Long-Term Exoplanet Habitability: How Chance Favors Prokaryotes

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Abstract

We utilize the Planet Model Code [1] to model the probability of survival of Earth-like life on habitable worlds (to 3 billion years post-abiogenesis). The Planet Model Code [1] was originally created by Tyrrell [2] to investigate the chances of intelligent life. This necessitates stability in a rather narrow temperature range. Here we expand the focus to the survival of any life, including extremophiles, with greater tolerance for variations in temperature. Specifically, we investigate the relationship between the long-term survival probability of life and larger temperature variations. Keywords: Exoplanet; Habitable; Prokaryote; Matlab; Planet Model Code References: 1. T. Tyrrell, Planets model code, (Oct. 2020) https://doi.org/10.5281/zenodo.4081451. 2. T. Tyrrell, "Chance played a role in determining whether earth stayed habitable", Commu- nications Earth & Environment 1, 1–10 (2020).

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Overview & Definitions

- Definitions
- Motivation
- Hypotheses
- Methods
- Results
- Conclusion

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Motivation

Planets Model Code [Tyrrell 2020b]

$$\frac{dT}{dt} = f(T) + \phi$$

- Eukaryotic viable temperature: **-10°C to 50°C** [Tyrrell 2020a]
- Prokaryotic viable temperature: **-22°C to 122°C** [Lingam & Loeb 2021]

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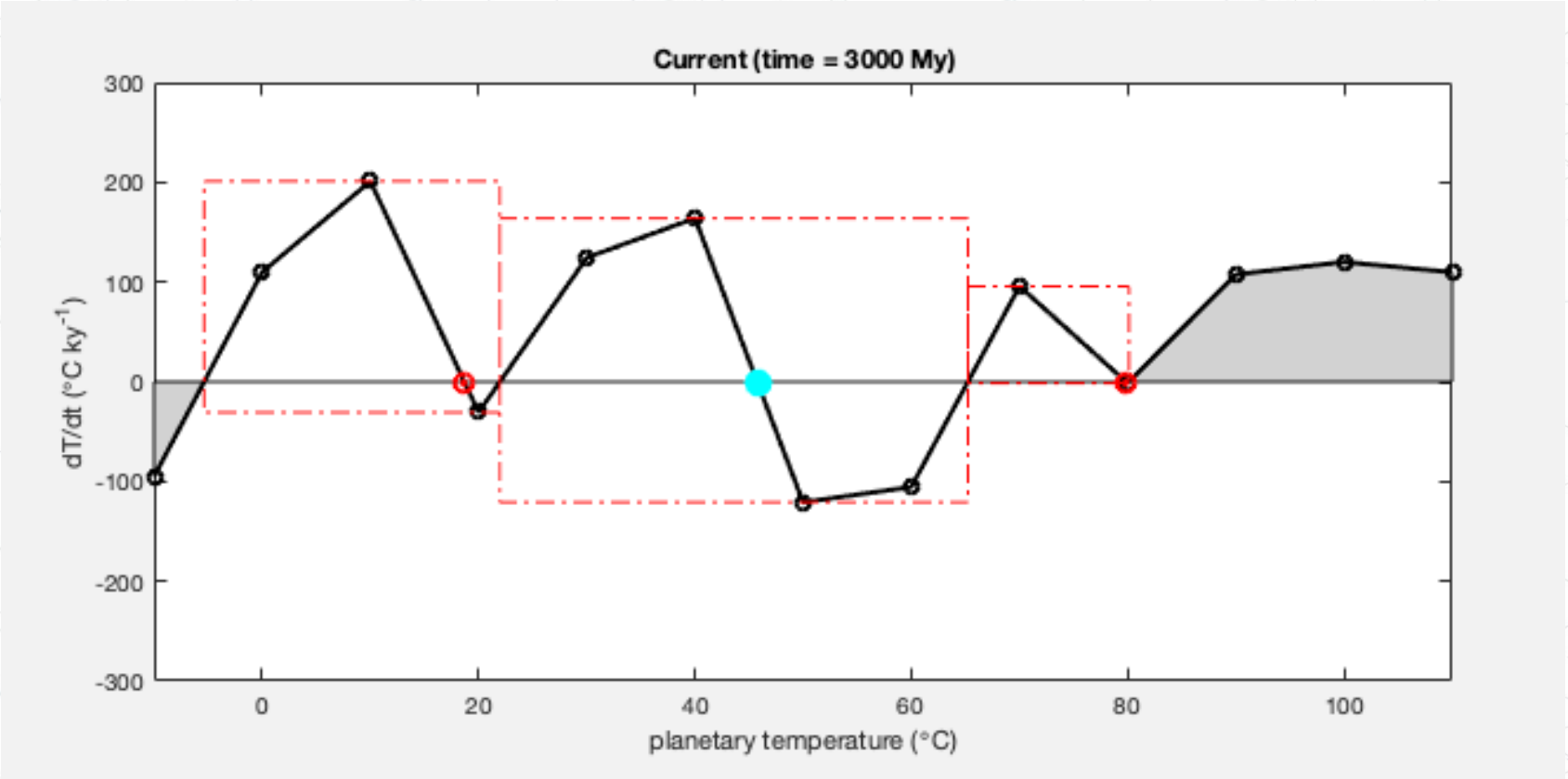

[Tyrrell 2020b]

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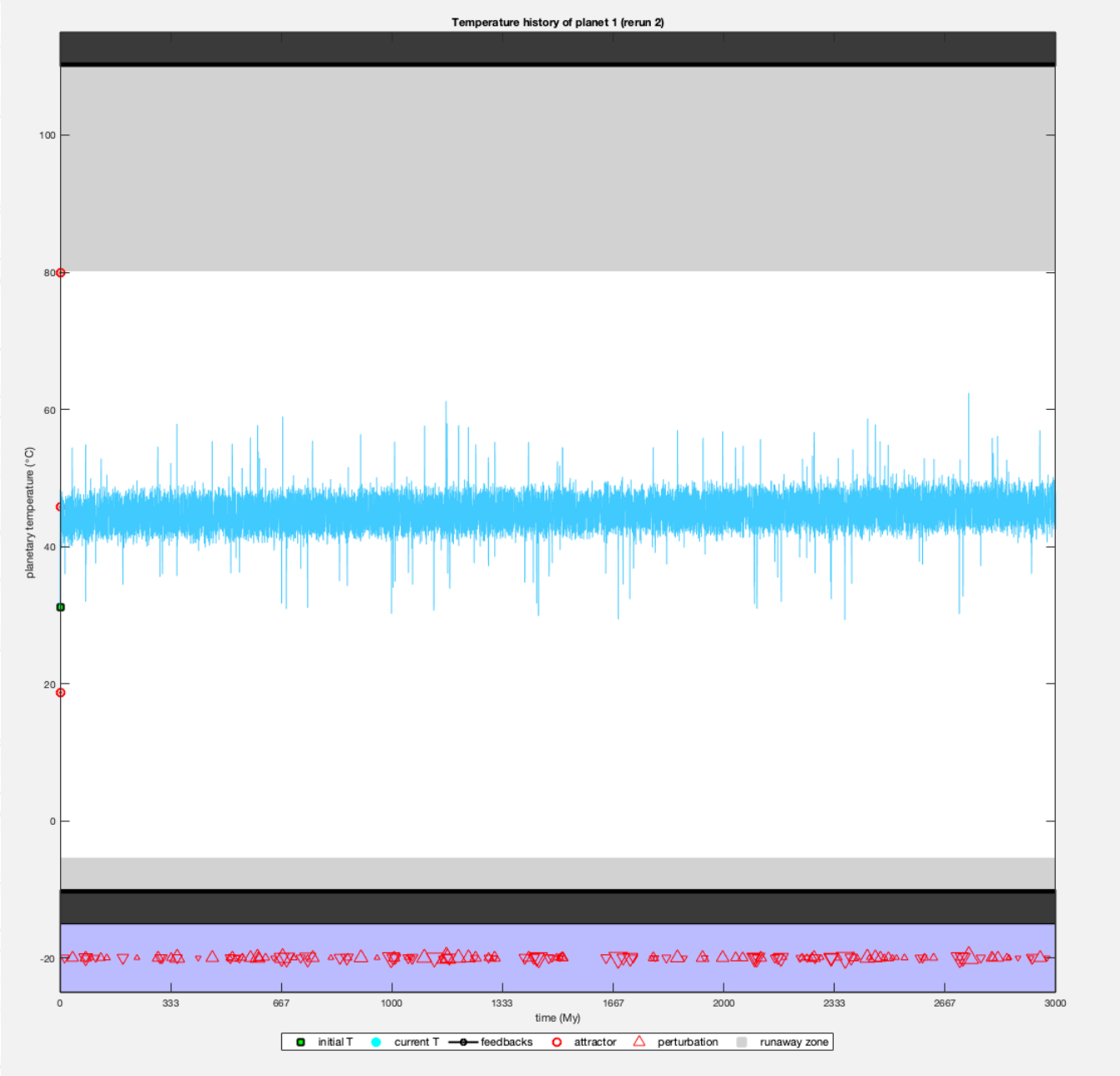

[Tyrrell 2020b]

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Hypothesis 1

Temperature Range (ΔT) Test

The chances of long-term survival of prokaryote-like life will increase in a non-linear fashion with an increase in viable temperature range.

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Hypothesis 2

Time Interval (Δt) Test

The chance of complex multicellularity will increase in a non-linear fashion as the time interval requirement for the duration of eukaryote-like conditions is decreased.

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Temp Interval (ΔT) Test Inputs:

Initial Experiment

Run #	Range °C	ΔT
1	-10 to 5	15
2	-10 to 20	30
3	-10 to 35	45
4	-10 to 50	60
5	-10 to 65	75
6	-10 to 80	90
7	-10 to 95	105
8	-10 to 110	120

- Each run consisted of 1,000 planets, each iterated twice.

Assumption Testing

Run #	Range °C	ΔT
1a	5 to 20	15
1b	50 to 65	15
1c	95 to 110	15
2a	35 to 65	30
2b	80 to 110	30
3	65 to 110	45
4	50 to 110	60
5	35 to 110	75
6	20 to 110	90
7	5 to 110	105
8	-10 to 110	120

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Time Interval (Δt) Test Inputs

Run #	ΔT_i °C	Δt (Ga)	ΔT_f °C
1	120	0.00	70
2		0.25	
3		0.50	
4		0.75	
5		1.00	
6		1.25	
7		1.50	
8		1.75	
9		2.00	
10		2.25	
11		2.50	
12		2.75	
13		3.00	

- Each run consisted of 1,000 planets, each iterated twice.

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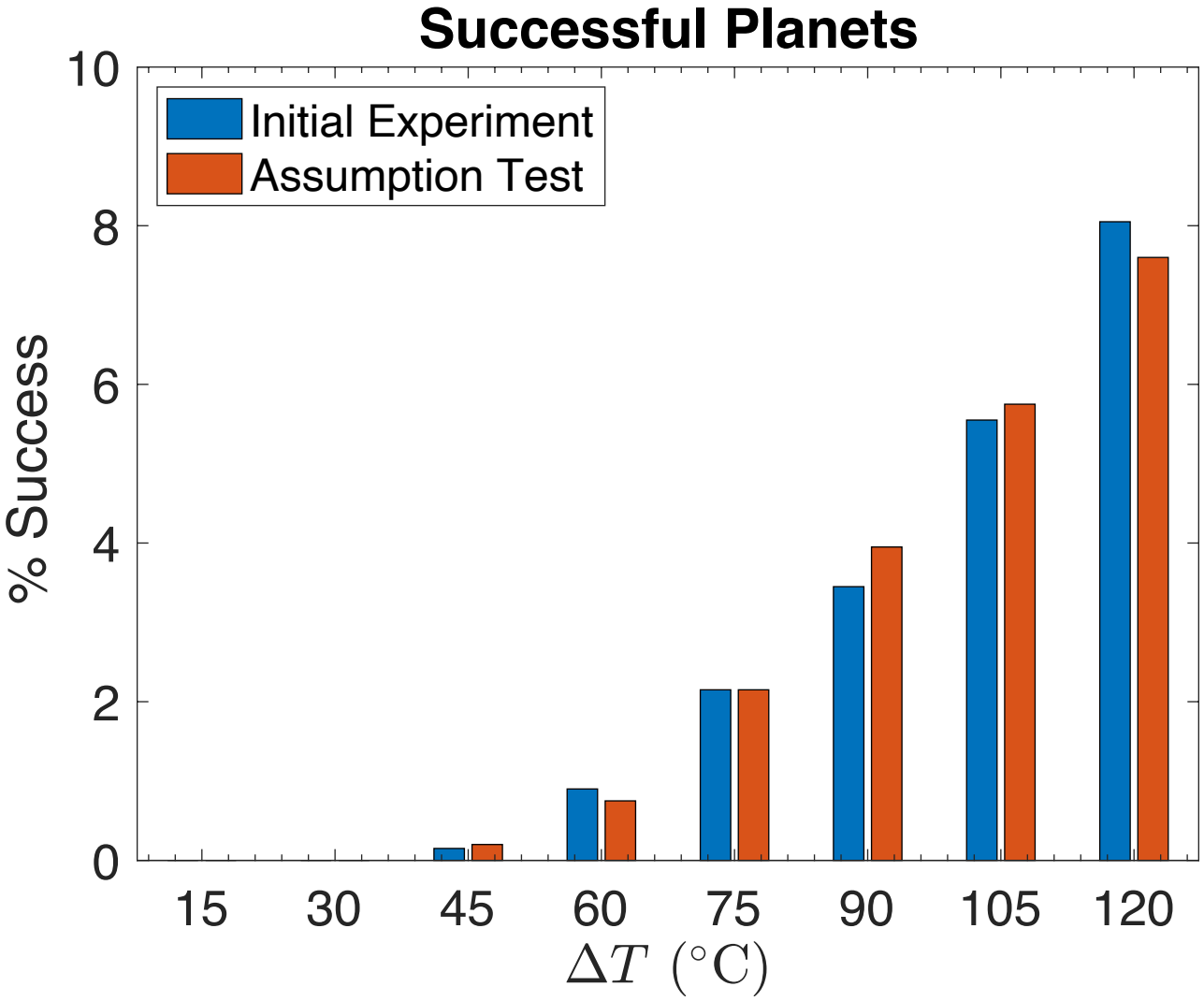
ΔT Results:



- Strong increase in long-term survival

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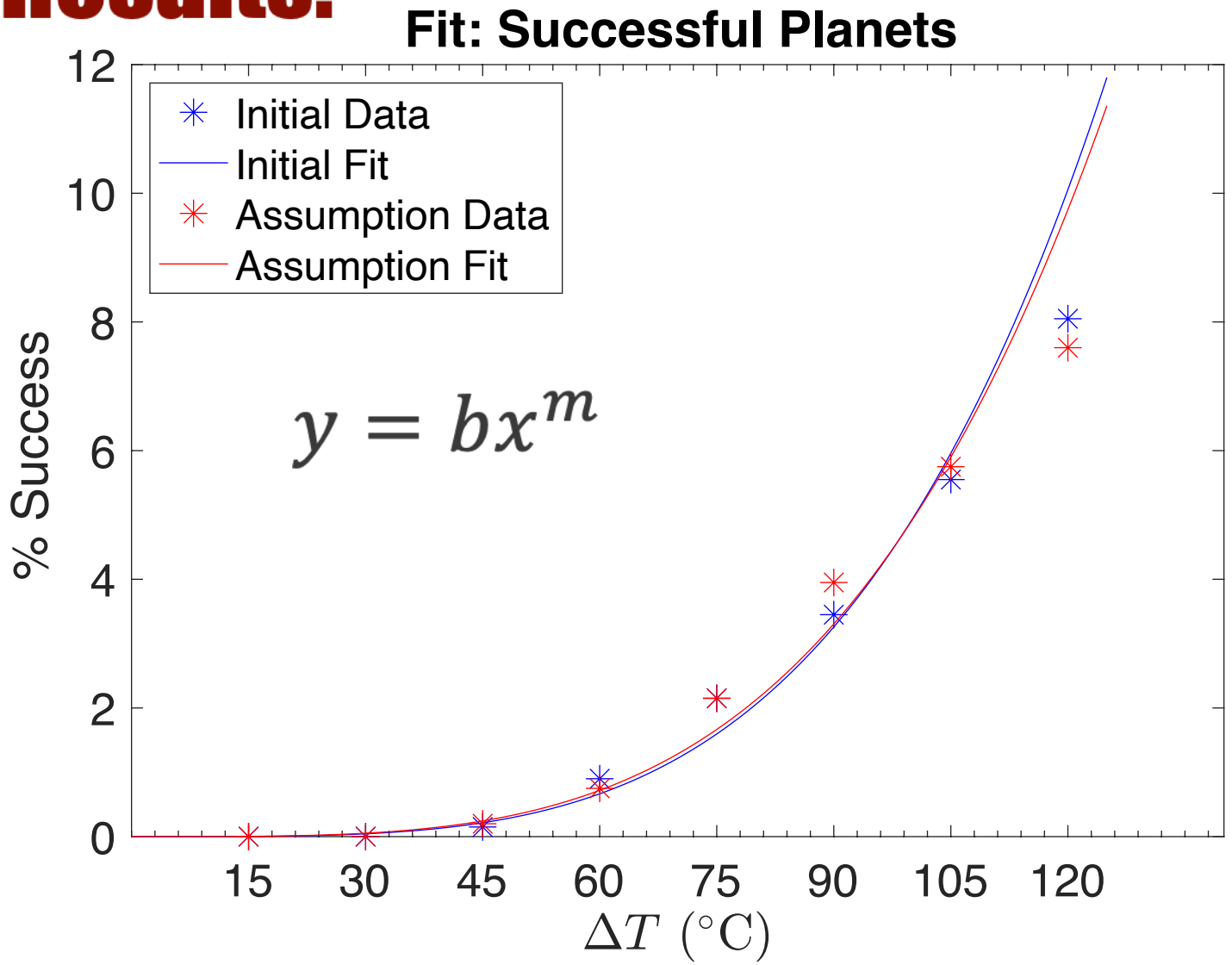
ΔT Results:



ID: m = 3.9 **AD: m = 3.8**

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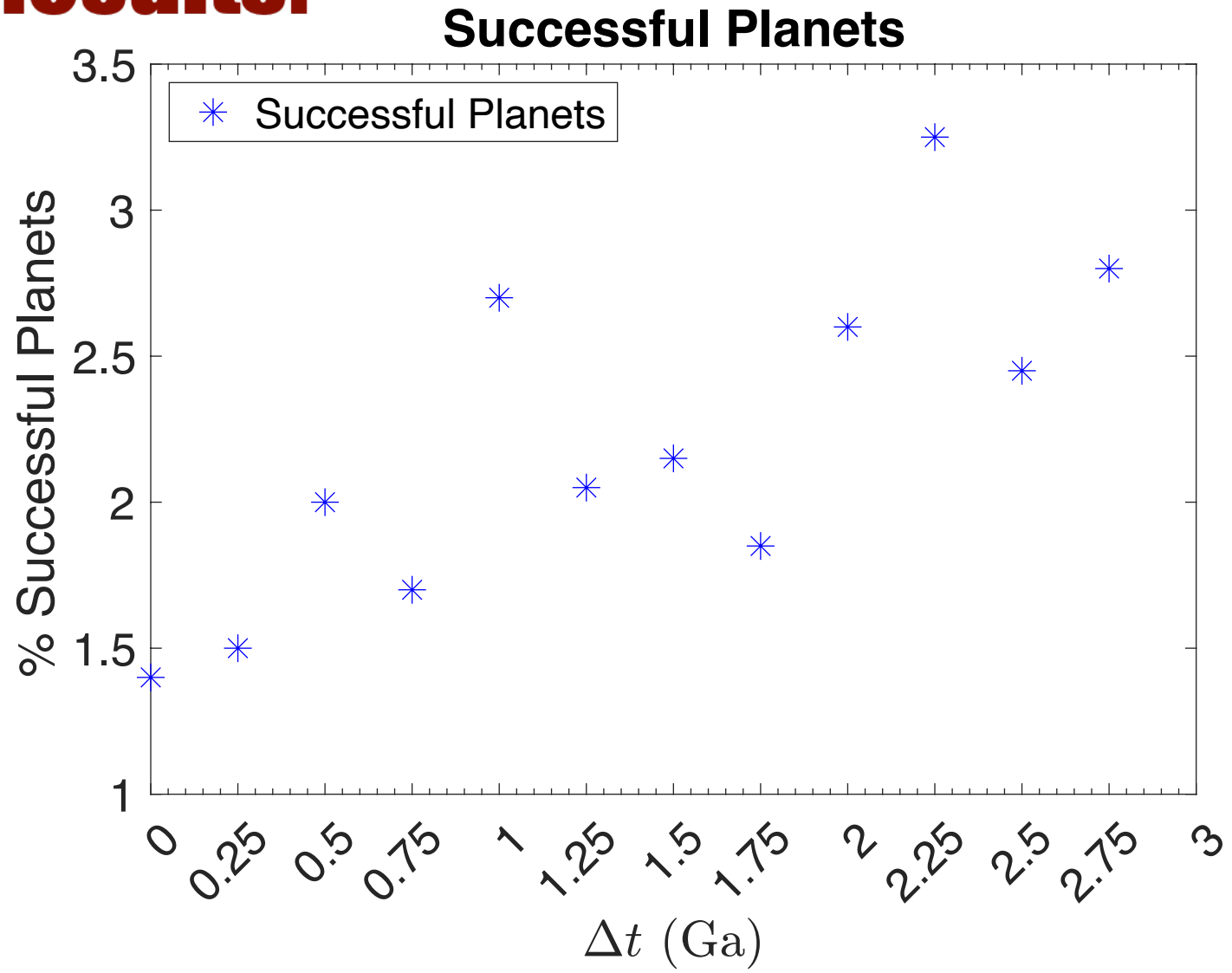
Δt Results:



- No significant increase in long-term survival

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Conclusion

$$\% \text{ Survival} \propto \Delta T^{3.9}$$

- Long-term survival increases strongly as a power-law function of increased viable temperature range.
- The chance of complex multicellularity does not increase significantly with a reduced duration requirement for eukaryotic-like temperature limits.

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Acknowledgements

- Dr. Tyrrell → Planets Model Code [2020]
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    - https://creativecommons.org/licenses/by/4.0/legalcode
  - Adaptations:
    - Modified temperature ranges
    - Added ability to modify temperature ranges mid-simulation

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References

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