Significance of large Neptune-crossing objects for terrestrial catastrophism

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Over the past few decades a substantial number of objects have been discovered on orbits beyond Neptune (*i.e.* transneptunian objects, in various sub-classes), crossing Neptune's orbit (here: the Neptune-crossers of interest), and also others crossing the orbits of any or all of the jovian planets (*i.e.* Centaurs). These range in size from tens of kilometres across to hundreds of kilometres and more. Although formally classified as minor planets/asteroids, plus a few dwarf planets, the physical reality of these objects is that they are giant comets. That is, they seem to be composed largely of ices and if they were to enter the inner solar system then they would demonstrate the commonly-observed behaviour of comets such as outgassing, and the formation of ion and dust tails.

Commonly-observed cometary behaviour, however, also includes fragmentation events and sometimes complete disintegration for no apparent cause (such as tidal disruption or thermal stresses). One might therefore wonder what the implications would be for life on Earth and terrestrial catastrophism if and when one of these objects, say 100 to 500 kilometres in size, dropped into a short-period orbit with perihelion distance (q) less than 1 au; or even $q \sim 5$ au, given what Jupiter's gravity might do to it.

How often might such events occur? One way to address that question would be to conduct numerical integrations of suitable test orbits and identify how often small-q orbits result, but this comes up against the problem of identifying very-infrequent events (with annual probabilities per object perhaps of order 10^{-12}–10^{-10}. For example, Emel'yanenko et al. [1] recently followed test orbits for approximately 5×10^{14} particle-years (8,925 objects with 200 clones of each, for 300 Myr) but because these were selected on the basis of initial values of q only below 36 (rather than $\sim$30) au many were not immediately Neptune-crossers; however, many test particles did eventually migrate into small-q orbits, including falling into the Sun.

Instead of the demanding computational requirements of numerical integrations I have instead employed a statistical technique which involves: (i) The probability of some test orbit encountering a perturbing planet (Neptune, here); and (ii) The relative probabilities of new orbital elements (in particular $q < 1$ au or $q < 5$ au) resulting from such encounters. This technique I introduced in a paper presented at *ACM III* in Uppsala in 1989 [2] but I have not used it much in the quarter-century since then.

I have presented elsewhere [3] some initial results from running this technique on a handful of known Neptune-crossing orbits, the results justifying the probabilities of order 10^{-12}–10^{-10} *per annum* that I mentioned above. Here I extend the range of computations and the variety of test orbits sampled in order to try to build a picture of how often the inner solar system might be subject to an incursion by a gigantic fragmenting comet, with obvious repercussions for all the terrestrial planets but especially for the evolution of life on Earth.

References: [1] Emel'yanenko, V.V., Asher, D.J. & Bailey, M.E. (2013) *Earth, Moon & Planets*, 110, 105–130. [2] Olsson-Steel, D. (1990) in *Asteroids, Comets, Meteors III*, Univ. of Uppsala Press, Sweden, 401–404. [3] Steel, D. (2014) *Geological Society of America Special Papers*, in press.