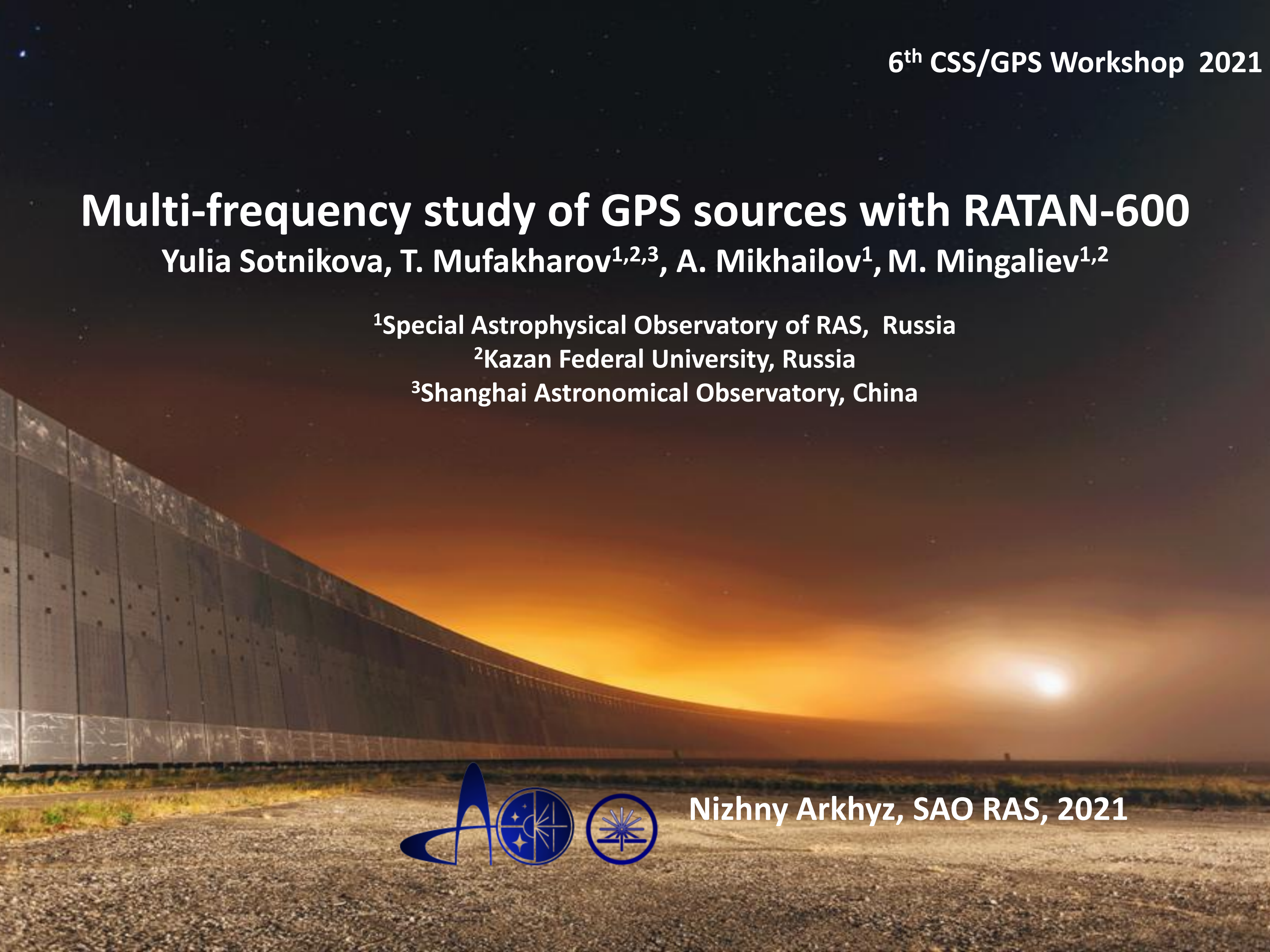

6th CSS/GPS Workshop 2021

Multi-frequency study of GPS sources with RATAN-600

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Nizhny Arkhyz, SAO RAS, 2021

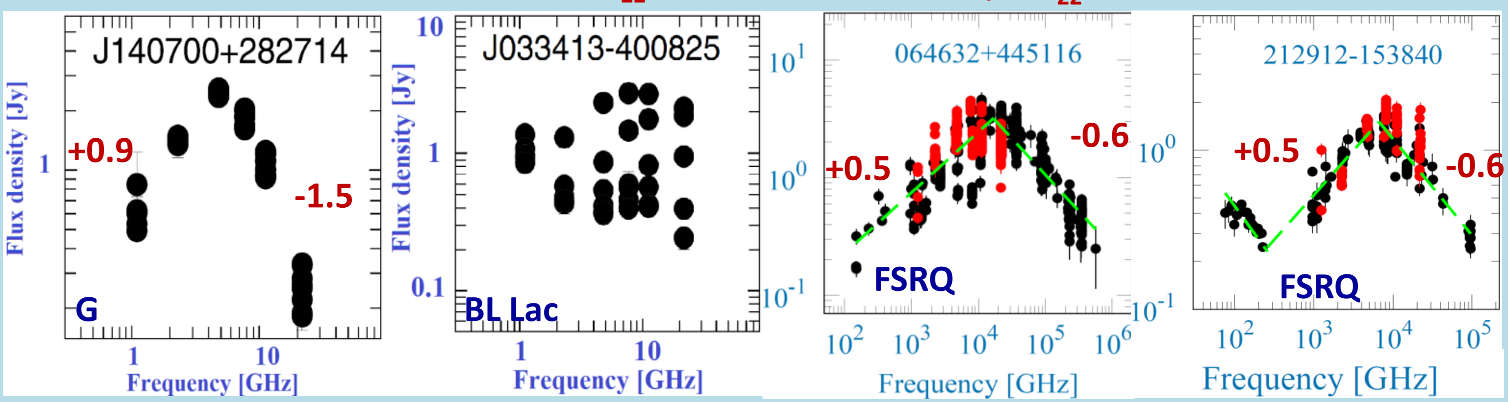
Introduction

- GPS classification /multi-frequency monitoring.
- RATAN observations 2006-2021 and samples.
- radio properties GPS galaxies and quasars.
- PS sources at high redshifts.
- blazars with peaked spectrum.
- new GPS candidates. MPS sources.
- search tools (CATS, BLcat)

Initial SPS samples:

Gopal-Krishna, Patnaik, & Steppe (1983)
O'Dea et al., 1991
Stanghellini et al., 1998
Fanti et al., 2001
Dallacasa 2000, 2002
...

FWHM=0.9; Var_{22}=16% Var_{22}=73%   FWHM=1.9; Var_{22}=65%   FWHM=1.2; Var_{22}=43%



RATAN-600, time scale is 2006-2010

RATAN-600 + CATS, 2017-2020

$$V_S = \frac{(S_{\max} - \sigma_{S_{\max}}) - (S_{\min} + \sigma_{S_{\min}})}{(S_{\max} - \sigma_{S_{\max}}) + (S_{\min} + \sigma_{S_{\min}})}$$

CATS: Astrophysical CATalogs support System; www.sao.ru/cats/

Samples and observations 2006-2021

Sample 1
Targeted GPS list (122), 76 QSO, 29 G, 22 un. type from Torniainen & Tornikoski (2003, 2005, 2007);
2006-2010

Sample 2
Complete GPS sample (457), 76 QSO, 29 G, 22 un. type.
$S_5 \geq 200$ mJy
2011-2019

Comparison Samples 3-4
GPS in a complete QSO samples:
$z \geq 3$; $S_{NVSS} \geq 100$ mJy (102, 48 blazars)
$z \geq 4$; $S_{NVSS} \geq 20$ mJy (37, 11 blazars)
2017-2021

RATAN obs at 1.2, 2.3, 4.7, 7.7/8.2, 11.2 and 22 GHz

2-4 times per year

Goals:
Radio continuum spectra
Variability
GPS classification
New CSS/GPS/MPS candidates

- Sotnikova et al., 2021, The high redshift QSO catalogue
- Sotnikova et al., 2019AstBu..74..348S, 2019yCatp033007403S
- Mingaliev et al., 2013AstBu..68..262M, 2013yCatp033006802M
- Mingaliev et al., 2012A&A...544A..25M, 2012yCat..35440025M

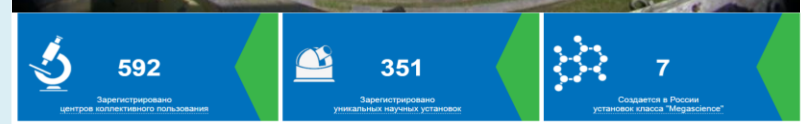
RATAN-600 SAO RAS

- 600 m multi-elements variable profile antenna
- simultaneous radio spectra at 1-22 GHz
- Declination range is -40º ÷ +90º

f_0 (GHz)	Δf_0 (GHz)	ΔF (mJy/beam)	$HPBW_x$ sec	AR arcsec
22.3	2.5	70	1.0	11
11.2	1.4	20	1.4	16
8.2	1.0	25	2.0	22
4.7	0.6	5	3.2	36
2.25	**0.08**	**40**	**7.2**	**80**
1.28	**0.06**	**175**	**15.4**	**170**

f_0 (GHz)	Δf_0 (GHz)	ΔF (mJy/beam)	$HPBW_x$ sec	AR arcsec
22.3	2.5	88	1.5	16.5
11.2	1.0	20	2.0	25
4.7	0.6	11	4.8	50

f_0 – central frequency;
Δf_0 - bandwidth;
ΔF – sensitivity (mJy/beam);
BW is the width of the diagram at average elevations;
AR – is angular resolution (for DEC=0°).



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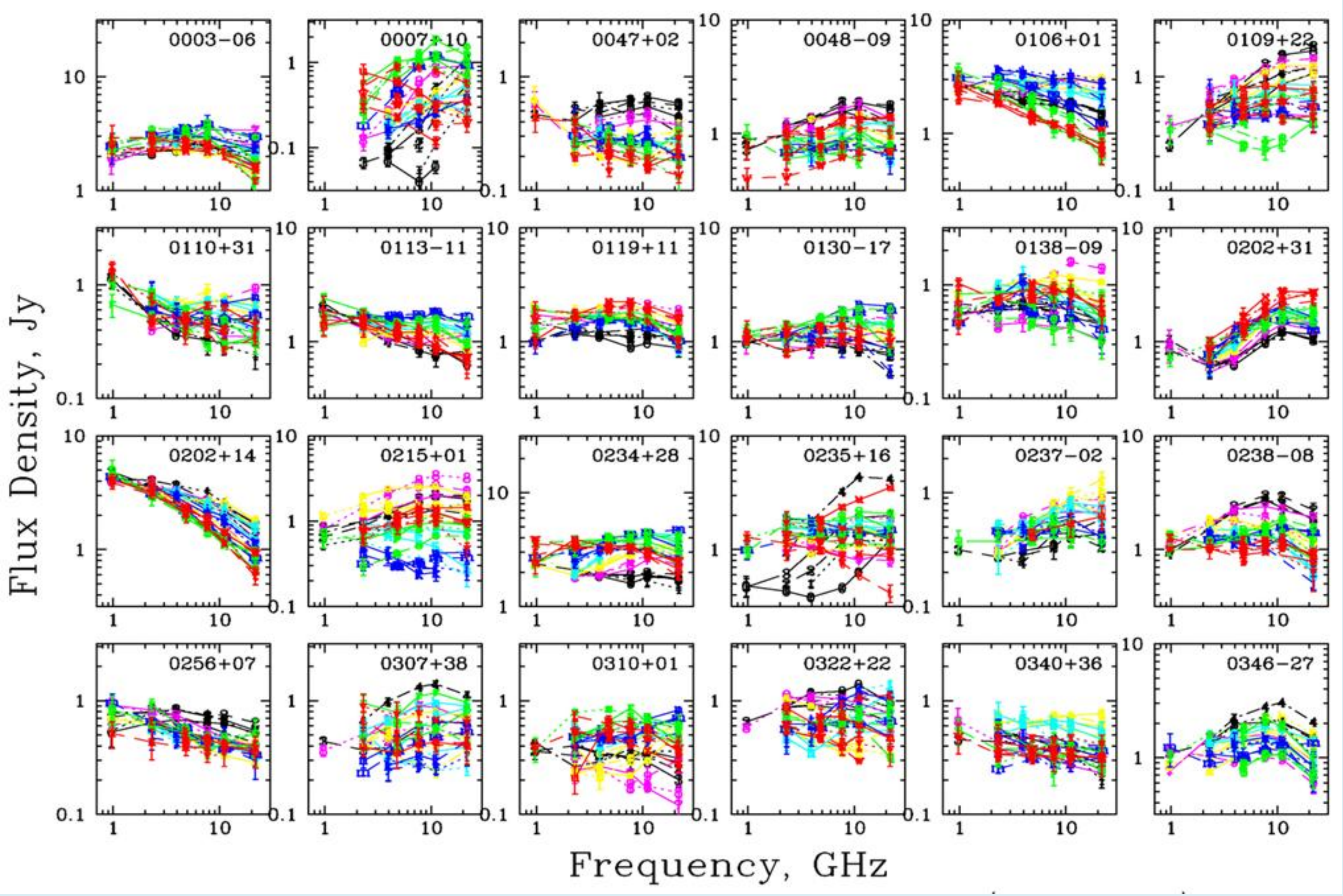
Karachai-Cherkessian Republic
Russia 369167 www.sao.ru

Quasi-simultaneous radio spectra

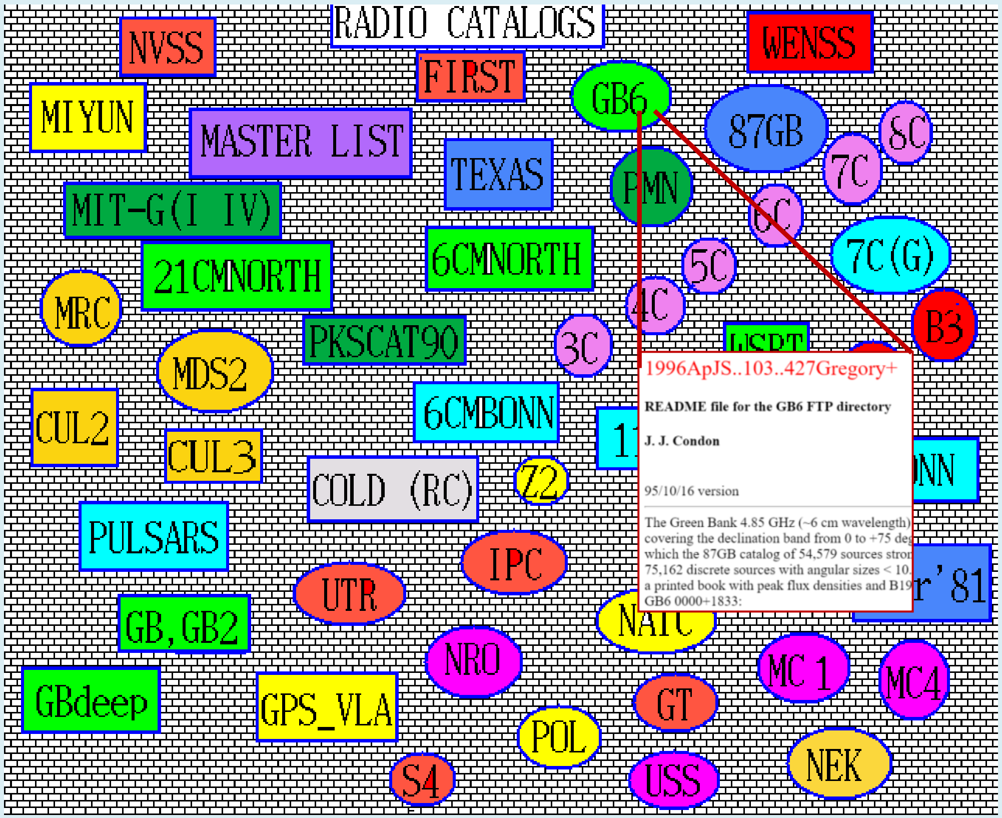


Kovalev et al., RATAN observations

Search tool: the CATS Database

Astrophysical CATalogs support System

www.sao.ru/cats/



literature data		
GLEAM	MRC	VCS
VLSS	NAIC	KOV97
TGSS	GPSDa	NCPMi
TXS	GPSTi	GPSRa
Kuehr	GPSSt	SRCAT
PKS90	NVSS	SRCKi
WENSS	QORG	WMAP
MIYUN	MSL	VLAC
WISH	PKSFL	VLASS

Cross identification of the catalogs; find measurements; construct the spectra; calculate fluxes, spectral indexes and variability at different frequencies; building the average continuum radio spectra.

- radio catalogues;
- ~630;
- descriptions, software, graphics.

(Verkhodanov et al., 1997, 2005, 2009)

GPS classification

Sample 1	PS	GPS	%
122	122	48	40

Sample 2	PS	GPS	%
~5000	467	112	2

Sample 3	PS	GPS	%
102	47	17	17

Sample 4	PS	GPS	%
37	16	6	16

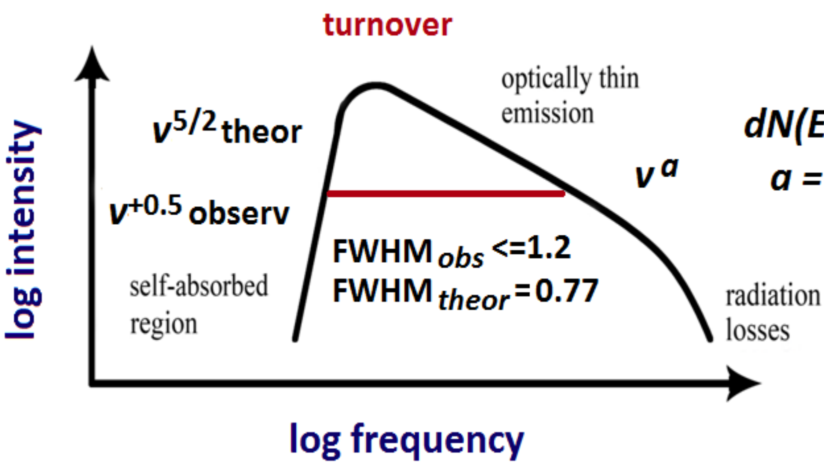
Criteria of canonical GPS adopted from de Vries et al., (1997). The value of FWHM is taken from O'Dea et al., (1991).

α_{below}	α_{above}	Var_{radio}	FWHM
0.5	-0.7	≤ 0.25	≤ 1.2

$S \sim \nu^{\alpha}$,

$$V_S = \frac{(S_{\max} - \sigma_{S_{\max}}) - (S_{\min} + \sigma_{S_{\min}})}{(S_{\max} - \sigma_{S_{\max}}) + (S_{\min} + \sigma_{S_{\min}})}$$

$$M = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(S_i - \frac{1}{N}\sum_{i=1}^{N} S_i)^2}}{\frac{1}{N}\sum_{i=1}^{N} S_i}$$

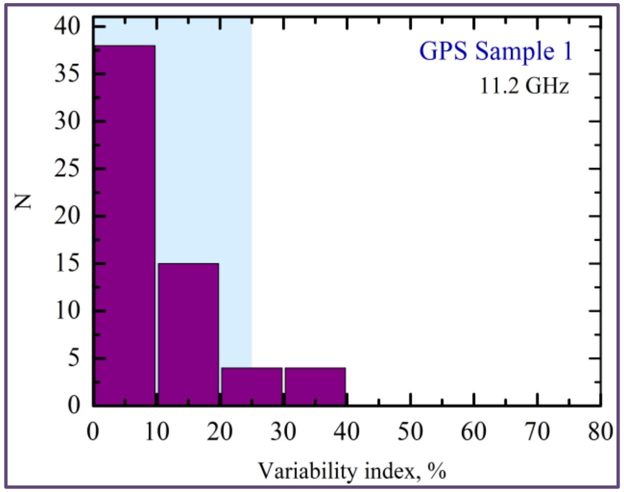


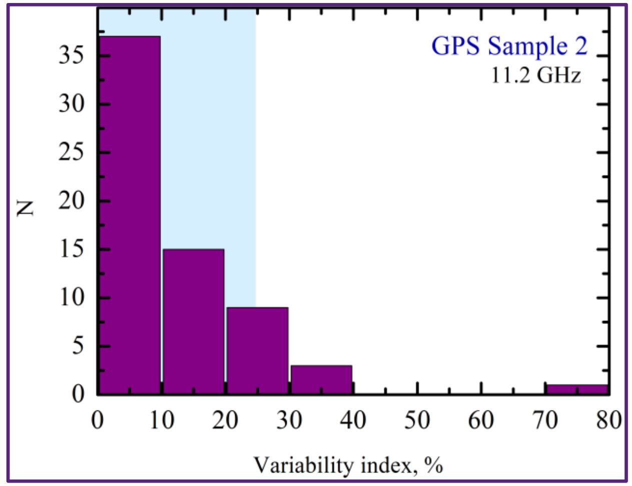
$dN(E) = kE^{-y}dE$

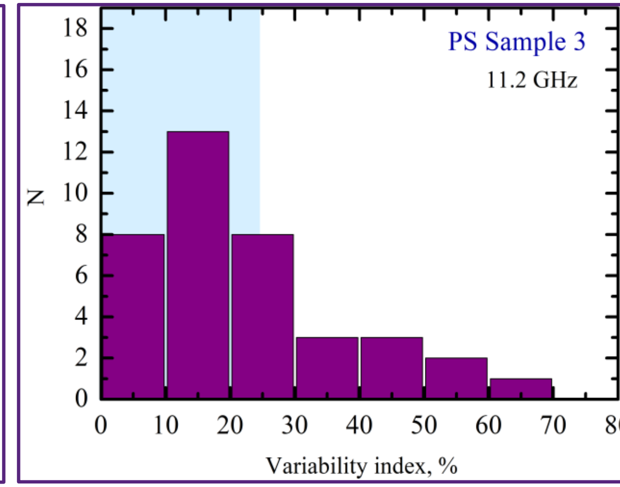
$a = (y - 1) / 2$

2012A&A...544A..25M

Variability

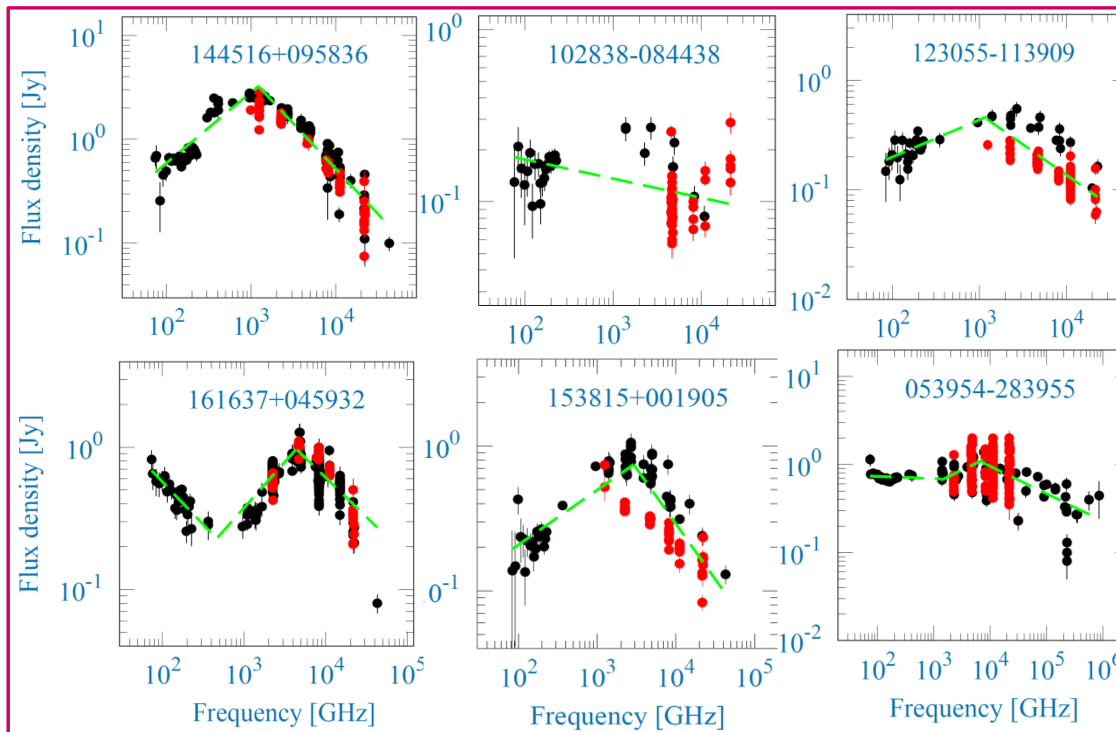






Sample	$Var_{11.2}$, %		Time period, years
	G	QSO	
1	5%	11%	5
2	8%	14%	12
3	-	23%	4

Sample 3, QSO, z≥3

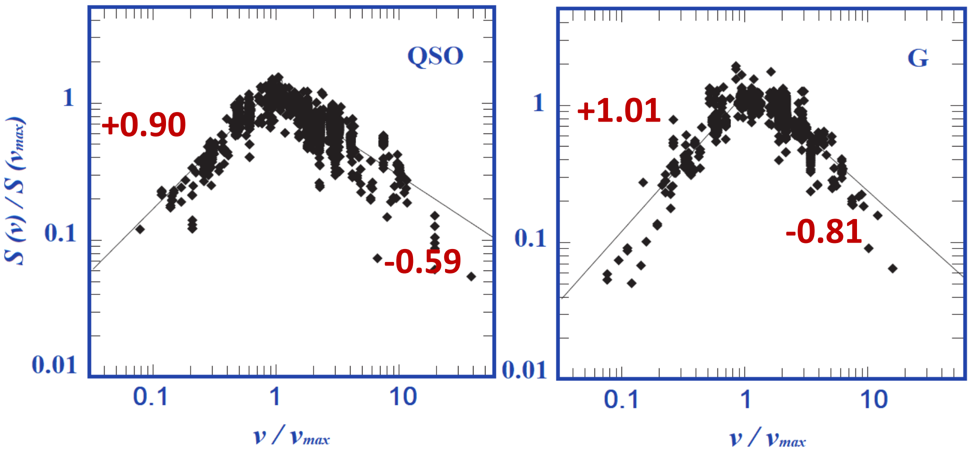


The objects have not been studied for enough time to discard blazars.

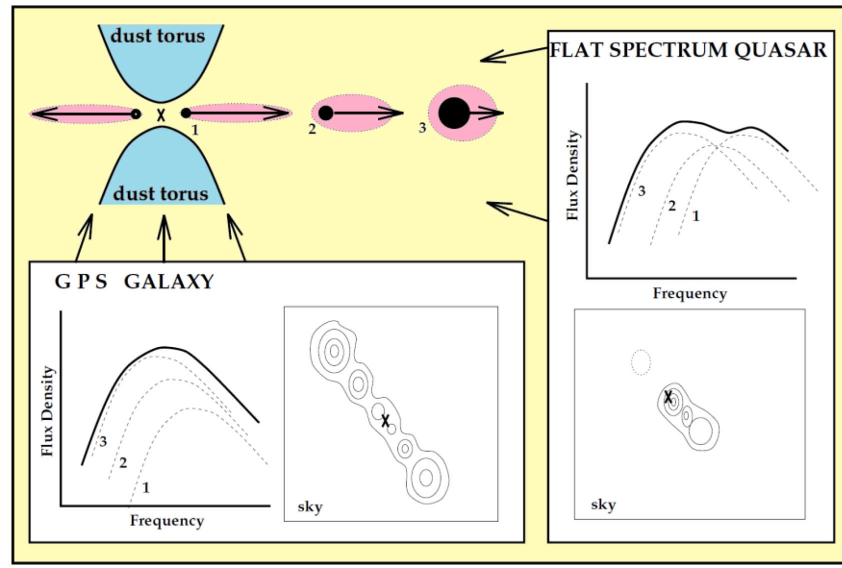
Sotnikova et al., 2021, MNRAS

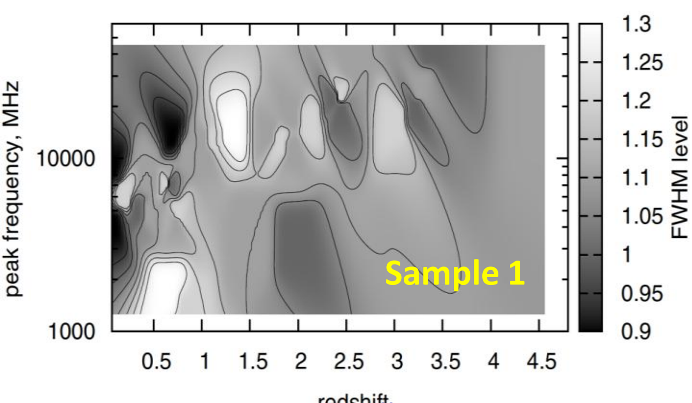
GPS galaxies and quasars

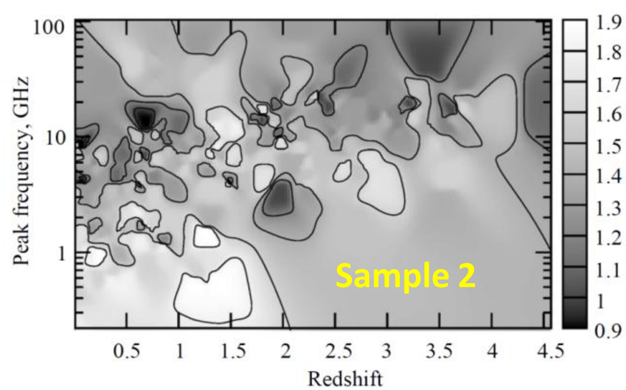
type	N	z	α_{below}	α_{above}	ν_{int}, GHz	FWHM	θ, mas	$L_{radio}\times 10^{43}$, erg/s
G	18	1.3	+1.01 (0.1)	-0.81 (0.3)	4.3 (0.6)	1.4	2.2 (0.6)	14 (3.2)
QSO	43	1.8	+0.90 (0.1)	-0.59 (0.2)	14.1 (1.4)	1.6	0.6 (0.2)	56 (13.5)



Normalized radio spectra of GPS QSO and G



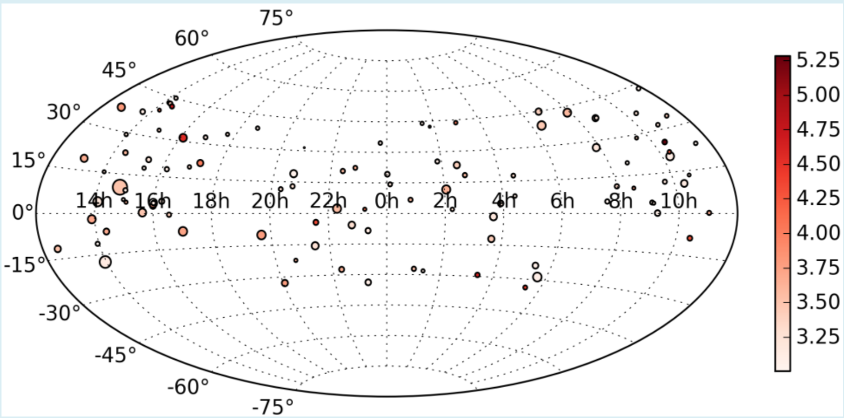


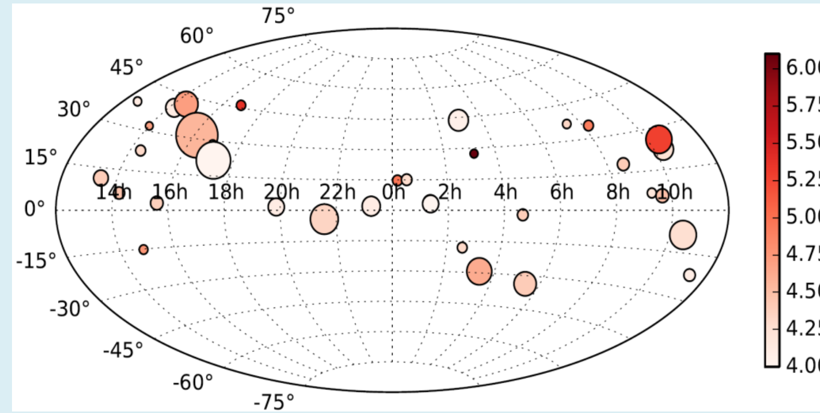


The decelerated component model combined with the orientation unification scheme (Snellen et al., 1998).

"z – ν_{peak} – FWHM" relation

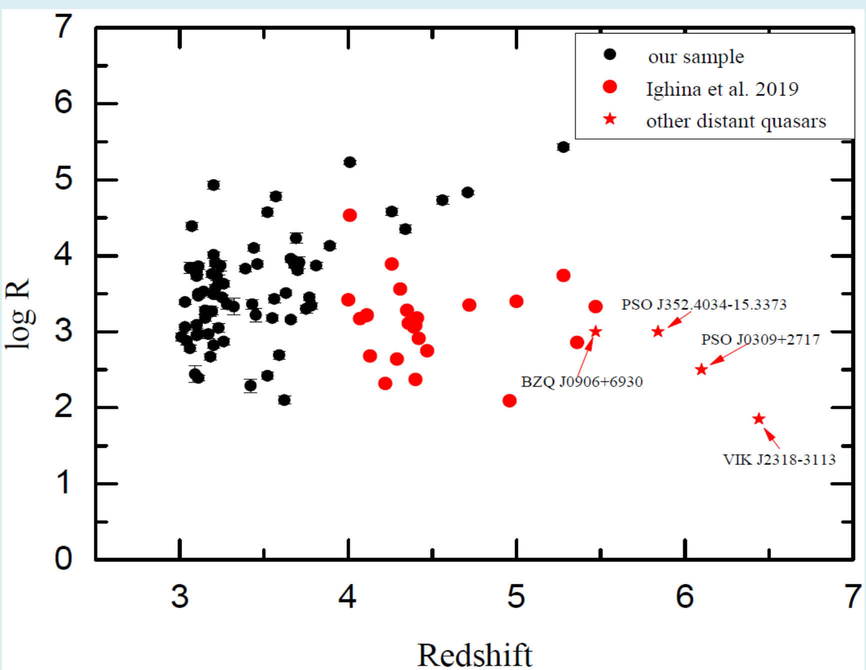
PS quasars at high redshifts

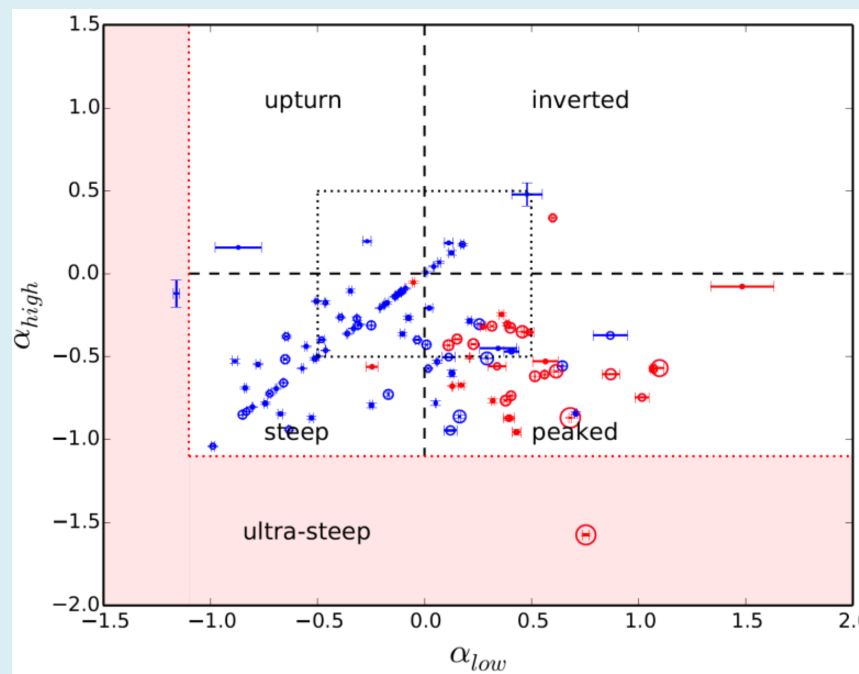




S3: 102 QSO, z≥3; $S_{1.4}$ ≥ 100 mJy (48 blazars by Massaro et al., 2009)

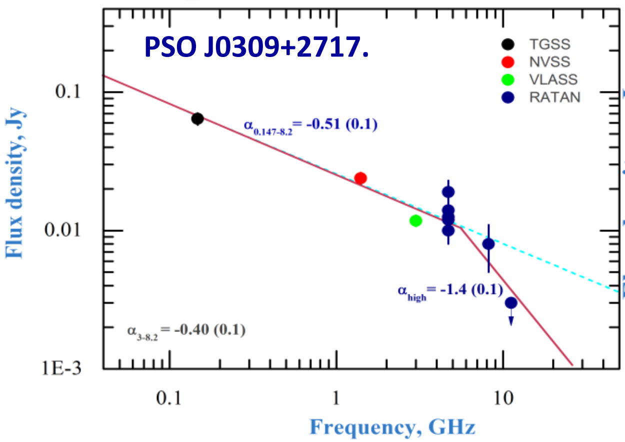
S4: 37 QSO, z≥4; $S_{1.4}$ ≥ 20 mJy (11 blazars)



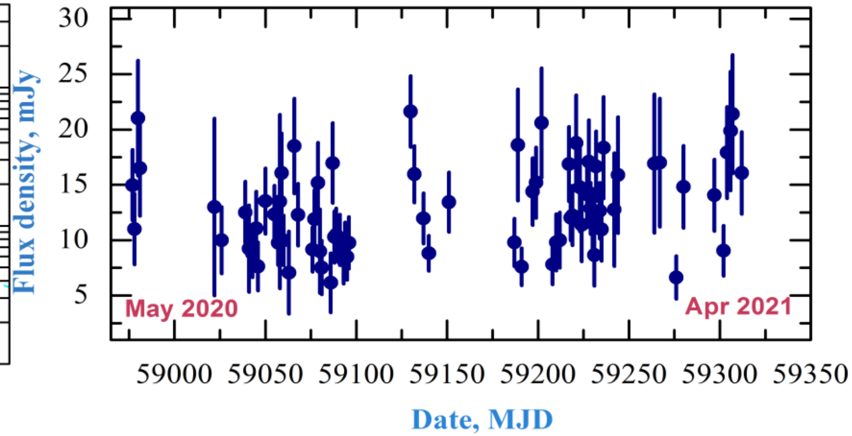


Sotnikova et al., 2021, MNRAS

PS at high redshifts. Blazar PSO J0309+2717 at z=6.1



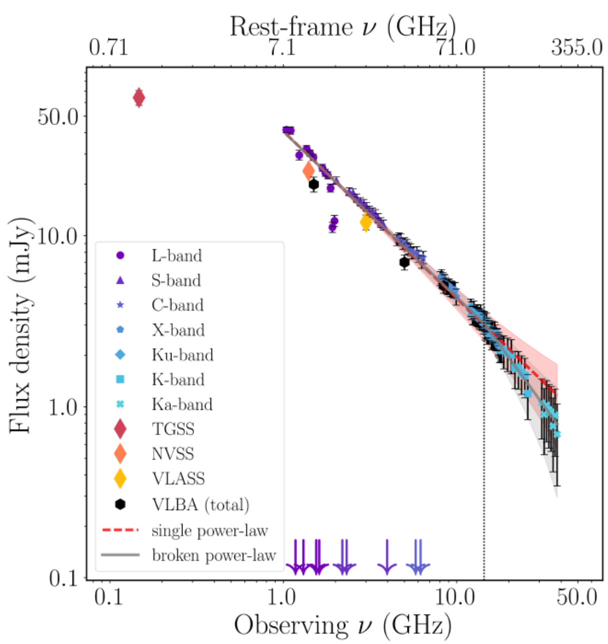
Radio continuum spectrum of J0309+2717.



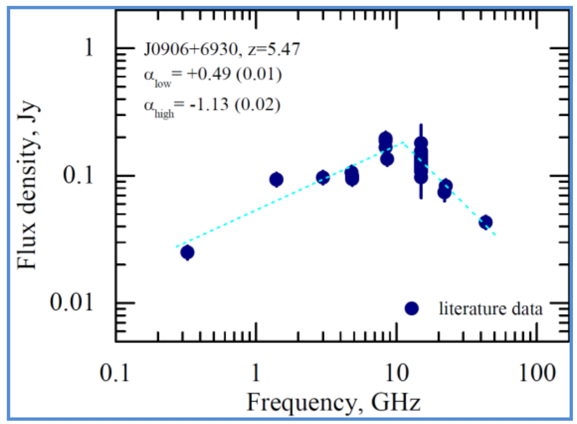
Light curve of the PSO J0309+2717 at 4.7 GHz constructed using measurements with S/N > 1.5, F=0.28 (0.02) (May 2020 - Apr 2021).

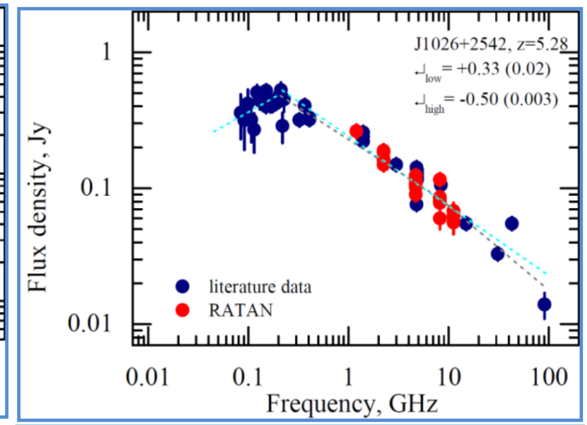
$$F_{var} = \sqrt{\frac{V^2 - \sigma_{err}^2}{\bar{x}^2}}$$

$$\Delta F_{var} = \sqrt{\left(\sqrt{\frac{1}{2N}}\frac{\sigma_{err}^2}{F_{var} * \bar{x}^2}\right)^2 + \left(\sqrt{\frac{\sigma_{err}^2}{N}}\frac{1}{\bar{x}^2}\right)^2}$$

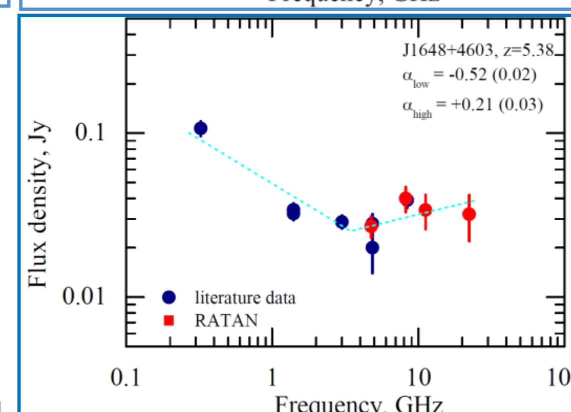


VLBA measurements, Spingola et al., 2020



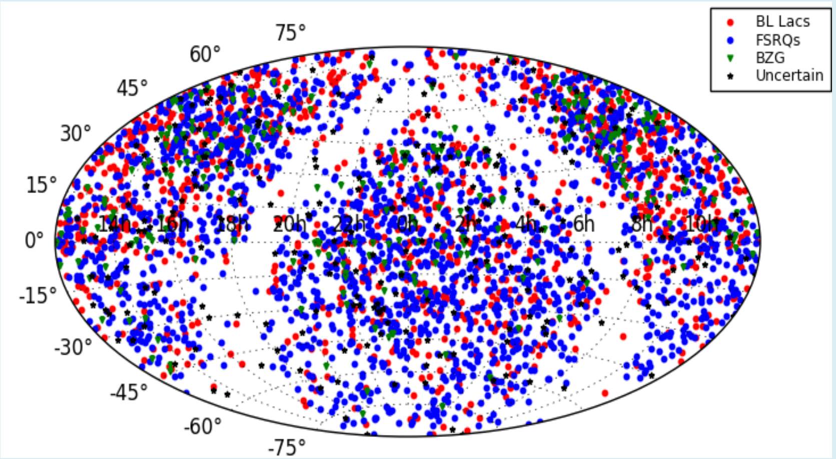


Radio spectra of three most distant blazars at redshifts z>5. Blue points are from literature and CATS, red points are the RATAN-600 measurements.

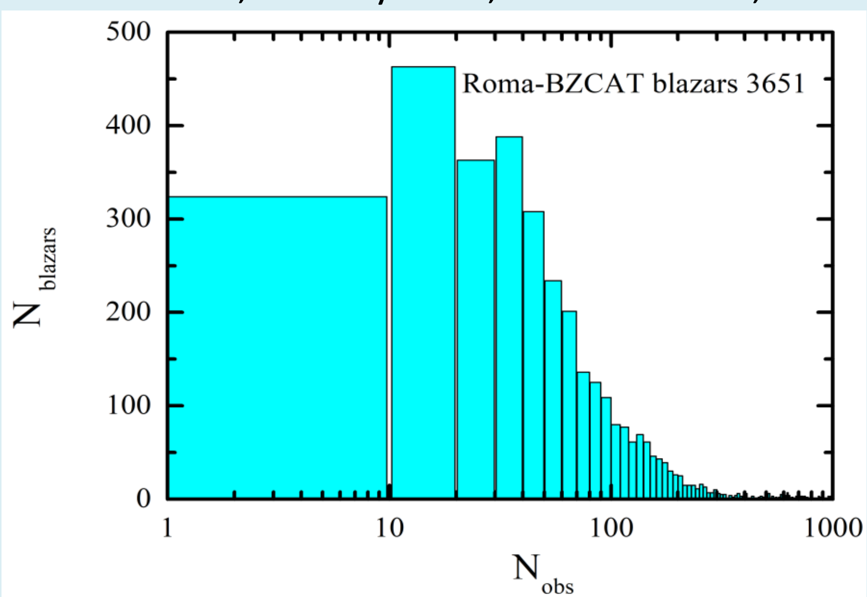


Mufakharov et al., 2021MNRAS.503.4662M

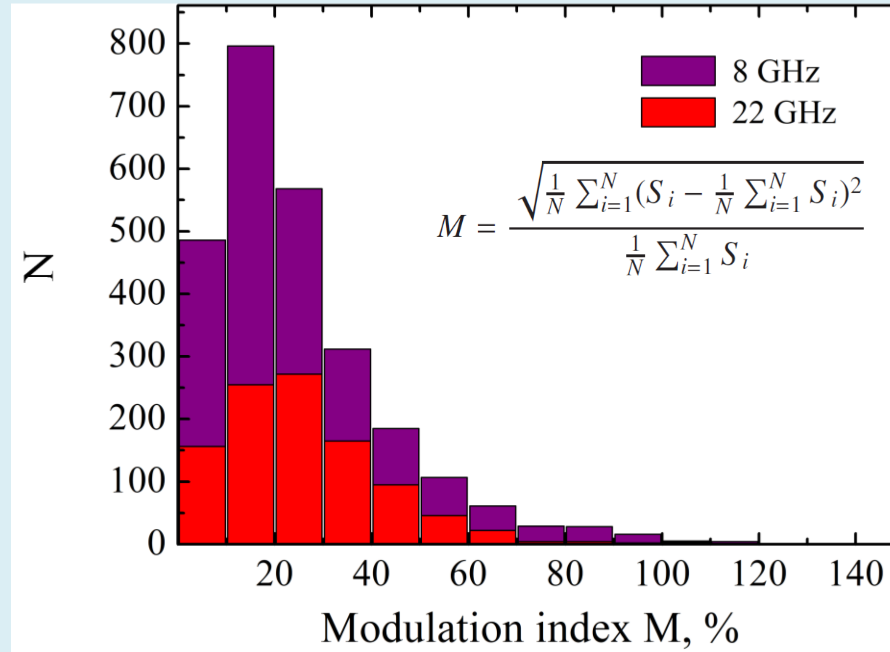
Blazars contamination.



The Roma BZCAT - 5th edition (3561)
Multi-frequency Catalogue of Blazars
Edition 5.0.0, January 2015, Massaro et al., 2009



Number of measurements for BZCAT blazars

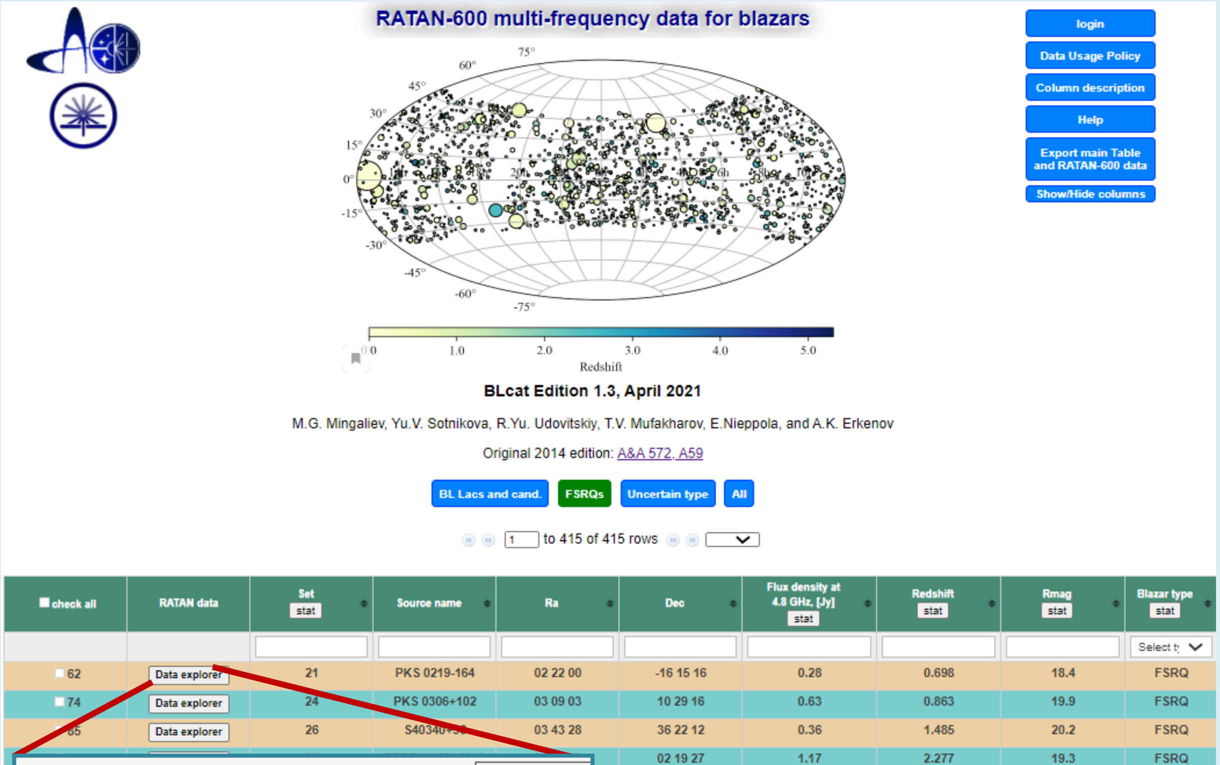


M_{mean} = 25% at 8 GHz; N= 2607
M_{mean} = 26% at 22 GHz; N = 1028

Spectral shape 3651	N	fraction
PS	508	14%
similar to classic GPSs	186	5%
≤ 20 data points	819	22%

Blazars classification is based on available measurements data (VLBA, SED, continuum, …)

Search tool: Blcat – RATAN-600 multi-frequency data for blazars



check all	RATAN data	Set	Source name	Ra	Dec	Flux density at 4.8 GHz, [Jy]	Redshift	Rmag	Blazar type
62	Data explorer	21	PKS 0219-164	02 22 00	-16 15 16	0.28	0.698	18.4	FSRQ
74	Data explorer	24	PKS 0306+102	03 09 03	10 29 16	0.63	0.863	19.9	FSRQ
85	Data explorer	26	S40340+36	03 43 28	36 22 12	0.36	1.485	20.2	FSRQ
					02 19 27	1.17	2.277	19.3	FSRQ

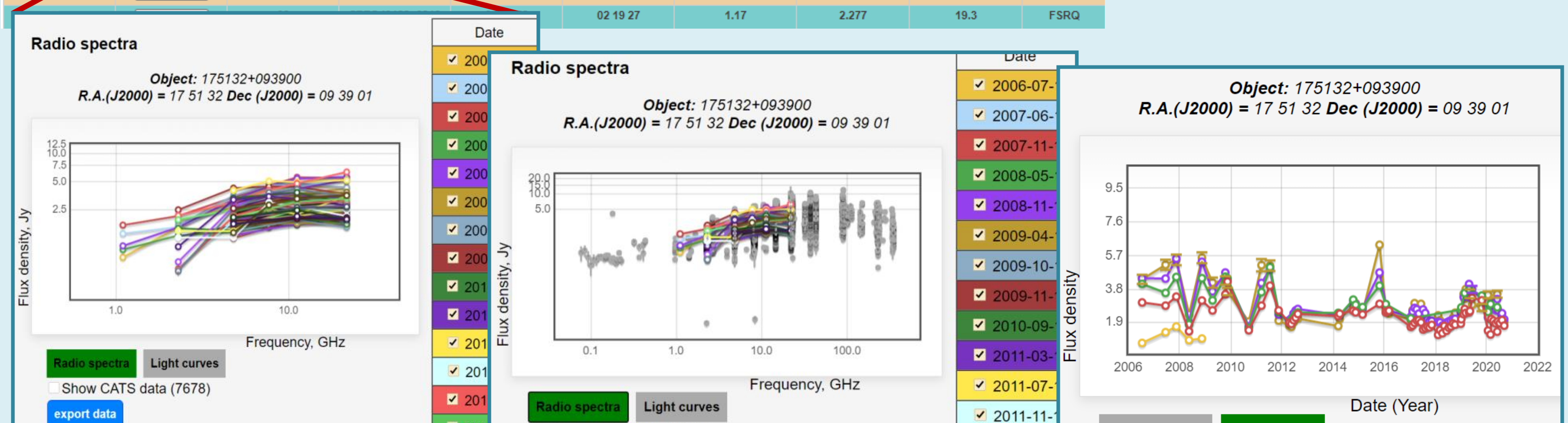
RATAN-600 multi-frequency data for the blazars
Mingaliev et al., A&A, 2014
www.sao.ru/blcat
2005-2021 rr. (~1200)

RATAN blazars sample

$S_{1.4}$ > 100 mJy, -35° < Dec < 45°

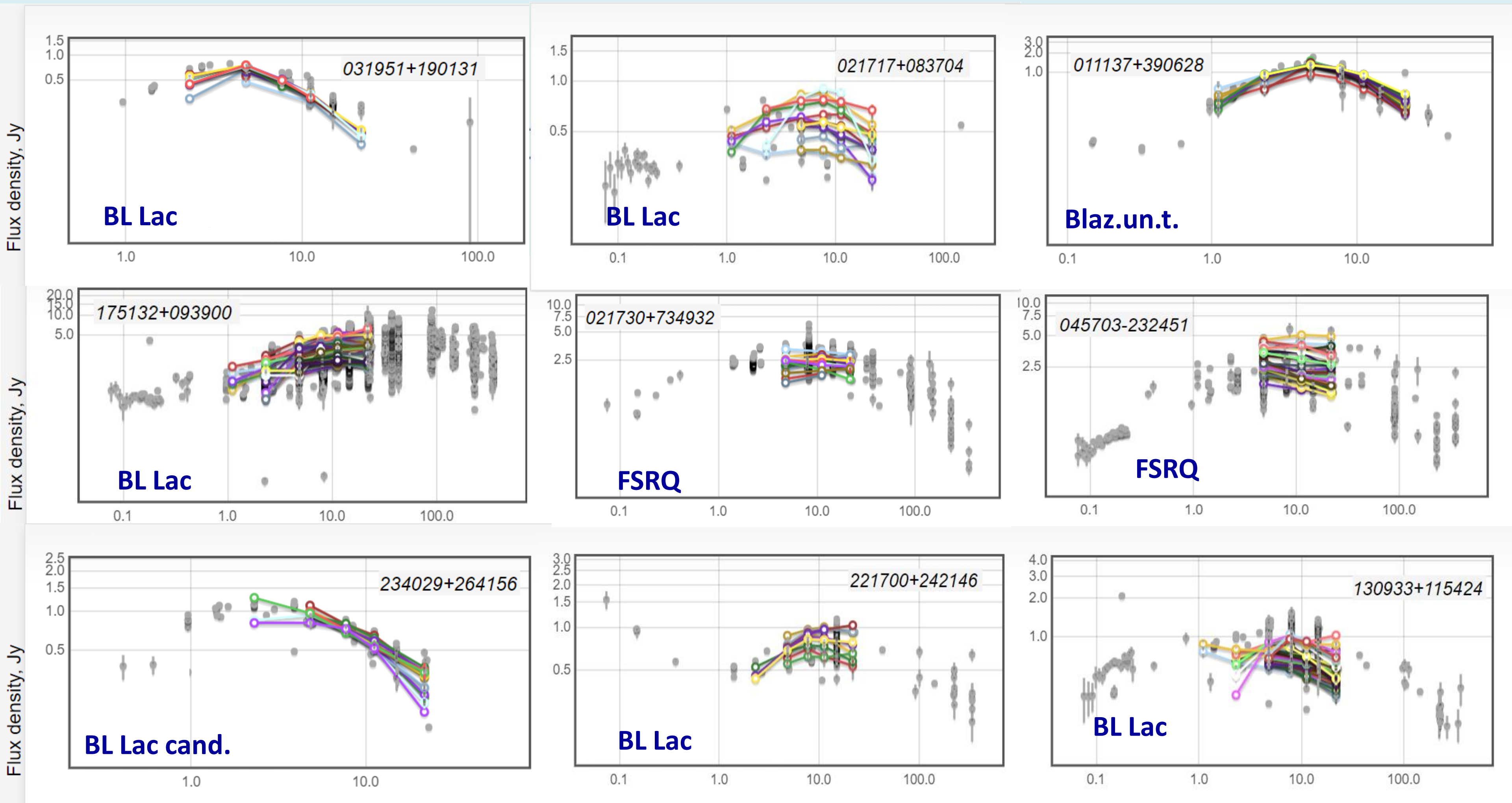
1.1, 2.2, 4.7, 8.2, 11.2, 22 GHz

2005 -2021



quasi-simultaneous **literature data**

PS blazars

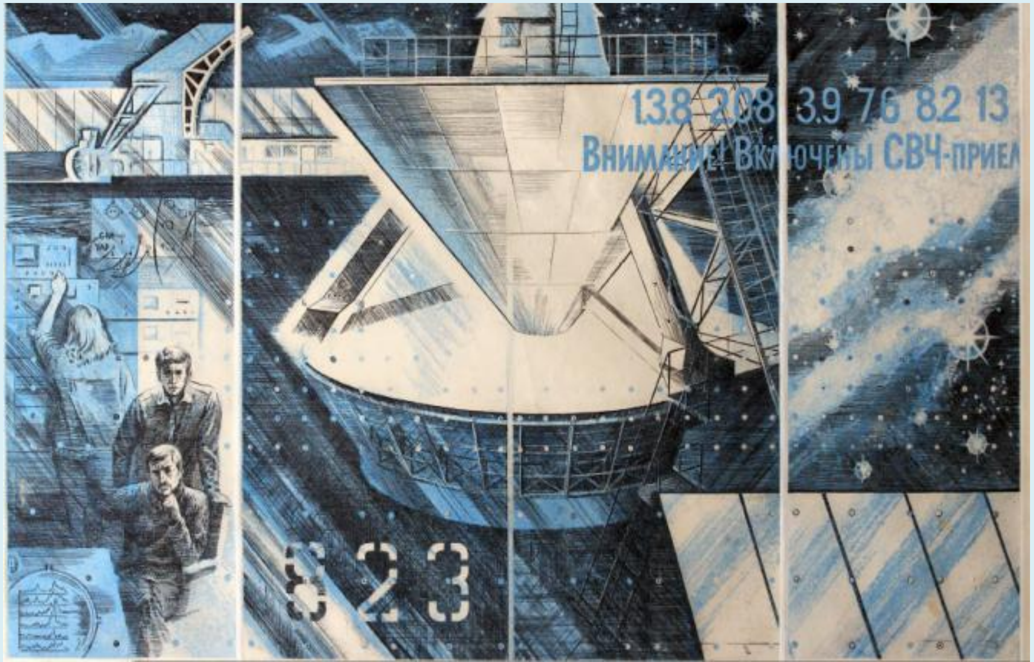


www.sao.ru/blcat   2014A&A...572A..59M
RATAN data: 2005-2021

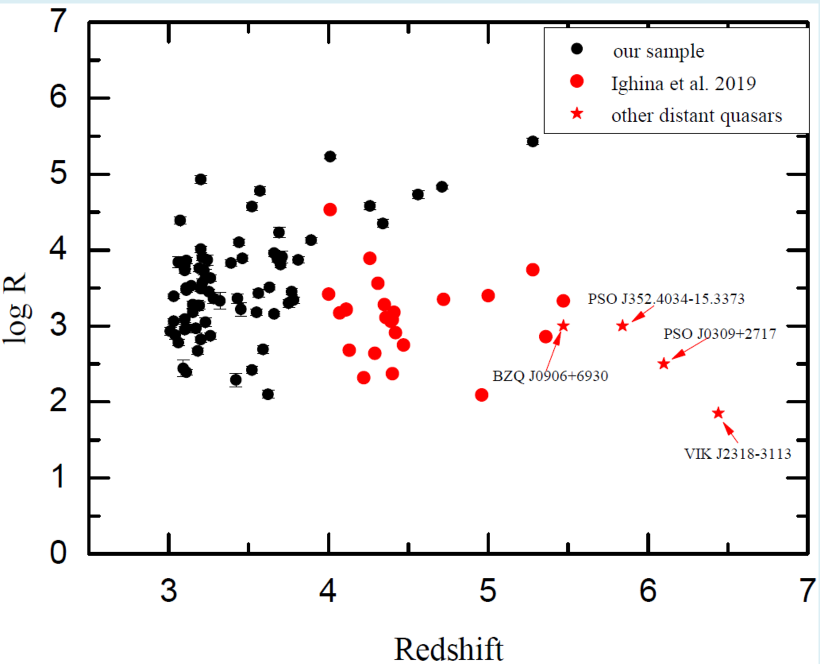
www.sao.ru/cats/ 2005BSAO...58..118V , 2009DatSJ...8...34V,
CATS: published literature data

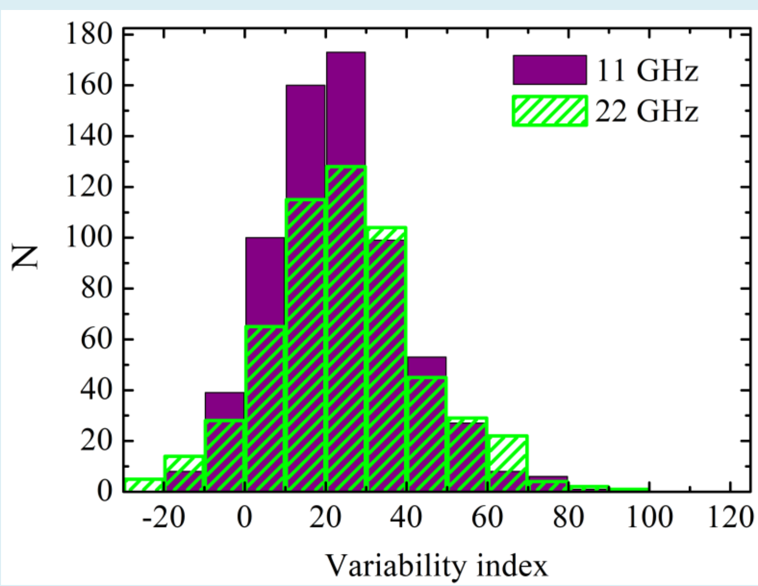
Summary

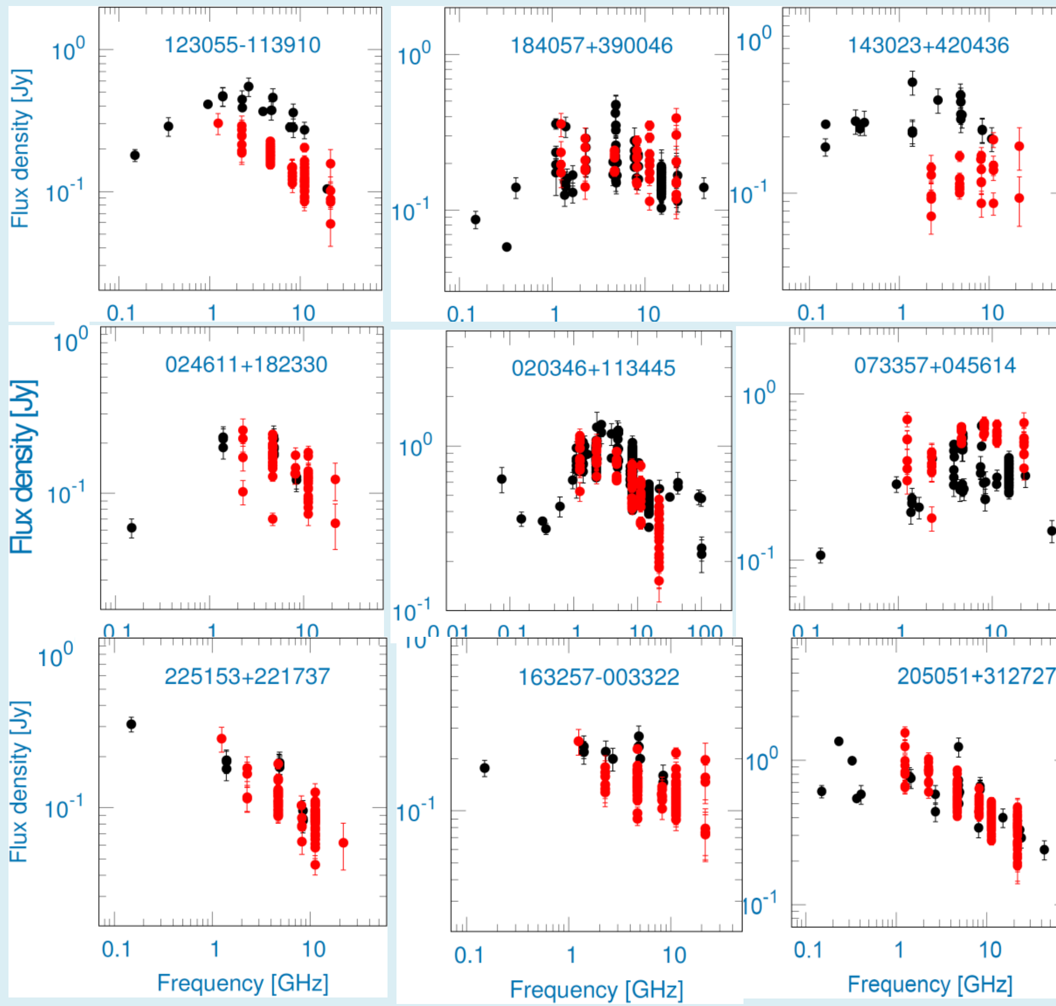
- Importance of multi-frequency and long-term monitoring. Broadband radio continuum spectra is one of the main tool for GPS search.
- A large fraction of PS sources exist (>10%).
- A very small fraction (1-2%) of bright radio sources can be considered as the GPS.
- About 40-50% QSOs at z>3 have a peaked spectrum.
- The blazars contamination is getting stronger at high redshifts. The blazars contamination is probably underestimated.
- CATS, BLcat – GPS search tools.



QSO at z ≥ 3 (2017-2021)







2021MNRAS.503..4662M; Flux-density measurements of the high-redshift blazar PSO J047.4478+27.2992…
2019AstBu..74..348S; Multifrequency study of the GPS sources.
2018AstBu..73..393V; Cosmological Evolution of Average Continuum Spectra of Radio Sources at Z >2 Redshifts.