Escape from the MONDian Galaxies

XuFen Wu, Garry W. Angus, (SUPA, U. of St Andrews,UK), Olivier Tiret (Paris Obs., Fr.),
B. Famaey (UL, Brussels), G. Gentile (U. of New Mexico), F. Combes,
HongSheng Zhao (SUPA, U. of St Andrews), A. Robin (Obs. Besançon, Fr.)

Abstract

In MOdified Newtonian Dynamics (MOND) the internal potential well of a galaxy is made shallower if considering the acceleration of the center of mass of the galaxy towards neighbouring galaxies. We numerically solve the modified Poisson equation of MOND, and show that the external acceleration of the Milky Way is consistent with the RAVE-observed 550 km/s escape speed for the solar neighbourhood stars. Moreover, we predict in galaxy clusters Low Surface Brightness (LSB) galaxy members are destroyed because of very shallow potential wells of these fast-accelerating satellites.

Introduction

Modified Newtonian Dynamics (MOND) is an alternative theory to Cold Dark Matter. The basic of MOND is that when gravity acceleration $a << a_0=1.2\times10^{-10}\ m/s^2$, acceleration a has a relation of $a^2/a_0 = g_N$, where g_N is Newtonian acceleration. This simply makes the rotation curves of galaxies become flat at large radius and fits the Tully-Fisher relation without the assumption of Cold Dark Matter (Milgrom 1983).

In isolated systems in MOND, $\Phi(r) \sim (GM/a_0)^{1/2}\log(r)$. No stars can escape from such systems. However, even for field galaxies, there is still an external gravity field about $0.01a_0 \sim 0.03a_0$ (Famaey et al. 2007) which comes from inhomogeneity of larger scale structure. Galaxies in clusters of galaxies are affected by external field ranging from $0.01a_0$ to $3a_0$ (Pointecouteau et al. 2005). The External Field Effect (EFE) enables stars escape even in MOND.

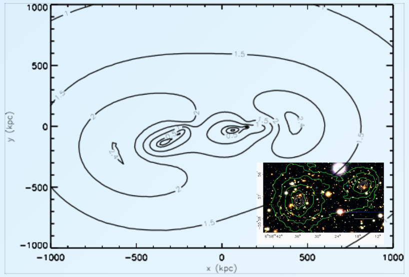

Fig.1 Gravity contours of 'Bullet Cluster'-cluster 1E 0657-558, in unit of a_0. Galaxies in central part of such galaxy clusters have a very strong external field . On the right-bottom is the optical image from the Magellan images.

Computing the Escape Speed

In MOND, consider a linear potential $-g_{ext}Y$ along the Y-direction, the Poisson equation in external is

$$\nabla\cdot[\mu(x)\nabla\Phi] = -4\pi G\rho, \qquad x \equiv |-\nabla\Phi|/a_0 = |\underline{g}_{int} + \underline{g}_{ext}|/a_0$$

At large radii from the center of free–falling system, we have $|g_{int}| << |g_{ext}|$, hence $\mu(x) \rightarrow \mu_e \equiv \mu(|g_{ext}|/a_0)=constant$, the solution at large radii goes to

$$\Phi^{\infty}_{int}(X,Y,Z) = -\frac{GM_{int}}{\mu_e\sqrt{(1+\Delta)(X^2+Z^2)+Y^2}}, \qquad \Delta = [d\ln\mu / d\ln x]_{x=|g_{ext}|/a_0}$$

Hence the internal potential Φ_{int} is finite, and approaches zero at large radii. The escape velocity at any location r is then defined as

$$v_{esc}(r) = \sqrt{-2\Phi_{int}(r)}$$

We numerically solve the Poisson Equation with simple μ function $\mu = x/(1+x)$ (Fameay & Binney 2005).

Escape from High Surface Brightness Galaxies

We use the Besançon Milky Way Model for the luminous matter density distribution, and in MOND frame instead of Cold Dark Matter halo component (Fig. 2a). We compute both rotation curves and escape speeds of the Milky Way when the galaxy is embedded different EF backgrounds. The weak EF is for a field galaxy and the strong EF is for Milky Way-like galaxies in galaxies clusters (Fig. 2b).

Note that galaxy become strong non-axisymmetric at large distances due to the strong External Field.

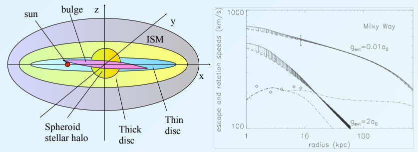

Fig.2 (a) Besançon Milky Way Model (Robin et al. 2006). The x-direction is sun-galactic center and z-direction is perpendicular to disc plane. (b) Rotation curves and escape speeds in different EFE. The diamonds observational circular velocities of Milky Way, the two dot-dashed lines are MOND fitting rotation curves, the one decreases from 300kpc is in External Field (EF) of $0.01a_0$ (weak), the other one (decreases from 5kpc) is in EF acceleration of $2a_0$ (strong). The shadow areas are for escape velocities in all directions. The error bar at 8.5kpc is RAVE survey escape speed at the solar neighbourhood, ranging from 498~608km/s, with a median likehood of about 550km/s. Our prediction is 545~558km/s, varying in this range when the μ-function or EF direction changes.

Escape from Low Surface Brightness Galaxies

Considering the LSB disk galaxies, we choose NGC1560 as a model, a exponential star disc and Gaussian distribution for gas component.
Both of circular velocities and escape velocities decrease when the external field becomes stronger. When the internal gravity and EF are comparable, the system becomes more non-axisymmetric (Fig. 3a) . Thus we predict such conventional LSBs (with axisymmetric disc, stable) will never be detected close to the center of galaxy clusters, they would be thickened to peanut bulges or dwarf elliptical galaxies. Moreover, the internal potential is strong distorted when EF is comparable to internal gravity (Fig. 3b). Thus we expect a statistics effect of most LSBs nearby center of clusters are non-axisymmetric.

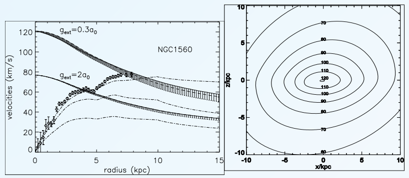

Fig.3 (a) Rotation curves and escape speeds for NGC1560 in different external fields. The symbols and curves are as in Figure 2b except diamonds with error bars are for observational circular velocities. Disc plane is x-y plane and it is axisymmetric, while z-axis is vertical direction. The top rotation curve is in weak EF of $0.01a_0$, the middle and the bottom ones are for strong EF of $0.3a_0$ and $2a_0$ in different environments of galaxy cluster. (b) Escape velocity contours for x-z plane in an EF of $0.3a_0$ in the direction of x-z plane diagonal.

Conclusion

1. The external field is essential in MOND to explain the 550km/s local escape speed.
2. Galaxy cluster members do not show Dark Matter behavior because of their fast acceleration inside the cluster.
3. LSB galaxies are destroyed in galaxy cluster. A future detection of any thin fast-rotating LSB disk in a cluster could falsify MOND.

References

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