Fast Radio Bursts: Australia's opportunity

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Fast radio bursts (FRBs) are luminous millisecond-timescale transients that occur at cosmological distances. Their extraordinary characteristics provide unique laboratories for fundamental physics and new ways to probe the structure of the Universe. When pinpointed to a host galaxy, comparison of the FRB dispersion measure to the host galaxy redshift yields a direct and unbiased measurement of the average density of ionised baryonic matter along the sight line. In aggregate, the bursts determine the extent and location of the $30-80\%$ of the baryonic matter missing in our local Universe, while the microsecond and polarimetric structure of individual bursts probe the density, turbulence, and magnetisation of individual galactic halos traversed (Bannister et al., Science, 2019; Prochaska et al., Science, 2019). These capabilities are either unique or highly complementary to other means of studying extragalactic and intergalactic media.

Owing to early-mover advantages enabled by leadership in wide-field time-domain radio-astronomy instrumentation, Australia has enjoyed preeminent position in the FRB field in successive phases of FRB studies:

1. Initial detection and coarse characterisation (with Parkes and then ASKAP)
2. Real-time detections and high time resolution analysis (UTMOST, and now ASKAP) and
3. Blind localisation to the (sub-)arcsecond precision necessary to unambiguously associate them with their host galaxies (ASKAP, and soon UTMOST-2D)

Maintenance of Australia's leading position requires radio facilities that will accelerate the rate of FRB detections and localisations to remain ahead of upcoming international facilities, along with commensurate access to 8-m class optical telescopes to identify and study the FRB host galaxies.

The current Australian FRB facility suite

While **Parkes** searches have been surpassed by ASKAP (and CHIME) in terms of raw FRB detection rate, the ultra-wideband (UWL) receiver offers an unsurpassed combination of sensitivity and fractional bandwidth for narrow-field followup studies of repeating FRBs.

ASKAP is currently the world-leading FRB localisation facility. Its $30\,\mathrm{deg}^2$ field of view and 6 km baselines makes it competitive in the detection and localisation of bursts; scientific return is further enhanced by its generation of sub-μs, full polarisation profiles of each burst.

UTMOST, operating at a complementary wavelength to ASKAP, produced the first ultra-high time resolution studies of FRBs, using a machine learning based real-time detection pipeline to trigger a voltage buffer.

The **MWA** has the potential to demonstrate FRB science on the SKA_LOW site at SKA_LOW frequencies, while opening up the low-frequency window to these events. The MWA is also triggered by FRB alerts from UTMOST or ASKAP to enable contemporaneous low-frequency detections place or limits on FRBs detected at these facilities.

While not directly used for FRB detection, the **ATCA** and **LBA** are used for follow up and characterisation of host galaxies.

Delivering high-impact science

Progress will be driven by the key sample of FRBs localised by interferometric detections, with host galaxy characterizations and redshifts provided by 8-m class optical telescopes. Supplementary to this is the capability to interpret burst properties (scattering, polarisation) at high time resolution to understand the emission process and propagation effects. Presently, Australia leads in all these areas, but will be challenged in the near future by new and upgraded facilities elsewhere.
The use of FRBs as a cosmological tool requires a large sample ($\gtrsim 100$) to be localised to host galaxies. ASKAP is currently delivering localised FRBs with a rate of ~1-2 per month. Once the funded and currently-underway UTMOST-2D build-out is complete, it is anticipated to localise FRBs at a rate of 0.5-1 per month.
A high priority is to further increase the FRB localisation rate. For ASKAP, this can be achieved by implementing a 1 ms-timescale fully coherent transient imaging system, which would increase the FRB detection rate by a factor of 5–20. For UTMOST-2D, a comparable increase can be achieved by deploying additional receivers on the existing mechanical structure. Both systems would achieve the sensitivity necessary to reach those rare bursts at high redshifts ($z > 1$) in sufficient numbers to undertake ambitious cosmological studies of the intergalactic medium. For reference, a coherent ASKAP facility would provide localisations at a rate a factor 3.5 greater than the Deep Synoptic Array (DSA-110) at Owens Valley and, 5 greater than MeerKAT, the two imminently competitive localisation facilities. A 100% build out of UTMOST-2D providing a complementary and comparable rate to these facilities.

Augmenting Australia's theory and multiwavelength capabilities

Fast radio burst science unites existing strengths across a broad swathe of the Australian astronomical community, including cosmology, super computing, optical and theory:

- **8-m telescope access** has proven essential to identify the faint counterparts of FRBs (even in nearby galaxies where bursts have found to lie in the faint outer spiral arms). The resources of ESO have been vital to the successful pursuit of burst identifications. When larger samples of bursts are detected statistical studies will be enabled by combining ASKAP and UTMOST-2D localizations with LSST photometric redshifts.
- FRBs are proving formidable cosmological tools, especially as probes of the Universe's baryonic content. This work must be underpinned by **optical, and theoretical/computational studies** of the circumgalactic media of galaxies, galaxy growth and baryon life cycle in galaxies undertaken by, e.g., ASTRO3D. The detection of $z > 3$ bursts would open up studies of ionisation history of the Universe (He at $z > 3$ and H at $z > 7$, if such bursts exist).
- Studies of the burst emission mechanism encompass searches for **multi-wavelength counterparts** including neutrinos, gamma-rays, and optical wavebands.
- The field draws in existing expertise in **plasma and high-energy theory**, which is challenged by the existence of coherent radio emission a factor 10^{12} more luminous than that observed in Galactic (pulsar) analogues.
- The extremely impulsive emission of FRBs also opens up opportunities to study wave propagation (**scintillation and gravitational lensing**) on grand scales, and to study the interstellar media and diffuse halos of galaxies over a large range of cosmic history.
- These scientific opportunities have been enabled by Australian leadership in fast transient instru-

mentation, deployed on our world-class facilities. The projects have trained the first generation of FRB postgraduate students and postdoctoral fellows; most international FRB facilities and projects have one or more Australian-trained scientists in leading positions.