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APPLICATION FOR OBSERVING TIME PERIOD: **96A**

Important Notice:

1. Title Category: **D–5**

The All-weather MUse Supernova Integral field Nearby Galaxies (AMUSING) survey II: ASAS-SN supernova rates with respect to environment properties

2. Abstract / Total Time Requested

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

The dependence of the supernova (SN) rate on stellar population properties such as age and metallicity has important implications for constraints on progenitors, the understanding of galaxies, and the use of SNe as tools to probe the Universe. To-date, the vast majority of SN rates have been estimated using galaxy-targeted searches, and have been achieved with respect to global host galaxy properties. Here, we propose MUSE observations of the hosts of SNe discovered by the All-Sky Automated Survey for Supernovae (ASAS-SN), the first all-sky, un-targeted supernova search. This will allow SN rates to be calculated with respect to environment properties such as age and metallicity, using SNe discovered through a search unbiased towards galaxy properties. These measurements will constrain the delay time of progenitors of different types, determine the importance of progenitor metallicity, together with investigating the influence of host galaxy extinction.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	96	MUSE	99h	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 and bad seeing conditions, and 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 last semester: SNe Ia (mainly discovered through targeted searches) environments with respect to transient properties. Here, we focus on SN rate calculations using an un-targeted SN search, to directly constrain the effects (on rates) of population parameters such as age and metallicity.

6. Principal Investigator: Joseph Anderson, janderso@eso.org, ESO, ESO Office Santiago

6a. Co-investigators:

L.	Galbany	Universidad de Chile,Cerro Calan,CL
H.	Kuncarayakti	Universidad de Chile,Cerro Calan,CL
S.	Sanchez	UNAM,Instituto de Astronomia,MX
T.	Kruehler	ESO Office Santiago,ESO

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7. Description of the proposed programme

A – Scientific Rationale: The rate of supernovae (SNe) is directly tied to the properties of their parent stellar populations. Hence, constraining rates with respect to population properties such as age and metallicity allows strong constraints to be made on progenitors. At the same time, SNe drive many astrophysical processes, and their relative rates have important impact on our understanding of the Universe and its evolution. SNe drive the chemical evolution of the Universe as they are the main producers of heavy elements. While the majority of iron-peak elements are formed by type Ia SNe (SNe Ia), core collapse (CC) SNe are the main producers of intermediate mass elements. Given the distinct delay times (time between star formation, SF, and explosion) between SNe Ia and CC SNe, estimates of their relative rates provide strong constraints on the chemical evolution of galaxies and the Universe as a whole (e.g. Kobayashi & Nomoto 2009). In addition, the large energies supplied by SNe affect their immediate environments, and can drive dynamical processes within galaxies and their evolution. The bulk of massive stars explode as SNe II, and hence these events are directly linked to the SF rate, and can be used as tracers of how this changes with respect to age and metallicity.

Traditional SN searches target nearby bright galaxies in order to maximise the number of detections. The LOSS program (Li et al. 2011) investigated how the SN rates correlate with galaxy colour, and related this to ages of distinct progenitor populations. However, rates from such a program are biased against SNe in low-luminosity galaxies. Correlating rates with broad observational parameters such as global host colour or Hubble type (as done in the majority of other rate calculations) also means that direct constraints on progenitor properties such as age and metallicity are often weak and degenerate. These issues can be significantly improved by a) estimating rates from SNe discovered by searches which repeatedly scan the sky with wide field of views (FoV) (see e.g. Bazin et al. 2009), and b) observing hosts with large FoV integral field spectrographs (IFS), to obtain spectral information of immediate explosion sites in relation to their global properties. This allows rate calculations to be made with respect to environmental parameters much more directly, and hence much stronger constraints can be made on progenitors.

We propose to observe host galaxies of SNe discovered by the All-Sky Automated Survey for Supernovae (ASAS-SN, Shappee et al. 2014), with MUSE. ASAS-SN scans the whole sky repeatedly every 2–4 days searching for SNe down to $V\sim$17 mag (see Fig. 1a). Hence, it is not biased towards bright galaxies (i.e. it is 'un-targeted', see Fig. 1b) meaning that a much more accurate SN rate can be estimated. The $1'\times1'$ FoV of MUSE will allow galaxy-wide SN environment studies, where analyses of both H II region emission lines, together with fits to the environment continuum will constrain properties of host parent stellar populations. Previous environments studies have concentrated on individual spectral features (e.g. Hα, see Anderson et al. 2015 and references therein) over the full extent of galaxies, or spectral observations of individual regions (see e.g. Anderson et al. 2010, Modjaz et al. 2011). In Galbany et al. (2014) the power of large FoV IFU studies for SNe environments was demonstrated, where environmental properties of explosion sites were compared to global host properties, and both were used to constrain progenitor differences between SN types. However, that SN sample was extremely heterogeneous, making any SN rate impossible. The combination of the galaxy un-targeted ASAS-SN survey and MUSE observations will allow SN rates to be accurately calculated with respect to stellar population properties such as age, metallicity and extinction for the first time. Investigating how the rate changes with these parameters will produce strong constraints on SN progenitors, and hence the continued use of SNe as probes of other processes in the Universe.

This proposal is a continuation of our All-weather MUse Supernova Integral field Nearby Galaxies (AMUSING) survey, which observes SN host galaxies with relaxed observing constraints. The project is building a database of MUSE SN host galaxies, and will be used to elucidate many questions pertaining to SN and galaxy physics. *It is planned that around 1 year after each observing season ends, public releases will be made of reduced data cubes, plus basic measured galaxy parameters.*

B – Immediate Objective: We propose MUSE observations of a total of 65 SN host galaxies (17 SNe II, 47 SNe Ia and 1 SN Ib), plus one candidate tidal disruption event, all discovered by ASAS-SN. These will be used to extract information on both the *immediate environments of SN explosions, together with all regions within host galaxies with sufficient flux*, in order to constrain the full range of stellar populations found within hosts. This will be achieved through measuring emission line fluxes and equivalent widths (EWs) of H II region spectral features (such as Hα, [N II], Hβ, [O III]), fitting stellar population models to extracted spectra, plus searching for and measuring the strength of narrow absorption features such as NaD. These measurements will then be analysed to estimate population ages (from emission line EWs, plus stellar population model fits), oxygen abundances (ratios of strong emission lines, using diagnostics such as those from Marino et al. 2013, plus model fits), and extinction (from the Balmer decrement, and the strength of NaD absorption). Parameters will be extracted for exact SN sites, global host properties, but also all regions within the hosts enabling spaxel statistics. Hence, one can ask questions such as: do certain SN types explode within higher or lower metallicity regions than the median of their host galaxies (see Fig. 2)? The requested data will be used to:

1) derive SN rates with respect to stellar population age, metallicity, and extinction. This will be achieved through measuring the numbers of SNe in different bins of stellar population properties.

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

2) constrain both the delay-time distribution of SNe (which affords direct constraints on the age of the parent progenitor population), and stellar evolution models using the above rates.
3) obtain spaxel statistics to determine if certain SN types 'prefer' higher or lower age, metallicity, extinction regions of their hosts, and further use this to constrain progenitor properties, and stellar evolution models.
4) investigate the environments of individual, well-studied transients, enabling investigation into trends between transient and environment parameters.
These data are also extremely useful for studies of galaxy dynamics, stellar populations, and chemical evolution. Our team is comprised of experts in the fields of environments, SN searches, 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 recently obtained MUSE SV data (P.I. L. Galbany, see Fig. 2), and in Sanchez et al. (2015) we present one of the largest ever catalogues of H II regions obtained for a single galaxy. We are also preparing a paper on the SNe within that galaxy, which will serve as a pilot study to the current statistical sample.
With this proposal we will obtain MUSE observations of 66 transient host galaxies. The target list is formed from all SNe discovered by ASAS-SN before 08–01–2015 (this limit is set to avoid contamination of SN light) which are observable from Paranal. This means a small number of elliptical galaxies are included, where we will fit stellar population models to the continuum light in order to extract population parameters.
Above we outlined our main goals and the possibilities now available through such studies enabled with MUSE. However, this is merely the tip of the iceberg. MUSE opens the era of 'big data' in spectroscopic terms, where data mining will become increasingly important (e.g. Ball & Bruner 2010). These data will open many new avenues for research in the field of SN environments and beyond.
REFERENCES: Anderson et al., 2010, MNRAS, 407, 2660; Anderson et al., 2015, MNRAS, 448, 732; Ball & Brunner, 2010, IJMPD, 19, 1049; Bazin et al., 2009, A&A, 499, 653; Galbany et al., 2014, A&A, 572, 38; Kobayashi & Nomoto, 2009, ApJ, 707, 1466; Li et al., 2011, MNRAS, 412, 1473; Marino et al., 2013, A&A, 559, 114; Modjaz et al., 2011, ApJ, 731, 4; Sanchez et al., 2015, A&A, 573, 105; Shappee et al., 2014, ApJ, 788, 48

Attachments (Figures)

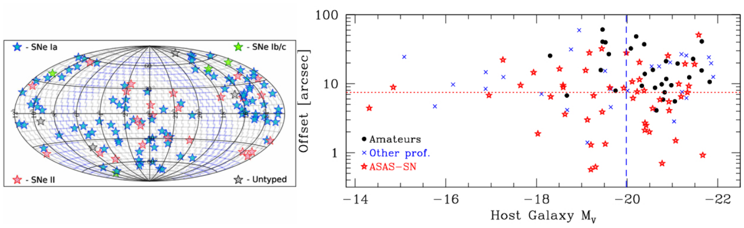

Fig. 1a (left): The all-sky distribution of SNe discovered by ASAS-SN. Fig. 1b (right) The distribution of bright supernovae as a function of absolute mag. of the host and the offset of the SN from its center. Among searches for bright SNe, ASAS-SN appears to be the least biased, discovering supernovae across the entire parameter space (giant and dwarf galaxies, galaxy cores and outskirts).

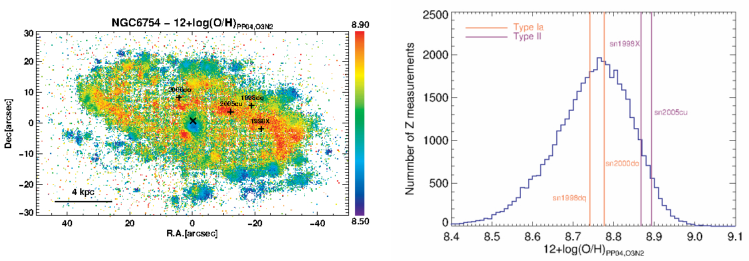

Fig. 2a (left): MUSE SV data of NGC 6754 showing the oxygen abundance map of the galaxy derived from the ratio of strong H II region emission lines. The explosion sites of 4 SNe are indicated. Fig. 2b (right) Histogram of these estimated oxygen abundances as compared the abundances of those 4 SNe (in essence, this is what we mean by 'spaxel statistics'). Such information has implications for the importance of progenitor metallicity on the rate of different SN types.

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. While bright time will affect our detected signal, especially in the blue, even in these cases we expect to detect at least Hα and [N II], and hence the majority of our science goals will be achieved.

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 (the galaxy continuum will be used for comparison to stellar population modeling, but this is of secondary importance). However, before execution the brightness of H II regions within these galaxies is unknown. Therefore, 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″. 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 modelling 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. In some cases, multiple pointings are needed to cover the full spatial extent of host galaxies. Hence, we require 99 hrs to observe our sample of 66 host galaxies, however *we recall that this is a 'filler' proposal, where any amount of data obtained will be beneficial to our project.*

We have recently 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 a paper based on these data (Sanchez et al. 2015). Within our team are world experts on the reduction, analysis and interpretation of IFS galaxy observations (Co-Is: Sánchez, Falcón, Perez, Galbany, lead much of the analysis from the CALIFA program). In addition, co-I Kruehler is the MUSE instrument fellow. Hence, while IFS data and their analysis can sometimes prove somewhat daunting, our team provides all the required knowledge to fully exploit this gold mine of data.

8a. Telescope Justification:

MUSE at the VLT is the only currently available 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 Sof N 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

092.D-0420: 4hr SM FORS2; data published in Lyman et al. (2014) (P.I. Levan)
093.D-0318: 3n VM SINFONI/VIMOS; data obtained, paper in preparation (PI: Kuncarayakti)
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; data reduced, analysis underway (PI: Kuncarayakti)
094.D-0358: 2.2hr SM FORS2; data reduced (ATEL 7162), paper in preparation (P.I. Bufano);
094.D-0283: 47hr SM FORS2; data reduced, paper in preparation (P.I. Anderson)
094.D-0290: 2n VM VIMOS, 7.5hrs SM SINFONI; data reduction in progress (P.I. Kuncarayakti);
60.A-9344: 2hr SV MUSE; data reduced and analysis underway (P.I. Kuncarayakti);
60.A.9329: 2hr SV MUSE; data reduced, 1 paper published (Sanchez et al. 2015) (P.I. Galbany)
095.D-0091: 99hr SM MUSE; data not yet obtained (P.I. Anderson)
095.D-0172: 3n VM MUSE; data not yet acquired (PI: Kuncarayakti)

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.

Are the data requested in this proposal in the ESO Archive (http://archive.eso.org)? No.

9b. GTO/Public Survey Duplications:

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

Below is a sample of publications within the last two years. However, there are many more publications than can be listed here focussing on SN environments, and IFU observations of galaxies.

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

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

Sánchez, S., et al., 2015, A&A, 574, 47: Imprints of galaxy evolution on H II regions. Memory of the past uncovered by the CALIFA survey

Anderson, J.P., et al. 2014, ApJ, 786, 67: Characterizing the V-band Light-curves of Hydrogen-rich Type II Supernovae

Holoien, T. W.-S., et al., 2014, arXiv 1411.3322: Discovery and Observations of the Unusually Luminous Type-Defying II-P/II-L Supernova ASASSN-13co

Holoien, T. W.-S., et al., 2014, ApJ, 785, 35: Discovery and Observations of ASASSN-13db, an EX Lupi-type Accretion Event on a Low-mass T Tauri Star

Anderson, J.P., et al. 2014, MNRAS, 441, 671: Analysis of blueshifted emission peaks in Type II supernovae

Sánchez, S., et al., 2014, A&A, 563, 49: A characteristic oxygen abundance gradient in galaxy disks unveiled with CALIFA

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

Kuncarayakti, H., et al., 2013, AJ, 146, 31: Integral Field Spectroscopy of Supernova Explosion Sites: Constraining the Mass and Metallicity of the Progenitors. II. Type II-P and II-L Supernovae

Kuncarayakti, H., et al., 2013, AJ, 146, 30: Integral Field Spectroscopy of Supernova Explosion Sites: Constraining the Mass and Metallicity of the Progenitors. I. Type Ib and Ic Supernovae

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	ASASSN-13an	13 45 36.5	-07 19 35	1			PGC 170294	
A	ASASSN-13ar	01 18 43.2	-07 27 05	2			PGC 004701	
A	ASASSN-13av	21 26 32.4	+12 11 03	1			NGC 7068	
A	ASASSN-13bb	01 55 22.0	+06 36 43	2			UGC 01395	
A	ASASSN-13cc	05 32 48.3	-14 03 46	6			NGC 1954	
A	ASASSN-13ch	16 16 33.8	-00 35 20	1			PGC 057687	
A	ASASSN-13cj	16 17 11.0	+04 33 15	1			CGCG 051-075	
A	ASASSN-13co	21 40 38.9	+06 30 35	1			PGC 067159	
A	ASASSN-13cp	15 33 48.9	+21 08 10	1			PGC 055442	
A	ASASSN-13cu	00 40 10.5	-10 26 26	1			PGC 002414	
A	ASASSN-13dd	09 07 36.6	+03 23 34	2			NGC 2765	
A	ASASSN-13dm	03 02 11.1	+15 55 39	1			PGC 2816341	
A	ASASSN-14ad	12 40 11.3	+18 03 42	1			anon	
A	ASASSN-14at	17 55 05.4	+18 15 26	1			UGC 11037	
A	ASASSN-14az	23 44 48.2	-02 06 54	1			anon	
A	ASASSN-14ba	10 21 31.9	+08 24 20	1			anon	
A	ASASSN-14bf	13 58 13.1	+17 31 52	1			CGCG 103-030	
A	ASASSN-14co	15 57 30.3	+01 06 43	1			CGCG 023-005	
A	ASASSN-14cu	12 47 02.7	-24 14 44	1			anon	
A	ASASSN-14db	22 02 01.8	-70 02 30	1			ESO 075-G049	
A	ASASSN-14dd	07 45 16.0	-71 24 38	4			NGC 2466	
A	ASASSN-14dl	12 21 49.0	-24 10 06	2			ESO 506-G004	
A	ASASSN-14dp	11 21 57.9	-37 53 58	2			ESO 319-G15	
A	ASASSN-14dq	21 57 59.7	+24 16 00	2			UGC 11860	
A	ASASSN-14dz	15 05 54.8	+12 44 39	1			Mrk 842	
A	ASASSN-14ef	22 12 10.4	-27 49 38	1			PGC 068269	
A	ASASSN-14eo	01 57 36.1	+16 46 22	1			PGC 007377	
A	ASASSN-14eu	15 00 38.8	-03 51 30	1			PGC 053612	
A	ASASSN-14ew	20 22 00.0	-51 47 48	1			anon	
A	ASASSN-14fa	02 52 22.3	-31 49 02	1			ESO 416-G039	
A	ASASSN-14fd	12 46 14.9	-40 48 47	1			PGC 043070	
A	ASASSN-14fo	20 34 06.2	-01 57 59	1			anon	
A	ASASSN-14fw	23 49 06.7	-07 02 55	1			MCG-01-60-44	
A	ASASSN-14gm	00 59 50.1	-07 34 41	6			NGC 337	
A	ASASSN-14hp	21 30 30.2	-70 38 49	1			anon	

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Target Notes: All targets above are transient host galaxies. 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: 2hrs is 2 pointings. At phase 2 these pointings will be given priorities such that those containing SN positions are observed first.

12. Scheduling requirements

13. Instrument configuration

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

6b. Co-investigators:

	...continued from Box 6a.	
J.L.	Prieto	Universidad Andres Bello,CL
S.	Gonzalez-Gaitan	Universidad de Chile,Cerro Calan,CL
F.	Förster	Other,CL
P.	James	Astrophysics Research Institute,Liverpool John Moores University,UK
M.	Hamuy	Universidad de Chile,Cerro Calan,CL
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.	Lyman	University of Warwick,UK
S.	Schulze	Institute of Astrophysics,Pontificia Universidad Catolica de Chile,,CL
K.	Stanek	Ohio State University,Department of Astronomy,US
B.	Shappee	Carnegie Institution of Washington,The Carnegie Observatories,US
C.	Kochanek	Ohio State University,Department of Astronomy,US
T.	Holoien	Ohio State University,Department of Astronomy,US
S.	Dong	Other,CN

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	ASASSN-14hr	01 50 41.3	-14 31 03	1			anon	
A	ASASSN-14hu	06 43 21.6	-69 38 30	1			ESO 058-G012	
A	ASASSN-14ig	01 16 04.9	-61 37 20	2			ESO 113-G032	
A	ASASSN-14ih	22 34 29.8	-24 39 52	1			PGC 069190	
A	ASASSN-14ii	22 16 40.8	-36 09 41	1			anon	
A	ASASSN-14il	00 45 32.6	-14 15 33	1			anon	
A	ASASSN-14iz	20 21 51.5	-31 17 23	1			ESO 462-G009	
A	ASASSN-14jb	22 23 16.6	-28 58 51	4			ESO 467-G051	
A	ASASSN-14jc	07 35 35.5	-62 46 10	1			anon	
A	ASASSN-14jg	23 33 12.2	-60 34 20	1			PGC 128348	
A	ASASSN-14jz	18 44 43.3	-52 48 19	1			anon	
A	ASASSN-14kd	22 53 24.7	+04 47 58	1			anon	
A	ASASSN-14ko	05 25 18.1	-46 00 21	1			ESO 253-G003	
A	ASASSN-14kp	00 39 52.6	-38 03 49	1			anon	
A	ASASSN-14kq	23 45 14.8	-29 47 00	1			anon	
A	ASASSN-14kr	12 54 13.1	-07 38 50	1			anon	
A	ASASSN-14lo	11 51 52.5	+18 32 47	2			UGC 06837	
A	ASASSN-14lp	12 45 08.6	-00 27 43	5			NGC 4666	
A	ASASSN-14lq	22 57 14.8	-20 58 01	1			anon	
A	ASASSN-14lt	03 11 02.5	-13 06 35	1			IC 0299	
A	ASASSN-14lu	14 10 39.7	-02 41 01	1			anon	
A	ASASSN-14lv	23 32 07.4	-41 16 10	1			anon	
A	ASASSN-14li	12 48 15.2	+17 46 26	1			PGC 043234	
A	ASASSN-14lw	01 06 47.9	-46 59 04	1			anon	
A	ASASSN-14ma	23 55 09.0	+10 12 53	1			anon	
A	ASASSN-14me	01 26 40.1	-57 59 51	2			ESO 113-G047	
A	ASASSN-14mf	00 04 54.6	-32 26 16	1			anon	
A	ASASSN-14mg	02 53 58.1	-21 38 55	1			anon	
A	ASASSN-14mw	01 41 30.9	-65 36 56	1			PGC 006240	
A	ASASSN-15ab	14 03 08.5	-38 28 31	2			ESO 325-G045	
A	ASASSN-15aj	10 52 53.6	-32 55 39	3			NGC 3449	