Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 19 October 2015 (MN LaTeX style file v2.2)

A new method to estimate dark matter halo concentrations

C. Poveda ⋆[1] J. E. Forero-Romero †[1] J. C. Muñoz-Cuartas ‡[2]

[1] *Departamento de Física, Universidad de los Andes, Cra. 1 No. 18A-10, Edificio Ip, Bogotá, Colombia*
[2] *Instituto de Física - FCEN, Universidad de Antioquia, Calle 67 No. 53-108, Medellín, Colombia*

19 October 2015

ABSTRACT

We present a new method to estimate the concentration of dark matter halos in N-body simulations. Our method finds the concentration value to match integrated mass profile as a function of halo radius. The main advantage of this method is that it uses the full particle informatio without any binning. We test our method both on mock and N-body halos to compare it against two popular methods to find concentrations: maximum radial velocity measurements and radial particle binning to estimate the density. Tests on the mock halos show that the accuracy of our method to recover input concentrations varies with the number of particles in the halo. For halos sampled with 20 particles our method recovers the input concentration with 10% accuracy, while for the maximumradial velocity and density methods the accuracy is on the order of 20% and 100%, respectively. For halos with 2×10^4 particles our method achieves an accuracy of 0.01% while the velocity and methods achieve 0.1% and 1%, respectively. We also measure the mass-concentration relationship on N-body data taking care of using halos sampled with at least 200 particles.. We find that at low masses $10^{12}h^{-1}\mathrm{M}_{\odot} < M < 10^{13}h^{-1}\mathrm{M}_{\odot}$ our method yields median concentration values lower by a $15\% - 20\%$ compared to the velocity and density methods. At higher masses $3\times10^{13}h^{-1}\mathrm{M}_{\odot} < M < 2\times10^{14}h^{-1}\mathrm{M}_{\odot}$ the three methods give similar results.

Key words: Cosmology: theory - large-scale structure of Universe - Methods: data analysis - numerical - N-body simulations

1 INTRODUCTION

In the concordance cosmological paradigm the matter content of the Universe is dominated by dark matter, a collisionless fluid shaped by gravitational interactions. In the last three decades simulations of dark matter dominated universes have provided valuable insights into the large scale structure formation process, showing a remarkable success in the comparison between theoretical results and observations of the galaxy distribution obtained from surveys. (Springel et al. 2005; Klypin et al. 2011).

On galactic scales the most striking result is that dark matter overdensities closely follow a universal density profile. In a first approximation this profile is spherically symmetric and its density only dependens on the radial coordinate. The universality of this profiles seems to be independent of the cosmological parameters and is self-similar for different spatial scales after an adequate re-scaling is applied. (Navarro et al. 1997; Taylor & Navarro 2001)

One the most popular parameterization for a dark matter halo radial density distribution is the Navarro-Frenk-White (NFW) profile (Navarro et al. 1997). This profile is a double power law in radius, where the transition break happens at the so-called scale radius, r_s. The ratio between the scale radius and the virial radius R_v, which defines a natural scale for the halo, is known as the concentration $c = R_v/r_s$. Simulations also show that the concentration is a strong function of halo mass and redshift.

However, high resolution simulations of Milky Way sized dark matter halos (Navarro et al. 2010) show that the universality property is not perfect and that a better fitting parameterization to the radial density profile is provided by the Einasto profile (Einasto 1965). Nevertheless, the NFW density profile and its concentration have become a standard metric to describe the structure of dark matter halos.

Observationally, the relationship between halo mass and concentration could provide a potential test of the Cold Dark Matter (CDM) paradigm on galactic scales. For this motivation a great deal of effort has been invested in calibrating this relationship with simulations (Neto et al. 2007; Duffy et al. 2008; Muñoz-Cuartas et al. 2011; Prada et al. 2012;

⋆ cn.poveda542@uniandes.edu.co
† je.forero@uniandes.edu.co
‡ xxxx@udea.edu.co

Ludlow et al. 2014) and finding the best possible way to constraint it with observations (Buote et al. 2007; Comerford & Natarajan 2007; Mandelbaum et al. 2008; Giocoli et al. 2014; Foëx et al. 2014; Shan et al. 2015).

In N-body simulations there are two main methods to estimate the concentration parameter of a dark matter halo in a N-body simulation. The first method takes the particles composing the halos and bins them in logarithmic radii to estimate the density in each bin, then it proceeds to fit the density as a function of the radius to the NFW profile. A second method uses an analytic property of the NFW profile that relates the maximum of the ratio of the circular velocity to the virial velocity. The concentration can be then found as the root of a algebraic equation dependent on this maximum value.

The first method is straightforward to apply but presents two disadvantages. First, it requires a large number of particles in order to have a proper density estimate in each bin. This makes the method robust only for halos with at least 10^3 particles. The second problem is that there is not a way to estimate the optimal radial bin size, different choices produce different results for the concentration.

The second method solves the two problems mentioned above. It works with low particles numbers and does not involve data binning. However, it effectively takes into account only a single data point and discards the behaviour of the ratio $V_{\rm circ}/V_{\rm vir}$ below and above its maxima. Additionally, small fluctuations on the value of this maximum can yield large perturbations on the estimated concentration parameter.

In this paper we propose a new method to estimate the dark matter halo concentration in halos from N-body simulations. Our method builds the cumulative mass profile from the particle to find the best possible concentration value fitting this distribution. This proposal has two advantages with respect to the two methods mentioned above. It does not involve any data binning and does not throw away data points.

REFERENCES

Buote D. A., Gastaldello F., Humphrey P. J., Zappacosta L., Bullock J. S., Brighenti F., Mathews W. G., 2007, ApJ, 664, 123

Comerford J. M., Natarajan P., 2007, MNRAS, 379, 190

Duffy A. R., Schaye J., Kay S. T., Dalla Vecchia C., 2008, MNRAS, 390, L64

Einasto J., 1965, Trudy Astrofizicheskogo Instituta Alma-Ata, 5, 87

Foëx G., Motta V., Jullo E., Limousin M., Verdugo T., 2014, A&A, 572, A19

Giocoli C., Meneghetti M., Metcalf R. B., Ettori S., Moscardini L., 2014, MNRAS, 440, 1899

Klypin A. A., Trujillo-Gomez S., Primack J., 2011, ApJ, 740, 102

Ludlow A. D., Navarro J. F., Angulo R. E., Boylan-Kolchin M., Springel V., Frenk C., White S. D. M., 2014, MNRAS, 441, 378

Mandelbaum R., Seljak U., Hirata C. M., 2008, JCAP, 8, 6

Muñoz-Cuartas J. C., Macciò A. V., Gottlöber S., Dutton A. A., 2011, MNRAS, 411, 584

Navarro J. F., Frenk C. S., White S. D. M., 1997, ApJ, 490, 493

Navarro J. F., Ludlow A., Springel V., Wang J., Vogelsberger M., White S. D. M., Jenkins A., Frenk C. S., Helmi A., 2010, MNRAS, 402, 21

Neto A. F., Gao L., Bett P., Cole S., Navarro J. F., Frenk C. S., White S. D. M., Springel V., Jenkins A., 2007, MNRAS, 381, 1450

Prada F., Klypin A. A., Cuesta A. J., Betancort-Rijo J. E., Primack J., 2012, MNRAS, 423, 3018

Shan H., Kneib J.-P., Li R., Comparat J., Erben T., Makler M., Moraes B., Van Waerbeke L., Taylor J. E., Charbonnier A., 2015, ArXiv e-prints

Springel V., White S. D. M., Jenkins A., Frenk C. S., Yoshida N., Gao L., Navarro J., Thacker R., Croton D., Helly J., Peacock J. A., Cole S., Thomas P., Couchman H., Evrard A., Colberg J., Pearce F., 2005, Nature, 435, 629

Taylor J. E., Navarro J. F., 2001, ApJ, 563, 483