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The Deeper Wider Faster Programme: Chasing the Fastest Bursts in the Universe

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Abstract. The Deeper Wider Faster programme (DWF) is a project that coordinates more than 30 multi-wavelength and multi-messenger facilities worldwide and in space, in order to detect and study fast transients (durations of milliseconds to hours). DWF has four main components: (1) simultaneous observations, where ∼10 major facilities, from radio to gamma-ray, are coordinated to perform short-cadence, deep, wide-field observations of the same field at the same time. Radio telescopes search for fast radio bursts, while optical imagers and high-energy instruments search for transient events whose time-scales are seconds to hours, (2) supercomputer data processing and candidate identification in real time (seconds to minutes), along with human inspection of candidates, also in real time (minutes), using sophisticated visualisation technology, (3) rapid-response (minutes) follow-up spectroscopy and imaging, and conventional ToO observations, and (4) long-term follow up by a global network of 1-m to 4-m telescopes. The principal goals of DWF are to discover and study counterparts to fast radio bursts and gravitational-wave events, as well as transients at all wavelengths that have durations of milliseconds to hours.

Keywords. Surveys, gravitational waves, supernovæ: general, stars: variables: other, stars: flare

1. Introduction

Many interesting transient events occur on short time-scales (hours to minutes, even milliseconds), e.g., supernova shock breakouts, gamma-ray bursts, stellar flares, and collisions between Type Ia supernovæ and their companion stars. Recently a short gamma-ray burst and its associated kilonova were demonstrated to be counterparts to gravitational waves (GWs; e.g., Abbott *et al.* 2017). Despite the *r*-processes generating an optical and infrared signal lasting for a few days, a cadence of only hours or minutes would enable us to characterise properly the rising phase and the peak of the blue precursor†. In addition to what we have learned from studying the electromagnetic counterpart to the GW170817 event, a population of kilonovæ and perhaps new types of counterparts to GW events still await discovery through a systematic deep exploration at short time-scales.

Fast Radio Bursts (FRBs; Lorimer *et al.* 2007) constitute another example of short time-scale transients. FRBs are detected as dispersed radio flashes lasting only a few milliseconds. More than 30 FRBs have been discovered to date (Petroff *et al.* 2016), but their nature is still unknown. Importantly, multi-wavelength and multi-messenger counterparts to FRBs and other fast transients may occur while (or even *before*) the burst is generated and/or detected, in which case simultaneous observations before, during, and after the burst occurs are necessary in order to study such phenomena.

† For a complete light-curve, see the *Open Kilonova Catalog*: https://kilonova.space/

The discovery of the repeating FRB 121102 (Spitler *et al.* 2016) and its association with a host galaxy marked an important step in understanding FRBs, and confirmed their extragalactic origin. However, many questions remain unanswered, including the nature of the FRB event itself, which physical process generates the coherent radio emission, and whether all FRBs are 'repeaters' or whether they come in more than one population.

2. The Deeper Wider Faster Programme

The faint and rapidly-evolving time-domain regime has been only rather poorly explored so far, mainly owing to the focus of past surveys on the science of supernova explosions and cosmology, and partly owing to technological limitations. The Deeper, Wider, Faster programme (DWF; http://dwfprogram.altervista.org/) overcomes previous obstacles by coordinating multiple multi-wavelength world-class facilities and capitalising on new observational and computational resources and technology.

DWF coordinates more than 30 multi-wavelength and multi-messenger observatories to perform 1) simultaneous, fast-cadence observations for research into the fast time-domain, 2) supercomputer data processing in real time (seconds to minutes) and human inspection (minutes) of the candidates using sophisticated visualisation technology, 3) rapid-response spectroscopic and photometric follow-up and conventional target of opportunity (ToO) observations with a range of small and large-aperture telescopes, 4) scheduled 'interleaved' observations with a nightly cadence, and scheduled long-term follow-up observations to monitor the behaviour of transient and variable sources in the weeks and months after the DWF observing run. DWF observing campaigns usually continue for 4 to 6 consecutive nights per semester, which favours the discovery and characterisation of transients having time-scales of milliseconds to a day, and maximises the simultaneous coverage of target fields with highly competitive facilities at all wavelengths. The DWF programme grew rapidly from involving 4 facilities in 2015 to more than 30 at the end of 2017. We expect to coordinate more than 40 telescopes in 2018.

2.1. *Simultaneous deep, multi-wavelength, fast-cadence observations*

Figure 1 shows the good match between the fields of view of telescopes capable of real-time FRB detection and identification. They include the Parkes and Molonglo radio telescopes, and world-class optical imagers such as Subaru/Hyper Suprime-Cam (HSC) and Blanco/Dark Energy Camera (DECam), along with other imaging and multi-object spectroscopic facilities at other wavelengths. The involvement of key major, simultaneous observing facilities located worldwide has resulted in a division of DWF into the DWF-Pacific and DWF-Atlantic programmes in order to capitalise on the number, diversity, and geographic locations of the participating facilities.

DWF-Pacific simultaneous observations

- **radio:** Parkes, Molonglo, Australian Square Kilometre Array Pathfinder (ASKAP), Australia Telescope Compact Array (ATCA), Murchison Wide-field Array (MWA);
- **optical/IR:** Blanco/DECam or Subaru/HSC, Zadko telescope, Antarctica Schmidt Telescopes 2 (AST3-2), University of Tokyo 1-m telescope, Mount Laguna Observatory (MLO), Anglo-Australian Telescope (AAT);
- **high energy:** *Hard X-ray Modulation Telescope* (HXMT), *Swift* (BAT, XRT, and UVOT instruments).

DWF-Atlantic simultaneous observations

- **radio:** MeerKAT;

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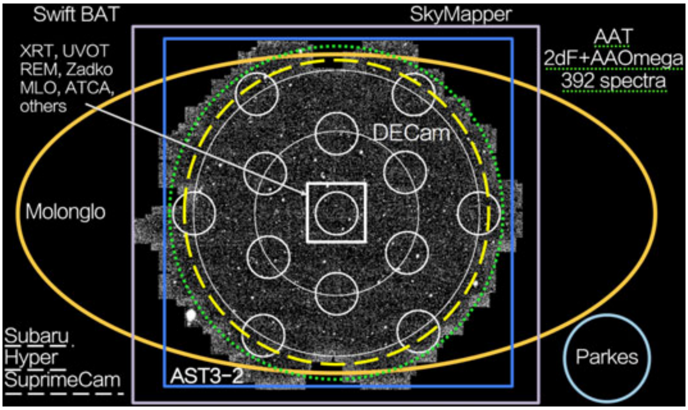

Figure 1. The fields of view of the DWF Parkes and Molonglo radio telescopes match very well the fields of view of DWF optical telescopes such as the Blanco/DECam, Subaru/HSC, SkyMapper and AST3-2 telescopes shown here. The detection of an FRB during a DWF run by more than one radio telescope and several other multi-wavelength facilities targeting the same region of the sky with deep, fast-cadence observations would help to resolve the overall nature of FRBs in one shot. DWF performs such coordinated observations, and also processes the data and identifies candidates in minutes, so as to trigger deep spectroscopic and imaging observations.

- **optical/IR:** Blanco/DECam, Rapid Eye Mount (REM) telescope, Astronomical Station Vidojevica (ASV), Virgin Islands Robotic Telescope (VIRT), Gamma-ray Burst Optical/Near-infrared Detector (GROND);
- **high energy:** HXMT, *Swift* (BAT, XRT, and UVOT instruments).

An important feature is that we coordinate the DWF campaigns with the LIGO/Virgo/GEO600 gravitational interferometer observing runs and other multi-messenger facilities, e.g., Pierre Auger Observatory, when possible. All the participating facilities can join forces in a centrally coordinated follow-up of GW triggers under the DWF MoU with the Ligo/Virgo Consortium.

2.2. *Real-time data processing and candidate identification*

DWF is an on-going project and has undergone rapid expansion; each component is being improved constantly. The DWF core team made the coordinated observations described above possible and effective, while developing dedicated infrastructures such as (1) a lossy compression code for rapid data transfer (Vohl *et al.* 2017), (2) a pipeline for rapid transient identification in optical images (Andreoni *et al.* 2017a), and (3) state-of-the-art visualisation technology and design of new collaborative workspaces (Meade *et al.* 2017) to enable efficient human inspection of candidates. In parallel, we manage dedicated projects to improve the identification of transient or variable sources with machine-learning techniques. The web-based interface we are developing engages astronomers, students and a broader community into the discovery and classification of transient and variable sources in real time and via archival analyses.

2.3. *Follow-up observations*

Rapid and long-term follow-up of discoveries is key to the success of the project. Some fast transients (e.g., the shock breakout at the birth of supernova explosions) are in fact associated with longer time-scale events and need to be monitored in the weeks following their identification. Currently, the following facilities operate in one or more follow-up modes (rapid-response – minutes, conventional ToO – hours, 'interleaved' – nightly, and long-term monitoring), depending on the DWF observing run: Gemini-South, Keck, AAT, SALT, Palomar, Gattini, Swift, REM, SkyMapper, Zadko, ASV, VIRT, GROND, ANU 2.3m, LCOGT, Kiso, MLO, Huntsman and Lick. Others will be participating in the future.

2.4. *First results*

To date, no FRB has been detected in real time during DWF observing. Nevertheless, we have unveiled thousands of transients and variables in the optical images acquired with DECam. We have discovered tens of fast optical transients evolving in time-scales of seconds to minutes; nearly all sources are of Galactic origin (e.g., flare stars). With the data in hand we can probe for the first time the minute time-scale time domain for fast extragalactic optical transients (Andreoni *et al.* 2019). Papers currently in preparation report the discovery of peculiar M-dwarf flares, early- and late-phase core-collapse and Type Ia supernovæ (among which are those reported in ATel#100072 and ATel#100078) with multi-wavelength photometric and spectroscopic follow-ups, plus several serendipitous discoveries. Five DWF collaborative facilities contributed to the study of the electromagnetic counterpart to the GW170817 event (Andreoni *et al.* 2017b) under the DWF MoU.

3. Summary

The DWF programme coordinates over 30 multi-wavelength, multi-messenger facilities around the world and in space to chase the fastest bursts in the sky, including FRBs and counterparts to GW events. We developed the necessary technology to enable simultaneous coordinated observations with real-time analyses, rapid-response follow-ups, nightly interleaved and long-term follow-ups to catch and study the fastest transients in the Universe. Over a hundred researchers worldwide have contributed in some part to the DWF observing campaigns and have greatly helped the maturity and efficiency of the programme. DWF presents a new approach to time-domain astronomy that will shape how future transient detections and studies can be performed.

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