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The Murchison Widefield Array: Phase II Science Showcase and Phase III Outlook

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The Murchison Widefield Array (MWA) is an open-access radio interferometric telescope based in the world's quietest radio astronomy zone: the Murchison Radio-astronomy Observatory (MRO) in rural Western Australia. In its role as the designated Precursor to the Square Kilometre Array (SKA) Low telescope, the MWA has revolutionised our understanding of the low-frequency (80−300 MHz) radio sky since the commencement of operations in mid-2013. The original "Phase I" MWA configuration of 128 tiles operated until mid-2016, during which time over 60 distinct observing programmes recorded over 20,000 hours of data and published 146 papers. Four key themes drive the scientific impact of the MWA: (i) observing the 21 cm signal from the Epoch of Reionisation (EoR), (ii) Galactic and extragalactic surveys, (iii) exploring the time-domain radio Universe, and (iv) studying Solar, heliospheric, and ionospheric phenomena.

The Phase I configuration was expanded on in mid-2016, with the addition of a further 128 tiles ushering in the dawn of the "Phase II" MWA. This expansion dramatically broadened the scientific and technical capabilities of the MWA. With the advent of Phase II, two distinct array configurations (each of 128 tiles) became possible: a *compact* configuration with a maximum baseline of around 200 metres, and an *extended* configuration with a maximum baseline approaching 5.3 km. In its compact configuration, the Phase II MWA possesses a unique baseline distribution, with tiles in both a redundant and pseudo-random layout. This provides significant surface brightness sensitivity to the ultra-faint cosmological 21 cm signal from the EoR, while preserving a high-fidelity point spread function (PSF), thus ensuring the best of both worlds for calibration and imaging of this mysterious epoch of the Universe. In its extended configuration, the Phase II MWA achieves a factor two resolution improvement over its previous incarnation, with nearly an order of magnitude improvement in the classical confusion limit. The overall baseline distribution of the Phase II extended configuration is extremely smooth, leading to a far more uniform PSF, significant reduction in sideline confusion, and dramatically enhanced point source sensitivity.

Since the commencement of Phase II, the MWA has enabled the publication of a further 170 peer-reviewed scientific papers across an expanded range of science themes. In 21 cm cosmology, the Phase II MWA has allowed astronomers to achieve the tightest limits to-date on the elusive signals of EoR and Cosmic Dawn across a vast redshift range. In the time-domain regime, the advent of Phase II has brought new rapid-response capabilities which, along with the MWA's unparalleled low-frequency bandwidth and rich archive, has allowed astronomers new insights into a plethora of explosive transient events and discovered unusual exotic phenomena such as a new ultra-long period magnetar. In the Solar, heliospheric and ionospheric regime, the Phase II MWA has ushered in a new era of precision broad-band and high time resolution studies of complex emission modes and physical processes at work on the surface of the Sun. Finally, the Phase II Galactic and extragalactic surveys have heralded a paradigm shift in our understanding of both the static and variable low-frequency sky, in both radio continuum and full polarisation. New insights have been unlocked into star formation in our own Galaxy and other galaxies; feeding and feedback mechanisms in some of the most spectacular radio sources across the sky; detections of intergalactic magnetic fields in the Universe's large-scale structure; detailed studies of novel non-thermal phenomena in complex cluster environments, and more besides.

In this talk, I will review the depth and breadth of the revolutionary scientific outcomes brought about by the Phase II MWA across the principal science themes, as well as the instrumental and software advances that made these outcomes possible. I will then conclude with an outlook toward the next-generation capabilities that are being realised following the 2021 upgrade to a GPU-based correlator system (dubbed 'MWAX'), signalling the dawn of the Phase III Murchison Widefield Array.