Galactic Dynamics in the Era of Large Surveys
Proceedings IAU Symposium No. 353, 2019
M. Valluri & J. A. Sellwood, eds.

doi:10.1017/S1743921319008810

Evolution of disk galaxies in MOdified Gravity (MOG)

Neda Ghafourian and Mahmood Roshan

Department of Physics, Faculty of Science, Ferdowsi University of Mashhad,
P.O. Box 1436, Mashhad, Iran
emails: n.ghafourian@mail.um.ac.ir, mroshan@um.ac.ir

Abstract. Evolution and the formation of bars in the galactic disks is studied in the context of Modified Gravity (MOG) by using N-body simulations. It is found that changing the value of free parameters of the model can effectively alter the strength of the bar and disk's stability.

Keywords. galaxies: evolution, galaxies: structure, methods: n-body simulations

1. MOdified Gravity (MOG)

MOG is a Scalar-Tensor-Vector model of Gravity in which the modification of action is achieved by introducing two extra fields (Moffat 2006). In the weak field limit, the potential is presented as

$$\Phi(r) = -\frac{GM}{r}\left(1 + \alpha - \alpha e^{-\mu_0 r}\right) \tag{1.1}$$

where α and μ_0 are the model's free parameters. The mean value of these parameters are presented as $\alpha = 8.89 \pm 0.34$ and $\mu_0 = 0.042 \pm 0.004\ kpc^{-1}$ by Moffat & Rahvar (2013). However, It has been shown that for the results to be consistent with observations, it is necessary for the parameters to vary in different environments (Haghi & Amiri 2016; Green & Moffat 2019). In our main simulations, we have adopted the mean values ($\alpha = 8.89$, $\mu = 0.042\ kpc^{-1}$), although we show that more stable disks are resulted from higher values of these parameters.

2. Numerical Method and Bar Formation in MOG

The comparison between the results of MOG to a bare Newtonian model, is performed by employing an exponential disk of particles. Our code is based on Aarseth's Nbody2 Fortran code, which uses a particle-particle method. Accordingly, implementing a high number of particles would not be affordable. Therefore, we have restricted the simulations to $2-10$k particles. However, many tests were performed to ensure the main results are unaffected by particle noise. Fig. 1(left) demonstrates the effect of MOG in stabilizing the disk against bar formation. In contrast to the Newtonian model, the formation of bar in MOG is slower and the final bar strength, which is calculated from Fourier $m = 2$ mode, is lower. More details and discussions on the disk's evolution could be found in Ghafourian & Roshan (2017).

3. Effect of the Free Parameters on the Evolution

Evolution of the galactic disk and the strength of the constructed bars are crucially influenced by the value of the model's free parameters α and μ (the scaled value of μ_0 in eq(1.1)). Higher values of these parameters lead to more stable disks and weaker bars. Two extreme cases and the resulted bar strength is demonstrated in Fig. 1(right).

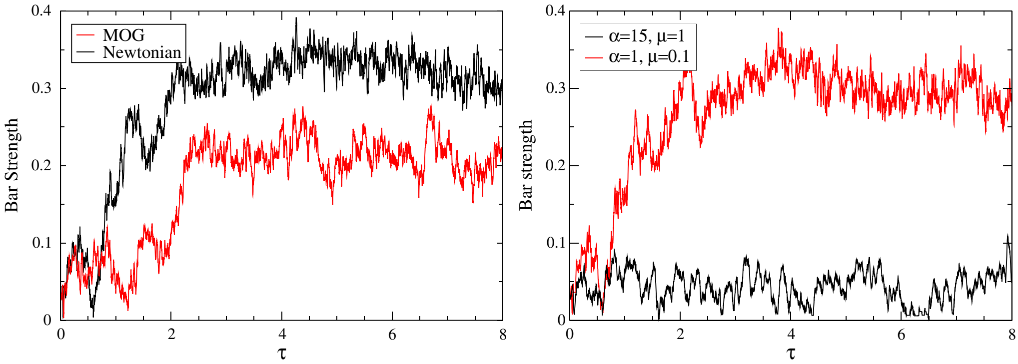

Figure 1. Bar formation under the effect of MOG in comparison to the bare Newtonian model(left), and the effect of altering model's free parameters on bar formation(right). The model with low values of α and μ results in bar strength comparable to bare Newtonian model.

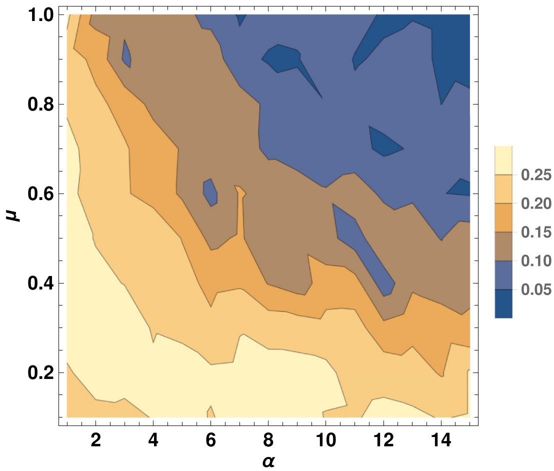

Figure 2. Effect of free parameters on the bar strength.

This effect is illustrated in more details in the contour plot of Fig. 2, where the mean value of bar strength is displayed for simulations with different values of α and μ (150 points/simulations). This behavior might provide a possible explanation for unbarred disk galaxies. However, to have a realistic view, it is necessary for the free parameters of the model to be compatible with observations.

The results of this code has been re-derived by high-resolution simulations of GALAXY code (Roshan 2018). The package is provided online by J. A. Sellwood (Sellwood 2014).

This work is supported by Ferdowsi University of Mashhad under Grant No 41395 (22/04/1395).

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