Thermodynamic Limits and Search Strategies for Long-Lived Technospheres

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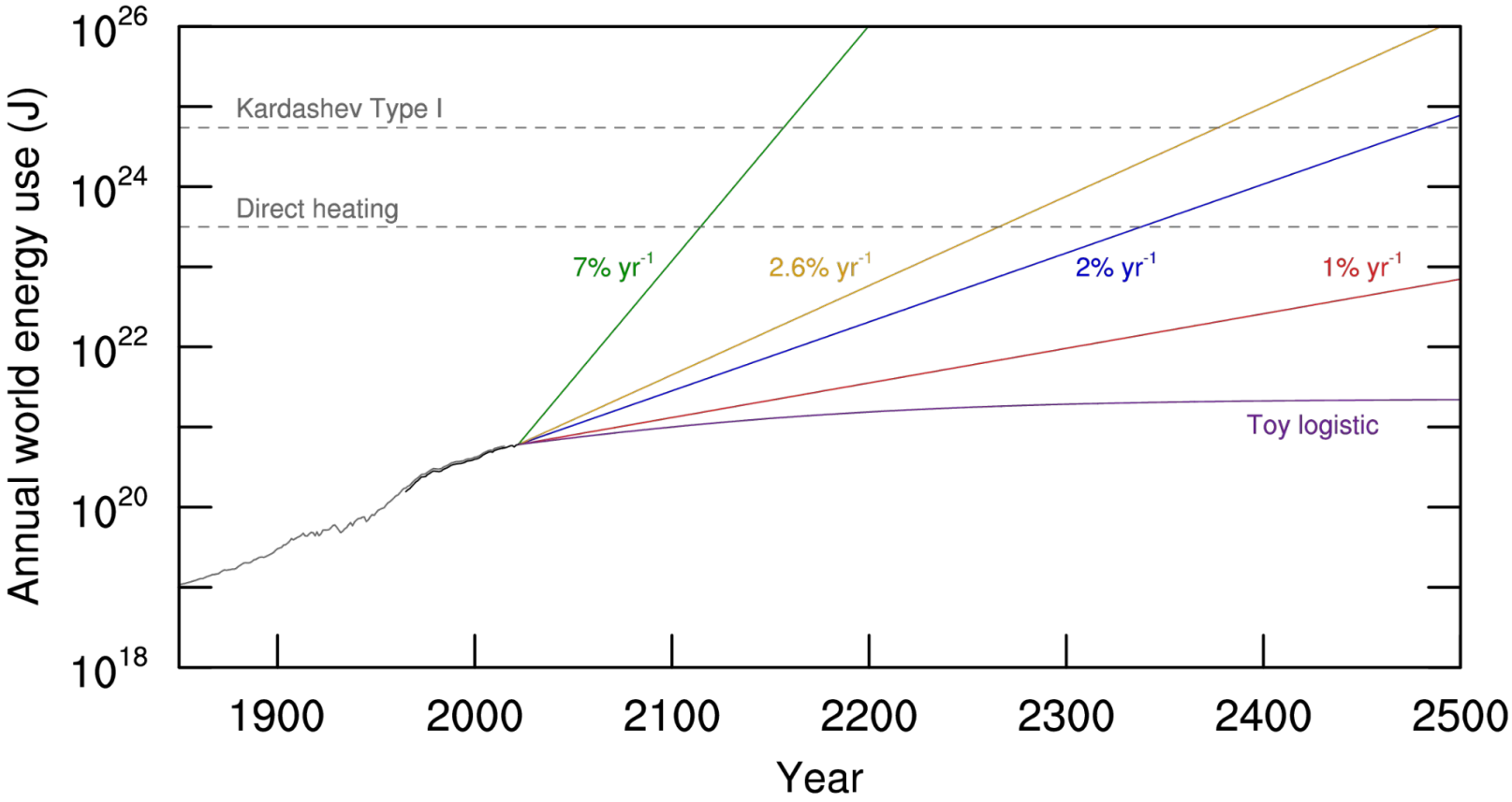
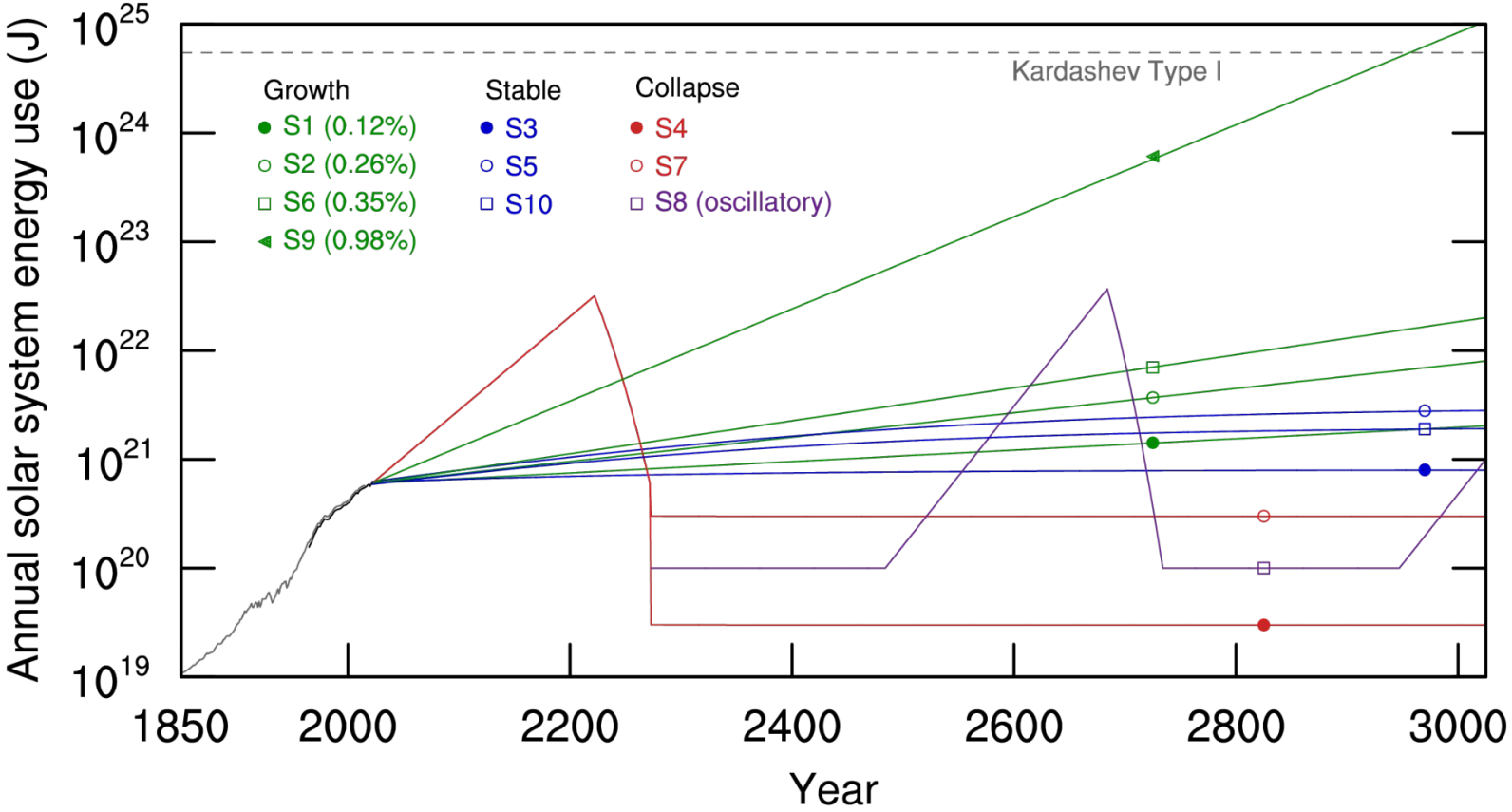
Projections of Earth’s technosphere can help to guide the search for technosignatures

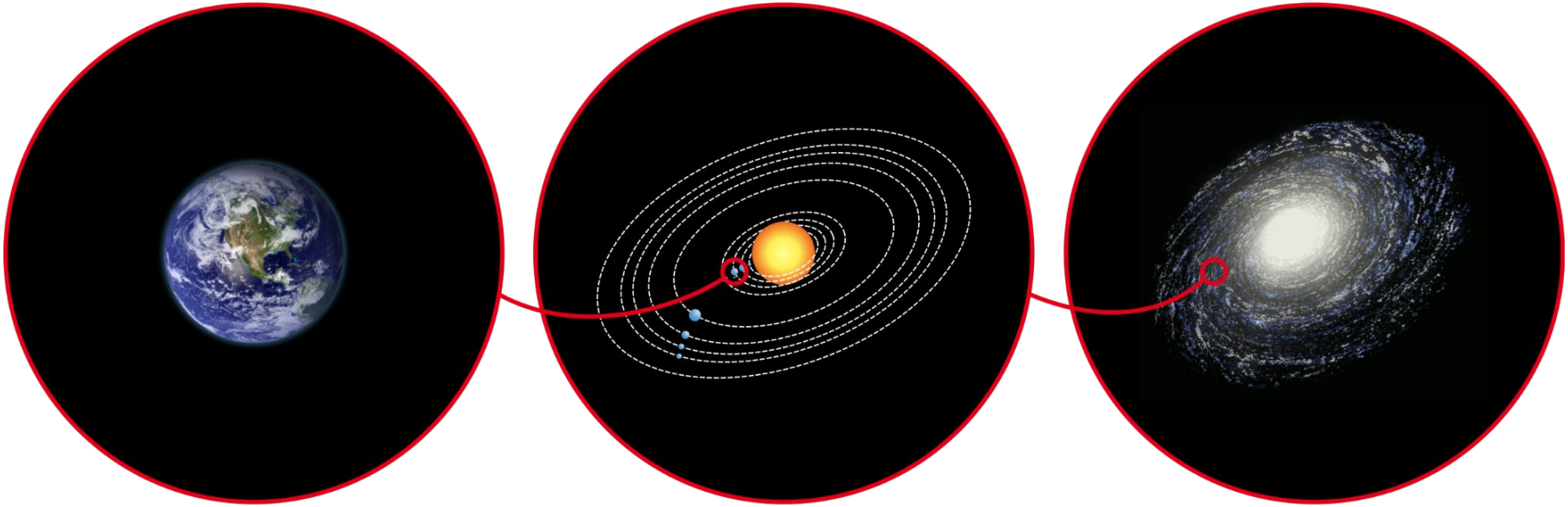


Haqq-Misra, J. (2025) Escaping the Great Filter: The future of civilization and the search for technosignatures. In *(Toward) Discovery of Life Beyond Earth & its Impact, Proceedings of IAU Symposium No. 387*, Cambridge University Press.



Haqq-Misra, J., Profitiliotis, G., & Kopparapu, R.K. (2025) Projections of Earth's technosphere: Scenario modeling, worldbuilding, and overview of remotely detectable technosignatures. *Technological Forecasting & Social Change* 218: 124194.

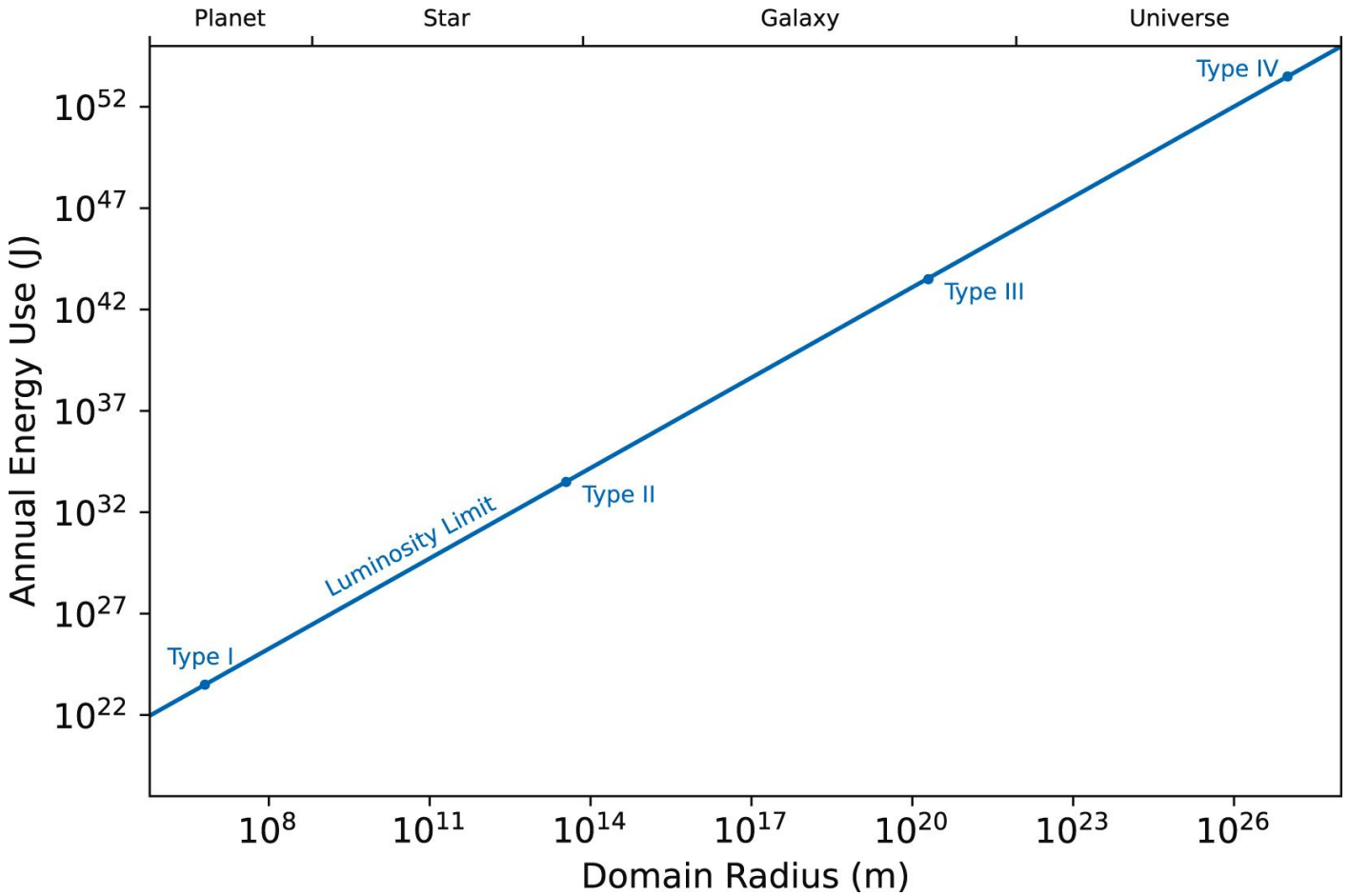
Kardashev Scale



Type I: 10^{16}W

Type II: 10^{26}W

Type III: 10^{36}W



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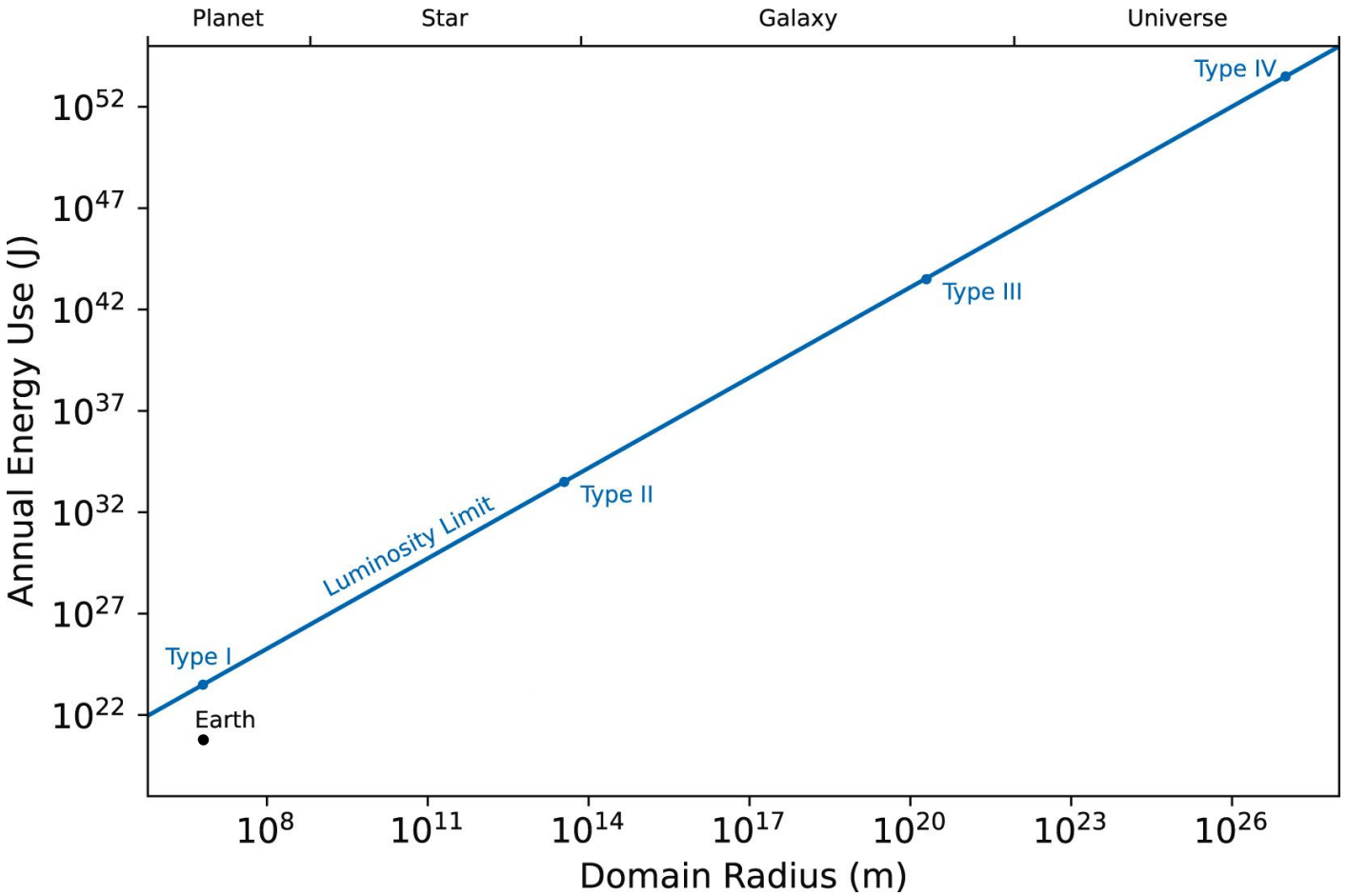

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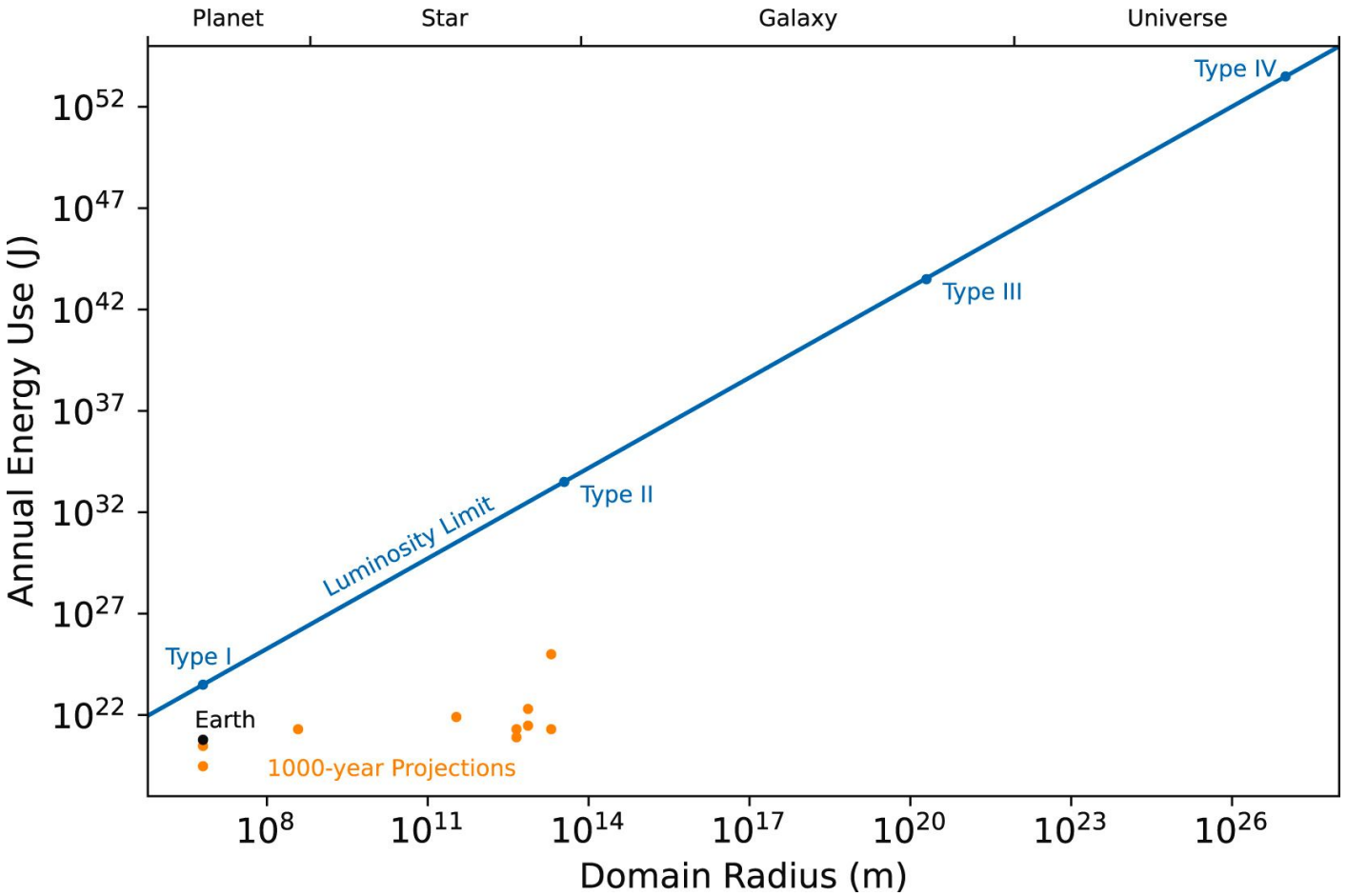

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For a *luminosity-limited* technosphere:

$$\textbf{Efficiency } \eta = \frac{\textbf{Exergy Output}}{\textbf{Stellar Luminosity}}$$

Second law of thermodynamics $\rightarrow \eta < 1$

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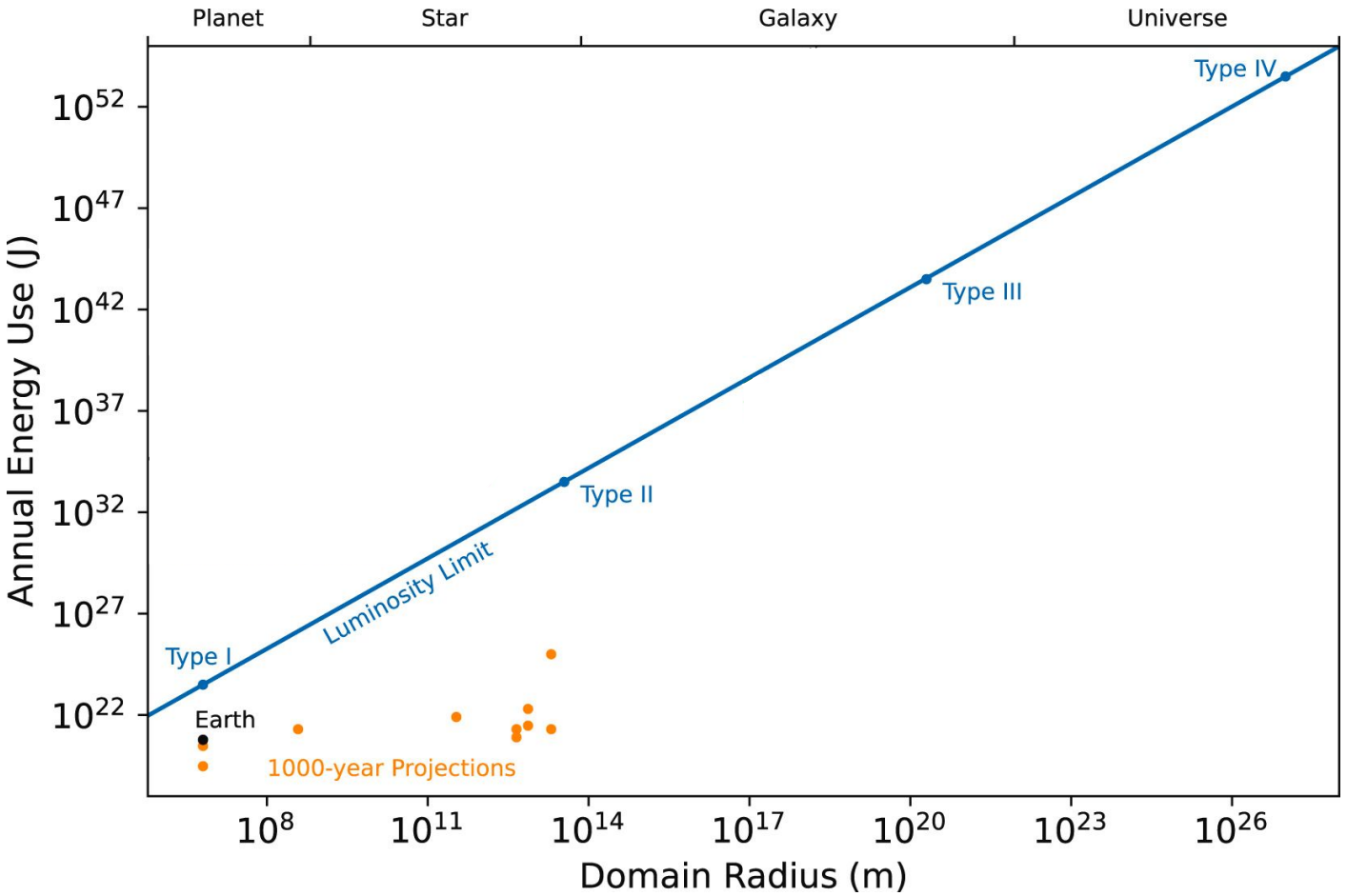

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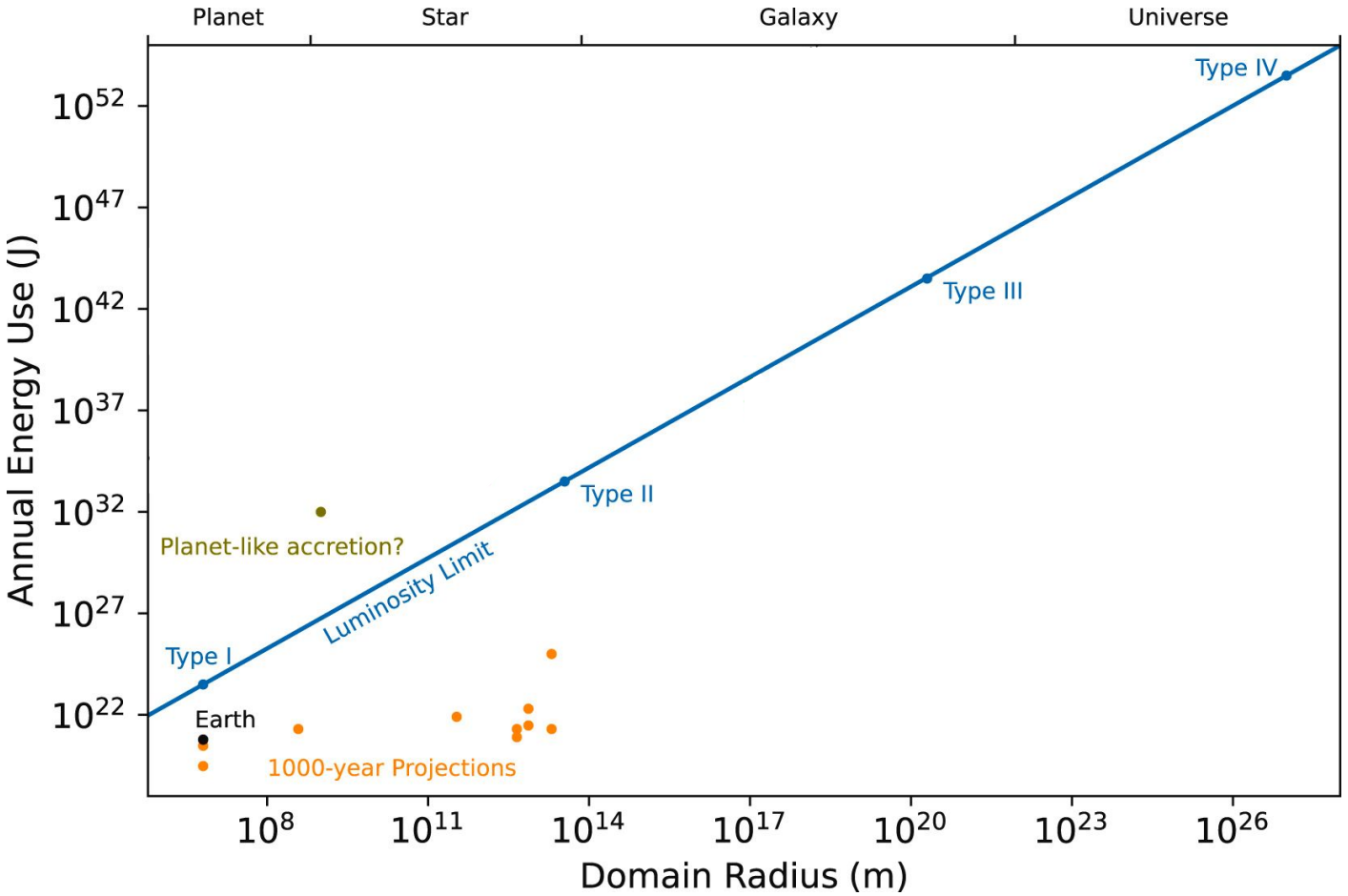

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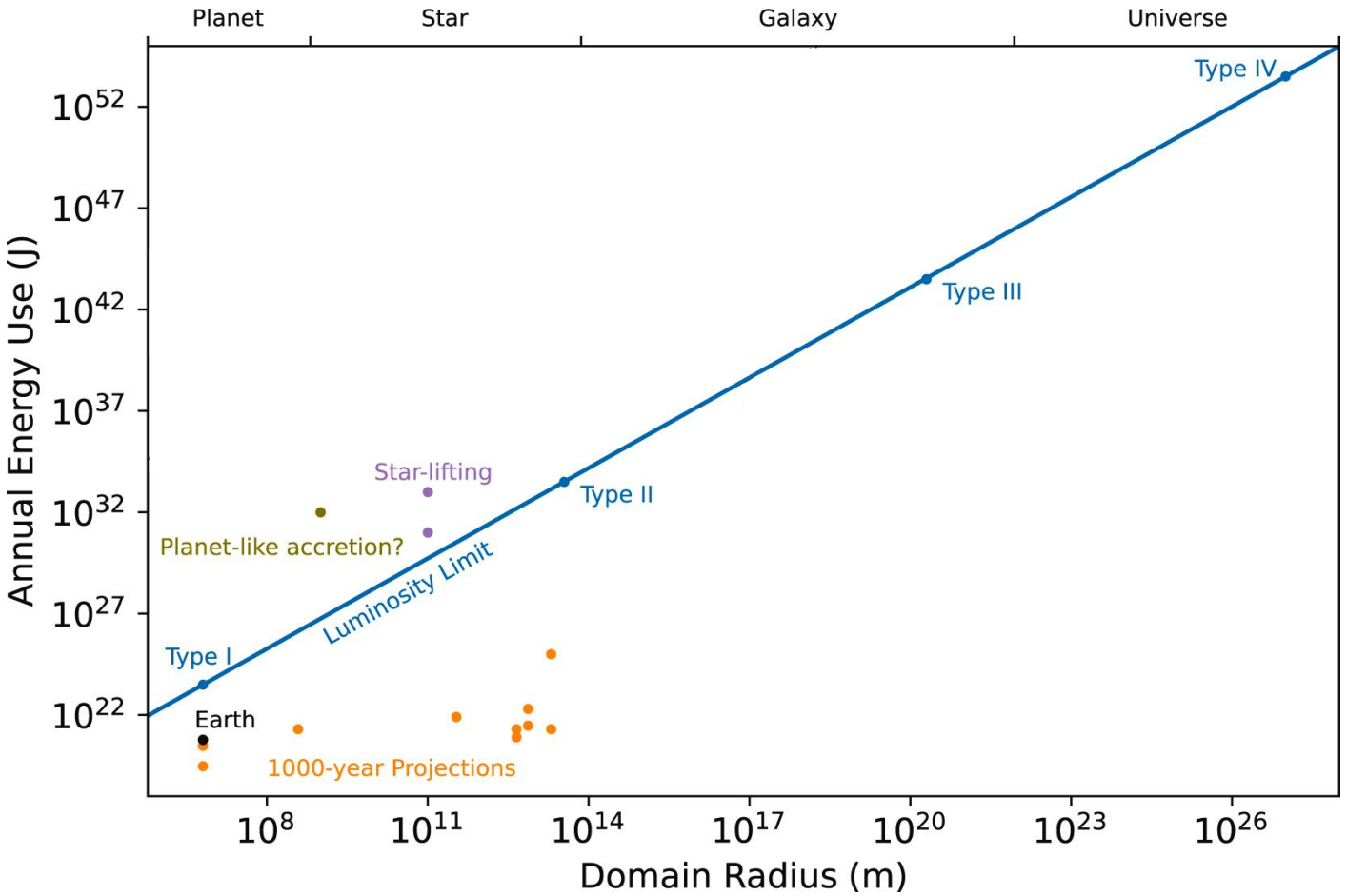

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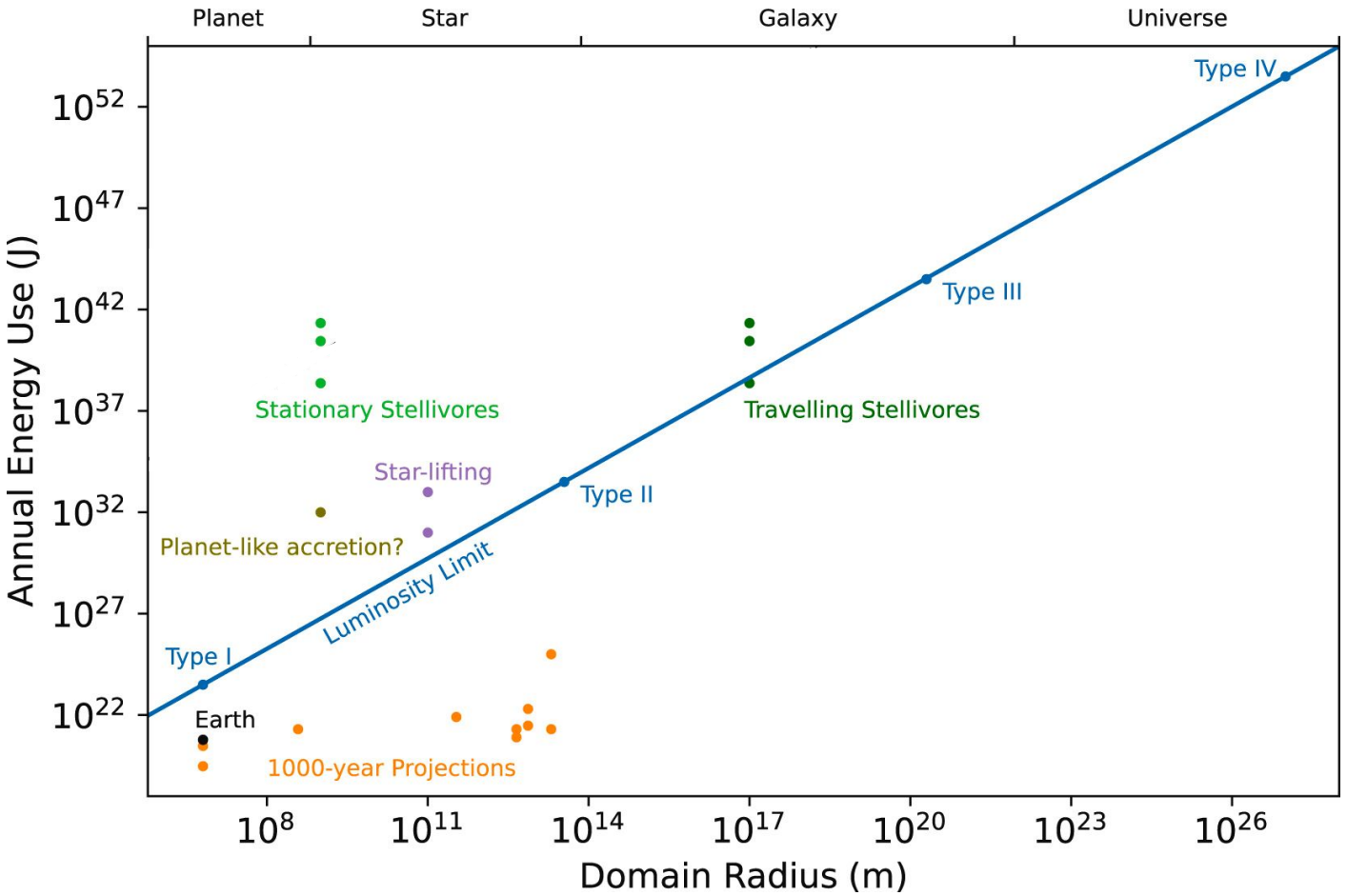

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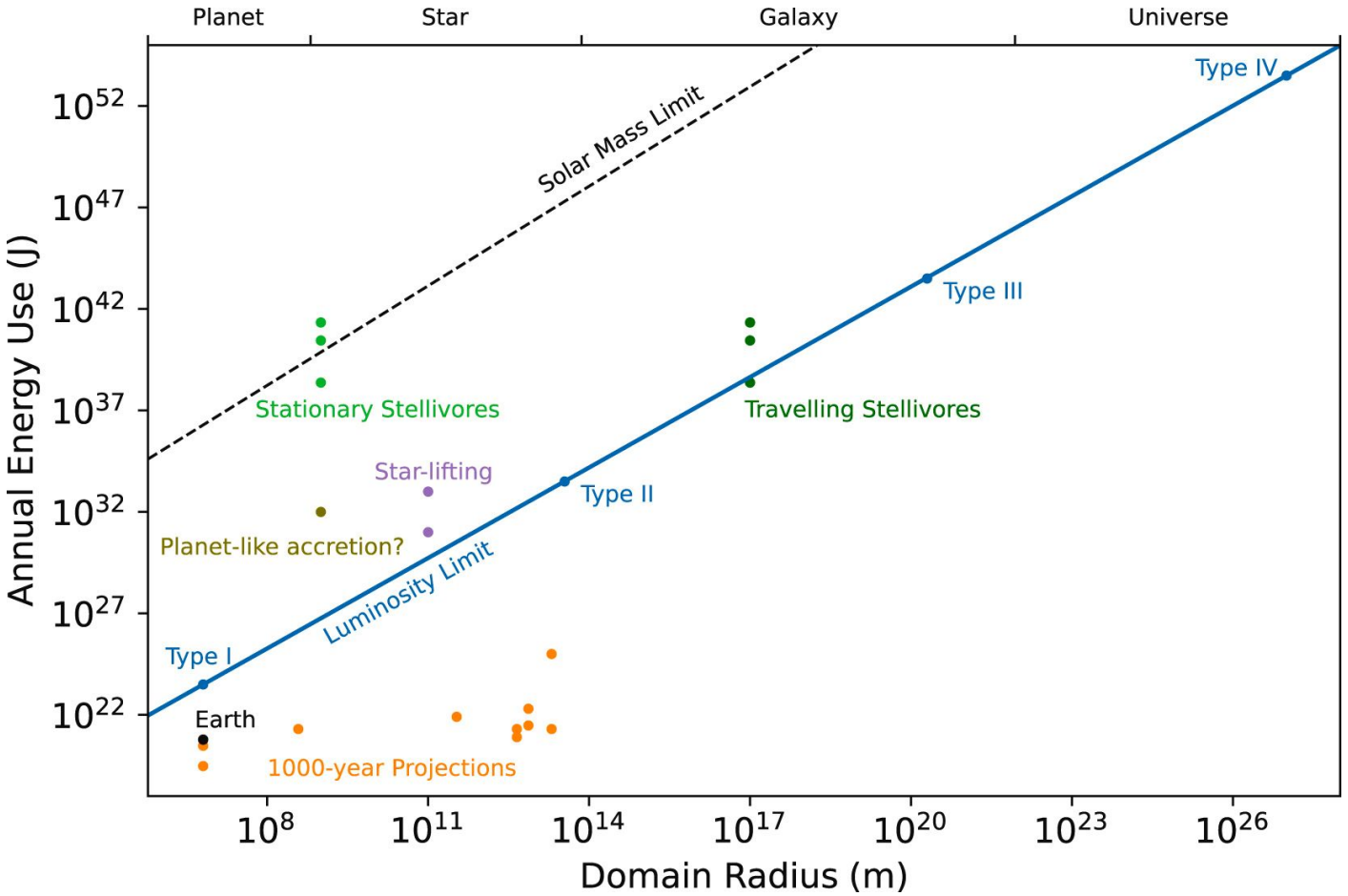

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For a *luminosity-limited* technosphere:

$$\text{Efficiency } \eta = \frac{\text{Exergy Output}}{\text{Stellar Luminosity}}$$

For a *mass-limited* technosphere:

$$\textbf{Efficiency } \epsilon = \frac{\textbf{Exergy Output} \times \textbf{Time}}{\textbf{Stellar Mass} \times c^2} < 1$$

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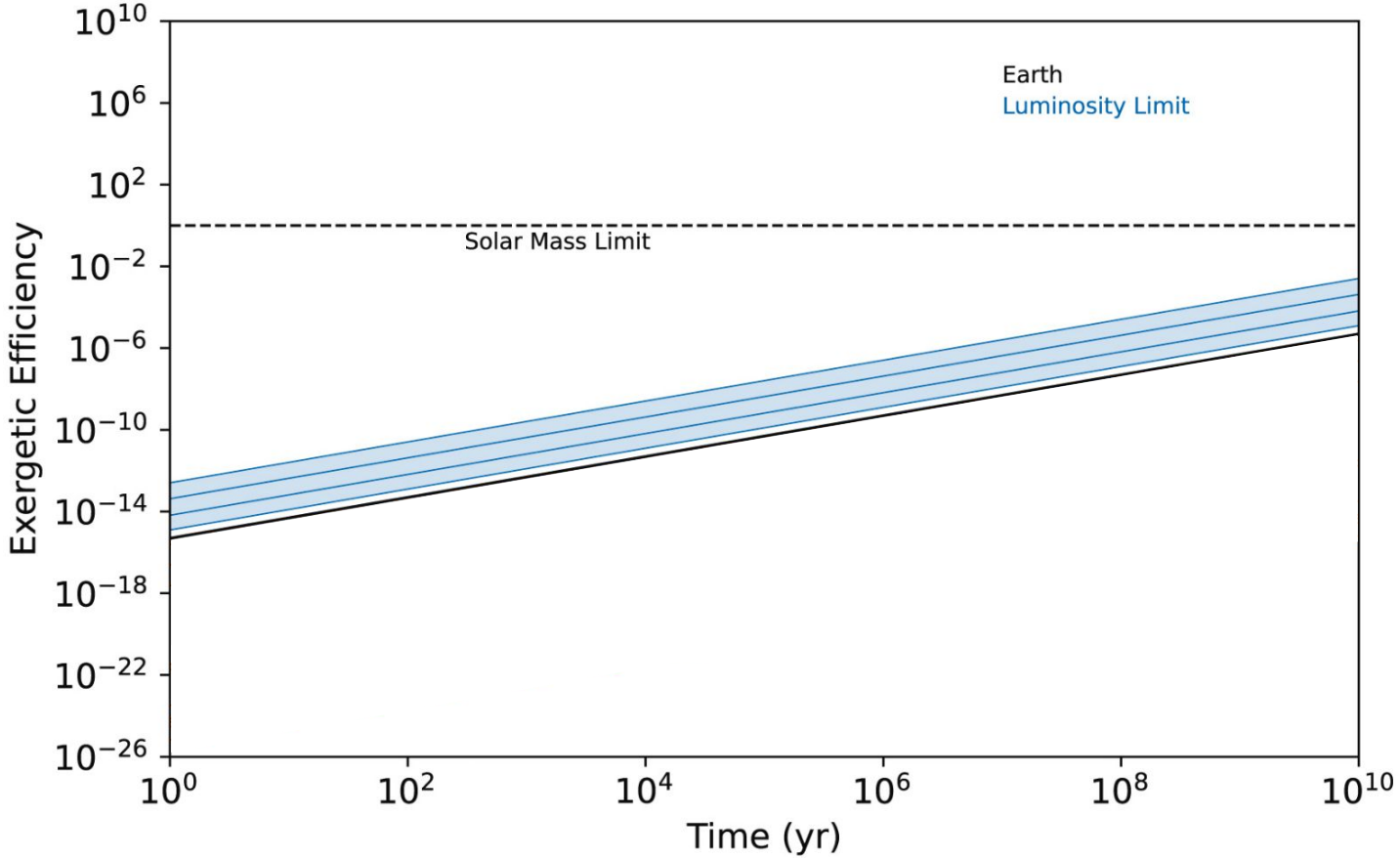

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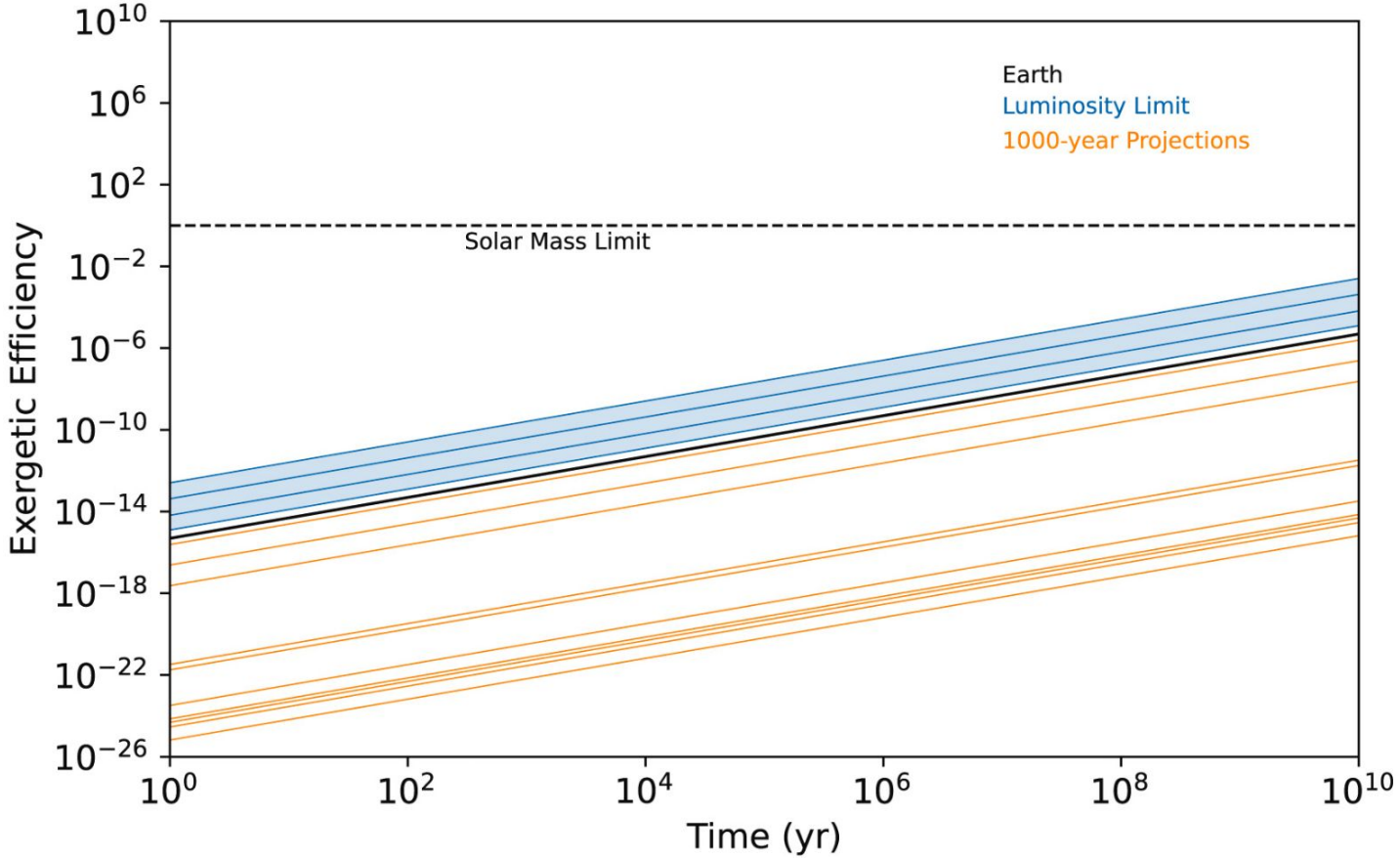

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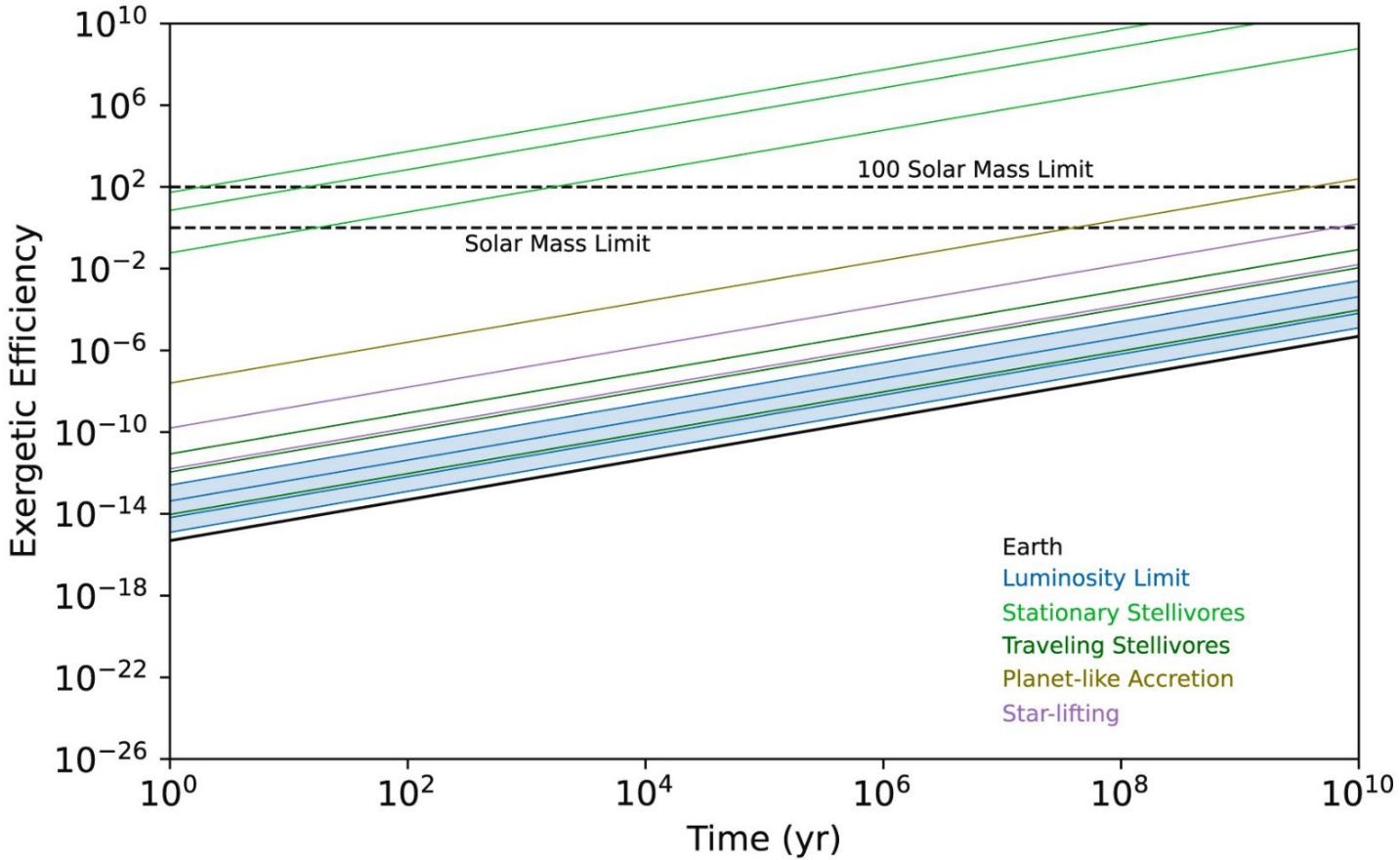

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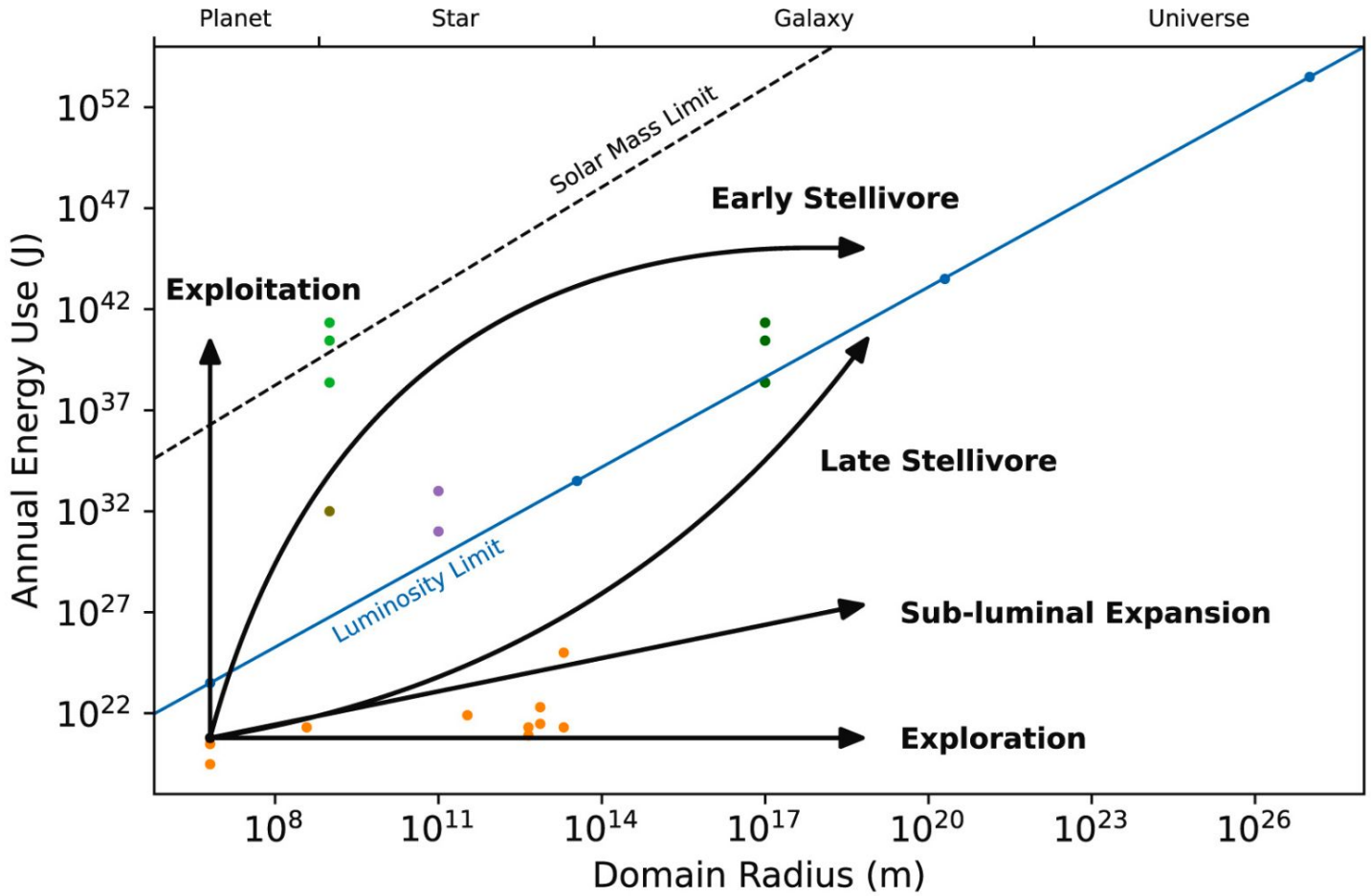
Long-lived technospheres may optimize between exploration and exploitation



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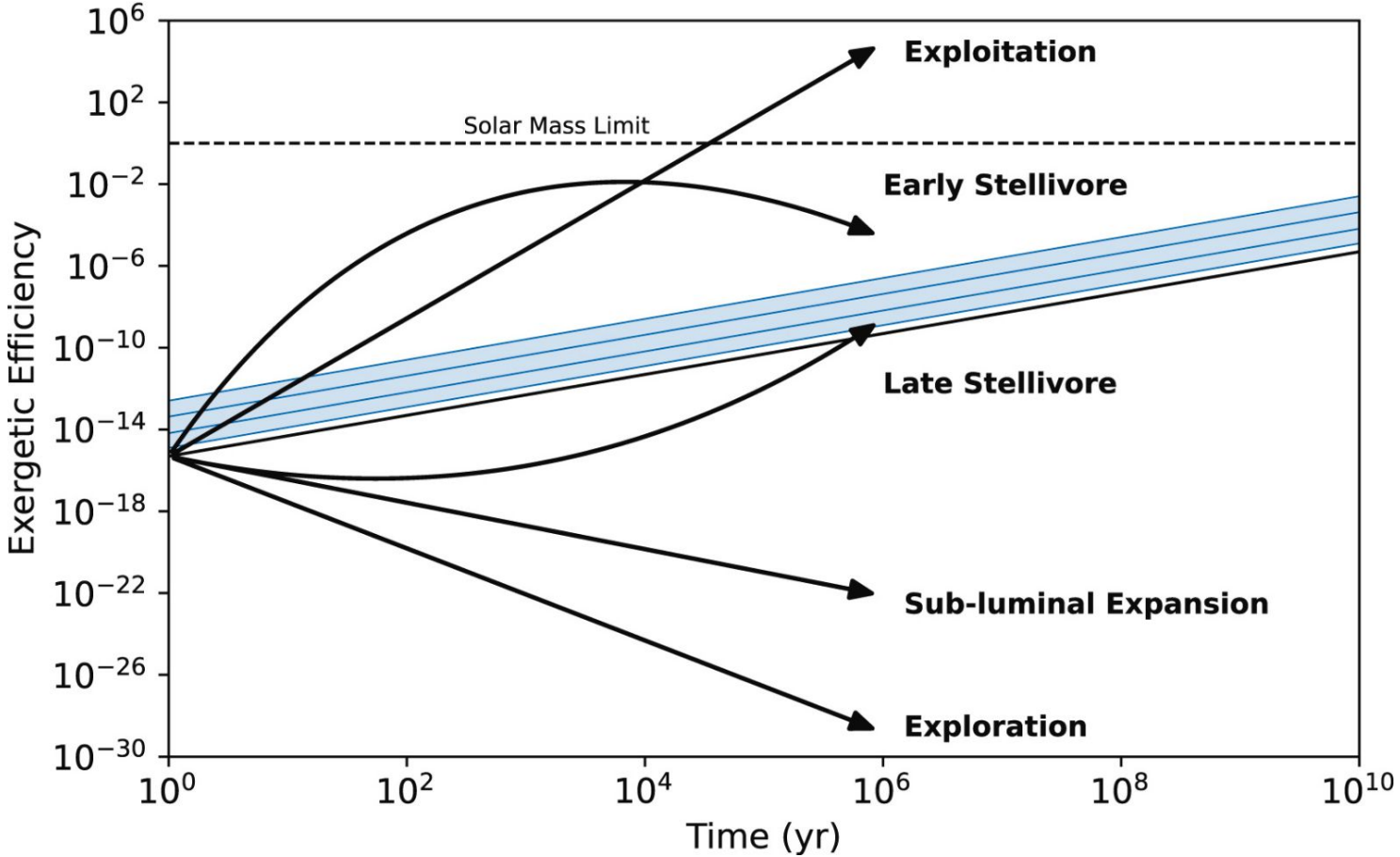

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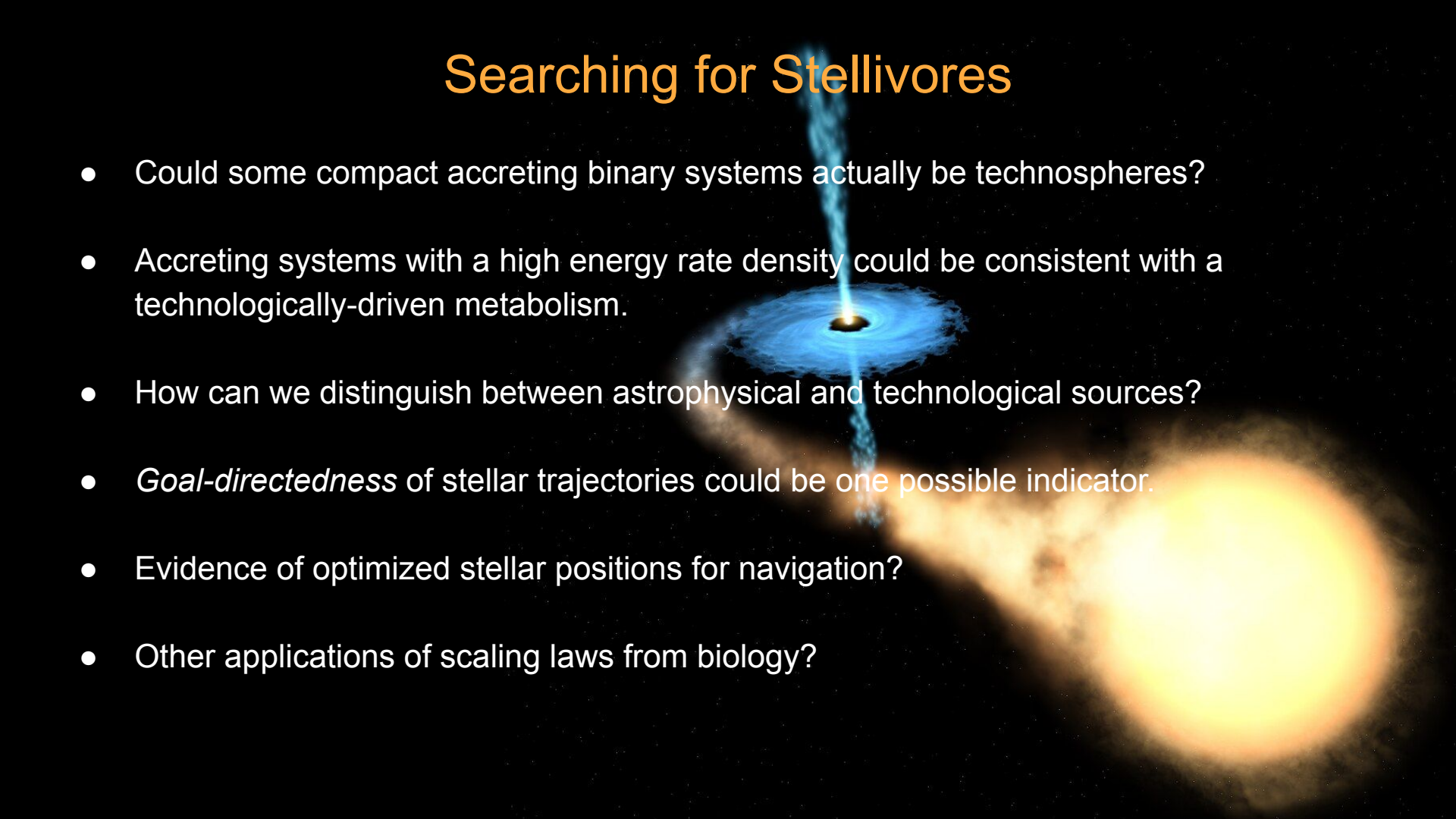
Searching for Stellivores

- Could some compact accreting binary systems actually be technospheres?
- Accreting systems with a high energy rate density could be consistent with a technologically-driven metabolism.
- How can we distinguish between astrophysical and technological sources?
- *Goal-directedness* of stellar trajectories could be one possible indicator.
- Evidence of optimized stellar positions for navigation?
- Other applications of scaling laws from biology?



Conclusions

- Earth today and Earth's future provide a basis for searching for technosignatures.
- The Kardashev scale is better understood as a "luminosity limit" to growth.
- Thermodynamic efficiency will limit the growth of luminosity-based technospheres.
- Technospheres may evolve to harvest stellar mass instead of luminous energy.
- Long-lived technospheres may optimize between exploration and exploitation.
- Could some compact accreting binary systems actually be technospheres?

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