Suzaku Observation of Abell 2204: Galaxy Cluster Gas Temperature Measurement up to the Virial Radius

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Measurements of the intracluster gas temperatures out to large radii, where much of the cluster mass resides, are of the utmost importance for the use of clusters in precision cosmology and for studies of cluster physics. Previous attempts to measure temperatures at the cluster virial radius have failed. The preliminary results from the Suzaku observation of Abell 2204 reported here show that such measurements appear feasible now for the first time, if care is taken to account for background and PSF effects.

§1. Introduction

Cosmologically, the most important parameter of galaxy clusters is their total gravitational mass. X-rays offer an ideal way to determine this mass through measurements of the intracluster gas temperature and density structures. X-rays are also a unique tool to study the physics of the hot cluster gas, e.g., gas temperature profiles allow constraints on (the suppression of) heat conduction relative to the Spitzer value. Consequently, constraining cluster temperature profiles has been the subject of many (partially contradictory) works in the recent past.[1)–12)]

Unfortunately, making the aforementioned measurements is quite challenging in outer cluster regions. Even with *XMM-Newton* and *Chandra* it is very difficult to determine temperature profiles reliably out to more than about 1/2 the cluster virial radius, $r_{\rm vir}$ (i.e., 1/8 of the cluster volume). The primary reason is not insufficient collecting area or spectral resolution of current instruments: the limiting factor is the high background. Here the X-ray CCDs onboard *Suzaku* come into play. Owing to its low Earth orbit, the background is much lower than for *Chandra* and *XMM-Newton*, making *Suzaku* a very promising instrument for finally settling the cluster temperature profile debate. Below, we confirm this unique expectation by comparing the (very preliminary) temperature profiles measured for the cluster A2204 with *Suzaku* *XMM-Newton*, and *Chandra*.

§2. Observation, Reduction, Analysis

Abell 2204 was observed with *Suzaku* on September 17–18, 2006. The good exposure amounts to about 50 ks (using standard filtering and combining 3x3 and 5x5 editing modes). Response files were created with xisrmfgen and xissimarfgen. Night Earth data were used to subtract particle background (spectra weighted by cutoff rigidity). The spectra of a local background region – beyond the estimated virial radius – were co-fitted with the source spectra to account for Galactic emission and the cosmic X-ray background. The spectra of all XIS detectors were fitted simultaneously.

§3. Results, Discussion

The combined *Suzaku* image is shown in Fig. 1 (left). This image was not corrected for vignetting or PSF effects. The center of this exceptionally round cluster was put close to the edge of the field-of-view in order to retain a region free of cluster emission.

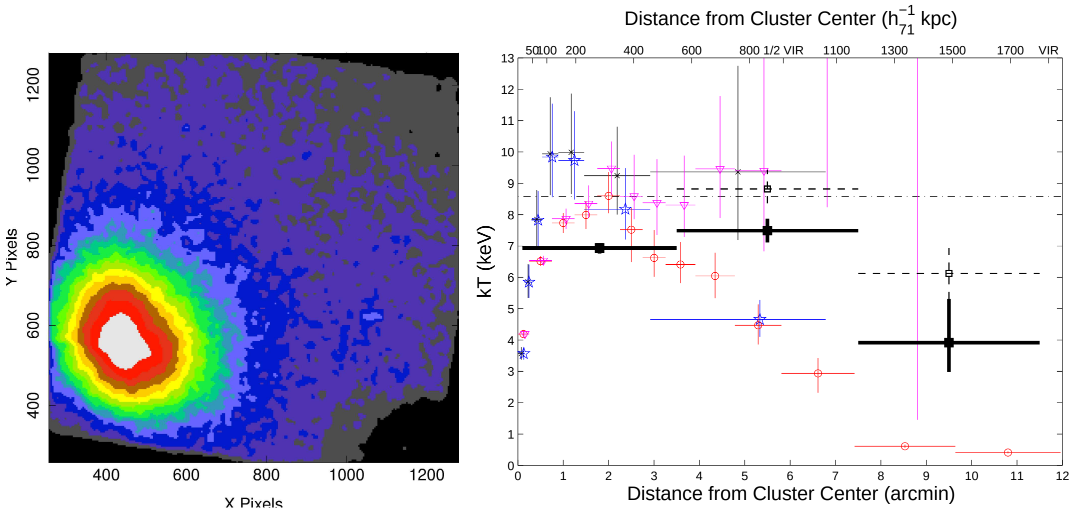

Fig. 1. Left: *Suzaku* image of A2204 combining all four XIS CCDs. Right: Preliminary measured gas temperature profiles using three different satellites. The symbols are as follows: black cross: *Chandra* background model 1; blue star: *Chandra* background model 2; red circle: *XMM-Newton* background model 1; magenta triangle: *XMM-Newton* background model 2; open black square: *Suzaku* predicted; filled black square: *Suzaku* measured. The radius that corresponds to $r_{\rm vir}/2$ ($r_{\rm vir}$) is indicated as "1/2 VIR" ("VIR") on the top axis.

Figure 1 (right) shows the very preliminary temperature profiles measured with *Suzaku* and other data. In the very center, the *Chandra* and *XMM-Newton* results agree nicely. At around 1 arcmin, *XMM-Newton* indicates a lower temperature than *Chandra*, possibly due to effects of *XMM-Newton*'s larger PSF. The background subtraction in the outer parts is tricky for both *Chandra* and *XMM-Newton*. Different simple but plausible methods for treating the background result in significantly different temperature estimates, rendering them rather uncertain at $\gtrsim r_{\rm vir}/2$.

Suzaku prediction (based on *Chandra* background model 1) and measurement match perfectly in the innermost bin. This is encouraging but also somewhat surprising considering the presence of gas at various different temperatures in this bin. The prediction for the second bin is higher than the result of the measurement. This is primarily due to *Suzaku*'s broad PSF and the very peaked surface brightness profile of this cluster in its central cool region (see the PSF discussion below). The measured temperature in the third bin – well beyond the reach of *Chandra* and *XMM-Newton* – is also lower than the prediction but the prediction had to be a guess anyway.

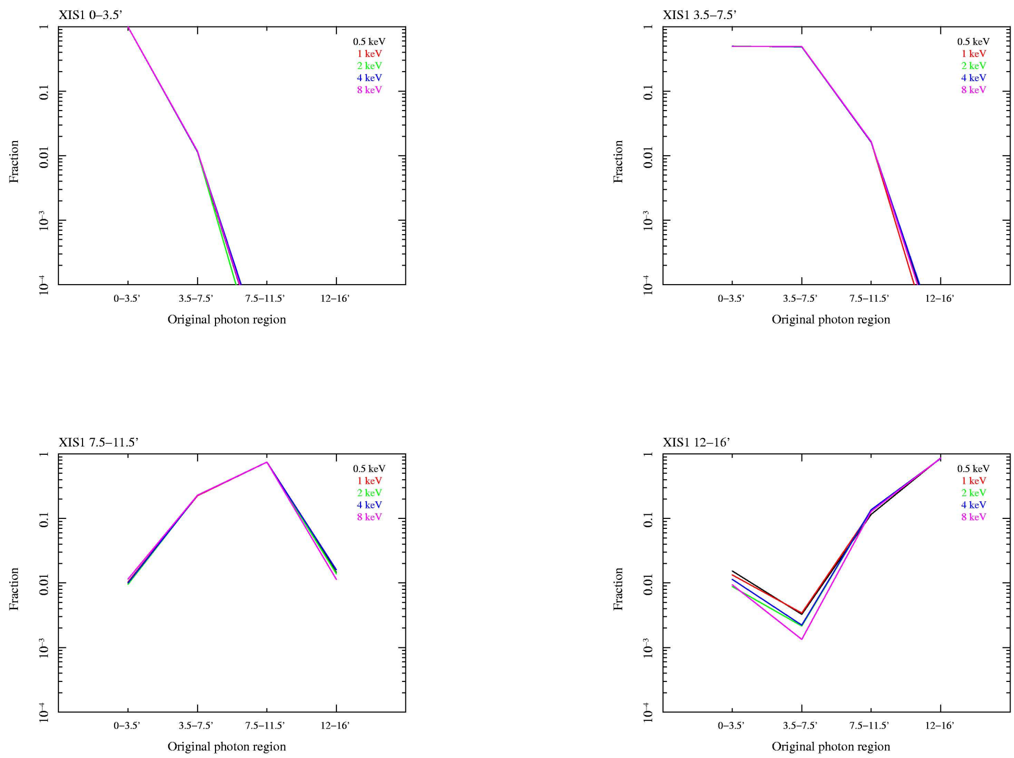

Fig. 2. Contamination fractions determined from ray tracing simulations.

In order to assess the contamination by photons from Abell 2204's bright cool core in the two outer bins due to PSF smearing we performed ray tracing simulations using the xissim tool (10^7 photons per energy and detector).[13] For this we assumed Abell 2204's surface brightness profile to follow the best double β model fit to the *Chandra* data. We followed a procedure very similar to the one described in Sato et al.[14] The results for XIS1 are shown in Fig. 2. The second innermost annulus ($3.5'$–$7.5'$) is significantly contaminated (about 50%) by the cluster center. The most important region, the third annulus ($7.5'$–$11.5'$) that extends to $r_{\rm vir}$, is contaminated by about 20%; i.e., a relatively small effect. The energy and detector dependence of the PSF is small enough to be negligible here. Therefore, it is straightforward to correct for the (anyway small) PSF contamination in the third annulus that extends to the virial radius.

In summary, even though a robust determination of the temperature beyond $r_{\rm vir}/2$ still requires more work (in progress), this analysis already demonstrates that temperature estimates in outer cluster parts appear feasible with the *Suzaku* XIS detectors for the first time.

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