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Link between the potentially hazardous Asteroid (86039) 1999 NC43 and the Chelyabinsk meteoroid tenuous

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ABSTRACT

We explored the statistical and compositional link between Chelyabinsk meteoroid and potentially hazardous Asteroid (86039) 1999 NC43 to investigate their proposed relation proposed by Borovička et al. (Borovička, J., et al. [2013]. Nature 503, 235–237). First, using a slightly more detailed computation we confirm that the orbit of the Chelyabinsk impactor is anomalously close to the Asteroid 1999 NC43. We find $\sim(1\text{–}3)\times 10^{-4}$ likelihood of that to happen by chance. Taking the standpoint that the Chelyabinsk impactor indeed separated from 1999 NC43 by a cratering or rotational fission event, we run a forward probability calculation, which is an independent statistical test. However, we find this scenario is unlikely at the $\sim(10^{-3}\text{–}10^{-2})$ level. Secondly, we note that efforts to conclusively prove separation of the Chelyabinsk meteoroid from (86039) 1999 NC43 in the past needs to meet severe criteria: relative velocity $\simeq$1–10 m/s or smaller, and $\simeq$100 km distance (i.e. about the Hill sphere distance from the parent body). We conclude that, unless the separation event was an extremely recent event, these criteria present an insurmountable difficulty due to the combination of strong orbital chaoticity, orbit uncertainty and incompleteness of the dynamical model with respect to thermal accelerations. This situation leaves the link of the two bodies unresolved and calls for additional analyses. With that goal, we revisit the presumed compositional link between (86039) 1999 NC43 and the Chelyabinsk body. Borovička et al. (Borovička, J., et al. [2013]. Nature 503, 235–237) noted that given its Q-type taxonomic classification, 1999 NC43 may pass this test. However, here we find that while the Q-type classification of 1999 NC43 is accurate, assuming that all Q-types are LL chondrites is not. Our experiment shows that not all ordinary chondrites fall under Q-taxonomic type and not all LL chondrites are Q-types. Spectral curve matching between laboratory spectra of Chelyabinsk and 1999 NC43 spectrum shows that the spectra do not match. Mineralogical analysis of Chelyabinsk (LL chondrite) and (8) Flora (the largest member of the presumed LL chondrite parent family) shows that their olivine and pyroxene chemistries are similar to LL chondrites. Similar analysis of 1999 NC43 shows that its olivine and pyroxene chemistries are more similar to L chondrites than LL chondrites (like Chelyabinsk). Analysis of the spectrum using Modified Gaussian Model (MGM) suggests 1999 NC43 is similar to LL or L chondrite although we suspect this ambiguity is due to lack of temperature and phase angle corrections in the model. While some asteroid pairs show differences in spectral slope, there is no evidence for L and LL chondrite type objects fissioning out from the same parent body. We also took photometric observations of 1999 NC43 over 54 nights during two

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apparitions (2000, 2014). The lightcurve of 1999 NC43 resembles simulated lightcurves of tumblers in Short-Axis Mode (SAM) with the mean wobbling angle 20°–30°. The very slow rotation of 1999 NC43 could be a result of slow-down by the Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect. While, a mechanism of the non-principal axis rotation excitation is unclear, we can rule out the formation of asteroid in disruption of its parent body as a plausible cause, as it is unlikely that the rotation of an asteroid fragment from catastrophic disruption would be nearly completely halted. Considering all these facts, we find the proposed link between the Chelyabinsk meteoroid and the Asteroid 1999 NC43 to be unlikely.

1. Introduction

Identifying the parent asteroid of meteorites in terrestrial collections (asteroid–meteorite linkage) is one of the ultimate goals of meteoritics. To reach that goal, dynamical models have been employed to link bolides to their source regions in the main belt or parent asteroids in the near-Earth asteroid (NEA) population based on their orbits. Bolide orbits are primary calculated based on video all sky camera networks and also surveillance footage.

On February 15, 2013, a 17–20 m diameter asteroid entered the atmosphere over Chelyabinsk, Russia, and disintegrated in an airburst with an estimated energy of $\sim$500 ± 100 kilotons of TNT (Brown et al., 2013). Orbit for the meteor was calculated using video recordings, which suggested a pre-impact orbit consistent with its origin in the inner main belt (Borovička et al., 2013). Borovička et al. (2013) noted that the orbit of the Chelyabinsk bolide also showed similarities with a Q-type potentially hazardous asteroid (PHA) (86039) 1999 NC43 (Binzel et al., 2004). However, no direct spectral/compositional link has been made beyond the dynamical argument as is the case for 1999 NC43.

Several hundred fragments from the airburst were recovered including a >600 kg meteorite that was hoisted from the bottom of Lake Chebarkul. Laboratory classification of recovered fragments by Kohout et al. (2013) shows that Chelyabinsk is an LL5 ordinary chondrite with olivine and pyroxene as major mineral phases. The meteorite included a dark-colored fine grain impact melt/shock component, which is a significant portion (1/3) of the meteorite apart from light-colored lithology typical of ordinary chondrites. LL chondrites are the least abundant of the ordinary chondrites (which include H, L and LL chondrites) comprising $\sim$10% of observed ordinary chondrite falls.

Laboratory spectral study of the recovered meteorites by Popova et al. (2013) suggested that the dark and light components had distinct spectral properties. They noted that absorption band depth comparison showed that some material in Chelyabinsk might be similar to H chondrites rather than LL chondrites. However, this result has not been confirmed by more in depth spectral and mineralogical studies by Kohout et al. (2013) and Reddy et al. (2014).

Kohout et al. (2013) measured the spectra, composition, density, porosity, and magnetic susceptibility of the Chelyabinsk meteorite. They concluded that compositionally the shock blackened/impact melt and LL5 chondrite lithologies are indistinguishable although their spectra and albedo varied. Bulk (3.32 g/cm^3) and grain densities (3.51 g/cm^3) of Chelyabinsk measured by Kohout et al. (2013) are also consistent with those of LL chondrites. The same study reported porosity values ranging from 1.5% to 11.4%. Unlike other LL chondrites, Chelyabinsk is reported to have more metallic iron, placing it between LL and L chondrites (Kohout et al., 2013).

Here we revisit in some detail statistical, dynamical and compositional arguments that led Borovička et al. (2013) to propose the link between 1999 NC43 and the Chelyabinsk meteorite: in Section 2 we present statistical and dynamical arguments, while in Section 3 we study the compositional similarity between 1999 NC43 and the Chelyabinsk body. Compositional links between Chelyabinsk and the source family in the main belt (Flora family) is the subject of another separate but related paper (Reddy et al., 2014).

2. Statistical and dynamical considerations

In this section, we examine whether the Chelyabinsk bolide could have came from 1999 NC43 using statistical and dynamical tools. Borovička et al. (2013) suggested a connection between the two bodies, with the Chelyabinsk bolide possibly ejected from 1999 NC43 via a collision. They based this on a brief probability calculation showing that the orbits of the bodies had a $\sim 10^{-4}$ chance of being similar to one another when compared to all known NEO orbits. Here we conduct a similar, though little more detailed calculation. We confirm that the orbit of the Chelyabinsk impactor is indeed anomalously close to the orbit of 1999 NC43, finding the probability is $\sim(1\text{–}3) \times 10^{-4}$ (Section 2.1). Adopting the hypothesis that the Chelyabinsk impactor is indeed a fragment ejected from 1999 NC43 in a significant cratering or mass-shedding event, we next perform a forward probability calculation that it would hit the Earth. While approximate, our result shows this is again an unlikely event with a probability of $\sim(10^{-3}\text{–}10^{-2})$ (Section 2.2). More support for the 1999 NC43-Chelyabinsk link hypothesis would come from a convergence of the two orbits in the past. However, the planet-crossing space is a dynamically harsh arena for this experiment to succeed: dynamical chaos caused by resonant interactions with the planets and the effects of planetary close encounters, unconstrained thermal accelerations and uncertainty in the Chelyabinsk pre-atmospheric orbit make it difficult to impossible to propagate NEO orbits far back into the past and thereby meet the conditions required by a collisional separation scenario. We give an example of such computation in Section 2.3.

2.1. Probability of the Chelyabinsk orbit to be near that of 1999 NC43

Before we describe our next analyses, we revisit the method used by Borovička et al. (2013) to determine a statistical link between the bodies based uniquely on their current orbits. Recall that taking the derived orbit of Chelyabinsk, these authors looked for the NEO with the most similar orbit in the known population over all of the Keplerian orbital elements except mean anomaly: this was 1999 NC43 at a distance of $d \simeq 0.050$ using the Southworth and Hawkins (1963) metrics and $d \simeq 0.018$ using the Drummond (1981) metrics. They also found that 227 NEOs brighter than this object can be found among the known NEOs.

Since Borovička et al. (2013) do not give details of their method, we decided to first re-derive their probability analysis. We consider the Chelyabinsk impactor to be a single-class event with no equivalent over the past decades. In order to put its individual orbit into the context of a population of possible NEA impactors, we used the debiased model of Bottke et al. (2002). These authors