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High-Time Resolution GPU Imager for FRB searches at low radio frequencies

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Fast Radio Bursts (FRBs) are mysterious extremely bright millisecond radio pulses of predominately extra-galactic origin. The physical mechanisms powering these unprecedentedly bright radio pulses still remain unexplained. Despite hundreds of FRBs discovered at frequencies above 400 MHz, only a handful were detected below 400 MHz. One of the reasons for this is the computational complexity of FRB searches at these frequencies. Firstly, dispersion of radio signals causes time delays of the order of tens of seconds, which required into large amounts of computer memory (even of the order of a Tb). Secondly, large fields of views (FoVs) of low-frequency aperture arrays require formation and searchers over multiple beams (or image pixels). Nevertheless, the FRB rates extrapolated from higher frequencies indicate that a wide-field low-frequency telescope with a moderate sensitivity (~100 Jy ms) can detect even one low-frequency FRBs per day [1]. Such detections can further our understanding of these puzzling events, by enabling detailed studies of the FRB progenitors, their local environments (relativistic plasma effects) and propagation effects (e.g. plasma lensing).

In order to address the above limitations and driven by optimistic predictions, we have developed a new high-time resolution imaging pipeline BLINK. It enables high-time resolution imaging and efficient FRB searches with low-frequency radio telescopes. The pipeline was born out of realisation that in the parameter space of low-frequency instruments, such as the Murchison Widefield Array (MWA) or SKA-Low, traditional inteferometric imaging is typically a few orders of magnitude computationally more efficient than beamforming. Additionally, the BLINK pipeline has been implemented in C++ and performs all the operations on Graphical Processing Units (GPUs). The input data are read only once, and the subsequent processing (correlation, application of calibration, imaging and FRB search) is performed withing the GPU memory. Hence, the need for multiple data conversions leading to heavy I/O operations (Terabytes) has been eliminated leading to further speed-up.

The pipeline has been deployed on Setonix, the new supercomputer at the Pawsey Supercomputing Centre in Perth, and will be initially used to process several Petabytes of high-time resolution voltage data from the MWA, and potentially SKA-Low telescope. The main compute power of Setonix is provided by AMD GPUs (MI 250X), which make it the 4th greenest supercomputer in the world. It has been shown that GPU software can be even an order of magnitude more energy and computationally efficient. Hence, our developments are also inline with the general trend of reducing carbon footprint of research infrastructure and computations.

We will present the GPU imager [2], its validation on real and simulated data, and comparison of resulting images with well established imagers (CASA, WSCLEAN or MIRIAD). We will also present the design and architecture of the full BLINK pipeline incorporating this GPU imager and streamlining processing from complex voltages to high-time resolution images within the GPU memory. Millisecond images produced from high-time resolution observations of bright pulsars B0950+08 and B0531+21 with the MWA will also be presented. These images show individual pulses from these pulsars (pulse widths of the order of 10 to 20ms) demonstrating that the pipeline can be used for image-based searches for individual millisecond pulses from FRBs, pulsars or other radio transients. We will also compare the benchmarks of our pipeline demonstrating that BLINK pipeline is at least 100 times faster than pipelines based on standard imaging packages.

Finally, we will discuss the future work, especially the on-going implementation of the FRB search engine. Once completed, the pipeline will be "unleashed" to process tens of Petabytes of high-time resolution data from the MWA. We would also like to make the pipeline applicable to future FRB, pulsar and transient searches with the SKA-Low, and potentially other radio telescopes.

1. Sokolowski et al., "A commensal Fast Radio Burst search pipeline for the Murchison Widefield Array", Publications of the Astronomical Society of Australia, Volume 41, article id. e011, February 2024

2. Sokolowski et al., "High-time resolution GPU imager for FRB searches at low radio frequencies " Publications of the Astronomical Society of Australia, Volume 41, id.e042, 17 pp, September 2024