Image credit: NASA/GSFC/Arizona State University

What do Apollo impact glasses tell us about post-Copernican impact flux?

Presenter: Ya-Huei Huang

Date: November 6, 2018 @ GSA, Indianapolis

AUBURN UNIVERSITY

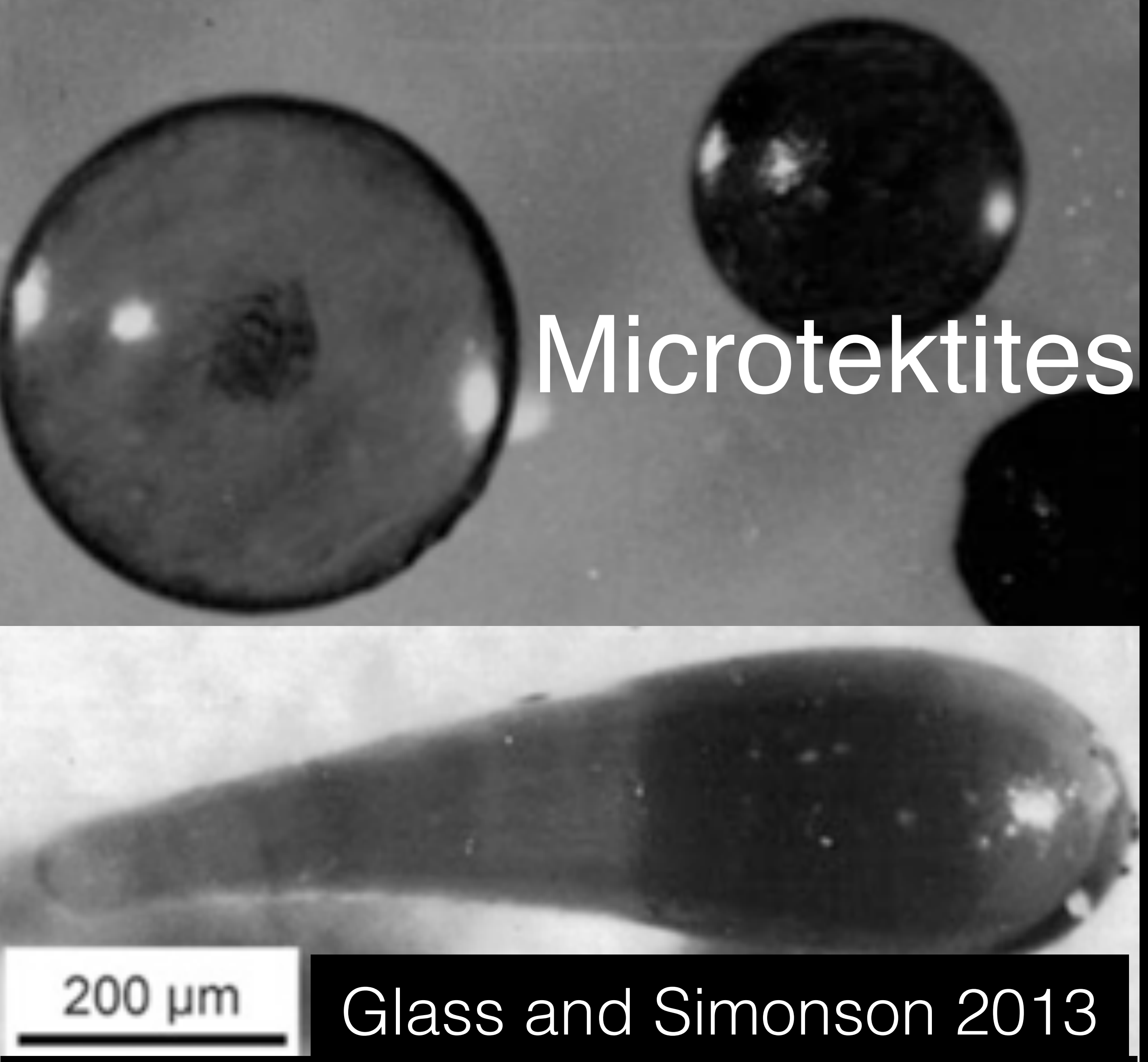
PURDUE

NASA Marshall Space Flight Center

ALBION COLLEGE

MICHIGAN STATE UNIVERSITY Founded 1855

Thanks to my collaborators: David Minton, Nicolle Zellner, Caleb Fassett, Masatoshi Hirabayashi, Jacob Elliott, Pham Qui Nguyen



EARTH

Impact glass spherule in lunar soil samples are physical evidence of impact-driven material transport and not uncommon in other planetary bodies of the Solar System.

MOON

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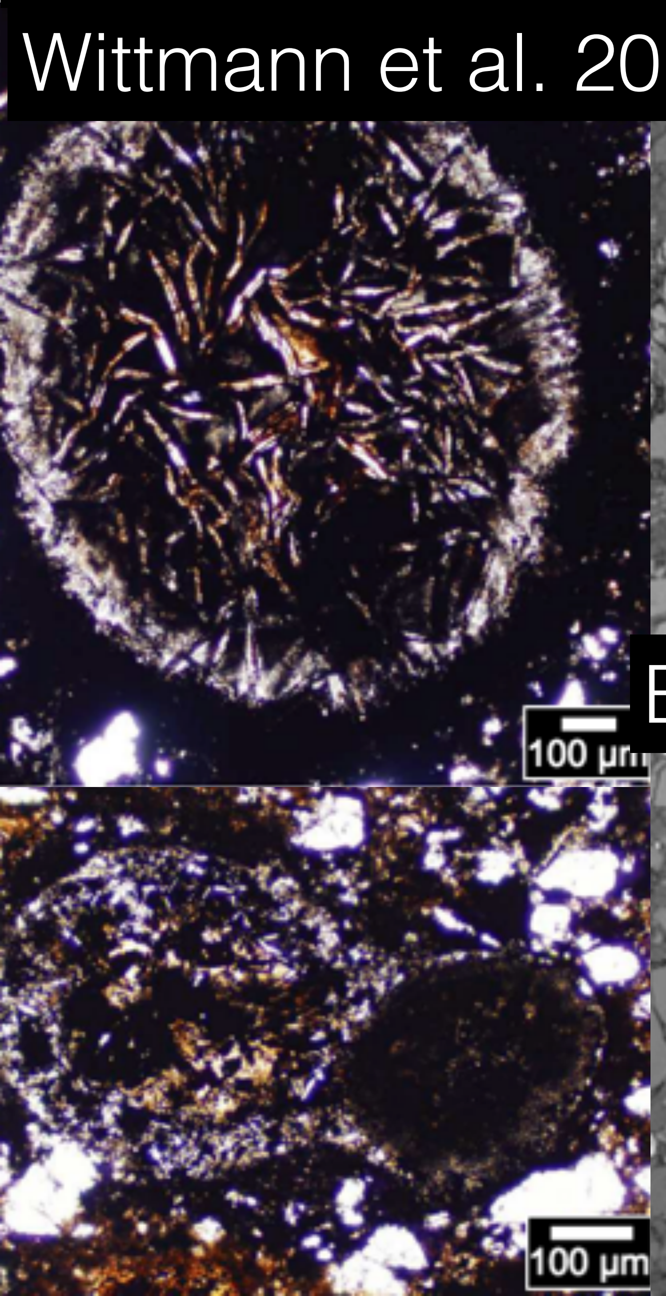

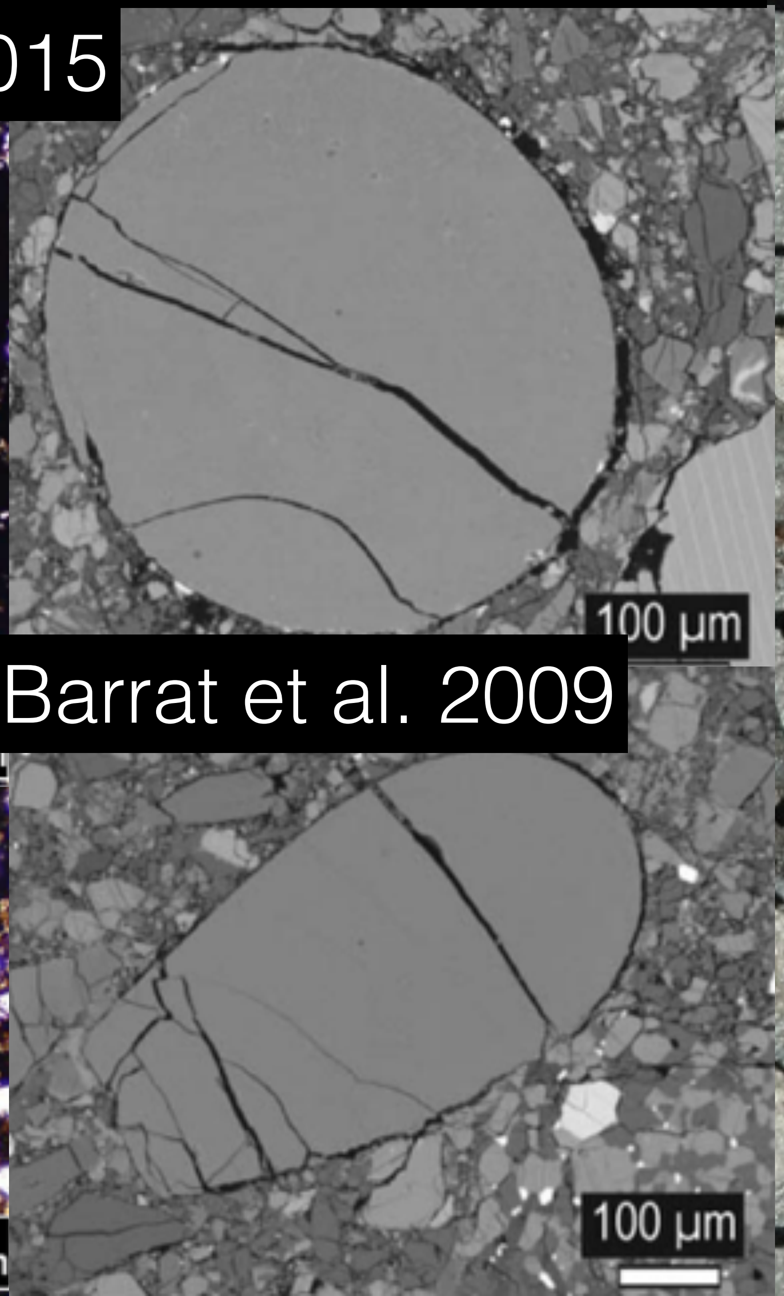

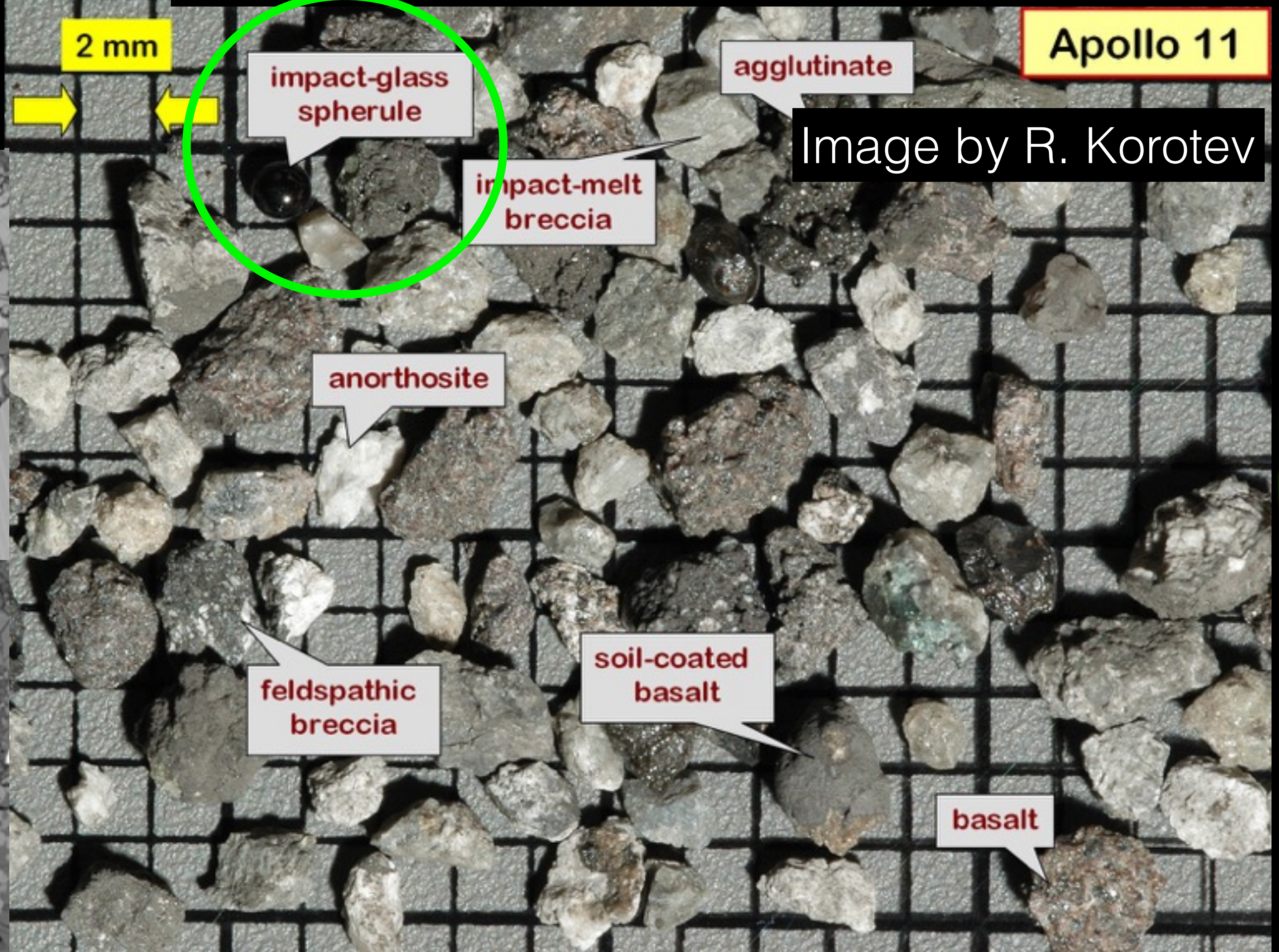

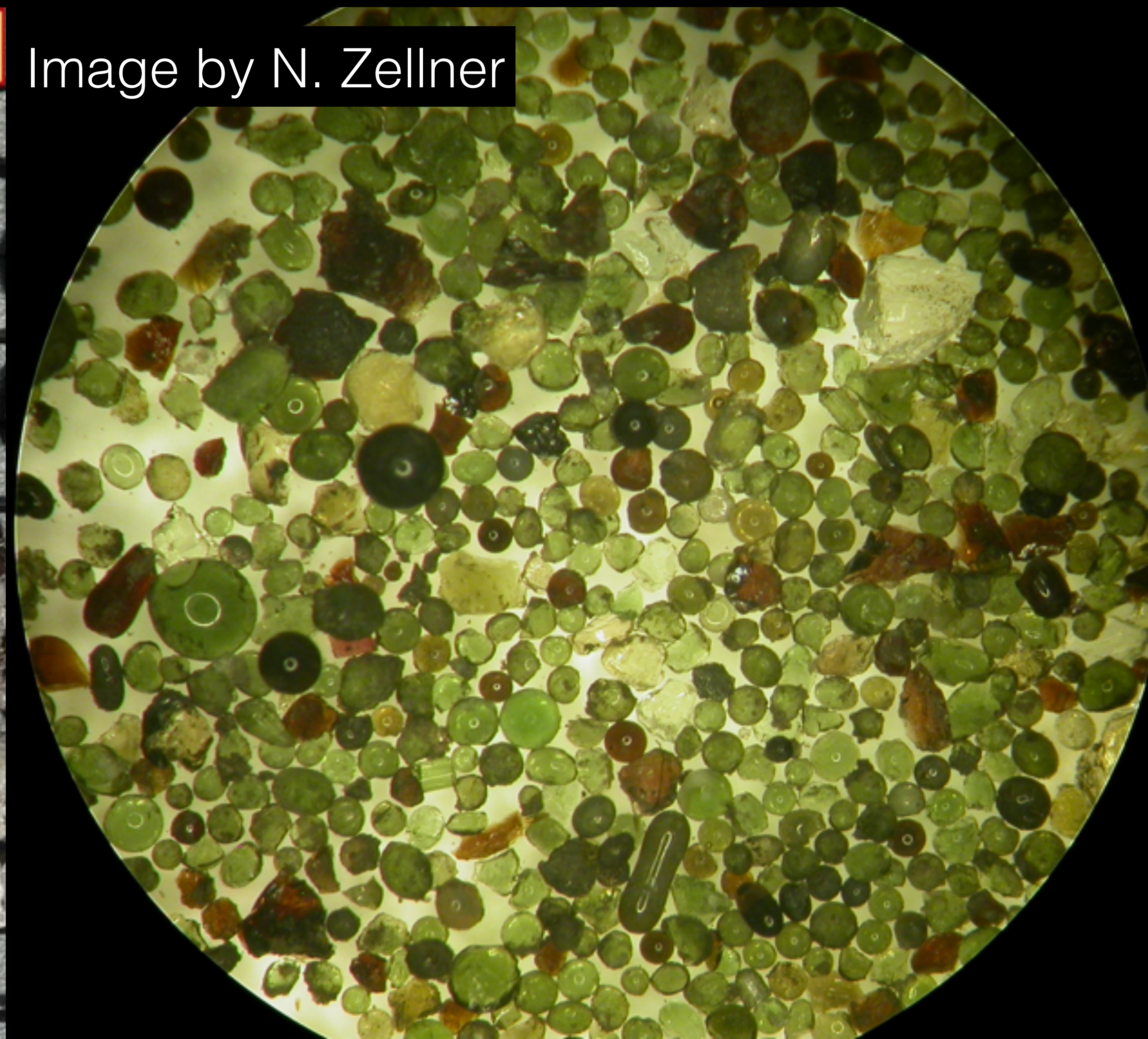

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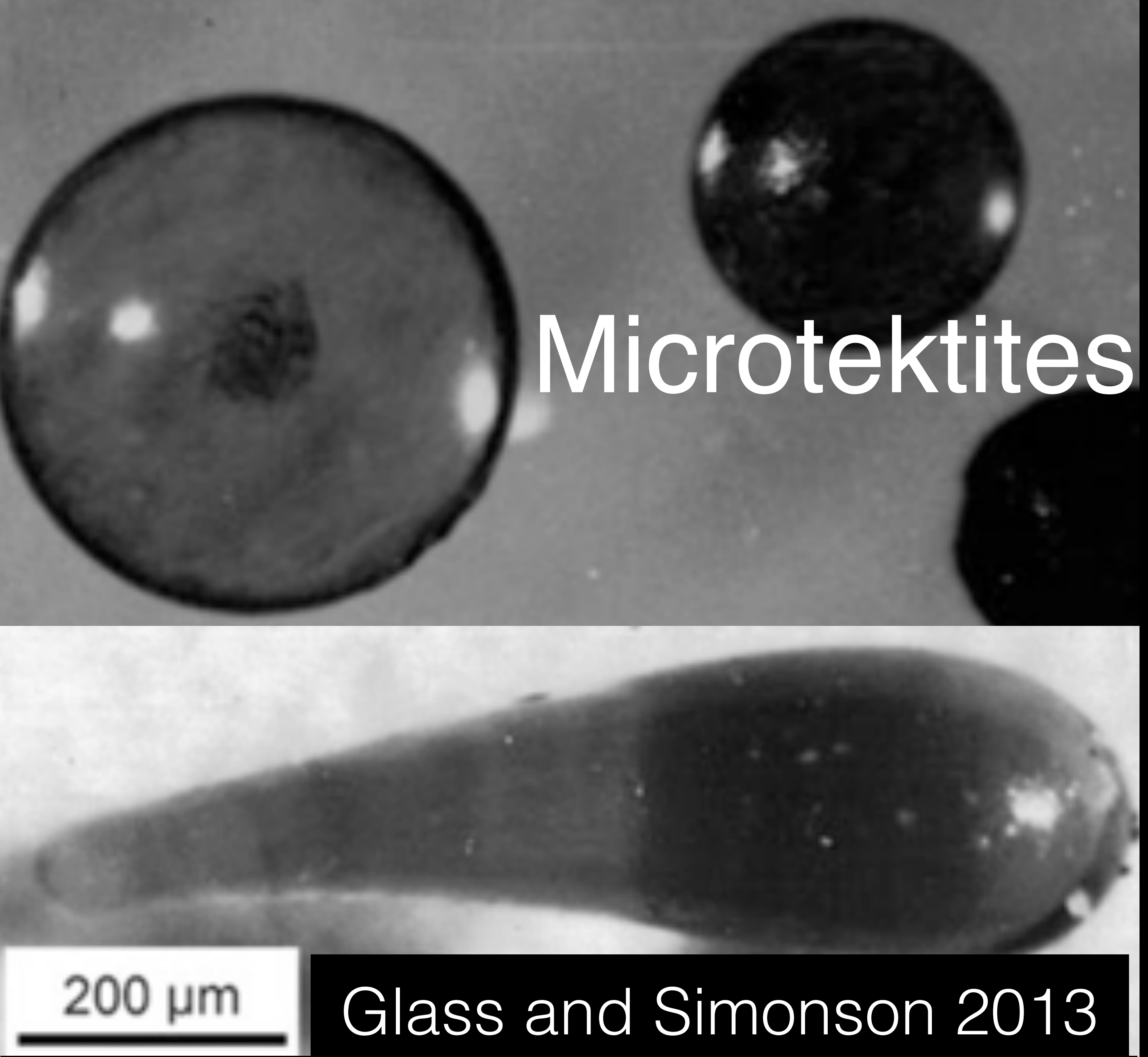

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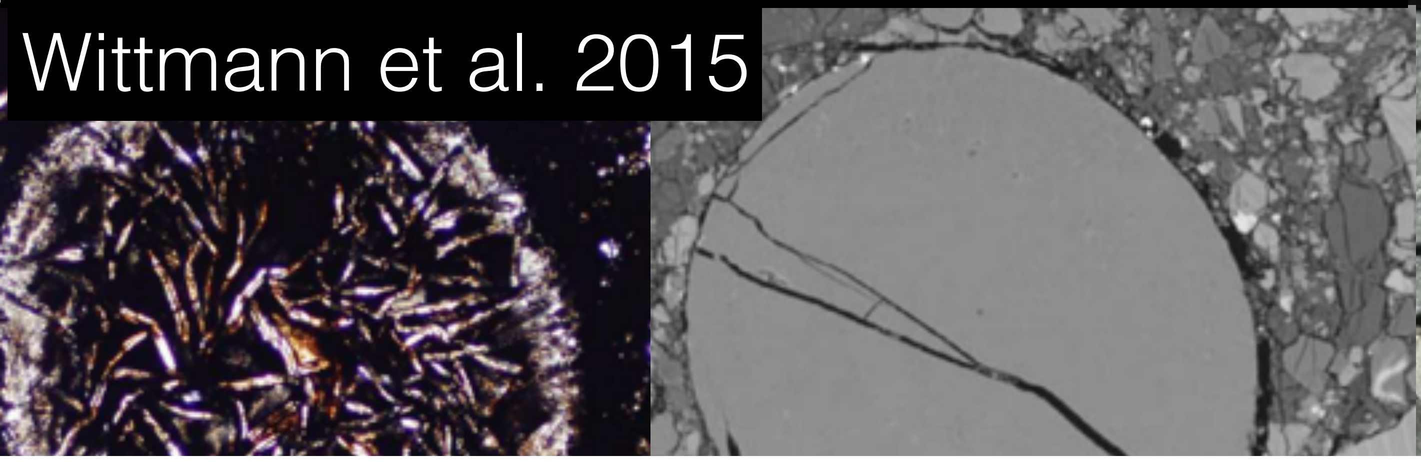
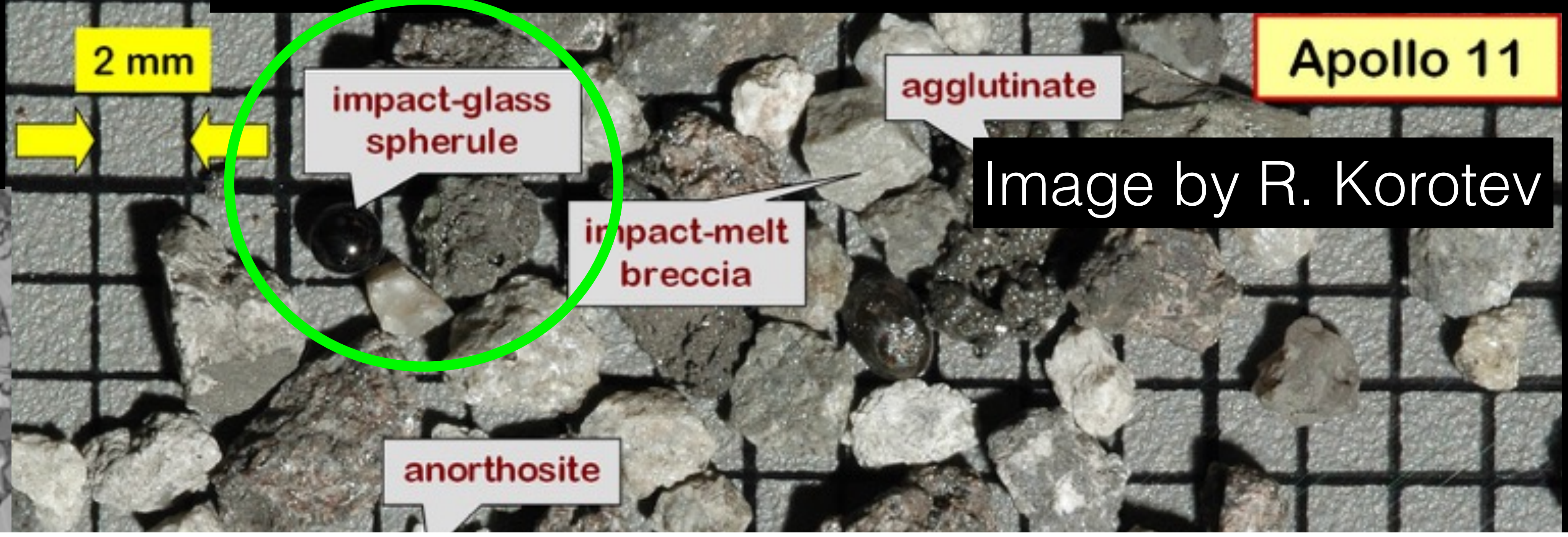
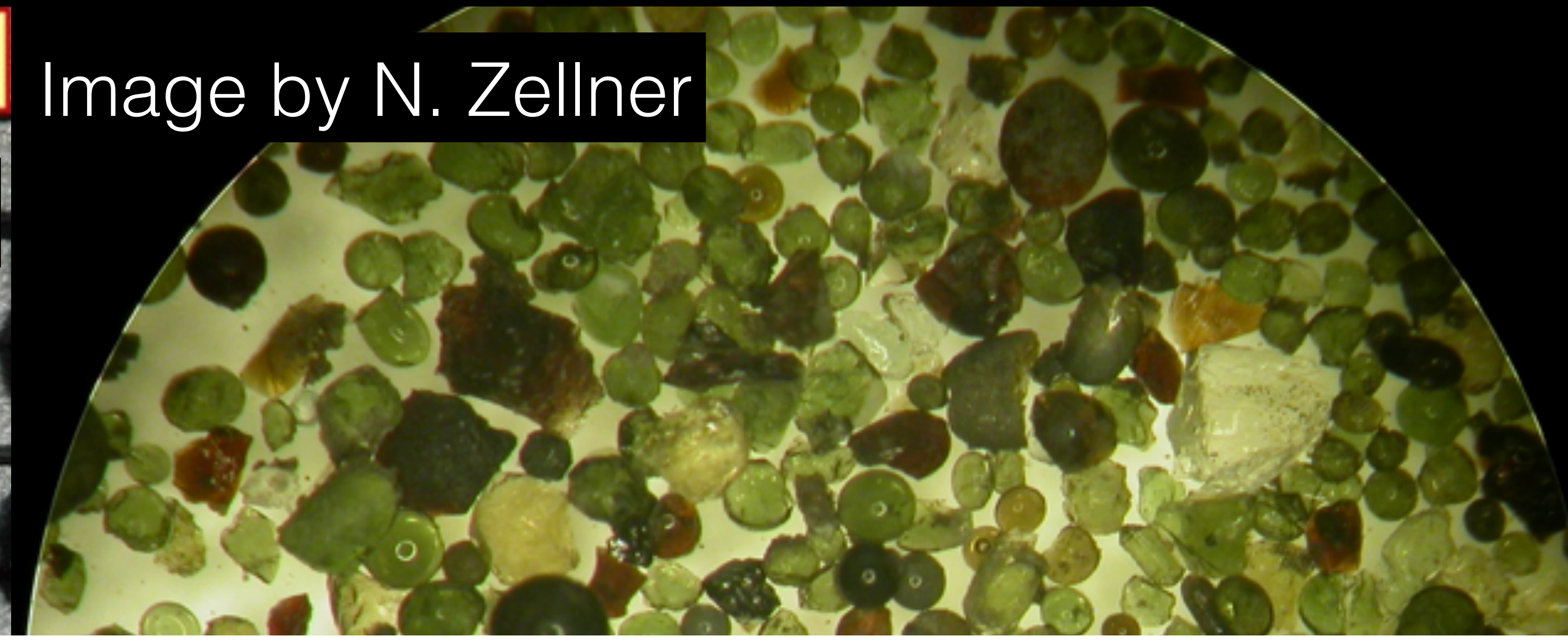
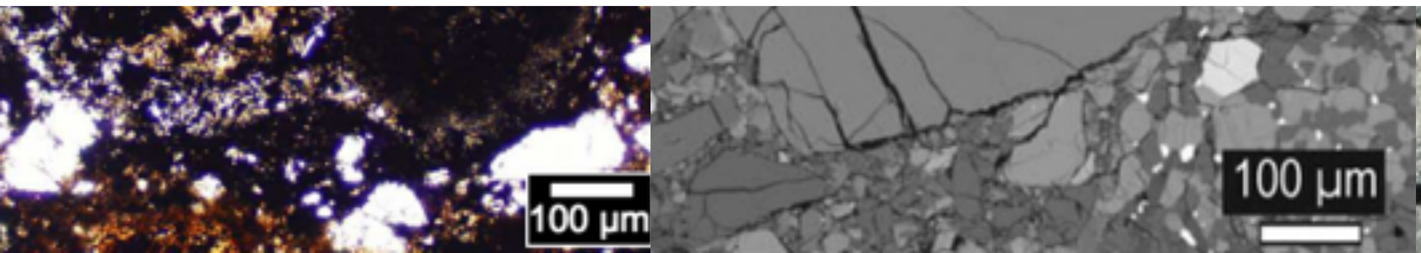
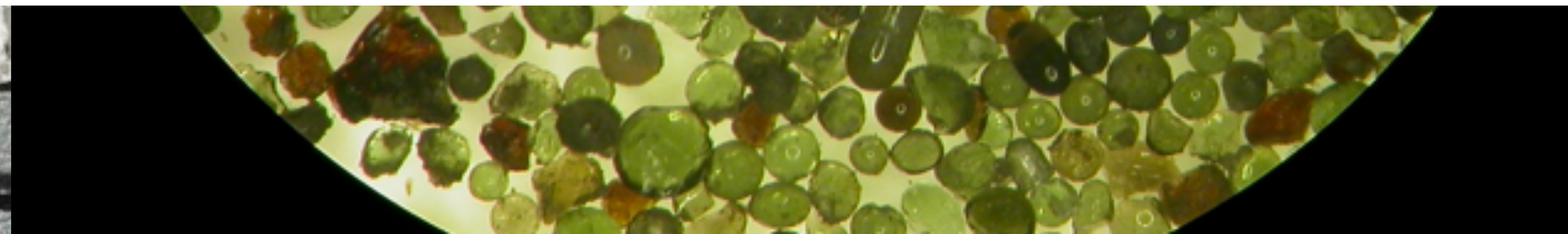




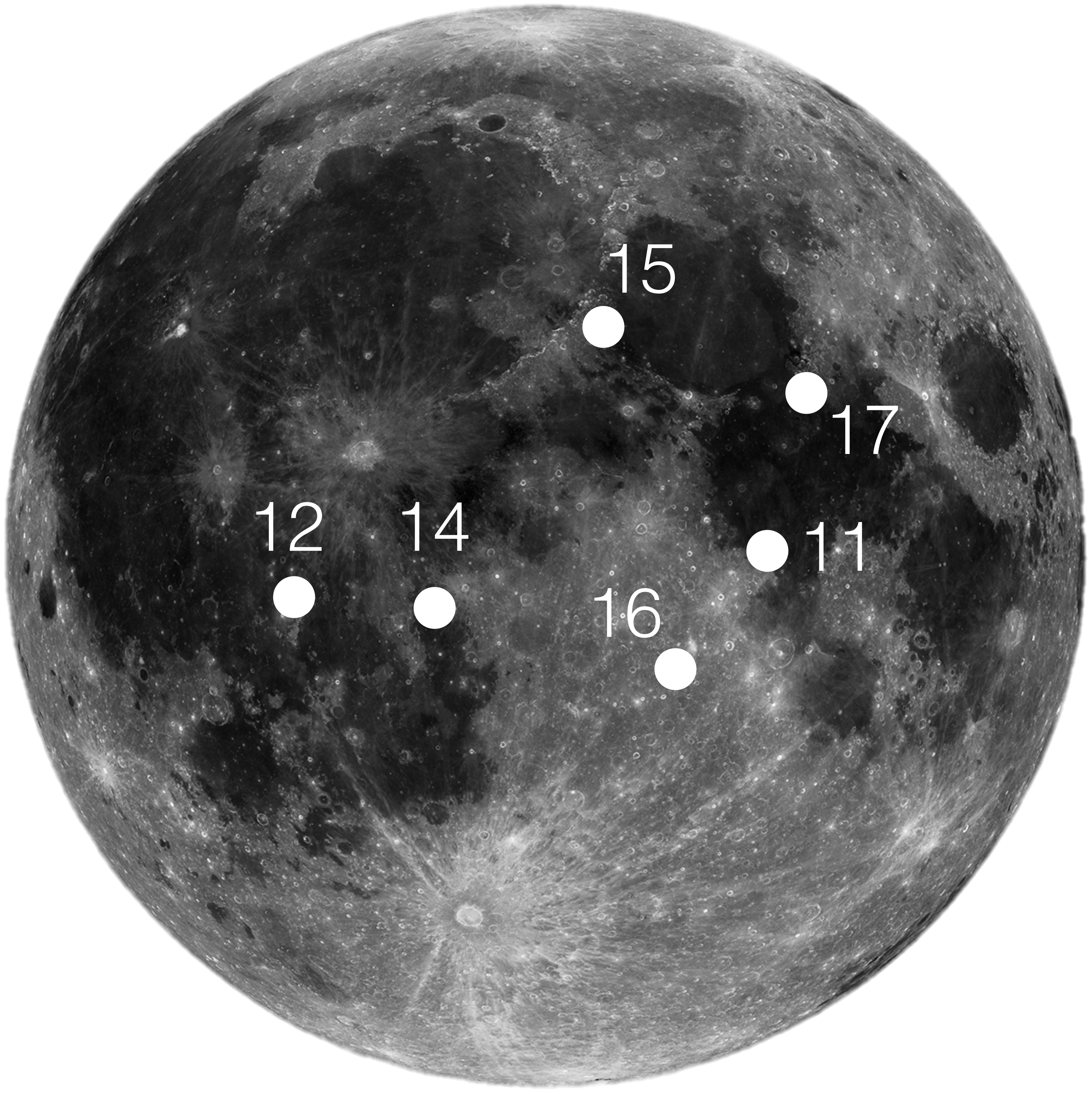


The fact of submillimeter in sizes of impact glass spherules indicates a similar physics process across different planetary bodies that form them.





The 40Ar-39Ar age distributions of lunar glass spherules in many soil samples show an excess at <500 Ma.



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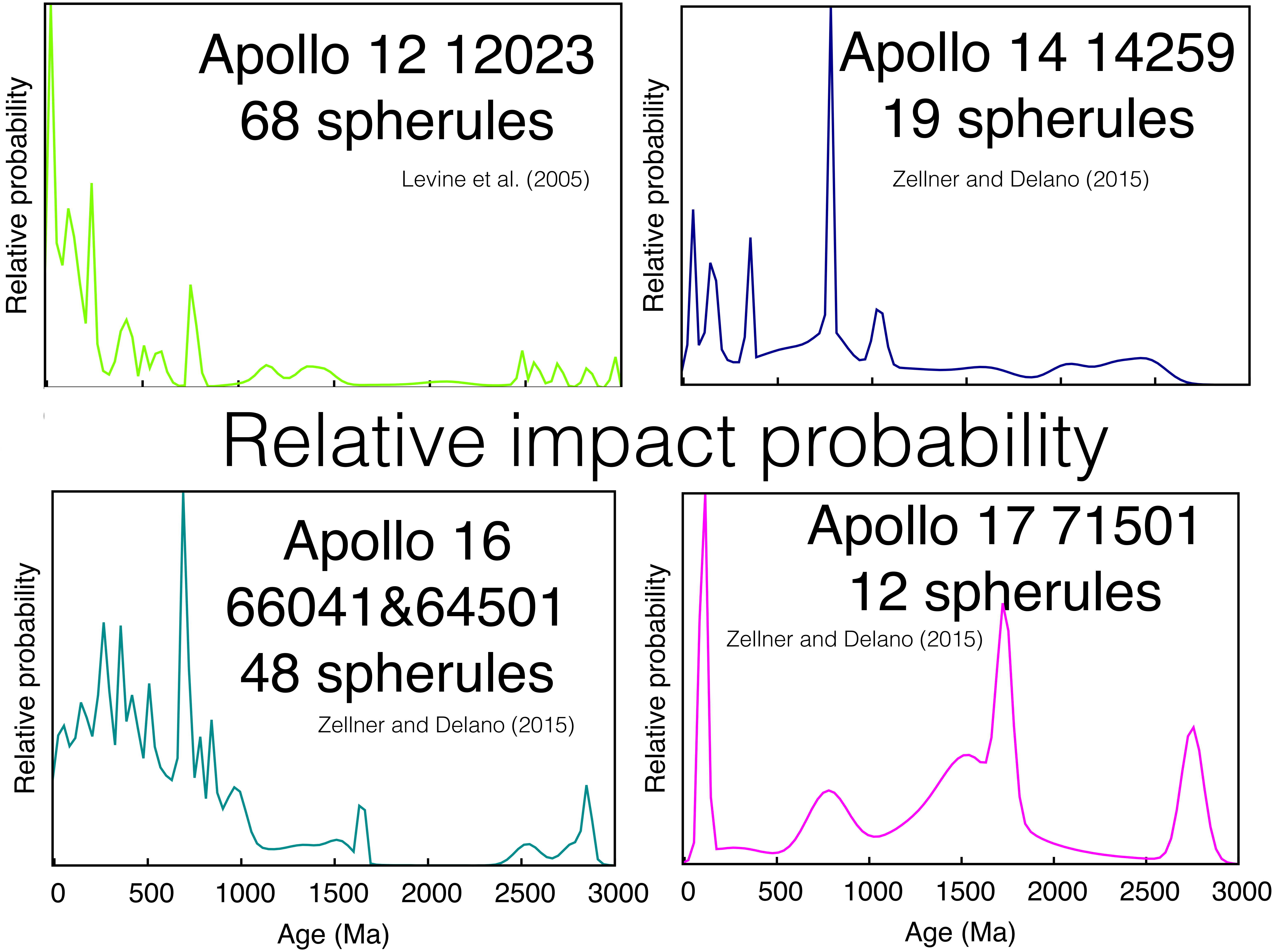

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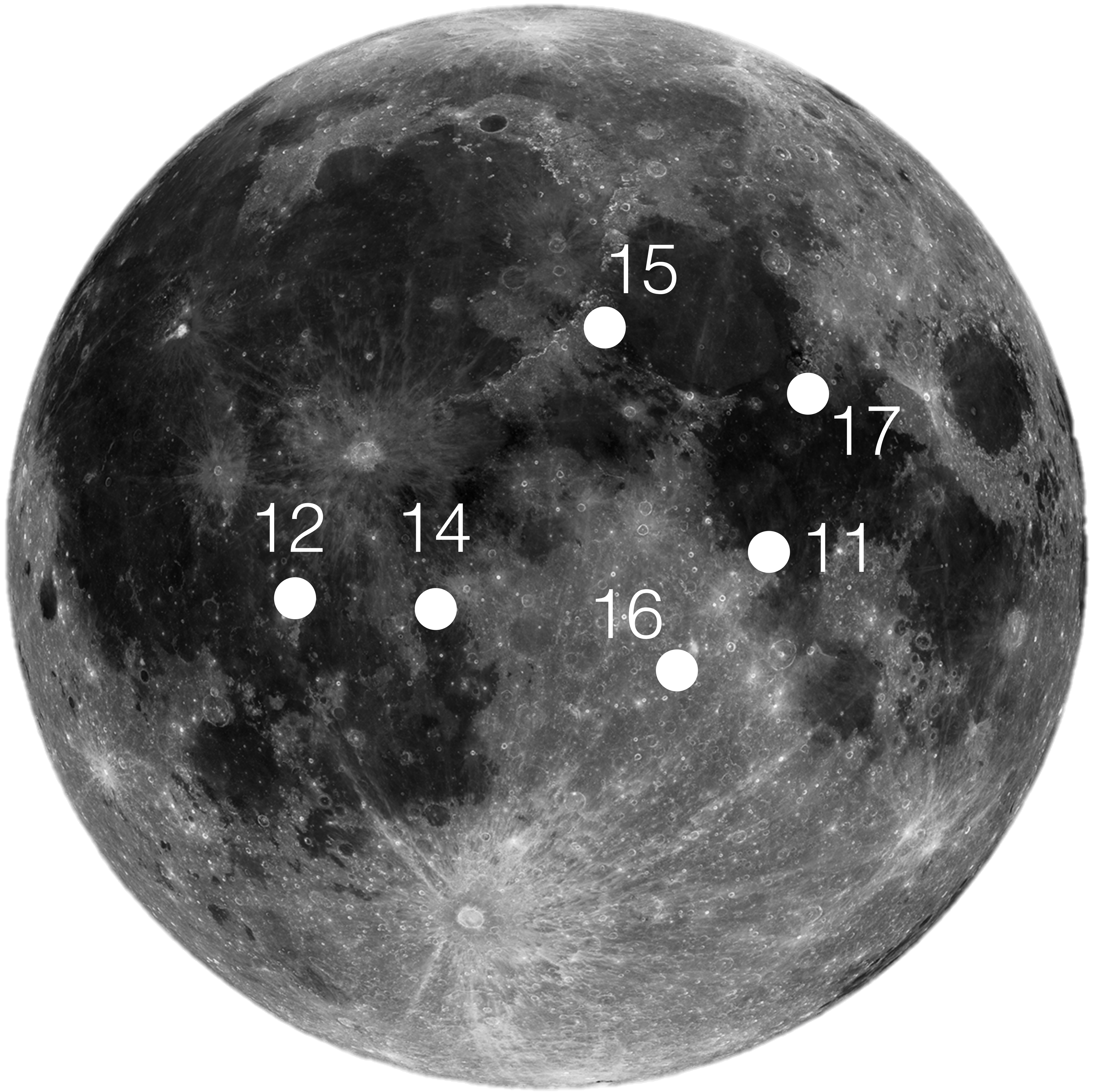

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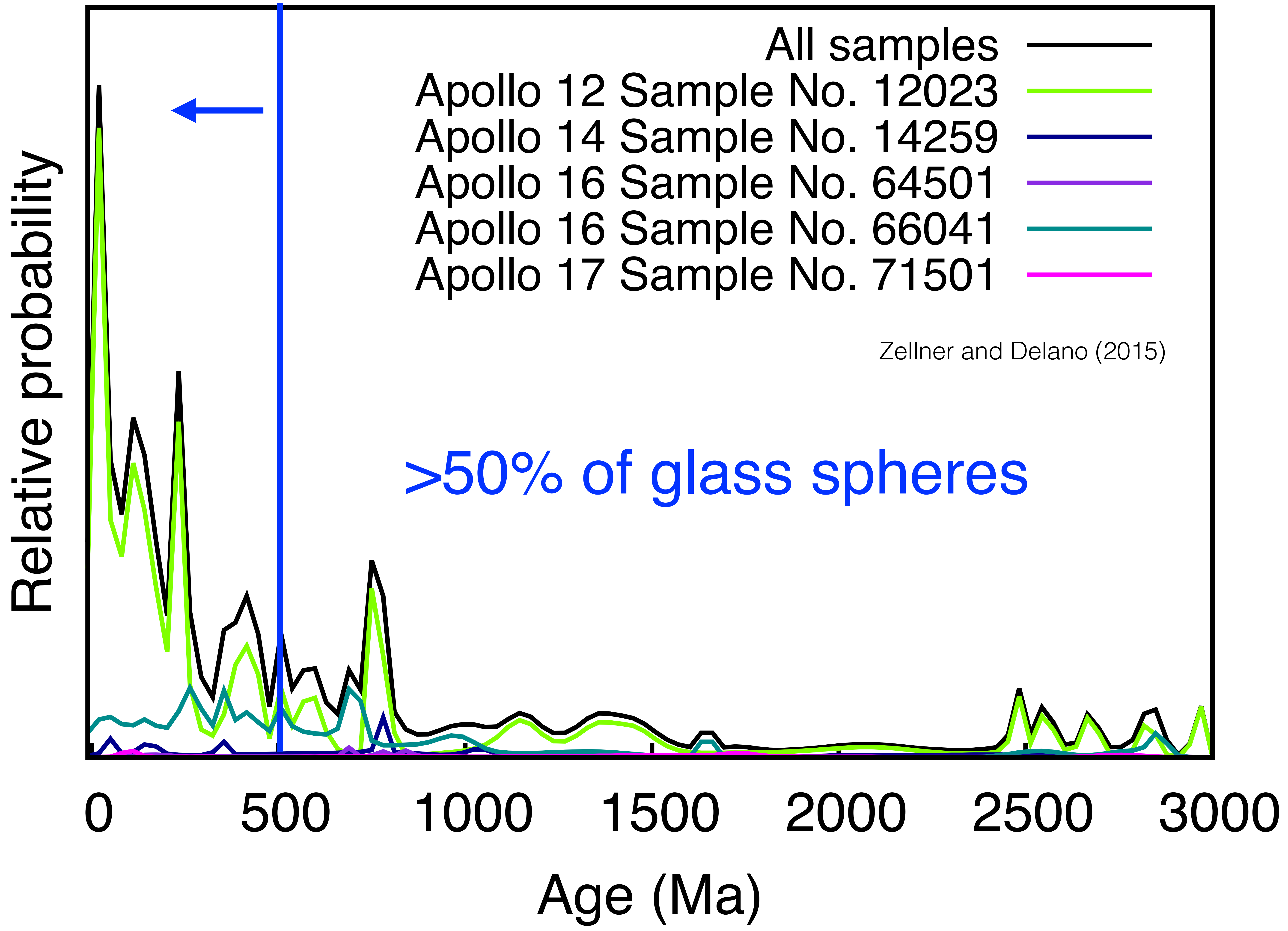

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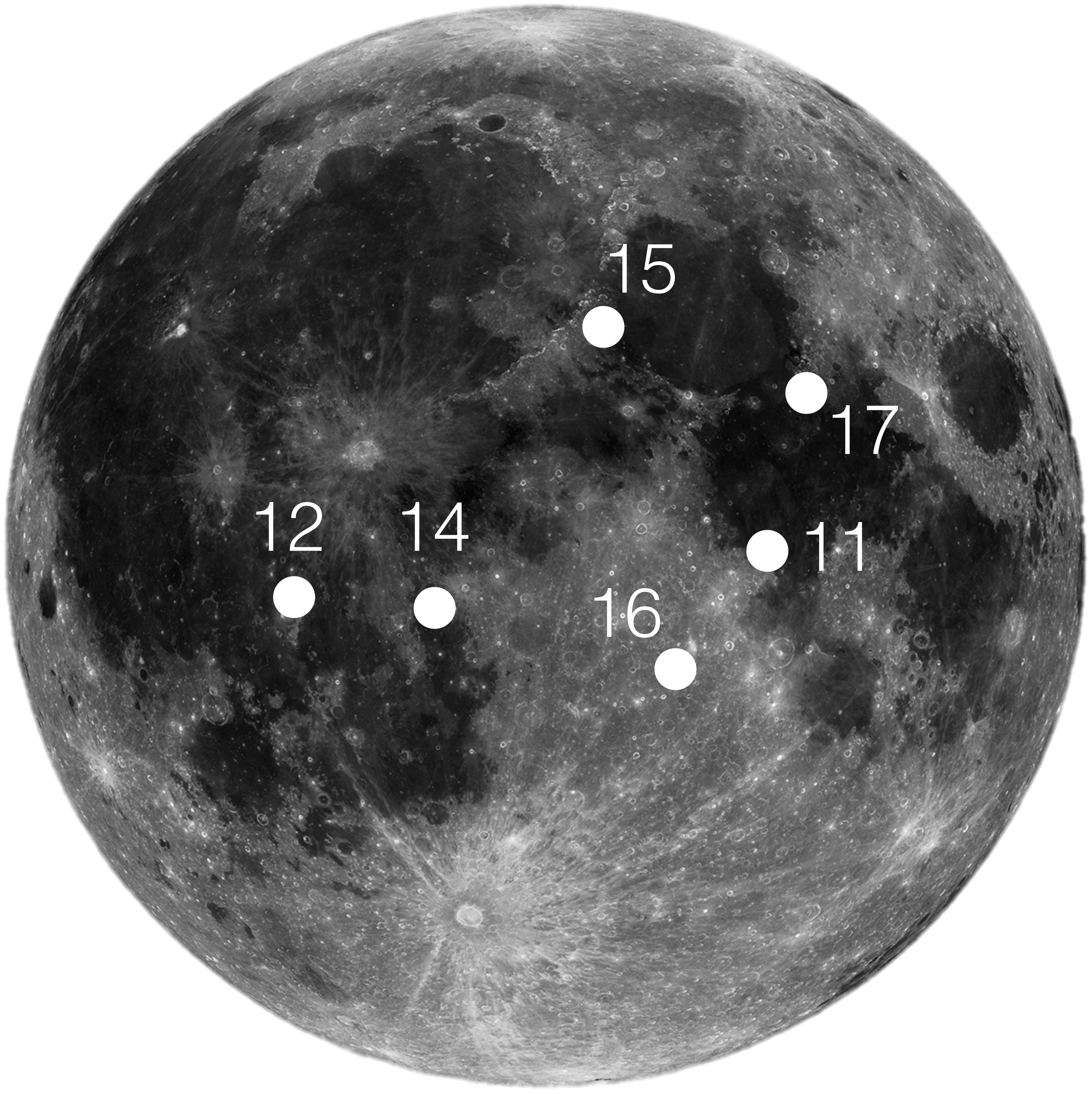

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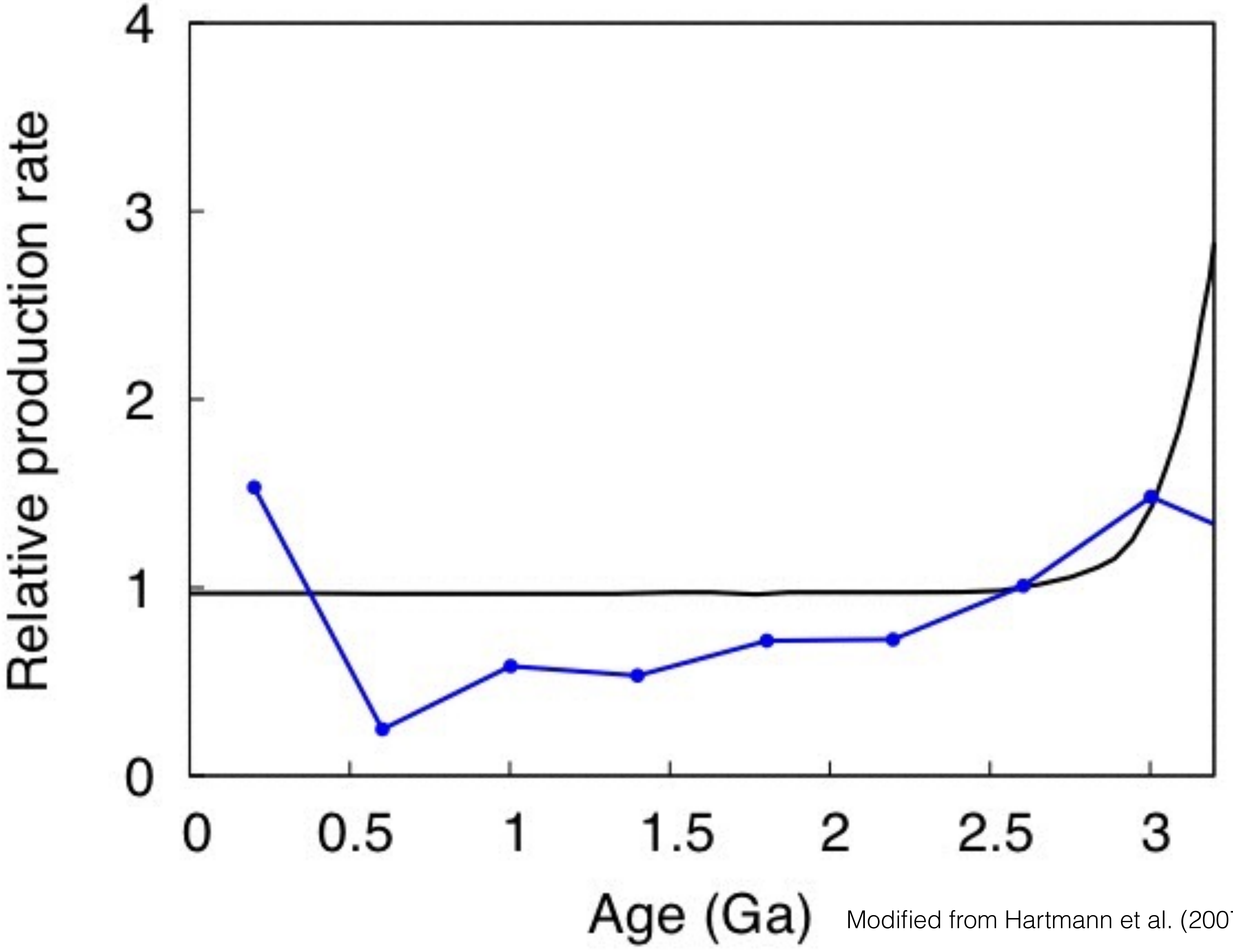
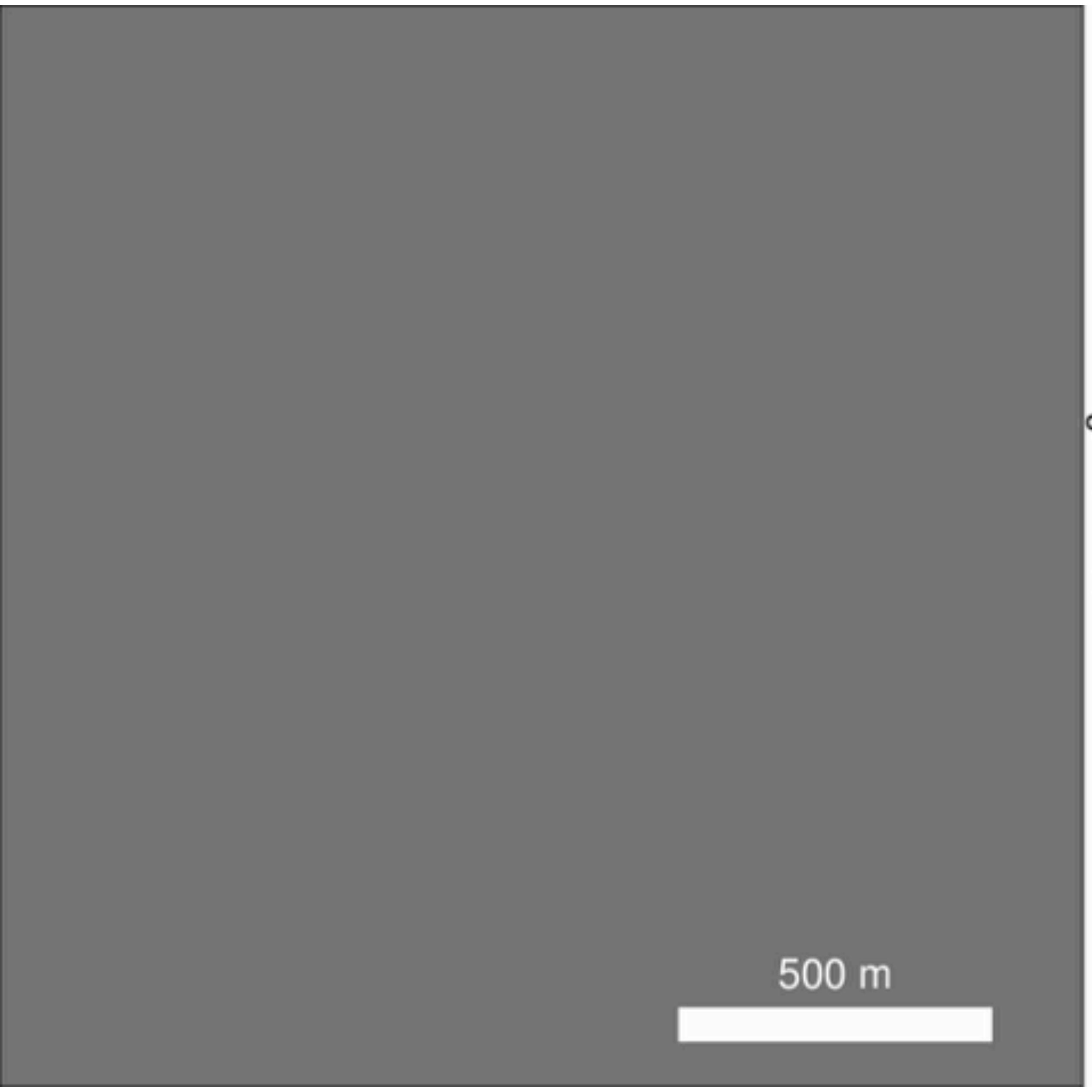
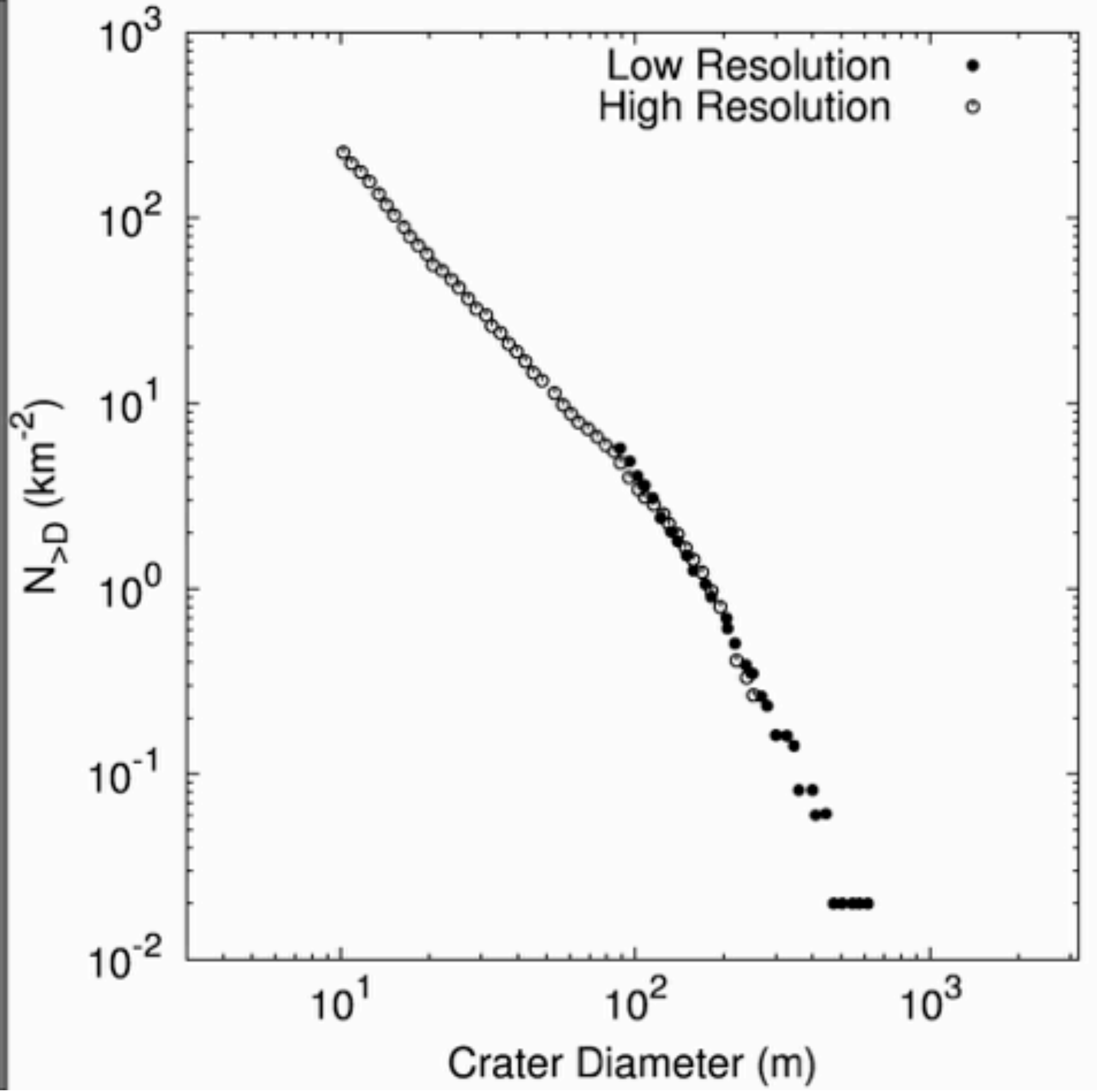


Modified from Hartmann et al. (2007)

Cratered Terrain Evolution Model (CTEM) is a Monte Carlo code for simulating the heavily-cratered surface and suitable for studying layering dominated environments .

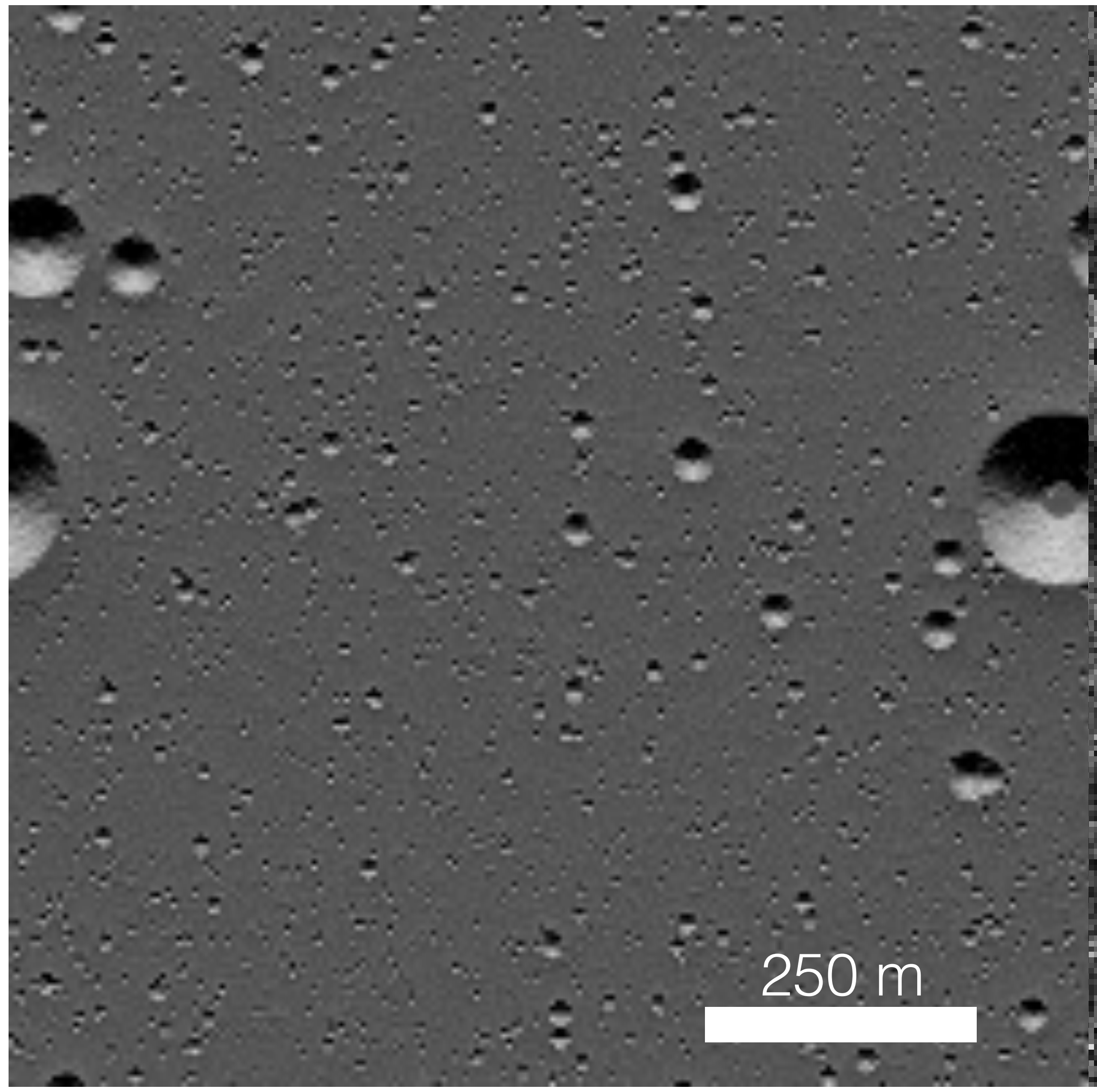
CTEM bombardment simulation



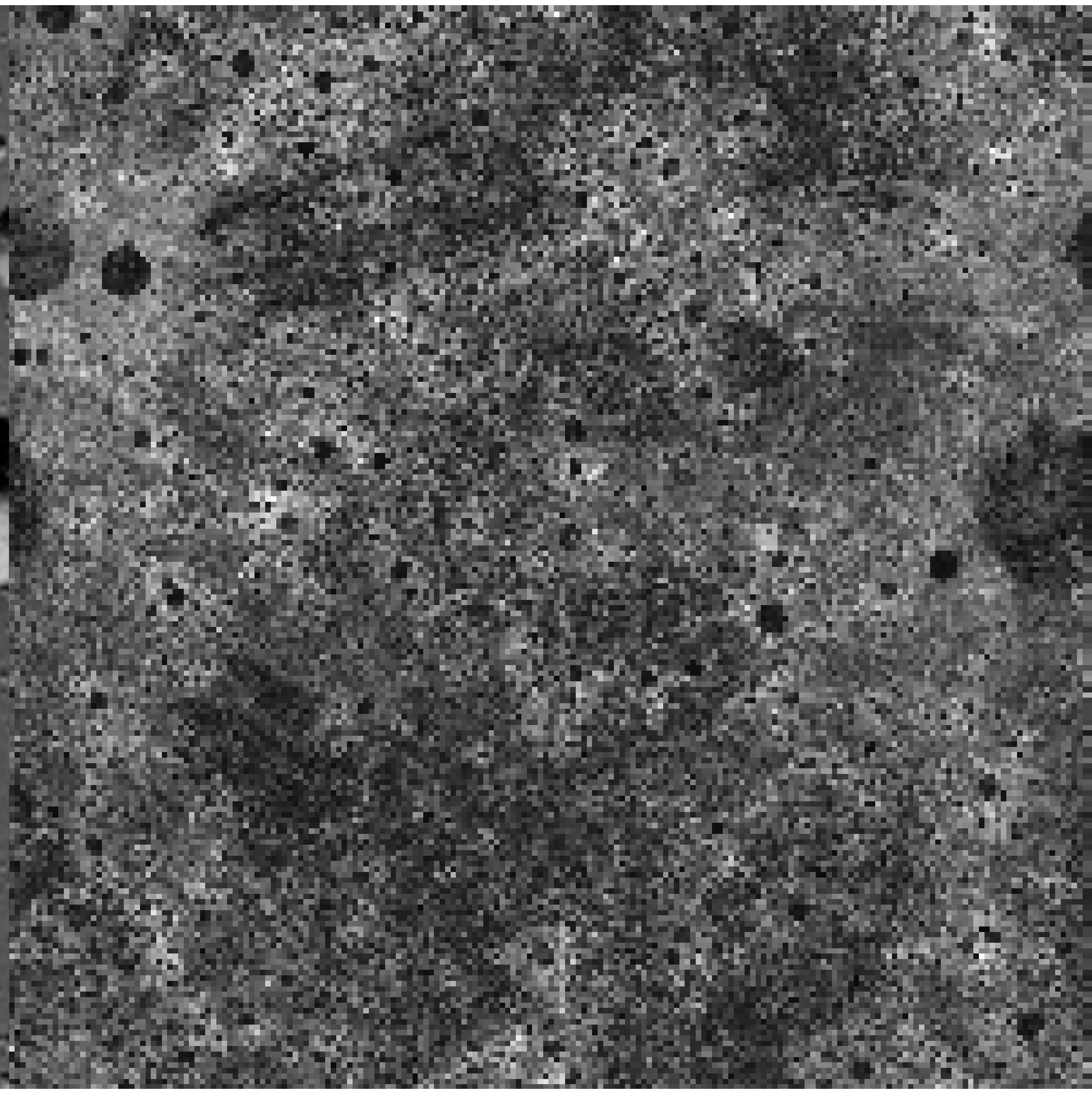


Richardson (2009), Minton et al. (2015), Huang et al. (2017)

CTEM bombardment simulation with a streamline based material tracking system



Digital elevation model



Ejecta layering model

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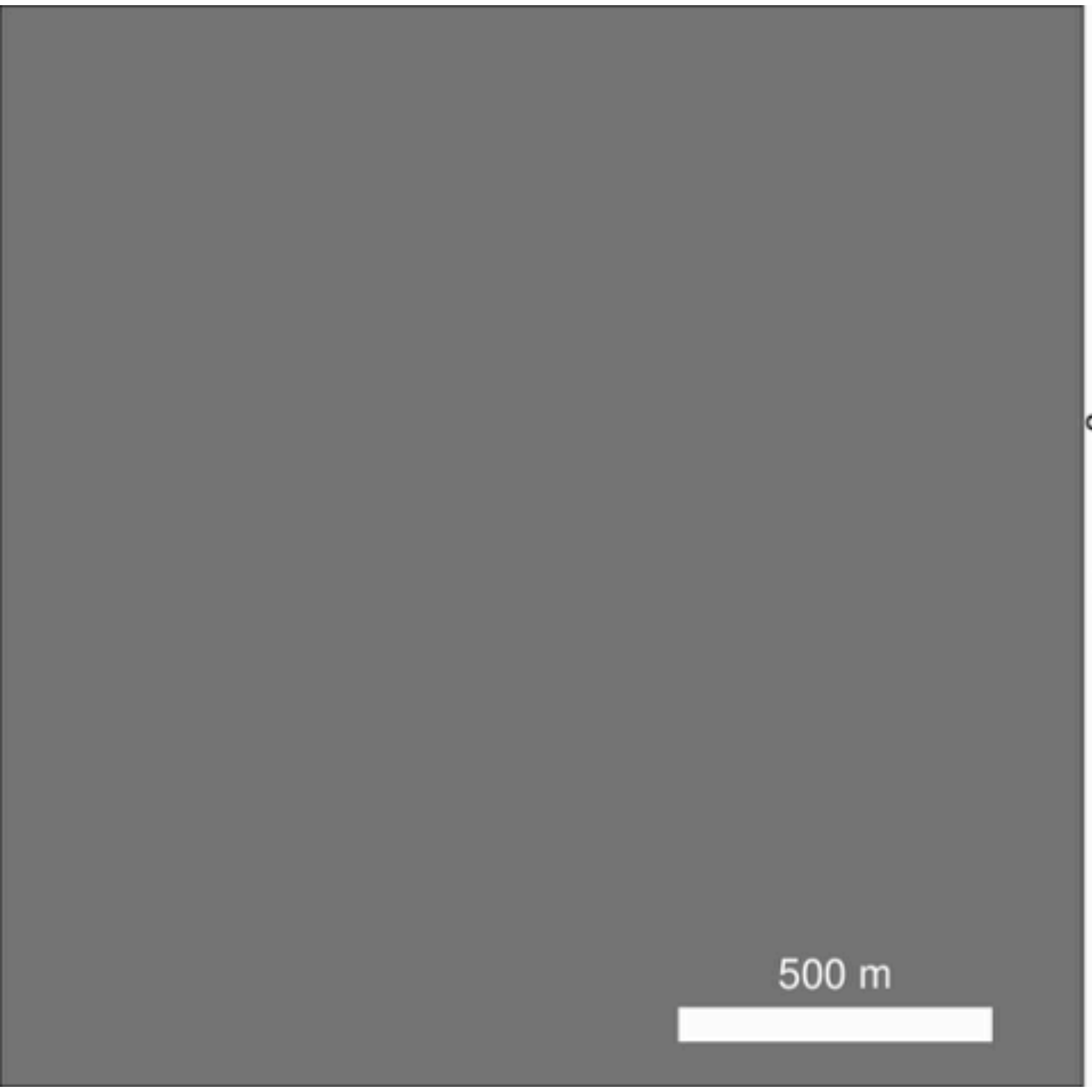

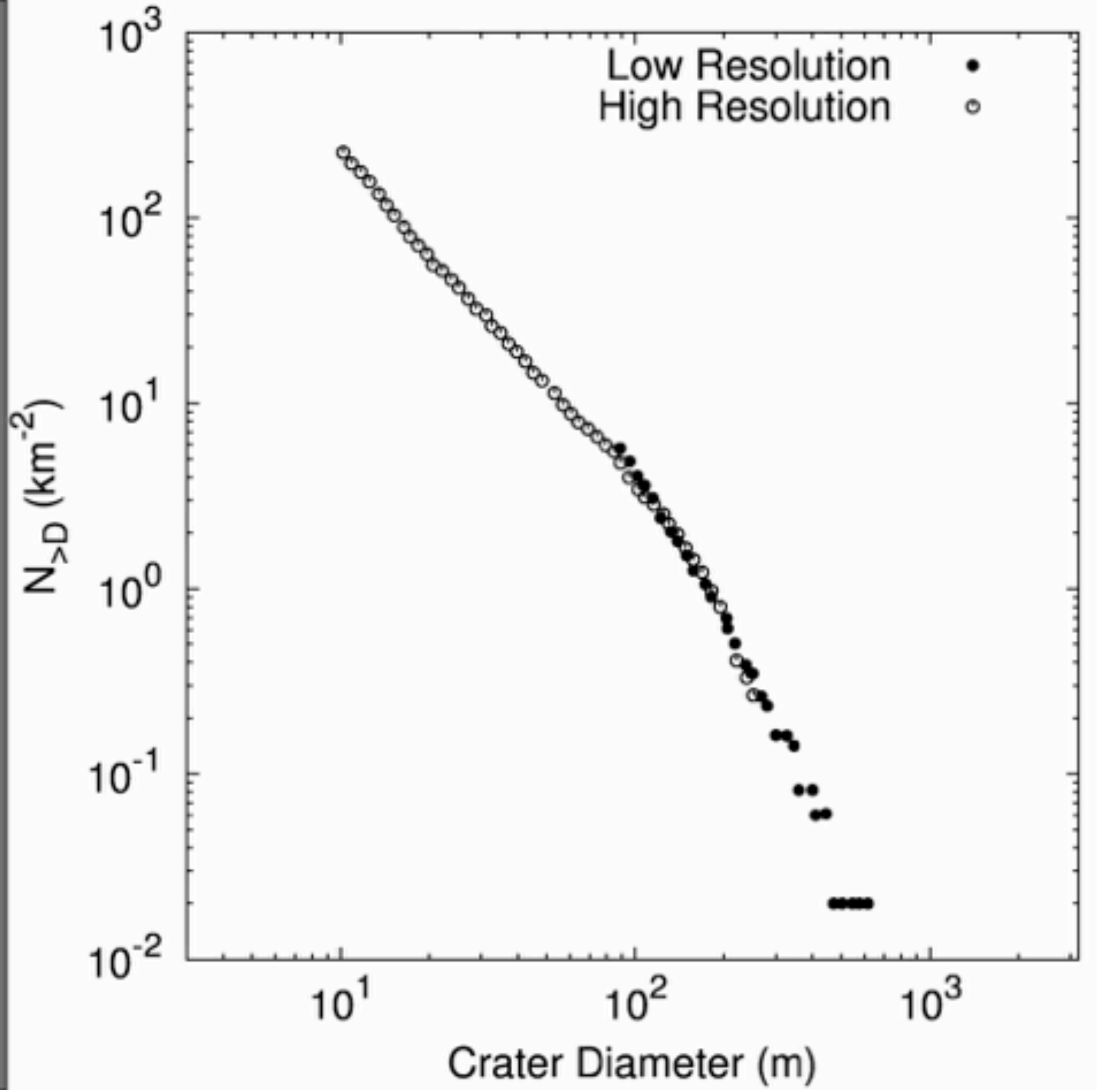

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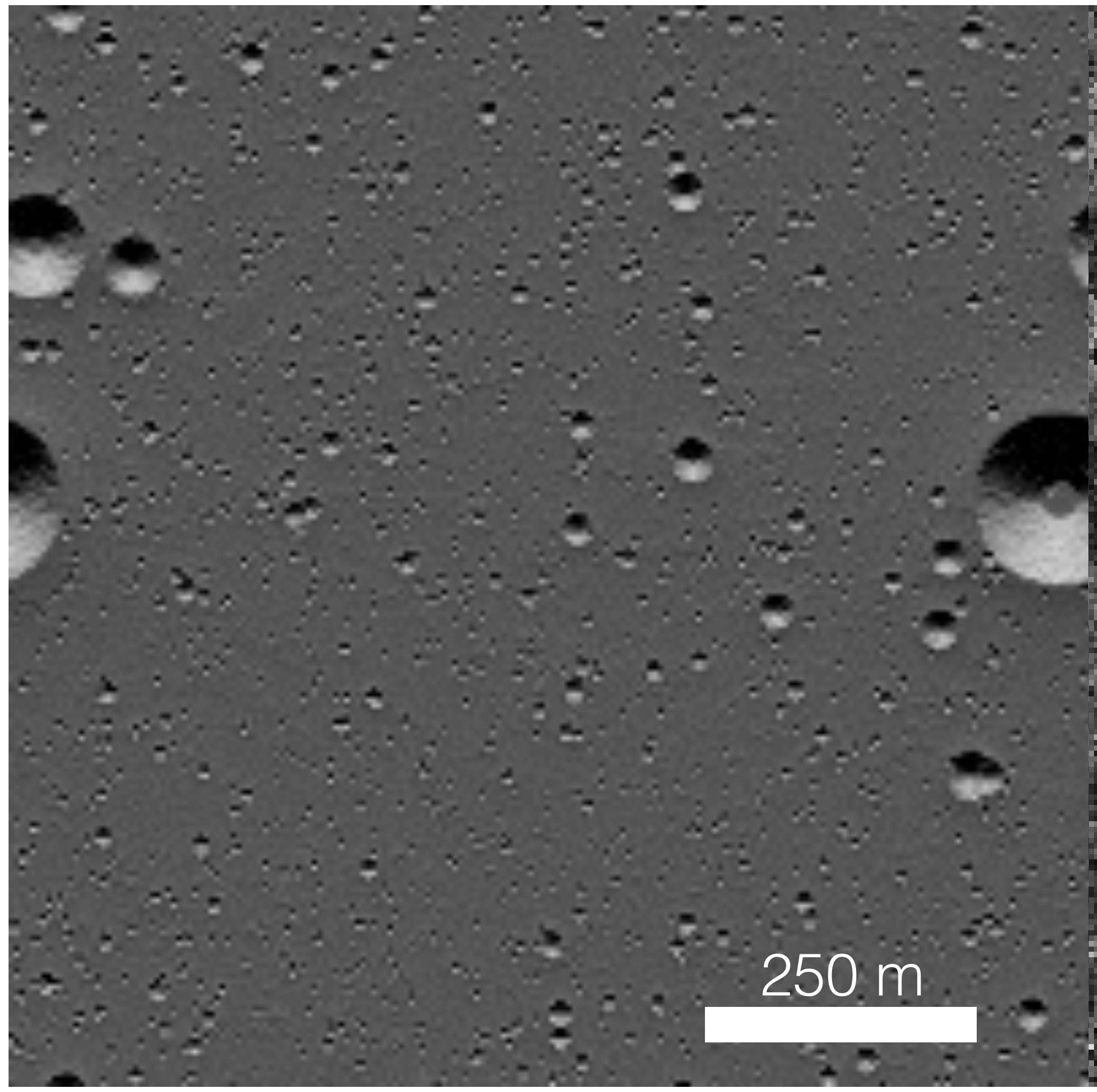

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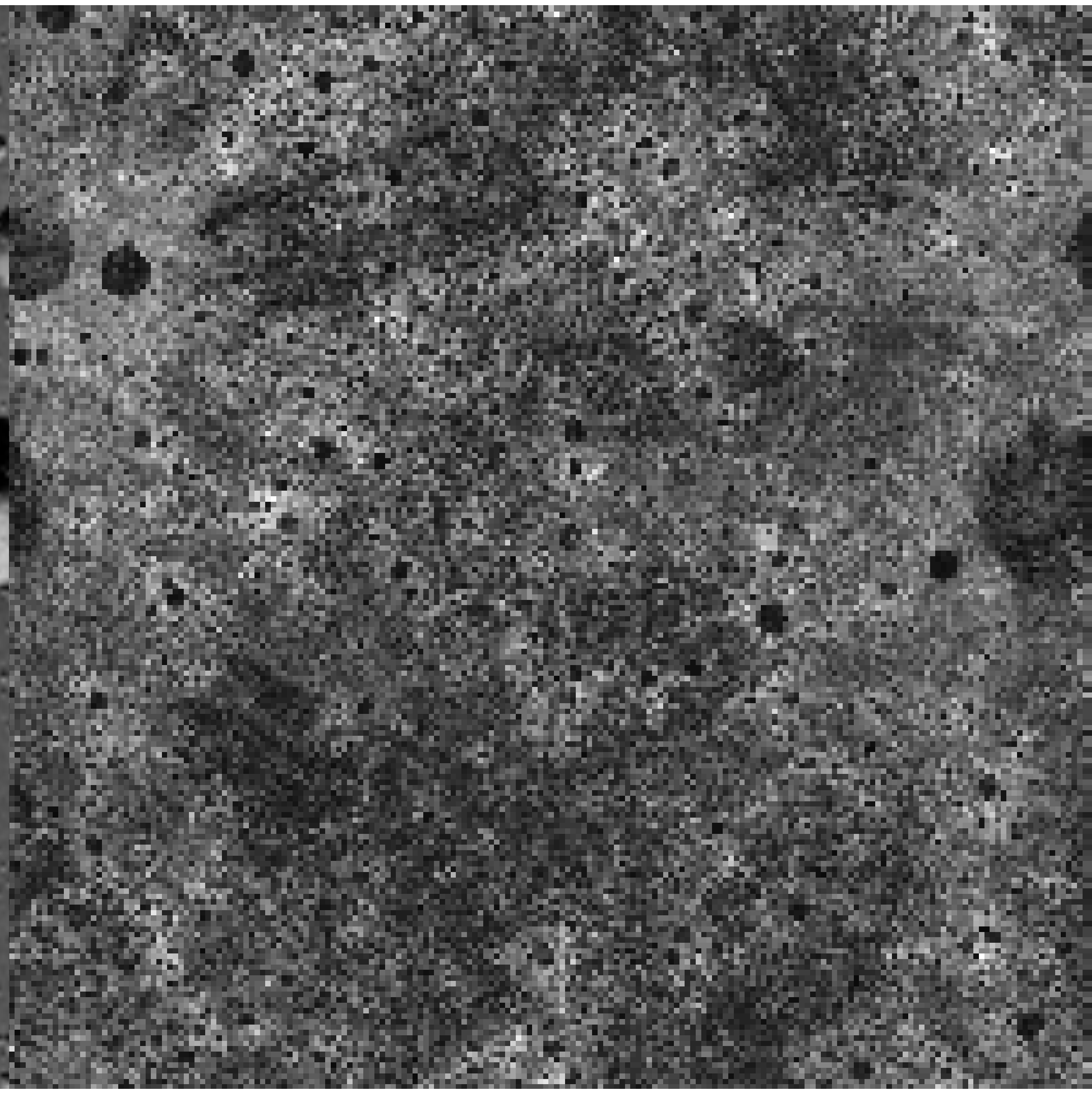

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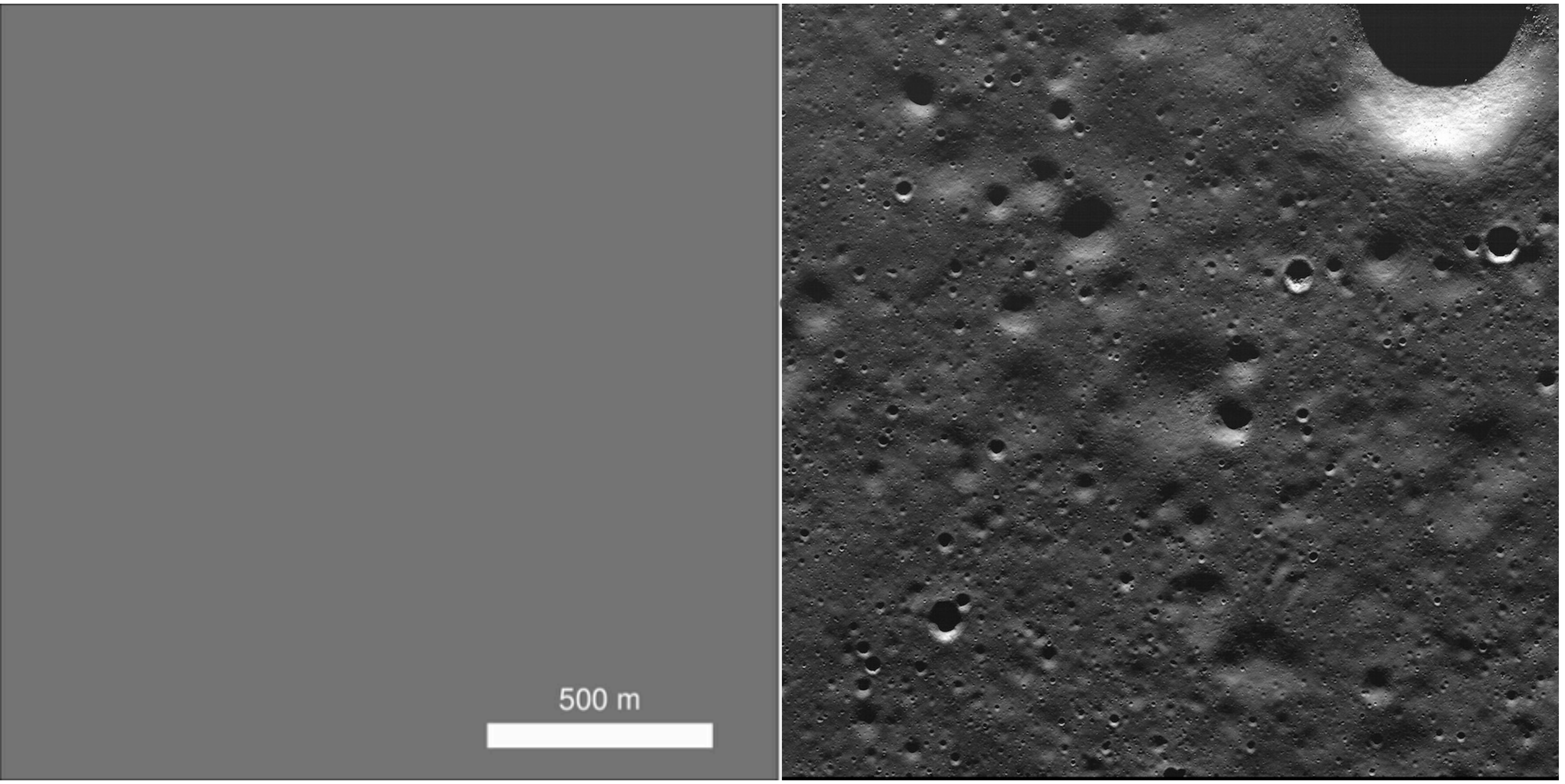

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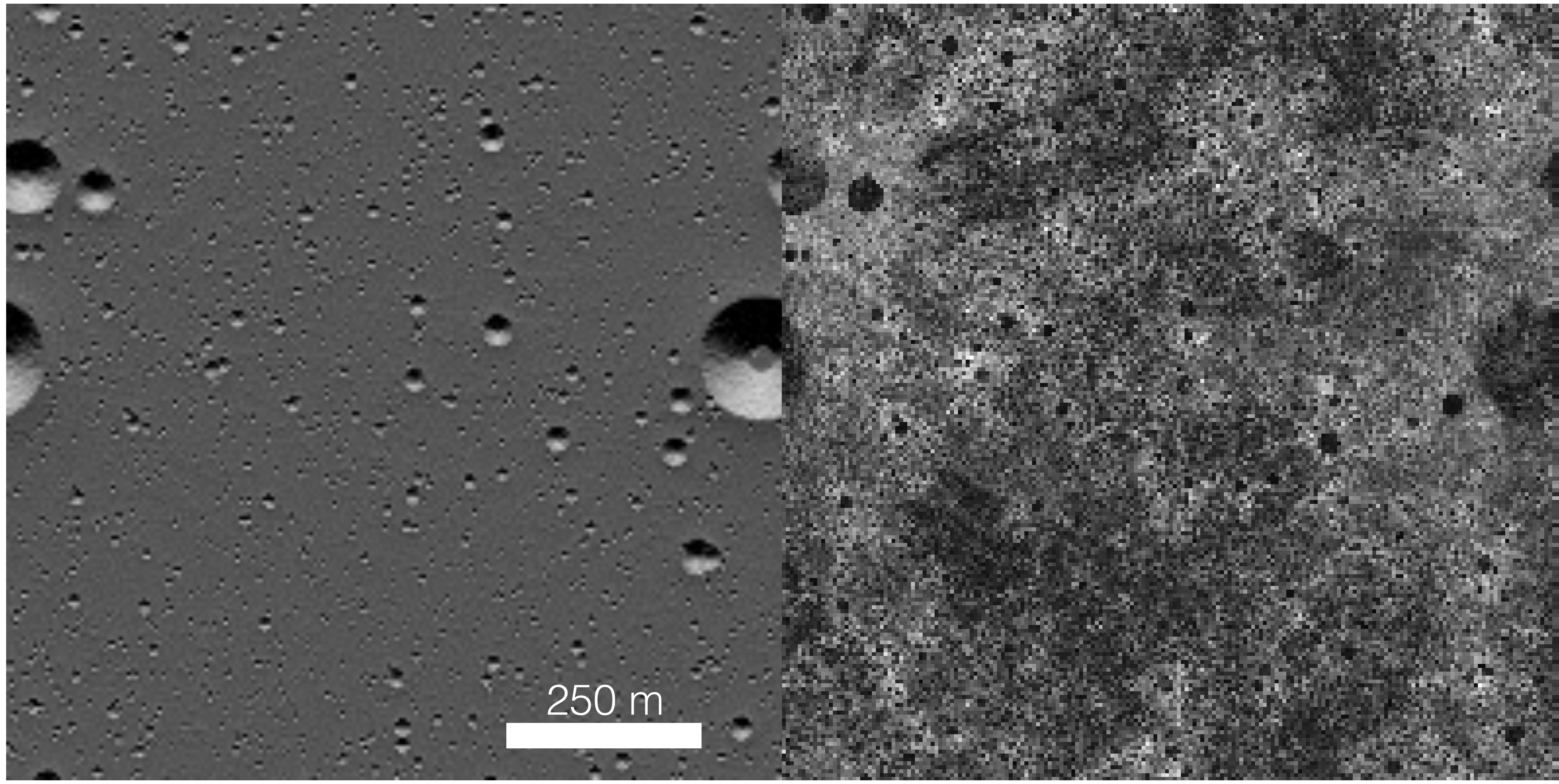


Digital elevation model

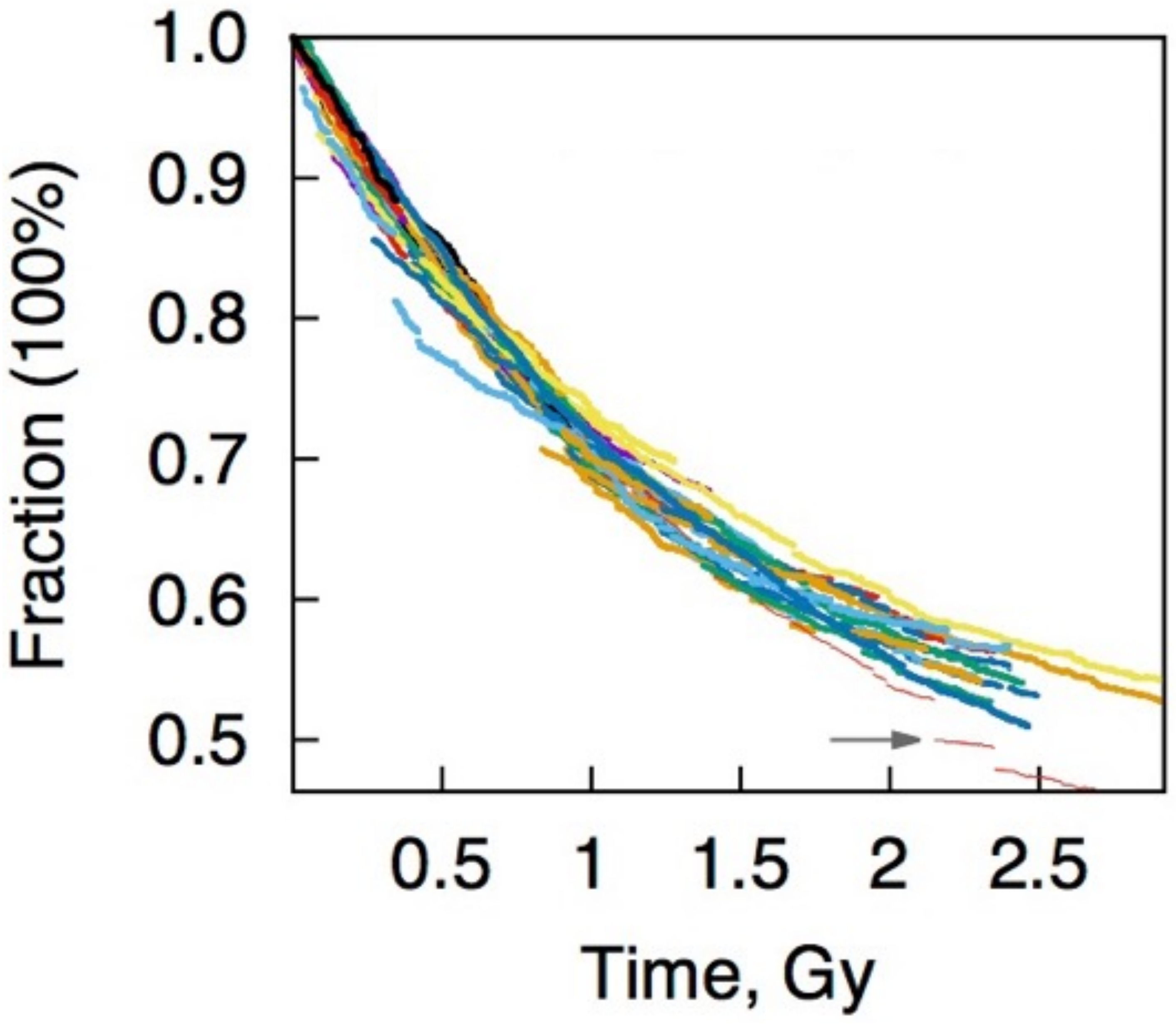
Ejecta layering model

Our model can explain the excess of young spherules in <500 Ma without changing the impact flux.

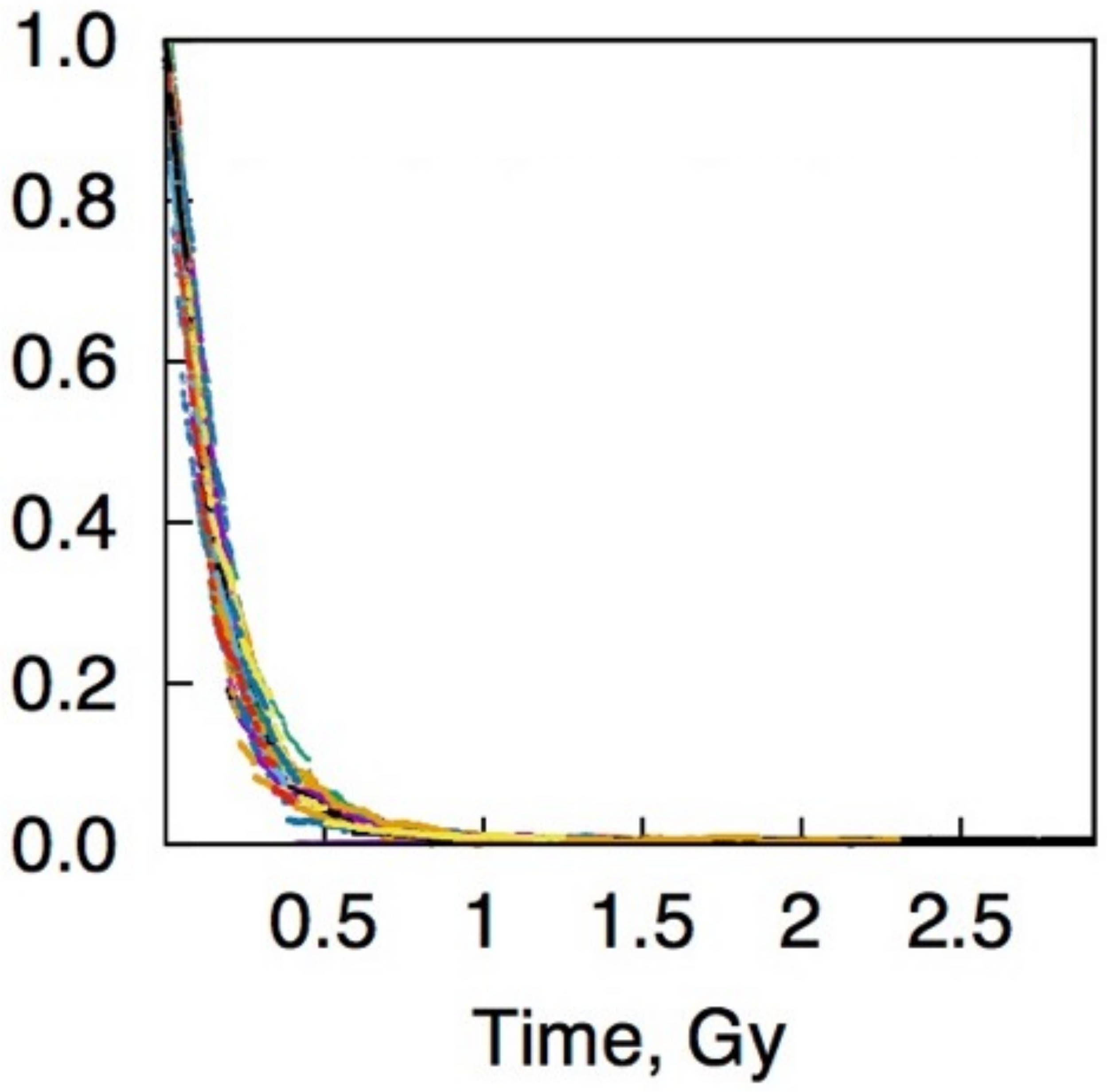
This result does not rule out a changing lunar impact, but suggests that this data set is too biased to draw any strong conclusions

A relation between residence times and resident depths of glass spherules suggests a half life.

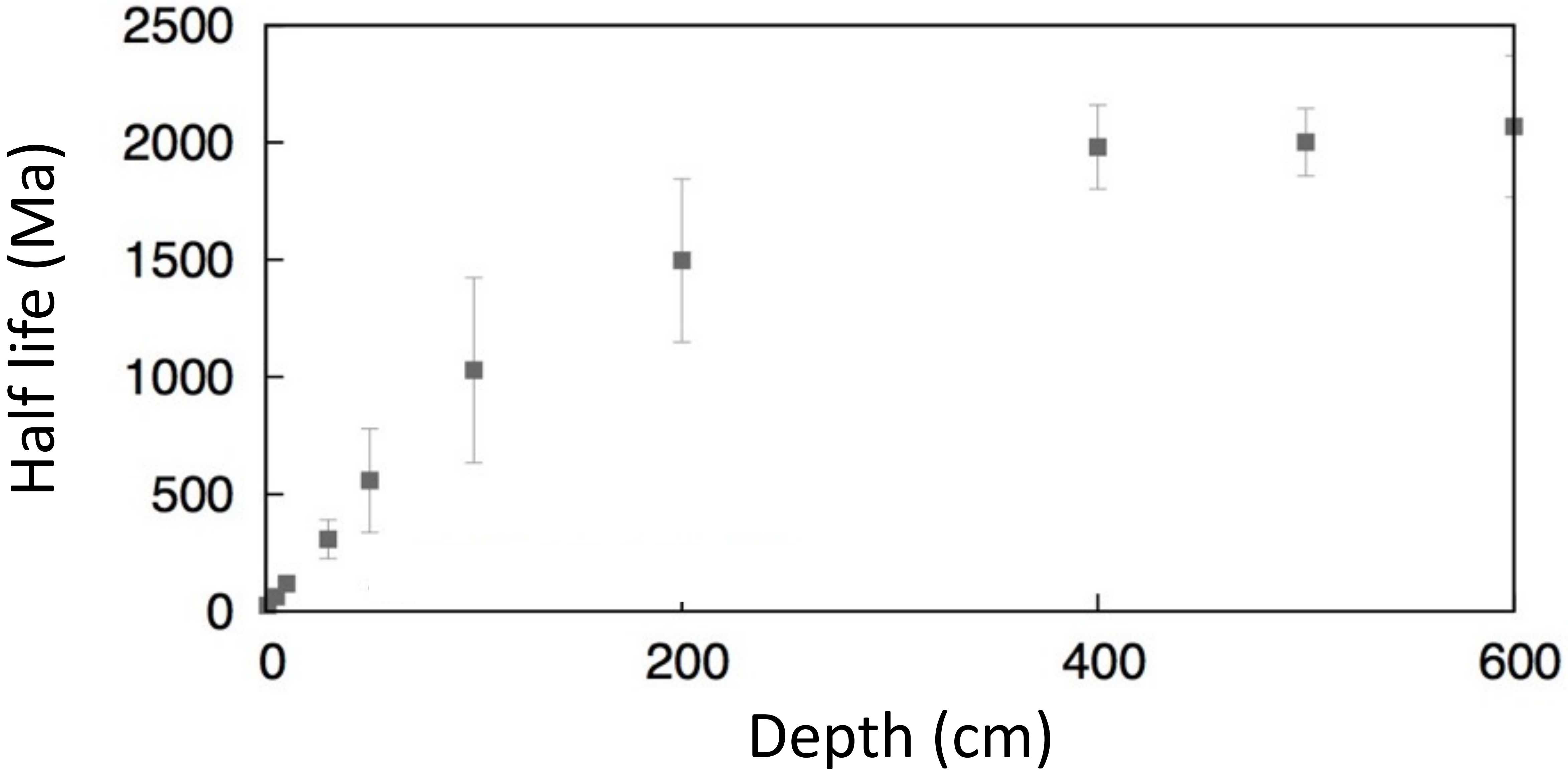
Spherule populations within a depth of 6 m



Spherule populations within a depth of 10 cm



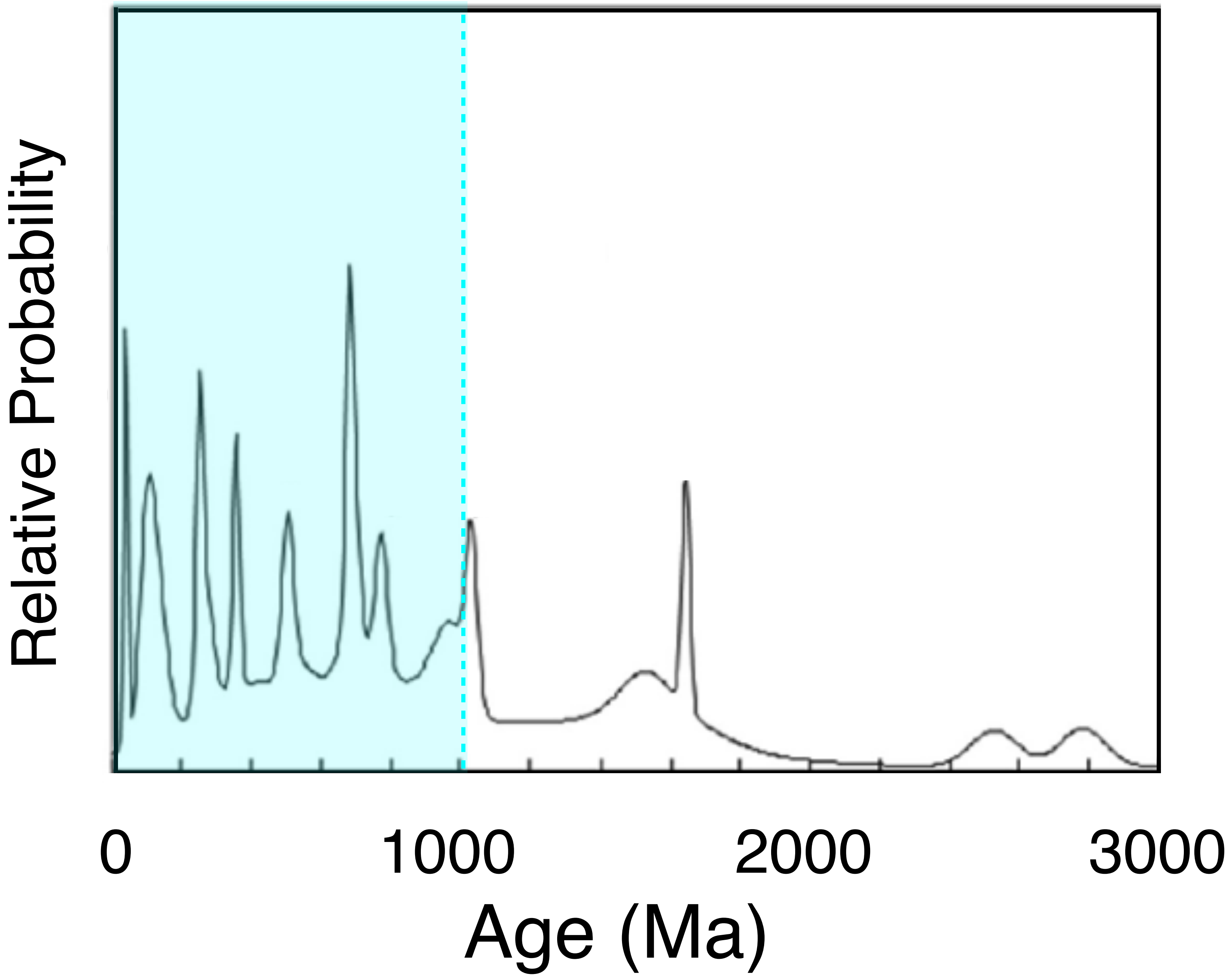
Half life of spherule populations versus depths



Huang et al. (2018) *GRL*

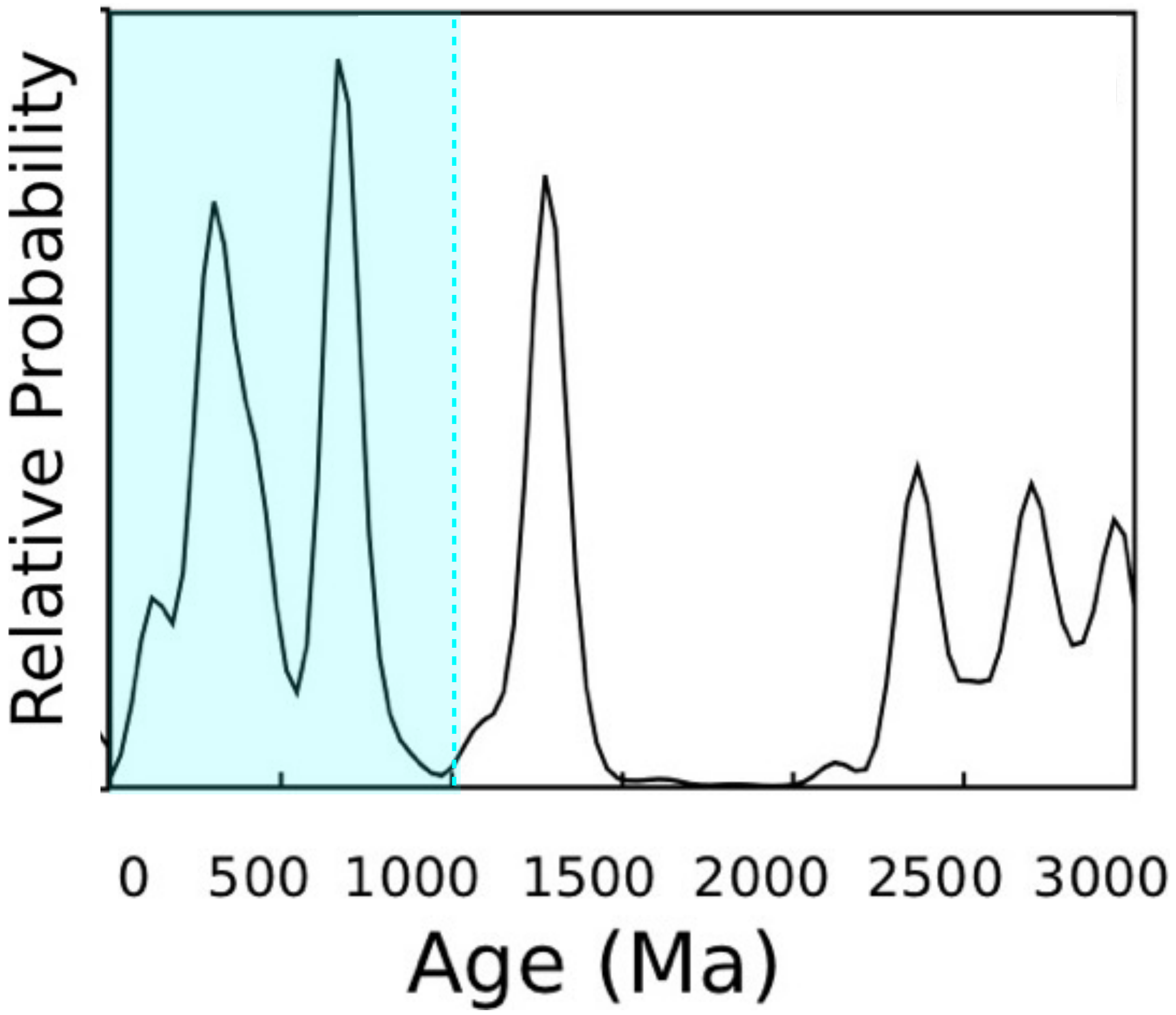
Different spherule populations reveal different age behavior, so we now focus on the "exotic" spherules".

(1) Sufficient sizes of spherules for argon diffusion loss



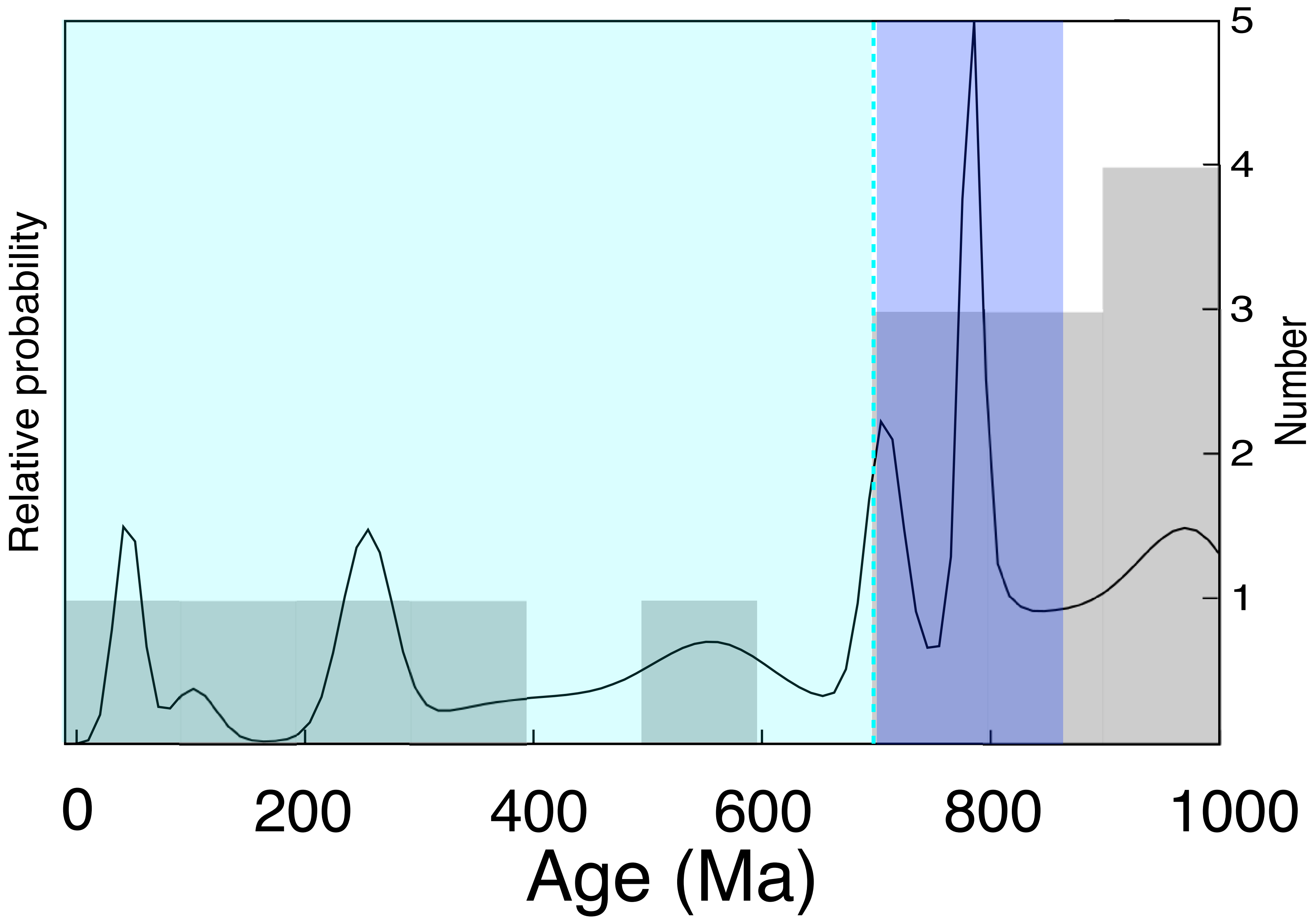
Zellner and Delano (2015) *GCA*

(2) Spherule age distributions collected from deeper depths



Huang et al. (2018) *GRL*

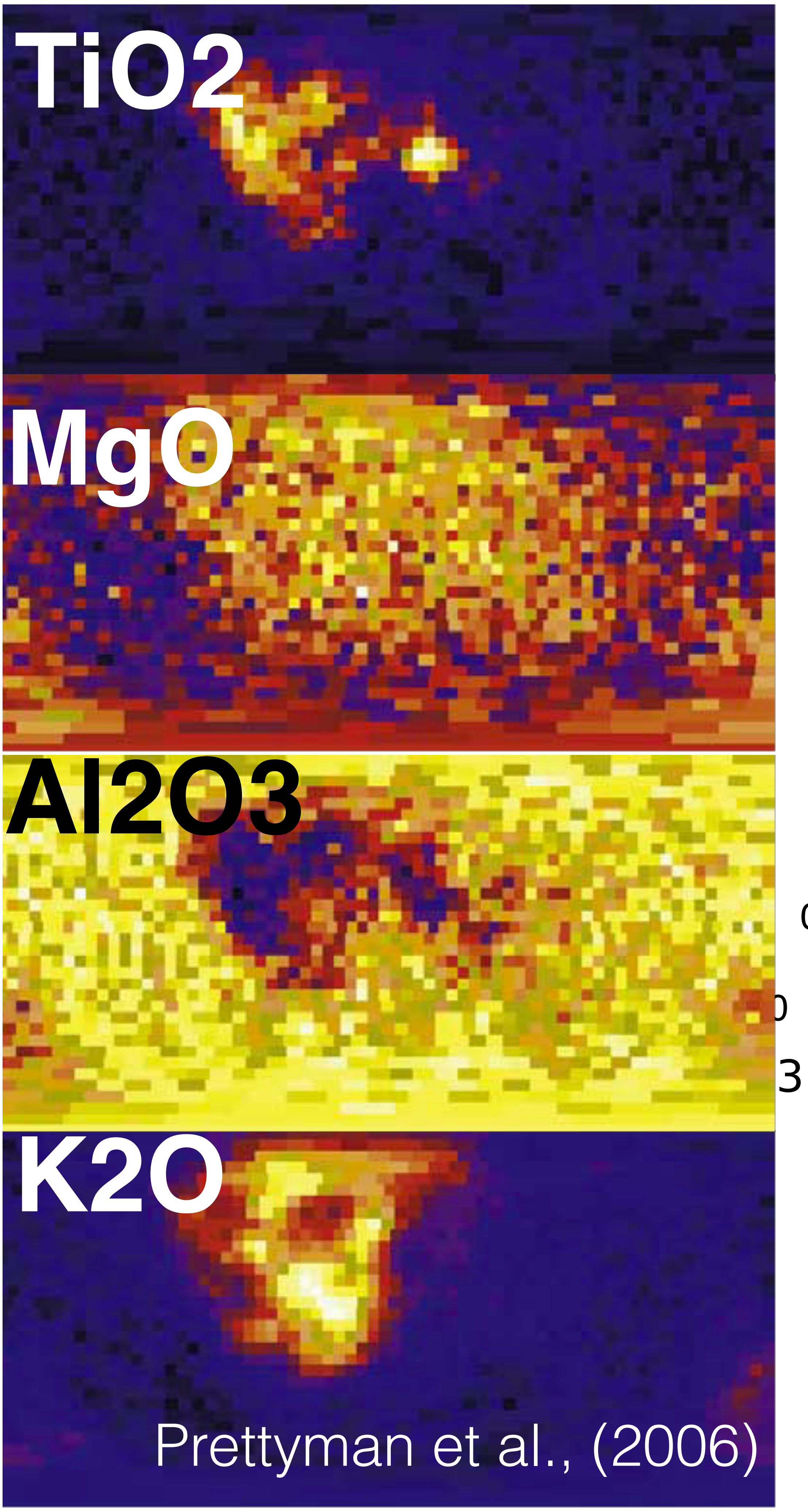
(3) Geochemically-distinct ("exotic") glass spherule age distributions

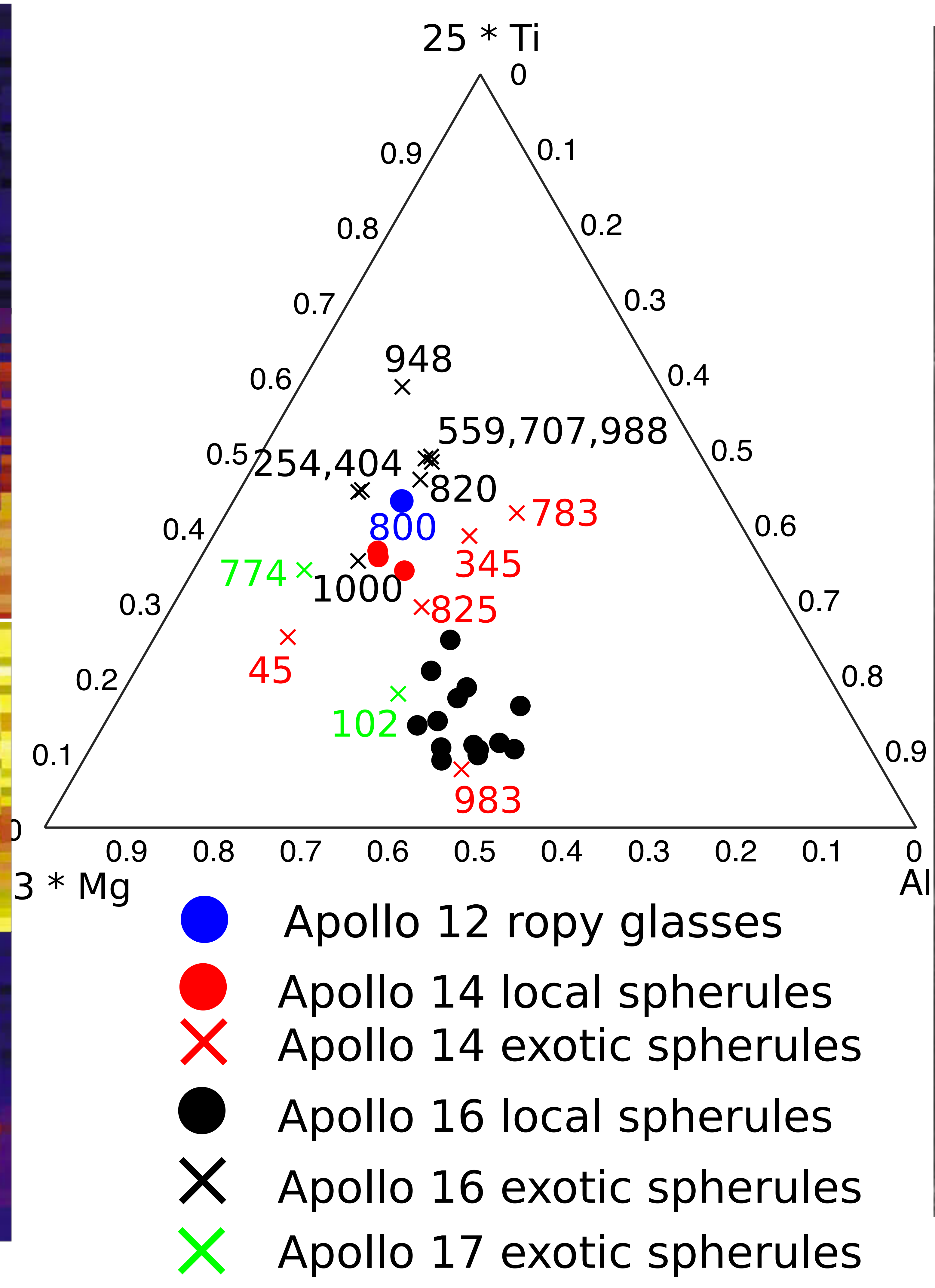


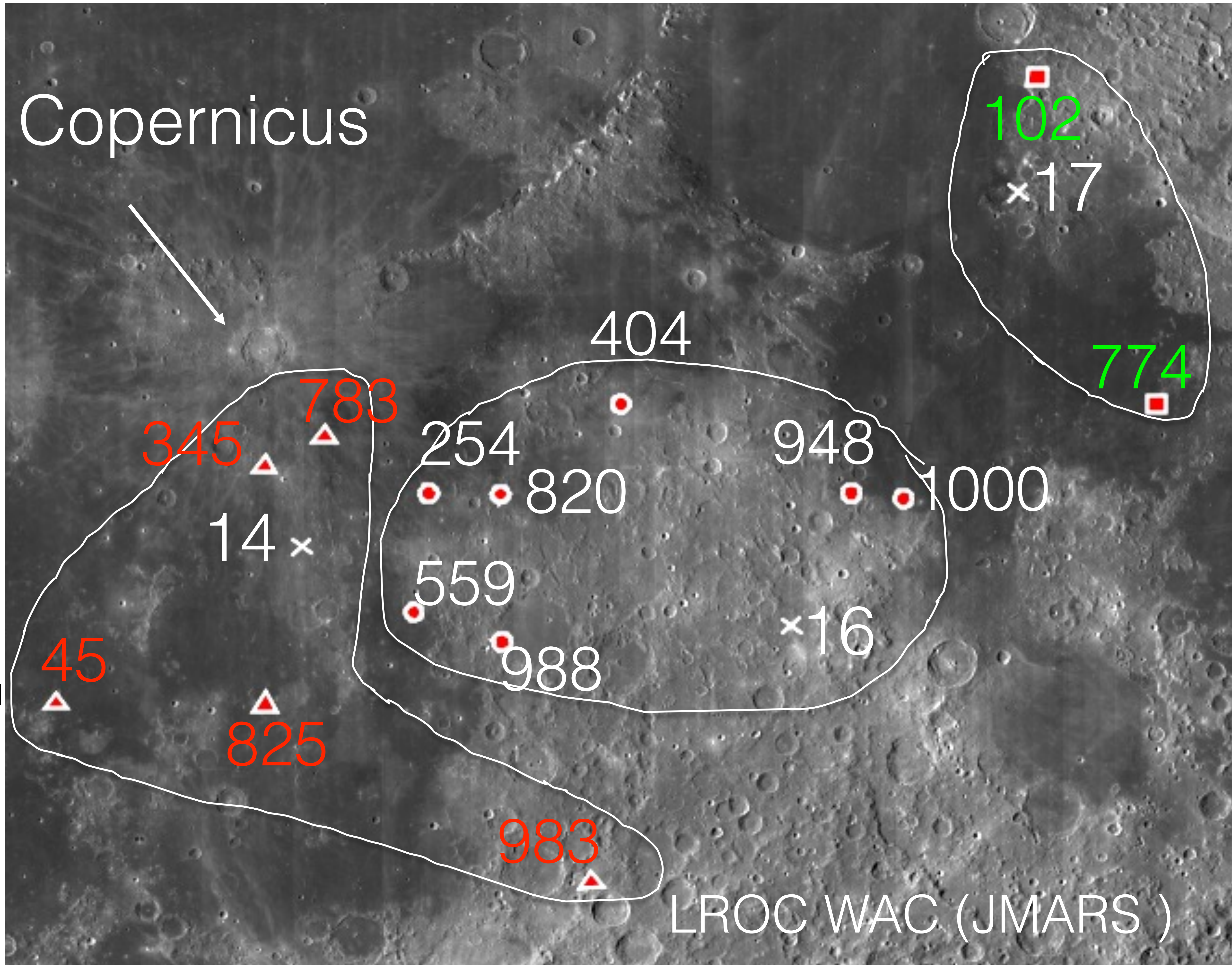
Huang et al. (2018) *Bombardment workshop*

Matching spherules' composition with Lunar Prospector Gamma-Ray Spectrometer abundance map, we identified 14 exotic spherules that are far away from collection sites.

Lunar Prospector Gamma Ray Spectrometer

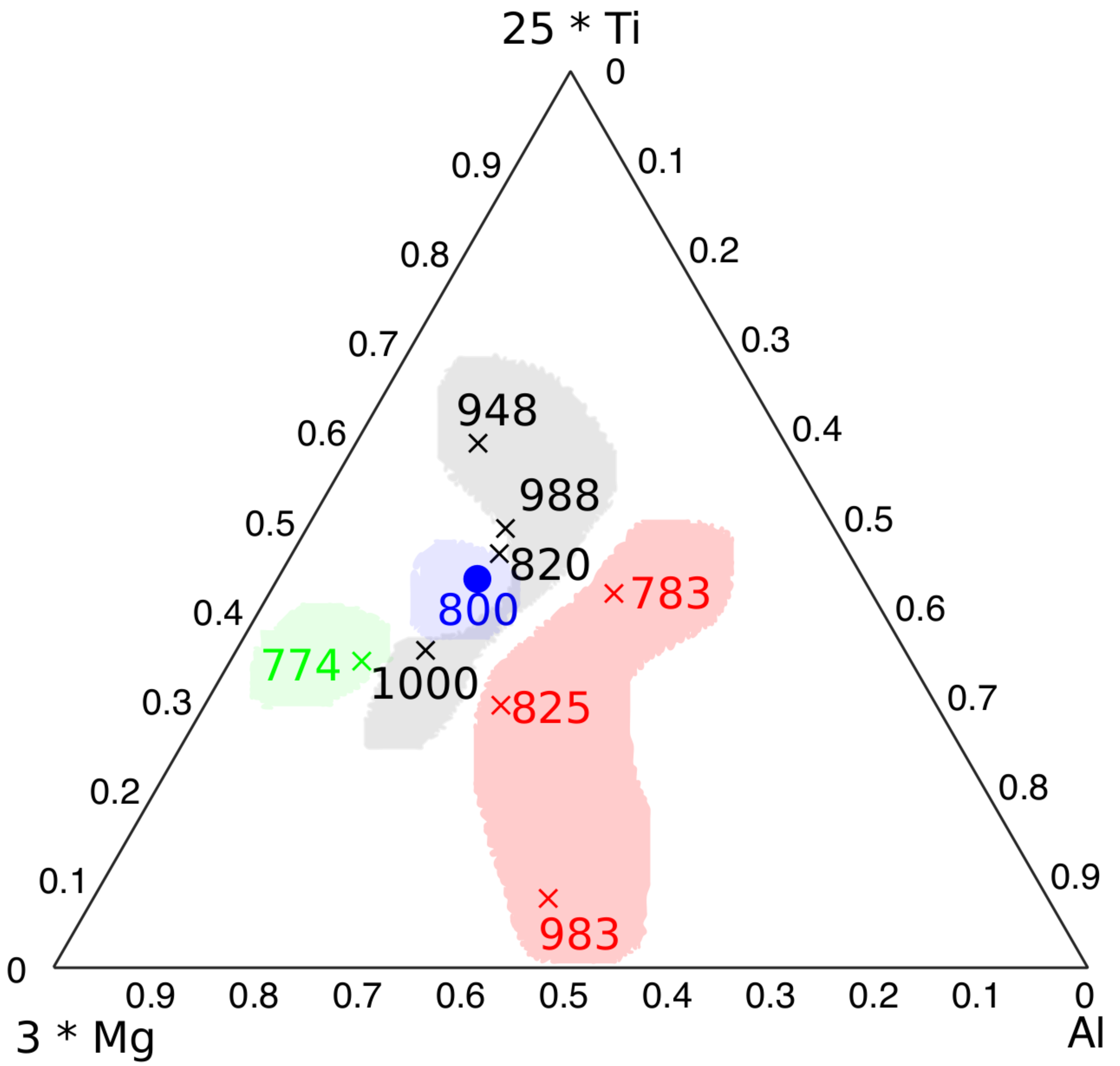


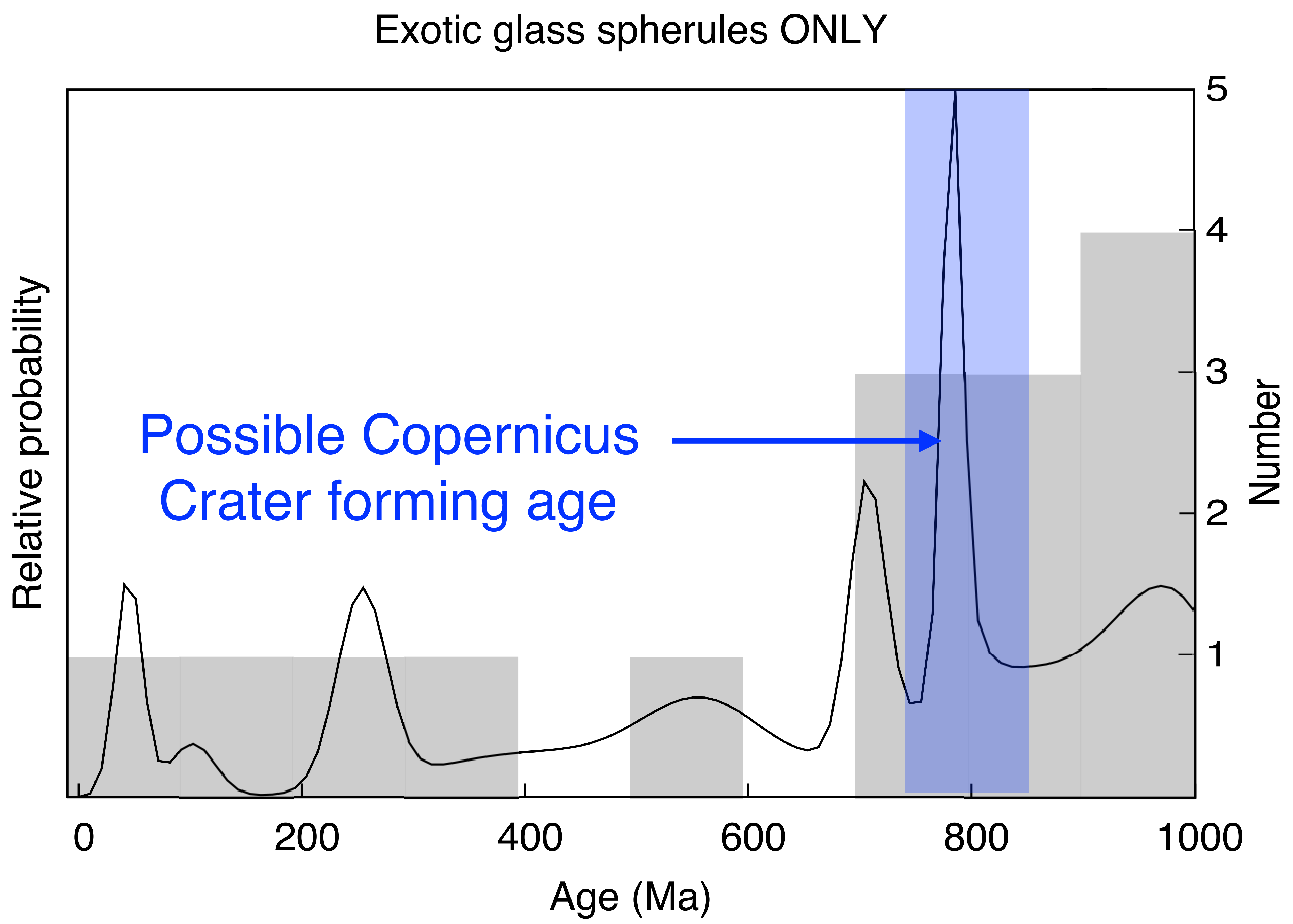




Huang et al. (2018) bombardment workshop and this workshop.

Exotic impact glass spherules told a different story of lunar impact flux, yet it is not explained by a constant impact rate.





14 exotic spherules from Apollo 14, 16, and 17 sites are selected from Zellner and Delano (2015) and Zellner et al. (2009) and three new spherules in this study.

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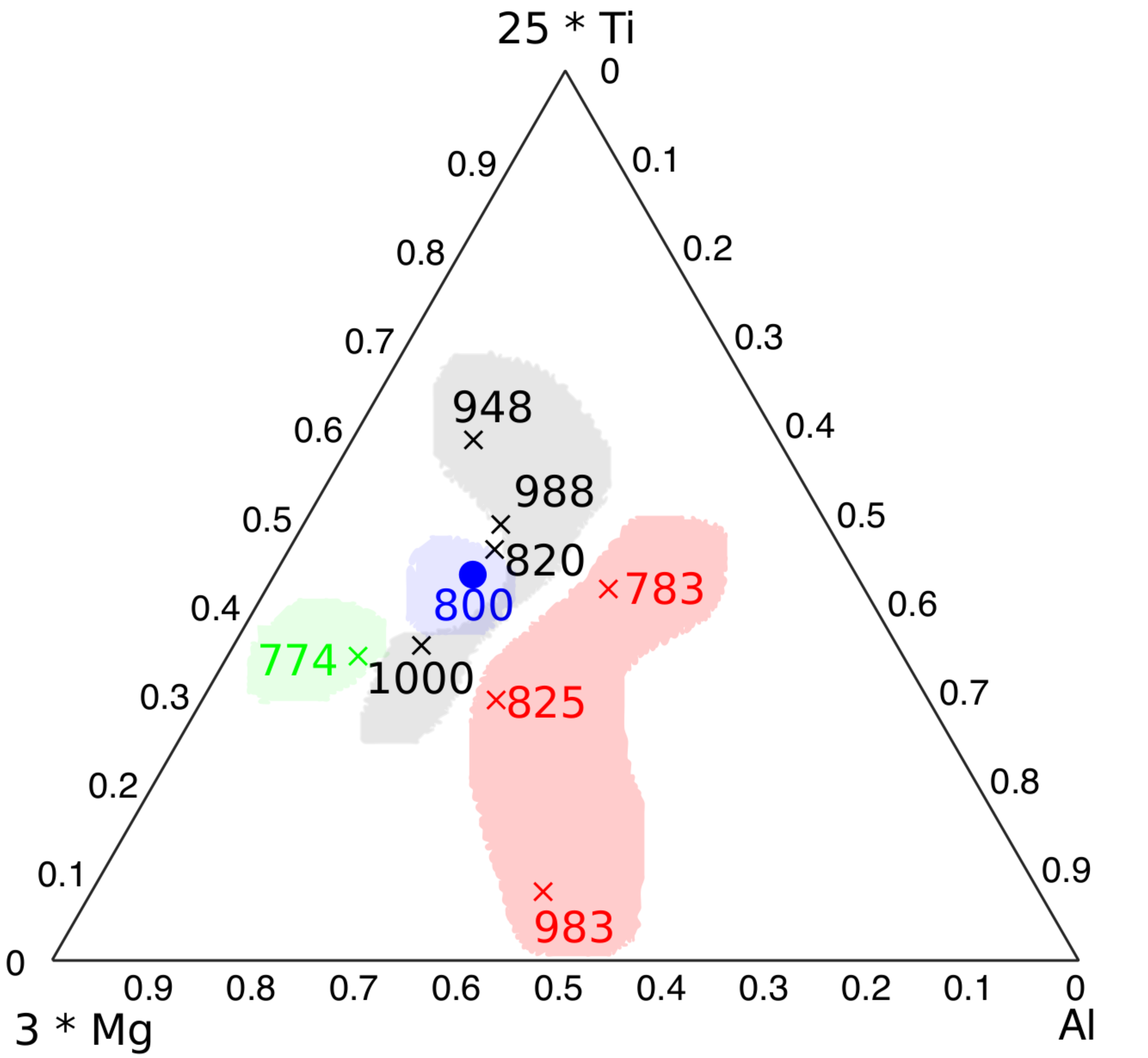

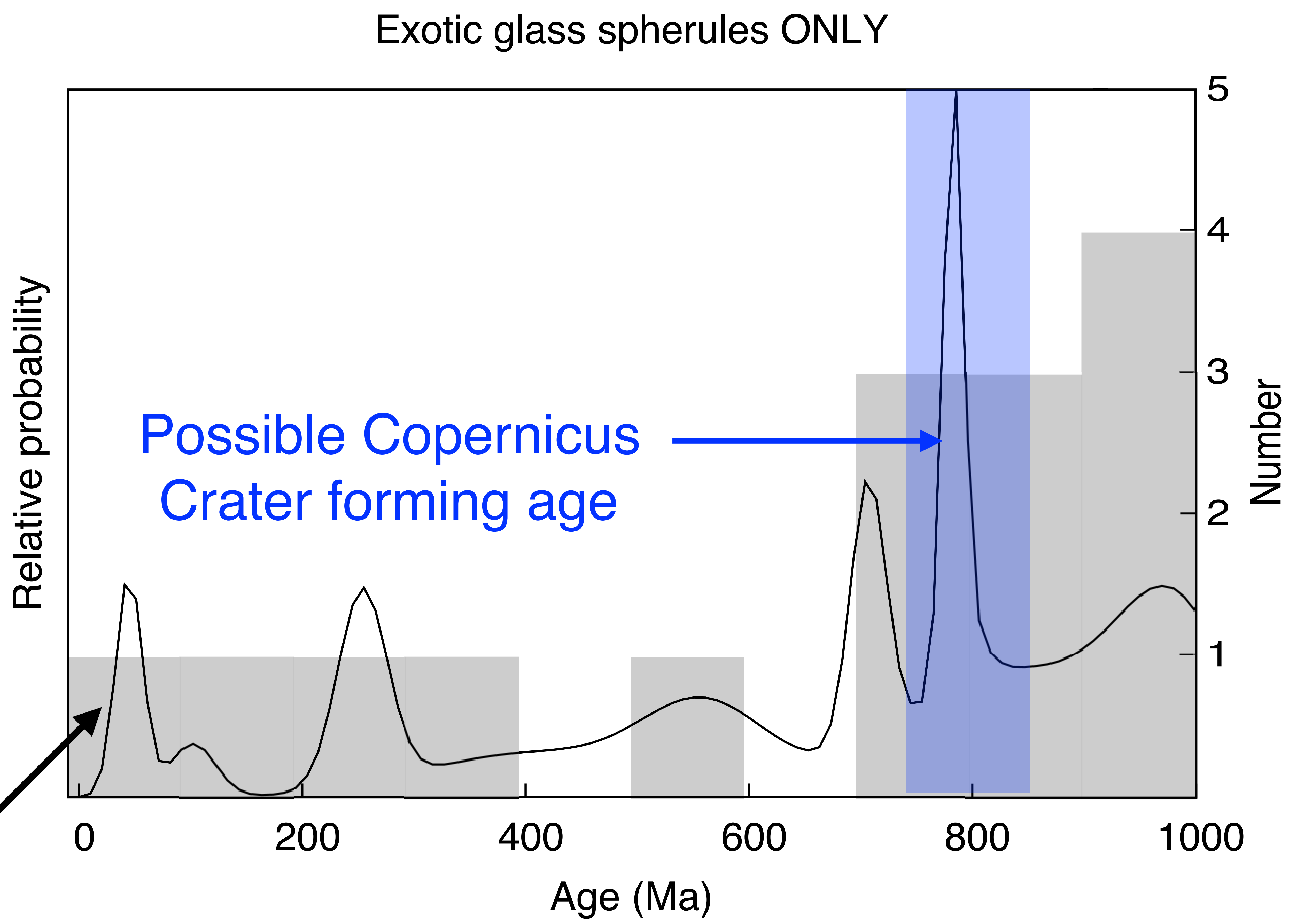

Observation 1: No tight clustering in the age distribution of simulated impacts in CTEM.

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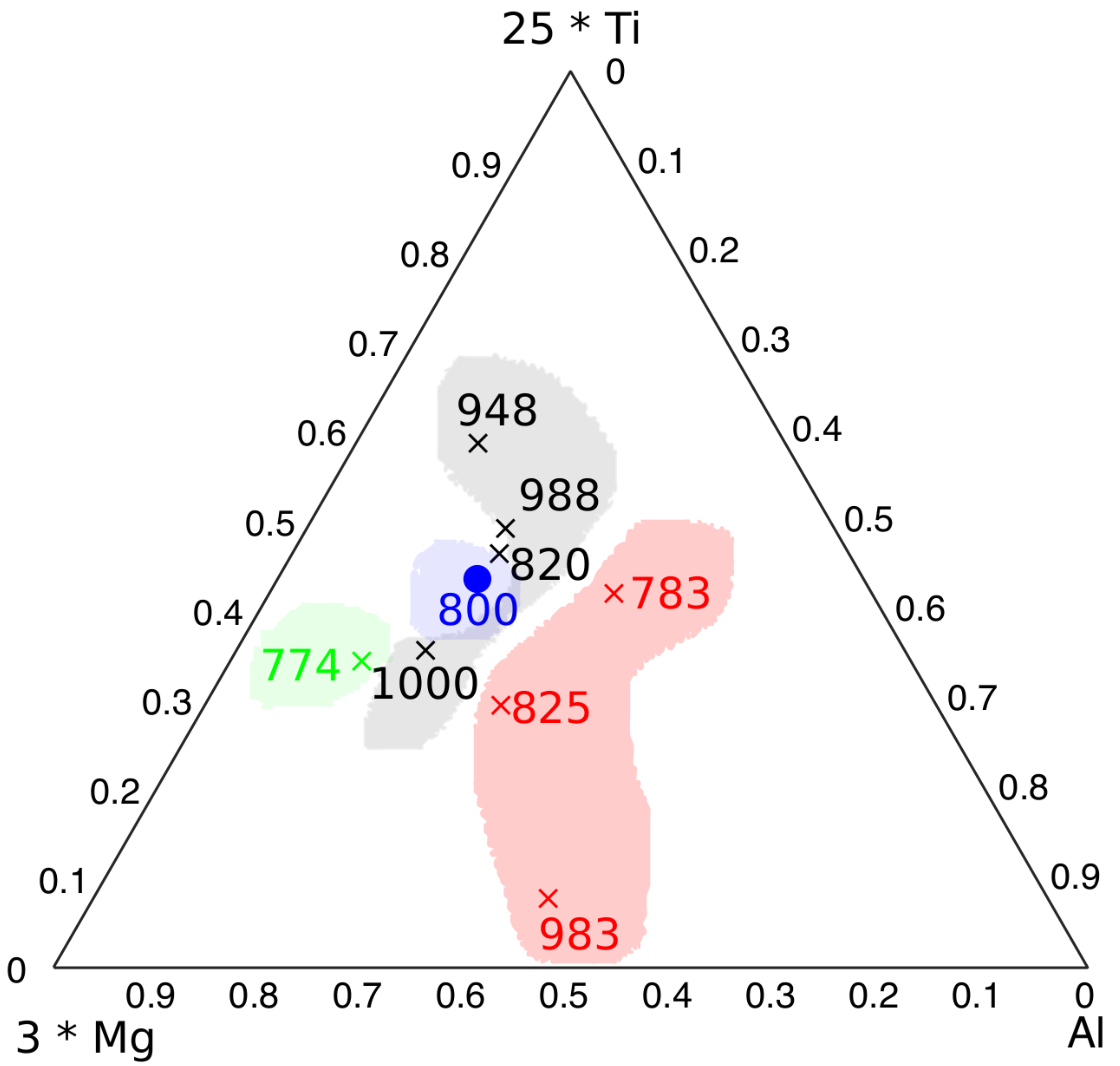

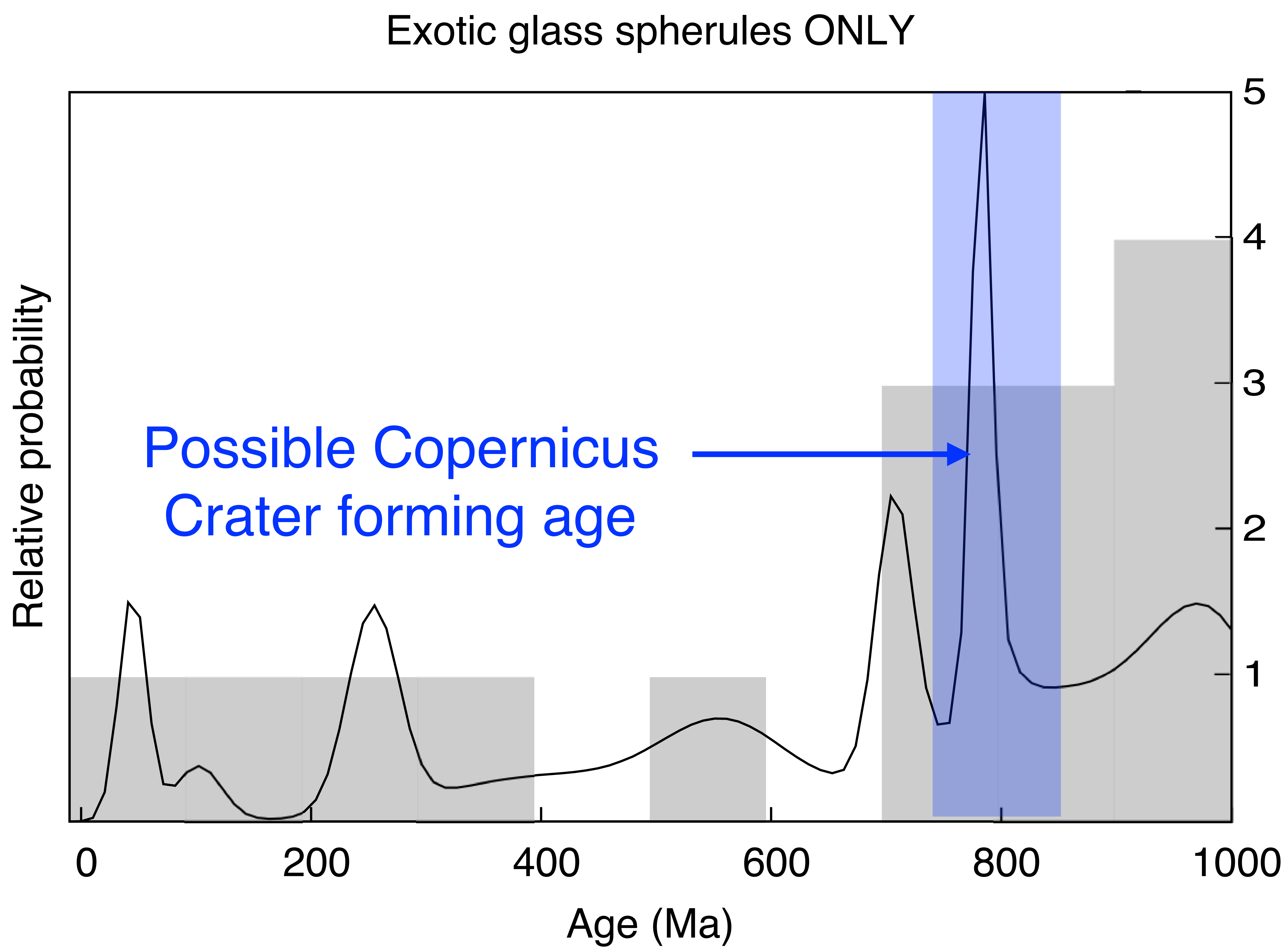

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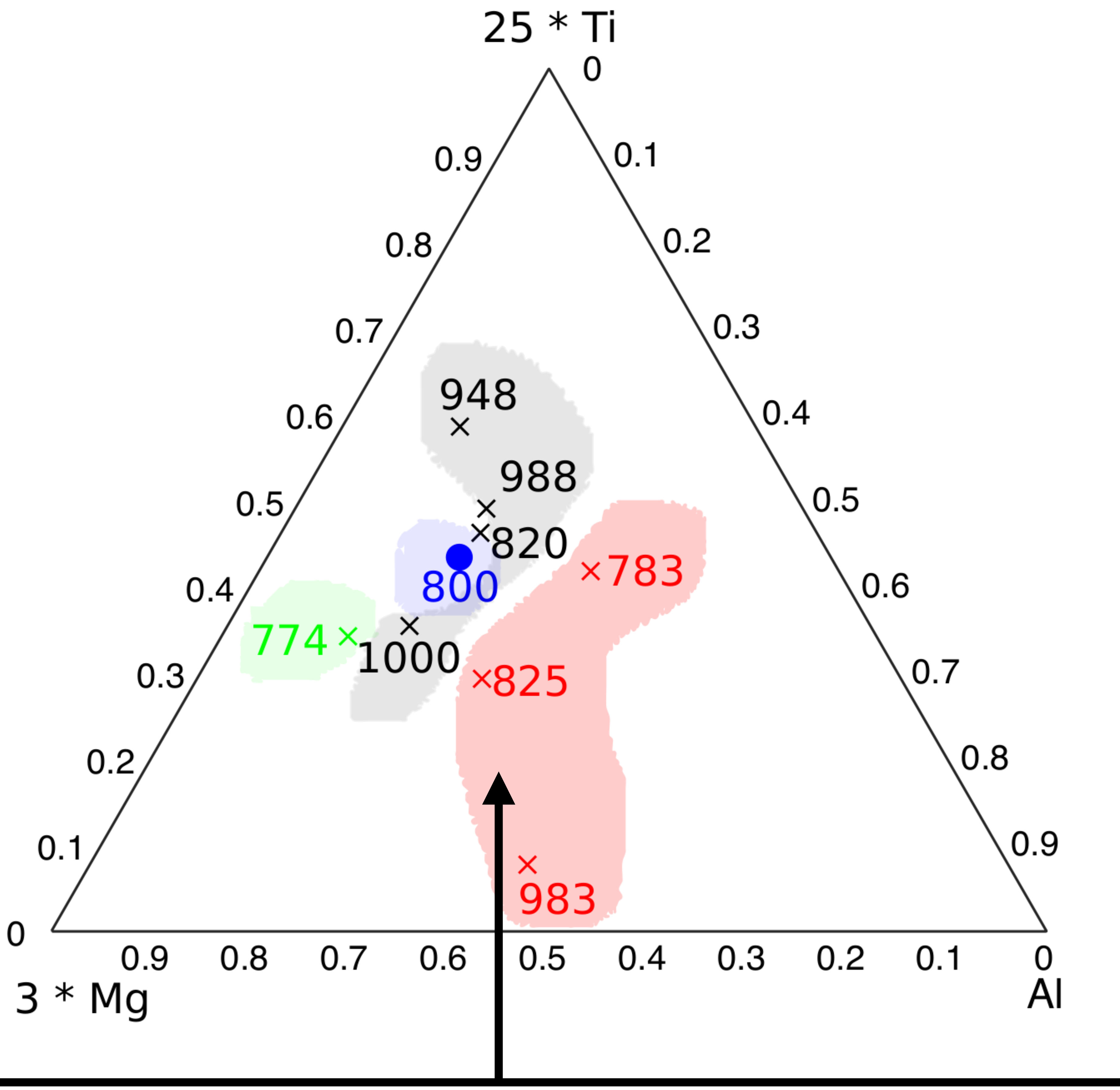
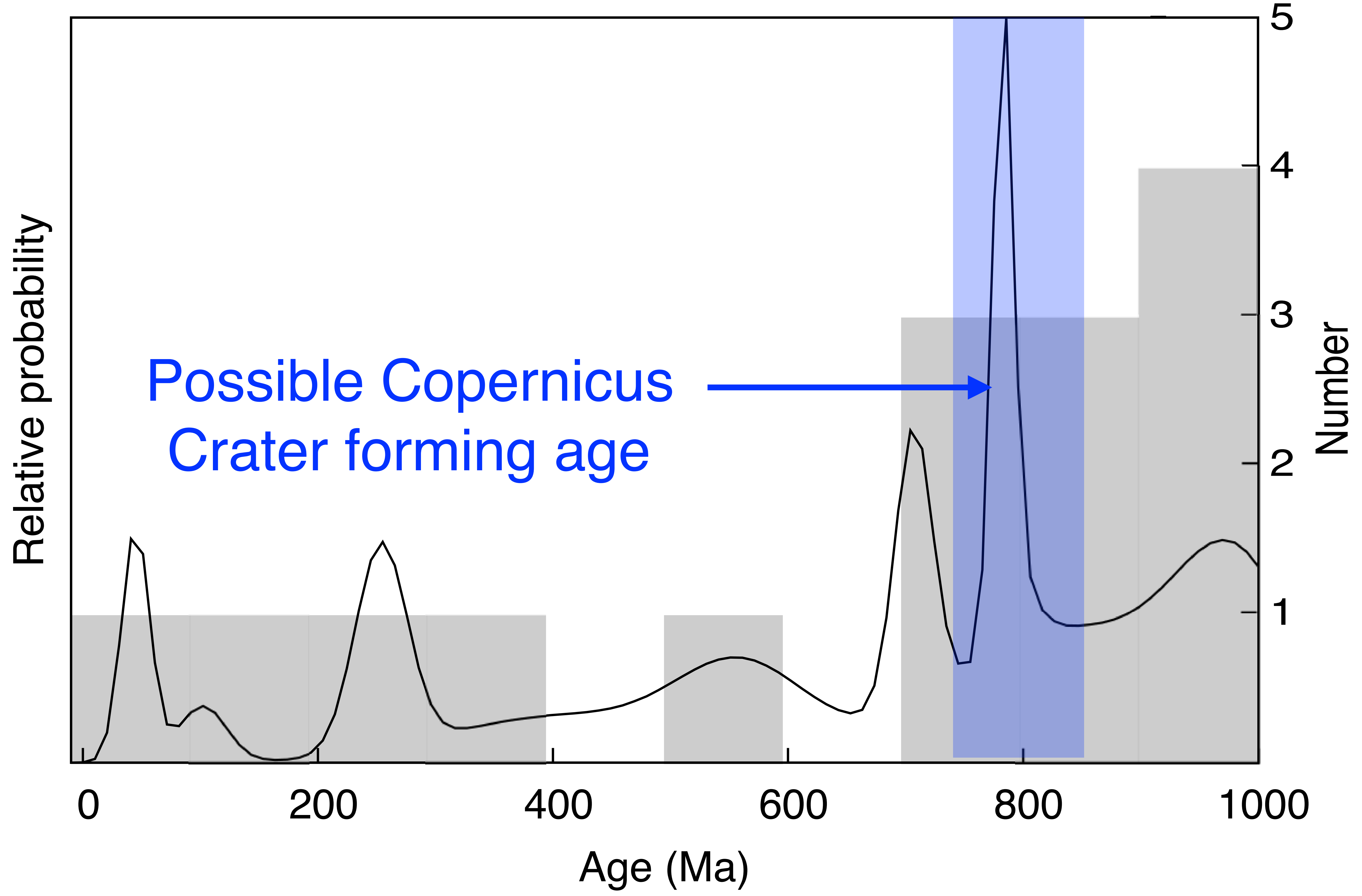


Observation 2: 800 Ma-old Exotic spherules are away from collections and in multiple landing sites.



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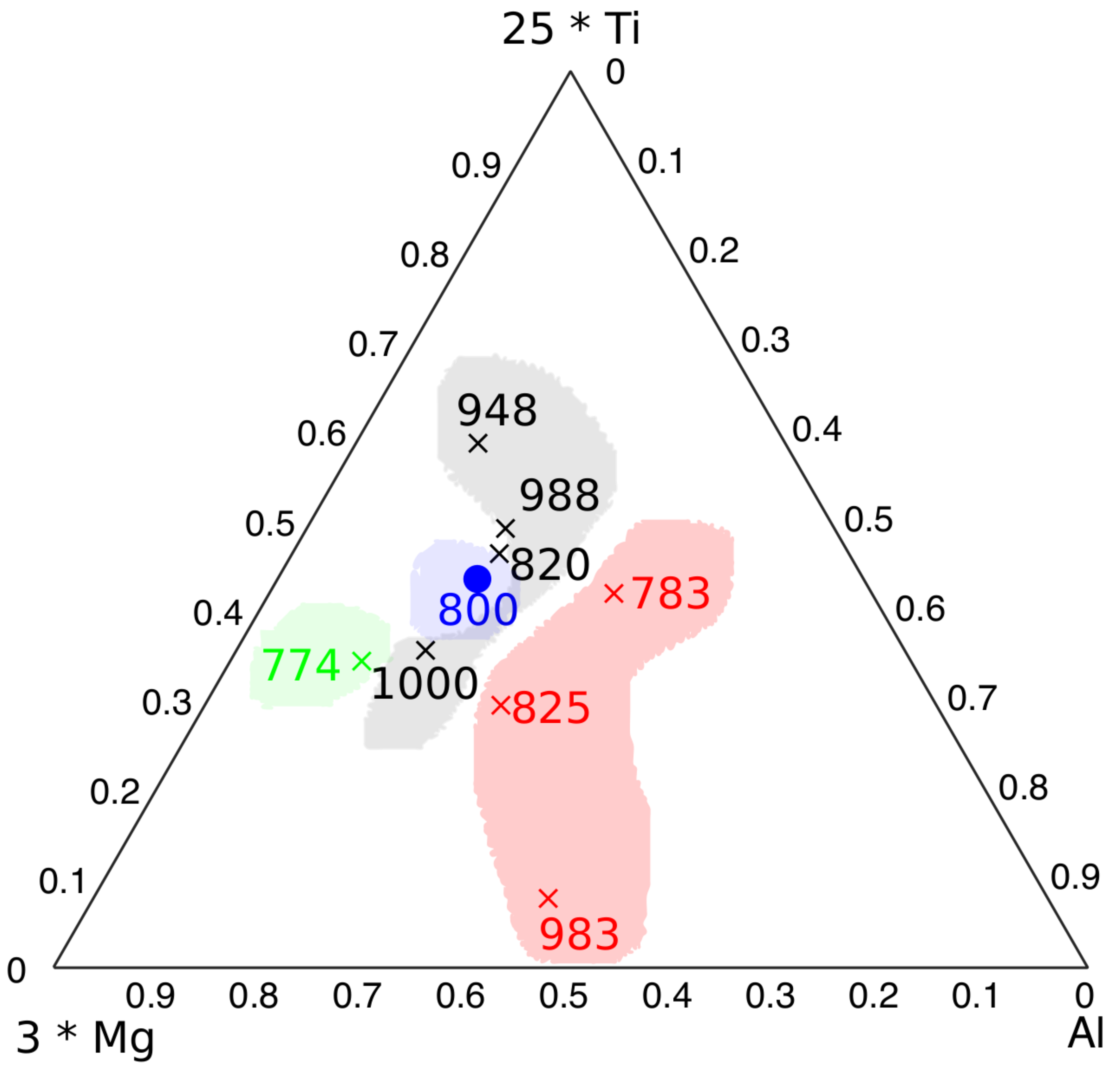

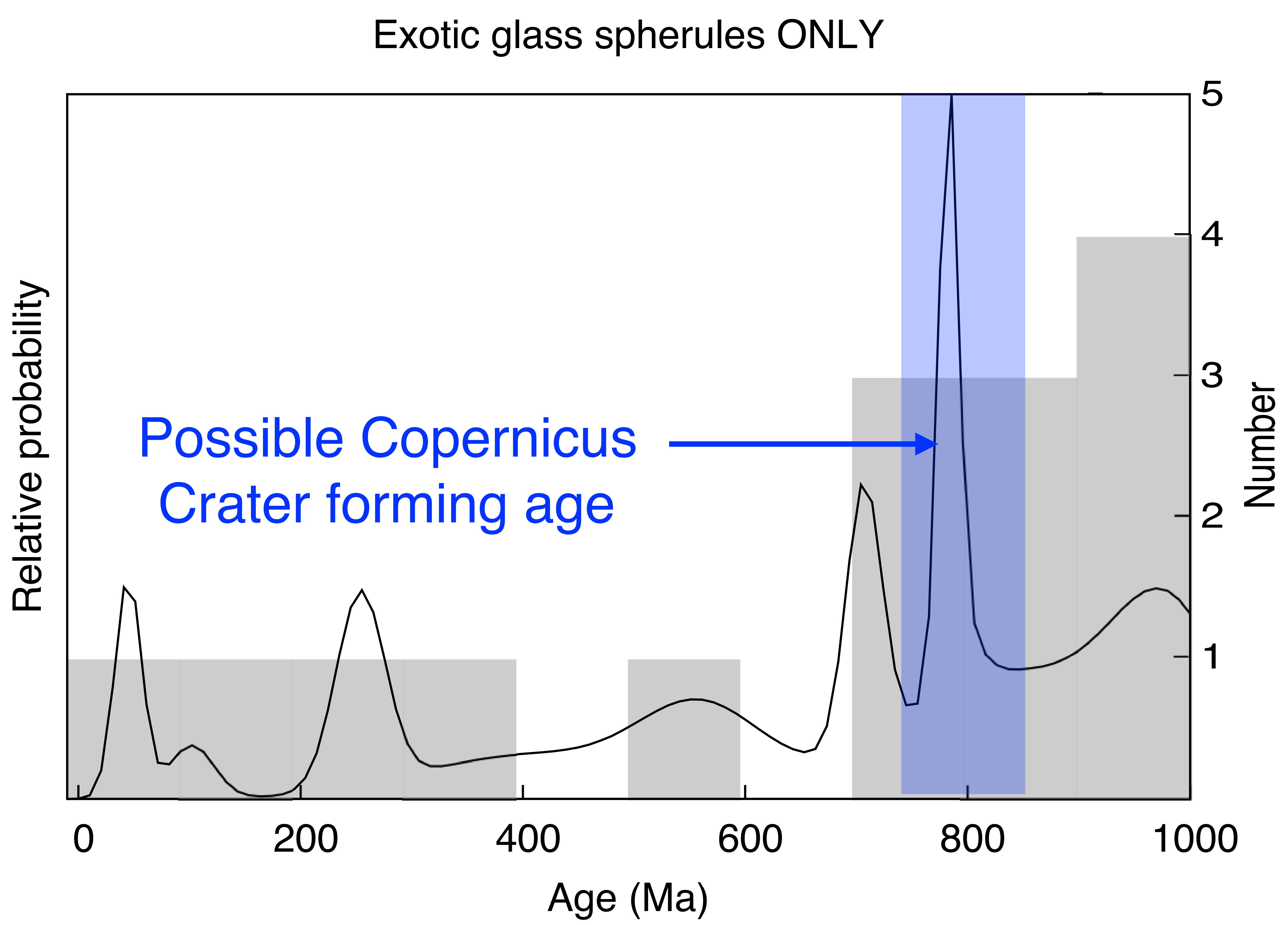

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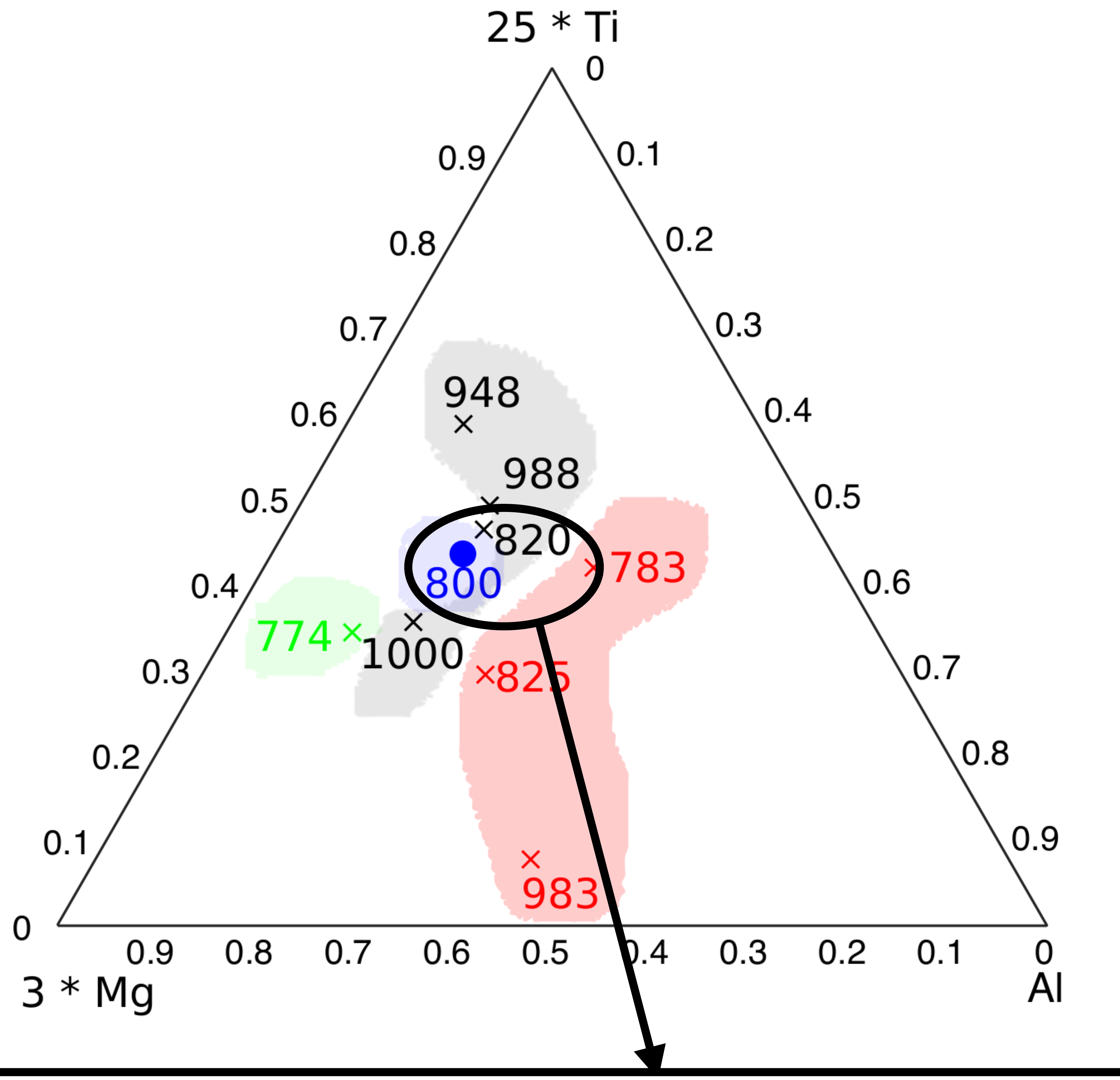
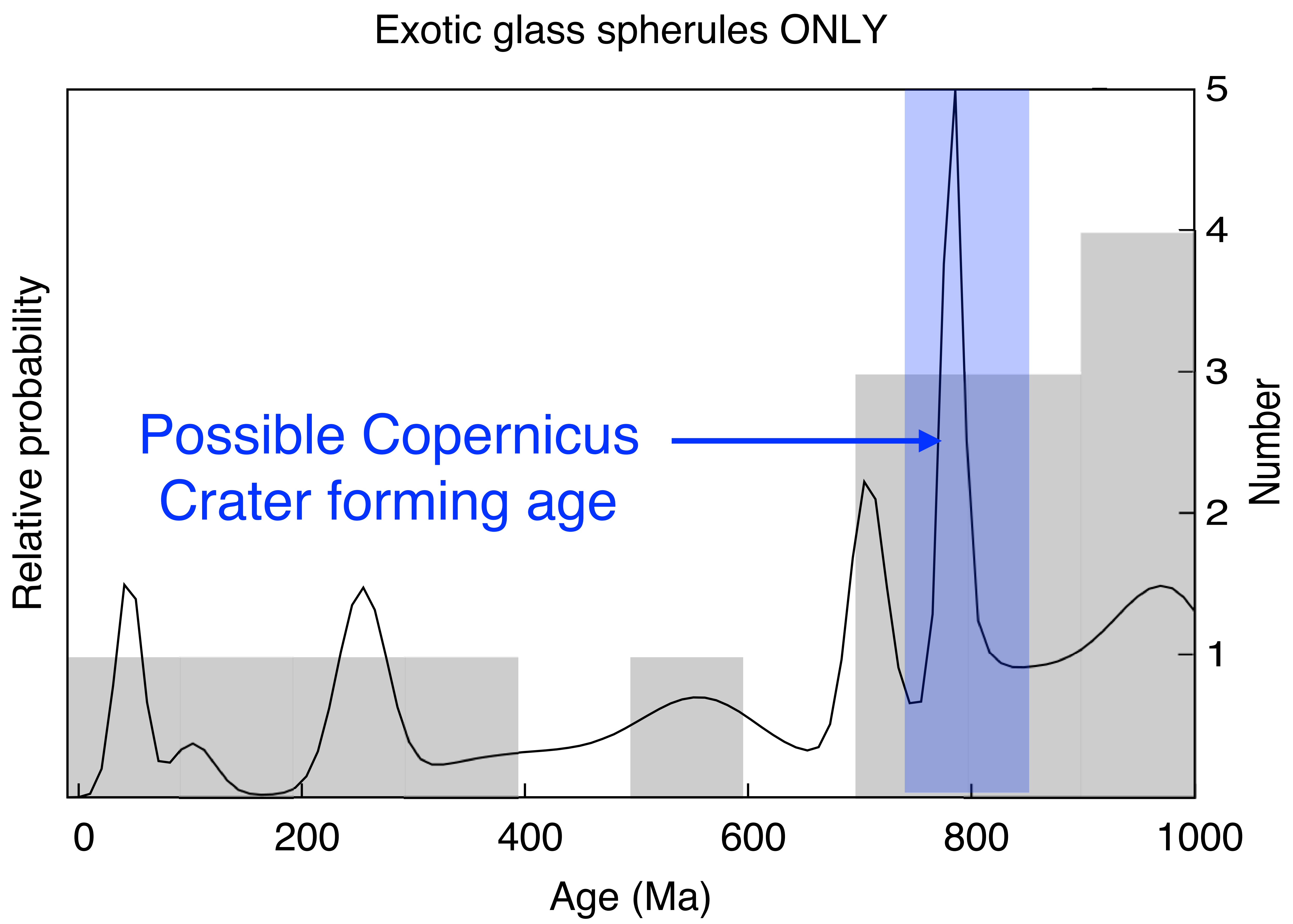


Observation 3: We found only one 800 Ma-old, exotic spherule geochemically similar to Apollo 12 ropy glasses.



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To explain the excess of ~800 Ma-old exotic glasses, we considered two possibilities.

Hypothesis 1: There was an increase in the lunar impact flux 800 Ma ago, and Copernicus Crater formed in this period.

Hypothesis 2: Exotic glasses were produced from re-impacting ejecta from Copernicus Crater.

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Most importantly, the melt production is dependent on impact velocity.

Fragments ejected at >3 km/s are suggested to be able to produce glass.

Impact velocity (km/s)	Peak pressure (vertical impact, GPa)	$P_m^i \approx 17.5\ GPa$ (~20% porosity*)	$P_m^i > 30\ GPa$ (0% porosity)
2.4	11.8	N	N
2.5	12.8	N	N
2.6	15.8	N	N
2.8	16.9	N	N
3.0	18.1	Y	N
3.2	20.4	Y	N

Assumed linear shock velocity:
$u_{sh} = c + su_p\ (c = 500\ m/s, s = 3.17,$ Güldemeister et al. 2013)
Peak pressure by Planar Impact Approximation (Melosh, 1989):
$P_{max} = \rho u_{sh} u_p\ \left(\rho = 2297\ kgm^{-3}, u_p = 0.5 v_{imp}\right)$
P_m^i: Incipient peak pressure for melting (Kowitz et al. 2013; Stöffler and Langenhorst, 1994)
*: Up to 80% melt and glass observed.

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Copernicus Crater secondary craters cannot generate melt.

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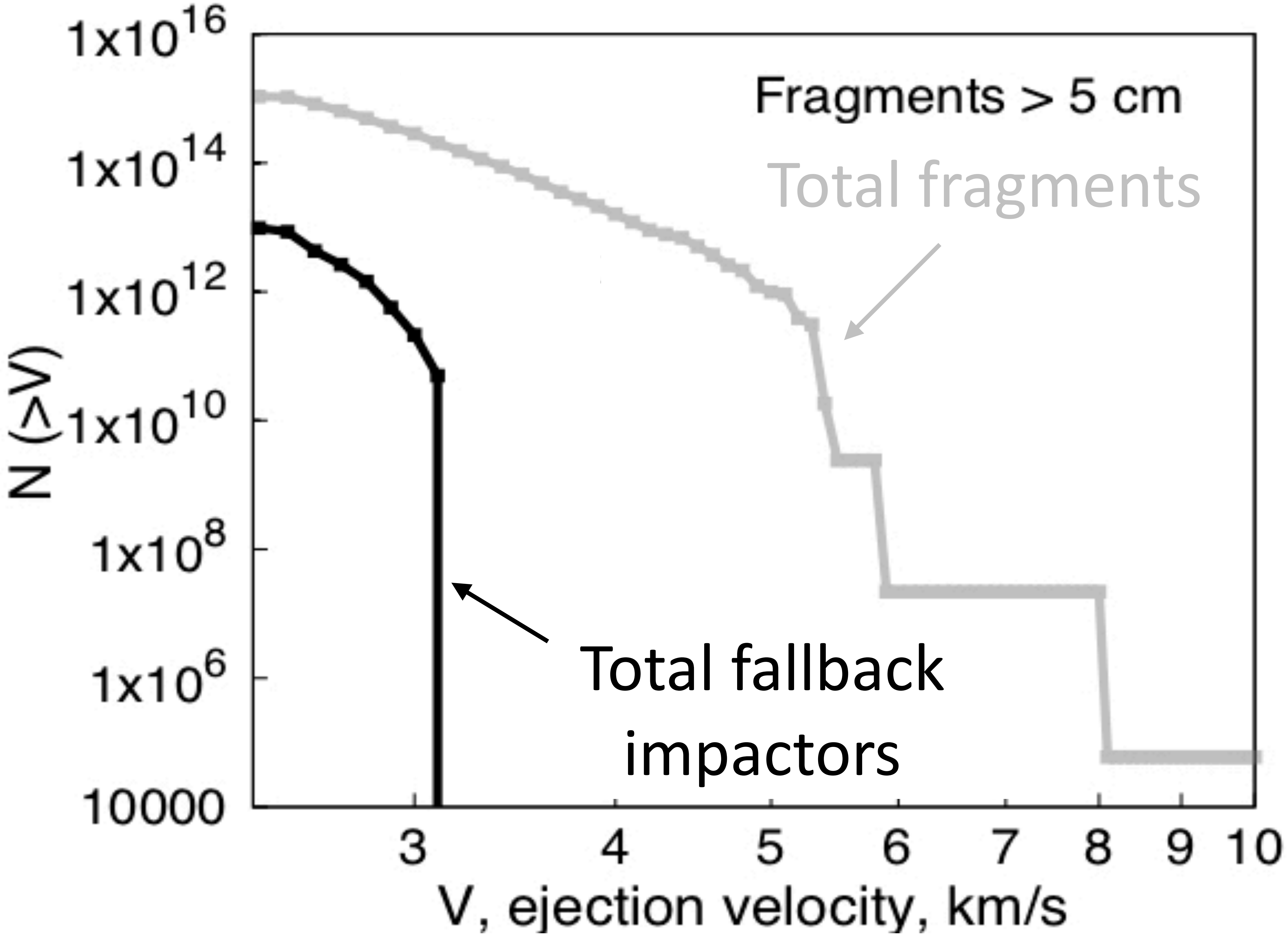
We combined fragmentation and N-body orbit dynamics codes, and generated a SFD of Copernicus Crater's ejecta fragments.



Huang et al. *Bombardment workshop* (2018)

SALES_2 run conditions

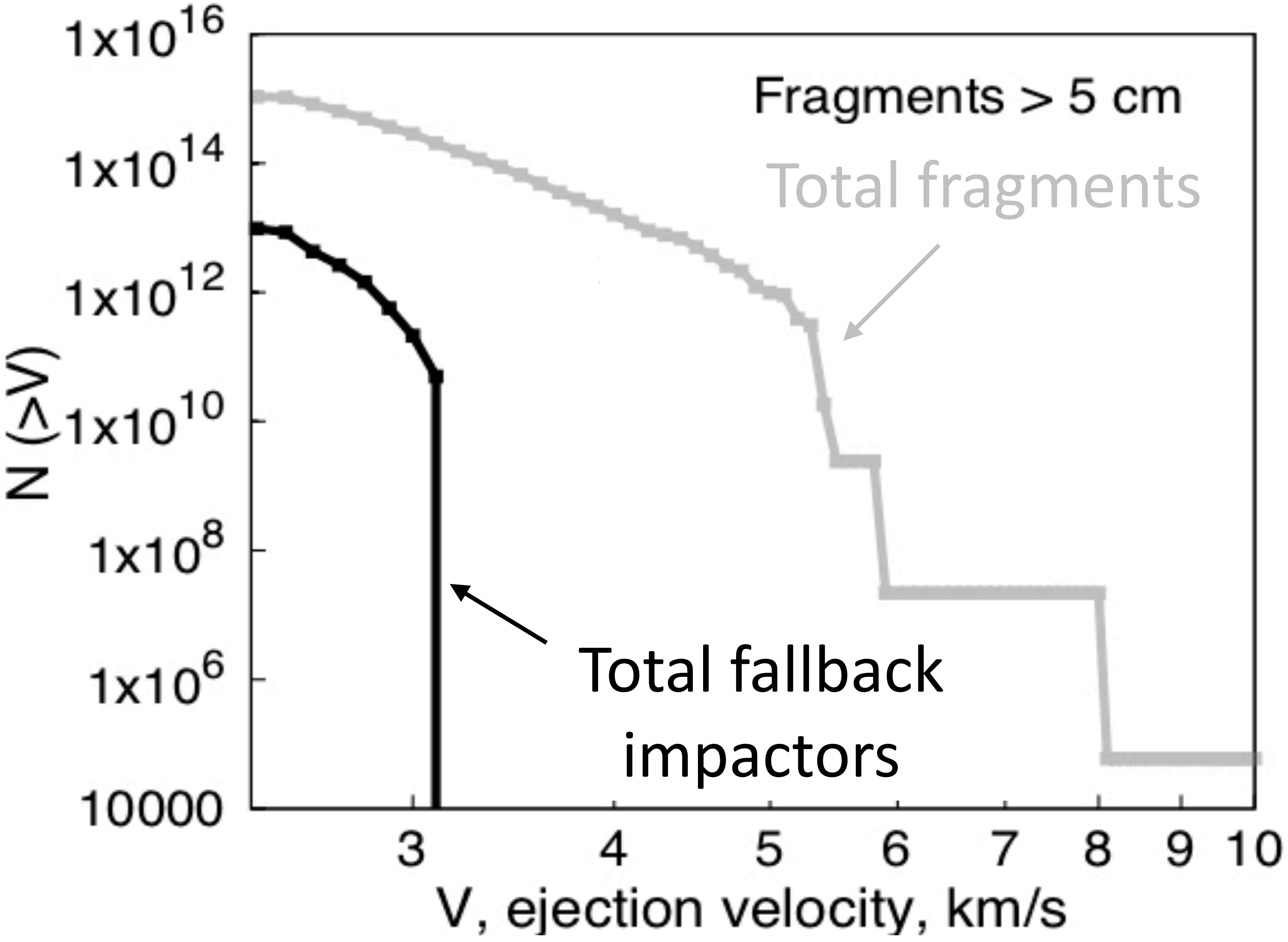
Impactor diameter	Impact velocity	Target material	Projectile material
7 km	10 km/s	Basalt	Basalt

Elliott and Melosh (2018)

REBOUND Luanch velocity (km/s)	2.4	2.5	2.6	2.8	3.0	3.2
Moon (% of 1000 teat particles)	3.9	1.9	0.9	0.7	0.2	0.0

Rein et al. (2012)

We combined fragmentation and N-body orbit dynamics codes, and generated a SFD of Copernicus Crater's ejecta fragments.



Huang et al. *Bombardment workshop* (2018)

SALES_2 run conditions

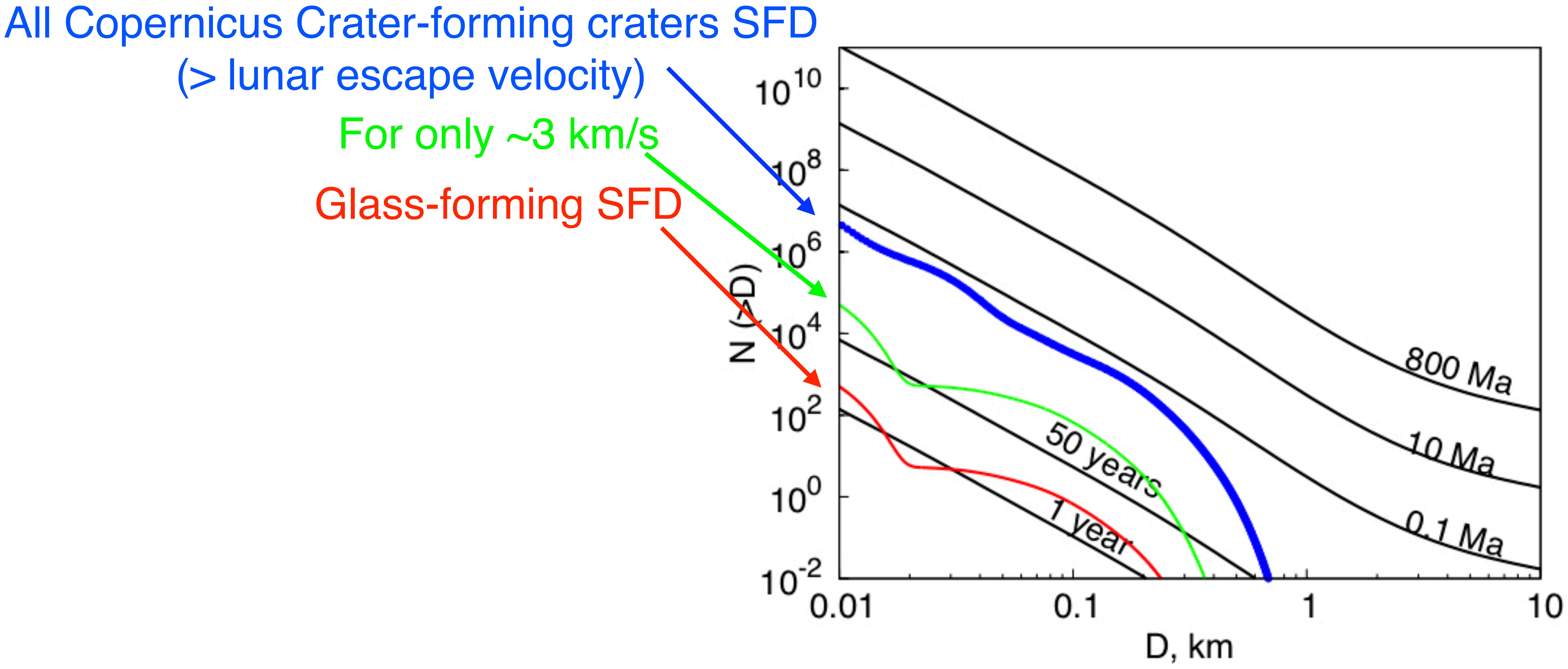
Impactor diameter	Impact velocity	Target material	Projectile material
7 km	10 km/s	Basalt	Basalt

Elliott and Melosh (2018)

REBOUND Luanch velocity (km/s)	2.4	2.5	2.6	2.8	3.0	3.2
Moon (% of 1000 teat particles)	3.9	1.9	0.9	0.7	0.2	0.0

Rein et al. (2012)

Considering that the lower velocity makes glass formation more difficult, sesquinary-forming spherules appears negligible.



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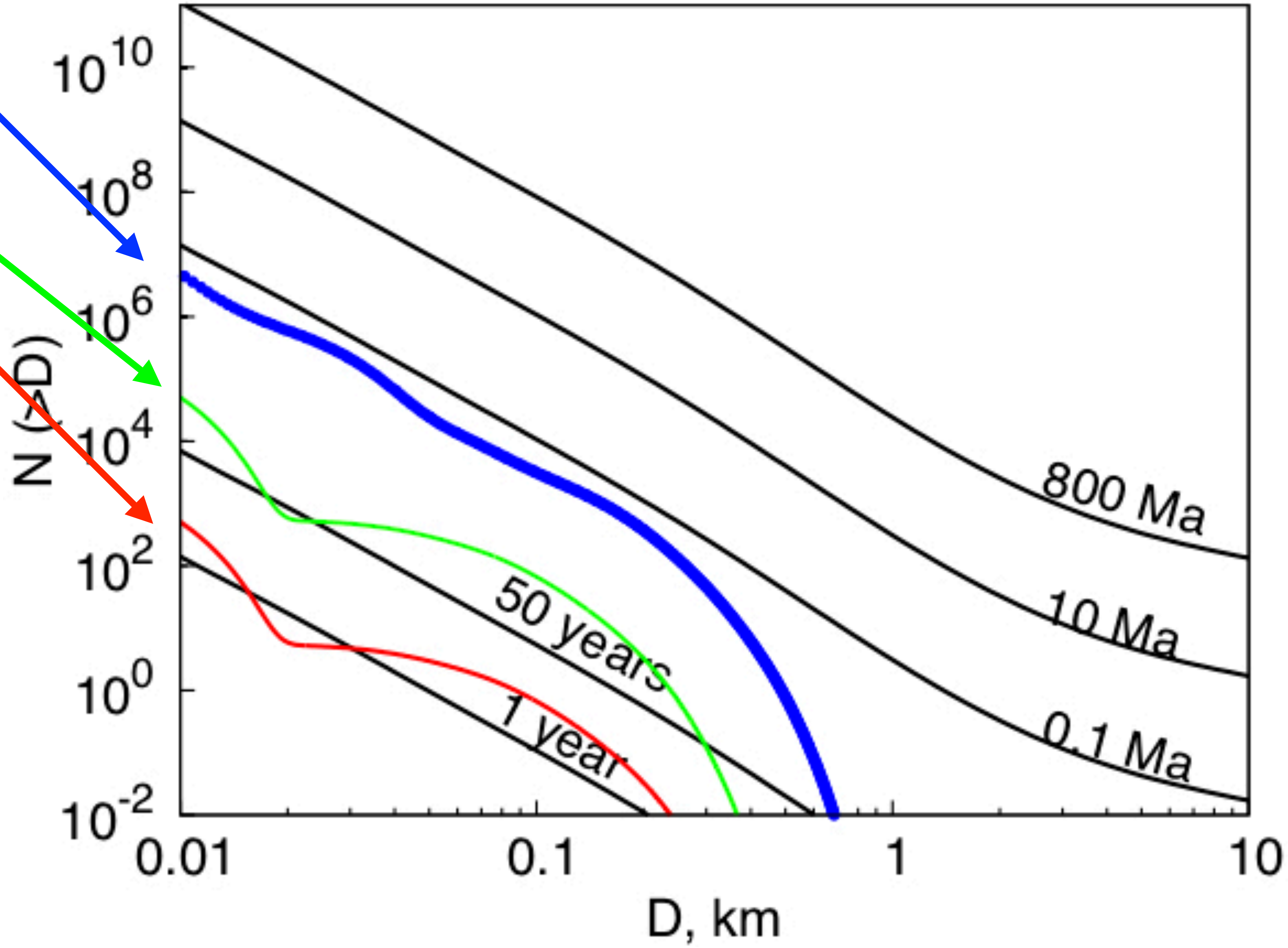
All Copernicus Crater-forming craters SFD (> lunar escape velocity)

For only ~3 km/s

Glass-forming SFD

Copernicus Crater may have been the largest crater produced in a short-lived impact spike at ~800 Ma as proposed by Zellner et al. (2009).



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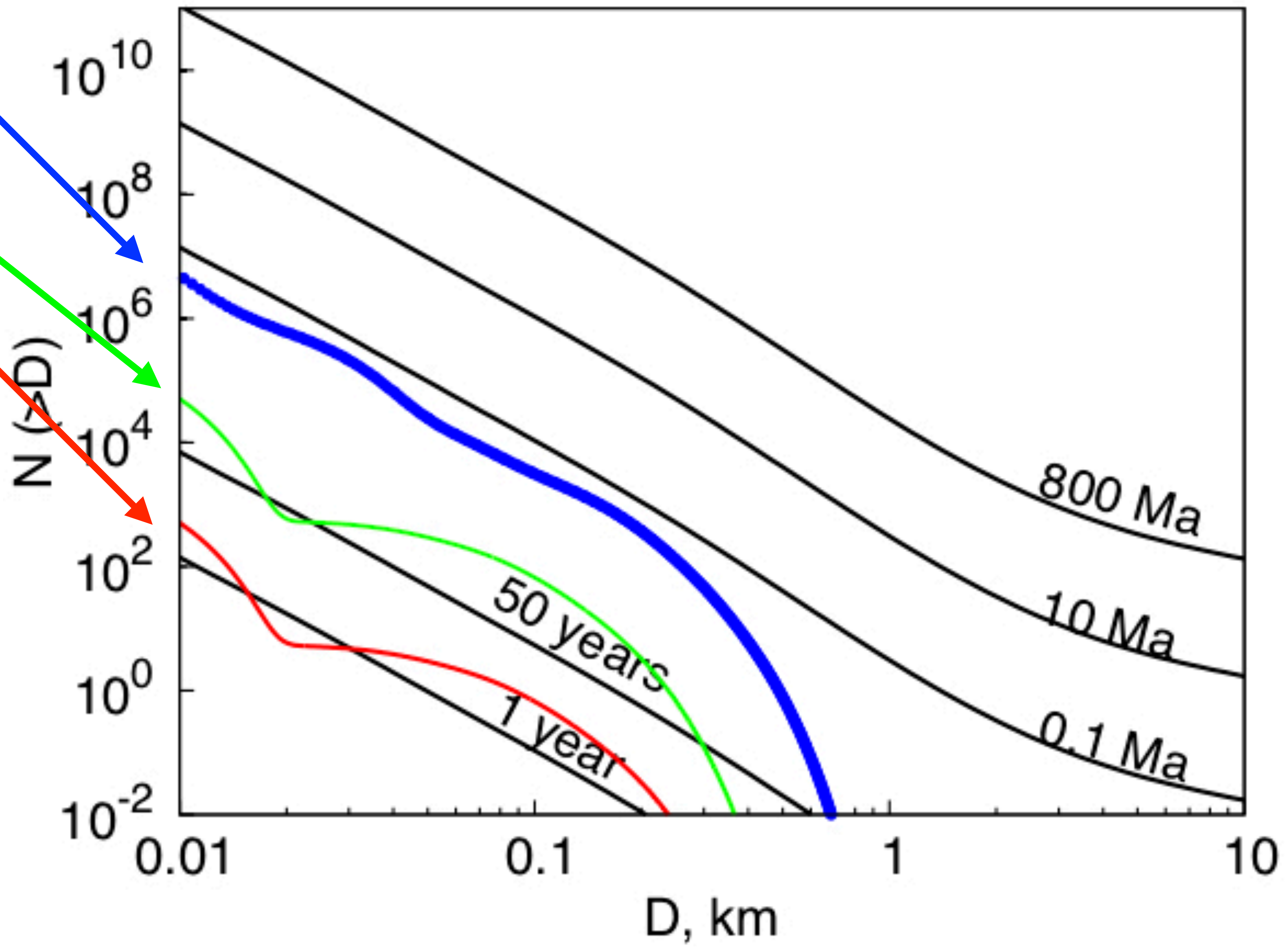
Or a link between geochemical composition of exotic glass spherules and Copernicus Crater needs to be further assessed.



Implications

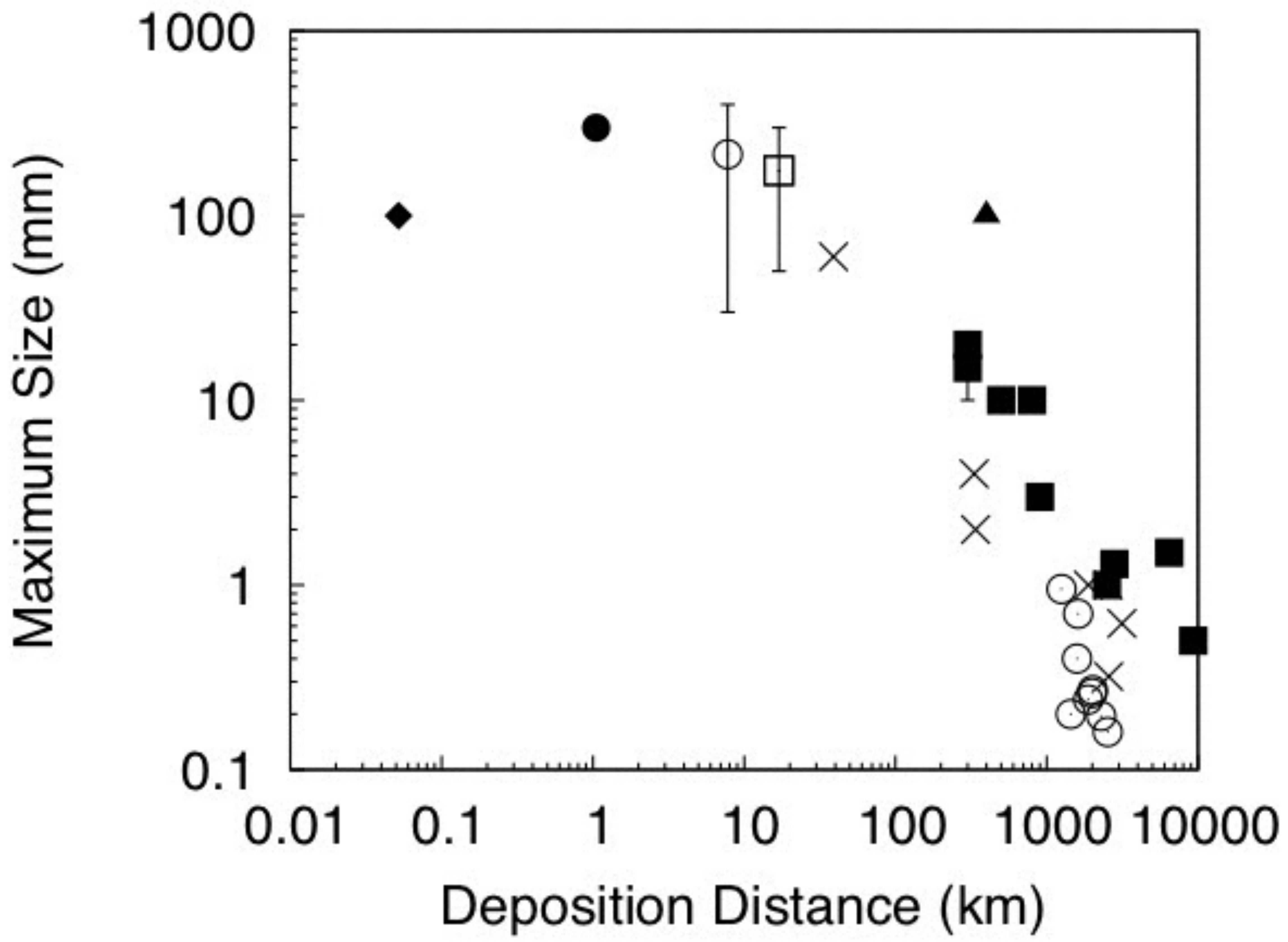
- The excess of lunar impact glass spherules in the last 500 Ma can be explained by our depth-dependent sampling bias model without changing the impact flux, but this does not rule out a possibility of a change in the lunar impact flux.

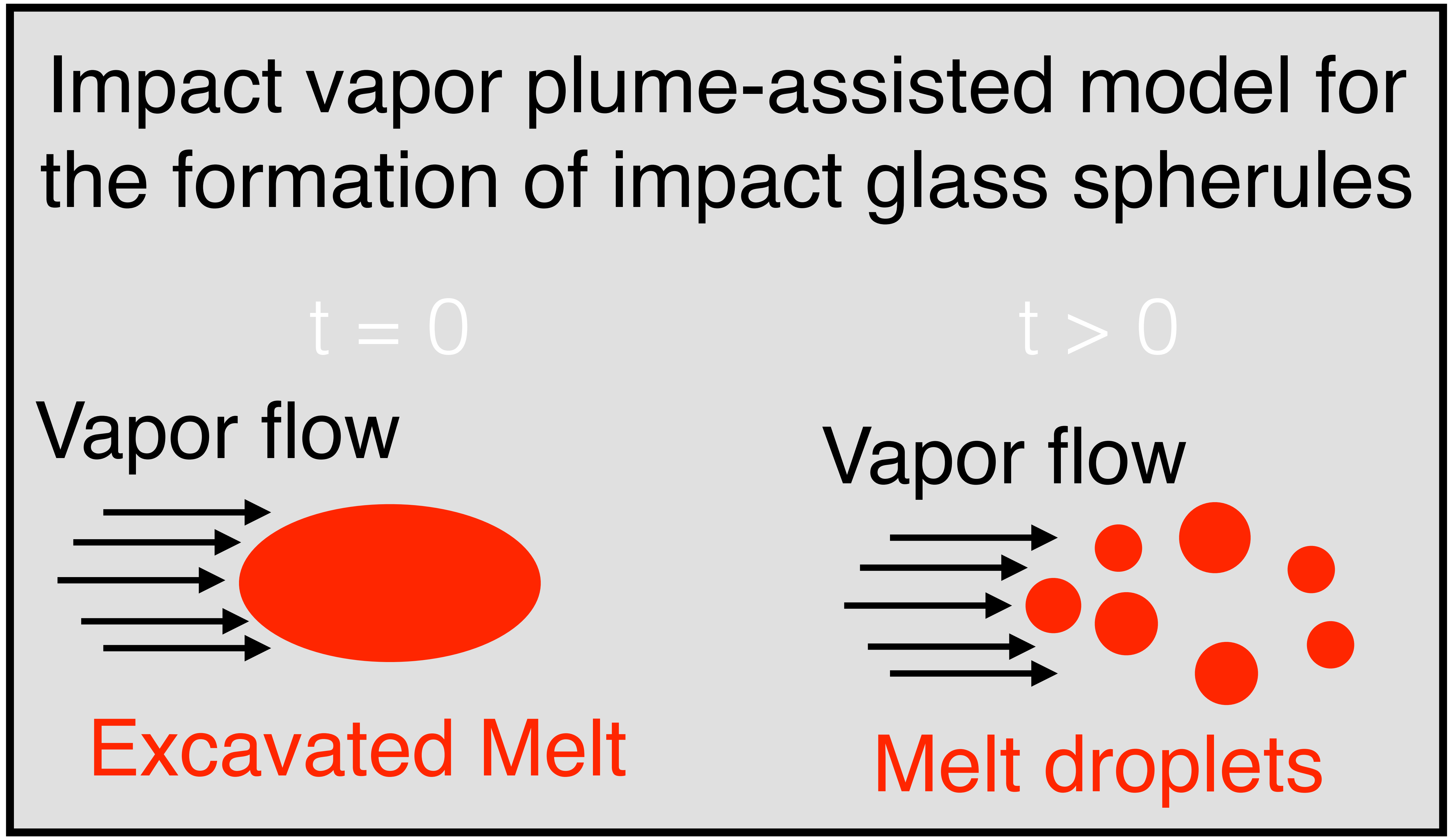
- Our identified fourteen exotic glass spherules show an excess of 800 Ma ages, which is consistent with an initial finding of Zellner et al. (2009).

- Due to a negligible amount of Copernicus Crater-forming spherules, Copernicus Crater alone cannot explain the excess of 800 Ma-old, exotic spherules, suggesting a possibility of a short-lived spike ~800 Ma ago on the Moon.

- Considering a target heterogeneity of Copernicus Crater regime, a further geochemical analysis for our identified “exotic” spherules and the subsurface of Copernicus Crater is needed.

Terrestrial microtektite distributions from crater's center may shed some light on the physics of impact glass spherules.





Melosh and Vickery (1991) and Johnson and Melosh (2014)

■ Chicxulub (34 km) × Chesapeake Bay (12.6 km) □ Ries (9.9 km)

⊙ Bosumtwi (4 km) ● Lonar (600 m) ◆ Kamil (20 m)

▲ Apollo 12 Ropy glasses (Copernicus, 38 km)

Huang et al. (2018) *GRL*

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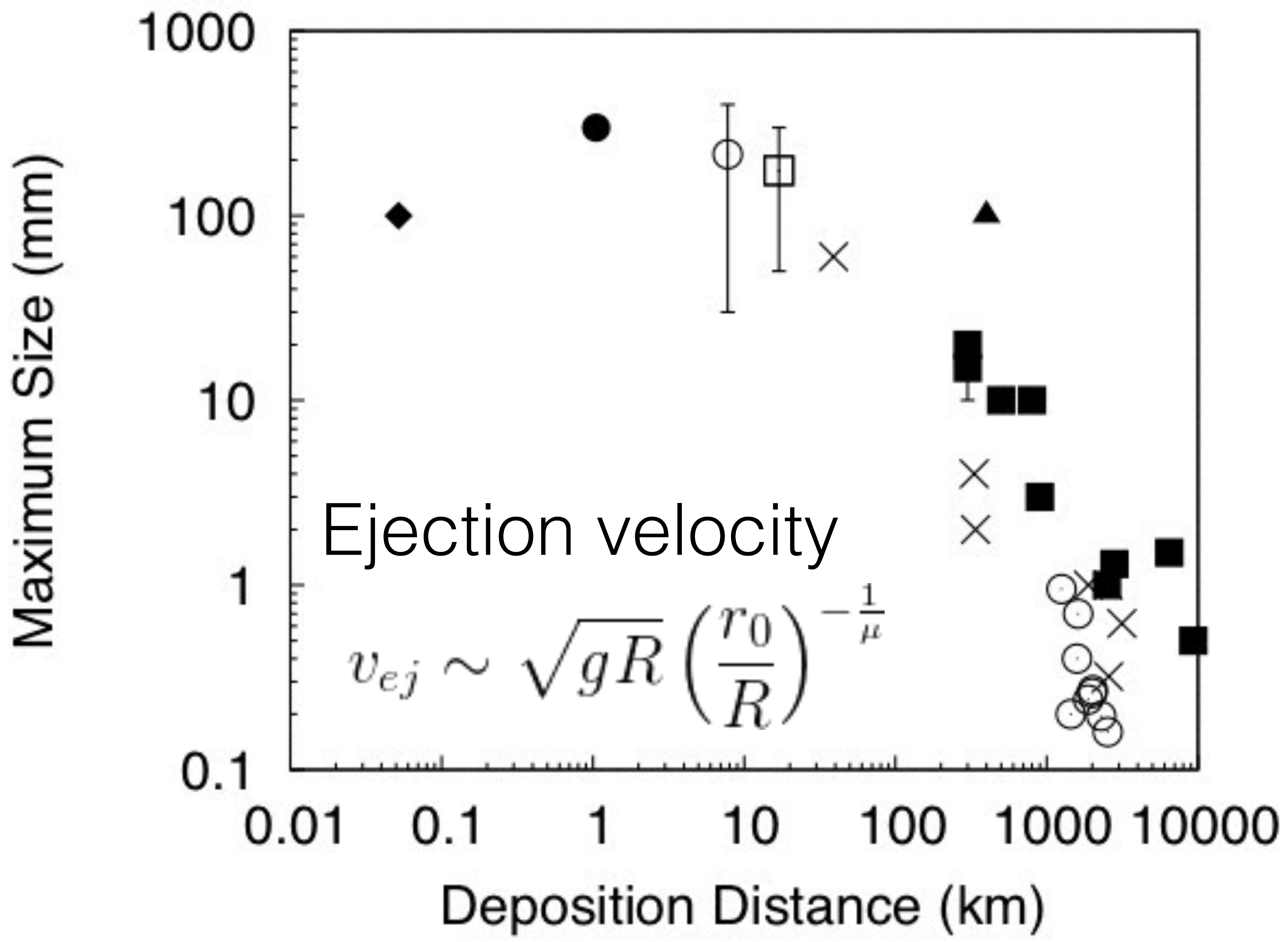

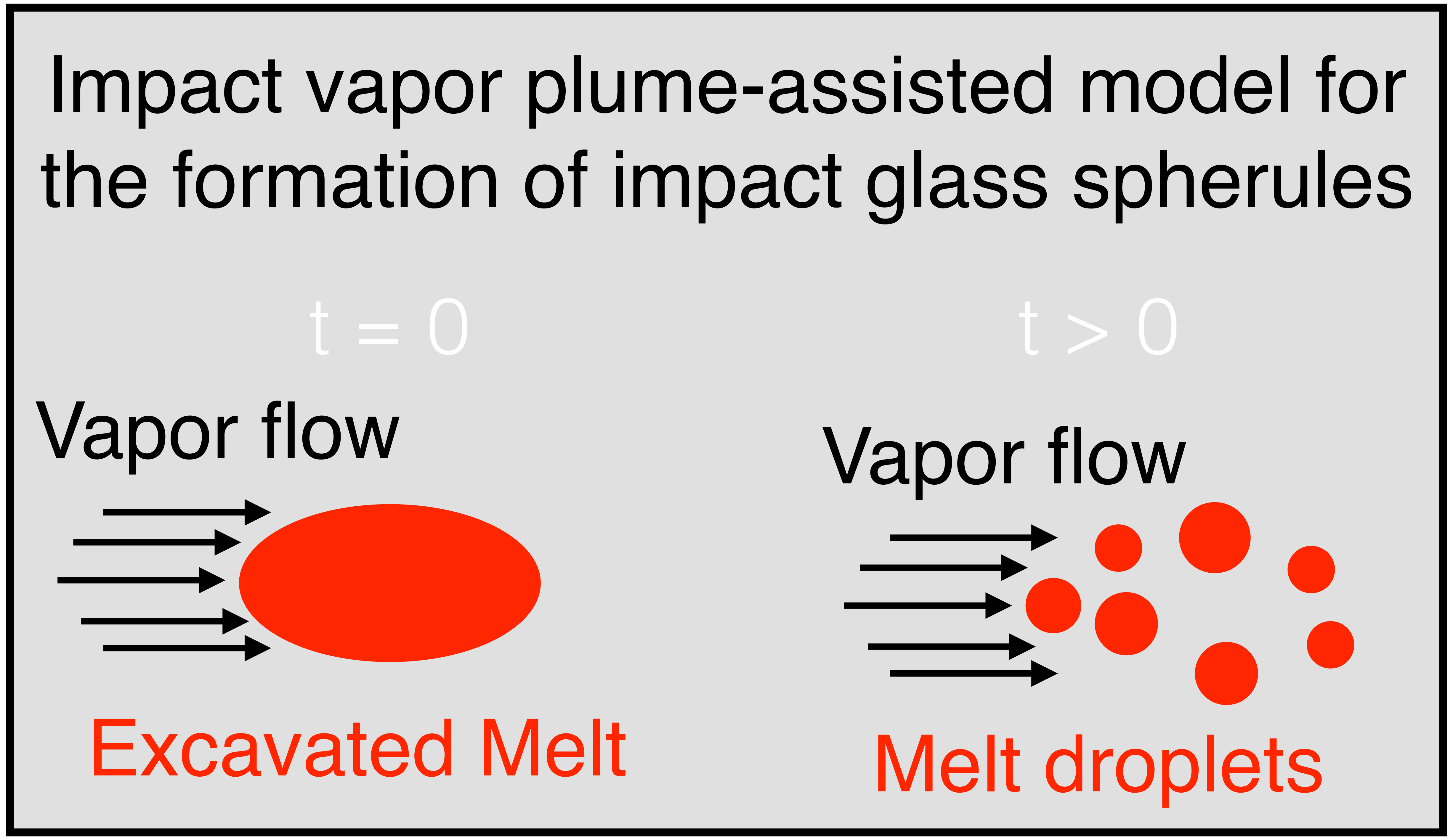

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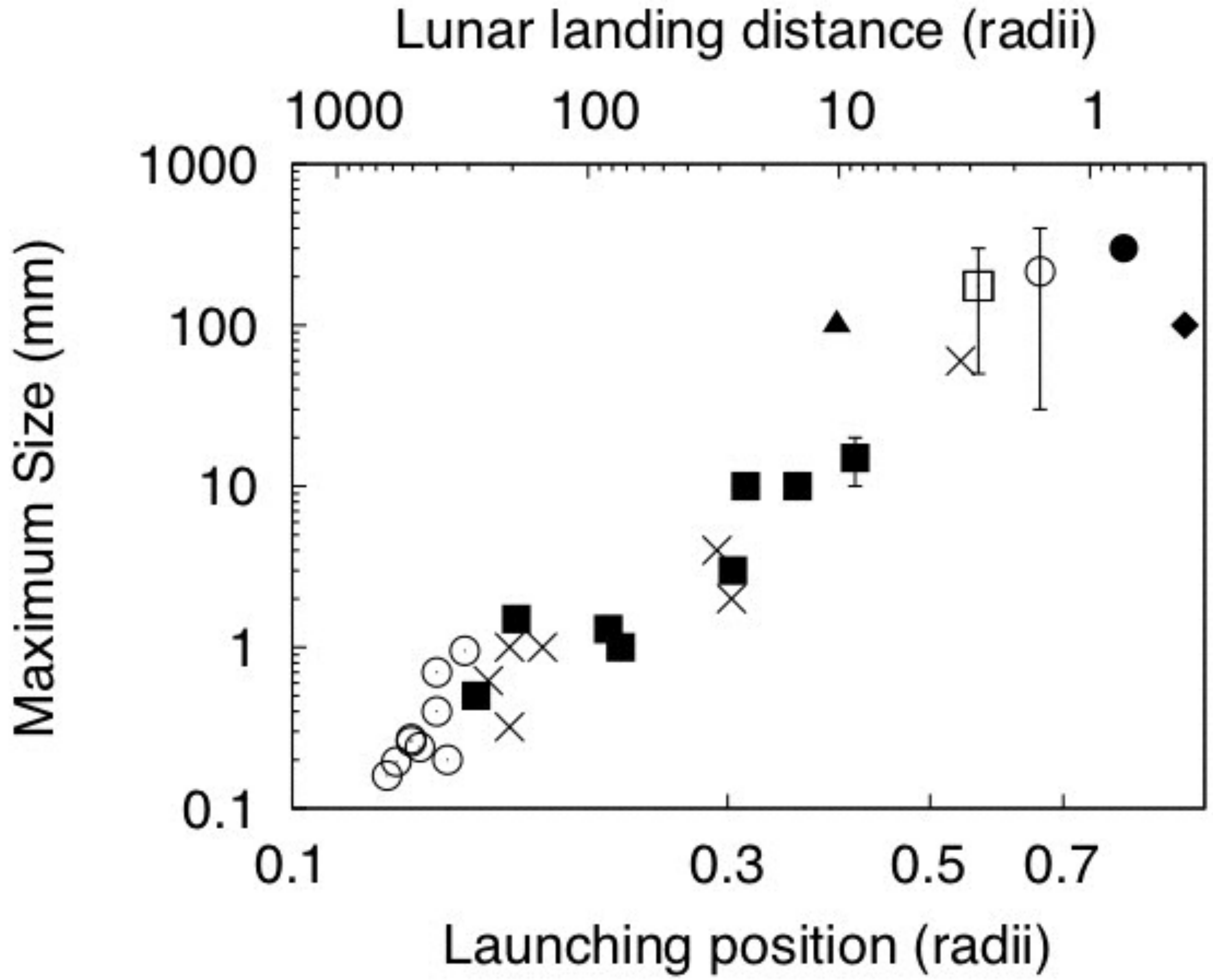

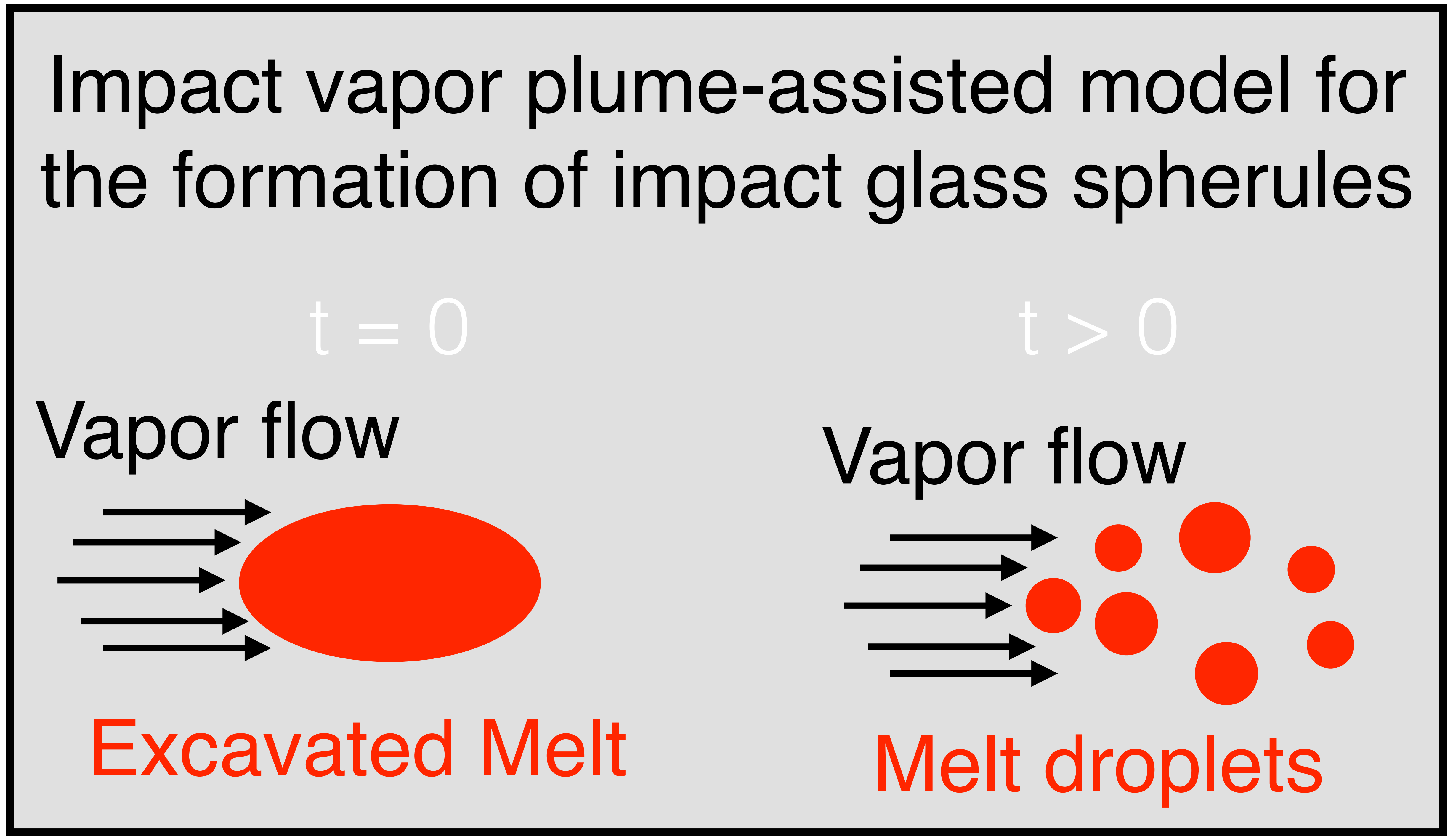

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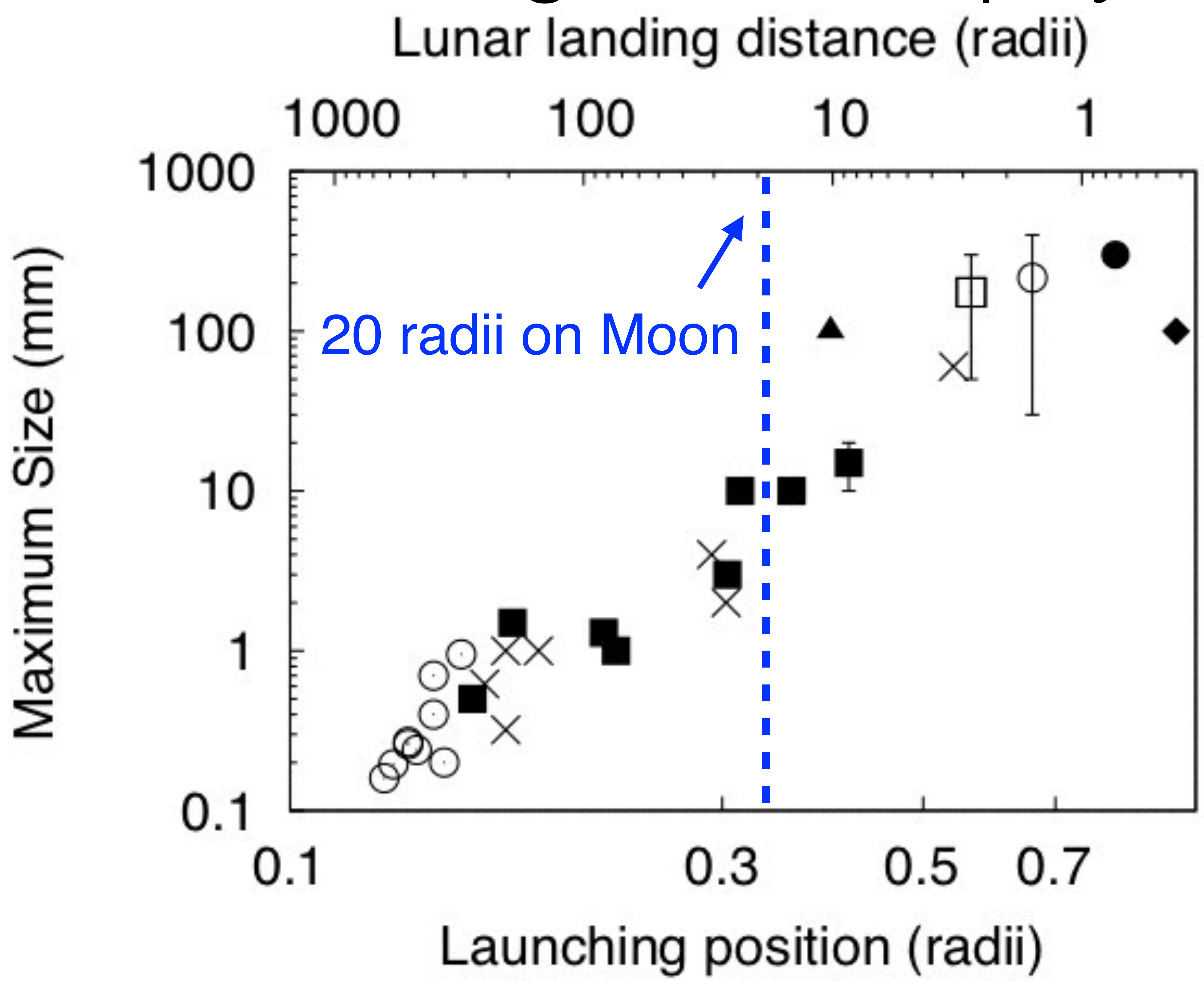

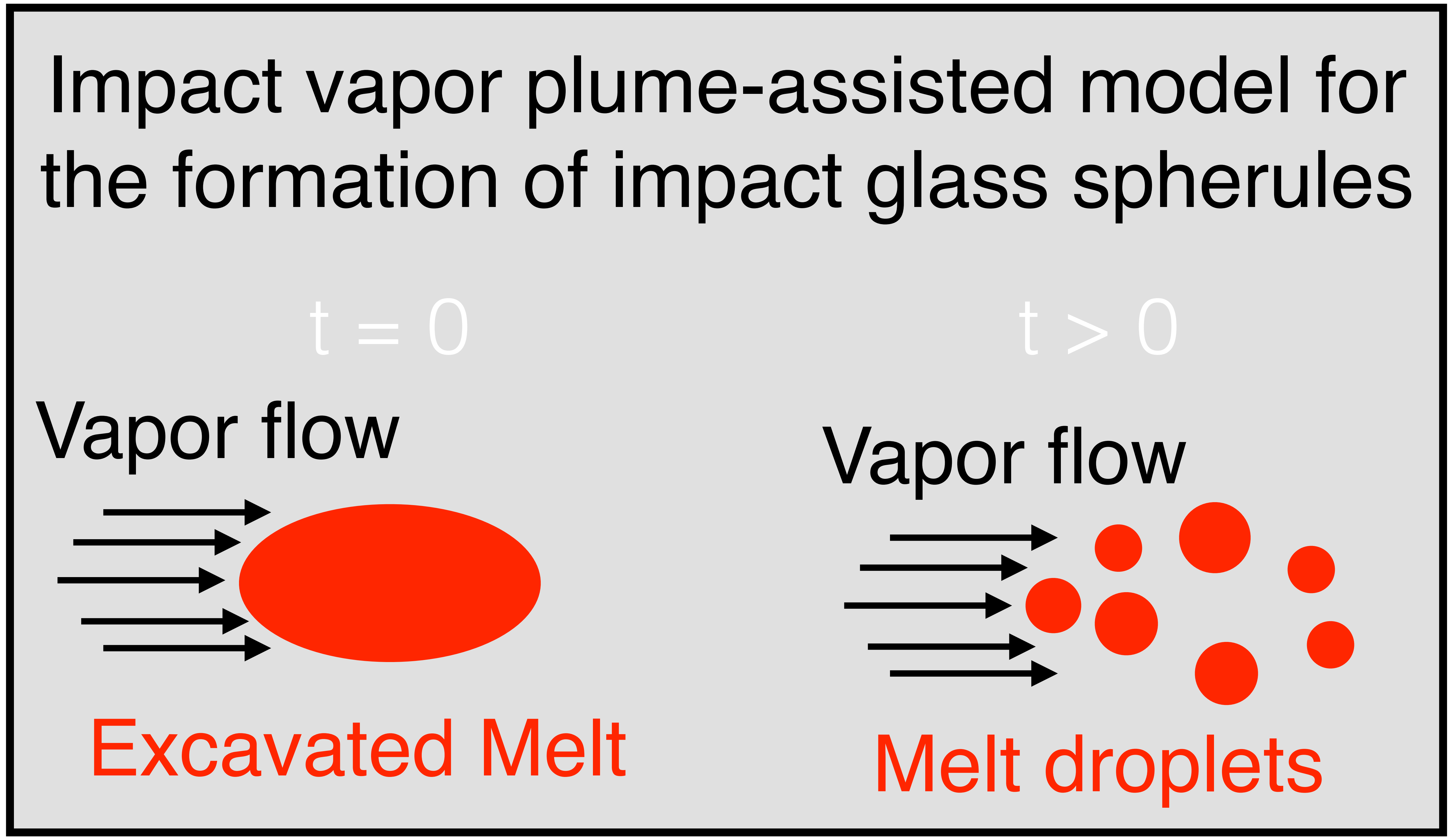

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