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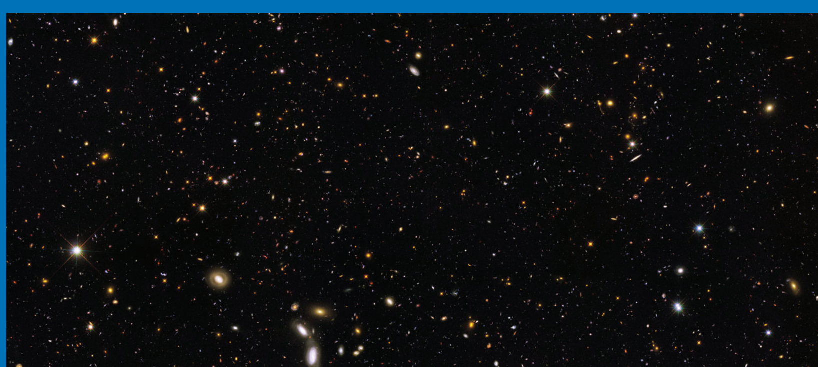
Galaxies at High Redshift and their Evolution over Cosmic Time

Edited by

Sugata Kaviraj



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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 ultrabiolet, 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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Edited by

SUGATA KAVIRAJ

Centre for Astrophysics Research, University of Hertfordshire

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Black holes and AGN at high redshift and their evolution with cosmic time

Long wavelengths at high redshift (ISM, IGM, gas-star formation connection)

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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 LCDM 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
Hatfied, UK, Feb 2016