Dark Matter Study of NGC 5055

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Abstract. This paper is about rediscovering dark matter (DM) in galaxies before the year 1970. It is an Italy-Malaysia Astroproject (SISSA-Radio Cosmology Research group), introducing to the field of DM. Investigations about the rotation curve (RC) of NGC 5055 or the Sunflower Galaxy at that time showed that there was a distinct possibility that they had the knowledge and also the theory of gravitation to initiate the study of dark matter. NGC 5055 was chosen because of its good kinematical and photometric data. Information of the surface brightness of this spiral galaxy will determine the disk length scale, $R_D$. Using this $R_D$ and by fitting the RC data of NGC 5055 with the velocity profile of the Freeman’s disk, we look at the results to conclude whether there are signs of dark matter in the Sunflower Galaxy.

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INTRODUCTION

In 1926, J. H Oort in discussing about the hypotheses of the stars of high velocity and the extent of the galactic system had mentioned about the existence of dark matter in the Milky Way after estimating its gravitational mass \cite{1}. He found that the total mass of the plane must be more than the mass of the material that could be seen in stars only. Fritz Zwicky (1933), another prominent astronomer and astrophysicist had applied the Virial theorem to the Coma Cluster of Galaxies and had also obtained evidence of dark matter of which he referred to as ‘Dunkle Materie’ \cite{2}.

Since then, studies in dark matter had been progressing where the true nature of this ‘mysterious matter’ is increasingly being unraveled. Spiral galaxies, one of the most convincing proofs to the presence of dark matter, are extensively being tested and examined closely their Rotation Curves (RC) to find signs of DM where it is perceived as a gravitational effect on luminous matter. Correspondingly, it is also expected that in the outer most regions of a spiral galaxy, there should be a turnover where its rotational velocity begins to decline according to Keplerian orbital motion. However, most RC’s appear to be flat and hence are commonly concluded that the true mass distribution is more than its visible part can account for.

Recent studies of the rotation curve in NGC 5055 (also known as M63 or the Sunflower Galaxy) had shown some presence of an extensive halo of dark matter \cite{3}. As an introduction and to rediscover the dark matter before the year 1963, the literature search of the first photometric investigation of NGC 5055 was found to be performed by Lindblad and Delhaye (1949) where they had used two colours for their photographic plate to observe its luminosity from its nucleus to about 50” away \cite{4}. Fish (1961) had further investigated using a three-colour photometry and extends it from radiiuses of 15” to 150” \cite{5}. Our data of NGC 5055’s surface brightness profile are based on his studies. In order to determine the disk scale length of NGC 5055, we have employed Freeman’s (1970) “law” of outer exponential component given by the expression (in flux units):

$$I(R) = I_0 e^{-\left(\frac{R}{R_0}\right)},$$  \hspace{1cm} (1)
where $R_D$ is the disk scale length, $I_0$ is the central surface brightness and $R$ is the radius of the disk. The disk is our focus of study because it contributes a large part of the total light and angular momentum [6]. This has been noted in M31 where about 75 percent of the blue light (de Vaucouleurs, 1958) and probably more than 95 percent of the total angular momentum (Takase, 1967) comes from the disk. The Freeman’s law, can be expressed in magnitude per second squared units as below

$$
\mu(R) = \mu(0) + 1.08 \left( \frac{R}{R_D} \right)^2
$$

(2)

where $\mu(0)$ is the central surface brightness. The Sunflower Galaxy surface brightness profile is analyzed using this equation.

The velocity of stars in the disk are examined using the expression,

$$
V_{Disk}^2 = \frac{1}{2} \frac{G M_D (3.2 x)^2}{R_D} \left[ I_0 K_0 - I_1 K_1 \right]
$$

(3)

Here, the definitions of the symbols are as follows:

$x = \frac{R}{3.2 R_D}$, $I_0 K_0$ and $I_1 K_1$ are the modified Bessel functions of the first kind and the second kind of the order 0 and 1 respectively, both of the modified Bessel functions are computed at $1.6 x$, $M_D$ is the disk mass and $G$ is the Universal Gravitational Constant. Equation (3) gives a good representation of how we expect disk galaxies to rotate [7].

**METHODS**

The NED database was used to search the literature published before 1963 and NGC 5055 was selected out of 12 candidates of spirals and barred spiral galaxies. NGC 5055 also exhibits good kinematical and photometric profile. The rotation curve of NGC 5055 was adopted from the paper of E. Margaret Burbidge et al. (1960) where we have converted the unit for the distance from center (radius) in seconds of arc to kiloparsec (kpc) in order to facilitate the fitting analysis [8]. The distance to the galaxy was adhered to $10.31 \times 10^6$ pc as to depict the original graph.

The light distribution or the surface brightness profile of NGC 5055 was extracted from Robert A. Fish (1961). From the photometric data of its major axis, we averaged the blue intensities and plotted them along with the radius. The fitting of the data with the surface brightness profile (eq. 2) yields the value of the disk scale length, $R_D$ (Figure 2). Incorporating this parameter into the velocity disk profile, we thus analyze the observed RC of NGC 5055.

**RESULTS AND DISCUSSION**

Figure 1 shows the result of the rotation curve for NGC 5055 after consideration of the unit conversion of the abscissa. An error bar of ± 10 km s$^{-1}$ was assumed for all the velocities as the original data was scaled at 20 km s$^{-1}$. This plot is actually a measure of Hα velocities where this galaxy contains a large number of HII regions in its outer part and hence suitable to obtain a rotation-curve. The radius of the nucleus is small ~ 0.2 kpc and having a volume of $10^{-4}$ so is it negligible to the contribution of the total mass. We can observe that the RC is rising from 0.5 kpc up to about 2.25 kpc then a small drop at 2.5 kpc and it rises again until about 3.75 kpc. From 4 to 8.5 kpc, the RC seems to be oscillating but nevertheless of constant velocity ranging about 200 to 250 km s$^{-1}$. Then the curve starts to decline till the last observable disk at 10 kpc. It seems we may interpret that there are a greater relative frequency of very massive stars in the central layer of the disk compared with exterior regions. This can be associated with early type stars of high velocity. For distances very far from the center of the galaxy, the velocity curve should become Keplerian and this is clearly shown at 8-10 kpc.
FIGURE 1. The rotation curve of NGC 5055 after the rescaling of its ordinate and abscissa. The radiiuses were converted to kiloparsec to correlate to the fitting analysis.

Figure 2 gives a presentation of how the surface brightness varies from the inner to the outermost disk. The luminosity increases as the radius increases thus the perception that there should be more stars at the outer disk. This is in fact, a contradiction with the observed RC that has been discussed above. Fish had noticed this problem and mentioned in his paper that there is serious disagreement of the color correspondence in the outermost regions when he compared his data with Lindblad-Delhaye photometry and of which the origin of the color discrepancy is unknown. He then inferred that as a first approximation and conformity, one should check the absorption-free luminosity with its mass distribution (if the mass to light ratio does not change rapidly then its density coefficients for the mass may be used to express the distribution of luminosity). Here, from the gradient of the graph, we obtain the disk scale length of \((3.05 \pm 0.18)\) kpc.

FIGURE 2. The plot is a fitting between the surface brightness profile and the averaged blue intensities of NGC 5055. The observed data are shown as dots.

In Figure 3, the plotting reveals how the velocity of disk or velocity from stars differs from the experimental data. As can be observed, it seems that the line follows the pattern of the curve although not quite closely. Thus, we could perceive that there is quite a major contribution coming from the stars only. The estimated mass for this model gives a value of about \((1.09 \pm 0.10) \times 10^{11}\) M\(_{\odot}\). A better evaluation for the mass in NGC 5055 would be if we
include the mass models from the HI gas in the disk and the galaxy’s halo such as being described by the Universal Rotation Curve model (URC) that was first pioneered by Persic and Salucci (1991) [9]. This also could give us a better fitting of the observational data. We will present a more detailed examination of NGC 5055, which includes these models in another paper.

**FIGURE 3.** The graph shows the comparison between observed data (dots with error bars) with the fitting for the velocity of the disk in NGC 5055.

**CONCLUSIONS**

Apart from our objective of introducing and rediscovering the field of DM, our aim is to consider whether there are signs of DM in NGC 5055 by studying the velocity contribution from the stars only. This serves as a preliminary search of proofs of DM as such that the steps that had been accomplished by J.H. Oort.

In this paper, we have not quantified the dark matter. However, since majority of spiral galaxies in the observable universe do have dark matter, we think there might be DM in NGC 5055. This can be evidenced by the analysis of a large number of RC’s of late type spiral galaxies which have been mainly catalogued by Persic and Salucci [10]. Nonetheless Paolo Salucci did not predict the existence of DM in this galaxy.

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**REFERENCES**