SMART-1 lunar highlights

Bernard H. Foing

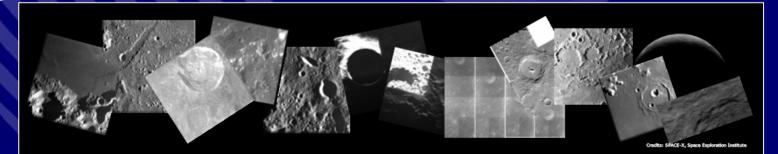
& SMART-1 Project & Operations team, SMART-1 Science Technology Working Team, SMART-1 Impact Campaign Team

http://sci.esa.int/smart-1/, www.esa.int











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Europe to the Moon: spacecraft, launch, operations (ESA+ industry) Instruments PIs + TIs from 5 countries Co-Is from 13 ESA + 6 non European countries

United States (US)

General Dynamics: Hydrazine Propulsion System Ithaco Space Systems Inc: Reaction wheels L3 Communications: Electrical Ground Support Equipment TECSTAR: Solar Cells

Finland (FIN)

Finish Meteorological Institute: Space plasma electron and dust detection (SPEDE)

Sweden (S)

Swedish Space Corporation: Prime Contractor Omnisys Instruments AB: Power Control and Distribution Unit SAAB Ericeson Space AB: Flight Module Assembly Integration and Testing, Antennae, Remote Terminal Unit, Bectromognetic Compatibility, Thermal Subsystem

Denmark (DK)

Terma A/S: On-board Indepedent Software Validation DTU Technical University of Denmark: Star tracker

Germany (D)

Astrium GmbH: Deep space X/Ka-band (KaTE) MPI Aeronomies: Near Infrared Spectrometer (SIR)

Switzerland (CH)

APCO Technologies SA: Structure and Mechanical Ground Support Equipment Contraves Space AG: Electric propulsion mechanism CSEM: Asteroid-moon micro imager (AMIE)

Italy (I)

LABEN SpA: Electric Propulsion Diagnostic (EPDP) RSIS: Radio science investigation (RSIS)

SHE United Kingdom (UK)

Rutherford Appleton Laboratory: Compact imaging X-ray spectrometer (D-CDS)

The Natherlands (NL)

Folder Space: Solar Arrays TNO/TPD: Son acquisition sensors

Belgium (8)

Spacebel S.A: On-board software detailed design Alcatel ETCA SA: Electric propulsion power processing

France (F)

SAFT Division Defence et Espace: Batteries Snecma Moteurs: Solar Array Mechanism, Electric Propulsion System (EPS) ATERMES: Electric propulsion pressure regulation Arianespace: Launcher (Ariane 5)

Spain (E)

Alcutel Espacio: S-band transponder CRISA: Battery management electronics

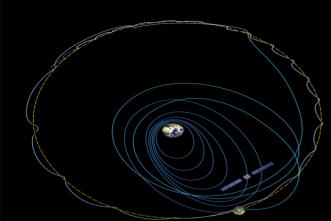
Solar Electric Primary Propulsion: 7 g thrust, 60 liters Xenon to the Moon

Photo: @ ESA

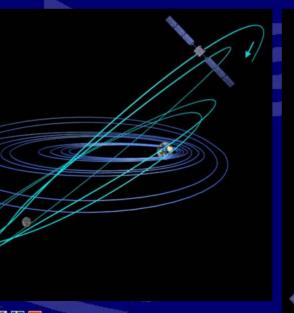


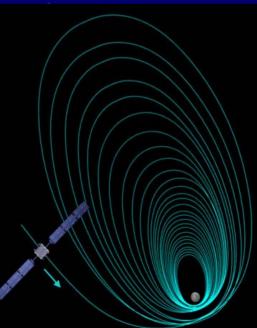
SMART-1: With Sun power to the Moon on 60 liters of fuel

Solar Electric Propulsion to the Moon



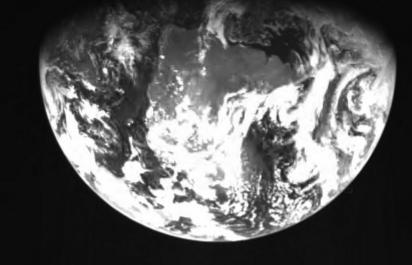
- Launched 27 Sept 2003 as Auxiliary passenger on Ariane 5 into Geostationary Transfer Orbit Spiral out cruise (13.5 month):
- lunar capture 15 November 2004, spiral down
- arrival 15 March 05 science(450 -2900 km): commissioned spacecraft/instruments at Moon, nominal science mission March-July 05
 reboosting 2 aug-15 Sept 05 to increase orbit lifetime for extension phase until Aug 2006





AMIE /SMART-1 End August 2006

Earth set & rise from the Moon



AMIE /SMART-1 May 21st, 2004 Earth view from ~70'000 km

ESA / SPACE-X Space Exploration Institute

First European Far Side Image of The Moon by AMIE/SMART-1

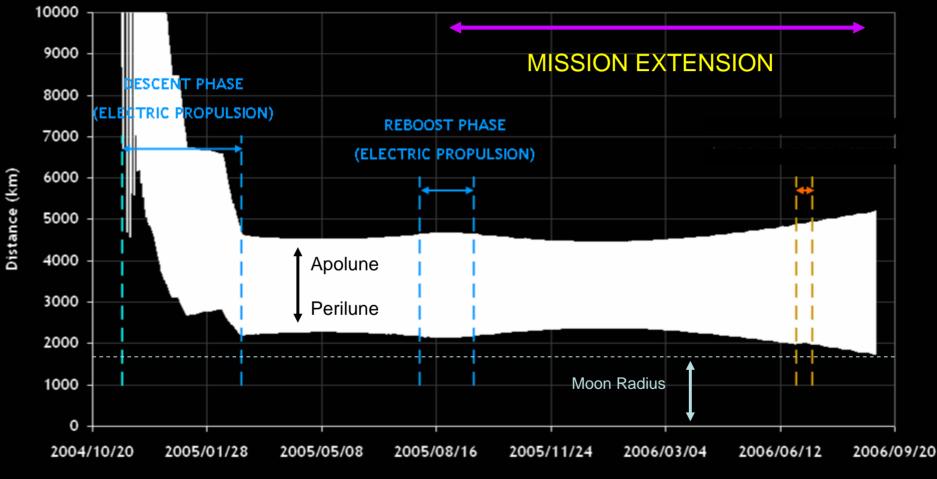
North Pole

12 Nov. 2004



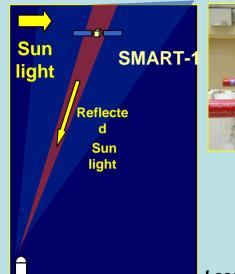
Moon Phase & Mission Extension

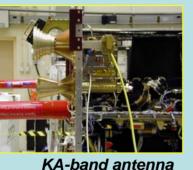
SC-to-Moon(Center) Distance

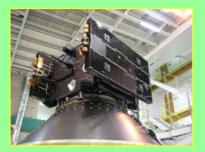


Date

Why the Moon: Innovative Technologies on Smart-1







Triple junction solar cells



On-board computer



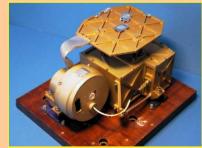
Platform Technologies



Multicolor microcamera



X-Ray Spectrometer



Infrared Spectrometer

Miniaturisation

Laser Link

Communication





OBAN

Autonomy



BHF 2007

SMART-1 Science and Exploration Themes

HOW DO EARTH-LIKE PLANETS WORK? GEOPHYSICS: volcanism, tectonics, craters, erosion, space weather, ices

HOW DO ROCKY PLANETS FORM AND EVOLVE? GEOCHEMISTRY: chemical composition, Earth-Moon origin, Moon evolution, accretion, collisions, giant bombardment

PREPARING FUTURE LUNAR/PLANETARY EXPLORATION LUNAR RESOURCES SURVEY (minerals, volatiles, illumination) HIGH RESOLUTION MAPS: for future LANDING SITES and OUTPOSTS SUPPORT TO FUTURE MISSIONS AND EXPLORATION

PUBLIC OUTREACH, INSPIRATION AND EDUCATION



What shapes rocky planets?

cratering.

Why the Moon? A laboratory for Geophysics

erosion, volatiles



Bombardment chronology

Tectonic winkles

volcanism

Calibration & Ground Truth

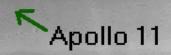
SMART-1 view of Apollo 11 site

- Distance 1764 km
- FOV 80 x 120 km

- Calibrations, see also
- Despan et al : geometrical analysis
- Kaydash et al: photogrammetry

Collins

Aldrin



AMIE SMART-1 High Res Colour



AMIE colour image Orbit 1438





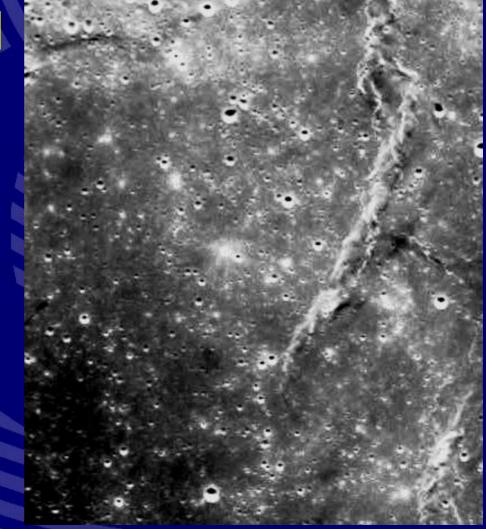




Clementine

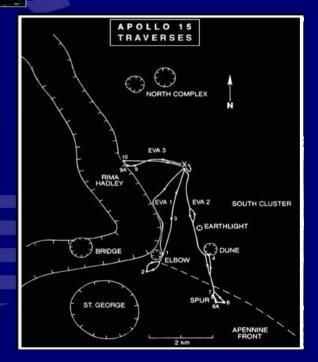
Serenitatis

Crater counts and lunar chronology





SMART-1 view of Hadley Rille (giant lava tube) near Apollo 15 landing site

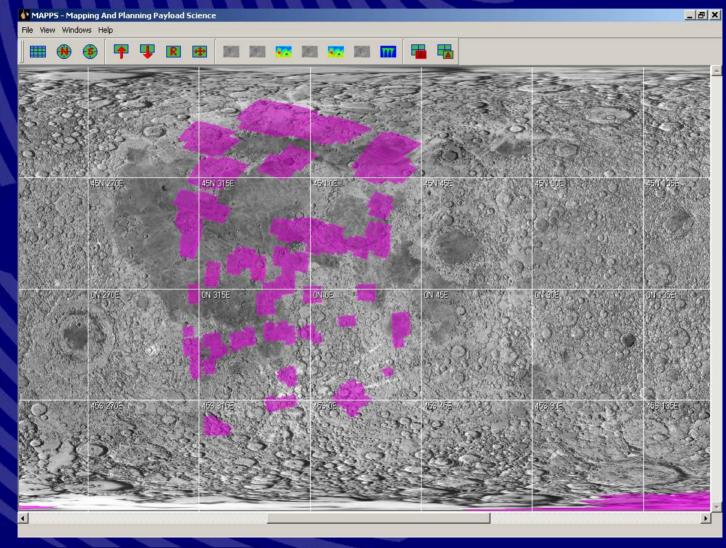


ESA / SPACE-X, Space Exploration Institute



100 km field

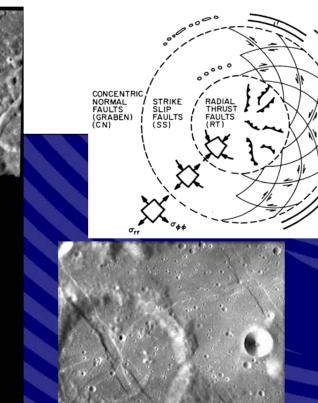
SMART-1 AMIE detailed targets: Procellarum and youngest basaltic flows

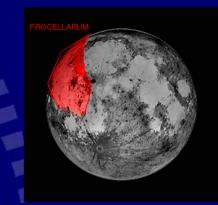


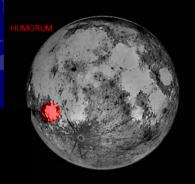
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Coupling between impacts and volcanism

- Humorum: Multiringed impact basin
- Procellarum: Irregular basin
- Tectonics of mascon loading







Peters et al 2007

+

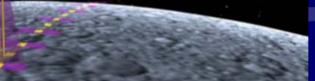
Meton: debris on the edge of Imbrium giant basin

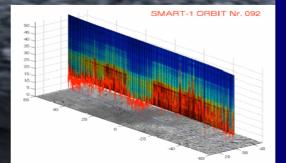


Minerals : the infrared Moon

The SIR spectrometer 0.9-2.4 microns:

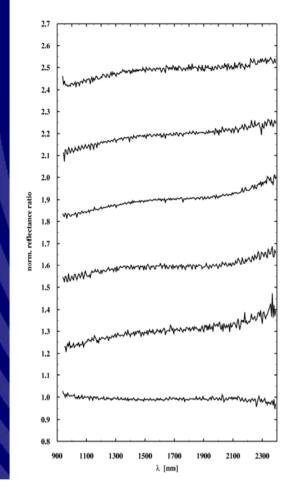
to chart the Moon's minerals to find the signature of volcanism and impacts

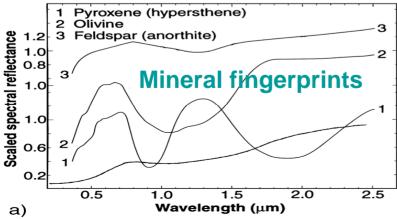






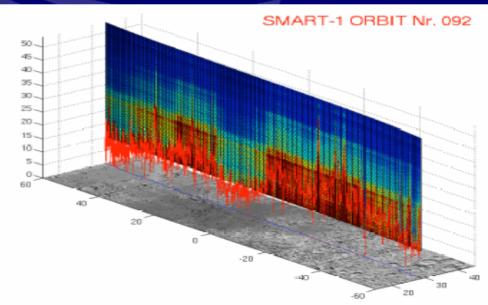






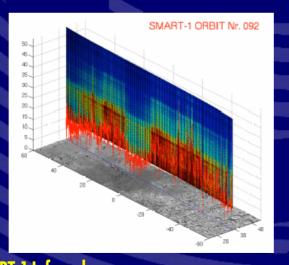
SIR infrared spectra across craters: window to the subsurface EPSC2 talks Vilenius et al Wiese et al

Mineral changes with SIR: from Highland to Mare



Formation and evolution of rocky planets

Origin of the Moon: geochemistry Evolution of Earth/Moon system Impact craters and basins Bombardment history in the inner solar system South Pole Aitken Basin





Edge debris from giant basin



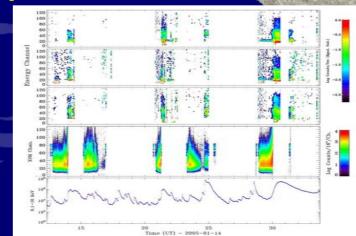
Mapping chemical resources: How D-CIXS works

- 1 The Sun shines on the Moon (in X rays)
- **2 The Moon fluoresces**
- 3 Each X-ray energy indicates unambiguously the abundance of a particular element
- **4 D-CIXS detects these X-rays**
- 5 Solar Monitor for Solar Input required for absolute abundances



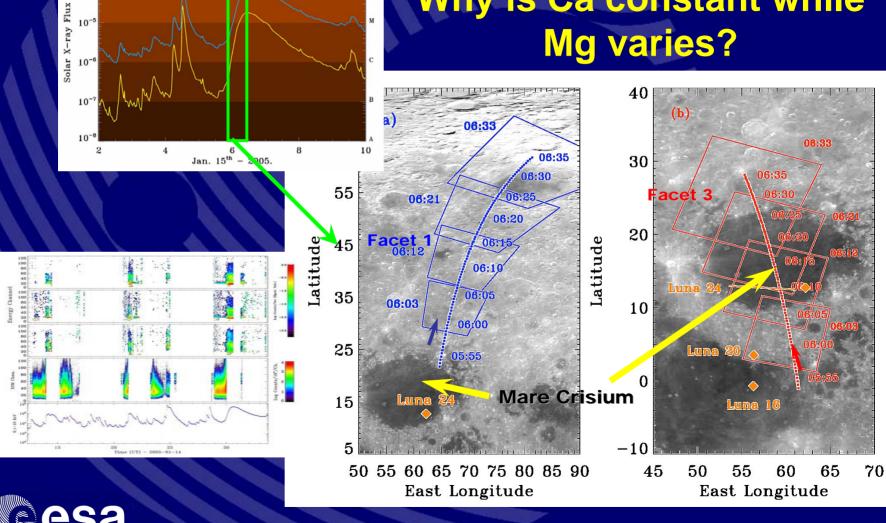


Sun Shines in X-rays



N trest

SMART-1 & Luna 24 samples in Mare Crisium : Why is Ca constant while **Mg varies?**



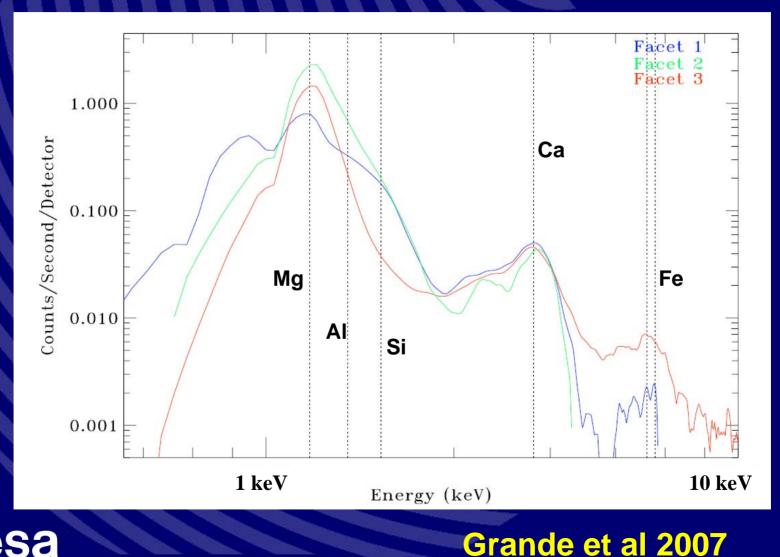
Sun - X-rays - 2005

 10^{-3}

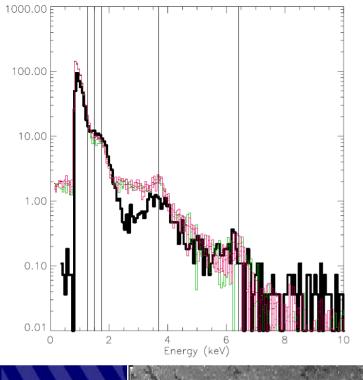
10-4

10-

X-ray signatures of Chemical Elements First ever remote sensing measurements of Ca at the Moon

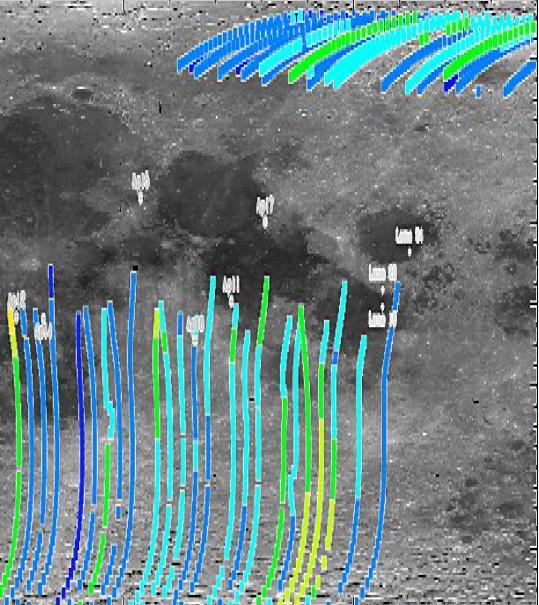


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Detailed task of fitting Lunar composition to the data.

This is close to the Apollo 12 landing site



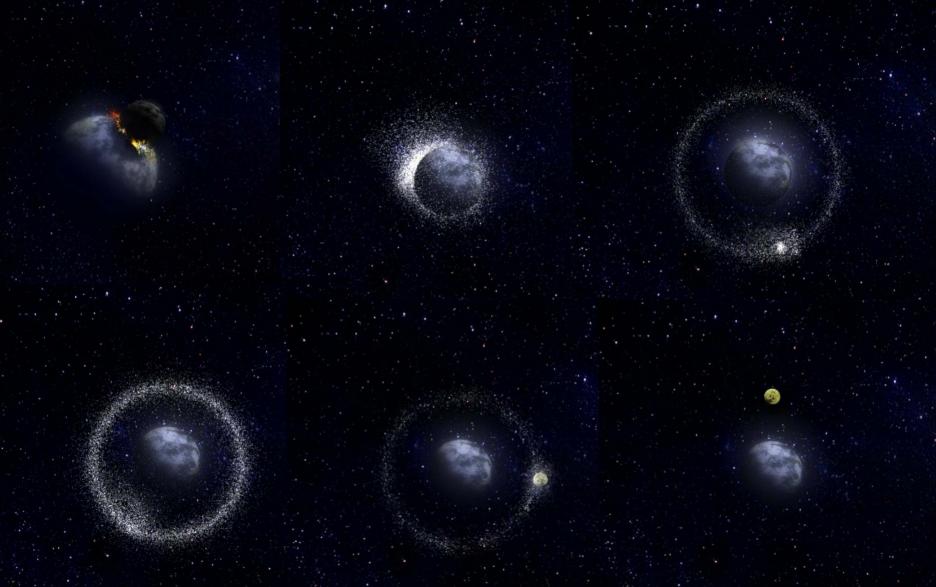


Unanswered questions about the Moon

- How did the Earth-Moon system form? - Giant Impact? Origin of impactor? Volatiles? How has the Moon evolved since? - Magma ocean? Necessary data
 - Composition (Mg, Al...)
 Age and isotopic composition



The Moon impact formation, 4.5 Gyr



PREPARING FUTURE LUNAR/PLANETARY EXPLORATION TECHNOLOGY LESSONS (ESTEC workshop January 2007)

LUNAR RESOURCES SURVEY - minerals, volatiles, illumination

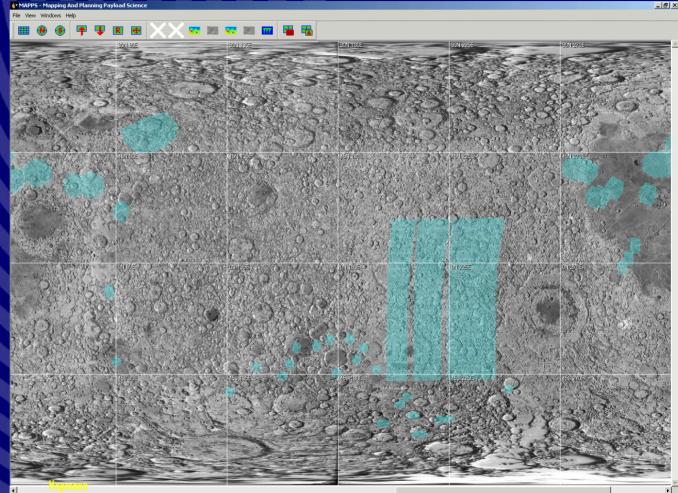
HIGH RESOLUTION MAPS: for future LANDING SITES and OUTPOSTS - mid resolution map North polar region - high res map of south polar region

SUPPORT TO FUTURE MISSIONS AND EXPLORATION

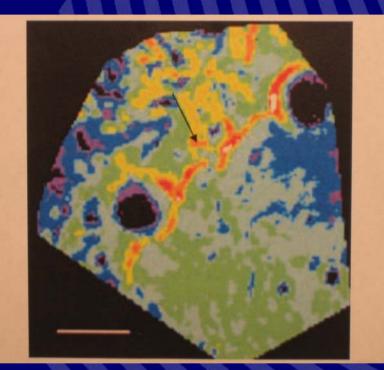
- support Chang'E 1 ground segment validation
- support Chandrayaan-1
- collaborations Selene, LRO/LCROSS
- from SMART-1 impact campaign to future impacts
- use of SMART-1 data and experience
- support lunar landers and sample return missions design



SMART-1 High res views of Targets in South Pole Aitken Basin For future sample returns



North pole peaks of light





Summer average illumination Clementine

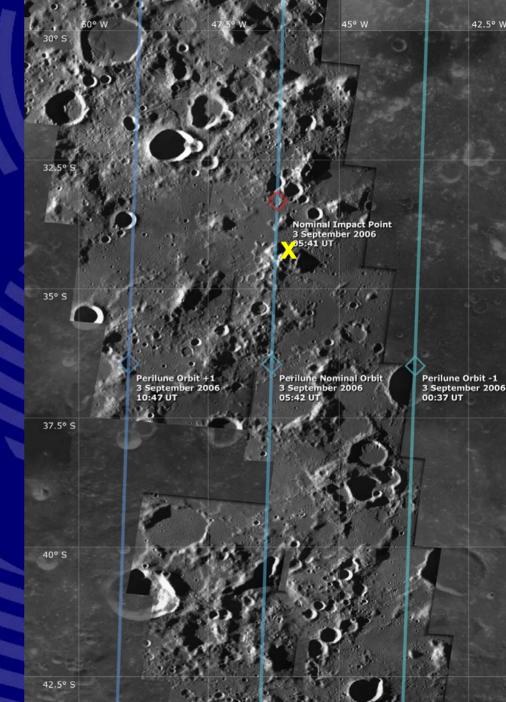


SMART-1 maps its own landing site Lake of Excellence 46.2 W 34.4 South

Highest resolution Reference for future detection of crater and Ejectas

Impact time: 3 sept 5h42:21.7 UT (within 1 s of prediction)



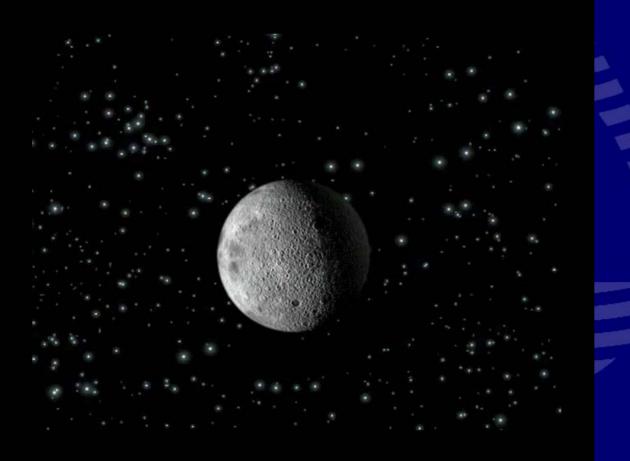


SMART-1 last orbit

ESA / SPACE-X Space Exploration Institute



Our last Moon travelling shot











SMART-1 a bridge to Future missions

- Data analysis & Interpretation
- Technology Lessons Learned
- Science & Exploration Results
- Preparation for human lunar missions

SMART-1 & next missions (collaborations)
2007 Chinese Chang'e 1 (ground station)
2007 JAXA Selene (science exchange)
2008 ISRO Chandrayaan-1 (SIR2, C1XS, SARA)
2008 LRO & LCROSS (planning, impact, outreach)
2011- Orbiters (ESMO, ASI, Moon Lite, BW)
2011- Landers, Rovers & Robotic village (US LPRP, Chang'e 2, Selene2, India, Lunaglob, ASI, D, UK, ESA)
2015- Sample return: Chang'e 3, Selene3, ESA NEXT,
2019- Human missions







ILEWG9/ILC2007 Intl Lunar Conference

- 22-26 October 2007, Sorrento, Naples Bay, Italy, Co-hosted by ASI & ESA
- Co-chairs: S. Di Pippo (ASI), Wu Ji (China), M. Wargo (NASA), B.H.Foing (ILEWG/ESA)
- 1. Inauguration & Keynote speeches
- 2. Results from SMART-1, and latest reports from Chang'E 1 and Selene
- 3. Agencies activities and plans
- 4. Keynote speeches: Science, Technology, Human exploration
- 5. Status of Future Missions: Chandrayaan-1, LRO/ LCROSS, Future Landers/Orbiters
- 6. Science and Exploration of the Moon: Results, Open Questions and New Approaches
- 7. Technologies, Infrastructures, Resources for Future Robotic and Human exploration
- 8. Societal, legal, policy, economics
- 9 Next steps for Robotic Landers, Rovers and Outposts
- 10 International Prospects for utilization and human exploration.
- 11 Reports and recommendations from working groups
- 12 ICEUM9 recommendations and declaration
- 13 Young Lunar Explorers session
- Outreach/education for public and Youth
- 14 Posters & interactive sessions
- Geological field trip



