Report from

the Short Term Mission – STM

Person Name:	***Janis Steinbergs***
Home Institute	*The Engineering Research Institute "Ventspils International Radio Astronomy Centre" of the Ventspils University College (VUC), Ventspils, Latvia*
Host Collaborator	*Aard Keimpema, Mark Kettenis* *Email: keimpema@jive.eu, kettenis@jive.eu*
Host Institute	Joint Institute For VLBI ERIC (JIV- ERIC)
Date of the STM:	20.08 – 02.09.2018

RadioNet has received funding from the EU's Horizon 2020 research and innovation programme under the grant agreement No 730562

Report:

1. Topic

Learning how use Jive SFXC Correlator, including calibration, fringe fitting for SFXC, and using SFXC with VDIF data format.

2. Proposed and Performed Work

Proposed

- It is proposed that applicant will get familiar prepare data for correlation with SFXC.
- Learn how to use SFXC in real time.
- Learn to customize correlation parameters for specific observations, including VEX file preparing, for observation with different number of channels and different BBC settings
- Understand calibration and fringe fitting process for SFXC
- Understand analyse of maser observation data in CASA, AIPS

Performed

- Discussed with JIVE experts SFXC correlator inner workings.
- Had practice experience preparing data for correlation with SFXC.
- Had practice experience using SFXC in real time.
- Discussed with JIVE experts possibilitys to customize correlation parameters for correlation.
- Learned algorithms for VEX file preparation, including creating THREAD and BITSTREAMS blocks.
- Learned to use JIVE developed scripts for fringe fitting process for SFXC.
- Learned to install, use JIVE developed post correlation tools, JPLOTTER, J2MS2, TCONVERT, and did first steps in AIPS to analyse maser observation data.
- Gain experience using JIVE developed observation planning tool pySCHED.

3. Cross-Disciplinarity

- As VIRAC technical workers have relatively small experience in full experiment setup for interferometric observation and preparing data for correlation and after correlation creating scientific work.
- This work is closely related with engineers, who created a signal processing pipeline for electromagnetic wave storing as data in hard drive. After that data can be processed using software (mentioned in section **performed**) what can be applied by scientists to interpret observation data. Using software (mentioned in

RadioNet has received funding from the EU's Horizon 2020 research and innovation programme under the grant agreement No 730562

section **performed**) and after that can be used by scientists to interpret observation data.

4. Impact

- It lead to creating new publication and posters about VLBI theme.
- Expanded practical experience and field of view of VIRAC staff knowledge will positively impact astronomical data processing including pre-correlation preparation, post-correlation data analyse.
- VIRAC stuff is now capable performing VLBI observation from planning to science, that includes data processing pipeline for VLBI observations, that is partly created by knowledge gain in this STM. Since than VIRAC stuff has conducted many successful observation together with Torun observatory.

5. Publications

J.Steinbergs, K. Skirmante, Vl.Bezrukovs, “VIRAC infrastructure and data processing pipeline for VLBI observations”, journal of VeUAS ITF, 2019 (submitted)

Vl. Bezrukovs, **J. Shteinbergs**, I. Shmeld, A. Aberfelds, M. Bleiders, A. Orbidans, K. Skirmante, M. Gawronski, R. Feiler “First interferometric observations in Irbene - Torun baseline conducted by VIRAC”, journal “Proceedings of Science, EVN 2019” (submitted)

Presentation**: Janis Steinbergs**, Vladislavs Bezrukovs, Ivars Shmelds, Karina Skirmante, Artis Aberfelds, Mārcis Bleiders, Artūrs Orbidāns, Marcin Gawroński, Roman Feiler, First VLBI maser observations in Irbene – Torun baseline, YERAC 2018.

The project leading to this publication has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]

PROCEEDINGS OF SCIENCE

First interferometric observations in Irbene - Torun baseline conducted by VIRAC[1]

Vl. Bezrukovs[a], J. Shteinbergs[a], I. Shmeld[a], A. Aberfelds[a], M. Bleiders[a], A. Orbidans[a], K. Skirmante[a], M. Gawronski[b], R. Feiler[b]

a) Engineering Research Institute "Ventspils International Radio Astronomy Centre" of Ventspils University of Applied Sciences

Inzenieru Street 101, Ventspils, LV-3601, Latvia

b) Torun Centre for Astronomy, Nicolaus Copernicus University

Gagarina street 11 87-100, Torun, Poland

E-mail: vladislavsb@venta.lv

Ventspils International Radio Astronomy Centre (VIRAC, Latvia) operates two radio telescopes RT-16 and RT-32 accordingly with 16 and 32 *m* fully steerable Cassegrain type antennas. The main receiving systems of the both telescopes are cryogenic receivers with 4.5 – 8.8 *GHz* frequency range; additionally, in 2019 radio telescope RT-32 will be equipped with new L band receiver. Data registration units of the both antennas are suitable for interferometric observations. The Nicolaus Copernicus University Department of Radio Astronomy in Torun, Poland, operates 32 *m* radio telescope RT-4, which also works in similar bands - L, C and M - and regularly participates in the VLBI observations. Also VIRAC has a high performance computer cluster with *SFXC* software correlator developed at JIVE.

In the spring 2018 VIRAC team with support from Torun group conducted several VLBI experiments in the baseline Irbene - Torun using Irbene radio telescope RT-16 and Torun RT-4. Successful fringes and FITS files with *uv* data obtained mean, that data correlation and post processing facilities established in VIRAC allow to run small scale interferometric tasks.

Keywords: VIRAC, radio astronomy, galactic masers, VLBI observations, SFXC, correlation

14th European VLBI Network Symposium & Users Meeting (EVN 2018)
8-11 October 2018
Granada, Spain

[1] Work is partialy financed by Ventspils University of Applied Sciences project "**Research of the possibility of creating a small VLBI array and radio astronomical data processing centre in VIRAC (TorIn)**; June – December 2018.

1. Introduction

The radio telescopes RT-32 and RT-16 at Irbene operated by VIRAC are equipped with broad band (frequency range 4.5-8.8 *GHz*) receiving systems and with modern VLBI data acquisition system [1]. The first fringes in the European VLBI Network (EVN) Network Monitoring Experiments were detected in April of 2012. This demonstrated ability of Irbene radio observatory to participate in the EVN as a VLBI station [2]. Since this time, VIRAC staff has been gradually improving the observation process, including investments in the infrastructure, developing software and refining VLBI data processing tools. Recent software solutions for VLBI and accessibility to High Performance Computers (HPC) allow to process large amount of radio astronomical data, typically 1 to 4 *Gbps* per each station, in several data flows in relatively small data processing centres like data processing centre established in VIRAC.

2. VLBI experiment scheduling and data processing pipeline

Typical organization of VLBI observation session includes the following steps: experiment planning and telescope time scheduling; performing radio astronomical observations under automatic control of Field System (*FS*) [3]; data acquisition and storage; data correlation and post-correlation data processing. In the Figure 1 VLBI data processing pipeline implemented in VIRAC is shown.

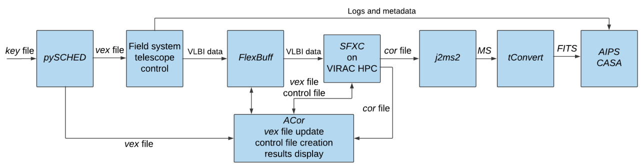

Figure 1: VLBI data processing pipeline established in VIRAC.

For observation scheduling VIRAC uses JIVE (the Joint Institute for VLBI ERIC) developed software *pySCHED* that creates *vex* file.[2] When *vex* file is created, it is loaded into *FS* that controls antenna movement and data acquisition. Input file for *pySCHED* is *key* file. *Key* file contains information about the participating stations, sources being observed and timing of planned scans. Observational VLBI data from stations in *VDIF*[3] or Mark5a/b formats are delivered to the data storage on VIRAC servers *FlexBuff-1* or *FlexBuff-2* by help of *Jive5ab* utilities. Total amount of disk space available for observation is 320 *TB*. Recorded data is sent to VIRAC HPC for correlation. Currently VIRAC uses two correlators, self-developed *KANA* [4] and JIVE developed *SFXC* (Software FX Correlator) [5]. Selection of correlator depends on observation type (near- or far-field sources). VIRAC HPC has 30 nodes with two Intel Xeon E5-2630 v3 processors and 128 *GB* RAM in each node and 10 *Gbps* connection to GÉANT[4].

VIRAC also has self-developed Automated Correlation System – *ACor* providing following functionality – *vex* file update, control file creation for *SFXC* correlator, correlation processing and display of correlation results. *ACor* system was developed using *AngularJS* framework and responsive web interface *Twitter Bootstrap* [6]. To correlate with *SFXC* a correlation control file is prepared and the *vex* file sections[5] TAPELOG_OBS, CLOCK, EOP, BITSTREAMS and THREADS are updated. Control file contains correlation parameters, like integration time, number of channels, location of data files. After correlation *.*cor* file is

[2] *vex* – VLBI Experiment file format.
[3] *VDIF* – VLBI Data Interchange Format.
[4] GÉANT pan-European network. https://www.geant.org.
[5] *vex* file sections definition: https://safe.nrao.edu/wiki/bin/view/VLBA/Vex2doc

created. Tool *jplotter* developed by JIVE is used to inspect the correlation results and to create the inspection plots, like station weights as function of time; auto-correlation and cross-correlation amplitudes and phases as functions of channels and others. To use *jplotter* it is necessary to convert **.cor* file to so called Measurement Sets (*MS*); JIVE developed tool *j2ms2* is used for this purpose. When *MS* is created, it can be converted to *FITS*[6] file using JIVE tool *tConvert*, and *FITS* file can be loaded then into *AIPS* (*Astronomical Image Processing System*) or *CASA* (*Common Astronomy Software Applications package*) for post-correlation data processing. For post-correlation data processing VIRAC currently uses *AIPS* package for data editing, calibration, fringe fitting and imaging tasks.

3. Irbene – Torun interferometric experiment

Since NEXPReS[7] project an important collaboration between Irbene and Torun was carried out with the aim of improving VLBI and e-VLBI (real time VLBI) data processing technique at both observatories. The Torun observatory operates with 32 *m* radio telescope working in similar bands – L, C, M and K and regularly participates in VLBI observations. In years 2012 – 2013 several e-VLBI sessions were organized involving Irbene and Torun antennas and using the *DiFX* (deployed in PSNC[8]) and *SFXC* (deployed in VIRAC) correlators. The management of the data processing was mutually exclusively taken by both operators. The data transfer in real-time was tested at multiple configurations of the antennas and the correlators, as well as at variable number of channels. The results of these experiments demonstrate technical possibility to correlate at least two data flows in real time. Unfortunately, the fringes have not been obtained. [2]. Attempts to create a working VLBI data processing pipeline in VIRAC was boosted in years 2017 and 2018 within two scientific projects ASTRA[9] and TorIn[10] which are related to galactic maser observations in single dish and VLBI mode. In April 2018 short VLBI observations of methanol maser W3(OH) were made with two radio telescopes: Irbene RT-16 and Torun RT-4. The purpose of the experiment was to practice in planning observations and in data processing steps. In this experiment VIRAC team created a schedule for each telescope, collected recorded data on *FlexBuff* server, made data correlation with *SFXC* correlator and converted measurement sets to the *FITS* files suitable for subsequent interpretation in the *AIPS* or *CASA*. On April 26, 2018 there was the first successful VLBI experiment at 6.7 *GHz* performed – data correlation returned the first fringes on baseline Irbene – Torun (530 *km*). The quasars 3C123 and 3C84 were chosen as calibrators and the target source was methanol maser W3(OH). Figure 2 clearly shows the cross-correlation functions with fringe pattern this baseline. Figure 3 shows cross-correlation results of amplitude and phase as function of channels, at left frame - source 3C84, at right frame - source W3(OH). The result of source 3C84 shows coherent phases and amplitude, indicating that strong quasar is clearly visible, both antennas were on source and signal from source is coherent. The result of source W3(OH) shows strong maser signal as expected. The final step of the post-correlation task usually is to create image (FFT of *uv*-plane) of the target source. Mentioned Irbene - Torun observation

[6] *FITS* - Flexible Image Transport System file format https://fits.gsfc.nasa.gov/fits_standard.html.

[7] NEXPReS - Novel EXplorations Pushing Robust e-VLBI Services (FP7 RI 261525), http://www.nexpres.eu.

[8] PSNC - The Poznan Supercomputing and Networking Centre.

[9] European Regional Development Fund project No. 1.1.1.1/16/A/213 "Physical and chemical processes in the interstellar medium" - ASTRA.

[10] Ventspils University of Applied Sciences project “Research of the possibility of creating a small VLBI array and radio astronomical data processing centre in VIRAC” - TorIn.

duration was only 30 *min* and with one baseline total number of visibilities was very small, so this step wasn't performed.

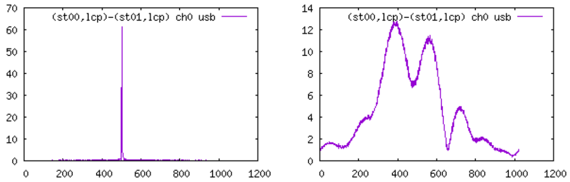

Figure 2: Cross-correlation functions at the baseline Irbene – Torun. Date: 26 Apr 2018, frequency: 6662.49 *MHz*, USB, LCP – LCP: calibrator 3C84 (left) and galactic maser W3(OH) (right).

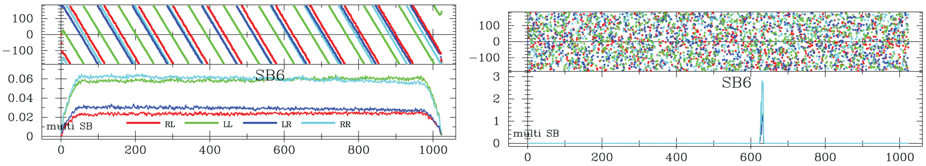

Figure 3: Amplitude and phase as function of channels at the baseline Irbene – Torun. Date: 26 Apr 2018, frequency: 6662.49 *MHz*, calibrator 3C84 (left) and galactic maser W3(OH) (right).

4. Conclusions

After modernization carried out during the years 2014 – 2015 and developing the appropriate data reduction program the both VIRAC radio telescopes of are suitable for VLBI and spectral line observations in the frequency range 4.5 – 8.8 *GHz* and starting with 2019 in 1.6 *GHz*. Additionally, to the other possible fields of research by means of these telescopes, both radio telescopes may be used as small baseline interferometer for exact measurements of coordinates and sizes of maser sources. However, it is necessary to add one or two additional radio telescopes (e.g. Torun or Onsala) in order to monitor motion dynamics of sources with characteristic distances tens of *mas* between spectral features.

The successful VLBI experiment conducted in the baseline Irbene – Torun which was scheduled and processed by VIRAC team shows ability of VIRAC correlation centre to conduct and correlate a small scale interferometric tasks.

5. References

[1] V. Bezrukovs. *Time and frequency synchronization on the VIRAC Radio telescope RT-32.* Latvian Journal of Physics and Technical Sciences, (2016) vol. 53.

[2] K. Skirmante, V. Bezrukovs, N. Jekabsons, I. Shmeld. *Preparation of the Virac Radio Telescope RT-32 for E-VLBI Observations*. Baltic Astronomy, (2013) vol. 22.

[3] N.R. Vandenberg et al. *Automation of the MARK III Field System*, (1980).

[4] J. Jekabsons, D. Kotlere, M. Nechaeva. *Mathematical and Algorithmic Description of Software Correlator for Space Debris Data Processing in VIRAC*. European Space Surveillance conf, (2011).

[5] A. Keimpem, et al. *The SFXC software correlator for Very Long Baseline Interferometry: Algorithms and Implementation.* Experimental Astronomy, (2015).

[6] J. Steinbergs, F. Kamisevs, K. Skirmante, K. *Automated Correlation System for radio astronomical data processing in VIRAC.* Space Review (2018) vol.5.

6. Acknowledgment

This publication has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet].