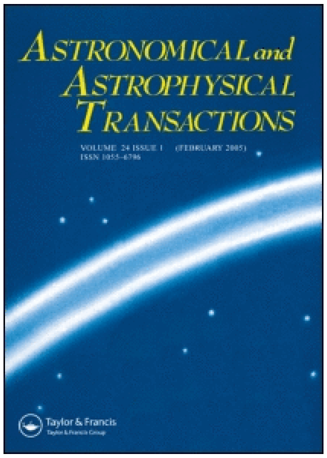

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Post-newtonian approximation and collapsed stars

F. Santoro [ab]; L. Neira [ac]; D. Ibaceta [ab]; R. Aquilano [ac]
[a] Instituto de Física Rosario (CONICET-UNR), Rosario, Argentina
[b] Facultad de Ciencias Exactas, Ingeniería y Agrimensura, Universidad Nacional de Rosario, Rosario, Argentina
[c] Observatorio Astronómico y Planetario Municipal de Rosario, Parque Urquiza, Rosario, Argentina

Online Publication Date: 01 January 1998
To cite this Article: Santoro, F., Neira, L., Ibaceta, D. and Aquilano, R. (1998) 'Post-newtonian approximation and collapsed stars', Astronomical & Astrophysical Transactions, 17:1, 77 - 81
To link to this article: DOI: 10.1080/10556799808235427
URL: http://dx.doi.org/10.1080/10556799808235427

Astronomical and Astrophysical Transactions, 1998,
Vol. 17, pp. 77–81
Reprints available directly from the publisher
Photocopying permitted by license only

POST-NEWTONIAN APPROXIMATION AND COLLAPSED STARS

F. SANTORO[1,2], L. NEIRA[1,3], D. IBACETA[1,2], and R. AQUILANO[1,3]

[1] *Instituto de Física Rosario (CONICET–UNR), Bv. 27 de Febrero 210 bis,
2000 Rosario, Argentina*
[2] *Facultad de Ciencias Exactas, Ingeniería y Agrimensura, Universidad Nacional
de Rosario, Av. Pellegrini 250,
2000 Rosario, Argentina*
[3] *Observatorio Astronómico y Planetario Municipal de Rosario, Parque Urquiza,
Casilla de Correo 606, 2000 Rosario, Argentina*

(Received August 26, 1996)

In this work we confirm the conclusions of papers Aquilano, Castagnino and Lara (1994); Aquilano, Castagnino and Neira (1994). We use of the post-Newtonian approximation to show that the oscillations of shells could be very important in the physics of astronomical objects with collapsed stars.

KEY WORDS Collapsed stars, relativistic effects, the shell oscillations

1 INTRODUCTION

In X-ray and gamma-ray bursters, the rapid variations of luminosity are generally interpreted as being due to their rotation, but these variations can alternatively be explained as radial oscillations of compact objects (Abramowicz, 1989). Energy fluctuations in stellar binary systems endowed with thermomechanical oscillations can be used to describe this astrophysical event.

X-ray bursters radiate an extraordinarily large amount of energy, mainly X-rays, reaching their maximum luminosity in milliseconds (Lewin and Clark, 1980; Shore, Livio and van den Heuvel, 1994). It is usually assumed that these explosions are related to neutron stars, white dwarfs or black holes, 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 stars's surface (if it is a neutron star or white dwarf). This matter is mainly hydrogen whose temperature rises to a critical value, causing thermonuclear fusion which produces helium and, later on, 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 consider a spherical atmosphere, neglecting the possible cylindrical shape of the accretion disk (but this is permissible using the post-Newtonian method) and the influence of the normal companion which we consider to be very far away from the neutron star, and only the radiation component in the stress-tensor of the right-hand side of the Einstein equation, neglecting the matter component.

This work is a continuation of previous papers Aquilano, Castagnino and Lara (1994); Aquilano, Castagnino and Neira (1994), but with post-Newtonian approximation (Aquilano, Castagnino and Neira, 1994, Weinberg, 1972), 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.

2 THE EQUATIONS OF MOTION

We can see that our post-Newtonian approximation method yields the equation of motion (see Aquilano, Castagnino and Neira, 1994),

$$dv/dt = -\bar{m}/R^2 - 2\bar{m}^2/R^3 + (3\bar{m}/R^2)v^2 + (d\tau/dt)^3(-m_0/2R^2 - L/m_0) \qquad (1)$$

$$R(A - B) = m_0 \qquad (2)$$

where m_0 may be interpreted as the gravitational mass of the shell (see Aquilano, Castagnino and Neira, 1994), $\bar{m}$ is the mass of the central body (the neutron star), R is the radius of the shell, L is the shell luminosity, and

$$A = (R'^2 - 2\bar{m}/R + 1)^{1/2}, \quad B = (R'^2 - 2m_0/R + 1)^{1/2} \qquad (3)$$

where the primes represent the time derivatives.

We now introduce two relations, a law of shell emission (see Aquilano, Castagnino and Lara, 1994),

$$L = 4\pi\sigma R^2 T^4 \qquad (4)$$

where σ is the Stefan–Bolzmann constant; and the other relation is

$$d\tau/dt = [(1 - 2\bar{m}/R)^2/(1 - 2\bar{m}/R + R'^2)]^{1/2} \qquad (5)$$

which, in our particular case we can expand up its order v^4 (Aquilano, Castagnino and Neira, 1994):

$$d\tau/dt = (1 - 2\bar{m}/R - R'^2 - 2\bar{m}R'^2/R)^{1/2}. \qquad (6)$$

The shell has a constant proper mass and emits as much radiation as that absorbed from the central body. In other words, the radiation emitted to the exterior by this system is not produced at the expense of the matter present in the shell, but originates in the central body.

The Newtonian approximation of this problem will be reached when we have low velocities, $R' \ll 1$. Thus in this case, we have $A = B \approx 1$ and $m_0 \approx m$ (see Castagnino and Umerez, 1983), therefore the gravitational mass approaches the proper mass, which is consistent with the assumption that this approximation is a Newtonian one.

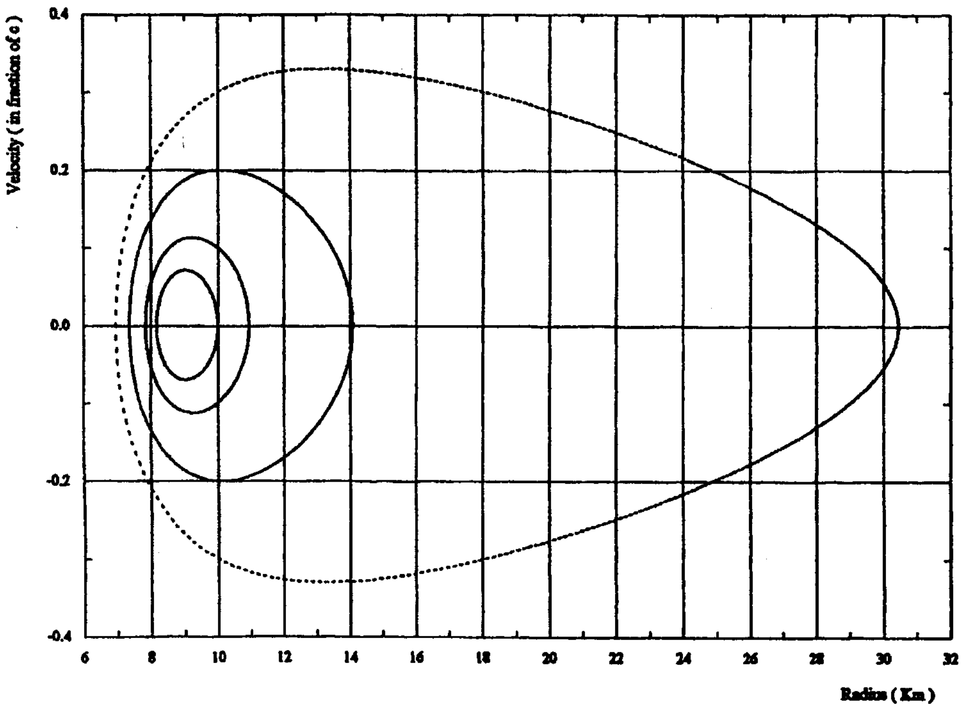

Figure 1 Phase diagram: velocity vs. radius for a neutron star of three solar masses and differents initial velocities. We can see the oscillations around the stable singular point.

3 COMPARISON WITH ASTRONOMICAL DATA

Therefore, the shell equation of motion will be

$$\begin{aligned} dv/dt &= -m/R^2 - 2\bar{m}^2/R^3 + (3m/R^2)R'^2 + (1 - 1/R - R'^2/R)^{3/2} \\ &\times (-m/2R^2 - 4\pi\sigma R^2 T^4/m) \end{aligned} \tag{7}$$

where we use the following astrophysical data for a central body (neutron star): $\bar{m} = 3M_\odot$ ($M_\odot$ = solar mass) according to Oppenheimer and Volkoff (see Oppenheimer and Volkoff, 1939), $R'_0 = 0.0c$ to $0.3c$ (c = light velocity), and $m = 0.002$, 0.02 and $0.2M_\odot$, with a temperature of 10^7 K, and the adiabatic cooling is neglected because the model is very simple, and we study the first parts of the curves.

We obtain stable oscillations for several values of the parameters (see Figure 1) and the most interesting result is that the oscillations have near of millisecond periods (see Figure 2). In all cases, the oscillations are a very simple mathematical calculus (a "toy model").

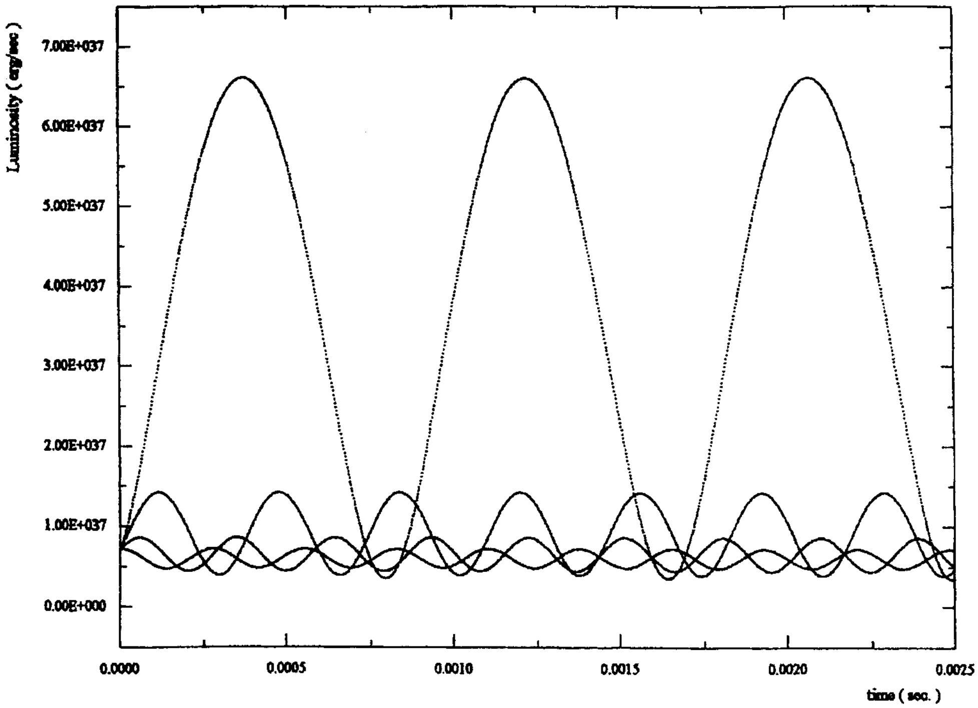

Figure 2 Luminosity vs. time, showing the luminosity pulsations.

4 CONCLUSION

In past work Castagnino and Umérez, 1983; Hamity and Gleiser, 1978; Hamity and Spinosa, 1984, it was found that the general relativistic effects will be very difficult to detect, because the central mass density is smaller, but now in bursters with neutron stars we have shown that it could be possible to detect a post-Newtonian effect using our model.

In this paper we obtain oscillations near to half a millisecond of time, a very important conclusion for this astrophysical event (see Benvenuto, Harvath and Vucetich, 1991).

Acknowledgements

This work has been carried out with the support of CONICET (Argentina) PiP 4410 and PEi 0126/97, and the Directorate General for Science, Research and Development of the European Communities, contract CI1*–CT94–0004.

References

Abramowicz, M. A. (1989) GRG Workshop on Relativistic Astrophysics, Preprint SISSA, 130A.

Aquilano, R., Castagnino, M., and Lara, L. (1994) *Gen. Rel. Grav.* **26**, 5.

Aquilano, R., Castagnino, M., and Neira, L. (1994) *Mod. Phys. Lett. A* **9**, No. 21, 1911.

Aquilano, R., Castagnino, M., Lara, L., and Neira, L. (1995) *Mod. Phys. Lett. A* **10**, No. 10, 799.

Benvenuto, O. G., Horvath, J. E., and Vucetich, H. (1991) *Mod. Phys.* **6**, No. 27, 4769.

Castagnino, M. and Umérez, N. (1983) *Gen. Rel. Grav.* **15**, 625.

Van den Heuvel, E. P. J. and Rappaport, S. A. (1992) *X-ray Binaries and Recycled Pulsars*, Kluwer Academic Publishers.

Hartle, J. (1973) In: W. Israel (ed.), *Relativity, Astrophysics and Cosmology*, Reidel, Amsterdam.

Hamity, V. and Gleiser, R. (1978) *Astrophys. Space Sci.* **58**, 353.

Hamity, V. and Spinosa, R. (1984) *Gen. Rel. Grav.* **16**, 9.

Lewin, W. and Clark, G. (1980) *Ann. N. Y. Acad. Sci.* **336**, 451.

Oppenheimer, J. R. and Volkoff, G. M. (1939) *Phys. Rev.* **55**, 374.

Shore, S. N., Livio, M., and Van den Heuvel, E. P. J. (1994) *Observations and Physical Processes in Binary Stars*, Springer–Verlag.

Weinberg, S. (1972) *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity*, Wiley, New York.