# The Study of Voids in the Universe


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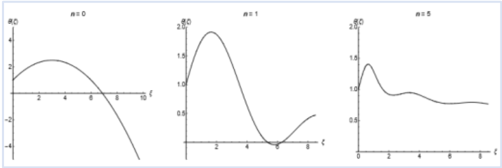
## Abstract

Astronomical observations reveal the existence of nearly empty space populated by small amounts of cosmic structures. The latter are often designated as voids in the Universe, exactly because they are vast areas that contain very few or no galaxies, in comparison to commonly observed dense structures. Voids are comprised mostly of invisible matter detected through gravitational effects, possibly being influenced by dark energy. In this poster, we report on a study of the conditions for the existence of voids, and we claim that the presence of a cosmological constant plays a significant role in the process of avoiding the collapse of matter into the empty region. We adopt a Newtonian approach, first, and then a relativistic approach to assess the role of a cosmological constant in providing appropriate conditions for the stability of voids. By the same token we argue that observations of the parameters characterizing voids may conversely give information about the cosmological constant.


## Generalized Lane-Emden Equation

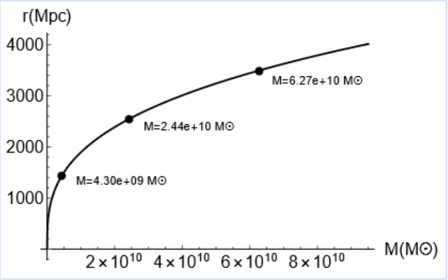
The Lane-Emden equation yields the density profile for regions of space where matter is described by the polytropic equation of state $p = K\rho^{1+1/n}$ applies. By generalizing the equation for a case where the cosmological constant is present with the purpose of explaining why the cavity doesn't collapse, we found that there is an initial increase in value of the density profile (meaning a positive pressure gradient) – when the Λ-term dominates – and then at larger values of r, when matter dominates, both the density profile and the pressure gradient recovers the usual negative character.



***Graph I**: Solutions to the generalized Lane-Emden equation for polytropic index n=0, n=1 and n=5, respectively.*

## N-Body Simulations Case Study

We examined void density profiles that are consistent with results from numerical N-body simulations, integrating to obtain three masses correspondent to three different radii: $\{R_{void}, 2R_{void}, 3\,R_{void}\}$.




***Graph II**: Threshold radius as a function of mass in a static equilibrium configuration.*

By plotting the points along with the function that relates the threshold radius of the void with the mass in a static equilibrium configuration, we find that the cosmological constant can sustain voids with radii significantly larger than those known for current cosmic cavities and form another Newtonian argument for the presence of Λ in cosmic voids.

## Relativistic Approach

It becomes important to switch from a Newtonian approach to a General Relativity model.

- This implies the consideration of a generalized Tolman-Oppenheimer-Volkov (TOV) equation, which accounts for the effects of the cosmological constant.

$$\frac{dp}{dr} = -\frac{\rho + p}{1 - \frac{2GM(r)}{r} - \frac{\Lambda}{3}r^2}\left(\frac{M(r)}{r^2} + 4\pi p r - \frac{\Lambda}{3G}r\right)$$

- We shall also consider an LTB model in which the spherical cavity of the cosmic void is filled with the cosmological constant, surrounded by Λ and cold dark matter (CDM).

Here we assume that either the cosmological constant is of different value outside the cavity or evolving due to an exchange of energy with the CDM.

## Work In Progress

The Tolman-Oppenheimer-Volkov (TOV) equation allows for a generalization of the Lane-Emden equation that applies to stars in a relativistic equilibrium configuration. We intend to follow the same procedure utilized in the Newtonian approach to this case, generalizing the TOV equation to include Λ with the purpose of studying void stability in this framework. With this equation, we should derive the relativistic generalized Lane-Emden equation and plot the solutions.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