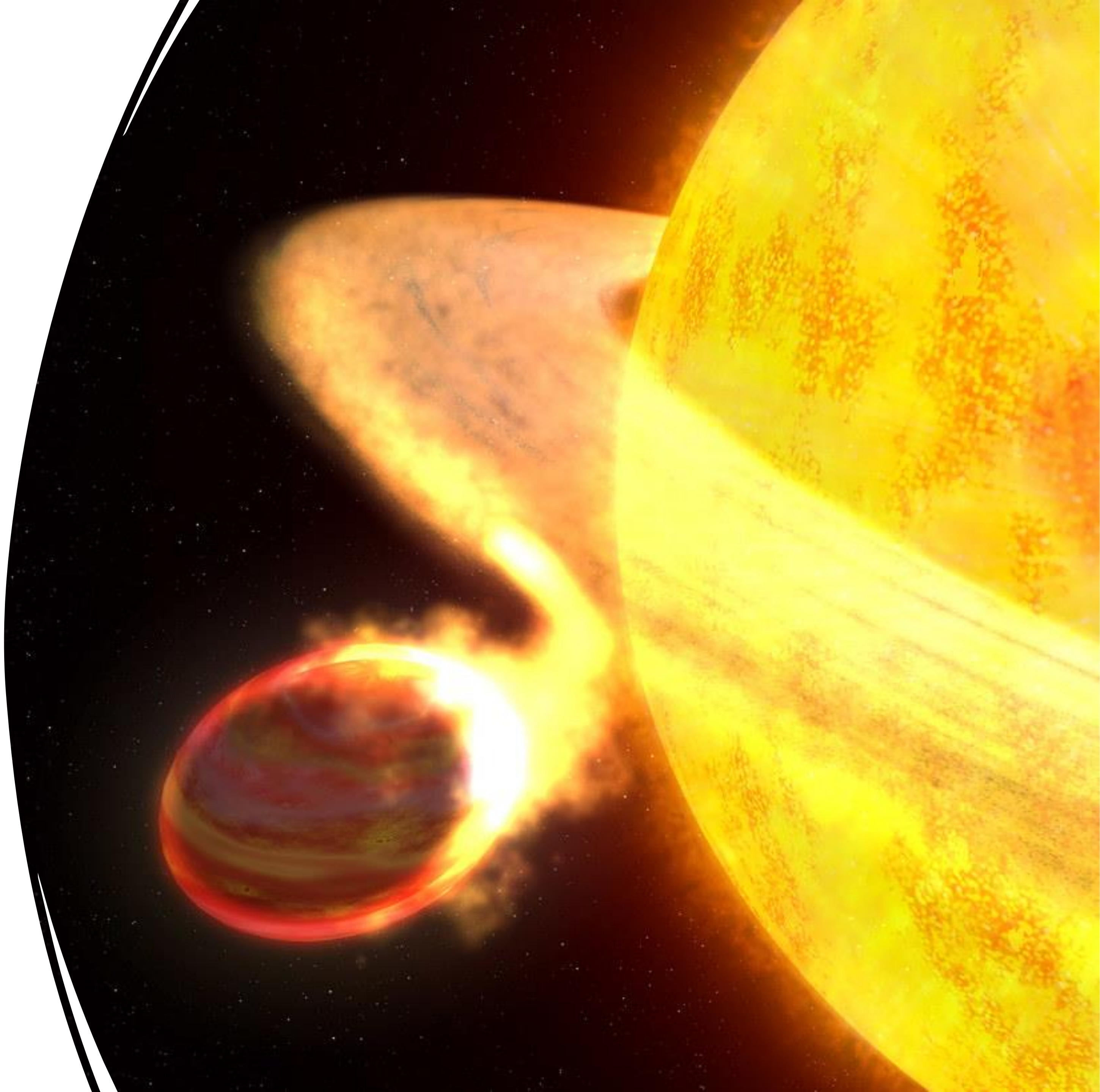
Tidal Dissipation in Cool Evolved Stars

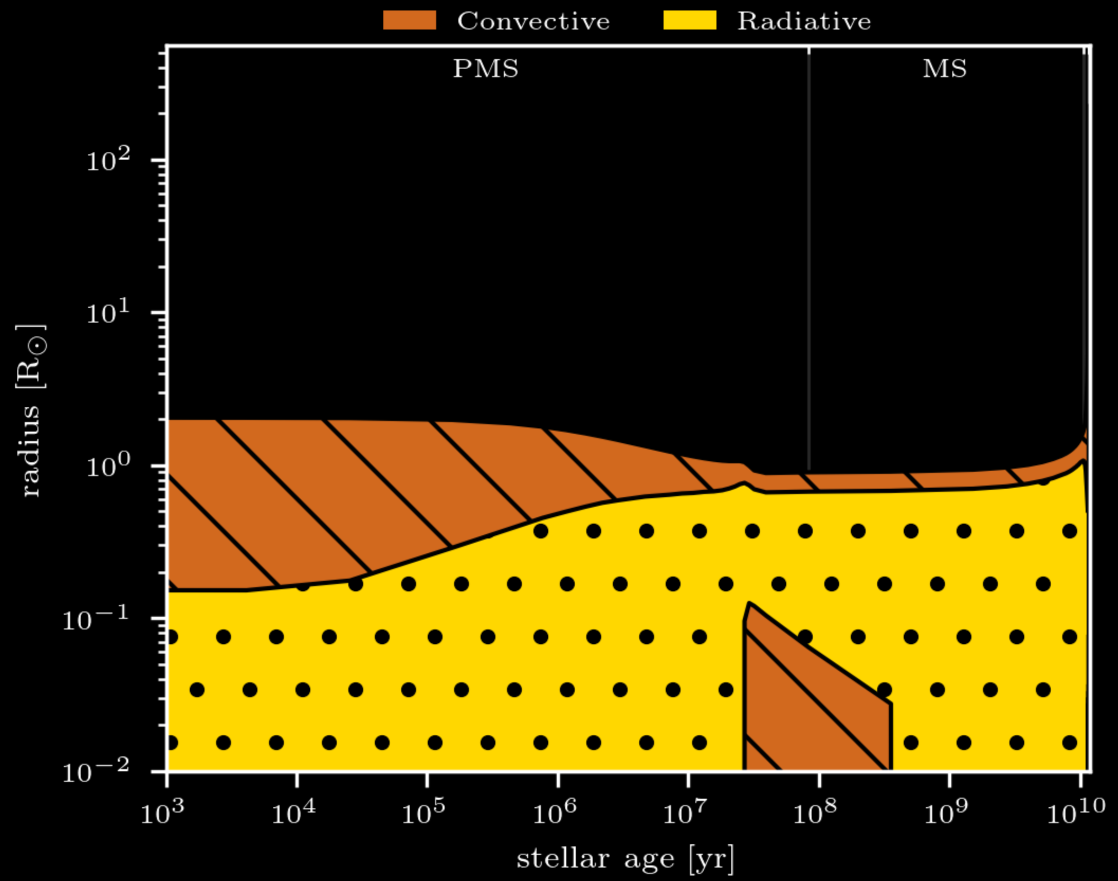
Mats Esseldeurs
Stéphane Mathis
Leen Decin

KU LEUVEN
DE LA RECHERCHE À L'INDUSTRIE
cea



Stellar Structure and Evolution ($1\ M_\odot$)

Internal structure



PMS

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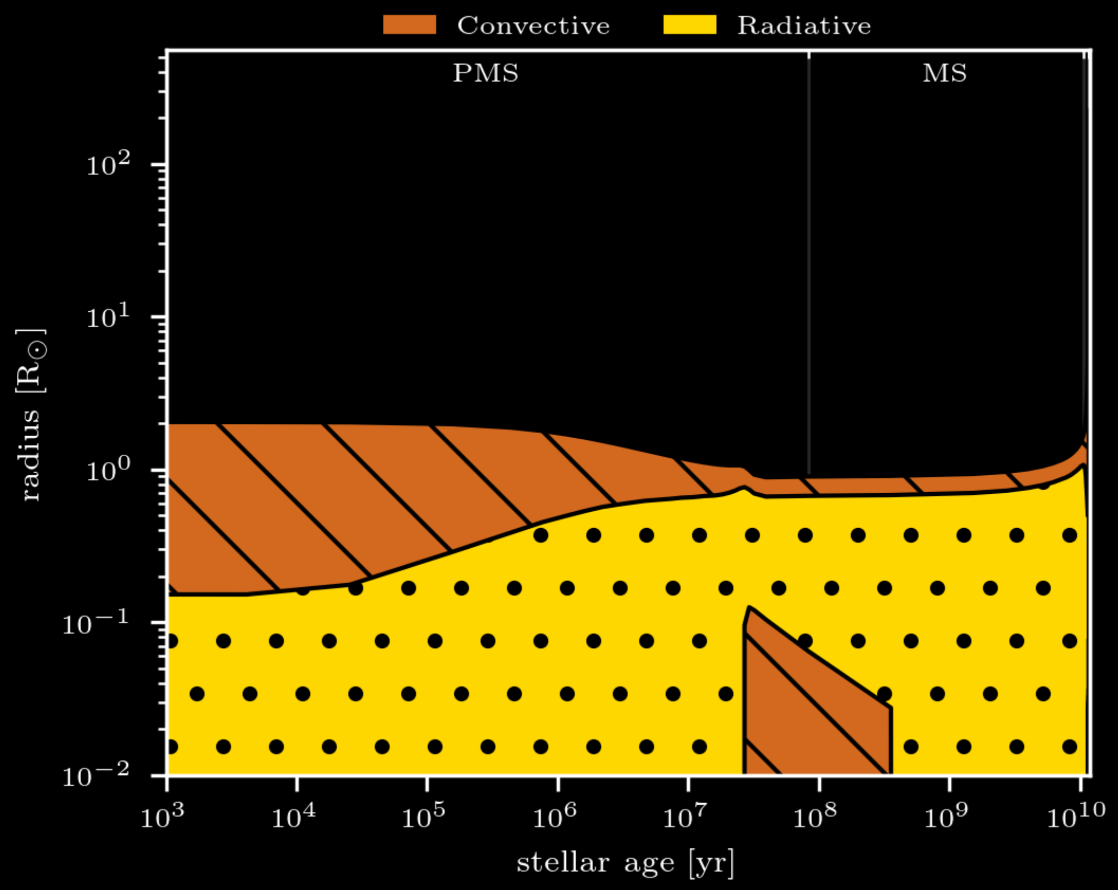

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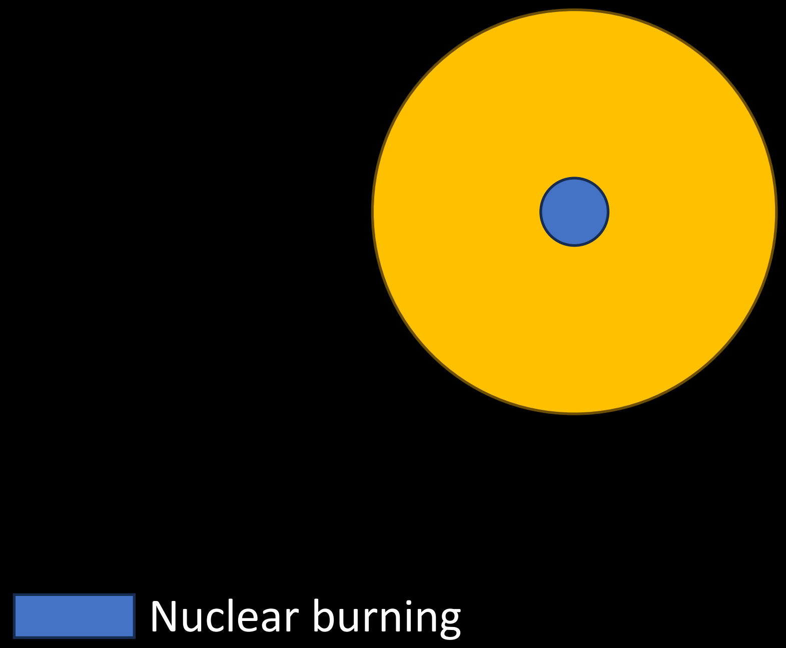

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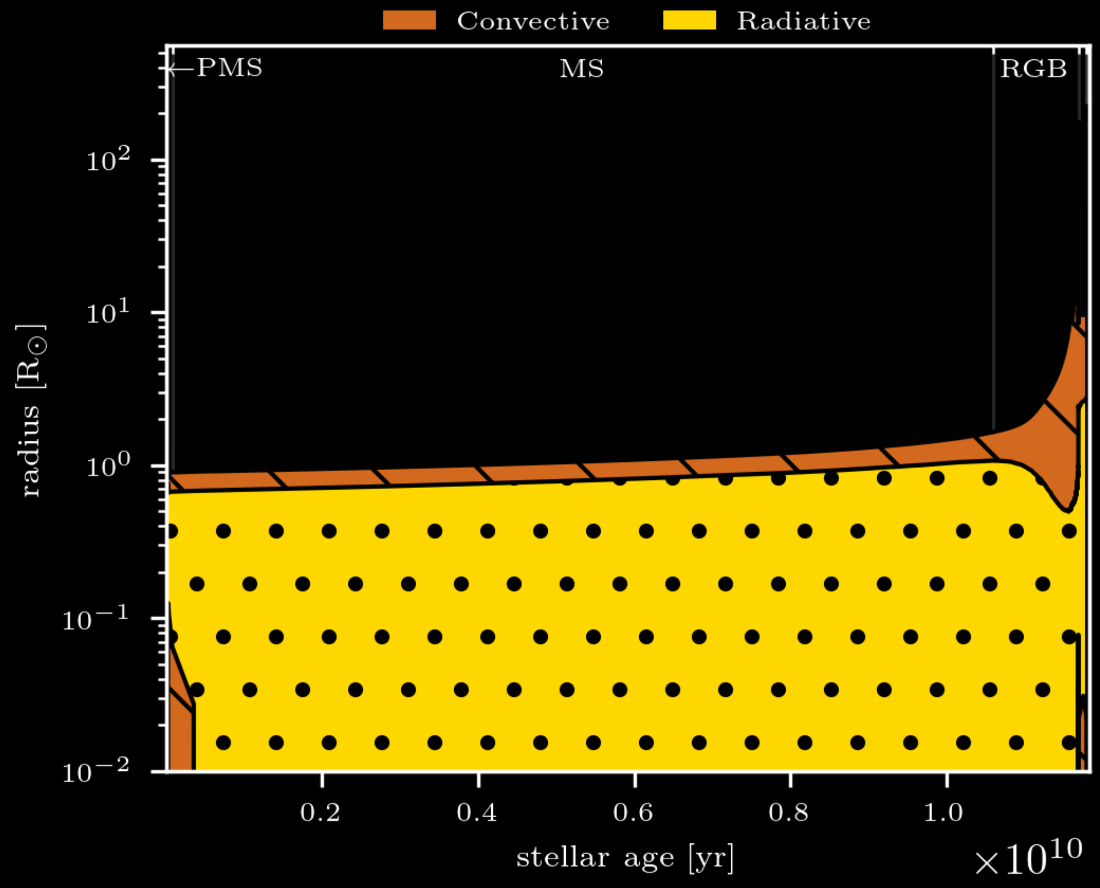

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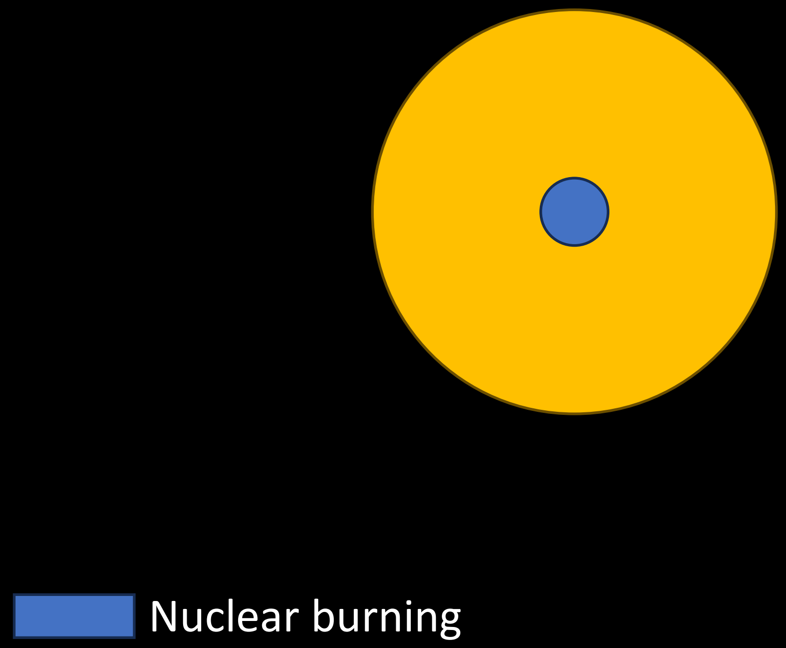

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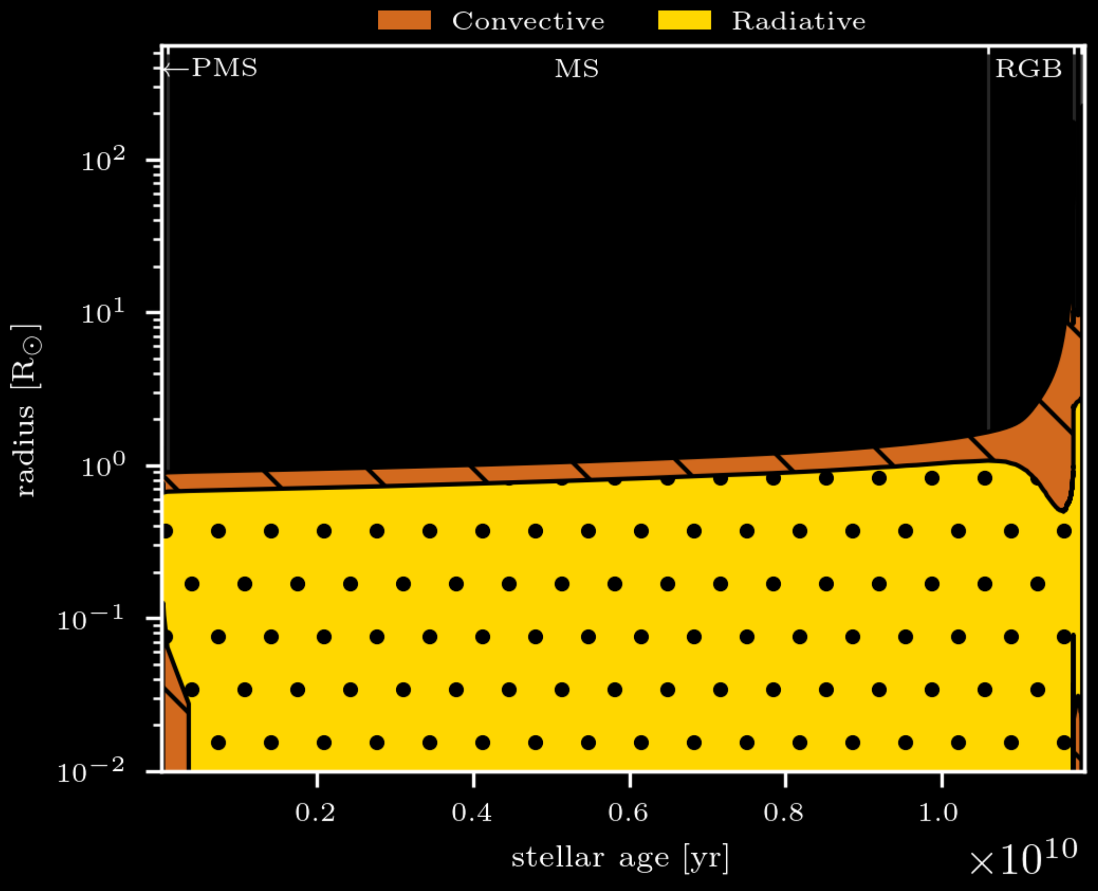

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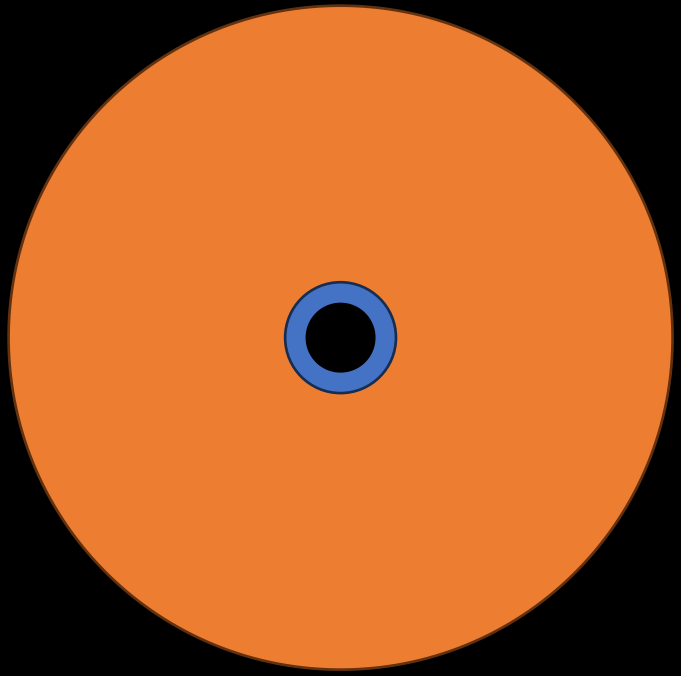
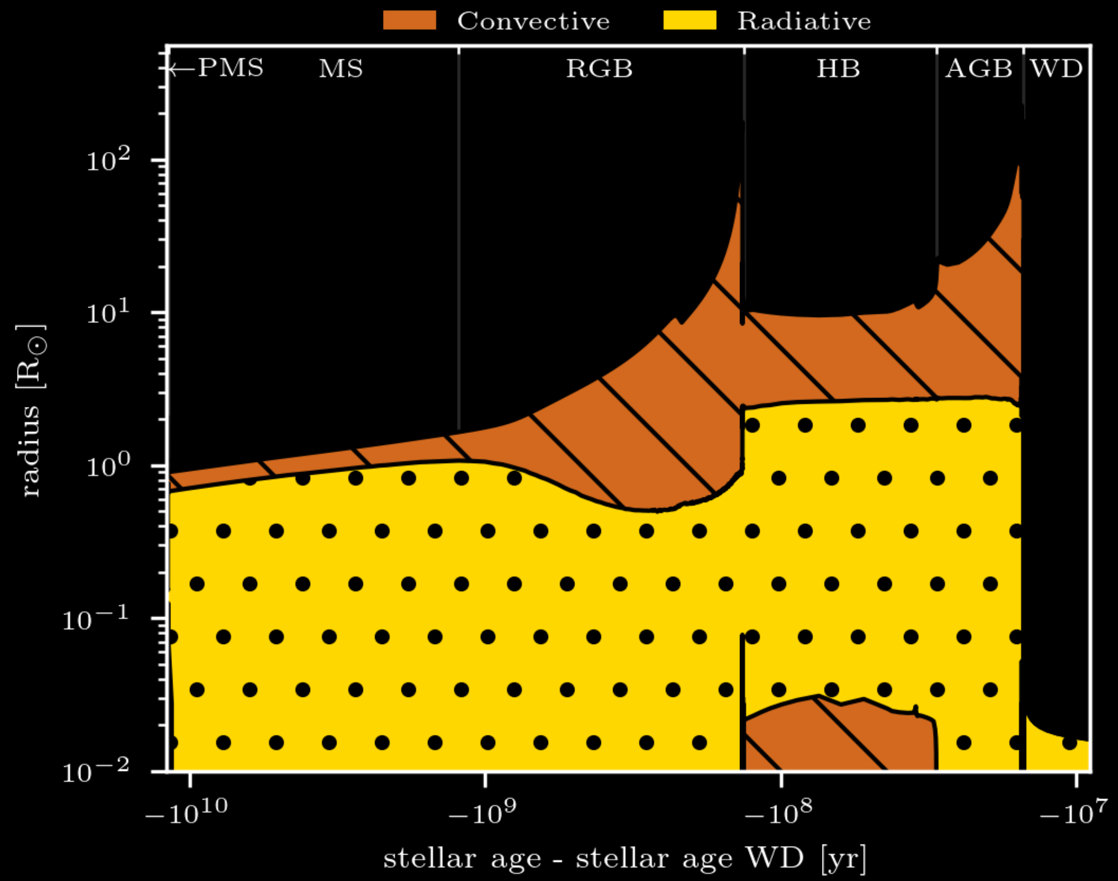


Nuclear burning

Stellar Structure and Evolution ($1\ M_\odot$)

Internal structure



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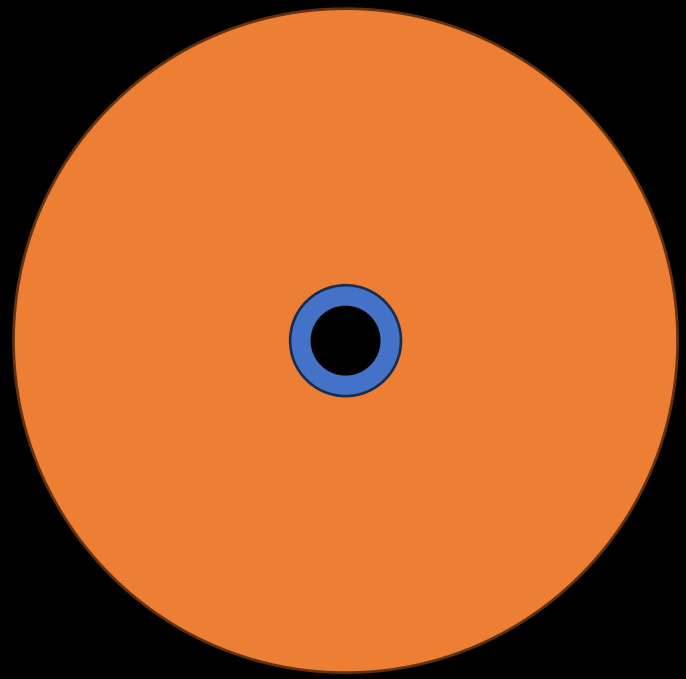

Nuclear burning

Stellar Structure and Evolution (1 $M_\odot$)

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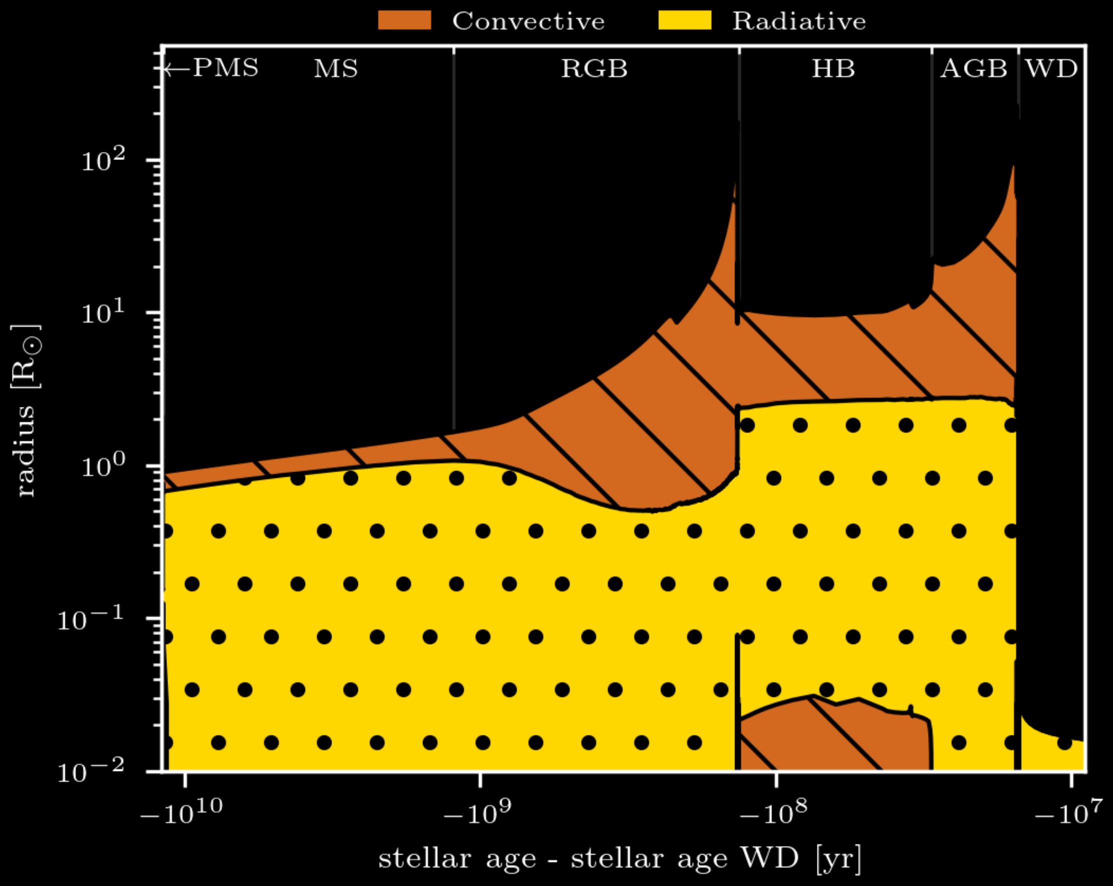

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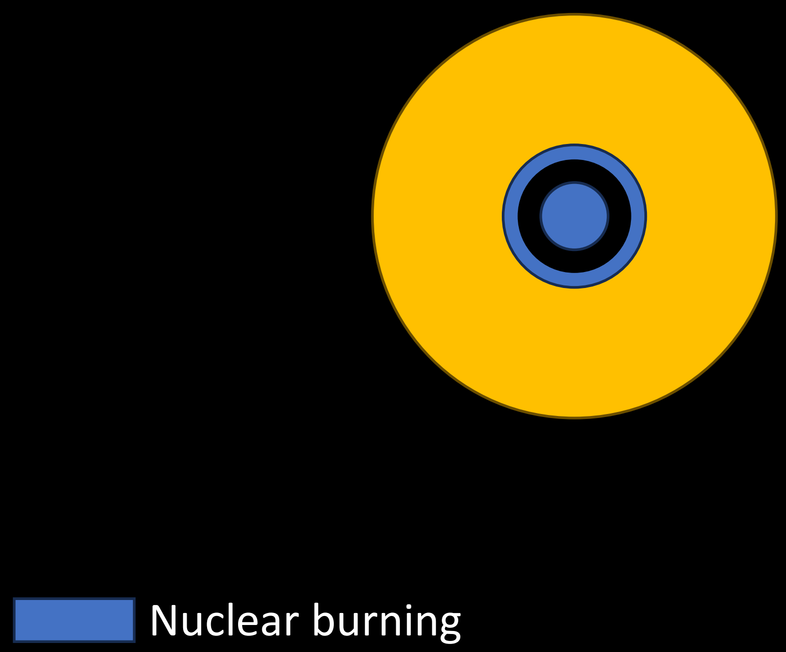
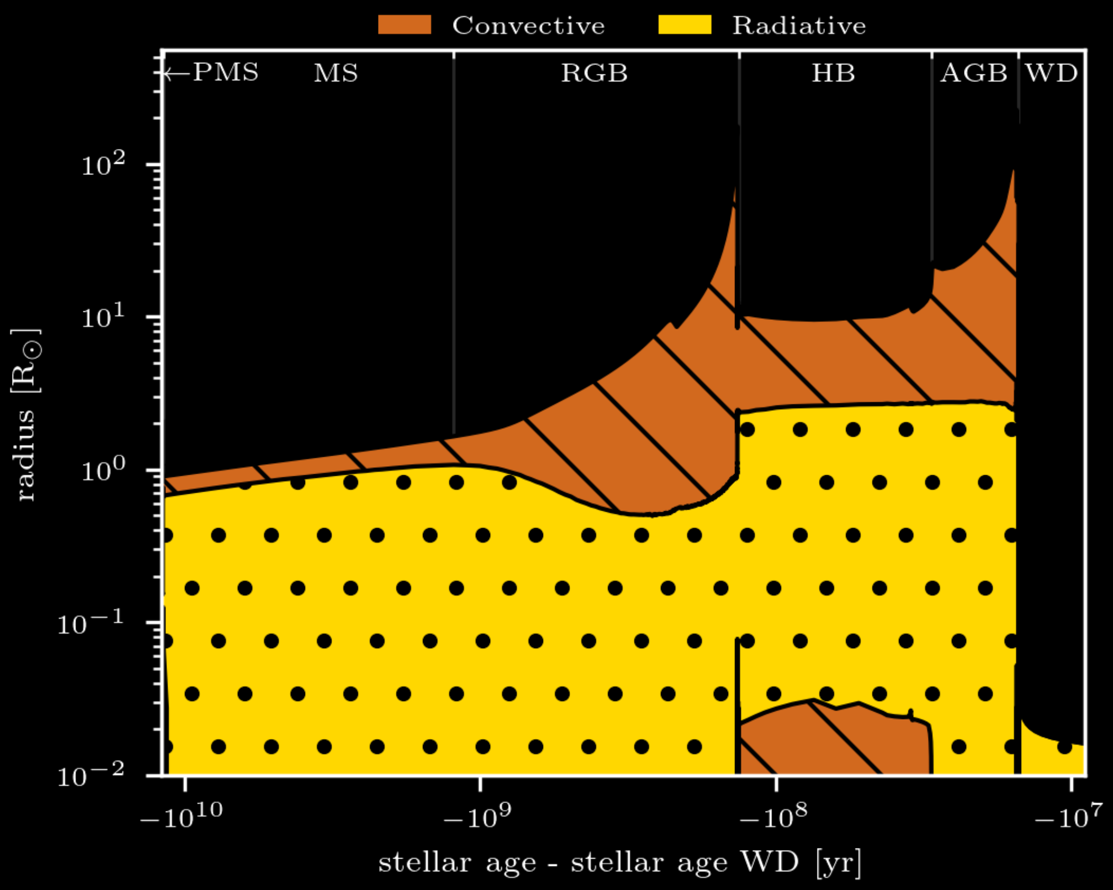


Stellar Structure and Evolution ($1\ M_\odot$)

Internal structure



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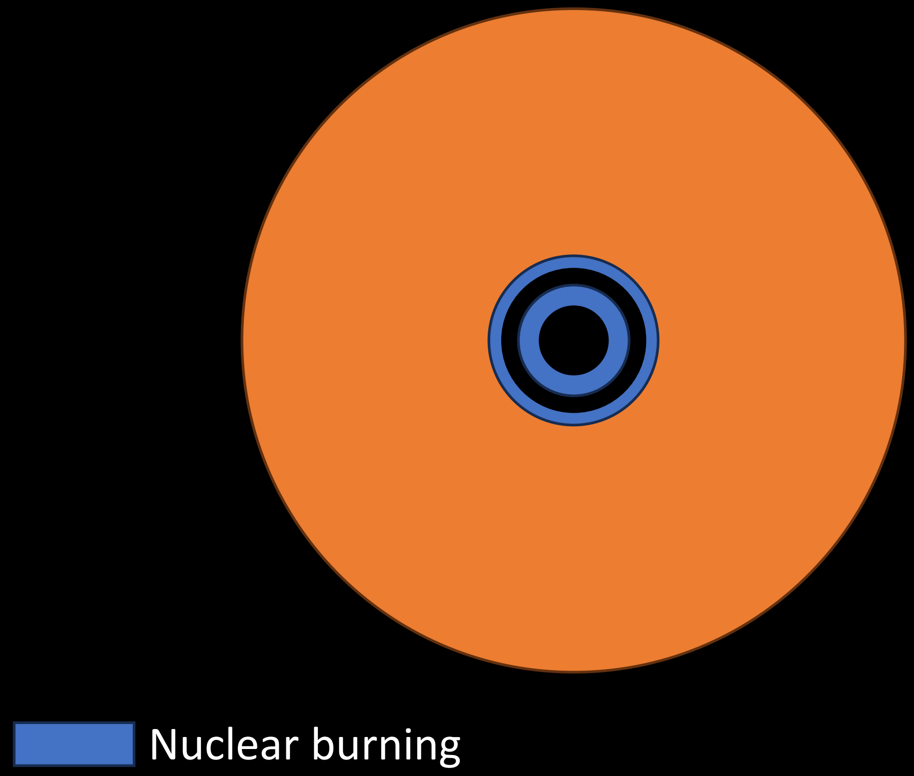

Stellar Structure and Evolution ($1\ M_\odot$)

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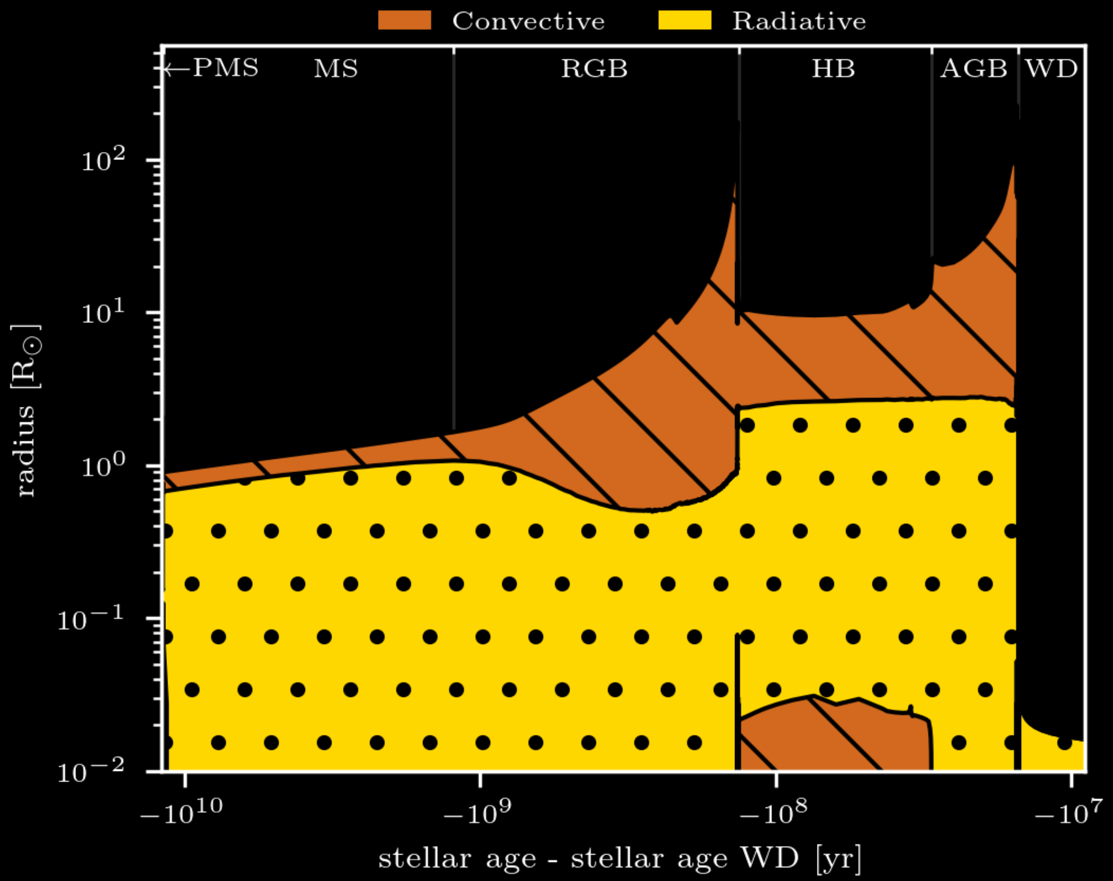

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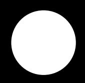
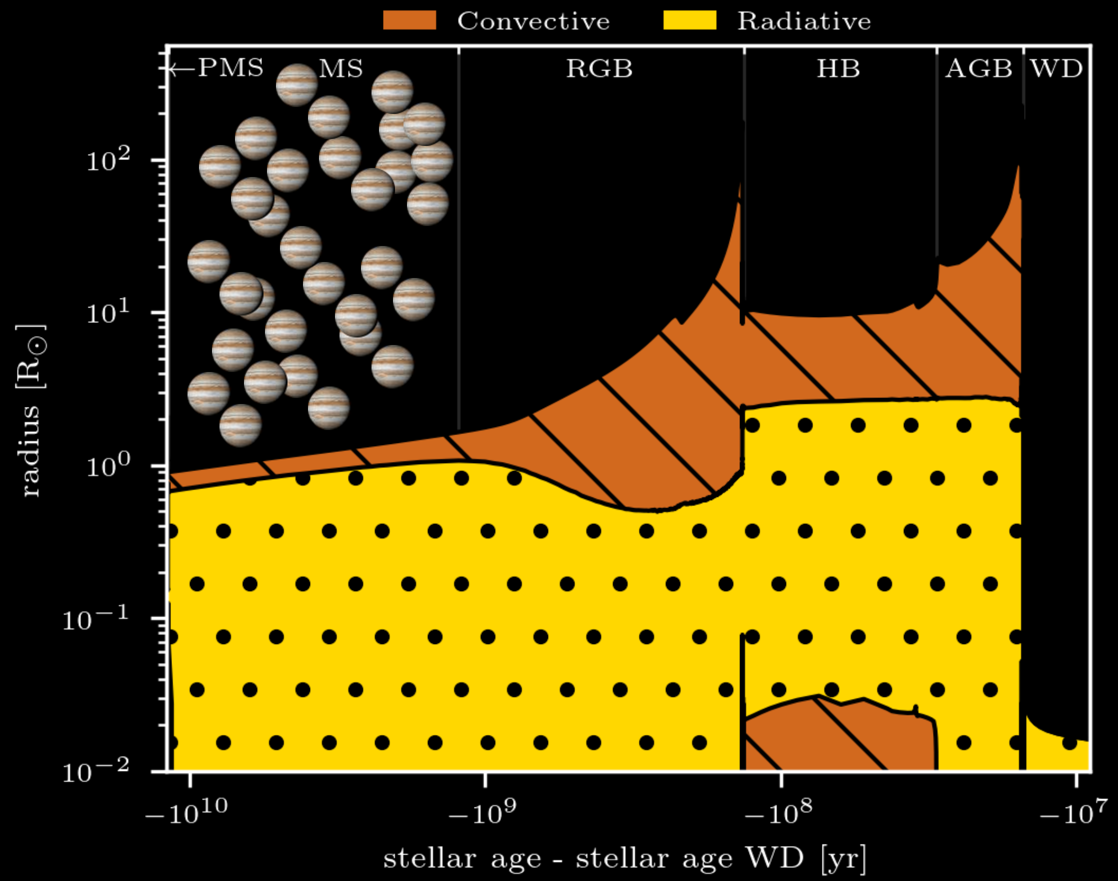


Planets around evolved stars

Internal structure



WD

Planets around evolved stars

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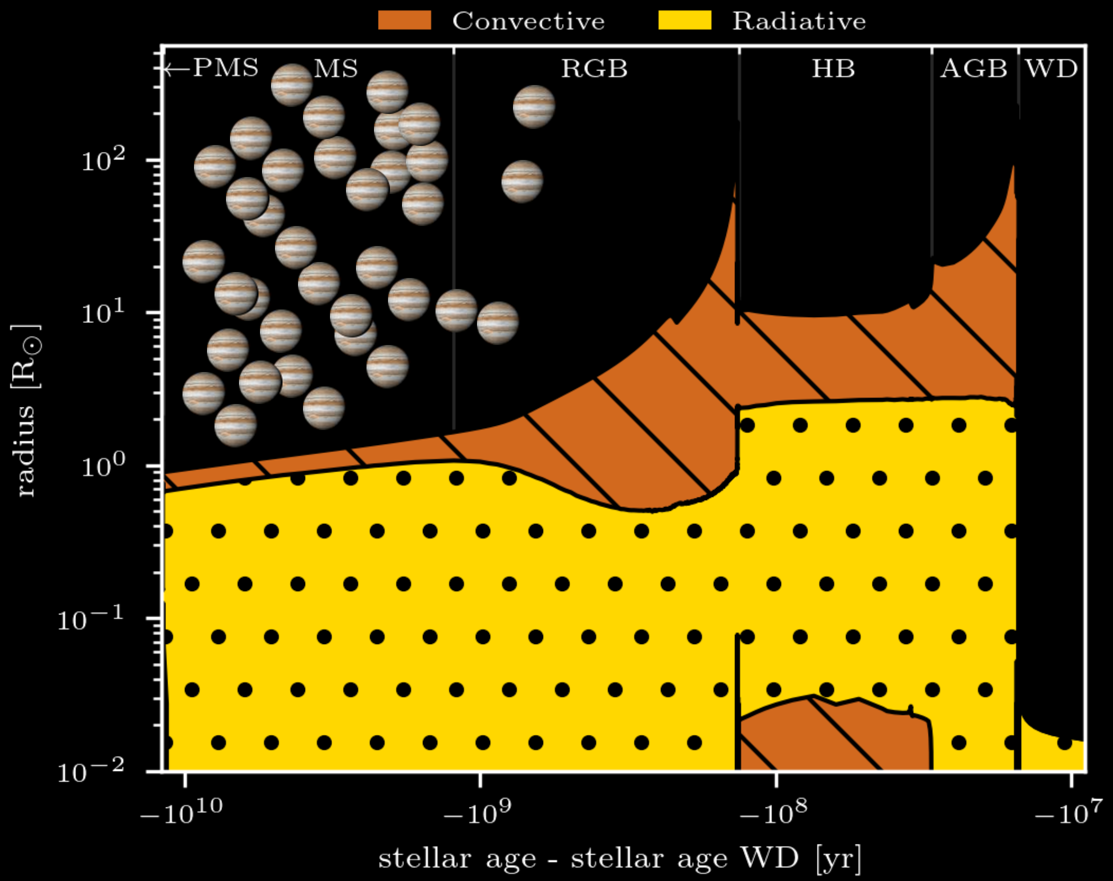

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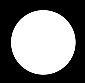

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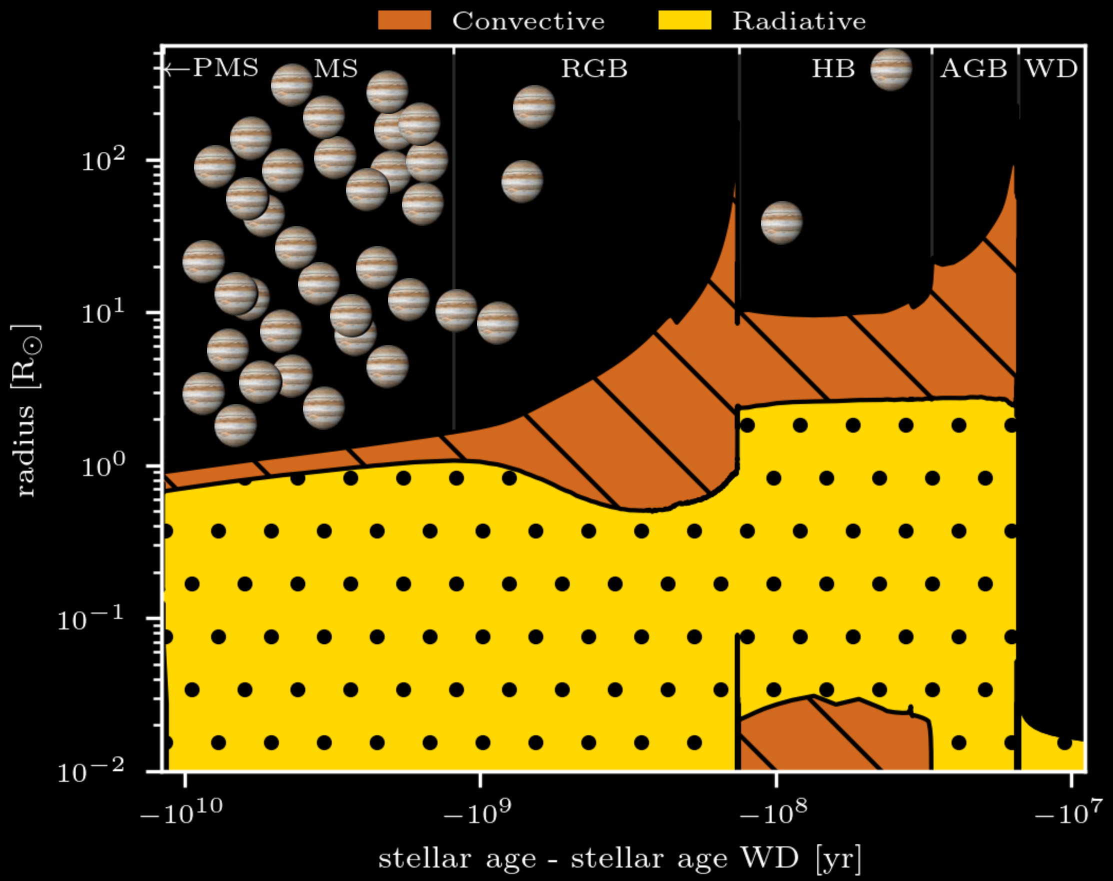

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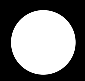
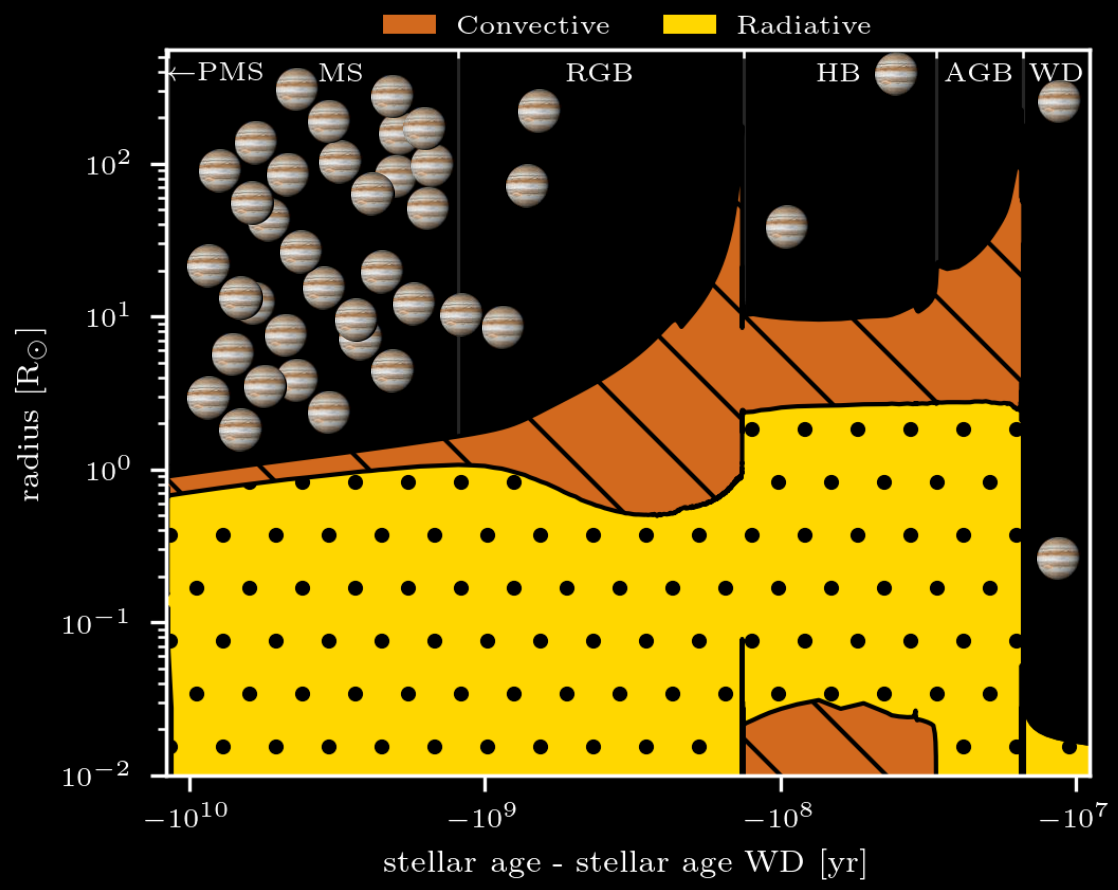


Planets around evolved stars

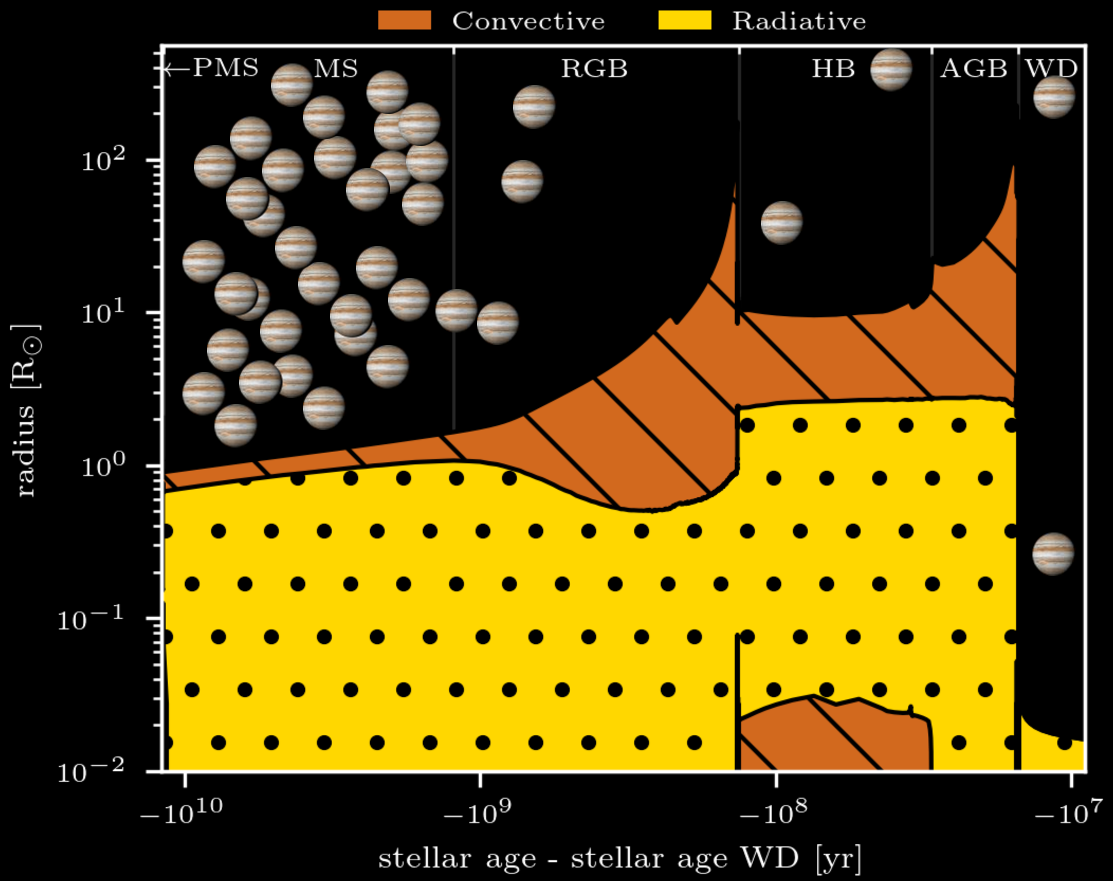
Internal structure



WD

Planets around evolved stars

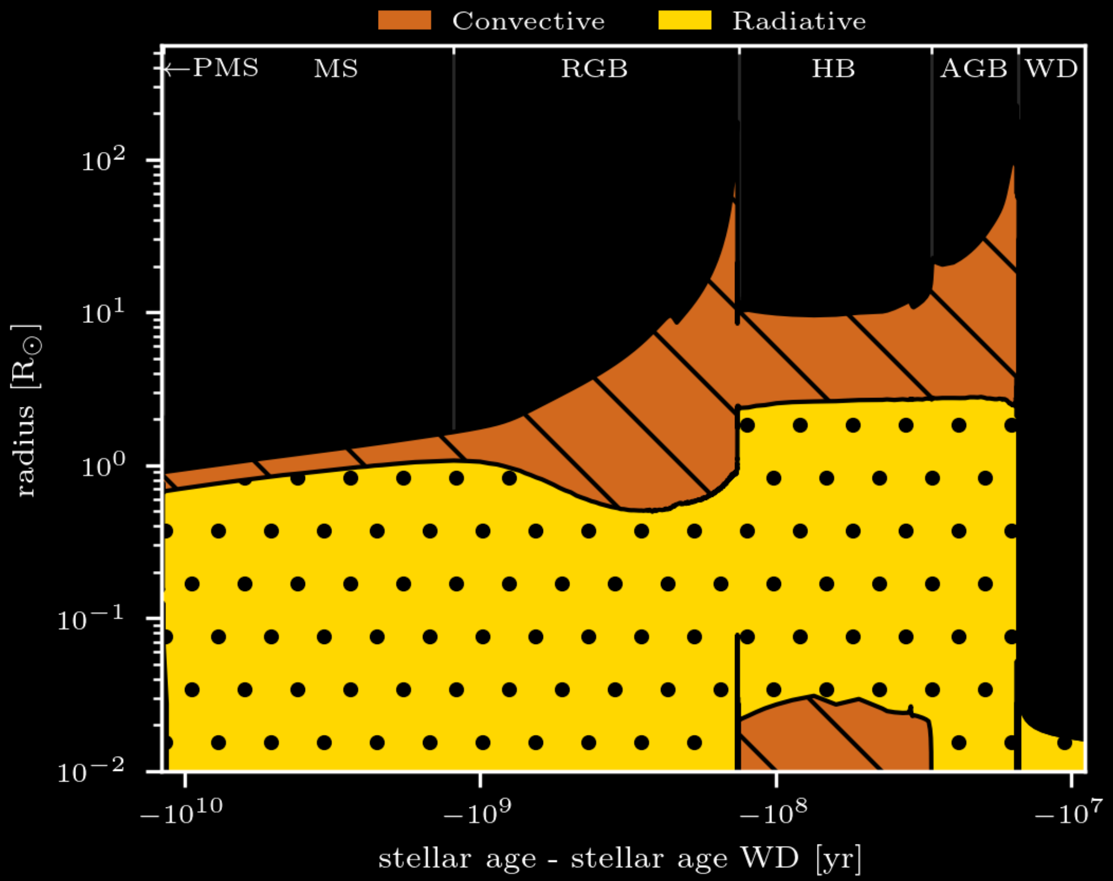
Internal structure



WD

Tidal dissipation in stars

Internal structure

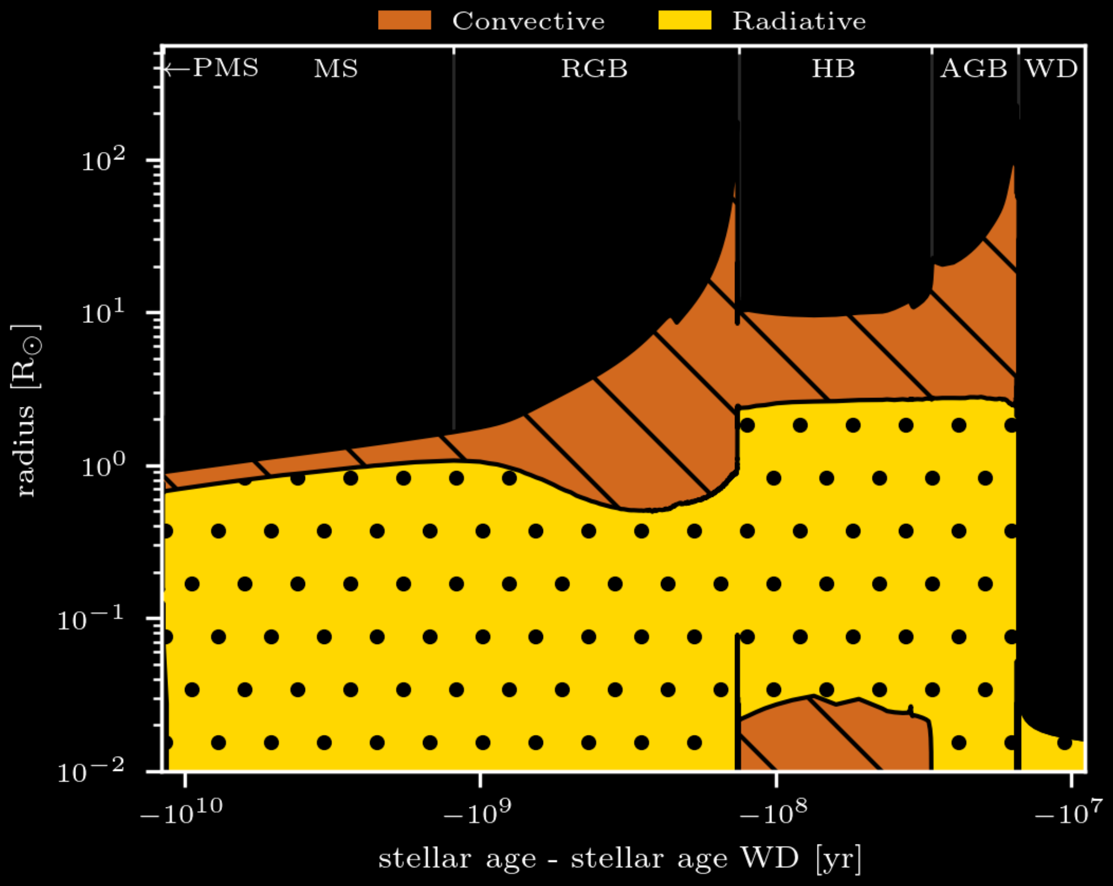


Tidal dissipation

- Equilibrium tide

Tidal dissipation in stars

Internal structure

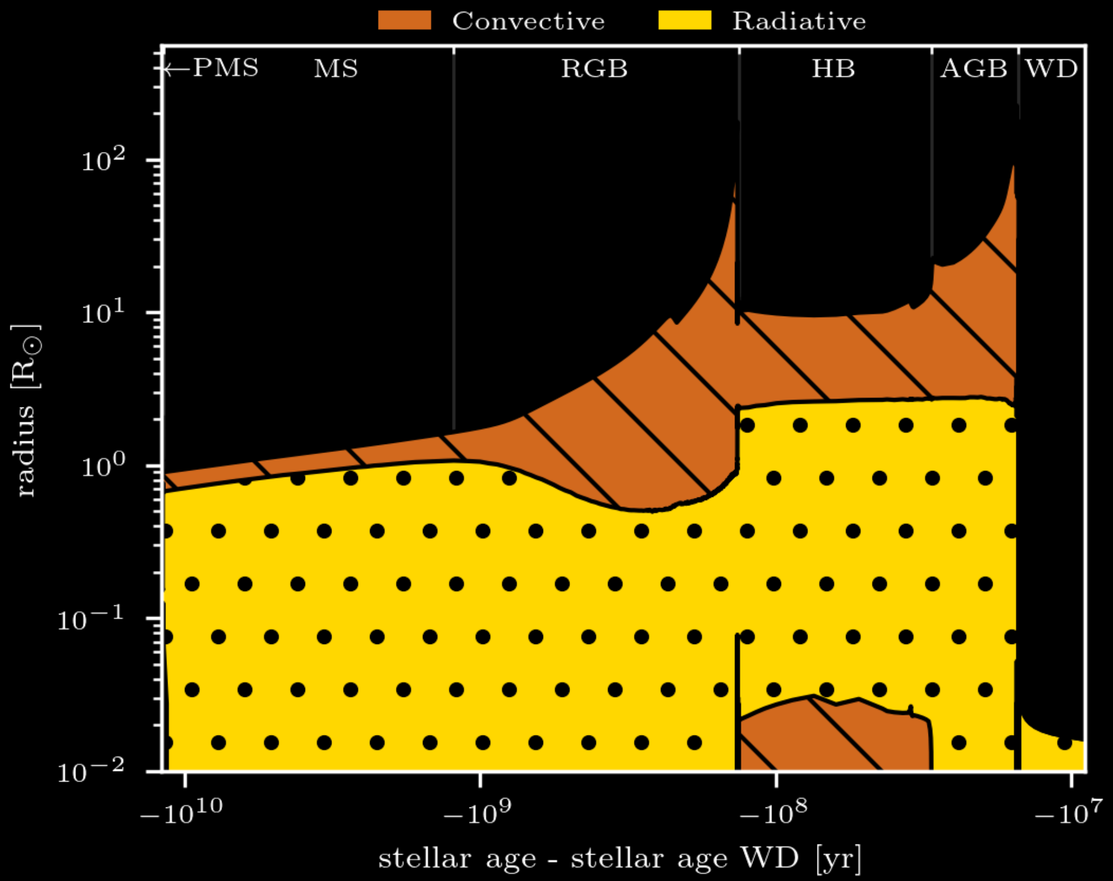


Tidal dissipation

- Equilibrium tide
- Dynamical tide
  - Inertial waves
  - Pressure waves
  - Gravity waves

Tidal dissipation in stars

Internal structure

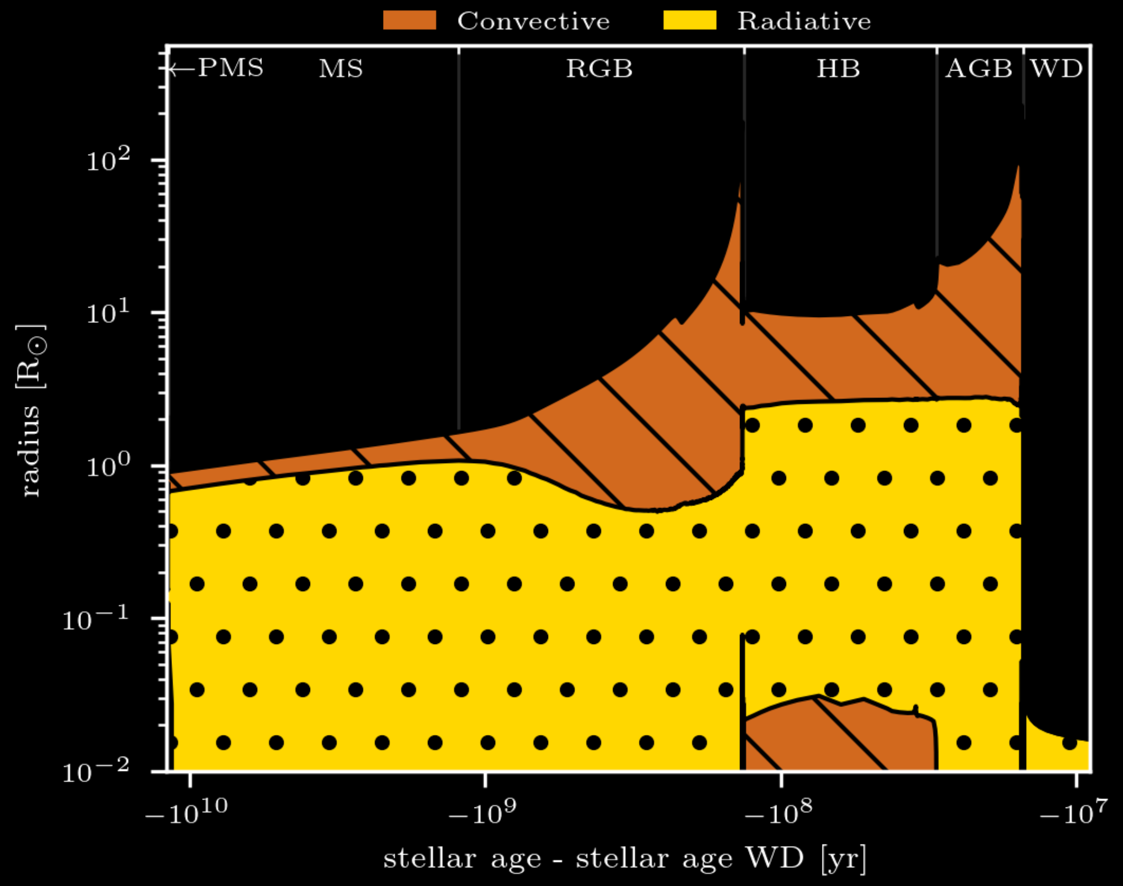


Tidal dissipation

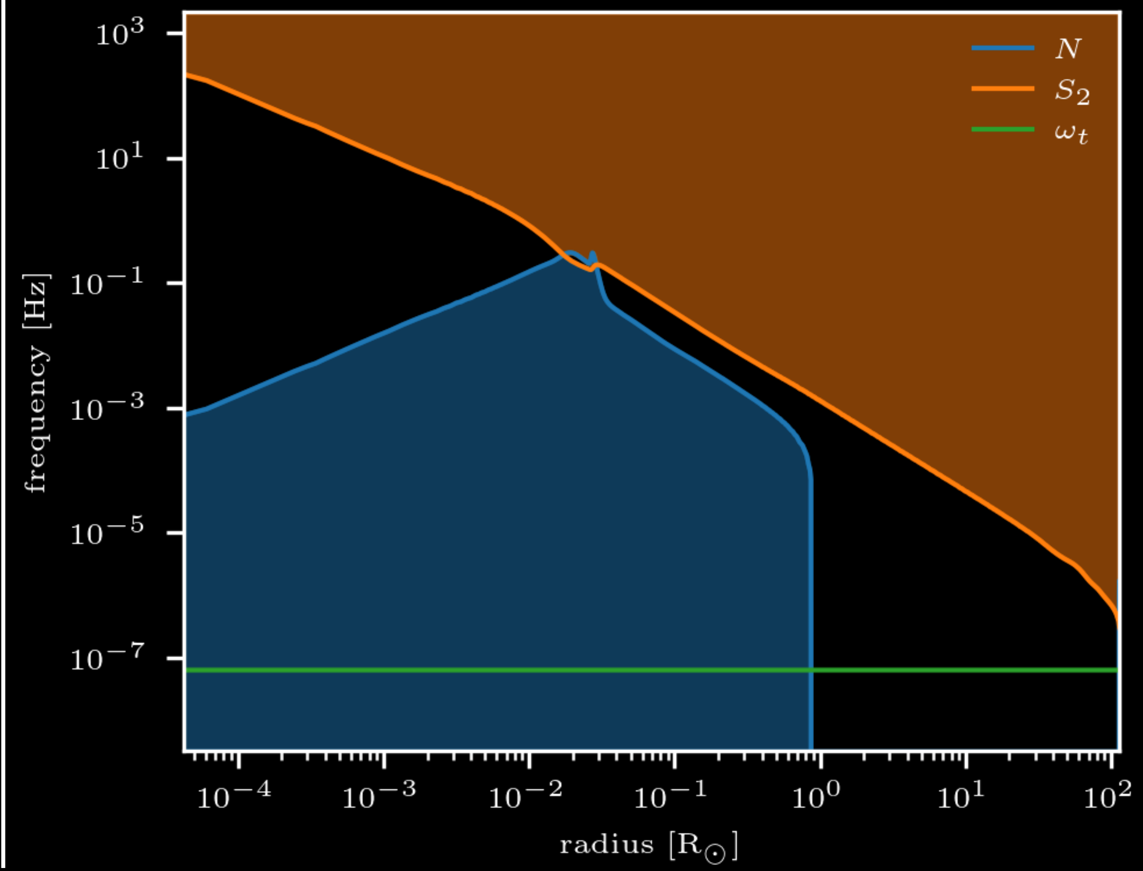
- Equilibrium tide
- Dynamical tide
  - ~~Inertial waves~~
  - Pressure waves
  - Gravity waves

Tidally Excited Waves

Internal structure

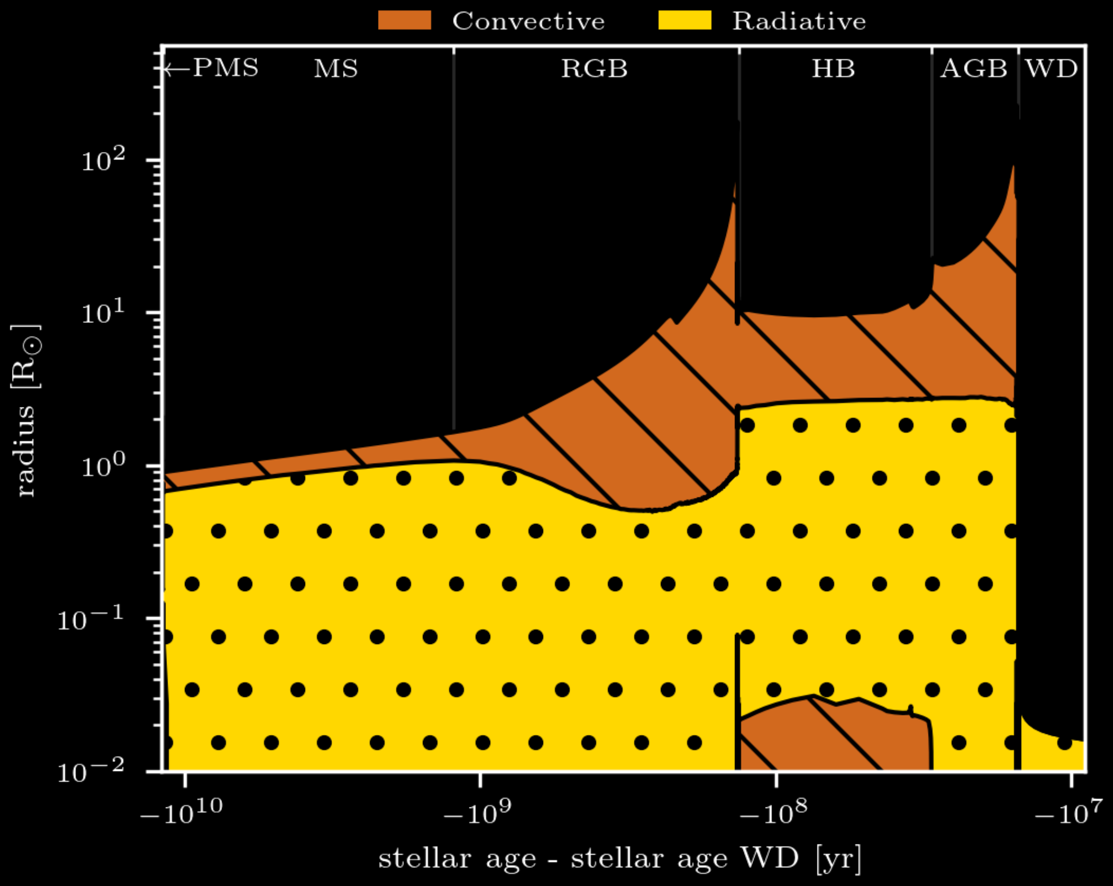


Wave excitation

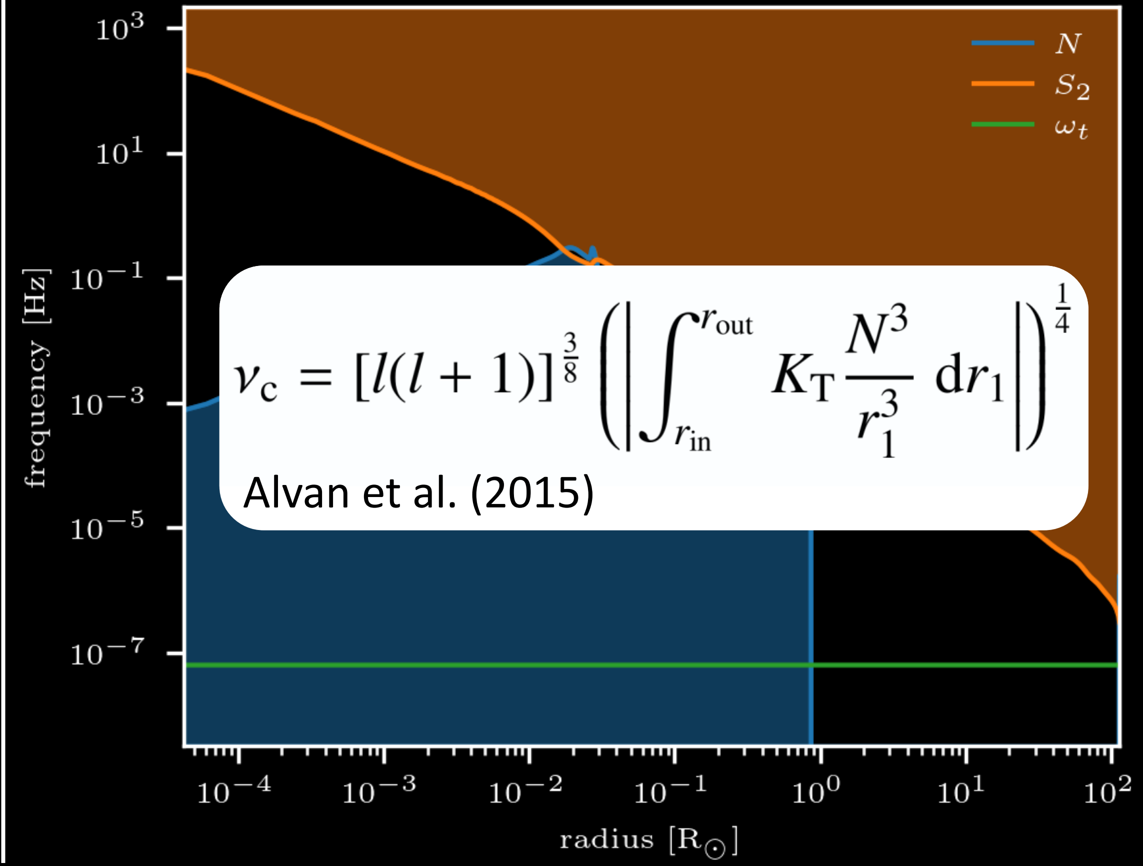


Tidally Excited Waves

Internal structure



Wave excitation

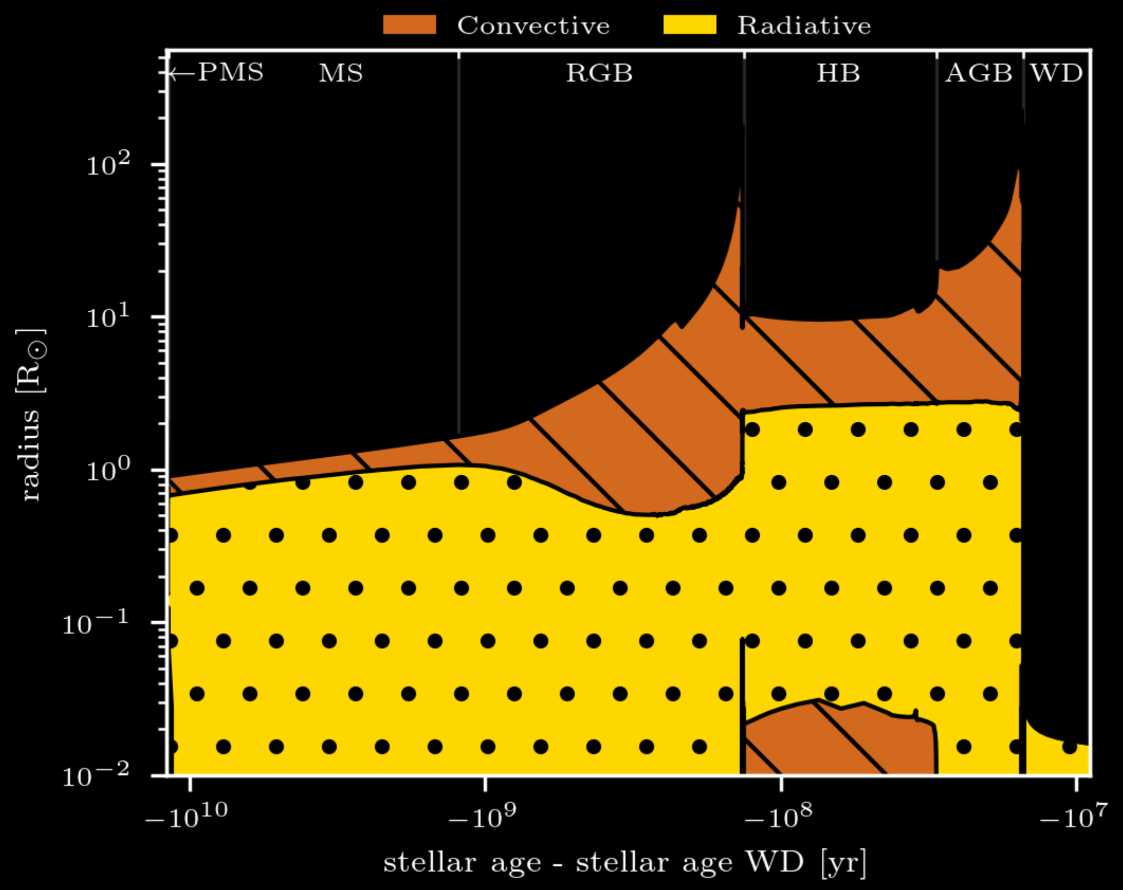


$$\nu_c = [l(l+1)]^{\frac{3}{8}} \left(\left| \int_{r_{in}}^{r_{out}} K_T \frac{N^3}{r_1^3} \, dr_1 \right| \right)^{\frac{1}{4}}$$

Alvan et al. (2015)

Tidally Excited Waves

Internal structure



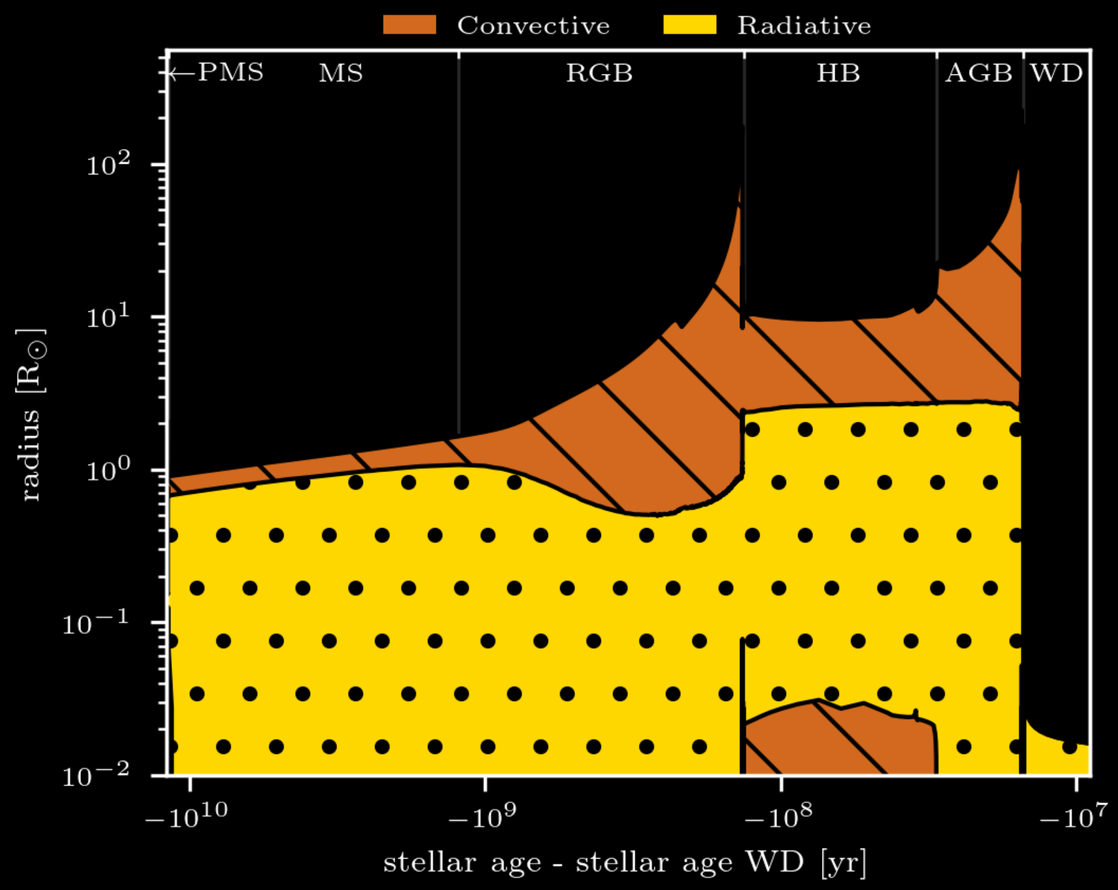
Tidal dissipation

- Equilibrium tide
- Dynamical tide
  - ~~Inertial waves~~
  - ~~Pressure waves~~
  - Gravity waves

  → Progressive internal gravity waves

Tidal Dissipation Computation

Internal structure



Tidal dissipation

$$\mathrm{Im}\left(k_2^2\right)_{\mathrm{eq}} = \frac{16\pi G\omega_t}{4(2l+1)R_\star|\varphi_T(R_\star)|^2}\int_0^{R_\star} r^2\rho\nu_t D_l(r)dr$$

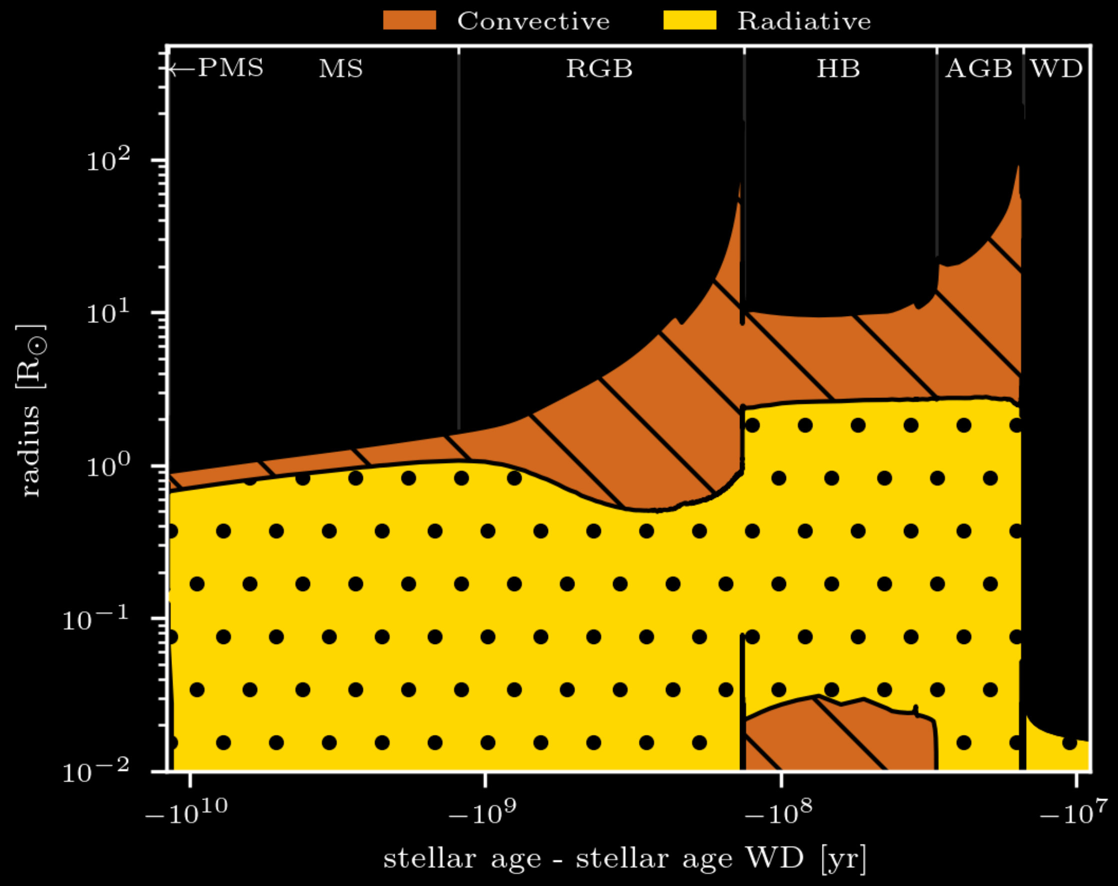
Barker (2020); Dhouib et al. (2024)

$$\mathrm{Im}\left(k_2^2\right)_{\mathrm{IGW}} = \frac{3^{-\frac{1}{3}}\Gamma^2\left(\frac{1}{3}\right)}{2\pi}[l(l+1)]^{-\frac{4}{3}}\omega_t^{\frac{8}{3}}\frac{a^6}{GM_2^2R_\star^5} \times\left(\rho_0\left(r_{\mathrm{in}}\right)r_{\mathrm{in}}\left|\frac{dN^2}{\mathrm{d}\ln r}\right|_{r_{\mathrm{in}}}^{-\frac{1}{3}}\mathcal{F}_{\mathrm{in}}^2 + \rho_0\left(r_{\mathrm{out}}\right)r_{\mathrm{out}}\left|\frac{dN^2}{\mathrm{d}\ln r}\right|_{r_{\mathrm{out}}}^{-\frac{1}{3}}\mathcal{F}_{\mathrm{out}}^2\right)$$

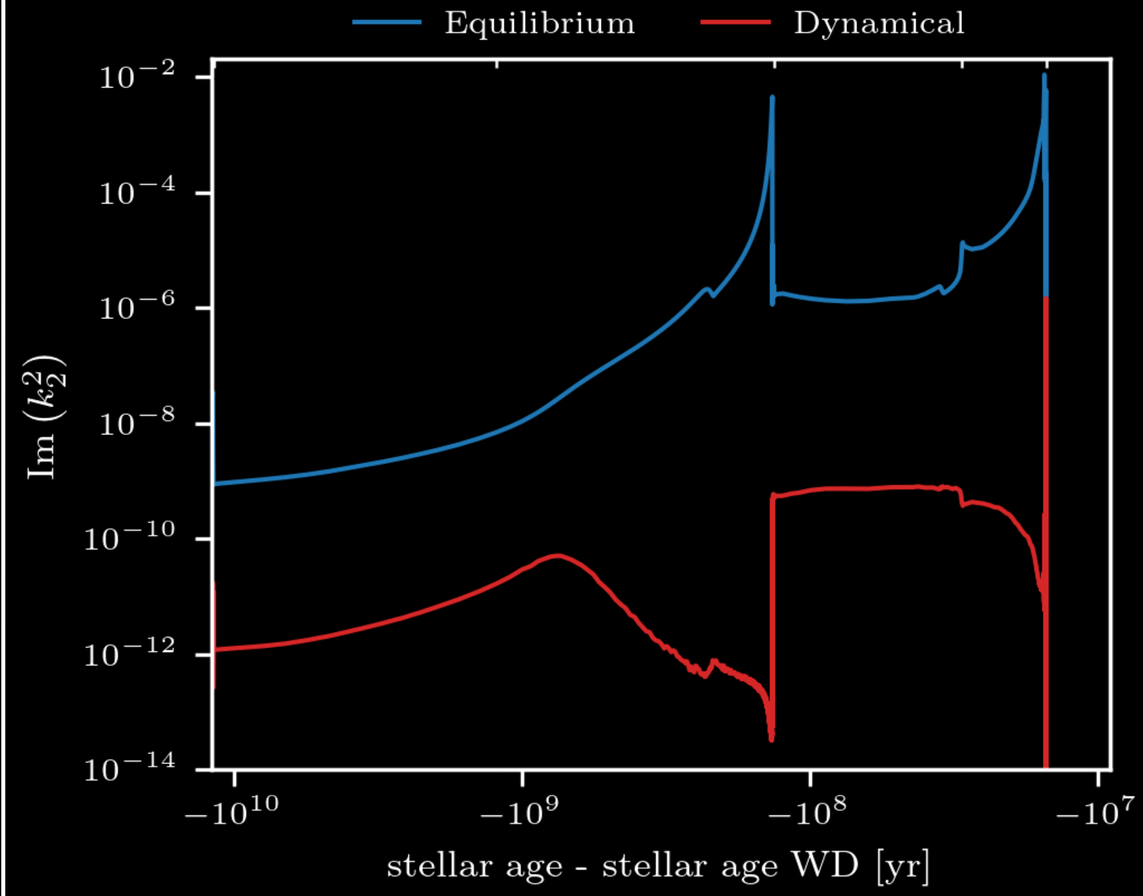
Ahuir et al. (2021); Esseldeurs et al. (2024)

Tidal Dissipation Computation

Internal structure



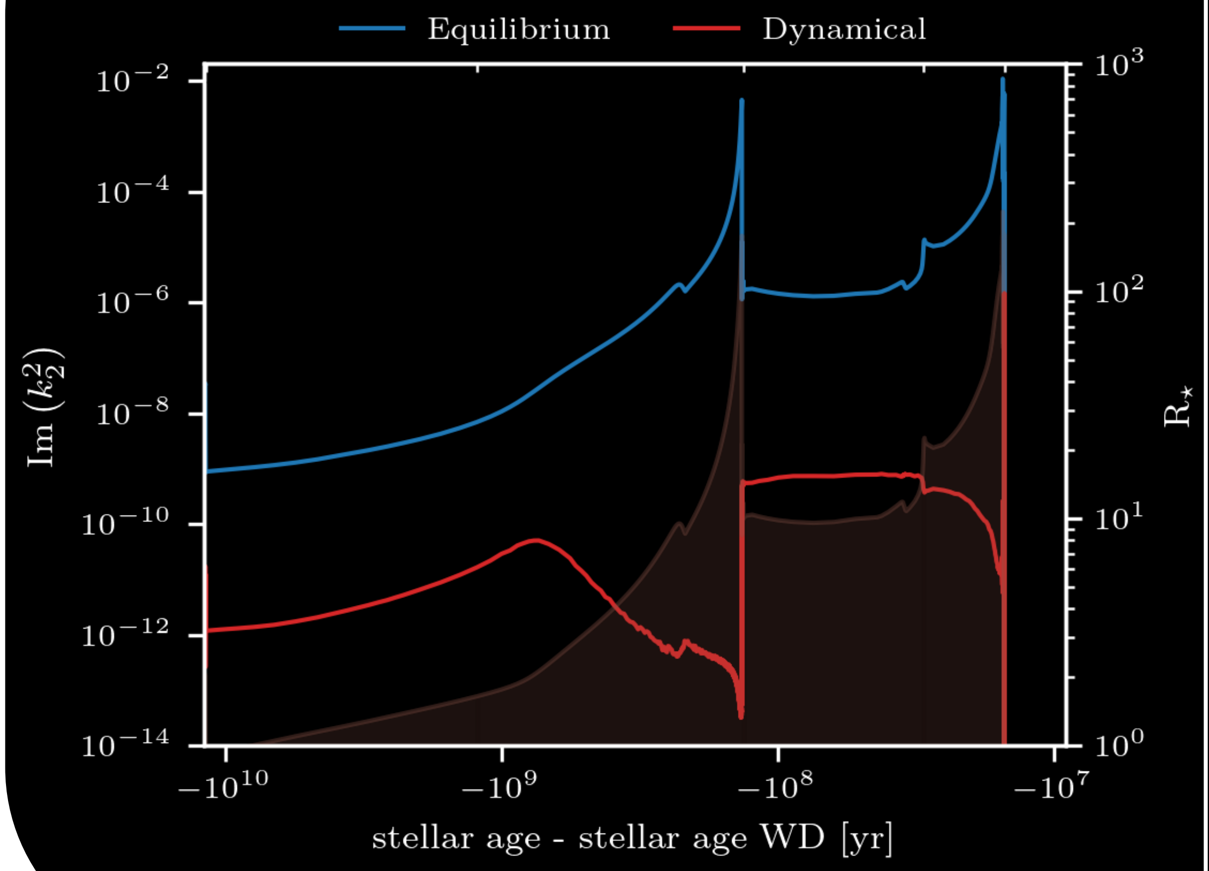
Tidal dissipation



P_{orb} = 1 year

Tidal Dissipation Computation

Tidal dissipation



$P_{orb} = 1$ year

Contributions

$$\mathrm{Im}\left(k_2^2\right)_{\mathrm{eq}} = \frac{16\pi G \omega_t}{4(2l+1)R_\star|\varphi_T(R_\star)|^2}\int_0^{R_\star} r^2 \rho \nu_t D_l(r) dr$$

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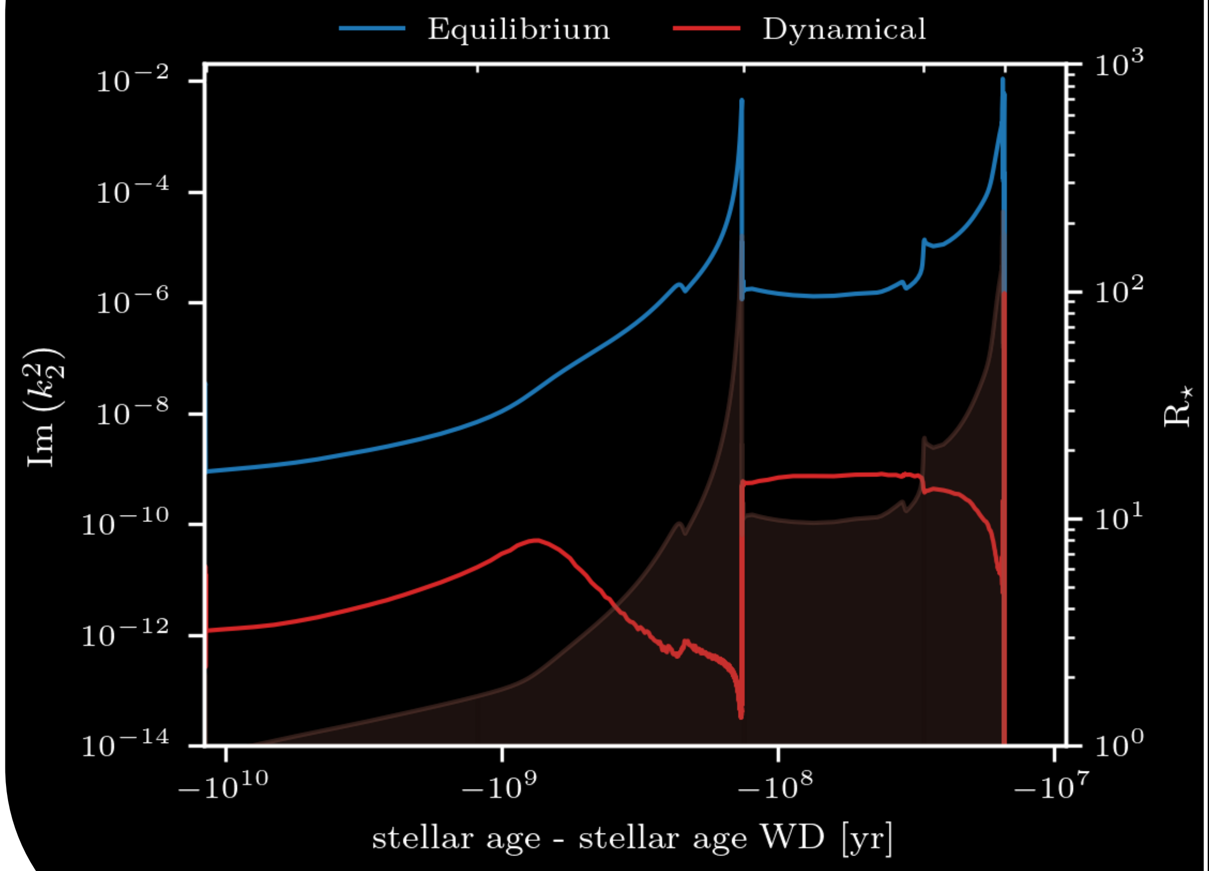
Tidal Dissipation Computation

Tidal dissipation



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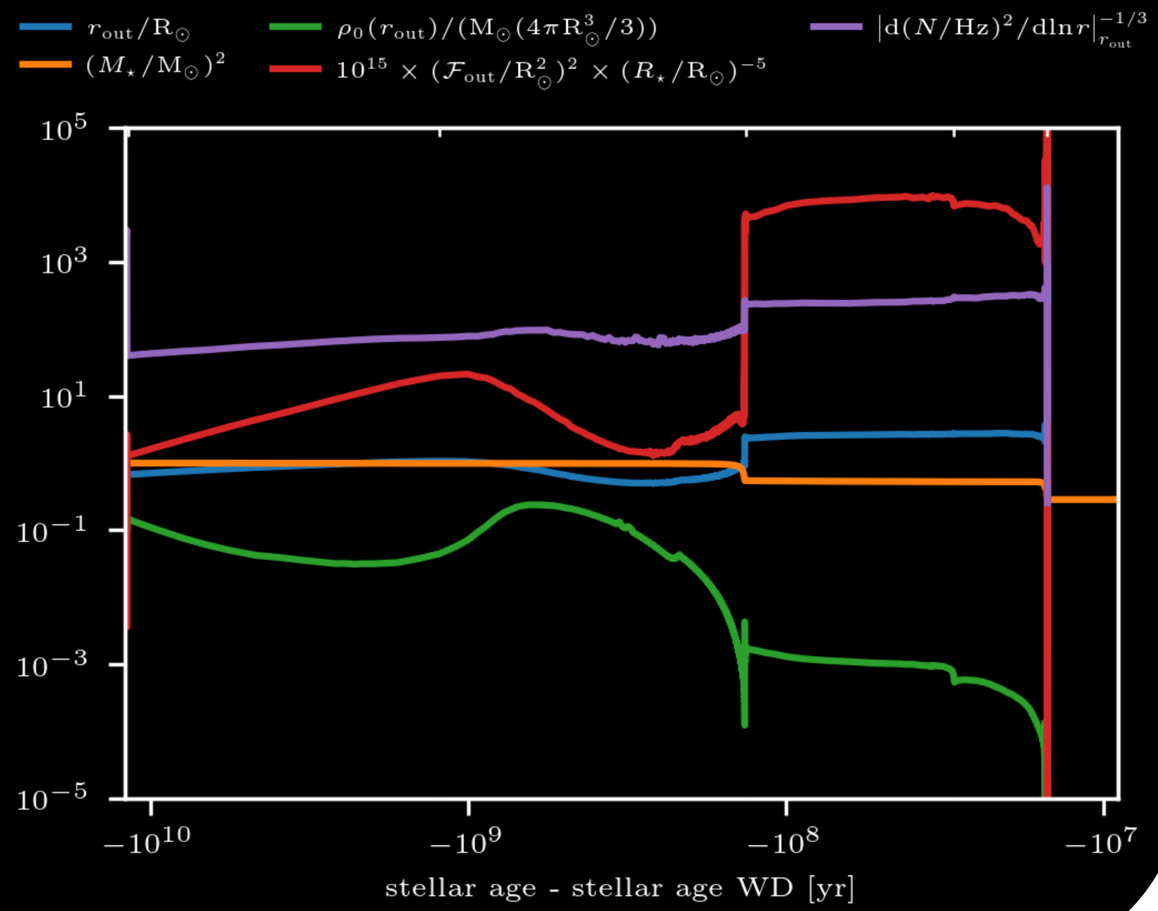
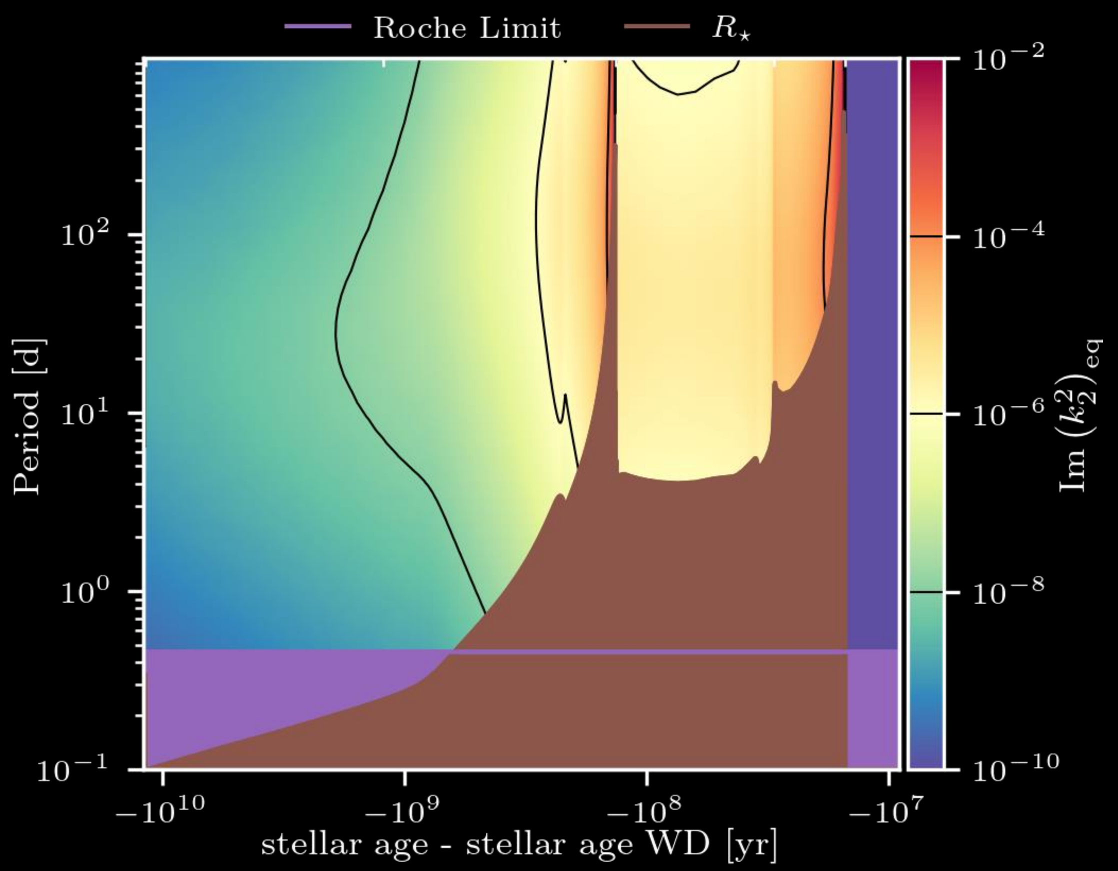


Dependance on Orbital Period

Equilibrium Tides



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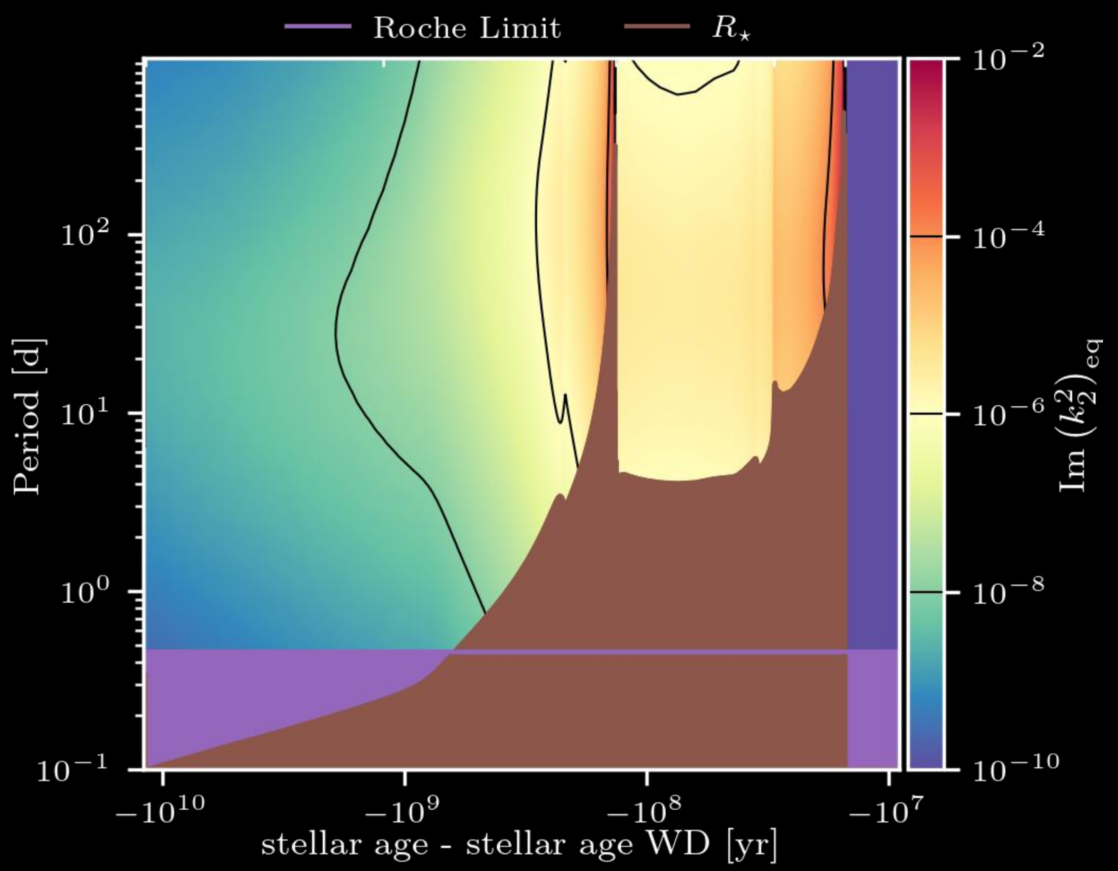
Barker (2020); Dhouib et al. (2024)

$$\nu_t = V_c l_c F(\omega_t),\ \ F(\omega_t) = \begin{cases} 5 & |\omega_t|t_c < 10^{-2} \\ \frac{1}{2}\left(|\omega_t|t_c\right)^{-\frac{1}{2}} & |\omega_t|t_c \in \left[10^{-2}, 5\right] \\ \frac{25}{\sqrt{20}}\left(|\omega_t|t_c\right)^{-2} & |\omega_t|t_c > 5\ , \end{cases}$$

Duguid et al. (2020)

Dependance on Orbital Period

Equilibrium Tides



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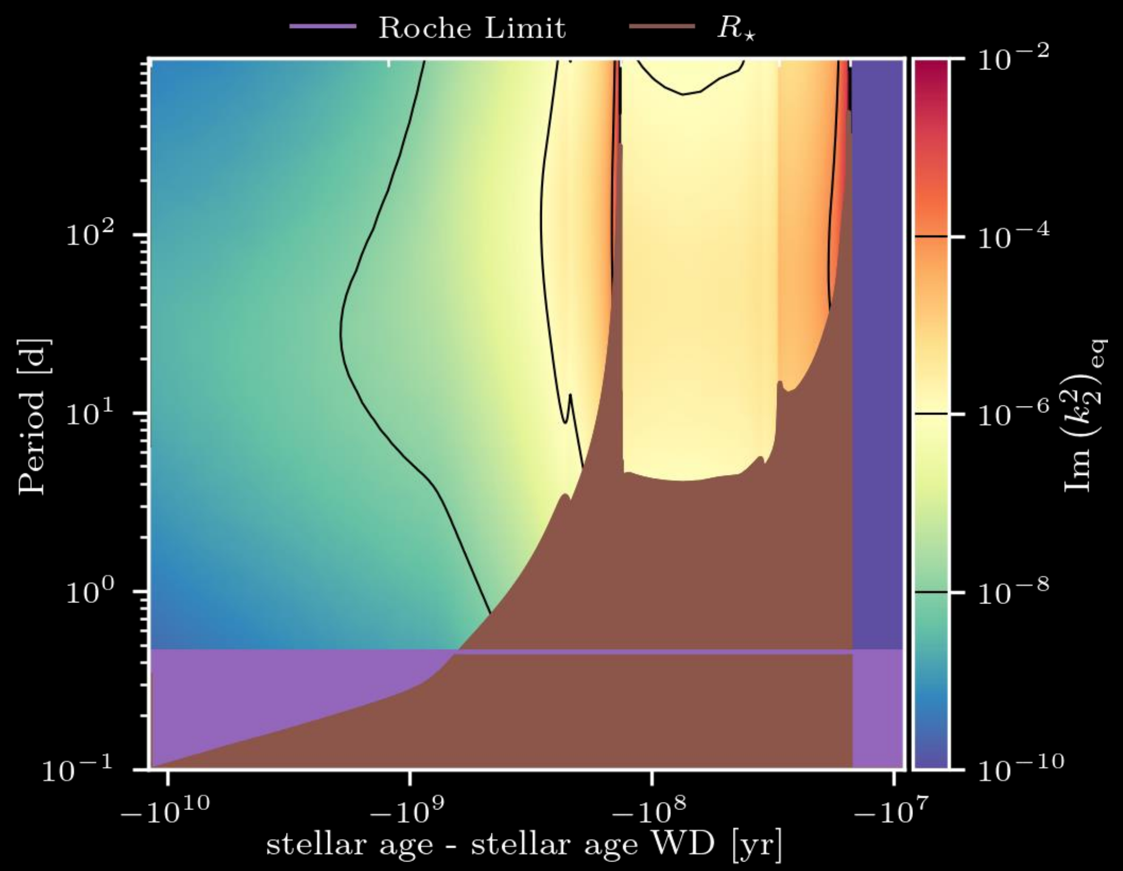

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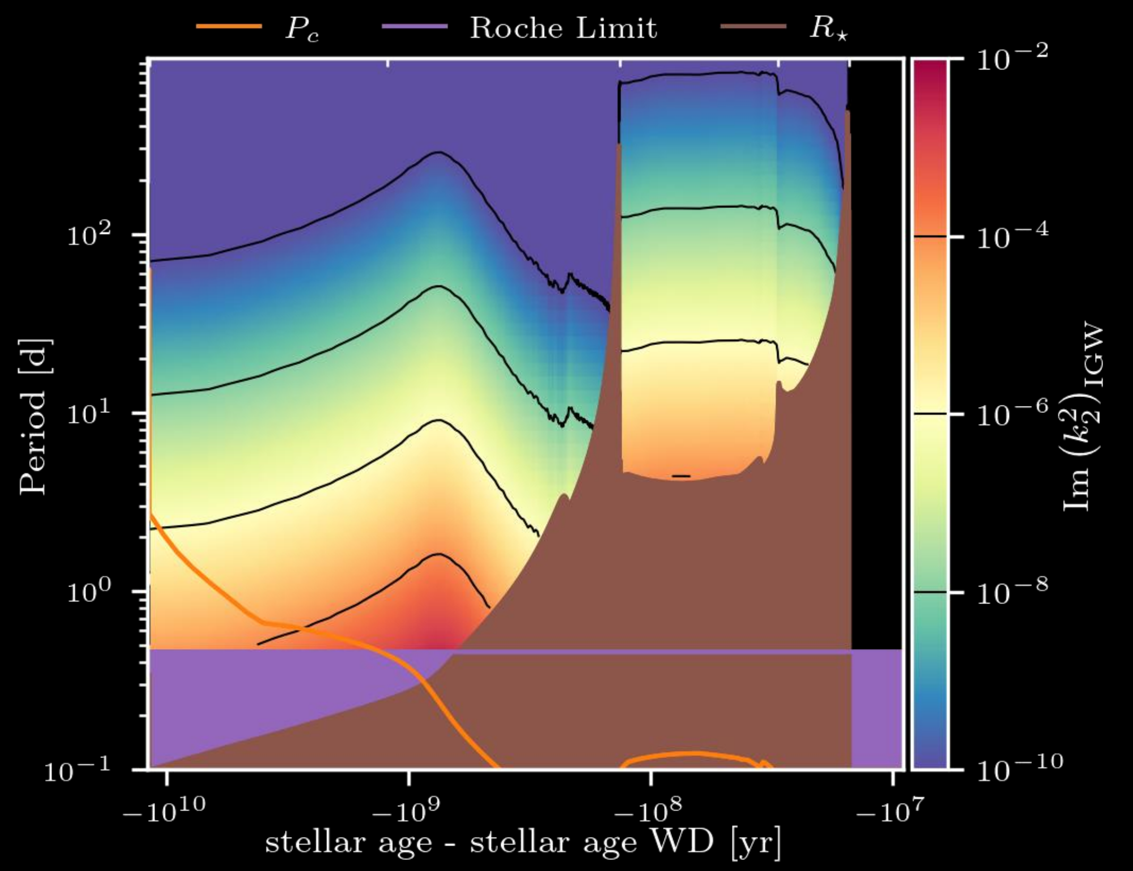
Dependance on Orbital Period

Dynamical Tides



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Dependance on Orbital Period

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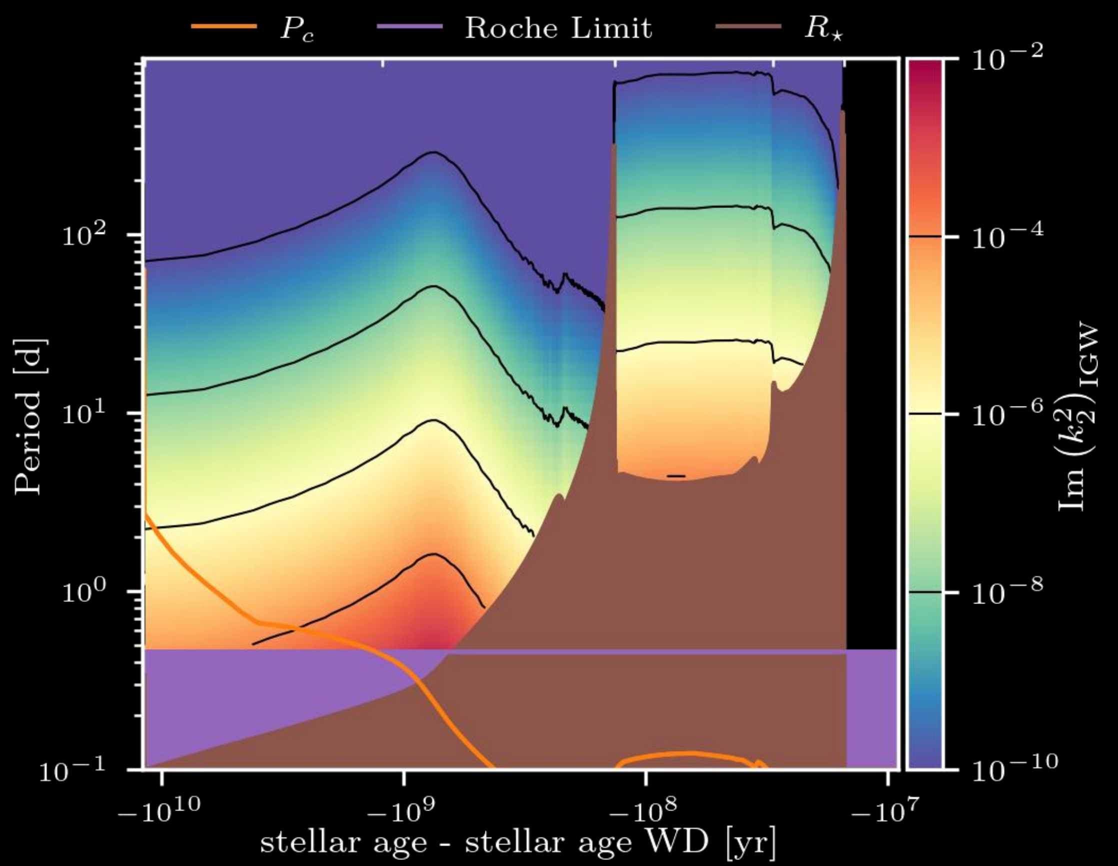

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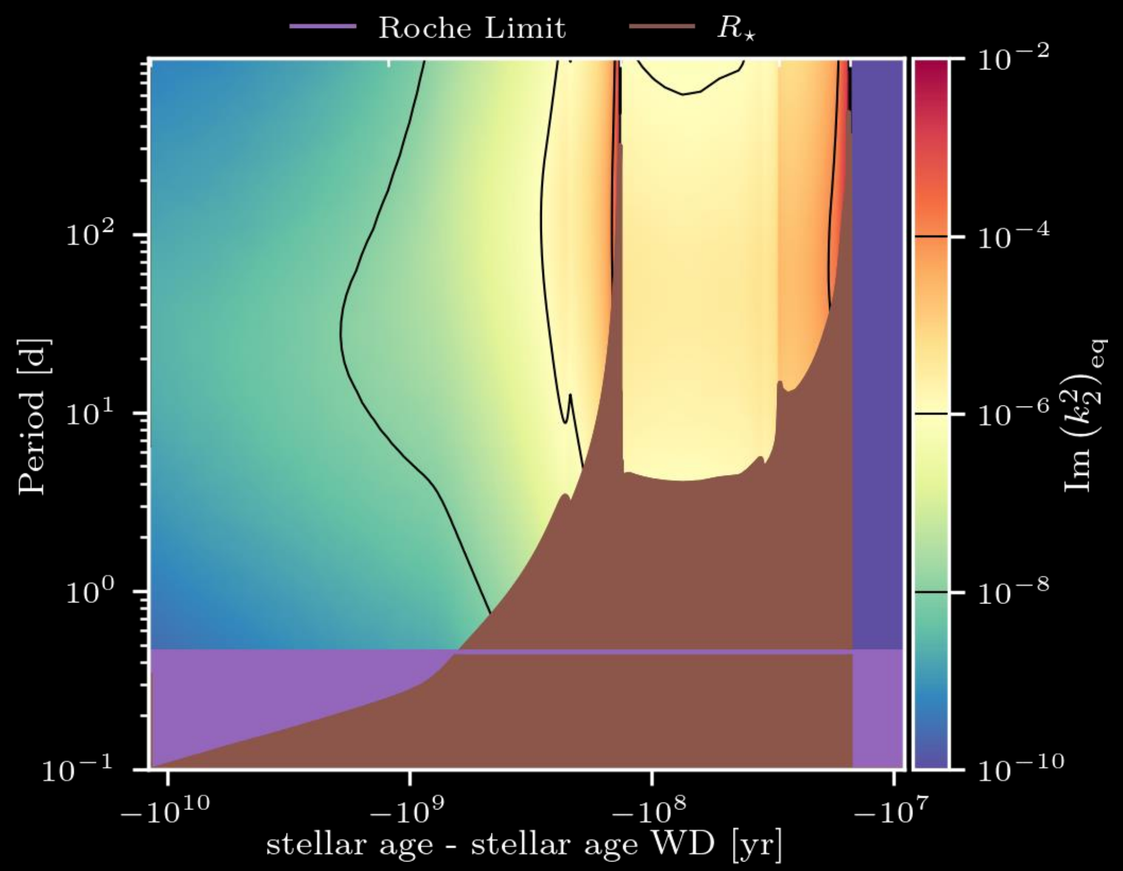
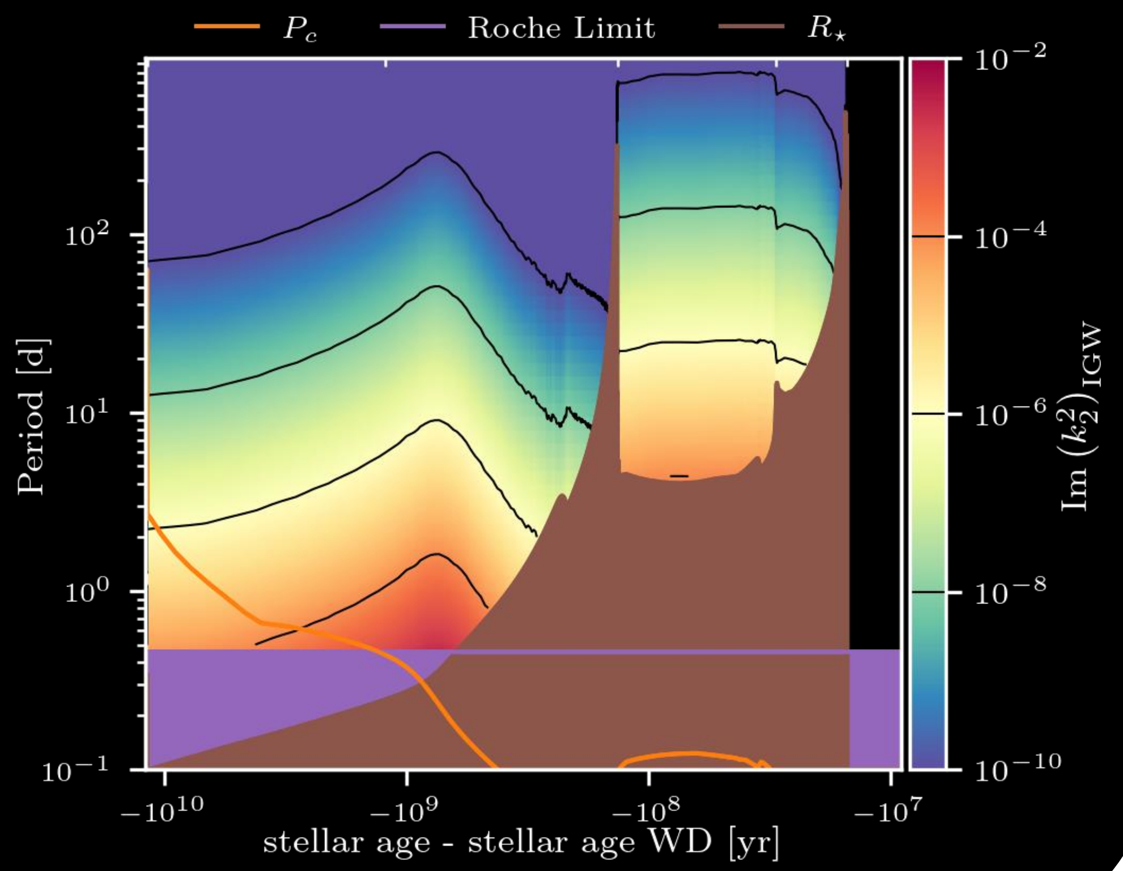
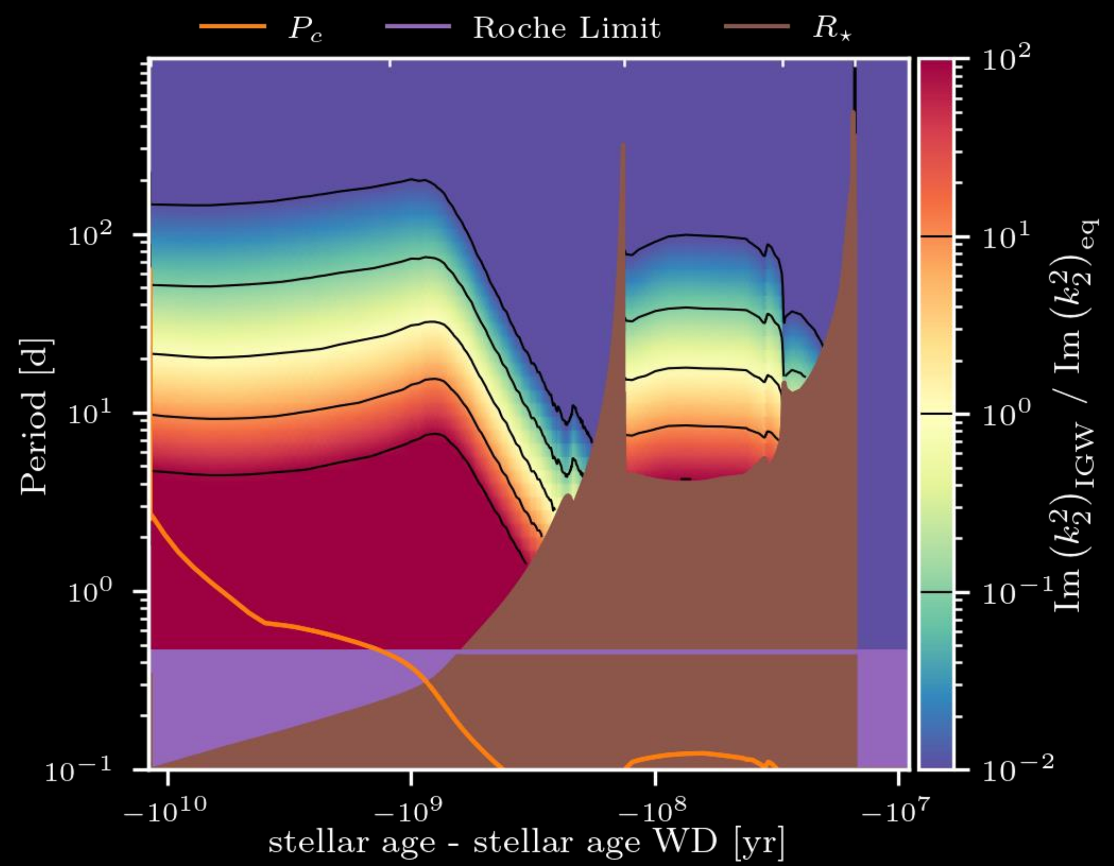


Dynamical Tides



Relative strengths of tidal dissipation

$1\ M_\odot$ Model



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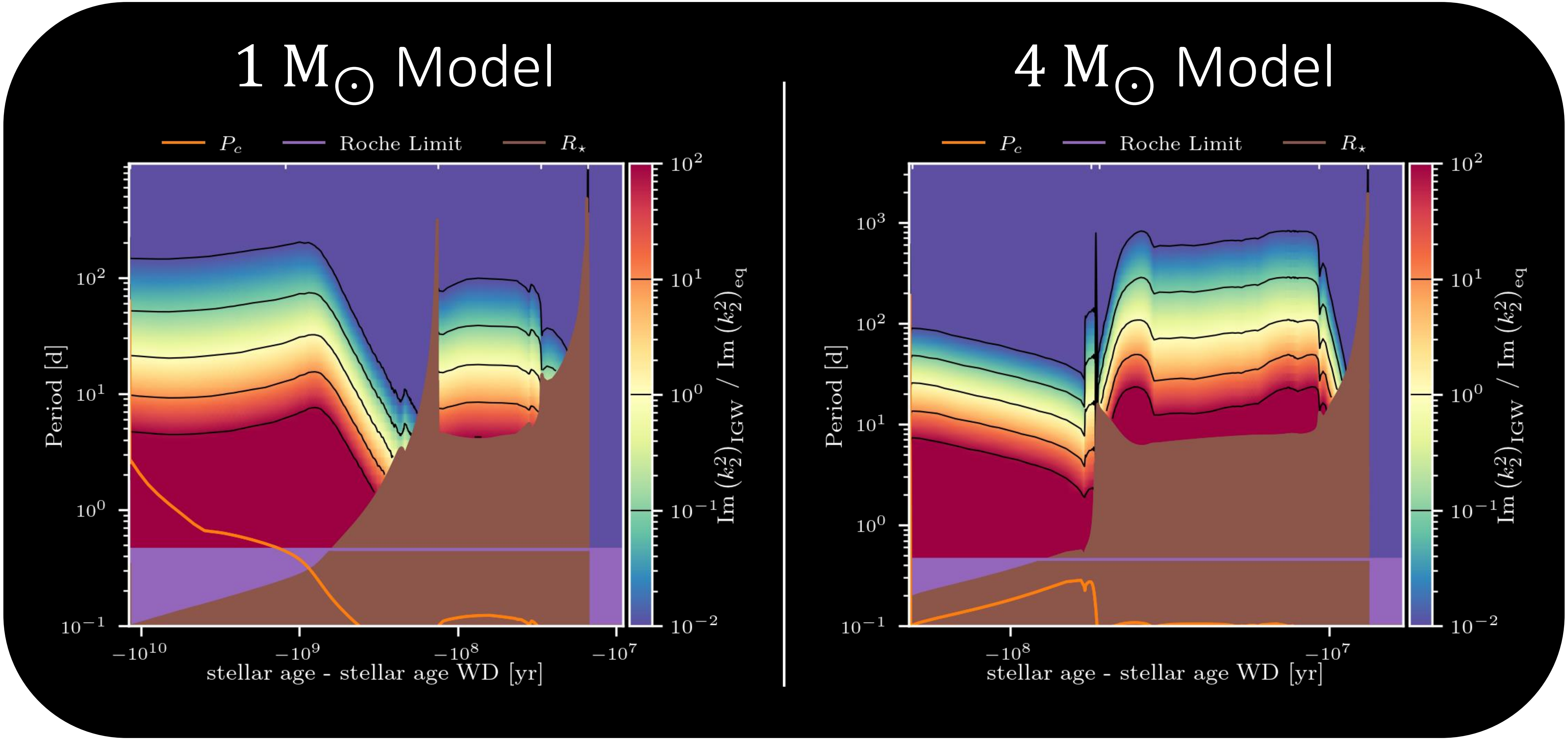
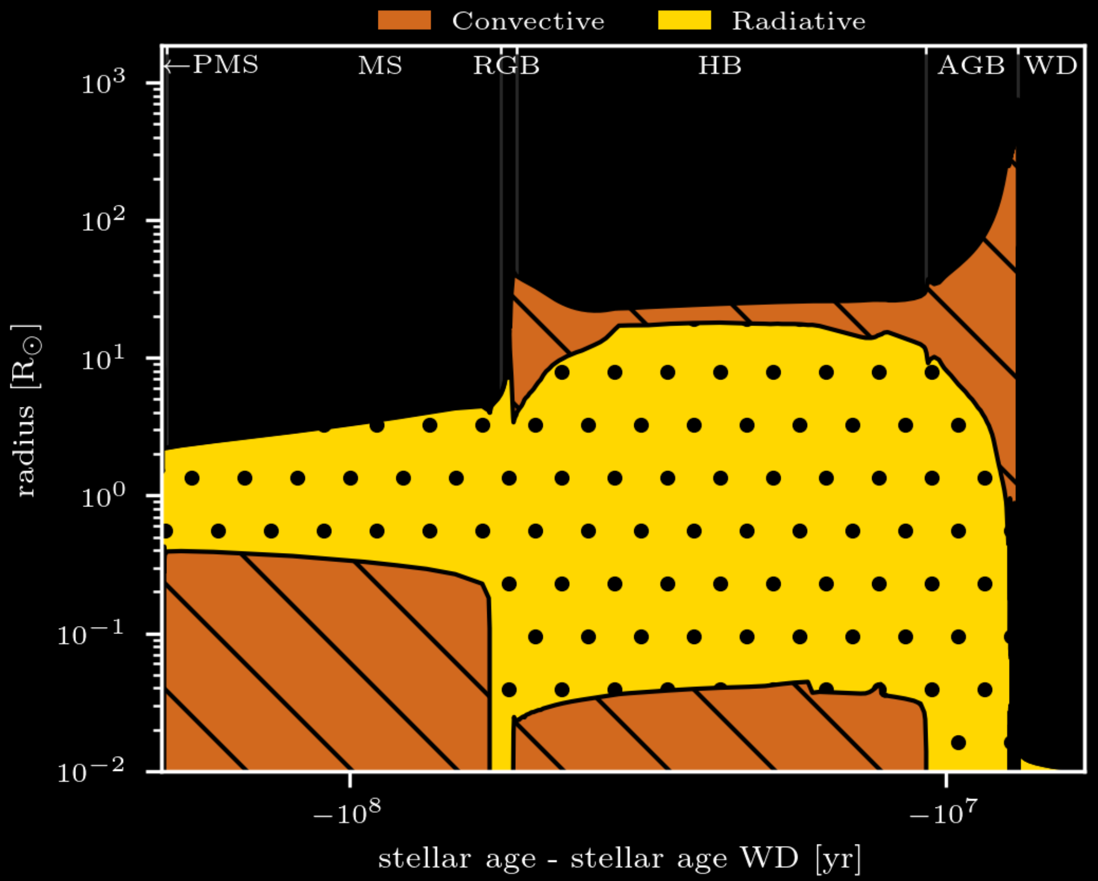
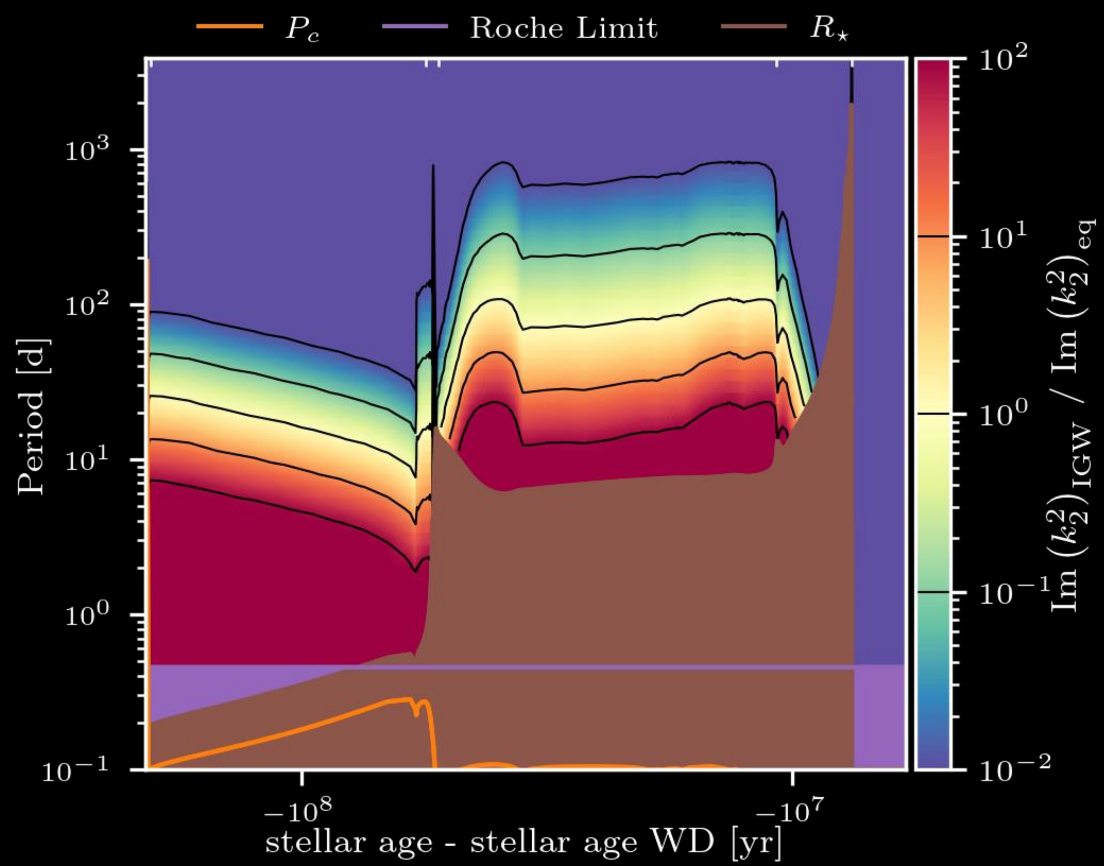


Relative strengths of tidal dissipation

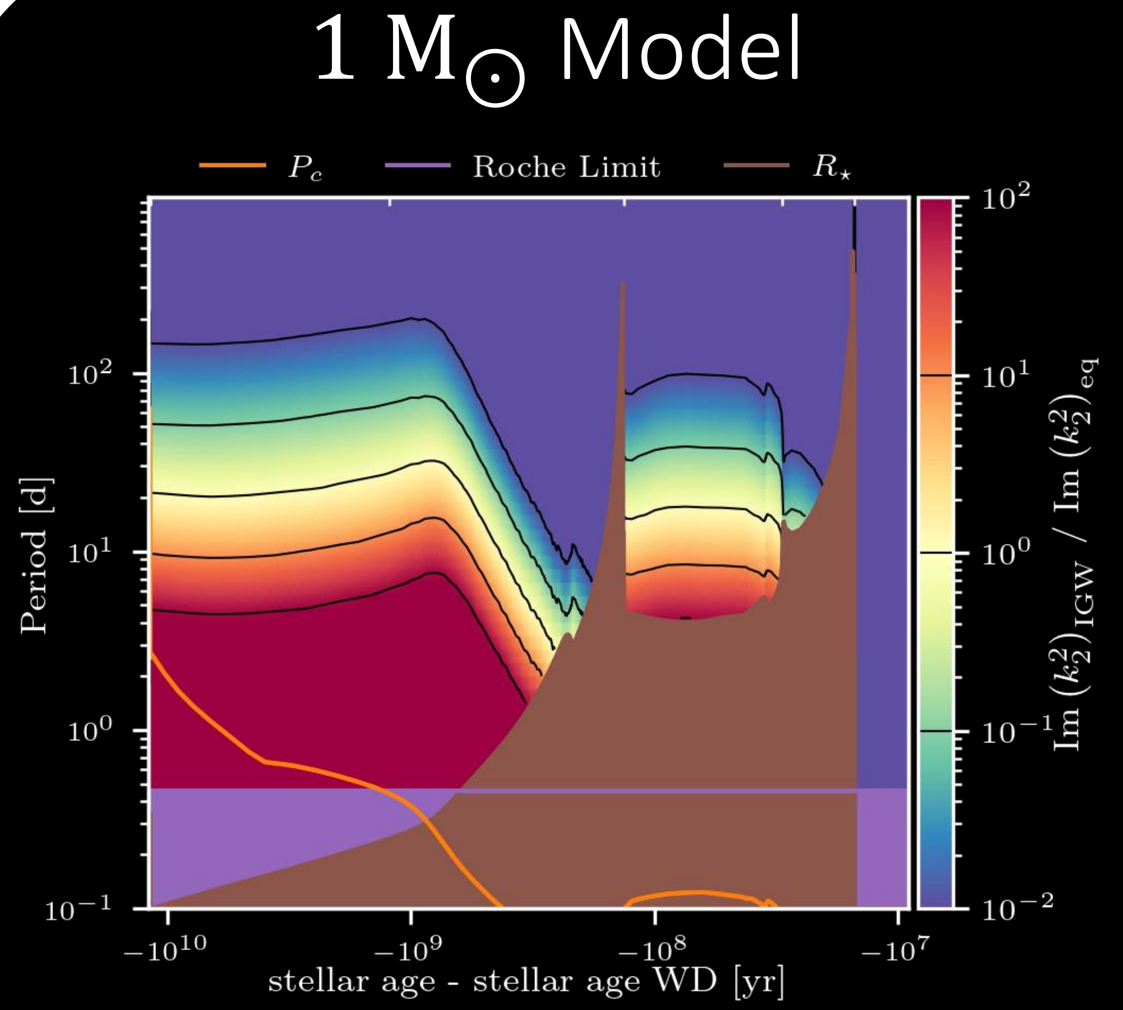
Internal structure

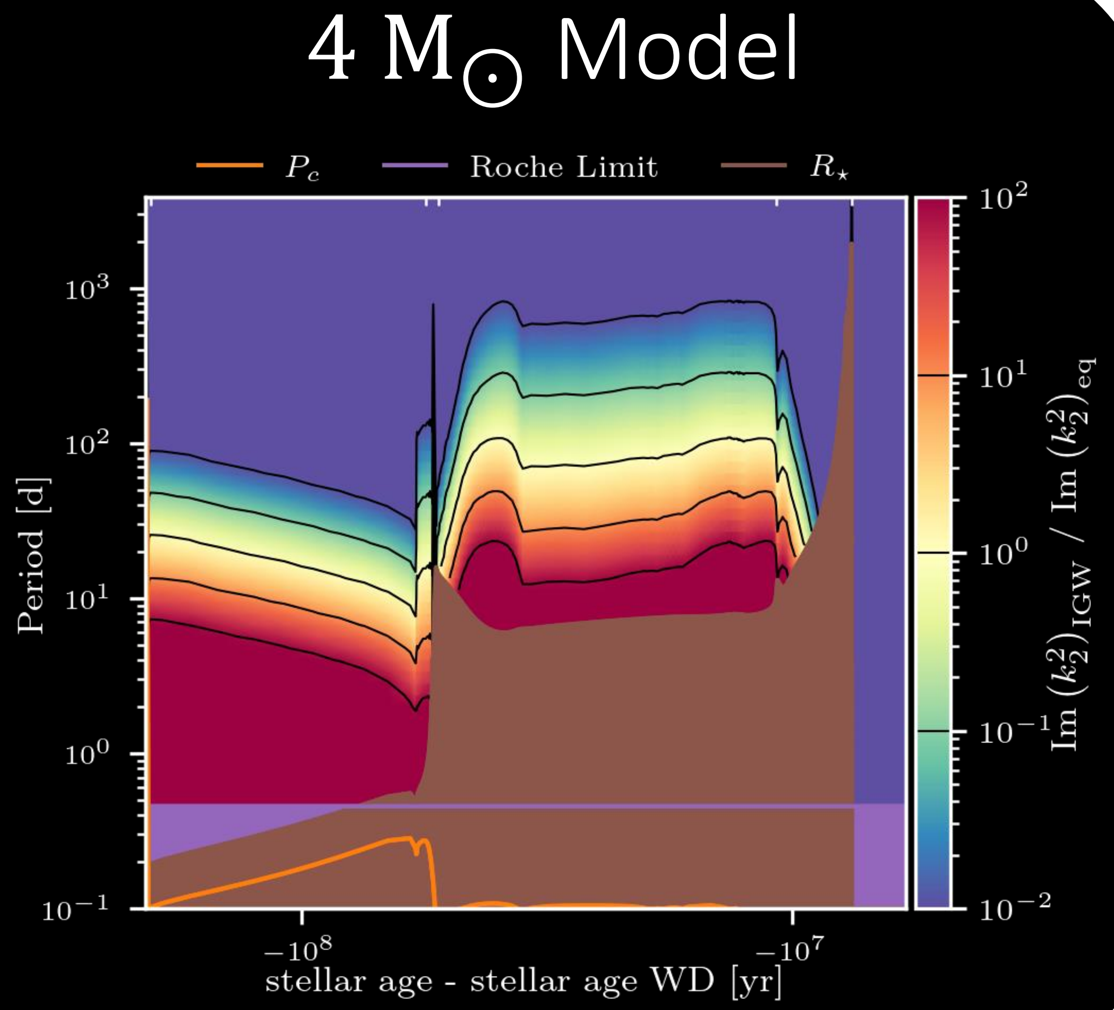


4 M⊙ Model



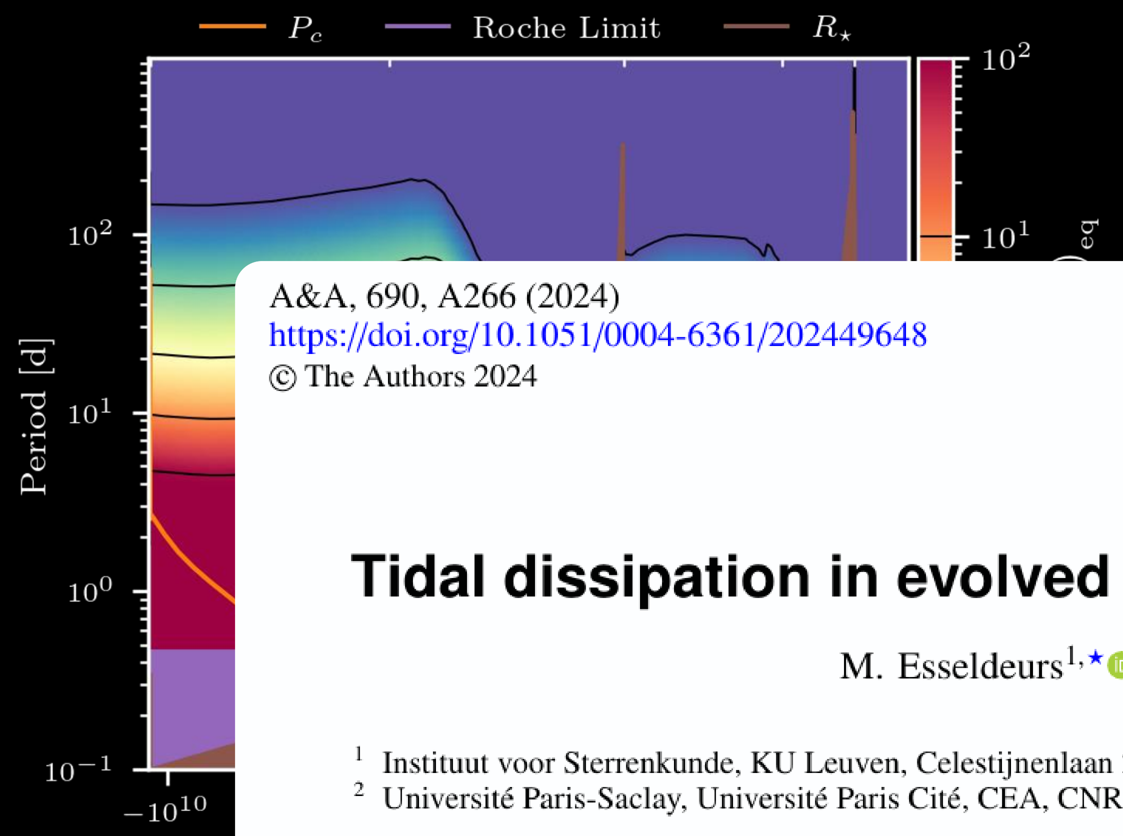
Relative strengths of tidal dissipation



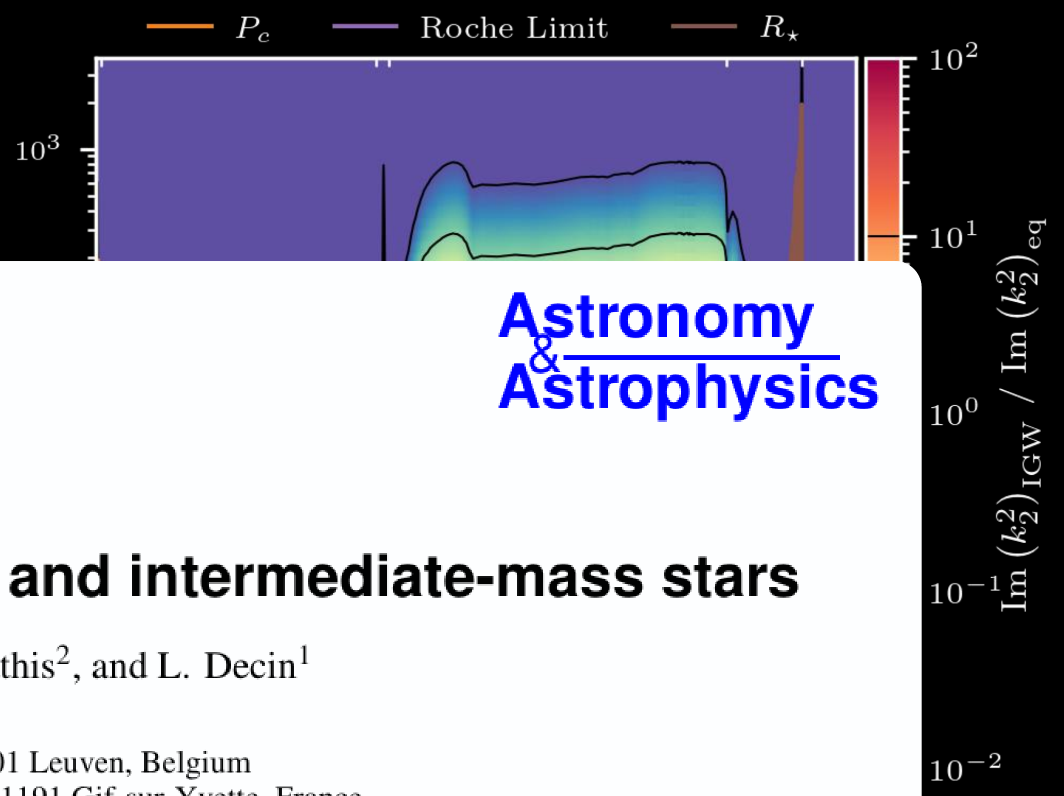


Relative strengths of tidal dissipation

1 $M_\odot$ Model



4 $M_\odot$ Model



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Tidal dissipation in evolved low- and intermediate-mass stars

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Conclusions

- During the MS, the dynamical tide dominates for orbital periods shorter than 10 days, while the equilibrium tide dominates for orbital periods longer than 50 days.
- When the star increases its size, so does the importance of the equilibrium tide, while the effect of the dynamical tide decreases.
- During the giant phases (RGB and AGB) the equilibrium tide dominates, and the dynamical tide is negligible.

Future prospects

- These tidal dissipation computations can now be used in orbital evolution codes to compute the orbital evolution for planets starting from the PMS, all the way to the WD phase.
- Improve the equilibrium tide dissipation prescription taking into account non-local effects of the viscosity.
- Potential effect of magnetism in the cores of giant stars, and their effect on tidal dissipation