EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME PERIOD: **78A**

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: **A–1**

ELT integrated spectroscopy of early–type galaxies at $z > 1$

2. Abstract

Despite early-type galaxies (ETGs) are crucial probes for cosmological and galaxy formation studies, their observation at high redshifts (e.g. $z > 1.5$) is extremely challenging due to their faintness and lack of emission lines which place them generally beyond the limits of 10m-class telescope spectroscopy. We propose here to obtain ELT spatially integrated spectroscopy of a sample of ≈500 ETGs at $1.5 < z < 5$ selected from future near-IR imaging surveys. Being these galaxies very compact ($r_e \approx 0.1 - 0.3$ arcsec), their spectroscopy does not require "high performance" AO correction. These observations will allow us to derive the redshift, stellar population content, age, metallicity and dynamical masses of these galaxies, and to use them to trace the cosmic history of galaxy mass assembly.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	79	SINFONI	300h	any	g	$\leq 0.4''$	CLR	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 ELT DRM represents only one example of the several science cases on galaxy formation and evolution which do not necessarily require "high performance" AO performances, but just an enhancement of the seeing to levels of 0.1"-0.3".

6. Principal Investigator: Andrea Cimatti (UniBO, I, a.cimatti@unibo.it)

CoI(s): Piero Rosati (ESO, ESO), Marijn Franx (Leiden, NL), Isobel Hook (Oxford, UK)

7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

8. Description of the proposed programme

A) Scientific Rationale: Early-type galaxies (ETGs) play a crucial role in cosmology. They are the most massive galaxies in the local Universe, contain most of the stellar mass and are the primary probes to investigate the cosmic history of galaxy mass assembly. As ETGs are the most clustered galaxies, they are also fundamental in tracing the evolution of the large scale structures as well as the evolution of galaxy clusters. Finally, due to the correlation between the black hole and bulge masses, ETGs must play a key role in the co-evolution of spheroids and their central supermassive black holes. Although ETGs in the nearby Universe are rather simple and homogeneous systems in terms of morphology, colors, stellar population content and scaling relations (Renzini 2006 and references therein), their formation and evolution is still a debated question.
The most recent surveys suggest the most massive ETGs (stellar mass $> 10^{11}$ $M_{\odot}$) were already in place at z≈0.8, with a number density consistent with the one at z=0 (e.g. Yamada et al. 2005; Bundy et al. 2006; Scarlata et al. 2007; Cimatti, Daddi & Renzini 2006; Bundy, Treu & Ellis 2007), whereas the evolution is more pronounced for the lower mass ETGs which may increase their mass from z≈0.8 to z=0 through the merging of disk and/or early-type galaxies (e.g. Bell et al. 2004). This mass–dependent evolution is known as "downsizing" (Cowie et al. 1996), i.e. with massive galaxies forming their stars earlier and faster than the low mass ones. It is unclear whether the downsizing can be extended to the stellar mass assembly evolution itself (e.g. Cimatti, Daddi & Renzini 2006; Bundy, Treu & Ellis 2007), and whether this may represent a significant problem for galaxy formation models where massive galaxies are expected to assemble their mass gradually through hierarchical merging of CDM halos (e.g. De Lucia et al. 2006).

The uncharted territory beyond $z \approx 1$

Beyond z≈1 the picture is even more controversial because the spectroscopic identification and study of ETGs at these redshifts is usually beyond the capabilites of 10m-class telescopes. Due to the strong k-correction, ETGs become rapidly very faint in the optical (e.g. $I > 25$ Vega) and extremely difficult to observe with optical spectroscopy. In addition, ETGs have spectra without strong emission lines, and the most prominent spectral features (e.g. the D4000 continuum break and CaII H&K absorption lines) are redshifted at $\lambda > 1\mu$m for $z > 1.5$, where ground-based spectroscopy is increasingly difficult due to the strong OH sky lines.
Pushing the 10m-class telescopes to their limits, it has been possible to unveil ETGs up to $z \approx 2$ with spectroscopy done either in the optical (Cimatti et al. 2004; McCarthy et al. 2004, Daddi et al. 2005) or in the near-IR (Saracco et al. 2005; Kriek et al. 2006). However, despite the very long integration times, spectroscopy was limited only to the very few brightest objects ($K < 19$, Vega) and to rather low spectral resolution (typically R<1000), and it was impossible to derive the dynamical masses through the velocity dispersion of the absorption lines.
The few distant ETGs spectroscopically identified at $1.5 < z < 2.5$ are very red ($R - K > 5 - 6$), compact ($r_e \approx 0.1 - 0.2$ arcsec), dominated by passively evolving old stars with ages of 1-4 Gyr, and have stellar masses typically $> 10^{11} M_{\odot}$, implying a star formation history characterized by strong (> 100 $M_{\odot}$/yr) and short-lived (0.1-0.3 Gyr) starbursts occurring at $z > 2 - 3$, then followed by passive evolution.
It has been recently found that ETG photometric candidates continue to be present in substantial number also at higher redshifts ($3 < z_{phot} < 6$) (Mobasher et al. 2005; Dunlop et al. 2006; Brammer & van Dokkum 2007; Rodighiero et al. 2007), but it is unknown if they are really old/passive systems or starbursts with extremely red colors due to strong dust obscuration. Also in this case, their faintness (e.g. $K_{AB} \approx 24 - -25$) makes the spectroscopic identification and study currently impossible.
The existence of old, massive, passive ETGs $z > 1.5$ was unexpected in the galaxy formation models available in 2004-2005, and opened the question on how it was possible to assemble such systems when the Universe was so young. A better agreement with the observations seems possible by "quenching" the star formation at high redshifts with some "feedback" mechanisms (e.g. AGN), but the question is still completely open (e.g. Menci et al. 2006), and more observations are required to clarify the picture.

B) Immediate Objective:
This kind of targets calls for an observational approach based on spatially integrated spectroscopy with a near–IR MOS working under "seeing enhanced" conditions, and complemented with an optical MOS. The main immediate scientific aims can be summarized as follows.
• Identify spectroscopically a large sample of ETGs in a wide redshift range and in a regime unaccessible to current telescopes (e.g. $1.5 < z < 5$).
• Perform detailed spectral analysis over the widest wavelength coverage (e.g. $0.6\mu\text{m} < \lambda_{obs} < 2.5\mu\text{m}$) in order to derive the properties of the stellar continuum, absorption and emission lines, to estimate the age, metallicity and star formation history of the stellar populations, and to break the degeneracies between these quantities.
• Trace the evolution of the ETG mass function and the history of mass assembly by measuring dynamical masses from the absorption line velocity dispersions. This will require moderate-to-high spectral resolution ($R > 1000$), but will not need spatially-resolved spectroscopy as ETGs are spheroidal and very compact at high-z ($r_e \approx 0.1 - 0.3$ arcsec). Current determination of the stellar mass function and its evolution is based on

8. Description of the proposed programme (continued)

the model–dependent method of "photometic masses" from multi-wavelength SEDs, whose reliability remains largely untested at $z > 1$.

• In synergy with the ELT DRMs on star-forming/disk galaxies, to determine the cosmic epochs when the mass assembly of spheroids and disks occured, study the origin of the star–formation and mass "downsizing" effects and the role of merging vs galaxy "transformation".

• In synergy with AO imaging observations (needed to derive the effective radius and surface brigthness r_e and μ_e), to study the scaling relations and their cosmic evolution to $z \approx 3$ involving a number of these physical parameters (e.g. mass-metallicity, fundamental plane, color-magnitude, morphology-density).

• Identify spectroscopically the red galaxies that will be found within the regions of high-z cluster candidates that will be selected in large numbers by the forthcoming X-ray (e-ROSITA) and S-Z (South Pole Telescope) surveys. This will allow to derive the cluster redshifts to characterize the environmental effects on ETG evolution.

• Provide stringent constraints for galaxy formation models.

Sample selection and synergy with other facilities

The ETG samples needed for this science case will be drawn from the next-generation near-IR surveys (e.g. VISTA) down to (e.g. $K < 22 - 23$ Vega) and from future X-ray and S-Z cluster surveys (e-ROSITA, SPT). This science case will also benefit from the synergy with JWST, which will provide rest-frame optical imaging of galaxies with superb spatial resolution over the widest redshift range, as well as low resolution integrated spectroscopy extended in the spectral regions unaccessible from the ground >2.5μm).

C) Telescope Justification:

Typical ETGs with stellar mass $M \approx M^*$ would have $Ks \approx 21$ (Vega) if observed at $z \sim$2–3. We aim at selecting the ETG sample at 1 magnitude deeper in order to include also the ETGs populating the lower mass end of the mass function and to have enough mass "leverage" for mass-dependent evolutionary studies.

The typical surface density of ETGs at $1 < z < 3$ that we expect in a sample selected in the near-IR to $K < 22$ (Vega) is ≈ 0.5gal/arcmin^2 (with significant variations due to the strong ETG clustering and to the ETG actual redshift distribution at $z > 1.5$). For instance, the surface density can increase to ≥ 1gal/arcmin^2 in case of over-dense regions (e.g. clusters), and decrease down to ≈ 0.1gal/arcmin^2 for the highest redshift ETG candidates (e.g. $z > 4$).

The sample size and surface densities imply a minimum field of view of 25 arcmin^2 and a multiplex factor of at least 10, possibly up to 50. Spectral resolutions $R \sim 1000 - 5000$ are required for adequate OH removal and measurement of absorption line velocity dispersions. Very high efficiency and sensitivity in the region of 0.9-1.3μm will be crucial due to the main spectral features redshifted in this range for $z \approx 2$. Simultaneous coverage of Y+J+H bands (or Y+J, H+K) would also be important to build the global SEDs. As a result, a deployable IFU system, or even a fiber–fed MOS, capable to work in "seeing enhanced" conditions (e.g. with MCAO down to FWHM ≈ 0.1 arcsec, and/or GLAO to $\approx 0.2 - 0.3$ arcsec) would be required in order to obtain "spatially integrated" spectra of these compact targets. The spatial sampling can be of the order of $\sim$100 mas. The typical exposure times are in the range of 10–20 hours, thus making the whole program feasible in roughly 300–600 hours for a sample of $\approx$500 high-z ETGs and with a field of 25 arcmin^2, and an average multiplex of 15 targets per pointing (note that 500 hours have been allocated to the largest VLT Large Programs like zCOSMOS). The requirements and main parameters of targets are summarised in Table 1.

Note that such a "seeing – enhanced" near-IR + optical MOS would have a wide range of scientific applications in the galaxy formation and evolution studies, and not only limited to the ETGs.

The case for a complementary optical MOS

The current plans for ELT instrumentation do not include an optical MOS. This would preclude the possibility to perform spectroscopy in the rest-frame UV for high-z galaxies, hence making a 42m telescope "blind" to a variety of physical processes and diagnostics observable in the UV.

A two–channel (optical and near-IR) MOS would be ideal in several scientific cases of galaxy evolution. In the specific case of ETGs, optical spectroscopy would be crucial to extend the wavelength coverage and to derive more stringent diagnostics on the stellar population content, star formation histories, evolutionary status and to better break the age–metallicity degeneracy.

D) Observing Mode Justification (visitor or service): service mode

E) Strategy for Data Reduction and Analysis: A more detailed feasibility study is underway.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: Grey-dark time is required only for $< 1\mu$m observations.

Time Justification: (including seeing overhead) **ELT ETC V2.5WG:** we considered the case of the oldest/reddest ETGs at $z = 2$ with a total magnitude $J = 24.5$ (Vega) ($K = 22$, $J - K = 2.5$), extended object, GLAO, 100 mas scale, J-band spectroscopy with R=5000. The integration time to reach S/N=5(10) is ≈2(8), 3(12), 5(20) hours for r_h= 250, 300, 400 mas respectively. For an ETG candidate at $z \approx 4.5$ (D4000 break in the K-band), $K = 23$ (Vega) (see e.g. Rodighiero et al. 2007), K-band grating with R=5000, the integration time to reach S/N=5 is ≈9 and 20 hours for r_h= 200 and 300 mas respectively. These represent the upper envelope to the integration times because they refer to some of the faintest expected targets.

We also tested similar cases by scaling the VLT-SINFONI and FORS2 integration times by $(8/42)^2$:
(1) - Faint ETG at $z \approx 2$: $J = 24.5$ (Vega), r_e=0.2", source diameter 0.4", surface brightness = m+2.5log(area)= 22.2 mag arcsec^{-2} (area = πr_e^2), no AO, seeing = 0.4", J-band grating with R=2000. The integration time to reach S/N=5 per pixel along dispersion (S/N=$5\times\sqrt{2} \sim 7$ in case of 2-pixel binning along λ) is about 590 hours, corresponding to 21 or 5 hours with a 42m-diameter ELT with a 100 or 250 mas pixel scale respectively.

(2) - ETG candidate at $z \approx 4.5$: $K = 23$ (Vega), 20.7 mag arcsec^{-2}, K-band grating with R=4000, the rest of parameters as above. The total integration time to reach S/N=5 per pixel along dispersion is about 425 hours, corresponding to 15 or 9 hours with a 42m-diameter ELT and with a 100 or 250 mas pixel scale respectively.

(3) - Optical spectroscopy: $z = 2$, $I = 27.5$ (Vega), r_e=0.2, surface brightness = 25.2 mag arcsec^{-2}, seeing = 0.4", airmass=1.2, grating 600z, Kinney's E template at $z = 2$. Total integration time to reach S/N=5 per pixel along dispersion is about 111 hours, scaling down to about 4 hours with a 42m-diameter ELT.

Calibration Request: Standard Calibration

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

ELT was not available :)

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

Table 1. – **Main Technical Requirements and Target Parameters**

Requirements	Range of values (minimum/ideal)
Field of View	25–100 arcmin^2
Wavelength range	0.6–2.5 μm
Multiplexing	10–50
Spatial sampling	100–200 mas
Spectral resolution R	1000–5000
PSF FWHM	0.1–0.3 arcsec
Target parameters	
Typical magnitude	21–23 (K_{Vega})
Target density	0.1–1 arcmin^{-2}
Object size	r_e = 0.1–0.5 arcsec
Typical Exptimes	10-50 hrs

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	GOODS-S	3:32:39.0	-27:47:00	10-100	25	DM	ang diam(')	note

Target Notes: ...

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

13. Scheduling requirements

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
79	SINFONI	A	SPE	JHK