European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **96Z**

DDT

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: **X–0**

Towards Understanding the Population of Ultra-Diffuse Galaxies in Clusters using VLT/VIMOS Spectroscopy

2. Abstract / Total Time Requested

Total Amount of Time:

Recent studies have identified a population of Ultra-Diffuse Galaxies (UDGs, with sizes $r_{eff} > 1.5$kpc) in local clusters. We have performed the first systematic photometric study of these galaxies in eight local clusters (vdBurg+16, subm.), which indicates that these galaxies are highly dark-matter dominated. Preliminary results from our weak-lensing study to *directly* measure their subhalo masses, are consistent with this puzzling result. For a robust interpretation of the lensing measurement, a spectroscopic verification of our statistical background correction, and a characterisation of interlopers, are paramount. We therefore propose this pilot study of a potential large bad-seeing program using VLT/VIMOS spectroscopy, which multiplexing capability optimizes the scientific return of such an investment. This DDT targets 60 UDG candidates in Abell 780, of which we expect to be able to confirm ∼40 to be part of the cluster, based on statistical arguments.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	96	VIMOS	7h	feb/mar	d	1.2	PHO	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:

Due to the large extent of the targeted galaxies, this program can be observed under conditions of bad-seeing with only a modest S/N penalty.

6. Principal Investigator: RFJvdBurg

6a. Co-investigators:

A.	Muzzin	1370
H.	Hoekstra	1716
C.	Sifón	1716

7. Description of the proposed programme

A – Scientific Rationale: There is a great interest in studying the dwarf galaxy population in the Universe. These galaxies are expected to be most sensitive to complex feedback processes such as supernova feedback and stellar winds (Sawala et al. 2010, Simpson et al 2012, Weinmann et al. 2012), and they may help provide an answer to the too big to fail problem (Boylan-Kolchin et al. 2011). Dwarf galaxies exist comprising a range of physical properties, and especially the most diffuse galaxies provide an observational challenge to study. Early studies already identified populations of low surface-brightness galaxies in the field and cluster environments (Impey et al. 1988, Turner et al. 1993, Dalcanton et al. 1997), but such investigations can now be performed to increasingly sensitive limits.

One would naively expect the most diffuse dwarf galaxies to have relatively shallow potential wells, and thus to be most vulnerable to tidal disruption and close encounters in high-density environments. Surprisingly however, a recent study identified a significant population of ultra-diffuse galaxies (UDGs; faint galaxies with effective sizes $r_{\rm eff} > 1.5\,{\rm kpc}$) to be present in the Coma cluster (van Dokkum et al. 2015a). Several other observational studies have followed-up on this work (Mihos et al. 2015, Koda et al. 2015, van Dokkum et al. 2015b) to study this population in the Coma (and some examples in the Virgo-) cluster. A first attempt at a theoretical explanation for their presence in clusters has been made by Yozin & Bekki 2015, but this is limited by the availability of observational constraints.

To improve the constraints provided by this exploratory work, the first systematic study (without a subjective by-eye investigation of galaxy images), was performed in eight clusters in the local ($0.044 < z < 0.067$) Universe (van der Burg, Muzzin, Hoekstra 2016, subm., hereafter vdB16). This study confirmed UDGs to be a general phenomenon in clusters, with an abundance that scales with cluster mass as $N \propto M_{200}{}^{0.93\pm0.16}$. vdB16 measured the radial distribution of UDGs in clusters, and found that these galaxies follow a profile expected for a dynamically old population, which is likely accreted several Gyr ago along with the general population of quiescent galaxies in the clusters. vdB16 also confirmed the view of van Dokkum et al. 2015, namely that UDGs exist down to, and thus seem able to resist the strong tidal forces at, a cluster centric distance of ~ 300 kpc. This resistance to tidal disruption suggests that they have a dark matter fraction of $\gtrsim$95%, even after potential stripping by the violent encounters expected to happen with other galaxies during their time in the clusters.

The estimated dark-matter content of the UDGs is so-far based on indirect measurements and assumptions (related to their radial distribution). To improve upon this, we are currently performing the first weak gravitational lensing study to *directly* measure the masses of UDGs in the vdB16 clusters (Sífon et al., in prep). After accounting for the overal signal induced by the cluster itself, we obtain a tentative *-sigma detection of the subhalo (see Fig. 1). This preliminary result confirms that these UDGs are completely dark-matter dominated, and this may have important implications for our theory of galaxy evolution. The only limitation in the interpretation of the lensing signal is our uncertainty of the back(and fore-)ground sources that enter into the lensing sample. Whereas the study in vdB16 gives the statistical contamination *fraction* (by number), knowing their redshifts is essential to estimate the signal they may contribute to the stacked lensing measurement. In particular for example, contaminating sources that appear to be at higher redshift than the cluster may add significantly to the lensing signal (because their total mass is higher at a given apparent magnitude).

B – Immediate Objective: We propose a pilot spectroscopic study of two three-hour masks with VLT/VIMOS on cluster Abell 780, which will allow us to obtain redshifts for ~60 UDG candidates. Covering an area up to R_{200c} (projected), we expect ~40 of these to be part of the cluster, based on statistical arguments (vdB16). This will greatly enhance the current sample of spectroscopically identified UDGs in clusters (to date, only one confirmed using Keck spectroscopy by van Dokkum et al. 2015b). Of similar importance for the present study, it also gives us a sample of ~ 20 fore- and background objects. Identifying the nature of these contaminants (in particular their redshifts) provides the key unknown for our weak gravitational lensing study. With this missing information we will be able to confirm our weak-lensing mass of these UDGs, providing their first *direct* mass measurement, and proof of their high dark matter content.

Besides this primary science driver for the DDT program, an execution in the next dark-time period (early March) will also help us to demonstrate which science scopes are feasible with a potential larger program (to be proposed with the P98 cycle). Using these proposed DDT data we can already put first constraints on the average stellar ages and metallicities of the UDGs. We will start a study of their projected phase space, as proposed by Weinmann et al. 2011 to be used to study and separate the dynamical histories of different galaxy populations in clusters. The many extra available slits will be placed on more compact cluster dwarf candidates, which serve as a reference in this analysis.

Our simulations show that even a seeing as large as FWHM=1.5" does not severally inpact the significance of the spectroscopic measurements (only 10% extra slit losses compared to a seeing of FWHM=0.7") of these extended galaxies. Most VLT/VIMOS programs have more stringent seeing restrictions (such as the large programs LEGA-C and VANDALS), which make this study an excellent alternative with high expected scientific return when the seeing is above the seeing limit imposed by other programs.

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

We expect the clusters in our sample to be at the ideal redshifts $0.04 \lesssim z \lesssim 0.06$ to maximize scientific merit of VLT/VIMOS, because these clusters are 1) nearby enough that UDGs can be easily identified with minimal contamination from fore- and background interlopers, and yet 2) distant enough that a significant number falls in the VLT/VIMOS FoV, which allows us to multiplex and maximize scientific return.

Attachments (Figures)

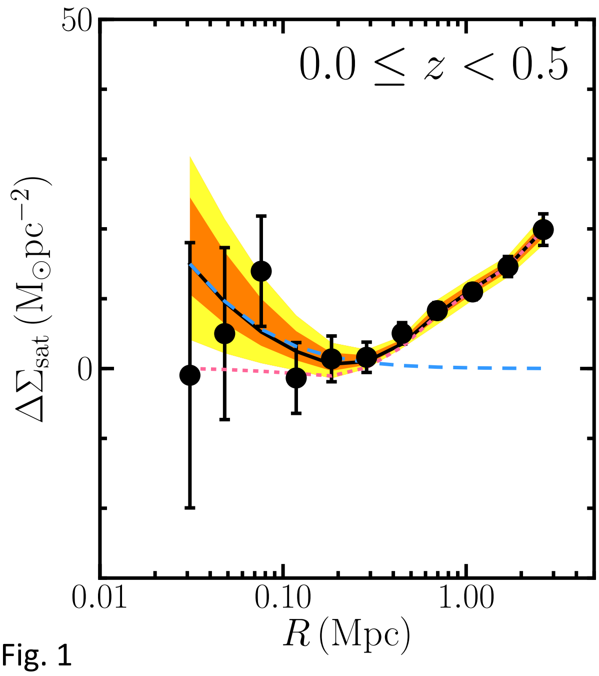

Fig. 1

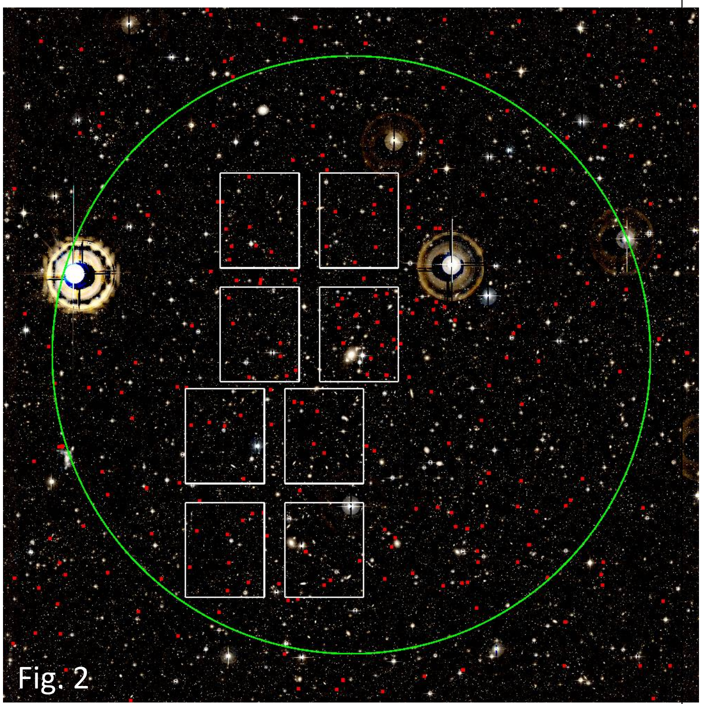

Fig. 2

Fig. 1: A caption for your figure can be inserted here.

Fig. 2: The $g-r$ colour image of Abell 780, with the estimated virial radius R_{200c}, centered on the BCG, shown with the green circle. The red circles mark the identified UDG candidates. The white rectangles mark the area of the cluster covered with two pointings of VLT/VIMOS. Besides covering ~ 60 UDG candidates, the same exposures allow us to go for deep spectroscopic identification of more compact dwarf galaxies, with the same total magnitude as the UDGs. This serves as an important comparison sample.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: Due to the very low surface brightnesses, the observations are only feasible under dark-time conditions. A three-hour integration under dark-time conditions corresponds to a **-hour integration under bright conditions.

Time Justification: (including seeing overhead) Here we illustrate the feasibility of getting a redshift for these things after three hours of integration.

8a. Telescope Justification:

The low surface brightness of these UDGs forces us to consider large-aperture telescopes. VLT/VIMOS provides a relatively large FoV which allows us to simultaneously observe ~ 30 UDGs per exposure. This multiplexing capability makes this the most efficient instrument to help understand their origin.

8b. DDT Justification:

We have a highly exciting preliminary weak-lensing mass measurement of UDGs in clusters, which is the first *direct* measurement of their masses, and this confirms the estimate that these galaxies are completely dominated by dark matter. With this DDT program we will be able to address the main remaining uncertainty which is essential for the analysis, namely to understand the nature of the contaminating sources in the UDG sample. Due to the synergy with VLT/VIMOS FoV and number of slits, we estimate that UDGs in clusters at a redshift of $z \sim 0.05$ are the ideal targets to optimise the scientific return due to our ability to multiplex and stack the spectra to learn more about their (average) properties. This relatively small pilot DDT program will help us confirm that this is the best strategy, and will demonstrate what science scopes are feasible for a possible larger bad-seeing program (to be proposed for cycle 98).

8c. Calibration Request:

Special Calibration - Adopt a special calibration

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

Report on the use of the ESO facilities during the last 2 years (4 observing periods). Describe the status of the data obtained and the scientific output generated.

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.

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9b. GTO/Public Survey Duplications:

Specify whether there is any duplication of targets/regions covered by ongoing GTO programmes. If so, please explain the need for the new data here. Details on the protected target/fields in these ongoing programmes can be found at:
GTO programmes: http://www.eso.org/sci/observing/teles-alloc/gto/index.html

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

Remco F.J. van der Burg, Adam Muzzin, and Henk Hoekstra, 2016, A&A submitted (ArXiv:1602.00002): "The abundance and spatial distribution of ultra-diffuse galaxies in nearby galaxy clusters"

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	Abell 780	09 18 05.7	-12 05 44.0	7				

Target Notes: This is a note about targets.

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
96	VIMOS	A	MOS-grisms	HR-Blue