Finding Fragmented Brightest Cluster Galaxies

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Finding fragmented brightest cluster galaxies

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Project Summary
Galaxy clusters are the gravitationally bound structure of hundreds or even thousands of galaxies. They are the largest virialized structure in the Universe. First-ranked galaxy in a cluster, also referred to as brightest cluster galaxy (BCG) is a unique class of object. They are the most luminous and massive galaxies in the Universe, being up to ten times brighter than typical elliptical galaxies. They are also large with characteristic sizes of over 10s of kiloparsecs. Most BCGs are central Dominant (cD) galaxies, characterised by an extended “envelopes” or halo over hundreds of kiloparsecs. BCGs also likely host the most massive supermassive black holes (SMBHs) in the universe, which was formed accompanying the formation of BCGs and can inject a large amount of energy into the surroundings to affect BCG evolution.

BCGs may be formed in several different ways: 1) Direct cooling from the hot-gas halo onto a pre-existing central galaxy, followed by star formation; 2) Rapid merging of galaxies during cluster collapse; 3) Tidal stripping of cluster galaxies which pass near the cluster centre; 4) Galactic cannibalism, in which the nascent BGC accretes its nearby neighbors.

Observations indicate that “cannibalism” among first-ranked cluster ellipticals almost certainly occurs and hence it appears to be the most acceptable formation scenario. Recent wide-field optical surveys (e.g., Sloan Digital Sky Survey — SDSS, DES, KIDS) have generated many large samples of BCGs up to redshifts of $\sim 1$. A lot of studies have been done recently on BCG formation, evolution and the evolution of SMBHs within. Most BCGs, especially nearby ones, only have a single component in optical — or a single galaxy, but quite some BCGs are dumbbells (two components) and more BCGs have been found to host three or even more components. However, there has not been any systematic work recently with the rich optical survey data to construct a sample of BCGs with multiple components (or fragmented BCGs as we call in this proposal), which is the focus of this RCEU proposal.

Dr. Sun’s group has already studied several BCGs with multiple components in the past, with multi-wavelength data. One recent example is the BCG of the galaxy cluster Abell 407, which is composed of seven components with luminosities comparable to the outlying cluster galaxies — we call it “seven-sister” BCG! Such studies shed light on the formation of BCGs, the growth of the SMBHs and the formation of cluster hot gas cores. It is important to extend these studies into a large sample.

We will focus on the redMaPPer sample of galaxy clusters from SDSS. There are 26111 clusters at $z = 0.081 - 0.60$ (median $z$ of 0.372), with robust mass calibration from weak lensing and sufficient optical spectroscopic data. The redMaPPer sample has been used in many studies including cluster cosmology, cluster scaling relations and galaxy evolution in
clusters.

Our science goals are:
1) Compile an unprecedentedly large, homogeneously selected sample of BCGs with multiple components. We are looking for offset between several kpc and 10 kpc for different components, which can be done with the SDSS data to $z = 0.60$ (where 10 kpc = 1.5"", well resolved by SDSS). It is emphasized that such a sample has never been constructed before. With such a large sample, we can examine the fraction of fragmented BCGs, and the relation between the fraction and the cluster richness (or mass), as well as redshift. 2) Study the properties of those components. We can also construct the luminosity function of all components. The distribution of their separation provides constraints on the dynamical time scales for cannibalism, which can be further compared with numerical simulations. We also emphasize such a large sample provides opportunities of follow-up studies in multi-wavelength.

**Student Prerequisites**
The successful applicant should have a good academic record (GPA > 3.3) and have finished introductory physics classes. The successful applicant should also have experience with computer programming (with e.g., python, R, C, Fortran) and scripting (with e.g., python, perl, shell).

**Student Duties**
The RCEU student will proceed the research with the following steps: 1) Extract the BCG catalog identified from the redMaPPer algorithm. There can be multiple BCGs with different probabilities for the same cluster. 2) Run SQL searches on the SDSS data server around the BCGs to select BCGs with multiple photometric objects within 50 kpc radius. 3) Candidates will be visually examined and verified. These two steps will be first performed on a small sample to optimize the selection criteria. The optimized criteria will be applied on the whole BCG sample. 4) For the final sample of BCGs with multiple components, the student will search for existing optical, radio, IR and X-ray data to further explore their properties, as well as examining the activities of their SMBHs.

This will also be a valuable sample for follow-up studies. Dr. Sun’s group will propose follow-up projects with *Chandra* and *HST* telescopes, both came with research grants. The results by the student will play an important role in our future proposals and papers. The student will be included in any publications with the sample. The student is also expected to present a poster on the project at a regional conference.

**Mentor Supervision and Interaction**
The mentor (Dr. Sun) has a large research group in the Department of Physics & Astronomy, with three postdocs (Dr. Liu, Dr. Ge and Dr. Chen) and five graduate students. Both the mentor and his postdocs/graduate students will interact with the RCEU student in regular basis and provide close tutoring. Dr. Sun’s postdoc, Chong Ge, is familiar with SQL and SDSS data and will interact with the student regularly. At the initial stage of the project, the student and mentor will meet about 2 hours per day to start the project. After the initial stage, the student will work more independently, consulting with the mentor and other group members when needed, also with weekly meetings with the mentor. Office space for the student will be provided in the Optics building. Laptop and workstation access can also be provided.
**Prior Awardees**

Dr. Sun supported one RCEU student in 2018, Cody A. McCammon, on the research project “Super-Massive Black Holes and Their Hot Gas Environment”. Mr. McCammon wrote scripts to analyze *Chandra* data of X-ray cool cores of some galaxy groups. He was able to derive some temperature profiles and obtain some interesting results. Mr. McCammon has presented the final poster of the work and we plan to have him present the work in a future regional conference. With this project, Mr. McCammon has gained experience on Linux system and commands, programming, scientific methods and presentation. He has also gained a deeper understanding of the evolution of supermassive black holes, galaxies and the general scientific research.