# Pipeline processing procedure for spectral experiments on KVAZAR VLBI network

Smirnov A. D., Melnikov A. E., Mikhailov A. G., Kharinov M. A.

*Institute of Applied Astronomy, Russian Academy of Sciences, St. Petersburg*

A procedure for reduction of spectral VLBI data has been developed. Based initially on the EVN pipeline procedure it was modified for processing maser experiments conducted on KVAZAR network. AIPS is used to perform data reduction and ParselTongue module for Python for managing the process. This procedure performs standard steps needed for calibration and imaging of spectral data. In comparison with EVN pipeline Doppler correction was added and changes specific for spectral data was made in fringe-fitting and bandpass correction algorithms.

## Observations

Since 2012 Institute of Applied Astronomy RAS and Space Research Institute RAS arranged the cooperative astrophysical programme [1]. The programme involved series of spectral observations of interstellar maser sources conducted on KVAZAR VLBI network.

- $H_2O$ masers in W49N and Orion KL, 1.35 cm.
- OH masers in W75 and W3(OH), 18 cm.

Several observations were made in collaboration with non-KVAZAR stations: Simeiz, Effelsberg, Medicina, Noto, Hartebeesthoek.
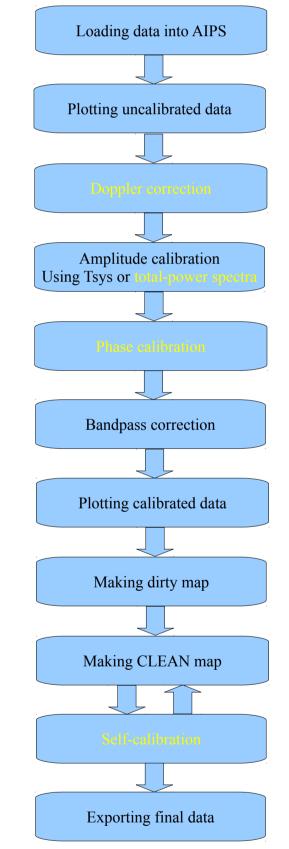Experimental data is correlated with DiFX software correlator at IAA correlation center.

## Existing software

Postcorellation data is processed using AIPS, the standard radioastronomy data reduction software developed at NRAO. AIPS is capable of performing all postcorrelation procedures necessary for imaging VLBI data. This includes amplitude and phase calibration, making CLEAN map, and self-calibration based on CLEAN model.

In an effort to simplify calibration process the EVN pipeline was developed at JIVE [2]. This procedure manages AIPS jobs and performs in an automated way all basic calibration and imaging steps with little contribution from end user.
EVN pipeline was originally created for Network Monitoring Experiments, simple experiments for assessing the performance of EVN array, but now it is applied to every experiment conducted on EVN as a means to provide preliminary results.
The old version of EVN pipeline was written as a procedure within AIPS using its own command processor called POPS. The modern version uses ParselTongue, the library which provides a Python interface to AIPS. This library allows writing versatile and flexible scripts for handling data processing in AIPS [3].

## RUP pipeline

Calibration of spectral experiments is distinct in some ways from generic continuum data calibration[4]. The EVN pipeline isn't suitable for processing spectral-line data and requires modification. In order to have a procedure for automatic processing of maser experiments, RUP pipeline was developed in IAA RAS. It is based on EVN pipeline which was modified according to aspects of spectral-line calibration. The properties of KVAZAR aray were also considered. The procedure is implemented as a Python script using ParselTongue library. Data calibration and imaging is performed within AIPS with Python script handling the process. The procedure consists of several sequential stages (fig. 1). It is arranged in a way that allows user to run the procedure partly, examine the results and, if needed, alter input parameters before continuation or repetition.

The stages of calibration process are described in the following, highlighting key differences from EVN pipeline algorithm.

1. Data is loaded into AIPS. This includes correlated visibility data for spectral source and calibration source (if any) as well as some auxillary data needed for calibration.
2. Various plots of initial data are made. This includes visibility data against time, total-power and cross-power spectrum, and coverage plot. This plots are useful for assessing quality of experiment data.
3. The Earth rotation and orbital movement causes the spectral line to drift across the spectrum. It doesn't affect continuum observations but for maser experiments this effect should be taken into account. To address this issue Doppler correction was added into RUP pipeline.
4. Conventional method of amplitude calibration makes use of $T_{sys}$ measurements taken during the observation. For spectral-line experiments alternative method is available which utilizes total-power template spectrum. In RUP pipeline both of this methods are implemented, and the one deemed more appropriate for given experiment can be used.
5. Phase calibration of spectral data must be handled differently from the calibration of continuum data. The spectral-line source cannot be used to determine the residual delay because the phase is a nonlinear function of frequency. In this case the continuum calibrator is used for residual delay computation. Then the residual rate can be estimated using the spectral source data. The range of spectral channels containing a strong line must be used for this estimation.
6. Bandpass correction should be performed to compensate the change of gain across the band. For spectral observations strong continuum calibrator must be used.
7. After initial calibration the plots of calibrated visibilities against time and frequency are created to examine quality of calibration.
8. Dirty map and dirty beam are made using the calibrated data. The channels containing emission from a single spectral line are used.
9. To obtain the final map, conventional iterative process is performed, which includes CLEAN deconvolution and self-calibration steps. CLEAN imaging process can be performed automatically or in interactive mode. The latter allows user to set constrainig windows for components search.
   KVAZAR array consists of three telescopes, which is not enough to conduct amplitude self-calibration. For joint experiments involving other stations, however, it can be performed. The procedure determines, whether amplitude self-calibration needs to be done, based on the number of participating telescopes.
10. Eventually final image and calibrated visibilities are exported as the files in FITS format.



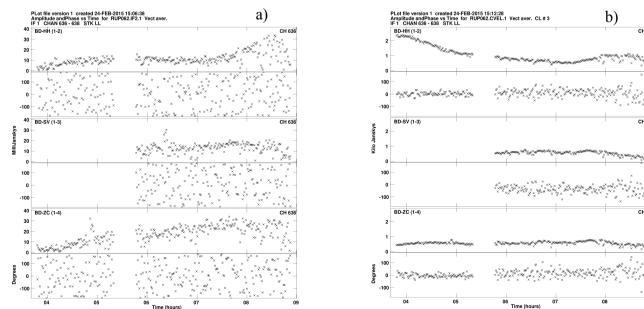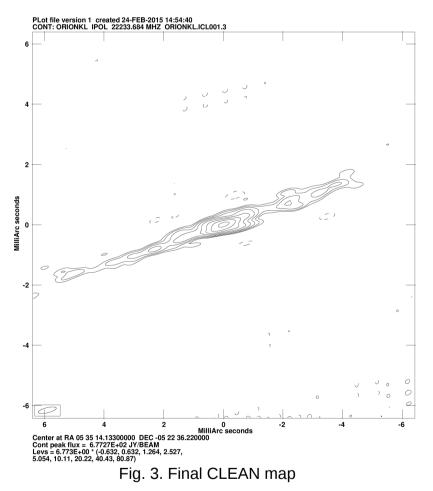Fig. 1. Algorithm of RUP pipeline procedure. Stages different from EVN pipeline highlited



Fig. 3. Final CLEAN map



Fig. 2. Visibility against time: a) Uncalibrated; b) Calibrated

## References

1. *A. V. Ipatov et al.,* Development of VLBI network "QUASAR" for astrophysical research on 18 cm and 1.35 cm wavelenghts, The IAA RAS journal, vol. 27, 2013
2. *Reynolds C., Paragi Z., Garrett M.,* Pipeline Processing of VLBI Data, arXiv:astro-ph/0205118v1, 2002
3. *Kettenis M., van Langevelde H. J., Reynolds C., Cotton B.,* ParselTongue: AIPS Talking Python, ASP Conference Series, Vol. 351, 2006.
4. *Diamond P. J.,* in Very Long Baseline Interferometry and the VLBA, ed. J. A. Zensus, P. J. Diamond, P. J. Napier, 1995