Nonlinear Tides in Close Binary Systems

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(Submitted on 5 Jul 2011 (v1), last revised 29 May 2012 (this version, v2))

We study the excitation and damping of tides in close binary systems, accounting for the leading order nonlinear corrections to linear tidal theory. These nonlinear corrections include two distinct effects: three-mode nonlinear interactions and nonlinear excitation of modes by the time-varying gravitational potential of the companion. This paper presents the formalism for studying nonlinear tides and studies the nonlinear stability of the linear tidal flow. Although the formalism is applicable to binaries containing stars, planets, or compact objects, we focus on solar type stars with stellar or planetary companions. Our primary results include: (1) The linear tidal solution often used in studies of binary evolution is unstable over much of the parameter space in which it is employed. More specifically, resonantly excited gravity waves are unstable to parametric resonance for companion masses M' > 10-100 M_Earth at orbital periods P = 1-10 days. The nearly static equilibrium tide is, however, parametrically stable except for solar binaries with P < 2-5 days. (2) For companion masses larger than a few Jupiter masses, the dynamical tide causes waves to grow so rapidly that they must be treated as traveling waves rather than standing waves. (3) We find a novel form of parametric instability in which a single parent wave excites a very large number of daughter waves (N = 10^3[P / 10 days]) and drives them as a single coherent unit with growth rates that are ~N times faster than the standard three wave parametric instability. (4) Independent of the parametric instability, tides excite a wide range of stellar p-modes and g-modes by nonlinear inhomogeneous forcing; this coupling appears particularly efficient at draining energy out of the dynamical tide and may be more important than either wave breaking or parametric resonance at determining the nonlinear dissipation of the dynamical tide.

Comments:	40 pages, 16 figures. Matches version published in ApJ; conclusions unchanged; some restructuring of sections; sect. 5 now provides simple physical estimates of the nonlinear growth rates that agree well with the detailed calculations given in the appendices
Subjects:	**Solar and Stellar Astrophysics (astro-ph.SR)**; Earth and Planetary Astrophysics (astro-ph.EP)
Journal reference:	ApJ, 751, 136, 2012

Cite as: arXiv:1107.0946 [astro-ph.SR]
(or arXiv:1107.0946v2 [astro-ph.SR] for this version)

Submission history

From: Nevin N. Weinberg [view email]
[v1] Tue, 5 Jul 2011 18:59:06 GMT (650kb)
[v2] Tue, 29 May 2012 16:34:23 GMT (655kb)