Transfer of mercurian impact ejecta to Earth and implications for mercurian meteorites. B. Gladman[1], [1]University of British Columbia, Department of Physics and Astronomy, 6224 Agricultural Road, Vancouver BC, V6T 1Z1. E-mail at gladman@astro.ubc.ca

Introduction: The existence of lunar and especially martian meteorites in our collections proves that escape from the gravitational well of Mercury (with escape speed of about 4.2 km/sec, less than that of Mars) should be possible, presumably via impact of asteroids or comets into the mercurian surface. Once impact ejecta is liberated from Mercury, it finds itself in orbit around the Sun. What fraction, if any, of this material would be able to subsequently find its way to Earth to perhaps give us mercurian meteorites? While several factors complicate the issue, new numerical simulations indicate that this number is order one tenth of one percent over ten million years, and possibly factors of several higher if the ejected particles are mechanical strength of the meteoroids is high, allowing them to survive for longer periods.

Background: Wetherill [1] and Gladman et al [2] previously estimated the terrestrial transfer efficiency (fraction of those ejecta particles which escape the gravity well of the parent planet which subsequently arrive on Earth) as 0.006% and 0.5%, respectively. This can be compared to of order 3% and 30%, respectively, for the martian and lunar meteorites [2]. However, the Wetherill [1] simulations were based on Monte Carlo simulations which are unable to model the effects of resonances in the inner solar system; these are known to be very important for increasing the efficiency and decreasing the time scale of delivery for martian meteorites [3]. Subsequent direct gravitational simulations of transfer from Mercury [2] estimated a 0.5% delivery efficiency, but based on the statistics of one particle. I here present the results of much more extensive simulations of ejecta transfer from Mercury, motivated by recent discussions [4,5] of the possibility of a mercurian meteorite.

Calculations: Three numerical simulations were conducted for 10 million years of simulation time. In each case 1000 particles were launched off Mercury in a spherically expanding shell of particles all of which will have the same speed at infinity relative to the planet after escaping from its gravity well (in the 2-body approximation); the three v-infinities chosen were 2, 4, and 6 km/sec, corresponding to launch speeds of 4.7, 5.8, and 7.3 km/s at the planetary surface. Such launch speeds are obviously plausible given the existence of martian meteorites; in a shock-wave interference model of launch [6] larger ejection speeds will be facilitated by the higher average impact speeds of comets or asteroids onto the mercurian surface, given how deep that planet is in the Sun's gravity well. Only gravitational forces were included; the presence of radiation pressure and Yarkovsky drift may very well have to be taken into account (see [4] and [2]), but are most likely going to decrease the yield by pulling meteoroids towards the Sun.

Numerical Results: The simulations were then monitored for impacts onto Earth and the other planets. Between 30 and 65% of the launched particles are re-accreted by Mercury in the first 10 Myr. The figure below shows the cumulative impact percentage of launched particles which reach the Earth (note vertical scale is per thousand launched). Even meteoroids launched at the highest-speed case are not on orbits which cross that of Earth; there is a period of order 1-4 Myr before the particles reach Earth-crossing orbits (in fact the barrier is to reach Venus-crossing orbits, and then the latter planet efficiently moves many particles into Earth-crossing orbits). Venus accretes 5-10% of the meteoroids in the first 10 Myr after launch, and as the figure shows Earth receives only of order 0.1% of the ejected meteoroids on this time scale, with a variation of a factor of roughly three depending on the launch speed. It is likely that the impact rate would then remain roughly constant over the next 10 Myr if the simulations were continued, giving a rough doubling of the fraction arriving at Earth..

Implications: The yield of order 0.1% is thus a factor of 30-50 lower than that for the martian meteorites, when computed in a purely gravitational model. Several factors may then alter this efficiency: **(A)** Poynting-Robertson drag on small (1 cm, 5 g/cc) meteoroids causes orbital collapse towards the Sun on 5-Myr timescales, removing most of the small ejecta [7]. **(B)** At dm to m-scale radii the Yarkovsky effect could cause outward and inward migration on time scales of tens of Myr [8]; this would assist some fraction of the meteoroids in reaching the important Venus-crossing threshold, should the meteoroids be capable of surviving over those time scales, because **(C)** solar system dust spirals towards the Sun and concentrates the impactors capable of destroying mercurian meteoroids; decimeter scale meteoroids may be destroyed in faster than Myr time scales [2], meaning that only larger meteoroids have any hope of surviving and reaching Earth-crossing orbits.

Given the roughly 20 meteorites of martian origin in the worldwide collection, the nominal yield calculated here means that we may be near the threshold of expecting a mercurian meteorite to be found. The factors discussed in the previous paragraph are likely to lower the efficiency. Another factor that must be considered is the relative impact rate of large objects onto Mercury (compared to the Moon and Mars). The high impact speeds expected of comets and asteroids onto Mercury mean that smaller impactors can liberate ejecta off the planet, but planet-crossing asteroids are rapidly depleted from Mercury-crossing orbits, and km-scale comets may have great difficulty reaching perihelia as small as Mercury's without disintegrating; whether this will result in a net increase or decrease of the frequency of successful launch events from Mercury (compared to Mars) is unclear. The lack of a Mercury-crossing main-belt asteroid population (present for Mars) means this is likely to be a negative factor and that the net yield will further decrease. The continued lack of mercurian meteorites in our collections is thus not a surprise, although we may be getting close...

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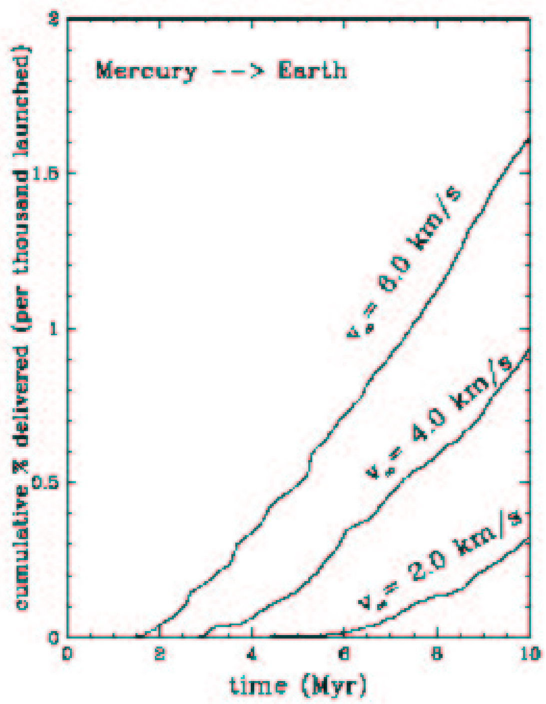

FIGURE : Cumulative Earth impact efficiency for ejected particles from Mercury. The graph shows the cumulative fraction of ejecta that will impact the top of the Earth's atmosphere as a function of time after ejection. NOTE that the vertical scale is in units of thousands of particles launched, and thus the fraction that has reached Earth at the end of the 10-Myr simulation of the 4 km/s case is about 0.1%. The fact that no transfers occur for the first several million years is due to the fact that no particles are initially on Earth-crossing orbits.