Quantization State of Baryonic Mass in Clusters of Galaxies

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The rotational velocity curves for clusters of galaxies cannot be explained by Newtonian gravitation using the baryonic mass nor does MOND succeed in reducing this discrepancy to acceptable differences. The dark matter hypothesis appears to offer a solution; however, non-baryonic dark matter has never been detected. As an alternative approach, quantum celestial mechanics (QCM) predicts that galactic clusters are in quantization states determined solely by the total baryonic mass of the cluster and its total angular momentum. We find excellent agreement with QCM for ten galactic clusters, demonstrating that dark matter is not needed to explain the rotation velocities and providing further support to the hypothesis that all gravitationally bound systems have QCM quantization states.

1 Introduction

The rotational velocity curves of galaxy clusters [1] are very similar to the rotational velocity curves of individual galaxies, with the rotational velocity value rising rapidly at very small radial distances only to quickly reach an approximately constant velocity for all greater radial distances from about 200 kpc to out beyond 1500 kpc. Newtonian gravitation using only the observed baryonic mass fails to explain the curves both for galaxies and for clusters of galaxies. In clusters, the baryonic mass is predominantly due to the hot intracluster gas that is observed by its free-free X-ray emissions. This gas fraction plus the stellar masses make up the observed baryonic mass of about 10%–15% of the dynamic mass required to explain the rotational velocity curves using Newtonian gravitation, an enormous discrepancy.

Three interesting possible explanations for galactic rotation curves have been proposed: (1) the dark matter hypothesis (DM) introduces non-baryonic matter that is insensitive to all interactions except gravitation, but there has been no detection of any possible form of dark matter; (2) a modified Newtonian dynamics (MOND) effective at all distance scales when the accelerations are less than 1.2×10^{-10} m/s^2, which has been very successful in explaining the rotation and luminosity curves of individual galaxies but has large discrepancies for galaxy clusters [2] in both the cluster core and in the outer regions; (3) quantum celestial mechanics (QCM) derived [3] from the general relativistic Hamilton-Jacobi equation which dictates that all gravitationally bound systems have quantization states. The QCM states are determined by two physical quantities only — the system's total baryonic mass and its total angular momentum. QCM agrees with MOND and the baryonic Tully-Fisher relation for individual galaxies.

In this paper, we compare the QCM predictions for the baryonic mass for ten galaxy clusters to the detected baryonic masses. Our new result is that the QCM baryonic mass values agree with the measured baryonic values even where DM succeeds and MOND fails. No dark matter is required to explain the observed rotation curves. The baryonic matter in a single QCM quantization state produces the correct rotational velocity for the cluster.

2 Conceptual review of QCM

In a series of papers [3, 4, 5], we derived a Schrödinger-like scalar wave equation from the general relativistic Hamilton-Jacobi equation via a tranformation that utilizes the total angular momentum of the gravitationally bound system instead of an angular momentum proportional to Planck's constant. We have shown agreement of its quantization state solutions with the energy states of the planets of the Solar System, of the satellites of the Jovian planets, and of the disk states of galaxies. In a preliminary table-top investigation with a torsion bar system that is now being modified to minimize possible extraneous influences, the QCM predicted quantization states with quantized energy per mass and quantized angular momentum per mass have been detected. The results from the improved apparatus will be reported.

According to QCM, the quantization state energies per orbiting particle mass μ are

$$\frac{E_n}{\mu} = -\frac{G^2 M^4}{2n^2 H_\Sigma^2} \qquad (1)$$

where G is the gravitational constant, M is the total mass of the gravitationally bound system, H_Σ is the system's total angular momentum, and n is an integer. Typically, E_n is on the order of $10^{-6}\mu c^2$. Unlike the quantum mechanics of atomic states whereby each electron is in its own quantum state, in QCM there can be billions of stars (i.e., particles)

Cluster	kT, keV	R_{200}, kpc	M_{200}, $\times 10^{14} M_\odot$	v_{kT}, $\times 10^6$ m/s	M, $\times 10^{13} M_\odot$	H_Σ, $\times 10^{70}$ kg$\times$m^2/s
A1983	2.18±0.09	1100±140	1.59±0.61	0.65±0.03	1.12±0.21	5.10±1.65
MKW9	2.43±0.24	1006±84	1.20±0.30	0.68±0.08	1.34±0.63	7.00±5.76
A2717	2.56±0.06	1096±44	1.57±0.19	0.70±0.02	1.50±0.17	8.57±1.71
A1991	2.71±0.07	1106±41	1.63±0.18	0.72±0.02	1.68±0.19	10.4±2.0
A2597	3.67±0.09	1344±49	3.00±0.33	0.84±0.02	3.11±0.30	30.7±5.1
A1068	4.67±0.11	1635±47	5.68±0.49	0.95±0.03	5.09±0.64	72.7±16.1
A1413	6.62±0.14	1707±57	6.50±0.65	1.13±0.03	10.2±1.1	245.±46
A478	7.05±0.12	2060±110	10.8±1.8	1.16±0.02	11.3±0.8	294.±36
PKS0745	7.97±0.28	1999±77	10.0±1.2	1.24±0.05	14.8±2.4	469.±132
A2204	8.26±0.22	2075±77	11.8±1.3	1.26±0.04	15.7±2.0	525.±116

Table 1: QCM predicted galactic cluster baryonic mass M and angular momentum H_Σ.

in the same QCM state. Also notice that there is no explicit distance dependence in this energy state expression, in sharp contrast to classical mechanics, because the state radial wave function extends over a large range. QCM tells us that gravitationally bound systems, such as planetary systems and galaxies, are quantized systems and that their behavior cannot be fully understood by classical general relativistic dynamics.

QCM has been used also to derive the general expression for the MOND acceleration $a_0 = 1.2\times10^{-10}$ m/s^2, this specific MOND value being an average value for many galaxies. Our general expression is

$$a_0 = \frac{G^3 M^7}{n^4 H_\Sigma^4}\,, \tag{2}$$

a result which suggests that a_0 would be slightly different for each galaxy instead of being taken as a universal value.

We combine these equations algebraically to solve for M and H_Σ in terms of the measured asymptotic rotational velocity and the MOND acceleration. Assuming that the virial theorem holds for galaxies, the velocity v is derived from Eq. 1 to yield

$$M = \frac{v^4}{G a_0}\,, \qquad H_\Sigma = \frac{v^7}{n G a_0^2}\,. \tag{3}$$

These expressions hold true for galaxies. In the next section they will be applied to clusters of galaxies and the predicted baryonic mass values will be compared to the dynamic mass values determined from observational data.

3 Galaxy cluster QCM masses

QCM is assumed to have universal application to isolated gravitationally bound systems. To a good approximation, clusters of galaxies are isolated gravitationally bound systems and therefore should demonstrate the quantization states dictated by QCM. In many cases the galaxy clusters have no dominant central mass, with the intragalactic gas dispersed throughout the cluster. For simplicity, we assume that the cluster system is in the $n = 1$ state, that the virial theorem applies, that $a_0 = 1.2\times10^{-10}$ m/s^2, and that the cluster is approximately a flattened ellipsoid similar to the Local Group [6] that includes our Galaxy and M31. The latter assumption is not strictly required but allows an easy analogy to disk galaxies where we know that QCM and MOND apply extremely well.

We use the ten galaxy clusters analyzed by Arnaud et al. [7] to determine the QCM predicted baryonic mass and angular momentum via Eqs. 3 above. Their radial distance R_{200} is the distance where inside that radius the mean mass density is 200 times the critical density of the universe, and their M_{200} is the total mass within this radius in solar masses $M_\odot$ as determined by a standard NFW universal density profile for a dark matter halo as determined by Navarro et al. [8] from N-body simulations. The kT (keV) represents the spectroscopic temperature of the $0.1 \leqslant r \leqslant 0.5 R_{200}$ region, and the velocity v_{kT} comes from these temperatures. Table 1 lists our results for the total baryonic mass M and the total angular momentum H_Σ.

4 Discussion

Our predicted QCM baryonic masses M in Table 1 for the clusters are about a factor of ten smaller (10^{13} vs. 10^{14}) than the dynamic masses M_{200} which were determined by assuming a dark matter NFW profile. There is reasonable agreement between our QCM baryonic mass values and the baryonic masses from the spectroscopic data. There is no need to invoke the gravitational consequences of DM. The galactic cluster is in a QCM quantization state. This result indicates that quantum celestial mechanics determines certain dynamic behavior of galaxies and galactic clusters.

One additional physical quantity we know now is the total baryonic angular momentum of each galactic cluster. This angular momentum value determines all the quantization states of the system in which the gas and the individual galaxies (i.e., particles) can occupy. Particles at all radii from the cluster center are in the same angular momentum quantization state. Note that we have assumed that $n = 1$ for each cluster; however, some clusters could have baryonic mass in the $n = 2$ state as well.

QCM has been applied successfully to solar systems, galaxies and clusters of galaxies. The results strongly suggest that the known baryonic mass in each system is sufficient to explain the rotational velocity values without invoking the gravitational consequences of dark matter. As expected from QCM, these gravitationally bound systems all behave as non-classical systems exhibiting quantization states determined by the total mass and the total angular momentum.

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