What would be the magnetic field of the Earth if it spun as slowly as Venus?

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The magnetic field of the Earth

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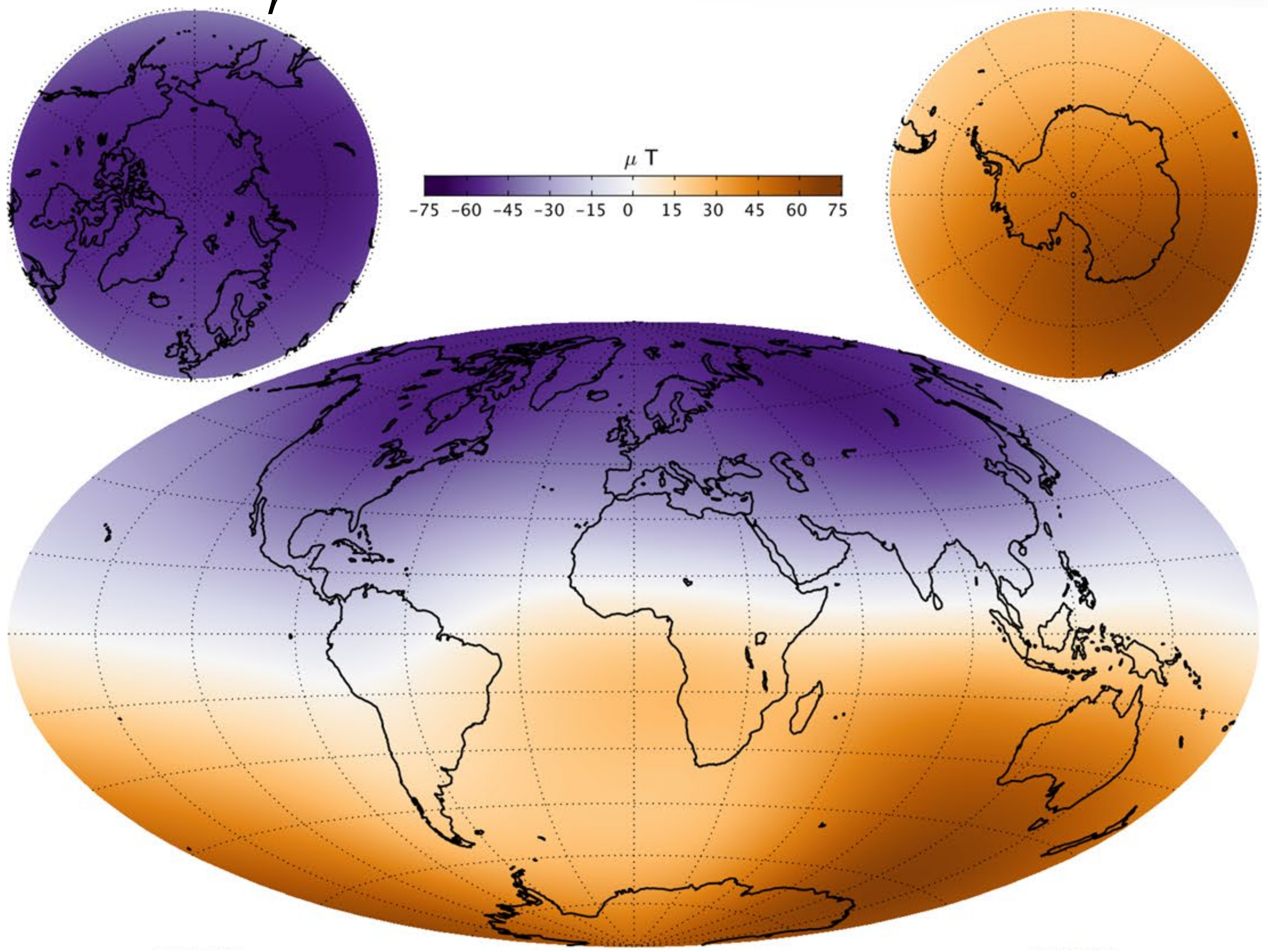
- B ~ 0.5 Gauss = 0.05mT at the Earth surface, 10 times larger at the top of the core, dominated by a **dipole** almost **aligned with Earth's spin axis**.

B_r at the surface of the Earth



Finlay+ 2020

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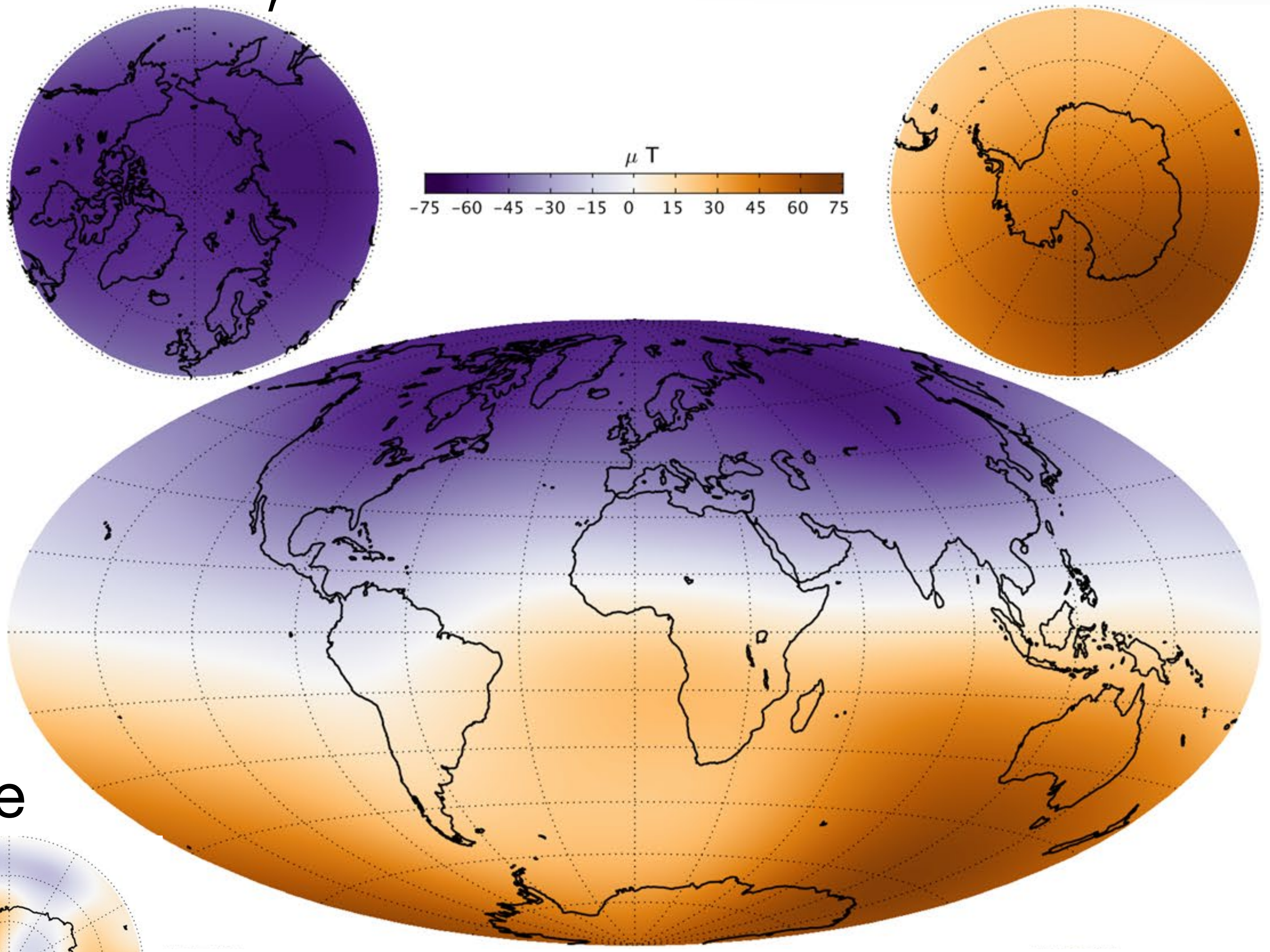
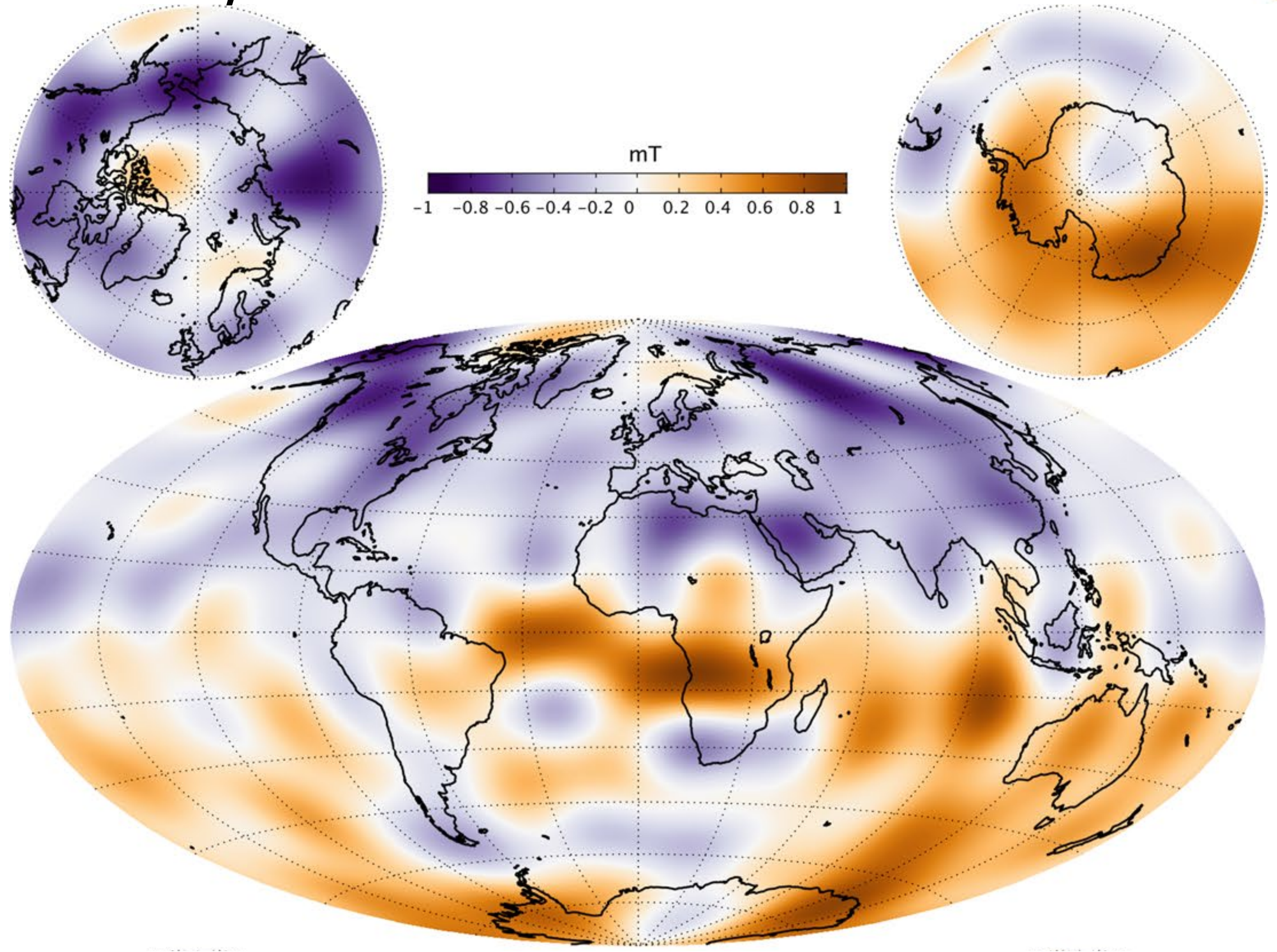


B_r at the top of the core



Finlay+ 2020

The magnetic field of the Earth

- B ~ 0.5 Gauss = 0.05mT at the Earth surface, 10 times larger at the top of the core, dominated by a **dipole** almost **aligned with Earth's spin axis**.
- Produced by a dynamo powered by thermo-compositional convection $\mathscr{P} \simeq 3$ TW.

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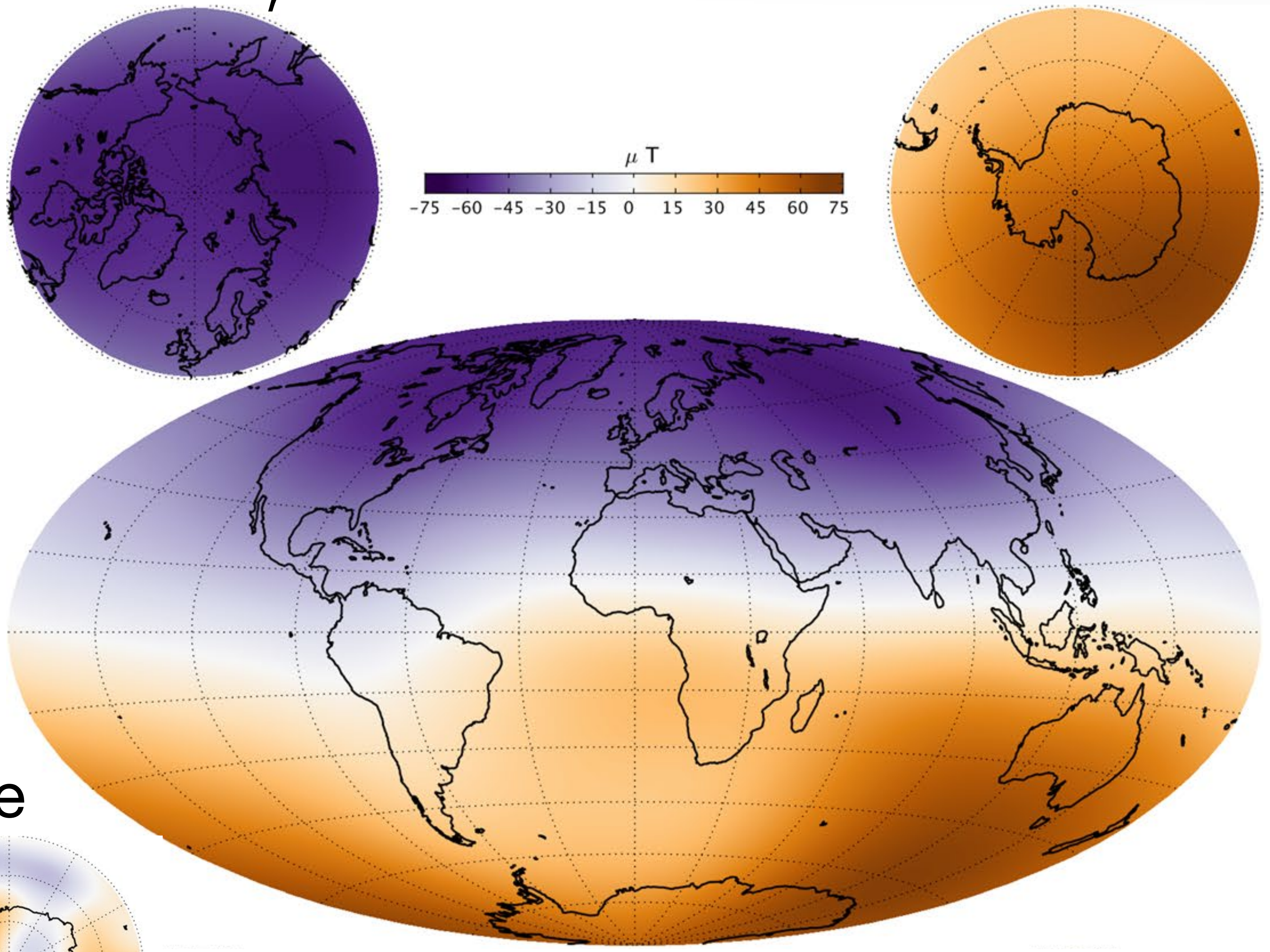

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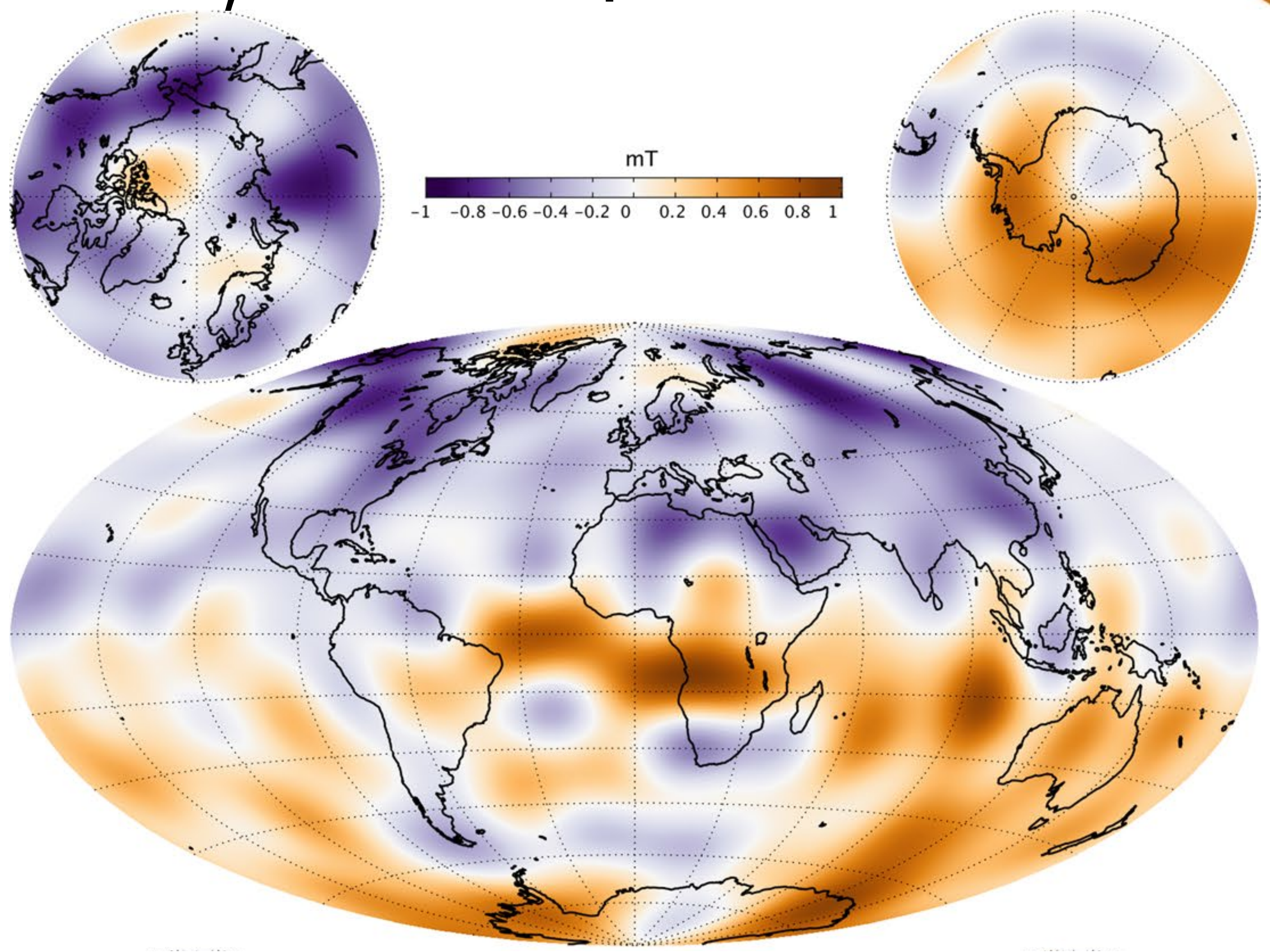

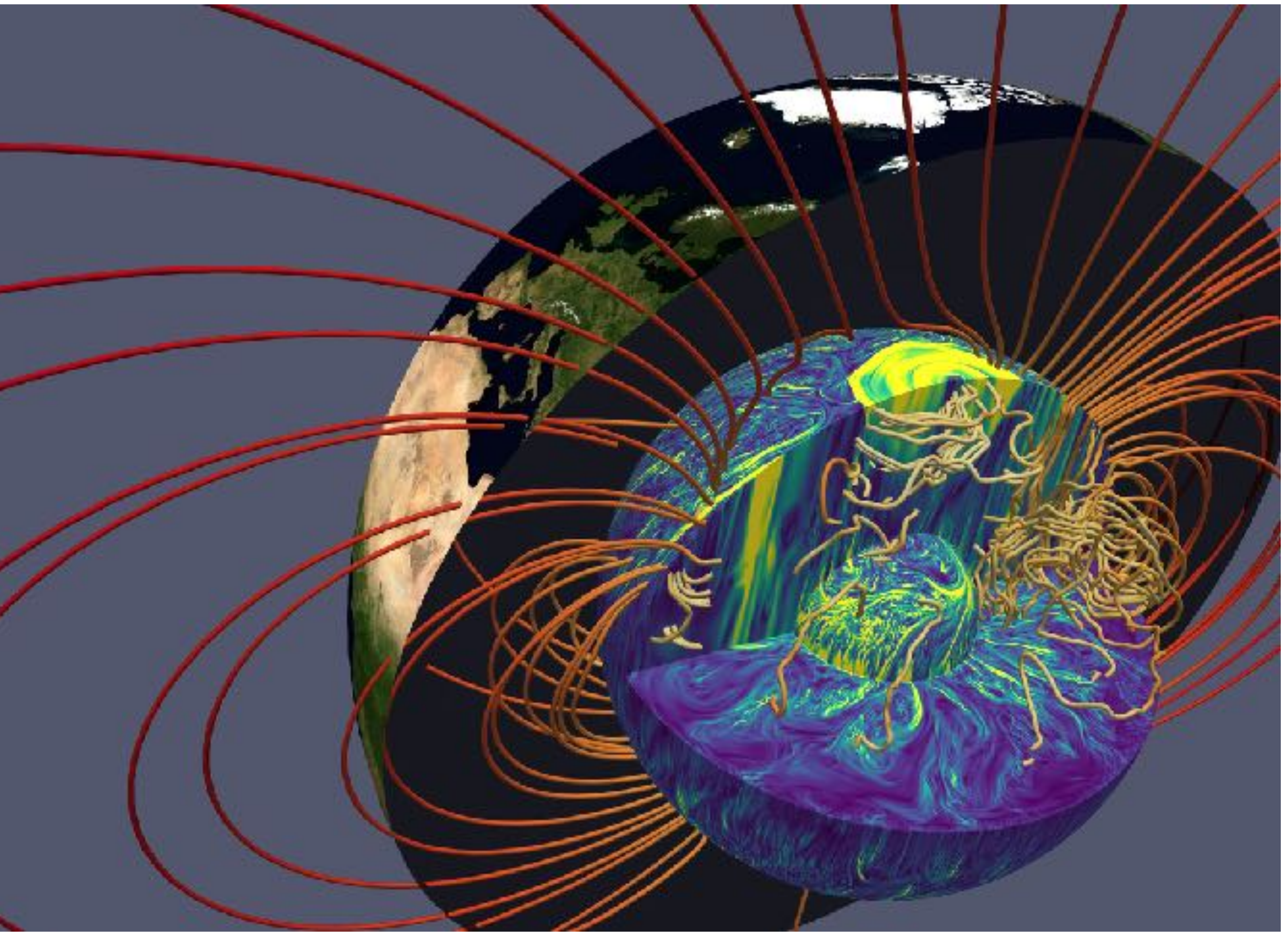

Schaeffer+ 2017

$t_\Omega = 1$ day

$\mathscr{P} \simeq 3$ TW

$B \simeq 3$ mT

$U \simeq 0.5$ mm/s

~flat spectra for $\ell \leq 10$

Roberts+ 2013; Gillet+2015

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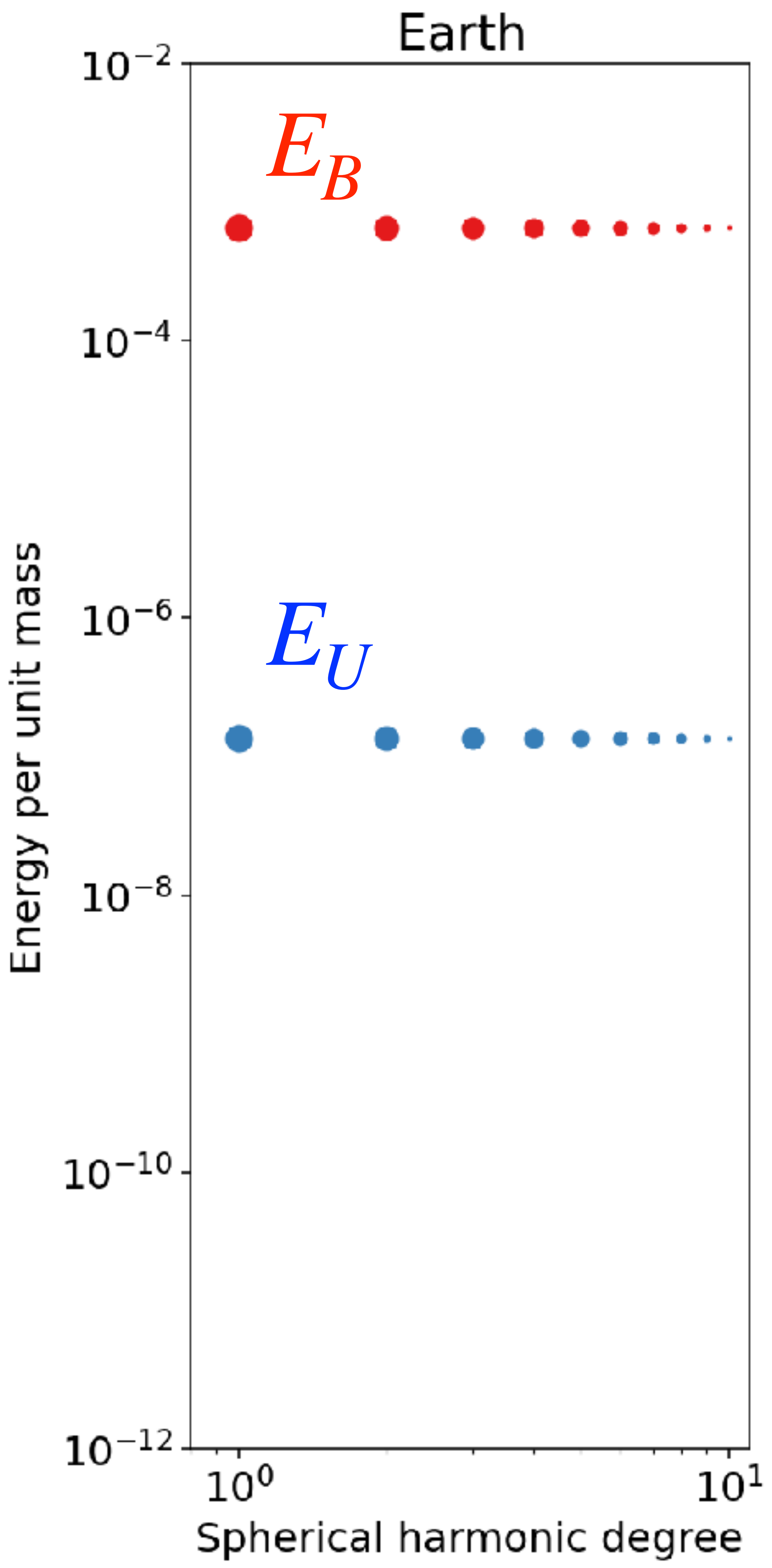

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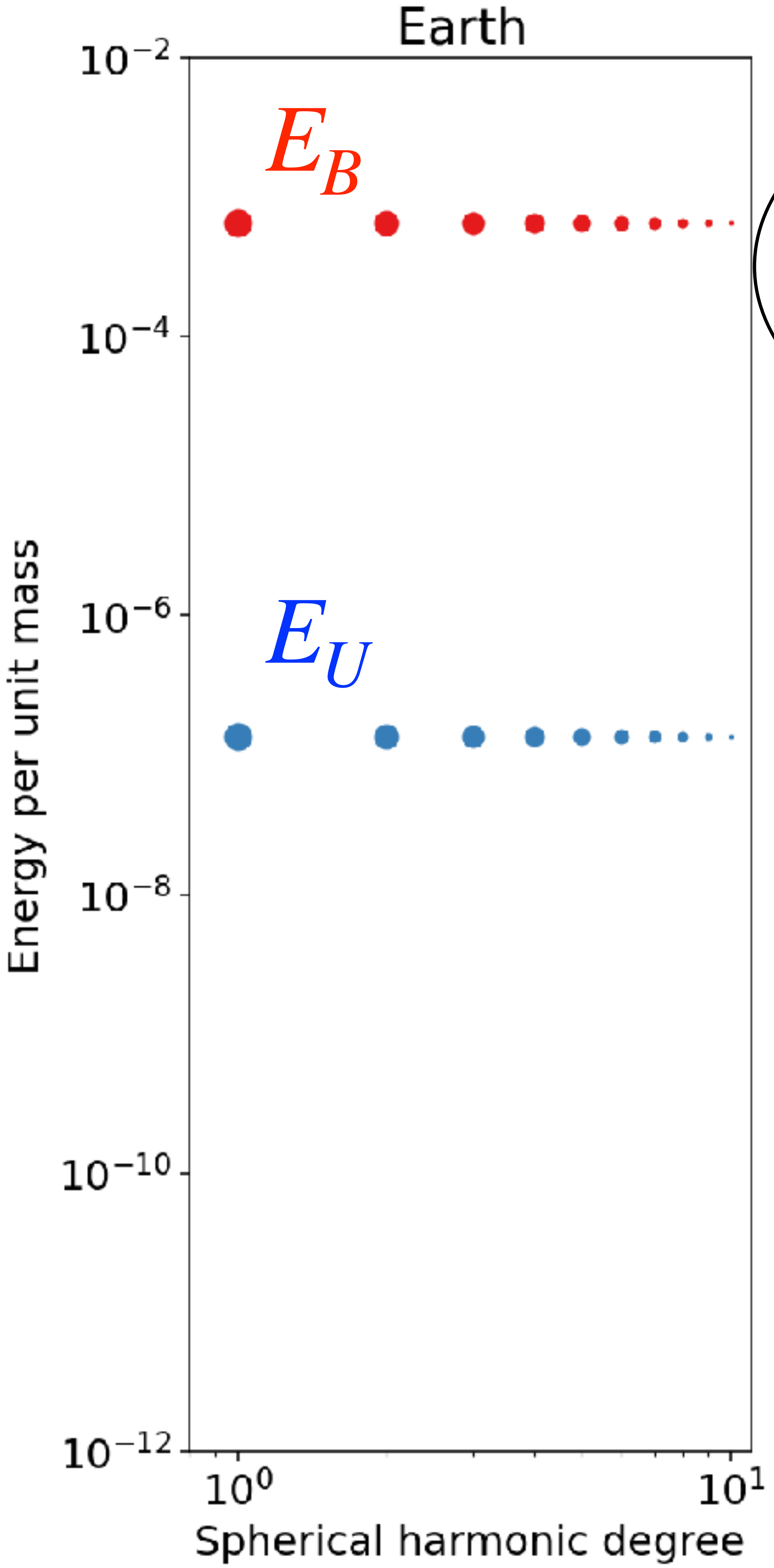

How would they change if the Earth spun as slowly as Venus?

The classical answer is...

Not much!
Both are « rapidly rotating dynamos » since their **Ekman** number is very small
$Ek < 10^{-12}$

$$Ek = \frac{\nu}{\Omega R^2}$$

$\nu = 10^{-6}$ m²/s	kinematic viscosity
$R = 3\,500$ km	radius of the core

Scaling laws for planetary dynamos

Indeed, the classical scaling law for **magnetic** intensity is ***independent*** of t_Ω

$$\frac{B}{\sqrt{\rho\mu}} \simeq R\left(\frac{\mathscr{P}}{MR^2}\right)^{1/3}$$

Christensen 2010

$\nu = 10^{-6}$ m²/s	kinematic viscosity
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$$U \simeq \frac{R}{\Omega^{1/3}}\left(\frac{\mathscr{P}}{MR^2}\right)^{4/9}$$

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which implies that the **Rossby** number would be **~1500 times larger**.

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force balance

These laws apply to dynamos in the QG-MAC regime (Quasi-Geostrophic Magneto-Archimedean-Coriolis)

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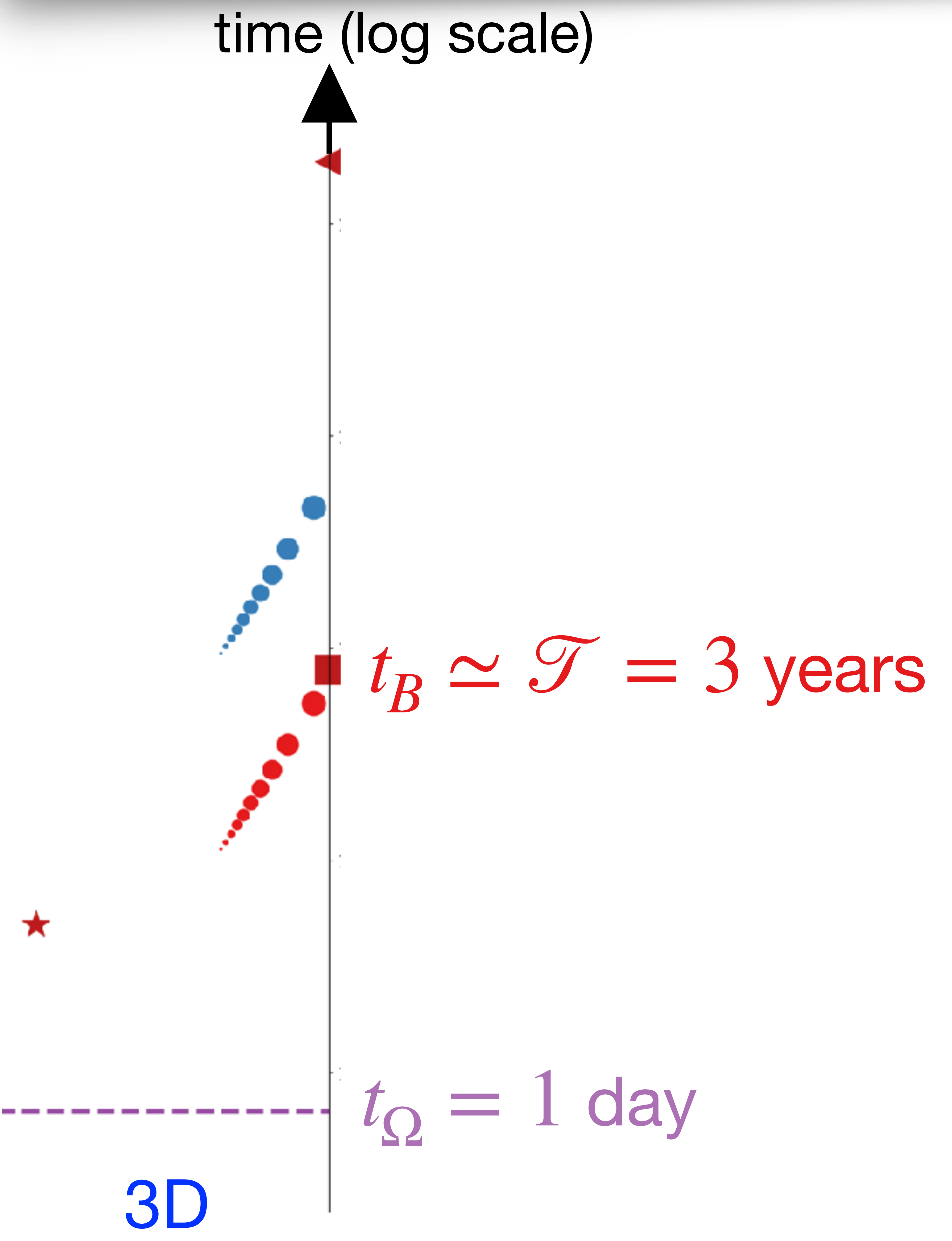
QG-MAC characteristic times for the Earth



A **'power' time** $\mathscr{T}$ is obtained from the power $\mathscr{P}$ and we recover **magnetic time** $t_B \simeq \mathscr{T}$ in this QG-MAC scenario.

$$t_B = \frac{R\sqrt{\rho\mu}}{B}$$

$$\mathscr{T} = \sqrt[3]{\frac{MR^2}{\mathscr{P}}}$$

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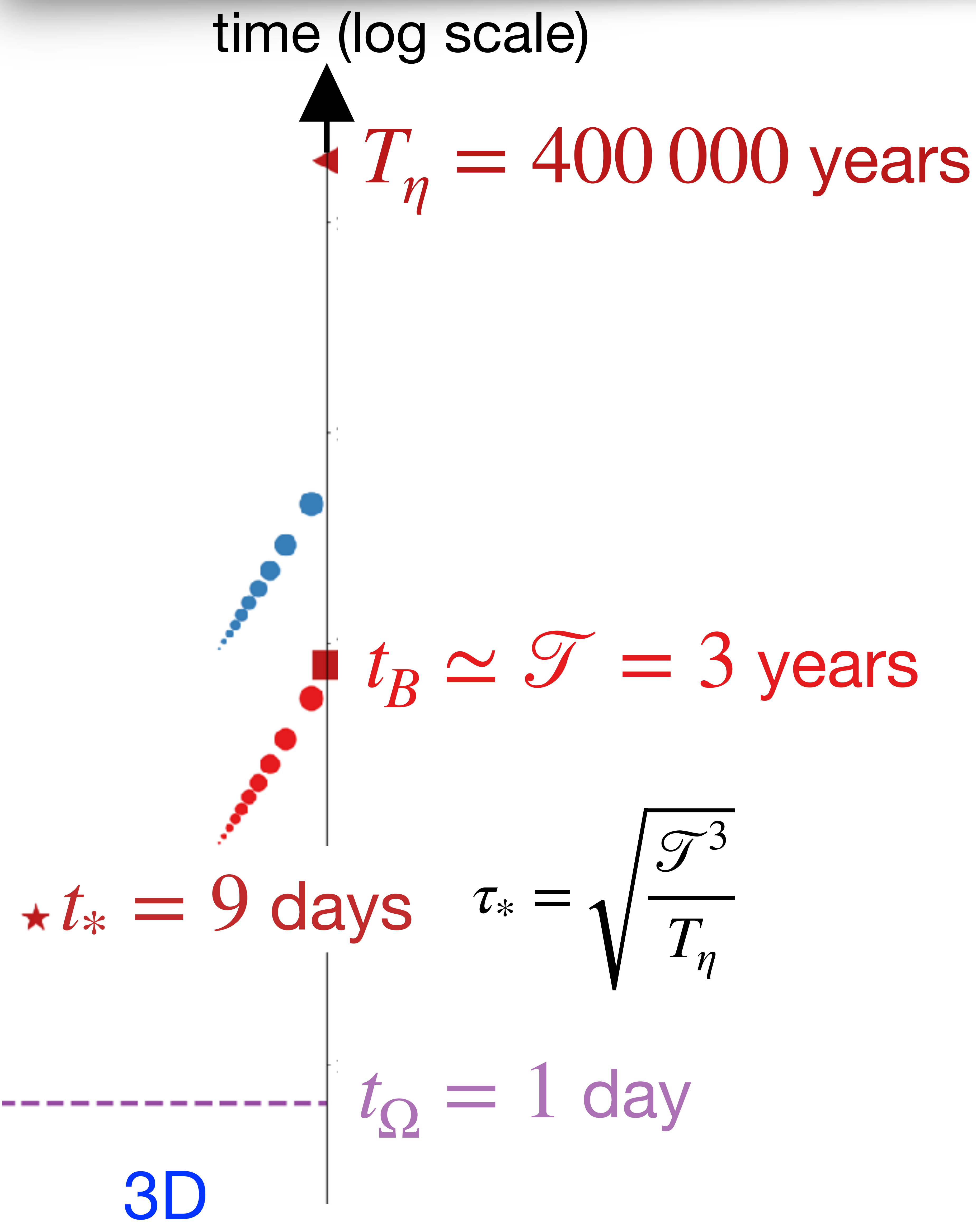

$$T_\eta = \frac{R^2}{\eta}$$

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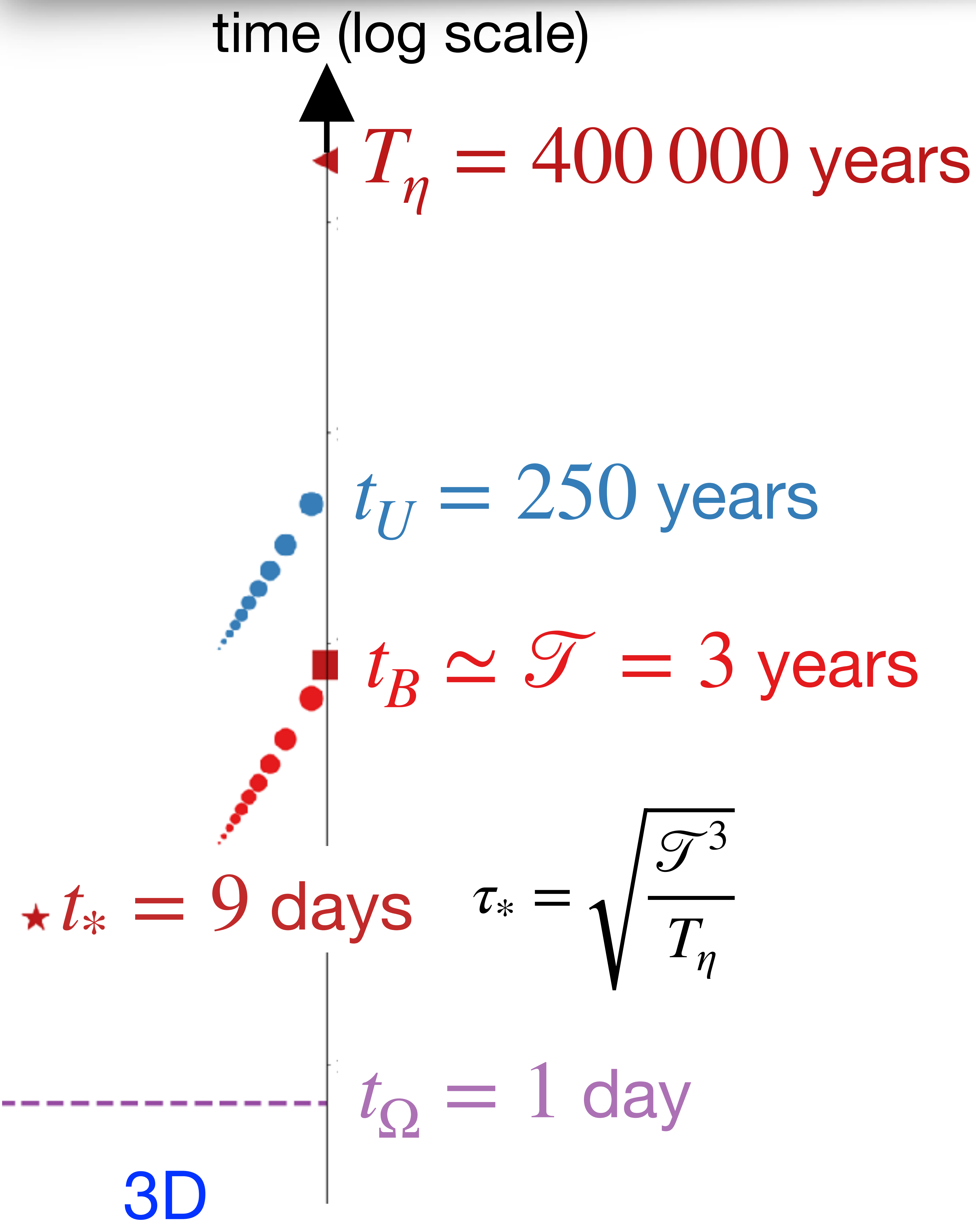

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$$\tau_* = \sqrt{\frac{\mathscr{T}^3}{T_\eta}}$$

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With t_* **larger** than t_Ω one gets $t_U \gg t_\Omega$: the flow is **quasi-geostrophic**.

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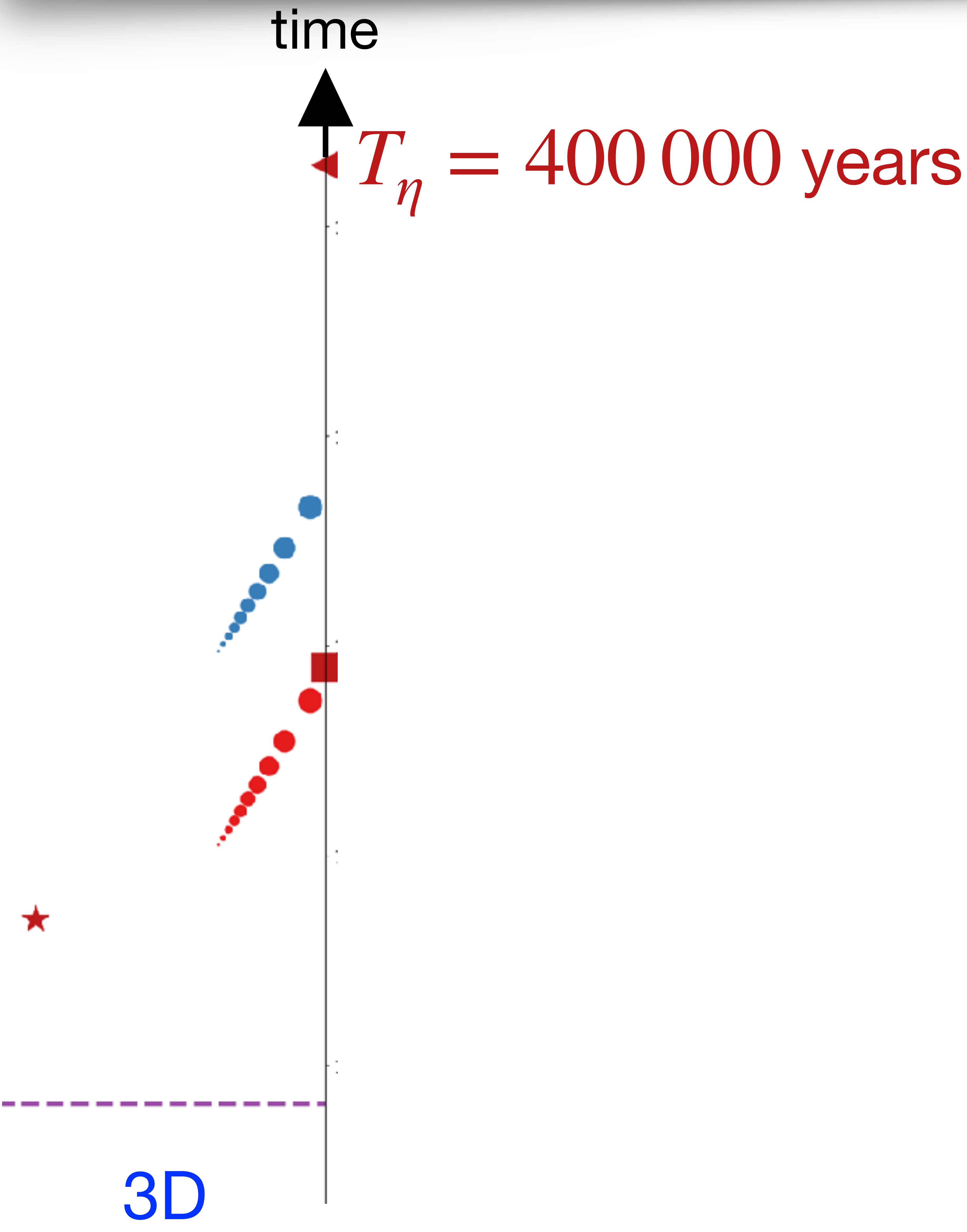

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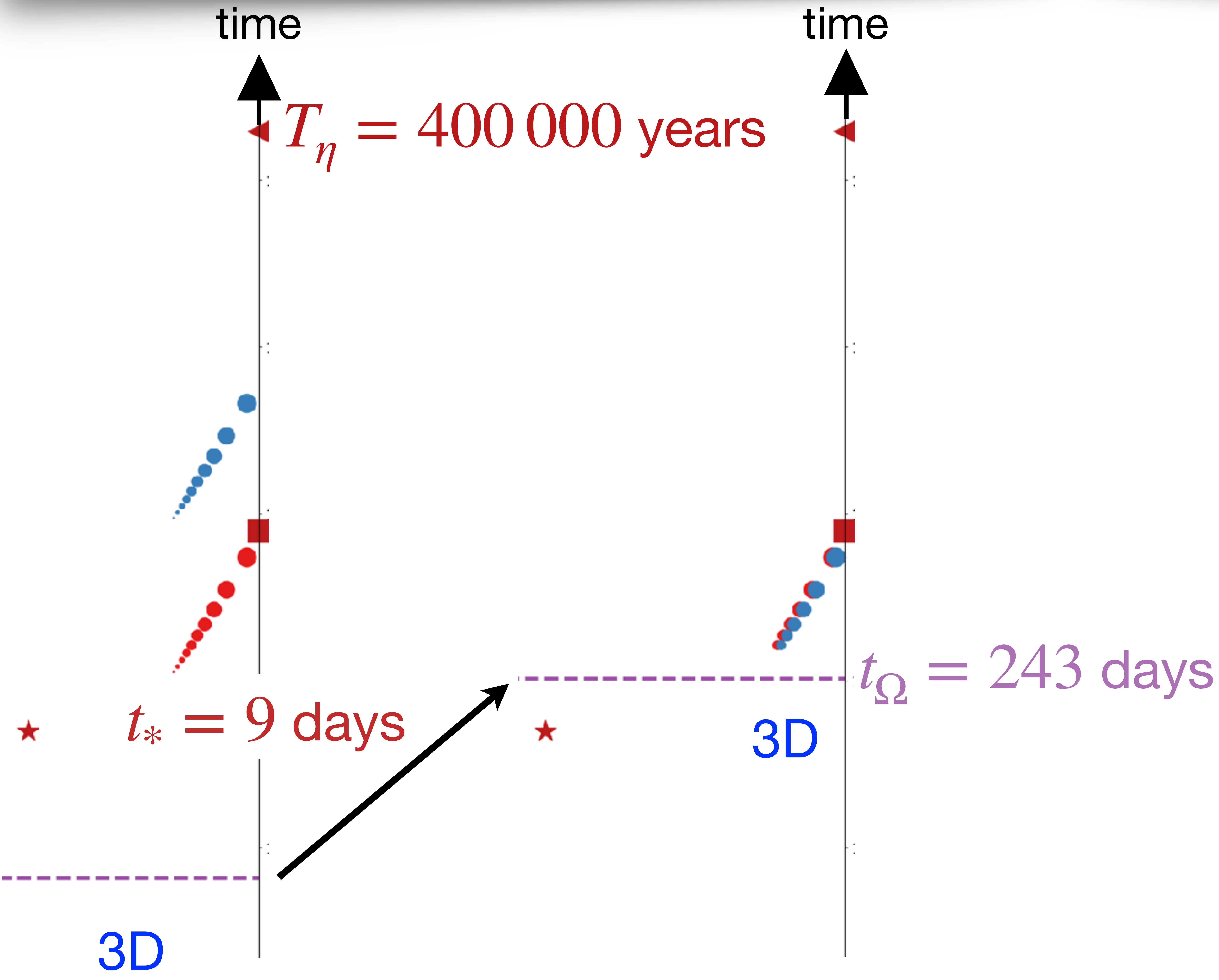

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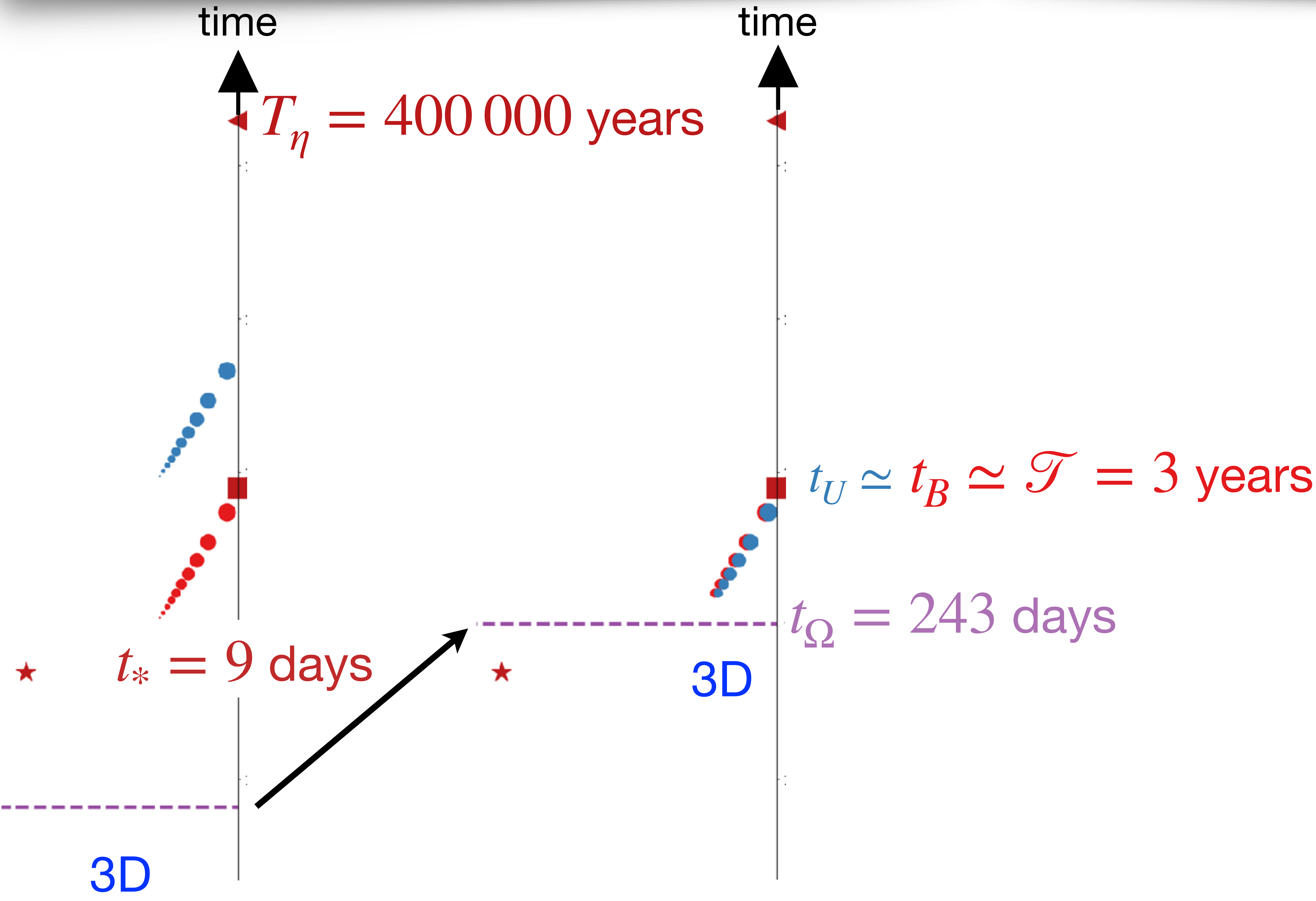

t_* is now **smaller** than t_Ω, and a QG-MAC scenario would yield a very rapid flow $t_U \simeq t_B \sim t_\Omega$, which would **not be** quasi-geostrophic anymore.

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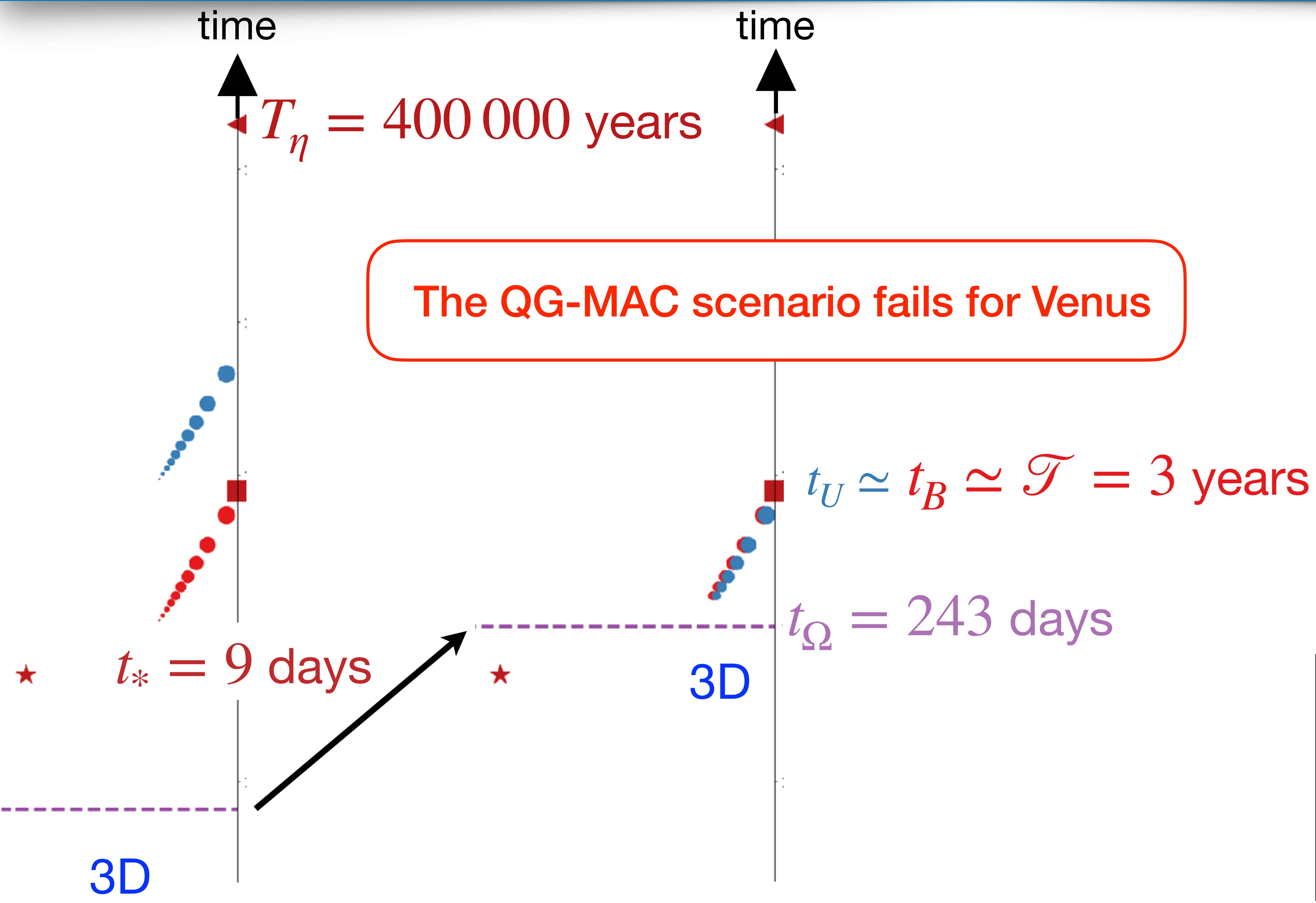

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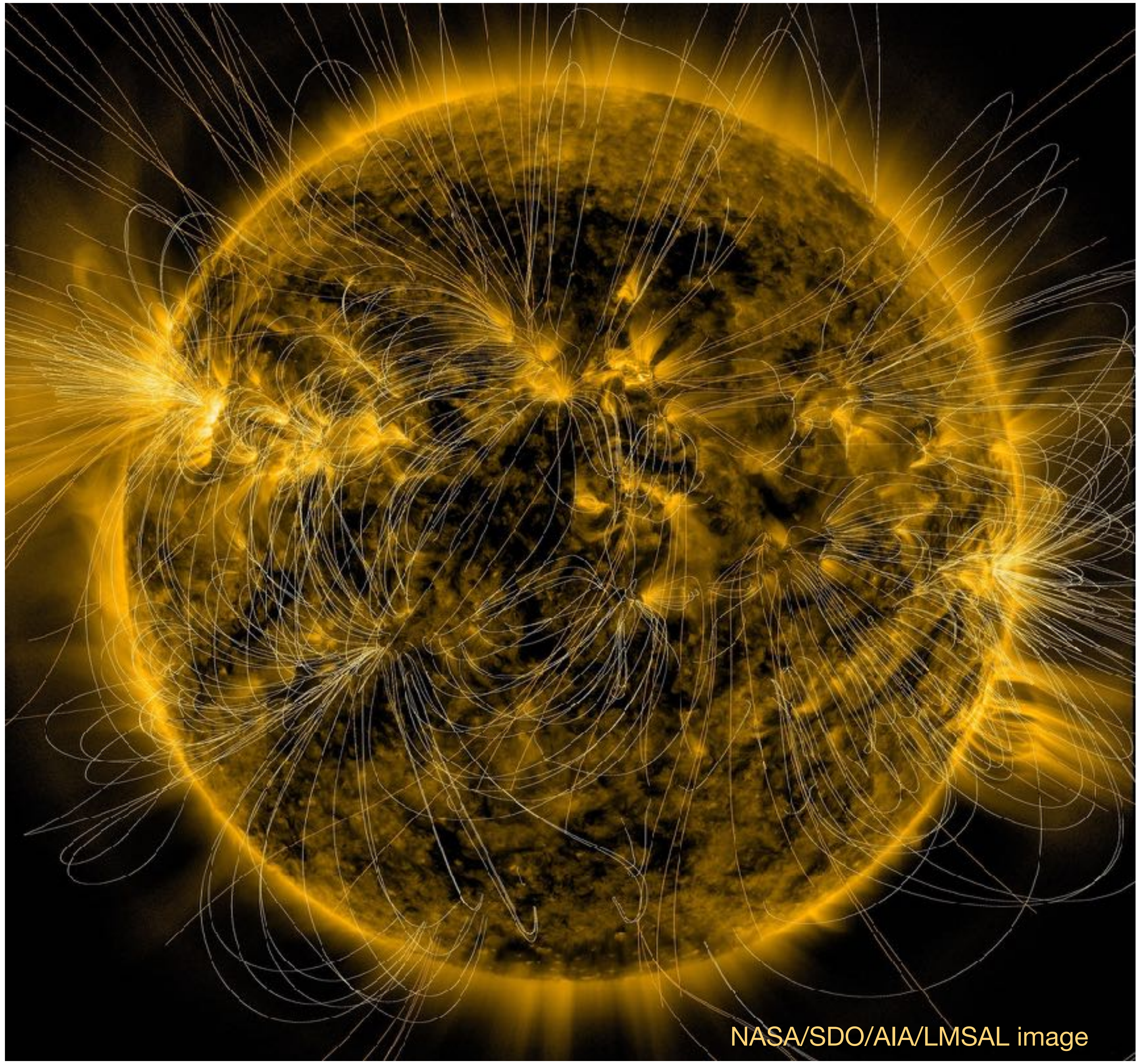
Its **kinetic energy is larger** than its magnetic energy.

Small-scales dominate over large-scales.

The Solar dynamo can be modeled with an **IMAC** scenario, in which inertia plays an important role.



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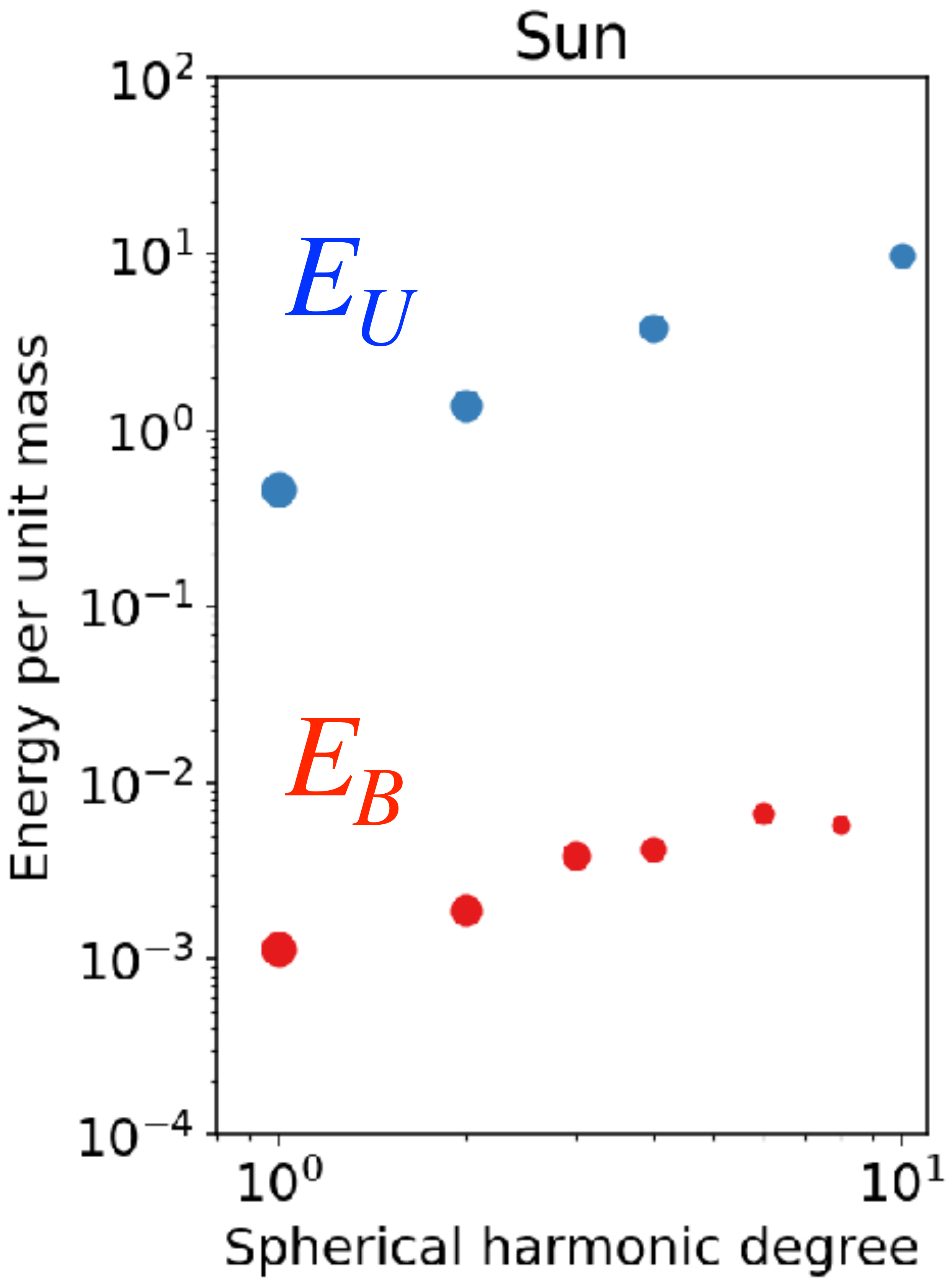
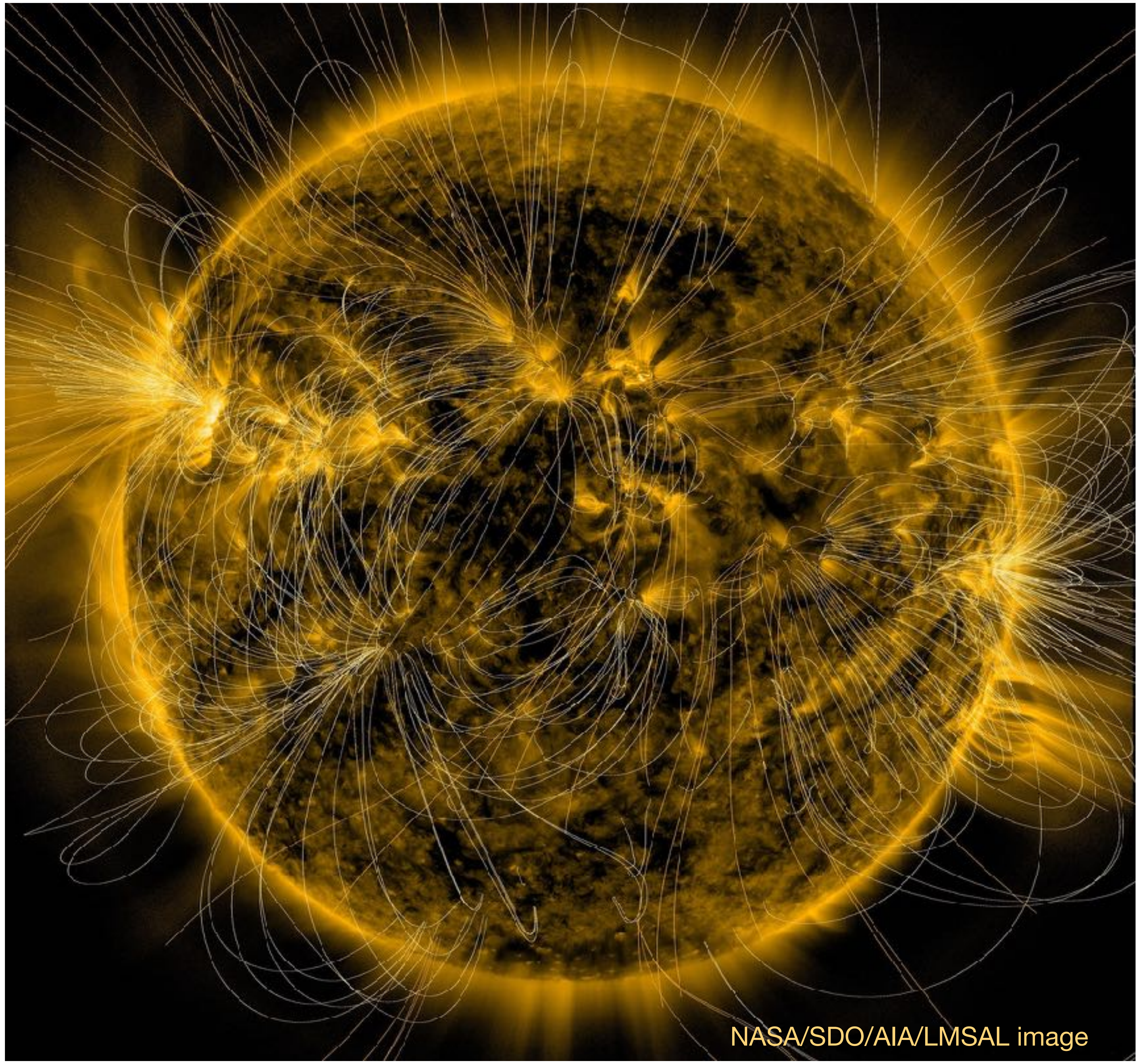
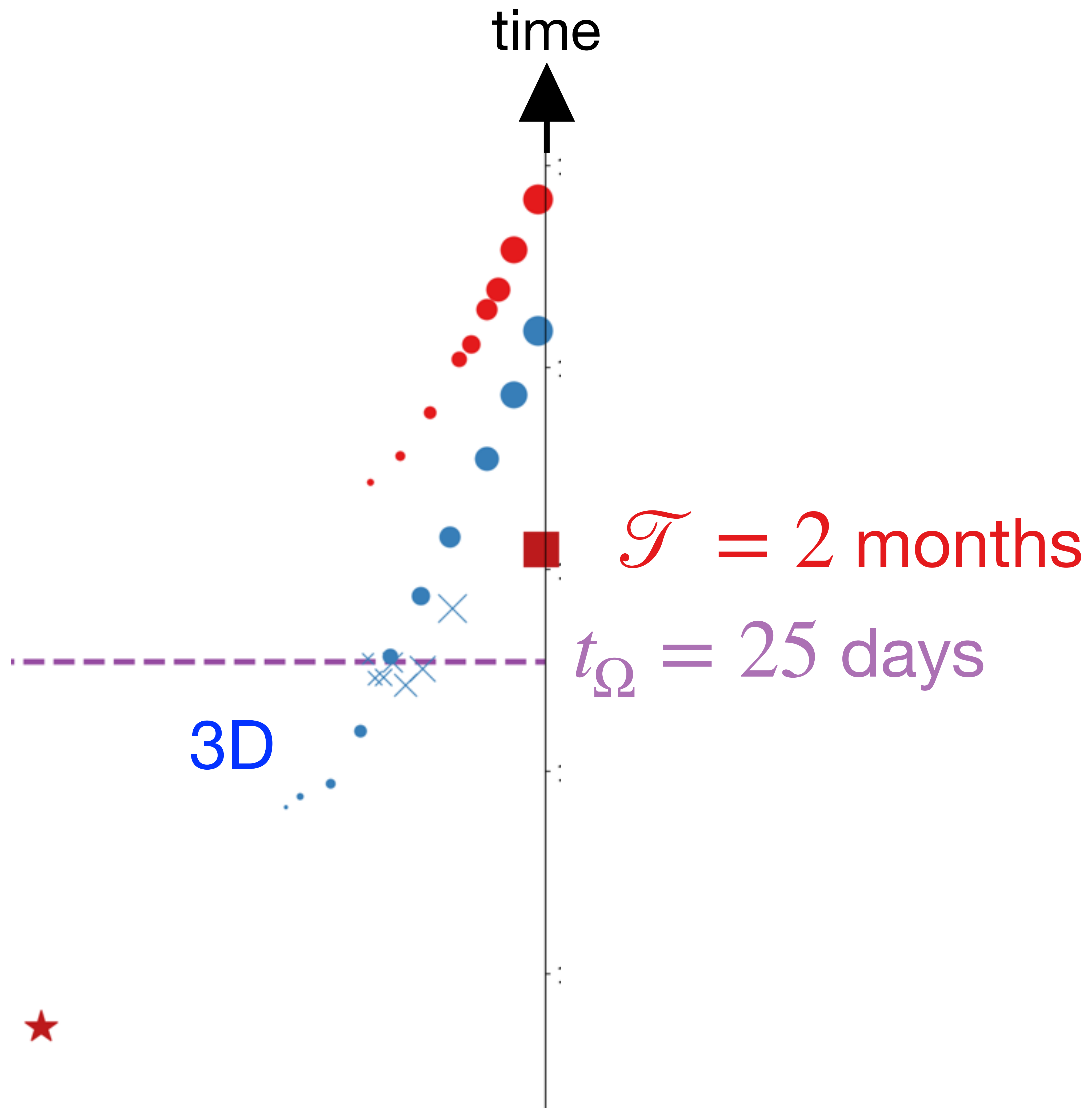


spectra adapted from Proxhauf, 2021 and Finley & Brun, 2023



IMAC characteristic times for the Sun



$\nu = 10^{-3}$ m²/s	kinematic viscosity
$R = 200\,000$ km	thickness of conv zone
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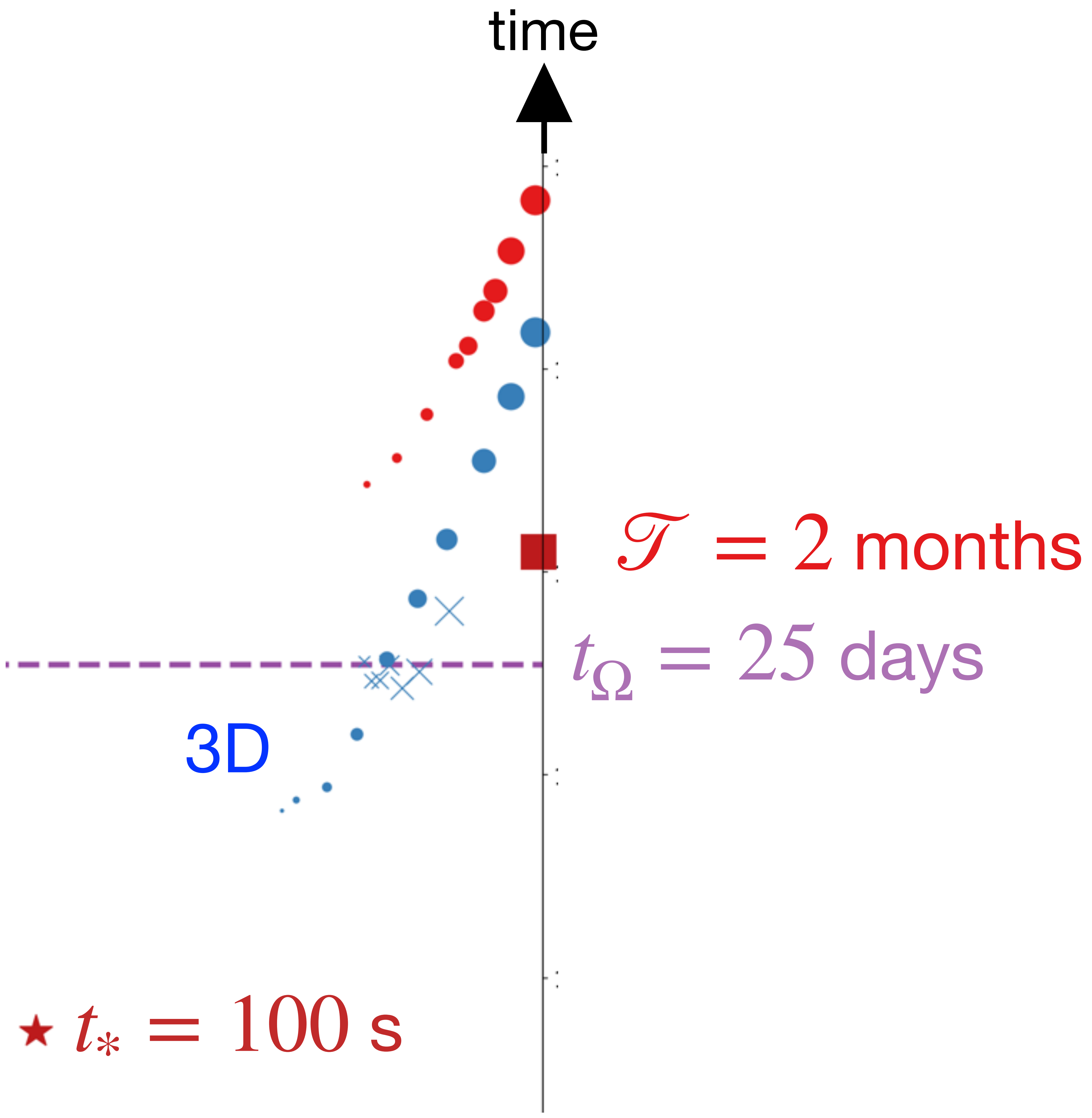

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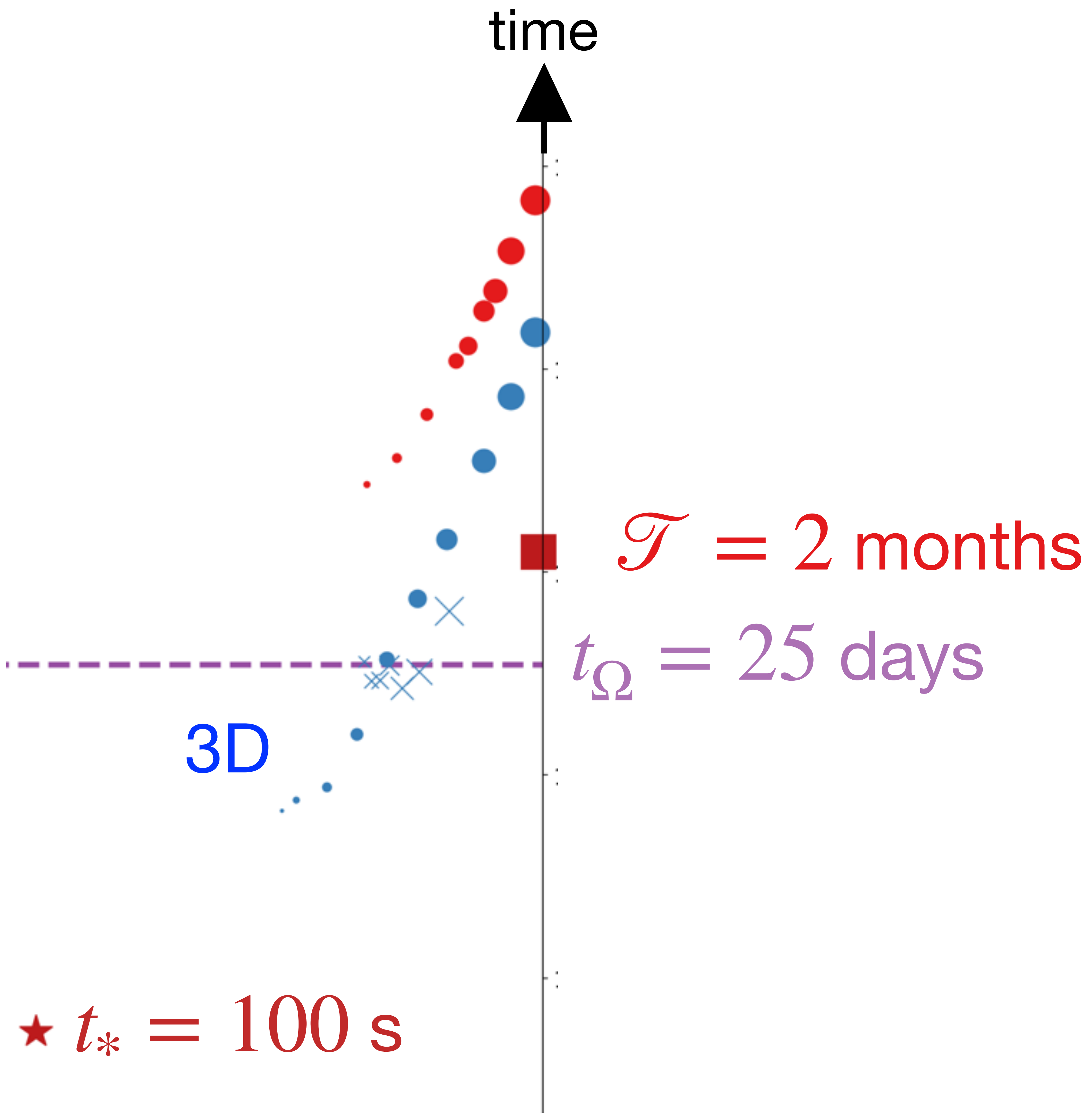

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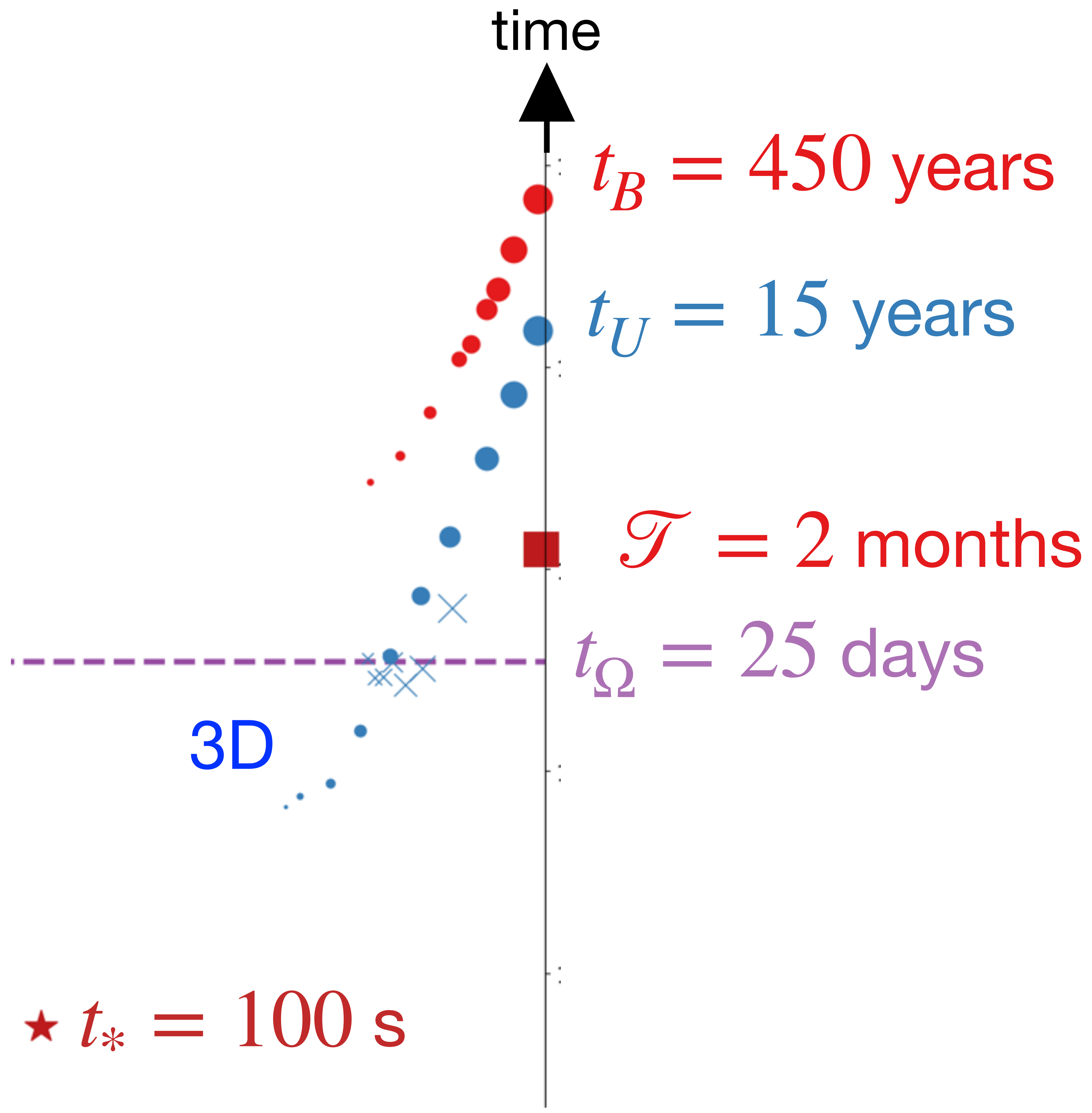

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Inertia-Magneto-Archimedean-Coriolis

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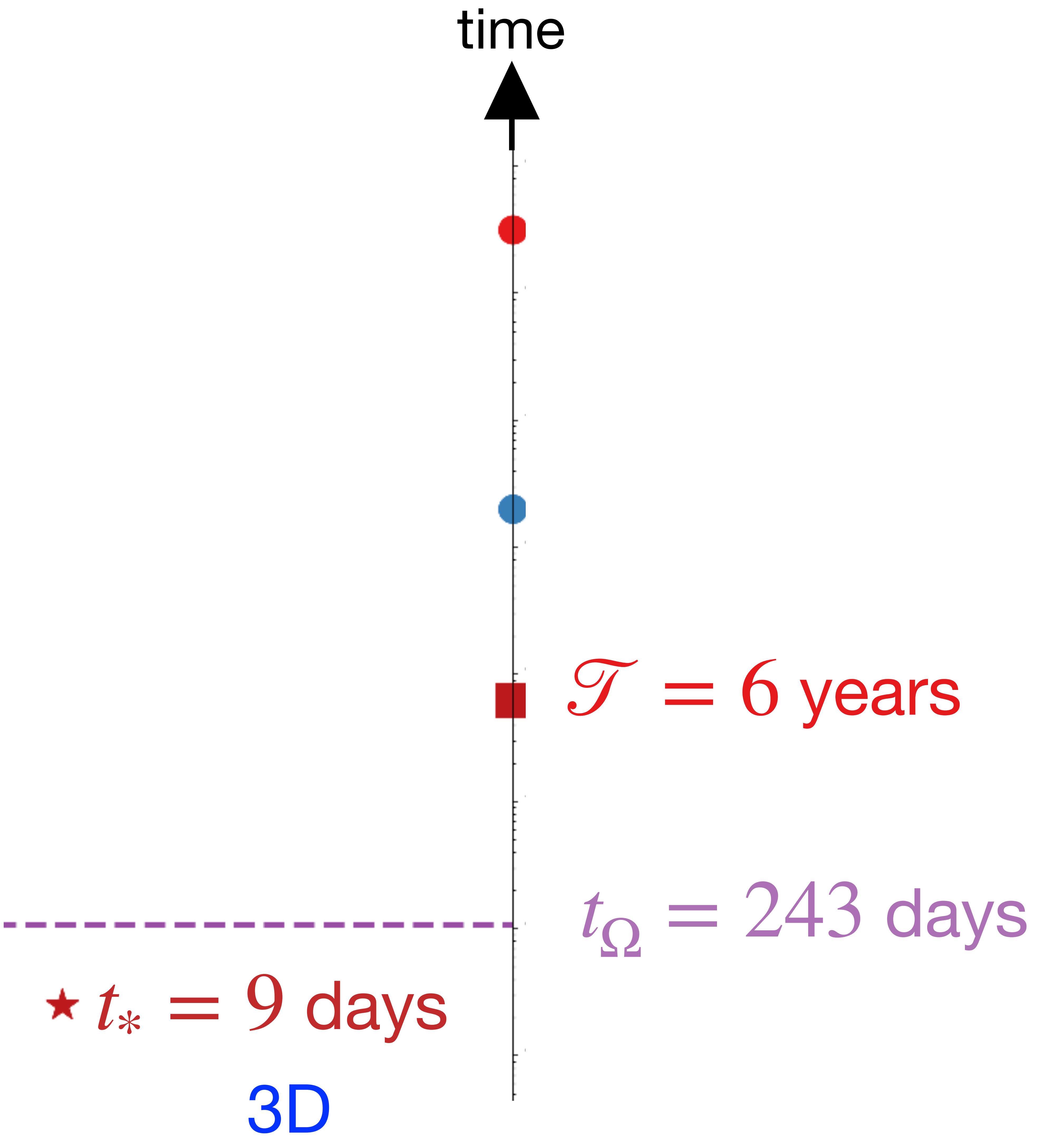

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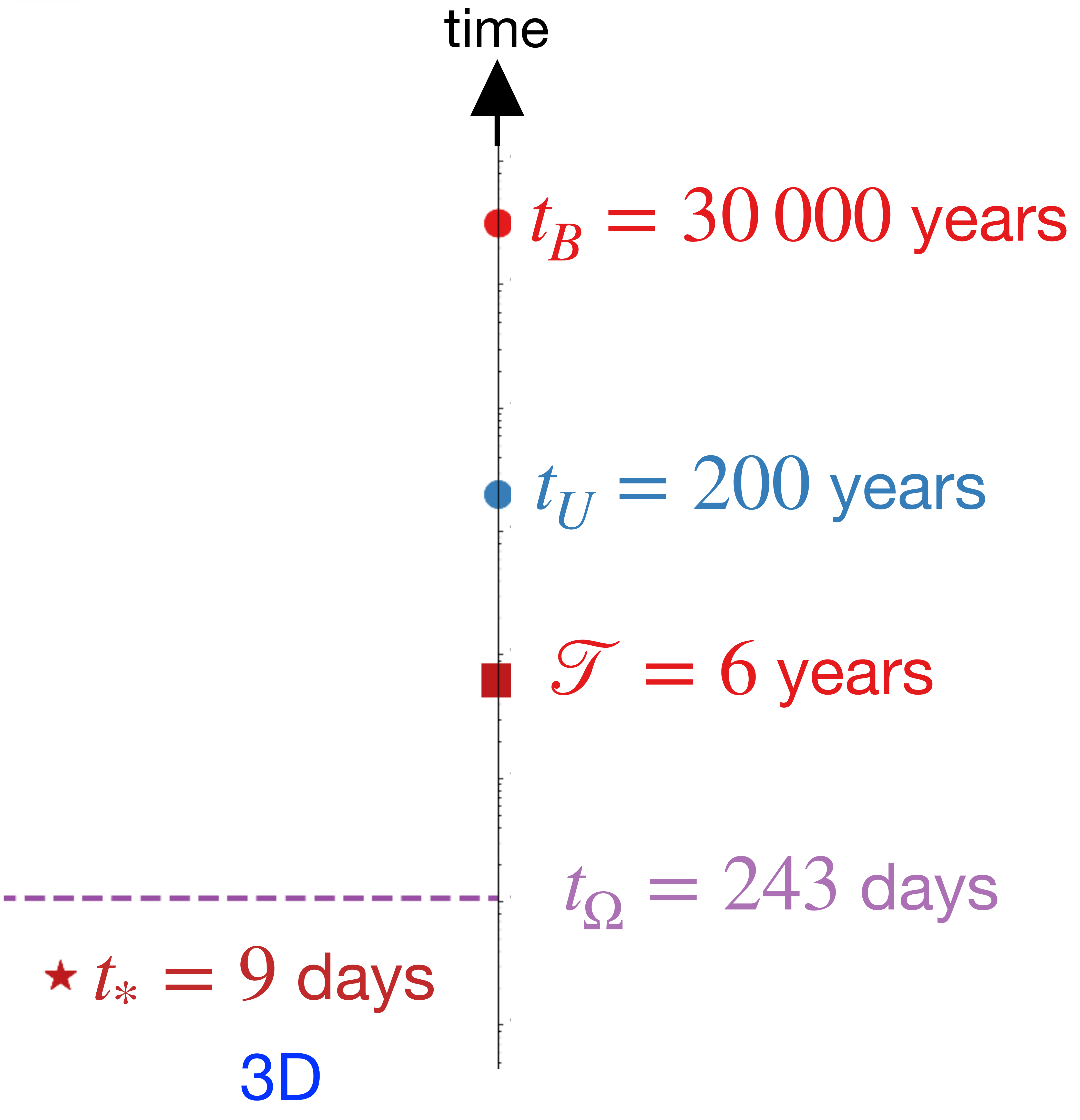

An IMAC force-balance scenario for Venus predicts that its large-scale magnetic field would be **10 000 times smaller** than that of the Earth.

It would be **dominated** by **small-scales**, and might therefore have **escaped detection**…

Zonal flows could be strong.

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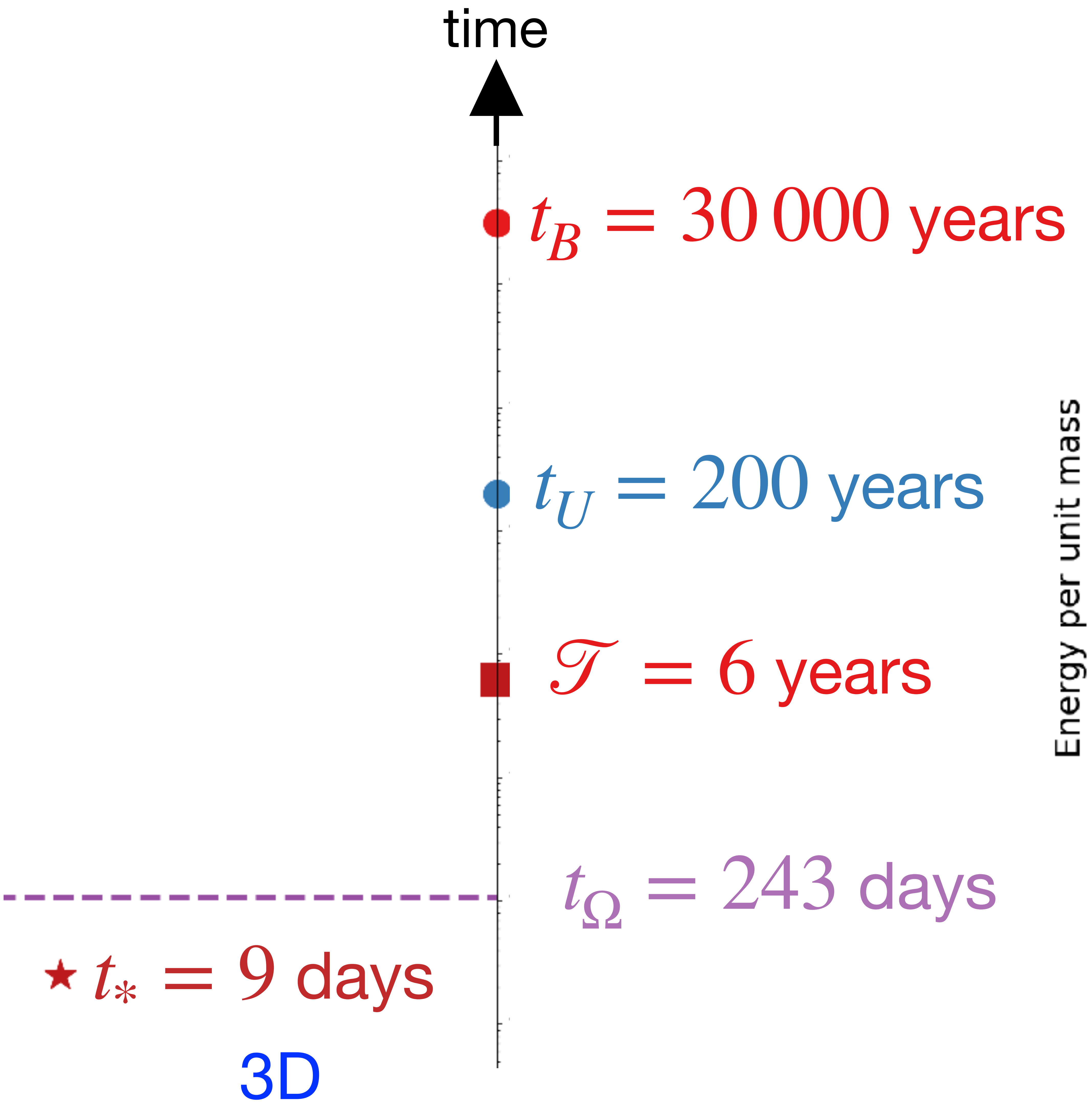

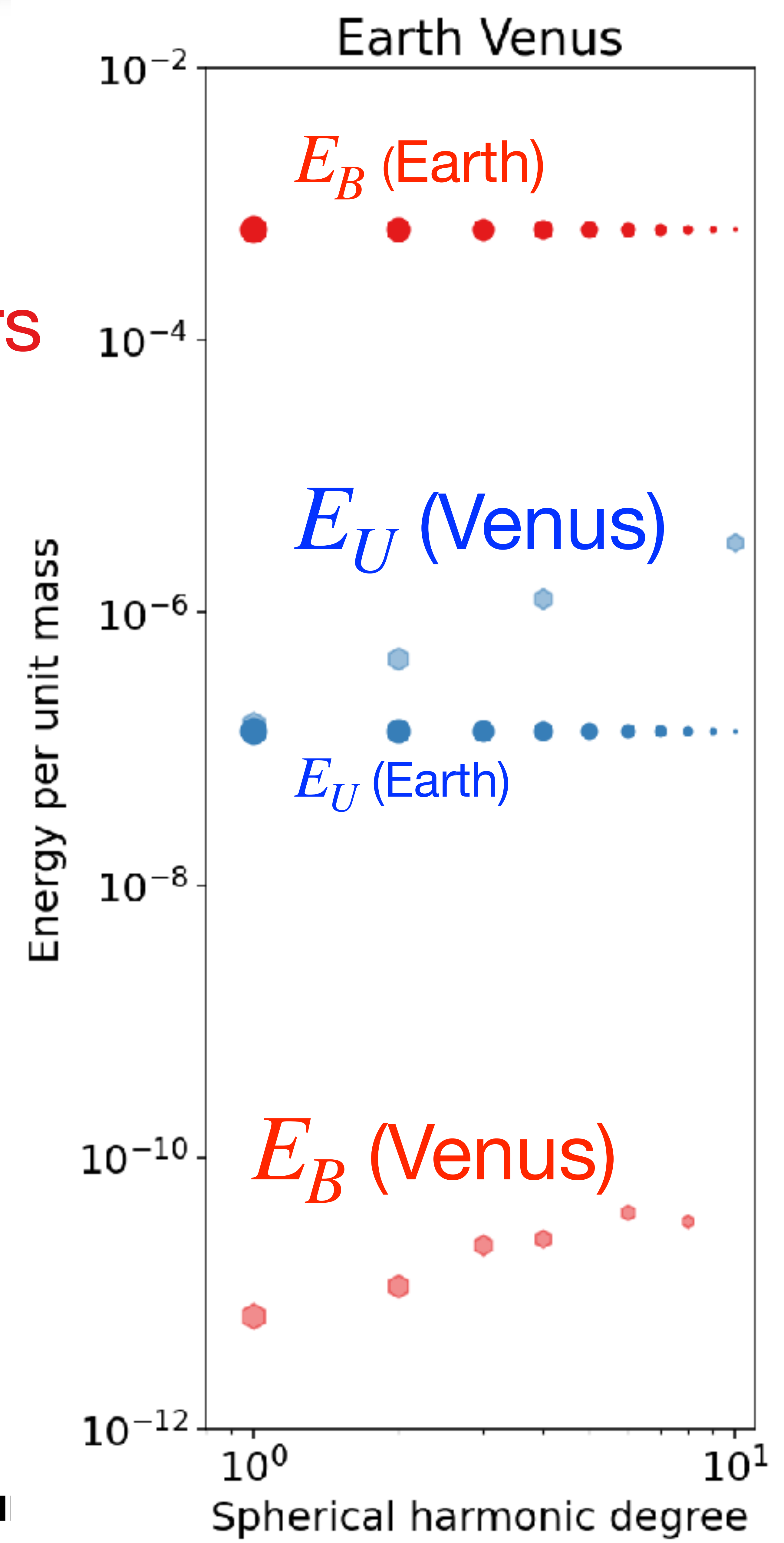

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Take-home messages

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Our analysis suggests an **alternative speculative scenario**: Venus is producing a weak small-scales dominated magnetic field that could have escaped detection…

$$t = t_{allocated}$$

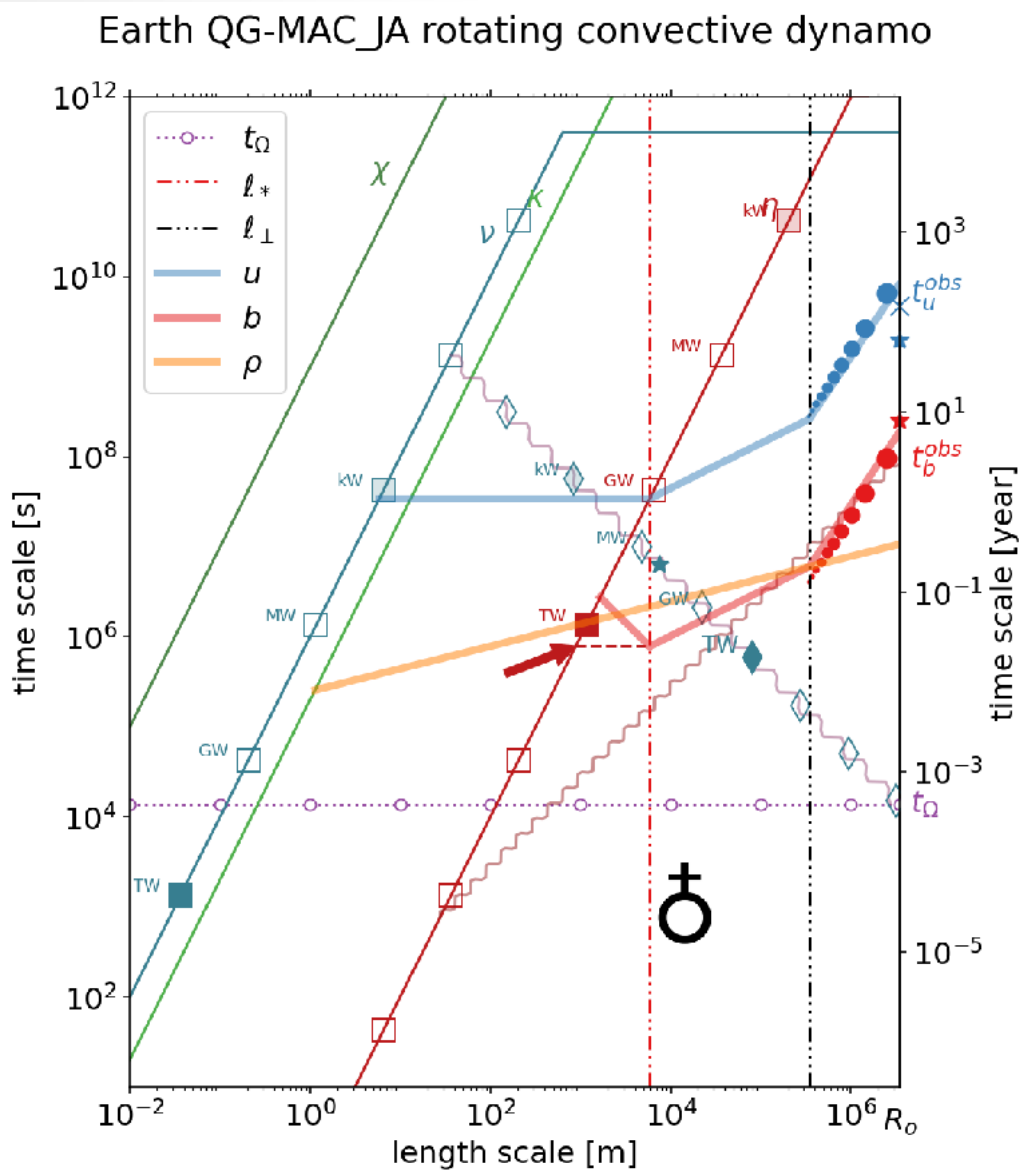
Thank you!

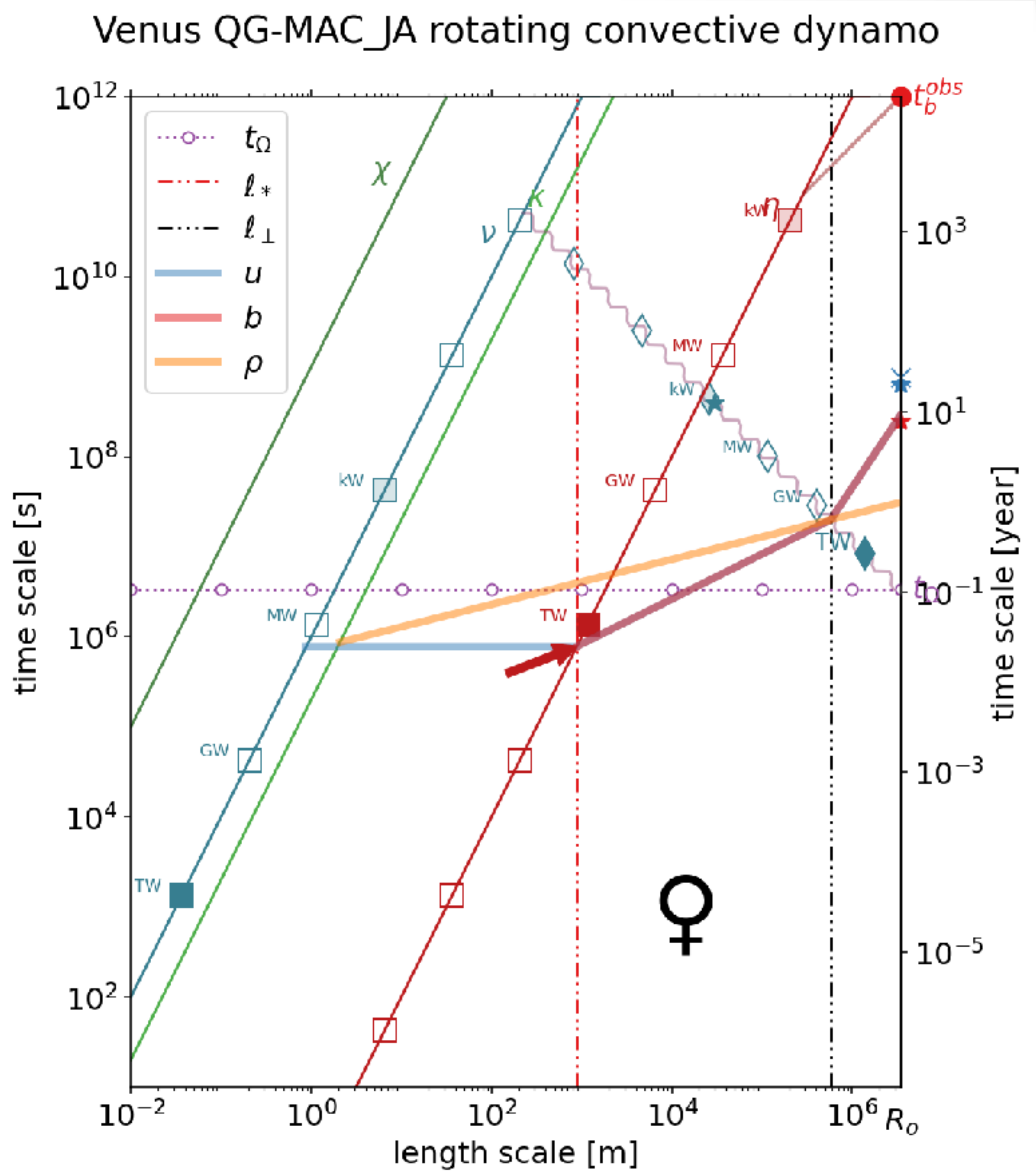
to dwell further with $t > t_{allocated}$

- Nataf H-C. & N. Schaeffer, Dynamic regimes in planetary cores: $\tau - \ell$ diagrams, *Comptes Rendus Géoscience*, **356**, 1-30, DOI, 2024.

- Noraz Q, A.S. Brun & A. Strugarek, Global turbulent solar convection: a numerical path investigating key force balances in the context of the convective conundrum, *The Astrophysical Journal*, **981** 206, DOI, 2025.

$\tau - \ell$ diagrams





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