International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 12
April 2018

An Attempt to Calculate Average Redshift of Optically Dark GRBs

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Abstract. *Dark Gamma Ray Bursts (DGRBs) are those in which Optical-to-X-ray spectral index (β_{OX}) is expected to be equal to or less than 0.5 of canonical GRB afterglow. High Redshift is also considered as one of the reason behind it. Here we present a carefully selected sample of Dark GRBs, to estimate unbiased GRB mean redshift (z_{mean}). An attempt has been made in the present work to find correlations between various GRBs and host properties.*

Keywords. Dark gamma ray burst; GRB, SRF, Redshift

1. Introduction

The most intense flashes of gamma rays releasing ~10^{52} ergs of energy (Berger 2014) and luminous explosion in the universe, known as GRBs, were supposed to emit optical counterpart in their afterglows. Because of the presence of afterglow GRBs were renamed as bright GRBs (van Paradijs et al. 1997). But soon after couples of months an anomaly was raised by GRB 970828 which was observed without any optical afterglow (Groot et al. 1998). It was pronounced as dark GRB with the justification that it had X-ray counterpart without (or almost dim) optical band in the afterglow. Initially, delay time between GRBs and optical afterglow was speculated as a reason behind this lack of detection, and further it was attributed to the ground based facilities which take several hours to set on target. Meanwhile afterglow of GRBs concurrently faded below their sensitivity threshold was the interpretation of such observations. But in 2004, picture became clear when the Swift was launched, which provided accurate GRB position within few minutes of the burst on the ground. Despite of indigenous observations of Swift -Bat, few of the GRBs did not show any optical counterpart. These unique observations led to the definition of 'dark burst' having X-ray counterpart without optical one in the afterglows. The comprehensive idea behind the existence of dark GRBs (dGRBs) could be due to: (1) a high column density inside the host galaxy, around the progenitors or in the form of molecular clouds, (2) very high red shift with presence of neutral hydrogen that absorbs optical emission inside the host, and (3) presence of low density medium around the burst (Tagliaferri et al. 2008). Thereafter Waxman & Draine (2000), Ramirez-Ruiz et al.,(2002), reported that 66% of dark GRBs originate as a result of dust extinction. In same year 2004, Christensen et al. (2004) established that at low and intermediate red shifts, the host of GRBs was predominately seen poor to be of both metallicity and dust. By earlier studies these were also categorized as sub-luminous galaxies with blue color (Fruchter et al.1999, Le Floc'h et al. 2003).

On contrary, in later studies, the analysis gave even more surprising suggestions that most dark GRBs originated from more luminous galaxies than bright GRBs and showed high redshifts, which enabled one to observe them more precisely (Berger 2014). However, due to expansion of the universe, the afterglow of very distant bursts is red shifted. So the light we detect on the earth is redder in colour than the light that left the bright GRBs and leaves more scope for further studies, on the other hand, varying behavior of dark GRBs have left still ample opportunities.

The above mentioned transient nature of observed dark GRBs and their hosts led us to investigate the properties more in detail critically revisiting the available data as given in table -1. In subsequent sections §2 and §3 we will brief the data collected from the literature and in §4 relations between various properties of the hosts .Finally the results, discussion and conclusion are in §5.

§2. **Data Description:**

Among all the observed dGRBs, from the literature we seek out those measured with redshifts, and the other relevant data.

GRB 970828 was the first best observed dGRB for which deep radio search to R~ 24.5 failed to detect optical afterglow. Using the Kennicutt's (1998) formula, the SFR was calculated by the [OII] line flux that was observed to be (1.63 ± 0.07) × 10^{-17} erg cm^{-2} s^{-1}. The SFR comes out to be ~ 1.2 $M_\odot$ yr^{-1}. The presence of Radio flare in the X-ray afterglow enabled us to find redshift and to identify the host galaxy. (Castro Ceron et al 2004)

In the beginning of the 2000, dGRB 000210 was detected by Swift –Bat. This 15 seconds duration dGRB showed a FRED-Like pulse. The [OII] line flux for this dGRB host was used to calculate SFR by Kennicutt's formula (1998) which turned out to be the SFR ~ 3 $M_\odot$ yr^{-1} (Piro 2002). The redshift was observed less than 5, which raised a query whether the dark circumburst medium was the reason behind the darkness (Reichart & Yost 2001).

Later in October, 2000 dGRB 001109 was observed without afterglow counterpart with R < 23 at 24 hrs after the burst, which proved it as a dark burst. Lack of optical afterglow could be explained by the estimated value of dust extinction A_v = 1.4.

However in 2002, another detected dGRB 020819 had been of much interest. It was one of the nearest burst with z =0.41. The large value of dust extinction was the reason behind the darkness A_v (1.8 – 2.6). The value of dust extinction was sufficient to suppress the optical afterglow of a burst.

In the same year dGRB 021211 was found with T_{90} = 2.30 ± 0.52 s. (Crew et al. 2003) lying near the boundary of long and soft burst. All together the spectral properties proved it to belong to the category of long dGRBs. It was an X- Ray rich burst with FRED-Like structure. Redshift of host galaxy was found z = 1.006.

Within the first month of the year 2003, dGRB 030115 showed photometric redshift of ~ 2.5, with very faint afterglow in the R-band after 24 hours. It had a fastest decay rate as compared to normal bright GRBs, with α ~ 1.5. The Afterglow colour suggested the presence of dust extinction along the line of sight. The host had red colour was observed by multicolor Hubble Space Telescope. It was the first host observed as the ERO (Extreme Red Object). (Levan et al. 2006)

The IBIS spectrum data of dGRB 040222 in the range of 20-200 keV was fitted by P. Filliatre (2005) using the Band model with a break energy of E_0 = 56 ± 2 keV, Peak energy E_{peak} = 41 ± 3 keV, the peak Flux of 1.8 x 10^{-7} ergs cm^{-2} s^{-1} and Fluence 3.4 x 10^{-7} .

Just after one year gap, dGRB 050223 was found to show T_{90} >2 sec whose host galaxy had luminosity L = 0.4 L*, a blue galaxy with z = 0.5 and strong SF (pellizza et al. 2006). A large value of dust extinction was found in the galaxy with observed A_v > 2 mag. dGRB located at z = 0.584

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Available at https://edupediapublications.org/journals

e-ISSN: 2348-6848
p-ISSN: 2348-795X
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± 0.005 and showed Luminosity of L ~ 0.42 L*. SFR > 7 $M_\odot$ y^{-1} and a large extinction Av > 2 mag were recorded by emission lines in the galaxy spectrum. The reported Specific SFR (SSFR) > 17.5 $M_\odot$ y^{-1} was little astonishing.

Moretti et al. (2005) reported dGRB 050326 as a long (T_{90} ~ 30 seconds) GRB which was observed by SWIFT with quite bright X-ray afterglow with a flux of 7 x 10^{-11} ergs cm^{-2} s^{-1} (0.3 – 8 keV). This X-ray bright GRB was only able to place very deep limits to optical and ultraviolet wavelength to Swift UVOT proving itself as 'truly dark' GRB.

The larger redshift z > 5 and A_v were recorded for dGRB 050904 and both high values made it in the dark burst category. Average amount of dust extinction at λ_{rest} = 3000 Å of A_{3000} = 0.25 ± 0.07 mag gave two strong reasons for host to give a hidden optical part burst, while the high redshift had already enriched its ISM (Interstellar Medium) with dust. (G. Stratta, 2011)

Another dGRB 051008 after one month exhibited long burst with SFR value, as calculated by Volnova (2014) 60 $M_\odot$ yr^{-1}. Isotropic Equivalent Energy of the burst E_{iso} = (1.15 ± 0.20) × 10^{54} erg made it a highly energetic long burst without afterglow and detectable spectral lag.

Castro- Tirado et al.(2007) revisited the data of dGRB 051022 having z = 0.809 and suggested that the presence of GMC (Giant Molecular Cloud) along the line of sight had been possible reason behind its darkness. It is one of the most intense dark GRB, with a bright source of luminosity greater than L*.

One week later a long dGRB 051028 (T_{90} =16 s) with redshift of 3.7 ± 1.8, without clue of having dust in the medium was reprted. So it is concluded to be intrinsically dim. The afterglow of this dark burst shows the classical temporal decay pattern (α = −0.9) from 0.1 days after the burst.

DGRB 070306 was the first case of the longest GRB ever observed with T_{90} = 210 ± 10 s, and β_{OX} < 0.5. Afterglow was highly obscured (reddened) while the host indicated no sign of reddening. This could be explained by the uneven distribution or variable concentration of dust or gas. Our galaxy is also own such patchy patterns (Jaunsen 2008).

But dGRB 071021 broke the record of dGRB 070306 in 2007 showing T_{90} = 225 s.The afterglow was observed with a fading source in NIR only. The dust in the ISM caused the red colour in the afterglow, as it worked as an extinction. The redshift of 2.452 too added red colour to the afterglow. (Thomas Kruhler et al 2012).

The host of dGRB 080207 came out to have a very obscured and red (Svensson et al 2011). The Infrared Luminosity observed by Hunt et al (2011) turned to be L_{IR} = (6.8 ±1.7) 10^{11} $L_\odot$. The calculation of Savaglio et al 2009 yielded SFR ~30 – 40 $M_\odot$ y^{-1} that was 3 – 4 times less than SFR inferred from L_{IR}.

Parley et al (2010) suggested that such a dGRB 080607 with $E_{peak,obs}$ = 902 keV could be used as the prototype for studying 'Dark GRBs' The reason was that the early luminosity of this burst was high which enabled to study its afterglow despite of high redshift(3.036) and A_v = 3.3 ± 0.4 (too much dust extinction in the line of sight).

Having the value of spectral ratio of Optical to X-ray β_{OX} < 0.2 − 0.5, dGRB 080325A was considered as a dark burst because of the observed photometric redshift of the host (z = 1.9) with larger value of dust extinction A_v = 0.8 in comparison of normal bright GRBs (Tetsuya Hashimoto et al 2014).

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In 2010, Holland et al reported an unusual long burst dGRB 090417B with extra large T_{90} = 2130 seconds, and multipeak in energy range 15 – 150 keV associated with a bright star forming galaxy of redshift z = 0.345. The galaxy identified was found bearing with high dust extinction (A_v > 12 mag.) in the line of sight making the burst as optically dark.

Although found bright enough in X-ray and radio part, but not detected in optical or near infrared was the dGRB 111215A with burst duration of 796 ± 250 s (van der Horst et al 2014). Deep studies suggested that the reason behind the non detection of nIR in the afterglow could be a relatively low star formation or the host is surrounded by heavily obscured by gas or dust.

E. Berger, (2012) compared optical afterglow with x-ray part and found very faint with a low spectral index, proving the GRB 120804 a dark one. It showed a rest frame extinction A_v ~ 2.5 mag at a redshift of ~ 1.3. The host was also observed to be associated with high star formation rate ~ 300 $M_\odot$ yr^{-1}. The emission line flux [OII] was obtained to be 48 ± 7.0 × 10^{-18} ergs/s/cm^2. Kennicutt (1998) formula provided SFR > 6.18 $M_\odot$ y^{-1}.

§3. **Data analysis:**

A systematic observed data of carefully selected Dark GRBs is present in the tabular format.

Average Redshift = 1.96

Table-1:

Sr. No	GRB	Redshift Z	A_v	SFR (in $M_\odot$ y^{-1})	T^{90}	Type	Epeak	Reference
1	970828	0.9575	0.112 mag	1.2				Castro Ceron et al 2004
2	981226	1.11						L. Christensen 2005
3	990506	1.3						bernard et al. 2002
4	000210	0.8463	0.9 – 3.2 mag	3	15 s	Long		bernard et al. 2002. piro et al. 2002, Gorosabel et al. 2002
5	001109	0.398	1.4 mag					castro ceron et al 2004
6	020127	1.9						Berger et al 2007
7	020819	0.41	1.8 – 2.6 mag	23.6				Kupcu yoldas et al. 2010
8	021211	1.006		825				Pandey et al 2003

9	030115	2.5	1 mag	4.4				Ievan et al. 2006
10	050219	0.211		0.6	23.7s	Long		Rossi et al 2014
11	050223	0.584	>2 mag	7 - 10	22.5 s	Long		pellizza et al. 2006
12	050326	6	2 mag		29.3 s	Long	200 ± 30 keV	Moretti et al. 2005
13	050904	6.3			174.2 s	Long		G. Stratta et al 2014
14	050915	2.53			40.9	Long		Fynbo et al 2009b
15	051008	2.8	0.3 mag	60	214 ± 30 s	Long	700 keV	Volnova et al. 2014
16	051022	0.807	1 mag	50	200 s	Long	510 keV	Castro-tirado et al. 2007
17	060210	3.91			255s	Long		Fynbo et al 2009b
18	060719	1.53			66.9s	Long		Fynbo et al 2009b
19	060814	1.92			145.3s	Long		Salvaterra et al. 2012
20	060904A	2.55			80 s	Long		Jausen et al. 2008
21	061222A	2.09			71.4s	Long		Fynbo et al 2009b
22	070306	1.496	5.5 mag	34	210 ±10 s	Long		Jausen et al. 2008
23	070419B	1.96			236s	Long		Thomas Kruhler et al 2012
24	070521	1.35			37.9s	Long		Fynbo et al 2009b
25	071021	2.452			225 s	Long		Thomas Kruhler et al 2012
26	080207	2.2	1 – 2 mag	119	340 s	Long		hunt et al. 2011
27	080325A	1.78	1.2 mag	35.6 - 47	124 ±34 s	Long		Tetsuya hashimoto et al 2014
28	080805	1.5			78s	Long		Fynbo et al 2009b and Greiner et al 2011
29	080607	3.036	3.3 mag		79 s	Long	902 keV	Perley et al. 2010
30	080913	6.7			8s	Long		Fynbo et al 2009b and Greiner et al 2011
31	081109	0.98			190s	Long		Kruhler et al 2011b and

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								Greiner et al 2011
32	090113	1.75			9.1 s	Long		Thomas Kruhler et al 2012
33	090404A	3			84 s	Long		Holland et al 2010
34	090417B	0.345	~ 12 mag		2130 s	Long		Stephen T. Holland et al 2010
35	090926B	1.24			109.7 s	Long		Fynbo et al 2009a and Greiner et al 2011
36	100621A	0.54			63.6	Long		Kruhler et al 2011b
37	111215A	2.06	50 mag	34	796 s	Long		Van der horst et al. 2014
38	120804A	1.3	2.5 mag	300	0.81s	short	135 keV	E Berger et al 2012
39	130528A	1.25	>6.18 mag	1.4	59.4 s	Long	118.3 keV	Jeong et al. 2014

3.2 **Some plots: Plots**

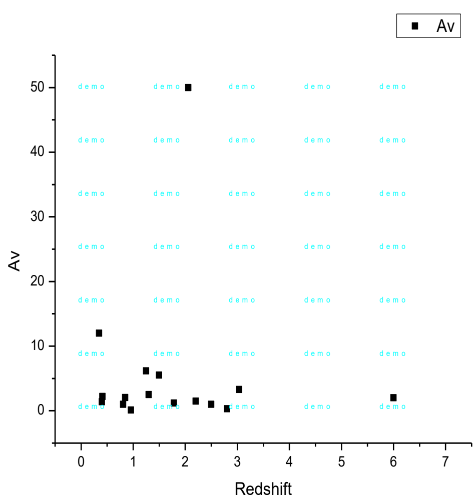

Fig. 1 Shows a graph between redshift z and dust extinction A_V.

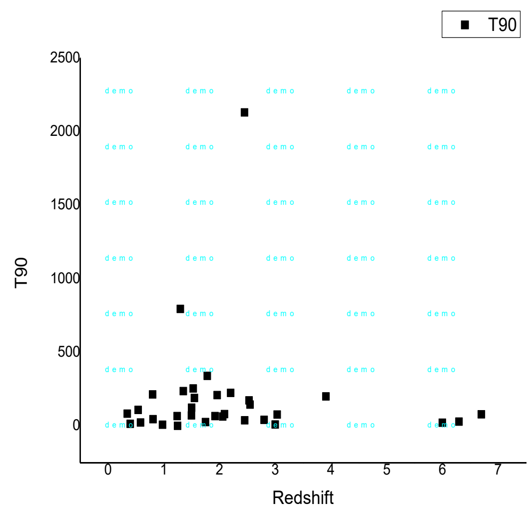

Fig. 2 Shows a graph between Redshift z and T_{90}.

e-ISSN: 2348-6848
p-ISSN: 2348-795X
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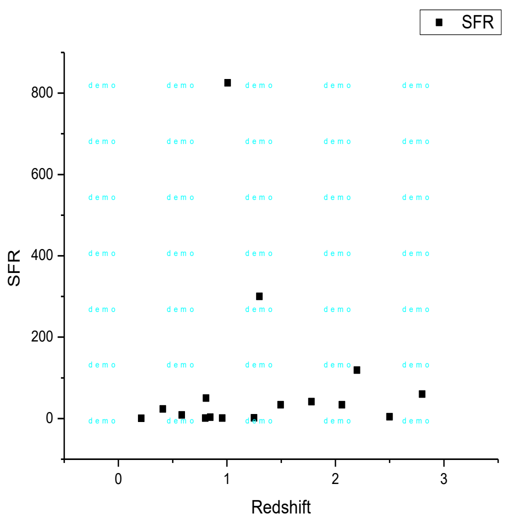

Fig. 3 Shows SFR and redshift relation.

§4 : Result and conclusion:

The average redshift of sub-mm galaxies (z_{mean}= 2.4: Chapman et al. 2003) is similar to average redshift of GRBs (z_{mean}= 2.8: Jokobsson et al 2005), But average redshift of dark GRBs is very less (z_{mean}= 1.3). These result are in favour of the fact that dark GRBs don't posses high redshift (Djorgovski et al. 2001b; Antonelli et al. 2000; Piro et al. 2002).

We can search other reasons behind this interesting fact, which will help us to understand the dark GRBs in better way. And likewise we can get more information about the host of dark GRBs.

Conclusions by graph: In Figure 1 GRB 111215A shows maximum dust extinction Av of 50 magnitude among all other observed dark GRBs having most of these between 0-5 mag. These dark GRBs are expected to keep dense dust extinction matter in their proximity during occurrence. However it may further be increased if DGRB happens to be merger of galaxies and also in the case of SN explosion. The Interstellar dust extinction may occur in the line of sight which indeed increases A_v. In case of SN and (G-G) for DGRBs, the probability of density of dust extinction will be exhausted because of breakup of heavy elements into lighter nuclei.

Figure 2 shows long dark GRB of (T_{90} = 0 to 4 minutes) have larger occurrence within range of 0.5 – 3 Redshift which indicates that the population of Galaxies and SN explosions have large probability to become proginator for Dark GRBs. This space is quite crowded with interstellar clouds extinguishing the radiation of GRBs to become Dark.

The observed few dGRBs (050306, 050904, 080913) at large z of the order of 6 to 7 may suffer the extinction of radiation by interstellar cloud present in the line of sight at z = 0.5 – 3. It is also possible that above dGRB are far away and photons flux is largely decreased.

Another important parameter SFR (Star Formation Rate) as plotted in figure 3, with observed Redshift z revealed that probability of star formation is large around z = 1 – 2. This predicts the existence of large density of cloud in which star may take birth, but at other z it is least (0.6).

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