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Analysis of Compact Stellar Objects: Complexity and Parametric Effects of the Equation of State

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Abstract. This paper considers how the Chaplygin equation of state (EoS) parameters affect the complexity of anisotropic compact stars. By solving the Einstein field equations, the model uses the Schwarzschild metric for the external region and applies boundary conditions at the stellar surface. The research incorporates observational data for validation through graphical and tabular analysis. The results indicate that although the complexity factor is not directly linked to specific EoS parameters, it increases with their values. While these parameters influence internal properties like anisotropy and density inhomogeneity, the overall complexity exhibits a consistent growth pattern.

Keywords: compact star, chaplygin EoS, anisotropy, Schwarzschild metric, complexity

Introduction. The theoretical modeling of compact stellar objects [1, 2] within the framework of General Relativity (GR) is essential for understanding their structure, stability, and evolution. These models require solving Einstein's field equations in conjunction with a suitable equation of state (EoS) to describe the matter distribution within the star. Anisotropic pressures, where radial and tangential pressures differ, play a crucial role in compact star models and arise due to factors such as high densities, exotic matter, or strong magnetic fields [3–9].

The Chaplygin EoS, initially from cosmology, is useful in compact star studies due to its non-linear nature, enabling smooth thermodynamic transitions. It supports exploring unconventional matter distributions and produces stellar models consistent with astrophysical observations.

The concept of complexity in self-gravitating systems, as introduced by Herrera [10], extends traditional uniformity concepts by incorporating anisotropy and density inhomogeneity into a complexity factor. This framework has been instrumental in deriving exact solutions to Einstein's equations and studying the internal composition of compact stars.

This study aims to examine the influence of chaplygin EoS parameters on the internal structure and complexity of compact stars. By analyzing the roles of anisotropy and inhomogeneity in complexity evolution using pulsar data, we establish a link between theoretical predictions and observational insights, providing deeper understanding of dense astrophysical objects.

Methods and materials; results. To construct a physically consistent stellar model, we assume a metric potential of the form:

$$e^{\lambda(r)} = \frac{1-2aCr^2}{1+aCr^2},$$

which has been successfully used in previous compact star studies under isotropic conditions and extended for anisotropic matter distributions.

For the matter distribution, we adopt a chaplygin equation of state:

$$p_r = \alpha \rho - \frac{\beta}{\rho},$$

where α and β are constants characterizing the EoS.

The Einstein field equations are solved for an anisotropic star to obtain the density, radial pressure, and tangential pressure. The interior solution is matched with the Schwarzschild exterior at the boundary, ensuring a smooth transition between the star's interior and exterior spacetime.

The constructed model is physically viable, regular, and free from singularities. It satisfies energy conditions, ensuring positive and physically meaningful density and pressure throughout the realistic star [11].

A key focus of this study is the complexity factor Y_{TF} . Our results reveal that for a fixed value of α , the complexity factor increases throughout the stellar interior as β grows. A similar trend is observed when α increases while β remains constant. These findings suggest that both EoS parameters contribute in a comparable manner to the complexity evolution in compact stars.

Conclusion. This study shows that while the complexity factor Y_{TF} is not directly dependent on individual chaplygin EoS parameters, it increases with either parameter. Variations in α and β affect anisotropy and inhomogeneity but do not alter the overall complexity trend. The findings establish a clear link between the chaplygin EoS parameters and stellar complexity, highlighting its potential as an indicator of the equation of state and offering deeper insights into the internal structure of compact stars.

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