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ORIGINAL ARTICLE

Plane symmetric gravitational collapse and linear equation of state

M. Sharif · Amal Majid

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Abstract This paper examines the gravitational collapse in plane symmetry with a perfect fluid using a linear equation of state $p = k\rho$. We find a class of collapse models satisfying the Einstein field equations and also the regularity as well as energy conditions. For a given initial data, the outcome of the collapse turns out to be a black membrane or a naked singularity depending upon the equation of state parameter. We conclude that this parameter plays a crucial role in determining the final fate of the collapse.

Keywords Gravitational collapse · Equation of state · Plane symmetry

1 Introduction

In general relativity, the end result of gravitational collapse of a massive star has always been an interesting issue for the researchers. Gravitational collapse occurs when the stability of a massive star is disturbed due to burning out of its nuclear fuel. In this process, gravity takes over and the star becomes vulnerable to collapse, which leads to a spacetime singularity (a region which contains geodesics that cannot be completed). Since all physical laws break down at singularity, astrophysics fails to explain any phenomenon at such a point.

To study the end state of collapse, Penrose (1969) presented a hypothesis called cosmic censorship hypothesis (CCH) which still lacks any mathematical proof. This hypothesis denies the existence of any naked singularity in the universe apart from the big bang singularity. It states that every singularity must be covered by an event horizon. A singularity is called a black hole if it is hidden, i.e., if it is covered by an event horizon. On the other hand, a singularity which can be observed is called a naked singularity.

Oppenheimer and Snyder (1939) were the pioneers who studied gravitational collapse of spherically symmetric dust models. They discussed the formation of an event horizon during the collapse that hides the singularity from view, i.e., a black hole appears as the final state of the collapse. Misner and Sharp (1964) extended this work to perfect fluid collapse. Ori and Piran (1987, 1988, 1990) studied self-similar perfect fluid spherically symmetric collapse with equation of state (EoS) $p = k\rho$ and found solutions which represent naked singularity as well as black hole for $0 < k \leq 0.4$. Joshi and Dwivedi (1992) explored this problem analytically and found solutions indicating naked singularity only.

Markovic and Shapiro (2000) explored the effects of positive cosmological constant on the rate of collapse. They concluded that the cosmological constant may decelerate the collapse but its role diminishes towards the end of the collapse. Lake (2000) studied spherically symmetric dust collapse with positive and negative cosmological constant. Sharif and Ahmad (2007a) discussed physical significance of apparent horizons for perfect fluid spherical collapse with positive cosmological constant. It was concluded that positive cosmological constant slows down the rate of collapse. Goswami and Joshi (2002, 2004a, 2004b) explored the role of initial data in the gravitational collapse of a massive star.

There are also some developments related to cylindrical collapse, which has improved our understanding about its dynamics (Bronnikov 1983; Bronnikov and Kovalchuk 1980, 1983, 1984; Hayward 2000; Oron 2002; Nakao and

M. Sharif (✉) · A. Majid
Department of Mathematics, University of the Punjab, Quaid-e-Azam Campus, Lahore 54590, Pakistan
e-mail: msharif.math@pu.edu.pk

A. Majid
e-mail: amalmajid89@gmail.com