Classifying RRATs and FRBs

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ABSTRACT

In this paper we consider the fact that the simple criterion used to label fast radio transient events as either fast radio bursts (FRBs, thought to be extragalactic with as yet unknown progenitors) or rotating radio transients (RRATs, thought to be Galactic neutron stars) is uncertain. We identify single pulse events reported in the literature which have never been seen to repeat, and which have been labelled as RRATs, but are potentially mis-labelled FRBs. We examine the probability that such ‘grey area’ events are within the Milky Way. The uncertainty in the RRAT/FRB labelling criterion, as well as Galactic-latitude dependent reporting bias may be contributing to the observed latitude dependence of the FRB rate, in addition to effects such as Eddington bias due to scintillation.

Key words: surveys — intergalactic medium — methods: data analysis

1 INTRODUCTION

Fast radio burst (FRB) is the name given to a handful of sub-second radio transient signals detected over the last decade (Keane & Petroff 2015). Because of their many potential uses as tools for studying extreme physical environments and the Universe up to redshifts of $\sim 2 - 3$ (Macquart et al. 2015), there is a large effort underway to search for these signals, both in dedicated ongoing surveys and in archival data (Thornton et al. 2013). FRBs manifest themselves as millisecond-duration events with dispersion measures of several hundred cm$^{-3}$pc. No FRB has yet been observed to emit more than one pulse (Petroff et al. 2015b).

Rotating radio transient (RRATs) is the name given to a group of sporadically pulsing sources (Keane & McLaughlin 2011). The majority of RRATs have been seen to repeatedly emit detectable pulses, and it seems clear, from the results of applying pulsar timing techniques (McLaughlin et al. 2006, 2009; Keane et al. 2011), that these sources are Galactic neutron stars with intermittent and/or highly variable pulsar emission.

Single-instance RRAT pulses are no different in appearance to FRB pulses. The criterion for deciding whether such pulses should be classified as FRB or RRAT is comparison of the dispersion measure (DM) with the predicted Galactic maximum of this parameter. In this paper, in §2 we examine the uncertainty in this classification. Then, in §3 we estimate the probability that various transients are Galactic or extragalactic, before presenting our concluding thoughts in §4.

2 NE2001 DISTANCES

The parameter used in deciding whether a dispersed radio burst is an FRB, i.e. extragalactic, is DM$_{MW}$, the maximum Galactic DM contribution for the particular line of sight. If the burst’s DM exceeds DM$_{MW}$ then it is extragalactic, an FRB, with an inferred $\sim$Gpc-scale distance. If the burst’s DM is less than DM$_{MW}$ then the source is Galactic, a RRAT, with an inferred $\sim$kpc-scale distance. In practice the model used has thusfar always been NE2001 (Cordes \& Lazio 2002); more specifically “NE2001b” as per the labelling of Schnitzeler et al. (2012). Here we investigate the uncertainty of this model, and thus the uncertainty in the RRAT/FRB classification of dispersed radio bursts which have not been seen to repeat.

There are a number of studies in the literature which have addressed the question of the accuracy of the NE2001 model for predicting distances. Deller et al. (2009) used distances to 41 pulsars, determined from VLBI and pulsar timing measurements of parallax, to estimate the distribution of distance errors of the model. More recently, Verbiest et al. (2010, 2012) identified and corrected the Lutz-Kelker bias in the by-then enlarged sample of pulsar distance measurements derived from parallax, supernova remnant associations and neutral hydrogen absorption. Taking the 120 sources in Verbiest et al. (2012) with DM measurements (i.e. those detected at radio wavelengths) we produce a Lutz-Kelker corrected version of the distance error distribution of Deller et al. (2009), shown in Figure 1.

An overestimate (underestimate) of the distance corresponds to an underestimate (overestimate) in the DM in-
3 FRB OR RRAT?

A search of the literature (see Table 1 for references) shows that there are 12 sources labelled as RRATs, which have never been seen to show a second radio pulse. In Table 1 these are considered in addition to the 16 published FRBs.

The probability that each of these events is extragalactic is tabulated, for each of the three distributions of NE2001 distance errors. Obtaining key additional information like this will be essential to elucidate the origins of sources like J1354+24.

4 DISCUSSION & CONCLUSIONS

We have considered the uncertainty in the DM excess parameter \( x = \frac{\text{DM}}{\text{DM}_{MW}} \), crucial in RRAT/FRB classification. By considering a simple probability-based estimator, we have determined that the FRB identifications made so far are reasonably secure with perhaps one exception (FRB 010621).

On the other side of the classification, we find the 'RRAT' J1354+24 has a \( \sim 20 - 40\% \) chance of being a mis-labelled FRB; this suggest it merits a deep observational study to address the question of whether it repeats. Similarly, the cumulative probability of at least one RRAT being mis-labelled is at the \( \sim 30 - 80\% \) level; a dedicated campaign to search for a second pulse from each of these sources is merited.

In the context of RRAT/FRB labelling, we can see the distinction is skewed, with overestimates more likely with a ratio of 70 : 50. However, there is evidence of lower latitude dependence in the distribution. Considering only those pulsars within 10 degrees of the Galactic plane the ratio of underestimated:overestimated distances is 31 : 55, but is 19 : 15 for sources that are more than 10 degrees from the plane. Assuming that finer resolution in Galactic latitude would see an insufficiently large sample for further resolution, we consider only these three distributions in estimating the accuracy of RRAT/FRB labelling.

Figure 1. The distribution of the errors in the NE2001 distance estimate, based on the 120 radio-detected sources in Verbiest et al. (2012). This distribution also represents (see text) the error in \( x = \frac{\text{DM}}{\text{DM}_{MW}} \). The error distribution is expressed in decibels, such that a negative (positive) value corresponds to an underestimate (overestimate). The three distributions which are overplotted are those based on the entire Verbiest et al. (2012) sample and the two sub-samples of sources which are below and above a Galactic latitude of 10 degrees.

The probability that each of these events is extragalactic is determined that the FRB identifications made so far are reasonably secure with perhaps one exception (FRB 010621).

Further, this rule is not applied to FRBs: they are simply reported when detected. Given this, and that much more observing time is spent closer to the Galactic plane (Burke & Johnston 2015) we suspect a Galactic-latitude dependent bias in the reported events. To enable correction for this effect survey teams should report single pulse events which appear to be of astrophysical origin, regardless of whether they are seen on a second epoch or have \( x < 1 \). Probability-based classifiers could then be used for determining the Galactic/extragalactic nature.

The observed FRB rate at Parkes (Petroff et al. 2014a) is higher at higher latitudes. With a perfect electron density model and no reporting bias, such a dependence can still arise, as a result of Eddington bias of the population due to diffraction scintillation at high latitudes (Macquart & Johnston 2015). In this scenario the true rate is that at low latitudes, and the 'boost factor' depends directly on the \( \log N - \log S \) distribution — the steeper the distribution the larger the boost. But it is clear that the difference between

\[ \log N - \log S = \left\{ \begin{array}{ll} < 0 & \text{for FRB 010621} \\
> 0 & \text{for FRB 121102} \end{array} \right. \]
the observed and intrinsic rates, and hence in our ability to uncover the true \( \log N - \log S \) and luminosity distributions, is a combination of a number of effects. In this paper we have tried to tackle the effect of the uncertainty of NE2001. With this, and a clear picture of single epoch pulse events, including those with \( x < 1 \) (most, but perhaps not all, will be within our Galaxy), we will be able to determine trustworthy metrics for determining the cosmic history of FRBs, whether or not they are standard candles, and their general utility as tools for precision cosmology.

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Table 1. Here we list the 12 RRAT sources in the literature which have not yet been seen to show repeat pulses, as well as the 16 published FRBs. The references in the table are given in the second column and are: [1] Thornton et al. (2013); [2] Champion et al. (2016); [3] Petroff et al. (2015a); [4] Masui et al. (2015); [5] Ravi et al. (2015); [6] Lorimer et al. (2007); [7] Burke-Spolaor & Bannister (2014); [8] Spitler et al. (2014); [9] Keane et al. (2011); [10] Karllaggio-Argetman et al. (2015); [11] Burke-Spolaor & Baeles (2010); [12] Burke-Spolaor et al. (2011). For each signal we then give the excess DM parameter \( \chi \) in the third column and (in dB) in the fourth column. The fifth, sixth and seventh columns each give the probability that the signal is an FRB, for the 3 distributions considered in the text. In each case the exact number of sources is given in parentheses next to the probability; the error on the probabilities is simply the Poisson 95% confidence level (Gehrels 1986). Based on each source’s Galactic latitude the more relevant distribution out of \( P_{\text{GRB}} \) and \( P_{\text{DD}} \) has been emblazoned. The 10 FRBs referred in the first row, are: FRBs 110703, 090625, 130729, 110220, 121002, 121227, 140514, 110626, 110523 and 130626. Similarly, the 8 RRATs referred to in the final row are: J0441–04, J0923–31, J1311–59, J0613–04, J1709–43, J1649–46, J1541–42 and J0845–36.