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LAMBDA – a Low-frequency Australian Megametre Baseline Demonstrator Array

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Abstract. LAMBDA is a planned low-frequency VLBI array to be built in Australia to pursue high resolution (sub-arcsecond) science at low frequencies. It is being designed to have good frequency overlap with the SKA-Low and will be capable of incorporating SKA-Low tied array data to provide a highly sensitive, low-frequency long baseline array in the Southern hemisphere.

1. Introduction

SKA-Low is being constructed in Western Australia and due to become operational in 2027. With a maximum baseline length of ∼ 74 km, SKA-Low will be unable to provide high resolution observations on its own, but will have a multi-beam tied array capability allowing it to participate as an element in conventional VLBI arrays (García-Miró et al. (2019)). By these means the community will be able to pursue the high-sensitivity high-resolution science cases that have been described (e.g. Paragi et al. (2019)). Currently there is a dearth of low frequency telescopes in the Southern Hemisphere which can provide a VLBI array for co-observing with SKA-Low. As a first major step to address this issue we have proposed LAMBDA - the Low-frequency Australian Megametre Baseline Demonstrator Array.

LAMBDA is planned to be a 5-6 station array distributed across Australia leveraging the existing site infrastructure of the cm-wavelength Long Baseline Array. Individual stations will comprise

- 256 dual-polarization dipoles providing comparable sensitivity to a single SKA station.
- a flexible backend designed by CSIRO which will provide a low-cost, largely COTS (consumer off-the-shelf), system with powerful multi-beam station processing (e.g. RFI mitigation, transient searching, pulsar timing, Technosignature searches, all-sky monitoring)
- power and timing using existing LBA infrastructure
- data transport and correlation using existing LBA infrastructure

2. The LAMBDA Backend

One of the key features of LAMBDA and a major focus of innovation, is the highly flexible backend which will support a broad range of data processing in addition to the basic VLBI beamforming required for the primary science case. A schematic of the backend is presented in Figure 1.

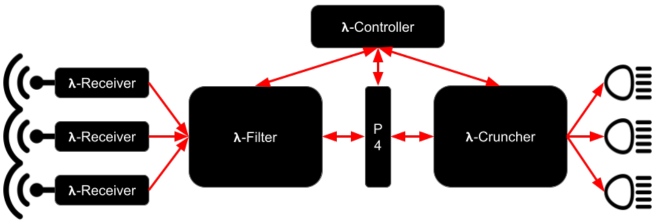

Fig. 1. The major components of the LAMBDA backend are: the λ-Receiver, λ-Filter, P4 Switch and λ-Cruncher

2.1. LAMBDA Receiver

The LAMBDA receiver will digitise the signal and be located adjacent to the antenna. An RFI-shielded enclosure provides excellent shielding from self-generated radio frequency emissions and also contains lightning protection. The receiver will generate high quality clocks to drive the analogue-to-digital converters (ADCs) and sample with sufficient bits (∼ 14) to cope with site RFI levels. The ensemble has low power consumption and is passively cooled.

2.2. LAMBDA Filter

The LAMBDA filter will provide clock and power support for the receiver and will implement several steps of the signal filtering and conditioning. These include the delay correction for the receiver, a filterbank for the digitised data, packetising and timestamping of the data, and optionally will be able to form a single VLBI beam from all the station elements. (More sophisticated beamforming may be implemented in the LAMBDA Cruncher if desired.) The required compute capacity is to be provided by an FPGA, likely the AMD Alveo card.

2.3. LAMBDA Cruncher

The LAMBDA filter will transmit data to a P4 switch from which the LAMBDA Cruncher can receive voltage data from all receiving elements in the station. The Cruncher will be implemented in a GPU allowing for antenna calibration and VLBI band reconstruction (32, 64 or 128 MHz re-sampled with 2 or 4 bits) and formatting as VLBI Data Interchange Format (VDIF) for transfer to a correlator. The Cruncher will have spare compute capacity to implement further station processing, including, but not limited to:

- pulsar timing
- RFI mitigation
- Additional beams including by innovative algorithms such as EPIC (Thyagarajan et al. (2017)) which may permit many beams or all sky monitoring
- bespoke filterbanks
- Technosignature searches

3. Array Configuration

In order to leverage existing infrastructure and constrain costs, the initial LAMBDA roll-out will focus primarily on sites already in use for the cm-wavelength Long Baseline Array (LBA). Those sites already have ready access to power, internet and timing systems, and have sufficient space available for an aperture array station. Working in tandem with the SKA-Low which will have a sub-arraying capability, these sites produce an array with reasonable imaging performance. Figure 2 shows indicative *u,v* coverage for an array comprising stations at existing LBA sites, plus one additional station near the Western Australian and South Australian state borders to provide intermediate spacings. One likely use of the phased SKA-Low is to form separate subarrays from the core and 3 outlying groups of stations towards the end of the spiral arms for a total of 4 subarrays, which significantly enhances the surface brightness sensitivity of the array.

The backend will be largely agnostic about the final choice of antenna. Antenna options currently being considered include the SKALA4 (de Lera Acedo et al. (2015)) and MWA CRAB (Curtin Radio Astronomy Bow-tie). While the RFI environment at the LAMBDA stations is substantially worse than at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory, where MWA and the SKA are hosted, it is likely that both antennas will perform adequately for a VLBI phased array at the proposed LAMBDA sites. The antenna choice will therefore likely be driven by cost and procurement issues. An antenna with a smaller physical footprint (larger field of view for a given number of elements) is advantageous for single-station work.

4. LAMBDA Correlator

LAMBDA will utilise the existing correlator infrastructure employed by the Long Baseline Array which consists of a DiFX (Deller et al. (2011)) installation at the Pawsey Supercomputing Research Centre in Perth. The available compute resources are adequate to support a ten-station low-frequency array operating full time.

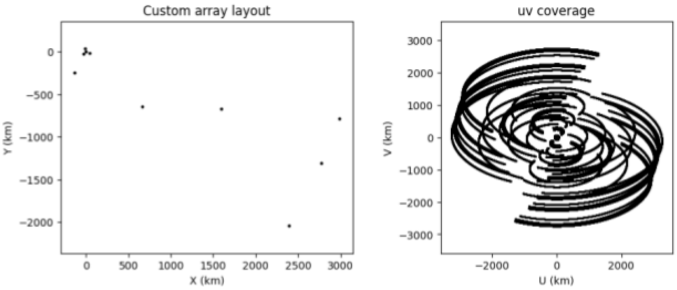

Fig. 2. Indicative single-frequency *u,v* coverage (no bandwidth synthesis) for LAMBDA in conjunction with a subarrayed phased SKA-Low. The 4 stations on the top left are clusters within the SKA-Low, the station at the bottom-right is Hobart. Others, from left to right, are Yarragadee, Balladonia (new site), Ceduna, Parkes and Narrabri.

5. Array Construction Timeline

The LAMBDA design is currently at an advanced stage with a testbed system being constructed in Narrabri. This testbed will allow for verification of component performance for the end-to-end system. The testbed should be fully in place by the middle of 2025, at which point planning for the roll-out of the first stations will be completed and procurement of hardware will begin. For reasons of logistical convenience the first two full 256-dipole stations are likely to be built at Narrabri and Parkes. The roll-out to other sites will take place over the ensuing few years as resource availability permits.

6. Conclusions

LAMBDA will play a vital role in the exploration of the low frequency sky in the southern hemisphere. With the phased SKA-Low as a highly sensitive element of the array, it will enable the exploration of new parameter space, enabling the SKA to achieve some of its key science goals. An extensive portfolio of science cases now exists for high-resolution, low-frequency observations in conjunction with the SKA – LAMBDA will be pivotal in realising these.

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