On the identification of the Fermi/LAT source 0FGL J2001.0+4352 with a BL Lac

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ABSTRACT

We report on the identification of the gamma-ray source 0FGL J2001.0+4352 listed in the Fermi bright source catalogue. This object, which has an observed 1–100 GeV flux of \(7.8 \pm 1.2 \times 10^{-9}\) ph cm\(^{-2}\) s\(^{-1}\) and is located close to the Galactic plane, is not associated with any previously known high-energy source. We use archival XMM–Newton and Swift/X-ray Telescope (XRT) data to localize with arcsec accuracy the X-ray counterpart of this GeV emitter and to characterize its X-ray properties: the source is bright (the 0.2–12 keV flux is \(1.9 \times 10^{-12}\) erg cm\(^{-2}\) s\(^{-1}\)), variable (by a factor of \(\sim 2\)) and with a steep power-law spectrum (\(\Gamma = 2.7\)). It coincides with a radio bright (\(\sim 200\) mJy at 8.4 GHz) and flat spectrum object [MG4 J200112+4352 in NASA/IPAC Extragalactic Database (NED)]. Broad-band optical photometry of this source suggests variability also in this waveband, while a spectroscopic follow-up observation provides the first source classification as a BL Lac object. The source SED, as well as the overall characteristics and optical classification, point to a high frequency peaked blazar identification for 0FGL J2001.0+4352.

Key words: X-rays: general – X-rays: individual: MG4 J200112+4352 – X-rays: individual: 0FGL J2001.0+4352.

1 INTRODUCTION

Following its launch in 2008 June, the Fermi gamma-ray telescope began to survey the sky at energies greater than 100 MeV. The catalogue of bright sources detected during the first 3 months of observations has recently been published by Abdo et al. (2009a) listing 205 objects with statistical significance greater than 10\(\sigma\). Both Galactic and extragalactic populations are visible. The active galactic nucleus (AGN) class consisting of 121 sources is the largest in the catalogue. It contains mostly blazars (BL Lac, Flat Spectrum Radio Quasars and objects of uncertain classification), but also two radio galaxies (CenA and NGC 1275) and the Large Magellanic Cloud. The Galactic population is primarily made of pulsars (29 members), plus two high-mass X-rays binaries, a globular cluster (or most likely a source in it) and the Galactic Centre. Thirty-seven of the Fermi sources have no obvious counterparts at other wave-lengths, and are therefore still unclassified. Searching for counterparts of these sources is of course a primary objective of the survey work but it is made difficult by the good but still large Fermi error circles. Cross-correlations with catalogues in other wavebands can be used as a useful tool with which to restrict the positional uncertainty of the objects detected by Fermi and therefore to facilitate the identification process. In particular, observations at softer X-ray energies, where the positional accuracy is much better, could be an invaluable aid in the identification and classification process but the use of data at other wavebands, for example the radio, is also useful to identify peculiar and potentially interesting candidate objects. Follow-up optical spectroscopy of likely candidates can then provide classification of interesting sources and consequently a firm identification. In this Letter, we report on the nature of the source 0FGL J2001.0+4352, one of the still unidentified objects in the Fermi catalogue. We use unpublished XMM–Newton and Swift/XRT data to localize the X-ray counterpart of this high-energy emitter and to characterize its X-ray spectrum. We further identify its radio counterpart and discuss its spectral properties. Finally, we report on an optical follow-up observation which provides the first source classification. All these data point to an identification of the MeV/GeV source with a blazar of BL Lac type.

2 X-/GAMMA-RAY DATA AND RESULTS

0FGL J2001.0+4352 is reported in the first Fermi catalogue (Abdo et al. 2009a) as a source located close to the Galactic plane (\(7.1^\circ\) in Galactic latitude) and having RA(J2000) = 20\(^{h}\)01\(^{m}\)05\(^{s}\)28 and Dec.(J2000) = +43\(^{\circ}\)52'15" with a positional 95 per cent uncertainty of 0.069. Due to the faint flux and hard spectrum only an
The source has a positional uncertainty of only 4.51 arcsec; the source from various catalogues and *Fermi* sources, we find a likely match between the XMM Slew source (Saxton et al. 2008) XMMSL1 J200112.7+435255 and *Fermi* J2001.0+4352. The XMM Slew source has a positional uncertainty of only 4.51 arcsec; the source 0.2–12 keV flux is \( \approx 5.5 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1} \) with \( \sim 60 \) per cent of the counts coming from the softest X-ray band (0.2–2 keV). On 2009 January 21, *Swift/XRT* (Gehrels et al. 2004) carried out an observation of 7.7 ks of the sky region containing the *Fermi* source, thus allowing a comparison with the XMM–Newton data.

XRT data reduction was performed using the XRT Data Analysis Software (XRTDAS) standard data pipeline package (**XRTPIPELINE** v. 0.12.1), in order to produce screened event files. All data were extracted only in the Photon Counting (PC) mode (Hill et al. 2004), adopting the standard grade filtering (0–12 for PC) according to the XRT nomenclature. Images have been extracted in the 0.3–10 keV band, while in the 1–100 GeV range the flux is \( 7.8 \pm 1.2 \times 10^{-9} \text{ ph cm}^{-2} \text{ s}^{-1} \). The source is not associated with any previously known gamma-ray object. Using the method developed by Stephen et al. (2005, 2006) to search for correlations between X-ray objects and *Fermi* sources, we find a likely match between the XMM Slew source (Saxton et al. 2008) XMMSL1 J200112.7+435255 and *Fermi* J2001.0+4352. The XMM Slew source has a positional uncertainty of only 4.51 arcsec; the source 0.2–12 keV flux is \( \approx 5.5 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1} \) with \( \sim 60 \) per cent of the counts coming from the softest X-ray band (0.2–2 keV). On 2009 January 21, *Swift/XRT* (Gehrels et al. 2004) carried out an observation of 7.7 ks of the sky region containing the *Fermi* source, thus allowing a comparison with the XMM–Newton data.

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**3 RADIO COUNTERPART**

The radio image of the sky region of interest here has been taken from the National Radio Astronomy Observatory (NRAO) Very Large Array (VLA) Sky Survey (NVSS; Condon et al. 1998) which covers the sky north of Declination (J2000.0) –40° at 1.4 GHz. This survey provides 45 arcsec full width at half-maximum angular resolution and nearly uniform sensitivity; the rms uncertainties in right ascension and declination are about 1 arcsec for sources stronger than 1 mJy. Fig. 2 is an NVSS image cut-out with over-imposed the *Fermi* error circle and XRT/XMM Slew positions. It is clear that a strong radio source is present in the *Fermi* error circle and further coincides with the X-ray object detected both by *Swift* and *XMM–Newton*. This radio counterpart is located at RA(J2000) = 20°01'13.15 and Dec.(J2000) = +43°52'33.1' (0.6 arcsec uncertainty) and has a 1.4 GHz flux of \( \sim 104 \text{ mJy} \). This source (named MG4 J200112+4352 in NED and hereafter) has been extensively observed at radio frequencies and appears in many radio catalogues although its nature has been poorly studied so far. To provide more information on this source, we have used SpecFind (Vollmer et al. 2005) and CATS (the on-line Astrophysical Catalogues Support System, at http://cats.sao.ru/; see also Verkhodanov et al. 1997); both are the tools used to cross-identify radio sources in various catalogues on the basis of self-consistent spectral index as
well as position. This allows us to combine data at different frequencies (see Table 1) and to estimate the source spectral index [$S(\nu) = A\nu^\alpha$], which in the case of MG4 J200112+4352 is around 0.1 (see also NED); the source is therefore a flat spectrum object and thus possibly associated with a blazar-type AGN.

## 4 OPTICAL SPECTROSCOPY

Within the respective X-ray/radio uncertainties, we find an optical/near-infrared source which has broad-band photometry available in the High Energy Astrophysics Science Archive Research Center (HEASARC) data base1 and which we report in Table 2. From this table is evident the possibility that the source may be variable in the optical; even taking into account uncertainties due to differences in the observations set-up such as detector apertures, filter sensitivities, etc., the change in magnitude is sufficiently high to suggest a change in the source flux at least in the optical bands. To firmly establish the nature of this X-ray/radio source, we next arranged and carried out a spectroscopic observation of its optical counterpart, USNO–B1.0 1338–0359203 (see Fig. 3). The source was spectroscopically observed on 2009 March 14 with the Bologna Astronomical Observatory 1.52-m ‘G.D. Cassini’ telescope equipped with Bologna Faint Object Spectrograph and Camera (BFOSC), which uses a 1300 × 1340 pixel EEV CCD. Observations started at 02:49 UT; three 1800 s spectra were acquired. In all exposures, Grism #4 and a slit width of 2 arcsec were used, providing a 3500–8700 Å nominal spectral coverage. The use of this setup secured a final dispersion of 4.0 Å pixel−1 for all spectra.

After cosmic ray rejection, the spectra were reduced, background subtracted and optimally extracted (Horne 1986) using IRAF.2 Wavelength calibration was performed using He–Ar lamps acquired soon after each spectroscopic exposure; all spectra were then flux-calibrated using the spectrophotometric standard BD+28°4211

![Figure 3. DSS-II-Red image of the field of the gamma-ray source Fermi 0FGL J2001.0+4352 with the 0.3–10 keV Swift/XRT (smaller circle) and the 0.2–12 keV XMM–Newton (larger circle) X-ray positions superimposed.](Image)

(oke 1990). Finally, the spectra were stacked together to increase the Signal-to-noise ratio. The wavelength calibration uncertainty was ∼0.5 Å for all cases; this was checked using the positions of background night sky lines.

The optical spectrum of the source (Fig. 4) shows a nearly featureless continuum, with only the atmospheric telluric lines and the Galactic diffuse interstellar band at 6280 Å apparent in absorption. No other line, either in absorption or in emission, is firmly detected. Regrettably this fact, also due to the relatively low signal-to-noise ratio of our data, does not allow us to pinpoint the redshift of this source. Nevertheless, at about 4800 Å, there seems to be a slope change in the optical spectrum. This may be due to a non-thermal component which merges with the light from the host galaxy, almost completely diluting the Ca break at ∼4000 Å. In this case, we can give a rough estimate of the source redshift as ∼0.2. After correction for the intervening Galactic reddening, $E(B-V) = 0.562$ mag (Schlegel, Finkbeiner & Davis 1998), the spectrum appears intrinsically blue and resembles those of BL Lac AGNs (see e.g. Sharrufatti et al. 2009 and references therein). This classification is also confirmed using the AGN classification approach of Laurent-Muehleisen et al. (1998).

## 5 IS MG4 J200112+4352 THE COUNTERPART OF 0FGL J2001.0+4352?

MG4 J200112+4352 is clearly a bright radio/X-ray source optically identified here as a BL Lac object. This by itself provides strong evidence that it is the counterpart of the Fermi source. The variability observed in the X-ray/optical band and the flat spectrum observed in radio further reinforce this conclusion. Are, however, the overall characteristics of the source compatible with other Fermi identified BL Lacs? Indeed, in the gamma (>100 MeV) versus radio (8.4 GHz) flux diagram MG4 J200112+435 is located well in

| Filter | Magnitude |
|--------|-----------|
| B      | 15.62–17.89 |
| V      | 16.86–17.82 |
| R      | 14.12–16.03 |
| I      | 14.78–15.90 |
| J      | 15.02     |
| H      | 14.16     |
| K      | 13.48     |

Table 1. Radio data.

| Frequency (MHz) | Flux (mJy) |
|-----------------|------------|
| 325             | 0.223 ± 0.011 |
| 1400            | 0.104 ± 0.003 |
| 4830            | 0.147      |
| 4850            | 0.201–0.239 |
| 8400            | 0.215–0.223 |

Table 2. Optical/near-infrared photometry.
Figure 4. Spectrum of the optical counterpart of the Fermi gamma-ray source identified and discussed in this Letter. The feature marked as NaD is the Galactic Na doubled at 5890 Å. Top panel: spectrum corrected for the intervening Galactic reddening assuming $E(B - V) = 0.562$ mag (Schlegel et al. 1998) and smoothed using a Gaussian filter with $\sigma = 3$ Å. The spectral features due to Galactic interstellar absorption are labelled. The symbol $\oplus$ indicates atmospheric telluric absorption bands. Bottom panel: the same spectrum, normalized to the continuum level.

the region populated by BL Lac objects (see fig. 14 in Abdo et al. 2009b). Also, the fluxes measured in the GeV bands suggest a hard source, that is more appropriate to a BL Lac object than to a flat spectrum radio quasar which is the other AGN typology detected by Fermi (Abdo et al. 2009b). Finally, the location of the source in the X-ray (0.5–2 keV) versus radio (1.4 GHz) flux density plot indicates agreement with the positions of other Fermi detected BL Lac objects and further suggests that MG4 J200112+4352 might be either a high frequency peaked blazar (HBL) or an intermediate frequency peaked blazar (IBL). In the widely adopted scenario of blazars, a single population of high-energy electrons in a relativistic jet radiate from the radio/far-infrared to the ultraviolet-soft X-ray by the synchrotron process and at higher frequencies by inverse Compton scattering soft-target photons present either in the jet [Synchrotron Self-Compton model], in the surrounding material [External Compton (EC) model], or in both (Ghisellini et al. 1998 and references therein). Therefore, a strong signature of the Blazar nature of a source is a double peaked structure in the spectral energy distribution (SED), with the synchrotron component peaking anywhere from infrared to X-rays and the inverse Compton extending up to GeV or even TeV gamma-rays. In Fig. 5, we construct the non-simultaneous SED of this enigmatic object by combining data collected in the optical/ultraviolet band, the X-ray spectrum is steep (hence belonging to the synchrotron component) and the Compton emission has a maximum in the GeV domain. We therefore conclude that all observational evidences point to the association of the Fermi source 0FGL J2001.0+4352 with the high frequency peaked BL Lac MG4 J200112+4352.

6 CONCLUSIONS

Through X-ray observations, we have been able to identify the counterpart of the newly discovered Fermi source 0FGL J2001.0+4352 and to associate it with the radio source MG4 J200112+4352 so far optically unclassified. Optical follow-up observations have provided the first optical spectrum of the source, which is a new BL Lac object. The source has many peculiar features which are typical of a blazar: it is a radio bright object with a flat spectrum; it is likely variable at X-ray and optical frequencies; it is also most likely a HBL as suggested by its SED.

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