The Inner SOlar System CHRONology (*ISOCHRON*) Discovery Mission: Returning Samples of the Youngest Lunar Mare Basalts

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Summary

- We propose the Inner SOlar System CHRONology (*ISOCHRON*) Discovery mission concept: an automated **lunar sample return** mission to mare basalt units south of the Aristarchus Plateau estimated to be ~1.5–2.0 Gyr old
- Will address fundamental questions about the time-stratigraphy of lunar magmatic processes and the composition of the lunar crust with implications for all of the terrestrial planets
- Addresses numerous key outstanding questions identified by several recent community assessments [1-3]

Science Goals

- **Primary: High-precision radiometric age measurements on young basalts to fill existing gap in age-correlated crater size-frequency distributions (CSFDs): will greatly improve this widely-used tool for estimating ages of exposed surfaces on rocky bodies**
- Provide critical insights on lunar thermal and magmatic history from comprehensive compositional and mineralogical data for direct comparison with older, Apollo- and Luna-returned samples
- Shed new light on regolith dynamical processes owing to samples' formation substantially after the Moon's heaviest period of bombardment

Background

- Full range of mare basalt compositions and ages has not yet been sampled [4,5]. Knowledge of the duration of mare volcanism comes from (a) radiometric dating of Apollo and Luna samples and lunar meteorites and (b) CSFD analysis of mare surfaces (especially those correlated with returned samples) from remote sensing data
- Existing CSFD models are calibrated by correlating measured ages of Apollo samples with the crater densities. Models are well-determined for ages >~3 Gyr, and reasonably constrained for very recent ages. But **there is a ~2 Gyr gap in age coverage** in these models (Fig. 1)
- **Thus CSFD age estimates of ~1-2 Gyr are uncertain to ~1.5 Gyr**

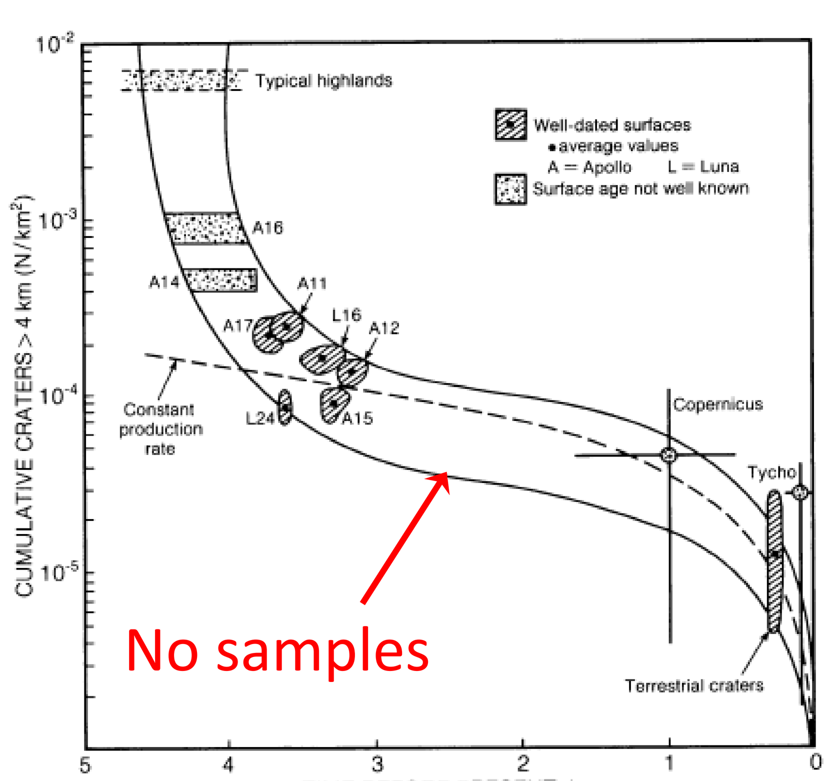


Figure 1. Summary of potential solutions to lunar CSFDs illustrating gap in data coverage. From [6].

- Problem exacerbated by application of lunar CSFD model to other bodies
- Need for sample return of young mare basalts has long been recognized
- *ISOCHRON* samples will yield crucial insight on lunar petrologic and geochemical evolution
- *ISOCHRON* will return samples of least-mature lunar regolith to constrain gardening dynamics & space weathering processes over time

Mission Concept

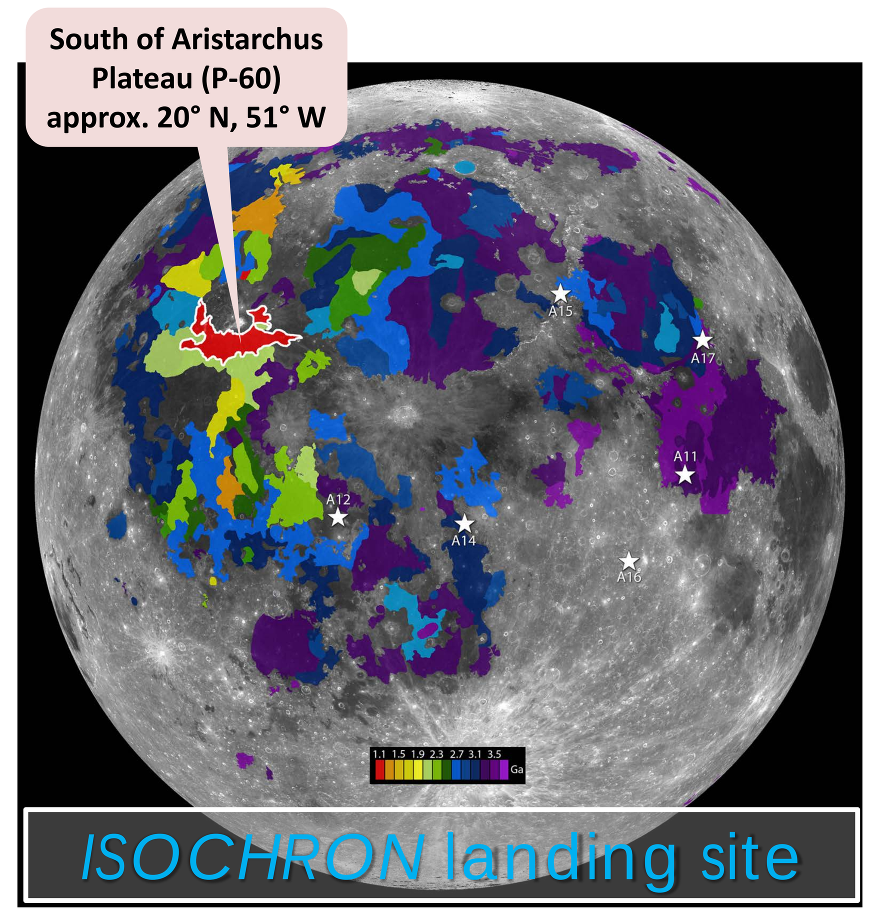
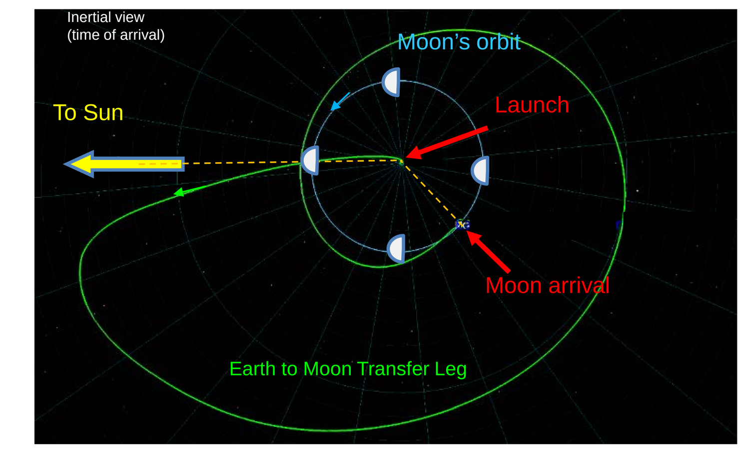
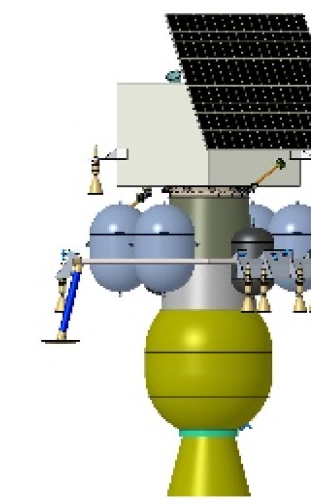


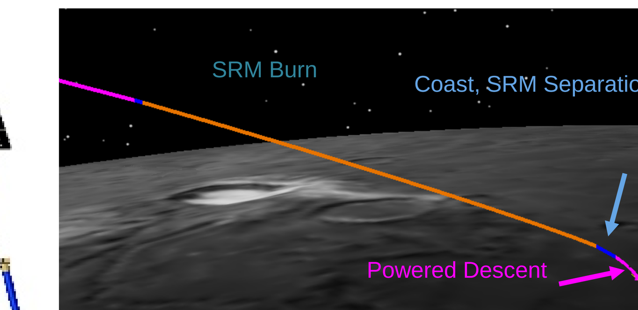
Figure 2. *ISOCHRON* landing site is large mare field south of Aristarchus Plateau, designated P-60 in [7] at 1.2 +0.32/-0.35 Gyr; 1.03 to 2.81 Gyr across the unit in [8].

Launch

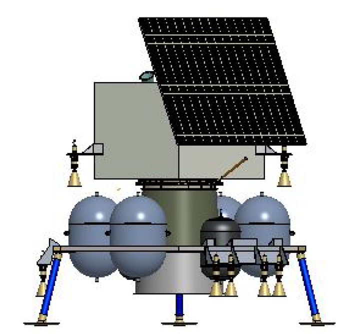


Cruise: Low-energy trajectory, ~6 month transit time

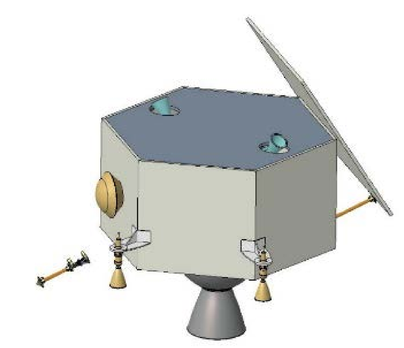




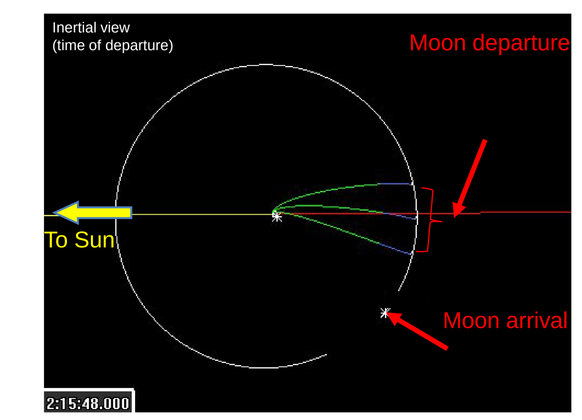
Direct Approach and Landing
- Land SW of Aristarchus, lunar morning
- Safe precision landing with Terrain Relative Navigation
- Powered descent

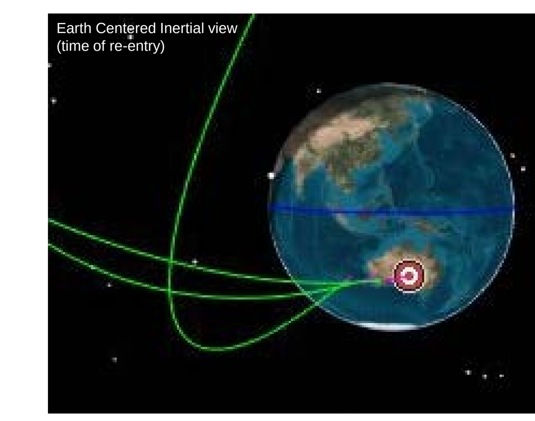


Surface Operations
- 4 Earth days max on surface
- Collect150g rocklets & regolith w/custom acquisition system
- Perform imaging



Ascent
- Ascent Vehicle launches from Lander





Return & EDL/Recovery (notionally Australia)
- Direct 4.5 day transfer
- Multiple return launch opportunities

Science Team, Measurements, Deliverables

	ISOCHRON science team			Subteam(s)					
First Name	Last Name	Affiliation	Role	Sample Chronology	Surface Chronology/ CSFD	Geochemistry/ Petrology/ Spectroscopy	Impact Science	Landing Site Context & Surface Geology	Surface Ops
Dave	Draper	JSC	PI						
Rachel	Klima	APL	DPI			x		x	
Brett	Denevi	APL	PS			x	x	x	x
Sam	Lawrence	JSC	PS		x	x		x	
Lars	Borg	LLNL	Co-I	Lead		x			
Jeremy	Boyce	JSC	Co-I	x		x			
Bill	Cassata	LLNL	Co-I	x					
Roy	Christoffersen	JSC	Co-I			x		x	
Mark	Cintala	JSC	Co-I				x		
Barbara	Cohen	GSFC	Co-I	x		x	Lead		x
Steve	Elardo	University of Florida	Co-I			x			
Amy	Gaffney	LLNL	Co-I	x		x			
Ben	Greenhagen	APL	Co-I			x		x	
John	Gruener	JSC	Co-I					x	
Harry	Hiesinger	Universität Münster	Co-I		Lead		x	x	
Brad	Jolliff	Washington University	Co-I		x	x		x	x
Katie	Joy	Manchester	Co-I	x		x			
Tom	Lapen	University of Houston	Co-I	x		x			
Julie	Mitchell	JSC	Co-I					x	
Clive	Neal	Notre Dame	Co-I			Lead		x	
Chip	Shearer	UNM	Co-I			x			
Justin	Simon	JSC	Co-I	x		x			
Angela	Stickle	APL	Co-I				x	x	
Julie	Stopar	LPI	Co-I		x			Lead	x
Aileen	Yingst	PSI	Co-I					x	Lead
Ryan	Zeigler	JSC	Co-I			x			

Science Measurement Objectives for Preliminary Examination Team (PET)	Measurements	Laboratory Instrumentation	Sample Type
Geochronology			
Basalt crystallization age from abundances of radioactive, radiogenic isotopes	Measurement of Rb-Sr, Sm-Nd, K-Ca and U-Pb radiochronometers	Mass spectrometers (TIMS, SIMS, [MC] ICP-MS)	Rocklets
Thermal exposure history from noble gas abundances and isotopic ratios	Measurement of Ar isotopes	Noble gas mass spectrometers	Rocklets
Basalt crystallization age from abundances of radioactive, immobile radiogenic isotopes	Lu-Hf Chronology and isotope tracer	Mass spectrometers (TIMS, SIMS, Nano-SIMS, ICP-MS)	Rocklets
Crystallization age of any phosphates or zircons	In Situ measurement of U-Th-Pb radiochronometers	Mass spectrometers (TIMS, Nano-SIMS, [MC] ICP-MS, SIMS)	Zircon or Phosphate
Mineralogy and Petrology			
Basalt origin and KREEP component from in-situ analysis of mineral composition and relationships	Bulk compositions, sub-micrometer characterization of structures, elemental abundances, and isotopic compositions	XRF, EPMA, SEM, TEM, ICP-MS, RIMS, SIMS	Rocklets
Crystallization and shock history of basalt from analysis of petrographic texture and mineral composition	Micrometer-scale mineralogy, petrology, mineral chemistry, and crystallinity	Optical microscope, SEM, EPMA, TEM, SIMS, ICP-MS, XRF, XRD	Rocklets
Regolith Evolution, Space Weathering and Exposure History			
Determine integrated sample/sub-sample history of processing by space weathering relative to pristine parent mare basalt	Mass fraction of total Fe in single magnetic domain state (nanophase Fe^{o}); total Fe mass fraction as FeO; Intra- and intergrain distribution of nanophase Fe0 in grain rims and agglutinitic glass.	I_s by electron spin/electron paramagnetic resonance, FeO preferably by non-destructive XRF/EPMA or other methods; SEM, TEM	Regolith
Determine the composition of lithic and glass fragments within the regolith to identify materials transported to the landing site via vertical and lateral impact mixing	Micrometer-scale mineralogy, petrology, mineral chemistry, and crystallinity	Optical microscope, SEM, EPMA, TEM, XRF, XRD	Regolith
Sample surface exposure history (topmost surface or near surface exposure)	Implanted solar noble gas concentration, grain solar flare track density, width and development of space weathered grain rims	Mass spectroscopy (type TBD), SEM, TEM	Regolith
Spectroscopy			
Grain-scale spectroscopy for spectral characterization of specific phases	Grain-scale spectroscopy for spectral characterization of specific phases	FTIR microscope	Regolith or Rocklets
Bulk spectroscopy of basaltic regolith to ground truth remote measurements	Bulk spectroscopy of basaltic regolith to ground truth remote measurements	UV, NIR, TIR spectrometers	Regolith

- ***ISOCHRON* Science Team** brings deep experience in lunar investigations, mission operations, sample analysis, and remote sensing
- Diversity and longevity, government + academia + international partnerships
- Strong and experienced engineering and hardware partners (proprietary)
- 75% of returned sample mass dedicated for curation & allocation to community

- Age determinations by leading geochronology laboratories using multiple isotopic and noble-gas systems: Concordance will close the ~2 Gyr gap in CSFD models
- Petrologic, geochemical, mineralogical studies using full range of analytical laboratories for lunar magmatic & thermal evolution, impact & shock processes
- Studies of regolith dynamical processes and evolution, space weathering, exposure history through high-resolution analytical and spectroscopic techniques

References [1] National Research Council (2011) Visions and Voyages: Planetary Science Decadal Survey, DOI: https://doi.org/10.17226/13117. [2] NRC Space Studies Board (2007), The Scientific Context for Exploration of the Moon: Final Report. [3] LEAG (2017) Advancing Science of the Moon SAT report. [6] Hörz F. et al. (1991) Lunar Source Book, 61. [7] Hiesinger H. et al. (2000) J. Geophys. Res. 105, 29239. [8] Stadermann A. C. et al. (2018) Icarus 309, 45.