The key role of the host star's rotational history on the evolution of the planetary system

The case of **TOI-849** and **Kepler-444**

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Strong XUV fluxes are able to erode the massive envelope of TOI-849b

(Pezzotti C., Attia O., Eggenberger P., et al. 2021, https://doi.org/10.1051/0004-6361/202141734)

TOI-849b is one of the few planets populating the hot-Neptune desert and it is the densest Neptune-sized one discovered so far [1]. Its extraordinary proximity to the host star, together with the absence of a massive H/He rich envelope on top of the 40.8 $M_\oplus$, calls into question the role played by the host star along the evolution of the system.

We couple rotating stellar models of TOI-849 to our orbital evolution code to study the impact of stellar tides on the evolution of the system. We also compute the evolution of the planetary atmosphere by means of the JADE code [2], which uses realistic XUV fluxes provided by our stellar models.

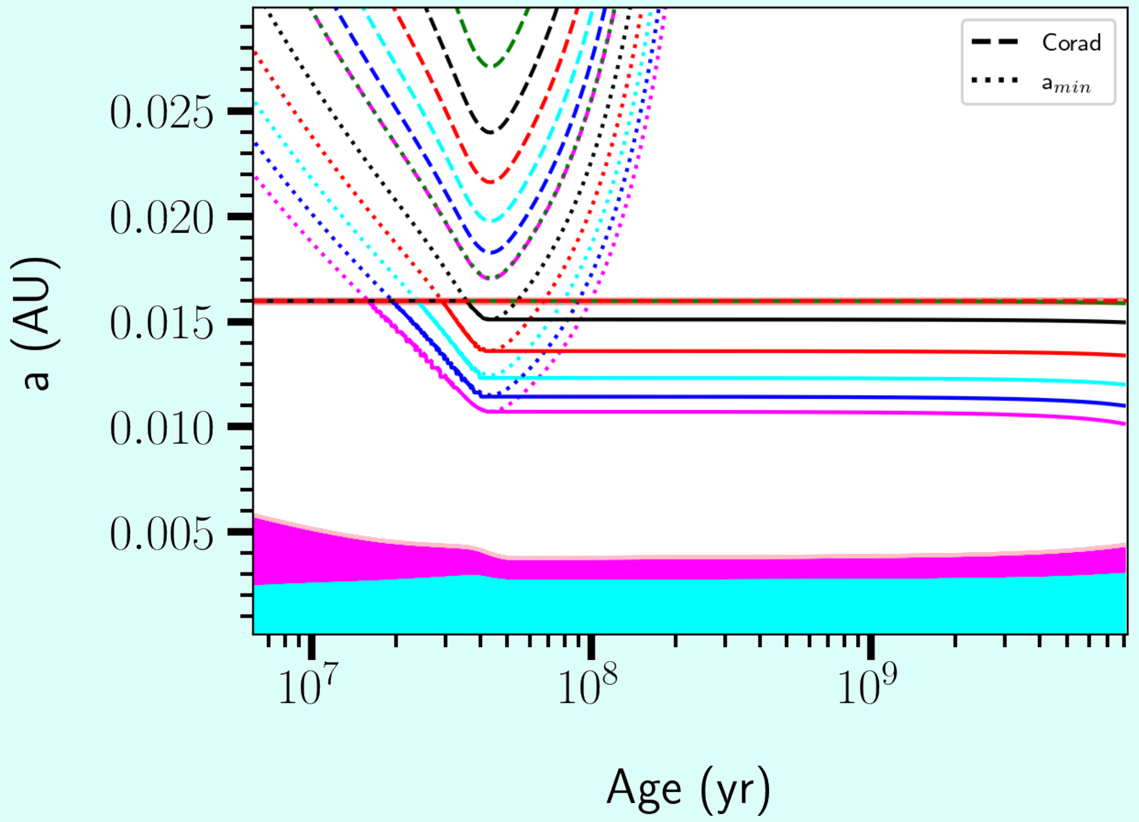

Fig. 1a Orbital evolution of TOI-849b for Ω_{in} = 5, 6, 7, 8, 9, 10 $\Omega_\odot$ (green, black, red, cyan, blue, and magenta). The cyan and magenta areas represent the extension of the stellar radiative and convective zones. Dotted lines indicate the evolution of the minimum orbital distance (a_{min}) above which dynamical tides become active. Dashed lines indicate the evolution of the corotation radius (Corad), defined as the distance at which the orbital frequency of the planet is equal to the stellar surface rotation rate.

Assuming that the planet was at its present-day position at the protoplanetary disc dispersal ($a = 0.01598\ AU$) with mass 40.8 $M_\oplus$, and considering a broad range of host star's initial surface rotation rates ($\Omega_{\rm in} \in [3.2,18]\ \Omega_\odot$), we found that only for $\Omega_{\rm in} \leq 5\ \Omega_\odot$ we do reproduce the current position of the planet (Fig. 1a). For $\Omega_{\rm in} > 5\ \Omega_\odot$ the orbit is deflected by the impact of dynamical tides. We simulated the evolution of the orbit also for values of $a_{\rm in} \neq 0.01598\ AU$ for each of the considered rotational histories and tested the impact of increasing the initial mass of the planet on the efficiency of tides, finding that a higher initial mass ($M_{\rm in} = 1\ M_{\rm Jup}$) does not change the results reported above.

Based on these results, the evolution of the planetary atmosphere was computed for a large range of initial masses above 40.8 $M_\oplus$. We found that the strong XUV flux received by the planet is able to remove the entirety of its envelope within the first 50 Myr of the evolution, even if it formed as a Jupiter-mass planet (Fig. 2a).

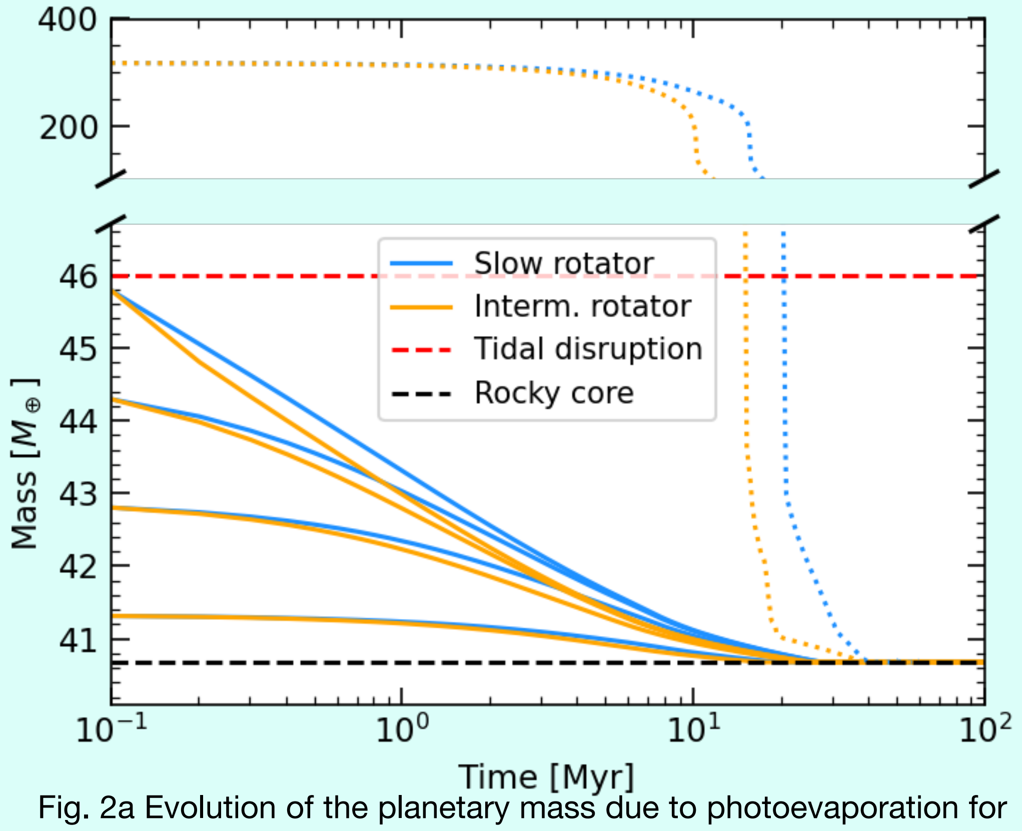

Fig. 2a Evolution of the planetary mass due to photoevaporation for different initial masses.

References

[1] Armstrong, D. J., Lopez, T. A., Adibekyan, V., et al. 2020, Nature, 583, 39
[2] Attia, O., Bourrier, V., Eggenberger, P., et al. 2021, A&A, 647, A40
[3] Bourrier, V., Ehrenreich, D., Allart, R., et al. 2017, A&A, 602, A106
[4] Buldgen, G., Farnir, M., Pezzotti, C., et al. 2019, A&A, 630, A126
[5] Johnstone, C. P., Bartel, M., & Güdel, M. 2021, A&A, 649, A96
[6] Sanz-Forcada, J., Micela, G., Ribas, I., et al. 2011, A&A, 532, A6
[7] Wright, N. J., Drake, J. J., Mamajek, E. E., & Henry, G. W. 2011, ApJ, 743, 48

Kepler-444-e: host star's activity history and survival of the primordial ice layer

(Pezzotti C., Eggenberger P., Buldgen G., et al. 2021, https://doi.org/10.1051/0004-6361/202039652)

Kepler-444 is one of the oldest planetary systems known thus far. Its peculiar configuration with five sub-Earth-sized planets orbiting the companion to a binary stellar system, together with the observations of HI-Lyα variations make its early history puzzling.

Kepler-444-e is the only planet of the system for which a measurement of the mass and an estimation of the mass loss rate are available. [3] proposed that the HI-Lyα variations are associated with the presence of a H-rich atmosphere trailing the planet, that might have formed beyond the snow line with a **Ganymede-like** composition (**up to 70%** $M_{\rm in}$ **of water ice**). Integrating backwards in time the mass loss rates obtained by the energy-limited formula for a constant XUV-flux, [3] found that this planet would have lost only the **27%** of its initial water content until today.

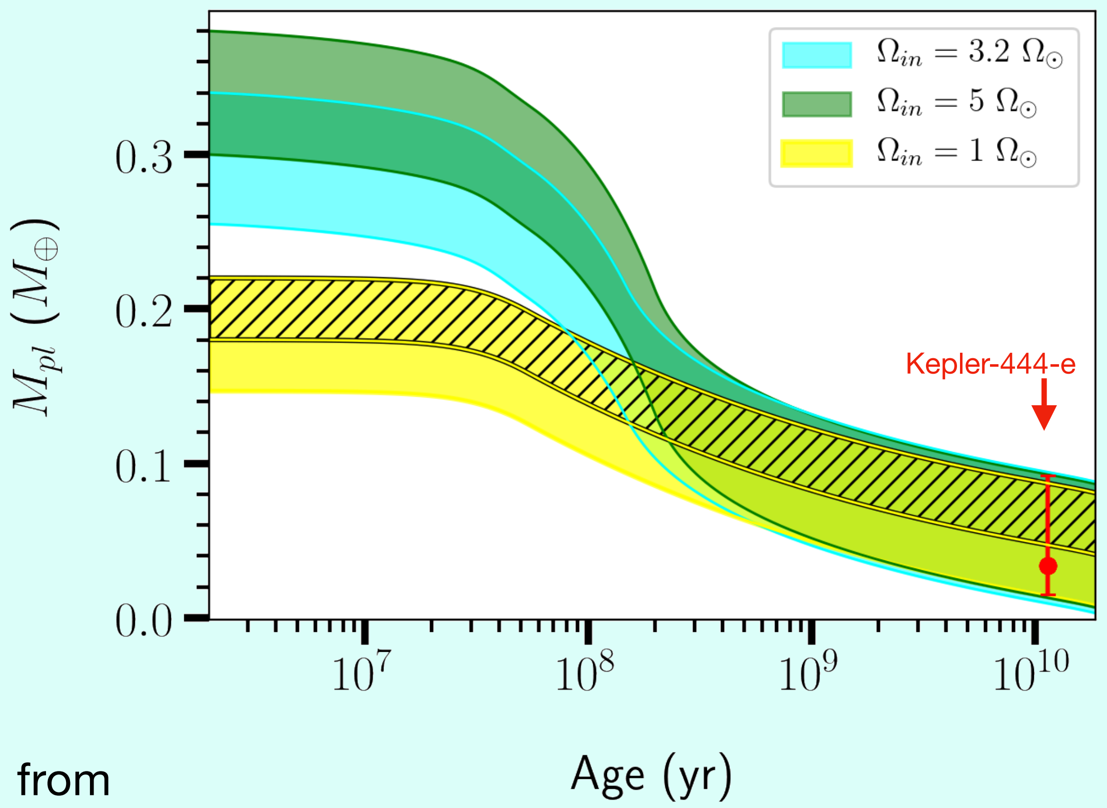

Fig. 1b Evolution of the planetary mass for different rotators. The black hatched area indicates the region of mass values compatible with an initial Ganymede-like composition.

Using rotating stellar models (whose parameters were derived from asteroseimic characterisations of the host star [4]) able to reproduce the rotation rate of Kepler-444-A, we computed the evaporation of the planet accounting for the **host star's rotational history** and **XUV activity** ([6, 7]).

● The total mass losses computed by considering the statistically more representative rotational histories ($\Omega_{\rm in} = 3.2{,}5{,}18\ \Omega_\odot$) are above the maximum percentage of 70% $M_{\rm pl_{in}}$ (initial mass) allowed for the planet to retain a fraction of its initial water ice content until today. → We considered the possibility that Kepler-444-A evolved as a **super-slow rotator ($\Omega = \Omega_\odot$)**, finding that for a restricted range of initial masses (**0.18 - 0.22 $M_\oplus$**) we predict total mass losses below 70% $M_{\rm pl_{in}}$ (Fig. 1b).

! This result does not hold anymore if we change the XUV-luminosity prescription. If we switch from [6, 7] to the recalibrated prescription of [5], we obtain mass loss rates above 70% $M_{pl_{in}}$ (see Fig. 2b).

Even if we consider the XUV-luminosity tracks computed following [6, 7], once we include the impact of the XUV-absorption radius the mass loss rates are too strong for the planet to retain some water at the age of the system, unless we assume a heating efficiency as low as 0.01.

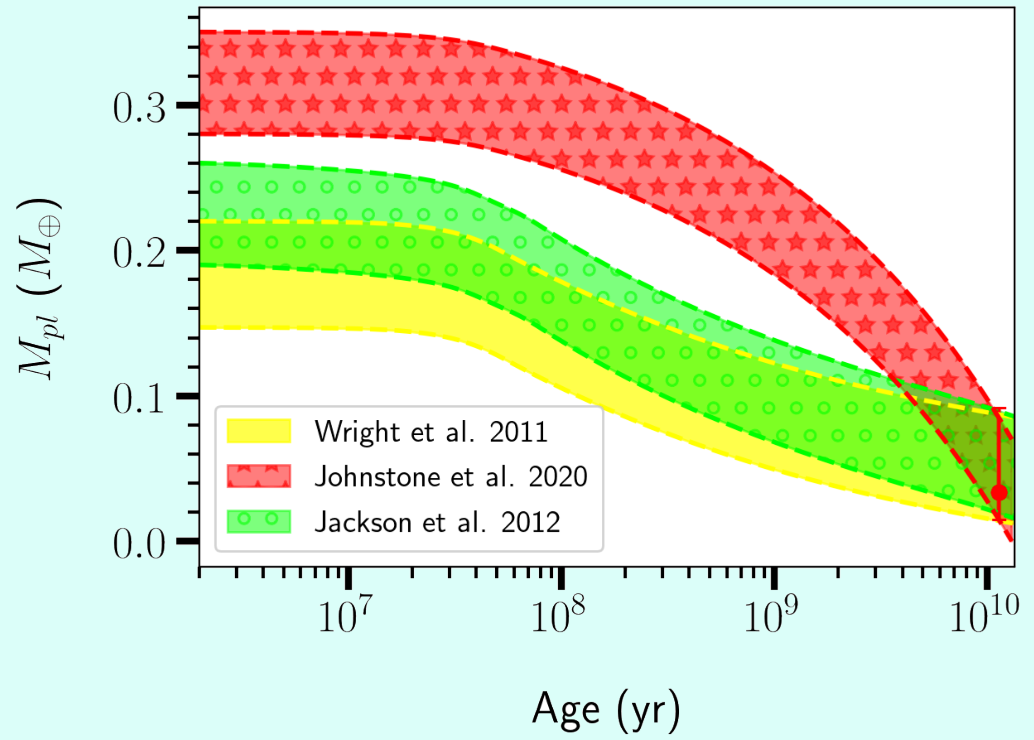

Fig. 2b Evolution of the planetary mass for $\Omega_{\rm in} = \Omega_\odot$, and different XUV luminosity prescriptions.

The need to adopt an exceptionally slow rotating star and/or a very low value of the heating efficiency to be in agreement with an initial Ganymede like composition points towards disfavouring the hypothesis that the HI-Lyα variations observed for this system are related with the presence of H-rich escaping atmospheres today, arising from oceans at the planet surface.