Dark Matter in the center of galaxies and galaxy clusters: ruling out the CDM scenario?

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Abstract. This work is focused on the preliminary results of the observations of H\textalpha rotation curves for some of the late type dwarf and LSB galaxies carried out at the TNG telescope. In light of the observational data and of the N-body simulations we have performed recently, we discuss some of the implications on the nature of the DM particles and the formation of the dark haloes.

1. Introduction

Cold Dark Matter (CDM) models provide a solid framework capable to explain most of the properties of the universe at large scales. In the last few years a very large effort has been spent in the investigation of the detailed structure of the virialized haloes within the CDM scenario, in which dark particles are assumed to be cold and collisionless. Using N-body simulations it was showed that virialized haloes are well described by an universal density profile, the Navarro, Frenk, & White model (1997; hereafter NFW). This profile diverges at the center showing a cuspy core: $\rho \propto 1/r$. Recent high-resolution N-body simulations show that as the numerical resolution is increased, the resulting dark density profile goes as $\rho \propto 1/r^{1.5}$ (Moore et al. 1999). On galactic scales the theory seem to be in conflict with the observations, since the rotation curves of LSB and dwarf galaxies rise too slowly with respect to the predictions of the CDM model. Indeed, the rotation curves of these galaxies call for a finite central density (soft core), in conflict with the cuspy cores predicted by the model. Note that LSB and dwarf galaxies are systems strongly dark matter dominated, so their rotation curves are good tracers of the underlying dark haloes gravitational potential and therefore good candidates to explore the innermost shape of the dark matter distribution. Recently, however, some authors have challenged the existence of soft cores in centers of galaxies measuring H\textalpha rotation curves of late-type dwarf and LSB galaxies. Basically they find two results: HI rotation curves for most of the galaxies are affected by beam-smearing and a good agreement with concentration values predicted by the NFW model (van den Bosch and Swaters 2000).
2. Soft core observational evidence

We have carried out H$\alpha$ rotation curves at the TNG of dwarf and LSB galaxies. The spatial resolution in the central regions is a factor 10 better than with respect the HI data published in literature for the same galaxies. In Fig.1 we reproduce the circular velocities for the galaxies UGC4325, UGC11861 and F571-8 (empty circles are our H$\alpha$ observations and filled circles are HI data). From a comparison between optical and radio data it is interesting to note that HI observations for these galaxies are not affected (or are very little) by beam smearing (see Marchesini et al. at this conference, for details). To discriminate between the NFW and King models as representative profile of the primeval dark halo, we built a fiducial galaxy. The dotted lines in the top panels represent a NFW profile while the dotted lines in the bottom panels are due to a King profile. Accounting for the disc formation (dashed lines) we computed next the adiabatic contraction of the DM component due to the cooling of the baryons into the virialized haloes. The final rotation curve is then obtained (solid lines) and compared with the H$\alpha$ data. The final curve is best fitted for all galaxies assuming that the dark matter in the primeval halo is distributed as a King profile. On galaxy cluster scale, there are at least two clusters with evidence of soft cores: CL0024+1654 as inferred by strong lensing technique (Tyson et al. 1998) and A1705 as revealed by the Chandra data (Ettori et al. at this conference). The central densities of the galaxies analyzed here or taken from the literature and of CL0024+1654 seem to confirm the evidence that the central density is independent on the halo mass (Firmani et al. 2000). Future observations will increase the sample and put these observational findings on a more robust basis.

3. Implications on the DM nature

The question is: how can we justify the existence of soft cores in galaxies and in galaxy clusters? Warm dark matter (WDM) has been proposed in order to solve the conflict with CDM models. However, even if interesting, this scenario is unable to produce soft cores at galactic scales (see e.g. Avila-Reese et al. 2001). A possible solution is to assume a weakly self-interacting cold dark matter (SIDM) (Spergel & Steinhardt 2000). It is well known that the NFW profile is far from thermal equilibrium, and shows, in fact, a inner positive temperature gradient. Collisions between dark particles would modify the velocity distribution to a Maxwellian distribution generating a constant velocity dispersion. We have developed different approaches to explore the SIDM regime: thermodynamic (Firmani et al. 2000) and dynamic models building a cosmological Boltzmann code (Firmani, D’Onghia, & Chincarini 2000, astro-ph/0010497). Here, we propose a new numerical procedure applied to N-body simulations (D’Onghia, Firmani, & Chincarini 2001, in preparation). Our technique is capable to simulate a single halo of any size and mass in a cosmological framework coupling semi-numerical technique and N-body simulations. The cosmological initial conditions are fixed by the mass aggregation history of the halo using semi-analytical models and only the dynamical evolution of the halo is followed by the N-body code. To achieve this, the HYDRA code has been ad hoc modified and our version can describe simulations both of collisional and collisionless dark haloes. In our simulations we assume a cross section inversely proportional to the particle velocity
Figure 1. Rotation curves of dwarf galaxies and LSB galaxies. Top panels: our H$\alpha$ observations with error bars (skeletal), HI data (filled points). An initial NFW profile is assumed for the halo (dashed line), the disc (dotted line) and the final rotation curve to be compared with data (solid line). Bottom panels: as above, however, an initial King profile is assumed for the dark halo (dashed line).

dispersion: $\sigma/m_x v_{100} = 10^{-24}$ cm$^2$/Gev with $v_{100}$ the halo velocity dispersion in units of 100 km/s. The top panels of Fig. 2 show the dark density profiles of haloes of $M = 10^{11} M_\odot$ (left panel) and $10^{15} M_\odot$ (right panel) as obtained in a SIDM model. Each halo have been modeled assuming the cross section value above (in the figure the corresponding density profiles have empty circles) and a cross section three times larger (filled circles). In the same plot solid lines are the NFW profiles. Within a Hubble time a modest self-interaction cross section value creates soft cores in haloes of any size and a three times stronger cross section value produces larger soft cores. Bottom panels of Fig. 2 show the corresponding halo radial dispersion velocity profiles (symbols have the same meanings as above). This is the case in which any trend towards the core collapse is avoided by the competition between a mass accretion determined by the halo merging history and a thermalization process by collisions.

4. Conclusions

H$\alpha$ rotation curves carried out at TNG of two late-type dwarf galaxies and one LSB galaxy show evidence of soft cores as the mass distribution of CL0024+1654 on galaxy cluster scales. Integrating the information from galaxies to clusters
of galaxies the halo central density seems to be independent of the halo mass. WDM in unable to produce visible soft cores, but SIDM in a very weak self-interacting regime ($\sigma/m_{\chi} v_0 = 10^{-24} \text{ cm}^2/\text{Gev}$) produces soft cores in agreement with the available observations on different scales.

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6. References

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