Suzaku Observations of TeV Galactic sources

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Abstract

It has been one of the biggest problems what is the origin of Galactic cosmic-rays. Previous X-ray surveys found several supernova remnants (SNRs) which have synchrotron X-rays, although the number is too small to account for the total energy of cosmic-rays. HESS, on the other hand, discovered tens of new unidentified (TeV unID) sources on the Galactic plane, which could be the main contributors of the Galactic cosmic-rays. However, we need follow-up observations to understand the nature of these TeV unID sources. Suzaku has already done deep follow-up observations of most TeV unIDs and pin-pointed their nature. Only one TeV inID source is categorized as an SNR, whereas several sources are identified as pulsar wind nebulae (PWNe). In this paper, we will discuss on what is the main contributors of TeV unID sources and Galactic cosmic-rays. We also discuss on GeV observations of TeV unIDs and future aspects.

Key words: acceleration of particles — shock waves — ISM: X-rays

1. Introduction

Cosmic rays are very high energy particles in the universe, and their origin is one of the biggest problem since the discovery (HESS 1912). Very high-energy gamma-rays with energies around TeV are powerful tools to investigate the cosmic accelerators. They arise from either leptonic (cosmic microwave background (CMB) or other soft seed photons up-scattered by accelerated electrons and their bremsstrahlung emission) or hadronic (the decay of neutral pions, arising from the collision of high energy protons and interstellar matter) processes. The strong evidence for electron acceleration up to more than ~ 10 TeV has been obtained with X-ray observations of, for example, young supernova remnants (SNRs) that are believed to be the most probable cosmic-ray accelerators in our Galaxy (e.g., Koyama et al. 1995, Bamba et al. 2003). On the other hand, we have not yet derived firm evidence for proton acceleration; although TeV gamma-rays have been detected by several of young SNRs (e.g., Aharonian et al. 2004). Pulsar wind nebulae (PWNe) are also strong candidates of cosmic ray acceleration, although we have no evidence of proton acceleration.

Recently, HESS TeV gamma-ray telescope has made Galactic plane survey (Aharonian et al. 2005, 2006) and discovered a few tens of new sources. They are on the Galactic plane and some are diffuse, thus they should be galactic accelerators. However, they have no counterpart in other wavelength, and are called as gTeV unIDsh. Now we have $\sim$50 TeV unIDs. They should be interesting sources, since they could be proton accelerators with bright TeV and faint X-rays, which remind us the emission from protons via pi-0 decay. However, nobody knows whether they are really faint in X-rays or just have no enough X-ray follow-ups. In order to untangle their origin, X-ray follow-ups are quite important since X-ray observations can detect synchrotron emission from accelerated electrons. Suzaku has large field of view, effective area, and low and stable background, thus is ideal to make follow-ups of TeV unIDs.

2. Suzaku follow-ups of TeV unIDs

Suzaku has already observed about half of TeV unIDs, and it is time to make systematic study of TeV unIDs with Suzaku follow-ups. Table 1 shows the Suzaku follow-up observations of TeV unIDs. The TeV unID source list is made from TeV source catalog (http://tevcat.uchicago.edu/). 26 sources are identified as PWNe including already known sources, whereas only 1 young SNR is found among the TeV unIDs. This result indicates that main contributors of TeV unIDs are not SNRs but PWNe. It is difficult to say PWNe are main contributors of cosmic rays since we have no clue of proton acceleration in PWNe. We have to make further observation to get information whether PWNe accelate protons or we have hidden SNRs.

Another interesting source category is TeV emission which associate with molecular clouds (MCs). Let us see HESS J1745−303, one of the TeV unIDs in the Galactic center region. Our Suzaku deep observations made very tight flux upper-limit in the X-ray band, and found

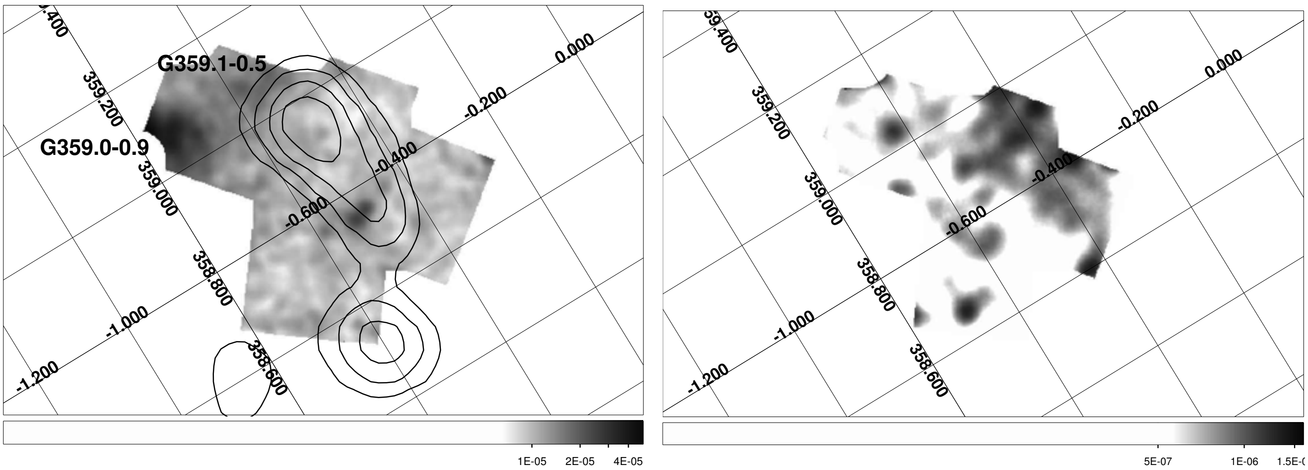

Fig. 1. Color images are 0.5–2.0 keV (left) and neutral iron line (right) images (Bamba et al. 2009). Countours are TeV emission by HESS (Aharonian et al. 2006).

that the TeV source emit neutral iron line (Bamba et al. 2009). Figure 1 shows the Suzaku 0.5–2.0 keV band and neutral iron line images of HESS J1745−303 region. It remind us the X-ray reflection nebulae like Sgr B2: they are giant molecular cloud which emits neutral iron line due to the reflection of past bright supermassive black hole in the Galactic center (Murakami et al. 2000). Our observations reveal us that HESS J1745−303 coincides with a molecular cloud.

This source also coincides with an old SNR G359.1−0.5 The SNR has OH masars and collides with the MC (Bamba et al. 2000). The TeV emission could be, thus, due to protons accelerated on the shocks of G359.1−0.5, with emission mechanism of pi-on decay in the molecular cloud (Bamba et al. 2009).

Sources with molecular clouds are rather difficult to make follow-ups only in X-rays. Other gdarkh TeV unIDs, thus, could be sources with molecular clouds and possible proton accelerators. We need to conduct multi-wavelength observations to point out their nature.

3. GeV aspects of TeV unIDs

Recently, Abdo et al.(2009) reported that Fermi detected GeV emission from 9 TeV unIDs. This number should be surprising since the total number of Fermi source in Abdo et al. (2009) is only 205, and 4Table 2 shows the TeV unIDs with Fermi detection. Surprisingly, two of these sources are quite dark in X-ray band with Suzaku observations (HESS J1616−508 and HESS J1804−216).

Figure 2 shows the wide band spectra of HESS J1616−508 and HESS J1804−216. We have no information on photon indices in the GeV band (Abdo et al. 2009), thus we assumed the same photon indices in the TeV band. The both spectra show very interesting features: gamma-ray emission is brighter and brighter when the observed energy goes down from TeV to GeV band, and after the observation energy gap on MeV band, they suddenly fall down in the X-ray band. The flux gap is more than 2 orders of magnitude. These results remind us again that Suzaku made really important upper-limits for these sources.

It is rather complicate to point out what is the origin of these gaps. The most interesting answer is that the large bump at GeV band is the pi-on decay bump of protons. This is actually the long awaited answer in these 100 years since the discovery of cosmic rays. HESS J1745−303 is the ideal example for such sources. However, we should not hurry up to answer it, because the spectra in TeV band (Γ=2.3–2.7) is similar to those of cosmic-rays (Γ=2.7). It is hard to realize if these emissions have same origin, since the particle spectrum should soften during the propagation.

Another scenario is more bothered, that X-ray emitters have already disappeared or moved: X-rays are from more energetic electrons than GeV/TeV photons, and have shorter time scale. One possibility is that they could be PWNe with high kick velocity. In some PWN systems, we can see offset of emission peaks between X-ray and TeV gamma-ray. However, it is very difficult to say that all of the dark sources are just offset PWNe.

Anyhow, their origin is still unclear although they are extremely interesting sources. Further follow-ups are critical to solve this problem. Making smaller the gobservation gaph between ∼10 keV and 1 GeV is especially important to resolve the emission mechanism: it should have difference in this missing energy band in the case of pi-on decay and nonthermal bremsstrahlung. ASTRO-H Hard X-ray imager (HXI) and Soft Gamma-ray Detector (SGD) will have high sensitivity between ∼10 keV to 600 keV (Takahashi et al. 2008), and be able to fill at

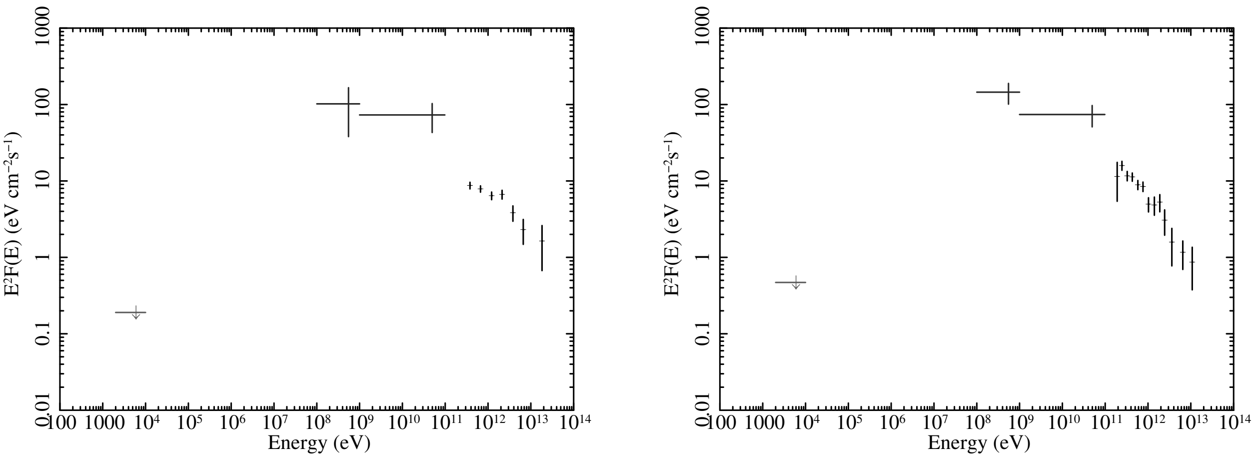

Fig. 2. Wide band spectra of HESS J1616−508 (left) and HESS J1804−216 (right). Data points are from Suzaku, Fermi, and HESS. Fermi flux is estimated with the assumption that the photon index is same in GeV and TeV bands for each source.

least a part of observational gaps. We might be able to point out the nature of these very exciting sources with ASTRO-H.

4. Summary

Now we are in the golden age to answer the origin of cosmic rays, although we have only pieces of the big puzzle. Suzaku follow-up observations of exciting cosmic ray accelerator candidate, TeV unIDs, show us that many TeV unIDs are hard to consider proton accelerators, just PWNe, and found several very interesting sources, which coincide with molecular cloud. Suzaku might be discovered gsmoking gunh of cosmic ray acceleration for the first time. Fermi detection of these sources also strengthens our scenario. ASTRO-H, our next generation X-ray mission, is awaited to solve this big puzzle.

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Table 1. Summary of Suzaku follow-ups for TeV unIDs

Source	Category	
HESS J1303−631	dark	(Chandra result)
HESS J1427−608	—	
HESS J1614−518	PWN	Matsumoto et al. (2008)
HESS J1616−508	dark	Matsumoto et al. (2007)
HESS J1626−490	—	
HESS J1632−478	—	
HESS J1634−472	—	
HESS J1702−420	dark	Fujinaga et al. (2009)
HESS J1708−410	—	
HESS J1731−347	SNR	
HESS J1741−302	unknown	Matsumoto et al. (2009)
HESS J1745−303	MC	Bamba et al. (2009)
HESS J1747−281	—	
HESS J1804−216	dark	Bamba et al. (2007)
HESS J1813−178	PWN	
HESS J1825−137	PWN	Uchiyama et al. (2009)
HESS J1834−087	PWN	(XMM result)
HESS J1837−069	PWN	Anada et al. (2009)
HESS J1841−055	—	
HESS J1843−033	—	
HESS J1857−026	—	
HESS J1858+020	—	
TeV J2032+4130	PWN	Murakami et al. (2009)
HESS J1640−465	PWN	
HESS J1718−385	PWN	
HESS J1809−193	PWN	
HESS J1833−105	PWN	
HESS J1846−029	PWN	(Kes 75)
HESS J1912+101	PWN	
HESS J1923+141	PWN	

Note: g—g represents we have no deep follow-up observations in the X-ray band.

Table 2. TeV unIDs with Fermi detection

HESS J1023−575	—
HESS J1418−609	—
HESS J1616−508	dark
HESS J1741−302	unknown
HESS J1804−216	dark
HESS J1813−178	PWN
HESS J1834−087	PWN
HESS J1923+141	—
TeV J2032+4230	PWN

Note: g—g represents that we have no deep X-ray follow-ups.