RadioAstron Space-VLBI AGN survey
strategy and initial results

ASTRO SPACE CENTER

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on behalf of the RadioAstron AGN Early Science Working Group

RadioAstron is a project to use the 10m spaceborne antenna for very long baseline interferometry. We describe a L/C/K-band fringe survey of brightest blazars at baselines up to 25 Earth diameters.

Space radio telescope

The 10m space radio telescope of the RadioAstron project is installed on board the dedicated SPEKTR-R spacecraft (Fig. 1). It was launched into a highly elliptical orbit on 2011 July 18 from the Baikonur Cosmodrome by a Zenit-3F rocket (Fig. 2-4). The orbit is selected so its parameters evolve under the gravitational pull of the Moon to provide a wide range of baseline projections for VLBI observations of various sky regions during the mission lifespan. The telescope is equipped with P, L, C and K-band receivers, an on-board hydrogen maser and a high-gain antenna system to downlink VLBI data to a ground station in real time. Currently, the 22m antenna of the Puschino radio astronomy observatory (near Moscow) serves as the ground data acquisition station.

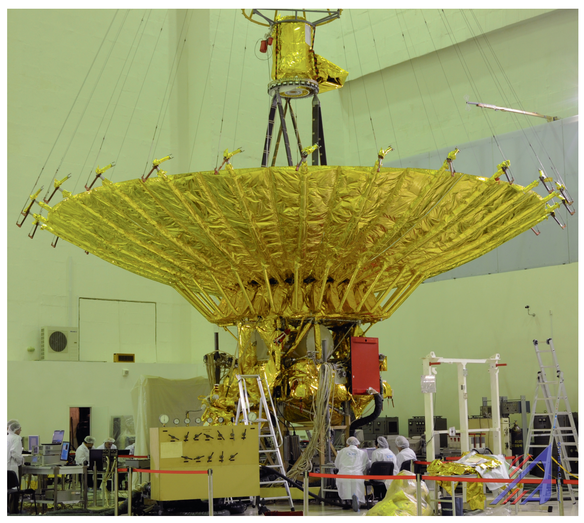

Fig. 1. SPEKTR-R assembled at Lavochkin Association.

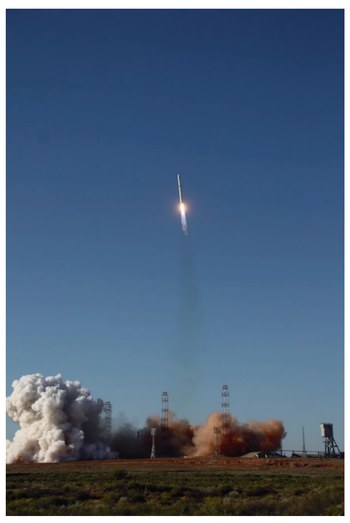

Fig. 2. SPEKTR-R launch from Baikonur.

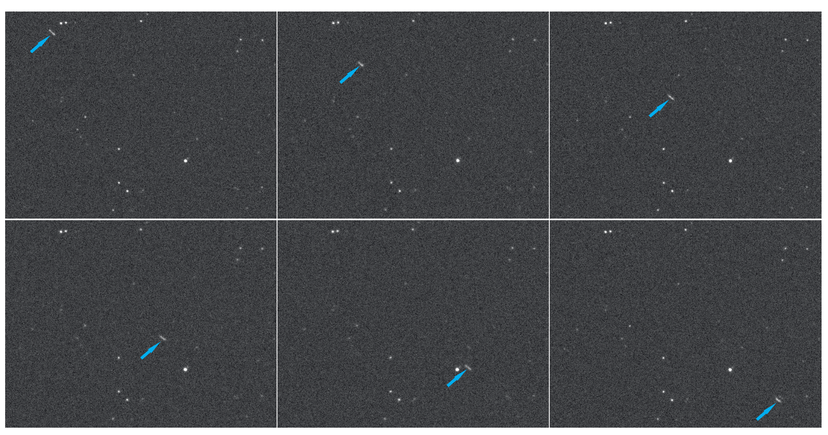

Fig. 3. SPEKTR-R in orbit. These six images were obtained on 2012 September 27, between 02:08 and 02:11 UT with a 0.43m telescope located in New Mexico, USA. Along with radiometric measurements and laser ranging, direct optical imaging is one of the methods regularly used for orbit parameters control.

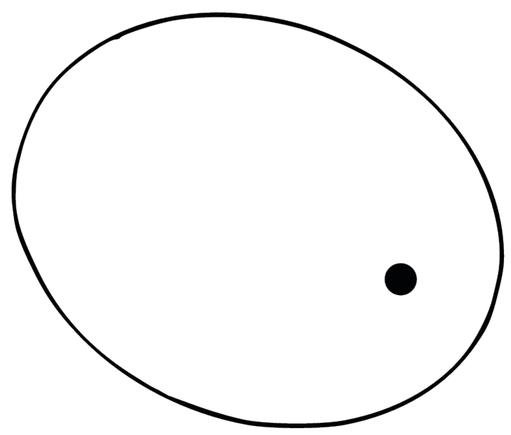

Fig. 4. SPEKTR-R orbit as of 2012 October 02: period 206 hours, perigee 73000 km, apogee 281000 km, inclination 79 deg. Earth is shown not to the scale.

AGN survey strategy

A fringe detection survey of radio-bright active galactic nuclei (AGN) is being conducted as part of the RadioAstron Early Science Program. The survey goals include search for extreme brightness temperatures (with a hope to resolve the Doppler factor crisis and constrain possible mechanisms of AGN radio emission), study the observed size distribution of the most compact features in AGN radio jets (with implications to their intrinsic structure and properties of the scattering interstellar medium in our Galaxy), and select promising targets for detailed follow-up observations (including Space-VLBI imaging). All four RadioAstron bands (P, L, C, and K) are employed in the survey, with the main focus on L, C, and K bands. Most observations are done in a dual-band mode: C+L or C+K. The target selection strategy is based on the results of correlated visibility measurements on longest ground-ground baselines from the existing VLBI surveys (see http://astrogeo.org/rfc). Within the satellite visibility constrains, the preference is given to sources containing brightest compact (on ground baselines) components for which we can obtain both short (<5 Earth diameters) and long space-ground baselines within one or a few SPEKTR-R orbital revolutions.

Survey target list

The list of AGN (mostly blazars) scheduled for RadioAstron observations in February-November 2012. The IAU B1950 source name is followed by a number of observations (N) and an alias. Three sources: 0716+714, 2013+370 and 2037+511 are selected as targets for RadioAstron-EVN observations due to the uv-coverage that is favorable for imaging.

#	IAU	N	Alias	#	IAU	N	Alias	#	IAU	N	Alias
0003-066	1	(NRAO 005)		0727-115	4			1749+096	2	(4C +09.57)	
0059+581	3			0738+313	4	(OI 363)		1803+784	7		
0104-408	1			0748+126	16	(OI 280)		1823+568	6	(4C +56.27)	
0133+476	3	(DA 55)		0754+100	9			1828+487	1	(3C 380)	
0212+735	6			0805-077	5			1846+322	2		
0234+285	3	(4C +28.07)		0823+033	1			1849+670	12		
0355+508	9	(NRAO 150)		0827+243	1	(OJ 248)		1921-293	1		
0430+052	1	(3C 120)		0834-201	2			1954-388	1		
0528+134	15			0836+710	3	(4C +71.07)		1954+513	2		
0529+483	6			0851+202	7	(OJ 287)		2013+370	8		
0537-441	2			1226+023	3	(3C 273)		2022+542	2		
0552+398	3	(DA 193)		1253-055	3	(3C 279)		2037+511	8	(3C 418)	
0607-157	2			1510-089	1			2136+141	1	(OX 161)	
0609+413	2			1611+343	1	(DA 406)		2145+067	6	(4C +06.69)	
0637-752	1			1633+382	2	(4C +38.41)		2200+420	30	(BL Lac)	
0642+449	9	(OH 471)		1637+574	1	(OS 562)		2227-088	2	(PHL 5225)	
0657+172	1			1641+399	5	(3C 345)		2230+114	6	(CTA 102)	
0716+714	30			1739+522	5	(4C +51.37)		2251+158	12	(3C 454.3)	

Participating ground telescopes

- Arecibo 300m & NRAO GBT 100m (USA),
- ATCA 6x22m, Parkes 64m, Mopra 22m, Hobart 26m, Tidbinbilla 70m (Australia),
- Effelsberg 100m (Germany),
- Evpatoria 70m (Ukraine),
- Hartebeesthoek 26m (South Africa),
- Jodrell Bank 70m (UK),
- Medicina 32m & Noto 32m (Italy),
- Shanghai 25m & Urumqi 25m (China),
- Svetloe 32m, Zelenchukskaya 32m, Badary 32m (Russia),
- Usuda 64m (Japan),
- WSRT 14x25m (Netherlands),
- Yebes 40m & Robledo 70m (Spain).

Arrays: EVN, Kvazar-KVO, and LBA.

Main scheduling constraints

- Sun avoidance angle: 90 deg.
- Satellite visibility to the tracking station (TS).
- TS visibility to the satellite's high-gain antenna.
- Target source visibility for ground telescopes.
- Thermal constraints limit observing time.

An example all-sky uv-coverage computed with these constraints is presented on Fig. 5. The plot represents a period of rather favorable observing conditions.

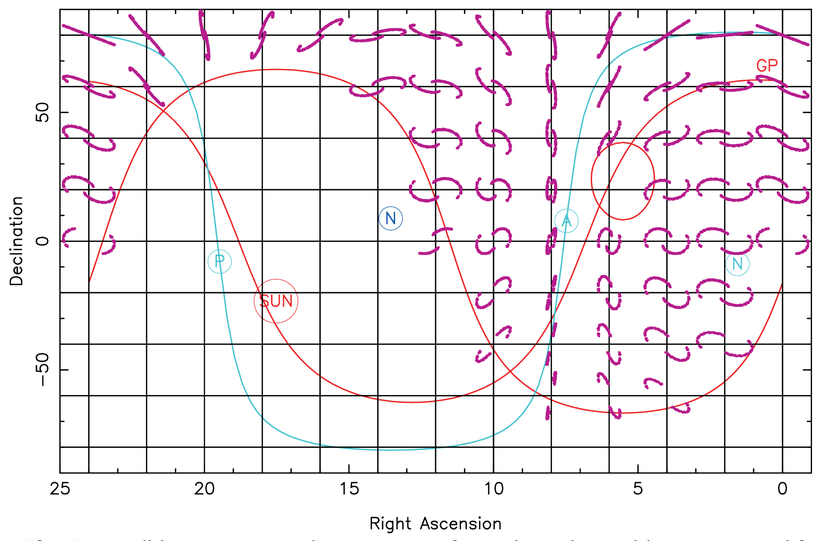

Fig. 5. Possible space-ground uv-coverage for various sky positions computed for 206 hours (one orbital revolution) starting on 2012 December 15 00:00 UT. Included telescopes: RadioAstron, EVN, LBA, Arecibo, GBT, Usuda. Also marked on the plot: Galactic plane, Sun avoidance region, satellite's orbital plane, perigee and apogee points, directions perpendicular to the orbital plane.

First results

While the first months of the survey were marked by continuing development of correlation techniques, choosing optimal space telescope observing modes and debugging the satellite VLBI data downlink system, the observations provided a few record-braking results. Fringes between the RadioAstron and the Effelsberg telescope at C-band were detected on **baseline projections up to 7.2 Earth diameters** for two lacertid-type blazars: **OJ 287** and **BL Lacertae** (Fig. 6). For OJ 287 fringes were not detected in the following observation at 12 Earth diameters indicating that the source is likely resolved-out at this baseline at the given position angle. For BL Lacertae no observations at longer baselines are available at the time of writing. RadioAstron-EVN observation of another lacertid blazar, **0716+714**, conducted on 2012 March 14-15 resulted in fringe detection at **baselines up to 5.2 Earth diameters** with a number of EVN telescopes including 30m-class. The correlated flux density level observed during the satellite's approach to the perigee is consistently higher than the one observed while the satellite was distancing (Fig. 7). This implies that the most compact region in 0716+714's C-band core is extended in one direction. The uv-coverage achieved in this experiment (Fig. 8) is suitable for image reconstruction. The subsequent RadioAstron-Effelsberg observation of 0716+714 at 7 Earth diameter baseline did not result in fringe detection which is not surprising considering that the position angle of this observation was aligned with the compact source's axis. A detailed analysis of this dataset is ongoing. The fact that three sources detected on long baselines are lacertids, not quasars, is likely a matter of coincidence: not many quasar-type sources could be scheduled at long baselines after the space-interferometer system reached its current performance. Observations of many quasar-type sources are planned for the autumn 2012.

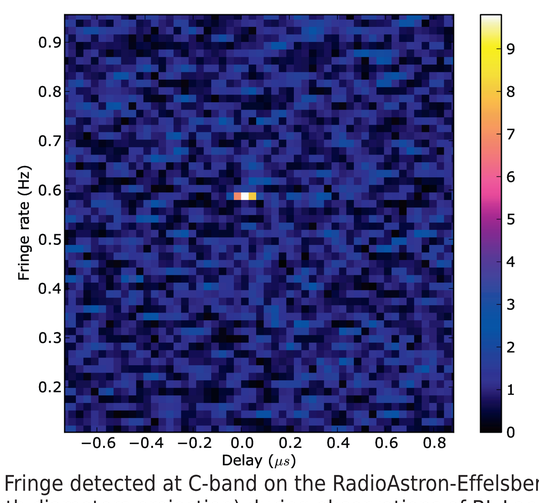

Fig. 6. Fringe detected at C-band on the RadioAstron-Effelsberg baseline (7.2 Earth diameters projection) during observations of BL Lacertae on 2012 June 26 01:10 UT. The colorscale represents fringe signal to noise ratio. The fringe solution interval is 65 seconds.

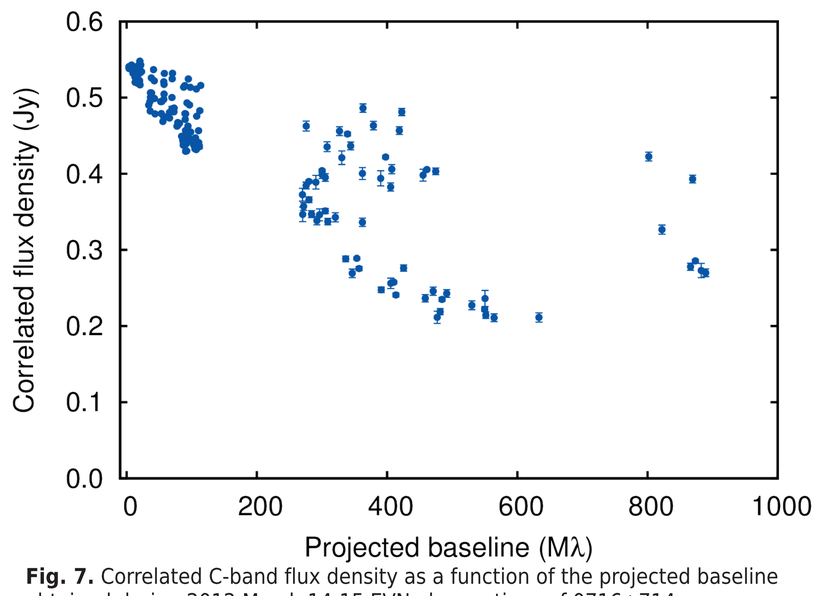

Fig. 7. Correlated C-band flux density as a function of the projected baseline obtained during 2012 March 14-15 EVN observations of 0716+714.

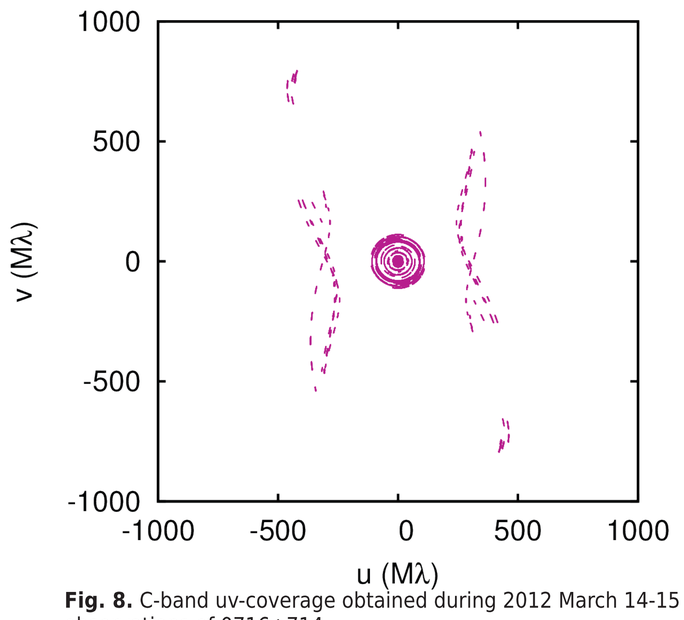

Fig. 8. C-band uv-coverage obtained during 2012 March 14-15 EVN observations of 0716+714.

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