GEOMETRY OF STABLE CAPTURE ZONES FOR PLANET EARTH AND IMPLICATIONS FOR ESTIMATING THE PROBABILITY OF STABLE GRAVITATIONAL CAPTURE OF PLANETOIDS FROM HELIOCENTRIC ORBIT;
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Mapping of two-dimensional, coplanar parameter space in the region of the earth’s orbit has led to the identification of two retrograde (clockwise motion) and two prograde (counterclockwise motion) zones for stable capture orientations. The parameters mapped are planet anomaly (position of the planet at the beginning of the encounter simulation) and orbital eccentricity of the planetoid (relative to a circular orbit for the planet). A Stable Capture Zone can be defined as a region of parameter space in which the orbital orientation at the time of the close encounter (a putative capture encounter) is favorable for long-term, post-capture orbital stability. The other major requirement for stable gravitational capture is that sufficient energy is dissipated by tidal action within the interacting bodies during the time of the close encounter. An estimate of the probability of capture for any given value of planetoid eccentricity for coplanar encounters can be obtained by measuring the line intercept length of planet anomaly within the Stable Capture Zone relative to the full orbit.

Over the past few years we have been able to demonstrate that whole-body, (gravitational) capture of a lunar-mass body is physically possible in a coplanar, three-body interaction context [1,2]. We use a fourth-order Runge-Kutta integration code with an energy dissipation subroutine that simulates energy dissipation within the interacting bodies during encounters within 20 Rₚ. All initial encounters for potential capture scenarios are focussed to 1.43 Rₚ. The critical planetoid body parameters for successful capture are (1) a sufficiently high displacement Love number (h) for the candidate planetoid so that sufficient energy can be temporarily stored in the body of the planetoid by tidal distortion during a close encounter at 1.43 Rₚ and (2) a sufficiently low Q (specific dissipation factor) so that a large fraction of the tidally stored energy can be dissipated as thermal energy during the timescale of the initial close encounter of an encounter scenario. We assume that the useful range of h values for a lunar-like planetoid is between 0.2 and 0.4 for Q values between 1 and 3. It was demonstrated by [3] that such low Q values are possible for lunar-like planetoids for intermediate values of effective planetary viscosity. The h and Q values of the planet are not important for dissipating the energy for capture although they are important for the subsequent (post-capture) orbital evolution.

A third, and very critical factor, for stable gravitational capture is the orientation of the major axis of the orbit at the time of the initial encounter of an encounter sequence. The orientation must yield a post-capture (geocentric) orbit that is stable relative to the effects of solar perturbations. For stable prograde capture, the major axis of the orbit of the candidate planetoid must be within + or - 5° of a line perpendicular to the tangent of the planet’s orbit and for stable retrograde capture, the major axis of the planetoid’s orbit must be within + or - 5° of a line parallel to the tangent of the planet’s orbit. These severe geometric constraints can be met over narrow bands (about 0.5% of planetoid orbital eccentricity) extending for several 10’s of degrees of planet anomaly as shown in Fig. 1.

A fourth, and not so critical factor, is the gradation in orbital energy within the stable capture zone at the time of closest approach of the planetoid to the planet. The main effect
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of this energy variation is that within certain portions of the zone less energy needs to be dissipated within the interacting bodies to bring about stable gravitational capture. Cursory examination of Fig. 1 suggests that the energy dissipation requirements for capture are considerably lower on the right portion of prograde stable capture zones and on the left portion of retrograde stable capture zones.

In summary, we have found that there are significant areas of parameter space that will yield orbital orientations that will permit stable gravitational capture. We have identified four such zones -- a prograde and a retrograde capture zone for planetoid orbits that are both slightly smaller and slightly larger than the planet’s orbit. About 50% of the field of prograde orientations is useful for capture for reasonable values of planetoid h and Q and over 80% of the field of retrograde orientations is useful for stable retrograde capture.


Figure 1. (a). Plot of Planet Anomaly vs. Planetoid Eccentricity showing approximate area of a Stable Prograde Capture Orientation for a planetoid encountering earth from an orbit that is inside the earth’s orbit (left) and one for a planetoid encountering the earth from an orbit that is outside the earth’s orbit (right). The patterned zone indicates portions of the zone that are useful for h values between 0.2 (right) and 0.4 (left). (b). Plot of Planet Anomaly vs. Planetoid Eccentricity showing approximate area of a Stable Retrograde Capture Orientation for a planetoid encountering earth from an orbit that is outside the earth’s orbit (center) and one for a planetoid encountering earth from an orbit that is inside the earth’s orbit (split). The patterned zone indicates portions of the zone that are useful for h values between 0.2 (left) and 0.4 (right).