Cosmological Origin for FRB 150418? Not So Fast

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Abstract: Keane *et al.* (2016) have recently claimed to have obtained the first precise localization for a Fast Radio Burst thanks to the identification of a contemporaneous fading slow (∼week-timescale) radio transient. We show that the quiescent radio luminosity of the proposed host galaxy points to the presence of an AGN, and therefore that the claimed transient may instead represent common AGN variability. We further show that the expected number of variable (rather than transient) sources in the Parkes localization region of FRB 150418 is order unity. Finally we show that the properties of the radio counterpart are incompatible with a synchrotron-emitting blastwave. Taken together, these results indicate that the claimed radio source is unlikely to be associated with FRB 150418, and hence that a precise localization and redshift determination cannot be justified.

Revision 1 (2016 Feb 26)

1. Introduction

The origin of Fast Radio Bursts (FRBs; Lorimer *et al.*, 2007) remains unknown, with both Galactic and extragalactic scenarios proposed (*e.g.*, Falcke & Rezzolla, 2013; Loeb *et al.*, 2014; Zhang, 2014). Keane *et al.* (2016) have recently claimed to have obtained the first precise localization for an FRB by identification of an associated radio transient that faded over the course of six days. This transient was located in a seemingly passive elliptical galaxy at $z = 0.498$, phenomenology consistent with the possible origin of (at least some) FRBs in compact object mergers (*e.g.*, Zhang, 2014). This would be a truly exciting discovery, confirming the cosmological origin of (at least some) FRBs and hence also their extreme physics, their utility as a probe of the intergalactic medium (*e.g.*, McQuinn, 2014), and the possibility that FRBs may be prompt, localizable electromagnetic tracers of gravitational-wave events (Abbott *et al.*, 2016).

We argue that the properties of the long-term radio emission from the proposed host[1] point to a different interpretation: that the observed variable radio emission is instead due to AGN activity and that the variable emission and galaxy are unrelated to FRB 150418.

2. Quiescent Luminosity of Host Galaxy Candidate

Keane *et al.* (2016) interpret two follow-up radio observations ∼90 and ∼190 days after FRB 150418 to suggest that the candidate host galaxy has quiescent radio emission at a level of 0.1 mJy at 5.5 GHz. We show the relevant data in Figure 1, isolated from non-detections and on both linear and logarithmic scales. At the redshift of the galaxy this corresponds to a radio spectral luminosity of $\sim 9 \times 10^{29}$ erg s^{-1} Hz^{-1}. Using the standard relations of Yun & Carilli (2002), the star formation rate (SFR) inferred from the radio spectral luminosity is $\sim 10^2$–10^3 M$_\odot$ yr^{-1}, orders of magnitude higher than the value of ≤ 0.2 M$_\odot$ yr^{-1} that

[1] We note that the host candidate is robustly detected in AllWISE imagery and may be referred to as WISE J071634.59−190039.2.

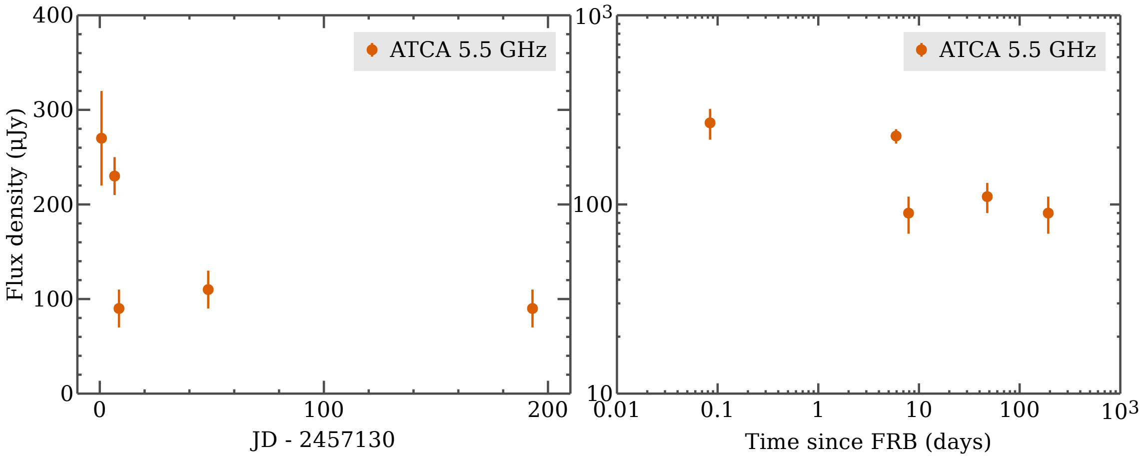

Figure 1: *Radio light curve of the candidate slow radio transient associated with FRB 1501418 at 5.5 GHz, shown in both linear and logarithmic axes. The ~week long brighter episode following the FRB discovery is interpreted by Keane et al. (2016) as a transient associated with the FRB, but it could also represent radio variability of an unrelated AGN. Data from Keane et al. (2016).*

the authors infer from Hα in the optical spectrum of the galaxy. Thus, the origin of the quiescent radio emission is not star formation activity.

As argued by Brown *et al.* (2011) in their investigation of the radio emission from bright early-type galaxies comparable to the candidate host, if the galaxy's bright radio emission is not due to star formation, the alternate source is AGN activity. This is immediately worrisome because AGN are both intrinsically and extrinsically variable (the latter due to scintillation, Rickett, 1990) and could thus falsely appear as a transient radio source. We argue that the radio light curve reported by Keane *et al.* (2016), with only five measurements and three within eight days of each other, is insufficient to reject long-term variability of the host, and is not atypical of AGN variability given the sampling (*e.g.*, Ofek *et al.*, 2011). While the spectrum of the host does not show clear quasar features, spectra of matched SDSS-FIRST sources show that optical signatures of AGN activity are frequently not visible in spectra of luminous early-type galaxies with radio emission similar to the candidate host of FRB 150418 (Ivezić *et al.*, 2002). Studies of radio-loud AGN demonstrate that its WISE colors are consistent with AGN activity (Gürkan *et al.*, 2014).

3. Probability of Coincident Variable Source

The chance of the coincidental discovery of a variable radio source in the localization region of FRB 150418 — to be contrasted with the chance of the coincidental discovery of an unassociated genuine radio transient — is non-negligible. In the analysis below, we adopt the area of the FRB localization region given by Keane *et al.* (2016) of $\sim$0.04 deg^2.

Fomalont *et al.* (1991) counted sources in deep VLA imaging at 5 GHz and determined that the areal density of sources brighter than a flux density of S μJy is $\Sigma(>S) = (23.2 \pm 2.8) S^{-1.18\pm0.19}$ arcmin^{-2}. At $S = 100$ μJy, this implies an expectation of $\sim$16 sources per Parkes beam, although the threshold for source identification used by Keane *et al.* (2016) is unclear. In a catalog of 3652 compact sources brighter than $\sim$0.1 mJy at 3 GHz, Mooley *et al.* (2016) find that $3.9^{+0.5}_{-0.9}$% of them are variable at the $>$30% level. Scaling to the expected number of sources in the Keane *et al.* (2016) search area, but ignoring the differences in observing frequency and flux density threshold, we expect ∼0.6 variable radio sources in each Parkes beam. The differences in observing frequency and flux density threshold should approximately cancel: while most sources will be fainter at the higher frequency used in the ATCA observations, it appears that the threshold for source detection in those observations was somewhat lower.

Ofek *et al.* (2011) used the VLA to search a total area of 2.66 deg^2 for radio transients and variables. They find that 30% (30 out of 98) of sources brighter than 1.5 mJy at 5 GHz are variable at the 4σ level. Assuming this variability fraction rather than the ∼4% value found by Mooley *et al.* (2016) results in an expectation of ∼5 coincident variable sources per Parkes beam. Ofek *et al.* (2011) note that the rate of variables found in their survey is higher than comparable surveys and attribute this to their choice of observing frequency, the short averaging times of their observations, and the low Galactic latitude ($b \sim$ 6–8°) of their survey; all of these factors apply to the observations of Keane *et al.* (2016), with the host candidate being found at $b \sim -3.2°$. The correlation between low Galactic latitude and increased incidence of variability is well established and is due at least in part to higher levels of refractive scintillation through the denser ISM (Spangler *et al.*, 1989; Rickett, 1990), implying that the increase in the number of variable sources is not only due to foreground objects.

We downloaded the catalog of flux density measurements from the survey of Ofek *et al.* (2011). For each source, we recalculated their metric "StD/$\langle f \rangle$" — that is, the standard deviation of each source's flux density measurements divided by their mean — but only keeping a random subset of five measurements, to maintain comparability with the 5.5 GHz data of Keane *et al.* (2016). Figure 2 compares these values as a function of median detection S/N to that determined from the five 5.5 GHz points reported by Keane *et al.* (2016), StD/$\langle f \rangle = 0.48$. The candidate transient is consistent with the high-variability sources observed by Ofek *et al.* (2011). We therefore conclude that the expected number of radio sources of similar brightness and variability level in the Parkes localization region of FRB 150418 is order unity.

4. Incompatibility of Proposed Light Curve with Extragalactic Transients

The only confirmed *slowly*-evolving extragalactic radio transients are synchrotron blastwaves, which show a clear relationship between evolutionary timescale and luminosity (Metzger *et al.*, 2015). From the observed flux of $F_\nu(5.5\,\mathrm{GHz}) \approx 0.27$ mJy at 0.09 days, and assuming expansion at $v \approx c$ we infer a brightness temperature of $T_B \approx 3 \times 10^{16}$ K, which clearly requires relativistic expanion with $\Gamma \approx 10^2$ to avoid the inverse Compton catastrophe limit of $T_B \approx 10^{12}$ K. Thus, if the observed emission is due to a synchrotron transient, it will obey the basic afterglow evolution of gamma-ray bursts (Granot & Sari, 2002).

The observed negative spectral index between 5.5 and 7.5 GHz at 0.09 days ($F_\nu \approx \nu^{-1.3}$) indicates that the peak of the synchrotron spectrum needs to be $\nu_m \lesssim 5.5$ GHz at this early time. This is highly unusual for a GRB afterglow. Moreover, in this case we expect the flux density at both 5.5 and 7.5 GHz to be declining in time roughly as $F_\nu \propto t^{-1}$, as opposed to the observed flat light curve at 5.5 GHz. Finally, the condition $\nu_m \lesssim 5.5$ GHz at 0.09 days places a direct constraint on the energy of the outflow; using the synchrotron afterglow model (Table 2 of Granot & Sari 2002) with standard microphysical parameters ($\epsilon_e = 0.1$, $\epsilon_B = 0.01$, $p = 2.5$) this leads to $E_{\mathrm{K,iso}} \lesssim 3 \times 10^{44}$ erg. However, with such a low energy, the only way to achieve the observed radio luminosity in turn requires an

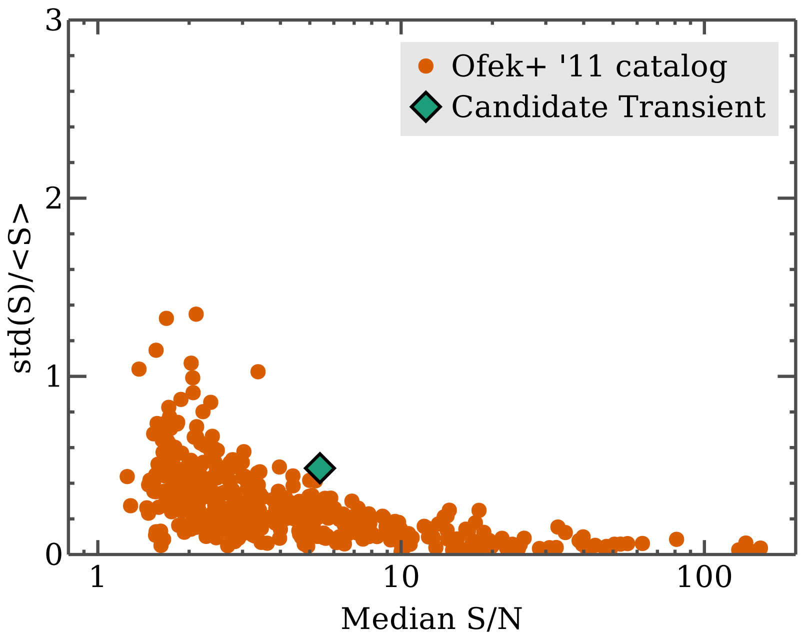

Figure 2: *A variability metric, StD/$\langle f \rangle$, against median S/N of detection, for the catalog of Ofek et al. (2011) and the data reported by Keane et al. (2016). Here we have recomputed the variability metric taking a random subset of 5 points for each source in the Ofek et al. (2011) to maintain comparability with the Keane et al. (2016) data. The candidate transient is consistent with the high-variability sources observed by Ofek et al. (2011).*

unreasonable density: $n \approx 10^8$ cm^{-3}. In fact, with such a high density the radio emission will be completely self-absorbed.

Thus, while Keane *et al.* (2016) claim that the observed slow "transient" is consistent with a short GRB afterglow, in detail the optically-thin spectrum at 0.09 days combined with the observed flux density lead to an unphysical set of outflow parameters. On the other hand, the optically-thin radio SED is consistent with AGN emission.

5. Summary

We argue that the proposed radio transient associated with FRB 150418 more likely originates in AGN variability. First, the quiescent level of radio emission from the host candidate implies that it indeed hosts an AGN. Second, the expected number of radio variables in a randomly-chosen Parkes field is of order unity. Third, if the proposed radio transient is genuine, its light curve is inconsistent with the physics of observed, well-understood extragalactic source classes. These arguments suggest that the radio source is unrelated to FRB 150418, hence negating the claimed demonstration of a cosmological origin.

6. Acknowledgments

We thank Ryan Chornock for helpful discussions. This work made use of NASA's Astrophysics Data System; the SIMBAD database, operated at CDS, Strasbourg, France; and the NASA/IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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