EPSC Abstracts
Vol. 6, EPSC-DPS2011-1589, 2011
EPSC-DPS Joint Meeting 2011

Where did Europa get its Large Inclination? Not From Evolution Deep in the Io-Europa 2:1 Resonance

D.P. Hamilton, Department of Astronomy, University of Maryland, College Park, Maryland, USA (dphamil@umd.edu)

Abstract

Europa's inclination of $0.47°$ is more that ten times greater than Io's and large enough to require an explanation. We explore here the possibility that Europa obtained its orbital tilt during interactions with Io in their mutual 2:1 resonance. We conclude that this did not happen.

1. Introduction

The orbits of Io, Europa, and Ganymede are locked together in a complicated system with four separate librating resonance arguments: the two first-order eccentricity resonances shown in Table 1, a 2:1 resonance between Ganymede and Europa with resonant argument $\Psi = 4n_G - 2n_E - 2\dot{\Omega}_E$, and the three-body Laplace resonance ($\Psi = 2n_G - 3n_E + n_I$), which is a necessary consequence of the others. Here n_i are mean motions, ϖ_i are longitudes of pericenter, Ω_i are longitudes of nodes, a dot indicates a time derivative, and each subscript represents a satellite. Although these are the strongest resonances currently affecting the moons, others may have been important in the past.

The dominant perturbations to inclinations are second order in small quantities as indicated in the "Strength" column of Table 2. The 2:1 commensurability splits into two first-order (Table 1), six second-order (Table 2), and 22 third-order (Table 3) resonances due to precession arising from Jupiter's equatorial bulge. The "Offset" column of each table accounts for this precession and shows where the resonances falls relative to the exact 2:1 commensurability with Io. Thus we might expect that since the inclination resonances are closer to Jupiter and further from Europa than the eccentricity ones, Io should encounter them first [2]. The combination of planetary and satellite tides, however, actually stabilizes the system in the "wings" of the strong eccentricity resonances well before the inclination resonances are encountered. So for Io to excite Europa's inclination, we must go deeper into resonance.

Table 1: All 1st-Order 2:1 Resonances

Resonant Argument Ψ	Strength	Offset (R_J)
$2n_E - n_I - \dot{\varpi}_E$	e_E	0.0006
$2n_E - n_I - \dot{\varpi}_I$	e_I	0.0030

Table 2: All 2nd-Order 4:2 Resonances

Resonant Argument Ψ	Strength	Offset (R_J)
$4n_E - 2n_I - 2\dot{\Omega}_E$	i_E^2	-0.0030
$4n_E - 2n_I - \dot{\Omega}_E - \dot{\Omega}_I$	$i_I i_E$	-0.0018
$4n_E - 2n_I - 2\dot{\Omega}_I$	i_I^2	-0.0006
$4n_E - 2n_I - 2\dot{\varpi}_E$	e_E^2	0.0006
$4n_E - 2n_I - \dot{\varpi}_E - \dot{\varpi}_I$	$e_I e_E$	0.0018
$4n_E - 2n_I - 2\dot{\varpi}_I$	e_I^2	0.0030

2. Origin Deep in Resonance?

Perhaps Io and Europa simple formed deep in resonance, as has been suggested by [1]. We simulate this possibility with our numerical integrator HNDrag, which has been optimize for satellite studies. To obtain our initial condition, we start from the current configuration ($e_I = 0.004$) and apply very intense planetary tides (10^4 times nominal) to drive Io rapidly outward and deeper into the two eccentricity resonances with Europa. We then shut off this force and allow planetary and satellite tides to naturally evolve the system back toward its current state. Eccentricities damp and the satellites separate. Along the way, various 2nd- and 3rd-order resonances first excite the inclinations of both Io and Europa, and then erase them (Fig. 1). So if Io and Europa formed in resonance, then Europa must have acquired its large inclination elsewhere.

3. An Excursion Deep into Resonance?

We also tried slowly moving Io deeper into resonance, as might occur if part of the satellite's interior melted.

Table 3: Relevant 3rd-Order 2:1 and 6:3 Resonances

Resonant Argument Ψ	Strength	Offset
$2n_E - n_I + \dot{\varpi}_I - 2\dot{\Omega}_I$	$e_I i_I^2$	-0.0091
$2n_E - n_I + \dot{\varpi}_I - \dot{\Omega}_I - \dot{\Omega}_E$	$e_I i_I i_E$	-0.0067
$2n_E - n_I + \dot{\varpi}_E - \dot{\Omega}_I^2$	$e_E i_I^2$	-0.0067
$2n_E - n_I + \dot{\varpi}_I - \dot{\Omega}_E^2$	$e_I i_E^2$	-0.0042
$2n_E - n_I + \dot{\varpi}_E - \dot{\Omega}_I - \dot{\Omega}_E$	$e_E i_I i_E$	-0.0042
$2n_E - n_I - \dot{\varpi}_E - \dot{\Omega}_I + \dot{\Omega}_E$	$e_E i_I i_E$	-0.0018
$2n_E - n_I - 2\dot{\varpi}_E + \dot{\varpi}_I$	$e_E^2 e_I$	-0.0018
$6n_E - 3n_I - \dot{\varpi}_E - 2\dot{\Omega}_I$	$e_E i_I^2$	-0.0018
$2n_E - n_I + \dot{\varpi}_E - 2\dot{\Omega}_E$	$e_E i_E^2$	-0.0018
$6n_E - 3n_I - \dot{\varpi}_I - 2\dot{\Omega}_I$	$e_I i_I^2$	-0.0010
$6n_E - 3n_I - \dot{\varpi}_E - \dot{\Omega}_E - \dot{\Omega}_I$	$e_E i_E i_I$	-0.0010

In this case, the i_I^2 resonance is encountered slowly and in the direction that allows trapping (Fig. 2). We then re-solidify Io, which allows the satellites to separate: Io's inclination decreases first, then the i_I^2 resonance exits, after which both eccentricities decrease. Europa finally loses its inclination in the $e_I i_E^2$ resonance at Offset= -0.0042 (Table 3) with a concurrent large excitation of Io's eccentricity.

Evolution is slow enough that trapping into third-order resonances is common; divergence of the satellite orbits leads to growth of $e, (i)$ for arguments with positive $\dot{\varpi}, (\dot{\Omega})$ coefficients. Negative coefficients mean that the corresponding element decreases. Hence the last six resonances encountered all act to decrease inclinations (Table 3). Thus we conclude that Io and Europa have not been this deep in resonance anytime since Europa acquired its $0.47°$ inclination.

4. Conclusions

We find that Io did not excite Europa's current inclination. We are investigating other possibilities and thank NASA's Origins program for supporting this research.

References

[1] Greenberg, R.: Galilean Satellites - Evolutionary paths in deep resonance. Icarus, Vol. 70, pp. 334-347, 1987.

[2] McGleam, C. and Hamilton, D.P.: Resonant History of Io and Europa. BAAS, Vol. 39, pp. 475, 2007.

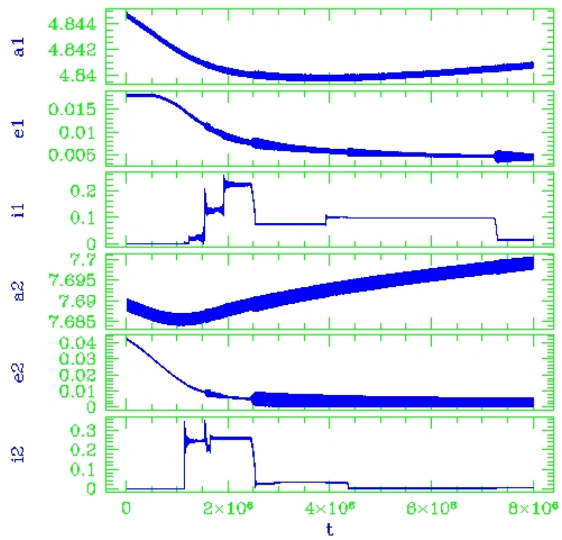

Figure 1: Evolution out of the 2:1 resonance. We plot the principal orbital elements of Io (top) and Europa (bottom) against time. The triplet of second-order inclination resonances i_E^2, $i_I i_E$, then i_I^2 excite inclinations prior to $t = 2 \times 10^6$ years. A bit later, trapping into the $e_E i_I i_E$ resonance with Offset= -0.0042 (Table 3) drops both inclinations toward zero while driving up eccentricities. The $e_I i_I^2$ resonance with Offset= -0.0091 ultimately erases Io's inclination at $t = 7 \times 10^6$.

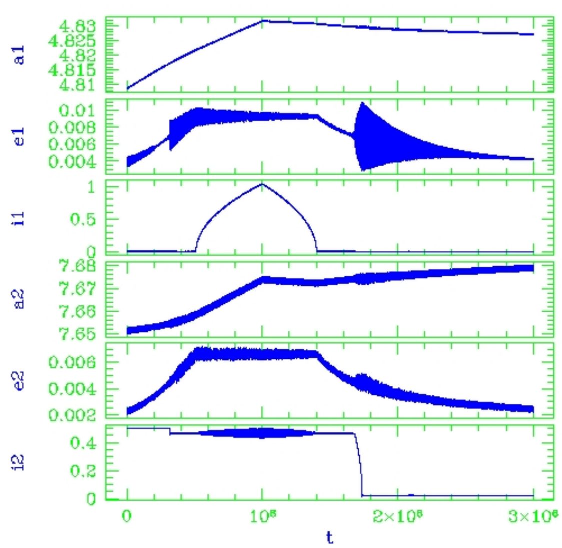

Figure 2: Evolution into and then back out of resonance. See text for discussion.