ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

FEBRUARY **1995**, PAGE 267

Astron. Astrophys. Suppl. Ser. **109,** 267-291 (1995)

Radio to X-ray energy distribution of BL Lacertae objects*

P. Giommi, S.G. Ansari and A. Micol

ESIS, Information Systems Division of ESA, ESRIN, Via G. Galilei, I-00044 Frascati, Italy

Received January 18; Accepted July 25, 1994

Abstract. — We present multifrequency spectra of a large number of radio and X-ray selected BL Lacertae objects constructed using non-simultaneous archival data. The data were obtained using the European Space Information System (ESIS) and are from several radio and optical catalogues, the IRAS Faint Source Catalogue, the *Einstein* and the EXOSAT databases. The sample includes 121 BL Lacs that have been extracted from the 1Jy and the S4 radio surveys (Stickel et al. 1991; Stickel & Kühr 1994), the *Einstein* IPC Slew Survey, the *Einstein* Extended Medium Sensitivity Survey (EMSS), the EXOSAT High Galactic Latitude Survey, and from the compilations of Giommi et al. (1990), and Veron & Veron (1993). We find that the shape of the radio to infra-red spectrum of Radio Selected and X-ray Selected BL Lacs is very similar. The difference between these two classes of objects is instead evident in the optical/X-ray part of the spectrum. The classical radio discovered BL Lacs are characterized by an energy spectrum with a sharp cutoff in the IR/optical band while in most of the X-ray discovered objects the turnover is located near the UV/X-ray band or at higher frequencies. For a given X-ray flux this diversity can give rise to radio fluxes different by a factor of 100 or more. We argue that BL Lac objects may be a single population of sources characterized by a wide range of energy cutoffs. In this scenario BL Lacs discovered in radio surveys are representative of the entire population, while objects characterized by an energy break near the X-ray band, which are abundantly detected at X-ray frequencies, are intrinsically a small minority.

Key words: BL Lacertae objects: general — radio continuum: galaxies — X-ray: galaxies

1. Introduction

BL Lac Objects are a class of rare AGN characterized by rapid variability at all frequencies, high radio and optical polarization and by the absence of emission lines in the optical spectrum. Their overall energy distribution shows a smooth continuum over a wide part of the electromagnetic spectrum, probably due to Synchrotron emission, followed by Compton emission at higher energies (Bregman et al. 1990; Kawai et al. 1991). The unusual and sometimes extreme characteristics of these sources are often explained in the framework of a relativistic beaming scenario (Padovani & Urry 1990; Ghisellini et al. 1993). BL Lacs have been mainly discovered in radio and X-ray surveys. Very few objects of this kind have so far been found at other frequencies (Impey & Brand 1982; Borra & Corriveau 1984; Jannuzi et al. 1993). It has often been reported that BL Lacs discovered in the radio band show higher optical variability and polarization than those discovered at X-ray frequencies. This has led to the subdivision of the class of BL Lacertae objects into two subclasses: RBL for radio-selected BL Lacs and XBL for X-ray selected BL Lacs (Stocke et al. 1990; Giommi et al. 1991).

All known BL Lacs (including XBLs) have been detected at radio frequencies. Stocke et al. (1990) reported that radio quiet BL Lacs, if they exist at all, must be a very small fraction of all BL Lacs or they must also be X-ray quiet. Jannuzi, Green and French (1993) reached the same conclusion from the results of a polarization survey in the optical band. This constant presence of radio emission is a striking difference with respect to the class of QSOs, 90% of which are radio quiet.

Well defined, flux limited samples of both subclasses have recently become available (Stocke et al. 1991; Stickel et al. 1991, Stickel & Kühr 1994). It is generally concluded that XBL greatly outnumber RBL of the same X-ray luminosity and that the two classes are characterized by different cosmological evolution (Maraschi et al. 1986, Morris et al. 1991; Stickel et al. 1991; Wolter et al. 1994).

In this paper we present radio-to-X-ray energy distribution of a large number of BL Lacertae objects and we study the differences between RBLs and XBLs from the viewpoint of their energy distribution.

The data used to construct the energy distributions are not simultaneous and have been taken from several catalogues and databases. All data have been retrieved

*Table 5 is only available electronically at the CDS via anonymous ftp 130.79.128.5

and combined into multifrequency spectra using the ESIS system (Giommi & Ansari 1993).

2. The samples

We have considered four samples including most of the BL Lacs presently known and representing different selection methods:

a) A sample of radio-selected BL Lacs taken from the 1Jy sample of Stickel et al. (1991), and from the S4 survey (Stickel & Kühr 1994) including 39 objects (see Table 1).
b) A sample of purely X-ray selected objects from the *Einstein* IPC Slew Survey (Elvis et al. 1992; Schachter et al. 1993) including 44 sources (see Table 2). This sample is not complete since many Slew Survey sources are still unidentified.
c) A sample of BL Lacs serendipitously detected in X-ray images from the *Einstein* Extended Medium Sensitivity Survey (Gioia et al. 1990; Stocke et al. 1991, 34 sources) and from the EXOSAT HGLS (Giommi et al. 1991, 11 sources) (see Table 3).
d) A compilation of well known BL Lacs from Giommi et al. (1990) and from Veron & Veron (1993) including 12 sources (see Table 4).

The tables are structured as follows Cols. 1 and 2 give the source name, and alternate name(s), Cols. 3 and 4 give the Right Ascension and Declination (J2000), and Col. 5 gives references to papers containing more detailed information.

The selection method of samples b) and c) are similar; the main difference is that while in pure X-ray surveys all kinds of BL Lacs can in principle be found, the serendipitous sample by definition excludes most of the well known objects since a large fraction of these sources were selected as targets of the X-ray observations. Some objects have been detected both in radio and X-ray surveys and therefore appear in more than one sample. Samples b) and c) also have a number of common objects.

The samples include a total of 121 distinct objects, or about 80% of all BL Lacs presently known.

3. The data

To construct the radio to X-ray energy distribution ($\nu f(\nu)$ vs ν) of all objects in our samples we have used archival data from several catalogues and databases and we have converted all fluxes to erg cm^{-2} s^{-1} according to the procedure described below.

The Radio and IR fluxes are directly available in Jansky and have been plotted after a simple unit conversion. The *UBV* colours were converted to monochromatic flux using the following formulae as adopted from Wills & Lynds (1978):

$$f_{3650\,\text{Å}}(\text{erg cm}^{-2}\ \text{s}^{-1}\ \text{Hz}^{-1}) = 10^{[-0.4(-0.2/\sin(|bII|)+m_U)-19.734]}$$
$$f_{4400\,\text{Å}}(\text{erg cm}^{-2}\ \text{s}^{-1}\ \text{Hz}^{-1}) = 10^{[-0.4(-0.2/\sin(|bII|)+m_B)-19.377]}$$
$$f_{5500\,\text{Å}}(\text{erg cm}^{-2}\ \text{s}^{-1}\ \text{Hz}^{-1}) = 10^{[-0.4(-0.2/\sin(|bII|)+m_V)-19.414]}$$

where bII is the galactic latitude of the object considered.

X-ray data were converted to monochromatic flux assuming a power law spectrum with energy index of 1.0 and no intrinsic absorption.

The radio data have been taken from the following catalogues: Veron & Veron (1993), the 6 cm survey of Condon et al. (1989), (Becker et al. 1991) the 20 cm survey (White & Becker 1992), the Dixon (1976) and the Parkes catalogue (Bolton et al. 1979). The IR data are from the IRAS Faint Source Survey (Moshir 1991). Optical data are from Veron & Veron (1993) and from the EMSS (Stocke et al. 1991), the IPC Slew Survey (Elvis et al. 1992; Schachter et al. 1993) and the HGLS (Giommi et al. 1991). The X-ray data are from the EMSS, the IPC Slew Survey, the HGLS and from the *Einstein* and the EXOSAT databases. *Einstein* data are from the IPC instrument and the EXOSAT data are from the CMA instrument in conjunction with the Lexan, Al/Par and Boron filters (when available).

All multi-frequency data are reported in table 5[1] where the 121 BL Lacs are listed in order of right ascension. Column 1 gives the source name, Cols. 2 and 5 give the frequency; Cols. 3 and 6 give the flux[2] in units of erg cm^{-2} s^{-1}; Cols. 4 and 7 give the reference where the original flux (or count rate) can be found.

Figures 1.1 to 1.39, 2.1 to 2.44, and 3.1 to 3.45, show the energy distributions ($\nu f(\nu)$ vs ν) of all the objects in the radio-selected (1Jy and S4 surveys), X-ray selected (Slew Survey) and the X-ray serendipitous (EMSS and HGLS) samples respectively. Figures 4.1 to 4.12 show the energy distribution of the objects in the miscellaneous sample. These last BL Lacs have been discovered mostly at radio frequencies. Their energy distribution is therefore similar to that of the objects shown in Figs. 1.1 to 1.39. Error bars are not plotted but in most cases their size is of the order of the size of the symbols or smaller.

The data shown in Figs. 1-4 are not simultaneous, so time variability, that is one of the defining characteristics of BL Lacs, can influence the overall shape of the spectrum increasing the scatter. The large dynamical range (usually

[1]Table 5 is only available in electronic form. It can be obtained via anonymous ftp from CDS (cdsarc.u-strasbg.fr 130.79.128.5).

[2]In the X-ray band, where the measurements are often near the instruments sensitivity limit, we also give the statistical error.

a factor of $10^3 - 10^4$) reduces the effect of time variability to a relatively small perturbation so that the general shape of the spectral distribution can still be recognized. In the X-ray band, however, flux variability can be of the order of a factor ten or more, and can play an important role.

Inspection of the figures shows that the energy distribution of the majority of BL Lacs is remarkably smooth over a large portion of the electromagnetic spectrum, except for large amplitude variability that is often visible in the high-energy data.

The multifrequency spectra are characterized by a smooth rise in the radio band which continues at least to the IR band, followed by a sharp cutoff that can occur in the IR/optical band or at higher frequencies. From Fig. 1.1 to 1.39 we see that the large majority of the RBLs show a cutoff in the IR-optical band, but in 3 sources (namely, S4 1101+364 (MKN 421), S4 1652+398 (MKN 501), PKS 2005-489) the spectrum continues to rise to higher energies. We therefore conclude that break energies in the UV or X-ray band are rare in the radio counts and occur with a frequency of $\approx 8 - 10\%$. A similar conclusion was reached by Ledden & O'Dell (1985) from the analysis of the $\alpha_{\rm ox}$, $\alpha_{\rm ro}$ and $\alpha_{\rm rx}$ distributions of smaller and non homogeneous samples of BL Lacs. Those sources in our radio sample for which no X-ray data are available are not expected to have a distribution that continues to high energies without a break. This is because in this case their X-ray flux would be of the order 10^{-11} erg cm^{-2} s^{-1} or higher and they would have been easily detected in the Slew Survey.

Since selection in the radio band is not expected to influence the position of the spectral turnover, the radio counts can be considered as an unbiased representation of the entire BL Lac population, unless the distribution of break energies depends on redshift or luminosity.

The energy distribution of the objects in the Slew Survey sample (Figs. 2.1-2.44) is similar to that of the radio selected sample between the radio and the optical band. Continuous rise up to UV/X-ray energies is much more common than among radio selected objects. The serendipitously selected BL Lacs (Figs. 3.1-3.45) almost invariably show a continuous rise from radio to X-ray energies. Spectral turnovers are rarely seen and when present they are between the optical and UV band.

4. Discussion

Our study shows that the energy distribution of radio selected BL Lacs is characterised by a smooth rise between the radio and the IR band followed by a cutoff that is very often located IR/optical frequencies. In a small fraction of the cases ($\approx 10\%$) the cutoff is located at higher frequencies. BL Lacs discovered in the X-ray band are instead characterized by a turnover that is very often located in the UV/X-Ray energy band.

Figures 5a and 5b show the energy distributions of a typical RBL (B2 1308+326) and of a typical XBL (1H 1426+428) with superposed a weighted parabola fit to the data (solid line). Note that these curves are only meant to be a description of the overall energy distribution and do not necessarily fit the observed spectrum in every energy band. In particular the X-ray spectral slope of RBLs can be much harder than that shown in Fig. 5a because of the appearance of the Compton component at high energies. Figure 6 shows the two curves of Figs. 5a and 5b scaled so that fluxes in the soft X-ray band are approximately equal. From this figure we can clearly see that for similar X-ray fluxes XBLs can be more than 2 orders of magnitude fainter than RBLs in the radio, IR and optical bands.

Since energy breaks in the IR/Optical part of the spectrum are very frequent and since the radio part of the energy distribution is very similar in all BL Lacs, selection at radio frequencies will mainly select objects with break at low energies. Conversely, because of the strong X-ray flux compared to the radio emission in XBLs (see Fig. 6), selection in the X-ray band strongly favours objects with break at high energies.

If we assume that the frequency of occurrence of breaks at low and high energy observed in the radio counts applies to all radio luminosities, our results are consistent with a scenario where BL Lacs are a single population of objects with similar radio to IR energy distribution (where the synchrotron emission dominates) and with a wide range of break energies at higher frequencies. In this scenario XBLs are those rare BL Lacs where the spectral break is at sufficiently high energy so that the X-ray flux is above the survey flux limit.

To support this hypothesis we perform the following simple calculation. The radio number counts estimated by Stickel et al. (1991) give $N(> 1\rm{Jy}) = 1\ 10^{-3}$ deg^{-2}. The typical radio flux of a XBL with X-ray flux of $\approx 5\ 10^{-13} - 1\ 10^{-12}$ erg cm^{-2} s^{-1} is of the order of 10 mJy. The number of radio selected BL Lacs at this flux limit is expected to be $N(S > 10$ mJy$)=1\ 10^{-3}$ (1000 mJy/10 mJy)$^{1.5} = 1.0$ deg^{-2} (if the Euclidean slope extends to ≈ 10 mJy). Assuming that only 10% of these objects possess a cutoff at sufficiently high energy so that their X-ray flux is above the EMSS threshold, then the density of XBLs in the EMSS should be ≈ 0.1 deg^{-2}. This value is very close to what has been observed (e.g. Maccacaro et al. 1989; Giommi et al. 1989). The above derivation requires an extrapolation of the radio Log$N$-Log$S$ of two orders of magnitude and can only be considered an *order of magnitude* estimate. Detailed calculations that take into account the radio luminosity function of RBLs estimated from the 1Jy sample have been performed by Giommi & Padovani (1994). These authors show that the X-ray number counts predicted from the radio counts under the hypothesis presented in this paper are in very good agreement with the experimental data.

The difference between RBL and XBL is often illustrated by means of the α_{ox} vs α_{ro} diagram (see Fig. 7) where XBLs (open circles) populate a different part of the $\alpha_{ox} - \alpha_{ro}$ plane than RBLs (filled circles) and all other types of AGN. This property was recently used as the basis of an efficient method for discovering new XBLs (Stocke et al. 1993; Schachter et al. 1993). The α_{ox} vs α_{ro} diagram is a crude way of showing the energy distribution from radio to the X-ray band so this plot must reflect the differences that are apparent in Fig. 1 to Fig. 4 of this paper. The main difference between RBLs and XBLs is the position of the energy cutoff, which is however always located after the IR band. Therefore if we plot α_{r-ir} instead of plotting α_{ro} XBLs and RBLs should populate similar areas of the α_{ox} vs α_{r-ir} plane. In Fig. 8 we plot all RBLs for which IRAS data (from the faint source catalogue) at 60 μ are available (13 objects). These sources are represented by filled circles when α_{ro} is used and as stars when $\alpha_{r-ir(60\mu)}$ is considered. When we use $\alpha_{r-ir(60\mu)}$ all points collapse to a region very similar to that populated by XBLs and the striking difference between XBLs and RBLs disappears.

Analyses of the available samples of BL Lacs has led to the conclusion that XBLs largely outnumber RBLs of the same X-ray luminosity (Maraschi et al. 1986; Urry, Padovani and Stickel 1991). This has been interpreted in the framework of relativistic jet models as the effect of a different opening angle of the radio and X-ray beams. (Ghisellini & Maraschi 1989, Urry et al. 1991; Celotti et al. 1993). The evidence presented in this paper, supports an alternative explanation where BL Lacs selected at radio frequencies are representative of the whole BL Lac population, while objects characterized by an energy distribution that continues to high energies, which are mainly discovered in the X-ray band, only make up a small fraction of the total.

There are several observed differences between RBLs and XBLs (luminosity variability, optical polarization, cosmological evolution etc.) that need to be studied to verify the consistency with the hypothesis presented in this paper. These issues are addressed in Giommi & Padovani (1994), and Padovani & Giommi (1995).

The statistical properties of the X-ray selected objects are expected to be the same as those of Radio selected BL lacs only if the fraction of objects detected in the X-ray band share the same basic characteristics of the remaining 90% of the population. The observed different properties of XBLs and RBLs could be the direct consequence of such a potential difference. Other causes, such as incompleteness due to difficulties in identifying new BL Lacs as described in Browne & Marchã (1993), can contribute to explain the differences between the statistical properties of RBLs and XBLs, especially if the XBLs are from high sensitivity surveys.

References

Becker R.H., White R.L., Edwards A.L. 1991, ApJS 75, 1
Bregman J.N. et al. 1990, ApJ 382, 508
Bolton J.G., Savage A., Wright A.E. 1979, Austral. J. Phys. Suppl. 46, 1
Borra E. F., Corriveau G., 1984, ApJ 276, 15
Browne I.W., Marchã, M.J.M. 1993, MNRAS 261, 795
Condon J.J, Broderick J.J., Seielstad G.A 1989, AJ 97, 1064
Dixon R.S. 1976, Proc. IAU Coll. 35, 167
Elvis M., Plummer D., Schachter J., Fabbiano G. 1992, ApJS 80, 257
Ghisellini G., Maraschi L. 1989, ApJ 340, 181
Ghisellini G., Padovani P., Celotti A., Maraschi L. 1993, ApJ 407, 65
Gioia I.M., Maccacaro T., Schild R.E. et al. 1990, ApJS 72, 567
Giommi P. et al. 1989, in "BL Lac Objects", eds. L. Maraschi, T. Maccacaro and M.-H. Ulrich (Springer-Verlag) 231
Giommi P., Barr P., Garilli B., Maccagni D., Pollock A.M.T. 1990, ApJ 356, 432
Giommi P. et al. 1991, ApJ 378, 77
Giommi P., Ansari S.G. 1993, Proceedings of the 3rd ADASS Conference, Victoria, Canada, in press
Giommi P., Padovani P. 1994, MNRAS 268, L51
Impey C.D., Brand P. 1982, MNRAS 201, 849
Jannuzi B., Green R., French H. 1993, ApJ 404, 100
Kawai N. et al. 1991, ApJ 382, 508
Ledden J.E., O'Dell S.L. 1985, ApJ 298, 630
Maccacaro T., Gioia I.M., Schild R.E. et al. 1989, in "BL Lac Objects", eds. L. Maraschi, T. Maccacaro and M.-H. Ulrich (Springer-Verlag) 222
Maraschi L., Ghisellini G., Tanzi E., Treves A. 1986, ApJ 310, 325
Moshir M. 1991, British Interplanet. Soc. J. 44, 495
Morris S.L, Stocke J.T., Gioia I.M. et al. 1991, APJ 380, 49
Padovani P., Urry C.M. 1990, ApJ 356, 75
Padovani P., Giommi P. 1995, ApJ, in press
Schachter J.F. et al. 1993, ApJ 412, 541
Stickel M., Fried J.W., Kühr H., Padovani P., Urry C.M. 1991, ApJ 374, 431
Stickel M., Kühr H. 1994, A&AS 103, 349
Stocke J.T., Morris S.L., Gioia I.M, Maccacaro T., Schild R.E., Wolter A. 1990, ApJ 348, 141
Stocke J.T., Morris S.L., Gioia I.M et al. 1991, ApJS 76, 813
Stocke J. T., Perlman E., Granados A. et al. 1993, In NASA. Ames Research Center, The Evolution of Galaxies and Their Environment, 311-312
Veron-Cetty M.P., Veron P. 1993, ESO Scientific Report No. 13
Urry C.M., Padovani P., Stickel M. 1991, ApJ 382, 501
Wills D., Lynds R. 1978 ApJS 36, 317
White R.L., Becker R.H., 1992, ApJS 79, 331
Wolter A., Gioia I.M., Maccacaro T., Morris S.L., Stocke J.T. 1991, ApJ 369, 314
Wolter A., Caccianiga A., Della Ceca R., Maccacaro T. 1994, ApJ, in press

Table 1. Radio selected BL Lacs 1Jy and S4 surveys

Source name	Other Name(s)	R.A. (2000.0)	Dec. (2000.0)	Ref
PKS 0048-097	OB -081,MC3 0048-097	00 50 41.3	-09 29 05	2,4
PKS 0118-272	OC -230.4	01 20 31.5	-27 01 24	2,4
PKS 0138-097	OC -065	01 41 25.7	-09 28 42	2,4
S4 0218+357		02 21 05.4	35 56 15	3,4
AO 0235+164	PKS 0235+164,OD 160	02 38 38.8	16 36 59	1,2,4
PKS 0426-380		04 28 40.4	-37 56 19	2,4
S5 0454+844		05 08 42.8	84 32 04	2,4
PKS 0537-441	IRAS 0537-441	05 38 50.2	-44 05 09	2,4
S5 0716+714		07 21 53.3	71 20 36	2,4
PKS 0735+178	OI 158, VRO 17.07.02	07 38 07.3	17 42 18	1,2,4
S4 0749+540	4C+54.15	07 53 00.9	53 53 00	3,4
S4 0814+425	OJ 425	08 18 16.1	42 22 45	2,3,4
PKS 0820+225	4C 22.21	08 23 24.8	22 23 03	2,4
PKS 0823+033	OJ 038	08 25 50.2	03 09 24	2,4
S4 0828+493	OJ 448, BP 077	08 32 23.2	49 13 20	2,3,4
OJ 287	PKS 0851+203, B2 0852+20	08 54 48.8	20 06 30	1,2,4
S4 0954+658		09 58 47.2	65 33 53	2,3,4
S4 1101+364	MKN 421	11 04 27.2	38 12 31	3,4
PKS 1144-379	MC 1144-379	11 47 01.3	-38 12 11	2,4
B2 1147+245	OM 280	11 50 19.1	24 17 53	1,2,4
B2 1308+326	AU CVn, OP 313	13 10 28.6	32 20 43	1,2,4
S4 1418+546	OQ 530, B2 1418+546	14 19 46.5	54 23 13	1,2,3,4
AP Lib	PKS 1514-241, OK 225	15 17 41.7	-24 22 19	1,2,4
PKS 1519-273	EQ 1519-273	15 22 37.6	-27 30 10	2,4
4C 14.60	PKS 1538+149	15 40 49.4	14 47 45	1,2,4
S4 1652+398	MKN 501, 4C 39.49	16 53 52.1	39 45 36	1,2,3,4
S4 1738+476	OT 465	17 39 57.0	47 37 58	3,4
S4 1749+701		17 48 32.9	70 05 50	2,3,4
PKS 1749+096	4C 09.57, OT 081	17 51 32.7	09 39 01	2,4
S5 1803+784	IRAS 1803+784	18 00 45.4	78 28 04	1,2,4
S4 1807+698	3C 371, 1H 1807+698, VII Zw 768	18 06 50.5	69 49 28	1,2,3,4
S4 1823+568	4C 56.27	18 24 06.8	56 51 01	2,3,4
S4 1926+611		19 27 30.4	61 17 32	3,4
S5 2007+777		20 05 30.8	77 52 43	2,4
PKS 2005-489	EQ 2005-489	20 09 25.3	-48 49 53	1,2,4
PKS 2131-021	4C -02.81	21 34 10.2	-01 53 17	2,4
S4 2200+420	BL Lac, PKS 2200+420, OY401	22 02 43.2	42 16 40	1,2,3,4
PKS 2240-260	OY -268	22 43 26.3	-25 44 30	2,4
PKS 2254+074	OY 091, MG 2257+0743	22 57 17.2	07 43 12	2,4

References- 1. Giommi et al. 1990 2. Stickel et al. 1991 3. Stickel & Kühr 1994 4. Veron & Veron 1993

Table 2. X-ray selected BL Lacs from the *Einstein* IPC Slew Survey

Source name	Other Name(s)	R.A. (2000.0)	Dec. (2000.0)	Ref
MS0158.5+0019	1E0158+0019	02 01 05.9	00 33 57	1,2,8
3C66A	PKS 0219+428	02 22 39.6	43 02 05	1,3,8
1ES0229+200		02 32 48.6	20 17 17	5
AO 0235+164		02 38 40.2	16 37 10	1,3,6,8
H 0323+022		03 26 14.8	02 25 04	1,3,8
1ES0347-121		03 49 23.2	-11 59 27	5
H 0414+009		04 16 53.7	01 04 56	1,3,8
1ES0502+675		05 07 56.2	67 37 24	5
EXO0507.1-0404		05 09 44.1	-04 01 08	1,4
PKS0548-322		05 50 41.5	-32 16 09	1,3,8
1ES0647+250		06 50 46.5	25 03 00	5
PKS0735+178	OI 158, VRO 17.07.02	07 38 05.2	17 42 03	1,3,6,8
MS0737.9+7441	1E0737+7441	07 43 59.5	74 33 50	1,2,8
1ES0806+524		08 09 49.2	52 18 58	5
OJ 287	PKS 0851+203, B2 0852+20	08 54 48.6	20 06 39	1,3,6,8
MS0950.9+4929		09 54 06.8	49 15 57	1,2,8
GB1011+496		10 15 00.8	49 26 11	1,8
1ES1028+511		10 31 18.5	50 53 36	5
1ES1101-232	H1101-232	11 03 36.5	-23 28 18	1,8
MKN 421	PKS 1101+384, OM 303	11 04 28.7	38 12 14	1,8
1ES1118+424	EXO 1118.0+4228	11 20 45.4	42 12 24	1,4
MKN 180	PKS 1133+704, VII ZW 412	11 36 18.1	70 09 37	1,3,8
ON 325	PKS 1215+303, B2 1215+303	12 17 50.9	30 05 54	1,3,8
2A1215+303	3A1218+303, 2A1219+305	12 21 20.3	30 10 33	1,3,8
ON231	W Com, B2 1219+285	12 21 27.5	28 14 00	1,8
B2 1308+326	AU CVn, OP 313	13 10 28.0	32 20 49	1,3,6,8
MS1312.1-4221	1E1312-4221	13 15 01.0	-42 36 24	1,2,8
MS1402.3+0416	1E14023+042	14 04 47.2	04 02 05	1,2,3,8
H 1426+428		14 28 34.5	42 40 19	1,3,8
1ES1440+122		14 42 48.3	12 00 40	5
1ES1517+656		15 17 49.3	65 25 33	1
1ES1544+820		15 40 15.7	81 55 06	5
MS1552.1+2020	1E1552+2020	15 54 26.7	20 11 35	2,8
PG 1553+11		15 55 41.3	11 11 38	1,8
MKN 501	1H 1652+398, 4C 39.49	16 53 52.4	39 45 36	1,3,6,8
H 1722+119	4U 1722+11	17 25 02.8	11 51 52	1,3,8
IZW186	OT 546, PKS 1727+50	17 28 19.2	50 12 53	1,3,8
3C 371	1H 1807+698, VII Zw 768, 4C 69.24	18 06 43.0	69 49 17	1,3,6,8
1ES1959+650		19 59 59.9	65 08 55	5
PKS2005-489		20 09 25.7	-48 49 55	1,3,6,8
PKS2155-304		21 58 51.6	-30 13 25	1,3,8
BL Lac	PKS 2200+420, OY401	22 02 43.8	42 16 18	1,3,6,8
3C446	PKS 2223-052, OY-039	22 25 45.1	-04 56 34	1,3,8
1ES 2343-151		23 45 38.4	-14 49 29	5

References- 1. Elvis at al. 1992 2. Gioia et al. 1990 3. Giommi et al. 1990 4. Giommi et al. 1991 5. Schachter et al. 1993 6. Stickel et al. 1991 7. Stocke et al. 1991 8. Veron & Veron 1993

Table 3. Serendipitous X-ray BL Lacs *Einstein* EMSS and EXOSAT HGLS

Source name	Other Name(s)	R.A. (2000.0)	Dec. (2000.0)	Ref
EXO0044.4+2001		00 47 08	20 17 44	3
MS0122.1+0903		01 24 44	09 19 01	2,4
MS0158.5+0019		02 01 06	00 34 26	2,4
MS0205.7+3509		02 08 40	35 23 22	2,4
MS0257.9+3429		03 01 01	34 41 25	2,4
MS0317.0+1834		03 19 51	18 45 36	2,3,4
MS0331.3-3629		03 33 14	-36 19 47	2,4
MS0350.0-3712		03 51 53	-37 03 46	2,4
MS0419.3+1943		04 22 18	19 50 53	2,4
EXO0507.1-0404		05 09 39	-04 00 35	3
EXO0556.4-3838	3A0557-38	05 58 05	-38 38 28	3
MS0607.9+7108		06 13 43	71 07 41	2,4
EXO0706.1+5913		07 10 28	59 08 17	3
MS0737.9+7441		07 44 08	74 33 59	2,4
EXO0811.2+2949		08 14 21	29 40 21	3
MS0922.9+7459		09 28 06	74 46 34	2,4
MS0950.9+4929		09 54 09	49 15 33	2,4
MS0958.9+2102		10 01 42	20 48 18	2,4
EXO1004.0+3509		10 06 56	34 54 39	3
EXO1118.0+4228	1ES 1118+424	11 20 48	42 12 27	3
MS1133.7+1618		11 36 18	16 01 45	2,4
MS1207.9+3945		12 10 26	39 29 10	2,3,4
EXO1215.3+3022	ON 325, PKS 1215+303, B2 1215+303	12 17 49	30 05 30	3
EXO1218.8+3027	2A 1219+305, 3A1218+303	12 21 22	30 10 29	3
MS1221.8+2452		12 24 24	24 36 20	2,4
MS1229.2+6430		12 31 32	64 14 21	2,4
MS1235.4+6315		12 37 39	62 59 05	2,3,4
MS1256.3+0151		12 58 52	-01 34 56	2,4
MS1258.4+6401		13 00 23	63 44 57	2,4
MS1312.1-4221		13 15 03	-42 37 16	2,4
MS1332.6-2935		13 35 30	-29 50 43	2,4
MS1402.3+0416		14 04 50	04 02 02	2,3,4
MS1407.9+5954		14 09 26	59 39 52	2,4
EXO1415.6+2557		14 17 56	25 43 56	3
MS1443.5+6349		14 44 36	63 36 25	2,4
MS1458.8+2249		15 01 03	22 37 54	2,4
MS1534.2+0148		15 36 47	01 38 09	2,4
MS1552.1+2020		15 54 24	20 11 47	2,4
MS1704.9+6046		17 05 34	60 42 16	2,4
MS1757.7+7034		17 57 09	70 33 51	2,4
EXO1811.7+3143		18 13 35	31 44 13	3
MS2143.4+0704		21 45 53	07 18 07	2,4
MS2336.5+0517		23 39 06	05 34 04	2,4
MS2342.7-1531		23 45 21	-15 14 49	2,4
MS2347.4+1924		23 50 00	19 41 35	2,4

References- 1. Elvis at al. 1992 2. Gioia et al. 1990 3. Giommi et al. 1991 4. Stocke et al. 1991

Table 4. Miscellaneous BL Lacs

Source name	Other Name(s)	R.A. (2000.0)	Dec. (2000.0)	Ref
GC 0109+224	S2 0109+22	01 12 05.7	22 44 38	1,2
4C 47.08	OE 400, EQ 0300+470	03 03 35.2	47 16 16	2
PKS 0306+102	OE 110, EQ 0306+102	03 09 03.6	10 29 16	2
PKS 0338-214		03 40 35.5	-21 19 31	2
PKS 0521-365	EQ 0521-3630	05 22 57.8	-36 27 03	1,2
PKS 0754+100		07 57 06.6	09 56 35	1,2
PKS 0818-128	OJ -131	08 20 57.3	-12 58 58	2
MC 1057+100		11 00 20.2	09 49 35	1,2
MC 1400+162	PKS 1400+160, OQ 100, 4C 16.39	14 02 44.4	15 59 55	2
PKS 1413+135		14 15 58.7	13 20 24	2
PKS1604+159	4C 15.54, OS 108.2	16 07 06.3	15 51 33	2
PKS 2032+107	PKS 2032+10.7	20 35 22.3	10 56 06	2

References- 1. Giommi et al. 1990 2. Veron & Veron 1993

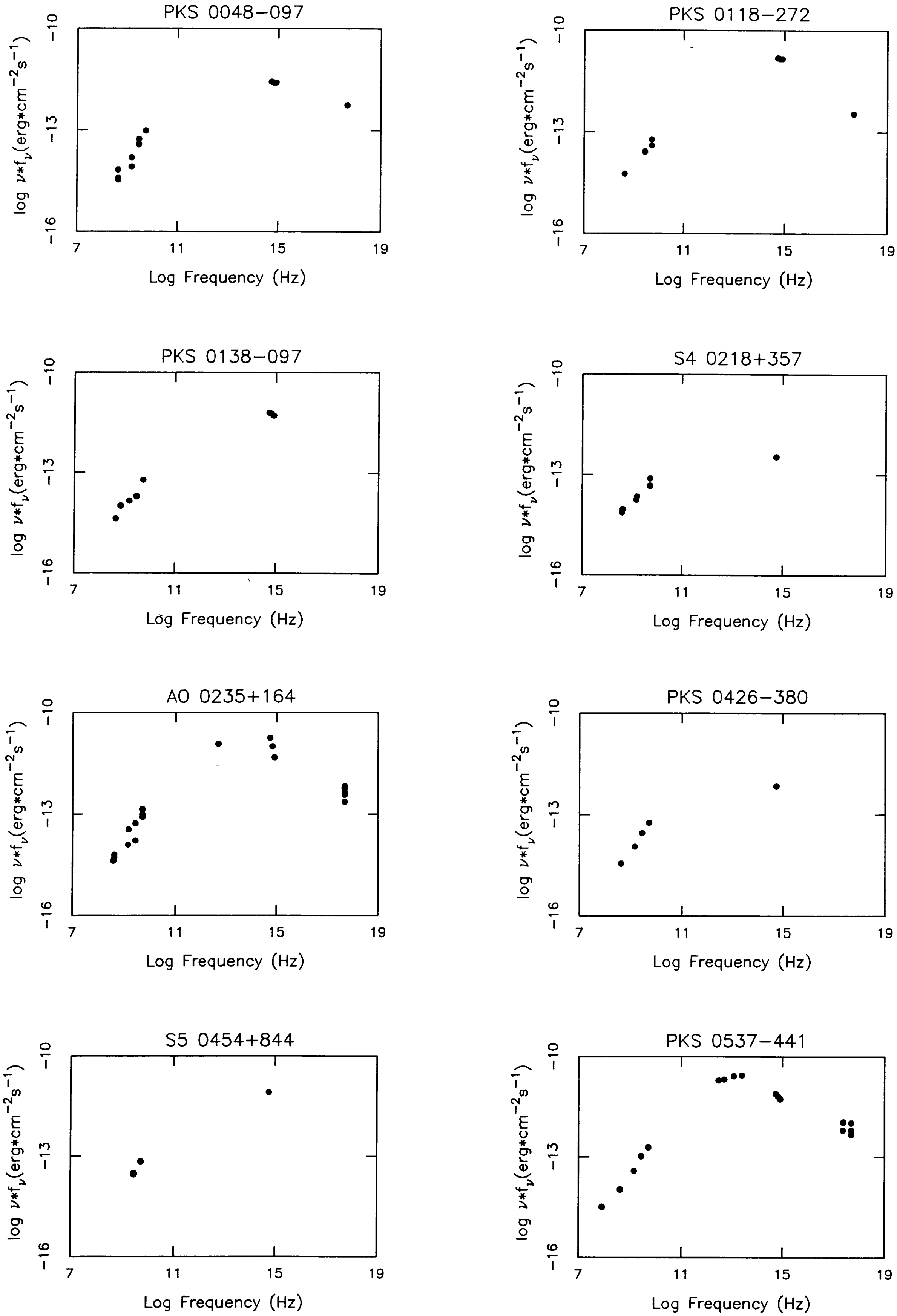

Fig. 1.1-1.39. Radio to X-ray energy distribution of a sample of 39 BL Lacs discovered in the 1Jy and S4 radio surveys

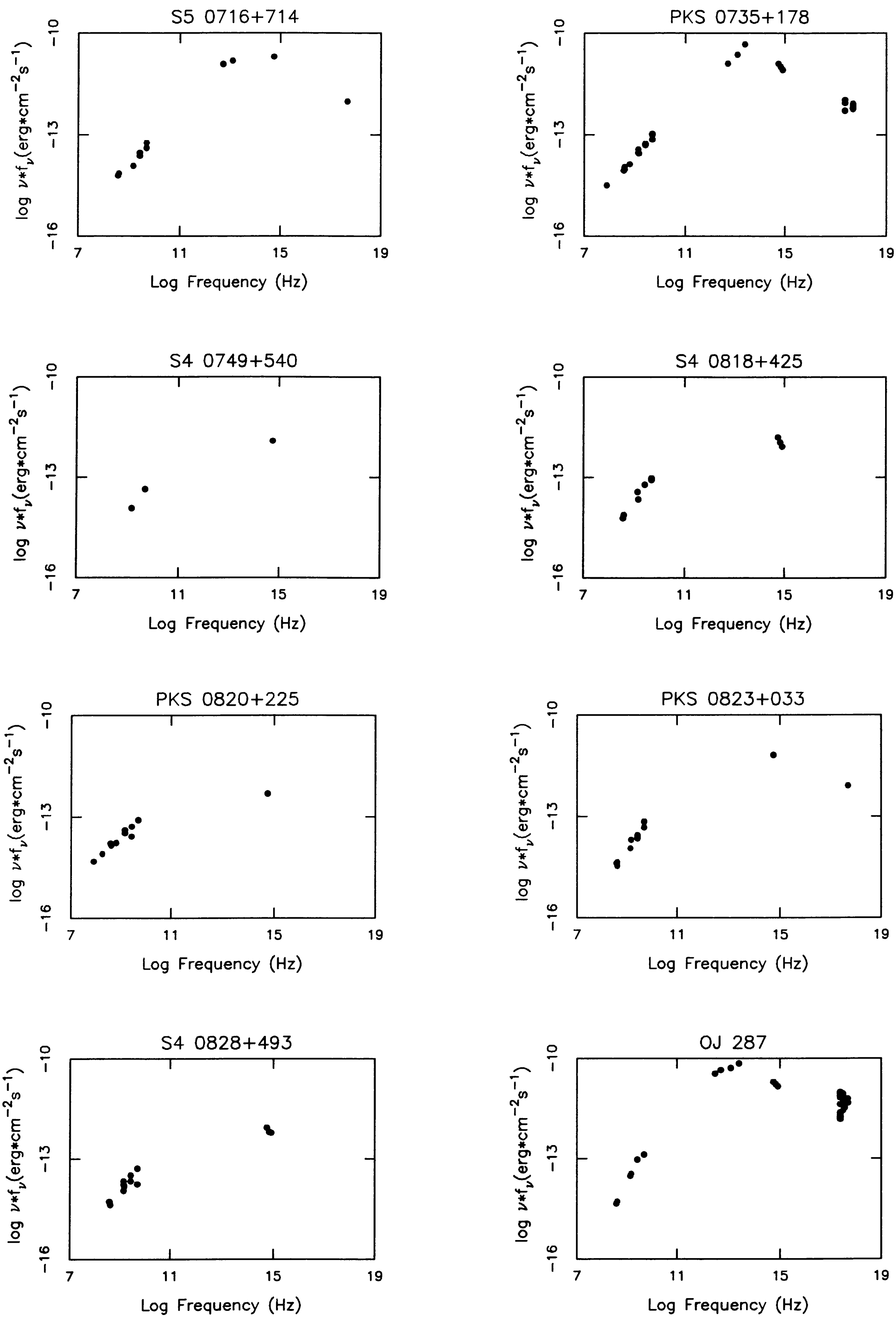

Fig. 1. continued

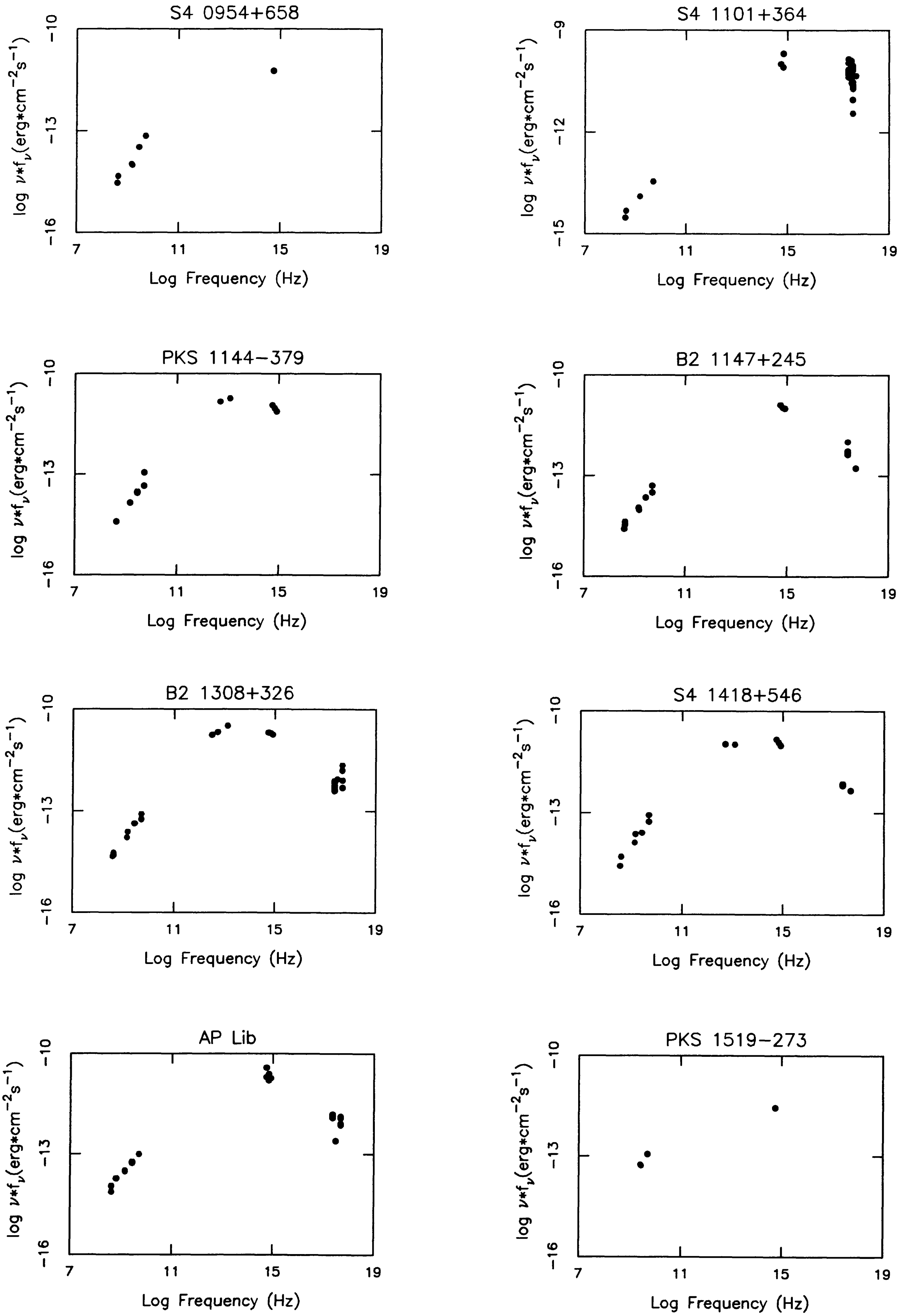

Fig. 1. continued

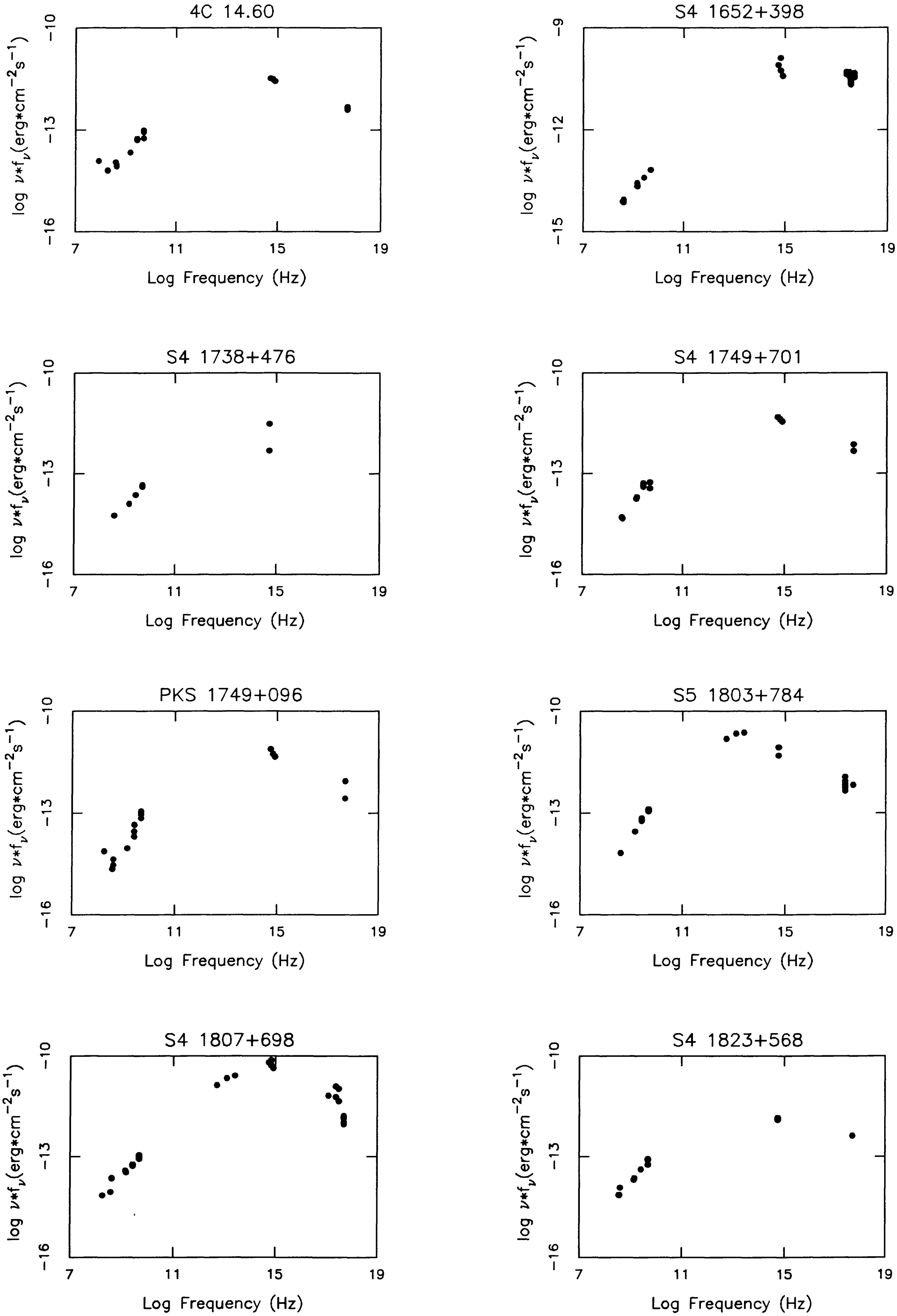

Fig. 1. continued

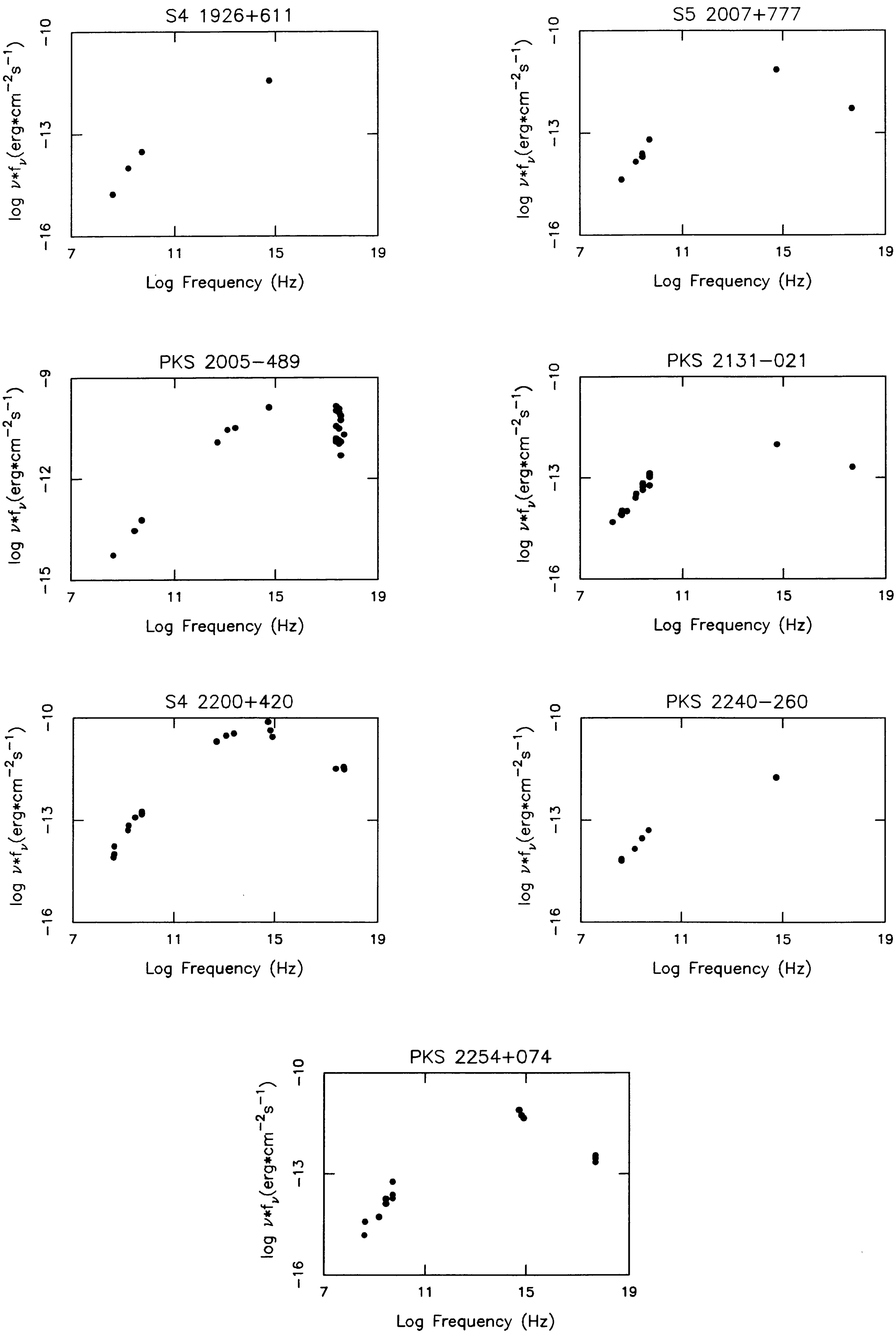

Fig. 1. continued

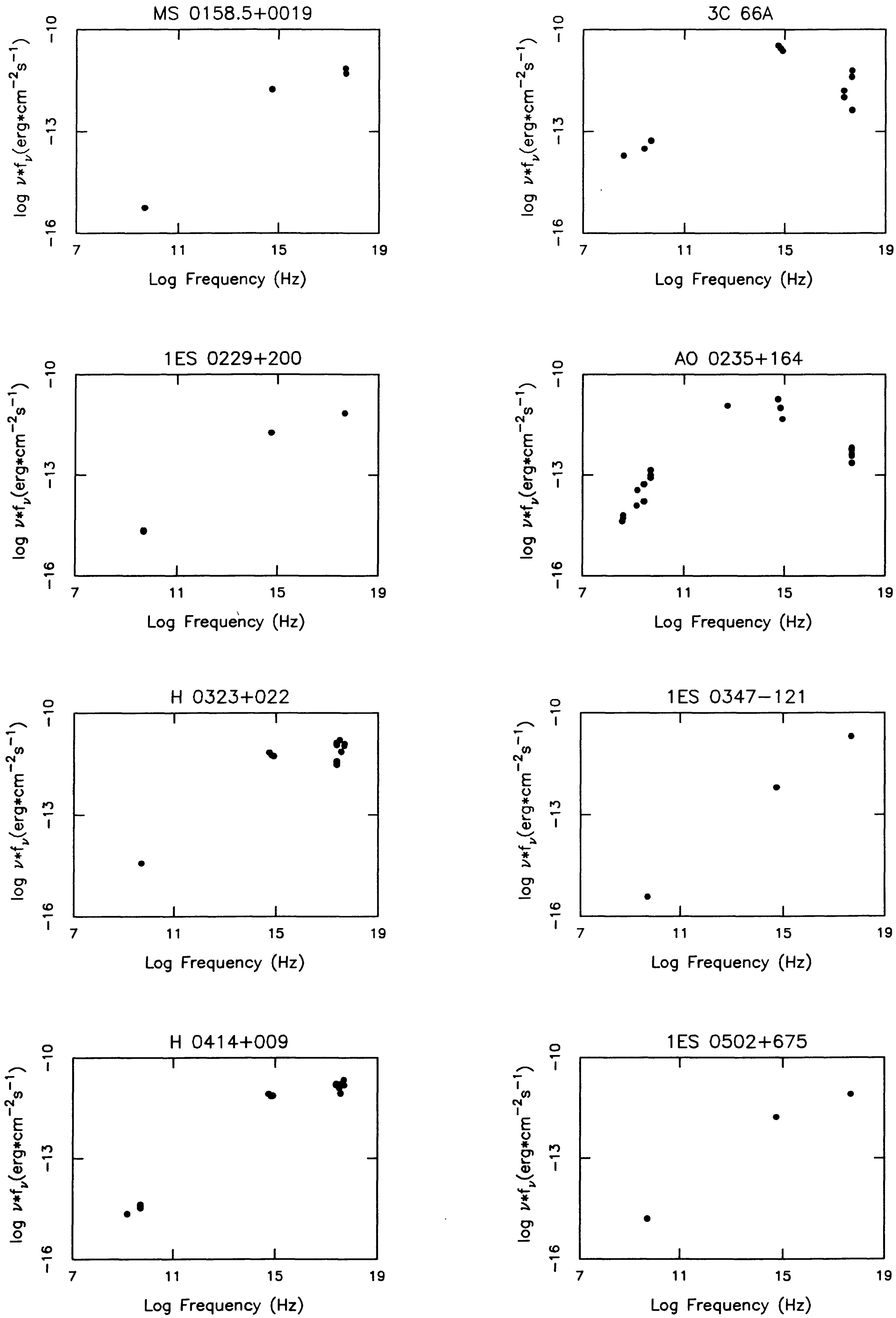

Fig. 2.1-2.44. Radio to X-ray energy distribution of a sample of 44 X-ray Selected BL Lacs detected in the *Einstein* IPC Slew Survey

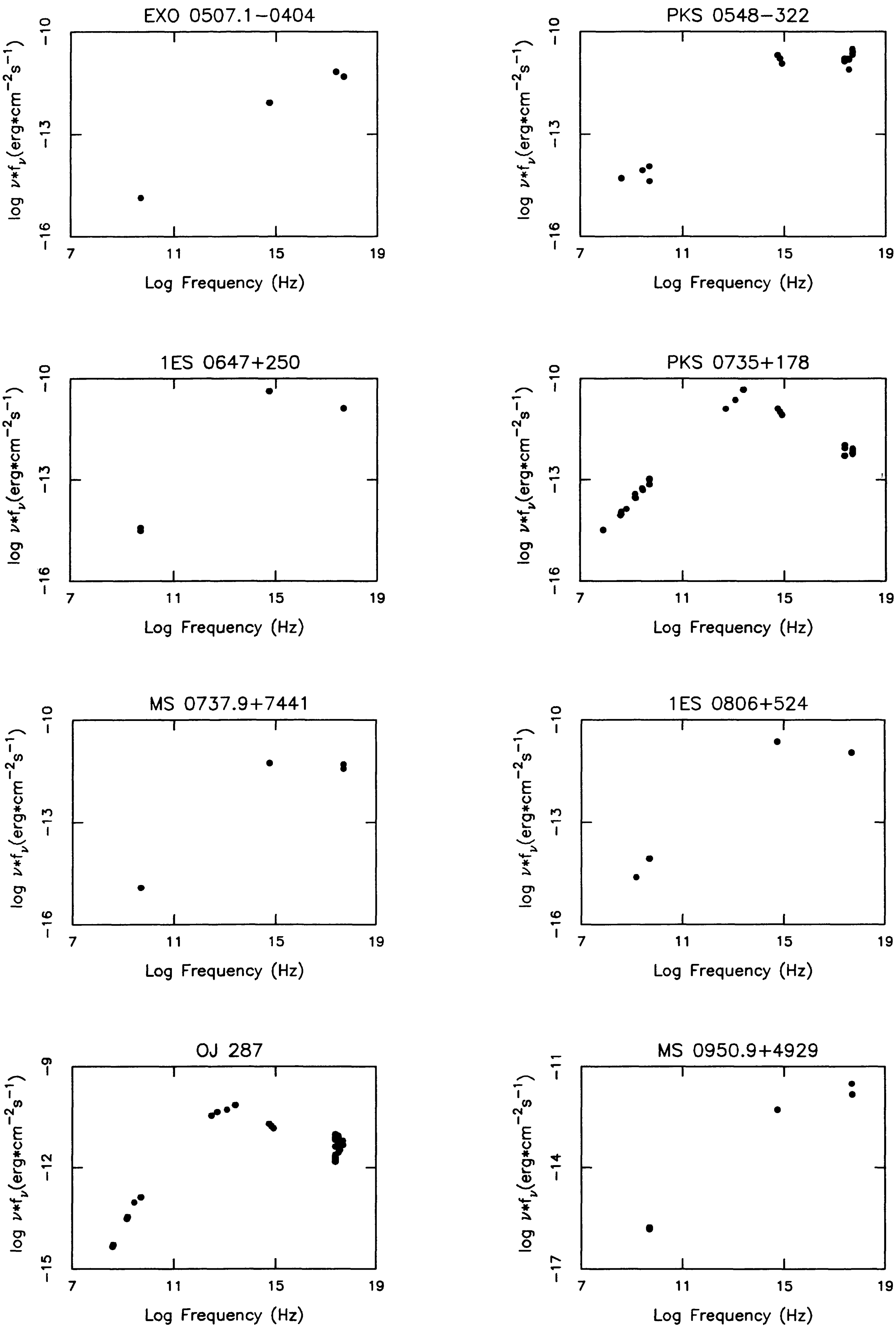

Fig. 2. continued

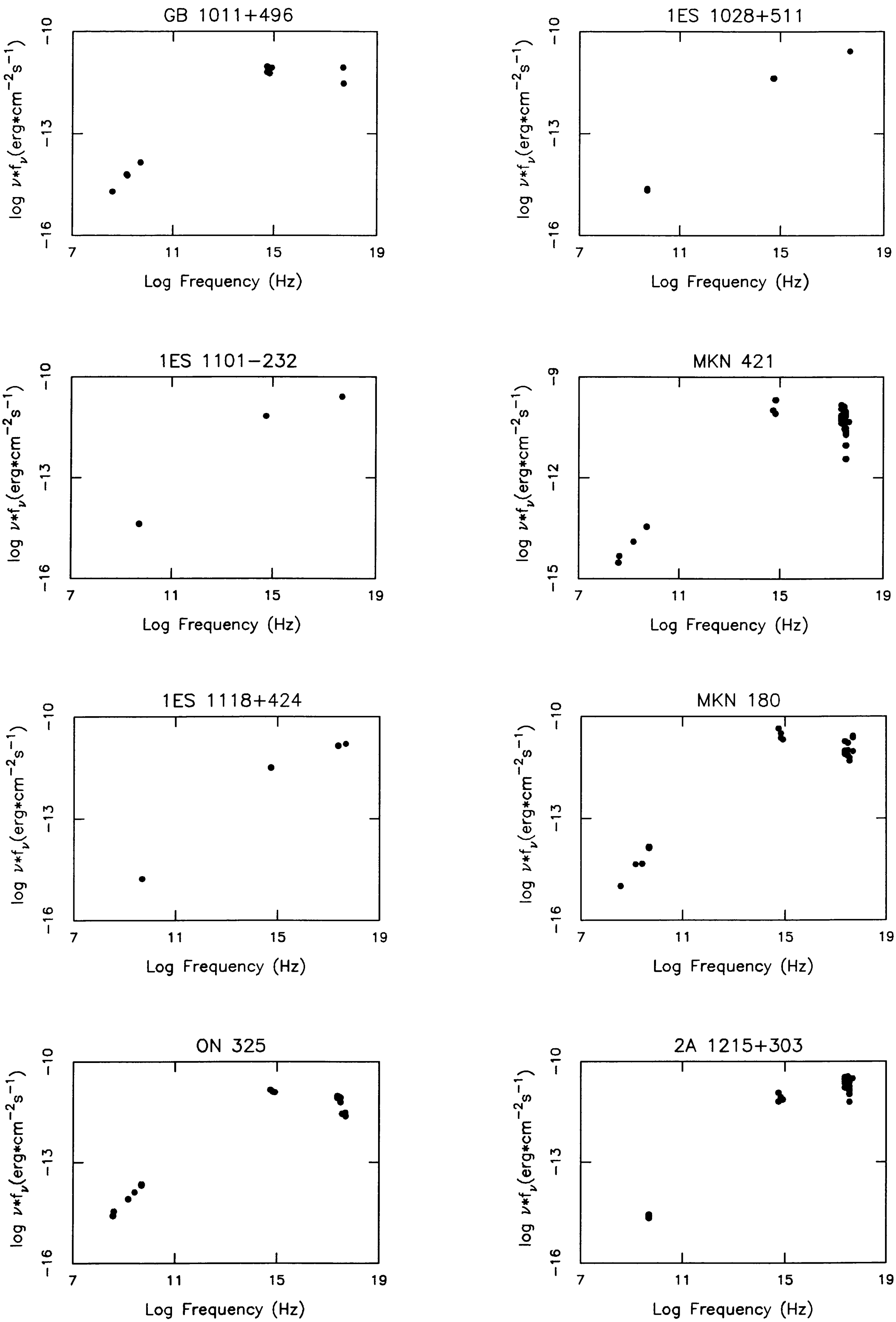

Fig. 2. continued

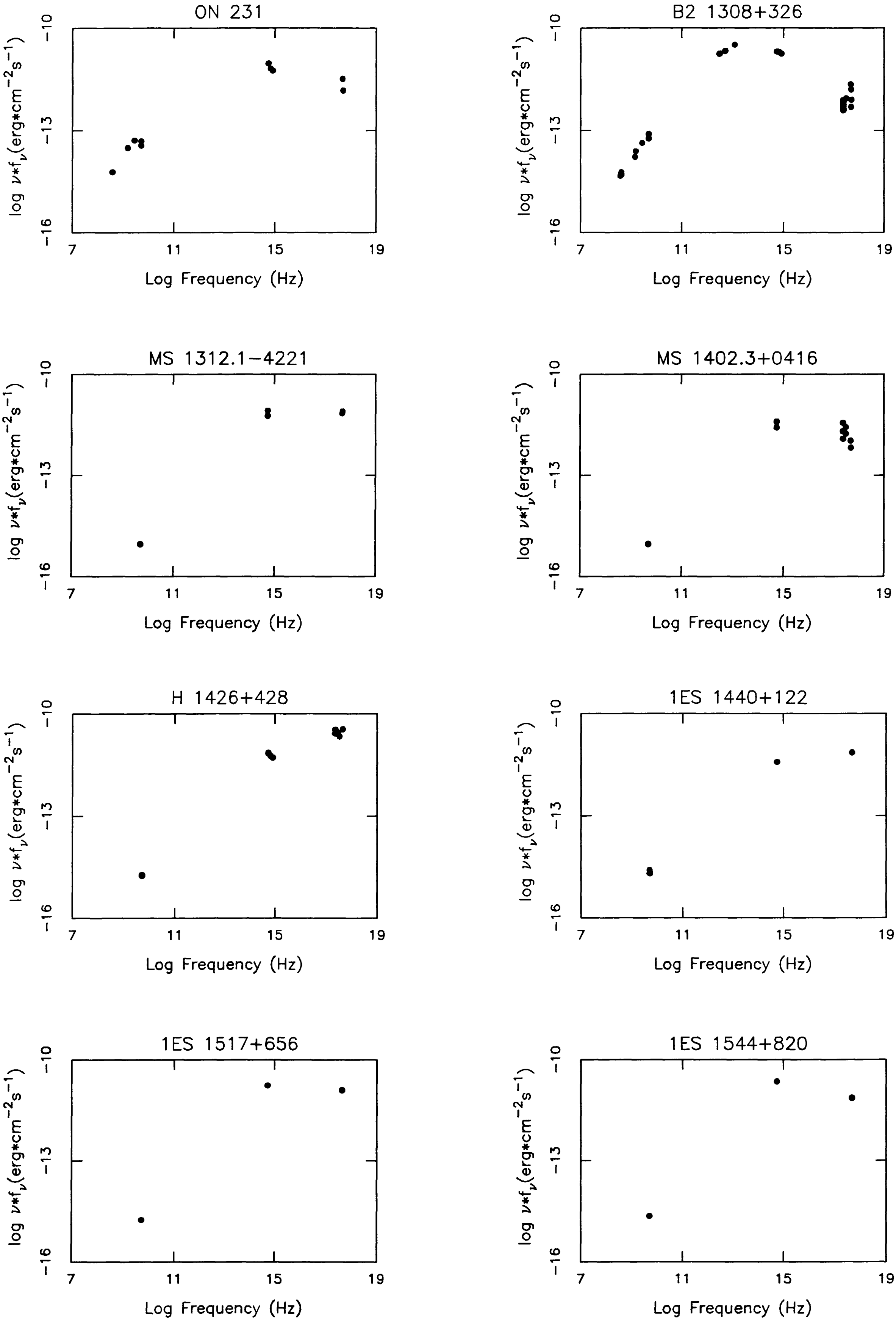

Fig. 2. continued

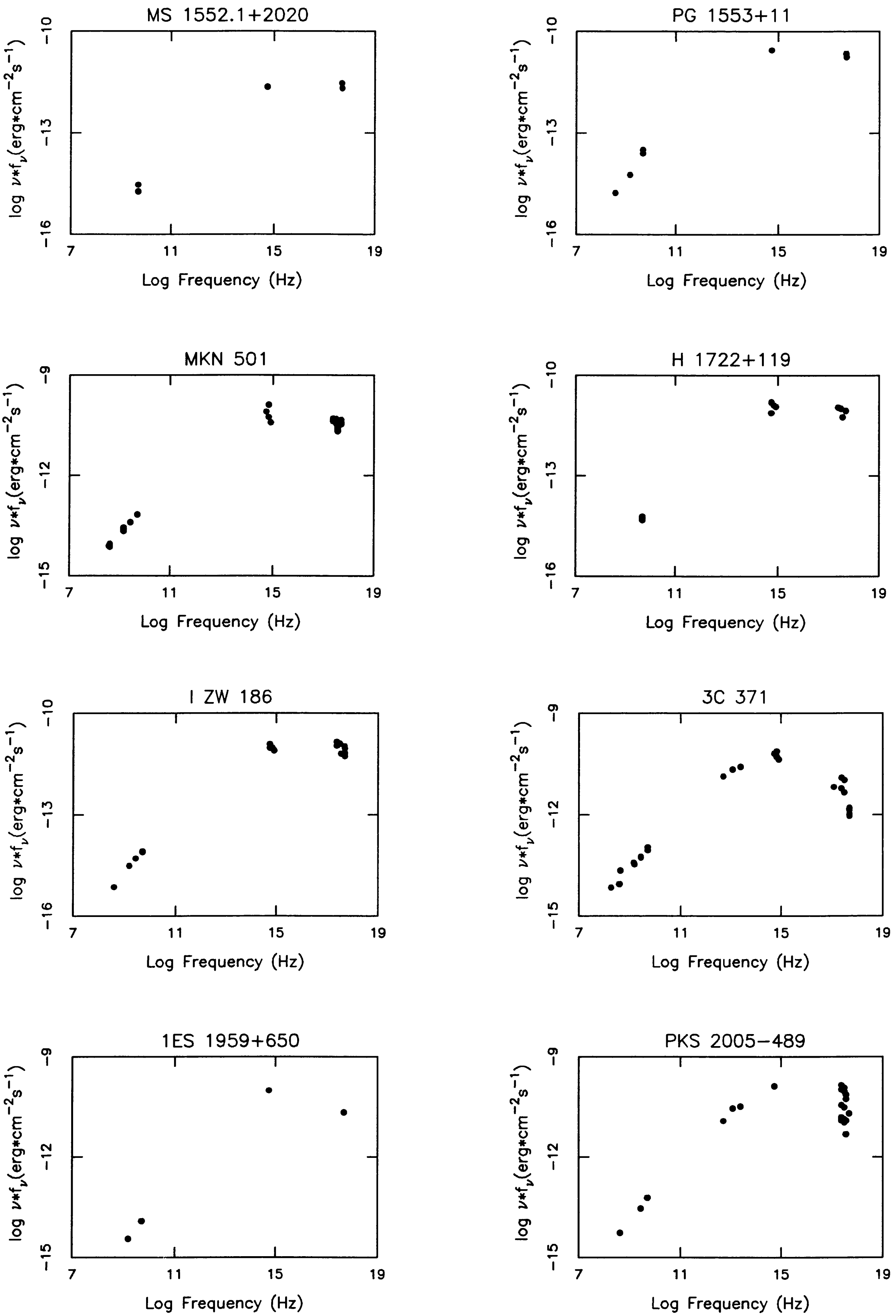

Fig. 2. continued

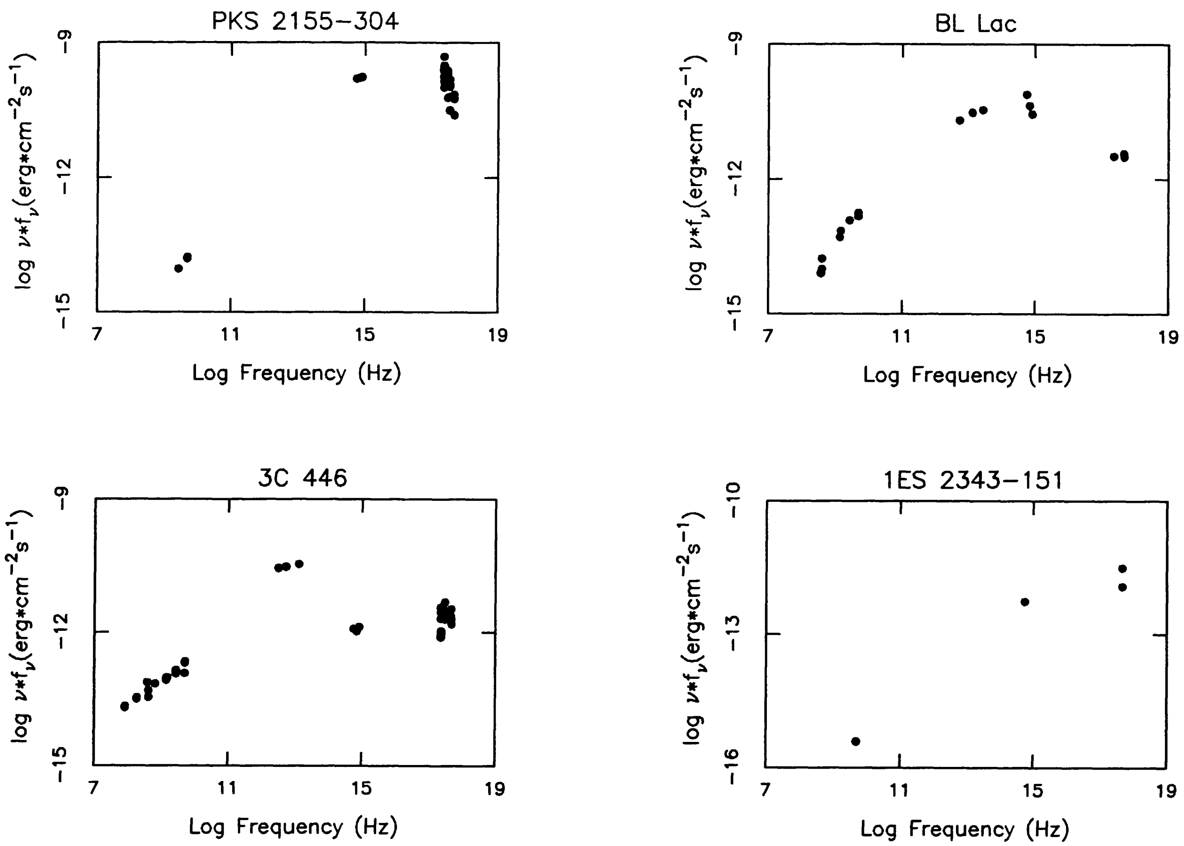

Fig. 2. continued

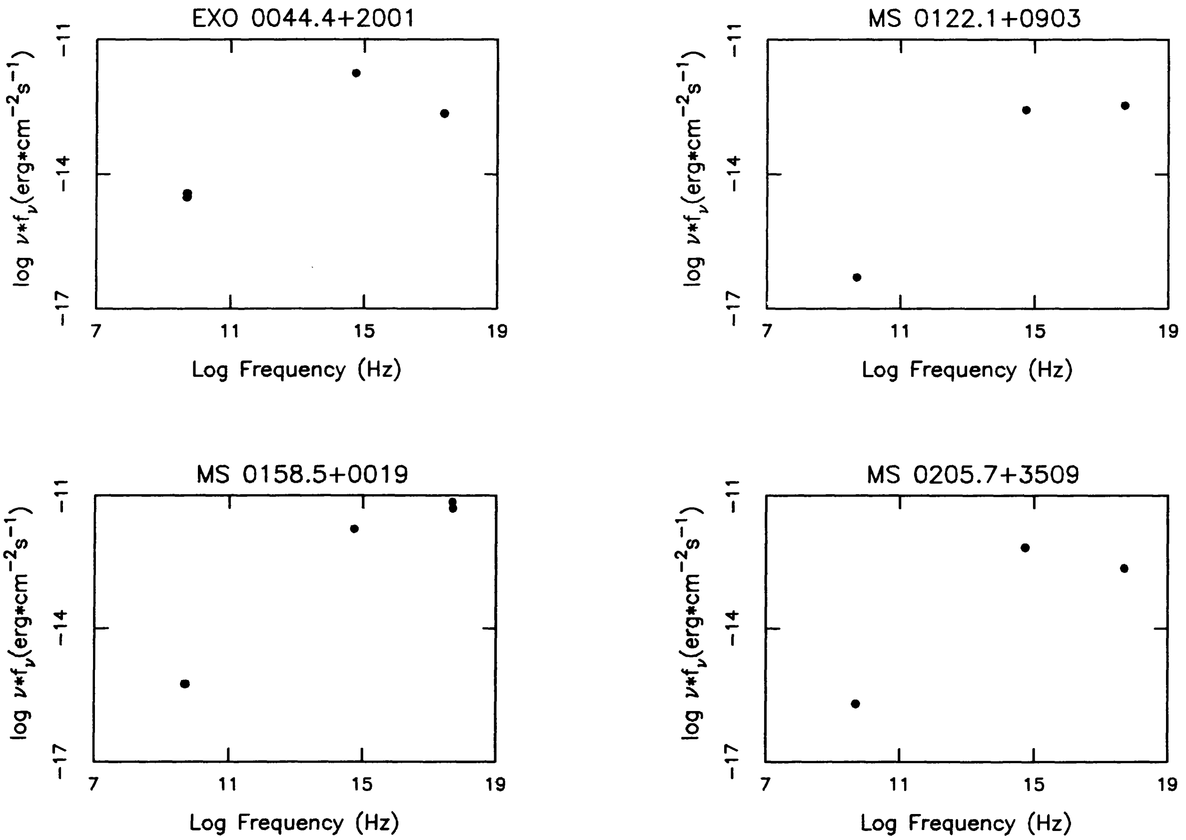

Fig. 3.1-3.45. Radio to X-ray energy distribution of a sample of 45 X-ray Selected BL Lacs from serendipitous surveys. The objects are from the *Einstein* Extended Medium Sensitivity Survey and the EXOSAT High Galactic Latitude Survey

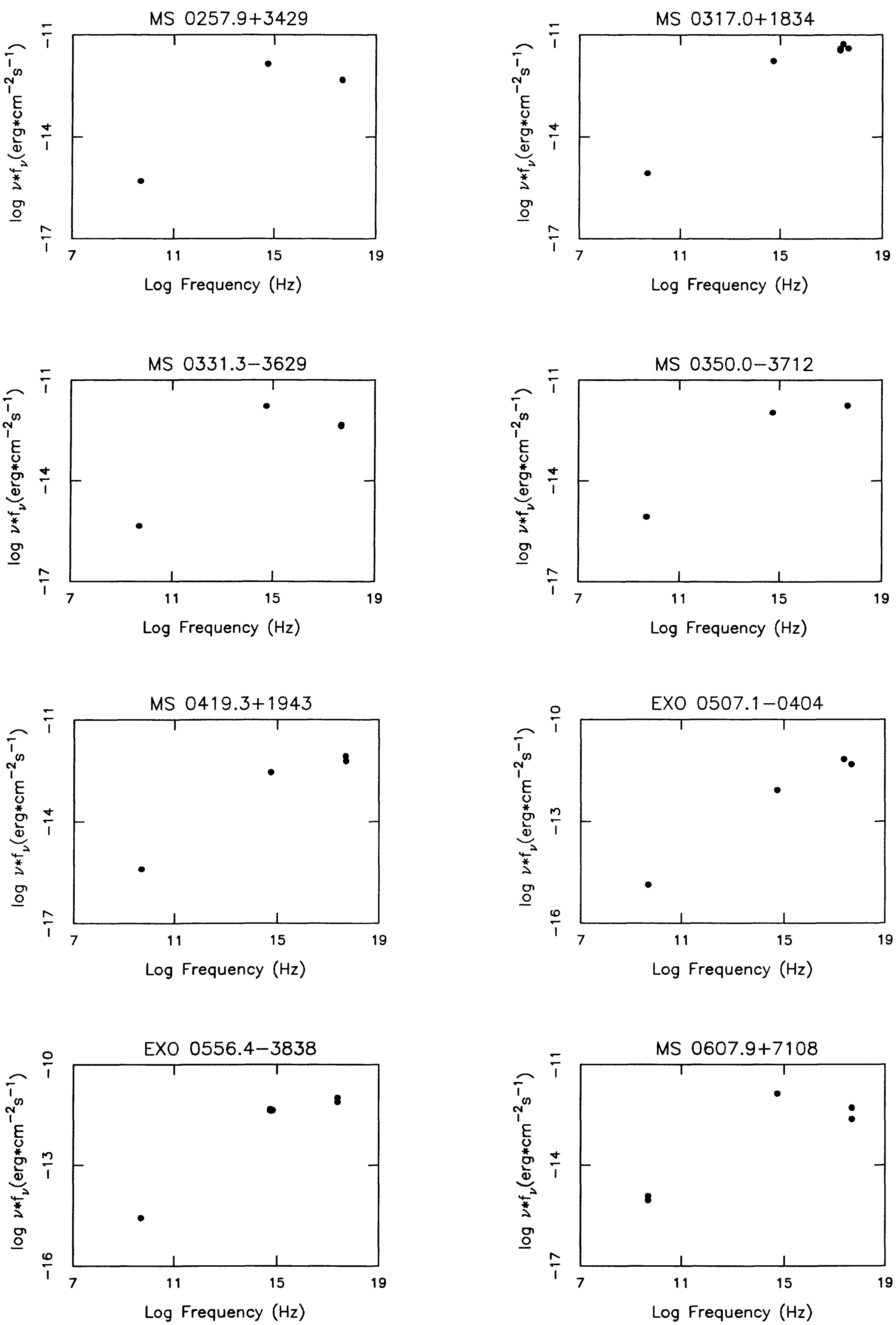

Fig. 3. continued

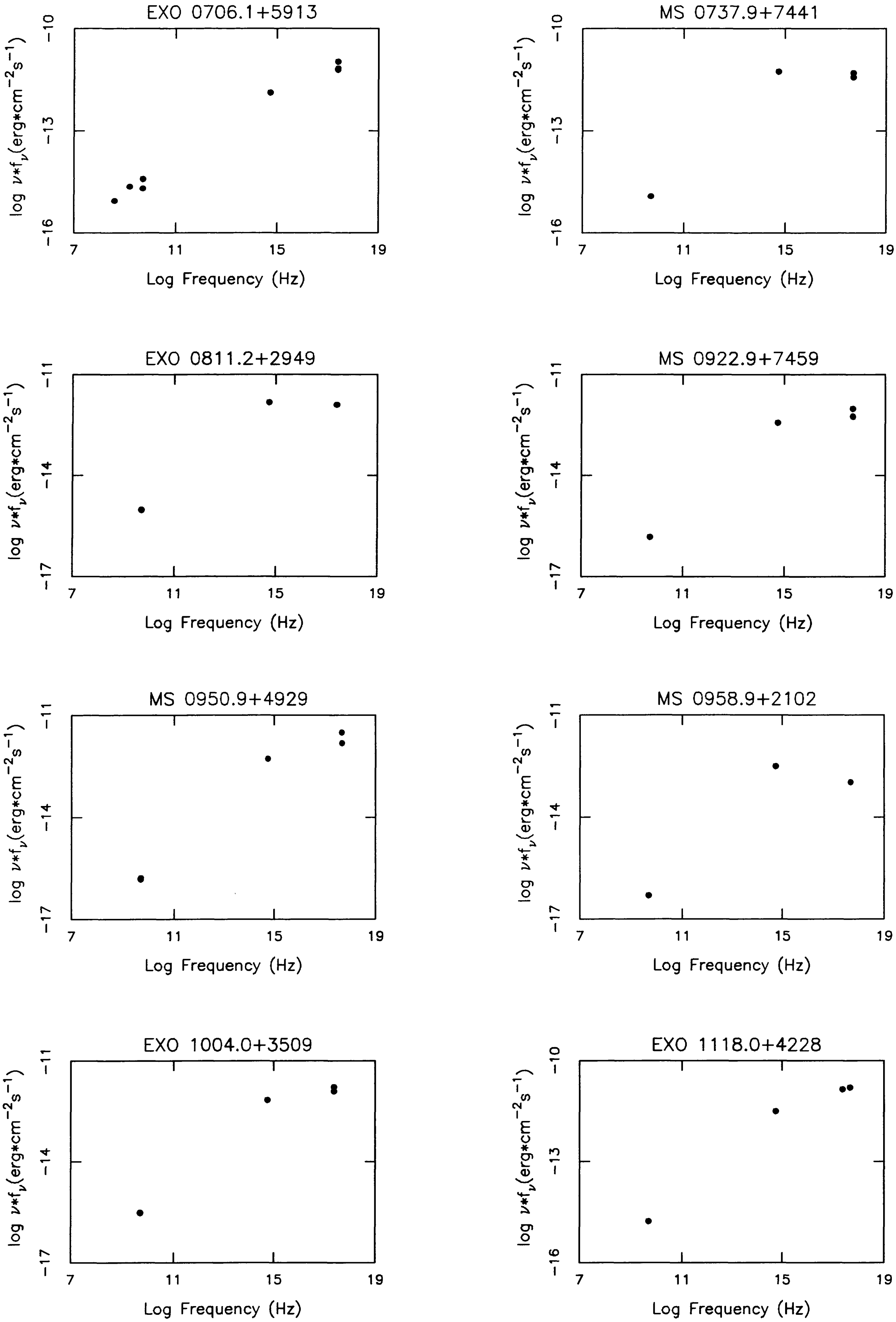

Fig. 3. continued

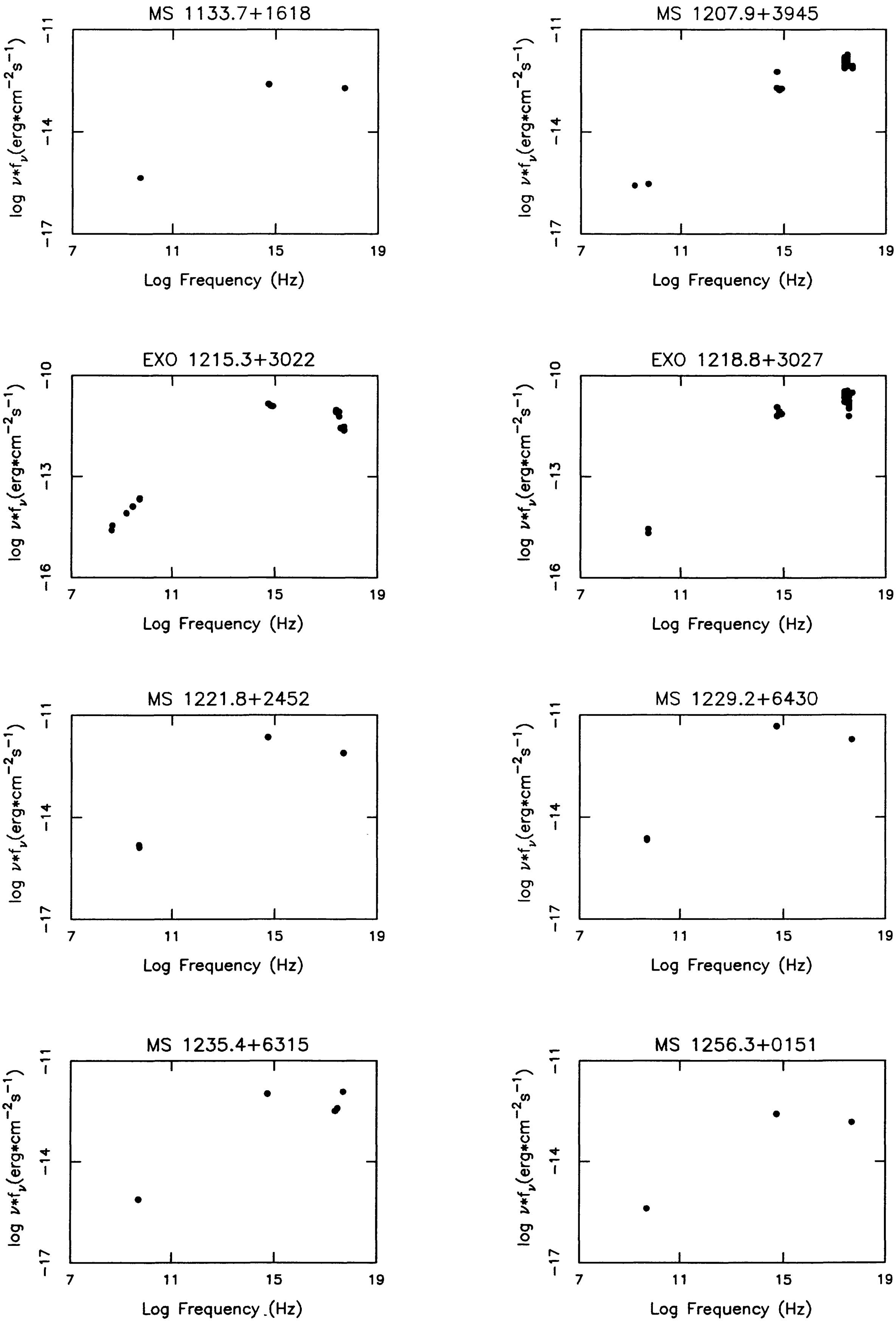

Fig. 3. continued

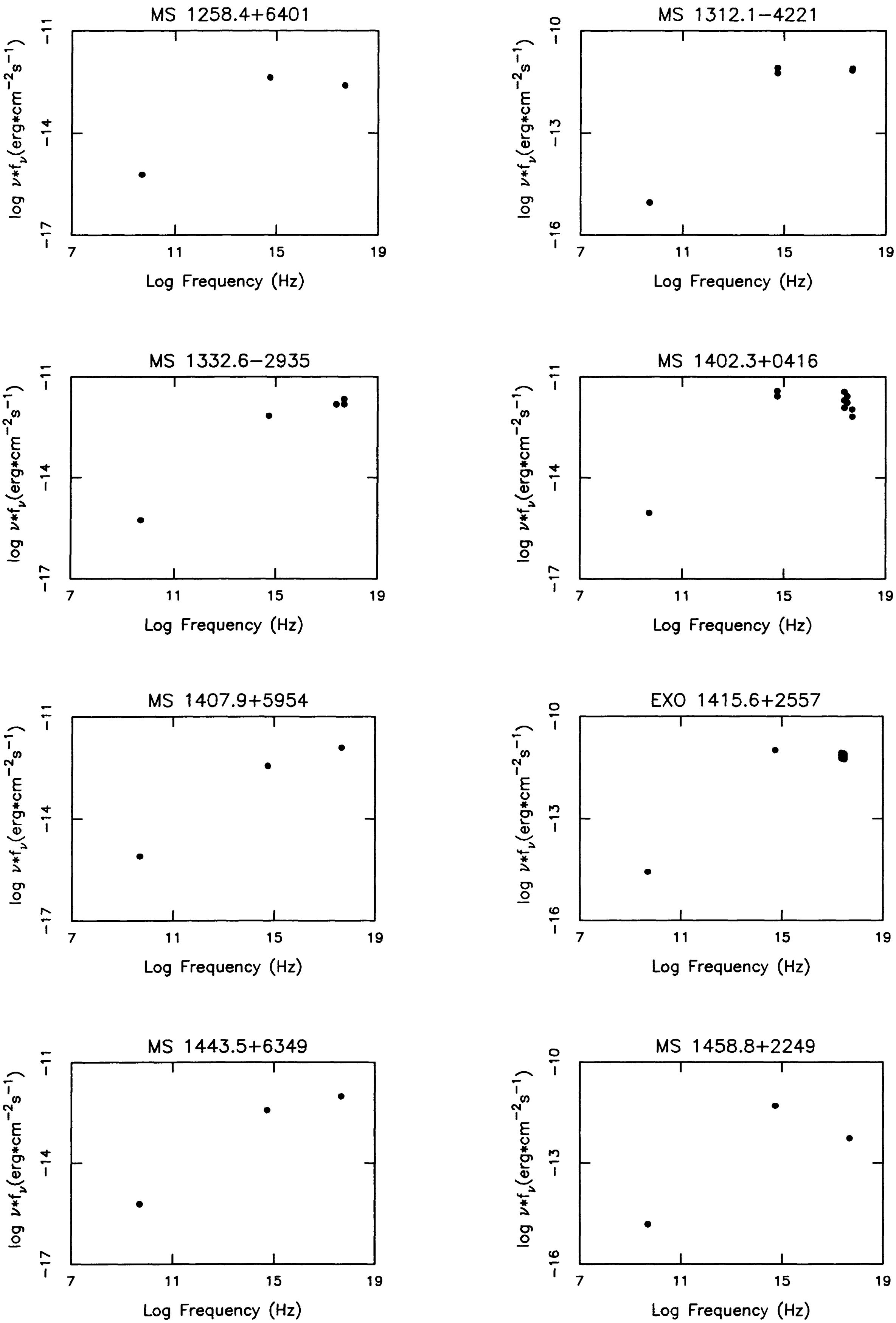

Fig. 3. continued

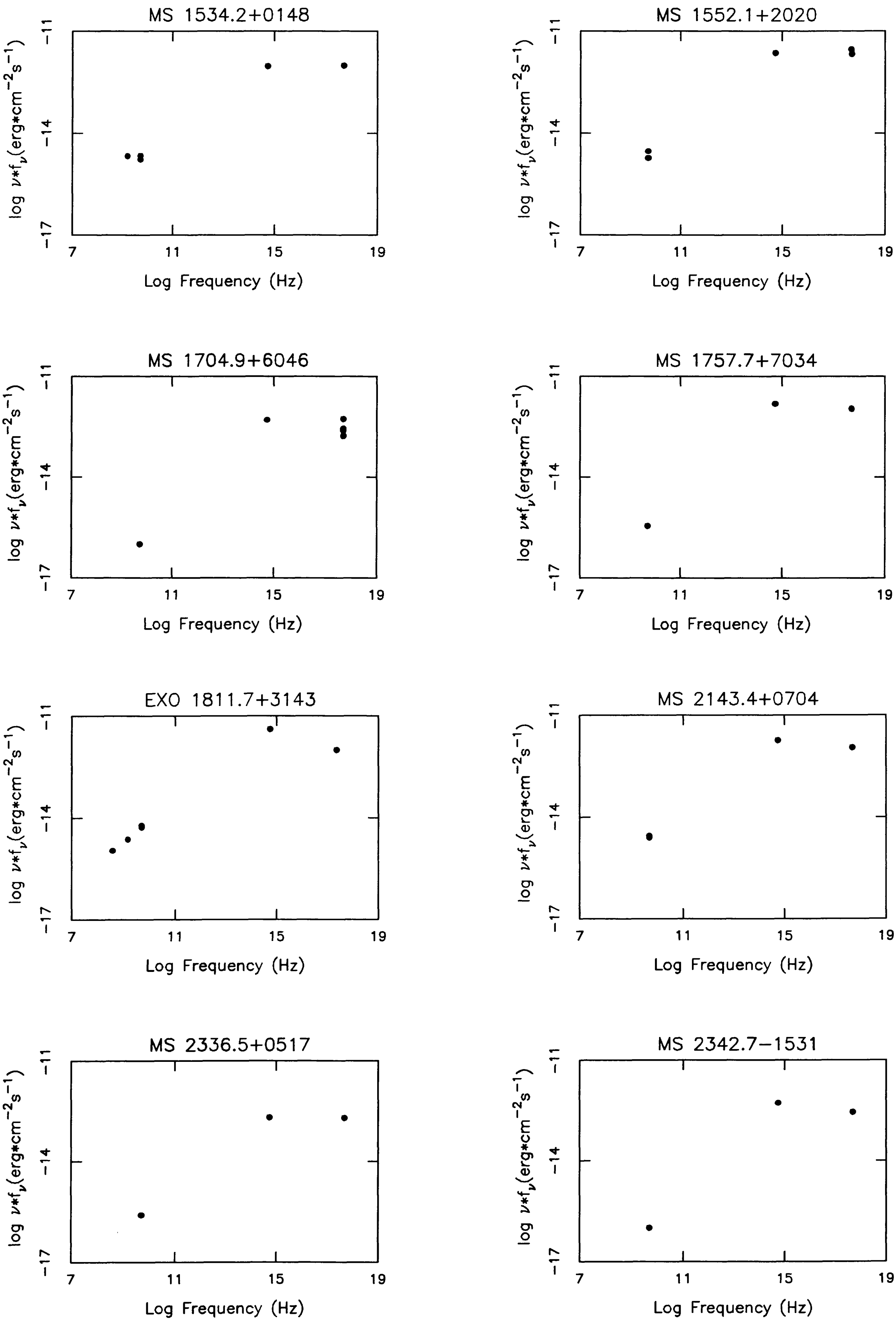

Fig. 3. continued

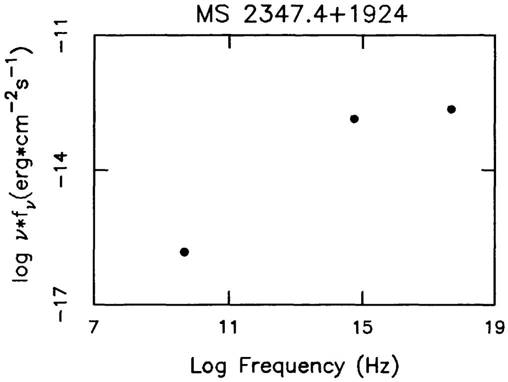

Fig. 3. continued

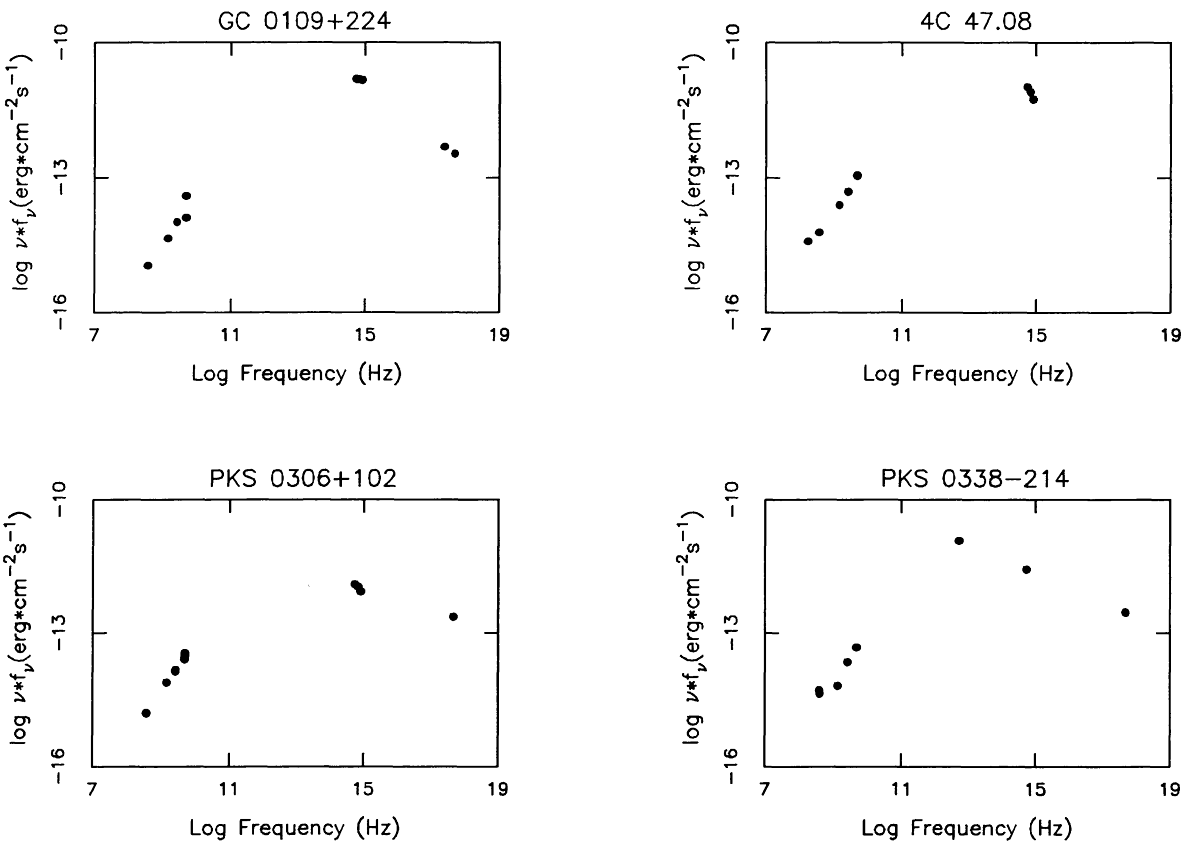

Fig. 4.1-4.12. Radio to X-ray energy distribution of a sample of 12 well known BL Lacs not included in the radio and X-ray surveys considered in this paper. Most of the objects in this sample have been discovered at radio frequencies

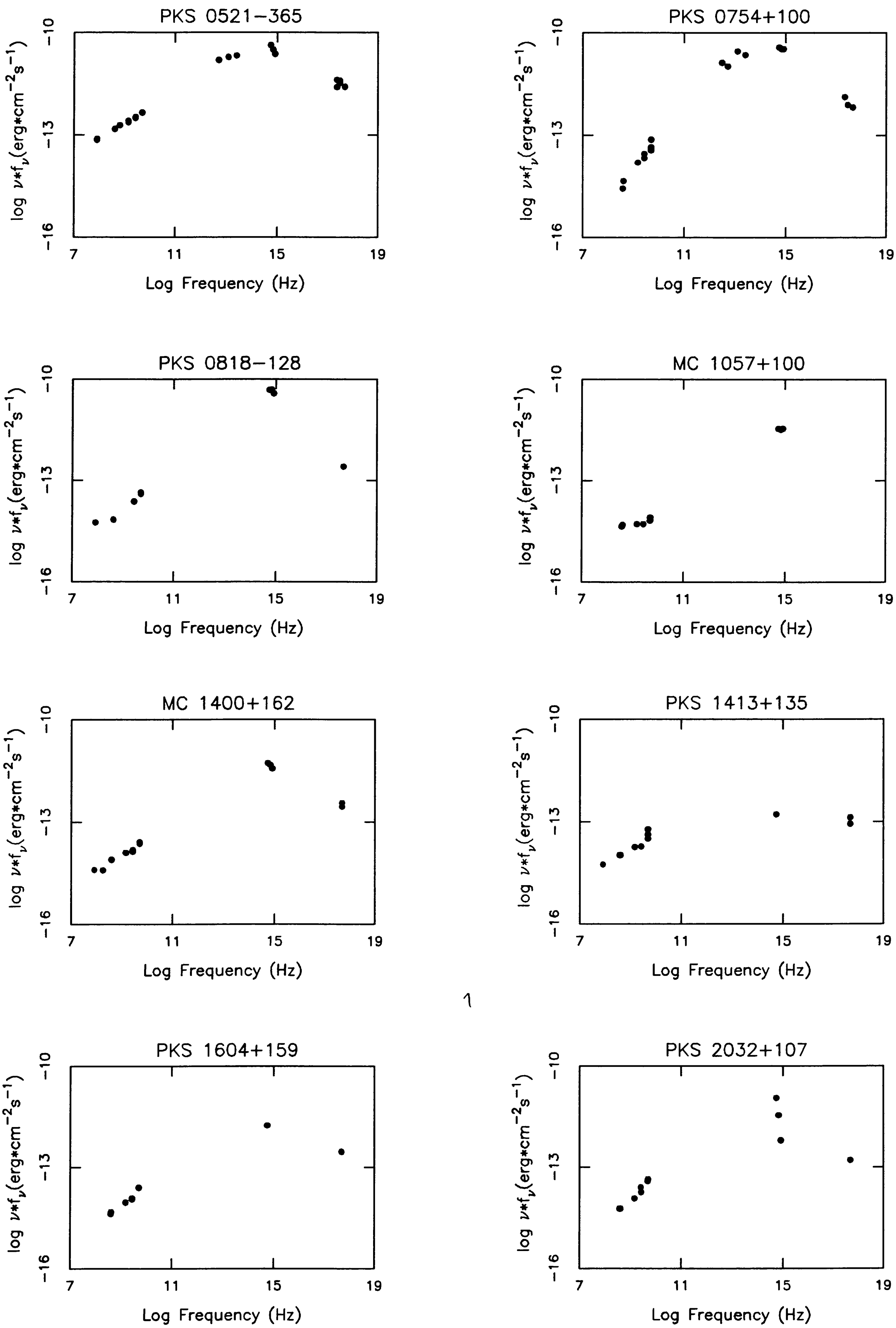

Fig. 4. continued

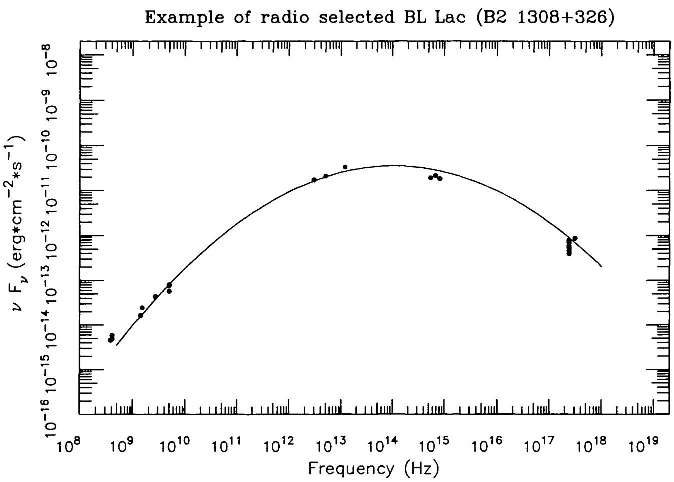

Fig. 5a. Energy distribution of a typical Radio Selected BL Lac (B2 1308+326). The solid line is a weighted parabola fit to the data

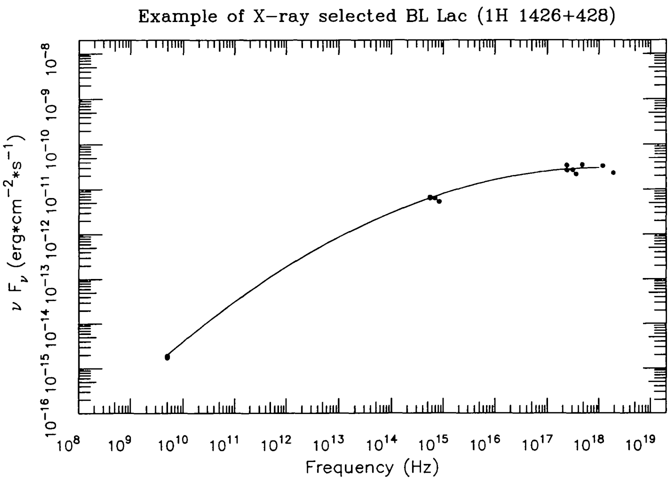

Fig. 5b. Energy distribution of a typical X-ray Selected BL Lac (1H 1426+428). The solid line is a weighted parabola fit to the data

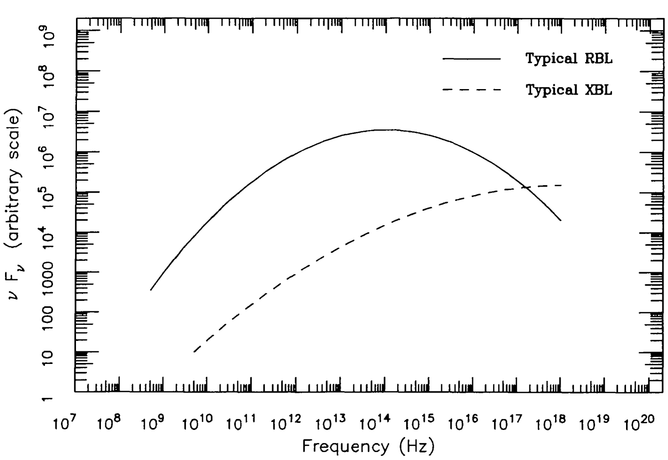

Fig. 6. Comparison between the energy distributions of a typical RBL (solid line) and a typical XBL (dashed line). The two distributions have been taken from Fig. 4a and Fig. 4b and have been scaled so that X-ray fluxes are approximately equal. For similar X-ray fluxes XBLs can be more than 2 orders of magnitudes fainter that RBLs in the radio band

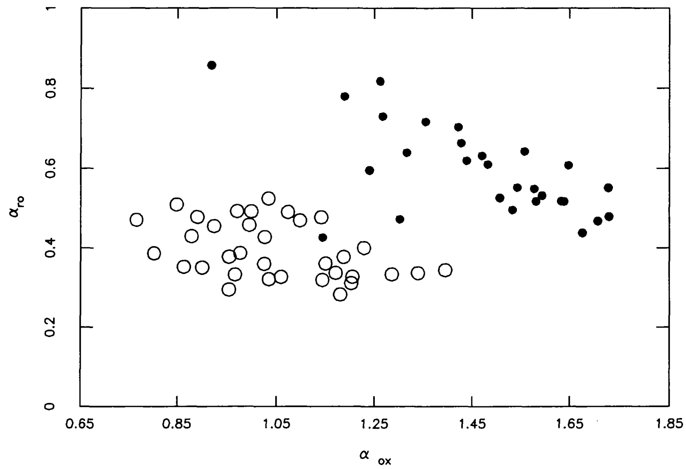

Fig. 7. The $\alpha_{\rm ro}$ vs $\alpha_{\rm ox}$ diagram of BL Lacertae objects. Filled circles represent RBLs open circles represent XBLs. The two subsamples are well separated on this diagram

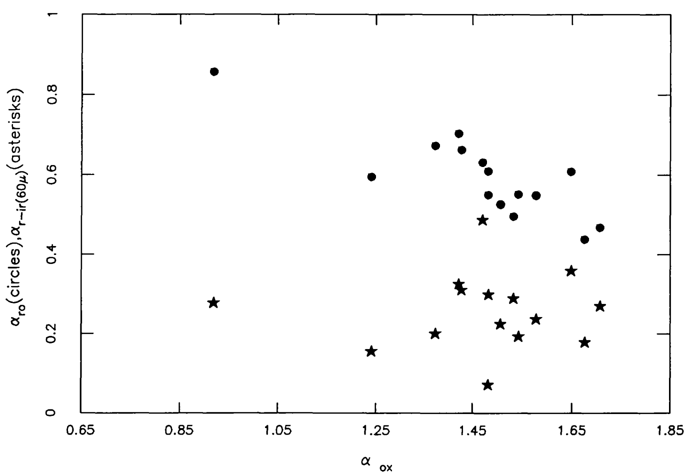

Fig. 8. The $\alpha_{\rm ro}$ (or $\alpha_{\rm r-ir(60\mu)}$) vs $\alpha_{\rm ox}$ diagram of the subsample of RBLs for which IRAS (faint source catalogue) data are available. Filled circles represent BL Lacs when $\alpha_{\rm ro}$ is used, stars represent the same objects when $\alpha_{\rm r-ir(60\mu)}$ is used. Note that when $\alpha_{\rm r-ir(60\mu)}$ is used all RBLs fall in the area normally occupied by XBLs and the clear distinction between the two classes disappears