Velocity Structure Diagnostics of X-Ray Galaxy Clusters

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Abstract

The velocity diagnostics accessible through future X-ray satellites like ASTRO-H or IXO can be used to characterise non-thermal motions of the hot ICM within galaxy clusters. Allowing to account for the dynamical in addition to hydrostatic pressure support, this will be important for improving mass estimations and can be also used as selection criterion to identify non relaxed galaxy clusters. Therefore an analysis of the velocity structure of the ICM for simulated cluster-size haloes has been performed. In our work we note the presence of rotational patterns and find them to be an intermittent phenomenon strongly related to the internal dynamics of substructures: surprisingly the expected building-up of rotation due to mass assembly gets easily destroyed by passages of gas-rich substructures close to the central region.

Key words: Galaxy clusters; numerical simulations

1. Introduction

Within the hierarchical scenario, galaxy clusters are key targets that allow to study both the dynamics on the gravity-dominated scale and the complexity of astrophysical processes dominating on the small scale. Though, in order to treat them as cosmological probes their mass is the most crucial quantity to be evaluated, and all the bulk properties measured from X-ray observations still provide the best way to estimate the mass, primarily through hydrostatic equilibrium. Mass estimates rely then on the assumptions made about the cluster dynamical state, since the Hydrostatic Equilibrium Hypothesis (HEH) implies that only the thermal pressure of the hot ICM is taken into account. Lately, it has been claimed for instance that non-thermal motions, as rotation, could play a significant role in supporting the ICM in the innermost region (e.g. Lau et al. 2009, Fang et al. 2009) biasing the mass measurements based on the HEH. The analysis of simulated cluster-like objects provides a promising approach to get a better understanding of the intrinsic structure of galaxy clusters, which can be eventually compared to X-ray observations. Because of the improvement of numerical simulations, the possibility to study in detail clusters has enormously increased and future satellites dedicated to high-precision X-ray spectroscopy, such as ASTRO-H and IXO, will allow to detect these ordered motions of the ICM. With this perspective, we perform a preliminary study on the ICM structure for some clusters extracted from a large cosmological hydrodynamical simulation, investigating in particular the presence of rotational motion in the ICM velocity field.

2. Simulation

Our data set consists of 9 high resolution re-simulations of cluster-size haloes including radiative cooling, star formation and supernova feedback, extracted from a large size cosmological simulation of a ΛCDM universe. In total there are 19 haloes with masses larger than $0.5 \times 10^{14} M_\odot/h$, ranging from isolated and potentially relaxed objects to very disturbed systems. The study of these clusters and their evolution in time allowed us to investigate how significant and common the rotational support of the ICM is.

3. A case study: g51

From the strong cooling in the innermost region of clusters (found both in simulations and observations), that leads to the contraction of the central part and to the spin up of the core because of angular momentum conservation, a rotational motion of the gas in the central region is generally expected. As a case study, we focused on g51, an isolated massive cluster of $1.3 \times 10^{14} M_\odot/h$. While it is likely to be the most relaxed object in the sample, at $z = 0$ the velocity structure of the ICM in the innermost region is far from showing a clear rotational pattern, as expected from nearly homogeneous collapse process. However it shows some rotational pattern at intermediate redshift. Therefore this case has been used to study the details of building up and destroying rotation in the hot ICM.

3.1. Rotational velocity evolution

The possibility to track back the history of the cluster-size halo given by simulated data, let us follow the red-

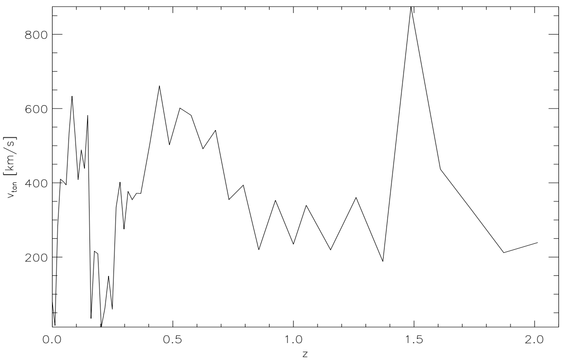

Fig. 1. Evolution with redshift of the tangential component of the ICM velocity within $0.1R_{500}$.

shift evolution of the rotational component of the ICM velocity in the innermost region of g51, taken to be $0.1R_{500}$. Up to $z = 2$, the tangential component of the ICM velocity has been calculated in the plane perpendicular to the direction of the gas mean angular momentum ("best equatorial plane"), so that rotation can be emphasized as much as possible. While in literature we found an inspiring work where values for the rotational velocity rise above $1000km/s$, in our study this never happens and values generally increase up to $650km/s$ as a maximum, except for high peaks probably related to merging events. In Fig. 1 we plotted the variation with redshift of v_{tan}. An interesting feature worth to be pointed out is the sudden drop of the value of v_{tan}, which steeply decreases twice at low redshift (at $z \sim 0$ and $z \sim 0.3$). A further investigation of the ICM internal dynamics has been then performed in order to understand the possible origin of this unexpected behavior.

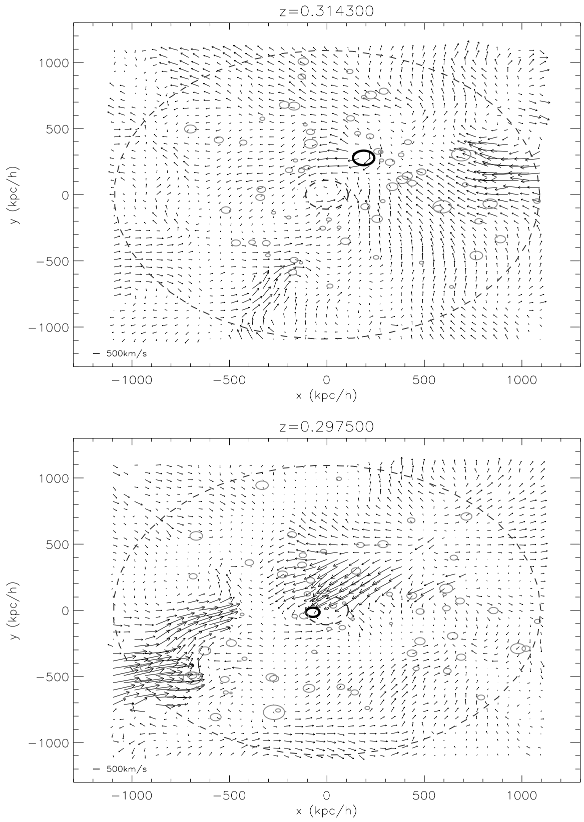

Fig. 2. Gas velocity fields at $z \sim 0.314$ (upper panel) and $z \sim 0.297$ (lower panel) projected onto the plane perpendicular to the direction of the gas mean angular momentum in the innermost region. The smaller and larger dashed circles mark respectively the regions of $0.1R_{500}$ and R_{500}, while the grey ones are DM-only subhaloes and the black circle is the gas-rich one passing through the plane.

3.2. ICM velocity maps

The velocity maps shown in Fig. 2 catch one of the two major decreases in the curve of v_{tan}, in particular the one at roughly $z \sim 0.3$, which is the first significant break in the increasing trend shown up to redshift ~ 0.5. Clearly, one can see the occurrance of a gas-rich subhalo (thicker circle) passage through the best equatorial plane, onto wich the gas velocity field has been projected in the Figure. Let us stress that there are several DM-only substructures permanently moving within the cluster and close to the innermost region, but they do not affect the building-up of rotation as gas-rich subhaloes do.

4. Conclusions

Although the detailed description of the building-up of rotation in the gas velocity structure due to collapse and cooling turned out to be quite complicated, a significant correlation between the internal dynamics of gas substructures and the cluster dynamical state is found. Even in the most relaxed cluster of the sample *no clear rotation* shows up *at low redshift because of some minor merging events* occurring *close to the innermost region*: the rotation of the core is found to be an intermittent phenomenon that can be easily destroyed by the passage of gas-rich subhaloes through the equatorial plane. This is likely to be then an important issue to handle in order to better understand deviations from the HEH, on which scaling laws are usually based. A statistics on a larger simulated sample and the investigation of the imprint of the gas rotational motion on the iron line profile will in the future provide more information to be compared to observations from future X-ray instruments. This will allow us to detect such rotational patterns in the ICM.

References

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