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FM 22. Mapping the Frontier Fields with Chandra X-ray Observations

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Abstract. Chandra has deeply observed the clusters and parallel fields in four Frontier Fields. These observations allow us to dramatically improve our understanding of cluster mergers by comparing the detailed mapping of the hot cluster gas with high resolution mass maps and by identifying merger shocks and cold fronts. In merging clusters, relativistic particles can be re-accelerated to produce radio relics. A comparison of lensing maps and Chandra images allows us to determine the cluster morphology and dynamical state and if there are offsets between the dark matter and the hot gas.

Keywords. X-rays: galaxies: clusters, dark matter, acceleration of particles, gravitational lensing, galaxies:peculiar

1. Introduction

Deep observations of the Frontier Fields with HST, Chandra, XMM-Newton, Spitzer, and the JVLA allow us to map the distributions of dark matter, cluster galaxies and the hot intracluster medium and to detect, through the high-magnification provided by the massive clusters, high redshift lensed galaxies and AGN. Our primary goals are to 1) understand cluster mergers; 2) compare the distribution of dark matter and baryonic matter, particularly the hot ICM; 3) identify merger shocks by mapping the ICM temperature and pressure; 4) identify and compare radio relics and halos with cluster merger properties to understand particle acceleration in the ICM; 5) determine the number density of very faint radio sources; and 6) understand the effects of mergers on galaxy evolution. This paper presents results for four Frontier Fields clusters MACSJ0717.5+3745, MACSJ0416.1-2403, MACSJ1149.5+2223 and A2744. X-ray images are shown in Fig. 1 (left).

2. The Frontier Fields Clusters

MACSJ0717.5+3745 ($z = 0.5458$), the most massive (10^{15} M_{sun}) Frontier Fields cluster, was previously found to be undergoing a quadruple merger event, along with the infall of gas along a filament, and evidence of shock heated gas (Ebeling *et al.* 2004; Ebeling *et al.* 2007; Ma *et al.* 2009, Zitrin *et al.* 2009, Jauzac *et al.* 2012). In the radio, MACSJ0717.5+3547 exhibits a 1.5 Mpc halo and an 850 kpc long relic, which combined make this cluster the most luminous extended radio source in the sky (van Weeren *et al.* 2009, Bonafede *et al.* 2009). Figure 1 (right) shows that the radio relic lies in a shocked gas region between two massive subclusters, supporting that the relic is produced by the reaccelation of relativistic particles (van Weeren *et al.* 2015). Due to its large magnified area, deep JVLA observations have yielded more than 50 lensed compact radio sources,

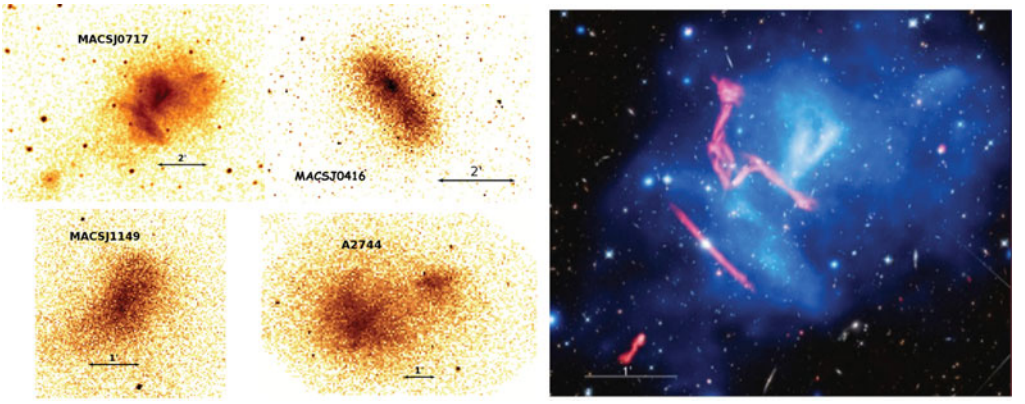

Figure 1. (left) Chandra X-ray images (0.5 - 3 keV) of the four Frontier Clusters. (right) the X-ray (blue) and radio (red) emission of MACS0717 superposed on the optical image. The radio source southeast of the relic is foreground.

primarily identified with galaxies at $1 < z < 2$ undergoing star formation at rates of 10 to 50 M_{sun} per year (van Weeren *et al.* 2015).

MACSJ0416.1-2403 is a massive merging cluster with an overall ICM temperature of 10 keV and X-ray luminosity of 9×10^{44} ergs s^{-1} (Mann and Ebeling 2012, Jauzac *et al.* 2012), Ogrean *et al.* 2015). From our deeper (365 ks) Chandra observations, Ogrean *et al.* (2015) found good agreement between the positions of the BCGs in the two primary subclusters and the centroid of each subcluster's X-ray emission. They also determined that the report of an offset between the BCG and the dark matter by Harvey *et al.* (2015) was caused by a mis-identification of the BCG in the southwestern subcluster.

From deep (365 ks) Chandra observations of MACSJ1149.6+2223, Ogrean *et al.* (2015) measured a 10.7 keV gas temperature and an X-ray luminosity of 1.6×10^{45} ergs s^{-1}. They also confirmed the radio halo is underluminous, as found by Bonafede *et al.* (2012).

From Chandra observations of A2744, Owers *et al.* (2011) determined that the cluster had undergone a major merger which disrupted the cores of both merging subclusters and likely produced "jellyfish" galaxies (Owers *et al.* 2012).

X-ray and radio studies of the Frontier Fields clusters, along with deep lensing observations, have improved our understanding of the growth of clusters through mergers and have detected lensed populations of high redshift radio and X-ray sources.

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