Interim report of SOuthern Astrometry Program (SOAP)

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1 Brief introduction to the project

The goal of the SOuthern Astrometry Program (SOAP) is to improve positions of those compact extragalactic sources with declinations $< -45°$ that can be detected with Auscope antennas for 5 minutes with SNR > 10. Positions of the the majority of these sources were determined from the Long Baseline Array Calibrator Survey (LCS) campaign (Petrov et al., 2011, 2019) using single band observations at 8.3 GHz. Due to hardware limitations of the LCS program, the achieved source position precision is at a 3 mas level. The goal of the SOAP is to improve position accuracy of observed sources down to 0.3 mas level, i.e. **one order of magnitude**.

The program had two parts, exploratory stage SOAP-E1 and astrometry stage SOAP-A1. The objective of SOAP-E1 campaign is to observe all the sources brighter 250 mJy at declinations $< -45°$ at X/S, except 38 objects observed in v561a experiment. The number of target sources: 253. Each source is observed in two scans of 4 minutes long. Two twenty-four hour experiments are required. The objectives of this campaign are 1) to determine the correlated flux density at the medium length baselines (Au-Au: 1000–3000 km) and long baselines, (Hh-Au: 8000–10000 km); 2) to improve source position by a factor of 2 to 1 mas level.

SOAP-A1 program includes all the sources detected with SOAP-E1. Each source is observed in ten scans of 5 minutes long. Fifteen to sixteen twenty-four hour experiments are required. The objectives of this campaign are 1) improve source position by a factor of 10 down to 0.3 mas level; 2) generate images at X and S-band; 3) determine jet direction; 4) evaluate kiloparsec scale flux density simultaneously with parsec-scale images, which allows us to determine the source compactness. The images will be derived from 80 observations per source, which is approximately equivalent to 2 scans at the VLBA.

Network: Hh-Ht-Ke-Yg-Ho-Ww-Wa.

2 Status by 2019.01.01

Two SOAP-E1 and 9 SOAP-A1 experiments have been observed, correlated, and processed by 2019.01.01.

All target sources were observed in SOAP-E1:

More than 2 X/S dual-band detections:	158
1–2 X/S dual-band detections:	20
No X/S dual-band detections:	37

A source is counted if it was detected at both X and S bands. Based on results of SOAP-E1 and v561a projects, a list of 204 target sources was generated. By 2019.01.01 two sessions of SOAP-E1 program and 9 sessions of SOAP-A1 program have been observed, correlated, and analyzed. In 9 SOAP-A1 sessions 144 target sources were observed in 10 or more scans and 22 target sources were observed in 1 to 9 scans. Among the sources observed in 10 or more scans, all but one (1733-565) have been detected and had at least 2 usable observations.

3 Astrometric results by 2019.01.01

I ran two regular global astrometric solutions: soap_plus and soap_minus. Solution soap_plus used all dual band X/S and X/C observing sessions, including SOAP, and X-band only LCS observations. Solution soap_minus used all observing sessions as in soap_plus, except 11 SOAP-E1 and SOAP-A1 observing sessions.

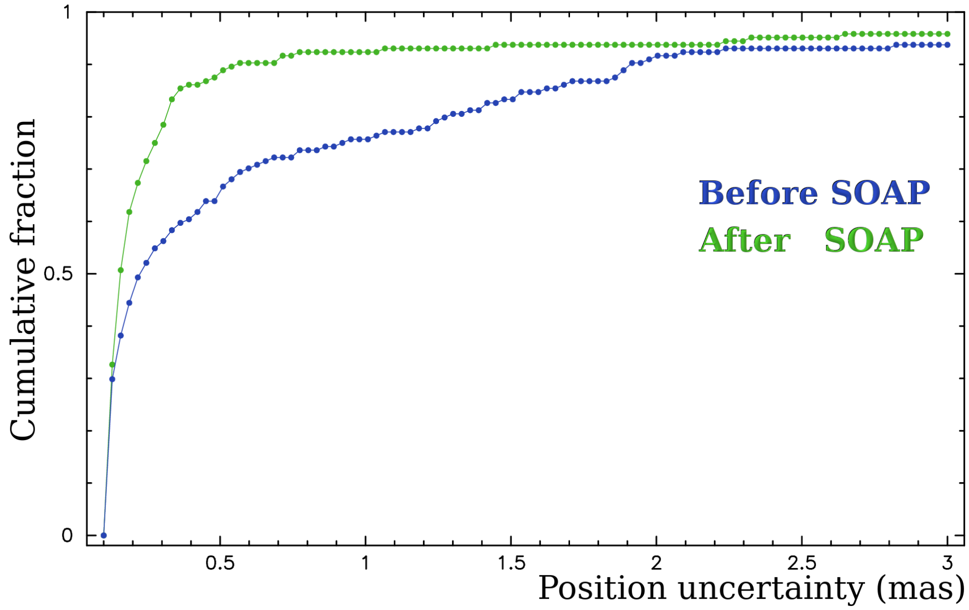

Figure 1: The cumulative distribution of position errors **before** and **after** the LCS program. Only 144 target sources that were observed in 10 or more scans are counted.

Among 144 target sources observed in SOAP, according to results of soap_plus solution, 92 have position uncertainty better 0.2 mas, 113 have position uncertainty better than 0.3 mas and 124 have position uncertainty better than 0.4 mas. Position uncertainty is the semi-major error ellipse axis derived from formal right ascension and declination errors, as well as the correlation between them reported by p-Solve. An additive weight correction was applied, and in the case of LCS observations weight scaling factor 1.8 and the additional correction proportional to the Global Total Electron Contents were applied. Figure 1 shows the cumulative distribution of position errors among 144 target sources. For comparison, cumulative distribution of position errors in soap_minus solution is shown.

The accuracy goal, 0.3 mas has been reached only for 78% sources. What is the reason? Figure 2 presents a graph of the number of scheduled and observations and used in the solution. There are only 2–3% of the sources that have been detected, but suppressed during data analysis. The differences between the number of used and correlated observations is due to non-detections, because antenna sensitivity was too poor to detect a source after 5 minutes integration. The median ratio of the number of used observations to correlated is 56%, which is disappointing.

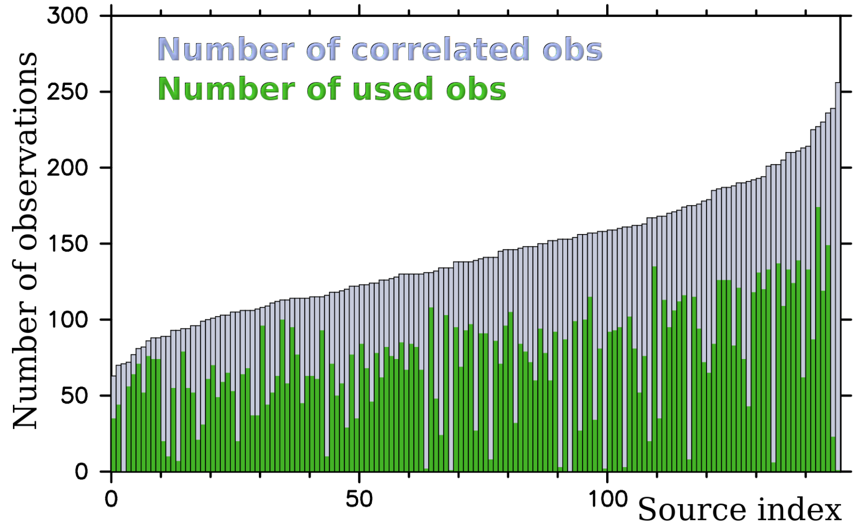

Figure 2: Statistics of the number of **correlated** and **used in solution** dual-band band observations in SOAP-E1 and SOAP-A1 campaigns.

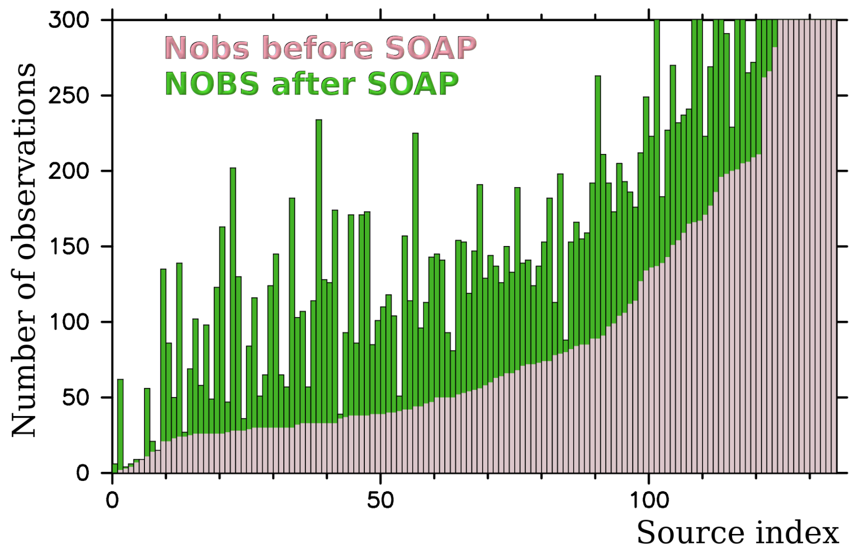

Figure 3: Statistics of the number of used observations **before** and **after SOAP** observing sessions.

Improvement in source positions occur because of a) using dual-band observations that eliminates ionosphere-driven systematic errors; b) an increase in the total number of observations. Figure 3 shows the increment in the number of used observations as a result of SOAP program.

Figure 4 shows a clear dependence of position uncertainty as a function of new SOAP observations. In order to reach the goal of the campaign, 0.3 mas position uncertainty, we need 80–100 **used** observations. If a given source is observed at a 4-station network, Ho-Ke-Ww-Yg and detected in each observation, the total number of observations in 10 scans will be 100. Hh or Ht stations participates only in 25% observations. If a source is observed at the 5-station network Hh-Ho-Ke-Ww-Yg, or Ht-Ho-Ke-Ww-Yg, then it will get 150 observations in 10 scans, provided the sources is observed in all of them. The second station at Hartebeesthoek or Warkworth is helpful for imaging, or determination of flux density at kiloparsec scale, but it does not

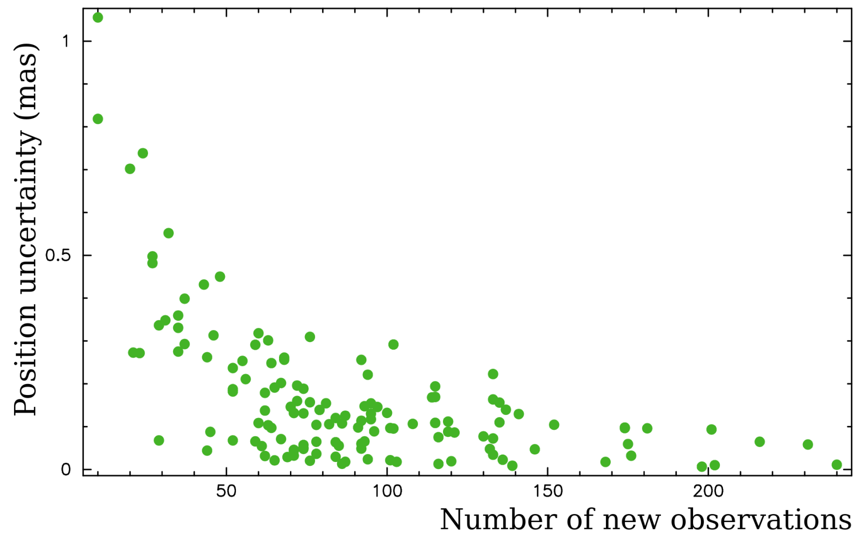

Figure 4: Dependence of the position uncertainty as a function of the number of new used SOAP observations.

provide new information for astrometry.

4 Discussion

4.1 What is good

Astrometric precision goal, 0.3 mas, has been reached for 78% targets. Position precision improved by a factor of 1.5–14.4 for 48 sources and by 20–50% for 21 more sources. This is the a quite substantial improvement.

Vienna group mastered correlation. For the first time, a university has managed to correlate entire program. No issues related to correlation of SOAP worth reporting is known.

4.2 What is not good

The project reached partial success. The detection rate in only 56% correlated observations. The sensitivity of Auscope antennas is so poor (one and half orders of magnitude worse than VLBA), that even 5 minutes long scans are not sufficient to always have a detection.

Stations not always use correct snap files, and some of them generate vex using drudg. Since drudg is not vex-1.5 compliant and does not support station start time offsets with respect to scan start time, this results in a loss of observing time.

Imaging is not started. Warkworth station still did not install Tsys, and no useful Tsys is available from either Ww or Wa. Imaging is postponed till Tsys measurements will be made and Tsys and the gain curve dependence on elevation angle will become available from Ww and Wa.

4.3 Suggestions for improvement

- To install amplitude calibration unit at Wa. To run a single-dish dry-run session with only Tsys recording to measure antenna gain. To built a model of Tsys. To investigate stability of receiver temperature. To run a Ww-Wa observing session of compact sources with total flux densities known from other observations. To derive a Tsys model and antenna gain for Ww.

- To start imaging using Wa Tsys for new observations and Tsys model for Ww and Wa for prior observations.
- To adjust integration time. To increase it from 5 to 10 minutes for sources that have detection rate less than 70% in SOAP-E1.
- To re-observe sources that had detection rate in range of 20% to 70% in priori SOAP-A1 observations in order to reach the project goal position uncertainty 0.3 mas.

4.4 Conclusion

The project is partly successful. I recommend to continue the efforts. There are good chances to finish it in 2019 and submit a paper with results.

References

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Petrov L., A. de Witt, E. M. Sadler, C. Phillips, S. Horiuchi 2019, MNRAS, in press, doi: 10.1093/mnras/stz242