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IS THE EGRET SOURCE 3EG J1621+8203 THE RADIO GALAXY NGC 6251?

R. MUKHERJEE
Dept. of Physics & Astronomy, Barnard College, Columbia University, New York, NY 10027
J. HALPERN, N. MIRABAL & E. V. GOTTHELF
Dept. of Physics & Astronomy, Columbia University, New York, NY 10027

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ABSTRACT

We discuss the nature of the unidentified EGRET source 3EG J1621+8203. In an effort to identify the gamma-ray source, we have examined X-ray images of the field from *ROSAT* PSPC, *ROSAT* HRI, and *ASCA* GIS. Of the several faint X-ray point sources in the error circle of 3EG J1621+8203, most are stars or faint radio sources, unlikely to be counterparts to the EGRET source. The most notable object in the gamma-ray error box is the bright FR I radio galaxy NGC 6251. If 3EG J1621+8203 corresponds to NGC 6251, then it would be the second radio galaxy to be detected in high energy gamma rays, after Cen A, which provided the first clear evidence of the detection above 100 MeV of an AGN with a large-inclination jet. If the detection of more radio galaxies by EGRET has been limited by its threshold sensitivity, there exists the exciting possibility that new high energy gamma-ray instruments, with much higher sensitivity, will detect a larger number of radio galaxies in the future.

Subject headings: gamma rays: observations — X-rays: observations — gamma-rays: individual (3EG J1621+8203) – radio galaxy: individual (NGC 6251)

1. INTRODUCTION

Surveys of the gamma-ray sky by the Energetic Gamma Ray Experiment Telescope (EGRET) on the Compton Gamma Ray Observatory (CGRO) in the 30 MeV to 10 GeV energy range have revealed 271 point sources of gamma rays (Hartman et al. 1999). Of these the largest group of identified sources are the active galaxies of the blazar class. Blazars are sources with high gamma-ray luminosity, which are characterized by flat radio spectra, rapid temporal variability at most frequencies, and a high degree of optical polarization. Besides the blazars, only two other extragalactic sources have been detected by EGRET, namely the radio galaxy Cen A, and the normal galaxy LMC. Most of the 65% other sources remain unidentified due to lack of convincing counterparts at other wavelengths.

EGRET sources have large error contours, typically $\sim 0.5^\circ - 1^\circ$, which makes identifications on the basis of position alone challenging. The principle method of identification of the EGRET sources relies on finding positional coincidences with flat-spectrum radio quasars (e.g. Thompson et al. 1995) or is based on the statistical evidence that blazars are the dominant population (e.g. Mattox et al. 1997; Mattox, Hartman & Reimer 2001), relying in part on the sources' 5 GHz flux density. Often additional information from observations at other wavebands are used to aid in the identification of the EGRET sources. Progress has been made with recent studies in the X-ray band carried out for several EGRET fields (e.g. Roberts et al. 2001), and used to suggest counterparts for a few unidentified EGRET sources, such as 3EG J2227+6122 (Halpern et al. 2001a), 3EG J1835+5918 (Mirabal et al. 2000; 2001; Reimer et al. 2001), and 3EG J2016+2657 (Mukherjee et al. 2000; Halpern et al. 2001b).

In this article we present gamma-ray and X-ray observations of one unidentified EGRET source, 3EG J1621+8203. In particular, we examine the evidence in order to see if 3EG J1621+8203 could be a second radio galaxy to be detected in high energy gamma-rays by EGRET.

2. THE GAMMA RAY OBSERVATIONS

3EG J1621+8203 is a high latitude source located at l=115.53, b=31.77, with a 95% confidence error radius of $0^\circ.85$ (Hartman et al. 1999). Recently, Mattox, Hartman, & Reimer (2001) have generated elliptical fits to the 95% confidence contours for the Third EGRET Catalog (3EG) sources. This analysis yields an error ellipse with semi-major and semi-minor axes of $0^\circ.97$ and $0^\circ.74$, respectively. Figure 1 shows the EGRET source position superimposed on the *ROSAT* X-ray image that is described in §3.

3EG J1621+8203 is not very bright in high energy gamma rays, and individual viewing periods yielded near-threshold detections by EGRET. In the cumulative exposure from multiple EGRET viewings, 3EG J1621+8203 was clearly detected and the measured flux above 100 MeV was 1.1×10^{-7} photon cm^{-2} s^{-1} (Hartman et al. 1999).

The background-subtracted γ-ray spectrum of 3EG J1621+8203 was determined by dividing the EGRET energy band of 30 MeV – 10 GeV into 6 bins and estimating the number of source photons in each interval, following the EGRET spectral analysis technique of Nolan et al. (1993). The data were fitted to a simple power law model of the form $F(E) = k(E/E_0)^{-\alpha}$ photon cm^{-2} s^{-1} MeV,$^{-1}$ where $F(E)$ is the flux measured at an energy E. The photon spectral index α and the coefficient k are the free parameters of the fit. The energy normalization factor E_0 is chosen so that the statistical errors in the power-law index and the overall normalization are uncorrelated. The fit to the gamma-ray spectrum of 3EG 1621+6203 yielded a photon spectral index of 2.27±0.53 and is shown in Figure 2. The majority of the high energy photons for this source are in the 100-500 MeV band.

3. THE X-RAY OBSERVATIONS

Archival X-ray imaging observations were available for the field of the EGRET source 3EG J1621+8203. *ROSAT* (Roentgen Satellite) observations with the Position Sensitive Proportional Counter (PSPC) in the range 0.2 – 2.0 keV covered most of the error contour of 3EG J1621+8203. Additional partial coverage was also available from the *ROSAT* High Resolution Imager (HRI) and the *ASCA* (Advanced Satellite for Cosmology and Astrophysics) Gas Imaging Spectrometer (GIS). Historically, these fields have been studied in X-rays because they contained the radio-loud active galaxy NGC 6251 (e.g. Sambruna, Eracleous, & Mushotzky 1999; Turner et al. 1997; Mack, Kerp & Klein 1997; Birkinshaw & Worrall 1993), and the gamma-ray burst GRB 970815, which generated target-of-opportunity observations (Murakami et al. 1997).

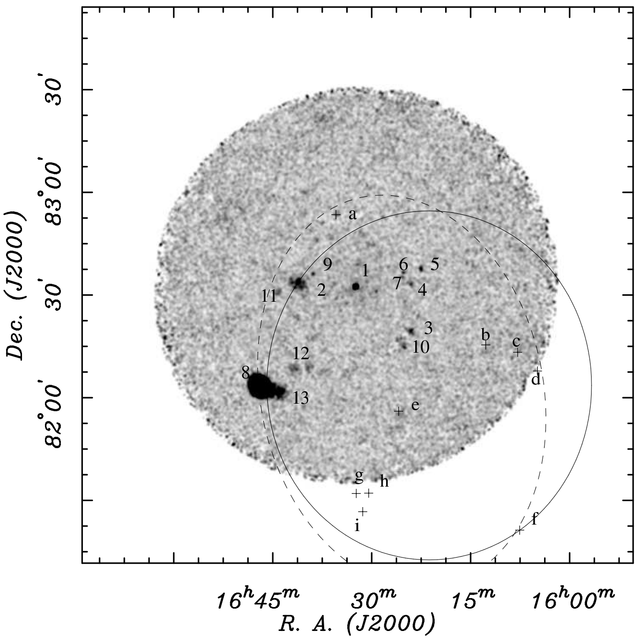

FIG. 1.— *ROSAT* PSPC soft X-ray image of 3EG J1621+8203, exposure-corrected and smoothed with a 3×3 top hat kernel. The scaling has been adjusted to highlight the faint emission. The circle corresponds to the ~ 95 % confidence contours from the 3EG catalog (Hartman et al. 1999). The dashed ellipse is the 95% error contour derived from elliptical fits to the 3EG data (Mattox, Hartman, & Reimer 2001). The numbers and letters correspond to sources described in §3 and Tables 1 and 2.

We have created *ROSAT* PSPC image of the field of 3EG J1621+8203 by co-adding exposure corrected sky maps of 14.7 ks of data taken during 1991 March 12-15, as shown in Fig. 1. The *ROSAT* HRI and *ASCA* GIS images of the partial field of 3EG J1621+8203 are shown in Fig. 3. The figures also show the EGRET positions for the source, both as derived from the 3EG catalog, as well as that from the elliptical fits to the EGRET data.

In the archival *ROSAT* and *ASCA* data overlapping the EGRET 95% error circle ellipse of 3EG J1621+8203 we find several faint X-ray point sources. In addition, we have also searched the *ROSAT* All Sky Survey (RASS) catalog for sources in the field of 3EG J1621+8203, particularly in the regions not covered by the pointed *ROSAT* PSPC and HRI data. The source positions are marked in figures 1 and 3, and listed in Table 1. Count rates for the *ASCA* and *ROSAT* sources were obtained following the method described in Gotthelf & Kaspi (1998). Photons were extracted using a $2'$ radius aperture and the background contribution was estimated using a large annulus away from the source.

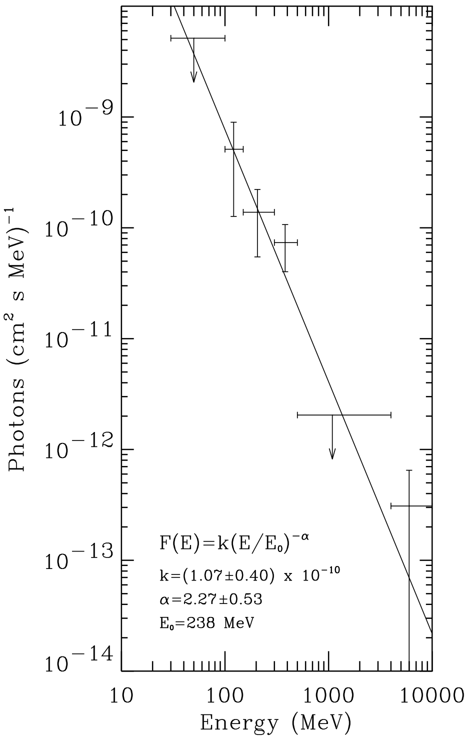

FIG. 2.— Photon spectrum of 3EG J1621+8203 in the the 30 MeV to 10 GeV energy range with superimposed fit to a simple power-law model.

The *ROSAT* sources are listed in Table 1 along with their background subtracted count rates, detection significances, and hardness ratios. Sources with count rates below 2.4×10^{-3} cts/s are not listed in the table. The faintest source in Table 1 is a detection at the 3.0σ level, with a background subtracted count rate of 0.0020 ± 0.0006 cts/s in a $2.0'$ diameter circular aperture. For this analysis we report all sources down to the 3σ detection level. The sources listed reached a minimum detectable intrinsic flux of 1.3×10^{-14} erg cm^{-2} s^{-1} in the 0.1 – 2.4 keV band, assuming a power-law photon spectral index of 2.0, and no absorption (estimated N_H is $\sim 5 \times 10^{20}$ cm,$^{-2}$ is expected to have a small effect).

We have searched for optical and radio counterparts to the *ROSAT* and *ASCA* point sources shown in figures 1 and 3. Most of the X-ray point sources have possible optical counterparts, as listed in Table 1, and some are coincident with faint radio sources. Individual sources denoted by their source numbers in Table 1 are described in the following section.

4. NOTES ON INDIVIDUAL SOURCES

1. *NGC 6251*: This is the bright FR I radio galaxy (Bicknell 1994; Urry & Padovani 1995) at a redshift of 0.0234 (implied distance 91 Mpc for H_0 = 75 km s^{-1} Mpc^{-1}). NGC 6251 is the parent galaxy of an exceptional radio jet from pc to Mpc scale which makes an angle of $\sim 45°$ to our line of sight (Sudou & Taniguchi 2000). High dynamic range observations of NGC 6251 with the VLBI show the presence of a bright core, and an asymmetric jet, that implies relativistic beaming in this source (Jones et al. 1986). The VLBI observations are described further in §6. NGC 6251 has been studied in X-rays in the past. A detailed investigation of the *ROSAT* PSPC data was carried out

TABLE 1

X-RAY SOURCES IN THE FIELDS OF 3EG J1621+8203

#[a]	RA	Dec	cts/s	HR[c]	Optical/Radio Position	Δ[d]	Suggested[e] Identification
1	16 32 32.5	82 32 15	0.102	0.92	16 32 32.0 +82 32 16	1”	NGC 6251, Radio Galaxy
2	16 41 05.1	82 32 54	0.053	0.99	16 41 08.6 +82 33 09	17”	2E 1646.6+8238, Galaxy Cluster, z = 0.26
3	16 24 30.0	82 19 00	0.006	0.45	16 24 26.2 +82 18 53	10”	USNO, R = 17.4, B = 16.9
4	16 24 12.7	82 32 48	0.005	0.92	16 24 06.0 +82 32 49	13”	USNO, R = 18.4, B = 19.4
5	16 22 32.6	82 37 06	0.008	0.66	16 22 34.0 +82 37 04	3.6”	R = 20.0, B = 20.2
6	16 25 13.2	82 36 13	0.004	0.83	16 25 13.4 +82 36 21	8”	USNO, R = 15.0, B = 16.2
7	16 25 27.3	82 34 49	0.002	0.91	16 25 28.2 +82 34 57	8”	USNO, R = 18.9, B = 19.1
					16 25 27.7 +82 34 57	8”	NVSS, 46.2 mJy at 1.4 GHz
8	16 46 04.1	82 02 34	0.503	0.24	16 45 58.2 +82 02 14	25”	HD 153751 (RS CVn type)
9	16 39 00.9	82 35 47	0.004	0.57	16 39 01.9 +82 35 49	3”	USNO, R = 14.5, B = 15.6
10	16 25 29.6	82 14 39	0.005	0.74	16 25 31.4 +82 14 55	16”	WN B1630.5+8221, 52 mJy at 0.325 GHz
11	16 44 12.6	82 30 07	0.009	0.33	16 44 07.8 +82 30 06	10”	USNO, R = 18.3, B = 18.0
12	16 41 18.9	82 07 56	0.014	0.03	16 41 11.8 +82 07 53	15”	USNO, R = 13.1, B = 14.4
13	16 42 58.1	82 01 02	0.016	0.13	...	...	...
14[b]	16 03 24.5	81 42 19	0.016	...	16 03 26.5 +81 42 21	4”	BD+82 477, B = 10.05, G0
15[b]	16 06 52.0	81 30 28	0.003	...	....	...	$V > 24.3$, GRB 970815
16[b]	16 13 17.3	81 23 33	0.010	...	16 13 20.6 +81 23 33	8”	USNO, R = 13.6, B = 14.3
17	16 37 20.6	82 07 36	...	...	16 37 27.3 +82 07 07.5	...	Seyfert 1, z = 0.0402

(*a*) Identifying number in *ROSAT* PSPC image, Fig. 1. (*b*) *ROSAT* HRI source, indicated in Fig. 3. (*c*) Hardness ratio; $HR = (B-A)/(B+A)$, where A is the count rate in the energy range 0.1-0.4 keV, and B is the count rate in the 0.5-2.0 keV band (Voges, et al. 1999). (*d*) Positional offset from the optical/radio position. (*e*) Most of the USNO objects are only suggested IDs, based on positional coincidence and/or color.

by Birkinshaw & Worrall (1993), who found the X-ray emission to be consistent with a point source at the position of the nucleus. Some extended X-ray emission surrounding the nucleus of NGC 6251 was noted, and a flat-spectrum power-law component (photon spectral index $\Gamma \sim 1$) plus emission of a thermal plasma ($kT \sim 0.5$ keV) was found to fit the *ROSAT* data best. The X-ray jet was studied in some detail by Mack, Kerp & Klein (1997) who found that the X-ray emission in the jet is mostly due to bremsstahlung and line emission of hot, thin plasma, rather than synchrotron or inverse Compton scattering. The *ASCA* data for NGC 6251 were analyzed by Turner et al. (1997) and Sambruna, Eracleous, & Mushotzky (1999). The *ASCA* spectrum was best modelled with a hard power law $\Gamma = 1.83^{+0.21}_{-0.18}$ plus a thermal plasma component $kT = 1.04^{+0.21}_{-0.18}$ keV that is harder than observed in the *ROSAT* data (Sambruna, Eracleous, & Mushotzky 1999).

2. *RX J1641.2+8233*: A galaxy cluster, at a redshift of 0.26, corresponding to the Einstein Imaging Proportional Counter (IPC) source 2E 1646.6+8238. This is an extended X-ray source with 90 galaxies within $3'$ of the X-ray centroid, and all within 3 magnitudes of the three brightest galaxies (Tucker, Tananbaum & Remillard 1995). Another X-ray point source, 2RXP J164016.6+823203 is located close to the galaxy cluster. It is not clear if this is a separate source or part of the cluster.

7. This is a possible QSO, based on its blue color and association with a weak radio source.

8. *HD 153751*: Also known as SAO 2770, this is the brightest X-ray source in the *ROSAT* image of 3EG J1621+8203. It is a variable star of the RS CVn type (Eker 1992). It has a B magnitude of 5.098 and a V magnitude of 4.22. Its spectral type is G5III.

10. *WNB1630.5+8221*: A weak radio source with a flux density of about 58 mJy at 0.925 GHz.

14. *BD+82 477*: Present only in a *ROSAT* HRI image of the region, it is also known as SAO 2659, and is a star of B and V magnitudes of 10.05 and 9.44, respectively, and spectral type G0 (Perryman et al. 1997).

17. *1AXG J163720+8207*: Using the MDM 2.4m telescope we have spectroscopically identified this source with a reddened Seyfert 1 galaxy at z=0.0402. The coordinates of this galaxy are (J2000) 16 37 27.3, +82 07 07.5. (It should not be confused with its physical companion, the galaxy IRAS F16419+8213, which lies $1'.3$ away and has the same redshift, but only H II region emission lines.) This X-ray source is therefore unlikely to be the EGRET source.

Source 5 was imaged on the MDM 1.3 m, and an object with R = 20.0 and B = 20.2 was found in the field. Such color is typical of a QSO. The field of source 15 was empty in the optical down to the DSS limit. We have observed this field at the MDM, and there is no optical counterpart to a V magnitude limit of 24.3. Source 15 is the possible afterglow of GRB 970815 (Smith et al. 1999; Murakami et al. 1997). The *ASCA* and *ROSAT* fields were observed as a result of the target of opportunity generated by the gamma-ray burst. Source 15 is a weak X-ray source seen both in the *ASCA* and *ROSAT* images, and is slightly outside the error box of the GRB event, as reported by the RXTE/ASM (Smith et al. 1997). *ASCA* observed the source three days after the GRB event, and the flux of source 15 remained stable at $\sim 3 \times 10^{-13}$ erg cm^{-2} s^{-1} during the observations. The association of source 15 with GRB 970815 remains uncertain.

TABLE 2

ROSAT ALL SKY SURVEY SOURCES IN THE FIELD OF 3EG J1621+8203[a]

Number[b]	Source Name	Cts/s	Optical Position	Δ^c	Magnitude[d]
a	1RXS J163525.2+825330	0.010	16 35 14.66 +82 53 31.7	20”	$R = 17.4$, $B = 18.2$
b	1RXS J161242.6+821525	0.009	16 12 46.30 +82 15 44.2	21”	$R = 18.7$, $B = 19.7$
c	1RXS J160752.0+821316	0.016	16 07 56.62 +82 13 03.2	16”	$R = 12.7$, $B = 13.1$
d	1RXS J160452.7+820748	0.022	16 04 56.66 +82 07 47.1	8”	$R = 15.7$, $B = 17.4$
e	1RXS J162554.6+815602	0.012	16 25 58.97 +81 55 56.7	11”	$R = 19.0$, $B = 18.8$
f	1RXS J160733.9+812118	0.014	...	...	...
g	1RXS J163027.4+813206	0.025	16 30 24.12 +81 32 09.6	8”	$R = 14.6$, $B = 16.3$
h	1RXS J163220.1+813201	0.015	16 32 23.19 +81 31 45.2	17”	$R = 12.4$, $B = 13.5$
i	1RXS J163121.3+812641	0.022	16 31 21.99 +81 26 43.7	3”	$R = 17.6$, $B = 19.0$

(*a*) *ROSAT* all sky survey sources *not* seen in the pointed PSPC and HRI images. (*b*) Identifying number in the *ROSAT* images (Fig. 1 & Fig. 3). (*c*) Positional offset from the optical position. (*d*) Most of the USNO stars are only suggested IDs, based on the fact that they are the nearest.

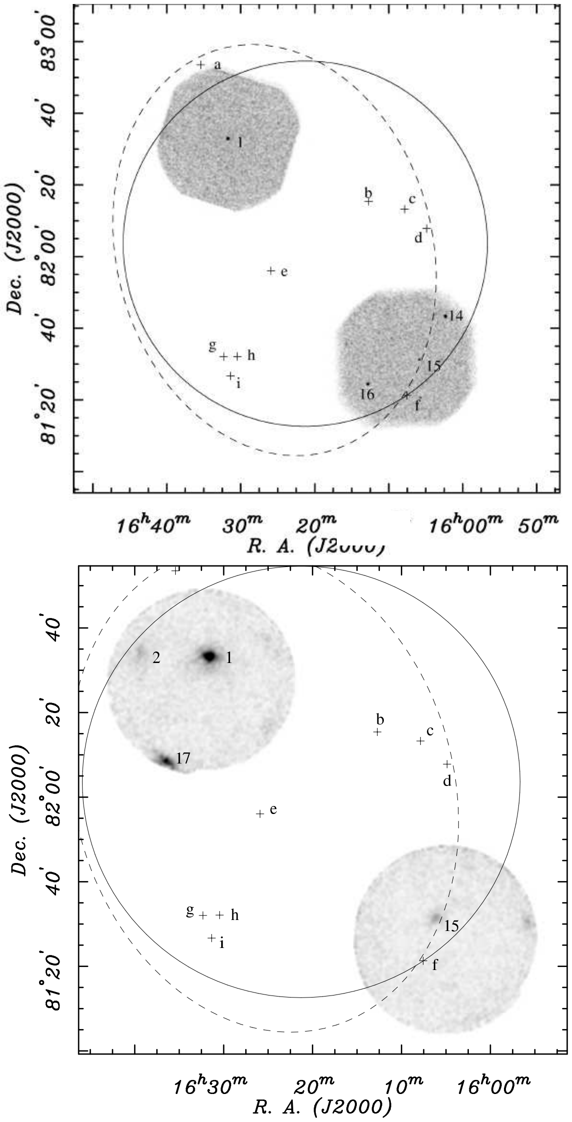

FIG. 3.— (Top) *ROSAT* HRI image and (Bottom) *ASCA* image in the field of 3EG J1621+8203. The circles corresponds to the ~ 95 % confidence contours from the 3EG catalog (Hartman et al. 1999). The dashed ellipses are the 95% error contours derived from elliptical fits to the 3EG data (Mattox, Hartman & Reimer 2001). The numbers and letters correspond to sources described in §3 and Tables 1 and 2.

The remaining numbered sources, except for 13, have positional correspondences with objects in the USNO star catalog. Their R and B magnitudes are included in Table 1.

ROSAT All Sky Survey Sources (RASS): In addition to the point sources in Table 1, Figs. 1 and 3 also show the locations of faint sources from the RASS catalog (Voges et al. 2000) not detected in the pointed PSPC and HRI data. The RASS field covers the entire EGRET error circle, even the areas not covered or detected by the pointed PSPC and HRI data sets. The RASS sources are marked with crosses and listed in Table 2. Except for the source marked “f” all the sources in Table 2 are positionally coincident with objects from the USNO catalog. Source “g” was determined to be a dMe star from spectroscopic observation on the MDM 2.4m.

5. THE RADIO OBSERVATIONS

We have searched the NRAO/VLA Sky Survey (NVSS) catalog (Condon et al. 1998) for possible 1.4 GHz radio counterparts to the X-ray point sources. There were 111 radio sources in the field of 3EG J1621+8203 of which only 10 had integrated radio fluxes > 100 mJy. These are shown in Fig. 4 and listed in Table 3. Of these, B_1 is NGC 6251 and $B_2 \cdots B_5$ probably correspond to emission from the jet of NGC 6251. No significant X-ray emission is seen at the positions of the other sources and the NASA Extragalactic Database (NED) reveals that these are steep spectrum radio sources. Mack, Kerp & Klein note another X-ray/radio coincidence east of source 7 at RA: 16 26 24.8 and Dec: 82 35 07. This source is 8C 1631+826, and has an X-ray flux density of $(9.8 \pm 2.9) \times 10^{-3}$ μJy.

It should be noted that that the most effective way to look for radio candidates for gamma-ray sources is to start not with the NVSS, but with a high-frequency radio catalog that is most likely to isolate the flat-spectrum, blazar candidates. The best such catalog in the northern hemisphere is the Becker, White, & Edwards (1991) 4.85 GHz survey. However, it covers only declinations between 0° and +75,° which excludes this field.

6. DISCUSSION

Our analysis of the archival X-ray data of the field containing 3EG J1621+8203 reveals that the region contains several bright stars, weak radio sources, a radio galaxy, and a galaxy cluster. We note that unlike the majority of the identified EGRET sources, 3EG J1621+8203 lacks a radio-loud, spectrally flat,

TABLE 3
BRIGHT (> 100 MJY) NVSS SOURCES IN THE FIELD OF 3EG J1621+8203

Number	RA	Dec	Flux (mJy)	Name
B1	16 32 26.14	+82 32 20.3	802	NGC 6251
B2	16 31 47.88	+82 32 54.7	144	NGC 6251 jet
B3	16 30 51.13	+82 33 45.6	875	”
B4	16 29 25.21	+82 35 34.1	131	”
B5	16 27 42.31	+82 42 26.1	114	”
B6	16 28 9.52	+81 50 21.3	137	8C 1632+819
B7	16 26 43.74	+81 58 50.8	172	8C 1631+820
B8	16 24 11.83	+82 09 14.1	334	8C 1628+822
B9	16 21 24.93	+81 35 34.1	100	WN B1621.7+8142
B10	16 07 29.40	+82 01 34.5	314	8C 1612+821

blazar-like source catalogued within its error circle that could be its potential counterpart. No radio counterpart search was carried out by Mattox, Hartman and Reimer (2001) for this source, as it is in a region of sky not covered by the 5 GHz Green Bank survey. Of the notable X-ray sources in Table 1 the brightest is the RS CVn star, source # 8. X-ray emission from such stars is believed to arise from coronal loop structures (Rosner et al. 1978), or perhaps as a result of interaction between the mass transfer stream and the mass gaining star in a binary system (Welty & Ramsey 1995). RS CVn stars are not known to be gamma-ray emitters, and thus we reject source # 8 as a counterpart to the EGRET source. Similarly, none of the other stars listed in Table 1 is likely [illegible]ond to the gamma-ray source.

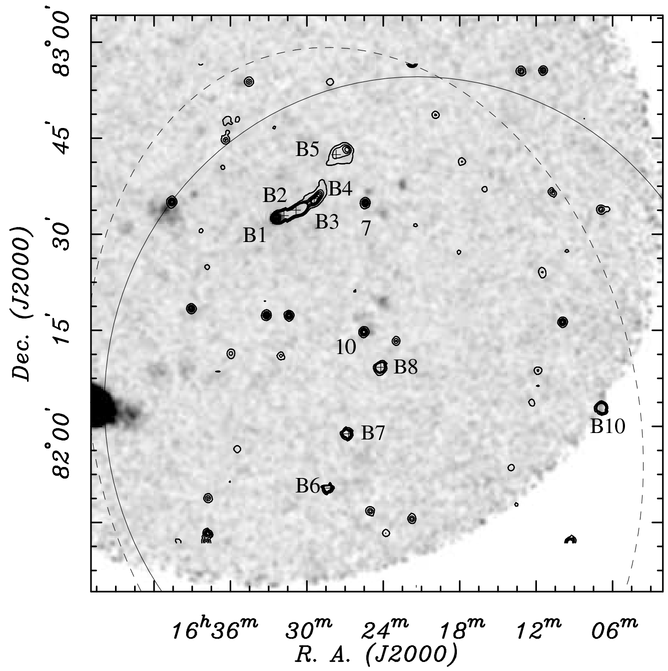

FIG. 4.— Contour map of NVSS sources in the field of the EGRET source 3EG J1621+8203 superimposed on the *ROSAT* PSPC image (grey scale). The source positions are listed in Table 3. Source B9, which is within the EGRET error contour but outside the X-ray image, is not shown. X-ray sources 7 and 10 are coincident with weak radio sources listed in Table 1.

The two sources of interest in Table 1, however, are the galaxy cluster 2E 1646.6+8238 and the radio galaxy NGC 6251. The question of whether gamma-ray emission above 100 MeV is possible from X-ray clusters is not yet resolved. It has been suggested that some of the unidentified EGRET sources at high latitudes could be gamma-ray clusters, perhaps a new population of gamma-ray emitting sources (Totani & Kitayama 2000). Gamma-ray emission in clusters is presumably due to the inverse Compton scattering of the cosmic microwave background photons off high energy electrons accelerated in the shock waves produced during cluster formation. However, Totani & Kitayama (2000) note that there is no statistically significant association of clusters from either the Abell catalog (Abell, Corwin & Olowin 1989) or the catalog of *ROSAT* Brightest Cluster Sample (Ebeling et al. 1998) with the error circles of the unidentified EGRET sources at high latitudes. In fact, the X-ray surface brightness and surface number density of galaxies in gamma-ray clusters are expected to be lower by a factor of about 200 and 30, respectively, than those of ordinary clusters (Totani & Kitayama 2000), and the likelihood of finding gamma-ray clusters in past X-ray and optical surveys is small. Brighter, closer sources of this class have not been previously detected by EGRET. In this case it is unlikely that the gamma-ray emission in 3EG J1621+8203 is due to the galaxy cluster 2E 1646.6+8238, despite the positional coincidence. Perhaps deeper searches with more sensitive X-ray and gamma-ray instruments (e.g. GLAST) will resolve this issue conclusively in the future.

Based on the present X-ray data, NGC 6251 appears to be the most likely candidate identification for the EGRET source 3EG J1621+8203. In that case, NGC 6251 would be the second radio galaxy to be detected by EGRET. In the 3EG catalog, Cen A (NGC 5128) is the only candidate detection of a radio galaxy at energies above 100 MeV (Sreekumar et al. 1999). Its derived gamma-ray luminosity is weaker by a factor of 10^{-5} compared to the typical EGRET blazar. All other active galaxies identified with EGRET sources are blazars, which are believed to have nearly aligned jets along our line-of-sight. Cen A has a jet that is offset by an angle of about 70° (Bailey et al. 1986; Fujisawa et al. 2000). Cen A happens to be the brightest and nearest radio galaxy ($z = 0.0018$, ~ 3.5 Mpc). It has a double-lobed radio morphology, as evidenced from radio studies and shows the presence of a one-sided X-ray jet, collimated in the direction of the giant radio lobes. Cen A has a relatively weak radio luminosity $\sim 10^{40}$ ergs s^{-1}, and is classified as a FR I radio galaxy. In the past Cen A was believed to be a misaligned blazar (Bailey et al. 1986).

High dynamic range VLBI and VLA maps are available for NGC 6251 at 6, 13, and 18 cm, showing a bright core, a jet/counterjet brightness ratio of $\sim$ 80 to 1 (Jones et al. 1986). The fact that the source has a nuclear structure and a large scale radio morphology, implies relativistic beaming. Blazars detected by EGRET are compact radio sources, with radio spectral indices ≥ -0.5. The kpc-scale jet of NGC 6251 has a slightly smaller spectral index (-0.64) (Saunders et al. 1981), but it could account for relativistic electrons and inverse Compton emission in this source (Jones, et al. 1986).

Figure 5 shows the spectral energy distribution of NGC 6251 assuming that it is the counterpart to 3EG J1621+8203. The radio through optical data for the plot are from Ho (1999) and the references therein. The *ROSAT* data is from Worrall & Birkinshaw (1994) who find that 90% of the total PSPC flux comes from an unresolved component of diameter $\leq 4''$. The *ASCA* data is from Sambruna, Eracleous & Mushotzky (1999) and agrees with the continuum model of Turner et al. (1997) who analyzed the data previously. We have also included VLBI and VLA data at 2.22, 6, and 18 cm (Jones et al. 1986). Similar to Cen A, the high energy gamma-ray emission from 3EG J1621+8203 represents a lower luminosity (3×10^{43} ergs/s) than that of other EGRET blazars (typically 10^{45} to 10^{48} ergs/s). Sreekumar et al. (1999) note that Cen A has a gamma-ray photon spectral index of 2.40 ± 0.28, which is steeper than the average power-law spectrum from gamma-ray blazars (2.15 ± 0.04), and the spectrum of the extragalactic gamma-ray background (2.10 ± 0.03). The gamma-ray spectral index of 3EG J1621+8203 has a larger error (2.27 ± 0.53), but it may be worth noting that it too is probably steeper than the average blazar spectrum. Unlike Cen A, however, NGC 6251 has not been detected by either COMPTEL or OSSE. There is no upper limit for this source in the first COMPTEL source catalog (Schönfelder et al. 2000).

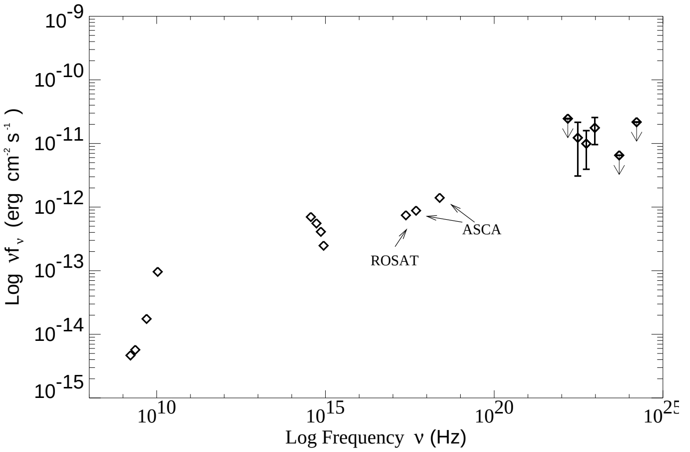

FIG. 5.— Broad-band spectral energy distribution plot of NGC 6251, assuming that it is the counterpart to 3EG 1621+8203. The radio through optical data are obtained from a compilation by Ho (1999).

The sensitivity of EGRET to off-axis emission from AGN, whose jets are pointed away from our line-of-sight, needs to be addressed. The total amount of scattered energy, F_1, as a function of viewing angle for an active galaxy may be estimated using the relation (see Dermer, Schlickeiser, Mastichiadis 1992; Weferling & Schlickeiser 1999),

$$F_1(s, \mu_s^*) = D^{3+s}(1-\mu_s^*)^{(s+1)/2} \tag{1}$$

where the gamma-ray flux seen by the observer is due to the scattered inverse Compton emission of ambient low energy photons by highly relativistic particles in the jet. In this case, the particles are assumed to be electrons and positrons, distributed in energy as a power-law with a spectral index of s. μ_s^* is the cosine of the angle between the jet axis and the direction to the observer, and D is the Doppler factor of the blob, defined as $D = \Gamma^{-1}(1-\beta\mu_s^*)^{-1}$, where βc is the bulk velocity of the plasma.

Figure 6 shows the decrease in scattered energy for off-axis emission, using the above relation, for different viewing angles, corresponding to two typical values of Lorentz factors (Γ) seen in blazars. The figure shows that a decrease in observer angle from 70° (e.g. Cen A) to 45° (e.g. NGC 6251) corresponds to an increase in the scattered energy by about a factor of 10, all other things assumed equal. Cen A (z = 0.0018) is the only source to be detected by EGRET with a large inclination angle, presumably due to its proximity to Earth. NGC 6251 (z = 0.0234) is much further away, but it is possible that the source is still detectable by EGRET due to its smaller jet angle.

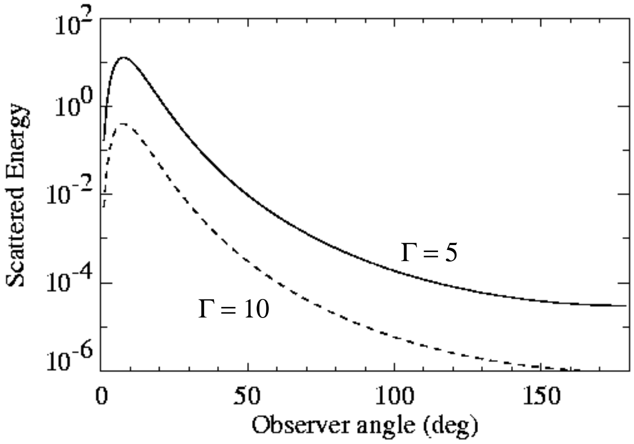

FIG. 6.— Decrease in the observed emission from a blazar as a function of jet orientation with respect to the observer (Weferling & Schlickeiser 1999; Sreekumar 1999).

The threshold sensitivity of EGRET (> 100 MeV) for a single 2-week observation was $\sim 3 \times 10^{-7}$ photons cm^{-2} s^{-1} (Thompson et al. 1993). Due to the intrinsically low luminosity of radio galaxies and the limitations of EGRET's sensitivity, it is not surprising that many radio galaxies have not been detected as gamma-ray sources above 100 MeV thus far. It is very likely that more distant radio-loud AGN with intermediate inclination angles will be detected in the future with higher sensitivity gamma-ray instruments. FR I galaxies have been hypothesized to be the likely parent populations of BL Lac objects, which are believed to be beamed FR I galaxies (Padovani & Urry 1990; Ghisellini et al. 1993). Since the number density of radio-loud FR I sources is nearly 1000 times larger than FSRQs and BL Lac objects, the possibility that such sources could form a new source class for future instruments like VERITAS (e.g. Weekes et al. 2000) or GLAST (e.g. Gehrels & Michelson 1999) is an exciting one. NGC 6251=3EG J1621+8203 and Cen A=3EG J1324-4314 could be examples of such sources. In fact, there exists the likelihood that such "misaligned blazars" could contribute to the extragalactic gamma-ray background around 1

MeV (Stienle et al. 1998; Sreekumar et al. 1999; Watanabe & Hartmann 2001). Gamma-ray sources not resolved by present-day detectors must contribute to the extragalactic gamma-ray background detected by EGRET in the 30 MeV to 100 GeV range. The contribution of misaligned blazars to the gamma-ray background has been calculated by Weferling & Schlickeiser (1999) where the authors modeled the EGRET-detected extragalactic gamma-ray background. The misaligned blazars clearly outnumber the aligned ones, but direct observation of these sources may only be possible in the future with more sensitive gamma-ray instruments.

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