INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: A**

Period AOT39 (April 2019 – September 2019) **Submit using: www.tng.iac.es/submit.html**

1. Title

Exploring the Universe with Gamma-Ray Burst Afterglows

2. Abstract

Since the end of 2004, thanks to more than 1000 bursts detected by the *Swift* satellite and to the remarkable observational efforts in which TNG has played a key role, our knowledge of the GRB phenomenology has largely improved. Nevertheless, crucial questions about GRBs and their environment are still open. We propose here to focus our research activities on a few well-defined scientific goals where the TNG capabilities can be more competitive now and in the next years. Moreover, since the proposed project relies upon the triggers from *Swift*, it is crucial to have active GRB follow-up programmes as long as this mission is in operations (funded at least up to 2019). The aim of this proposed project is to: **a**) identify and follow-up all the short GRBs readily visible from the TNG; **b**) observe bursts suspected to be at high redshift, in order to confirm their redshift, investigate their environment and use them as probes of the early Universe;**c**) study in detail, with photometry and spectroscopy, GRBs at low redshift in order to discover and monitor the evolution of any supernova possibly associated to these events; **d**) secure redshifts and characterize the properties of a carefully selected and unbiased sample of bright events.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
12.5		5				

3b. Observing modes

TNG:		Visitor	X	Service	X	ToO
REM:		Rapid Response		Queuing		ToO

4a. Preferred months

first choice: second choice:

4b. Other scheduling constraints (use also box 14)

5a. Past and future of the project

a) Hours already awarded to the project: 400

b) Hours foreseen to complete the project:
(not including this request)

6. Principal investigator

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8. Status of the project

Telescope	Instrument	Date	Hours	Notes
TNG	DOLoRes	2016-01-18	1.5	GRB 160117B, bright GRB
TNG	DOLoRes	2016-01-31	0.5	GRB 160131A, bright GRB
TNG	NICS	2016-03-31	1.0	GRB 160327A, high redshift GRB
TNG	NICS	2016-05-13	1.3	GRB 160509A, high redshift GRB
TNG	DOLoRes	2016-06-05	0.7	GRB 160625B, bright GRB
TNG	NICS	2016-07-01	2.0	GRB 160625B, bright GRB
TNG	DOLoRes/NICS	2016-08-30	2.2	GRB 160804A, bright GRB
TNG	DOLoRes	2016-08-22	1.3	GRB 160821B, short GRB
TNG	DOLoRes	2016-09-27	0.3	GRB 160927A, short GRB
TNG	DOLoRes	2016-10-14	1.0	GRB 161014A, bright GRB
TNG	DOLoRes	2016-10-17	1.0	GRB 161017A, bright GRB
TNG	NICS	2017-01-19	1.0	GRB 161017A, bright GRB
TNG	DOLoRes	2016-12-26	2.7	GRB 161219B, GRB with associated SN
TNG	DOLoRes	2017-05-01	1.2	GRB 170428A, short GRB
TNG	DOLoRes	2017-06-26	0.5	GRB 170626A, bright GRB
TNG	NICS	2017-07-16	1.0	GRB 170714A, faint GRB
TNG	DOLoRes	2017-07-28	1.2	GRB 170728B, bright GRB
TNG	NICS	2017-12-06	0.5	GRB 171205A, GRB with associated SN

Description

Starting from AOT22 our team has been awarded by three (four semester each) Long Term programs (AOT22-25 PI: Palazzi; 26-29 PI: D'Avanzo, 32-35; PI: D'Elia) and two normal programs (30 and 36, PI: D'Elia). We focused on 4 scientific cases: i) high-redshift ($z > 2$) GRBs, ii) short-duration GRBs (SGRBs), iii) GRB-Supernova association and iv) a complete (in redshift) sample of GRBs. The expected rate of GRBs observable from TNG falling in these categories was of 5 events/semester. During the last long term program (AOT32-AOT35) we observed 15 targets (in line with our expectations). In particular, we observed 3 SGRBs (GRB 160821B, GRB 160927A and GRB 170428A), 3 burst with $z > 2$ (GRB 151027B, GRB 160327A and GRB 160509A), 7 bright long GRBs (GRB 151027A, GRB 160117B, GRB 160131A, GRB 160625B, GRB 160804A, GRB 161014A and GRB 161017A) and 2 GRB with an associated SN (GRB 150818A and GRB 161219B). For four of these events (27% of the total; GRB 160117B, GRB 161031A, GRB 160625B and GRB 161017A) we were able to measure the redshift. The TNG data collected with these observations led to a publication outcome of 10 GCN Circulars and 5 papers. 4 more GRBs were observed in AOT36 (5 published GCNs and one paper in preparation).

Publications

Ashall, C., et al., 2018 Nat. Astr., subm. - D'Avanzo, P., et al., 2016 GCN. 19956 - D'Avanzo, P., et al., 2016, GCN 20078 - D'Avanzo, P., et al., 2017, GCN 21055 - D'Avanzo, P., et al., 2017, GCN 21350 - D'Avanzo, P., et al., 2017, GCN 21372 - D'Avanzo, P., et al., 2017, GCN 21373 - D'Elia, V., et al. 2016, GCN 18915 - D'Elia, V., et al. 2016, GCN 19601 - D'Elia, V., et al. 2018, A&A, 619, 66 - Malesani, D., et al. 2016, GCN 18965 - Malesani, D., et al. 2016, GCN 19770 - Melandri, A., et al. 2015, GCN 18961 - Melandri, A., et al. 2016, GCN 20048 - Melandri, A., et al. 2016, GCN 20071 - Melandri, A., et al. 2017, GCN 21270 - Melandri, A., et al. 2017, GCN 22189 - Nappo, F., et al. 2017, A&A, 598, 23 - Tanvir, N., et al. 2018, A&A, Subm.

9a. If this proposal is a part of a PhD thesis, write here the name of the student, the thesis title and briefly describe the relevance of these observations for the thesis goals.

9b. Is this, or a similar application submitted to other time allocation committees (e.g. ESO, TNG-CAT, ITP)? If yes, please specify which and explain if and why the proposals should be considered complementary.

Our team submitted associated proposals to LBT, ESO, REM. Some of us are members of the teams having GTO on GRBs at ESO/VLT (X-shooter), Liverpool, Faulkes and REM telescopes. In response to the TNG/NOT joint call policy a similar proposal has been submitted for the NOT call (PI: Jakobsson).

10. Description of the programme (max. 3 pages, including references, tables, and figures.)

A) Scientific rationale After more than 40 years since their discovery, GRBs still represent one of the most exciting research fields in modern astrophysics. They are γ-ray explosions, the most powerful since the formation of the Universe, with most of their observed electromagnetic energy released in the 0.01-1 MeV and occurring at a rate of 1-2 per day over the whole sky. Their remnants, multi-wavelength long-lived fading sources, the afterglows, can outshine every other known object in the Universe, both in the optical/near-infrared (NIR) (e.g. Racusin et al. 2008) and in the X-rays (Cusumano et al. 2006). Currently there are four high energy satellite missions which can rapidly deliver (a few seconds after the trigger) GRB positions with few arcmin (*Swift*, *INTEGRAL*, *AGILE* and *Fermi*) or sub-arcmin (*Swift*) errors providing information at high energies. Follow-up with ground-based optical instruments has given a substantial contribution allowing to derive multi-wavelength information essential for a proper physical modeling of the GRB phenomenon as well as investigating their environment. In this scenario the TNG and its instrumentation is a competitive telescope well suited to perform this kind of science as testified by the many and very important results achieved by our team in the last 16 years of observations. To best exploit the TNG capabilities, we propose to carry out four well-defined GRB projects.

Short GRBs. The distribution of GRB durations (T) is bimodal, with peaks at ~ 0.2 and ~ 20 s and a boundary at ~ 2 s (Kouveliotou et al. 1993). The two classes of long (LGRBs, $T \geq 2$ s) and short GRBs (SGRBs, $T \leq 2$ s), show substantial evidences for different origins. While it has been firmly established that LGRBs, or at least a significant fraction of them, originate in core-collapse supernova (SN) explosions (see Woosley & Bloom 2006, for a review), the field of SGRB progenitors is now undergoing a major breakthrough. The discovery by the LIGO/Virgo interferometers of a gravitational wave (GW) event associated for the first time with an electromagnetic counterpart (GW170817, a bynary neutron star (NS) coalescence, Abbott et al. 2017), and the connection of the latter with a SGRB (GRB170817A), brilliantly confirmed that SGRBs are associated with the merging of binary systems of compact objects with at least a NS (Eichler et al. 1989; Narayan et al. 1992). A different origin with respect to the LGRB class was indeed supported by the lack of detection of the underlying SNe in the light curves of their optical afterglows (Hjorth et al. 2005; Covino et al. 2006; Kann et al. 2008; D'Avanzo et al. 2009) and by the observed larger variety in SGRB host galaxy types compared to those of the LGRBs (Fong et al. 2013). In addition, the conclusive detection of a "kilonova" (a predicted final product of a double compact object merging) associated with GW170817/GRB170817A (Pian et al. 2017) represented the smoking gun of the elusive SGRBs progenitors. Apart from the GW event, our present knowledge is still based on a handful of SGRBs. In particular, only two afterglows have available absorption spectra one of which, remarkably, could be secured also at the TNG (Antonelli et al. 2009).
Thus, the observation and characterization of GRBs is of paramount importance to investigate their still uncertain nature and to constrain their redshift distribution, also in the light of the forthcoming LIGO/Virgo run starting in March 2019.
The small number of SGRBs triggered by satellites ($\sim 1/10$ of the total), together with the flux of their optical afterglow (which is typically fainter than that of LGRBs, e.g. Nysewander et al. 2009) makes 4m size telescopes, such as the TNG, very suitable for SGRB afterglow observations. Indeed, small robotic telescopes are generally unable to go deep enough to catch them and/or to monitor the evolution of their light curve until it reaches the host galaxy level.

GRBs as cosmic probes. GRBs are detectable up to distances larger than any other astrophysical object to date, so they are an effective way to investigate the very early Universe. The brightness of their afterglows makes them detectable up to very high redshift, as shown by GRB 050904 (observable for a few days, $z \sim 6.3$; Tagliaferri et al. 2005), GRB 080913 ($z \sim 6.7$; Greiner at al. 2009), GRB 090423 ($z \sim 8.2$; Salvaterra et al. 2009, Tanvir et al. 2009) and GRB 090429B ($z \sim 9.4$; Cucchiara et al. 2011). Therefore they are powerful tools to probe the reionisation of the Universe. Recent results from WMAP data suggest that it was completed by $z \sim 6-7$, and began at considerably higher redshifts ($z \sim 9-13$, Dunkley et al. 2009; Komatsu et al. 2010), where GRBs can still be detectable. Indeed the afterglow brightness allows us also to study galaxies that are too faint to be detected by traditional flux-limited deep surveys. This provides a very promising new tool, to study the very first phases of structure formation in the Universe and the reionization epoch.
Moreover, given the association between GRBs and star formation, GRBs offer a unique opportunity to probe the existence of stars up to redshifts > 10 and to investigate the medium in which they formed. The studies of the afterglow spectral absorption lines are an excellent complement to the studies of QSO sightlines to detect absorbing gas in the intervening galaxies and within the ISM of the GRB host itself. Indeed, GRBs may possibly be more effective than QSOs in probing the high-redshift diffuse medium thanks to their brightness, the lack of proximity effects, and simpler continuum determination.
Our team was able to obtain, following earlier photometric indications, the NIR spectrum of the afterglow of GRB 090423 with the TNG, 14 hours after the *Swift* trigger, and measure its redshift $z = 8.2$ (Salvaterra et al. 2009). This shows that, also in the 8m class telescopes era, **the study of the very high redshift Universe by using GRB observations is well within the TNG capabilities.**

GRB-SN association. As mentioned above, it has been firmly established that LGRBs, or at least a significant fraction of them, originate in core-collapse SN explosions. However, some LGRBs (e.g. GRB 060614 at $z = 0.125$ and GRB 060505 at $z = 0.089$), surprisingly show no evidence for SN emission down to very deep limits suggesting a new phenomenological type of massive stellar death (Della Valle et al. 2006; Fynbo et al. 2006).

The SN component underlying the optical afterglow of LGRBs is expected to produce “bumps” in the afterglow light curves at about $15 \times (1+z)$ days after the explosion (Fig. 1). While at high redshifts the lack of a detected SN bump may be easily explained by the weakness of the (rest-frame UV) SN component, we would expect SNe to be always detected in low redshift GRBs. The exception of GRB 060614 and GRB 060505 indicates that not all long GRBs are connected with luminous SNe, but rather could be related to extremely weak SNe or to a class of completely different progenitors. **This makes the systematic search for SN bumps crucial to understand the GRB diversity, beyond the long vs short dichotomy**.

A complete sample of bright *Swift* GRBs. Our team selected a sample of *Swift* LGRBs that is almost complete in redshift. The sample considers only GRBs with favorable observing conditions for ground-based follow-up searches, that are bright in the 15-150 keV *Swift/BAT* band (i.e. with 1-s peak photon fluxes ≥ 2.6 ph s^{-1} cm^{-2}). The original sample (up to May 2011) is composed of 58 bursts, 56 of them with redshift (a completeness level of 96.5%). The GRBs belonging to this sample show on average optical afterglows whose brightness is well within the spectroscopic capabilities of the TNG (see also below). **A systematic measurement of the redshift of the new events that will be detected satisfying our criteria would increase the size of the sample keeping its completeness, making it a useful tool for statistical studies aimed at the characterization of the long GRB rest frame properties in an unbiased way.** From May 2011, other 79 bursts fell within the BAT6 selection criteria, 45 of which with measured redshift.

B) Scientific Aim

TNG, thanks to its diversified instrumentation and large collecting area, can play a significant role in the worldwide GRB competition as testified by the results we have obtained so far. The proposed program is not especially time consuming due to the low number of triggers we ask for. As described above (box 8), the previous long term programmes on this subject awarded to our team led to a significant publication outcome, particularly good if compared to the relatively little amount of consumed time (see also Fig. 1). Thanks to the observations detailed below, we propose here to keep on giving a substantial contribution to the GRB field making also a profitable use of the still remarkable qualities of an intermediate size telescope as the TNG. Furthermore, being the proposed project related to the italian experience and involvement in the *Swift* mission, we ask to continue our GRB follow-up programme at least till the next *Swift* Mission Review by NASA (foreseen for 2019). Our programme will significantly contribute ensuring the ground-based systematic follow of Swift GRBs, reinforcing the legacy of this mission.
Short GRBs are related to the coalescence of binary compact object systems, as proved by the recent detection of the GW source GW170817 originated by the merging of a binary neutron star system (Abbott et al. 2017). This opened a new era for multi-messenger observations and the investigation of the physics of some of the most powerful phenomena in the universe. Despite the GRB emission is collimated into jets, the detection of an off-axis γ-ray component at low z as in the case of GRB170817A (Savchenko et al. 2017), makes the chances of joint GW- SGRB observations higher than previously thought. The subsequent “kilonova”, the key signature of a compact binary system with at least one NS, is well in the reach of the TNG capabilities which, with early-time multi-band photometric follow-up, will enable to constrain the afterglow temporal and spectral evolution. A well sampled, multicolor lightcurve is fundamental to constrain the afterglow properties, and achieve a robust identification of this additional kilonova component with late-time follow-up with large aperture telescopes. In addition, with TNG it will be possible to pinpoint the short GRB host galaxies, selecting a sample for accurate studies (including redshift measure) to be carried out with large aperture telescopes.
GRB observations are effective and economic tools to single out very high redshift galaxies. At present in more than twelve years of *Swift* observations, a handful events at redshift greater than 5 have been detected. With another programme of continuous observations we have thus the opportunity to enlarge the existing sample, opening the possibility to perform detailed studies of the high-redshift Universe and to constrain the SFR history. This can be one of the most rewarding scientific programs carried out at a 4m-class (flexible) telescope, in particular considering the relatively modest amount of required observing time.
So far just 12 SNe clearly associated with GRBs have been observed (four of them, connected with GRB 130427A, GRB 130702A, GRB 150818A and GRB 161219B have been intensively followed-up with TNG). These are peculiar objects pushing to the extreme the properties of regular SNe, and thus allowing us to test competing models and better understand the possible evolutionary role of these rare and very energetic events. Again, in the next period we can have a sizeable probability to increase the sample.
Finally, increasing the size of the complete sample of bright *Swift* long GRBs will enable statistical studies aimed at characterize the physics of these events, as already demonstrated by the results published by our team (Fig. 2).
The involvement at the highest level of some of the Co-Is of this proposal in the *Swift* mission and in other approved proposals at various facilities worldwide both guarantee that data gathered by the TNG will be included in large-scope papers and that the TNG can carry on playing an important role in this highly competitive area of modern astrophysical research. In addition, many of the Co-Is are involved in the TNG GW follow-up programme (PI: Piranomonte). This will avoid duplications and guarantee optimal observation strategy and the highest scientific return for the TNG time.

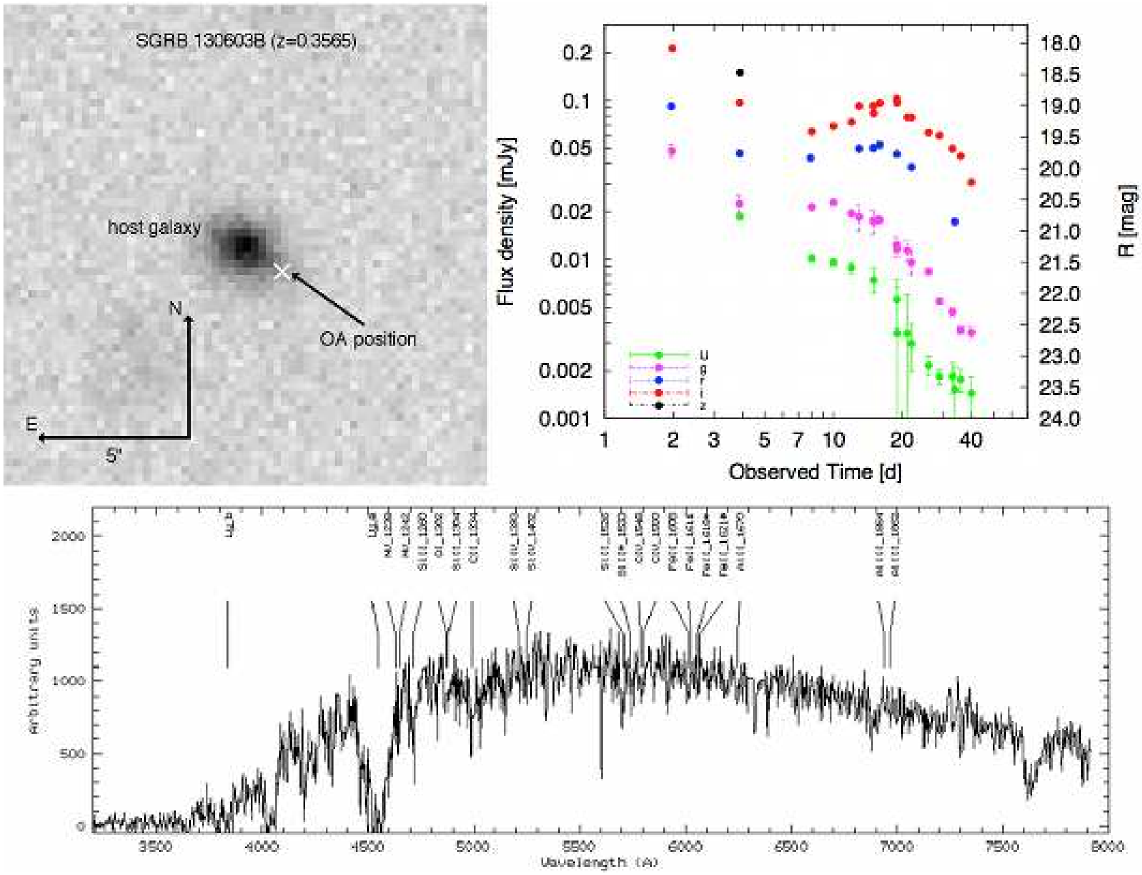

Figure 1: A selection of the results obtained by our team with the last LTP on GRBs. *Clockwise from top:* the host galaxy detection of GRB 130603B (de ugarte Postigo et al. 2013); the TNG/VLT optical light curve of GRB 130702A associated with SN 2013dx (D'Elia et al. 2015); the optical spectrum and redshift measurement (z=2.32) of the bright GRB 140206A (Götz et al. 2014).

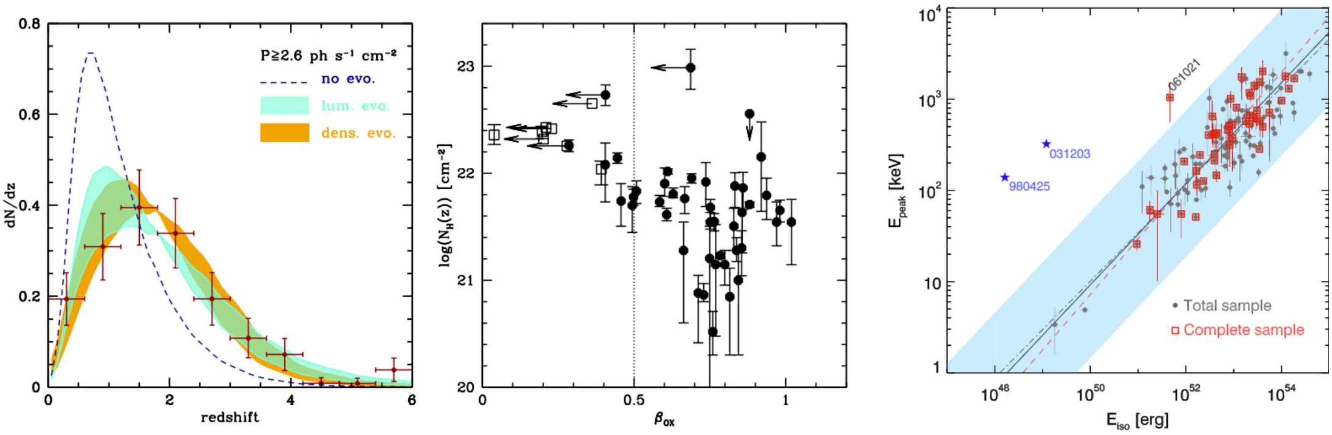

Figure 2: First results obtained from the study of the complete sample of bright *Swift* long GRBs selected by our team. *Left.* The normalized redshift distribution shows that a strong evolution in density or in luminosity is required to account for the observations (Salvaterra et al. 2012). *Center.* Distribution of the spectral index β_{OX} (computed by Melandri et al. 2012) as a function of the intrinsic X-ray absorbing column density (N_H). Dark bursts ($\beta_{OX} < 0.5$ according to Jakobsson et al. 2004 definition) are all heavily intrinsically absorbed ($N_H \geq 10^{22}$ cm^{-2}; from Campana et al. 2012). *Right.* The $E_{peak} - E_{iso}$ correlation (Amati et al. 2002) found for the burst of the complete sample are consistent with those found for the whole sample of GRBs with measured z and E_{peak}. This means that the total sample commonly used to study this correlation is not strongly biased (Nava et al. 2012).

References

Abbott et al. 2017, ApJL, 848 13 - Antonelli et al. 2009, A&A, 507, 45 - Campana et al. 2012, MNRAS, 449, 61 - Covino et al. 2006, A&AL 447, 5 - Cucchiara et al. 2011, ApJ, 736, 7 - Cusumano et al. 2006, A&A, 462, 73 - D'Avanzo et al. 2009, A&A 498, 711 - Della Valle et al. 2006, Nature, 444, 1050 - Dunkley et al. 2009, ApJS, 180, 306 - Eichler et al. 1989, Nature, 340, 129 - Ferrero et al. 2006, A&A, 457, 857 - Fong et al. 2013, ApJ, 769, 56 - Fynbo et al. 2006, Nature, 444, 1047 - Greiner at al. 2009, ApJ, 693, 1610 - Hjorth et al. 2005, Nature, 437, 859 - Kann et al. 2008, arXiv:0804.1959 - Komatsu et al. 2011, ApJS, 192, 18 - Kouveliotou et al. 1993, ApJL 413, 101 - Lazzati & Perna, 2010, arXiv:1001.0538 - Lee & Ramirez-Ruiz 2007, New J Phys, 9, 17 - Melandri et al. 2012, MNRAS, 421, 1265 - Narayan et al.1992, ApJ, 395, 83 - Nava et al., 2012, MNRAS, 421, 1256 - Nysewander et al. 2009, ApJ, 701, 824 - Pian et al 2017, Nature, 551, 67 - Racusin et al. 2008, Nature, 455, 183 - Salvaterra et al. 2008, MNRAS, 380, L45 - Salvaterra et al. 2009, Nature, 461, 1258 - Salvaterra et al. 2012, ApJ, 749, 68 - Savchenko et al. 2017, ApJL, 848, 15 Tagliaferri et al. 2005, A&A, 443, 1 - Tanvir et al. 2009, Nature, 461, 1254 - Woosley & Bloom 2006, ARA&A, 44, 507

11. List of targets (note that the absence of a proper object list and information may weaken the proposal)

Name	α	δ	Epoch	Mag.	Time	Additional Information
GRB	00 00 00	00 00 00	J2000	$10\div24$	ToO	

12. Observational strategy and justification of requested time, including overheads.

Based on the vast experience of observations of Swift GRBs with the TNG, we expect that $\sim$ 5-6 GRBs in one semesters, accurately localised by space-based experiments and suitably observable from TNG, will meet our selection criteria. We plan to observe these targets with the reported strategy:

2 short events: 2 hours with DOLoRes and 1 hour with NICS, to identify the counterpart, secure spectroscopy in the (unlikely) case of a bright event, monitor the early time afterglow temporal and spectral evolution, pinpoint the host galaxy. The total requested time is thus 4 hours with DOLoRes and 2 hours with NICS.

1 high redshift ($z > 5$) event for spectroscopic studies, 3 hours with DOLoRes and 2 hours with NICS, to localise and spectroscopically identify the counterpart in case of high ($z > 5$) or very high ($z > 7$) GRB, respectively. The NIR spectroscopy will be preferentially carried out with the AMICI prism.

1 SN associated with a GRB, 4 hours with DOLoRes and a total of 1 hours with NICS, to perform a two-band (RI or RH) photometric monitoring starting a few days after the event and then periodically till about 2 months after the GRB, to cover the whole evolution of the possible associated SN (~ 10 observations within the 2 month period). In case the SN is bright enough ($R \leq 21$) we also ask for spectroscopic monitoring.

2 bright long *Swift* GRBs, 45 minutes with DOLoRes to secure the redshift. The total requested time is thus 1.5 hours with DOLoRes.

The requested time for each observational step described has been computed by using the available Exposure Time Calculator, both for optical and NIR imaging and spectroscopy, by requesting: a good S/N (larger than 10), the expected magnitudes, 1" seeing and an airmass less than 1.5, and including all overheads (i.e. filter and/or instrument changes, detector read-out, telescope offsets, etc.)

The resulting total request time is thus: **12.5 hours with DOLoRes and 5 hours with NICS**.

Given the unpredictability of GRBs, we do not distinguish among bright, grey or dark time. The reported estimates are to be intended as representative on an average case. We will avoid activation of our observations in case of unfavourable events (high airmass, high extinction, etc).

Details on ToO Request

Triggers: 6 ToO time 18 Service time

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
1	DOLoRes	1x1	U,B,V,R,I,z	none	none	32hr	
2	DOLoRes	1x1	none		grism #1 or #2 or #3	16hr	
3	NICS	1x1	J,H,K'	none	none	20hr	
4	NICS	1x1	none	none	AMICI	7hr	

14a. Moonlight constraints

Max. # of days from new moon ☐

14b. Scheduling constraints, special requirements and other remarks
(please include justification of constraints in 14a)

For very bright events ($R < 19$), the measure of polarimetry would be very scientifically rewarding. If the DOLORES polarimeter PAOLO will be available we ask the possibility to use it during this programme. Given the unpredictability of GRB observational characteristics, following a well established procedure developed in recent years, there is the possibility that we will need to move observing hours from DOLORES to NICS (and reverse) without of course exceeding the total amount of hours awarded to this proposal.

15. Observational background of the applicants

Name of the observer(s) at TNG:

Experience of the observer(s) with the requested TNG instrument(s)

Experience of the observer(s) with other telescopes/instruments

INAF-TAC LaTeX style file vAOT39 October 2019.