Abell 2390 revisited: hints of ripples, bubbles and sloshing

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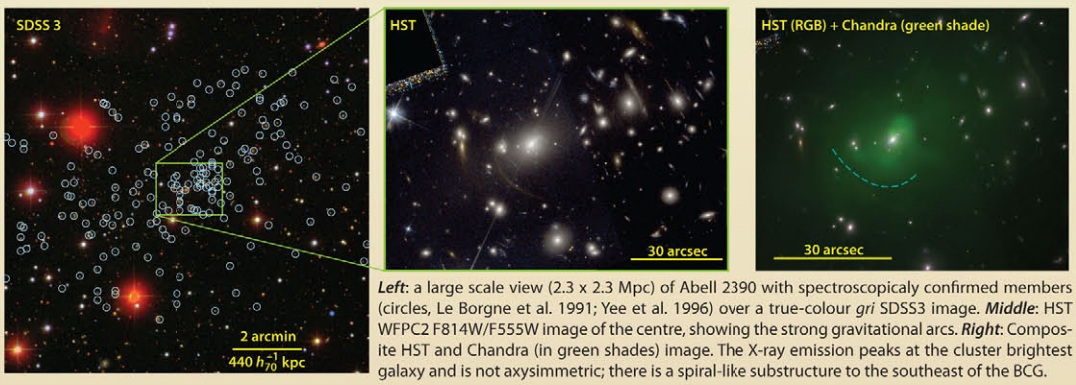
Abstract: Abell 2390 is a well-studied, massive, rich cluster with hot intracluster gas, ranging from ~7 to 12 keV. It has a central galaxy with a strong radio activity, being a "Perseus-like" cluster at 10 times higher *z*. Previous work has focused mainly on the overall intracluster medium (ICM) physical properties and showed the presence of bubbles in the intracluster gas.

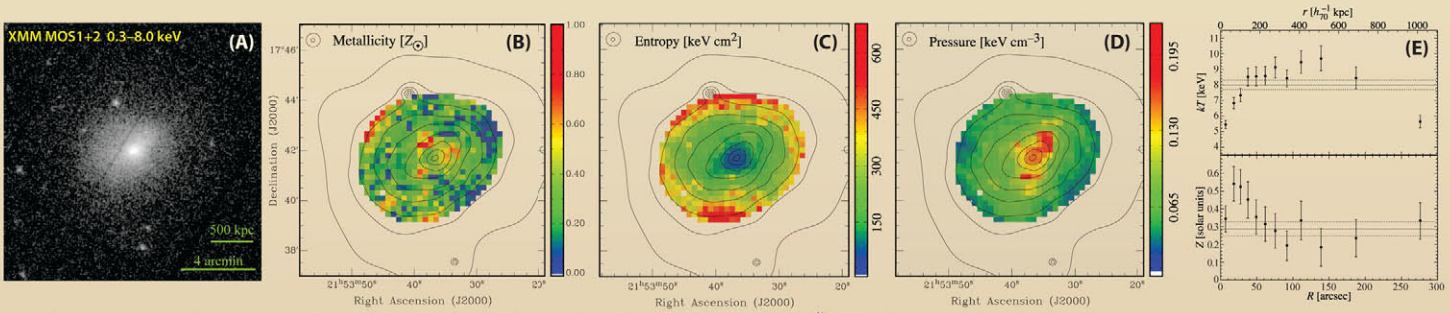
We have reprocessed both XMM-*Newton* and *Chandra* data in order to investigate not only the existence of faint features in the ICM, but also their connection with the cluster central galaxy and cluster dynamics (based on the gas temperature map). We show here that this cluster presents substructure in the gas temperature map, showing evidence of recent dynamical activity, perhaps in the form of sloshing. We also detect with the deep *Chandra* image signs of bubbles and ripples due to acoustic waves. However, about 10 times more exposure is needed to confirm the presence of acoustic waves in the ICM, such as the one observed in the Perseus Cluster.

Abell 2390, a rich, massive cluster at $z = 0.228$, has been observed extensively. It has been observed by HST multiple times both with the WFPC and the ACS/WFC, plus most recently observed with the NIR camera of the WFC3. In addition Abell 2390 has been observed multiple times by *Spitzer* as well as in the radio, and from the ground (eg. Hutchings & Balogh 2000).

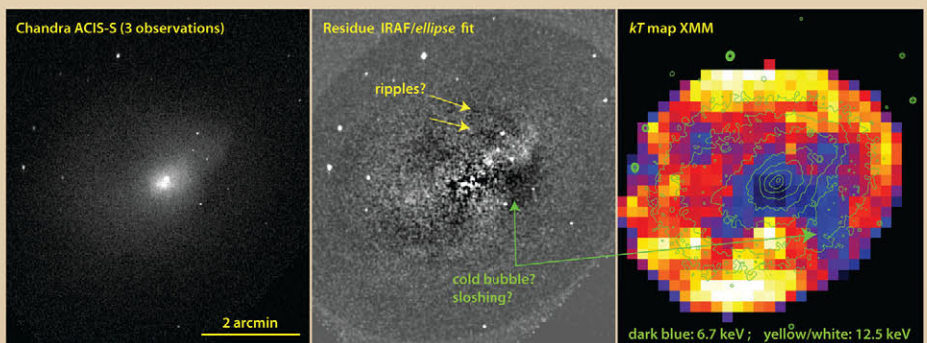
The central galaxy in Abell 2390 is a strong and complex radio source, very luminous in Hα and IR (Augusto et al. 2006, Egami et al. 2006). It is similar in its activity and peculiarity to NGC 1275 (Perseus Cluster BCG). We may expect to observe the same BGC–ICM interplay in Abell 2390 as in Perseus.



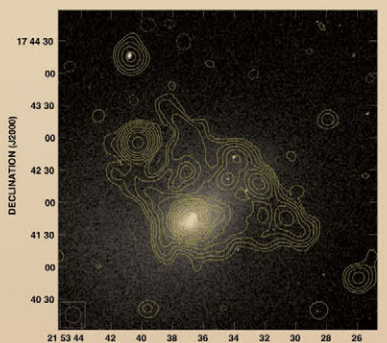
Left: a large scale view (2.3 x 2.3 Mpc) of Abell 2390 with spectroscopicaly confirmed members (circles, Le Borgne et al. 1991; Yee et al. 1996) over a true-colour *gri* SDSS3 image. ***Middle***: HST WFPC2 F814W/F555W image of the centre, showing the strong gravitational arcs. ***Right***: Composite HST and Chandra (in green shades) image. The X-ray emission peaks at the cluster brightest galaxy and is not axysimmetric; there is a spiral-like substructure to the southeast of the BCG.



We have downloaded and reprocessed the public available XMM-*Newton* data. The useful data, after high background filtering, corresponded to 9.2, 8.8, and 5.8 ks for MOS1, MOS2 and pn detectors, respectively. With the cleaned event files, we produced metallicity, entropy, pressure and temperature maps following the method used by Durret & Lima Neto 2008 and Laganá et al. 2010. The results are shown in the figures above: **(A)** Broadband XMM image. **(B)** Metallicity map. **(C)** "Entropy" ($S = T \times I^{-1/3}$). **(D)** "Pression" ($P = T \times I^{1/2}$). **(E)** Radial averaged metallicity and temperature gradients shows a minimum in the centre followed by a rise and then declines ouwards, not unlike Perseus. The structures seen on the 2D metallicity map may reflect some past dynamical activity, making the star formation rate higher in the cluster galaxies. On the other hand, the entropy map shows a more axisymmetric distribution with a steep gradient. We present below the temperature map together with the *Chandra* imaging analysis.



We have merged 3 previous ACIS-S7 *Chandra* observations. After filtering out the time periods with high particle background we are left with a total of 109.6 ks (92.65 ks alone from the last observation in 09/2003). For each individual exposure we have generated a binned 2 x 2 pixel, exposure-map corrected images (0.3–7.0 keV), and then added them together with IRAF task *imcombine* (***left panel***).
The combined image was modelled with the IRAF task *ellipse*, with which we produced a smooth model and a residue map (***middle panel***). There is a hint, in the residue image, of 2 parallel ripples to the northwest from the centre. Allen et al. (2001) and Vikhlinin et al. (2006) have shown that in the core of Abell 2390 bubbles probably exist in the plasma of the ICM.
The temperature distribution (***right panel***, from XMM data) is not symmetric, suggesting some recent perturbation such as gas sloshing. The cooler gas westward coincides spatially with the regions of lower emission intensity (lower density).



VLA 20cm radio contours (from Bacchi et al. 2003) overlaid the *Chandra* X-ray image showing the central galaxy activity. As Bacchi et al. notes, the halo morphology and structure in Abell 2390 is similar in nature to the radio emission in Perseus.

In conclusion, Abell 2390 shares many similar features with the Perseus cluster, in particular the ICM metallicity and temperature properties and the strong activity of the central galaxy. Abell 2390 is thus an ideal target to search for subtle substructures on the intracluster plasma such as ripples produced by acoustic waves, so far only observed in Perseus.

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Chandra ObsID: 500, 501, 4193 (PIs: A. Fabian, S. Allen).
XMM-Newton ObsID: 0111270101 (PI: M. Watson)

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