Production of near-Earth asteroids and high-strength meteoroids on cometary (?) retrograde orbits. S. Greenstreet[1], B. Gladman[1], H. Ngo[2], M. Granvik[3], S. Larson[4], [1]University of British Columbia, Vancouver, British Columbia, Canada (sarahg@phas.ubc.ca), [2] Queen's University, Kingston, Ontario, Canada, [3]University of Helsinki, Helsinki, Finland, [4]University of Arizona, Tucson, Arizona, USA.

Introduction: A new NEO orbital distribution model [1] was computed in order to optimize a pointing strategy for Canada's space telescope NEOSSat (Near-Earth Object Surveillance Satellite), set to launch in mid 2012. Analysis of our NEO model integrations uncovered the unexpected production of retrograde orbits from main-belt asteroidal sources. This population of retrograde NEAs makes up only ~0.1% of the total steady-state NEA population (q<1.3 AU). Given our integration and the estimated total NEA population, the existence of roughly a few retrograde 1 km NEAs is expected, in line with the recent identification of two such objects. This population of NEAs on retrograde orbits may also answer the outstanding question in the meteoritical literature on the origin of high-strength, high-velocity meteoroids on retrograde orbits.

Typical Retrograde NEA Orbital Evolution: The typical path taken by particles which become retrograde in the integrations begins with a random walk in semimajor axis due to planetary close encounters with the terrestrial planets after leaving their asteroidal source regions. The majority of the particles that become retrograde find their way into the 3:1 mean motion resonance. Some mechanism in the resonance causes the particle to flip past 90° inclination; the nature of this mechanism is still unclear. If the retrograde particle stays in the resonance it can terminate almost immediately (as little as 1000 years later) when the resonance pushes the high-e particle into the Sun. Roughly 97% of the retrograde NEAs are eliminated from the integrations because they reach perihelia distances which lie inside the Sun [2]. The median lifetime once they become retrograde is ~3000 years, but if kicked out of the resonance due to a planetary close encounter, they can live tens of millions of years.

Two Known Retrograde NEAs: There are currently two known retrograde NEAs, 2007 VA85 (a=4.23 AU, e=0.74, i=131.8°) and 2009 HC82 (a=2.53 AU, e=0.81, i=154.5°) , found by LINEAR and the Catalina Sky Survey, respectively. The Catalina team has recently carefully examined their available imaging of both objects for any evidence of a coma and have found none. It is thus possible these objects could be asteroids that have become NEAs and found their way to i>90° orbits rather than retrograde comets.

Integrations of 2007 VA85's nominal orbit indicate a cometary-like behavior. We believe 2007 VA85 is most likely a devolatilized Halley-type comet nucleus of which we expect ~20 to exist with $a < a_{Jupiter}$. 2009 HC82 on the other hand, is on an orbit very near the 3:1 resonance where it most likely flipped to a retrograde orbit. We believe 2009 HC82 is most likely an NEA on a retrograde orbit and is NOT cometary in origin.

Cometary Meteoroids: Large numbers of meteoroids have been observed to enter Earth's atmosphere from high-velocity, retrograde orbits, such as the recurring Leonid meteor streams. However, the majority of the meteoroids on retrograde orbits is made of weak material which comes apart easily upon entry into the Earth's atmosphere [3].

High-Strength, High-Velocity Meteoroids on Retrograde Orbits: The production of retrograde orbits from main-belt asteroidal sources may also resolve an outstanding question on the origin of high-strength, high-velocity meteoroids on retrograde orbits. The existence of strongly-differentiated material on very high entry-speed orbits (which must be retrograde) has been known since the 1970s through photographic meteor spectral properties [4] and more recent meteor surveys have succeeded in precisely measuring the pre-atmospheric orbits of high-strength (deep atmospheric penetration depth) meteoroids from retrograde heliocentric orbits [3]. The uncomfortable explanation offered to date for the origin of these high-strength retrograde meteoroids has been cometary [3], but the puzzle existed as to how macroscopic solid rocky components could be on “cometary" orbits. It had been suggested that comets may have internal inhomogeneity which would account for this population of high-strength retrograde meteoroids [3], but little discussion of this appears in the literature.

We propose the simpler explanation that these meteoroids are derived from main-belt asteroidal sources. In this scenario, larger (0.01 – 1 km) NEAs are transferred to long-lived retrograde orbits near (but not in) main-belt resonances and then serve as targets. The collisional production of fragments off these retrograde NEAs would produce smaller retrograde debris on orbits similar to these parent bodies and this debris would then produce the observed high-strength retrograde meteoroids. This could explain both the high-velocity, retrograde orbits as well as the high-strength of these meteoroids better than the ad-hoc cometary source hypothesis.

References: [1] Greenstreet, S. et al. (2012), *Icarus*, 217, 355-366. [2] Farinella, P. et al. (1994), *Nature*, 371, 314-317. [3] Borovička, J. et al. (2005), *Icarus*, 174, 15-30. [4] Harvey, G. (1974), *AJ*, 79, 333-347.