TIDAL DISSIPATION IN BINARIES OF ASTEROID PAIRS. L. Pou[1] and F. Nimmo[1], [1]Department of Earth and Planetary Sciences, University of California Santa Cruz, CA 95064, USA (lpou@ucsc.edu)

Introduction: The amplitude and phase of the tidal response of a body provide information about its interior structure [1,2]. Tidal dissipation in a body due to viscoelastic effects also cause changes in its spin rate and orbital parameters [3] . Thus, orbital evolution of a body can be used in special circumstances to infer its tidal response [4-6].

Constraining the tidal response of binary asteroids is challenging as it requires accurate knowledge of their age [7], and their semi-major axis and eccentricity evolution can be impacted by non-tidal effects such as the BYORP effect [8]. However, the age of asteroid pairs, i.e. pairs of genetically related asteroids on highly similar heliocentric orbits, can be determined [9] assuming they formed by rotational fission [10,11]. In this work, we constrain the tidal dissipation in binary systems existing within asteroid pairs.

Studied bodies: The studied bodies considered for this work are based on table 4 of [9], where the authors studied many asteroid pairs and constrained their age by numerical integration of clones under tidal forces and different Yarkovsky effect accelerations, with a range based on the works of [12]. We call the biggest member of the asteroid pair the primary, while the second member is the unbound secondary; the bodies that makes their primary a binary asteroid (or more) are called bound secondaries to distinguish them from the second asteroid pair member. For simplicity, we are assuming that all bodies are homogeneous spheres, and same bulk density for primaries and bound secondaries.

Binary age and secondary age: The ages of the asteroid pairs determined in [9] are not necessarily the ages of the bound secondaries. However, given the very high rotation speed of the primaries and lack of bound secondaries for slower rotators, the preferred means of explaining the existence of both the bound secondaries and the asteroid pairs is rotational fission [10], either through secondary fission, [5] or cascade fission [9,13]. In all cases, the age of the asteroid pair would be an upper bound for either the age of the bound secondary, or the last time (neglecting possible impacts) since its spin rate and orbit were chaotically excited before being able to go through tidal locking and orbit circularization.

Tidal locking: As the bound secondary exerts a tidal forcing on the primary, a tidal bulge is raised on the surface of the primary. If the bound secondary is above synchronous height, the tidal bulge is carried ahead of the tide-raising bound secondary by an angle δ called the geometric lag angle [14]. The bulge creates a tidal torque on the primary changing the semi-major axis and causing its spin rate to decrease until it is tidally locked. This tidal despinning timescale is [15-17]:

$$\tau_{spin,p} = \frac{2}{3}\,\alpha_p \frac{Q_p}{k_{2,p}} \frac{m_p(m_s+m_p)}{m_s^2} \left(\frac{a_{orb}}{R_p}\right)^3 \frac{w_{init}}{n^2}$$

where m is the mass, R is the radius, w_{init} is the initial spin rate of the satellite and n its orbital period. The subscripts p and s denote the primary and secondary, respectively. Q is the tidal dissipation factor or quality factor: for degree 2 tides, we have [18]:

$$\delta = \frac{1}{2Q}$$

α is linked to the body's moment of inertia Γ:

$$\Gamma = \alpha\, m\, R^2$$

and for a homogeneous sphere, we have $\alpha = 0.4$.

While the bound secondary exerts a tidal forcing on the primary, the reverse is also true: the tidal bulge of the bound secondary will be misaligned with the primary, causing a change in the bound secondary spin rate. Similarly, the timescale for the bound secondary is:

$$\tau_{spin,s} = \frac{2}{3}\,\alpha_s \frac{Q_s}{k_{2,s}} \frac{m_s\left(m_s+m_p\right)}{m_p^2} \left(\frac{a_{orb}}{R_s}\right)^3 \frac{w_{init}}{n^2}$$

Orbit circularization: If the orbit of the bound secondary is not circular, tidal dissipation in the interior of the satellite can both heat it and circularize its orbit. Assuming most of the angular momentum of the satellite is carried by its orbital momentum, the timescale for the eccentricity damping is [17,19]:

$$\tau_e = \frac{2}{21} \frac{Q_s}{k_{2,s}} \frac{m_s}{m_p} \left(\frac{a_{orb}}{R_s}\right)^5 \frac{1}{n} \frac{1}{1-e_{init}^2}$$

with e_{init} the initial eccentricity. This timescale typically is greater than t_{spin}.

Constraints on Q/ $\boldsymbol{k_2}$: For the primary, tidal despinning can be used to constrain $Q_p/k_{2,p}$. Since none of the primaries are tidally locked with their bound secondaries, we have:

$$\tau_{age} < \tau_{spin,p}$$

which puts a lower bound on $Q_p/k_{2,p}$.

For secondaries that are both tidally locked and with no eccentricity, we have:

$$\tau_{age} \geq \tau_{spin,s} \quad and \quad \tau_{age} \geq \tau_e$$

This gives two upper bounds on $Q_s/k_{2,s}$. However, since $\tau_e > \tau_{spin,s}$, the more constraining upper bound is given by the eccentricity damping timescale.

For secondaries that are tidally locked but with a non-circular orbit, we have:

$$\tau_{age} \geq \tau_{spin,s} \;\; and \;\; \tau_{age} < \tau_e$$

giving both upper and lower bounds on the $Q_s/k_{2,s}$ ratio.

Finally, for non-tidally locked bodies with non-zero eccentricity, we have:

$$\tau_{age} < \tau_{spin,s} \text{ and } \tau_{age} < \tau_e$$

Since $\tau_e > \tau_{spin,s}$, the more constraining lower bound for $Q_s/k_{2,s}$ is given by the tidal despinning timescale.

Application to asteroid pairs: The constraints on Q/k_2 for the bound secondaries of binaries in asteroid pairs are shown in Table 1. Figure 1 illustrates the first bound secondary of (3749) Balam, which is tidally locked but not fully circularized.

Binary asteroid	Age (kyr)	Rs (km)	$Q_s/k_{2,s}$
(3749) Balam	401^{+317}_{-217}	0.94	$3\ 10^4$ - $1\ 10^6$
(3749) Balam	401^{+317}_{-217}	0.49	$\geq 1\ 10^{-2}$ †
(6369) 1983 UC	671^{+454}_{-349}	0.61	$\leq 2\ 10^5$
(8306) Shoko	458^{+384}_{-149}	≥ 0.48	$\leq 2\ 10^5$
(9783) Tensho-kan	671^{+1403}_{-293}	0.61	$\leq 4\ 10^5$
(21436) Chaoyichi	31^{+109}_{-21}	0.34	$\geq\ 6\ 10^2$ †
(25021) Nischaykumar	925^{+1014}_{-416}	0.25	$\leq 1\ 10^6$
(26416) 1999 XM84	272^{+563}_{-167}	≥ 0.43	$\leq 9\ 10^5$ *
(26420) 1999 XL103	252^{+586}_{-107}	≥ 0.20	$\leq 4\ 10^4$ *
(43008) 1999 UD31	272^{+460}_{-77}	≥ 0.32	$\leq 4\ 10^6$
(44620) 1999 RS43	742^{+986}_{-549}	0.37	$\leq 5\ 10^5$ *
(46829) McMahon	766^{+418}_{-226}	0.50	$\leq 6\ 10^6$ *
(80218) 1999 VO123	143^{+819}_{-44}	0.14	$\leq 2\ 10^5$

Table 1: Estimated ages of asteroid pairs with their primary also having bound secondaries. Ages and radii of the bound secondaries are from [9]. (3749) Balam is mentioned twice since it possesses two bound secondaries. Bound secondaries that are neither tidally locked nor on a circular orbit are marked by †; only a lower bound can be given on their $Q_s/k_{2,s}$. Since (10123) Fideöja does not have a maximal age, its upper bound is ill-defined and its $Q_s/k_{2,s}$ cannot be reliably constrained. For values missing in Table 4 of [9] we assume a tidally locked secondary and circular orbit as per their comments in section 5.2 (indicated here by *).

Discussion: In most cases all that can be determined is an upper bound on $Q_s/k_{2,s}$, and a lower bound on $Q_p/k_{2,p}$. These upper bounds for $Q_s/k_{2,s}$ are generally consistent with estimates of ~10^4-10^6 derived by [5] for binary asteroids which are probably rubble piles [20]. In the case of the first bound secondary of (3749) Balam, we obtain a range for $Q_s/k_{2,s}$ of $3\text{x}10^4$-$2\text{x}10^6$ fully consistent with the [5] estimates. Most of the lower bounds for $Q_p/k_{2,p}$ are too low (~10^2-10^3) to truly constrain the structure of the primary. However, we are assuming that tidal torques are dominant compared to YORP and BYORP torques, when the latter two could also modify the despinning of primaries and secondaries, and circularization of bound secondaries.

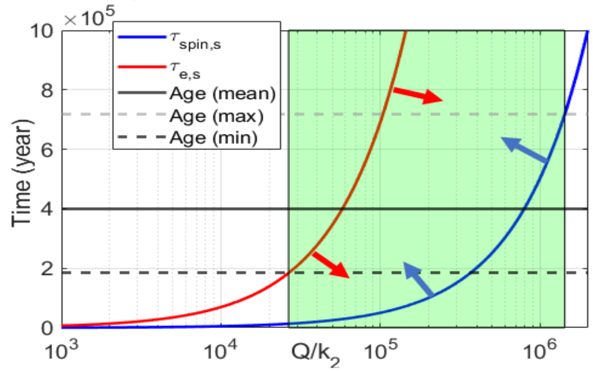

Figure 1: Possible Q/k_2 ratios for the first bound secondary of (3749) Balam compared to its age, the damping eccentricity timescale τ_e and the tidal despinning timescale $\tau_{spin,s}$. Since this body is tidally locked, its age must be greater than $\tau_{spin,s}$; however, as its eccentricity is nonzero, its age must be smaller than τ_e. Compatible Q/k_2 ratios correspond to the green area. Initial spin rate is 2.8 h, and initial eccentricity is 0.8.

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