BOSE-EINSTEIN CONDENSATE DARK MATTER MODEL TESTED BY GALACTIC ROTATION CURVES

MAREK DWORNIK*, ZOLTÁN KERESZTES and LÁSZLÓ Á. GERGELY

Departments of Theoretical and Experimental Physics, University of Szeged, Szeged, 6720 Dóm tér 9., Hungary

**E-mail: marek@titan.physx.u-szeged.hu*

Rotation curves of spiral galaxies are fundamental tools in the study of dark matter. Here we test the Bose-Einstein condensate (BEC) dark matter model against rotation curve data of High and Low Surface Brightness (HSB and LSB) galaxies, respectively. When the rotational velocities increase over the whole observed range, the fit of the BEC model is similar to the one of the Navarro-Frenk-White (NFW) dark matter model. When however the rotation curves exhibit long flat regions, the NFW profiles provide a slightly better fit.

Keywords: Dark matter; Galactic rotation curve.

1. Introduction

The observation of galactic rotational curves show that the amount of luminous matter does not suffice to keep the curves flat.[1] Numerical N-body simulations in the framework of the ΛCDM model predict a density profile (Navarro-Frenk-White) with a central cusp.[2] However on the observational side, rotation curves show a shallower density distribution.

It has been proposed that galactic dark matter halos could be Bose-Einstein Condensates (BEC) in Ref. 3,4. In the BEC model, light bosons are in the same quantum ground state, yielding a repulsive interaction among them. This prevents the formation of a cuspy central density and predicts a nearly constant density core, in better agreement with the observations.

Here we confront the galactic rotation curves of HSB and LSB galaxies with both the BEC and the NFW model.

2. Dark matter models

2.1. *Bose-Einstein Condensate*

The mass density distribution of dark matter BEC is[4]

$$\rho_{DM}(r) = \rho_{DM}^{(c)} \frac{\sin kr}{kr} \ , \tag{1}$$

where $\rho_{DM}^{(c)}$ is the central density of the condensate; $\rho_{DM}^{(c)} = \rho_{DM}(0)$. The size R_{DM} of the dark matter BEC halo is defined as $\rho(R_{DM}) = 0$, giving $k = \pi/R_{DM}$.

The mass profile of the galactic halo, defined as $M_{BEC}(r) = 4\pi \int_0^r \rho_{DM}(r) r^2 dr$, is $M_{BEC}(r) = \frac{4\pi\rho_{DM}^{(c)}}{k^2} r \left(\frac{\sin kr}{kr} - \cos kr\right)$. The velocity profile is obtained as

$$v_{DM}^2(r) = \frac{4\pi G \rho_{DM}^{(c)}}{k^2} \left(\frac{\sin kr}{kr} - \cos kr\right), \tag{2}$$

where G is the gravitational constant.

2.2. *The Navarro-Frenk-White dark matter profile*

N-body simulations performed in the framework of the ΛCDM model give the mass density profile[2]

$$\rho(r) = \frac{\rho_s}{(r/r_s)\,(1 + r/r_s)^2}\ , \tag{3}$$

where ρ_s and r_s are the characteristic density and scale radius, respectively.

The mass within a sphere with radius $r = yr_s$ is then given by

$$M_{NFW}(r) = 4\pi\rho_s r_s^3 \left[\ln(1+y) - \frac{y}{1+y}\right] \tag{4}$$

where y is a dimensionless radial coordinate. The rotational velocity arises as

$$v_{NFW}^2(r) = \frac{GM_{NFW}(r)}{r}. \tag{5}$$

3. The baryonic model

In the case of LSB galaxies, the baryonic component consists of a thin exponential disk with the circular velocity profile[5]

$$v_d^2(x) = \frac{GM_D^{HSB}}{2h^{HSB}} x^2 (I_0 K_0 - I_1 K_1), \tag{6}$$

where $x = r/h^{HSB}$. I_n and K_n are the modified Bessel functions calculated at $x/2$. Finally M_D^{HSB} and h^{HSB} are the total mass and the length scale of the disk, respectively. In a HSB galaxy, beside the disk component there is a spherically symmetric bulge. The rotational velocity distribution of the bulge is

$$v_b^2(r) = \sigma \frac{G\mathcal{N}(D)}{rF_\odot} 2\pi \int_0^r I_b(r) r dr, \tag{7}$$

where $F_\odot\,(D)$ is the apparent flux density of the Sun at a distance D, σ is the mass-to-light ratio of the bulge and $I_b(r)$ is the Sérsic function.[6] Finally $\mathcal{N}(D) = 4.4684 \times 10^{-35}\,(D/1\ \mathrm{Mpc})^{-2}\ \mathrm{m}^{-2}\ \mathrm{arcsec}^2$.

4. Confronting the model with rotation curve data

We tested the validity of the BEC model by fitting the rotation curves of 2 HSB galaxies[7] and 2 LSB galaxies[8] with the sum of the predicted velocity profiles (2), (6) and (7). The results are compared with the sum of (6), (7) and (5).

We determined the best-fit parameters with a χ^2 minimization technique for both the BEC+baryonic and NFW+baryonic models. The fitted curves are shown on Figs. 1 and 2. For the ESO 322G77 (HSB) and DDO 189 (LSB) galaxies, where the rotational velocities increase over the whole observed region, the quality of the

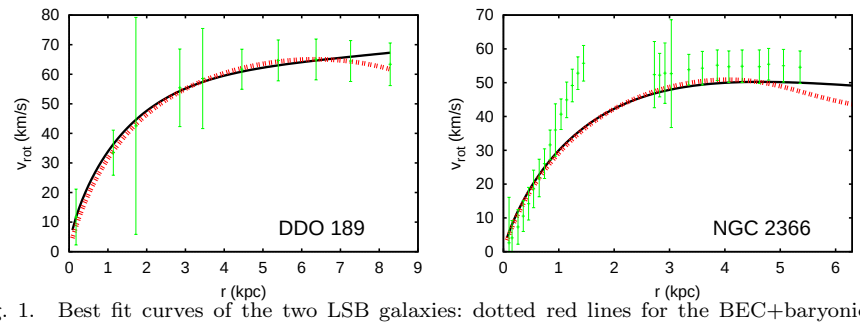

Fig. 1. Best fit curves of the two LSB galaxies: dotted red lines for the BEC+baryonic, solid black lines for the NFW+baryonic model. For the DDO 189 galaxy both models give comparable fits, while in the case of NGC 2366 galaxy, the NFW model gives a slightly better fit.

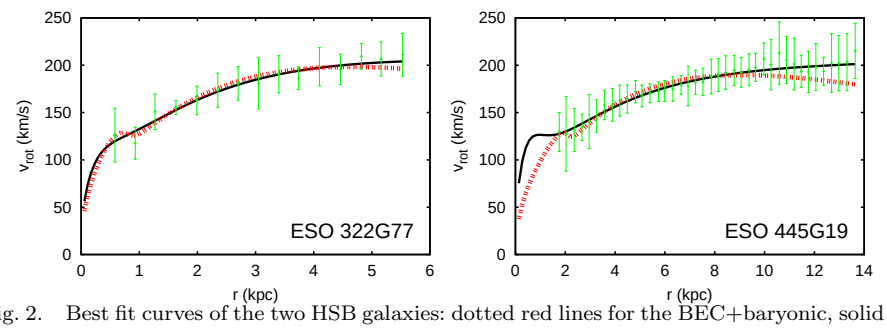

Fig. 2. Best fit curves of the two HSB galaxies: dotted red lines for the BEC+baryonic, solid black lines for the NFW+baryonic model. For the ESO 445G19 galaxy both models give comparable fits, while for the ESO 445G19 galaxy, the NFW model gives a slightly better fit.

fits were comparable for the two models. Similar results were obtained in Ref. 9 for the NGC 3274 (LSB) galaxy. However in the case of the ESO445G19 (HSB) and NGC2366 galaxies (LSB), the fits of the NFW model were slightly better.

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