Finding and localising FRBs with the MeerKAT and ASKAP telescopes

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Abstract

The MeerKAT and ASKAP telescopes have been scanning the skies for FRBs over the last few years and have made remarkable discoveries and strides in the field. These discoveries and localistaions These have facilitated studies of FRB host galaxies, their local environments and possible progenitor systems.

1. Introduction

About a decade and a half ago, the discovery of mysterious flashes of short, intense radio waves originating all over the sky intrigued astronomers [1]. These flashes have since evolved into an astrophysical class of their own called fast radio bursts (FRBs) [2]. FRBs last about a thousandth of a second and are a billion times brighter than any of the other known astrophysical sources. The inferred high radio luminosities required to produce such extreme events at cosmological distances is what makes them tantalizing [2]. Their current rate suggests about 3 bursts occur every minute at random locations across the sky. Though this all-sky FRB rate is remarkably high, small field-of-view searches have yielded limited results. ~20 FRBs have been seen to repeat so far, suggesting that at least a subset of FRBs have progenitors that can survive the energetic events which generate the bursts of radio emission. However, it is presently unclear whether all FRBs repeat [3]. What is most exciting about FRBs is that they are cosmic messengers from at least halfway across the Universe; bearing the imprint of the material they traverse [4]. As a result, FRBs are expected to be extremely formidable and potent tools to study cosmology in a fundamentally new way.

Thousands of FRBs have been discovered since 2007, with a remarkable diversity of observed properties. Despite this growth and progress, several fundamental questions remain unanswered. Are there multiple populations and production mechanisms of FRBs? What do FRB localisations reveal about their progenitors? How distant are their host galaxies? Are they produced in the same extreme processes as other astrophysical transients such as gravitational waves? How can use them as probes of cosmology? Progress in the field relies on answers to these questions. With much still to learn about FRBs, their origin(s) is one of the biggest unsolved mysteries in modern astronomy. Consequently, the quest to answer the fundamental questions on their mysterious nature, progenitors, environments and uses is gaining enormous momentum. The MeerKAT and ASKAP telescopes are surveying the skies and making huge strides in the field to unravel the engines and environs of FRBs and characterize their use as effective cosmological probes. This paper follows the progress of the field and presents a few recent science highlights of the results from the MeerKAT and Australian Square Kilometre Array Pathfinder (ASKAP) telescopes.

2. Host galaxies and progenitors

The scientific payoff from an astrophysical source is only truly realised upon localisation. With the advent of discoveries with interferometers like MeerKAT and ASKAP, and discoveries of repeating FRBs, localisations and associations with host galaxies have become more common. FRB 20121102A was the first one to be localised due to its repeating nature [5]. It is seen to lie in a star forming region in the outskirts of the dwarf galaxy at a redshift of $z = 0.19273(8)$ and is offset from the centre of light of the galaxy [6]. The submilliarcsecond localisation showed that it is physically associated with a compact (<0.7 pc), persistent radio source [7], which might be key to understanding the energetics and the formation of the FRB source. Recently, a second repeating FRB, FRB 20190520 is seen to have similar characteristics to FRB 20211102A in terms of host galaxy properties, burst activity and association with a persistent radio source [8]. This suggests that such persistent emission may be ubiquitous in at least some FRBs and may play a vital role in their lives and evolution.

Until now, persistent radio sources have only been associated with repeating FRBs. Recent observations of the (apparently) non-repeating FRB 190714A with the MeerKAT telescope showed that it may possibly be associated with compact, persistent emission (Figure 1) [9]. However, higher time resolution imaging is necessary to confirm this association. Amongst the numerous progenitor models, few predict persistent radio emission associated with non-repeating FRBs, and hence a confirmation would have profound implications for progenitor classes.

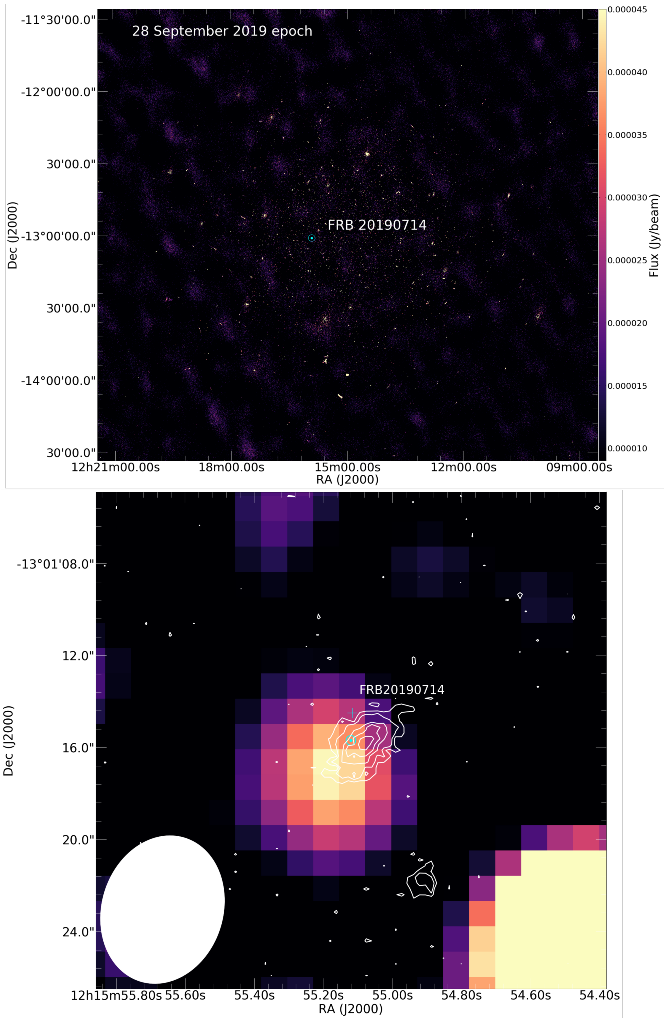

Figure 1: FRB 20190714A MeerKAT image (top) and a zoom-in (bottom) around the position of the FRB indicated by the cyan circle. White contours (levels: 300, 500, 900, 1200, 1600 counts) represent the PanSTARRS *i*-band optical counterpart coincident in position with the persistent radio emission [9]. The white ellipse in the bottom left corner represents the beam size of MeerKAT. The cyan cross indicates the position of the detected compact emission in e-MERLIN VLBI observations [9].

Of the thousands of discovered FRBs, ~20 (including repeating and apparently non-repeating FRBs) have been localised and associated with host galaxies with spectroscopic redshift measurements in the range of z ~ 0.0001–0.66 (https://frbhosts.org/). Several authors have studied the global properties of a sample of host galaxies comprising repeating and one-off FRBs to constrain their progenitors (e.g. [10, 11]). The host galaxies of FRBs are seen to range from starburst to nearly quiescent with most FRB positions being offset from the host galaxy centers [10, 11]. High spatial resolution images show most FRBs to be in the arms of these galaxies. Interestingly, these physical offsets are consistent with those observed for short Gamma-ray bursts, core-collapse supernovae, and Type Ia supernovae suggesting that the FRB progenitors' host population shares similar characteristics to those of these transients [10, 11]. It is seen that magnetars formed via regular core-collapse supernovae, binary neutron star mergers and accretion-induced collapses of white dwarfs are plausible progenitors to FRBs. Overall, the current sample of FRB host galaxies are moderately star forming with star formation rates in the range 0.03–8 solar masses per year. Most FRB hosts are emission-line galaxies that appear to favour AGN and LINER populations (Figure 2). The FRBs do not track the stellar mass and overall are not hosted in old, red and dead galaxies which possess an older stellar population. While both repeating and apparently one-off FRBs have, and are continuing to be localised, the connection between them (if any) remains unclear at the moment and therefore understanding their host galaxies and immediate environments is crucial.

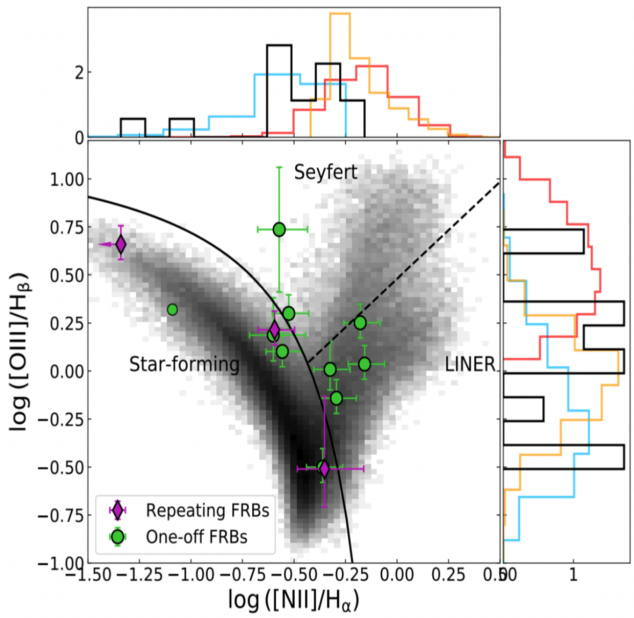

Figure 2: Emission line properties for the host galaxies of a sample of well-localised FRBs compared to star-forming galaxies, LINER galaxies, and AGN [11]. The sample here corresponds to highly probable host-galaxy associations based on the FRB localization and galaxy photometry. Most FRB hosts are observed to lie away from star-forming main sequence and are concentrated more towards LINER galaxies. The host galaxy of FRB 121102 is an obvious outlier lying close to the tail-end of the star-forming sequence [11].

3. Future prospects

The last few years have revolutionized FRB astronomy, and accelerated progress is being made on all scientific fronts by MeerKAT, ASKAP and other telescopes across the world. The full potential of FRBs will only be realized in the era of routine FRB detections and corresponding host galaxy identifications [12]. We can expect multiple new detections, host galaxy identifications and physical insights in the next few years. The future holds an abundance of exciting science for the field of FRB astronomy.

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