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Peculiarities of Maser Data Correlation / Postcorrelation in Radioastron Mission

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Abstract. We discuss specific aspects of space-ground VLBI (SVLBI) data processing of spectral line experiments (H_2O & OH masers) in Radioastron project. In order to meet all technical requirements of the Radioastron mission a new software FX correlator (ASCFX) and the unique data archive which stores raw data from all VLBI stations for all experiments of the project were developed in Astro Space Center. Currently all maser observations conducted in Radioastron project were correlated using the ASCFX correlator. Positive detections on the space-ground baselines were found in 38 sessions out of 144 (detection rate of about 27%). Finally, we presented upper limits on the angular size of the most compact spots observed in two galactic H_2O masers, W3OH(H_2O) and OH043.8-0.1.

Keywords. Space vehicles, radio lines: ISM, instrumentation: high angular resolution.

1. Correlator and Data Archive Overview

ASCFX correlator (first Fourier transform and then cross-spectrum multiplication) developed in Astro Space Center has the following properties (Likhachev *et al.* 2017): (1) Full support of all modern VLBI data formats: Radioastron data format (RDF), Mark5A, Mark5B, VDIF, VLBA, K5; (2) Computing cluster with 1 Tflop/s performance (about 100 processor cores); (3) Online raw data storage of 90 TB for correlation; (4) Online data storage for correlated observations – 250 TB; (5) Raw data archive of 3000+3000 TB: 1st copy on hard drives and 2nd copy on tapes; (6) Correlator can operate in "Continuum", "Spectral Line" and "Pulsar" modes. (7) The unique data archive stores all raw data (including data from ground stations) for all observations. This allows to re-correlate the data of any experiment with the updated information, like improved reconstructed orbit, different coordinates of phase center, different coordinates for ground stations, clock offsets etc.

2. Specific aspects of calibration and data processing

In comparison to the ground VLBI, SVLBI observations require correlator to take into account: relativistic effects of highly elongated elliptical orbit, significantly wider range of possible values for geometric delay, delay rate and acceleration term (see Likhachev *et al.* 2017). Galactic masers often characterized by the presence of a large number of features scattered over a relatively large area, so that at longer baselines it become important to perform initial fringe search in a very wide window and to correlate the data with multiple phase centers corresponding to different parts of a source.

Amplitude calibration & Bandpass calibration. Typically in VLBI observations amplitude calibration of each band is mainly based on T_{sys} measurements done by inserting noise calibration signal during the gaps between observing scans. In case of strong maser lines better precision might be achieved using a template calibration method based on total power spectra obtained from a reliable antenna. Amplitude bandpass calibration can be derived from spectral observations itself by flagging channels with maser emission and from observations of continuum calibrator or off-source position. Performing complex bandpass is possible only for short baselines where a very high SNR could be obtained in observations of strong continuum sources.

Fringe fitting & delay calibration. Since the baselines for SVLBI are significantly longer than the Earth diameter (ED) at 22 GHz we have a limited sample of unresolved continuum sources which can be used as delay calibrators for spectral line soures. In significant part of observations we should rely on the reconstructed orbit, that currently provides an accuracy of 200 m in the position (0.7 μs in delay) (Likhachev *et al.* 2017), and other information is known a priori. Fringe rate fitting is possible using spectral line data itself.

3. Preliminary results: estimation of angular size of H_2O maser spots

To estimate the size of the most compact features we used the data from two 1 hour long observations of two galactic masers (W3OH(H2O) and OH 043.8-0.1) at 22 GHz water line. Experiments were conducted within the maser survey during the Early Science Program and Announcement of Opportunity 2 period and then processed using the ASCFX correlator. Even in case of short observations with a limited sampling of the UV-plane it is still possible to estimate some parameters of a source using simplifed assumption like a circular Gaussian brightness distribution. After performing the calibration procedure, we constructed the "visibility amplitude versus baseline projection" dependence for the brightest detected features and then calculated their angular size using the expression: $\Theta_r = \frac{2\sqrt{ln2}}{\pi}\frac{\lambda}{B}\sqrt{ln(\frac{V_0}{V_q})}$, where B - projected baseline length, V_0 and V_q - visibilities at zero-space and current baseline respectively.

W3OH(H2O), experiment RAES02A, ground stations: Effelsberg, Yebes. A two-component model can be assumed, which is composed of an extended "halo" and a bright compact detail. Unfortunately, because of the big gap between the space and ground baselines, it's impossible to perform reliable fit for these two components together. We performed separate fitting for each potential component and obtained their sizes: extended "halo" – $\approx$ 740 μas and the upper limit for the size of compact detail – $\approx$ 42 μas.

OH043.8–0.1, experiment RAGS11AZ, ground stations - Medicina, Yebes, HartRAO 26m. In this experiment the length of space-ground baselines was smaller than 1 ED and the visibility data well fitted with a single component providing the angular size of 73 μas.

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