CAN THE TAIL TRANSIT WITHOUT THE PLANET?

Radiation-Driven Atmospheric Escape Around Evolving Stars

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INTRODUCTION

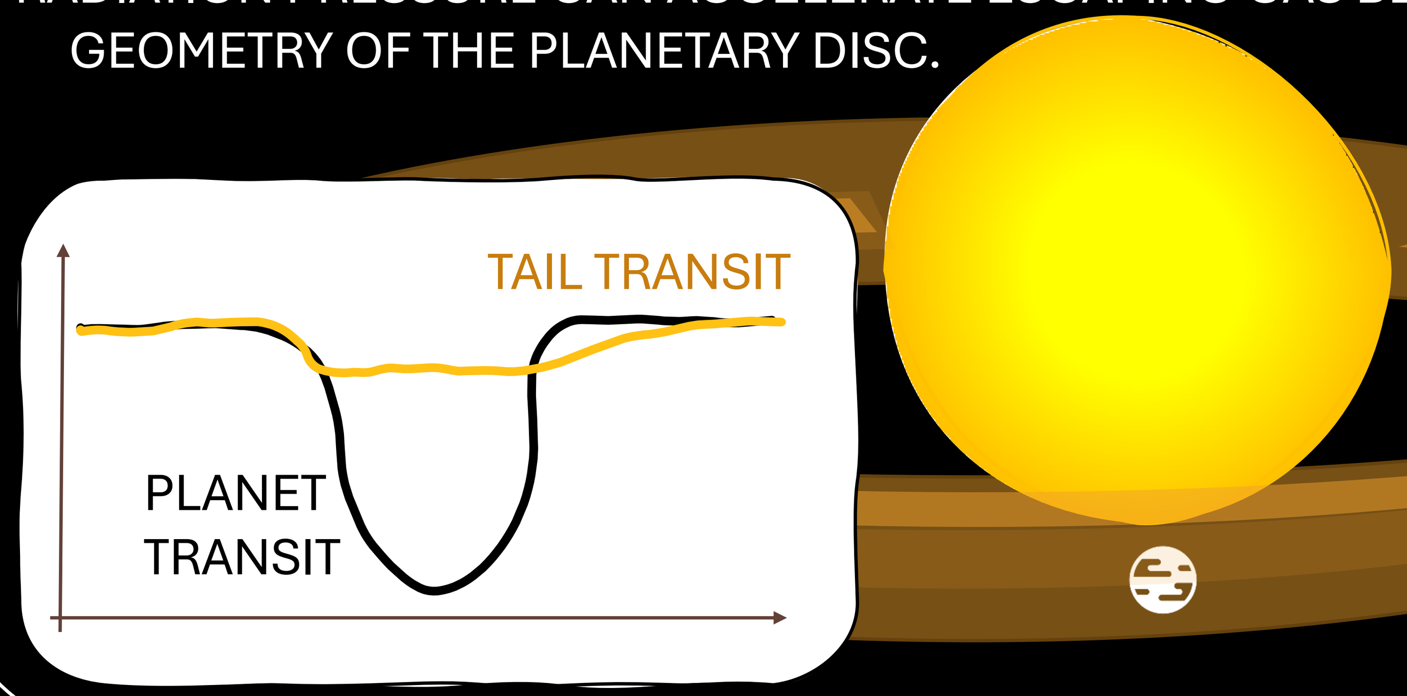
Close-in exoplanets experience intense stellar irradiation that heats and expands their upper atmospheres, driving atmospheric escape. The first detection came from HD 209458 b, where Lyman-α absorption revealed neutral hydrogen extending beyond the planet's Roche lobe, demonstrating that giant planets can lose atmospheric material to space [1]. Atmospheric escape has since been observed in hydrogen, helium and numerous metals. Some planets develop structures extending far beyond the planetary radius. WASP-12 b may host a circumstellar gas torus produced by atmospheric escape [2-4], while KELT-9 b exhibits an extended hydrogen atmosphere together with escaping neutral and ionised metals [5,6], showing that atmospheric escape persists even around hot, early-type stars. Most atmospheric escape models focus on individual systems at their current evolutionary stage [7]. As host stars evolve, their spectra change substantially, altering radiation pressure, ionisation balance and the dynamics of escaping gas.

In this work, we investigate how atmospheric escape evolves from the pre-main sequence to the main sequence by coupling stellar evolution models, species-dependent radiation pressure calculations [8] and a one-dimensional hydrodynamic tail model [9]. Finally, we explore whether radiation-driven tails could produce observable transit signatures even when the planet itself does not transit the star.

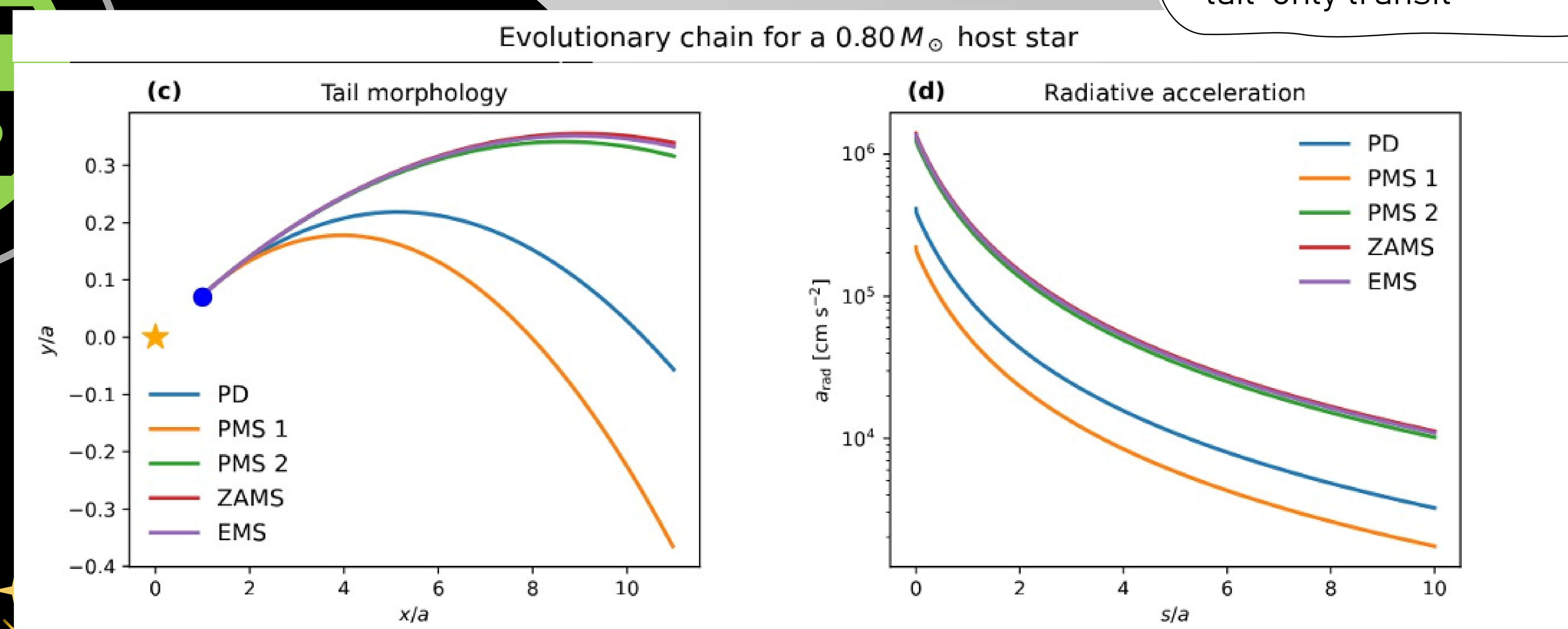
- How does the tail morphology evolve?
- Do different species trace different tails?
- When could a tail transit without the planet?

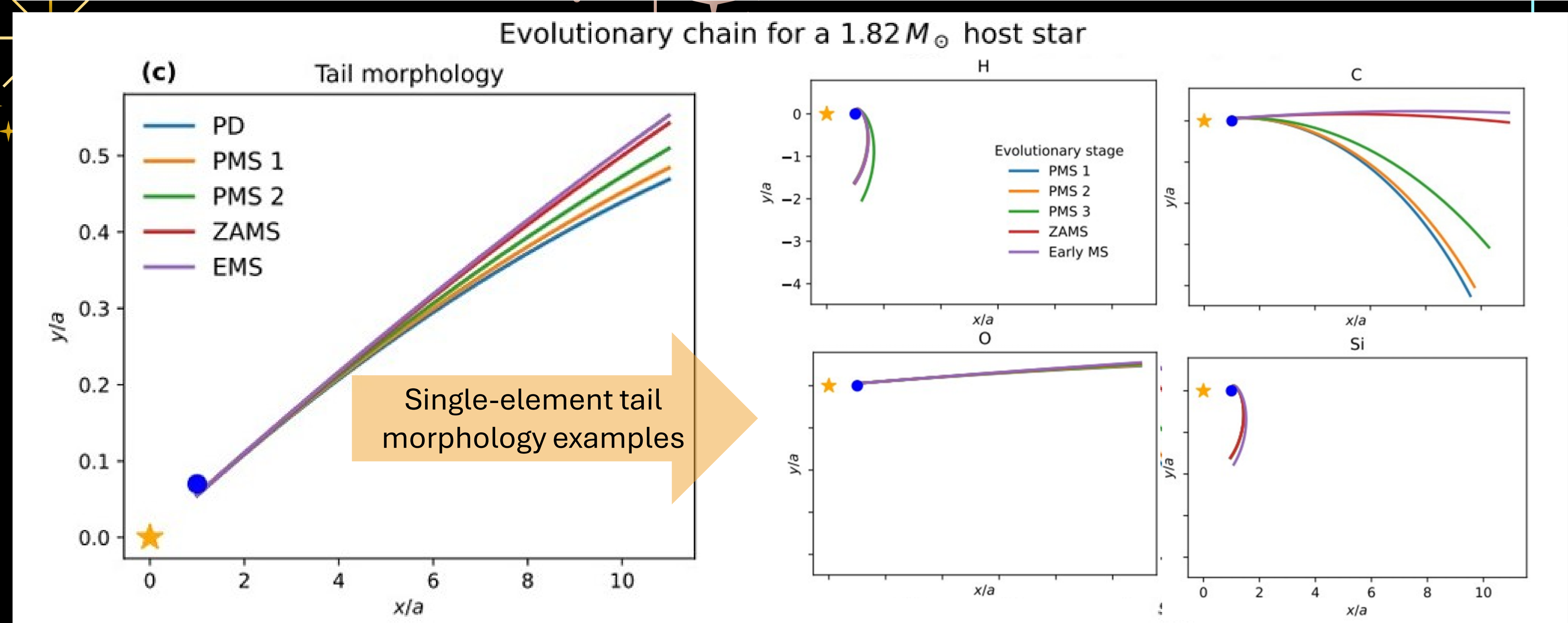
CAN AN ESCAPING PLANETARY TAIL TRANSIT EVEN WHEN THE PLANET DOES NOT?

RADIATION PRESSURE CAN ACCELERATE ESCAPING GAS BEYOND THE GEOMETRY OF THE PLANETARY DISC.

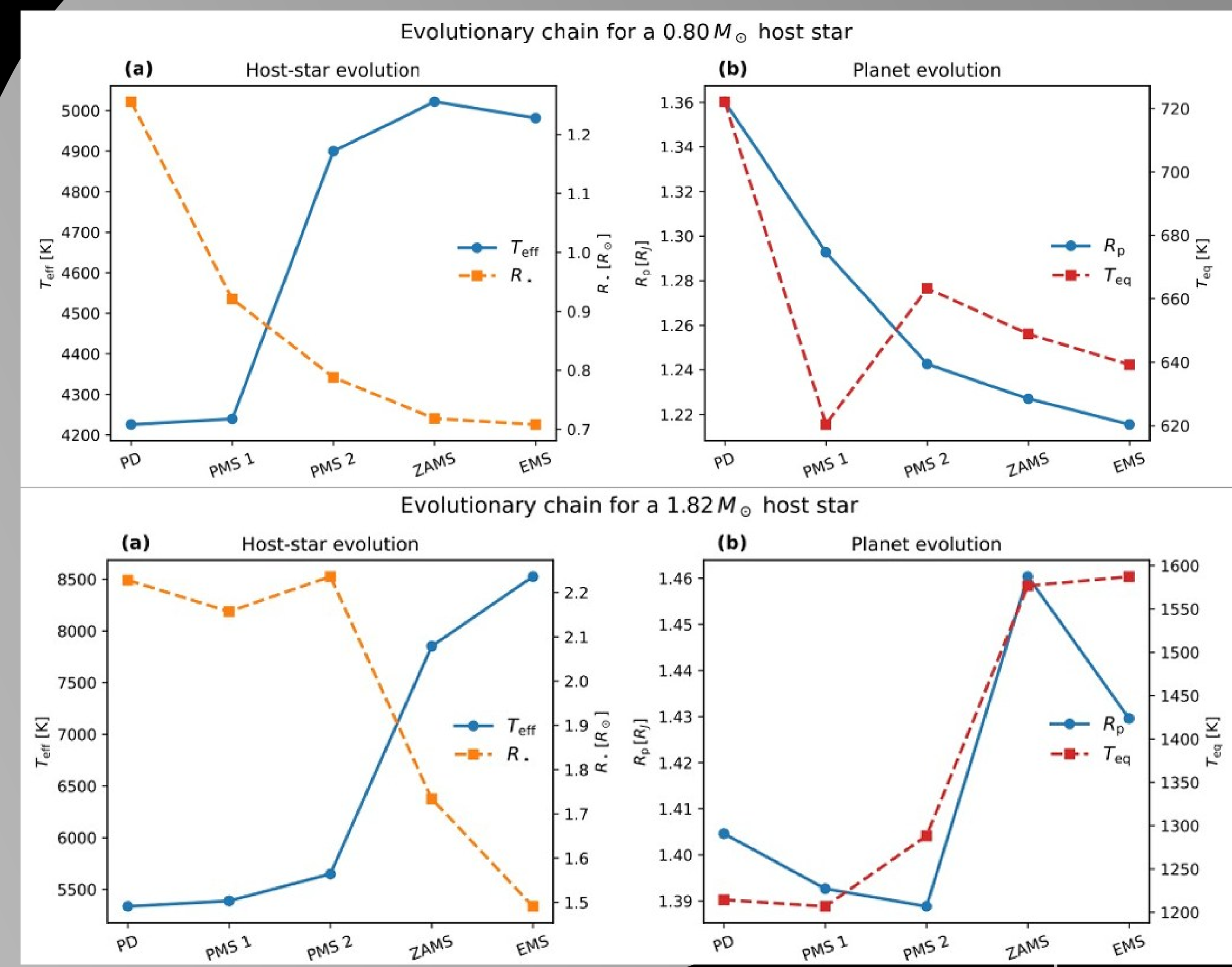


Possible signatures
- asymmetric transit
- pre-transit absorption
- post-transit absorption
- longer duration
- tail-only transit





FOLLOWING THE STAR, PLANET, AND TAIL THROUGH TIME



$$\beta = \frac{F_{\mathrm{rad}}}{F_{\mathrm{grav}}}$$

$$a_{rad+grav} = (\beta - 1)\frac{GM_*}{r^2}$$

Stages of evolution:
PD – Post-Disc at 3 Myr
PMS – Pre-Main Sequence
ZAMS – Zero-Age Main Sequence
EMS – Early Main Sequence

FIRST RESULTS

The morphology of an escaping atmosphere changes as its host star evolves. Coupling species-dependent radiation pressure and ionisation to a 1D hydrodynamic tail model, we find that the evolving stellar spectrum modifies the acceleration of individual atomic species and, consequently, the bulk tail morphology.

The bulk tail model includes H, He, C, O, Na, Mg, Si, and Ca across ionisation stages I–V.

WHY DOES THIS MATTER?

Future transit surveys, including the Nancy Grace Roman Space Telescope, may detect extended or asymmetric occultations produced by escaping atmospheres. Extended atmospheric tails could produce asymmetric, prolonged, or grazing occultations that differ from conventional planetary transits. Could some transit-like signals trace escaping material rather than the planetary disc itself?

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