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: **B–2**

The Resolved Stellar Populations of Elliptical Galaxies

2. Abstract

Elliptical galaxies represent the majority of luminous mass in the Universe and all the indirect observational indications, from the discovery of Elliptical galaxies in high red-shift surveys, to studies of integrated stellar populations, suggest that they are predominantly very old systems. However, the main theory of galaxy formation predicts that they assembled their mass relatively recently, and should therefore be dynamically young. It is important to accurately quantify this apparent contradiction. The only way to uniquely resolve this issue is to make CMDs of the resolved stellar populations in a sample of Elliptical galaxies, using the techniques developed for studies of Local Group galaxies. This means we need to reach the Virgo cluster, 17Mpc away. The detailed properties of Ellipticals will also be compared to the properties of a range of other large galaxies in the Local Group, and at distances out to and beyond Virgo to understand the effect of environment.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	79	FORS2	20h	any	d	$\leq 0.4''$	PHO	v
B	79	FORS2	66h	any	d	$\leq 0.4''$	PHO	v

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:

Please give us time before we retire.

6. Principal Investigator: **Eline Tolstoy** (RUG, NL, etolstoy@astro.rug.nl)

CoI(s): The Rest (Elsewhere, ESO)

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: One of the main unsolved questions in astronomy is how galaxies form and evolve. In 1936 Edwin Hubble presented his tuning fork diagram classifying the different types of galaxy to be found in the Universe. This was the first attempt to find a pattern in the properties of different systems and thus search for a common evolutionary link. Elliptical galaxies appear to be shaped predominantly by a single component composed of old stars, while spiral galaxies have several components with a range of stellar ages, gas disks, dust and stellar bars. This 'Hubble tuning fork' diagram survives until today as the standard manner of presenting the morphologies of galaxies, with the addition of small dwarf spheroidal and irregular type galaxies. Fitting all these galaxy types into a common evolutionary scenario still remains to be achieved. According to the most widely accepted current structure formation scenario (the Cold Dark Matter, or CDM paradigm), all galaxies are built up from smaller pieces, the fundamental building blocks of galactic evolution, coalescing through time starting in the early universe (at high red-shift) to form the galaxies we see today. The present day systems we see around therefore provide a unique insight into the galactic assembly process and the chemo-dynamical evolution of the galaxy distribution.

The directly observable components of any galaxy are gas, dust and stars, and there is an intimate link between them. Stars form from gas, and synthesise elements in their interiors and the stars that explode at death disperse these elements into the gas from which dust and subsequent generations of stars are formed. All galaxies are thus the integrated products of all the star formation during their entire lifetimes, and the chemical elements in the stellar populations of different ages provide the most detailed evidence for this past star formation. Because low mass stars can have lifetimes comparable to the age of the Universe, the low mass tail of the ancient star formation that occurred at the formation epoch of a galaxy remains visible today and provides unique clues to the earliest physical process in the Universe. Stars of all ages provide an accurate and detailed probe of changing galaxy properties. By observing large numbers of individual stars we can measure how the rate of star formation and chemical composition of a galaxy has varied from its formation to the present and thus how galaxies were built up over time. To unravel this formative epoch detailed spatial, kinematic and chemical surveys of resolved stellar populations are required; providing a unified picture between local near-field cosmology, predictions from high red-shift surveys and theoretical simulations of galaxy formation and evolution.

Until now the sensitivity and resolution limitations have meant that detailed studies have only been possible within the Local Group and specifically around our own Galaxy. This means that only small dwarf type galaxies have had their ancient stellar populations accurately probed; massive galaxies still await this careful scrutiny. The Local Group contains only two massive galaxies (spiral systems M31 and the Milky Way) and around 40 smaller, mostly dwarf, galaxies. This is hardly representative of the range of galaxy types, and our Local Group is not necessarily representative of the high-density regions of the Universe where most galaxies live. Careful studies of dwarf galaxies have already shown inconsistencies between observations and the standard CDM picture and these need to be extended to larger galaxies to make an accurate comparison with the properties of small galaxies.

To make significant progress we need to study large numbers of resolved stars in a range of galaxy types and this requires us to look beyond the halo of the Milky Way.

B) Immediate Objective:

The Virgo cluster is the real prize for studying Elliptical galaxies. Virgo at an average distance of 17 Mpc, with over 2000 member galaxies of all morphological types, is the nearest large cluster of galaxies.

Thus, the objective of this proposal is to understand the formation and evolution of Elliptical galaxies in a range of environments using ancient stars as probes of the earliest history of star formation in the Universe. The first step is to resolve individual stars down to the oldest main sequence turnoffs, where possible (e.g., M32 a Local Group dwarf elliptical galaxy, and perhaps at the distance of Cen A). In M32 the problem to date in detecting the oldest main sequence turnoffs is partly due to sensitivity but most due to insufficient spatial resolution. For more distant galaxies, such as NGC3379, and the Virgo galaxies it is important to push for photometry below the Horizontal Branch (to detect the presence of stars > 10 Gyr old) and also to obtain main sequence turnoffs down to intermediate ages ($\sim 6 - 8$ Gyr). Two galaxies are selected for observing run A.

The goal is to make accurate Colour-Magnitude Diagrams (CMDs), with errors in magnitude < 0.05 mag at the faint limit, at least down to the Horizontal Branch (V,I,K ~ 32, in Virgo) in regions with a range of stellar density and stellar luminosity. These CMDs can then be used to determine accurate star formation histories and also to give targets for follow up spectroscopy to directly measure metallicity.

Elliptical galaxies require the highest spatial resolution and sensitivity. But, as with all galaxies - they have dense central region and a diffuse halo. This gives some degree of flexibility where we can make our CMDs, which is difficult to be certain of a priori - because the conversion from a surface brightness to a number of stars depends on the star formation history of the region. For example, for the same surface brightness a galaxy which is still forming stars will have fewer stars per square arcsec, because the individual stars are brighter, than a galaxy which stopped forming stars several Gyr ago.

Spiral galaxies are also interesting objects for the same type of study, but they have slightly different technical requirements, as there are quite a few examples closer than Virgo they have slightly lower demands on both sensitivity and spatial resolution. However, partly because they are closer by they are typically larger on the sky (in our sample). They also contain (typically) a sparser stellar density in their outskirts - meaning that spatial resolution can be compromised for field of view. But these "wide" field images should always be complemented on deeper fields - with higher sensitivity and spatial resolution. This broader science case is represented in the galaxies listed in observing run B.

C) Telescope Justification: We need the ELT because of the spatial resolution AND the faintness of the point sources. We would ideally like to use images with a field of view of around 30 arcsec or greater but most important is to have images at the diffraction limit of the telescope.
I have included VIJHK filters, the minimum required is I and K. Ideally V and K.

D) Observing Mode Justification (visitor or service): visitor mode is preferred as we just love to sit in tin boxes and would like to see the Eiffeltower on its side.

E) Strategy for Data Reduction and Analysis: Here I outline the technical requirements for each galaxy in run A.

NGC4660 - A Virgo Elliptical

This is the most challenging case. At a distance modulus $(m - M)_0 \sim 31.2$. This means that the tip of the RGB is at I∼27.2, K∼25.; the HB at I∼31.8, K∼31.7; the oldest MSTO at I∼35.7, K∼35. The central surface brightness of this galaxy is given as I(0)= $\mu_0 = 16$ mag/arcsec^2 (in B, Gavazzi et 2005 A&A 430, 411), with a half-light radius $r_e = 8.6$arcsec and I(R_e) = 14.7 mag/arcsec^2 in H [H-K = 0.25mag, typically]; $r_e = 15.3$arcsec and I(R_e) = 19.6 mag/arcsec^2 in B; from Goldmine:
`http://goldmine.mib.infn.it/search-by-name.html`
(Gavazzi et al. 2004 A&A, 417, 499). The major axis of this galaxy is 1.9 arcmin; minor axis 1.24 arcmin. The total extent (∼4 disk scale lengths, 25mag/arcsec^2) is 140 arcsec ($2\times r_{ext}$). I estimate, at r_e we will have more than 5000 stars per arcsec^2 at the Horizontal branch magnitude (average star to star separation of 15mas), and in the centre, r_0, around 1 million stars per arcsec^2 (average star to star separation of 1mas), also at the Horizontal Branch. This means that the positioning of the image field depends strongly upon the achievable resolution, and the depth of the photometry.
See Tolstoy 2005 proceedings IAU 232 "Extremely Large Telescopes", eds Whitelock, Leibundgut and Dennefeld (astro-ph/0604065) for more details.
There are 2MASS images (in J,H,K), these can be obtained from web (via NED)
There are HST images (ACS), from Andres Jordan (g, z sloan filters).

NGC3379 (M105) - A slightly closer Giant Elliptical Galaxy, in Leo Group

At a distance modulus $(m - M)_0 \sim 30.3$. This means that the tip of the RGB is at I∼26.3, K∼24.1; the HB at I∼30.9, K∼30.8; the oldest MSTO at I∼34.8, K∼34.1.
The surface brightness at the half-light radius $r_e = 28.5$arcsec is I(R_e) = 15.5 mag/arcsec^2 in K (16.5 in J).
The major axis of this galaxy is 4.5 arcmin; minor axis 4.5arcmin (in R).
There are 2MASS images (in J,H,K), you can also find them via NED.
There are HST images (ACS + NICMOS, apparently quite deep).

I also send a list of stars in a typical elliptical galaxy, which stopped forming stars 5Gyr ago - so you have a representative stellar population to begin the modelling. It is just a list of stars with no fancy assumptions - no incompleteness - no noise etc. this should ideally come from the conversion into an image.
It is assuming a surface brightness= 24 mag/arcsec^2 and a limiting absolute magnitude= +6 (this is just to limit the number of stars - it doesn't make much difference after a certain point). List is no of stars, Mv, B-V, V-I, V-J, V-H, V-K, V-L, V-M.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: We require the maximum sensitivity and photometric accuracy possible which means dark time.

Time Justification: (including seeing overhead) Using the ELT- Experimental ETC (Version 2.4WG) assuming that Laser tomography Adaptive Optics is available, 5mas pixels for an average star (e.g., A0) we can obtain images with point sources down to a magnitude of V=28, I=31 and K=28 in approximately one hour of integration per filter. This means that in I, K filters we can detect the oldest MSTOS in a CMD for galaxies closer than (m-M)<25.; the Horizontal Branch for galaxies (m-M)< 27.5 - 30.5 (depending upon the HB properties); the tip of the RGB for galaxies closer than (m-M)<35.
In the case of the two galaxies in observing run A - we would like to detect the Horizontal Branch - which means V, I and K$\sim$ 31. I have not used the ETC to determine accurate exposures times instead I await the results of more detailed determinations of feasibility- and for each galaxy I list (run A and B) the required depth for detecting the TRGB (basic requirement); HB (intermediate requirement); Main Sequence Turnoffs (dream requirement).

Calibration Request: Special Calibration - Regular observations of standard star fields (!)

10. 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.

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

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	name	RA	DEC	time(hrs)	mag	DM	ang diam(')	note
A	NGC3379 (M105)	10 47 50	+12 34 54	5 fields	30.9, 30.8	30.3	5	second closest giant early type galaxy
A	NGC4660	12 44 32	+11 11 26	5 fields	31.8, 31.7	31.2	2	Virgo Elliptical
B	M87 (NGC4486)	12 30 49	+12 23 28	10x2hrs	31.8, 31.7	31.2	11	central elliptical in Virgo
B	M59 (NGC4621)	12 42 02	+11 38 49	5x2hrs	31.8, 31.7	31.2	8	Typical Virgo Giant Elliptical
B	M 32 (NGC221)	00 42 42	+40 51 55	5 fields	29, 28.3	24.5	9	Local Group dwarf elliptical
B	CenA (NGC5128)	13 25 28	-43 01 08.8	10x2hrs	30.5, 29.8	26	30	Closest giant early type galaxy
B	NGC4486B	12 30 32	+12 29 26	2hrs	31.8, 31.7	31.2	0.5	Virgo compact dwarf elliptical
B	Sombrero (M104)	12 39 59	-11 37 23	5x2hrs	30.3, 30.2	29.7	9	Nearest Sa galaxy
B	M83	13 37 00	-29 51 57	10x2hrs	28.9, 28.8	28.3	12	Nearest face on MW-type spiral
B	NGC300	00 54 54	-37 41 04	10x2hrs	30.3, 30.1	26.3	22	Sculptor Spiral galaxy
B	M100 (NGC4321)	12 22 55	+15 49 21	5x2hrs	31.6, 31.5	31	8	Virgo Spiral Galaxy
B	NGC 891	02 22 33	+42 20 57	5x2hrs	30.6, 30.5	30	15	Edge-on Milky Way twin
B	IC5052	20 52 01	-69 11 36	3x2hrs	29.4, 29.3	28.8	6	Edge-on galaxy
B	M 31	00 42 44	+41 16 09	20x2hrs	28.9, 28.2	24.4	200	Local Group Spiral Galaxy
B	M 33	01 33 51	+30 39 36	10x2hrs	29.1, 28.4	24.6	70	Local Group small spiral galaxy
B	NGC 55	00 14 54	-39 11 48	10x2hrs	30.2, 29.5	25.8	32	Nearby Edge-on irregular/spiral galaxy

Target Notes: The targets in run A and the main ones for this exercise; the targets in run B give a more general impression of the types of (large) galaxy we might like to observe with an ELT with the same requirements as run A.

Number of points per field listed with time, I, K mags listed. Angular diameter is the total size of the entire galaxy not always necessary to observe the entire galaxy.

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	FORS2	A	IMG	VIJHK
79	FORS2	B	IMG	VIJHK