Necessity for High Accuracy Rotation Curves in Spiral Galaxies

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Abstract. In the last 20 years, rotation curves derived from H I kinematics obtained on radio synthesis instruments were used to probe the dark matter distribution in spiral and dwarf irregular galaxies. It is shown, with the aid of the Sd galaxy NGC 5585, that high resolution 2–D H II kinematics is necessary to determine accurately the mass distribution of spirals. New CFHT Fabry–Perot Hα observations are combined with low resolution Westerbork H I data to study its mass distribution. Using the combined rotation curve and best fit models, it can be seen that the $(M/L_B)_{\star}$ of the luminous disk goes from 0.3, using only the H I rotation curve, to 0.8, using both the optical and the radio data. This reduces the dark–to–luminous mass ratio by $\sim$ 30%.

1. Introduction

Is has often been argued that since H I observations probe the gravitational potential well outside the optical radius, in the dark matter dominated region, they are best suited to derived the characteristics of the mass distribution, thus of the dark mass distribution. However, this is skipping the fact that the parameters of the mass models (and especially of the DM distribution) are very sensitive, as shown below, to the rising inner part of the rotation curve which can be derived with greater precision using 2–D H α observations (see e.g. Amram et al. 1996).

The left part of figure 1, which shows the mass distribution of NGC 5585 using its H I rotation curve, illustrates the now commonly used method to study the mass distribution (Carignan & Freeman 1985). First, the rotation curve...
is obtained by fitting a “tilted–ring” model to the H I velocity field in order to represent the warp of the H I disk which is very often present. The accuracy of the model representation is then checked by looking at the residuals (data - model) map. Then, the luminosity profile, preferentially in the red, is transformed into a mass distribution for the stellar disk assuming a constant \((\mathcal{M}/L_B)\) \(_\star\) (Casertano 1983, Carignan 1985). For the contribution of the gaseous component, the H I radial profile is used, scaled by 4/3 to account for He. The difference between the observed rotation curve and the computed contribution of the luminous (stars & gas) component is thus the contribution of the dark component which can be represented by an isothermal halo (Carignan 1985) or some other functional form.

The H I observations, often optimized for maximum sensitivity in the outer parts, have in most of the published studies a resolution of only 20–45 ″. The example of NGC 5585 will show that this is clearly not sufficient to well determine the rising part of the rotation curve and that this part is crucial since it strongly constrains the three free parameters of the mass model (see also Swaters et al. in these proceedings).

2. Observations and data analysis

The Fabry–Perot observations of the H\(\alpha\) emission line were obtained in 1994 February at the Canada–France–Hawaii Telescope (CFHT). The Fabry–Perot etalon (CFHT1) was installed in the CFHT’s Multi–Object Spectrograph (MOS). A narrow–band filter (\(\Delta \lambda = 10\) Å), centered at \(\lambda_0 = 6570\) Å (nearly at the systemic velocity of NGC 5585, \(V_{sys} \approx 305\) km s\(^{-1}\)), was placed in front of the etalon. The available field with no vignetting was \(\approx 8.7\times 8.7\) ″, with \(0.34\) ″ pix\(^{-1}\). The free spectral range of 5.66 Å (258 km s\(^{-1}\)) was scanned in 28 channels, giving a sampling of 0.2 Å (9.2 km s\(^{-1}\)) per channel. Eight minutes integration was spent at each channel position.

After standard reduction, images are assembled in a cube and phase calibrated in order to get one particular wavelength in a plane. A velocity map is then obtained using the intensity weighted mean of the H\(\alpha\) peak in each pixel.

The rotation curve have been deduced from the velocity field following two different methods. The first estimate was made using ROCUR (Begeman 1987) where annuli in the plane of the galaxy (ellipse in the plane of sky) are fitted to the velocity field in order to minimize the velocity dispersion inside these rings. This allows to determine the rotation center, systemic velocity, position angle and inclination.

The ADHOC package (Boulesteix 1993) have then been used to fine tuned these parameters by direct visualization and comparison with residual velocity field. Note that the internal errors on H II rotation curves data points are usually larger than on H I rotation curves data points reflecting the larger local motions in the H II regions.
3. Mass models

For our adopted mass model of NGC 5585, we combine the high resolution H$\alpha$ data in the inner parts with high sensitivity of the H I data in the outer parts. Since we are doing best-fit models, we have to be careful. First, as explained earlier, the H II data points have larger intrinsic errors. This means that they will carry smaller weights in the fitting process. On the other hand, because of the higher resolution, there is more H II data points than H I data points. This means that the optical data would tend to have a higher weight than the radio data. To avoid any bias, we decided to use for the final model the H$\alpha$ data for $r < 120''$ and the H I data for $r > 120''$. Table I gives the parameters of the mass models constructed using only the H I rotation curve, the H$\alpha$ rotation curve, and those for the model using the combined H I & H$\alpha$ rotation curve.

This adopted model is shown in the right part of figure I. As expected, $\sigma$ is very similar in the combined H I & H$\alpha$ curve than in the H I rotation curve. This is the case because this parameter is a measure of the maximum amplitude of the rotation curve which is mainly defined by the H I data in the outer parts. However, the two other parameters ($M/L_B$)$_*$ for the stellar disk and $r_c$ of the dark halo (which are coupled) have nearly the same values than those derived with the H$\alpha$ curve. Again, this is because the ($M/L_B$)$_*$ of the luminous stellar disk, and hence the scaling parameter of the dark halo $r_c$, are mainly constrained by the H II data in the inner parts.

In summary, adding the H$\alpha$ data to the H I data of NGC 5585, increases in the best-fit model the ($M/L_B$)$_*$ of the stellar disk from 0.3 to 0.8. The result is to push the dark halo outward and reduced by $\sim 30\%$ the dark–to–luminous mass ratio.

4. Conclusions

The importance of an accurate determination of the rising part of the rotation curves using full 2–D high resolution Fabry-Perot observations is well illustrated by the example of NGC 5585 which resulted in a $\sim 30\%$ difference in its dark–to–luminous mass ratio. This is one of the motivation behind the GHASP project, which intends to map accurately the H$\alpha$ velocity fields of $\sim 200–300$ nearby spiral and dwarf galaxies using Fabry–Perot observations. The candidate galaxies will be selected from the WHISP project, which intend to map the H I in 1000–3000 galaxies in the next ten years. This should be the best way to study possible correlations between the parameters of the DM halos and other properties of the galaxies.

References

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### Table 1. Parameters of the mass models of NGC 5585.

| Parameter                   | H I RC | Hα RC | Combined H I & Hα RC |
|-----------------------------|--------|-------|----------------------|
| Luminous disk component:    |        |       |                      |
| \( (\mathcal{M}/L_B)_* \)  | \( (\mathcal{M}_\odot/L_\odot) \) | 0.3 ± 0.3      | 0.9 ± 1.5            | 0.8 ± 0.2          |
| \( \mathcal{M}_* \)        | \( (\mathcal{M}_\odot) \) | 3.3 × 10^8     | 9.9 × 10^8           | 8.8 × 10^8         |
| \( \mathcal{M}_{HI+He} \)  | \( (\mathcal{M}_\odot) \) | 1.4 × 10^9     | 1.4 × 10^9           | 1.4 × 10^9         |
| Dark halo component:        |        |       |                      |
| \( r_c \) (kpc)            |        |       |                      |
| \( \sigma \) (km s\(^{-1}\)) |        |       |                      |
| \( \rho_0 \) \( (\mathcal{M}_\odot pc^{-3}) \) |        |       |                      |
| At \( R_{H_0} \) \( r = 6.5 \) kpc: |        |       |                      |
| \( \rho_{\text{halo}} \) \( (\mathcal{M}_\odot pc^{-3}) \) | 0.0035  | 0.0041 |                      |
| \( \mathcal{M}_{\text{dark}+\text{lum}} \) \( (\mathcal{M}_\odot) \) | 1.2 × 10^{10} | 1.1 × 10^{10} |                      |
| \( (\mathcal{M}/L_B)_{\text{dyn}} \) | 10.6   | 10.3  |                      |
| \( \mathcal{M}_{\text{dark}}/\mathcal{M}_{\text{lum}} \) | 8.7    | 5.5   |                      |
| At the last measured point \( r = 9.6 \) kpc: |        |       |                      |
| \( \rho_{\text{halo}} \) \( (\mathcal{M}_\odot pc^{-3}) \) | 0.0013  | 0.0016 |                      |
| \( \mathcal{M}_{\text{dark}+\text{lum}} \) \( (\mathcal{M}_\odot) \) | 1.7 × 10^{10} | 1.8 × 10^{10} |                      |
| \( (\mathcal{M}/L_B)_{\text{dyn}} \) | 10.6   | 10.3  |                      |
| \( \mathcal{M}_{\text{dark}}/\mathcal{M}_{\text{lum}} \) | 9.5    | 7.2   |                      |

![Figure 1](image1.png)  
**Figure 1.**  
(a) Best fit mass model for NGC 5585 using the H I rotation curve (left) and Hα & H I (right).  
(b) Dark–to–luminous mass ratio as a function of radius.
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