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# DETECTION OF EXCESS HARD X-RAY EMISSION FROM THE GROUP OF GALAXIES HCG 62

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## ABSTRACT

We detected an excess of hard X-ray emission at energies above ∼4 keV from the group of galaxies HCG 62 using data from the *ASCA* satellite. The excess emission is spatially extended up to ∼10′ from the group center and somewhat enhanced toward the north. Its spectrum can be represented by either a power law of photon index 0.8–2.7 or a bremsstrahlung of temperature greater than 6.3 keV. In the 2–10 keV range, the observed hard X-ray flux, $(1.0 \pm 0.3) \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$, implies a luminosity of $(8.0 \pm 2.0) \times 10^{41}$ ergs s$^{-1}$ for a Hubble constant of 50 km s$^{-1}$ Mpc$^{-1}$. The emission is thus too luminous to be attributed to X-ray binaries in the member galaxies. We discuss possible origins of the hard X-ray emission.

*Subject headings:* galaxies: clusters: individual (HCG 62) — galaxies: evolution — X-rays: galaxies

## 1. INTRODUCTION

Clusters of galaxies are thought to have released a large amount of dynamical energy in their initial collapse phase. During their subsequent evolution, starburst-driven winds, cluster mergers, radio galaxies, and random galaxy motions may have supplied additional heating energy to the intracluster space. Presumably, these processes have generated energetic particles (e.g., Kang, Ryu, & Jones 1996; Takizawa 2000), as evidenced by diffuse synchrotron radio emission from some clusters.

Such energetic particles are expected to produce nonthermal X-rays as well, by Compton-boosting cosmic microwave background (CMB) photons. Long searches for such effects among galaxy clusters have recently revealed two candidates: the excess soft X-ray emission detected with the *Extreme Ultraviolet Explorer* (Lieu et al. 1996; Mittaz, Lieu, & Lockman 1998; Bowyer & Berghofer 1998) and the spectral hard X-ray tail observed with *BeppoSAX* (Fusco-Femiano et al. 1999; Kaastra et al. 1999). However, the exact nature of these emission components remains unclear.

Groups of galaxies are the poorest class of galaxy clusters. Their thermal emission is limited to energies below ∼5 keV, because the temperature of their hot intragroup medium is about 1 keV (e.g., Mulchaey et al. 1996; Fukazawa et al. 1996). Therefore, they allow us to search for nonthermal X-ray emission, even with instruments operating below an energy of ∼10 keV. Here we report the detection of excess hard X-ray emission from the group of galaxies HCG 62 with the *ASCA* Gas Imaging Spectrometer (GIS; Ohashi et al. 1996; Makishima et al. 1996). We employ 90% confidence limits throughout this Letter and use the Hubble constant of 50 km s$^{-1}$ Mpc$^{-1}$. Solar abundances refer to Anders & Grevesse (1989).

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## 2. OBSERVATIONS AND DATA REDUCTION

With a redshift of 0.0137 (Hickson, Kindl, & Huchra 1988), HCG 62 is one of the nearest Hickson compact galaxy groups. It was observed twice with *ASCA*: on 1994 January 14–15 in a single pointing and on 1998 January 13–17 in four pointings to cover the whole group region. The GIS was operated in PH mode, and the Solid-State Imaging Spectrometer (SIS) in 2-CCD FAINT mode in 1994. We do not use the SIS data taken in 1998 because of the insufficient field of view of 1-CCD mode employed at that time. After an appropriate gain correction, we co-added all the available data from different sensors, chips, and pointings, separately for the GIS and the SIS. The live time is ∼30 ks for the 1994 observation and ∼20 ks for each of the four pointings of the 1998 observation. The total GIS live time thus amounts to 110 ks.

For our purpose, it is important to accurately subtract the GIS background, which consists of cosmic X-ray background (CXB) and intrinsic detector background (IDB). We first summed data of the *ASCA* Large Sky Survey (Ueda et al. 1999), conducted in 1993 December and 1994 June over blank sky fields, with a total exposure time of 233 ks. Then, after Ikebe (1995), we excluded regions in the GIS images where the count rate exceeds those from surrounding regions by $\geq 2.5\ \sigma$. This eliminates faint sources with 2–10 keV flux greater than $8 \times 10^{-14}$ ergs s$^{-1}$ cm$^{-2}$.

We next corrected the IDB level of each pointing individually for its gradual increase by 2%–3% yr$^{-1}$ and for its random day-by-day fluctuation by 6%–8% (Ishisaki et al. 1997). For this purpose, we derived three GIS spectra, denoted $S(E)$, $B(E)$, and $N(E)$, from the on-source data, the blank sky data prepared as above, and night Earth data, respectively. They were accumulated over an annulus of radius 13′–25′ from the GIS field center and in the 6–10 keV energy range, to ensure that $S(E)$ is free from the HCG 62 emission and that the CXB is relatively minor compared to the IDB in $S(E)$ and $B(E)$. Then, assuming that the IDB spectrum and its radial profile are both constant, we fitted $S(E)$ with a linear combination $B(E) + fN(E)$; here $f$ is a free parameter and $fN(E)$ represents the secular IDB change between the two epochs when $S(E)$ and $B(E)$ were acquired. We have obtained $f = 0.00$ and $f = 0.08$–$0.12$ for the 1994 and 1998 data, respectively, in agreement with the IDB long-term increase (Ishisaki et al. 1997). By analyzing various *ASCA* data, we also confirmed

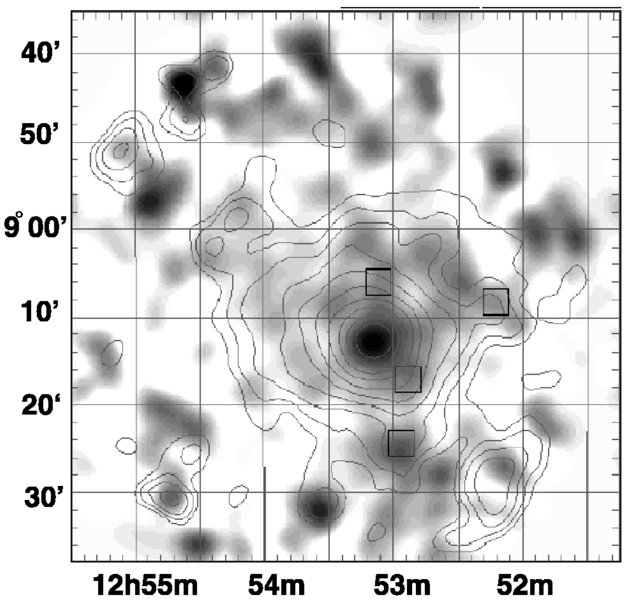


FIG. 1.—Background-subtracted GIS image of HCG 62 in 4.5–8 keV (*gray scale*) and 1.0–2.4 keV (*contours*). Both images have been smoothed with a Gaussian filter of $\sigma = 1'$, and their scales are logarithmic. The four squares are positions of the *ROSAT* point sources that would also be detected with the GIS.

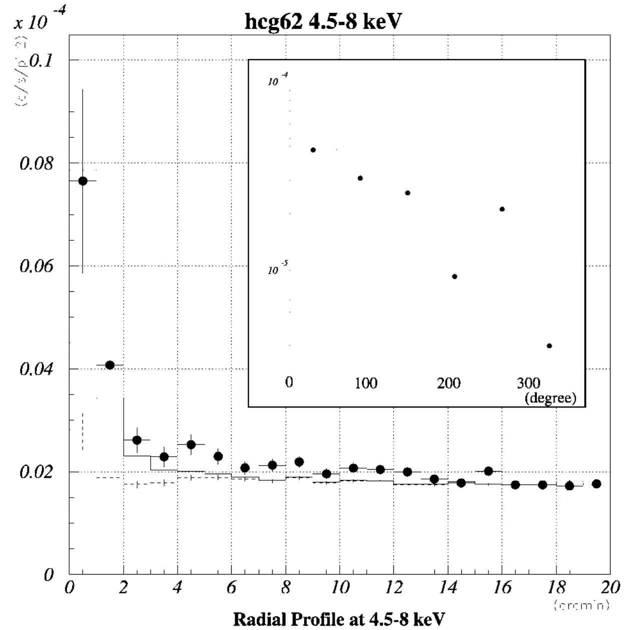


FIG. 2.—GIS radial count rate profile of HCG 62 (*crossed circles*) centered on the soft X-ray peak position, including the background. The dashed crosses represent the estimated background, and the solid line shows the *ASCA* X-Ray Telescope + GIS PSF plus the estimated background. The inset shows the background-subtracted azimuthal count rate profile in 4.5–8 keV (*crossed circles*) and 1.0–2.4 keV (*dotted histogram*). The angle is defined counterclockwise, with east being the origin.

that this method can reproduce, to within 5%, the GIS background spectra and its radial profiles acquired at any epoch over 1993–1999.

The SIS has a lower efficiency in the hard X-ray band, a shorter exposure time, and a smaller field of view than the GIS. We therefore utilize the SIS spectrum only to determine the soft thermal emission from the intragroup medium. We subtract the SIS background in a conventional way, utilizing the archival SIS background set.

## 3. RESULTS

To avoid the diffuse thermal emission with a typical plasma temperature of $kT \sim 1.0$ keV (Ponman et al. 1993; Fukazawa et al. 1998; Davis, Mulchaey, & Mushotzky 1999), we produced the GIS image of HCG 62 in the hard 4.5–8 keV band, as shown in Figure 1. There we overlaid the 1.0–2.4 keV image as a measure of the thermal emission, of which the brightness peak coincides in position with the group center to within $1'$. The image reveals a hard X-ray emission, which apparently extends up to $\sim 10'$ from the group center.

Figure 2 shows the radial GIS count rate profile in the energy band of 4.5–8 keV, centered on the soft X-ray brightness peak. Also shown are the instrumental point-spread function (PSF) and the profile of the estimated background. Thus, the background level is well reproduced at larger radii within 5%, and the hard X-ray emission is more extended than the PSF, detectable up to $10'$ from the group center. As shown in the inset to Figure 2, the hard X-ray surface brightness is higher in the north region than in the south region. Such a feature cannot be explained as a spillover from the 1 keV thermal emission. The hard X-ray brightness is not correlated with the galaxy distribution, either, including emission-line galaxies (de Carvalho et al. 1997).

The observed hard X-ray emission, although apparently extended, could simply be a result of several hard point sources, such as active galaxies, either related or unrelated to HCG 62. To answer this issue, we examined the archival *ROSAT* image of HCG 62 and found four point sources with 0.1–2 keV fluxes of $(4–8) \times 10^{-14}$ ergs $s^{-1}$ $cm^{-2}$ (Fig. 1, *open squares*) at the locations where the hard-band GIS image actually exhibits possible enhancements with the implied 2–10 keV fluxes of $\sim 10^{-13}$ ergs $s^{-1}$ $cm^{-2}$. The flux ratio between *ASCA* and *ROSAT* indicates that the source spectra have a power-law shape of photon index $\sim 1.5$. We have accordingly excluded photons falling within $2'.5$ of these four sources. In addition, in order to remove possible pointlike sources at the central region of HCG 62, we excluded photons within $3'$ of the group center. Then, the 4.5–8 keV GIS2 + GIS3 flux from the on-source data has become $3772 \pm 61$ photons over the radius of $3'–15'$, compared to $3351 \pm 20$ expected from the background count rate. The excess, $421 \pm 65$ counts, well exceeds the $\sim 60$ counts expected for the 1 keV thermal emission. Thus, the presence of the extended excess hard X-ray emission is significant from the GIS imagery even after excluding possible point-source contamination.

In order to examine the excess hard X-ray emission through spectroscopy, we have produced spectra over the radius of $3'–15'$ by utilizing all the available data from the GIS and only the first pointing data from the SIS. The regions within $2'.5$ of the four pointlike sources were again excluded. We discarded the SIS data above 4 keV for the reason described before. The obtained spectra are presented in Figure 3. We fitted them simultaneously by a single-temperature plasma emission model (Raymond & Smith 1977; R-S model) with solar abundance ratios (Fukazawa et al. 1996, 1998), modified by photoelectric absorption. As shown in Table 1 and Figure 3, the model successfully reproduced the data in lower energies, and the derived temperature and metallicity are consistent with those of Fu-

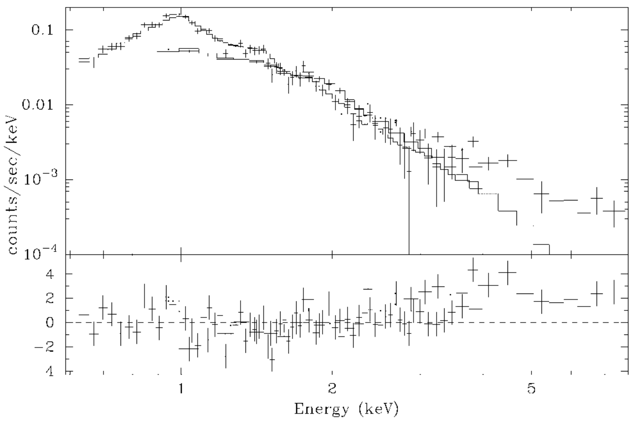


FIG. 3.—GIS + SIS simultaneous spectral fitting of HCG 62 with the single-temperature R-S model. The crosses and solid lines represent the data and model, respectively. The SIS data above 4 keV are discarded.

kazawa et al. (1998). However, the model is not acceptable due to significant residuals seen in the GIS fit over energies of greater than 3 keV. When we limit the energy band to less than 2.4 keV, the fit becomes acceptable with a reduced $\chi^2$ of 1.29 and the best-fit temperature of 0.95 ± 0.05 keV. In contrast, when we use only the hard energy band above 2 keV, the best-fit temperature increases to 2.1 ± 0.3 keV; this is inconsistent with that indicated by the soft-band data and is much higher than the prediction from the galaxy velocity dispersion of ∼300 km $s^{-1}$ (Mulchaey et al. 1996). These results reconfirm the presence of excess hard X-ray emission above the prediction of the thermal emission of temperature ∼1 keV. The results of Finoguenov & Ponman (1999), who reported a high temperature of greater than 1.5 keV around 5′ of the group center, are also consistent with ours.

We refitted the whole-band spectra by adding a bremsstrahlung or a power-law component to represent the excess hard X-ray emission. As summarized in Table 1, either modeling has given an acceptable joint fit to the *ASCA* spectra. The bremsstrahlung temperature has been constrained as greater than 6.3 keV, while the power-law photon index $\alpha_{ph}$ was found at $1.5^{+1.2}_{-0.7}$. Although $\alpha_{ph}$ can be as high as 2.7, such a steep power law forces the R-S component to have an extremely high metallicity. When we fix the metallicity of the R-S component at 0.30 solar, which is typically found from clusters of galaxies, the upper limit on $\alpha_{ph}$ becomes 2.2. Below, we utilize this limit instead of the original one. The normalization of the hard component does not change by more than 20% if we use plasma emission codes other than the R-S code.

The upper limit on narrow Fe K line features at ∼6.6 keV is uninteresting, several keV in equivalent width. The absorption column density cannot be constrained in any case and is consistent with the Galactic value of $2.9 \times 10^{20}$ $cm^{-2}$ (Stark et al. 1992). The 2–10 keV X-ray flux and luminosity of the hard X-ray component are $(1.0 \pm 0.3) \times 10^{-12}$ ergs $cm^{-2}$ $s^{-1}$ and $(8.0 \pm 2.0) \times 10^{41}$ ergs $s^{-1}$, respectively, regardless of the choice between the two modelings. This amounts to about 20% of the 0.5–10 keV thermal component luminosity of $4.9 \times 10^{42}$ ergs $s^{-1}$ (Fukazawa 1997).

Although we have carefully estimated the background, it is still important to examine to what extent our results are affected by possible background uncertainties. To see this, we intentionally increased the IDB background level by 5% and found that the 2–10 keV flux and luminosity of the hard component become $(5.5–8.4) \times 10^{-13}$ ergs $s^{-1}$ $cm^{-2}$ and $(4.3–6.5) \times 10^{41}$ ergs $s^{-1}$, respectively. Thus, the hard emission remains statistically significant.

## 4. DISCUSSION

From the galaxy group HCG 62, we have detected the excess X-ray emission with a very hard spectrum, which extends up to more than 10′ from the group center and is somewhat enhanced at the north region. Although its surface brightness is only ∼20% of that of the GIS background, we have confirmed its reality through careful analysis. Below, we discuss the origin and nature of this phenomenon.

An immediate possibility is a collection of binary X-ray sources in the member galaxies of HCG 62. However, based on the total optical luminosity of HCG 62 (∼$1 \times 10^{11}$ $L_{\odot}$; de Carvalho et al. 1997) and the optical versus X-ray luminosity correlation among elliptical galaxies (Matsushita 1997), this contribution is estimated to be at most $4 \times 10^{40}$ ergs $s^{-1}$, which is an order of magnitude short of the observed luminosity. A second possibility is an assembly of faint active galactic nuclei (AGNs) in HCG 62. However, the optical evidence for AGNs in HCG 62 is moderate (de Carvalho et al. 1997), and we have already subtracted such candidates based on the *ROSAT* image. Any remaining AGNs are estimated to contribute no more than 30%–40% of the total hard X-ray emission. Yet another possibility is the fluctuation of background faint sources. Utilizing the log $N$–log $S$ relation in the 2–10 keV band (Ueda et al. 1999), this contribution is estimated to be at most ∼$2 \times 10^{-13}$ ergs $cm^{-2}$ $s^{-1}$ over the radius of 3′–15′, which is again too low to explain the data. From these considerations, we conclude that the excess hard X-ray emission cannot be explained by the assembly of discrete hard X-ray sources, whatever their nature be.

Considering the loose constraint on the Fe K line, the excess emission might be of thermal origin from very hot plasmas. Actually, Buote (2000) described the *ASCA* spectra of HCG 62, integrated over a radius of 0′–3′, by a two-temperature

TABLE 1
RESULTS OF JOINT FITTING OF THE GIS AND SIS SPECTRA OF HCG 62 WITH VARIOUS MODELS

| Model | $\chi^2$/Degrees of Freedom | $N_H$[a] ($\times 10^{20}$ $cm^{-2}$) | $kT$[b] (keV) | Solar Abundance[b] | Normalization[b] ($\times 10^{17}$ $cm^{-5}$) | Normalization of Hard Component[c] |
|---|---|---|---|---|---|---|
| R-S .......................... | 2.24 | <3.7 | 1.02 ± 0.03 | 0.15 ± 0.02 | 7.2 ± 0.6 | |
| R-S + bremsstrahlung[d] ...... | 0.99 | <3.5 | 0.95 ± 0.05 | 0.18 ± 0.05 | 5.9 ± 1.0 | $1.2^{+0.7}_{-0.2} \times 10^{17}$ |
| R-S + power law[e] ........... | 0.99 | <3.4 | $0.96^{+0.3}_{-0.6}$ | >0.14 | $5.6^{+1.3}_{-3.5}$ | $1.7^{+5.7}_{-1.0} \times 10^{-4}$ |

[a] Column density of photoelectric absorption.
[b] Parameters of R-S model.
[c] Normalization of bremsstrahlung model or power-law model in units of $cm^{-5}$ or counts $s^{-1}$ $cm^{-2}$ $keV^{-1}$, respectively.
[d] Temperature of bremsstrahlung model $kT_{bremss} > 6.3$.
[e] Power-law photon index $\alpha_{ph} = 1.5^{+1.2}_{-0.7}$.

plasma model of $kT = 0.7$ and $kT = 1.5$ keV. We have independently reconfirmed their results. However, our spectra (Fig. 3) that are accumulated over the 3′–15′ range require a temperature of greater than 6.3 keV; the original two-temperature model found by Buote (2000) gives a very poor fit ($\chi^2/\nu = 1.66$). Thus, thermal emission with an "ordinary" temperature cannot explain the data. Insignificant detection of excess hard X-rays over a radius of 0′–3′ might be due to poor photon statistics and complex spectra of thermal components (Fukazawa et al. 1998) at the center region, spectral change of hard components, and so on. There might still be plasmas much hotter than the escape temperature, as is actually found in starburst galaxies (e.g., Ptak et al. 1997). However, within 15′ of HCG 62, there are no bright *IRAS* sources with the 60 $\mu$m flux exceeding 2 Jy (SkyView at the High Energy Astrophysics Science Archive Research Center). We therefore conclude that the thermal interpretation of the excess hard X-ray emission is unrealistic.

Given the difficulties with the discrete source and thermal interpretations of the diffuse hard X-ray emission, we regard the nonthermal interpretation as the most promising. One popular scenario of nonthermal X-ray production is inverse Compton scattering of the CMB photons by relativistic electrons with Lorentz factor $\gamma \sim 10^3$–$10^4$, as has been invoked to explain the excess hard X-ray emission from rich clusters (e.g., Fusco-Femiano et al. 1999). However, we cannot constrain the intragroup magnetic field in HCG 62 because of a lack of information on the diffuse radio flux. If we assume a representative magnetic field intensity of 1 $\mu$G, we would observe synchrotron radio emission with a flux density of ∼0.3 Jy. Since such a strong radio emission is not seen from HCG 62 (SkyView; NRAO Very Large Array Sky Survey image), the inverse Compton interpretation holds for HCG 62 only if its magnetic field is much weaker than 1 $\mu$G. The reality of such a weak magnetic field is an open question and in an apparent contradiction to the generally accepted intergalactic field strengths of ∼1 $\mu$G (Kronberg 1994), even though such a condition is suggested by the *BeppoSAX* and *RXTE* observations of some rich clusters of galaxies (Valinia et al. 1999; Fusco-Femiano et al. 1999).

An alternative interpretation is nonthermal bremsstrahlung between the thermal gas and subrelativistic particles, as proposed for the hard X-ray emission from Abell 2199, of which diffuse radio flux is quite weak (Kempner & Sarazin 2000), as in the case of HCG 62. Let us assume for simplicity that the nonthermal electrons have typical energies of 10–100 keV and their spatial density distribution is similar to that of the thermal intragroup gas. Then, the nonthermal to thermal luminosity ratio in the 0.5–10 keV band becomes $\sqrt{10}\alpha$, where $\alpha$ is the density ratio of the nonthermal electrons to the thermal ones. The observed luminosity ratio of ∼0.2 implies $\alpha \sim 0.06$, indicating that the energy density of nonthermal electrons is 0.6–6 times as high as that of thermal electrons (depending on the spectrum). If this is the case, the mechanism of such particle acceleration becomes an important issue. In addition, the nonthermal pressure associated with such a particle population would considerably increase the total mass of HCG 62, and hence its dark matter content, estimated from the X-ray data.

The diffuse hard X-ray emission has been observed with *ASCA* from some other galaxy groups as well (Fukazawa 1999). However, its prominence relative to the thermal X-ray emission appears to scatter from object to object, similar to that seen in rich clusters (Molendi et al. 1999), with HCG 62 being one of the strongest cases. Although what makes such variety is yet to be studied, the hard X-ray emission might be related with transient phenomena such as mergers.

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