NIHAO-RiNG: A Comparison of Simulated Disk Galaxies from GASOLINE and GIZMO

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Abstract

We utilize the public `GIZMO` code to re-simulate 12 galaxies selected from the NIHAO simulation suite which were run with the `GASOLINE` code, then compare their properties. We find that while both codes with the same initial conditions and large-scale environments can successfully produce similar galactic disks in Milky Way-mass systems, yet significant differences are still seen in many aspects, particularly the circum-galactic medium (CGM) environment they reside in. Specifically, the thermal feedback recipe used in `GASOLINE` results in ubiquitous long-term large-scale outflows, primarily driven by high-density hot inter-stellar medium (ISM) from the galaxy center, preventing the inter-galactic medium (IGM) from falling efficiently. Recycled gas and inflows in CGM appear at $10^{4\sim5}$K, playing a crucial role in the formation of cold disks in the NIHAO simulations. In contrast, disk galaxies simulated by `GIZMO` do not exhibit prominent outflows at low redshifts, but instead display quasi-virialized hot gas halos that arise from the interaction between inflows and feedback-driven outflows. Therefore, the origins of mass and angular momentum of the cold disk in the two simulations are quite different, even though the final morphology of corresponding galaxies are both disky. The differences in the distribution of CGM gas are mainly due to different feedback models implemented in the two codes, future observations of CGM could provide valuable insight into the physics governing baryon cycle in galaxies.

Basic Properties of 6 MW Mass Samples

Table 1. Columns from left to right: system name, particle mass of dark matter and baryon, force softenings, whether the galaxy is disk dominated at $z = 0$. Numbers in brackets denote the spin parameter of the halo in which the galaxy is embedded.

system (L/h^{-1}Mpc)	$m_{\rm dm}/m_{\rm b}$ (10^5M$_\odot$)	$\epsilon_{\rm dm}/\epsilon_{\rm b}$ (pc)	disk or not (λ)	
			`GASOLINE`	`GIZMO`
g6.96e11 (60)	1.523 / 0.278	267 / 113	$\surd$ (0.060)	$\surd$ (0.037)
g7.08e11 (60)	1.110 / 0.203	267 / 113	$\surd$ (0.079)	$\surd$ (0.077)
g7.55e11 (60)	1.523 / 0.278	267 / 113	$\surd$ (0.053)	$\surd$ (0.047)
g8.26e11 (60)	2.169 / 0.396	267 / 113	$\surd$ (0.078)	$\surd$ (0.075)
g1.12e12 (60)	1.523 / 0.278	200 / 66.7	$\times$ (0.024)	$\times$ (0.020)
g2.79e12 (60)	5.141 / 0.938	300 / 100	$\surd$ (0.047)	$\surd$ (0.049)

Baryon Recycle on Phase Diagram

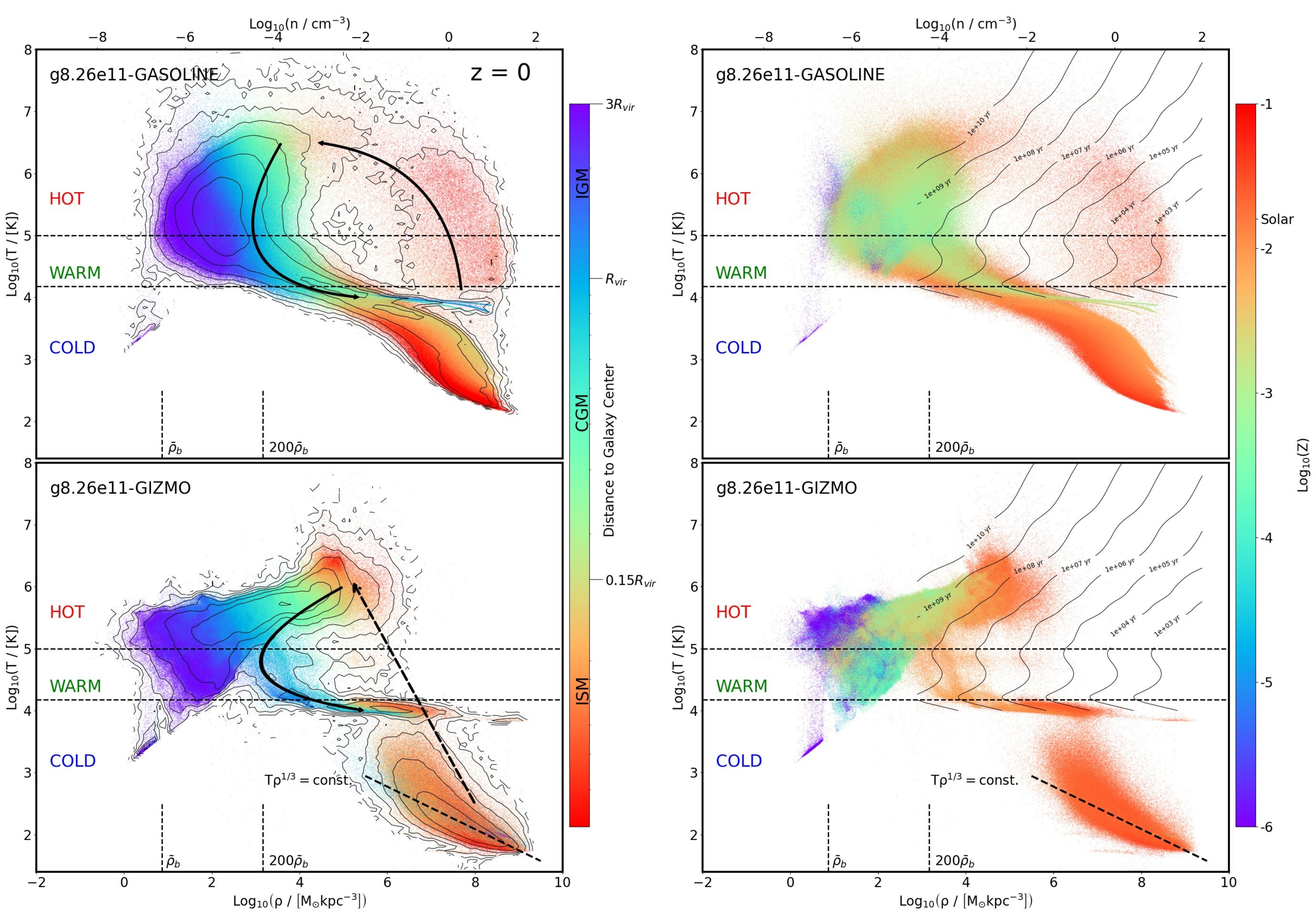

Figure 1. Comparison of density-temperature diagram of gas particles within $3R_{\rm vir}$ in g8.26e11 system. The colors of the dots in the left and right panels denote the distance (in logarithm) to the galaxy center and metallicity (in mass fraction and also in logarithm), respectively. The left contour maps give the mass distribution of gas particles on the diagram, while the right contour maps show the cooling time of gas with solar metallicity under the assumption of collisional ionization equilibrium (CIE). The black dashed line in the lower panels demonstrates the best fitting polytropic state of the cold ISM.

Disk Formation

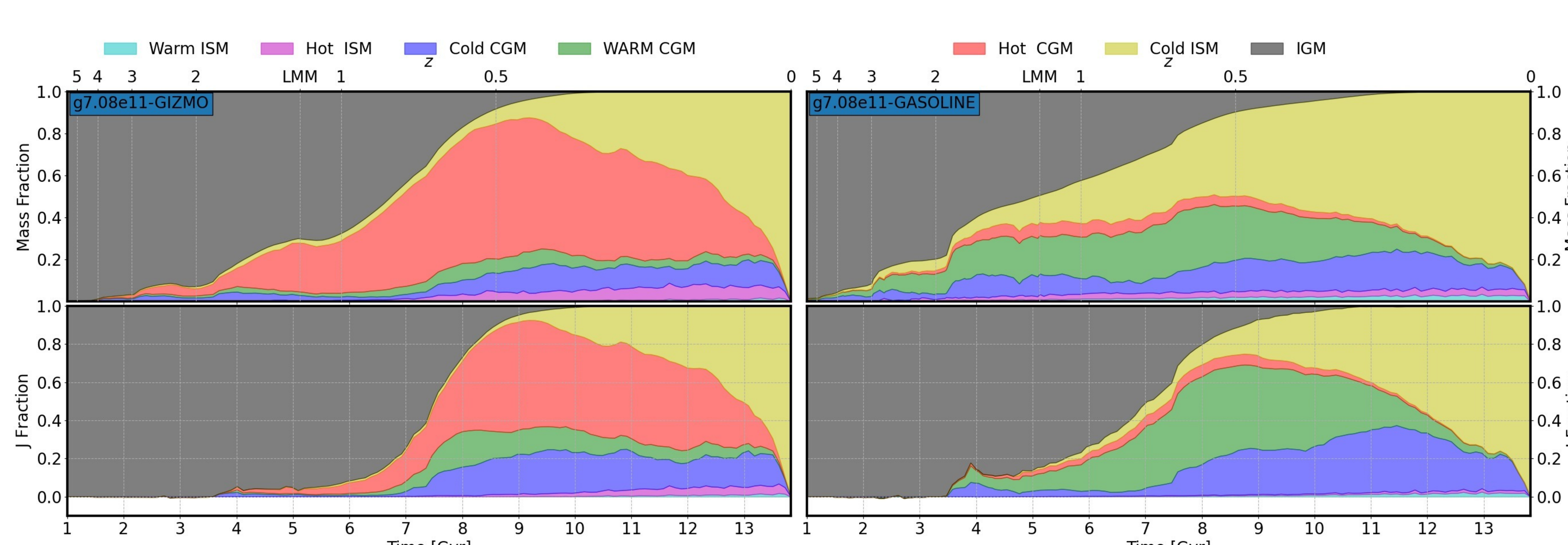

Figure 2. Whereabouts of the final cold disk of the g7.08e11 in two simulations across the cosmic time.

Comparison of Three Simulated MW-like Disk Galaxies at z=0

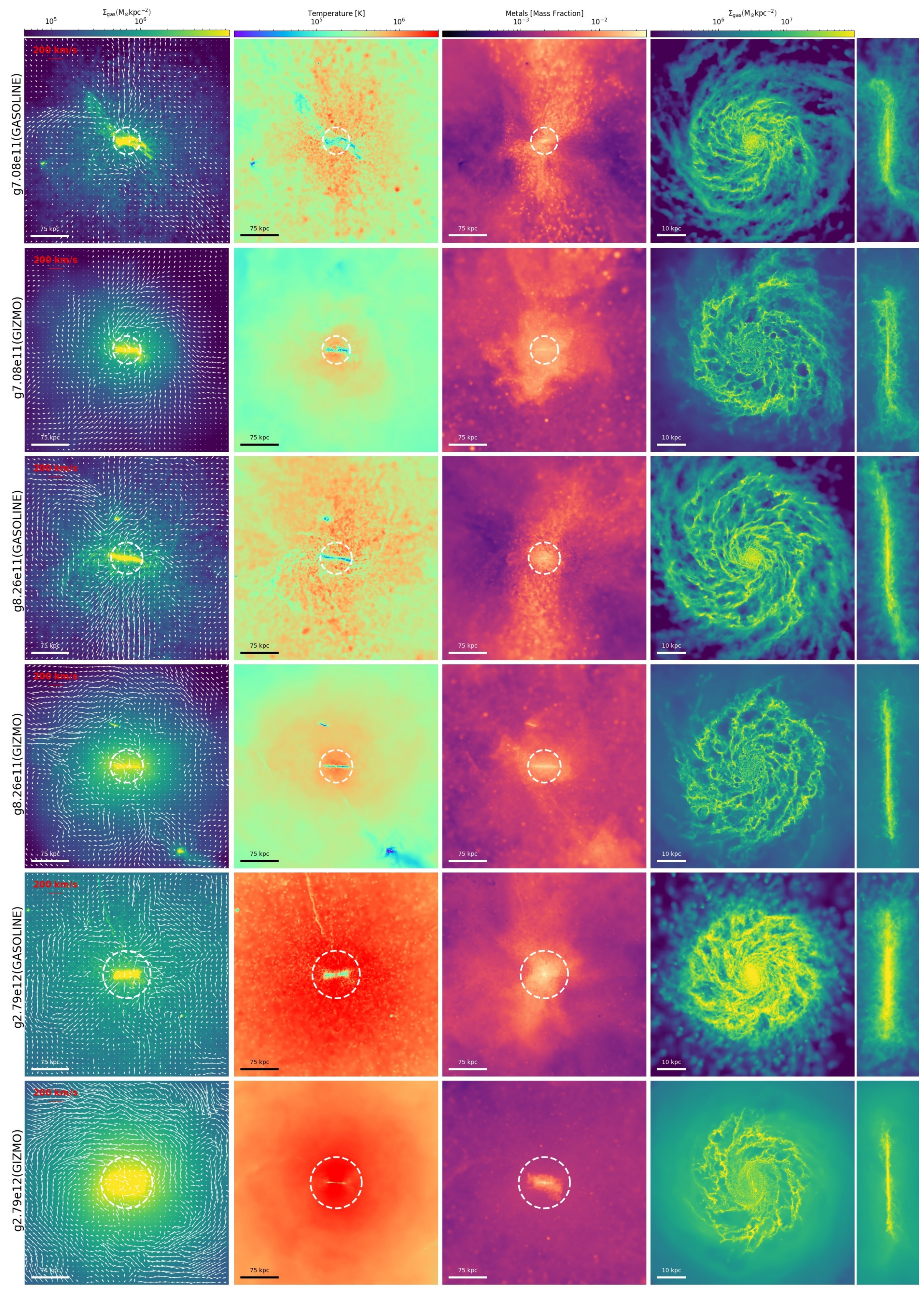

Figure 3. Columns from left to right: 2D density map of gas in edge-on view with pixelized velocity vectors overlaid on top, 2D temperature map averaged by gas density in edge-on view, 2D metallicity map averaged by gas density in edge-on view, 2D zoom-in density map of gas disk in face-on and edge-on view. The dashed circle indicates the range of $0.15R_{\rm vir}$.

Inflow and Outflow

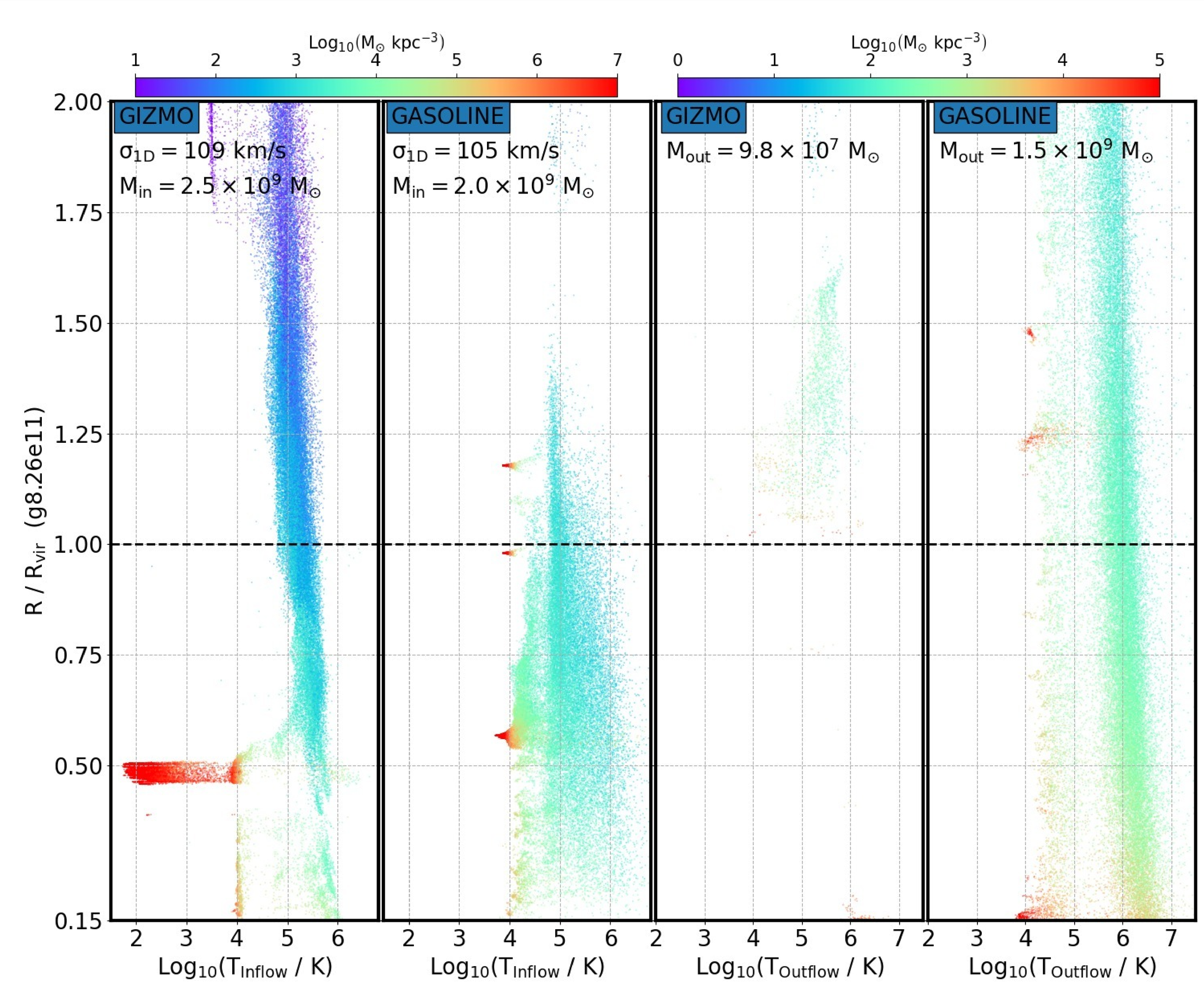

Figure 4. The temperature distribution of the inflow and outflow gas at different radii. The 1D velocity dispersion of the halo and the mass of total inflow/outflow gas within $2R_{\rm vir}$ is denoted in each panel.

Conclusions

- Both `GASOLINE` and `GIZMO` with the same ICs and LSS environments can successfully produce similar galaxy disks, yet significant differences are still seen in many properties, particularly the CGM environment.
- `GASOLINE` recipe effectively suppresses star formation processes, resulting in ubiquitous long-term large-scale outflows driven by the high-density hot ISM. In contrast, strong outflows are hardly observed in RiNG galaxies at late times, but instead display quasi-virialized hot gas halos that arise from the interaction between inflows and feedback-driven outflows.
- Mergers are crucial for disk formation in RiNG galaxies. They lead to a sudden deepening of the gravitational well, confining nearly all feedback gas within $R_{\rm vir}$, and transforming bursty SFHs into continuous and smooth ones. In contrast, the impact of merger events on the formation of NIHAO-UHD galaxies is imperceptible.