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The Radio Fundamental Catalogue. I. Astrometry

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ABSTRACT

We present . . .

Keywords: Astrometry

1. INTRODUCTION

Talk about DR1 vs DR2 **Corr 1**
paper I, paper II **Corr 2**
Later **Corr 3**

2. OBSERVING CAMPAIGNS

VLBI observations are organized in campaigns that can contain one or more segments also called experiments. A target source or several target sources, as well as several calibrator sources, are observed for 1–12 hours in a typical astronomical VLBI experiment. A goal of such a dedicated experiment is to observe either a single source of interest or a small group of sources (less than ten objects). Such sources are studied in detail at full sensitivity that is achieved for long integration time. This allows to reconstruct high fidelity images and/or get highly accurate source positions using differential VLBI. In contrast, tens to hundreds sources are observed in a given survey experiment, and a VLBI survey campaign may involve observations of several thousand sources. The goal of survey experiments is to study a population of sources. Inevitably, shorter integration time us used in survey experiments. That results in poorer images and worse position accuracy than in dedicated experiments, but a much larger number of objects is observed.

Most of the surveys fall into three categories: pathfinder surveys, follow-up surveys, and high-frequency extensions. The goal of pathfinder VLBI surveys is to detect target sources never observed with VLBI before, to determine their positions at a milliarcsecond level of accuracy, and to reconstruct their images. Since VLBI has a small field of view, typically in a range of $10''$ to $5'$ at 2–24 GHz, a blind surveys would be very inefficient, because the probability to find a source with flux density 10–100 mJy wihthin such a narrow field of view by chance is low. Therefore, target sources in pathfinder surveys are selected among those detected in prior connected radio interferometers at resolutions 1–$40''$ or single dish observations at resolutions $0.5'$–$5'$. VLBI observations just follow up objects already detected at low resolutions. Only a fraction of target sources is detected with VLBI pathfinder survey. Depending on the criteria used for source selection, the fraction of detected sources is in a range of 5 to 98% with 59% being the median fraction.

The follow-up VLBI surveys target samples of the sources previously detected in prior VLBI pathfinder surveys with the goal to improve position accuracy or get a higher quality images. The radiotelescope sensitiviy is usually the highest in a range of 1–9 GHz, and source flux density is usually falling with frequency. Therefore, chances to detect a source using given integration time are in general higher at lower frequencies. Sources detected at low frequencies are often followed-up at higher frequencies in the third type of surveys, called high-frequency extensions. The goal of

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these extensions is to get images of the sources at higher frequencies that better characterize the core region, evaluate the suitability of source as a calibrator at high frequencies, and in some cases to improve position accuracy.

In our work we collected data from all VLBI surveys for which we could find visibilities in public archives. This inlcudes all surveys that we designed ourselves or particiapted as co-investigators, and all surveys found in literature. We combed through VLBA and EVN surveys and examained observing campaigns in countinuum at frequencies above 4 GHz that observed target sources without phase calibration. In addition, we used all geodetic VLBI data since April 1980 as an auxilliary dataset. Although these data had only marignal direct impact on source position, their use significanly improved estimates of station positions and the Earth Orientation Parameters (EOP) that are nuisance parameters in the context of this work, but are essential for reducing systematic errors due to stability of the VLBI network and its motion with respect to the origin of the coordinate system.

Radio wave propagation is described by differential equation againt source coordinates and other variables. Their solution requires three initial conditions that define the orientation of the celestial coordinate system as well as initial conditions that define the origin and orientation of the terrestrial coordinate system. These intial conditions are aribtrary and cannot be determined from observations in principle. When positions of all sources from all campaigns are derived in a single least square (LSQ) solution, there are three free parameters. This can be done when there is an overlap between observing stations and observed sources between different campaigns. In an extreme case when two campaigns used different networks and different source lists without a common station and common source, and determined Earth Orientation Parameters (EOP) independetly, for their processing in a single LSQ solution three additional arbitrary parameters have be used that describe rotations of the source positions between two campaigns. Such a solution would have little value. To avoid this situation, source lists in observing campaigns have a significant overlap by design. In addition to avoiding degenerices in estimation of source coordinates, sources are observed in different campaigns to improve their position and/or image with respect to the previous campaign, to observe at different frequency, or by mistake because a source was not checked thoroughly whether it was observed in previous campagin. The share of unique sources that are detected only in a given campagin is in a range of 0 to 88%.

Table 1. Bla-bla-bla

Campaign	Network	Id	Reference	Frequency low GHz	Frequency high GHz	Dur. hour	Num ses	Number of sources obs	Number of sources det	Number of sources unique	Dates start	Dates end
Pathfinder surveys:												
VCS1	VLBA	bb023	Beasley et al. (2002)	2.3	8.4	263.5	11	1838	1829	1	1994.08.12	1997.08.27
VCS2	VLBA	bf071	Fomalont et al. (2003)	2.3	8.7	47.8	2	371	366	2	2002.01.31	2002.05.14
VCS3	VLBA	bp110	Petrov et al. (2005)	2.3	8.7	71.6	3	533	485	0	2004.04.30	2004.05.27
VCS4	VLBA	bp118	Petrov et al. (2006)	2.3	8.7	71.9	3	504	409	0	2005.05.12	2005.06.30
VCS5	VLBA	bk124	Kovalev et al. (2007)	2.3	8.7	71.6	3	748	702	0	2005.07.08	2005.07.20
VCS6	VLBA	bp133	Petrov et al. (2008)	2.3	8.7	47.8	2	347	328	0	2006.12.18	2007.01.11
VCS7	VLBA	bp171	Petrov (2021)	4.2	7.6	73.1	17	1626	966	492	2013.02.08	2013.08.01
VCS8	VLBA	bp177	Petrov (2021)	4.4	7.6	47.5	10	1386	926	517	2014.01.07	2014.02.23
VCS9	VLBA	bp192	Petrov (2021)	4.4	7.6	527.8	99	11016	5673	4246	2015.08.07	2016.09.07
VCS10-CX	VLBA	bp242	PI: A. Popkov, 2019	4.4	7.6	89.2	20	2589	1448	1205	2019.07.24	2020.03.17
VCS10-SX	VLBA	bp245u	PI: A. Popkov, 2020	2.3	8.7	23.0	6	638	208	30	2020.03.02	2020.03.23
VCS11	VLBA	br235	PI: T. Readhead, 2020	4.4	7.6	107.9	18	3326	2616	2293	2020.09.11	2021.02.16
NPCS	VLBA	bk130	Popkov et al. (2020)	2.3	8.7	71.7	3	526	192	6	2006.02.14	2006.02.23
V2M	VLBA	bc191	Condon et al. (2017)	8.7		589.1	94	2694	1855	490	2010.07.15	2012.06.05
VLBApls	VLBA	bh019	Fomalont et al. (2000)	2.3	22.2	15.8	1	228	214	0	1996.06.05	1996.06.05

Table 1 *continued on next page*

Table 1 *(continued)*

Campaign	Network	Id	Reference	Frequency low GHz	Frequency high GHz	Dur. hour	Num ses	Number of sources obs	Number of sources det	Number of sources unique	Dates start	Dates end
	VLBA	bb041	PI: T. Beasley, 1995	2.3	8.4	39.7	2	57	56	0	1995.06.25	1996.02.16
	VLBA	bm252	Majid et al. (2009)	8.7		19.8	2	74	53	31	2006.11.06	2006.11.13
VIPS	VLBA	bt085	Helmboldt et al. (2007)	4.9		174.1	16	858	857	275	2006.01.03	2006.08.12
			Petrov & Taylor (2011)									
	VLBA	s2078	Linford et al. (2012)	4.9		76.3	7	308	308	1	2009.11.22	2010.07.30
1FGL-VLBI	VLBA	s3111	PI: Y. Kovalev, 2010	8.7		71.8	3	283	279	86	2010.12.05	2011.01.09
2FGL-VLBIa	VLBA	s4195	PI: Y. Kovalev, 2013	7.6		72.0	3	322	289	142	2013.05.07	2013.06.22
2FGL-VLBIb	VLBA	bs241	Schinzel et al. (2015)	7.6		54.3	7	451	307	77	2015.02.16	2015.07.01
2FGL-VLBIc	VLBA	s5272	Schinzel et al. (2015)	7.6		47.4	4	211	153	49	2013.08.06	2013.12.05
3FGL-VLBI	VLBA	s7104	Schinzel et al. (2017)	7.6		63.3	9	607	416	107	2016.06.25	2016.07.26
VOFUS-1	VLBA	bs262	PI: F. Schinzel, 2018	4.4	7.6	70.1	21	970	882	338	2018.04.08	2018.07.24
VOFUS-2	VLBA	sb072	PI: F. Schinzel, 2018	4.4	7.6	110.0	31	1467	1319	576	2018.08.25	2019.02.17
VGaPS	VLBA	bp125	Petrov et al. (2011a)	24.5		71.8	3	543	386	25	2006.06.04	2006.10.20
EGaPS	EVN	ep066	Petrov (2012)	22.2		47.7	1	437	178	55	2009.10.27	2009.10.27
AGaPS	EAVN	ap001a	PI: L. Petrov, 2018	22.2		23.7	4	193	113	0	2018.10.09	2019.01.28
VEGaPS	VERA	r07030a	PI: L. Petrov, 2007	22.2		27.6	2	125	109	0	2007.01.30	2007.03.21
GC-KVN	KVN	n20lp01	PI: L. Petrov, 2020	22.7	43.9	69.3	14	400	137	18	2020.03.05	2020.06.16
OBRS-1	EVN	gc030	Petrov (2011)	2.3	8.4	47.9	1	115	115	1	2008.03.07	2008.03.07
			Bourda et al. (2011)									
OBRS-2	EVN	gc034	Petrov (2013)	2.3	8.4	215.5	7	378	377	73	2010.03.23	2012.05.27
			Bourda et al. (2011)									
SOFUS	LBA	sofus	PI: L. Petrov, 2017	8.5		39.7	2	133	49	13	2017.04.07	2017.07.10
VEPS-1	CVN	veps	Shu et al. (2017)	8.6		424.8	18	4571	878	154	2015.02.13	2017.12.14
BeSSel-Cal1	VLBA	br145	Immer et al. (2011)	8.4		152.8	34	1536	359	188	2009.11.16	2010.08.29
BeSSel-Cal2	VLBA	br149	PI: M. Reid, 2012	2.3	8.0	40.8	13	554	164	58	2012.08.07	2013.08.04
	VLBA	bg069	Liuzzo et al. (2009)	5.0		44.4	3	60	54	4	1997.04.06	2005.06.17
	EVN	ec013	Charlot et al. (2004)	8.4	2.3	70.9	3	161	159	0	2000.05.31	2003.10.17
	VLBA	bu007	Ulvestad et al. (1999)	4.9		11.8	1	163	162	69	1996.12.19	1996.12.19
	VLBA	bb119	Britzen et al. (2007)	5.0		71.9	3	88	87	0	1999.11.21	1999.11.26
LCS-1	LBA	v254	Petrov et al. (2011b)	8.4		95.8	4	530	520	167	2008.02.05	2009.07.04
LCS-2	LBA	v271dr	Petrov et al. (2019)	2.3		367.9	16	1401	948	493	2009.12.12	2016.06.28
Astrometric follow-ups surveys:												
RDV	VLBA	rdv	Petrov et al. (2009)	2.3	8.4	4451.9	185	2045	2012	0	1994.07.08	2020.07.07
	VLBA	bf025	Fey & Charlot (1997)	2.3	8.4	47.9	2	226	225	0	1997.01.10	1997.01.11
VEPS-V1	VLBA	bs250	Shu et al. (2017)	2.3	8.7	31.9	4	163	163	0	2016.03.22	2016.05.19
VEPS-2	VLBA	bs264	PI: F. Shu, 2018	2.3	8.7	47.9	6	357	357	0	2018.03.21	2018.06.15
VEPS-3	CVN	epa	PI: L. Petrov, 2018	2.3	8.6	44.3	2	182	180	0	2018.01.24	2018.02.10
GAIA-V1	VLBA	bp222	PI: L. Petrov, 2018	2.3	8.7	303.7	38	1367	1366	0	2018.05.15	2020.04.19
GAIA-L2	LBA	v561	PI: L. Petrov, 2017	2.3	8.6	71.0	2	306	304	0	2017.06.16	2018.03.14

Table 1 *continued on next page*

NVSS	$-40^\circ < \ \ 90^\circ$	18036	100%
SUMSS	$-90^\circ < -30^\circ$	2651	98%
ALL-WISE	$-90^\circ < \ \ 90^\circ$	15026	77%
TGSS	$-53^\circ < \ \ 90^\circ$	13656	73%
PanSTARRS	$-30^\circ < \ \ 90^\circ$	11607	69%
Gaia EDR3	$-90^\circ < \ \ 90^\circ$	11940	62%
AT20G	$-90^\circ < \ \ 0^\circ$	4313	52%
GALEX	$-90^\circ < \ \ 90^\circ$	6233	32%
ROSAT	$-90^\circ < \ \ 90^\circ$	3625	19%
2RXS	$-90^\circ < \ \ 90^\circ$	2936	15%
2CXPS	$-90^\circ < \ \ 90^\circ$	2958	15%
FERMI	$-90^\circ < \ \ 90^\circ$	2809	14%
2CXO	$-90^\circ < \ \ 90^\circ$	2708	14%
BZCAT	$-90^\circ < \ \ 90^\circ$	11940	12%
2MASS	$-90^\circ < \ \ 90^\circ$	1728	9%

Table 1 *(continued)*

Campaign	Network	Id	Reference	Frequency		Dur.	Num	Number of sources			Dates	
				low	high		ses	obs	det	unique	start	end
				GHz	GHz	hour						
VCS-II	VLBA	bg219	Gordon et al. (2016)	2.3	8.7	196.2	9	2597	2588	0	2014.01.04	2015.03.17
VCS-III	VLBA	uf001	PI: A. Fey, 2017	2.3	8.7	477.8	20	3654	3647	0	2017.01.16	2017.10.21
VCS-IV	VLBA	ug002	PI: D. Gordon, 2018	2.3	8.7	572.9	24	4416	4235	22	2018.01.18	2019.01.21
SOAP	LBA	aua	PI: L. Petrov, 2017	2.3	8.6	568.2	24	444	420	6	2017.08.22	2019.12.04
GC-VLBA	VLBA	bp251	PI: Y. Pihlstrom, 2021	24.0	43.2	8.4	2	53	53	0	2021.03.19	2021.04.15
	KVN	n13jl01	PI: J. A. Lee, 2013	23.0		195.6	7	790	733	0	2013.09.04	2014.12.24
High frequency extensions:												
K/Q-Survey	VLBA	br079	Lanyi et al. (2010) Charlot et al. (2010)	24.5	43.2	335.7	14	343	332	0	2002.05.15	2011.02.05
	VLBA	bj083	PI: A. de Witt, 2015	24.6		105.0	5	286	286	0	2015.07.21	2016.06.20
	VLBA	ud001	PI: A. de Witt, 2017	23.6		564.1	24	738	734	0	2017.01.08	2018.07.22
GAJI	KVN	gaji	PI: L. Petrov, 2018	21.7	43.8	22.3	4	151	78	0	2018.09.25	2018.12.29
Total						12787.2	898	33883	19404	12310		

3. DATA ANALYSIS

3.1. *Analysis of visibilities*

3.2. *Analysis of group delays*

3.3. *Global parameter estimation*

4. ERROR ANALYSIS

4.1. *Errors of dual-band observations*

4.2. *Errors of single-band observations*

4.3. *Reweighting*

5. MULTIPLE SOURCES

6. THE CATALOGUE

7. SUMMARY

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APPENDIX

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Pathfinder surveys:

1. VLBA Calibrator survey 1 (VCS1), (Beasley et al. 2002); VLBA BB023; S/X bands; 11 segments; since 1994.08.12 through 1997.08.27.

2. VLBA Calibrator survey 2 (VCS2), (Fomalont et al. 2003); VLBA BB071; S/X bands; 2 segments; since 2002.01.31 through 2002.05.14.

3. VLBA Calibrator survey 3 (VCS3), (Petrov et al. 2005); VLBA BP110; S/X bands; 3 segments; since 2004.04.30 through 2004.05.27.

4. VLBA Calibrator survey 4 (VCS4), (Petrov et al. 2006), VLBA BP118; S/X bands; 3 segments; since 2005.05.12 through 2005.06.30.

5. VLBA Calibrator survey 5 (VCS5), (Petrov et al. 2006), VLBA BK124; S/X bands; 3 segments; since 2005.07.08 through 2005.07.20.

6. VLBA Calibrator survey 6 (VCS6), (Petrov et al. 2008), VLBA BP133; S/X bands; 3 segments; since 2006.12.18 through 2007.01.11.

7. VLBA Calibrator Densification 7 (VCS7), (Petrov 2021); VLBA BP171; C/X bands; 17 segments; since 2013.02.08 through 2013.08.01.

8. VLBA Calibrator Densification 8 (VCS8), (Petrov 2021); VLBA BP177; C/X bands; 10 segments; since 2014.01.07 through 2014.02.23.

9. VLBA Calibrator Densification 9 (VCS9), (Petrov 2021); VLBA BP192; C/X bands; 99 segments; since 2015.08.07 through 2016.09.07.

10. Study of the population of steep-spectrum compact radio sources, 1st part (VCS10); VLBA BP242; C/X bands; 19 segments; since 2019.07.24 through 2020.02.11.

11. Study of the population of steep-spectrum compact radio sources, 2nd part (VCS10); VLBA BP245; S/X bands; 6 segments; since 2020.03.02 through 2020.03.23.

12. Completion of Surveys for a Gravitational Lens Search to Explore Dark Matter (VCS11), PI: T. Readhead; VLBA BR235; 18 segments; since 2020.09.11 through 2021.02.16.

13. Northern Polar Cup Survey, Popkov et al. (2020); VLBA BK130; X band; 3 segments; since 2006.02.14 through 2006.02.23

14. A systematic search for inspiraling, binary, and recoiling black holes in nearby galaxies (V2M), Condon et al. (2017); VLBA BC191, BC196, BC201; X band; 94 segments; since 2010.07.15 through 2012.06.05.

15. The VSOP Pre-launch VLBA Observations (VLBApls), (Fomalont et al. 2000); VLBA BH019; C band; 1 segment; 1996.06.05.

16. BB041, PI: T. Beasley; VLBA BB041; S/X bands; 2 segments; since 1995.06.25 through 1995.02.16.

17. Compactness of Weak Radio Sources at High Frequencies, (Majid et al. 2009); VLBA BM252; X-band; 2 segments; since 2006.11.06 through 2006.11.13.

18. VLBA Imaging and Polarimetry Survey at 5 GHz, (VIPS), (Helmboldt et al. 2007; Petrov & Taylor 2011); VLBA BT085; C-band; 16 segments; since 2006.01.03 through 2006.08.12.

19. Low Luminosity gamma-ray blazars (Linford et al. 2012); VLBA S2078, BT110; C-band; 7 segments; since 2009.11.22 through 2010.07.30.

20. 1FGL Active Galactic Nuclei at parsec scales, PI: Y. Kovalev; VLBA S3111; X-band; 3 segments; since 2010.12.05 through 2011.01.09.

21. 2FGL Active Galactic Nuclei at Parsec Scales, PI: Y. Kovalev; VLBA S4195; X-band; 3 segments; since 2013.05.07 through 2013.06.22.

22. 2FGL AGNs at parsec scales, 2nd survey, (Schinzel et al. 2015); VLBA BS241; X-band; 7 segments; since 2015.02.16 through 2015.07.01.

23. VLBI follow-up of Fermi sources, (Schinzel et al. 2015); VLBA S5272; X-band, 4 segments; since 2013.08.06 through 2013.12.05.

24. 3FGL at parsec scales, (Schinzel et al. 2017); VLBA S7104; X-band; 9 segments; since 2016.06.27 through 2016.07.26.

25. VLBA Survey of unassociated gamma-ray objects in the 7-year Fermi/LAT catalog, PI: F. Schinzel, VLBA BS262; C/X bands; 21 segments; since 2018.04.08 through 2018.07.24.

26. VLBA Survey of unassociated gamma-ray objects in the 7-year Fermi/LAT catalog, 2nd survey; PI: F. Schinzel; VLBA SB072; C/X bands; 31 segments; since 2018.08.25 through 2019.02.17.

27. The VLBA Galactic Plane Survey (VGaPS), (Petrov et al. 2011a); VLBA BP125; K band; 3 segments; since 2006.02.04 through 2006.10.20.

28. The EVN Galactic Plane Survey (EGaPS), (Petrov 2012); EVN EP066; K band; 1 segment; 2009.10.27.

29. Detection of the background position noise due to non-stationary of the Galactic gravitational field, PI: L. Petrov, KVN GAJI; K/Q bands; 5 segments; since 2018.09.25 through 2018.12.29.

30. VERA Galactic Plane Survey, PI: L. Petrov; VERA R07030A, R07100A; K band; 2 segments; since 2007.01.30 through 2007.03.21.

31. Asian VLBI Galactic Plane Survey, PI: L. Petrov; EAVN AP001A; K band; 4 segments; since 2018.10.09 through 2019.01.28.

32. A search for high-frequency calibrators within 10 degrees of the Galactic center, PI: L. Petrov; KVN N20LP01; K/Q bands; 14 segments; since 2020.03.05 through 2020.06.16.

33. K- and Q-band VLBI Calibrators near the Galactic Center, PI: Y. Pihlstrom; VLBA BP251; K/Q bands; 2 segments; since 2021.03.19 through 2021.04.15

34. Searching for candidate radio sources for the GAIA astrometric link (OBRS-1), (Petrov 2011); VLBA+EVN GC030; 1 segment; 2008.03.07.

35. Searching for candidate radio sources for the Gaia astrometric link and Global VLBI observations of weak sources (OBRS-2), (Petrov 2011); VLBA+EVN GC034,GB073; 7 segments; since 2010.03.23 through 2012.05.27.

36. Search for SOuthern Fermi Unassociatied sources (SOFUS), PI: L. Petrov; LBA SOFUS; X-band; 2 segments; 2017.04.07 through 2017.07.10.

37. VLBI Ecliptic band survey with the CVN (VEPS-1), (Shu et al. 2017); CVN VEPS; X band; 17 segments; since 2015.02.13 through 2017.12.14.

38. Bessel Calibrator Search (BeSSel), (Immer et al. 2011); VLBA BR145; X-band; 34 segments; since 2009.11.16 through 2010.08.29.

39. Bessel Calibrator Search follow-on, PI: M. Reid; VLBA BR149; X-band; 13 segments; since 2012.08.07 through 2013.08.04.

40. The Bologna Complete Sample of Nearby Radio Sources, (Liuzzo et al. 2009); VLBA BG069, BG094, BG158; 2 segments; since 1997.04.06 through 2000.01.22.

41. Densification of the International Celestial Reference Frame, (Charlot et al. 2004); EVN EC013, EC017; S/X bands; 3 segments; since 2000.05.31 through 2003.10.17

42. A VLBA Survey of Flat-Spectrum FIRST Sources, (Ulvestad et al. 1999) VLBA BU007; C band; 1 segment; 1996.12.19

43. Caltech Jodrell Bank snapshot survey, (Britzen et al. 2007); VLBA BB119; C band; 3 segments; since 1999.11.21 through 1999.11.26.

44. LBA Calibrator Survey-1 (LCS–1), (Petrov et al. 2011b); LBA V254, V271; X band; 4 segments; since 2008.02.05 through 2009.12.12

45. LBA Calibrator Survey–2 (LCS–2), (Petrov et al. 2019); LBA V271, V441, V493; X band; 14 segments; since 2010.03.11 through 2016.06.28.

Astrometric follow-ups:

46. Regular Geodesy with VLBA (RDV), (Petrov et al. 2009), VLBA RV, RDV, BR, TC, BW, RDG, WAP, CN18, CN19; S/X bands; 189 segments, since 1994.07.08 through 2020.07.07.

47. S/X Astrometry Program, (Fey & Charlot 1997), VLBA BF025; S/X bands; 2 segments; since 1997.01.10 through 1997.01.11.

48. VLBA Ecliptic Plane Survey (VEPS-1), (Shu et al. 2017); VLBA BS250; S/X bands; 4 segments; since 2016.03.22 through 2016.05.19.

49. VLBA Ecliptic Plane Survey 2 (VEPS-2), PI: F. Shu; VLBA BS264; S/X bands; 6 segments; since 2018.03.21 through 2018.06.15.

50. VLBI Ecliptic Plane Survey followup, PI: L. Petrov; CVN VEPS-F; S/X bands; 2 segments; since 2018.01.24 through 2018.02.10.

51. Probing milliarcsecond optical structure through VLBI observations of Gaia detected AGNs, PI: L. Petrov; VLBA BP222,BP236; X/S bands; 38 segments; since 2018.05.15 through 2020.04.19.

52. Revealing milliarcsecond optical structure through VLBI observations of Gaia detected AGNs at Southern Hemisphere, PI: L. Petrov; LBA V561; S/X bands; 2 segments; since 2017.06.16 through 2018.03.14.

53. Second epoch VLBA Calibrator survey (VCS-II) (Gordon et al. 2016); VLBA BG219; S/X bands; 9 segments; since 2014.01.04 through 2015.03.17.

54. Third epoch VLBA Calibrator survey (VCS-III); PI: A. Fey; VLBA UF001; S/X bands; 20 segments; since 2017.01.16 through 2017.10.21.

55. Fourth epoch VLBA Calibrator survey (VCS-IV), PI: D. Gordon; VLBA UG002; S/X bands; 24 segments; since 2018.01.18 through 2019.01.21.

56. SOuthern Astrometry Program, PI: L. Petrov; LBA AUA; S/X bands; 24 segments; since 2017.08.22 through 2019.12.04.

High frequency extensions:

57. K-band KVN calibrator survey, PI: J. A. Lee; KVN N13JL01, S14JL01; K-band; 7 segments; since 2013.09.04 through 2014.12.24.

58. K/Q survey, (Lanyi et al. 2010; Charlot et al. 2010); VLBA BR079,BL115,BL122,BL151,BL166; X/K/Q bands; 14 segments; since 2002.05.15 through 2011.02.05.

59. UD001 K-band astrometry, PI: A. de Witt; VLBA UD001; K band; 24 segments; since 2017.01.08 through 2018.07.22.

60. Improving the K-band Celestial Reference Frame in the North; PI: A. de Witt; VLBA BJ083; K band; 5 segments; since 2015.07.21 through 2016.06.20