

Decoding the Universe: Exploring Quasar Absorption Systems with Machine Learning

The universe is vast, mysterious, and constantly evolving. One of the most effective ways astronomers study its history is by analyzing **quasar absorption systems (QAS)**, the signatures left behind when light from distant quasars passes through the vast expanse between galaxies i.e, **intergalactic medium (IGM)**. These absorption features help scientists probe the **temperature and ionization state of the IGM** and investigate the **missing baryon problem**, a long-standing mystery about the location of nearly half of the universe's ordinary matter.

Traditionally, studying quasar absorption lines involves **complex and time-consuming mathematical modeling**, where scientists fit Voigt profiles to extract critical physical parameters. However, this process is prone to errors due to noise in observations, overlapping spectral features, and computational limitations. As astronomical surveys like **SDSS, DESI, and 4MOST** continue to generate massive amounts of data, traditional methods become increasingly inefficient.

This project proposes a groundbreaking shift: integrating **machine learning (ML)** and artificial intelligence (AI) into quasar absorption spectroscopy. Instead of relying on manual fitting techniques, **deep learning models** can be trained to automatically classify absorption systems and accurately determine their physical properties. The approach includes: (i) **AI-powered absorption line discovery**: ML models will rapidly identify and classify absorption features in quasar spectra, distinguishing between different chemical elements and ionization states, (ii) **Automated Voigt profile fitting**: Instead of using slow and expensive computational methods, neural networks will be trained to fit spectral lines efficiently, making analysis faster and more reliable, (iii) **Physics-informed AI models**: Unlike black-box ML approaches, our models will incorporate real astrophysical knowledge, ensuring physically meaningful and interpretable results, and (iv) **Cross-survey adaptability**: The AI framework will be designed to work across multiple telescopes and datasets, enabling robust and universal analysis of quasar spectra.

By applying these cutting-edge AI techniques, this project will transform the way we study the universe. The research will provide more accurate measurements of the distribution of the baryon content, improve our understanding of how the IGM evolves over cosmic time, and refine models of structure formation and reionization. Beyond astrophysics, this work represents an important step in the broader integration of AI into scientific discovery, setting the stage for more automated, precise, and large-scale exploration of the cosmos.

To maximize impact, we will publicly release our ML framework, allowing researchers worldwide to leverage AI-driven spectral analysis for their own studies. This pioneering

approach will not only help us uncover missing matter in the universe but also pave the way for future AI-powered advancements in space science.

AI is not just transforming technology – it is unlocking the deepest mysteries of the cosmos!