Searching for GRB remnants in nearby galaxies

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Abstract. Gamma Ray Bursts (GRBs) are expected to leave behind GRB remnants, similar to how "standard" supernovae (SN) leave behind SN remnants. The identification of these remnants in our own and in nearby galaxies would allow a much closer look at GRB birth sites, and possibly lead to the discovery of the compact object left behind. It would also provide independent constraints on GRB rates and energetics. We have initiated an observational program to search for GRB remnants in nearby galaxies. The identification is based on specific line ratios, such as OIII/H_β and HeII/H_β, which are expected to be unusually 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 planetary nebulae surveys of spiral galaxies are discussed.

INTRODUCTION

The intense X-ray/UV radiation accompanying GRBs has dramatic effects on their environment: it can photoionize regions of $\sim$ 100 pc size (Perna & Loeb 1998), and destroy dust on scales of tens of pc (e.g. Waxman & Draine 2000). Moreover, similarly to what happens for SN remnants, a powerful blast wave is driven into the medium. While it takes a very short time (compared to the duration of the most intense X-ray UV radiation from the burst) to alter the equilibrium state of the medium, it takes a very long time for the medium to recover its original state, as detailed in the next section. This means that, while it is highly unlikely to observe a GRB in a nearby galaxy, there is a significant probability to find a GRB remnant.

Identification of GRB remnants in our own and nearby galaxies would allow a close study of GRB birth sites, and therefore provide independent diagnostic of their progenitors. Similar to how pulsars are found in association with SN remnants, the compact remnant objects left over from the GRB explosions can then be found in association with GRB remnants. Moreover, an estimate of the number of GRB remnants in the local universe would allow independent constraints on GRB rates and energetics.

GRB REMNANTS

Two phases can be distinguished in the life of a GRB remnant:

Cooling remnants (Perna, Raymond & Loeb 2000): due to the radiation flux of the GRB and its afterglow.
The X-ray/UV radiation accompanying a GRB heats and ionizes the surrounding medium. An emission spectrum is expected to be produced from the cooling ionized gas, the cooling time being of the order of $\sim 10^5 (T/10^5\mathrm{K})/(n/\mathrm{cm}^{-3}))$ yr.

Slowing remnants (Loeb & Perna 1998; Efremov et al. 1998): due to the slowing blastwave.
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 $\sim (10^6 - 10^7 f_b\,\mathrm{yr})^{-1}$ per galaxy (f_b is the beaming fraction) (e.g. Wijers *et al.* 1998), it can be seen that there is a substantial probability of finding GRB remnants in any galaxy at any given time.

Identifying GRB Remnants

In this paper, we report on our initial search strategy for cooling GRB remnants. Although the duration of the cooling phase is much shorter than the lifetime of the blastwave, these cooling remnants are much easier to identify due to their unique spectral signatures that allow one to distinguish them from other sources such as shock heated gas in SN remnants, HII regions and planetary nebulae (Perna, Raymond & Loeb 2000).

- High value for the line ratio [OIII]λ5007 /H_β ($\sim$ 100 for most of the cooling phase).
- Unusally high value for He II λ4686 /H_β ratio (up to $\sim$ 100 at the beginning of the cooling phase).
- Time-dependent increase in the ratio [OIII]/[OII] indicating cooling of the gas.
- High SIIλ6717/H_β as compared to HII regions.

HII regions are also photo-ionized like GRB remnants and can sometimes have high OIIIλ5007/H_β ratios ($\approx$ 3), but are characterized by lower temperatures in comparion to GRB remnants. Therefore it is 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 planetary nebulae (PNe) which look like point sources in external galaxies.

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:	$10' \times 10'$	$7' \times 7'$	$14' \times 14'$

OBSERVATIONS

VBO data

We have initiated our observational search for cooling GRB remnants using the 2.34 m Vainu Bappu Telescope (VBT) at Kavalur, India, and plan to use the new 2 meter Himalayan Chandra Telescope of the 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 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] λ5007 and Hα + [NII] exposures, along with a λ5300 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]λ5007/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; Osterbrock 1989).

Table 1 shows the telescope parameters.

SEARCH STRATEGIES

The images are reduced in the standard manner using the IRAF software. All images are aligned and positionally registered before continuum subtraction. Our goal is to identify candidate 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]λ5007/ 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]λ5007 / Hα ratios.

Each candidate is then visually inspected to confirm their candidature against 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. 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 preliminary candidates 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 a typical galaxy would subtend 2 arcmin. We require a multiple-fibre spectrograph which can take simultaneous spectra across the entire image of a nearby galaxy.

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