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Tolman-Oppenheimer-Volkoff conditions beyond spherical symmetry

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In most cases the TOV equation appears as the relativistic counterpart of the classical condition for hydrostatic equilibrium, and characterises the static equilibrium of bound, spherical distributions of matter such as stars. In the present work we aim at showing that a generalised TOV equation also characterises the equilibrium of models endowed with other symmetries besides spherical. We resort to the dual null formalism applied to spacetimes with two dimensional spherical, planar and hyperbolic symmetries, and consider a perfect fluid as the source. Static configurations assume the existence of a time-like Killing vector field orthogonal to the surfaces of symmetry, and homogeneous dynamical solutions arise when the Killing field is space-like. In order to treat equally all the aforementioned cases, we discuss the definition of a quasi-local energy for the spacetimes with planar and hyperbolic foliations, since the Hawking–Hayward definition only applies to compact foliations. This procedure enables us to translate our geometrical formalism to the fluid dynamics language in a unified way, to find the generalised TOV equation, for the three cases when the solution is static, and to obtain the evolution equation, for the homogeneous spacetime cases. Remarkably, we show that the static solutions which are not spherically symmetric violate the weak energy condition (WEC). We also show that the counterpart of the TOV equation $\rho + P = 0$, defines a cosmological constant-type behaviour, both in the hyperbolic and spherical cases. This implies a violation of the strong energy condition in both cases, added to the above mentioned violation of the weak energy condition in the hyperbolic case. We illustrate our unified treatment obtaining analogs of Schwarzschild interior solution, for an incompressible fluid $\rho = \rho\_0$ constant.

Primary authors: Prof. MIMOSO, José Pedro (IA - Instituto de Astrofísica e Ciencias do Espaço & Faculty of Science, University of Lisbon); Dr MACIEL, Alan (Universidade Federal do ABC, S. Paulo. Brasil); Dr LE DELLIOU, Morgan (Institute of Theoretical Physics, School of Physical Science and Technology, Lanzhou University, China)

Presenter: Prof. MIMOSO, José Pedro (IA - Instituto de Astrofísica e Ciencias do Espaço & Faculty of Science, University of Lisbon)

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