Science Cases and Requirements for the ESO ELT

Report of the ELT Science Working Group

30 April 2006

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Executive Summary

The ESO-ELT Science Working group studied science cases for the ESO-ELT in the beginning of 2006. The activities were limited to the short period of 3 months, and the study is therefore not very exhaustive or detailed, and yet it is felt to be representative. The working group met three times to establish, develop, and discuss a list of individual science cases and how these would be impacted by trade-offs in the telescope aperture and instrumentation suite. A number of science cases were adapted from existing documents, most notably the Opticon ELT Science document (editor I.Hook, 2005), along with equivalent drawn up by the GMT and TMT projects. The science cases have been adapted to the expected performance of 30m to 60m telescopes. One of the important goals of the Science Working group was to estimate the scientific capabilities using a homogeneous set of assumptions. Wherever possible, the science cases have been analyzed using a new exposure time calculator made available by ESO. We note that this new calculator required modifications until the time of submission of this document, and the results can therefore not be regarded as final. Several of the current science cases will need significant simulations for further assessment. Another major difference with the previous OWL studies is the fact that the field-of-view can be larger for 30m–60m telescopes, and science cases are now developed for larger fields-of-view. The science cases are described in the Science Working Group report, and a table of requirements is given at the end of the report. The list of science cases is not complete, but thought to be representative. Those searching for more complete lists may want to consult the documents listed in the appendix of the SWG report. The study presented here should be useful as a guideline on what capabilities are needed. Some general conclusions concerning the science cases for an ELT can be made without hesitation:

1) The ELT will enable fantastic science, from exo-planets to cosmology, and it will enable a very large step forward in all aspects of astronomy.
2) Careful trade-offs will need to be made to find an optimal design, site, instrumentation. The considerations are the science cases listed here, the synergy with other facilities, and, in general, the expected needs during the life-time of the facility. Most of the science cases described here are based on expected performance at the start of the project, and this might be quite different from the performance at the end.
3) The most interesting science is often the unexpected science. The opening-up of the high redshift universe by 8-m class telescopes was largely unexpected when the 8-m telescopes were being developed. Similarly, the most interesting science that will be done by the 30-m to 60-m telescopes may be very different from the cases described here. Hence it is important to construct a facility which is efficient and effective in a general sense, and not just optimized to do one or 2 science cases well.
4) Synergy with JWST is a very important driver for the ELT in many of the science cases. This is a strong argument for a speedy development of the ELT, as the current launch date for JWST is summer 2013, with a 5-10 year mission duration.

The Science Working Group came to these general conclusions concerning the required capabilities for an ELT:

1) Many of the science cases require studies in the optical, down to 4500 Ångstrom, or below.
2) Performance in the UV (below 4000 Ångstrom) should not be a driver, but several science cases benefit from the accessibility of 4000-4500 Ångstrom
3) Thermal-IR capability is important, as it is required by prominent science cases (see below)
4) Sub-mm performance should not be a driver at this moment.
5) Adaptive Optics, from Ground Layer AO giving partial corrections to full-fledged extreme AO, is required for many of the science cases.
6) Multiplexing, and hence field size and image scale are important parameters as the effectiveness of the telescope scales linearly with multiplex for several prominent science cases.
7) Synergy with ALMA and VLT is deemed very important. Hence the location of the ELT should be such that studies using all facilities are possible and effective. Synergy with JWST is equally important, and it is required that the instrumentation suite of the ELT is chosen carefully increase complementarity and avoid unnecessary overlap.

In the last meeting of the Science Working Group, 8 prominent science cases were selected. These science cases require a representative range of capabilities, and will be given special emphasis in further studies. They can play an important role when trade-offs need to be made. These trade-offs will benefit from a "design reference mission" in which these prominent science cases are developed into observational programs. The table with prominent science cases and their requirements is given on the next page.

The Science Working Group notes that a careful study is needed to see which instruments can be built for the first years of operations. It is desired that most of the prominent science cases can be performed with those instruments. An instrument not included in the current list from the Instrumentation Working Group is a multi-object near-ir spectrograph for integrated light studies of distant galaxies.

1. *Table of requirements for Prominent Science Cases*

#	Science case	FOV	Spatial Resolution milli-arcsec	Spatial Resolution Strehl	Photometric uniformity	Photometric accuracy	Guide star distance, colour	Spectral R	Wavelength microns	Multiplex	Magnitude (typical)	Object Size arcsec	Exposure typical time, hr	Usage (freq, rare)
	Planets and Stars													
S3	**Extrasolar planets:**													
S5	**Stellar clusters (inc. Galactic Centre)**	1'x1' or larger	0.2"	diff. limit		5%		1000	0.7 - 5	few to 10	R,K < = 27	1'x1'	to 10h	
S9	**Circumstellar disks, young and debris**	10"x10"	diff lim (0.7?-2) to 20 micron		10%	5%		10/300/3000/50000	(0.7 or 2)-20	IFU	faint ext objs	few	~ 1-10	
	Stars and Galaxies													
G4	**Resolved stellar populations:**													
	- Colour-Magnitude diagram Virgo	1-10"		diff. limit	0.02 mag	0.05mag/goal 0.02		10	0.8-3 (goal 0.6)	no	27-28	point sources	8-10h	
	- abundances & kinematics Sculptor galaxies	10"-3'	50%EE<0.1 (goal)	Light collector				5000-8000	0.8-0.9	>10 (goal 50)	24-26	point sources	8-10h	
	- abundances & kinematics M31- CenA	1-5"	50%EE<0.1 (goal)	Light collector				>25000 (40000)	0.45-0.75	few-10	21-23	point sources	8-10h	
G9	**Black holes/AGN**	5"	few mas	diff. limit				1000-50000	1-3.5	1	SB H=18/sq arcsec	5pc	10hr	
	Galaxies and Cosmology													
C2	**Dynamical measurement of universal expansion**	few arcsec	80& EE in 0.6"					150000 (>= 50000)	0.4-0.68(goal 0.38)		15-17	point sources	0.2-0.3h x many	
C4	**First light - the highest redshift galaxies**	10'x10'-17'x17'	200 mas					>3000	0.9-2	100	AB = 28	0.1-0.2	100	
C7	**Metallicity of the low-density IGM**		300 mas					100000	0.55-0.7		16-17.3	point sources	20-90h	
C10	**Physics of high-z galaxies**													
	- integrated spectroscopy	5'x5 '	0.2"-0.4"					1000-10000	0.4-2.5	50-100	23-26	0.1-0.5"	5-50h	
	- high resolution imaging	>1'x1'		strehl > 0.5				10	1-2.5		23-26	0.1-0.5"	2-5h	
	- high spatial resolution spectroscopy	3'x3'	50%EE in 0.05"					1000-10000	1-2.5	>10	23-26	0.1-0.5"	50-100h	

#	Science case	Target density arcmin^-2	Dynamic range	Background/ emissivity	Astrometric/plate scale stability	Polarization	Sky coverage required	Date/time constraint	Can be done with 30m	42m	60m	JWST	Observation type
	Planets and Stars												
S3	**Extrasolar planets:**												
S5	**Stellar clusters (inc. Galactic Centre)**	up to 1000			better than 1%		galactic center	baseline 1-2 years	yes	yes	yes	yes/c	imaging & spectros
S9	**Circumstellar disks, young and debris**	low	10^3-10^5	v low thermal bkg	1%	linear	all sky		yes	yes	yes	c	imaging + IFU spectros
	Stars and Galaxies												
G4	**Resolved stellar populations:**												
	- Colour-Magnitude diagram Virgo		$\sim 10^4$	dark+stable	critical for spectro targets		north+south OK		hard	ok	yes		HR imaging
	- abundances & kinematics Sculptor galaxies			dark+stable	important for MOS		north+south OK		hard	ok	yes		multiobj spectroscopy
	- abundances & kinematics M31- CenA			dark+stable			north+south OK		hard	ok	yes		spectroscopy
G9	**Black holes/AGN**						maximum		yes	yes	yes	c	IFU spectroscopy
	Galaxies and Cosmology												
C2	**Dynamical measurement of universal expansion**	low		dark time	.02-.05" centering		lowest airmass		yes*	yes*	yes*	no	hi accuracy spectros.
C4	**First light - the highest redshift galaxies**	0.1 - 1					to airmass 2		yes	yes	yes	o/c	spectroscopy
C7	**Metallicity of the low-density IGM**						to 40 deg ZD		yes	yes	yes	no	spectroscopy
C10	**Physics of high-z galaxies**												
	- integrated spectroscopy	0.1-1					to airmass 2		yes	yes	yes	c	spectroscopy
	- high resolution imaging	1 to 5					to airmass 2		yes	yes	yes	c	imaging
	- high spatial resolution spectroscopy	1 to 5					to airmass 2		yes	yes	yes	c	spectroscopy

#	Science case	Comments
	Planets and Stars	
S3	**Extrasolar planets:**	
S5	**Stellar clusters (inc. Galactic Centre)**	
S9	**Circumstellar disks, young and debris**	strong complementarity with ALMA
	Stars and Galaxies	
G4	**Resolved stellar populations:**	
	- Colour-Magnitude diagram Virgo	see detailed comments in the document for this case; need careful modelling to accurately define feasibility in a range of circumstances
	- abundances & kinematics Sculptor galaxies	
	- abundances & kinematics M31- CenA	
G9	**Black holes/AGN**	high contrast is important; objects out ti Virgo; rare high-z objects
	Galaxies and Cosmology	
C2	**Dynamical measurement of universal expansion**	*total collecting area must be large (see detailed sc. case). Need improved ETC
C4	**First light - the highest redshift galaxies**	images also required (as JWST has only 5-yr lifetime). If M-IFU field size > 1"x1"
C7	**Metallicity of the low-density IGM**	Similar requirements to CODEX (except only vis-red needed). Can S/N=1000 be reached?
C10	**Physics of high-z galaxies**	
	- integrated spectroscopy	*better ETC needed
	- high resolution imaging	*better ETC needed
	- high spatial resolution spectroscopy	*better ETC needed. Multiple IFUs, each FOV 1.5-2arcsec

I. Introduction

This document contains science cases for a 30m-60m Extremely Large Telescope and the related requirements. It was prepared by the ESO-ELT Science Working group in the short period of 3 months, and is not a finished and polished document. In two meetings (17 January and 17 February) the list of science cases was established and the individual science cases were then prepared by the working group members. The science cases presented here have been taken from other science documents, especially those listed on the Opticon ELT Science document (editor I.Hook, 2005) and documents from the GMT and TMT projects. The science cases have been adapted to the expected performance of 30m to 60m telescopes. One of the important goals of the Science Working group was to estimate the scientific capabilities using a homogeneous set of assumptions. Whereever possible, the science cases have been analyzed using a new exposure time calculator made available by ESO. We note that this new calculator required modifications until the time of submission of this document, and the results can therefore not be regarded as final. Several of the current science cases will need significant simulations for further assessment. Another major difference with earlier European studies is the fact that the field-of-view can be large for 30m–60m telescopes, and the first science cases are now being developed for field-of-views of 10 arcmin.

The list of science cases presented here is not complete in anyway. Those searching for complete lists may want to consult the documents listed above. This document should be useful, however, as a guideline on what capabilities are needed. Readers outside the committee might therefore find the table of requirements the most useful for inspection. Again, this table is based on the current assumptions concerning the performance of the ELT, and these are not final by any means.

Some general conclusions concerning the science cases for an ELT can be made without hesitation:

1) The ELT will enable fantastic science, from planets to cosmology, and it will enable a very large step forward in all aspects of astronomy.
2) Careful trade-offs will need to be made to find an optimal design, location, instrumentation. The considerations are the science cases listed here, the synergy with other facilities, and, in general, the expected needs during the life-time of the facility. The science cases described here are based on expected performance at the start of the project, and these will be quite different from the performance at the end.
3) The most interesting science is often the unexpected science. The opening-up of the high redshift universe by 8-m class telescopes was largely unexpected when the 8-m telescopes were being developed. Similarly, the most interesting science that will be done by the 30-m to 60-m telescopes may be very different from the cases described here. Hence it is important to construct a facility which is efficient and effective in a general sense, and not just optimized to do one or 2 science cases well.
4) Synergy with JWST is a very important driver for the ELT in many of the science cases. This is a strong argument for a speedy development of the ELT, as the current launch date for JWST is summer 2013, with a 5-10 year mission duration.

II. Science Cases: Stars and Planets

S1. Solar System Comets:

Hans-Uli Käufl

The properties of cometary nuclei and the conditions which lead to active zones on cometary surfaces after the NASA Deep Impact Mission (see M. A'Hearn 2005) appear even more enigmatic than before. However, a detailed understanding of these issues is important to judge and calibrate the 'weathering' cometary nuclei have undergone since their formation, to use them as reliable tracers for the conditions of the Solar System during formation.

Methodology: Chemical and constitutional differences in comets are revealed when parent volatiles from the ices and the dust component are studied directly. The richest wavelength domain for volatile studies is the near-IR between 3 and 5 µm. Using high-dispersion spectroscopy a number of parent gas species from cometary ices (H_2O, CO, NH_3, CH_4, C_2H_2, C_2H_6, CH_3OH, HCN) can be measured. The constitutional structure and composition of the dust is revealed by low- to medium resolution spectroscopy from other insgtruments. Both techniques are successfully applied with the respective instrumentation at 8-10m class telescopes. However, for sensitivity reasons they are limited to bright comets only. The goal to establish a map of the formation regions and conditions for comets in the solar system is only reachable using similar instrumentation at a telescope of larger light collecting power since only this way a much larger sample of comets, in particular the barely represented Jupiter Family Comets, can be measured. Infrared Spectroscopy of gas outflow in the 3-5 µm region allows measuring the nuclear spin statistics of protons in H_2O and NH_3. This is considered a reliable thermometer preserving a temperature reading over >106 years. It must, however, be debated, if the spin statistics is not altered by interaction with the solar radiation, once the molecules are released from the nucleus. The high spatial resolution, which can be achieved with an ELT in long slit spectroscopy will allow for a study of the gas within seconds after it has left the surface so that the "true" spin temperature can be derived.

Requirements	
Field of view	10"-20" (long-slit spectroscopy)
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited	diffraction limited at 3µm
photometric uniformity in field and/or time	needs to be calibratable
photometric accuracy	N/A
spectral resolution	200000
wavelength (µm)	2-5µm
multiplex	N/A
typical magnitude	N/A (not limited by brightness, but by the spatial resolution which translates in time resolution for the ouflowing jet
object size	N/A
typical exposure time	0.5 to 2 hours
target density	single source
dynamic range	N/A
background/emissivity	good IR performance
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	±10 degrees from ecliptic Could profit, if observations can be done up to 2 airmasses
Date/Time constraint	comets are often morning or evening objects
can be done with 30m can be done with 42m can be done with 60m	yes yes yes
can be done with JWST	no, required high spectral resolution not available
obs type	Long-slit high-resolution spectroscopy
comments - add additional requirements	

S2. Extra-Solar-System Comets

Hans-Uli Käufl

Falling Evaporating Bodies: In high dispersion spectra of metal absorption lines around beta-Pictoris time variable red shifted narrow absorption features have been observed. These lines are attributed to the evaporation of falling bodies (comets? (Lagrange96). However, beta-Pictoris has remained the only example. An ELT in combination with a high-resolution near-infrared spectrograph would allow a systematic survey around 100s of younger stars with IR-excess. Combination with a suitable IR-imager would allow this truly well targeted. Spectroscopy in the near-infrared would allow a search both for metal line systems (e.g. the Na-doublet in the K-band) or for real organic cometary lines such as H_2CO at 3.3 µm. Thus the quest for extra-solar planets could be complemented searching extra-solar comets.

Field of view	2"
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited	diffraction limited - Strehl>60%
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	200000
wavelength (µm)	2-5µm
multiplex	cross-dispersed spectrograph
typical magnitude	
object size	point source
typical exposure time	time series 4 to 6 hours potentially jumping between 5 to 10 stars
target density	single source
dynamic range	N/A
background/emissivity	good IR performance sufficient
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	up to 2 airmasses (to support long time series)
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	up to 300pc up to 420pc up to 600pc
can be done with JWST	no (insufficient spectral resolution)
obs type	cross-dispersed spectroscopy
comments - add additional requirements	The distance up to which FEBs could be observed is based on beta-Pic and CRIRES sensitivities assuming a S/N of 100 in typically 5 minutes. In nearby clusters of young stars a raster of 4-6 stars could be observed.

S3. From giant to terrestrial exoplanets: detection, characterisation and evolution

R. Rebolo and S. Udry

Context

The recent discovery that at least 7% of solar-type stars host giant planets at separations of less than 5 AU has opened a new domain for research. High precision radial velocity measurements of stars and microlensing techniques provide increasing evidence that planets with terrestrial mass and radius may also be abundant. The diversity of the properties (orbital distances, eccentricities and projected mass distributions) of known giant exoplanets has already challenged traditional theories of planet formation: do these planets form via gravitational instabilities in protoplanetary disks or via accretion of planetesimals? what are the planetary environments around other stars? how typical is our Solar System? are there other Earths? how important is evolution for habitability? Characterisation via direct imaging and low-resolution spectroscopy of exoplanets in various evolutionary stages will be key to answer these questions. Direct detection will make feasible the determination of masses, radii, composition, atmospheres and temperatures both for giant and terrestrial planets at different times of evolution. This will offer unique information to understand how planets form and evolve.

Extremely large telescopes will enable the direct study of planetary systems during their formation from proto-planetary discs for many nearby very young stars. Observations of giant planets in young stellar clusters and star forming regions will trace their evolution as a function of age. An ELT will also be capable of detecting reflected light from mature giant planets (Jupiter to Neptune-like) orbiting at separations smaller than 1 AU around thousands of stars up to distances of 50 pc. It will explore and characterise other solar systems including possible terrestrial planets around nearby stars (d< 25 pc). Direct detection of earth-like planets in extra-solar systems may also lead to the search for bio-markers (e.g. water in the near infrared and oxygen bands in the optical far red) via low resolution spectroscopy with a sufficiently large diameter telescope.

Key requirements

The ELT will be a uniquely powerful facility for the study of exoplanets, from direct or indirect detection, through characterisation by spectroscopy, to elucidating their evolution.

Direct detection–Imaging

We focus on the requirements imposed by the most demanding case: the detection of terrestrial planets in the habitable zone (at 1 AU) of solar-type stars. If the frequency of terrestrial planets in such orbits is similar to that of giant planets (i.e. a few percent), we will need to survey a minimum of several hundred solar-type stars to have a significant probability of finding an Earth-like planet. There are only four solar-type stars (αAql, τCeti, εEri and εIndi) within 5 pc of the Sun, it is required to explore a volume 100 times larger to find a sufficient number of these stars. Thus, the telescope should have sufficient diameter to be able to resolve a terrestrial planet orbiting at 1 AU of a solar-type star up to a distance of 25 pc from the Sun (angular separation of 40 mas). It should detect these planets as close as 40 milliarcsec from the star. Given the high contrast imaging needed (Sun´s energy intercepted by Earth is $4.5 \cdot 10^{-10}$ $L_{\odot}$), specific instruments with coronagraphs or differential imaging cancellation will also be required. At present the highest contrast images obtained at 8-10m telescopes in the near infrared are of order 10^6 at 10 λ/D, but extreme-AO systems are planned which may improve contrast by two orders of magnitude in the near future. We will assume here that specially dedicated instruments (coronagraphs and differential imagers) may achieve brightness contrast of 10^{10} at 10 λ/D at the time of operation of the ELT. In summary, this sets a requirement for a telescope with a PSF less than 4 mas in the J-band, and therefore a diameter in the range 50-60m.

Practical case

Assuming the reflected light of a terrestrial planet resembles in the near infrared the spectrum of a G2 star, we estimate that the total integration time required to detect in the J-band such a planet around a star at 25 pc is 16000 s (S/N=5) for a 60 m telescope. Low resolution J-band spectroscopy (R=100) of a similar planet located at a distance of 10 pc would be feasible with an integration time of 18000 s. Because of prohibitively large observing time these spectroscopic studies may not be feasible at distances larger than 20 pc. The same telescope would be able to detect old giant planets in reflected light up to distances of 300 pc and young (brighter) planets in stars of many star forming regions up to distances of a several kpc.

Indirect detection: Radial-velocities

The continuation of indirect exoplanet detections (radial-velocity search) with ELT's will lead to unique results in at least three main aspects of exoplanetary science:

- Determination of planetary parameters (radius, density) for Earth-mass planets detected by transit searches (CoRoT, Kepler)
- Discovery of Earth-like planets
- Jupiter-mass planets around faint stars

Practical case

Again, we focus on the most demanding case: the detection of terrestrial planets in the habitable zone (at 1 AU) of solar-type stars. Such a detection with RV techniques will require a long term RV accuracy of a few cm/s (effect of the Earth on the Sun is 8 cm/s). To achieve such a goal, we need a high-resolution, very stable spectrograph (e.g. the CODEX spectrograph proposed for OWL). Supposing the instrument available, we have then to overcome 3 main limitations:

1) Photon Noise: Extrapolating from HARPS results (1 m/s in 1 minute for a V=7.5 K0 dwarf) and taking into account that RV precision scales linearly with the S/N ratio (going from 1 m/s down to 3 cm/s will require 10^3 more photons), we expect

+ 3 cm/s precision in 1 hour for a V~9 K0 on a 30-m telescope
+ 3 cm/s precision in 1 hour for a V~10 K0 on a 42-m telescope
+ 3 cm/s precision in 1 hour for a V~10.5 K0 on a 60-m telescope

Notes:

- For G0 dwarfs, the same precision is reached for stars 1 mag brighter
- The follow-up of Kepler candidates will not need such high precisions as i) the periods and phases of the orbits will be known and ii) the candidates will probably be closer to their parent stars (transit probability).
- For faint stars: with a 42-m telescope, 1 m/s is reached in 1 hour for a V=17.5 K0

2) Stellar Activity Noise: RV jitter related to 'stellar activity' is produced by the transit of inhomogeneities across the stellar surface, or by the net effect of asymmetric convective motions. HARPS results indicate however that this jitter can be below 1 m/s.
3) Stellar Acoustic Noise: RV variations due to acoustic p-modes and beats between the modes. Scaling the results of the best observations (μAra, αCen) the peak to peak variations of the 'quiet' star are well below 1 m/s and the beat induced variations are probably

i) of the order of 20 cm/s when averaging the measurements over a timescales corresponding to timescale of the modes (10-15 minutes)
ii) of the order of a few cm/sec if the average is done over several hours.

A possible strategy to overcome these stellar limitations to detect Earth-like planets could consist in

a) several exposures/night to average out the acoustic modes, for a total of about 1 hour/night for each star (limiting ourselves to solar-type dwarfs)
b) A few hundreds of such nights over a few years (i.e. 100 nights over 4 years) to average the jitter and cover the period

Requirements	direct imaging	radial velocity detection
Field of view	10"-20"	small (a few arcsec)
-diameter of 50% enclosed energy circle		not a constraint
-strehl ratio (or "diff. lim." for diffraction limited)		
photometric uniformity in field and/or time		
photometric accuracy	1%	
spectral resolution	R=100	R=100000 (requires a dedicated instrument, e.g. CODEX)
wavelength (μm)	0.8-2μm	visible
multiplex	no	no
typical magnitude	>28	V=5-11
object size	point source	point source
typical exposure time	1 hour	1 hour
target density		
dynamic range		
background/emissivity		
astrometric/plate scale stability		
polarisation		
sky coverage		
Date/Time constraint		
can be done with 30m	exo-earth detection up to 10pc	
can be done with 42m	exo-earth detection up to 15pc	
can be done with 60m	exo-earth detection up to 25pc	
can be done with JWST	high contrast imaging and spectroscopy	
obs type		high-resolution spectroscopy
comments - add additional requirements	development of high performance techniques for speckle suppression is critical	requires development of high performance techniques for wavelength calibration, precise and stable over years

S4. *Freely-floating planetary mass objects*

F. Comeron, M. McCaughrean, & H. Zinnecker

While the existence of isolated objects with masses down to a few Jupiter masses is now well established, little is known about their spectral characteristics and their properties in a variety of environments. Such objects have been directly detected thus far only in star forming regions, which are the most favorable ground for detection due to their brightness and detectability as short wavelengths. Even in such conditions, a 5 Myr object with 1 MJup at the distance of the nearest star forming regions (~150pc) is expected to have K = 23, allowing little more than detection with 8m class telescopes. Spectroscopy of such objects will be possible only with ELTs using laser tomography AO. At such young ages they are still bright in the near infrared and even in the far-red, where the spectrum should be similar to that of field T dwarfs, although with a much lower surface gravity (log g ~ 3 vs. log g ~5 for field T dwarfs), which may introduce important differences. Spectroscopy would allow one to detect weather effects in them, determine the characteristics of dust in their atmospheres, and validate evolutionary models at such a difficult region of the parameter space.

Within a field of view ~10''x 10'', a deep exposure of the surroundings of a freely-floating object would contain sufficient extragalactic background objects to serve as astrometric reference. An astrometric accuracy of 0''.01 would allow the determination of transverse velocities of members of nearby star forming regions to an accuracy of ~7 km/s with a baseline of ~1 year. Their possible origin as ejected objects could then be studied by tracing back the trajectories to the parent star.

Deep ELT fields in very young star forming regions could be used to probe young clusters in three bands, or two intermediate bands (methane filters) down to the Jupiter-mass level in less than one night at distances up to ~1 kpc. The distance limit is given by the need to have an acceptable AO correction over a large field (~1'x1') using GLAO, given an absolute magnitude M_K=13.6 for M=1 M_{Jup}, age =1 Myr, and assuming an extinction of 1 mag at K. A 5h integration with GLAO in K reaches K=24.3 for a 30m ELT, and 25.1 for a 60m, corresponding to distances in the 870 to 1250 pc range. At those distances, a field of view of 1'x1' corresponds to 0.3 pc x 0.3 pc, thus sampling a sizeable fraction of a typical cluster and yielding a high likelihood of finding objects of these masses. More nearby clusters, with brighter and more sparsely distributed members, should be best explored with smaller telescopes having larger field of views. The scientific interest of going to more distant clusters lies in exploring a wider range of star formation environments.

A freely-floating planetary mass object of 10 M_{Jup} at age=5 Myr has K=25 at 10 kpc, and it could be in principle detected by a 60m ELT anywhere in the Galaxy. At even younger ages, a 10 M_{Jup} object 1 Myr old could be detected in the Magellanic Clouds at K=27 with diffraction-limited imaging, opening the possibility of studying the photometric characteristics of newly formed freely-floating planetary mass objects in low metallicity environments. Diffraction limited capabilities are needed in such cases both to boost sensitivity and to lower the confusion limit. The lowest end of the initial mass function well into the brown dwarf domain could be studied over a wide range of metallicities and environments.

ELT goals:

- Weather effects detection and monitoring through IZJHK spectroscopy
- Dust mineralogy in the photospheres: spectroscopic evidences for dust sedimentation
- Validation of evolutionary models
- Astrometric membership and trajectory reconstruction.
- Detection and identification (based on peculiar colors) in distant galactic star forming regions (1 kpc for 1 MJup at 5 Myr; anywhere in the Galaxy for 10 M_{Jup} at 5 Myr)
- Detection and identification (based on peculiar colors) of objects down to 10 M_{Jup} at age 1 Myr in the Magellanic Clouds.

Requirements	
Field of view	1'x1' or larger (galactic studies) minimum 30"x30"
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	diffraction limited (spectroscopy, Magellanic Cloud Searches) GLAO assisted, wide area searches
photometric uniformity in field and/or time	N/A
photometric accuracy	10%
spectral resolution	100 over the whole spectral range
wavelength (µm)	0.7-2.4µm
multiplex	N/A
typical magnitude	K=23 (1 M_{Jup}) in nearby star forming regions K=27 useful limit in the Magellanic Clouds (10 M_{Jup}, 1 Myr)
object size	point source
typical exposure time	1 hour for spectroscopy with laser tomography (S/N=20 at K=23 at a 30m ELT) 5 h (imaging of distant regions and Magellanic Clouds with 60m ELT) snapshot for astrometric measurements in nearby regions.
target density	1 per 10'x10' (very uncertain!) in nearby star forming regions
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	better than 1%
polarisation	N/A
sky coverage	N/A
Date/Time constraint	observations baseline 1 to 2 years for astrometry
can be done with 30m can be done with 42m can be done with 60m	yes (imaging, spectroscopy of ~few M_{Jup} objects) yes (imaging, spectroscopy of ~few MJup objects) yes (required for LMC)
can be done with JWST	complementary (JSWT for spectroscopy of individual targers beyond 2.5µm)
obs type	high resolution imaging, low resolution long-slit spectroscopy
comments - add additional requirements	

S5. Young stellar clusters (incl. Galactic Centre)

F. Comerón, M. McCaughrean, H. Zinnecker

Systematic studies of distant galactic clusters will be possible by obtaining IFU spectroscopy on fields of ~10"x10", or larger if possible (at 5 kpc, a compact cluster 1 pc across has an angular size of 40"; the size of the galactic centre cluster is also similar to that value), enabling spectral classification of members and radial velocity membership determination. Probing deep into the galactic center with full AO correction will allow to determine orbits of objects of all stellar masses in the neighbourhood of SgrA*.

The entire mass function of embedded clusters down to a few Jupiter masses (depending on age) will be available to observations for clusters across the Galaxy. A detailed spectral characterization of members over the full mass range will become possible for the nearest aggregates, including spectroscopy down to ~0.7 microns for the least obscured brown dwarfs: as a reference, a R=1,000 spectrum of a 10 MJup object obscured by A_V=10 mag at the distance of Rho Ophiuchi in the R band would have SNR=5 per resolution element after 10h of integration with a 42m telescope.

High spatial resolution imaging will make it possible to probe the full range of stellar and brown dwarf companion masses in nearby regions such as Rho Ophiuchi, Lupus, R CrA, or Chamaeleon down to separations of ~2 AU, well within the brown dwarf desert. Direct imaging with high contrast will enable the detection of brown dwarfs and giant planets orbiting within several AU of the central star: a 60m ELT can image a 10 Myr old Neptune-mass planet in the J, H, or K bands in 10h of integration (and probably less if the luminosity output of the object is dominated by light reflected from the central star at those wavelengths), and Saturn-mass planets are well within the reach of a 30m ELT with similar integration times.

With an ELT, studies of embedded clusters in the Magellanic Clouds and other Local Group dwarf irregular galaxies will be possible to a level of detail comparable to that available only a little more than one decade years ago for the nearest embedded clusters. At the distance of the LMC, a Rho Ophiuchi analog subtends an angle of ~20'' and its most massive, lightly obscured brown dwarfs have a magnitude of K=25 (assuming 1 Myr of age and one magnitude of extinction at K). GLAO-assisted imaging can detect such objects at S/N=5 in 5h with a 60m ELT. An exposure time of 10h at a 30m ELT can still detect such objects at S/N~4.

ELT goals:

- Complete census of the stellar content of embedded clusters up to distances of several kpc
- Spectroscopic characterization of brown dwarf members from the red to the near-IR.
- Spectroscopic characterization of planetary-mass members in the IR.
- Complete, unbiased binarity statistics (separations, mass ratio distributions).
- Direct detection of planetary-mass companions
- Photometric studies of embedded clusters in the Magellanic Clouds.
- Orbital determination of all stars in the proximity of SgrA*

Requirements	
Field of view	1'x 1' or larger (galactic studies), 10"x10" (Magellanic Clouds)
-diameter of 50% enclosed energy circle	0"2 (wide-field imaging), diffraction-limited (spectroscopy, companion detection)
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	5%
spectral resolution	1000 from red to 2.4μm
wavelength (μm)	0.7-5μm
multiplex	a few tens of objects in a 1'x 1' field of view (lowest mass freely-floating members of cluster up to 1 kpc); IFU over a 30"x 30" field
typical magnitude	down to R~27, K~23 (spectroscopy); K~25 (imaging in the Magellanic Clouds)
object size	1'x 1' (distant clusters); point source (indivudual objects)
typical exposure time	up to 10h (spectroscopy, Magellanic Clouds imaging)
target density	up to ~1000 sources/sq.arcmin
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	better than 1% (galactic center)
polarisation	N/A
sky coverage	observations covering up to ~few years for astrometry at the galactic center
Date/Time constraint	observations baseline 1 to 2 years for astrometry
can be done with 30m	yes, but not LMC case
can be done with 42m	yes, required for LMC
can be done with 60m	yes, required for LMC
can be done with JWST	complementary (JSWT for spectroscopy of individual targers beyond 2.5μm)
obs type	high resolution imaging, high contrast imaging, low resolution long-slit spectroscopy, IFU spectroscopy
comments - add additional requirements	

S6. Magnetic fields in star formation and in very low-mass objects

Eike Guenther (TLS) and Hans Zinnecker (AIP)

Magnetic fields are considered to be of crucial importance for the physics of accretion disks and their associated outflows. For example, in the magnetic accretion scenario a strong magnetic field couples the disk to the star, so that matter can flow inwards, while angular momentum is transported outwards. In order to better understand these processes, it is required to measure the field strength of a large variety of stars, and also to measure the field strength in the disk itself. With the current technology it is only possible to measure the magnetic field strength of a few slowly rotating bright stars with a low accretion rate. Thus, it is currently not possible to search for any correlation between magnetic field strength, the rotation rate and the accretion rate. The generation of the fields and their relation to the accretion can currently not be studied directly. While the situation for the stars is already difficult and few T Tauri stars have measured fields (Guenther etal. 1999, AA 341, 768 who detected kiloGauss field strengths in T Tau and LkCa 15), the situation for the disks is even worse, as the magnetic field strength of just one disk of a young, low-mass star has been measured up to now.

Brown dwarfs (BDs) are objects which are not massive enough to sustain thermonuclear fusion of hydrogen at their centers but are distinguished from gas-giant planets by their ability to burn deuterium. What makes these objects interesting is that their properties are in many respects intermediate between planets and stars. The recent discovery of large flares indicating the presence of strong magnetic field in at least some BDs was very surprising. The question now arises whether these fields are like those of M-dwarfs or a scaled up version of those of the planets in the solar system. For both active and inactive stars there is a correlation between the X-ray and the radio emission of the corona which works over 10 orders of magnitude. While only a few old brown dwarfs have so far been observed at GHz frequencies, these dramatically violate the X-ray/radio-emission relation, as they are 4 to 5 orders of magnitude too bright in the radio regime. Observations with the VLA of an old BD imply a magnetic field strength (averaged over the whole surface!) which might be of the order of a few hundred gauss! Thus, while it is now clear that at least some old BDs have strong magnetic fields, the properties of the resulting coronae are strikingly different from those of stars! Possibly, not only the coronae differ from those of stars but also the structure of the magnetic field itself. Fields of fully convective objects (like BDs) are expected not to be concentrated in small star spots but to be distributed on a global scale. Additionally, due to the low temperature of old BDs the degree of ionisation in the atmosphere is very low, leading to a very low degree of the coupling between the magnetic field and the atmosphere. If this were true, BDs with strong magnetic fields should not have spots despite the fact that they might have strong magnetic fields. The logical next step would then be to investigate the fields of the so-called free-floating planets. Do these objects still form via magnetic accretion like stars?

ELT goals:

- Measure the magnetic field strength of young stars, brown dwarfs, and the so-called free floating planets, in order to find out whether these objects have magnetic fields, and whether these fields are important for the formation and evolution of these objects.

- Map the field distribution on the surface of the stars, brown dwarfs, and the so-called free floating planets in order to find out how the fields are generated and how the field strength is distributed on the stellar surface.
- Measure the magnetic field strength of the disks of young stars and possibly also young BDs. With an ELT it should be possible to spatially resolve these disks, and to map out the field strength at different distance from the host star.

In order to detect magnetic fields of only a few hundred gauss, a spectrograph with a resolution of R=100000 is required. The expected Stokes V signals are in the range of few percent. In order to measure these, a S/N of 100-300 is required for each of the two beams. Since the Zeeman-splitting delta lambda is proportional to λ^2, measurements of the magnetic fields are better carried out at infrared wavelength. However, the real gain is only proportional to lambda, as the width of the lines (rotational broadening) also increases with $v \sin i$ and hence with λ ($v/c = \Delta\lambda/\lambda$). There are several lines that are useful for measuring magnetic fields. Examples are the g=2.5 TiI line at 2.23µm, or the MgI line at 12µm, or even FeH-band around 0.99µm in the far red regime. With an ELT of 30m aperture, the limiting magnitude would be about 12 mag in the K-band to detect a Stokes V signal of only 1 percent in 1 hour. This would allow us to observe all T Tauri stars in all nearby (150pc) star-forming regions and would also bring brown dwarfs into view. With an aperture of 60m even free-floating planets in these regions could be studied at slightly reduced accuracy with an exposure-time of about 1 hour.

This case would make use of a high-resolution IR spectrograph with polarisation optics on an ELT.

Requirements	
Field of view	<1 arcsec
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	<0.1 arcsec
photometric uniformity in field and/or time	N/A
photometric accuracy	
spectral resolution	~10000
wavelength (μm)	J,H,K
multiplex	single objects
typical magnitude	
object size	point source (individual objects)
typical exposure time	up to 10h (spectroscopy, Magellanic Clouds imaging)
target density	
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	
polarisation	yes
sky coverage	
Date/Time constraint	
can be done with 30m can be done with 42m can be done with 60m	
can be done with JWST	no
obs type	spectropolarimetry
comments - add additional requirements	

S7. *Origin of massive stars*

H. Zinnecker, H.-U. Käufl, M. McCaughrean

Massive stars (M>20Mo) are beacons, wreckers, and engines of change within their galactic and extragalactic environment. When they die and explode as supernovae, they dramatically deposit lots of kinetic energy and chemically enriched material in the interstellar medium. Yet despite their enormous overall importance for galactic dynamical and chemical evolution, their origins and birth processes remain poorly understood (see IAU-Symp. 227, eds. Cesaroni et al. 2005).

Here we make the case how future ELTs (>30m diameter) help to understand the formation and early dynamical evolution of massive stars embedded in highly obscured very compact HII regions. We suggest to exploit the ELT's near- and thermal IR enhanced sensitivity and angular resolution with the aim to peer through huge amounts of dust extinction (A_V > 200 mag) and to take direct nearly diffraction limited images. These images should allow us to find clear observational evidence for or against disk accretion and binary stellar mergers (two of the leading contenders of formation models, see Bally & Zinnecker 2005 and Bonnell & Bate 2005).

Although a number of formation sites associated with ultracompact (0.1pc) and hypercompact (0.01pc) HII regions have been identified, the gas column density ($3\ 10^{23}$ cm^{-2}) and dust extinction (A_V > 100 mag) are too high to detect them, their photospheres that is, with current 10m-class telescopes. Also, the angular resolution is too low (0.1") for the typical distance (2-4 kpc) and the dense clustering of objects to spatially resolve the stellar substructure of these HII regions (several very compact radio sources within 2"x2", see the case of W3-IRS5, a proto-Trapezium; Megeath et al. 2005)

An ELT larger than 30m in diameter equipped with adaptive optics and spatial resolution of around 10 mas can penetrate an UCHII region like W3-IRS5 and resolve an embedded dense star cluster. Given a distance modulus of 11.5 mag (2.5 kpc), and an extinction of A_V = 200 mag (cf. Faundez et al. 2004) equivalent to 22.5 mag in the K-band and 4.5 mag in the M-band (Rieke & Lebofsky 1985), the telescope needs to reach a limiting apparent magnitude of K=28 and M=11, resp., assuming an absolute magnitude for massive stars on the ZAMS of ca. M_K = -6 mag and M_M = -5 mag. A nearby near-infrared guide star will often be available, but sometimes a laser guide star may be needed. High proper motion (several mas/yr) including dynamical ejections (so-called runaway phenomenon) at velocities in excess of 30 km/s due to close encounters (ca. 20 AU) in mini-cluster multiple systems can be monitored by successive imaging over a 1-2 year baseline. IFU 2-5 micron spectroscopy will be useful to study the complex interaction zone of the incipient protocluster, including circumstellar disks and massive molecular outflows, and to infer the extinction to the individual point sources by means of the Brackett α (4.05 μm) to Bracket γ(2.17 μm) recombination line ratios; for details see Zinnecker (2006).

In summary, the ELT's very high angular resolution will allow us to see if the formation sites of massive stars (i.e. UCHII) have the high stellar densities necessary for stellar collisions and coalescence to occur, or whether the protostars are more isolated as expected in the conventional accretion scenario.

References

Bally & Zinnecker 2005, AJ 129, 2281
Bonnell & Bate 2005, MNRAS 362, 915
Faundez et al. 2004, A&A 426, 97
Megeath, Wilson & Corbin 2005, ApJ 622, L141
Rieke & Lebofsky 1985, ApJ 288, 618
Zinnecker 2006, Proc. "ELT" IAU-Symp. 237 (CapeTown), eds.

Requirements	
Field of view	20"
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	10mas >30%
photometric uniformity in field and/or time	0.03mag
photometric accuracy	3%
spectral resolution	10000
wavelength (μm)	2-5μm
multiplex	yes, multi-object or IFU spectroscopy
typical magnitude	K~28
object size	star cluster with nebulosity
typical exposure time	10 hours
target density	4000 sources/sq.arcmin
dynamic range	ca. 100
background/emissivity	nebulosity
astrometric/plate scale stability	var << FWHM
polarisation	ca. 1%
sky coverage	galactic plane
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	no yes yes
can be done with JWST	yes
obs type	imaging and IFU spectroscopy
comments - add additional requirements	laser guide star? strong synergy with ALMA! need for proper motion and RV measurements 4kx4k infrared array desirable

S8. LMC and SMC field star population

H. Zinnecker & F. Comerón

We propose to take deep adaptive optics images in the JHK bands in several fields in the Large Magellanic Clouds, clear of extinction and nebulosity, to infer the luminosity function of low-mass main sequence stars (with masses below a solar mass). This luminosity function can be translated into the low-mass field star initial mass function (IMF) and be compared with the corresponding distributions in the solar neighorhood (e.g. Reid et al. 2002. AJ 124, 2721). There are indications that the LMC low-mass IMF in young Lucke/Hodge associations is steeper than the one in our solar vicinity (Gouliermis, Brandner and Henning 2005, ApJ 623, 846), based on HST data.
Star formation processes in the LMC and SMC may be different from our Galaxy, due to the lower overall metallicity (1/4 solar for LMC, 1/10 solar for SMC) of their interstellar gas. An investigation of the sub-solar field star IMF in the LMC and SMC (stars which did not evolve over their 10 Gyr lifetime) is more robust than a similar investigation in young associations, as it does not depend on on any assumption of the history of star formation or foreground/background contamination by stars in the same galaxy, just on star counts as a function of apparent magnitude (the distance to all LMC or SMC stars is practically the same). Near-infrared is preferred, as the stars are red and adaptive optics (with decent Strehl) works best in the near-infrared.
Using the stellar density above 0.7 solar masses measured by Gouliermis et al. (2005) at the transition region between the LMC bar and the disk, and extrapolating using the galactic IMF down to 0.2 solar masses, we expect an angular surface density of about one star point per arcsec2 down to 0.2 solar masses. The quantity is highly uncertain due to the present lack of determinations of the low-mass IMF in the LMC and SMC, which is the goal of this project. In a 20x20 arcsec image, there will be some 400 objects for which we need to obtain good near-infrared photometry (3\% accuracy). Depending on the actual AO performance the observed LMC field could be selected either closer to the bar or in the outer disk, so as to increase or decrease the expected surface density, respectively. We expect less severe crowding problems at the SMC due to its lower surface density. We want to reach stars with masses as low as 0.2 solar masses, which have absolute K magnitudes of 7.5. Given a distance modulus of 18.5 mag to the LMC, our faintest stars to be measured should be around K=26 (J magnitudes up to 1 mag fainter). We will have to choose fields with a bright field star for wavefront sensing, which could be a foreground galactic star. GLAO will be needed due to the need to have a good image quality over a field of view a few tens of arcsecond across.
A comparison between the field star luminosity function in the LMC and SMC will be extremely valuable, as these nearby galaxies have substantially different metallicities (1/4 vs. 1/10 solar) which could offer unique clues as to whether metallicity effects are important in low-mass star formation.

photometric uniformity in field and/or time	0.03mag
photometric accuracy	3%
spectral resolution	R=5
wavelength (µm)	1-2µm
multiplex	no
typical magnitude	26 (0.2 solar masses at the LMC)
object size	point sources
typical exposure time	10 hours (42m) for S/N=5
target density	about 4000 sources/sq.arcmin
dynamic range	ca. 1000
background/emissivity	N/A
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	LMC/SMC
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	yes yes yes
can be done with JWST	yes
obs type	medium contrast imaging using GLAO
comments - add additional requirements	crowded field AO photometry, star counts

S9. Circumstellar Disks

M. McCaughrean, W. Benz. H.-U. Käufl

Circumstellar disks appear to be an inevitable consequence of the birth of low-mass stars and brown dwarfs, a repository for excess angular momentum as a molecular cloud core collapses to form one or more protostars. These disks are also thought to be launching pads of the highly-collimated jets and outflows seen to arise during the first few million years in the life of a young star, as twisting magnetic fields lift material off the disk along the polar axes of the star. Most importantly, however, they are believed to be the progenitors of planets, born out of dust and gas in the disks. This `nebular hypothesis' for the formation of planetary systems dates back to Descartes, Kant, Swedenborg, and Laplace for our own solar system, and has been spectacularly vindicated in the past decade by direct imaging observations of disks surrounding young stars in many nearby star-forming regions.

While this basic paradigm is well established, there are many key details which remain poorly understood, including the mechanism by which gas giant planets are formed, the time scales over which dust particles agglomerate into planetesimals and over which the gas is removed from a disk, the chemical processing in a disk and how it is affected by the central protostar and its surrounding environment, and how young planetary systems evolve dynamically into the broad and largely unanticipated array of architectures observed in the solar neighbourhood today. Finally, even though almost all young low-mass stars are known to have disks at 1\,Myr, it is still not yet clear what fraction actually form long-lived planetary systems.

Thus, the formation and evolution of circumstellar disks is an important area of study in astrophysics, from the optically-thick, gas-rich disks seen at 1 Myr to the debris disks of reprocessed dust surrounding stars of 100 Myr and beyond. The European ELT will make crucial contributions to this field, alongside complementary observations to be made with infrared long-baseline interferometers such as the VLTI, millimetre imaging arrays such as ALMA, and highly-sensitive thermal infrared observatories such as the JWST.

The first core capability of an ELT in this context will be filled u,v-plane, high spatial resolution and high contrast imaging to investigate the spatial structure of disks in the putative habitable terrestrial planet-forming zone of young disks in nearby star-forming regions in scattered light in the near-infrared (a diffraction-limited 40-m diameter ELT yields a spatial resolution of 2 AU at 150 pc) and in self-emission from dust in debris disks around nearby stars in the thermal-infrared (the same telescope has a resolution of 1 AU at 20 pc). The goal will be to search for gaps non-axisymmetric structure such as spirals and hotspots in the young and more mature disks indicative of ongoing or completed planet formation. High quality, high constrast adaptive optics over a limited field (few arcsec) is required at 2-20 microns: in many cases, the parent star can be used for on-axis wavefront sensing, although a near-infrared wavefront sensor would be highly recommended for more embedded sources. Post-wavefront sensing coronography will be required in almost all cases in order to suppress the central star. It would also be highly advantageous to be able to image in narrow-band filters, in order to use emission lines in HII regions to provide high contrast images of disks seen in silhouette, as in Orion. Here the aim would be to image the outer edge structure of the disks to obtain insight into truncation mechanisms and the potential evidence for grain growth. Polarimetry may be useful for the scattered-light near-infrared observations.

Fundamentally, in all of these cases, high spatial resolution is the key requirement and where an ELT will win over the JWST.

The second capability is spectroscopy in the near- and mid-infrared (3-20 microns), in order to study the dynamics of the disks (as traced in CO bandhead emission, for example) and the chemical processing of dust, gas, and ices. Disk spectra will include features from a wide variety of gas-phase molecules, amorphous and crystalline silicates, PAHs, ices, and organic materials, and it is important to trace the processing of these materials by UV radiation, X-rays, and thermal radiation from the central protostar and other, more massive stars in the local environment. These materials cycle back and forth between gas a solid phases as a disk evolves and by studying the astrochemical evolution in detail, it will be possible to trace the formation history of planetesimals and other solid bodies, their composition, their processing, and search for signs of complex organic molecules, the precursors of life. Finally, it will be important to study the evolution of warm molecular gas is disks as the building material for giant planets. Spatially resolved, simultaneous spectroscopy in a number of rotational lines of H_2 will make it possible to determine the radial distribution of mass and temperature and, in tandem with ALMA studies in the dust continuum, the gas-to-dust ratio.

If at all possible, these studies would ideally be carried out in an imaging mode using integral field spectroscopy, again over field of a few arcsec (up to 5). Low (R=300), medium (R=3000), and high (R=50000) spectral resolution capabilities are required to cover the broad range solid and gas phase species. High dynamic range spectroscopy is required in order to allow the tracing of faint features against the bright continuum of the central young star.

Requirements	
Field of view	5"x5' to 10"x10" (maximum)
-diameter of 50% enclosed energy circle	
-strehl ratio (or "diff. lim." for diffraction limited)	Diffraction-limited from 2 to 20 microns; ideally diffraction-limited at 0.7µm for scattered light imaging; difficult though since telescope scattering etc. would need to be well-controlled in order to accurately imaging faint structures in disks
photometric uniformity in field and/or time	not a major issue: 10%
photometric accuracy	0.05
spectral resolution	10/few 100/few 1000/50000
wavelength (µm)	Require 2 to 20 µm Goal 0.7 to 20 µm Desirable extension 200 to 850 µm for sub-mm continuum imaging
multiplex	one object per field only; but need an IFU for spatially resolved spectroscopy
typical magnitude	wide range: extended targets so down to very low surface brightness when resolved
object size	few arcseconds typically
typical exposure time	Very wide range of possibilities: typically for imaging <1 hour per source; for high-resolution spectroscopy, perhaps 10 hours per source
target density	very rarely more than on per field
dynamic range	Perhaps 10^4 - 10^5 in visible, provide a coronagraphic option is used to block central star More like 10^3 - 10^4 in thermal IR
background/emissivity	Good thermal-IR performance, particularly at 20 µm requires low temperatures and low water vapour, strongly favours high altitude site and/or Antarctica
astrometric/plate scale stability	1% stability
polarisation	Linear polarisation capability highly desirable in optical/near-IR for scattered light imaging; not so important in thermal IR as dust emission will be largely unpolarised
sky coverage	Objects all over the sky: wide coverage required
Date/Time constraint	N/A
can be done with 30m	Optical/near-IR yes; thermal-IR limited
can be done with 42m	Yes at all wavelengths
can be done with 60m	Significant gains in thermal-IR due to additional resolution and sensitivity (time required going as D2 for extended sources)
can be done with JWST	Largely complementary: JWST more sensitive in thermal-IR, but significantly lower spatial resolution (factor of 5-10 worse); also JWST spectroscopy in thermal-IR limited in resolution (100-2000), ELT should provide complementary high-resolution spectrosco
obs type	Optical/near-IR/thermal-IR imaging and spectroscopy; IFU capabilitystrongly preferred
comments - add additional requirements	Strong complementarity with ALMA

S10. Stellar remnants: black holes and neutron stars

R. Rebolo

Low-mass X-ray binaries (LMXBs) are transient systems formed by a compact object (either a black hole or a neutron star) and a slightly evolved star. The best known examples of stellar black holes are found in these binaries where a precise determination of the dynamical mass of the compact object can be obtained from radial velocity measurements of the secondary star. Mass transfer from the secondary onto the compact remnant produces transient outbursts which are recurrent in timescales of several decades. Many new transients will be discovered by X-ray monitoring satellites in the coming years enabling a systematic study of the most exotic states of matter. Spectroscopy of the secondaries in these systems informs us about the mass of the remnant (radial velocity measurements) and about the mass of the progenitor (chemical element studies).

Thousands of LMXBs are indeed expected in our Galaxy as a consequence of the evolution of binaries with very massive primary stars. Several tens have already been identified but only a small subsample is bright enough for detailed study with current very large telescopes. The vast majority of the new discoveries will also be too distant to be observed with the current generation of large telescopes, thus an ELT is essential if we aim to explore the physics of the accretion disks and the properties of the highly-peculiar secondary stars.

We shall aim to characterise LMXBs anywhere in our Galaxy, including globular clusters and the Galactic halo. Determining the radial velocity curves, which have typical amplitudes of 400 km s^{-1} and orbital periods ~10 h, requires 20 or more spectra with S/N≥10 and resolving power ~5000, distributed around the orbit. Circularized orbits imply fast rotating secondaries and constrain the exposure times to rather short integrations to avoid line smearing. The final co-added spectra will also allow a chemical composition study of the star and potential characterisation of the nucleosynthesis processes in the material ejected during the formation event of the compact object. Typical LMXB secondary stars are of K-M spectral type. A 30 m telescope may provide radial velocity measurements with adequate S/N and time resolution (1000 s) for such stars up to a distance of 10 kpc, for instance in the nearest globular clusters. Detection and characterisation of these systems throughout the disk of the Galaxy and in a large fraction of the Galactic halo (up to 20-30 Kpc) will require a 50-60 m class telescope.

Such a data set will allow the determination of the distribution of masses among black holes and neutron stars, its dependence on location and also to trace the heavy-element abundance production of progenitor stars at various epochs of our Galaxy.

Optical and higly time-resolved photometry of *isolated* neutron stars is also important to probe their interiors and may provide a better understanding of baryonic matter. An ELT can directly observe neutron stars (i.e. not the accretion-flow emission in an X-ray binary) up to distances of several kpc. Optical counterparts of many millisecond pulsars could be investigated.

These objects are faint in the optical (likely candidates have V~29 at 1 kpc), and a search for e.g. their nonradial oscillations (predicted periods in the range of milliseconds or 100's of microseconds) obviously require an ELT, and would be quite challenging. About 4h of observing in phase with the pulsar's period would be required to build up a 300-point light curve of a V = 26 pulsar resembling the Crab (30 ms period).

Requirements	
Field of view	10"-30"
-diameter of 50% enclosed energy circle	<100mas (to resolve LMXBs in globular clusters)
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	few percent
spectral resolution	R=5000
wavelength (µm)	optical and near-IR
multiplex	no
typical magnitude	>25
object size	point sources
typical exposure time	<1000s
target density	N/A
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	milliarcsec
polarisation	N/A
sky coverage	N/A
Date/Time constraint	N/A
can be done with 30m	up to 10kpc
can be done with 42m	
can be done with 60m	up to 20kpc
can be done with JWST	no
obs type	imaging and spectroscopy
comments - add additional requirements	

S11. Asteroseismology

S. Udry

Asteroseismology, which consists in measuring properties of acoustic oscillations (also called p-modes) in stars, provides a unique insight to drill stellar interior and is nowadays the most powerful constraint to the theory of stellar evolution. The success of helioseismology stimulated various attempts to detect a similar signal on other solar-type stars. The difficulty comes from the extremely small amplitude of p-modes which is at the level of 10-100 cm/s in radial velocity measurements (more efficient than photometric observations). Recent improvements in Doppler spectroscopy (HARPS), mostly driven by intensive search for exoplanets, have led to the accuracy needed to detect p-mode oscillations from the ground on bright solar-type stars. However, in several cases, modes identification is uncertain or impossible mostly due to an insufficient signal-to-noise. HARPS is limited to the study of few tens solar-type stars with magnitude less than V~6. Furthermore, the achieved accuracy on individual points (photon-noise limited at 40-100 cm/s) do not allow the characterization of the tiniest modes with amplitudes of a few cm/s.

The main advantages for asteroseismology of large telescopes, with a high-resolution spectrograph like e.g. HARPS/CODEX, will be multifold:

- To obtain an increased S/N for a given magnitude and exposure time. An HARPS-like spectrograph coupled with a 42-m telescope would typically reach a photon noise of 50 cm/s on a 11~magnitude star in a 1~mn exposure time.
- In addition to improved S/N, the main advantage would reside in the unique capability to perform seismic studies for fainter stars located in clusters (mv=9-13). Cluster membership offers constraints on the star characteristics like metallicity and ages. Asteroseismology results would then provide broader constraints for stellar models.
- Same arguments for halo deficient stars

Note also the importance of having a good model for p-modes oscillations if we want to remove their effects on radial-velocity measurements and be able to detect more easily Earth-like planets.

Requirements	
Field of view	> few arcmin (for cluster fields)
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	N/A
photometric uniformity in field and/or time	N/A
photometric accuracy	none
spectral resolution	R>80000
wavelength (µm)	visible (0.38-0.7)
multiplex	not mandatory, but terrific tool for astroseismology in clusters
typical magnitude	9-11
object size	point sources
typical exposure time	~1 min
target density	all over the sky
dynamic range	N/A
background/emissivity	not important
astrometric/plate scale stability	none
polarisation	N/A
sky coverage	Z<1.5-2.0 => on star for several hours
Date/Time constraint	>~7-10 days
can be done with 30m can be done with 42m can be done with 60m	probably only the brightest stars of the closest cluster (Hyades) access to several open clusters more targets
can be done with JWST	no
obs type	high-resolution spectroscopy on a fibre-fed spectrograph
comments - add additional requirements	Same kind of observations then for exoplanet searches

III. Science Cases – Stars and Galaxies

G1. The intracluster stellar population

Magda Arnabodli

Abstract

There are growing evidence that the formation of nearby clusters, Virgo and Coma for example, is still on-going. A sensitive probe of this evolution is the dynamics of intracluster stars, which are unbound from galaxies while the cluster forms, according to cosmological simulations. With an ELT of from 30 to 60 meter in diameter, we can study the number density distribution, the spatial-velocity phase-space diagram and the CaII chemistry for the population of the red giant branch stars associated with the diffuse light in nearby clusters. This multi-parameter space contains the fossil record of the cluster assembly as galaxies formed and evolved.

Scientific background

Cosmological simulations of structure formation predict that galaxies are dramatically modified by galaxy interactions during the assembly of galaxy clusters, losing a substantial fraction of their stellar mass which today must be in the form of intracluster stars (Murante et al. 2004). Diffuse intracluster light (ICL) has now been observed in nearby (Feldmeier et al. 2004, Mihos et al. 2005) and in intermediate redshift clusters (Zibetti et al. 2005, Krick et al. 2006). Recent studies show that the ICL contains of the order of 10% of the mass in stars overall (Aguerri et al. 2005, Zibetti et al. 2005), but in cores of dense and rich clusters like Coma, the local ICL fraction can be as high as 50% (Bernstein et al. 1995).

Individual stars as the intracluster planetary nebulae (ICPNs) are presently the only tracers which allow us to measure the kinematics and dynamics of the ICL, using their [OIII] 5007 Å emission for identification and radial velocity measurements with ground 8 meter class telescopes (Arnaboldi et al. 2004, Gerhard et al. 2005). One current limitation in their use is that these ICPNs sample are sparse, with few tens candidates in 0.5 deg diameter field, and therefore they can map different subpopulations on regions of this size only.

The red giant branch stars (IRGBs) associated with the parent IC stellar population are intrinsically much brighter in the continuum than ICPNe, as the tip of the RGB is at $M_{I;TRGB}$ = -4:06 ±0:07 (Ferrarese et al. 2000), and they are indeed more abundant. From a surface brightness measurement of μ_V = 27.5 magarcsec^2 in the ICL in Virgo, see Fig. 1, we would expect about 0.1 RGB star arcsec^2 down to m_v = 29.7. Therefore their represent the ideal tracers to resolve the ICL stellar populations locked into substructures like tails (few arcmin wide and few tens arcmin in length) or plumes (ten arcmin in size) in a metallicity -position-velocity space.

By measuring the projected position-velocity space of IRGBs and their metallicity distribution function from deep Colour-Magnitude diagrams (CMD), we can constrain the dynamical age of the ICL component, how and when this light originated. With the presently avaliable instrumentation, we can only measure the IRGBs number counts and integrated V-I colors from space, with the ACS and HST, in the Virgo cluster, at a distance of 15 Mpc. To be able to carry out these science goals from the ground, it would require larger collecting areas and higher angular resolution. With an ELT

facility, with a 30-60 meter diameter range a number of studies of the ICL become accessible from the ground.
Deep CMD of IRGBs - resolving the RGBs in the low surface brightness regions of the ICL in nearby groups and clusters and study their metallicity distribution function via deep CDM. This project includes the Sculptor, M81, Leo group, the Fornax, Virgo, Hydra and Centaurus clusters.
CaII spectroscopy of RGB stars - the goal is to measure the LOS velocity distribution of these stars and look for substructures in the position-velocity space. This can be then correlated with the metallicity distribution function from deep CMDs. This project can be carried out with a 60 m telescope out to 10 Mpc
Abundances of RGB stars - CaII higher resolution spectroscopy for the oldest stars in the RGB + detailed abundance analysis - only possible out to Cen A.

Science heading: Resolved Stellar population in the diffuse halos and ICL

Science case : Deep CMD of IRGBs

science case : CaII spectroscopy of IRGB stars

Requirements	Colour-magnitude diagrams	CaII spectroscopy
Field of view	few arcminutes	few arcminutes
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	0."1	LTAO
photometric uniformity in field and/or time	0.01mag	0.01mag
photometric accuracy	0.05mag	0.05mag
spectral resolution	Imaging	1000-5000
wavelength (μm)	0.5-1μm	0.8μm
multiplex	N/A	yes
typical magnitude	>26	>24
object size	point sources	point sources
typical exposure time	3 hours	20 hours
target density	0.1 RGB star/arcsec^2	0.1 RGB star/arcsec^2
dynamic range	10-20	10
background/emissivity	dark time	dark time
astrometric/plate scale stability	N/A	N/A
polarisation	N/A	N/A
sky coverage	from -50 DEC to equatorial fields (Virgo + 12 DEC)	from -50 DEC to equatorial fields (Virgo +12 DEC)
Date/Time constraint	N/A	N/A
can be done with 30m can be done with 42m can be done with 60m	out to 10Mpc out to 25Mpc out to 50Mpc	out to 4Mpc out to 9Mpc out to 14Mpc
can be done with JWST	yes, direct overlap	complementary
obs type	imaging	spectroscopy
comments - add additional requirements		

G2. Planetary Nebulae as traces of the element abundances in early type galaxies and diffuse light in clusters

Magda Arnaboldi

Planetary nebulae can be used to trace metallicity at a variety of angular distances, from the center of elliptical galaxies to their outer halos. Complementary to deep color magnitude diagrams of intracluster red giant branch stars, they can also trace the metallicity distribution function of the diffuse light in clusters and help to clarify how the elliptical galaxies form and to identify the progenitors of intracluster stars.

Scientific background

Metallicity gradients in elliptical galaxies are important diagnostic of how and when elliptical galaxies formed. A monolithic dissipative collapse produce steep gradients (Carlberg 1984) and mergers dilute them (White 1980). Observations show that metallicity gradients are present in early-type galaxies, but they appear somewhat flatter than those predicted by the pure dissipational collapse, which suggests that both dissipative processes and mergers play a role, with steeper gradients expected for galaxies that have not undergone major mergers. Furthermore, simulations of monolithic collapse models predict a significant steepening beyond 1 effective radius, which still need to be verified observationally.

How reliable are the metallicity gradients measured in ellipticals? They are based on colors and absorption-line strengths (Mg, Fe and H) measured on long slit, integrated light spectra of galaxies, but their interpretation is affected by the well-know age-metallicity degeneracy. Indeed the metallicity of single stars may help, but even with an ELT this may be possible only within 10 Mpc distance, for high resolution spectroscopy.

Planetary Nebulae (PNe) in early-type galaxies and in the diffuse light in the nearby clusters offer a possibility in this respect: we can detect them individually, out to 3-4 effective radii, and by measuring the fluxes of the diagnostic emission lines, it should be possible to derive Oxigen and other element abundances at different projected radii in order to study the metallicity gradient directly, and circumvent the age-metallicity degeneracy.

We aim at detecting the [OIII] 4363 Å and [NII] 5755 Å lines for a reliable electron temperature determination, and for those cases when this is not achievable, a number of stronger lines can be used for an empirical determination of element abundances and metallicities, especially the S23 parameter defined as S23 = ([SII] 6717, 6731 + [SIII] 9069, 9532) / Hβ (Diaz & Montero (2000).

Emission line spectroscopy

Requirements	
Field of view	few arcminutes
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	 LTAO
photometric uniformity in field and/or time	0.01mag
photometric accuracy	0.05mag
spectral resolution	1000-5000
wavelength (μm)	0.3-1.1μm
multiplex	yes
typical magnitude	>27 (target fluxes are 1-1.5 x 10^{-19} ergs cm^{-2} s^{-1} Å)
object size	point sources
typical exposure time	20 hours
target density	about 1 PN/$arcsec^2$
dynamic range	2
background/emissivity	dark time
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	from -50 DEC to equatorial fields (Virgo + 12 DEC)
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	out to 5Mpc out to 10Mpc out to 15Mpc
can be done with JWST	no
obs type	spectroscopy
comments - add additional requirements	current ETC does not include template spectrum of emission line objects. Estimates based on VLT data.

G3. *Stellar Clusters and the Evolution of Galaxies*

Arne Ardeberg and Peter Linde

The evolution of galaxies is poorly understood, as we lack a representative sample of all galaxy types with age and abundance data for the stellar populations. The closest sample is the Virgo cluster at 16 Mpc. At 16 Mpc, neither the spatial resolution nor the light collection of VLTs suffice for adequate studies of stellar ages and chemistry. We need an ELT for evolutionary histories of Virgo galaxies from colour-magnitude (CMD) and metallicity (MD) diagrams for stellar clusters, ideal probes of evolution.

The main-sequence turn-off point (TOP) is an ideal key to the ages of clusters and stellar populations. A colour-index measure of the impact of spectral lines of heavy elements gives the metallicity. For Virgo, TOP and metallicity data of unevolved stars, photometry is the only realistic method. For age and, especially, metallicity, photometry at visual wavelengths is highly preferable. Since diffraction-limited ELT resolution naturally favours shorter wavelengths, they are a prerequisite for safe metallicity indices. Solid age and abundance data are obtained in the Strömgren (u)vby intermediate-band system of photometry. We expect first-light ELT adaptive optics (AO) to operate at wavelengths above 1 - 2 µm only, corresponding operation at visual wavelengths a few years later.

Prime ELT parameters are aperture and Strehl ratio. We studied the requirements on them, modelling stellar clusters and simulating (u)vby photometry. With the clusters embedded in galactic environments and located at various distances, we generated and measured faintest possible cluster stars and surrounding fields. This gave the distance dependence of age and abundance, derived as described. Corresponding measurement series with different apertures and Strehl ratios were used to evaluate the implications of these parameters for a diffraction-limited ELT (Ardeberg and Linde, 2006a, 2006b, 2006c; Linde and Ardeberg, 2006a, 2006b).

Conclusions: Age and metallicity data for Virgo galaxies require an ELT. For TOP and abundance photometry of low to intermediate age stellar clusters in the Virgo galaxy cluster, an ELT aperture of 30 m is too small, 40 m is a limiting case, while 50 m suffices for necessary spatial resolution and photon collection. For a 50 m ELT, a Strehl ratio of 0.2 is marginally sufficient, 0.3 – 0.5 adequate, 0.6 excellent. Exposures of 8 hours per filter are a minimum. Photometric dependence on temporal and spatial variations of the point-spread function (PSF) need further study, based on optical phase differences, converted to point-spread functions (PSFs), work in progress (Ardeberg et al., 2006).

References

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Ardeberg, A., Linde, P., 2006a, Proc. Ringberg Workshop, Instr. for ELTs, in print.
Ardeberg, A., Linde, P., 2006b, Proc. Ringberg Workshop, Instr. for ELTs, in print.
Ardeberg, A., Linde, P., 2006c, Proc. IAU Symp. 232, in print.
Linde, P., Ardeberg, A., 2006a, Proc. Ringberg Workshop, Instr. for ELTs, in print.
Linde, P., Ardeberg, A., Proc. IAU Symp. 232, in print.

Summary of requirements (Stellar Clusters and Evolution of Galaxies)

Reference: http://www.astro.lu.se/~torben/euro50/index.html

Requirements	
Field of view	5" diameter
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	 diffraction limited
photometric uniformity in field and/or time	0.01mag over 5" diameter field 0.01mag over integration times down to 1 second
photometric accuracy	0.01-0.02 mag
spectral resolution	R=10 (intermediate-band photometry)
wavelength (μm)	0.4-5μm
multiplex	N/A
typical magnitude	V=20-36
object size	smaller than 5" (complete cluster)
typical exposure time	8-24 hours
target density	up to 10^7 stars/arcsec^2
dynamic range	up to 10^3-10^4
background/emissivity	limit defined by host galaxy (tolerable) sky background: darker than 21 mag/arcsec^2 in V
astrometric/plate scale stability	not critical
polarisation	not critical
sky coverage	Ideally 65° from Zenith (50° acceptable)
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	no marginally yes, solidly
can be done with JWST	no
obs type	(intermediate-band) photometry
comments - add additional requirements	Preferred ELT aperture: 50m (or more) pixel scale: 1mas Adaptive Optics: SCAO sufficient Object S/N over full field: 10^4 Virgo Cluster of galaxies preferably less than 30° from Zenith in the meridian

G4. Imaging & Spectroscopy of Resolved Stellar Populations in Galaxies

E. Tolstoy

Abstract: Here I cover the general principles of resolving individual stars at various densities, luminosities and colour. This is potentially useful for many different projects – some of which are individually discussed in particular science cases. The larger the telescope the denser the region can be probed, and also down to fainter magnitudes. These, in general terms are the main trades offs in considering telescope size: how far into the central regions of galaxies do we wish to look and down to what magnitude limits. Any gain in telescope size is useful in general terms but it only gets truly exciting if considerable improvements can be made in sensitivity and spatial resolution over existing or planned space telescopes.

The science case for an ELT is the photometry and spectroscopy of red-giant branch (RGB) stars at various distances. With a 42m diameter telescope it is possible to aim for: imaging of individual stars at the tip of the RGB at a distance of Virgo; intermediate resolution spectroscopy to determine abundances and velocities at distances of up to 5-10Mpc and high resolution spectroscopy in M31 and CenA.

General Science Case: To understand the formation and evolution of any galaxy we investigate the different stellar components, which together carry a memory of the entire star forming history. We know that galaxies fall more or less into a Hubble Sequence, but we don't understand the details of why and how massive galaxies find themselves separated into these different classes. Ellipticals are perhaps the biggest mystery because we don't have an example that is easy in detail nearby.

Low mass stars have extremely long life times, comparable to the age of the Universe, and can retain in their atmospheres the gas, with the elemental abundances intact, from the time of their birth. Thus if the stars of different ages are picked out of a stellar population, and this is most accurately done if the population is resolved into individual stars, then the star formation rate and metallicity at different times is measured directly. This requires accurate photometry: the measurement of luminosity and colour for each star. By counting stars of different ages in a Colour-Magnitude Diagram at the main sequence turnoffs the rate at which stars are formed throughout time is directly obtained. This information becomes less direct if brighter evolved stellar evolutionary phases are used. Abundances and kinematics can be measured from spectra of individual stars of known ages and thus the varying abundance of different elements and their kinematic history can be directly measured with time. It is also interesting to study (young) massive stars in a range of environments to try and understand the reasons for star formation to occur at different rates at different times in a variety of environments. The separation of a galaxy into its individual stars for the detailed reconstruction of the history of its formation and evolution requires high spatial resolution and sensitivity (see Figure 1). The exact requirements depend upon the stellar density at a given magnitude in the region being probed.

The Sample: It is difficult to reach definitive conclusions on the general formation path of massive galaxies with a sample of just two (the Milky Way and Andromeda). However, to enlarge our sample we need to move considerably further away in distance, the Sculptor Group and the M81 group (both at about 2-3Mpc distance) contain several more large spiral galaxies, but still no elliptical galaxy. For the nearest large elliptical galaxy we have to go to NGC5128 (Centaurus A, which is a very peculiar galaxy, S0+ Spec) at 3.5Mpc distance, but unfortunately as this system is so complex it is unlikely to be representative. The Leo Group at ~10Mpc distance contains the nearest nearly normal elliptical galaxy, NGC3379 (E1 or S0). But of course the Virgo cluster is the real prize for studying elliptical galaxies. Virgo at an average distance of 17Mpc, with over 2000 member galaxies of all morphological types, is the nearest large cluster of galaxies, and the nearest ``dense'' environment which may be better representative of the surroundings in which most galaxies live and hence most star formation occurs in the Universe. It has a sequence of bright elliptical galaxies and a luminosity sequence reaching down the smallest dwarf elliptical. The Virgo Cluster also contains spiral and irregular galaxies of all luminosities with a variety of globular cluster populations as well as dwarf galaxies, and intracluster stellar popualations. These galaxies have never been studied in such detail in a galaxy cluster. This would also have implications for understanding high redshift observations. See Table 1 for a list of potential targets.

Observing Goals (Imaging): There are distinct regions of a Colour-Magnitude Diagram which are easy to interpret in terms of a star formation history (see Table 2; Figure 2):

1. *Main Sequence Turnoffs (MSTOs)* , at $M_I \leq +4$. Ancient MSTOs are at, $M_I \sim +4$. If accurate photometry is obtained for stars this faint then an almost unambiguous star formation history can be determined, especially in combination with metallicity determinations of RGB stars (at $M_I \geq -4$). Brighter Main Sequence Turnoffs are also interesting but provide information going less far back in the history of the galaxy (e.g., $M_I \sim +2$ is 1-3Gyr; $M_I \sim 0$ is few 100Myr).
2. *The Horizontal Branch (HB)*, at $M_I \sim 0$. These are ancient stars (> 10Gyr old) and looking at the structure of the HB, and the relative numbers of blue and red HB stars, as well as the relative fraction the HB stars in a CMD gives a rough measure of the relative importance of ancient star formation in a galaxy. This population can also be probed with RR Lyr variable stars.
3. *The Red Giant Branch (RGB),* between $M_I \sim -4$ and $M_I \sim 0$. These stars are all >1Gyr old and include ancient stars. They are easy to measure abundances. The tip of the RGB, at $M_I = -4$ is a constant and useful distance indicator if correctly identified. It is hard to determine ages of RGB stars due to the age-metallicity degeneracy, but combining photometry and spectroscopy it is possible to obtain a reliable indication of metallicity and age spreads.
4. *Massive Stars:* $M_I < -4$ These are O, B, A stars which are short lived – in the case of OB, extremely short lived – and they give a measure of the instanteous star formation rate, and metallicity. Blue loop stars in metal poor galaxies provide a lot of detailed spatially resolved information on age, metallicity and star formation rate over a period of 200-800Myr ago (see Dohm-Palmer et al. 1998 AJ, 115, 152). Bright and uncrowded – picked out to large distances.
5. *AGB & Carbon stars:* very luminous ($M_I >> -4$) and very red (best studied in the IR ($M_K < -6.5$) and in principle their numbers and luminosity distribution can be correlated to age and metallicity and SFR of intermediate age stellar populations.

In Figure 3 the global effect of observing a CMD at different wavelengths in the standard broad band filter set can be seen. Here are plotted theoretical isochrones, from new Yale set (Yi et al. 2003), [Fe/H]=-0.7 ages are 1, 2, 3, 5, 10, 13 Gyr. It is clear that in the M_K vs. J-K CMD the important information - the main sequence turnoffs - and the RGB tracks are much less distinct than in other filter combinations. Particularly the limited colour spread requires much higher photometric accuracy in IR-only CMDs. Looking at I-K, for example - things improve dramatically. Here there is a good spread between the different age isochrones, which can thus be hoped to be disentangled in photometric studies. It is also important to note that the MSTOs are clearly distinguished in certain colour combinations - allowing an accurate interpretation of the CMD in terms of age.

<u>The imaging science case</u> is to detect stars at the tip of the RGB at a distance of Virgo. This means M_I ~ 27-28; with a strehl of at least 30% and a wavelength coverage starting with at least I-band in the optical, preferably also V-band. These studies also require photometric accuracy of at least 0.05mag, with a goal of 0.02mag over the field of view which should be ideally be larger than 1x1arcsec, and usefully as large as 10x10arcsec. These stringent requirements will also allow us to make very interesting studies of much closer by objects, such as detecting ancient Main Sequence turnoffs in Cen A.

Summary of General Requirements (Imaging):

Spatial resolution	Diffraction limited
Photometric uniformity in field	0.02 mag
Photometric uniformity in time	repeatability important
Photometric accuracy	0.05 mag (goal 0.02mag)
Wavelength range	8 – 3 μm (ideally 0.6 - 3 μm)
Object size (fov)	1-10 arcsec
Typical exposure time	8 – 10 hours
Dynamic range	maximum ~10^4
Sky Background	dark and stable as possible
Astrometric image plane stabilit	critical for spectroscopy targets
Polarisation	No importance
Sky coverage required	North or south OK
Date/Time constraint	No importance
Obs type	imaging
Adaptive optics type	LTAO
Signal-to-noise ratio central pixels	>10
Preferred ELT aperture	>50 m

Observing Goals (Spectroscopy): To understand the kinematic properties or accurate abundance properties of individual stars spectroscopy is required. There are established approaches with medium and high resolution spectroscopy on any of the stellar populations listed in the imaging goals. The resolution required varies between R~5000 for a basic metallicity indicator such as CaII triplet (at 860nm), and a velocity accuracy of a few km/s, and R~40 000 for accurate high resolution abundances of numerous different elements, and velocities accurate to < 1km/s. Most science goals benefit from multiplex spectroscopy for optimal efficiency. The lower the resolution the more important the multiplex capability is. Reasonable abundances can be measured for RGB stars at R~ 20 000, but this is more interesting if the multiplex allows samples larger than ~50 be be observed in one go. CaII triplet measurements are also more useful for large samples of stars. However high resolution, R ~ 40 000 can be interesting even in single slit mode for abundance measurements.

<u>The intermediate resolution (R~5000) science case</u> is for stars on the RGB at a distance of the Sculptor group, perhaps even the Leo Group. This means M_I ~ 24-26; a wavelength coverage 0.8-0.9µm (CaII triplet lines are at 850, 854, 866 nm) and a resolution R ~ 5000-8000. The field of view should ideally be larger than 10x10arcsec, and usefully as large as 3x3arcmin. Here sensitivity is the main issue – image quality only matters in as far as it gets light efficiently through the slit(s).

Summary of General Requirements (R~5000 Spectroscopy):

Spatial resolution	Diffraction limited
Spectral resolution	R= 5000 - 8000
Wavelength range	>0.8µm
Multiplex	10+ (goal 50+)
Object size (fov)	10" – 3'
Typical exposure time	8 – 10 hours
Sky Background	dark and stable as possible
Astrometric image plane stability	critical
Polarisation	No importance
Sky coverage required	north or south ok
Date/Time constraint	No importance
Obs type	MOS
Adaptive optics type	??
Signal-to-noise ratio central pixels	>10
Preferred ELT aperture	50 m (or more)

<u>The high resolution science case (R~40000) science case</u> is for RGB stars at the distance of M31 and CenA. This means M_I > 21, and a wavelength coverage from 450 – 750 nm. The field of view is unimportant – one unresolved star down a slit with enough information about the sky on either side is what is required. As with the intermediate resolution case sensitivity is the main issue, not image quality as long as light goes down the slit.

Summary of General Requirements (R>25000) Spectroscopy):

Spatial resolution	Diffraction limited
Spectral resolution	R = >25000 (prefered 40000)
Wavelength range	.45 – 0.75 µm
Multiplex	not necessary
Object size (fov)	1-5''
Typical exposure time	8 – 10 hours
Sky Background	dark and stable as possible
Astrometric image plane stability	no importance
Polarisation	No importance
Sky coverage required	north or south ok
Date/Time constraint	No importance
Obs type	LSS
Adaptive optics type	??
Signal-to-noise ratio central pixels	>40
Preferred ELT aperture	50 m (or more)

Summary of general requirements (resolved stars at 3Mpc):

Field of view	10’
Target density	> 10^3 stars/arcsec
Pixel scale	1-5mas
MSTO (M_I ~ +4)	I<31.4
HB (M_I ~ 0)	I~27.4
TRGB (M_I > -4)	I>23.4
OB (M_I < -5)	I<22.4

Comment: Sculptor group (2.5Mpc) is in the southern hemisphere and M81 group (3.5Mpc) in the north.

Summary of requirements (resolved stars at 10Mpc):

Field of view	3’ – 10’
Target density	>10^3 stars/arcsec
Pixel scale	1-5mas
MSTO (M_I < +4)	I<34.
HB (M_I ~ 0)	I~30.
TRGB (M_I > -4)	I>26.
OB (M_I < -5)	I<25.

Comment: Leo group is equatorial/north

Summary of requirements (resolved stars at 18Mpc):

Field of view	10” – 1’
Target density	>10^3 stars/arcsec^2
Pixel scale	1-5mas
MSTO (M_I < +4)	I<35.2
HB (M_I ~ 0)	I~31.2
TRGB (M_I > -4)	I>27.2
OB (M_I < -5)	I<26.2

Comment: Virgo cluster is equatorial/north and Fornax cluster is south.

Requirements	imaging	spectroscopy
Field of view	stars at 3Mpc: 10' stars at 10Mpc: 3'-10' stars at 18Mpc: 10"-1'	10"-5'
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	diffraction limited	diffraction limited
photometric uniformity in field and/or time	field: 0.02 mag time: repeatability important	
photometric accuracy	0.05 mag (goal: 0.02)	
spectral resolution		5000-40000
wavelength (μm)	0.6-3μm	0.4-1.5μm
multiplex	N/A	100+ @LR (~5000) 50+ @ IR (~20 000) 5+ @ HR (~40 000)
typical magnitude	see table below	see table below
object size	1" - 5"˚ (10"-5')	
typical exposure time	8-10 hours	8-10 hours
target density	stars at 3Mpc: 10^3 stars/arcsec^2 stars at 10Mpc: >10^3 stars/arcsec^2 stars at 18Mpc: >10^3 stars/arcsec^2	
dynamic range	maximum ~10^4	
background/emissivity	as dark and stable as possible	as dark and stable as possible
astrometric/plate scale stability	critical for spectroscopic targets	critical
polarisation	no importance	no importance
sky coverage		north and south ok
Date/Time constraint	no importance	no importance
can be done with 30m can be done with 42m can be done with 60m	For both imaging and spectroscopy the larger the aperture the more can be done at greater distances	
can be done with JWST		
obs type	imaging	mulit-object or single-object spectroscopy
comments - add additional requirements	Preferred ELT aperture: 50m (or more) pixel scale: 1-5mas Adaptive Optics: LTAO S/N central pixel: >10 Virgo Cluster of galaxies preferably less than 30˚ from Zenith in the meridian	Preferred ELT aperture: 50m (or more) pixel scale: 1-5mas Adaptive Optics: LTAO S/N central pixel: >10@LR --->>40@IR and HR Virgo Cluster of galaxies preferably less than 30◦ from Zenith in the meridian

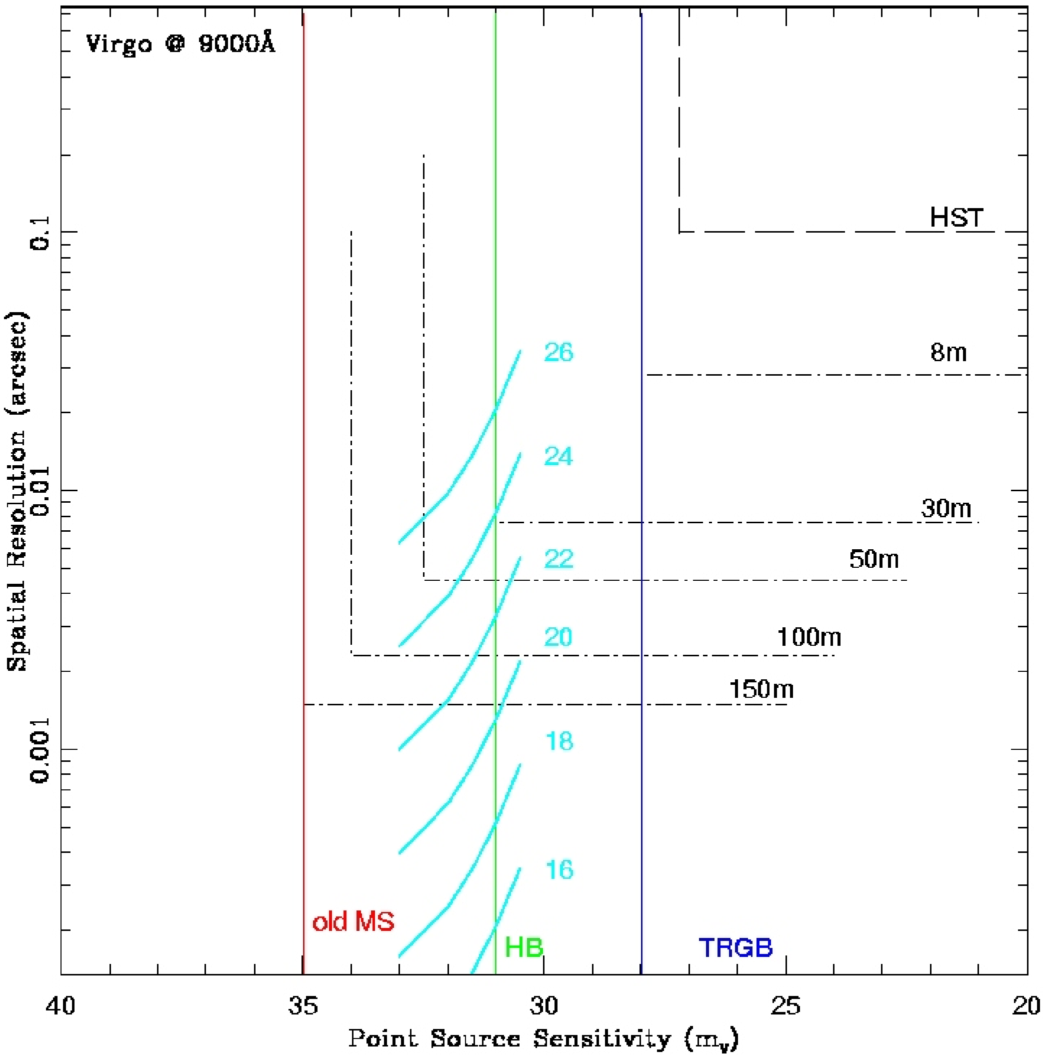

Figure 1: Here are the results of ELT sensitivity and spatial resolution calculations in I. The dashed half-box lines show the parameter space accessible to different aperture telescopes at an observing wavelength of 900nm. The spatial resolution is simply defined by the diffraction limit of the telescope aperture. The point source sensitivity is determined using a simple scaling of an 8m telescope capabilities, assuming exposure times 3hours and a Strehl of 30%. We have also plotted the known limit of HST/WFPC2 from experience observing resolved stellar populations in the Local Group. The 3 vertical lines at m_I = 35, 31 & 28 represent the observed magnitudes, at the distance of Virgo, of the oldest, 13~Gyr, main sequence turnoffs (old MS); the Horizontal Branch (HB) and the tip of the Red Giant Branch (TRGB), respectively. Also plotted are a series of sloping lines centred at m_V ~31.5 which represent the requirement to resolve the stars in an elliptical galaxy for the point source sensitivity at a variety of surface brightness levels.

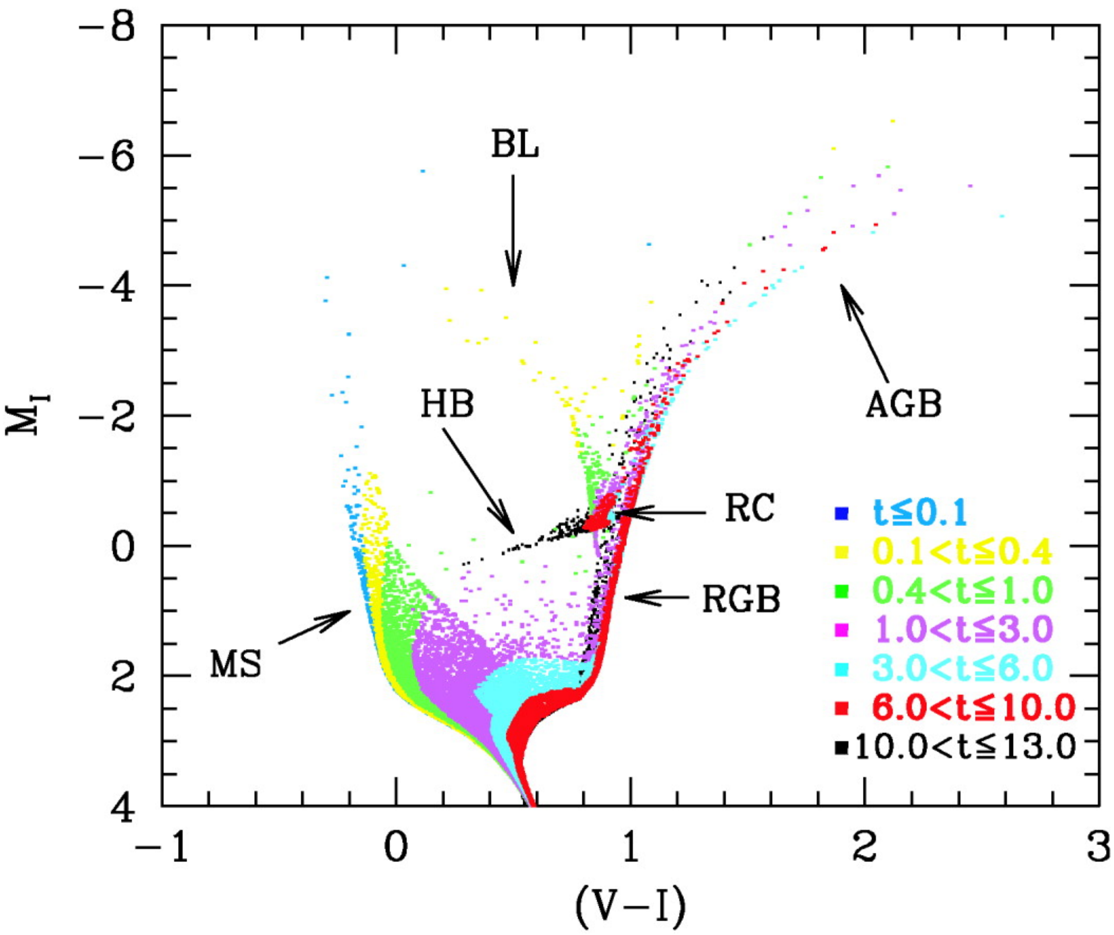

Figure 2: Synthetic Colour-Magnitude Diagram computed using constant star formation rate from 13 Gyr ago to the present and with metallicity linearly increasing from Z = 0.0001 to Z = 0.02. Stars in different age intervals are plotted in different colours, and the colour code is given in the figure, in Gyr. Labels indicate the different evolutionary phases: BL - blue loop; HB - Horizontal Branch; RC - Red Clump; RGB - red giant branch; AGB - asymptotic giant branch. From Aparicio & Gallart (2004 AJ 128 1465).

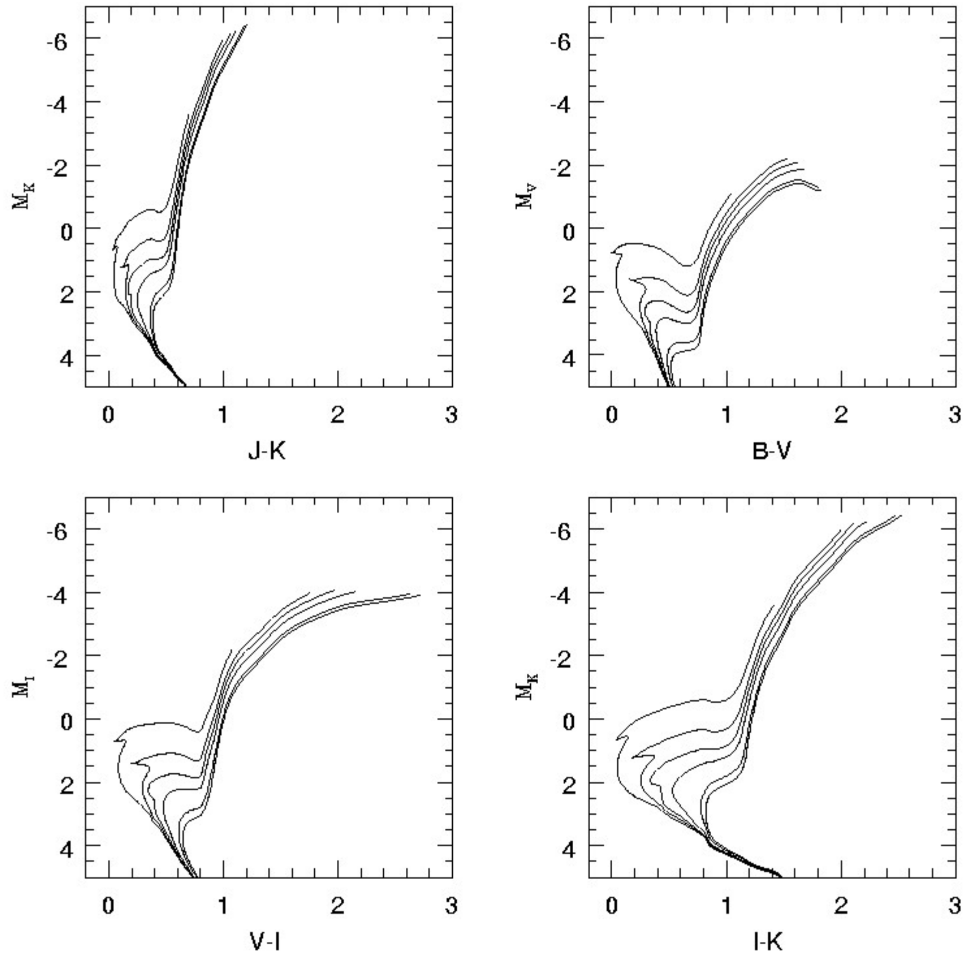

Figure 3: Here are plotted theoretical isochrones, coming from Yi et al. (2003, ApJS, 144, 259), new Yale isochrones, in 4 different colour and magnitude combinations. On each figure are plotted 1,2,3,5, 10 & 13 Gyr old isochrones for a metallicity, [Fe/H]=-0.7.

Table 1. Potential targets for an ELT

Object	$(m-M)_0$	θ(1 pc)	Ra(J2000)	Dec
LMC	18.5	4"	05 23	–69 45
M31	24.3	0.3"	00 43	+41 16
Sculptor Group	26.5	0.1"	00 23	–38 00
M81/82	27.8	0.06"	09 55	+69 40
Cen A	28.5	0.04"	13 25	–43 00
Leo Group	30.0	0.02"	10 48	12 35
Virgo Cluster	31.2	12 mas	12 26	+12 43
Fornax cluster	32.0	11 mas	03 37	-35 37
50Mpc	33.5	4 mas	…	…
Arp220	34.5	2 mas	15 34	+23 30
Perseus Cluster	34.5	2 mas	03 18	+41 31
Stephan's Quintet	35.0	2 mas	22 36	+33 57
Coma Cluster	35.0	2 mas	13 00	+28 00
Redshift z~0.1	38.5	0.5mas		…
Redshift z~0.3	41	0.2mas		…

G5. Spectral observations of star clusters:

Kissler-Patig

Following case 4.3.2 of the Science Case for the E.ELT and expanding it to medium resolution spectroscopy.
N.B not covered by the GMT or TMT science case documents.

Rational for sub-case 1:

Internal kinematics and detailed chemical abundance studies. The goal is to perform high resolution (R~30.000) spectroscopy of the integrated light of clusters in nearby galaxies (up to Virgo/Fornax distance) in order to study the internal kinematics and detailed chemical abundances of the star clusters. This allows the study of the formation process of the star clusters, the conditions in the host galaxy at formation, and finally to use them as tracers of the major epochs of star formation in galaxies. The spectral resolution is needed given the low velocity dispersion of star clusters (5-15 km/s). Star clusters at the Virgo/Fornax distances have typical half-light radii of 2-10 pc or 20-100mas, i.e. slit width of 50 to 100 mas are acceptable since integral properties are to be studied. The visual magnitudes of the clusters range from V=19 to 26. The traditional diagnostic lines are in the visible (400-600 nm) but could be found in the NIR also. Typical object densities in the center are several per sq.arcmin for the brightest objects, up to 100 per sq.arcmin down to V=24 (in bright ellipticals).

ETC: R~50.000, V=23, S/N=30 in V, 3x3 100mas spaxels
60m seeing: 12h integration; 60m GLAO: 8h
42m seeing: 25h integration; 42m GLAO: 17h
; 30m GLAO: 37h

ETC: R~50.000, V=23, S/N=30 in H, 3x3 100mas spaxels
60m seeing: 3h integration; 60m GLAO: 1.5h
42m seeing: 6h integration; 42m GLAO: 3h
30m seeing: 12h integration; 30m GLAO: 5.5h

Rational for sub-case 2:

Age and metallicities of star cluster systems. The goal is to perform by medium resolution (R~3000) spectroscopy to measure pseudo-equivalent widths (e.g.Lick indices) of many star clusters in a system in order to determine kinematics (radial velocities of the individual clusters) as well as rough ages, metallicities and abundance anomalies for several hundred clusters in a host galaxy. The star cluster properties are then related to the assembly and star formation history of the galaxy. By the same mean, one can study the intra-galaxy cluster population or even stellar populations in streams connecting over-densities, as star clusters are reliable tracers of the surrounding stellar population but can be observed out to much greater distances (i.e. reach local filaments, nearby clusters out to Coma, etc). Quantities as above, except that for distance of 100 Mpc (e.g. Coma) they become: sizes 4-20 mas half-light radii, integrated V=22.5 to 30, surface densities in the intra- and inter-galaxy cluster medium are expected to be low (few per 100kpc square, i.e. per 3-4 arcmin square).

ETC: R~1000, V=25, S/N=30 in V, 3x3 50mas spaxels
60m seeing: 22h integration; 60m GLAO: 13h
42m seeing: 45h integration; 42m GLAO: 26h
; 30m GLAO: 52h

ETC: R~5000, V=25, S/N=30 in H, 3x3 50mas spaxels

60m seeing: 25h integration; 60m GLAO: 6h
42m seeing: 50h integration; 42m GLAO: 12h
; 30m GLAO: 24h

Requirements	internal kinematics	age and metallicities
Field of view	single objects or multiplex over 1'x1', ideally 5'x5'	multiplex over 1'x1'; ideally 5'x5'
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	integrated properties, no need for resolving object >20mas (100mas ok)	integrated properties, no need for resolving objects >5mas (50mas ok)
photometric uniformity in field and/or time	N/A	N/A
photometric accuracy	N/A	N/A
spectral resolution	5km/s; 30000-50000	visible~1000; NIR>3000
wavelength (μm)	0.4-2.5μm	0.4-2.5μm
multiplex	single object ok, but ideally 10+ over 5'x5'	mandatory, ideally 10+ over 5'x5', min 10+ over 1'x1'
typical magnitude	19 to 26 (needed: V<23, old stellar pop V K=2-3)	23 to 30 (needed: V<25, old stellar pop V K=2-3)
object size	20-100 mas half-light radii	4-20 mas half-light radii
typical exposure time	6-12 hours and more	6-12 hours and more
target density	10 - 100 per $arcmin^2$	highly variable; from few per 5'x5' to 100 per 1'x1'
dynamic range	N/A	N/A
background/emissivity	N/A	N/A
astrometric/plate scale stability	N/A	N/A
polarisation	N/A	N/A
sky coverage	nearby galaxies (full sky coverage)	nearby galaxies (full sky coverage)
Date/Time constraint	N/A	N/A
can be done with 30m	barely (if NIR diagnostic lines can be found)	not realistically
can be done with 42m	yes	only if GLAO is available and NIR diagnostic lines are used
can be done with 60m	yes	yes, but would strongly profit from GLAO
can be done with JWST	no, but could be complementary for the imaging	no, but could be complementary for the imaging
obs type		
comments - add additional requirements		

G6. *Young, massive star clusters*

Kissler-Patig

N.B not covered by the GMT or TMT science case documents.
Update of case 4.9 in the science case for an E.ELT and extension.

Rational:

The goal is to investigate young massive star clusters in order to study the formation conditions of star clusters and the formation of high mass stars in general. The method is a combination of high resolution (R~50.000) spectroscopy and high spatial resolution imaging in order to derive dynamical masses. The obvious extension of this case is the investigation of the structural parameters of extremely massive star clusters and ultra-compact dwarf / dwarf-globular transition objects to understand the sequence of hot stellar systems from masses of 10^5 Mo up to masses of early-type galaxies. Chemical compositions could also be investigated but are more difficult to explore in these young stellar systems.
The targets for such studies are typically located in regions of (past) violent star formation, i.e. starburst galaxies or nearby mergers, located on average between 20 and 50 Mpc from us. The star clusters have masses of 10^8 and below, translating (as a function of age) to absolute magnitudes of V>12, more typically 20-24 mag. The objects are young (10-500 Myrs), i.e. rather observed in the visible light. The expected velocity dispersions range from 5-30 km/s. The half-light radii are expected to vary from 2 to 20 pc, i.e. 5 to 40 mas at the considered distances. The object densities are typically a few in a star forming region of 10 kpc across, i.e. a few in 1'x1'.

Spectroscopy:

ETC: R~10.000, V=23 (B-type), S/N=25 in B, 1x1 50mas spaxel
60m GLAO: 19h integration; 60m LTAO: 14h
42m GLAO: 43h integration; 42m LTAO: 32h
; 30m LTAO: 76h
(other band tried but not found better)

Imaging:

ETC: V=24, S/N=50 in B, 1x1 5mas spaxels
60m seeing: 10h integration; 60m GLAO: 5h
42m seeing: 20h integration; 42m GLAO: 10h
; 30m GLAO: 20h

Requirements	imaging	spectroscopy
Field of view	at least 30"x30"; ideally 2'x2'	
-diameter of 50% enclosed energy circle	resolving the half-light radii of >5mas, i.e. 5mas pixels	integrated properties, no need for resolving objects <40mas (50mas spaxels ok)
-strehl ratio (or "diff. lim." for diffraction limited)		
photometric uniformity in field and/or time	N/A	N/A
photometric accuracy	N/A (PSF stability over long integrations is more important as structural parameters are derived from 5-10 times 1 hour integrations)	
spectral resolution		10000-30000
wavelength (µm)	0.4-0.6µm(goal 0.3)	0.4-0.6µm(goal 0.3)
multiplex		single object ok, but ideally 5-10 over 1'x1'
typical magnitude	V=20-24	
object size	5-40 mas half-light radii	
typical exposure time	5-15 hours and more	
target density	~10 per arcmin^2	
dynamic range	N/A	N/A
background/emissivity	N/A	N/A
astrometric/plate scale stability	N/A	N/A
polarisation	N/A	N/A
sky coverage	limited choice of nearby galaxies (full sky coverage)	
Date/Time constraint	N/A	N/A
can be done with 30m	no realistically	not realistically
can be done with 42m	potentially	only with LTAO (i.e. loss of multiplexity
can be done with 60m	yes, if GLAO is available	yes, if GLAO is available
can be done with JWST	partial overlap (structural properties measured in the NIR vs. optical)	no, but could be complementary for the imaging
obs type		
comments - add additional requirements		

G7. Measuring the stellar IMF in local group galaxies

Guido de Marchi

The initial mass function (IMF) is a fundamental physical property of stellar populations and is one of the most crucial ingredients in models of galaxy formation and evolution. Knowledge of the IMF is very much needed if we want to understand the star formation history and chemical enrichment of galaxies of various types as well as their photometric properties. Differences at the high-mass end of the IMF can have profound effects on the feedback process and self-enrichment of star forming clouds, whereas variations at low masses affect directly the mass-to-light ratios of galaxies, since most of the baryons are hidden in low mass stars. It is presently unknown whether the shape of the IMF at very low and very high mass depends on the environment.

In practically all known stellar populations, over the mass range from about 1 through to 10 $M_{\odot}$ the IMF is well described by a power-law of the type $dN/dm \propto m^{-2.3}$ (the Salpeter IMF; see the recent reviews by Kroupa 2002 and Chabrier 2003). At the extremes of the distribution, however, the situation is far more complex. There is today general consensus (see Corbelli, Palla & Zinnecker 2005) that, at least in the Milky Way where it can be measured, the IMF becomes less steep below $\sim 1 M_{\odot}$ and flattens out and probably turns over well before the H-burning limit, thus resembling a log-normal (Paresce & De Marchi 2000; Chabrier 2003) or more likely a tapered power-law (De Marchi et al. 2005). The characteristic or ``peak" mass of the IMF, however, is not the same everywhere and appears to be larger for globular clusters ($\sim 0.3 M_{\odot}$; Paresce & De Marchi 2000) than for younger clusters (~ 0.15 $M_{\odot}$; Chabrier 2003, De Marchi et al. 2005). At the other end of the distribution, the IMF becomes considerably steeper than the Salpeter value, and no stars more massive than ~ 150 $M_{\odot}$ are observed, although there would be enough material for them to form, thus suggesting the existence of an upper-mass cutoff (Weidner & Kroupa 2004; Figer 2005; Oey & Clarke 2005).

These departures from a simple power-law are expected to depend on the physical conditions of the natal cloud and thus offer us a powerful tool to understand the star formation process throughout time by studying the properties of the IMF. According to Larson (1998), if the Jeans mass argument holds, the characteristic stellar mass mentioned above must increase with redshift and decrease with metallicity. This is because the temperature of the background radiation field, below which a molecular cloud cannot cool, increases with redshift, whereas less metals inhibit cooling. To test all of this observationally, we need access to stars with a wide range of masses and metal content, to probe a star formation environment as diverse as possible. Today, we do not have access to a single star-burst system in which the IMF is known for all stellar masses. Even in 30 Dor, the nearest star-burst region, there is considerable uncertainty about the shape of the IMF below ~ 2 $M_{\odot}$ (Sirianni et al. 2000) and nothing is known about the bottom of the main sequence.

The availability of the Extremely Large Telescope, with its unprecedented combination of resolving power and collecting area, will make this research possible for the first time. The ELT will allow us to detect and measure stars down to the bottom of the main sequence throughout the entire local group. A large variety of stellar systems with [Fe/H] values spanning two dex will be accessible, thus allowing for a systematic search for IMF variations as predicted by theory. We would have a sizeable number of young clusters for which the IMF can be determined, for the first time, over the entire stellar mass range. By resolving individual stars in very young clusters, we will be able to refine the fundamental maximum stellar limit and to test whether it depends on metallicity. By observing the IMF in exotic stellar systems such as the satellite dSph galaxies, which formed early in cosmological times and are the most dark-matter dominated objects (Wyse et al. 2002), we will have a direct view of the star formation process in the primeval universe. Beyond the Magellanic clouds, this investigation is only truly possible with the ELT, as not even the JWST will have the resolution needed to count the smallest stars.

Additonal comments:

- availability of a multi-conjugate AO systems at visible wavelengths (0.6 micron and up) would benefit this investigation tremendously, since what dominates the noise here is the brightness of the sky at near-IR wavelengths. The JWST will enjoy a sky brightness about 8 mag/arcsec^2 lower in these bands, but its limited angular resolution will make this investigation impossible, except perhaps in the Magellanic clouds.

References

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Oey, M., Clarke, C. 2005, ApJ, 620, L43

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Requirements	
Field of view	depends on platescale used, which in turns depends on distance modulus > 3" x 3" at 1 mas/pixel > 30" x 30" at 10 mas/pixel
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	diffraction limited
photometric uniformity in field and/or time	photometric uniformity much more important across field than in time: across field < 0.1 mag over time not important, provided it does not change during the exposure, since relative calibration is possible
photometric accuracy	< 0.1 mag is sufficient
spectral resolution	R=5 (imaging)
wavelength (μm)	0.8-1.6μm if multi-conjugate AO works at shorter wavelenghts enormous gains in photometric speed are possible due to the much lower sky background
multiplex	N/A
typical magnitude	J=30, H=30
object size	point sources
typical exposure time	depends on desired minimu mass, times to reach very low masses at H=30: 30m: 90 hours 42m: 45 hours 60m: 25 hours
target density	very crowded fields typical star-to-star distance ranges from 0.2" in the LMC to 0.03" in Leo I (at 250kpc)
dynamic range	to be determined from simulations
background/emissivity	If MCAO were possible at shorter wavelengths (e.g. R or I) exposure times would decrease dramatically
astrometric/plate scale stability	plate scale must be stable during exposure vatiations must be << PSF-FWHM
polarisation	not needed
sky coverage	30°
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	yes, but takes long exposure times yes yes
can be done with JWST	no
obs type	high-contrast imaging
comments - add additional requirements	

G8. Star formation history through supernovae

Bruno Leibundgut

As one of the end products of stellar evolution, supernovae trace the star formation history. Through their luminosity at explosion and given the short lifetime of some progenitors they are extremely well suited to explore the star formation rate throughout a large fraction of the observable universe. The core-collapse supernovae are descendants of massive stars ($M>10M_{\odot}$), whose lifetime is less than 20 million years. Hence, the rate of core-collapse supernovae gives essentially the instantaneous star formation rate. Another advantage of core-collapse supernovae is that they originate from much lower-mass objects than, e.g., the objects responsible for Lyα or Hα gas emission in galaxies. The latter are direct measures of the UV flux, which is dominated by very high-mass stars ($M>40M_{\odot}$) and a SFH derived from core-collapse supernovae would depend a lot less on the upper end of the mass function. Since the mass function is populated very strongly towards lower-mass objects the statistical uncertainty is dramatically decreased.

The lifetime of progenitor stars of thermonuclear supernovae (Type Ia supernovae) are not well known at the moment. Depending on the evolutionary history of the progenitors relatively short lifetimes (as small as 30 Myr) or long (more than 3 Gyr) have been proposed. This implies that the SNe Ia cannot trace the star formation directly, but can provide constraints on earlier star formation. The advantage of SNe Ia is their higher luminosity and hence larger distance and lookback time that can be reached by them. This means that earlier epochs of star formation can be probed at least in an integrated way. The lack in our knowledge of the exact progenitor system, however, severely hampers the derivation of detailed SFRs from SNe Ia.

Simply counting the supernovae of different types as a function of redshift provides a measure of the (global) star formation history of the universe. The goal then has to be to find sufficient supernovae over all redshifts. In the following we assumed that we can observe SNe out to z=4 and would like to bin the data in redshift bins of 0.1. For 1000 SNe this translates into about 25 objects per bin, or a statistical uncertainty of 20% per bin. Since we further have to separate core-collapse from thermonuclear supernovae, the stastistical uncertainty will be even higher. Binning in larger bins is an option, but it even with bin widths of 0.5 one still has a roughly 10% uncertainty per bin.

SNe Ia reach a peak luminosity of M_B=–19.5. Including the redshift we derive apparent magnitudes of

Filter	Redshift	Magnitude	K-correction
J	1.7	24.2	-2.2
H	2.8	24.8	-2.9
K	4	24.8	-3.8

SNe II typically show a plateau of about 100 days in the optical filters. Due to time dilation this will be prolonged by a factor (1+z) in the observer frame.

The ETC provided the following sensitivities in the K-band:

K_{AB}	Imaging			Spectroscopy		
	30m	42m	60m	30m	42m	60m
23.9	0.05	0.03	<0.02	<0.05	<0.03	<0.02
24.9	0.32	0.05	0.08	0.23	0.12	0.07
25.9	2	1	0.5	1.5	0.83	0.5
26.9	12.5	6.3	3.2	8.8	4.5	2.3
27.9	78	40	19.5	55	28	14

The following parameters have been used:
Imaging: GLAO, pixel size 50mas, 3x3 pixels integration area, S/N=10
Spectroscopy: LTAO, pixel size 10mas, 3x3 pixels integration area, S/N=10, R=100
If we assume that we spend 1 hour integrations with a 42m telescope to search for the supernovae we conclude from the following table that we will find ~4 (~15) objects in a 5'x5' (10'x10') field. For 1000 SNe this implies 250 (~70) individual 1-hour exposures distributed over about one to two years for a sampling of the light curves. The spectroscopy can be achieved in around 830 hours.
According to Dahlén & Fransson (A&A, 350, 349) we expect the following number of supernovae per square arcminute for a given limiting magnitude

Limiting magnitude (K_{AB})	# core collapse SNe	# SNe Ia	Total	3'x3' FoV	5'x5' FoV
24	<0.008	<0.003	<0.01	<0.1	<2.5
25	~0.04	<0.02	<0.06	~0.5	1.5
26	0.1	0.06	0.16	1.4	4
27	0.4	0.1	0.5	4.5	12.5
28	1	0.2	1.2	11	30

Requirements	Imaging	Spectroscopy
Field of view	>5'x5'	
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	use GLAO	use LTAO
photometric uniformity in field and/or time	Uniform in time and over the field to be able to do accurate relative photometry. Absolute photometry required for a few epochs	
photometric accuracy	Not for the SFH directly. Essentially this is counting sources. However, if the colours and brightness need to be used to derive type or redshift, then the accuracy has to be better than 5%.	
spectral resolution		a few hundred
wavelength (µm)	0.6-2.5µm	0.6-2.5µm
multiplex	Small – imaging and single source spectroscopy. In some cases several source per field may be observable.	
typical magnitude	K_{AB}>24	
object size	point sources	
typical exposure time	2 hours (30m telescope) 1 hour (42m telescope) 0.5 hours (60m telescope)	
target density	see calculation above	
dynamic range	Not a problem. All objects are very faint. As long as the several magnitudes (Δm>5 mag) can be observed simulatenously.	
background/emissivity	N/A	
astrometric/plate scale stability	N/A	
polarisation	N/A	
sky coverage	overlap with JWST area, possibly overlap with another ELT (equatorial regions)?	
Date/Time constraint	monitoring programme	
can be done with 30m can be done with 42m can be done with 60m	difficult, if large FoV is not possible difficult, without large FoV possible without large FoV	Except for a 30m well possible for almost all Sne brighter than K_{AB}=26.9
can be done with JWST	Searching and low-resolution spectroscopy can be done by JWST ("o"). This is one of the JWST key programmes. Even the spectroscopy might be better done with JWST.	
obs type	searching and monitoring	single source
comments - add additional requirements	Detailed simulations are required. Most of this is in Dahlén and Fransson. Should probably be further refined. Extension to other wavebands probably useful, Should be attempted.	

G9. AGN Demographics

R. Fosbury

Rationale

The relationship between host galaxy bulge mass and black hole (BH) mass is well established for both active and currently inactive galaxies (McLure & Dunlop, 2002, MNRAS, 311, 795). Except for the very nearest of galaxies - including the Milky Way - BH masses are determined rather indirecly using methods that rely on various geometric assumptions. To confidently detect and measure the mass of a nuclear BH, we need to probe the volume within which the BH dominated the galactic dynamics. Called the 'Sphere of Influence', this region has a radius defined as: r_i = GM_BH/(sigma)^2 = 4.3 pc $(B_{BH}/10^7 M_{\odot})(\sigma/100\text{km/s})^{-2}$ where σ is the stellar velocity dispersion. A typical scale is around 7 pc.
There are currently only two cases where this region has been probed directly to show that a massive BH is the only physical possibility: our Galaxy and NGC4258. However, using AO instruments on the VLT, other nearby galaxies are being examined (eg. Genzel et al).

The high angular resolution and sensitivity of an ELT will allow:
I. to resolve nuclear sub-structures down to a few pc at distances of tens of Mpc (depending on aperture and PSF). This will allow mass determination of BHs with masses similar to the one in the center of the Milky Way out to the distance of Virgo.
II. to resolve the sphere of influence for the most massive BHs with masses of greater than 10^9 $M_{\odot}$ at all redshifts (where they exist) using an aperture greater than 50m. Mass determination of black holes will be limited by the available light only. Mass determination for $10^9 M_{\odot}$ BHs will be possible out to a distance of 100 Mpc, allowing the collection of statistical samples of such objects.
III. to resolve bright stars in the circumnuclear region and so the measurement of age, metallicity and velocities of the nuclear stellar populations in the host galaxy - an extension of the work in our Galaxy to other hosts.
IV. to carry out R~1000 resolution spectroscopy of indicative lines in bright QSOs out to very high redshifts and thereby obtain estimates of BH masses throughout the universe.
Such measurements are fundamental to the understanding of the relationship between the evolution of the BH and the host galaxy, including the possible connection between AGN and starburst activity.

Requirements	
Field of view	5"
-diameter of 50% enclosed energy circle	a few mas
-strehl ratio (or "diff. lim." for diffraction limited)	diffraction limited
photometric uniformity in field and/or time	
photometric accuracy	
spectral resolution	R~5000-50000
wavelength (µm)	1-3.5 µm
multiplex	1
typical magnitude	surface brightness H = 18/sq arcsec
object size	5pc
typical exposure time	10h
target density	galaxies out to Virgo, rare objects at high z
dynamic range	
background/emissivity	
astrometric/plate scale stability	
polarisation	
sky coverage	
Date/Time constraint	
can be done with 30m	yes
can be done with 42m	yes
can be done with 60m	yes
can be done with JWST	complementary
obs type	high-spatial resolution, high-contrast IFU, low resolution high sensitivity spectroscopy
comments - add additional requirements	high contrast is important for this type of observation in order to avoid contamination by non-nuclear light from the host galaxy.

IV. Science Cases – Galaxies and Cosmology

C1. Dark Energy – Type Ia Supernovae as Distance Indicators

Isobel Hook

Type Ia supernovae have provided convincing evidence for the existence of Dark Energy and the accelerating expansion of the Universe (Perlmutter et al 1999, Riess et al 1998, Leibundgut 2001) and have begun to constrain the value of the equation of state parameter w (=pressure/density) of the Dark Energy (Riess et al 2004, Tonry et al. 2003, Knop et al 2003, Astier et al 2006). The value of w, and in particular its variation with time, is an important discriminator between the cosmological constant and other, fundamentally different, Dark Energy models.

Measuring the time variation of w out to redshift z~1.7 is probably best achieved with a dedicated satellite such as the proposed SNAP/JDEM mission (through luminosity distances to SNe Ia and weak lensing). Although JWST is also planning to observe SNe Ia, it is unlikely to achieve the required statistical sample for an accurate measurement of the time derivative of w. In any case a large ground-based telescope will be required to provide a reliable classification of supernovae with z>2 and accurate redshifts for them.

In the OPTICON ELT science case book, the case was made that a 50-100m ELT would be capable of finding and following supernovae of all types to much higher redshifts than currently possible. The advantage of reaching very high redshift is that the earlier parts of the universal expansion history can be mapped. Any additional 'quintessence' field active during this period would be detectable, if a coordinated programme between JWST and an ELT could be run. In the OPTICON ELT science case book (Hook (Ed). 2005), it was estimated that an ELT can provide spectroscopic redshifts for SNe Ia to z=4, if of 100m diameter, and that this redshift range decreases to z~1.7 for a 30m telescope.

Below we re-calculate the accessible redshift range for a telescope with 30-60m in diameter, using recently simulated PSFs for AO on an ELT. The results are critically dependent on whether OH-suppressed spectroscopy is available. For the case of a 30-42m telescope without OH-suppressed spectroscopy, the accessible redshift range is out to about z=1.7 (within reasonable exposure times – clearly the exposure time is reduced for larger telescopes). With OH-suppression, spectroscopy of SNe Ia out to z=4 becomes possible with a 30-42m in a reasonable exposure time. In either case the primary contribution of the ELT to this science case remains the same, namely obtaining the spectroscopic observations that allow accurate redshift measurement and confirmation of the Type of the supernova. In addition, photometric monitoring (in imaging mode) near maximum light will be possible to z~3 for a 30-42m telescope. Finding the SNe based on imaging searches will be possible in terms of sensitivity, but difficult because of the large FOV needed (see requirements notes below).

An additional benefit would be the systematic characterisation of distant supernovae with high S/N spectroscopy. The underlying assumption, tested with many photometric methods like colours, light curve shapes, and luminosity scatter, that SNe Ia do not considerably change their luminosity as a function of universal age and other parameters (most prominently metallicity) is best checked through detailed spectroscopy. Qualitative comparisons of spectra at low and high-z have been performed using 8–10m class telescopes on supernovae up to z~1 (Figure 5.3; Lidman et al 2005, Matheson et al 2005) and the first quantitative comparisons have recently been attempted (Hook et al

2005) but the low signal-to-noise obtainable allows only first-order comparisons to be made. Detailed high signal-to-noise spectroscopy will only be possible with the next generation of ELTs.

Requirements

Field of view:
According to Dahlén & Fransson (1999) we expect the following number of supernovae per square arcminute for a given limiting magnitude. (see also the previous case on the SFR history by Bruno Leibundgut):

Limiting magnitude (K_{AB})	# core collapse SNe	# SNe Ia	Total	3'x3' FoV	5'x5' FoV
24	<0.008	<0.003	<0.01	<0.1	<2.5
25	~0.04	<0.02	<0.06	~0.5	1.5
26	0.1	0.06	0.16	1.4	4
27	0.4	0.1	0.5	4.5	12.5
28	1	0.2	1.2	11	30

For comparison, a 30m, 42m and 60m telescope have a K-band limiting magnitude in 1 hr of 23.6, 24.0 and 24.4 Vega K magnitudes respectively (based on the ESO ELT ETC), = 25.4, 25.8 and 26.2 in K_{AB}.
Therefore to find at least one supernova per field we would need a FOV of at least 25 sq arcmin (=5'x5' for a 30m), 20 sq arcmin (4.5'x4.5') for a 42m or at least 14 sq arcmin (3.8'x3.8') for a 60m.
To find multiple SNe in the field would require longer exposure times, higher strehl AO or a larger FOV (or a combination of all three).
spatial resolution expressed in one of two ways:
-diameter of 50% enclosed energy circle
-strehl ratio (or "diff. lim." for diffraction limited)
SNe are point sources and so they benefit from the best possible spatial resolution. However large FOV is also important for finding the supernovae (in imaging mode). For the imaging exposure time calculations I have assumed GLAO (because it is provided as an option in the ETC), but other types of AO such as MCAO may give better results for this program.
photometric uniformity in field and/or time:
Uniform in time and over the field to be able to do accurate relative photometry. Absolute photometry required for a few epochs.
photometric accuracy:
This needs to be better than 5% - need to check this with simulations.
spectral resolution:
Spectral Resolution: R~5 (for imaging) and R of a few hundred for spectroscopy. Note that although only low resolution is needed (since SN features are broad), higher spectral resolution may be needed to reduce the effects of night sky lines in the IR. As can be seen in the exposure time tables below, OH-suppressed spectroscopy makes spectroscopic observations much more manageable for these faint targets (by about a factor 20 in exposure time).

wavelength (micron):
Near-IR J,H and K bands are most valuable for supernovae with z>1. I and z bands would also be useful for colour measurements and for lower-redshift supernovae.
A wide simultaneous wavelength coverage is needed in order to observe the key spectral features in SNe Ia. Useful features in the rest frame are at ~3600A to 6150A. At z=2 this corresponds to 1.1 - 1.6 microns, at z=3 to 1.4 – 2.4 microns and at z=4 to 1.8 - 3.1 microns. However, usually the redshift is not usually known accurately before the spectrum is taken, so in order to efficiently obtain a useful spectrum of a candidate in the range 2 < z < 4 ideally requires spectroscopy over the range 1.1 -3.1 microns in one shot.
Multiplex
Low. This case requires imaging and single source spectroscopy. In some cases several source per field may be observable.
Typical magnitude (e.g., 16, > 27, etc):
SNe Ia are brightest in the rest-frame B band, thus in general when observing them at high redshift it is most efficient to observe at the corresponding redshifted B-band. For example at z=1.7, rest-frame B corresponds to observed J-band. However at very high redshifts this means observing in the H and K bands where the sky background is very high. In the section on exposure times below, we consider a few example redshifts where the centre of the observed IR band corresponds roughly to rest-frame B, and calculate the PEAK apparent magnitude. This calculation used the SNOC code of Goobar et al (2002), version 2.00.
Object size:
Point sources.
Typical exposure time (in hours):
First we estimate the exposure time needed to detect the SN in imaging mode when at peak magnitude and when 1 magnitude fainter than the peak (needed in order to measure the lightcurve)

Redshift	Peak magnitude	Imaging exposure time at peak (hrs)			Imaging exposure time 1 magnitude below peak (hrs)		
		30m	42m	60m	30m	42m	60m
1.7	J =24.3	0.2	0.1	0.05	1.0	0.5	0.25
2.8	H=24.7	2.1	1.1	0.5	13.0	6.6	3.3
4.0	K=24.8	8.0	4.0	2.0	50	25.0	12.3

The following parameters have been used in the ESO ELT exposure time calculator:
Imaging mode: GLAO, pixel size 100mas, 3x3 pixels integration area, S/N=10. Assumed an AOV SED normalised in the same band as the observation. Note that despite using the largest available aperture in the ETC, the % enclosed energy in the aperture is still only ~50%).
Next we consider spectroscopy of the SNe. Here only low-resolution spectroscopy is required because the SN features are broad. R=100 is also sufficient to obtain the redshift of the host galaxy. It is assumed that the spectrum is obtained at maximum light.
In the ESO ELT ETC, the following assumptions were used: Spectroscopy: LTAO, pixel size 100mas, 3x3 pixels integration area, S/N=10. S/N calculated in 3(spec) x 2(spatial) pixels. The values below in square brackets were derived using R=100 in the ETC (which assumes flux from bright OH lines in the sky). The values without brackets

are values computed assuming R=1000 in the ETC and re-binning by a factor 10. This corresponds to OH-suppressed spectroscopy (implemented either in the instrument hardware or in data processing software). However we note that a wide wavelength range is required for each spectrum which may not be possible when observing at higher resolution.

Redshift	Peak magnitude	Spectroscopic exposure time at peak (hrs)		
		30m	42m	60m
1.7	J =24.3	0.16 [3.6]	0.07 [1.8]	0.03 [0.9]
2.8	H=24.7	1.7 [50]	0.9 [26]	0.4 [13]
4.0	K=24.8	6.1 [>100]	3.2 [93]	1.6 [44]

In summary it can be seen that a SNIa at z~1.7 can be observed with a 30m telescope in both imaging and spectroscopic modes, including observations of the lightcurve away from maximum light. Assuming OH-suppressed spectroscopy, A SN Ia at z~2.8 could be detected at peak with a 30m in imaging and spectroscopic modes but a 40-60m is needed for a lightcurve measurement in a reasonable amount of time. A z~4 SN at peak would be detectable in imaging and spectroscopic modes with a 42m but a 60m telescope would be needed to measure the light-curve in a reasonable exposure time.

Target density:
see above calculation for FoV
Dynamic range:
Not an issue for this program (all targets are faint).
Background/emissivity:
N/A
astrometric/plate scale stability:
N/A
polarization:
N/A
sky coverage required (e.g., in terms of zenith distance at a typical night):
Overlap with JWST area, possibly overlap with another ELT (equatorial regions)?
Date/Time constraint:
Repeated observations of the same field are required.
can be done with 30m - yes but only to z~1.7. Search likely impossible, if large FoV (5'x5' or larger) is not possible
can be done with 42m - yes to z~3. search very difficult without large FoV (4.5'x4.5' or larger)
can be done with 60m **-** yes to z~4. Again, search difficult without large FoV (3.8' x 3.8' or larger).
JWST (where we note "o" for direct overlap (i.e., competition), and "c" for complementarity.)
Searching and low-resolution spectroscopy can be done by JWST ("o"). This is one of the JWST key programmes (the JWST Design Reference Mission includes a survey for Type Ia Supernovae which aims to find about 50 SNe in the redshift range 1 to 1.5).
Obs type (e.g.,high contrast imaging and spectroscopy, Imaging and spect. etc):
Imaging (to find SNe) and spectroscopy (to obtain redshifts and types, and detailed comparisons of spectral features at all redshifts)

Comments - add additional requirements here
Detailed simulations of supernova rates are required, such as using information in Dahlén and Fransson and other studies.
Extension to other wavebands (e.g. I and z) is probably useful.
MCAO-like AO simulations are needed for this case, as the improved PSF from MCAO may make a large difference to the signal-to-noise on point-sources such as supernovae (although the FOV may not be sufficient).
Functionality to calculate optimal photometry using the ETC would be very usedful. At present a basic square aperture is assumed which probably does not give the optimal signal-to-noise.
A further step for the science case is to calculate expected constraints on cosmological parameters given the potential sample of supernovae that the ELT will produce.

References

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Requirements	Imaging	Spectroscopy
Field of view	>5'x5' (see discussion in text)	
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	SNe are point sources and so they benefit from the best possible spatial resolution. However large FOV is also important for finding the supernovae (in imaging mode). For the imaging exposure time calculations GLAO was assumed, but other types of AO such	use LTAO
photometric uniformity in field and/or time	Uniform in time and over the field to be able to do accurate relative photometry. Absolute photometry required for a few epochs	
photometric accuracy	better than 5% - needs to be checked with simulations	
spectral resolution	R~5	few hundred Note that although only low resolution is needed (since SN features are broad), higher spectral resolution may be needed to reduce the effects of night sky lines in the IR.
wavelength (μm)	0.8-2.5μm J,H and K bands are most valuable for supernovae with z>1. I and z bands would also be useful for colour measurements and for lower-redshift supernovae.	
multiplex	Small – imaging and single source spectroscopy. In some cases several source per field may be observable.	
typical magnitude	depends on redshif t- see text	
object size	point sources	
typical exposure time	see text	
target density	see calculation above	
dynamic range	Not a problem. All objects are very faint.	
background/emissivity	N/A	
astrometric/plate scale stability	N/A	
polarisation	N/A	
sky coverage	overlap with JWST area, possibly overlap with another ELT (equatorial regions)?	
Date/Time constraint	repeated observations of the same field required	
can be done with 30m	yes, but only to z~1.7. Search likely impossible, if large FoV (5'x5' or larger) is not possible	
can be done with 42m	yes to z~2. Search very difficult without FoV (4.5'x4.5' or larger)	
can be done with 60m	yes to z~2.5. Search difficult without large FoV (3.8'x3.8' or larger)	
can be done with JWST	Searching and low-resolution spectroscopy can be done by JWST ("o"). This is one of the JWST key programmes (the reference mission includes a survey for SNe Ia which aims to	
obs type	Imaging (to find SNe) and spectroscopy (to obtain redshifts and types, and detailed comparisons of spectral features at all redshifts)	
comments - add additional requirements	Detailed simulations are required. Most of this is in Dahlén and Fransson. Should probably be further refined. Extension to other wavebands probably useful, Should be attempted.	

C2. A dynamical measurement of the expansion history of the Universe

M. Haehnelt

Background:

Measuring the time derivative of the redshift $\dot{z}$ of objects at fixed coordinate distance offers the unique possibility to measure the expansion history of the Universe directly. Recent observations of the luminosity distance of moderate and high redshift supernovae of type Ia in tandem with other observations have established the presence of a form of Dark Energy which appears to have a very similar effect to that of Einstein's cosmological constant within the framework of a Friedman-Robertson-Walker Universe as described by 4D General Relativity. The introduction of the concept of dark energy is somewhat reminiscent of the "Ether" in 19th century physics and is arguably the biggest conundrum of present-day physics. It is thus important to measure the dynamical effects of "dark energy" directly.

Measuring $\dot{z}$:

The time derivative of the redshift of light emitted by a source at fixed coordinate distance is related in a simple manner to the evolution of the Hubble parameter between the epoch of emission and receiving,

$$\dot{z} = \frac{dz}{dt} = (1+z)\,H_0 - H(t_e)$$

The wavelength shift corresponds to a Doppler shift of about 2-20 cm/s over a period of 10 yrs. It has a very characteristic redshift dependence and increases linearly with time. Measuring such a small wavelength shift requires a substantial improvement in the accuracy of the wavelength calibration compared to existing spectrographs and a sufficient numbers of photons to measure the shift statistically from a large number of spectral features observed with very high signal-to noise.

The recent concept study of CODEX (coordinated by Luca Pasquini) has addressed both these issues in considerable detail the results of which are here summarized here. Building on the HARPS experience the required improvements in the accuracy of the wavelength calibration should be attainable with reasonable extrapolations of current technological capabilities. ESO has furthermore started a project to investigate the suitability of the Laser comb technology developed at the Max-Planck Institute of Quantum optics (Nobel prize 2005) for astrophysical spectroscopy.

The CODEX concept study (see Pasquini et al. 2005 for a summary) identified the numerous absorption lines in the spectra of high-redshift QSOs in the redshift range from $1.5<z<4$ as the most promising targets for a measurement of $\dot{z}$ (Pasquini et al.). A detection of the dynamical effect of dark energy should be feasible with a 30m telescope over a period of 20 years. A quantitative characterisation of the dark energy and its evolution would require either a larger collecting area or a longer time baseline or both. Note that the total collection area not the aperture is relevant and that results obtained at different telescopes can be combined provided a suitable wavelength standard is available. Note further that the spectra obtained for measuring $\dot{z}$ will also be tremendously useful to study the variation of fundamental constants and the metal enrichment of the IGM (see respective science cases).

References

OWL Instrument Concept Study, OWL-CSR-ESO-00000-0160
Pasquini et al., 2005, The Messenger, 122, 10

Requirements	
Field of view	single object - few arcseconds
-diameter of 50% enclosed energy circle	80% of the EE in ~0.6" in B and V (bad seeing)
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	150000 (>50000)
wavelength (μm)	0.4-0.68μm minimum
multiplex	N/A
typical magnitude	15-17
object size	point sources
typical exposure time	10-20 minutes in a single exposure, many hours per object in total reference signal to noise calculation with ETC S/N = 2332 for 10h exposure of object with mV = 16.0 at R=100 000 for 60m.
target density	30-100 brightest accessible objects in the whole sky
dynamic range	N/A
background/emissivity	N/A (dark sky observations)
astrometric/plate scale stability	N/A, but good accuracy in centering the object in the foal plane and keep it there is required at the level of 0.02" to 0.05" (TBC)
polarisation	N/A
sky coverage	observations should be taken at the lowest possible airmass
Date/Time constraint	no constraints
can be done with 30m can be done with 42m can be done with 60m	yes, relevant is the total collecting area not the aperture. For apertures <60m results from several telescope will have to be combined and/or the time baseline has to be extended to >10 yr for a quantitative characterisation of dark energy
can be done with JWST	no
obs type	photon-noise limited high-resolution spectroscopy with ultra-accurate wavelength calibration
comments - add additional requirements	

Note that the ETC has not yet an option suitable for spectroscopy of point sources with an 0.5-1arcsec slit to assess the effect of AO. Value was calculated with surface brightness option which assumes that all light is collected. Note further that the overall optical efficiency assumed by the ETC (25%) is rather large for a fiber-fed Echelle spectrograph.

C3. Testing the variability of fundamental constants with QSO absorption spectra

Martin Haehnelt

Background:

Fundamental constants cannot be deduced from first principles and are supposedly universal and invariable quantities. Testing for their variability probes fundamental physics. Measured variations would have far reaching consequences for the unified theories of fundamental interactions, for the existence of extra dimensions of space and/or time and for the existence of scalar fields acting in the late universe. Only astronomical observations hold the potential to probe the values of fundamental constants in the past, and in remote regions of space. Observations of absorption lines in the spectra of distant astronomical objects provided the first hints that the fine-structure constant, - the central parameter in electromagnetism - might change its value over time (Webb et al. 1999, Murphy et al. 2001), but recent observations are consistent with a null result (Chand et al. 2004).

Measuring $\Delta\alpha/\alpha$:

High-resolution spectroscopy of QSOs with an ultra-accurate wavelength calibration and ultra-high S/N as obtainable with an ELT will provide a substantial improvement of the constraints on the variability of fundamental constants.

The measurement of $\Delta\alpha/\alpha$ from an absorption spectrum is essentially a measurement of the relative wavelength shift of a pair of absorption lines with different sensitivity of the wavelength to variations of α. The accuracy of a $\Delta\alpha/\alpha$ measurement is therefore determined by the accuracy of the wavelength measurement. The best estimate of $\Delta\alpha/\alpha$ has an uncertainty of ~ $\sigma_{\Delta\lambda/\lambda}$/(Q1-Q2), where Q1 and Q2 are dimensionless coefficients characterizing the sensitivity of the two lines to changes of (. For current spectrographs with R~40000 the observed line positions in the absorption spectra of bright QSOs can be measured with an accuracy of about 1 mÅ (or (v = 60m/s at 5000 Å). The corresponding accuracy of the wavelength measurement $\Delta\lambda/\lambda \sim 2\cdot10^{-7}$ therefore translates into a sensitivity $\Delta\alpha/\alpha \sim 2\cdot10^{-5}$, for a typical |Q1 - Q2| = 0.01.

The achievable accuracy depends on the wavelength calibration, the width of the absorption line and the photon noise. The metal lines in QSO absorption spectra have intrinsic widths of a few km/s, rarely of less than 1 km/s. A resolving power of R=150,000 is thus optimal. Building on the HARPS experience significant improvements in the accuracy of the wavelength calibration should be attainable with reasonable extrapolations of current technological capabilities. ESO has furthermore started a project to investigate the suitability of the Laser comb technology developed at the Max-Planck-Institute of Quantum optics (Nobel Prize 2005) for astrophysical spectroscopy.

The recent concept study of CODEX (see Pasquini et al. 2005 for a summary) concluded that even for long exposures on a 100m telescope and bright QSOs it should be possible to reach the photon noise limit for the wavelength measurement of absorption features. It should thus be possible to reach a sensitivity of $\Delta\alpha/\alpha \sim 10^{-7}$ - 10^{-8} an improvement of two to three orders of magnitudes.

References

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OWL Instrument Concept Study, OWL-CSR-ESO-00000-0160
Pasquini et al., 2005, The Messenger, 122, 10

Requirements	
Field of view	single object - few arcseconds
-diameter of 50% enclosed energy circle	80% of the EE in ~0.6" in B and V (bad seeing)
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	150000 (>50000)
wavelength (μm)	0.4-0.68μm minimum
multiplex	N/A
typical magnitude	15-17
object size	point sources
typical exposure time	10-20 minutes in a single exposure, many hours per object in total reference signal to noise calculation with ETC S/N = 2332 for 10h exposure of object with mV = 16.0 at R=100 000 for 60m.
target density	30-100 brightest accessible objects in the whole sky
dynamic range	N/A
background/emissivity	N/A (dark sky observations)
astrometric/plate scale stability	N/A, but good accuracy in centering the object in the foal plane and keep it there is required at the level of 0.02" to 0.05" (TBC)
polarisation	N/A
sky coverage	observations should be taken at the lowest possible airmass
Date/Time constraint	no constraints
can be done with 30m can be done with 42m can be done with 60m	yes, relevant is the total collecting area not the aperture. For apertures <60m results from several telescope will have to be combined and/or the time baseline has to be extended to >10 yr for a quantitative characterisation of dark energy
can be done with JWST	no
obs type	photon-noise limited high-resolution spectroscopy with ultra-accurate wavelength calibration
comments - add additional requirements	same comments as for the cosmic expansion case apply here as well

C4. First light - The Highest Redshift Galaxies (z>10)

M. Franx

One of the important challenges in astronomy is to find the earliest galaxies. Obviously, we currently know very little about z>10 galaxies. At the time of writing, the galaxy with the highest spectroscopically-confirmed redshift is at z=6.6. Bremer & Lehnert (2005a) estimated the surface density of UV bright galaxies at z=9-10 at m_{AB}=27 to be as high as 0.2 per square arcminute. Using broad-band imaging with HST-NICMOS, Bouwens et al (2005) found spectroscopically-unconfirmed candidates at z=7-8 with a surface density of 1 per sq. arcmin, at a typical magnitude of 27 (m_{AB}). Given that multiple studies (e.g. Lehnert & Bremer 2003, Bunker et al 2004, Bouwens et al 2005) indicate that the space density of these galaxies is likely to be significantly lower than that of similar star forming galaxies at z=3-4, the very high redshift population is both faint and rare.

The faintness of the galaxies will make continuum spectroscopy with JWST hard, and only achievable to about m_{AB}=29 in very long exposures at low resolution. Hence ELT will play a very important role in this field, by doing high resolution spectroscopy. Ultra deep imaging by JWST or ELT should identify z>10 candidates over large areas and to very faint magnitudes (to $m_{AB} \sim 29.8$ with JWST in one band in 10 hours).

In typical integration times of 100 hours one can expect to achieve a depth of about 28-28.5 depending on the source sizes with a 30m telescope (S/N of 10 in H-band at a resolution of R=100). Given these long integration times and the rather low surface density, it is clear that the ELT must have a relatively wide-area spectroscopic capability (though not necessarily a filled focal plane for the spectroscopy - see notes on requirements). Given the expected source densities, a 5x5 $arcmin^2$ is the minimum requirement, being matched to the field size of NIRCAM on JWST. The desired area is 10x10 $arcmin^2$, which is of sufficient area and volume-grasp to allow studies of large scale structure at these redshifts, providing 10 or more such fields are studied to overcome cosmic variance.

Although various studies have shown that galaxies become smaller with increasing redshift (e.g. Roche et al 1998, Bremer et al 2004b, Bouwens et al 2004a), the high redshift galaxies observed to date are resolved with typical half- light radii of 0.1-0.2 arcsec. Consequently, diffraction-limited performance is not necessary, it is more important to have sufficient image quality to concentrate the light from galaxies on the 0.1-0.2 arcsec scale.

We note that this work can extend to z=13.8, where the Ly alpha emission line disappears in the atmospheric extinction feature at wavelengths of 1.8- 2μm. Longward of 2μm, the emission from the telescope and the atmosphere significantly affects the ability to reach the depths indicated above.

These observations will give us redshifts, but also spectral characteristics like emission lines, etc, leading to significant insight into the nature of these sources. It might be expected that the earliest galaxies have dramatically different spectral properties from z=3-5 galaxies. At extremely low metallicities, the emission lines of NIV, CIV, HeII, etc. are expected to become very strong (as the mean temperature of the ISM is thought to be higher than at low redshift due to the lack of coolants, hence the lines from highly ionised species). These unique diagnostic lines can be used to determine the ionisation state of the gas and thereby constrain its metallicity.

The same spectral information will allow determination of the spectral properties of the earliest stars, possibly allowing identification of galaxies with a substantial population

III component. At high redshift, many of these lines shift into the thermal infrared, but at least CIV is accessible out to z=10.5 from the ground.

Clustering

The next step in this research is to determine the clustering, giving crucial insight into the properties of the dark matter halos in which they reside. Quantifying this in a statistically useful manner at the highest redshifts requires large samples with spectroscopic redshifts (at least 1000 redshifts). This again requires a large multiplex and field-of-view.

This can be quantified in the following way: we wish to obtain 1000 redshifts in 1000 hours, hence the telescope should be able to get 1 redshift per hour. For a 60m telescope going to a depth of 28 in 100 hours, that requires a Field-of-view of 120 $arcmin^2$, assuming a source surface density of 0.8/sq arcmin For a 30m telescope going to a depth of 27.3 in 100 hours, that requires a field-of-view of 300 $arcmin^2$, assuming a surface density of 0.3/sq arcmin. These surface densities have been derived from the z=6 luminosity function from Bouwens et al (2005).

Imaging

This science case requires very deep imaging. JWST can provide this very efficiently with NIRCAM.The ELT can provide deep imaging in J, H, K in approximately the same integration time as required for spectroscopy. Hence a wide field, GLAO assisted imager will be extremely useful.

Requirements	
Field of view	10'x10' (60m), 17'x`17' (30m)
-diameter of 50% enclosed energy circle	0.2"
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	>3000
wavelength (µm)	0.9-2µm
multiplex	100
typical magnitude	AB=28
object size	0.1-0.2
typical exposure time	100 hours
target density	0.1-1 objects/arcmin^2
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	airmass 2
Date/Time constraint	
can be done with 30m	yes
can be done with 42m	yes
can be done with 60m	yes
can be done with JWST	overlap and complementary
obs type	spectroscopy
comments - add additional requirements	an imager would also be required, as JWST flies only for 5 years (specs)

C5. *Galaxies and AGN at end of reionizaion*

M. Franx

Reionization finishes by z=6.5, and may have started at redshifts around 8-10. It is of great interest to understand the sources of ionizing photons properly. Are these bright, rare sources, possibly even active nuclei, or are these faint galaxies? Whereas JWST can address questions concerning the number counts, spectroscopy will be much harder to do with JWST. Groundbased physical studies of these galaxies are needed to understand them properly. Especially high resolution spectroscopy with R=1000 to 10000 will be needed for a characterization. This science case has much in common with the science case concerning first light above, with the major difference that we know when the end of reionization occurred, and we know the luminosity function of the galaxies at z=6.5 fairly well. Bouwens et al (2006) found that the typical luminosity is z(ab)=27, and the density of objects brighter than 27 is 1 per sq arcmin, and brighter than 28 is 5 per sq. arcmin. The spectroscopy will be used to measure emission lines and absorption lines, determine kinematics, and accurate redshifts for correlation studies.

In typical integration times of 100 hours one can expect to achieve a depth of about 28, depending on the source sizes with a 30m telescope (S/N of 10 in H-band at a resolution of R=100). Given these long integration times and the surface density, it is clear that the ELT must have a relatively wide-area spectroscopic capability (though not necessarily a filled focal plane for the spectroscopy - see notes on requirements). Given the expected source densities, a 5x5 arcmin^2 is the minimum requirement, being matched to the field size of NIRCAM on JWST. The desired area is 10x10 arcmin^2, which is of sufficient area and volume-grasp to allow studies of large scale structure at these redshifts, providing 10 or more such fields are studied to overcome cosmic variance.

The galaxies have typical sizes 0.1-0.2 arcsec (half-ligth radius). Consequently, diffraction-limited performance is not necessary, it is more important to have sufficient image quality to concentrate the light from galaxies on the 0.1-0.2 arcsec scale.

Requirements	
Field of view	5'x5'
-diameter of 50% enclosed energy circle	0.2"
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	>3000
wavelength (μm)	0.9-2μm
multiplex	100
typical magnitude	AB=28
object size	0.1-0.2
typical exposure time	100 hours
target density	0.1-1 objects/arcsec^2
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	airmass 2
Date/Time constraint	
can be done with 30m	yes
can be done with 42m	yes
can be done with 60m	yes
can be done with JWST	overlap and complementary
obs type	spectroscopy
comments - add additional requirements	an imager would also be required, as JWST flies only for 5 years (specs)

C6. Probing reionization with GRBs and quasars

J. Bergeron & P. Shaver

Rationale

The reionization epoch is the frontier of observational astronomy. Current telescopes find galaxies, quasars and GRBs up to z = 6-7, just beyond which lies the reionization epoch, when the first stars and galaxies formed. The next generation of telescopes will be required to explore this epoch, which is of fundamental importance to our understanding of the evolution of the Universe.

There is no clear evidence for evolution of the cosmic metal density at 2<z<5. This suggests an early pollution of the IGM by the first stars and galaxies. The smallest column densities of individual CIV absorbers detectable with 8-10 m telescopes are $N(CIV)\sim10^{11.5}$ cm^{-2} (spectroscopy of bright quasars at high resolution R~40000 and high S/N~100). The carbon cosmic density derived for these CIV systems (excluding all Lyman limit systems, i.e. selecting only absorbers with $N(HI)<10^{17}$ cm^{-2}) is $\Omega_b(CIV)\sim5\cdot10^{-8}$ (Songaila 2001; Pettini et al. 2003), yielding a mean abundance $[C/H]=\log[\Omega_b(C)/\Omega_b(C)_{\odot}]=-2.9$, assuming an ionization correction (CIV/C)=0.30. It should be noted that the HI column densities of the detected CIV absorbers at z~3 are not small enough to probe IGM gas overdensities close to unity. Consequently, the metallicity of the IGM underdense regions could be smaller than 10^{-3} solar.

During reionization, OI may be the dominant species, at least outside the regions of active star formation, as suggested by the high number density of OI absorbers recently detected at z~6 (observed range: 9000-9500 A) with $N(OI)>10^{13.7}$ cm^{-2} which yields $\Omega_b(OI[z\sim6])\sim7\cdot10^{-8}\sim\Omega_b(CIV[z\sim3])$ (Becker et al. 2005).

Specific goal

Spectroscopy at intermediate resolution of bright z>8 sources will be used to trace the metal enrichment of the IGM and the clustering of metal-rich sites, up to the onset of reionization of the universe. The level of clustering will shed some light on the cosmic evolution of the luminosity/mass of the reionization sources.

The main IGM absorption signatures (metal forest) at z~7-15 are OI, CII and CIV detectable at $\lambda<2.1$ μm up to z=15.1, 14.7 and 12.5, respectively. CIV absorption will probe the ionized regions around sites of star and black hole (BH) formation. There may be discrete HI absorptions associated with these CIV systems at redshifts close to that of the background target. OI absorption will trace the neutral IGM. The prime targets are high z GRBs, population III SNe and, if they exist, quasars with massive BHs.

There is no transmitted flux in the Ly-alpha forest at z>6 (HI/H>0.01). Consequently, information on the metallicity at early epoch will require coupling 21 cm discrete absorptions in the spectra of background radio sources to metal absorptions in the NIR spectra of these sources (one of the SKA science goal).

Targets

Although rare, GRBs are bright transient objects, currently identified up to z=6.3 (Haislip et al. 2005; Tagliaferri et al. 2005). They should outshine quasars at z~8-10. The afterglow fluxes of an average GRB at z=10 should decrease from K_{AB}=23.6 (1.5 μJy) to K_{AB}=27 (0.05 μJy) at 1 to 10 days after explosion. The most luminous GRBs are

20 times brighter, and thus are easily observable with ELTs up to 10 days after explosion.
Population III SNe should exist at the onset of reionization, when the metallicity was less than 10^{-4} solar (Heger et al. 2001; Bromm et al. 2003). Stars with masses in the range 140-260 $M_\odot$ will explode as a pair-instability supernova. At z=9, 12 and 16, they have typical magnitudes of J_{AB}=24.4, H_{AB}=24.8 and K_{AB}=25.2, respectively (derived from z=20 fluxes given by Heger et al. 2001) and their theoretical light curve shows a long plateau of about 1-2 month at z=20. Their detection will require dedicated NIR searches for transient sources.
Bright SDSS quasars at z~6 are a rare population of objects. Their number density equals $n=2\cdot10^{-3}$ deg^{-2} down to z'_{AB}=20.2 (or M_{1400}=-26.7), and their z'_{AB}-J_{AB} colour is close to zero (Fan et al. 2001, 2003, 2004). Using the observed evolution of the comoving spatial density of SDSS quasars (Fan et al. 2004), the expected number of z~10 bright quasars with M_{1400}<-26.7 is 2 to 3 over the whole sky. Assuming that the z~6 SDSS quasars are emitting at the Eddington limit, their BH masses are about (1-5)$\cdot10^9$ $M_\odot$. The mass of their progenitors can be estimated assuming an accretion efficiency of 0.15 and Eddington accretion rate; the derived masses are M_{BH}=(1-5)$\cdot10^6$ $M_\odot$ at z~10 and a few 10^3 $M_\odot$ at z~20-30. Open issues are the possible efficient merging of thousands of high z, 10^3 $M_\odot$ BHs or the existence of primordial BHs. For comparison with population III SNe, the mass of a z=9 quasar with J_{AB}=24.4 is $5\cdot10^7$ $M_\odot$ (Eddington limit). The expected number of such bright high z quasars is small and their search will require dedicated strategies, as e.g. the on-going UKIRT infrared deep sky survey. The LBG colour selection technique also uncover quasars at a level of 3% among the 2<z<4 LBG samples (Steidel et al. 1999, 2003, 2004). Assuming that this is also the ase at z~6 and using the Subaru high z LBG surveys (Shimasaku et al. 2005), our rough estimate of the number density of z'_{AB}=24.5 quasars is n~0.2 deg^{-2}. Faint quasars together with bright LBGs could then be used to probe the metal-rich sites of the IGM at z~7-8 with spectroscopic observations at low resolution (R~1000).

Results from ETC

Population III SNe at z=16

spectral resolution R=5000 - A(px) = 2(spectral)x3(spatial) -
S/N=30 - ground-layer AO
K_AB=25.2 (K_Vega=23.4)
60m : t=80 hr

Average GRBs at z=10, one day after explosion

spectral resolution R=5000 - A(px) = 2(spectral)x3(spatial) -
S/N=60 - ground-layer AO
K_AB=23.6 (K_Vega=21.8)
60/30m : t=17.5/70 hr

Faint quasar at z=8

spectral resolution R=1000 - A(px) = 2(spectral)x3(spatial) -
S/N=30 - ground-layer AO
J_AB=25.5 (J_Vega=24.7)
30m : t=39 hr

Requirements	
Field of view	single target - no constraint
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	0.3"
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	1000-5000
wavelength (μm)	1.0-2.2μm
multiplex	N/A
typical magnitude	AB=22-25.5
object size	point sources
typical exposure time	20-80 hours
target density	N/A
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	as large as possible
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	yes yes yes
can be done with JWST	no
obs type	bright high-z GRBs and population III SNe and quasars (lower spectral resolution)
comments - add additional requirements	Time lag between discovery of these transient objects and ELT spectroscopic follow-up : at most a few days and a few weeks for GRBs and population III SNe, respectively. High and dry site to maximize accessible wavelength range

C7. Is the low density IGM metal-enriched?

J. Bergeron

Rationale

The level of metal-enrichement of IGM underdense regions strongly depends on (1) the number and spatial distribution of sources ejecting metals during the reionization epoch (SN explosions, stellar winds, galactic outflows), (2) galactic superwinds at later times (z<5).

The IGM metal-enrichment is very inhomogeneous and the relative contribution to the cosmic metals of the general IGM versus metal-rich sites is not yet well known. Nevertheless, the lack of evidence for evolution of the cosmic metal density at 2<z<5 suggests an early pollution of the IGM by the first stars and galaxies. The mean IGM abundance, derived from CIV absorption surveys, is $[C/H]=\log[\Omega_b(C)/\Omega_b(C)_{\odot}]=-2.9$ (Songaila 2001; Pettini et al. 2003). The HI column densities associated with these CIV absorbers are not small enough to probe IGM gas overdensities close to unity. Consequently, the metallicity of IGM underdense regions could be much smaller than 10^{-3} solar. A statistical approach does not constrain either the metallicity of these regions. Indeed, the pixel optical depth method provides only median opacities in bins of τ(HI), with the associated mean τ(CIV), thus an average over a range of metallicities for each bin of τ(HI).

Specific goals

The metallicity of IGM underdense regions will be determined by a spectroscopic survey at very high resolution and S/N of bright z~3 quasars. Hydrodynamic simulations with and without galactic superwinds predict an abundance in regions with gas overdensities close to unity of [Z/H]~-2.1 and -3.7, respectively (Cen et al. 2005). This yields expected CIV column densities of $10^{10.4}$ and $10^{8.8}$ cm^{-2}, respectively, when assuming that photoionization is the dominant process. There is a significant fraction (~25%) of Ly-alpha absorbers with N(HI) in the range 10^{12}-10^{14} cm^{-2}, i.e. underdense regions in the simulations, with metallicity in excess of 10^{-2} solar.

The smallest CIV column densities detectable with 8-10m telescopes are N(CIV)~$10^{11.5}$ cm^{-2} (spectroscopy of very bright quasars at high resolution R=40000 and high S/N=100). Probing the low gas density regions of the IGM at z~3 implies a gain of a factor 100 in the detection limit of individual CIV doublets.

Targets

There are few very bright quasars at z~3. Query of the SIMBAD data base gives 24 quasars at 2.5<z<3.3 with V<17 (brightest V=15.8) over the whole sky. Using the most recent survey of weak CIV systems (Songaila 2005), with extrapolation down to N(CIV)~$10^{10.3}$ cm^{-2} (see below), yields dn/dX=33 for $10^{10.3}$<N(CIV)<10^{12} cm^{-2} (comoving) at a mean redshift z=2.7. This leads to an expected number of weak CIV absorbers per line of sight N~110 in the interval 2.5<z<3.0.

The Ly-alpha forest associated with these CIV systems can be studied with 8-10 m class telescopes.

If a very prompt response to the discovery of a bright, z~3 GBR was possible, a short exposure time would be required for a V=12 GRB at the time of ELT spectroscopic observations (see below).

Results from ETC

Bright quasars at z=3

spectral resolution R=100000 - A(px) = 2(spectral)x3(spatial) -
S/N = 1000 - ground-layer AO
(1) R_Vega=17, (2) V=16
(1) 30 m : t = 88.3 hr, (2) 60 m : t = 22.5 hr
(3) V=16, (4) V=12
(3) 42 m : t = 21.7 hr, (4) 42 m : t = 35 min

Note - this resolution and S/N yield N(CIV)~$10^{10.3}$ cm^{-2} for a 5σ detection of CIV(λ1548). With this limit, one can probe IGM regions with overdensities close to unity and metallicities down to 10^{-2} solar.

Requirements	
Field of view	single target - no constraint
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	0.3"
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	100000
wavelength (µm)	0.55-0.7µm
multiplex	N/A
typical magnitude	AB=16-17.3
object size	point sources
typical exposure time	20-90 hours
target density	N/A
dynamic range	N/A
background/emissivity	
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	40°
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	yes yes yes
can be done with JWST	no
obs type	QSO absorption lines
comments - add additional requirements	these requirements are very similar to those of the CODEX experiment, although only the visible-red channel is needed here issue - can a S/N = 1000 be reached with foreseen detectors?

C8. *Topology of the IGM at z = 2-3*

J. Bergeron

There is already some evidence for feedback of galaxy winds on the IGM (e.g. Adelberger et al. 2003, 2005). These winds can affect the temperature and density structure, as well as the metallicity, of the IGM. Infall from the IGM can also trigger star formation.

Studying the global evolution of the IGM on the Mpc scale (130" at z=3) implies a density of background sources n~0.2 per arcmin square. This is rougly the surface density of Lyman break galaxies (LBGs) at 2.5<z<3.5 with 22.5<R_{AB}<24.3 (Steidel et al. 1999, 2003). Among these LBG samples, there are 3% of quasars. These sources can be observed at high spectral resolution to probe the IGM and the environment of fainter galaxies (Ly-alpha forest and metal absorption lines). Field selection can be done with multi-colour imaging surveys conducted on 8-10 m class telescopes to get photometric redshifts. A few fields around brighter quasars (R<20) could be included. The surface density of faint z~3 LBG candidates down R_AB=27, i.e. sub L* galaxies, is n~9 per arcmin square (Sawicki & Thompson 2005, 2006). Although photometric imaging surveys of these sources can be done with 8-10m telescopes (~10 hour for 4 bands), it would be best to get photometric redshifts with good accuracy from deep ELT imaging surveys of pre-selected fields with know brighter LBGs and quasars. The spectral identification of the faint LBGs will then be obtained with large surveys at low spectral resolution and high multiplexing (IFUs).

Constraining the topology of the IGM at z=2-3 and understanding the interplay between galaxies and the IGM will thus require large set of data at both low and high spectral resolution, together with deep pre-imaging.

Results from ETC

Bright LBGs and quasars at z=3

spectral resolution R=10000 - A(px) = 2(spectral)x3(spatial) -
S/N = 30 - ground-layer AO
R_{Vega}=24
30/60m: t = 43/10.8 hr

Fainter LBGs at z=3

spectral resolution R=1000 - A(px) = 2(spectral)x3(spatial) -
S/N = 10 - ground-layer AO
R_{Vega}=27
60m: t = 26.7 hr

Note - the encircled energy with the above binning is only 22.6%, thus more realistic exposure times will be obtained when larger binning options are included in the ETC.

Requirements	bright LBGs and quasars	faint LBGs
Field of view	at least 5'x5'	5'x5'
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	0.5"	0.5"
photometric uniformity in field and/or time	yes	yes
photometric accuracy	a few %	a few %
spectral resolution	10000	1000
wavelength (μm)	0.4-0.7μm	0.4-0.7μm
multiplex	10 IFUs (per 25 arcmin^2)	>100 IFUs
typical magnitude	AB=(19)21-24	AB=25-27
object size	compact sources: half-light diameter ~500mas	compact sources: half-light diameter ~500mas
typical exposure time	10-50 hours	20-80 hours
target density	~0.2 objects/arcmin^2	10 objects/arcmin^2
dynamic range	30 (possibly up to 100)	20
background/emissivity	N/A	N/A
astrometric/plate scale stability	N/A	N/A
polarisation	N/A	N/A
sky coverage	30°	30°
Date/Time constraint	N/A	N/A
can be done with 30m	yes	yes (with lower S/N and spectral bining)
can be done with 42m	yes	yes (with spectral binning)
can be done with 60m	yes	yes (S/N=10)
can be done with JWST	no	no
obs type	multi-object high-resolution spectroscopy of compact LBGs and quasars	multi-object higgh-resolution spectroscopy of compact LBGs
comments - add additional requirements	more realistic exposure times will be obtained when larger binning options are included in the ETC more realistic overall transmission should also be included as it will strongly depend on the optimization in the NIR versus Blue-Visible of the mirrors _ c	more realistic exposure times will be obtained when larger binning options are included in the ETC more realistic overall transmission should also be included as it will strongly depend on the optimization in the NIR versus Blue-Visible of the mirrors _ c

C9. Galaxy Formation and Evolution

A.Cimatti & P.Rosati

Mass Assembly of Galaxies:

Over the last decade, the synergy of 8-10m class telescopes with HST has strongly reinvigorated the field of galaxy formation and evolution by unveiling very distant galaxies (z~6), by allowing the first determination of the global star formation history since redshift z~6 and by providing the first insights on the stellar mass assembly history out to z~3. Despite this recent progress, the outstanding question remains on *how and when* galaxies assembled their *baryonic* mass across cosmic time. The ΛCDM standard model has provided a satisfactory scenario describing the hierarchical assembly of dark matter halos, in a bottom-up sequence which is now well-established over the whole mass structure spectrum. In contrast, little progress has been made in the physical understanding of the formation and evolution of the baryonic component because the conversion of baryons into stars is a complex, poorly understood process. As a result, all intellectual advances in galaxy formation and evolution over the last decade have been essentially empirical, often based on phenomenological (or "semi-analytical") models which heavily rely on observations to describe, with simplistic rules, such processes as star formation efficiency, energy feedback from star formation and AGN, chemical evolution, angular momentum transfer in merging, etc. Cornerstones observations in this empirical framework are the (total and stellar) mass of galaxies and their physical properties, including age and metallicities of their underlying stellar populations, dust extinction, SF rate, structural/morphological parameters. The study of well-established scaling relations involving a number of these physical parameters (e.g. mass-metallicity, fundamental plane, color-magnitude, morphology-density) are essential for understanding the physical processes driving galaxy evolution. However, with the current generation of 10m-class telescopes, we have been able to construct for example the fundamental plane of early-type galaxies, or to measure the Tully-Fisher relation of late types over a wide range of masses only at low redshifts, whereas only the brithest or most massive galaxies have been accessible at z>~1, and a direct measuremnt of masses has been almost completely out of reach at z>~2. Thus, our ability to explore the evolution and origin of the aforementioned scaling relations has rapidly reached the limit of 10m-class telescopes. As a result, most of the outstanding questions arisen from recent observational galaxy evolution studies which have pushed the VLT to its limit call for an ELT, specifically to extend the spectroscopic limit by at least two magnitudes.

An ELT, equipped with an optical-nearIR MOS, will directly probe physical properties of galaxies as a function of their masses and environment over 90% of the age of the Universe, thus providing the ultimate test of models of cosmic history of mass assembly on galactic scales.

Specific crucial measurements and topics include:

- Trace the evolution of the galaxy mass function by measuring dynamical masses of the first massive galaxies, i.e. 10 times more massive of the Milky Way ($M{\sim}10\,M_{MW}$), at virtually any redshift and as well as lower mass galaxies ($\sim 0.1\,M_{MW}$) over 90% of the age of the Universe. This will require moderate-to-high resoution (R=1000+) integral field or multi-object spectroscopy to measure velocity dispersions from absorption-lines in early-type galaxies and the rotation curves from emission lines in disk-like systems. The latter case will also require LTAO to spatially resolve disks at high redshifts.

- Determine the cosmic epochs over which the mass assembly of spheroids and disks occured. Current observations suggest that the build-up of spheroids was largely over by z~1, just when the major build-up of disks was ramping up to dominate later on. This will require coordination with JWST for high anular resolution rest-frame optical morphologies.
- Current determination of the stellar mass function and its evolution is based on the model dependent method of "photometic masses" from multi-wavelength surveys, whose reliability remains largely untested. The ELT will provide crucial calibration of this method by allowing masses to be determined, via dynamical methods or strong gravitational lensing, for galaxies over range of redshifts and morphological type.
- Observe the transition of massive star formation from high-density environments to the field (current understanding would place the apoch of such transition at z>~4-5).
- Study the migration of star formation rate from high to low masses as galaxies evolve ("downsizing effetct"), by measuring M/L ratios of distant galaxies over a wide range of masses (only the most massive galaxies can be probed today out to z~1)
- Evolution of the velocity distribution function of satellites of nearby galaxies down to ~30 km/s (Loeb & Peebles 2003) as a direct probe of DM halo properties and as a test of CDM predictions.

Synergies with other facilities:

Most of the issues to be addressed with the ELT in the field of galaxy evolution will benefit greatly from the synergy with JWST, which will provide rest-frame optical imaging of galaxies superp spatial resolution over the widest redshift range. These space capabilities are likely to remain unmatched even in the era of ELT with LTAO. The galaxy samples needed for this science case will likely be drawn from the next-generation of near-IR large field surveys with VISTA or sub-mm surveys with ALMA.
The ELT-ETC was used to estimate exposure times needed to measure dynamical masses via internal velocity dispersion of an early-type galaxy at z~1.5 of 10^10 solar masses, or sigma_v~80 km/s. This roughly corresponds to two magnitudes fainter than L*, which at z~1.5 is K(Vega)~20 or J(Vega)~21. To measure sigma_v with ~10% accuracy, a near IR spectrum with S/N~30 per resolution element is required with R~5000. The case for the rotation curve of a starforming galaxy at z~>3 requires S/N~>5 and R=1000 with demanding AO correction to spatially resolve an emission line (see Case 1 in Physics of High Redshift Galaxies)
Spectral type : A0V (flat spectrum)
J=23.0 (Vega) (L*+2 early-type at z~1.5)
Surf brigh=22/arcsec^2 --> for seeing-limited mode
Pixel scale = 100 mas/pix
Observation band : J
Spectroscopy with R=5000 (for other R, S/N scales linearly with R)

Diameter	AO	Integration_time (DIT=600s) (S/N=30)
8m	no (0.8")	168h
30m	no (0.8")	11h
42m	no (0.8")	6h
60m	no (0.8")	3h

Requirements	
Field of view	5'x5'
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	0.1"-0.4"
photometric uniformity in field and/or time	not critical
photometric accuracy	not critical
spectral resolution	1000-5000
wavelength (μm)	0.6-2.5μm
multiplex	50-100
typical magnitude	AB=23-26
object size	0.1"-0.5"
typical exposure time	5-? hours
target density	0.1-1 objects/arcmin^2
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	up to airmass~2
Date/Time constraint	N/A
can be done with 30m can be done with 42m can be done with 60m	yes yes yes
can be done with JWST	no
obs type	seeing limited spectroscopy (extreme-AO spatially resolved spectroscopy for rotation curves of high-z galaxies)
comments - add additional requirements	a multi-object spectroscopic instrument (possibly with movable IFUs) is needed. FoV of a few arcminutes with LTAO or >5 arcmin for seeing limited observations.

C10. Physics of High Redshift Galaxies

A. Cimatti & P. Rosati

Introduction

About ten years ago, the advent of the 10m-class optical/near-IR telescopes opened the possibility to identify spectroscopically normal galaxies out to z~7 and to perform the first studies on galaxy formation and evolution in the framework of the successful scenario of LambdaCDM cosmology. However, these observations have rapidly reached their limits both in the spectroscopic identifications and in obtaining the moderate- to high-resolution (R~1000+) spectra of high-z galaxies required to derive their physical and evolutionary properties (with the exception of the brightest galaxies at each redshift). Future ELTs will allow to overcome the above limitations and to identify and to perform detailed spectroscopic studies of high-z galaxies that now are simply impossible. The availability of high-performance AO and IFU systems will also allow obtaining spatially resolved spectral information. This will provide crucial information on baryon physics in galaxy evolution models and to drive the transition from current phenomenological models to a physical understanding of galaxy formation and evolution. The information that can be derived with future ELT observations in the optical and/or near-IR is extended to several cases that can be divided into two main groups and summarized as follows.

1) Physical parameters from integrated spectroscopy at moderate- to high-resolution

- Dust extinction is currently very difficult to estimate because the Balmer lines are redshifted in the near-IR, where the current sensitivity is often not enough to detect lines such as Hbeta. With ELT spectroscopy it will be possible to easily derive E(B-V) from Balmer line ratios. The knowledge of E(B-V) is essential to derive physical parameters reliably and to break the complex degeneracies due to dust extinction.
- The star formation rate (SFR) will be derived from the extinction-corrected emission line luminosity (e.g. Halpha to z~2.5, [OII] to z~5, ...), and compared with other indicators coming from multi-wavelength observations (e.g. ALMA, Herschel, JWST). The knowledge of the dynamical masses will constrain the specific star formation rates (SSFR=SFR/Mass) and the mass growth history in galaxies.
- The ratios of rest-frame optical emission lines redshifted in the near-IR will allow to constrain the ionization processes (e.g. stellar vs AGN photo-ionization, shock-ionization) and the metallicity of the ionized gas (e.g. from R23=([OII]3727+[OIII]4959,5007)/Hβ). Additional constraints on metallicity will come from UV absorption lines redshifted in the optical.
- The detailed properties of the stellar continuum, absorption and emission lines will be used to derive the age, metallicity and star formation history of the stellar population and to break the degeneracies between these quantities that affect the interpretation of the current results.
- The relative velocity of emission and absorption lines of different species will place important constraints of the ISM physical state and dynamics. This will also allow to identify the sources of feedback processes (energy injection into ISM, superwinds, outflows, AGN) and the origin of the SF quenching in massive halos and its possible link with the onset of the massive black hole - bulge relation and galaxy/AGN co-evolution.

- It will be possible to quantify the role, physics and rate of merging in modulating star formation, mass assembly and morphology evolution by studies of galaxy pairs and groups as a function of redshift.
- By measuring masses, ages, and metallicities of galaxies along the red sequence, it will be possible to understand the physical origin and evolution of the old early-type galaxy population and the onset and evolution of their scaling relations (e.g. Fundamental Plane, Mass-Size, ...).
- It will be possible to study in details the dependence of several physical and evolutionary properties as a function of the environment.

2)Detailed Physics of individual galaxies

- The large diameter of the ELT will enable very high spatial resolution imaging and spectroscopy, and thereby unique insight into the physical processes occurring in the high redshift galaxies. The resolution will be of order 0.01 arcsec in the H band, equivalent to 80pc at z=3. Imaging at this resolution will give immediate insight into the dynamical state of the galaxy, and will address questions like: is the galaxy merging; is there a rain of small galaxies/units falling in; does the galaxy have a wind; does it have a cold disc, etc. We will be able to analyze these galaxies with the same physical resolution as we can observe galaxies in Virgo with 1arcsec resolution imaging
- High spatial resolution spectroscopy will be able to provide direct kinematics of stars and gas. To allow reasonable integration times, the spectroscopy will be performed at lower resolution (0.05 arcsec) over the full galaxy (typical sizes of 0.5-1 arcsec). The central parts can be observed at the highest resolution (0.01 arcsec). The spatially resolved spectroscopy will provide unique insight into the interaction between stars and gas, flows, and possibly, ordered motion in either the stars or the gas, enabling much more accurate mass estimates. The high spatial resolution spectroscopy will not be achievable by any other means (ALMA, JWST, etc), and therefore completely unique.

3)Spectroscopic identification of high-z galaxies and surveys

- ELTs will be essential to derive the spectroscopic redshifts and the main physical properties of the high-z galaxies that are too faint for the current optical and near-IR spectroscopy. Examples are represented by old/passive systems at z>1.5-2, dust-obscured systems, very faint Lyman-break galaxies, galaxies belonging to proto-cluster structures, high-z clusters found with S-Z surveys. Future imaging surveys in the near-IR to millimeter (e.g. HAWK-I, VISTA, Herschel, ALMA, JWST) will provide large samples of distant galaxy targets that will be beyond the spectroscopic capabilities of the 10m-class telescopes.

The two examples addressed with the ELT-ETC were chosen in order to bracket most cases expected to be relevant in the study of phycal properties of distant galaxies:
1) A faint Lyman-break galaxy at z~5, for which we aim deriving spectra with R~1000 in the near-IR in order to detect and study the continuum, the rest-frame UV absorptions, and emission lines (e.g. [OII]3727 in the K-band). We adopt H_{Vega}=24.0 as we know it is typical for LBGs at z~5 (Ks ~ 23-24).
2) A very red old passive-like system at z~3 (it can be taken also as a proxy of a DRG or a dust-obscured galaxy with a very continuum), for which we want to obtain a spectrum of the continuum with S/N ratio sufficient to detect CaII H&K and D4000 in H-band. We adopt H(Vega)=24, expected in case of a very red system with Ks~23, H-Ks~1, J-Ks~2 (Vega).

Spectral type : A0V (flat spectrum)
H=24.0 (Vega) (representative for both galaxy cases)
Surf brigh=24/arcsec^2 --> for seeing-limited mode
Pixel scale = 100 mas/pix
Observation band : H
Spectroscopy with R=1000
S/N=5 (between OH lines !!) --> for emission lines
S/N=10 for absorptions and breaks --> multiply Integration_time x 4
S/N=20 for absorptions and breaks --> multiply Integration_time x 16
For H=25 --> multiply Integration_time x (2.5)^2 = 6.25

Diameter	AO	Integration_time (S/N=5)
8m	no (0.8")	50h
30m	no (0.8")	4h
42m	no (0.8")	2h
60m	no (0.8")	1h

The case of AO (ground-layer) with r_h=300 mas gives unclear results (to be discussed at the meeting):

30m	ground-layer	52h ?
42m	ground-layer	26h ?
60m	ground-layer	13h ?

Requirements	Integrated spectroscopy	High resolution spectroscopy
Field of view	5'x5'	3'x3' (goal 5'x5')
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	0.2"-0.4"	0.02"-0.05"
photometric uniformity in field and/or time	not critical	
photometric accuracy	not critical	
spectral resolution	1000-10000	
wavelength (μm)	0.4-2.5μm	1-2.5μm
multiplex	50-100	10-20
typical magnitude	AB=23-26	
object size	0.1"-0.5"	
typical exposure time	5-50 hours	50-100 hours
target density	0.1-1 objects/arcmin^2	1-5 objects/arcmin^2
dynamic range	N/A	
background/emissivity	N/A	
astrometric/plate scale stability	N/A	
polarisation	N/A	
sky coverage	up to airmass~2	
Date/Time constraint	N/A	
can be done with 30m can be done with 42m can be done with 60m	yes yes yes	yes yes yes
can be done with JWST	complementary	
obs type	seeing limited spectroscopy, moderate AO and spectroscopy	high spatial resolution spectroscpy
comments - add additional requirements	crucial to have a multi-object spectroscopic instrument with movable IFUs. Useful also a Fabry-Perot-like system for deep surveys for emission-line galaxies at very high redshifts (e.g. Lyα at 9<z<17 in J, H, K bands).	AO should be optimized for enclosed energy in 0.05 arcsec

C11. Gravitational Lensing

P.Rosati & P.Shaver

Over the last decade, gravitational lensing has been an invaluable tool for detailed studies of the mass distribution of systems over a wide range of mass scales. Gravitational magnification has been exploited to uncover the most distant galaxies and the time delay between multiple images to constrain cosmological parameters.

Interestingly, the use of clusters as gravitational telescopes to magnify distant galaxies above the current sensitivity limit has given us the first glimpse of the science which will become routine in the ELT era. Text book examples in this direction include: the high S/N, R~8000 spectrum with the Keck telescope of an L* Lyman-break galaxy at z=2.7 (cB58, Pettini et al. 2001), magnified by a factor of 30, which has yielded chemical abundances and physics of a distant star forming galaxies and sorrounding IGM with unprecedented details (a unique case so far); the rich rest-frame UV spectrum of an HII galaxy at z=3.357, magnified by a factor 10 (by a cluster at z=0.6, the Lynx arc, Fosbury et al. 2003), for which the inferred very low metallicity and very hot ionizing continuum suggest the presence of a primordial population III star forming region. These high quality spectra of distant galaxies, so rich in physical information, will be routinously obtained for *unlensed sources* with a 30-40m ELT. In addition, lensing magnification will allow less massive distant galaxies (e.g. dwarf galaxies at z~3) to be studied with similar details for the first time.

Observations of the mass distribution of the cores of structures across a wide range of masses, from dwarf galaxies to galaxy clusters, has long been advocated as one of the most stringent tests of the Cold Dark Matter (CDM) paradigm. CDM numerical simulations predict a universal density profile of DM halos across the mass function, with a power law form (NFW 1997) in the cores. Gravitational (strong) lensing has the unique capability of constraining the slope and concentration of the inner mass density profile, as eloquently demonstrated by recent studies which combine HST imaging and Keck/VLT spectroscopy (e.g. Broadhurst et al 2004, Sand et al. 2003). A widespread application of this method has been hindered primarily by the lack of spectroscopic sensitivity, aw well as by limited angular resolution of ground-based observations. Due to the same limitations, 8-10m telescopes have struggled to obtain secure redshifts of galaxies at z>~7, which can be found in highly magnified regions (critical curves) of massive clusters (e.g. Ellis et al. 04). An ELT, even at the lowest end of diameter range, albeit with somewhat demanding AO capabilities, will lead to the full exploitment of gravitational lensing techniques, which are the most likely to open unimaginable routes.

Some specific science goals include:

a)- obtain redshifts of a large number of multiple images in massive clusters to vastly improve the reconstruction of the mass distribution, particularly the inner mass slope. For example, the analysis of the spectacular lensing pattern obtained with HST-ACS deep imaging of A1689, a cluster at z=0.18 with one of the largest Einstein radius known, revealed over 100 multiple images, half of which are beyond the current spectroscopic limit.

By deriving the inner DM mass profile of systems over a range of mass scales (10^{12}-10^{15} solar masses) and redshifts, the CDM theoretical framework can be directly tested, in particular the predicted universality of the density profile and the evolution of the central concentrations of DM halos (which depends on the formation redshift).

An IFU spectrograph, with demanding AO correction, is needed in many cases due to the close angular separations (0.2-1 arcsec) of arclets or multiple images from lensing galaxies (or cluster galaxies). Spectroscopy in the UV-B band is often used in these cases to minimize the contamination of red cluster galaxies, a requirement which evidently clashes with AO. Detailed simulations will have to be carried out on HST images, convolved with predicted AO PSF patterns, to firmly assess the efficiency of an ELT in measuring redshifts of faint images lensed by both isolated galaxies and clusters.

b)- obtain spectra of highly magnified galaxies well beyond z=6. With short (~1 hr) exposures a 30-40m ELT will secure redshifts of all z>6 lensed galaxies currently known. For example, the triply lensed galaxy in A2218 (likely at z=6.5-7) has J_{Vega}=23.5 (z_{AB}=25), for which a R=1000 spectrum with S/N=10 can be obtained in ~7(4)h exposure with a 30(42)m ELT, which will be sufficient to also get physical insights from line diagnostics.

An IFU+AO system, with 10-20" FoV, could be plugged onto sky regions near the critical curves of clusters like A2218, A1689 (where magnifications of 1-3 mags are not unusual), to explore chunks of volumes of the Universe which peer well into the ionization epoch (e.g. measure redshifts of L* galaxies well beyond z=10). Also for this case, the performance of planned AO systems is a critical feasibility issue, as the exposure times above depend critically on the PSF, sky background and surface brightness of multiple images/arclets.

c)- follow-up observations of multiply images QSOs by galaxy-scale and cluster-scale lenses (mass distribution and time delay monitoring)

Synergies with other facilities:

It is easy to envisage how NGST could provide candidates and accurate positions of very distant lensed images, with synergies similar to HST-Keck/VLT. The combination of ALMA with an ELT promises to be very powerful for gravitational lensing, due to the high surface density of sub-mm galaxies and the small contribution of lensing galaxies to sub-mm flux. Large area surveys will also be needed to find a large number of lensing systems. For example, LSST expect to produce at least an order of magnitude increase in galaxy-scale lenses.

C12. Deep Galaxy Studies at z=2-5

M. Franx

Whereas we have currently a relatively good understanding of bright optically selected galaxies at z=2-4, our understanding of optically faint galaxies very limited. Even the shape of the luminosity function at the faint end is uncertain. This situation is particularly uncomfortable, as

(i) the UV luminosity function implies that much of the flux is emitted at magnitudes fainter than 25.5, well past the capability of 8m telescopes,

(ii) many massive high redshift galaxies are intrinsically red, and therefore difficult to study in the optical; and

(iii) the progenitors of "normal" galaxies at z=0 are expected to be faint (typical r-band magnitude of 27).

A redshift survey of optically faint galaxies is needed to move beyond the current selection limits, and obtain a more comprehensive view of the universe. This redshift survey will produce proper luminosity function, characterization of the UV continuum and emission lines, and correlation function as a function of mass, luminosity, color, and other parameters.

It is required to study a large number of galaxies for this survey. At least 10.000 galaxies are needed with typical magnitude of 27. The typical integration times are 10 hours for a 30-m telescope, based on current experience with 10-m class telescopes. Hence, in order to be able to execute this science case effectively, a large multiplex is needed (at a level of 100 to be able to perform this study in 1000 hours). The density of sources is high: 30-50 galaxies per sq arcmin, and hence the accessible field of view does not need to be very large (although a larger field-of-view will allow more effective studies through a sparse sampling).

Requirements	
Field of view	3x3 arcmin
-diameter of 50% enclosed energy circle	<0.4"
-strehl ratio (or "diff. lim." for diffraction limited)	
photometric uniformity in field and/or time	N/A
photometric accuracy	N/A
spectral resolution	>3000
wavelength (µm)	0.4-0.9µm
multiplex	100
typical magnitude	AB=27
object size	0.2-0.4
typical exposure time	10 hours
target density	30-50 objects/arcsec^2
dynamic range	N/A
background/emissivity	N/A
astrometric/plate scale stability	N/A
polarisation	N/A
sky coverage	airmass 2
Date/Time constraint	
can be done with 30m	yes
can be done with 42m	yes
can be done with 60m	yes
can be done with JWST	overlap and complementary
obs type	spectroscopy
comments - add additional requirements	

V. Prominent Science Cases

The Science Working Group has made a first selection of the science cases listed above. These sciences cases, hereafter called "prominent science cases", are thought to be the most important, and can be used to derive the most-desired capabilities. The prominent science cases are:

1) Planets and Stars:
   - Extrasolar Planets (S3)
   - Circumstellar disks (S8)
   - IMF in Stellar Clusters (S5)

2)Stars and Galaxies:
   - Resolved Stellar Populations (G4)
   - Black Holes/AGN (G9)

3)Galaxies and Cosmology
   - First light-the highest redshift galaxies (C4)
   - Studies of Absorption lines: Dynamical measurement of universal expansion, IGM studies (C2, C7)
   - Physics of high redshift galaxies (C10)

These cases will be given emphasis in the further development of the science case for the ELT. They will be used for the definition of the Design Reference Mission.

VI. Table of Requirements

The following 3 pages contain the summary table of requirements. The details for each of these cases can be found in sections II to IV. The prominent science cases are listed in boldface and are underlined.

#	Science case	FOV	Spatial Resolution milli-arcsec	Spatial Resolution Strehl	Photometric uniformity	Photometric accuracy	Guide star distance, colour	Spectral R	Wavelength microns	Multiplex	Magnitude (typical)	Object Size arcsec	Exposure typical time, hr	Usage (freq, rare)
	Planets and Stars													
S1	Solar system comets	10"-20"		diff. limit at 3µm	na if calibratable			200000	2 - 5				0.5 - 2	2-3 per yr
S2	Extrasolar-system comets (FEBs)	2"		diff. limit (>60%)				200000	2 - 5	x-dis spectr.		point sources	series of 4 hr	
S3	**Extrasolar planets:**													
	- imaging	10"-20"				1%		100	0.8 - 2	no	> 28	point sources	1	
	- radial velocities	2"						100000	visible	no	V = 5-11	point sources	1	
S4	Free-floating planets	1'x1' or larger		diff. limit		10%		100	0.7-2.4		23-27	point sources	01-May	1-2 per year
S5	**Stellar clusters (inc. Galactic Centre)**	1'x1' or larger	0.2"	diff. limit		5%		1000	0.7 - 5	few to 10	R,K < = 27	1'x1'	to 10h	
S6	Magnetic fields in star formation regions													
S7	Origin of massive stars	20"	10	>30%	0.03 mag	3%	LGS ?	10000	2 - 5	yes	28	neb. Cluster	10	
S8	LMC field star population	10-30"	10	>30%	0.03 mag	3%	LGS ?	5	1 - 2	no	25	point sources	1	
S9	**Circumstellar disks, young and debris**	10"x10"	diff lim (0.7?-2) to 20 micron		10%	5%		10/300/3000/50000	(0.7 or 2)-20	IFU	faint ext objs	few	~ 1-10	
S10	Stellar remnants	10"-30"	<100			few %		5000	optical+NIR		>25	point sources	<0.5	
S11	Asteroseismology	>few arcmin						>80000	0.38-0.7	if possible	9-11	point sources	1 min or smaller	
	Stars and Galaxies													
G1	Intracluster population													
	- Colour-Magnitude diagrams	few arcmin	0.1"		0.01	0.05			0.5-1		>26	point sources	3	
	- CaII spectroscopy of IRGB stars	few arcmin		LTAO	0.01	0.05		1000-5000	0.8	yes	>24	point sources	20	
G2	Planetary nebulae and galaxies	few arcmin		LTAO	0.01	0.05		1000-5000	0.3-1.1	yes	>27	point sources	20	
G3	Stellar clusters and the evolution of galaxies	5"		diff. limit	0.01 mag	0.01-0.02 mag		10	0.4 - 5		V = 20-36	< 5 "	8-24h	
G4	**Resolved stellar populations:**													
	- Colour-Magnitude diagram Virgo	1-10"		diff. limit	0.02 mag	0.05mag/goal 0.02		10	0.8-3 (goal 0.6)	no	27-28	point sources	8-10h	
	- abundances & kinematics Sculptor galaxies	10"-3'	50%EE<0.1 (goal)	Light collector				5000-8000	0.8-0.9	>10 (goal 50)	24-26	point sources	8-10h	
	- abundances & kinematics M31- CenA	1-5"	50%EE<0.1 (goal)	Light collector				>25000 (40000)	0.45-0.75	few-10	21-23	point sources	8-10h	
G5	Spectral observations of star clusters:													
	- internal kinematics & chemical abundances	5 x 5 '	100					30000-50000	0.4-2.5	1 - 10+	V = 19-26	20-100 mas	6-12+	
	- ages and metallicities of star cluster systems	5 x 5 '	50					1000(vis), >3000(IR)	0.4-2.5	10+	V = 23-30	4-20 mas	6-12+	
G6	Young, massive star clusters	2'x2'												
	- imaging	2'x2'	5						0.4-0.6		V=20-24	5-40mas	>5-15	
	- spectroscopy	2'x2'	40					10000-30000	0.4-0.6	5-10	V=20-24	5-40mas	>5-15	
G7	The IMF throughout the Local Group	>3" and >30"		diff. limit	<0.1 mag	< 0.1 mag		5 (imaging only)	0.8-1.6		J,H = 30	point sources	25-90	
G8	Star formation history through supernovae													
	- search and light curves	>5'x5'	GLAO		<1%	5%			0.6-25		K>24	point sources	2	1 per month
	- spectroscopy			LTAO				a few hundred	0.6-2.5	minor	K>24	point sources	2	
G9	**Black holes/AGN**	5"	few mas	diff. limit				1000-50000	1-3.5	1	SB H=18/sq arcsec	5pc	10hr	
	Galaxies and Cosmology													
C1	Dark energy: Type Ia SNe as distance indicators													
	- search and light curves	>5'x5'	GLAO/MCAO(tbd)		few 0.01 mag	<5%		5	0.8-2.5		see text(AB=24-25)	point sources	see text	1 every two weeks
	- spectroscopy			LTAO				a few hundred	0.8-2.5	low	see text(AB=24-25)	point sources	see text	
C2	**Dynamical measurement of universal expansion**	few arcsec	80& EE in 0.6"					150000 (>= 50000)	0.4-0.68(goal 0.38)		15-17	point sources	0.2-0.3h x many	
C3	Constraining fundamental constants	few arcsec	80& EE in 0.6"					150000 (>= 50000)	0.4-0.68		15-17	point sources	0.2-0.3h x many	
C4	**First light - the highest redshift galaxies**	10'x10'-17'x17'	200 mas					>3000	0.9-2	100	AB = 28	0.1-0.2	100	
C5	Galaxies and AGN at the end of reionization	5'x5'	200 mas					>3000	0.9-2	100	AB = 28	0.1-0.2	100	
C6	Probing reionization with GRBs and quasars		300 mas					1000-5000	1.0-2.2		22-25.5	point sources	20-80h	
C7	**Metallicity of the low-density IGM**		300 mas					100000	0.55-0.7		16-17.3	point sources	20-90h	
C8	IGM tomography													
	- bright LBGs and quasars	>5'x5'	500mas		yes	few %		10000	0.4-0.7	10 IFU	21-24	0.5"	10-50	
	- faint LBGs	5'x5'	500mas		yes	few %		1000	0.4-0.7	>100 IFU	25-27	0.5"	20-80	
C9	Galaxy formation and evolution:	5'x5'	0.1"-0.4"					1000-5000	0.6-2.5	50-100	23-26	0.1-0.5"	> 5	
C10	**Physics of high-z galaxies**													
	- integrated spectroscopy	5'x5 '	0.2"-0.4"					1000-10000	0.4-2.5	50-100	23-26	0.1-0.5"	5-50h	
	- high resolution imaging	>1'x1'		strehl > 0.5				10	1-2.5		23-26	0.1-0.5"	2-5h	
	- high spatial resolution spectroscopy	3'x3'	50%EE in 0.05"					1000-10000	1-2.5	>10	23-26	0.1-0.5"	50-100h	
C11	Gravitational lensing	1'x1'	0.1"-0.4"					500-5000	0.4-2.5	50-100	24-27	0.1-0.5"	2-20h	
C12	Deep Galaxy Studies at z=2-5	3'x3'	<0.4"					>3000	0.4-0.9	100	27	0.2-0.4	10h	
	Prominent science cases have been given in boldface													

#	Science case	Target density arcmin^-2	Dynamic range	Background/ emissivity	Astrometric/plate scale stability	Polarization	Sky coverage required	Date/time constraint	Can be done with 30m	42m	60m	JWST	Observation type
	Planets and Stars												
S1	Solar system comets			good IR perfomance			ecliptic +/-10deg	often morn/eve	yes	yes+	yes++	?	long-slit spectroscopy
S2	Extrasolar-system comets (FEBs)			good IR performance			dec -60 to +10		300pc	400pc	600pc	no	x-dispersed spectroscopy
S3	**Extrasolar planets:**												
	- imaging								10pc	15pc	25pc		hi contrast im+sp
	- radial velocities												hi-res spectroscopy
S4	Free-floating planets	0.01			better than 1%			baseline 1 year	yes	yes	yes	c	hi-res spectroscopy
S5	**Stellar clusters (inc. Galactic Centre)**	up to 1000			better than 1%		galactic center	baseline 1-2 years	yes	yes	yes	yes/c	imaging & spectros
S6	Magnetic fields in star formation regions												
S7	Origin of massive stars	4000	100	nebulosity	scale vars << FWHM	ca. 1%	gal. plane		no	yes	yes	yes	imaging + IFU spectros
S8	LMC field star population	20000	1000				LMC/SMC		yes	yes	yes	yes	imaging
S9	**Circumstellar disks, young and debris**	low	10^3-10^5	v low thermal bkg	1%	linear	all sky		yes	yes	yes	c	imaging + IFU spectros
S10	Stellar remnants				milliarcsec				10kpc		20kpc	no	imaging & spectros
S11	Asteroseismology						on star for several hours	long run 7-10 days	some	few	more	no	high resolution spectroscopy
	Stars and Galaxies												
G1	Intracluster population												
	- Colour-Magnitude diagrams	0.1 RGB	10-20	dark time			from -50° to +20°		10Mpc	25Mpc	50Mpc	yes	imaging
	- CaII spectroscopy of IRGB stars	0.1 RGB	10	dark time			from -50° to +20°		4Mpc	9Mpc	14Mpc	c	spectroscopy
G2	Planetary nebulae and galaxies	1 PN	2	dark time			from -50° to +20°		5Mpc	10Mpc	15Mpc	no	spectroscopy
G3	Stellar clusters and the evolution of galaxies	up to 10^7	up to 10^4	V>21 mag/min^2			to 50-65 deg ZD		no	poss	yes	no	intermed-band photom
G4	**Resolved stellar populations:**												
	- Colour-Magnitude diagram Virgo		~10^4	dark+stable	critical for spectro targets		north+south OK		hard	ok	yes		HR imaging
	- abundances & kinematics Sculptor galaxies			dark+stable	important for MOS		north+south OK		hard	ok	yes		multiobj spectroscopy
	- abundances & kinematics M31- CenA			dark+stable			north+south OK		hard	ok	yes		spectroscopy
G5	Spectral observations of star clusters:												
	- internal kinematics & chemical abundances	10-100					maximum		no	yes	yes	no	
	- ages and metallicities of star cluster systems	0.1-100					maximum		no	yes	yes	no	
G6	Young, massive star clusters												
	- imaging	~10					maximum		no	poss	yes	c	
	- spectroscopy	~10					maximum		no	poss	yes	no	
G7	The IMF throughout the Local Group	10^5 - 10^7	tbd		scale vars << FWHM		to 30 deg ZD		yes	yes	yes	no	high contrast imaging
G8	Star formation history through supernovae	< 1											
	- search and light curves	see text					overlap with other tels	monitoring	diff	diff	poss	yes	searching and monitoring
	- spectroscopy	see text							diff	yes	yes	yes	spectroscopy
G9	**Black holes/AGN**						maximum		yes	yes	yes	c	IFU spectroscopy
	Galaxies and Cosmology												
C1	Dark energy: Type Ia SNe as distance indicators	< 1											
	- search and light curves	see text					overlap with other tels	monitoring	yes	yes	yes	o	searching and monitoring
	- spectroscopy	see text							yes	yes	yes	o	spectroscopy
C2	**Dynamical measurement of universal expansion**	low		dark time	.02-.05" centering		lowest airmass		yes*	yes*	yes*	no	hi accuracy spectros.
C3	Constraining fundamental constants	low		dark time	.02-.05" centering		lowest airmass		yes*	yes*	yes*	no	hi accuracy spectros.
C4	**First light - the highest redshift galaxies**	0.1 - 1					to airmass 2		yes	yes	yes	o/c	spectroscopy
C5	Galaxies and AGN at the end of reionization	0.1 - 1					to airmass 2		yes	yes	yes	o/c	spectroscopy
C6	Probing reionization with GRBs and quasars						maximum		yes	yes	yes	no	spectroscopy
C7	**Metallicity of the low-density IGM**						to 40 deg ZD		yes	yes	yes	no	spectroscopy
C8	IGM tomography												
	- bright LBGs and quasars	0.2	30-100				30 deg ZD		yes	yes	yes	no	multiobj spectroscopy
	- faint LBGs	10	20				30 deg ZD		yes	yes	yes	no	multiobj spectroscopy
C9	Galaxy formation and evolution:	0.1-1					to airmass 2		yes	yes	yes	no	spectroscopy
C10	**Physics of high-z galaxies**												
	- integrated spectroscopy	0.1-1					to airmass 2		yes	yes	yes	c	spectroscopy
	- high resolution imaging	1 to 5					to airmass 2		yes	yes	yes	c	imaging
	- high spatial resolution spectroscopy	1 to 5					to airmass 2		yes	yes	yes	c	spectroscopy
C11	Gravitational lensing	1 - 50					to airmass 2		yes	yes	yes	yes	imaging & IFU spec.
C12	Deep Galaxy Studies at z=2-5	30-50					to airmass 2		yes	yes	yes	o/c	spectroscopy
	Prominent science cases have been given in boldface												

#	Science case	Comments
	Planets and Stars	
S1	Solar system comets	differential tracking up to 60-100 arcsec/hr required
S2	Extrasolar-system comets (FEBs)	rasters of 4-6 stars in nearby star clusters. Nearby SF regions possible with 42m
S3	**Extrasolar planets:**	
	- imaging	high performance techniques for speckle suppression are essential
	- radial velocities	need high performance techniques for wavelength calibration, precise & stable to few cm/sec over years
S4	Free-floating planets	
S5	**Stellar clusters (inc. Galactic Centre)**	
S6	Magnetic fields in star formation regions	
S7	Origin of massive stars	star cluster proper motion + RV, 4k x 4k array (IFU, ca. 100000 pixels)
S8	LMC field star population	crowded field AO photometry, star counts
S9	**Circumstellar disks, young and debris**	strong complementarity with ALMA
S10	Stellar remnants	
S11	Asteroseismology	30m: brightest stars in closest cluster (Hyades); 42 m: several clusters; 60m more targets
	Stars and Galaxies	
G1	Intracluster population	
	- Colour-Magnitude diagrams	
	- CaII spectroscopy of IRGB stars	
G2	Planetary nebulae and galaxies	Estimates based on VLT data
G3	Stellar clusters and the evolution of galaxies	pixel scale: 1mas; SCAO sufficient; Virgo within less than 30° from Zenith
G4	**Resolved stellar populations:**	
	- Colour-Magnitude diagram Virgo	see detailed comments in the document for this case; need careful modelling to accurately define feasibility in a range of circumstances
	- abundances & kinematics Sculptor galaxies	
	- abundances & kinematics M31- CenA	
G5	Spectral observations of star clusters:	
	- internal kinematics & chemical abundances	
	- ages and metallicities of star cluster systems	
G6	Young, massive star clusters	
	- imaging	
	- spectroscopy	
G7	The IMF throughout the Local Group	MCAO in visible would be great advantage. JWST does not have sufficient ang resolution
G8	Star formation history through supernovae	
	- search and light curves	Detailed simulations are required. Most of this is in Dahlén and Fransson. Should probably be further refined.
	- spectroscopy	Extension to other wavebands probably useful, Should be attempted.
G9	**Black holes/AGN**	high contrast is important; objects out ti Virgo; rare high-z objects
	Galaxies and Cosmology	
C1	Dark energy: Type Ia SNe as distance indicators	
	- search and light curves	Detailed simulations required. Extension to other wavebands probably useful.
	- spectroscopy	
C2	**Dynamical measurement of universal expansion**	*total collecting area must be large (see detailed sc. case). Need improved ETC
C3	Constraining fundamental constants	*total collecting area must be large (see detailed sc. case). Need improved ETC
C4	**First light - the highest redshift galaxies**	images also required (as JWST has only 5-yr lifetime). If M-IFU field size > 1"x1"
C5	Galaxies and AGN at the end of reionization	images also required (as JWST has only 5-yr lifetime). If M-IFU field size > 1"x1"
C6	Probing reionization with GRBs and quasars	Response mode within few days; high and dry site for maximum accessible wavelength range
C7	**Metallicity of the low-density IGM**	Similar requirements to CODEX (except only vis-red needed). Can S/N=1000 be reached?
C8	IGM tomography	
	- bright LBGs and quasars	Need improved ETC
	- faint LBGs	Need improved ETC
C9	Galaxy formation and evolution:	*better ETC. MOS instrument (poss. with movable IFU). FOV ~3' (LTAO) or >5" (seeing lim)
C10	**Physics of high-z galaxies**	
	- integrated spectroscopy	*better ETC needed
	- high resolution imaging	*better ETC needed
	- high spatial resolution spectroscopy	*better ETC needed. Multiple IFUs, each FOV 1.5-2arcsec
C11	Gravitational lensing	AO simulations (including sky emissivity) for grav lensing cases are essential
C12	Deep Galaxy Studies at z=2-5	
	Prominent science cases have been given in boldface	

VII. Appendices

1. Synergies and Operations

The scientific use of modern facilities is strongly shaped by the operational models with which they are run. The optimal use of atmospheric and other conditions requires that the telescope is equipped with a set of instruments to make best use of the prevailing conditions. At the same time sufficient observational programmes for the given conditions are necessary for an optimal scheduling of the resources.

It is assumed that there will be instruments to cover bright time as well as dark time periods. While this has become less of an issue in the past decade due to the move towards infrared and high-spectral resolution observations, it should not be neglected. The success of queue scheduling appears to make the use of service observing mandatory for the future telescopes as well. Another advantage of this mode is the improved performance for target of opportunity observations.

Since the parameter space has been expanded considerably to shorter and more sudden events, a rapid response mode should be considered. Even though time dilation will slow down the most distant GRBs they still have durations of only a few hours. Other astrophysical process have very short duration or rapid changes (e.g. flashes from the galactic centre, outbursts on stellar surfaces, neutron stars and black holes, shock emission from the shock outburst in core-collapse supernovae, etc.). Opening up this time domain will happen with smaller telescopes, but the rapid spectroscopic follow-up is needed with the largest facilities available. Hence, the telescope should be able to point within minutes at any accessible part of the sky. The acquisition process should be trimmed accordingly.

Operational models should explore the entire chain from proposal submission to data delivery and analysis. The optimal use of the telescope implies that the extraction of the information from the data will need to be facilitated as much as possible.

Issues are the time scale for proposal submission (continuous or in semesters as so far?), quality control, data distribution, data reduction and analysis support, archiving and combination with data from other telescopes. Some of these issues depend on the site selection (e.g. data rates from remote sites).

Another item is the coordination of proposals among different facilities. There have been attempts to do this with the existing telescopes (space- and ground-based) and it quite possible that there will be further scientific integration among different facilities. After all it is one of the stated goals to have synergies between JWST and the ELTs. The examples of HST and the Keck and the VLT have been mentioned regularly in the past.

2. JWST

JWST and ELT will be very complementary in their capabilities. Above 2 micron, JWST will be the prime instrument for deep imaging with medium spatial resolution, and spectroscopy with resolution up to 3000. ELT will provide very high spectral resolution spectroscopy, and diffraction limited imaging with a very high spatial resolution. Between 1 and 2 micron, ELT will be most effective for spectroscopy with a resolution higher than 100; but JWST will be very suitable for very deep imaging of extended sources. The speed for low resolution spectroscopy (R=100) is similar for JWST and ELT in this wavelength regime, and the multiplex and need for full wavelength coverage will determine to a large extent the overall effectiveness. The large field-of-view of JWST, the large multiplex, and the absence of atmospheric absorption features can make it very effective at these wavelengths. Overall, the complementarity between the capabilities of JWST and ELT is a strong motivation to try to build ELT on a fast timescale. The nominal mission lifetime of JWST of 5 years with a goal of 10 years would only allow substantial overlap if ELT is build within 10 years from now.

3. *Considerations for the ELT Site*

Synergy considerations for the ELT site

Summary

Given the distribution of potential sites around the world, the ELT will be located either within a few degrees of ALMA or more than 40-50 degrees away in geographical latitude. A large latitude difference will have serious negative consequences for scientific synergy between the two facilities. Considering the importance of both facilities in the coming decades, this should be a major factor in selecting the site for the ELT.

Latitude distribution of sites

In terms of latitude difference from ALMA, the distribution of potential ELT sites is effectively bimodal - the sites are either within a few degrees of ALMA, or over 40-50 degrees away.

ALMA is being built on the Llano de Chajnantor in the Atacama region of Chile, at a latitude of -23 degrees. Several potential sites for the ELT are within a few degrees of this latitude. Almost all the others are in the northern hemisphere, at latitudes ranging from 43 to 62 deg north of ALMA (all but one (Mauna Kea) are more than 50 deg away from ALMA in latitude). The only site significantly to the south of ALMA is Dome C in the Antarctic, 52 degrees away. Thus, the sites under consideration for the ELT are either optimally placed in latitude for scientific synergy with ALMA, or very far away. This is illustrated in fig. 1.

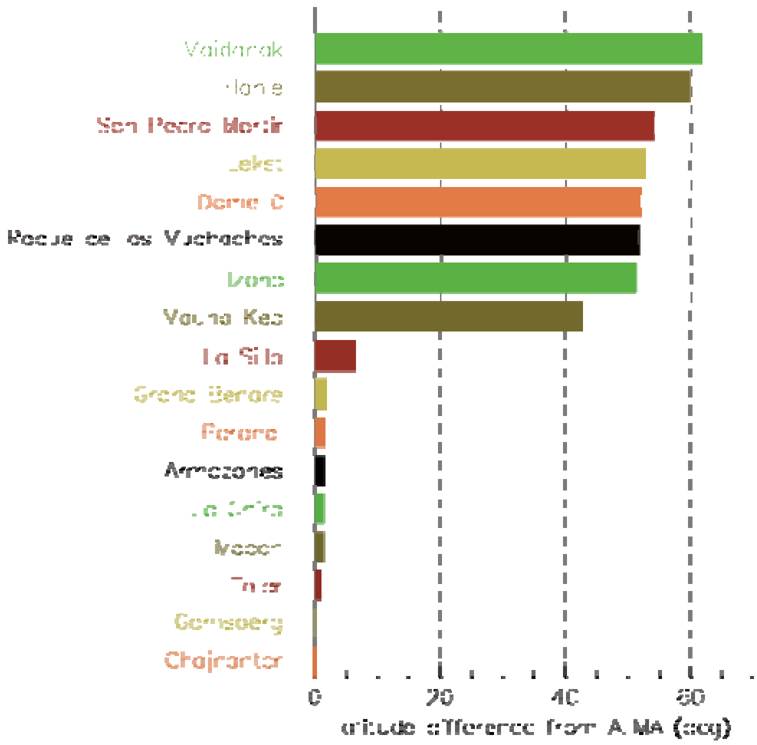

Fig 1 - Distribution of latitude difference between ALMA and possible ELT sites. Note that the distribution is bimodal: the ELT latitude is either within 5 deg of that of ALMA, or more than 40 deg away

Effect of latitude difference on observational efficiency

At 50 deg. zenith distance, at optical and near-infrared wavelengths, an ELT would only achieve 65% to 70% of the S/N that would be achieved at zenith – it would require 2.2 times longer integration time to achieve the same S/N as at zenith (see fig. 2). Thus, for a source that transits overhead of ALMA, observations using an ELT located 50 deg away would be 2.2 times less efficient than if the ELT were located at the same latitude as ALMA. In addition, the image quality (seeing) would be worse by 30%, and there would be serious consequences for the performance of adaptive optics.

Conversely, for a source that transits overhead of an ELT located 50 deg away from ALMA, the S/N achieved by ALMA would be only 40% and 72% of that at zenith for 650 and 345 GHz respectively – the integration times would have to be 6 and 1.9 times longer at 650 and 345 GHz respectively to achieve the same sensitivity as at zenith (fig. 3). In addition, the phase stability for ALMA observations at 50 deg ZD would be about 25% worse than at zenith, further diminishing both the S/N and the image quality. (Phase errors cause a loss of coherence of visibilities and limit the spatial resolution.)

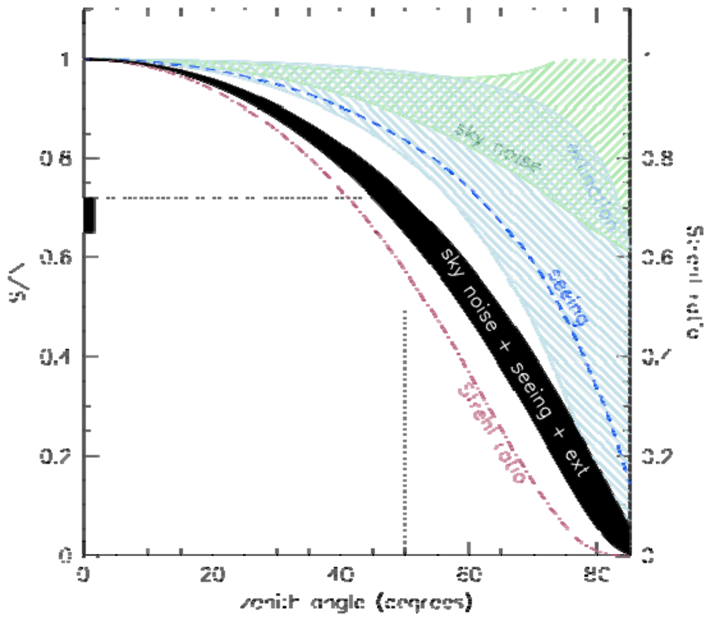

Fig 2 - Signal-to-noise ratios of an ELT normalised to that maximally achieved at zenith. The shaded areas show the effects of atmospheric extinction and sky brightness, ranging from U-band to I-band, and the dashed line shows the effect of seeing. The black band shows the combined effect. The dash-dot line indicates the AO performance as a function of zenith distance. Projected on the y-axis is the expected S/N at 50 deg zenith distance.

Suppose one were to choose an optimal field for a joint ALMA-ELT deep survey. If the latitude difference between ALMA and an ELT were small, such a field would likely be chosen at a declination close to -23 deg. If one observed this field for four hours centered around transit (HA from -30 to +30 deg), the total S/N ratios relative to observing a source at 0 deg ZD would be between 97% to 98% for the optical to near-IR, and between 94% and 99% for ALMA frequencies ranging from 650 GHz to 100GHz. Obviously, the total efficiency of such an experiment would be very high.

Now consider an ELT located at +27 degrees latitude, i.e., 50 deg away from ALMA. In this case the survey field would probably be chosen close to the equator. Taking the same observational strategy as above, the integrated S/N ratios would drop to between 86% and 88% in the optical/near-IR, and the S/N ratios in the ALMA band would be 77% in at 650 GHz, 91% at 345 GHz, and 96% at 100 GHz. A combined I-band – 650 GHz survey would have a S/N ratio of 69% compared to 91% for a survey with ALMA and ELT at the same latitude. This translates into a difference of factor 1.7 in the combined ALMA-ELT observing time. For a combined I-band – 100 GHz survey, this difference would be a factor 1.2. Of course, one would not want to restrict all observations to this narrow declination band.

As another example therefore, we consider what the effect on efficiency would be if the ELT were to observe 'typical' ALMA sources. Suppose that ALMA will typically observe sources over the declination range -50 to 0 deg, with hour angles between -30 and 30 deg. The integrated S/N ratios compared to observing at zenith are high, between 88% and 98%, for the 650 GHz to 100 GHz bands, respectively. If an ELT at latitude -23 deg were to observe the same sources, the integrated S/N ratios would be approximately 95% of those at zenith. However, if the ELT were at +27 deg, the relative S/N ratios would drop by a factor 1.5, corresponding to a factor 2.2 in integration time.

It should be noted that all of these estimates are optimistic because not all observational factors have been taken into account – any others can only make matters worse.

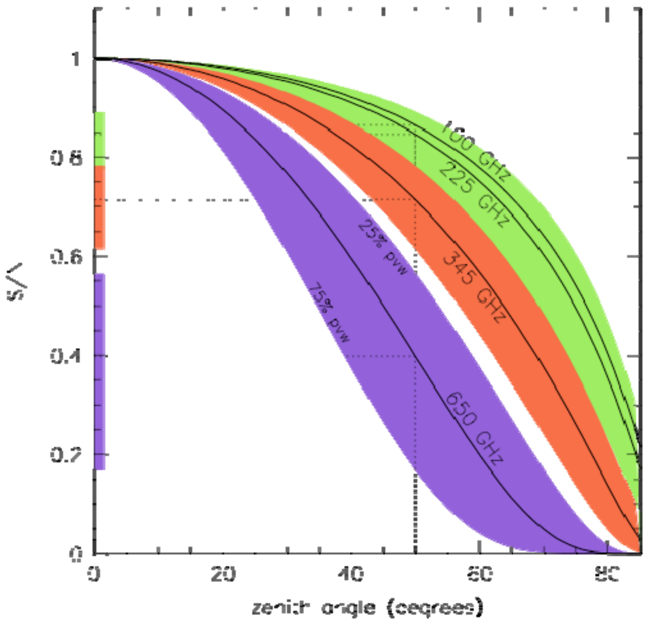

Fig 3 - Signal-to-noise ratios for four ALMA bands, normalised to that maximally achieved at zenith. Both the effect on optical depth and the tropospheric effect on system temperature are taken into account. The bands indicate the range between the 25th and 75th percentiles of the precipitable water vapour (pwv) at Chajnantor. Projected on the y-axis are the expected S/N values at 50 deg zenith distance.

Discussion

The scientific synergies between ALMA and an ELT cover most of the science cases of each, ranging from the first objects that reionized the Universe and the entire subsequent evolution of galaxies, to the formation of stars and planets in our own Galaxy. It is therefore important that these two facilities be able to work together as efficiently as possible, and this requires that they be located at similar latitudes. The VLT, and three of the four sites currently under study for the SKA, are also located within a few degrees of the latitude of ALMA; if future synergy with these facilities is also considered desirable, this adds further to the case for the ELT site being in that latitude range – not to mention the many unique features of the southern sky.

Acknowledgements

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M. Zwaan, P. Shaver - ESO

7 February 2006

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5. *Useful links*

OWL Blue Book (2005):

http://www.eso.org/projects/owl/Phase_A_Review.html
in particular the science section
http://www.eso.org/projects/owl/Blue_Book/3_Science_case.pdf

OPTICON ELT science case:

http://www-astro.physics.ox.ac.uk/~imh/ELT/Book/book.html

a summary of these science cases is also available in the Messenger:
http://www-astro.physics.ox.ac.uk/~imh/ELT/Docs/ELT_mess.pdf

The Euro-50 proposal:

http://www.astro.lu.se/~torben/euro50

The American projects are

TMT:

http://www.tmt.org
The individual partners have their own Web pages for this project, e.g.

Caltech:

http://www.astro.caltech.edu/observatories/tmt/

University of California - Santa Cruz:

http://tmt.ucolick.org/

AURA:

http://www.aura-astronomy.org/nv/nuresult.asp?nuid=67

The original Green Book (CELT proposal) from 2002:

http://celt.ucolick.org/greenbook
and its science chapter:
http://celt.ucolick.org/greenbook/ch02.pdf

GMT:

http://www.gmt.org
in particular their Science Case (2004):
http://www.gmto.org/sciencecase/new_science_case_Sep10_2004.pdf
and their Science Requirements Document (2004):
http://www.gmto.org/sciencecase/Science_Requirements_2.pdf

The original GSMT science case book (2003):
http://www.aura-nio.noao.edu/gsmt_swg/SWG_Report/SWG_Report_7.2.03.pdf

The Japanese ELT project can be found at
http://optik2.mtk.nao.ac.jp/futureplan/eltproje.htm

6. *Further work needed*

As noted in the document, many of the science cases require further work. Below we give an (incomplete) list of work needed in the coming year:

1) Simulation of crowded field photometry with adaptive optics. This requires realistic PSF's and their variations across the field, realistic input fields, and refined analysis. This is especially relevant for the stellar populations science case, but also other science cases (e.g., dense star cluster, galactic center)
2) Improved exposure time calculations are needed for many of the science cases.The prominent science cases have the highest urgency. Some examples:
    a) For many cases in galaxies and cosmology, integrated light spectroscopy in the near-ir is required. The performance using GLAO could only be estimated using simplistic assumptions. Better PSFs are needed at several wavelengths, and S/N estimates using observational strategies optimizing the S/N ratio.
    b) The same for the optical, where GLAO may or may not help to increase the efficiency.
    c) Optimized extraction of pointsource light for spectroscopy and imaging under various AO modes.
3) In general, simulations are needed of the PSF for a 30m telescope with the various AO modes.
4) A tool to produce realistic images including the effects of variable PSF for the AO modes of the telescope
5) Specific improvements needed for science cases:
    a) Exo-planets: need more detail on requirements. Example: what S/N needed for spectroscopy
    b) Resolved populations: detailed simulations.
       1) Take typical Virgo Elliptical or nearest elliptical
       2) Estimate number density of stars which can be detected (from MS to AGB); construct CM diagram + density distribution
       3) Simulate observations in V through K, using realistic PSFs
       4) Check simulations by comparison with what has been done now with AO systems (e.g., Naco)
       5) Investigate IR spectroscopic indicators (or, do we need the visible)
    c) Integrated light spectroscopy of distant galaxies: how does a galaxy look like when observed with GLAO, and how to optimize spectroscopy ?
    d) Mid-ir simulations for cosmology cases
    e) Better point-source sensitivities for distant SuperNovae using realistic PSFs
    f) Estimates of Mid-IR sensitivity 3-20 micron. This must depend strongly on site and telescope design. Some estimates would be useful.
6) A more detailed comparison of the effectiveness of JWST and ELT in the regime from 0.6 to 2.4 micron. Current estimates indicate that they are comparable for R=100 spectroscopy for extended sources (faint distant galaxies). Detailed comparisons are needed for R=1000, R=3000 spectroscopy; for distant galaxy imaging; and for point-source work.

7. Terms of Reference

ESO ELT
Basic Reference Design
1st Phase (Jan.-April 2006)
ESO/Community Working Groups
Terms of Reference

In order to pursue ESO's highest strategic goal of international leadership in the era of ELTs (Council resolution of December 2004) and in response to the OWL Concept Design Review, ESO will form 5 Working Groups consisting of experts drawn from the ESO staff and the community. The Working Groups are:

WG-1 Science
WG-2 Instruments
WG-3 Site Evaluation
WG-4 Telescope Design
WG-5 Adaptive Optics

The **general** terms of reference of all Working Groups will be:

- To synthesize and collate ELT capabilities in the specified topic area, noting existing community studies and ongoing efforts
- To propose a basis for prioritising capabilities in the specified topic area, a list of key tradeoffs and an initial prioritisation of an ESO ELT capabilities
- To conduct an initial meeting in January 2006 and a concluding meeting in February 2006
- To submit a report of synthesized requirements to the ESO DG by 28 February 2006

The **specific** terms of reference of each Working Group will be:

WG-1 Science:

- To categorize science aims according to the related capabilities of an ELT and its instruments: field, pixel size, spectral resolution, multiplex capabilities and complementarity with other facilities

WG-2 Instruments:

- To categorize instruments according to ELT size, listing possible capabilities, complexity, demands on the Telescope and AO.

WG-3 Site Evaluation:

- To categorize site characteristics, corresponding relevance for type of observation, stability and measurement method. List all sites being considered throughout the World (including Antarctica), presently available information, advantages and disadvantages, including access costs

WG-4 Telescope Design:

- To categorize the type of designs in the 30m to 60m range, listing advantages and disadvantages, capabilities offered by each (field, pixel size, integrated AO, ...), technical risks and cost drivers

WG-5 Adaptive Optics:

- To categorize AO systems and Laser Guide Stars System to be used on an ELT, according to size, capabilities, corresponding requirements (e.g. components, computing facilities), level of development and risk as well as cost drivers

8. Meeting agendas

17 January 2006, ESO Garching

9:00 Introduction: Catherine Cesarsky
(together with Instrumentation WG)
9:30 Technical boundary conditions: Guy Monnet
(together with Instrumentation WG)
10:00 Discussion of goals of the SWG and relevant parameters in the science cases
10:30 Coffee
11:00 Discussion of available science cases
12:30 Buffet Lunch
13:30 Distribution of work
15:00 Coffee
15:30 Discussion of the structure of the document to be prepared
16:00 Date of next meeting, AoB
16:30 End of meeting

17 February 2006, ESO Garching

9:00 Meeting room will be open with prints of science cases
10:30 Start of meeting
Opening
10:45 Discussion on general issues which came up during the preparation of science cases
11:00 Group discussions on individual science cases
12:30 Lunch
13:30 Full group discussion on individual science cases
14:30 Missing science cases/science cases sent in from the outside
15:00 Break
15:30 Determination of structure of document
16:00 Working plan for the coming 2 weeks.
17:00 Closing

23 March 2006, ESO Garching

9:00 Opening
9:10 Discussion of science cases and capabilities in the sub-panels
10:10 Break
10:30 Plenary group presentation of the most important science cases each case will be presented, 6 presentations total, followed by discussion
11:30 Plenary group presentation of the capabilities
12:30 Lunch
13:30 Report from the ESE meeting on Tuesday
14:30 Discussion on instruments/capabilities missing or otherwise relevant based on the documents from the other working groups
16:00 Setting future work.
17:00 Closing