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SUZAKU WIDE-BAND X-RAY SPECTROSCOPY OF THE ELLIPTICAL GALAXY NGC 4382

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ABSTRACT

Elliptical galaxies are generally luminous sources of X-ray radiation, and contain large amounts of hot, interstellar gas. We present high spectral resolution study of the giant elliptical galaxy NGC 4382, obtained with the X-ray Imaging Spectrometer (XIS) detector onboard Suzaku observatory.

A detailed analysis allowed us to determine the metal abundances of oxygen, silicon, sulfur and iron. In this work, the versions of APEC model 1.3.1 and 3.0.2 are applied for comparison with previous work. The variation in the values of the abundance and temperature with the new version of APEC model 3.0.2 were reported. Since O, Ne, and magnesium have been assembled mostly by supernova (SNe) type II, the observed abundance refers to the contribution of SN Ia products in elliptical galaxies. With the Suzaku observation of galaxy NGC 4382, we measured the ISM temperature, metal abundances of O, Ne,Mg, and Fe, and their abundance ratios for the region within 3re of the galaxy's center and 5re outside for background.

Keywords: Galaxies abundances; galaxies individual (NGC 4382); galaxies ISM; X-rays ISM.

1. INTRODUCTION

Metallicities of the stars in elliptical galaxies can be estimated from optical broad-band photometry and spectroscopic measurement of selected absorption line indices. Since the hot interstellar medium primarily originates from stellar mass loss, X-ray observations provide most features about abundance information. Most of stars are old population in early-type galaxies and the star formation activity is low. The early-type galaxies have a hot gas in the X-ray emission from expanded hot interstellar medium (ISM) emitting X-ray , which is considered to be gravitational limited [12]. For understanding the metal enrichment processes, the Suzaku satellite is a powerful tool, due to a better energy resolution

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and lower background than any previous X-ray CCD detector [9]. The elliptical galaxy NGC 4382 is in the Virgo Cluster, but it differs from other Virgo early-type galaxies by being rather inconspicuous in X-rays. The ISM temperature ranges from 0.5-1 keV for early type galaxies [13] so that most of their emissions are radiated in the soft X-ray band. We can determine the metal abundances of the ISM directly by using the X-ray observational data, and restriction the stellar metallicity of the entire galaxy. Therefore, we can estimate the hot plasma temperature and metallicity at hot ISM with small systematic uncertainties through X-ray spectra. Resent observations as XMM-Newton satellite have provided means for measuring the concentrations of metals from O and magnesium in some systems, but has been obtained from reliable results only for a few cases of central galaxies, in groups and clusters [18].

With the Suzaku X-ray satellite, the abundances of the elliptical galaxy NGC 4382 for O, Ne,Mg, and Fe have been measured; the O, Ne, and Mg abundances are well obtained because the energy resolution of Suzaku is a better accuracy, and its background is lower than any previous X-ray CCD detector,therefore Suzaku can measure O and Mg with high sensitivity [9].

In this work, we report the results of spectral analysis of the S0 galaxy NGC 4382 observed by the XIS detector on board Suzaku and present the abundance and temperature in the ISM within 3re. Here, re is the effective radius of the galaxy, where we use this parameter to determine regions of galaxies. The NGC 4382 is an elliptical galaxy belonging to the Virgo cluster, it is away 1.7 Mpc from the galaxy of M87 and the position of NGC 4382(Right Ascension, Declination) in J2000.0 is (12h 25m 25s, 18◦ 11'27") and the red shift is (z= 0.002432). This data was taken from the NASA/IPAC extragalactic database (NED). However, NGC 4382 has been observed with ROSAT [6], Chandra [20], and XMM-Newton [17]. The temperature of ISM in elliptical galaxy NGC 4382 is (0.3-0.4 keV), this result is suggested from X-ray observations by Suzaku satellite. Since no inter cluster medium (ICM)has been detected around the NGC 4382, since this galaxy is suitable for investigating heavy elements in the ISM [18]. Throughout this paper, we used the Hubble constant H0= 70 km s-1 Mpc-1, and the virial radius is defined by, $r180 = 1.95\ h^{-1} 100\sqrt{k(T)/10}$ keV Mpc [11];[8]. We use the solar abundance values obtained by Lodders (2003) [10] in this analysis.

2. THE SUZAKU OBSERVATION OF NGC 4382

The NGC 4382 was observed with Suzaku on (2008-7-04 at the time of 04:37:27) for about 99 ksec and a red shift of (z= 0.002423). The log observation of NGC 4382 is present in table1. We analyzed the public data PROC version 2. We extracted the spectra of the source and background regions at the effective radius 3re and 5re - 8re respectively [18] centered on the X-ray peak as show in figure 1.

Table 1. The observation log of NGC4382.

Field	Center
Sequence number	803005010
(RA, Dec) in J2000.0	12h 25m 25s, 18◦ 11' 27"
Date of observation	2008-7-04 04:37:27
Exposure time	99 ks

The effective radius is about 0.91 arcmin [4] ,we convert these regions to pixel scales. The small circle is centered the source at 3re and other annulus for the background which are located at 5re - 8re. We analyzed only the XIS data, although Suzaku observations were performed with both (XIS) [9] and the Hard X-ray Detector [21, HXD], which operate in normal modes. The XIS consists of three front-illuminated (FI: XIS0,XIS2 and XIS3) CCD cameras and one back illuminated (BI:XIS1) CCD camera. During observations of the sample galaxies, the XIS was operated in normal clocking mode (8 s exposure per frame), with the standard 3×3 and 5×5 editing mode. Event files from both instruments

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were screened using XSELECT V2.4c of the Suzaku pipeline processing. The XIS response matrix file (RMF) and ancillary response files (ARF) were produced with the latest calibration files available, with the ftools tasks "xisrmfgen" and "xissimarfgen" respectively. We used the "xisrmfgen" and " xissimarfge"n version created on 2006-10-26 to make RMF and ARF files, respectively. The source mode of the "xissimarfgen" was set to SKYFITS, which is appropriate for analyzing the extended objects. To subtract the contribution of non-X-ray background (NXB), we used the " xisnxbgen" task to generate the NXB spectrum from a dark Earth database [22].

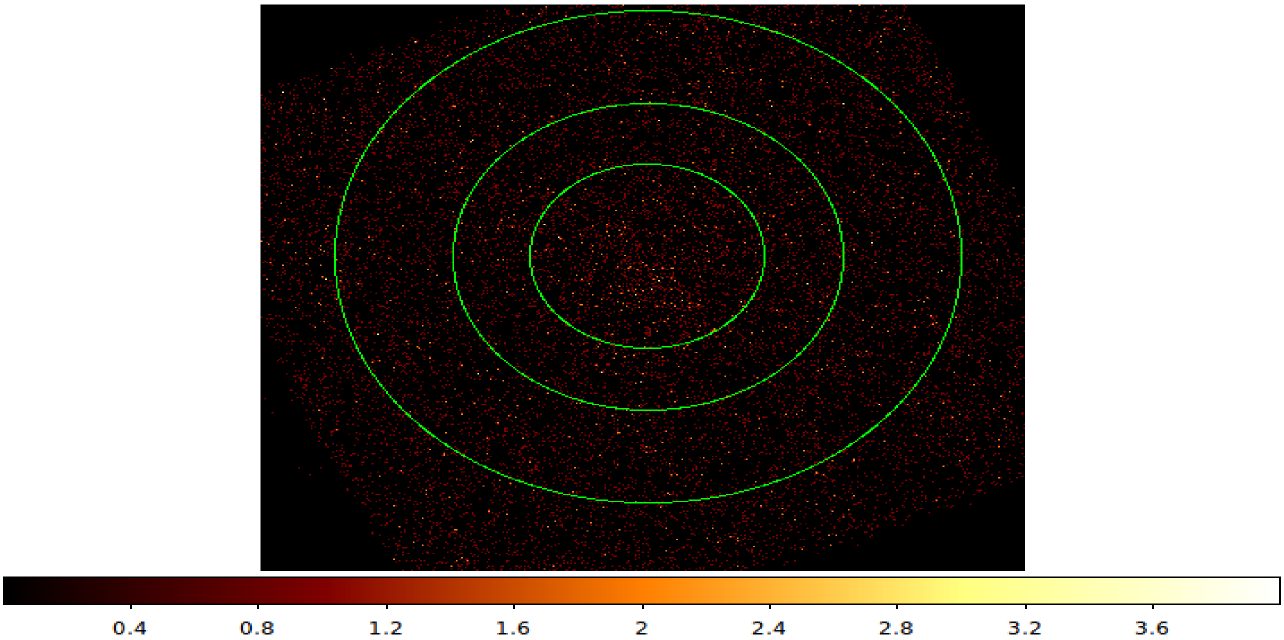

Fig 1: The X-ray image (0.4-5keV) of NGC 4382 observed at the center region. The non X-ray background (NXB)is subtracted, and the vignetting effects and the difference in exposure times are corrected. Boundaries of analysis regions are shown by two circles.

3. THE SPECTRAL ANALYSIS AND RESULTS

As shown in figure 1, we extracted the spectra within a 3re circle centered on the optical center of NGC 4382. We also used the region outside 5re to estimate the background. The spectra of XIS detectors (XIS0, XIS2 and XIS3 are ombined together as FI spectra and XIS1 as BI spectra) were fitted simultaneously with a model consisting of the ISM emission, unresolved discrete sources, cosmic X-ray background (CXB), and Galactic components. Here, the spectra of the NXB were subtracted. In this section we will discuss the emission from galactic background and the spectral fitting.

3.1 The emission from the galactic background

In order to study the emission from NGC 4382 correctly, we have to estimate the background accurately. This consists of the instrumental non X-ray background (NXB), the cosmic X-ray background (CXB) [2] and the foreground Galactic X-ray emission (GXE). We estimated the NXB spectra in each analysis region using the tool "xisntebgdgen", by means of the weighted sum of the night Earth observations. We estimated the CXB contribution by using an uniform-sky ARF, which is generated with "xissimarfgen" generates the Ancillary Response Files (ARFs) of the Suzaku XIS detectors through Monte-Carlo simulations for many combination of user-input, such as arbitrary X-ray emitting region and event extracting region. The GXE consists of a Local Hot Bubble (LHB) component and a Milky Way Halo (MWH)

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component [7]. We fitted the spectra with the NXB subtracted outside of 5re from the center of NGC 4382 to derive the contribution from the CXB and Galactic emission. In this study, we assumed that there is no emission from the galaxy beyond 5re as suggested by [18], and fitted the GXE spectrum with two-temperature APEC models for galactic absorption by multiplying with wabs model and Milky Way. The CXB can be fitted well with the absorbed power law, where the temperature was a free parameter and fixed the metal abundances to one solar at the center. Table 2 shows the data for background object NGC 4382, and figure 2 exhibiting the best fit for two version of APEC models. The reduced chi-squared is = 1.1719 (411/417) degrees of freedom for the background of NGC 4382 with (CXB) and (GXE). For the CXB component, we adopted a power-law model with a photon index $\Gamma = 1.4$ [18]. Galactic emission arises mainly from the local hot bubble (LHB) and the Milky Way halo (MWH). The temperature and normalization derived from two components in the Galactic emission are free parameters; the temperature values of the two APEC models are consistent with the typical values for the LHB and MWH by [18].

Table 2. The spectral parameters of CXB and GXE using two APEC models.

Regions	models	parameters	values
cosmic X-ray background (CXB)	wabs*pow	photon-index	1.4
	power-law	normalization	1.24e-03±2.45e-05
	power-law	normalization	1.2e-03±2.42e-05
Galactic X-ray emission(GXE)	APEC1.3.0	kT (keV)	0.3095 ±0.01481
	====	normalization	1.293e-03±1.289e-04
	APEC3.0.2	kT (keV)	0.2872±0.01392
	====	normalization	1.093e-03±1.119e-04
Milky Way Halo(MWH) Local Hot Bubble (LHB)	APEC1.3.1	kT (keV)	0.07611 ±0.008637
	====	normalization	0.03373±0.02022
	APEC3.0.2	kT (keV)	0.07907 ±0.01417
	====	normalization	0.02742 ± 0.02274

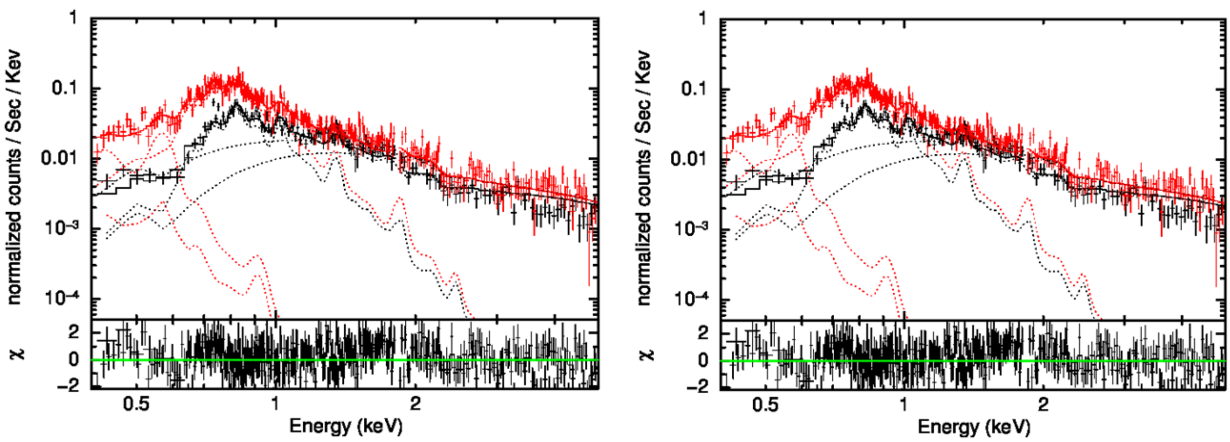

Fig 2: Same as Figure 3, but for the background region.

3.2 The ISM component of Hot Plasma

One of the fundamental problems in the abundance determination is how to select the most appropriate gas emission model. Even though the measured of abundances critically depend on the adopted emission model. The X-ray spectral

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fitting often does not statistically require a complex, but a realistic model. It is essential to feel confident that the fitting results of X-ray spectra require reasonable statistics (e.g., X^2 per degree of freedom ~1). However, spectral fitting results (particularly the best fit of Fe abundance) can be significantly different when determined, for example, by applying a single-temperature model or a multiple temperature model. The spectra of the hot X-ray emitting interstellar medium (ISM) of elliptical galaxies carry valuable information on the composition of both the stellar and the Type Ia supernova (SNIa) ejecta in the late phases of the galactic evolution. Generally, one can estimate that the contribution of SNIa to the metal enrichment of the hot ISM is very important, and perhaps being more than 60% [19]. Using X-ray observations, we can directly determine the metal abundances of the ISM, and constrain the stellar metallicity of the entire galaxy. The atomic data for lines at X-ray wavelengths and the structure of the hot ISM is not complex as compared with the optical spectra; therefore, we can estimate the temperature and metallicity of the hot ISM through X-ray spectra within small systematic uncertainties. The metallicities derived from fitting thermal plasma models are driven primarily by the Fe abundance. Since it has generally been assumed that abundances of the mass losing stars are supersolar,and since Type SNIa are expected to further enrich the hot gas to Fe abundances of at least three times solar. The ISM abundances of O, Ne, and Mg are often determined by SNII ejecta ,that is to say O and Mg come from stars from outer layer.

3.3 Spectral fitting

The NGC 4382 Suzaku XIS0+3 and XIS1 spectra are simultaneously fit in the 0.4-5.0 keV band using Xspec 12.8.1g with a source model consisting of a single temperature thermal plasma (vapec) model with a single set of heavy element abundances (C, N, O, Ne, Mg, Al, Si, S, Ar, Fe, Ni) plus a 7 keV thermal bremsstrahlung component to account for the LMXBs; both components were assumed to be attenuated by Galactic absorption, which was fixed at NH= 2.5×1020cm-2. The vAPEC model was used for the former model, while the abundances of O, Ne, Mg, Si, Fe were free parameters, the C, N, and Al abundances were fixed at 1.0 solar, and the S, Ar, and Ca abundances were tied together with the Si abundance. For more details, we divide the metals into several elemental groups (He= C = N, O, Ne , Mg = Al, Si, S= Ar = Ca, Fe = Ni), and modified the abundance of the He = C = N group to solar, but the metal abundances of S= Ar = Ca are taken as the same value of Si. The abundances of other groups were treated as free parameters. We used the spectra from the BI (XIS1) and FI (XIS0, 1 and 3) sensors for the energy ranges of 0.4-5.0 keV since it is difficult to subtract the background lines above the energy of 5.0 keV, on the other hand, it is found that the ISM does not emit photons above this energy range. The energy range around the Si K-edge (1.82-1.84 keV) was ignored as a result of a problem in the response matrix files. The spectra of XIS detectors (XIS0, 1, and 3) were fitted simultaneously with a one model including all the parameters of the ISM emission, cosmic X-ray background (CXB), and Galactic components. We applied the vAPEC model for the emission from NGC 4382 and the BREMSS model with a temperature fixed to 7.0 keV [15] for the hard component, and the other component is the power law for CXB with a photon index of Γ =1.4. All these parameters are multiplied in the photo-electric absorption using Wisconsin [16]. For all of the analyzed regions, the fitted energy range was 0.4-5 keV, because the specrta less than 0.4 keV is difficult to analyze due to large systematic errors, and the contribution of NXB is a dominant above ~5 keV [7]. The bremss model describe the total spectra of discrete source in early-type galaxies well, and was successfully used for this role in previous studies [1]. This component as well as the ISM component was also subjected to a common absorption with fixed NH at the Galactic value [5]. The fitting result is shown in figure 3 and include the chi-squired which show the best fit models.

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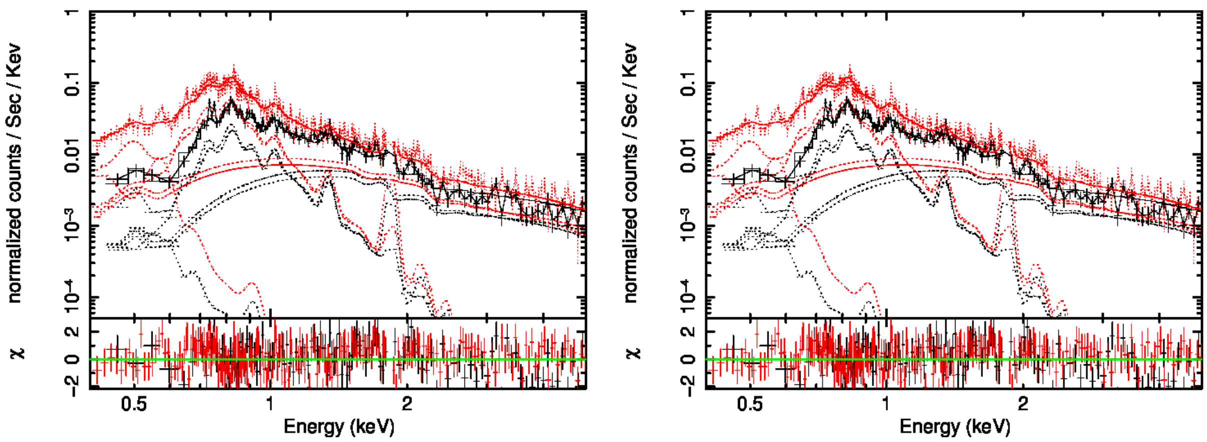

Fig 3: The spectral fitting region of NGC 4382. Black and red crosses show the observed spectra of FI and BI, respectively. Black and red thick lines show the best fit model of the emission plasma with a BREMSS model using the two versions APEC for the FI and BI spectra. At the bottom panel of figure 3, we present residuals fit.

4. RESULTS

We consider the uncertainties in the abundance determination due to those in the spectral models and in the calibration of the detectors. The temperature of the hot gas is set primarily by the depth of the potential well of the galaxy. At the temperatures found in elliptical galaxies, many lines of the X-ray emission is emission line due to heavy elements. Thus, the X-ray spectra can be used to measure values of the abundances, particularly the abundance of iron. It was expected that the gaseous abundances would be moderately to extremely high, depending on the supernova rate. The ISM temperature within 3re is about 0.29-0.31 keV. This temperature is lower than those of early-type galaxies (NGC 720, NGC 1399, NGC 1404, and NGC 4636) which have been observed with Suzaku [14, 23, 7]. This temperature is consistent with those derived from previous observations with the ROSAT telescope [6], Chandra [20],and XMM-Newton [17]. Most of ISM abundance ratios of NGC 4382 and the elliptical galaxies are located between those of SNe Ia (present Fe abundance) and SNe II(mass loss of elements O.Mg,Ne,...). This means that the metals in the ISM are a mixture of the SNe Ia and SNe II yields. With the Suzaku X-ray satellite, we can measure the abundances of O, Ne, Mg,Si and Fe of the elliptical galaxy NGC 4832 with two APEC models. This is shown in table 3. In table 3 summarizes the best-_t parameters of the temperature and abundances. The emission features consist of multiple emission lines from various transitions. Given that the gas temperature in elliptical galaxies ranges from 0.3 keV to 1.2 keV, the strong emission lines are typically from O, Ne, Mg, Si, S and Fe in various ionization stages. The ISM temperature within 3re is about 0.29-0.31 keV. This temperature is lower than those of early-type galaxies (NGC 720 and NGC 4636) which have been observed with Suzaku ([23];[7]). From table 3, we notice that the temperature result when applying APEC 3.0.2 and the values of abundances are most accurate this is clear from the value of X 2 , via the X 2 value of error in APEC 3.0.2 is less than ratio 0.1. In new model the values of error of abundances are near from absolute value this leads to the APEC 1.3.1 model is better in error, this shown in Si abundance. For unresolved X-ray emission on the galactic plane, we added a BREMSS model, in which the temperature at 7 kev in APEC 1.3.1 and APEC 3.0.2.

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Table 3. The spectral _tting of NGC 4832 for the emission plasma+BREMSS model using two version APEC models.

Abundance(solar)	APEC 1.3.1	APEC 3.0.2
kT(keV)	0.2873±0.009343	0.3095±0.01282
O	0.28 ±0.1089	0.7477 ±0.7063
Ne	0.6376±0.2298	1.59±1.446
Mg	0.5483±0.2439	1.127 ±1.033
Si	1.664±1.352	2.273±2.078
Fe	1.06 ±0.3751	1.544±1.337
Normalization of vAPEC model	5.939 e-04±1.939 e-04	2.342e-04±2.075e-04
Normalization of BREMSS model	9.751e-05±_2.477e-06	9.85e-05±2.448e-0
Reduced X2	1.2046(302/311) degrees	1.135 (302/311) degrees

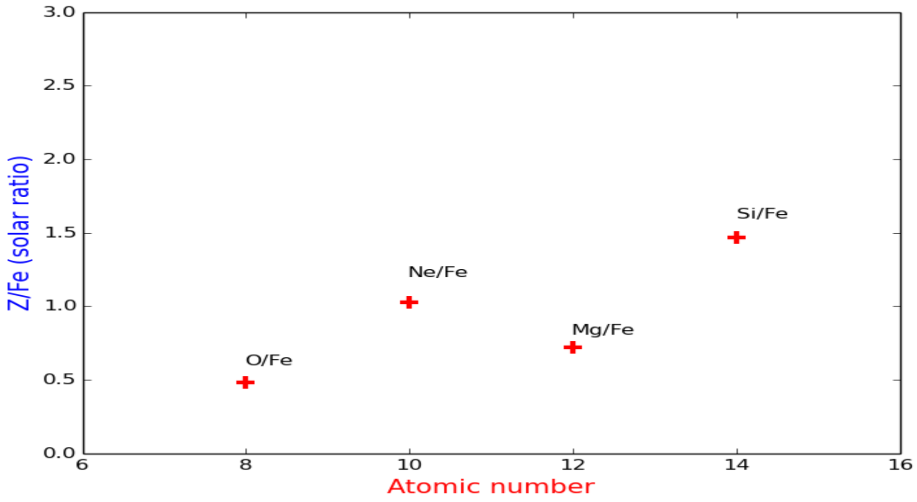

Fig 4: The relation between ratio of abundance by relative to Fe Z/Fe vs. atomic number.

Figure 5 show the ratio of abundance elements to Fe, we see the heavy element abundances in stars in the central regions of elliptical galaxies are rather high, and Type Ia supernovae may further enhance the abundances this show from figure the Si abundance is very high at atomic number 14 of Silicon element, and too from table 3 the heavy elements as Si is very higher than Fe abundance this show when applying APEC 3.0.2. However, the values of reduced X2 become improved, when we apply the new version of APEC model. The ratio of O abundance relative to Fe is about 0.48 (about half of the other elements), although Si,Ne abundances are larger than Fe abundance this show in table 4. From table 4 the abundance ratios of O/Fe, Ne/Fe, and Mg/Fe have subsolar values of 0.2-1 in solar units this results are corresponding to [18] and increase in Si abundance. By comparing our results with [18], this reference neglect the value of Si because large error and problem in response files. The O/Fe Abundance ratio clearly smaller than those of Ne/Fe and Mg/Fe, although the value has a large error, this show in table 4.

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Table 4. The ratio of abundance in NGC4382 by relative to Fe abundance by using results of APEC 3.0.2

Fixed results	Ratio of abundance	Atomic number of elements
O = 0.747	O/Fe = 0.48	O = 8
Ne=1.59	Ne/Fe = 1.03	Ne = 10
Mg=1.12	Mg/Fe = 0.72	Mg = 12
Si=2.27	Si/Fe = 1.47	Si = 14
Fe=1.54		Fe = 26

5. SUMMARY AND CONCLUSION

The elliptical galaxies are the most massive and the oldest stellar systems in the universe.

Analyses of their stellar spectra and their evolution with time have indicated that most of the stars formed at very high redshift. Ideally, the metal abundances can be measured by fitting proper models to the observed X-ray spectra and the related uncertainties can be constrained by applying proper statistics. Practically, however, there are various systematic effects and simplified assumptions which affect the results but are not easy to fully take into account. We observe from previous study as Chandra observations the morphological and thermal structures of the hot ISM in gas-rich elliptical galaxies are quite complex, because the stellar populations are old and stars are metal-rich and expect high (super-solar) abundances in the hot ISM, especially of Fe, due to SNIa enrichment.

* The star formation activity is low becuase most of stars are old population.

* The stellar metallicity reflects the past activity of star formation.

* The metal abundances in hot ISM have information of star formation histories of galaxies.

In elliptical galaxies, the O and Mg abundances in the hot gas should be equal to those in mass losing stars, since these elements are not synthesized to any great extent by SN Ia. Therefore, X-ray observations can probe the stellar metallicity over the entire galaxy, which is virtually impossible with optical observations. The oxygen-to-iron ratio in the different stellar populations is a tracer of the chemical enrichment by supernovae of types II and I: SNII/SNI along the Galaxy lifetime, given that the bulk of oxygen is produced and ejected by massive stars, whereas the bulk of iron is produced by SNI of intermediate masses. With the Suzaku observation of galaxy NGC 4382, we measured the ISM temperature, metal abundances of O, Ne, Mg, and Fe, and their abundance ratios for the region within 3re of the galaxy's center and annulus for background. The temperature, 0.29-0.31 keV is smaller than other elliptical galaxies. The internal metallicity in the ISM within the galaxy, as suggested from the significant gradient in the stellar metallicity within re [3]. However, no information is available about the stellar metallicity in larger scales. Suzaku satellite is best in observation than Chandra and XMM Newton especially in study of abundance in elliptical galaxy. Suzaku is giving us the oxygen and other abundances in galaxies and clusters, with promises of constraints on enrichment history and on SN models and giving too the new sensitivity to any soft-excess cluster emission, Good prospects for cluster temperature and mass maps to the virial radius.

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