

# Preface

The birth of the first stars and galaxies, and their impact on the diffuse matter permeating the early Universe, is one of the final frontiers in cosmology. Recently, measurements of the fluctuations in the cosmic microwave background (CMB), sourced only a few hundred thousand years after the Big Bang, provided robust insight into the overall physical content of our Universe. On the other end of the timeline, groundbreaking telescopes, such as the Hubble Space Telescope, provide us a picture of the complexities of the galaxy-rich Universe in which we now live, billions of years later. However, we know almost nothing about the astrophysics of the first billion years. During this relatively brief epoch, a tiny fraction of matter condensed inside the first galaxies, forming the first stars. The light from these objects and subsequent generations of galaxies began spreading throughout the vast, web-like intergalactic medium (IGM). This culminated in the final major phase change of our Universe, cosmological reionization, when ionizing radiation stripped electrons from almost every atom in our Universe. Reionization lifted the cosmic fog, allowing visible light to finally spread throughout space. The Universe was no longer a cold, dark place. This mysterious epoch or reionization corresponds to the transition between the relative simplicity of the early Universe and the complexity of the present-day one, 14 billion years later. It is fundamental in understanding our cosmic origins, and its impact on structure formation resonates even to this day.

Until recently, we had very little observational insight into the epoch of reionization. Our first hints came when the Sloan Digital Sky Survey (SDSS) discovered bright quasars, already in place only a billion years following the Big Bang. These bright objects serve as distant lighthouses, allowing us to see the intervening IGM in their spectra. Their spectra showed long stretches of zero flux, so-called Gunn-Peterson (GP) troughs. GP troughs were increasingly more prevalent in the most distant quasars, and this evolution was initially interpreted as evidence of the final stages of reionization. The next breakthrough came shortly afterwards, as the Wilkinson Microwave Anisotropy Probe (WMAP) satellite detected the optical depth to electron scattering for the CMB. This is an integral measurement of how many free electrons lie between the present-day Universe and the primordial one. The relatively high value of this optical depth implies that reionization must

have started hundreds of millions of years before even the earliest SDSS quasar. Subsequent observational and theoretical advancements have begun to paint a picture of a complicated, extended, inhomogeneous process, whose details remain elusive.

At its core, the process of cosmological reionization involves understanding how stars and clumps of gas impact each other and eventually the entire Universe. The challenges associated with such an enormous range of relevant scales, coupled with our relatively poor understanding of the dominant astrophysics, have thus far impeded efforts to form a robust theoretical framework for reionization. As such, the interpretation of even the sparse reionization data currently available remains controversial.

Luckily, we are on the cusp of a dramatic increase in our knowledge of this uncharted cosmological frontier, driven by a wave of upcoming observations. These include: (1) 21 cm interferometry; (2) high-redshift infrared quasar spectra; (3) wide-field surveys of high-redshift galaxies including Lyman alpha emitters (LAEs); (4) the E-mode CMB polarization power spectrum; (5) secondary CMB anisotropies from the inhomogeneous kinetic Sunyaev-Zeldovich (kSZ) effect; and (6) high-resolution studies of the metal content of early galaxies. Our ability to interpret this wealth of data is also increasing thanks to more sophisticated analytical and numerical approaches. Investigations have become subtler, discarding the “one size fits all” approach to simulations, in favor of focused studies with specialized tools.

The aim of this volume is to summarize the current status and future outlook of the reionization field, on both the theoretical and observational fronts. We bring together leading experts in many subdisciplines, highlighting the measurements that are likely to drive the growth of our understanding of reionization and the cosmic dawn. We seek a roadmap to interpreting the wealth of upcoming observations. *What is the best use of limited observational resources? How do we develop theoretical tools tailored for each observation? Ultimately, what will we learn about the epoch of reionization and our galactic ancestors?*

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Challenges and Progress

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