Proposal for PhD and MSc Projects 2013-2014 and 2014-2015 by David Sobral and José Afonso

The Universe seems to contain roughly a trillion galaxies, each with hundreds of billions of stars. But how and when were galaxies like ours formed? Which were the first ones to exist? What they did look like in the past and how did they change across time? These PhD and MSc projects allow the students to obtain/use state-of-the-art data-sets from the largest telescopes (observing trips will be part of most projects), to address and answer many of the open questions in galaxy formation and evolution. The results are expected to be significant contributions to the field, leading to a much more complete understanding how galaxies like our own formed and evolved over the bulk of the age of the Universe.

PhD Projects:

The KMOS/VLT revolution: rotation curves, metallicities, dust extinction and galaxy formation and evolution with hundreds of galaxies at 0.8<z<2.23

Facilities: VLT/KMOS, VLT/SINFONI, ALMA, CFHT/WIRcam, Subaru/FMOS
Supervisors: David Sobral, Mark Swinbank (Durham), José Afonso

By conducting very large 5-10 deg^2 narrow-band surveys to search for emission-line sources with WIRCam/CFHT and WFCAM/UKIRT, we have found thousands of individual distant Hα emitters at z=0.8 ,0.84, 1.47 and 2.23. These are ideal samples to study the metallicities, dust extinction and rotation curves of star-forming galaxies and how these have evolved from the peak of the star-formation history (z~2.5) till today. By using KMOS (a second-generation VLT instrument that is starting observations at the end of 2013), the student will be able to gain unprecedented detailed information on a large sample of galaxies. KMOS, with its 24 Integral Field Units (IFUs) allows to target up to 24 galaxies at the same time, obtaining an image and a near-infrared spectrum for each pixel. This is a unique opportunity to map the distribution and intensity of star formation, dynamics and metallicity on ~4 kpc scales and address: (i) What is the fraction of primitive disks, spheroids and mergers; (ii) Is the distribution of star formation at high-z more centrally concentrated than comparably luminous/turbulent galaxies at z~0? and iii) Are chemical abundance gradients weaker or stronger than local spiral galaxies and do those change with time? Answers to these questions using our well selected samples will address whether stellar mass assembly at z~1-2 is dominated by secular isolation or via merger-induced growth and will provide some of the strongest tests/constraints to the most sophisticated models of galaxy formation and evolution. By selection, all of the targets have known Hα fluxes and all are sufficiently bright so their resolved properties can be recovered and the survey efficiency will be ~100%.

One unique aspect of this project is that there are significant over-densities in the very large samples of Hα emitters, and thus, with KMOS, the student will be able to confirm and characterise the high redshift structures, derive accurate metallicities, measure the mass-metallicity relation, obtain Balmer decrement extinctions and identify AGN for a sample of hundreds of Hα-selected galaxies and investigate if the environment plays a role in setting these galaxy properties. This project's approach is unique: not only will it advance our knowledge at z=2.2, 1.47, 0.8 with robust, Hα selected samples that can be built very quickly and used to access evolution, but it will also unveil any dependence on environment of SFRs, dust extinction, metallicities, and AGN fraction for the first time even at z > 2.

Finding, confirming and studying the most distant (first) galaxies at z>7 before JWST and E-ELT: a (very) wide-field approach

Facilities: CFHT/WIRcam, VISTA/VIRCam), VLT/SINFONI
Supervisors: David Sobral, José Afonso, Bahram Mobasher (UC Riverside)

When did the first stars and galaxies form? Over the last decade, galaxies have been robustly identified out to z~7.2, just ~700 Myr after the Big Bang, and a GRB has been confirmed at an even earlier epoch (z~8.2). The refurbished HST/WFC3 has opened a window to even earlier epochs, allowing the selection of z~7-10 very faint candidates. Despite the great progress, all z>7.3 candidates are simply too faint to be spectroscopically confirmed, a consequence of them being found by very deep, very small-area surveys. A very effective approach towards overcoming the current limitations is to look for relatively luminous Lyα emitters at wavelengths which are easily accessible from the ground. The reasons are simple: it opens the possibility of targeting very large volumes required to find the most luminous sources at z~7-9, but also because, by selection, it will find sources with relatively luminous Lyα emission, enabling the spectroscopic confirmation and detailed study of such distant sources for the first time. With the advent of near-infrared wide-field cameras, this can now be done very effectively, and our group has just completed by far the largest contiguous narrow-band near-infrared survey (~20x larger than the previous largest one) for Lyα emitters at z~8.8. The student will be able to work on both the follow-up of the current best candidates for the highest redshift galaxies, but also to participate in extending the survey to both lower luminosities, but also to even larger areas and different redshifts by using different telescopes/instruments. The results will allow for the most accurate determination of the evolution of the Lyα luminosity function up to z~9, with extremely important consequences to studying the re-ionisation of the Universe.

The confirmation of even a single z~8.8 Lyα emitter will allow for completely unprecedented science and follow-up observations, because any confirmed source will be bright enough to be studied by the largest telescopes/facilities available right now. This would be a fantastic opportunity to explore ALMA, Keck, the VLT(SINFONI/KMOS) and HST to unveil the nature of z~9 galaxies, many years before the next generation of large telescopes allows this to be done for the much fainter sources.

Unveiling the 3-D structure of a remarkable distant super-cluster and the roles of environment, mass and galaxy properties at z~0.8

Facilities: VLT/VIMOS, HST, Subaru/Suprime-cam, Herschel
Supervisors: David Sobral, José Afonso, Philip Best (Edinburgh)

Why were galaxies in the distant Universe so efficient at producing new stars? What were the roles of "nature" (stellar mass) and "nurture" (environment) in the past, how did they change with cosmic time and is there a connection between those and the declining star formation activity? Is our current view of how galaxies form and evolve correct? By probing a very wide range of environments (from fields to clusters of galaxies) and masses, we are now obtaining a much better picture of the roles and inter-dependences of mass and environment in the distant Universe. However, there are significant limitations in current studies, due to the small sample sizes, lack of multi-wavelenght data in cluster fields, projection effects, and the dilution/confusion of environments (e.g. filaments vs small groups). In order to obtain the sharp view that we need, overcoming current limitations (from the use of photometric redshifts), the student will use the VLT (with VIMOS, 40 hours of observations already conducted at the VLT, all in excellent conditions) to accurately map in 3-D a unique super-structure at $z = 0.84$ in the COSMOS field (10 × 13 Mpc). This massive, large structure contains 3 confirmed massive X-ray clusters/groups and shows a striking filamentary structure of star-forming galaxies. By targeting > 1000 galaxies residing in such structure, the student will measure accurate redshifts (from both emission and absorption lines) and make a detailed/accurate 3-D map of the complex structure, identifying filaments, fields, outskirts, small groups and the cluster cores. The student will obtain independent mass estimates from the absorption lines, and map SFRs down to even the least active galaxies, but also detect post-starburst galaxies (K+As) and map their fraction in the cluster, group, filament and field environments over the entire structure. The results of this project will reveal exactly where star formation activity is being enhanced/quenched, clearly disentangling the roles of mass and environment in the distant Universe in a robust way for the first time.

Moreover, due to the fact that this super-structure is in the COSMOS field, the student will be able to fully explore the rich multi-wavelenght data-set to detail and expand the conclusions of the study, particularly by investigating the morphologies (with Hubble Space Telescope imaging), but also to look at radio, near- (Spitzer) and far-infrared (Herschel) properties of galaxies residing in the various environments within the super-structure.

Lyα wide-field surveys at z=2-3 and matched Lyα - Hα: what does Lyα really tell us?

Facilities: INT/WFC, UKIRT/WFCAM, VLT
Supervisors: David Sobral, Huub Röttgering (Leiden), José Afonso

Many studies rely on the Hydrogen Lyα (Lyα) emission line to survey, study and understand the distant Universe ($z>2$-3), as it is often the only feature available to spectroscopically confirm/study such galaxies. However, its escape fraction (f_escape) is highly uncertain at $z>2$, and much is unknown about what Lyα actually traces. How much are we missing in/how biased is our current view of the very high redshift, almost completely based on Lyα? In order to answer such questions, the student will conduct and work on very large (~5-10 deg^2) Lyα surveys at $z\sim2$-3 (the likely peak of the star-formation history). This includes a perfectly matched Lyα-Hα survey at $z=2.23$ by using a costume-made narrow-band filter specifically designed for this project (delivered to the INT in May 2013). By measuring Lyα/Hα ratios for a sample of hundreds of galaxies at $z=2.23$, the student will robustly measure f_escape and the Lyα/Hα ratio as a function of mass, colour, environment and SFR and empirically calibrate Lyα for the first time, with very important applications/consequences for $z>2$ studies.

Furthermore, while deep Lyα (Lyα) surveys at $3<z<7$ have been extremely successful at detecting a relatively high number of Lyα emitting sources, and show that there is little evolution at $3<z<6$ at faint luminosities, there are big discrepancies at the bright end, as surveys simply lack the volume to constrain it. By conducting by far the largest survey

(>2-4 orders of magnitude larger in volume than any other) for the most luminous Lyα emitters at z~2-3, the student will also detect >3000 powerful Lyα emitters and >100 Lyα "blobs" (the largest ~contiguous objects found in the Universe, many times the size of a single galaxy), determine their Luminosity Function for the first time and measure their correlation function and evolution. This will provide the first robust sample that can be directly compared with the highest redshift samples, to directly test whether there is evolution in the bright end of the Lyα luminosity function. This project will allow the student to observe on large telescopes to obtain the data directly (~20 nights over the first years), but also to do follow-up studies with e.g. VLT or ALMA to unveil and detail the nature of Lyα blobs.

MSc/BSc Projects:

A large z~0.2 Hα survey and the direct comparison with large z > 1 surveys

Facilities: INT/WFC, CFHT, UKIRT
Supervisor: David Sobral

Wide-field narrow-band Hα surveys at z~1 and beyond have been increasingly successful over the past years. However, at z<0.4, the current samples cover only a very small fraction of high-z volumes, are tremendously affected by cosmic variance, are limited to low star formation rates (SFRs) and are not capable of selecting samples in the same way as z>1. Thus, any evolutionary claims based on the current data-sets (z<0.4 and z~1-2) are highly uncertain and likely dominated by the differences in the selection. In order to overcome such limitations the student will work on a new survey, designed to be a perfect match to those at high redshifts. This targets a co-moving volume of 2×10^6 Mpc^3 (matching even the largest z~2.2 survey) down to 0.1L* (10% of the typical luminosity at z=0.2) and obtain fully comparable samples by applying the same selection. The project will allow the selection of hundreds of Hα emitters over ~40 deg^2 and take advantage of two costume-made narrow-band filters which can work together to obtain two slices of the Universe at z=0.19 and z=0.21 and recover all >0.1L* star-forming galaxies within such slices. The survey will image regions of the sky where multi-wavelenght data is already available, allowing for detailed studies to be immediately conducted.

The student will derive an accurate Hα luminosity function at z=0.2, but also conduct comparison studies with large samples at z=0.4-2.23 to search for evolution in fundamental relations. This unique sample will also be the basis of follow-up observations to directly compare the nature, morphologies, metallicities and dust extinction properties with those derived from KMOS/SINFONI at z~1-2.

The sizes of star-forming galaxies in the last 11 Gyrs

Facilities: UKIRT/WFCAM, CFHT/WIRCam, HST
Supervisor: David Sobral

The student will measure sizes and morphologies (and their evolution) across redshift for star-forming galaxies selected in the same way. It will be possible to measure both Hα (where new stars are being formed) sizes and broad-band/continuum sizes (where old stars exist) and how both evolve with time since z=2.23 (z=1.47, z=0.84, z=0.80, z=0.4). Comparing the sizes at different environments will also be possible and will yield strong constraints on the role of the environment in quenching/enhancing star formation in galaxies. The project will be based on stacking of both Hα (tracing recent Star formation) and continuum/broad-band emission (tracing mass), and using high resolution HST imaging to fully control, test and statistically correct the sizes.

AGN vs Star-formation over the last 11 billion years

Facilities: UKIRT/WFCAM, XMM, Chandra, VLT, NTT
Supervisors: David Sobral, José Afonso

This project aims to investigate the fraction of AGN-dominated sources within samples of Hα selected galaxies at $0.4 < z < 2.23$ selected in a uniform way. The student will explore radio, X-ray, spectroscopic, optical, near-IR and far-IR data to constrain the nature of all sources, identifying those that are very likely AGNs, those that are likely star-forming galaxies, and potential composite ones. The results will allow the student to study the evolution in the AGN fraction in samples of Hα emitters in the last 11 billion years, provide empirical relations to predict the prevalence of AGN in these samples and finally derive the most accurate star-formation history of the Universe, by robustly correcting for the AGN contribution to the Hα luminosity function.

Calibrating [OII] as a star-formation indicator with a matched Subaru+UKIRT narrow-band survey at z~1.5

Facilities: Subaru/Suprime-cam, UKIRT/WFCAM
Supervisor: David Sobral

The student will use a combination of Subaru/Suprime-cam NB921 and UKIRT/WFCAM data to take full advantage of a perfectly matched [OII] + Hα (both emission lines that should originate near/from star-forming regions) survey at z=1.47 and derive/test the [OII] (3727A) emission line as a star-formation indicator at high-z/in the distant Universe. This will be done by directly looking at [OII]/Hα as a function of galaxy parameters/properties for a sample of ~1000 star-forming galaxies. The student will learn how to reduce Suprime-cam data, produce catalogues and analyse the data. The results have strong applications to studies of high redshift galaxies, where the [OII] emission line is the only line available to constrain star formation rates of galaxies.

Searching for luminous Lyα emitters at z~6-7

Facilities: Subaru/Suprime-cam
Supervisor: David Sobral

The student will use Subaru/Suprime-cam narrow-band data data to look for luminous Lyα emitters at redshift z=6.6. The student will start with reduced data and learn the basics of the narrow-band technique and the Lyman-break technique to isolate high-redshift Lyman-alpha emitters and produce a sample of robust candidates. Finally, the reduction of further data taken with the same instrument/set-up will allow the student to obtain the largest sample of luminous Lyα emitters at z~6.6 and to follow-up such sources.