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Close-up view of an ongoing merger between the NGC 4839 group and the Coma cluster

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Abstract. We analyse archival *XMM-Newton* observations of the massive galaxy group NGC 4839 falling into the Coma cluster core, which reveal a complex morphology for the merger. By comparing high quality X-ray maps of the merging subcluster with SPH simulations, we propose an infall scenario which qualitatively reproduces the observed structure of the NGC 4839 tail.

Keywords. galaxies: clusters: individual (Abell 1656 (Coma), NGC 4839 group), X-rays: galaxies: clusters

1. Introduction

According to the current concordance cosmological model, galaxy clusters form hierarchically through rare dramatic merger events and more gentle continuous accretion of smaller objects. The Coma cluster of galaxies, as one of the nearest massive galaxy clusters, provides an excellent laboratory for studies of structure formation processes. Optical and X-ray observations have revealed a wealth of substructures in Coma (Vikhlinin, Forman & Jones 1997; Adami *et al.* 2005; Neumann *et al.* 2003). One of the most prominent is the NGC 4839 group of galaxies. It lies in the cluster outskirts ($\sim$1 Mpc in projection) South-West from the cluster center. The X-ray image exhibits an edge-like structure at the head of the galaxy group and an elongated tail of ram pressure stripped gas extending toward the South-West (see Fig. 1, upper right panel), i.e. opposite to the direction of the Coma center. The NGC 4839 group appears to be falling onto the Coma cluster core, and the infall direction coincides with a filament connecting the Coma cluster with Abell 1367. It has been debated for a long time (i) whether this infall is radial (Colless & Dunn 1996) or non-radial (Biviano *et al.* 1996; Adami *et al.* 2005), and (ii) whether we observe the first passage (Colless & Dunn 1996; Neumann *et al.* 2001; Ogrean & Brüggen 2013; Akamatsu *et al.* 2013) or if the group has already passed the Coma cluster center (Burns *et al.* 1994).

Here, we analyse available *XMM-Newton* observations and compare X-ray maps with SPH simulations to constrain the 3D geometry and a trajectory of the infalling group. More details can be found in Lyskova *et al.* (2019). All our results are scaled to a flat ΛCDM cosmology with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and a Hubble constant $H_0 = 70$ km s^{-1} Mpc^{-1}, which implies the linear scale of 27.98 kpc arcmin^{-1} at Coma's redshift $z = 0.0231$ (NED database).

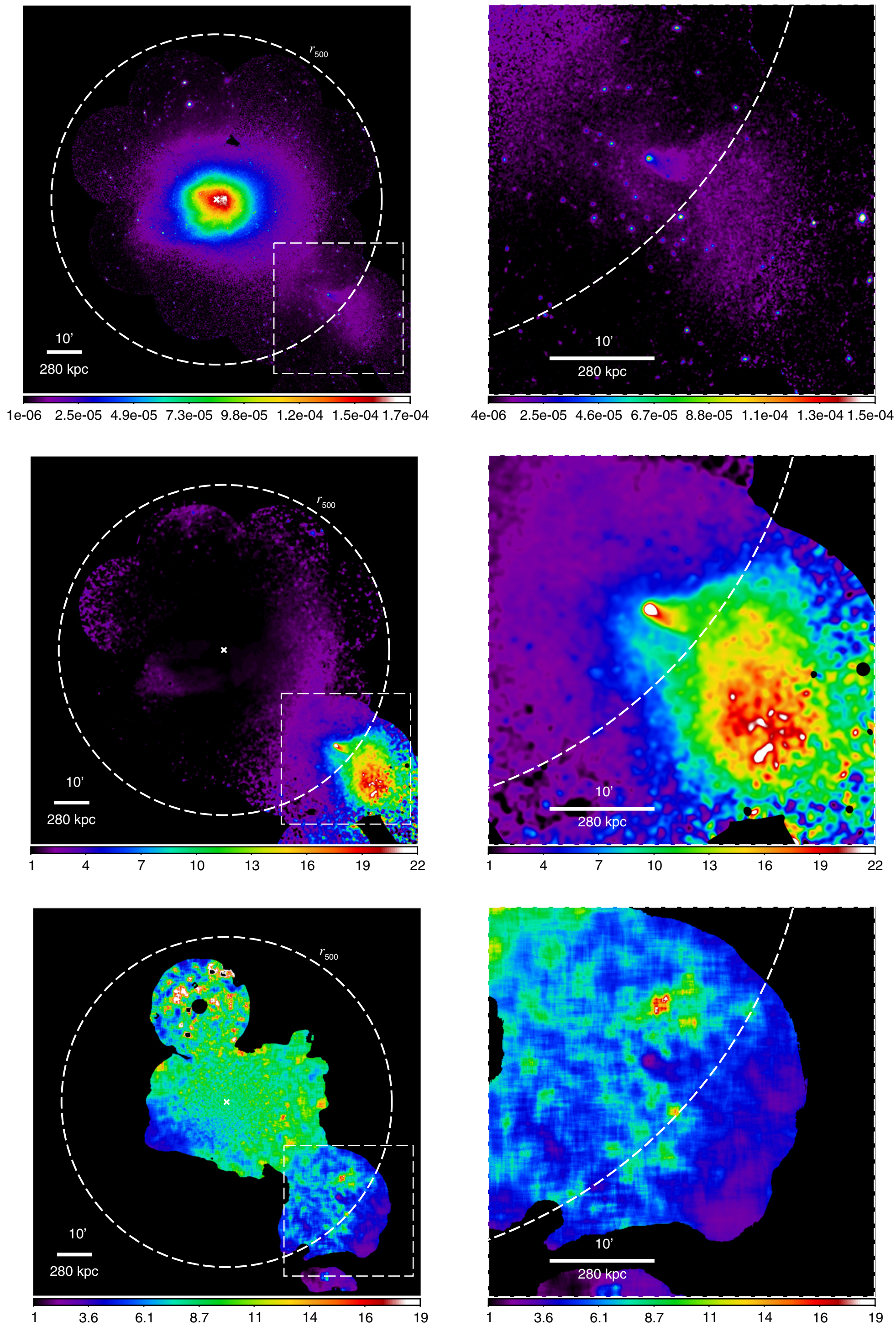

Figure 1. *Upper row: XMM-Newton* image of the Coma Cluster (left panel) and the NGC 4839 group (right panel) in the 0.5–2.5 keV energy band. *Middle row:* Surface brightness excess over the best β-model. *Bottom row:* Projected temperature map. The white dashed circle marks the radius of $r_{500} = 47$ arcmin (Planck Collaboration *et al.* 2013).

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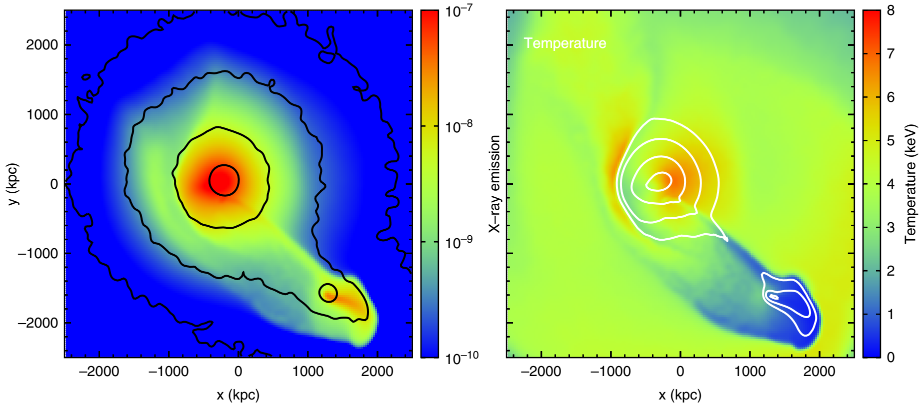

Figure 2. X-ray surface brightness (left panel) and X-ray weighted temperature (right panel) images of our 'best-fit' model at the moment just after the primary apocentric passage of the group. The black and white contours represent the mass surface density and the X-ray surface brightness distributions, respectively. Our model shows a good match to the X-ray morphology of the NGC 4839 group (e.g., its asymmetric tail).

2. The Coma Cluster and the NGC 4839 group

We have analysed publicly available *XMM-Newton* data of Coma and constructed the background-subtracted, exposure- and vignetting-corrected image in the 0.5-2.5 keV energy band (Fig. 1, upper left panel). The zoom-in view of the NGC 4839 group is shown in the upper right panel of Fig. 1.

To describe the surface brightness profile of the Coma cluster, we extracted X-ray counts from within circular annuli centred at (RA, DEC) = (194.94458, 27.95). We exclude the sector containing the NGC 4839 group. The measured distribution is well fit with the one-dimensional β-model (Cavaliere & Fusco-Femiano 1978) with the core radius $r_c = 9.9$ arcmin $\simeq 277$ kpc and $\beta = 0.71$. To remove the global cluster emission and highlight the surface brightness deviations from the smooth underlying model, we divide the X-ray image (Fig. 1, upper row) by the best-fitting β-model. The result is shown in the middle row of Fig. 1. In addition to the extended X-ray emission around and behind (SW) the NGC 4839 group, there is a prominent X-ray excess in the West, elongated in the North-South direction, and a filamentary shaped excess (though not very prominent in this image) to the East of the cluster centre, elongated in the East-West direction (Vikhlinin, Forman & Jones 1997; Neumann *et al.* 2003).

To construct a (projected) temperature map of the Coma cluster, we follow a technique described in Churazov *et al.* (1996). We model the ICM as a single thermal component with the thin-plasma emission code APEC (Smith *et al.* 2001) absorbed by the Galactic hydrogen column density $N_H = 9 \times 10^{19}$ cm^{-2} (Dickey & Lockman 1990). The resulting temperature map is shown in Fig. 1 (bottom row).

3. Comparison with simulations

We performed smoothed-particle hydrodynamic (SPH) simulations† to investigate the merging scenario of the NGC 4839 group. We model the Coma cluster and the group both as spherical objects consisting of a dark matter halo and a gas halo (see Zhang, Yu & Lu 2014, 2015 for a detailed description of the simulation method). We fix the mass of the Coma cluster $M = 1.2 \times 10^{15} M_\odot$ and the mass ratio between the main cluster and the

† We adopt the Gadget-2 code throughout this work (Springel *et al.* 2001).

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group $\xi = 10$ in our simulations (see Colless & Dunn 1996), but vary the initial relative velocity (V) and the impact parameter (P) to find a 'best-fit' merging configuration.

We find that an off-axis merger with $V = 500$ km s^{-1} and $P = 2000$ kpc provides a good match between the modelling and the real X-ray observations (see Fig. 1), when the group is close to the primary apocentre. Fig. 2 shows the simulation results for our 'best-fit' model at the moment just after the apocentric passage of the group. An asymmetric tail trailing the infalling group in the X-ray image (left panel) is similar with that seen in Fig. 1, upper right panel. This structure is formed in the following way. While crossing the apocentre center, the group slows down, which however contributes a significant gravitational drag to its wake. This overshooting wake subsequently sweeps over the group and forms the tail-like structure.

4. Conclusions

The majority of recent studies (e.g., Ogrean & Brüggen 2013; Akamatsu *et al.* 2013) argue that the NGC 4839 group is most likely to come from the south-west direction along the filament connecting Coma with Abell 1367 and that it has just started to penetrate the Coma ICM. Our analysis of *XMM-Newton* data and comparison of obtained X-ray maps with SPH simulations suggest a possible alternative scenario. Indeed, before the pericenter passage, the tail of the subcluster appears symmetric, while X-ray data reveal a complex structure and an asymmetric shape for the tail of the NGC 4839 group. The group may be caught at the moment just after the apocentric passage. In this merger scenario, rotation of the gas core forms the observed morphology of the tail.

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