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Radio afterglows of gamma ray bursts

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Abstract. Radio observations of Gamma Ray Burst (GRB) afterglows are excellent means to probe the GRB environments and constrain their density. Late time radio observations of a GRB afterglow, when it has made transition to non-relativistic phase, can provide most accurate energy estimate independent of the jet geometry. Radio emission also allows us to see late time important transitions in the afterglow physics, which in turn provide key diagnostics to the fundamental parameters of the explosion. Here we will present a statistical analysis of GRB afterglows and derive important conclusions and predictions about their detectability in radio bands.

Keywords : radiation mechanisms: non-thermal – shock waves – gamma-rays: bursts – radio continuum: general

1. Introduction

In a gamma ray burst (GRB) explosion, the relativistic ejecta interacts with the circumburst medium and gives rise to synchrotron emission in all wavelengths across the electromagnetic spectrum. The synchrotron emission is a smooth power law along with some breaks in the spectrum, such as synchrotron self absorption turn over, spectral peak and the cooling break. The afterglow emission is expected to be independent of the initial explosion and by measuring temporal evolution of various break frequencies along with the flux measurements gives some of the fundamental properties of the afterglow, such as kinetic energy, microscopic parameters, and electron energy index. GRB 970228 was the first GRB for which an afterglow was detected in the X-rays.

The radio emission, by virtue of being the lowest frequency emission, comes out last. Radio afterglows deserve special mention because long lived afterglow emission

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traces afterglow properties, when the GRB jet has made transition to sub-relativistic phase and its geometry has become quasi-spherical. This allows us to determine the accurate energetics of the GRB independent of its jet geometry, e.g. GRB 970508 (Frail et al. 2000), GRB 030329 (van der Horst et al. 2008). In addition, measurements of early time scintillation can put strong constraints on the fireball size, e.g. GRB 970508 (Frail et al. 1997), GRB 070125 (Chandra et al. 2008). Very Long Baseline Interferometry (VLBI) measurements of GRB 030329 have not only measured the fireball size but subsequent size measurements have confirmed the relativistic expansion of the fireball. In addition, radio emission is the only way to estimate the density of the circumburst medium, since synchrotron self absorption turn over is observable only in radio bands. This has been crucial to reveal extremely different environments of two very high redshift GRBs, e.g., GRB 050904 (Frail et al. 2006), and GRB 090423 (Chandra et al. 2010). Due to the effect of negative k-correction effect, GRBs are observable at very high redshift in radio bands (Frail et al. 2006; Chandra & Frail 2012).

2. Detectability of radio afterglows

Since the launch of Swift, there has been a revolution in the afterglow physics. In optical bands, the afterglow detection rate jumped from 48% to 75%, whereas in X-ray bands it increased from 42% to 93% (Chandra & Frail 2012). This is owing to X-ray telescope (XRT) and ultra-violet (UVOT) instruments on-board Swift which could promptly look for the afterglows, but also due to faster response of the Burst Alert Transient (BAT), due to which ground based telescopes could point towards the bursts within minutes and catch the afterglow at early epoch. However, radio detection rate has remained about 1/3rd of total radio observed afterglows and unchanged (34% to 29%). Radio emission being long lasting emission, time has not been a constraint, however, we have attempted to determine whether the non-detectability of the afterglows in the radio bands are sensitivity limited. We have carried out a study to determine the detectability of radio GRBs.

We compare various properties of the GRB radio afterglows which were observed from 1997 onwards and until 2010, i.e. before the expanded Very Large Array (EVLA). We have found that the higher average redshift of Swift GRBs is not responsible for lack of increased GRB detections (Fig. 1, left panel). This is owing to negative-k correction effects (Ciardi & Loeb 2012). However, detectability of radio afterglows is a function of their prompt energy, fluence, X-ray emission and optical emission (Fig. 2). We estimated that 86% of the radio detected afterglows have fluences higher than 10^{-6} erg cm^{-2}. We also found that there is higher probability for an afterglow to be detectable in radio bands if the bolometric energy is higher. The 63% of the radio detected afterglows had isotropic energy > 10^{53} ergs. Similarly detectability of radio afterglows is a strong function of their optical and X-ray flux. In Fig. 2 (lower panel), we plot detectability as a function of 0.2–10 keV X-ray flux at 11 hr and R-band optical flux at 11 hr. It is clear that the radio detected events peak

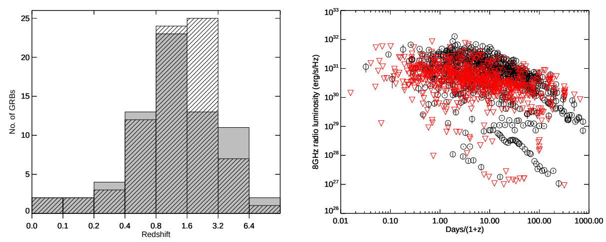

Figure 1. Left: The redshift distribution of the detected (hatched histogram) vs. non-detected (filled histogram) radio afterglows for the complete sample. Right: The k-corrected radio spectral luminosities at 8.5 GHz for radio-detected afterglows (black circles) vs. non-detected 3σ luminosity upper limits (red triangles) with respect to the rest-frame time.

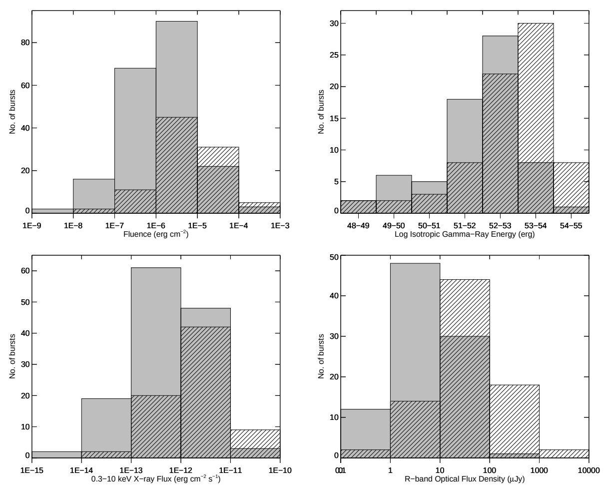

Figure 2. Upper left panel: fluence distribution of the radio-detected sample (hatched histogram) vs. the non-detected sample (filled histogram). Upper right panel: isotropic-equivalent γ-ray energy distribution of the radio-detected sample (hatched histogram) vs. the non-detected sample (gray filled histogram). Lower left panel: X-ray flux at 11 hr distribution of the radio-detected sample (hatched histogram) vs. the non-detected sample (gray filled histogram). Optical flux density distribution of the radio-detected sample (hatched histogram) vs. the non-detected sample (gray filled histogram).

in the range of $10^{-12} - 10^{-11}$ erg cm^{-2} s^{-1} in X-rays and in $10 - 100$ μJy in the optical bands, whereas non-detected events peak in the $10^{-13} - 10^{-12}$ erg cm^{-2} s^{-1} range in X-rays and in $1 - 10$ μJy range in the optical bands. This clearly indicates that the above four properties can be a good indicator whether a burst will be detected in radio bands or not.

3. Sensitivity limitation versus different population

The peak flux density of the radio detected bursts show no correlation with the above properties (Chandra & Frail 2012). We also note that the radio peak flux density is spread only in 2 orders of magnitude, whereas the fluence, the optical and the X-ray fluxes of the GRBs have at least 4 orders of magnitude spread. This may indicate that we may be sensitivity limited in radio bands. To show this we plot detected and non-detected events (see right panel of Fig. 1). Here the average luminosity for the detected events is 1.1×10^{31} erg s^{-1} Hz^{-1}, whereas the average 3σ upper limit for non-detections is 6.4×10^{30} erg s^{-1} Hz^{-1}. We, therefore, suggest that radio detections of radio afterglows is highly sensitivity limited. With the higher sensitivity of the Karl J. Jansky Very Large Array (JVLA), we anticipate detecting many more radio afterglows. However, Hancock et al. (2013) have used visibility stacking method and claim that there are two populations of bursts, one which is intrinsically radio dim and other is radio bright. They anticipate that no more than 70% of GRB afterglows are truly radio-bright. However, with enough sample collected from JVLA, one will be able to resolve this issue.

4. Conclusions

We have carried out a comparative and correlative study of the radio observed GRBs across the full electromagnetic spectrum. We find that radio afterglows are rather insensitive to redshift. We examined the observed GRB and afterglow parameters for the radio sample and we found that the radio-detected GRBs had higher fluences, larger energies, and brighter X-ray and optical fluxes on average, compared to radio non-detections.

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