Mg_2 gradients as a signature of brightest cluster galaxy evolution

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Abstract

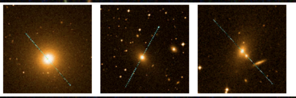
We have fitted the Mg_2 absorption index gradients for 21 brightest cluster galaxies (BCGs), in the nearby Universe, for which we have obtained high signal-to-noise ratio, long-slit spectra on the Gemini telescopes. This is a sub-sample of a large optical, spatially-resolved, spectroscopic sample of BCGs which allows possible connections between the kinematical, dynamical and stellar population properties to be studied. We find a weak correlation between the Mg_2 gradients and central velocity dispersion, with gradients becoming steeper with increasing mass. An equivalent correlation for normal ellipticals in the same mass range is not found, suggesting that the BCG stellar population profiles are shaped by mechanisms related to the potential well of the cluster where they live. This suggestion is reinforced by the existence of a correlation between the Mg_2 gradients and the BCG distance to the X-ray peak luminosity of the cluster.

Introduction

BCGs are very unique, with extremely high luminosities, and dominant locations in clusters. Because of this special location, they are believed to be sites of very interesting evolutionary phenomena (for example dynamical friction, galactic cannibalism, cooling flows). This special class of objects may follow a separate evolutionary path from other massive early-type galaxies, one that is more influenced by their special location in the cluster. Studying BCGs may, therefore, give us information about the formation of the clusters themselves.

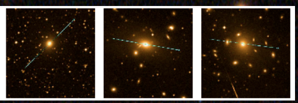
Despite the fact that BCGs have been extensively investigated through both observational and theoretical studies, we do not currently have a clear picture of their formation mechanisms. Different processes (for example, cooling flows or galactic cannibalism) will leave different imprints in the dynamical properties and in the detailed chemical abundances of the stars in the BCGs. In particular, stellar population gradients derived from high signal-to-noise (S/N) ratio spectroscopy can reveal important information about the physical processes at work in galaxy formation. Such gradients and their relationships to galaxy structural parameters and the host cluster properties, therefore, provides strong constraints on galaxy formation.

Galaxy Sample, Observations and Data Reduction



Our sample comprises of the dominant galaxies closest to the X-ray peaks in the centres of clusters. The sample selection, spectroscopic data, and the reduction procedures were presented in Loubser et al. (2008; 2009). The galaxy spectra of the entire sample were binned in the spatial direction to a minimum S/N of 40 per Å in the Hβ region of the spectrum, ensuring acceptable errors on the index measurements. Twenty-six galaxies have four or more bins when the central 0.5 arcsec, to each side, are excluded. Those galaxies that did not meet this criterion were eliminated from the final sample. Thus, the Mg_2 gradients were investigated for 25 galaxies, after one galaxy was excluded because of emission contamination that could not be corrected with GANDALF (Sarzi et al. 2006). The Mg_2 gradients of four of these galaxies were asymmetrical. Thus, 21 Mg_2 gradients were fitted.

The observations of this sub-sample were all obtained with Gemini using GMOS. The slit was placed along the major axis, although exceptions occurred if there were no suitable bright guide stars, which forced the slit to be rotated to an intermediate axis. On average our derived gradients reach a fraction of 0.4 of the effective radius of the galaxy.



Mg_2 gradients

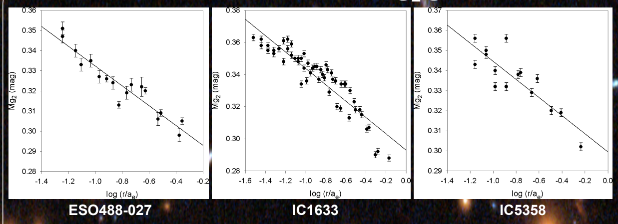


Fig. 1: *BCG Mg_2 gradients. All data is folded with respect to the galaxy centres. The central 0.5 arcsec, to each side (thus in total the central 1 arcsec, comparable to the seeing), were excluded.*

Gradients are taken to be significantly different from zero if the slope is greater than three times the 1 sigma error on that gradient. Four galaxies in our sample have gradients that are compatible with being null, within the errors.
We find a mean gradient of -0.047 ± 0.009 mag for the 21 BCG Mg2 gradients. This is consistent with previous studies of both BCGs, and massive ellipticals.

The negative Mg_2 gradients (above) arises because the gas, which contains new metals ejected by evolving stars, sinks inwards because of dissipation. As stars continue to form their composition reflect the abundance gradient. Negative metallicity gradients must be predicted by every theory of elliptical galaxy formation, but the correlations (or lack thereof) between gradients and other global galaxy properties should provide the tests of the different evolutionary scenarios.

BCGs

Cluster influence?

Numerical simulations predict that the offset of the BCG from the peak of the cluster X-ray emission is an indication of how close the cluster is to the dynamical equilibrium state (Katayama et al. 2003).

We find a significant correlation between Mg_2 gradients and R_{off} with a probability of P = 0.044 (therefore the probability that these two parameters are not related is four per cent according to a statistical t-test at 95 per cent confidence level) when all the Mg_2 gradients are included, and an even stronger correlation (P < 0.0001) when only the significant gradients are included.

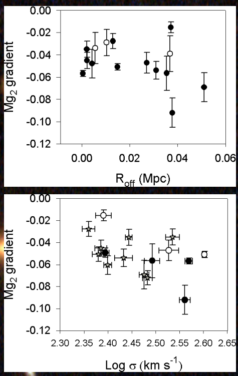


Fig. 3: *The upper plot shows the Mg_2 gradients against projected distance between BCG and X-ray peak (the empty symbols indicate the non-significant gradients). The lower plot shows the significant Mg_2 gradients against BCG velocity dispersion where different symbols indicate whether or not the BCG is hosted by a cooling flow cluster (the grey stars indicate the non-cooling flow clusters, the empty circles indicate the cooling flow clusters, and the black filled circles indicate the clusters where the cooling flow status is not known).*

Mg_2 gradient – velocity dispersion correlation

For elliptical galaxies, gradients get steeper with mass for galaxies with masses below ~10^{11} $M_{\odot}$, while the opposite behaviour is observed for more massive galaxies (although the slope is much flatter and the scatter also increases). This transition also corresponds to the separation of rapidly and slowly rotating, and more or less to the boxy/disky, core/power-law separation, where the correlation inverts and gradients become flatter with mass.

We do a linear fit inversely weighted by the errors on both the Mg2 gradients as well as the velocity dispersion for all the BCGs, regardless of slit orientation, and find a correlation with a slope of −0.060 ± 0.049. We find a probability of 23 per cent (P=0.229) that these two parameters are not related according to a statistical t-test at 95 per cent confidence level. The steepening of gradient with mass is not due to the sole increasing metallicity of the galactic core (see **Figure 2**).

For ellipticals in the same mass range (from Sanchez-Blazquez et al. 2006, and Carollo et al. 1993), we find slopes consistent with zero (see Loubser & Sanchez-Blazquez 2011).

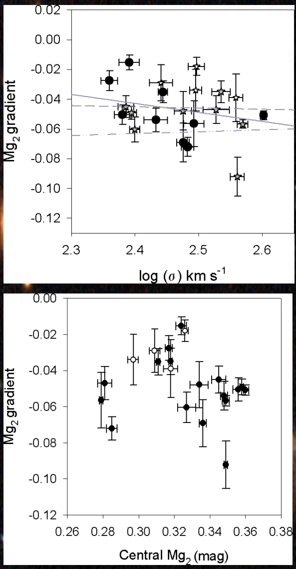


Fig. 2: *Mg_2 gradients plotted against central velocity dispersion and central Mg_2 measurements. The Mg_2 gradients where the PA was placed within 15 degrees of the MA (where the MA was known) are shown with filled circles, and the rest of the gradients with grey stars (with the exception of the four non-significant gradients which are shown with empty stars). The solid grey line shows the Mg_2 gradient – velocity dispersion correlation we find for all 21 BCG Mg_2 gradients. The correlation for the SB06 elliptical sample (with velocity dispersion larger than 2.2 km s^{-1}) are shown with the dashed grey line, and the correlation for the Carollo et al. (1993) sample are shown with the dot-dash grey line.*

Acknowledgements:

Observations presented here were obtained with the Gemini North and South telescopes

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