TAG: JMU

LIVERPOOL TELESCOPE
APPLICATION FOR TELESCOPE TIME

Ref: PL/18A/xxx

Semester: 18A **Duration (Semesters):** 1 **PROGID:**

Applicants (PI First)	**Institution**	**email**
Chris Ashall	**ARI LJMU**	**chris.ashall24@gmail.com**
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⊗ Data are to be used in a PhD thesis of: Simon Holmbo, Aarhus university

Title: Obtaining a untargeted census of supernova in the local universe, with NUTS.

Abstract:

We request XXX hours on the Liverpool Telescope (LT) to obtain high-cadence photometric of 5-10 scientifically interesting supernoave. We plan to follow these targets in collaboration with the NUTS which also has members in two SN search programs, namely ASAS-SN and Gaia. Both search programs provide a wealth of bright and young targets to classify and follow. Specific science areas include the study of supernova discovered within hours to days from explosion, the study of Type Ia SN progenitors and the physics of their explosions, the progenitors of core collapse SN, the study of SN rates compared to star formation rates, and peculiar interacting transients.**What no SLSN? ha ha ha, i think you speak way too much about NUTS, make it sound more like this is to support the sicence that YOU wanna do within the NUTS collaboration, so i remove all the NTUS BS in the beginning, if I were a brit reading this i would say fuck NUTS.**

TIME REQUESTED

This semester (hours): 42 **Total (hours):** 42

Min. Useable %: 50

Jan ⊗ Feb ⊗ Mar ⊗ Apr ⊗ May ⊗ Jun ⊗ Jul ⊗ Aug ⊗ Sep ○ Oct ○ Nov ○ Dec ○

SCHEDULING CONSTRAINTS

Timing: **Group Cadence (days):** 3

ToO: Y **ToO Likelihood (%):** 100

Seeing (arcsec): **Sky Brightness:** +4

Photometric: N

INSTRUMENTS

IO:O	⊗	**Filters**	uBVgriz
IO:I	○	**Filters**	
RINGO3	○		
RISE	○		
SPRAT	○		
FRODOSpec	○	**Gratings**	
Other*			

Always consult the Call for Proposals and LT web-pages before applying to use ANY instrument.

Summary of progress on previous, related LT Programmes:

PROPID	Alloc.	Rank	Used	Comments
JL17B02 +JL17B01	35	B	7	Time was combined to get joint followup for both projects. It has been sucessful with follow up of objects such as SN 2017glq, SN 2017eaw, SN 2017faf, SN 2017gir, SN2017drh see publications (Bose, S 2017 Kuncarayaki 2017, Tartaglia 2017)
JL17A05	30	A	30	Successful, See publication (Ashall 2017)
JL17A09	17	A	17	Successful, See publication (Jiang 2017- Nature)
JL16B11	17	A	17	Successful, data collected on many objects including SN 2017drh, SN 2017bas
JL16A05	17/10	A/B	17/10	Successful, See publication (Shivers 17) data also obtained for many objects including iPTF16abc, SN 2016hnk and SN 2016gpx
JL16A07	10/10	A/B	10/10	Successful, See publication (Prentice 2017)

List of previous related and unrelated LT Publications:

All publications include C Ashall:
Ashall, C., et al. 2017, 2017arXiv170204339A, SN 2016jca
Shivvers, I., et al 2017 2017MNRAS.471.4381S, SN 2015G
Bose, S., et al. 2017, submitted ApjJ, 2017arXiv170800864B, SN2017egm
Prentice, S. J. et al. 2017, submitted MNRAS, 2017arXiv170903593P, SN 2016coi
Jiang, J. et al. 2017 accepted **Nature** (under press embargo)
Kuncarayaki, H et al. 2017, submitted ApJL, SN 2017dio
Tartaglia, L. et al. 2017, submitted ApJ, SN 2016ija

Details of related/complementary proposals to this or other facilities:

To achieve a high cadence and good follow up coverage we have a selection of telescope time available. As this proposal is part of the NUTS collaboration we have time on many facilities. We have time on the Nordic Optical Telescope until Period 58 (i.e. semester 19B). This time works out as about 151 hours of time per-semester, this is a mixture of ToO and fixed night time. Furthermore, Co-Is (M. Stritzinger and S. Mattila) from NUTS are part of ASAS-SN and the GAIA alerts team, which will provide an abundance of targets for us to follow. We also have time on the TNG and GTC (La Palma) to obtain late phase spectroscopy. Furthermore, there is a SNe project at Lijiang 2.4m telescope (LJT), LiONS, equipped with instrumentation similar to the LT. The LJMU SNe team and LiONS team share and collaborate with telescope time. This collaboration guarantees frequent sampling of very young SN, even if the weather is poor on La Palma.

TARGET LIST:

Sources of targets: We will follow up SN that have already been classified and selected as scientifically interesting by the NUTS collaboration. For an objects to be deemed as scientifically interesting, it must fall into one of the science categories (e.g. it has to be within days of explosion, a rare event or in an interesting location). Last semester NUTs followed 74 SNe, with the range of follow up varying from classification, to high cadence time series of data, and 15 SNe were followed into the nebular phase. 25 of the targets followed were from Atels, 17 from ASAS-SN, 22 from Gaia and 10 from other surveys such as iPTF, KAIT and MASTER. As NUTs has members in both ASAS-SN and Gaia alerts team we will have immediate access to the sources. For example last semester Gaia discovered SN 2017egm, which was determined to be the closest every super luminous SN, it broken certain trends such as it was the first low redshift event and was the first type of these events located in a massive super solar host galaxy. SN 2017egm demonstrates that Gaia finds interesting important transient objects. The LT was critical in early time spectroscopic follow up of this object where the LT contributed to 40% of the pre maximum spectra, see Bose, et al. 2017. It should be noted that to examine the physics of SNe explosions we require long duration detail followup, hence low redshift and bright targets are preferred. Our source of targets will provide this.

SCIENTIFIC CASE:

Motivation: Thermonuclear supernova (SNe Ia) and core-collapse SNe (CC-SN) play a significant role in shaping our universe. SNe Ia come from the explosion of a C/O white dwarf (WD) approaching the Chandrasekhar mass (Ch-mass), and are used as cosmological distance indicators. CC-SN come from the collapse of massive stars, $\sim 8M_{\odot}$, at the end of their lives. These SNe play a vital role on our understanding the last stages of stellar evolution, the synthesis of heavy elements, and the feed back processes in galaxy evolution. However, previously SN surveys tended to be targeted (i.e., SN were searched for in preselected galaxies), this had the advantage that they are more likely to find SNe, but the disadvantage that they will have a very biased sample, and possibly neglect to find certain transients all together. However, time domain astrophysics is now moving into a new era of un-targeted surveys (e.g., ASAS-SN, ZTF and LSST). These surveys will scan the entire nights sky ensuring that close SNe are caught at very early phases, they will also detect hostless SNe and SNe within the nuclear regions of galaxies. Two of these surveys are All-Sky Automated Survey for Supernovae (ASAS-SN) and the Gaia's all-sky survey. ASAS-SN surveys the entire visible sky every other night, with the aim of discovering all nearby (m_v <17 mag) SN in an untargeted way, and Gaia all-sky survey is expected to discover over 1000 SNe per year brighter than 19 mag. **Gaia has already been operational so instead of says expected can't you report on actual progress?** Both ASAS-SN and the Gaia all-sky survey are operational and producing an abundance of targets to be followed.

The NUTS Survey aims to obtain an untargeted census of supernova in the local Universe. It is a 3 year survey, which began in semester 17A, based on a number of telescopes, including the Nordic Optical telescope and the TNG. NUTS has a number of members both in ASAS-SN (e.g. M. Strintzinger) and the Gaia alerts team (e.g. S. Mattila), which means it has access to a large number of young transient sources. NUTS has a number of science work packages including: SN within hours of explosion, SNe Ia progenitors and the physics of their explosions, the progenitors of core collapse SN, the study of SN rates compared to star formation rates, the study of SNe interacting circumstellar material, tidal disruption events, and fast-and-faint transients. Due to the limited space of the proposal, we will describe some of the science that is of most interest to the group.

SN within hours of explosion: Early SN Ia light curves and spectra help to distinguish between different progenitor scenarios. At early times there may be additional emission in the explosion due to collision of the SN ejecta with the WDs companion (Kasen 2010), whilst no evidence for excess emission also puts constraints on the progenitor companion. Early time spectra can also be used to directly constrain information about the progenitor scenario. Using the abundance stratification technique (Stehle 2005), in which the ARI LJMU SN team is world leaders at, time series of spectra can be modelled to obtain physical information about the SN ejecta. We note for the abundance stratification analysis the spectra need to be accurately flux calibrated using the relative photometry. If the spectra are early enough (within ∼4 days of explosion) the properties, such as the metallicity, of the progenitor scenario can be obtained, see Figure 1. The NUTs collaboration often obtain data within days of explosion, which is perfect for this type of analysis.

The extremes of interacting transients: There is a wide heterogeneity of transient events showing strong interaction with their circumstellar medium (CSM). They can be generated by terminal explosions in H-rich environments (SNe IIn; e.g. Pastorello 2002), or by stars exploding in a He-rich medium (SNe Ibn; e.g. Pastorello 2015). In other cases, sneak powerful eruptions of luminous blue variables (LBVs) may mimic the appearance of interacting SNe. The latter are commonly known as SN impostors (e.g. Tartaglia 2015), and recently a new class of CSM SNe has been discovered, SNe Ic-CSM, See Figure 2 (Kuncarayaki 2017) (An ApJ letter from the NUTS collaboration has recently been submitted on this new type of object). The sample size is still small for interacting transients, and their diversity is poorly understood. We will carry out extensive high cadence long term monitoring campaigns of these transients in attempt to determing their explosion parameters, and eventually establish the nature of their progenitor systems.

This proposal: We aim to follow in detail between 7-12 objects among those described above and of interest for the NUTS collaboration, e.g. SNe Ia, SNe II, SLSN and Tidal disruption events . In order to have a more complete view of these transients, we need to combine the NUTS spectra with a good high cadence multiband photometry. We propose to get this photometry from the LT. The program we propose perfectly suits the capabilities and the efficiency of LT. Objects will be followed from a few days after explosion, into the nebular phase (∼300 days after

Table 1: The exposure times and number of observations required for a typical SN light curve. For observations a minimum S/N of 25 is assumed.

Phase	Cadence	$\overline{mag}$	exp. times	time per obs [a]	no of obs	total time per SN
	d	mag	u′BVg′r′i′z′(s)	s		hours
-10d to +0d	daily	17.5	100/50/50/50/50/70/70	785.5	10	2.19
+0d to +24d	3	16.5	90/30/30/30/30/30/30[b]	609.5	7	1.18
+24 to +120	10	18	150/60/60/60/60/100/100	934.5	10/9/6/3/0 [c]	2.59/2.33/1.56/0.78/0
total						5.96/5.7/4.93/4.15/3.37

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[a] including overheads

[b] We note that the minimum exposure time is 30s to ensure the stars in the field have a reasonable S/N

[c] Depending on how long the SN is visible for and when we start observing it, see below.

TECHNICAL CASE:

We plan to photometrically follow 5-10 SNe, for our calculations we will assume 8 SNe (which is reasonable given the diverse set of objects we plan to observe, and our previous observational and publication record of last semester. We have already published/submitted papers from 3 NUTS objects observed with the LT in semester 17B). All of the objects that we plan to follow will be closer than 150 Mpc, with objects ranging from 14-19 mag, depending on distance and phase of the object. This is close enough for us to follow them from explosion to the nebular phase at about +300 days (although we will apply for the late time followup in the following semester).

For the purpose of calculating the exposure times we assume a SNe at a distance of 100 Mpc and and a peak absolute magnitude of -18.5 mag, hence an apparent magnitude of 16.5. We require multi-band photometry in u′BVg′r′i′z′, as this allows for the most robust comparison to other objects, and for us to map the SN evolution in the most detail.

There are three different phases of a SN LC where different cadences are required, Pre-peak post peak and late time. Pre-peak we require a daily cadence as this is where the SN develops the quickest (Cao et al., 2015), between peak and +24d days we require observations every 3 days, and between +24d to +300d we require observations every 10 days where the SN development is very slow.

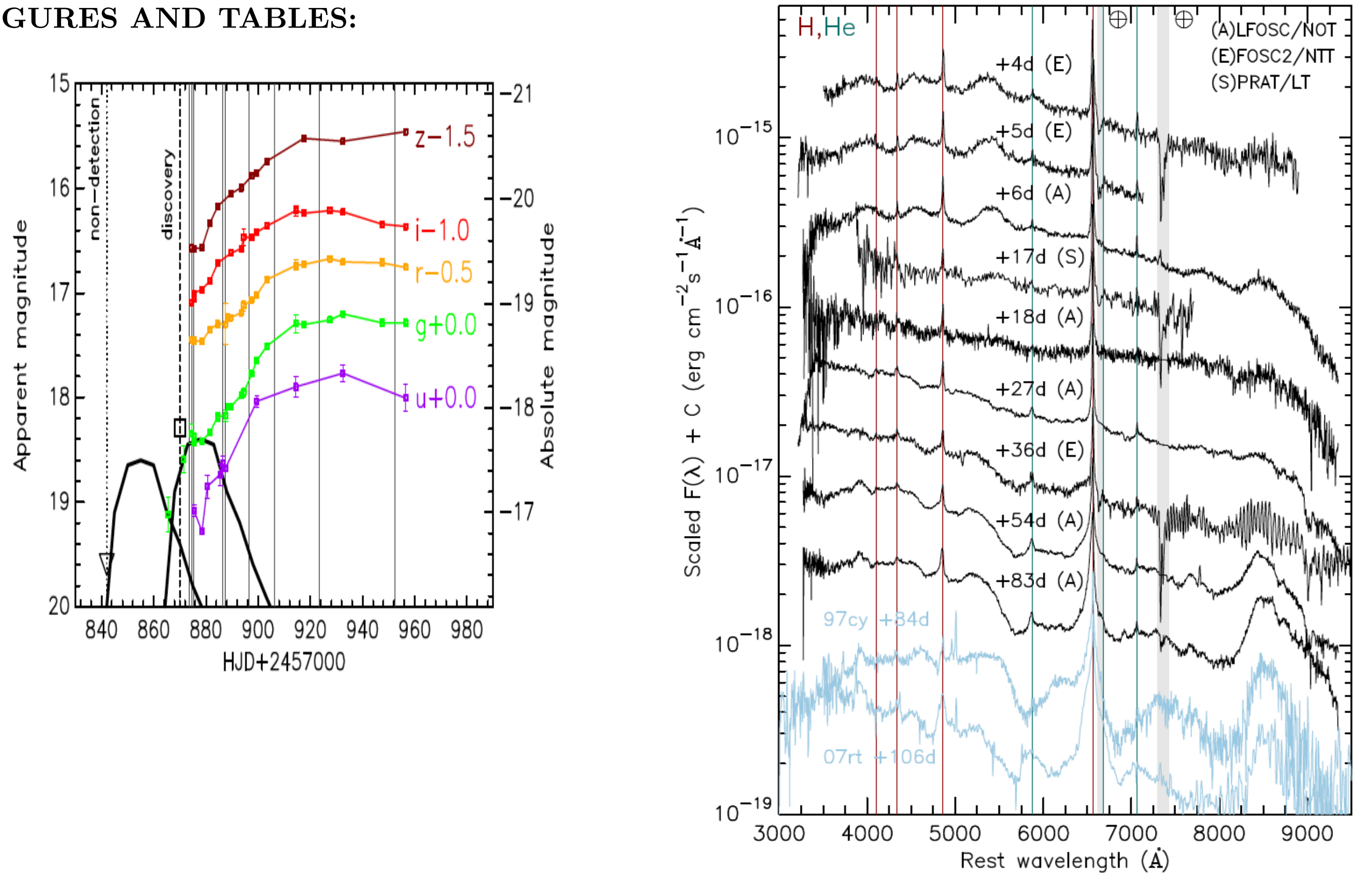
We assume that we will discover the objects evenly over the semester i.e. one per month. We will only start to observe a SN if it is visible from pre peak (-10d) to at least +24 days past maximum light. However, an object will probably go behind the sun at some point, hence we make the assumption that it will likely only be visible for a total maximum of 120 days post peak, and cap our observation calculaions at +120d. Therefore, all 8 SNe will be observed from -10 to +24d, the first 4 SNe followed up will be observable until +120d, the 5th until +110d, the 6th +80d, and 7th +50d, and the 8th +24d. Therefore, at late times (after +24d) we require a total of 10 observations for the first 4 SNe, 9 for the 5th, 6 for the 6th and 3 for the 7th.

In table 1 we show our average exposure times, and the time per observation at each phases for a typical SN. In total **4** SN will require **5.96 hours** of observations, **1** will require **5.70 hours**, **1** will require **4.93 hours**, **1** will require **4.15 hours** and **1** will require **3.37 hours**. Therefore for following 8 SN we require **42** hours of LT time In the following semester we will put in a follow up proposal with to obtain the photometry from +150 to +300days of the objects observed in semester 18A with the LT.

References:

Ashall, C. et al. 2014, MNRAS, 445, 4427 • Sullivan M et al. 2011 ApJ, 732, 118 • Moriya et al. 2017 MNRAS, 466, 2085 • Foley 2012 et al. 2013 ApJ 767 57 • Kasen 2010 ApJ 708 1025 • Stehle et al. 2005 MNRAS 360 1231 • Mazzali P. A., et al, 2014,MNRAS,439,1959 • Cao, Yi et al. 2015, Nature, 521, 328C • Pastorello, A et al. 2002, MNRAS, 333, 27 P • Tartaglia, L. et al. 2015, MNRAS, 447, 117T • Kuncarayaki, H et al. 2017 submitted •

FIGURES AND TABLES:



Above, Figure 2. *left*: The light curve of SN 2017dio, an example of a new type of SN studied by our collaboration. All photometry in the figure was taken with the LT and reduced with a python-based pipeline built by NUTS memebers. The bottom black curves represent the possible contribution from the underlying SNe Ic. *right*: A time series of spectra of SN 2017dio, including one SPRAT spectrum. At early times the SN appears to have some spectral features similar to a SN Ic, where as by day +18 it has evolved, and exhibits features consistent with an SN IIn. Interestingly if the +18 spectrum is assumed to be the CSM component, and is subtracted from the +6 spectrum, the residual SN component looks very similar to a broad-line SN Ic.

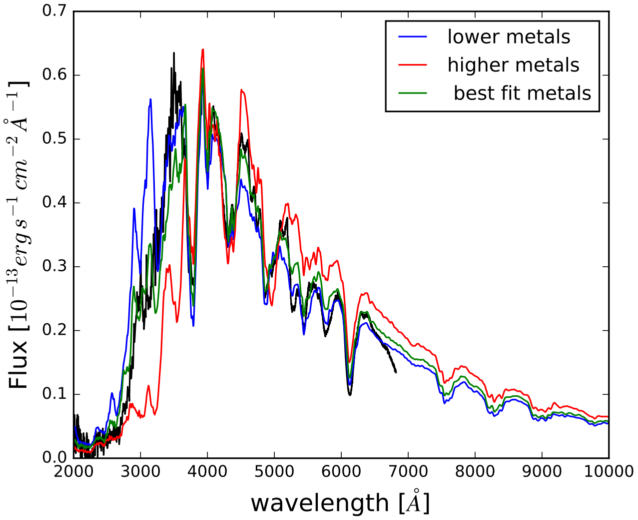


Figure 1. *left*: Spectral models produced using the abundance stratification technique of Sn 2011iv. The three models have varying abundances of iron group elements in the outer layers. At early times this can be linked back to the metallicity of the exploding white dwarf, and the type of progenitor system.