Studying the Nature of Dark Energy with Current and Future Instruments

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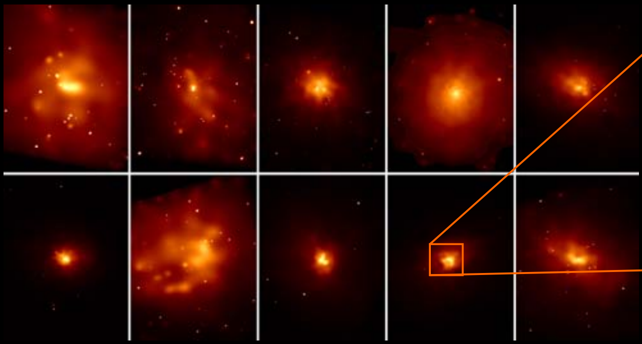
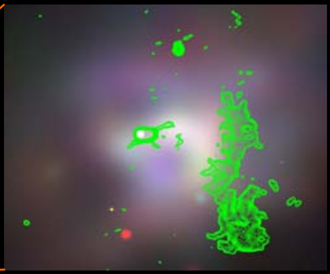
Understanding the nature of dark energy is one of the most important quests in modern cosmology and fundamental physics. Among others, observations of galaxy clusters at low and high redshifts can be used to place constraints on the equation of state of dark energy. Here, we report on our use of state-of-the-art X-ray and optical observatories for this purpose and also briefly comment on the need for specific future instruments.

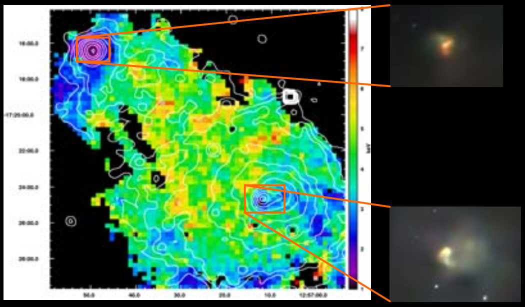
Analysis of follow-up observations of a complete, low redshift, X-ray selected galaxy cluster sample (*HIFLUGCS*, Reiprich & Böhringer 2002) with Chandra and XMM-Newton is under way. Such detailed observations are necessary because, currently, systematic effects related to cluster physics dominate the 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 and XMM-Newton, because of its high throughput and larger field of view, is used to study effects in cluster outskirts.



Adaptively smoothed central X-ray surface brightness distributions for ten *HIFLUGCS* clusters observed recently with Chandra.

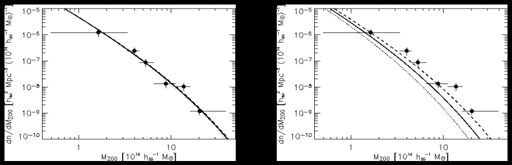


Adaptively smoothed X-ray false color image of the very center of Abell 4038. Red corresponds to soft, green to intermediate, and blue to hard emission.Overlaid in green are 1.4 GHz VLA radio contours (provided by T. Clarke). Notice the depressions ("bubbles") in the X-ray surface brightness close to the central radio source and how well the X-ray and radio emission to the west of the center seem to be aligned .



X-ray gas temperature map of Abell 1644 obtained with XMM-Newton (Reiprich et al., ApJ, in press). 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. Also shown are Chandra false color images of the centers of both sub clusters. One notes that the complexity of this exceptional system, apparent on large scales, continues down to the very centers.

The MMT 6.5m telescope on the summit of Mt. Hopkins in Arizona. Also shown is Megacam, a new 36-CCD wide field camera, that will be used for weak lensing observations of distant clusters, allowing for independent gravitational mass determinations (first run in July).



Constraining the equation of state of dark energy, *w*: Shown are galaxy cluster mass functions (number densities as functions of mass) at low redshift (*z=0.05*, left) and high redshift (*z=0.61*, right). Solid lines assume *w=-1*, dashed lines *w=-0.5*, and dotted lines *w=-1.25*. Notice how the model mass functions split up at high redshift, allowing to constrain *w*. 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.

In the near future, the X-ray missions ROSITA and DUO/JDEM (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 constraints on the nature of dark energy.