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Super-Massive Black Holes and Their Hot Gas Environment

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Project Summary

Energy output from super-massive black holes (SMBHs) has become an important ingredient in the cosmic structure formation — the feedback energy injected from a SMBH would simultaneously limit its growth along with the growth of the galaxy. A SMBH actively accreting is called an active galactic nucleus (AGN) and AGN can be luminous from radio to X-rays. Perhaps the most interesting SMBHs are those at the nucleus of the brightest central galaxies (BCGs) at the center of galaxy clusters, as they may be the most massive SMBHs in the universe. For their deep gravitational potential, these BCGs are generally embedded in a halo of hot, X-ray emitting gas with temperatures of 10 - 100 million K. The hot gas in fact accounts for the most baryons in galaxy clusters. The dense core of hot gas around a BCG is called X-ray cool core. With strong cooling in X-ray cool cores, a large amount of young stars should exist in BCGs with time, which is usually not observed. This is the classical "cooling flow" problem and now can be again explained by the feedback energy from SMBHs to keep hot gas from cooling. The hot gas provides a historical chronicle of the SMBH activity. Energy output from SMBHs will perturb the surrounding hot gas, creating cavities and shocks. These features serve as calorimeters for the total energy outputs of the central SMBH. Thus, it is important to study the hot gas properties around the BCGs.

We have defined a sample of 98 nearby BCGs, as a representative sample for massive BCGs with luminous X-ray cool cores. There are *Chandra* X-ray data for all galaxies in the sample (so we know the properties of the hot gas), as well as radio data from surveys. We have also accumulated large amount of data in optical, infrared and radio to study the amount of cold gas in hot X-ray cool cores and the radio AGN. With all the data, the following outstanding questions will be addressed:
1) Understand the typical activity of SMBHs associated with BCG in different bands. What is the typical accretion rate of SMBHs associated with BCGs? A SMBH active on radio is not necessarily active on other bands, e.g., optical and X-rays. How are AGN activity in different bands connected? What can we learn about the conversion from mass to radiation or kinetic energy output? 2) The feeding of SMBHs, cold gas or hot gas? How is the AGN activity triggered? To study SMBH accretion, we need to resolve regions very close to SMBHs where the gravity of SMBHs dominates. This is why we focus on nearby BCGs. X-rays reveal temperature and density of the hot gas, while the properties of the cold gas can be determined

by Hα and FIR data. AGN activity in different bands can be studied. For example, SMBHs of many BCGs are active in radio. The classical idea for radio-mode feedback is hot gas accretion. However, accretion of the cold gas has been suggested recently as an alternative channel. Simulations predict the precipitation condition of $t_{\rm cooling}/t_{\rm ff} \leq 10$ (or the ratio of the cooling time to the free-fall time), especially at 0.1 - 10 kpc radii. We can test these models with the inner temperature profile of the hot gas and the $t_{\rm cooling}/t_{\rm ff}$ profile. 3) Understand the conditions for precipitation or multiphase medium, as well as energy transfer for gas in different phases, also key questions in galaxy formation. If precipitation is triggered from thermal instabilities of the hot gas, gas at the cold phase, warm phase and hot phase should be tightly correlated, which is not the case if the cold gas observed is from stellar mass loss or infall galaxies. This will be tested with our large, representative sample. 4) Study the effect of AGN feedback on BCGs and calibrate the AGN power with the *Chandra* data.

Student Prerequisites

The successful applicant should have a good academic record (GPA > 3.2) and have finished introductory physics classes. The successful applicant should also have experience with computer programming (with e.g., python, C, Fortran) and scripting (with e.g., python, perl, shell).

Student Duties

The RCEU student will work on the *Chandra* X-ray data of BCGs, including removing time intervals with high particle background, gain correction, generating new event files etc. The student will work on about ten BCGs, with about 500 ksec *Chandra* data in about 20 observations. The RCEU student will generate X-ray images that are background-subtracted, exposure-corrected and point-source-removed, temperature profiles around the central SMBH, heavy element abundance profiles and the X-ray gas density profile. Assuming hydrostatic equilibrium, potential profile can be derived, as well as the free-fall time profile. Then cooling time vs. free-fall time ratio profile can be derived. Potential profile can also be derived by assuming isothermal gravitational potential. For systems significantly perturbed by the energy output from SMBHs, temperature map and entropy map may also be generated. The RCEU student will also be part of a large international collaboration on BCGs, providing important results on hot gas.

Mentor Supervision and Interaction

The mentor (Dr. Sun) has a large research group in the Physics department, with four postdocs (Dr. Morandi, Dr. Liu, Dr. Ge and Dr. Chen) and five graduate and undergraduate students. Both the mentor and his postdocs/students will interact with the RCEU student in regular basis and provide close tutoring. 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.