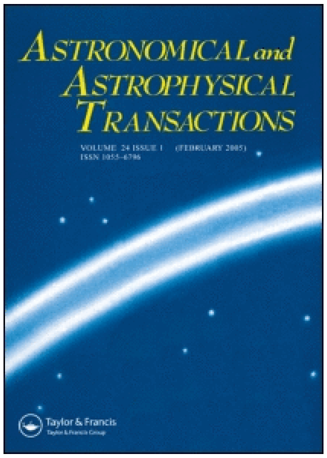

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ASTROPHYSICS OF RADIATING SHELLS

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A seminumerical method was used to study the evolution of a general-relativistic radiating shell in its post-Newtonian and Newtonian approximations. The solutions, where the main parameters are given reasonable values, show that a relativistic effect can be found in X-ray burster-like objects.

Keywords: Astrophysics; Radiating shells

1 INTRODUCTION

The spherical radiating shell model corresponds to a stellar model in which a compact star, such as a neutron star, is encompassed by a plasma envelope at very high densities and temperatures (Hartle, 1972; Lewin and Clark, 1980; Shane *et al.*, 1994). This could produce thermonuclear fusion with X-ray emission. It is usually assumed that the subsequent explosions are associated with neutron stars belonging to binary systems where matter is gravitationally drawn from the normal companion and forms an accretion disc around the binary. The matter is later deposited over the collapsed star's surface.

The theoretical model of the shell consists of a three-dimensional (two space-like dimensions and one time-like dimension) singular hypersurface with a Schwarzschild metric inside and a Vaidya metric outside. We consider an energy-stress tensor for a dust configuration of the shell.

2 EQUATION OF MOTION

Using the post-Newtonian approximation method (Weinberg, 1972), generalized for an external force by Aquilano *et al.* (1994b), the equation of motion takes the following form:

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{1}{2r^2} + \frac{1}{2r^3} + \frac{3}{2r^2}v^2 + \left(1 - \frac{3}{2}v^2\right)\left(-\frac{\hat{m}}{m^-}\,\frac{1}{4r^2} - \frac{2(m^-)^3}{\hat{m}}1.73 \times 10^{-24} r^2\right) \quad (1)$$

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$r = r(t)$ with t the time coordinate, where $\hat{m}$ is the shell mass. We have considered that the shell radiates like a black body (Castagnino *et al.*, 1983):

$$L = 4\pi\sigma R^2 T^4,$$

where L is the luminosity, σ is the Boltzmann constant and T is the temperature of the shell.

The non-relativistic equation of motion for a shell can be calculated, assuming spherical symmetry, by considering three forces, namely the gravitational attraction of the central mass, the self-gravity of the shell and the momentum originating from the emitted radiation:

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{1}{2r^2} - \frac{\hat{m}}{m^-}\frac{1}{4r^2} - \frac{2(m^-)^3}{\hat{m}} 1.73 \times 10^{-24} r^2. \tag{2}$$

All the previous equations are dimensionless versions (Hamity and Gleiser, 1978; Castagnino and Umérez, 1983; Hamity and Spinosa, 1984; Aquilano *et al.*, 1994a,b, 1995; Santoro *et al.*, 1996, 1997).

3 NUMERICAL SOLUTION OF THE EQUATIONS

Equations (1) and (2) can be solved numerically using the Burlish–Stoer method. This method is based upon the Richardson extrapolation. The integration can be performed by attributing particular values to the two free parameters. Thus, we give values to the central body mass m^- and the shell mass $\hat{m}$. For each pair of parameters we provide a set of initial conditions to the equations.

With the initial conditions

$$\hat{m}_0 = 0.002 M_{\text{solar mass}},$$
$$m^- = 2 M_{\text{solar mass}}$$

and

$$r_{\mathrm{i}} = 10\,\mathrm{km},$$
$$v_{\mathrm{i}} = 0.2c,$$
$$T_{\mathrm{i}} = 10^7\,\mathrm{K},$$

TABLE I The Evolution of the Shell for the Post-Newtonian Equation of Motion

t *(ms)*	*r* *(cm)*	*v* *(units of c)*	*L* *(erg s^{-1})*
0.0	1.0×10^6	0.40	7.50×10^{36}
0.2	3.0×10^6	0.30	6.70×10^{37}
0.4	4.6×10^6	0.23	1.50×10^{38}
0.6	6.0×10^6	0.18	2.40×10^{38}
0.8	6.7×10^6	0.14	3.27×10^{38}
1.0	7.5×10^6	0.11	4.00×10^{38}
1.5	8.7×10^6	0.05	5.40×10^{38}
2.0	9.0×10^6	0.000 13	5.88×10^{38}
2.5	8.7×10^6	−0.05	5.40×10^{38}
3.0	7.5×10^6	−0.11	4.00×10^{38}
3.5	5.3×10^6	−0.20	2.00×10^{38}
4.0	1.0×10^6	−0.39	7.01×10^{36}

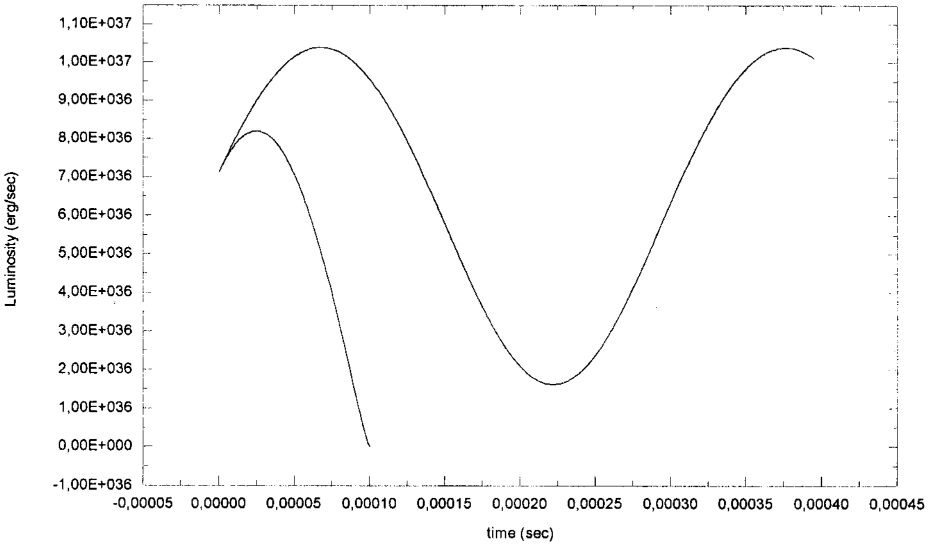

FIGURE 1 Luminosity profile of the post-Newtonian and Newtonian solutions of the shell equation of motion. The lower profile corresponds to the Newtonian solution.

Table I shows the evolution of the shell calculated for the post-Newtonian equation of motion. The velocity v and luminosity L of the shell are listed, together with the time t and the distance r.

Also, we show a comparison between the post-Newtonian approximation and the non-Relativistic equations of motion, where the solutions are shown for a particular selection of the initial conditions in Figure 1.

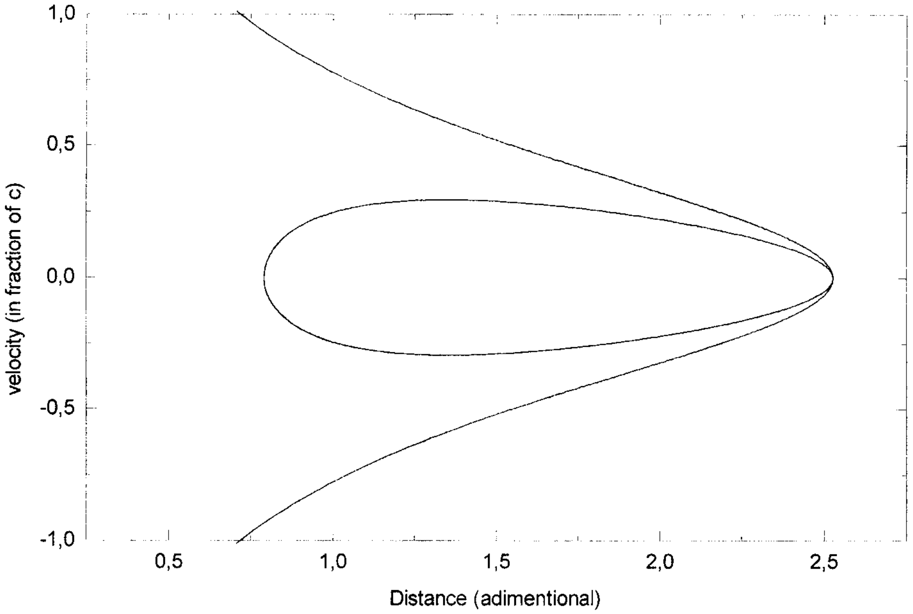

FIGURE 2 The phase space. The inner curve corresponds to the post-Newtonian solution. In the non-relativistic solution we have a collapsed shell.

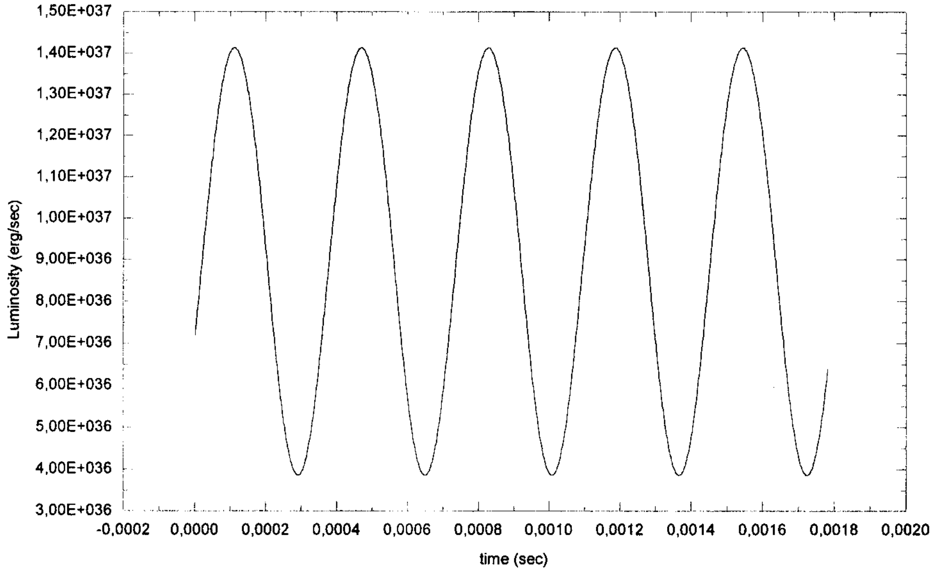

FIGURE 3 A sample of oscillatory luminosity profiles for the post-Newtonian case. Here the central body mass is $3M_{\text{solar mass}}$, with a shell mass of $0.002M_{\text{solar mass}}$. The integration begins from a radius of 10 km.

Figure 2 shows, within the phase space, the collapsed shell in the case of the non-relativistic movement and in the same figure the closed curve correspond to the post-Newtonian movement. Hence, within the framework of general relativity, incorporating post-Newtonian connections, we have an oscillation around a stable singular point.

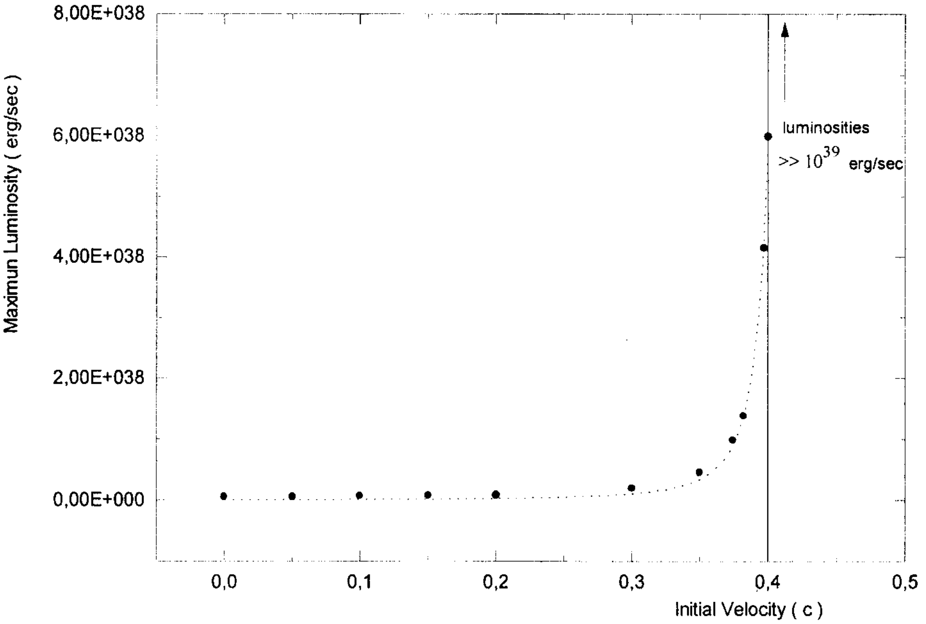

FIGURE 4 Maximum luminosity for different initial velocities of integration.

4 CONCLUSIONS

This model is very simple. Indeed, we are working with an extended object (the shell) of two space dimensions. Inside this shell there is vacuum; that is, there is no gas that supports the shell. This can be seen in the non-relativistic model, where we observe a collapse on to the central star. Nevertheless, in the case of post-Newtonian corrections, there seems to be a new force, a *relativistic force*, which generated an oscillatory phenomenon (Fig. 3).

To associate this model with a burster, we must realize that the observed luminosity for this type of object is of the order of $10^{38}\,\mathrm{erg\,s^{-1}}$. Then we must find a superior limit to the initial conditions (initial velocities), which enable us to obtain acceptable numerical solutions. Figure 4 provides this limit.

In other articles (Neira *et al.*, 1998) we have been working with strange matter stars, and radiating shells, and the conclusions are very similar with neutron stars.

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