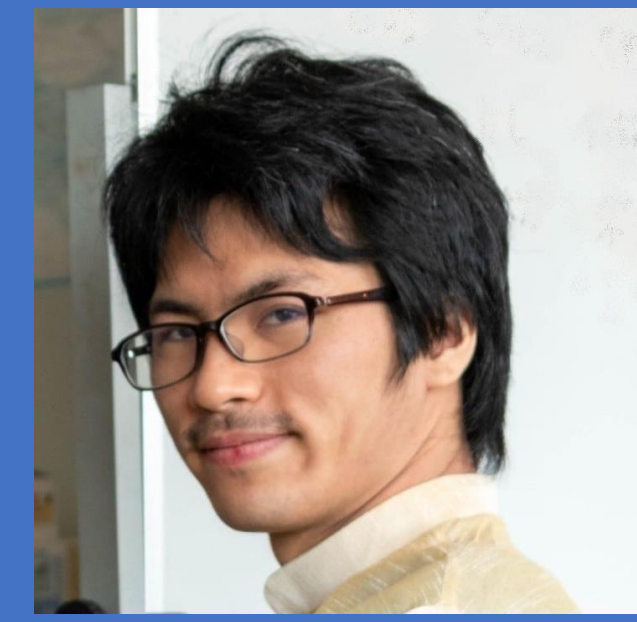


Effect of latitudinal differential rotation on long-time evolution of stellar spin

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Introduction

1. Spin-down Evolution (SDE)

- Low-mass stars spin down by magnetized stellar wind.

- Problems of SDE models:

- The solar wind torque $\tau_{w,\odot}$

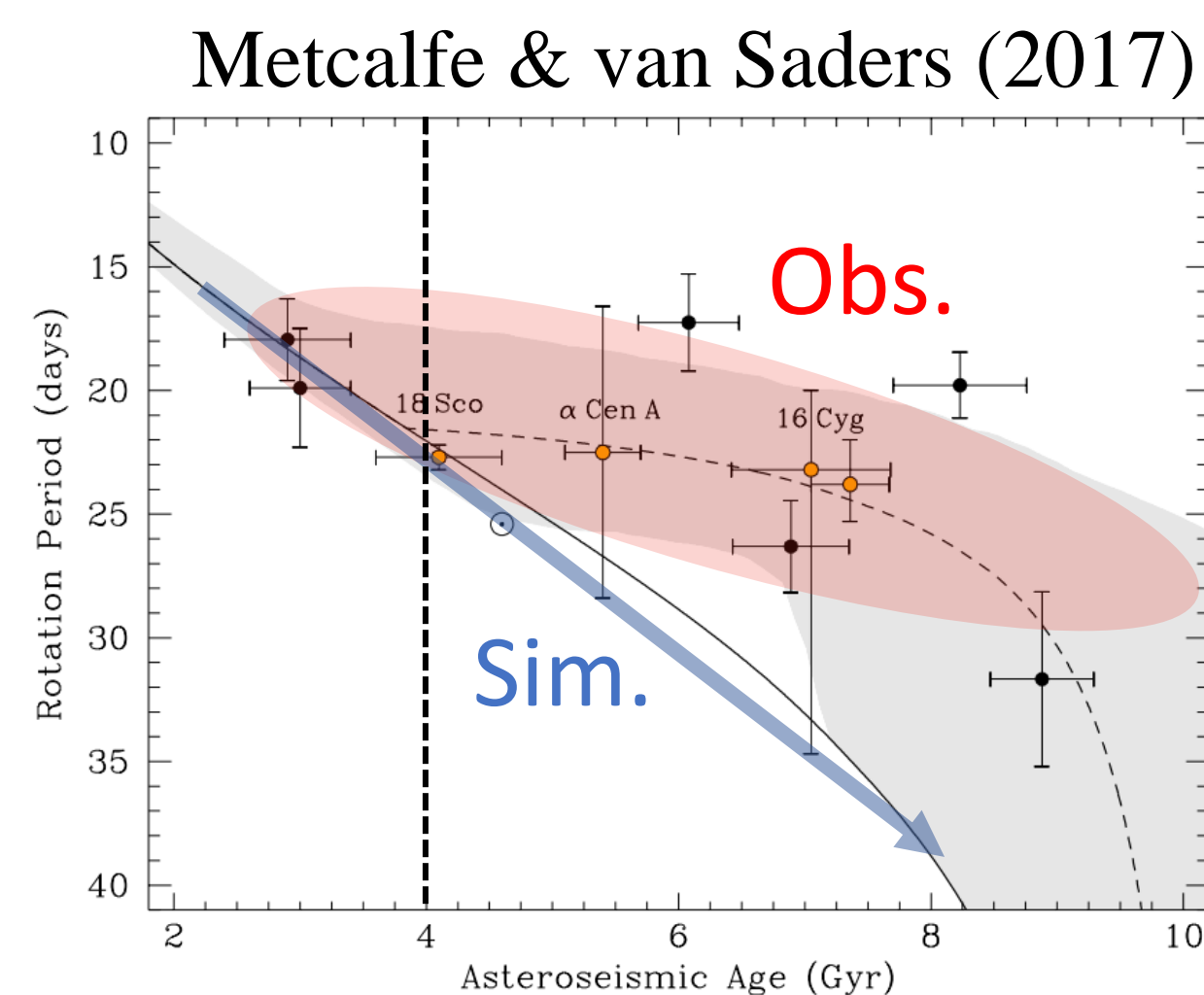
Star : $\tau_{w,\odot} \sim 7 \times 10^{30}$ erg

(Matt et al. 2015)

Sun : $\tau_{w,\odot} \sim 3 \times 10^{30}$ erg

(Finley et al. 2019)

- Decreasing of the spin-down rate (in $t \gtrsim 4$ Gyr)



2. Differential Rotation (DR)

- Asteroseismology with rotational splitting

(e.g. Benomar et al. 2018)

- Rapid DR is common.

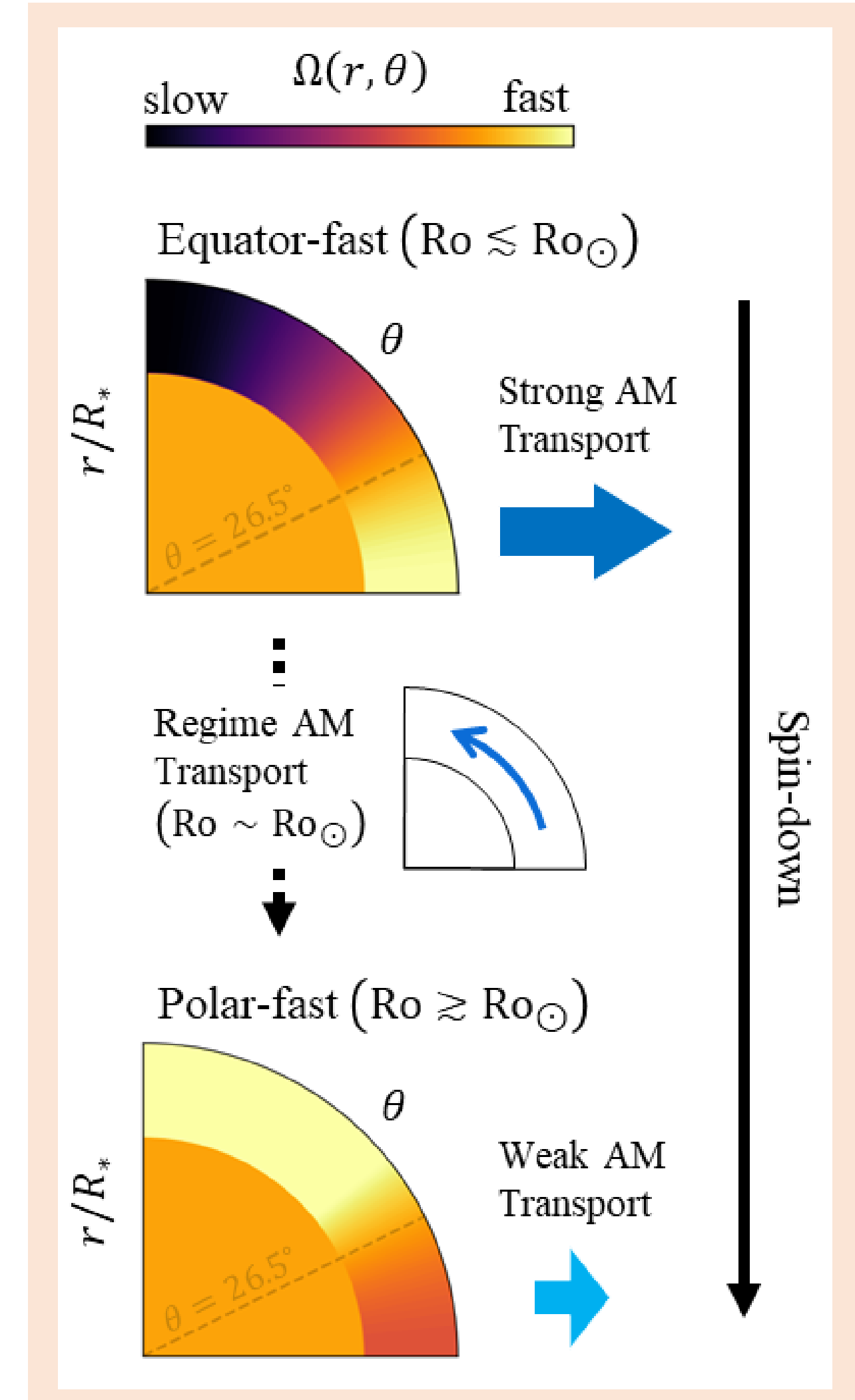
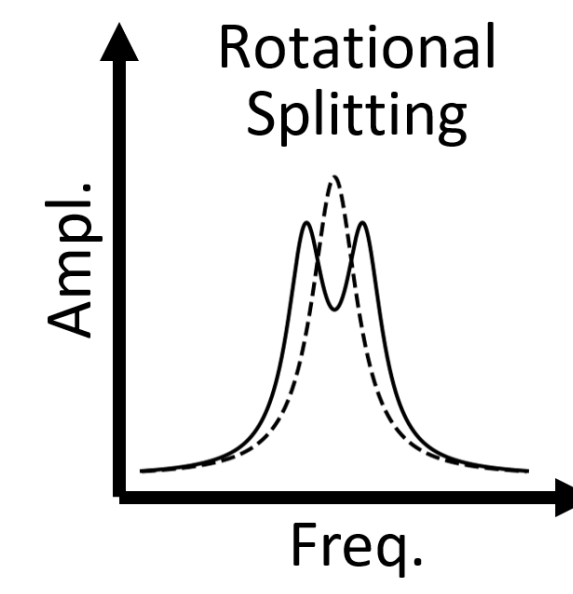
- 3D MHD simulation (e.g. Brun et al. 2022)

- $Ro \lesssim Ro_{\odot}$: Equator-fast

- $Ro \gtrsim Ro_{\odot}$: Polar-fast

* $Ro (\propto \Omega^{-1})$: Rossby number

- Previous SDE models : uniform rotation



Purpose : Consider the effects of DR to solve the problems of previous SDE models.

Method

1. Outline

- I. Stellar evolution by MESA

$$M(t), R(t), \tau_{cz}^{CS}(t)$$

- II. Rossby number, DR model

$$Ro(\Omega_{core}, \tau_{cz}^{CS}, \Omega_{equa}(\Omega_{core}, Ro))$$

- III. Stellar wind torque model

$$\tau_w(M, R, Ro, \Omega_{core}, \Omega_{equa})$$

- IV. Calculate spin evolution with I - III

$$\frac{dL}{dt} = -\tau_w$$

* τ_{cz}^{CS} : Empirical convective turnover time (Cranmer & Saar 2011)

* $Ro \equiv 2\pi/(\Omega_{core}\tau_{cz}^{CS})$: Rossby number (in Obs.)

2. Model

- Angular momentum : $L = I\Omega_{core}$

* I : moment of Inertia

- The solar wind torque : $\tau_{w,\odot} = 3 \times 10^{30}$ erg

- DR model : (cf. Brun et al. 2022)

$$\frac{\Delta\Omega_{core}}{\Omega_{core}} = \begin{cases} \propto Ro^{-2} & \text{at } Ro \lesssim Ro_{crit} \\ \alpha_{ef} (Const. > 0) & \text{at } Ro_{crit} \lesssim Ro \lesssim Ro_{\odot} \\ \alpha_{pf} (Const. < 0) & \text{at } Ro_{\odot} \lesssim Ro \end{cases}$$

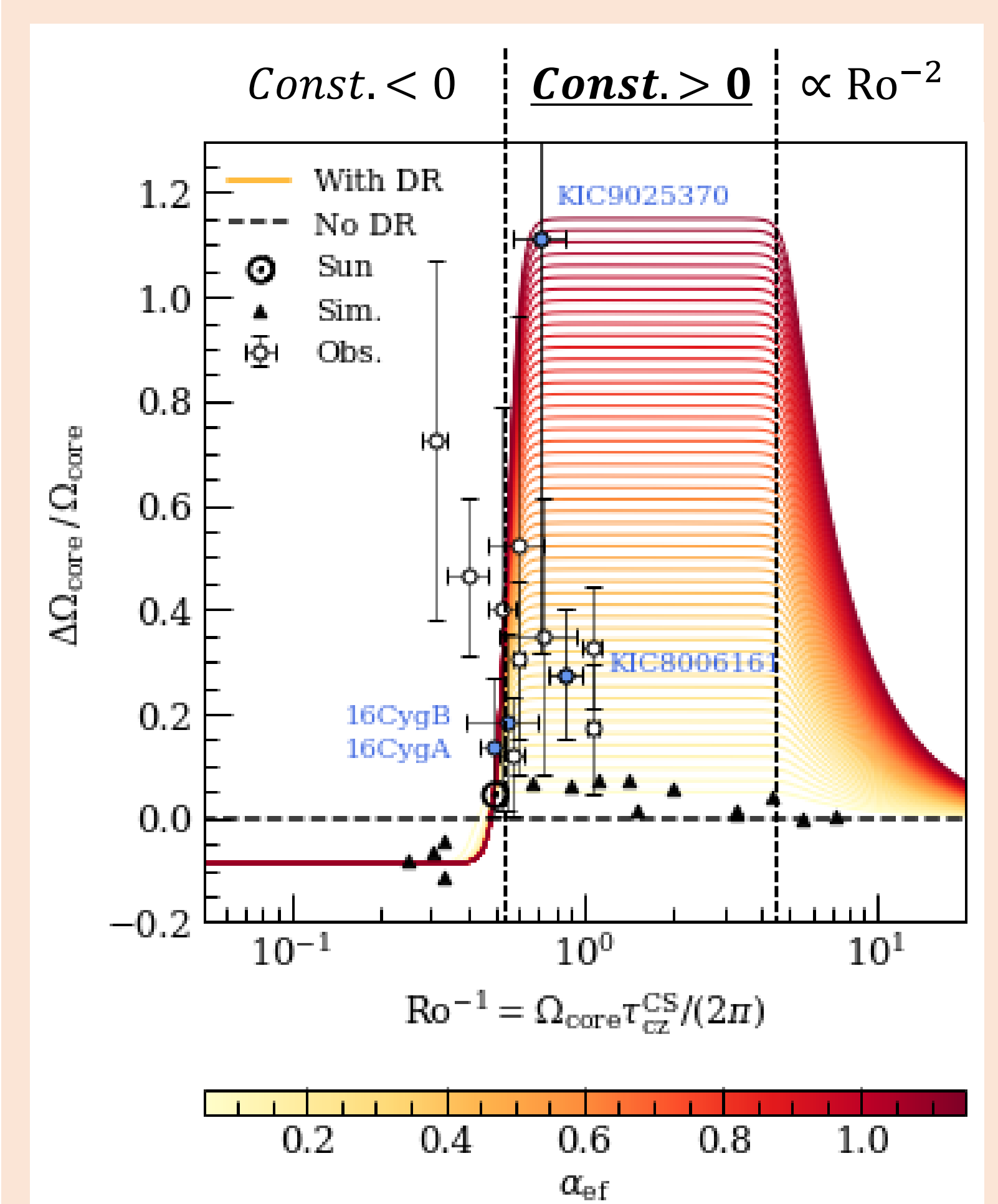
* $\Delta\Omega_{core} \equiv \Omega_{equa} - \Omega_{core}$: extent of DR (>0 : Eq, <0 : Po)

- Stellar wind Torque model : (cf. Matt et al. 2015)

Previous : $\tau_w \propto M^{0.5} R^{3.1} \tau_{cz}^{CS} \Omega_{core}^p$

Our : $\tau_w \propto M^{0.5} R^{3.1} \tau_{cz}^{CS} \Omega_{core}^{p-q} \Omega_{equa}^q$

* We set to $p = 3$ (Skumanich's law)

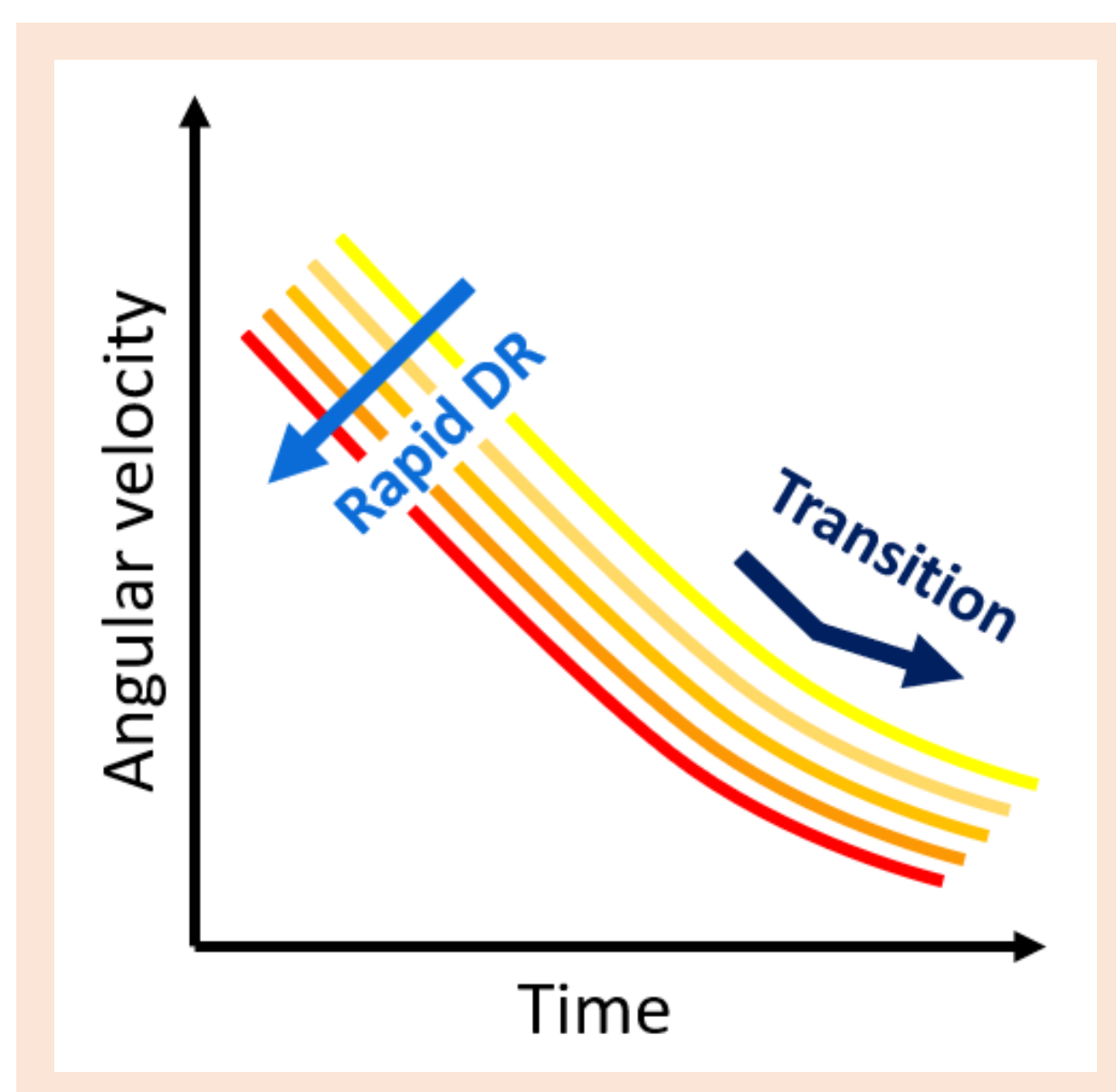


Result

1. Solar spin-down evolution

The rapid equator-fast DR

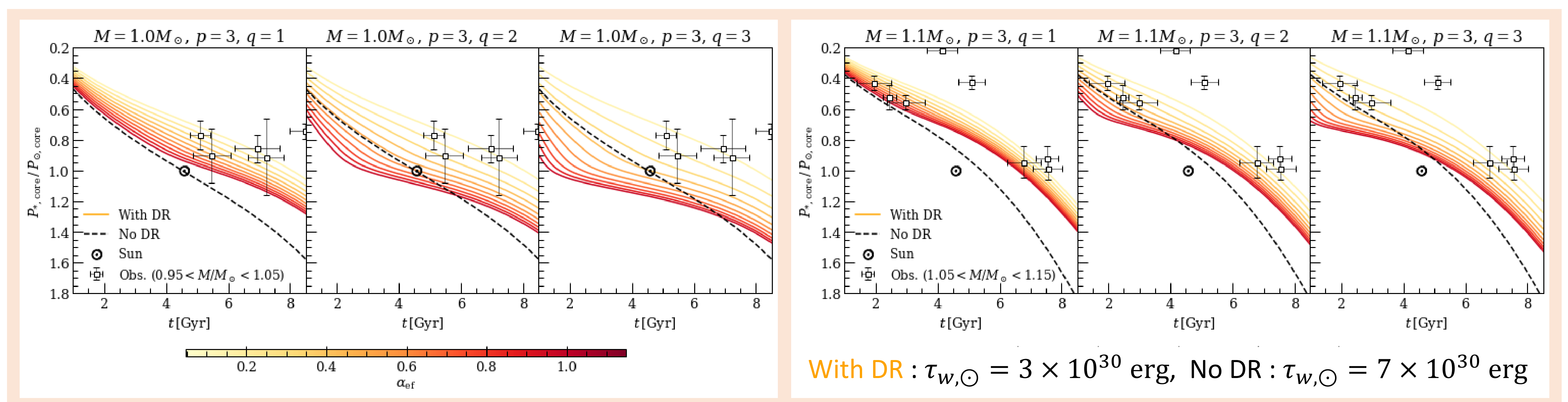
⇒ Reproduction of the solar value using $\tau_{w,\odot} = 3 \times 10^{30}$ erg



2. Spin-down rate decreasing

the transition from (rapid) equator-fast DR to polar-fast DR

⇒ Spin-down rate decreases.



With DR : $\tau_{w,\odot} = 3 \times 10^{30}$ erg, No DR : $\tau_{w,\odot} = 7 \times 10^{30}$ erg

Conclusion & Future work

1. Conclusion

- We construct the spin-down evolution model considering the DR effect for wind torque.
- Assuming the rapid equator-fast DR, the discrepancy of the solar-wind torque can be solved.
- Due to the transition from equator-fast DR to polar-fast DR, the trend of spin-down evolution can be reproduced.

2. Future work

DR effect in MHD simulation, The effect of metallicity, The indices of the stellar wind torque etc.