The Power of Relativistic Jets: A Comparative Study

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Summary: We present the results of a comparison between different methods to estimate the power of relativistic jets from AGN. We selected a sample of 32 objects (21 FSRQs, 7 BL Lac objects, 2 misaligned AGN, and 2 changing-look AGN) from the VLBA observations at 43 GHz of the Boston University blazar program. We then calculated the total, radiative, and kinetic jet power from both radio and high-energy gamma-ray observations, and compared the values. We found an excellent agreement between the radiative power calculated by using the Blandford & Königl (BK1979) model with 37 or 43 GHz data and the values derived from the high-energy γ-ray luminosity. The agreement is still acceptable if 15 GHz data are used, although with a larger dispersion, but it improves if we use a constant fraction of the γ-ray luminosity. We found a good agreement also for the kinetic power calculated with the BK1979 model with 15 GHz data and the value from the extended radio emission. We also propose some easy-to-use equations to estimate the jet power.

👉 For more details, see: Foschini, L., et al., 2024, *Universe* **10**, 156. → Scan the QR code to download the paper

Jet Model by Blandford & Königl (1979, ApJ 232, 34)

Eq. (29)

$$S_\nu \sim \frac{1}{2}(1+z)\underbrace{k_{\rm eq}^{\frac{5}{6}}\Delta^{-\frac{17}{12}}(1+\frac{2}{3}k_{\rm eq}\Lambda)^{-\frac{17}{12}}}_{k_1}\underbrace{\Gamma^{-\frac{17}{6}}\beta^{-\frac{17}{12}}\delta^{\frac{13}{6}}(\sin\theta)^{-\frac{5}{6}}\phi_{\rm obs}^{-1}}_{k_2}P_{44}^{\frac{17}{12}}d_{\rm L,9}^{-2}$$

k_1: Need an educated guess

k_2: Observed/derived quantities

- S_ν: Radio flux density at frequency ν [Jy]
- Equipartition: $u_{\rm e} = k_{\rm eq}u_{\rm B}$
- $\Delta = \log\frac{r_{\rm max}}{r_{\rm min}}$: Size of the emitting region
- $\Lambda = \log\frac{\gamma_{\rm e,max}}{\gamma_{\rm e,min}}$: Electron energy distribution (random Lorentz factors), $N(\gamma_{\rm e}) = K\gamma_{\rm e}^{-2}$
- Γ: Bulk Lorentz factor
- β: Jet speed
- δ: Doppler factor
- θ: Jet viewing angle
- Jet opening semiangle: $\phi_{\rm obs} = \frac{\phi}{\sin\theta}$
- P_{44}: Jet Power $[10^{44}{\rm erg\cdot s^{-1}}]$
- $d_{\rm L,9}$: Luminosity distance [Gpc]

Rearrange →

$$P \sim k_1 k_2\left(\frac{S_\nu d_{\rm L,9}^2}{1+z}\right)^{\frac{12}{17}}10^{44}\,[{\rm erg\cdot s^{-1}}]$$

Total (radiative+kinetic) jet power

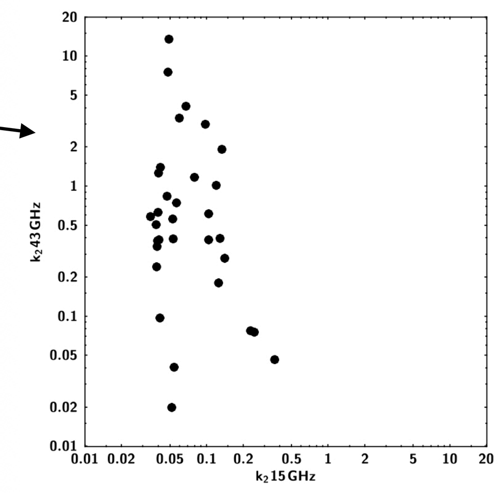
$$k_1 = \left(\frac{1}{2}\right)^{-\frac{12}{17}}k_{\rm eq}^{-\frac{10}{17}}\Delta(1+\frac{2}{3}k_{\rm eq}\Lambda) \sim 24.5$$

$k_{\rm eq} = 0.5$, $\Delta = 5$, $\Lambda = 3$: Educated guess by Blandford & Königl (1979)

$$k_2 = \Gamma^2\beta\delta^{-\frac{26}{17}}(\sin\theta)^{\frac{10}{17}}\phi_{\rm obs}^{\frac{12}{17}}$$

All these quantities can be measured/derived from VLBI radio observations

k_2 from 15 and 43 GHz VLBA data



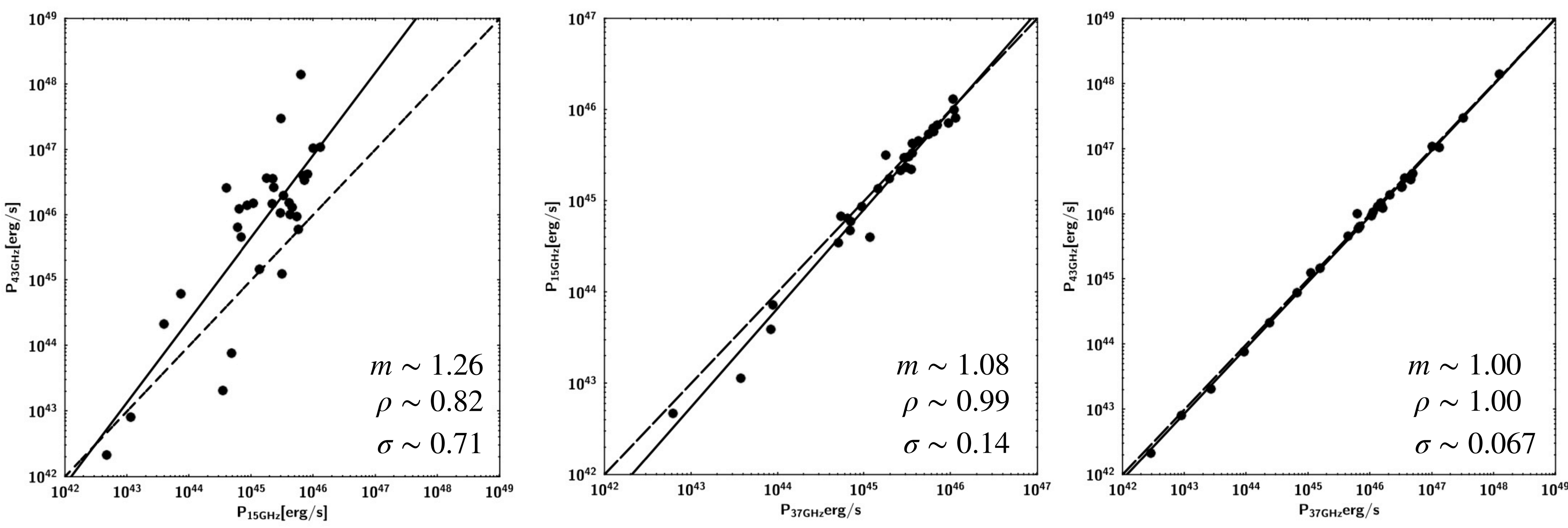
$$P_{\rm rad} = \frac{k_{\rm eq}}{2(1+\frac{2}{3}k_{\rm eq}\Lambda)}P \sim \frac{1}{8}P \rightarrow P_{\rm kin} \sim \frac{7}{8}P$$

Radiative and kinetic contribution to the total jet power

Table 1. Sample of jetted AGN derived from [11]. Column explanation: (1) IAU source name referred to J2000, (2) a more common alias, (3) right ascension ([deg], J2000), (4) declination ([deg], J2000), (5) classification (BLLAC: BL Lac object; MIS: misaligned AGN; FSRQ: flat-spectrum radio quasar; CLAGN: changing-look AGN), and (6) redshift. Information for columns (5) and (6) was taken from [22].

Name (1)	Alias (2)	RA (3)	Dec (4)	Class (5)	z (6)
J0238 + 1636	PKS 0235 + 164	39.66	+16.62	BLLAC	0.940
J0319 + 4130	NGC 1275	49.95	+41.51	MIS	0.0176
J0339 − 0146	PKS 0336 − 01	54.88	−1.78	FSRQ	0.852
J0423 − 0120	PKS 0420 − 01	65.82	−1.34	FSRQ	0.915
J0433 + 0521	3C 120	68.30	+5.35	MIS	0.0336
J0530 + 1331	PKS 0528 + 134	82.73	+13.53	FSRQ	2.07
J0830 + 2410	S3 0827 + 24	127.72	+24.18	FSRQ	0.941
J0831 + 0429	PKS 0829 + 046	127.95	+4.49	BLLAC	0.174
J0841 + 7053	4C +71.07	130.35	+70.89	FSRQ	2.17
J0854 + 2006	OJ 287	133.70	+20.11	BLLAC	0.306
J0958 + 6533	S4 0954 + 65	149.70	+65.56	BLLAC	0.368
J1058 + 0133	4C +01.28	164.62	+1.57	FSRQ	0.892
J1104 + 3812	Mkn 421	166.11	+38.21	BLLAC	0.0308
J1130 − 1449	PKS 1127 − 145	172.53	−14.82	FSRQ	1.19
J1159 + 2915	Ton 599	179.88	+29.24	FSRQ	0.725
J1221 + 2813	W Comae	185.38	+28.23	BLLAC	0.102
J1224 + 2122	4C +21.35	186.23	+21.38	FSRQ	0.434
J1229 + 0203	3C 273	187.28	+2.05	FSRQ	0.158
J1256 − 0547	3C 279	194.05	−5.79	FSRQ	0.536
J1310 + 3220	OP 313	197.62	+32.34	FSRQ	0.996
J1408 − 0752	PKS B1406 − 076	212.24	−7.87	FSRQ	1.49
J1512 − 0905	PKS 1510 − 089	228.21	−9.10	FSRQ	0.360
J1613 + 3412	OS 319	243.42	+34.21	FSRQ	1.40
J1626 − 2951	PKS B1622 − 297	246.52	−29.86	FSRQ	0.815
J1635 + 3808	4C +38.41	248.81	+38.13	FSRQ	1.81
J1642 + 3948	3C 345	250.74	+39.81	FSRQ	0.593
J1733 − 1304	PKS 1730 − 13	263.26	−13.08	FSRQ	0.902
J1751 + 0939	OT 081	267.89	+9.65	CLAGN	0.320
J2202 + 4216	BL Lac	330.68	+42.28	BLLAC	0.0686
J2225 − 0457	3C 446	336.45	−4.95	CLAGN	1.40
J2232 + 1143	CTA 102	338.15	+11.73	FSRQ	1.04
J2253 + 1608	3C 454.3	343.49	+16.15	FSRQ	0.858

Comparison of the total jet power from BK1979 estimated by using VLBA data of MOJAVE Program (15 GHz), Boston University blazar program (43 GHz), and single-dish Metsähovi Radiotelescope (37 GHz).



Data from:

- MOJAVE Program: https://www.cv.nrao.edu/MOJAVE/
- Boston University Program: https://www.bu.edu/blazars/BEAM-ME.html
- Metsähovi Radio Observatory: https://www.metsahovi.fi/AGN/data/
- CATS: https://www.sao.ru/cats/

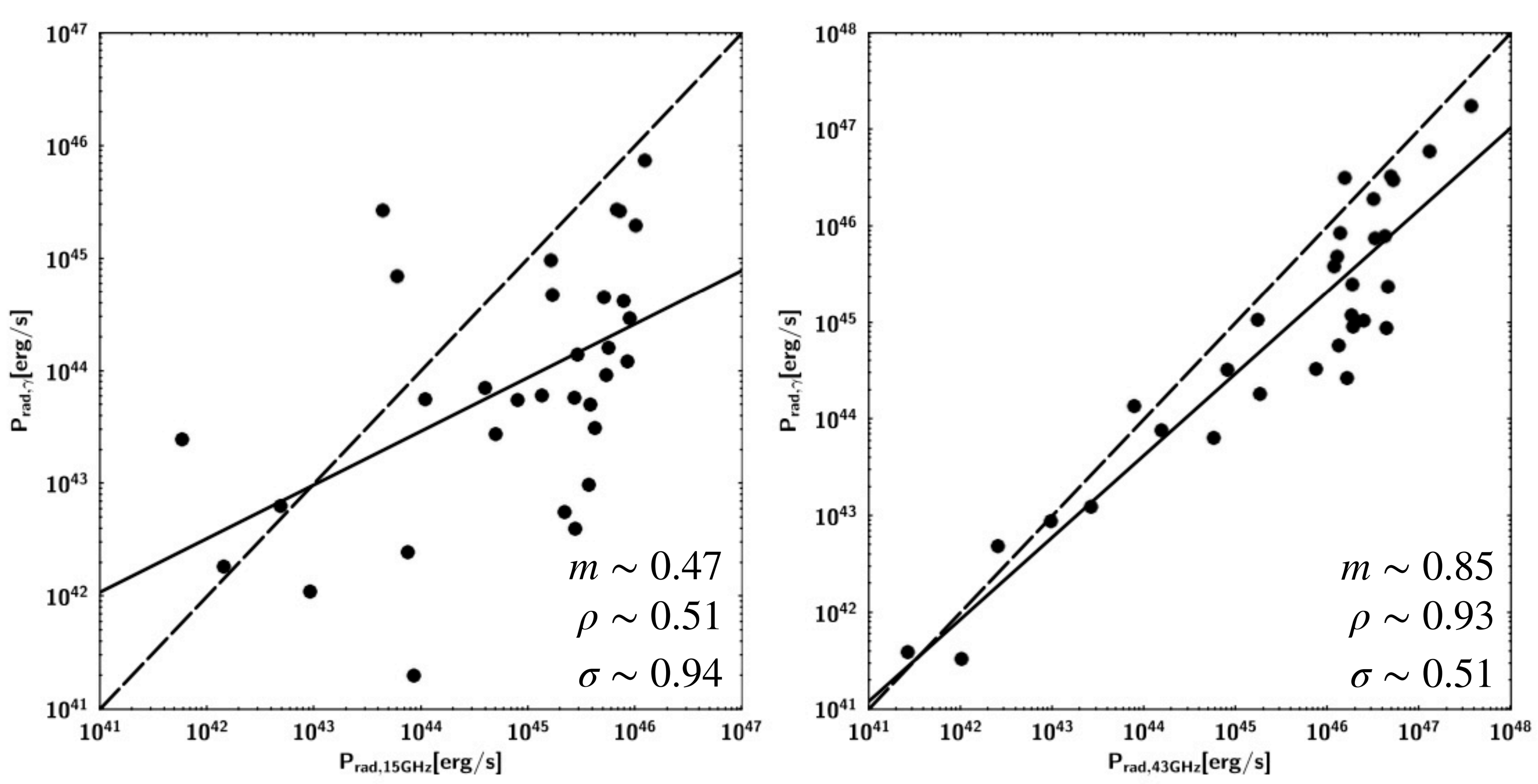
All linear fits shown are in the form:

$\log P_1 = m\log P_2 + C$

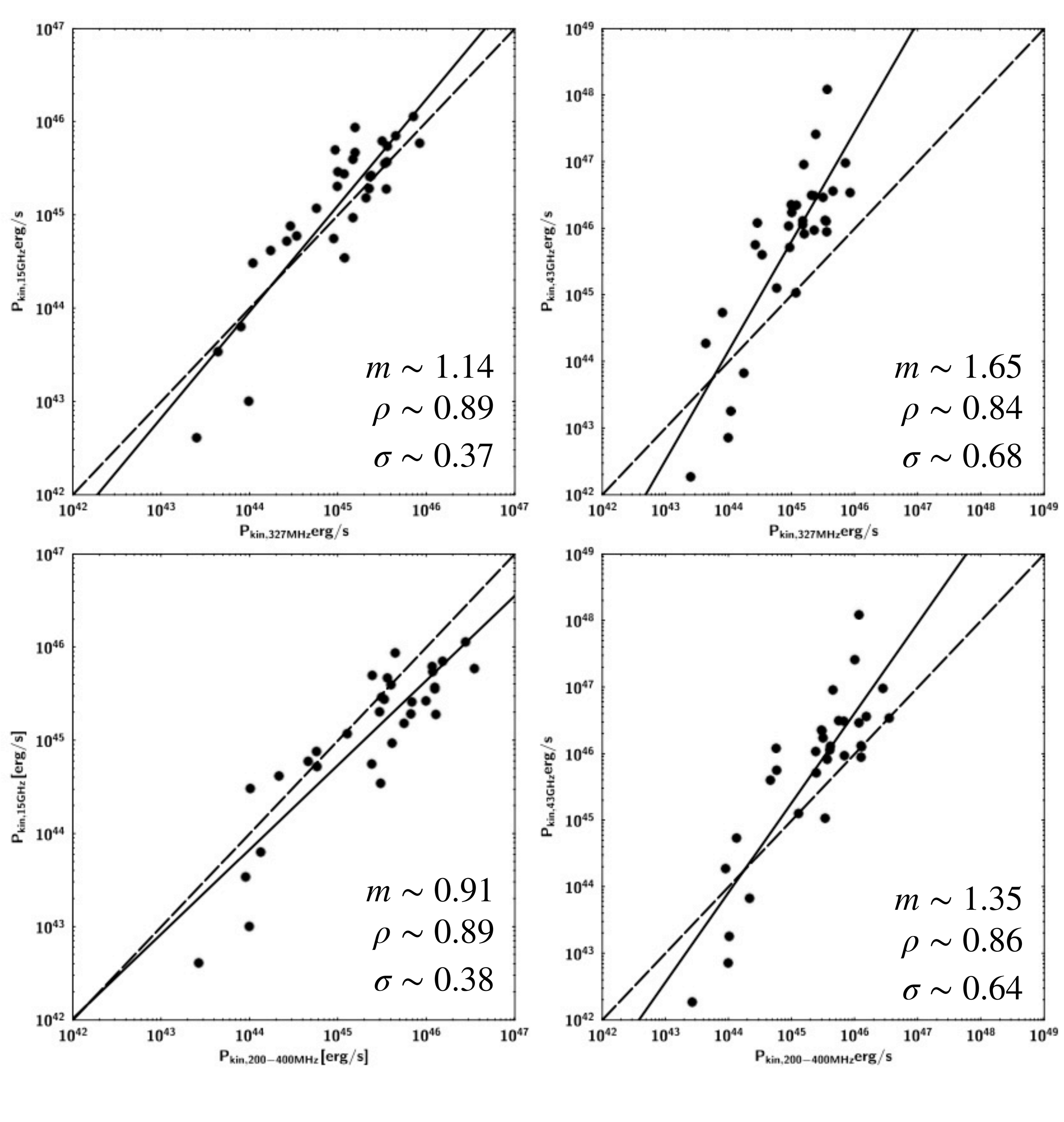
ρ: correlation coefficient

σ: dispersion

Comparison of the radiative jet power from BK1979 estimated by using VLBA data of MOJAVE Program (15 GHz), Boston University blazar program (43 GHz) vs the corresponding value estimated from high-energy gamma-rays detected by Fermi LAT (0.1-100 GeV).



Comparison of the kinetic jet power from BK1979 estimated by using VLBA data of MOJAVE Program (15 GHz), Boston University blazar program (43 GHz), and the kinetic power from extended radio emission estimated according to Bîrzan et al. (2008, ApJ 686, 859; 327 MHz) and Cavagnolo et al. (2010, ApJ 720, 1066; 200-400 MHz).



Easy-to-use equations to estimate the jet power

$$P_{\rm total} \sim (4.5\times10^{44})\left(\frac{S_\nu d_{\rm L,9}^2}{1+z}\right)^{\frac{12}{17}}\ [{\rm erg/s}]$$

$$P_{\rm kinetic} \sim (3.9\times10^{44})\left(\frac{S_\nu d_{\rm L,9}^2}{1+z}\right)^{\frac{12}{17}}\ [{\rm erg/s}]$$

$$P_{\rm radiative,synchrotron} \sim (5.6\times10^{43})\left(\frac{S_\nu d_{\rm L,9}^2}{1+z}\right)^{\frac{12}{17}}\ [{\rm erg/s}]$$

$$P_{\rm radiative,Compton} \sim (2.7\times10^{-3})L_\gamma\ [{\rm erg/s}]$$

- S_ν: radio flux density at the frequency ν [Jy]
- $d_{\rm L,9}$: luminosity distance [Gpc]
- z: redshift
- L_γ: γ − ray luminosity [erg/s]