European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **104A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title

Category: **D–5**

The All-weather MUse Supernova Integral field Nearby Galaxies (AMUSING) survey X: star formation in low-mass galaxies as traced by extra-galactic transients

2. Abstract / Total Time Requested

Total Amount of Time: 0 nights VM, 99 hours SM

Core-collapse supernovae (CCSNe) - the deaths of massive stars - are accurate tracers of recent star formation (SF). CCSNe discovered through modern surveys have uncovered previously unknown galaxies of low-luminosity that contribute to the overall SF in the Universe. Long duration Gamma-Ray Bursts (LGRBs) meanwhile appear to preferentially explode in low-luminosity galaxies. However, given the rarity of such events, spatially resolved analyses of their hosts is difficult. Here, we investigate low-luminosity hosts in the local Universe that have either a) been host to CCSNe, or b) are analogues to higher-redshift LGRB hosts. This study will: 1) characterise low-metallicity (implied from low-mass hosts) SF; 2) further elucidate the possibility of using type II SNe as extra-galactic metallicity indicators; and 3) determine whether LGRB host H II regions are representative of the overall SF in their hosts and thus whether LGRBs are good tracers of SF within the Universe.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	104	MUSE	50h	any	n	n	THN	s	
B	104	MUSE	49h	any	n	n	THN	s	

4. Number of nights/hours

	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

This project is a ‘filler’ program, with targets across the full RA and DEC range, and that are observable in THN, bad seeing conditions, and during bright time. We understand that only part of the observations may be completed. This is a continuation of the AMUSING survey. Here, we investigate low-mass host galaxies CC SNe together with LGRB host analogues, where the science case is distinct from previous semesters. This proposal is split into two runs: one that will use WFM adaptive optics and one that will not.

6. Principal Investigator: (moved to the CoI list)

6a. Investigators:

All CoIs moved to the end of the document.

7. Description of the proposed programme

A – Scientific Rationale: Historical discoveries of extra-galactic transients in the local Universe were dominated by events found in bright, nearby galaxies due to the biased nature of their search strategies. This has changed with modern surveys that scan large areas of the night sky. The discovery of core-collapse supernovae (CCSNe) in low-luminosity hosts has uncovered previously uncatalogued galaxies and thus previously unaccounted for star formation (SF, see e.g. Sedgwick+19). Meanwhile, a significant fraction of the SF in the early Universe (z=2-3) takes place in low mass and metal-poor galaxies, and yet the details of the chemical build-up and ISM conditions of such galaxies is poorly understood due to the associated observational challenges. Local analogues of 'typical' high redshift galaxies have thus been used in order to infer what the interstellar properties might be like of distant, metal-poor, star forming galaxies. Complementary to this is the use of long-duration gamma-ray bursts (LGRBs), whose luminous, intrinsically featureless afterglow offer a direct probe of the host galaxy interstellar properties from the absorption imprint that is left by intervening material.

This proposal aims to study SF within low-mass galaxies in the local Universe through two samples. First, we will use a sample of low-luminosity galaxies within which CCSNe have been discovered. Second, we will observe a sample of local analogues of the high-redshift host galaxies of LGRBs selected by their emission line properties. The latter will serve as an important probe to the conditions in the high redshift Universe. These samples – observed with MUSE – will enable a characterisation of SF within low-mass galaxies and elucidate questions as to the use of LGRBs as SF probes, and how much SF is missed in the local Universe through samples defined through standard methods (i.e. not through their hosting of CCSNe).

CCSNe are accurate tracers of recent SF given that they are the end points in stellar evolution for the majority of stars more massive than 8 $M_{\odot}$. There are some indications that the rate of the various subtypes of CCSNe is different in low-luminosity host galaxies (see e.g. Arcavi+12). Such results imply progenitor-metallicity related effects on the later stages of stellar evolution leading to different final explosions than those taking place within higher mass galaxies. Type II SNe (SNe II) have been shown to be good tracers of environment metallicity (Anderson+16), as predicted by spectral modelling of their explosions (Dessart+14). However, detailed analyses of the hosts of CCSNe have generally been restricted to larger, more luminous host galaxies. This work will characterise a sample of low-luminosity galaxies that have been uncovered by the discovery of CCSNe within them. The CCSN sample is derived from the samples presented in Arcavi+10; Anderson+14; and Gutierrez+18, taking those CCSNe that exploded within hosts dimmer than −18 in the B band.

LGRBs signal the catastrophic death of a massive star, and the lines of sight to their natal, star forming region thus intersect a significant fraction of the host galaxy ISM, leaving deep absorption features from neutral gas and ionic metal species imprinted on the otherwise featureless GRB afterglow spectrum. Such observations provide a powerful probe of the metal-contents, dust properties, ionisation state and kinematics of the interstellar medium in high-redshift galaxies at z=2-3. However, to optimise the use of GRBs as cosmic probes, it is important to be able to relate the GRB line of sight view of their host galaxies to the galaxy-averaged properties. Most GRB host galaxies are too distant to study their spatially resolved emission properties in detail, and instead we will therefore use a sample of high-z local galaxy analogues. Bian+2016 found that by selecting those galaxies within SDSS that lay in the same region of the BPT diagram as high-z galaxies, their sample of local analogues showed similar galaxy size-$M_{\star}$, and $M_{\star}$-metallicity relations to high-z galaxies. Using similar selection criteria, this proposal will investigate the distribution of a number of ISM properties, such as ionisation state and metallicity, which will thus provide a greater understanding of how representative GRB line of sight properties are of the global conditions of the galaxies that they probe. From a more general perspective, these data will provide an important dataset with which to investigate the spatially resolved scaling relations of high-z galaxies that can otherwise not be studied through direct observations.

Combining a sample of low-luminosity galaxies from discoveries of CCSNe together with known galaxies that act as analogues to LGRBs will allow a detailed study of the properties of SF happening within low-metallicity environments.

B – Immediate Objective: MUSE observations will be obtained for the host galaxies of: 1) 50 SNe II and 2) 49 LGRB host analogues. These observations will enable characterisation of these host galaxies both on a global scale and on an individual parent stellar population scale (i.e. at the exact explosion site of each transient). Specifically, we will answer the following questions:

1) What is the amount of SF that is missed by classical galaxy surveys without the aid of CCSN detections? This will be acheived by quantifying the SF within these galaxies and using CCSN rates as a function of galaxy type to estimate the missing SF fraction.

2) How representative are LGRB host H II regions of all other star-forming regions and the global properties of their host galaxies? If we can show that the sight lines of LGRBs within their hosts *are* globally representative, then this will provide strong arguments for the future use of LGRBs as SF probes out to high redshift.

3) Do the properties of SF within low-metallicity environments differ from that at higher metallicity? This will be possible through a comparison to our other samples of SN-host galaxies already obtained through AMUSING (>350 galaxies to date), and can be studied in both a global and spatially resolved manner.

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

4) Does the correlation between SN II metal-line equivalent widths with host H II region metallicity continue to the lowest metallicity? For the sample of SN II hosts included here we already have light curve and spectral information during the photospheric phase of their evolution meaning we can tie environmental properties derived from our MUSE data to SN properties.
A MUSE sample of low-luminosity CCSN hosts and LGRB-host analogues in the local Universe will enable these questions to be investigated in unprecedented detail. Finally, this data will provide a gold mine for further study; it will be extremely useful for studies of galaxy dynamics, stellar populations and chemical evolution, and hence we expect many other projects to spawn from the proposed dataset. The AMUSING project has run for 7 semesters (plus data being collected currently in P102, and observations planned for P103). The main purpose of this project is to perform environmental analyses of SNe. The project has already submitted/published 12 papers (Sánchez et al. 2015 A&A, 573, A105; Galbany et al. 2016, MNRAS, 455, 4087; Prieto et al., 2016, ApJ, 830, 32; Sánchez-Menguiano et al., 2016, ApJ, 830, 40; Krühler et al., 2017, A&A, 602, A85; López-Cobá et al., 2017, ApJ, 850, 17; Lyman et al., 2018, MNRAS, 473, 1359; Sánchez-Menguiano et al., 2018, A&A, 609, 119; Anderson et al., 2018, NatAs, 2, 574; Galbany et al., 2018, MNRAS, 479, 262; Anderson et al., 2018, NatAs, 2 574; Meza et al., 2019, arXiv1811.11771; Tucker et al., 2019, arXiv1903.05115), and many other projects are currently ongoing.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: Our targets can be observed in any lunar phase as this project is a ‘filler’ program.

Time Justification: (including seeing overhead) Our proposed MUSE observations aim to detect and measure the strength of H II region emission lines throughout target galaxies, together with narrow absorption features seen on top of the galaxy continuum. To estimate exposure times, we assume a typical r-band surface brightness of 21 mag per arcsec^2 for faint HII regions (James et al. 2004). We then use the MUSE ETC to estimate our required exposure times. We assume an ‘Infinitely extended source’ and the HII region template (at a redshift of 0.05) together with an r-band surface brightness of 21 mag per arcsec^2. As a ‘filler’ proposal we set conditions to 7 days from new moon with an airmass of 1.4 and seeing $1.5''$.
In order to remove the edges of each IFU on the detector (artifacts of the image slicer) it is best to combine observations with all four 90 degree angles. With 4×550 second exposures the ETC gives a S/N of $\sim$5 in the continuum, which translates to a S/N of more than 100 for all the emission lines we wish to detect (e.g., Hα, [NII], [O III], Hβ). In many galaxy regions we will obtain much higher S/N in the continuum, and this will allow more detailed analysis of stellar populations, using absorption line indices as an indicator of stellar metallicities in place of the gas phase values. This is required for the small number of elliptical galaxies expected in our sample. Together with 2×220 second sky exposures and overheads, this totals roughly 1 hr per galaxy.
Most galaxies in our sample are covered by one MUSE pointing, so we require 99 hrs to observe our sample of 99 host galaxies. However *as a ‘filler’ proposal, any amount of data obtained will be beneficial to our project.*
Our targets are split into two runs. 50 objects will be observed in no-AO mode in order to enable observations to be taking even in THK clouds. 49 objects will be observed in AO mode in order to obtain the best possible spatial resolution.
We have previously obtained MUSE data with very similar conditions/observing strategy to that outlined above, and with the above exposure times we are able to make the necessary measurements. We have already published several papers based on these data (see publications section). Our team has experts on the reduction, analysis and interpretation of IFS galaxy observations, hence, while IFS data and their analysis can sometimes prove somewhat daunting, our team provides all the required knowledge to fully exploit this rich data set.
These data will remain in the archive as a legacy for future extragalactic studies.

8a. Telescope Justification:

MUSE at the VLT is the only currently available IFU instrument that has a FoV of sufficient size to cover the majority of our targets, while at the same time having high spatial resolution, high sensitivity, and being extremely efficient, hence enabling targets to be observed in a relatively small amount of time.
We stress here that even in relatively bad seeing conditions (in which the data will sometimes be observed, given the ‘filler’ nature of our proposal) we will still have the potential to unravel kinematic and population substructure in these galaxies over a large FoV. Indeed, even in bad seeing conditions these data will still be a better position to probe SN environments and galaxy characteristics than any current or past IFU survey (SAURON, ATLAS3D, CALIFA, SAMI, MaNGA).

8b. Observing Mode Justification (visitor or service):

Targets are observable throughout the semester, and as this is a ‘filler’ program, service mode is required.

8c. Calibration Request:

Standard Calibration

9. Report on the use of ESO facilities during the last 2 years

101.D-0748: 99hr SM MUSE (P.I. Kuncarayakti); data have been reduced and analysis is in progress;
2101.D-5023: 9hr SM XShooter and FORS2 (P.I. Leloudas); 1 publication accepted, Anderson+2018;
102.D-0356: 50hr SM FORS2 (P.I. Kuncarayakti); observations are ongoing;
102.D-0095: 99hr SM MUSE (P.I. Anderson); observations are ongoing;
102.D-0919: 37hr SM FORS2 (P.I. Gutierrez); observations are ongoing;
103.D-0440: 99hr SM MUSE (P.I. Anderson); observations not yet started

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

A number of the objects requested for observation in the proposal have been observed with FORS2. However, in that case only the host H II region of the SN was observed. Here we will observe the full extent of the host galaxies thus enabling our scientific goals to be met.

9b. GTO/Public Survey Duplications:

10. Applicant's publications related to the subject of this application during the last 2 years

In **bold** those publications using MUSE data)

Tucker et al., 2019, arXiv 1903.05115: Clearing the Smoke: Nebular Spectra of 100+ Type Ia Supernovae Exclude Single Degenerate Progenitors

Meza et al., 2019, arXiv 1811.11771: The Extraplanar Type II Supernova ASASSN-14jb in the Nearby Edge-on Galaxy ESO 467-G051

Anderson et al., 2018, A&A, 620A, 67A: A nearby super-luminous supernova with a long pre-maximum & plateau and strong C II features

Anderson et al., 2018, NatAs, 2, 574: The lowest-metallicity type II supernova from the highest-mass red supergiant progenitor

Galbany, et al., 2018, ApJ, 855,107: PISCO: The PMAS/PPak Integral-field Supernova Hosts Compilation

Kuncarayakti, et al., 2018, A&A, accepted: Constraints on core-collapse supernova progenitors from explosion site integral field spectroscopy

Lyman, et al., 2018, MNRAS, 473, 1359: Investigating the diversity of supernovae type Iax: a MUSE and NOT spectroscopic study of their environments

Moreno-Raya, et al., 2018, MNRAS, 476, 307: Elemental gas-phase abundances of intermediate redshift type Ia supernova star-forming host galaxies

Sánchez-Menguiano, et al., 2018, A&A, 609, A119: The shape of oxygen abundance profiles explored with MUSE: evidence for widespread deviations from single gradients

Lopéz-Cobá, et al., 2017, ApJL, 850, L17: Serendipitous Discovery of an Optical Emission-line Jet in NGC232

Krühler, et al., 2017, A&A, 602,A45: Hot gas around SN1998bw: Inferring the progenitor from its environment

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	SN1992ba	05 41 47.14	-64 18 00.87	1			II	
A	SN2002ig	01 36 36.72	00 55 25.6	1			II	
A	SN2003bn	10 02 35.51	-21 10 54.5	1			II	
A	SN2003cx	13 57 06.46	-17 02 22.6	1			II	
A	SN2003E	04 39 10.88	-24 10 36.5	1			II	
A	SN2006Y	07 13 17.19	-51 41 18.8	1			II	
A	SN2007ld	20 49 29.59	00 00 14.0	1			II	
A	SN2007od	23 55 48.68	18 24 54.8	1			II	
A	SN2009lq	04 14 52.54	-62 50 14.8	1			II	
A	SN2014cw	22 15 26.55	-10 28 34.6	1			II	
A	SN2015W	06 57 43.03	13 34 45.6	1			II	
A	SN2015bm	12 08 00.10	19 44 26.6	1			II	
A	ASASSN-15kz	13 37 18.66	-28 39 23.5	1			II	
A	ASASSN-15lx	20 36 05.29	-73 06 34.3	1			II	
A	ASASSN-15oz	19 19 33.46	-33 46 01.3	1			II	
A	ASASSN-15rp	00 03 37.25	-34 33 24.2	1			II	
A	SN2016B	11 55 04.24	01 43 06.7	1			II	
A	SN2016X	12 55 15.61	00 05 59.3	1			II	
A	SN2016aqf	05 46 23.91	-52 05 18.8	1			II	
A	SN2016ase	11 42 34.64	-25 54 45.2	1			II	
A	SN2016blz	15 40 29.23	00 54 36.3	1			II	
A	SN2016egz	00 04 03.85	-34 48 51.8	1			II	
A	SN2016hmq	04 25 04.91	-07 33 56.2	1			II	
A	SN2016hpt	21 54 36.58	-42 51 01.9	1			II	
A	SN2016iyd	07 37 09.76	-52 19 04.1	1			II	
A	SN2017pn	04 46 24.58	-11 59 18.2	1			II	
A	SN2017vp	09 02 35.11	09 45 11.5	1			II	
A	SN2017dht	09 27 06.82	12 42 03.5	1			II	
A	SN2017hpi	08 15 43.46	-28 51 19.8	1			II	
A	SN2017imr	04 21 04.78	-04 43 06.0	1			II	
A	SN2017ipa	06 37 58.15	-15 22 00.5	1			II	
A	SN2017ivv	20 28 49.84	-04 22 57.2	1			II	
A	SN2017jne	09 11 43.32	-00 15 31.9	1			II	
A	SN2018fqm	05 03 21.58	-28 43 53.7	1			II	
A	SN2018anu	17 36 14.32	18 58 57.0	1			II	

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Target Notes: Targets are split into two runs. A) contains CCSN hosts in low-luminosity host galaxies using no-AO modde, while B) contains LGRB host analogues using WFM-AO. Column 6 for the run B) targets gives the r-band magnitude of the relevant tip-tilt star.

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
104	MUSE	A	WFM-NOAO-N	-
104	MUSE	B	WFM-AO-N LGS	-

6b. Investigators:

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J. Anderson
F. Förster
J. Falcón-Barroso
L. Galbany
S. González-Gaitán
C. Gutierrez
P. James
H. Kuncarayakti
J. Lyman
E. Perez
J. Prieto
F. Rosales-Ortega
S. Sánchez
P. Schady

11a. List of targets proposed in this programme

…continued from box 11.

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	SN2018evk	23 15 44.95	06 54 39.7	1			II	
A	SN2018fit	23 25 16.17	13 56 02.6	1			II	
A	SN2018fus	21 02 31.29	-05 37 30.0	1			II	
A	SN2018gsr	00 08 30.39	-01 31 29.8	1			II	
A	SN2018hfm	09 36 08.69	06 15 27.7	1			II	
A	SN2018iuq	07 05 53.43	12 53 34.6	1			II	
A	SN2018jfz	03 20 18.73	-00 17 47.0	1			II	
A	PTF09dfk	23 09 13.42	07 48 15.4	1			Ib	
A	PTF09gyp	01 58 56.76	-07 16 56.9	1			IIb	
A	PTF10bfz	12 54 41.27	15 24 17.0	1			IcBL	
A	PTF10bip	12 34 10.52	08 21 48.5	1			Ic	
A	PTF10dk	05 08 21.54	00 12 42.9	1			II	
A	PTF09cvi	21 47 09.80	08 18 35.6	1			II	
A	PTF09gpn	03 43 43.26	-17 08 43.1	1			II	
A	PTF09iex	12 02 46.86	02 24 06.8	1			II	
B	analogue1	00 06 57.0	00 51 26.0	1	12.87		GRB-analogue	
B	analogue2	00 10 42.8	-01 02 00.9	1	13.00		GRB-analogue	
B	analogue3	00 21 01.0	00 52 48.1	1	14.37		GRB-analogue	
B	analogue4	00 21 46.5	00 19 02.4	1	14.29		GRB-analogue	
B	analogue5	00 42 36.9	16 02 02.6	1	12.55		GRB-analogue	
B	analogue6	00 55 27.4	-00 21 48.8	1	14.50		GRB-analogue	
B	analogue7	01 00 00.2	00 17 27.4	1	14.95		GRB-analogue	
B	analogue8	01 36 30.5	-00 37 56.0	1	12.85		GRB-analogue	
B	analogue9	01 40 22.0	-00 40 01.3	1	11.80		GRB-analogue	
B	analogue10	01 47 07.0	13 56 29.3	1	12.68		GRB-analogue	
B	analogue11	02 13 06.6	00 56 12.4	1	11.54		GRB-analogue	
B	analogue12	02 20 37.6	-09 29 07.3	1	14.49		GRB-analogue	
B	analogue13	02 27 14.4	01 05 36.10	1	15.91		GRB-analogue	
B	analogue14	02 40 52.2	-08 28 27.4	1	13.03		GRB-analogue	
B	analogue15	02 43 55.1	01 11 48.7	1	16.15		GRB-analogue	
B	analogue16	02 47 02.7	01 15 29.4	1	13.13		GRB-analogue	
B	analogue17	02 52 34.2	01 14 43.9	1	12.75		GRB-analogue	
B	analogue18	02 57 54.7	00 27 26.7	1	13.94		GRB-analogue	
B	analogue19	03 05 35.1	00 40 59.2	1	14.27		GRB-analogue	
B	analogue20	03 05 39.7	-08 39 05.24	1	15.65		GRB-analogue	
B	analogue21	03 09 03.8	00 38 46.68	1	13.84		GRB-analogue	
B	analogue22	03 26 13.6	-06 35 12.56	1	14.43		GRB-analogue	
B	analogue23	03 27 08.2	-00 25 51.8	1	13.06		GRB-analogue	
B	analogue24	03 53 34.7	-00 19 04.9	1	12.88		GRB-analogue	
B	analogue25	08 40 00.3	18 05 31.0	1	12.69		GRB-analogue	
B	analogue26	08 40 34.1	13 44 51.4	1	13.37		GRB-analogue	
B	analogue27	08 44 14.2	02 26 21.1	1	13.27		GRB-analogue	
B	analogue28	08 52 21.7	12 16 51.7	1	11.18		GRB-analogue	
B	analogue29	08 53 24.0	19 30 22.6	1	11.40		GRB-analogue	
B	analogue30	09 25 32.3	14 03 13.1	1	12.46		GRB-analogue	
B	analogue31	09 27 28.6	17 40 18.6	1	15.15		GRB-analogue	
B	analogue32	09 28 16.7	03 05 47.4	1	15.31		GRB-analogue	
B	analogue33	09 42 23.1	-01 12 19.2	1	13.64		GRB-analogue	
B	analogue34	09 43 06.0	00 19 12.8	1	13.10		GRB-analogue	
B	analogue35	09 46 46.6	03 38 12.8	1	14.42		GRB-analogue	

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11a. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
	…continued from previous page.							
B	analogue36	09 50 23.3	00 42 29.3	1	11.59		GRB-analogue	
B	analogue37	09 57 53.9	09 23 02.5	1	13.06		GRB-analogue	
B	analogue38	10 16 29.8	07 34 04.9	1	13.00		GRB-analogue	
B	analogue39	11 01 16.3	00 48 14.5	1	13.72		GRB-analogue	
B	analogue40	11 37 03.7	00 28 17.3	1	13.41		GRB-analogue	
B	analogue41	11 48 40.8	17 56 33.0	1	11.23		GRB-analogue	
B	analogue42	12 19 03.9	15 26 08.5	1	13.72		GRB-analogue	
B	analogue43	12 26 11.9	04 15 36.1	1	12.49		GRB-analogue	
B	analogue44	12 44 23.3	02 15 40.5	1	13.04		GRB-analogue	
B	analogue45	12 45 09.0	10 43 40.2	1	14.74		GRB-analogue	
B	analogue46	12 48 34.6	12 34 02.9	1	13.89		GRB-analogue	
B	analogue47	12 57 31.3	01 55 59.8	1	14.43		GRB-analogue	
B	analogue48	13 11 15.0	-00 27 57.9	1	14.35		GRB-analogue	
B	analogue49	13 11 31.2	-00 38 44.4	1	11.91		GRB-analogue	