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Investigating the EGRET-radio galaxies link with \textit{INTEGRAL}:

The case of 3EG J1621+8203 and NGC 6251

L. Foschini\textsuperscript{1}, M. Chiaberge\textsuperscript{2}, P. Grandi\textsuperscript{1}, I. A. Grenier\textsuperscript{3,4}, M. Guainazzi\textsuperscript{5}, W. Hermes\textsuperscript{6,7}, G. G. C. Palumbo\textsuperscript{8}, J. Rodriguez\textsuperscript{4,9}, S. Chaty\textsuperscript{3,4}, S. Corbel\textsuperscript{3,4}, G. Di Cocco\textsuperscript{1}, L. Kuiper\textsuperscript{6}, and G. Malaguti\textsuperscript{1}

\textsuperscript{1} Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF) del CNR/INAF, Sezione di Bologna, via Gobetti 101, 40129 Bologna, Italy
\textsuperscript{2} Istituto di Radioastronomia (IRA) del CNR/INAF, via Gobetti 101, 40129 Bologna, Italy
\textsuperscript{3} Université Paris VII Denis-Diderot, 2 place Jussieu, 75251 Paris Cedex 05, France
\textsuperscript{4} CEA Saclay, DSM/DAPNIA/SAp (CNRS FRE 2591), 91191 Gif-sur-Yvette Cedex, France
\textsuperscript{5} XMM-Newton SOC - European Space Astronomy Center of ESA, Vilspa, Apartado 50727, 28080 Madrid, Spain
\textsuperscript{6} SRON National Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands
\textsuperscript{7} Astronomical Institute “Anton Pannekoek”, University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands
\textsuperscript{8} Dipartimento di Astronomia, Università di Bologna, via Ranzani 1, 40127 Bologna, Italy
\textsuperscript{9} INTEGRAL Science Data Centre, Chemin d’Ecogia 16, Versoix, Switzerland

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Abstract. The analysis of an \textit{INTEGRAL} AO2 observation of the error contours of the EGRET source 3EG J1621 + 8203 is presented. The only source found inside the error contours for energies between 20 and 30 keV at 5\(\sigma\) detection significance is the FR I radio galaxy NGC 6251. This supports the identification of NGC 6251 with 3EG J1621 + 8203. The observed flux is higher and softer than observed in the past, but consistent with a variable blazar-like spectral energy distribution.

Key words. X-rays: galaxies – galaxies: active – galaxies: individual: NGC 6251

1. Introduction

One of the long standing problems of modern high-energy astrophysics is to understand the nature of sources emitting the highest energy \(\gamma\)-rays. The Energetic Gamma-Ray Experiment Telescope (EGRET) Catalog, obtained from high-energy \(\gamma\)-ray observations \((E > 100\) MeV\) performed between 1991 and 1995 (Hartman et al. 1999), changed our understanding of the \(\gamma\)-ray sky. The third version of this catalog contains 271 point sources and about 150 of them are still unidentified. The search for the counterparts of these sources is particularly challenging because the point spread function (PSF) of EGRET is about 6° at 100 MeV (FWHM) and the error contours are large, typically extent 0.5°–1°. During recent years, much effort has been spent in gathering all the useful data from the online multiwave-length archives, searching for possible counterparts. Despite some interesting results, the quest is still open (for a review see, e.g., Caraveo 2002; Grenier 2004; Mukherjee & Halpern 2004; Thompson 2004).

The EGRET sources of extragalactic origin are mainly blazars. The correlation of EGRET error boxes with flat-spectrum radio sources has been revisited using deeper radio interferometric surveys at 8.4 GHz and improved radio spectral measurements in the northern and southern sky, down to \(\delta < -40°\) (Sowards-Emmerd et al. 2003, 2004). These interferometric data have allowed us to discriminate more efficiently between sources with a flat spectrum core from those with softer lobe emission. Combined with the associations proposed by Mattox et al. (2001) using older surveys at \(\delta < -40°\), a total of 128 AGN counterparts have been proposed. 60\% of the identifications are considered very likely. Five associations with nearby Fanaroff-Riley type I and II radiogalaxies (FRI and FRII, respectively), namely 3EG J0459 + 3352 (Sowards-Emmerd et al. 2003), 3EG J1324–4313 (Cen A, Steine et al. 1998), 3EG J1646–0704 (Sowards-Emmerd et al. 2003), 3EG J1736–2908 (Di Cocco et al. 2004), 3EG J1735–1500 (Combi et al. 2003) and 3EG J1621 + 8203 (Mukherjee et al. 2002) open the exciting possibility of studying misaligned blazars in gamma rays. While blazars can be powerful \(\gamma\)-ray emitters because of relativistic beaming and amplification, the identification of \(\gamma\)-ray radiogalaxies poses interesting problems.

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According to the unified scheme of AGN by Urry & Padovani (1995), the transition from blazars to radio galaxies is based on a combination of orientation and relativistic beaming. Specifically, radio galaxies of type FR I and BL Lac objects are similar AGN with jet directions at large angles to the observer’s view or close to it. On the other hand, FR II radio galaxies and flat spectrum radio quasars (FSRQ), share the same orientation. The detection by EGRET of copious γ-rays from blazar jets implies that FR I and FR II radio galaxies are also intrinsically powerful γ-ray emitters, but their observation at large aspect angle should yield a much fainter flux and softer spectrum. This is indeed the case for Cen A (Steinle et al. 1998), that has a photon spectral index in the EGRET energy range ($E > 100$ MeV) of $\Gamma = 2.40 \pm 0.28$, that appears to be slightly softer than the average value for blazars ($\Gamma = 2.15 \pm 0.04$), although still consistent within the measurement errors. Cen A has a large inclination angle ($\sim 70^\circ$), so that it is difficult to explain the detection of emission in the EGRET energy range, but some explanations have been proposed (see the discussions in Sreekumar et al. 1999; and Mukherjee et al. 2002).

Therefore, it is very interesting to search for other radio galaxies that may be counterparts of EGRET sources. Their identification with EGRET sources would have a large impact yielding, for instance, valuable constraints on the collimation of γ-ray emission from the jet and the energy of the jet particles. In addition, it would have a significant impact on population studies since the density of radio galaxies is far higher than that of blazars, and a significant reassessment of the origin of the diffuse extragalactic γ-ray background would be required.

Among the different cases available, we focus our attention on 3EG J1621 + 8203, that Mukherjee et al. (2002) have associated with the FR I radio galaxy NGC 6251 ($z = 0.02488$). They analyzed data from X-ray satellites (ROSAT, ASCA) and by cross-correlating with the NRAO VLA Sky Survey (NVSS), they found that, among the several sources found in the EGRET error contours, NGC 6251 is the most promising candidate to be a high-energy γ-ray emitter. However, it should be noted that inside the EGRET error contour there are several other X-ray and radio sources, some of them unidentified. Therefore, NGC 6251 was considered the best candidate among the known sources.

In order to resolve this doubt, we requested for a long observation with the IBIS telescope (Ubertini et al. 2003) on board the INTEGRAL satellite (Winkler et al. 2003). IBIS has a large field of view of $19^\circ \times 19^\circ$ at half response, with a high angular resolution of $12'$ sampled in 5' pixels in the low energy (0.015–1 MeV) detector ISGRI (Lebrun et al. 2003) and in 10' pixels in the high energy (0.175–10 MeV) layer PIScST (Di Cocco et al. 2003). The point source location accuracy (PSLA) of ISGRI can be down to 1' for a 30σ detection (Gros et al. 2003). These characteristics make IBIS a valuable instrument to search for hard X-ray ($E > 20$ keV) counterparts in the large error contours of the EGRET sources.

Here we report the analysis of the region containing the 3EG J1621 + 8203 error contours and the hard X-ray emission from NGC 6251.

Throughout the paper we adopted $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

## 2. INTEGRAL data analysis

INTEGRAL observed 3EG J1621 + 8203 from June 17, 2004, 18\textsuperscript{h}28\textsuperscript{m} to June 23, 2004, 08\textsuperscript{h}13\textsuperscript{m} UTC with a 5 × 5 dither pattern. The region of interest was about 4° × 4° inside the EGRET error contours is NGC 6251, found at coordinates (J2000) $\alpha = 16^h33^m10^s$ and $\delta = +82^\circ35'46''$ with an uncertainty of 5" at the 90% confidence level (Fig. 1). The count rate in the 20–30 keV energy band is $0.11 \pm 0.02 \pm 0.015$ (1σ error) corresponding to a flux of $(6.7 \pm 2.1) \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ (90% confidence level). There is no detection in higher energy bands, with an upper limit of 0.05 counts s$^{-1}$ in the 30–40 keV energy band, corresponding to a flux of $4 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ assuming a Crab-like spectrum.

![Fig. 1. IBIS/ISGRI deconvolved significance map of the 3EG J1621 + 8203 sky region (exposure of 424 ks), in the 20–30 keV energy band, with a S/N threshold set to 3σ. The 3EG J1621 + 8203 probability contours at 95% and 99% confidence level are shown. “A” indicates the unknown excess at $\approx 3.5\sigma$. See the text for more details.](image-url)
for the jet axis $\approx 45^\circ$ to understand the flux difference. The flux and photon observation and we can exclude any contamination. Moreover, Chiaberge et al. (2003) evaluated also the beaming factor $\delta = 3.2$, that is lower than for blazars ($8 \leq \delta \leq 23$), but greater than the case of Cen A ($\delta = 1.2$).

The SSC model establishes a link between the radio and the hard X-ray emission, but before the present work, the only observation at energies greater than 10 keV was performed by the BeppoSAX PDS. However, there could be some doubt about the flux evaluation with the PDS, since it is a collimated detector with a field of view (FOV) of 1.3° and there is an active Seyfert nucleus at a distance of 27' from NGC 6251 (see the source No. 17 in the Fig. 3 of Mukherjee et al. 2002). Thanks to the unprecedented angular resolution of IBIS/ISGRI, it is possible to distinguish between the different contributions. The Seyfert nucleus is not detected in the present INTEGRAL observation and we can exclude any contamination. Moreover, IBIS/ISGRI shows that no other source or excess is present in the error contours of EGRET down to a flux of $\approx 5.4 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ (4$\sigma$, 20–30 keV energy range).

The SED of NGC 6251, updated with the data from the present observation, is shown in Fig. 2. The model SED has been derived using the numerical code described in Chiaberge & Ghisellini (1999). The data at different wavelengths are not obtained simultaneously, therefore, it is not possible to draw firm conclusions. However, with the INTEGRAL data it is possible to fit the data with the SSC, showing the source in a state with an overall higher flux. The parameters of the fit are similar to those in Chiaberge et al. (2003): in the present case the size of the source is slightly smaller by about a factor of less than 2 and the beaming factor increases from $\delta = 3.2$ to 3.8. Although the non-availability of simultaneous data prevents us from performing a detailed spectral modeling, we speculate that the “high state” observed during the INTEGRAL pointings might be produced by a smaller region, located even closer to the jet base.

Another key question is still unexplained: the X-ray variability. It is indeed known that blazars display strong variability...
Table 1. Fluxes in the 20–30 keV energy band obtained in different epochs. In the case of ASCA and XMM-Newton, the value is extrapolated from the best fit model (see the notes for details). Columns: (1) Satellite name; (2) Date of the observation [DD–MM–YYYY]; (3) Photon index; (4) Flux [10^{-12} erg cm^{-2} s^{-1}]. The uncertainties in the parameters are at the 90% confidence level.

| Detector | Date            | \(\Gamma\)  | \(F\)      |
|----------|-----------------|-------------|------------|
| ASCA\(^a\) | 28-10-1994  | 1.8 \pm 0.2 | 0.50 \pm 0.06 |
| BeppoSAX\(^b\) | 19-07-2001  | 1.79 \pm 0.06 | 1.73 \pm 0.07 |
| XMM-Newton\(^c\) | 26-03-2002 | 1.91^{0.08}_{-0.03} | 1.19^{0.08}_{-0.06} |
| INTEGRAL\(^d\) | 17-06-2004  | 2.1\(^{+5.0}_{-7.0}\) | 6.7 \pm 2.1 |

\(^a\) Sambruna et al. (1999). Flux extrapolated from the fit in the 0.6–10 KeV energy band.
\(^b\) Guainazzi et al. (2003), Chiaberge et al. (2003). Flux extracted from the joint fit LECS, MECS, PDS, in the 0.1–200 keV energy band.
\(^c\) Gliozzi et al. (2004). Flux extrapolated from the fit in the 0.4–10 keV energy band.
\(^d\) Present work.

The conversion from rate to flux was done by assuming a Crab-like spectrum.

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