Investigating the X-ray and Gamma-ray Properties of the Galactic Supernova Remnants Kes 69, 3C 396, 3C 400.2

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1 Abstract
Kes 69, 3C 396, and 3C 400.2 are mixed-morphology (MM) Galactic supernova remnants (SNRs), where Kes 69 and 3C 396 are interacting with molecular clouds (MCs). Previous X-ray studies showed that the emission from these SNRs is thermal. It has been suggested that MM SNRs interacting with MCs are potential candidates for recombining plasma (RP) in X-rays and hadronic γ-ray emission. Recently, Chandra observations revealed signs of RP in 3C 400.2. Our preliminary analyses show that the X-ray emission of NW and SE region of 3C 400.2 arises from recombining plasma. We detected GeV γ-ray emission from Kes 69 and 3C 396 above 5σ.

2 Introduction
Kes 69, 3C 396, and 3C 400.2 are mixed-morphology (MM) Galactic supernova remnants (SNRs), where Kes 69 and 3C 396 are interacting with molecular clouds (MCs). Previous X-ray studies showed that the emission from these SNRs is thermal. It has been suggested that MM SNRs interacting with MCs are potential candidates for recombining plasma (RP) in X-rays and hadronic γ-ray emission. Recently, Chandra observations revealed signs of RP in 3C 400.2. Our preliminary analyses show that the X-ray emission of NW and SE region of 3C 400.2 arises from recombining plasma. We detected GeV γ-ray emission from Kes 69 and 3C 396 above 5σ.

3 X-ray Observations and Analysis
These SNRs observed with X-ray Imaging Spectrometer (XIS; Koyama et al. 2007) onboard Suzaku. Their observation logs are listed in Table 1. The data reduction and analysis were carried out with HEASOFT package version 6.16 and XSPEC version 12.9.0 (Arnaud 1996) with AtomDB 3.0.3 (Smith et al. 2001; Foster et al. 2012).

The background spectra were extracted from the source-free region in the same field of view. The background emission consists of the instrumental non X-ray background (NXB), cosmic X-ray background (CXB) and Galactic ridge X-ray emission (GRXE) for these SNRs. We estimated the NXB spectra using the tool xisnxbgen (Tawa et al. 2008).

The source spectra were extracted from circular and ellipses regions for these SNRs. For spectral fitting, we used a non-equilibrium ionization (NEI) recombining collisional plasma model with variable abundances (VRNEI in XSPEC). We used the absorption TBABS model in XSPEC (Wilms et al. 2000) and abundances of Wilms et al. (2000).

4 γ-ray Analysis
To search for a γ-ray counterpart of the SNRs Kes 69, 3C 396, and 3C 400.2 in the GeV energy range, we analyzed the γ-ray data of Large Area Telescope (LAT) on board Fermi Gamma Ray Space Telescope (Fermi) for the time periods as given in Table 2.

Using gtselect of Fermi Science Tools, we selected the Fermi-LAT Pass 8 ‘Source’ class and front+back type events coming from zenith angles smaller than 90° and from a circular region of interest (ROI) with a radius of 20° centered at the corresponding SNR position as shown in Table 2.

We applied the maximum likelihood fitting method on the spatially and spectrally binned data within a square region of 28° × 28° and used the instrument response function version P8R2.SOURCE.V6. While mod-
Table 1: Log of the Suzaku observations

| SNRs     | Obs.ID       | Obs.Date       | Exposure (ks) |
|----------|--------------|----------------|---------------|
| Kes 69   | 509037010    | 2014-09-27     | 77.4          |
| 3C 396   | 509038010    | 2014-04-26     | 82.8          |
| 3C 400.2 NW | 509068010    | 2014-04-23     | 21.5          |
| 3C 400.2 SW | 509069010    | 2014-04-14     | 24.2          |
| 3C 400.2 SE | 509070010    | 2014-04-23     | 24.9          |
| 3C 400.2 NE | 509071010    | 2014-04-23     | 20.2          |

Table 2: Log of the Fermi-LAT observations

| SNR Name | Obs. Start Date | Obs. End Date | ROI R.A.(J2000) | ROI Decl.(J2000) |
|----------|-----------------|---------------|-----------------|------------------|
| Kes 69   | 4 August 2008   | 15 May 2016   | 18 h 32 m 45 s.12 | −10° 08′ 00″.12 |
| 3C 396   | 4 August 2008   | 14 May 2016   | 19 h 04 m 08 s.12 | +05° 28′ 00″.12 |
| 3C 400.2 | 4 August 2008   | 6 January 2015| 19 h 38 m 50 s.00 | +17° 14′ 00″.12 |

5 Preliminary Results and Discussion

In this work, we present the Suzaku and Fermi-LAT preliminary analysis results of the MM SNRs Kes 69, 3C 396, and 3C 400.2.

We found that the overionized plasma in SE and NW regions of 3C 400.2. The X-ray emission of SW and NE regions is well represented by a two thermal plasma model; a high-temperature in NEI and a low-temperature in collisional ionization equilibrium (CIE) condition. Using Chandra data, Broersen & Vink (2015) found overionizing plasma in all parts of this remnant. 3C 400.2 showed no significant γ-ray emission, when fitted as a point-like source at the radio-location with a simple power-law type spectrum. The nearby region of 3C 400.2 contains a spot of brighter γ-ray excess (Figure 1 right panel), which needs to be further analyzed using more data.

The X-ray spectrum of 3C 396 is described by two component thermal model with a column density $N_H \sim 6.1 \times 10^{22} \text{ cm}^{-2}$. The γ-ray analysis revealed significant γ-ray emission at the radio-SNR location of 3C 396 with a significance of $\sim 25\sigma$ assuming 3C 396 to be a point-like source with a power-law type energy spectrum. Since the analysis region contains areas of excess γ-ray residuals (Figure 1 center panel), it requires further investigation.

We found that the X-ray emission from Kes 69 is well fitted by a combination of NEI and CIE model with absorbing column density of $N_H \sim 2.8 \times 10^{22} \text{ cm}^{-2}$. Kes 69 was detected $\sim 16\sigma$ by modeling the SNR as a point-like γ-ray source having a simple power-law type spectrum. There is a 3rd Fermi-LAT catalog source (3FGL J1833.5−1033) about a distance of 0.47° away from Kes 69 that exhibits an excess of γ rays (Figure 1 left panel). Also there is another γ-ray excess region very close to Kes 69, where no counterparts exist. So, the analysis needs to be refined by taking the excess γ-ray emission in the neighborhood of Kes 69 into account. This will...
**Figure 1:** *Left Panel:* The gamma-ray residual map of Kes 69 (left), 3C 396 (center), and 3C400.2 (right). The residual maps are smoothed with a 3-sigma Gaussian kernel. The black contours are from Suzaku with 8.0, 9.0, 10.0 counts for Kes 69, 0.0, 9.3 and 18.6 counts for 3C 396 and 3.4, 4.2, 5.0 for 3C400.2.

help us to better characterize the $\gamma$-ray emission originating from Kes 69.

**Acknowledgments**

TE thanks to the support by the Young Scientists Award Program (BAGEP-2015). AS is supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) through the BİDEB-2219 fellowship program. RY is supported in part by grant-in-aid from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) of Japan, No. 15K05088.

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