

Some Limits on Optical Emission of Fast Radio Bursts

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Abstract—A statistical analysis of survey observations conducted by the global network of MASTER robotic telescopes over 20 years has been used to derive independent constraints on the optical emission associated with Fast Radio Bursts (FRBs). The method is based on simulating a synthetic catalog of FRBs uniformly distributed across the sky and in time and subsequently checking for the absence of random coincidences with optical observations. As a result, a constraint on the ratio of the burst energy in the optical band to the energy in the radio band has been obtained: $\eta < 4.5 \times 10^4$. Although this limit is less strict than that provided by the Gaia mission, it offers an independent test for FRB origin models and is less dependent on assumptions about the duration of the optical signal. The results place important constraints on theoretical models that predict significant optical emission from FRBs.

Keywords: FRB, neutron stars, magnetars

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1. INTRODUCTION

Fast radio bursts (FRBs) are short and bright events observed in the radio range [1]. All sources except one are extragalactic [2]. The duration of an FRB is tens of μm . The main difficulty in constructing a theory of fast radio bursts is the almost complete lack of observations in all ranges except radio. The only exception is the galactic FRB, whose source is a magnetar [3]. A series of soft gamma-ray flares were observed from it [4].

FRBs are divided into at least two types: repeated and single. Although some of the single events may be sufficiently rare repeaters, a statistical analysis suggests that there are two classes of events [5].

Furthermore, some repeaters exhibit periodic activity [6]. That is, it is impossible to predict accurately the moment of the next event, but there are certain periods of activity, where the density of bursts is higher, and periods of “silence”.

A theory of the origin of FRBs must include two key components. First: the central engine, i.e., the source of energy. There is a sufficiently wide range for speculation here, since we have no idea of the bolometric luminosity of these events. The second important point is the radiation mechanism. The fact is that the brightness temperature of FRBs is extremely high, which suggests that the emission mechanism must be synchrotron.

The various theories of FRB origin differ very significantly in the proposed analogues of FRBs in other ranges. For example, models related to the interaction

of asteroids and comets with neutron stars practically exclude the possibility of observation in ranges other than radio. However, there are models that suggest significant energies in the optical, X-ray, and gamma ranges.

At the moment, there are two main models of the central engine. The first of these can only apply to non-recurring events. According to this model, FRBs are born from the merger of neutron stars. Such emission was predicted even before the discovery of FRBs [7]. The second model is also suitable for repeaters. In this case, FRBs are born due to the activity of magnetars. After the discovery of the galactic FRB, it became clear that magnetars are indeed the source of at least some of the fast radio bursts.

Although no optical analogue of FRBs has been discovered so far, even the upper limits carry useful information, as they can limit the range of possible models.

The main difficulty in observing FRBs is the duration of the signal. During the burst, no telescope is able to point at the source. There are two remaining observation options. The first is observation of repeaters. The second option is a random observation.

In the case of repeaters, several large campaigns, including on the MASTER Global Network, were carried out [8–10]. Although none of these campaigns were successful, many interesting results, such as a synchronous constraint on the optical luminosity of FRBs, as well as some properties of the host galaxies, were obtained.

This paper is devoted to the second method of searching for FRBs: random detections, or rather, their absence, and the limitations this absence imposes on the optical luminosity.

2. METHOD

We can consider the distribution of FRBs in the sky to be completely random. However, MASTER telescopes operate in a rather complex mode. Part of the time is devoted to alert observations, part to surveys; in connection with this, as well as due to various weather conditions and the location of the telescopes, the limits vary over a sufficiently wide range and it is not possible to make any averaging. Therefore, we simply take real observations from the MASTER global network database for 20 years from all observatories and select the “successful” ones, i.e., with sufficiently deep limits, moderate FWHM, and not manually excluded by observers when searching for transients.

Next, a synthetic FRB catalog is simulated. We randomly distribute FRBs evenly across the sky and also over a time interval. We assume that the optical transient is short in the sense that it “falls through” completely into the exposure. Since most shots have a shutter speed of 180 s, this is a sufficiently “soft” assumption that must not significantly affect the results.

To simplify the distribution of FRBs by coordinates and distances, we randomly determine the Cartesian rectangular coordinates of FRBs, taking the Earth as

the reference point, and then transform them into spherical ones. This allows FRBs to be distributed simultaneously over distance and spherical coordinates without computationally complex transformations of the distribution functions. We vary each of the Cartesian coordinates from -2000 to 2000 Mpc, which is assumed to cover the entire range of distances with a margin.

In [11] the following average rate of FRBs with energy greater than 10^{39} erg is indicated: $7.4 \times 10^4 \text{ Gpc}^{-3} \text{ year}^{-1}$. We use this rate to calculate the wait time for the next FRB, assuming it is exponentially distributed.

We take the energy distribution from the same study, but simplify it somewhat by replacing the slope of the probability density function with -1.13 on -1 . This concerns energy in the radio range. Next, we multiply it by the coefficient η , which is equal to the ratio of energy in the optical range to energy in the radio range. Obviously, this is a sufficiently crude approach, but making assumptions about the optical spectrum of FRBs would be even more difficult due to the large number of free parameters.

The frame limits are constructed by the robot “with a reserve”. Therefore, we regularly open objects “weaker” than this conditional limit. To take this into account, we constructed a dependence of the number of transients on the difference between the stellar magnitude of the object and the frame limit (see Fig. 1). When the difference is equal to unity, a “collapse” occurs. However, there are many objects that are open

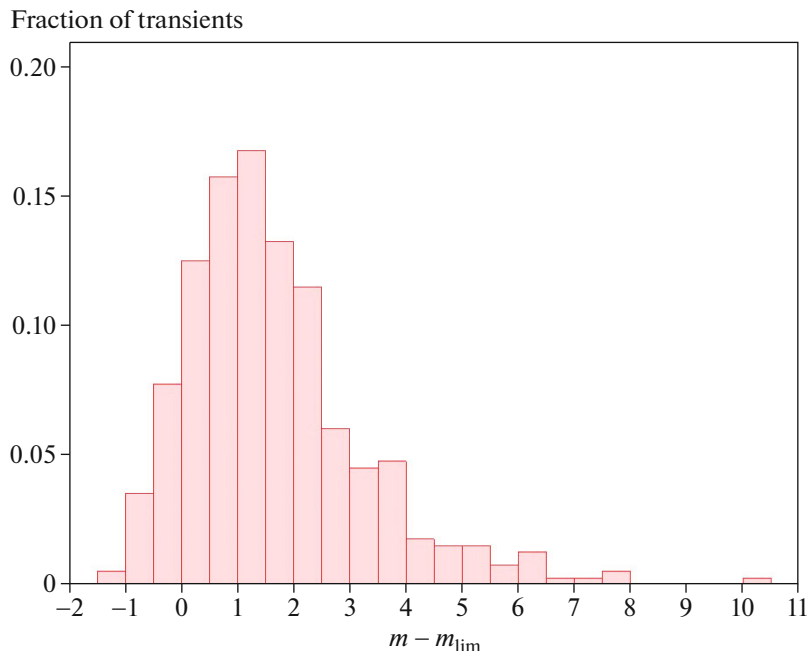


Fig. 1. Dependence of the number of found variable objects on the difference between the stellar magnitude of the object and the frame limit.

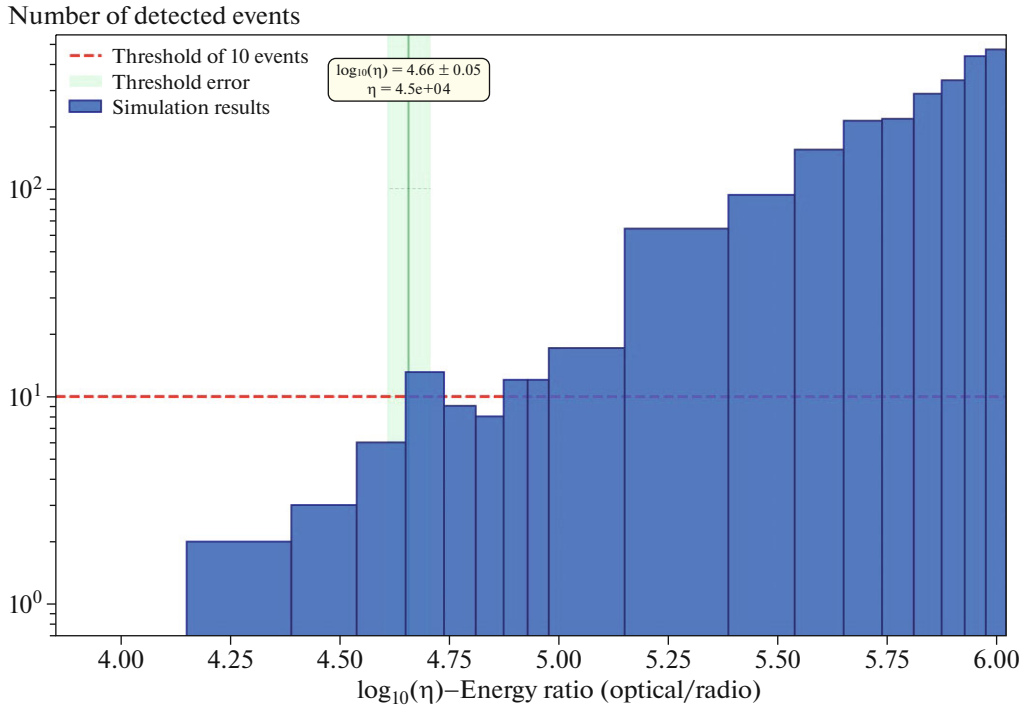


Fig. 2. Dependence of the number of detections of synthetic FRBs on the logarithm of the ratio of energies in the optical and radio ranges.

even with a negative difference. This is due to the fact that the formal frame limit is somewhat understated. For simplicity, we simply select the minimal difference in such a way that all objects weaker than the obtained value “compensate” for the resulting collapse. Thus, we believe that we could detect a source if its magnitude was at least 0.25 smaller than the frame limit. Furthermore, we multiply the detection probability by 0.8, considering that $\sim 20\%$ of transients could be missed.

The synthetic FRB catalog over 20 years was generated 10 times, and the number of detections was summed up. This is done in order to increase the “detection threshold”.

The dependence of the number of “detected” synthetic FRBs on the ratio of energy in the optical and radio ranges, η , is shown in Fig. 2. We set the detection threshold at $N = 10$ (on average, at least 1 every 20 years). The number of detections increases at $\eta = 4.5 \times 10^4$. We can consider this value as an estimate of the limit for optical energy.

3. DISCUSSION

When analyzing the obtained results, we primarily rely on the study [12]. It presented observational constraints and theoretical estimates of FRB brightness.

The following model is proposed in [13]. Magnetars produce powerful magnetic bursts that form shock

waves that act as masers. When one wave hits the tail of another, a powerful optical burst is generated, lasting up to one second. Size η in this case can be up to 10^5 .

In [14], the probability of observing an optical source is estimated as very low. However, under specific conditions (associated mainly with the surrounding matter), this probability increases sharply. The impact of such conditions on statistics is a topic for separate studies.

The best observational constraints on the optical emission were given, by far, by the GAIA instrument [15]. This is facilitated by a large field of view and good time resolution. In [12], an estimate is given as $\eta \leq 10^3$. The only problem is that this estimate is highly dependent on the estimated and completely unknown duration of the optical analogue of the FRB.

All other observational limits are above 10^7 [16]. Therefore, although the limit obtained in this study is higher than that of GAIA, it provides an independent check and, in addition, is less dependent on the duration of the burst.

Thus, in our study, we obtained an independent constraint on the optical emission of FRBs based on random coincidences: $\eta = \frac{\text{Fluence}(\text{opt})}{\text{Fluence}(\text{radio})} < 4.5_{-3.2}^{+3.4} \times 10^4$. Obviously, this is a very rough estimate. To obtain

a more complete picture, it is necessary to make various more accurate assumptions about the structure of the signal in the optical range, for example, about its duration. But even the obtained very weak limits carry useful limitations. Currently, this is the only way to search for non-recurring FRBs.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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