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Increased delivery of condensation nuclei during the Late Heavy Bombardment to the terrestrial and martian atmospheres

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During the period of the Late Heavy Bombardment (LHB), between 4.1 and 3.8 Ga, the impact rate within the entire Solar System was up to a few thousand times higher than the current value (Ryder 2002, Bottke et al. 2012, Fassett and Minton 2013). Multiple basin-forming events on inner planets that occurred during this time had a strong but short-lasting (up to few thousands of years) effect on atmospheres of Earth and Mars (Sleep et al. 1989, Segura et al. 2002, 2012). However, the role of the continuous flux of smaller impactors has not been assessed so far. We calculated the amount of meteoric material in the 10^{-3} kg to 10^{6} kg size range delivered to Earth and Mars during the LHB based on the impact flux at the top of the Earth's atmosphere based on results from Bland and Artemieva (2006). Those values were recalculated for Mars based on Ivanov and Hartmann (2009) and then recalculated to the LHB peak based on estimates from Ryder (2002), Bottke et al. (2012), Fassett and Minton (2013). During the LHB, the amount of meteoritic material within this size range delivered to Earth was up to $\sim 1.7 * 10^{10}$ kg/year and $1.4 * 10^{10}$ kg/year for Mars. The impactors that ablate and are disrupted during atmospheric entry can serve as cloud condensation nuclei (Rosen 1968, Hunten et al. 1980, Ogurtsov and Raspopov 2011). The amount of material delivered during LHB to the upper stratosphere and lower mezosphere (Hunten et al. 1980, Bland and Artemieva 2006) is comparable to the current terrestrial annual emission of mineral cloud condensation nuclei of $0.5\text{-}8 * 10^{12}$ kg/year (Tegen 2003). On Mars, the availability of condensation nuclei is one of the main factors guiding water-ice cloud formation (Montmessin et al. 2004), which is in turn one of the main climatic factors influencing the hydrological cycle (Michaels et al. 2006) and radiative balance of the planet (Haberle et al. 1999, Wordsworth et al. 2013, Urata and Toon 2013). Increased delivery of condensation nuclei during the LHB should be taken into account when constructing models of terrestrial and Martian climates around 4 Ga.

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