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A high-inclination collision leading to gas sloshing in the galaxy cluster Abell 2199

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Abstract. Non-frontal collisions of galaxy clusters may trigger the phenomenon of sloshing, in which cool gas is removed from the dense cluster core and forms a spiral feature. Abell 2199 shows signs of sloshing in its core and it has been proposed that the orbital plane of the collision might be seen under a large inclination. We aim to investigate whether the properties of Abell 2199 may be understood as a sloshing spiral seen nearly edge-on. To explore this, we carried out dedicated hydrodynamical N-body simulations of an off-axis encounter with a galaxy group having $M_{200} = 1.6 \times 10^{13}$ M$_\odot$. We obtained an acceptable model in which the pericentric passage took place approximately 0.8 Gyr ago, with a separation of 292 kpc. The simulated temperature maps display good agreement with X-rays observations, as do the residuals from a β-model fit to the simulated X-ray emission. We find that even under a large inclination angle of $i = 70°$ the simulation results are consistent with the morphology of the observations.

Resumo. Colisões não-frontais de aglomerados de galáxias podem desencadear o fenômeno de sloshing, no qual o gás frio é removido do núcleo denso do aglomerado e forma uma estrutura espiral. Abell 2199 mostra sinais de sloshing em seu núcleo e foi proposto que o plano orbital da colisão pode estar sendo visto sob uma grande inclinação. Nosso objetivo é investigar se as propriedades de Abell 2199 podem ser entendidas como uma espiral sloshing vista quase de perfil. Para explorar isso, realizamos simulações hidrodinâmicas de N-corpos de um encontro não-frontal com um grupo de galáxias com $M_{200} = 1.6 \times 10^{13}$ M$_\odot$. Obtivemos um modelo aceitável em que a passagem pericêntrica ocorreu há aproximadamente 0.8 Gyr, com separação de 292 kpc. Os mapas de temperatura simulados mostram uma boa concordância com as observações de raios-X, assim como os resíduos de um modelo β ajustado à emissão de raios-X simulada. Descobrimos que mesmo sob um grande ângulo de inclinação de $i = 70°$ os resultados da simulação são consistentes com a morfologia das observações.

Keywords. Galaxies: clusters: intracluster medium – Methods: numerical

1. Introduction

The phenomenon of gas sloshing (Ascasibar & Markevitch 2006) occurs when a cool-core cluster undergoes a non-frontal encounter with a secondary cluster or group. The gravitational disturbance causes the cool gas to form a spiral feature. Examples of merging clusters interpreted as seen nearly along the line of sight are rare in the literature (Dupke et al. 2007; Ueda et al. 2019).

Abell 2199 is a galaxy cluster that displays signatures of a recent collision. In particular, it has been proposed (Nulsen et al. 2013) that its X-ray asymmetries might be understood as the result of sloshing seen nearly edge-on. We aim to evaluate the plausibility of such scenario.

2. Simulation setup

We performed hydrodynamical N-body simulations of cluster collisions using the Gadget-2 code. The initial conditions of the main cluster were created such as to satisfy the observed bulk properties of Abell 2199, such as virial mass, baryon fraction and azymuthally-averaged radial temperature profile. The gas and dark matter halo are represented by 10^6 gas particles each and the collision simulation was carried out for at least 2 Gyr. Further details can be found in (Machado et al. 2022).

3. Results

From the output of the simulation, we produced temperature maps and also maps of the residuals between the simulated X-ray emission and the fitted β model. These maps may be projected under different inclinations. We explored the parameter space of possible collisions and obtained a best model. The time evolution of the temperature and X-ray residuals is shown in Fig. 1 for the inclination $i = 70°$.

Observational comparisons are shown for the temperature maps (Fig. 1) and the X-ray residuals (Fig. 2), with data from Chandra and XMM-Newton, respectively. The simulated temperature map recovers the appropriate ranges and the overall morphology. Likewise, the X-ray residuals indicate a fair agreement, with the caveat that the very inner region (of a few tens of kpc) cannot be expected to be accurately reproduced, because our models do not include AGN feedback.

4. Conclusions

We obteined a model which reproduces several observed features of Abell 2199, such as the morphology of the temperature and X-ray maps. In this model, the perturber has a mass of $M_{200} = 1.6 \times 10^{13}$ M$_\odot$. The pericentric passage took place 0.8 Gyr ago, with a separation of 292 kpc. Based on this set of models, we argue that the scenario of an edge-on sloshing is a plausible explanation for the dynamical history of this cluster.

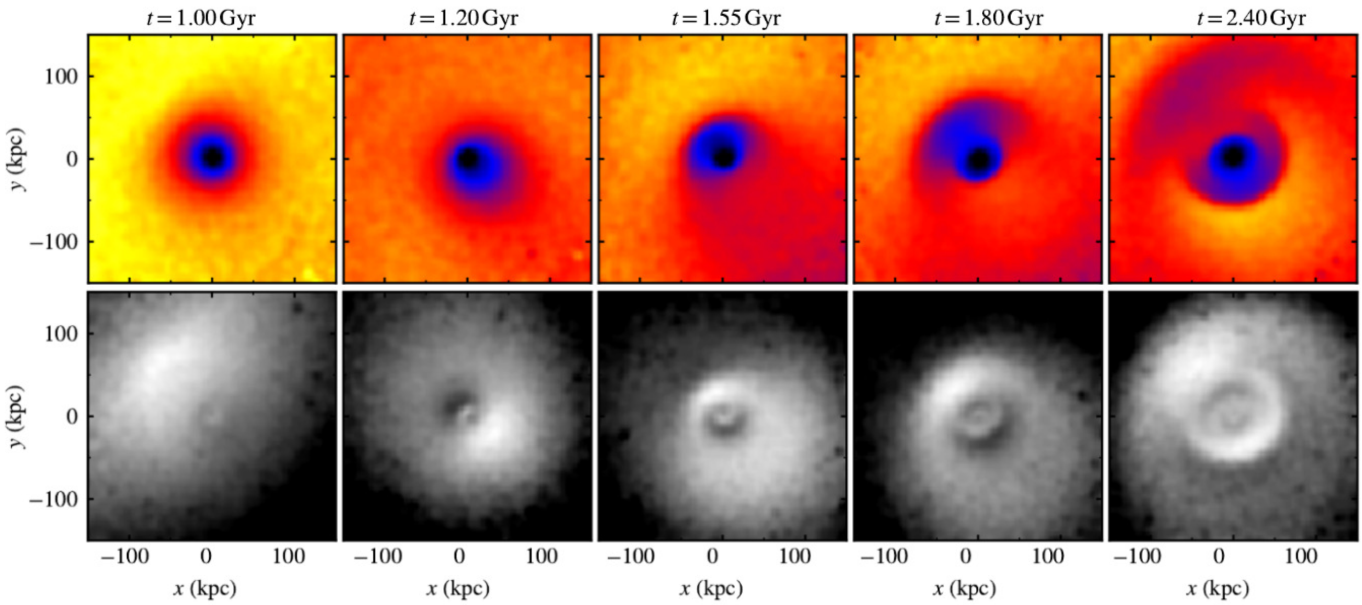

Figure 1. Time evolution of the best model with an inclination of $i = 70°$. The upper row shows temperature and the bottom row shows residuals from the β model fit.

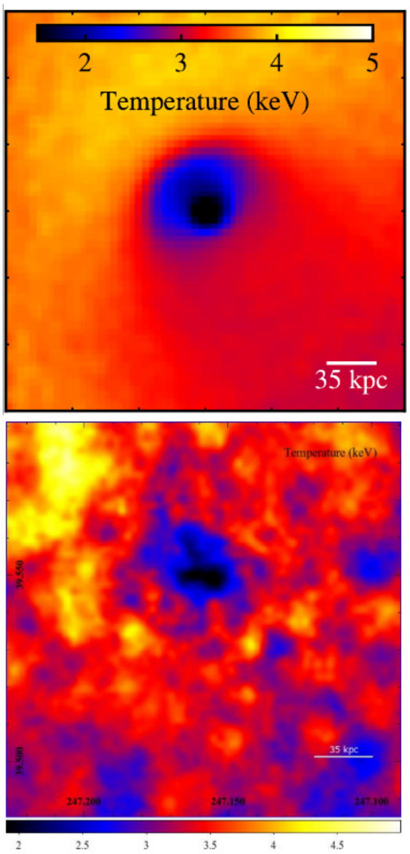

Figure 2. Temperature maps, comparing simulation (top) and observation (bottom). The simulated frame from $t = 1.55\,\mathrm{Gyr}$ is compared to Chandra data.

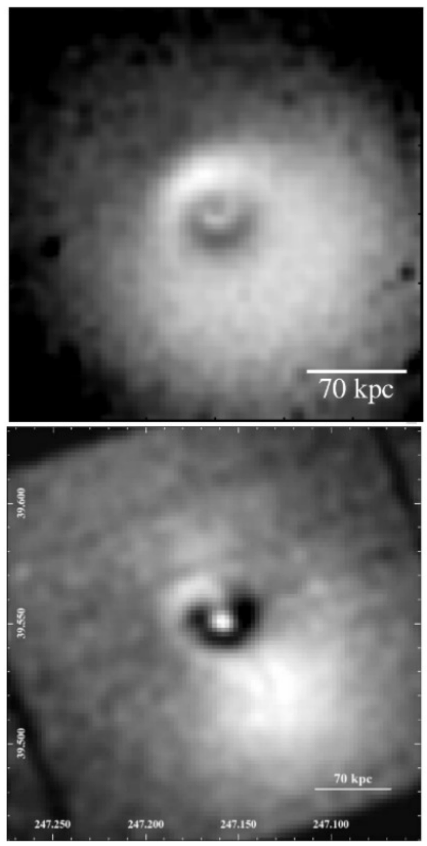

Figure 3. Residual maps, comparing simulation (top) and observation (bottom). The simulated frame from $t = 1.55\,\mathrm{Gyr}$ is compared to XMM-Newton data.

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