Dark Matter Inferences from Rotation Curve Fitting

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Abstract

Rotation curves (RC) of disk galaxies are often used to probe the gravitational potential of their hosting dark matter (DM) haloes. Combining kinematic and photometric data several authors argue that the density profile of galactic halos is nearly flat in the central region ($\rho_{inner} \propto r^0$). This fact is in contradiction with the steep profile expected from cosmological cold dark matter simulations ($\rho_{inner} \propto r^{-1}$), challenging both observers and theoreticians (so called the core/cusp problem). It is worth nothing however that inherent uncertainties exist in both approaches, preventing a definite verdict on this problem thus far.

In this work we attempt to bring the analysis of observations and cosmological simulations closer together. For this we apply the full observers' pipeline on a large set of mock data from simulated disk galaxies that were chosen to reproduce several realistic features. Our mock catalog includes SDSS multiband photometry created with the radiative transfer code SUNRISE plus HI intensity and velocity maps similar to those of the THINGS survey. The results are compared to the real density profiles as directly measured from the snapshots and the agreement is quantified in terms of several critical parameters such as inclination or the amount of non-axysimmetric features in the light/velocity distributions. Our approach thus provides an accurate assessment of potential systematic uncertainties in the interpretation of the observational data

Methodology

As a first test we have simulated a disk-like galaxy in isolation following one of the models described in Cox et al. (2008) using the SPH code GADGET (Springel 2005). It is composed af an exponential disk of stars and gas, plus a NFW dark matter halo and a central black hole. Numerical parameters are described in the table below. It is worth noting that this system has been fine tuned to evolve into a spiral galaxy with realistic morphological features and, more than that, with realistic luminosities and colours in several bands (Rocha et al. 2008; Jonsson et al. 2010).

Then for different timesteps we have created a set of mock data from the snapshots. We have used the multiwavelength radiative transfer code SUNRISE (Jonsson 2006; Jonsson et al. 2010) to image the galaxy in the SDSS bands. We used the mean transfer functions in Doi et al. (2010) along with a mean PSF, mean atmospheric and instrumental parameters, and a low noise component.

In addition we have created mock HI datacubes following the motions of the gas in the simulation box. Our datacubes resemble those of the THINGS survey (Walter et al. 2008) regarding velocity resolution, spatial resolution, and detection limit. Then we build the gas emission map and HI velocity field from the datacubes. The THINGS survey was chosen because it is very up-to-date and it has been used to probe real galaxies in the literature of the cusp/core problem (Oh et al. 2011; de Blok et al. 2008).

We used the ELLIPSE task from IRAF to create surface brightness profiles (SBP) from the optical images, and the harmonic decomposition routine KINEMETRY (Krajnovic et al. 2008) in order to analize the velocity field in elliptical rings. From these complementary analyses we define a fiducial set of geometrical parameters (center, position angle, inclination) and our final SBPS and rotation curves.

Finally, a bulge/disk decomposition is implemented when necessary according to the shape of the SBP. With all these data just a mass-to-light ratio criterium for the baryonic components would be necessary in order to subtract their contribution to the observed rotation curve and guess the shape of the dark matter halo an observer would infere.

The whole procedure is repeated for different inclinations of the galaxy in the sky at a distance of 10 Mpc, namely 15°,30°,45°,60°,75°, and it is planned to be repeated for a large sample of simulated galaxies with different masses.

Galaxy parameters

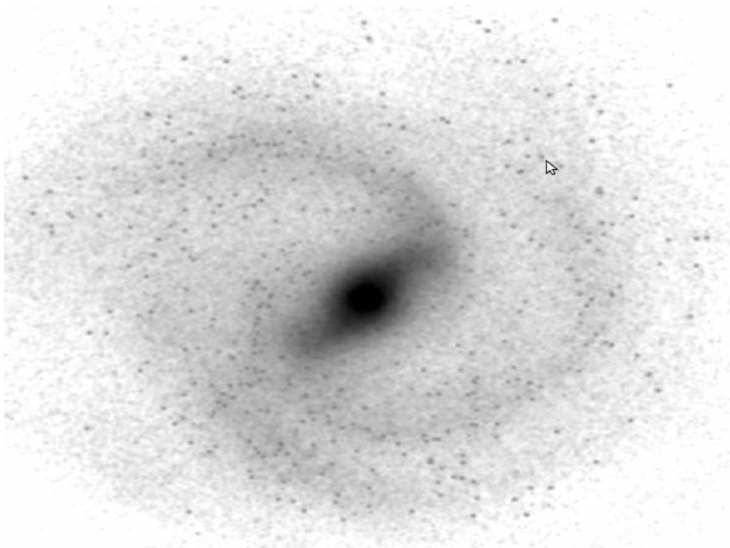
Mtot	$M_\star$	M_{gas}	$N_\star$	R_d	z_0	N_{gas}	R_g	N_{DM}	R_{50}	c
$(10^{10}M_\odot)$	$(10^{10}M_\odot)$	$(10^{10}M_\odot)$	(10^6 part.)	(kpc)	(kpc)	(10^6 part.)	(kpc)	(10^6 part.)	(kpc)	
116	3.28	0.8	3.2	2.85	0.4	3.2	8.5	7.7	3.86	6

Results

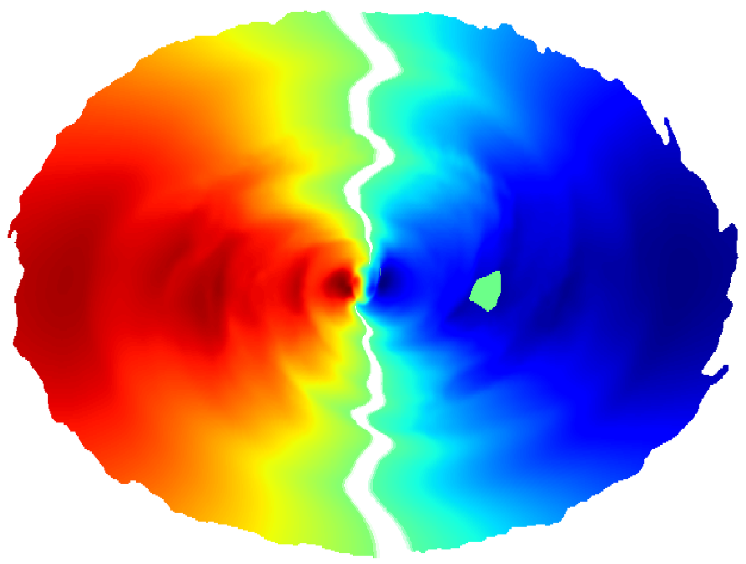
As a first step we run ELLIPSE and KINEMETRY letting the geometrical parameters free to vary. The right inclination and position angles are fairly recovered by the latter in most of the cases while the former basically fails. We attribute this to the formation of bar-like structures which dominate the morphology in the optical but have a small impact in the more extended gaseous disk. This suggests that HI observations are intrinsically better for detecting the underlying disk geometry. As the center of the isophotal contours we choose the brightest point in the r-band photometry as commonly done in the literature (e.g Kassin 2006). We found that Ellipse tends to the same position in the inner region and that this center agrees well with the real center of the DM halo potential.

We compare the real rotation curve calculated from the potential in the plane of the disk with the observed RC and found that in some cases the shape is well recovered but there is a mismatch in the normalization because of small inclination errors. More interesting is that in some cases the observed RC systematically understimates the true circular velocities in the inner region for all inclinations, leading to a potential underestimation of the central DM halo density profile. More likely this is caused by the strong bar. The discrepancy diminishes if one allows HI emission exclusively from a very thin disk in the equatorial plane. These facts show that non-axysimmetric features and the presence of gas outside the disk may act as potential sources of systematics and it is worth determining the impact they have in the context of the core/cusp controversy.

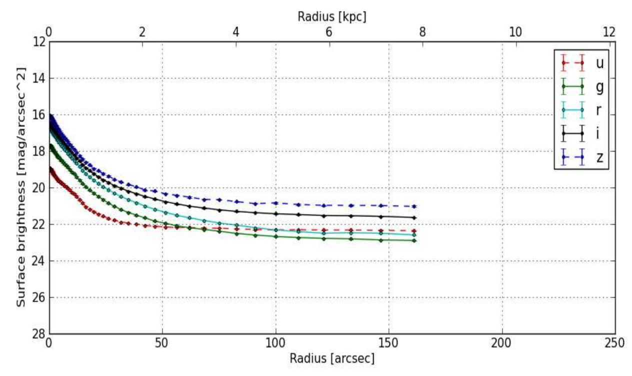
Example of the data products



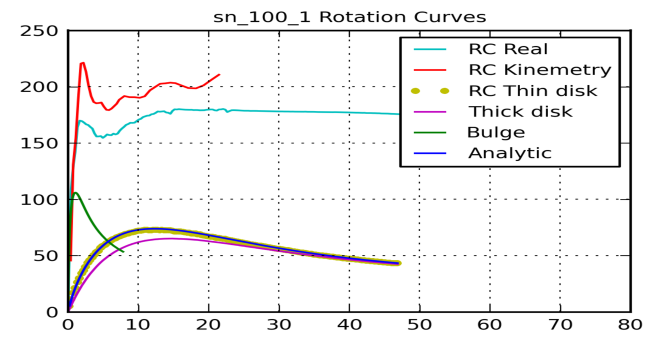
r-band image



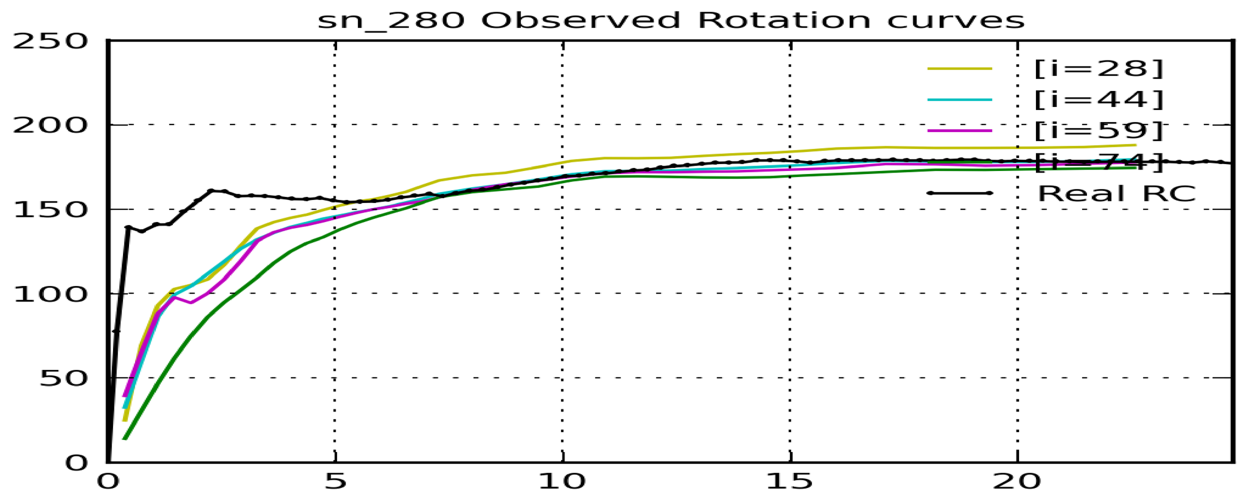
HI velocity map

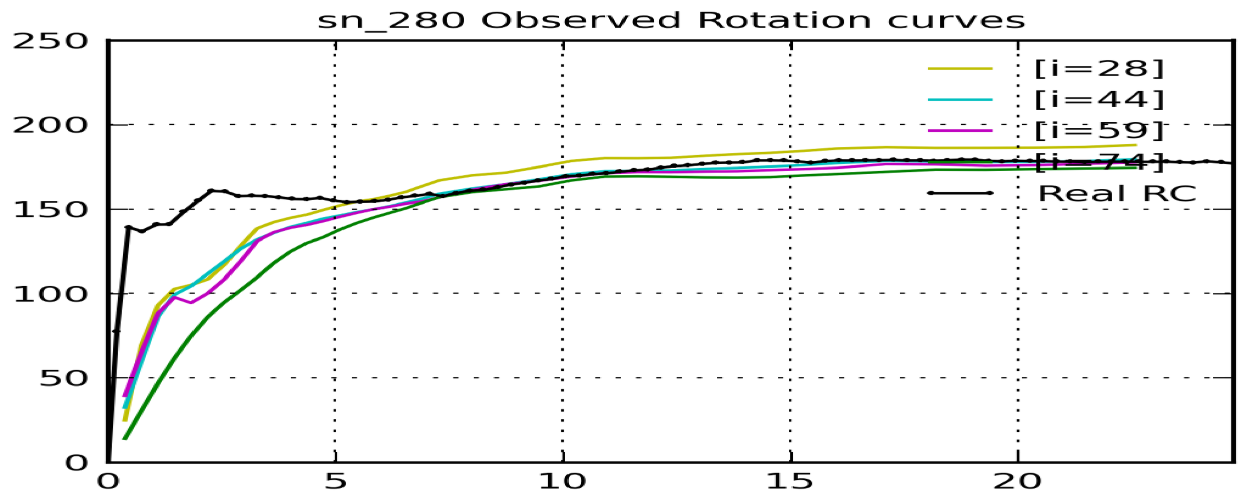


Surface Brightness Profiles



RC for each component





Comparison between real and observed RCs

Acknowledgements

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