

NATIONAL CENTRE FOR NUCLEAR RESEARCH

Abstract

Probing the baryon cycle of primordial galaxies in the ALMA and JWST era

Prasad SAWANT

Over the past two decades, significant advancements in the observational capabilities have revolutionized our exploration of the early Universe. The combined capabilities of Atacama Large Millimeter/submillimeter Array (ALMA), Hubble Space Telescope (HST) and James Webb Space Telescope (JWST) have enabled comprehensive multiwavelength studies of distant galaxies. These facilities have unveiled a diverse population of high redshift systems, including a substantial number of dusty star-forming galaxies that challenge our traditional models of galaxy evolution. The detection and characterization of dust in these early galaxies provide critical insights into the processes governing star formation, chemical enrichment, and the build-up of baryonic matter shortly after the Big Bang.

Despite this progress, our understanding of the interstellar medium (ISM) in these galaxies remains incomplete. The complex mechanisms responsible for the accumulation of large gas and dust reservoirs at early epochs are still not fully understood, majorly due to degeneracies and inadequacies inherent in both observations and theoretical models. Quantifying the relative importance of dust production and destruction processes in this context remains a challenging task.

As we probe galaxies at increasingly higher redshifts, it has become evident that these systems contribute substantially to the cosmic star formation rate density (SFRD). However, most attempts to constrain the dust-obscured SFRD have relied on detections of extremely dusty submillimeter galaxies, which do not represent the bulk of the high-redshift galaxy population and may bias our interpretations.

A turning point in this field was marked by the widespread detection studies of the [C II] 158 μm emission line, a key far-infrared (FIR) cooling line in star-forming galaxies at high redshifts probed by ALMA. This line traces the molecular gas fuelling star formation in the ISM of galaxies while providing crucial information about morphology and kinematics of the system. This paved the way for ALPINE-ALMA [C II] survey, which systematically targeted the rest-frame FIR emission of 118 main-sequence galaxies at $z \sim 5$, providing a statistically robust sample for studying their gas and dust properties.

The aim of this thesis is to characterize the baryon cycle in the ISM of subsample of 98 galaxies observed by ALPINE survey. In order to quantify dust production/destruction mechanisms by employing spectral energy distribution (SED) fitting methods and chemical evolution models, I utilize multi-wavelength observations for these galaxies ranging from UV/optical to FIR bands. In this study, I employ CIGALE to derive physical properties of these galaxies and analyze diagnostic plots to trace their gas and dust evolution. Through chemical evolution models, I quantify the contributions from different producers of dust and probe the effects of different destruction mechanisms, gas inflows and outflows on the gas and dust content. I also test the hypothesis of variable initial mass function (IMF) against canonical prescriptions of IMF to reconcile the observations, particularly of rapid dust build-up in galaxies with age less than 100 Myr.

In this work, I refine chemical evolution models to reproduce the observed gas and dust content. I find that dust masses in galaxies older than 600 Myr can be explained regardless of the IMF assumed. For galaxies aged approximately 300 - 600 Myr, dust growth in the ISM is necessary, while for the youngest galaxies (age < 300 Myr), a top-heavy IMF is required to match observed dust masses. Overall, 65% of the sample aligns with models assuming a Chabrier IMF, increasing to 93% when adopting a top-heavy IMF.

The findings of this study provide an opportunity to test our state-of-the-art models of dust formation using a representative and sizeable galaxy sample. They also emphasize the importance of expanding such observational efforts to even higher redshifts. With the advent of the JWST, which offers unprecedented sensitivity in the optical and near-infrared bands, a new era of exploration has begun, opening fresh avenues for understanding the early Universe, some of which are discussed in this thesis.