Dynamic SEDs of southern blazars

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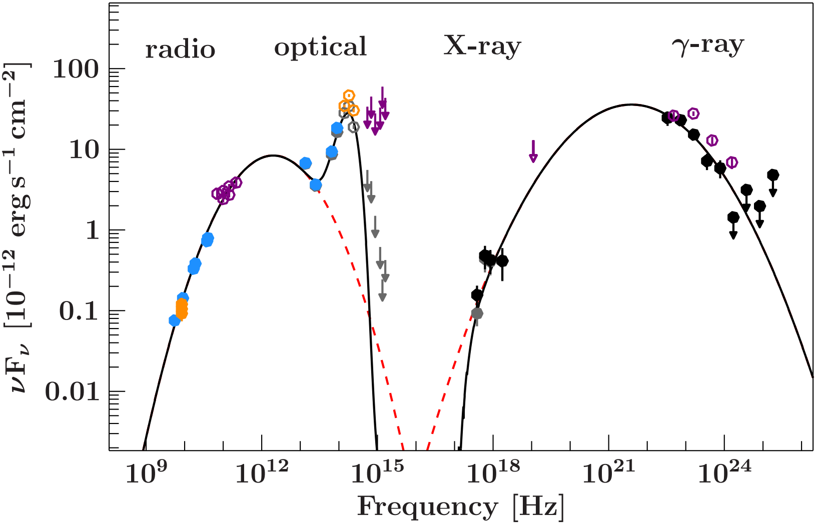
GRAPPA
GRavitation AstroParticle Physics Amsterdam

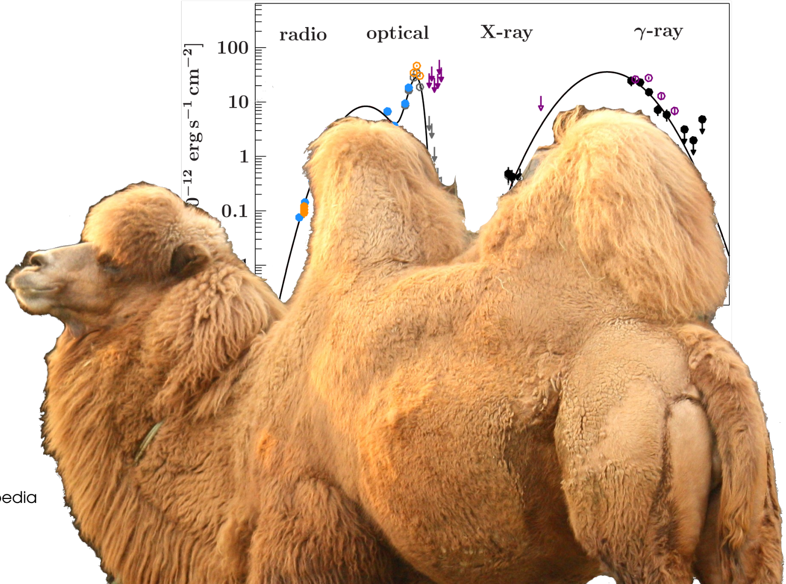
TANAMI

Fermi
Gamma-ray Space Telescope

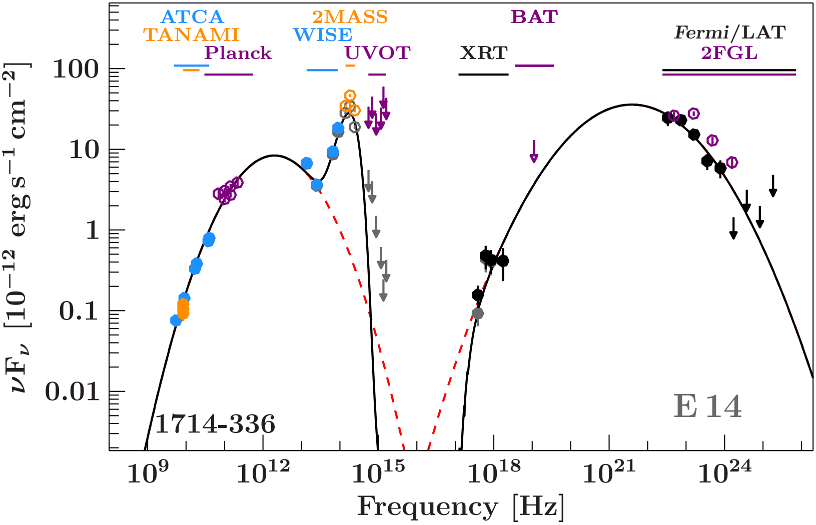
@FeKrauss



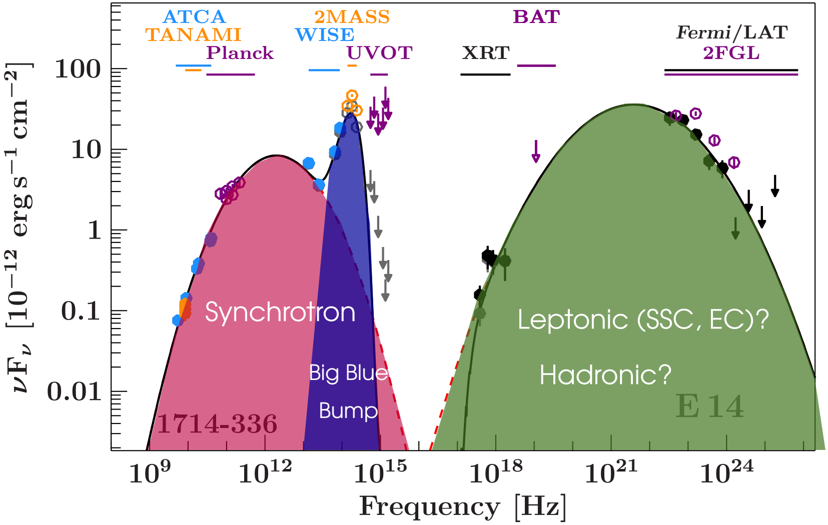
Krauß F., Kadler M., et al., A&A, 2014, 556, L7



Wikipedia



Krauß F., Kadler M., et al., A&A, 2014, 556, L7

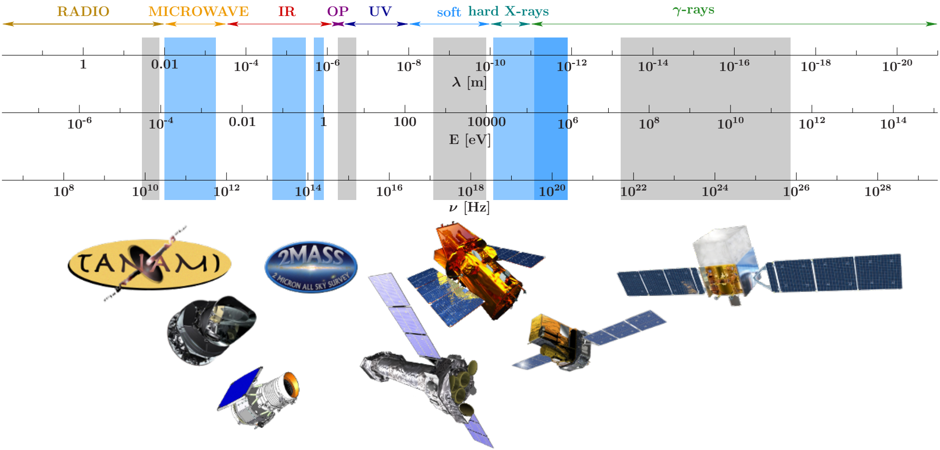


Krauß F., Kadler M., et al., A&A, 2014, 556, L7

- What is the origin of the big blue bump?
- What do we learn from the fundamental plane of black holes?
- Does the blazar sequence hold?
- What is Fermi's blazar divide?

DYNAMIC SEDS: METHODS

The electromagnetic spectrum



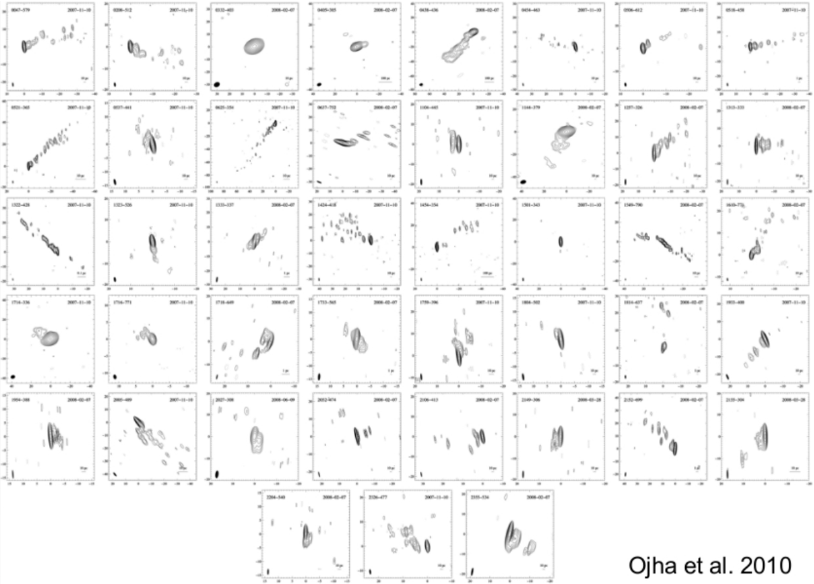
DYNAMIC SEDS: THE TANAMI MULTIWAVELENGTH PROGRAM

VLBI

Multiwavelength/multimessenger

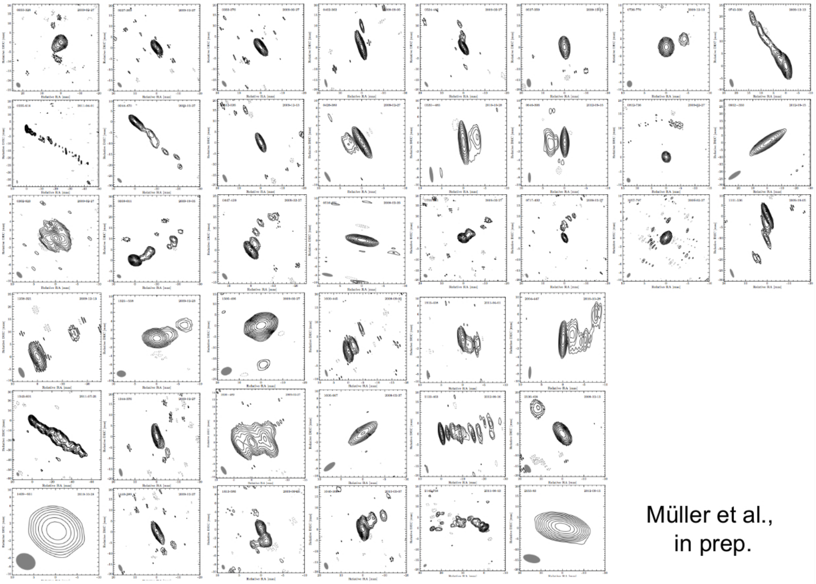
- First light in 2007
- Monitoring of > 80 AGN jets at < -30°
- LBA++
  - 5 LBA antenna
  - Hartebeesthoek, BKG, DSN, Auscope antennas
- X & K -band (8.4 and 22.3 GHz)
- 3-4 epochs per year

First epoch TANAMI images



Ojha et al. 2010

New sources



Müller et al.,
in prep.

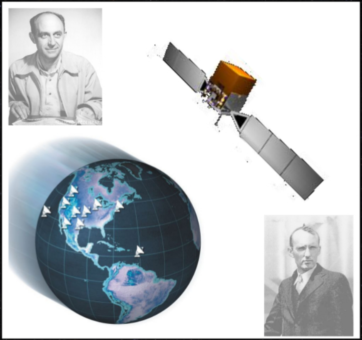
VLBI AGN-Jet Science

- VLBI Jet Components, Features
  - ➔ Shocks/Instabilities
- Core Shift (Multifrequency VLBI)
  - ➔ B-field, Pressure Gradients, etc.
- Brightness Temperature
  - ➔ Doppler Factor, Physical Gradients along the Jet
- Linear and Circular Polarization
  - ➔ B-field Orientation
- Structural Changes
  - ➔ Lorentz Factor, Ejections, Jet Interactions, HEA Connection
- Multiwavelength, Multi-Messenger Correlations
  - ➔ Jet Content, Broadband Emission, Particle Acceleration, Neutrino and UHECR Sources

General VLBI-Gamma Results

- Gamma-bright jets are faster
- Gamma-variable jets are faster than non-variable sources
- Gamma-bright jets show higher Doppler factors
- Gamma-bright jets tend to be in “radio active” states
- Gamma-bright jets show larger apparent opening angles
- Radio/Gamma time delay of ~2 months

Lister et al. 2009, Kovalev et al. 2009, Savolainen et al. 2010, Pushkarev et al. 2010, 2010b, Ojha et al. 2010, Müller et al 2011, Abdo et al. 2009a, 2009b, 2009c, 2010a, 2010b, 2010c, 2010d, 2011, Böck et al. 2016

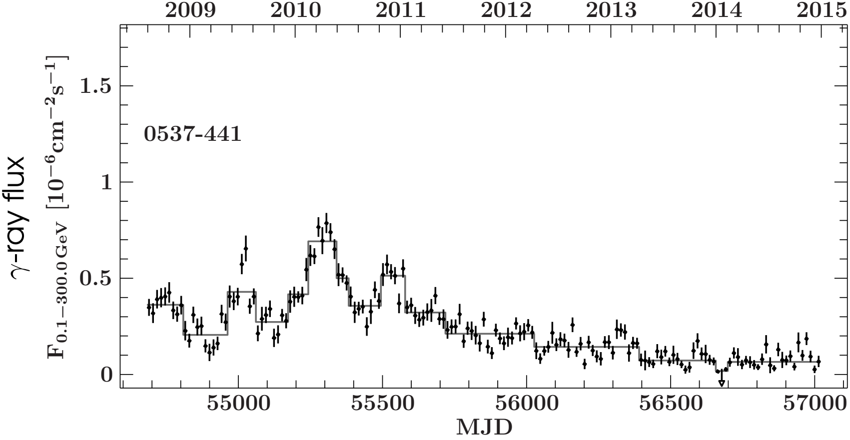


Forward-folding method

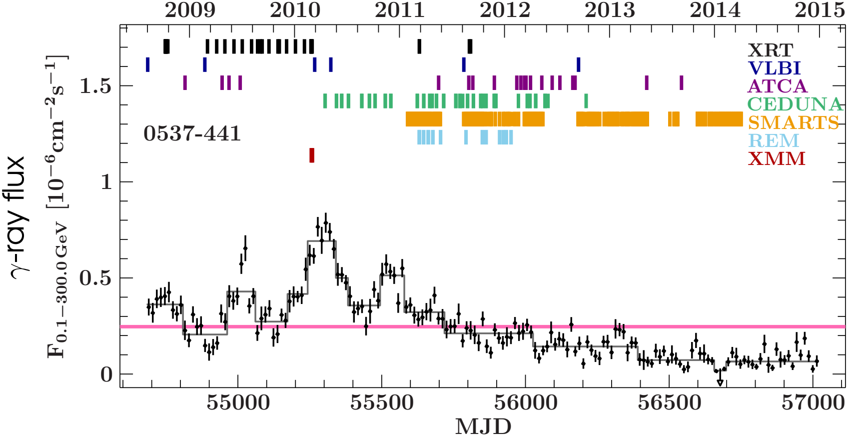
ISIS (Interactive Spectral Interpretation System):

- Model-independent fluxes (exception: LAT)
- fitting in detector space (diagonal matrices for flux data)
- accurate treatment of photoelectric absorption and extinction as part of the model

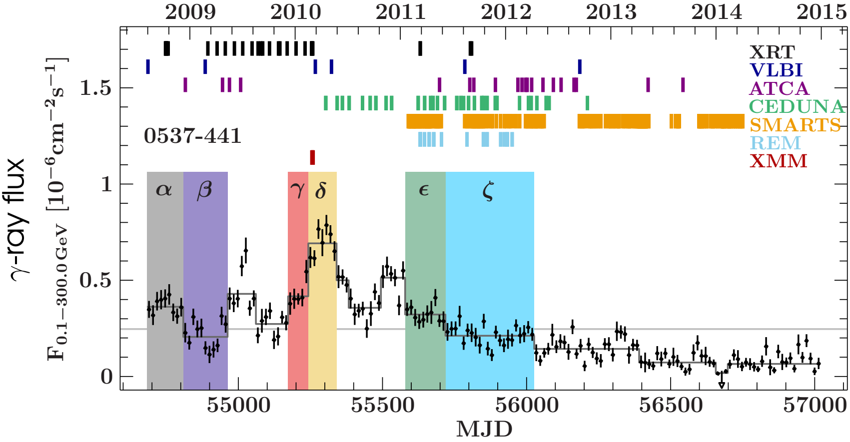
METHODS II: LAT LIGHT CURVES



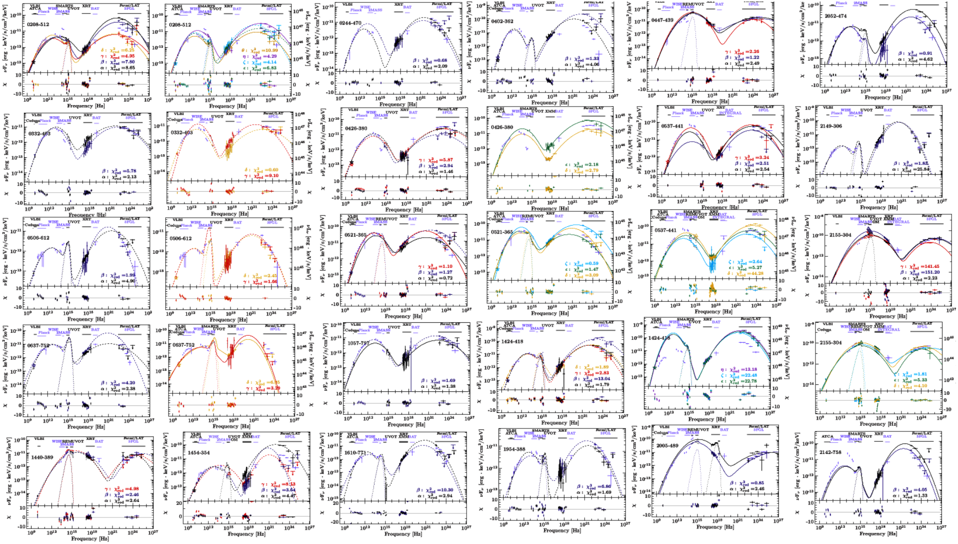
Krauß et al., 2016



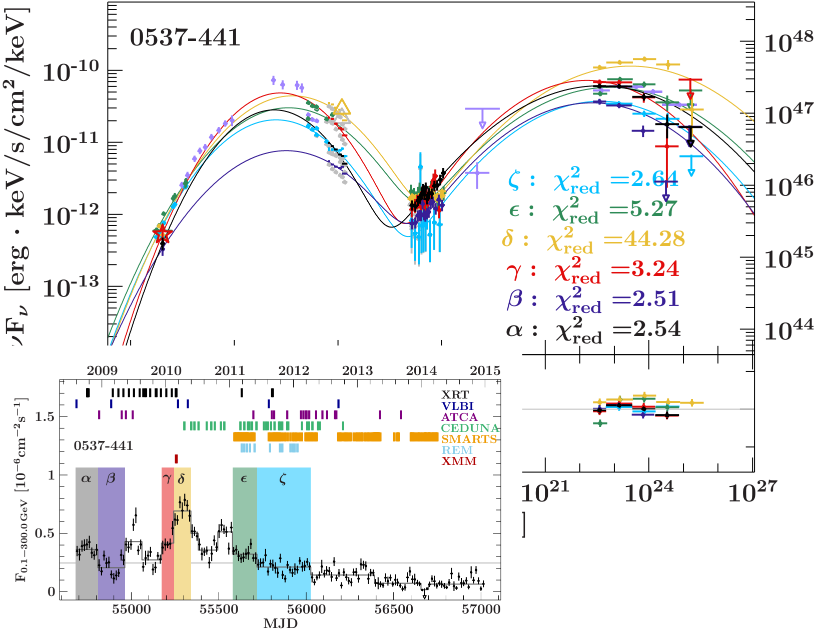
Krauß et al., 2016

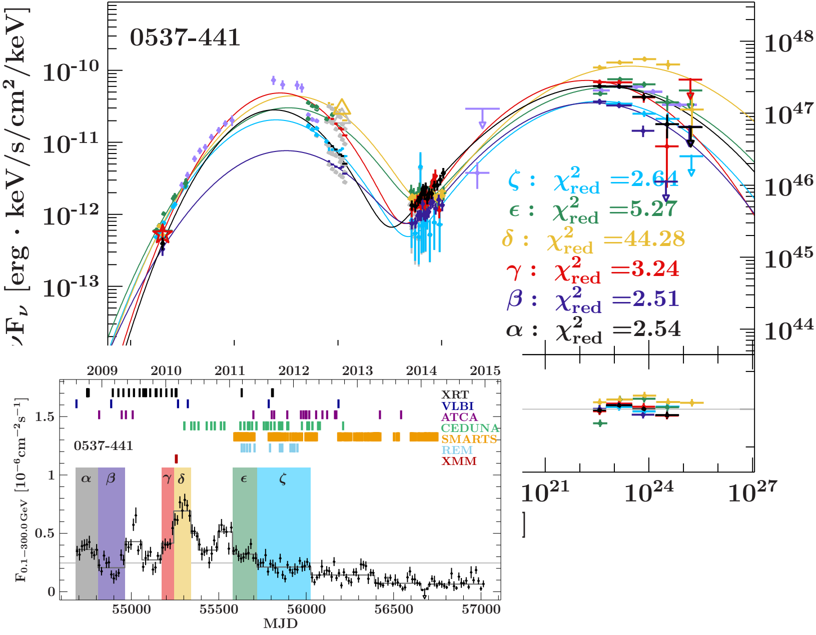


Krauß et al., 2016

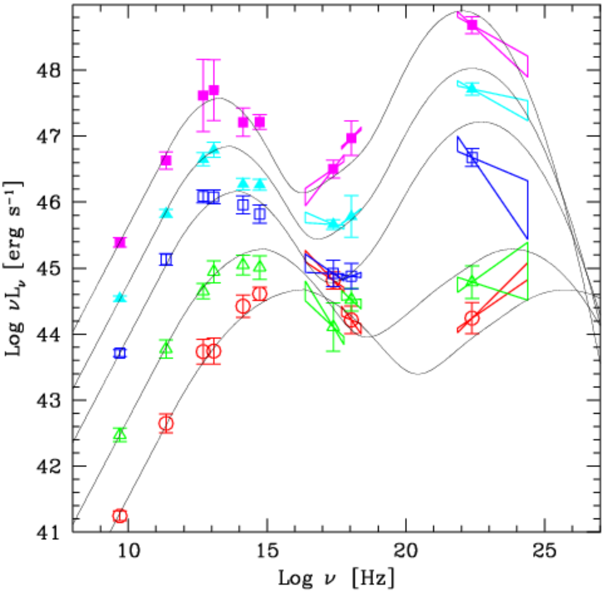


Krauß et al., 2016

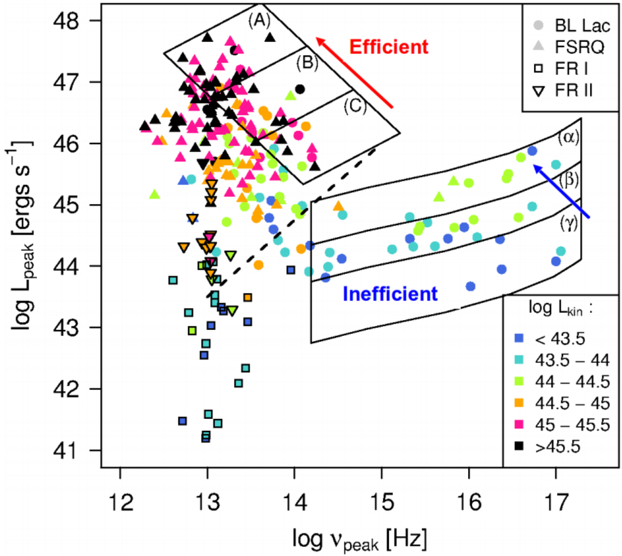

0537-441
νFν [erg · keV/s/cm²/keV]
ζ : χ²red =2.64
ϵ : χ²red =5.27
δ : χ²red =44.28
γ : χ²red =3.24
β : χ²red =2.51
α : χ²red =2.54
2009
2010
2011
2012
2013
2014
2015
XRT
VLBI
ATCA
CEDUNA
SMARTS
REM
XMM
0537-441
α
β
γ
δ
ϵ
ζ
F0.1−300.0 GeV [10⁻⁶cm⁻²s⁻¹]
MJD


0537-441
νFν [erg · keV/s/cm²/keV]
10-10
10-11
10-12
10-13
10^48
10^47
10^46
10^45
10^44
ζ : χ²red =2.64
ϵ : χ²red =5.27
δ : χ²red =44.28
γ : χ²red =3.24
β : χ²red =2.51
α : χ²red =2.54
10^21
10^24
10^27
2009
2010
2011
2012
2013
2014
2015
XRT
VLBI
ATCA
CEDUNA
SMARTS
REM
XMM
0537-441
α
β
γ
δ
ϵ
ζ
F0.1−300.0 GeV [10⁻⁶cm⁻²s⁻¹]
1.5
1
0.5
0
55000
55500
56000
56500
57000
MJD

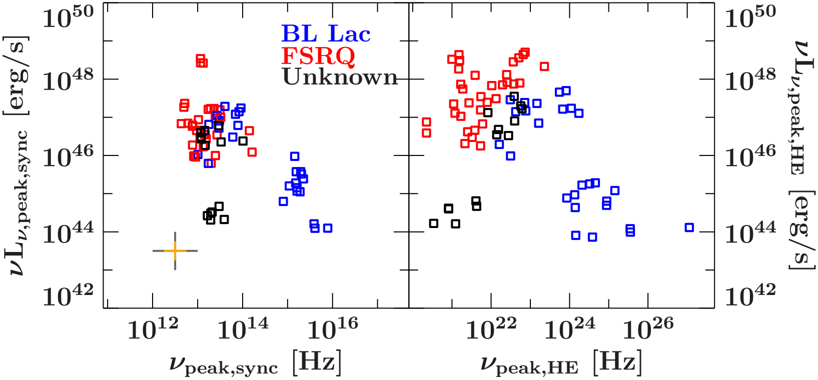
DYNAMIC SEDS: RESULTS



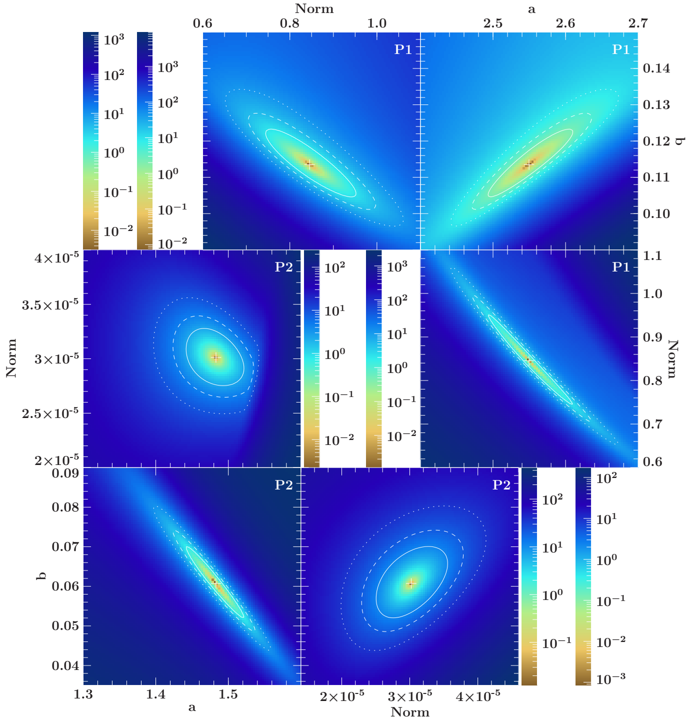
Donato et al. 2001, after Fossati et al. 1998



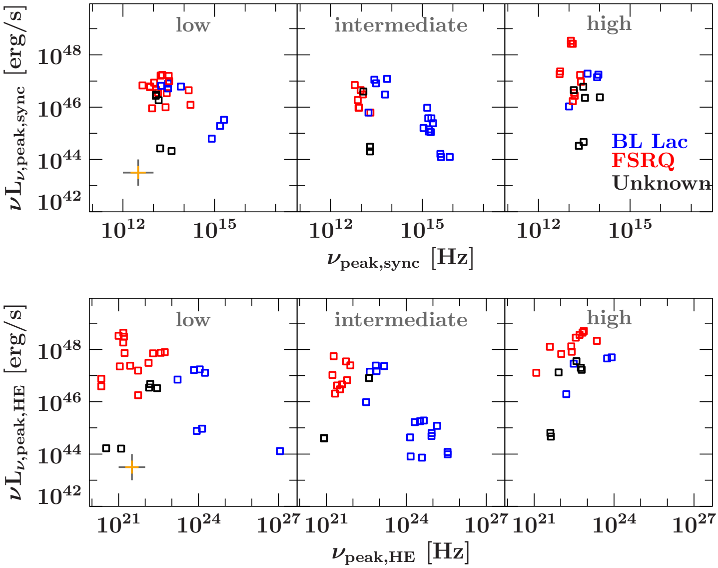
Meyer et al. 2011, 2012



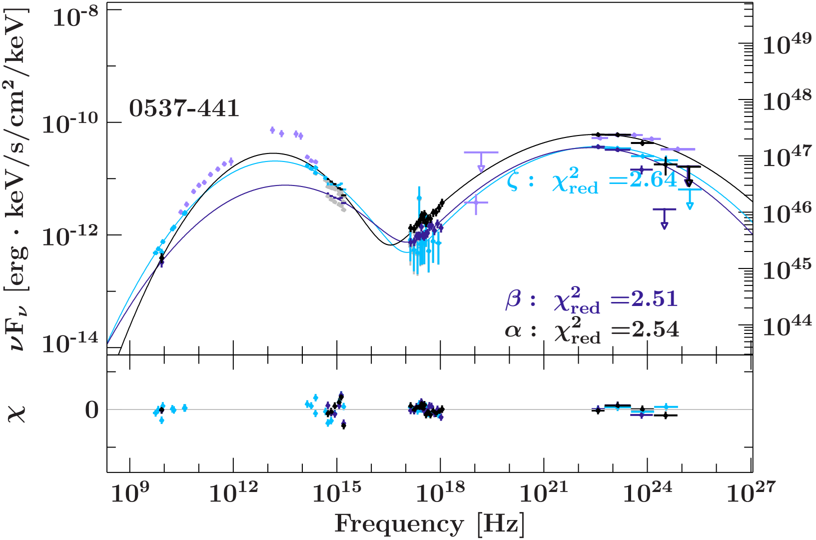
Krauß et al., 2016



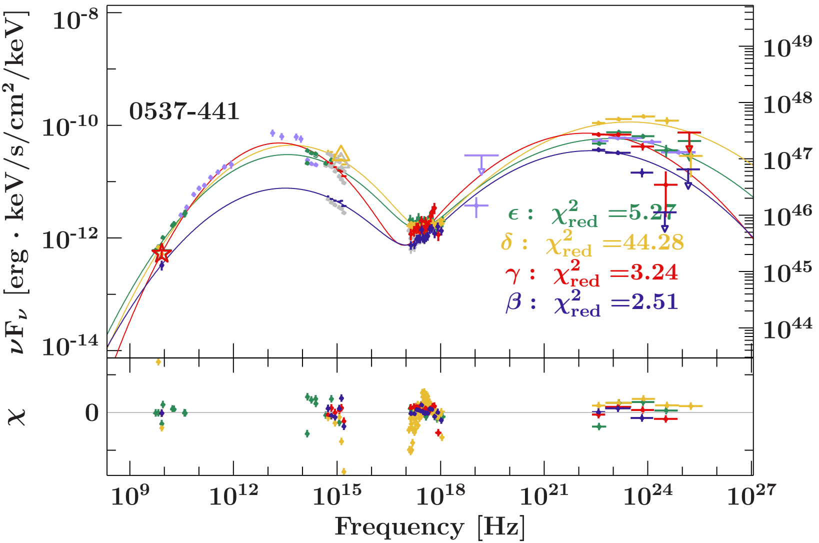
Norm
a
0.6
0.8
1.0
2.5
2.6
2.7
P1
P1
P1
P2
P2
P2
b
Norm
Norm
b
a
Norm
0.14
0.13
0.12
0.11
0.10
1.1
1.0
0.9
0.8
0.7
0.6
4×10^{-5}
3.5×10^{-5}
3×10^{-5}
2.5×10^{-5}
2×10^{-5}
0.09
0.08
0.07
0.06
0.05
0.04
1.3
1.4
1.5
2×10^{-5}
3×10^{-5}
4×10^{-5}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}



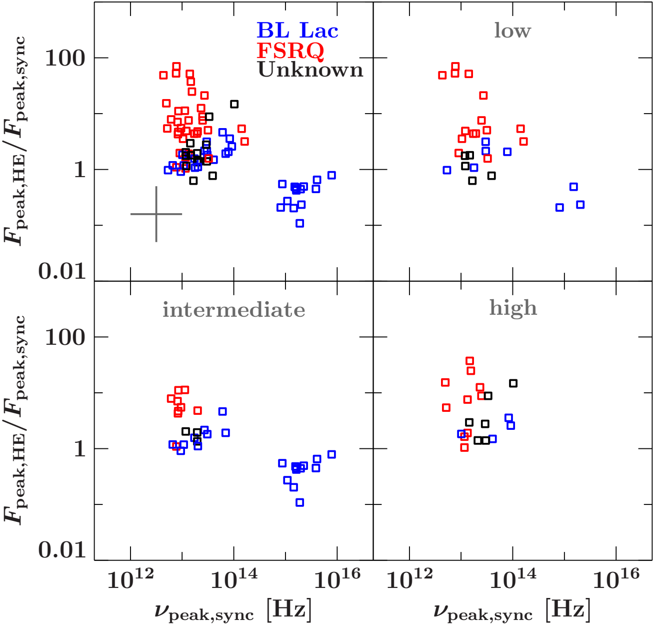
Krauß et al., 2016



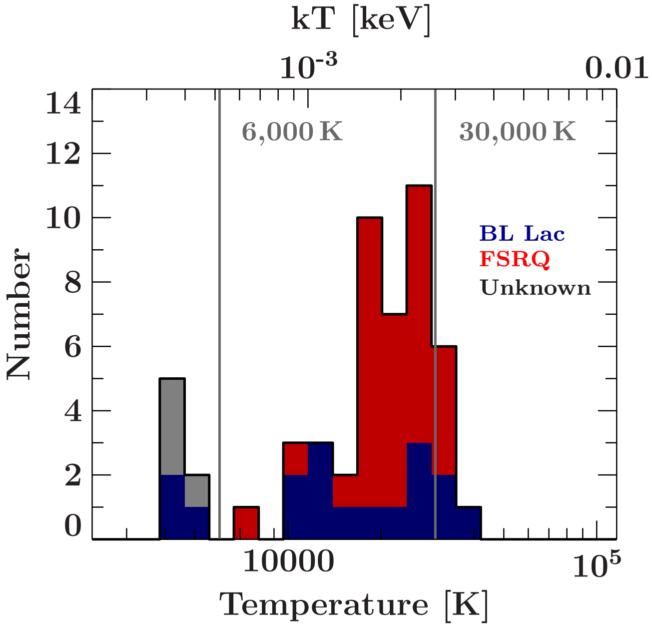
0537-441
ζ : χ²red =2.64
β : χ²red =2.51
α : χ²red =2.54
νFν [erg · keV/s/cm²/keV]
χ
Frequency [Hz]


0537-441
ϵ : χ^2_{red} =5.27
δ : χ^2_{red} =44.28
γ : χ^2_{red} =3.24
β : χ^2_{red} =2.51
νF_ν [erg · keV/s/cm^2/keV]
χ
Frequency [Hz]

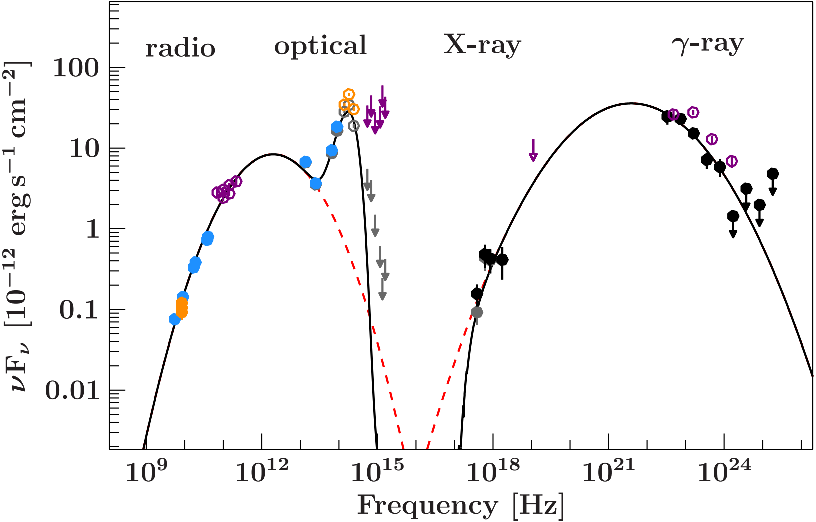
Compton dominance (see Finke 2013)



ACCRETION DISK?

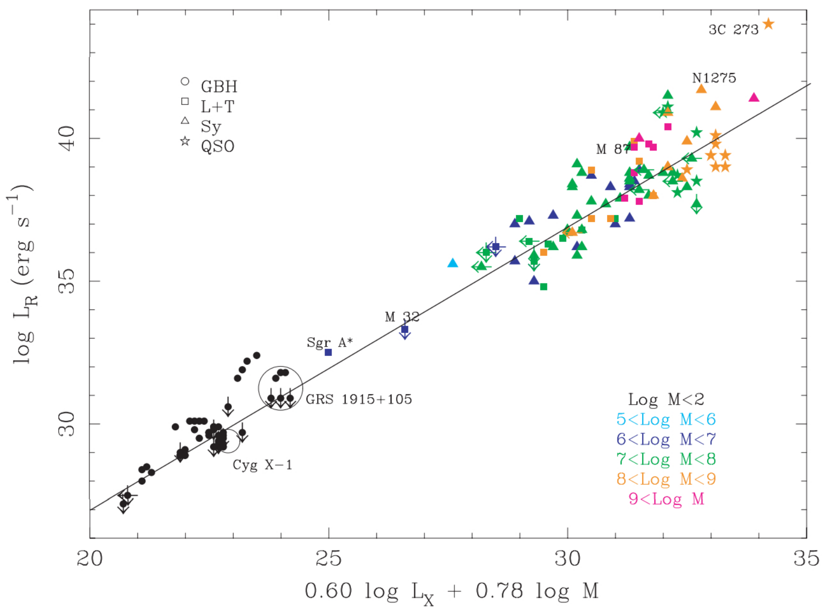


Krauß et al., 2016



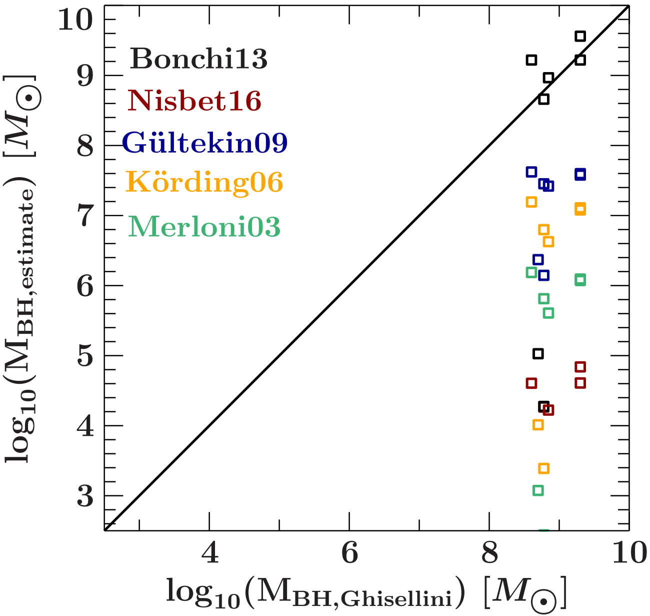
Krauß F., Kadler M., et al., A&A, 2014, 556, L7

BLACK HOLE MASS AND THE FUNDAMENTAL PLANE

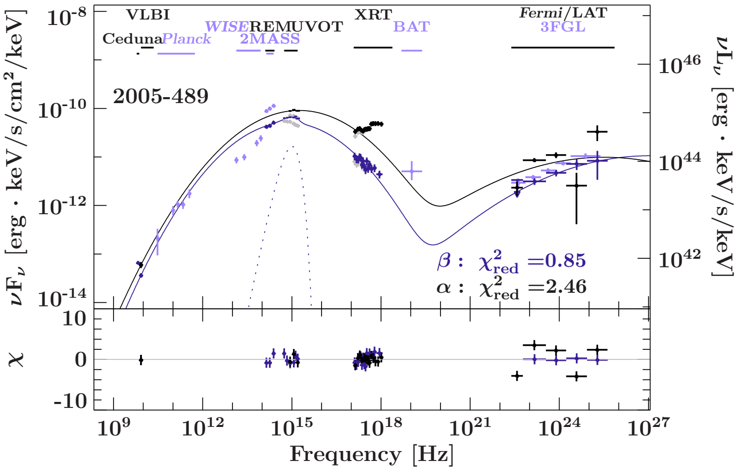


Merloni et al. 2003

Source	M_{BH} [$M_\odot$]	$M_{BH,Merloni}$ [$M_\odot$]	$M_{BH,Koerding}$ [$M_\odot$]	$M_{BH,Gültekin}$ [$M_\odot$]	$M_{BH,Bonchi}$ [$M_\odot$]	$M_{BH,Nisbet}$ [$M_\odot$]
0208-512	8.8	5.7 ± 0.9	6.7 ± 1.0	7.4 ± 0.4	8.8 ± 1.3	4.06 ± 0.04
0244-470		5.1 ± 2.6	6.2 ± 2.7	7.2 ± 1.2	8 ± 4	3.08 ± 0.24
0402-362		5.2 ± 2.7	6.3 ± 2.7	7.3 ± 1.3	8 ± 4	2.9 ± 0.4
0426-380	8.6	6.0 ± 1.3	7.0 ± 1.5	7.6 ± 0.6	9.1 ± 1.9	4.49 ± 0.04
0447-439	8.8	2.5 ± 2.0	3.4 ± 1.5	6.2 ± 1.0	4.3 ± 2.5	0.3 ± 0.5
0506-612		5.7 ± 1.5	6.7 ± 1.6	7.4 ± 0.7	8.8 ± 2.1	4.14 ± 0.05
0521-365		3.6 ± 1.2	4.6 ± 1.1	6.6 ± 0.6	5.6 ± 1.6	1.67 ± 0.17
0537-441	9.3	6.4 ± 1.1	7.4 ± 1.4	7.7 ± 0.5	9.8 ± 1.7	5.05 ± 0.04
0637-752		5.7 ± 1.5	6.7 ± 1.6	7.5 ± 0.7	9.2 ± 2.1	4.409 ± 0.027
1057-797	8.8	5.8 ± 2.5	6.8 ± 2.8	7.5 ± 1.1	9 ± 4	4.27 ± 0.04
1424-418		6.0 ± 1.1	7.1 ± 1.2	7.6 ± 0.5	9.0 ± 1.5	3.98 ± 0.06
1440-389		1.9 ± 2.0	2.8 ± 1.4	5.9 ± 1.1	3.7 ± 2.5	−0.1 ± 0.5
1454-354	9.3	6.0 ± 1.8	7.0 ± 2.0	7.6 ± 0.8	9.2 ± 2.6	4.567 ± 0.009
1610-771		5.9 ± 2.6	6.9 ± 2.8	7.5 ± 1.1	9 ± 4	4.35 ± 0.08
1954-388		5.7 ± 2.5	6.7 ± 2.8	7.4 ± 1.1	9 ± 4	4.408 ± 0.017
2005-489	8.7	3.1 ± 2.7	4.0 ± 2.2	6.4 ± 1.3	5 ± 4	1.1 ± 0.5
2052-474		6.1 ± 2.6	7.1 ± 2.9	7.6 ± 1.1	9 ± 4	4.39 ± 0.06
2142-758		5.5 ± 2.6	6.5 ± 2.7	7.4 ± 1.2	9 ± 4	3.85 ± 0.13
2149-306		5.3 ± 1.6	6.3 ± 1.6	7.4 ± 0.8	8.9 ± 2.2	3.58 ± 0.13


Bonchi13
Nisbet16
Gültekin09
Körding06
Merloni03
$\log_{10}(M_{BH,estimate})$ $[M_\odot]$
$\log_{10}(M_{BH,Ghisellini})$ $[M_\odot]$
10
9
8
7
6
5
4
3
4
6
8
10

HADRONIC SIGNATURES?



Krauß et al., 2016

Caveats

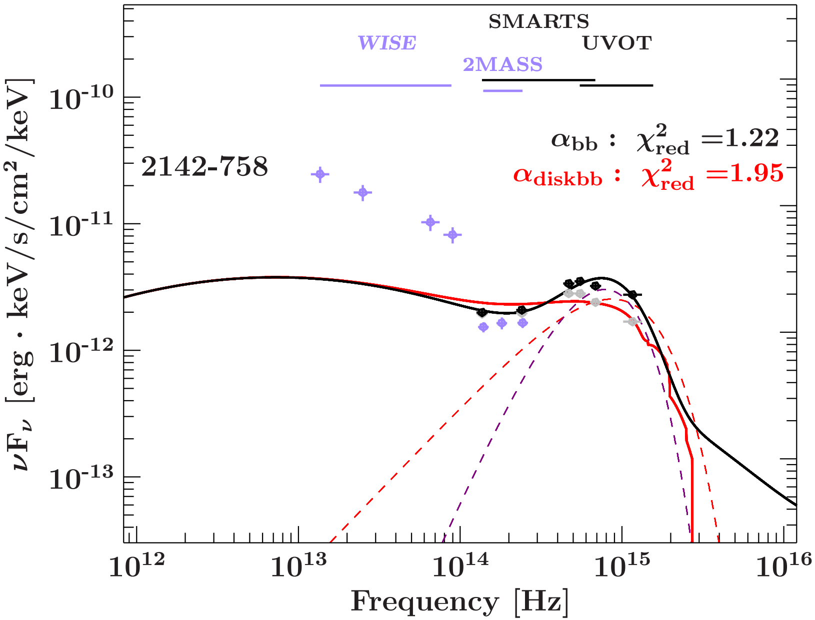
- Lack of monitoring at other wavelengths
- Different scales and time delays
- Sample bias, representative for γ-ray bright

- blazar SEDs multi-epoch quasi-simultaneous
- accretion disk origin of big blue bump?
- low masses estimated from fundamental plane
- hadronic SED signatures?

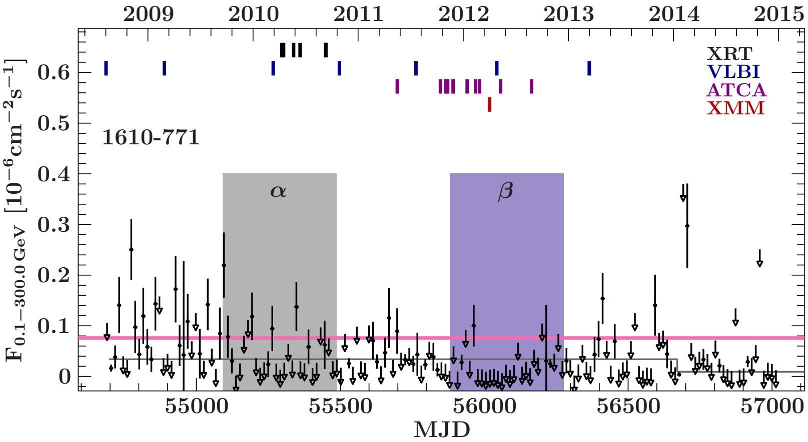
BACKUP

No	Source	Catalog	3FGL	Class.	z	α [J2000]	δ [J2000]	N_H [10^{20} cm^{-2}]	# SEDs
1	0208−512	PKS 0208−512	J0210.7−5101	BCU [a]	0.999[b]	32.6925[c]	−51.0172[c]	1.84	8
2	0244−470	PKS 0244−470	J0245.9−4651	FSRQ[d]	1.385[e]	41.5005[d]	−46.8548[d]	1.89	2
3	0332−376	PMN J0334−3725	J0334.3−3726	BL Lac[d]	?	53.5642[a]	−37.4287[a]	1.54	2
4	0332−403	PKS 0332−403	J0334.3−4008	BL Lac[d]	?	53.5569[c]	−40.1404[c]	1.48	4
5	0402−362	PKS 0402−362	J0403.9−3604	FSRQ[d]	1.423[f]	60.9740[c]	−36.0839[c]	0.60	2
6	0426−380	PKS 0426−380	J0428.6−3756	BL Lac[d]	1.111[g]	67.1684[c]	−37.9388[c]	2.09	5
7	0447−439	PKS 0447−439	J0449.4-4350	BL Lac[h]	0.107[i]	72.3529[a]	−43.8358[a]	1.24	3
8	0506−612	PKS 0506−61	J0507.1−6102	FSRQ[h]	1.093[j]	76.6833[c]	−61.1614[c]	1.95	4
9	0521−365	PKS 0521−36	J0522.9−3628	BCU	0.055[f]	80.7416[c]	−36.4586[c]	3.58	6
10	0537−441	PKS 0537−441	J0538.8−4405	BL Lac[d]	0.892[k]	84.7098[l]	−44.0858[l]	3.14	6
11	0637−752	PKS 0637−75	J0635.7−7517	FSRQ[d]	0.651[m]	98.9438[c]	−75.2713[c]	7.82	4
12	1057−797	PKS 1057−79	J1058.5−8003	BL Lac[d]	0.581[n]	164.6805[c]	−80.0650[c]	6.34	2
13	1424−418	PKS B1424−418	J1427.9−4206	FSRQ[d]	1.522[o]	216.9846[c]	−42.1054[c]	7.71	7
14	1440−389	PKS 1440−389	J1444.0−3907	BL Lac[d]	0.065[p]	220.9883[d]	−39.1445[d]	7.83	3
15	1454−354	PKS 1454−354	J1457.4−3539	FSRQ[d]	1.424[q]	224.3613[r]	−35.6528[r]	6.60	3
16	1610−771	PKS 1610−77	J1617.7−7717	FSRQ[d]	1.710[s]	244.4551[c]	−77.2885[c]	6.76	2
17	1954−388	PKS 1954−388	J1958.0−3847	FSRQ[d]	0.630[t]	299.4992[u]	−38.7518[u]	6.43	2
18	2005−489	PKS 2005−489	J2009.3−4849	BL Lac[d]	0.071[v]	302.3558[c]	−48.8316[c]	3.93	2
19	2052−474	PKS 2052−47	J2056.2−4714	FSRQ[d]	1.489[w]	314.0682[c]	−47.2465[c]	2.89	2
20	2142−758	PKS 2142−75	J2147.3−7536	FSRQ[d]	1.139[w]	326.8030[c]	−75.6037[c]	7.70	2
21	2149−306	PKS 2149−306	J2151.8−3025	FSRQ[h]	2.345[j]	327.9813[c]	−30.4649[c]	1.63	4
22	2155−304	PKS 2155−304	J2158.8−3013	BL Lac[d]	0.116[x]	329.7169[y]	−30.2256[y]	1.48	6

Notes. Columns: (1) source number (2) IAU B1950 name, (3) 3FGL association, (4) 3FGL catalog name (Acero et al. 2015), (5) classification, (6) redshift, (7) right ascension, (8) declination, (9) absorbing column (Kalberla et al. 2005; Bajaja et al. 2005), (10) number of SEDs
[a] Skrutskie et al. (2006), [b] Wisotzki et al. (2000), [c] Johnston et al. (1995), [d] Healey et al. (2007), [e] Shaw et al. (2012), [f] Jones et al. (2009), [g] Heidt et al. (2004), [h] Véron-Cetty & Véron (2006), [i] Craig & Fruscione (1997), [j] Hewitt & Burbidge (1987), [k] Peterson et al. (1976), [l] Beasley et al. (2002), [m] Hunstead et al. (1978), [n] Sbarufatti et al. (2009), [o] White et al. (1988), [p] Jones et al. (2004), [q] Jackson et al. (2002), [r] Fey et al. (2006), [s] Hunstead & Murdoch (1980), [t] Browne et al. (1975), [u] Ma et al. (1998), [v] Falomo et al. (1987), [w] Jauncey et al. (1984), [x] Falomo et al. (1993), [y] Fey et al. (2004)



SMARTS
WISE
UVOT
2MASS
α_{bb} : χ^2_{red} =1.22
α_{diskbb} : χ^2_{red} =1.95
2142-758
νF_ν [erg · keV/s/cm^2/keV]
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
Frequency [Hz]



2009
2010
2011
2012
2013
2014
2015
XRT
VLBI
ATCA
XMM
1610-771
α
β
0.6
0.5
0.4
0.3
0.2
0.1
0
$F_{0.1-300.0\,GeV}$ $[10^{-6} cm^{-2} s^{-1}]$
55000
55500
56000
56500
57000
MJD

Reference	d	e	f	$\nu_{\rm radio}$ [GHz]	source population
Merloni et al. (2003)	1.28 ± 0.15	0.77 ± 0.17	9.40	5.0	Quasars, LINERs, Seyferts
Körding et al. (2006)	1.28 ± 0.30	0.73 ± 0.20	10.49	5.0	Quasars, LINERs, Seyferts
Gültekin et al. (2009)	0.48 ± 0.17	0.24 ± 0.16	0.83	5.0	Seyferts, Transition Objects, Unclassified Objects
Bonchi et al. (2013)	1.47	0.57 ± 0.07	24.43	1.4	Type 1 & Type 2
Nisbet & Best (2016)	1.45 ± 0.22	0.94 ± 0.18	8.01	1.4	LINERs