European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME PERIOD: **98A**

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 IV: Reducing the scatter in the Near Infrared SN Ia Hubble diagram

2. Abstract / Total Time Requested

Total Amount of Time: 0 nights VM, 45 hours SM

Optical observations of type Ia supernovae (SNe Ia) have proved essential to measure accurate cosmological distances, once their light curves have been properly standardized. However, SNIa are superior standard candles in the near-infrared (NIR), both because their light curves are intrinsically more similar in the NIR, and reddening effects are greatly reduced. SN Ia Hubble residuals using optical data correlate with global host galaxy parameters (such as total mass), and the addition of a term in the SN Ia light curve standardization accounting for these environmental parameters, has proved to reduce further the scatter in the SN Ia absolute magnitude at peak. In this proposal we aim to obtain MUSE observations of galaxies that hosted SN Ia, which were followed up in the NIR.We will reduce further the scatter in the NIR SN Ia Hubble diagram by looking for the first time for correlations between SN Ia residuals and both global and local galactic properties.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	98	MUSE	45h	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:	UT4	25h

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 to investigate the host galaxies of SNe, where the current science case is distinct from previous semesters. For this specific project, we would still require to observe another set of 20 galaxies during semester P99 (RA 17h to 3h, see box 4b).

6. Principal Investigator: Lluis Galbany, lluisgalbany@gmail.com, CL, Universidad de Chile,Cerro Calan

6a. Co-investigators:

J.	Anderson	ESO Office Santiago,ESO
T.	Kruehler	Max Planck Institut fuer extraterrestrische Physik,D
W. M.	Wood-Vasey	University of Pittsburg,Department of Physics & Astronomy,US
K.	Ponder	University of Pittsburg,Department of Physics & Astronomy,US

Following CoIs moved to the end of the document ...

7. Description of the proposed programme

A – Scientific Rationale: Optical observations of type Ia supernovae (SNe Ia) have been widely used in the last decades to measure cosmological distances, and have been key to measure the Hubble constant and demonstrate cosmic acceleration (Riess+98; Perlmutter+99; Betoule+14). Although SNe Ia show significant dispersion ~2.5 mag in their absolute peak magnitudes in optical wavelengths, a correlation between peak brightness and both the shape of the light curve (LC) and intrinsic color, enabled their standardization and converted SNe Ia into the most precise (7%) extragalactic distance indicators. In the last years, the literature sample of optical SNe Ia at cosmological distances has grown substantially, and at this point statistical errors are comparable to systematic uncertainties (Goobar+11). Further improvement in reducing these systematic errors would require a much better understanding of the physical model of the explosion, which is still incomplete, a direct observational constraints on which kind of progenitors can produce SNe Ia, which is still lacking, as well as a better control of reddening effects due to interstellar and/or circumstellar dust.

Increasing evidence suggests that SNIa are very nearly 'natural' standard candles at NIR wavelengths, even before correction for LC shape and/or reddening, yielding more precise distance estimates to their host galaxies than optical data alone (Krisciunas+04, Wood-Vasey+08, Weyant+14, Friedman+15). Compared to the optical, SN Ia in the NIR are both better standard candles (σ_J ~0.16), and relatively immune to the effects of extinction and reddening by dust (extinction corrections are a factor of 4-6 smaller than in the optical B-band, Stanishev+15). However, SN Ia cosmology in the NIR is still poorly developed compared to the optical, since current efforts are focused on increasing the number of objects observed in J- and H-bands, and are constrained to low redshifts (z<0.2). The next generation of telescopes (>20-30m) will be needed to get NIR observations at higher redshifts to complement the current low-z SN Ia by observing in K- or even redder bands.

In optical studies of SNIa, it has now been firmly established that there is a dependence of Hubble residuals on host galaxy parameters, such as mass, age, and metallicity (Sullivan+10, Lampeitl+10, Gupta+11, D'Andrea+11, Childress+13, Johansson+13). Moreover, these galaxy parameters might in principle affect the properties of the progenitor star, which might in turn influence the observed SN properties. The addition of an extra term in the standardization of SN Ia absolute magnitudes in the optical that accounts for these environmental properties, e.g., the 'mass step' or the γ metallicity term (Moreno-Raya+16), has proved to reduce further the scatter in the Hubble residuals. Most of these studies are based on analyses of the integrated or central host galaxy spectra, and broad-band or narrow-band Hα imaging. The effect of the local environment of SN Ia within galaxies in cosmological studies is almost unexplored, and the advent of Integral Field Spectroscopy (IFS) opens a new opportunity to give new insights in SN Ia magnitude standardization.

The focus of the current proposal is, for the first time, to search for correlations between SN Ia NIR Hubble residuals and the properties of both their global and local environments (e.g., metallicity, age, SFR), through observing their host galaxies with MUSE. Our sample is built from the SweetSpot survey (Weyant+14) that compiled NIR observations of 115 SNIa at redshifts z<0.1 (see Fig. 1). These planned MUSE observations will allow a detailed characterization of both the global and the local environment of these SNe Ia, as well as the ability to then map galaxy-wide SN host properties, and analyze where within the overall distribution of, e.g., host metallicity (see Fig. 2) the SN environment falls. In addition, observations will be used to further constrain the age and metallicity of the SN Ia progenitor population.

B – Immediate Objective: We propose to obtain MUSE observations of a sample of 36 nearby (z<0.1) SN Ia host galaxies, with SN Ia NIR observations from the SweetSpot survey, and that are observable from January to March 2017 from Paranal. These will provide both global host properties in addition to spectral information on the immediate environments of SNe (and every single environment within the host). Using these observations, maps will be made of line-of sight ISM and stellar features, such as that of gas-phase and stellar metallicity, stellar age, and star-formation rate (SFR, Fig. 2). This will allow a detailed study of the correlations between the SNIa residuals to the ΛCDM cosmology in the NIR Hubble digram (Fig. 1) and both the global and the local environmental properties, further reducing systematic uncertainties in the determination of cosmological distances with SN Ia observations in the NIR. The immediate goals of this proposal are:

1) Produce host galaxy maps of: age (through both stellar population modeling and Hα equivalent width measurements), metallicity (through emission line ratios, population modeling, and absorption line ratios), and SFR. SN environments will then be placed within these distributions providing further progenitor constraints.

2) Look for correlations between the SNIa residuals in the NIR Hubble digram and the local/global environmental properties, and use them to further refine the use of SNe in the NIR as precise distance indicators; and

These data are also extremely useful for studies of galaxy dynamics, stellar populations, and chemical evolution. Our team is comprised of world leaders in the fields of SN environments, and galaxy IFS studies, meaning that data reduction, analysis and subsequent publications will be achieved in a timely manner, in several distinct fields. Indeed, we have already published two papers using MUSE data. In Sanchez et al. (2015, A&A, 573, 105) we presented one of the largest ever catalogues of HII regions obtained for a single galaxy, and in Galbany et al. (2016, MNRAS, 455, 4087) we showed the HII region statistics technique that will be used with the data from this proposal to constrain SNIa progenitors (Fig. 2). Finally, these data will provide a gold mine for

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

further study. Our team is already significantly experienced in reducing and analyzing such data, and hence we expect many other projects to spawn from the proposed dataset.

References: Betoule, M. et al 2014,A&A, 568, 22; Childress, M. et al 2013, ApJ, 770, 108; D'Andrea, C.B. et al 2011, ApJ, 743, 172; Friedman, A., et al. 2015, ApJS, 220, 9; Goobar & Leibundgut, 2011, ARNPS, 61, 251; Gupta, R.R. et al 2011, ApJ, 740, 92; Johansson, J. et al 2013, MNRAS, 435, 1680; Krisciunas, K., et al. 2004, ApJ, 602, 81; Lampeitl, H. et al 2010, MNRAS, 401, 2331; Moreno-Raya, M. et al. 2016, 2016, ApJ, 818, 19; Stanishev et al. 2015, arXiv:1505.07707; Sullivan, M. et al 2010, MNRAS, 406, 782; Perlmutter, S. et al. 1999, ApJ, 517, 565; Riess, A. et al 1996, 473, 88; Weyant, A. et al. 2014, ApJ, 784, 105; Wood-Vasey, W.M. et al. 2008, ApJ, 689, 377.

Attachments (Figures)

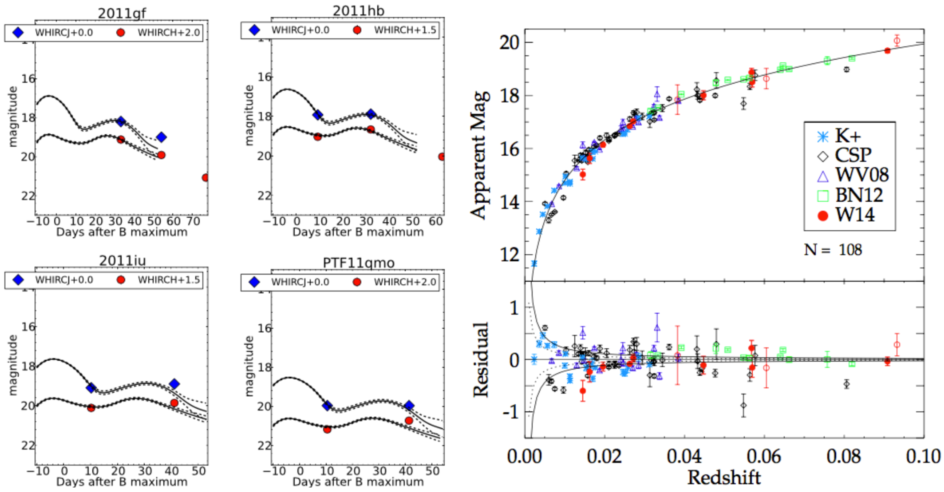

Fig. 1: (Left panels) Four SN Ia J-band (blue) and H-band (red) light-curves from the SweetSpot Survey with LC templates in black. (Right panel) H-band Hubble diagram and residual (in mag) to the ΛCDM model of SweetSpot SNe Ia (in red) with all SN Ia from the literature observed in the NIR (all colors). Figure is taken from Weynat et al. (2014).

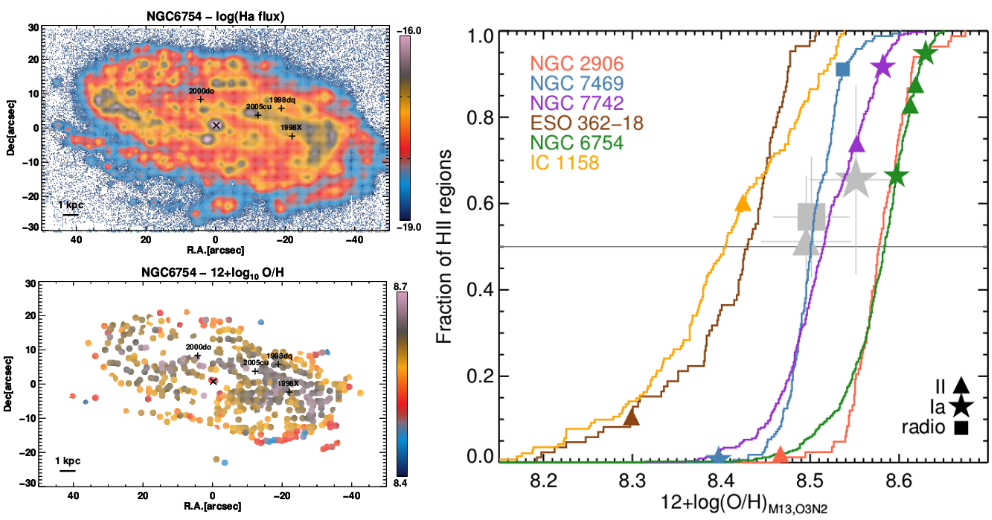

Fig. 2: (Left) Hα emission map of NGC 6754 observed during the MUSE Science Verification (PI: Galbany). The positions of the 4 SNe this galaxy hosted are marked with '+'. We run a segmentation code in this Hα map to select HII regions. Below, we show the result of stacking the spectra within each HII region, measure the oxygen abundance in each HII regions, and represent the variation in a HII region map. (Right) HII region statistics for the 6 galaxies studied in Galbany et al. (2016). The distributions are constructed with the oxygen abundance values measured in all HII regions of each galaxy, and the symbols represent the parent HII region of the SNe.

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 with the following parameters 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 our proposal is submitted as a 'filler' we set conditions to: 7 days from new moon; airmass 1.4; 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 ∼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, [N II], [O III], Hβ). In many galaxy regions we will obtain much higher S/N in the continuum, and this will allow more detailed analysis modeling stellar populations, using absorption line indices as an indicator of stellar metallicities in the place of gas phase values. This is required for the small number of elliptical galaxies included in our sample. Together with 2×220 second sky exposures and overheads, this totals roughly 1 hr per galaxy. The extent of all galaxies in our sample is covered by one MUSE pointing, with the exception of four targets that will need multiple pointings. Hence, we require 45 hrs to observe our sample of 36 host galaxies, however *we recall that this is a 'filler' proposal, where any amount of data obtained will be beneficial to our project.*

We previously obtained MUSE SV data, where we observed the galaxy NGC 6754. These data were obtained with very similar conditions/observing strategy to that outlined above, and show that with those exposure times we are able to make the necessary measurements. We have already published two papers based on these data (Sanchez et al. 2015, Galbany et al. 2016). Within our team are world experts on the reduction, analysis and interpretation of IFS galaxy observations (Co-Is: Sánchez, Falcón, Pérez, Galbany, lead much of the analysis from the CALIFA program). 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.

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, 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

292.D-5042: 3hr SM FORS2; data reduced (ATEL: 6014), paper in preparation (P.I. Anderson);
094.D-0290: 3n VM VIMOS, 7,5h SM SINFONI; 1 paper in press (PI: Kuncarayakti);
094.D-0358: 2.2hr DDT FORS2; data reduced (ATEL 7162), paper in preparation (P.I. Bufano);
094.D-0283: 47hr SM FORS2; 1 paper published (Anderson et al. 2016) (P.I. Anderson);
60.A-9344: 2hr SV MUSE; 1 paper submitted (P.I. Kuncarayakti);
60.A.9329: 2hr SV MUSE; 2 papers published (Sanchez et al. 2015, Galbany et al. 2016) (P.I. Galbany);
095.D-0091: 99hr SM MUSE; data reduced, analysis underway (P.I. Anderson);
095.D-0172: 3n VM MUSE; data reduction in process (PI: Kuncarayakti);
096.D-0296: 95.5hr SM MUSE; data reduction in process (P.I. Anderson);
296.D-5003: 2hr DDT MUSE; paper submitted (P.I. Anderson);
097.D-0-408: 99hr SM MUSE; data not yet acquired (P.I. Anderson);

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.

We checked for available observations of all of our targets on the ESO archive, and indeed in two cases (PTF11qpc, SN2012fr) we found suitable observations, hence these have been removed from the sample.

9b. GTO/Public Survey Duplications:

No.

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

Anderson, J.P., et al., 2015, PASA, 32, 19: Statistical Studies of Supernova Environments

Anderson, J.P., et al., 2015, MNRAS, 448, 732: On the environments of SNe Ia within host galaxies

Catalán-Torrecilla, C., et al., 2015, A&A 584, 87: Star Formation in the Local Universe from the CALIFA sample. I. Calibrating the SFR using IFS data

Friedman, A. S., Wood-Vasey, W. M., et al, 2015, ApJS, 220, 9: CfAIR2: NIR Light Curves of 94 Type Ia SNe

Galbany, L., Anderson, J. P., et al., 2016, MNRAS, 455, 4087: Characterizing the environments of supernovae with MUSE

Galbany, L., et al., 2014, A&A, 572, 38: Nearby supernova host galaxies from the CALIFA Survey: I. Sample, data analysis, and correlation to star-forming regions

Galbany, L., et al., 2016, A&A, accepted, arXiv:1603.07808: Nearby supernova host galaxies from the CALIFA Survey: II. Supernova environmental metallicity

Moreno-Raya, M. E., et al., 2016, ApJL, 818, 19: On the dependence of the type Ia SNe luminosities on the metallicity of their host galaxies

Sánchez, S., Galbany, L., et al., 2015, A&A, 573, 105: Census of H II regions in NGC 6754 derived with MUSE: Constraints on the metal mixing scale

Sánchez-Menguaino, L., et al., 2016, A&A, 587, 70: Shape of the oxygen abundance profiles in CALIFA face-on spiral galaxies

Weyant, A., Wood-Vasey, W. M., et al., 2014, ApJ, 784, 105: SweetSpot: Near-infrared Observations of 13 Type Ia Supernovae from a New NOAO Survey Probing the Nearby Smooth Hubble Flow

Ponder, K. A., Wood-Vasey, W. M., et al., 2015, ApJ, accepted, astro-ph:1511.04647: Incorporating Astrophysical Systematics into a Generalized Likelihood for Cosmology with Type Ia Supernovae

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	PSNJ03034	03:03:47.9	+00:24:14.6	1			SDSSJ030347.55	
A	LSQ13crf	03:10:50.26	+01:25:19.19	1			GALEXASCJ03105	
A	LSQ12fmx	03:12:52.93	-00:12:23.92	1			2MASXJ03125293	
A	SN2011ha	03:57:40.29	+10:09:51.10	1			2MASXJ03574051	
A	LSQ13cwp	04:03:50.24	-02:39:27.10	1			2MASXJ04035024	
A	SN2014dm	04:08:07.12	-08:49:37.10	1			NGC1516	
A	LSQ12fuk	04:58:15.81	-16:18:00.20	1			GALEXASCJ04581	
A	iPTF13dge	05:03:35.09	+01:34:17.00	1			NGC1762	
A	PSNJ07250	07:25:00.41	+23:47:03.20	1			NGC2370	
A	CSS130317	08:28:47.99	+29:30:37.10	1			2MASXJ08284799	
A	PS15mb	08:59:40.20	+15:11:12.50	1			2MFGC07022	
A	CSS121114	09:02:02.18	+10:17:59.74	1			SDSSJ090202.19	
A	ASASSN-15ho	09:09:23.89	-04:43:30.10	1			2MASXJ09092454	
A	ASASSN-15hg	09:53:48.62	+09:11:37.80	1			CGCG063-098	
A	PS15mt	09:54:44.25	+23:11:51.90	1			SDSSJ095444.27	
A	PTF11qmo	10:06:48.60	-07:41:13.30	1			2MASXJ10064866	
A	LSQ14aeg	10:19:36.79	+19:33:20.30	1			2MASXJ10193682	
A	PSNJ1029	10:29:27.99	+22:00:46.80	1			UGC05691	
A	PS15aez	11:00:09.81	+05:33:48.80	1			2MASXJ11000988	
A	SN2013cb	11:35:01.95	+16:07:12.23	1			SDSSJ113501.95	
A	LSQ14ahm	11:41:22.63	-12:23:58.80	1			GALEXASCJ11412	
A	SN2014aa	11:45:03.58	+19:58:25.40	3			NGC3861	
A	SN2012cg	12:27:12.83	+09:25:12.90	1			NGC4424	
A	LSQ14xi	12:30:40.89	-13:46:22.80	1			2MASXJ12304088	
A	SN2013be	12:36:27.64	+11:45:28.00	3			IC3573	
A	PTF11qri	12:47:06.30	-06:19:43.15	1			LCRSB124431.1	
A	SN2011jh	12:47:15.30	-10:03:47.60	3			NGC4682	
A	SN2012bo	12:50:46.02	-14:16:06.30	1			NGC4726	
A	SN2011iy	13:08:58.38	-15:31:04.00	4			NGC 4984	
A	SN2013cs	13:15:13.14	-17:57:58.40	1			ESO576-G017	
A	LSQ14age	13:24:08.54	-13:26:29.90	1			GALEXASCJ13240	
A	SN2013da	13:45:36.47	-07:19:34.10	1			2MASXJ13453653	
A	PS1-14ra	14:41:29.02	+09:25:51.50	1			IC1044	
A	PSNJ15044	15:04:40.55	+12:38:00.70	1			NGC5837	
A	LSQ14act	15:59:44.65	-10:26:40.80	1			2MASXJ15594429	

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Target Notes: All targets above are SN Ia from the SweetSpot sample well-observable from Paranal from January to March 2017. The transient name is given in the first column, followed by the RA and Dec of its host galaxy. When available the galaxy name is also listed. For targets with multiple pointings the total time is indicated: 3hrs is 3 pointings. At phase 2 these pointings will be given priorities such that those containing SN positions are observed first. We would still require to observe another set of 20 galaxies during semester P99 (see box 4b), that are not observable during this semester (RA 17h to 3h).

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
98	MUSE	A	WFM-NOAO	-

6b. Co-investigators:

...continued from Box 6a.

S.	González-Gaitán	Universidad de Chile,Cerro Calan,CL
H.	Kuncarayakti	Universidad de Chile,Cerro Calan,CL
S.	Sánchez	UNAM,Instituto de Astronomia,MX
M.	Stritzinger	University of Aarhus,DK
F.	Förster	Other,CL
P.	James	Astrophysics Research Institute,Liverpool John Moores University,UK
M.	Phillips	Las Campanas Observatory,US
J.	Falcón-Barroso	Instituto de Astrofisica de Canarias, Headquarters,E
E.	Perez	Instituto de Astrofisica de Andalucia (IAA),E
E.	Aquino	ESO Office Santiago,ESO
J.L.	Prieto	Universidad Diego Portales,CL
J.	Lyman	University of Warwick,UK
F.	Rosales-Ortega	Instututo Nacional de Astrofisica Optica y Electronica (INAOE),MX
J. C.	Maureira	Other,CL
L.	Wang	Universidad de Chile,Cerro Calan,CL
A.	Razza	Universidad de Chile,Cerro Calan,CL

11a. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
	...continued from box 11.							
A	PS15sv	16:13:11.61	+01:35:31.80	1			GALEXASCJ16131	