High-speed cylindrical collapse of two perfect fluids

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Abstract In this paper, the study of the gravitational collapse of cylindrically distributed two perfect fluid system has been carried out. It is assumed that the collapsing speeds of the two fluids are very large. We explore this condition by using the high-speed approximation scheme. There arise two cases, i.e., bounded and vanishing of the ratios of the pressures with densities of two fluids given by \( c_s, d_s \). It is shown that the high-speed approximation scheme breaks down by non-zero pressures \( p_1, p_2 \) when \( c_s, d_s \) are bounded below by some positive constants. The failure of the high-speed approximation scheme at some particular time of the gravitational collapse suggests the uncertainty on the evolution at and after this time. In the bounded case, the naked singularity formation seems to be impossible for the cylindrical two perfect fluids. For the vanishing case, if a linear equation of state is used, the high-speed collapse does not break down by the effects of the pressures and consequently a naked singularity forms. This work provides the generalisation of the results already given by Nakao and Morisawa (Prog Theor Phys 113:73, 2005) for the perfect fluid.

Keywords High-speed · Cylindrical collapse · Two perfect fluids

1 Introduction

One of the central issues in the general theory of relativity has always been the question of gravitational radiation. Historically, the first gravitational radiation problem
considered was the radiation from a spinning rod [2–4]. One of the important issues of gravitational radiation is the gravitational collapse. General relativity suggests that gravitational collapse of massive objects results in the formation of spacetime singularities in our universe [5–7]. The known physical laws break down very near to the spacetime singularity. At this stage, quantum theory of gravity is applied to describe the physical phenomena in the neighbourhood of the spacetime singularity. One of the important issues “whether the spacetime singularities, (far from the region where the gravitational collapse occurs) formed in our universe, can be seen by observer or not” has attracted many people.

Penrose [8] investigated this problem and suggested a cosmic censorship hypothesis. This hypothesis includes two versions, one is called strong version and other is called weak version. According to the strong version, a spacetime singularity formed by non-singular initial data is not visible from infinity while according to the weak version, a spacetime singularity formed by non-singular initial data is invisible for any observer [9]. The singularity claimed by the strong version is named as naked singularity, while the singularity claimed by the weak version is known as globally naked singularity. Nakamura et al. [10] conjectured that large spacetime curvatures move away to infinity in the form of gravitational radiation in the neighbourhood of globally naked singularities (if exist).

The spherically symmetric systems are considered to be very useful [11] to discuss the problem of naked singularity formation. These systems are simple and have well-defined physical significance. We shall take non-spherical perturbations to this system [12–16] to study the problem of gravitational radiation. We consider cylindrically symmetric system because there is a degree of gravitational radiation and the spacetime singularity formed in this system is naked [17,18]. There is a great literature [19–24] available on gravitational radiation through cylindrical gravitational collapse. Some numerical work on the gravitational radiation has also been done by different people [25–27].

Recently, Nakao and Morisawa [1] have discussed the gravitational collapse of a cylindrical thick shell composed of a perfect fluid to the case of non-vanishing pressure. Nakao and Morisawa [28] have also specialized this work for the complete dust case. These investigations have provided interesting results about the gravitational collapse. This paper has been addressed for the high-speed cylindrical collapse of the two perfect fluids. We use high-speed approximation scheme by considering perturbation analysis. For this purpose, the collapsing speeds of the two perfect fluids are assumed almost equal to the speed of light. Further, we take the deviation of the 4-velocities of the two fluids from null as a small perturbation. We investigate the effects of the pressures for the large collapsing velocities. It is verified that our results reduce to the perfect fluid case as obtained by Nakao and Morisawa [1].

The rest of the paper is outlined as follows. In Sect. 2, we give the basic structure of the spacetime with whole-cylinder symmetry [29]. Section 3 is devoted to discuss the high-speed approximation scheme for the two perfect fluids. In Sect. 4, we interpret the effects of pressures of the two fluids on the high-speed gravitational collapse. Finally, Sect. 5 contains summary and discussion.