MASS DEFECT IN GALAXY CLUSTERS

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ABSTRACT

Galaxy clusters and mass discrepancy blend and dwell together quite harmoniously. Mass discrepancy is always stumbled upon when galaxy clusters are studied. The orbital velocities of galaxies within galaxy clusters are unusually higher than expected and the observable baryonic matter alone cannot account for all the mass and gravity for the overall observed stability of the cluster. The presence of additional matter in the form of dark matter is required to explain the gravitational stability at such high velocities as baryonic matter is insufficient to explain the anomaly. In this paper I present a theory to account for the mass discrepancy within galaxy clusters without involving dark matter.

Key words: galaxy clusters - mass discrepancy - baryonic matter.

1 INTRODUCTION

The quest for the mysterious dark matter began almost 84 years ago. In 1933, Swiss astrophysicist Sir Fritz Zwicky while studying the Coma cluster pointed towards the mass discrepancy after observing that the galaxies within the cluster were moving much faster than their escape velocities calculated with respect to the mass due to the luminous matter that the cluster contained. The study of the Virgo cluster by Sir Sinclair Smith in 1936 yielded a similar result of mass discrepancy.

A rich galaxy cluster such as the Coma cluster contains thousands of galaxies distributed in an almost spherical enclosure. The mass of the cluster can be obtained from the orbital velocities of galaxies (velocity dispersion of galaxies) or from the observable luminosity of all the galaxies present within the cluster. However, a bizarre mass discrepancy is introduced when these two methods are compared. This was exactly what Sir Fritz Zwicky came across in the 1930s while studying the Coma cluster. The mass of cluster obtained from velocity dispersion of galaxies was found to be more than the mass that could be optically observed, that is, much of the mass within the cluster was not emitting any visible photons like ordinary matter, this gave rise to the mass discrepancy (difference between the mass obtained from cluster dynamics and the observable baryonic mass).

In simple, there is more mass within the cluster that cannot be observed and is keeping the galaxies and hence the entire cluster gravitationally bound, because the luminous matter alone cannot account for all the mass and hence the gravity to keep the cluster gravitationally bound in a stable configuration, that is, the cluster should have broken apart. Now, since all galaxy clusters appear quite stable as they do not expand or break apart, therefore, a necessity originated to consider the presence of invisible mass responsible for keeping the clusters stable. This invisible gravitating mass was termed as dark matter.

It would be quite interesting to note that the Coma cluster and the Virgo cluster were studied back in the 1930s when astronomers and astrophysicists relied mostly on optical techniques to study the celestial objects. Non-optical astronomy gained importance after many years; particularly the space-based X-ray astronomy that became possible only after 1970s. The baryonic intracluster medium (ICM) that forms the enclosed mass between the galaxies and shines brightly in X-rays would remain optically invisible while still adding mass to the galaxy cluster. Therefore, we can say that the ICM was the baryonic dark matter back then in optical wavelength. Study of galaxy clusters by utilizing modern day astronomical techniques has revealed much of the baryonic mass present within the clusters that initially remained hidden, however, much of the mass within galaxy clusters still remains lurking in an unknown form (non-baryonic dark matter) as the ICM and the galaxies (baryonic part of the cluster) are not massive enough to account for the entire mass of the cluster. Mass discrepancy within galaxy clusters still remains at large.

The main objective of this paper is to explain the mass discrepancy in galaxy clusters on the basis of mass defect, according to which the mass of a system bound by energy E will be less by an amount of mass equivalent to E/c^2.

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2 EXPLAINING THE MASS DISCREPANCY

The observed mass discrepancy within galaxy clusters is attributed to the mass defect (a property that holds true for a bound system). Mass defect is the reason for the difference between the observed dynamic mass (obtained from velocity dispersion of galaxies) and the observable baryonic mass of the cluster (mass of galaxies and ICM).

Large amount of energy is released when the cluster constituents gravitationally bind together to form the cluster. This energy when removed from the cluster carries away along with it an equivalent amount of mass and gives rise to the mass discrepancy within the cluster. And usually, the more the energy removed, the greater will be the amount of missing mass or the mass discrepancy within the cluster.

The missing mass in galaxy clusters is quite large; this indirectly suggests that the removed energy after the binding process is also extremely high. Since, the removed energy after the binding process carries away along with it an equivalent amount of mass, therefore, the observable baryonic mass of the cluster is less than the observed dynamic mass of the cluster. This removed energy gravitationally binds the cluster stable and accounts for the mass discrepancy (Δm).

The theoretical explanation for the mass defect or the mass discrepancy is based on Sir Albert Einstein's mass-energy equation $E = mc^2$. The energy equivalent to this missing mass or the mass discrepancy is the gravitational binding energy of the cluster. The mass discrepancy can therefore be written as,

$$\Delta m = M_D - M_B \tag{1}$$

where M_D is the observed dynamic mass and M_B is the observable baryonic mass. This mass difference or the amount of mass discrepancy is equivalent to the energy required to break the cluster apart. The difference M_D - M_B or Δm (best considered to be the mass of non-baryonic dark matter present within the galaxy cluster) is actually the amount of mass that goes missing when an equivalent amount of energy due to gravitational binding is removed from the cluster. Therefore, the energy E removed that causes the cluster to lose an equivalent amount of mass (Δm) can be written as,

$$E = \Delta mc^2 \tag{2}$$

where Δm is the difference between the observed dynamic mass and the observable baryonic mass obtained from equation (1). Equation (2) holds true for a bound system and it denotes the amount of energy removed after binding. This is the amount of energy that holds the cluster constituents intact. Therefore, the mass of a cluster bound by gravitational binding energy E will be less by an amount of mass equivalent to E/c^2, where $E/c^2 = \Delta m = M_D - M_B$.

Now, since the cluster is bound by the virtue of both; the gravitational binding energy of the cluster as well as the amount of baryonic mass present within the cluster, therefore, the cluster should not break apart; it should remain stable. The high orbital velocity of a galaxy orbiting within the cluster is balanced against the observable baryonic mass of the cluster and the gravitational binding energy of the cluster equivalent to the missing mass (Δm). The baryonic mass of the cluster appears to be less to account for the cluster dynamics. However, the gravitational binding energy also plays an important role apart from the baryonic mass in keeping the entire cluster intact. A galaxy orbiting within the cluster is not just held by the observable baryonic mass, it is also held by the unobservable gravitational binding energy of the cluster equivalent to the amount of missing mass (Δm). The binding energy being energy entity remains undetectable while still binding the cluster constituents; therefore, one would believe that there is more mass within the cluster holding upon the cluster constituents apart from the observable baryonic mass.

Now, since the amount of baryonic mass present within the cluster appears to be extremely less to account for the observed cluster dynamics, therefore, the presence of an additional mass in the form of non-baryonic dark matter is required to bridge the gap between the observed dynamic mass (M_D) and the observable baryonic mass (M_B). Δm amount of mass that the cluster loses when an equivalent amount of energy due to binding is removed from the cluster is the missing mass in galaxy clusters.

CONCLUSIONS

(1) Mass discrepancy within galaxy clusters has been explained on the basis of mass defect since it holds true for a bound system.

(2) The mass discrepancy within galaxy clusters seems more like mass defect. The mass that the cluster loses due to the removal of an equivalent amount of energy after the binding process gives rise to the mass discrepancy (Δm).

(3) The mass of the cluster bound by energy E will be less by an amount of mass equivalent to E/c^2. This implies that the cluster constituents (galaxies and ICM) are not just bound to the cluster by the virtue of the observable baryonic mass; they are also bound by the virtue of the unobservable gravitational binding energy of the cluster.

(4) Δm amount of mass that the cluster loses due to the removal of an equivalent amount of energy after the binding process is the missing mass in galaxy clusters.

(5) The gravitational binding energy equivalent to the missing mass accounts for the cluster's stability.

ACKNOWLEDGEMENTS

I am thankful for reviewing my manuscript.

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