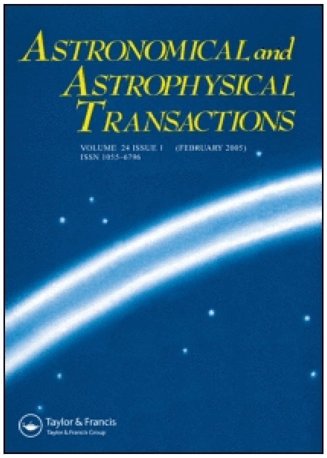

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GENERAL RELATIVITY EFFECTS IN X-RAY BURSTERS

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Relativistic effects could eventually be detected in X-ray bursters; the conclusions of Castagnino and Umérez (1983) can be improvement.

KEY WORDS X-ray bursters, general relativity

1 INTRODUCTION

In our formalism we used the General Relativity theory, the shell is a three-dimensional (two space like dimensions, one time-like dimension) singular hypersurface (Castagnino and Umerez, 1983; Gallagher and Starrfield, 1978; Hartle, 1973; Hamity and Gleiser, 1978) with a Schwarzschild metric inside and a Vaidya metric (Hamity and Spinosa, 1984) outside.

In the present paper we have used the model to study the possibility of detection of relativistic effects to different astronomical object, X-ray bursters, and find that in this case the effect can be detected, at least in principle. Thus this work is continuation of Castagnino and Umerez (1983) and can be considered as a concluding remark to show that there are objects in the universe where our formalism may eventually yield the detection of a relativistic effect.

X-ray bursters radiate an extraordinarily large amount of energy, mainly X-rays, reaching maximum luminosity in milliseconds (Van der Klis, 2000). It is usually assumed that these explosions are related to neutron stars that belong to binary systems and receive matter from their normal companion, forming an accretion disk around them; the matter is later deposited over the star's surface. This matter is mainly hydrogen whose temperature rises to the critical one, causing thermonuclear fusion which produces helium and, later one, carbon. When carbon is formed X-rays are emitted, heating the rest of the matter and producing an increase of the stellar luminosity.

We shall simply postulate that the radiation of the shell is proportional to its surface, i.e. to the radius squared and the fourth power of the temperature.

In our simplified model we shall consider:

- a spherical atmosphere, neglecting the possible cylindrical shape of the accretion disk, and the influence of the normal companion that we consider to be very far away from the neutron star;
- only the radiation component in the stress-tensor of the r.h.s. of the Einstein equation, neglecting the matter component;
- no magnetic field, because we suppose that we are dealing with an old neutron star.

We can fit our model to the experimental data, and we shall obtain a difference between the classical and relativistic models, i.e. a relativistic effect that could possibly be detected.

2 THE EQUATION OF MOTION

Hamity and Spinosa (1984) found the following equations of motion of the shell, where the case $L^- = 0$ has been previously studied by Castagnino and Umeréz (1983):

$$R(A - B) = m_0, \tag{1a}$$

$$m_0 \ddot{R} = -A\frac{m_0^2}{zR^2} - \frac{m^- m_0}{R^2} - AL^+ + BL^-, \tag{1b}$$

where m^- is the mass of the central body, m^+ is the mass of the shell plus the mass of the central body $(m + m^-)$, R is the radius of the shell, m_0 is the total energy of ejected matter, L^- is the luminosity of the central star at the time of the explosion, L^+ is the shell luminosity, and

$$A = \left(\dot{R}^2 - \frac{2m^-}{R} + 1\right)^{1/2}, \quad B = \left(\dot{R}^2 - \frac{2m^+}{R} + 1\right)^{1/2}.$$

3 NEWTONIAN APPROXIMATION. INTERPRETATION OF THE EQUATION

If low velocities are assumed, i.e. $\dot{R} \ll 1$, the newtonian approximation of this problem will be reached. Thus if $m^- \ll R$, and $m^+ \ll R$ we obtain

$$A = 1 + \frac{1}{2}\left(\dot{R}^2 - \frac{2m^-}{R}\right) + \text{order}\left(\dot{R}^2 - \frac{2m^-}{R}\right)^2,$$

$$B = 1 + \frac{1}{2}\left(\dot{R}^2 - \frac{2m^+}{R}\right) + \text{order}\left(\dot{R}^2 - \frac{2m^+}{R}\right)^2 .$$

Then

$$A - B = \frac{m}{R} + \text{order}\left(\dot{R}^2 - \frac{2m^\pm}{R}\right)^2 , \tag{2a}$$

where $m = m^+ - m^-$, and may be interpreted as the gravitational mass of the shell.

Also, from (1a) we have

$$A - B = \frac{m_0}{R}. \tag{2b}$$

Hence, (2a) and (2b) may be used to write

$$m_0 \simeq m + \text{order}\left(\dot{R}^2 - \frac{2m^+}{R}\right)^2 .$$

Therefore gravitational mass approaches proper mass, which is consistent with the assumption that this approximation is a newtonian one. Thus from Eqs. (2a) and (2b) we obtain

$$m_0\ddot{R} = -\frac{m_0^2}{2R^2} - \frac{m^- m_0}{R^2} - L^+ + L^- . \tag{2c}$$

This is the equation that would have been obtained if the evolution of this system had been treated within the framework of newtonian theory, using m_0 as the classical rest mass of the shell. The first term of the right hand side is the self-gravity force of a shell with mass m_0 and radius R, while the second is the interaction force between such a shell and a spherically concentric body with mass m^-. The third term is the momentum transferred to the shell per unit time by the radiation emitted by the shell itself, and the fourth term is the momentum transferred to the shell per unit time by the radiation emitted by the central body and absorbed at the interior surface of the shell.

4 CLASSICAL VS. RELATIVISTIC MODELS

We calculate the light curve classically and relativistically to observe their differences. We choose $L^+ = 4\pi\sigma R^2 T^4$ and $L^- =$ constant (σ is the Stefan–Boltzmann constant).

Equation (1a) becomes

$$m\ddot{R} = -A\frac{m_0^2}{2R^2} - \frac{m^- m_0}{R^2} - A4\pi\sigma R^2 T^4 + BL^- \tag{3a}$$

and Eq. (2c) becomes

$$m\ddot{R} = -\frac{m^2}{2R^2} - \frac{m^- m}{R^2} - 4\pi\sigma R^2 T^4 + L^- . \tag{3b}$$

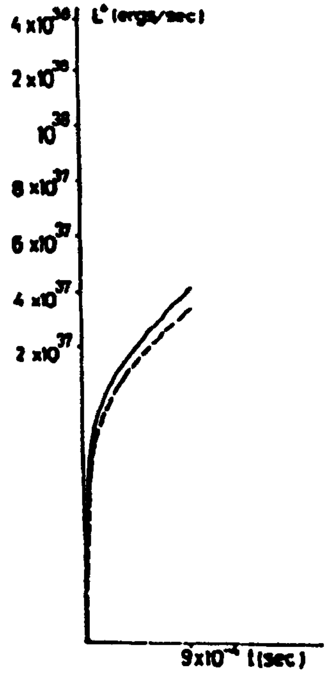

Figure 1 Time vs. luminosity curves for $\dot{R}_0 = 0.4c$: solid line, relativistic curve A; dashed line, classical curve A'.

These equations can be solved numerically to obtain a light curve. We shall take the following data to fit the observed light curves to our model: $R_0 = 10$ km, $m^- = 1$ solar mass, $\dot{R}_0 = 0.5c$ (c – light velocity) (Figure 2) and $0.4c$ (Figure 1), the first velocity for curves B and B', and the second velocity for curves A and A', and $m = 0.002$ solar mass.

The temperature increases from 10^7 to 10^8 K in one second approximately (Lewin and Clark, 1980). The adiabatic cooling is neglected because we study the first part of the light curve, and it is only important in the falling part of the light curve. These data allow us to compute the two terms of the relativistic correlation in the coefficient α:

$$\alpha = \dot{R}^2 - \frac{2m^-}{R},$$

where

$$\dot{R}_0^2 = \left(\frac{0.4c}{1c}\right)^2 = 0.16, \quad \frac{2m^-}{R_0} = 0.29.$$

Thus $\alpha = -0.13$. The first comes from Special Relativity and the second from General Relativity, so that we can see that we shall find not only special relativistic effects but general relativistic ones as well.

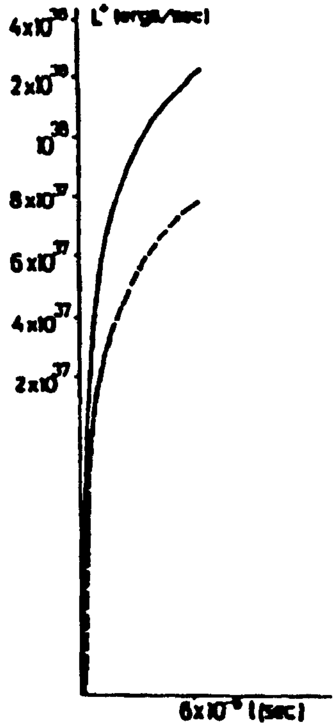

Figure 2 Time vs. luminosity curves for $\dot{R}_0 = 0.5c$: solid line, relativistic curve B; dashed line, classical curve B'.

5 CONCLUSION

The flux exceeds 10^{38} erg s^{-1} in some objects, and the maximum luminosity is reached in milliseconds or less. The light curves that we obtained fit both requirements nicely. The difference between classical and relativistic curves shows the existence of a relativistic effect.

In the previous paper (Castagnino and Umerez, 1983) we reached the conclusion that the general relativistic effects will be very difficult to detect, because the mass density is smaller in ordinary novae and supernovae, but in the X-ray bursters with the existence of neutron stars, we have shown that it could be possible to detect a general relativistic effect using our formalism.

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