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Multicomponent Photoionization Modelling of the First Dwarf Galaxies

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The epoch of cosmic reionization marks a pivotal stage in the history of the Universe, during which the first sources of ionizing radiation transformed the intergalactic medium from a neutral to an ionized state. While it was traditionally believed that massive galaxies and quasars played the dominant role in this process, recent observations and theoretical models increasingly suggest that low-luminosity dwarf galaxies may have been key contributors to early Universe reionization due to their large number and radiation efficiency [1, 2]. Thus, studying the spectral properties of ionizing radiation emitted by dwarf galaxies is crucial for understanding the early cosmological evolution of the Universe, as it provides critical insights into their contribution to the ionizing photon budget and the nature of early galaxy populations.

Accurately modeling spectral energy distribution (SED) of dwarf galaxies requires detailed consideration of the hydrodynamic structure of their nebular environment, since ionizing radiation from stars passes through the nebular environment surrounding the star-forming region before reaching the intergalactic medium. The morphology of the nebula is shaped by a superwind originating from the central region, which hosts young, extremely low-metallicity stars.

This work proposes a new analytical–numerical method for the multicomponent photoionization modelling, developed on the basis of the approach presented by Koshmak and Melekh (2018) [3], which enables the reproduction of the main hydrodynamic characteristics of a superwind bubble structure observed in high-resolution hydrodynamic simulations, while requiring minimal computational resources. The proposed approach not only reproduces the evolution of the superwind bubble, but also allows for detailed consideration of all important elementary processes that provide the ionizing radiation transfer through the inhomogeneous nebular environment. A key advantage of our model is the ability to track the transformation of the ionizing spectral energy distribution as it propagates through the distinct nebular components of a superwind bubble.

We compute the ionization structure and spectrum of ionizing radiation passing through the components of the nebular environment of a dwarf galaxy surrounding the region of active star formation during the era of cosmic reionization of the Universe. The resulting models provide SEDs of output radiation from dwarf galaxies into the intergalactic medium. After such radiative transfer, output SED contains the emission lines, with the Lyα line in particular showing strong intensity, which may significantly affect the spectra of the first molecules.

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