Correlation between the $\gamma$-ray and the radio emissions

J.H. Fan and G. Adam
CRAL Observatoire de Lyon, 9, Avenue Charles Andr, 69 563 St-Genis-Laval Cedex, France

G.Z. Xie
Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011, China

S.L. Cao
Department of Astronomy, Beijing Normal University, Beijing, China

R.G. Lin
Center for Astrophysics, Guangzhou Normal University, Guangzhou 510400, China

Y. Copin
CRAL Observatoire de Lyon, 9, Avenue Charles Andr, 69 563 Saint-Genis-Laval Cedex, France

Received ___________________; accepted ___________________
ABSTRACT

In this paper, the correlation between the $\gamma$-ray and the radio bands is investigated. The results show that there is a closer correlation between the $\gamma$-ray emission and the high frequency (1.3mm, 230GHz) radio emission for maximum data than between the $\gamma$-ray and the lower frequency (5GHz) radio emissions, which means that the $\gamma$-ray is associated with the radio emission from the jet.

Subject headings: Active Galactic Nuclei (AGNs) – $\gamma$-ray emissions – Jets
1. Introduction

The most important result of the CGRO/EGRET instrument in the field of extragalactic astronomy is the discovery that blazars (i.e., flat-spectrum radio quasars—(FSRQs) and BL Lac objects) emit most of their bolometric luminosity in the high $\gamma$-ray ($E > 100$ MeV) energy range. Many of the $\gamma$-ray emitters are also superluminal radio sources (von Montigny et al. 1995). The common properties of these EGRET-detected AGNs are the following: The $\gamma$-ray flux is dominant over the flux in lower energy bands; The $\gamma$-ray luminosity above 100 MeV ranges from less than $3 \times 10^{44}$ erg/s to more than $10^{49}$ erg/s; Many of the sources are strongly variable in the $\gamma$-ray band on timescales from days to months, but large flux variability on short timescales of $<1$ day has also been detected (see 0716+714 for instance, Cappi et al. 1994) and the photon spectrum in the EGRET energy range (30 MeV to 30 GeV) are generally well represented by power laws with an average photon spectral index of 2.0.

Various models for $\gamma$-ray emission have been proposed: (1) the inverse Compton process on the external photons ($ECS$), in which the soft photons are directly from a nearby accretion disk (Dermer et al. 1992; Coppi et al. 1993) or from disk radiation reprocessed in some region of AGNs (e.g. broad emission line region) (Sikora et al. 1994; Blandford & Levinson 1995); (2) the synchrotron self-Compton model ($SSC$), in which the soft photons originate as synchrotron emission in the jet (Maraschi et al. 1992; Bloom & Maraschi 1992, 1993; Zdziarski & Krolik 1993); (3) synchrotron emission from ultrarelativistic electrons and positrons produced in a proton-induced cascade ($PIC$) (Mannheim & Biermann 1992; Mannheim 1993; Cheng & Ding 1994). From these models it is clear that the $\gamma$-ray emission is from the jet. Observations suggest that most of the objects in the EGRET sample show superluminal motion, which yields also strong evidence that the $\gamma$-ray radiation from these objects comes from the relativistic jets and is strongly beamed.
As the models indicate, there is no consensus yet on the dominant emission process (see 3C273 for instance, von Montigny et al. 1997). It is well known that the emission might imply various relations among wave bands that can be used to distinguish among a variety of emission mechanisms. Dondi & Ghisellini (1995) have studied the correlation between emission in the γ-ray and in the lower energy bands, and found that the γ-ray luminosity is more correlated with the radio luminosity than with other bands luminosities (e.g. optical and X-ray band); but Mücke et al. (1997) reported that there is no correlation between the γ-ray and the radio bands. Xie et al. (1997) found that the luminosity correlation between the γ-ray and the infrared band is closer than that between the γ-ray and the optical or the X-ray band. Fan (1997) has investigated the correlation between the γ-ray band and the lower energy bands by means of the multiple regression method. He found that there is an indication of a correlation between the γ-ray flux and the radio flux while there is no correlation between the γ-ray flux and the optical flux or between the γ-ray flux and the X-ray flux, and proposed that the γ-ray emission is from the SSC process and that the correlation between the γ-ray and the radio bands is probably due to the fact that both the γ-ray and the radio emissions are beamed. Observations show that there is a correlation between the γ-ray and radio bands (Valtaoja & Teräsranta 1995) although there is no simple one-to-one relation between them (Pohl et al. 1996; Mücke et al. 1996a). We think that the reason for these different results comes from the following factors: 1) Luminosity-luminosity correlation can not be considered as a true correlation because of the known fact that luminosity depends on redshift; 2) The lower frequency radio emission is not only from the jets and is variable; 3) The γ-ray emissions show large flux variation (von Montigny et al. 1995, see also Hartman 1996). These facts suggest that the correlation between the γ-ray and the radio bands is difficult to conclude. So, we will propose that it is necessary to use the high frequency radio data to investigate the association between the γ-ray and the radio band emissions. Here we will use the observed maximum data in
the γ-ray and radio bands, the sources are listed in table 1. In section 2, we give the data and the correlation between the γ-ray and the radio bands; In section 3, we give some discussion.

2. Correlation

2.1. Data

Blazars are known to be strongly variable in the γ-ray as well as in the radio band on time scales of days to months (von Montigny et al. 1995). Therefore, simultaneous observations should be adequate for a correlation analysis (Mücke et al. 1997). Unfortunately, there is scarcity of such simultaneous observations. So, we can only choose the observed maximum high frequency data in the radio band at 230GHz and the observed maximum data in the γ-ray band to investigate the correlation between the γ-ray and the radio emission. Radio data obtained after 1990 have been chosen because this corresponds to the operation period of EGRET.

In this paper, we discuss 44 γ-ray loud AGNs with available high frequency radio (230 GHz) flux densities (see Table 1). 35 are FSRQs (19 highly polarized quasars – HPQs with $P > 3\%$; 11 are lowerly polarized quasars–LPQs with $P < 3\%$; and 5 objects have no available polarization measurements); 9 of which are BL Lac objects and are marked with a †. Col.1 gives the name of the source; Col. 2, the redshift, Col.3, the observed maximum γ-ray photon in $10^{-7}$ photon/cm$^2$/s with the error, Col. 4, the spectral index; Col.5, reference for Col. 3 & 4; Col. 6, the radio flux in Jy at 5GHz; Col. 7, reference for Col. 6 (see also Comastri et al. 1997; Mücke et al. 1997); Col. 8 the observed maximum high frequency radio flux in Jy and the error, Col. 9 references for Col. 8. As in the paper of Comastri et al. (1997), the adopted γ-ray data of 1622-297 is not the peak
value of $(210\pm70)\times10^{-7}$ photon/cm$^2$/s (Mattox & Wagner 1996) but the data compiled by Mukherjee et al. (1997). It is found that the $\gamma$-ray spectrum tends to harden with increasing $\gamma$-ray flux for EGRET sources (Mücke et al. 1996b). A strong correlation has also been found for the spectral index and the integral flux above 100Mev for 3C273 (von Montigny et al. 1997). So, we chose the flat spectral index if there are more than one spectral index available for the sources considered in the paper.

2.2. Analysis Results

The observed photons are converted to flux densities at 1GeV. It is done as follows: If the photon density is expressed as $n(\nu) = n_0\nu^{-(\alpha_\gamma+1)}$, then the flux density can be expressed as $f_\nu = n(\nu)h\nu \propto n_0\nu^{-\alpha_\gamma}$. $n_0$ can be determined from the observation result ($N$ photon/cm$^2$/s), $N$ photon/cm$^2$/s should be equal to $\int_{100\text{MeV}} n(\nu)d\nu$. So, we obtained a formula to convert the observed photons to the flux densities at 1 GeV,

$$f_{1\text{GeV}}(pJy) = N_{(>100\text{MeV})}\alpha_\gamma 10^{(2-\alpha_\gamma)}$$

where $N_{(>100\text{MeV})}$ is in a unit of $10^{-7}$ photons/cm$^2$/s. The flux densities are k-corrected according to $f_\nu = f_\nu^{\alpha}(1+z)^{\alpha-1}$, where $\alpha$ is the spectral index at the frequency $\nu$ ($f_\nu \propto \nu^{-\alpha}$). The spectral index is set to 0.87 and 1.25 for BL Lac objects and FSRQ (Comastri et al. 1997) for which the $\gamma$-ray spectral index is unknown, and it is chosen to be 0.0, following Mücke et al. (1997) for radio band. For BL Lac object 0716+714, a lower limit of $z = 0.3$ has been adopted, and for 0446+112, a redshift of 1.0 has been used because the redshift is about 1.0 for most objects listed in the table. When the linear regression analysis is performed on the data, the following results are obtained:

$$log f_\gamma = (0.15 \pm 0.02)log f_{5\text{GHz}} + (1.49 \pm 0.001) \quad (1)$$
Table 1: A Sample of γ-Ray Loud AGNs with Available High Frequency Radio Data at 230 GHz.

| Name          | Redshift | $N_{\text{100MeV}}(\sigma)$ | $\alpha_\gamma$ | References | $f_{5\text{GHz}}$ | Ref | $f_{230\text{GHz}}(\sigma)$ | Reference |
|---------------|----------|-------------------------------|-----------------|------------|-----------------|-----|---------------------------|-----------|
| 0202+149      | 1.202    | 2.6(0.60)                     | 1.50            | F94        | 2.49            | K81 | 0.85(0.07)                | T96       |
| 0208-512      | 1.003    | 13.19(2.47)                   | 0.70            | T95,M97    | 3.31            | K81 | 2.60(0.21)                | T96       |
| 0234+285      | 1.213    | 2.91(1.13)                    | 1.70            | T95        | 2.36            | P82 | 2.66(0.30)                | S92       |
| 0235+164†     | 0.940    | 8.25(0.91)                    | 0.90            | T95        | 2.85            | S91 | 3.82(0.31)                | T96       |
| 0236-019      | 0.852    | 18.62(0.76)                   |                 | M97        | 2.84            | K81 | 1.35(0.12)                | T96       |
| 0240-014      | 0.915    | 5.12(1.05)                    | 0.90            | T95,M97    | 3.72            | P82 | 5.34(0.38)                | T96       |
| 0244-003      | 0.844    | 8.44(1.20)                    |                 | M97        | 3.17            | W85 | 0.78(0.07)                | S92       |
| 0246+112      | 1.13(2.06)| 0.80                         |                 | T95        | 1.22            | K81 | 1.39(0.12)                | T96       |
| 0245-234      | 1.009    | 1.40                          |                 | vM95       | 2.20            | L85 | 0.88(0.06)                | T96       |
| 0245-463      | 0.858    | 2.90                          | 0.90            | vM95       | 2.97            | K81 | 0.51(0.04)                | T96       |
| 0248-020      | 2.286    | 3.08(0.95)                    |                 | M97        | 2.04            | L85 | 0.92(0.10)                | T96       |
| 0250-612      | 1.093    | 0.60                          |                 | vM95       | 1.50            | K81 | 0.45(0.04)                | T96       |
| 0251-365      | 0.055    | 3.75(1.12)                    | 1.2             | T95,M97    | 9.70            | K81 | 3.98(0.32)                | T96       |
| 0258+134      | 2.070    | 30.76(3.46)                   | 1.30            | T95,M97    | 4.30            | P82 | 4.21(0.35)                | T96       |
| 0257-441†     | 0.894    | 8.98(1.45)                    | 1.00            | T95,M97    | 4.00            | S91 | 5.73(0.46)                | T96       |
| 0271+714†     | 4.40(1.1 )| 0.90                         |                 | T95,M97    | 1.12            | K81 | 3.03(0.31)                | S92       |
| 0275+178†     | 0.424    | 4.09(2.13)                    |                 | M97        | 3.65            | G94 | 0.92(0.11)                | T96       |
| 0281+243      | 0.939    | 6.81(1.44)                    | 1.30            | M97,F94    | 0.67            | B91 | 1.33(0.11)                | T96       |
| 0283+710      | 2.172    | 4.53(1.13)                    | 1.40            | T95        | 2.67            | P82 | 0.93(0.09)                | S93       |
| 0285+202†     | 0.306    | 2.90                          |                 | Sh96       | 2.70            | K81 | 2.50(0.26)                | T96       |
| 0290+430      | 0.670    | 3.20                          |                 | C97        | 1.80            | K81 | 0.40(0.04)                | S88       |
| 0294+658      | 0.368    | 1.43(0.40)                    | 0.90            | T95        | 1.46            | K81 | 0.54(0.05)                | S88       |
| 0297+645      | 1.187    | 9.27(2.29)                    | 1.15            | S96        | 7.46            | K81 | 1.22(0.09)                | T96       |
| 0315+295      | 0.729    | 22.86(5.48)                   | 1.0             | T95        | 1.65            | G94 | 0.83(0.08)                | T96       |
| 0317+285†     | 0.102    | 1.7                           | 0.40            | vM95       | 0.97            | G91 | 0.19(0.04)                | T96       |
| 0322+216      | 0.435    | 8.29(2.02)                    | 0.90            | T95        | 1.26            | G91 | 0.45(0.04)                | T96       |
| 0326-023      | 0.158    | 5.57(1.19)                    | 1.40            | T95,M97    | 4.59            | K81 | 26.19(1.89)               | T96       |
Table 2: A Sample of $\gamma$-Ray Loud AGNs with Available High Frequency Radio Data at 230 GHz.

| Name      | Redshift | $N_{(100MeV)}(\sigma)$ | $\alpha_\gamma$ | References | $f_{5GHz}$ | Ref | $f_{230GHz}(\sigma)$ | Reference |
|-----------|----------|-------------------------|------------------|------------|------------|-----|---------------------|-----------|
| 1229-021  | 1.045    | 1.41(0.41)              | 1.92             | S96,T95    | 1.10       | K81 | 0.18(0.03)          | T96       |
| 1253-055  | 0.538    | 28.70(1.09)             | 0.90             | T95        | 16.58      | K81 | 15.26(1.07)         | T96       |
| 1406-076  | 1.494    | 12.7 (2.34)             | 1.0              | M97,T95    | 0.5        | C97 | 0.76(0.06)          | T96       |
| 1510-089  | 0.361    | 4.83(1.80)              | 1.3              | T95        | 3.35       | K81 | 2.42(0.37)          | T96       |
| 1606+106  | 1.227    | 6.03(1.28)              | 1.20             | T95        | 1.78       | K81 | 0.64(0.30)          | T96       |
| 1622-297  | 0.815    | 24.56(3.18)             | 1.2              | M97        | 1.92       | K81 | 1.0                 | M96       |
| 1633+382  | 1.814    | 10.51(0.94)             | 0.90             | T95        | 4.08       | W85 | 1.4 (0.15)          | S96       |
| 1730-130  | 0.902    | 13.69(4.29)             | 1.39             | T95        | 6.90       | Gr94| 2.61(0.19)          | T96       |
| 1739+522  | 1.375    | 5.38(1.11)              | 1.2              | T95        | 1.98       | K81 | 0.56(0.09)          | S88       |
| 1741-038  | 1.054    | 3.40                    | 2.00             | vM95       | 3.72       | K81 | 1.43(0.12)          | T96       |
| 1933-400  | 0.966    | 9.66(3.3)               | 1.40             | T95        | 1.48       | K81 | 0.63(0.05)          | T96       |
| 2005-489† | 0.071    | 1.8                     | vM95             | C97        | 1.50       | C97 | 0.79(0.07)          | T96       |
| 2052-474  | 1.489    | 3.76(2.16)              | 1.40             | T95,M97    | 2.52       | K81 | 0.66(0.05)          | T96       |
| 2155-304† | 0.117    | 3.23(0.78)              | 0.71             | V95,M97    | 0.27       | L85 | 0.33(0.03)          | T96       |
| 2200+420† | 0.07     | 7.81(3.83)              | 1.21             | Ca97,M97   | 4.77       | K81 | 5.4 (0.6)           | S93       |
| 2230+114  | 1.037    | 4.90(1.4)               | 1.60             | L96,T95    | 4.10       | P82 | 2.28(0.16)          | T96       |
| 2251+158  | 0.859    | 13.17(2.07)             | 1.20             | L96,T95    | 23.30      | W85 | 10.80(0.87)         | T96       |

†: BL Lac object

References:

B91: Becker et al. (1991); Ca97: Catanese et al.(1997); C97: Comastri et al(1997); F94: Fichtel et al.(1994); G91: Gregory & Condon (1991); G94: Gear et al. (1994); Gr94: Griffith et al. (1994); K81: Kühr et al. (1981); L85: Ledden & O’Dell (1985); L96: Lin et al. (1996); M96: Mattox & Wagner (1996); M97: Mukherjee et al. (1997); P82: Perley (1982); S88: Steppe et al.(1988); S91: Stickel et al. (1991); S92: Steppe et al.(1992); S93: Steppe et al.(1993); S96: Sreekumar et al.(1996); Sh96: Shrader et al.(1996); T95: Thompson et al.(1995); T96: Tornikoski et al.(1996); V95: Vestrand et al.(1995); vM95: von Montigny et al.(1995); W85: Wall & Peacock (1985).
with a correlation coefficient of $r = 0.16$ and a possibility of the relationship having occurred by chance $p = 36\%$.

$$log f_\gamma = (0.28 \pm 0.01)log f_{230GHz} + (1.55 \pm 1.8 \times 10^{-4})$$

with $r = 0.347$ ($p = 1.7\%$), where $f_\gamma$ stands for the observed maximum $\gamma$-ray flux density in $\text{pJy}$, $f_{5GHz}$ and $f_{230GHz}$ stand for the observed radio flux density in Jy at 5 GHz and 230 GHz respectively. The results are shown in figure 1 and 2.

3. Discussion

Observations show that the $\gamma$-ray loud AGNs are clearly associated with compact, flat radio spectrum sources. These objects show evidence for superluminal motion (von Montigny et al. 1995). Schachter & Elvis (1993) reported that there is a correlation between the $\gamma$-ray and radio emission at 6cm (5GHz), but a negative result was reported by M"{u}cke et al. (1997). We think that the problem is from the facts mentioned in the introduction. For large $\gamma$-ray flares in blazars, they only occur when the sources are in a high state, and many blazars are detected only in a flare state (Hartman 1996; also see McHardy 1996). So, a $\gamma$-ray emitter is more easily detected when it is in a flare state. If the $\gamma$-ray emission is from the SSC model, there should be a correlation for the fluxes in the flare between the radio flux and the $\gamma$-ray flux. The $f_\gamma - f_{\text{radio}}$ correlation places an observational constraint on the $\gamma$-ray radiation mechanism and can be applied to test the radiation models of the emitting region. It is clear from section 2 that there is a correlation for the maximum fluxes between the $\gamma$-ray and the 230GHz bands, but the correlation between the $\gamma$-ray and the radio emission at 5 GHz is weaker.

It is well known that both the radio radiation of blazars and the $\gamma$-ray emission are
Fig. 1.— The diagram of γ-ray flux density in pJy against the radio flux density in Jy at 5 GHz
Fig. 2.— The diagram of γ-ray flux density in pJy against the radio flux density in Jy at 230 GHz, the solid line shows the best fit with 3C273 excluded.
strongly beamed, which means that there should be a correlation between the γ-ray and the radio data in the jets, and it is hard for us to get a good correlation between the γ-ray and the (5 GHz) radio band since the 5 GHz radio flux is not wholly from the jet. That may be why different results have been reported.

From the figures, we can see that 3C273 lays at bottom right, which suggests that the object was not in its flare state when it was observed. If we exclude this object, a better correlation: \( \log f_\gamma = (0.38 \pm 0.02) \log f_{230 \text{GHz}} + (1.57 \pm 4 \times 10^{-4}) \) with \( r = 0.421(p = 5.0 \times 10^{-3}) \) shows up (see the straight line in figure 2), which means that the γ-ray is associated with the high frequency radio emission or with the radio emission in the jets and suggests that the γ-ray emission is likely from the SSC process in this case. From the correlation, letting \( \alpha_\gamma = 1.0 \), we would expect that the flare value of 3C273 is about \( 20 \times 10^{-7} \text{photon/cm}^2/\text{s} \) in the \( E > 100\text{MeV} \) band.

The association between the γ-ray and the radio bands has been further investigated. Recently, Valtaoja & Teräsranta (1995) found a correlation between the initial phase of a mm-wavelength outburst and the EGRET γ-ray flaring phase of high optically polarized quasars. Our results is consistent with theirs.

There is a correlation for the maximum data between the γ-ray and the high frequency radio emissions, which suggests that the high frequency radio emission (or radio emission in the jet) is very important for γ-ray emission.

The authors thank the anonymous referee for his/her comments and the detail annotations! This work is supported by the National Scientific Foundation of China (the ninth five-year important project) and the National Pandeng Project of China. JHF thanks Dr. M. Tornikoski for providing their radio data.
REFERENCES

Becker R.H., White R.L., Edwards A.L., 1991, ApJS 71, 1

Blandford R.D., Levinson A. 1995, ApJ 441, 79

Bloom S.D., Maraschi A.P. 1992 in the Compton Observatory Science Workshop, ed C.R. Shrader, N. Gehrels, B. Dennis, p339

Bloom S.D., Maraschi A.P. 1993 in AIP conf; Proc. 280, Proc. Compton Symp. ed. M. Friedlander, N. Gehrels, D.J. Macomb, p578

Cappi M., Comastri A., Molendi S. et al. 1994, MNRAS 271, 438

Catanese M., Akerlof C.W., Biller S.D., et al. 1997, ApJ 480, 562

Cheng K.S., Ding W.K.Y. 1994, A&A 288, 97

Comastri A., Fossati G., Ghisellini G., Molendi S. 1997, ApJ 480, 534

Coppi P.S., Kartje J.F., Königl A. 1993, in AIP conf; Proc. 280, Proc. Compton Symp. ed. M. Friedlander, N. Gehrels, D.J. Macomb, p559

Dermer C.D., Schlickeiser R., Mastichiadis A. 1992, A&A 256, L27

Dondi L., Ghisellini G. 1995, MNRAS 273, 583

Fan J.H. 1997, Ap&SS 246, 119

Fichtel C.E., Bertsch D.L., Chiang J. et al. 1994, ApJS 94, 551

Gear W.K., Stevens J.A., Hughes D.H. et al. 1994, MNRAS 267, 167

Gregory P.C., Condon J.J., 1991, ApJS 75, 1011.

Griffith M.R., Wright A.E., Burke B.F., Ekers R.D. 1994, ApJS 91, 111
Hartman R.C. 1996, ASP Conf. Ser. 110, p33
Kühr H., Witzel A., Pauliny-Toth I.I.K., Nauber U. 1981, A&AS 45, 367
Ledden J.E., O'Dell S.L. 1985, ApJ 298, 630
Lin Y.C., Bertsch D.L., Dingus B.L. et al. 1996, ApJS 105, 331
Mannheim K., 1993, Phy. Rev. D48, 2408
Mannheim K., Biermann P.L. 1992, A&A 253, L21
Maraschi L., Ghisellini G., Celotti A. 1992, ApJ 397, L5
Mattox J.R., Wagner S.J. 1996, ASP Conf. Ser. Vol. 110, p352.
McHardy I. 1996 ASP Conf. Ser. 110, p293
Mücke A., Pohl M., Reich P. et al. 1997, A&A 320, 33
Mücke A., Pohl M., Reich P. et al. 1996a, A&AS 120, 541
Mücke A., Pohl M., Kanbach G., et al. 1996b, IAU Symp 175. eds R. Ekers, C. Fanti, L. Padrielli, p285
Mukherjee R., Bertsch D.L., Bloom S.D. et al. 1997, ApJ 490, 116
Perley R.A., 1982, AJ 87, 859
Pohl M., Reich W., Schlickeiser R., et al. 1996, A&AS 120, 529
Schachter J., Elvis M., 1993, ApJS 92, 623
Shrader C.R., Hartman R.C., Webb J.R. 1996, A&AS 120, 559
Sikora M., Begelman M.C., Rees M.J. 1994, ApJ 421, 153.
Sreekumar P., Bertsch, D.L., Dingus, B.L., et al. 1996, ApJ 464, 628

Steppe H., Paubert G., Sievers A. et al. 1993, A&AS 102, 611

Steppe H., Liechti S., Mauersberger R. et al. 1992, A&AS 96, 441

Steppe H., Salter C.J., Chini R. et al. 1988, A&AS 75, 317

Stickel M., Padovani P., Urry C.M., et al. 1991, ApJ 374, 431

Thompson D.J., Bertsch D.L., Dingus B.L. et al. 1995, ApJS 101, 259

Tornikoski M., Valtaoja E., Teräsranta H. et al. 1996, A&AS 116, 157

Valtaoja E., Teräsranta H., 1995, A&A 297, L13

Vestrand W.T., Stacy J.G., Sreekumar P., 1995, ApJ 454, L93

von Montigny C., Aller H, Aller M. et al. 1997, ApJ 483, 161

von Montigny C., Bertsch D.L., Chiang J. et al. 1995, ApJ 440, 525

Wall J.V., Peacock J.A. 1985, MNRAS 216, 173

Xie G.Z., Zhang Y.H., Fan J.H. 1997, ApJ 477, 114

Zdziarski A.A., Krolik J.H., 1993, ApJ 409, L33

\hline

This manuscript was prepared with the AAS \texttt{\LaTeX} macros v4.0.