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The near-Earth asteroid population from two decades of observations

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ABSTRACT

Determining the size and orbital distribution of the population of near-Earth asteroids (NEAs) is the focus of intense research, with the most recent models converging to a population of approximately 1000 NEAs larger than 1 km and up to approximately 10^9 NEAs with absolute magnitude $H < 30$. We present an analysis of the combined observations of nine of the leading asteroid surveys over the past two decades, and show that for an absolute magnitude $H < 17.75$, which is often taken as proxy for an average diameter larger than 1 km, the population of NEAs is 920 ± 10, lower than other recent estimates. The population of small NEAs is estimated at $(4 \pm 1) \times 10^8$ for $H < 30$, and the number of decameter NEAs is lower than other recent estimates. This population tracks accurately the orbital distribution of recently discovered large NEAs, and produces an estimated Earth impact rate for small NEAs in good agreement with the bolide data.

1. Introduction

With an observed population exceeding 14,000 bodies, up from a few hundred only two decades ago, NEAs represent a threat of impact with Earth, as well as targets for robotic and human exploration, and a potential for in-space resource utilization. In order to estimate the size frequency and orbital distributions of the NEA population, the techniques typically adopted include the characterization of the detection efficiency of a reference survey and subsequent simulated detection of a synthetic population (Stuart and Binzel, 2004; Mainzer et al., 2011), or the statistical tracking of NEAs from their source regions in the main belt to the inner solar system and subsequent comparison to the detections by a reference survey (Bottke et al., 2002; Morbidelli et al., 2002), or the combination of these two approaches (Granvik et al., 2016). The redetection of NEAs has also been used to estimate the level of completeness in the search of NEAs (Harris and D'Abramo, 2015). The first approach is typically adopted by single-survey studies which have access to all the observing data and meta-data and can accurately assess the detection efficiency, and this has limited in the past the adoption of this approach on a multi-survey scale. The other approaches require the introduction of weights on the contributions of source regions which are fitted as free parameters, or bootstrapping procedures in order to generate NEA population close to the observed one.

An opportunity to produce an improved NEA population model comes from the development of a survey characterization technique which relies only on publicly available observational data. This technique was recently used to analyze the large volume of observational data (10,033 nights over two decades) from nine of the most active asteroid surveys (Tricarico, 2016), to determine their nightly detection efficiency as a function of asteroid apparent magnitude and apparent velocity. We present the NEA population estimate methods in Section 2, including an assessment of the trailing loss, the role of commensurability with the Earth's orbit period, and the computation of the Earth impact rate. Then in Section 3 we present the main results: the NEA population as a function of absolute magnitude, the orbital distribution, and the comparison to bolide data. Conclusions are briefly drawn in Section 4.

2. Methods

The baseline analysis of the observational data (Tricarico, 2016) included only observations at apparent velocities up to 100 arcsec/hour, while NEAs can move at several deg/day, so we need to extend this analysis here and include the effect of trailing losses. Trailing losses can be important for asteroids with large apparent velocities, and this becomes even more important when including very small asteroids which are only visible when close to the Earth. In practice, approximately 90% of all NEAs observations are at apparent velocities below 3 deg/day, and approximately 99% below 10 deg/day. The trailing loss effects can be estimated directly from data, by comparing the number of asteroids observed at a given range in apparent velocity with the number expected from the modeled population for the same apparent velocity range, af-

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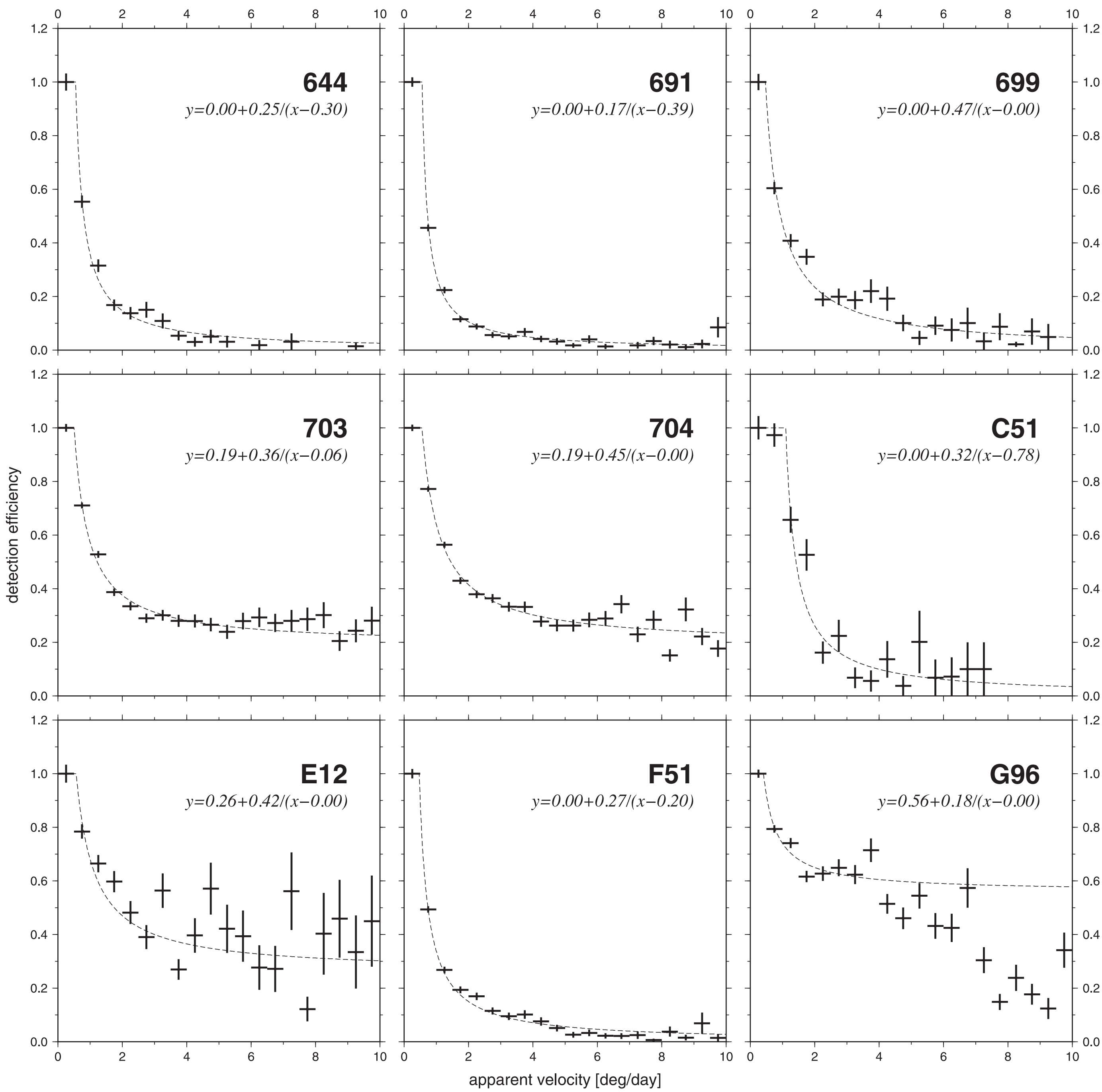

Fig. 1. Trailing loss effect as determined from the observations of the nine surveys included, see Tricarico (2016) for the MPC codes and the properties of each survey. The data points are the ratio between the number of NEAs observed at a given apparent velocity, and the expected number of NEAs observed for the same velocity range given the modeled population. Binning is in increments of 0.5 deg/day, the first bin is normalized to 1.0, and the uncertainty is from counting statistics.

ter accounting for the detection efficiency as modeled in Tricarico (2016). The trailing loss effects are estimated separately for each survey, using a fitting function

$$y = c_0 + \frac{c_1}{x - c_2} \qquad (1)$$

where the detection efficiency $y = \eta_{\rm trail}$ decays as $1/\dot{\phi}$ with $x = \dot{\phi} = U$ apparent velocity, see the specific discussion later in this section. The three free coefficients which are obtained by least-square fitting and allow the function to be shifted vertically (c_0), stretched (c_1), and shifted horizontally (c_2) in order to better match the observations. The results for each survey are displayed in Fig. 1, and in general the fit seems satisfying except for G96 for which it was obtained only for points below 3.5 deg/day. The reason of the difficulty in the G96 fit is unclear, but it may be related to changes in the observing strategies. Note that since the trailing loss affects the modeled population, and the modeled population affects the trailing loss, several iterations are necessary before the trailing loss estimate and the modeled population are stable within a few percents.

The progress in searching for NEAs is tracked by generating $\sim 10^6$ synthetic NEA orbits, and then numerically propagating the orbits over the two decades period considered, while checking against the sky coverage and detection efficiency of the surveys