

Suzaku Observation of the Metallicity in the Interstellar Medium of NGC 4258

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ABSTRACT

The Suzaku X-ray satellite observed the nearby spiral galaxy NGC 4258 for a total good exposure time of 100 ks. We present an analysis of the Suzaku XIS data, in which we confirm that the 0.5–2 keV spectra of the interstellar medium (ISM) are well-represented by a two-temperature model. The cool and hot ISM temperatures are 0.23 ± 0.01 and 0.58 ± 0.01 keV, respectively. Suzaku's excellent spectral sensitivity enables us to measure the metal abundances of O, Ne, Mg, Si and Fe of the ISM for the first time. The resultant abundance pattern of O, Mg, Si, and Fe is consistent with that of the new solar abundance table of Lodders (2003), rather than Anders and Grevesse (1989). This suggests that the metal enrichment processes of NGC 4258 and of our Galaxy are similar.

KEY WORDS: galaxies: abundances — galaxies: interstellar medium

1. Introduction and Observation

Metal abundances in the hot X-ray emitting interstellar medium (ISM) are important for understanding the star formation history and evolution of galaxies. A large fraction of metals in the ISM are synthesized by type Ia and type II supernovae (SNe Ia/II). O and Mg are predominantly synthesized by SNe II, while Fe is mainly produced by SNe Ia. Therefore, the abundance ratios provide useful information on the contribution of both types of SNe enriching the metals. Suzaku carried out an observation of NGC 4258 in 2006 June for 100 ksec. NGC 4258 is a non-starburst spiral galaxy and hosts an obscured low luminosity active galactic nucleus (LLAGN).

2. Spectral Analysis

We extracted spectra from the following two regions. The one is an ellipse region, with semimajor and semiminor axes of $8.3'$ and $3.6'$. This region is NGC 4258 components. The other is the entire XIS field of view was used, after excluding the above NGC 4258 component and three additional $1.5'$ radius circular point source regions. This is background components.

We simultaneous fit for NGC 4258 and background

regions. We fitted the galaxy spectra with the model: $\text{phabs}_G \times (\text{vapec}_{1\text{T or }2\text{T}} + \text{bremss}) + \text{phabs}_{\text{AGN}} \times \text{power-law}_{\text{AGN}} + \text{phabs}_G \times (\text{power-law}_{\text{CXB}} + \text{apec}_{\text{MWH}}) + \text{apec}_{\text{LHB}}$, where the last term represents the background model. In the model, phabs_G means the Galactic absorption in the direction of NGC 4258. The term $(\text{phabs}_{\text{AGN}} \times \text{power-law}_{\text{AGN}})$ shows the LLAGN contribution; its absorbing column was fixed at $1.07 \times 10^{20} \text{ cm}^{-2}$, and the $\text{power-law}_{\text{AGN}}$ slope and normalization at $\Gamma = 1.86$ and $Norm = 4.22 \times 10^{-3} \text{ photons keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$ at 1 keV, both after Yamada et al. (2009). The term $(\text{phabs}_G \times (\text{power-law}_{\text{CXB}} + \text{apec}_{\text{MWH}}) + \text{apec}_{\text{LHB}})$ represents the background component. We assumed a power-law model for the CXB component, and a two temperature model for the Galaxy to represent emission from local hot bubble (LHB) and Milky Way halo (MWH).

The ISM emission of NGC 4258 was modeled with one or two-temperature models, as indicated by the subscripts 1T or 2T, respectively, employing the vapec code (Smith et al. 2001). The abundances of He, C, and N were fixed to the solar value. We also divided the other metals into five groups as O, Ne, (Mg & Al), (Si, S, Ar, Ca), and (Fe & Ni), based on the metal synthesis mechanism of SNe, and allowed them to vary. The

abundances were constrained to be common all temperature components. The brems model, with $kT = 10$ keV, represents the integrated LMXB component (Makishima et al. 1994; Yamada et al. 2009). In order to constrain the background component contained in the above fitting model, we simultaneously fitted the source and background spectra, over the 0.5–2 keV and 0.5–5 keV regions, respectively. When fitting the background spectra, the normalizations of vpec, brems, and powerlaw_{AGN} were all fixed to be 0. The fit statistics shown in table 1 clearly favor the two-temperature model, which gives the two temperatures as 0.23 and 0.59 keV. The derived parameters are summarized in table 1.

3. Discussion

The present Suzaku observation has clearly revealed emission line features from the ISM in the spiral galaxy NGC 4258. We successfully measured the metal abundances of O, Ne, Mg, Si and Fe for the first time. Figure 1 shows our metal-to-Fe ratios, which were derived from the two-parameter confidence contours. The ISM emission is here modeled with two temperatures.

In figure 1, the abundance pattern of NGC 4258 is compared with those indicated by the solar abundance table of Anders and Grevesse (1989) and the new solar abundance table of Lodders (2003). Thus, the abundance pattern of the ISM of NGC 4258 measured with Suzaku agrees better with that of Lodders (2003), rather than that of Anders and Grevesse (1989).

In order to investigate differences between spiral and starburst galaxies, we also plot in figure 1 the abundance pattern of the hot ISM in disk and halo regions of the starburst galaxy NGC 4631 (Yamasaki et al. 2008), and that of the “cap” region of the extreme starburst galaxy M 82 (Tsuru et al. 2007). The results of NGC 4631 disk are consistent with those of Lodders (2003) as is

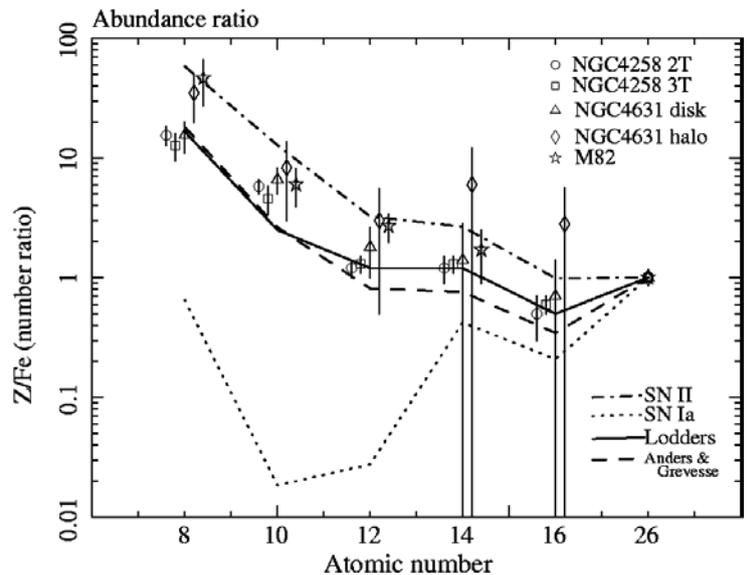


Fig. 1. Number ratios of O, Ne, Mg, Si and S to Fe for the two model of the ISM in NGC 4258. Solid and dashed lines indicate the number ratios of metals to Fe due to Lodders (2003) and Anders and Grevesse (1989), respectively. Dot-Dashed and dotted lines represent the number ratios of metals to Fe for the SN II and SN Ia products (Iwamoto et al. 1999; Nomoto et al. 2006).

the case of NGC 4258, while the respective patterns of M 82 “cap” and the halo region of NGC 4631 are close to those expected from SN II yields. We may conclude that solar abundance pattern are common in normal spiral galaxies, including NGC 4258 and our Galaxy. The fact that the disk region of NGC 4631 also has a similar abundance pattern to normal spirals, suggests that the metallicity of the ISM after its starburst era may look quite similar. In contrast, in starburst galaxies, SN II products such as O effectively escape into the halo region as a result of the energetic explosions. Thus, observations of abundance patterns such as ours play a key role in investigating the processes of galaxy evolution and enrichment of the intergalactic medium.

Table 1. Summary of the best-fit parameters

Parameters	1T for ISM	2T for ISM
Γ_{CXB}	1.42 ± 0.04	1.41 ± 0.04
kT_{MWH} (keV)	0.3 (fix)	0.3 (fix)
kT_{LHB} (keV)	0.1 (fix)	0.1 (fix)
$kT_{1\text{T}}$ (keV)	0.38 ± 0.01	0.23 ± 0.01
$kT_{2\text{T}}$ (keV)	-	0.58 ± 0.01
O (solar)	$0.36^{+0.10}_{-0.07}$	$0.56^{+0.17}_{-0.08}$
Ne (solar)	$1.20^{+0.29}_{-0.20}$	$1.28^{+0.62}_{-0.20}$
Mg, Al (solar)	$0.79^{+0.21}_{-0.15}$	$0.99^{+0.47}_{-0.15}$
Si, S, Ar, Ca (solar)	$1.59^{+0.54}_{-0.39}$	$1.11^{+0.50}_{-0.18}$
Fe, Ni (solar)	$0.49^{+0.12}_{-0.08}$	$0.64^{+0.29}_{-0.09}$
$\chi^2/\text{d.o.f.}$	1333/740	993/738

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