
ma·re
[mä'rā]
noun; Moon Age and Regolith Explorer
Revealing the Impact History of the
Inner Solar System
87Rb → 87Sr
NASA
ASU
MDA
HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation
Malin Space Science Systems
Principal Investigator
F. Scott Anderson
and the MARE team

Outcome of MARE?

- Demonstration of what can now be done using new technology and recent developments in cratering chronology
- Opportunities for the future direction of LEAG (see Conclusion)

MARE Team

- PI: F. Scott Anderson
  - DPI: Phil Christensen
  - PS: David Draper
  - DPS: Samuel Lawrence
  - PM: Kim Ess
  - DPM: Jon Olansen
  - PSE: Ken Bollweg
  - Payload: John Andrews
- Science:
  - Marc Norman: Geochronology, geochemistry
  - Jeff Plescia: Cratering, Geochronology
  - Stuart Robbins: Crater counting
  - Jim Head: Crater counting, geology
  - Josh Bandfield: Mineralogy, thermophysics
  - Vicky Hamilton: Mineralogy
  - Rachel Klima: Mineralogy
  - Jonathan Levine: Geochronology
  - Ryan Ziegler: Geochemistry
  - Alan Treiman: Geochemistry
  - Harry Hiesinger: Crater Counting
  - Jacob Bleacher: Geology, Volcanology
  - Michelle Minitti: Geology, operations
- Instruments
  - Tom Whitaker: Lunar CDEX (µscopic chemical imaging & Rb-Sr dating)
    - Peter Wurz: Lunar geochemistry & mass spectrometer subsystem
    - Steve Beck: Laser subsystem
  - Phil Christensen: IRES (NIR/IR point spectrometer; mineralogy and thermophysics)
  - Aileen Yingst: EEC (Context and microscopic imager; MAHLI variant)
  - Sean Dougherty: MDA: Arm, gripper, rake
  - Kris Zacny: HoneyBee Grinder (RAT variant)
- Morpheus/NAVIS & ALHAT team

MARE Goals

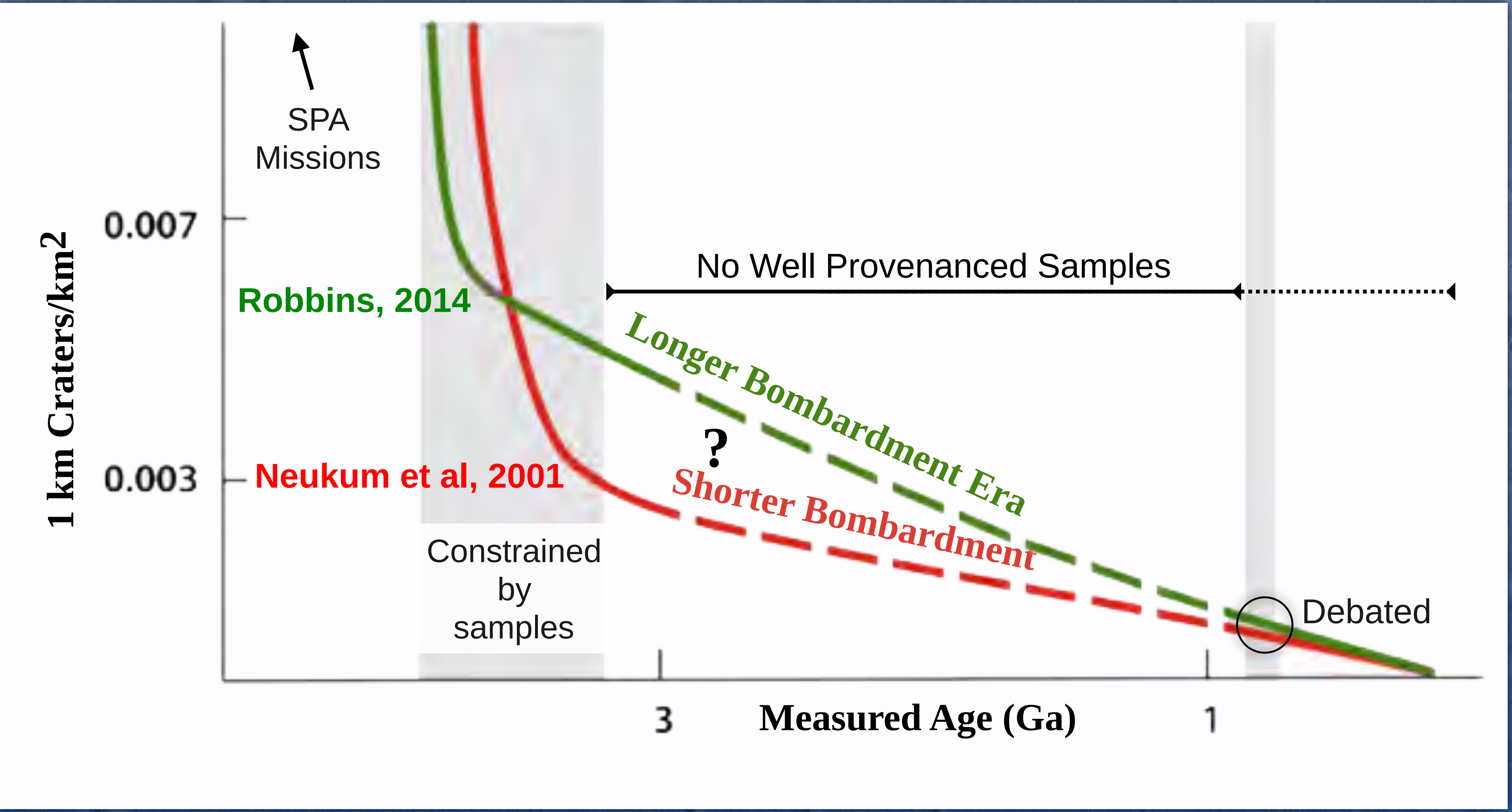
- Goal 1: Determine the impact history of the inner solar system
  - Determine age of lunar mare basalts SE of Schiaparelli crater
  - Fill major gap in lunar crater chronology to bridge young and old terrain
  - Assess implications for lunar and inner solar system history

- Goal 2: Assess evolution and differentiation of the interiors of one-plate planets
  - Determine geochemistry and mineralogy of young basalts
  - Determine petrological and thermal evolution of the lunar mantle
  - Apply insights to understanding of one-plate planet evolution

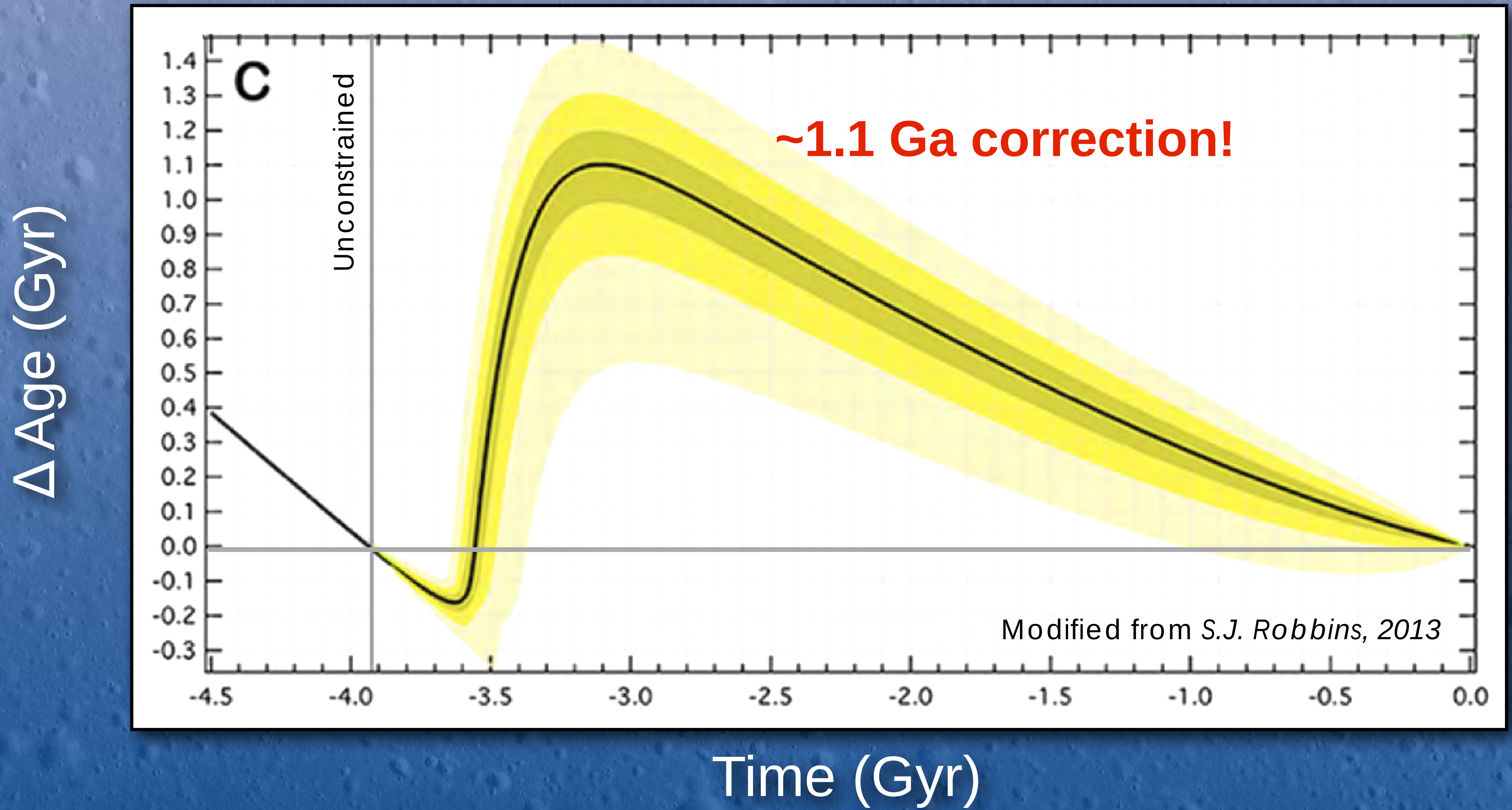
- Addresses Goals and Objectives of DS, LEAG, SCEM

What is the problem?

- Multiple crater flux models with major differences
- Many crater counts consistently higher than previous efforts
- More craters observed in LROC data; implies higher impactor flux

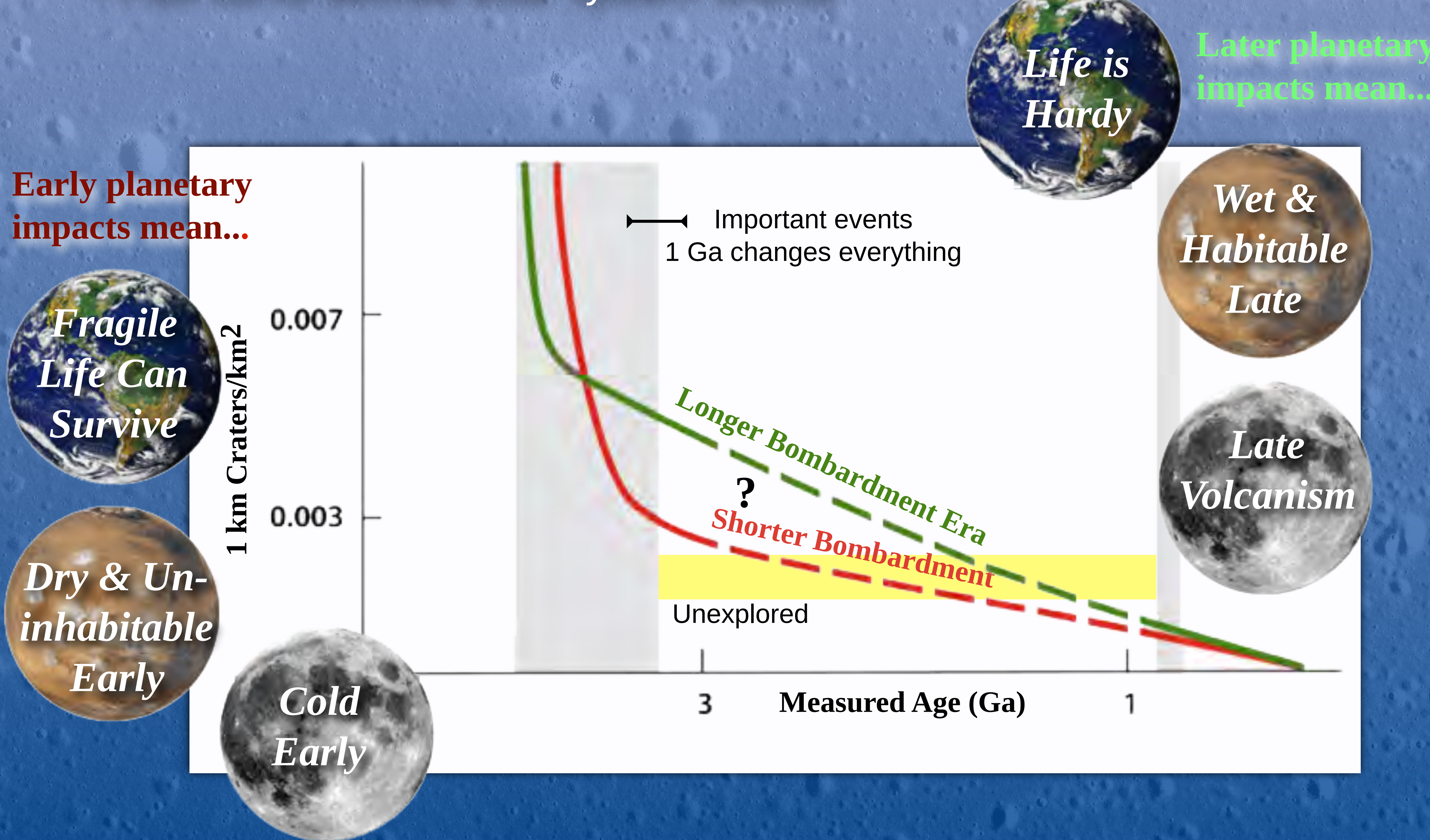


Robbins, Marchi Models Imply 1 Ga Correction



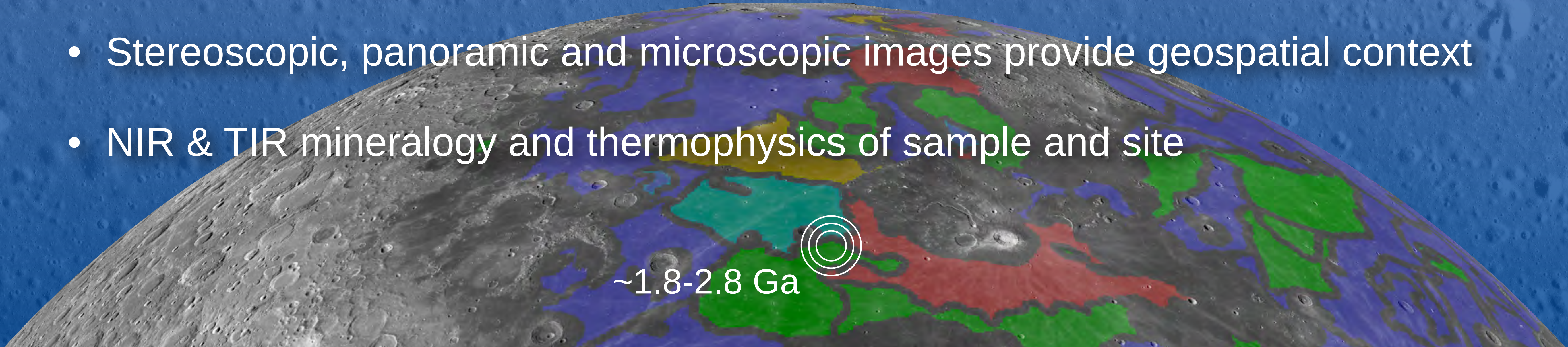
Goal 1: Reveal the history of the inner solar system

- Important solar system events occurring during 3-3.5 Ga
- Flux curve defines solar system events

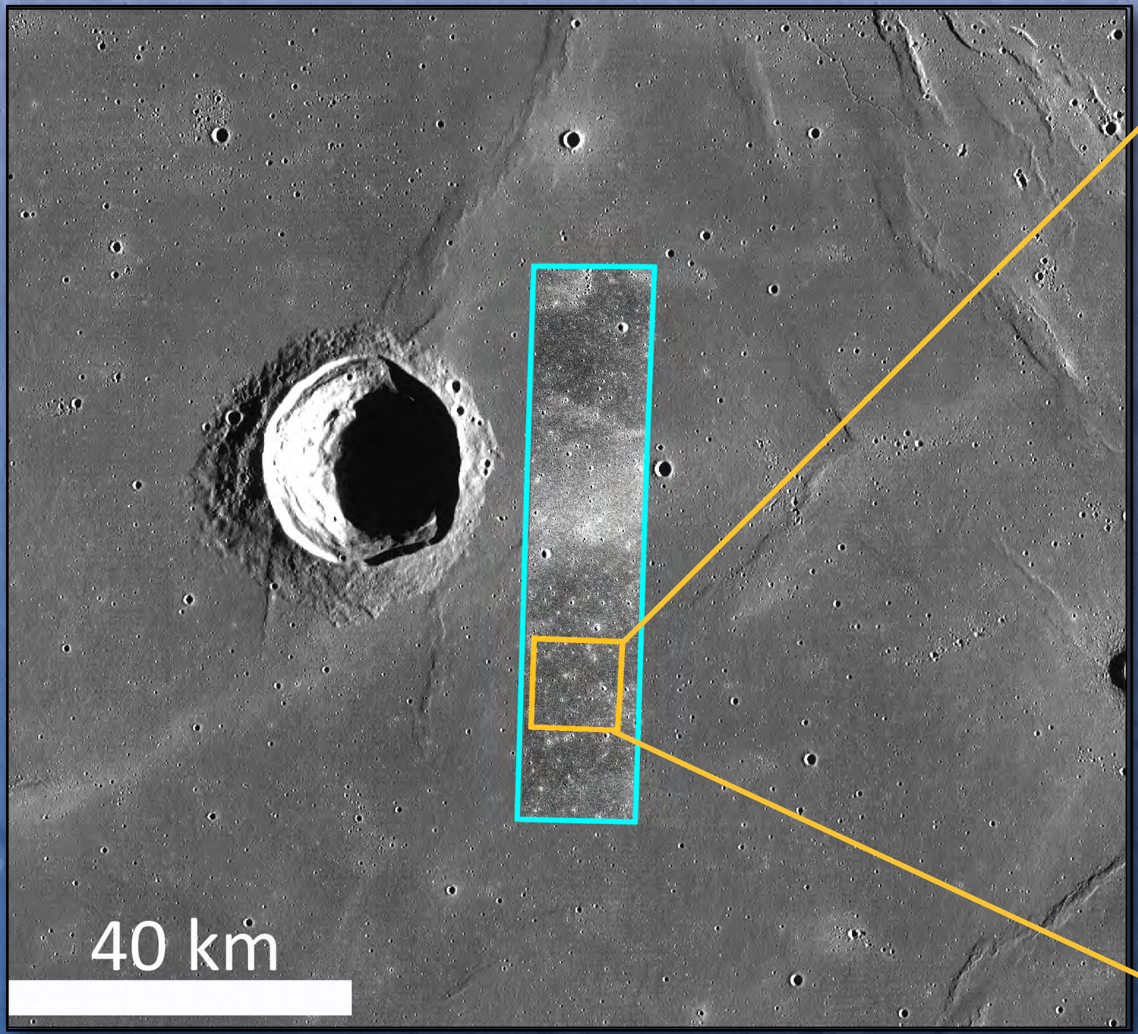


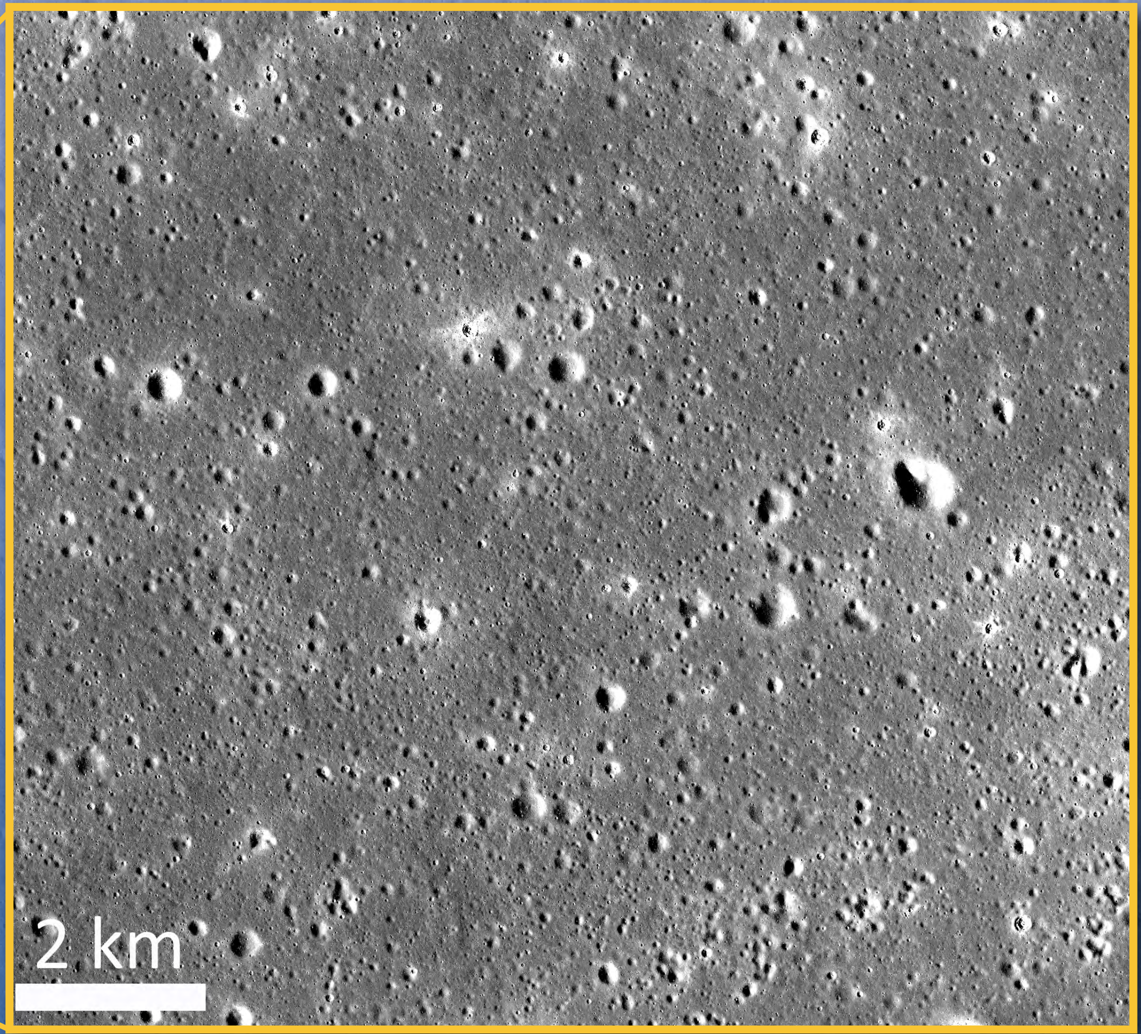
MARE Overview

- Land and measure the chronology (CDEX-LARIMS) and composition (CDEX-LAMS, IRES, EEC) of a 1.8-2.8 billion year old planetary surface
  - MARE’s robotic arm & rake will acquire and assess 20 lunar rock samples
    - Threshold: 5
    - Baseline 10
    - 10 more as operational contingency
    - Plus acquisition contingency: ~50 samples, 30% usable
    - Binomial jujitsu: 98%+ odds of 9 measurable samples
- Stereoscopic, panoramic and microscopic images provide geospatial context
- NIR & TIR mineralogy and thermophysics of sample and site



DRR 1 Site ~23.7°N 47.4°W: SE of Schiaparelli



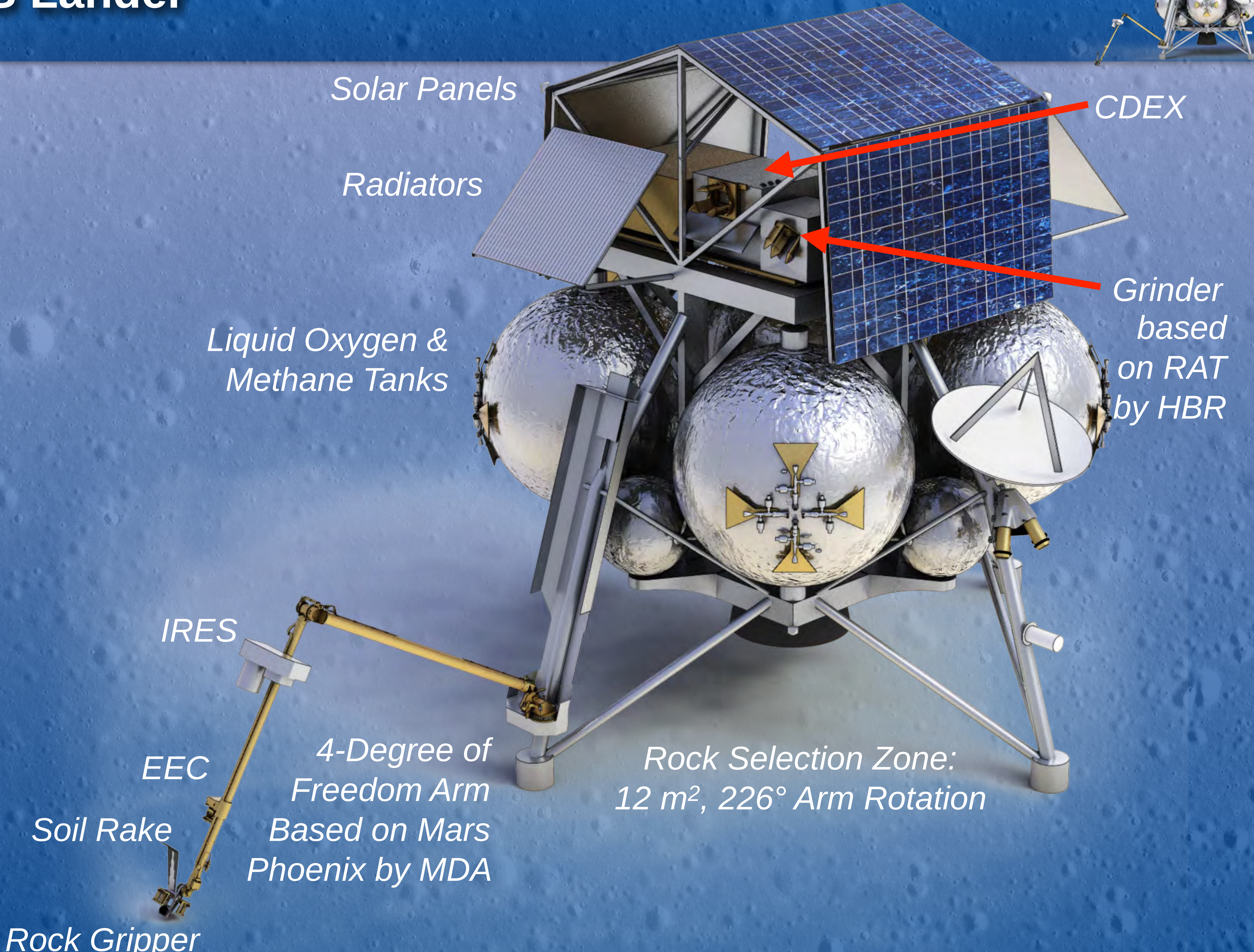


- Crater count well understood
- Lunar Prospector:
  - Chemically homogenous
  - 4-6 ppm Th => 7-8 ppm Rb
- Extremely smooth
- 2-m DTM for ALHAT
- 50-1000+ rocks + rake results
- DRR2: N of Flamsteed Crater

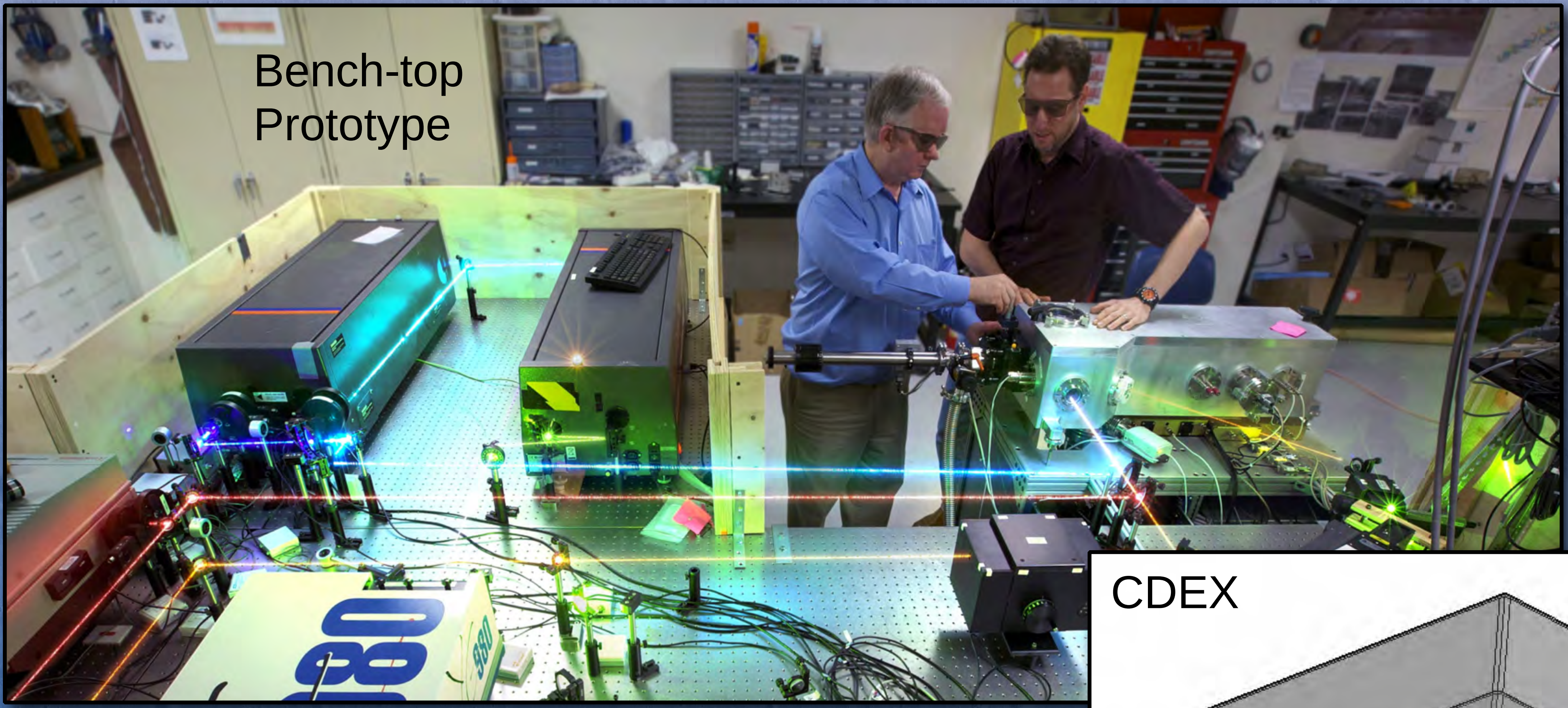
NAVIS Lander based on JSC Morpheus

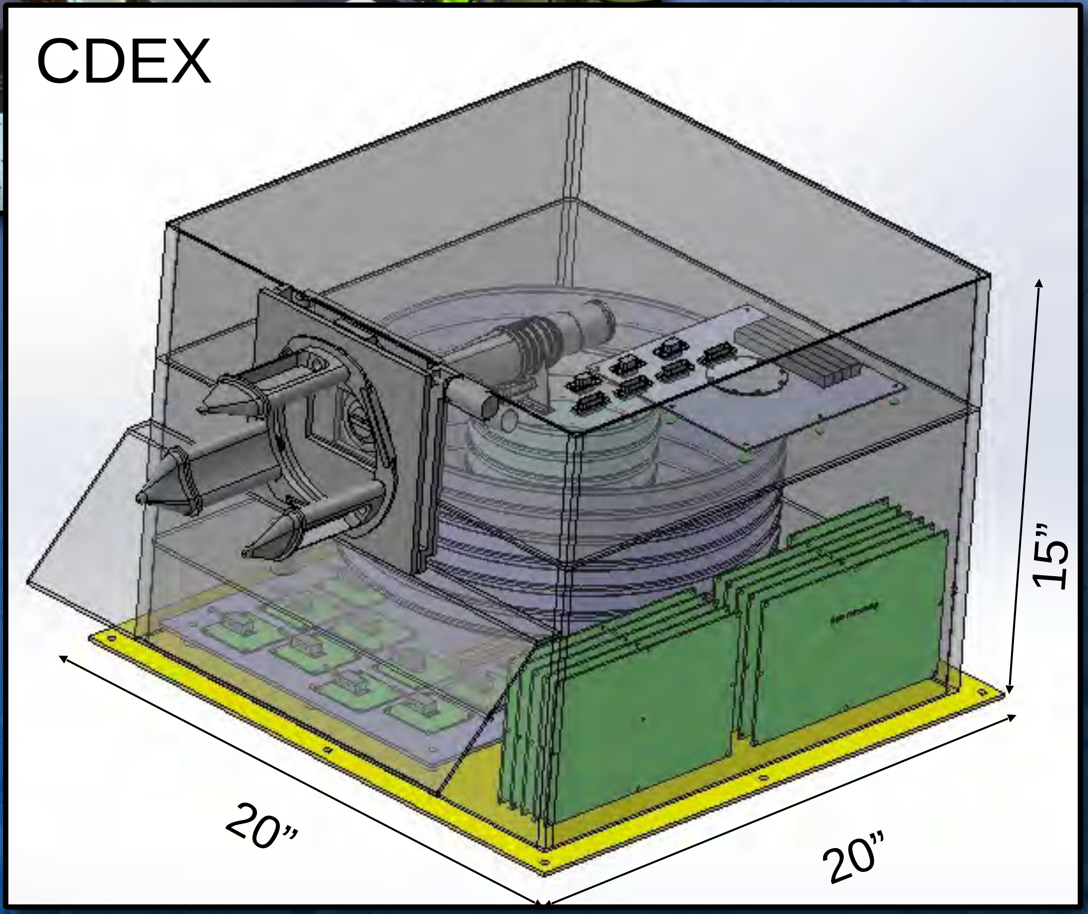
- Only full-scale test-bed lunar lander currently in active testing, including 15 of flights and demonstrated autonomous high precision landing

NAVIS Lander



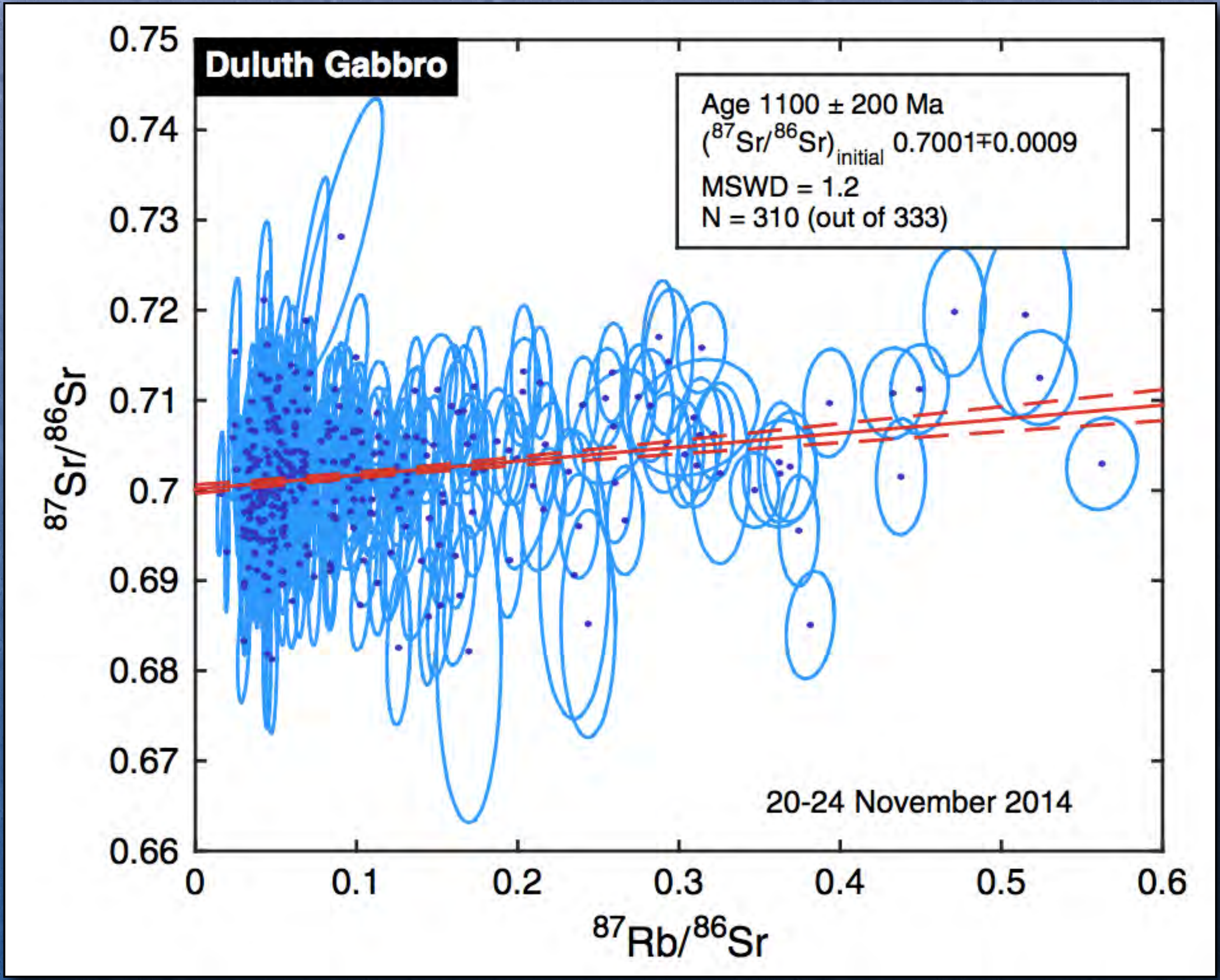
Chemistry and Dating EXperiment





- CDEX-LARIMS for Rb-Sr
- CDEX-LAMS for elemental abundance
- Miniaturization under MatISSE

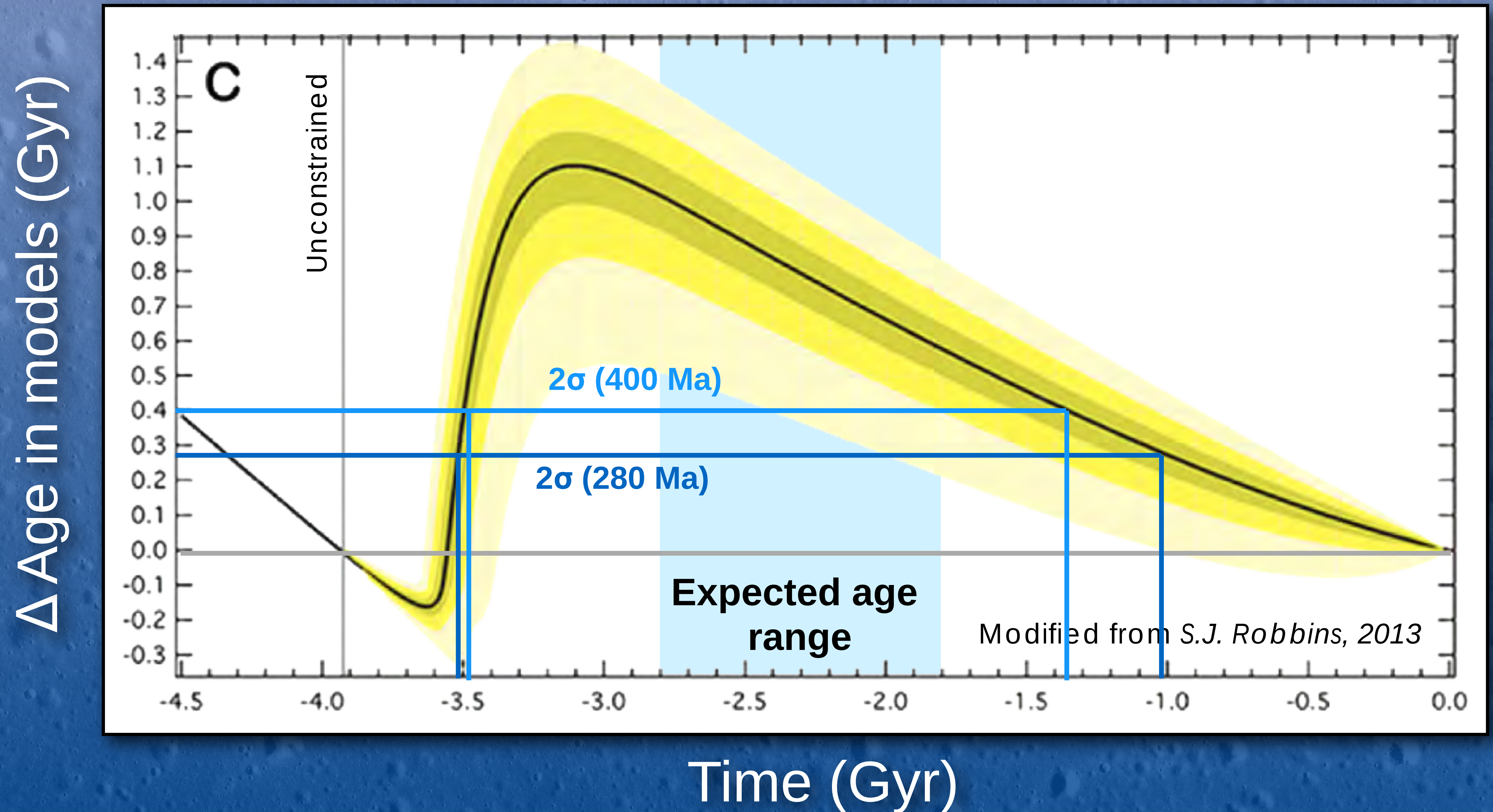
Lunar Analog Duluth Gabbro



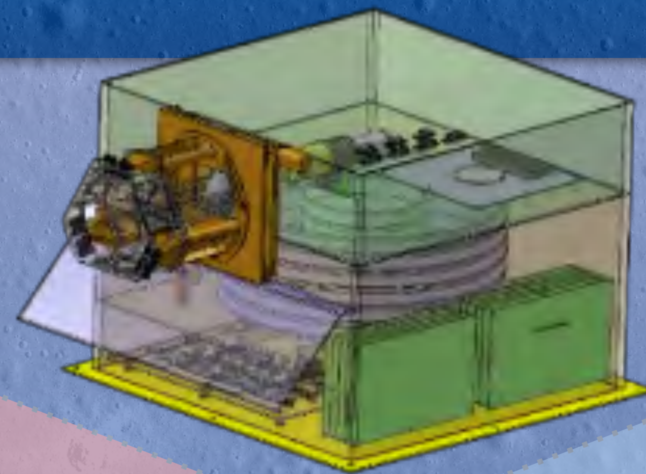
- TIMS: 1094±14 Ma
  $^{87}Sr/^{86}Sr$ = 0.7055±3
  - Dates for Duluth and Zagami are published
- Accurate abundances, e.g. Rb ~4.4 ppm
  - 2X harder than DRR1
- Intercept good to <1%
  - Precision meets requirement, but
  - Accuracy 3X worse
  - Further calibration expected to improve this

What does this mean for flux-curves

- Can differentiate models at 2-σ (2 x 200 Ma) for expected age range
- 3 samples to be confident of provenance
- Improvement in age to ~140 Ma (current limit due to systematic error)



Science Instrument Complement



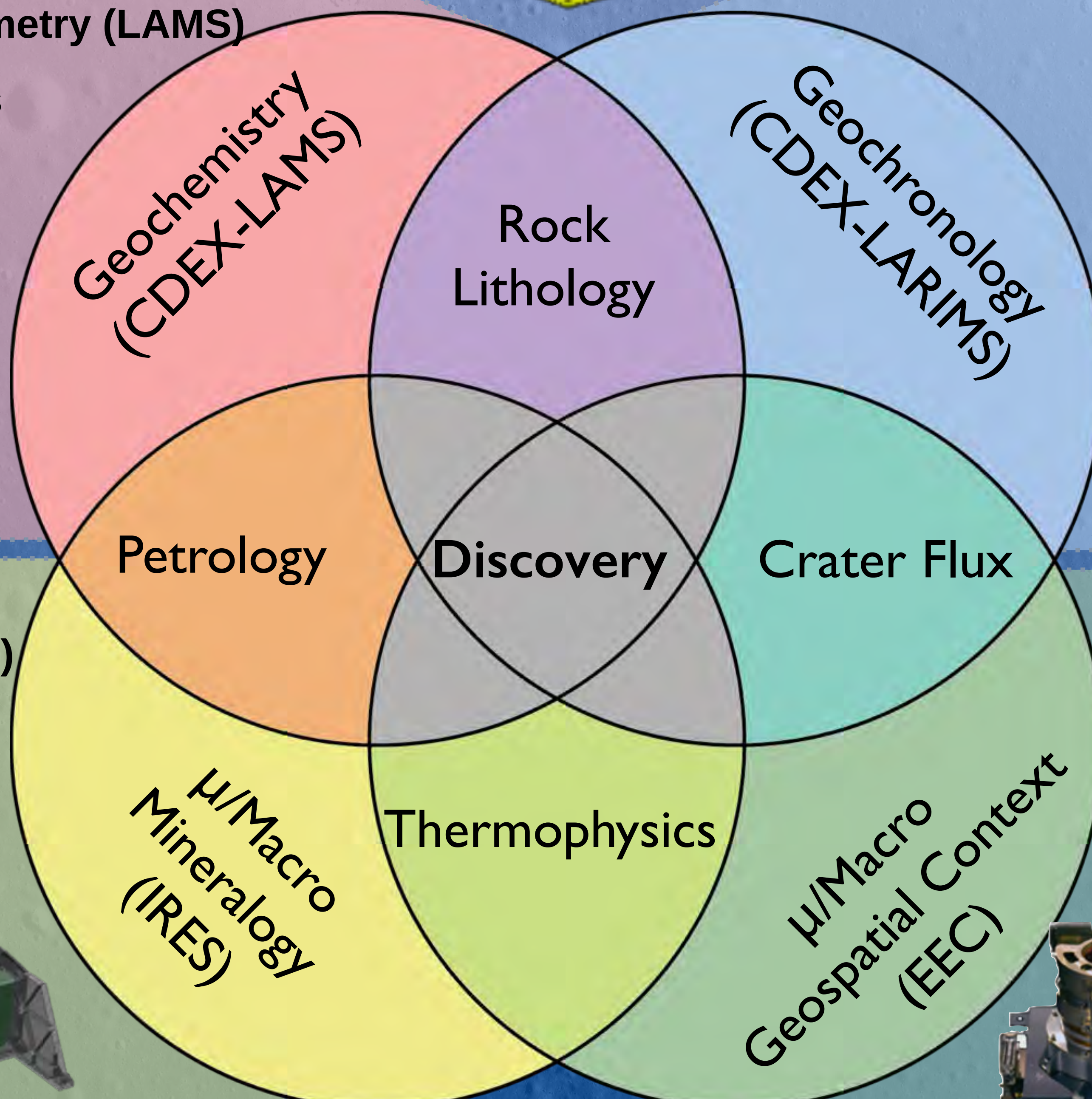
Chemistry and Dating Experiment (CDEX)

Laser-Ablation Mass Spectrometry (LAMS)

- Elemental, and isotopic analysis
- ±2% accuracy for >1 wt%
- ±5% for >1000 ppm abundance
- 240 point analyses per sample

Laser-Ablation Resonance Ionization Mass-Spectrometry (LARIMS)

- Rb-Sr age ± 200Ma
- Minimal sample preparation
- Robust Aerospace laser system
- High TRL mass spectrometer



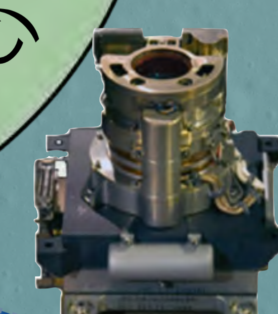
Infrared Reflectance and Emission Spectroscopy (IRES)

- Point NIR and TIR spectra
- Wavelengths 1 to 2.5 um and 5.5 to 50 um
- Based on MER Mini-TES
- 10 cm^{-1} resolution

IRES

Eagle Eye Camera (EEC)

- Hi-res, stereoscopic images
- Pre/post analysis images
- Focus 2.1cm to ∞
- Based on MSL MAHLI



EEC

Conclusions: Clives Questions

- *What are the implications of new observations for the geologic evolution of the Moon and solar system geology?*
  - Recent crater flux models have major implications for the history of the Moon and inner solar system requiring new chronology measurements from multiple terrains
- *How do current mission results affect the current Decadal Survey and influence our planning for the next?*
  - Add unifying theme for a campaign of dating missions for the Moon and inner solar system
- *How do these new discoveries affect planning for future human missions?*
  - Humans provide the perfect sample acquisition for in-situ triage and sample return
- *What future measurements are needed to address unknowns, including strategic knowledge gaps, regarding the Dynamic Moon?*
  - More chronology!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