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Simulations of merging galaxy clusters with very hot shock fronts and observed near the pericentric passage

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Abstract. The largest gravitational structures in the universe are the galaxy clusters. Clusters are formed by highly energetic mergers with smaller structures and the energy dissipated during this process by shock waves warms the intracluster medium (ICM). Using hydrodynamical N-body simulations, we look for models that best represent the binary merger of the PLCKESZ G036.7+14.9 (z = 0.15; hereafter G036) and PLCK G292.5+22.0 (z = 0.30; hereafter G292), focusing particularly on shock fronts and temperature maps. With initially spherical halos separated by 3 Mpc each simulation include an evolution of 3 Gyr. The simulations brought us data that reproduces the observed properties of the clusters. In G036 we have a non frontal collision and at the best instant, which is only 50 Myr before the pericentric passage, the orbital plane must be inclined at 50° with respect to the plane of the sky. However in G292 we observed a frontal collision and viewed at a inclination of 18° with the best instant just 150 Myr before the central passage.

Resumo. As maiores estruturas gravitacionais do Universo são os aglomerados de galáxias. Aglomerados de galáxias se formam por fusões altamente energéticas de estruturas menores e a energia dissipada durante esse processo por meio de ondas de choque aquecem o meio intra-aglomerado (ICM). Utilizando simulações hidrodinâmicas de N-corpos, buscamos modelos que melhor representem a fusão binária dos aglomerados de galáxias PLCKESZ G036.7+14.9 (z = 0.15; daqui em diante G036) e PLCK G292.5+22.0 (z = 0.30; daqui em diante G292), focando particularmente nas frentes de choque e nos mapas de temperatura. Com halos inicialmente esféricos e separados por 3 Mpc, cada simulação compreende uma evolução de 3 Gyr. As simulações nos trouxeram dados que reproduzem as propriedades observadas dos aglomerados. Em G036 temos uma colisão não frontal e no melhor instante, que é de apenas 50 Myr antes da passagem pericêntrica, o plano orbital deve estar inclinado em 50° em relação ao plano do céu. No entanto, em G292 observamos uma colisão frontal vimos uma inclinação de 18° com o melhor instante apenas 150 Myr antes da passagem central.

Keywords. Methods: numerical – X-rays: galaxies: clusters – Galaxies: clusters: intracluster medium

1. Introduction

Clusters of galaxies form by the merging of smaller structures. Among the major disturbances caused by galaxy cluster mergers are supersonic shockwaves heating the intracluster gas (e.g., Markevitch et al. 2002). We analyzed the PLCKESZ G036.7+14.9 (z = 0.15; hereafter G036) and PLCK G292.5+22.0 (z = 0.15; hereafter G292) and performed binary mergers by hydrodynamical N-body simulations and present models that reproduce observational data, particularly temperature maps.

We generate initial conditions for the subcluster, formed by dark matter and gas, this gas being the intracluster medium (ICM). We used a Dehnen (1993) profile for the gas component and a Hernquist (1990) profile for the dark matter halo.

For each simulation, we follow an evolution of 3 Gyr and in each situation, two initially spherical and relaxed subclusters, separated by 3 Mpc collide with an initial velocity and a given impact parameter. Among the objectives, we seek to reproduce the properties observed in the clusters, determining the inclination in relation to the sky plane during the pericentric passage and calculating the Mach numbers ($\mathcal{M}$) from the temperature jumps (T_2/T_1) on the shock fronts for the best moments of time. Thus, the Mach number is given by:

$$\frac{T_2}{T_1} = \frac{5\mathcal{M}^4 + 14\mathcal{M}^2 - 3}{16\mathcal{M}^2}\,. \qquad (1)$$

Table 1. Initial condition parameters for the G036 and G292 simulations. This table gives: M_{500}, r_{500}, central temperature, the radius R within which mass was measured, and the mass.

Cluster	M_{500} ($M_\odot$)	r_{500} (kpc)	T (keV)	R (kpc)	$M(<R)$ ($M_\odot$)
G036N	3.1×10^{14}	1028	8.5	105	0.7×10^{14}
G036S	3.6×10^{14}	1036	9.5	105	0.9×10^{14}
G292N	8.0×10^{14}	1913	6.5	670	4.1×10^{14}
G292S	3.6×10^{14}	1467	5.5	360	1.5×10^{14}

The simulations were performed using the Gadget-2 code (Springel 2005), and the initial conditions were generated with the Clustep[1] code. To generate temperature and density maps it was necessary to use a code adapted for ionized gas from the original code of yt-Project[2].

2. Results

The simulation for G036 reveals a best time at t = 2.59 Gyr and that this merger is not a frontal collision, because it has an impact parameter b = 1600 kpc and an initial relative velocity v_0 = −700 km/s. During its best time, the cluster is ∼ 50 Myr before the pericentric passage. To match the observed separation

[1] https://github.com/ruggiero/clustep

[2] https://yt-project.org/

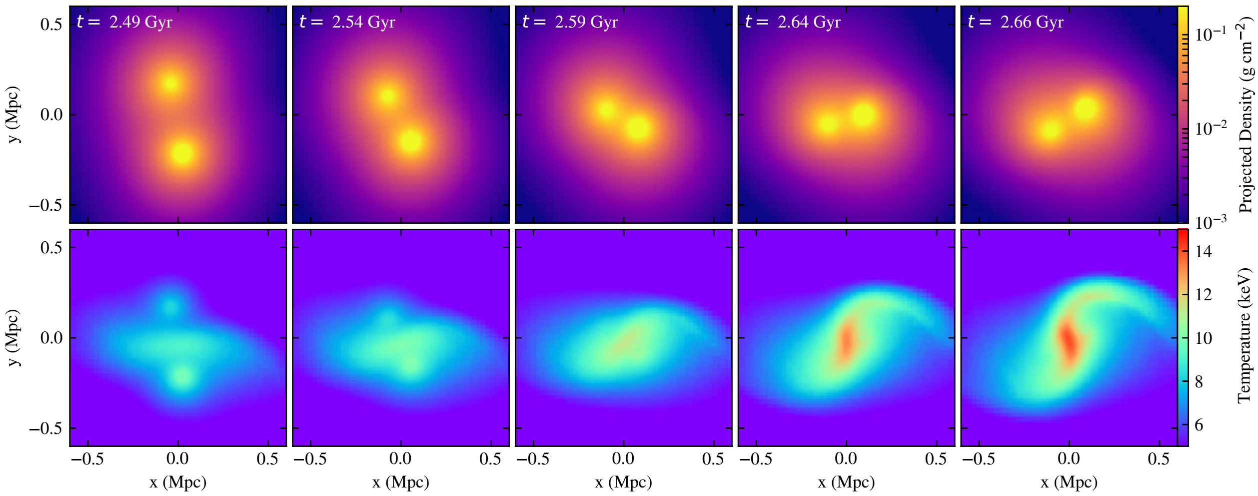

Figure 1. Considering that the best time (t = 2.59 Gyr) is in the center panel, above we have a temporal evolution of simulated G036 where the upper panels show projected density maps and lower panels show density-weighted projected temperature maps.

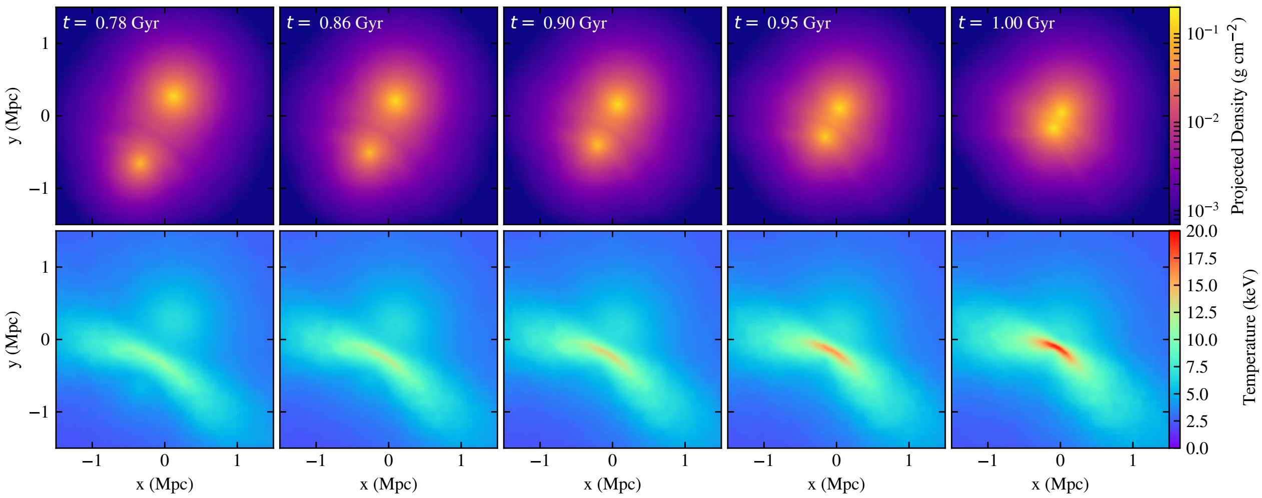

Figure 2. Considering that the best time (t = 0.90 Gyr) is in the center panel, above we have a temporal evolution of simulated G292 where the upper panels show projected density maps and lower panels show density-weighted projected temperature maps.

values at 178 kpc, the plane of the orbit must be inclined with respect to the plane of the sky by $i = 50°$.

Under these conditions, our best model reveals that the shock temperature would be approximately 9.5–10.8 keV, while pre-shock gas would be in the range of 6.6–7.4 keV. Thus, the temperature ratio resulted in Mach numbers of approximately $\mathcal{M} \sim 1.3$–1.6, which is consistent with the observational estimate of $\mathcal{M} \sim 1.3$. However, without a inclination, Mach's numbers would be in the range $\mathcal{M} \sim 1.5$–2.0 at the same instant and consistent with Zhang et al. (2015).

Unlike G036, G292 showed results consistent with a frontal collision, that is, an impact parameter $b = 0$ kpc and a initial relative velocity $v_0 = -2000$ km/s. Through the best model, we obtain that the best instant occurs at 150 Mpc before the central passage, which represents a better time at $t = 0.90$ Gyr and during this instant, the collision axis needs is inclined to $i = 18°$ with respect to the plane of the sky.

The shock front has a temperature between 11.4–13.6 keV, where pre-shock gas is between 6.6–7.2 keV, which implies a Mach number in $\mathcal{M} \sim 1.6$–2.0. The observational estimate is $\mathcal{M} \sim 1.5$. However, if temperatures had been measured without inclination, the resulting Mach numbers would have been slightly higher in the range $\mathcal{M} \sim 1.9$–2.1.

3. Conclusion

We obtained models that reproduce some of the properties observed in the galaxy clusters and found that the simulated Mach numbers are compatible with the observational estimates, from the amplitudes of the temperature jumps in the shock fronts in both cases. Numerical simulations such as these provide useful information about the history and dynamic state of clusters. For further details, see Laganá et al. (2019).

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