Contribution ID: **30** Type: **Contributed talk**

Using metallicity gradients to trace the evolution of galaxies

Tuesday, 16 May 2023 16:00 (15 minutes)

Thanks to integral field unit (IFU) spectroscopy, spatially-resolved metallicities have been measured in thousands of galaxies. This has built up a census of the baryonic cycle in local galaxies, which is crucial to understand how processes local to the interstellar medium (ISM) contribute to global trends in galaxies and influence the dynamics of the circumgalactic medium (CGM). JWST has already begun to push boundaries by obtaining spatially-resolved metallicity measurements for galaxies beyond $z > 3$. To provide physical explanations for the trends revealed by these observations, we develop a new, first-principles model for the evolution of spatially-resolved gas-phase metallicities in galaxies. Crucially, and in contrast with existing models, we include a comprehensive treatment of metal dynamics and galactic winds, both of which are expected to play a bigger role at high redshifts. When normalized by metal diffusion, metallicity gradients are governed by the competition between radial advection, metal production, and accretion of metal-poor gas from the cosmic web. Reproducing the observed mass-metallicity and mass-metallicity gradient relations in the local Universe from the model shows that galaxies transition from the advection-dominated to the accretion-dominated regime as they increase in mass. The shape of metallicity-based galaxy scaling relations is governed by the metal enrichment of galactic winds, and the model predicts winds in low-mass galaxies are more metal enriched as compared to their ISMs. The model also predicts a complex and non-linear dependence of metallicity gradients on the gas velocity dispersion at high redshifts, which can be directly tested by JWST.

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Session Classification: Parallel session

Track Classification: NOVA NW1