List of science papers – #3

full list of scientific papers based on ASTRODEEP results

UEDIN for the Astrodeep project

ASTRODEEP

"Unveiling the power of the deepest images of the Universe"

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ABSTRACT

In this document we present the publications obtained within ASTRODEEP during the period 01/01/2015 – 31/12/2015.
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Prepared by: J. Dunlop
Approved by: AEC
Date: 05/01/2016

Summary of Science Papers

During 2015 a substantial number of science results have been produced with the support of the AstroDEEP project. Here we provide the title, authorship, journal reference and abstract for each paper published or submitted in 2015 that contains an explicit acknowledgement of AstroDEEP support. These papers all present significant scientific advances based on early versions of catalogues within the key survey fields that are the focus of the AstroDEEP project. In several cases the analysis undertaken en route to science results has revealed both the strengths and deficiencies of existing catalogues, reaffirming the central premise of AstroDEEP that high-quality data products can only be produced and validated in conjunction with cutting-edge research.

We list first those papers that have been published in peer-reviewed journals, followed by the papers that are in press or have been submitted for publication. In total we list 24 papers.

Abstracts of papers published in peer-reviewed journals

The SCUBA-2 Cosmology Legacy Survey: ALMA Resolves the Rest-frame Far-infrared Emission of Sub-millimeter Galaxies
Simpson, J. M.; Smail, Ian; Swinbank, A. M.; Almaini, O.; Blain, A. W.; Bremer, M. N.; Chapman, S. C.; Chen, Chian-Chou; Conselice, C.; Coppin, K. E. K.; and 19 coauthors
2015, ApJ, 799, 81
We present high-resolution (0.''3) Atacama Large Millimeter Array 870 μm imaging of 52 sub-millimeter galaxies (SMGs) in the Ultra Deep Survey field to investigate the size and morphology of the sub-millimeter (sub-mm) emission on 2-10 kpc scales. We derive a median intrinsic angular size of FWHM = 0.''30 ± 0.''04 for the 23 SMGs in the sample detected at a signal-to-noise ratio (S/N) >10. Using the photometric redshifts of the SMGs we show that this corresponds to a median physical half-light diameter of 2.4 ± 0.2 kpc. A stacking analysis of the SMGs detected at S/N <10 shows they have sizes consistent with the 870 μm bright SMGs in the sample. We compare our results to the sizes of SMGs derived from other multi-wavelength studies, and show that the rest-frame ~250 μm sizes of SMGs are consistent with studies of resolved ^{12}CO (J = 3-2 to 7-6) emission lines, but that sizes derived from 1.4 GHz imaging appear to be approximately two times larger on average, which we attribute to cosmic ray diffusion. The rest-frame optical sizes of SMGs are around four times larger than the sub-millimeter sizes, indicating that the star formation in these galaxies is compact relative to the pre-existing stellar distribution. The size of the starburst region in SMGs is consistent with the majority of the star formation occurring in a central region, a few kiloparsecs in extent, with a median star formation rate

surface density of 90 ± 30 $M_{\odot}$ yr^{-1} kpc^{-2}, which may suggest that we are witnessing an intense period of bulge growth in these galaxies.

Stellar masses from the CANDELS survey: the GOODS-South and UDS fields
Santini, P.; Ferguson, H. C.; Fontana, A.; Mobasher, B.; Barro, G.; Castellano, M.; Finkelstein, S. L.; Grazian, A.; Hsu, L. T.; Lee, B.; and 28 coauthors.
2015, ApJ, 801, 97
We present the public release of the stellar mass catalogs for the GOODS-S and UDS fields obtained using some of the deepest near-IR images available, achieved as part of the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS) project. We combine the effort from ten different teams, who computed the stellar masses using the same photometry and the same redshifts. Each team adopted their preferred fitting code, assumptions, priors, and parameter grid. The combination of results using the same underlying stellar isochrones reduces the systematics associated with the fitting code and other choices. Thanks to the availability of different estimates, we can test the effect of some specific parameters and assumptions on the stellar mass estimate. The choice of the stellar isochrone library turns out to have the largest effect on the galaxy stellar mass estimates, resulting in the largest distributions around the median value (with a semi interquartile range larger than 0.1 dex). On the other hand, for most galaxies, the stellar mass estimates are relatively insensitive to the different parameterizations of the star formation history. The inclusion of nebular emission in the model spectra does not have a significant impact for the majority of galaxies (less than a factor of 2 for ∼80% of the sample). Nevertheless, the stellar mass for the subsample of young galaxies (age < 100 Myr), especially in particular redshift ranges (e.g., $2.2 < z < 2.4$, $3.2 < z < 3.6$, and $5.5 < z < 6.5$), can be seriously overestimated (by up to a factor of 10 for < 20 Myr sources) if nebular contribution is ignored.

Cosmic Reionization and Early Star-forming Galaxies: A Joint Analysis of New Constraints from Planck and the Hubble Space Telescope
Robertson, Brant E.; Ellis, Richard S.; Furlanetto, Steven R.; Dunlop, James S.
2015, ApJ, 802, L19
We discuss new constraints on the epoch of cosmic reionization and test the assumption that most of the ionizing photons responsible arose from high-redshift star-forming galaxies. Good progress has been made in charting the end of reionization through spectroscopic studies of $z \simeq 6$-8 QSOs, gamma-ray bursts, and galaxies expected to host Lyα emission. However, the most stringent constraints on its duration have come from the integrated optical depth, τ, of Thomson scattering to the cosmic microwave background. Using the latest data on the abundance and luminosity distribution of distant galaxies from Hubble

Space Telescope imaging, we simultaneously match the reduced value τ =0.066+/- 0.012 recently reported by the Planck collaboration and the evolving neutrality of the intergalactic medium with a reionization history within 6≲ z≲ 10, thereby reducing the requirement for a significant population of very high redshift (z > 10) galaxies. Our analysis strengthens the conclusion that star-forming galaxies dominated the reionization process and has important implications for upcoming 21 cm experiments and searches for early galaxies with the James Webb Space Telescope.

The SCUBA-2 Cosmology Legacy Survey: ALMA Resolves the Bright-end of the Sub-millimeter Number Counts

Simpson, J. M.; Smail, Ian; Swinbank, A. M.; Chapman, S. C.; Geach, J. E.; Ivison, R. J.; Thomson, A. P.; Aretxaga, I.; Blain, A. W.; Cowley, W. I.; and 13 coauthors

2015, ApJ, 807, 128

We present high-resolution 870 μm Atacama Large Millimeter/sub-millimeter Array (ALMA) continuum maps of 30 bright sub-millimeter sources in the UKIDSS UDS field. These sources are selected from deep, 1 degree^2 850 μm maps from the SCUBA-2 Cosmology Legacy Survey, and are representative of the brightest sources in the field (median $\{S\}_{\{SCUBA}$-2} = 8.7 ± 0.4 mJy). We detect 52 sub-millimeter galaxies (SMGs) at >4σ significance in our 30 ALMA maps. In $\{61\}_{-15}^{+19}$% of the ALMA maps the single-dish source comprises a blend of ≥2 SMGs, where the secondary SMGs are Ultra-luminous Infrared Galaxies (ULIRGs) with $\{L\}_{\{IR\}} \gtrsim 10^{12}$ {\text{}}{L}$_\odot$. The brightest SMG contributes on average $\{80\}_{-2}^{+6}$% of the single-dish flux density, and in the ALMA maps containing ≥2 SMGs the secondary SMG contributes $\{25\}_{-5}^{+10}$% of the integrated ALMA flux. We construct source counts and show that multiplicity boosts the apparent single-dish cumulative counts by 20% at S_{870} > 7.5 mJy, and by 60% at S_{870} > 12 mJy. We combine our sample with previous ALMA studies of fainter SMGs and show that the counts are well-described by a double power law with a break at 8.5 ± 0.6 mJy. The break corresponds to a luminosity of ˜6 × 10^{12} {\text{}}{L}$_\odot$ or a star formation rate (SFR) of ˜10^3 {\text{}}{M}$_\odot$ {{yr}}$^{-1}$. For the typical sizes of these SMGs, which are resolved in our ALMA data with $\{R\}_{\{e\}}$ = 1.2 ± 0.1 kpc, this yields a limiting SFR density of ˜100 {\text{}}{M}$_\odot$ yr^{-1} kpc^{-2} Finally, the number density of $S_{870} \gtrsim$ 2 mJy SMGs is 80 ± 30 times higher than that derived from blank-field counts. An over-abundance of faint SMGs is inconsistent with line-of-sight projections dominating multiplicity in the brightest SMGs, and indicates that a significant proportion of these high-redshift ULIRGs are likely to be physically associated.

GOODS-HERSCHEL: star formation, dust attenuation and the FIR-radio correlation on the Main Sequence of star-forming galaxies up to z~4

Pannella, Maurilio; Elbaz, David; Daddi, Emanuele; Dickinson, Mark E.; Hwang, Ho Seong; Schreiber, Corentin; Strazzullo, Veronica; Aussel, Herve; Bethermin, Matthieu; Buat, Veronique; and 18 coauthors

2015, ApJ, 807, 141

We use the deep panchromatic dataset available in the GOODS-N field, spanning all the way from GALEX ultra-violet to VLA radio continuum data, to select a star-forming galaxy sample at z∼[0.5-4] and robustly measure galaxy photometric redshifts, star formation rates, stellar masses and UV rest-frame properties. We quantitatively explore, using mass-complete samples, the evolution of the star formation activity and dust attenuation properties of star-forming galaxies up to z∼4. Our main results can be summarized as follows: i) we find that the slope of the SFR-M correlation is consistent with being constant, and equal to ∼0.8 at least up to z∼1.5, while the normalization keeps increasing to the highest redshift, z∼4, we are able to explore; ii) for the first time in this work, we are able to explore the FIR-radio correlation for a mass-selected sample of star-forming galaxies: the correlation does not evolve up to z∼4; iii) we confirm that galaxy stellar mass is a robust proxy for UV dust attenuation in star-forming galaxies, with more massive galaxies being more dust attenuated; iv) strikingly, we find that this attenuation relation evolves very weakly with redshift, the amount of dust attenuation increasing by less than 0.3 magnitudes over the redshift range [0.5-4] for a fixed stellar mass, as opposed to a tenfold increase of star formation rate; v) this finding explains the evolution of the SFR-Auv relation reported in literature: the same amount of star formation is less attenuated at higher redshift because it is hosted in less massive, and less metal rich, galaxies; vi) the correlation between dust attenuation and the UV spectral slope evolves in redshift, with the median UV spectral slope of star-forming galaxies becoming bluer with redshift. By z∼3, typical UV slopes are inconsistent, given the measured dust attenuation, with the predictions of commonly used empirical laws.

The Herschel view of the dominant mode of galaxy growth from z=4 to the present day

Schreiber, Corentin; Pannella, Maurilio; Elbaz, David; Béthermin, Matthieu; Inami, Hanae; Dickinson, Mark E.; Magnelli, Benjamin; Wang, Tao; Aussel, Hervé; Daddi, Emanuele; and 13 coauthors.

2015, A&A, 575, 74

We present an analysis of the deepest Herschel images in four major extragalactic fields GOODS-North, GOODS-South, UDS and COSMOS obtained within the GOODS-Herschel and CANDELS-Herschel key programs. The picture provided by 10497 individual far-infrared detections is supplemented by the stacking analysis of a mass-complete sample of 62361 star-forming galaxies from the CANDELS-HST H band-selected catalogs and from two deep ground-

based Ks band-selected catalogs in the GOODS-North and the COSMOS-wide fields, in order to obtain one of the most accurate and unbiased understanding to date of the stellar mass growth over the cosmic history. We show, for the first time, that stacking also provides a powerful tool to determine the dispersion of a physical correlation and describe our method called "scatter stacking" that may be easily generalized to other experiments. We demonstrate that galaxies of all masses from z=4 to 0 follow a universal scaling law, the so-called main sequence of star-forming galaxies. We find a universal close-to-linear slope of the logSFR-logM_* relation with evidence for a flattening of the main sequence at high masses (log(M_*/Msun) > 10.5) that becomes less prominent with increasing redshift and almost vanishes by z∼2. This flattening may be due to the parallel stellar growth of quiescent bulges in star-forming galaxies. Within the main sequence, we measure a non varying SFR dispersion of 0.3 dex. The specific SFR (sSFR=SFR/M_*) of star-forming galaxies is found to continuously increase from z=0 to 4. Finally we discuss the implications of our findings on the cosmic SFR history and show that more than 2/3 of present-day stars must have formed in a regime dominated by the main sequence mode. As a consequence we conclude that, although omnipresent in the distant Universe, galaxy mergers had little impact in shaping the global star formation history over the last 12.5 Gyr.

The SCUBA-2 Cosmology Legacy Survey: the submillimetre properties of Lyman-break galaxies at z = 3-5

Coppin, K. E. K.; Geach, J. E.; Almaini, O.; Arumugam, V.; Dunlop, J. S.; Hartley, W. G.; Ivison, R. J.; Simpson, C. J.; Smith, D. J. B.; Swinbank, A. M.; and 21 coauthors

2015, MNRAS, 446, 1293

We present detections at 850 μm of the Lyman-break galaxy (LBG) population at z ≈ 3, 4, and 5 using data from the Submillimetre Common User Bolometer Array 2 Cosmology Legacy Survey in the United Kingdom Infrared Deep Sky Survey `Ultra Deep Survey' field. We employ stacking to probe beneath the survey limit, measuring the average 850 μm flux density of LBGs at z ≈ 3, 4, and 5 with typical ultraviolet luminosities of $L_{1700} \approx 10^{29}$ erg s^{-1} Hz^{-1}. We measure 850 μm flux densities of (0.25 ± 0.03), (0.41 ± 0.06), and (0.88 ± 0.23) mJy, respectively, finding that they contribute at most 20 per cent to the cosmic far-infrared (IR) background at 850 μm. Fitting an appropriate range of spectral energy distributions to the z ˜ 3, 4, and 5 LBG stacked 24-850 μm fluxes, we derive IR luminosities of $L_{8\text{-}1000\,\mu m} \approx 3.2$, 5.5, and 11.0×10^{11} $L_\odot$ [and star formation rates (SFRs) of ≈50-200 $M_\odot$ yr^{-1}], respectively. We find that the evolution in the IR luminosity density of LBGs is broadly consistent with model predictions for the expected contribution of luminous-to-ultraluminous IR galaxies at these epochs. We observe a positive correlation between stellar mass and IR luminosity and confirm that, for a fixed mass, the reddest LBGs (UV slope $\beta \rightarrow 0$) are redder due to dust extinction, with SFR(IR)/SFR(UV) increasing by about an order of

magnitude over -2 < β < 0 with SFR(IR)/SFR(UV) ˜ 20 for the reddest LBGs. Furthermore, the most massive LBGs tend to have higher obscured-to-unobscured ratios, hinting at a variation in the obscuration properties across the mass range.

GOODS-Herschel: identification of the individual galaxies responsible for the 80-290 μm cosmic infrared background

Leiton, R.; Elbaz, D.; Okumura, K.; Hwang, H. S.; Magdis, G.; Magnelli, B.; Valtchanov, I.; Dickinson, M.; Béthermin, M.; Schreiber, C.; and 7 coauthors

2015, A&A, 579, 93

Aims: We propose a new method of pushing Herschel to its faintest detection limits using universal trends in the redshift evolution of the far infrared over 24 μm colours in the well-sampled GOODS-North field. An extension to other fields with less multi-wavelength information is presented. This method is applied here to raise the contribution of individually detected Herschel sources to the cosmic infrared background (CIRB) by a factor 5 close to its peak at 250 μm and more than 3 in the 350 and 500 μm bands.

Methods: We produce realistic mock Herschel images of the deep PACS and SPIRE images of the GOODS-North field from the GOODS-Herschel key program and use them to quantify the confusion noise at the position of individual sources, i.e., estimate a "local confusion noise". Two methods are used to identify sources with reliable photometric accuracy extracted using 24 μm prior positions. The clean index (CI), previously defined but validated here with simulations, which measures the presence of bright 24 μm neighbours and the photometric accuracy index (PAI) directly extracted from the mock Herschel images.

Results: Both methods converge to comparable depths and fractions of the CIRB resolved into sources individually detected with Herschel. After correction for completeness, thanks to our mock Herschel images, individually detected sources make up as much as 54% and 60% of the CIRB in the PACS bands down to 1.1 mJy at 100 μm and 2.2 mJy at 160 μm and 55, 33, and 13% of the CIRB in the SPIRE bands down to 2.5, 5, and 9 mJy at 250 μm, 350 μm, and 500 μm, respectively. The latter depths improve the detection limits of Herschel by factors of 5 at 250 μm, and 3 at 350 μm and 500 μm as compared to the standard confusion limit. Interestingly, the dominant contributors to the CIRB in all Herschel bands appear to be distant siblings of the Milky Way ($z \sim 0.96$ for $\lambda <$ 300 μm) with a stellar mass of $M_\star \sim 9 \times 10^{10} M_\odot$.

Probing the galaxy-halo connection in UltraVISTA to z ~ 2

McCracken, H. J.; Wolk, M.; Colombi, S.; Kilbinger, M.; Ilbert, O.; Peirani, S.; Coupon, J.; Dunlop, J.; Milvang-Jensen, B.; Caputi, K.; and 3 coauthors.

2015, MNRAS, 449, 901

We use percent-level precision photometric redshifts in the UltraVISTA-DR1 near-infrared survey to investigate the changing relationship between galaxy stellar mass and the dark matter haloes hosting them to z ~ 2. We achieve this by measuring the clustering properties and abundances of a series of volume-limited galaxy samples selected by stellar mass and star-formation activity. We interpret these results in the framework of a phenomenological halo model and numerical simulations. Our measurements span a uniquely large range in stellar mass and redshift and reach below the characteristic stellar mass to z ~ 2. Our results are: 1. At fixed redshift and scale, clustering amplitude depends monotonically on sample stellar mass threshold; 2. At fixed angular scale, the projected clustering amplitude decreases with redshift but the co-moving correlation length remains constant; 3. Characteristic halo masses and galaxy bias increase with increasing median stellar mass of the sample; 4. The slope of these relationships is modified in lower mass haloes; 5. Concerning the passive galaxy population, characteristic halo masses are consistent with a simply less-abundant version of the full galaxy sample, but at lower redshifts the fraction of satellite galaxies in the passive population is very different from the full galaxy sample; 6. Finally we find that the ratio between the characteristic halo mass and median stellar mass at each redshift bin reaches a peak at log(M_h/M_sun) ~ 12.2 and the position of this peak remains constant out to z ~ 2. The behaviour of the full and passively evolving galaxy samples can be understood qualitatively by considering the slow evolution of the characteristic stellar mass in the redshift range probed by our survey.

New redshift z ~ 9 galaxies in the Hubble Frontier Fields: Implications for early evolution of the UV luminosity density

McLeod, Derek J.; McLure, Ross J.; Dunlop, James S.; Robertson, Brant E.; Ellis, Richard S.; Targett, Thomas T.

2015, MNRAS, 450, 3032

We present the results of a new search for galaxies at redshift z ~ 9 in the first two Hubble Frontier Fields with completed HST WFC3/IR and ACS imaging. To ensure robust photometric redshift solutions, and to minimize incompleteness, we confine our search to objects with H_{160} < 28.6 (AB mag), consider only image regions with an rms noise sigma_{160} > 30 mag (within a 0.5-arcsec diameter aperture), and insist on detections in both H_{160} and J_{140}. The result is a survey covering an effective area (after accounting for magnification) of 10.9 sq. arcmin, which yields 12 galaxies at 8.4 < z < 9.5. Within the Abell-2744 cluster and parallel fields we confirm the three brightest objects reported by Ishigaki et al. (2014), but recover only one of the four z > 8.4 sources reported by Zheng et al. (2014). In the MACSJ0416.1-240 cluster field we report five objects, and explain why each of these eluded detection or classification as z

~ 9 galaxies in the published searches of the shallower CLASH data. Finally, we uncover four z ~ 9 galaxies from the previously unsearched MACSJ0416.1-240 parallel field. Based on the published magnification maps we find that only one of these 12 galaxies is likely boosted by more than a factor of two by gravitational lensing. Consequently we are able to perform a fairly straightforward reanalysis of the normalization of the z ~ 9 UV galaxy luminosity function as explored previously in the HUDF12 programme. We conclude that the new data strengthen the evidence for a continued smooth decline in UV luminosity density (and hence star-formation rate density) from z ~ 8 to z ~ 9, contrary to recent reports of a marked drop-off at these redshifts. This provides further support for the scenario in which early galaxy evolution is sufficiently extended to explain cosmic reionization.

The galaxy luminosity function at z ~ 6 and evidence for rapid evolution in the bright end from z ~ 7 to 5

Bowler, R. A . A.; Dunlop, J. S.; McLure, R. J.; McCracken, H. J.; Milvang-Jensen, B.; Furusawa, H.; Taniguchi, Y.; Le Fevre, O.; Fynbo, J. P. U.; Jarvis, M.J.,; Haussler, B.

2015, MNRAS, 452, 1817

We present a sample of 266 bright (-22.7 < M_UV < -20.5) Lyman-break galaxies at 5.5 < z < 6.5 found within a total of 1.65 square degrees of imaging in the UltraVISTA/COSMOS and UKIDSS UDS/SXDS fields. The deep near-infrared imaging available in the two independent fields, in addition to deep optical (including z'-band) data, enables the sample of z ~ 6 star-forming galaxies to be securely detected long-ward of the break (in contrast to several previous studies). By simulating the potential contamination of our sample by cool galactic brown dwarfs, we find that the expected contamination rate of our initial sample is < 3 percent and that dwarf stars can be effectively removed by fitting dwarf star spectral templates to the photometry. At z ~ 6 the galaxy surface density in the UltraVISTA field exceeds that in the UDS by a factor of ~ 1.8, indicating strong cosmic variance even between degree-scale fields at z > 5. We calculate the bright end of the rest-frame Ultra-Violet (UV) luminosity function (LF) at z ~ 6. The galaxy number counts are a factor of 2 lower than predicted by the recent LF determination by Bouwens et al.. In comparison to other smaller area studies, we find an evolution in the characteristic magnitude between z ~ 5 and z ~ 7 of dM* ~ 0.4 mag, and show that a double power-law or a Schechter function can equally well describe the LF at z = 6. Furthermore, the bright-end of the LF appears to steepen from z ~ 7 to z ~ 5, which could indicate the onset of mass quenching or the rise of dust obscuration, a conclusion supported by comparing the observed LFs to a range of theoretical model predictions.

Cold dust emission from X-ray AGN in the SCUBA-2 Cosmology Legacy Survey: dependence on luminosity, obscuration and AGN activity

Banerji, Manda; McMahon, R. G.; Willott, C. J.; Geach, J. E.; Harrison, C. M.; Alaghband-Zadeh, S.; Alexander, D. M.; Bourne, N.; Coppin, K. E. K.; Dunlop, J. S.; and 8 coauthors

2015, MNRAS, 454, 419

We study the 850-μm emission in X-ray-selected active galactic nuclei (AGN) in the ˜2 deg^2 COSMOS field using new data from the SCUBA-2 Cosmology Legacy Survey. We find 19 850-μm bright X-ray AGN in a `high-sensitivity' region covering 0.89 deg^2 with flux densities of S_{850} = 4-10 mJy. The 19 AGN span the full range in redshift and hard X-ray luminosity covered by the sample - $0.7 \lesssim z \lesssim 3.5$ and $43.2 \lesssim \log_{10}(L_X) \lesssim 45$. We report a highly significant stacked 850-μm detection of a hard X-ray flux-limited population of 699 z > 1 X-ray AGN - S_{850} = 0.71 ± 0.08 mJy. We explore trends in the stacked 850-μm flux densities with redshift, finding no evolution in the average cold dust emission over the redshift range probed. For type 1 AGN, there is no significant correlation between the stacked 850-μm flux and hard X-ray luminosity. However, in type 2 AGN the stacked submillimeter flux is a factor of 2 higher at high luminosities. When averaging over all X-ray luminosities, no significant differences are found in the stacked submillimeter fluxes of type 1 and type 2 AGN as well as AGN separated on the basis of X-ray hardness ratios and optical-to-infrared colours. However, at $\log_{10}(L_{2-10}/\mathrm{erg\ s^{-1}}) > 44.4$, dependences in average submillimeter flux on the optical-to-infrared colours become more pronounced. We argue that these high-luminosity AGN represent a transition from a secular to a merger-driven evolutionary phase where the star formation rates and accretion luminosities are more tightly coupled. Stacked AGN 850-μm fluxes are compared to the stacked fluxes of a mass-matched sample of K-band-selected non-AGN galaxies. We find that at $10.5 < \log_{10}(M_*/M_\odot) < 11.5$, the non-AGN 850-μm fluxes are 1.5-2 times higher than in type 2 AGN of equivalent mass. We suggest these differences are due to the presence of massive dusty, red starburst galaxies in the K-band-selected non-AGN sample, which are not present in optically selected catalogues covering a smaller area.

Evolution of star formation in the UKIDSS Ultra Deep Survey Field - II. Star formation as a function of stellar mass between z = 1.46 and 0.63

Drake, Alyssa B.; Simpson, Chris; Baldry, Ivan K.; James, Phil A.; Collins, Chris A.; Ouchi, Masami; Yuma, Suraphong; Dunlop, James S.; Smith, Daniel J. B.

2015, MNRAS, 454, 2015

We present new results on the evolution of the cosmic star formation rate as a function of stellar mass in the Subaru/XMM-Newton Deep Survey-Ultra Deep Survey field. We make use of narrow-band-selected emission line galaxies in four redshift slices between z = 1.46 and 0.63, and compute stellar masses by

fitting a series of templates to recreate each galaxy's star formation history. We determine mass-binned luminosity functions in each redshift slice, and derive the star formation rate density (ρ_{SFR}) as a function of mass using the [O III] or [O II] emission lines. We calculate dust extinction and metallicity as a function of stellar mass, and investigate the effect of these corrections on the shape of the overall $\rho_{SFR}(M)$. We find that both these corrections are crucial for determining the shape of the $\rho_{SFR}(M)$, and its evolution with redshift. The fully corrected $\rho_{SFR}(M)$ is a relatively flat distribution, with the normalization moving towards lower values of ρ_{SFR} with increasing cosmic time/decreasing redshift, and requiring star formation to be truncated across all masses studied here. The peak of $\rho_{SFR}(M)$ is found in the $10^{10.5} < M_{\odot} < 10^{11.0}$ mass bin at z = 1.46. In the lower redshift slices, the location of the peak is less certain; however, low-mass galaxies in the range $10^{7.0} < M_{\odot} < 10^{8.0}$ play an important part in the overall $\rho_{SFR}(M)$ out to at least $z \sim 1.2$.

The galaxy stellar mass function at 3.5<z<7.5 in the CANDELS/UDS, GOODS-South, and HUDF fields

Grazian, A.; Fontana, A.; Santini, P.; Dunlop, J. S.; Ferguson, H. C.; Castellano, M.; Amorin, R.; Ashby, M. L. N.; Barro, G.; Behroozi, P.; and 31 coauthors.

2015, A&A, 575, 96

The galaxy stellar mass function (GSMF) at high-z provides key information on star-formation history and mass assembly in the young Universe. We aimed to use the unique combination of deep optical/NIR/MIR imaging provided by HST, Spitzer and the VLT in the CANDELS-UDS, GOODS-South, and HUDF fields to determine the GSMF over the redshift range 3.5<z<7.5. We utilised the HST WFC3/IR NIR imaging from CANDELS and HUDF09, reaching H~27-28.5 over a total area of 369 arcmin^2, in combination with associated deep HST ACS optical data, deep Spitzer IRAC imaging from the SEDS programme, and deep Y and K-band VLT Hawk-I images from the HUGS programme, to select a galaxy sample with high-quality photometric redshifts. These have been calibrated with more than 150 spectroscopic redshifts in the range 3.5<z<7.5, resulting in an overall precision of sigma_z/(1+z)~0.037. We have determined the low-mass end of the high-z GSMF with unprecedented precision, reaching down to masses as low as $M^* \sim 10^9$ M_{sun} at z=4 and $\sim 6 \times 10^9$ M_{sun} at z=7. We find that the GSMF at 3.5<z<7.5 depends only slightly on the recipes adopted to measure the stellar masses, namely the photo-z, the SFHs, the nebular contribution or the presence of AGN on the parent sample. The low-mass end of the GSMF is steeper than has been found at lower redshifts, but appears to be unchanged over the redshift range probed here. Our results are very different from previous GSMF estimates based on converting UV galaxy luminosity functions into mass functions via tight M/L relations. Integrating our evolving GSMF over mass, we find that the growth of stellar mass density is barely consistent with the time-integral of the SFR density

over cosmic time at z>4. These results confirm the unique synergy of the CANDELS+HUDF, HUGS, and SEDS surveys for the discovery and study of moderate/low-mass galaxies at high redshifts.

T-PHOT: A new code for PSF-matched, prior-based, multiwavelength extragalactic deconfusion photometry

Merlin, E.; Fontana, A.; Ferguson, H. C.; Dunlop, J. S.; Elbaz, D.; Bourne, N.; Bruce, V. A.; Buitrago, F.; Castellano, M.; Schreiber, C.; and 12 coauthors

2015, A&A, 582, 15

Context. The advent of deep multiwavelength extragalactic surveys has led to the necessity for advanced and fast methods for photometric analysis. In fact, codes which allow analyses of the same regions of the sky observed at different wavelengths and resolutions are becoming essential to thoroughly exploit current and future data. In this context, a key issue is the confusion (i.e. blending) of sources in low-resolution images.

Aims: We present t-phot, a publicly available software package developed within the astrodeep project. t-phot is aimed at extracting accurate photometry from low-resolution images, where the blending of sources can be a serious problem for the accurate and unbiased measurement of fluxes and colours.

Methods: t-phot can be considered as the next generation to tfit, providing significant improvements over and above it and other similar codes (e.g. convphot). t-phot gathers data from a high-resolution image of a region of the sky, and uses this information (source positions and morphologies) to obtain priors for the photometric analysis of the lower resolution image of the same field. t-phot can handle different types of datasets as input priors, namely i) a list of objects that will be used to obtain cutouts from the real high-resolution image; ii) a set of analytical models (as .fits stamps); iii) a list of unresolved, point-like sources, useful for example for far-infrared (FIR) wavelength domains.

Results: By means of simulations and analysis of real datasets, we show that t-phot yields accurate estimations of fluxes within the intrinsic uncertainties of the method, when systematic errors are taken into account (which can be done thanks to a flagging code given in the output). t-phot is many times faster than similar codes like tfit and convphot (up to hundreds, depending on the problem and the method adopted), whilst at the same time being more robust and more versatile. This makes it an excellent choice for the analysis of large datasets. When used with the same parameter sets as for tfit it yields almost identical results (although in a much shorter time); in addition we show how the use of different settings and methods significantly enhances the performance.

Conclusions: t-phot proves to be a state-of-the-art tool for multiwavelength optical to far-infrared image photometry. Given its versatility and robustness, t-phot can be considered the preferred choice for combined photometric analysis of current and forthcoming extragalactic imaging surveys.

t-phot is publicly available for downloading from http://www.astrodeep.eu/t-phot/

The imprint of rapid star formation quenching on the spectral energy distributions of galaxies

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2016, A&A, 585, 43

In high density environments, the gas content of galaxies is stripped, leading to a rapid quenching of their star formation activity. This dramatic environmental effect, which is not related to typical passive evolution, is generally not taken into account in the star formation histories (SFHs) usually assumed to perform spectral energy distribution (SED) fitting of these galaxies, yielding a poor fit of their stellar emission and, consequently, biased estimate of the star formation rate (SFR). In this work, we aim at reproducing this rapid quenching using a truncated delayed SFH that we implemented in the SED fitting code CIGALE. We show that the ratio between the instantaneous SFR and the SFR just before the quenching (r_{SFR}) is well constrained as long as rest-frame UV data are available. This SED modeling is applied to the Herschel Reference Survey (HRS) containing isolated galaxies and sources falling in the dense environment of the Virgo cluster. The latter are Hi-deficient because of ram pressure stripping. We show that the truncated delayed SFH successfully reproduces their SED, while typical SFH assumptions fail. A good correlation is found between r_{SFR} and Hi-def, the parameter that quantifies the gas deficiency of cluster galaxies, meaning that SED fitting results can be used to provide a tentative estimate of the gas deficiency of galaxies for which Hi observations are not available. The HRS galaxies are placed on the SFR-M_* diagram showing that the Hi-deficient sources lie in the quiescent region, thus confirming previous studies. Using the r_{SFR} parameter, we derive the SFR of these sources before quenching and show that they were previously on the main sequence relation. We show that the r_{SFR} parameter is also recovered well for deeply obscured high redshift sources, as well as in the absence of IR data. SED fitting is thus a powerful tool for identifying galaxies that underwent a rapid star formation quenching.

The Lyman continuum escape fraction of galaxies at z = 3.3 in the VUDS-LBC/COSMOS field

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2016, A&A, 585, 48

Context. The ionizing Lyman continuum flux escaping from high-redshift galaxies into the intergalactic medium is a fundamental quantity to understand

the physical processes involved in the reionization epoch. However, from an observational point of view, direct detections of HI ionizing photons at high redshifts are feasible for galaxies mainly in the interval z ~ 3-4. Aims: We have investigated a sample of star-forming galaxies at z ~ 3.3 to search for possible detections of Lyman continuum ionizing photons escaping from galaxy halos.
Methods: We used deep ultraviolet (UV) imaging in the COSMOS field, obtained with the prime focus camera LBC at the LBT telescope, along with a catalogue of spectroscopic redshifts obtained by the VIMOS Ultra Deep Survey (VUDS) to build a sample of 45 galaxies at z ~ 3.3 with L> 0.5 L^*. We obtained deep LBC images of galaxies with spectroscopic redshifts in the interval 3.27 <z< 3.40 both in the R- and deep U-bands (magnitude limit U ~ 29.7 at S/N = 1). At these redshifts, the R-band samples the non-ionizing 1500 Å rest-frame luminosity and the U-band samples the rest-frame spectral region just short-ward of the Lyman edge at 912 Å. Their flux ratio is related to the ionizing escape fraction after statistical removal of the absorption by the intergalactic medium along the line of sight.
Results: A subsample of ten galaxies apparently shows escape fractions >28%, but a detailed analysis of their properties reveals that, with the exception of two marginal detections (S/N ~ 2) in the U-band, all the other eight galaxies are most likely contaminated by the UV flux of low-redshift interlopers located close (in angular position) to the high-z targets. The average escape fraction derived from the stacking of the cleaned sample was constrained to f_{esc}^{rel} < 2%. The implied hydrogen photoionization rate is a factor two lower than that needed to keep the intergalactic medium ionized at z ~ 3, as observed in the Lyman-α forest of high-z quasar spectra or by the proximity effect.
Conclusions: These results support a scenario where high redshift, relatively bright (L ≥ 0.5L^*) star-forming galaxies alone are unable to sustain the level of ionization observed in the cosmic intergalactic medium at z ~ 3. Star-forming galaxies at higher redshift and at fainter luminosities (L ≪ L^*) can only be major contributors to the reionization of the Universe if their physical properties are subject to rapid changes from z ~ 3 to z ~ 6-10. Alternatively, ionizing sources could be discovered looking for fainter sources among the active galactic nuclei population at high redshift.

Abstracts of papers submitted for publication or in press

The galaxy UV luminosity function at z ~ 2 - 4; new results on faint-end slope and the evolution of luminosity density
Parsa, Shaghayegh; Dunlop, James S.; McLure, Ross J.; Mortlock, Alice
2015, arXiv:1507.05629
We present a new, robust measurement of the evolving rest-frame UV galaxy

luminosity function (LF) over the key redshift range z = 2 - 4. Our results are based on the high dynamic range provided by combining the HUDF, CANDELS/GOODS-South, and UltraVISTA/COSMOS surveys. We utilise the unparalleled multi-frequency photometry available in this survey `wedding cake' to compile complete galaxy samples at z ~ 2,3,4 via photometric redshifts (calibrated against the latest spectroscopy) rather than colour-colour selection, and to determine accurate rest-frame UV absolute magnitudes from SED fitting. Our new determinations of the UV LF extend from M_{1500} ~ -22 down to M_{1500} = -14.5, -15.5 and -16 at z ~ 2, 3 and 4 respectively (thus reaching ~ 3 - 4 magnitudes fainter than previous blank-field studies at z ~ 2 - 3). At z ~ 2 - 3 we find a much shallower faint-end slope (alpha = -1.32 +- 0.03) than the steeper values (alpha ~ -1.7) reported by Reddy & Steidel (2009) or by Alavi et al. (2014), and show that this new measurement is robust. By z ~ 4 the faint-end slope has steepened slightly, to alpha = -1.43 +- 0.04, and we show that these measurements are consistent with the overall evolutionary trend from z = 0 to z = 8. Finally, we find that while characteristic number density (phi*) drops from z ~ 2 to z ~ 4, characteristic luminosity (M*) brightens by ~ 1 mag over this redshift range. This, combined with the new flatter faint-end slopes, has the consequence that UV luminosity density (and hence unobscured star-formation density) peaks at z ~ 2.5 - 3, when the Universe was ~ 2.5 Gyr old.

The SCUBA-2 Cosmology Legacy Survey: galaxies in the deep 850-micron survey, and the star-forming `main sequence'

Koprowski, M.; Dunlop, J. S.; Michalowski, M. J.; Roseboom, I.; Geach, J. E.; Cirasuolo, M.; Aretxaga, I.; Bowler, R. A. A.; Banerji, M.; Bourne, N.; and 7 coauthors

2015, arXiv:1509.07144

We investigate the properties of the galaxies selected from the deepest 850-micron survey undertaken to date with SCUBA-2 on the JCMT. This deep 850-micron imaging was taken in parallel with deep 450-micron imaging in the very best observing conditions as part of the SCUBA-2 Cosmology Legacy Survey. A total of 106 sources were uncovered at 850 microns from ~150, sq. arcmin in the centre of the COSMOS/UltraVISTA/CANDELS field, imaged to a typical rms depth of ~0.25 mJy. We utilise the wealth of available deep multi-frequency data to establish the complete redshift distribution for this sample, yielding <z> = 2.38 +- 0.09, a mean redshift comparable with that derived for all but the brightest previous sub-mm samples. We have also been able to establish the stellar masses of the majority of the galaxy identifications, enabling us to explore their location on the star-formation-rate:stellar-mass (SFR:M*) plane. Crucially, our new deep sample reaches flux densities equivalent to SFR ~ 100 Msun/yr, enabling us to confirm that sub-mm galaxies form the high-mass end of the `main sequence' (MS) of star-forming galaxies at z > 1.5 (with a mean specific SFR of sSFR = 2.25 +- 0.19 /Gyr at z ~ 2.5). Our results are consistent with no

significant flattening of the MS towards high masses at these redshifts, suggesting that reports of such flattening possibly arise from under-estimates of dust-enshrouded star-formation activity in massive star-forming galaxies. However, our findings add to the growing evidence that average sSFR rises only slowly at high redshift, resulting in log(sSFR) being an apparently simple linear function of the age of the Universe.

The bulge-disk decomposition of AGN host galaxies
Bruce, V. A.; Dunlop, J. S.; Mortlock, A.; Kocevski, D. D.; McGrath, E. J.; Rosario, D. J.
2015, arXiv:1510.03870
We present the results from a study of the morphologies of moderate luminosity X-ray selected AGN host galaxies in comparison to a carefully mass-matched control sample at 0.5 < z < 3 in the CANDELS GOODS-S field. We apply a multi-wavelength morphological decomposition analysis to these two samples and report on the differences between the morphologies as fitted from single Sersic and multiple Sersic models, and models which include an additional nuclear point-source component. Thus, we are able to compare the widely adopted single Sersic fits from previous studies to the results from a full morphological decomposition, and address the issue of how biased the inferred properties of AGN hosts are by a potential nuclear contribution from the AGN itself. We find that the AGN hosts are mixed systems which have higher bulge fractions than the control sample in our highest redshift bins at the >99.7% confidence level, according to all model fits even those which adopt a point-source component. This serves to alleviate concerns that previous, purely single Sersic, analyses of AGN hosts could have been spuriously biased towards higher bulge fractions. This dataset allows us to further probe the physical nature of these point-source components; we find no strong correlation between the point-source component and AGN activity, and that these point-source components are best modelled physically by nuclear starbursts. Our analysis of the bulge and disk fractions of these AGN hosts in comparison to a mass-matched control sample reveals a similar morphological evolutionary track for both the active and non-active populations, providing further evidence in favour of a model where AGN activity is triggered by secular processes.

The evolution of the equivalent width of the Ha emission line and specific star-formation rate in star-forming galaxies at 1<z<5
Marmol-Queralto, E.; McLure, R. J.; Cullen, F.; Dunlop, J. S.; Fontana, A.; McLeod, D. J.
2015, arXiv:1511.01911
We present the results of a study which uses spectral energy distribution (SED) fitting to investigate the evolution of the equivalent width (EW) of the Halpha emission line in star-forming galaxies over the redshift interval 1<z<5. After first

demonstrating the ability of our SED-fitting technique to recover EW(Ha) using a sample of galaxies at z~1.3 with EW(Ha) measurements from 3D-HST grism spectroscopy, we proceed to apply our technique to samples of spectroscopically confirmed and photometric-redshift selected star-forming galaxies at z>=1 in the CANDELS UDS and GOODS-S fields. Confining our analysis to a constant stellar mass range ($9.5<\log(M/M_{sun})<10.5$), we find that the median EW(Ha) evolves only modestly with redshift, reaching a rest-frame value of EW(Ha)=301+/-30 Angs by redshift z~4.5. Furthermore, using estimates of star-formation rate (SFR) based on both UV luminosity and Ha line flux, we use our galaxy samples to compare the evolution of EW(Ha) and specific star-formation rate (sSFR). Our results indicate that over the redshift range 1<z<5, the evolution displayed by EW(Ha) and sSFR is consistent, and can be adequately parameterized as: propto $(1+z)^{1.0+/-0.2}$. As a consequence, over this redshift range we find that the sSFR and rest-frame EW(Ha) of star-forming galaxies with stellar masses $M\sim10^{10}$ M_{sun} are related by: EW(Ha)/Ang=(63+/-7)sSFR/Gyr^{-1}. Given the current uncertainties in measuring the SFRs of high-redshift galaxies, we conclude that EW(Ha) provides a useful independent tracer of sSFR for star-forming galaxies out to redshifts of z=5.

Identification of z >2 Herschel 500 micron sources using color-deconfusion
Shu, X. W.; Elbaz, D.; Bourne, N.; Schreiber, C.; Wang, T.; Dunlop, J. S.; Fontana, A.; Leiton, R.; Pannella, M.; Okumura, K.; and 12 coauthors
2015, arXiv:1512.00167
We present a new method to search for candidate z>2 Herschel 500um sources in the GOODS-North field, using a S500um/S24um "color deconfusion" technique. Potential high-z sources are selected against low-redshift ones from their large 500um to 24um flux density ratios. By effectively reducing the contribution from low-redshift populations to the observed 500um emission, we are able to identify counterparts to high-z 500um sources whose 24um fluxes are relatively faint. The recovery of known z~4 starbursts confirms the efficiency of this approach in selecting high-z Herschel sources. The resulting sample consists of 34 dusty star-forming galaxies at z~>2. The inferred infrared luminosities are in the range $1.5x10^{12}$-$1.8x10^{13}$ L_{sun}, corresponding to dust-obscured star formation rates (SFRs) of ~260-3100 M_{sun}/yr for a Salpeter IMF. Comparison with previous SCUBA 850um-selected galaxy samples shows that our method is more efficient at selecting high-z dusty galaxies with a median redshift of z=3.07+/-0.83 and 10 of the sources at z>4. We find that at a fixed luminosity, the dust temperature is ~5K cooler than that expected from the Td-LIR relation at z<1, though different temperature selection effects should be taken into account. The radio-detected subsample (excluding three strong AGN) follows the far-infrared/radio correlation at lower redshifts, and no evolution with redshift is observed out to z~5, suggesting that the far-infrared emission is

star formation dominated. The contribution of the high-z Herschel 500um sources to the cosmic SFR density is comparable to that of SMG populations at z~2.5 and at least 40% of the extinction-corrected UV samples at z~4 (abridged).

Chandra counterparts of CANDELS GOODS-S sources

Cappelluti, N.; Comastri, A.; Fontana, A.; Zamorani, G.; Amorin, R.; Castellano, M.; Merlin, E.; Santini, P.; Elbaz, D.; Schreiber, C.; and 11 coauthors

2015, arXiv:1512.00510

Improving the capabilities of detecting faint X-ray sources is fundamental to increase the statistics on faint high-z AGN and star-forming galaxies.We performed a simultaneous Maximum Likelihood PSF fit in the [0.5-2] keV and [2-7] keV energy bands of the 4 Ms Chandra Deep Field South (CDFS) data at the position of the 34930 CANDELS H-band selected galaxies. For each detected source we provide X-ray photometry and optical counterpart validation. We validated this technique by means of a ray-tracing simulation. We detected a total of 698 X-ray point sources with a likelihood L>4.98 (i.e. >2.7 sigma). We show that the prior knowledge of a deep sample of Optical-NIR galaxies leads to a significant increase of the detection of faint (i.e. $\sim 10^{-17}$ cgs in the [0.5-2] keV band) sources with respect to "blind" X-ray detections. By including previous catalogs, this work increases the total number of X-ray sources detected in the 4 Ms CDFS, CANDELS area to 793, which represents the largest sample of extremely faint X-ray sources assembled to date. Our results suggest that a large fraction of the optical counterparts of our X-ray sources determined by likelihood ratio actually coincides with the priors used for the source detection. Most of the new detected sources are likely star-forming galaxies or faint absorbed AGN. We identified a few sources sources with putative photometric redshift z>4. Despite the low number statistics, this sample significantly increases the number of X--ray selected candidate high-z AGN.

Infrared color selection of massive galaxies at z > 3

Wang, T.; Elbaz, D.; Schreiber, C.; Pannella, M.; Shu, X.; Willner, S. P.; Ashby, M. L. N.; Huang, J.-S.; Fontana, A.; Dekel, A.; and 22 coauthors

2015, arXiv:1512.02656

We introduce a new color-selection technique to identify high-redshift, massive galaxies that are systematically missed by Lyman-break selection. The new selection is based on the H_{160} and IRAC 4.5um bands, specifically H - [4.5] > 2.25 mag. These galaxies, dubbed "HIEROs", include two major populations that can be separated with an additional J - H color. The populations are massive and dusty star-forming galaxies at z > 3 (JH-blue) and extremely dusty galaxies at z < 3 (JH-red). The 350 $arcmin^2$ of the GOODS-N and GOODS-S fields with the deepest HST/WFC3 and IRAC data contain 285 HIEROs down to [4.5] < 24 mag.

We focus here primarily on JH-blue (z > 3) HIEROs, which have a median photometric redshift z ~4.4 and stellar mass $M_* \sim 10^{10.6}$ M_{sun}, and are much fainter in the rest-frame UV than similarly massive Lyman-break galaxies (LBGs). Their star formation rates (SFRs) reaches ~240 M_{sun} yr^{-1} leading to a specific SFR, sSFR ~4.2 Gyr^{-1}, suggesting that the sSFRs for massive galaxies continue to grow at z > 2 but at a lower growth rate than from z=0 to z=2. With a median half-light radius of 2 kpc, including ~20% as compact as quiescent galaxies at similar redshifts, JH-blue HIEROs represent perfect star-forming progenitors of the most massive ($M_* > 10^{11.2}$ M_{sun}) compact quiescent galaxies at z ~ 3 and have the right number density. HIEROs make up ~60% of all galaxies with $M_* > 10^{10.5}$ M_{sun} identified at z > 3 from their photometric redshifts. This is five times more than LBGs with nearly no overlap between the two populations. While HIEROs make up 15-25% of the total SFR density at z ~ 4-5, they completely dominate the SFR density taking place in $M_* > 10^{10.5}$ M_{sun} galaxies, and are therefore crucial to understanding the very early phase of massive galaxy formation.