GRAVITATIONAL RADIATION AND SPIRALLING TIME OF CLOSE BINARY SYSTEMS (V)

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Abstract. Forty-six binary systems with their primary component masses between 2 $M_\odot$ and 3 $M_\odot$ have been considered for gravitational radiation study. Power output by gravitational radiation (P_B) and spiral time τ_0 for all individual systems have been evaluated. A relation has been given between P_B and τ_0. The rate of decrease of orbital period ($\dot{P}$) has also been given for 10 eccentric orbit systems.

1. Introduction

In continuation of our earlier work (Padalia, 1991; hereafter referred to as Paper IV) on the subject, where binary systems with primary components only in the mass range between 1 $M_\odot$ and 2 $M_\odot$ were considered, we have evaluated P_B and τ_0 values for 46 close binary systems with their primary component masses between 2 $M_\odot$ and 3 $M_\odot$. New relations between P_B and τ_0 have been established. Unlike in Paper IV, where the same mass range systems formed two distinct groups, the present systems seem to fall into one group. Out of the total binary systems investigated in the present paper, 10 systems have eccentric orbits. For these 10 systems, the rate of decay of orbital periods, due to the loss of energy from the system via gravitational radiation emission, has also been given. The masses, periods, eccentricities and radii of relative orbits adopted in the present paper are given in Table I.

2. Discussion and Results

The equations used for determining P_B, τ_0 and $\dot{P}$ are given below:

$$P_B = \left(\frac{\mu}{M_\odot}\right)^2 \left(\frac{M}{M_\odot}\right)^{4/3} P^{-10/3}\, 3.0 \times 10^{26}\,\mathrm{W}, \tag{1}$$

$$\tau_0 = \frac{5c^5 a_0^4}{256 G^3 \mu M^2}, \tag{2}$$

$$\frac{\dot{P}}{P} = -\frac{96 G^3 \mu M^2}{5c^5 a_0^4 (1-e^2)^{7/2}} \left(1 + \frac{73}{24}e^2 + \frac{37}{96}e^4\right). \tag{3}$$

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TABLE I

Gravitational radiation, spiralling time and rate of change of period ($\dot{P}$) due to gravitational radiation emission of 46 binary systems.

Name of the systems	M_1 ($M_\odot$)	M_2 ($M_\odot$)	Orbital period (in days)	Radius of relative orbits $a_0(R_\odot)$	Power output (PB) (W)	Spiral time (τ_0) (years)	X ($\log P_B - 19$)	Y ($\log \tau_o - 10$)	Eccentricity of the orbits	Rate of change of the period ($\dot{P}$) due to gravitational radiation emission
VW Cyg	2.50	0.70	8.430	25.69	0.9E+19	1157.21E+10	−0.045	3.063	—	—
QY Aql	2.69	0.76	7.229	23.77	1.9E+19	673.53E+10	0.278	2.828	0.06	−1.20E−15
V 377	2.10	1.24	8.252	25.68	2.0E+19	743.94E+10	0.301	2.871	—	—
RS Ari	2.00	1.30	8.803	23.68	2.1E+19	782.29E+10	0.322	2.893	—	—
V 535 Oph	2.00	0.90	6.055	19.93	2.9E+19	449.68E+10	0.462	2.653	—	—
SY Cyg	2.14	0.86	6.006	20.06	3.1E+19	436.35E+10	0.491	2.639	—	—
AS Eri	2.02	0.25	2.664	10.62	4.2E+19	165.01E+10	0.623	2.217	—	—
WZ Cet	2.90	2.01	6.645	25.28	5.3E+19	212.31E+10	0.724	2.326	—	—
S Eqr	2.96	0.36	3.436	14.28	6.3E+19	174.97E+10	0.799	2.243	—	—
Y Cam	2.15	0.47	3.306	12.87	7.470E+19	154.25E+10	0.873	2.188	—	—
TU Mon	2.30	1.00	5.049	18.43	8.1E+19	2462.80E+10	0.908	2.390	0.20	−0.29E−14
TL Mi	2.56	0.35	3.020	12.55	9.2E+19	141.55E+10	0.966	2.150	—	—
RU Mon	2.34	0.63	3.585	14.16	11.2E+19	136.6E+10	1.049	2.135	0.28	−0.44E−14
ST Per	2.36	0.43	2.648	11.19	15.2E+19	82.78E+10	1.182	1.918	—	—
YZ Cas	2.11	1.27	4.467	17.12	16.3E+19	141.10E+10	1.212	2.149	—	—
CD Aqr	2.22	1.52	4.838	18.68	18.6E+19	143.56E+10	1.269	2.157	—	—
CP And	2.14	1.34	3.609	15.00	37.3E+19	75.20E+10	1.572	1.876	—	—
AN And	2.42	1.32	3.220	14.31	67.0E+19	50.21E+10	1.826	1.700	0.03	−0.65E−14

TABLE I Continued.

Name of the systems	M_1 ($M_\odot$)	M_2 ($M_\odot$)	Orbital period (in days)	Radius of relative orbits $a_0(R_\odot)$	Power output (PB) (W)	Spiral time (τ_0) (years)	X ($\log P_B - 19$)	Y ($\log \tau_o - 10$)	Eccentricity of the orbits	Rate of change of the period ($\dot{P}$) due to gravitational radiation emission
V348 Cen	2.03	0.96	2.152	10.11	106.9E+19	39.27E+10	2.029	1.594	—	—
TT Vel	2.00	0.95	2.108	9.92	109.8E+19	25.70E+10	2.041	1.410	—	—
TX Leo	2.74	1.05	2.445	11.90	130.0E+19	27.3E+10	2.113	1.436	0.06	−0.920E-14
CQ Ori	1.37	0.81	1.717	8.19	154.9E+19	17.64E+10	2.190	1.246	—	—
XY Cet	2.27	2.07	2.780	13.57	206.4E+19	24.7E+10	2.314	1.393	—	—
V 477 Cyg	2.37	1.60	2.347	11.76	250.9E+19	18.90E+10	2.398	1.276	0.30	1.42E-14
Delta Lib	2.96	1.31	2.327	11.98	256.8E+19	18.51E+10	2.409	1.267	0.07	−1.32E-14
YY Sqr	2.36	2.29	2.628	13.37	314.3E+19	18.92E+10	2.497	1.276	—	—
RS Tri	2.10	1.28	1.908	10.07	355.6E+19	16.84E+10	2.551	1.226	—	—
V526 Sqr	2.11	1.66	1.919	10.11	433.7E+19	11.77E+10	2.637	1.070	—	—
V451 Oph	2.38	1.98	2.197	11.61	453.9E+19	13.10E+10	2.657	1.117	—	—
W UMi	2.68	1.19	1.701	9.39	527.1E+19	9.37E+10	2.722	0.972	0.09	2.40E-14
UU Cra	2.90	1.98	2.238	12.21	587.2E+19	11.80E+10	2.769	1.072	—	—
AA And	1.92	0.58	0.935	5.46	631.45E+19	4.75E+10	2.800	0.678	—	—
BZ Cas	2.89	1.95	2.126	11.77	674.6E+19	10.48E+10	2.829	1.020	—	—
RS Cha	2.17	1.76	1.670	9.30	767.5E+19	7.69E+10	2.885	0.885	—	—
AI Dra	2.18	1.03	1.199	6.98	951.0E+19	4.90E+10	2.978	0.690	—	—
IM Aur	2.97	0.89	1.247	7.64	1023.0E+19	4.97E+10	3.009	0.696	—	—

TABLE I Continued.

Name of the systems	M_1 ($M_\odot$)	M_2 ($M_\odot$)	Orbital period (in days)	Radius of relative orbits $a_0(R_\odot)$	Power output (PB) (W)	Spiral time (τ_0) (years)	X ($\log P_B - 19$)	Y ($\log \tau_o - 10$)	Eccentricity of the orbits	Rate of change of the period ($\dot{P}$) due to gravitational radiation emission
TW Cas	2.90	1.18	1.428	8.52	1050.4E+19	5.61E+10	3.021	0.749	—	—
AS Mon	2.89	1.97	1.836	10.69	1120.2E+19	7.02E+10	3.049	0.846	—	—
V505 Sqr	2.22	1.18	1.183	7.07	1300.0E+19	4.10E+10	3.114	0.613	—	—
TT Her	2.44	0.90	0.912	5.91	2205.0E+19	2.47E+10	3.343	0.393	—	—
DO Cas	2.04	0.64	0.685	4.54	2342.0E+19	1.81E+10	3.369	0.258	0.12	−4.22E-14
ST Aqr	2.38	0.72	0.781	5.20	2374.2E+19	2.05E+10	3.375	0.312	—	—
SU Aqr	2.53	1.26	1.044	6.76	2722.0E+19	2.57E+10	3.435	0.410	—	—
AG Vir	2.16	0.67	0.643	4.43	3410.0E+19	1.4E+10	3.532	0.146	0.14	−5.29E-14
DK Aqr	2.91	1.76	0.945	6.78	8530.4E+19	1.31E+10	3.931	0.117	—	—
CZ Aqr	2.96	1.48	0.863	6.27	8742.6E+19	1.18E+10	3.942	0.073	—	—

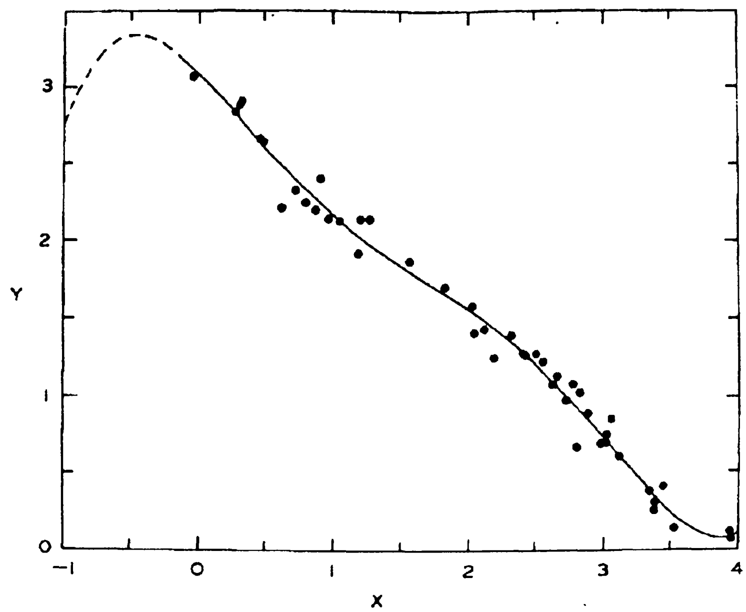

Fig. 1. Relation between gravitational radiation (along X-axis) and spiralling time(along Y-axis) for the 46 binary systems given in Table I. Due to paucity of observational data we cannot make any specific statements regarding the dashed extrapolated portion of the curve in Fig. 1.

The above three equations have been cited in our earlier papers Padalia (1987) and Paper IV. The values of P_B, τ_0 and $\dot{P}$ thus determined are reported in Table I. We found that P_B is inversely proportional to τ_0.

Gravitational radiation P_B (in Watt) along X-axis and spiralling time τ_0 (in years) along Y-axis have been plotted in Fig. 1. It is found that X and Y follow the relation:

$$Y = 0.02536\,X^5 - 0.2137\,X^4 + 0.5597\,X^3 - 0.410\,X^2 - 0.87\,X + 3.07$$

where, $X = \log P_B - 19$ and $Y = \log \tau_0 - 10$. The rate of decrease of orbital period ($\dot{P}$) due to gravitational wave emission of the eccentric systems (out of the present 46) is reported in the last column of Table I. It is found that ($\dot{P}$) is of the order of 10^{-14} . This rate of period change is similar to the four binary systems in the mass range between 1 $M_\odot$ and 2 $M_\odot$ reported in Paper IV.

In Papers III (Padalia, 1990) and IV, we noticed that out of a number of binary systems considered in each paper a few systems formed different groups as per P_B and τ_0 relations. In Paper III, the binary systems considered were taken with different masses, that is, primary components between masses 0.8 $M_\odot$ to 47 $M_\odot$, or the systems were taken in a random way. In Paper IV, however, all the systems were takenfrom the same mass group between 1 $M_\odot$ and 2 $M_\odot$ (primary component); therefore, in this case, a conclusion was drawn in regard to bifurcation, that the mechanism of binary star formation and evolution or a possible gravitational radiation burst might be responsible for this deviation. Since the systems of paper III were of a different mass group, no such conclusion can be drawn. For the present close binary systems, the P_B vs. τ_0 relation follows a single curve and thus shows no bifurcation. It indicates that the factors affecting 1 $M_\odot$ systems are not operative for 2 $M_\odot$ systems. Therefore, to make this study more conclusive, it is required that binary systems systematically in the mass range 3 $M_\odot$ and onwards need investigation for gravitational radiation study.

In a number of binary star systems, after a lapse of several decades since their discovery, period variations have been observed. For most of the systems, causes for period variations have not been given; in a few cases, mass transfer, mass loss from the system and other such regions have been given. In the course of our gravitational radiation (GR) study for various binary systems, we may come across such systems whose rates of period decrease $\dot{P}$ due to GR alone may be around 10^{-12} to 10^{-13} causing total period change of about 10^{-7} to 10^{-8} days in a span of about 100 years. Therefore, whatever other causes of period variations may be, correction factors for period variations due to loss of GR from the systems would have to be introduced for all such (period) variable systems. Only after such a correction, can net values of period variation attributed to mass transfer, mass loss, etc, be estimated. Hence, binary systems possessing high eccentric orbits and low periods require further investigation.

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