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ORIGINAL ARTICLE

Isothermal plasma wave properties of the Schwarzschild de-Sitter black hole in a Veselago medium

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Abstract In this paper, we study wave properties of isothermal plasma for the Schwarzschild de-Sitter black hole in a Veselago medium. We use ADM $3+1$ formalism to formulate general relativistic magnetohydrodynamical (GRMHD) equations for the Schwarzschild de-Sitter spacetime in Rindler coordinates. Further, Fourier analysis of the linearly perturbed GRMHD equations for the rotating (non-magnetized and magnetized) background is taken whose determinant leads to a dispersion relation. We investigate wave properties by using graphical representation of the wave vector, the refractive index, change in refractive index, phase and group velocities. Also, the modes of wave dispersion are explored. The results indicate the existence of the Veselago medium.

Keywords $3+1$ formalism · SdS black hole · Veselago medium · GRMHD equations · Isothermal plasma · Dispersion relations

1 Introduction

Our solar system is filled with a wide range of celestial objects. Black hole is one of such objects, having so strong gravitational pull that no nearby matter or radiation, not even light can escape from its gravitational field. Astronomers are curious to extract real life examples of black hole. The presence of matter in the form of white dwarfs and neutron stars suggests the existence of stellar mass black holes. The accumulated evidence for the black hole existence is now very captivating. It is believed that collapse of a massive star under its own gravity leads to the formation of black hole (Das 2004). Plasmas are abundant in nature, almost found everywhere in an interstellar medium. It is a distinct state of matter with free electric charge carriers which behave collectively and respond strongly to electromagnetic fields (Raine and Thomas 2005). Black hole (in its surroundings) attracts plasma towards the event horizon due to its strong gravitational pull. The plasma forms an accretion disk due to interaction of plasma field with black hole gravity.

The theory of general relativistic magnetohydrodynamics is the most reliable discipline to examine the dynamics of magnetized plasma and effects of black hole gravity. The de-Sitter spacetime is a vacuum solution of the Einstein field equations including a positive cosmological constant (Rindler 2001). The Schwarzschild de-Sitter (SdS) metric describes a black hole expressing a patch of the de-Sitter spacetime. Since the SdS black hole is non-rotating, so plasma in magnetosphere moves only along the radial direction. According to the recent cosmological and astrophysical observations, our universe is accelerating rather than decelerating and inclusion of positive cosmological constant reveals the expanding universe (Reiss et al. 1998; Bahcall et al. 1999; Perlmutter et al. 1997). That is why our universe approaches to de-Sitter universe in future. This motivates the study of plasma waves in de-Sitter spacetime.

Petterson (1974) investigated the strong gravitational field close to the surface of compact objects for the Schwarzschild black hole. Narayan (2005) suggested that compact objects having mass three times the solar mass can be identified as black hole candidates. Plasma present in magnetosphere is perturbed by gravity of black hole. Zerilli (1970a, 1970b, 1970c) used linear perturbation to explore

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