



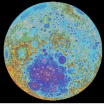
Sample Return from the South Pole-Aitken Basin

A White Paper submitted to the 2023
Planetary Science Decadal Survey,
presented 11-30-2020

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And 38 co-signatories

Oblique view of central South Pole-Aitken basin along day-night terminator derived from
Lunar Reconnaissance Orbiter data [NASA/GSFC/ASU] (credit: Ernie Wright, GSFC SVS)





Sample Return from the South Pole-Aitken Basin would fulfill important planetary science objectives.

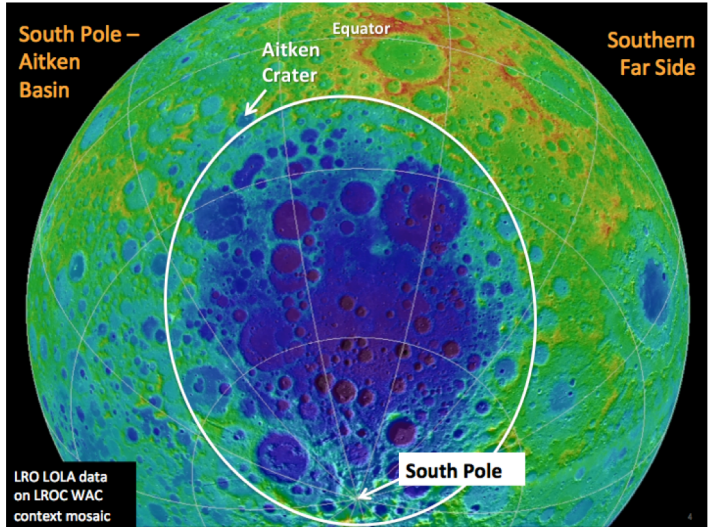
SPA: largest and oldest clearly recognizable impact basin on the Moon

SPA event completely resurfaced this part of the Moon and reset ages over an enormous area.

As such, SPA anchors the lunar impact chronology.

SPA sample return addresses high priority planetary science

SPA sample return addresses major cross-cutting Planetary Science themes



South Pole-Aitken Basin is among the largest in the Solar System.



South Pole-Aitken Sample Return answers fundamental questions about the early Moon and Solar System.

Was there a cataclysmic impact bombardment in the early Solar System?

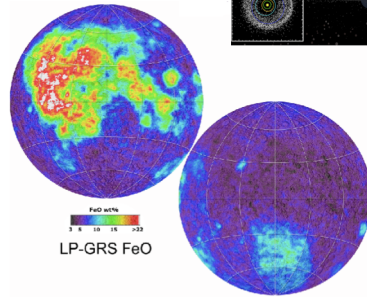
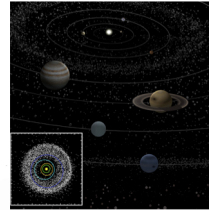
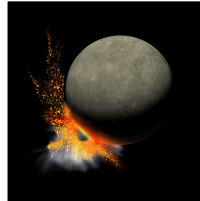
What was its onset and duration?

Record is bound in the rocks of the South Pole-Aitken (SPA) impact basin

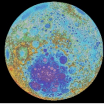
Did the impact that formed the SPA basin cause widespread magmatic activity, recorded in its ancient rocks?

Did the impact excavate materials from the Moon's mantle?

What can those materials, and later-formed volcanic rocks, reveal about the nature of the Moon's early differentiation and formation of its planetary-scale asymmetries?

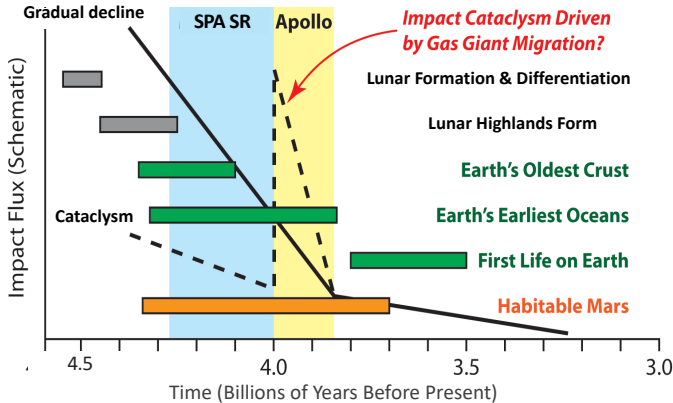


Moon's South Pole-Aitken Basin preserves a record of Solar System dynamics.



Did the inner Solar System experience a cataclysmic event?

Return of SPA samples builds on chronology and chemistry from Apollo, but the cataclysm test cannot be done solely with Apollo samples.

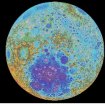


Gradual decline: older ages for SPA chronology, no support for cataclysm and gas giant migration

Cataclysm: younger age for SPA chronology, support for gas giant planet migration

To understand early Solar System environments, we must acquire new samples from the most ancient of lunar impact basins: South Pole-Aitken.

SPA samples will test models for the impact history of the inner Solar System.



What does the SPA basin-forming event tell us about the early Moon, Earth and Solar Systems generally?

SPA sample return: paradigm-shifting in our understanding of how Solar Systems work and how life may have evolved.

Late Heavy Bombardment (LHB) proposed in 1974

Based on analysis of samples from large, late, near-side basins

SPA is the oldest and largest, with >50 basins formed after it and several basins and large craters formed within it..

- Uniquely suited to test the LHB hypothesis

2005: “Nice” model – coupled LHB to the orbital dynamics of giant planets

Paradigm-shift potential for our understanding of how solar systems work

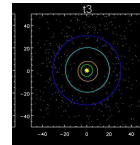
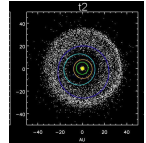
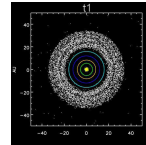
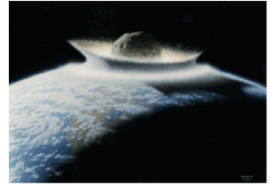
Importance for Earth, early life, habitability

Importance for inner Solar System

Understanding of giant planet orbital dynamics

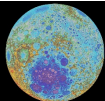
Applicable to other Solar Systems

PSRD-Lunar Cataclysm (2001)



Gomes et al.,
2005, Nature

Will test models for evolution of Solar Systems and environments under which life originated and evolved.



What were the effects of large impact events on planets and moons in the Solar System?

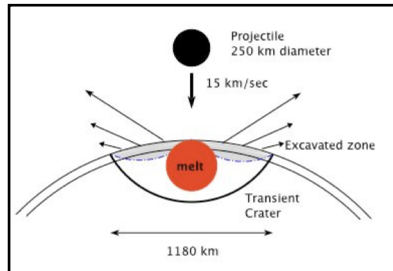
As the largest impact basin in the Solar System, the SPA basin and the Moon provide an accessible natural laboratory for examining how giant impacts shaped the terrestrial planets.

How are planetary crusts formed and shaped by giant impacts such as the SPA basin?

How do planetary mantles respond to giant impacts?

Are giant impacts responsible for episodes of planetary magmatism?

Will the rocks reveal evidence of SPA impact-melt differentiation?



Giant impacts shaped the evolution of planetary bodies.



How do planets differentiate to produce global scale asymmetries?

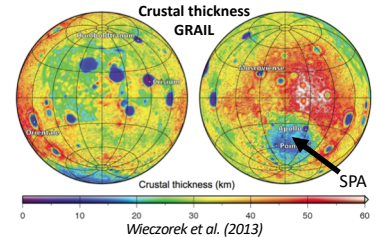
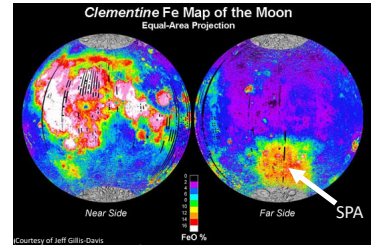
SPA basin provides access to lunar crust and mantle that is distinct from regions sampled by Apollo.

What role did primordial differentiation and subsequent processes play in producing global crustal asymmetries?

Basalts are probes of planetary mantles. Does the lunar mantle show asymmetries in composition, thermal history, and age that mimic the asymmetrical lunar crust?

What role did primordial differentiation play in producing global mantle asymmetries?

How was the distribution of thorium controlled by differentiation?



Primordial differentiation influenced planetary evolution.



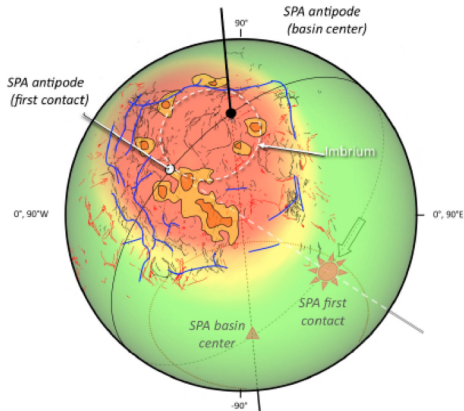
Was there a relationship between SPA impact event and global lunar magmatic activity?

46th Lunar and Planetary Science Conference (2015)

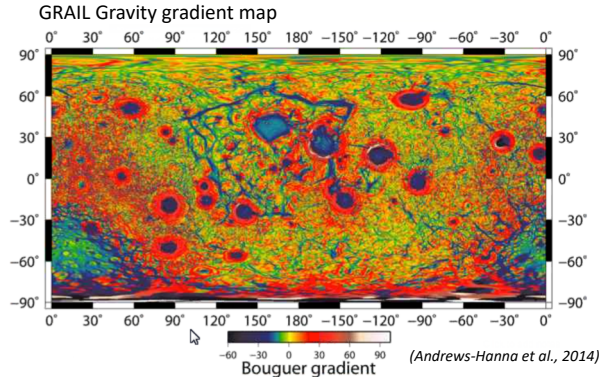
2416.pdf

SPA-IMPACT ORIGIN FOR THE NEARSIDE DIKE SYSTEM ON THE MOON. P. H. Schultz¹ and D. A. Crawford², ¹Brown University, Providence, RI 02912 (peter_schultz@brown.edu), ²Sandia National Laboratories, Albuquerque, New Mexico 87185, USA.

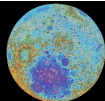
- Potential causal relationship of SPA to global magmatic activity on Moon.



See also Kring et al., 2015, #3009



Rift valleys possibly formed during an episode of crustal magmatism



Was there a relationship between SPA impact event and global lunar magmatic activity?

44th Lunar and Planetary Science Conference (2013)

1563.pdf

EVIDENCE FOR WIDESPREAD MAGMATIC ACTIVITY AT 4.36 GA IN THE LUNAR HIGHLANDS FROM YOUNG AGES DETERMINED ON TROCTOLITE 76535. Lars Borg¹, James Connelly², William Cassata¹, Amy Gaffney¹, Richard Carlson³, Dimitri Papanastassiou⁴, Jerry Wasserburg⁴, Erick Ramon¹, Rachael Lindval¹ and Martin Bizzarro². ¹Chemical Sciences Division, Lawrence Livermore National Laboratory, Livermore CA 94550 USA. ²Centre for Star and Planet Formation, University of Copenhagen, Denmark. ³Department of Terrestrial Magnetism, Washington, DC 20015-1305 USA. ⁴California Institute of Technology, Pasadena CA 91109 USA.

WHAT LUNAR ZIRCON AGES CAN TELL? M. L. Grange^{1,2}, A. A. Nemchin^{1,2}, and N. E. Timms¹, ¹Department of Applied Geology, Curtin University, GPO box 198 (m.grange@curtin.edu.au), ²Centre for Lunar Science and Exploration.

44th Lunar and Planetary Science Conference (2013)

- Recent chronologic evidence for a spike in magmatic activity > 4.3 Ga...
- What was the role of SPA?

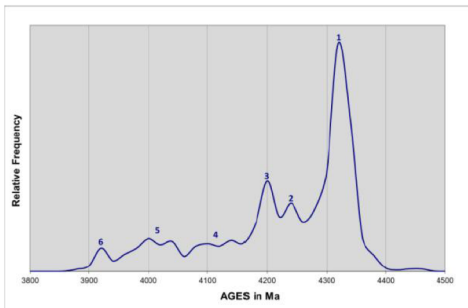
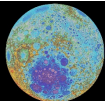


Figure 1: distribution of U-Pb ages of lunar zircon grains from Apollo 12, 14, 14 and 17 landing sites.



Was there a relationship between SPA impact event and global lunar magmatic activity?

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Troctolite 76535: A sample of the Moon's South Pole-Aitken basin?

Ian Garrick-Bethell^{a,b,*}, Katarina Miljković^c, Harald Hiesinger^d, Carolyn H. van der Bogert^d, Matthieu Laneuville^e, David L. Shuster^{f,g}, Donald G. Korycansky^a

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^b School of Space Research, Kyung Hee University, Republic of Korea

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^d Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany

^e Earth-Life Science Institute, Tokyo Institute of Technology, Tokyo, Japan

^f Dept. of Earth and Planetary Science, University of California, Berkeley, CA, USA

^g Berkeley Geochronology Center, Berkeley, CA, USA

- Do we have samples in the Apollo collection that were excavated by the SPA event?

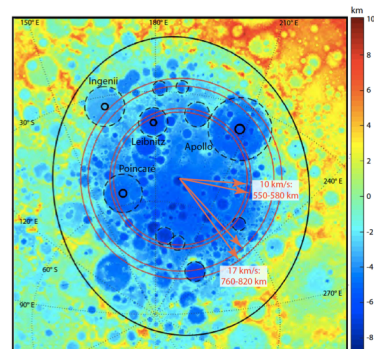
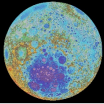


Fig. 17. South Pole-Aitken basin topography and ejecta deposit areas. Black ellipse is the outer topographic boundary defined by Garrick-Bethell and Zuber (2009). The ejecta deposition annuli for material derived from 45 to 65 km depth and shocked <6 GPa, for two different impactor speeds, are shown (red lines, centered at 53.2° S, 191° E, also shown in Fig. 16). Dashed black circles highlight some of the largest candidate craters for spalling sample 76535 to the nearside. Smaller solid black circles represent the area within $\Delta R_e = 1.5-1.75$



Importance of SPA “Chronology”

Was the impact that caused the SPA basin part of the Late-Heavy Bombardment?

Imbrium dominates Apollo sample chronology.

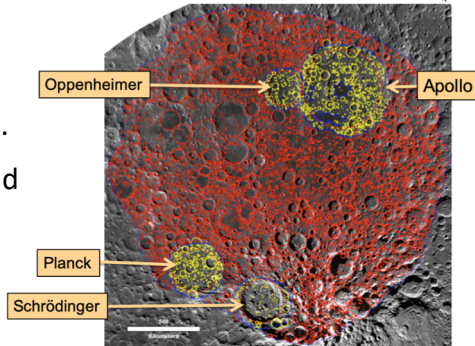
Age of Nectaris is uncertain, but key to the Cataclysm hypothesis.

The “chronology” of SPA and the basins and large craters contained within it are needed to test the Cataclysm.

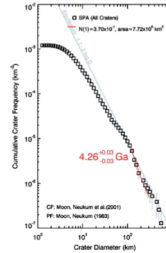
43rd Lunar and Planetary Science Conference (2012)

2863.pdf

NEW CRATER SIZE-FREQUENCY DISTRIBUTION MEASUREMENTS OF THE SOUTH POLE-AITKEN BASIN. H. Hiesinger¹, C. H. van der Bogert¹, J. H. Pasckert¹, N. Schmedemann², M.S. Robinson³, B. Jolliff⁴, and N. Petro⁵; ¹Institut für Planetologie (IfP), WWU Münster, Wilhelm-Klemm-Straße 10, 48149 Münster,



Model age of SPA basin



Apollo: ~3.91 Ga
 Planck: 4.09 Ga
 Schrödinger: 3.92 Ga
 Oppenheimer: 4.04 Ga

Problem: Chronology poorly constrained >4 Ga

Relative ages of basins within SPA

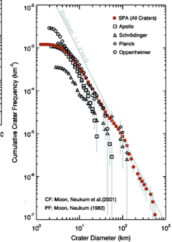


Figure 2. SPA count area (blue) and counted craters (red) within the SPA basin. Craters superposed on Planck, Oppenheimer, Schrödinger, and Apollo craters/basins shown in yellow.



Importance of SPA “Chronology”

Was the impact that created the SPA basin part of the Late-Heavy Bombardment?

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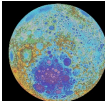
Age of Nectaris is uncertain, but key to the Cataclysm hypothesis.

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SPA

Clarifying the magnitude and length of the Late Heavy Bombardment has implications across the full range of planetary geosciences, from understanding the dynamical evolution of the Solar system to surface conditions on the terrestrial planets early in their history.

Fassett and Minton, 2013, Nature Geoscience



Conclusions

South Pole-Aitken Basin Sample Return remains a high priority objective for Solar System Science

- as stated by two previous Planetary Science Decadal Surveys (NRC, 2003; NRC, 2011)
- > Test of the Cataclysm hypothesis. *Need the SPA impact chronology.*
- > If Cataclysm occurred, what caused it?
 - Giant planet migration? When?
- > What will the samples reveal about nearside-farside asymmetry?
 - Volcanic samples → lunar mantle
 - Are there direct samples of mantle rocks in SPA breccias?
 - KREEPy samples: is KREEP globally uniform?
- > What were the effects of the giant SPA impact on the thermal and magmatic evolution of the Moon?
 - Did SPA trigger a global magmatic episode?

SPA

SPA Chronology bears on Solar System issues; New Frontiers category science.