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The host galaxies and progenitors of Fast Radio Burst

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Abstract

The Australian Square Kilometre Array Pathfinder (ASKAP) telescope has started to localise Fast Radio Bursts (FRBs) to arcsecond accuracies from the detection of a single burst, allowing their host galaxies to be reliably identified. These localisations have facilitated the studies of the host galaxies of FRBs, their local environments and progenitor systems.

1 Introduction

An evolution in the tools and techniques of radio astronomy has given birth to a rapidly evolving field of FRBs. These enigmatic phenomena of unknown progenitor systems were first discovered in the high time resolution studies of the Universe using single dishes [1]. Significant advances in understanding the nature of these cosmological and energetic millisecond duration radio transients have been made in the last 4 years, with remarkable advances in just the last 12 months. Around 100 FRBs have now been discovered, with Parkes, Arecibo, Green Bank, Molonglo, ASKAP, the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and the Deep Synoptic Array all contributing [2]. Based on models of the intergalactic medium [3], their large dispersion measures (DMs) imply that they originate at redshifts $z \sim 0.1-2$ which makes them excellent tools for probing cosmology.

The first breakthrough was the discovery of repeat pulses from the faint Arecibo burst FRB 121102 [4]. Follow-up searches – enabled by the realfast system at the Very Large Array (VLA) [5] – resulted in the localisation of the burst source to a low-metallicity dwarf galaxy (HG 121102) at a redshift of $z = 0.19$ [6, 7]. Follow-up observations suggest the burst source to be embedded in a plerion (a radio nebula powered by a central object), and the repeating bursts were observed to have high rotation measures (RM)[8]. The environment and host of the FRB 121102 source led to a *concordant* model for FRBs [9], in which bursts are produced by young and highly magnetised neutron stars, themselves produced in a powerful stellar explosion of a much massive star. These explosions preferentially occur in metal-poor dwarf galaxies, and the dense and highly magnetized environments explain the observed nebulae and the high rotation measures.

More recently, wide-field surveys have delivered large samples of FRBs. Since mid-2018, the CHIME telescope has been surveying for bursts in the 400 – 800 MHz band. With a wide field-of-view and great sensitivity, CHIME has published the detection of 30 FRBs, 17 of which are repeating [10, 11, 12, 13]. Additionally, the recent localisation of the repeating CHIME FRB 180916.J0158+65 by European Very-long-baseline-interferometry Network (EVN) to a nearby and massive spiral galaxy suggests that repeating FRBs originate from diverse host galaxies and local environments [14]. Therefore, the localization of a larger sample of FRBs, both repeating and non-repeating, to their hosts will facilitate exploration of the host galaxy population, their global properties, and the local FRB environment, which is crucial in understanding FRB progenitor systems.

2 FRBs with ASKAP

Despite the recent discovery of the further repeating burst sources by the CHIME telescope and the ASKAP telescope [12, 13, 15], the FRB population is still dominated by one-off and ostensibly non-repeating events. They currently dominate statistical analyses of the FRB phenomenon, and they might have a different progenitor type and arise from cataclysmic implosions or mergers.

The facility to instantaneously observe a wide area on the sky with 36 beams simultaneously (covering a 30 square degree field of view at 1.4 GHz) using the phased array feed (PAF) technology [16], makes ASKAP an excellent instrument for blind searches of the closer and brighter population of FRBs. The Commensal Real-Time ASKAP Fast Transients (CRAFT) [17] survey is an FRB search program operating with ASKAP. Initially running in a fly's-eye mode (in which multiple dishes are used, each pointing in different locations on the sky), the project found 25 FRBs[1] with a range of DMs, luminosities and widths in the latter half of 2018 [19, 20, 21, 22].

2.1 Localisation of FRBs

Since late 2018, CRAFT has been operating the facility in incoherent-sum (ICS) mode, where all operating dishes are pointing to the same location and the signals are combined

[1] An additional burst was found in offline incoherent sum search [18]

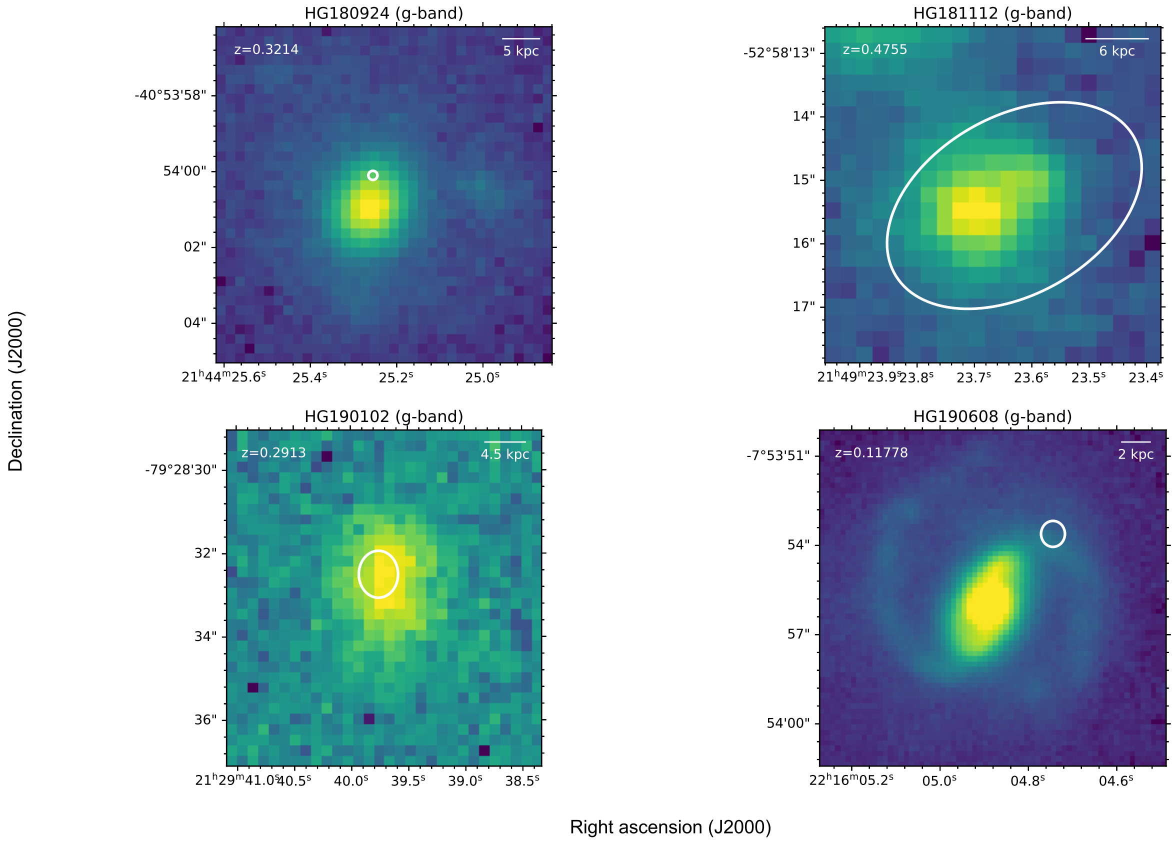

Figure 1. g-band images of the host galaxies for a sample of localised FRBs (FRB 180924, FRB 181112, FRB 190102 and FRB 190608), over-plotted with the positions of each FRB. The white circle/ellipse represents the total uncertainty in the FRB position.

incoherently. FRBs detected in this way trigger a real-time voltage download across all dishes. These voltages are correlated offline and imaged at the DM and time of the FRB for its localisation. The astrometry of FRB position is carried out using the Australia Compact Array Telescope (ATCA). The process involves observation of three bright calibrators around the FRB field and transferring phase calibration solutions using each of those calibrators to the background continuum sources in the field of FRB. The position of background sources obtained in ATCA radio image is compared with ASKAP image and astrometric corrections are applied (if any) to FRB position. Thereafter a sub-arcsecond localisation of an FRB is obtained.

The most recent breakthrough has been the localisation of one-off (i.e., apparently non-repeating) bursts namely FRB 180924 and FRB 181112 [23, 24]. Between 2018 Sept – 2019 June, four FRBs were localised with ASKAP, each of which was unambiguously associated to a host galaxy (See Fig 1). Optical observations including imaging and spectroscopic were conducted using the facilities such as Very Large Telescope (VLT), Gemini, Keck Telescope, Magellan and Las Cumbres Observatory. The observations and analysis suggest that the hosts of four FRBs are massive galaxies (log($M_*/M_\odot$) $\sim 9.4 - 10.4$) with modest star-formation rates of up to 2 $M_\odot$ yr^{-1} — very different to the host galaxy of the first repeating FRB 121102, which is a dwarf galaxy with a high specific star-formation rate. Radio observations were performed using telescopes such as ATCA and VLA to study the radio properties of FRB hosts. None of them contains a persistent compact radio source as intrinsically luminous as that seen in the host galaxy of FRB 121102, suggesting relatively quiescent environments.

3 ASKAP FRB hosts and their progenitors

The global properties of the host galaxies suggest that FRB progenitors can arise from a general stellar population rather than a very young stellar progenitor. Additionally, compact merger events such as neutron star merger and energetic explosions of massive stars seem to be a plausible mechanism for at-least a population of FRBs. The localisation of ASKAP FRBs (particularly FRB 180924 and FRB 190608) to the outskirts of their host galaxies show (i) that FRBs indeed come from galaxies, and (ii) that they are typically not coincident with the nucleus of their hosts. This information already appears to disfavor a range of models involving supermassive black holes found at the centre of a galaxy.

4 Atypical FRB 121102

An analysis of the properties of ASKAP-localised FRBs and their hosts has shown that the repeating source FRB 121102 is atypical. The energies of most of the published repeating bursts from the source of FRB 121102 are $10-100$ times lower than any of the ASKAP FRBs. The RM observed for FRB 121102 is a thousand times higher than for any of the ASKAP FRBs, suggesting an unusual (or at least atypical) environment for this repeating FRB. The host galaxy for FRB 121102 is a low-mass dwarf and has an elevated SFR for its stellar mass, very different from the hosts of ASKAP localised FRBs. None of the ASKAP localised FRBs have a compact persistent radio source as luminous as the one in the FRB 121102 host galaxy. Lastly, the ASKAP bursts have not been seen to repeat at the rate observed for FRB 121102 [25]. It seems very unlikely that FRB 121102 is drawn from the same population as the ASKAP FRBs.

5 Future Work

While it is clear we have learned much about bursts in the last year, there are still fundamental open questions about the bursts. Central is the relationship between repeating and one-off burst sources. Do repeating sources generically reside in metal-poor dwarf galaxies or is the association a coincidence? Are there two channels for producing fast radio burst sources? Are there two distinct emission mechanisms? With a population of localised bursts emerging it is now possible to start assessing the utility of FRBs as probes of the intergalactic medium, and to what extent bursts are polluted by their host environment. However, a much larger sample of localised FRBs both repeating and non-repeating is required to answer the aforementioned questions.

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