Surface Brightness Profiles: Calculating Rotation Curves without Dark Matter

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Abstract

Keplerian and Newtonian physics tell us that the rotational velocities of planets must decrease with any increase in radial distance from the sun. The same theoretical assumption is made for the rotational velocities of all visible mass including stars around spiral galaxy cores. As spiral galaxy brightness profiles diminish in luminosity from core to disc edge the assumptions to date are that because the observed rotation curves of galaxies are flat, this is not consistent with the distribution of visible mass in spiral galaxy discs. And that either new physics or dark matter halos must be invoked to explain why the observed flat rotation curves do not match the rapidly and exponentially diminishing brightness of the galaxy's surface brightness profile as the radius increases. Here in this paper a new rotation curve calculation is made which shows that the surface brightness profiles of visible mass in galaxies can be made to favourably fit the observed flat galaxy rotation curves without having to invoke any new physics or dark matter.

Introduction

In the 1930's Jan Hendrick Oort (4) observed that the mass profiles of spiral galaxies based on galaxy brightness curves did not match the rotational velocities of stars. This mismatch was later confirmed by others including Vera Rubin (5) in the 1970's. Although there have been analyses that indicate visible mass can favourably model the observed rotation curves (2), the generally accepted notion is that somehow either models of Newtonian gravity are incorrect or that a new invisible dark matter halo needs to be invoked to explain an apparent mismatch between surface brightness profiles and the observed rotational velocities of galaxies (3). Here in this paper a separate calculation is made for a visible mass only rotation curve that can be made to fit favourably to the observed rotation velocity data of M33 galaxy without having to invoke dark matter.

Method

The calculations provided below show that as the disc volume increases with an increase in radius this offsets the decreased mass density at a similar increase in radius (table 1). Using only the known and generally accepted average ratio of spiral disc radius to height of 15:1 and the surface brightness profile (1) of M33 a template of relative rotational velocities can be calculated and favourably fit to the observed rotation curve (6) of M33. The surface brightness profile of M33 is first converted to a linear profile, normalised and then used to derive normalised relative mass densities, and then relative masses, for each radius band. Here the calculations use Kiloparsecs but any unit that shows radius (arc degrees, minutes etc) can be used as only the relative proportions of volume and density to radius are necessary to generate an accurate galaxy rotation curve template.

M33 does not have an observable height (thickness) as its disc is roughly 3/4 face on to observers but an average spiral disc radius to height ratio of 15:1 (7) is used here to assume a disc thickness for M33. The diameter of M33 is ~ 70.8 arc minutes or 18.7 kpc (8). From this a radius of 9.35kpc (35.4 arc minutes) for M33 is derived. Separately a steepening of the brightness curve beyond ~ 0.6 arc degrees (1) is also observed from star counts only (not photometry) but is not included in analysis here. Using the generally accepted spiral disc ratio of 15:1 (radius to height/thickness) this gives the height/thickness of M33 as being ~ 0.62 kpc. Based on the generally accepted assumption that the surface brightness profile is a good indicator of the relative density of visible mass at any radii, the log magnitude surface brightness (Fig 2) curve for the galaxy is first converted to a linear brightness curve. From which the total visible mass for each nested radius band (Fig1) can then be calculated.

To calculate a new rotation curve for M33, a calculation of how the disc volume increases with radius is made. The galaxy is assigned a 3-dimensional flattened disc shape which is then divided into equal radii nested concentric bands (Fig 1). Next, using the linear surface brightness curve (Fig2), average densities and thus total masses for each concentric radius bands are then calculated. From which the data for a final velocity rotation curve for the galaxy can be calculated (table 1). Comparison (fig 3) is made to the galaxy's observed rotation curve (6)

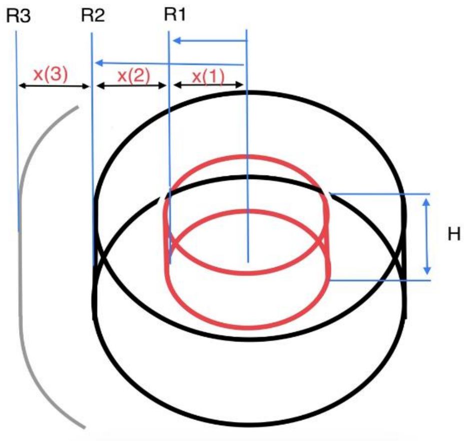

Fig 1) Volume of galaxy disc is represented as a 3-dimensional series of nested concentric bands defined by galaxy radii R, and galaxy disc thickness H. Each successively larger radii band will have a larger total volume. Outside the central core (shown here as x1) the first band, x2 located between radius R1 & R2, will have a smaller volume than any band at larger radii (x3,x4,x5, etc). Using this one can then calculate the volume of each nested band in the disc. For example: Volume for radius band x2 (volume between Radius 1 and Radius 2) is calculated by subtracting total volume within radius R1 from total volume within radius R2.

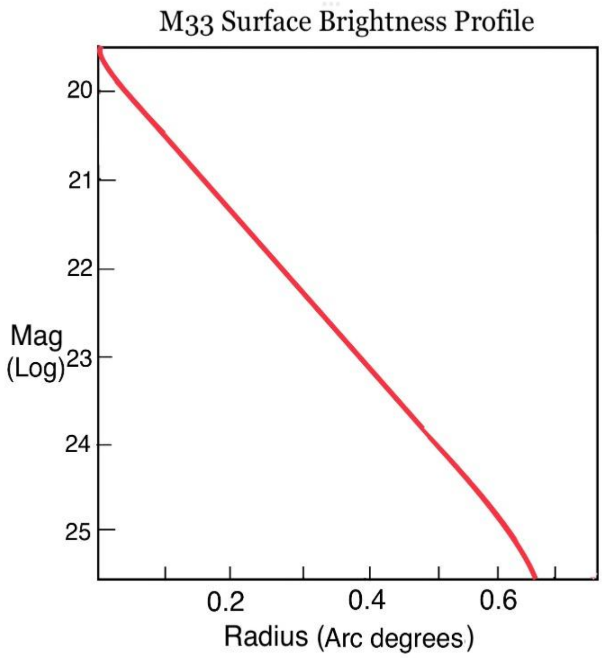

Fig 2) Log mag surface brightness profile (1) from which a linear surface brightness magnitude profile is derived, datasets shown in table 1. The densities of visible mass for each of the successive nested concentric radius bands are then calculated from the linear profile

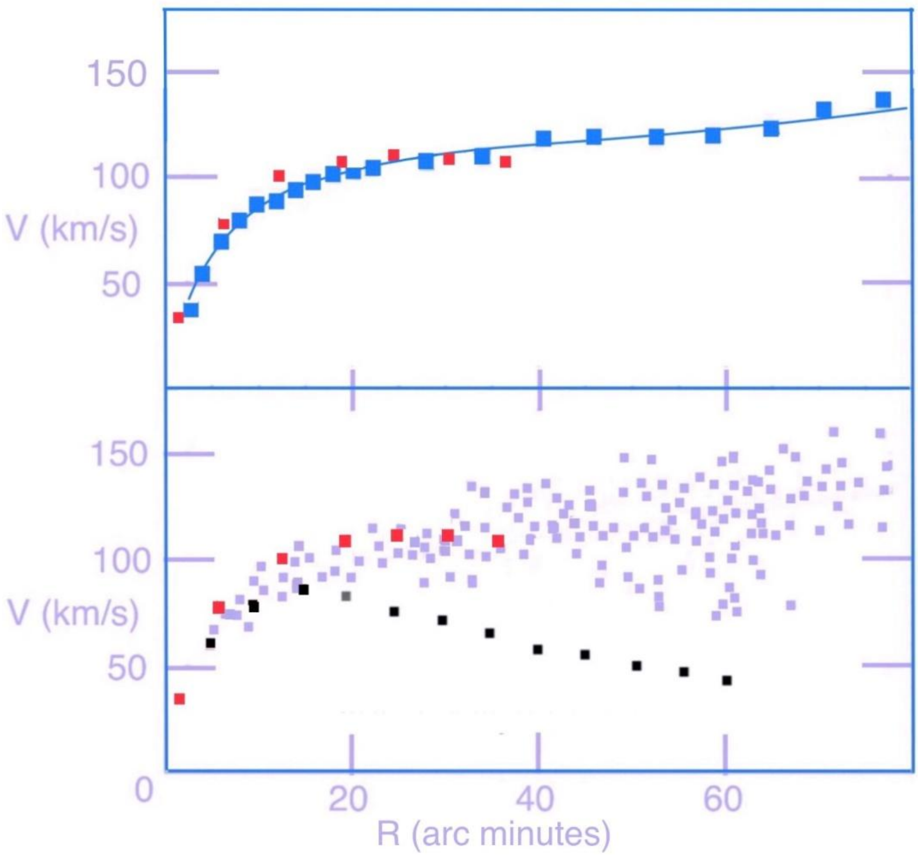

Fig 3) **Top panel**; Blue curve best fit Rotation curve from all data for M33(6). **Bottom panel**; Individual deconvolved velocity datapoints in light blue with overlaid black visible mass curve from Corbelli et al, 2024, (3,6). **Top & bottom**; Additional red velocity curve from datapoints calculated here in this paper from the surface brightness profile data (table 1). M33 Surface brightness (fig 2) is for only ~0.6 arc degrees radius.

Calculations

The 3-dimensional disc of M33 is represented here as a series of nested concentric bands defined by the radius R and height H (fig 1) of the spiral galaxy M33. The disc radius and thickness of 9.35 kpc (0.6 arc degrees) and 0.62kpc respectively are used to calculate the overall volume of the spiral disc which is then subdivided into multiple nested bands of 0.05 arc degrees each (fig1). And then used with the average visible mass density from the linear surface brightness profile for each corresponding concentric radius band (table 1) to calculate a new Galaxy rotation curve for M33 (Fig 3). First the log mag data of M33 (1) is converted to a linear scale. This normalised linear surface brightness profile represents relative mass densities at any given radius across the disc radius. The data from this linear profile is then divided into separate radius bands across the disc from core to disc edge (~0.6 arc degrees, 9.35 kpc) of radius widths of 0.05 arc degrees (~0.78 kpc) each. To calculate an average mass density for each 0.05 arc degree radius band the data points within each 0.05-degree band from the linear profile are binned into 5 further subdivisions and averaged to give a single mass density for each 0.05 arc degree radius band. The visible mass density data is combined with the disc volume data to calculate total mass per radius bands. Then with $V = \sqrt{GM/r}$, a rotation curve (red datapoint profiles in Fig3) is generated for the M33 galaxy using all cumulative mass from column 4 within any given radius r. This compares favourably with the observed galaxy rotation curve (6) for M33. Fig 3 shows a graph of different profile fits to the observed rotation curve data. Notice the velocity curve profile, calculated in this paper from stellar mass and shown in red on the graph, does not start to decay until 30 -35 arc minutes radius. Whereas the usual predicted velocity profile (6) from visible mass and shown in black on the graph starts to decay at only 15 arc minutes.

Radius (arc degrees)	Band Volume (kpc^2)	Normalised Mass Density per band	Relative Mass per radius Band	Relative Velocity
0.01 (.156 kpc)	0.047	117	5.5	35
0.05 (0.78 kpc)	1.18	100	118	55
0.1 (1.56 kpc)	4.74	43.6	206	85
0.15 (2.34 kpc)	10.66	27.3	291	95
0.2 (3.12 kpc)	18.96	17.6	332	103
0.25 (3.9 kpc)	29.62	12	355	110
0.3 (4.68 kpc)	42.66	8.3	353	111
0.35 (5.46 kpc)	58.07	6	348	113
0.4 (6.24 kpc)	75.84	4.2	319	114
0.45 (7.02 kpc)	95.99	2.8	268	111
0.5 (7.8 kpc)	118.5	1.93	227	112
0.55 (8.58 kpc)	143.39	0.86	123	109
0.6 (9.36 kpc)	170.64	0.46	79	105

Table 1) From left; 1st column is radius, 2nd column is total volume for each radius band, 3rd column is mass density per radius band, 4th column is volume x density calculated from first two columns. Using $V = \sqrt{GM/r}$, cumulative data for r in column 4 is converted to a best fit template match to the observed rotational curve of M33. (Fig 3). Column 5 is relative velocities from the best fit template.

Conclusions

If one follows the generally accepted assumption (4,5) that a surface brightness profile of a spiral galaxy can be used as the basis for a calculation of the total visible i.e., baryonic mass of that galaxy, then it can be shown here that a galaxy rotation curve calculated from visible mass only with no dark matter can still compare favourably with the observed rotation curve for the same galaxy. Here in this paper it is shown that although mass density falls exponentially with radius it is offset by a similar proportional increase in volume of the disc over radius to give a much better match to the observed rotation curve than usually assumed in any previous analysis.

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