EPSC Abstracts
Vol. 13, EPSC-DPS2019-1169-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

A Dangerous Class of Asteroids that is Nearly Invisible

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Abstract

Near Earth Asteroids (NEAs) that have high angular velocities are harder to detect than those that move across the sky more slowly. Even when detected, fast-moving objects often are not recovered: their ephemeris uncertainty grows very rapidly, making follow-up observations so difficult that many observers do not attempt them. Because of this, global ability to discover NEAs declines dramatically with increasing angular velocity – causing a strong bias against discovery of asteroids with high inclination and/or high eccentricity. Such objects never encounter Earth at low relative velocity, and their angular velocities can be low only with improbable viewing geometries. Hence, global NEA discovery capability remains almost blind to highly inclined/eccentric NEAs – especially at small yet still dangerous sizes in the 20-140 meter range. The bias against detecting such objects is already severe in regimes of moderate inclination and eccentricity that are known to be well-populated by larger NEAs. Hence, the abundance of small NEAs in these orbits is uncertain and hard to measure – yet their high velocities make their impacts especially damaging. We quantify the bias against these objects and suggest strategies to mitigate it.

1. The ATLAS Survey

The Asteroid Terrestrial-impact Last Alert System (ATLAS)[1] is a Hawaii-based asteroid survey optimized to find small but dangerous asteroids (diameter 20 to 140m; absolute magnitude (H) from 22 to 27) on their final plunge toward impact with Earth. So far, such an object has not impacted the Earth since ATLAS began operations in 2015, but ATLAS has detected many NEAs in this size range making close approaches to Earth without impacting. It is not as sensitive to faint asteroids as other surveys, but it scans the sky faster, meaning it detects a large fraction of Earth-approaching asteroids that brighten past its sensitivity limit in any part of the accessible sky. This high completeness makes ATLAS data a good starting point for simulations probing the populations of small NEAs in the Solar System.

2. Velocity Bias in NEA Detection

We have simulated the detection of asteroids in 15 months of ATLAS data, from June 2017 to August 2018. The simulation is very realistic because we place fake asteroids in the actual ATLAS images obtained during this period and detect them using the same methodology ATLAS uses to detect real NEAs. The motions of the fake asteroids are also very realistic because each is based on a consistent dynamical orbit from the Granvik model[2], cloned by adding small random variations to the Keplerian orbital elements. In all, we simulated 2×10^{8} NEAs with H brighter than 25, and an additional 4.2×10^{10} with H from 25 to 30. These are a few orders of magnitude larger than the numbers of real NEAs believed to exist in the respective size ranges, enabling us to probe survey selection effects with great statistical power. The most interesting bias we have found is against the detection of objects that encounter Earth at large relative velocity, as shown in Figure 1.

Since the asteroids plotted in Figure 1 all came close enough to the Earth that they could have been detected, the loss of sensitivity to high velocity objects is not due to greater distance from Earth. Instead, it is due their greater *angular* velocity. Fast angular velocities make asteroids difficult to detect in two ways. First, the asteroid image elongates into a streak and tends to fade into background noise. Second, even if the asteroid is detected, its fast motion across the sky makes follow-up observations difficult to obtain. The first effect causes the gap between the gray and blue histograms in Figure 1, while the second contributes to the gap between the blue and red lines. This last is because our simulation counted any object detected by ATLAS as having been discovered, although in reality some high-velocity detections do not lead to discoveries (even though the objects were unmistakably real) because no other observatory successfully recovers them.

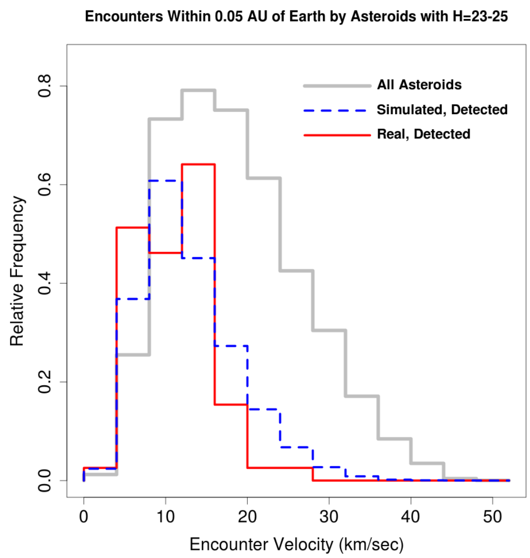

Figure 1: Bias against detection of high velocity near-Earth asteroids with H from 23 to 25 (size about 30 to 100m) in a 15-month simulation of the ATLAS survey.

3. Orbital Bias in NEA Detection

The bias against high encounter velocities shown in Figure 1 translates into a bias against the detection of asteroids in certain types of orbits, because such asteroids never encounter Earth at low relative velocity. Figure 2 shows the correlation of encounter velocity and inclination. Note that these orbits are not expected to be unpopulated: 7% of known NEAs with H magnitude brighter than 20 have inclinations or eccentricities producing typical encounter velocities higher than 25 km/sec. By contrast, less than 1% of known NEAs with H from 22 to 25 inhabit such orbits: another example of the bias against finding small asteroids with high encounter velocities. Note that an asteroid striking the Earth at 25 km/sec explodes with ten times the energy of an equal-mass object striking at only 8 km/sec.

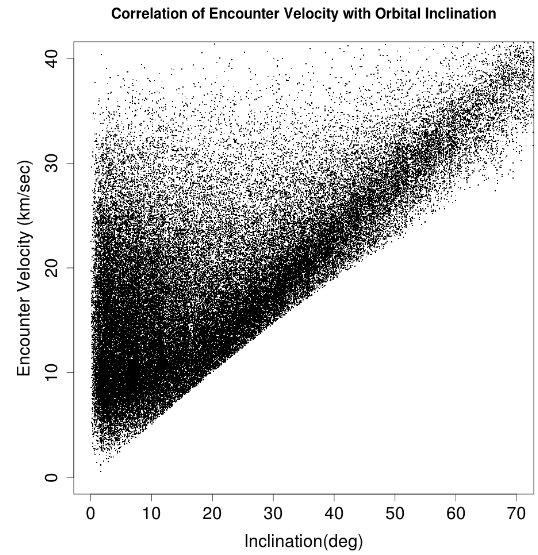

Figure 2: Asteroids in highly inclined orbits never encounter Earth at low relative velocity. Hence, the bias against detection/discovery of high velocity objects produces an orbital bias.

4. Mitigating the Bias

The velocity bias must be addressed in order to obtain an accurate estimate of the total population of 20-140m NEAs, and a correspondingly accurate assessment of the threat they pose to Earth. Simulations such as we have performed are a good first step to quantifying the bias, but observational strategies to reduce the bias are also needed. These could include better algorithms for trail detection in survey images; and better communication and prioritization for rapid follow-up observations of fast-moving candidate NEAs.

References

[1] Tonry, J. L., Denneau, L., Heinze, A. N. et al.: Publications of the Astronomical Society of the Pacific, Volume 130, Issue 988, pp. 064505, 2018.

[2] Granvik, M., Morbidelli, A., Jedicke, R. et al.: Icarus, Volume 312, pp. 181-207, 2018.