Asymmetric impacting on the Moon and its dependence on debiased NEA models

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Motivation: Rayed crater distribution on the Moon

- Synchronized rotational & orbital motion of satellites (1:1 commensurability)
- More craters around apex
- Typically observed on Galilean satellites of Jupiter
- Confirmed on the Moon
- More craters around apex
- Young, rayed craters
- Small $v_{\text{relative}}$ (vs. $v_{\text{impact}}$)
- Strong asymmetry
- Large $v_{\text{relative}}$
- Weak asymmetry
- Potential constraints on the origin of the projectiles

This poster - Confirmation of the lunar crater asymmetry by numerical integrations
- w/ debiased NEA populations
- w/ steady-state NEA model


Numerical integration [1]: Initial conditions and method

- Debiased NEA population (A)
  - Bottke et al. (2002, Icarus, 156, 398-413)
  - 18,000 particles
  - 5 source regions
  - $J_2$ resonance
  - 1:1 MMR
  - Mars-crossers
  - outer MB
  - TNO disk

- Debiased NEA population (B)
  - Morbidelli (2000, unpublished)
  - 18,000 particles
  - 5+2 source regions
  - $J_2$ resonance
  - 1:1 MMR
  - Mars-crossers
  - outer MB
  - TNO disk

- "Raw" NEA-like particle population (C)
  - Apollo, Amor, Aten-like
  - 10,000 particles as of 2010. July
  - ~7,000 original + clones
  - No debiasing procedure, mostly $\approx$18

Steady-state NEA model

- In many previous studies
  - NEA flux decreases
  - Impact distribution changes
  - Along with orbit distribution change

- NEA flux ~ constant over 3 Gyr
  - From lunar crater record
  - Constant supply of particles

- Steady-state NEA flux in a numerical model
  - ($v_{\text{impact}}$, $v_{\text{relative}}$, $r_1$)

- Reproduction of steady-state NEA flux

Encounter statistics at Earth's $r_1$

- Encounter velocity
  - $v_{\text{impact}}$
  - $v_{\text{relative}}$
  - $v_{\text{relative}}$ distribution

- Encounter position
  - $r_1$

Impact statistics on the Moon

- Relative fraction

Asymmetric $v_{\text{impact}}$ distribution

- $v_{\text{total}}$ (~1 km/s) < $v_{\text{impact}}$ (~22 km/s)

Concentration

- Leading: $\delta$ larger
- Trailing: $\delta$ smaller

Impact velocity on the Moon

- Debiased population (A,B) $\rightarrow$ larger
- Daw NEA population (C) $\rightarrow$ smaller

Impact angle

- Quite isotropic for both the Earth and the Moon

- Debiased population (A,B)
  - Imp., $v_{\text{impact}}$, $r_1$, ... , ...
  - Retrograde $r_1$
  - Positive $v_{\text{impact}}$
  - Rel. fraction
  - Good to make an orbital distribution function

More particles for the Moon

- Generate many particles ("clones") from the orbital distribution function
- $N_r$ clones
- $N_r$ particles

Orbital integration of Earth + Moon + sun + $10^2$ "clones" $\rightarrow$ Numerical integrations [2] (Total $N_{\text{clone}}$ $\rightarrow$ 10$^{19}$)

Need more particles for the Moon

- ~3,000 test particles at ~2AU
- ~100 collisions on the Earth
- Some collisions on the Moon
- Statistically meaningful?

Asymmetric impact distribution

- Leading: $\delta$ larger
- Trailing: $\delta$ smaller

Impact velocity on the Moon

- Debiased population (A,B) $\rightarrow$ larger
- Daw NEA population (C) $\rightarrow$ smaller

Impact angle

- Quite isotropic for both the Earth and the Moon

Conclusion

- Both debiased models (A,B) yield similar results in terms of the cratering asymmetry
- Weaker asymmetry than the actual rayed crater record, indicating the presence of more "slower" objects
- Raw NEAs have lower ($v_{\text{impact}}$) - but still consistent with the rayed crater record
- Rayed crater data should be updated (Kaguya, ...), as well as the NEA orbital distribution (Pan-STARRS, ...)

Search area by Motoda & Furumoto (2003, GP&G, 226, 313-322)
Total 222 rayed craters ($D>$5km) detected

Map of rayed crater data

Figures

- Reproduction of steady-state NEA flux

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