1988IAUS..126..671A

TIDAL EFFECTS ON STELLAR EVOLUTION IN CLOSE BINARIES FORMED IN GLOBULAR CLUSTERS

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A mechanism of forming x-ray binaries by close collision of a neutron star and a normal star in a globular cluster core (GC) was proposed by Fabian, Pringle and Rees (1975). Press and Teukolsky (1977) (PT) made detailed computaions of tidal energy deposition in the non-radial modes of a main sequence (MS) star (approximated by a n = 3 ploytrope) and two-body tidal capture cross-section. Here, we correct numerical errors in PT for the n = 3 plytrope; extend the calculation to the n = 3/2 case which better approxiamtes a fully convective low mass star most abundant in GC; we discuss the effects of tidal energy dissipation on the evolution of the MS star and the binary orbit. The energy transferred to tides in the normal star during the encounter with a netron star (NS) is:

$$E_{tide} = \left(\frac{GM_*^2}{R_*}\right)\left(\frac{M_n}{M_*}\right)^2 \sum_{\ell=2}^{\infty} \left(\frac{R_*}{R_{min}}\right)^{2\ell+2} T_\ell(\eta)$$

Here M_* is the main sequence star's mass ($=0.6M_\odot$), R_* it's radius ($=4.5 \times 10^{10}$cm), M_n the neutron star mass ($=1.4\ M_\odot$), R_{min} the separation at periastron. The function $T_\ell(\eta)$ is defined in PT and we display its corrected values in Fig. 1 (here, $\eta = \{M_*/(M_* + M_n)\}^{1/2}(R_{min}/R_*)^{3/2}$). The n=3/2 polytrope gives a larger energy transfer compared to the n=3 case for similar collision parameters and also a larger cross-section. Fig. 2, which displays the ratio of tidal energy deposited in a spherical shell of unit thickness to the mean energy density, shows that a large part of the tidal energy is deposited near the surface for n=3/2 polytrope. In a fully convective star, the mechanical tidal energy is quickly dissipated due to the viscosity of turbulent eddies and gives a large thermal luminosity. We use the effective viscosity (cf Goldreich and Keeley, 1977) $\nu_t^{eff} = \nu_t/\beta^2$ reduced from the canonical value $\nu_t = (1/3)\ \ell_{mix}\ v_{conv}$ for turbulent eddies in the mixing length approximation whenever $\beta=\tau_{conv}/P_{osc} > 1$ (here τ_{conv} = eddy turnover time, P_{osc} is tidal oscillations period). For typical MS stars in GCs, this is roughly 10^4 years. The resulting thermal luminosity at various times after first encounter is displayed in Fig. 3. Thermal luminosity transmitted from below the stellar surface is 700 times normal stellar luminosity after a few hundred years, causing the star to reach a new equilibrium at a large radius. An isolated low mass ($0.6M_\odot$) Pop II star (opacity of outer radiative layers due to H^- atoms), transmitting $100L_\odot$ expands to an equilibrium radius at $R \simeq 10R_\odot$ (cf Stein (1966) for L_*-R_* relation). But the normal star's Roche-lobe radius ($R_c = 1.6R_*$) after orbit circularization is well within this for the assumed binary mass ratio. Thus, the normal star quickly overflows to form a circumbinary envelope. The NS spirals in towards the core of the normal star under frictional drag of envelope. Spiral-in timescale

J. E. Grindlay and A. G. Davis Philip (eds.),
The Harlow-Shapley Symposium on Globular Cluster Systems in Galaxies, 671–672.
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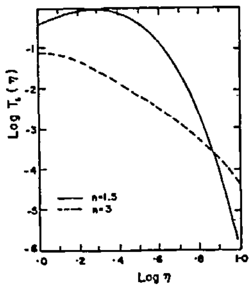
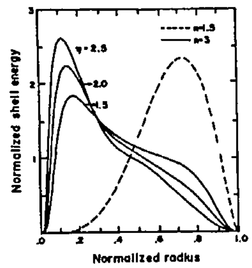
1988IAUS..126..671A





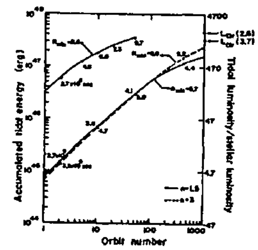


Fig. 1. Dimensionless function $T_\ell(\eta)$ for energy in quadrupole (ℓ=2) tide
Fig. 2. Distribution of tidal energy vs stellar radius.
Fig. 3. Accumulated tidal energy vs orbit number. Time elapsed since 1st encounter marked on each curve. R_{min} initial periastron distance in R_*. Right ordinate indicates luminosity in units of normal L_* ($0.17L_\odot$).

τ_D is related to orbital period P_{orb} (Paczynski, 1976) by: $\tau_D/P_{orb} \sim \langle\rho\rangle/\rho$; $\langle\rho\rangle$ = mean density of envelope inside NS orbit, ρ = density at the NS orbit. Further evolution of this common envelope binary depends on what fraction of the envelope mass is ejected, which in turn depends on whether the hydrodynamic ejection time-scale of a given mass of envelope is short or long compared to the thermal transport time across it (Taam et al (1978)). Four different end products of this binary are possible: (1) a detached binary where the MS star contracts to the original size inside Roche lobe before the NS orbit shrinks too much; (2) a contact x-ray binary where the common envelope is ejected fast compared to the Roche-lobe overflow of the MS star and where the orbital decay of the NS stops due to lessened friction; (3) Thorne-Zytkow Red Supergiant where the NS spirals in all the way to the center of the MS star without ejecting its envelope; and (4) a bare NS with a planetary nebula where NS ejects all matter in the MS star if common envelope density is too high. Thus, x-ray binaries form in 2-body tidal captures only part of the time but in such case the MS star starts filling the Roche-lobe soon after formation.

A.R. thanks VITA, Univ. of Virginia for hospitality and assistance.

REFERENCES

Fabian, A. C., Pringle, J. E. and Rees, M. J. 1975 Monthly Notices Roy. Astron. Soc. 172, 15.
Goldreich, P. and Keeley, D. A. 1977 Astrophys. J. 211, 934.
Paczynski, B. 1976 in IAU Symposium No. 73, Structure and Evolution of Close Binary Systems, P. Eggleton, S. Mitton and J. Whelan, eds., Reidel, Dordrecht, p. 75.
Press, W. H. and Teukolsky, S. A. 1977 Astrophys. J. 213, 183.
Stein, R. F. 1966 in Stellar Evolution, R. F. Stein and A. G. W. Cameron, eds., Plenum Press, New York, p. 23.
Taam, R. E., Bodenheimer, P. and Ostriker, J. P. 1978 Astrophys. J. 222, 269.

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