**Suzaku** observation of the metallicity in the hot interstellar medium of the isolated elliptical galaxy NGC 720

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**Abstract**

We present the results from a Suzaku observation of an elliptical galaxy NGC 720. Though well-studied elliptical galaxies are often in clusters and groups of galaxies, NGC 720 is isolated; hence, it is free from attenuation by intracluster medium. Thanks to good energy resolution and high efficiency of Suzaku, the O, Ne, and Mg K-lines can be resolved from the Fe L-line complex, which enable us to measure metal abundance more precisely and reliably. With the 180 ks XIS observation, the O, Ne, Mg, and Fe abundances are obtained to be about 0.4, 0.3, 0.5 and 0.7 solar, respectively. Although these absolute values are affected by background, assumed XIS contamination model, and assumed spectral model, relative abundances are well-constrained; the obtained abundance ratio of O/Fe is 0.5 solar with accuracy of ~20%.

1. Introduction

The metal content in the hot interstellar medium (ISM) of early-type galaxies can provide basic information on the history of star formation and evolution of such galaxies. The ISM is enriched by Type Ia supernova (SN Ia) ejecta and stellar mass loss; the latter process is considered to provide mainly Type II supernova products, which were ejected in the early epoch of galaxy formation. Since oxygen is not synthesized by SN Ia and iron is mainly product of SN Ia, the abundance ratios of oxygen and iron can provide key information on the contribution of both type of supernovae to metal enrichment.

Past measurements of metal abundances of the ISM were performed mainly for X-ray bright elliptical galaxies. However, such X-ray bright galaxies are often surrounded by large emissions from a hot intracluster medium (ICM; Matsushita, 2001), which significantly hinders us from investigating the properties of the ISM itself in elliptical galaxies (Humphrey & Buote 2006 and references therein). Most isolated elliptical galaxies are faint and compact in X-rays, and hence it has been difficult to derive well-constrained abundances. A very low abundance of 0.1–0.2 was reported in the early phase (Lowenstein 1994), though the accuracy was not high.

Recently, Chandra and XMM-Newton have enabled us to study X-ray faint isolated elliptical galaxies, thanks to their good efficiency in the low energy band and their good angular resolution. Humphrey & Buote (2006 and references therein) revealed that extremely subsolar (ZFe < 0.4) abundances can be excluded for the early-type galaxies with normal and moderate X-ray to optical luminosity ratios. Still, abundances are poorly determined especially for lighter metals.

The advantage of the Suzaku observations is that the onboard CCD detector (the XIS) has much less of a low energy tail (Koyama et al. 2007) than the Chandra ACIS and the XMM-Newton EPIC. Figure 1 demonstrates the power of Suzaku. For instance in the PN spectra, iron L-line emission is significant down to 0.4 keV (hatched region), because of the instrumental response; if iron is much more abundant than oxygen, iron L-lines conceal oxygen lines. The Suzaku XIS has better energy resolution, and oxygen lines can be resolved from iron L-lines.

![Figure 1. Folded vAPEC model with the Suzaku XIS1 (red) and the XMM-Newton PN (black) and MOS (blue). The dotted line represents a vAPEC model without metals, the dashed one is a model without metal other than Fe, and the solid is the case for with metals of O, Ne, and Mg (all metals, if included, are set to be 0.5 solar). The attenuation of the XIS contaminant for NGC 720 observation is taken into account (the quantum efficiency is ~60% of the original at the energy of 0.65 keV).](image.png)

In this paper, we report results from a Suzaku observation of a nearby and isolated elliptical galaxy NGC 720. We investigated the emission-weighted spectra of the central region of NGC 720, and determined abundances of various elements. Unless otherwise specified, we adopt solar abundances by Feldman (1992), where the solar O and Fe abundances relative to H are 8.51 × 10^{-4} and 3.24 × 10^{-5} in number. Results with the new solar abundances by Lodders (2003: O and Fe abundances relative to H are 4.90 × 10^{-4} and 2.95 × 10^{-5}, respectively) is described in §4. We use 90% confidence error regions, unless otherwise specified.

2. Observation and Data Reduction

NGC 720 was observed from 2005 December 30 to 2006 January 4, as a part of the initial performance verification of Suzaku. The XIS was operated in Normal mode. Throughout when performing spectral fits, we used the following response matrix files: ae_xi1(0,2,3)_20060213.rmf for the front side illumination (FI) detectors (XIS0, XIS2, and XIS3), and ae_xi1_20060213c.rmf for the back side illu-
mination (BI) detector (XIS1). We used the energy range from 0.3 to 7.0 keV for the XIS1 and from 0.4 to 7.0 keV for the XIS0, XIS2, and XIS3, since the signal-to-noise ratio is not good in the energy region above 7 keV. We also excluded the energy range of 1.82–1.84 keV from the spectral fitting, because the XIS energy calibration has not been fixed in this energy band.

We used the cleaned rev0.7 data screened with the following criteria: the elevation angle from the earth limb > 5°, the elevation angle from the earth limb irradiated by the sun > 20°, and the satellite is not in South Atlantic Anomaly. The net exposure obtained was 180 ks for each XIS. The XIS image clearly shows X-ray emission from NGC 720, and the X-ray peak corresponds to the optical position of the NGC 720.

In order to determine the source-photon integration region, we created the radial profile of the X-ray emission. By comparing the point spread function, it is evident that the emission is extended; still the constancy at radii larger than ∼5 arcmin indicates that the X-ray emission is not extended in the whole XIS field of view. Thus, we utilized the r = 5–8' region to estimate the background level, and we collected the source photons in a radius smaller than 3 arcmin where the count rate is more than 2 times larger than the background level.

We estimated background spectra using two methods: one set of background spectra are estimated from the outer region of this NGC 720 observation (hereafter we call local sky BGD), and the other set utilized spectra from the same r < 3' region during another observation of a very faint source (specifically, we utilized the Arp 220 observation from 2007 Jan 7 to 9). The latter is superior to the local sky BGD in the point that the result is less affected by the XIS contamination model. On the other hand, the sky “background” is not isotropic (e.g., Snowden et al. 1995), and the local sky BGD can be considered to be better as long as we assume that sky background emission shows no small-scale structure. For instance, if background spectra have sharp structure at the energy of the line of interest, resultant abundance could be easily affected by background spectra. Thus, we examined the background spectra carefully [See details in Tawara et al. 2007 (hereafter, Paper I)]. We mainly used the Arp 220 r < 3' data as the background in spectral analyses hereafter, and a fit with sky background model was also performed to look at the effect by the choice of background.

3. Spectral Analysis

We fitted each XIS spectrum separately with a spectral model consisting of optically-thin thermal plasma and absorbed bremsstrahlung emissions; both components are assumed to be attenuated by Galactic absorption, which is fixed at $N_H = 1.55 \times 10^{20} \text{ cm}^{-2}$. The vAPEC model is used for the former model, while abundances of O, Ne, Mg, Si, Fe are free parameters, the C, N, and Al abundances are fixed at 1.0 solar, and the S, Ar and Ca abundances are tied together with the Si abundance. The latter component is represented for emissions from spatially-unresolved point sources, and the parameters other than the bremsstrahlung normalization are fixed at $kT = 7 \text{ keV}$ and $N_H = 1 \times 10^{21} \text{ cm}^{-2}$ (e.g., Jeltema et al. 2003). Actually, we included a varabs component into the above model to represent for contamination, and ARFs without contamination are used (namely, ae_xi(0,1,2,3)_xisnom4_20060615.arf)¹ The parameters for varabs are fixed at the values from the contamination model released in May 2006. The results are summarized in Table 1. After confirming the consistency of the results among the XISs, we next fitted 4 XIS data simultaneously with the same model. Here we added a constant into the model to represent uncertainty of calibration in absolute flux among the XIS detectors. This result is also listed in Table 1, and the data and the folded best-fit model are shown in Fig. 2. The confidence contour of oxygen and iron abundances is shown in Fig. 3. The obtained $\chi^2$ values are rather large in all the fits. With several trial fits (See Paper I), we regarded that this is likely due to incomplete iron L-line atomic data (Matsushita et al. 2007 and references therein), and that the effect on the derived abundances is insignificant. Thus, we did not concern ourselves with this problem in the later analyses.

We next estimated the uncertainty of abundances arising from the uncertainty of the contamination model, and the results are summarized in Table 2. We looked at the XMM-Newton EPIC data in order to utilize to estimate the XIS contamiant. We fitted the MOS spectra from the $r < 3'$ region centered on the X-ray peak (including point-source emission)² with the same spectral model in Table 1 (though, varabs which represent for the XIS contaminant

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¹ These ARFs are intrinsically for point-sources observed at the xis nominal position with the photon-integration region of $r < 4$ mm, which is equivalent to ∼2.9 arcmin.

² See other details about the XMM-Newton data reductions in Fukazawa et al. (2006). We did not utilize the PN data because of the following reasons: 1) the energy resolution of the PN is worse than that of the MOS and the XIS, and 2) if we fitted the PN data only, the resultant abundance for every metal is lower than that from the MOS and XIS data, and the obtained Mg and Si abundances are inconsistent even among the PN and the MOS.
including the 0.52–0.6 keV data (listed in Table 1). We compared with the best-fit model. Here we fitted the 4 extracted spectra actually show a deficit at around 0.65 keV is 10–20%.

This ratio is still under investigation and a smaller fraction in the derived abundances (Table 2). Up to here we have the model, and the we fitted the same spectral model. The contamination-model–predicted values and zero for the absolute flux among detectors. The obtained best-fit pa-

Table 2. Results from the fits with several contamination model to the Suzaku XIS and XMM-Newton MOS data

<table>
<thead>
<tr>
<th>C contaminant column density</th>
<th>Ne, XIS0</th>
<th>O, XIS1</th>
<th>Ne, XIS2</th>
<th>Mg, XIS1</th>
<th>Si, XIS2</th>
<th>Fe, XIS1</th>
<th>χ²/dof</th>
</tr>
</thead>
<tbody>
<tr>
<td>C:O=6:1</td>
<td>2.1</td>
<td>2.7</td>
<td>3.4</td>
<td>5.0</td>
<td>0.33</td>
<td>0.31</td>
<td>0.46</td>
</tr>
<tr>
<td>C:O=6:1</td>
<td>1.4</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>C:O=10:1</td>
<td>1.5</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>C:O=20:1</td>
<td>1.5</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Note.— With the latest contamination-model updated in Oct 2006, the column densities of C contaminant are predicted to be 1.6, 2.5, 3.0, and 4.7 in the unit of 10¹⁸ cm⁻² for the XIS0, XIS1, XIS2, and XIS3, respectively.

are not included). After confirming the EPIC results are consistent with that from the XIS within the errors, we fitted the XIS and EPIC data simultaneously with the same spectral model. The varabs model is included into the model, and the varabs parameters were fixed at the contamination-model–predicted values and zero for the XISs and the EPIC, respectively. A constant parameter is again introduced to represent uncertainty of calibration in absolute flux among detectors. The obtained best-fit parameter values are between those from the Suzaku fits and the XMM-Newton fits, which is quite reasonable. Then, we fitted the Suzaku and XMM-Newton data, allowing the XIS contaminant thickness vary. For the XIS1 (BI), the obtained column density of carbon contaminant is consistent with the model-predicted value; but for the others (FI), the values are constrained to be smaller than the model-predicted values by 20–40%. Still, the ambiguity of the contaminant for the FIIs makes only ≲10 % difference in the derived abundances (Table 2). Up to here we have assumed the contaminant is composed of C:O=6:1, but, this ratio is still under investigation and a smaller fraction of oxygen is suggested. Thus, as a trial we tested the two cases assuming the contaminant is composed of C:O=10:1 and 20:1, while the column density of the contaminant for each XISs was set free. In general, larger C/O ratio resulted in smaller abundances; but it makes 20 % difference at most case. In summary, we can conclude that the uncertainty of abundances caused by the contaminant model is 10–20%.

We also checked the effect on derived metal abundances by the adopted background. As described in Paper I, one concern of the Arp 220 background spectra is excess emission from O VI K-line, and the Arp 220 background subtracted spectra actually show a deficit at around 0.65 keV compared with the best-fit model. Here we fitted the 4 XIS spectra ignoring the data in this energy band of 0.52–0.6 keV. The obtained parameters are listed in Table 3 (labeled with “Arp 220 BGD”), and consistent with those including the 0.52–0.6 keV data (listed in Table 1). We also tested the other background case, specifically using the local sky BGD model as well as the instrumental back-

ground spectra (“local sky BGD” in Table 3): we evaluated the folded model spectra for r<3’ and r=5–8’ regions with the local sky BGD model and the ARFs including the XIS contamination model. We then calculated the ratio of the r<3’ model spectra to the r=5–8’ spectra for each XISs. By multiplying the instrumental-background subtracted r=5–8’ spectrum by this ratio, the background spectrum for the r=3’ region were obtained. We performed a fit to 4 XIS data subtracting these background. Here we used the ARFs created by xissimarfgen version 2006-05-28 (Ishisaki et al. 2007) for the r=3’ region. The obtained parameters are summarized in Table 3. By comparing this result with the result with the Arp 220 data, the difference among each parameter was found to be as small as about half of its statistical 90% error region. Hence, we concluded that our results are not affected significantly by the choice of background.

Finally, in order to investigate the uncertainty of abundance measurements caused by the assumed spectral model, we fitted the Suzaku data with various spectral models. We tested another thin-thermal model vMEKAL, and a two temperature plasma model using two vAPEC components while each element abundance are assumed to be same among the components. Uncertainty caused by the point source modeling was also examined. We replaced a bremsstrahlung for point source emission with a power-law, and performed a fit with a single vAPEC plus point-source model (PNT1 model in Table 3). The power-law component is assumed to be attenuated by an absorption of N_H=1×10²¹ cm⁻². With this fit, the fraction of the point source flux to the total photon flux (f_pnt) becomes larger (f_pnt in the 0.3–2 keV is 18%, whereas that with the absorbed bremsstrahlung model in Table 1 is 12%). Therefore, the vAPEC abundances resulted in higher values; still relative abundances remain consistent with those from the previous fits (Fig 3). We modeled the point-source emission again with a bremsstrahlung component, while both the temperature and the absorption for it are allowed to vary (PNT2 model in Table 3). The obtained best-fit values of the absorption column density became zero (The 90 % upper-limit
Table 3. Simultaneous fits to the 4 XIS data with different background, or several spectral models

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Arp 220 BGD†</td>
<td>0.32$^{\pm0.04}_{-0.07}$</td>
<td>0.29$^{\pm0.07}_{-0.06}$</td>
<td>0.43$^{\pm0.09}_{-0.08}$</td>
<td>0.46$^{\pm0.14}_{-0.12}$</td>
<td>0.63$^{\pm0.09}_{-0.08}$</td>
<td>710.4/381</td>
</tr>
<tr>
<td>local sky BGD</td>
<td>0.39$^{\pm0.10}_{-0.06}$</td>
<td>0.31$^{\pm0.07}_{-0.06}$</td>
<td>0.44$^{\pm0.09}_{-0.08}$</td>
<td>0.42$^{\pm0.19}_{-0.16}$</td>
<td>0.63$^{\pm0.09}_{-0.08}$</td>
<td>462.0/390</td>
</tr>
<tr>
<td>vMEKAL</td>
<td>0.31$^{\pm0.04}_{-0.04}$</td>
<td>0.14$^{\pm0.08}_{-0.05}$</td>
<td>0.54$^{\pm0.09}_{-0.07}$</td>
<td>0.44$^{\pm0.14}_{-0.16}$</td>
<td>0.60$^{\pm0.11}_{-0.10}$</td>
<td>7975.5/389</td>
</tr>
<tr>
<td>2T vAPEC</td>
<td>0.32$^{\pm0.09}_{-0.06}$</td>
<td>0.39$^{\pm0.10}_{-0.09}$</td>
<td>0.52$^{\pm0.09}_{-0.07}$</td>
<td>0.54$^{\pm0.14}_{-0.16}$</td>
<td>0.75$^{\pm0.14}_{-0.13}$</td>
<td>7251.3/388</td>
</tr>
<tr>
<td>PNT1</td>
<td>0.49$^{\pm0.13}_{-0.13}$</td>
<td>0.42$^{\pm0.10}_{-0.10}$</td>
<td>0.61$^{\pm0.12}_{-0.12}$</td>
<td>0.67$^{\pm0.19}_{-0.17}$</td>
<td>0.93$^{\pm0.17}_{-0.17}$</td>
<td>749.7/389</td>
</tr>
<tr>
<td>PNT2</td>
<td>0.54$^{\pm0.23}_{-0.13}$</td>
<td>0.50$^{\pm0.13}_{-0.13}$</td>
<td>0.73$^{\pm0.07}_{-0.07}$</td>
<td>0.73$^{\pm0.19}_{-0.17}$</td>
<td>1.07$^{\pm0.22}_{-0.22}$</td>
<td>7274.3/388</td>
</tr>
</tbody>
</table>

Fig. 3. The confidence contours of O and Fe abundances. The fit with single temperature model (4 XISs in Tab. 1) is shown with red color. Cyan curves are the case while the parameter of carbon in contamination model is free and the number ratio of carbon to oxygen is assumed to be 6. Magenta curves are for the 2 temperature fit, and blue curves are for the single temperature vAPEC with simple power-law model (PNT1 in Tab. 3). The color curves show the 90% confidence, and black ones show the 68% confidence. Four straight lines denote the O/Fe ratio of 0.4, 0.5, 0.6, and 1 (left to right).

was $3 \times 10^{20}$ cm$^{-2}$. Again, this fit resulted in a higher contribution of the point source emission in the soft X-ray band ($f_{\text{pt}}$ in the 0.3–2 keV is 23%), and the vAPEC abundances got higher. Still, the relative abundances are again consistent with those with other models.

4. Summary and Discussion

With the Suzaku observation of NGC 720, emission-weighted abundances of O, Ne, Mg, Si, and Fe in the ISM were derived for the central region within a radius of 3 arcmin. In this section, we representatively use the abundances derived from the spectral fit in Table 1 labeled with 4 XISs. The O, Ne, Mg, and Fe abundances are obtained to be about 0.4, 0.3, 0.5 and 0.7 solar, respectively, though these absolute values are affected by background, XIS contamination model, and assumed spectral model, and the resulting uncertainties are as high as several tens of %. However, relative abundances are well-constrained: the O/Fe, Ne/Fe, and Mg/Fe abundance ratios derived from most of the fits are consistent with each other within their statistical errors. One exception is the Ne/Fe and Mg/Fe ratios with vMEKAL model, indicating that Ne and Mg abundances are quite subject to the iron L-line atomic data. The abundance ratio of O/Fe, Ne/Fe, and Mg/Fe is 0.52, 0.46, and 0.70 solar with accuracy of ~20%, respectively. These values increase to 0.81, 0.67, and 0.74, adopting new solar abundances by Lodders (2003).

Humphrey & Buote (2006) reported from Chandra observations that the iron abundance is $0.70^{+0.21}_{-0.20}$ from NGC720, and $0.51^{+0.23}_{-0.18}$ solar from the mean of their sample. Our results are consistent with both of these values. They also reported from NGC 720 that the abundance ratios of O/Fe, Ne/Fe, and Mg/Fe are of 0.18±0.17, 0.42±0.41, and 1.23±0.34, respectively. Their results are roughly consistent with our Suzaku results; apparently, our Suzaku results give tighter constraints especially for O/Fe, and Ne/Fe.

The O and Mg abundances are well-constrained in the NGC 720 ISM, and these species reflect the metallicity of mass-losing stars in this galaxy. Stellar metallicity can be derived from the optical spectroscopy, and the Mg$_2$ and Mg$_b$ indices are observed for NGC 720 in the very central region. Kobayashi & Arimoto (1999) derived that extrapolated stellar metallicity ([Fe/H]) is 0.25. Rembold et al.(2005) also reported stellar metallicity of $+0.0932 < [\text{Fe/H}] < 0.5595$ from a similar observation of NGC 720. These optical results are higher than that from X-ray ISM observation. This discrepancy may be partially explained by the fact that the index depends not only on the metallicity but also on the age distribution of the star, and/or by the fact that optical spectroscopy tends to be limited to within the central region of galaxies. Further Suzaku observation of ISM metallicity can advance our understanding of stellar metallicity in elliptical galaxies.

More discussions and full descriptions on analyses are presented in Paper I.

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References

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