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Dynamical simulations of the impact rate, encounter and impact velocities of Mars-crossing asteroids and NEAs.

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Abstract

The impact history of the terrestrial planets is recorded in the craters we observe on their surfaces. Impact experiments give us a relationship between impact speed and crater size, but the actual velocity distribution of the impactors on the terrestrial planets is unknown. We therefore use state-of-the-art dynamical modelling software to ascertain realistic encounter velocities and impact rates for 6,321 *Mars-crossing* and *-grazing* asteroids along with 1,615 *NEAs*.

1. Introduction

High resolution spacecraft imagery has allowed us to obtain accurate measurements of the sizes of impact craters on Mercury, the Moon, Mars, Vesta and many of the Jovian and Saturnian satellites. In order to achieve a better understanding of the size distribution of craters on the terrestrial planets (and other minor bodies), knowledge of the range of asteroid impact energies and geometries is required.

To begin to examine this, we used the population of Mars-crossing asteroids and ran dynamical simulations for 100 Myr forward in time. In total 6,321 particles (with each particle representing a known asteroid) were integrated using the 'Hybrid' algorithm of the *Mercury* dynamical simulation package [1]. We report the impact rate on the Martian surface along with a statistical estimation of the encounter and incident velocities.

2. Method and Target Selection

After performing a number of tests using different algorithms [3] we ended up using, for all the aforementioned simulations, the Hybrid algorithm of the *Mercury* dynamical simulation package. This enables us to track, with high accuracy, the trajectory of each asteroid inside the Hill's radius, R_{Hill}, of each planet.

Before we select the target group of asteroids, we integrated the Solar System with the same configuration and for the same amount of time in order to calculate the oscillation of Mars' perihelion, q, which reaches $\approx$1.71AU.

Therefore, 3,339 asteroids were selected as the *Mars-crossing* population, according to JPL Horizon's catalogue [2], 2,797 *outer-grazers*, 185 *inner-grazers* and 1,615 *NEAs* including all the known members of Amors, Apollos, Atens and Atiras families.

3. Results

We present results from two runs of the entire population examined, each run having the same configuration except for the symplectic time step resolution,one based on Mercury and one on Venus' orbital periods [7]. The impact rates which are presented in Table 1 were obtained from the first run and illustrate the directly observed impacts from the simulation. Impact events were recorded for all terrestrial planets, Jupiter and Saturn. No events were recorded on the two ice giants, Uranus and Neptune. Due to constant perturbations with the planets 10.3% of bodies collided with the Sun, while 39.6% were ejected from the Solar System.

Table 1: Annual impact rates on planets.

Planet	Impact rate [yr^{-1}]
Mercury	2.52×10^{-8}
Venus	1.36×10^{-7}
Earth	1.23×10^{-7}
Mars	2.9×10^{-8}
Jupiter	2.2×10^{-8}
Saturn	1.0×10^{-9}

After filtering the results for close encounters between planets and asteroids whose minimum distance was within 1, 0.5 and 0.2 R_{Hill}, we extracted the distributions for each planet for each group of asteroids. For each planet, minimum, maximum and mean relative velocities (Table 2) were calculated with an expected increase for the encounters which occur closer to each planet.

Table 2: Mean encounter velocities, in 0.2 R_{Hill} of each planet, using the observed populations of *Mars-crossers*, *inner & outer Mars-grazers* and $NEAs$.

	Encounter velocities [km/s]		
Planet	minimum	mean	maximum
Mercury	4.40	32.37	95.95
Venus	1.90	21.10	81.90
Earth	1.72	17.23	69.47
Mars	1.27	11.31	54.43
Jupiter	4.53	14.42	82.64
Saturn	2.61	9.59	42.28
Uranus	1.41	5.46	10.68
Neptune	0.95	3.85	8.26

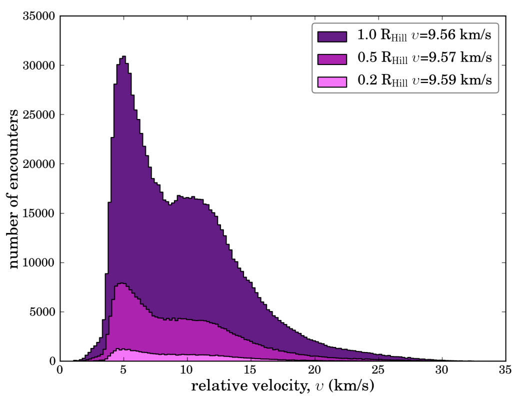

Figure 1: The relative velocity distribution on Mars from the *Mars-crossing* population, showing a double peak characteristic pattern.

We will present analytical results for all planets and the behaviour of all groups of *Mars-crossers*, *Mars-grazers* and *NEAs* and a comparison with previous studies [5] [6]. In addition, a correlation of *Mars-crossing* sub-groups (MB, MB2, HU, EV [4]) will be done with the distinct features in relative velocity distributions. Each impact event is analysed and a statistical estimation of the incident angles will also be presented.

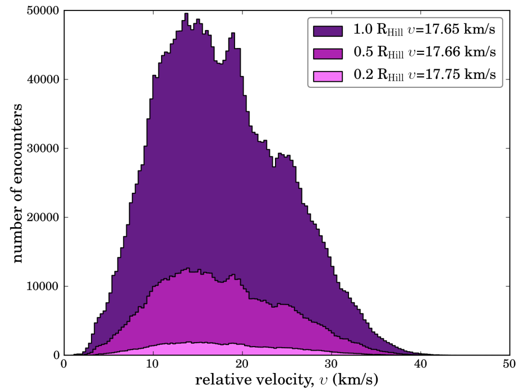

Figure 2: The relative velocity distribution on Earth from the *NEA* population.

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