Lunar Missions and Datasets

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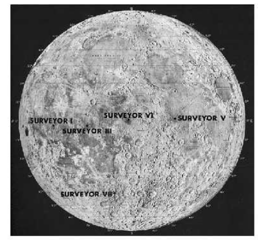
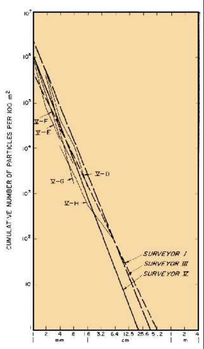
Surveyor

- Surveyor I
  - Launch: 30 May, 1966
  - Landed: 2 June, 1966, 06:17:37 UT
  - Flamsteed P (2.45°S, 316.79°E)
  - Sun elevation 28°
- Surveyor III
  - Launched: 17 April, 1967
  - Landed: 20 April, 1967, 00:04:53
  - Oceanus Procellarum (2.94°S, 336.66°E)
  - Sun elevation 11°
- Surveyor V
  - Launch: 8 September, 1967
  - Landed: 11 September, 1967, 00:46:44 UT
  - Mare Tranquillitatus (1.41°N, 23.18°E)
  - Sun elevation 17°
- Surveyor VI
  - Launch: 07 November, 1967
  - Landed: 10 November, 1967, 01:01:06 UT
  - Sinus Medii (0.46°N, 358.63°E)
  - Sun elevation 3°
- Surveyor VII
  - Launch: 07 January 1968
  - Landed: 10 January 1968, 01:05:36 UT
  - Tycho Crater North Rim (41.01°S, 348.59°E)
  - Sun elevation 13°



Surveyor Summary

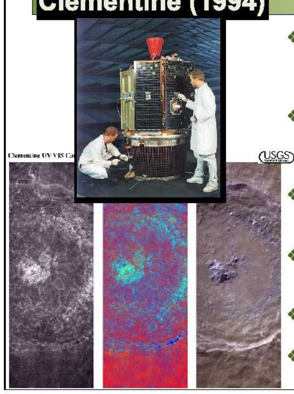
- 3-18% occupied by fragments > 1mm
- Greatest number of fragments at Surveyor VII
  - fragments >1 mm cover 18%
  - fragments >10 cm cover 10%
  - order of magnitude more frequent than at V and VI sites
- Rounded isolated large blocks embedded in regolith
- Angular blocks are typically brighter than surrounding regolith



Galileo

- Primary mission to explore Jupiter and its satellites, but Moon flybys on Dec. 8, 1990 and Dec. 8, 1992.
- Multi-spectral imaging in Vis-NIR

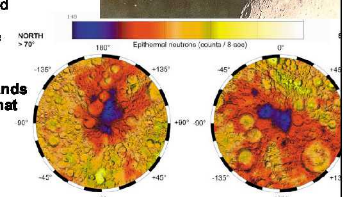
Clementine (1994)



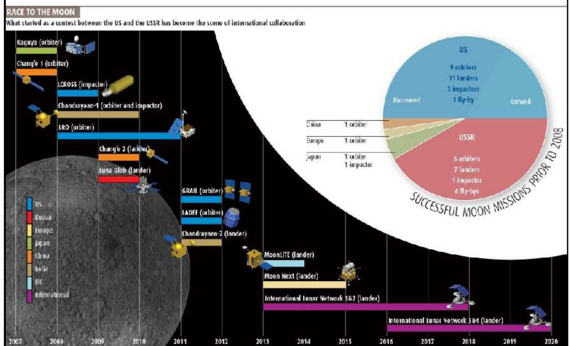
- Deep Space Program Science Experiment (DSPSE) joint project between the Ballistic Missile Defense Organization and NASA
- Objectives: test components in space environment and observe the Moon and near-Earth asteroid Geographos (failed)
- Mapped most of the lunar surface at a number of resolutions and wavelengths from UV to IR
- **The Moon is has distinct terrains with different geochemical signatures**
- **Trends of soil maturity and space weathering**
- **Composition of "pristine" central peaks as depth probes**

Lunar Prospector (1998-1999)

- Third Discovery mission
- Gamma Ray Spectrometer (GRS) - global element maps (U, Th, K, Fe, Ti, O, Si, Al, Mg, Ca) at 150 km/px and variable precision
- Neutron Spectrometer (NS) – H abundance at 150 km/ px
- Doppler Gravity Experiment (DGE), Magnetometer and Electron Reflectometer (MAG/ER), Alpha Particle Spectrometer (APS) (damaged)
- **The lunar farside highlands are much less Fe-rich that Apollo 16 "highlands"**
- **Lunar poles have concentrated volatile elements**



Upcoming lunar missions

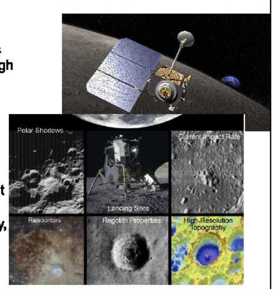


D. Mackenzie, New Scientist, July 11 2008

Mission	Kaguya (Japan) 2007-	Chang'e (China) 2007-2009	Chandrayaan (India) 2008-	LRO/LCROSS (NASA) 2009-
Imaging:				
Camera (VIS monochrome)	x	x	x	x
Typical VIS image resolution (m)	10 (global)	120 (global?)	5 (global)	0.5 (regional)
UV imaging	x			x
IR imaging	x	x	x	x
Thermal (broadband) IR				x
Multi-band UV-VIS-IR imaging	x		x	x
Spectroscopy:				
Gamma Ray Spectrometer	x	x	x	
Neutron Spectrometer				x
Alpha Particle Spectrometer	x			
X-Ray Spectrometer	x	x	x	
Infrared Spectrometer	x		x	
Planetary shape and structure				
Radar	x	x	x	x
Laser Ranging/Altimeter	x	x	x	x
Gravity	x (far side)	x	x	x
Particles and fields:				
High-energy Detector	x	x		
Solar Wind Detector		x	x	
Solar X-Ray Monitor			x	
Lunar Radiation Environment				x
Plasma Analyzer	x			
Plasma Imager (terrestrial)	x			
Radio Science (lunar ionosphere)	x			
Radiometer		x		
Magnetometer	x			
Impactor experiments:			x	x

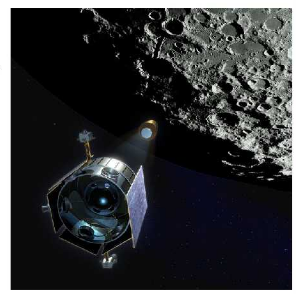
LRO (2009)

- Lunar Reconnaissance Orbiter (LRO) – ESMD mission initiated in 2004 as the first step back to the Moon in the Vision for Space Exploration. Focus is on datasets to help plan future human activities. Goddard project, managed under LPRP at MSFC
- **LRO Objectives:**
  - Characterize the lunar radiation environment, biological impacts, & potential mitigations. Develop a high res global, 3D geodetic topographical grid of the Moon for selecting future landing sites.
  - Assess the resources & environments of the Moon's polar regions.
  - High spatial resolution assessment of the Moon's surface addressing elemental composition, mineralogy, & Regolith characteristics



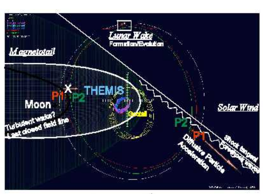
LCROSS (2009)

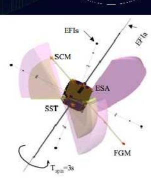
- Lunar Crater Observation & Sensing Satellite - secondary payload on LRO vehicle, Ames project under LPRP management at MSFC
- **LCROSS Objectives:**
  - Confirm the presence or absence of water ice in a permanently shadowed crater at a lunar pole
  - Create an ejecta plume and analyze it for the presence of water (ice and vapor), hydrocarbons and hydrated materials
  - Provide technologies and modular, reconfigurable subsystems that can be used to support future mission architectures



ARTEMIS (2010)

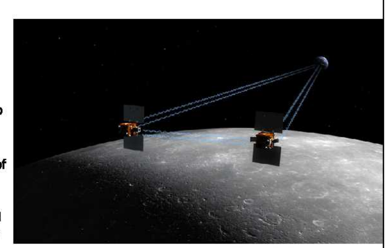
- ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interaction with the Sun) moves two THEMIS (Heliophysics MIDEX mission) satellites into orbits around the Moon
- **ARTEMIS objectives**: Study the lunar space environment, solar wind, magnetotail and lunar wake using MIDEX particles and fields instrumentation.





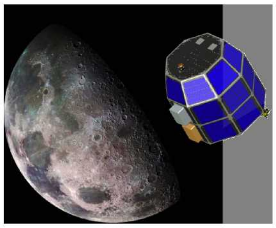
GRAIL (2011)

- Gravity Recovery and Interior Laboratory- an SMD PI-led mission by Dr. Maria Zuber at MIT, managed by Discovery program at MSFC
- Based on GRACE on the Earth - twin spacecraft with mutual microwave ranging to very precisely map the moon's gravity field
- **GRAIL Objectives:**
  - Determine the structure of the lunar interior from the crust to core
  - Advance the understanding of the thermal evolution of the moon extending to other planets



LADEE (2012)

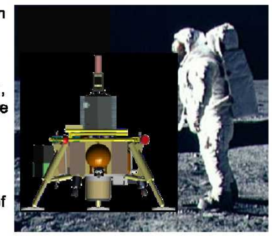
- Lunar Atmosphere, Dust and Environment Explorer - Ames/GSFC project, managed by Lunar Quest Program at MSFC



- **LADEE objectives:**
  - Determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity
  - Determine if the Apollo astronaut sightings of diffuse emission at 10s of km above the surface were Na glow or dust
  - Document the dust impactor environment (size-frequency) to help guide design engineering for the outpost and also future robotic missions.

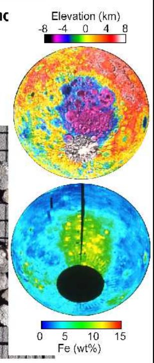
ILN Anchor Nodes (2015)

- ILN is a geophysical network that accomplishes high priority science by coordinating landed stations from multiple space agencies
- ILN Anchor Nodes: 2-4 US landers planned. Project jointly implemented by MSFC/APL, managed by Lunar Quest Program at MSFC
- **ILN Objectives:** Understand the interior structure and composition of the moon
  - Determine the thickness of the lunar crust (upper and lower)
  - Determine the size, composition, and state (solid/liquid) of the core of the moon.
  - Characterize the chemical/ physical stratification in the mantle
  - Characterize the thermal state of the interior



Robotic Sample Return (?)

- South Pole-Aitken basin is the oldest lunar basin anc one of the largest and deepest in the solar system (2000 km diameter, 13 km vertical relief)
- Excavated deeply - identifiable melt sheet
- Age anchor for early impact history of the terrestrial planets



Lunar Meteorites

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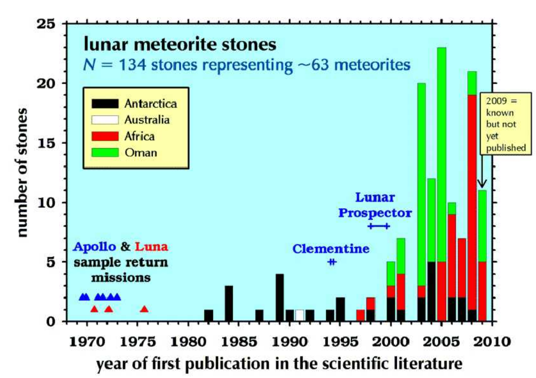
Lunar Meteorites

- ~150 separate stones representing ~65 different meteorites
  - 1 in 1200 meteorites
- Recovered from Antarctica, African and Arabian deserts, and Australia
- First recognized: ALH 81005 recovered from Antarctica in 1982
- $1000-$40,000 per gram (gold is $11/ gram)
- Have fusion crusts and cosmogenic nuclides indicating a trip through space
  - lunar escape velocity 2.3 km/s
  - average trip time ~ 1Myr
- Randomly ejected from small craters on the Moon
  - not enough large craters to explain them al
  - come from shallow depths
  - ejection shock is light

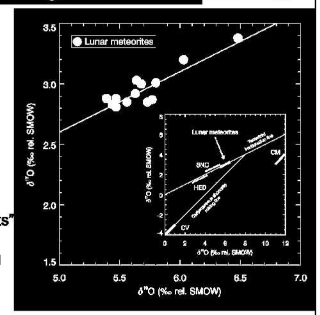


How do we know they are meteorites?

- Meteorites = Rocks from space!
- Commonly contain free metal – no free O_2 on parent
- Cosmogenic isotopes from travel through space
- Fall through Earth's atmosphere
  - Lose mass – must be big enough to survive
  - Friction heating on outside - glassy black fusion crust
- Detailed observations of fireballs can yield information about orbit and source
- Most (99.8%) meteorites are from asteroids
  - 0.01% from Mars
  - **0.01% from the Moon**

How do we know they are lunar?

- Apollo collection was well-characterized by 1982
- Brian Mason, Smithsonian curator: "some of the lasts resemble the anorthositic clasts described from lunar rocks"
- JSC curation staff: it looks like a piece of the Moon
- Detailed chemical and isotopic analysis "fingerprints" groups of meteorites
  - Feldspar and other mineral compositions
  - K-La correlation
  - O isotopes

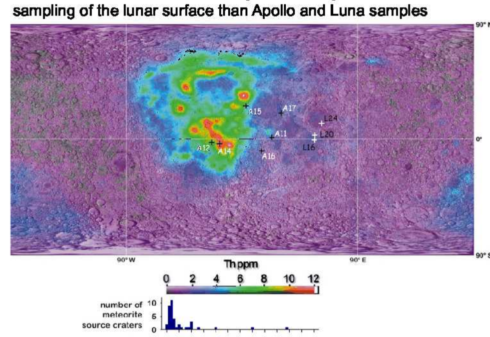


Where on the Moon did they originate?

- No meteorite source craters yet identified with certainty
- No evidence of nearside/farside impact rate difference
- Some evidence for leading/trailing dichotemy (western (leading) hemisphere of the Moon is hit slightly more frequently), so possibly more western meteorites
- Not exactly 50-50 that any given meteorite came from near or far side
  - More basalt on the near side than the far side
  - Less Th and Fe on the far side

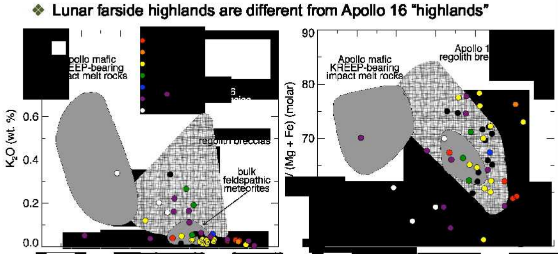
Why are lunar meteorites important?

- Lunar meteorites are a more ***complete*** and ***representative*** sampling of the lunar surface than Apollo and Luna samples



Why are lunar meteorites important?

- Most lunar meteorites are breccias composed of fine material from near the surface of the Moon, mixed by many impacts
- Composition and mineralogy of feldspathic lunar meteorites are more representative of the region from which it came
- Lunar farside highlands are different from Apollo 16 "highlands"



Why are lunar meteorites important?

- Several lunar meteorites are crystalline basalts that are different from any collected on the Apollo and Russian Luna missions
- Extend knowledge about the composition and timing of volcanism
- The Northwest Africa 773 stones are different from any rock in the Apollo collection