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# X-ray Morphological and Spectral Properties of NGC 1407

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## ABSTRACT

We present a detailed study of nearby group centred on its bright central galaxy NGC 1407. From an archival Chandra observation, we found a dynamically disturbed environment with evidences of sloshing of the intergalactic medium. The surface brightness profile of NGC 1407 was fitted using one dimensional β-model, the model clearly shows the excess emission in core. The spectroscopy study revels the azimuthally averaged temperature profile increasing radial outward direction. Hence, the excess emission from centre and the increasing temperature in radial outward direction indicate the presence of cooling gas flow radially inward direction in BCG. From the Chandra residual image we have identify the multiple putative surface brightness depression region surrounded by centre of NGC 1407. This has been probably interpreted as an indication of multiple possible radio outbursts occurring at different time scale.

**Keywords:** Galaxies: clusters: general – galaxies: groups: individual (NGC 1407) – X-rays: galaxies: groups and cluster

## I. INTRODUCTION

This The hot intracluster medium (ICM) contains the largest baryonic material in groups and clusters of galaxies (Gonzalez et al. 2013). In the most relaxed galaxy clusters, the ICM cools and come towards the centre and make the high-density gas reservoirs in near of the brightest cluster galaxies (BCG). The density profile of the ICM is normally fitted with the β model (Cavaliere & Fusco-Femiano 1978), consisting of a flat core and rapidly decreasing outskirts. However, in many clusters, the core electron density is not accurately described by a one β profile, but is observed to be a sharply peaked, reaching values considerably larger than the typical $n_e \sim 10^{-3}$ cm$^{-3}$.

The cold inner gas is thought to fuel the super massive black hole (SMBH) in the BCG, which in turn, launches the powerful jets which capable of creating the surface brightness depressions (the so-called X-ray cavities) in the ICM (McNamara & Nulsen 2007, 2012). The tight correlation between the ICM thermodynamical state and the activation of the central active galactic nucleus (AGN) points to the existence of a feedback in BCG (e.g., Bîrzan et al. 2004; Edge 2001; Peterson & Fabian 2006, Vagshette et al.

2019). AGN is expected to play an important role in regulating cooling, ultimately inducing tight scaling relations between the SMBH (Gaspari et al. 2019; Pasini et al. 2021).

NGC 1707 belong to Eridanus supergroup, which contains three main groups: the NGC 1407 group, the NGC 1332 group, and the Eridanus group (Brough et al. 2006). Among them NGC 1407 group is the most dynamically and relaxed. NGC 1407 is the brightest one in the supergroup. The NGC 1407 group has comparatively relaxed X-ray morphology and has a cool core centred on NGC 1407 (Zhang et al. 2007). NGC 1407 is X-ray luminous ($L_X = 8.6 \times 10^{40}$ erg $s^{-1}$ in 0.1–2.0 keV, Irwin 2013).

The paper is structured as follows: In section 2 we describe the observation and data analysis. Section 3 explains surface brightness distribution, structure of NGC 1407 galaxy, and spectroscopic hot gas properties in NGC 1407 and finally section 4 summarises the our conclusion.

The organization of this document is as follows. In Section 2 (Methods and Material), I'll give detail of any modifications to equipment or equipment constructed specifically for the study and, if pertinent, provide illustrations of the modifications. In Section 3 (Result and Discussion), present your research findings and your analysis of those findings. Discussed in Section 4(Conclusion) a conclusion is the last part of something, its end or result.

## II. OBSERVATION AND DATA REDUCTION

An X-ray data of NGC 1407 was taken from Chandra archive which was observed by Dr. Raymond White on Aug 16 2000 (obsID 791) for 48.5 ks, with ACIS-235678 chips. The data were analyzed with CIAO-3.4 and heasoft 6.9 and reprocessed with level 2 event file, following Chandra standard data processing threads, we extract the light-curve to iden- tify and remove the high period of background, the total good exposure time of the resultant cleaned image is 38 ks. The cleaned image were used for further analysis.

The spectra were extracted using CIAO-3.4 script of *acisspec*. Each spectra has been grouped to at least 20 counts per spectral bin. We used XSPEC and Sherpa to fit the model to the spectra. For all the fitted models, the absorption column was fixed at the galactic value ($N_H$=5.43 × $10^{20}$ $cm^{-2}$; Dickey & Lockman 1990). For the resolved sources and diffuse emission we limited the spectral range to 0.5 - 6 keV. Background was taken from source free region, far from galaxy but is in S3 chip.

## III. RESULTS AND DISCUSSION

### 3.1 Surface Brightness Distribution

We extract the radial surface brightness profile in circularly- concentric annular rings centered on the center on NGC 1407, and excluded all the point sources. The 0.3-10.0 keV band emission was detectable out to 2′ radius. We chose an annular region far from centre of galaxy to extract the back-ground region. We fit a single β model to the gaseous surface brightness distribution, but this does not provide acceptable fit, it

Shows some excess emission in a inner region.

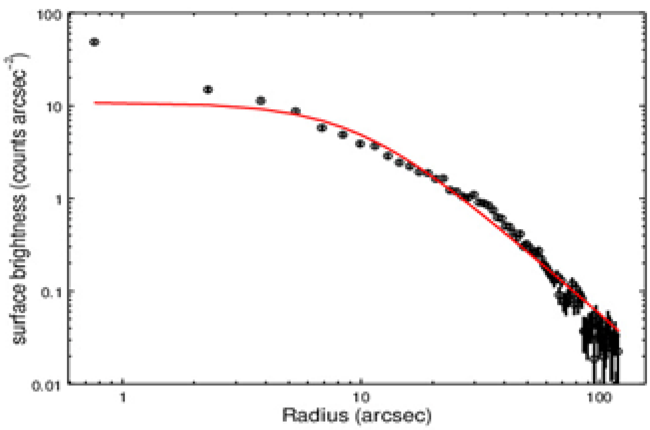


Figure 1. Exposure-corrected 0.3–3 keV surface brightness profile fitted with 1D-beta model

### 3.2 Hot gas properties

To determine the physical properties of hot gas in BCG NGC 1407, we extracted a radial spectral profile centered on the galaxy. After excluding the contribution of resolved point sources, we produced projected radial temperature profiles by extracted a spectra of 14 circular annuli centered on the peak of X-ray emission. The spectra were fitted with absorbed MEKAL thermal plasma model. The electron density is derived from emission integral $EI = \int n_e n_p dV$ where V is the volume and n=0.82ne in ionized cluster plasma. The pressure and entropy was calculated as P=nkT and $S = kT\,S^{-2/3}$ respectively. Figure 2 shows the resulting temperature, density, pressure and entropy profile. The resultant temperature and surface brightness profile clearly evident the NGC 1407 galaxy shows the cooling flow nature i.e. Gas flow radial inward direction.

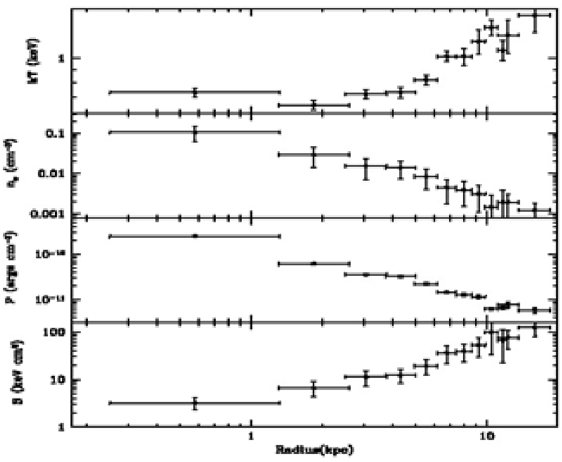


Figure 2. Radial profiles of temperature, density, and pressure and entropy in NGC 1407.

### 3.3 X-ray imaging

To enhance the visibility of diffuse emission, bright resolved sources were removed, and region containing point sources were “filled in” using Poisson distribution, whose mean value equal to the local annular background region. Using 2-d β-model (see Dong et al. 2009) imaging technique, we have created the residual image to enhance the hidden features in galaxy. Figure 3 show the NGC 1407 is not smoothly distributed but is instead perturbed with the cavity and edges. The surface brightness depressions are clearly visible along North and South direction from the centre of galaxy. This depression is nothing but the cavities and are created from jet when interact with environment of galaxy and cluster. This image also reveals that hot gas is highly perturbed this may possible due to sloshing motion due to the merging of galaxies.

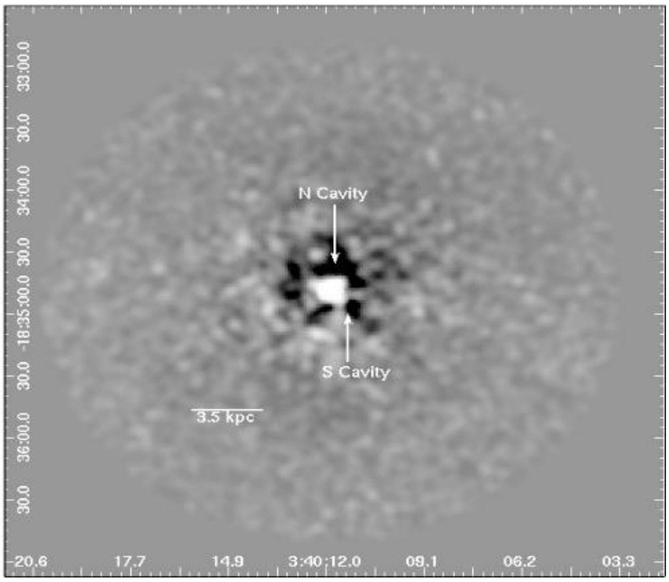


Figure 3 2D beta model subtracted *Chandra* residual image of NGC 1407

## IV. CONCLUSION

The *Chandra* observation of NGC 1407 shows the presence of sloshing movement of the IGM. The dynamically disturbed environment which evidences of sloshing in the intergalactic medium. The surface brightness profile and radial temperature profile indicate the presence of cooling gas flow radially inward direction in BCG. From the Chandra residual image we have identify the multiple putative surface brightness depression region surrounded by centre of NGC 1407. This has been probably interpreted as an indication of multiple possible radio outbursts occurring at different times.

## V. ACKNOWLEDGEMENT

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