# Chronos Program

## Unraveling the bombardment history of the inner Solar System*

**Lunar Science for *Landed Missions Workshop*, NASA Ames, Jan 2018**

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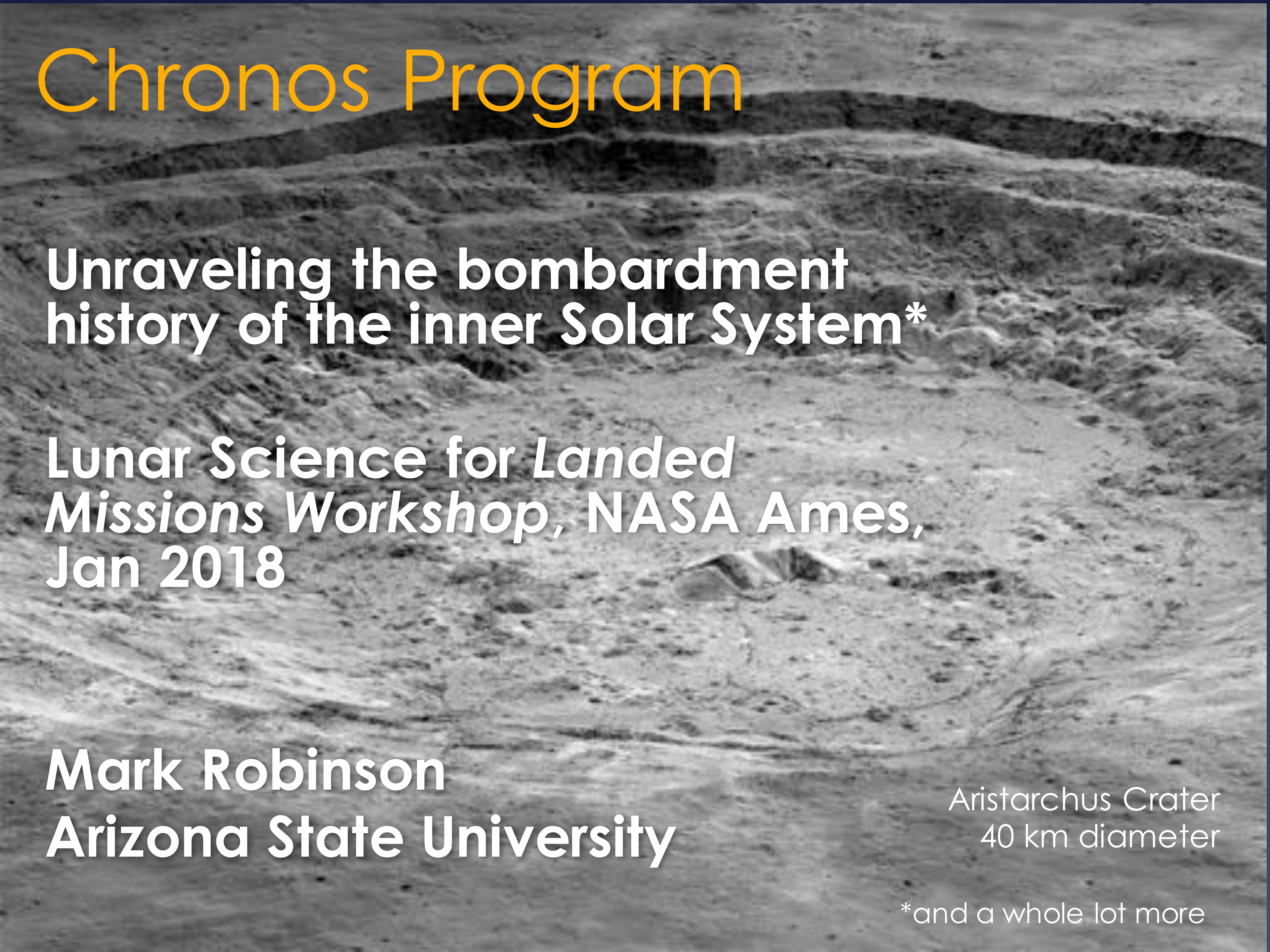


Aristarchus Crater
40 km diameter

*and a whole lot more

# Chronos Program

## Rationale

Determine timing of key events on the Moon and thus within the Solar System, by developing a sustainable lunar sample return program with future relevance to Mars Sample Return

## Need

Understand conditions within the early Solar System and the evolution of the Moon

# Goals

*Primary* – Determine the age of formation of key landforms on the Moon over a ~4 billion year period

- Calibration points for the lunar cratering chronology are missing for events >3.8 Ga and for about 3.0-1.0 Ga
- Unequivocal samples for many large basins are missing from the collection

*Secondary* – Determine the geochemical evolution of the Moon over time

# Objectives

Develop a cost effective robotic system to collect and bring samples from multiple locations with return to Earth from lunar orbiting asset

1) land safely and accurately within ± 100 m of assigned target
2) collect appropriate sample for radiometric age sampling
3) store sample in sealed container
4) return sample to Earth in pristine state

# Most Important Plot in Planetary Sciences?

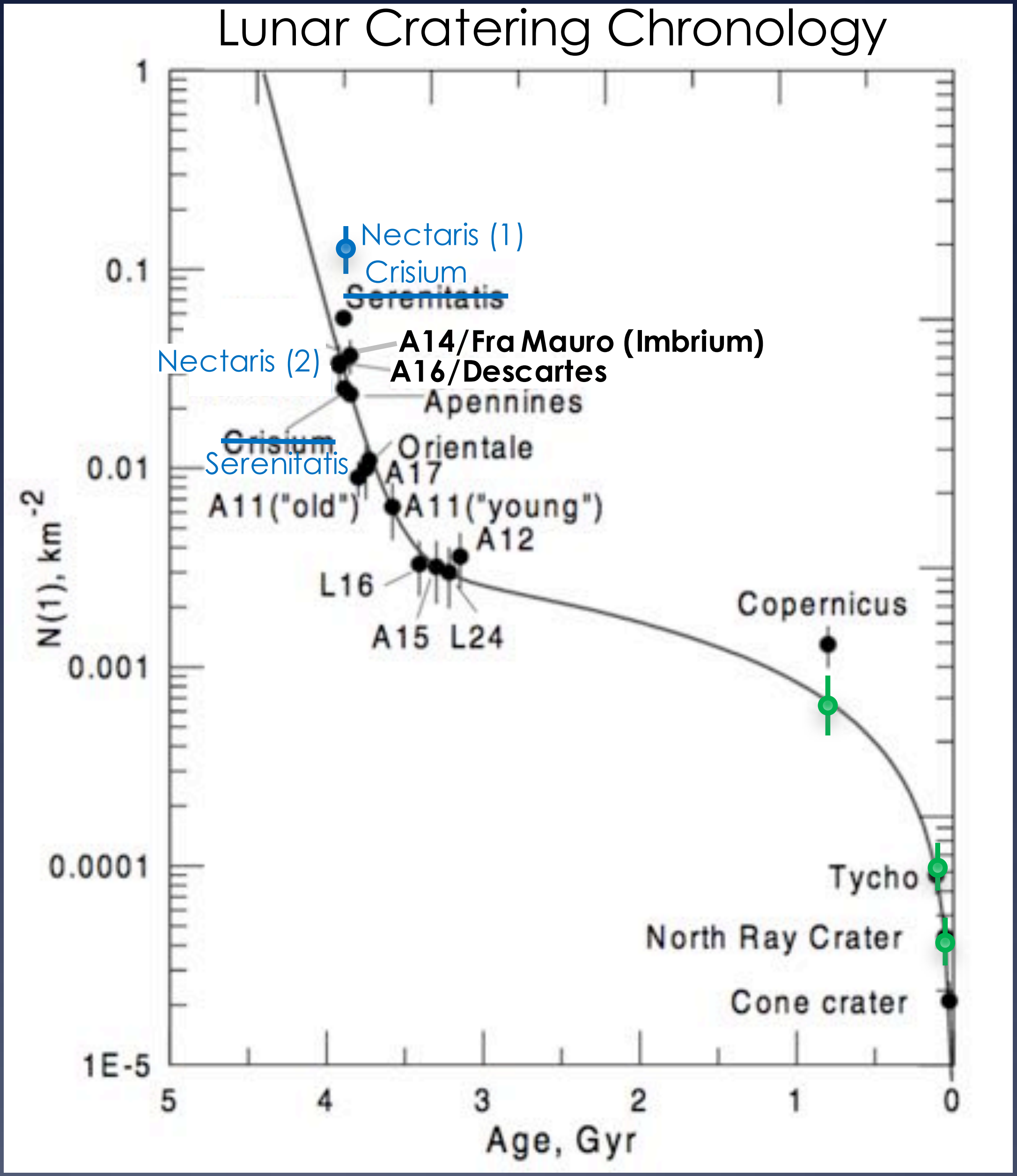
Cratering chronology used to derive absolute model ages on the Moon (and other terrestrial planets, moons, and asteroids)

Challenges:
-Assignment of current samples to specific basin events,

-Effects of target properties/self-secondary cratering on CSFDs of young craters

Chronology best defined by Fra Mauro, Descartes, mare basalts, and Copernican craters

Extreme view is that we only know one basin age: Imbrium!


Lunar Cratering Chronology

Chronology as summarized in Stöffler and Ryder (2001), with updated sample associations (Stöffler et al. 2006; blue), and updated N(1) values (Hiesinger et al. 2012; green)

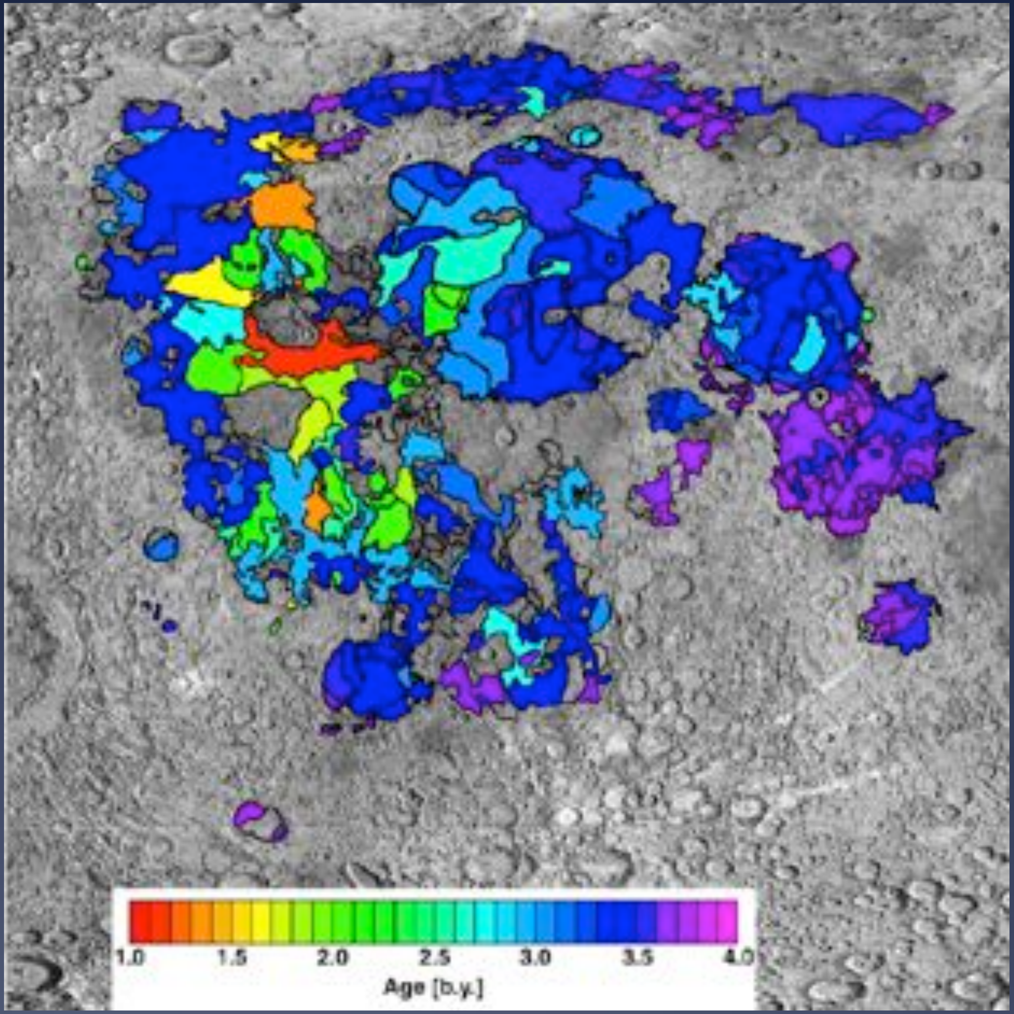
# CSFD
# Model Ages

CSFDs allow dating of unsampled units across the Moon (and solar system), e.g.,

- Mare basalt units defined via spectral data
- Geomorphological units
- Impact melt, ejecta, and basin deposits
- Non-mare volcanics
- Structural features (lobate scarps, wrinkle ridges, graben)

CSFDs provide reliable relative ages

Quality of absolute age results depends on the precision/accuracy of the chronology function



Hiesinger et al., 2003

# Chronos
# Basic ConOps

- From lunar orbit
- Land precisely and safely
- Obtain and seal relevant sample, document sample area
- Return sample to orbital asset for eventual Earth return
- Refuel
- Repeat...

Orion

Deep Space Gateway

# Potential Sampling Locations

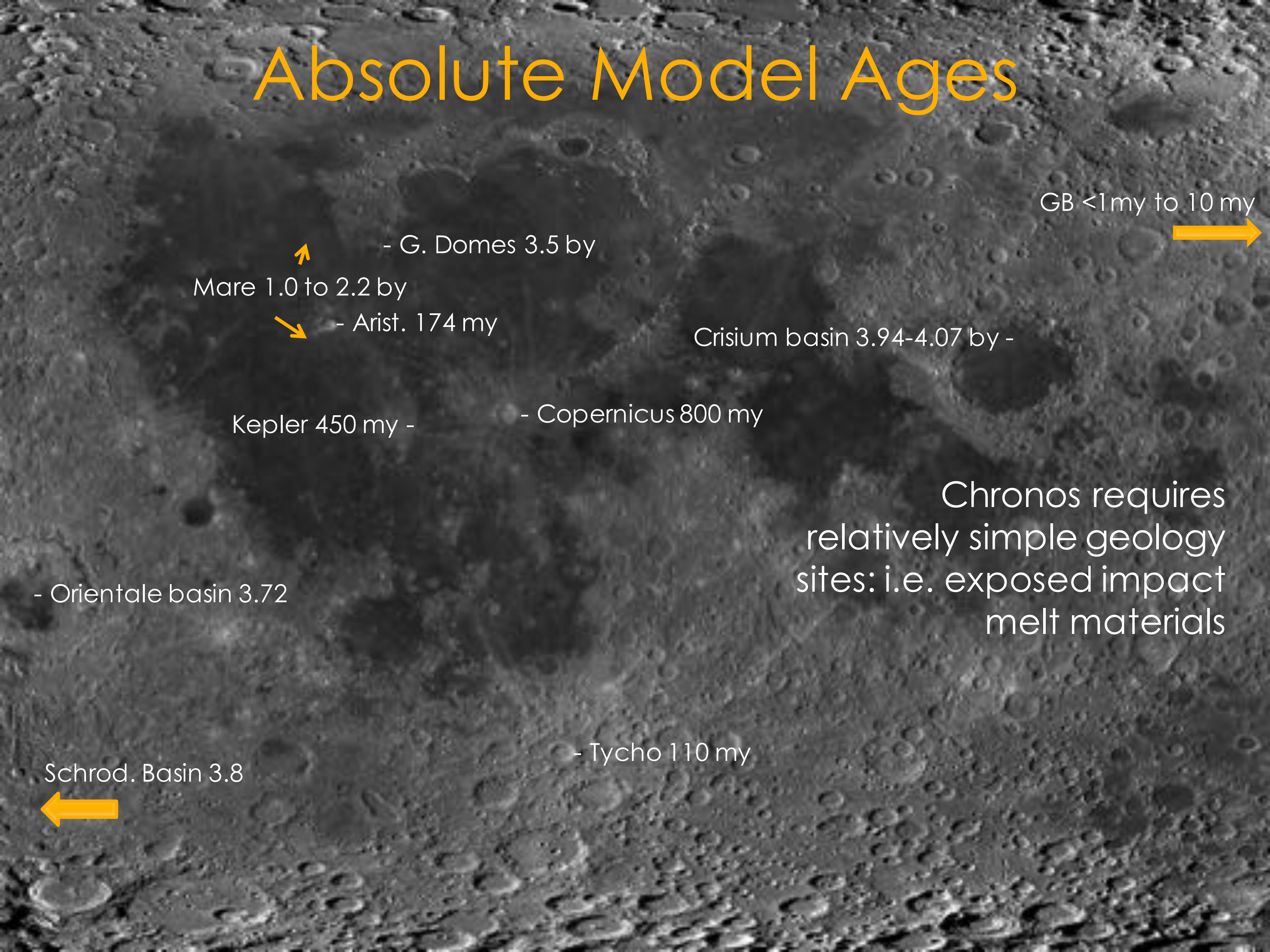
Chronos landing sites and best estimated ages from the literature.

In this example nine nearside locations and 2 farside locations

EXAMPLE ONLY – MANY MANY VIABLE TARGET SETS

| Sampling Site | Latitude | Longitude | Est. Age (MY) |
|---|---|---|---|
| Kepler | 7.757° N | 322.510° E | 450 |
| Aristarchus | 23.723° N | 312.548° E | 174 |
| Gruithuisen | 36.550° N | 319.483° E | 3500 |
| Oc. Proc. P39 | 35.42° N | 304.66° E | 2200 |
| Tycho | 42.800° S | 350.565° E | 110 |
| Copernicus | 9.888° N | 339.982° E | 810 |
| Oc. Proc. P60 | 22.49° N | 306.31° E | 1200 |
| Orientale | 17.147° S | 260.777° E | 3720 |
| Schrödinger | 75.672° S | 130.493° E | 3800 |
| Crisium | 22.593° N | 63.911° E | 3940-4070 |
| Giordano Bruno | 36.318° N | 102.588° E | <10 |

# Absolute Model Ages



GB <1my to 10 my

- G. Domes 3.5 by

Mare 1.0 to 2.2 by

- Arist. 174 my

Crisium basin 3.94-4.07 by -

Kepler 450 my -

- Copernicus 800 my

- Orientale basin 3.72

- Tycho 110 my

Schrod. Basin 3.8

Chronos requires relatively simple geology sites: i.e. exposed impact melt materials

# Value of Returned Samples

- See other talks at this meeting! Also SCEM report, NAC Meeting report, Planetary Decadal Study, so on and so forth. Finally, corner Clive and ask him if sample return is useful.

# Constraints

Giordano Bruno
1000 yrs to 10 my

- Cost
  - NASA led development cost ≤New Frontiers mission ($900M), subsequent flights should be *substantially* less (fuel, container, ops)
  - Private industry led, substantially lower cost?
- Design lifetime: ten round trips (orbit to lunar surface)
- Minimize risk through minimalist design, no Christmas trees
- Mass is everything (grapple, no extras)

# Potential Engineering Feed Forward Benefits

- Autonomous hazard avoidance at terminal stage of descent
- Perfect sampling and sealing operations and technology
- Perfect return capsule capture by orbital asset (human or robotic control)

Single Mars sample return mission is estimated to cost between $5 and$ 20 billion

# Value of Chronos Program

- Better known sample provenance

- Expand to events with ages >3.8 Ga and about 3.0-1.0 Ga

- Explore target property and self-secondary effects for CSFD measurements

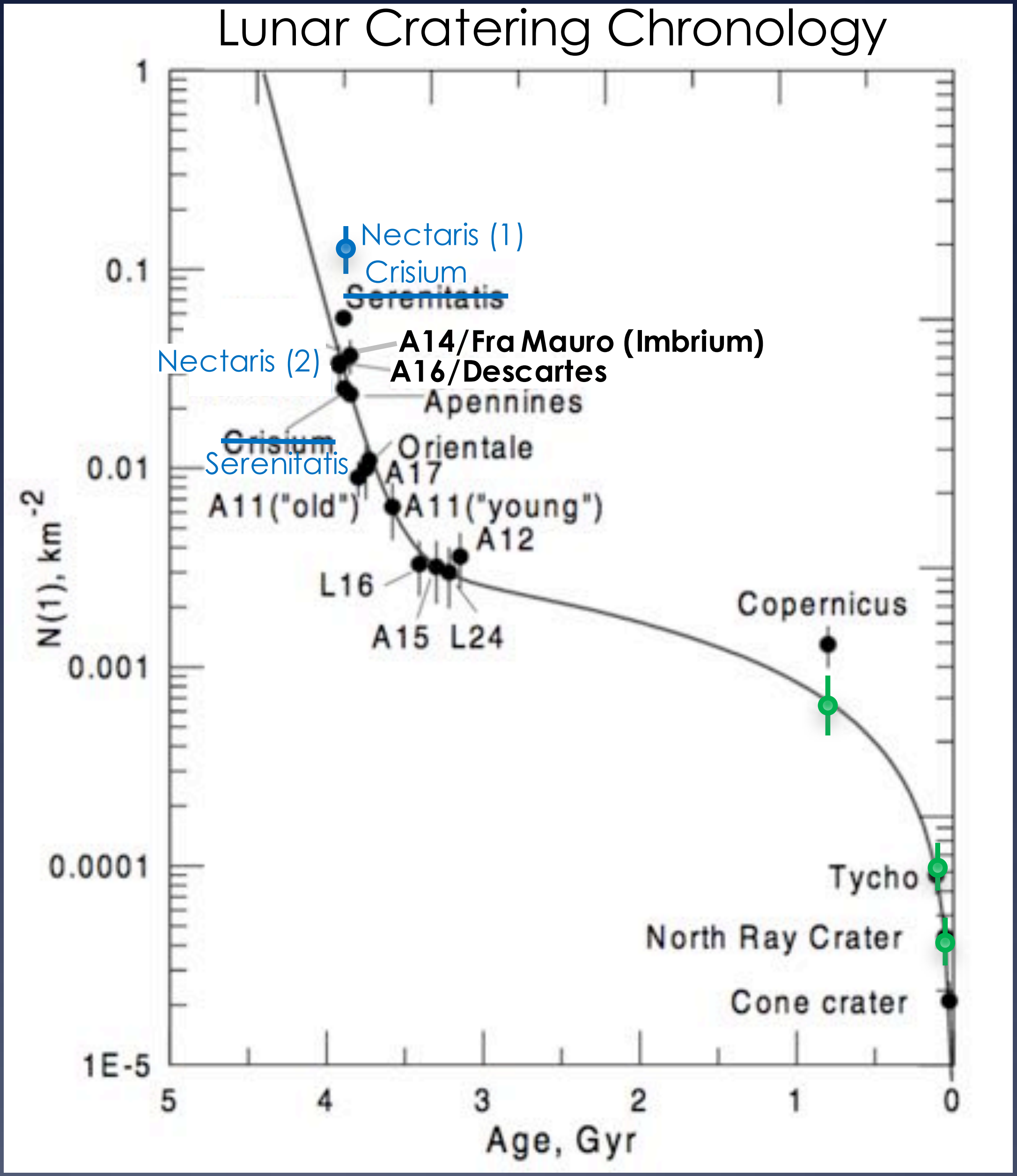
- Illuminate early solar system bombardment

- And the geochemistry!

- Technology development

- Complements human return

How could we not proceed?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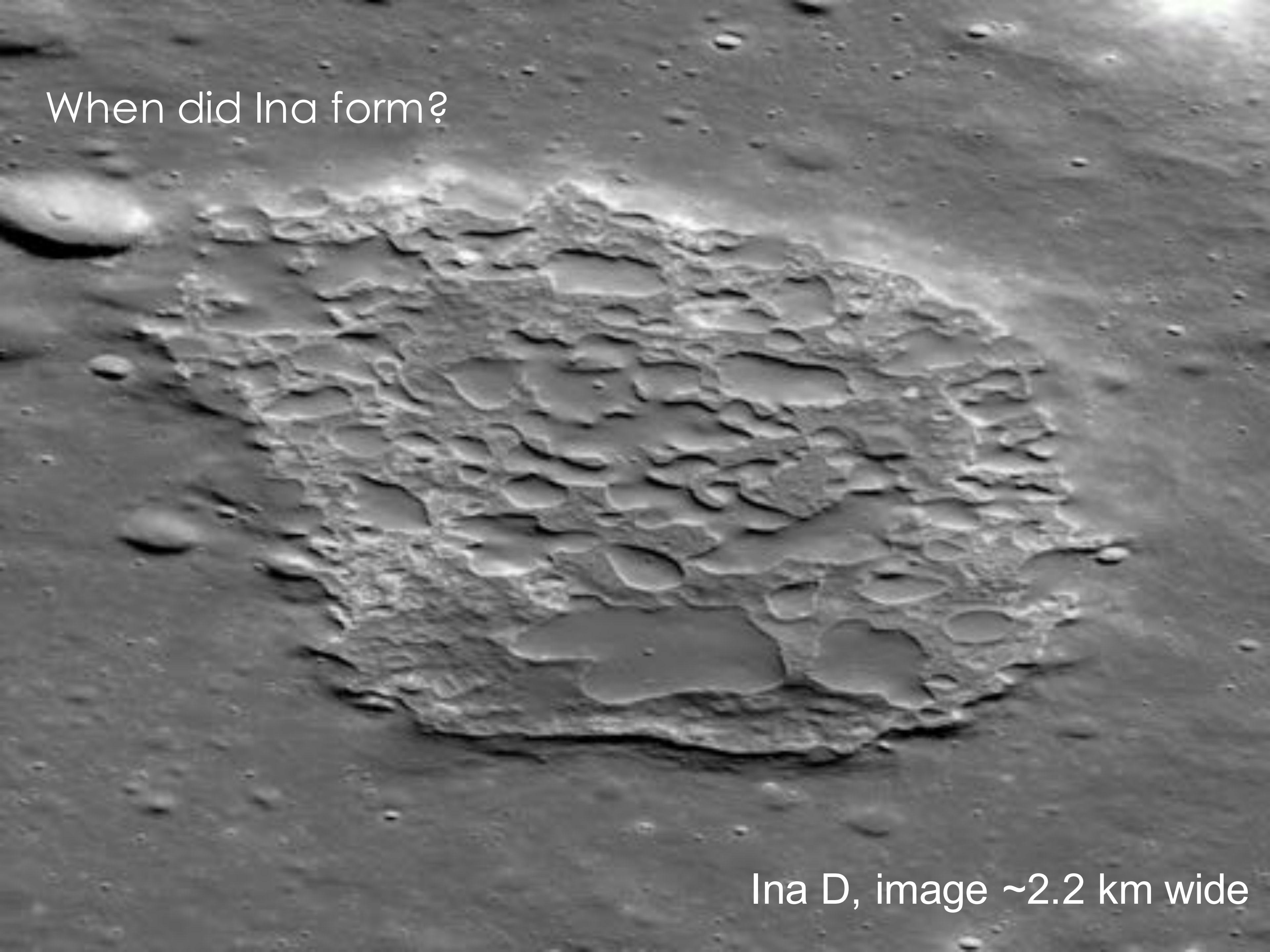
# When did Ina form?



Ina D, image ~2.2 km wide