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INTEGRAL IGR J18135−1751 = HESS J1813−178: A NEW COSMIC HIGH-ENERGY ACCELERATOR FROM keV TO TeV ENERGIES[1]

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ABSTRACT

We report the discovery of a soft gamma-ray source, namely, IGR J18135−1751, detected with IBIS, the Imager on Board the *INTEGRAL* Satellite. The source is persistent and has a 20–100 keV luminosity of $\sim 5.7 \times 10^{34}$ ergs s^{-1} (assuming a distance of 4 kpc). This source is coincident with one of the eight unidentified objects recently reported by the HESS collaboration as part of the first TeV survey of the inner part of the Galaxy. Two of these new sources found along the Galactic plane, HESS J1813−178 and HESS J1614−518, have no obvious lower energy counterparts, a fact that motivated the suggestion that they might be dark cosmic ray accelerators. HESS J1813−178 has a strongly absorbed X-ray counterpart, the *ASCA* source AGPS 273.4−17.8, showing a power-law spectrum with photon index ∼1.8 and a total (Galactic plus intrinsic) absorption corresponding to $N_H \sim 5 \times 10^{22}$ cm^{-2}. We hypothesize that the source is a pulsar wind nebula embedded in its supernova remnant. The lack of X-ray or gamma-ray variability, the radio morphology, and the *ASCA* spectrum are all compatible with this interpretation. In any case we rule out the hypothesis that HESS J1813−178 belongs to a new class of TeV objects or that it is a cosmic “dark particle” accelerator.

Subject headings: gamma rays: observations — X-rays: general — X-rays: individual (HESS J1813−178, IGR J18135−1751, AGPS 273.4−17.8)

Online material: color figures

1. INTRODUCTION

The HESS (High Energy Stereoscopic System) collaboration has recently reported results from the first sensitive TeV survey of the inner part of our Galaxy (Aharonian et al. 2005a). This survey revealed the existence of a population of high-energy gamma ray objects, most of which were previously unknown. These findings have an important astrophysical meaning because of the possibility of studying cosmic particle accelerators by means of TeV observations. Various types of sources in the Galaxy can act as cosmic accelerators: pulsars and their pulsar wind nebulae (PWNs), supernova remnants (SNRs), star-forming regions, and possibly binary systems with a collapsed object such as a microquasar or a pulsar. At least for two sources from the HESS survey (HESS J1813−178 and HESS J1614−518), no known radio or X-ray counterparts have been found so far, raising the possibility that they represent a new class of objects. The lack of X-ray emission, very recently confirmed by a *Chandra* observation for HESS J1303−631 (Mukherjee & Halpern 2005) is particularly interesting, since it suggests that the accelerated particles are nucleons rather than high-energy electrons. Therefore, the detection of X-ray or gamma-ray emission from these TeV sources is a key issue to disentangle the mechanisms active in the different emitting regions and, in turn, the source nature. To perform this task, the IBIS gamma-ray imager on board the *International Gamma-Ray Astrophysics Laboratory* (*INTEGRAL*) is a powerful tool: it allows source detection above 20 keV and up to the MeV range (i.e., in the “nonthermal process” region) with millicrab ($\sim 10^{-11}$ ergs cm^{-2} s^{-1}) sensitivity in well-exposed regions, an angular resolution of 12′, and a point-source location accuracy of 1′–2′ for moderately bright sources (Ubertini et al. 2003). Furthermore, *INTEGRAL* has regularly observed the entire Galactic plane during the first $2\frac{1}{2}$ years in orbit, providing above 20 keV a Galactic survey with unprecedented sensitivity, that is, on the order of a millicrab for a 1 Ms exposure (Bird et al. 2004). A second catalog, utilizing more sky coverage and deeper exposures, has recently been submitted (Bird et al. 2005). The first survey indicates clear associations for a number of TeV-detected objects: AX J1838.0−0655 (Aharonian et al. 2005a), Sgr A* (Aharonian et al. 2004a), MSH 15−52/PSR 1509−58 (Aharonian et al. 2005b), and the Crab Nebula (Aharonian et al. 2004b). In this Letter, we report the discovery of a newly detected IBIS/ISGRI source, namely, IGR J18135−1751, which is the soft gamma-ray counterpart of the TeV source HESS J1813−178, one of the two objects for which lack of detection in the X-ray and radio bands suggested it might be a “dark particle” accelerator.

2. THE HESS SOURCE AND ITS COUNTERPARTS

HESS J1813−178 is one of the eight previously unknown sources found in the HESS survey of the inner regions of the Galactic plane. It is located at R.A. = $18^h13^m37^s.9$ and decl. = −17°50′34″ (J2000) with a positional uncertainty in the range of 1′–2′. The source does not seem pointlike, although it is only slightly extended (3′) compared with the HESS point-spread function (PSF). The statistical significance of the TeV detection is around 9 σ. The source is fairly bright above 200 GeV, with a flux of 12×10^{-12} photons cm^{-2} s^{-1}. No obvious counterparts

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were found within the source extension, although HESS J1813−178 lies close (10′) to the radio source W33, a bright star-forming region characterized by a visually obscured compact radio core (G12.8−0.2) located inside a molecular cloud complex (Haschick & Ho 1983; see § 2.3 for a detailed discussion).

2.1. *The INTEGRAL IBIS Source*

The sky region containing HESS J1813−178, although covered in the first IBIS/ISGRI survey, did not provide any significant detection, because of the limited exposure dedicated to this area. The second survey (Bird et al. 2005) represents a major improvement in both exposure time and sky coverage and makes the search for a high-energy counterpart possible. The IBIS coded-mask instrument (Ubertini et al. 2003) on board *INTEGRAL* (Winkler et al. 2003a) is made up of a combination of two detector layers: ISGRI (Lebrun et al. 2003), an upper CdTe layer sensitive in the range 20 keV to 1 MeV, and PICsIT (Di Cocco et al. 2003), a lower CsI layer sensitive in the range 200 keV to 8 MeV. In the present Letter, we refer to data collected with the low-energy ISGRI detector, as the source is only detected at low energies, namely, in the range 20–100 keV. The data reported here belong to the Core Programme (i.e., they were collected as part of the *INTEGRAL* Galactic Plane Survey and Galactic Centre Deep Exposure; Winkler et al. 2003b), as well as to public open-time observations, and they span from revolution 46 (2003 February) to revolution 210 (2004 June) inclusive. A detailed description of the source extraction criteria can be found in Bird et al. (2004, 2005): Briefly, ISGRI images for each available pointing are generated in 10 narrow energy bands using the *INTEGRAL* Science Data Centre offline scientific analysis software OSA, version 4.1 (Goldwurm et al. 2003), including background-uniformity corrections (Terrier et al. 2003). Source ghosts are removed from each image using a catalog of sources built iteratively and containing at the end all detected objects. The ∼7000 images are then mosaicked using a custom tool to produce deep all-sky maps; finally, images from adjacent energy bands are added together to obtain a map in a given energy range, which is then used for peak detection. The primary search tool used is SExtractor (Bertin & Arnouts 1996), employing a simple Gaussian PSF filter. Sources are then searched for in various energy bands above a given, quite conservative, sensitivity threshold (typically 6 σ) and then included in the IBIS/ISGRI catalog list. As a further check, the map is visually inspected to confirm detection and avoid spurious excesses due to imperfect image cleaning. Figure 1 shows the 20–40 keV band image of the region surrounding HESS J1813−178: coincident with the TeV object, an IBIS/ISGRI source (IGR J18135−1751) is detected with a significance exceeding 10 σ at R.A. $= 18^h13^m27^s.12$ and decl. $= -17°50'56''$ (J2000) and with a positional uncertainty of ∼2′, corresponding to 90% error for a 10 σ source (Gros et al. 2003). Apart from the source of interest here, two other bright objects are visible in the map: the low-mass X-ray binary GX 13+1 and the transient source SAX J1818.6−1703, approximately 44′ and 87′ away from the new IBIS/ISGRI source, respectively. Contamination from the bright source GX 13+1 is unlikely, as IGR J18135−1751 is well outside the major peak of the PSF and does not appear to be coincident with any systematic structure from that source. Other structures present in the region containing the source have been carefully checked in terms of statistical significance and PSF: they are all too far below the threshold to be possibly considered real sources and do not fit the expected IBIS detector spatial response (Goldwurm et al. 2003).

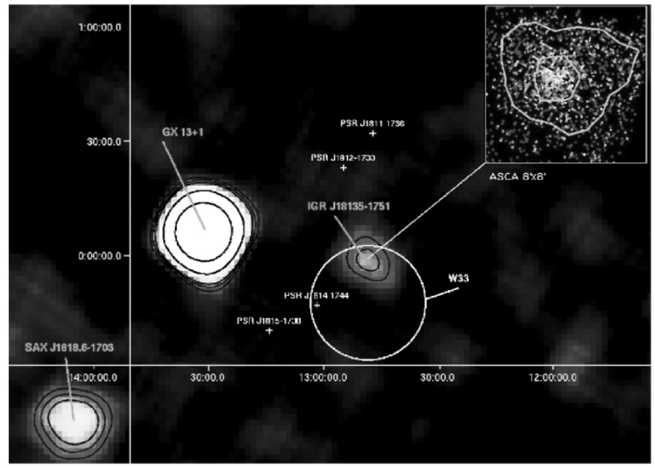

FIG. 1.—IBIS/ISGRI 20–40 keV significance map, showing the location of IGR J18135−1751 and relative significance contours. The gamma-ray contours shown are 6 (for the external one), 8, 10, 20, and 40 σ; the source spatial profile is compatible with the detector response to a point source. The extension of HESS J1813−178 and the position of AGPS 273.4−17.8 are both contained within the internal IBIS/ISGRI contour. Also shown are the location (and extension) of W33 and the four nearest radio pulsars (PSR J1814−1744, PSR J1812−1733, PSR J1815−1738, and PSR J1811−1736). The *ASCA* SIS image is shown as an inset at upper right. The box covers an 8′ × 8′ region centered on the *ASCA* source position; the contour levels (1, 2, and 3 counts pixel^{-1}) provide marginal evidence of extended emission. GX 13+1 and the transient source SAX J1818.6−1703 also are visible in the image but contribute no contamination to the region around IGR J18135−1751 (see text for details). The coordinates displayed are in the Galactic system. [*See the electronic edition of the Journal for a color version of this figure*.]

HESS J1813−178 is inside the first ISGRI contour, indicating a clear spatial association between the IBIS/ISGRI object and the TeV source, while the formal distance between the two sources is less than 2′.2. The mean count rate of IGR J18135−1751 is 0.139 ± 0.015 and 0.093 ± 0.016 counts s^{-1} in the 20–40 and 40–100 keV bands, respectively; these count rates correspond to fluxes of 1.3 and 2.1 mcrab, respectively, or to an average flux of 2.1×10^{-11} ergs cm^{-2} s^{-1} in the 20–100 keV band. The flux relative to each individual pointing has been used to generate the source light curves in different energy bands. No bursts or flares are visible in the light curves, nor does the source show any sign of variability; unfortunately, the low significance of the detection prevents a search for pulsations in the IBIS/ISGRI data.

2.2. *AGPS 273.4−17.8: The X-Ray Counterpart*

We have also searched the HEASARC archive[7] for the presence of the source in the data from past X-ray missions. HESS J1813−178 is located in the Galactic plane, so it is likely that its X-ray counterpart is heavily absorbed. The Galactic H I column density in the source direction is 1.89×10^{22} cm^{-2} (Dickey & Lockman 1990); this value implies strong depletion of soft X-rays, more so if molecular hydrogen is added to the column density estimation. It is therefore likely that any soft X-ray emission is either very weak or undetected. There is no *Röntgensatellit* (*ROSAT*) source inside the HESS error circle, although a WGACAT object (1WGA J1813.7−1755) is only

[7] See http://heasarc.gsfc.nasa.gov.

5′.4 from the TeV position; this X-ray source is associated with the $V = 10.8$ mag star HD 166981, of spectral type B8. Despite being very close, this soft X-ray source is outside both the IBIS/ISGRI error circle and the HESS extension. Similarly, other soft X-ray emitters are all located farther away (more than 10′ from the TeV source) and so are incompatible with the HESS/*INTEGRAL* positional uncertainty. At higher energies, we found a possible counterpart in the archival data from the *Advanced Satellite for Cosmology and Astrophysics* (*ASCA*): AGPS 273.4−17.8, which was clearly detected by both the Solid-State Imaging Spectrometer (SIS) and Gas Imaging Spectrometer (GIS). The sky region surrounding this X-ray source is strongly contaminated (particularly in the GIS image) by the presence of a very bright nearby object (likely GX 13+1), and this is probably the reason why AGPS 273.4−17.8 does not appear in the *ASCA* Galactic Plane Survey (Sugizaki et al. 2001) despite its detection; for this reason, we consider here only the SIS data. The *ASCA* position is set at R.A. = $18^h13^m35^s.8$ and decl. = −17°49′43″.35 (J2000) with an associated uncertainty of 1′ in radius and is therefore contained within the first IBIS/ISGRI contour. In the X-ray band the source is fairly bright, showing a 2–10 keV flux (corrected for absorption) of 1.8×10^{-11} ergs cm^{-2} s^{-1}; the broadband spectrum (after background subtraction and correction) is characterized by an absorbed power law with a hard photon index $\Gamma = 1.76 \pm 0.25$ and a column density $N_H = 5.15^{+1.70}_{-1.24} \times 10^{22}$ cm^{-2} in excess of the Galactic value (errors correspond to the 90% confidence level for a single parameter variation, that is, $\Delta\chi^2 = 2.7$; see the XSPEC ver. 11.3 manual).[8] On top of this power law, the source shows marginal evidence of an extended soft emission (see Fig. 1, *inset*). The best fit to this component is obtained with thermal bremsstrahlung with $kT = 0.42^{+0.30}_{-0.14}$ keV, absorbed by a column density compatible with the Galactic value. However, the total emitted power of this possible soft excess, not detected by Brogan et al. (2005), is irrelevant, being 50–100 times less than the synchrotron power-law component. The SIS light curve shows no variability over the 100 ks observation period, and the minimum data binning of 300 s prevents a search for fast pulsation. Detection by *ASCA* and *INTEGRAL* over different observing periods suggests that the source is a persistent rather than a transient object.

2.3. *Counterparts at Other Wavelengths*

The column density measured in X-rays (Galactic plus intrinsic) implies a visual extinction $A_V \sim 27$ (Predehl & Schmitt 1995), sufficient to obscure any optical counterpart. Therefore, searches for candidate objects at lower frequencies should concentrate on data less affected by absorption, such as in the radio wave band. Indeed, we find a bright NRAO VLA Sky Survey (NVSS; Condon et al. 1998) radio source within the *ASCA* positional uncertainty: NVSS J181334−174849, with coordinates R.A. = $18^h13^m34^s.32$ and decl. = −17°48′49″.1 (see Fig. 2). This source has a 20 cm flux of 327 mJy and a positional uncertainty of only 1″, and it is not polarized; the source axes are 1′.85 and 1′.25 (Fig. 2, *ellipse*), indicating that the object is probably extended at 20 cm. It is located in a crowded region showing three other objects, all of which have much lower flux at 20 cm. This radio complex is contained within both the IBIS and HESS circles, but only the bright object, NVSS J181334−174849, is possibly associated with the *ASCA* source. Within its 1″ positional uncertainty, we do not find any optical or infrared counterpart. Recently, Brogan et al. (2005) discovered nonthermal radio emission from a young shell-type SNR (G12.8−0.02) associated with the radio complex NVSS. The source is reported as extended (3′), located at a distance of ≥4 kpc, and positionally coincident with HESS J1813−178. Helfand et al. (2005) conclude the TeV emission is due to inverse Compton scattering of starlight from W33 off the high-energy electrons from G12.8−0.02 responsible for synchrotron X-ray emission.

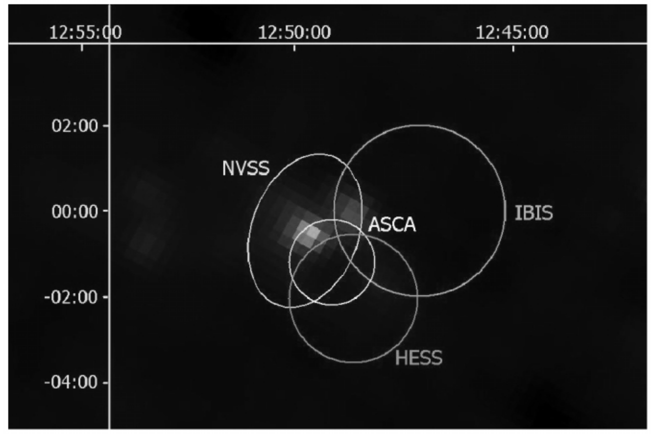

FIG. 2.—NVSS (20 cm) image of the region surrounding IGR J18135−1751/HESS 1813−178. The *ASCA*, IBIS/ISGRI, and HESS sources (with radii of 1′, 2′, and 1′.5, respectively), are superposed, as is the extent of NVSS J181334−17849 (*ellipse*). The radio resolution is 45″ FWHM, and the rms noise is 0.45 mJy $beam^{-1}$. The coordinates displayed are in the Galactic system. [*See the electronic edition of the Journal for a color version of this figure*.]

Finally, there are four radio pulsars within 30′ of HESS J1813−178, but despite being potential candidates, their distances from HESS J1813−178 argue against a possible association. Clearly, a search for likely candidates inside the HESS source extension is the best way to approach the problem of source identification. This is possible with archival data, as well as through dedicated observations such as those performed by *INTEGRAL*.

3. DISCUSSION

The basic evidence from the present work is that HESS J1813−178 has an X-ray counterpart with power-law emission from 2 to 10 keV, a coincident soft gamma-ray source emitting up to 100 keV, and an associated radio counterpart. The presence of a spatially coincident X-ray to soft gamma-ray flux, with a power-law–type emission process, rules out the hypothesis that this source belongs to a “new class” of Galactic objects or that it is a cosmic “dark particle” accelerator: it is a nonthermal source, accelerating electrons and positrons that radiate through synchrotron and inverse Compton mechanisms. This is suggestive of the presence of a PWN or SNR, as already found in most newly detected TeV objects (Aharonian et al. 2005a, 2005b, and references therein). On the other hand, IBIS/ISGRI preferentially sees plerion-type supernovae: six out of seven remnants detected in the second catalog are associated with PWNs, and only one (Cas A) has a shell-type morphology (Bird et al. 2005). Our findings are in agreement with the recent radio results of Brogan et al. (2005) and Helfand et al. (2005); this indicates that we are indeed dealing with a shell-type SNR. However, it cannot be ruled out at this stage that this supernova is of a composite type, for example, a centrally filled morphology embedded inside a shell-like remnant. In these objects,

[8] See http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/.

the central radio/X-ray emission is interpreted as synchrotron radiation from a bubble of relativistic particles supplied by the central source, which is generally an isolated, spinning down pulsar like PSR 1509−58. Unfortunately, the weakness of the gamma-ray signal and the integration time of the X-ray data do not permit further investigation of a possible pulsed emission.

On the other hand, the binary scenario, for example, a typology similar to HESS J1303−631/PSR B1259−63, where the gamma rays are generated by inverse Compton scattering of electrons at the termination shock region of the pulsar wind of the companion star's photons, is unlikely. Apart from the radio results, these systems have variable emission, which is not present in our data. In fact, a long integration time is necessary to detect the gamma-ray source in view of its weakness, and the *ASCA* X-ray data are compatible with a lack of flux variation over the total observing time of about 100 ks. The good spectral match between *INTEGRAL* and *ASCA* data can be taken as further evidence for a constant X-ray/gamma-ray emission. Finally, the scenario proposed by Helfand et al. (2005), in which the TeV source is due to the upscattering of starlight from W33 by electrons accelerated in the SNR, is not incompatible with the IBIS/ISGRI detection.

The source luminosity is 4 and 3.4 times $(d/d_4)^2 \times 10^{34}$ ergs s^{-1} (where d is the distance of the source and $d_4 = 4$ kpc) in the 2–10 and 20–100 keV bands, respectively, to be compared with a 0.2–10 TeV luminosity of $(1.2–1.9)(d/d_4)^2 \times 10^{34}$ ergs s^{-1}. These values are both compatible with those observed for a few HESS sources that have been clearly associated with either shell-type or plerion-type supernova remnants (Malizia et al. 2005). The source spectral energy distribution (SED) from X-ray to TeV energies is shown in Figure 3, together with the Crab pulsar wind nebula. The shape of the SED resembles that of the Crab pulsar wind nebula, although with a quite different ratio of X-rays to TeV gamma rays. Future *XMM-Newton* or *Chandra* observations could definitively unveil the true nature of this source.

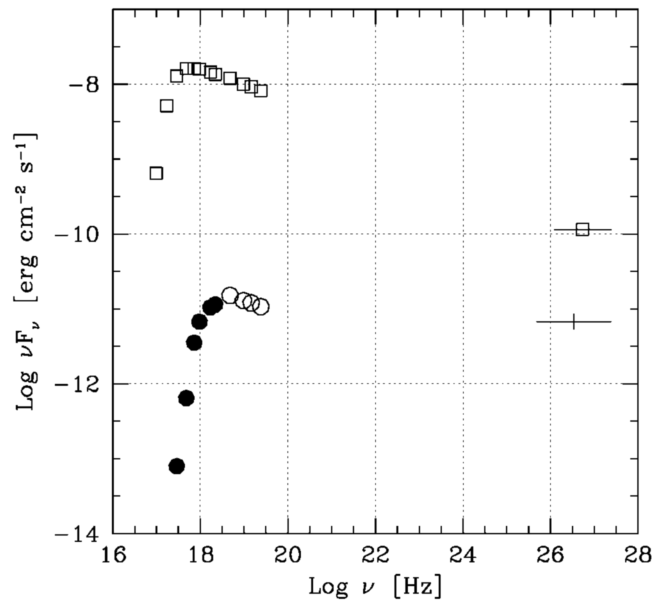

FIG. 3.—Spectral energy distribution from radio to TeV frequencies of IGR J18135−1751/HESS J1713−178 (*bottom*) and the Crab Nebula (*top*). The *ASCA* X-ray data (*filled circles*) cover the range 2–10 keV, the *INTEGRAL* IBIS ones (*open circles*) correspond to the 20–100 keV band, and the HESS point is from 200 GeV to 10 TeV. Flux uncertainties are smaller than the symbols used.

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