# A Trip to the Early Solar System: First Results from Returned Asteroid Ryugu Samples


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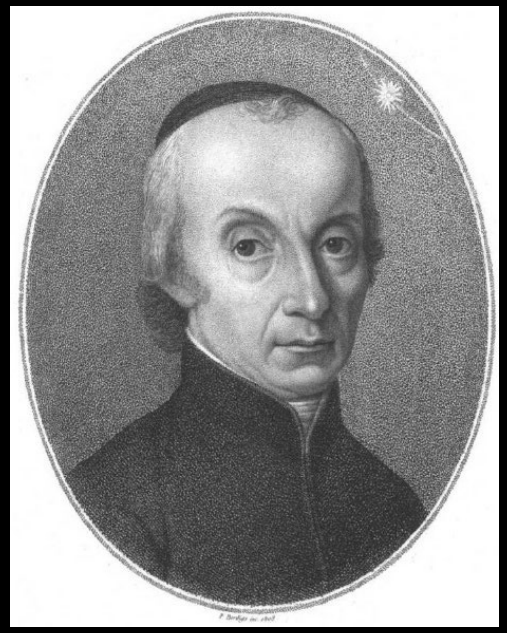
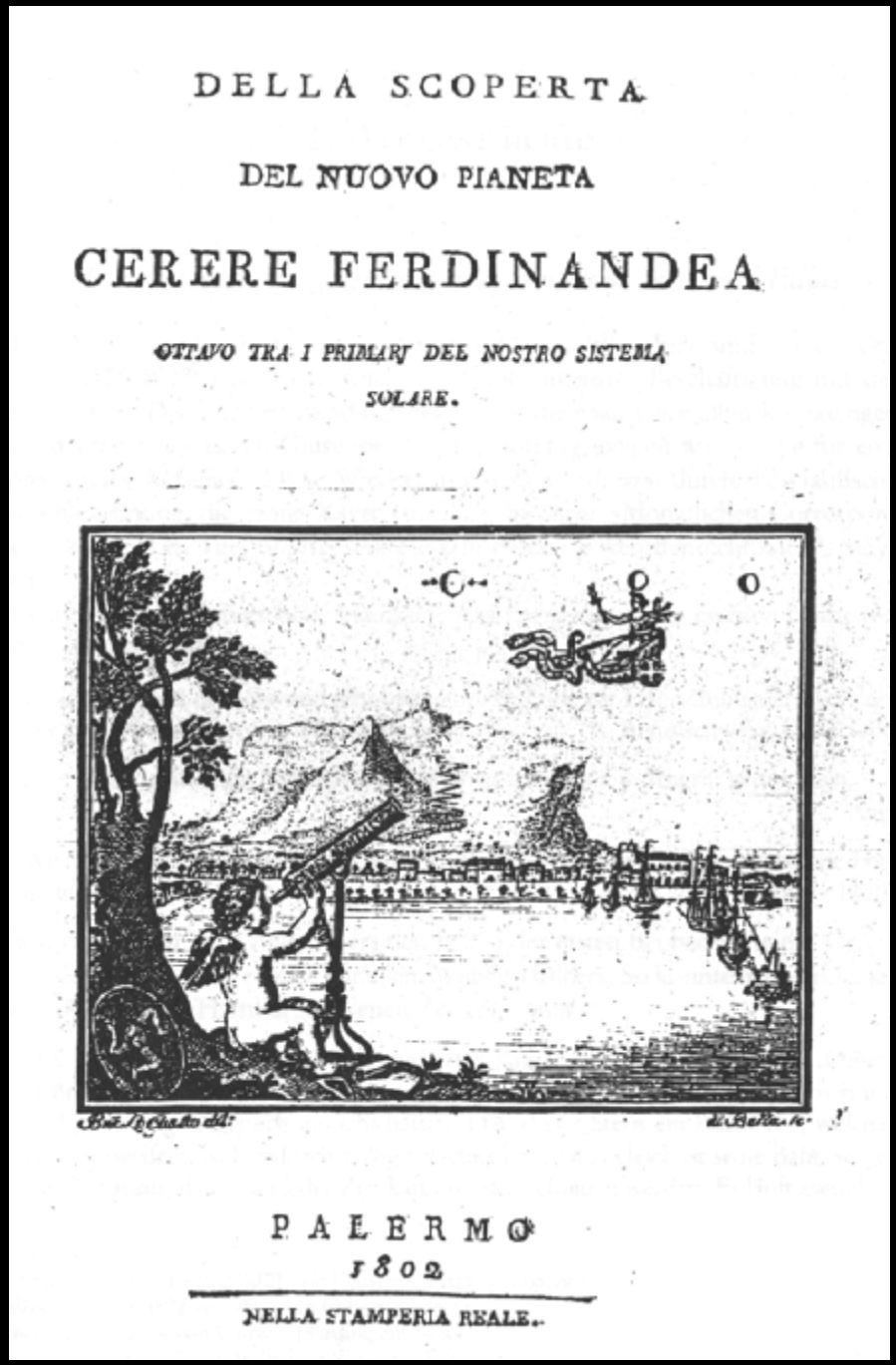
SESE Colloquium September 7, 2022

JAXA NASA



- 1801:  Giuseppe Piazzi (Palermo) discovered new planetary body between Mars and Jupiter that he named Cerere Ferdinandea, soon shortened to Ceres



DELLA SCOPERTA

DEL NUOVO PIANETA

CERERE FERDINANDEA

OTTAVO TRA I PRIMARJ DEL NOSTRO SISTEMA SOLARE.

PALERMO

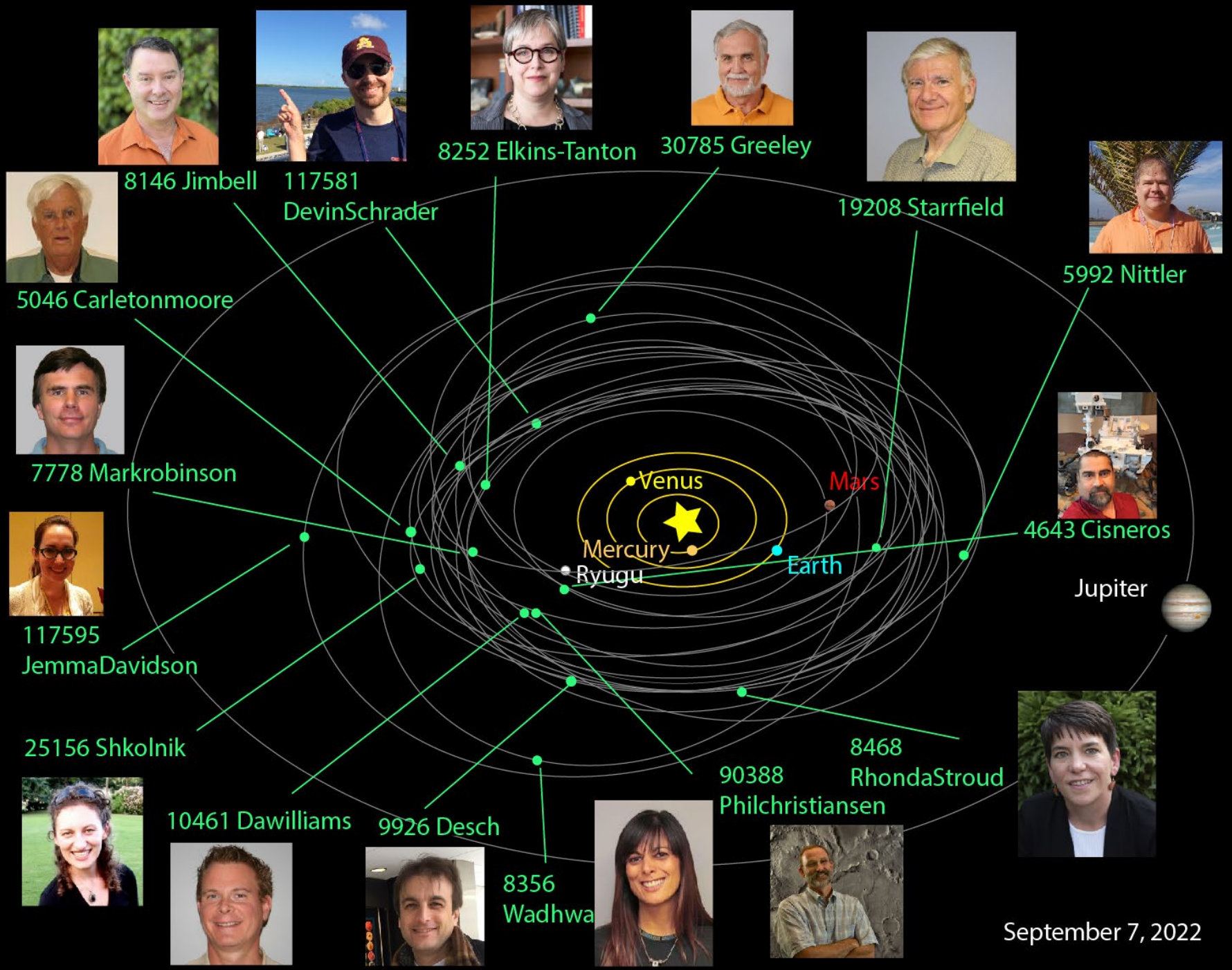
1802

NELLA STAMPERIA REALE.

# Ceres discovery followed shortly by discovery of Pallas (1802), Juno (1804), Vesta (1807) …

New class of small bodies between Mars and Jupiter, named *asteroids* (star-like, star-shaped) by Sir William Herschel in 1802

- >100 discovered by end of 19th century
- >1,000,000 by today


8146 Jimbell
117581
DevinSchrader
8252 Elkins-Tanton
30785 Greeley
19208 Starrfield
5992 Nittler
5046 Carletonmoore
7778 Markrobinson
Venus
Mars
Mercury
Ryugu
Earth
4643 Cisneros
Jupiter
117595
JemmaDavidson
25156 Shkolnik
10461 Dawilliams
9926 Desch
8356
Wadhwa
90388
Philchristiansen
8468
RhondaStroud
September 7, 2022

# Ceres discovery followed shortly by discovery of Pallas (1802), Juno (1804), Vesta (1807) …

New class of small bodies between Mars and Jupiter, named *asteroids* (star-like, star-shaped) by Sir William Herschel in 1802

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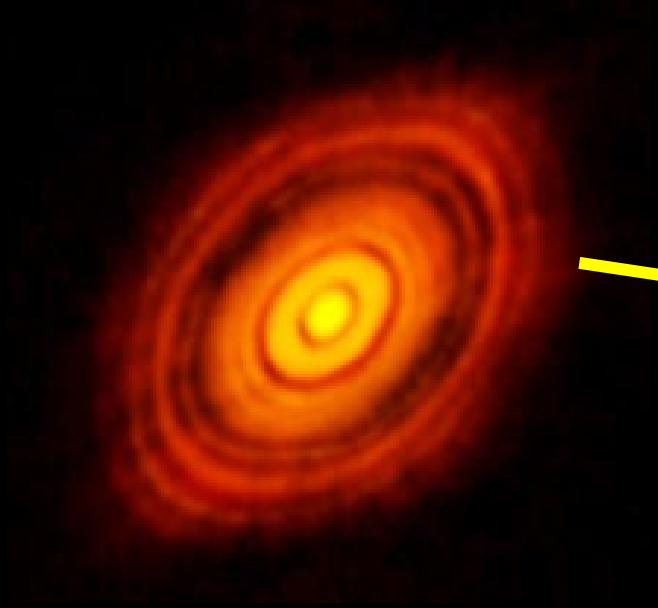
- >1,000,000 by today

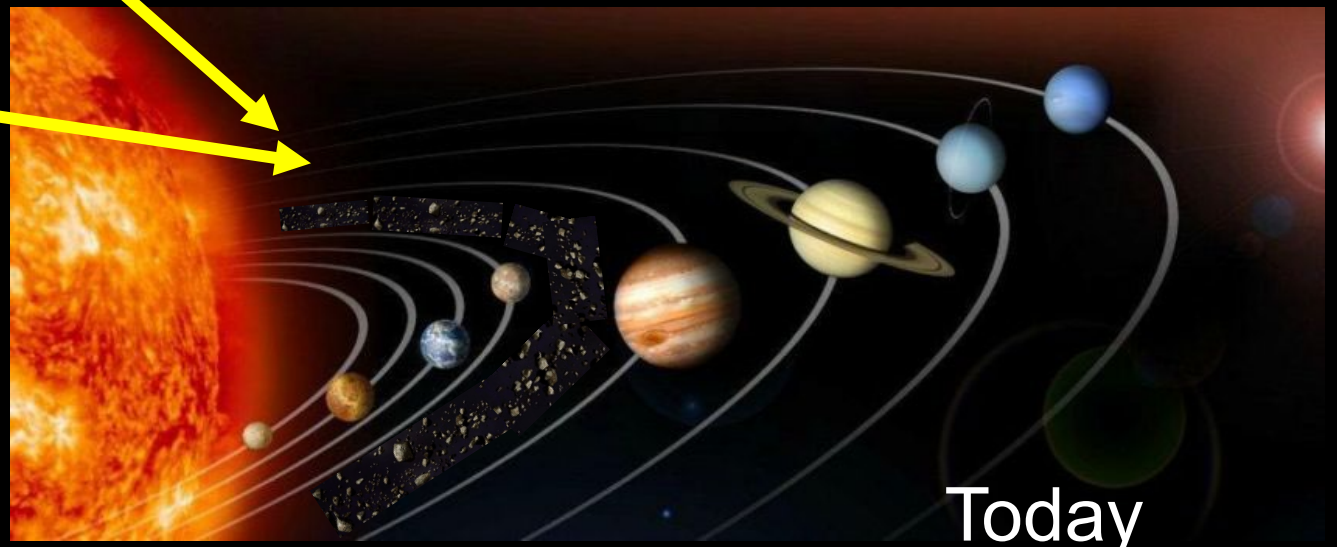
*Why should we care?*

- Sun and planets formed from disk of gas/dust
- *Accretion*

  dust -> rocks-> planetesimals -> planets

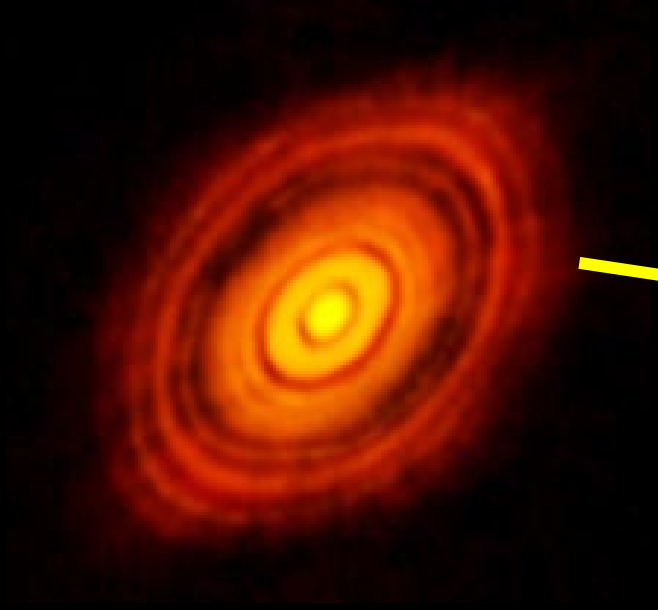


4.6 billion years ago

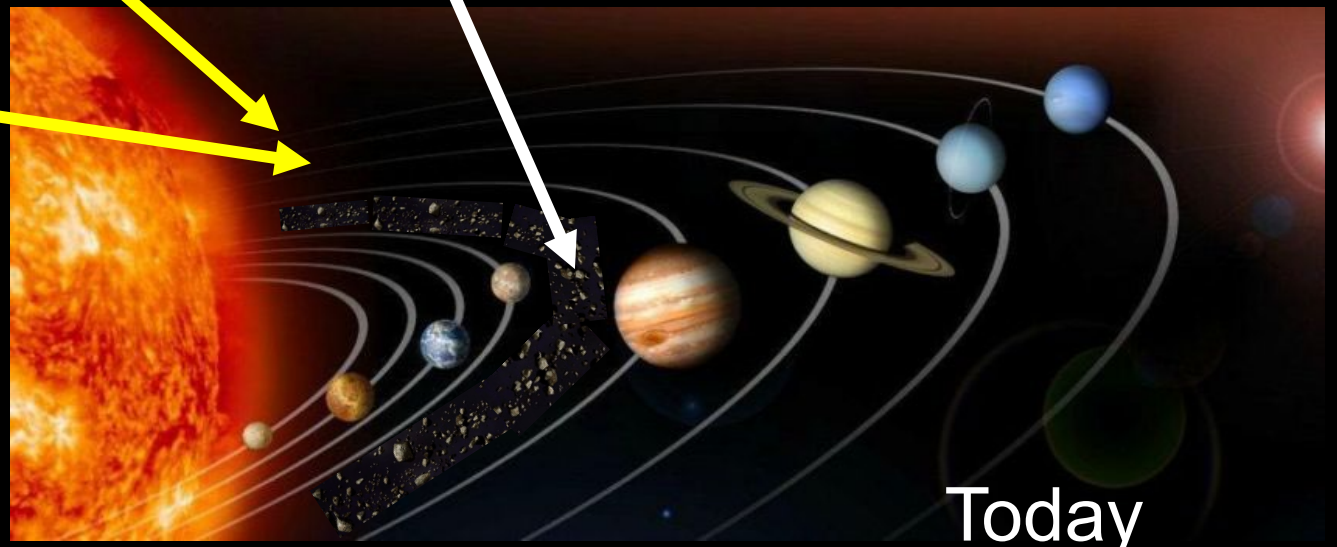


Today

- Sun and planets formed from disk of gas/dust
- *Accretion*
  dust -> rocks-> planetesimals -> planets
- Asteroids are surviving planetary building blocks



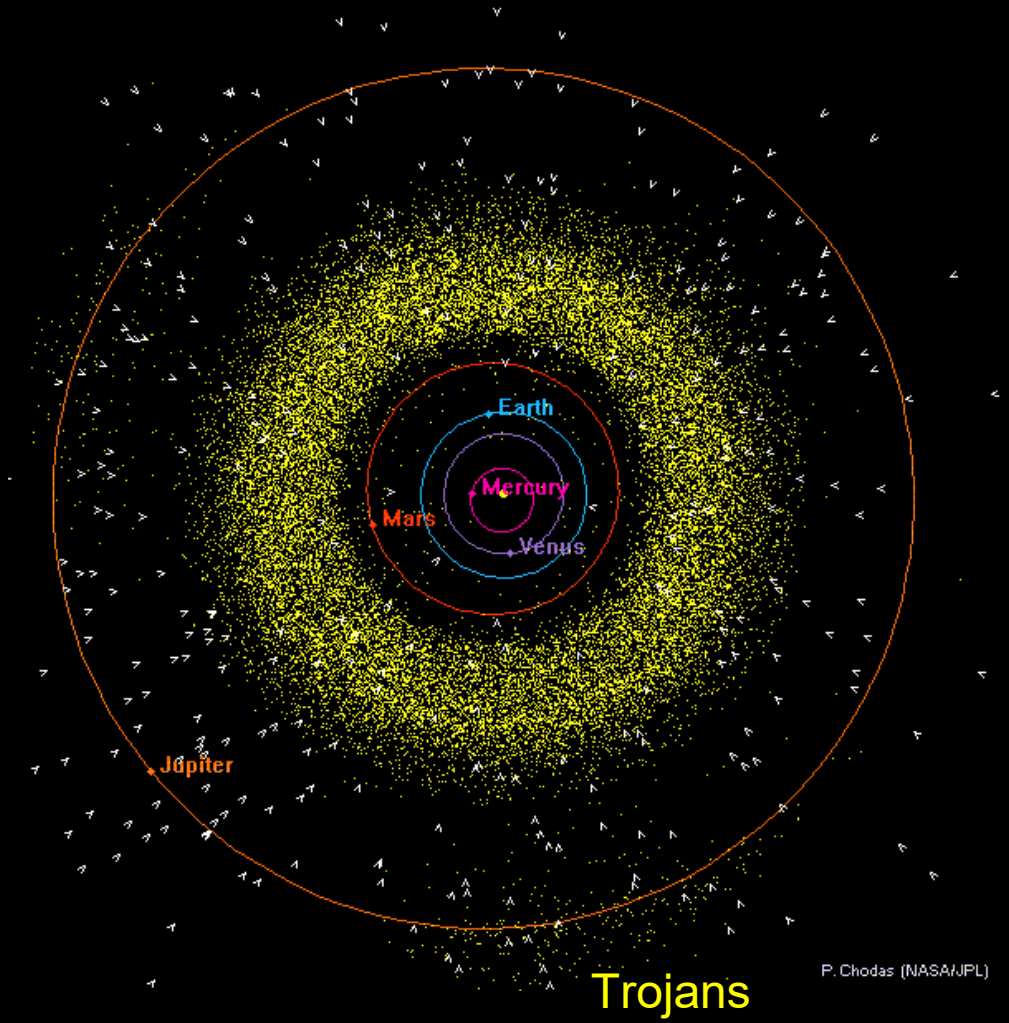
4.6 billion years ago



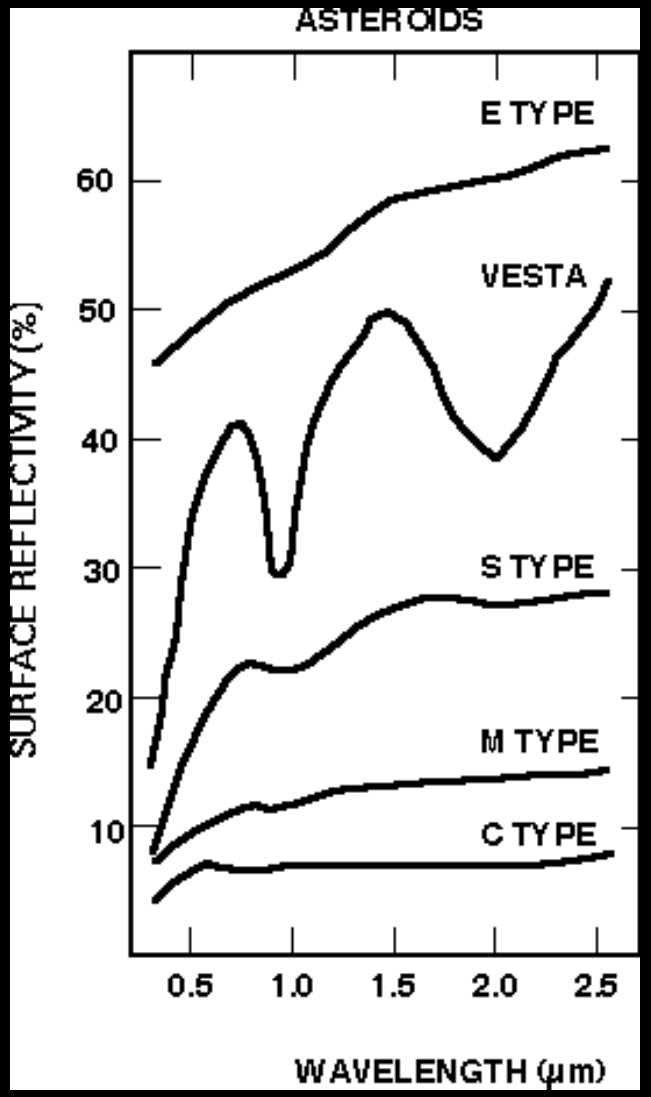
Today

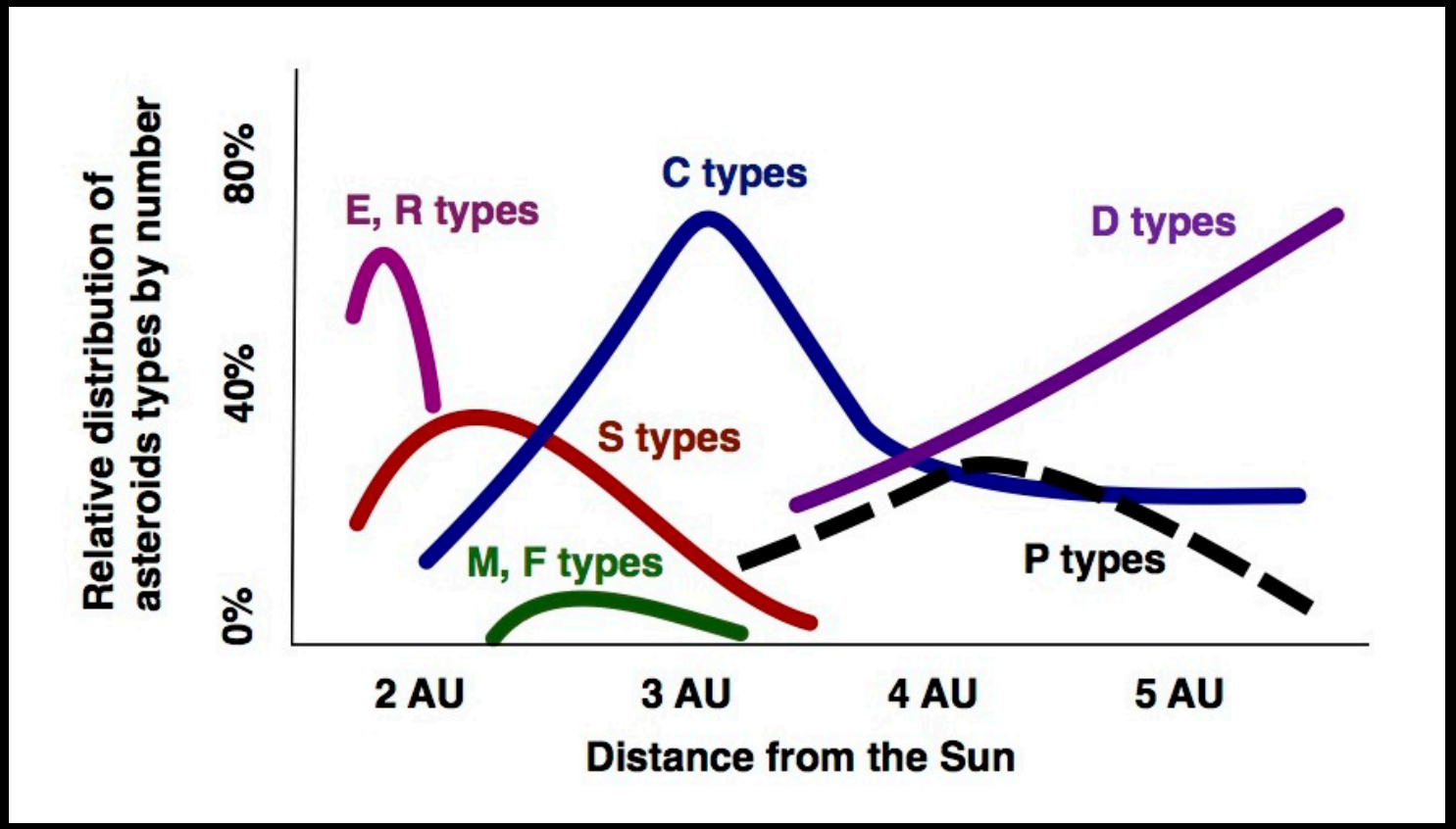
# Leftovers of planet formation

- Fossil record of Sun's protoplanetary disk
- Contain water/ organic molecules: may have delivered water/organics to early Earth



# Telescopic observations reveal diversity of asteroid composition

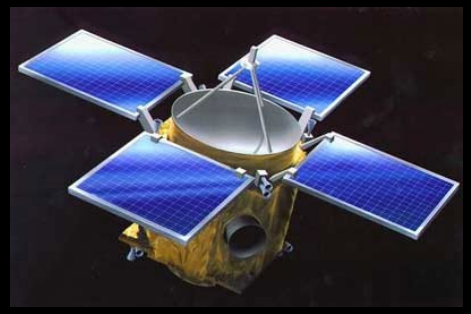


# Spacecraft reveal compositional/geomorphic diversity

Galileo
(1991-93)


NEAR (2000-2001)



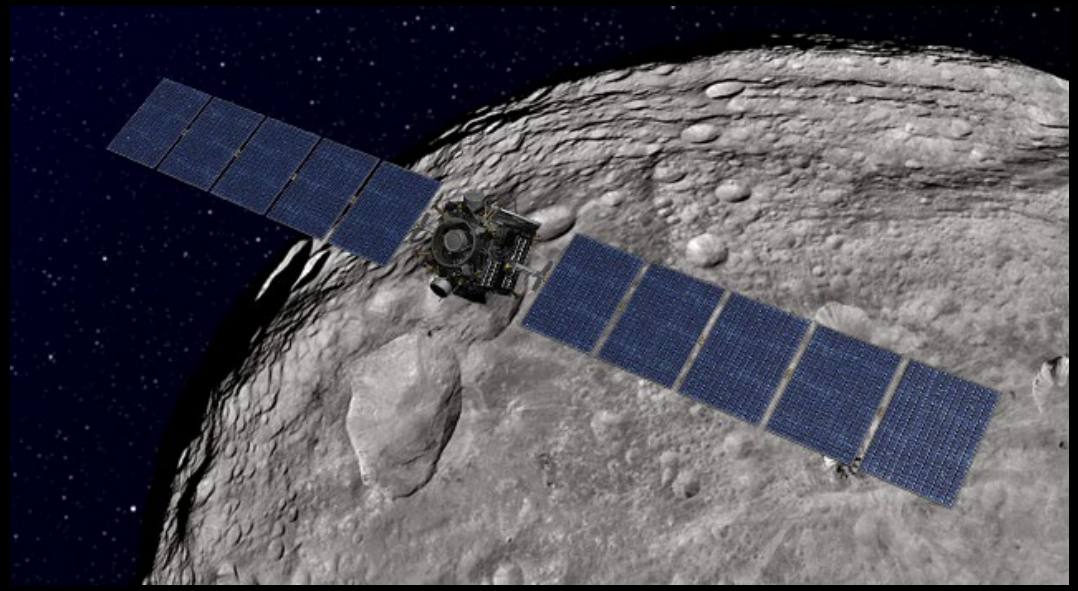
Mathilde

Dactyl

Ida

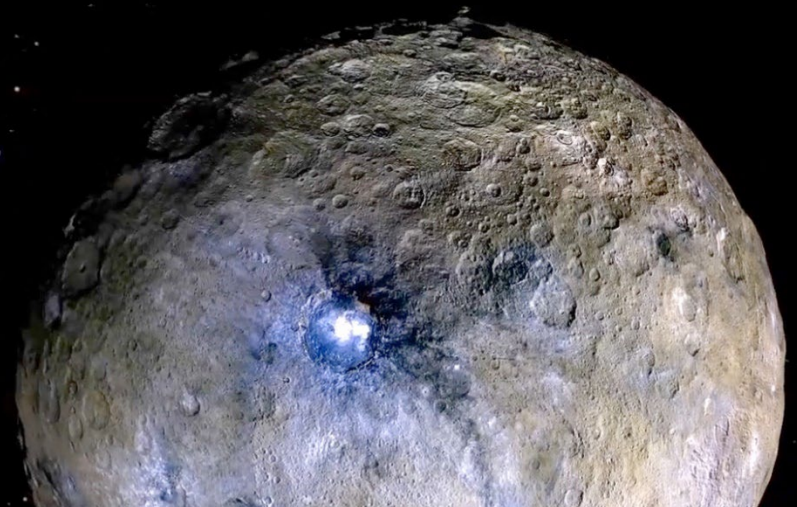
Eros

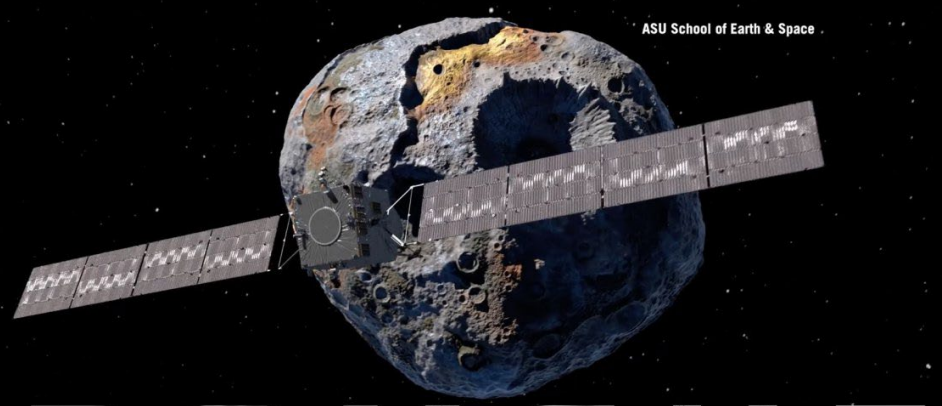
# Spacecraft reveal compositional/geomorphic diversity



DAWN at Vesta (2011-12)…

… and Ceres (2015-18)






PSYCHE

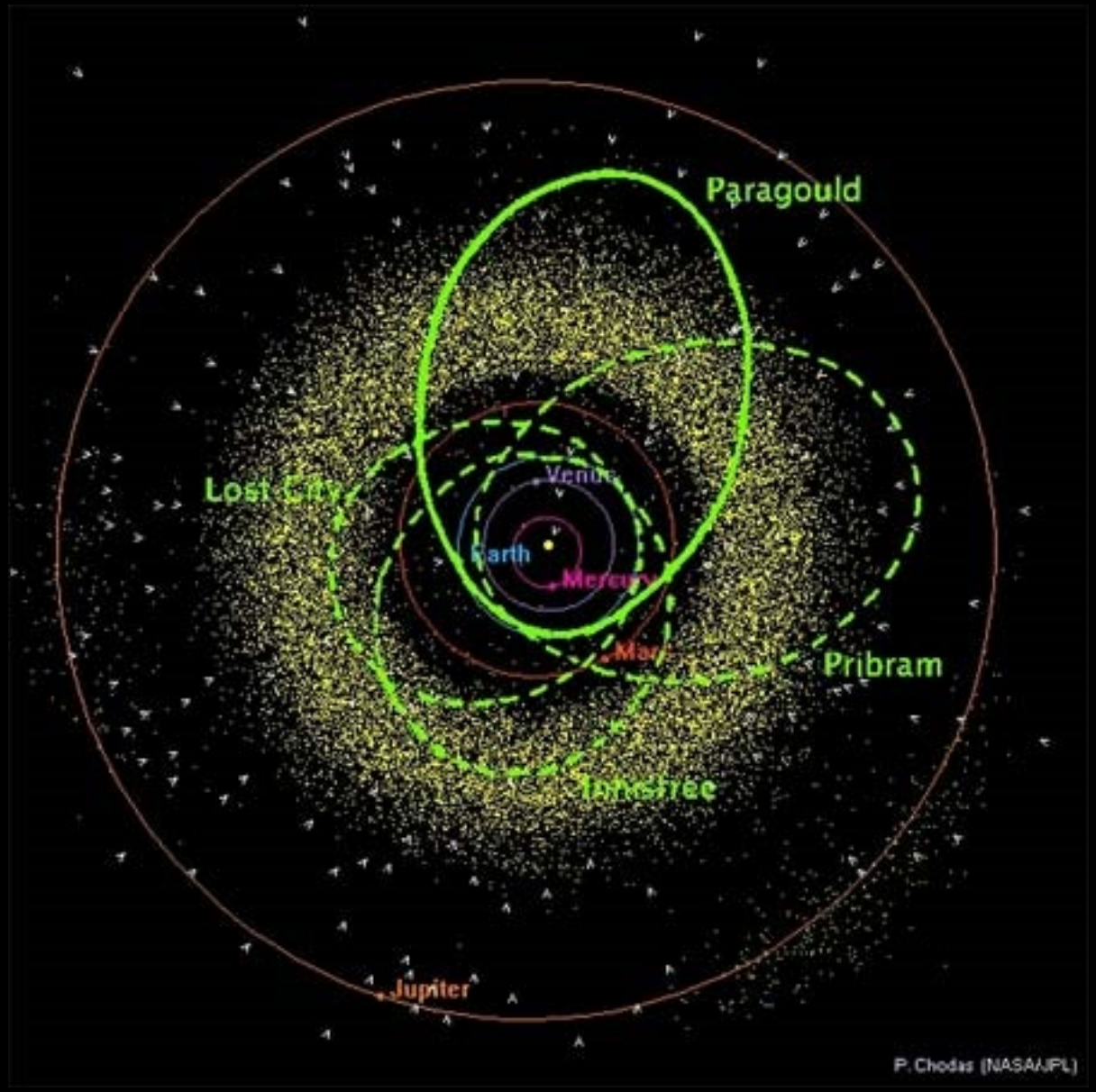
# Direct sampling of asteroids - meteorites


Ensisheim
November 7, 1492

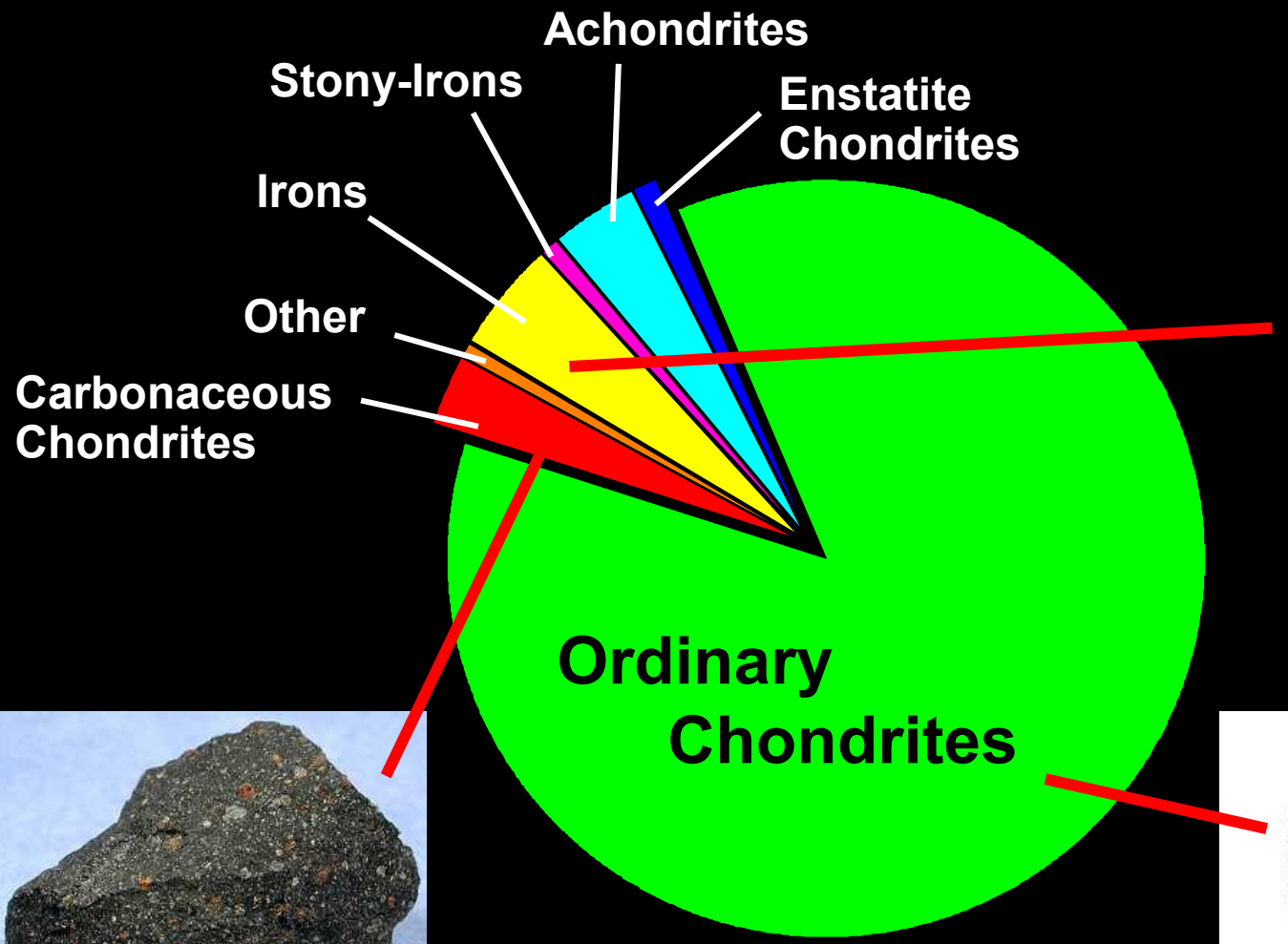
Weston (CT)
Dec 14, 1807

# (most) Meteorites sample asteroids

- Fireball reconstruction indicates origin in asteroid belt



# Diversity of meteorite types



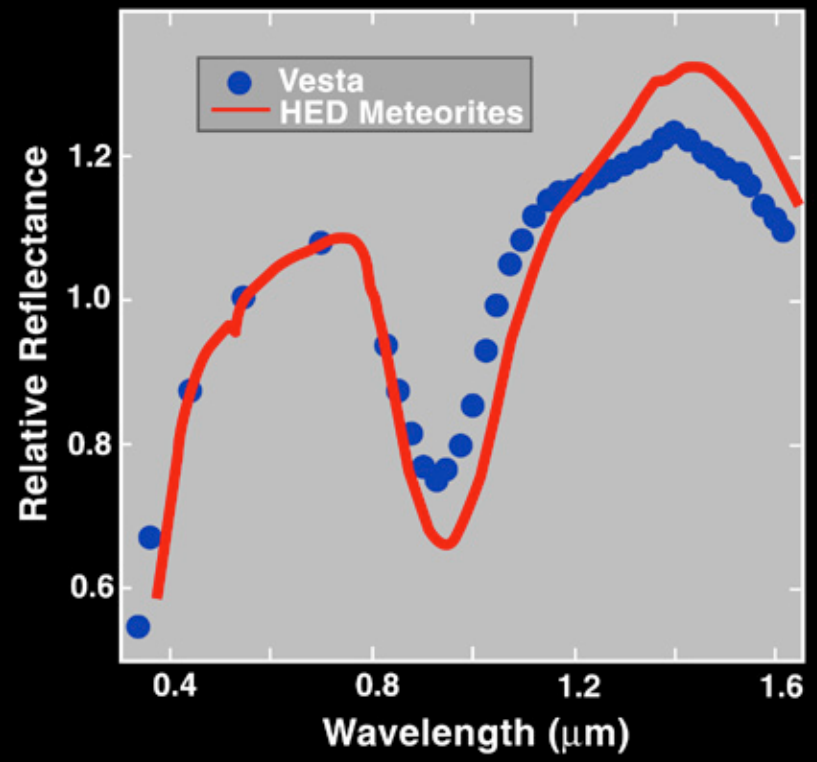


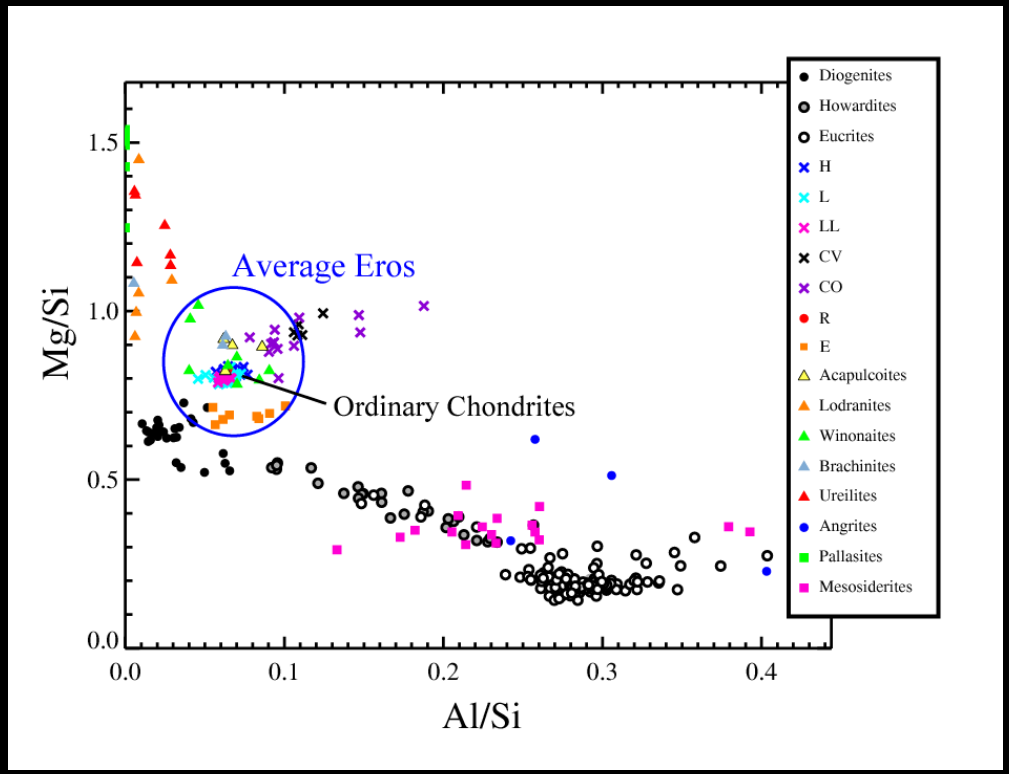

# Carbonaceous chondrites

4,567.3±0.2 million years old

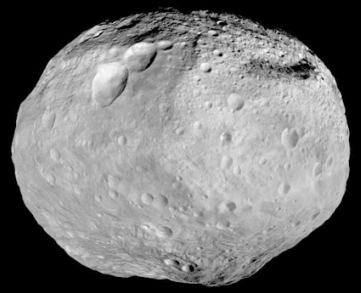
- Heterogeneous mixtures of minerals (silicates, metal, sulfides, carbonates) and carbon (few %) from the protoplanetary disk
- Bulk composition similar to the Sun
- Accreted with water ice that melted and reacted with minerals
- Important sources of organic C to early Earth

# Meteorite-asteroid connections?



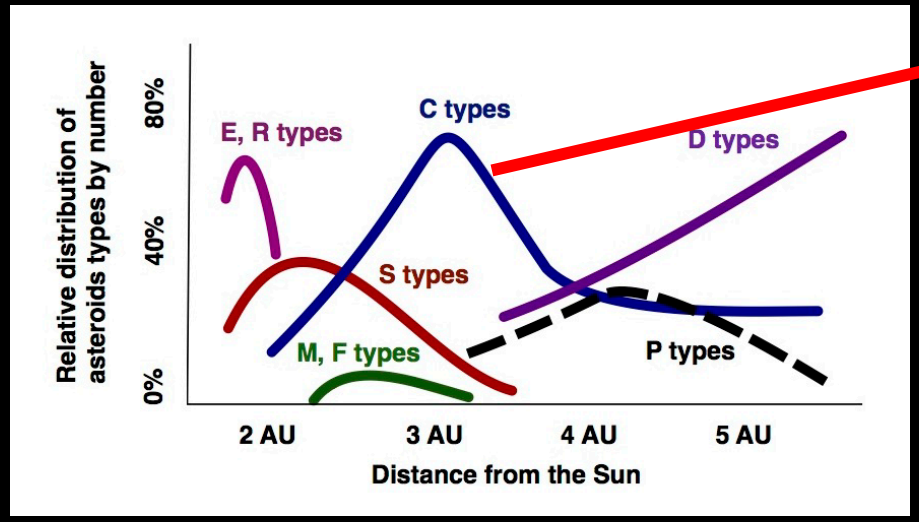

Nittler et al. (2001)



# Meteorite-asteroid connections?

C-asteroid Mathilde

??

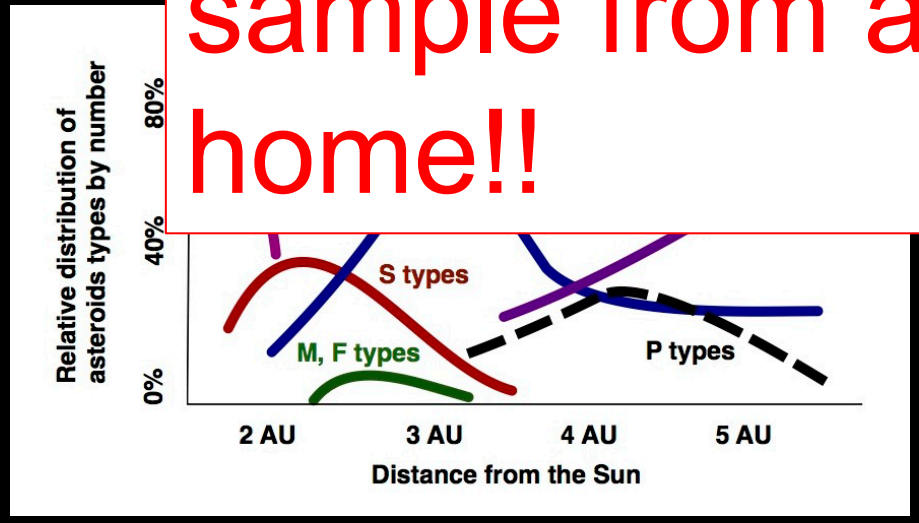



# Meteorite-asteroid connections?

C-asteroid M

??

Best way to find out: Go pick up sample from asteroid and bring it home!!

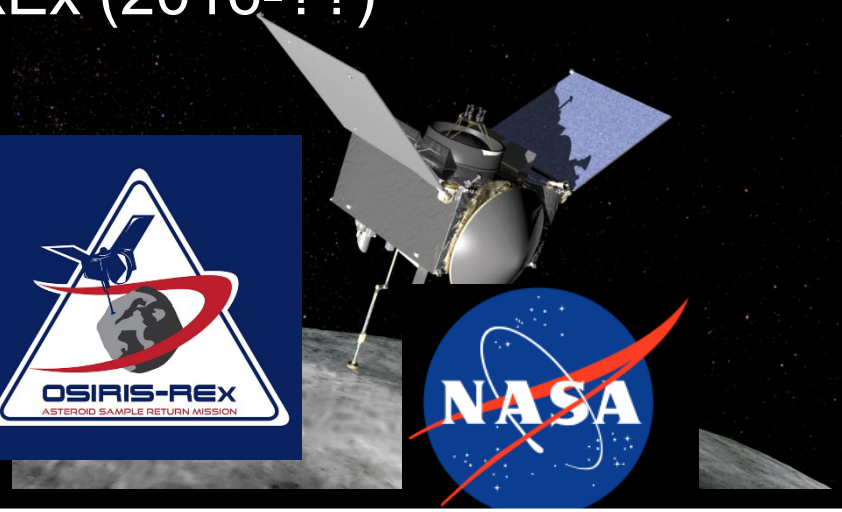



# Asteroid Sample Return Missions

Hayabusa (2003-10)

Hayabusa2 (2014-??)

OSIRIS-REx (2016-??)



# **Hayabusa** (2003-2010)

Sample return mission from an S-type near Earth asteroid

**Itokawa**

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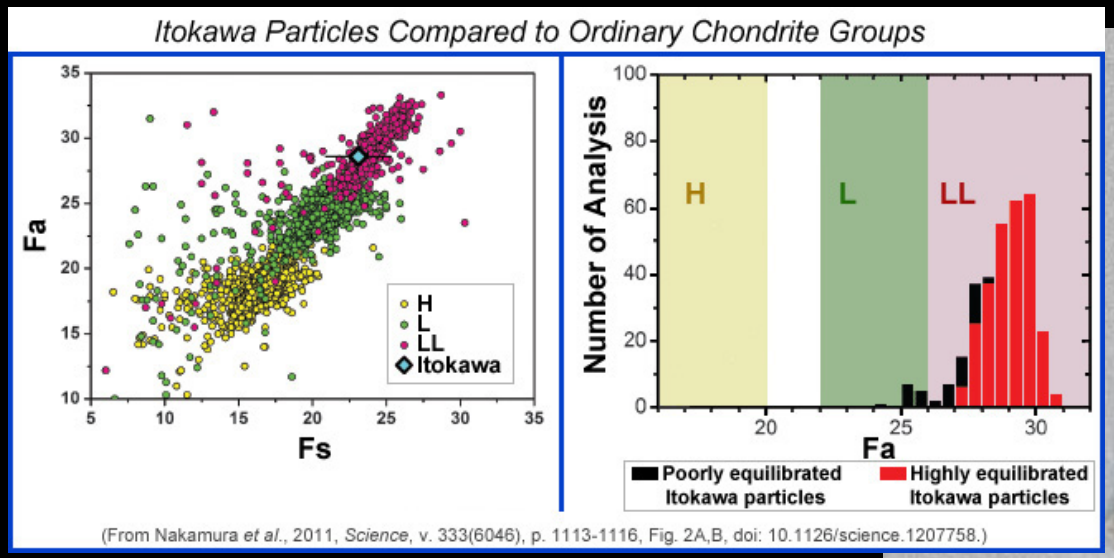
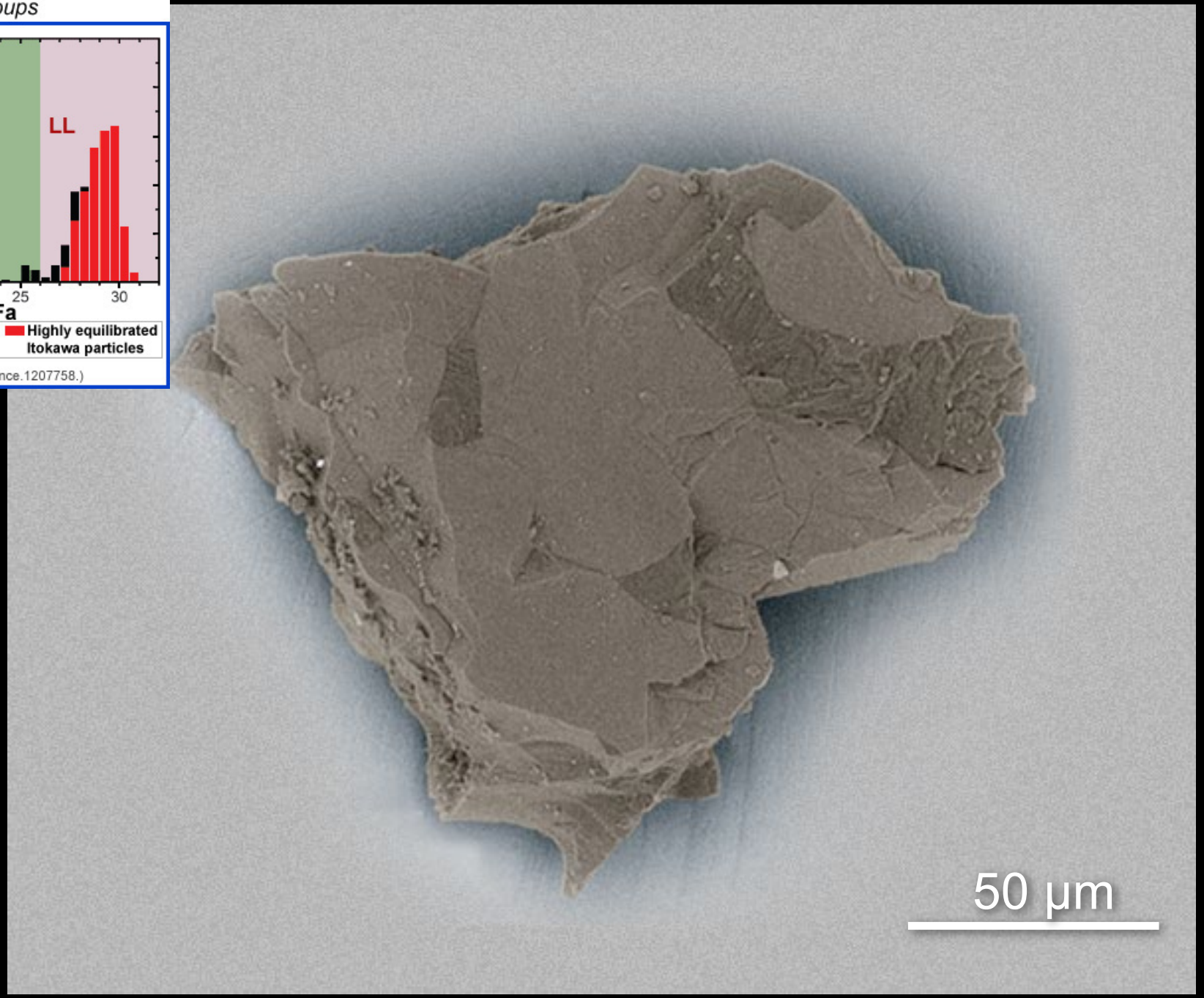
Sample return mission from an S-type near Earth asteroid

**Itokawa**




**Analysis of Itokawa samples confirmed connection between ordinary chondrite meteorites and S asteroids**

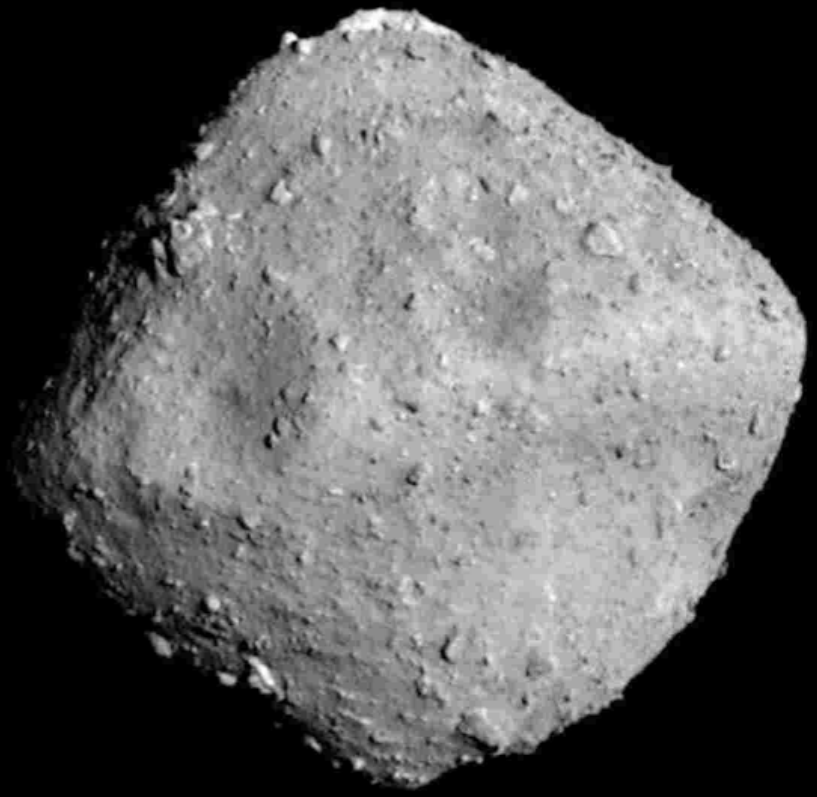


Hayabusa2

*Sample return mission from a C-type near Earth asteroid (2014-?)*

Ryugu (C-type)

*Dragon Palace under the sea*

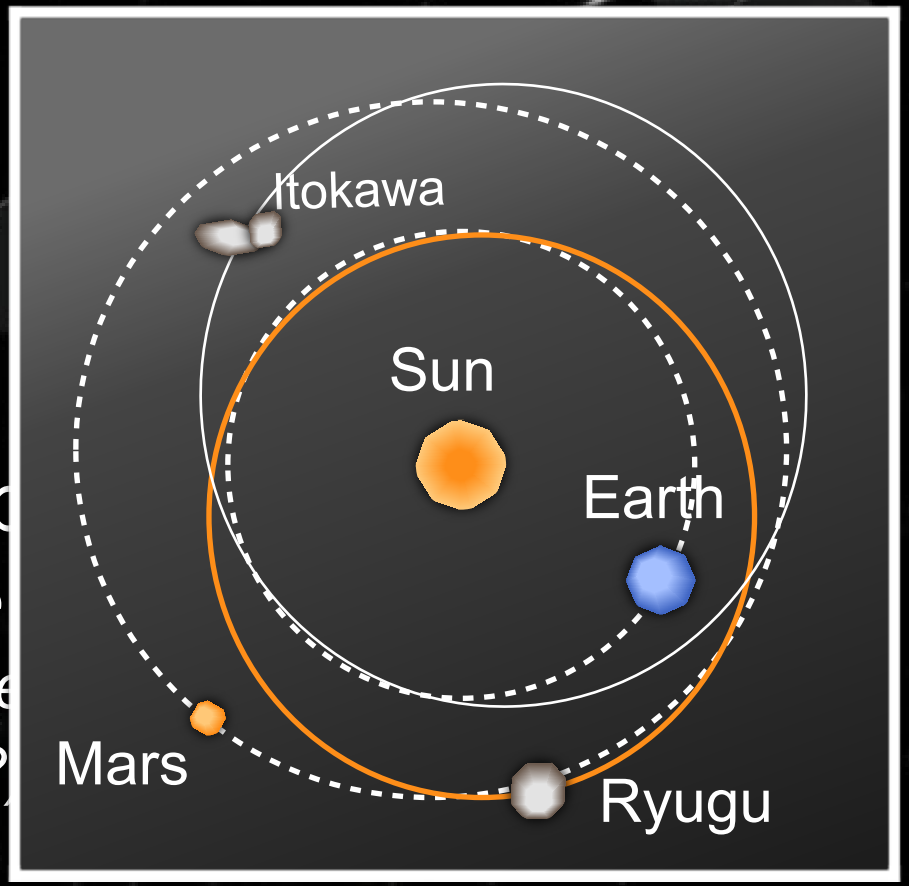


Hayab

*Sample*

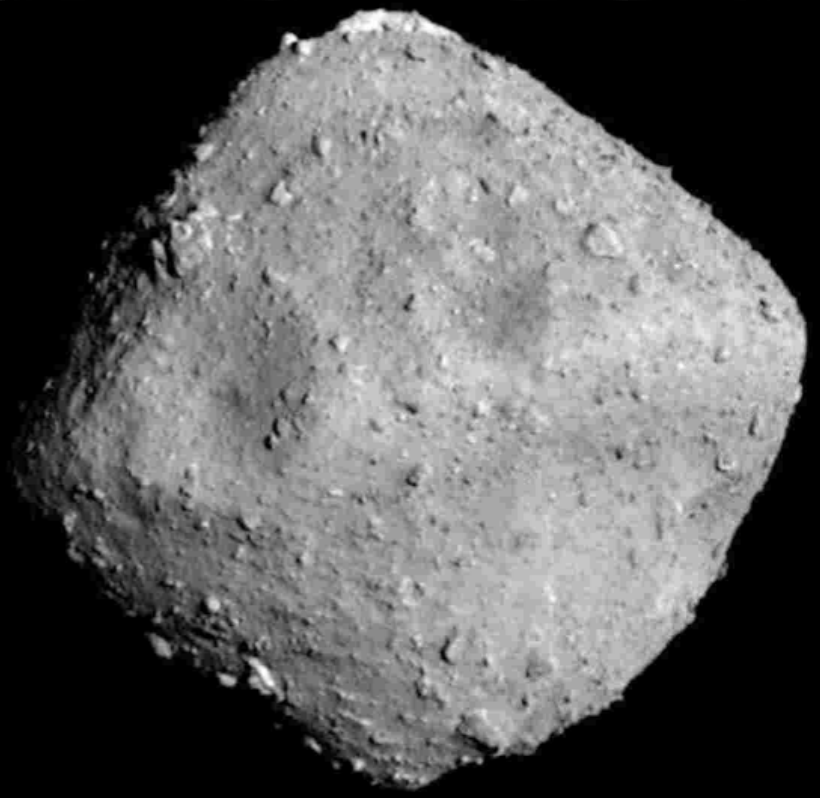
*a C-type*

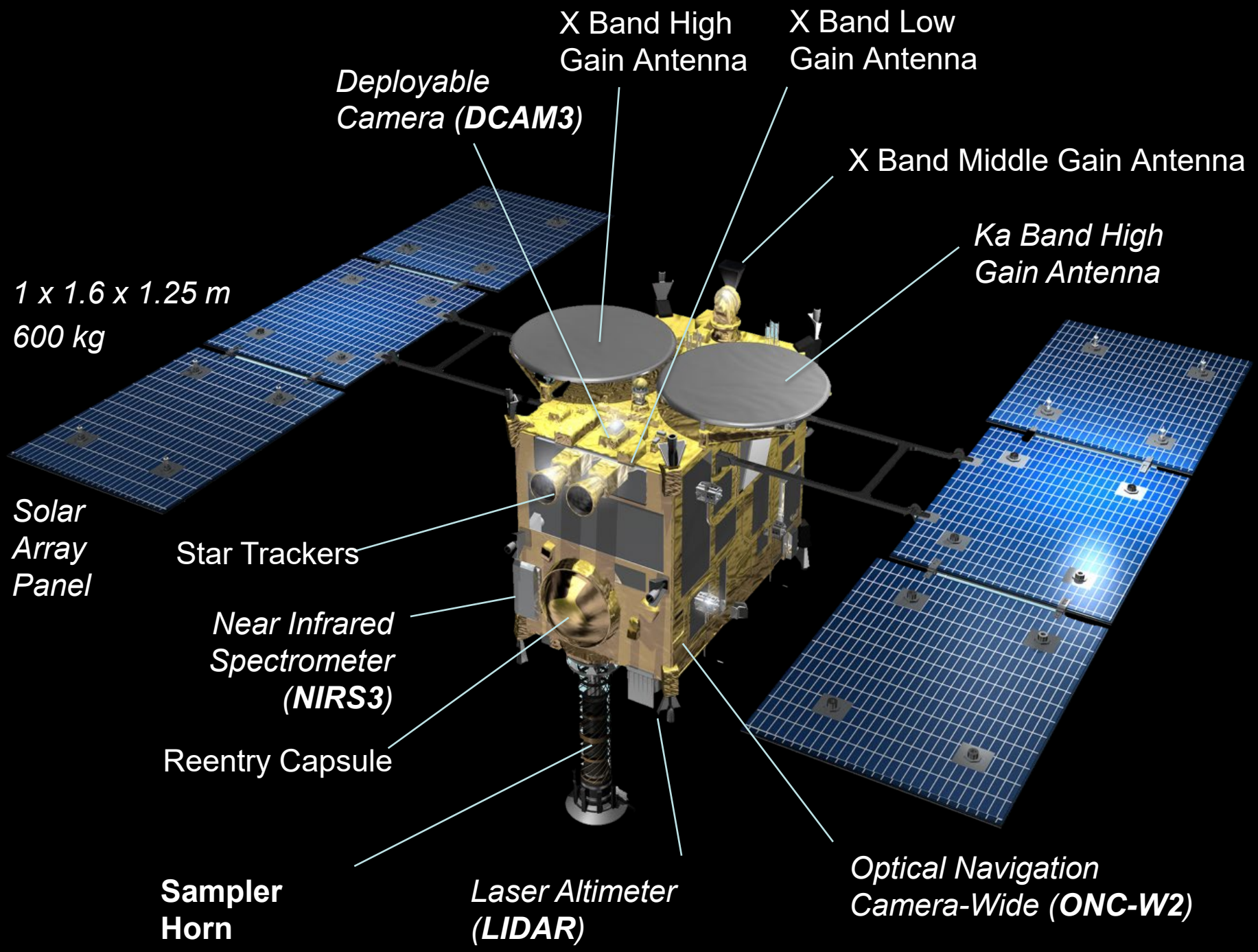
*(2014-?)*




Ryugu (C-type)

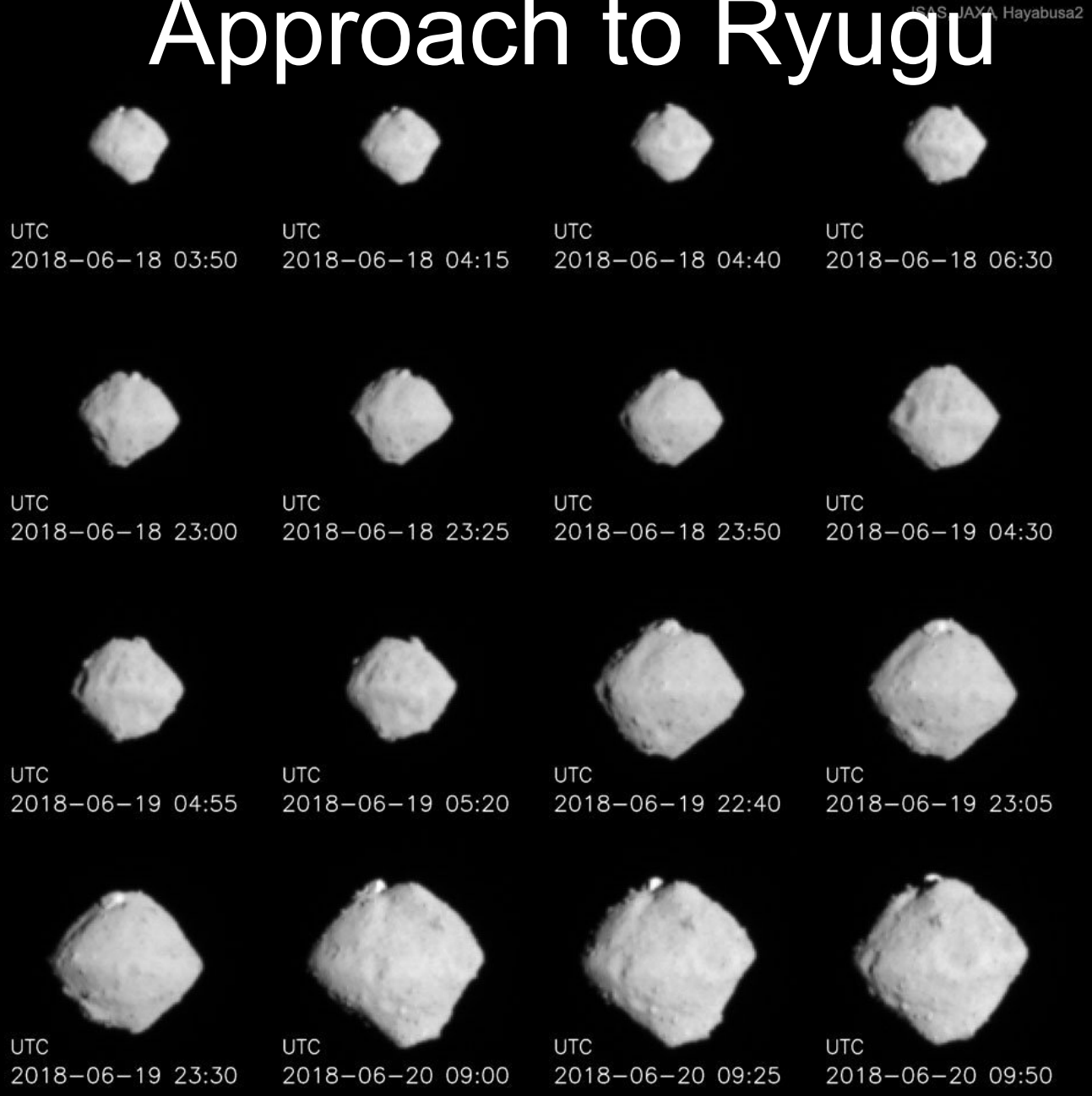
*Dragon Palace under the sea*

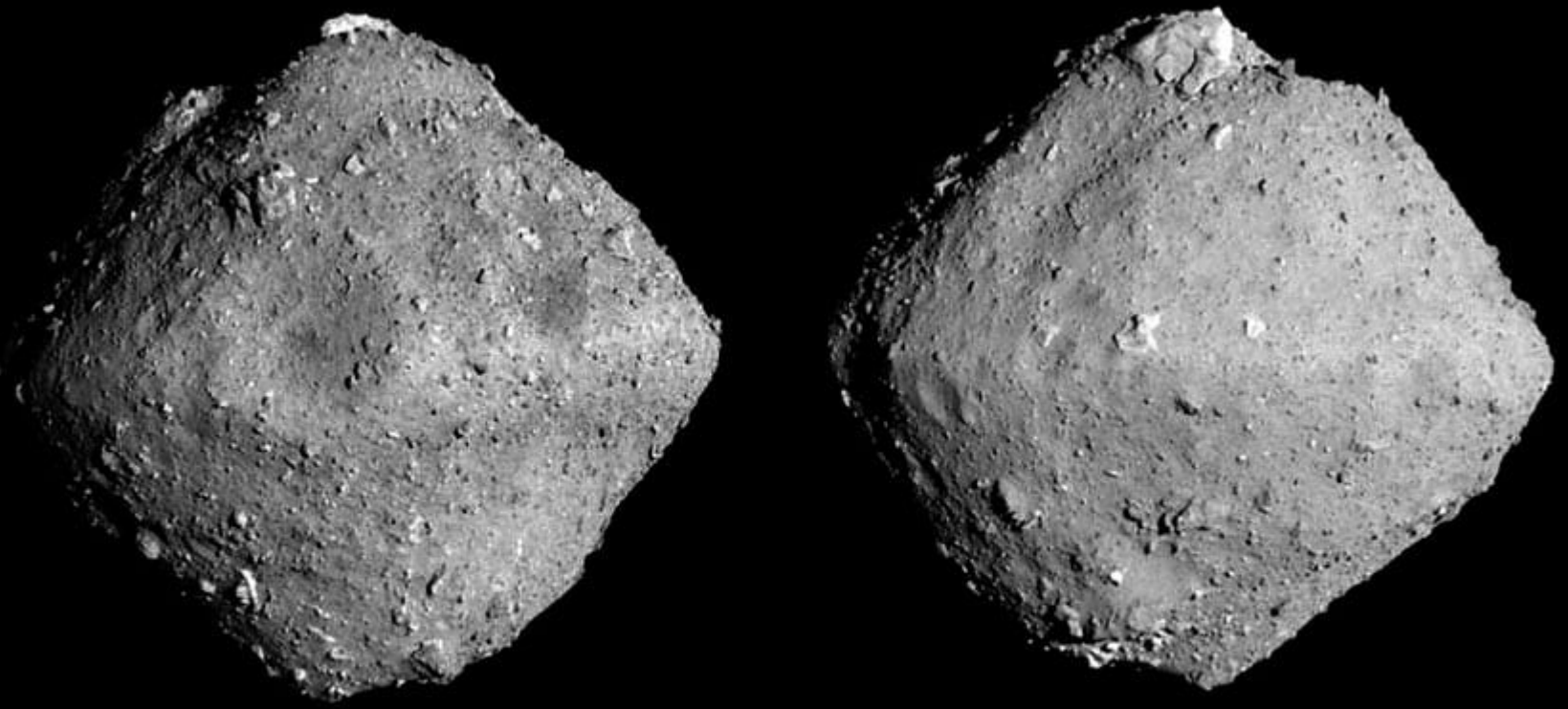



X Band High Gain Antenna
X Band Low Gain Antenna
Deployable Camera (DCAM3)
X Band Middle Gain Antenna
Ka Band High Gain Antenna
1 x 1.6 x 1.25 m
600 kg
Solar Array Panel
Star Trackers
Near Infrared Spectrometer (NIRS3)
Reentry Capsule
Sampler Horn
Laser Altimeter (LIDAR)
Optical Navigation Camera-Wide (ONC-W2)

# December 2, 2014

# Approach to Ryugu





*diameter: ~870 m (~1/2 mile)*
*rotation period: 7.625 h*

Diamond shaped, covered with boulders!


Arizona State University
Desert Financial Arena
Bronze and A.M. Eatery
Buffalo Wild Wings
Peda Haus Brewery
PSF
E University Dr
Casey Moore's Oyster House
Hayden Library
ASU Art Museum
Moeur
ISTB4
ASU Tempe Campus - Registrar Office
ASU Gammage
E Apache Blvd
Whataburger
Tempe St Luke's Hospital


PSF
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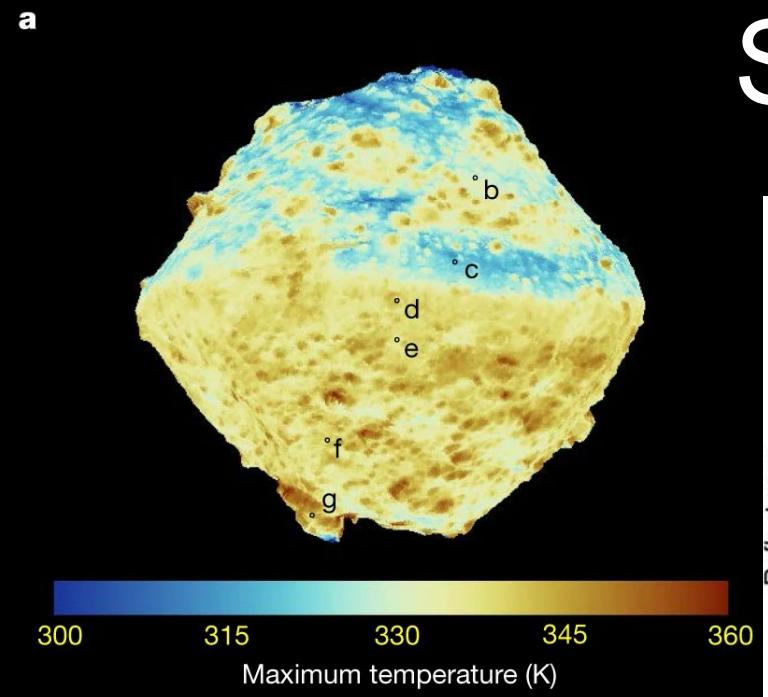
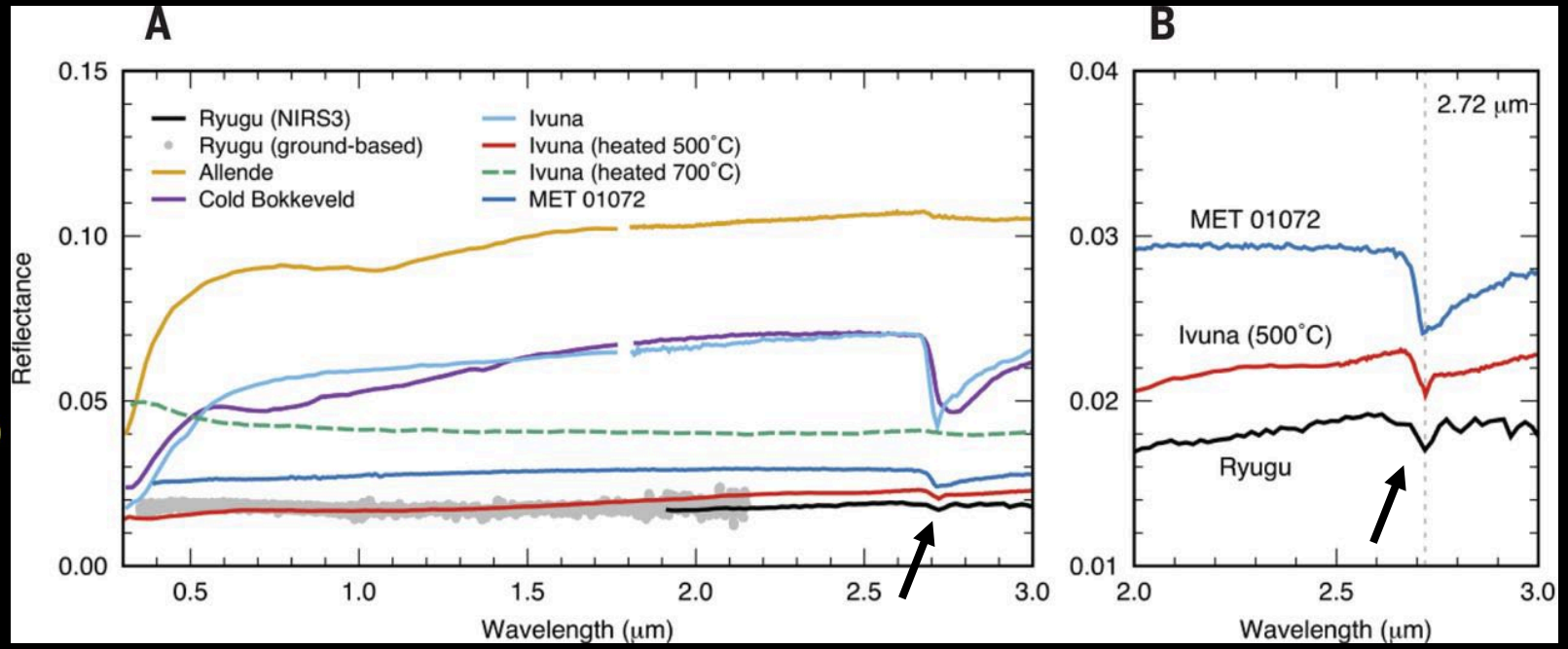
Buffalo Wild Wings
E University Dr
Casey Moore's Oyster House
Little E. Coor Hall
ASU Art Museum
ASU Gammage
Dutch Bros Coffee
Mango Rabbit Boba
E Apache Blvd
Whataburger
Mercy Phoenix Temple & ASU Area
Tempe St Luke's Hospital
S Rural Rd
S Mill Ave

# Science from orbit




Thermal properties indicate Ryugu is very porous

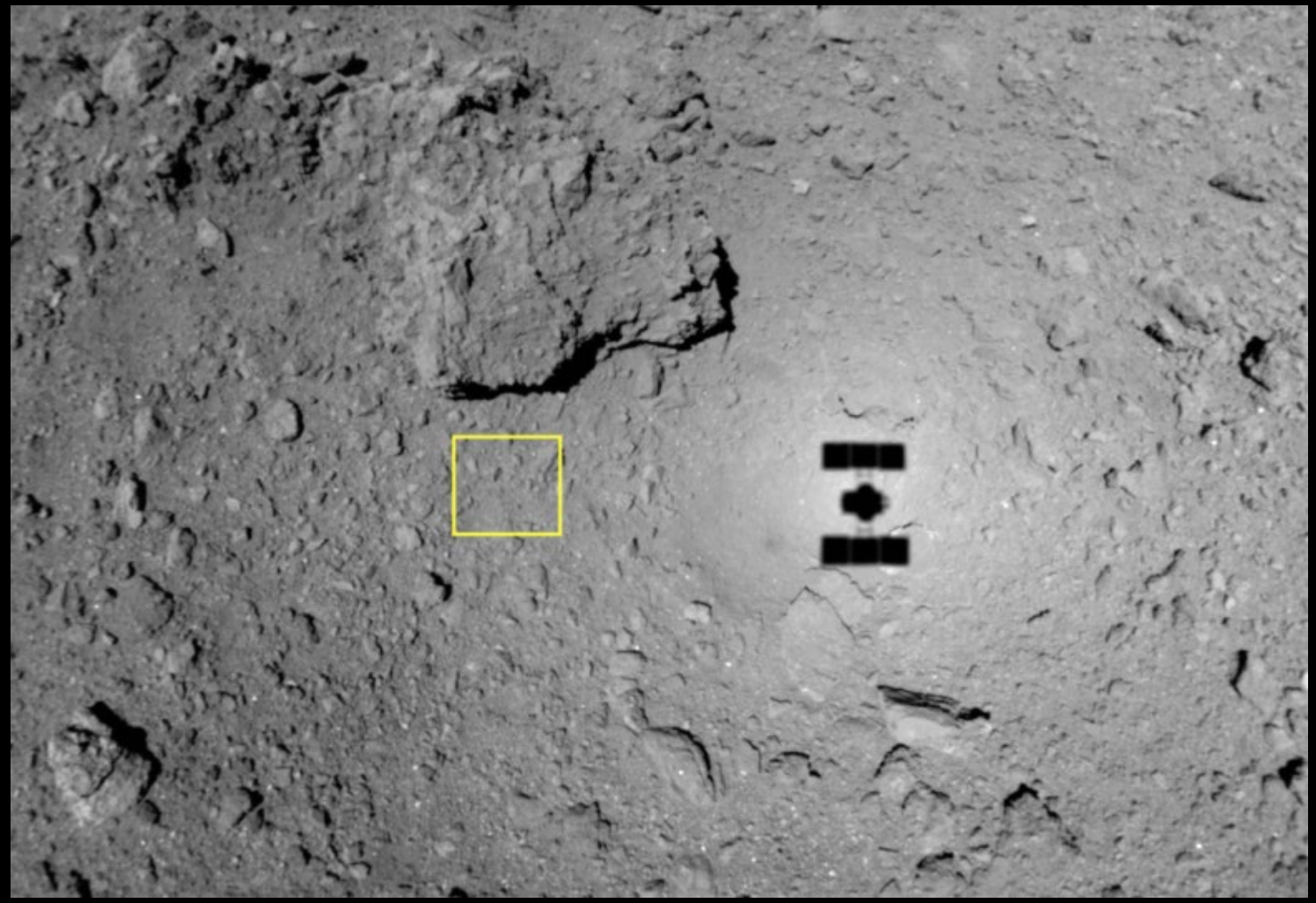
*Rubble Pile*

Spectrally, Ryugu looks like a carbonaceous chondrite meteorite that has been heated up.

But what about sample return?

# Sampling an asteroid

# 1st touchdown (Feb 21, 2019)



https://youtu.be/-3hO58HFa1M

# 1st touchdown (Feb 21, 2019)

# Small Carry-on Impactor (SCI)

April 5, 2019

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April 5, 2019

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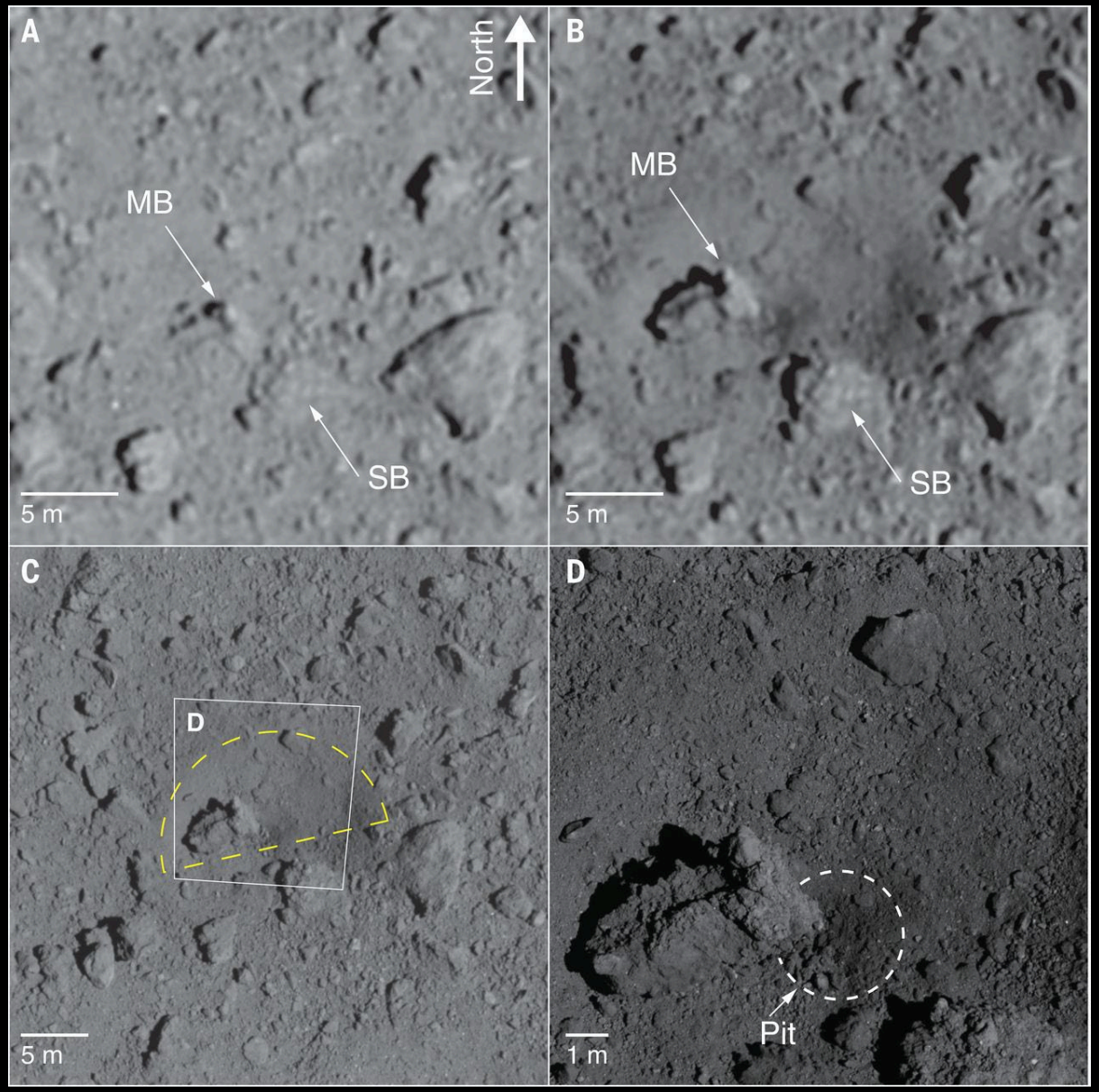
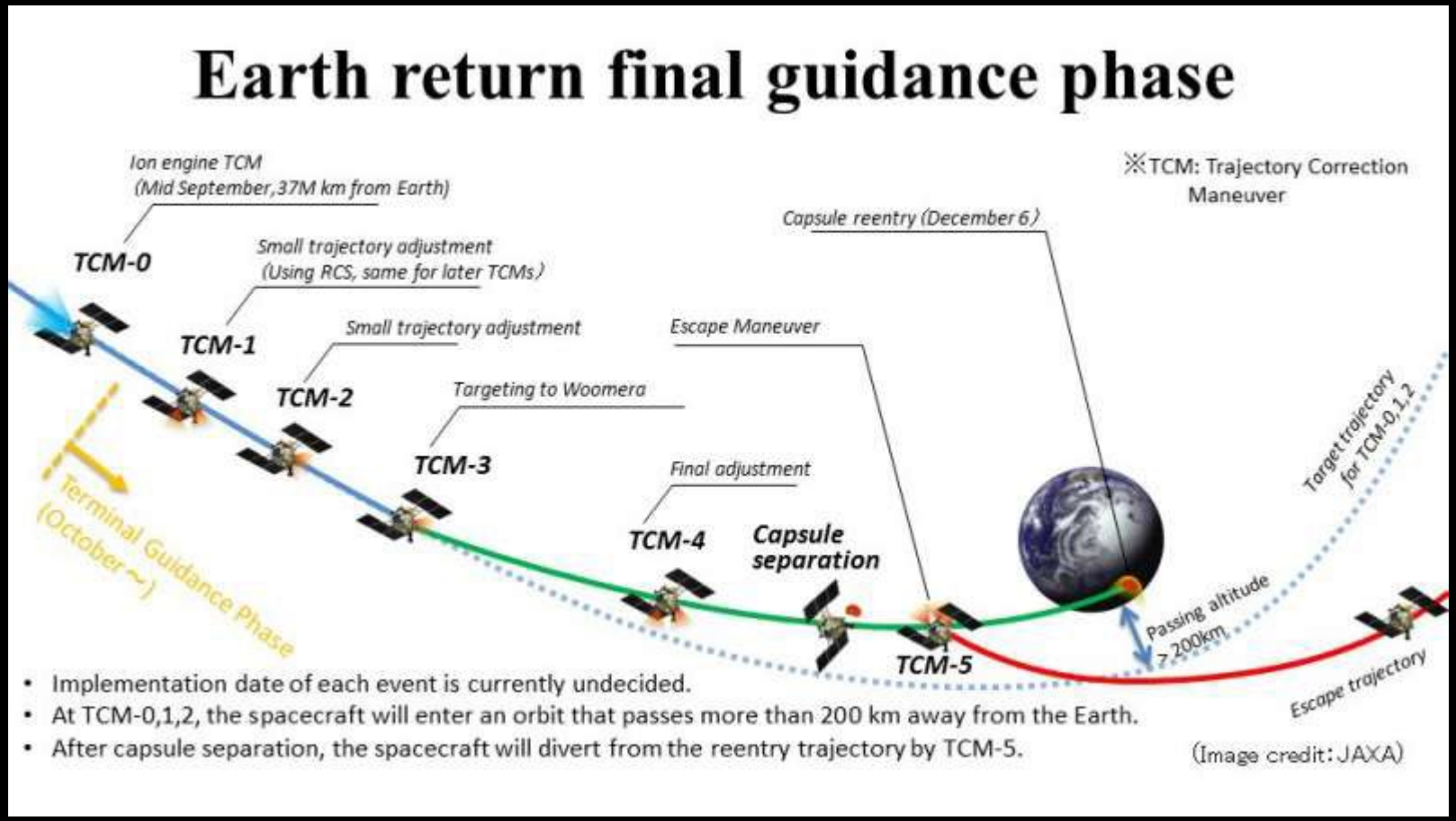


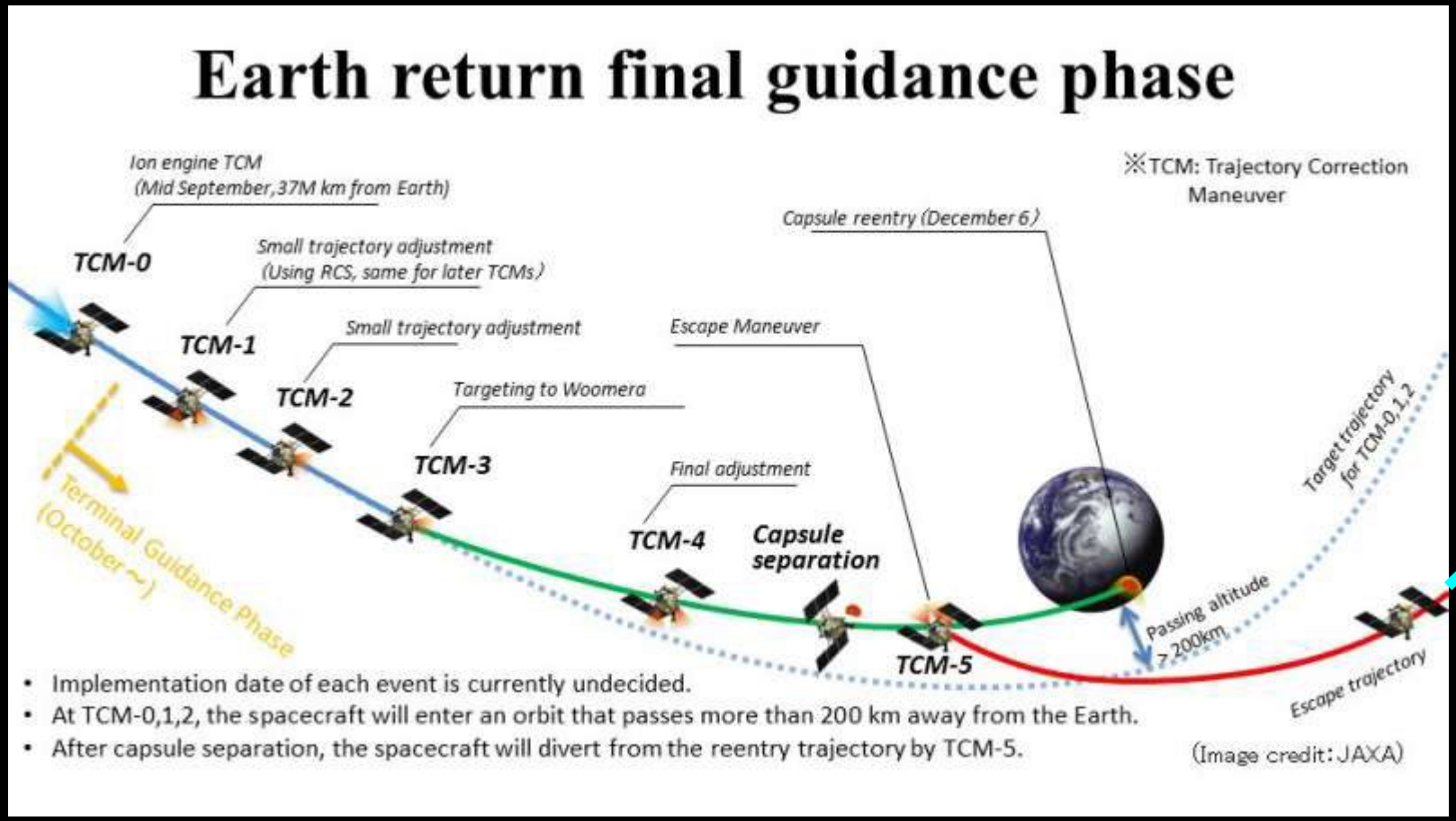
# 2nd touchdown (July 25, 2019)

# Sample Return!




December 5, 2020

# Sample Return!

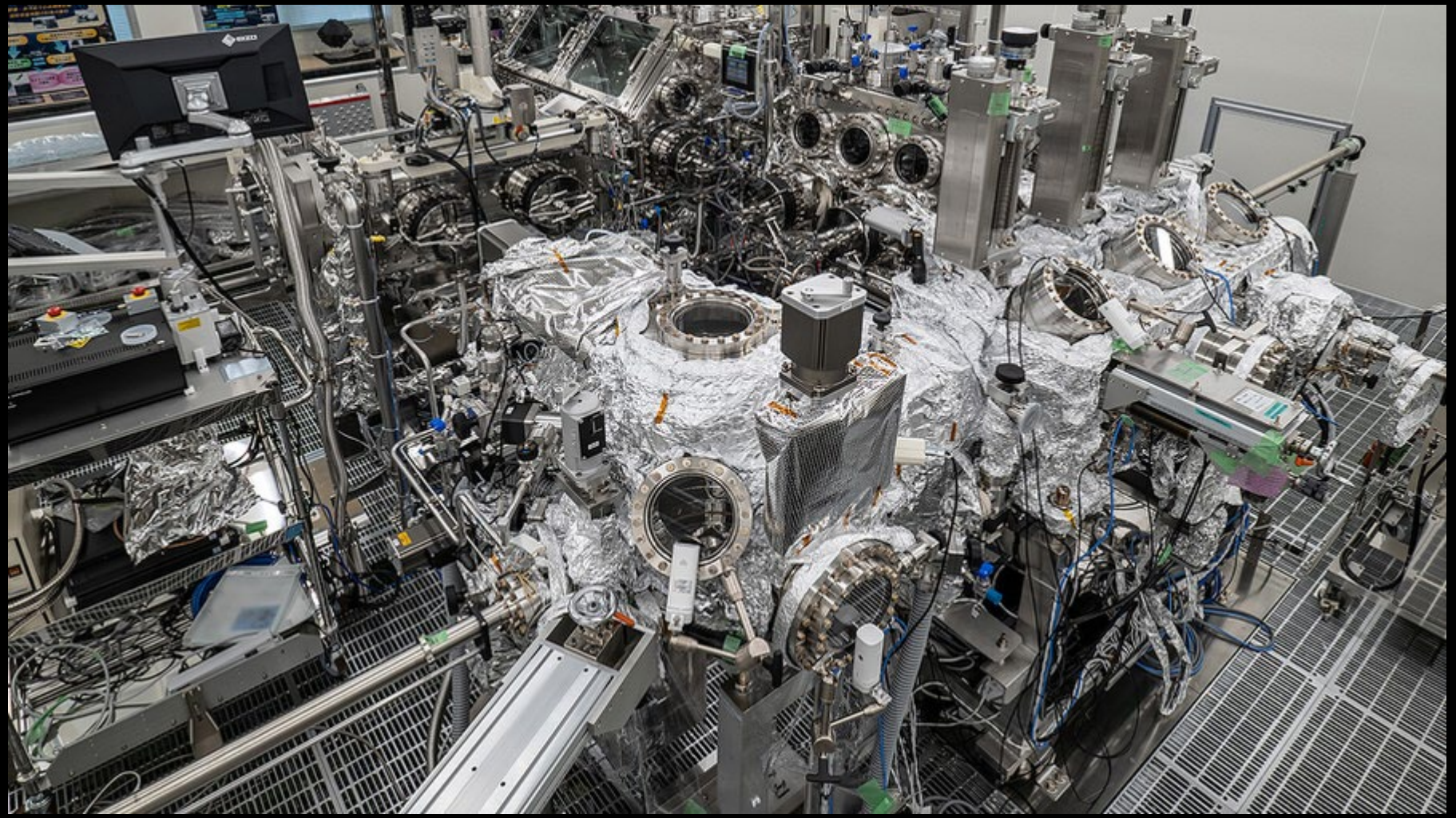



December 5, 2020

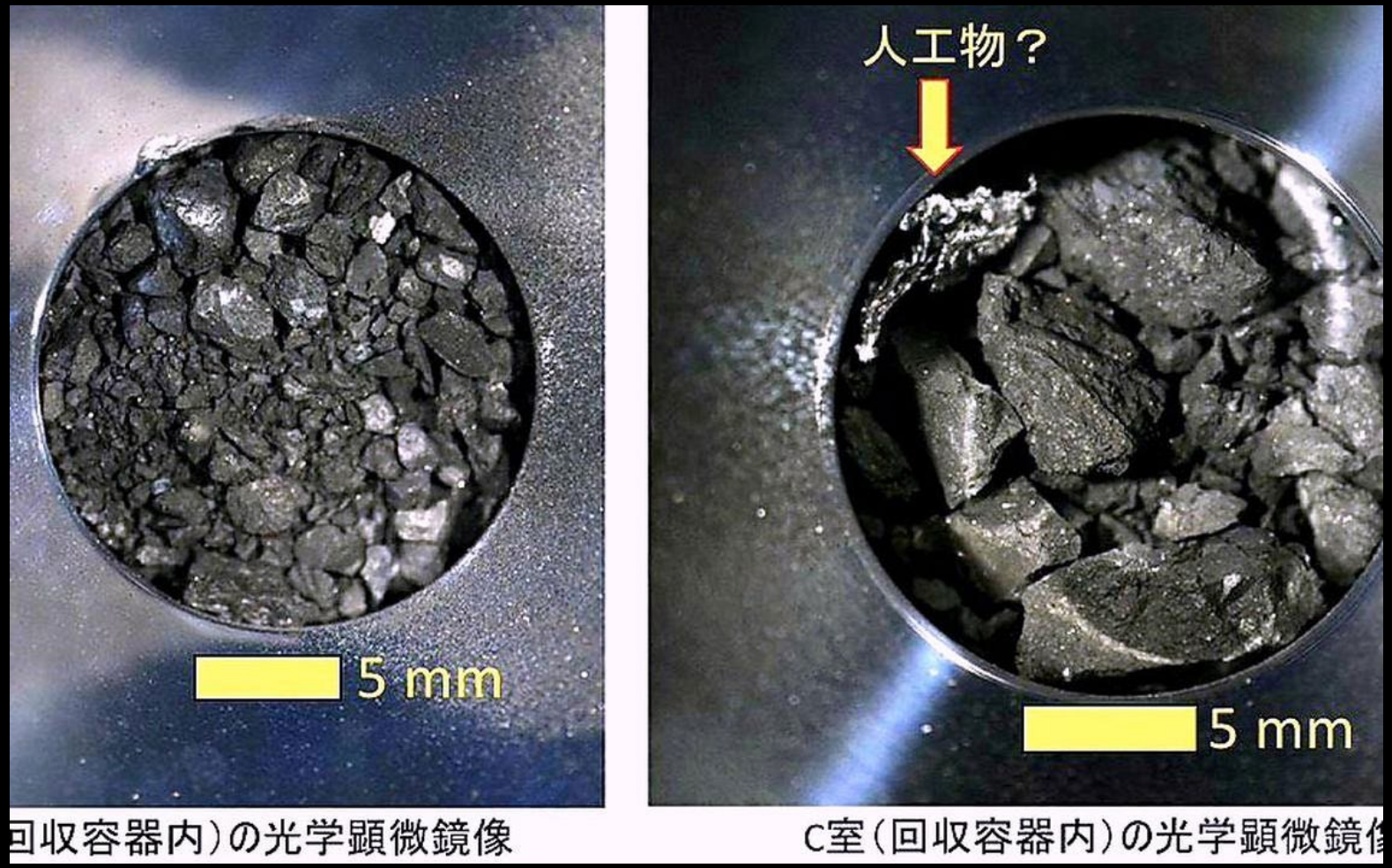
Onward to 2001 $CC_{21}$ and 1998 $KY_{26}$

# Sample Return!

December 5, 2020



Clean Chamber @JAXA

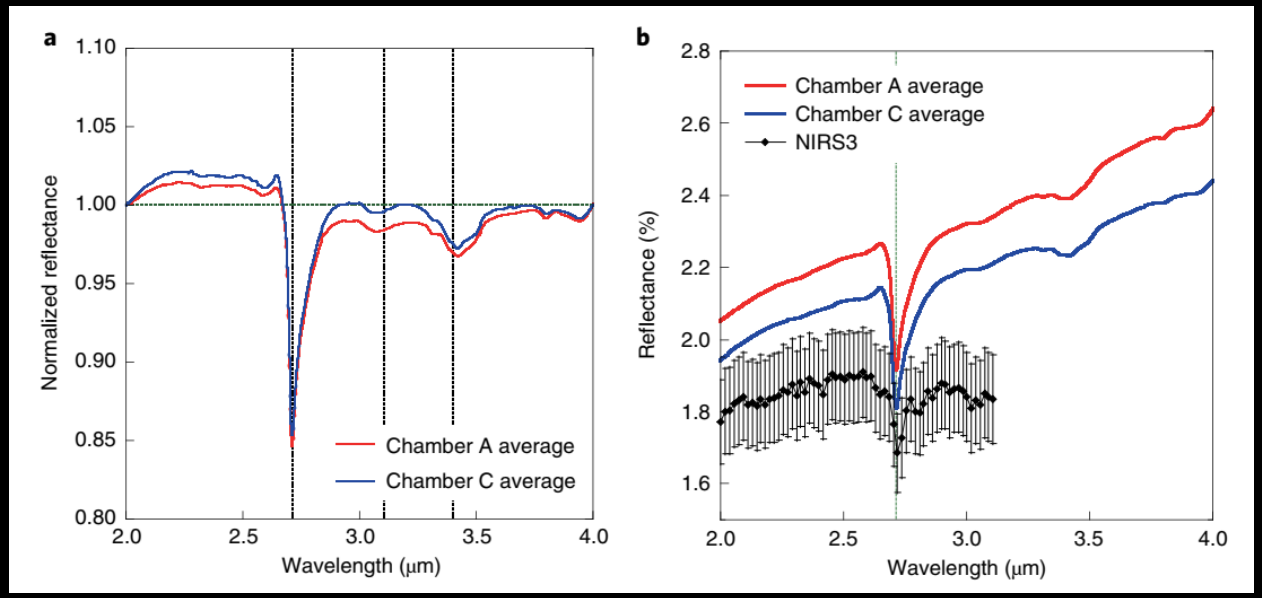



Collected 5.4 grams! (*doesn't sound like much but there's a LOT you can do with modern laboratory instruments – goal was 100 milligrams!*)

# Hayabusa2 Sample Analysis

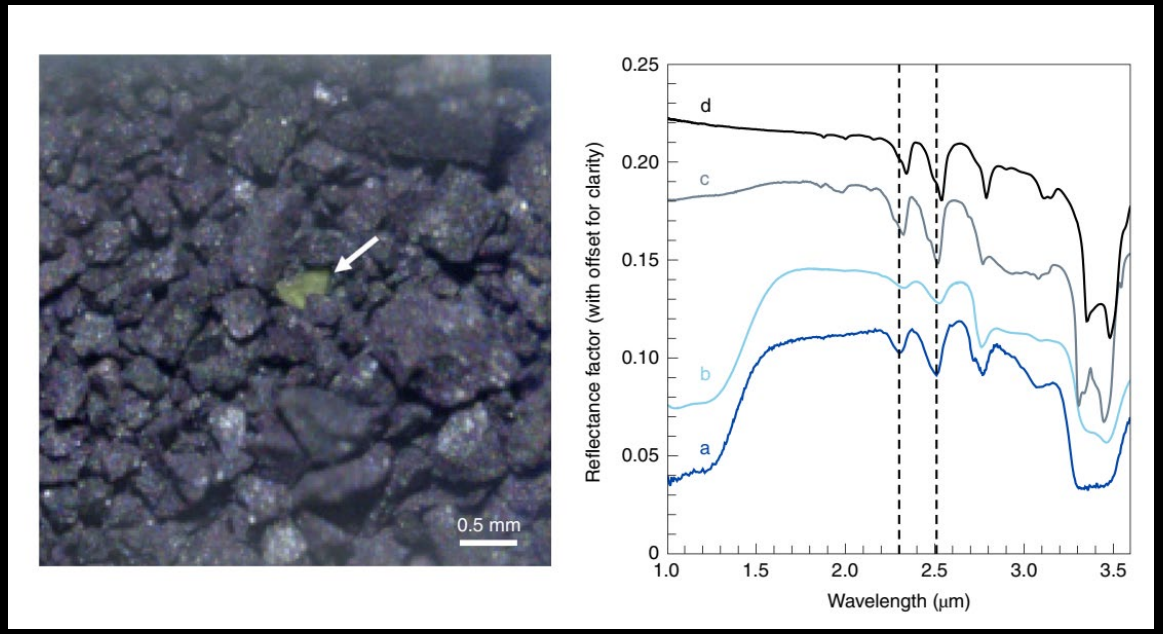
- January 2021 – July 2021:
    - Curation team did basic characterization (density, size, IR spectroscopy) of Ryugu particles under vacuum in order to generate a sample catalog and provide samples to Initial Analysis Science Team
    - 1st results published in late 2021

# Initial Curation Results

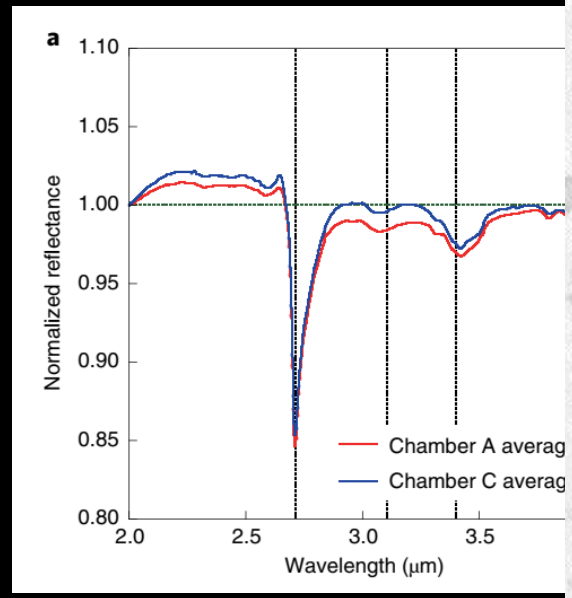



Yada et al. (2021)

- IR spectra show evidence of hydrated silicates, carbonates
- No sign of chondrules/calcium-aluminum rich inclusions
  - **Looks most like CI chondrites**

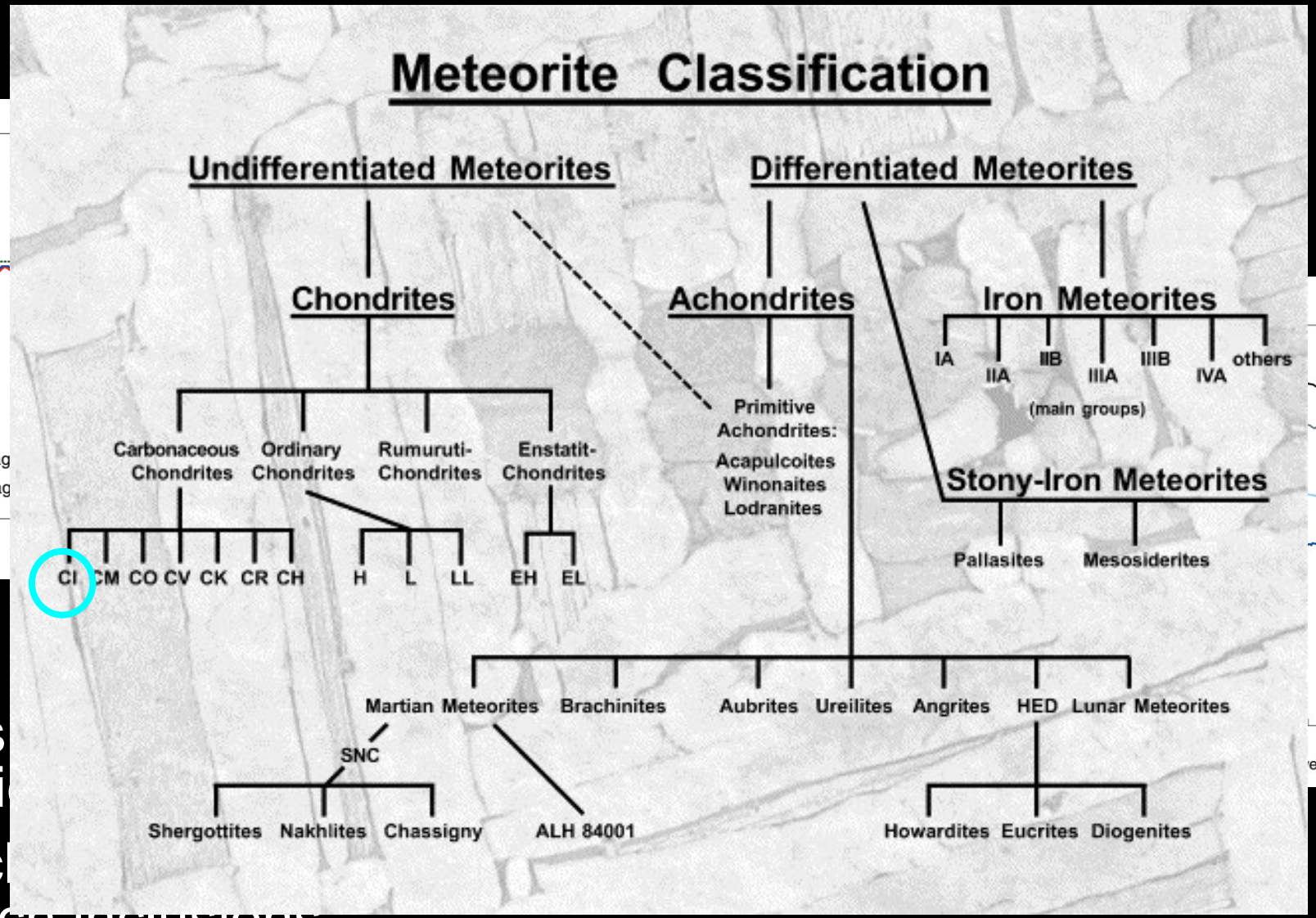


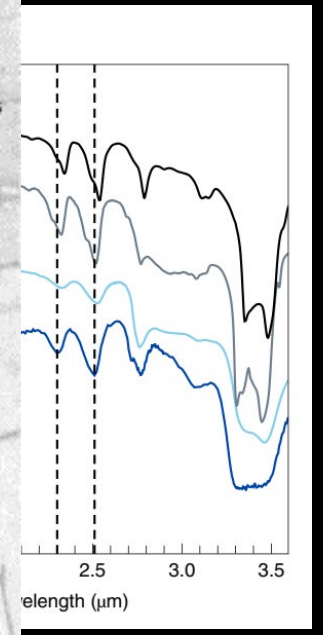

Pilorget et al. (2021)




Yada et al. (2021)

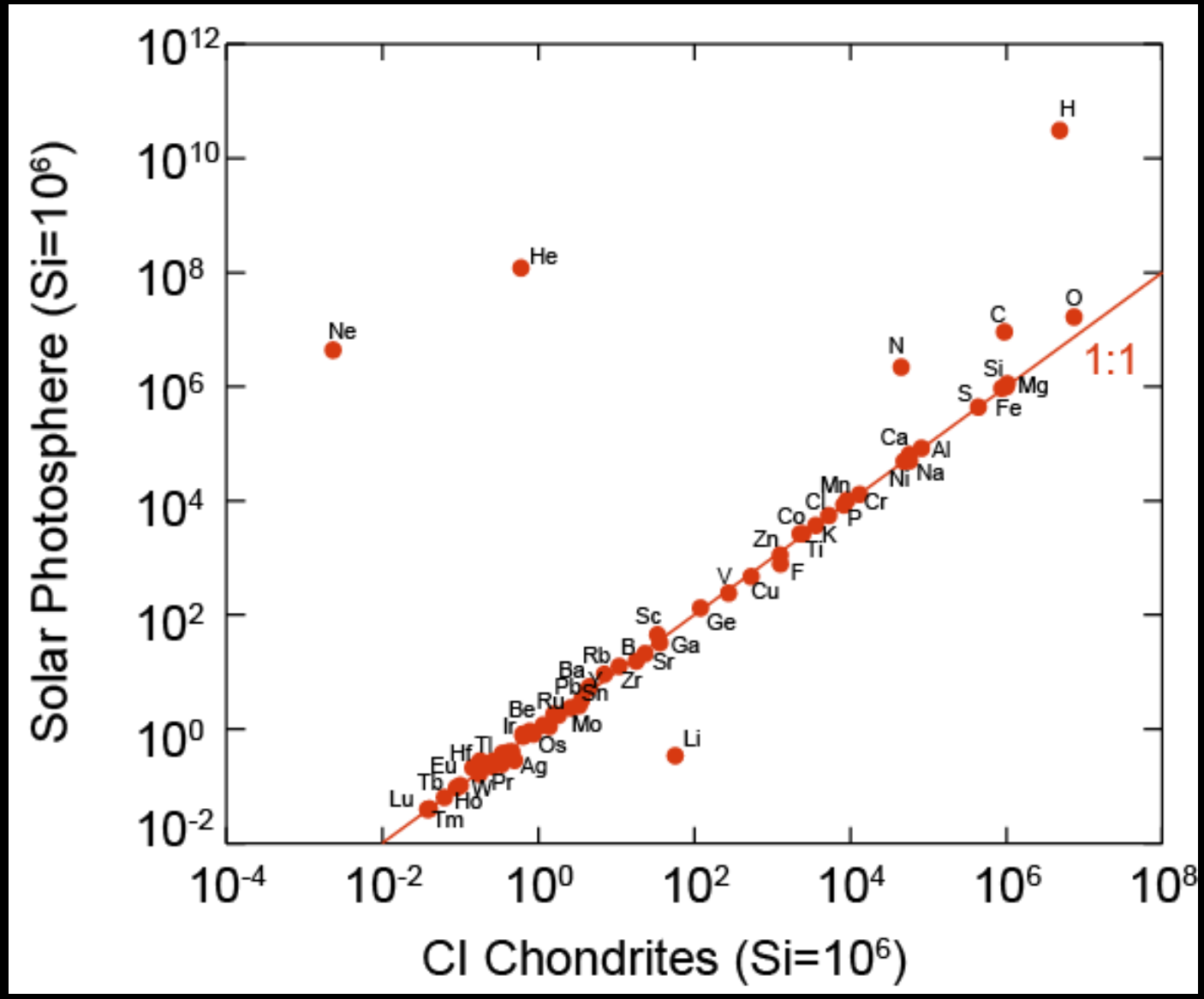
- IR spectra s
  hydrated sili
- No sign of c
  aluminum rich inclusions
  - **Looks most like CI chondrites (~0.1 % of known meteorites)**



# CI Chondrites

- Elemental composition = Sun
- Extensively aqueous altered (consist of fine-grained phyllosilicates, carbonates, sulfides, organics)



# Hayabusa2 Initial Analysis Team (IAT)

- Preliminary Examination – 7 science sub-teams, >350 members from across globe
- July 2021- June 2022

| | |
|---|---|
| ✓ *Chemistry* | *H. Yurimoto* |
| ✓ *Mineralogy and Petrology of Coarse Grains* | *T. Nakamura* |
| ✓ *Mineralogy and Petrology of Fine Grains* | *T. Noguchi* |
| ✓ *Volatiles* | *R. Okazaki* |
| ✓ *Insoluble Organics* | *H. Yabuta* |
| ✓ *Soluble Organics* | *H. Naraoka* |
| ✓ *Integration: History of Ryugu & Solar System* | *S. Tachibana* |

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| ✓ *Volatiles* | *R. Okazaki* |
| ✓ *Insoluble Organics* | *H. Yabuta* |
| ✓ *Soluble Organics* | *H. Naraoka* |
| ✓ *Integration: History of Ryugu & Solar System* | *S. Tachibana* |

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Akihisa Takeuchi
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Mitsuru Ebihara
Mitsutaka Haruta
Mizuha Kikuiri
Mizuki Yamamoto
Moe Matsuoka
Montagnac, Gilles
Motoo Ito
Mutsumi Komatsu
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Naoya Sakatani
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Satomi Enju
Satoshi Hata
Satoshi Takeshita
Satoshi Tanaka
Scott Sandford
Scott Sitzman
Seiji Sugita
Shigekazu Yoneda
Shigeru Wakita
Shin Watanabe
Shinsuke Kawagucci
Shintaro Komatani
Shinya Yamada
Shogo Tachibana
Shohei Yamashita
Shoichi Itoh
Shota Okumura
Shun Sekimoto
Shunsaku Nagasawa
Smaîl Mostefaoui
Stefano Rubino
Stephen R. Sutton
Steven B. Simon
Tadayuki Takahashi
Taichi Kawamura
Taiga Okumura
Taiga Wada
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Toshihiro Yoshimura
Toshiki Koga
Trevor Ireland
Tsukasa Nakano
Tsuyoshi Iizuka
Véronique Vuitton
Wataru Fujiya
Yasuhiro Miyake
Yasuhiro Oba
Yasuko Terada
Yasuo Takeichi
Yohei Igami
Yohei Matsui
Yoko Kebukawa
Yoshihiro Furukawa
Yoshinari Abe
Yoshinori Takano
Yoshio Takahashi
Yoshito Chikaraishi
Yuichiro Yamashita
Yuki Araki
Yuki Hibiya
Yuki Kimura
Yuki Masuda
Yuma Enokido
Yuri Amelin
Yuri Fujioka
Yusuke Seto
Yusuke Tamenori
Yuta Ino
Yuuya Nagaashi
Zack Gainsforth
Zahia Djouadi
Zélia Dionnet
Zita Martins

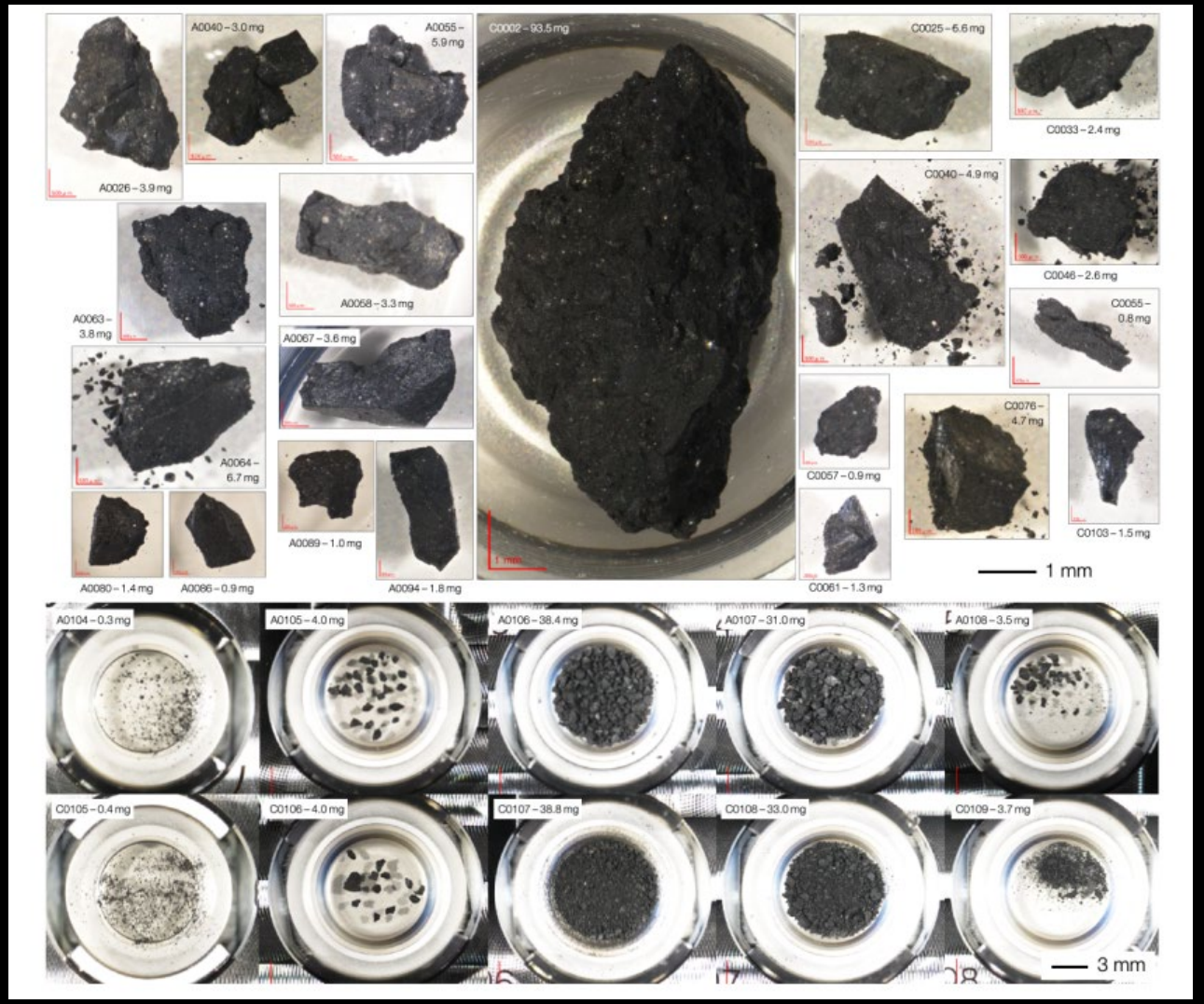
SESE
Former SESE

# Hayabusa2 Initial Analysis Team (IAT)

| | |
|---|---|
| ✓ *Chemistry* | *H. Yurimoto* |
| ✓ *Mineralogy and Petrology of Coarse Grains* | *T. Nakamura* |
| ✓ *Mineralogy and Petrology of Fine Grains* | *T. Noguchi* |
| ✓ *Volatiles* | *R. Okazaki* |
| ✓ *Insoluble Organics* | *H. Yabuta* |
| ✓ *Soluble Organics* | *H. Naraoka* |
| ✓ *Integration: History of Ryugu & Solar System* | *S. Tachibana* |

- Characterize elemental and isotopic composition and macromolecular carbon in Ryugu samples to compare with meteorites/comets and better understand origin and evolution of asteroids and early Solar System

# Hayabusa2 Initial Analysis

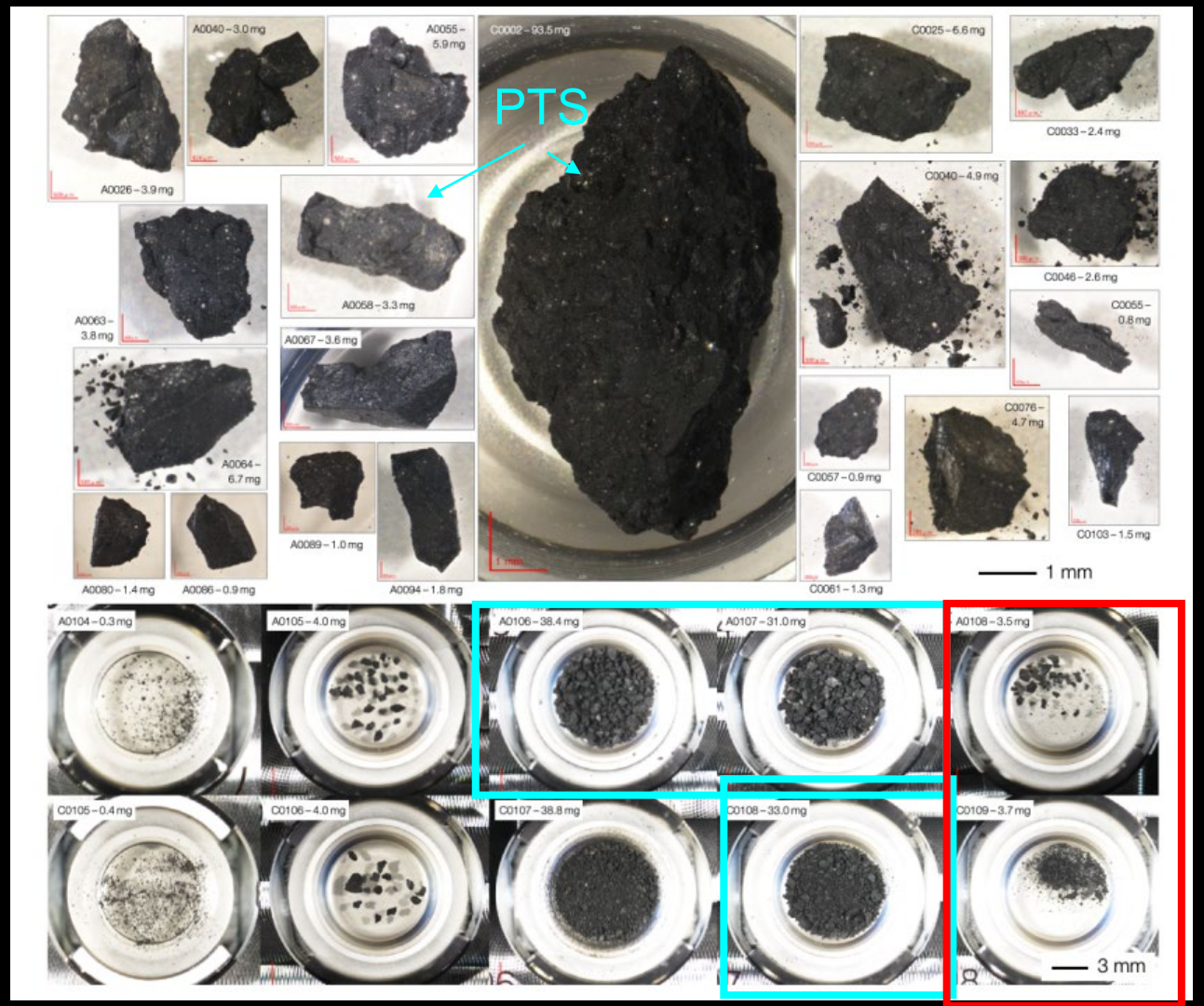



- 0.3 g allocated to IAT

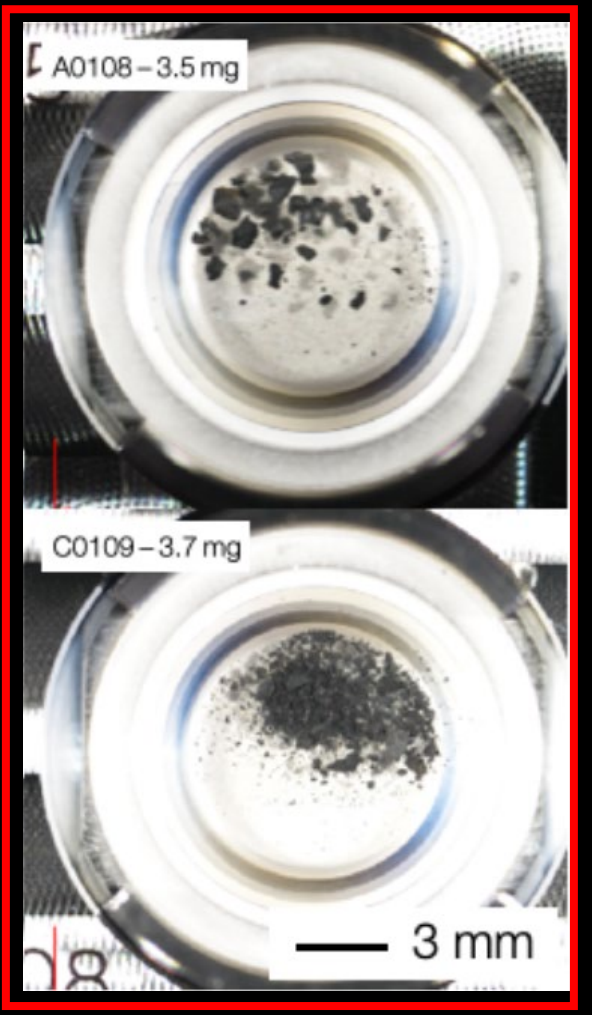
Tachibana et al. (LPSC 2022)

# Hayabusa2 Initial Analysis


~125 mg allocated to Chemistry Team




- 0.3 g allocated to IAT




~8mg allocated to Macromolecule Team

# Hayabusa2 IAT Chemistry Results

Science

RESEARCH ARTICLES

Cite as: T. Yokoyama *et al.*, *Science*
10.1126/science.abn7850 (2022).

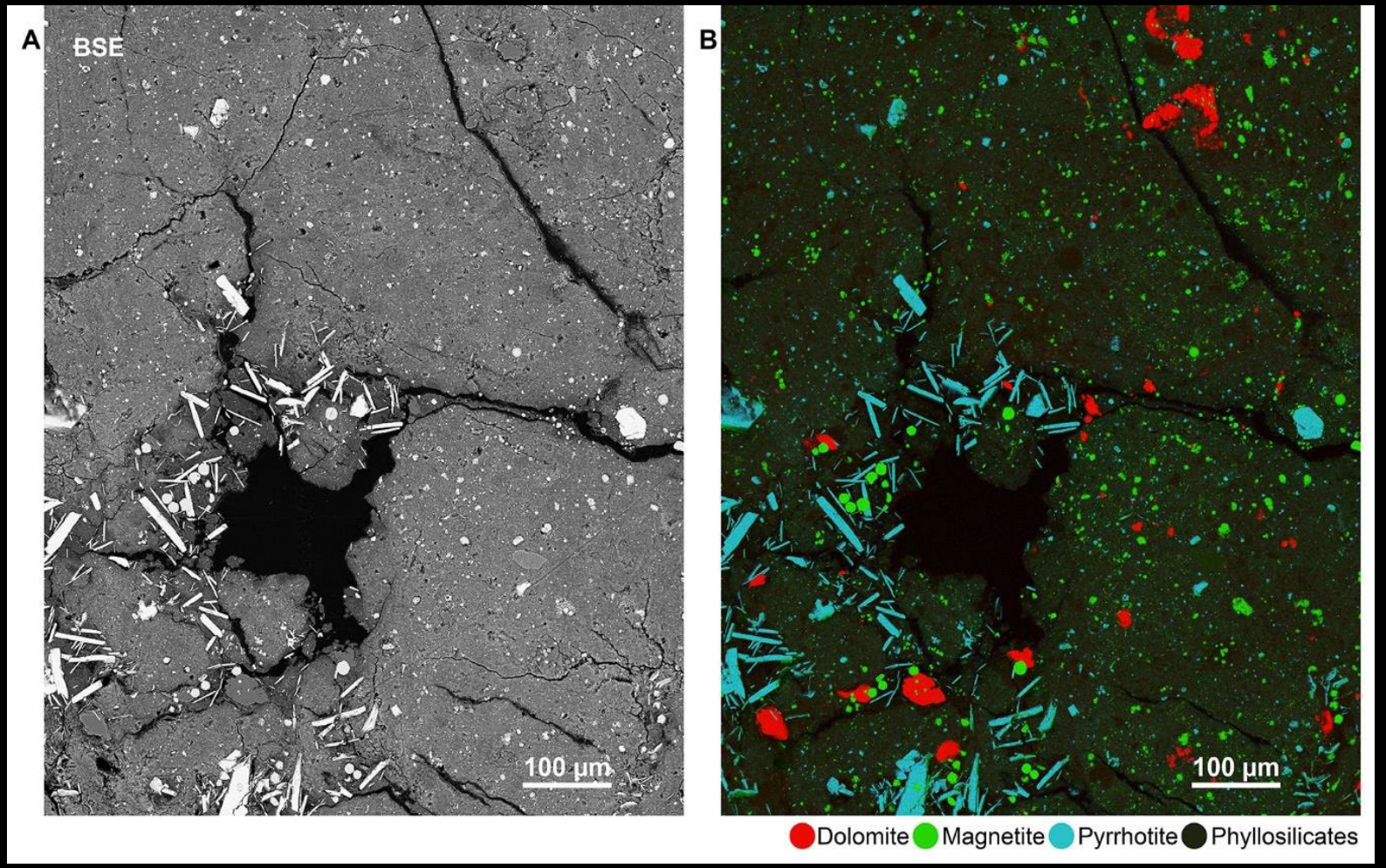
## Samples returned from the asteroid Ryugu are similar to Ivuna-type carbonaceous meteorites

**Tetsuya Yokoyama[1]†, Kazuhide Nagashima[2]†, Izumi Nakai[3], Edward D. Young[4], Yoshinari Abe[5], Jérôme Aléon[6], Conel M. O'D. Alexander[7], Sachiko Amari[8], Yuri Amelin[9], Ken-ichi Bajo[10], Martin Bizzarro[11], Audrey Bouvier[12], Richard W. Carlson[7], Marc Chaussidon[13], Byeon-Gak Choi[14], Nicolas Dauphas[15], Andrew M. Davis[15], Tommaso Di Rocco[16], Wataru Fujiya[17], Ryota Fukai[18], Ikshu Gautam[1], Makiko K. Haba[1], Yuki Hibiya[19], Hiroshi Hidaka[20], Hisashi Homma[21], Peter Hoppe[22], Gary R. Huss[2], Kiyohiro Ichida[23], Tsuyoshi Iizuka[24], Trevor R. Ireland[25], Akira Ishikawa[1], Motoo Ito[26], Shoichi Itoh[27], Noriyuki Kawasaki[10], Noriko T. Kita[28], 0Kouki Kitajima[28], Thorsten Kleine[29], Shintaro Komatani[23], Alexander N. Krot[2], Ming-Chang Liu[4], Yuki Masuda[1], Kevin D. McKeegan[4], Mayu Morita[23], Kazuko Motomura[30], Frédéric Moynier[13], Ann Nguyen[31], Larry Nittler[7], Morihiko Onose[23], Andreas Pack[16], Changkun Park[32], Laurette Piani[33], Liping Qin[34], Sara S. Russell[35], Naoya Sakamoto[36], Maria Schönbächler[37], Lauren Tafla[4], Haolan Tang[4], Kentaro Terada[38], Yasuko Terada[39], Tomohiro Usui[18], Sohei Wada[10], Meenakshi Wadhwa[40], Richard J. Walker[41], Katsuyuki Yamashita[42], Qing-Zhu Yin[43], Shigekazu Yoneda[44], Hiroharu Yui[45],**

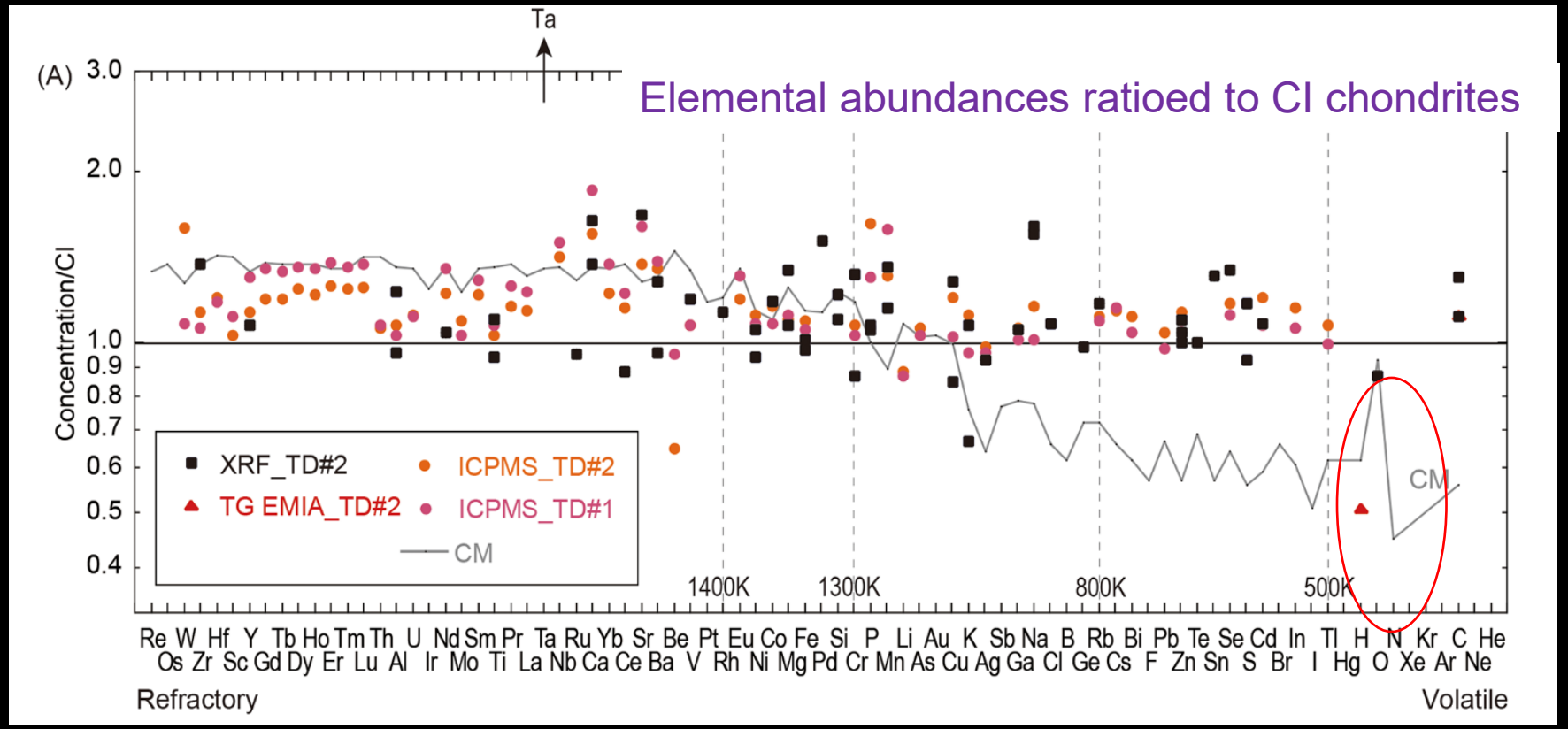
**Ryugu is a CI Chondrite**

# Ryugu is a CI Chondrite

- Two touchdown site samples very similar
- Abundant phyllosilicates, carbonates, sulfides
- Typical CI mineralogy except no sulfates observed (terrestrial weathering)



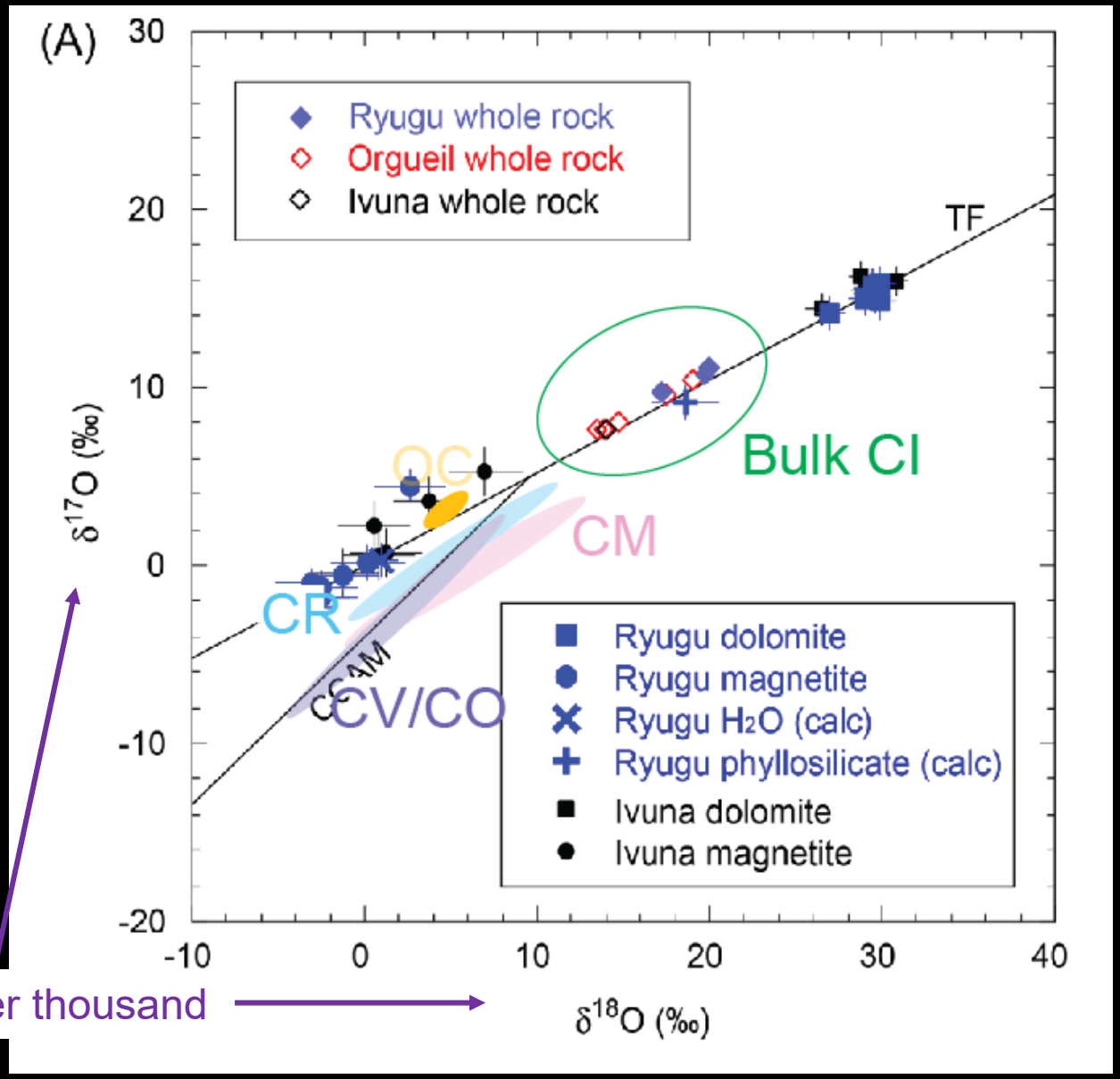
# Ryugu is a CI Chondrite




- Flat abundance pattern indicates CI for most elements (cf CM pattern)
- Offset due to lower H, O -> less incorporated $H_2O$ (terr. contam.?)
  - 6.8 wt% $H_2O$ vs 12.7% for Ivuna; 4.6 wt% C (3 % organic) in Ryugu

# Ryugu is a CI Chondrite

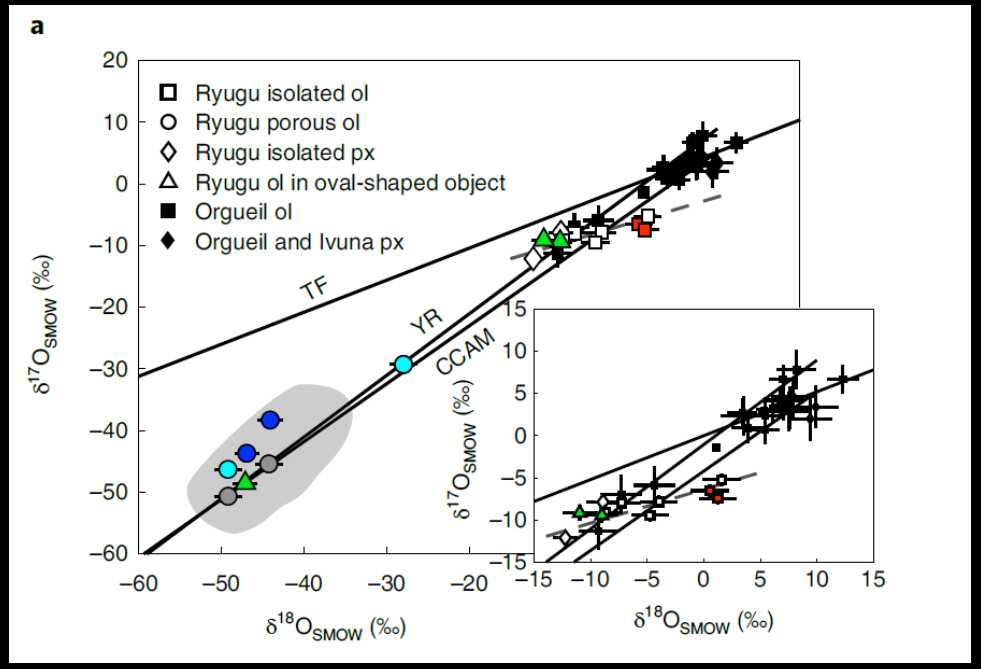
- O isotopes essentially identical to CI chondrites
  - Different chondrite groups show distinct O isotopic trends
  - Very small difference (~0.01%) may be due to terrestrial contamination

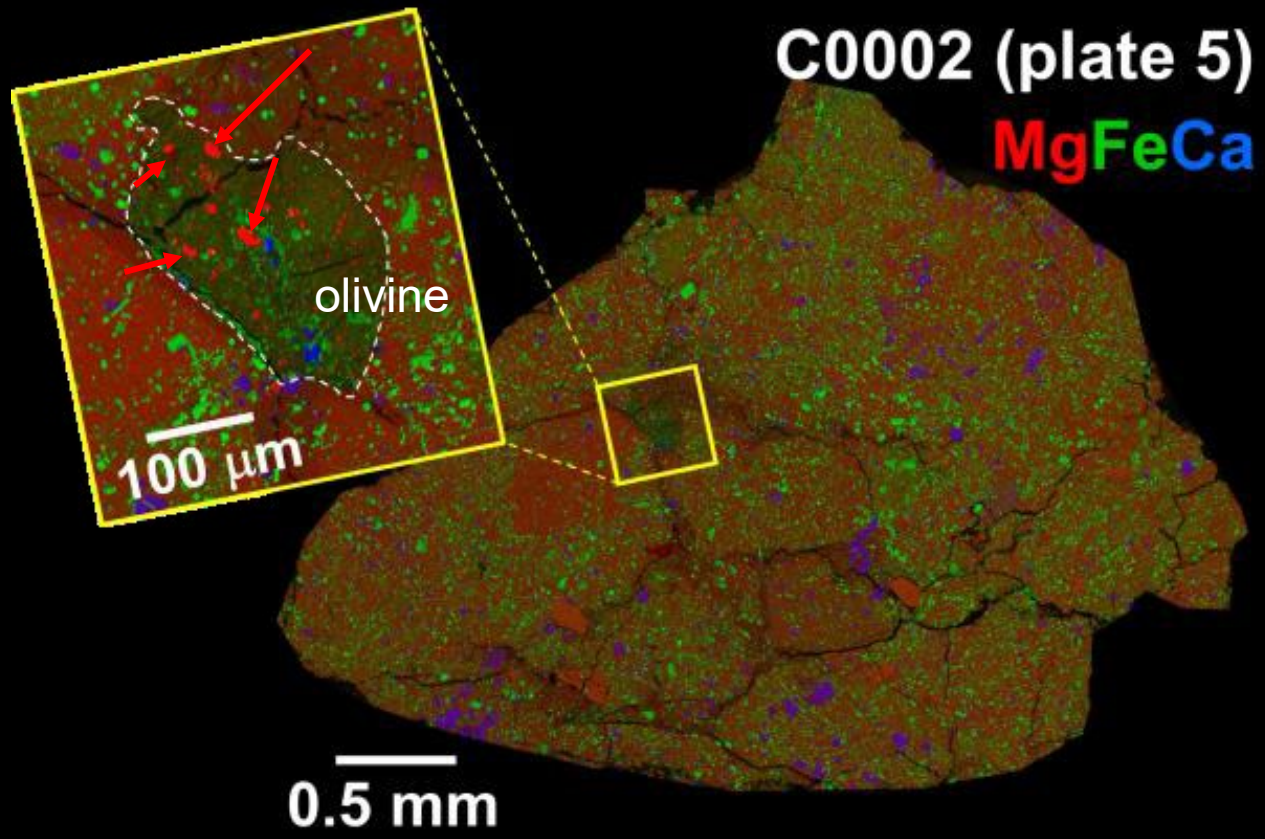



Difference from Earth oceans in parts per thousand →

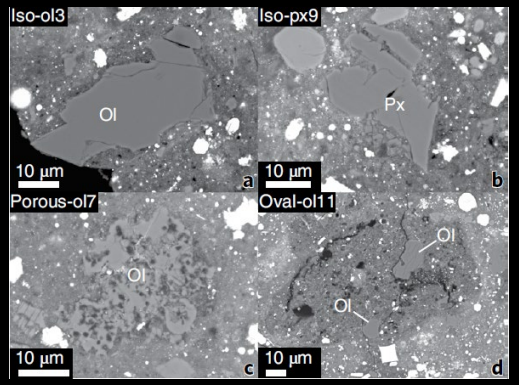
# Anhydrous minerals

- Some Chamber C (TD2) samples have less-altered clasts containing unaltered silicates- Ryugu not fully aqueously altered!




Mikouchi et al. (LPSC 2022)



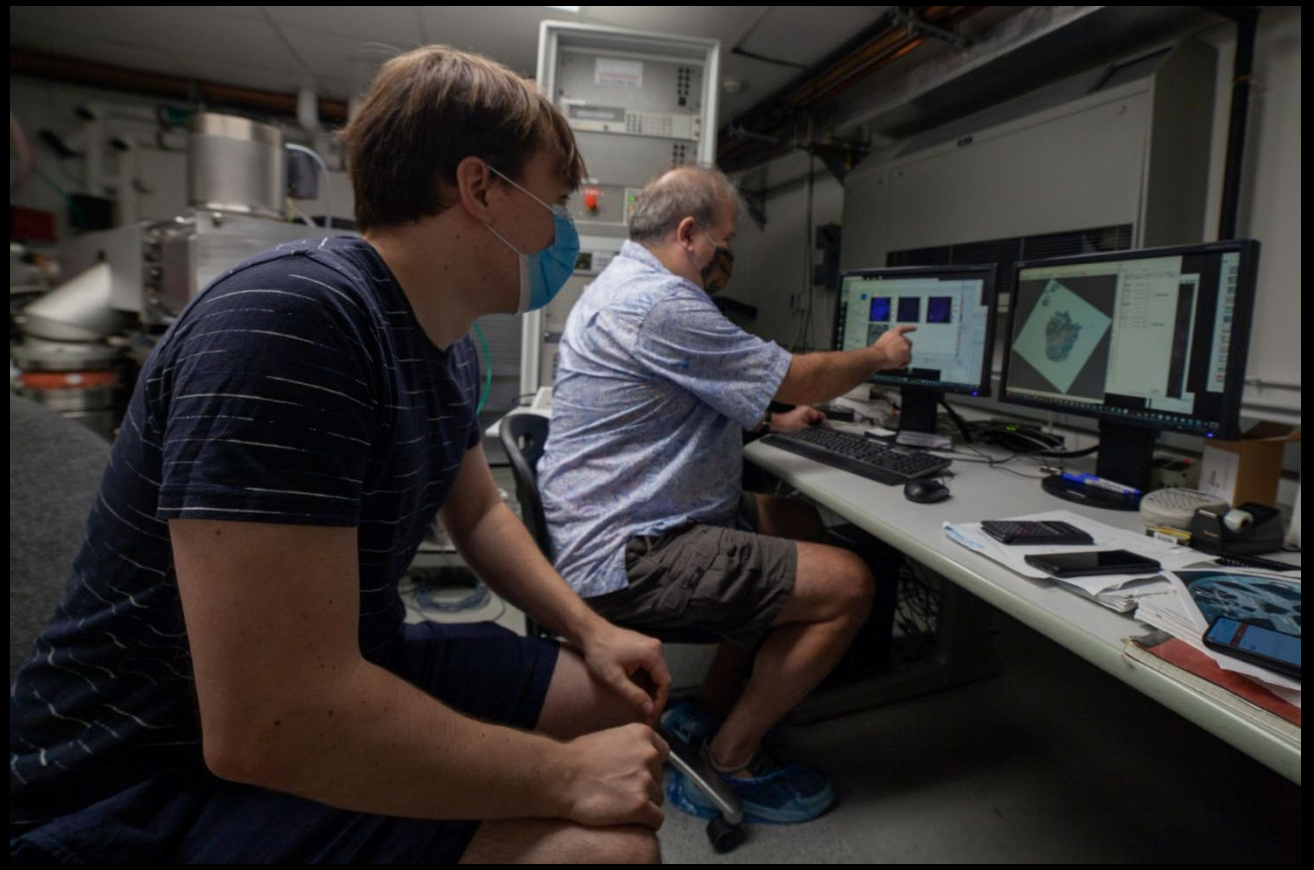

Liu, M-C et al. (*Nature Astronomy,* 2022)

# NanoSIMS and Ryugu samples

NANOSIMS 50L

(allows sub-μm isotopic and elemental characterization of solid samples)

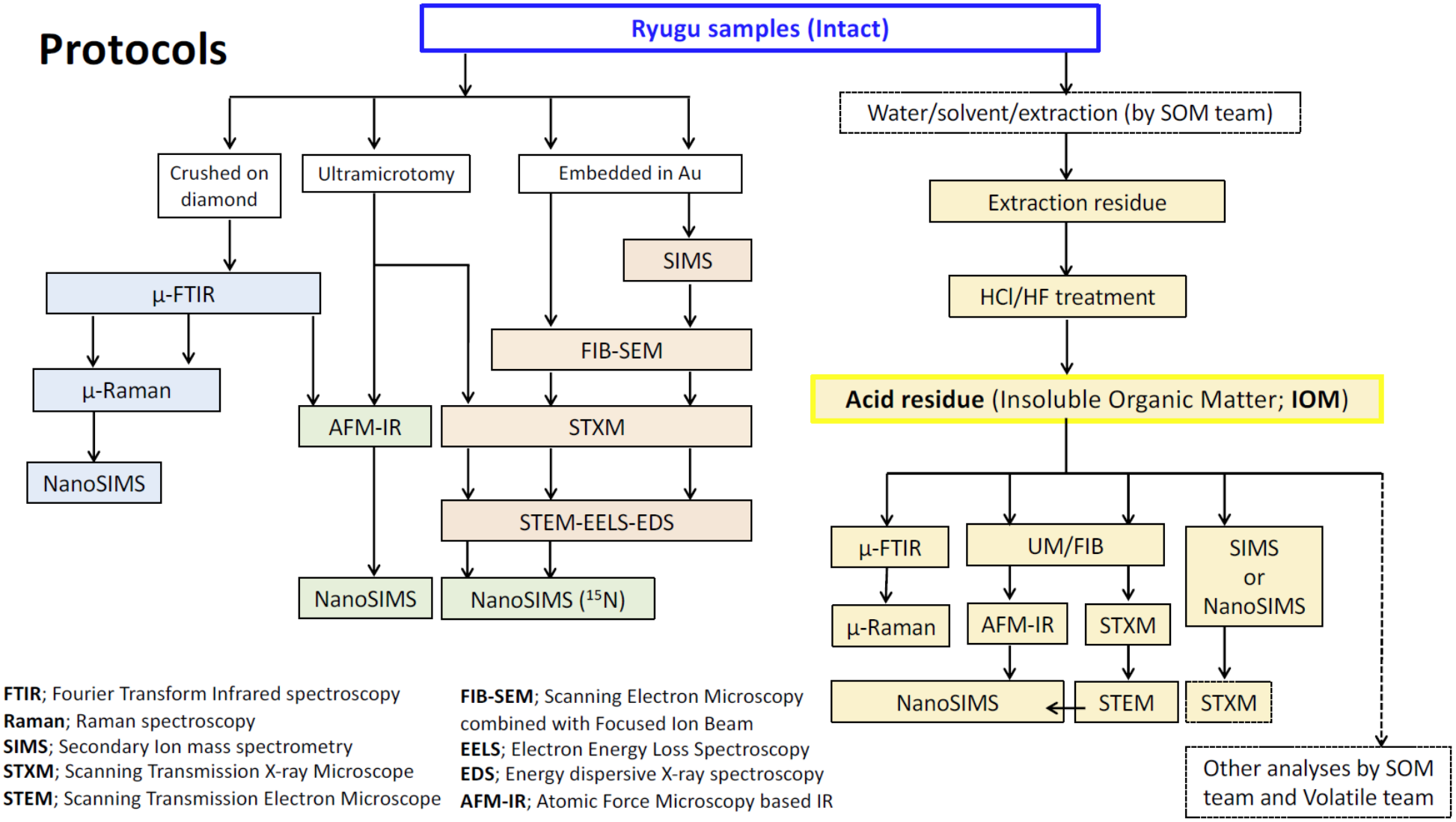
- IOM Team: Characterized H, C, and N isotopes in Ryugu organic matter at microscale
- Chemistry Team: Searched for *presolar grains*



LRN + Jens Barosch at Carnegie Inst. NanoSIMS (K. Cain)

# organic macromolecule analysis team

## Protocols

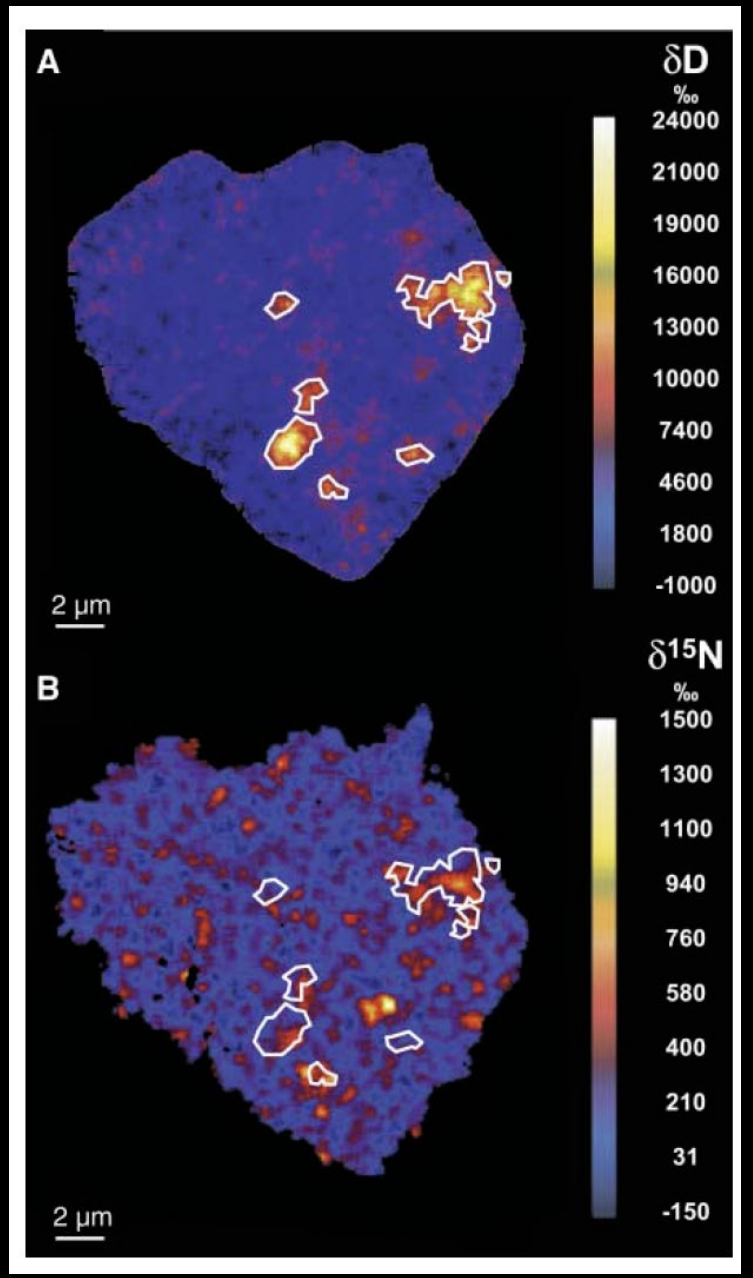



**FTIR**; Fourier Transform Infrared spectroscopy
**Raman**; Raman spectroscopy
**SIMS**; Secondary Ion mass spectrometry
**STXM**; Scanning Transmission X-ray Microscope
**STEM**; Scanning Transmission Electron Microscope

**FIB-SEM**; Scanning Electron Microscopy combined with Focused Ion Beam
**EELS**; Electron Energy Loss Spectroscopy
**EDS**; Energy dispersive X-ray spectroscopy
**AFM-IR**; Atomic Force Microscopy based IR

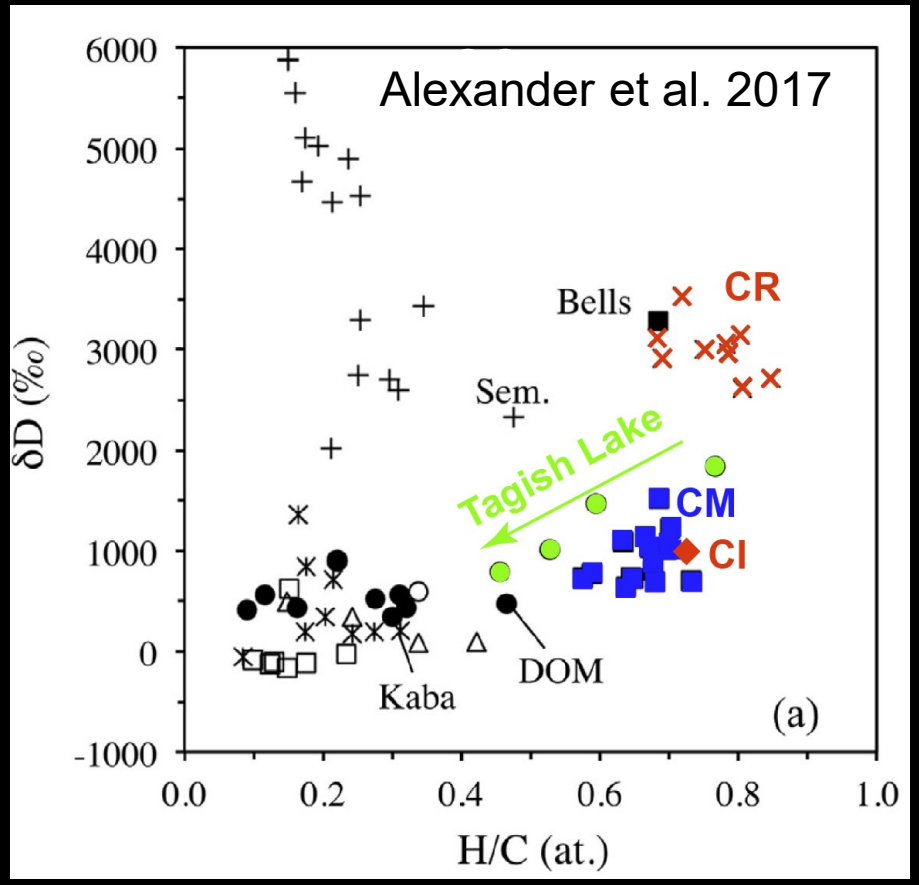
# Organic matter in C Chondrites

- Makes up to 3-4 wt.% of carbonaceous chondrites
- Enormous diversity of soluble organic molecules including many of astrobiological interest, but C budget dominated by refractory insoluble organic matter (IOM)
- Origin unknown, but isotopic enrichments in D and $^{15}N$ suggest heritage in presolar molecular cloud or outer protoplanetary disk.

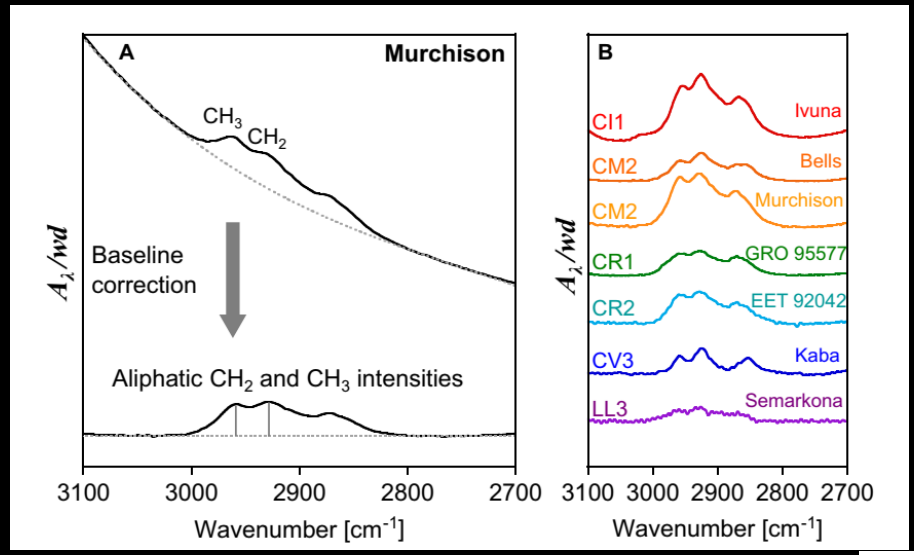



Busemann et al. 2006

# Organic matter in C Chondrites

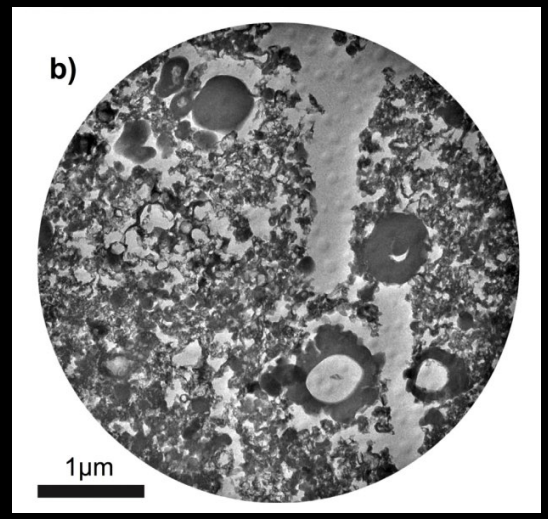



- Affected by parent body processing (hydrothermal alteration, metamorphism)

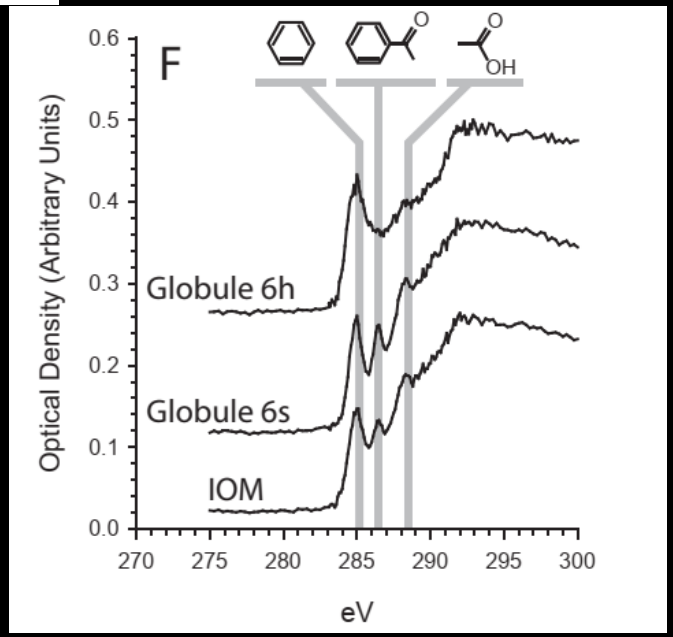



Kebukawa et al. 2019

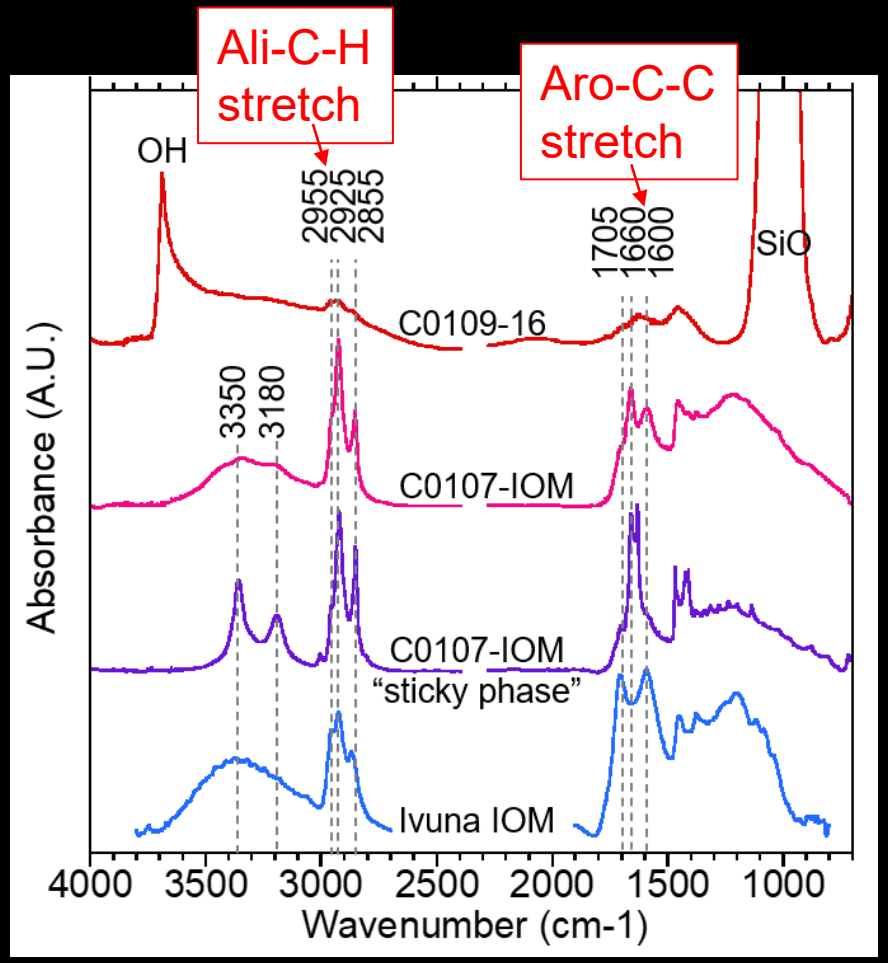
- Diversity of morphologies (inc. “nanoglobules”) and chemical functionality




De Gregorio et al. 2013

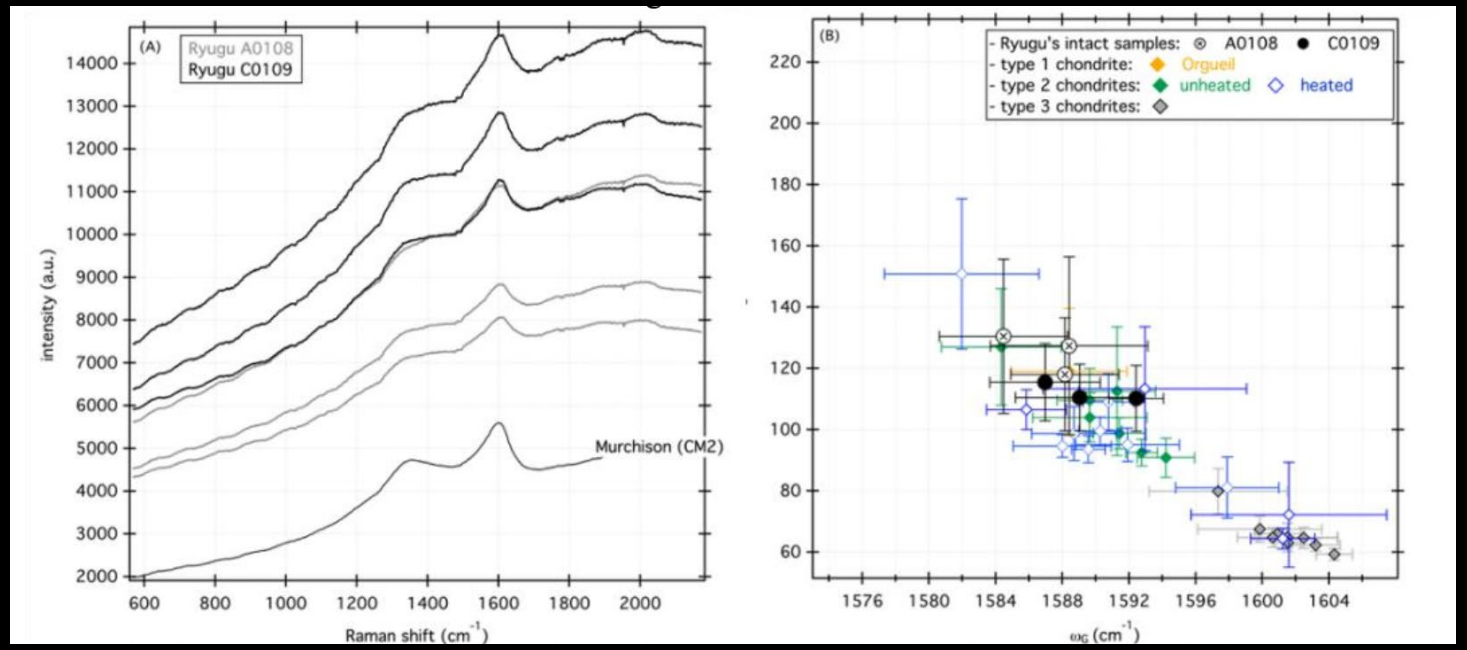


# Initial Macromolecule Results: FTIR/Raman




FTIR: Ryugu A=C, similar to CI chondrite organics

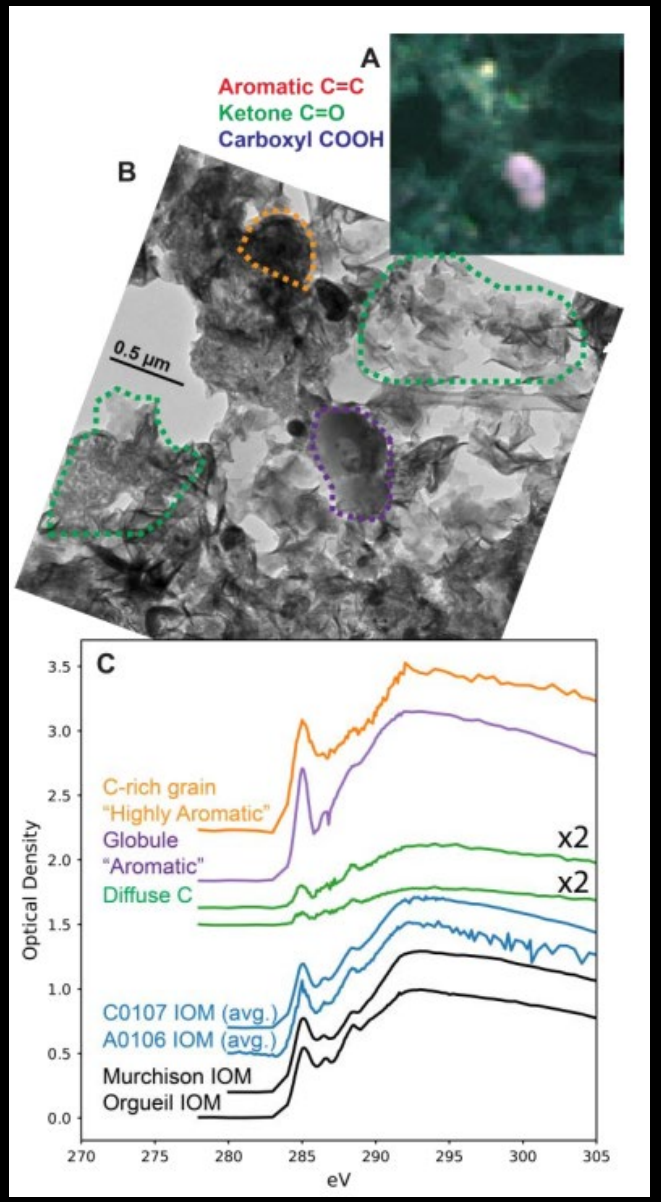
Kebukawa et al.; Quirico et al. (LPSC 2022)



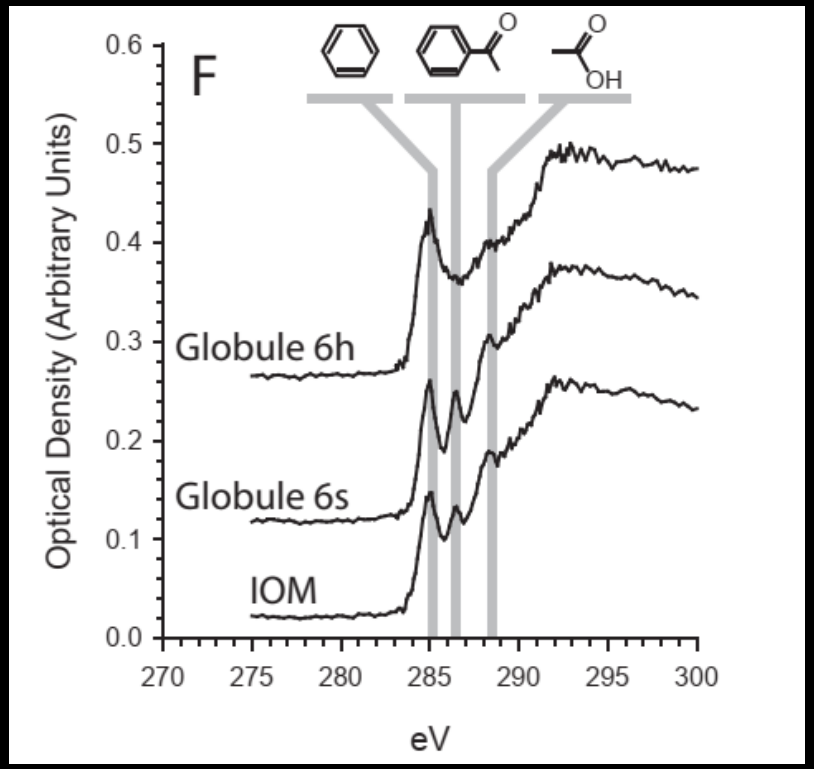

Raman Spectroscopy: Ryugu similar to unheated C chondrites, including CI

Bonal et al. (LPSC 2022)

# Initial Macromolecule Results: C-XANES



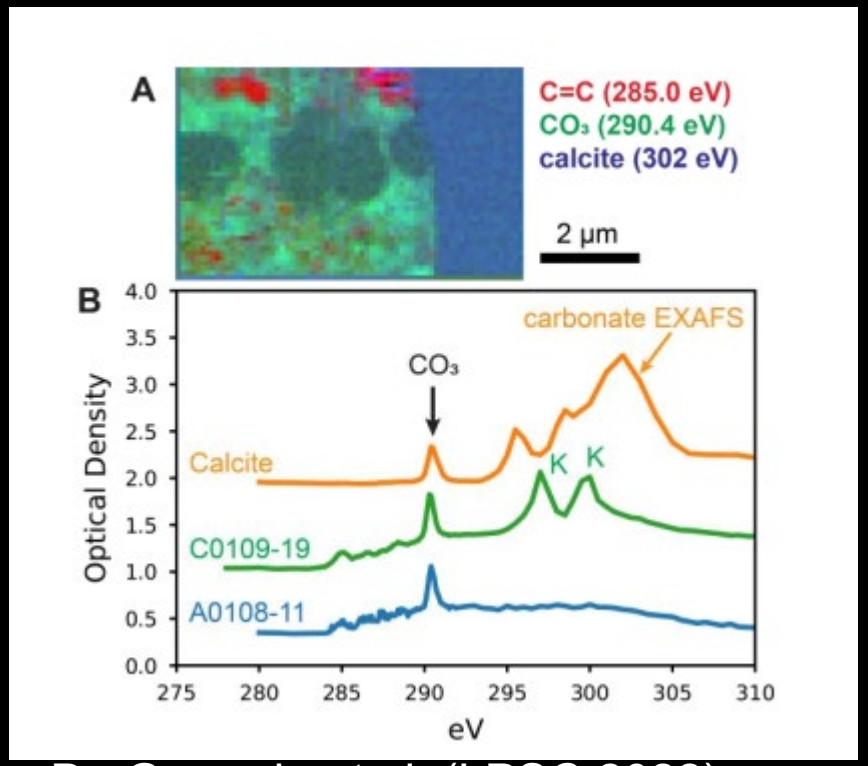

- C-XANES
  - Pervasive C-rich grains >200-nm and *diffuse* C associated with phyllosilicates
  - Spectral diversity, similar to C chondrites



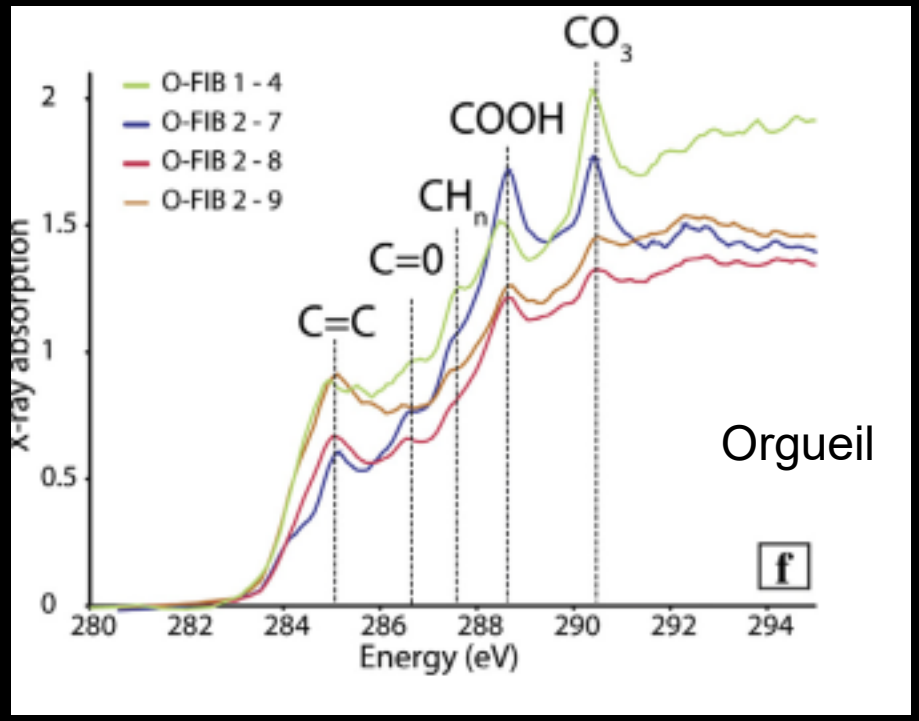

De Gregorio et al. (2013)

De Gregorio et al. (LPSC 2022)

# Initial Macromolecule Results: C-XANES




De Gregorio et al. (LPSC 2022)

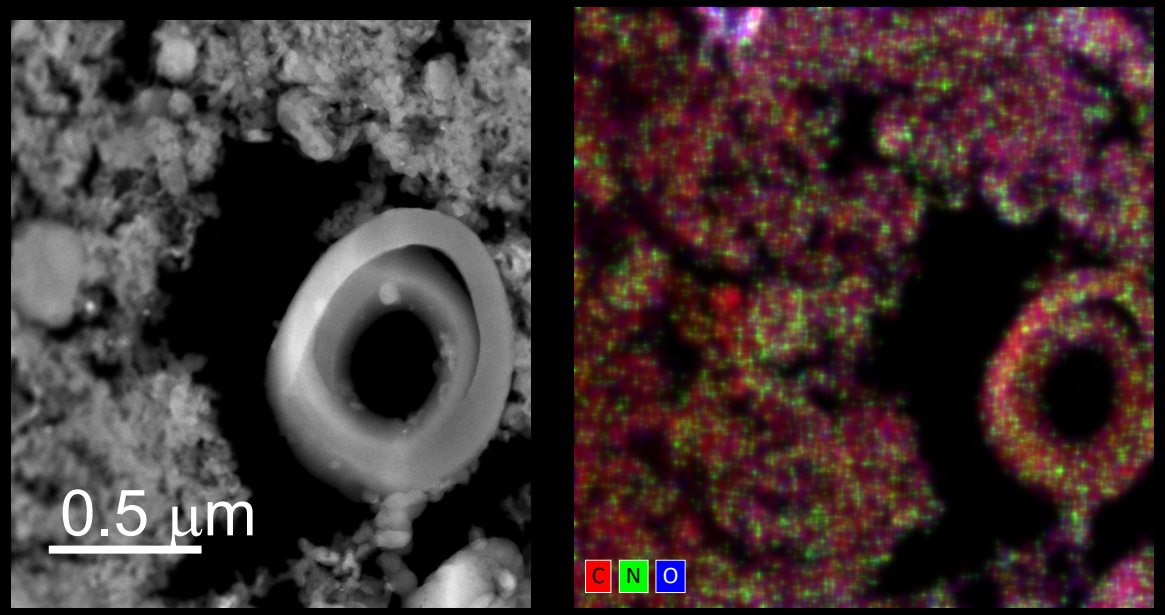


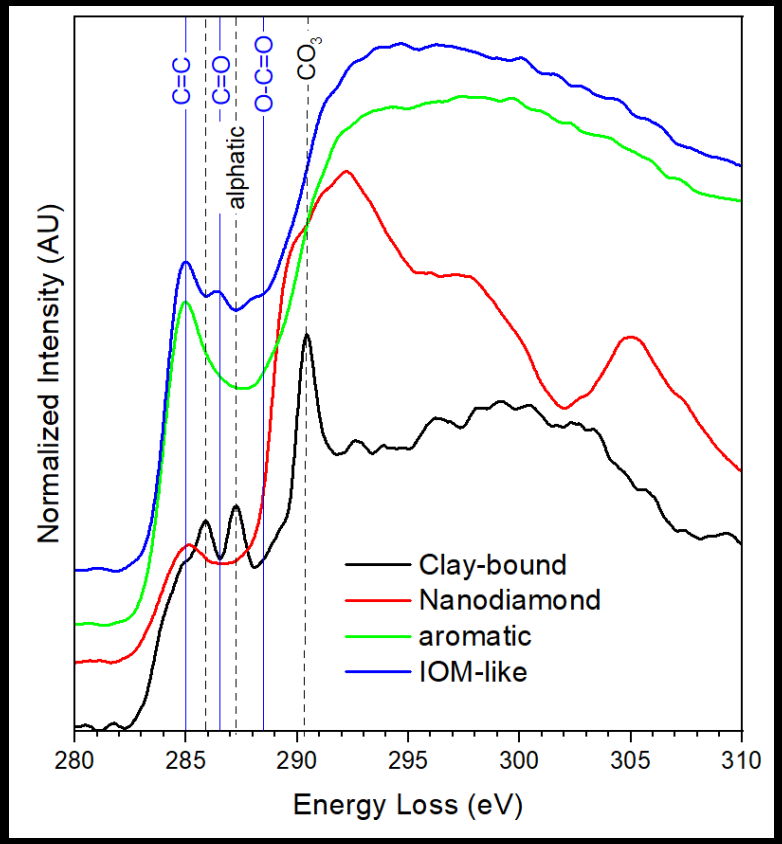

Le Guillou et al. (2014)

- C-XANES
  - Interesting 290.4 eV feature seen in intact particles (not IOM), associated with phyllosilicates – not crystalline carbonate!
  - Previously seen in some C chondrites
  - Molecular carbonate? Initial stages of carbonate formation? (Le Guillou et al. 2014)

# Initial Macromolecule Results: STEM

## Ryugu IOM



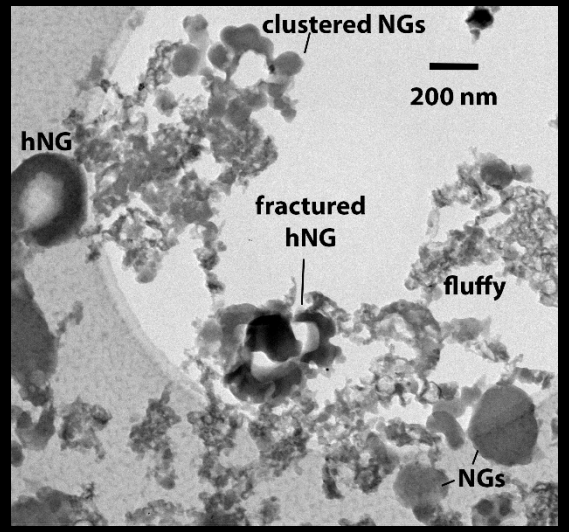




- STEM allows nm-scale mapping of composition and functional chemistry
  - Diversity of C morphologies – diffuse clay-bound C, hollow/soild, nanoglobules, fluffy material
  - 290.4 feature associated with phyllosilicates
  - (presolar?) Nanodiamonds present

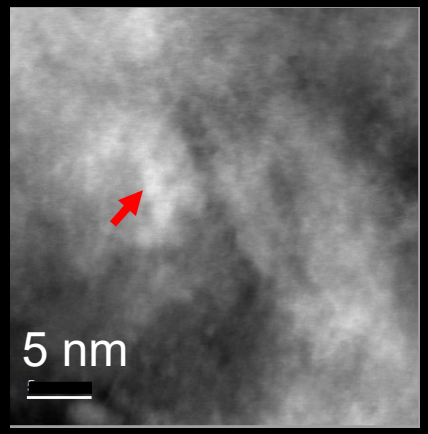
R. Stroud

# Initial Macromolecule Results: STEM

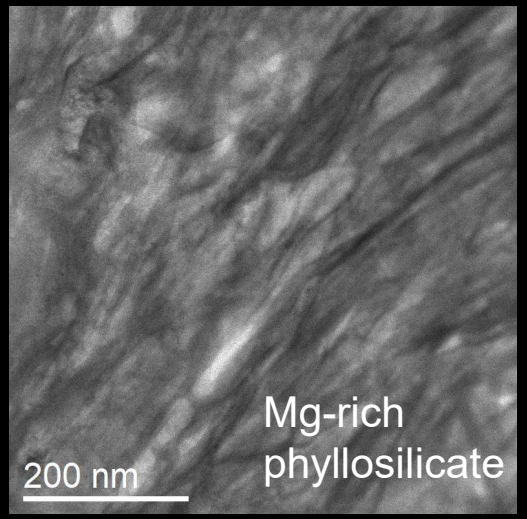
## Nanoglobules

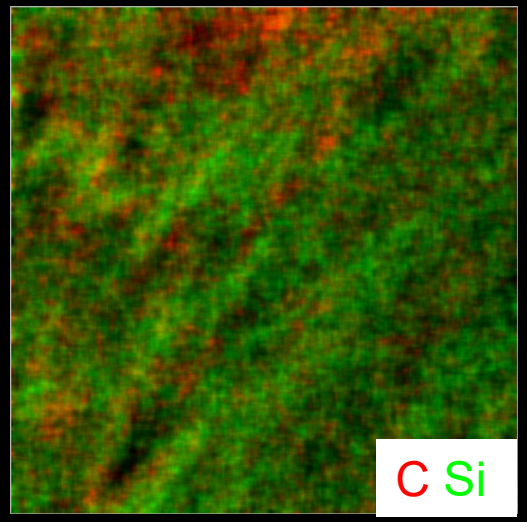



## Nanodiamonds

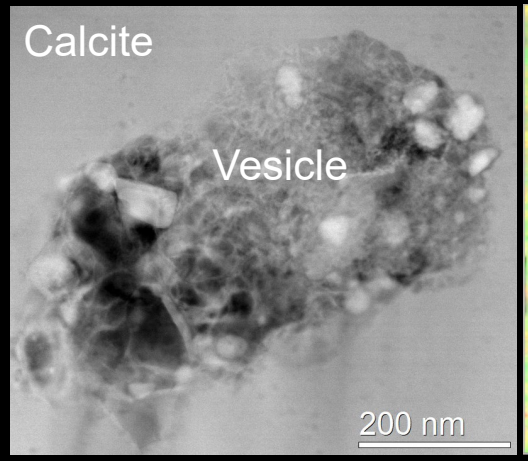


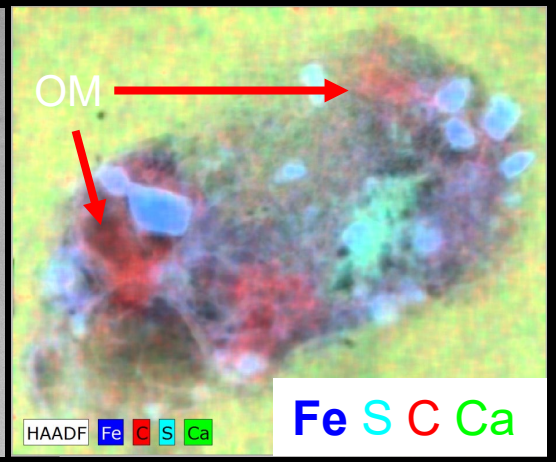

## Diffuse C, intergranular & mixed into phyllosilicates



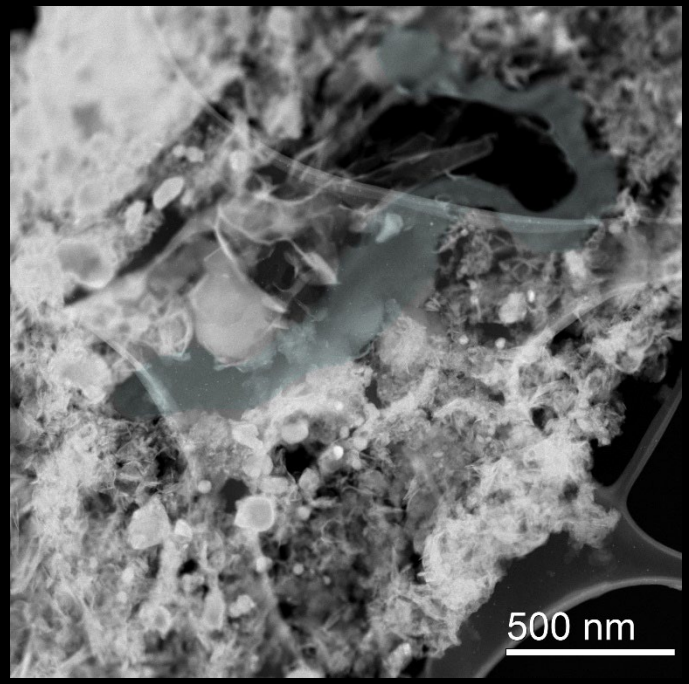




## In vesicles in carbonate and pyrrhotite grains



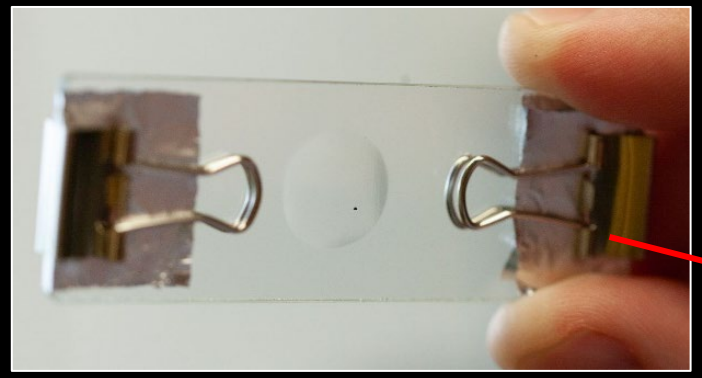



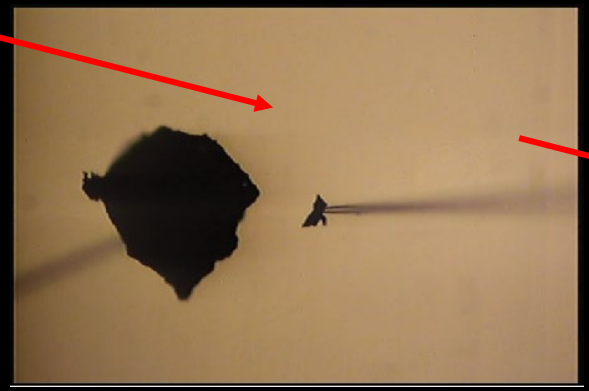

## Dense, irregular shaped

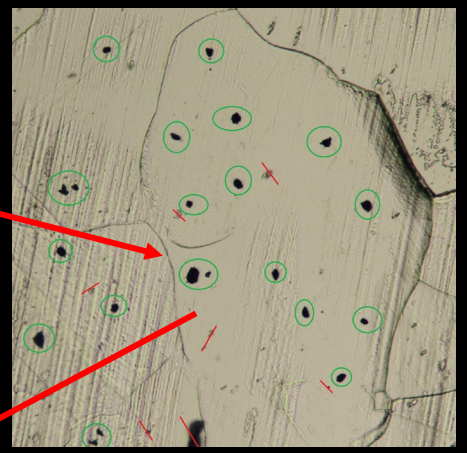


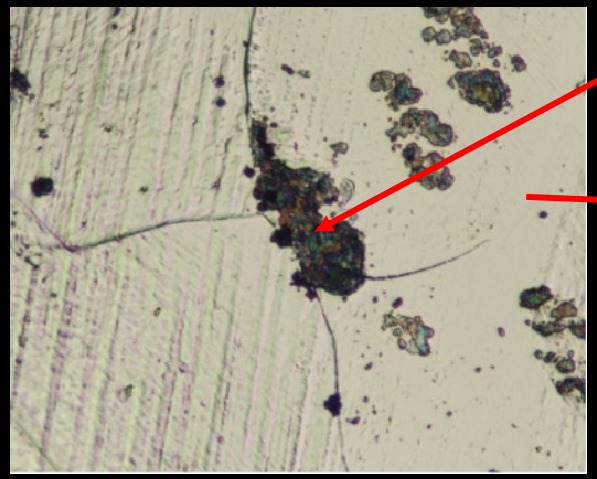

R. Stroud

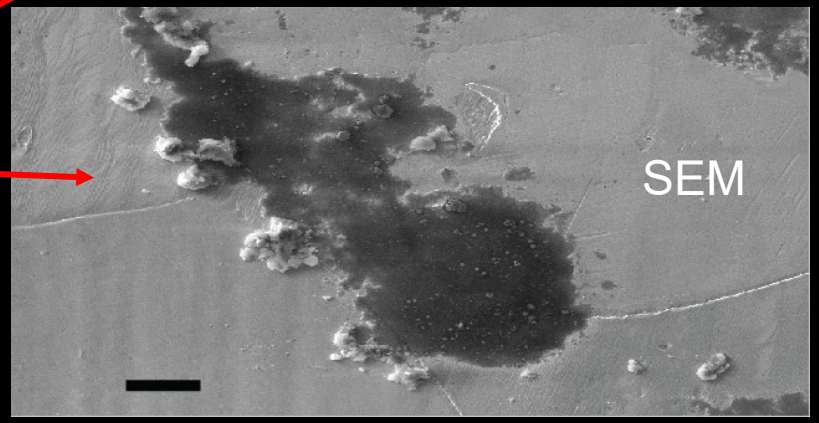
# NanoSIMS







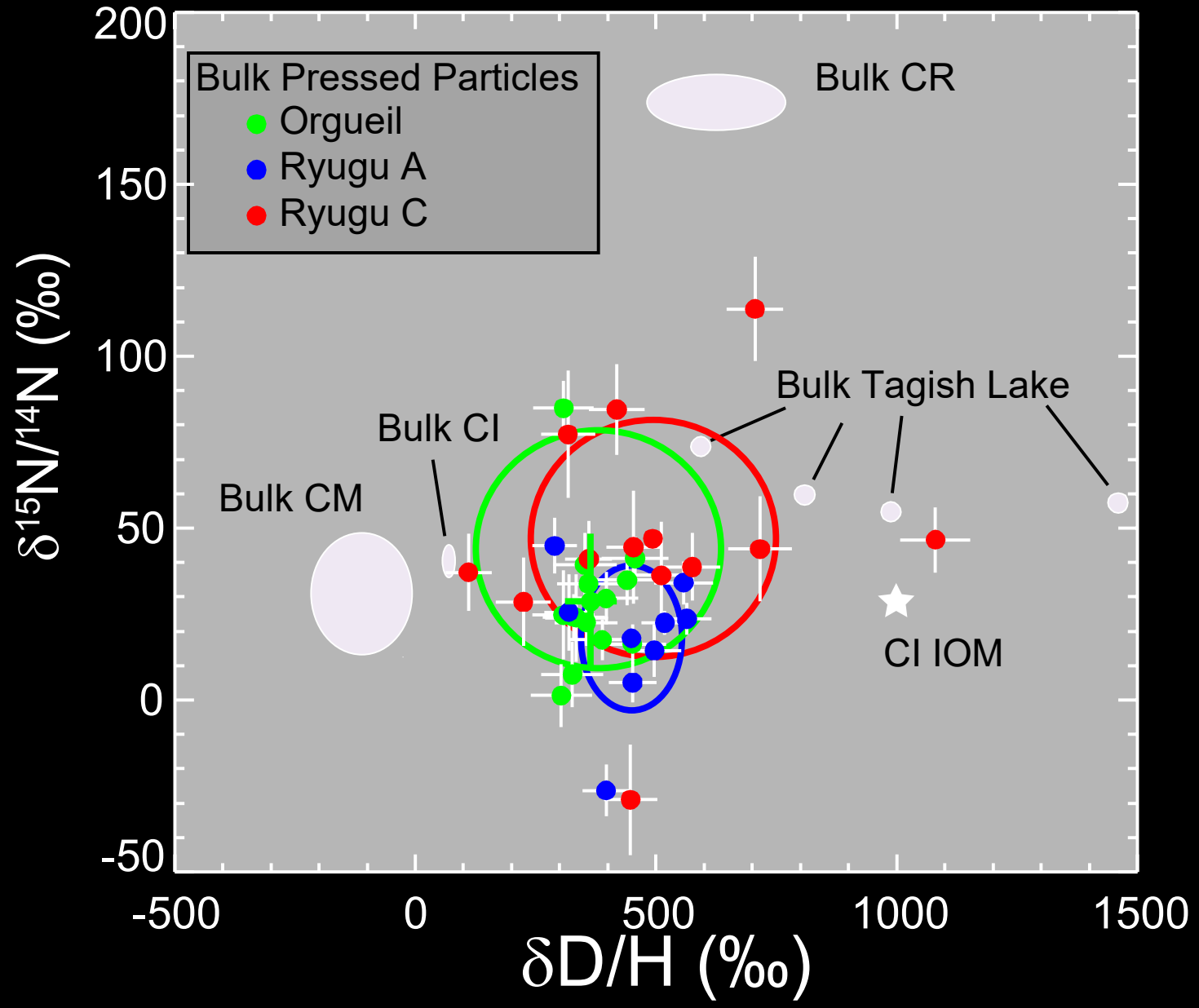





- Few dozen 15-30 μm particles (Ryugu and Orgueil) pressed into Au foils
- Analyzed for H, C, and N isotopes in imaging mode on Carnegie NanoSIMS 50L (Standard methods)

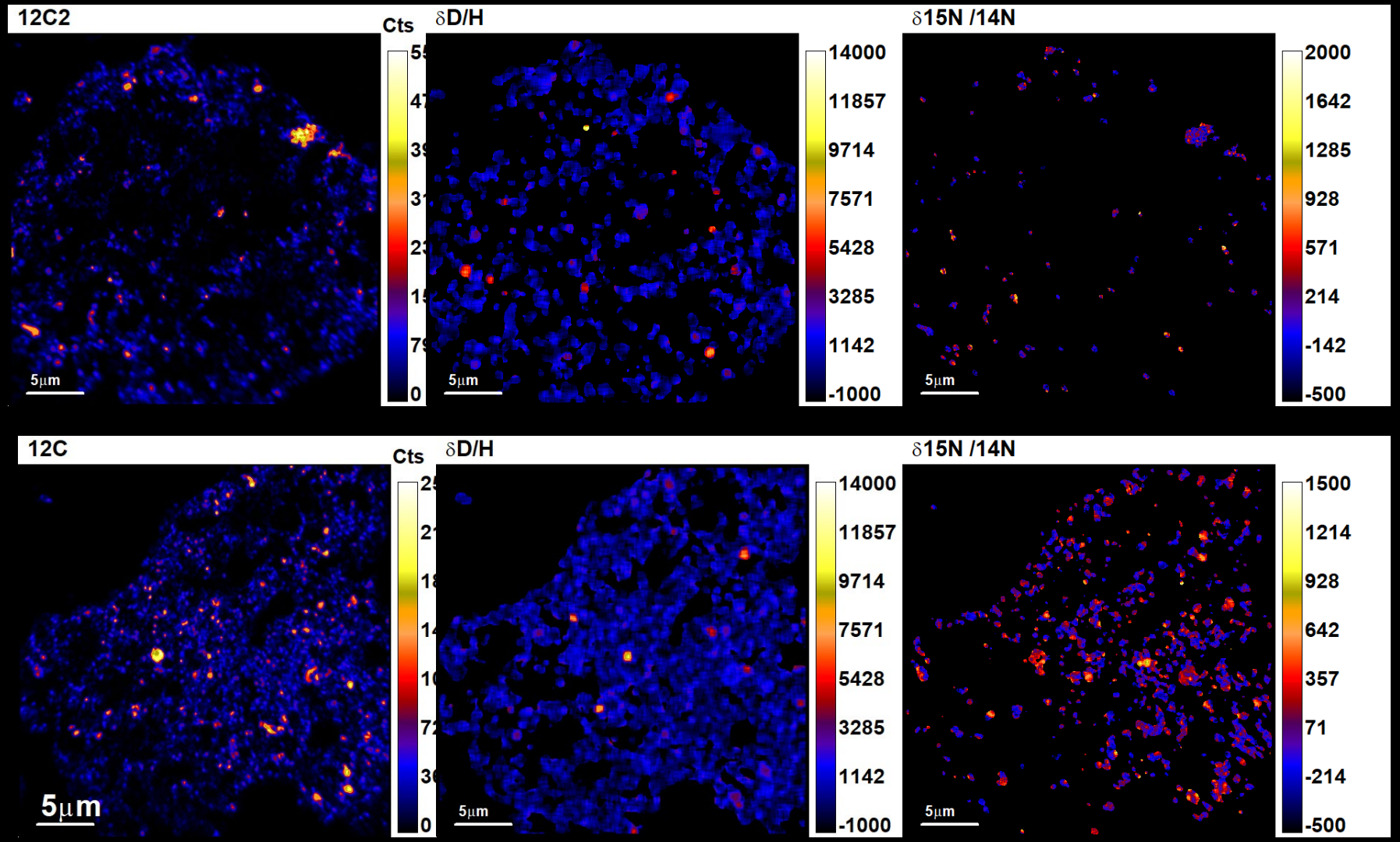
# Bulk results

- SIMS measurements of Ryugu in good agreement with Orgueil
  - Same $^{15}N/^{14}N$
  - D/H between bulk CI and CI IOM
- Particle-to-particle variability (10s micron scale) due to microscale isotopic diversity

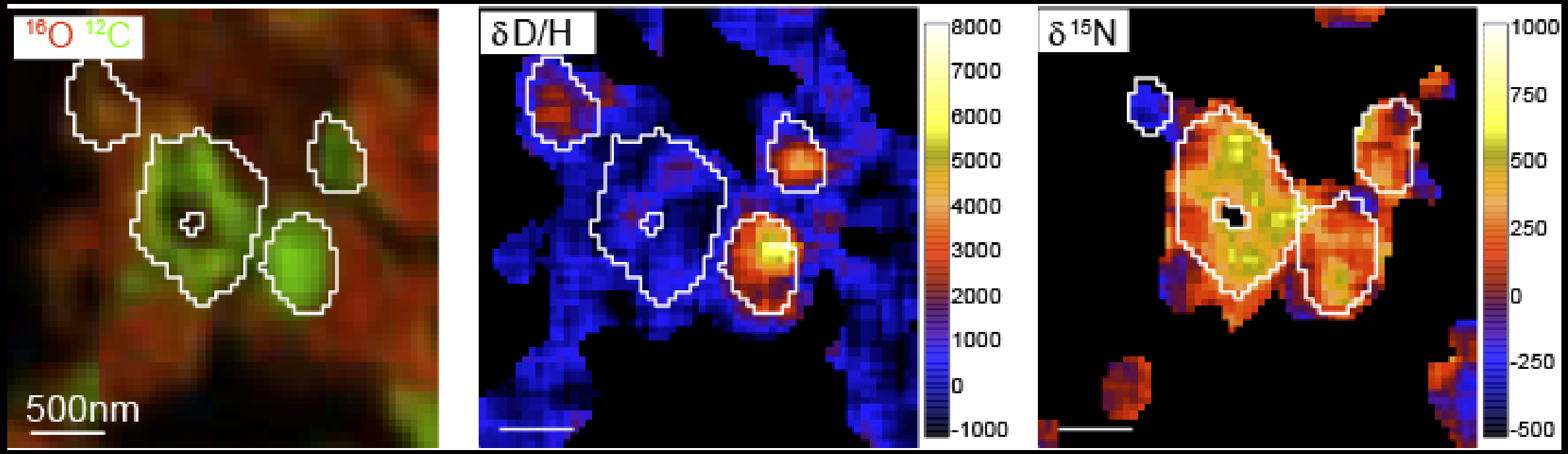


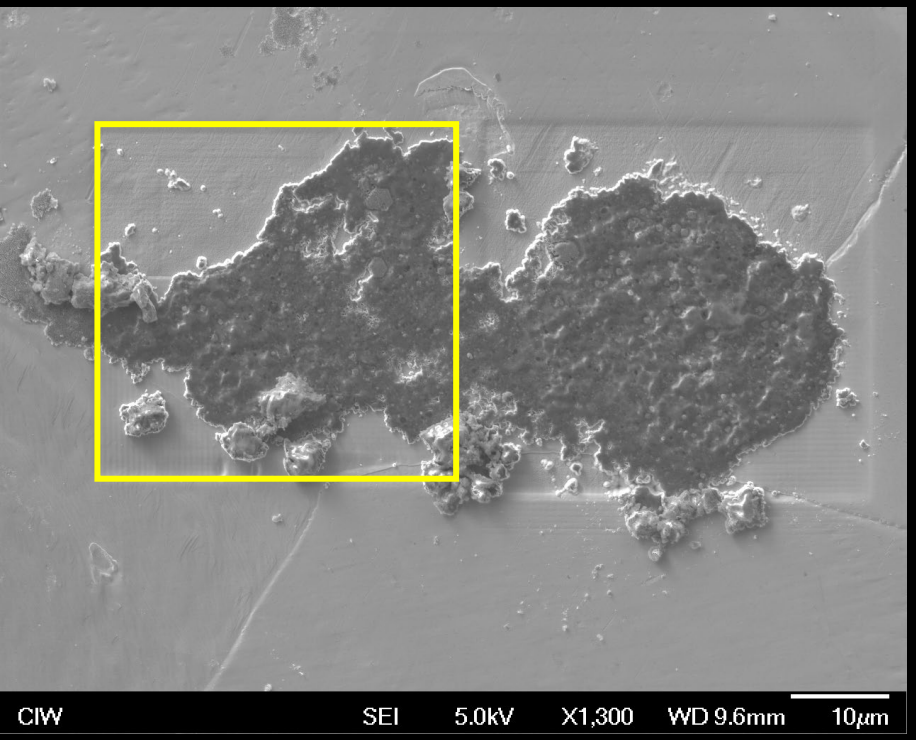
# Microscale Isotopic Diversity

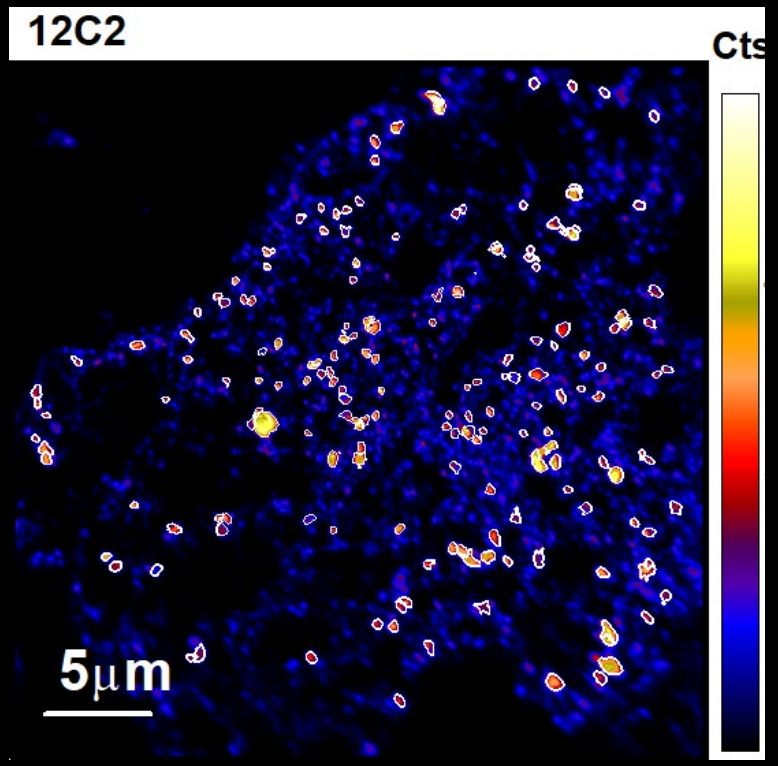
- C largely present as particles, mostly round but range of morphologies.
- Very wide range of H and N isotopes

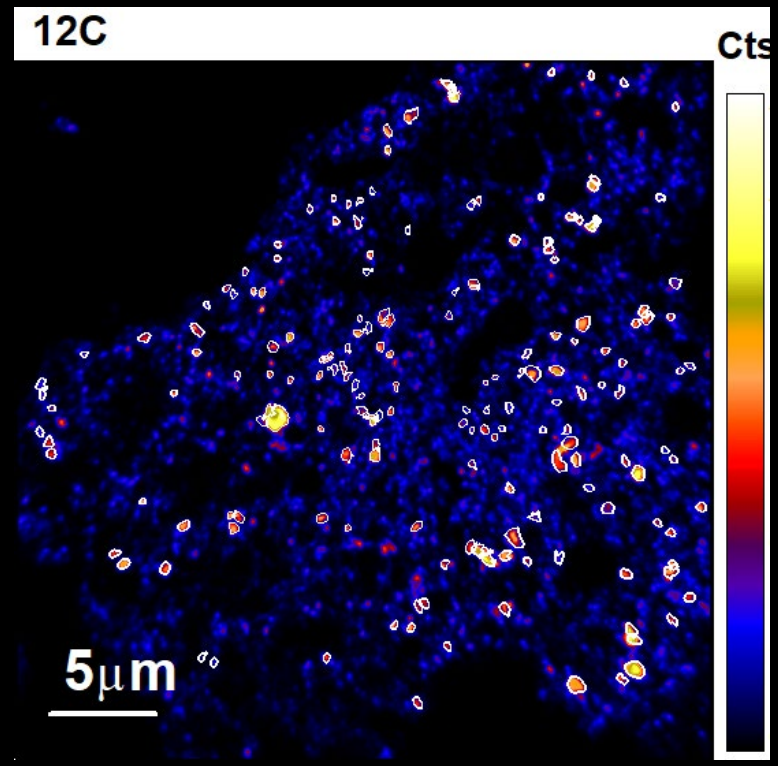


# Microscale Isotopic Diversity



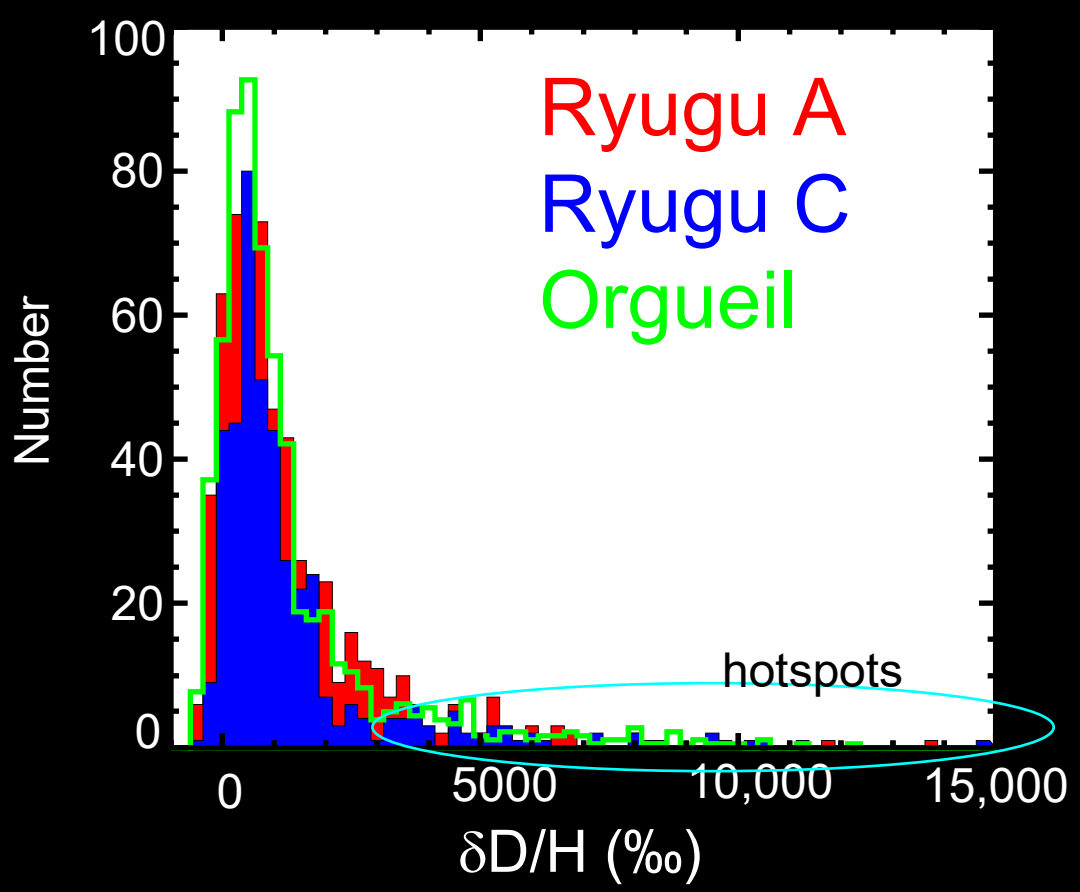


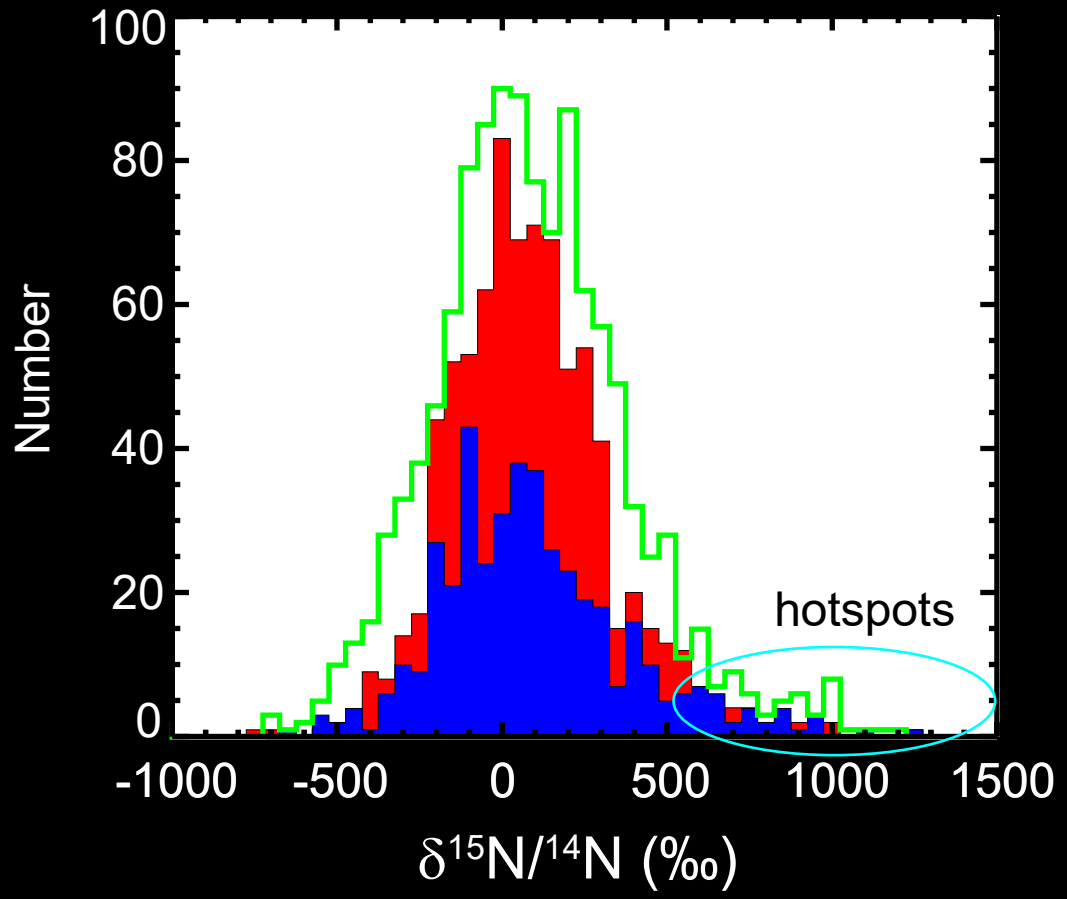




- Define C-rich ROIs in C images from both sets of measurements and correlate them
- Total of a few thousand C-rich ROIs defined in Ryugu A, C, and Orgueil particles

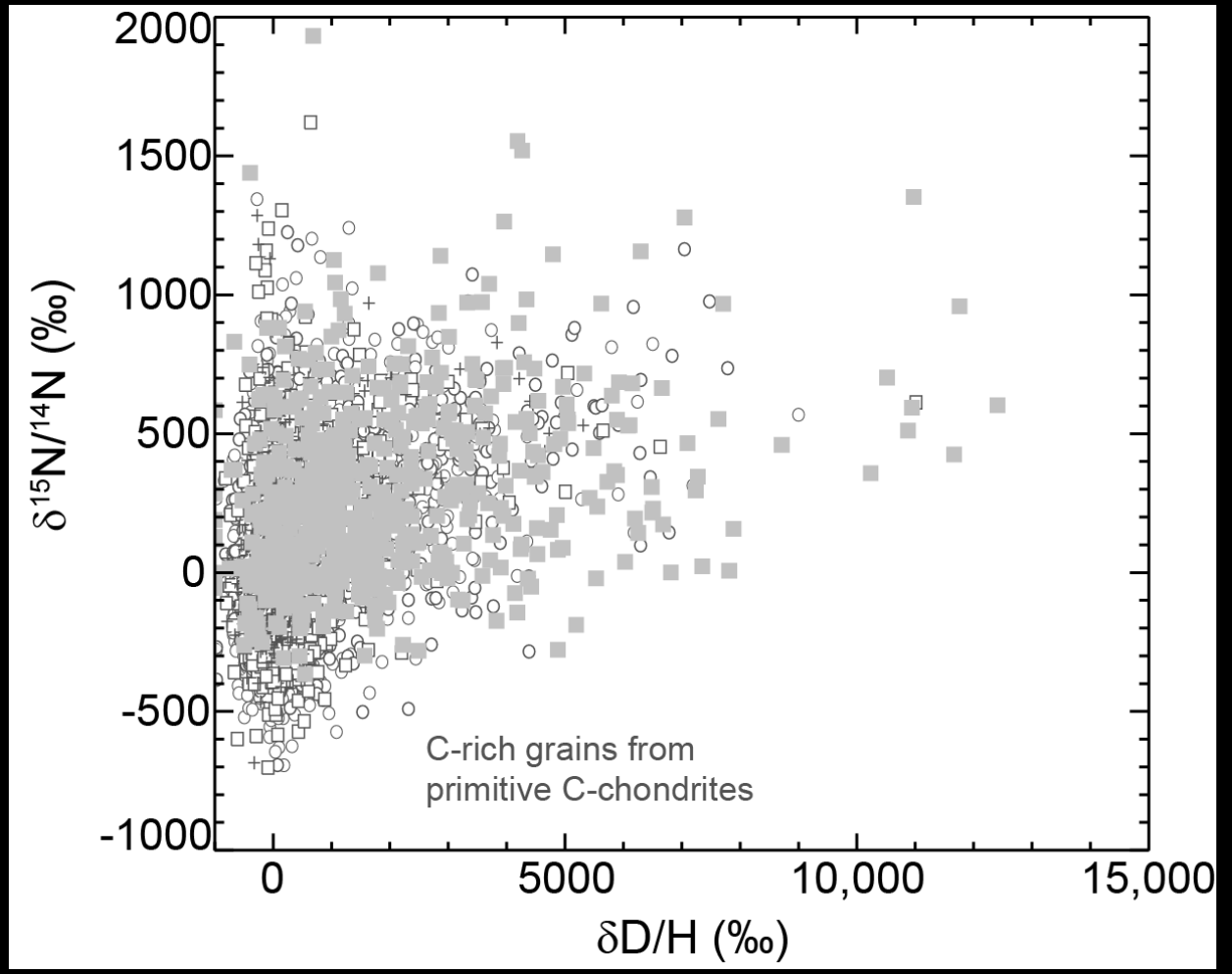
# Microscale Results



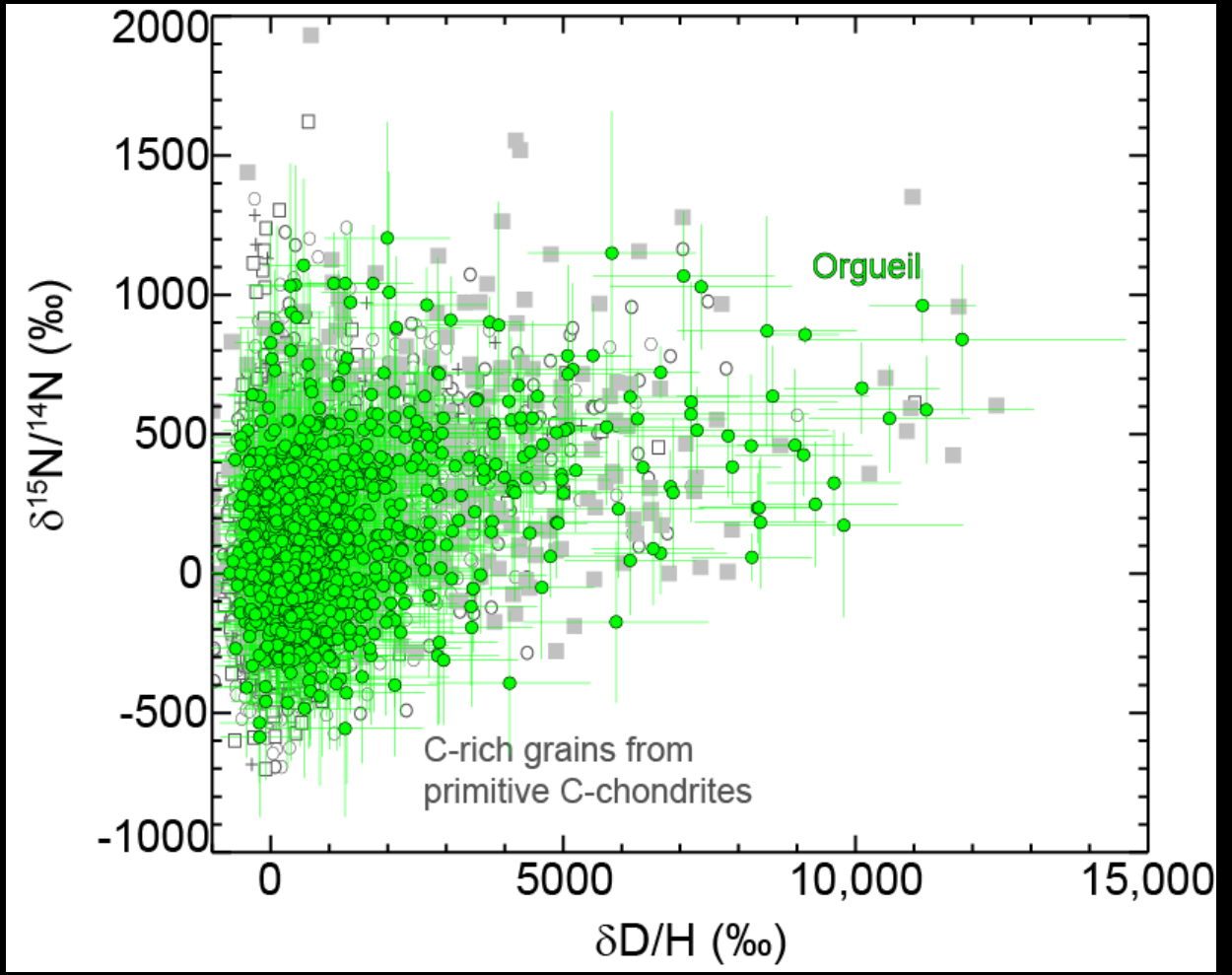

- A ~ C ~ Orgueil in H and N isotope distributions
- Most ROIs have ~bulk H, N isotopes, 5-10% are outliers (“hotspots” and “coldspots”)

# Microscale Results



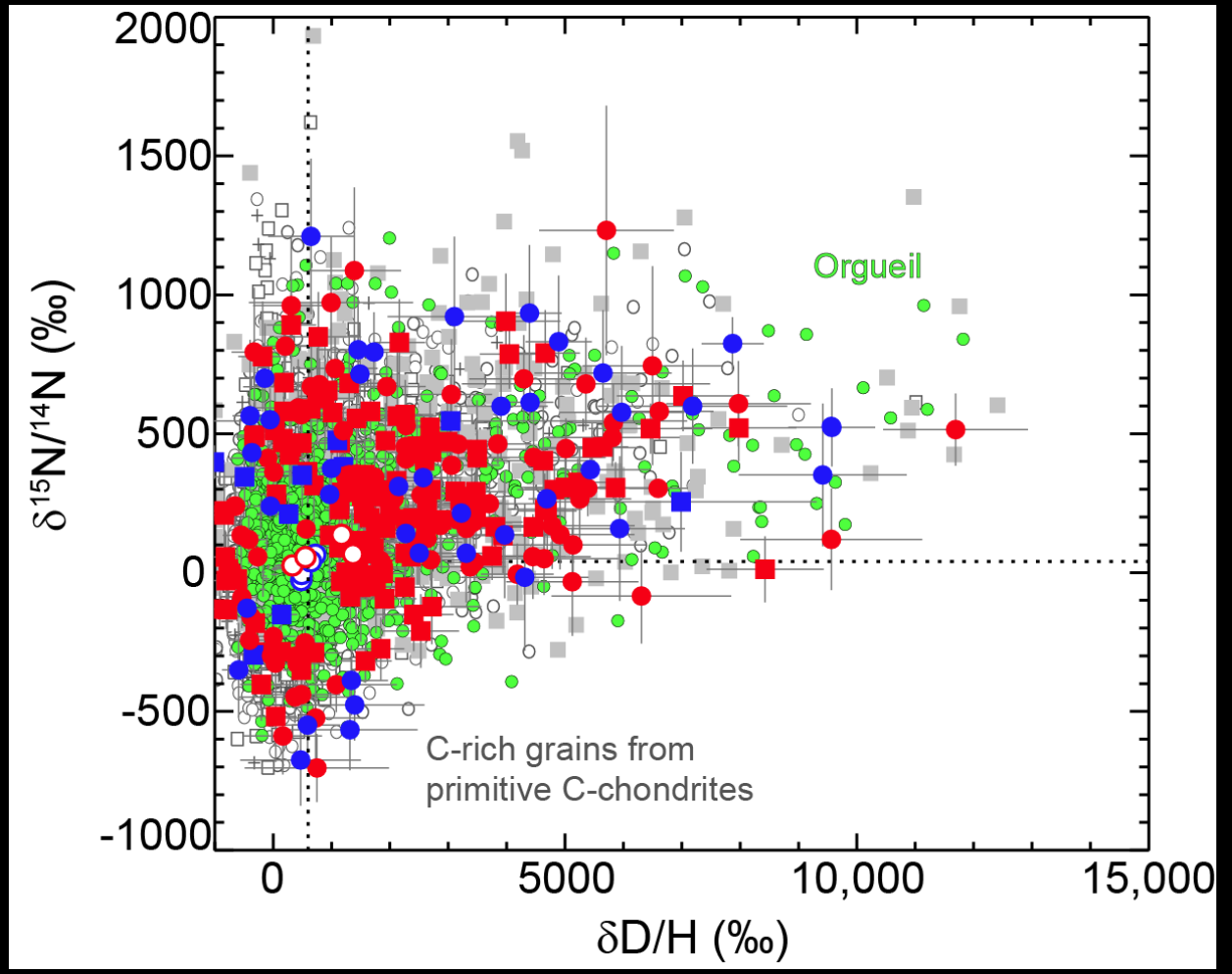

C-chondrites:
Nguyen+, unpub.,
Nittler+ Metsoc
2021

# Microscale Results




C-chondrites: Nguyen+, unpub., Nittler+ Metsoc 2021

# Microscale Results



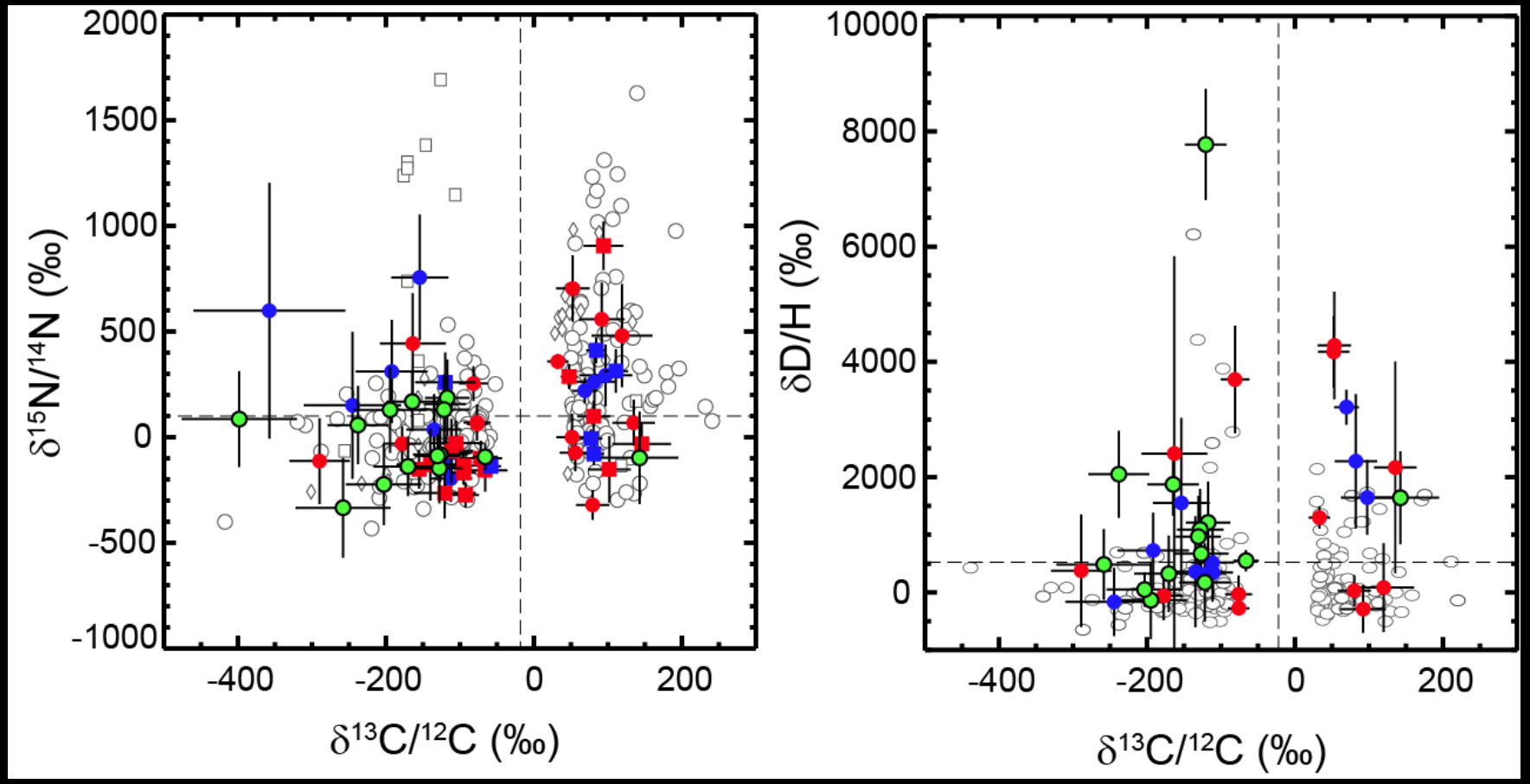

Ryugu Chamber A
Ryugu Chamber C
Pressed particles
Bulk C-rich
Anom. ROIs
Microtome Sections
Anom. ROIs

C-chondrites:
Nguyen+, unpub.,
Nittler+ Metsoc
2021

Microtome:
Yabuta+ in review

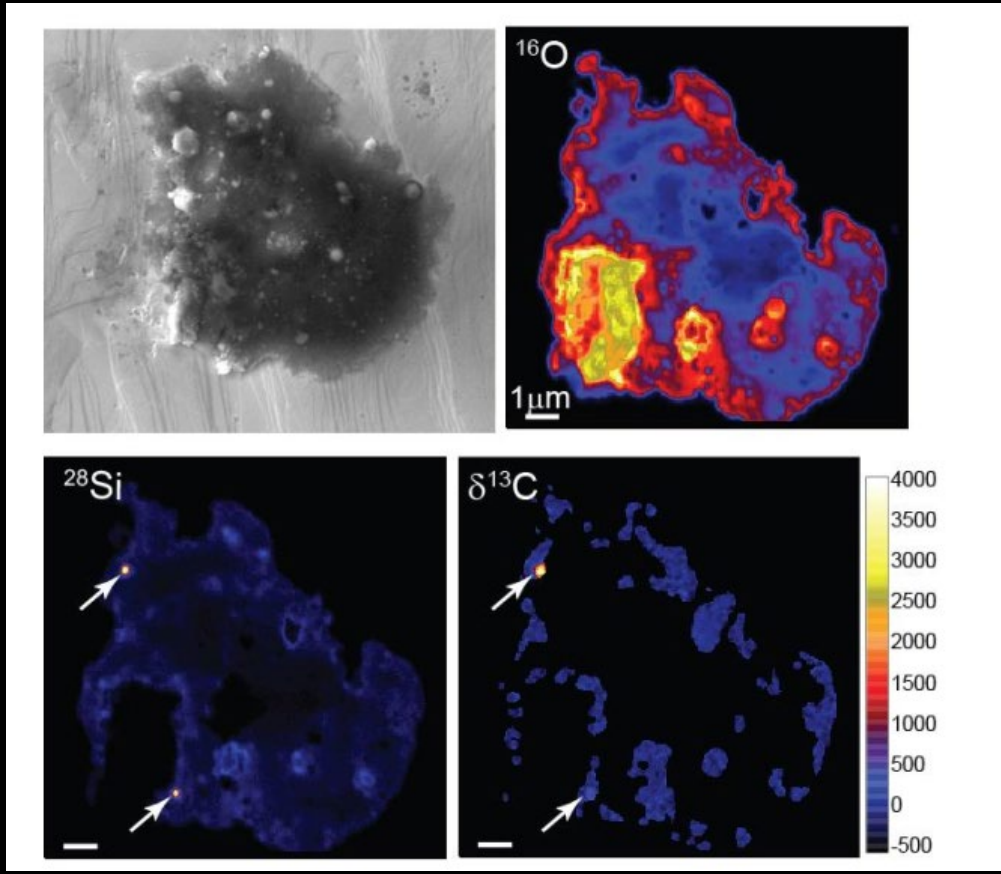
- Essentially identical distributions for Ryugu A , C, Orgueil
- No correlation between δD and $\delta^{15}N$: diversity of origins of solar system organics

# Microscale Results




- <2% of organic ROIs show anomalous $^{13}C/^{12}C$ ratios
- Similar to primitive CCs, no correlation with H or N isotopes

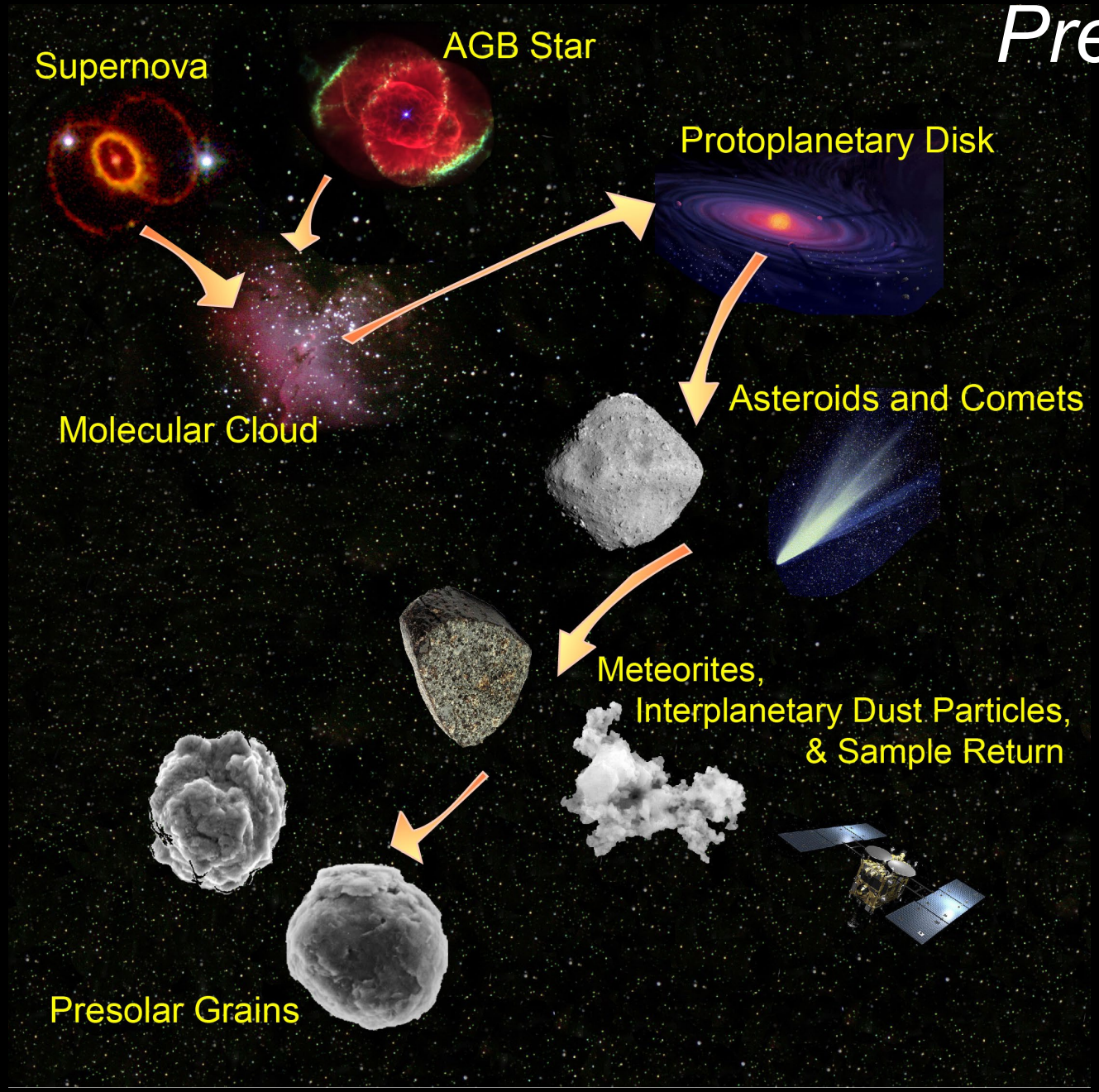
# Initial Macromolecule Results: Presolar SiC




Barosch et al (*ApjL* 2022)

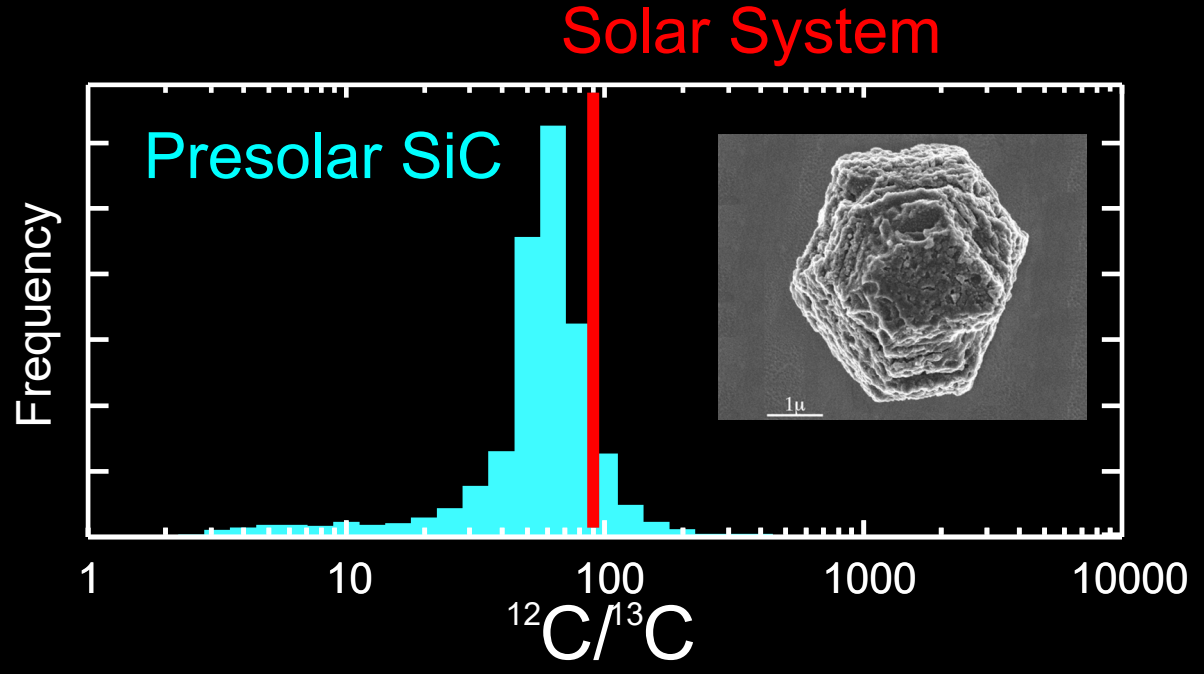
- C isotope measurements also revealed *presolar SiC grains*
- Extreme $^{13}C$ isotope enrichments point to an origin in previous generations of evolved stars

# *Presolar Stardust Grains*




(e.g., Nittler & Ciesla, *ARAA*, 2016)

- Rare component of meteorites
- Extreme isotope anomalies require nuclear reactions
  origin in stars!
- Provide info on stellar astrophysics, building blocks of solar system, early planet formation



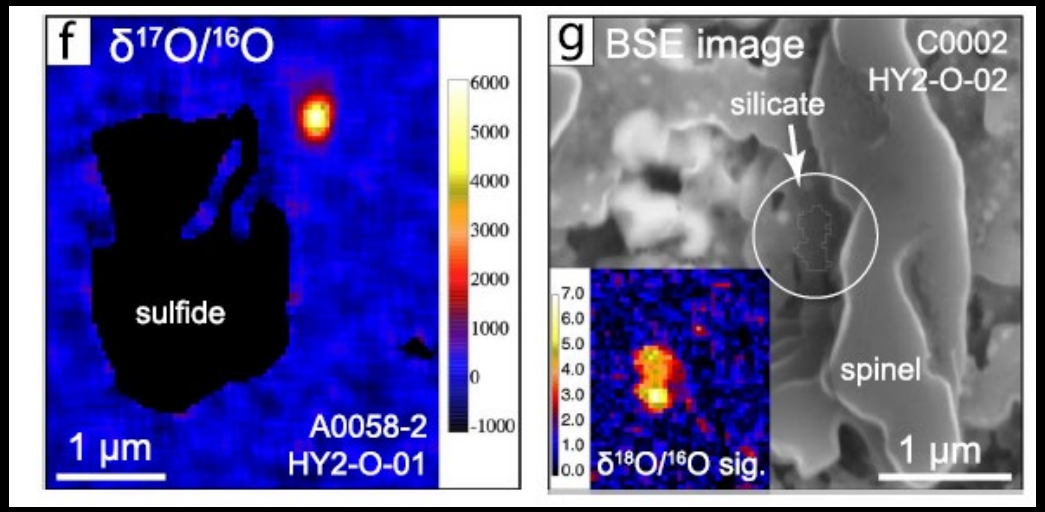
The Astrophysical Journal Letters, 935:L3 (12pp), 2022 August 10 https://doi.org/10.3847/2041-8213/ac83bd

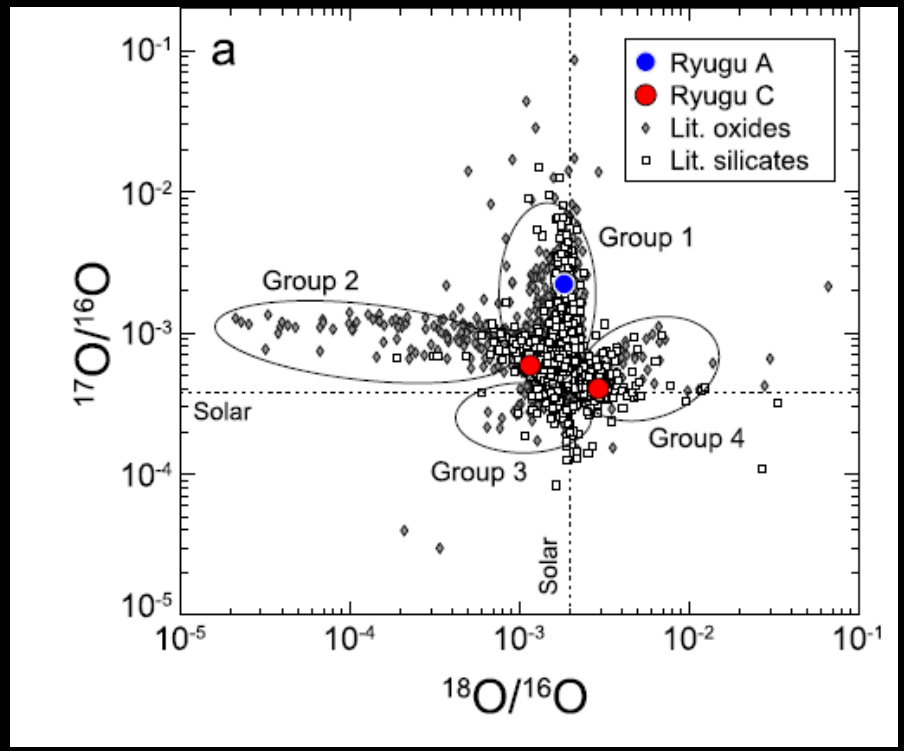

# Presolar Stardust in Asteroid Ryugu

Jens Barosch[1], Larry R. Nittler[1,2], Jianhua Wang[1], Conel M. O'D. Alexander[1], Bradley T. De Gregorio[3], Cécile Engrand[4], Yoko Kebukawa[5], Kazuhide Nagashima[6], Rhonda M. Stroud[2,3], Hikaru Yabuta[7], Yoshinari Abe[8], Jérôme Aléon[9], Sachiko Amari[10,11], Yuri Amelin[12], Ken-ichi Bajo[13], Laure Bejach[4], Martin Bizzarro[14], Lydie Bonal[15], Audrey Bouvier[16], Richard W. Carlson[1], Marc Chaussidon[17], Byeon-Gak Choi[18], George D. Cody[1], Emmanuel Dartois[19], Nicolas Dauphas[20], Andrew M. Davis[20], Alexandre Dazzi[21], Ariane Deniset-Besseau[21], Tommaso Di Rocco[22], Jean Duprat[9], Wataru Fujiya[23], Ryota Fukai[24], Ikshu Gautam[25], Makiko K. Haba[25], Minako Hashiguchi[26], Yuki Hibiya[27], Hiroshi Hidaka[28], Hisashi Homma[29], Peter Hoppe[30], Gary R. Huss[6], Kiyohiro Ichida[31], Tsuyoshi Iizuka[32], Trevor R. Ireland[33], Akira Ishikawa[25], Motoo Ito[34], Shoichi Itoh[35], Kanami Kamide[7], Noriyuki Kawasaki[13], A. L. David Kilcoyne[36], Noriko T. Kita[37], Kouki Kitajima[37], Thorsten Kleine[38], Shintaro Komatani[31], Mutsumi Komatsu[39,40], Alexander N. Krot[6], Ming-Chang Liu[41], Zita Martins[42], Yuki Masuda[25], Jérémie Mathurin[21], Kevin D. McKeegan[41], Gilles Montagnac[43], Mayu Morita[31], Smail Mostefaoui[9], Kazuko Motomura[44], Frédéric Moynier[17], Izumi Nakai[45], Ann N. Nguyen[46], Takuji Ohigashi[47], Taiga Okumura[32], Morihiko Onose[31], Andreas Pack[22], Changkun Park[48], Laurette Piani[49], Liping Qin[50], Eric Quirico[15], Laurent Remusat[9], Sara S. Russell[51], Naoya Sakamoto[52], Scott A. Sandford[53], Maria Schönbächler[54], Miho Shigenaka[7], Hiroki Suga[55], Lauren Tafla[41], Yoshio Takahashi[32,56], Yasuo Takeichi[56], Yusuke Tamenori[57], Haolan Tang[41], Kentaro Terada[58], Yasuko Terada[59], Tomohiro Usui[24], Maximilien Verdier-Paoletti[9], Sohei Wada[13], Meenakshi Wadhwa[2], Daisuke Wakabayashi[56], Richard J. Walker[60], Katsuyuki Yamashita[61], Shohei Yamashita[56], Qing-Zhu Yin[62], Tetsuya Yokoyama[25], Shigekazu Yoneda[63], Edward D. Young[41], Hiroharu Yui[64], Ai-Cheng Zhang[65], Masanao Abe[24], Akiko Miyazaki[24], Aiko Nakato[24], Satoru Nakazawa[24], Masahiro Nishimura[24], Tatsuaki Okada[24], Takanao Saiki[24], Satoshi Tanaka[24], Fuyuto Terui[66], Yuichi Tsuda[24], Sei-ichiro Watanabe[28], Toru Yada[24], Kasumi Yogata[24], Makoto Yoshikawa[24], Tomoki Nakamura[67], Hiroshi Naraoka[68], Takaaki Noguchi[35], Ryuji Okazaki[68], Kanako Sakamoto[24], Shogo Tachibana[32], and Hisayoshi Yurimoto[13,52]

# Presolar grains in Ryugu

- In addition to particles analyzed for organics, performed systematic searches for presolar C- and O-anomalous grains in two Ryugu thin sections (and Ivuna section)

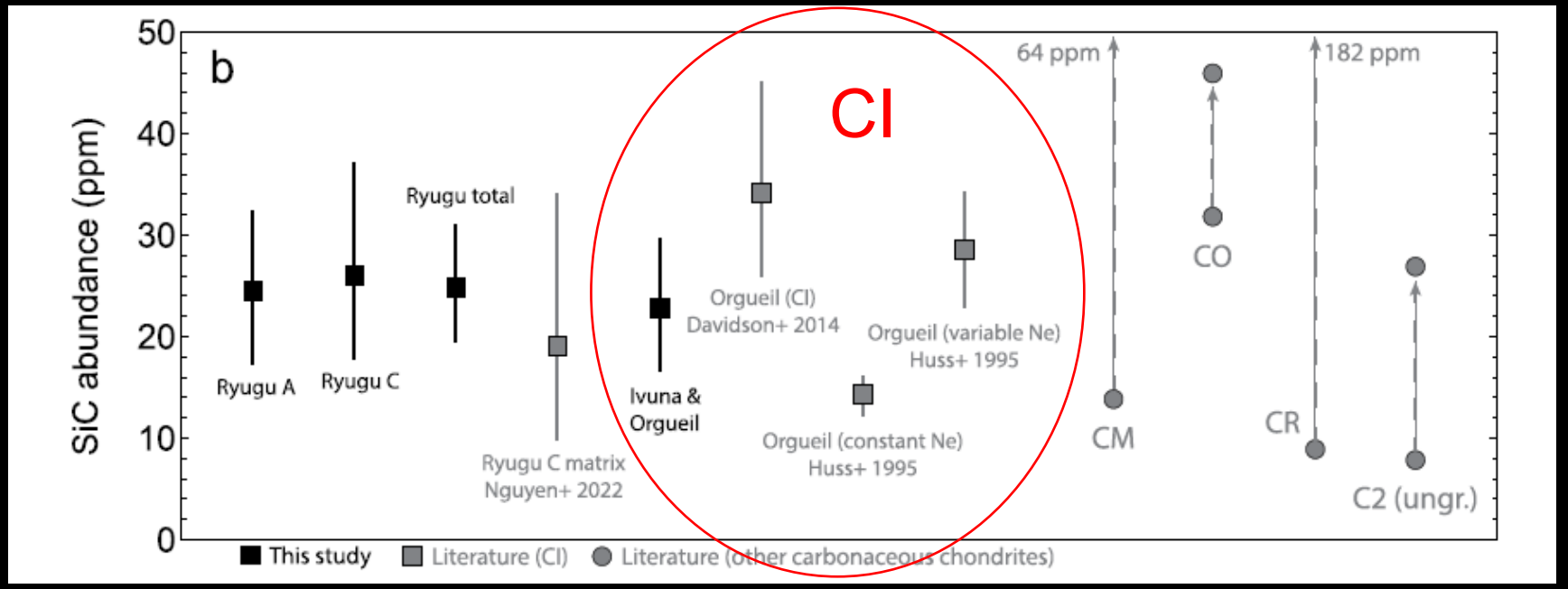



- 3 O-anomalous grains (AGB star and SN origins)
  - At least one silicate!!
  - in less altered area of Chamber C section
  - Low abundance (5 ppm)

# Presolar grains in Ryugu

- Identified 38 SiC and 16 anomalous carbonaceous (graphite or organic) grains



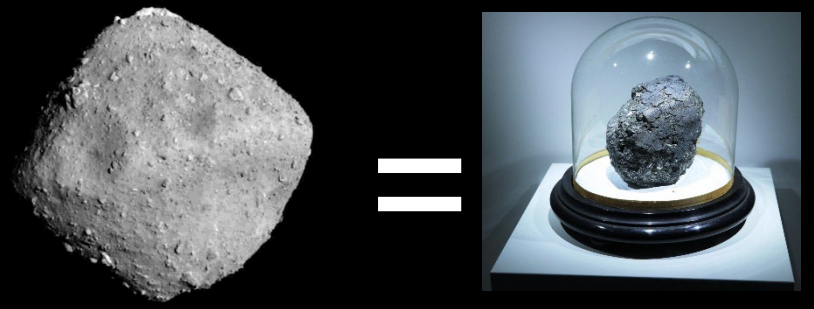

- SiC Abundance in excellent agreement with CI chondrites (this work and literature)
  - Further support for Ryugu-CI connection

# Ryugu open questions

- Why is Ryugu so dark?
  - Darker than CIs, but similar mineralogy, C contents, etc.
- Why did remote-sensing suggest Ryugu is dehydrated?
  - Surface space-weathering effect?
- Why do hydrated Ryugu samples have less $H_2O$ than CI chondrites?
  - Loss due to space weathering?
  - Addition of terrestrial water to meteorites?

# Conclusions

- Initial analysis of samples returned by Hayabusa2 mission reveal asteroid Ryugu to be closely related to CI chondrites
  - Bulk composition, mineralogy, isotopes, presolar grains
  - No systematic differences yet seen between two touchdown sites
  - Most (minor) differences are likely due to terrestrial contamination of CIs, but less altered Ryugu material found (not yet seen in CI)
- 3 wt% organic C, present as discrete sub-μm to μm sized particles and diffuse C associated with phyllosilicates
  - Highly diverse in elemental and isotopic composition, morphology, and functional group chemistry, very similar to that seen in primitive C chondrites.
  - Far, far more to do ….



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- 3
  - p
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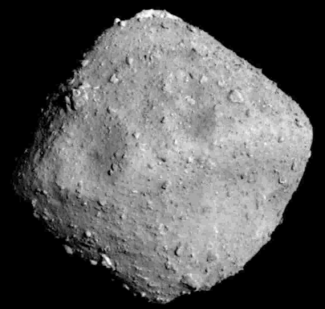
THANK YOU JAXA !!!!



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