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A DEEP CHANDRA OBSERVATION OF MS1137.5+6625

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We present results from a deep Chandra observation towards the MS1137.5+6625 cluster of galaxies. MS1137.5+6625 is a distant (z=0.783), massive cluster of galaxies, which appears relaxed and regular in the X-ray image. With less than a handful of similarly massive clusters currently known at such high redshifts, and this observation provides much needed information on the dynamical state of these rare systems. We discuss the density and temperature structure of the cluster, and compare the X-ray image with a deep optical image and with interferometric Sunyaev-Zel'dovich effect data.

1 Introduction

A deep observation of the galaxy cluster MS1137.5+6625 with the Chandra Observatory's Advanced CCD Imaging Spectrometer (ACIS) reveals that this massive, distant cluster appears relaxed and symmetric, and an ideal subject for cosmological tests.

2 Observations

MS1137.5+6625 was observed for 120 kiloseconds with the Chandra ACIS instrument as part of the Van Speybroeck Guaranteed Time Observation (GTO) cosmology project. The GTO observations are designed to create a set of X-ray observations of galaxy clusters which is suitable for measuring cosmological parameters to high accuracy. Most notably, a cluster's cosmology-dependent angular diameter distance, D_A, can be determined from the temperature and X-ray surface brightness profile of the cluster, when the X-ray data are analyzed in conjunction with a measurement of the cluster's Sunyaev-Zel'dovich effect (*c.f.* Hughes & Birkinshaw[4]; Reese *et al.*[6]; Patel *et al.*[5]).

The observations are chosen so that the dataset includes a sufficient number of cluster observations to overcome systematic errors in the cluster distance determination which arise from cluster ellipticity and orientation. The clusters in the sample are also distributed widely

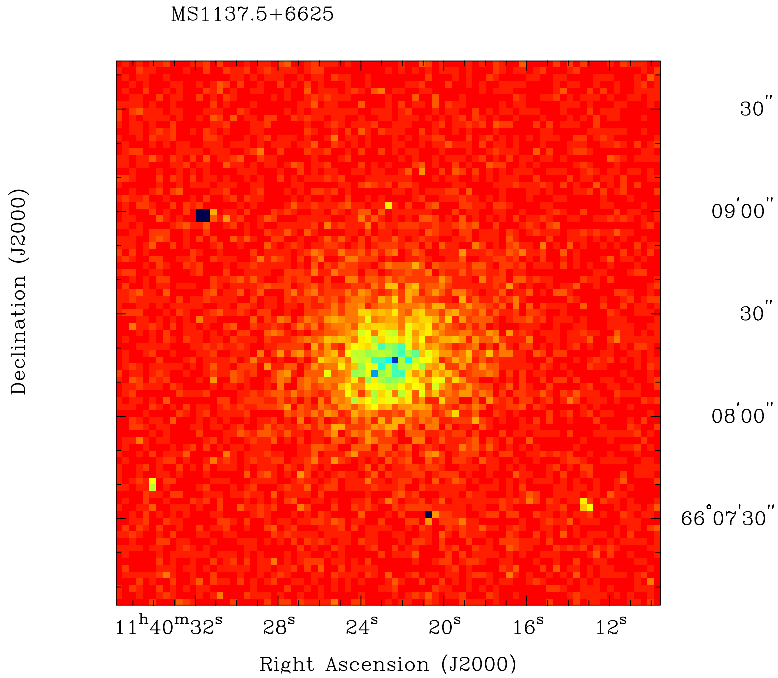

Figure 1: Raw image of MS1137.5+6625, blocked into 2″ pixels.

in redshift, including the most distant X-ray emitting clusters known, so that the evolution of Hubble's constant with redshift can be used to constrain cosmological parameters. Over 1,250 kilseconds of Chandra time is scheduled in A01 and A02 for this project, and it is expected to include over 40 clusters by the close of A02.

The Chandra Observatory has unprecedented angular resolution in the X-ray band, and is well-suited to studying the detailed structure of distant clusters. This resolution, and the observatory's ability to measure X-ray spectra up to high energies ($kT_e \sim 10$ keV) make the Chandra observatory a very good instrument with which to study the distant, massive clusters in the cosmology project. In Figure 1, we present a raw image from this observation, without background subtraction, blocked into 2″ pixels.

3 Intracluster Medium Temperature

We fit the cluster emission within the central arcminute to a MEKAL plasma model, using a background spectrum from a number of long integrations on blank fields . We find the emission-weighted mean temperature for the intra-cluster medium (ICM) to be $7.62^{+3.00}_{-1.74}$ at 90% confidence. The best-fit metal abundance is 0.22 times the solar abundance. We determine the two-parameter confidence regions for emission-weighted ICM temperature and metal abundance, as shown in Figure 2; the constraint on metal abundance is the strongest constraint on high-redshift clusters yet determined.

We compare these results to those obtained by Donahue *et al.*[3], who use ASCA observations of this cluster to determine $kT_e = 5.7^{+2.1}_{-1.1}$ and an abundance of $0.43^{+0.40}_{-0.37}$. These results are formally consistent with the Chandra results, though the electron temperature is noticeably lower. This is partially due to the presence of a strong X-ray point source about 65″ from the cluster center which is removed from the Chandra data but is necessarily included in the ASCA-derived spectrum. If we mimic the ASCA observation by allowing the point source flux to contribute to the Chandra cluster spectrum, the best-fit electron temperature is lower.

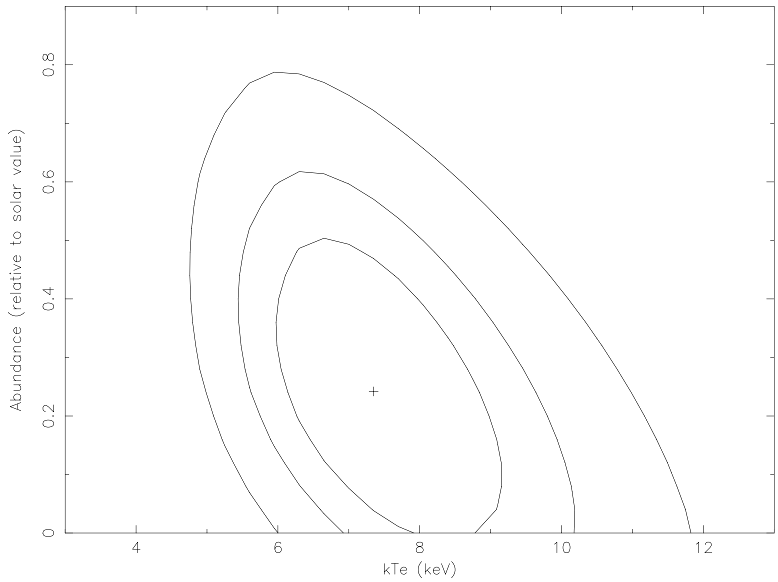

Figure 2: Two-parameter confidence region for emission-weighted temperature (kT_e) and metal abundance. The regions correspond to 68.3%, 90%, and 99.0% confidence on the two parameters. The '+' marks the best-fit value.)

4 Image

To describe the cluster's surface brightness profile, we fit an image made from the energy range 0.3 keV to 10.0 keV to a beta-model (*c.f.* Cavaliere & Fusco-Femiano [1]; Cavaliere & Fusco-Femiano [2]), which parametrizes the X-ray surface-brightness profile in the form:

$$S_X = S_{X0}\left(1 + (\theta/\theta_c)^2\right)^{3-\beta/2}, \tag{1}$$

where β is the power law index and θ_c is the cluster's core radius, its characteristic size. We fit a two-dimensional beta-model, in which the profile can be elliptical, rather than spherical. The best fit axis ratio for the cluster is 1.0. Using the centroid from the two-dimensional fit, we derive a one-dimensional surface brightness profile from the image and fit it to the beta-model in Equation 1. In Figure 3 we show the data, the best fit model, and the fit residuals; the best-fit model has β=0.63 and a core radius of 12.5$''$. The confidence intervals on the surface-brightness shape parameters are shown in Figure 4. The small core radius of this cluster reinforces the importance of Chandra's high angular resoution for studying high-redshift clusters.

5 Hardness Ratio

To investigate whether there is any temperature or metallicity structure in this cluster, we make adaptively smoothed background-subtracted images in the 0.3-2.5 keV and 2.5-10.0 keV energy ranges and make a map of the high energy band divided by the low energy band. This image is shown in Figure 5. There is some small structure, most likely due to the statistical fluctuations from the small numbers of photons outside of the cluster, but no significant structure is apparent.

6 Conclusions

The distant galaxy cluster MS1137.5+6625 appears regular and relaxed with a small core radius and no discernable temperature or metallicity structure.

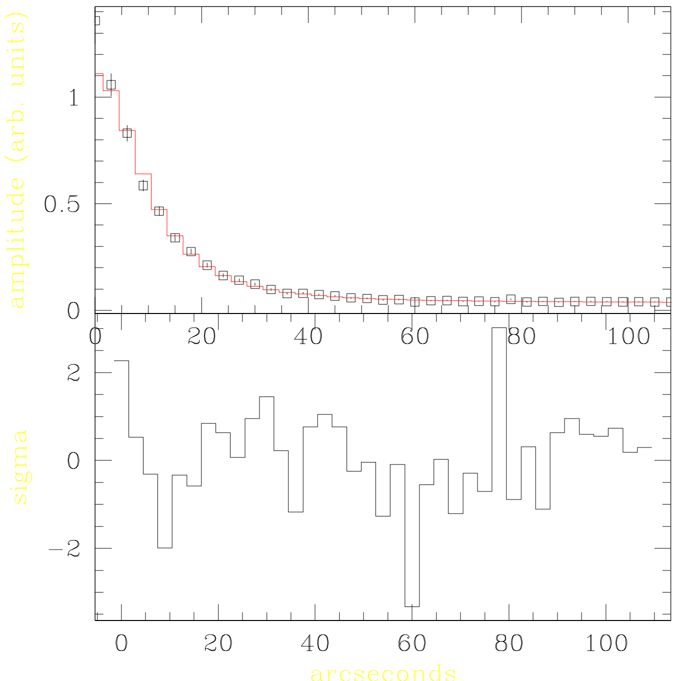

Figure 3: One-dimensional surface brightness profile of cluster MS1137.5+6625, its best-fit beta-model, and fit residuals.

References

1. A. Cavaliere, & R. Fusco-Femiano *Astronomy & Astrophysics* **49**, 137 (1976)
2. A. Cavaliere, & R. Fusco-Femiano *Astronomy & Astrophysics* **70**, 677 (1978)
3. M. Donahue *et al. Astrophysical Journal* **527**, 525 (1999)
4. J. P. Hughes, & M. Birkinshaw *Astrophysical Journal* **501**, 1 (1998)
5. S. K. Patel *et al. Astrophysical Journal* **541**, 37 (2000)
6. E. Reese *et al. Astrophysical Journal* **533**, 38 (2000)

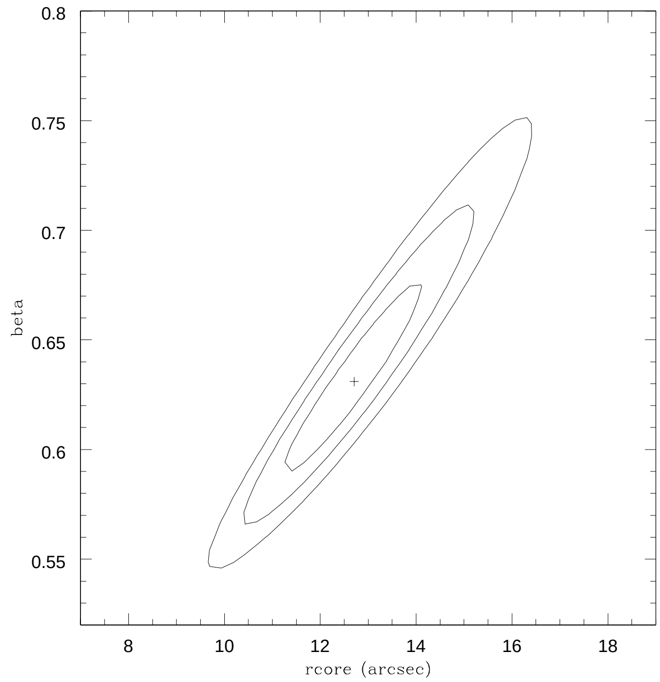

Figure 4: Two-parameter confidence region for β and θ_c for the one-dimensional beta-model fit to MS1137.5+6625. The confidence contours correspond to 68.3%, 90%, and 99.0% confidence on the two parameters. The best-fit model is marked with an 'x'.

Figure 5: Thank you

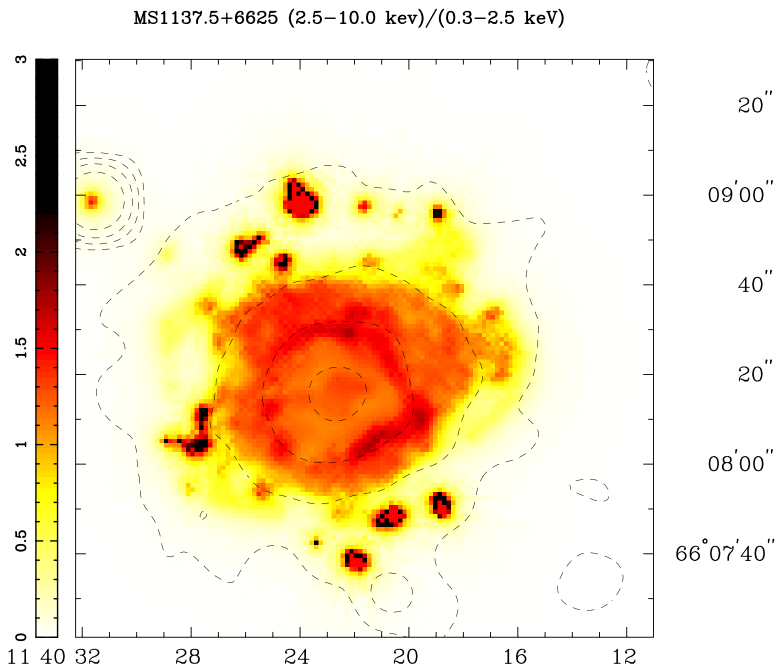

Figure 6: Hardness-ratio map of MS1137.5+6625. The background-subtracted cluster image in the 2.5-10.0 keV energy range is divided by the equivalent 0.3-2.5 keV image. The dotted lines follow the total 0.3-10.0 keV surface brightness contours.