Weighing Dark Matter in Brightest Cluster Galaxies

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Abstract. Some authors have noted the peculiarity that a sub-sample of BCGs exhibit a rising velocity dispersion profile, contrary to massive elliptical galaxies not located in the centres of the clusters. This letter highlights novel research that will be conducted on a sample of BCGs in an attempt to shed some light on their peculiar rising velocity dispersion profile. The angle of approach is to determine whether there is a possible correlation between the dark matter (DM) profile and velocity dispersion profile of a galaxy. In particular, a discussion is given on the algorithms generating detailed stellar-mass map estimates and which also constrains the dynamical mass of the galaxy from the stellar velocity dispersion measurements.

1. Introduction

The central galaxies in galaxy clusters have many special properties: they are very massive early-type galaxies (ETGs), have very high luminosities, are diffuse in structure with extended envelopes, and reside at the central locations of clusters. Due to their special location they are exposed to interesting evolutionary phenomena such as dynamical friction, galactic cannibalism, and cooling flows.

An observational aspect difficult to understand, appreciated in the work of [1–3], is the rising velocity dispersion profile of a subsample of BCGs. Murphy [3] summarises the dilemma by asking wheter a rising dispersion profile is a true reflection of the gravitational potential of the galaxy (which includes the effects of DM), or if its is simply a snapshot of a dynamical system that has not yet reached equilibrium. Cleary then, there exists an unwanted degeneracy between the contribution of DM, a system that has not yet virialised, or perhaps a combination between the two.

Bahcall & Kulier [4], for example, put forth the argument that the observed cumulative M/L profile rises on small scales, thereby reflecting the increasing M/L of the central brightest galaxy of the cluster, and then flattens to a nearly constant ratio on scales above $\sim 300h^{-1}$kpc, where light follows mass on all scales and in all environments. They further suggest that most of the dark matter in the universe is located in the large halos of individual galaxies. However, after considering that some BCGs exhibit a positive dispersion slope and the remainder not, this begs the question whether the DM profile truly takes on the same shape in each galaxy, and exactly how universal the distribution is. In other words, the question of *'where is the DM'* still remains.

In this study, a systematic comparison between the dynamical- and stellar-masses of the BCGs will be made for a sample of ~ 20 (from Loubser [1]) of nearby BCGs at relatively low redshift. Of these 20 BCGs, 8 show a clear positive velocity dispersion gradient.

2. Mass profile estimates

A Multi-Gaussian Expansion (MGE) parametrization pioneered by Cappellari [5] is adopted for the stellar density map $\left[M_{\odot} \cdot \mathrm{pc}^{-2}\right]$ due to its accuracy in reproducing the surface brightness profiles of real galaxies. If the x-axis is aligned with the photometric major axis, then the surface brightness $\Sigma\ \left[L_{\odot} \cdot \mathrm{pc}^{2}\right]$ at the location $\left(x^{'}, y^{'}\right)$ on the sky can be written as

$$\Sigma\left(x^{'}, y^{'}\right) = \sum_{k=1}^{N} \frac{L_k}{2\pi\sigma_k^2 q_k^{'}} \exp\left[-\frac{1}{2\sigma_k^2}\left(x^{'2} + \frac{y^{'2}}{q_k^{'2}}\right)\right] \tag{1}$$

where N is the number of the adopted Gaussian components, having total luminosity L_k, observed axial ratio $0 \leq q_k^{'} \leq 1$ and dispersion σ_k along the major axis. Once this parametrization has been obtained for the surface brightness of the real galaxy, then it can be converted into a *stellar surface density map* $\left[M_{\odot} \cdot \mathrm{pc}^{-2}\right]$. Consequently a mass-profile is generated for the baryonic, luminous matter component of the galaxy.

On the other hand, a parametrization for the dark matter mass profile cannot be obtained in this way because DM cannot be observationally detected. Therefore from purely theoretical and simulation arguments, different radial profiles for the dark matter accompanying galaxies have been constructed over the years. Examples of such DM profiles include the Navarro-Frenk-White (NFW) profile [6], the Einasto profile and the Sersic profile [7]. However, the question of which profile is most appropriate for the BCG investigated still remains.

The velocity dispersion measurements of the BCGs play the crucial role in constraining the radial distribution of the DM, as well as constraining the black hole mass and anisotropy profile of the BCG. What the preceding entails for this specific study is as follows: Initially, an arbitrary DM profile is superimposed onto the stellar mass profile (obtained via MGE), thereby representing the *total* mass profile of the BCG. Also, an educated guess is made for the anisotropy profile of the BCG *and* the mass of its black hole. The total mass profile, anisotropy profile, luminosity density and black hole mass are then fed into the Jeans Anisotropic Modelling (JAM) algorithm [8] in order to compute the projected second velocity moment of the BCG coupled to these parametrizations (equation (50) of Cappellari [8]). By deducing the offset between the observed dispersion measurements (extracted from optical spectroscopy) and the predicted JAM dispersion profile, a χ^2 can be computed giving the goodness of the model fit to the data.

This process is then iteratively repeated for numerous other DM profiles, black-hole masses, and anisotropy profiles, thus amounting to 3 free parameters. A final estimate for DM profile, black hole mass, and anisotropy profile for the BCG is obtained depending on which set of parameters yields the minimum χ^2. This minimum χ^2 corresponds to the most accurate fit possible to the observed velocity dispersion profile. Notice that the luminosity density is not a free parameter, but remains fixed during the procedure. This is motivated by the fact that it is stringently derived from the MGE algorithm.

3. Summary

The work done by Loubser [1] details the spatially-resolved kinematics of the sample of ~ 20 BCGs. In [1] the William Herschel telescope (WHT) and Gemini North and South telescopes were used to perform long-slit spectroscopy on the sample of BCGs. Radial velocity and dispersion profiles were extracted from the long-slit spectroscopy via the ppxf algorithm [9]. Hence, with the available velocity dispersion profiles at hand, it is possible to constrain the dark matter profiles of the 20 BCGs. This of course will be facilitated by the JAM algorithm. Furthermore, luminous stellar mass maps will be obtained by feeding Hubble WFPC2 photometry into the MGE algorithm. The JAM algorithm will also put constraints on the black hole mass, and anisotropy profile of the BCG.

To conclude, the 3 free parameters (DM profile, anisotropy profile, and black hole mass) for each BCG are solved for from the Jeans equations once the minimum χ^2 value has been obtained from the fit. Finally, there will be investigated if there is any connection between the DM profile and the varying dispersion gradients found for different BCGs. It is also instructive to see how the result obtained from this method compares with the values found in literature.

Acknowledgments
The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and not necessarily to be attributed to the NRF.

HCB would like to express his sincerest thanks and appreciation to SIL and KS for their continued support, helpful comments and insights.

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