Searching for GRB remnants in nearby galaxies

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Abstract. The quest for the origin of GRBs still remains the principle goal of all studies in GRB astronomy. While the main focus lies in increasing the afterglow data base, it would also be interesting to explore other ways that would lead us to the main goal. Knowledge of GRB environments will allow us to understand the nature of their progenitors. We have initiated an observational program to search for GRB remnants in nearby galaxies. The identification is based on certain line ratios viz., OIII/H_β, HeII/H_β etc expected to be very high in case of GRB remnants according to the theoretical predictions of Perna et al. (2000). The observing strategies and preliminary studies from a test run at 2.34 m VBT as well as archival data from PNe surveys of spiral galaxies are discussed.

INTRODUCTION

Despite the major developments in GRB astronomy in the last 7 years we still do not have a clear understanding of the progenitors of Gamma Ray Bursts. At present, the main focus is on increasing the afterglow data base in order to obtain a better statistical sample for theoretical modelling and their classification. Besides multi-wavelength observations of the GRB afterglows several other aspects are of interest viz. luminosity functions, clustering properties etc, which also require a good statistical sample to derive meaningful results. Therefore we need to put in several years of efforts to obtain a significatly large afterglow data base.

In the meanwhile, it would be interesting to explore other possibilities that would lead us to the understanding of progenitors of GRBs. One of the ways to go about it is by studying the environments of GRBs i.e, to ask **'how do the birth places of GRBs look like?** At a gross level we understand that long bursts come from dusty and gas-rich environments and this has observational evidence. But we do not have any observational evidence to support the suggestions that short bursts could be coming from low density environments. Alternatively one could turn around ask: how do GRBs affect their immediate surroundings? Do they leave behind observable remnants? Can we identify unique spectral signatures among such remnants? If so, any such features found elsewhere in the sky would be the possible explosion sites where bursts occured unnoticed. These studies would be useful in establishing the GRB rates, beaming factor and energetics.

GRB REMNANTS

Perna, Raymond & Loeb (2000) have shown that 2 kinds of GRB remnants are possible:

Cooling remnant : due to the effect of radiation of GRB and its afterglow.
The UV afterglow flux of a GRB heats and ionizes the surrounding medium. An emission spectrum is expected to be produced from the cooling ionized gas, the cooling rate being as slow as $\sim 10^5$ yrs

Slowing remnant : due to the slowing blast-wave.
The relativistically expanding blast wave resulting from a GRB explosion takes $\sim 10^7$ years to slow down and merge with the ISM.

Combining these time scales with the present GRB rate of $\sim (10^6 - 10^7 \mathrm{fb\,yr})^{-1}$ per galaxy (Wijers *et al.* 1998), it has been estimated that few such GRB remnants should be present in every galaxy at any given time.

Identifying the GRB Remnants

The cooling remnats are expected to have following unique spectral signatures that would distinguish them from other sources such as shock heated gas in SNRs, HII regions and PNe (Perna, Raymond & Loeb 2000).

- High value for the line ratio [OIII]λ 5007/H_β
- Unusally high value for He II λ4686 /H_β ratio
- Time-dependent increase in the ratio [OIII]/[OII] indicating cooling of the gas
- High SIIλ 6717/H_β as compared to HII regions

HII regions are also photo-ionized like GRB remnants and can sometimes have high OIII/H_β ratios ($\approx$ 3), but are characterized by lower temperatures in comparion to GRB remnants. Therefore it would be useful to measure the [OIII]λ 5007/[OIII]λ 4363 line ratio which is temperature sensitive and increases with time in a cooling gas. The oxygen-rich SNR might show high OIII/H_β occationally but only during a brief period of incomplete cooling. The He II λ4686 /H_β ratio is weak in both HII regions as well as SNRs. Further, GRB remnants have physical sizes of $\sim$ 100 Pc and can be distinguished from PNe which look like point sources in external galaxies.

OBSERVATIONS

VBO data

In our present program we choose to observe nearby galaxies to search for the cooling remnants. We have initiated the observing program using the 2.34 m Vainu Bappu Telescope (VBT) at Kavalur, India and plan to use the new 2 meter Himalayan Chandra

TABLE 1. Telescope Parameters

	VBO	IOA	KPNO
Size	2.34 m	2.01 m	4 m
Longitude:	78°49′36″E	78°57′51″E	111°36′59″W
latitude:	12°34′36″N	32°46′46″N	31°57′12″N
Altitude:	725 m	4500 m	2100 m
Seeing (typ.):	2″.5	$< 1''$	1″
F-ratio:	f/3.25 prime	f/9 cassegrain	f/3.1 prime
Image scale:	0″.6/pix	0″.17/pix	0″.42/pix
FOV:	$10' \times 10'$	$7' \times 7'$	$14' \times 14'$

Telescope of Indian Astronomical Observatory (IOA), at Hanle featured by cloudless skies and low atmospheric water vapour. Nearby galaxies will be observed in narrow-band filters [OIII]λ 5007, [OIII]λ 4363, He II λ4686 and H_β to measure the various line ratios and to identify the candidate GRB remnants for further investigations.

In a test run of observations in this summer NGC 3627 and NGC 3351 were imaged at the 2.34 m VBT using the narrow-band filters [OIII]λ 5007, [OIII]λ 4363 and H_β.

KPNO archival data

In addition to the narrow-band data taken with the VBT, we are searching for GRB remnants using archival data originally taken to search for planetary nebulae in spiral galaxies (Feldmeier et al. 1997; Ciardullo et al. 2002). The data consists of narrow band [O III] λ 5007 and Hα + [NII] exposures, along with a λ 5300 continuum image. In some cases, there is additional R data as well. The seven galaxies (NGC 891, 2403, 3627, 3351, 3368, 5194/5, 5457) are all luminous spiral galaxies, and should provide reasonable targets for search.

While the [OIII]/H_α ratios are typically 5 in PNe, we expect it to be $\sim$ 30 for a candidate GRB remnant (using H_α/H_β of 2.8 for emission nebulae; See Osterbrock 1989).

Table **??** shows the telescope parameters.

SEARCH STRATEGIES

The images are reduced in the standard manner using the IRAF software. All images are aligned & positionally registered before continuum subtraction. Our goal is to identify possible GRB remnants, and follow them up with additional imaging and spectroscopic observations. Since we have just begun our search, our results are still preliminary. In order to separate the potential GRB remnant candidates from other sources (HII regions, SN remnants, and PNe), we are using the following selection criteria:
1. Objects must have a signal-to-noise greater than 9
2. Objects must appear non-stellar, and have a SExtractor star/galaxy classifier value less

than 0.95
3. Objects must have an [OIII] / Hα ratio that is 2σ larger than the mean of the distribution. This removes almost all H II regions from the sample, as they have low [O III] / Hα ratios.

Each candidate is then visually inspected to confirm their candidature agaianst artifacts. Currently, we are finding tens of candidates in each galaxy, though there is signifigant scatter from galaxy to galaxy (NGC 891 having none, most likely due to its edge-on orientation). We require further observations to confirm the list of candidates.

CONCLUSIONS

In this paper we report the preliminary studies we carried out to search for the GRB remnants in nearby galaxies from a test run at VBT as well as archival data from KPNO. The data set used is incomplete in filter coverage. In the present investigations we find about 20-30 candidates in each galaxy. Additional observations are required to measure other line ratios and to check the validity of candidates. We also plan to use data from other existing surveys to find the preliminary candida tes in nearby galaxies. A photoionized remnant of radius $\sim$ 100 pc would subtend an angle of $2''$ on the sky at the distance of Virgo cluster ($\sim$ 20 Mpc), where as a typical galaxy would subtend 2 arcmin. We require a multiple-fibre spectrograph (like Integral Field Unit) which can take simultaneous spectra across the entire image of a nearby galaxy.

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