

National Aeronautics and
Space Administration



Advanced Curation of Astromaterials

Supporting Future
Sample Return
Missions



JSC's Astromaterials Acquisition & Curation Office

Our past 50 years – planning for and curating multiple collections



Lunar (1969)

Apollo program lunar rocks and soils; Luna samples



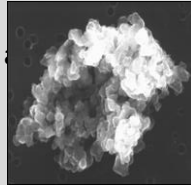
Meteorite (1977)

Antarctic Search for Meteorites (ANSMET) program



Cosmic Dust (1981)

Cosmic dust grains from Earth's stratosphere



Micro-particle Impacts (1985)

Space exposed hardware from spacecraft



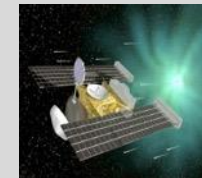
Genesis (2004)

Genesis solar wind samples at Earth-Sun L1 point



Stardust (2006)

Cometary and interstellar samples from Comet Wild 2



Hayabusa (2012 - US)

Samples collected from JAXA asteroid mission to Itokawa



Our Future

Hayabusa II (2020)

Subset of samples collected from JAXA asteroid mission to (162173) 1999



OSIRIS-REx (2023)

Asteroid sample return from 101955 Bennu

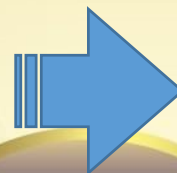


Mars

(~ 2030s +)

Mars Sample Return

Over 50 years in the planning (est. 1964)



Solar System Future Missions

**Asteroids,
Moon, Comets,
Planets and
their moons**



Sample science forms a critical base for planetary science and understanding solar system evolution


- NASA's Johnson Space Center curates all of NASA's extraterrestrial samples – the most extensive set of astromaterial samples available to worldwide research community.
- Our charge is to preserve, protect and provide samples for current and future scientific research, and maintain their scientific and cultural value.
- Sample integrity from each collection is a result of the early partnership between curation scientists and the mission scientists and engineers, a practice started before Apollo



NASA JSC Astromaterials Curation Facilities and Operations



The Astromaterials Acquisition and Curation Office comprises a large complex of labs and supporting infrastructure

- 8 clean room suites and associated laboratories including 22 clean rooms (ISO class 4-7), sample vaults for pristine and return samples, experiment labs, thin section labs, core and saw rooms, precision tool cleaning facilities, UPW, Air handling, filtering and N₂ systems.
 - 45+ year archives (mission & sample documents, living records of all aspects of sample handling) and public database
 - Uniquely trained curatorial and technical staff of ~30
 - Close and continuing coordination with mission and research communities
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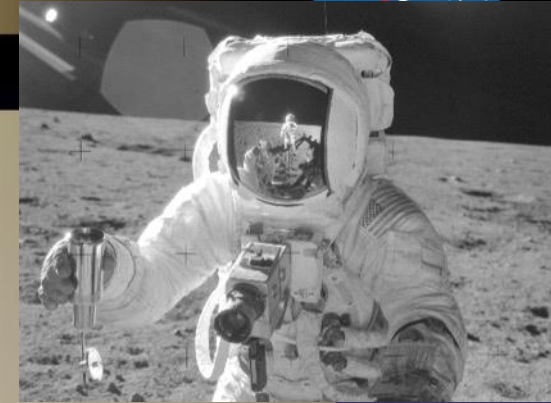
Apollo Lunar Samples: 1969-1972



- 6 Apollo Missions landed on the Moon's surface, returning 382 kg of sample
- We annually distribute >500 samples to science teams

Careful partnerships with mission scientists/engineers and Earth-based clean room operations enabled key discoveries that include fundamental knowledge about the Earth-Moon system and early history of the solar system

- Moon formed through impact of Mars-sized body early in solar system history
- Lunar samples (many > 4 billion years) provide data for earliest Earth history
- Samples record flux of impacts in inner solar system, spiking 3.9 billion years ago. Drop-off in impacts is coincident to beginning of life on Earth
- The Moon contains water



Enabling Groundbreaking Science from the Apollo Missions



- Curation scientists participated in mission design, sampling strategy, tool design, astronaut training, sample return, early processing, and curation
- Lunar lab complex is our largest suite of clean rooms and labs (ISO 5-6)
 - Clean room, storage and working areas designed to minimize contamination from the environment and other samples
 - Preliminary examination techniques, documentation and databases developed to share samples and data with global research community
 - Our labs and protocols have successfully preserved samples for increasingly sophisticated analyses over 45 years, enabling new discoveries.





Key Developments: Apollo Program Isolation Technology



- High Vacuum Complex (F-201 Vacuum Glovebox) & Class III Biological Gloveboxes used behind biocontainment barrier
 - Materials were chosen with emphasis on reducing contamination with low particle shedding and outgassing properties: Stainless Steel (316L and 304), Teflon; Aluminum (6061 and 6063); Viton (fluorinated hydrocarbon); Pyrex Glass
- After Apollo 12, hi vacuum complex replaced with gaseous N2 gloveboxes: Sterile negative P line & non-sterile positive P line
- After Apollo 14, no quarantine requirements (sterile negative pressure N2); only positive pressure gloveboxes were used.
- Today, Lunar samples are handled in positive P gloveboxes in an ISO Class 6 cleanroom environment. The gloveboxes are constructed with 316L stainless steel, polycarbonate and glass windows, Viton seals, and neoprene gloves.



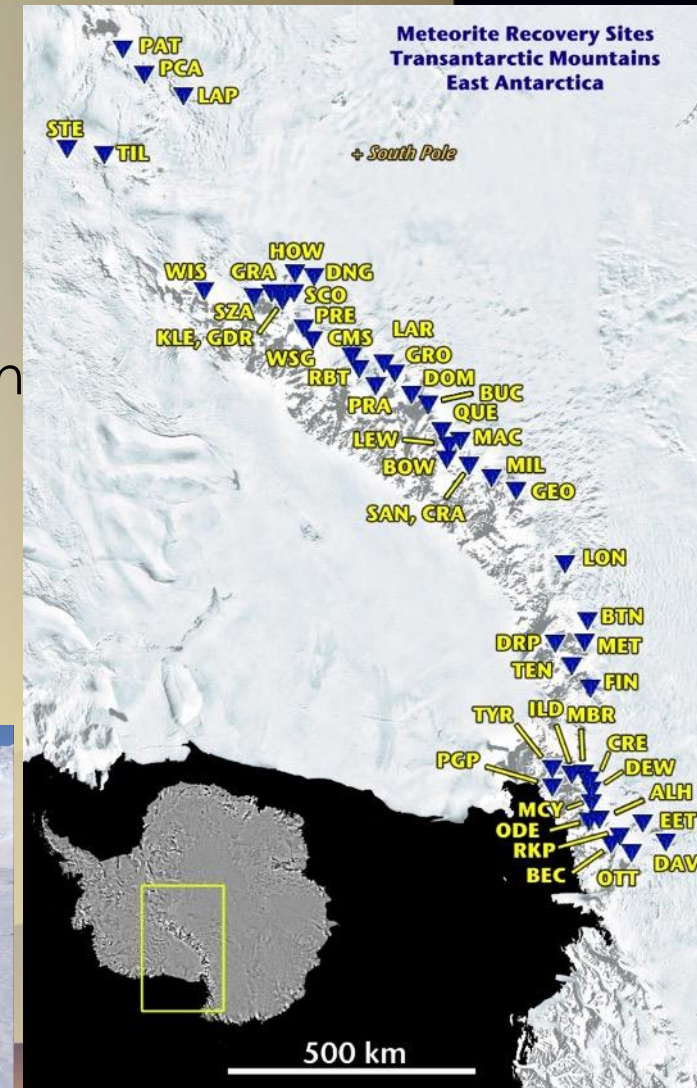
Today's Lunar Lab:
ISO Class 6 cleanroom

Antarctic Meteorite Collection: 1977-Present



Each field season, hundreds of new meteorites are found on Antarctica's blue ice fields

- To date, more than 21,000 meteorites have been collected from the Moon, Mars and more dozens of asteroid bodies
- NASA Curation cleans & assembles field sampling tools, collection bags, tags, and coordinates sample transportation and initial receiving of samples
- Restricted materials and well-developed protocols keep samples uncontaminated at time of collection, contained, and frozen to preserve sample integrity



Antarctic Meteorite Curation



Careful curation of meteorites enable key discoveries

- Martian meteorites – our only samples from Mars – provide a snapshot of Mars history (4.5 billion to 165 MY)
 - Most samples have water in minerals - suggests water was present throughout much of Mars history
 - Key samples for discussion of life existing beyond Earth
- Meteorites are from a rich continuum of bodies – undifferentiated, differentiated planetesimals, asteroids, the Moon and Mars
- Carbonaceous chondrites contain primitive solar system & organic materials.
 - Provide constraints on condensation processes in early solar system
 - Suggest ubiquity of organic materials

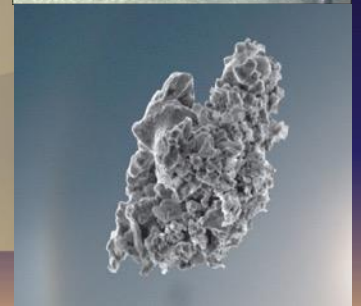


Cosmic Dust from the Stratosphere



Tons of dust grains fall into the atmosphere each day
NASA collects samples on collectors using high altitude aircraft

- Clean room protocols (ISO 5) and specialized sample handling techniques allow isolation and preservation of samples from comets, asteroids, and interstellar dust.
- Collectors are archived as part of the collection
- Cosmic dust curation protocols has required the science community to **develop skills for handling and analyzing very small particles (<<10 microns), enabling missions like Stardust.**
- Key studies provide insight into the nature and abundance of organic matter in primitive bodies in the solar system.



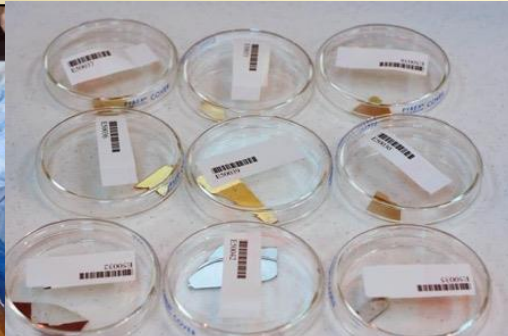
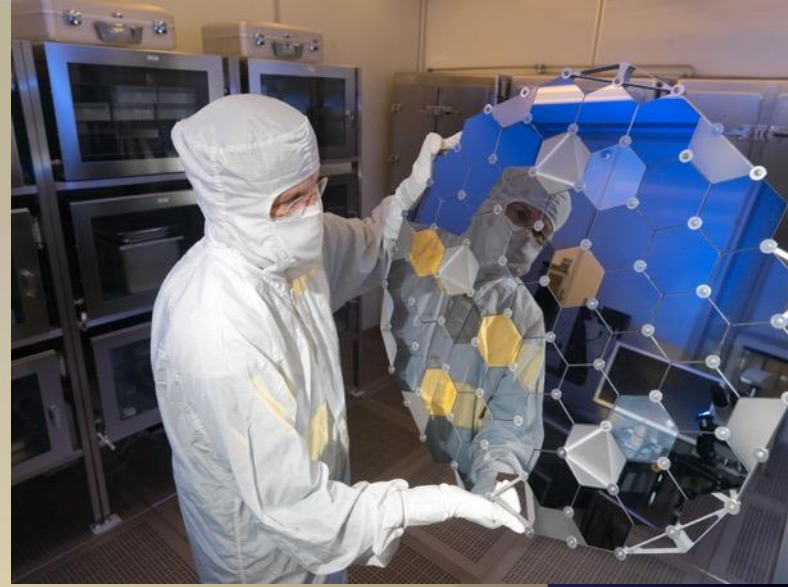


GENESIS Samples from the Sun: Solar Wind Atoms and Ions



Genesis Mission demonstrates key benefits gained from early partnerships between mission team (engineers and science team) and curation scientists including collaboration on materials, cleaning, assembly, documentation & archival.

- Enabled science success despite hard landing
- Solar wind atoms provide a direct measure of solar composition and >99% of solar nebula material at the time of planet formation.
- Results have changed our understanding of early solar system processes – e.g. rocky planets were enriched in heavy oxygen, and Solar nitrogen is more like Jupiter



Key Developments: Genesis Mission Technology



- Cleaned, assembled, closed-out science canister in an ISO Class 4 Cleanroom; used semiconductor grade ultrapure water (UPW)
- Mission planning and design; continued through recovery, receiving, and early science
- Mission Design
 - Collector material purity, cleanliness and variety
 - Thruster plume not in line-of-sight of exposed collectors
 - Re-entry filtration/sorbent during re-pressurization
- Genesis Reference Coupons
 - Enabled critical blanks for measurement of solar wind
 - Extensive cleaning and contamination testing
 - Experimental implants for assessing solar wind loss during surface cleaning
 - Complete environmental history documentation





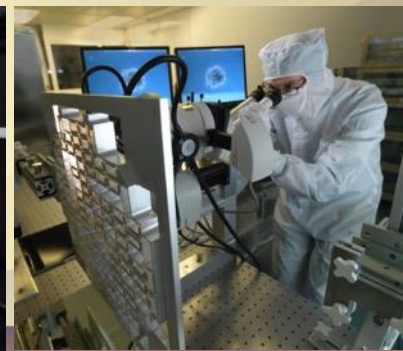
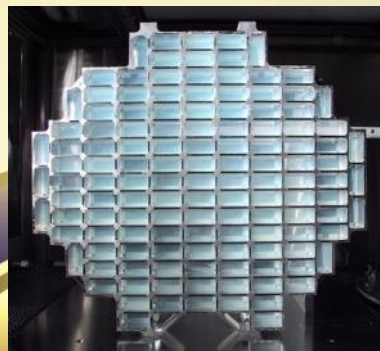
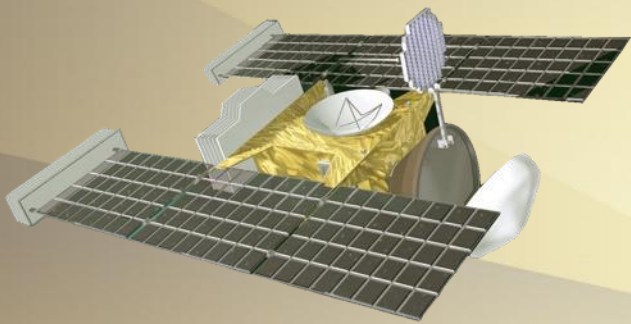
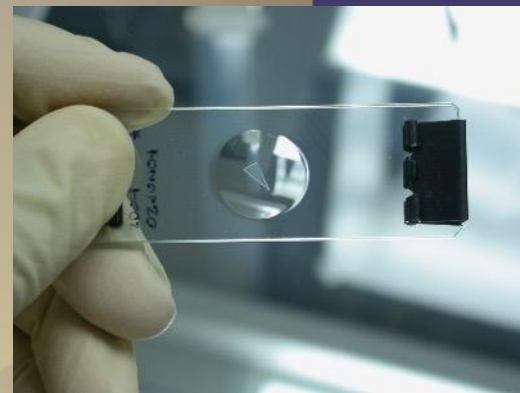
STARDUST Comet & Interstellar Grains: 2 Missions in 1 Spacecraft



Comet particles collected in aerogel collectors
Stardust revolutionized our understanding of the early solar nebula:

- Comet particles have materials formed at high ($>1300\text{ }^{\circ}\text{C}$) & low (-243°C) temperatures, indicating large scale mixing in the early solar system.
- Comet particles are complex with very different minerals similar to chondritic meteorites, suggesting a comet-asteroid continuum.
- We collected **Interstellar particles** from outside our solar system

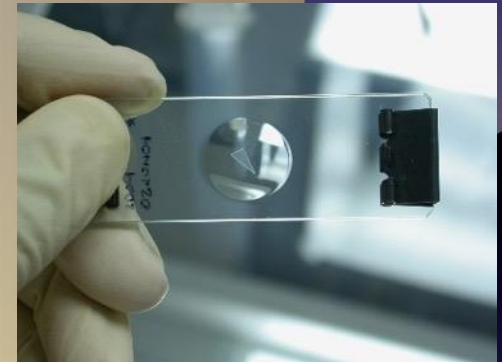
Science success enabled by development of contamination control plan and careful archival of witness plates and materials coupons



Key Developments: Stardust Mission Technology

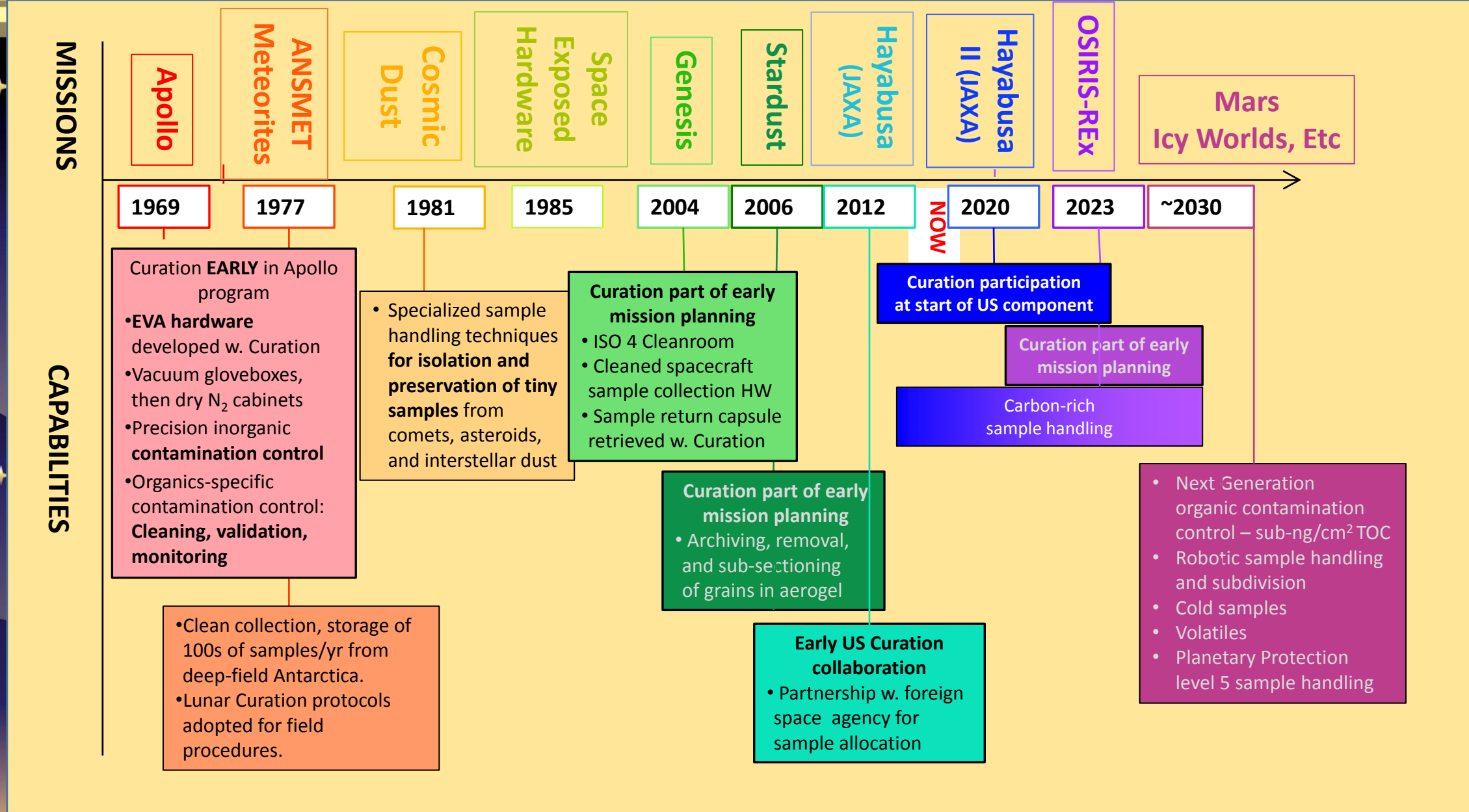


- Assembly of convertible ISO Class 5 cleanroom
- Curation of spacecraft materials for contamination knowledge
- Advanced curation focused on sample handling
 - Detailed imaging of aerogel to locate tracks and particles
 - Extraction by keystoning aerogel with tracks
 - Sample handling and subdivision of extremely small (microns) and fragile samples embedded in aerogel to enable coordinated analyses
 - Subdivision and transport enabled collaborative analyses across disparate laboratories on individual particles
- Techniques leveraged from Cosmic Dust experience and applicable to future small particle collections



Advanced Curation Timeline

Progressive Development of Critical Curation Capabilities





New Initiatives in Astromaterials Curation



- Collaborate with mission teams on new high precision cleaning and validation techniques for sampling materials and witness plates
 - **Adventitious contamination** – especially carbon – is pervasive
 - **Cleanliness is technique dependent:** surface species v. total contaminants in surface volume
 - **Material composition and surface properties are critical**
- Achieving and maintaining increasingly high levels of cleanliness (organic and inorganic) for sampling devices and labs
 - Goal: enable methods of analyses for all elements and all relevant organic species
 - Work to date: baseline lab measurements, including particle counts and compositions; test plan for increased monitoring



New Initiatives in Astromaterials Curation



- Sample handling and containment challenges
 - 10-300 micron handling & precision subdivision procedures are required
 - Robotic sample handling, particulate cross contamination
 - Gas containment and extraction
- Cold curation research
 - Build requirements for cold containment and sample handling
 - Design tests related for preservation and handling of samples at extremely low temperatures ($<-25^{\circ}\text{C}$)

New Initiatives in Astromaterials Curation



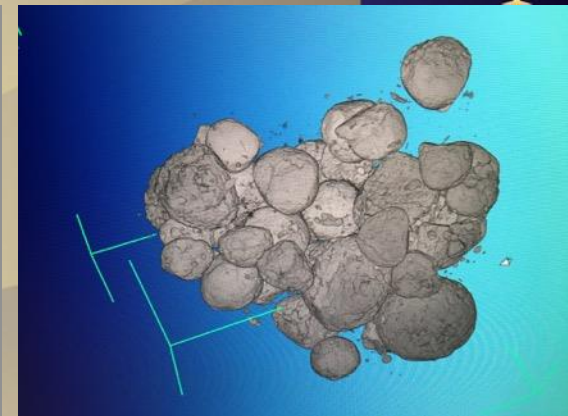
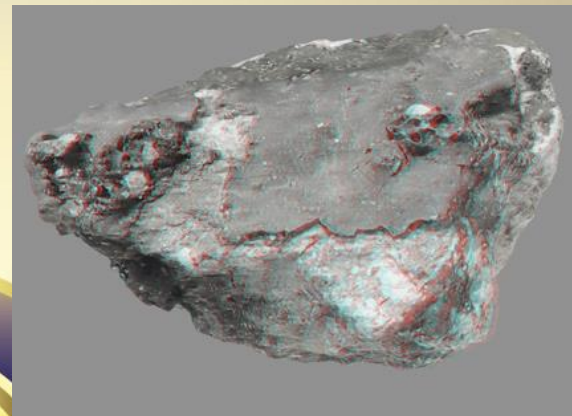
New examination & documentation tools

- Remote lab access - Networked cameras and microscope on Lunar Glovebox
- Non-destructive characterization: Detailed imaging in 3D – visible imaging of external surface and micro-CT imaging of interior



Left: Anaglyph Structure-From-Motion (SFM) 3D reconstruction of Apollo Lunar Sample 60639 produced from the high-resolution precision images. 60 micron resolution.

Right: MicroCT image of bencubbinte meteorite MIL07411,0



New Initiatives in Astromaterials Curation



Serving more and better data

- Curation database upgrades enabling broader access to imagery and meta-data associated with samples (curator.jsc.nasa.gov)

Database Upgrades: New User Interfaces Digital Compendia on Individual Samples High Resolution Imagery: Rocks, Thin Sections, SEM Analytical Data and Data Links

Lunar Sample Catalog (left) and data corresponding to sample (right) in the Lunar Sample Compendium for Sample 15555

reference	Pyler 2001	Pyler 2001	Chappell 73	Nasa74	NORMALIZE Nasa2001
silica	4.014	4.009	43.7	44.8	45.62
SiO ₂ %	44.8	45	43.7	44.8	45.62
TO2	2.3	2.02	2.45	2.08	2.03
Al ₂ O ₃	0.21	0.16	0.3	0.19	0.16
FeO	22.75	21.49	23	21.3	21.98
MgO	0.262	0.275	0.28	0.28	0.29
MgO	11.16	11.32	11.1	11.2	11.26
CaO	0.31	0.47	0.2	0.18	0.22
Na ₂ O	0.238	0.234	0.24	0.28	0.27
K ₂ O	0.042	0.038	0.04	0.04	0.04
PO ₅	0.065	0.063	0.1	0.1	0.08
Σ %					
Σ wt					

Summary of Age Data for 15555

Reference	Age (Myr)	U/Pb	Pb/Pb	Sm/Nd
Chappell et al. 1971	3.94 ± 0.13	Al/Al		
Woodward, Pap 1971	3.32 ± 0.09			
Alwood et al. 1971		3.33 ± 0.09		
Staudt et al. 1971		3.3 ± 0.06		
Maurity et al. 1971		3.22 ± 0.09		
Probst et al. 1971		3.21 ± 0.09		
Yokoyama et al. 1972		3.31 ± 0.05		
Chappell et al. 1972		3.34		
Papamarcou, W 1973		3.32 ± 0.06		
Bank et al. 1973		3.34 ± 0.09		
Tanaka et al. 1973			3.3 (and 4.45)	
Tera and Wasserburg 1976			3.3 (and 4.42)	
Andersen and Hildebrand 1978				3.38 ± 0.06
Nippa et al. (1990)				3.22 ± 0.04
(this)				3.41 ± 0.02

Caution: These ages have not been updated using new decay constants.

Apollo sample 15555 photo micrographs

Compositional data for Apollo sample 15555

- Data recovery of legacy Lunar datasets, host these on database with access to IEDA/Earthchem/PetDB tools (www.earthchem.org)



Advanced Curation Elements for Mission Success



- **NASA's Astromaterials Acquisition & Curation Office has 5 decades of mission experience**
 - End-to-end mission support and successful planning
 - Archival of diverse collections of astromaterials and associated hardware.
- **Curation supports mission science, engineering & operations**
 - Ensure that sampling and contamination concerns for any sample return mission are understood and integrated into a design with materials selection, seals and containment, precision cleaning, assembly and operational scenarios.
- **Future mission challenges require new technologies**
 - High precision cleanliness (new materials – new surfaces),
 - Sample collection-preservation-handling at low temperatures,
 - Preservation and subdivision of volatiles,
 - Precision sample subdivision of micron and sub-micron particles,
 - Possible collection and curation of samples from destination that could harbor life.

NASA's Advanced Curation R & D Directions



Inorganic Cleanliness

Knowledge Gap: achieve and maintain high levels of inorganic cleanliness across the periodic table

Partnership Opportunities:

- High-precision cleaning, validation methods
- New materials that are easy to clean
- Keeping materials clean



Sample Handling

Knowledge Gap: study handling; containment of astromaterials

Partnership Opportunities:

- Particulate & cross-contamination research (organic/inorganic) contamination control
- Precision sample subdivision

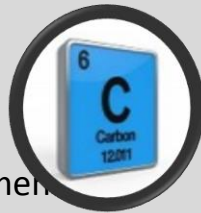


Organic Cleanliness

Knowledge Gap: achieve and maintain high levels of organic cleanliness – below 1 ng/cm².

Partnership Opportunities:

- High-precision cleaning & validation methods
- Cleanliness preservation
- Organic species detection/measurement
- Microbial identification, curation, biocontainment



Robotics / Sample Handling Tech

Knowledge Gap: robotic sample handling solutions to control inorganic /organic contamination, planetary protection requirements, extreme environments

Partnership Opportunities:

- Robotic and astronaut handling hardware
- Automated robotic sample handling
- Short & long-term sample containment
- Transport containers in space and on-Earth



Cold Curation

Knowledge Gap: collect samples that have been preserved at sub-freezing or even cryogenic temperatures.

Partnership Opportunities:

- Cryogenic curation at 40 K
- Low Temperature curation at – 25°C
- Working with small particles at low T



Mission Ops / Spacecraft Design

Knowledge Gap: curation requirements for spacecraft HW, mission operations – materials, design, and ops procedures for maintaining contamination control.

Partnership Opportunities:

- Sample handling/collection/containment
- Sample return capsule (SRC) development

