

EAGLE Spectroscopy of Resolved Stellar Populations Beyond the Local Group

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Abstract. We give an overview of the science case for spectroscopy of resolved stellar populations beyond the Local Group with the European Extremely Large Telescope (E-ELT). In particular, we present science simulations undertaken as part of the EAGLE Phase A design study for a multi-integral-field-unit, near-infrared spectrograph. EAGLE will exploit the unprecedented primary aperture of the E-ELT to deliver AO-corrected spectroscopy across a large (38.5 arcmin²) field, truly revolutionising our view of stellar populations in the Local Volume.

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1. Introduction

As we look ahead to the end of the coming decade, we will be entering the era of the Extremely Large Telescopes (ELTs). Plans are well advanced for three ELT projects with filled apertures well in excess of current optical-IR facilities: the Giant Magellan Telescope (GMT, with an equivalent diameter of 21.4m), the Thirty Meter Telescope (TMT) and the 42m European ELT (E-ELT). When coupled with sophisticated adaptive optics (AO) systems to correct for atmospheric turbulence, the ELTs will provide us with unique views of stellar populations in the Local Volume. Although planning a decade ahead may seem far removed, the lead-in times on these ambitious projects is more akin to those commonly associated with space missions, i.e. construction planning, detailed science simulations, conceptual instrument designs and the financial planning are all well advanced on all three ELT projects. Here we introduce the EAGLE Phase A instrument study for the E-ELT, highlighting its performance for observations of resolved stellar populations.

2. Resolved Stellar Populations: Today & in the ELT Era

Photometric methods are immensely powerful when applied to extragalactic stellar populations, but only via precise chemical abundances and stellar kinematics can we break the age-metallicity degeneracy, while also disentangling the populations associated with different structures, i.e. follow-up spectroscopy is required. Over the past decade the Calcium Triplet (CaT, spanning 0.85-0.87 μm) has become an increasingly used diagnostic of stellar metallicities and radial velocities in nearby galaxies, providing new views of their star-formation histories and sub-structure, e.g. the VLT-FLAMES DART large programme (Tolstoy *et al.* 2004). However, 8-10m class telescopes are already at

their limits in pursuit of CaT spectra of the evolved populations in galaxies at distances greater than ~ 300 kpc, e.g. Keck-DEIMOS observations in M31 struggled to yield useful signal-to-noise below the tip of the red giant branch at $I > 21.5$ (Chapman *et al.* 2006).

With its vast primary aperture and excellent angular resolution, the E-ELT will be *the* facility to unlock spectroscopy of evolved stellar populations in the broad range of galaxies in the Local Volume, from the edge of the Local Group, out towards the Virgo Cluster. This will bring a wealth of new and exciting target galaxies within our grasp, spanning a broader range of galaxy morphologies, star-formation histories and metallicities than those available to us at present in the Local Group. These observations can then be used to confront theoretical models to provide a unique view of galaxy assembly and evolution. There are many compelling and ground-breaking targets for stellar spectroscopy with the E-ELT including, in order of distance:

- NGC 3109 and Sextans A with sub-SMC metallicities ($Z < 0.2Z_{\odot}$), both at 1.3 Mpc.
- The spiral dominated Sculptor ‘Group’ at 2-4 Mpc.
- The M83/NGC5128 (Centaurus A) grouping at ~ 4 -5 Mpc.
- NGC 3379, the nearest normal elliptical at 10.8 Mpc.
- The Virgo Cluster of galaxies at 16-17 Mpc, the nearest massive cluster.

In contrast to proposed E-ELT observations of high-redshift galaxies, targets for CaT spectroscopy are readily available. For example, deep ground-based and *HST* imaging in galaxies in the Local Volume has begun to investigate their stellar populations (e.g. Rejkuba *et al.* 2005, de Jong *et al.* 2007, Dalcanton *et al.* 2009), yet the stellar magnitudes are well beyond spectroscopy with existing facilities. Note that although we have focussed mostly on southern-hemisphere targets here, there are equally compelling northern hemisphere targets, including the M81 group, and deeper studies in M31 and M33.

3. EAGLE: A Multi-IFU, Near-IR Spectrograph for the E-ELT

The EAGLE Phase A study is a French-UK partnership to provide an advanced conceptual design of an AO-corrected, near-infrared spectrograph with multiple integral-field units (IFUs). The baseline design is summarised in Table 1, and has been shaped by five top-level science topics:

- Physics and evolution of high-redshift galaxies
- Detection and characterisation of ‘first light’ galaxies
- Galaxy assembly and evolution from stellar archaeology
- Star-formation, stellar clusters and the initial mass function
- Co-ordinated growth of black holes and galaxies

EAGLE will employ multi-object adaptive optics (MOAO, e.g. Assémat, Gendron & Hammer 2007) to provide significantly improved image quality for selected target fields within the focal plane. This entails an array of six laser guide stars and five natural guide stars (NGS) to map the atmospheric turbulence. The deformable mirror in the telescope (M4) will be used to correct for the low-order wavefront error terms, with the high-order terms corrected by deformable mirrors in each science channel. An integral part of the EAGLE project is the CANARY on-sky demonstrator on the William Herschel Telescope in La Palma (Myers *et al.* 2008).

The consortium has calculated MOAO point-spread functions (PSFs) which take into account real NGS configurations, illustrative of relatively good and poor performance given the spatial distribution and magnitude of the available guide stars. In the following section we summarise EAGLE observations of resolved stellar populations beyond the Local Group, which would be used to probe the assembly history and chemical evolution of the host galaxies.

Table 1. EAGLE Baseline Design. The patrol field is the instrument field-of-view within which IFUs can be configured to observe individual targets.

Parameter	Specification
Patrol Field	Eqv. 7' diameter
IFU field-of-view	1''.65 × 1''.65
Multiplex (# of IFUs)	20
Spatial resolution	30%EE in 75 mas (<i>H</i> band)
Spectral resolving power (<i>R</i>)	4,000 & 10,000
Wavelength range	0.8-2.5μm

4. EAGLE Performance: CaT Spectroscopy

Simulated EAGLE observations of the CaT region were computed using a modified version of the IFU tool developed to characterise the MOAO requirements for ELT observations of high-redshift galaxies (Puech *et al.* 2008). A synthetic CaT spectrum ($T_{\text{eff}} = 4,000 \text{ K}$, $\log g = 2.0$) is adopted as a template from the Kurucz model atmosphere calculations for the *GAIA* mission (Munari & Castelli 2000). The synthetic spectra were calculated for $R = 20,000$, i.e. sufficiently over-sampled so as to be degraded to either of the two spectral resolving powers provided by EAGLE. To this template we appended an additional continuum region to provide a line-free region with which to investigate the signal-to-noise (S/N) of the spectra in the resulting datacubes. The principal assumptions in the simulations were:

- Telescope: 42-m primary, with central obscuration of 9%
- Exposure time: 10 hrs (20x1800s)
- λ -range: 8400-8750 Å, at $R = 10,000$
- Spatial sampling: 37.5 mas spatial pixels
- Total throughput: 0.19 [telescope (0.8); atmos. (0.95); EAGLE (0.25 @ 0.85μm)]
- Detector: read-out noise: $5e^-/\text{pixel}$ & dark current: $0.01e^-/\text{pixel/s}$

Assuming a Paranal-like site, we have investigated two sets of seeing conditions in the simulations: 0''.65 at $\lambda = 0.5\mu\text{m}$ at zenith (the mean VLT seeing at Paranal; Sarazin *et al.*, 2008) and 0''.90 at a zenith distance (ZD) of 35°, providing a good investigation of the performance from execution of a 'Large Programme'-like survey.

The signal-to-noise (S/N) recovered, as a function of *I*-band magnitude, for the two NGS configurations is given in Table 2. These results are for spectra extracted from the central spatial pixel of a point source at the centre of the cube (optimal PSF-fitting extractions should be able to improve on these results). The key result is that $S/N \geq 10$ is recovered from a stacked 10hr exposure at $I = 24.5$, in mean seeing, in both NGS configurations. This corresponds to spectroscopy of stars at the tip of the red giant branch (RGB), with $M_I = -4$, out to $\sim 5 \text{ Mpc}$ in just 10 hrs. This is four magnitudes deeper than FLAMES using the LR08 grating ($R = 6,500$) with the same exposure time. Similar calculations at $R = 4,000$ for $I = 24.5$ and 26.0 (with the latter approx. the tip of the RGB in NGC 3379) yield $S/N \geq 10$ in 5 and 80 hrs, respectively.

Table 2. EAGLE CaT results: Continuum S/N obtained for $R = 10,000$, $t_{\text{exp}} = 10 \text{ hrs}$.

I_{VEGA}	Seeing = 0''.9 @ ZD=35°		Mean VLT Seeing (0''.65 @ ZD=0°)	
	NGS 'good'	NGS 'poor'	NGS 'good'	NGS 'poor'
22.5	40	27	56	48
23.5	16	11	28	24
24.5	8	4	13	10

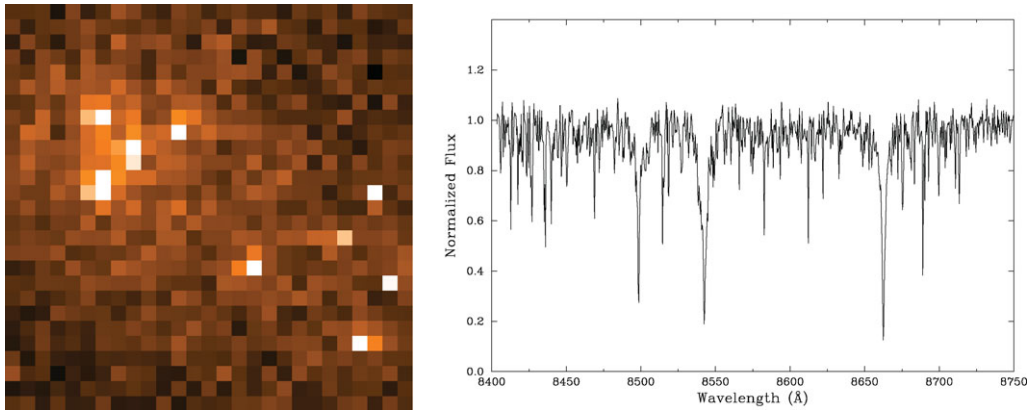


Figure 1. *Left:* Front slice of simulated IFU datacube for EAGLE observations in the central region of NGC 55; *Right:* Simulated CaT spectrum for a star with $I = 23.5$, yielding $S/N \sim 25$ in the continuum.

An example EAGLE Large Programme is to undertake spectroscopy of evolved stars in the five spiral galaxies in the Sculptor Group, by observing multiple EAGLE fields across the major and minor axes of each galaxy. These galaxies represent the most immediate opportunity to study the star-formation history and mass assembly of spirals beyond the limited sample available at present, i.e. the Milky Way, M31 and M33. The left-hand panel of Figure 1 shows the central $1'' \times 1''$ of an IFU observation in the core region of NGC 55 (at 1.9 Mpc), with the right-hand panel showing a simulated CaT spectrum. The magnitudes and relative positions of the stars are from *HST* imaging in the core region of NGC 55, taken as part of the GHOSTS survey (de Jong *et al.* 2007). This example illustrates perfectly the gain in effective multiplex from the IFUs (i.e. nine stars in this $1'' \times 1''$ region), with minimal impact from crowding.

5. Summary

EAGLE provides a unique combination of abilities to harness the power of the E-ELT for spectroscopy of resolved stellar populations. The image quality from MOAO will be significantly better than that obtained from seeing-limited or ground-layer AO modes, enabling us to explore spatially-resolved, extragalactic stars across a wide field of more than five arcminutes. A range of large programmes can be envisaged, each of which will help provide a fundamentally new view of stellar populations in the local Universe; from mapping of the Sculptor galaxies, to deeper observations of the most luminous evolved stars in selected fields in galaxies at 10 Mpc and beyond.

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