Saving Doomed Planets: Mass Loss and Angular Momentum Return Boost Hot Jupiter Survival Rates

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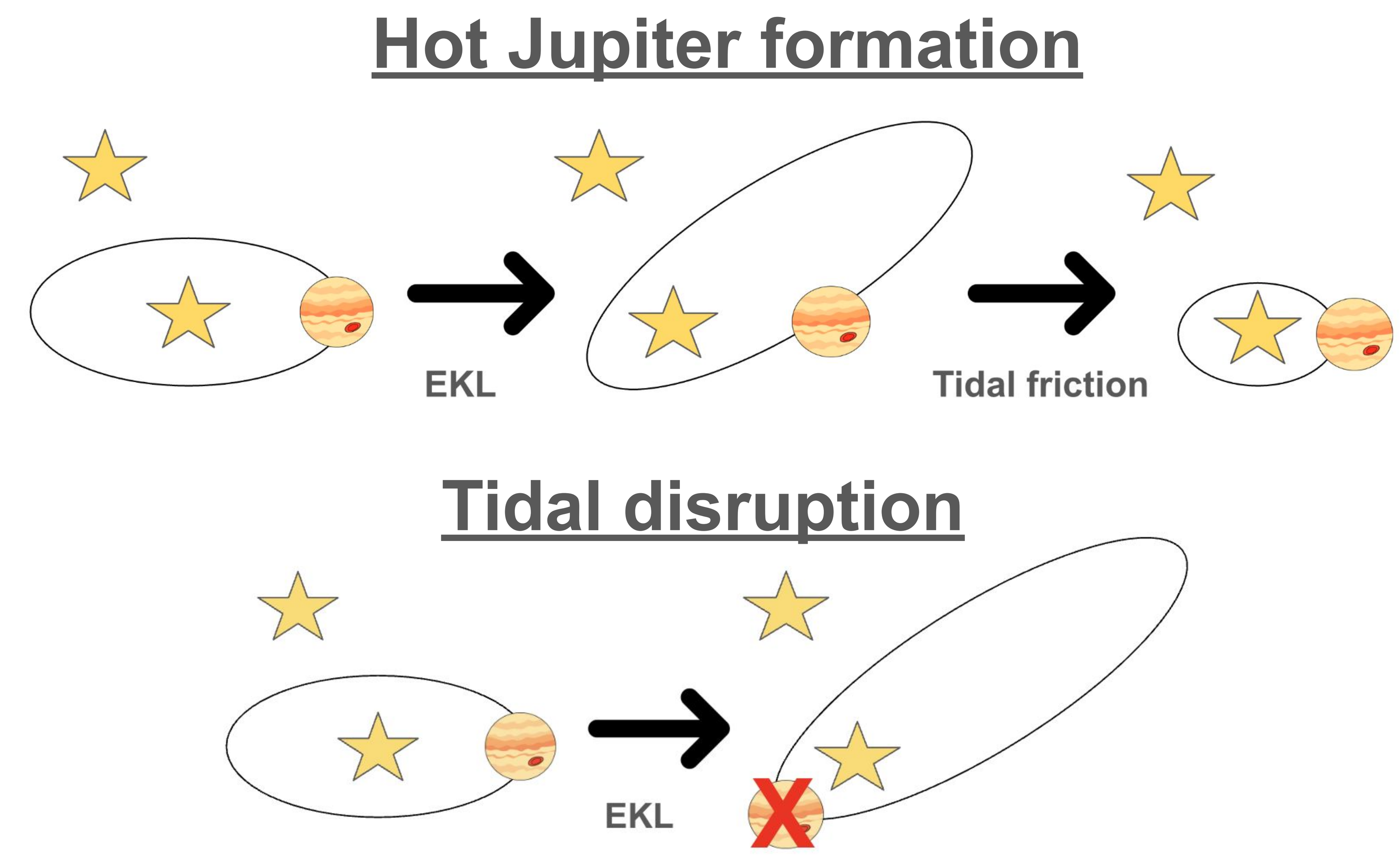
Background

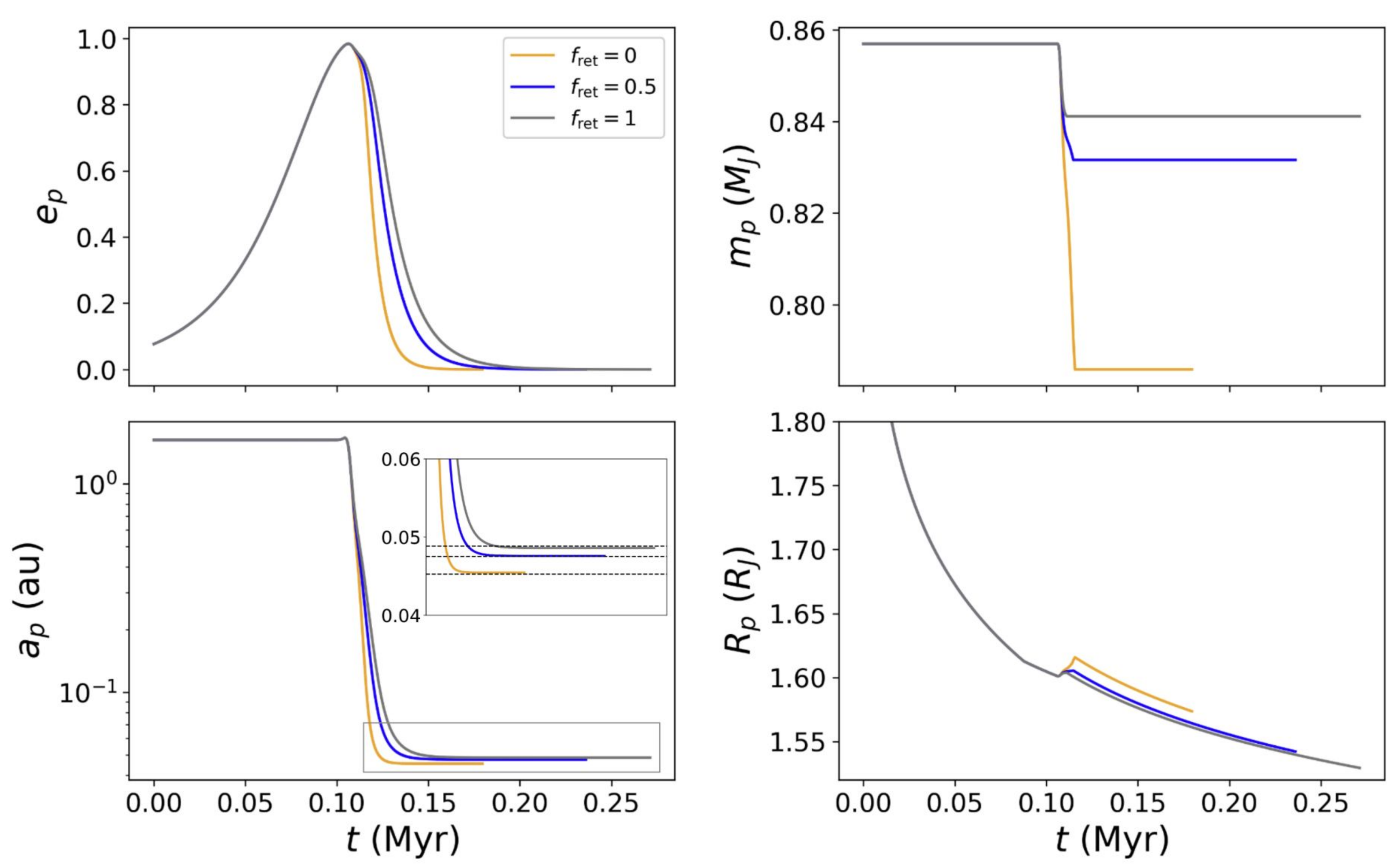
The existence of giant planets on short-period orbits ("hot Jupiters") represents a challenge to theories of planet formation. High-eccentricity migration has been proposed as an explanation for their origin. In this channel, an initially wide-orbiting planet's eccentricity is excited to values of order unity, then tidal dissipation at periastron shrinks and circularizes the orbit. Eccentricity excitations may be driven by perturbations from a distant planetary or stellar companion, e.g., the Eccentric Kozai-Lidov (EKL) mechanism. While observations of orbital misalignment support this scenario, theoretical models have struggled to reproduce the observed hot Jupiter occurrence rate. **Prior studies (e.g., Naoz et al 2012, Petrovich 2015, Anderson et al 2016) have found that ~20-40% of source cold Jupiters may be destroyed by tidal disruption during highly eccentric passages, yielding very few surviving hot Jupiters.**



Numerical model

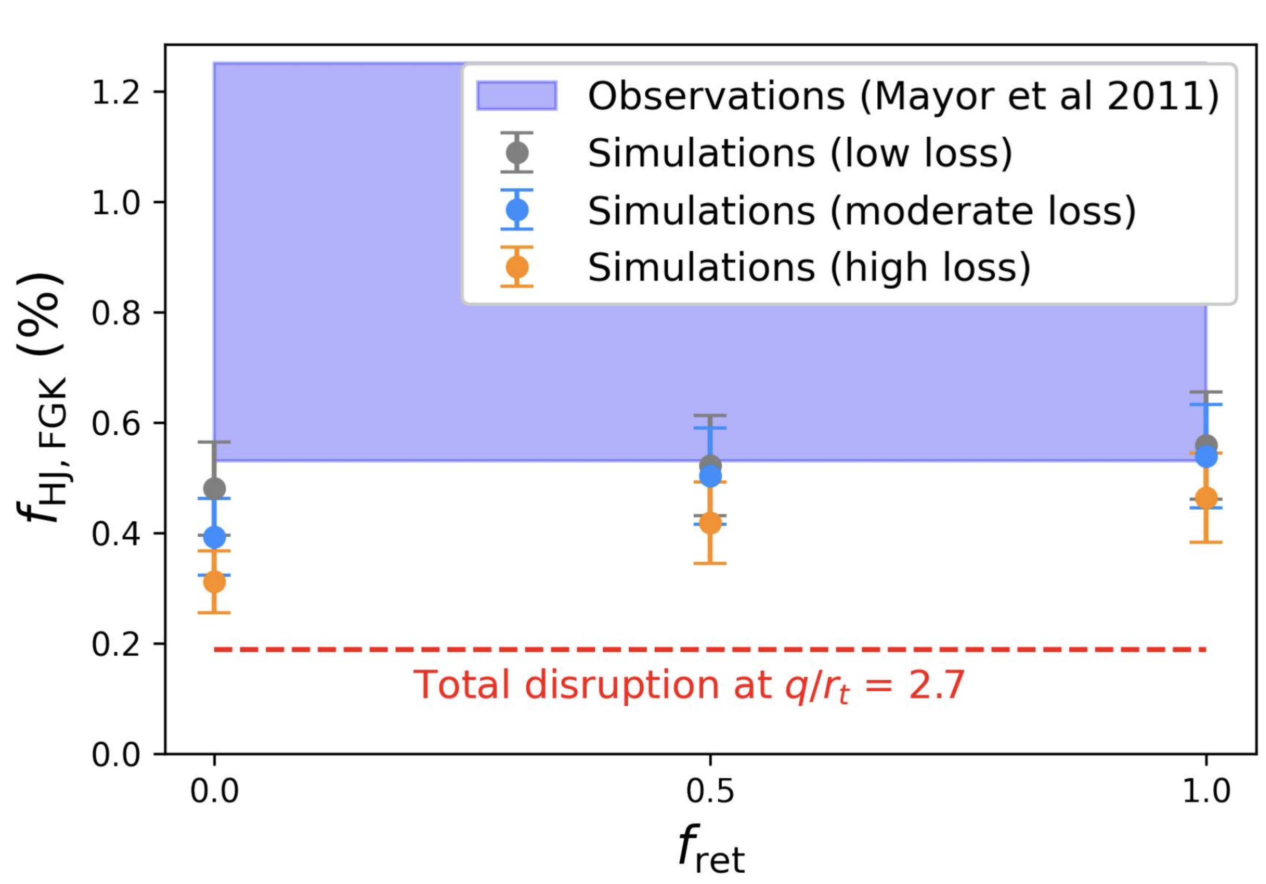
We revisit this question with improved treatments of the mass loss and angular momentum experienced by tidally perturbed planets. Prior studies assumed all planets are completely disrupted immediately upon crossing the Roche limit. In reality, planets may graze the Roche limit and only undergo partial disruption. As lost mass accretes onto the host star, angular momentum may return to the planetary orbit via torques (we test angular momentum return fractions of 0, 0.5, and 1). Partial mass loss fractions are informed by hydrodynamical simulations (Guillochon et al 2011), and the structural evolution of the planet is taken from MESA.

We consider a star+planet system orbited by a widely separated stellar companion in a hierarchical triple configuration. We evolve the dynamics using a secular code that slows at high eccentricities to resolve orbit-by-orbit mass loss. An example evolution is shown on the right. **The planet loses mass at high eccentricity, but does not undergo catastrophic tidal disruption and ultimately survives as a hot Jupiter.**

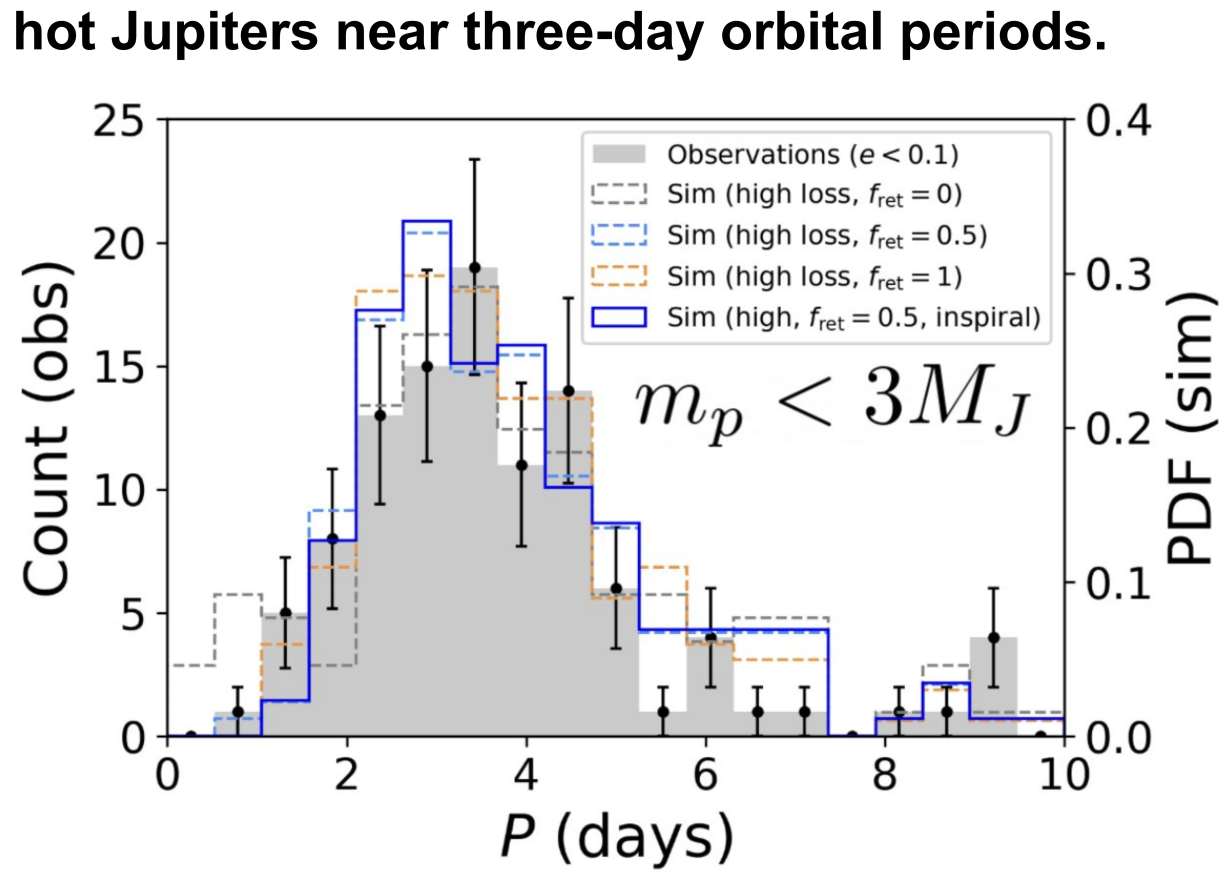


Population synthesis results

Using the above model, we perform a population synthesis study of initially cold Jupiters in wide stellar binaries with similar initial conditions as previous studies. We find that under the new treatment, the **hot Jupiter occurrence rate is enhanced by a factor of ~2-3**, bringing theoretical predictions in closer agreement with observed occurrence rates (≳0.5% around FGK stars). Therefore, **EKL-induced high-eccentricity migration may be a dominant formation channel for the population of hot Jupiters.**



Mass loss and angular momentum return may lead to the well-known "pileup" of hot Jupiters near three-day orbital periods.



Analytical model

We analytically model the system outcomes using a modified version of the framework in Muñoz et al 2016. We calculate the maximum eccentricity induced by EKL (accounting for general relativity and tides), then compare to the critical periastra required for migration, partial mass loss, or complete tidal disruption. The final circularization location is also calculated. As in the numerical simulations, we find that **planets that undergo partial mass loss represent a majority of hot Jupiters**, and angular momentum return may produce a pile-up near three days.