

Editorial for the Special Issue *Universe*: Feature Papers 2024—"Galaxies and Clusters"

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1. Introduction

Galaxies and galaxy clusters represent the fundamental visible components of the cosmic web and provide unique laboratories for investigating the physical processes that shape the Universe across a vast range of spatial and temporal scales. Studies of their structure, dynamics, stellar populations, gaseous content, dark matter distribution, and environmental interactions are essential for understanding both astrophysical evolution and cosmological structure formation [1–14]. In recent years, advances in observational facilities, numerical simulations, and data-driven methodologies have transformed our ability to probe these systems, allowing for increasingly detailed investigations of phenomena ranging from the internal kinematics of galaxies to the assembly of clusters and the nature of dark matter itself [15–32]. The Special Issue "Galaxies and Clusters" was conceived to show the most recent developments in these interconnected fields. The twelve contributions collected in this volume span a remarkable diversity of topics, including galactic structure, the interstellar medium, galaxy dynamics, cluster evolution, cosmological simulations, machine-learning applications, modified gravity theories, and the role of dark matter in shaping cosmic structures. Together, they provide a representative snapshot of current research directions and highlight both the progress achieved and the challenges that remain in our understanding of galaxies and clusters.

2. Overview of the Contributions

1. This Special Issue opens with a detailed study of the structure of our own Galaxy by Tkachenko et al. [33], who determine the scale length and scale height of the Milky Way's thick disc using large samples of RR Lyrae stars from Gaia DR3, Pan-STARRS1, and ASAS-SN-II. Employing Bayesian inference through Markov chain Monte Carlo and nested sampling techniques, the authors derive robust estimates for the thick-disc structural parameters and characterize the density profile of the inner stellar halo. Their work provides important constraints on galactic formation scenarios and demonstrates the power of RR Lyrae stars as tracers of old stellar populations.

2. The gaseous component of galaxies and its interaction with the surrounding environment are explored by Reach et al. [34] through new SOFIA observations of the edge-on spiral galaxy NGC 5775. By combining [C II] 157.7 μm spectroscopy with archival H α imaging, the authors reveal extensive extraplanar gas reaching several kiloparsecs above the galactic plane. Their analysis shows that the extraplanar gas largely follows disk rotation while exhibiting measurable lag velocities. Particularly intriguing is the discovery of a narrow H α plume extending approximately 7 kpc from the nucleus, possibly linked to nuclear starburst activity or past energetic events. This study provides valuable insight into disk–halo interactions and feedback processes in star-forming galaxies.



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3. The issue also includes a contribution that connects galaxy observations with fundamental particle physics. Zhang and Luo [35] propose a novel mechanism through which photon–dark photon oscillations may arise from gravitational separation effects during propagation through the interstellar medium. Using gravitational lensing observations of quasars, the authors derive constraints on dark photons within a specific mass range and discuss possible applications to compact astrophysical environments such as neutron stars and black hole accretion disks. Their work illustrates how extragalactic observations can serve as probes of physics beyond the Standard Model.

4. A notable methodological contribution is presented by Chegeni et al. [36], who investigate the classification of galaxy rotation kinematics using convolutional neural networks. By training a CNN on stellar kinematic maps from the SAMI survey, they demonstrate that machine-learning techniques can distinguish fast and slow rotators with remarkable accuracy and precision. The application of Integrated Gradients further allows for the identification of the kinematic features driving the classifications. Their study highlights the growing importance of artificial intelligence in astronomical data analysis and its potential role in future integral-field spectroscopic surveys.

5. The dynamics of galaxy clusters is addressed by Costa et al. [37], who revisit the Coma Cluster with particular attention to the role of low-luminosity galaxies. Often neglected because of observational limitations, these faint systems prove to be crucial tracers of substructure and infall patterns. The authors show that excluding low-luminosity galaxies can significantly underestimate the number of substructures present both within the cluster and throughout its surrounding large-scale environment. Their results emphasize the importance of complete galaxy samples for reconstructing the dynamical history of clusters and understanding the growth of cosmic structures.

6. Dark matter remains one of the central themes of modern astrophysics, and several contributions in this Special Issue address this topic from complementary perspectives. In a provocative review and perspective article, Salucci [38] critically examines common assumptions and methodological practices employed in studies of galactic dark matter. Rather than proposing a specific alternative model, the author discusses conceptual issues that may hinder progress and argues that the nature of dark matter will ultimately be inferred from a careful reconstruction of the observational evidence. This contribution provides a valuable reflection on the current state of the field and the challenges facing future investigations.

7. The intragroup medium and its chemical enrichment are the focus of the work by Padawer-Blatt et al. [39], who analyze abundance profiles in galaxy groups using the new SIMBA-C cosmological simulations. By implementing an updated chemical enrichment model, the authors obtain abundance distributions that are generally in better agreement with observations than previous versions of the simulation. Their study demonstrates the sensitivity of intragroup metallicity profiles to feedback processes, metal mixing, and enrichment prescriptions, highlighting the importance of physically motivated sub-grid models for reproducing observed group environments.

8. A particularly intriguing challenge to the standard cosmological framework is presented by Haslbauer and collaborators [40], who investigate the occurrence of Magellanic Cloud-like systems in the IllustrisTNG simulations. By comparing the observed phase-space configuration of the Large and Small Magellanic Clouds with simulated analogues, they find a significant tension between observations and Λ CDM expectations. Their analysis suggests that the close association and dynamical properties of the Magellanic Clouds represent a rare configuration within the simulations, raising important questions about satellite galaxy formation and the interpretation of Local Group dynamics.

9. The interplay between bars, gas, and bulges in disk galaxies is explored by Machado et al. [41] through a suite of hydrodynamical N-body simulations. The authors examine how gas content influences the transfer of angular momentum from bars to classical bulges and find that increasing gas fractions systematically reduce bulge rotation and alter its structural evolution. Their results provide new insight into the formation of composite bulges and the secular evolution of barred galaxies.

10. Alternative explanations for galactic dynamics are investigated by Pascoli and colleagues [42], who test the κ -model against the extensive SPARC galaxy database. The κ -model is compared with MOND and other modified-gravity frameworks that seek to reduce or eliminate the need for dark matter. By analyzing a large sample of galaxy rotation curves, the authors explore the relationship between the characteristic acceleration scale and baryonic matter distribution, contributing to the ongoing debate concerning the interpretation of galactic dynamics.

11. Another innovative approach to dark matter phenomenology is presented by Benetti et al. [43], who continue their series on fractional gravity. In this contribution, they apply the framework to dwarf irregular galaxies, dwarf spheroidals, and the ultra-diffuse galaxy DragonFly 44. Using high-quality kinematic data, the authors demonstrate that fractional gravity can reproduce both rotation curves and velocity-dispersion profiles with considerable success, often outperforming standard Newtonian models. These results further motivate the exploration of non-local gravitational effects as potential explanations for dark matter-related phenomena.

12. The Special Issue concludes with a broad investigation of one of the most fundamental scaling relations in extragalactic astronomy. D’Onofrio et al. [44] revisit the luminosity–velocity dispersion relation observed in both early-type galaxies and active galactic nuclei. By examining the curvature of the Faber–Jackson relation, the projections of the Fundamental Plane, and the existence of the Zone of Exclusion, the authors propose a new interpretative framework linked to hierarchical galaxy formation. Extending the analysis to actively accreting supermassive black holes, they demonstrate intriguing similarities between galaxies and AGN and discuss the physical mechanisms underlying these correlations.

3. Emerging Themes

Although the contributions span a broad range of topics, several common themes emerge. First, the continuing effort to understand the distribution and nature of dark matter remains a major driving force in studies of galaxies and clusters. This is reflected in both observational and theoretical investigations, as well as in the exploration of alternative gravity frameworks. Second, the increasing integration of simulations, observations, and advanced statistical techniques is transforming the field. Whether through cosmological simulations, Bayesian inference, or machine-learning approaches, modern studies increasingly rely on sophisticated computational tools to interpret the growing volume of astronomical data. Third, the importance of environment appears repeatedly throughout the issue. From extraplanar gas and galactic feedback to cluster substructures and satellite galaxy dynamics, environmental effects continue to play a central role in shaping the observed properties of galaxies. Finally, several contributions highlight the value of studying low-luminosity and often overlooked components of cosmic structures, including RR Lyrae populations, faint cluster members, dwarf galaxies, and diffuse intragroup media. These systems frequently provide crucial information about the assembly histories and dynamical states of larger structures.

4. Conclusions

The twelve papers collected in this Special Issue provide an excellent overview of the diversity and vitality of contemporary research on galaxies and clusters. Together, they address fundamental questions concerning galactic structure, galaxy evolution, cluster dynamics, chemical enrichment, dark matter, modified gravity, and the large-scale organization of matter in the Universe [45–51]. The breadth of topics represented here reflects the increasingly interdisciplinary nature of extragalactic astronomy, where observations, simulations, theoretical developments, and data-science methodologies converge to advance our understanding of cosmic structures. We hope that the contributions assembled in this volume will stimulate further research and foster new collaborations across these interconnected areas of astrophysics. As Guest Editor, I would like to express my sincere gratitude to all authors for contributing their excellent work to this Special Issue. I also thank the reviewers for their careful evaluations and constructive suggestions, which significantly improved the quality of the published papers. Finally, I am grateful to the editorial staff of *Universe* for their professional support and dedication throughout the preparation of this collection.

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