No Snowball Bifurcation on Tidally Locked Planets

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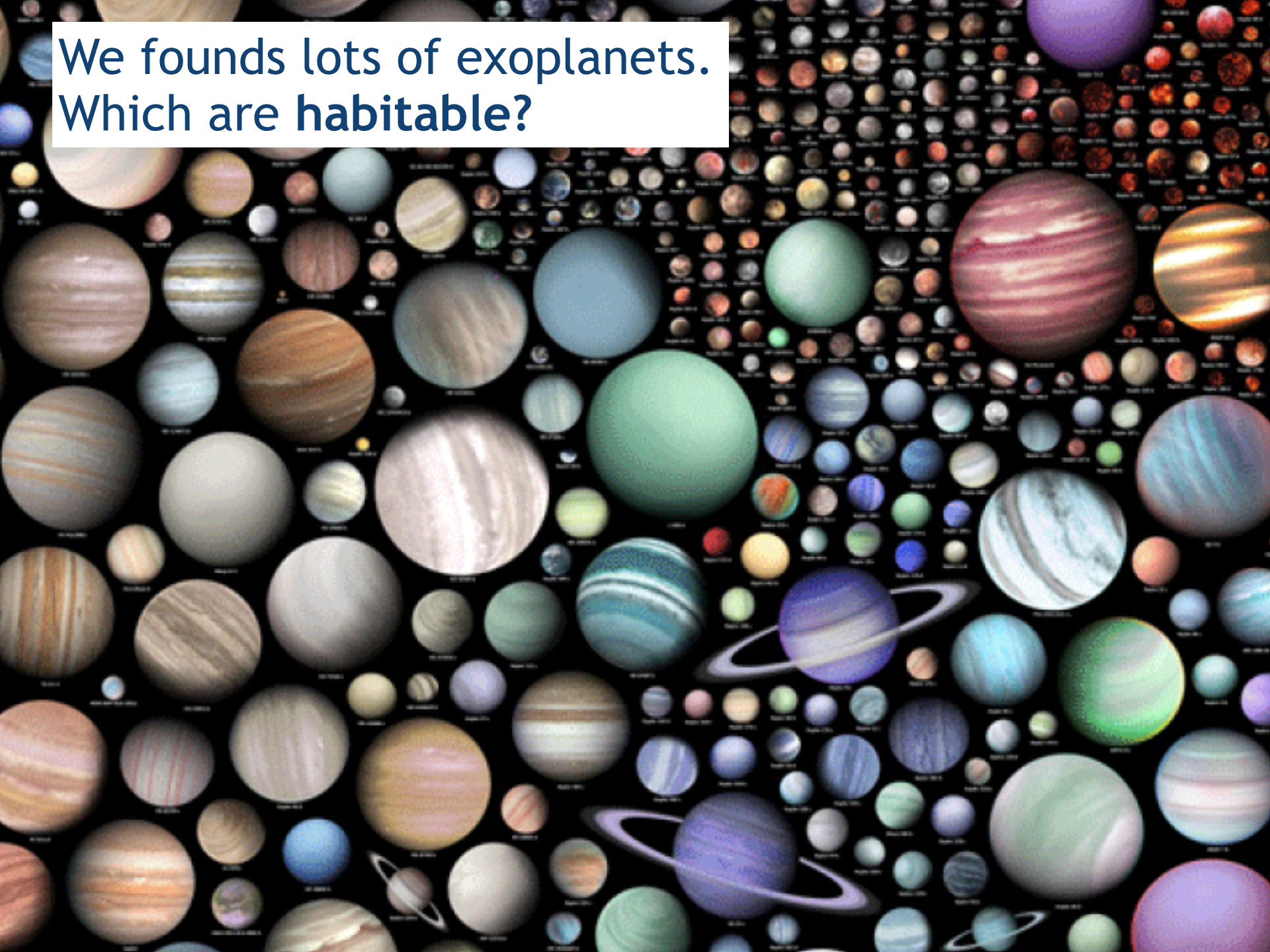
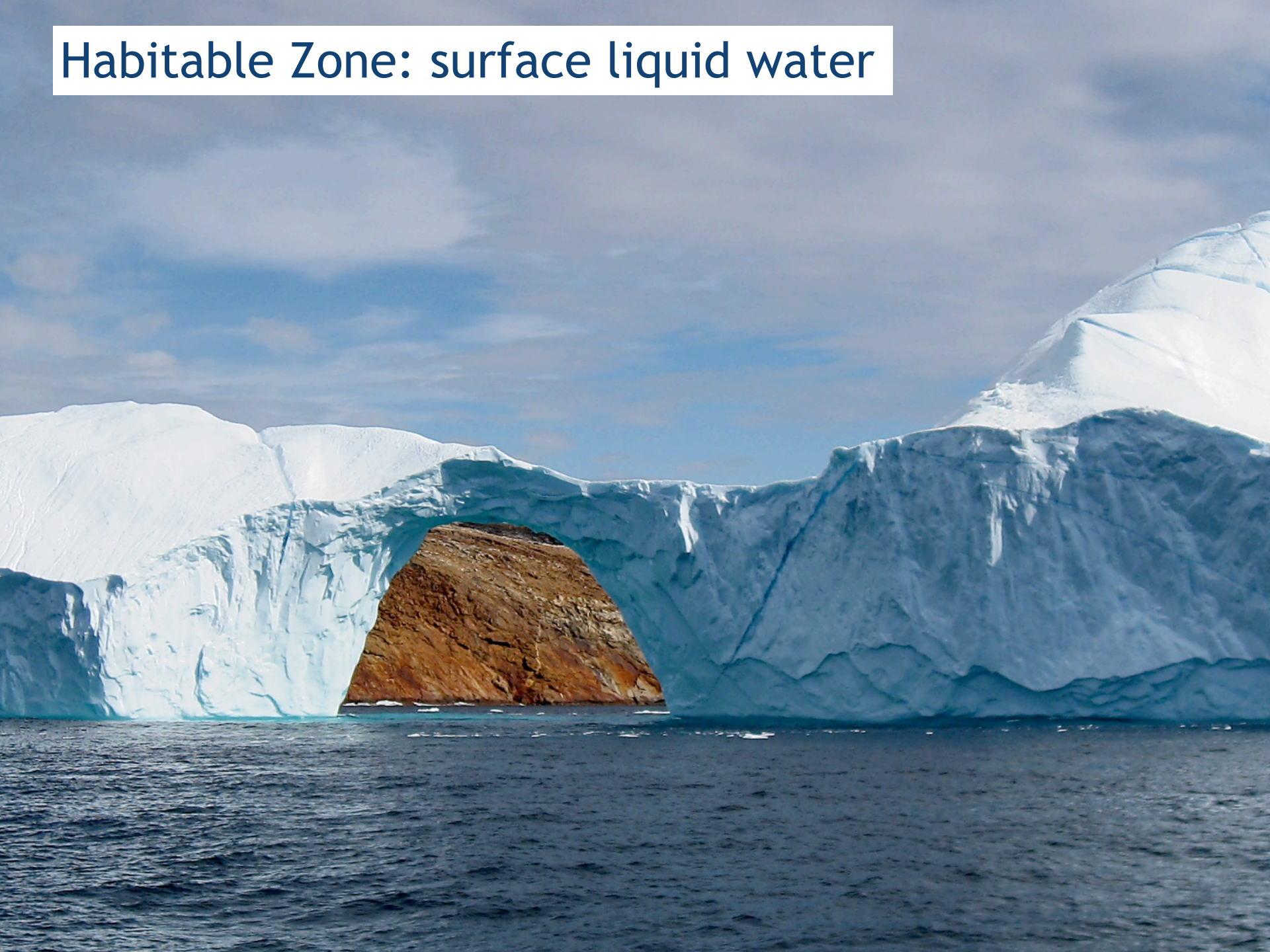
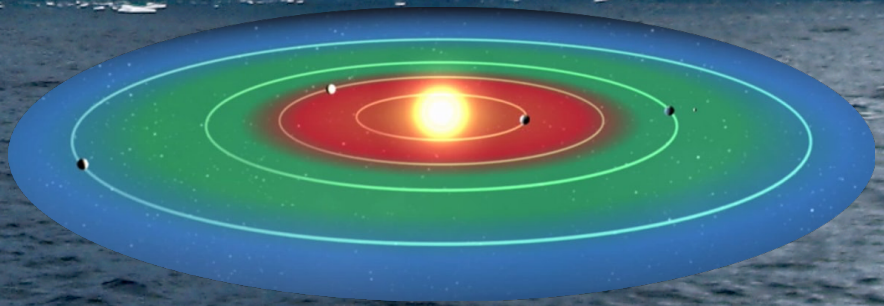

We founds lots of exoplanets.
Which are **habitable?**

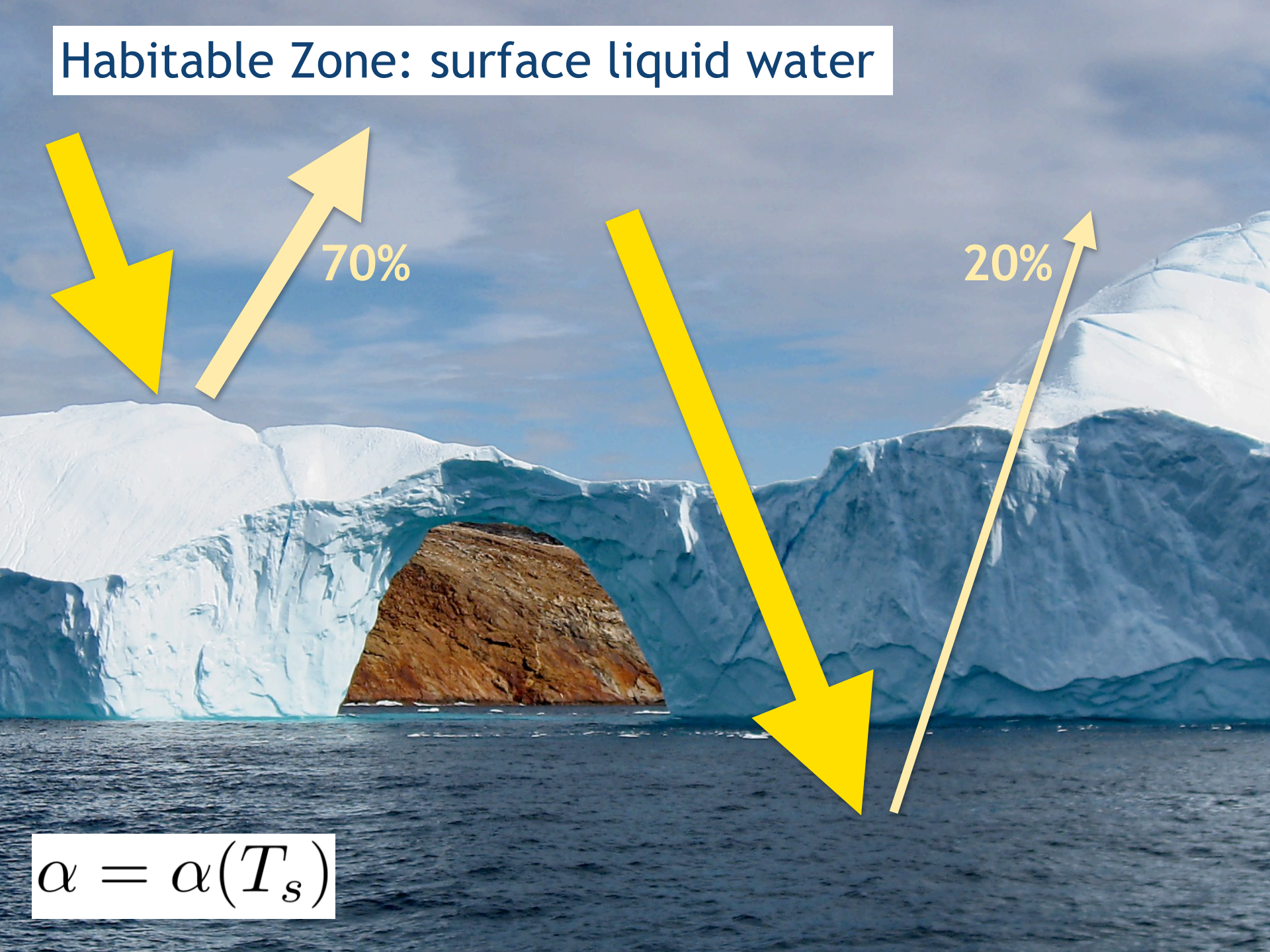
Habitable Zone: surface liquid water



Habitable Zone: surface liquid water

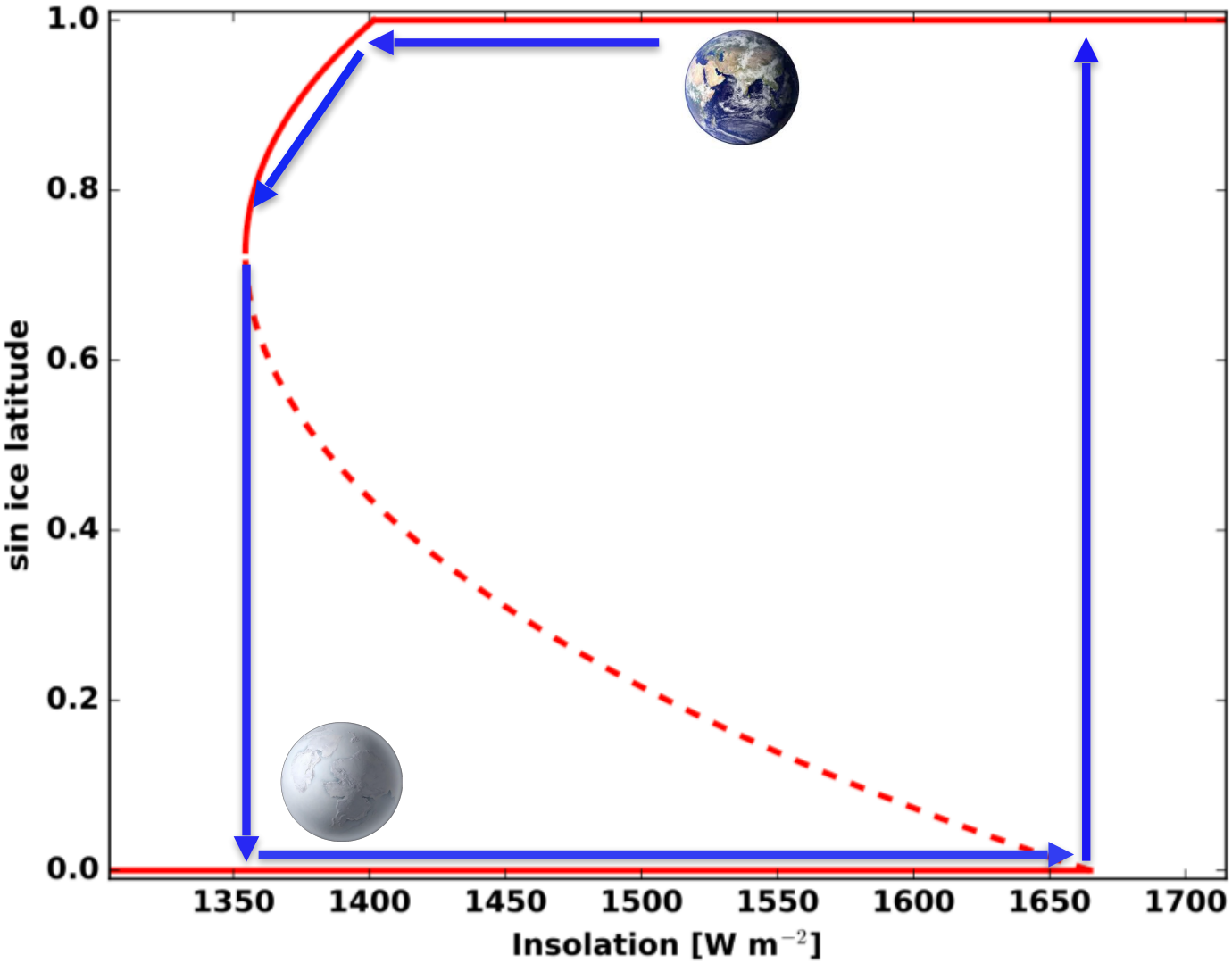


Habitable Zone: surface liquid water



$$\alpha = \alpha(T_s)$$

Snowball bifurcation



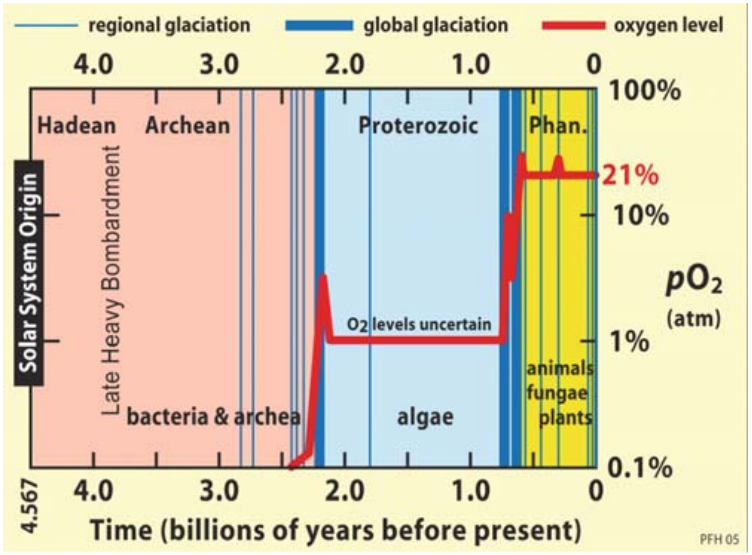
[Budyko, 69; Sellers, 69; Walker+, 81; Kirschvink, 92; Hoffman+, 98]

Snowball Events: O_2 and complexity of life

?

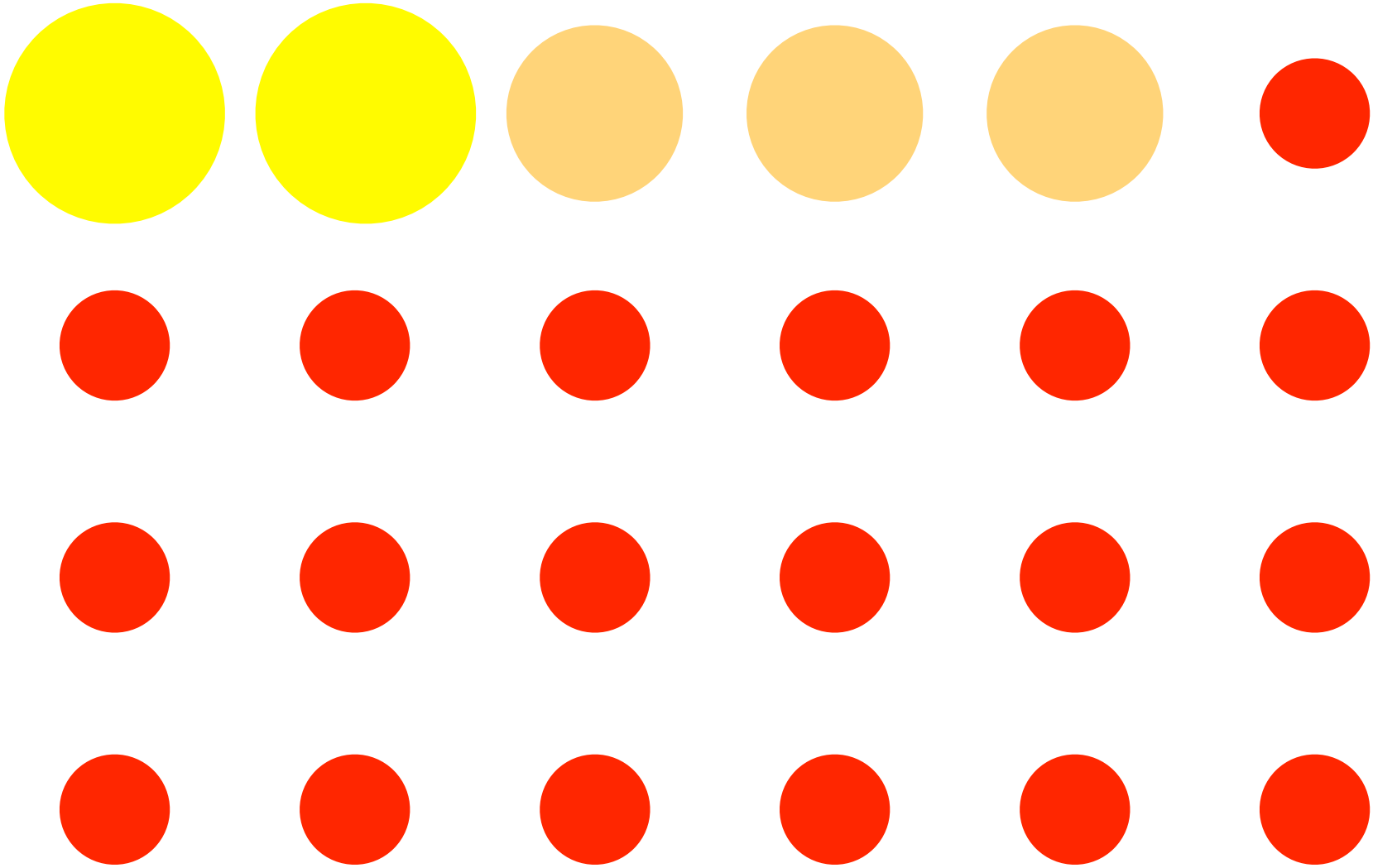
?

Cambrian Explosion

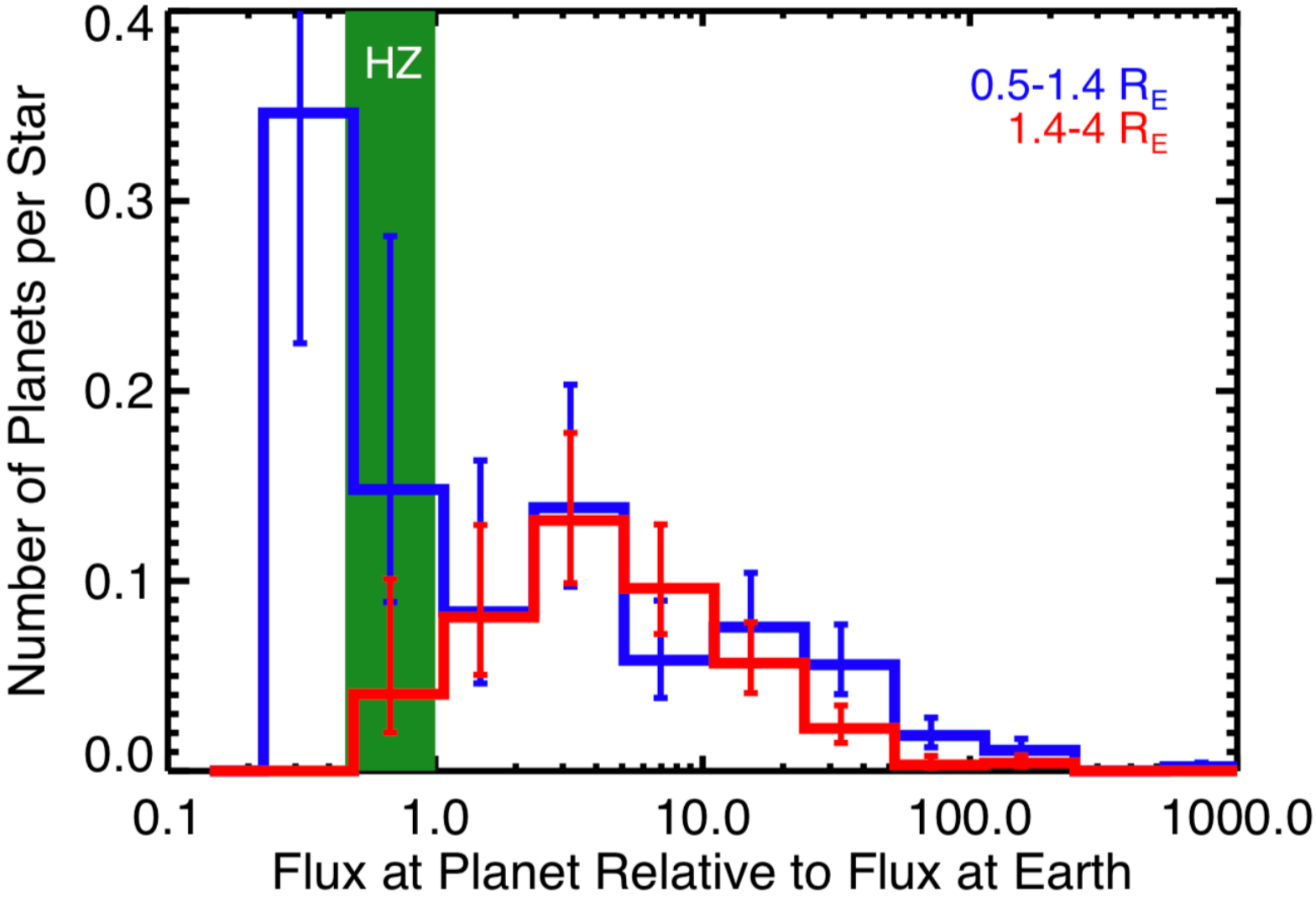


Credit: Paul Hoffman

Lots of M-stars

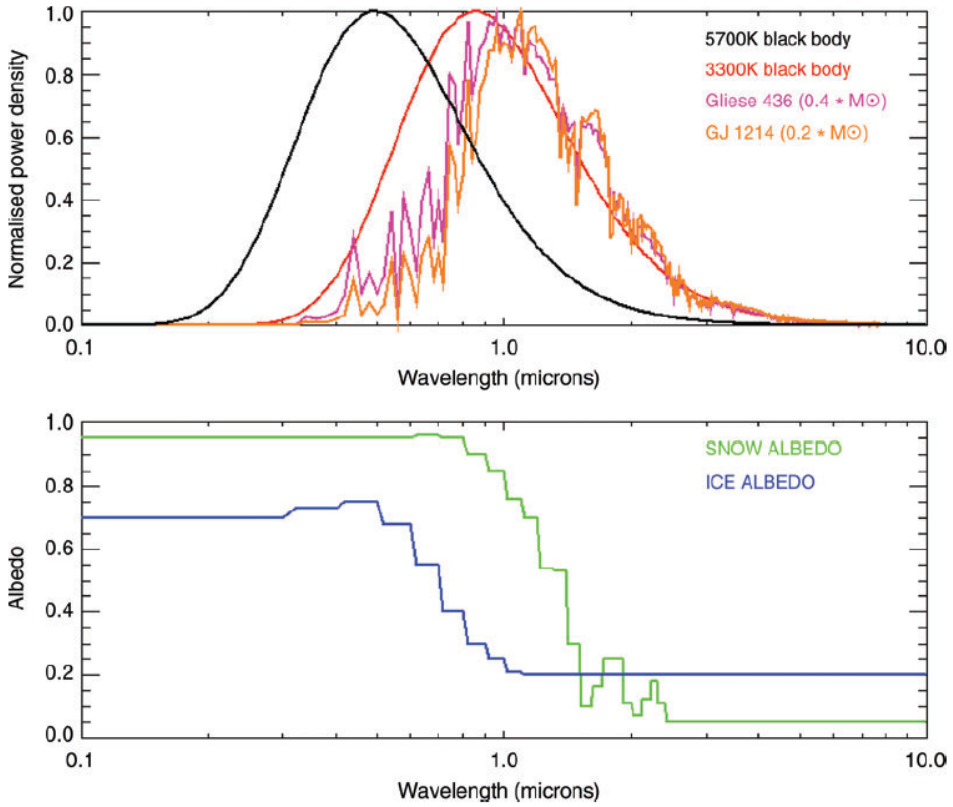


15% M-stars host habitable zone target

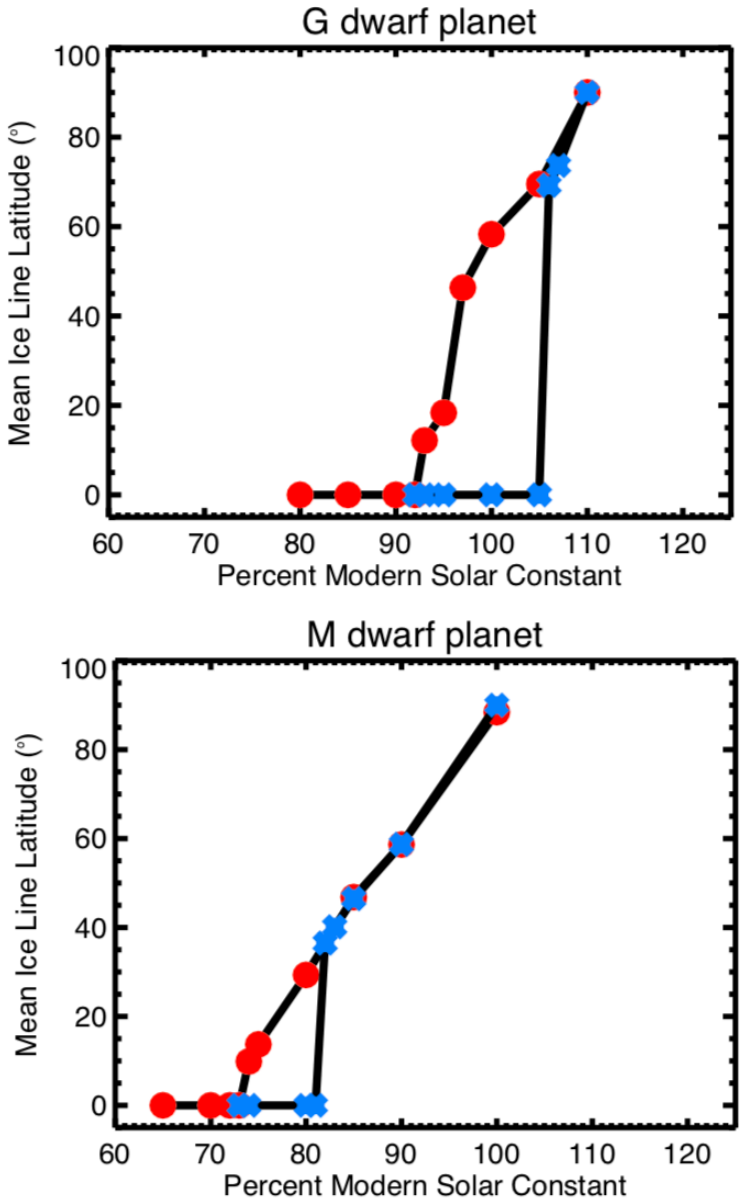


[Dressing and Charbonneau, 2013]

M-star spectrum reduces albedo contrast

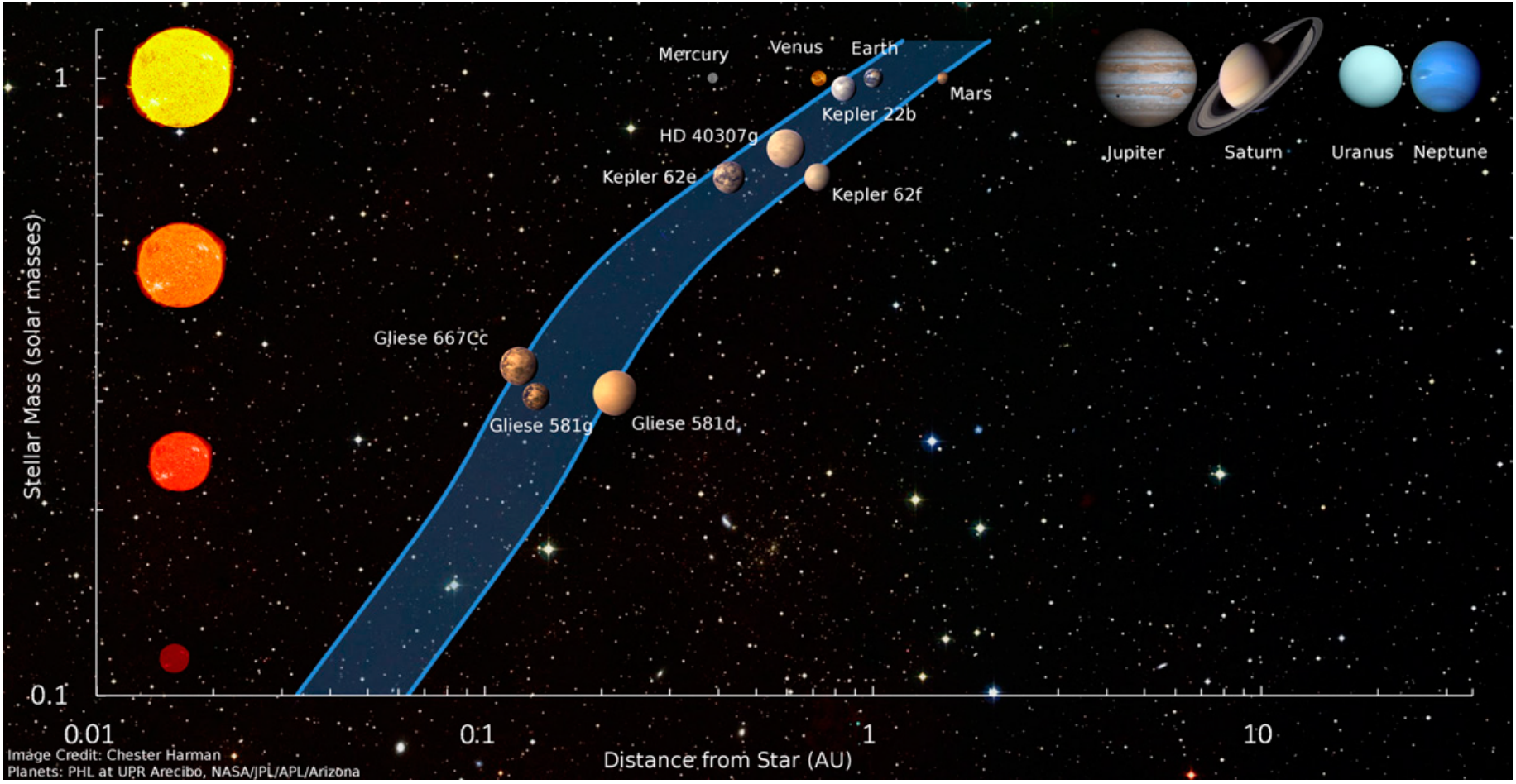


[Joshi, 2012]



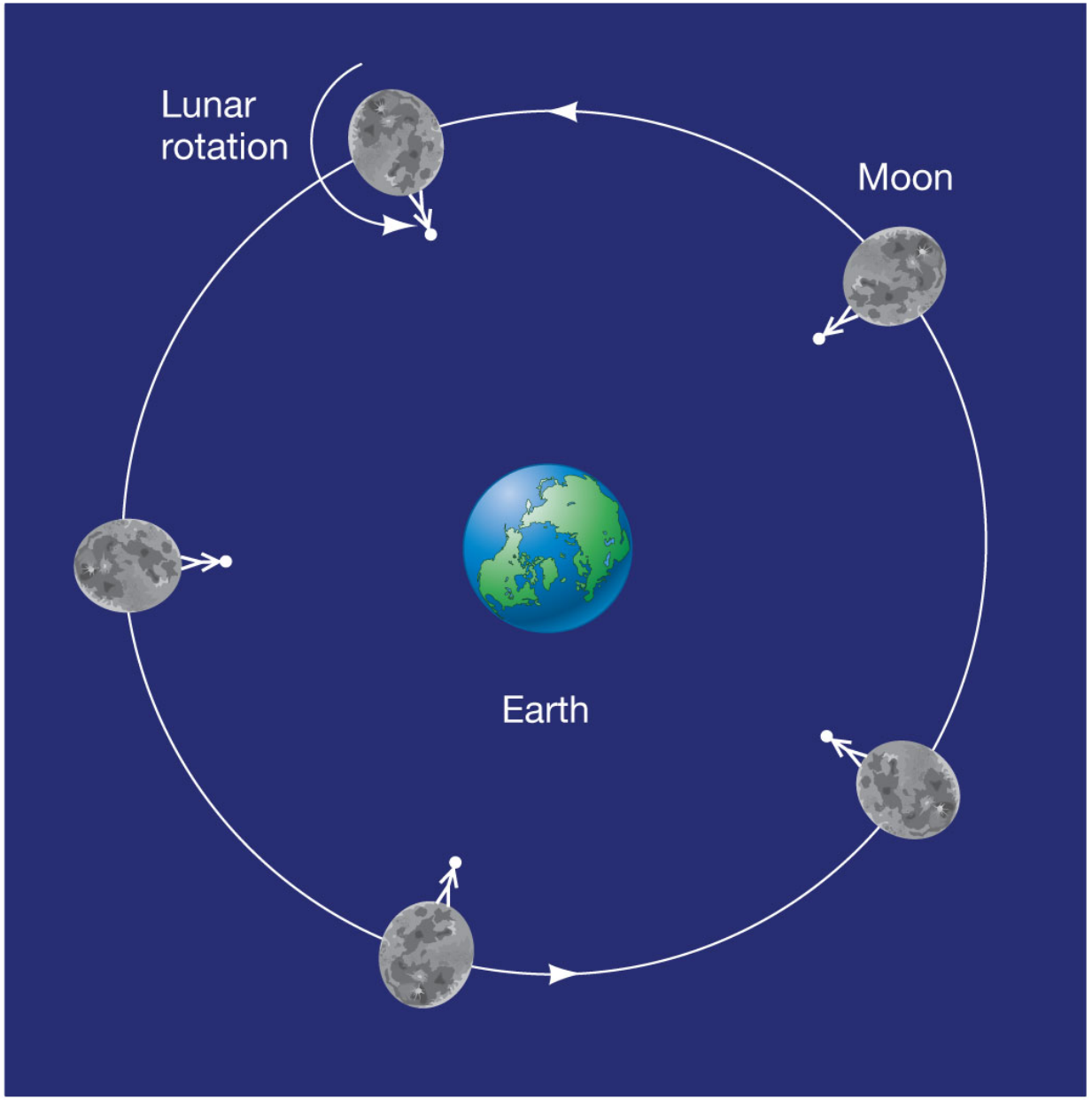
[Shields+, 2014]

Habitable zone of small stars is close-in



[Kasting+, 1993, 2013]

Tidal locking of Hab Zone planets around M-stars



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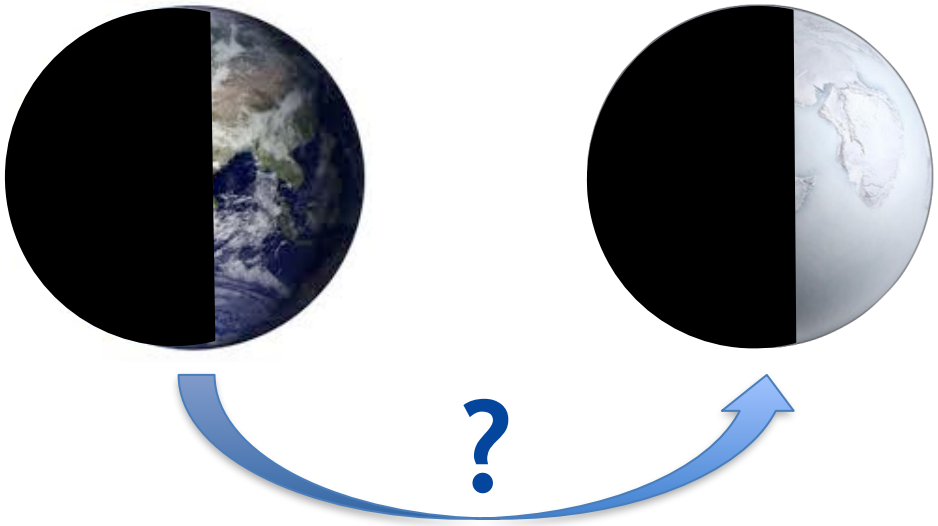
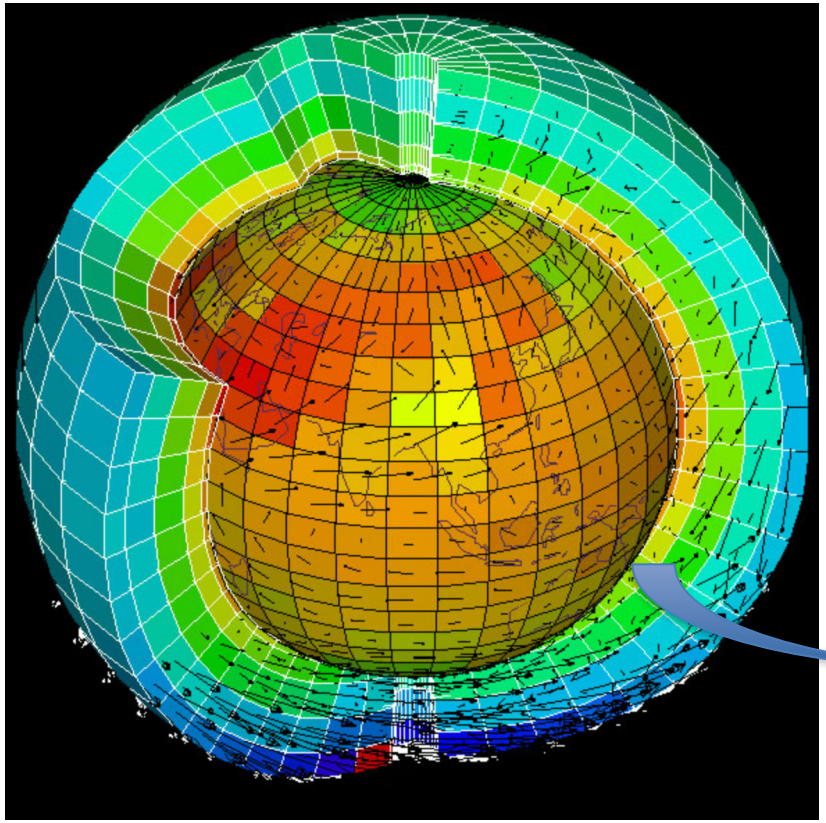
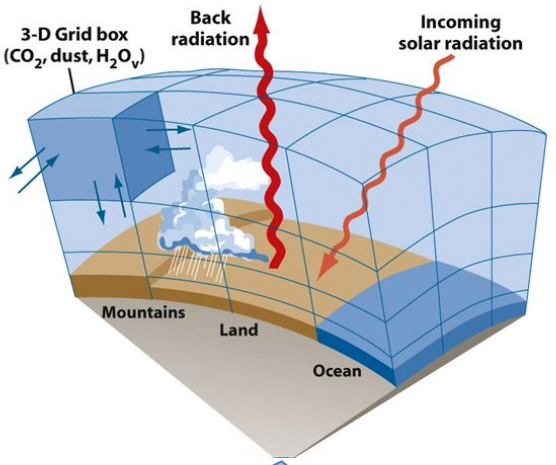
What happens to the snowball bifurcation on tidally locked planets?

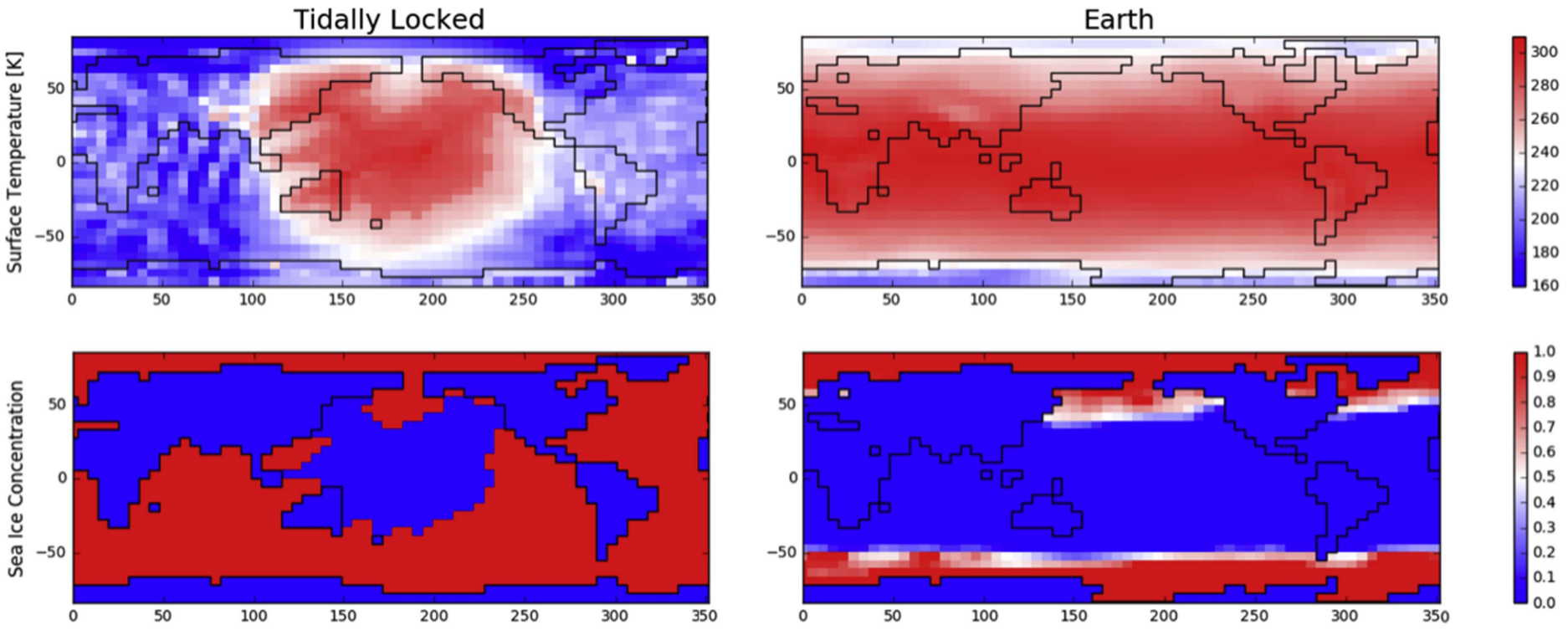


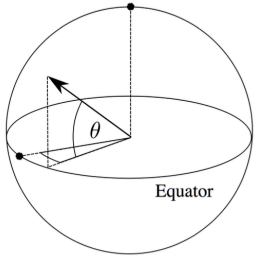
Global Climate Model (GCM) PlaSim



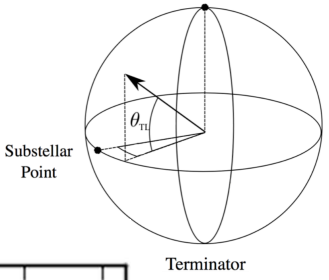


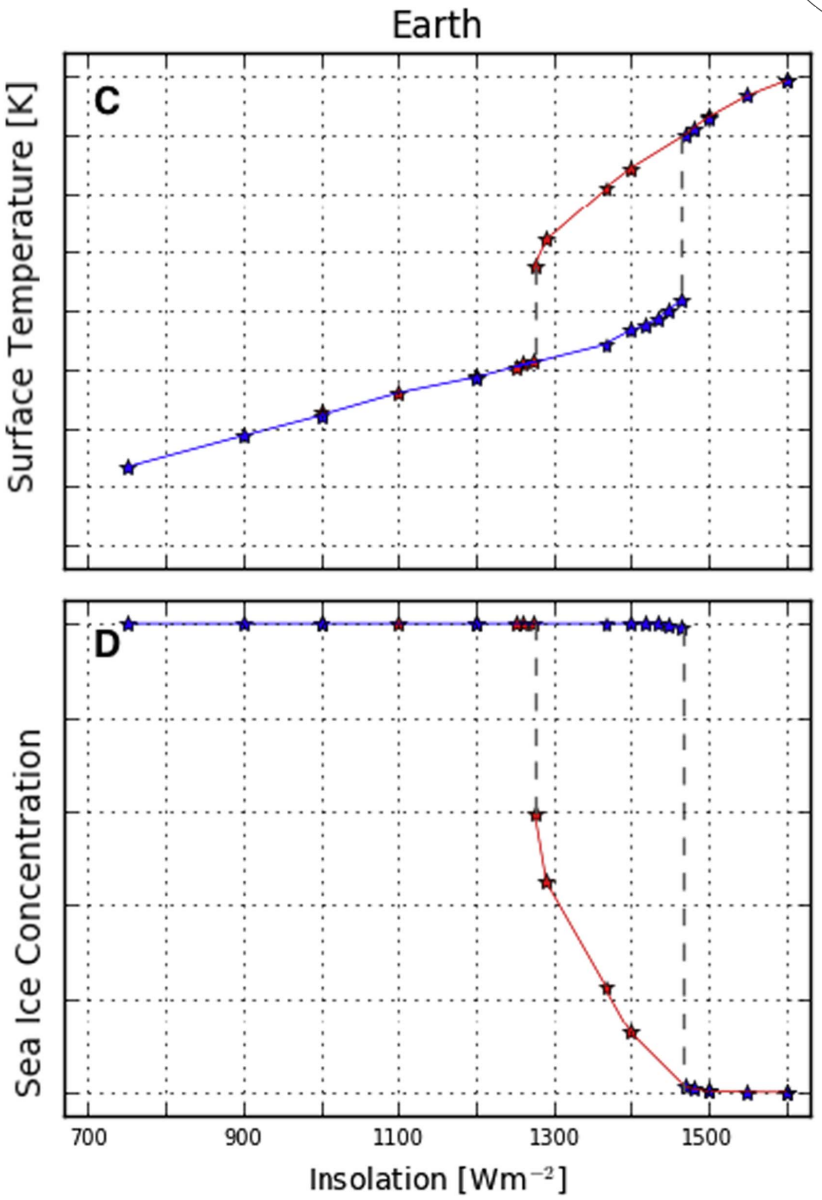
PlaSim GCM simulations



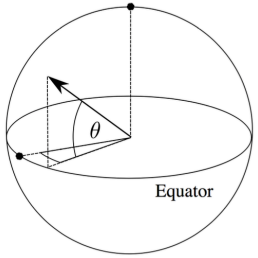


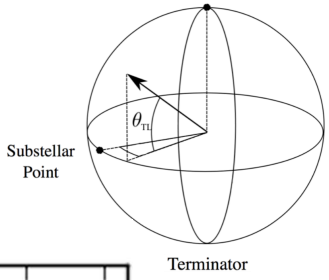
Earth PlaSim has snowball bifurcation





No bifurcation when tidally locked





Tidally Locked

Earth

A

B

C

D

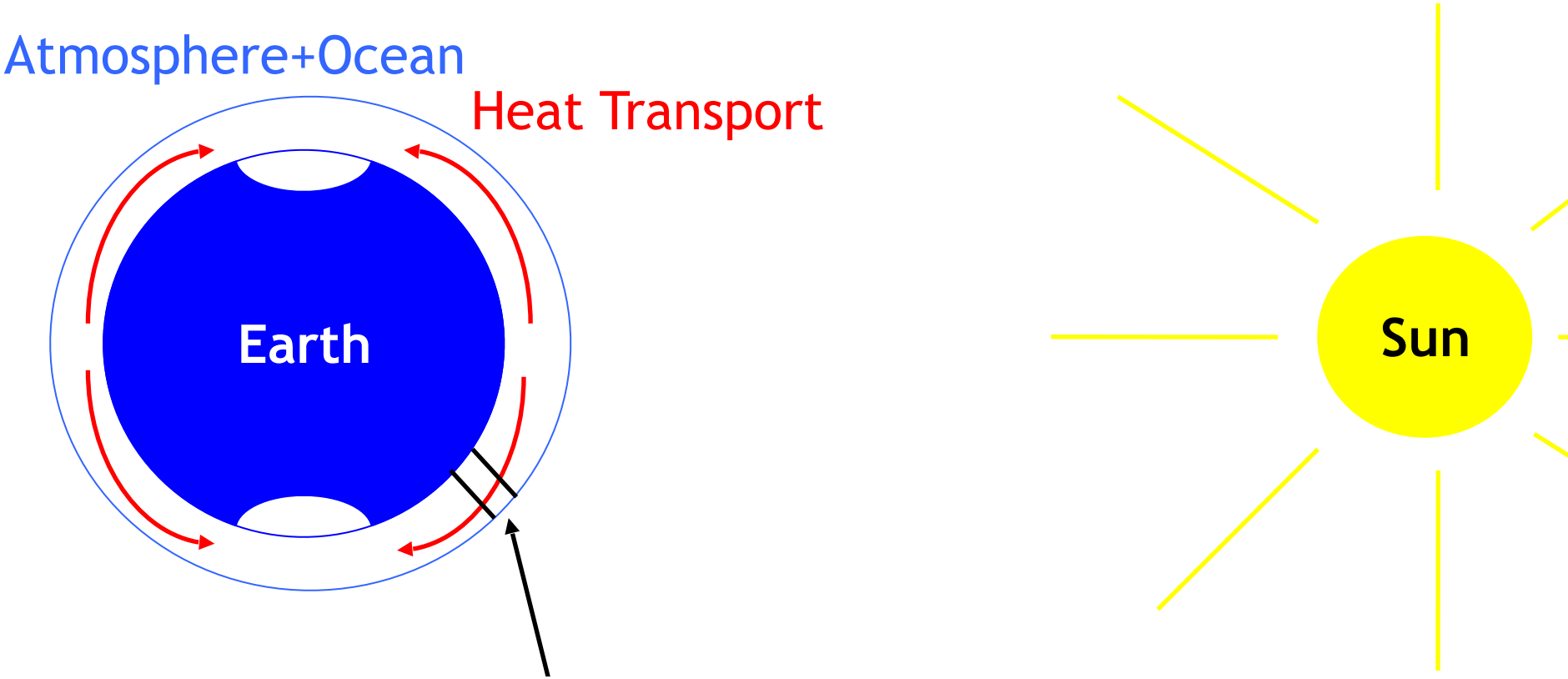
Surface Temperature [K]

Sea Ice Concentration

Insolation [Wm^{-2}]

Insolation [Wm^{-2}]

Energy Balance Model (EBM)

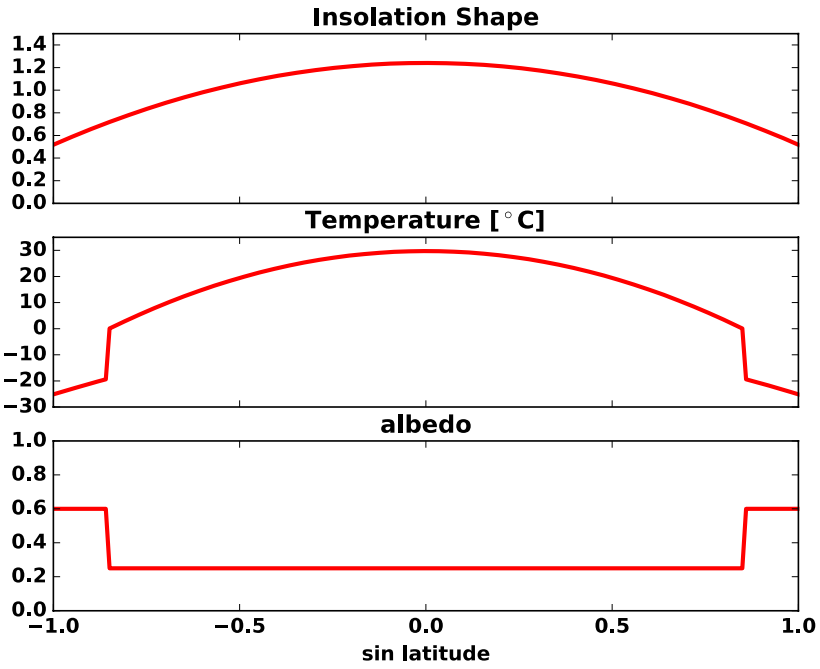


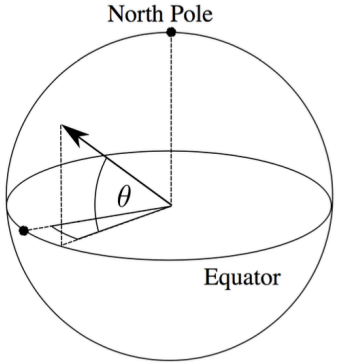
$$\underbrace{\frac{Q}{4}S(x)(1-\alpha(T(x)))}_{\textbf{Absorbed solar}} = \underbrace{A+BT(x)}_{\textbf{OLR}} + \underbrace{C(T(x)-\overline{T})}_{\textbf{Heat transport}}$$

[Budyko, 1969; Sellers, 1969]

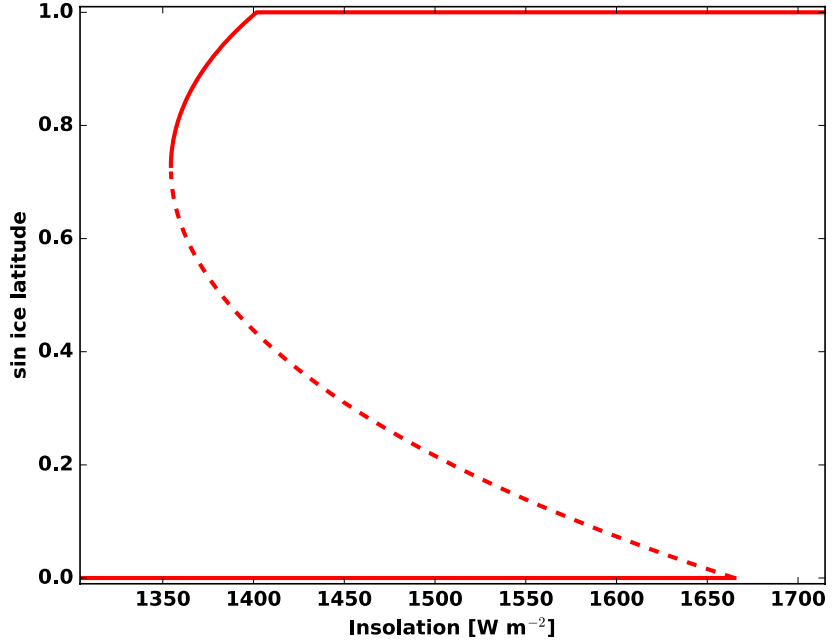
EBM: rapidly rotating

Example State



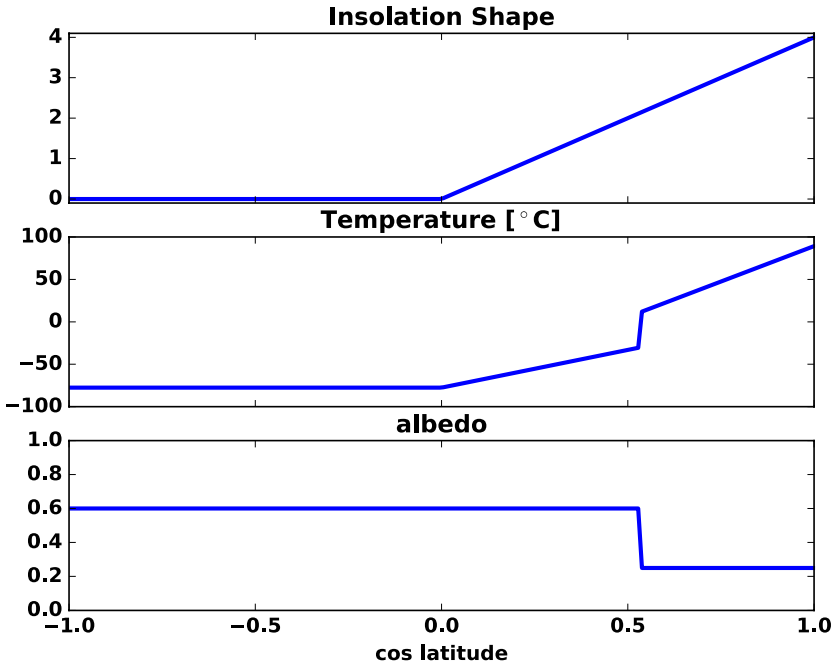


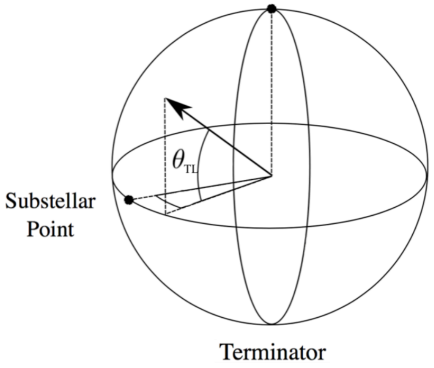
Bifurcation Diagram



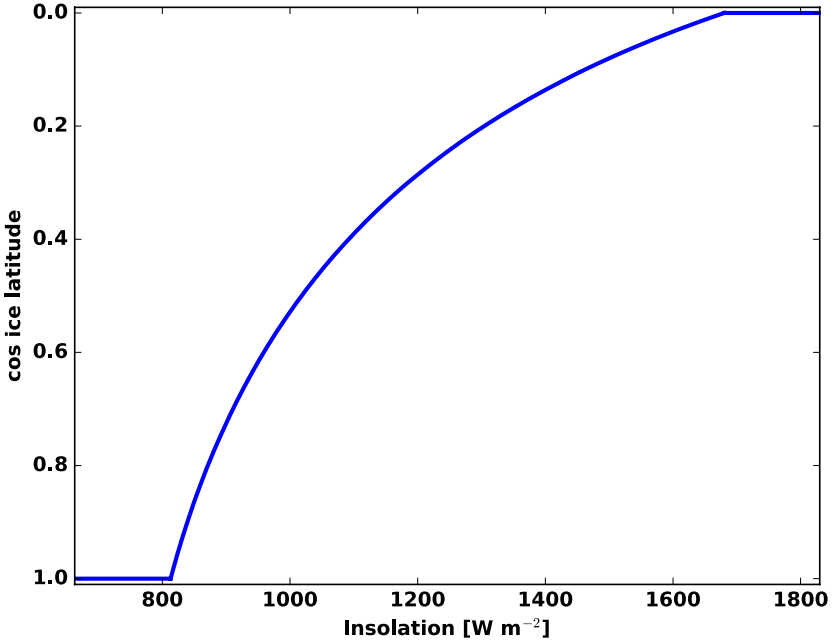
EBM: tidally locked

Example State

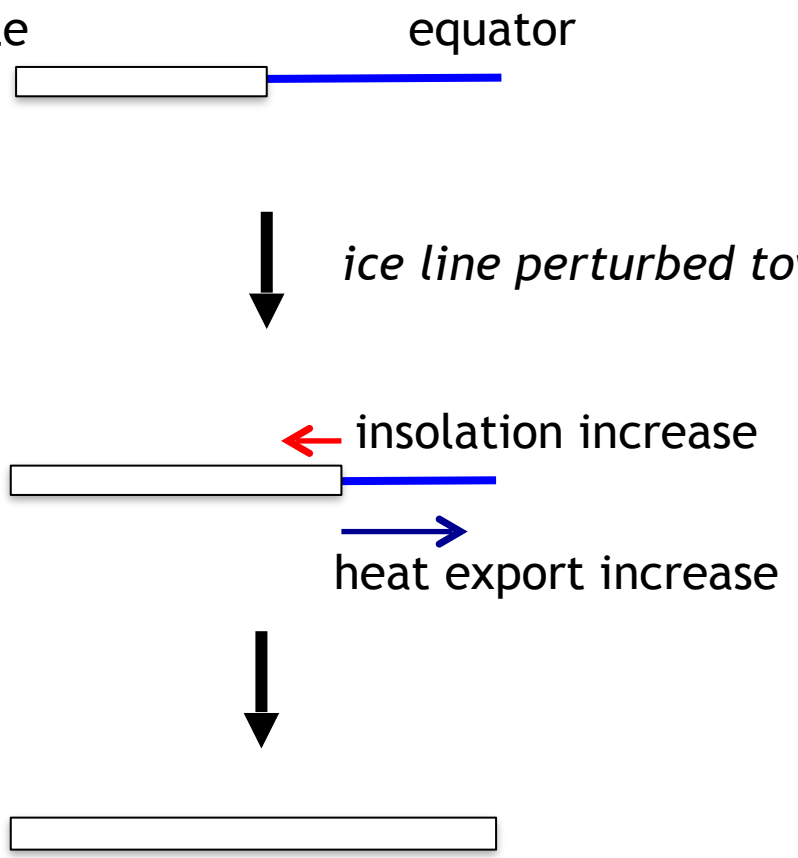




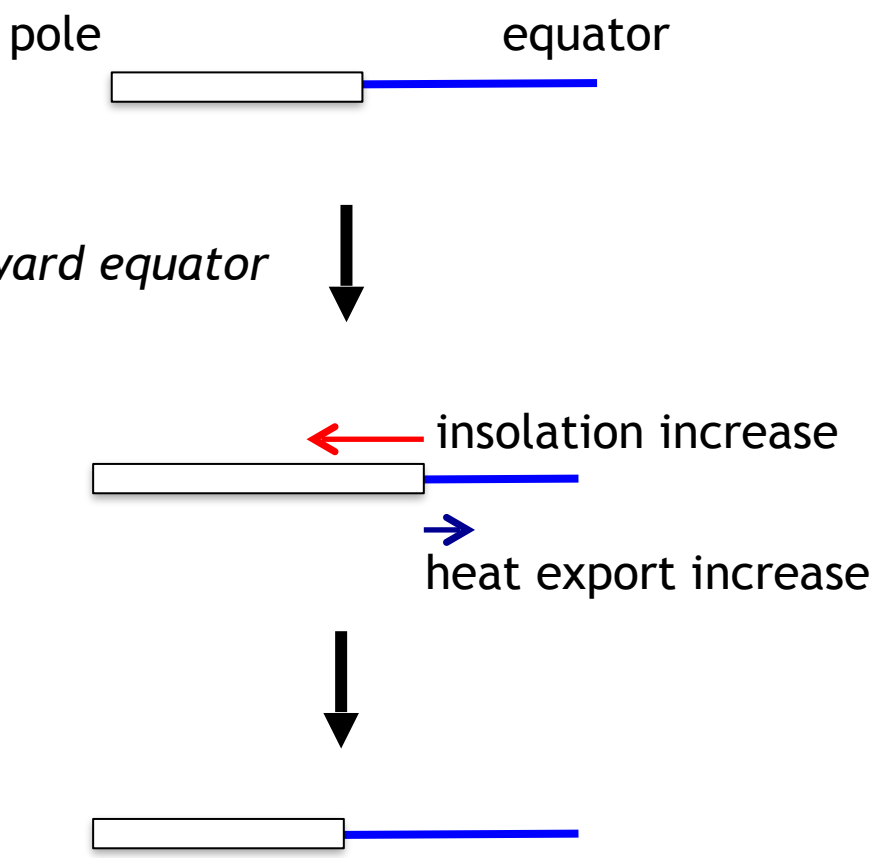
Bifurcation Diagram



Rapidly-rotating (Earth): Snowball Bifurcation

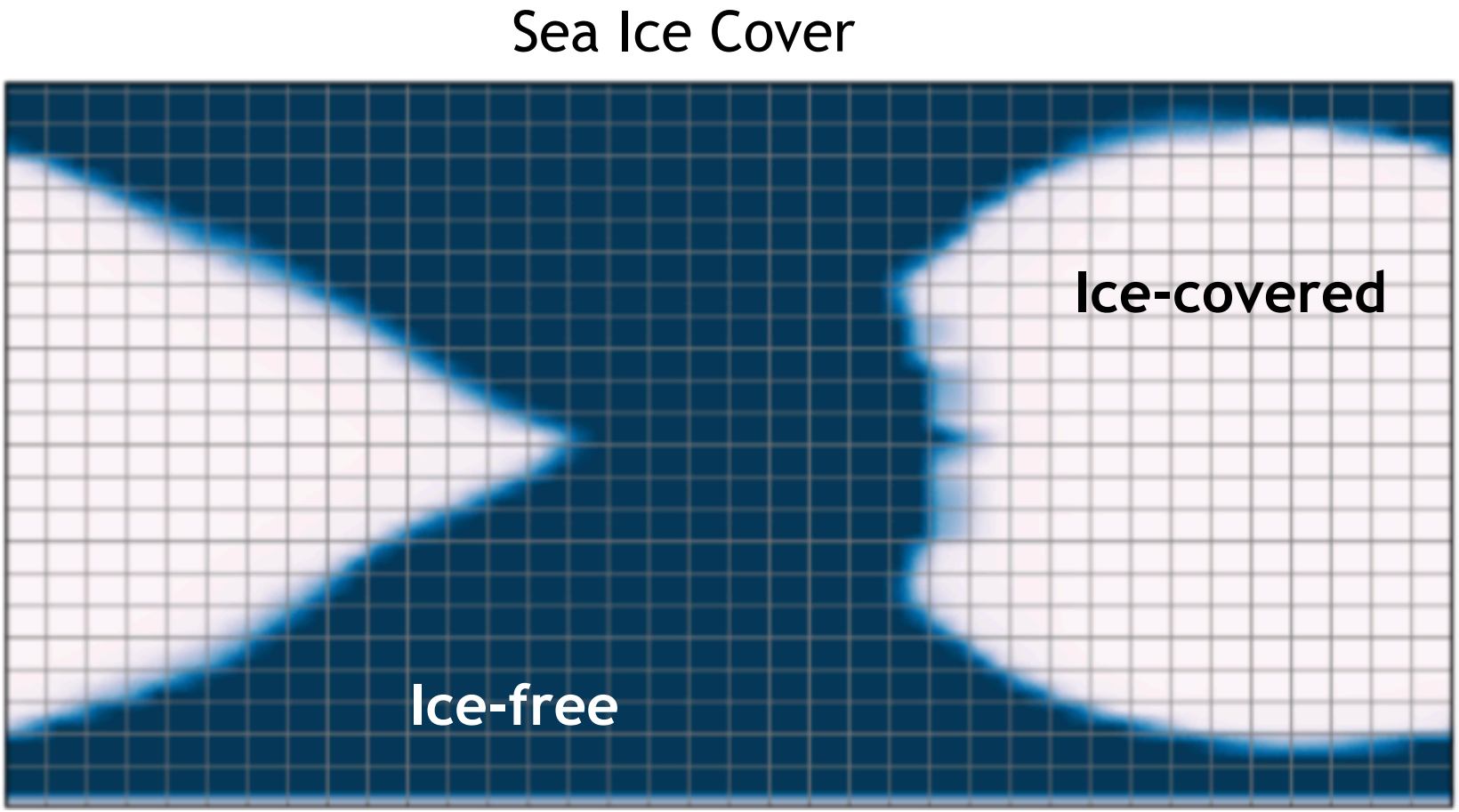


Tidally Locked: Stable

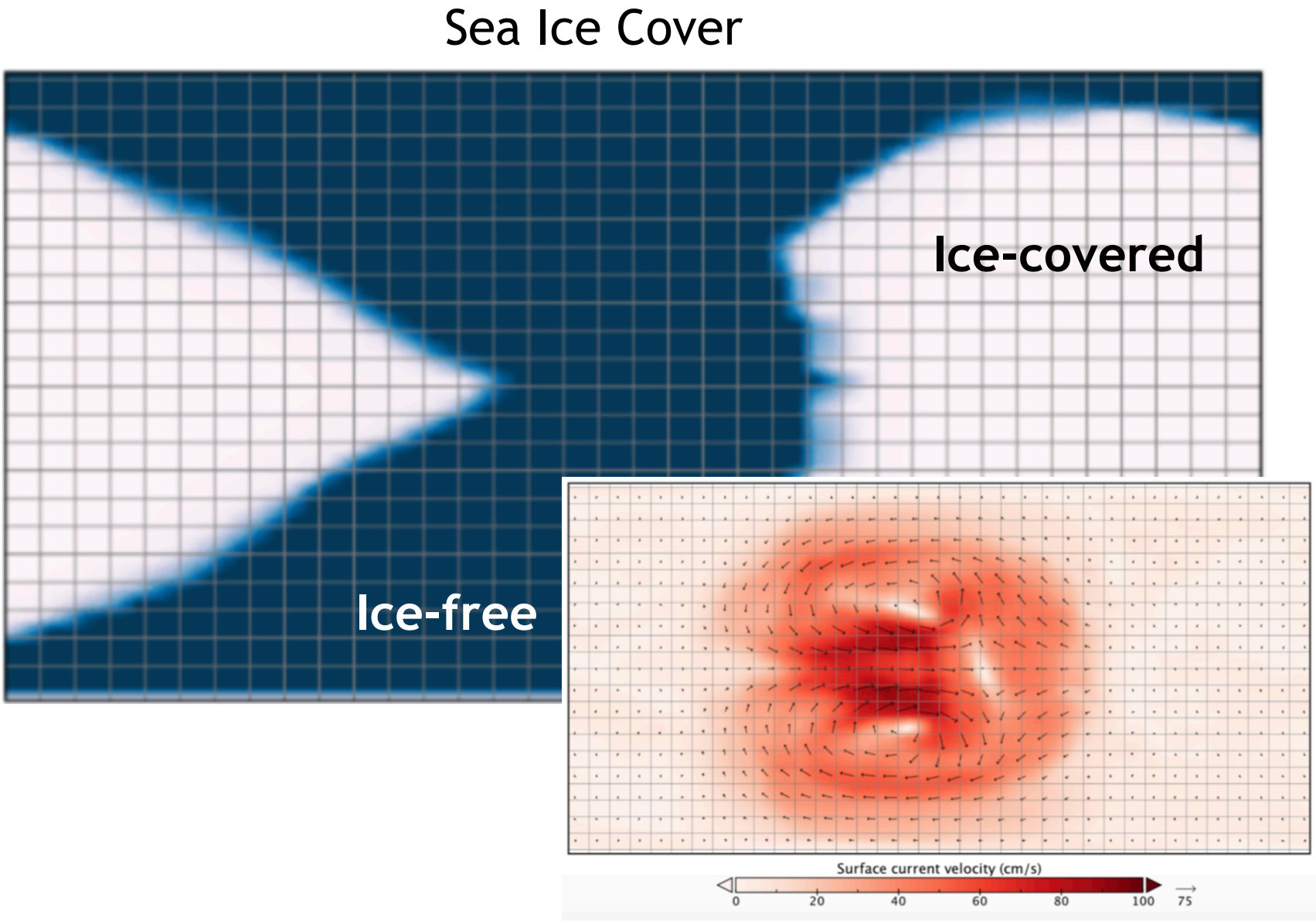


Can we recover the bifurcation with a dynamic ocean?

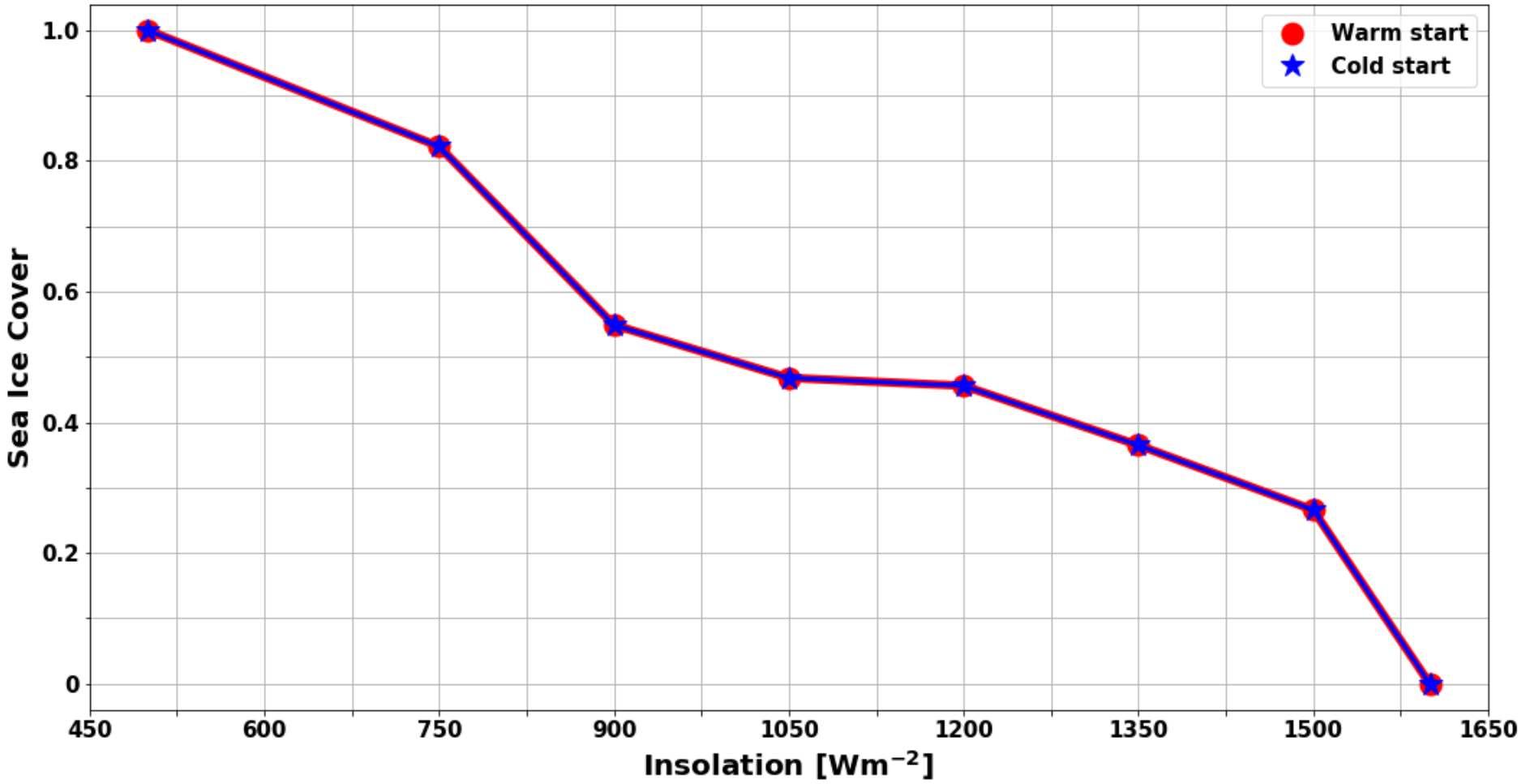
ROCKE-3D with dynamic ocean



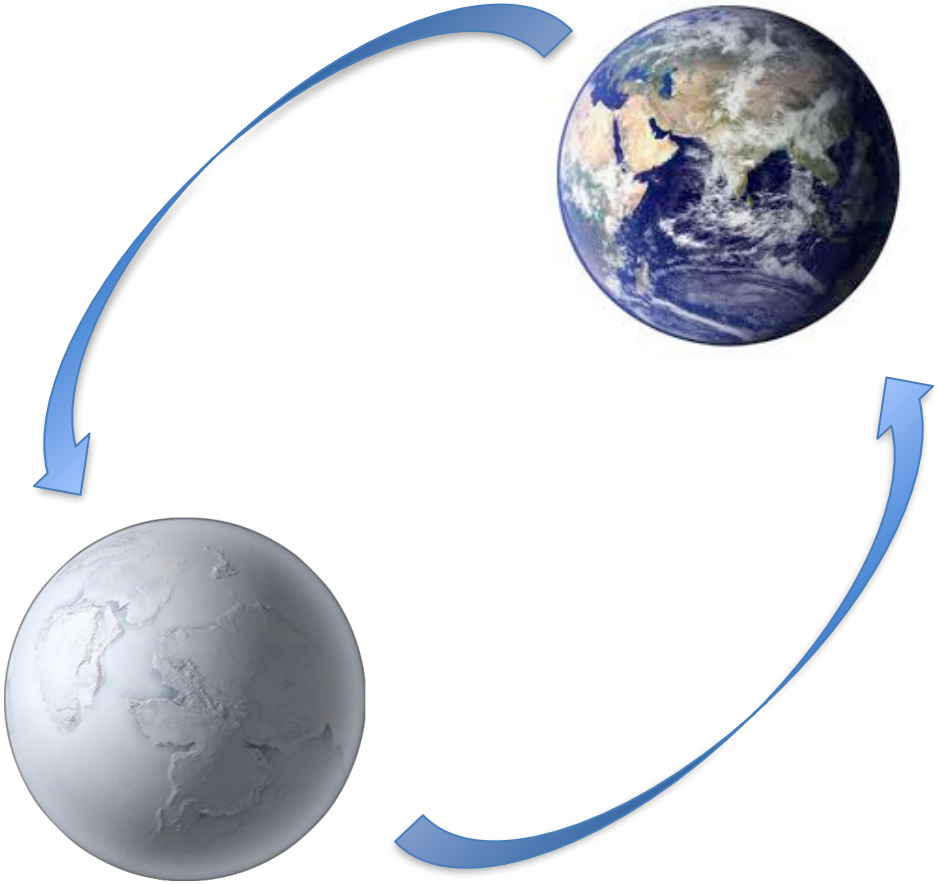
ROCKE-3D with dynamic ocean



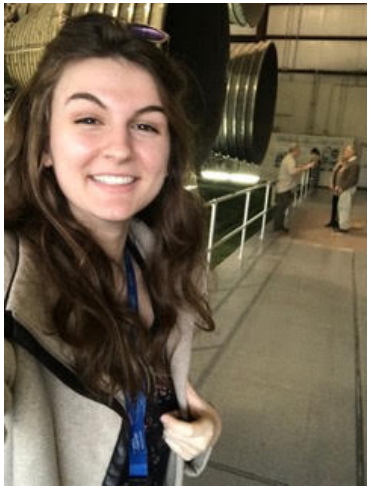
No bifurcation even with a dynamic ocean!



The Snowball bifurcation causes climate limit cycles at the outer edge of the Hab Zone



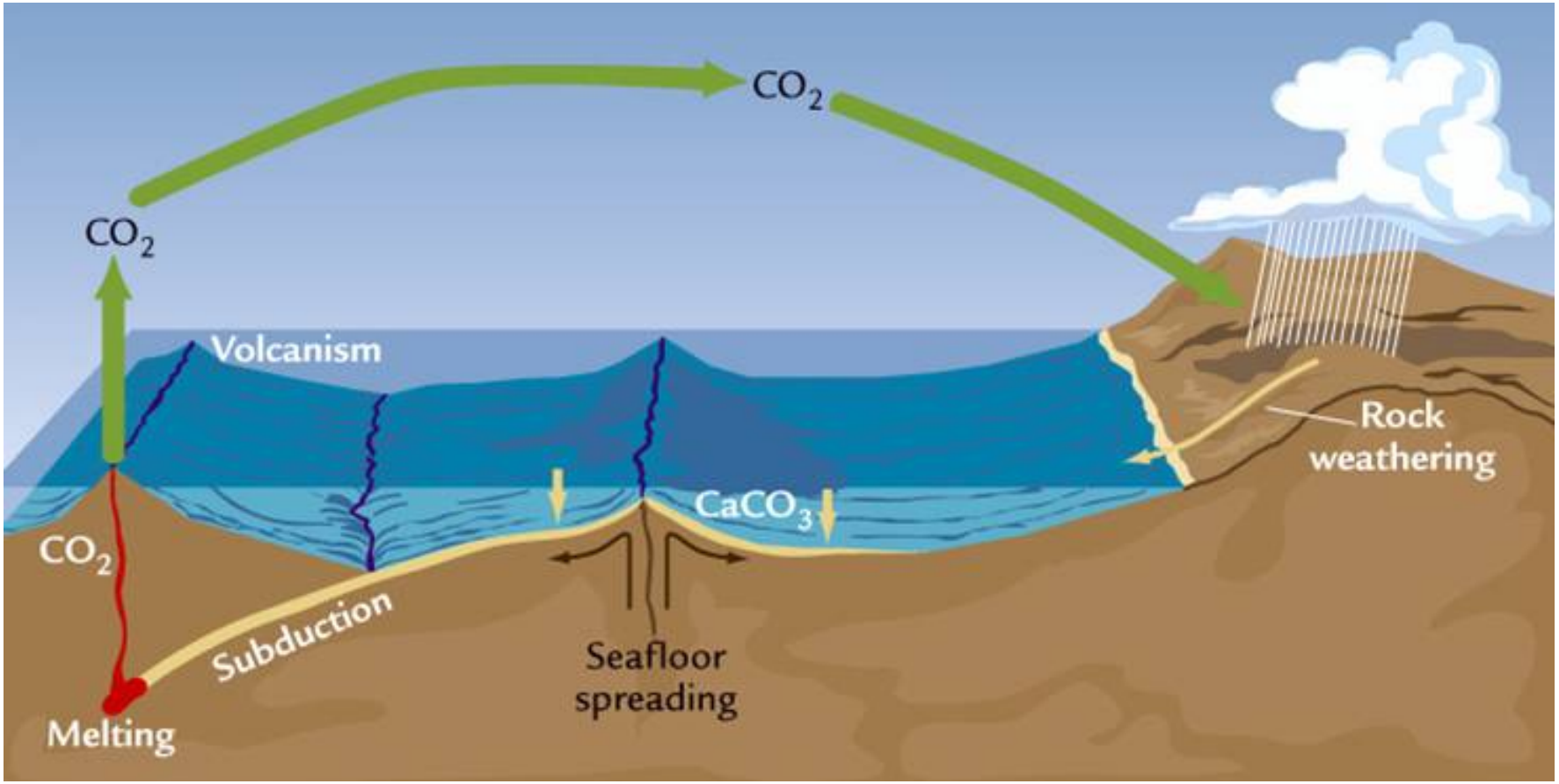
Andrea Salazar



Silicate-weathering feedback

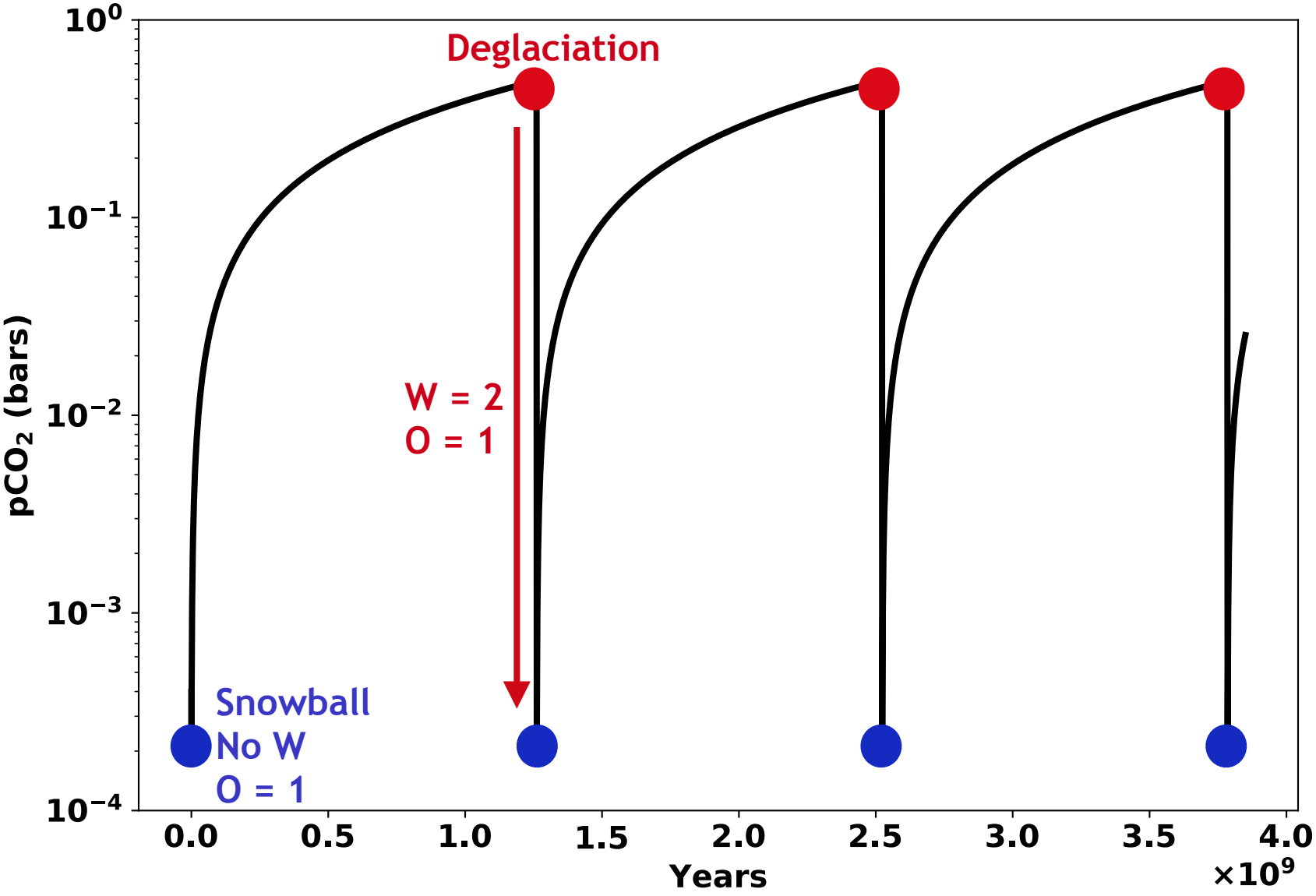
$W = W(CO_2, T_s)$

Equilibrium: Weathering (W) = Outgassing (O)

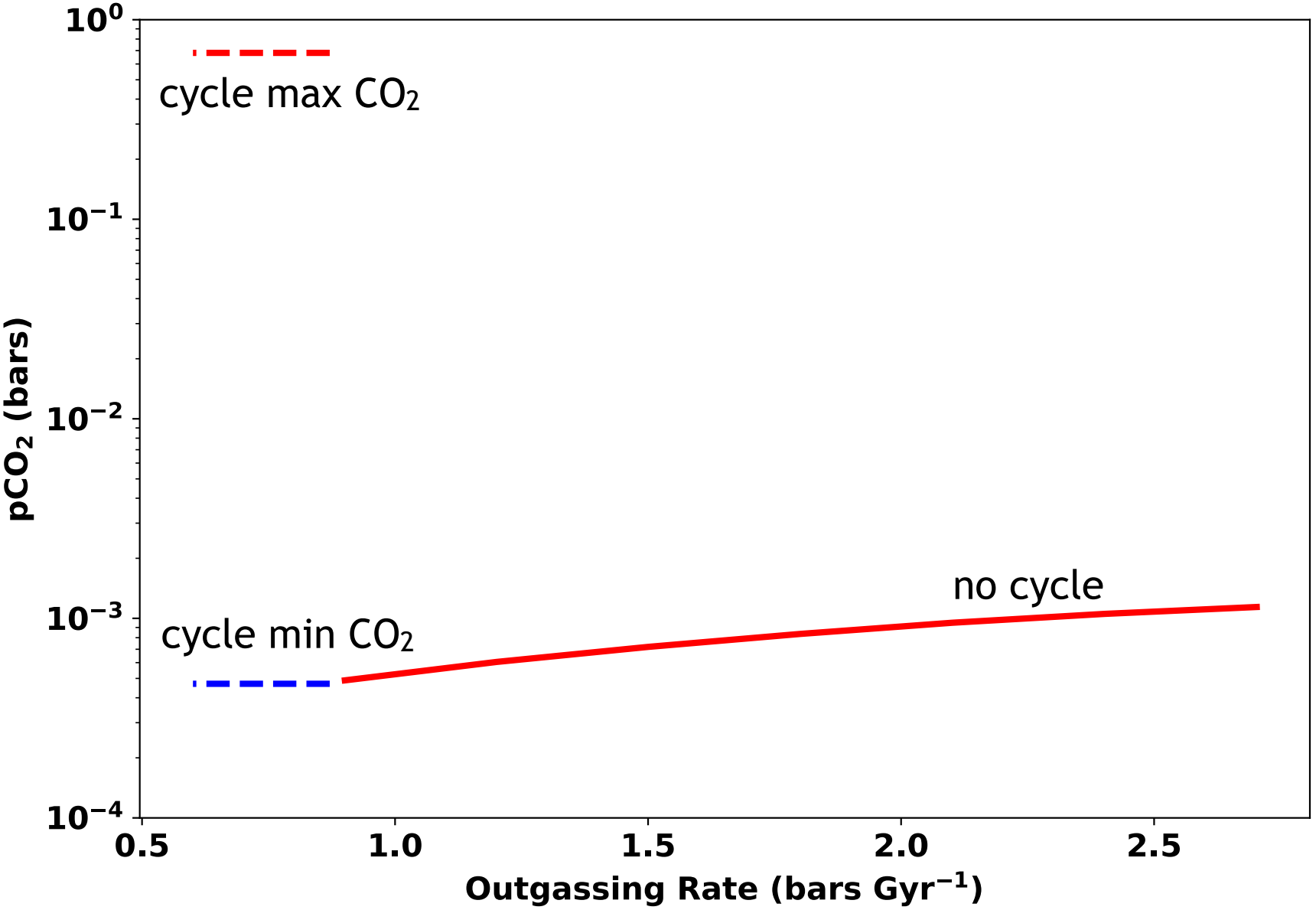


[Walker et al., 1981, Kasting 1993]

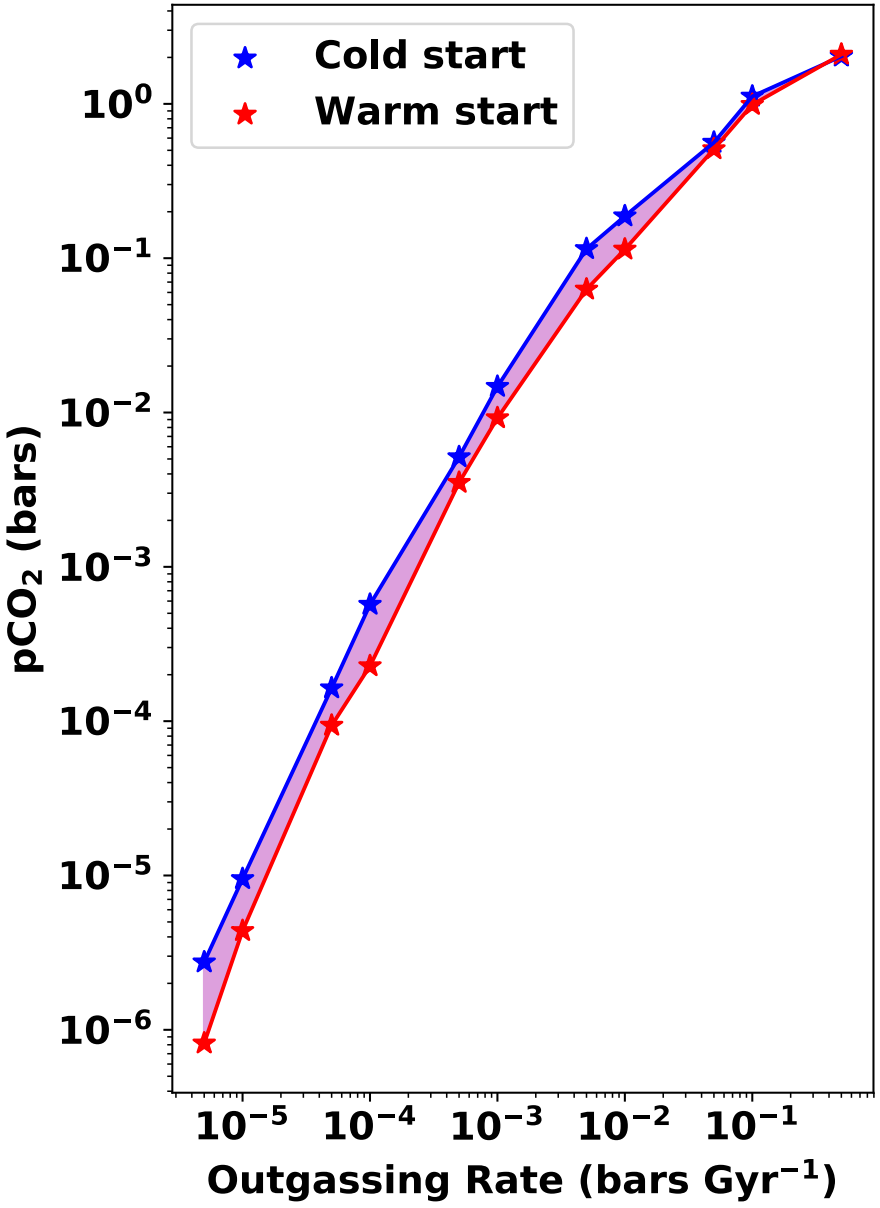
Climate cycles in rapidly rotating planets

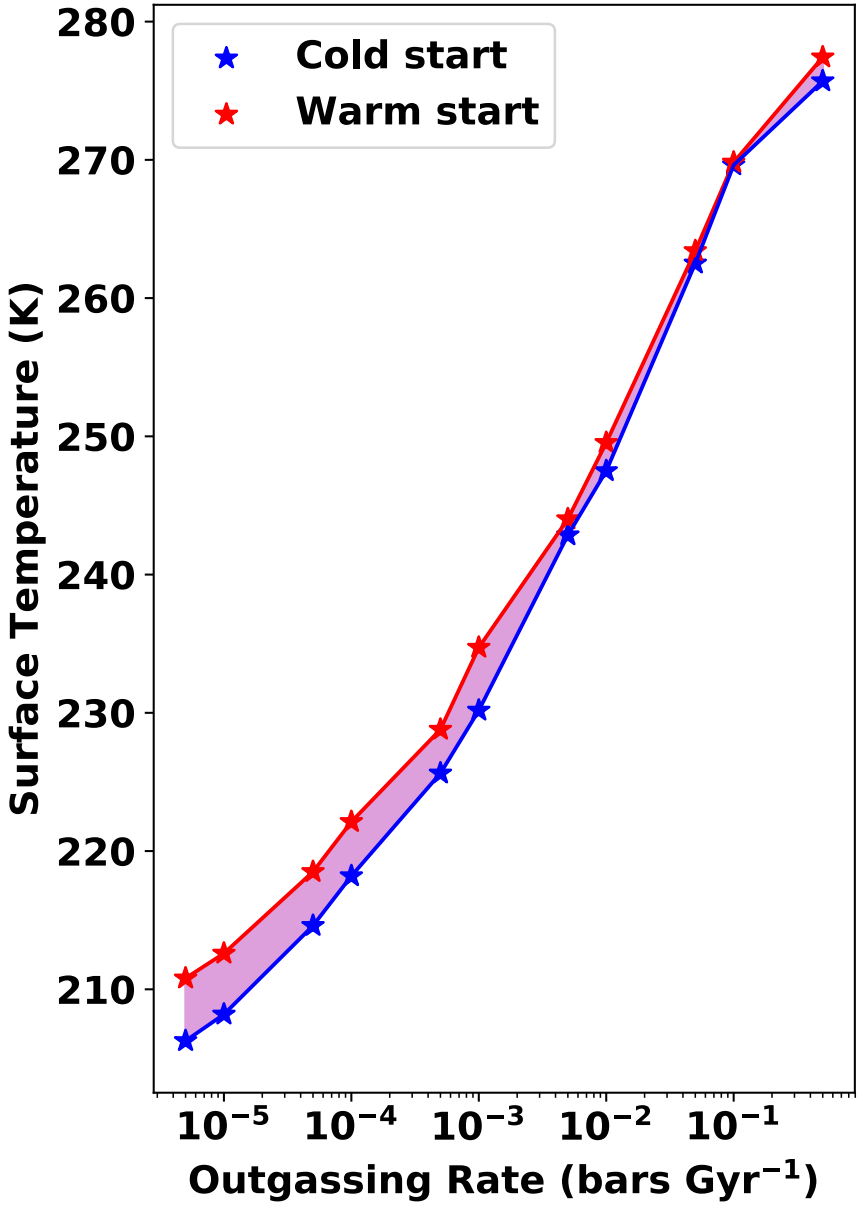


Cycles only occur at low outgassing



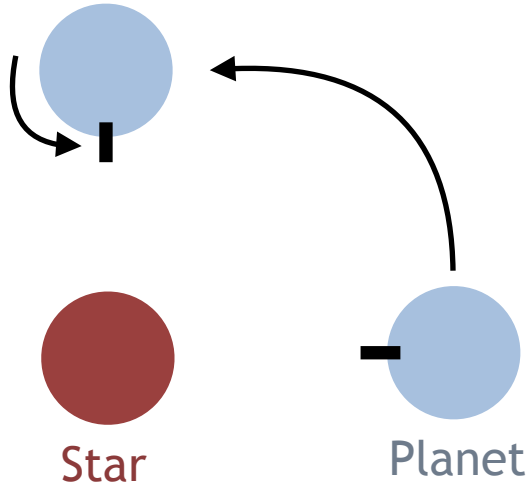
Tidally locked: no hysteresis, no cycles!



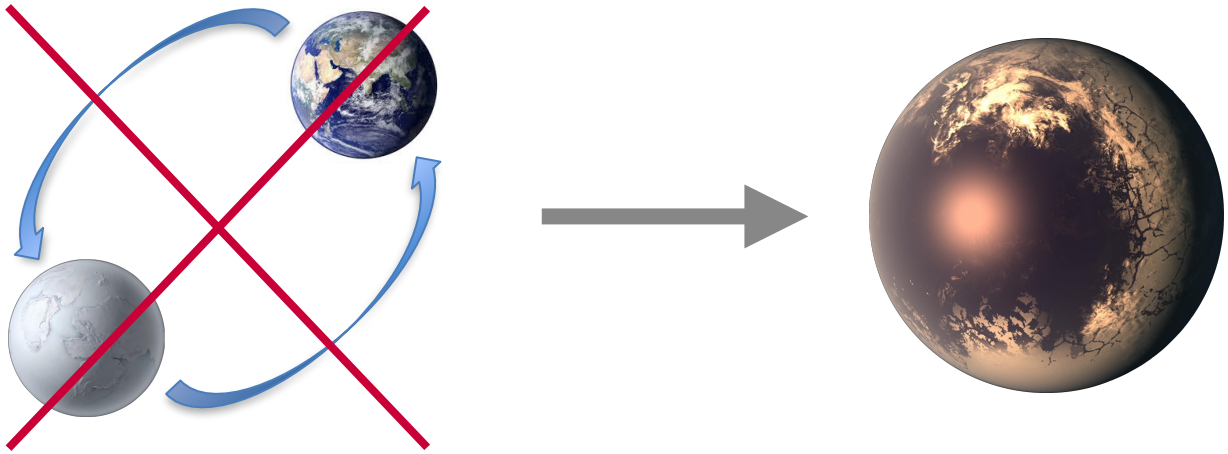


Take-home

Tidally Locked:



No bifurcation
No climate cycles
No snowball



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