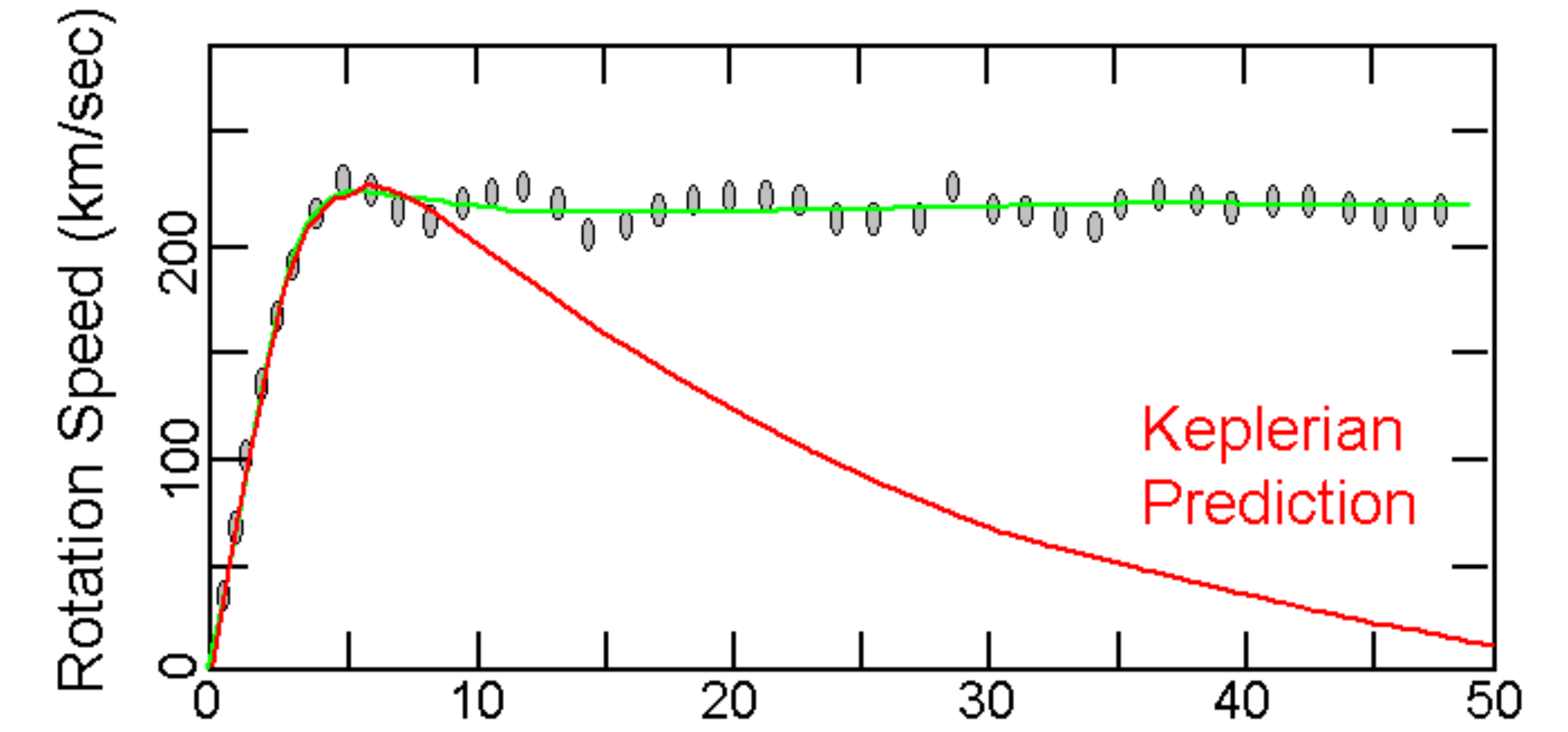
MODELING DARK MATTER HALOS WITH NON-LINEAR FIELD THEORIES

Dark matter is one of the most important open problems in Physics. It does not interact with electromagnetic force and, therefore, it cannot be directly seen. However, its gravitational effects are essential to explain the structure formation and dynamics of galaxies. To assume dark matter existence is necessary, for instance, to particularly explain the spiral galaxies rotation curves. While classical newtonian gravity theory requires that the orbital circular velocity X distance to galactic center curve after attaining its maximum decays as one moves away from the galactic center, observations show that the velocity remains approximately constant in this interval.



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There is a plethora of dark matter particles candidates: axions, sterile neutrinos, WIMPS (weakly interactive massive particles)... Among these candidates one can quote the Bose-Einstein Condensate. In such a model, the nature of dark matter is completely determined by a fundamental scalar field endowed with a scalar field potential.

The main goal of this work is to show an analytical approach that can be used in general to study Bose-Einstein Condensate dark matter. Our aim is to investigate possible galactic dark matter models based on the nonlinear scalar field theories coupled to the gravity sector.

$$\mathcal{S} = \int dx^4 \sqrt{-g}\left[\frac{R}{2\kappa} + \frac{1}{2} g^{\mu\nu}\partial_\mu \psi \partial_\nu \psi^* - V(\psi\psi^*)\right] \qquad (1)$$

The Bose-Einstein condensate is represented by the field ψ in (1).

$$\psi(r,t) = \phi(r,t) + i\chi(r,t) \qquad (2)$$

The scalar field is divided into a real and an imaginary part.

$$\mathcal{S} = \int dx^4 \sqrt{-g}\left[\frac{R}{2\kappa} + \frac{1}{2} g^{\mu\nu}(\partial_\mu \phi \partial_\nu \phi + \partial_\mu \chi \partial_\nu \chi) - V(\phi,\chi)\right] \qquad (3)$$

Effectively one has a two scalar field model.

$$\alpha' + \beta' = \kappa(\rho + p_{\rm r}) r e^{\beta} \qquad (4)$$

$$\beta' = \kappa \rho r e^{\beta} - \frac{1}{r}(e^{\beta} - 1) \qquad (5)$$

$$e^{\beta-\alpha}\ddot{\phi} - \phi'' - \left(\frac{\alpha' - \beta'}{2} + \frac{2}{r}\right)\phi' + e^{\beta} V_{\phi} = 0 \qquad (6)$$

$$e^{\beta-\alpha}\ddot{\chi} - \chi'' - \left(\frac{\alpha' - \beta'}{2} + \frac{2}{r}\right)\chi' + e^{\beta} V_{\chi} = 0 \qquad (7)$$

By varying (3) with respect to the metric and with respect to the scalar field, for a spherically symmetric metric and anisotropic energy momentum tensor, one obtains (4)-(7).

For a given potential, the solutions for the field are

$$\chi(r) = -\frac{2}{\left(\sqrt{c_0^2 - 4}\right)\cosh[2\mu(r - r_0)] - c_0} \qquad (8)$$

$$\phi(r) = -\frac{\left(\sqrt{c_0^2 - 4}\right)\sinh[2\mu(r - r_0)]}{\left(\sqrt{c_0^2 - 4}\right)\cosh[2\mu(r - r_0)] - c_0} \qquad (9)$$

- The profiles of the rotation curves for this model are shown in the following figures, in which the blue solid lines represent our solutions while the orange dashed lines are analytical fit to observational data. The difference between the top and bottom panels is merely a change in the values of the free parameters of the model.
- Our approach yields a good fit for the analytical observational curve even for larger values of r.