Studying the Nature of Dark Energy with Current and Future Instruments

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Abstract. Understanding the nature of dark energy is one of the most important quests in modern cosmology and fundamental physics. Observations of galaxy clusters at low and high redshifts can be used to place constraints on the equation of state of dark energy and its evolution. Here, we briefly illustrate an ongoing project to constrain dark energy using state-of-the-art X-ray and optical observatories.

Low Redshift Cluster Observations: Analysis of follow-up observations of a complete, low redshift, X-ray selected galaxy cluster sample (*HIFLUGCS*, Reiprich & Böhringer 2002) with Chandra and XMM-Newton is under way. Such detailed observations are necessary because, currently, systematic effects related to an incomplete understanding of cluster physics dominate the total error budget on cosmological parameter estimates from clusters. Because of its superb angular resolution, Chandra is ideally suited to study processes in cluster centers (Fig. 1; notice, e.g., A4038's depressions, "bubbles," in the X-ray surface brightness close to the central radio source and how well the X-ray and radio emission to the west of the center seem to be aligned) and XMM-Newton, because of its high throughput and larger field of view, is used to study effects in cluster outskirts (Fig. 2).

High Redshift Cluster Observations: Figure 3 illustrates how constraints on the equation of state of dark energy, w, can be obtained. Notice how the model mass functions split up at high redshift. Chandra and XMM-Newton observations of a complete sample of distant galaxy clusters are being proposed. Total masses will, additionally, be determined through optical, weak gravitational lensing observations. Megacam, a new 36-CCD wide field camera at the MMT 6.5m telescope on Mt. Hopkins in Arizona, is being used for the weak lensing observations of the distant clusters (first run completed, second run scheduled).

In the near future, the X-ray missions ROSITA and DUO (1), XEUS and Constellation-X (2) will be vital because they will allow to construct much larger statistical distant cluster samples (1) and to study the individual distant clusters in much more detail (2), allowing to tighten dark energy constraints.

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References

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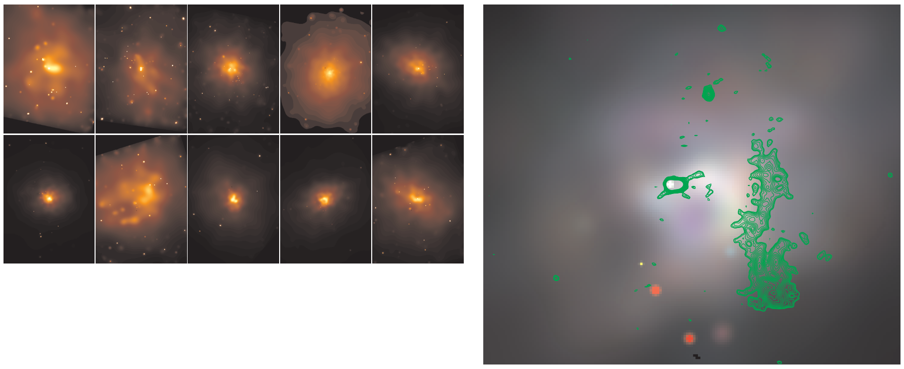

Fig. 1. (**a**) Adaptively smoothed central X-ray surface brightness distributions for ten HIFLUGCS clusters observed recently with Chandra. (**b**) Adaptively smoothed X-ray false color image of the very center of Abell 4038. Red corresponds to soft, green to intermediate, and blue to hard emission.Overlaid in green are 1.4 GHz VLA radio contours (provided by T. Clarke)

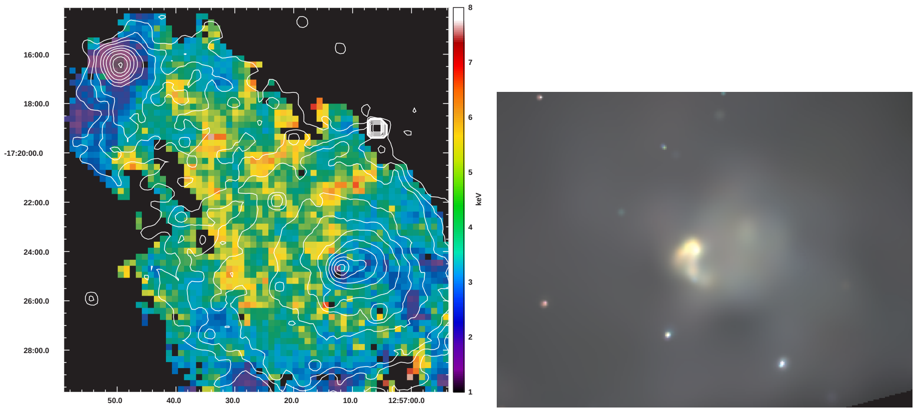

Fig. 2. (**a**) X-ray gas temperature map of Abell 1644 obtained with XMM-Newton (Reiprich et al. 2004). Overlaid are X-ray surface brightness contours. Notice the two sub clusters with cool (blue) cores. The northern sub cluster appears to be leaving a trail of cooler gas behind. (**b**) Chandra false color image of the center of the southern sub cluster. One notes that the complexity of this exceptional system, apparent on large scales, continues down to the very center.

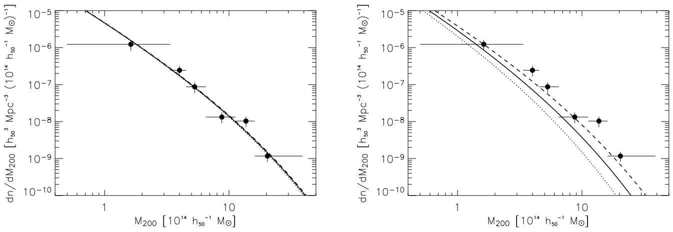

Fig. 3. Shown are galaxy cluster mass functions (number densities as functions of mass) at (**a**) low redshift ($z = 0.05$) and (**b**) high redshift ($z = 0.61$). Solid lines assume $w = -1$, dashed lines $w = -0.5$, and dotted lines $w = -1.25$.