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BULLET GROUPS AS A TEST OF ΛCDM

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ABSTRACT

We estimate the expected distribution of displacements between the two dominand dark matter peaks in halos within a mass range corresponding to galaxy groups. We find that the probability of finding a system similar with displacements of ∼400 kpch^{-1} is between 40% for z= 0 and 60% for z= 1 and ΛCDM standard model, which correspond to the observational constraint the object SL2S J08544-0121 that is a gravitational lens found in the SL2S and located at z= 0.35. Given the larger abundance of groups with respect to clusters, finding multi-modal groups and baryonic-dark matter displacements.

Subject headings: cosmology: theory – dark matter

1. INTRODUCTION

The Bullet Cluster provided a new kind of observational evidence of the existece of dark matter. Quantifying the displacement between dark matter and the dominant baryonic component (hot X-ray emitting gas) has been used to test the CDM paradigm itself by quantifying the substructure velocity requiered to produce such displacement and also by estimating the expected abundance of such events in the Universe.

Since that time there are other observations of other Bullet-like systems [...].

Recently (Gastaldello et al. 2014) observed baryonic-DM displacement if 124 ± 20 kpc in a group-like system with a total mass $2.4 \pm 0.6 \times 10^{14}M_\odot$. Systems of this mass are ~ 10 times more massive than cluster systems in the mass range $> 10^{15}h^{-1}$M$_\odot$, this opens up the possibility of observationally finding bullet groups in a fair amount to impose constraints on ΛCDM. This greater abundance has to be weighted by the fraction of systems that present large displacements. Such study has been performed for clusters but not for lower mass systems.

In this Letter we present prediction for the abundance of group-like systems that might show a DM-baryon displacement. To this end we use a N-body cosmological simulation with such a resolution that allows us to identify multimodal dark matter clumps in the circular velocity range $300 - 1000\,\mathrm{km\ s^{-1}}$.

This paper is organized as the follows. In Section 2 we present the simulation and the halo catalogs used in this work. We continue in Section 3 with the geometry of the problem at hand and the measurements setup. Next in Section 4 we present our results to finish with a discussion and conclusion in Sections 5 and 6.

2. SIMULATION AND HALO CATALOGS

The analysis presented in this paper uses mainly the Bolshoi (250 Mpch^{-1} simulation box, 1 kpch^{-1} resolution) Database simulation described in Klypin et al. (2011). The simulation follows the evolution of 8.6 billion particle cosmological N-body simulation from z=80 to z=0 in a comoving cube of 250 Mpch^{-1} on a side. The cosmology used corresponds to the spatially flat concordance model with the following parameters: the density parameter for matter (dark matter+baryons) $\Omega_m = 0.27$, the density parameter for baryonic matter $\Omega_b = 0.0469$, the density parameter for dark energy $\Omega_\Lambda = 0.73$, the Hubble parameter $h = 0.7$, the normalization of the Power spectrum $n = 0.95$ and the amplitude of mass density fluctuation (at redshift z=0) $\sigma_8 = 0.82$. The number of particles used for each of the DM component was 2048^3, resulting in a mass resolution of 1.35×10^8 M$_\odot$h^{-1}.

3. BULLET GEOMETRY AND MEASUREMENT SETUP

4. RESULTS

4.1. *Cumulative Probability Distributions*

We selected four snapshot of the simulation for four different redshifts (z= 0, z= 0.25, z= 0.5 and z= 1) based in the distribution of redshift in the Figure 1 by Verdugo & Foex (2014), and for each sample in redshift we selected the host halo with circular velocities greater than 300 kms^{-1} and was split in two principal groups: The first group correspond to host halo with circular velocities between 300 kms^{-1} to 700 kms^{-1} with mass in the range of 10^{12} M$_\odot$ to 10^{14} M$_\odot$ in the range of mass of the Bullet Groups, and second group correspond to host halo with circular velocities greater than 700 kms^{-1} with mass $\geq 10^{14}$ M$_\odot$, in the range of mass of the Bullet Clusters, in the Table 1 is shown the two groups selected in this work. For each group, we classified the corresponding substructures most massive and associated with the corresponding host halo. The configuration of this system is shown in Figure 1, where you an distinguish the host halo and substructure for a particular configuration in z= 0. In this work, we estimate the expected distribution of displacements ($d_{real,(X,Y)}$) in the projection 2-D that can estimate by observations, these displacements correspond to the separation between the minimal potential of the host halo and the minimal potential of the substructure, both are dark matter distributions.

In order to explore the distribution of displacements expected in the observational, we define a new parameter given by:

Sample	Minimum Mass $M_\odot h^{-1}$	Maximum Mass $M_\odot h^{-1}$	# Halos $z = 0$	# Halos $z = 0.25$	# Halos $z = 0.5$	# Halos $z = 1$
Host Halo	0.35×10^{14}	1.09×10^{14}	400	362	310	192
Substructure	0.38×10^{11}	0.30×10^{14}	400	362	310	192

TABLE 1
Mass ranges for the two groups selected in this work in different redshifts.

$$\frac{\nu_{circ,sub}}{\nu_{circ,halo}} = 0.5 \quad (1)$$

Figure 2 shows the scatter plot of the parameter $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right)$ vs the displacement $(d_{2d,(X,Y)})$ between the host halo and the substructure and for different redshifts. This parameter is consistent with the observations. The red star simbol in the Figure 2 is equal to 0.54 corresponding to the fraction in velocity dispersion in the line-of-sigth of the group SL2S SJ08544-0121 ($\sigma_{host,halo} = 341^{+43}_{-109}$ kms^{-1} and $\sigma_{substructure} = 185^{+30}_{-62}$), reported by Muñoz et al. (2013). Based in the parameter $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right) > 0.5$, we estimate the expected distribution of displacements and this is shown in the Figure 3 for the two groups classified in this work.

4.2. *Number expected of Bullet Groups in the sample*

In order to estimate the number of Bullet Groups expected in the Bolshoi Cosmological Simulation, we define the configuration of this system as one where the substructure is coming out of the host halo ($cos(\theta) > 0.5$). For this we make the scalar product between the velocity vector and position vector that defines the separation between the host halo and the substructure, as shown below:

$$cos(\theta) = \frac{\vec{\nu}\cdot\vec{r}}{\|\nu\|\,\|r\|} \quad (2)$$

where, $\vec{\nu} = \vec{\nu}_{sub} - \vec{\nu}_{halo}$ and $\vec{r} = \vec{r}_{sub} - \vec{r}_{halo}$, in the Figure 4 is shown the scatter plot of $cos(\theta)$ vs $X_{off,new} = \frac{d_{2d,(X,Y)}}{R_{virial,halo}} = \frac{d_{real,(X,Y)}}{R_{virial,halo}}$.

5. DISCUSSION

6. CONCLUSIONS

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FIG. 1.— Configuration for a host halo (dashed circle) and sub-structure (black circle) in the sample.

FIG. 2.— Scatter $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right)$ vs $d_{2d,(X,Y)}$ for different redshifts. The horizontal dashed line correpond to $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right) = 0.5$ and the red star simbol correspond to $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right) = 0.54$ for SL2S SJ08544-0121 in Muñoz et al. (2013). The four top panels are the sample with circular velocities > 700 kms^{-1} and the four down panels are the sample with circular velocities between 300 km s^{-1} to 700 kms^{-1}.

FIG. 3.— Cumulative distribution (P> $d_{2d,(X,Y)}$) of displacements for the projection (X,Y). **Left panel:** Sample with $\nu_{max} > 700$ kms^{-1} for different redshifts. The vertical dashed line, correspond to the separation between dark matter to dark matter estimate in this work as the double of separation between the collisional gas and dark matter of 124±20 kpc reported by Gastaldello et al. (2014) for the group SL2S J08544-0121. **Right panel:** Sample with 300 kms^{-1} $< \nu_{max} <$ 700 kms^{-1} for different redshifts.

FIG. 4.— Scatter of $cos(\theta)$ vs $X_{off,new}$. The red dashed line correpond to the limit for $cos(\theta) > 0.5$, where the substructure is emerging from the host halo and $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right) \geq 0.5$, cicular velocities $<$ 700 kms^{-1} and different redshifts.

FIG. 5.— Cumulative distribution of $d_{real,(X,Y)}$ for $cos(\theta) > 0.5$, $\left(\frac{\nu_{circ,sub}}{\nu_{circ,halo}}\right) \geq 0.5$, cicular velocities $<$ 700 kms^{-1} and different redshifts.