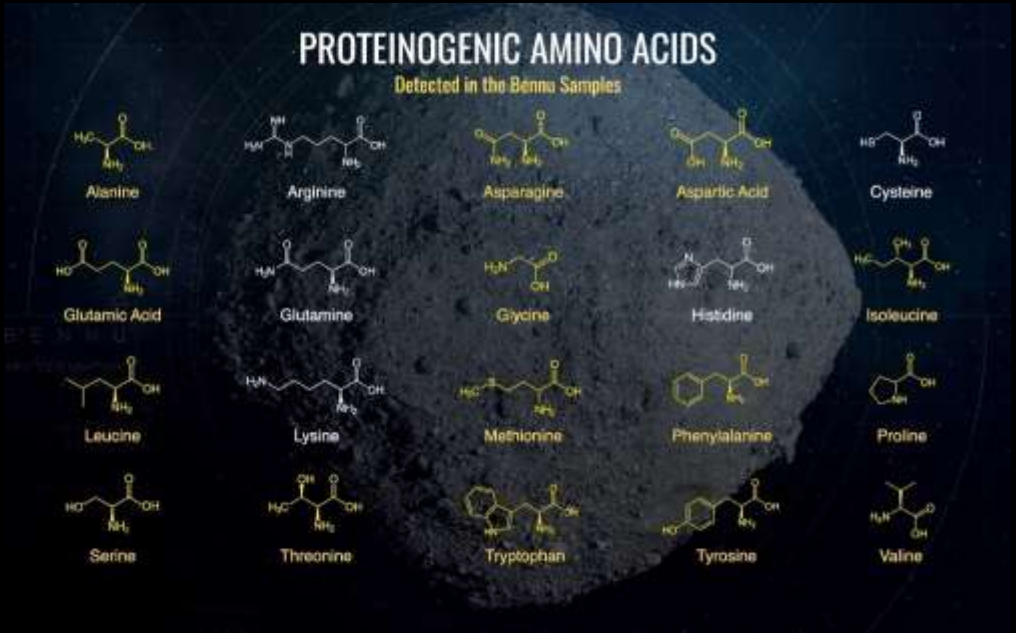
Hirakawa *et al.* (2026) *Nature*, in review

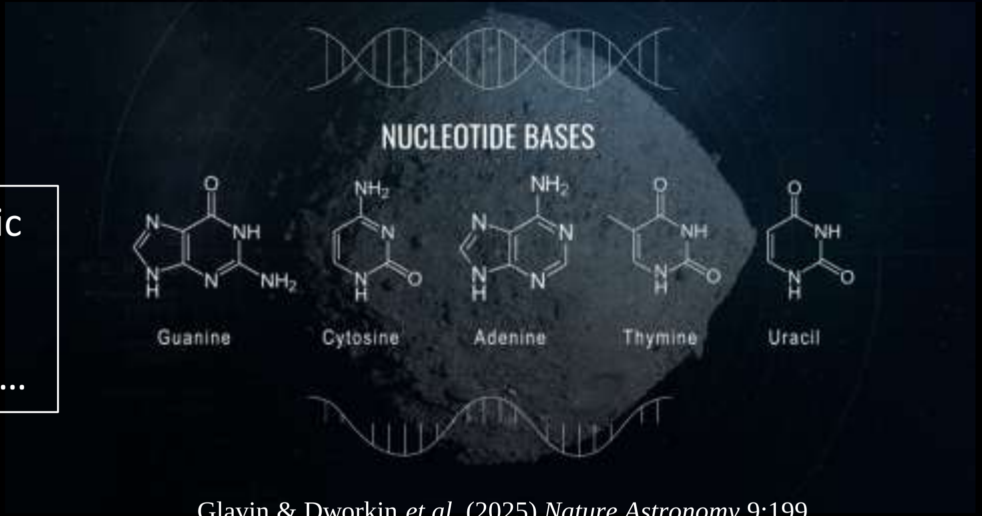
Chemical Ingredients for Life Formed ~4.5 Gyr in a Wet and Salty World!



Credit: NASA/Goddard/University of Arizona/Dan Gallagher

+ sugars, carboxylic acids/lipids, polyphosphates, alkyl phosphates, …

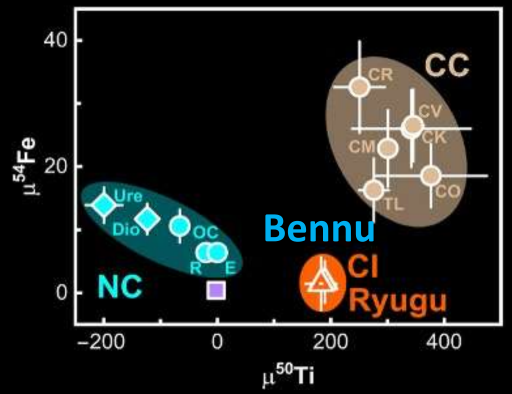


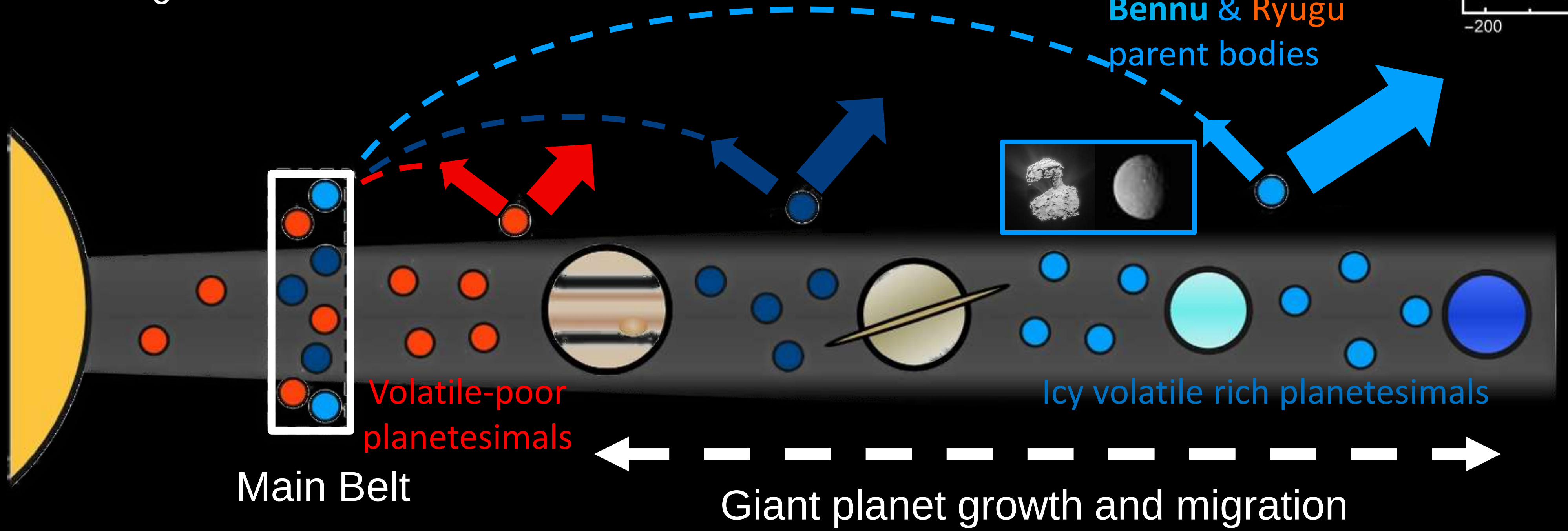


Glavin & Dworkin *et al.* (2025) *Nature Astronomy* 9:199
McCoy & Russell *et al.* (2025) *Nature* 637:1072

Isotope Anomalies and ^{15}N-rich Organic Matter Point to an Outer Solar System Origin of Bennu

Large (~100 km diameter) icy outer solar system bodies may have been an important source of volatiles in the inner solar system required for the origin of life



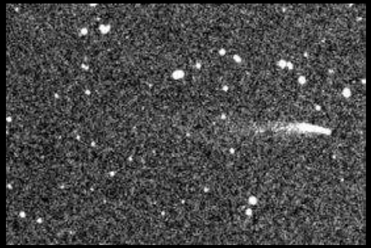


Bottke *et al.* (2015) *Icarus* 247:191
Hopp *et al.* (2022) *Science Advances* 8:eadd8141
Brennecka *et al.* (2024) Goldschmidt Conference, Abstract 22852
Barnes & Nguyen *et al.* (2025) *Nature Astronomy* 9:1785

Is Bennu a Remnant of an Icy Ocean World or Fragment of an Extinct Comet?

(101955) Bennu

Other Class-B asteroids are active



107P/(4015) Wilson-Harrington

Undifferentiated
Salty
Very Cold
Minimal rock-water interaction
Ammonia
Icy

67P/Churyumov–Gerasimenko

Comet

Differentiated
Salty
Cold
Extensive rock-water interaction
Ammonia
Wet

(1) Ceres   Enceladus

Ocean Worlds

?

Future sample return from a comet nucleus and an icy world important to investigate chemical links between active asteroids and primitive icy bodies.

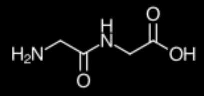
Implications for the Origin and Search for Life

- **Volatile-rich asteroids like Bennu contain biologically important organic molecules that were spread throughout the early Solar System.**

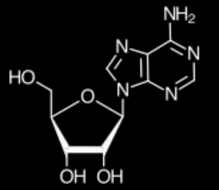
- **Bennu's parent body could qualify as a habitable world (Ceres or Enceladus-like)**
  - ➢ Mild temperatures (T_{max} < 55°C)
  - ➢ Salty (evaporite minerals)
  - ➢ Alkaline fluids (pH ~ 8.2)
  - ➢ Wet (clays)
  - ➢ High soluble carbon, nitrogen, phosphorous, and sulfur
  - ➢ Organic molecules essential for life as we know it

Why didn't prebiotic chemistry advance further in Bennu's parent body to form larger organic polymers? What did the early Earth have that Bennu didn't?

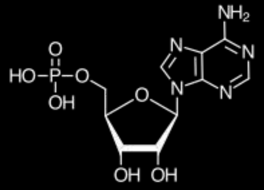
dipeptides



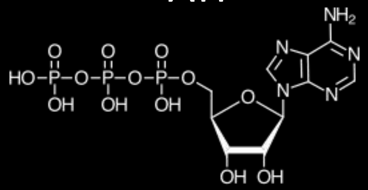
nucleosides



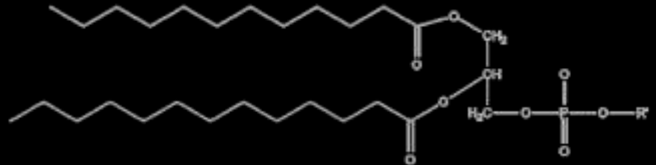
nucleotides



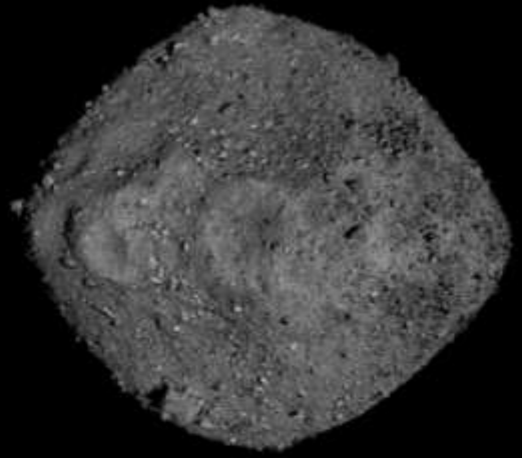
ATP



Phospholipids



Thank you!



We are grateful to the entire OSIRIS-REx Team for making the return of samples from asteroid Bennu possible!

OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

NASA.gov/OSIRIS-REx

NASASolarSystem

AsteroidMission.org

NASASolarSystem

NASASolarSystem

Sample Catalogue

OSIRIS-REx LAUNCH	ARRIVAL AT BENNU	SCIENTIFIC OBSERVATION	SAMPLE COLLECTION	TRAVEL BACK TO EARTH	SAMPLE ARRIVAL IN UTAH	UP NEXT... OSIRIS-APEX RENDEZVOUS WITH ASTEROID APOPHIS
SEPT. 8, 2016	DEC. 2018	DEC. 2018 – OCT. 2020	Oct. 20, 2020	OCT. 2020 – SEPT. 2023	SEPT. 24, 2023	APR. 13, 2029