Study of dark matter distribution in spiral galaxy and galaxy clusters

Shailesh Pincha[1] and Venktesh Singh*[2]
[1]*Department of Applied Physics, Sardar Vallabhbhai National Institute of Technology, Surat-395017, INDIA*
[2]*Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, INDIA*
**Email: venkaz@yahoo.com*

1. Introduction

Human beings are blessed with a property called curiosity. This made us to pose several questions to understand the "mother nature". One of such questions is "what are fundamental constituents of the universe?" In the quest for answer various theories are being proposed, simulations are being developed and experiments are being performed. Unlike normal matter, dark matter does not interact with the electromagnetic force. This means that it does not absorb, reflect or emit light, making it extremely hard to detect. Till today, we are able to infer the existence of dark matter only from the gravitational effect it seems to have on visible matter.

2. Evidences of dark matter

In astrophysics, things that cannot be seen directly have been discovered through their effects on visible objects. Therefore, astronomical observations reveal properties of structures in the universe like galaxies and galaxy clusters. The observed phenomenon on these structures provides evidences for the existence of dark matter. Astronomers have long relied on photometry to obtain estimates on mass of cosmological structures from well-defined M/L ratio. Galaxy clusters are formed by gravitational pull of cosmic matter over a region of several mega parsecs (3.1×10^{19} km). They contain large number (~100−1000) of visible galaxies and hot Intra-Cluster Medium (ICM). The studies based on cluster dynamics, X-ray emission from ICM and gravitational lensing give strong evidences for dark matter in galaxy clusters. In 1933, Swiss astronomer Fritz Zwicky measured the velocities of eight galaxies in the Coma cluster, by determining the redshift for galaxies. The galaxies exhibited slightly different redshifts. This indicates a spread in velocities and the dispersion was found to be 1019±360 km/s. Zwicky coupled this dispersion with Hubble's estimate of mass for a typical galaxy and obtained total kinetic energy of galaxies in the clusters. As, the clusters are bound for very long time so Virial theorem can be used to obtain cluster mass by relating kinetic and potential energy: $2\langle T \rangle = -\langle U \rangle \sim [GM^2_{cluster} / 2\langle r \rangle]$, where $\langle T\rangle$, $\langle U\rangle$ are the average kinetic and potential energy, respectively. The measured masses are usually expressed as mass to light ratio (M/L) normalized by M/L of the Sun (5.1×10^3 kg/W). Here, M being inferred from gravitational dynamics by using virial theorem, and L from visible light emitted by the galaxies of cluster. Zwicky found that gravitational mass was higher by a huge factor. He for the first time termed this missing, non-luminous mass as "dark matter". The modern estimates on 29 clusters by ESO Nearby Abell Cluster Survey (ENACS) found an average value of M/L = 454h ($M^{\odot}/L^{\odot}$), where h is Hubble constant in terms of 100 km/s/Mpc and ($M^{\odot}/L^{\odot}$) is mass to light ratio of the Sun. Thus, supporting the same basic conclusion that the "galaxy clusters are dominated by unseen matter". The most intuitive and clearest evidence for existence of dark matter comes from the study of rotational dynamics of spiral galaxy such as Milky-way. Assuming circular orbits for stars and gases in the disk, Newtonian dynamics can be used to predict their rotational velocity. By equating centripetal and gravitational forces, we get $F = (mv^2) / r = (GmM / r^2)$, where m, v are mass and velocity of stars or gases, respectively. M is total mass of galaxy contained by an orbit of radius r and G is the gravitational constant. Therefore, velocity as a function of r is obtained by $v(r) = \sqrt{(GM/R)}$. Thus, M can be inferred from observation on motion of nearby visible objects. Hence, the motion of stars carries information about the surrounding mass distribution. These velocity measurements are based on observed Doppler shifts in various spectral features. Experimental measurements on v as a function of r were first presented by Vera Rubin and W. K. Ford on the outermost stars of Andromeda galaxy. Fig. 1 is the summary similar study on several galaxies. The observed rotation curves show remarkably flat velocity distributions at larger radii. These observations with Newtonian mechanics will be consistent for a roughly spherical mass distribution with total enclosed mass proportional to radius, i.e. the visible matter is embedded in large spherically symmetric dark matter halo, which extends well beyond visible spiral galaxy. Without the gravitational mass of this halo, the disc at large radii would fly apart.

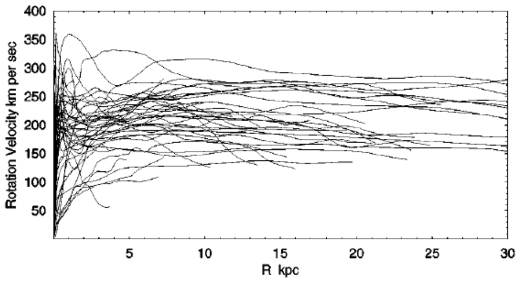

Fig. 1: Superposition of rotation curves for various spiral galaxies depicting unexpected flat nature at larger radii [1].

Thus, if dark matter components are dominant in a region, they must show a higher gravitational impact on an object. Hence, the curve will show larger deviations, than that expected from Newtonian version of Kepler's Law. We exploit this property to see how the rotation curve varies in a cluster. These variations will, thus, show how Dark Matter is distributed in a cluster. We thus study these variations in rotation curves for the Local group with Milky Way and its neighbours. This contains a set of 9 galaxies and the variation in rotation curves are studied with the distance of galaxies from the centre of group. Thus, another calculation was carried on the galaxies of Ursa Major cluster comprising of 25 galaxies and the variation is studied.

3. Rotation curve variation for local group

For the *Local Group*, we studied rotation curve variation with the distance of galaxies from the group centre. From the rotation curves we obtained the values to suffice the study of rotation curve variations.

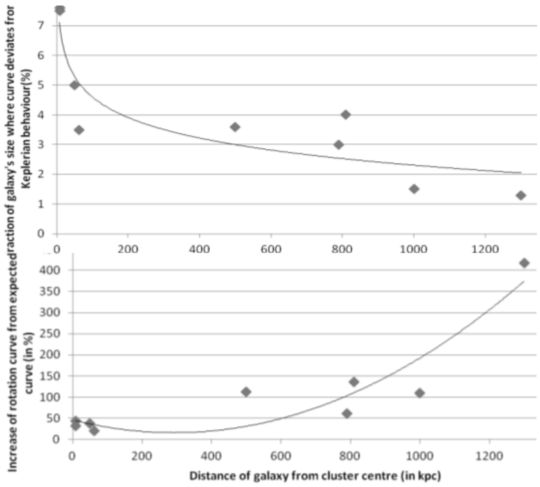

Fig. 2: (a) Rotation curve variation of first kind for *Local group* **(b)** Rotation curve variation of second kind for *Local group.*

Fig. 2 (a) shows that curve of farther galaxies disobey the Keplerian behaviour. Rotation curve variation of first kind has a greater value for galaxies near the centre of the group. This means that galaxies near the centre obey Keplerian behaviour for longer distances and indicates that they are more attached to the galaxies by the virtue of visible matter than the galaxies nearer to edge of the group. It could only be possible when the Dark Matter effects excel in the galaxies farther away from the centre of the group and the gravitational effects of Dark Matter results in flat or increasing rotation curves of the galaxies. Fig 2(b) shows that the visible matter dominates near the centre as the deviation of rotation curve for the galaxies near the centre of group is not large. The rotation curve of second kind hints, here, about the fact that this is a result from the contribution of Cluster properties [2]. There could be a contribution of Dark Matter as well for this nature of the curve. The galaxies in a cluster move in such a way that as the distance from the centre increases, the flatness of rotation curve of the galaxies is obtained at higher velocities.

References

[1] Y. Sofue and V. Rubin, Annu. Rev. Astron. Astrophys., **39**, 137 (2001).
[2] B. Whitmore and D. Forbes, Astro. Phys. J, **333**, 542 (1998).