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AKARI observations of the multiphase intergalactic medium of Stephan's Quintet

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Abstract. Stephan's Quintet (SQ, HCG92) is a well studied compact group of galaxies with a disturbed intergalactic medium (IGM). An "intruder" galaxy NGC 7318b is currently colliding with the IGM at a relative velocity of 1000 km s^{-1}, causing a large-scale shock front. We observed SQ with the Far-Infrared Surveyor (FIS) aboard AKARI in four far-infrared (far-IR) bands at 65, 90, 140, and $160\mu m$. The $160\mu m$ image clearly shows an additional peak of emission overlying structure extending in the North-South direction along the shock ridge seen in the $140\mu m$ band, and in H_2 and X-ray emission. Whereas most of the far-IR emission in the shocked region is from cold dust (20 K), the [CII]$158\mu m$ emission - whose luminosity is comparable to that of the warm H_2 gas - can significantly contribute to the single peak emission in the $160\mu m$ band. We conclude that the [CII] line emission comes from the warm H_2 gas in the shock. Our result represents the first detection of shock-excited [CII] line emission.

Keywords. ISM: structure - galaxies: individual - galaxies: interactions - infrared: ISM

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1. Introduction

Stephan's Quintet (SQ, HCG92) is a compact group of galaxies (Hickson 1982) with a disturbed intergalactic medium (IGM). An intruder galaxy, NGC 7318b, is currently colliding with the IGM, causing a large-scale shock front. The shock front has been detected as a ridge in radio and X-ray emission (Allen and Hartsuiker 1972, Pietsch *et al.* 1997). Appleton *et al.* (2006) discovered powerful H_2 rotational line emission from warm molecular gas in the center of the shock ridge with an extremely large equivalent width (EW). This may indicate that far-infrared (far-IR) fine-structure lines such as [CII]158 μm line also show extremely large EWs towards the shock, making a significant contribution to the far-IR luminosity. However, this fact has yet to be revealed observationally.

The Far-Infrared Surveyor (FIS)(Kawada *et al.* 2007) aboard *AKARI*(Murakami *et al.* 2007) has four far-IR bands with central wavelengths of 65, 90, 140, and 160 μm. The well sampled allocation of *AKARI*/FIS 4 bands can provide the spectral information to constrain both the dust temperature and the [CII]158 μm line emission. In this paper we report the observation of SQ with the FIS, and discuss the origin of the far-IR emission in the IGM.

2. Observations and data reduction

SQ was observed with AKARI in the four bands N60 (65 μm), WIDE-S (90 μm), WIDE-L (140 μm), and N160 (160 μm). The four-band images are presented in Fig. 1. At the centers of the shocked region, NGC 7319, and NGC 7320, we derive the flux densities

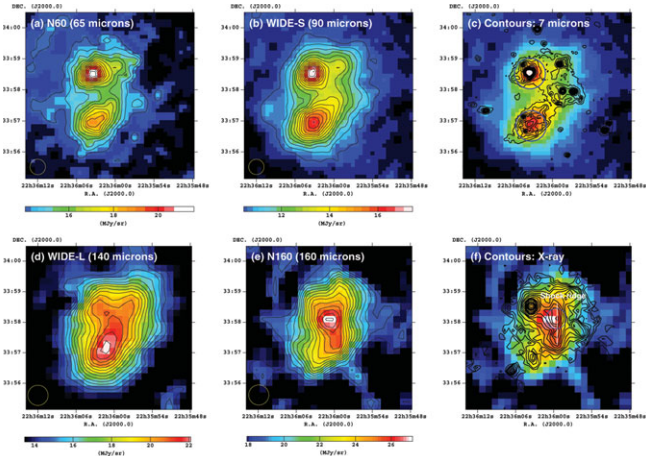

Figure 1. Four-band images of the SQ in the N60 (top-left), WIDE-S (top-middle), WIDE-L (bottom-left), and N160 (bottom-middle) bands. In each image, the FWHM of the PSF is shown in the lower left corner. The upper-right and bottom-right panels show the images of WIDE-S and N160 bands overlaid on *AKARI* 7 μm and XMM/Newton X-ray contours, respectively. The three apertures for photometry of the shocked region ($r = 20''$), NGC 7319 ($r = 30''$), and NGC 7320 ($r = 30''$) are shown in the panels of (c) and (f). As a reference, the shock ridge is shown by the solid white line in the panel (f).

by integrating the surface brightness within circular apertures. Figure 2(a) shows the resulting spectral energy distributions (SEDs) at these positions. Note that the fluxes in Fig. 2(a) are not the fluxes for the whole areas of the shocked region and the galaxies.

3. Results

In Fig. 1, N60 and WIDE-S images show emission from NGC 7319 and NGC 7320. While the WIDE-L image shows a structure extending in the North-South direction along the shock ridge, the N160 image clearly shows an additional single peak of emission overlaid on this structure. There are no corresponding additional peaks associated with the individual galaxies in N160. Figure 1(f) shows that the spatial distribution of the 160 μm emission is quite similar to that of X-ray emission in the shocked region.

The dust temperatures in the shock and surrounding galaxies are about 20-30 K. Because the flux ratio between the N160 and WIDE-L bands is not very sensitive to the dust temperature, the difference in the spatial distribution of far-IR emission between the two bands is hard to explain only by the presence of a cold dust component. An alternative possibility is a contribution from the shock-powered [CII]158 μm line emission to the N160 band. For SQ, the wavelength of [CII]158 μm line is redshifted to 161 μm (Hickson (1992)). Thus, its contribution to the N160 band is larger than to the WIDE-L band. To estimate the contribution from the [CII] line, the WIDE-L flux density $F_{\rm WL}$ is simply subtracted from the N160 flux density $F_{\rm N160}$ by assuming that the dust emission is constant in units of F_ν over the two bands (Fig. 2(b)). By using the same aperture as that in Fig. 1(f), the subtracted flux density $F_{\rm sub}$ is estimated to be 40^{+18}_{-22} mJy. The [CII] luminosity surface density $\Sigma_{L_{\rm [CII]}}$ [erg sec^{-1} kpc^{-2}] is given by $4\pi D^2 (F_{\rm sub} A^{-1})(R_{\rm N160} \Delta\nu_{\rm N160}^{-1} - R_{\rm WL} \Delta\nu_{\rm WL}^{-1})^{-1}$, where D is the distance to the SQ of 94 Mpc, A is the aperture area at the shocked region (260 kpc^2), $R_{\rm N160}$ and $R_{\rm WL}$ are the relative responses of the N160 and WIDE-L bands at 161 μm, respectively, and $\Delta\nu_{\rm N160}$ and $\Delta\nu_{\rm WL}$ are the effective bandwidths of N160 and WIDE-L, respectively. From Kawada *et al.* 2007, $R_{\rm N160}$, $R_{\rm WL}$, $\Delta\nu_{\rm N160}$, and $\Delta\nu_{\rm WL}$ are taken as 0.96, 0.59, 0.4 THz, and 0.8

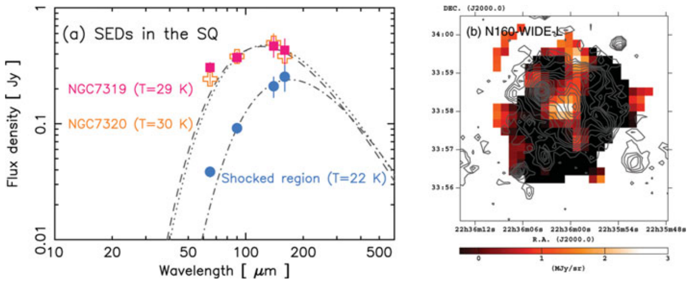

Figure 2. (a) SEDs at the shocked region, NGC 7319, and NGC 7320. The positions of the apertures are shown in Figs 1(c) and (f). The dashed, dotted, and dash-dotted lines show the single temperature modified blackbody spectrum with the emissivity power-law index of unity for NGC 7319 (filled squares), NGC 7320 (croses), and the shocked region (filled circles), respectively. (b) The N160 image shown after subtraction of the WIDE-L image. The contours show XMM/Newton X-ray contours that are the same as those in Fig. 1(f).

THz, respectively. Thus, $\Sigma_{L_{[\rm CII]}}$ is estimated to be $(1.0^{+0.4}_{-0.5}) \times 10^{39}$ erg sec^{-1} kpc^{-2}, which is comparable to the H_2 line luminosity surface density $\Sigma_{L_{\rm H_2}}$ of 2×10^{39} erg sec^{-1} kpc^{-2}(Cluver *et al.* 2010). By using the dust emission at 160 μm, the EW of the [CII] line is estimated to be ∼10 μm, about 10 times larger than that typical for nearby galaxies Boselli *et al.* (2002).

To investigate the possibility of luminous [CII] line emission from the shocked region, the C^+ abundance per hydrogen atom $X_{\rm C^+}$ is estimated with assumptions that the [CII] line emission comes from the warm H_2 gas and is optically thin. Within these assumptions, $X_{\rm C^+}$ is given as

$$X_{\rm C^+} = 1.1 \times 10^{-4} \left(\frac{\Sigma_{L_{[\rm CII]}} \;\; L_\odot {\rm kpc}^{-2}}{\Sigma_{\rm M_{H_2}} \;\; M_\odot {\rm kpc}^{-2}} \right) \left(\frac{1 + 2{\rm exp}(-91~{\rm K}/T) + n_{\rm H}^{\rm crit}/n_{\rm H}}{2{\rm exp}(-91~{\rm K}/T)} \right), \tag{3.1}$$

where T is the kinetic temperature of H_2 gas, $n_{\rm H}^{\rm crit}$ is the critical density of the [CII] line emission for HI collisions, and $n_{\rm H}$ is the number density of HI. At the shocked region, T and $n_{\rm H}$ are 158 K and $> 10^3$ cm^{-3}, respectively (Cluver *et al.* 2010). $n_{\rm H}^{\rm crit}$ is 3.0×10^3 cm^{-3} at 158 K (Langer *et al.* 2010). Thus, $X_{\rm C^+}$ is estimated to be $\sim 1 \times 10^{-4}$. Assuming that the carbon in the [CII] line emitting region is in singly ionized form, the carbon abundance in the shocked region is in agreement with that in an interstellar gas-phase (1.4×10^{-4}, Cardelli *et al.* (1996)). Therefore, the luminous [CII] line emission from the shocked region is physically plausible provided that C^+ is the main carbon form in the warm H_2 gas.

References

Allen, R. J. & Hartsuiker, J. W. 1972, *Nature*, 239, 324
Appleton, P. N. *et al.* 2006, *Ap. Lett.*, 639, L51
Boselli, A., Gavazzi, G., Lequeux, J., & Pierini, D. 2002, *A&A*, 385, 454
Cardelli, J. A., Meyer, D. M., Jura, M., & Savage, B. D. 1996, *ApJ*, 467, 334
Cluver, M. E. *et al.* 2010, *ApJ*, 710, 248
Hickson, P. 1982, *ApJ*, 255, 382
Hickson, P., Mendes de Oliveira, C., Huchra, J. P., & Palumbo, G. G. 1992, *ApJ*, 399, 353
Kawada, M. *et al.* 2007, *PASJ*, 59, 389
Langer, W. D., Velusamy, T., Pineda, J. L., Goldsmith, P. F., Li, D., & Yorke, H. W. 2010, *A&A*, 521L, 17L
Murakami, H. *et al.* 2007, *PASJ*, 59, 369
Pietsch, W., Trinchieri, G., Arp, H., & Sulentic, J. W. 1997, *A&A*, 322, 89