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Galaxies at High Redshift and their Evolution over Cosmic Time

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Sugata Kaviraj

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GALAXIES AT HIGH REDSHIFT AND THEIR
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COVER ILLUSTRATION:

A mosaic taken in 2009 with the then-newly-installed Wide Field Camera 3 (WFC3) and in 2004 with the Advanced Camera for Surveys (ACS), both on board the Hubble Space Telescope. The image combines colors from ultraviolet, through visible light and into the near-infrared and shows around 7500 galaxies in the Great Observatories Origins Deep Survey (GOODS) field. The closest galaxies seen here emitted their observed light about a billion years ago, while the farthest galaxies appear as they used to be around 650 million years after the Big Bang.

Credit: NASA, ESA, R. Windhorst, S. Cohen, M. Mechtley, and M. Rutkowski (Arizona State University, Tempe), R. O'Connell (University of Virginia), P. McCarthy (Carnegie Observatories), N. Hathi (University of California, Riverside), R. Ryan (University of California, Davis), H. Yan (Ohio State University), A. Koekemoer (Space Telescope Science Institute) and Z. Levay (STScI)

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**PROCEEDINGS OF THE 319th SYMPOSIUM
OF THE INTERNATIONAL ASTRONOMICAL
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AUGUST 11–14, 2015**

Edited by

SUGATA KAVIRAJ

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Table of Contents

Preface	x
The First Few Billion Years	
Dark Matter Halos and the Main Sequence of Starforming Galaxies <i>H. Aussel, S. Peirani & L. Vigroux</i>	1
Anomalies in the GRBs' distribution <i>Z. Bagoly, I. Horváth, J. Hakkila & L. V. Tóth</i>	2
Spatial distribution of GRBs and large scale structure of the Universe <i>Z. Bagoly, I. I. Rácz, L. G. Balázs, L. V. Tóth & I. Horváth</i>	3
Alignment of Red-Sequence Cluster Dwarf Galaxies: From the Frontier Fields to the Local Universe <i>W. A. Barkhouse, H. Archer, J. Burgad, G. Foote, C. Rude & O. López-Cruz</i>	5
Chemical Enrichment of the First Binaries <i>K.-J. Chen</i>	6
Galaxies at $z \sim 6$: physical properties at the edge of the cosmic reionization.... <i>S. de Barros, E. Vanzella, L. Pentericci, A. Fontana, A. Grazian & M. Castellano</i>	7
Characterizing the galaxy populations within different environments in the RCS2319 supercluster <i>A. Delahaye & T. Webb</i>	10
Wide-Field Slitless Spectroscopy with JWST's NIRISS <i>W. V. Dixon, S. Ravindranath & C. J. Willott</i>	11
A MUSE View of the HDFS: The Ly α Luminosity Function out to $z \sim 6$ <i>A. B. Drake, B. Guiderdoni, J. Blaizot, J. Richard, R. Bacon, T. G. T. Hashimoto & the MUSE Consortium</i>	12
Clustering of massive compact galaxies at $1 \leq z \leq 3$ in CANDELS/3D-HST ... <i>L. Fan, X. Lin, X. Kong & G. Fang</i>	16
The self-regulated AGN feedback loop: the role of chaotic cold accretion..... <i>M. Gaspari</i>	17
Properties of high z galaxies in the ELTs era <i>L. Greggio, M. Gullieuszik, R. Falomo, D. Fantinel & M. Uslenghi</i>	21
The VIMOS Ultra Deep Survey: Ly α Emission and Stellar Populations of Star- Forming Galaxies at $2 < z < 6$ <i>N. P. Hathi, O. Le Fèvre & the VUDS team</i>	22
The impact of stellar feedback on high- z galaxy populations..... <i>M. Hirschmann & G. De Lucia</i>	26
UV escape fraction and dust distribution of star forming galaxies at $z = 0 - 3$: a new dust attenuation model <i>H. Kusakabe, K. Shimasaku & I. Shimizu</i>	27

Quenching of Star-formation Activity of High-redshift Galaxies in Clusters and Field	28
<i>S.-K. Lee, M. Im, J.-W. Kim, J. Lotz, C. McPartland, M. Peth & A. Koekemoer</i>	
The contribution of major mergers to the creation of spheroidal galaxies and the build up of stellar mass at $z \sim 2$	29
<i>E. K. Lofthouse, S. Kaviraj, C. J. Conselice & A. Mortlock</i>	
The Galaxy UV Luminosity Function Before the Epoch of Reionization	33
<i>C. A. Mason, M. Trenti & T. Treu</i>	
High-redshift quasars and blazars and their relation to high-redshift galaxies . .	34
<i>A. Micaelian, H. Abrahamyan & G. Paronyan</i>	
Can we infer the Initial Mass Function of galaxies at $z \sim 2$?	35
<i>T. Nanayakkara, K. Glazebrook & The ZFIRE Team</i>	
Probabilistic Selection of High-redshift Quasars with Subaru/Hyper Suprime-Cam Survey	39
<i>M. Onoue</i>	
New Results on DLA Systems: Statistics	40
<i>S. Rao, D. Turnshek, E. Monier & G. Sardane</i>	
Ultra-Fast Outflows in Typical Redshift 2 Star-Forming Galaxies	41
<i>O. Roos & F. Bournaud</i>	
A consistent view on star-forming galaxies at high redshift from multi-wavelength observations and SED modeling	45
<i>D. Schaerer, S. de Barros & F. Boone</i>	
Probing Reionization at $z \gtrsim 7$ with <i>HST</i> 's Near-Infrared Grisms	49
<i>K. B. Schmidt & The GLASS Team</i>	
Toward unveiling internal properties of HII regions and their connections at the cosmic noon era	53
<i>R. Shimakawa, T. Kodama, M. Hayashi, K.-i. Tadaki, T. L. Suzuki, Y. Koyama, I. Tanaka & M. Yamamoto</i>	
Limits to Seeing High-Redshift Galaxies Due to Planck-Scale-Induced Blurring .	54
<i>E. Steinbring</i>	
Prime Focus Spectrograph: A very wide-field, massively multiplexed, optical & near-infrared spectrograph for Subaru Telescope	55
<i>N. Tamura & PFS collaboration</i>	
Photometric Redshifts in the Hawaii-Hubble Deep Field-North	56
<i>G. Yang, Y. Q. Xue, B. Luo, W. N. Brandt, D. M. Alexander, F. E. Bauer, W. Cui, X. Kong, B. D. Lehmer, J.-X. Wang, X.-B. Wu, F. Yuan, Y.-F. Yuan & H. Y. Zhou</i>	
Photometric Redshift Techniques in Big-data Era	57
<i>Y.-X. Zhang & Y.-H. Zhao</i>	

Black holes and AGN at high redshift and their evolution with cosmic time	
Wide-Angle Quasar Feedback	58
<i>G. Chartas & S. Strickland</i>	
The Keck OSIRIS Nearby AGN (KONA) Survey: AGN Fueling and Feedback . .	59
<i>Erin K. S. Hicks, F. Müller-Sánchez, M. A. Malkan & P.-C. Yu</i>	
Metallicities in cosmological simulations with AGN feedback	60
<i>C. Kobayashi & P. Taylor</i>	
The quasar clustering and its evolution in a semi-analytic model based on ultra high-resolution N -body simulations	61
<i>T. Oogi, M. Enoki, T. Ishiyama, M. A. R. Kobayashi, R. Makiya & M. Nagashima</i>	
The High-Redshift Clusters Occupied by Bent Radio AGN (COBRA) Survey . .	62
<i>R. Paterno-Mahler, E. L. Blanton, J. Wing, M. L. N. Ashby, M. Brodwin & E. Golden-Marr</i>	
AGN - Dust-Obscured Galaxies at $z \sim 1-3$ revealed by near-to-far infrared SED-fitting.	63
<i>L. Riguccini, et al.</i>	
SuperMassive Blackholes grow from stellar BHs of star formation history?	64
<i>B. Rocca-Volmerange</i>	
Probing the Interplay between AGN Outflows and their Host Galaxies: Optical Integral Field Unit and Radio Imaging.	66
<i>P. Shastri on behalf of the S7 team</i>	
Large Scale Outflow from a Radio Loud AGN in Merging Galaxies at Redshift 2.48	67
<i>H.-Y. Shih & A. Stockton</i>	
Properties of galaxies around the most massive SMBHs	71
<i>Y. Shirasaki, Y. Komiya, M. Ohishi & Y. Mizumoto</i>	
The evolution of high-redshift massive black holes	72
<i>M. Volonteri, M. Habouzit, F. Pacucci & M. Tremmel</i>	
Discovery of a 12 billion solar mass black hole at redshift 6.3 and its challenge to the black hole/galaxy coevolution at cosmic dawn	80
<i>X.-B. Wu, F. Wang, X. Fan, W. Yi, W. Zuo, F. Bian, L. Jiang, I. D. McGreer, R. Wang, J. Yang, Q. Yang, D. Thompson & Y. Beletsky</i>	
Long wavelengths at high redshift (ISM, IGM, gas-star formation connection)	
Dusty Galaxies at the Highest Redshifts	84
<i>D. L. Clements, J. Greenslade, D. A. Riechers, J. Wardlow, I. Pérez-Fournon, The HerMES Red Collective, The HerMES & H-ATLAS Consortia</i>	
New emerging results on molecular gas, stars, and dust at $z \sim 2$, as revealed by low star formation rate and low stellar mass star-forming galaxies	88
<i>M. Dessauges-Zavadsky, M. Zamojski, D. Schaerer, F. Combes, E. Egami, P. Sklias, M. A. Swinbank, J. Richard & T. Rawle</i>	

SXDF-UDS-CANDELS-ALMA 1.5 arcmin ² deep survey	92
<i>K. Kohno, Y. Yamaguchi, Y. Tamura, K. Tadaki, B. Hatsukade, S. Ikarashi, K. I. Caputi, W. Rujopakarn, R. J. Ivison, J. S. Dunlop, K. Motohara, H. Umehata, K. Yabe, W.H. Wang, T. Kodama, Y. Koyama, M. Hayashi, Y. Matsuda, D. Hughes, I. Aretzaga, G. W. Wilson, M. S. Yun, K. Ohta, M. Akiyama, R. Kawabe, D. Iono, K. Nakanishi, M. Lee & R. Makiya</i>	
Massive and dusty H α emitters in protocluster revealed by ALMA and JVLA . .	96
<i>M. Lee & 4C23.56 Protocluster team</i>	
Are quiescent galaxies truly devoid of star formation? The mid-, far-infrared and radio properties of quiescent galaxies at $z = 0.1 - 3$	97
<i>A. W. S. Man</i>	
A selection of AKARI FIS BSC extragalactic objects	101
<i>G. Marton, L. V. Tóth, L. G. Balázs, S. Zahorecz, Z. Bagoly, I. Horváth, I. I. Rácz & A. Nagy</i>	
The Planck List of High- z source candidates : A laboratory for high- z star-forming galaxies	102
<i>L. Montier on behalf of the Planck collaboration</i>	
A snapshot beyond the Local Universe with Herschel/SPIRE	103
<i>S. Pinter, G. Marton, L. V. Toth, C. Pearson, Z. Bagoly, L. G. Balazs, I. Horvath & I. I. Racz</i>	
The Intricate Role of Cold Gas and Dust in Galaxy Evolution at Early Cosmic Epochs.	105
<i>D. A. Riechers, P. L. Capak & C. L. Carilli</i>	
Dusty Starbursts within a $z=3$ Large Scale Structure revealed by ALMA	109
<i>H. Umehata</i>	
Herschel/SPIRE colors of galaxies at $z>2.5$	110
<i>F.-T. Yuan, V. Buat, D. Burgarella, L. Ciesla, S. Heinis, S. Shen, Z.-Y. Shao & J. -L. Hou</i>	
The evolution of galaxy morphology and galaxies at low redshift	
Ultra Massive Passive Galaxies at $z\sim 1.7$	111
<i>L. Arcila-Osejo, M. Sawicki, A. Golob, S. Arnouts & T. Moutard</i>	
Environmental Effects on Galaxy Evolution: Multifrequency study of nearby clusters.	112
<i>H. Bravo-Alfaro, Y. Venkatapathy, F. Durret, C. A. Caretta & V. Gamez</i>	
Exploring the vertical age structure of the Galactic disc	113
<i>L. Casagrande</i>	
Understanding the size growth of massive galaxies through stellar populations. .	114
<i>I. Ferreras, I. Trujillo, E. Mármol-Queraltó, P. Pérez-González & the SHARDS team</i>	
Galaxy morphologies in the era of big-data surveys	118
<i>M. Huertas-Company</i>	

The Green Peas: Searching for LyC Emitters at Low Redshift	126
<i>A. Jaskot & S. Oey</i>	
Life in Low Density Environments – Field Galaxies from $z = 1.0$ to the Present.	127
<i>I. Jørgensen, S. Fisher, C. Woodrum, T. Kwan & J. Bieker</i>	
Early and Late Life - Bulge-Dominated Galaxies over the Last 8-9 Gyr.	128
<i>I. Jørgensen, K. Chiboucas, M. Bergmann, S. Toft & R. Schiavon</i>	
The evolution of the spiral galaxy M51a	129
<i>X. Kang, F. Zhang & R. Chang</i>	
Minor mergers: fundamental but unexplored drivers of galaxy evolution	130
<i>S. Kaviraj</i>	
Variability in the light curve of tidal disruption events	137
<i>Z.-J. Lu, D.-B. Lin, L.-H. Xie & E.-W. Liang</i>	
Evolution of bulgeless low surface brightness galaxies	138
<i>X. Shao, F. Hammer, Y. B. Yang & Y. C. Liang</i>	
Comparing the host galaxies of different type supernovae	139
<i>Y. C. Liang, X. Shao, M. Dennefeld, X. Y. Chen, L. Zhou & F. Hammer</i>	
Environmental Effects on LRGs as Cosmic Chronometers	140
<i>G. Liu, Y. Lu, L. Xie, X. Chen & Y. Zhao</i>	
Identifying Remote Halo Giants in High-Latitude Fields with Kepler 2	141
<i>R. C. Peterson</i>	
MHD simulations of ram pressure stripping of disk galaxies	143
<i>M. Ramos-Martínez & G. C. Gómez</i>	
The Distribution of Stellar Populations within Galaxies	144
<i>L. Sodré Jr. & P. M. de Novais</i>	
The Enhancement of BAO in the SDSS MGS	145
<i>H. J. Tian, M. C. Neyrinck, T. Budavári & A. S. Szalay</i>	
Comparison of Approaches to Photometric Redshift Estimation of Quasars	146
<i>Y. Tu, Y.-X. Zhang, Y.-H. Zhao & H.-J. Tian</i>	
Author index	147

Preface

Over the last two decades, a convergence of powerful observational facilities and high-performance computing has significantly advanced our understanding of galaxy evolution. Detailed empirical studies have quantified the evolution of galaxy properties (particularly over the latter half of cosmic time) and theoretical models, within the framework of the Λ CDM paradigm, have met with significant success in reproducing these properties. While our knowledge is still dominated by work in the nearby ($z < 1$) Universe, an explosion of multi-wavelength data at high redshift is revolutionising our understanding of emergent galaxies at $z > 1$. Since the bulk of the cosmic stellar-mass assembly and black-hole growth takes place at these redshifts (both peaking around $z \sim 2$), answers to basic questions at these epochs are central to a complete understanding of galaxy evolution. For example, what processes drove the growth of early stellar populations and black holes? How did interactions between galaxies and their constituent black holes shape the Universe we see today? How did the morphological mix of the visible Universe evolve into today's Hubble sequence? How well do our current theoretical models reproduce the properties of galaxies in the early Universe?

Recent and ongoing work is delivering a dramatic improvement in our understanding of these fundamental questions. HST surveys like CANDELS, combined with facilities like Spitzer and Herschel, are now constraining galaxy parameters, such as star-formation rates, ages, metallicities, masses and sizes, to $z \sim 2$ and beyond. Together with deep Chandra observations, these data are probing the co-evolution of early galaxies and their black holes, and the role of AGN in shaping their host systems at these early epochs. High-resolution near-infrared imaging from the HST is quantifying the origin and evolution of the Hubble sequence in the early Universe, allowing us to probe the evolving morphological mix of the visible Universe over cosmic time. In parallel, near-infrared integral-field spectrographs on 10m class telescopes such as SINFONI and OSIRIS, together with facilities like IRAM, are enabling detailed spatially-resolved studies of the kinematics, star formation and molecular gas in significant samples of early galaxies, yielding crucial insights into what drives the assembly of the stellar populations that dominate our Universe today. This growing empirical literature is motivating an array of theoretical work, in particular high-resolution hydro-simulations, which are elucidating the cosmic drivers of stellar-mass buildup, black-hole growth and morphological transformations with unprecedented accuracy.

Our current understanding of galaxy evolution will shortly be bolstered by new instruments with multiplexing capabilities, such as KMOS, MUSE and MOSFIRE, and those that offer high-resolution imaging in the long-wavelength regime, such as ALMA and the SKA precursors (e-MERLIN, LOFAR, etc.). These will enable unprecedented studies of stellar and gas kinematics at high redshift and allow us to investigate the poorly-understood interplay between gas and star formation in the early Universe. Looking further ahead to the turn of the decade, the field is poised for yet another revolution, both in terms of the ground-breaking depth and area offered by future imaging and spectroscopic surveys (e.g. LSST, Euclid, DES, 4MOST, MOONS), and our ability to comprehensively probe galaxy evolution all the way up to the epoch of reionization, using instruments like the JWST and the ELTs.

The time is therefore ripe for bringing together the wealth of empirical and theoretical studies that are leveraging today's instruments, and set the stage for the exploitation of new and forthcoming facilities. For example, the interpretation of current multi-wavelength survey data (e.g. HST programmes like CANDELS, Herschel, etc.) will

be mature, and large sets of data will be available from new instruments such as KMOS, ALMA and e-MERLIN. In the same vein, while theoretical simulations are just starting to produce realistic assembly histories for early galaxies, more accurate analyses are expected shortly (quite possibly revealing new questions and challenges).

IAU Symposium 319 was designed as a conference that critically reviewed our current and ongoing studies of the early Universe and identified the community's key challenges and goals in the context of future instrumentation. The overall aim of the Symposium was to bring together theorists, observers and instrumentalists to (1) showcase the community's accumulating knowledge of the early Universe (2) connect these high-redshift studies to the past literature to construct a coherent picture of galaxy evolution over $\sim 90\%$ of cosmic time and (3) lay the groundwork for the exploitation of the groundbreaking instruments that will become available post-2015.

Sugata Kaviraj
SOC Co-Chair
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