Haystack Observatory VLBI Correlator 2015–2016 Biennial Report

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Abstract This report summarizes the activities at the Haystack Correlator during 2015–2016.

Fig. 1 Partial view of the Haystack DiFX correlator, showing two racks containing seven computer servers, three file storage servers, one Qlogic infiniband switch, and two Mark 6 playback units.

MIT Haystack Observatory

Haystack Correlator

IVS 2015+2016 Biennial Report

1 Introduction

The DiFX VLBI correlator of the MIT Haystack Observatory, located in Westford, Massachusetts, is supported by the NASA Space Geodesy Program and the National Science Foundation. It is dedicated mainly to the pursuits of the IVS, with a smaller fraction of time allocated to processing radio astronomy observations for the Event Horizon Telescope (EHT) project. The Haystack correlator serves as a development system for testing new correlation modes, such as those needed for the VGOS observations, and for recorder developments, such as the Mark 6 system. Some software support is provided to similar DiFX installations at the U.S. Naval Observatory, to the Max Planck Institute for Radioastronomy in Bonn, Germany, and to the general IVS community for DiFX processing of IVS experiments.

2 Summary of Activities

2.1 VGOS Activities in General (Formerly Referred to as Broadband Delay)

The last two years have marked a significant ramping up of the VGOS project. A regular series of experiments using the GGAO12M–Westford baseline established the attainable accuracy of the technique, then the build-out, testing and commissioning of the Kokee12M antenna expanded the VGOS network to three stations. Interspersed with that, international sites such as the RAEGYEB antenna at Yebes, Spain and the Wettzell South VGOS antenna in Wettzell, Germany joined the

US network in many commissioning tests using IF signal chains of their own design and digital back ends comprised of an amalgam of DBBC2s, ADS3000s, and Haystack-designed RDBEs. A site in Ishioka, Japan also joined in for a smaller number of tests using their own IF signal chain and ADS3000 recorders. All this combined to make a VGOS network of six stations. Regular experiments in the form of a VGT then VGP series comprised of collections of these antennas in various combinations were conducted in order to validate and/or improve performance of the equipment at each of the sites. Much effort has especially been put into diagnosing and fixing various problems seen in the European DBBCs, which have displayed various performance deficiencies. Overall, we are progressing rapidly toward a functioning network but some fundamental problems need to be solved, most notably phase and amplitude stability across the band with the Yebes and Wettzell systems.

2.2 Kokee12M VGOS Commissioning

An extensive series of experiments was conducted in order to test the data acquisition rack, detect initial fringes, and validate the integrity of the signal chain of the newly constructed 12-m antenna built at Kokee Park. The series included zero baseline tests of the data acquisition rack while set up at the Westford site using its signal chain split with Westford, on-site fringe test experiments with GGAO12M and Westford, then complete 24-hour experiments in standard VGOS mode with GGAO12M and Westford. Also, "mixed mode" tie experiments were conducted with the Kokee 20M antenna recording in parallel using traditional S/X mode and the Kokee12M, Westford, or GGAO12M recording in broadband mode. These tests successfully showed the signal chain to be of high quality and equivalent to the extensively tested GGAO12M and Westford signal chains, and tied the position of the new 12-m antenna into the reference frame of the traditional S/X network. An entire series of about 17 experiments devoted to Kokee12m commissioning was conducted.

2.3 Wettzell South, Yebes (RAEGYEB), Ishioka and Kashima VGOS Antenna Commissioning

The Wettzell South and Yebes RAEGYEB antennas began participating in the VGOS experiment series starting in mid-2016. Initial serious problems with the DBBC2 backends were mostly overcome through repeated testing and revision of the DBBC2 firmware and hardware. The Ishioka broadband antenna in Japan also joined for some fringe tests and one 24-hour experiment. The quality of their data was quite good. It should also be noted that in January 2015, a Kashima antenna VGOS signal chain broadband fringe test was conducted and they subsequently joined a VGOS broadband experiment (v15020) for one hour in the highest band; good fringes were found.

2.4 R1 and RD1606 Mixed Mode Tag-along to IVS Experiments

Some combination of GGAO12M and/or Westford tagged along to four IVS S/X R1 sessions namely R1706, R1708, R1716, and R1718 through the second half of 2015 in an effort to develop a "mixed mode" method of tying the traditional S/X stations to the new broadband network. Most recently, Westford tagged along to IVS S/X session RD1606 in mid-July. Much has been learned through these test observations and the process of making them production ready is progressing.

2.5 Mark 6 Real Time Playback

Two methods of playing back data from Mark 6 playback units directly on the correlator were developed over the last two years. Broadband VGOS data sets were provided to the Bonn correlator where, in collaboration with Walter Brisken, they devised a method of directly playing back VGOS format recorded data. Some further development work continued at Haystack in order to fix some bugs, and now this method is used to play back all VGOS data in production mode.

An entirely different real time playback system was developed at Haystack by Geoff Crew and that method has been used extensively for EHT cluster processing. It has also been adapted and used by the Bonn correlator for their portion of EHT processing.

Mark 6 is thus now fully integrated into the production processing system.

2.6 Fourphase Development

A program designed to automate the tedious task of determining X/Y delay and phase offsets needed in order to combine the polarizations of broadband VGOS data has been under development for some time and is now in its testing phase.

2.7 Mark 5B Directory and Data Readback Fixes

Various problems were encountered over the last two years related to reading directories and data from Mark 5B modules. An iterative exchange with Walter Brisken has addressed all of them, although some issues still crop up intermittently.

2.8 64 Channel Processing Development

A method of processing simultaneously all 64 channels in a full broadband VGOS recording was developed by Roger Cappallo in 2015. This was essential to efficient production processing of VGOS broadband data.

2.9 nuSolve Install

The Goddard "nuSolve" package, including database making tools such as vgosDbMake, was installed by Tim Morin. It is now used to generate all databases for VGOS correlated experiments.

2.10 DiFX Software Support

Support for the community continues for difx2mark4, fourfit, and HOPS. This support includes addition of features requested by users, other enhancements, and bug fixes.

2.11 DiFX Cluster Developments

Some upgrades to the "geodetic cluster" were made. The geodetic cluster moved to a new master node and more storage space for e-VLBI was installed. An entirely new cluster built for the purpose of processing large number of stations and future 64 Gb/sec recordings has been constructed by the EHT project, is in routine use and is set to be greatly expanded.

2.12 CorreIX Development

An entirely new software correlator was developed by Antonio Vazquez under the auspices of the Astro and Geoinformatics group led by Victor Pankratius. This work is soon to be released to the public.

2.13 Haystack 37 Meter Antenna Recommissioning

Re-commissioning of the rebuilt Haystack 37-meter antenna for VLBI observations was conducted in the second half of 2016. Fringe tests were performed with the VLBA array at 3-mm and 7-mm wavelengths and good fringes were found in both bands.

2.14 e-VLBI

Non-real-time transfers have continued. Data from 29 sessions were transferred to Haystack during the past two years from 16 stations: five in Japan (Ishioka, Kashima34, Kashima11, Koganei, and Tsukuba), four in Western Europe (Onsala, Ny-Ålesund, Yebes, and Wettzell), three in Australia (Hobart, Yarragadee, and

Katherine), one in South America (Fortaleza), two in South Africa (Hart15M and HartRAO) and one in China (Tianma65).

3 Experiments Correlated

In 2015–2016, 87 geodetic VLBI sessions were processed, at least in part, consisting of 16 R&Ds, six T2s, and 65 VGOS-related sessions that were either broadband, mixed mode, or tests of other types, some of which were touched on in the summary above. As usual, smaller tests were not included in the above count because they were too small to warrant individual experiment numbers. All production and test experiments were done on the DiFX cluster.

4 Current/Future Hardware and Capabilities

The geodetic DiFX cluster currently consists of six PCs, each with dual hex core 2.66 GHz Intel Xeon processors. Three file storage servers, which can also act as DiFX compute nodes, provide >200 TB of file storage. These are all connected through a 40 Gb/sec infiniband network fabric using a Qlogic switch. Six Mark 5B and two Mark 6 playback units with DiFX fully installed are connected to the infiniband fabric.

An entirely new EHT cluster consisting of 16 PCs, each with single decacore 2.8 GHz Intel Xeon processors, two equivalent master nodes, and seven Mark 6 playback units, along with 197 TB of data storage space connected through a 40 Gb Ethernet network fabric was constructed and is in operational use since mid-2016. This cluster is mostly dedicated to Galactic Center observations of the EHT, but was also used to process some VGOS broadband experiments. This cluster is set to more than double in compute power and playback unit number in early 2017. The infrastructure is already installed for the new equipment and it is purchased and on its way.

5 Staff

Staff who participated in aspects of DiFX, Mark 5/6, and e-VLBI development and operations include:

5.1 Software Development Team

- John Barrett - software development/support
- Roger Cappallo - post processing; Mark 5B & 6; correlator software integration and troubleshooting; DiFX correlator development
- Geoff Crew - DiFX correlator development, post processing software; Mark 6
- Kevin Dudevoir - correlation; maintenance/support; Mark 5A/5B/5C; e-VLBI; computer system support/development; DiFX correlator development
- Tim Morin - cluster installation/development/maintenance and s/w support
- Jason SooHoo - cluster installation/development/ maintenance and s/w support, e-VLBI; Mark 5A/5B/5C/6
- Jon Rose - cluster installation/development/maintenance and s/w support
- Chester Ruszczyk - e-VLBI; Mark 5A/5B/5C/6
- Alan Whitney - system architecture; Mark 5A/5B/5C/6; e-VLBI

5.2 Operations Team

- Peter Bolis - correlator maintenance
- Alex Burns - playback drive maintenance; Mark 5/6 installation and maintenance; general technical support
- Brian Corey - experiment correlation oversight; station evaluation; technique development
- Morgan Goodrich - general technical support
- Glenn Millson - correlator operator
- Arthur Niell - technique development
- Don Sousa - correlator operator; experiment setup; module library and shipping
- Mike Titus - correlator operations oversight; experiment setup; computer services; software & hardware testing

- Ken Wilson - correlator maintenance; playback drive maintenance; general technical support

6 Conclusion/Outlook

Build-out, commissioning, and expansion of the VGOS broadband network will continue. Standardization and automation of procedures in order to export broadband VGOS processing to other correlators will proceed. Mixed mode observation/correlation methods will be developed and exported. Routine geodetic processing continues as well.