# KaVA/EAVN OBSERVING APPLICATION

**VLBI:** ☐ **KaVA** or ☒ **EAVN**

**TERM:** 2018B

**Proposal ID:** EAVN 18A-00
**Received Date:** 2018/00/00

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**1. Title of proposal:**
The Asian VLBI Galactic Plane Survey

**2. Authors:** (PI on the 1st line)

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| | | | |

\***If any student is involved, please give the following information.**
☐ M.S.   ☐ Ph.D   For thesis? ☐ Yes   ☐ No

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**4. Staff support:**
– Schedule preparation: ☒ None   ☐ Consultation   ☐ Extensive help
– Data reduction: ☒ None   ☐ Consultation   ☐ Extensive help

**5. Proposal type:** ☐ KaVA normal proposal(<100hrs) ☐ KaVA ToO proposal ☐ Continuation ☐ Recovery
☒ EAVN normal proposal(<24hrs) ☐ EAVN large proposal   • Related proposal ID (if any):_

**6. Scientific categories:**
☐ Galactic   ☒ Extragalactic   ☒ AGN   ☐ Star formation   ☐ Evolved star   ☒ Absolute astrometry

**7. Observing type:**
☒ Continuum   ☐ Spectral line   KaVA only: ☐ Fast antenna nodding   ☐ 1-beam (K/Q) hybrid

**8. Observing frequency:**
☒ 22GHz   ☐ 43GHz,   KVN setup (see explanation): ☒ 22GHz   ☒ 43GHz   ☒ 86GHz

**9. Observing sessions:** ☒ single epoch   ☐ multiple epochs
– Total time requested: _24 hrs_
– Number of sessions: _4_ ;   Number of hour each: _6 hrs_ ;   Min/Max Separation: _any days_
– Min/Max LST (HH:MM:SS): _hh1:mm1:ss1_ − _hh2:mm2:ss2_
– Preferred range of dates or dates which are NOT acceptable:

**10. Abstract (200 words max)**

We propose to observe a list of 107 Galactic plane sources to improve their absolute position accuracy to the 0.3 mas level. These sources have: 1) a Gaia counterpart; 2) are within 7.5 degrees of the ecliptic bands; 3) are likely strong enough to be ALMA phase calibrators. The sources from the list that are determined to be small in angular size will be used for space navigation, studies of AGN physics associated with VLBI/Gaia offsets and ALMA phase calibrators above 90 GHz.

When your proposal is scheduled the contents of this application form (but not supporting material) will be made public.
*This LaTeX form was generated on May 30, 2018*

**VLBI**

## Title of Proposal: The Asian VLBI Galactic Plane Survey

| **11. Recording format:** | ☒ 16 MHz × 16 channels | ☐ 32 MHz × 8 channels | ☐ 128 MHz × 2 channels (KaVA only) |
|---|---|---|---|
| **Recording rate:** | ☒ 1 Gbps | | |

**12. Spectroscopy only (if more lines, please attach list)**

| Items | | Line 1 | Line 2 | Line 3 | Line 4 | Line 5 |
|---|---|---|---|---|---|---|
| Transitions to be observed | | n/a | n/a | n/a | n/a | n/a |
| Velocity range in LSR (km s$^{-1}$) | | | | | | |
| Channel bandwidth (kHz) | | | | | | |
| Rest frequency (MHz) | | | | | | |

**13. Total number of sources (including calibrators):**    107    [If more than 8 sources, please attach list]

| **14. Name** [sorted in ra] | **Coordinates (J2000)** | | **Approx. Frequency (MHz)** | **Approx. Flux Density (mJy/beam)** | **Time Requested (min)** | **Cal? (Y/N)** |
|---|---|---|---|---|---|---|
| | **RA** (hh:mm:ss.ss) | **DEC** (±dd:mm:ss.ss) | | | | |
| | | | | | | |

**15. Correlation setup:**

128 Default (128/512 channels per 16 MHz bandwidth for continuum and spectral line, respectively)

☐ Special request (if so, please provide following information)

− Averaging time: <u>0.8 sec</u> ;    Spectral channels per bandwidth: <u>128</u>

**16. Special requirements**

− Sites :
− Dates :
− Frequencies : Should be spread over 512 MHz bandwidth
− etc :

**17. Attach a scientific justification maximum 2 pages including figures. If necessary, attach a technical justification (1 page only). Minimum font size 10 point.**

*KaVA_Proposal.tex; Version 2018B*

The source list. *Beginning...*

|  | RA J2000 | DEC J2000 | Freq (GHz) | Flux (mJy) | Int time (min) | Pos. Err (mas) |
|---|---|---|---|---|---|---|
| 2359+548 | 00:02:00.529465 | +55:10:38.88187 | 22 | > 75 | 6 | 0.9 |
| 0034+623 | 00:37:04.331556 | +62:36:33.30936 | 22 | > 75 | 6 | 0.5 |
| 0155+576 | 01:59:25.604268 | +57:51:57.58525 | 22 | > 75 | 6 | 0.8 |
| 0252+636 | 02:56:08.194740 | +63:51:11.14571 | 22 | > 75 | 6 | 1.0 |
| 0309+525 | 03:12:50.673216 | +52:45:25.18541 | 22 | > 75 | 6 | 1.0 |
| 0344+622 | 03:48:35.382627 | +62:21:45.64039 | 22 | > 75 | 6 | 0.7 |
| 0414+547 | 04:18:46.099759 | +54:53:45.65351 | 22 | > 75 | 6 | 9.6 |
| 0429+448 | 04:32:40.381369 | +45:00:13.76112 | 22 | > 75 | 6 | 0.8 |
| 0438+349 | 04:41:47.712955 | +35:01:17.85766 | 22 | > 75 | 6 | 0.8 |
| 0448+334 | 04:51:33.774412 | +33:30:11.17184 | 22 | > 75 | 6 | 0.8 |
| 0459+345 | 05:02:29.946102 | +34:36:34.56708 | 22 | > 75 | 6 | 4.3 |
| 0458+384 | 05:02:08.112053 | +38:29:12.85459 | 22 | > 75 | 6 | 0.9 |
| 0500+339 | 05:03:56.784663 | +34:03:28.11421 | 22 | > 75 | 6 | 0.6 |
| 0516+276 | 05:19:33.027179 | +27:44:04.34226 | 22 | > 75 | 6 | 0.7 |
| 0516+276 | 05:19:33.027179 | +27:44:04.34226 | 22 | > 75 | 6 | 0.7 |
| 0526+249 | 05:29:10.143410 | +25:00:51.57523 | 22 | > 75 | 6 | 1.2 |
| 0529+359 | 05:33:21.533971 | +35:59:46.28295 | 22 | > 75 | 6 | 1.5 |
| 0532+255 | 05:35:49.947015 | +25:32:14.52688 | 22 | > 75 | 6 | 0.6 |
| 0539+284 | 05:43:01.860232 | +28:25:21.85734 | 22 | > 75 | 6 | 1.0 |
| 0540+303 | 05:43:54.237053 | +30:23:39.66042 | 22 | > 75 | 6 | 0.5 |
| 0542+407 | 05:46:24.791527 | +40:44:03.43668 | 22 | > 75 | 6 | 0.9 |
| 0548+165 | 05:51:18.851322 | +16:36:41.31318 | 22 | > 75 | 6 | 2.0 |
| 0548+165 | 05:51:18.851322 | +16:36:41.31318 | 22 | > 75 | 6 | 2.0 |
| 0547+287 | 05:51:09.760109 | +28:47:25.30385 | 22 | > 75 | 6 | 4.4 |
| 0605+086 | 06:08:13.011121 | +08:40:25.20384 | 22 | > 75 | 6 | 0.5 |
| 0606+099 | 06:08:47.396183 | +09:54:48.95884 | 22 | > 75 | 6 | 0.7 |
| 0617+279 | 06:20:23.615323 | +27:54:13.04503 | 22 | > 75 | 6 | 0.6 |
| 0617+279 | 06:20:23.615323 | +27:54:13.04503 | 22 | > 75 | 6 | 0.6 |
| 0620−011 | 06:22:57.942452 | −01:09:27.11785 | 22 | > 75 | 6 | 0.5 |
| 0620+082 | 06:23:06.206733 | +08:11:55.18363 | 22 | > 75 | 6 | 0.8 |
| 0621+109 | 06:24:27.359151 | +10:53:19.28964 | 22 | > 75 | 6 | 1.0 |
| 0621−010 | 06:24:01.685085 | −01:03:28.14516 | 22 | > 75 | 6 | 0.7 |
| 0625+034 | 06:27:38.283562 | +03:24:59.48619 | 22 | > 75 | 6 | 0.6 |
| 0627−050 | 06:29:55.030890 | −05:05:00.07230 | 22 | > 75 | 6 | 0.9 |
| 0630+154 | 06:33:38.353509 | +15:27:33.09304 | 22 | > 75 | 6 | 2.1 |
| 0640+054 | 06:43:24.041082 | +05:21:59.03512 | 22 | > 75 | 6 | 1.1 |
| 0646+056 | 06:49:35.904023 | +05:38:23.85205 | 22 | > 75 | 6 | 0.6 |
| 0647−130 | 06:50:12.433205 | −13:06:26.58070 | 22 | > 75 | 6 | 0.8 |
| 0658−152 | 07:00:56.635159 | −15:17:04.18891 | 22 | > 75 | 6 | 6.0 |
| 0701−049 | 07:04:02.767915 | −04:59:23.82778 | 22 | > 75 | 6 | 1.1 |
| 0706−153 | 07:09:12.516907 | −15:27:03.45000 | 22 | > 75 | 6 | 2.1 |
| 0707−036 | 07:10:20.133307 | −03:43:27.86531 | 22 | > 75 | 6 | 3.2 |
| 0711−037 | 07:13:30.820015 | −03:50:47.12513 | 22 | > 75 | 6 | 5.2 |
| 0718−154 | 07:21:13.491445 | −15:30:41.01081 | 22 | > 75 | 6 | 0.6 |
| 0722−063 | 07:24:29.078717 | −06:24:33.26982 | 22 | > 75 | 6 | 0.9 |
| 0727−253 | 07:29:26.333155 | −25:27:34.21929 | 22 | > 75 | 6 | 8.6 |
| 0728−197 | 07:30:33.640301 | −19:54:07.76266 | 22 | > 75 | 6 | 0.7 |
| 0728−320 | 07:30:38.298351 | −32:08:20.18014 | 22 | > 75 | 6 | 0.6 |
| 0733−224 | 07:35:56.936660 | −22:32:59.30697 | 22 | > 75 | 6 | 2.3 |
| 0734−154 | 07:37:16.234666 | −15:34:05.87806 | 22 | > 75 | 6 | 0.7 |
| 0737−290 | 07:39:40.202857 | −29:11:19.01103 | 22 | > 75 | 6 | 0.6 |
| 0739−266 | 07:41:55.681194 | −26:47:30.49322 | 22 | > 75 | 6 | 0.6 |
| 0744−124 | 07:47:10.056336 | −12:37:18.13970 | 22 | > 75 | 6 | 0.7 |
| 0752−385 | 07:54:41.564714 | −38:42:37.04916 | 22 | > 75 | 6 | 0.8 |
| 0757−182 | 07:59:43.699789 | −18:21:59.17423 | 22 | > 75 | 6 | 1.6 |
| 0758−200 | 08:00:13.592452 | −20:11:28.07517 | 22 | > 75 | 6 | 1.0 |
| 0759−283 | 08:01:46.493970 | −28:31:06.87049 | 22 | > 75 | 6 | 0.5 |
| 0839−314 | 08:41:32.602474 | −31:36:35.69492 | 22 | > 75 | 6 | 0.7 |
| 0842−375 | 08:44:52.321197 | −37:42:09.37784 | 22 | > 75 | 6 | 0.6 |
| 0843−371 | 08:45:42.496404 | −37:18:55.01447 | 22 | > 75 | 6 | 0.8 |
| 0844−342 | 08:46:10.893807 | −34:24:33.58964 | 22 | > 75 | 6 | 0.6 |
| 0847−354 | 08:49:45.623486 | −35:41:01.27921 | 22 | > 75 | 6 | 0.5 |
| 0851−382 | 08:53:00.184276 | −38:24:16.51273 | 22 | > 75 | 6 | 1.0 |

The source list ... *Continue*

| | RA J2000 | DEC J2000 | Freq | Flux | Int time | Pos. Err |
|---|---|---|---|---|---|---|
| | RA J2000 | DEC J2000 | (GHz) | (mJy) | (min) | (mas) |
| 1656−314 | 16:59:48.917804 | −31:30:47.71472 | 22 | > 75 | 6 | 1.3 |
| 1657−298 | 17:01:09.862829 | −29:54:40.47491 | 22 | > 75 | 6 | 3.0 |
| 1715−287 | 17:18:49.379683 | −28:50:41.09982 | 22 | > 75 | 6 | 0.6 |
| 1718−164 | 17:21:34.655800 | −16:28:55.53098 | 22 | > 75 | 6 | 0.8 |
| 1718−164 | 17:21:34.655800 | −16:28:55.53098 | 22 | > 75 | 6 | 0.8 |
| 1724−198 | 17:27:19.976463 | −19:51:46.66246 | 22 | > 75 | 6 | 0.7 |
| 1724−198 | 17:27:19.976463 | −19:51:46.66246 | 22 | > 75 | 6 | 0.7 |
| 1734−228 | 17:37:02.033703 | −22:51:55.39451 | 22 | > 75 | 6 | 0.6 |
| 1742−283 | 17:45:52.495417 | −28:20:26.28703 | 22 | > 75 | 6 | 5.8 |
| SGR−A | 17:45:40.036068 | −29:00:28.16822 | 22 | > 75 | 6 | 1.9 |
| 1745−291 | 17:48:45.683764 | −29:07:39.40348 | 22 | > 75 | 6 | 4.1 |
| 1748−253 | 17:51:51.262525 | −25:24:00.06315 | 22 | > 75 | 6 | 0.6 |
| 1749−299 | 17:52:33.108083 | −29:56:44.91519 | 22 | > 75 | 6 | 1.1 |
| 1749−300 | 17:52:30.950090 | −30:01:06.68301 | 22 | > 75 | 6 | 1.4 |
| 1755−237 | 17:58:23.017662 | −23:43:12.11615 | 22 | > 75 | 6 | 1.1 |
| 1800−278 | 18:03:16.992547 | −27:48:13.98590 | 22 | > 75 | 6 | 14.5 |
| 1809−286 | 18:12:40.192245 | −28:36:26.94349 | 22 | > 75 | 6 | 0.6 |
| 1815−171 | 18:18:02.902755 | −17:05:40.89705 | 22 | > 75 | 6 | 1.6 |
| 1818−212 | 18:21:05.469347 | −21:10:45.24827 | 22 | > 75 | 6 | 1.1 |
| 1819−245 | 18:22:21.054115 | −24:30:01.31809 | 22 | > 75 | 6 | 2.1 |
| 1819−245 | 18:22:21.054115 | −24:30:01.31809 | 22 | > 75 | 6 | 2.1 |
| 1820−274 | 18:23:19.653617 | −27:26:26.43834 | 22 | > 75 | 6 | 10.2 |
| 1825−214 | 18:28:19.487025 | −21:23:38.76964 | 22 | > 75 | 6 | 2.0 |
| 1827−161 | 18:30:10.745449 | −16:06:55.94734 | 22 | > 75 | 6 | 4.3 |
| 1828−187 | 18:31:23.141658 | −18:43:34.84633 | 22 | > 75 | 6 | 0.8 |
| 1828−187 | 18:31:23.141658 | −18:43:34.84633 | 22 | > 75 | 6 | 0.8 |
| 1830−21B | 18:33:39.839651 | −21:03:41.27898 | 22 | > 75 | 6 | 0.5 |
| 1833+087 | 18:36:11.724167 | +08:46:18.28186 | 22 | > 75 | 6 | 0.7 |
| 1835−293 | 18:39:03.603227 | −29:20:48.62351 | 22 | > 75 | 6 | 0.9 |
| 1843+098 | 18:45:37.600682 | +09:53:45.00261 | 22 | > 75 | 6 | 0.6 |
| 1850+143 | 18:52:50.580468 | +14:26:39.70088 | 22 | > 75 | 6 | 0.5 |
| 1851+147 | 18:54:03.483855 | +14:47:18.14824 | 22 | > 75 | 6 | 0.6 |
| 1853−226 | 18:56:36.463461 | −22:36:16.72061 | 22 | > 75 | 6 | 0.7 |
| 1903+165 | 19:05:16.427643 | +16:37:03.32910 | 22 | > 75 | 6 | 1.0 |
| 1903+168 | 19:05:21.676405 | +16:54:48.58922 | 22 | > 75 | 6 | 0.8 |
| 1910+248 | 19:12:23.730517 | +24:56:06.26204 | 22 | > 75 | 6 | 0.8 |
| 1927+090 | 19:29:47.863269 | +09:10:03.64447 | 22 | > 75 | 6 | 0.6 |
| 1950+179 | 19:52:39.680557 | +18:03:12.17700 | 22 | > 75 | 6 | 0.7 |
| 1959+437 | 20:01:12.873744 | +43:52:52.83894 | 22 | > 75 | 6 | 0.7 |
| 2033+315 | 20:35:39.956697 | +31:43:25.34453 | 22 | > 75 | 6 | 0.7 |
| 2122+507 | 21:24:39.370730 | +50:58:25.79217 | 22 | > 75 | 6 | 0.5 |
| 2153+620 | 21:54:30.530104 | +62:17:07.70765 | 22 | > 75 | 6 | 0.6 |
| 2330+571 | 23:33:01.403115 | +57:28:20.84476 | 22 | > 75 | 6 | 2.2 |
| 2354+675 | 23:56:56.451074 | +67:51:38.73700 | 22 | > 75 | 6 | 2.2 |

# Asian VLBI Galactic Plane Survey

## 1   Introduction

Since 80s through 2018 VLBI was the king of absolute astrometry. VLBI position accuracy was one to two orders of magnitude higher than position accuracy of any other techniques. Gaia DR2 that was made available in April 25, 2018 has demonstrated that Gaia position uncertainties of 8801 matching sources are smaller than the VLBI position uncertainties (See Figure 1). At the same time a more careful analysis revealed (Petrov & Kovalev 2017a, Kovalev et al. 2017), there is a systematic difference between Gaia and VLBI positions: position offsets directions Gaia wrt VLBI prefer directions along the parsec-scale jets. It was explained as a manifestation of mas-scale optical jets. Petrov & Kovalev (2017b) presented extensive argumentation showing that other possible sources of anisotropy in the offset directions are one order of magnitude too small.
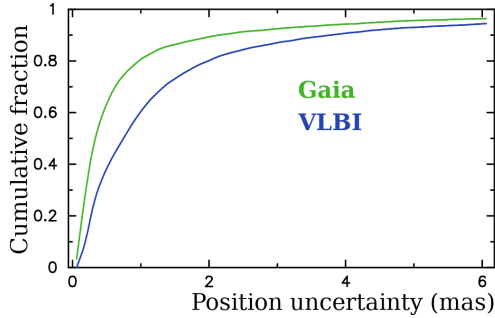


Figure 1: Cumulative distribution of semi-major error ellipse axes of position errors from **Gaia** and **VLBI**.

One of the consequences of the systematic differences VLBI/Gaia is a prediction based on Gaia DR1 that an increase in position accuracy will not reconcile VLBI/Gaia differences, but will measure them more precisely. Gaia DR2 has confirmed prediction: the anisotropy became stronger. As it was stressed in Petrov & Kovalev (2017b), we cannot "borrow" Gaia positions for radio applications that require accuracy better 10 nrad. There are two applications that require high position accuracy: a) space navigation and b) measurement VLBI/Gaia position offset for studying AGN physics.

The quality of ALMA images made from array configurations larger than about 1 km (16 km is the maximum) depends on the small separation between the target science source and the phase reference calibrator. Over the last three years, most of the good quality quasars from the RFC catalog[1] have been observed at 90 and 230 GHz in order to determine if they are sufficiently strong at 90 GHz (typically brighter 20 mJy), and the accurate positions from the VLBI catalog (< 3 mas) are critical for the accurate image registration. However, near the galactic plane additional calibrators are needed for ALMA. We expect that many of the target sources after the proposed observation will be sufficiently unresolved for ALMA, will have accurately-measured positions, and will be above the 10-sigma antenna-based detection for each ALMA 30-sec calibrator observation using $\sim$40 antennas.

## 2   Proposed observations

Currently, there is a number of observing programs that pursue these goals. The current proposal is aiming to include the EAVN instrument in the area where it shines: precise astrometry of Galactic plane objects. The presense of interstellar medium causes scattering that is proportional to $\lambda^2$. As it was clearly demonstrated by Pushkarev & Kovalev (2017b), scattering is increased in low galactic latitudes. Figure 2 shows an example of distortion of source image at 4.3 GHz by scattering. Image at 7.6 GHz is distorted much less.

Scattering decreases correlated flux density at low baselines, and of a sources is not strong enough, it is not detected at long baselines. Since observations at long baselines are more sensitive to positions, as a result, position accurate within the Galactic plane is systematically lower. The remedy is to
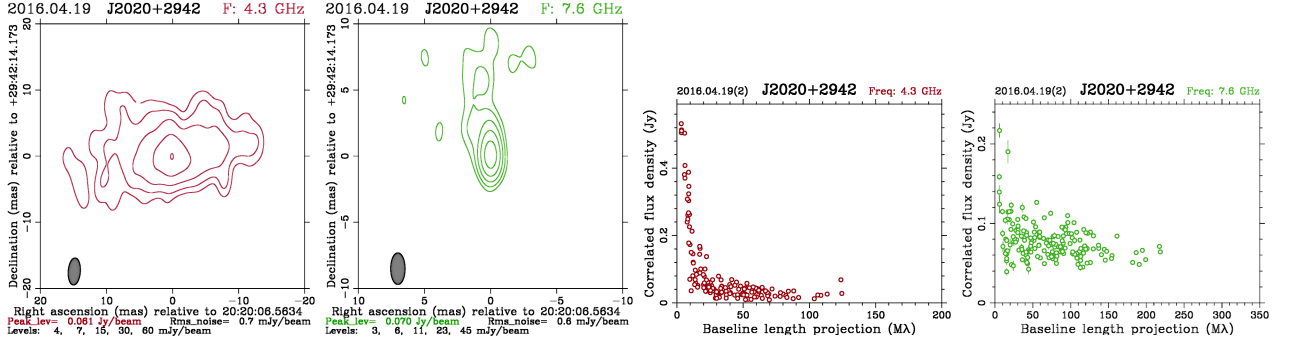
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[1]http://astrogeo.org/rfc

Figure 2: Example of the impact of interstellar medium scattering of a source with galactic latitude $-4°$.

observe at higher frequencies. There were several successful programs (Petrov et al. 2011, **?**, **?**) that have demonstrated that observing at 22 GHz we can detect sources at long baselines that are resolved at lower frequencies due to scattering. Intensive comparison of X/S and K-band positions in (Lanyi et al. 2010) has shown lack of systematic errors exceeding 0.3 mas.

We propose K-band observations of 107 sources in the Galactic plane with the goal of improving their positions. We define Galactic plane as a region with $|l| < 15°$ and $|b| < 12°$ or $|l| > 15°$ and $|b| < 7°$. First, we selected 1127 known sources observed before with VLBI which position accuracy is worse than 0.5 mas. Among these sources, we have selected those that are a) brighter 75 mJy at any band among C, X, or K; b) either detected with Gaia or have ecliptic latitude $|\beta| < 7.5°$. We are going to observe 107 target sources in three scans of 120 s each. Observations will be done in astrometric mode: the observations will be organized in sequence that minimizes slewing time and at the same time provides a good $uv$-coverage. Each hour a burst of calibrator sources at low (15–30°) and high $> 50°$) elevations will be inserted to improve estimates of residual atmospheric path delay and tie the orientation of coordinate system to the Radio Fundamental Catalogue. We will also make images of target and calibrator sources. Since the target sources are distributed very non-uniformly over right ascensions, the observations are split into four 6-blocks. We have selected EAVN for this project because we need th high sensitivity TIANMA65 provides. We do not need NOBEYAMA.

## 3    Expected significance of proposed observations

The goal of our project is to improve position accuracy of target sources down to 0.3 mas level observing at the frequency that is affected by scattering in the interstellar medium a factor of 7–8 less than at X-band. We have selected the sources that are either targets for space navigation since they have low ecliptic latitude or have a Gaia counterpart and therefore, improvement in accuracy of measurement of their VLBI/Gaia offset will contribute to better understanding of AGN physics as it was shown in (Petrov & Kovalev 2017b).

We waive proprietary period. Results of data analysis, source positions and images, will be made publicly available within 30 days of correlation of the last segment and then published in a referred journal paper. The good quality sources will also be added to the ALMA catalog of calibrators used for phase referencing.

## References

Lanyi, G. E., et al., 2010, AJ, 139, 1695.

Kovalev, Y.Y., Petrov, L, & Plavin, A., 2017, A&, 598, L1.

Petrov L., 2011, AJ, 142, 35.

Petrov L., et al, AJ, 143, 35

Petrov L., 2012, MNRAS, 419, 1097–1105.

Petrov L. & Kov alev, Y.Y. 2017, MNRASL, 467, L71–L75.

Petrov L. & Kovalev, Y.Y. 2017, MNRAS, 2017, 471, 3775–3787.

Pushkarev, A. B., Kovalev, Y. Y., 2015, MNRAS, 452, 4274.

# Technical justification for "Asian VLBI Galactic Plane Survey" project

We propose to observe at 22 GHz at $16 \times 0.016$ GHz mode with 16 IFs spread over 0.512 GHz. The central frequency is selected to have the best sensitivity.

The EVN calculator shows that for 2 minute integration time a 10 mJy source will be detected at T6-Ky baseline and at 75 mJy source will have SNR 44.

We will need so-called ANT-files with a priori model computed by the correlator. The correlator output will be analyed with PIMA, Psolve and Difmap.

We propose the KVN stations in addition to recording at K-band record also Q band (1x0.512 GHz) and W band (2x0.512 band, dual polarization) as a commensal science. We will analyze Q and W band data using the frequency escallation approach with the goal to detect sources at these frequencies and get their flux density.