

TESTING THE DARK MATTER BY QUANTUM GRAVITATION THEORY IN THE LOCAL GROUP, THE VIRGO AND THE COMA CLUSTERS

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ABSTRACT

The aim of this work is to test the novel theory called Dark Matter by Quantum Gravitation theory (DMbQG hereafter) at cluster scale.

This theory was initially developed for galaxies and afterward was extended to clusters. The main paper where the theory is developed at galaxy scale is [5] Abarca, M. 2024, also in this paper there are some validation test using the rotation curves of MW and M31. The theory was fully extended to cluster in [2] Abarca, M. 2024, also in the paper there are some validation test using data referred to the Local Group and the Virgo clusters.

In this work are compiled some test introduced in the both papers and also there are two new tests referred to the Coma cluster, using data published recently.

The tests are mainly focused on the turnaround radius, also called zero velocity radius, and its gravitating mass associated, in addition regarding the LG of galaxies there is another important test focused on its virial mass as well.

The theoretical calculus has been validated using four papers published by well known team researchers in recent years. Namely the years: 2017, 2018, 2023 and 2025.

1. INTRODUCTION

This work presents some tests to validate some formulas obtained in the framework of DMbQG theory using the three most important clusters. The results have been a complete success for the DMbQG theory.

The tests are mainly focused on the turnaround radius, also called zero velocity radius, and its gravitating mass associated although in the LG of galaxies there is another important test focused on its virial mass as well.

In the epigraph 2 are referred conveniently the formulas obtained in the papers [2] Abarca, M. 2024. or [5] Abarca, M. 2024 used in this work.

The theoretical calculus has been validated using four papers published by well known researcher teams in recent years. Namely 2017, 2018, 2023 and 2025.

2. FORMULA FOR THE TURNAROUND RADIUS AND ITS ASSOCIATED MASS IN DMbQG THEORY

In the paper [2] Abarca, 2024, the turnaround radius is called the zero velocity radius R_{zv} and the R_{200} is considered the virial radius. By its own definition the relation between M_{200} and R_{200} is equal to $M_{200} = 100 \cdot H^2 \cdot R_{200}^3 / G$

In that paper, merging the formulas (5.15) and (4.10) it is obtained that the ratio R_{zv} versus Virial radius is 4.38 as a general formula for all the clusters. This theoretical result has been got considering $\Omega_{DE} = 0.7$ and $H = 70 \text{ km/s/Mpc}$ i.e. $h = 0.7$

The formula (5.16), paper [2], stated that the gravitating mass associated to the turnaround radius is 1.5 the virial mass of the cluster and also depend on the values $\Omega_{DE} = 0.7$ and $h = 0.7$. The gravitating mass is the addition of the total mass (baryonic plus DM) plus a negative mass associated to the DE.

The concept of gravitating mass is taken from a quite simple model developed by [3] Chernin et al. They stated that the DE is equivalent to a negative mass, namely they have demonstrated that the effective DE density as mass is minus two times the DE of the Universe as a constant value into the whole space, see equation (2) of Chernin's paper.

3. TESTING THE DMbQG THEORY IN THE COMA CLUSTER

3.1 THE SOURCE OF THE COMA CLUSTER DATA

The source of Coma data is [1] Benisty 2026. In this epigraph are summarized some important data such as virial radius and mass, the turnaround radius and its mass associated. In case the reader wants to look for these data in the original paper, in the following epigraphs each data is properly referred.

In his paper, the authors consider $h = 0.73$ so the formulas (4.3) and (4.4) stated a lower bound turnaround radius equal to 6.7 Mpc and an upper bound one equal to 11.8 Mpc.

In the Discussion epigraph, page 26, the authors give an estimate for the virial radius equal to 2.67 Mpc

In the epigraph 4.3 Virial theorem, the authors give for the virial mass the range $(1.45 \text{ to } 1.72) \cdot 10^{15} M_{\odot}$. Also they refer that this value is consistent with other studies of M_{200} equal to $1.3 \cdot 10^{15} M_{\odot}$ obtained by weak lensing method. This statement means that the authors consider the virial mass closely related to M_{200} as is usual in clusters.

In the page 20 the equation (4.6) gives the range $(0.7 \text{ to } 3.9) \cdot 10^{15} M_{\odot}$ for the mass associated to the turnaround radius.

3.2 TURNAROUND RADIUS AND ITS MASS ASSOCIATED CALCULUS BY THE DMbQG THEORY

According $R_{vir} = 2.67$ Mpc and using the theoretical formula $R_{zv} = 2.67 \times 4.38 = 11.7$ Mpc. This value is just below the upper bound for the turnaround radius, published by [1] Benisty, equal to 11.8 Mpc.

According the formula (5.16) of paper [2], the gravitating mass enclosed by the R_{zv} is $M_G = 1.5 \cdot M_{200}$ so using the virial mass range given by [1] Benisty $M_G = M_{TA} = 1.5 \cdot (1.45 \text{ to } 1.72) \cdot 10^{15} M_\odot = (2.18 - 2.58) \cdot 10^{15} M_\odot$ that is fully centred into the range of masses given by the equation (4.6), $M_{TA} = (0.7 \text{ to } 3.9) \cdot 10^{15} M_\odot$, according [1] Benisty.

4. TESTING THE DMbQG THEORY IN THE LOCAL GROUP OF GALAXIES

In this epigraph it will be used two different data sources for the Local Group. Namely the papers are [6] Shaya, E et al. and [4] Santos-Santos et al.

4.1 TESTING THE TOTAL MASS OF THE LOCAL GROUP UP TO 770 KPC

In the abstract of [6] Shaya, E et al. paper, the authors affirm that the mass for the MW plus M31 is equal to $M_{LG} = (5.15 \pm 0.35) \cdot 10^{12} M_\odot$

In the paper [5] Abarca, the DMbQG theory is introduced and developed fully. The DM theory is initially developed into the halo region of the galaxies and the paper ended showing a way to extend the theory to the clusters. According this theory each cluster of galaxies has a specific parameter a^2 which may be obtained by the addition of the specific parameter associated to each galaxy. For example in the table 19, the LG parameter a^2 is $4.28E21 \text{ m}^{2.5}/\text{s}^2$, obtained by the addition of the parameters ones associated to MW, M31, M33 and LMC.

The DMbQG theory stated that the total mass is unbounded and the total mass at a specific radius is calculated by the Direct mass: $M_{TOTAL} = a^2 \cdot r^{0.5} / G$.

In the last column of the table 20 of paper [5] Abarca, it is calculated the total mass at different distances for the L.G. using the value for the parameter $a^2 = 4.28E21 \text{ m}^{2.5}/\text{s}^2$ Namely for a radius equal to 770 kpc (distance between MW and M31) the total mass is equal to $4.97 \cdot 10^{12} M_\odot$ that match fully with the data provided by [6] Shaya, E

4.2 TESTING THE DMbQG THEORY BY THE L.G. TURNAROUND RADIUS

In the abstract of paper [4] Santos-Santos et al. the authors stated that the LG turnaround radius is 1.25 Mpc. In this epigraph it will be compared that measure with its theoretical value in the framework of DMbQG theory.

In the chapter 13 of paper [5] Abarca, it is obtained the formula (13.8) for the zero gravity radius R_{ZG} , a concept introduced by [3] Chernin, A., but calculated specifically in the framework of the DMbQG theory. In the table 22 is calculated the R_{ZG} for the LG equal to 2.2 Mpc. To do such calculus is used the formula (13.8) which depends on a^2 . Do not mislead zero gravity radius with turnaround radius, called zero velocity radius as well.

In the paper [2] Abarca, the DMbQG theory is extended fully to clusters of galaxies and in the epigraph 5.4 it is demonstrated the *zero velocity theorem* which stated that the R_{ZV} or turnaround radius is equal to $0.6 \cdot R_{ZG}$, See the expression (5.15). Therefore for the LG, the $R_{TA} = 0.6 \cdot 2.19 = 1.3$ Mpc that match almost mathematically with the result published by [4] Santos-Santos $R_{TA} = 1.25$ Mpc .

Additionally, also in the abstract of the paper [4] Santos-Santos et al. the authors affirm that the pure Hubble flow (i.e. where the radial velocity becomes comparable to $H \cdot d$) is not reached out to at least 3 Mpc.

This result may be explained by the concept of zero gravitating radius (2.2 Mpc for the LG), because at such distance the total mass (DM plus baryonic matter) is counterbalanced by the DE obtaining a gravitating mass equal to zero and consequently at 2.2 Mpc the galaxies cannot have an adequate Hubble flow so it is needed an extra distance to reach the Hubble flow regime.

5. TESTING THE DMbQG THEORY IN THE VIRGO CLUSTER

In this epigraph it will be used two different data sources for the Virgo cluster. The data sources for this important cluster are [6] Shaya,E 2017 and [7] Karachentsev,I. et al.2018.

5.1 TESTING THE DMbQG THEORY BY THE VIRGO TURNAROUND RADIUS

In the abstract of [6] Shaya,E. paper , the authors affirm that the mass of Virgo Cluster is $M_{VIRIAL} = (6.3 \pm 0.8) \cdot 10^{14} M_{\odot}$ and the turnaround radius is $R_{TA} = 7.3 \pm 0.3$ Mpc

In clusters, a common approximation is to consider the virial mass equal to M_{200} , that by definition is related with R_{200} by the formula $M_{200} = 100 \cdot H^2 \cdot R_{200}^3 / G$. Therefore it is possible to clear up the $R_{200} = 1.77$ Mpc. So using the relation obtained in the framework of DMbQG theory $R_{TA} = 4.38 \cdot R_{200} = 4.38 \cdot 1.77$ Mpc = 7.75 Mpc that match quite well with the data provided by [6] Shaya and [7] Karachentsev.

5.2 TESTING THE MASS ASSOCIATED TO THE TURNAROUND RADIUS

In the abstract of [7] Karachentsev, the authors affirm that the $R_{TA} = 7.3 \pm 0.3$ Mpc and the mass enclosed by the turnaround radius is $M (< R_{TA}) = (8.3 \pm 0.9) \cdot 10^{14} M_{\odot}$. In the framework of DMbQG theory, according to the expression (5.16) of paper [2], the gravitating mass enclosed by the R_{zv} is $M_G = 1.5 \cdot M_{200}$ so $M_G = 1.5 \cdot (6.3 \pm 0.8) \cdot 10^{14} M_{\odot}$

$= (9.45 \pm 1.2) \cdot 10^{14} M_{\odot}$. This theoretical result match perfectly with the data provided by the paper [7] if it is considered the errors associated.

6. CONCLUDING REMARKS

This work presents some tests to validate the formulas for the turnaround radius and its mass associated using the three most important clusters. The results have been a complete success for the DMbQG theory.

Regarding the Coma cluster, the theoretical formulas for the turnaround radius and its gravitating mass associated give solutions that match perfectly with the results published by [1] Benisty. In addition the solution for the gravitating mass give a narrower range quite centred regarding the range given by [1] Benisty.

The solution for the turnaround radius is just the upper bound one published by [1] Benisty. This fact is totally right because through the long Universe history all the galaxies enclosed by the turnaround radius have had the time to fall toward the Coma cluster. Therefore the upper bound turnaround radius noted by [1] Benisty gives the measure of the gravitational influence limit of the Coma cluster.

Regarding the L.G. the turnaround radius calculated by the DMbQG theory matches almost mathematically with the result published by [4] Santos-Santos, but even more impressive is the calculus of the LG mass that match fully with the result published by [6] Shaya, E.

Finally in the chapter 5 devoted to the Virgo cluster, the turnaround radius and its mass associated formulas, derived through the DMbQG theory, have been validated with data published by [6] Shaya and [7] Karachentsev.

7. BIBLIOGRAPHY

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