

Physical processes of high-redshift galactic outflows detected by JWST and galaxy formation

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Star-forming galaxies drive multiphase outflows that regulate baryon cycling and metal transport between the interstellar medium (ISM), the gas and dust within galaxies that fuel star formation, and the circumgalactic medium, shaping the ISM and galaxy evolution. A major issue is whether outflows escape or remain bound and recycle. Failed outflows are those that fail to escape and therefore recycle via reaccrretion. A widely used proxy labels outflows as unbound when their characteristic velocity is about three times the circular velocity ($3 v_{\text{circ}}$).

Arima and Mori (in prep.) show that this proxy follows from transonic solutions (Igarashi et al. 2023) for supernova-driven, quasi-steady, spherically symmetric outflows in a realistic galaxy potential. The energy budget from the sonic radius to infinity defines a critical mass-loading factor. Above this threshold, the terminal velocity approaches about three times the circular velocity, and the flow becomes unbound; below it, the flow decelerates and recycles.

Using recent JWST constraints (Carniani et al. 2024; Zhang et al. 2024; Cooper et al. 2025; Xu et al. 2025), we test the transonic unbinding condition in high-redshift galaxies and show that 80% of outflows previously classified as failed are instead predicted to be unbound. We then map the dependence of terminal velocity on mass loading and delineate the domain of validity of the empirical $3 v_{\text{circ}}$ criterion.

In addition, the mass-loading factors estimated by our model are approximately one order of magnitude smaller than those inferred in previous studies. This difference may reflect the fact that the two models trace different outflow phases.

We find two high-redshift candidates in the XST regime, which may connect to inflow solutions, potentially probing sites of cusp–core transformation in dark matter halos.

We suggest transonic model will provide a practical diagnostic for JWST and ALMA era outflow measurements.