KaVA/EAVN OBSERVING APPLICATION

VLBI: ☐ **KaVA or** ☒ **EAVN**

TERM: 2018B

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

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.

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: 0.8 sec ; Spectral channels per bandwidth: 128

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 RA J2000	DEC J2000 DEC J2000	Freq (GHz)	Flux (mJy)	Int time (min)	Pos. Err (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.

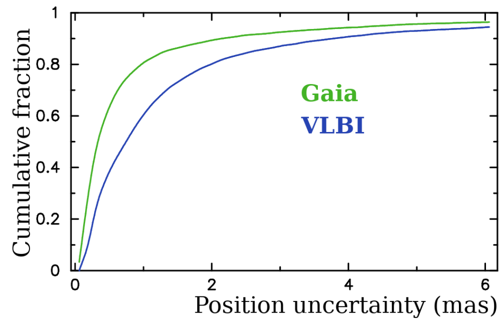

Figure 1: Cumulative distribution of semi-major error ellipse axes of position errors from **Gaia** and **VLBI**.

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 λ^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

[1] http://astrogeo.org/rfc

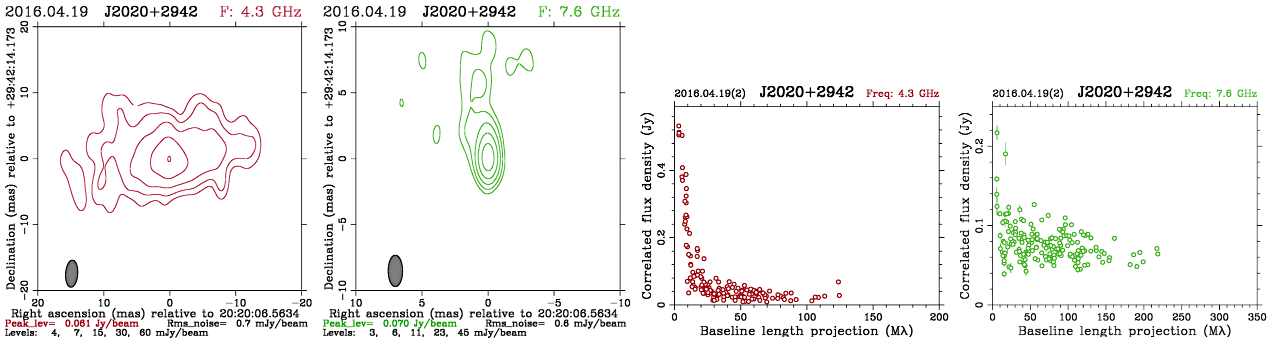

Figure 2: Example of the impact of interstellar medium scattering of a source with galactic latitude $-4°$.

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 16×0.016 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.