INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: D**

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

1. Title

Observing supernovae from the Zwicky Transient Facility with the TNG

2. Abstract

We (Department of Astronomy in Stockholm) propose a TNG program to observe supernovae (SNe) discovered by the Zwicky Transient Facility (ZTF) survey. We have successfully carried out a TNG+DOLORES follow-up program to observe SNe from the intermediate Palomar Transient Factory (iPTF) during AOT32, 33, 35, 36, 37 and from ZTF (within the current AOT38), and we want to continue this effort for the SNe that are going to be discovered by ZTF. The proposed follow-up program will complement our hard-trigger program for SNe at the NOT. The main goal is to study core-collapse SNe until late epochs to constrain the nature of their progenitor stars. This goal will be reached with different techniques. For example, in the case of stripped-envelope (SE) SNe we will build and model bolometric light curves and photospheric velocities until late epochs, and derive the initial mass of the progenitors from the nebular spectra with sophisticated models developed in Stockholm. For interacting SNe IIn we can model the spectral emission lines to infer the mass-loss history of the progenitors and their initial masses. TNG data will also be shared with the ZTF collaboration to allow for the follow-up and study of a large number of interesting SNe.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
25						

3b. Observing modes

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

4a. Preferred months

first choice: second choice:

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

We require 25 hours distributed throughout the entire semester.

5a. Past and future of the project

a) Hours already awarded to the project: 170

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

6. Principal investigator (Nordic Time)

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7. Co-investigators (name and institution)

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L. Tartaglia, Stockholm University, Astronomy
A. Sagues Carracedo, Stockholm University, Physics

8. Status of the project

Telescope	Instrument	Date	Hours	Notes
TNG	DOLORES	AOT32	30	Oct. 2015-Mar. 2016
TNG	DOLORES	AOT33	30	Apr. 2016-Sep. 2016
TNG	DOLORES	AOT35	30	Apr. 2017-Oct. 2017
TNG	DOLORES	AOT36	30	Oct. 2017-Mar. 2018
TNG	DOLORES	AOT37	25	Apr. 2018-Sep. 2018
TNG	DOLORES	AOT38	25	Oct. 2018-Mar. 2019, ongoing

Description

We have followed-up SNe from the iPTF during period AOT32, 33, 35 and beginning of AOT36 and SNe from ZTF from the end of period AOT36 to AO38. In the following we report each object, along with the publication (already accepted or submitted, see publication list) their data are included in. We have observed 20 stripped-envelope SNe: iPTF15cna (F18), iPTF15cpq (F18), iPTF15dtg (T16,F18,T18b), iPTF15dqi (F18), iPTF15dqb (F18), iPTF11mnb (T18a) iPTF16asu (W17), iPTF16he (F18), iPTF15dqg (F18), iPTF15dvg (F18), SN2017dcc, iPTF16hgp (F18), iPTF16flq (F18), ZTF18aalrxas, ZTF18aabcwtr, ZTF18aahmxqa, ZTF18aagrdcs, ZTF18aaqjovh, ZTF18aarpqof, ZTF18abivonr. We have also observed 12 strongly-interacting SNe: iPTF13z, SN 2005ip, SN 2006jd, SN 2010jl, iPTF15eoz, iPTF16bkn, iPTF15aym, iPTF17bkj (Ad18), iPTF16tu, iPTF16fir, SN2017dio, ZTF18aakuewf. Furthermore, we observed 10 SNe II, showing either early signs of CSM interaction or exhibiting peculiar properties: iPTF14hls (Ar17,S18), iPTF16bn, iPTF16by, iPTF15dum, iPTF16br, iPTF15dof, iPTF16gqr, ZTF18aaayemw, ZTF18aainvic, ZTF18abimhfu. As outlined below, 9 papers are already published (3 accepted) and include the data of 14 of the observed SNe. At least 8 more papers are already in preparation with the obtained data.

Publications

A list of papers that makes use of the data described above is provided below:
1) iPTF15dtg: a double-peaked Type Ic Supernova from a massive progenitor, Taddia, Fremling, Sollerman, et al. 2016, A&A, 592, A89. (T16) 2) PTF11mnb: First analog of supernova 2005bf. Long-rising, double-peaked supernova Ic from a massive progenitor, Taddia, Sollerman, Fremling et al. 2018, A&A, 609, A106 (T18a) 3)The luminous late-time emission of the type Ic supernova iPTF15dtg - evidence for powering from a magnetar?, Taddia et al. 2018, in press (T18b) 4)Late-time observations of the extraordinary Type II supernova iPTF14hls, Sollerman et al. 2018, in press (S18) 5)Analysis of broad-lined Type Ic supernovae from the (intermediate) Palomar Transient Factory, Taddia et al. 2018, in press. 6) Energetic eruptions leading to a peculiar hydrogen-rich explosion of a massive star, Arcavi et al. 2017, Nature, 551, 210, (Ar17) 7) iPTF16asu: A Luminous, Rapidly-Evolving, and High-Velocity Supernova, Whitesides et al. 2017, ApJ, 851, 107. (W17) 8) iPTF Survey for Cool Transients, Adams et al. 2018, PASP, 130, 034202 (Ad18) 9) Oxygen and helium in stripped-envelope supernovae, Fremling et al. 2018, A&A, 618, 37. (F18) 10)The Zwicky Transient Facility: Science Objectives, Graham et al, to be published in PASP 11) Normal supernovae Ic from (i)iPTF, Barbarino et al. 2018 in prep.

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.

Several PhD students will be involved in the analysis of these data.
Ana Sagues Carracedo recently joined the physic department and will be actively involved in ZTF. She has already observing experience as she took part in the NOT student project. A new PhD student will start working in our group in 2019, working full time on ZTF.

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.

This proposal is complementary to the ToO program we have been running for many years at the Nordic Optical Telescope (P.I.s J. Sollerman, A. Goobar, F. Taddia in 2018), where we will classify and follow ZTF SNe at early times. With the TNG we will be able to cover also later epochs.

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

A) Scientific rationale We ask for a service program at the TNG, with the goal of observing core-collapse (CC) SNe discovered by the Zwicky Transient Facility (ZTF). We (Department of Astronomy in Stockholm) are members of the intermediate Palomar Transient Factory (iPTF) survey since 2013 and of its continuation ZTF (which is fully operational since April 2018). ZTF is going to discover ∼10 times the number of SNe found by iPTF and it is aimed at finding SNe just after explosion, thanks to its high cadence. Like iPTF, ZTF is making use of the Palomar P48 telescope to discover new SNe, and of many other telescopes [including P60, P200, Keck, Gemini and Nordic Optical Telescope (NOT)] to provide spectrophotometric coverage. We want the TNG to continue to be an essential part of this large survey. The early time, rapid-response observations at the NOT have been the main observational contribution that we have brought to the iPTF, and we will continue with ZTF. Just in the last year NOT spectra of iPTF13dqy (Yaron+17), iPTF16geu (Goobar+17), and iPTF14hls (Arcavi+17) were published in Nature and Science. NOT is well suited for rapid-response-observations of bright SNe, but a larger telescope such as the TNG is needed to follow-up the most interesting targets until later epochs. The number and variety of interesting SNe that we discovered and classified with iPTF is unprecedented and it is going to be ∼10 times higher with ZTF. Despite the availability of multiple facilities, without the TNG time that we were awarded for period AOT32, 33, 35, 36, 37 and 38 we would have faced a lack of spectroscopic time to follow up interesting SNe, especially when these transients were faint. For example late-time TNG data are important part of our publications on iPTF15dtg (Taddia+16,+18c), PTF11mnb (Taddia+18a), iPTF14hls (Arcavi +17,Sollerman+18), iPTF16asu (Whitesides+17), and iPTF17bkj (Adams+18). Therefore, we hereby ask for a TNG observing program to be able to follow-up ZTF SNe until late epochs. Our team, which includes a number of experienced observers and also has a strong modelling expertise, is mainly focused on studying:

1) Stripped-envelope (SE) supernovae: For SE SNe we still know little about their progenitors, which could be either massive Wolf-Rayet stars or less massive stars in binary systems. For example the SN Ib iPTF13bvn, which we studied in Fremling+14,16, was initially thought to arise from a massive Wolf-Rayet star (Cao+14), although our analysis on late epochs data suggested a less massive progenitor star. This illustrates the importance of late-time follow-up observations to establish the nature of SE SN progenitors. With our TNG observations we have already significantly contributed to monitoring these SNe until late epochs. For example, with TNG we have spectroscopically followed iPTF15dtg (Taddia+16,18c, Fig. 2a), a long-rising SN Ic whose derived ejecta mass is compatible with a massive, single-star progenitor, in contrast with the binary scenario currently favored for SE SNe. Furthermore, the very-late epochs of iPTF15dtg, which we monitored with TNG, were very surprising and revealed the presence of a magnetar powering the late-time light curve (Taddia+18c). In another work, Whitesides+17 (Fig. 2b) makes use of our TNG obsevations and we found another magnetar as the possible responsible for the emission of iPTF16asu, a peculiar SN Ic-BL, with a uniquely short rise time. In Fremling+18 (Fig. 2d) we used a large sample of SE SN spectra, including 8 SNe observed with TNG, to study the spectral properties of the different subtypes (Ib, Ic, IIb). In Taddia+18d (Fig. 1d) we analyse a sample of SNe Ic-BL, including 3 TNG spectra, to charachterize the proprierties of the SNe of this class. Late-time TNG data of SE SNe from ZTF will allow us to further investigate the connection between these transients and their progenitors, through several techniques such as: a) The modelling of nebular spectra (e.g., Jerkstrand+15, Fig. 1c), which can provide a measurement of the progenitor zero-age-main-sequence mass via the oxygen emission lines. b) The modelling of the light curves and velocity profiles obtained from photometric and spectroscopic observations which provide ejecta masses, explosion energies and ^{56}Ni mass or magnetar energy (e.g., Taddia+15a,16,18a,18b,18c).

2) Type IIn supernovae: SNe IIn interact with their circumstellar environment (CSM). We want to use our theoretical machinery to model the shock interactions (e.g., Fransson+14, Fig. 1a) and probe the mass-loss history of the progenitor star (e.g., Taddia+13, Fig. 1b), which could include various types of star such as Luminous Blue Variables and Red Supergiants. This is also suggested by the study of the SN IIn environments (Taddia+15b). TNG spectra will help us to monitor the properties of the spectral emission lines, such as flux and velocities, which are connected to the mass-loss history of the progenitor star. Late-time spectra are also important to look for signs of nucleosynthesis such as the presence of broad oxygen emission lines (useful to estimate the SN progenitor initial mass). TNG spectra would also allow to measure the metallicity and the star formation rate at SNe IIn's locations, further constraining the characteristics of their progenitors.

The TNG observations would be of extreme importance not only for our group, but also for a larger community of SN astronomers with whom we collaborate in the frame of the ZTF survey. We are currently working with groups at Caltech and Weizmann which are also interested in CC SNe. Stockholm will decide on the observations at TNG but will share the data with other groups. An example of this collaboration is our recent Nature paper on the unique SN iPTF14hls (Arcavi+17), where TNG was used to follow the evolution of this mysterius transient, possibly powered by a black hole. The TNG was important also for a further spectroscopic follow-up of this transient (Sollerman+18, Fig. 2c) which revealed an important unexpected role of the CSM.

B) Scientific aim We propose a service program to follow-up the most interesting SNe discovered by ZTF until late epochs with DOLORES, with particular focus on SE and CSM-interacting SNe. Together with the data obtained by other facilities available for the ZTF collaboration, TNG data will be crucial to study these SNe and infer the nature of their progenitor stars.

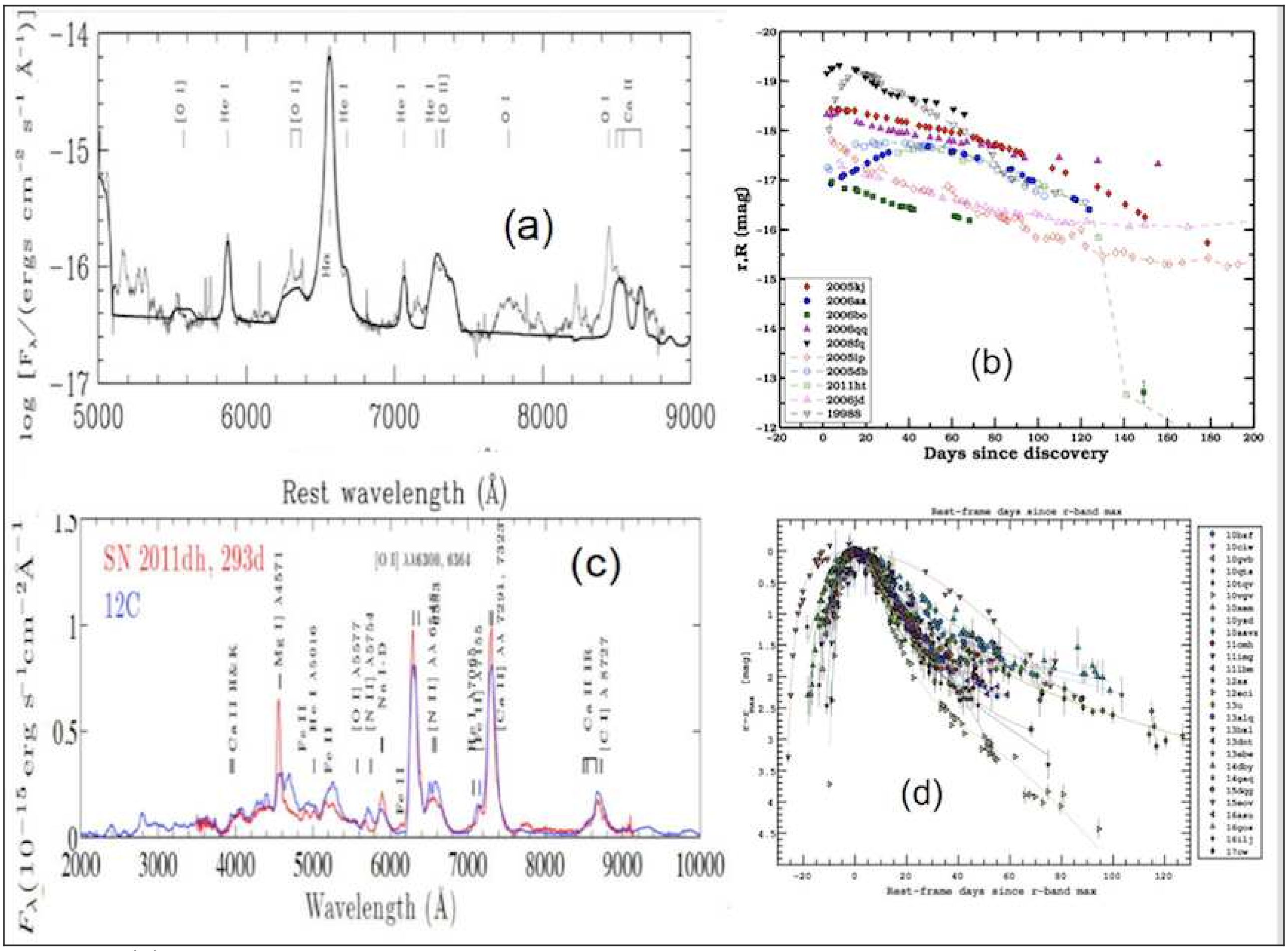

Figure 1: (a) Modelling of a late-time spectrum of the SN IIn 1995N, from Fransson et al. 2002. We aim to take spectra of SNe IIn and other interacting SNe discovered by ZTF, to derive their CSM and progenitor properties. (b) The variety of SN IIn light curves that we presented in Taddia et al. (2013). With TNG we will be able to follow newly discovered ZTF SNe IIn until late epochs. (c) Late time spectral modelling of SNe IIb 2011dh, from Jerkstrand et al. (2015). (d) SNe Ic-BL light curves from Taddia et al. (2018d). We followed these SNe until late epochs, deriving explosion parameters to charactherize the proprierties of this class of SNe.

References:

Adams et al. 2018, PASP, 130, 034202
Arcavi et al. 2017, Nature, 551, 210
Fransson et al. 2014, ApJ, 797, 118
Fransson et al. 2002, ApJ, 572, 350
Fremling et al. 2018, A&A, 618, 37
Fremling et al. 2016, A&A, 593, A68
Fremling et al. 2014, A&A, 565, A11
Goobar et al. 2017, Science, 356, 291
Jerkstrand et al., 2015, A&A, 573, A12
Sollerman et al. 2018, arXiv:1806.10001
Taddia et al. 2018a, A&A, 609, A106
Taddia et al. 2018b, A&A, 609, A136
Taddia et al. 2018c, arXiv:1806.10000
Taddia et al, 2018d, A&A, in press
Taddia et al. 2016, A&A, 592, A89
Taddia et al. 2015a, A&A, 574, A60
Taddia et al. 2015b, A&A, 580, A131
Taddia et al. 2013, A&A, 555, A10
Yaron et al. 2017, Nature Physics, 13, 510
Whitesides et al. 2017, ApJ, 851, 107

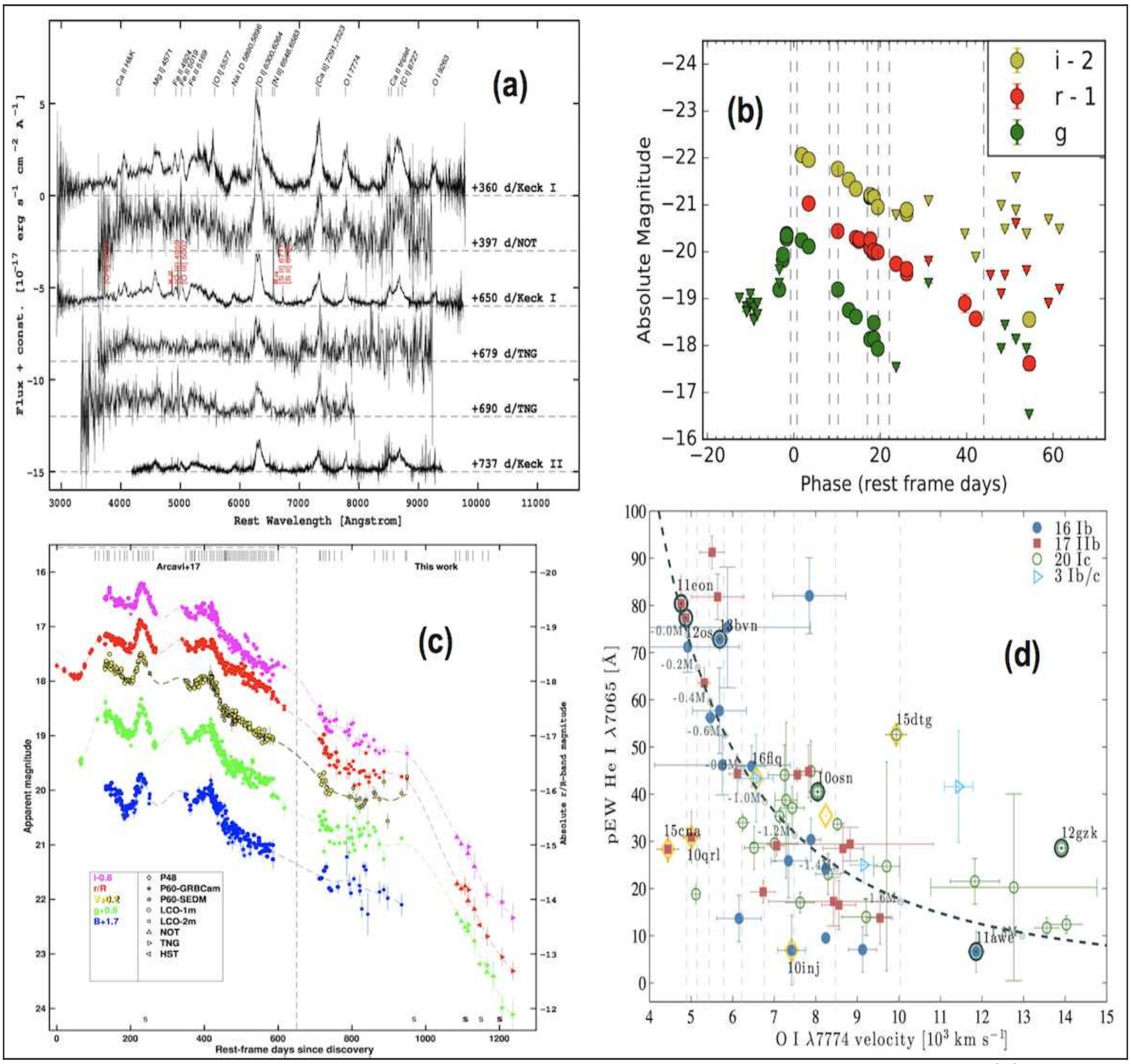

Figure 2: Figures from four of the nine publications including TNG data from our programs: (a) our spectral sequence of iPTF15dtg (Taddia+18c), which includes TNG+DOLORES spectra. This SN revealed a very broad light curve, indicating a massive ejecta. Its late epochs revealed the likely presence of a magnetar. (b) Light curves and spectral epochs (dashed lines) for iPTF16asu (Whitesides+17). We obtained TNG late time photometry and a spectrum for this SN, which reveal s a very fast rise, unprecedented among SNe Ic-BL. We inferred the presence of a magnetar powering the early peak. (c) The extraordinary long lived emission of iPTF14hls, which we observed with TNG in spectroscopy (Sollerman+18). Spectroscopically iPTF14hls resembled a normal SN II, but its luminosity remained very high for two years, about 6 times longer than for a normal SN II. (d) A correlation between the equivalent width of He lines and the velocity of the oxygen lines in SE SNe from iPTF. For this study (Fremling+18) we used the TNG spectra of eight SE SNe.

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
ZTF19xyz						Supernovae to be discovered by ZTF in 2019
SN2019xy						Other SNe to be discovered in 2019

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

Low-resolution spectra and imaging with DOLORES

The targets will mainly be discovered by the P48 telescope on Palomar, and the coordination will be led from Stockholm University. The follow-up observations will be conducted on particularly interesting supernovae. This program includes photometric light curve monitoring of SNe up to $\sim$300-400 days after explosion, as well as spectroscopic monitoring with DOLORES. We would like to monitor in some detail about 10 different SNe during the forthcoming semester, to complement our ZTF studies. During the semester ZTF will certainly provide at least 10 interesting SNe among CC SNe (in particular SNe IIn and SE SNe), as its discovery rate will be about 10 times higher than the one of iPTF, which already provided several interesting candidates per semester. We foresee typically 2-3 monitoring epochs per supernova (the interval depends very much on the supernova Type, SNe Ibc evolve fast (weeks), while SNe IIn can display timescales of months). We need typically < 1 hour per SN. This adds up to $\sim$1 hour $\times$ 2-3 triggers $\times$ 10 objects $\simeq$ 25 hours.

We stress that it would be optimal to distribute the required 25 hours across $\sim$10 different nights, to observe with regular cadence during the semester (2.5 hours every $\sim$18 days). This is how our time was distributed during the periods AOT32, AOT33, AOT35, AOT36, AOT37, AOT38.

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
1	Dolores	1x1		1.0"	LR-B		
2	Dolores	1x1		1.0"	LR-R		
3	Dolores	1x1		1.5"	LR-B		with poor seeing
4	Dolores	1x1		1.5"	LR-R		with poor seeing
5	Dolores	1x1	U,B,V,R,I,u,g,r,i,z				mainly for faint objects

14a. Moonlight constraints

Max. # of days from new moon $\boxed{10}$

14b. Scheduling constraints, special requirements and other remarks

(please include justification of constraints in 14a)

We do not require strong constraints on the seeing and on the moon phase as we will be always able to observe bright SNe. We would like to distribute the required 25 hours across 10 different nights to allow for a regular cadence (2.5 hours every ~18 days) in case of fast evolving SNe.

15. Observational background of the applicants

Name of the observer(s) at TNG: We ask for service mode.

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

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

The P.I. observed in visitor mode with NTT+EFOSC2/SOFI. The P.I has been already involved in AOT37 taking care of data reduction and in AOT38 including also the telescope triggers. Several co-P.I.s are experienced users of the NOT and of the ESO telescopes in Chile.