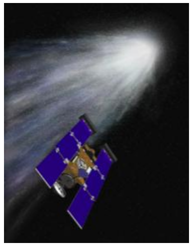


The Power of Sample Return Missions – Stardust, Hayabusa, and Beyond

Scott Sandford, NASA-Ames Research Center, IAU #280, 2011

The Advantages of Sample Return Missions

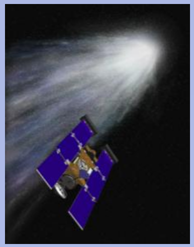
Allows for use of state-of-the-art analytical techniques and equipment, providing for the ultimate current precision, sensitivity, resolution, and reliability

Avoids limitations associated with spacecraft cost, power, mass, and reliability

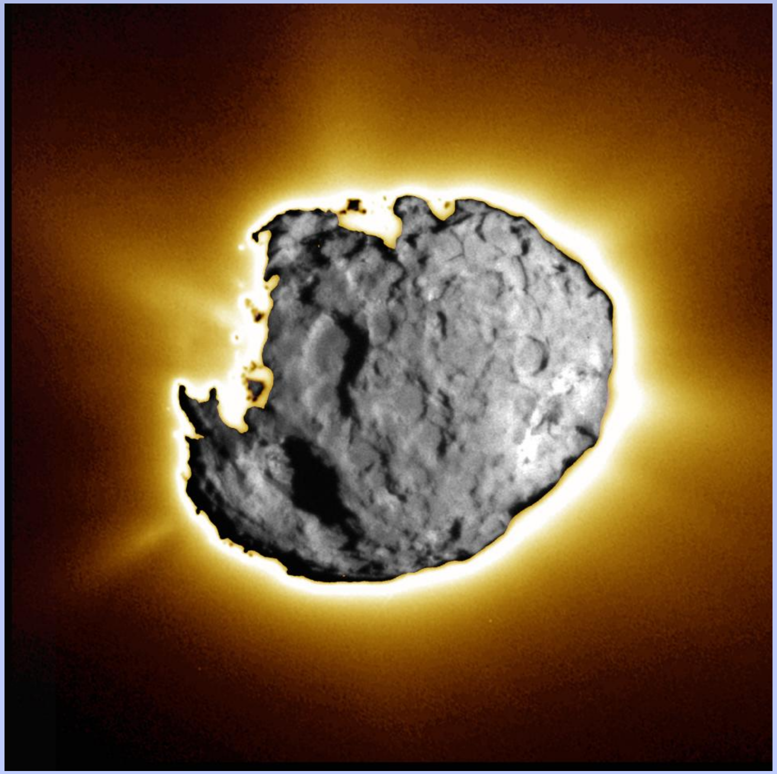
Analyses are iterative and fully adaptive - results are not limited by current ideas

Analyses can be fully calibrated, replicated, verified, done with multiple techniques and instruments, and contamination can be fully evaluated

The returned samples are a resource for current and *future* studies by a broad international community

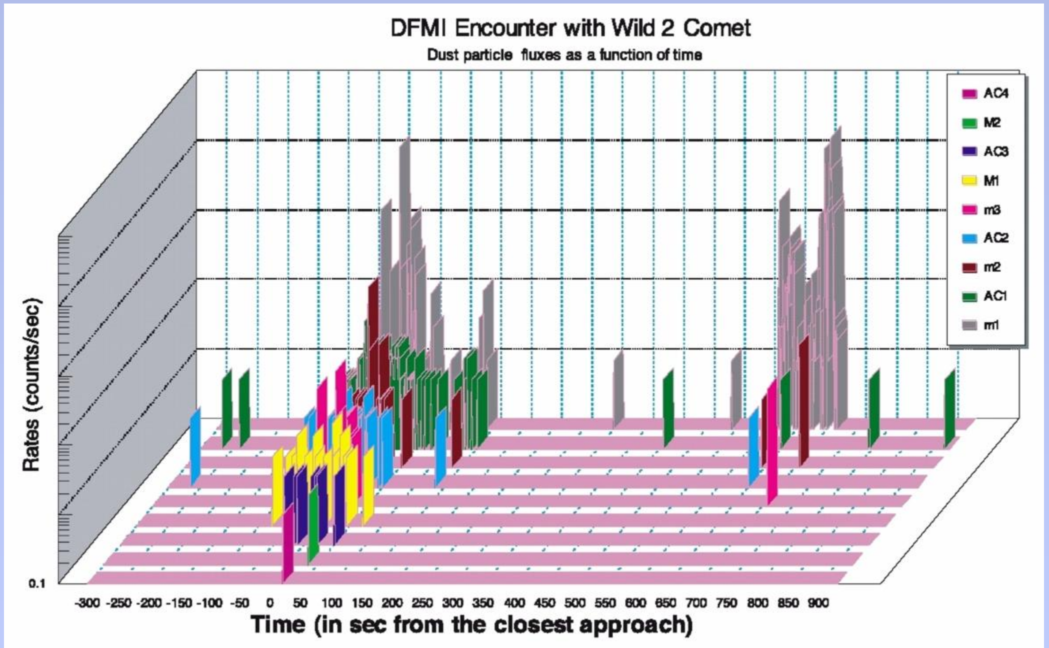


Material was collected as Stardust flew through the coma of 81P/Wild 2



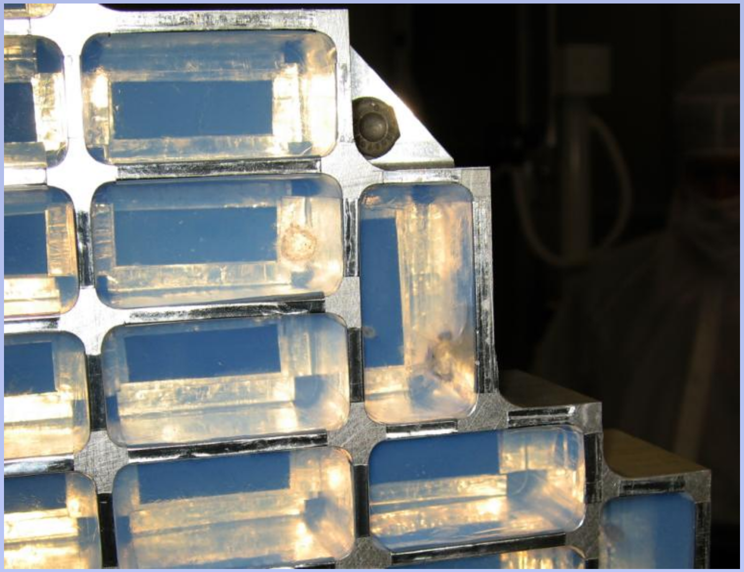
Encounter with Comet Wild 2

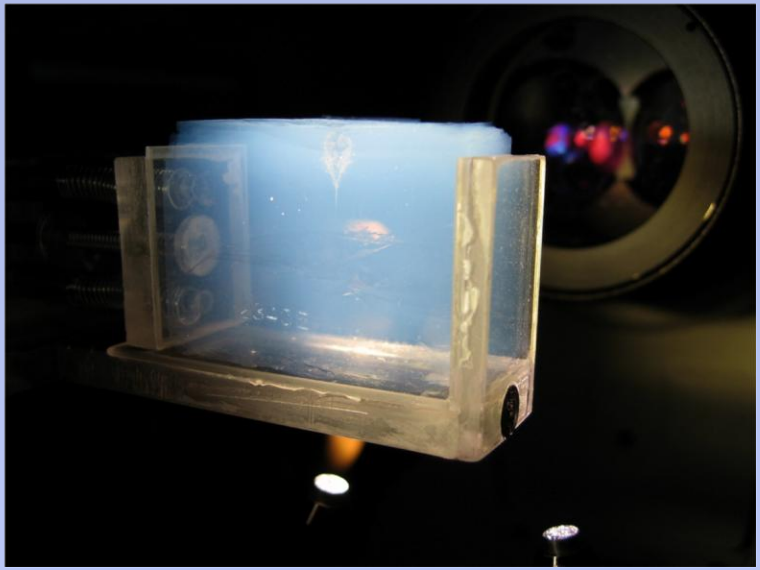
January 2, 2004

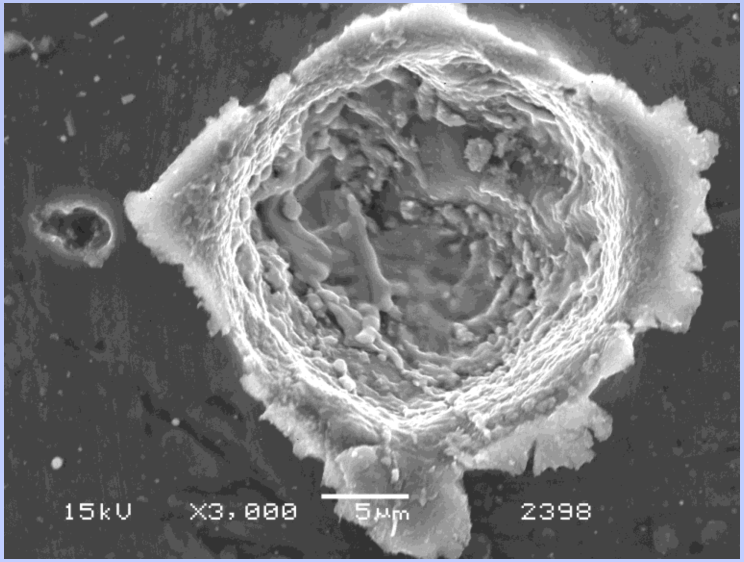


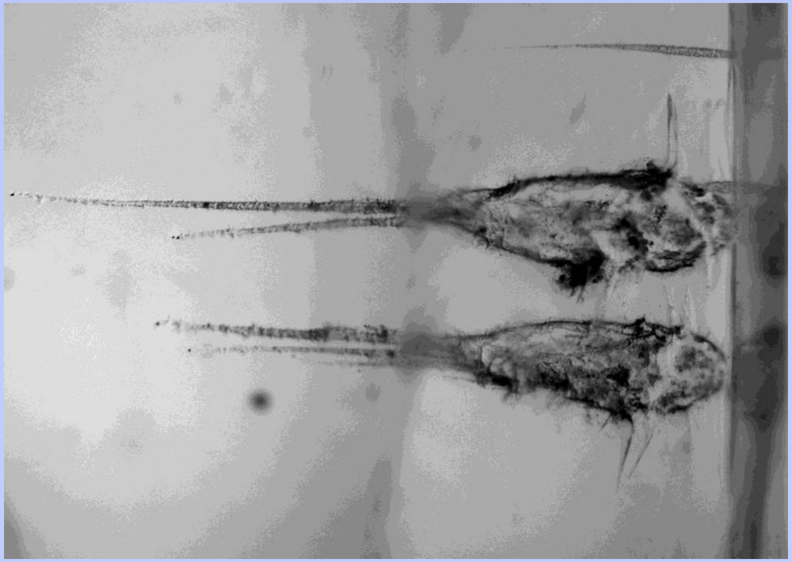
The onboard Dust Flux Monitor recorded multiple dust impacts on the spacecraft. These largely came from two different jets and are believed to be samples that came from some depth.

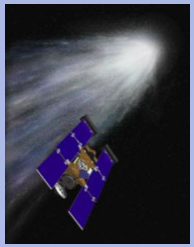
Impacts were seen to exist on the aluminum foils and in the aerogel











Preliminary Examination

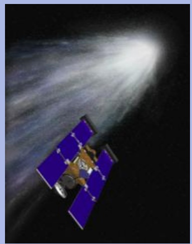
Samples removed from the capsule were studied by a Preliminary Examination Team (PET) of ~175 scientists from around the world who studied the samples using a host of analytical techniques

Initial results of the PET's efforts were published in:

15 December 2006 issue of *Science*

January/February 2008 issue of *Meteoritics and Planetary Science*

As with other collected extraterrestrial samples, additional studies will be ongoing for decades to come and scientific papers on these samples are now being published with regularity in a variety of peer-reviewed publications

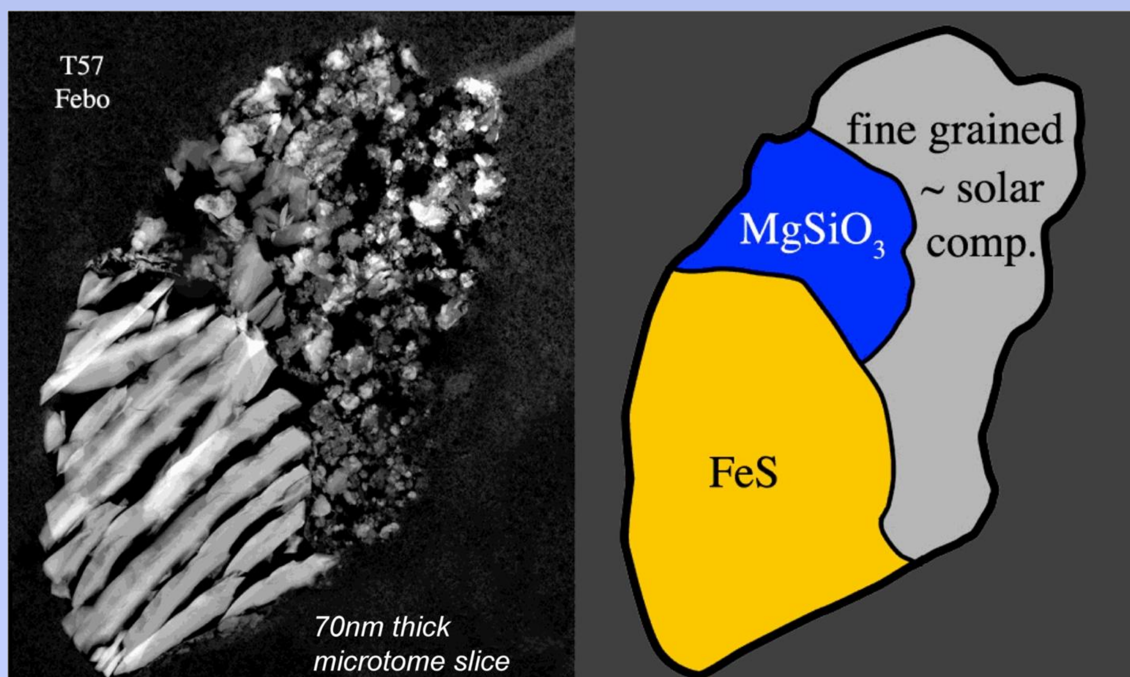


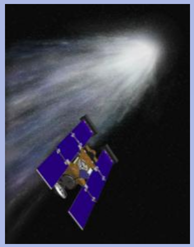
A Brief *Stardust* Top Hits List – #1 – Unequilibrated Materials

Comet 81P/Wild 2 is a repository of largely unprocessed protosolar nebular materials:

(1) **The distribution of minerals and organics (abundance and composition) is heterogeneous both within and between particles - they represent an *unequilibrated* reservoir of materials.**

(2) **This suggests most materials experienced very little parent body processing after incorporation into the comet.**



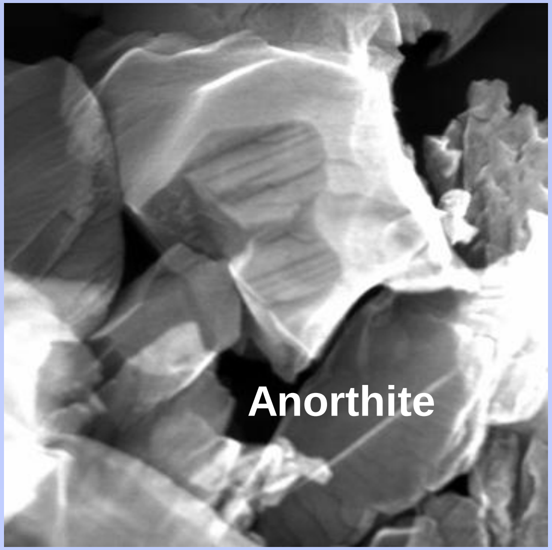


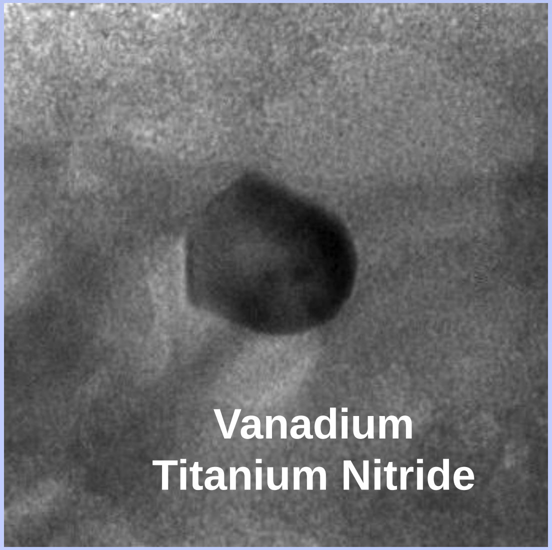
A Brief *Stardust* Top Hits List – #2 – Protosolar Nebular Mixing

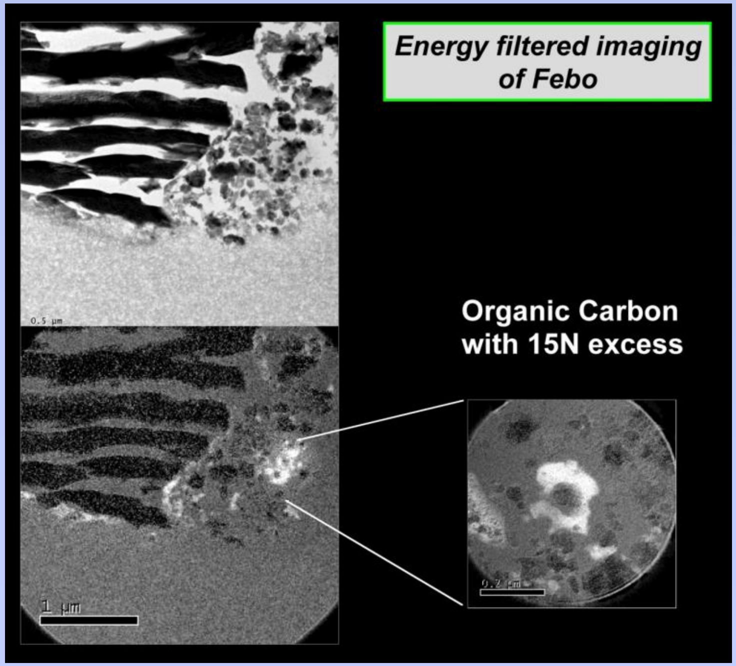
The protosolar nebula experienced mixing that spanned essentially its entire extent *prior* to the formation of the comet:

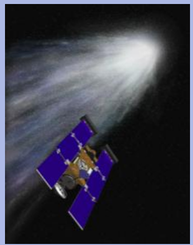
(1)Wild 2 samples contain everything from very high temperature minerals to highly volatile organics.

(2)These various components could not have been made together – some formed near the protosun and others could never have been inside the orbit of Jupiter, and yet they all got together in the comet formation zone.









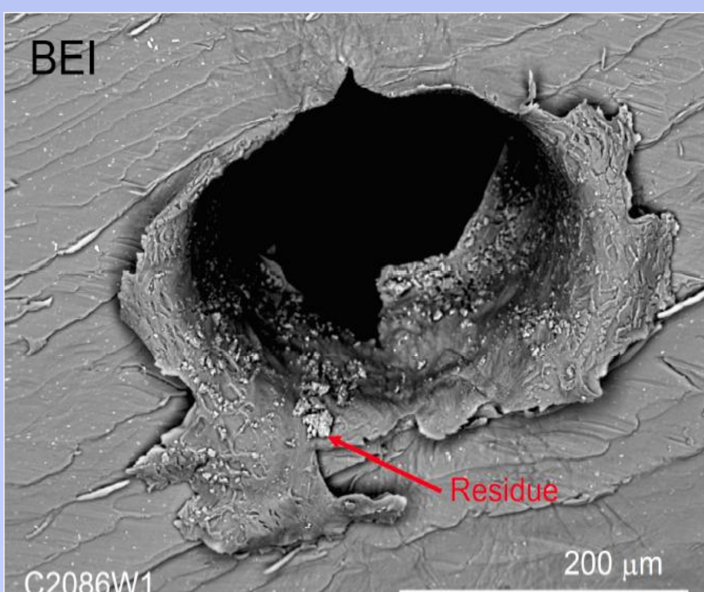
A Brief *Stardust* Top Hits List – #3 – Mostly Protosolar, *not* Presolar

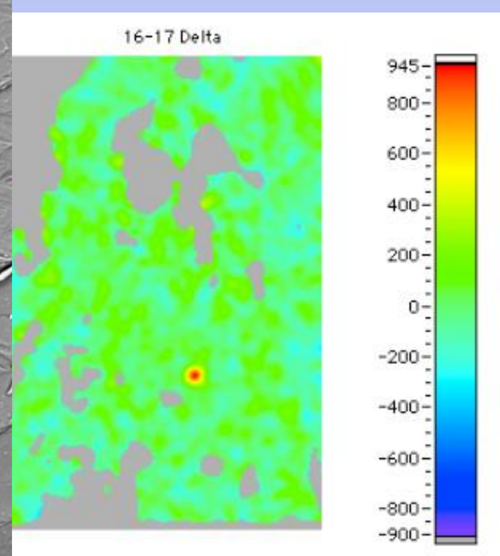
Comet 81P/Wild 2 is not simply an assemblage of presolar (circumstellar and interstellar) materials:

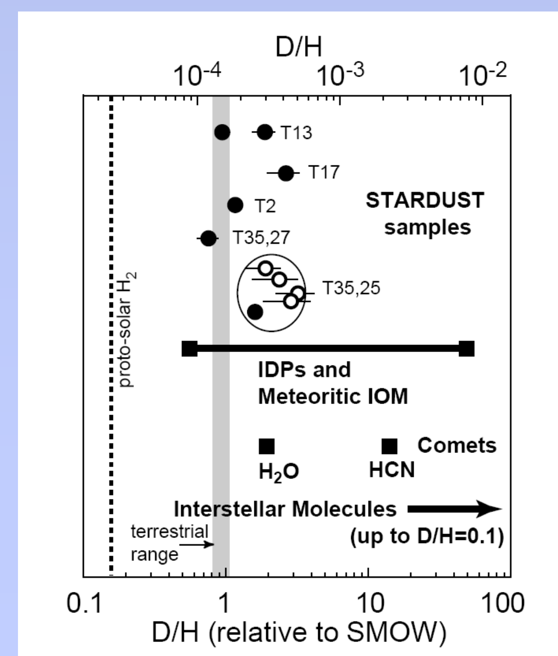
(1) Most of the minerals in the samples are crystalline and look very 'meteoritic' in composition and isotopic composition.

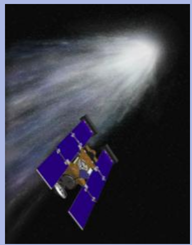
(2) Isotopically anomalous *circumstellar* grains are uncommon.

(3) Interstellar materials are more common - organics having an interstellar-protonebular heritage (excesses of D and ^{15}N) are frequently seen.









A Brief *Stardust* Top Hits List – #4 – Organics are Present and Varied

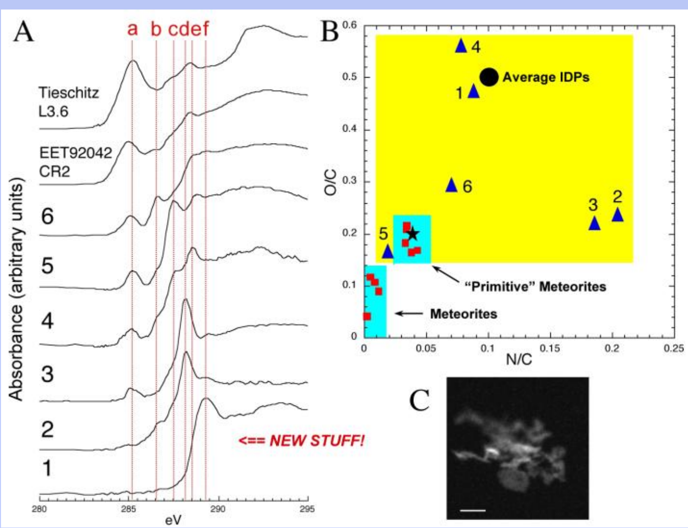
Organics are present and show a large compositional diversity:

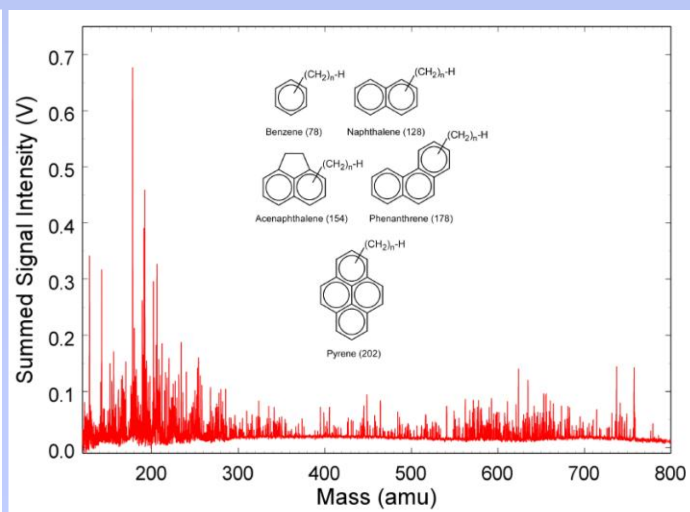
(1) Some organics look similar to the Insoluble Organic Matter (IOM) that dominates the carbonaceous material in primitive meteorites.

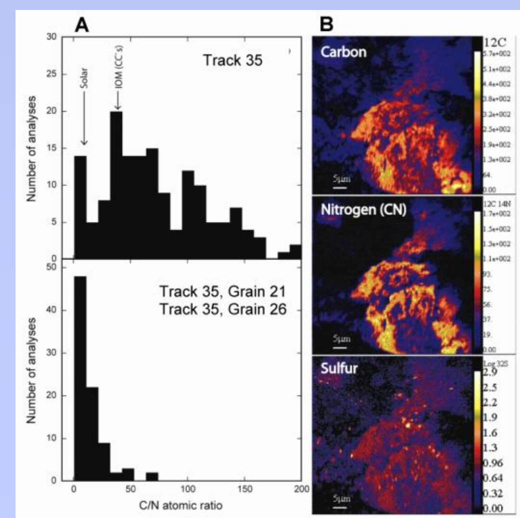
(2) Some organics have a simpler, more aromatic-poor chemistry than the bulk of organics seen in meteorites. Glycine has been identified.

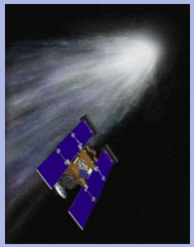
(3) The organics examined so far are generally very rich in both O and N, which are often distributed in a very inhomogeneous manner.

(4) Some of the organics contain non-solar D and ^{15}N excesses.









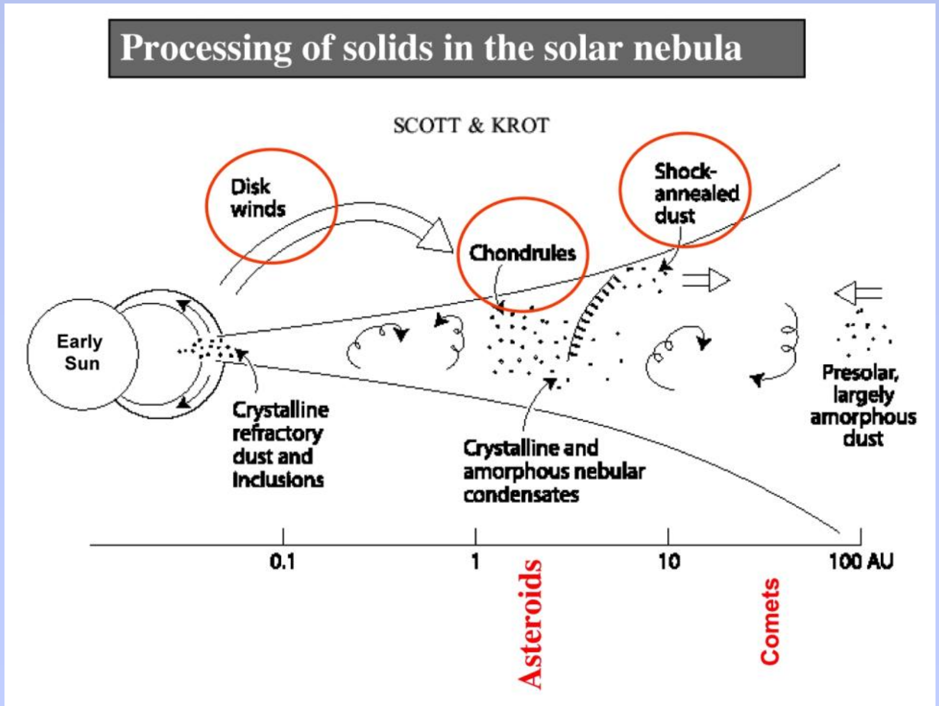
Stardust Top Hits List – Summary

The close association of all these *unequilibrated* phases implies that:

(1) **There was 'A Whole Lot of Mixing Going On' in the Early Solar Nebula.**

(2) **Comets contain materials from the inner *and* outer parts of the protosolar nebula as well as some presolar materials.**

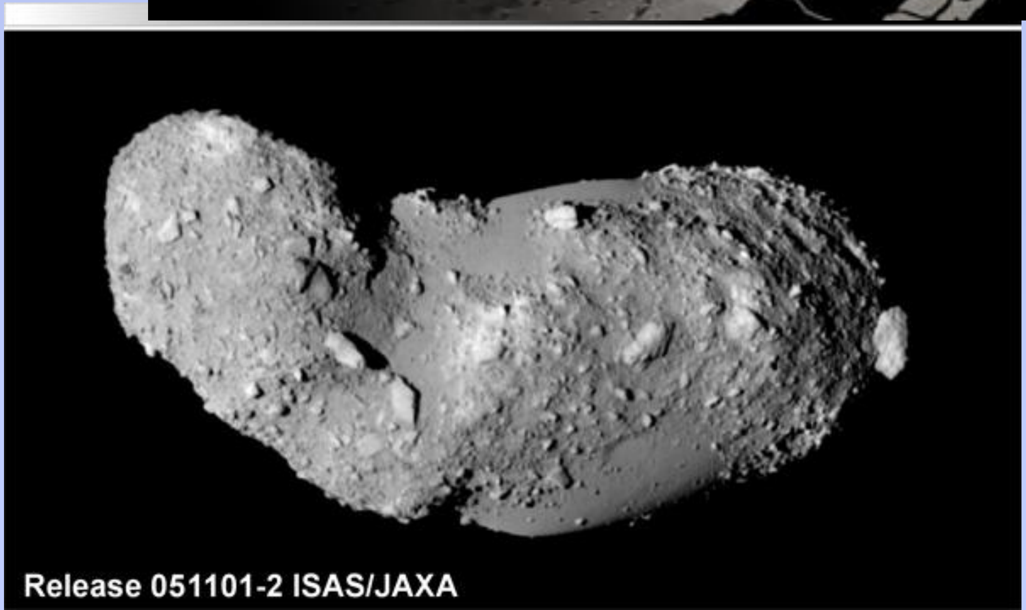
(3) **Most materials were not processed to any great extent after they were incorporated into the comet.**



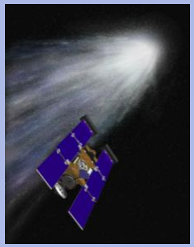
(4) **Wild 2 materials shows no clear affinities with any specific meteorite type, although most of its major compositional components are similar to those found in primitive meteorites.**

(5) **The enormous heterogeneity highlights the dangers of inferring cometary compositions on the measurements of individual species.**

The Japanese Hayabusa ("Falcon") Asteroid Sample Return Mission

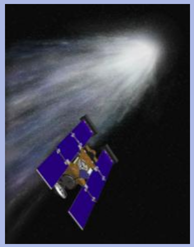


Hayabusa captured samples from the near-Earth asteroid Itokawa and returned them to Earth in June 2010

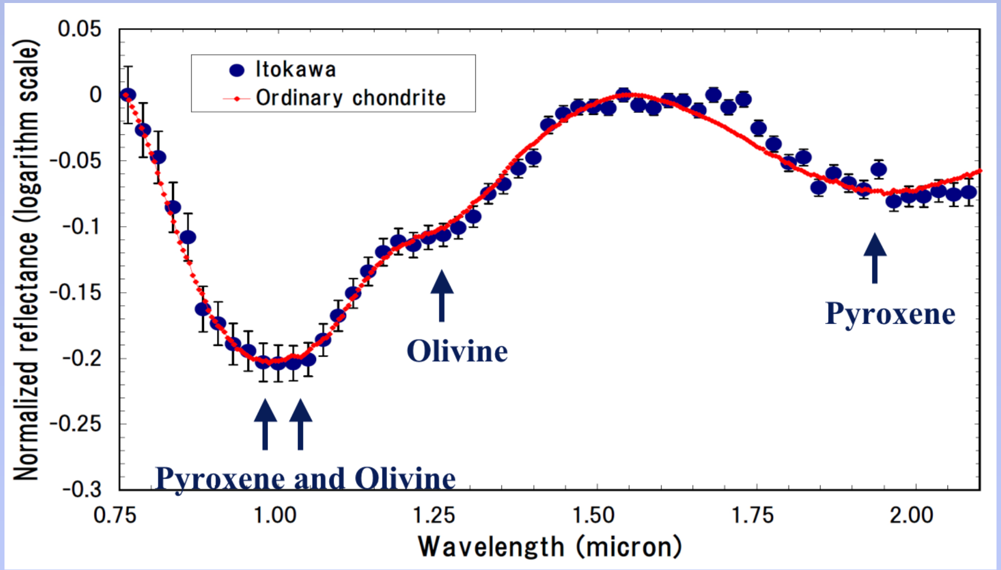


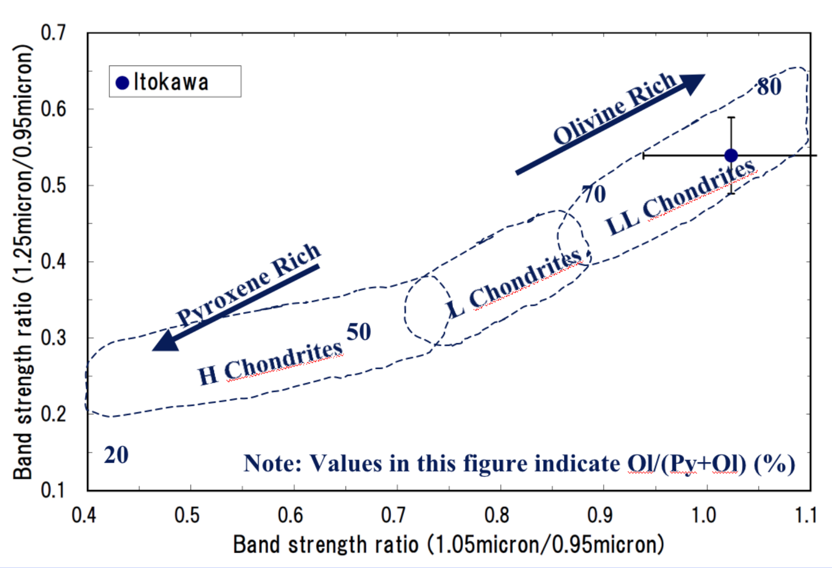
Itokawa is *not* a very large asteroid and appears to be a “rubble pile”

Itokawa (~540 m long) vs The Golden Gate Bridge (2824 m long)



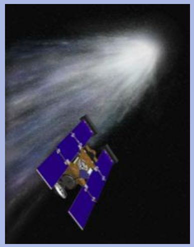
Itokawa's Near Infrared Reflectance Spectrum: A link between S-type Asteroids and LL Ordinary Chondrite Meteorites



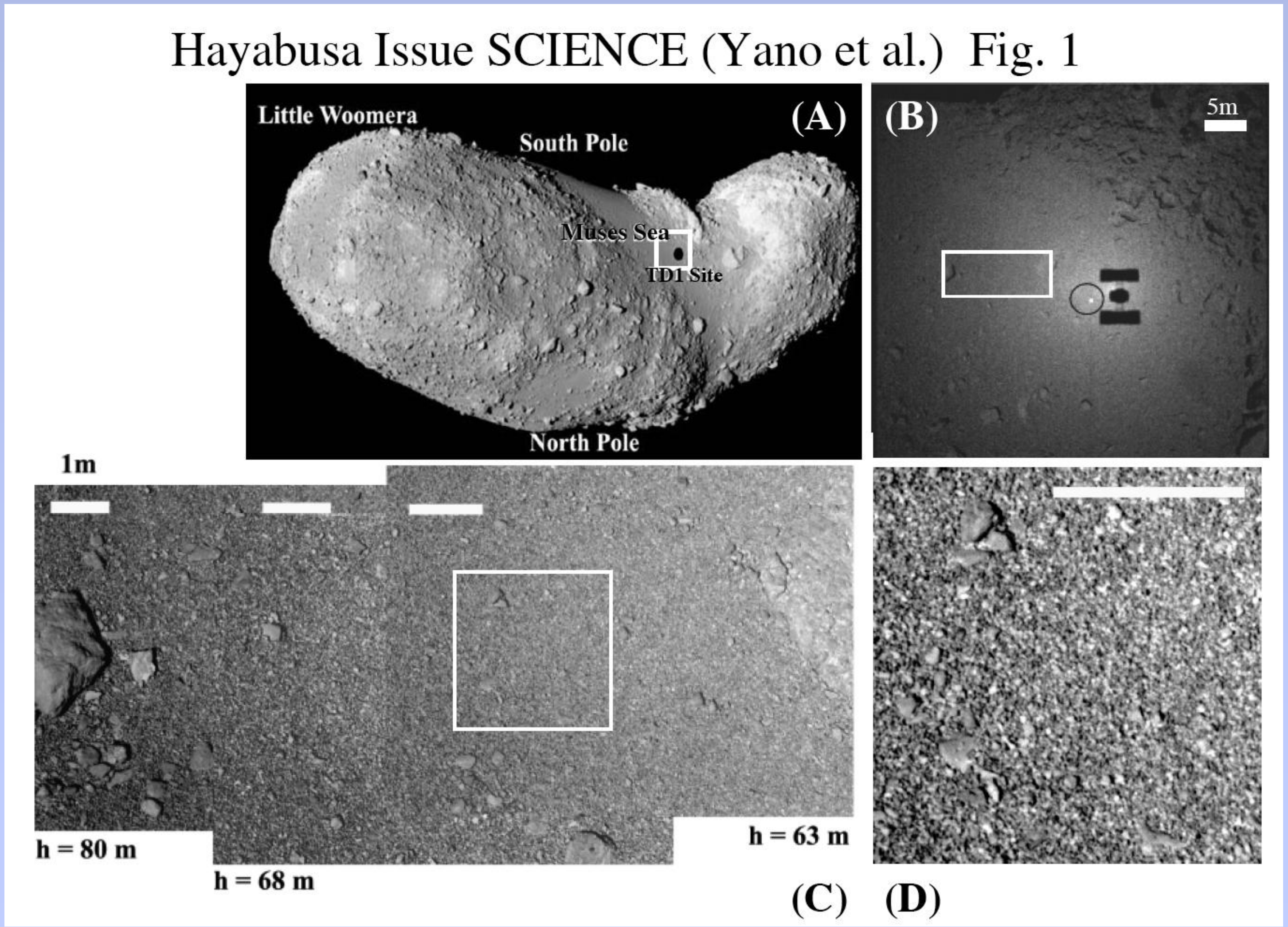


- Spectra indicate the surface of *Itokawa* contains olivines and pyroxenes.
- The reflectance spectrum of *Itokawa* is similar to that of LL ordinary chondrites.

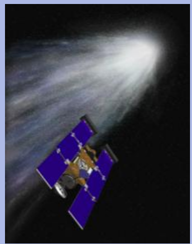
(M. Abe et al., *Science* (2006))



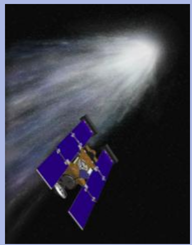
The sample touchdowns in November 2005 didn't go as planned, but some samples were obtained



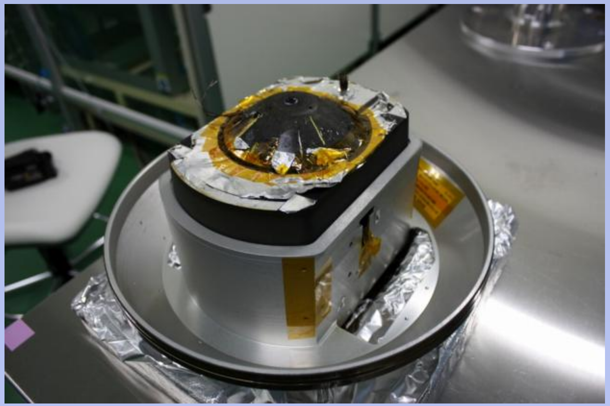
Samples of dust were captured from the "Muses-Sea" region, whose surface is dominated by small gravel.

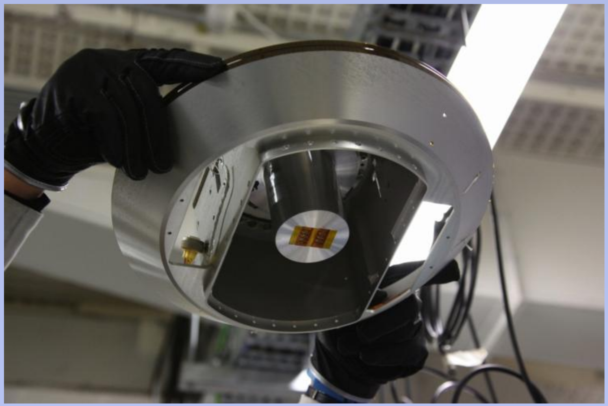


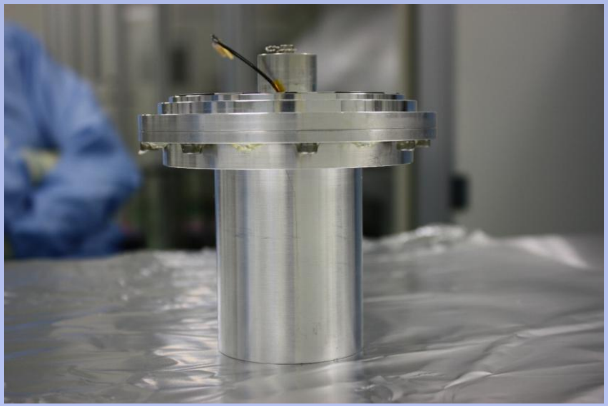
Reentry of the Hayabusa SRC and Shipment to JAXA in Japan for Opening – June 2010

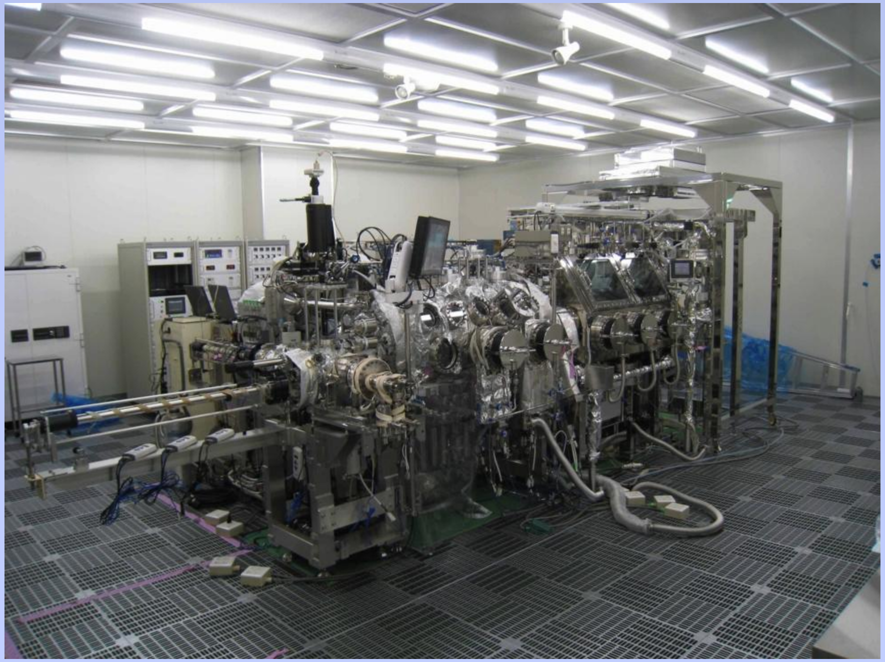


The SRC was unpackaged, disassembled, and then opened in a large vacuum handling system

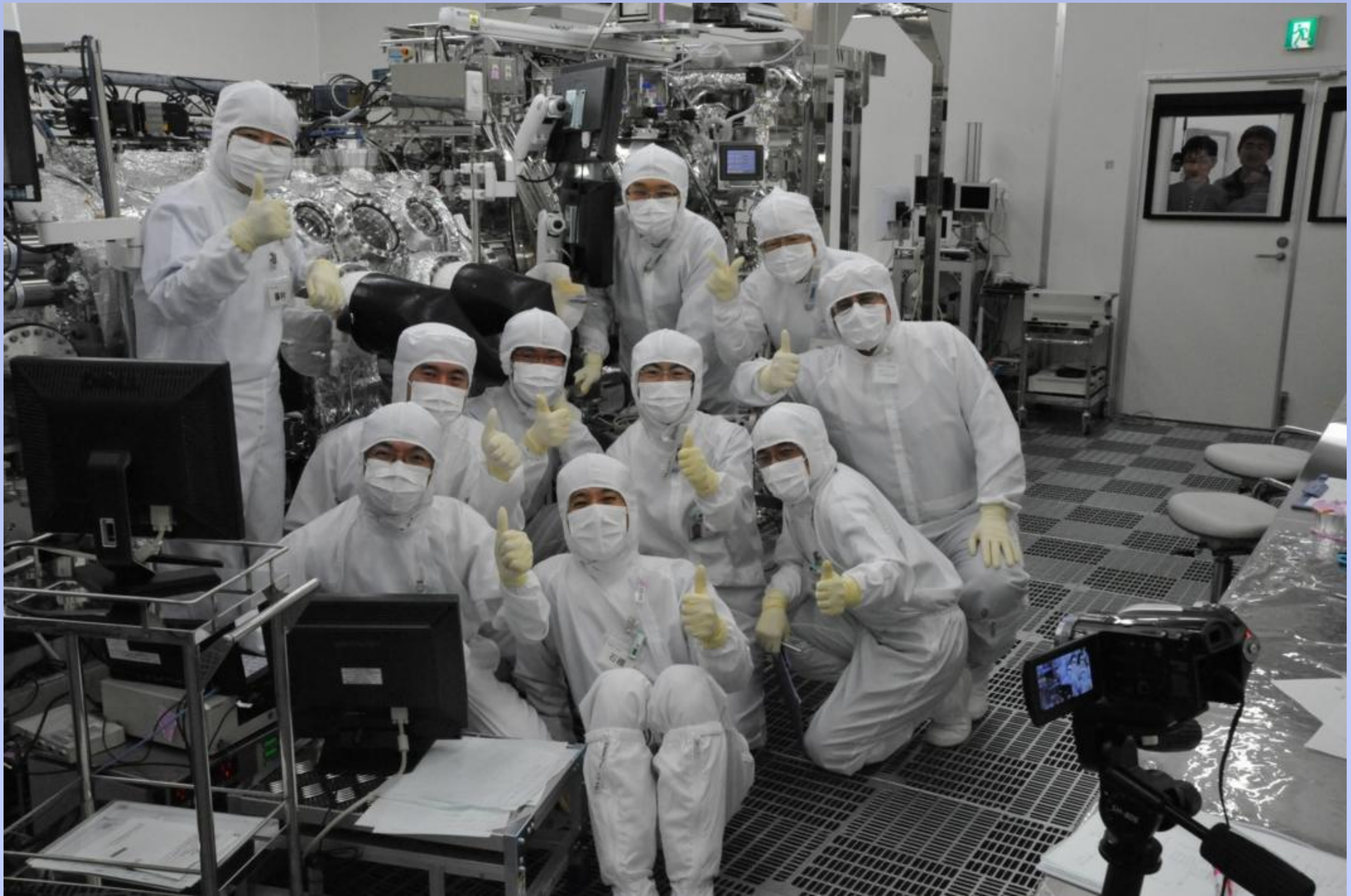


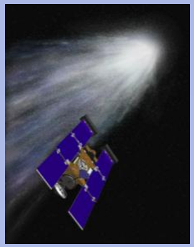






The Victorious Cleanroom Crew after the Opening of the Sample Canister





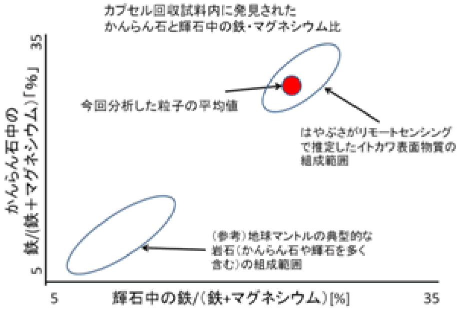
Dust particles have been removed from the sample canister and shown to be asteroidal

添付資料1

はやぶさ帰還カプセルの試料容器から回収された微粒子がイトカワ起源であると判断する根拠

- 回収された約1500個の微粒子の鉱物種(左表)とそれらの存在割合、及び、それら鉱物の成分比率(右図にかんらん石と輝石の成分比率の例を示す)が隕石の特徴と一致し、地球上の岩石と合わないこと。
- 「はやぶさ」に搭載されていたリモートセンシング機器(NIRS、XRS)で推定した表面物質のデータ(右図)と整合すること。
- 回収された試料容器内からは地球上の一般的な火成岩(玄武岩や安山岩やデイサイトなど)の破片が見つかっていないこと。なお、桜島の火山岩はデイサイトである。

今回見つかった鉱物	隕石(普通コンドライト)に存在する鉱物
かんらん石	◎(最も多く存在)
輝石	○
斜長石	○
硫化鉄	○
その他の微量鉱物	○



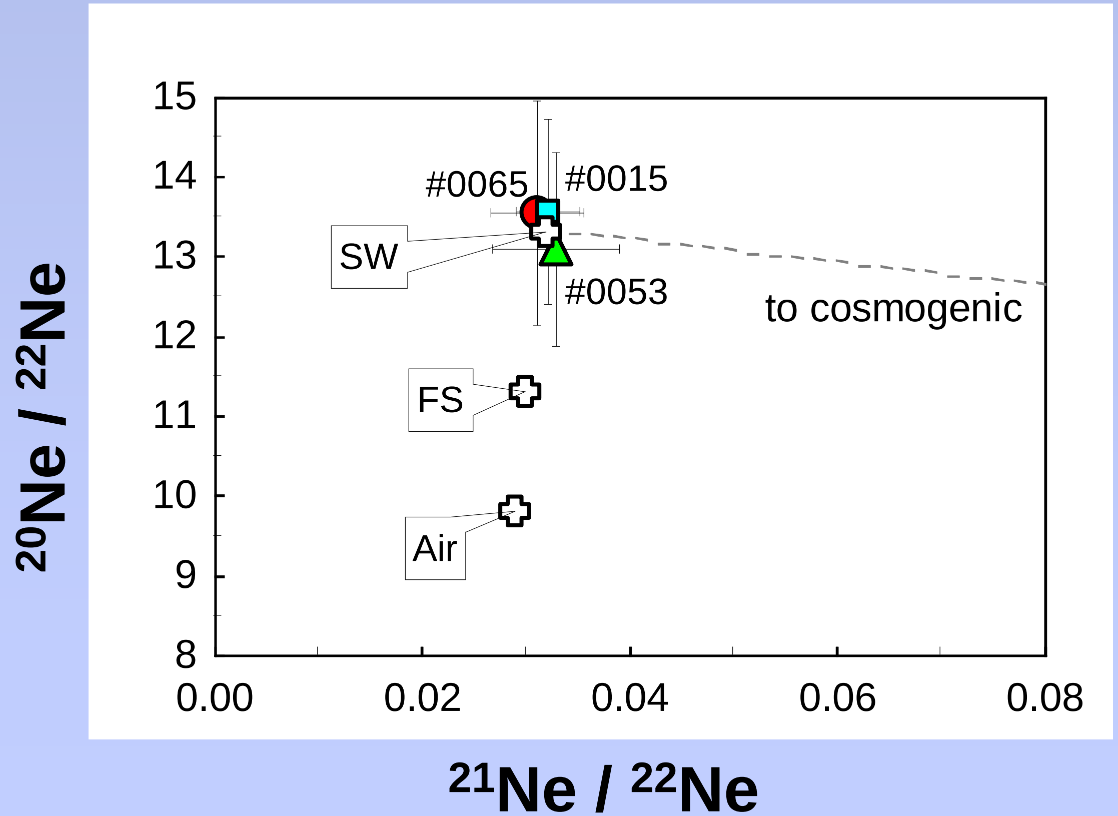
Early SEM-EDX data demonstrated that the dust in the sample canister contained both contaminants and a population of minerals consistent with an LL meteorite parent body origin.

A Brief *Hayabusa* Top Hits List – #1 – Solar Wind Gases

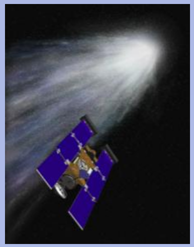
Noble gases extracted from individual grains show the presence of trapped Solar Wind gases:

(1) These are a clear indication of the extraterrestrial nature of the grains.

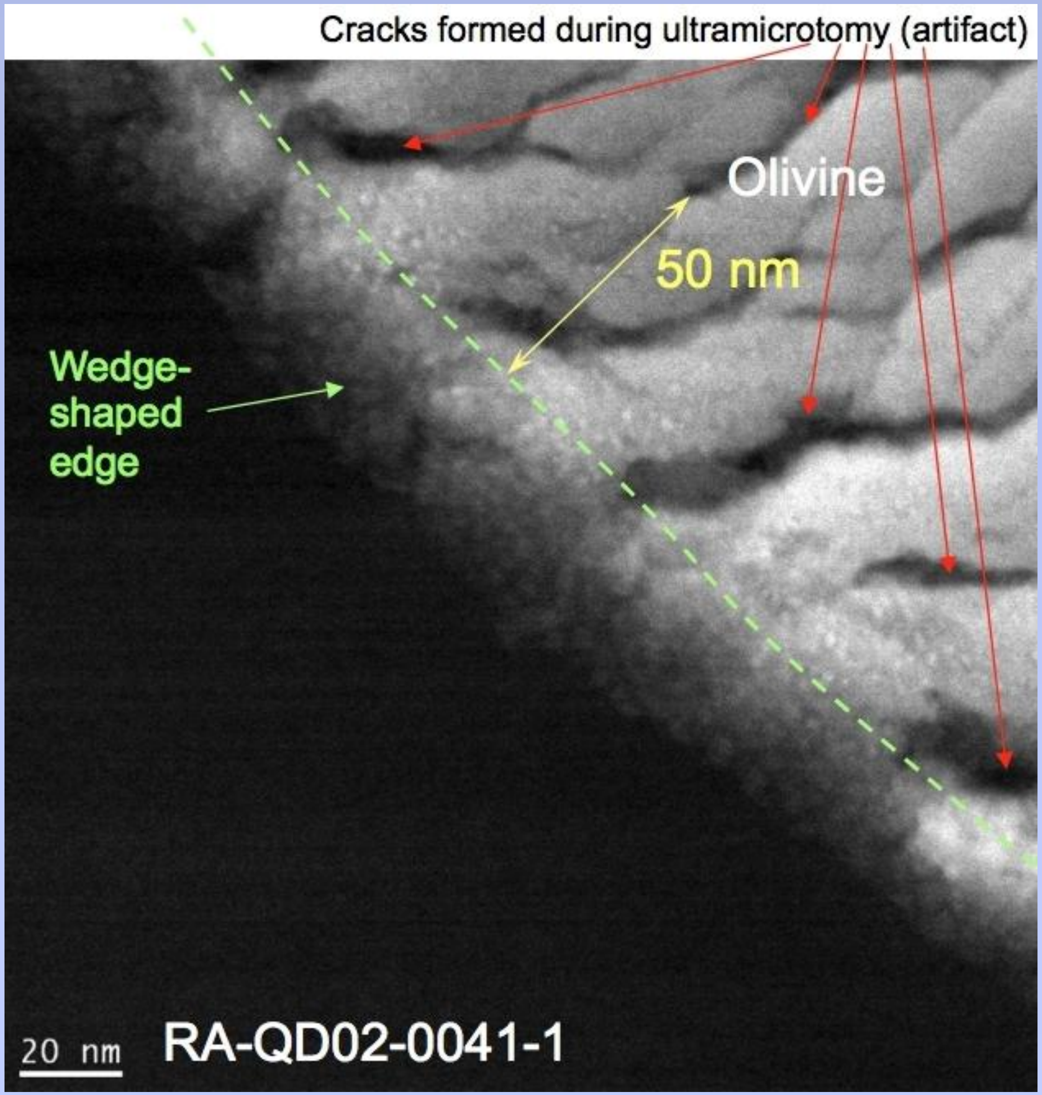
(2) Gas compositions and concentrations imply short exposure ages (<35 My).



Nagao et al.
LPSC 42 (2011)



A Brief *Hayabusa* Top Hits List – #2 – Space Weathering



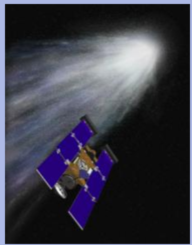
About 50% of the particles examined to date show some evidence of space weathering:

(1) The weathering is thought to be dominated by sputtering by Solar Wind.

(2) The weathered layers are not as ‘mature’ as those seen in lunar soils, implying lower total exposures.

Noguchi et al.

LPSC 42 (2011)



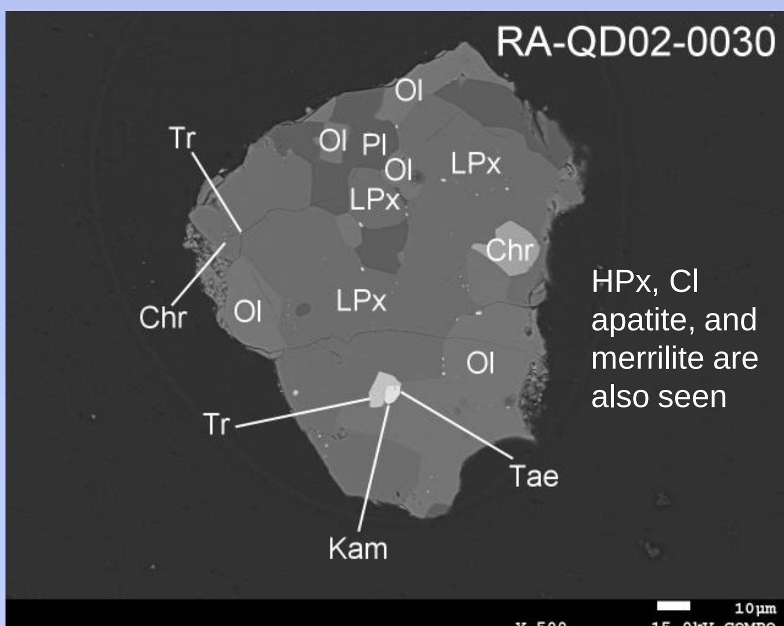
A Brief *Hayabusa* Top Hits List – #3 – Mineralogy

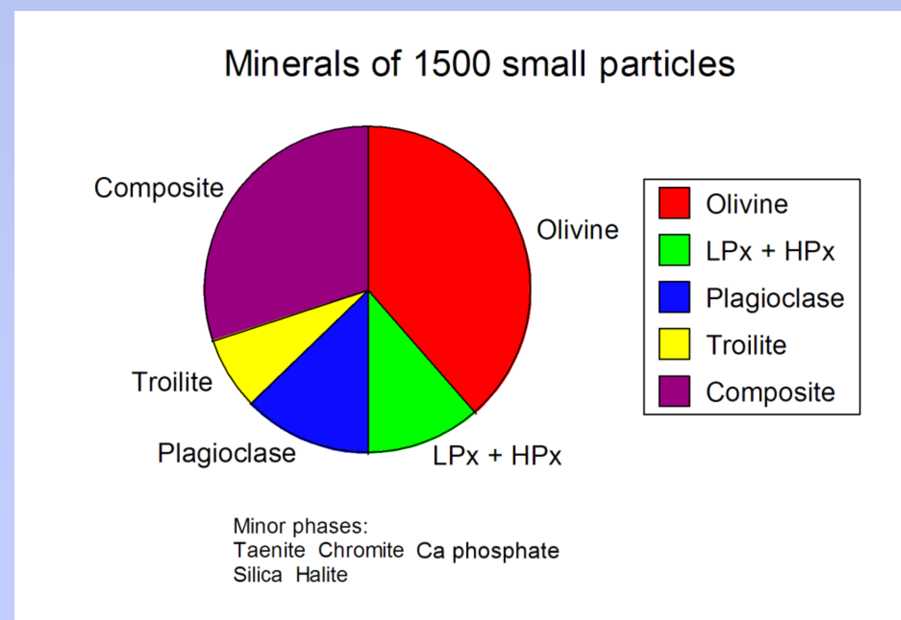
Mineral types, compositions, and relative abundances are a good match to LL Ordinary Chondrites, as are particle densities:

(1) **Particles range from monomineralic to polymineralic.**

(2) **Both poorly- and highly-equilibrated phases are seen (mix is ~ 20% to 80%)**

(3) **Less equilibrated pyroxenes look like those in LL4 ordinary chondrites, but the more abundant highly-equilibrated pyroxenes look more like LL5-6.**





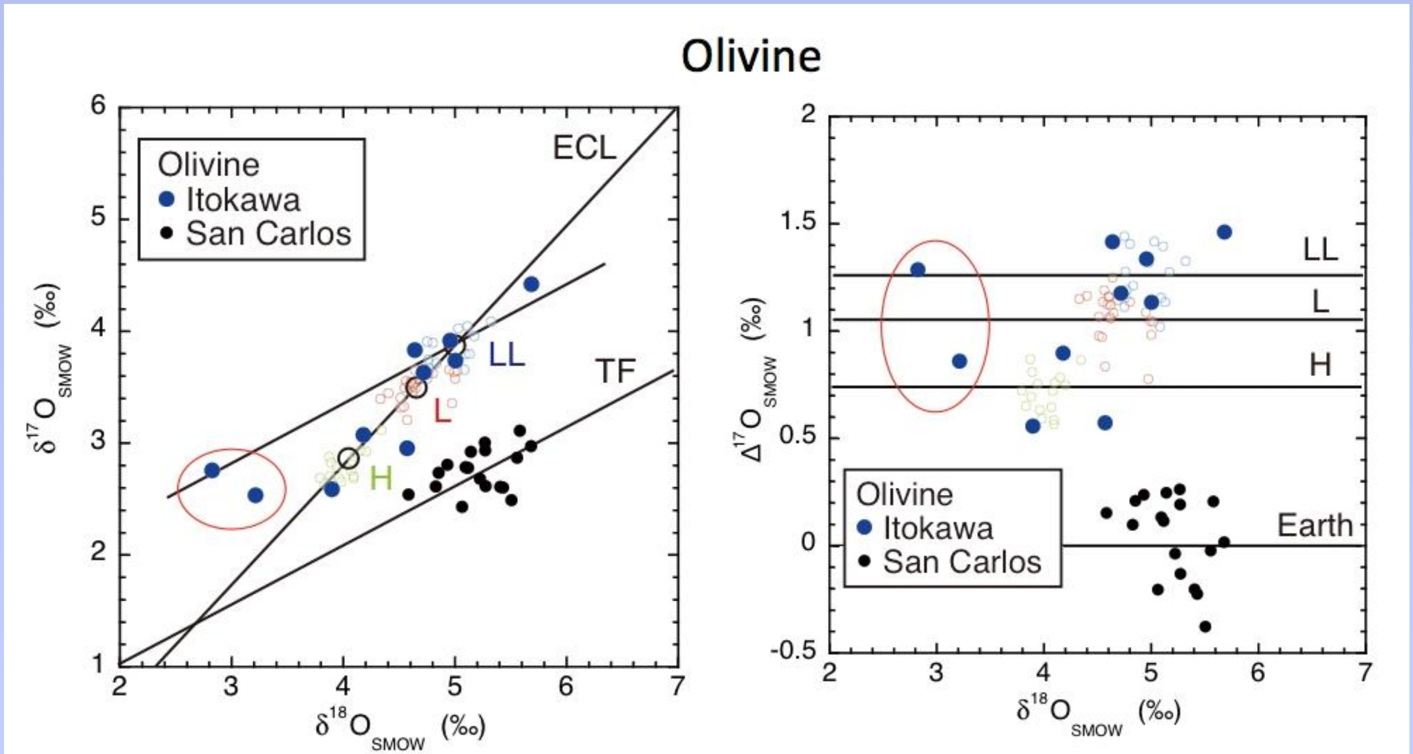
Nakamura et al. & Tsuchiyama et al. - LPSC 42 (2011)

A Brief *Hayabusa* Top Hits List – #4 – Oxygen Isotopes

Preliminary measurements show non-terrestrial O-isotopes:

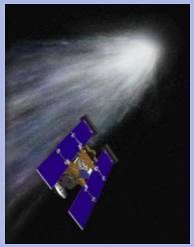
(1) These are a clear indication of the extraterrestrial nature of the grains.

(2) Current data are consistent with ordinary chondrites.



ECL: equilibrium chondrite line   TF: terrestrial fractionation line

Yurimoto et al. LPSC 42 (2011)



Looking to the Future: More Sample Return Missions are Coming

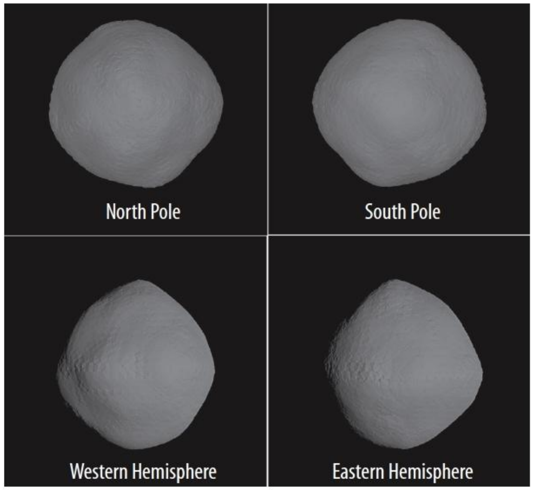
NASA is in the process of selecting its next New Frontiers mission. One of the three ‘semi-finalists’ is OSIRIS-REx, an asteroid sample return mission.

OSIRIS-REx would launch in 2016 and return a sample from asteroid 1999 RQ36 in 2023.

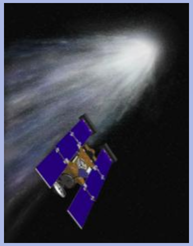
JAXA is already working on Hayabusa 2.

ESA is considering the Marco Polo mission.

Stay tuned!



Ground-based radar observations reveal the shape and rotation state of RQ36.



And remember, returned samples are a legacy that will be used by scientists for generations to come

Even in the absence of new missions, there's still lots of work to be done!

Stowing the Stardust Cometary Tray (or "Scott plays the Aerogel guitar")