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ΛCDM and the dark matter distribution in spirals

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We present the HI data for 5 spiral galaxies that, along with their Hα rotation curves, are used in Gentile et al. (2004, MNRAS, 351, 903) to derive the distribution of dark matter within these objects. The HI rotation curves obtained are derived by constructing model data cubes that are iteratively compared to the observed ones. The HI rotation curves agree well with the Hα data, where they coexist. Moreover, the combined Hα + HI rotation curves are smooth, symmetric and extended to large radii.

The rotation curves are decomposed into stellar, gaseous and dark matter contributions and the inferred density distribution is compared to various mass distributions: dark haloes with a central density core, Λ Cold Dark Matter (ΛCDM) haloes (NFW, Moore profiles), HI scaling and MOND. The observations point to haloes with constant density cores of size $r_{core} \sim r_{opt}$. ΛCDM models are in clear conflict with the data. HI scaling and MOND cannot account for the observed kinematics: we find some counter-examples.

We also present some projects aimed at making steps forward in unveiling the properties of dark matter, in particular its outer density distribution.

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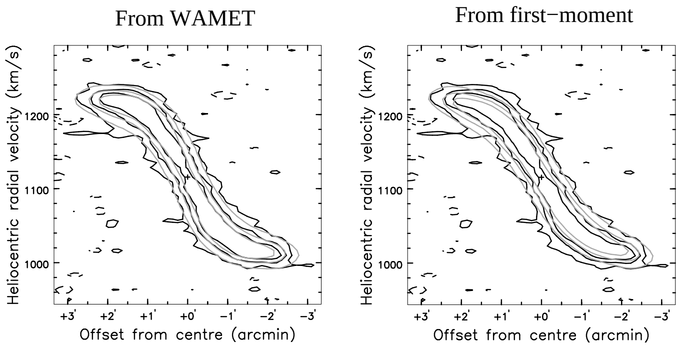

Figure 1: Comparison between the *observed* data cube (black contours) and 2 *model* data cubes (grey contours) for ESO 116-G12: the WAMET rotation curve (left) and the first-moment rotation curve (right).

1. Introduction

The nature of dark matter is one of the most important and yet unanswered questions in astrophysics, even though its existence has been inferred for several decades. Despite a large amount of observational projects, some of the most fundamental issues, such as the validity of the Cold Dark Matter (CDM) scenario on galactic scales (e.g. [7], [6]), are still under debate. Several studies cast serious doubts on one of the fundamental properties of CDM haloes, namely their 'cuspiness' in the galaxy centres, and infer the presence of large core radii in the DM density profiles (see [3] and references therein). However, due to the many steps in the data analysis, there can be subtle systematic errors that might distort the results. Therefore, there is an ongoing debate on the reliability of the data and how well the mass models are really constrained. There are claims that the observations could actually be consistent with the dark matter density profiles predicted by the CDM simulations (e.g. [9]). This is the reason why particular care should be taken in choosing a suited sample and in performing the data analysis.

We therefore built a sample of galaxy rotation curves ideal for deriving the properties of the dark matter haloes around galaxies, made of 5 late-type spiral galaxies. One of the main concerns is that the rotation curve has both a high spatial resolution and a large extension, i.e. beyond the optical radius; this is typically achieved by combining optical (Hα) and radio (HI) data. The former provide the necessary high resolution (1 - 2 “) while the latter allow us to trace the potential out to large radii, typically 2–3 times the optical radius.

2. The data

The optical rotation curves were taken from the sample of [8], while the HI rotation curves were first derived with the WAMET (WArped Modified Envelope Tracing) method (which accounts for warps and projection effects, see [3]) then refined by constructing model data cubes with the task GALMOD within GIPSY, that been then compared to the observed HI data cubes. Fig. 1 shows that the WAMET method is a better way to derive the rotation curve than the standard first moment analysis. A series of geometrical and physical parameters, among which the rotation curve,

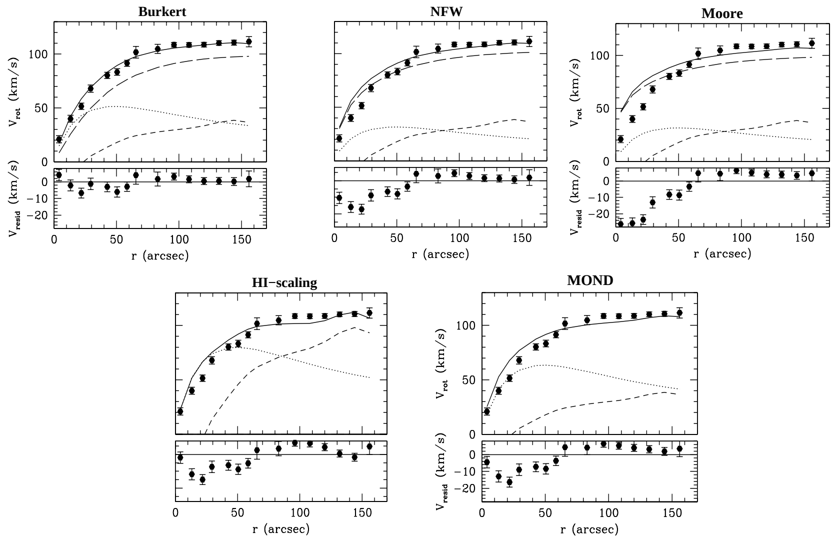

Figure 2: Mass models for the galaxy ESO 116-G12. The solid line represents the best-fitting model, the long-dashed line is the contribution of the dark matter halo, and the dotted and short-dashed lines are the contributions of the stellar and gaseous discs, respectively. Below the plots we also show the residuals of the fits.

allows us to create model observations of the HI discs. These models, when compared to the real data cubes, verify whether they are a fair representation of the HI disc. The so-derived HI rotation curves are in excellent agreement with the Hα data.

3. Mass models

We model the circular velocity $V(r)$ in terms of the disc, gas and halo components. The contribution of the stellar disc is derived from photometry and is scaled according to the chosen (stellar, I-band) M/L ratio. The contribution of the gaseous disc is derived from the HI surface density distribution and scaled up by a factor 1.33 to account for primordial helium. The contribution of the dark halo, derived under the following assumptions: 1) a cored halo (e.g. a Burkert halo, [2]), 2) a NFW halo ([7]), 3) a Moore halo ([6]), 4) scaling-up of the HI contribution and 5) MOND ([5]).

4. Results

The Burkert profile – as well as any cored profile – has the best fits to the rotation curves, with no systematic deviation from the observed rotation curves seen in all galaxies. In Fig. 2 we show an example of the mass models. The core radii are of the order of the optical radii. The best-fitting stellar I-band mass-to-light ratios are consistent with population synthesis models (e.g., [1]).

The minimum χ^2 values for the NFW haloes are much higher than for the Burkert haloes. A large number of data points (9) is totally inconsistent (i.e., residuals larger than 3 σ) with the fits performed with the NFW halo. The Moore haloes provide even worse results, with very high χ^2 values compared to the cored haloes. The inability of the Moore haloes to reproduce the observed kinematics appears also in the large number of points (25) having residuals larger than 3 σ.

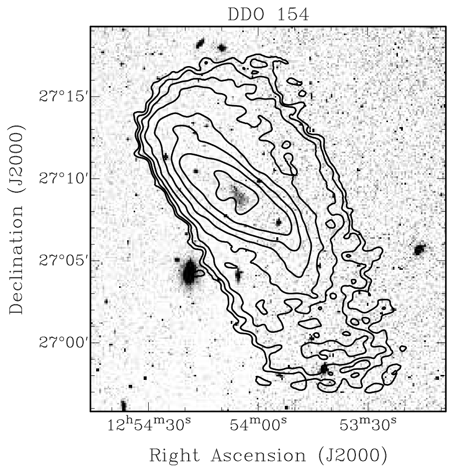

Figure 3: Optical-HI overlay of the galaxy DDO 154 from our new Westerbork observations; notice the huge extent of the HI disk compared to the optical one.

The HI-scaling and the MOND models give reasonable results in a few cases, but with some decisive counter-examples: we have a significant number of points that are inconsistent with the fits in both cases. The values of the HI scaling factors are consistent with previous studies ([4]).

5. The future

We are currently pursuing observational projects aimed at making steps forward in the understanding of the properties of dark matter. One of them (see Fig. 3) involves HI observations of the dwarf galaxy DDO 154, which will allow us to derive the most extended rotation curve observed until now (in terms of the optical size); it will be used to infer some properties of the outer dark matter distribution.

References

[1] Bell, E. F., de Jong, R. S., 2001, ApJ, 550, 212

[2] Burkert, A., 1995, ApJ, 447, L25

[3] Gentile, G., Salucci, P., Klein, U., Vergani, D., Kalberla, P., 2004, MNRAS, 351, 903

[4] Hoekstra, H., van Albada, T. S., Sancisi, R., 2001, MNRAS, 323, 453

[5] Milgrom, M., 1983, ApJ, 270, 365

[6] Moore, B., Governato, F., Quinn, T., Stadel, J., Lake, G., 1998, ApJ, 499, L5

[7] Navarro, J.F., Frenk, C.S., White, S.D.M., 1996, ApJ, 462, 563

[8] Persic, M., Salucci, P., 1995, ApJS, 99, 501

[9] Swaters, R. A., Madore, B. F., van den Bosch, F. C., Balcells, M., 2003, ApJ, 583, 732