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Locally Rotationally Symmetric Class II Space-time Perturbations by Electromagnetic, Gravitational, and Plasma Effects

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Abstract

We look at first-order perturbations on homogeneous and hypersurface orthogonal LRS class II spacetimes that are gravitational, electromagnetic, and plasma-related. The examined backgrounds' anisotropy allows us to add a nonzero magnetic field up to the zeroth order. Due to this inclusion, we discover intriguing interactions between the electromagnetic and gravitational variables in the perturbations that are already of the first order. The Ricci identities, Bianchi identities, Maxwell's equations, Einstein's field equations, particle conservation, and an energy-momentum conservation method for the plasma components are all used to get the equations regulating these perturbations. The analyzed quantities and equations are decomposed with regard to the preferred directions on a 1 + 1 + 2 covariant split of space-time. The system is then reduced to a set of ordinary differential equations in time and certain constraints by linearizing the decomposed equations around an LRS background, carrying out a harmonic decomposition, and imposing the cold Magneto Hydrodynamic (MHD) limit with a limited electrical resistivity. The system decouples into two closed and independent subsectors once some harmonic coefficients are solved for in terms of the others. We then examine various methods for producing magnetic field perturbations by numerical calculations, which exhibit certain characteristics like those of earlier research utilising Friedmann-Lemaître-Robertson-Walker (FLRW) backgrounds. Furthermore, due to interference between gravitational waves and plasmonic modes in the short wavelength limit, beat-like patterns are seen.

Keywords: Electromagnetic; Stewart-walker lemma; Perturbations

Introduction

Most astronomical data on a cosmic scale may be described by the standard model of cosmology, which is based on the homogeneous and isotropic Friedmann-Lemaître-Robertson-Walker (FLRW) space times. Some riddles are yet unanswered, though. One of these puzzles has to do with the formation of the massive magnetic fields that can be seen at the scale of galaxies and galaxy clusters. Although several different techniques for producing and increasing these magnetic fields have been suggested, the subject has reportedly generated some controversy. In the middle of the debate, a widely accepted theory suggests that the magnetic fields were initially formed extremely early in the universe's existence. Then it is proposed that later galactic dynamo processes may have led to the amplification of these primordial seed fields [1]. The suggested procedures for producing the seeds could be insufficiently strong

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or, in some situations, uncomfortable near to it. Along with the strength need, there are other strict limitations on the seeds' coherence length, thereby restricting the potential. If there were a technique for amplifying the seeds after they were generated but before the galactic dynamo began, it would be one way to get over the strict constraints and enlarge the pool of potential candidates. This type of potential processes has already been suggested in several cases. Examples include gravitational wave interaction-based processes and velocity changes in the cosmic plasma. The possibility of a mechanism based on the dynamics of a self-gravitating plasma and classical general relativity is still intriguing, as it would not explicitly depend on any additional exotic physics, even though some of the mechanisms for amplifying the seed fields have been suggested to be too weak. The FLRW space times appear to have served as the zeroth order backgrounds for the majority of the perturbative investigations of self-gravitating plasmas in cosmic scenarios. However, since the background magnetic field would otherwise determine a preferred spatial direction, it is practically impossible to have a non-zero magnetic field 3-vector due to the isotropy of the FLRW space times. Numerous methods have been employed to get around this issue [2]. The weak-field approximation is a method that works by such that the magnetic field shouldn't change the underlying geometry and, in a sense, shouldn't go against the background space-time's isotropy. However, this method encounters some formal issues since the carefully investigated produced magnetic field perturbations are not gauge invariant in the strictest meaning of the Stewart-Walker lemma. Second-order techniques have also been utilised to more effectively minimise interference from degrees of freedom linked to gauge. Instead of being present in the background, the magnetic field is then introduced as a first-order perturbation. Since the electromagnetic fields' by-products and other first-order variables are involved, the interaction between gravitational effects and electromagnetic fields subsequently becomes a second-order quantity. But some attention is still required. Assuming that the background magnetic field is sufficiently faint to not affect the energy-momentum tensor, which includes squares of the magnetic field. Using this supposition, Since the produced magnetic field is not gauge invariant, it is not absolutely valid to construct explicit formulations for it by integrating the second-order findings for the gauge-invariant variables. Therefore, in order to infer anything about the produced magnetic fields, one is limited to interpreting gauge-invariant numbers. The last strategy, which will be applied in this case, is to abandon the FLRW space times in favour of an anisotropic backdrop model. The isotropy issue is thereby resolved, and a non-zero magnetic field of the zeroth order is permitted without seriously impairing the background geometry. Therefore, the goal of this study is to determine if using a specific class of anisotropic backgrounds will result in intriguing gauge-invariant interactions in the perturbations that are already of the first order as opposed to FLRW space times [3].

Conclusion

This study examines linear electromagnetic, gravitational, and plasma-related perturbations on homogeneous and orthogonal LRS class II space times with a non-zero background magnetic field. We have constructed a closed set of equations regulating the harmonic coefficients of the perturbations using a 1+1+2 covariant formalism, followed by the cold MHD limit. As a result of our analysis of the system, we have seen that initial perturbations in tentorial quantities connected to gravitational waves lead to the formation of magnetic field disturbances. Then, in line with earlier studies utilising FLRW backdrops, it was shown that the produced fields depended quadratically on the characteristic length scale in the super horizon limit. However, the parallels were less obvious at the sub horizon limit.

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