Cosmology with a 100m telescope

Contents

1 Introduction

Cosmology is going through a golden age with expanding observing capabilities. Astrophysics in general, and cosmology in particular, has reached the particle physics goal, and is observationally beyond teh Standard Model. Many of the resulting new fundamental questions are being addressed with the current and planned facilities. The formation of structure (galaxies, galaxy clusters and filaments) is emerging from the cosmic background. At the same time, the cosmological parameters seem to indicate that we may have reached a consistent view of the universe.

Yet, there are still considerable gaps in our understanding of the 'big picture', e.g. the conversion of gas into stars and galaxies, the nature and distribution of 'dark matter', the nature of the 'dark energy', the agglomeration of the largest structures, or the detection of the first luminous objects in the universe after re-ionization.

Every new observational facility will try to address these questions. One should, however, be open to surprises. Dark energy is a notion which appeared only a few years ago and added a new component, the biggest in terms of energy density, to the universe.

There are some special considerations for extremely large telescopes which have to be taken into account when discussing science cases. One is that galaxies are extended objects at all cosmological distances. The typical half-light radius of Ly-break galaxies at $z \sim 3$ are about 0.2 to 0.3 arcseconds (Giavalisco et al. 1996). This means that for studies of their integrated light, it would be best to match the spatial resolution to this angular size. In many of the theoretical models the present-day galaxies are assembled from smaller parts and it will a goal to identify these objects.

At the same time at 100m telescope gathers many photons from the sky background. The table below gives the expected count rates (per second) for a (0.1 arcsec)^2 pixel scale in wide-band filters.

	sky		photons/s/pix	
	dark	bright	dark	bright
B	22.8	22.6	260	310
V	21.9	21.7	360	440
R	21.0	20.8	1660	2000
J	16.7	15.7	23000	58000
H	14.8	13.8	78000	197000
K	12.5	11.5	344000	865000

It is clear from this table that especially in the near-infrared broad-band work is not possible at such a spatial resolution. Going to higher resolution will reduced the background, but also will start to resolve the galaxies. It will need detailed simulations to assess the optimal settings. The impact on spectroscopy will have to be evaluated with more careful calculations using different resolving powers and realistic sky spectra.

Cosmological point sources (angular size <1 mas) are quasars, GRBs, supernovae, and HII regions at larger redshifts (cf. Figure 1). A regular HII region of about 50 pc subtends about 0.005 arcseconds at $z > 1$. The diffraction limit for a 30m in J is 0.01 arcseconds which probes to about 90pc at redshifts $z > 1$. Typical HII region sizes in the Galaxy are more like 50pc and a higher spatial resolution is required. A 100m telescope could just barely start to resolve such HII regions.

The Hβ luminosity of Orion is 3×10^{36} erg s^{-1}. We calculate the observable flux as a function of redshift below.

It has to be assessed what the limit for the 100m telescope for these emission line fluxes is.

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2 How did present-day galaxies form?

2.1 Tomography of Gas as a Function of Redshift

Stars form out of gas. The process whereby this gas is compressed out of an initially nearly uniform Inter-Galactic Medium (IGM) by gravitational instabilities and converted to stars, and also the possible effects of feedback from the gas expelled from stars in their

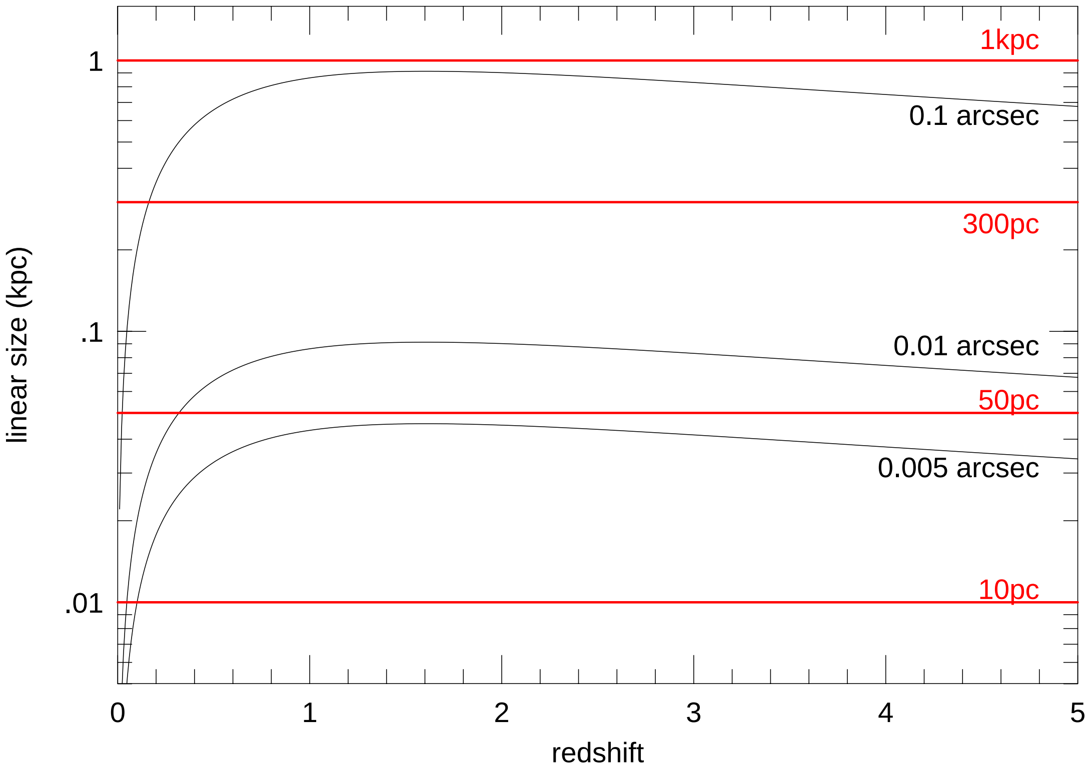

Figure 1: Linear size as a function of redshift. The underlying cosmology for this figure is $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3, \Omega_\Lambda = 0.7$. Typical linear sizes of a starburst region (1kpc), a giant HII region (300pc), a small HII region (50pc) and a globular cluster (10pc) are indicated.

later evolutionary stages, is currently the realm of theorists alone. With an ELT it will be possible to obtain high spectral resolution absorption line data for sufficiently faint QSOs (and possibly high z galaxies) to allow us to fully map out the 3D structure of the gas in a number of sightlines and to directly relate this to the galaxy distribution.

Since the intergalactic gas is known to be ionized by z 5, the epoch of reionization, the result of "first light" in the universe must occur at $z > 6$. OWL gives access to direct observations of the sources of reionization out to z 19, where the Lyman alpha line moves out of the K-band. How bright are the first galaxies expected to be? A simple model based on the collapse of peaks in the density spectrum (assumed to contain a baryon fraction of 8% which would be turned into stars in 30% of the age of the universe at that time) has been proposed by Miralda-Escude and Rees (1998) and shows that AB magnitudes around 30 band are to be expected, for rest-frame UV (1250 A) emission redshifted into J-K bands (corresponding to z 8 to 14 for the reionization epoch). Such magnitudes are within reach for a diffraction-limited 100m OWL under the reasonable assumption that the first sources of ionization are pointlike. Hence a 100m OWL can find these very distant galaxies by the now well-developed drop-out technique, searching for J and H-band dropouts.

redshift	log F(erg s^{-1} cm^{-2})
0.1	-17.87
0.2	-18.52
0.3	-18.92
0.4	-19.22
0.5	-19.45
0.75	-19.87
1.0	-20.18
1.5	-20.62
2.0	-20.92
2.5	-21.16
3.0	-21.35
4.0	-21.65
5.0	-21.88

Having identified these high-z galaxies, can OWL then demonstrate that these are the objects that reionize the universe, i.e., are the first generation of galaxies? This requires spectroscopy. The reionizing objects will create cosmic HII regions with (being dust-free) a prominent Lyman-alpha line. Equivalent widths of 100-200 Å(rest-frame) are expected under dust-free conditions, and this will be detectable spectroscopically for any z 8-19 galaxy found by the dropout technique. A characteristic feature of the Lyman alpha profile will be a promounced asymmetry caused by Lyman alpha absorption on the blue side of the line. Detecting this asymmetry requires spectrally resolving the line, which will be a challenge even for a 100m OWL.

A further characteristic of the first generation of stars will be that they are metal-free, hence not subject to UV-blanketing, and therefore very hot. In addition, models suggest that they may have higher masses than present-day stars. Regardless of the latter point, the lack of metals gives rise to a strong helium-ionizing continuum and therefore the resulting HII regions will produce very bright HeII 1640A emission. Thus, the first stellar populations can be found by looking for Ly-alpha and HeII 1640Åemission in parallel. This can be done at redshifts out to 14 where the HeII line is in K-band while the Ly-alpha line is in H-band. The expected flux of HeII at the highest of these redshifts would be 0.2-1.0e-19 erg/s/cm2 for a metal-free star formation rate of 1 Mo/yr (Tumlinson et al. 2001).

What if the galaxies giving rise to reionization are fainter than expected? For reionization at z 8 (1250A rest-frame observed in J-band) this is not a problem, but it will become a problem at higher redshifts (z 10-14) where the rest-frame UV shifts to H and K-bands, where the limiting magnitudes are not as deep as in J-band, and the source of reionization would be fainter. However, in this case it will still be possible to detect the Lyman-alpha emission of the ionizing sources, even without detecting the underlying UV-continuum. This would require emission line surveys, using a massive integral field spectrograph, or, preferably, a set of narrow-band (or tunable) filters. Follow-up spectroscopy would still have to be performed in the same way.

Figure 2 shows the prediction from a Smooth Particle Hydrodynamic simulation of an 11h^{-1} Mpc volume at a range of redshifts from 3 to the present day. (For a LCDM cosmology, this corresponds to angular scales of $\approx$30 arcmin on a side for $z > 1$). The simulation does not have the resolution or physics to precisely identify where galaxies will form, but it is likely that these will be found at the locations of the white dots, where the hydrogen column density is higher than 10^{16} cm^{-2}. The simulation predicts that lower column density gas will be found in filaments and sheets surrounding the galaxies, and that this gas will rain down into the galaxies as time goes on.

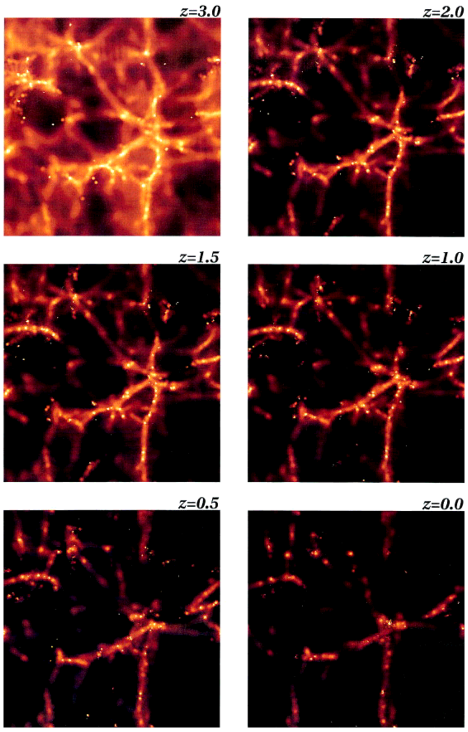

Figure 2: Davé et al. 1999, 11h^{-1} Mpc on a side. Column density of neutral hydrogen through a 200 km s^{-1} slice of the LCDM simulation volume at z=3,2, 1.5, 1, 0.5, and 0 (from top left to bottom right panels). Red corresponds to $N_H = 10^{13}$–10^{14} cm^{-2}, orange to $N_H = 10^{14}$–10^{15} cm^{-2}, yellow to $N_H = 10^{15}$–10^{16} cm^{-2}, and white to $N_H > 10^{16}$ cm^{-2}.

This experiment is also a way of directly relating the location of galaxies relative to the Dark Matter, in that for the linear regime, the Lyα optical depth is expected to be proportional to the Dark Matter overdensity ($\Delta\rho/\rho$).[1] Thus correlating the low column density gas distribution and that of galaxies allows one to directly measure the evolution of biasing.

There are two complementary approaches to parameterising the Lyα absorption –

[1] $\Delta\rho/\rho \sim \Delta\rho_H/\rho_H \sim 20(N_H/10^{14}\ \mathrm{cm}^{-2})^{0.7}10^{-0.4z}$.

either by considering the absorbers to be discrete entities and fitting Voigt profiles, or alternatively by looking at the optical depth distribution directly.

2.1.1 Some Numbers

A typical b-value for Voigt profile fits to Lyα absorbers is 20–30 km/s, corresponding to a FWHM of 50-100 km/s. A spectral resolution matched to this will be sufficient to detect absorbers down to reasonable column densities ($\sim 10^{14}$ cm^{-2}). This corresponds to $5000 < R < 10000$. One would need a S/N of 10-20 per spectral resolution element. The Table below gives the limiting magnitude in V for which this S/N can be achieved in 8 hours for three different telescope diameters, and assuming diffraction limited performance. In fact, the image quality requirements could probably be relaxed as these objects are not extremely far below the sky. A spectral aperture of 0.1×0.1 arcsec)^2 gives a typical V band sky contribution magnitude of 26.5.

Using the ESO S/N calculator, with a relative efficiency of 0.5 (giving a total throughput of 30%), a central wavelength of 585 nm, a spectral dispersion of 0.12 nm/resolution element, a 50 mas wide slit, and an 8 hour exposure, one can calculate that one will obtain a S/N of ~ 20 for the limiting magnitudes given below:

Telescope Diameter (m)	30	70	100
Central Obscuration (m)	10.3	24	34.3
V Magnitude	25	27	28

Number densities of QSOs at these faint magnitudes are currently unknown. A rough estimate is that about 1 to 3% of all galaxies down to $I \leq 27$ may contain an AGN (Sarajedini et al. 2000). An independent study estimates that there are about 16000 AGN ($V < 27$ and $z < 3.5$) per square degree (Conti et al. 1999).

This then would place 450 behind a field of 10 by 10 (arcmin)^2.

An alternative source of background sources would be high redshift galaxies. This introduces the complications of (a) summing over the extended light of the galaxy, and (b) a more complex intrinsic continuum shape, with the reward being a substantially higher surface density of probes. If such probes are usable, then it is likely that this project can be done by a 30m class telescope. Yet further alternatives might be the use of high-z SNe or $\gamma-$ray bursters. **need to calculate the SN rate at these magnitudes**

One clear requirement for this project is a fairly wide FOV multi-object spectrograph (presumably fiber fed). One would like to survey fields of around 10-30 arcminutes to sample the full range of cosmic environments shown in Figure 2. The multiplex gain from observing 100-200 probes at once would obviously also make a huge difference. Thanks to the fairly relaxed image quality requirements, it is probable that only low level seeing correction is needed.

A case could be made for going to considerably higher spectral resolution for this survey on objects that are sufficiently bright. Higher spectral resolution would allow one to reduce the effects of blending, measure b-values (or thermal widths) of the absorbers, search for deviations from pure Voigt profiles in the absorbers (and hence for bulk motions), and also allow detection of weak, narrow, metal line systems.

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2.2 The structure and evolution of high-redshift galaxies

OWL will provide a unique opportunity to study the early evolution of galaxies through the era of their formation, starting around redshift 5, through redshift 1 where the structures we see today were probably pretty much in place. We first note the typical sizes of galactic structures at these redshifts, which are almost independent of redshift beyond $z \approx 1$ (Figure 1).

2.2.1 Chemical abundances

It should be possible to gain considerable information on the chemical composition of galaxies at an early stage in their life providing valuable insights into star formation rates, gas flows and dust content.

We know that Hα and Hβ can be well observed by current large telescopes in the near-infrared in exceptional cases. Line shapes and strengths of several galaxies at $z \approx 2.2$ have been determined with the VLT (Moorwood et al. 2000) while star forming galaxies at a redshift of $z = 3.09$ have been observed even with UKIRT (Pettini et al. 1998). The typical Hβ luminosities of $\sim 7 \times 10^{42}$ erg s^{-1} (line flux 4 to 8×10^{-17} erg s^{-1} cm^{-2}) correspond to a star formation rate of some tens to hundreds M$_\odot$ per year via Kennicutt's (1998) formula L(Hβ)$\approx 4 \times 10^{40}$ SFR(M$_\odot$ yr^{-1}) erg s^{-1}. These rates probably represent starbursts, and the expected flux from a normal bright giant HII region of the kind seen and analysed in the spiral galaxies nearby to our own would be a factor 100 to 200 lower at 2×10^{40} erg s^{-1} (or even less).

The aperture gain of OWL implies that we could therefore analyse fairly normal HII regions (e.g. Orion with L(Hβ)= 3×10^{36} erg s^{-1}, size $<$ 50 pc; Shields 1990), determine absolute abundances and investigate abundance gradients in forming galaxies at $z \approx 3$. The diagnostics used would be the strong line indicator R23, which relies on [OII] 3727, [OIII] 5007, Hβ and Hα (or Hγ, if Hα is not available). Figure 3 shows at what redshifts all these lines are simultaneously accessible – basically at around $z = 1.4$, $z = 2.4$, and (without good de-reddening from the hydrogen lines) $z = 3.2$. Another excellent diagnostic is the ratio [NII]/Hα – provided care is taken in avoiding the effects of the harsh radiation field of galactic nuclei, but these become inaccessible above a redshift of about 2.3. Spatially resolved snapshots of the normal chemical abundances of galaxies at these nicely spaced redshifts would be an invaluable probe of their chemical evolution. A resolution of 0.01 arcseconds would just be beginning to resolve the larger regions (giving maximum signal-to-noise), and clearly show the spatial distribution of the HII regions and their elements across the galaxies.

The abundances of starburst regions at $z \approx 3$ could also be studied in detail, the sensitivity gain of OWL allowing the use of more reliable abundance indicating lines such as [OIII] 4363 at 1/20 – 1/100 the strength of Hβ. Edmunds and Henry (2001) believe that

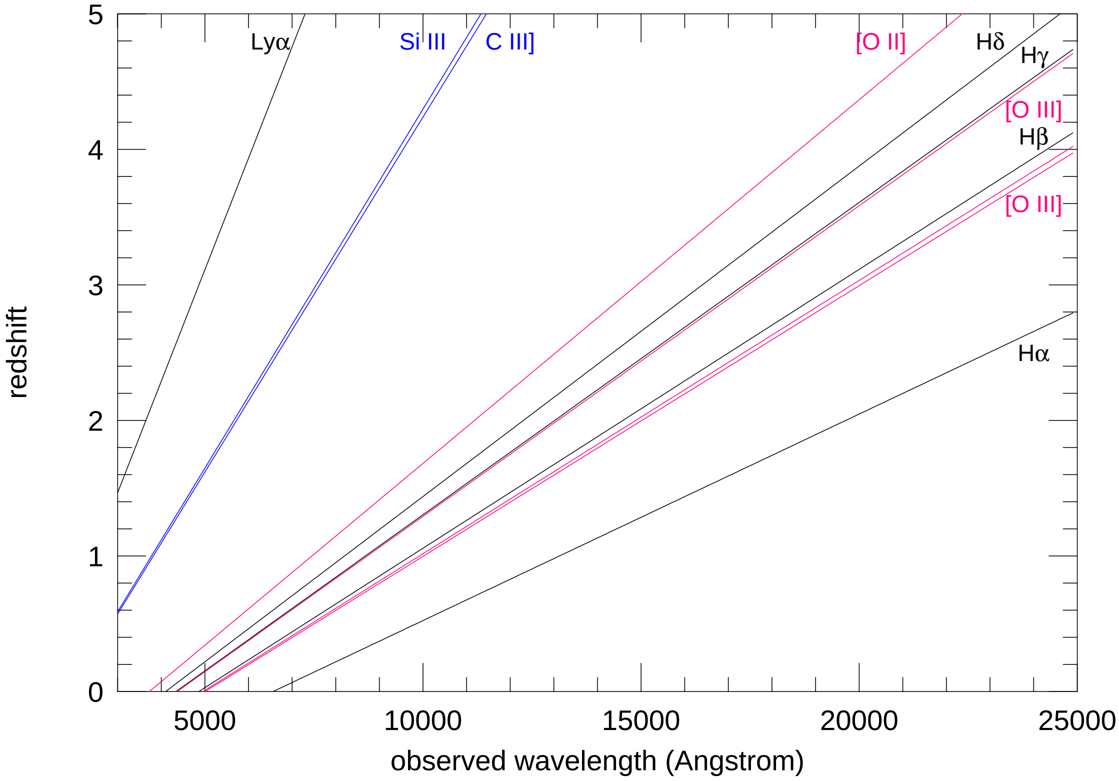

Figure 3: Observability of major emission lines

there may be suitable line ratios in the rest ultraviolet that can also be used for abundance determinations. At $z \approx 2-3$ these appear in the optical, but at only around 1/20 – 1/100 of the strength of Hβ (or perhaps a little less with some dust extinction). The aperture gain, plus the greater detection efficiency in the optical, will allow their observations. Spectral resolution of greater than 1000 is required. With OWL (and preparatory work with 10m and 30m telescopes) these lines can be checked and calibrated in $z \approx 3$ starburst galaxies with the R23 abundances, and the ultraviolet line diagnostics then used to probe the chemical abundances of starburst galaxies in the redshift range 3 to 5, where the classical optical line indicators are no longer observable. This is a fascinating prospect, since we may expect to be observing all kinds of galaxies in early formation – including possibly ellipticals – either as monolithic collapses or mergers. The line ratios may also allow estimates of dust abundances – again a crucial quantity in early galaxy studies, given the recent SCUBA results indicating the existence of early dust-enshrouded objects. Spatial resolution for starbursts can be relaxed for abundance studies to 0.1 arcseconds.

2.2.2 Kinematics and nuclei

According to the current models of galaxy formation, typical progenitors of the Milky Way become progessively smaller as the redshift increases. In order to resolve their internal kinematics one needs progressively higher spatial resolving power. A practical limit for OWL will be z=5.5. This limit is dictated by the need of observing [OII] 3727 in the K band. The brightest progenitor of the Milky Way within z=5.5 requires R=10,000 in order to be studied.

The kinematics of early systems should be accessible through the range $z \approx 1$ to 4 by use of either [OII] 3727 or Hβ in J, H or K, and by CIII] 1909 in the optical. NV 1240 may be useful for $z \approx 2 - 5$. Spatial resolutions of order 0.01 arcsec would seem a reasonable compromise, although in brighter systems there may well be information to be gained on smaller spatial scales (down to 0.001 arcsec), especially near galactic nuclei. A velocity resolution of 30 km s^{-1} implies a spectral resolution of 10000.

For general spectroscopy of galactic nuclei, it may be noticed that in nearby galaxies the (active) nucleus can be comparable to, or brighter than, large HII regions. The implication is that OWL will be able to study nuclei in detail at $z \approx 3$. Again the "snapshot" set of $z = 1.3$, 2.4, 3.2 plus some less detailed information in the range $z = 3.5$–5 should give a real handle on the early evolution of galactic nuclei. Spatial resolution of 0.01 arcsec may be adequate for many of these studies, although 0.001 arcsec may well be advantageous for the faintest nuclei (both faint intrinsically and at higher redshifts).

An ELT would be very effective in identifying faint nuclei embedded in spiral galaxies. Consider an L$_\star$ spiral galaxy with a scale radius of 3 kpc. Assuming that we want to detect an AB=30 source and that the detection requires the galaxy contribution in the central pixel to be two magnitudes fainter, we find that such a nuclear sources would be detectable in galaxies with apparent magnitudes as follows:

redshift	m$_{AB}$
1	19.68
2	20.63
3	21.06
4	21.32
5	21.49
6	21.62
7	21.71
8	21.79
9	21.85
10	21.9

Consider now the case of an elliptical galaxy nucleus. Many Extremely Red Objects have been detected that resemble 1 Gyr ellipticals at high-z and they would be the focus of this study. The brightest surface brightness level detected with HST is $m = 12V$ mag arcsec^{-2} for a Virgo galaxy. Assuming that a galaxy brightens up by 2.5 magnitudes corresponding to the bolometric brightening of a population 18 Gyr old when its age is reduced to 1 Gyr, we obtain about M$_{AB} = -21.5$ mag in the innermost 10 pc. Considering that the typical size of an ELT pixel is 20 pc, this implies between m$_{AB} = 20.5$ to m$_{AB} = 24.5$ for the innermost pixel. Clearly at this level of brightness any separate, very faint nucleus would not be easily detectable. Thus the detection of nuclei in spirals will depend critically on the precise cusp slopes shown by these objects.

2.2.3 Star clusters

Further more detailed simulations are needed to quantify how well OWL could study forming globular clusters, since the ability to do any spectroscopy in the visible will depend critically on the restframe ultraviolet flux. Extant simulations suggest that it is worth looking at the problem for z=3 galaxies. Here the highest spatial resolution (0.001 arcsec) may be critical. The extent of star cluster formation in any kind of galaxy (or merger of galaxies), and its evolution with redshift is of great interest. The forming clusters may generate their own HII regions for times of order 10^6 years, and hence be accessible to emission line analysis up to $z \approx 3$ for star formation rates of order 1 $M_\odot$ yr^{-1}, and perhaps higher redshift if the burst is more violent.

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2.3 QSO Host Galaxies

Recent evidence linking the mass of the huge black holes seen in the cores of nearby galaxies to their bulge masses (Gebhart et al. 2000) implies a tight (possibly causal) relationship between the formation of the stars and the black hole. This then in turn leads to the question of whether all massive galaxies go through a QSO phase in their early lifetime (during which the massive black hole is formed), and if they do, what effects on the galaxy will the QSO have?

In order to answer this question, one would like to image the host galaxies of QSOs over the entire redshift range over which we think massive galaxies are forming (i.e. $z > 1$ through to z of at least 5).

Imaging and spectroscopy at low redshift ($z < 0.6$) (Marquez et al. 2001, Nolan et al. 2001, Figure 4) suggest that in the present day universe QSOs find themselves in a wide range of galaxy types, although with a tendency for higher luminosity radio loud QSOs to be found in giant elliptical galaxies. The situation at high redshift, ($2 < z < 5$, where the peak in the QSO space density occurs) is unknown. Ridgway et al. (2001) and Hutchings et al. (2001) start to probe the properties of this population, but run into severe S/N problems.

This science topic has clear synergies with proposals aiming at understanding the reionisation of the universe (i.e. do QSOs or stars make a dominant contribution).

There are several levels of detail one might want to achieve. Broad band colours would allow one to make crude statements about the stellar populations as a function of position within the host galaxy. Low dispersion spectroscopy would allow one to estimate the ionization conditions as a function of location and hence the relative contributions from non-thermal ionizing radiation and locally produced starlight, while high dispersion spectroscopy would allow one to study the stellar and gas dynamics in the host galaxy.

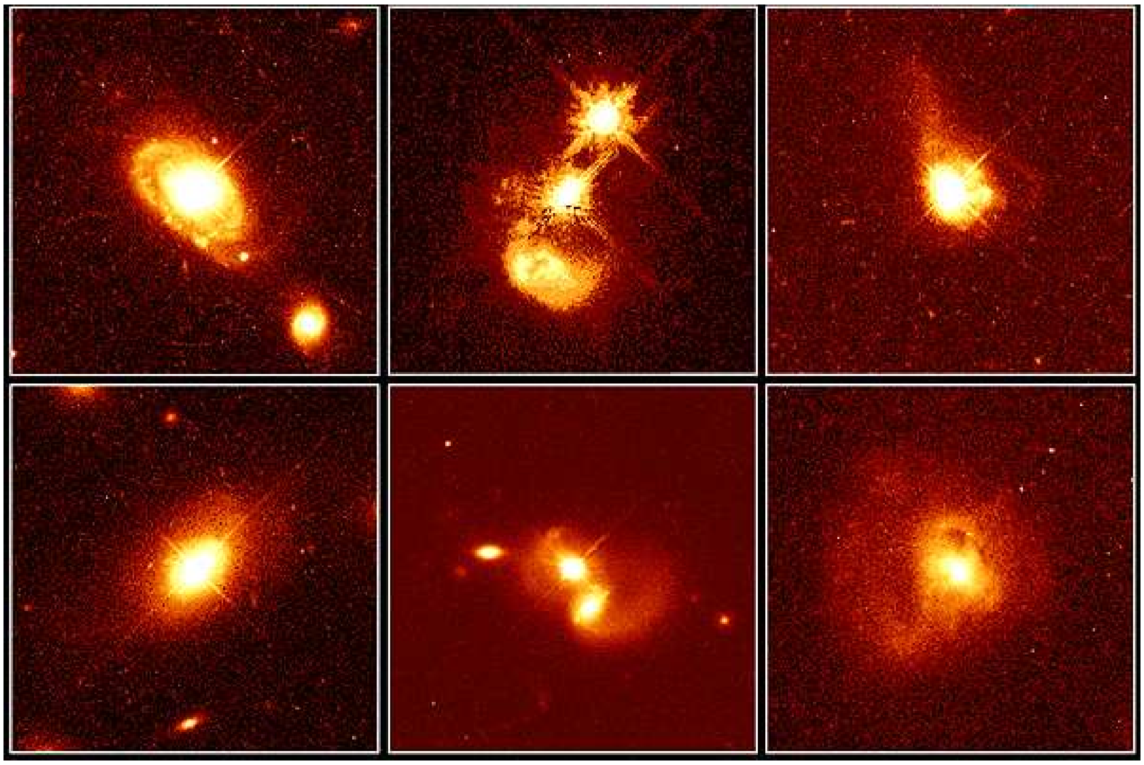

Figure 4: Some examples of low redshift QSO host galaxies from HST. Note the complex morphologies and frequent evidence for merging.

2.3.1 Some Numbers

There are two major challenges in observing QSO host galaxies. The first is the problem of scattered light from the QSO itself, which will dominate the emission from stars and gas for the more luminous (and hence more interesting) QSOs. If one obtains high resolution imaging (some combination of AO and coronography) to suppress this contamination, then one has the problem of detecting (and ideally obtaining spectra for) fairly low surface brightness features such as those shown in Figure 4 (cf. Bahcall et al. 1997). The challenges and potential pitfalls here are exemplified by the early claims from HST imaging for a large number of QSOs with no host galaxies that were later withdrawn when smoothing and/or binning revealed the galaxies in the images.

A large aperture telescope such as OWL will gain in two ways: first by having a much smaller diffraction limited PSF, and reducing the size of the region contaminated by the QSO light, and secondly by having the massive collecting area needed to allow one to do spectroscopy on the 0.1 – 1 kpc scale that one would like to sample.

Not done: need a simulation to estimate optimal spatial binning to use, and gains from AO. Without calculation suspect one will want high Strehl AO to shrink the QSO core, but then only spatially sample the resulting image at the 0.1 or 1 kpc level (i.e. 0.01 or

0.1 arcsecond level) to get high enough S/N for spectroscopy.

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3 Emergence of Large-Scale Structure

3.1 Identifications and characterization of the Sunyaev-Zeldovich detections

The number of clusters of galaxies is strongly model dependent. In the current favoured ΛCDM model (Pryke et al. 2001, Stompor et al. 2001) the expected number is ~ 25 cluster per square degree (Holder et al. 2000), with ~ 20 % of them expected at $z \geq 1$. Beyond $z \geq 0.6$ only about a hundred clusters have been directly observed mostly in the Palomar cluster survey (Postman et al. 1996), and in the EIS survey (Lobo et al. 2000); this agrees well with the number of clusters expected in the ΛCDM model.

Several surveys to detect high redshift clusters in the optical and in the near IR are in progress with telescopes $\sim 2-4$ m (see http://www.noao.edu/noao/noaodeep); these surveys will likely provide hundreds of clusters at $z \geq 0.5$ to be investigated spectroscopically with 10m and larger telescopes.

An alternative method to detect clusters is through the distortion produced in the spectrum of the Cosmic Microwave background (CMB) by the interactions between the CMB photons and the hot electrons in the intracluster medium (the Sunyaev-Zeldovich effect). Up to now only a few cases have been observed; several ground based programmes are in progress with the aim to observe the SZ effect in several tens of clusters. The detection of the SZ effect is also one of the major goals of the Planck mission (see http://astro.estec.esa.nl/SA-general/Projects/Planck). From the simulations by da Silva et al. 2000, it is expected that Planck will detected ~ 1 cluster per square degree in the case of a ΛCDM model, and ~ 0.6 for a pure matter flat model.

The more sensible channels for the detection of the SZ in the Planck mission are those at frequencies around 300-400 GHz; for these channels the expected angular resolution is ~ 5 arcminutes, which is of the order of, or larger than the expected field of view of an ELT. Therefore, a sensible strategy to characterize such clusters would be to take broad-band images with a 10 m telescope covering a field of ~ 200 arcminutes. With these we will identify the position of the cluster and the brightest galaxies within it. Then the galaxies will be observed with the ELT in deep broad- and narrow-band images, and with spectroscopy mainly in the K band. A point that should be noted is that the typical size of the core of a cluster at $z \sim 1$ is about 5x5 square arcminutes, and then it will not be possible to cover it in the diffraction limit with a single observation.

An estimation of the luminosity function (LF) in clusters of galaxies at $z \sim 1$ have been made by de Propris et al. (1999). They found that at $z \geq 0.4$ the LF is compatible with a simple, passive luminosity evolution in which galaxies form all their stars in a burst at $z \geq 2$. They found $K^* \sim 18.5$ at $z = 1$. Using these results we can estimate that an

ELT will be able to take spectroscopy with a resolution of a few Å of the galaxies in a cluster at $z \sim 1$ further than the dwarf regime ($K = K^* + 5$). Although it is necessary to extend the models at $z \geq 1$ it is likely that an ELT will be able to make spectroscopy of the dwarf galaxies in clusters at $z \sim 2$. Comparing these, with the predictions of the stellar populations synthesis model it will be possible to determine the age, metallicity and the evolution of the galaxies in the cluster even in the dwarf regime.

Additionally with an ELT at the diffraction limit resolution it will be possible to perform imaging of all such objects characterizing the morphology of thousands of galaxies per cluster. Considering that the typical effective radius is ~ 1 Kpc for an elliptical galaxy, it will be possible to determine in detail the structural parameters working with resolution of 1 mas in the H or in the K bands. This will allow the study of the morphological segregation and the evolution with z. Interesting phenomena like the study of the nucleation of the dwarf galaxies, the process of formation by aggregation of globular clusters, the role of the tidal forces, the formation of the ellipticals in clusters and in the field will be studied in detail. For instance considering that the luminosity of globular clusters is in the range $-10 \leq M_v \leq -4$ in deep imaging, an ELT will be able to detect the bright part of the LF of globular clusters at redshifts 1-2.

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3.2 Proto-clusters

3.2.1 Finding them

Of the many possible methods, we consider two:

- **Ultra-steep radio galaxies** USRGs are almost always associated with high-redshift galaxies. In addition, those where the radio source shows very high rotation measures appear to be invariably associated with large halos of gas and/or clusters of galaxies. The Leiden group (Miley et al.) have extensively studied candidate proto-clusters at $z = 2.16$ with HST, ROSAT, Chandra and the VLT. FORS spectroscopy shows that many of the objects have strong and narrow Lyα emission reminiscent of star formation. The HST images show that the central part of the concentration contains several bright knots (galaxies) of about 1 arcsecond diameter. ROSAT shows that the object is an X-ray source (in pointed observations) and Chandra shows that the 0.2 to 10 KeV emission comes predominately from the star forming knot, and about 10% from the intergalactic medium. Analysis of the data indicated the most plausible origin for the diffuse X-rays is a hot intracluster medium, consistent with the high rotation measure of the radio emission. the total luminosity of the source is comparable with that of a rich (10^{15} M$_\odot$) cluster of galaxies.

  The object also shows an extended (160 kpc) luminous Lyα halo. There is a very strong mm-continuum source in the field which is associated with a very dusty source forming stars at about 200 $M_\odot$ per year, characteristic of extreme starbursts, such as found in mergers.

So it is plausible that this object is indeed a proto-cluster of galaxies. It is clearly forming galaxies and it contains several luminous objects that appear to be massive galaxies. This technique can be extended to higher redshift, mapping the very first clusters.

- **Clustering of Lyman-break galaxies** This approach has been pioneered by Steidel and collaborators. It consists simply in plotting the redshift distribution of LBGs and examining the peaks. They have published one peak at $z = 3.09$ that contains about 15 galaxies within a volume comparable to that of a rich cluster of galaxies. Subsequent observations show about 24 objects with emission. A comparison with the predictions of CDM indicates that these LBGs form in very high mass peaks in the dark matter distribution with masses of about 10^{15} $M_\odot$, and that the galaxies themselves are also massive. A preliminary analysis of the data suggests that such large structures are common at $z \sim 3$.

  The cluster at $z = 3.09$ contains at least one strong SCUBA source with a high inferred SFR.

3.2.2 OWL observations

From the above considerations it does not pay either to search for these objects or to get their redshifts with OWL (in other words to identify them as clusters). Of course, wide-field surveys for high-redshift objects using either the filter drop-out technique or the slitless grism technique is bound to be interesting, but such surveys are not essential for the OWL science case, as we may be confident with extant facilities that catalogs of proto-clusters will exist. Wide-field surveys such as mentioned with 10m class telescopes should be sufficient to produce well-populated catalogs.

At high redshifts these objects have total sizes of 10 to 30 arcseconds, ideal for MCAO observations with OWL. The aim of these observations would be to investigate the morphologies of the luminous (massive) galaxies in these clusters and to study the evolution of structure.

In order to quantify these observations we have assumed that at least some of these objects are bona-fide elliptical galaxies already at that redshift. This is almost certainly a worse case scenario for the estimation of exposure times, because the observations already show that the proto-cluster galaxies are blue and bright. This is probably also a consistent requirement for the spatial resolution because the core of at least some nearby ellipticals have sizes comparable to those of large globular clusters.

Therefore, if proto-cluster galaxies are clumpy or if they have already developed a relaxed light profile, the same resolution of 5pc (0.001 arcsec) is required to resolve their structure at any redshifts larger than $z = 0.5$.

Using the OWL exposure time calculator in the diffraction limited regime with standard parameters we estimate that we can reach a surace brightness of $\mu_V = 18$ mag/(arcsec)^2) in the K band ($z \sim 3$) in 7 hours and $\mu_V = 19$ mag/(arcsec)^2) in H ($z \sim 2$) in 5 hours integrations. For nearby ellipoticals this surface brightness is reached at radii of several 100 pc (up to 1 kpc). Therefore, using OWL in the diffraction limited mode, it should be possible to make very detailed studies of the morphology of individual high-redshift galaxies ($z \sim 3-4$) and hence study as a function of redshift the evolution of the morphology–density relation and the dynamical evolution of galaxies.

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4 Evolution of cosmological parameters

4.1 Determining the change of the equation of state parameter

The failure of the traditional FRW cosmology with minimal parametrisation, even when perturbed with arbitrarily large amounts of dark matter of arbitrary properties, makes cosmology one of the most intellectually and observationally subjects in basic science. Indeed, the existence of a "dark energy" seems generally accepted now. This is inferred from the faintness of type Ia supernovae around a redshift of 0.5, the flatness of global space-time and the low matter density of the universe (Turner & Tyson 1999, Bahcall et al. 1999). The combination of these three parameters also provides an age of the universe, which is consistent with the determinations of its oldest known components.

This picture of the universe does not, however, match very well with the expections of current particle physics theories. The vacuum energy predicted by these theories disagrees by many orders of magnitude with the measured values. An alternative explanation is provided by the introduction of a particle field releasing negative-pressure energy through its decay ("quintessence"; Caldwell et al. 1998). In this case, the vaccum is not a constant, but changes with time. This can be measured as a change of the equation of state parameter $\omega = p/\rho$, which describes the ratio of pressure to density. The current data can constrain this parameter with the assumption of a flat universe and no time dependence to $\omega < -1/3$ (Garnavich et al. 1998, Perlmutter et al. 1999b, Wang & Garnavich 2001). For a cosmological constant $\omega = -1$ at all times, whereas for a decaying particle field there would be a time dependence (e.g. Saini et al. 2000).

Since the changes are expected to be rather slow, e.g. the most distant supernova observed to date at z=1.7 implies that the universe at that time was still matter dominated (Riess et al. 2001), the luminosity distances have to be mapped carefully for all accessible redshifts. The redshift range from 0.8 to 3 is the most critical as the signal is expected to be strongest there (Figure5). However, there is currently no clear reason to single out a specific epoch for the transition and it is possible that it occured at even higher redshifts.

The required observations are photometry and spectroscopy of the supernovae. While the photometry can be done out to redshifts of about 1.2 with existing telescopes, it will need sizes in the range of 20 to 30 meters for higher redshifts. The observed wavelenghts preferably would shift along with the redshift to sample as closely as possible the B and V rest-frame filter bands. The table gives estimated peak magnitudes in the optimal filter bands for given redshifts. The underlying cosmology is a flat universe with $\Omega_\Lambda = 0.7$ and a

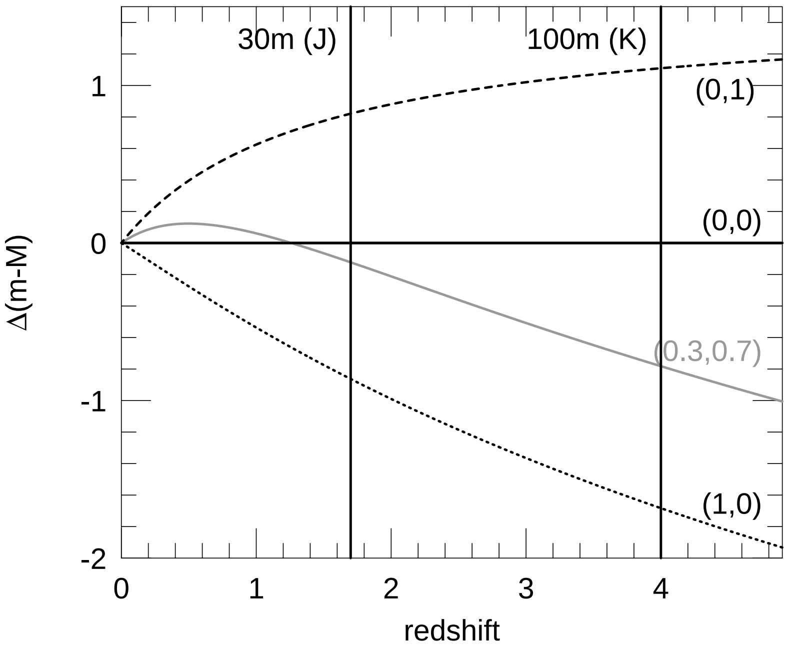

Figure 5: Relative distance modulus. The graph shows the expected luminosity distances for different cosmological parameters $(\Omega_M, \Omega_\Lambda)$. The spectroscopic limits for a 30m and a 100m telescope are shown.

Table 1:

observed passband	redshift (B band)	peak magnitude	K_{corr}
J	1.7	24.2	-2.2
H	2.8	24.8	-2.9
K	4	24.8	-3.8

normalisation of the supernovae as provided by the nearby sample (e.g. Riess et al. 1998, Perlmutter et al. 1999, Leibundgut 2001).

needs to be checked Already at a redshift of 1.7 a 30m telescope would be stretched to obtain spectra with a S/N of 5 (several hours of exposure). A 100m telescope could observe supernovae out to a redshift of 4.

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