Suzaku Observation of the Diffuse X-Ray Emission from the Open Cluster Westerlund 2: a Hypernova Remnant?

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Abstract

We present the analysis of Suzaku observations of the young open cluster Westerlund 2, which is filled with diffuse X-ray emission. We found that the emission consists of three thermal components or two thermal and one non-thermal components. The upper limit of the energy flux of the non-thermal component is smaller than that in the TeV band observed with H.E.S.S. This may indicate that active particle acceleration has stopped in this cluster, and that the accelerated electrons have already cooled. The gamma-ray emission observed with H.E.S.S. is likely to come from high-energy protons, which hardly cool in contrast with electrons. Metal abundances of the diffuse X-ray gas may indicate the explosion of a massive star in the past. The details of this study are presented in Fujita et al. (2009a).

Key words: stars: winds, outflows — ISM: cosmic rays — ISM: individual (RCW 49) — ISM: supernova remnants — Galaxy: open clusters and associations: individual (Westerlund 2)

1. Introduction

Westerlund 2 is one of the clusters from which gamma-ray emission has been detected with H.E.S.S. (Aharonian et al. 2007). It is ionizing the large HII region RCW 49 (NGC 3247). The gamma-ray emission is extended ($\sim 0.2°$), and the whole cluster is buried in it. Observations in the X-ray band are crucial to find the origin of the diffuse gamma-ray emission from the cluster and the mechanism of particle acceleration. In particular, the strength of non-thermal X-ray emission can be used to discriminate between the hadronic and the leptonic origin of the gamma-rays. In this paper, we report the results from Suzaku observations of Westerlund 2.

2. Spectral Analysis

We analyze the XIS spectrum of the diffuse emission around Westerlund 2. Since the angular resolution of the XIS is moderate ($\sim 2'$), we need to estimate the amount of X-ray emission from point sources that contaminates the diffuse X-ray emission from the cluster. Moreover, since the diffuse emission is faint, the background spectrum must be constructed carefully.

In order to estimate the contamination of the point sources, we used Chandra archive data of Westerlund 2. In order to extract the positions and spectra of the point sources, we used the ACIS Extract (AE) software package (Broos et al. 2002). Using the positional and spectral data, we simulate an XIS observation of the point sources with the XIS simulator `MKPHLIST` and `XISSIM`.

Since the TeV gamma-ray emission from Westerlund 2 covers the entire XIS field, we used the spectrum of a blank region $\sim 1.7°$ away from Westerlund 2 as the background. Westerlund 2 and the blank region are both affected by the Galactic Ridge X-ray Emission; we considered their influence in the following spectral analysis.

Including the leaked X-rays from the point sources and the X-ray background emission, we analyze the spectrum of the diffuse emission from Westerlund 2. We refer to the diffuse X-ray emission around Westerlund 2 excluding the unwanted components as the gas component. We find that the spectrum of the gas component can be represented by three thermal models or two thermal models and one power-law model with absorptions. That is, PHABS $*$ VAPEC + PHABS $*$ (VAPEC + VAPEC) or PHABS $*$ VAPEC + PHABS $*$ (VAPEC + POWER). We call the former 3T model and the latter 2TP model.

The results of the fits are shown in Table 1. The temperatures of the thermal components for 3T model are kT_1, kT_2, and kT_3. Their intrinsic fluxes in the 0.7–10 keV band are f_1, f_2, and f_3, respectively. We assume that the X-ray emission comes from the entire XIS field ($17'.8 \times 17'.8$). For 2TP model, kT_3 and f_3 are replaced by the photon index (Γ) and the non-thermal flux ($f_{\rm NT}$), respectively. The absorption N_{H1} is the one for the lower temperature component (kT_1), and N_{H2} is the one for the higher.

Table 1. Best-fit parameters for the gas component

Parameter	3T	2TP
N_{H1} (10^{22} cm^{-2})	$0.96^{+0.16}_{-0.37}$	$1.1^{+0.0}_{-0.5}$
kT_1 (keV)	$0.12^{0.04}_{-0.01}$	$0.12^{+0.04}_{-0.01}$
N_{H2} (10^{22} cm^{-2})	$1.1^{+0.4}_{-0.3}$	$1.4^{+0.2}_{-0.4}$
kT_2 (keV)	$0.88^{+0.21}_{-0.15}$	$1.0^{+0.3}_{-0.1}$
kT_3 (keV)	$4.2^{+2.1}_{-1.2}$	.....
Γ	.....	$2.2^{+0.4}_{-0.4}$
C, N, O (solar)	$0.24^{+0.71}_{-0.20}$	$0.57^{+1.2}_{-0.43}$
Ne (solar)	$0.04^{+0.09}_{-0.04}$	$0.07^{+0.17}_{-0.07}$
Mg (solar)	$0.46^{+0.32}_{-0.17}$	$0.77^{+0.98}_{-0.42}$
Si (solar)	$0.35^{+0.20}_{-0.12}$	$0.38^{+0.47}_{-0.19}$
S (solar)	$0.86^{+0.43}_{-0.32}$	$0.78^{+1.2}_{-0.31}$
Fe, Ni (solar)	$0.0^{+0.13}_{-0.0}$	$0.0^{+0.33}_{-0.0}$
f_1 (ergs cm^{-2} s^{-1})	$8.7^{+0.0}_{-1.7}\ 10^{-12}$	$1.3^{+0.3}_{-0.4}\ 10^{-11}$
f_2 (ergs cm^{-2} s^{-1})	$2.2^{+0.4}_{-0.0}\ 10^{-12}$	$3.0^{+0.3}_{-0.2}\ 10^{-12}$
f_3 (ergs cm^{-2} s^{-1})	$4.6^{+0.5}_{-0.8}\ 10^{-12}$	.....
$f_{\rm NT}$ (ergs cm^{-2} s^{-1})	.....	$5.4^{+0.7}_{-1.4}\ 10^{-12}$
χ^2/d.o.f.	1719.56/1725	1729.06/1725

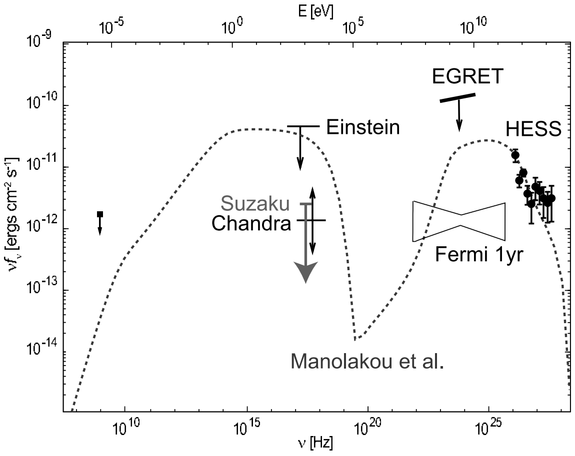

Fig. 1. Multi-wavelength measurements of Westerlund 2. A theoretical prediction of (Manolakou et al. 2007) is shown by the dotted line (their model of $t = 10^5$ yr). See Fujita et al. (2009a) for details.

3. Discussion

3.1. Upper limit of Non-thermal Flux

Since the power-law component in 2TP model can be replaced by a thermal component (3T model), the power-law component gives the upper limit of non-thermal X-ray flux from the cluster. Assuming that the non-thermal emission comes from the entire XIS field, the upper limit of the flux is $f_{\rm NT} < 2.6 \times 10^{-12}\,{\rm ergs\,cm^{-2}\,s^{-1}}$ (0.7–2 keV) and $6.1 \times 10^{-12}\,{\rm ergs\,cm^{-2}\,s^{-1}}$ (0.7–10 keV). The observed ratio of the 1–10 TeV energy flux obtained with H.E.S.S to the 2–10 keV energy flux is $R_{\rm TeV/X} > 2.7$ (Fig. 1).

We found that X-ray surface brightness of a region that is $> 8'$ away from the cluster in the XIS field is comparable to the one estimated from the blank region. Thus, the emission from the outside of the XIS field does not much contribute to the total diffuse emission from Westerlund 2.

3.2. Particle Acceleration

Recently, Fukui et al. (2009) discovered jet and arc-like molecular feature around Westerlund 2. In particular, the latter suggests a past stellar explosion (or past stellar explosions) in the cluster. Particles might be accelerated around a shock formed through the explosion.

Assuming that the explosion occurred $\sim 10^4$–10^5 yrs ago, the accelerated protons should not have lost their energy because of their long cooling time. Thus, the protons accelerated in the past may be producing the TeV gamma-rays through *pp*-interactions in the surrounding molecular gas. On the other hand, accelerated electrons should have lost their energy through synchrotron emission. Therefore, the current ratio of gamma-ray to X-ray energy flux should be large, because the electrons are the source of the X-ray flux through synchrotron emission (Yamazaki et al. 2006). This is consistent with the observations of Westerlund 2. Such stellar explosions in dense clouds could be the sources of unidentified TeV sources and the so-called PAMELA anomaly (Bamba et al. 2009; Fujita et al. 2009b).

The mass of the star responsible for the explosion could be extremely large, because stars in an open cluster form almost simultaneously and massive stars with $\sim 80\,M_\odot$ still survive in Westerlund 2. In general, such massive stars produce ejecta with a large α-element to iron abundance ratio (Kobayashi et al. 2006). This trend is consistent with the metal abundances shown in Table 1. Since some of the stars with masses of $> 30\,M_\odot$ explode as hypernovae, the one exploded in Westerlund 2 might be such a hypernova and might trigger a gamma-ray burst.

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