Understanding Lyman-alpha emitters
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The regulation of the Lyman-alpha Emission Line in Star Forming Galaxies

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Lyman alpha emission line (Lyα) has become a very common tool to investigate the high redshift universe, contributing significantly in our understanding of the star fomation history and overall properties of distant galaxies. However, due to the resonant nature of this line, the interpretation of this observations are subject to large uncertainties. Since this category of objects cannot be resolved, one has to carry out detailed studies of local analogs.

I will present the results of our imaging compaign of six starburst galaxies. We found low Lyα escape fraction values which are always below 10%. The dust is not found to be always the main attenuation factor of the Lyα line. A high HI column density associated to an early evolutionary stage prevents the escape of Lyα radiation. Evidences of an inhomogeneous ISM are also observed. When dust resides in neutral clouds, the Lyα photons can escape through ionised holes easier than H-alpha or continuum radiation. These complex effects, which may be different for each individual galaxy, makes the calibration of high-z observations far from trivial.

VIRUS-P Survey for Lyman Alpha Emitters at $2 < z < 4$

Guillermo A. Blanc

University of Texas

We present the first results of a blind search for Lyman Alpha Emitters (LAE) in the $1.9 < z < 3.8$ range with the VIRUS-P integral field spectrograph on the 2.7m Harlan J. Smith telescope at McDonald Observatory. We obtained spatially resolved spectroscopy over an area of 114 square arcminutes. In this work we present the analysis of a subsample of the data covering 40 square arcminutes on the central region of the COSMOS field, where we have detected 45 LAEs and 10 ambiguously classified objects consistent with being LAEs to a flux limit of $\sim 6 \times 10^{-17}$ ergs/s/cm^2. The extremely large $1.8' \times 1.8'$ field of view of VIRUS-P together with its $3550 - 5850$ Angstroms wavelength coverage allows us to survey the Lyman Alpha line over a comoving volume of 21000 cubic Mpc in a single pointing. This corresponds to a 50 times larger volume per area on the sky than the one sampled by typical narrow-band surveys. The observed redshift distribution of LAEs is in rough agreement with our predictions for different models evolution of the Lyman Alpha luminosity function from $z \sim 4$ to $z \sim 2$. Although the current low number of objects and uncertainties in spectral classification do not allow us to discern significantly between different evolution models, this will be possible after the pilot survey is completed. VIRUS-P is the prototype instrument for VIRUS, a massively replicated integral-field spectrograph consistent in 150 units like VIRUS-P, which will be installed on the 9.2m Hobby-Eberly Telescope. With VIRUS we will be able to produce a sample of $\sim 1'000'000$ LAEs which will allow us to map the large scale structure of the universe at high redshift in order to set constraints in the evolution of the Dark Energy equation of state through baryonic acoustic oscillations (BAO) as part of the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). The pilot survey will continue for the next year in order to better constrain the properties of LAEs in preparation for HETDEX. We expect to produce a final sample of ~ 300 LAE over an area of ~ 270 square arcminutes.

The evolution of Lyα emitters between $z = 2$ and $z = 6.7$: a sample of ~ 110 sources from VVDS spectroscopy

Paolo Cassata

University of Massachusetts Amherst

Vimos VLT Deep Survey (VVDS) produced amazing results on galaxy evolution, collecting spectra for about 8000 galaxies with $m_i < 24$ (deep survey) and for about 1200 galaxies with $m_i < 24.75$ (ultradeep survey). These two datasets constitute an unique opportunity to search for Lyα emitters between $z = 2$ and $z = 6.7$. In particular, deep survey slits cover an effective area on the sky of 22.5 arcmin^2, the red grism gives a wavelength range between 5500 and 9200 Å, and the integration time of 16200 seconds allows to detect Lyα lines down to fluxes of about $\sim 5 \times 10^{-18}$ erg/cm^2/s. On the other hand, ultradeep slits cover 3.5 arcmin^2, the blue+red grisms produce a wavelength range between 3000 and 9200 Å, and the longer exposure time (65000 s.) allows to reach line fluxes of $\sim 2 \times 10^{-18}$ erg/cm^2/s. Finally, we assembled a sample of about 110 Lyα emitters with redshifts between $z = 2$ and $z = 6.7$, with a median redshift $< z >= 3.5$ and 5 candidates at $z > 6.3$. We will present the main properties of the sample (EW, line fluxes, SFR, line shapes, optical identifications), and we will discuss the first preliminar results on the evolution of the luminosity function of these Lyα galaxies.

The Star Formation and Dust Properties of $z = 3.1$ Lyman-alpha Emitters

Robin Ciardullo

Pennsylvania State University

We use a well-measured, statistically complete sample of $z \sim 3$ Lyman-alpha Emitters (LAEs) in the Extended Chandra Deep Field South to investigate the objects star-formation and extinction properties. By combining our narrow-band photometry with the deep broadband magnitudes from MUSYC, we probe the distribution of LAE star-formation rates and dust content. We show that $z \sim 3$ LAEs have low star formation rates (a few solar masses per year), high specific star formation rates ($\sim 10^{-8}$/yr), and a small, but non-negligible amount of dust. These properties indicate that while $z \sim 3$ LAEs are quite young, they are not truly primordial Population III objects.

What Powers the Lyman Alpha Blob?

James Colbert

Spitzer Science Center

The physical origins of Lyman alpha blobs (LABs) are still unknown, with the two most likely models shocks from supernova-driven winds and escaping AGN illumination, although cooling flows remain a third possibility. LABs are an extremely energetic class of objects (10^{44} ergs/s), so far found only in high-redshift, overdense regions. Their high observed interaction/merger rate suggests these luminous sources could be high-mass mergers, like those predicted to build giant ellipticals. We present Spitzer IRS Long Low and MIPS 24 micron imaging of all the Ultraluminous Infrared Galaxies (ULIRGs) associated with high-redshift LABs. We present detections of PAH features and estimate the relative contribution of AGN versus starburst. Half of all known LAB ULIRGs lie at $z = 3.09$, where the majority of strong PAH features would actually lie outside the 24 micron filter. For this half of the sample we present 850/24 micron ratio, which roughly measures the relative contribution of hot and cold dust emission, placing strong constraints on AGN energy contributions.

Discovery of a multiply-imaged Ly-alpha galaxy at the redshift of a SCUBA galaxy at $z = 2.56$

Helmut Dannerbauer

MPIA

We present a multi-wavelength analysis - focusing on exquisite rest-frame UV spectroscopy - of a newly discovered, highly lensed multiply-imaged source with strong Ly-alpha emission. This young, blue star-forming galaxy lies at the redshift of the massive submillimeter bright galaxy SMM J14011+0252, $z = 2.56$, in the field of the strong lensing cluster Abell 1835 ($z = 0.25$). This multiply-imaged source was discovered within a program aiming to search for a potential (proto)cluster structure at the redshift of this submillimeter galaxy, using narrow-band imaging at redshift $z \sim 2.56$.

Especially, we obtained deep UV-restframe spectroscopy of this strongly lensed source with the VLT and detected several prominent rest-frame UV-lines like strong Ly-alpha emission and CIII]. Carrying out deep VLT NIR narrow-band imaging we even obtained significant H-alpha flux. Deep HST-ACS images revealed that this source consists of two components. The exquisite multi-wavelength photometric data sets including deep VLT (e.g. V, J, H, K), WFPC2 (F702W), ACS (F850LP), IRAC (all channels) and MIPS (24micron), allows us to study the multi-wavelength properties by SED fits and the nature of this peculiar Ly-alpha galaxy in great detail.

The Polarization and Pressure of Scattered Lyα Radiation

Mark Dijkstra

CfA, Harvard University

Scattered Lyα radiation is highly polarized in a wide range of models that are intended to represent the environment of galaxies. The precise level of polarization, and its frequency dependence, encode more information on the properties of the medium through which the photons are scattering, than the spectrum alone. Spectral polarimetry may therefore be very useful in interpreting observations of Lyα emitting galaxies. It may also provide an independent way to distinguish high-z Lyα sources from lower-z interlopers. Furthermore, I will show that the pressure exerted by scattered Lyα radiation may exceed gravity by orders of magnitude, and drive outflows of HI gas in both the interstellar and the intergalactic medium.

Understanding the Stellar Populations in Lyman Alpha Galaxies

Steven Finkelstein

Arizona State University

While Lyman alpha emitting galaxies (LAEs) have been thought to be predominately young and primitive, recent work has shown that many LAEs exhibit signs of dust extinction, implying that they are more evolved than perhaps thought. The presence of dust gives rise to a scenario for enhancement of the Lyman alpha line, whereby the Lyman alpha to continuum ratio is enhanced due to the resonant scattering of Lyman alpha photons in an inhomogeneous interstellar medium. Our recent results show that this scenario is widespread in a sample of 15 LAEs, with two-thirds of the sample exhibiting signs of a clumpy ISM. This helps to explain the large number of high equivalent widths seen in many previous studies. We also notice that two of our LAEs appear to be much older objects, exhibiting strong Lyman alpha emission solely due to dust enhancement. Combining the results of Monte Carlo simulations for each object, we find that our LAEs are likely to fall in to two age bins: "young" ($1 - 10$ Myr) and "old" (> 400 Myr), implying that some physical mechanism may be responsible for the lack of "middle-age" LAEs. We will also present new results on the populations in very low redshift LAEs, finding that they are in general older, and more massive.

LAEs are Different from Other High-redshift Galaxies

Johan Fynbo

Dark Cosmology Centre

In these two talks (Fynbo & Gawiser) we discuss LAEs in comparison with other classes of high-z galaxies. We focus first on differences and then on similarities.

LAEs are Similar to Other High-redshift Galaxies

Eric Gawiser

Rutgers University

In these two talks (Fynbo & Gawiser) we discuss LAEs in comparison with other classes of high-z galaxies. We focus first on differences and then on similarities.

The X-ray properties of Lyman-alpha Blobs

Jim Geach

Durham University

Lyman-alpha Blobs (LABs) are highly extended (up to 100kpc) emission-line nebulae found at high-redshift ($z > 2$). In many cases these halos appear to be associated with extremely luminous galaxies, but the origin of the extended emission is still not clear – cooling of gas during the formation of galaxies and/or feedback from the host galaxies themselves may be contributing to their power. Unravelling the relative contribution from each power source is the key to understanding LABs formation mechanisms. I will present the results of a 400ks Chandra X-ray survey (part of the Durham Chandra Deep Protocluster Survey) of 30 LABs in the SA22 protocluster ($z = 3.09$) – the sensitive X-ray observations reveal active galactic nuclei in LAB host galaxies. Our results suggest that LABs are simply low-luminosity, radio-quiet analogues to the Ly-α halos observed around some high-redshift radio galaxies, and that the line emission could be connected to accretion-related outflows in these objects. This fits in with the scenario that LABs in general represent the sites of feedback interactions between galaxies and the IGM, and thus are a fascinating and unique population for the study of galaxy formation and evolution models.

The Luminosity Function of $z = 3.1$ Lyman-alpha Emitters

Caryl Gronwall

Pennsylvania State University

We describe a deep, 0.28 square degree survey for Lyman-alpha emitters in the Extended Chandra Deep Field South. Using the CTIO 4-m telescope, a Mosaic CCD camera, and two ~ 50 Angstrom FWHM interference filters, we identify a sample of ~ 250 Ly-alpha emitters (LAEs) in the redshift range $3.08 < z < 3.15$ down to a limiting flux of 1.5×10^{-17} ergs/cm^2/sec. Using these data, we define the LAE emission-line luminosity function; by combining our narrow-band data with deep archival broadband photometry from MUSYC (Multiwavelength Survey by Yale-Chile), we derive the objects equivalent width distribution and rest-frame UV luminosity function. We discuss the properties of these functions, the evolution of the LAE population from $z \sim 2$ to $z \sim 6$, and the relationship of LAEs to the Lyman-break galaxy population.

The Spectral Energy Distribution of LAEs at $2 < z < 3.1$

Lucia Guaita

Pontificia Universidad Catolica de Chile

We studied the multiwavelength Spectral Energy Distribution (SED) of a sample of 162 Lyman alpha-emitting (LAE) galaxies discovered in the Extended Chandra Deep Field-South (ECDF-S) at $z \sim 3.1$. We used deep narrow-band imaging obtained with the ~ 5000 Angstrom filter of the MOSAIC-II camera on the CTIO 4-m telescope. LAEs were selected to have observed frame equivalent widths (EW) > 80 Angstrom and emission line fluxes $> 1.5 \times 10^{-17}$ erg/cm^2/s. The broad band MUSYC photometry of the ECDF-S permitted us to build an observed SED and to fit it with stellar population models to determine the star formation history. A two-population SED fit to the stacked UBVRIzJK+[3.6, 4.5, 5.6, 8.0] micron fluxes of the IRAC-undetected objects finds that a typical LAE has low stellar mass ($\sim 1.0 \times 10^9$ solar masses), moderate star formation rate (~ 2 solar masses per year), a young component age of 20 Myr and little dust ($A_v < 0.2$). The best-fit model has 20% of the mass in the young stellar component, but models without evolved stars are also allowed. We used these best-fit properties to generate galaxy evolutionary tracks and to simulate broadband (U, V, B, R) colors of LAE at $2 < z < 3$. Thanks to the Lyman alpha decrement and the blue continuum that characterizes galaxies in this range of redshift, we can build broad band color selection criteria. They permit us to select a larger and more reliable sample of LAEs than with just an EW limit by differentiating LAEs at lower equivalent widths from low redshift interlopers.

Flies in the web: the satellite galaxies of a massive $z = 2$ forming galaxy

Nina Hatch

Leiden Observatory

The massive, forming, $z = 2$ galaxy, MRC 1138-262, is encompassed by a 200kpc Ly-alpha halo, has extended diffuse star formation and is surrounded by many satellite galaxies. Half of the satellites are Ly-alpha emitters, and almost all lie within the Ly-alpha halo. Using multi-band high resolution imaging, I present the properties of the central and satellite galaxies. I discuss the differences and similarities between the Ly-alpha-emitting and red satellite galaxies, including morphology, mass and the evidence for increased star formation in satellites close to the centre of the halo. These results are discussed in the context of cosmological models of galaxy formation.

Lyman-alpha imaging of starburst galaxies at $z \sim 0$

Matthew Hayes

Observatory of Geneva

I will review the (relatively short) history of the imaging of Lyman-alpha (Lyα) emission (and absorption) from local galaxies.

In recent years it has become possible to image Lyα at zero redshift using the Advanced Camera for Surveys onboard the Hubble Space Telescope. Such observations can typically resolve scales of a few 10s of pc, around two orders of magnitude better than are generally obtained at cosmological distances. Furthermore the accessibility of other wavelength domains allow the stellar populations and interstellar media to be studied at similar levels of detail to Lyα.

I will discuss the correlations between Lyα and dust, stellar age, and H-alpha (i.e. the ionised ISM). In all cases studied at low-z, the resonance scattering of Lyα is found to have a profound impact on the emission of Lyα. On small scales, little correlation is found between Lyα flux or equivalent width with any of the previously listed parameters. Lyα morphologies never resemble those of H-alpha and, when Lyα is found globally in emission, evidence for scattering haloes is found. Generally, any global estimates based upon Lyα (star-formation rates, Q, ...) are found to be discrepant from their true values by an order of magnitude. Due to the non-linear impacts of resonance scattering and geometrical effects, dust correction does not offer a reconciliation.

Lyman alpha Emitters in historical and cosmic perspective

Esther Hu

University of Hawaii

In the first part of this talk I will present a historical review of the search for Lyman alpha emitters. These objects have traditionally been sought as a means of investigating the very early stages of galaxy formation and high-redshift universe. We now know of substantial populations of Lyman alpha emitters at redshifts between 5.5 and 7. However, recent studies have revealed a population of very low metallicity, ultra-strong emission-line objects around $z \sim 1$ that may be low-redshift analogs of the high-redshift Lyman alpha emitter population. In the second part of the talk I'll discuss ongoing work characterizing the properties of these objects in comparison with the very high-redshift Lyman alpha emitters.

LAE in Hierarchical Galaxy Formation

Masakazu Kobayashi

National Astronomical Observatory of Japan

We present a new theoretical model for Lyman-alpha emitters (LAEs) in the framework of hierarchical galaxy formation. We extend a semi-analytical model of galaxy formation without changing the original model parameters but with the introduction of physically motivated modeling to describe the escape fraction of Lyman-alpha (Lyα) photons from host galaxies (f_{esc}). We incorporate two new effects on f_{esc}: extinction by interstellar dust and galaxy-scale outflows induced as star formation feedbacks. We compare our model with all of the available observational statistical quantities of LAEs at redshift $z = 3 - 7$: Lyα luminosity functions (LFs), rest-frame ultraviolet (UV) LFs, distributions of Lyα equivalent width (EW), and distributions in the UV magnitude-EW(Lyα) plane (Ando plane). The values of the free parameters in f_{esc} are determined to reproduce the Lyα LF of the LAEs at $z = 5.7$, and they are fixed in our study.

It is found that our model nicely reproduces the observed Lyα LFs of the LAEs at $z < 6$. On the other hand, the absorption of Lyα photons by neutral hydrogen in the intergalactic medium is required in order to reproduce the Lyα LFs of the LAEs at $z > 6$. Before comparing the other quantities, we compare the UV LFs of all of the galaxies in our model with LBGs and find that the UV luminosity of each galaxy in our model is predicted to be somewhat brighter if the Milky Way (MW) type extinction curve is adopted. This overluminosity is reasonably interpreted as follows; the extinction curve of high-z galaxies including LAEs and LBGs is steeper than the MW type, the initial mass function is inclied to massive stars, and/or time delay of Lyα photons to escape their host relative to continuum is indispensable. If the UV luminosity of all of the model galaxies is slightly dimmed, our model can reproduce the UV LFs, EW(Lyα) distributions, and distributions in the Ando plane consistently. In particular, the number fraction of the LAEs with EW(Lyα) > 240 Å and the observed deficiency of UV-luminous LAEs with large EW(Lyα) are naturally reproduced. We discuss the nature of the LAEs with EW(Lyα) > 240 Å and the physical interpretation to the deficiency.

Semi-analytical modelling of LAE evolution

Cedric Lacey

University of Durham

I will discuss modelling of Ly-alpha emitters in the framework of LambdaCDM using semi-analytical models of galaxy formation. I will describe the assumptions and methodology of this approach, as well as model results for different variants of the GALFORM model (with & without variable IMF and AGN feedback). For these different cases, I will present predictions for the evolution of the LAE luminosity function, as well as physical properties of LAEs such as Ly-alpha equivalent widths, stellar, gas and dark halo masses, SFRs, galaxy radii, metallicities and ages. I will also show predictions for luminosities of LAEs at other wavelengths, including IR/sub-mm wavelengths dominated by dust emission.

In a companion talk, Alvaro Orsi will present predictions for the clustering of LAEs based on the same semi-analytical model combined with N-body simulations.

Spectroscopic observations of Lyman-alpha emitters in the Local Universe

Miguel Mas-Hesse

CAB-LAEFF

Lyman alpha is considered as an important spectral signature in young galaxies at high redshift since its expected luminosity could amount to a few percent of the total galaxy luminosity. Moreover, Lyman alpha becomes the strongest emission line detectable in the optical for galaxies at redshift above $z = 2$. Nevertheless, already the first surveys in the Local Universe showed that the intensity of the line, and even the number of emitting objects, were much lower than expected. The same result was found later on at higher redshifts. The resonant nature of the Lyman alpha transition makes it much more sensitive to the presence of neutral gas than the lines of the Balmer series. Observations with IUE first, and HST GHRS + STIS later on, have allowed to determine the physical conditions driving the visibility and intensity of the line: column density and kinematics of neutral gas, dust abundance, starburst evolutionary state, effect of intergalactic clouds, ...

In this review we will describe the results derived from spectroscopic observations of the Lyman alpha line in Local Universe starburst galaxies, starting with the IUE observations in the '80s, up to HST-STIS long slit observations in the late '90s.

Informing theory with observations of Lyα emitters

Sangeeta Malhotra

Arizona State University

TBD

A Panoramic Search for Ly-alpha Blobs at $z = 3$

Yuichi Matsuda

National Astronomical Observatory of Japan

We present the recent results and the current status of our panoramic search for Ly-alpha blobs (LABs) at $z = 3$. In order to examine the basic properties of LABs (i.e. the number density, clustering properties and size distribution), we took very deep Ly-alpha images in extended SSA22, GOODSN, Subaru Deep Field (SDF), Subaru-XMM Deep Fields (SXDF) at $z = 3$ with Subaru/Suprime-Cam. The total survey area is ~ 3 square degrees (the co-volume is $\sim 1.5 \times 10^6$ Mpc^3). As a result, we identified ~ 100 LABs larger than 30 kpc. The local number density of LABs in the SSA22 proto-cluster is a factor of 10 times lager than those in the blank fields. In our sample, there are a few new giant LABs; a LAB (size ~ 200kpc) in another over-density region of compact Ly-alpha emitters and a LAB (~ 100kpc) around radio-loud quasar in extended SSA22, and a LAB (~ 80kpc) in SXDF. We also briefly introduce our new proto-cluster surveys around known giant LABs and high-z radio galaxies with giant Ly-alpha halos at $z = 2.5 - 4$ with Suprime-Cam.

Lyman alpha emission from GRB host galaxies

Bo Milvang-Jensen

Dark Cosmology Centre

I will report the first results of searching for Lyman alpha emission in GRB host galaxies as part of an ESO large VLT programme (PI: J. Hjorth). The survey has targeted a carefully selected sample of 71 Swift GRBs. The selection is primarily based on X-ray afterglow detection, in order to avoid biases against dusty or high-redshift objects. For the 23 systems at $z = 2 - 4.5$ we have obtained spectroscopy using FORS1 (exposure time typically 2 hours) targeting Lyman alpha. Contrary to previous pre-Swift findings using smaller samples, not all the GRB hosts in our sample show Lyman alpha emission.

Evolution of Lyman Alpha Emitters and Lyman Break Galaxies

Masao Mori

University of Tsukuba

We perform ultra-high-resolution hydrodynamic simulations (1024^3 grids) of a galaxy, including star formation cycles and supernova (SN) explosions. We find that an early "sparkling" starburst phase with multitudinous SN explosions at less than 3×10^8 years exhibits intense Lymanα emission from cooling shocks and well resembles Lymanα emitters (LAEs) that have been recently discovered at redshifts greater than 3. Subsequently, the galaxy shifts to a stellar continuum radiation-dominated phase within 10^9 years, which appears like Lyman break galaxies (LBGs). At the LAE phase, the abundance of heavy elements is subsolar and shows strong spatial variance, but it convergently reaches the level of solar abundance at the LBG phase. Hence, it turns out that LAEs and LBGs correspond to the on-going and major phases of chemical enrichment in galaxies. The stellar dynamics after the LBG phase is also pursued, and it is found that the galaxy eventually reaches the area of elliptical galaxies on the fundamental plane. The comparisons of such simulation results with the observations of elliptical galaxies allow us to conclude that LAEs and LBGs are infants of elliptical galaxies or bulge systems in the nearby universe.

Theoretical modelling of LAEs in the cosmological context of LCDM model

Ken Nagamine

University of Las Vegas

I will review the recent theoretical modelling of LAEs in the cosmological context of concordance Lambda cold dark matter (LCDM) model. While observational data on high-z LAEs are growing rapidly, theoretical explanations of LAEs still remain somewhat unsatisfactory due to large uncertainties in various physical parameters. I will primarily discuss the successes and failures of the models based on cosmological hydrodynamic simulations and semi-analytic models of galaxy formation, and examine whether we can derive any firm conclusions on the properties of LAEs based on the current models.

The overview of our search for Lyman-alpha emitters and absorbers at $z = 3.1$

Yuki Nakamura

Tohoku University

We conducted an extensive narrow-band survey in the Suprime-Cam 7 FoVs (200×80 Mpc) over the SSA22 proto-cluster regions as well as in the general fields (SXDS 3 FoVs, SDF, GOODS-N) at $z = 3.1$. Then, we detected ~ 1400 Lyman-alpha emitters and ~ 250 Lyman-alpha absorbers in the SSA22 region and we also found that the number density of Lyman-alpha emitters in SSA22 region is a factor of ~ 2 times larger than the general region. We studied these objects in terms of statistic value like clustering property, overdensity and luminosity function. Furthermore, we attention to the Lyman-alpha emitters with large equivalent width(EW) (EW$_{rest} >= 200$ Å, ~ 60 objects), which we detected in SSA22 region. These objects are very interesting because they may suggest that they can be very young objects, shorter than 10^6 yr, or the star formation preferentially to very large mass occurs in such galaxies. I will present the whole view of our observational results and Lyman-alpha emitters with large EW.

Evolution in the properties of Lyman-alpha emitters between redshifts $z \sim 3$ and $z \sim 2$

Kim Nilsson

Max-Planck-Institut für Astronomie

Observations of intermediate redshift emitters are now getting under way. These observations are of great interest in the understanding of Lyman-alpha emitters, as at this redshift it is easier to study the continuum of the sources due to higher signal-to-noise in the detections and larger wavelength coverage by optical and infrared detectors. In this talk I will present our survey for $z \sim 2.2$ LAEs with the ESO2.2m/MPG WFI, covering 0.2 sq.deg. in a central part of the COSMOS field. In this survey we have found 166 LAE candidates and the analysis of this sample has revealed significant evolution in the properties of this type of galaxy between redshifts ~ 3 and ~ 2.2. The galaxies appear to be redder and have lower equivalent widths and star formation rates, as measured in the Lyman-alpha line. We will present all the results from the analysis of this sample and give suggestions as to what may have changed since redshift 3.

Stellar populations of $z = 3.1$ and 3.7 Lyman Alpha Emitters with K$\sim 23 - 27$ from deep 0.5-8um photometry

Yoshiaki Ono

University of Tokyo

Stellar populations of Lyman alpha emitters (LAEs) have not been constrained well in comparison with those of other high-redshift galaxies such as Lyman-break galaxies, because most LAEs are too faint to be detected in near infrared observations. We examine stellar populations of LAEs over a wide mass range using a large LAE sample which contains bright, NIR detected objects, as well as many faint ones appropriate for stacking analysis.

Recently, Ouchi et al. (2008) constructed the largest available sample of $z = 3.1$ and 3.7 LAEs in a 1.0 square degree area of the Subaru/XMM-Newton Deep Field. In this sample, 219 (74) LAEs at $z = 3.1$ (3.7) have deep JHK photometry from UKIRT/UKIDSS-UDS and $3.6 - 8.0\mu$m photometry from Spitzer/SpUDS, among which 7 (6) are detected in K (brighter than the 3 sigma magnitude). For K-undetected objects we make median stacked images for individual passbands. This LAE sample thus enables us to constrain stellar populations of LAEs over a very wide K magnitude range (from K~ 23 for K-detected objects, to K~ 27 for stacked objects).

We will present stellar masses, star formation rates, ages, and color excesses (and correlations between these quantities) for our LAEs derived from spectral energy distribution fitting. We will also discuss connections between LAEs and other high-redshift galaxy populations.

The clustering of Ly-alpha emitters in a LCDM Universe

Alvaro Orsi

University of Durham

We combine a semi-analytical model of galaxy formation with a very large simulation which follows the growth of large scale structure in a LCDM universe to predict the clustering of Ly-alpha emitters. We find that the clustering strength of Ly-alpha emitters has only a weak dependence on Ly-alpha luminosity but a strong dependence on redshift. With increasing redshift, Ly-alpha emitters trace progressively rarer, higher density regions of the universe.

We construct mock catalogues of Ly-alpha emitters and study the sample variance of current and forthcoming surveys. We find that the number and clustering of Ly-alpha emitters in our mock catalogues are in agreement with measurements from current surveys, but that there is a considerable scatter in these quantities.

Details of the semi-analytical model, and other predictions for Ly-alpha emitters, will be given in a companion talk by C. Lacey.

Role of Lyα Emitters in the History of Galaxy Formation

Masami Ouchi

Carnegie Institution of Washington

I review results from recent Lyα emitter (LAE) studies, and discuss the nature of LAEs in the context of galaxy formation based on their photometric, spectroscopic, and clustering properties as well as evolution from $z \sim 2$ to 7. LAEs are being recognized as clues for understanding galaxy formation. The faint continuum, weak clustering, and small stellar mass indicate that LAEs are high-z counterparts of young dwarf galaxies, some of which may include population III star-formation. Intensive surveys for extended Lyα emitters, or Lyα blobs, are being conducted, claiming candidates of galaxies with outflow or cold accretion. The combination of normal LAEs and Lyα blobs sheds light on missing pieces of galaxy formation that are not addressed by studies of the other high-z populations, such as Lyman break galaxies, distant red galaxies, and sub-mm galaxies. At the end of my talk, I talk about on-going efforts and future prospects, such as searches for $z > 7$ LAEs and detailed studies of $z = 2 - 7$ LAEs with forthcoming powerful instruments.

The physical properties of high redshift Ly-alpha emitting galaxies

Laura Pentericci

INAF

A significant fraction of high redshift starburst galaxies presents strong Ly-alpha emission. Understanding the nature of these galaxies is important to assess the role they played in the early Universe and to shed light on the relation between the narrow band selected Ly-alpha emitters and the LBGs: are the Ly-alpha emitters a subset of the general LBG population? or do they represent the youngest galaxies in their early phases of formation? We therefore studied a sample of UV continuum selected galaxies from $z \sim 3.5$ to $z \sim 6$ from the GOODS-South survey, that have been observed spectroscopically and show the Ly-alpha line in emission. In particular we investigated their physical properties, such as total masses, ages, SFRs, extiction as determined from a spectrophotometric fit to the multiwavelength (U band to mid-IR) SEDs, and their dependence on the emission line characteristics.

We find that although most emitters are less massive and younger than the general LBG population, a non negligible fraction contains an evolved stellar population, with ages of several hundreds Myr and up to ~ 1 Gyr. This is inconsistent with most models, that represent Ly-alpha emitters as short lived events, i.e. primaeval galaxies in their first burst of star formation in essentially dust free environments. Models where the vast majority of LBGs has intrinsic Ly-alpha emission and where dust is the main physical parameter responsible for the observed variety of line strenghts and profiles, seem to be consistent with the observed trends, such as the absence of massive galaxies with strong line emission, the correlation between Ly-alpha strength and the dust extinction and the lack of correlation betwen Ly-alpha EW and stellar ages. We also plan to explore a scenario where clumpy dust could enhance the line EW by selectively extinguishing the continuum emission while allowing the Lyman alpha photons to escape, as recently proposed by several authors.

Exploring Sites of Galaxy Formation: Large Lyα Nebulae at $z \sim 2-3$

Moire Prescott

University of Arizona

Large (> 100 kpc) Lyα nebulae or "Lyα blobs" are likely sites of ongoing massive galaxy formation. They have been found in small numbers around $z \sim 2-3$, a key epoch of galaxy and black hole growth, but many fundamental questions remain about their environments, excitation mechanisms, and space density. While many Lyα nebulae have been discovered via narrowband imaging of known overdensities, one of the largest Lyα nebulae was discovered in the NOAO Deep Wide-Field Survey (NDWFS) without any a priori knowledge of its environment, offering an unbiased test of the association between Lyα nebulae and overdensities. Using deep intermediate-band imaging we find that this Lyα nebula is sitting within a factor of 3 overdensity of Lyα-emitting galaxies and rule out a chance coincidence at the < 1% level. A detailed, multiwavelength study of the Lyα nebula itself has yielded new insights into the excitation mechnisms for these rare sources, revealing a complex system that contains an obscured AGN and several nearby young galaxies. In addition, diffuse continuum and HeII emission suggest that this Lyα nebula is excited primarily by spatially-extended star formation. Inspired by the discovery of this source, we conducted a systematic search for other large Lyα nebulae within the 9 square degree NDWFS broadband imaging. The survey covers a large redshift range ($z = 1.9-2.9$) and has yielded a number of discoveries, including a new > 70 kpc Lyα nebula and a strong lower limit on the space density of the largest Lyα nebulae.

Ultra-Deep Searches for Lyman alpha Emission at $z \sim 3$

Michael Rauch

Carnegie Observatories

I will report on some recent ultra-deep, mostly spectroscopic searches for faint Lyman alpha emitters at redshift 3. The physical origin of the emission lines detected and the problem of contamination by foreground galaxies will be discussed. The results will be considered in the context of previously known types of high redshift galaxies.

Connection between LAEs and LBGs

Naveen Reddy

National Optical Astronomy Observatory

I will discuss previous work to constrain the intrinsic Lyman-alpha equivalent width, W(Lyα), distribution of continuum selected galaxies at $z \sim 2-3$, and the statistically significant trend of increasing W(Lyα) with redshift between $z \sim 2$ and $z \sim 3$ as determined from spectroscopy. I will focus on how the presence of LAEs at high redshifts affects our inferences of the faint-end slope of the UV LF for all star-forming galaxies, and present spectroscopic results on the key mechanisms that may modulate the emergent Lyα emission. Finally, I will present some work from an ongoing study to quantify the star formation rates, stellar populations, and stellar masses of LAEs at $z \sim 1.9$ and their relation to continuum-selected galaxies at these redshifts, and constraints on the evolution of the LAE luminosity function.

Extended Lyα nebulae: cold accretion or population III stars?

Claudia Scarlata

Spitzer Science Center

Stellar mass growth in galaxies can be due to either mergers or gas accretion with sequent star formation. Recent theoretical works suggest that the gas accretion modes depend on the mass of the dark matter halo, and on the galaxy redshift. Although at redshift $z > 3$ the so called "cold accretion" mode is predicted to be the dominant mechanism for a galaxy to acquire its gas, only a few (non conclusive) observations exist. Here we present the results of our study of an extended Lyman-alpha (Lyα) nebula located in a known overdensity region at $z \sim 2.4$. The data include multiwavelengths photometry covering the spectral range from 0.3 to 850μm, and a deep rest frame UV spectroscopy of the nebula and nearby sources. The rest frame UV spectrum of the nebula shows a significant detection of HeII emission line. The width of the line, together with the absence of other high ionization emission lines, and the shape of the continuum, suggest that the studied nebula is produced by cold accretion of pristine gas into a regular starburst galaxy.

3D Lyman-alpha radiation transfer and applications to starburst galaxies

Daniel Schaerer

Observatoire de Geneve

We will review recent developments in Lyman-alpha (Lyα) and continuum radiation transfer modeling, highlighting the main physical processes responsible for determining Lyα escape and the line profile in staburst galaxies. We will show how this can be used to infer properties of the ISM and stellar populations of starburst galaxies, and apply the models to a variety of observations. The insight gained from such modeling allows us to understand a variety of properties, correlations etc. of LBGs, LAEs, and related objects.

Theoretical Model of Lyman alpha Emitters and the Relation to Multi-Wavelength Observations

Ikkoh Shimizu

University of Tsukuba

Lyman alpha emitters (LAEs) are observed at redshifts $3 < z < 7$, and the nature of LAEs has not been elucidated very well. We have recently constructed a theoretical model of LAEs, where they correspond to the early evolutionary phase of galaxies (Mori & Umemura 2006, Shimizu et al. 2007).

Many surveys of high-z galaxies in the various wavelength bands (e.g., optical, infrared, and sub-mm, etc) have been performed actively. However, we still do not understand how LAEs are related to galaxies that are observed with various bands.

To explore the multi-band evolution of young galaxies, we perform cosmological N-body simulations and pursue individual star formation history by solving spectral evolution with a spectral synthesis code "PEGASE". Moreover, we consider the effect of the dust absorption of Lyman alpha emission. As a result, we find that not only the early evolutionary phase of galaxies but also the accreting phase of aged galaxies might be observed as LAEs. In the latter, the early LAE phase has been finished once and the star formation is activated again by gas accretion onto aged galaxies. Furthermore, we find that the spatial distribution of aged LAEs are corresponding to those of galaxies observed by (near) infrared band (e.g. MOIRCS mounted on the Subaru Telescope, SPITZER, etc). The detailed results and the implications are argued.

A detailed study of Lyman alpha emission in $z = 3$ galaxies

Bram Venemans

IoA, University of Cambridge

I will present unique ACS narrowband observations of a sample of $z = 3$ Lyman alpha emitters (LAEs). These LAEs were discovered in narrow- and broadband VLT images, and subsequently confirmed to be at $z = 3$ using VLT spectroscopy. By comparing the HST narrowband imaging with both the ground-based Lyman alpha images and very deep ACS broadband images, the spatial extent of the line emitting gas can be derived. The morphologies of the emission line regions range from unresolved to diffuse and extended. By analysing the continuum colours of the LAEs evidence is found that besides extinction, the gas kinematics can be very important for the escape fraction of Lyman alpha photons. The observations of $z = 3$ LAEs will also be compared with those of local starforming galaxies with Lyman alpha in emission. Finally I will discuss the global properties (luminosity function and star formation rates) of a sample of > 150 confirmed LAEs at $z = 3 - 4$.

Effects of Lyman-alpha radiation transfer in galaxies

Anne Verhamme

Observatoire de Geneve

Thanks to the 3D radiation transfer code we developped, MCLya (Verhamme et al. 2006), including gas and dust, we fitted 12 Lyman-alpha spectra of Lyman break galaxies at $z \sim 3$ (Schaerer & Verhamme 2008, Verhamme et al. 2008). This study shows for the first time that constraints on the gas and stellar properties of these objects can be derived from their Lyman-alpha line. In particular, the Lyman-alpha escape fraction correlates with the extinction in the interstellar gas, and a fit formula is proposed. In this case, a measurement of the observed EW(Lyα) can yield E(B-V), if the intrinsic EW(Lyα) is known or assumed. We show that there is a clear overlap between the two high-redshift starburst galaxies, LBGs and LAEs, and propose a unified scenario for these populations.

Intense starbursts at $z \sim 5$: First stellar mass assembly in the progenitors of present-day spheroids

Aprajita Verma

University of Oxford

We describe a comprehensive multiwavelength program to study high redshift galaxies selected from deep optical imaging surveys complemented by infrared data and follow-up spectroscopy. Using the Lyman-break technique we have identified a robust sample of $z \sim 5$ UV luminous star-forming galaxies for which we present a complete statistical study of their physical properties as derived from their rest-frame UV-to-visible SEDs. The characteristic properties of this sample differ from LBGs at $z \sim 3$ of comparable luminosity in that they are a factor of ten less massive ($\sim$ few $\times 10^9$ solar masses) and the majority ($\sim 70\%$) are considerably younger (< 100 Myr). We estimate the contribution of this young population to the global star formation rate and stellar mass density of the universe at $z \sim 5$. The constraint derived for the latter is affected by their young ages and short duty cycles which imply $z \sim 5$ LBG samples may be highly incomplete. Their high unobscured star formation rate intensities (~ 100s solar masses per year per square kpc), suggest these galaxies drive outflows and winds that enrich the intra- and inter-galactic media with metals. Many of these LBGs show prominent Lyman alpha emission and we compare their physical properties to LAEs at similar redshifts. We do not find any strong differences between their properties (mass, SFR, age or dust) and the presence of Lyman alpha suggesting that local conditions (neutral gas fraction, winds, geometry) more likely influence the emergence and strength of Lyman alpha emission. The general picture that emerges from our study is that $z \sim 5$ LBGs are "in-formation" and are accumulating their first significant stellar mass. They have properties consistent with being the progenitors of the densest stellar systems in the local Universe – the centres of old bulges and early type galaxies.

Physical Properties of Dark Matter Halos at $z = 0$, 0.8, and 2.2 Descended from LAEs at $z = 3.1$

Jean Walker-Soler

Rutgers University

The Millennium simulation results can be accessed by SQL queries to attain the physical properties and merger trees of both halos and subhalos, thus allowing us to study the evolution of the dark matter halos. Using the median dark matter halo mass of Lyman Alpha Emitting galaxies (LAEs), log(M)$= 10.9^{+0.5}_{-0.9}$, and the comoving number density for these galaxies, n=$1.5 \pm 0.3 \times 10^{-3}$ Mpc^{-3}, by Gawiser et al. (2007) as parameters in our Millennium Simulation queries, we have the ability to study the evolution of halos at $z = 3.1$ towards $z = 0$,$z = 0.8$, and $z = 2.2$ (corresponding to BX/SFG, DEEP2, and SDSS surveys). We use a number of models to assign LAEs to dark matter halos at $z \sim 3.1$, thus characterizing the range of possible descendants. We present the mass histograms of the descendants of LAEs at the different final redshifts. Results from the descendants show that the median mass to be 1.3×10^{12} solar masses, about the mass of an L* galaxy in agreement with Gawiser et al. (2007).

POSTERS

A joint model of the Lyman alpha emission and absorption properties of DLAs

Luke Barnes

IoA, University of Cambridge

The recently discovered population of ultra-faint extended line emitters with fluxes of a few times 10^{-18} erg s^{-1} cm^{-2} can account for the majority of the incidence rate of Damped Lyα systems (DLAs) if the line emission is interpreted as Lyman alpha (Rauch et al. 2008). We show that a model similar to that proposed by Haehnelt, Steinmetz, & Rauch (1998, 2000) to explain the incidence rate and kinematics of DLAs in the context of ΛCDM models for structure formations also reproduces the size distribution of the new population of faint Lyman alpha emitters for plausible parameters. This lends further support to the interpretation of the emission as Lyman alpha, as well as the identification with the hitherto elusive population of DLAs host galaxies. The observed space density suggests a duty cycle of $\sim 0.2 - 0.4$ for Lyman alpha emission from DLA host galaxies. We further show that cooling radiation is expected to contribute little to the Lyman alpha emission for the majority of emitters. This strengthens the case for the suggestion that DLA host galaxies exhibit centrally concentrated star formation at a rate of a few tenths $M_\odot$ yr^{-1}, surrounded by extended Lyman alpha haloes with radii of 30-50 kpc. Both the luminosity function of Lyman alpha emission and the velocity width distribution of the low ionization absorption require that galaxies with Dark Matter (DM) haloes with virial velocities $50 - 70$ km s^{-1} contribute little to the incidence rate of DLAs. This suggests that energy and momentum input due to star formation efficiently removes gas from these haloes. Galaxies with DM haloes with virial velocities $100 - 150$ km s^{-1} appear to account for the majority of DLA host galaxies. DLA hosts should thus become the building blocks of typical present-day galaxies like our Milky Way.

Broad- and Narrow-Band Morphologies of Lyman Alpha Emitters at $z \sim 3$

Nicholas Bond

Rutgers University

We present a V- and z-band morphological analysis of ~ 200 $z \sim 3.1$ Lyman Alpha Emitters (LAEs) in the Chandra Deep Field South. We used HST images taken as part of the GEMS and GOODS surveys to fit Sersic profiles and obtain concentration and asymmetry parameters. Initial results from the GOODS portion of the field (Gronwall et al. 2008) suggest that LAEs have a wide range of Sersic indices ($1 < n < 10$) and tend to be very concentrated ($C > 2.5$). In addition, the half-light radii are typically < 1 kpc. A subsample of rest-frame Lyman Alpha narrow-band morphologies are included in the analysis and compared to their broadband counterparts.

Measuring the Contribution of Low-Luminosity Sources to Cosmic Reionization with SINFONI

Benjamin Clément

Laboratoire d'Astrophysique de Marseille

We present our preliminary results obtained in a spectroscopic blind search of $z \sim 9$ Lyman Alpha Emitters conducted at VLT with SINFONI. We have used the strategy to survey the region of maximum magnification near critical lines of the massive lensing cluster Abell 1689. The recent study of Stark et al. (Stark et al 2007; ApJ, 663, 10) using the NIRSPEC Keck spectrograph has uncovered six promising candidates with $8.7 < z < 10.2$ of which three are behind A1689. Given the small volume surveyed, these finding suggests a large abundance of low-luminosity star-forming sources at $z \sim 9$, contributing significantly to the UV photons budget necessary for cosmic reionization.

The Clustering properties of LAEs in MUSYC

Harold Francke

Universidad de Chile

We present results on the clustering properties of 250 Lyman Alpha Emitting Galaxies (LAEs) detected in the MUSYC narrow band imaging of the Extended Chandra Deep Field South. For $z = 3.1$ LAEs selected to have Lyman Alpha emission line fluxes $> 1.5 \times 10^{-17}$ erg/cm^2/s, we measure a spatial correlation length $r_0 = 3.6 \pm 1.0$ Mpc (gamma=1.8), which corresponds to a bias factor of $1.9^{+0.4}_{-0.5}$. These results imply dark matter halos with median mass log(Mmed)$=$ $10.8^{+0.5}_{-0.9}$ and number densities of $3^{+27}_{-2} \times 10^{-2}$ Mpc^{-3}. This in turn implies that LAEs occupy 4^{+11}_{-3}% of the available dark matter halos. We used the excursion set approach to predict the descendants of dark matter halos hosting $z = 3.1$ LAEs and found that their median mass today log(Mmed)$= 12.8 \pm 1.2$, corresponding roughly to the mass of present day L* galaxies like the Milky Way.

A Lyman-alpha Narrow-band survey at $z = 7.7$ with WIRCam at CFHT

Pascale Hibon

KIAS (Seoul)

Searching high redshift galaxies is one of the most active fields of observational cosmology and is essential to the characterization and understanding of the formation and evolution of the galaxies. Galaxies at redshift are routinely found. Detection of $z \sim 7$ galaxies is however still rare. From $z = 6.5$ to $z = 7.7$ light dimming due to luminosity distance is 30% and the age of the Universe varies from 0.85 to 0.69 Gyr. At these redshift, the Universe is thought to be undergoing re-ionization. One tracer of high z galaxies is the Lyman alpha line which can be detected through Narrow Band (NB) imaging or in blind spectroscopic surveys. The Luminosity Function (LF) of high z LAEs is one of the few observables of the re-ionization epoch accessible to date with $8 - 10$m telescopes. The determination of the Lyman alpha LF at high z is actively pursued by several groups (Ota et al. 2007, Mesinger et al. 2007 etc.). The evolution of the Lyman alpha LF involves both the evolution of the re-ionization state of the Universe and of the Lyman alpha population which can also be traced by the evolution of the UV LF. This evolution with redshift allows us to constrain the evolution of LAEs and their role in re-ionizing the Universe at the end of the Dark Ages. Results on the evolution of both UV LF and LAEs LF at $z \sim 7$ are still limited and occasionally contradictory (Richard et al. 2008, Dijkstra et al. 2006 etc.).

We have carried out a 40 hours NB imaging program in the NIR at the CFHT, targeting LAEs at $z \sim 7.7$ in the CFHT-LS D1 field using the WIRCam instrument. We observed an area of $20' \times 20'$. The data were taken over 2 years : 20 hours in 2005, and 20 hours in 2006. We reached a detection limit of 9.65×10^{-18} erg/s/cm^2. With these observations, we achieved a factor of 10 improvement in area at the same detection limit over programs carried out with ISAAC at 1.19 micron. From these observations, we have derived a photometric sample of LAEs candidates at $z \sim 7.7$, using other observational material such as 20 hours of broad band filters J and K WIRCam observations. We selected objects detected in the NB 1.06 microns images with no optical counterpart (u,g,r,i,z). We also required the candidates to be detected in each of the two stacks corresponding to one year data in order to remove transient objects (slow moving objects, supernovae). To select emission line objects, we also adopted J-NB1.06> 0 (modulo our detection limits in both NB and J filters).

From this sample, after careful evaluation of possible sources of contamination, and accounting for cosmic variance, we inferred the LF at $z \sim 7.7$ LAEs. We compared our data sample to the different LF produced by the different existing models such as the model of Mao et al. (2007) and the GALFORM model of Baugh et al. (2005). We find out that our data does not constrain neither the $z \sim 7.7$ nor the models. These results will need to be confirmed by both spectroscopic follow-up and complementary imaging programs.

SuprimeCam ultimate $z \sim 7.3$ LAE survey with red-sensitive CCDs

Masanori Iye

National Astronomical Observatory

To explore the ultimate limit of SuprimeCam LAE survey, we got $2+$ nights approved to make imaging survey for $z \sim 7.3$ LAEs in the SXDF field using Subaru SuprimeCam equipped with new red-sensitive CCDs with quantum efficiency as high as 40% at 1000nm and a custom made narrow band filter NBF1006. The prospect of the observation, and some initial results if available, will be reported in light of our previous discovery of $z = 6.96$ LAE.

Volumetric Ly-α searches with large-area integral-field spectrographs

Matt Jarvis

University of Hertfordshire

I will present results from our survey for Ly-alpha emitters in a single VIMOS-IFU data cube extending over ~ 1 sq.arcmin. We show that this may be an ideal technique with which to probe the faint end of the Ly-α luminosity function in a consistent way from $z = 2$ through to the epoch of reionisation.

A census of the galaxies in the protocluster around MRC 0316-257

Ernst Kuiper

Leiden Observatory

High redshift radio galaxies pinpoint the location of galaxy overdensities in the early Universe, which are likely to form the massive galaxy clusters we see in the local Universe. The radio galaxy, MRC 0316-257, situated at $z = 3.13$, is surrounded by populations of Lyman alpha emitters (LAES) and [OIII] emitters whose numbers are overdense when compared to the field. I will present the results obtained from multi-passband imaging of the protocluster around MRC 0316-257. I will present correlations between the spatial distribution, and the properties, of several types of galaxies within the protocluster, including LAEs & [OIII] emitters, Lyman Break Galaxies, and Distant Red Galaxies. I will discuss the similarities and differences between the protocluster galaxies and field galaxies, as well as between the different galaxy types within the protocluster itself.

Deep optical and near-IR spectroscopy of a very bright Lyman alpha emitter

Chris Lidman

ESO - Santiago, Chile

We present very deep optical and near-IR spectroscopy of the brightest Lyman alpha emitter in the WFILAS catalogue. With an apparent luminosity of 1×10^{-16} erg/s/cm^2 in the Lyman alpha line, it is one of the brightest Lyman alpha emitters at $z = 5.7$. Although we detect the continuum redward of the Lyman alpha with high significance, thus allowing us to measure the equivalent of the Lyman alpha line and the slope of the continuum, we do not detect any emission lines other than Lyman alpha. We discuss what limits these observations place on the properties of this very bright object.

Lyman Alpha Galaxies at $z \sim 3.1$: Probes of Large Scale Structure

Emily McLinden

Arizona State University

Investigating the LSS of LAEs allows one to probe LSS and dark matter distribution in the early universe and especially in this work, to determine halo masses. Data for this work was collected on the 90 Prime Camera on the Bok telescope at the Steward Observatory. An OIII filter was used to select Lyα emission from galaxies around $z = 3.1$ and selection of LAE candidates is proceeding using the three selection criteria outlined in a Rhoads and Malhotra ApJ Letter from 2001. The SWIRE Lockman Field has been investigated so far and work will likely extend to NDWFS Bootes Field and the well studied COSMOS field to include a larger sample of LAE candidates for study. At over 8 square degrees, these data should result in the largest sample of LAEs known to date, thus yielding the large sample needed to study the clustering properties of Lyman-alpha galaxies.

Deep VLT spectroscopy of Ly-alpha envelopes around $z = 4.5$ RQQs

Pierre North

Ecole Polytechnique Fédérale de Lausanne (EPFL)

We report the first results of a spectroscopic search for Ly-alpha envelopes around radio quiet quasars at $z = 4.5$ and presenting a wide range of luminosities. Using the FORS2 spectrograph attached to the UT1 of the VLT in the multi-slit mode, we can observe not only the quasar itself and its immediate vicinity, but also PSF stars. The latter are used to subtract the spectrum of the quasar using the MCS deconvolution technique, which makes the extended Ly-alpha emission easier to detect. Out of the three objects observed so far, we detect two Ly-alpha envelopes, the extent of which appears larger than expected, i.e. $10'' - 13''$. On the other hand, their surface brightness is faint: about 10^{-18} and 10^{-20} erg/s/cm^2/$''^2$. Gathering narrow band imaging of such envelopes would be needed to know their shape and their luminosity function.

Stellar populations of LBGs at $z \sim 5$

Kouji Ohta

Kyoto Univsersity

LBGs are high-z galaxies closely related to LAEs, and revealing stellar populations of LBGs is also important to understand nature of LAEs. Here we present results of SED fitting for LBGs at $z \sim 5$ in the GOODS-N and its flanking fields. Among ~ 600 LBGs, we select ~ 100 objects which are uncontaminated in IRAC images by eye inspection. Using publicly available IRAC images in the GOODS-N and IRAC images we observed in the flanking fields, we constructed the rest-frame UV to optical SEDs and made SED fittings for the sub-sample of LBGs. We compare the distributions of the derived parameters (stellar masses, ages, color excesses, and star formation rates) with those of $z = 2 - 3$ LBG sample and of $z = 5 - 6$. The results are also confronted with those of LAEs at $z = 4.8$ derived with the same method in a separate contribution by Yuma et al.

Unbiased survey for Ly-alpha blobs

Tomoki Saito

Ehime University

I will review the current status of unbiased survey for Lyα blobs (LABs) at $z \sim 3-5$ and subsequent follow-up observations. LABs are characterized by their spatially extended Lyα emission and the large equivalent widths, and are thought to be candidates for extremely young galaxies under very early phases of their assembly. Recent follow-up multi-wavelength studies suggest that the majority of them are likely to have a superwind activity driven by their hidden starburst regions. However, such follow-up studies were carried out only for fairly restricted samples, i.e., those associated with protoclusters. Constructing a large, systematic, and unbiased sample is highly needed to obtain general understanding of the nature of LABs. I will also present our new results suggesting that the physical origins of LABs are quite diverse, and introduce our on-going survey to obtain a new systematic sample of LABs at $z \sim 3$ using COSMOS data.

A wide-field search for the brightest Lyman-α Haloes

Daniel Smith

Liverpool John Moores University

I will present our very wide-field (~ 15 deg^2) narrow-band survey for Lyman-α haloes at redshifts around three. Through introducing a new sample of Lyman-alpha Haloes (thought to be inconsistent with those sources that traditionally populate Lyman-α emitter luminosity functions) I will discuss some properties of previously unknown haloes, including their ionization and environmental properties both individually and as a population.

Escape fraction of ionizing photons from high-z Lyman alpha emitters and Lyman break galaxies

Hidenobu Yajima

University of Tsukuba

The escape fraction of ionizing photons from high-z galaxies is a crucial quantity controlling the reionization of the universe. Using the results from the ultra-high-resolution chemodynamic model of a primeval galaxy simulated by Mori & Umemura (2006), we perform three-dimensional radiative transfer calculations to obtain the escape fraction of ionizing photons for Lyman alpha emitters (LAEs) and Lyman break galaxies (LBGs). As a result, we find that the LAEs and LBGs have large escape fraction ($\sim 15\%$ - 40%) because the interstellar gases in LAEs and LBGs are highly ionized by shock heating of multitudes supernovae and UV radiation from young stars. Moreover we show that the large scatter of the relative escape fraction derived by observations is originated from the inhomogeneity of the ionization structure of the interstellar mediums. The relative escape fraction varies greatly depending upon the viewing directions. We also discuss the infrared luminosity of LAEs and LBGs from the estimation of the absorption of UV photons by interstellar dusts simultaneously.

Line Profiles of Lyman Alpha Emitters

Toru Yamada

Tohoku University

We have obtained more than ~ 100 spectra of the Lyα emitters at $z = 3.1$ with enough spectral resolution. Interestingly, more than $\sim 25\%$ of these objects show very similar shape, namely apparently asymmetrical emission with a small bump at the blue side, which may be due to the strong attenuation by nutral gas slightly blue shifted. We present the observational results and comparison with the gas/dust outflow models.

Extended Lyman alpha Nebulae at $z = 2.3$: An Extremely Rare and Strongly Clustered Population?

Yujin Yang

University of Arizona

The abundance and the environment of extended Lyman-alpha nebulae, the so-called “Lyman-alpha blobs”, are poorly understood because most blobs have been discovered serendipitously or by targeting a known over-dense region. To obtain unbiased sample of bright Lyman-alpha blobs, we have undertaken a wide-field narrow-band imaging survey in the NOAO Deep Wide Field Survey Bootes field with the 90Prime on the Steward Bok-2.3m telescope. We discover four Lyman-alpha blobs with L(Lyα)$= 1.6 - 5.3 \times 10^{43}$ ergs/s and isophotal areas of $28 - 57$ sq. arcsec, after searching a 4.82 sq. deg region on the sky at $z = 2.3$. None of four blobs are radio-loud as the high-z radio-galaxies that often shows extended Lyman-alpha halos. Two blobs are detected in X-rays with L(2-7 keV)$= 2 - 410^{44}$ ergs/s, implying that they are associated with strong AGNs. Its spectrum reveals that one of these two blobs contains a broad-line quasar at $z = 2.3$. MMT spectroscopy also confirms that the remaining two blobs are $z = 2.3$ Lyman-alpha blobs with almost identical redshifts and broad line profiles. The discovery of the four Lyman-alpha blobs over 4.82 sq. deg sky coverage yields a number density of $\sim 3 \times 10^{-6}$ Mpc^{-3}, which is 3 times lower than that found by Matsuda et al. survey at $z = 3.1$ after taking into account the over-density of that proto-cluster region. Surprisingly, the two X-ray undetected blobs are separated by only 70 arcsec (500 kpc). Given the rarity and the strong clustering of the blobs, we speculate that they occupy the highest density regions and thus may be precursors of todays rich cluster environment.

Stellar populations of LAEs at $z = 4.8$

Suraphong Yuma

Kyoto University

We present a study of Lyman Alpha Emitters (LAEs) at $z = 4.8$, selected via a narrowband survey in GOODS North and its flanking fields by using Suprime-Cam on Subaru Telescope. With the publicly available IRAC data in GOODS-N and further IRAC observations in its flanking fields, we select 6 LAEs which are not contaminated by neighbouring objects in IRAC images and construct the observed spectral energy distributions (SEDs) of LAEs from Suprime-Cam Ic and z' bands and IRAC 3.6 and 4.5 micron bands which cover from rest-frame UV to rest-frame optical wavelength ranges. Fitting the observed SEDs with the stellar population synthesis models by Bruzual & Charlot, we derive stellar masses, ages, color excesses, and star formation rates. Assuming the constant star formation rate history, we find that the stellar masses range from 10^8 to 10^{10} Msun and stellar ages range from 1 Myr to 25 Myr. Although the ages are not very well constrained, LAEs are likely to be very young. The color excess are between 0.0-0.5 mag. Star formation rates are derived to be in the ranges of 8-3000 $M_\odot$/yr. Comparing with other studies of stellar populations of LAEs, we find that our derived stellar masses are broadly comparable to those of LAEs at other redshifts. We also compare the results of our sample to other studies of LBGs. The comparison to LBGs at $z \sim 5$ with the same population synthesis models shows that the distributions of stellar masses and ages of LAEs lie at the low mass end and young age end of the distributions of LBGs at $z \sim 5$.

DoubleBlind

Göran Östlin

Stockholm Observatory

I will describe the “double blind” project, a simultaneous blind survey for Halpha and Lyman alpha emitters at $z = 2.2$ in fields with available deep optical-NIR data. The strategy allows for characterising the Lyman alpha escape physics for Lyman alpha-, Halpha-, and continuum selected galaxies.