THE LUMINOSITY OSCILLATION OF X-RAY BURSTERS AND RECURRENT NOVAE

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Abstract. 'Thermo-mechanical' oscillations of a radiating spherically-symmetric shell containing a fermion gas (i.e., oscillations where only mechanical, thermodynamical, and eventually radiation phenomena are taken into account) are studied. With a reasonable choice of the three relevant parameters all other observational data are similar to the ones of X-ray bursters and recurrent novae.

Therefore, thermo-mechanical oscillations could play an important role in the oscillation spectrum of these astronomical objects.

1. Introduction

About the center of our Galaxy and in certain globular clusters we can observe the same peculiar astronomical object, that emits great quantities of energy, in the form of X-rays, in a few seconds, and then vanishes away, reaching its constant emission level, i.e., the level before the eruption, in a few seconds or minutes.

During the eruption, approximately $10^{39}$ ergs of energy are emitted, in the X-ray wavelength only, i.e., an energy equivalent to the one emitted by the Sun, in all wave-lengths, in one or two weeks.

Normally these objects are associated with binary stellar systems, where one of the components is a white dwarf or a very dense star, and the other one a normal star. Some matter, mostly hydrogen, is taken from the upper part of the atmosphere of the normal star (generally a giant star) by the powerful gravitation field of the white dwarf. When this hydrogen fall to this second star liberates a great part of its potential energy as a continuous X-ray emission.

When the hydrogen reaches the surface of the star it is accumulated in a very thin layer. The fusion of hydrogen nuclei, to form helium, originates a second layer behind the first one. When approximately $10^{21}$ g are accumulated (cf. Lewin and Clark, 1980) the density and the temperature became critical and the helium nuclei undergo a sudden thermonuclear fusion that yields carbon nuclei. This phenomenon can be observed from the Earth as a fulguration of X-rays; we call X-ray bursters to these objects.

In some cases the emission of X-radiation is more intense than in the case of the bursters and the duration of the bright X-ray source is about some days or month. In these cases we shall call the object an X-ray nova.

Usually the eruption is repeated periodically with quiet regular intervals. The periods are very different from an object to another. These periods range from some seconds to one months or years, as in the novae case.

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In this work we shall introduce a highly simplified model. In fact, the aim of this work is to show that purely 'thermo-mechanical' oscillations (i.e., oscillations where only mechanical, thermodynamical, and eventually phenomena are taken into account) could be an important ingredient to explain the luminosity oscillations of X-ray bursters and recurrent novae.

Thus we shall study a very elementary model with spherical-symmetry, white dwarf at the center, and an atmosphere of a fermion gas around it, enclosed by an external shell, with negligible thickness, where we concentrate all the inertial mass. This shell could be a real object in the novae, but in our model it is mainly a mathematical device, to make the computation feasible, as we shall see below. Anyhow, as we shall show, this extremely schematic model could explain, by itself, the oscillation period of several objects (cf. Table I). In our model the thermonuclear fusion is disregarded (perhaps its only role is to start the thermomechanical oscillations). Of course, we do not pretend that it is really so. We only want to stress, in this paper, that thermomechanical oscillation must be taken into account in a future complete model, where all the relevant phenomena would be considered. Then these kinds of oscillations will be probably only a component of the total oscillation spectrum.

The shell will undergo adiabatic oscillations, attracted by the intense gravitational central field, produced by the white dwarf, and pushed by the internal pressure and eventually the radiation emitted by the shell, which is in thermal equilibrium with the gas. We suppose that the gas evolution is adiabatic because, in general, the oscillation periods are smaller than the characteristics time of energy transfer.

We shall present a simple analytical solution of the model and show that the physical parameters fit with the ones of real objects.

2. The Shell Dynamics

To built our simplified model we shall consider that the shell is thermical equilibrium with the gas which undergoes an adiabatic evolution, as we have said. Besides, we shall suppose that the masses of the shell and the gas are constant of the motion, and that the gas density is uniform and equal to

$$\rho(R) = \frac{\lambda}{R^3},$$

(1) where \(R\) is the shell radius and \(\lambda\) a constant given by

$$\lambda = \frac{3}{4\pi} \, mg,$$

(2) with \(m_g\) the mass of the fermion gas. The pressure is

$$P = \alpha \rho^{5/3}.$$ 

(3) Different \(\alpha\) give different isotropic evolutions.