INSTITUTO DE ASTROFÍSICA DE CANARIAS

38200 La Laguna, Tenerife, (Islas Canarias)
Teléfono: 922 605 200 - Fax: 922 605 210

REQUEST FOR OBSERVATIONAL TIME (NIGHTTIME TAC)

CAT Español

Observatorio del Roque de Los Muchachos and Observatorio del Teide

1. Title

Late-time observations of supernovae and rare transients

2. Personal data

2.1. PI

Auni Somero	Instituto de Física de Altas Energías - Universidad

2.2. Co-I

Nancy Elias de la Rosa	Osservatorio di Padova
Seppo Mattila	University of Turku
Maximilian Stritzinger	Aarhus University
Peter Lundqvist	University of Stockholm
Hanindyo Kuncarayakti	University of Turku
Tuomas Kangas	Space Telescope Science Institute Baltimore
Morgan Fraser	University College Dublin
Erkki Kankare	Queen's University of Belfast
Rubina Kotak	University of Turku

2.3. Contact person

Name:	Auni Somero	**Address:**	SPAIN
Center:	Instituto de Física de Altas Energías -		
Phone:	+34922425743		
Fax:		**E-mail:**	asomero@ifae.es

3. Abstract

Wide-field imaging surveys now provide a large database of extragalactic transients including ordinary supernovae (SNe) and much more rare types of transients such as superluminous SNe and tidal disruption events (TDE). We are running a large programme at the Nordic Optical Telescope (NOT) to obtain optical and near-infrared spectroscopy of objects brighter than ~19 mag in their early phases. However, there is exciting and unique science that can be achieved by combining these data with GTC spectra taken at later phases once the objects have faded in luminosity and are no longer reachable by the NOT. This has already shown to be a succesful strategy in the previous semesters. Therefore, we propose to obtain GTC+OSIRIS spectroscopy of approximately 10 transients which requires a total of 20 h in this semester.

4. Is it collaboration with GTC time? No

5. Field of Research

Estrellas Masivas, Binarias Interactivas y Medio

6. Is it continuation of a programme with awarded time? No

7. Is this programme for a PhD thesis? No

8. Will more time be needed in the future? Yes

9. Large programme proposal? No

10. Observation time requested

Telescope	Instrument	Sem.	Nights/Sho	Hours	Moon	Optimal Dates	Impossible Dates
GTC	Osiris			20.000 00000	G	20180301-20180831	
Instr. Cfg.:			**2ndary I.:**			**Visit. ins.:**	
Configuration:	LongSlitSpectroscopy	BroadBandImage					
Obs. mode: Colas		**Seeing:**	0	**Clouds:**	Cualq.	**Water Vapour:**	

10.1. Justification of impossible dates

No impossible dates.

11. Comments

- The co-Investigator list contains only a small subset of the members of the NOT Unbiased Transients Survey (NUTS) collaboration (http://csp2.lco.cl/not/).
- We would like to continue the programme for the full duration of the NOT Large Programme (i.e. a total of 3 years: Apr. 2016 - Mar 2019) and apply here GTC time for the semester 18A.
- This proposal is continuation to the following programmes with awarded time: 45-GTC32/17B, 45-GTC20/17A, 59-GTC40/16B, 68-GTC60/16A
- Several Ph.D. theses will utilize the data obtained in this proposal.
- The instrumental configurations needed for this proposal are: R300B, R500B/R, R1000B/R, R25000R, griz

12. Previous awarded times as IP/CoI in the last 3 years

12.1. Spanish CAT

69-LT9/17A V Sagittae - an arrow gone astray. Supersoft X-ray source or an exotic hot binary?

Comment: Full data set now reduced. Analysis in progress.

Publications:

12.2. IAC/Florida Agreement

12.3. IAC/México Agreement

12.4. CAT México

12.5. IAC Nordic

12.6. EMIR Special Time

12.7. CIRCE Special Polarimetry

13. Date of submission

Tuesday, 3 October 2017

S. Scientific Justification

S.1. Scientific Rationale and Immediate Objectives [Max. 1 page].

The observations of supernovae (SNe) and other stellar transients is a unique tool to probe stellar evolution theories. In particular, monitoring these objects along their entire evolution provides us with different pieces of the puzzle. While the early follow-up can be carried out with small to mid-size telescopes, late-time (nebular) SN spectra, taken $\sim 6-12$ months after the explosion, requires bigger aperture. In the nebular phase the SN ejecta becomes optically thin and this enables us to peer into the inner SN ejecta and the core of the progenitor star, constraining the properties of the progenitor star prior to the explosion and the explosion mechanisms. The intensity of individual spectral lines, their widths and profiles provide crucial information. For example, the width of an emission line gives an estimate of the velocity distribution of the emitting species, and the detailed shape encodes asymmetries in the spatial distribution of the ejected gas [e.g. 1, 2]. Therefore, nebular spectra are invaluable to complete the picture of stellar explosions [e.g. 3], and this is more crucial when we investigate novel types of SN explosions [e.g. 4].

Selected science goals. In the last few years, the new generation of all-sky transient searches (incl. the All-Sky Automated Survey for Supernovae and the ESA Gaia Survey) led to the discovery of new classes of transients that are challenging the existing stellar evolution models. These events are manifesting an unexpected diversity that may depend on stellar mass, metallicity, binarity, and mass loss history. We are interested in studying traditional SNe as well as more rare, or recently discovered, types of transients. We obtain optical and near-infrared spectroscopy and photometry of bright targets during their early phases with the 2.5m Nordic Optical Telescope (NOT) within the NUTS (NOT Unbiased Transient Survey) Large Program. However, with the NOT only spectra of targets brighter than ~ 19 mag are observable with sufficiently high S/N. *While the NOT can provide data during the early phases, the GTC+OSIRIS spectroscopy can characterize the late phases enabling us in providing unprecedented scientific results.* We will mostly concentrate on the following types of targets:

1. Normal core-collapse SNe. Spectral modelling in the nebular phase will be used to probe nucleosynthetic yields in the progenitor core, which will place tight constraints on the progenitor initial mass. The strength of the nebular emission lines (in particular [O I] 6300,6364A) will be used as a diagnostic of the progenitor properties [5] in combination with the information obtained by other means incl. pre-explosion detections [e.g. 6]. *GTC late spectra will allow direct estimates of progenitor initial masses through in intensity of nebular emission lines.*
2. Nuclear transients. Until very recently the transients occurring within the nuclei of galaxies have been largely overlooked mainly due to difficulties in their detection. This includes tidal disruption events (TDEs; e.g. [7]; [8]), nuclear supernovae (SNe; e.g., [9]) and exotic, extremely energetic transients whose nature is hotly debated [6; 11; 12]. In [6] we show that extensive spectroscopic monitoring with a medium spectral resolution is often crucial in order to distinguish between these alternatives (e.g. see Fig. 1 right). *GTC late-time spectra in combination with observations from the NOT will allow us to charactesize this still largely overlooked population of luminous transients with potential implications to both understanding of the nuclear SN population and astrophysics of TDE.* .
3. Super-luminous SNe (SLSNe). Their absolute magnitude exceeds −21, and may occasionally reach −22 mag, which is orders of magnitude brighter than normal SNe. They have a slow photometric evolution, and are preferentially hosted in very faint, likely metal-poor, dwarf galaxies [13]. Most of them are H-poor [14], though some others show evidence of H spectral lines originated in the circumstellar medium (CSM) [15]. In addition, due to their intrinsic luminosity, some SLSNe have been proposed as standardizable candle candidates to redshifts z ≈ 3-4 [16]. *The late GTC spectra of these transients will allow us to distinguish among the different populations of SLSNe, and will provide insightful information on the different explosions scenarios proposed for their massive progenitors (core-collapse, magnetar, pulsational pair-instability plus shell-shell collisions, and thermonuclear stellar disruption via pair production). Fig.1 shows late-time GTC spectra of an SLSN Gaia16apd.*.

Our science goals require a large telescope to link well observed nearby SNe with their progenitor stars and understand the nature of rare types of stellar explosions and transients occurring within the nuclear regions of galaxies. To spectroscopically monitor the late phases of the transients described above, we need a 8-10m class telescope. *Our program suits the capabilities and the efficiency of GTC.* Our team has already very successfully managed monitoring programs based on NUTS targets, with late-time data obtained from GTC.
Several papers including GTC spectra have already been published by members of our team, e.g. [17], on the SLSN Gaia 16apd (see Fig. 1).

References

1. *Nebular emission-line profiles of Type Ib/c supernovae - probing the ejecta asphericity,* Taubenberger et al., 2009, MNRAS, 397, 677.
2. *Nebular phase observations of the Type-Ib supernova iPTF13bvn favour a binary progenitor,* Kuncarayakti et al., 2015, A&A, 579, 9.
3. *3D deflagration simulations leaving bound remnants: a model for 2002cx-like Type Ia supernovae,* Kromer et al., 2013, MNRAS, 429, 2287.
4. *Luminous Supernovae,* Gal-Yam, 2012, Science, 337, 927.
5. *The progenitor mass of the Type IIP supernova SN 2004et from late-time spectral modeling,* Jerkstrand et al., 2012, A&A, 546, 2.8
6. *The disappearance of the progenitor of SN 2012aw in late-time imaging,* Fraser M., 2016, MNRAS, 456, 16.
7. *ASASSN-15lh: A highly super-luminous supernova,* Dong el al., 2016, Science, 351, 257.
8. *The superluminous transient ASASSN-15lh as a tidal disruption event from a Kerr black hole,* Leloudas et al., 2016, Nature Astronomy, 1, 2.
9. *First results from GeMS/GSAOI for project SUNBIRD: Supernovae UNmasked By Infra-Red Detection,* Kool et al., 2017, MNRAS, accepted, arXiv:1709.08307.
10. *A population of highly energetic transient events in the centres of active galaxies,* Kankare et al., 2017, Nature Astronomy, accepted,
11. *PS16dtm: A Tidal Disruption Event in a Narrow-line Seyfert 1 Galaxy,* Blanchard et al., 2017, ApJ, 843, 106.
12. *Superluminous Transients at AGN Centers from Interaction between Black Hole Disk Winds and Broad-line Region Clouds,* Moriya et al., 2017, ApJ, 843, 19.
13. *Hydrogen-poor superluminous stellar explosions,* Quimby et al., 2011, Nature, 474, 487.
14. *Ultra-bright Optical Transients are Linked with Type Ic Supernovae,* Pastorello et al., 2010, ApJ, 724, 16.
15. *The supernova CSS121015:004244+132827: a clue for understanding superluminous supernovae,* Benetti et al., 2014, MNRAS, 441, 289.
16. *Superluminous Supernovae as Standardizable Candles and High-redshift Distance Probes,* Inserra & Smartt, 2014, ApJ, 796, 87.
17. *Gaia16apd - a link between fast-and slowly-declining type I superluminous supernovae,* Kangas et al., 2017, MNRAS, 469, 1246.

Graphics

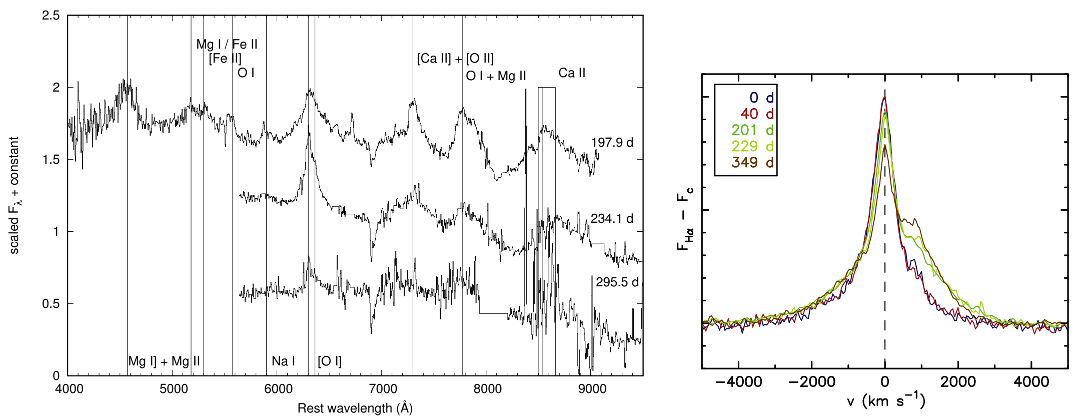

Figure 1: *Left:* Late-time spectra of the type I superluminous supernova (SLSN) Gaia16apd/SN2016eay, obtained using GTC/OSIRIS. Probable line identifications are included. The spectra closely resemble those of slowly-evolving type I SLSNe despite a fast early photometric evolution, indicating that the fast and slow subtypes of type I SLSNe are not discrete populations but occupy a continuum of photometric and spectroscopic properties. The narrow [Ca II]/[O II] peak at 7300 suggests an origin in the inner, slowly moving, hot and strongly ionized ejecta, consistently with a magnetar spin-down power source. This peak shifts to [O I] after 200 days as temperature decreases [paper 6 in Section R, another paper in preparation]. *Right*: Evolution of the Hα line profile of the energetic nuclear transient PS1-10adi showing a red shoulder which we attribute to asymmetry [6].

R. Provide up to 6 references from the research team related to this proposal.

1. *PTF12os and iPTF13bvn. Two stripped-envelope supernovae from low-mass progenitors in NGC 5806,* Fremling et al., 2016, A&A, 593, 68.
2. *The multifaceted Type II-L supernova 2014G from pre-maximum to nebular phase,* Terreran et al., 2016, MNRAS, 462, 137.
3. *Dead or Alive? Long-term evolution of SN 2015bh (SNhunt275),* Elias-Rosa et al., 2016, MNRAS, 463, 3894.
4. *Common Envelope ejection for a Luminous Red Nova in M101,* Blagorodnova et al., 2017, ApJ, 834, 107.
5. *Gaia16apd - a link between fast-and slowly-declining type I superluminous supernovae,* Kangas et al., 2017, MNRAS, 469, 1246.
6. *A population of highly energetic transient events in the centres of active galaxies,* Kankare et al., 2017, Nature Astronomy, accepted,

T. Description of the observing plan, data reduction and analysis. Backup program.

T.1. Jusfitify the amount of requested time (number of targets to be observed and exposure time per target), prioritized target list, including coordinates, magnitude and other properties defining the observing program. In the case of use of own equipments, please follow the instructions of the Observatory and provide additional detail in attached sheets if necessary.

Name	R.A. (hh mm ss)	Dec. (° ′ ″)	magnitude	exposure time
SN2018XX	00 00 00.00	00 00 00	R=21.5	∼1 h

The goal of this programme is the study of normal SN explosions, unusual stellar transients produced by explosions of very massive stars and energetic nuclear transients. The targets will be supplied mainly by the discoveries of the ASAS-SN and Gaia surveys, but also amateur astronomers that constantly patrol the nearest galaxies in the of Northern hemisphere.
To obtain a good coverage of the multi-band photometric and spectroscopic evolution of the selected objects, the targets will be observed by the Large Programme at the NOT (NUTS; PI: S. Mattila, M. Stritzinger, P. Lundqvist, N. Elias-Rosa, A. Pastorello; http://csp2.lco.cl/not/). **Here we propose to use GTC+OSIRIS to complement our data sets by one or more observations during the nebular phase for each target selected by the large programme**. On average, we intend to observe 10–15 SNe per semester, above $-30°$ in declination, and at $\leq$50 Mpc (up to about 150 Mpc for intrinsically luminous events). The magnitudes of our targets during the nebular phase will span from about 20 to 23 mag. We would need more than one observation per target only in particular cases of evident variability of the transient. The list of targets will be updated due time.
We intend to obtain spectra with S/N ~ 20 of at least 10–15 transients in the wavelength range from 4000 to 9000 Å, where most prominent nebular emission lines are located. In general, low-intermediate resolution spectra is sufficient for our scientific purposes. The spectroscopic setup for each trigger will depend on the scientific case. For example, we will use R1000B/R grisms for SNe where higher spectral resolution is needed in order to resolve narrow lines. The resolutions of R300B/R and R500B/R grisms are instead sufficient for the observation of normal SNe. Also, we will use blue, red or both grisms for the same object according to each case. Depending on the magnitude of the target, and the setup needed, the required exposure times will be between 45 min and 1.5 hr for spectroscopy. These exposure times are based on the OSIRIS SNR Calculator estimates, as well as on our several semester-long previous observational experience of transients with OSIRIS. For very faint objects with ≥ 22 mag (note that our list of objects is still uncompleted), and using only the blue grism (the features at the red part of the spectrum of a core-collapse SNe are weak and practically not usable at this phase), we assume an exposure time of $\sim$ 1–1.5 hr (since it is advised by the GTC staff that the total duration of an observing block should be kept below 1 hour, we will split the blocks if it lasts longer). Therefore, considering an average total execution time of ~ 2 hr including pointing, acquisition, and readout overheads, and assuming an average of 10 SNe per semester and one epoch per SN, this translates into a request of ~ 20 hr per semester for spectroscopy.
In total we thus need ∼ 20 hr scheduled throughout the semester, preferably during grey–dark time and seeing ≤ 1.2 arcsec (for the brightest targets in our list also a seeing between 1.2 and 1.5 arsecs could be good enough), and in queue-scheduled mode (even though classical visitor or "remote" mode are also acceptable).
Our previous experience at GTC has allowed us to verify the efficiency of using OSIRIS in similar projects. Our team is very experienced in reducing and analysing optical spectra of SNe and has previous experience with GTC+OSIRIS data.

T.2. Has the group previous observational experience with similar instrumentation?

Yes [X] No [ ]

T.3. Is extra time needed once the program has been started?
Yes, we would like to request additional time for this project in the next semesters.

T.4. Backup Program: Title and short description.
We have no need for a backup program as we ask for observations in the queue mode. As this proposal is for observing SNe at late phases when the evolution of the targets become much slower than at early phases we have no strict constrains when the observations can be excuted.

T.5. Are simultaneous observations required?
There is no need for simultaneously coordinated observations with other facilities. However, our observations will be complementary with optical and near-infrared observations at earlier phases of the target evolution obtained with the NOT (Spain).

T.6. Justification for the use of the selected telescope with respect to other available alternatives.
The GTC provides us with a unique tool at the Northern hemisphere to efficiently obtain late-time spectra of SNe when they are too faint to be observed with smaller telescopes available for us.

A. Are there other observations of the same targets in the telescope archive?

Yes [ ] No [X]

A.2. If positive, justify the need for new observations.

C. Critical questions related to this program.

No critical issues are identified.