Boletim da Sociedade Astronômica Brasileira, **35**, no. 1, 248-249
© SAB 2024

Hydrodynamic simulations to unveil the complex merging of the Abell 2744 from JWST images

R. P. Albuquerque[1], R. E. G. Machado[1], L. V. Costa[2] E. S. Cypriano[2] R. Monteiro-Oliveira[3].

[1] Universidade Tecnológica Federal do Paraná, Paraná, Brasil. e-mail: `richards_pereira12@hotmail.com`
[2] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo, Brasil.
[3] Academia Sinica Institute of Astronomy and Astrophysics, Taiwan.

Abstract. Cluster mergers are a compelling area of research due to their potential to provide valuable insights into the properties and dynamics of dark matter and the intracluster medium. Abell 2744 is known as one of the most complex merging clusters in existence. The complexity of Abell 2744 arises from the presence of numerous subclusters of galaxies and an interloper gas on the west, the origin of which is difficult to comprehend. Our objective is to reconstruct the time evolution of the collision between the substructures in the Abell 2744 to understand its dynamics. We used preliminary weak lensing results from the ultra-deep JWST images in order to constrain the masses and concentrations of each simulated substructure. We performed multiple hydrodynamic N-body simulations to simultaneously reconstruct the dynamic history of the five substructures of Abell 2744. Preliminary results indicate that the optimal models are those that involve a collision between Core-S, Core-N, and N, occurring near the plane of the sky, with NW-1 and NW-2 colliding along the line of sight. Our model reproduces the distance constraints of the dark matter peaks but falls short of achieving a well-defined peak of gas, as observed. We obtained a slight gas overdensity on the west side of the NW-1 and NW-2 peaks. However, we did not achieve a well-defined peak of gas near the north cluster. Further simulations are required to confirm and refine these results.

Resumo.
As fusões de aglomerados são uma área de pesquisa fascinante devido ao seu potencial para fornecer pensamentos valiosos sobre as propriedades e dinâmicas da matéria escura e do meio intra-aglomerado. Abell 2744 é conhecido como um dos aglomerados de fusão mais complexos. A complexidade de Abell 2744 decorre da presença de numerosos subaglomerados de galáxias e de um gás a oeste, cuja origem é difícil de compreender. Nosso objetivo é reconstruir a evolução temporal da colisão entre as subestruturas em Abell 2744 para entender sua dinâmica. Utilizamos resultados preliminares de lentes fracas a partir de imagens ultraprofundas do JWST para restringir as massas e concentrações de cada subestrutura simulada. Realizamos múltiplas simulações hidrodinâmicas de N-corpos para reconstruir simultaneamente a história dinâmica dos cinco subaglomerados de Abell 2744. Resultados preliminares indicam que os melhores modelos envolvem uma colisão entre Core-S, Core-N e N, ocorrendo próximo ao plano do céu, com NW-1 e NW-2 colidindo ao longo da linha de visada. Nosso modelo reproduz as distância obtidas observacionalmente dos picos de matéria escura, mas não obtém picos de gás bem definidos, como observado. Obtivemos uma ligeira sobredensidade de gás no lado oeste dos picos NW-1 e NW-2. No entanto, não conseguimos obter um pico bem definido de gás próximo ao aglomerado norte. Mais simulações são necessárias para confirmar e aprimorar esses resultados.

Keywords. (Galaxy:) globular clusters: individual: Abell 2744 – Gravitational lensing: weak– (Cosmology:) dark matter

1. Introduction

Recently, the James Webb Space Telescope observed the cluster of galaxies Abell 2744 (also known as ‘Pandora’s cluster’). These images allowed us to improve previous models that estimated its mass. Through the analysis of weak gravitational lensing, it was possible to identify the substructures of the clusters and their respective masses. Cluster mergers are a compelling area of research due to their potential to provide valuable insights into the properties and dynamics of dark matter and the intracluster medium. Abell 2744 is known as one of the most complex merging clusters in existence, which was studied by Medezinski et al. (2016) and Merten et al. (2011). The complexity of Abell 2744 arises from the presence of numerous subclusters of galaxies and an interloper gas on the west, the origin of which is difficult to comprehend.

2. Methods

By analyzing weak gravitational lensing, we were able to estimate the mass and position of each substructure, as shown in Fig. 1. We found five mass clumps (Core-N, Core-S, NW-1, NW-2, N) with approximate masses of (3.9, 0.9, 0.5, 2.1, 1.9) $\times 10^{14}$ $M_\odot$, respectively. By properly setting the initial conditions for the simulations, ensuring that the M_{200} of the simulated halos matched the M_{200} from the weak gravitational lensing analyses. We positioned the distant halos with approaching velocities in such a way that the simulation results were analogous to the lensing map, as shown in Fig. 1. Due to the complexity of the scenario, we conducted the simulations in pairs to understand each collision mechanism separately. As a preliminary simulation, we initiated a collision between Core-N and Core-S with an initial separation of 400 kpc and an approach velocity of $v_0 = 0\,\mathrm{km\,s^{-1}}$. Additionally, we positioned the N cluster with an initial distance of 3000 kpc from the mass center of the Core-N and Core-S, with an impact parameter of $b = 400\,\mathrm{kpc}$, and $v_0 = 1000\,\mathrm{km\,s^{-1}}$. Separately, we collided NW-1 and NW-2 in the line of sight, with an initial distance of 3000 kpc, an impact parameter of $b = 400\,\mathrm{kpc}$, and $v_0 = 1000\,\mathrm{km\,s^{-1}}$. Finally, we combined the Core-N, Core-S, and N collision with NW-1 and NW-2, separating them with a distance from the mass center of 2500 kpc, $b = 400\,\mathrm{kpc}$, and $v_0 = 1000\,\mathrm{km\,s^{-1}}$. With this collision scenario, we conducted

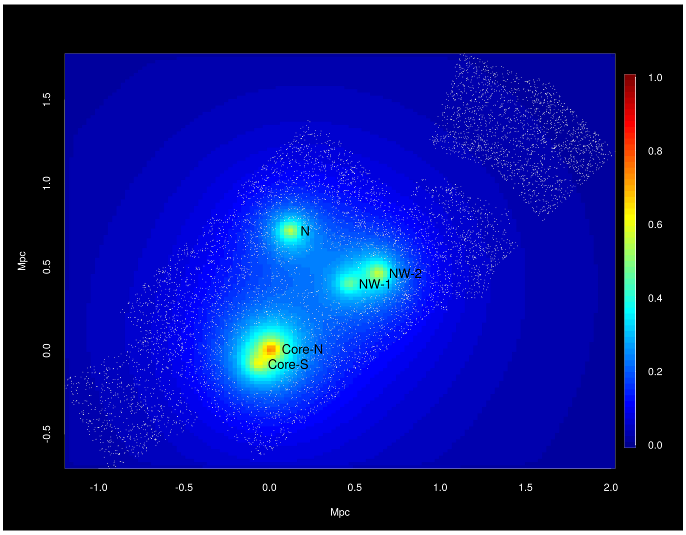

Figure 1. Mass distribution in the field of the Abell 2744 Cluster. In the figure, we see the result of the best fit of 5 NFW profiles to the weak gravitational shear data defined by the shapes of background galaxies (white points). The colors refer to convergence, or the projected mass density on the plane of the sky in units of the critical density for gravitational lensing (2.3×10^{15} M$_\odot$/Mpc^2). The choice of the number and position of substructures comes from the observation of gravitational arcs.

simulations that met the distance constraints of the dark matter peaks.

3. Simulation results

The evolutionary history of Abell 2744 is complex due to the large number of substructures. To better understand it, we will describe the collisional systems separately. In an attempt to detect an interloper gas on the west side, we collided the NW-1 and NW-2 clusters along the line of sight, as shown in the third row of the Fig. 2. Combining the Core-N, Core-S, and N clusters collision with NW-1 and NW-2, we obtained the results shown on the right painel of Fig. 3. A noticeable slight overdensity region on the west side is detected in the observations and reproduced with lower resolution in the simulations. Preliminary results aimed to accurately reproduce the distance of the dark matter peaks and the position of the gas density peaks. More simulations are required to refine the model and achieve a well-defined peak of gas near the north cluster. In the current model, only diffuse gas in that region was obtained. The contour lines of the final model did not resolve the core region in Core-1 and Core-2. The next step is to adjust the initial conditions to better capture these two substructures.

4. Conclusions

In this work, we conducted a modeling of the dynamic history of the Abell 2744 cluster. The Abell 2744 cluster proved to be very complex due to its multiple collisions and dissociative processes. As preliminary results, we were able to achieve a consistent model for the position of the dark matter peaks. To arrive at such a scenario, it was necessary to collide the Core1 and Core2 clusters in a way that they remained close to each other, And then the N cluster passed through the central region, losing its gas and shifting a little the peak of gas density. We propose that the NW1 and NW2 clusters a collision along the line of sight axis. Further simulations are required to confirm and refine the results, achieving a more defined peak of gas density in the position constrained by observations.

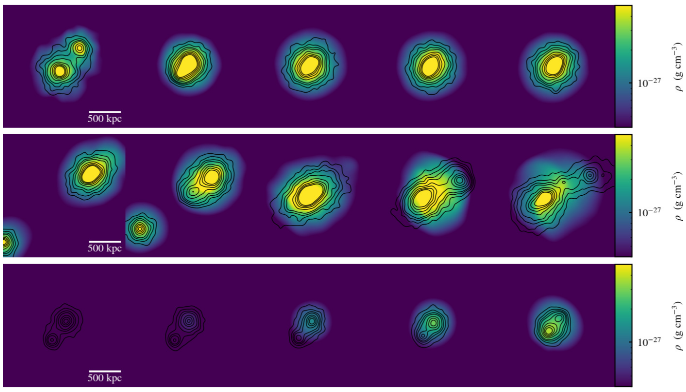

Figure 2. In the first row, we have the time evolution of the gas density of Core-N and Core-N clusters, in the second row, the N cluster experiences an almost head-on collision with the Cores, and in the third, the NW1 and NW2 clusters. Contour lines on the plot represent the distribution of dark matter.

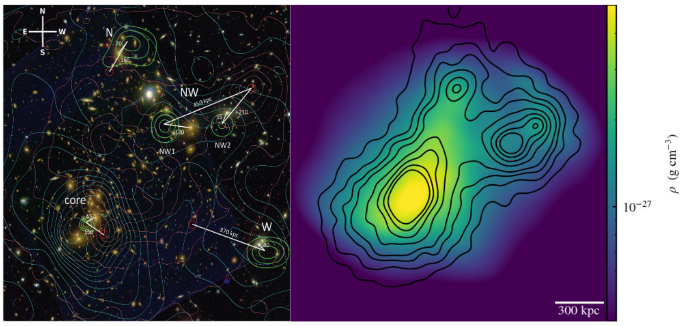

Figure 3. On the left, the field of Abell 2744 where the red contour lines indicate the gas density in that region (Merten et al. 2011). On the right, the best snapshot from the hydrodynamic simulation of the cluster. The color map represents the gas density, and the contour lines the distribution of dark matter.

5. Perspectives

For future research, it will be necessary to combine the gravitational lensing map with the X-ray emission map to obtain an overall view of the cluster. This is a preliminary model, and more simulations are required to achieve the appropriate distances between the peaks of gas and dark matter density, as well as the distances between each cluster.

Acknowledgements. CAPES, CNPq and UTFPR

References

Merten et al. 2011, MNRAS, 417, 333-347.
Medezinski et al. 2016, Apj, 817, 24-40.