

Analysis of the X-ray Emission from the Cluster-scale AGN Outbursts in Hydra A, Hercules A and MS 0735.6+7421 Galaxy Clusters

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INTRODUCTION

AGN in the cluster's central galaxy are considered the best candidate to solve the cooling flow problem in the clusters of galaxies (e.g. Peterson & Fabian 2006). High-resolution X-ray images reveal that AGN outbursts create a complex structure of the large-scale shocks and cavities in the cooling cores (Wise et al. 2007). The details of the feedback loop responsible for the balance between heating and cooling of the gas in the cooling cores are still unknown. The most powerful cluster-scale AGN outbursts are presented in MS 0735.6+7421 (McNamara et al. 2005; Wise et al. 2010), Hercules A (Nulsen et al. 2005a; Hardcastle & Croston 2010) & Hydra A (Nulsen et al. 2005b; Wise et al. 2007; Simionescu et al. 2009a, 2009b; Kirkpatrick et al. 2009; Gitti et al. 2011) clusters of galaxies.

OBSERVATIONS AND DATA ANALYSIS

The observations from the Chandra Data Archive (ObsIDs 4969 & 4970 for Hydra A, total exposure ~200 ks; 4197, 10468 – 10470, 10822, 10918 & 10922 for MS 0735.6+7421, total ~500 ks; 5796 & 6257 for Hercules A, total ~100 ks) were processed using CIAO 4.3 and CALDB 4.4.3. Background flares were excluded, time-dependent gain and charge transfer inefficiency corrections were applied using standard techniques detailed in the CIAO on-line documentation. The resulting images were then added to form mosaics combining all the data sets for each object. The hardness ratio maps were created using the weighted Voronoi tessellation binning algorithm (Cappellari & Copin 2003; Diehl & Statler 2006).

RESULTS

We have investigated the hardness ratio for Hydra A, MS 0735.6+7421 & Hercules A clusters of galaxies using the adaptive binning instead of the adaptive (or fixed-scale) smoothing to reveal location of gas with distinctive spectral properties compared to the surrounding in the cooling cores.

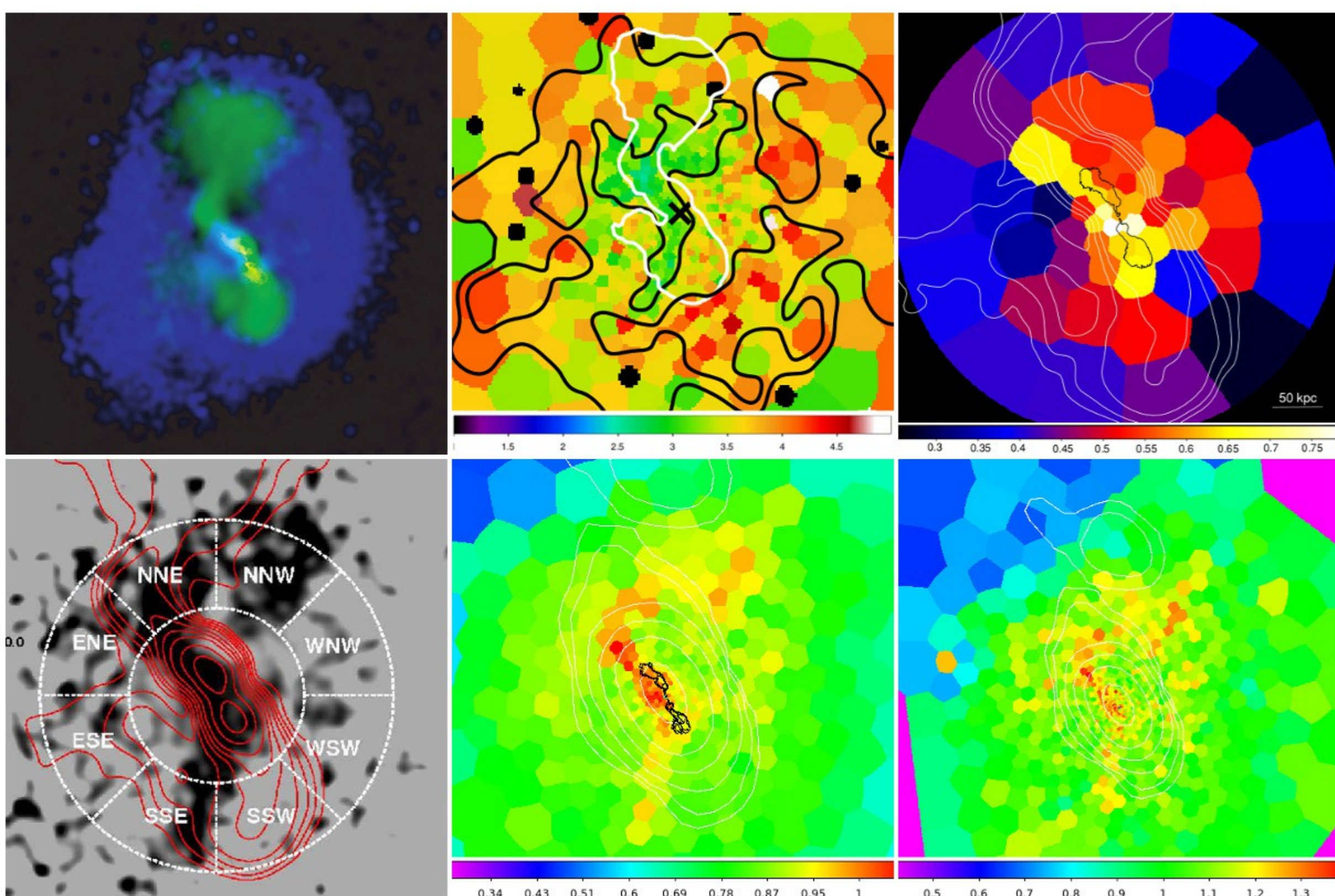


Figure 1.

Figure 1. Hydra A cluster of galaxies. Top left: composite color image from Wise et al. (2007) – residual X-ray intensity map shown in blue and radio emission shown in green & yellow. Top middle: temperature map from Simionescu et al. (2009a) created using the adaptive binning with 2500 counts per spatial bin – colorbar units are keV, radio contours are in white, temperature contours are in black. Top right: metallicity map from Kirkpatrick et al. (2009) created using the adaptive binning with 22500 counts per spatial bin – colorbar units are dex, radio contours are in white & black. Bottom left: hardness ratio map (1.5-7.5 keV to 0.3-1.5 keV) from Gitti et al. (2011) created using the fixed-scale smoothing – radio contours are in red. Bottom middle & right: hardness ratio maps (0.3-1.2 keV to 1.2-7.5 keV & 0.3-1.2 keV to 1.2-3.0 keV) obtained in this work were created using the adaptive binning with 900 & 400 counts per spatial bin – radio contours are in white & black.

Figure 2. MS 0735.6+7421 cluster of galaxies. Top: composite color image from McNamara et al. (2005) – X-ray intensity map shown in blue, radio emission shown in red and optical image shown in white. Middle & bottom: hardness ratio maps (0.3-1.4 keV to 1.4-7.5 keV & 0.3-1.4 keV to 1.4-3.0 keV) obtained in this work were created using the adaptive binning with 400 counts per spatial bin – scales are approximately the same as in the top picture.

Figure 3. Hercules A cluster of galaxies. Top: X-ray intensity map from Nulsen et al. (2005a) – radio contours are in black. Middle & bottom: hardness ratio maps (0.3-1.4 keV to 1.4-7.5 keV & 0.3-1.2 keV to 1.2-3.0 keV) obtained in this work were created using the adaptive binning with 400 counts per spatial bin – radio contours are in black.

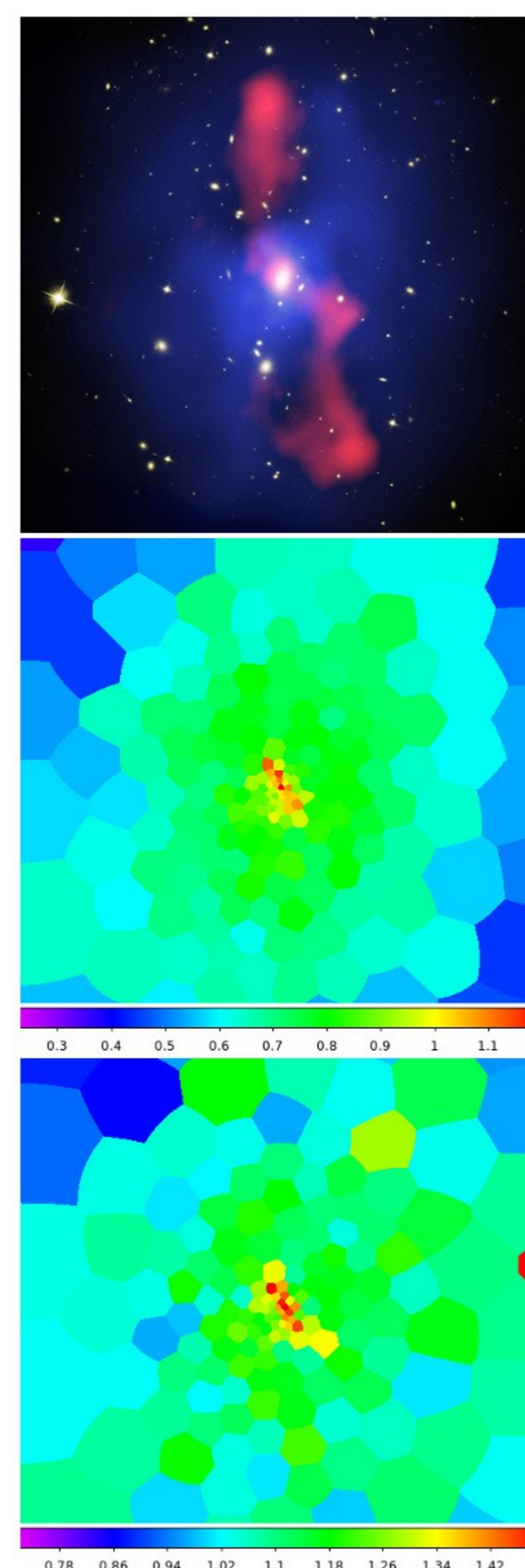


Figure 2.

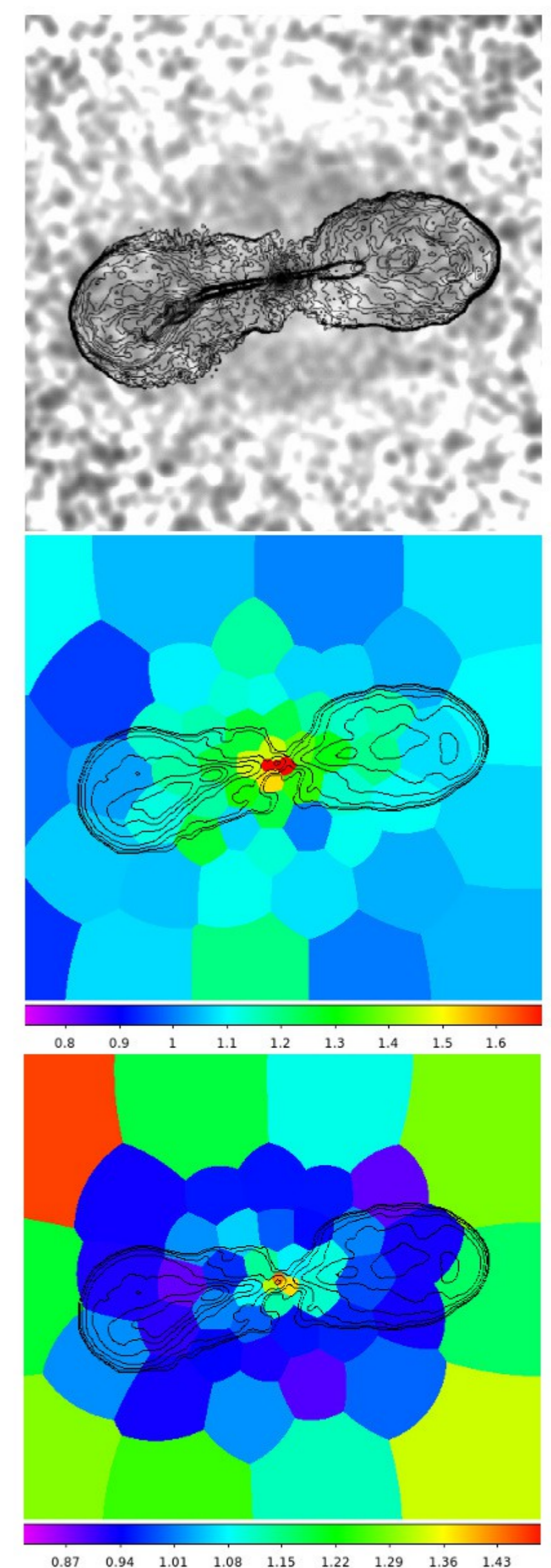


Figure 3.

DISCUSSIONS

In this work we obtain the hardness maps for the first time for Hercules A and with higher resolution for Hydra A and MS 0735.6+7421 clusters of galaxies. We reveal a fine structure of plasma flows in the core region of Hydra A cluster. Similar plasma flows are visible in MS 0735.6+7421 cluster. In contrary to the Hydra A and MS 0735.6+7421 cases in Hercules A cluster we clearly see the signature of hard emission excess from the cluster-scale outburst shock bounded region described by Nulsen et al. (2005a).

REFERENCES

- Cappellari, M., & Copin, Y. 2003, MNRAS, 342, 345
 Diehl, S., & Statler, T. S. 2006, MNRAS, 368, 497
 Gitti, M., Nulsen, P. E. J., David, L. P., McNamara, B. R., & Wise, M. W. 2011, ApJ, 732, 13
 Hardcastle, M. J., & Croston, J. H. 2010, MNRAS, 404, 2018
 Kirkpatrick, C. C., Gitti, M., Cavagnolo, K. W., McNamara, B. R., David, L. P., Nulsen, P. E. J., & Wise, M. W. 2009, ApJ, 707, L69
 McNamara, B. R., Nulsen, P. E. J., Wise, M. W., Rafferty, D. A., Carilli, C., Sarazin, C. L., & Blanton, E. L. 2005, Nat, 433, 45
 Nulsen, P. E. J., Hambrick, D. C., McNamara, B. R., Rafferty, D. A., Birzan, L., Wise, M. W., & David, L. P. 2005, ApJ, 625, L9
 Nulsen, P. E. J., McNamara, B. R., Wise, M. W., & David, L. P. 2005, ApJ, 628, 629
 Peterson, J. R., & Fabian, A. C. 2006, Phys. Rep., 427, 1
 Simionescu, A., Werner, N., Böhringer, H., Kaastra, J. S., Finoguenov, A., Brüggem, M., & Nulsen, P. E. J. 2009a, ApJ, 493, 409
 Simionescu, A., Roediger, E., Nulsen, P. E. J., Brüggem, M., Forman, W. R., Böhringer, H., Werner, N., & Finoguenov, A. 2009b, ApJ, 495, 721
 Wise, M. W., McNamara, B. R., Nulsen, P. E. J., Houck, J. C., & David, L. P. 2007, ApJ, 659, 1153
 Wise, M. W., McNamara, B. R., Nulsen, P. E. J., Cavagnolo, K. W., Rafferty, D. A., Birzan, L., & Kirkpatrick, C. C. 2010, cosp, 38, 2625