European Organisation for Astronomical Research in the Southern Hemisphere

OBSERVING PROGRAMMES OFFICE • Karl-Schwarzschild-Straße 2 • D-85748 Garching bei München • e-mail: opo@eso.org • Tel.: +49 89 320 06473

APPLICATION FOR OBSERVING TIME

PERIOD: **97A**

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 III: constraining supernova progenitors through understanding the origin of narrow absorption features

2. Abstract / Total Time Requested

Total Amount of Time:

Type Ia SNe (SNe Ia) are used as accurate distance indicators. However, the nature of their progenitors is still unclear. In particular, differentiating between the single degenerate (WD and non-degenerate donor star) and double degenerate (two WDs) scenarios is a key issue. The single degenerate model received significant backing through the detection of blue-shifted narrow sodium absorption within SNe Ia spectra, as compared to other SN types, which has been attributed to circumstellar material. However, the exact origin of this feature is hotly debated. In this proposal we will constrain its nature using MUSE observations of SN host galaxies. SNe with intermediate-resolution spectroscopic observations, where narrow absorption features can be detected, will be compared with environment observations tracing ISM properties. This will constrain the nature of the narrow sodium absorption, while also allowing constraints to be made on progenitor age and metallicity.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	97	MUSE	99h	any	n	n	THN	s	

4. Number of nights/hours

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 to investigate the host galaxies of SNe, where the current science case is distinct from previous semesters.

6. Principal Investigator: janderso

6a. Co-investigators:

L.	Galbany	1822
T.	Kruehler	1496
S.	González-Gaitán	1822
L.	Wang	1822

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

7. Description of the proposed programme

A – Scientific Rationale: Studies of host galaxies of supernovae (SNe), can provide constraints on their progenitors, and help us understand specific transient features in relation to their environment. While core-collapse (CC) SNe are only found in star-forming galaxies, Type Ia SNe (SNe Ia) are found to explode in both early and late types, and their presence in the former constrains (at least a fraction of) their progenitors to be evolved systems. However, the exact range of ages from which progenitors explode is not well constrained. Neither is its relation to progenitor metallicity. Indeed, a strong debate exists as to whether SNe Ia arise from accretion onto a single white dwarf (WD) star (SD scenario), or from the coalescence of two WDs (DD scenario). These questions are particularly pertinent given the use of SNe Ia in many other areas of astrophysics. Similar issues persist in our understanding of core-collapse (CC) SNe. Here, the main questions are to the nature of mass-loss mechanisms late in the evolution of progenitors which produce the observed transient diversity.

Both SNe Ia and CC SNe show narrow absorption features within their spectra. These are generally attributed to ISM, however there have also been arguments for a circumstellar material (CSM) origin. If the lines arise from the former then understanding their strength in relation to line of sight extinction is crucial to obtain intrinsic absolute magnitudes and colours. A CSM origin would have strong constraints on the nature of progenitors and mass-loss processes close to the epoch of explosion. The focus of the current proposal is to understand the origin and nature of these features by comparing SN properties to those of their host environments.

With respect to SNe Ia, specific constraining evidence from recent years has been the detection and excess of blue-shifted (with respect to host galaxy recession velocity) narrow sodium (NaD) absorption in SN Ia spectra, *as compared to other SN types* (see Sternberg et al. 2011, Science, 333, 856; Maguire et al. 2013, MNRAS, 436, 222; Phillips et al. 2013, ApJ, 779, 38). It is difficult to assign this excess to the ISM (where one expects statistically a similar ratio of red- and blue-shifted exponents as found in other SN types), and hence it has been claimed that at least some of the NaD arises from circumstellar material (CSM). It is then argued that this is strong evidence for the SD scenario, where one expects CSM as a result of the massive binary companion. Phillips et al. have shown that other narrow absorption features, in particular diffuse interstellar bands (DIBs) correlate very well with extinction, whereas NaD lines present an excess absorption for a given extinction. This indicates that another source different from ISM may be generating this excess Na absorption. It has also been found that NaD absorption correlates with SN properties (together with colour, Anderson et al. 2015, MNRAS, 448, 732), such as colour evolution and nebular velocities (Förster et al. 2012, ApJ, 772, 19; 2012, ApJ, 754, 21) suggesting a non-ISM origin of the absorbing material. To complicate matters further Park et al. (2015, arXiv 1507.03342) suggested that blue-shifted NaD absorption lines are expected in galactic outflows and have been observed in galactic spectra. It is therefore crucial to understand if the blue-shifts observed in SN spectra are really generated by the ISM or rather by the SN progenitor. Understanding the origin of this excess together with narrow absorption features in general, has strong implications for differentiating progenitor scenarios, and demands further study. With respect to core-collapse (CC) SNe, there is little discussion of the origin and nature of narrow absorption features. However, such a study can bring insights both into the mass-loss of progenitors close to explosion (in the case of a CSM origin), and to line of sight extinction effects on SN colour diversity (ISM). Together with furthering our understanding of SN progenitors, such insights are also crucial for our continued use of SNe (both Ia and CC) as probes of different processes in the Universe.

While Maguire et al. investigated how the presence, nature and magnitude of NaD absorption is correlated with overall galaxy properties, to date no study has analysed the specific environments within host galaxies where SNe –which have sufficient resolution transient spectra to search for narrow ISM/CSM absorption features– are found. This is the focus of the current proposal: understanding the origin and nature of narrow NaD absorption in intermediate-resolution SN spectra ($R\sim10000$ or greater), and its relation to either ISM or CSM material, through observing host environments with MUSE. Our sample is built from those investigations listed above (Sternberg; Maguire; Phillips) who obtained intermediate-resolution SN spectra and analysed the properties of narrow absorption lines. We also include other SNe in the literature with published spectra of sufficient resolution (needed in order to detect and characterise narrow absorption features). Both SNe Ia and CC SNe are included and the latter will be used a) as a control sample with which to compare the SN Ia analysis, and b) provide its own study of line of sight material towards massive star explosions hence constraining both extinction estimates and pre-SN mass-loss.

In addition, observations will be used to further constrain the age and metallicity of the SN Ia and CC progenitor population. The planned observations will also allow us to infer stellar population effective extinction laws, R_V. In studies of SNe Ia R_V has been found to be lower than the canonical value of 3.1 measured in the Milky Way (e.g. Conley et al. 2011, ApJS, 192, 1). Here, we can test these conclusions by independently deriving stellar population R_V values for galaxy-wide environments using MUSE.

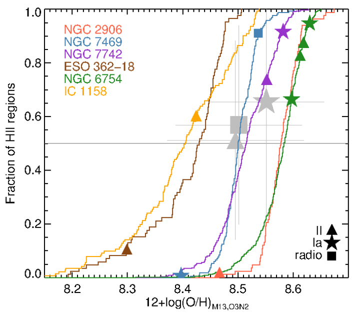
These planned MUSE observations will allow a detailed comparison of the properties ISM/CSM spectral lines observed in SN spectra, with similar lines found in host galaxy environments. While this study will concentrate on line of sight absorption features, many other environment properties such as age and metallicity will be derived, hence further constraining SN progenitors. The key to obtaining MUSE observations is the ability to then map galaxy-wide SN host properties. This means one can analyse where within the overall distribution of host e.g. metallicity (see Fig. 1) or NaD absorption (see Fig. 2) the SN environment falls.

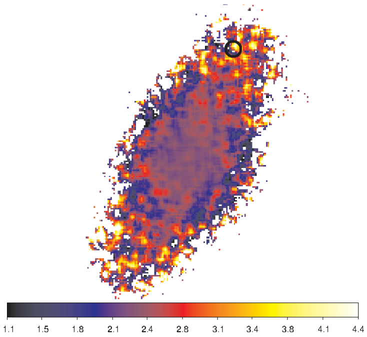
7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

B – Immediate Objective: We propose to obtain MUSE observations of a sample of 54 SN Ia and 22 CC SN host galaxies, where intermediate-resolution spectra are available of the transients. 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 features, such as that of NaD as shown in Fig. 2 (note that the significant NaD absorption expected within spectra of a stellar origin, see e.g. Park at al., will be removed by fitting population sythesis models to the underlying stellar population and subtracting this to leave the ISM component). This will allow a detailed study of the origin and nature of narrow absorption lines observed in SN spectra, leading to strong constraints on progenitor systems and host galaxy extinction. In addition, MUSE data will be used to produce galaxy–wide maps of stellar population parameters such as metallicity, as shown in Fig. 1, together with age, extinction. The immediate goals of this proposal are:
1) Obtain maps of ISM galaxy absorption features and compare these to the nature of the features observed in SN spectra. This will constrain the origin of narrow absorption features in SN spectra, which will have strong implications on SN progenitors, and line of sight extinction.
2) Produce host galaxy maps of: age (through both stellar population modelling and equivalent width measurements), metallicity (through emission line ratios, population modelling, and absorption line ratios when the S/N allows), extinction (from absorption lines, Balmer decrements, and stellar population fitting), and extinction laws (R_V, through fits to the stellar continuum). SN environments will then be placed within these distributions providing further progenitor constraints (see Fig. 1).
3) Compare environmental information to light-curve and spectral properties, to constrain progenitor diversity, and use correlations to further refine the use of SNe to probe astrophysical processes.
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 one paper using MUSE data in Sanchez et al. (2015, A&A, 573, 105) where we present one of the largest ever catalogues of H II regions obtained for a single galaxy. A second paper using those same data, together with other commissioning/SV data has also recently been submitted, and a figure is reproduced in Fig. 1.
Together with allowing strong constraints to be made on SN progenitors, and enabling us to confront the key issue of the origin of blue-shifted sodium absorption, these data provide a gold mine for further study. Our team is already significantly experienced in reducing and analysing such data, and hence we expect many other projects to spawn from the proposed dataset.

Attachments (Figures)





Left: Fig. 1, Cumulative distributions of O3N2 oxygen abundances for 6 galaxies observed with MUSE. In each galaxy distribution the SN environment value is indicated. Such plots show how MUSE data will be used in the study of SN environments. *Right:* Fig. 2, Map of the equivalent width of NaD absorption within the host galaxy of SN 2007hj (with the SN position indicated by the circle), NGC 7461, produced from MUSE observations. Similar maps will be produced for all SN hosts within our sample, and compared to the appearance and strength of narrow absorption features within SN spectra. (We note that a significant fraction of the absorption shown in this plot probably arises from the underlying stellar population. To probe the component related to ISM, this population will first be subtracted by fitting population synthesis models to the spectra.)

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″. 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. Using these exposure times we have already demonstrated the feasibility of detecting narrow absorption in Fig. 2. 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 77 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 a paper based on these data (Sanchez et al. 2015), with a second paper submitted (Galbany et al.). 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). 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 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

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 submitted (P.I. Anderson)
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), another paper submitted (P.I. Galbany)
095.D-0091: 99hr SM MUSE; data reduction in process (P.I. Anderson)
095.D-0172: 3n VM MUSE; data reduction in process (PI: Kuncarayakti)
096.D-0296: 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 four cases we found suitable observations, hence these are removed from the sample and replaced by other SNe which meet our selection criteria. In the following cases: 2003gd, 2012fr, 2007sr, 1986G, 2007af and 2013aa, there are MUSE observations of the target hosts in the archive. However, the previous pointings do not coincide with the position of our SNe, hence we request further observations. One target, 2008C was unobserved as part of our P95 allocation, hence the repeat request here.

9b. GTO/Public Survey Duplications:

No.

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

González–Gaitán, S., et al., 2015, MNRAS, 451, 2212: The rise-time of Type II supernovae

Nicholl, M., et al., ApJ, 807, 18: LSQ14bdq: A Type Ic Super-luminous Supernova with a Double-peaked Light Curve

de Jaeger, T., et al., 2015., ApJ, 807, 63: SN 2011A: A Low-luminosity Interacting Transient with a Double Plateau and Strong Sodium Absorption

Kuncarayakti, H., et al., 2015, A&A, 579, 95: Nebular phase observations of the Type-Ib supernova iPTF13bvn favour a binary progenitor

Smartt, S., et al., 2015, A&A, 579, 40: PESSTO: survey description and products from the first data release by the Public ESO Spectroscopic Survey of Transient Objects

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, PASA, 32, 19: Statistical Studies of Supernova Environments

Pastorello, A., et al., 2015, MNRAS, 449, 1941: Massive stars exploding in a He-rich circumstellar medium - V. Observations of the slow-evolving SN Ibn OGLE-2012-SN-006

Leloudas, G., et al., 2015, MNRAS, 449, 917: Spectroscopy of superluminous supernova host galaxies. A preference of hydrogen-poor events for extreme emission line galaxies

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

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

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

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	2008dh	00 35 11.32	+23 15 15.1	1			2MASX...	
A	2012hd	01 14 07.46	-32 39 07.7	1			IC1657	
A	2003gd	01 36 42.65	+15 44 19.9	1			NGC628	
A	2004fc	01 51 03.85	-09 42 06.9	1			NGC701	
A	2009le	02 09 17.14	-23 24 44.8	2			E478-G006	
A	2007gj	02 19 33.85	-37 48 44.2	3			E298-28	
A	2010A	02 32 39.46	+00 37 10.2	1			UGC2019	
A	2008J	02 34 24.20	-10 50 38.5	3			M-02-07-033	
A	2009ig	02 38 11.61	-01 18 45.1	1			NGC1015	
A	PTF12iiq	02 50 07.76	-00 15 54.4	1			2MASX...	
A	2012fr	03 33 35.99	-36 07 37.7	1			NGC1365	
A	2001el	03 44 30.57	-44 38 23.7	1			NGC1448	
A	2007on	03 38 50.9	-35 34 30	1			NGC1404	
A	PTF12jgb	04 15 01.44	-15 20 53.7	1			2MASX...	
A	2008V	04 29 31.30	-26 42 39.8	1			NGC1591	
A	2007rz	04 31 10.84	+07 37 51.5	1			NGC1590	
A	2009K	04 36 36.77	-00 08 35.6	1			NGC1620	
A	2004ff	04 58 46.19	-21 34 12.0	1			E552-G40	
A	2009kr	05 12 03.30	-15 41 52.2	1			NGC1832	
A	2005gn	05 48 49.07	-24 22 45.5	1			E488-G30	
A	2012hr	06 21 38.46	-59 42 50.6	1			E121-26	
A	2008C	06 57 11.53	+20 26 13.7	1			UGC3611	
A	2008fp	07 16 32.60	-29 19 31.7	2			E428-G14	
A	2008ia	08 50 35.15	-61 16 40.6	1			E125-G006	
A	2008hv	09 07 34.06	+03 23 32.1	2			NGC2765	
A	2009ao	09 38 08.54	+09 31 00.7	1			NGC2939	
A	LSQ12hzj	09 59 12.43	-09 00 08.3	1			2MASX...	
A	2009dq	10 08 49.95	-67 01 57.4	1			IC2554	
A	2002bo	10 18 06.51	+21 49 41.7	1			NGC3190	
A	2012A	10 25 07.39	+17 09 14.6	1			NGC3239	
A	2010ev	10 25 28.99	-39 49 51.2	3			NGC3244	
A	2012aw	10 43 53.76	+11 40 17.9	1			NGC3351	
A	2005Z	10 45 09.18	+22 04 38.3	1			NGC3363	
A	2007am	10 46 33.62	+13 45 09.3	1			NGC3367	
A	2012ht	10 53 22.75	+16 46 34.9	1			NGC3447	

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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
97	MUSE	A	WFM-NOAO	-

6b. Co-investigators:

…continued from Box 6a.

H.	Kuncarayakti	1822
S.	Sánchez	1774
E.	Hsaio	1909
M.	Stritzinger	1909
F.	Förster	5667
P.	James	1134
M.	Hamuy	1822
M.	Phillips	1086
J.	Falcón-Barroso	1393
E.	Perez	1392
E.	Aquino	1261
J.L.	Prieto	8645
J.	Lyman	1241
F.	Rosales	1401
C.	Gutiérrez	1261
A.	Razza	1822
S.	Schulze	1628

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	2005lw	11 08 03.21	-12 29 09.4	1			IC672	
A	2009ds	11 49 04.11	-09 43 44.9	2			NGC3997	
A	2004aw	11 57 50.24	+25 15 55.1	1			NGC3905	
A	2007sr	12 01 52.80	-18 58 21.7	1			NGC4038	
A	2006X	12 22 53.99	+15 48 33.1	1			NGC4321	
A	2012cg	12 27 12.83	+09 25 13.2	1			NGC4424	
A	1994D	12 34 02.37	+07 42 04.7	1			NGC4526	
A	2007rw	12 38 03.64	-02 15 40.1	1			UGC7798	
A	2008aq	12 50 30.42	-10 52 01.4	1			M-02-33-20	
A	2012cu	12 53 29.35	+02 09 39.0	2			NGC4722	
A	2008aw	13 04 14.12	-10 19 12.3	1			NGC4939	
A	2011iy	13 08 58.39	-15 31 04.1	1			NGC4984	
A	2009nr	13 10 58.95	+11 29 29.3	1			UGC8255	
A	2009ev	13 14 17.58	-42 58 48.8	1			NGC5026	
A	1986G	13 25 36.46	-43 01 54.17	1			NGC5128	
A	SNF20080514-002	13 29 13.6	+11 16 33	2			UGC8472	
A	2006E	13 53 28.65	+05 12 22.8	2			NGC5338	
A	2013aj	13 54 00.68	-07 55 43.8	1			NGC5339	
A	2009mz	14 03 24.64	-06 03 31.3	1			NGC5426	
A	2002cr	14 06 37.59	-05 26 21.9	1			NGC5468	
A	2007af	14 22 21.03	-00 23 37.6	1			NGC5584	
A	2013aa	14 32 33.88	-44 13 27.8	1			NGC5643	
A	2006cu	14 47 43.31	+09 39 33.9	1			UGC9530	
A	2006be	15 45 39.00	+28 05 19.2	2			IC4582	
A	2008cg	15 54 15.15	+10 58 25.0	1			FGC1965	
A	SNF20080612-003	16 15 28.6	+19 13 34	1			2MASX...	
A	2004dk	16 21 48.93	-02 16 17.3	1			NGC6118	
A	2001cp	17 11 02.58	+05 50 26.8	2			UGC10738	
A	2006ca	18 22 54.15	+12 26 03.2	2			UGC11214	
A	2008fq	20 25 06.19	-24 48 27.6	1			NGC6907	
A	2002ha	20 47 18.58	+00 18 45.6	1			NGC6962	
A	LSQ12dbr	20 58 51.89	-02 58 27.1	1			anon	
A	2012fw	21 01 58.99	-48 16 25.9	1			E235-37	
A	2006cm	21 20 17.46	-01 41 02.7	2			UGC11723	
A	2007fs	22 01 40.44	-21 30 29.6	2			E601-G5	
A	2002jg	22 19 28.80	+29 23 04.5	2			NGC7253B	
A	2007le	23 38 48.41	-06 31 21.3	1			NGC7721	
A	2012et	23 42 38.82	+27 05 31.5	1			CGCG476-11	
A	2003hg	23 51 24.13	+20 06 38.3	1			NGC7771	
A	2001da	23 53 32.78	+08 07 02.6	1			NGC7780	
A	LSQ12gdj	23 54 43.3	-25 40 34.0	2			E472-G007	
A	2007fb	23 56 52.37	+05 30 31.8	1			UGC12859	