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Investigating the secular contamination of the surface of Vesta

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Abstract

The Dawn mission recently completed its investigation of Vesta and left the asteroid leading for its second target, Ceres. While orbiting Vesta, the Dawn spacecraft revealed the presence of dark material on the surface and in buried veneers exposed in the walls of craters. In close association to the dark material, the instruments on-board Dawn revealed also the presence of OH and H-rich material.

In this work we briefly report some of the results obtained in studying the delivery of the dark material and other contaminants as a natural result of the continuous flux of impactors on Vesta since the Late Heavy Bombardment.

1. Introduction

One of the scenarios proposed to explain the dark material and the water observed by the Dawn spacecraft on Vesta is that they were delivered by one or few large, stochastic impacts events [1, 2]. [3] and [4] proposed instead that the dark material is delivered on Vesta by a more or less continuous flux of impactors. The two scenarios are not necessarily mutually exclusive: even in the case of a continuous flux, in fact, about half of the dark material would be delivered by a handful of large impactors, as already noted by [3].

In this work we refined the calculations performed by [3] to estimate the amount of dark material delivered on Vesta since the Late Heavy Bombardment taking into account the evolution of the population of the asteroid belt [5]. We also extended these calculations to assess the amount of water-equivalent material and non-dark exogenous material (e.g. ordinary chondrites) and compared our results with the findings of the Dawn mission [1, 2, 3, 4].

2. Impacts on Vesta

We run our model over the two temporal interval of interest: the post-Late Heavy Bombardment period, i.e. the last 3.98 Ga, and the post-Rheasilvia period, i.e. the last 1 Ga.

Table 1: Number of impacts on Vesta due to all impactors and to dark impactors only over the last 3.98 Ga and the last 1 Ga.

Impactors	Temporal Interval	Number of Impacts
All	3.98 Ga	1141
Dark	3.98 Ga	244
All	1.00 Ga	265
Dark	1.00 Ga	55

The first comparison we performed was with the number of impacts estimated by [3] and the number of impacts that would take place on Vesta if the population of the asteroid belt was stationary to its present level. The assumption of a stationary asteroid belt produces more accurate results than that of a linearly decaying one. The former gives a number of impacts that is 10% lower than our reference case of an exponentially decaying asteroid belt, while the latter supplies a number of impacts that is 20% larger than our reference case. When focusing on the last 1 Ga, moreover, the exponentially decaying asteroid belt and the stationary one produce essentially the same results within 1% accuracy.

A quick look to the numbers in Tabs. 2 reveals that the $2-3$ largest impact events of each class of impactors (i.e. dark and non-dark) deliver about 30% of the whole budget of the respective exogenous material over 3.98 Ga. The largest $6-8$ impact events deliver, moreover, about 50% of the whole budget of the relevant exogenous material. This fact supports our idea that the “stochastic events” scenario advocated by [1] and [2] is not in contrast with the "continuous flux" scenario discussed by [3] and [4] but is just a natural by-product of it.

Table 2: Masses delivered to Vesta over 3.98 Ga by dark and non-dark (labeled "bright") impactors.

D_i (in km)	M_{dark} (in g)	M_{brigth} (in g)
0.98	1.2928×10^{16}	5.2900×10^{16}
1.23	1.9239×10^{16}	7.8728×10^{16}
1.55	2.8742×10^{16}	1.1761×10^{17}
1.96	4.2658×10^{16}	1.7456×10^{17}
2.46	6.0185×10^{16}	2.4628×10^{17}
3.10	8.2586×10^{16}	3.3794×10^{17}
3.91	1.0823×10^{17}	4.4287×10^{17}
4.92	1.3366×10^{17}	5.4695×10^{17}
6.19	1.5700×10^{17}	6.4243×10^{17}
7.79	1.7681×10^{17}	7.2351×10^{17}
9.81	1.9285×10^{17}	7.8913×10^{17}
12.40	0.00	8.4895×10^{17}
15.60	0.00	8.8493×10^{17}
≥ 19.60	0.00	0.00

3. Contamination of Vesta

We analyzed the amount of dark and non-dark materials delivered to Vesta since the Late Heavy Bombardment focusing on the following three components: water-equivalent material (e.g. OH and H-rich material), Fe and Ni. Assessing the amount of water delivered by impactors is difficult, as the flux of the different types of meteorites we observe on Earth is likely not a good planetary analogue, e.g. due to the selection bias caused by the atmosphere. Nevertheless, under the best assumption we can presently make the amount of water-equivalent material, which we estimated would be delivered on Vesta, is broadly consistent with the measurements on the Dawn spacecraft. The assessment of the amount of Fe and Ni delivered to Vesta by all impactors is comparatively more easy based on the present collection of meteorites [6]. The secular delivery of Fe, once diluted into the Vestan regolith, does not significantly affect its total Fe content: this is in agreement with the fact that the Fe content of howardites is virtually identical to that of a pure 2:1 mixture of basaltic eucrites and diogenites [6]. Ni proved to be a more useful tracer of the contamination of the Vestan regolith by exogenous material. If mixed to the Vestan regolith, which we assumed to have Ni content of a 2:1 mixture of eucrites and diogenites or, equivalently, the lower limit to the Ni content of howardites, the amount of Ni delivered by impactors produce the same range of values observed in howardites by [7].

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