Outskirts of Galaxy Clusters: Intense Life in the Suburbs
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Enrichment of the intracluster medium from infalling galaxies

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Abstract. We present first results of numerical simulations of the dynamics of all three components of a galaxy cluster: the dark matter, the intracluster gas, and the member galaxies. Our first aim is to understand the enrichment of the gas component by studying various interaction processes between cluster galaxies and the intracluster gas, notably ram-pressure stripping and galactic winds. Our second aim is to find out how fast metals originating from such interaction processes diffuse throughout the cluster, in order to understand observed metallicity maps of galaxy clusters obtained from X-ray observations.

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1. Introduction

From X-ray spectra it is evident that the Intra-Cluster Medium (ICM) is abundant in metals. As heavy elements are only produced in stars the processed material must have been ejected by cluster galaxies into the ICM. Several different mechanisms for interaction between the cluster galaxies and the ICM are possible but their efficiency of metal enrichment of the cluster and their time evolution are still not known. Suggested processes which remove enriched material from the galaxies are ram-pressure stripping, galactic winds, superwinds driven by starburst activity and jets from active galaxies. First results of high resolution hydrodynamic simulations on cluster scales are presented to investigate the effect of these different pollution mechanisms.

2. Numerical method

We devised a combined N-body, hydrodynamic, and phenomenological approach to simulate the interaction between the ICM and the cluster galaxies. Large-scale structure formation is simulated using an N-body tree code with an additional semi-numerical model for galaxy formation (van Kampen et al. 1999). From these simulations halo merger trees are extracted, which describes where and when galactic dark haloes form. A simple description of gas dynamics and star formation provides a means to calculate the amount of stars forming in these haloes. Stellar population synthesis models then provide the spectral evolution, i.e. luminosities and colours, of these galaxies.

The large-scale dark matter potential and the trajectories and evolving properties of the galaxies are stored, to be used as input for a hydrodynamical simulation of the ICM. These simulations are performed on cluster scale (20 h^{-1} Mpc), and employ a shock capturing grid based Piecewise Parabolic Method (PPM; Colella & Woodward 1984) on four

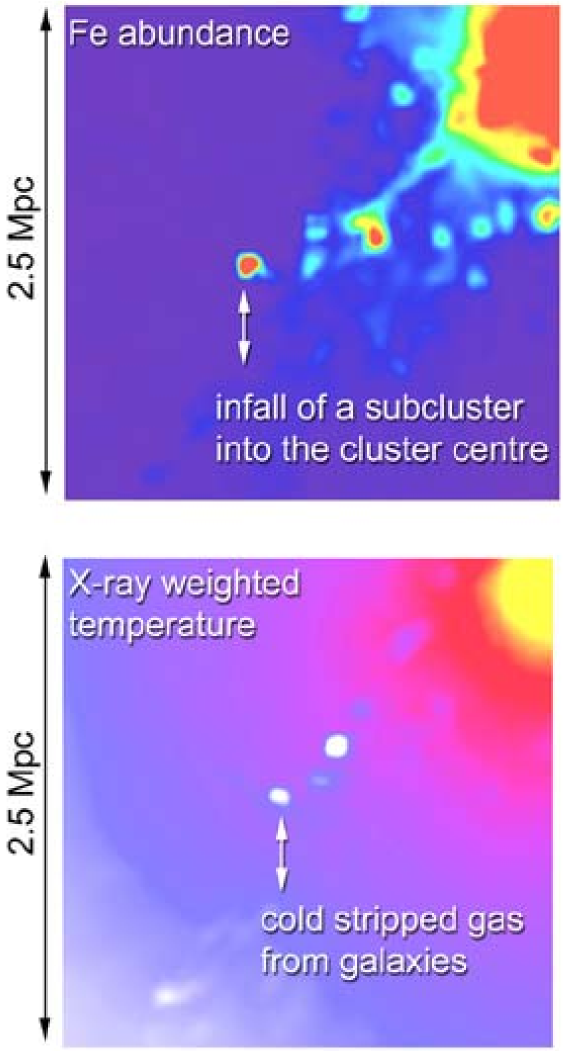

Figure 1. As galaxies and subclusters fall onto the centre of a cluster they feel more and more pressure of the intra-cluster gas. At some point this can lead to ram-pressure stripping. The galaxies lose their cool, metal-enriched gas to the intra-cluster gas. Here we show the distribution of the iron abundance and the temperature in a simulated cluster. The centre of the cluster is in the upper right corner. Top: regions of high iron abundance are visible, where subclusters and galaxies have been stripped. Bottom: the cool gas stripped off galaxies is visible for a while in the temperature map. It is surrounded by the hotter intra-cluster medium.

nested grids (Ruffert 1992), which allows us to cover the cluster center, where most of the stripping is expected to happen, with high enough resolution. The simulations include the effect of ram-pressure stripping using the criterion of Gunn and Gott (1972). Metallicity is used to trace the stripped material. For more information on the simulation method, as well as images and movies, see `astro.uibk.ac.at/astroneu/hydroskiteam/index.htm`.

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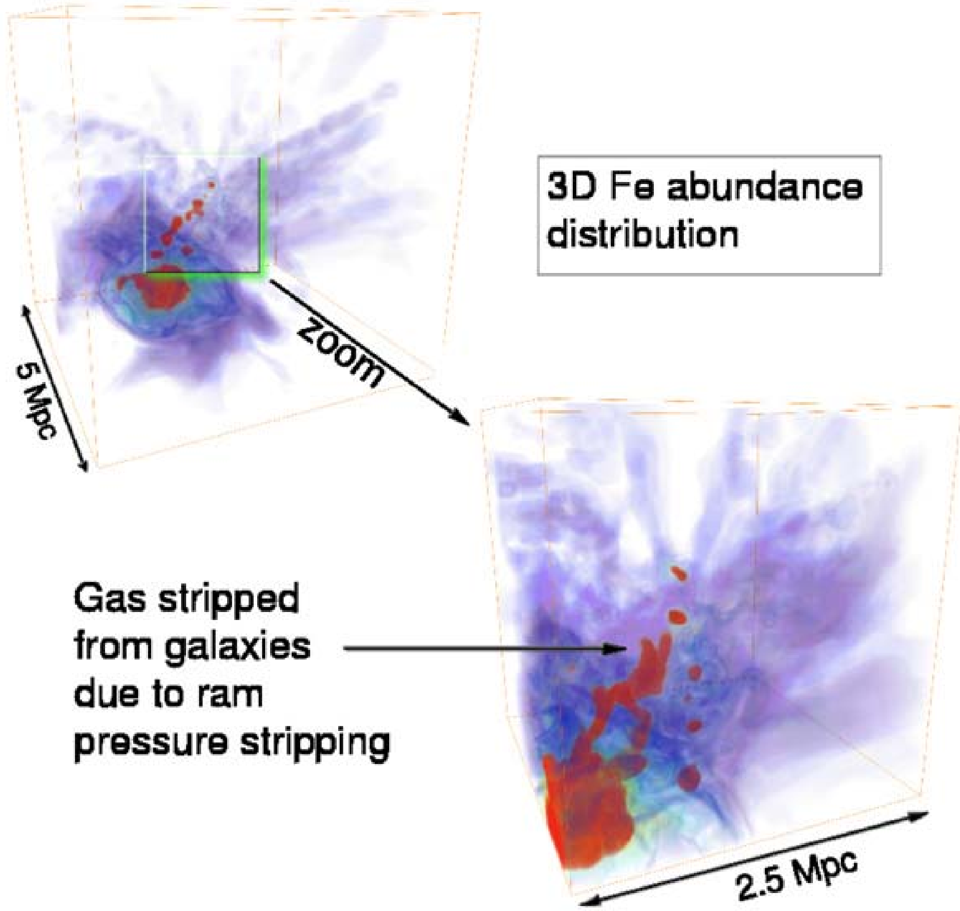

Figure 2. 3D distribution of the iron abundance in the ICM after the ISM has been stripped off the galaxies. Two different scales (5 Mpc and 2.5 Mpc) are shown.

3. Interaction between galaxies and the ICM

The metal content of the intra-cluster gas is on average roughly one third of the solar value. As the total amount of metals in the intra-cluster gas is about the same as in all galaxies together, a lot of gas must have been transported from the galaxies into the ICM. Several transport processes have been suggested: ram pressure stripping (Gunn & Gott 1972), galactic winds (De Young 1978), galaxy-galaxy interaction, jets from AGN and others. A closer look at the different metal enrichment processes is therefore very important for the understanding of cluster formation and galaxy evolution.

So far numerical simulations including only some of the processes gave quite discordant results on the efficiency of the different processes (e.g. Cen & Ostriker 1999; Aguirre et al. 2001; Metzler & Evrard 1994, 1997). To improve on this we have started a comprehensive project, using the hydrodynamic simulations described above, and including all possible enrichment processes. We calculate simulated metallicity maps for direct comparison with observations.

First results of the simulations are shown in Figs. 1 and 2. The simulations shown here include so far only ram-pressure stripping. While many other simulations have concentrated on the effect of the stripping on the galaxies (Abadi et al. 1999; Mori & Burkert 2000; Quilis et al. 2000; Vollmer et al. 2001; Schulz & Struck 2001; Toniazzo & Schindler 2001; Otmianowska-Mazur & Vollmer 2003), we concentrate here on the effects of the stripping process on the intra-cluster gas.

The gas that is stripped off the galaxies is visible not only in the metallicity maps of the intra-cluster gas, but also in the temperature maps, because this gas is cooler than the surrounding intra-cluster medium. It takes a while for the gas from the galaxies to mix with the intra-cluster gas. Sometimes one can see even shock waves passing over these cool regions and the cool gas is not heated up immediately. Also the metallicity distribution is not expected to be homogeneous shortly after the stripping, because the gas is not mixed immediately. This expectation is indeed supported be the metallicity variations observed in the metallicity maps mentioned above. In the simulations we see the highest stripping rate and hence the highest metallicities in regions where subclusters fall onto the main cluster. It also appears that shocks originating from subcluster mergers provide the means to spread stripped metals all over the cluster, but the timescale for this process has not been established yet.

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References

Abadi, M.G., Moore, B., Bower, R.G., 1999, MNRAS, 308, 947
Aguirre, A., Hernquist, L., Schaye, J., Katz, N., Weinberg, D.H., et al. 2001, ApJ, 561,521
Castillo-Morales, A., Schindler S., 2003, A&A, 403, 433
Cen, R., Ostriker, J.P., 1999, ApJ, 519, L109
Colafrancesco, S., Dar, A., De Rujula, A., 2003, submitted to A&A, astro-ph/0304444
Colella P., Woodward P.R., 1984, JCP, 54, 174
De Filippis, E., Schindler, S., Castillo-Morales, A., 2003, A&A, 404, 63
De Young, D.S., 1978, ApJ, 223, 47
Dolag, K., Schindler, S., 2000, A&A 364, 491
Ettori, S., Tozzi, P., Rosati, P., 2003, A&A 398, 879
Evrard, A.E., Metzler, C.A., Navarro, J.N. 1996, ApJ, 469, 494
Furusho T., 2002, Proceedings of the Japan-German workshop on "Galaxies and Clusters of Galaxies", Shuzenji, Japan, http://www-x.phys.metro-u.ac.jp/docs/workshop/cluster-2002-10-29/proceedings/
Furuzawa A., Morishita T., Hudaverdi M., Tanaka T., Takahashi S., et al., 2002, Proceedings of the Japan-German workshop on "Galaxies and Clusters of Galaxies", Shuzenji, Japan, http://www-x.phys.metro-u.ac.jp/docs/workshop/cluster-2002-10-29/proceedings/
Giovannini G., Feretti, L., 2002, in "Merging Processes in Galaxy Clusters", Astrophysics and Space Science Library, Feretti L., Gioia I.M., Giovannini G. (eds.), Kluwer, p.197
Gil-Merino R., Schindler, S., 2003, A&A, in press
Gunn, J.E., Gott, J.R.III, 1972, ApJ, 176, 1
Hudaverdi M., Akimoto F., Furuzawa A., Shibata R., Tanaka T., et al., 2002, Proceedings of the Japan-German workshop on "Galaxies and Clusters of Galaxies", Shuzenji, Japan, http://www-x.phys.metro-u.ac.jp/docs/workshop/cluster-2002-10-29/proceedings/
Johnstone, R.M., Allen S.W., Fabian A.C., Sanders, J.S., 2002, MNRAS 336, 299
Lenzen, F., Schindler, S., Scherzer, O., 2003, submitted to A&A
Metzler, C.A., Evrard, A.E., 1994, ApJ, 437, 564
Metzler, C.A., Evrard, A.E., 1997, astro-ph/9710324
Mori, M., Burkert, A., 2000, ApJ, 538, 559
Otmianowska-Mazur, K., Vollmer, B., 2003, A&A, 402, 879

Piffaretti, R., Jetzer, Ph., Schindler, S., 2003, A&A 398, 41
Quilis, V., Moore, B., Bower, R., 2000, Science, 288, 1617
Reiprich, T., Böhringer, H., 2002, ApJ, 567, 716
Rosati, P., Borgani, S., Norman, C., 2002, ARA&A 40, 539
Ruffert M., 1992, A&A 265, 82
Schindler, S. 1996, A&A, 305, 756
Schmidt, R. W., Fabian, A. C., Sanders, J. S., 2002, MNRAS 337, 71
Schulz, S., Struck, C., 2001, MNRAS, 328, 185
Toniazzo, T., Schindler, S., 2001, MNRAS, 325, 509
van Kampen, E., Jimenez, R., Peacock, J. A., 1999, MNRAS, 310, 43
Vollmer, B., Cayatte, V., Balkowski, C., Duschl, W. J., 2001, ApJ, 561, 708
Tanaka T., Hudaverdi M., Akimoto F., Furuzawa A., Tawara Y., Yamashita K., 2002, Proceedings of the Japan-German workshop on "Galaxies and Clusters of Galaxies", Shuzenji, Japan, http://www-x.phys.metro-u.ac.jp/docs/workshop/cluster-2002-10-29/proceedings/
Yamasaki N.Y., Furusho T., Ohashi T., 2002, Proceedings of the Japan-German workshop on "Galaxies and Clusters of Galaxies", Shuzenji, Japan, http://www-x.phys.metro-u.ac.jp/docs/workshop/cluster-2002-10-29/proceedings/