Early and late heavy bombardments in the inner solar system as recorded in extra-terrestrial zircon

S. J. MOJZSIS[1*]

[1]University of Colorado, Department of Geological Sciences, Boulder, Colorado 80309-0399 USA
(*correspondence: mojzsis@colorado.edu)

Zircons in asteroidal, lunar, and martian rocks are rare, but a modest number have been documented from eucrites (from 4 Vesta), Apollo samples and lunar meteorites, and recently from the NWA7034/7533 martian meteorite "clan". Sub-micrometer distributions of trace elements (Ti, U, Th, REEs) and ^{235,238}U-^{207,206}Pb ages were investigated in zircons identified in brecciated eucrites [1], Apollo 14 impact rocks [2], and NWA 7034 [3]. Data reveal different age domains correlative to mineral chemistry in cores vs. mantles within individual zircons, as well as in different zircon age populations. These compositional differences (e.g. $[Th/U]_{zrc}$, Ti-in-zircon thermometry, REE partitioning, and Pb* isotope discordance) can be related to ancient thermal events to the 4 Vesta, Moon and Mars. Results confirm that Vesta's crust solidified within a few million years after the formation of CAIs (4561±13 Ma), in good agreement with previous work. Subsequent zircon age re-setting occurred less than 40 Myr later (ca. 4530 Ma). At least three distinct age populations for the Moon (4334 ± 10, 4245 ± 10 and 3953 ± 10 Ma) were identified. For Mars, a 4428 ± 20 Ma age with ca. 1700 Ma lower intercepts confirms previous work (Humayun et al., 2013). Analytical modeling to account for the thermal field required to re-crystallize zircon in the younger domains from these objects shows that impact velocities to the asteroid belt, Mars and the Moon must have been substantially different from today. Differences in recorded ages for these different planetary objects is attributable to differences in mineral closure temperatures (T_c zircon >> apatite) and changes to the velocity distributions of impactors in the asteroid belt during the long tail of accretion. I will review how these results lend support to the idea that instead of a simple unimodal "Late Heavy Bombardment" scenario, or a monotonic decline in impacts, the inner solar system was battered by multiple cataclysms since ca. 4240 Ma, and perhaps earlier. Such Early *and* Late Heavy Bombardments – or "Picket fence"-like bombardment – best describes the mode and tempo of impacts that accompanied the late stages of solar system formation and giant planet migration.

[1] Hopkins et al. (2015) *Icarus* 245:367–378; [2] Hopkins and Mojzsis (2015) *CTMP* **169**; 30; [3] Humayun et al. (2013) *Nature* **503**, 513-517.