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Characterizing Galaxy Merger Remnants with Photometry and Kinematics

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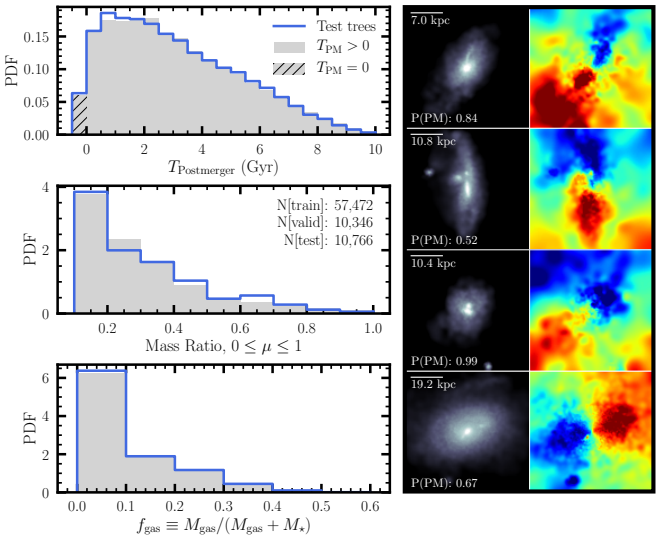
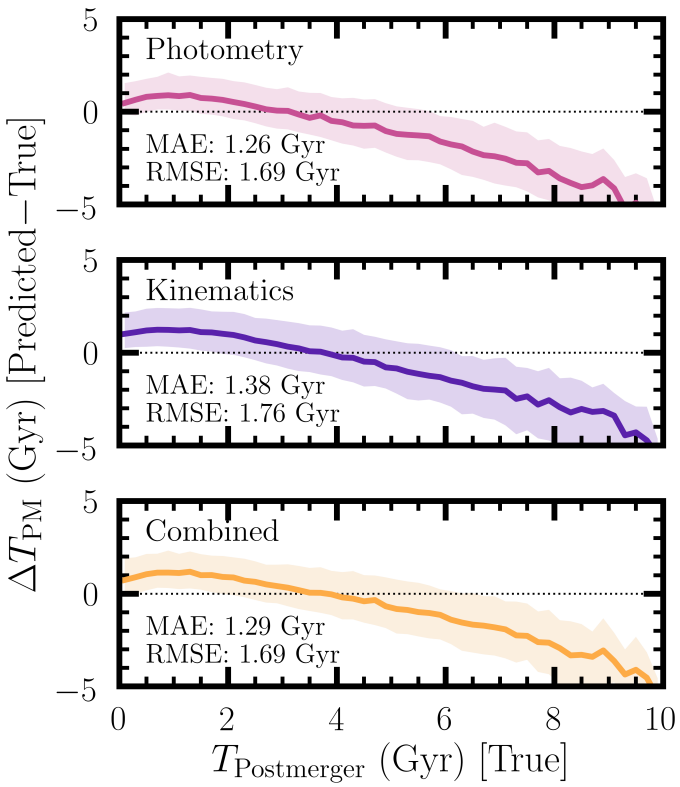
Abstract: Deep classification and regression neural networks are used to establish links between ***observable*** features of galaxies to quantitative characteristics of their merger histories. Using simple synthetic images, MUSE-like velocity maps, and the merger trees of galaxies from the TNG100 cosmological hydrodynamical simulation, we show that a single image and/or velocity map is sufficient to estimate the time since a galaxy most recently merged, $T_{\rm postmerger}$, out to ~4 Gyr with ~1 Gyr accuracy. The novelty of this approach is that ***the models can be applied indiscriminately to any galaxy*** by assuming that every galaxy is the remnant of a merger at some epoch. The accuracy and precision of $T_{\rm postmerger}$ estimates decay acutely with increasing time-since-merger and decreasing merger mass ratios. That such a relation can be established for many gigayears (well after tidal features have disappeared) supports a scenario in which the current morphological and kinematic states of galaxies are almost entirely dominated by their recent merger histories.

Galaxy Sample: We first select all galaxies from TNG100-1 in $0 \leq z \leq 1$ with stellar masses $10 \leq \log M_\star/M_\odot \leq 12$. Using each galaxy's merger tree, we determine the time since its most recent merger, $T_{\rm postmerger}$, with a companion at least a tenth of its stellar mass out to $z = 2$. We also determine the mass ratio, $0.1 \leq \mu \leq 1$, and gas fraction, $f_{\rm gas}$, of every such merger event. The final sample includes 78,584 galaxies. Crucially, the galaxies are then partitioned into training, validation, and test sets *by tree* (i.e. galaxies at different epochs within the same tree are always allocated to the same partition).

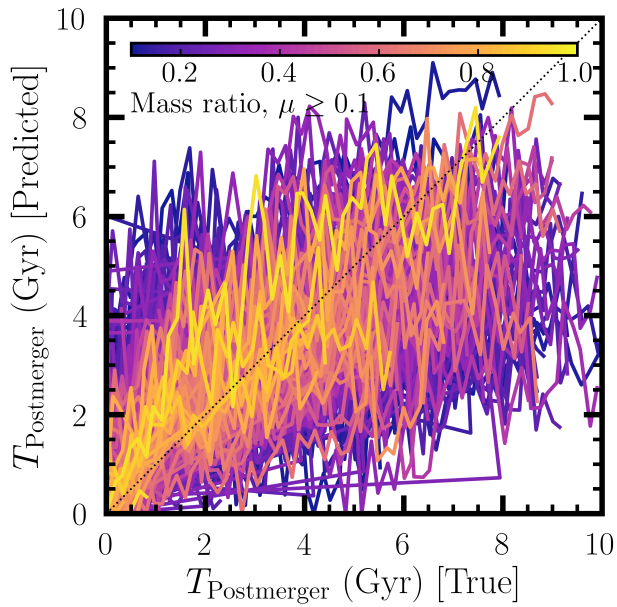


Synthetic Maps: Synthetic images and velocity maps are made for each galaxy along four lines of sight. These images are idealized and include no realism designed to emulate observations with specific instruments. This work assesses the *theoretical* degree to which the morphologies and kinematics of galaxies are connected to their most recent merger events using the intrinsic observables properties of galaxies — with no additional observational effects.



Results — Estimating the time since the most recent merger: Deep convolutional regression models are calibrated on training and validation sets to connect (a) photometry, (b) velocity maps, and (c) photometry and kinematics *combined* to the $T_{\rm postmerger}$ values obtained from the merger trees. We show that single images and velocity maps can be used to estimate $T_{\rm postmerger}$ out to ~4 Gyr with systematic and random errors not exceeding 1 Gyr.

Results — Sensitivity to merger properties: The scatter in the difference between predicted and true $T_{\rm postmerger}$ values increases with increasing $T_{\rm postmerger}$. The scatter is also driven by low- mass ratio mergers at all $T_{\rm postmerger}$ which do not trigger strong or long-lived features. In contrast, $T_{\rm postmerger}$ estimates for high- mass ratio mergers are tightly coupled with the true values. Indeed, galaxies whose most recent mergers were between progenitors with $\mu \gtrsim 0.9$ have $T_{\rm postmerger}$ predictions that are accurate up to 8 Gyr after the merger event.



Broader Impact: The ability to quantitatively heterogenize binary merger/non-merger samples using estimates for the time since galaxies' most recent merger events has ground-breaking applications to observed galaxies. The theoretical significance of these results are that they imply that a galaxy's current morphological and kinematic states are deeply (and predominantly) tied to their most recent merger activity.