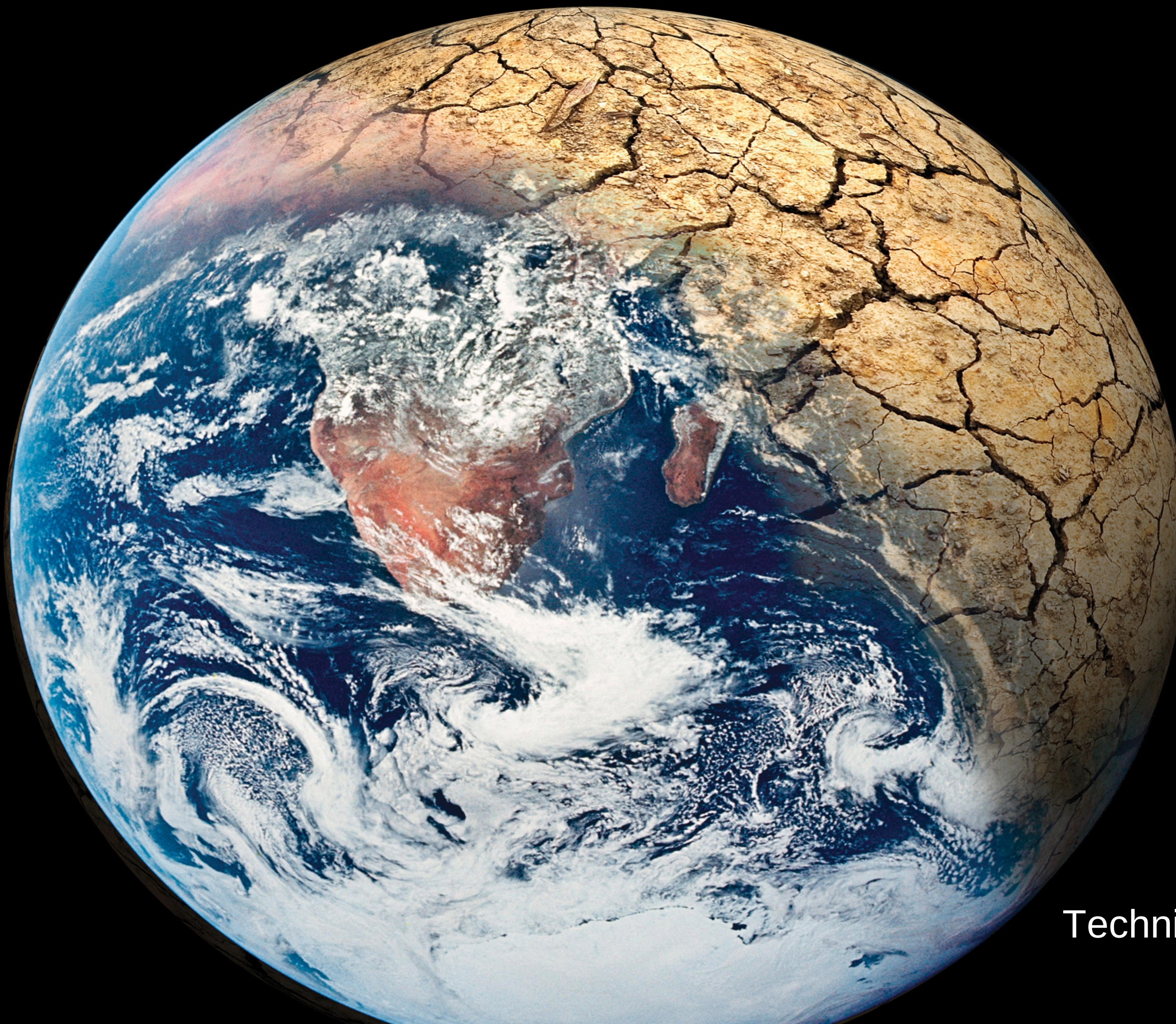
Adaptable habitability, niche filling and exo-climate change



Hagai Perets
Technion – Israel institute of Technology

Overview

- Life on Earth
- Exo-climate change
- Niche filling
- Adaptive habitability
  - Habitability depends on how life respond to changes
  - Habitability can not be defined at a given point in time and space, but depends on the evolution of both the physical conditions and the evolution of life and their rate

Work in progress

Overview

- Life on Earth
- Exo-climate change
- Niche filling
- Adaptive habitability
- Why do habitability care about general relativity

Work in progress

Complex life evolves though several stages with different timescales

On Earth:

Stage	Time to develop(Myr)	Time (Myr)
Earth forms	0	~4600
Initial: Prokoryotic life	<500 ?	~4100
Early: Eukoryotic life	~2000	~2100
Late: Multi-cellular organisms	~1400	~700

Planets contain diverse range of environmental conditions in both time and space

- **Time**
  - Day/night
  - Seasons
  - Solar cycles
  - Milankovitch cycles
  - Stellar activity
  - ...
- **Space**
  - Latitude
  - Topography
  - Shelter (caves, oceans, forests)
  - ...

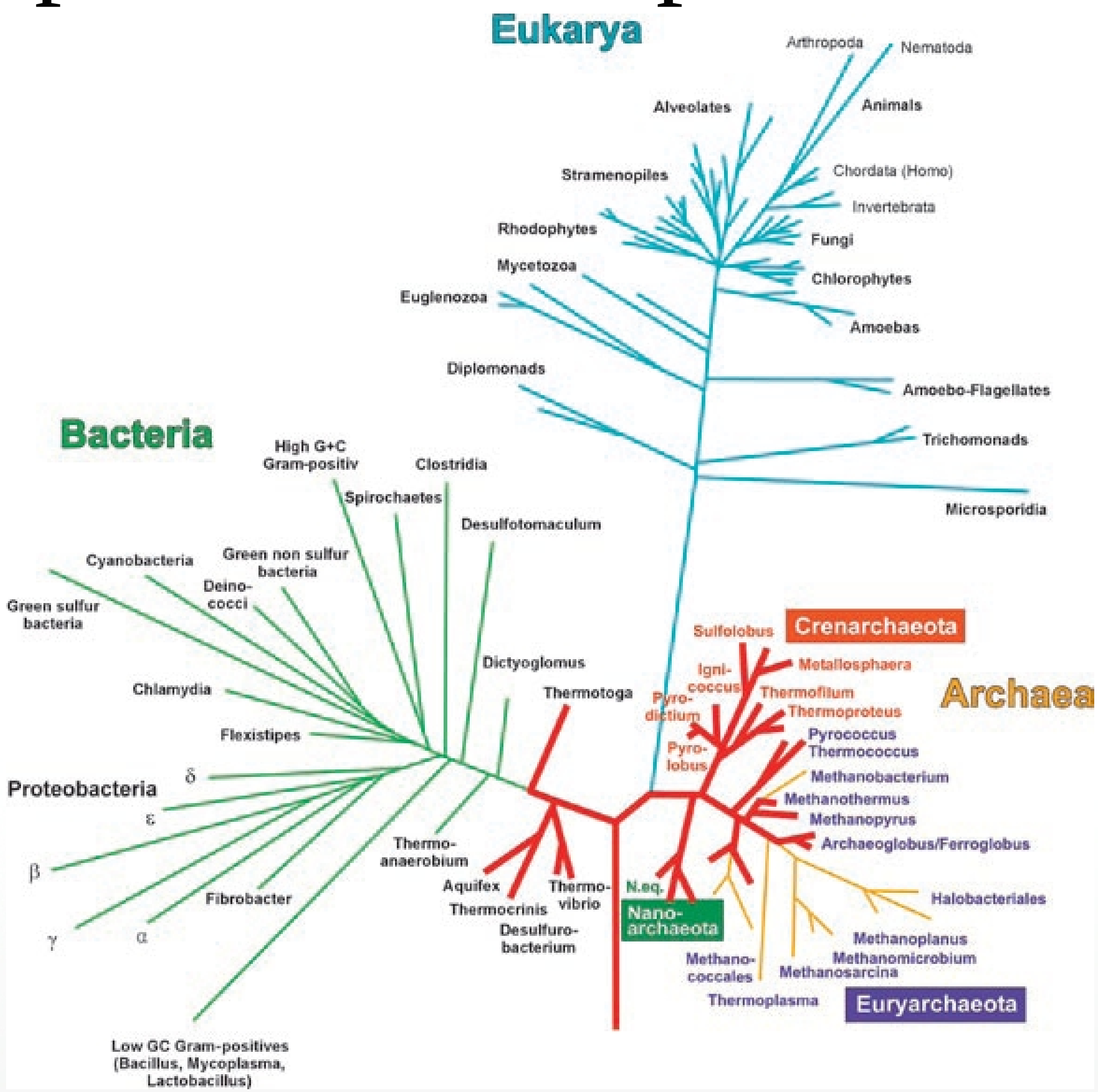
Given sufficient time, life fills spatial and temporal niches

- Fast genetic evolution allows them to adapt to a range of environmental niches in time and space (at which stage does evolution become fast ?)

  T_dev(Eukoyotic)<T_dev(Prokoyotic)<T_dev(multicelluler)

- Time: e.g. night vs. day animals; winter sleep ...
- Space: e.g. extremophiles – temperature, salinity, pressure etc.

Given sufficient time, life fills spatial and temporal niches



Stetter 2006

Exo-climate change: The physical planetary conditions may evolve with time

- **Each change has some characteristic amplitude A_change and characteristic timescale – T_change**
- **Exo-climate change can also occur periodically**
- **Changes due to external effects**
  - Orbital dynamics (e.g. Milankovitch cycles)
  - Planet migration
  - Tidal evolution
  - Stellar evolution
  - Impacts
  - ...
- **Changes due to internal effects**
  - Geophysically induced changes (e.g. volcanoes)
  - Biologically induced changes (e.g. oxidation)

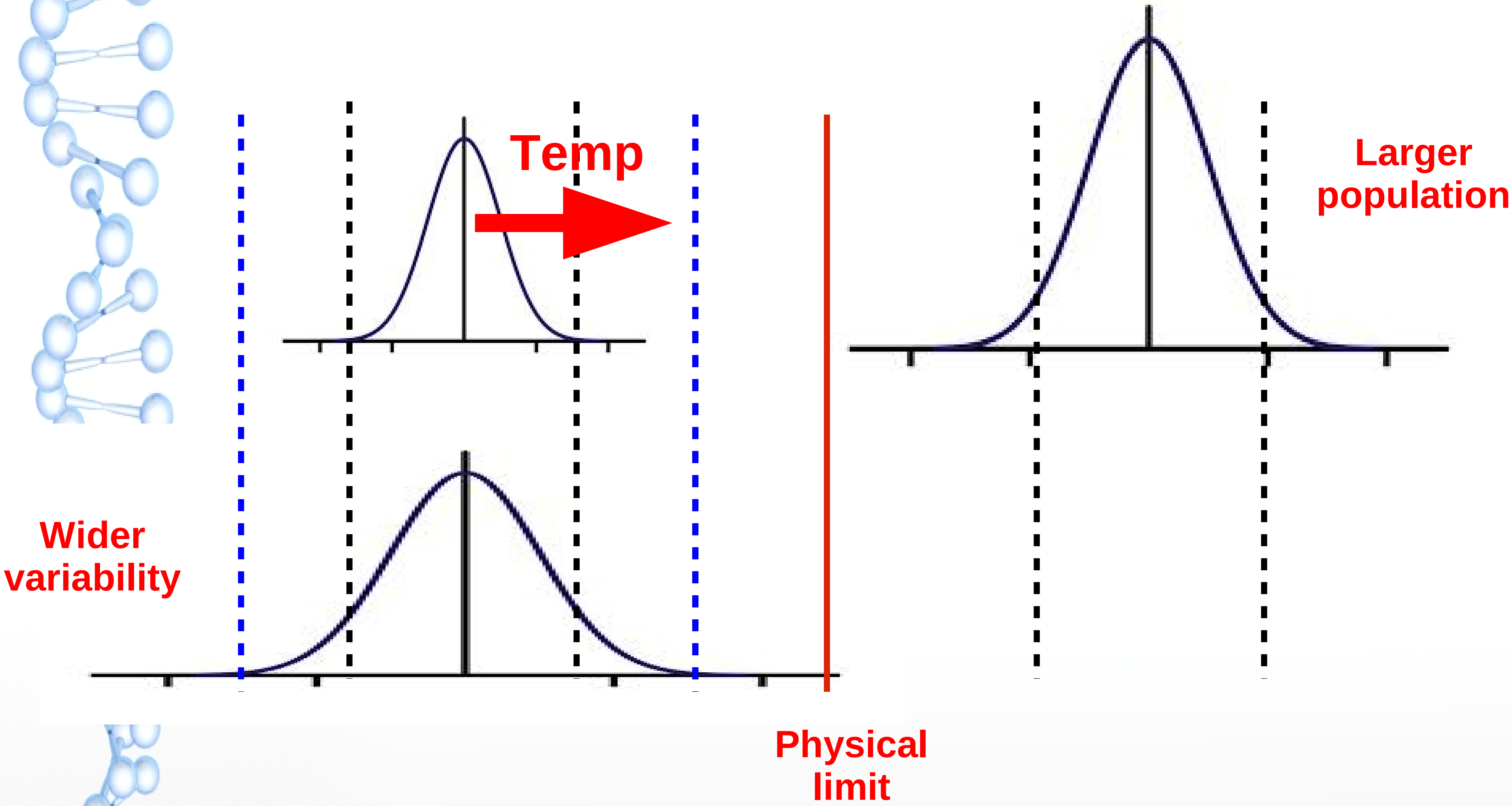
Life respond and adapt to environmental changes through different processes and rates

- Variation of traits
  - Plastic and behavioral changes
  - Geographical/environmental migration
  - Genetic phenotipic variation (population) – T_adapt=T_phe ; R_adapt=A_change/T_adapt
- Genetic evolution of traits –

  T_adapt = T_gen

  - mutations (population)
- There are physical limits e.g. temperature, beyond which no life can exist, irrespective of time

Phenotypic evolution:
A larger population and/or with a larger phenotypical variability better adapts



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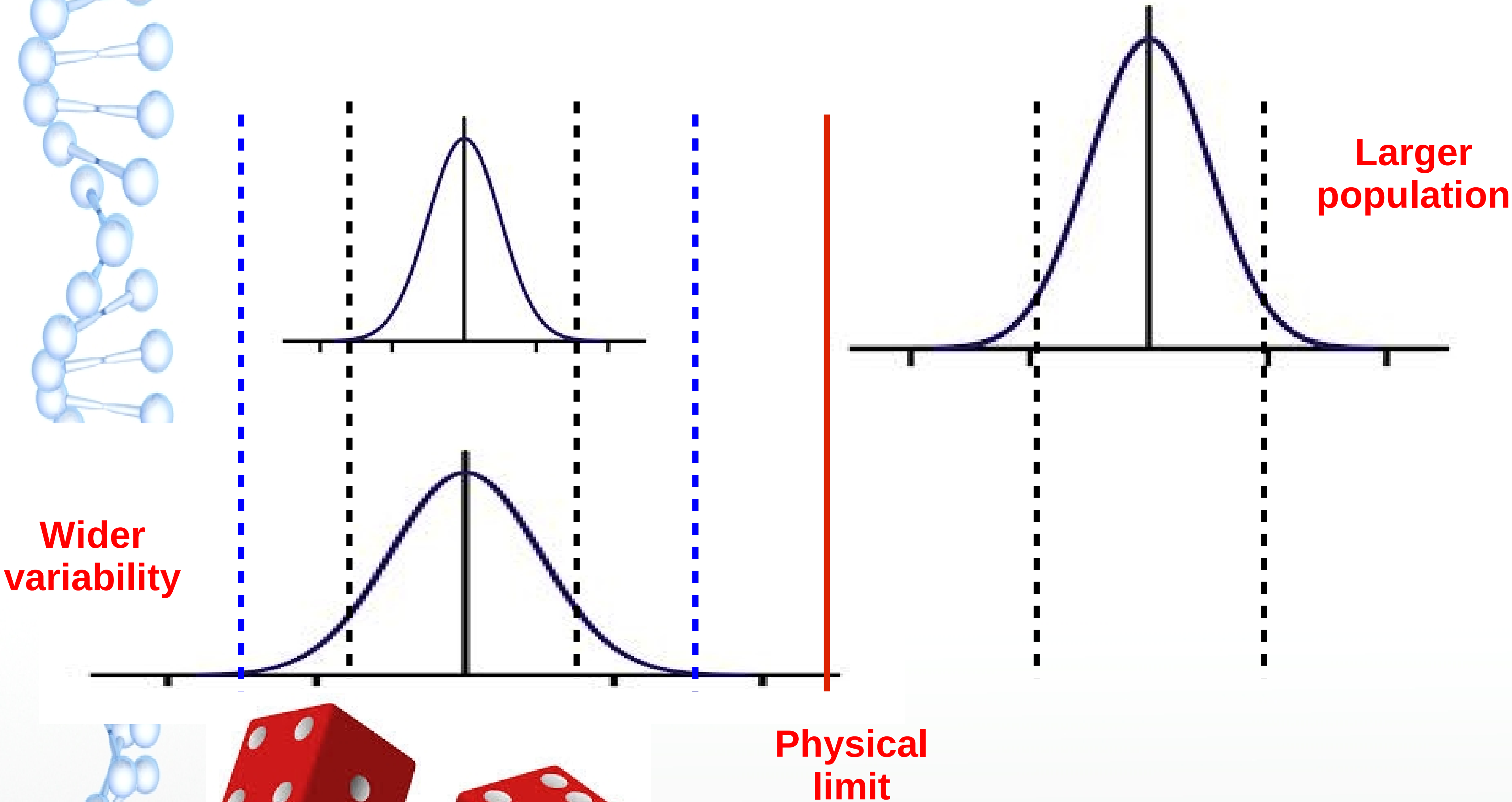

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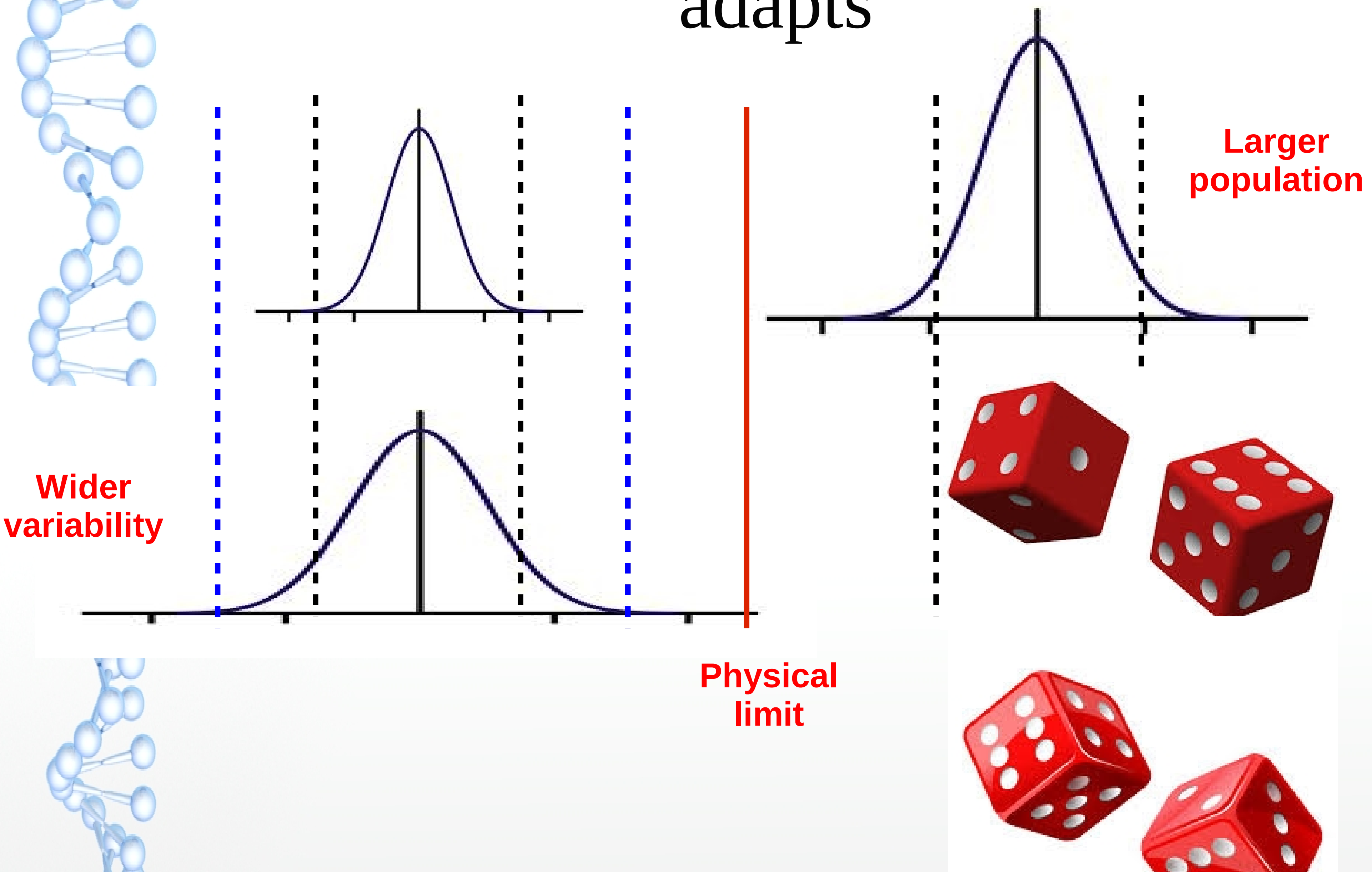

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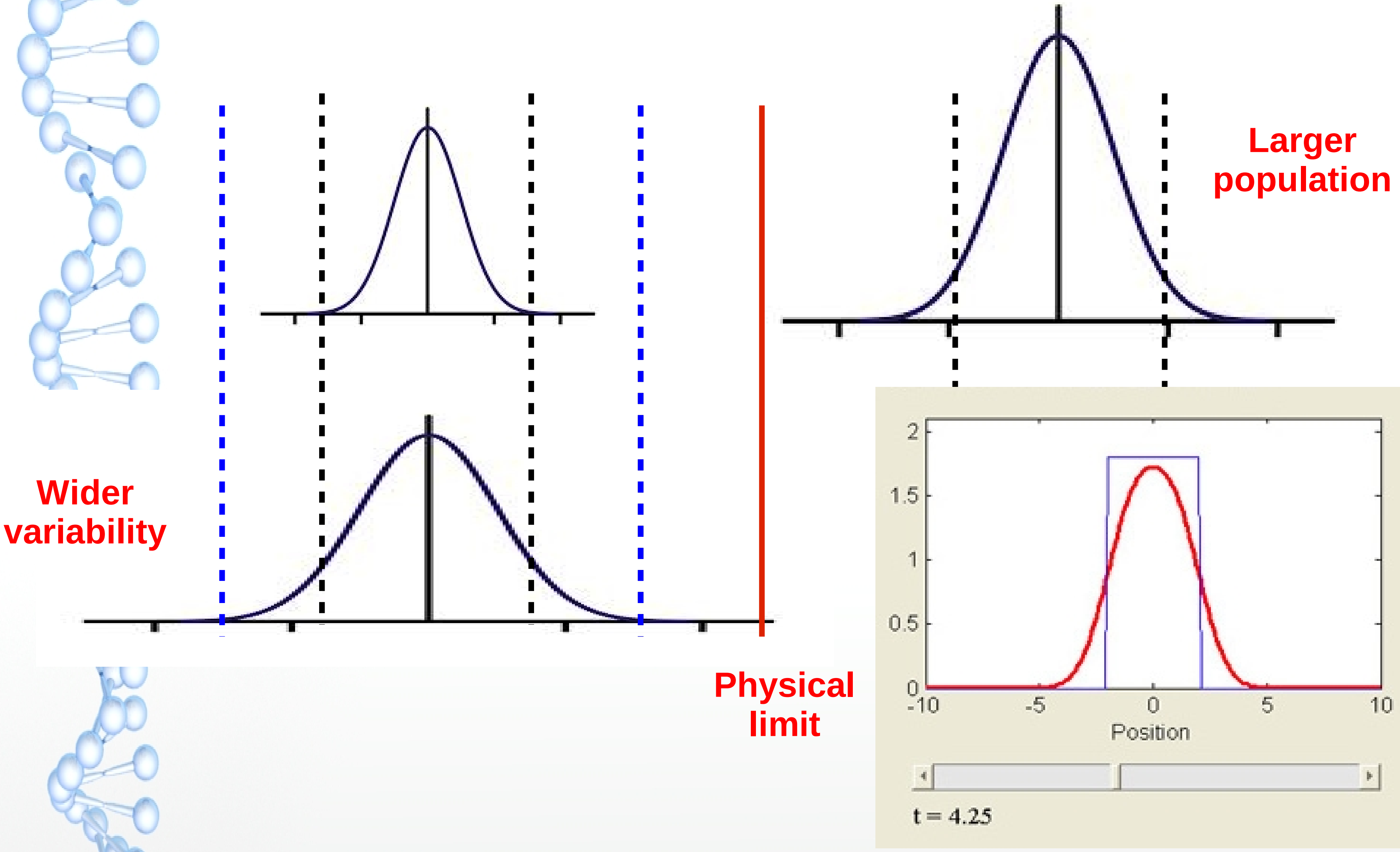
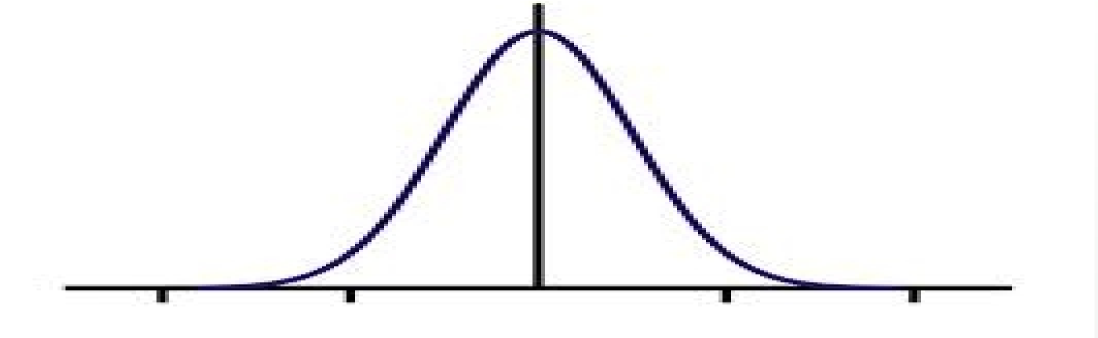


Genetic evolution:
A larger population with a larger mutation rate better adapts

Various models are used to describe evolutionary adaptation

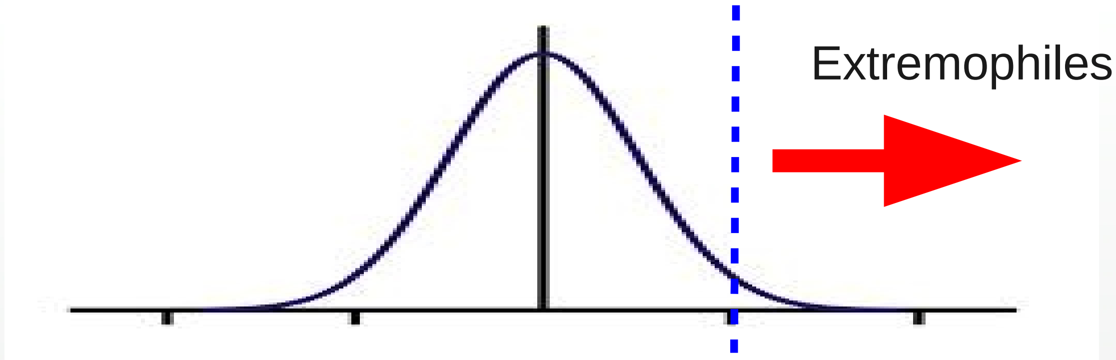
- See Hoffman & Sgro (2011) for a review
  - Simplest form - Breeder's equation (and the multivariate one)
    - R=h^2*S
      - (R-response to selection; h^2 is heratibility, S is selection differential)
- One can use more complex stochastic Monte-carlo models to account for various processes



Planet habitability measures the potential to **develop and sustain** life

Adaptive habitability deals with the planetary scale version of evolutionary adaptation

- One can scale evolutionary adaptation to the planetary scale
- Replace the variability and rate of genetic evolution of a population of a specific species with that of the the whole population of organisms (or even pre-biotic chemical “population”) on a given planet



Adaptive habitability is about the potential to **develop and sustain** life through the response to exo-climate change

- For example: If R_adapt<R_change
  - If phenotypical variability is sufficiently large

    => Survival
  - If phenotypical variability is too small

    => Extinction

    => A living planet can become inhabitable to its current organisms
    - It could be a habitable planet which is “adaptively inhabitable”

Adaptive habitability depends on the evolutionary stage

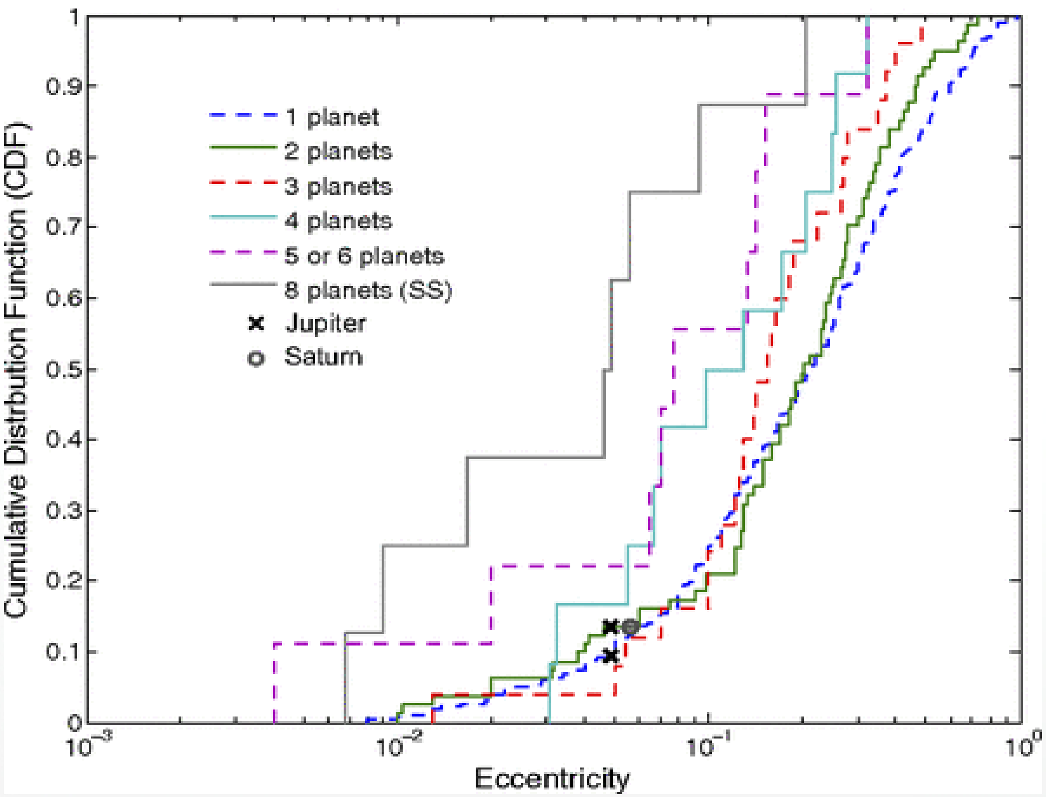
- The adaptability rate can be qualitatively different at the life development (initial), the single-cell (early) and multi-cellular (late) stages
- A planet can be adaptively habitable at the late stage, when life can rapidly adapt, but adaptively inhabitable at the early single-cell stage
- In case of a periodic climate change one can have periodic habitability
- Adaptive habitability can also depend on phase and on the direction of change
- The type of life evolved also depends on the exo-climate change history

Most planets are on eccentric orbits

- The orbit averaged flux on an eccentric orbit

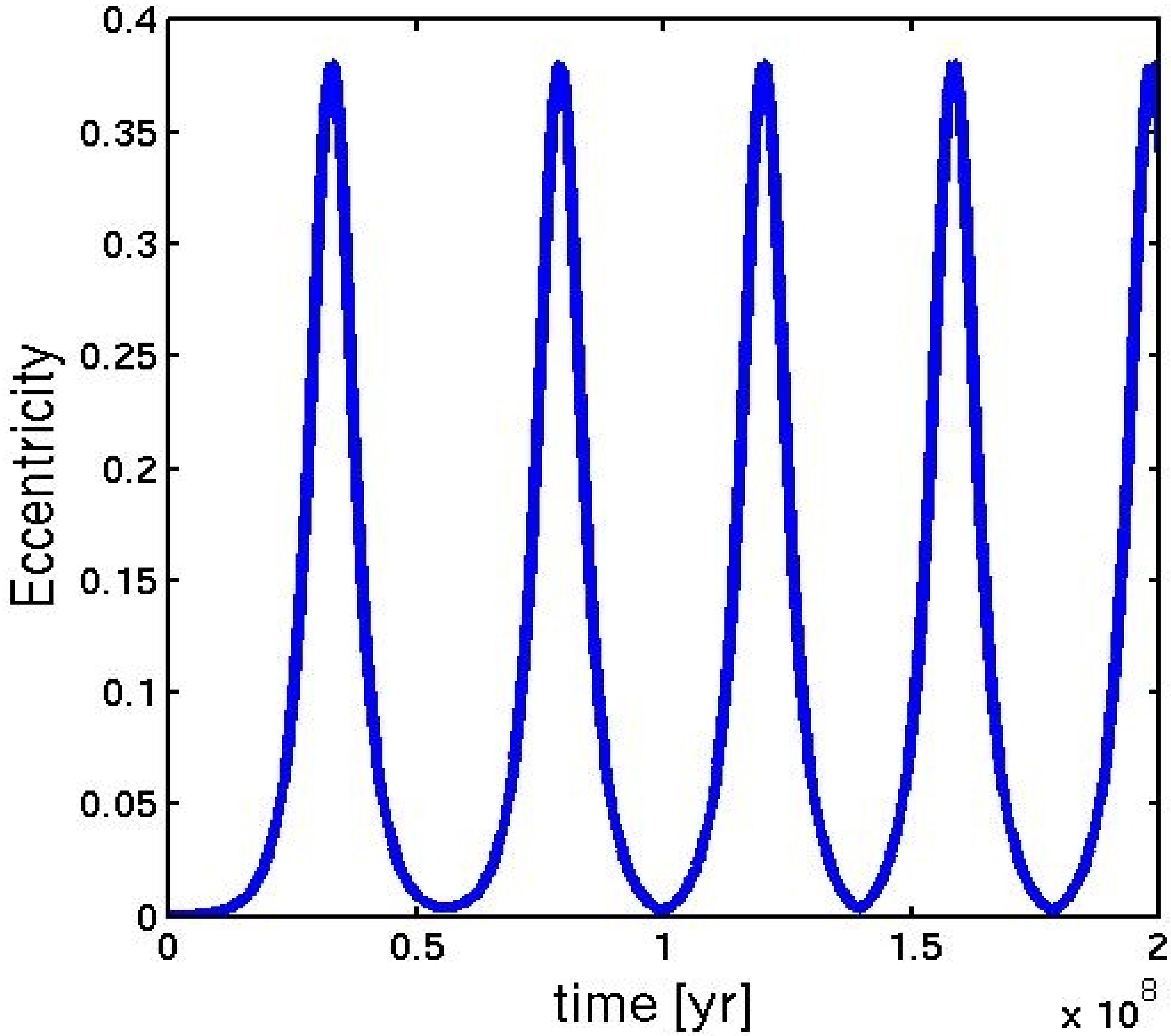
$$\langle F \rangle = \frac{L}{4\pi a^2(1-e^2)^{1/2}}.$$

Williams & Pollard 2002



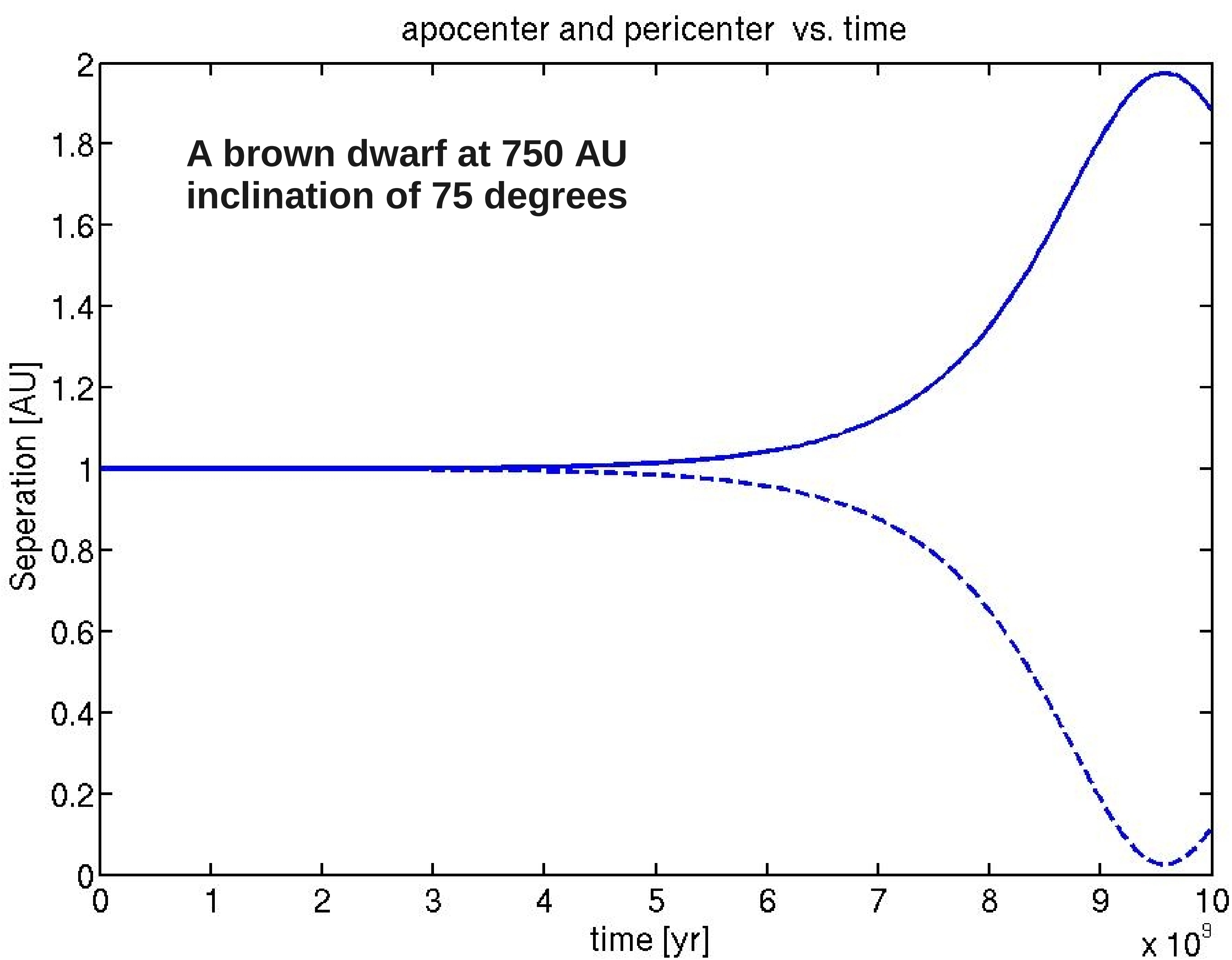
Limbach & Turner 2015

Example:
Secular Kozai evolution

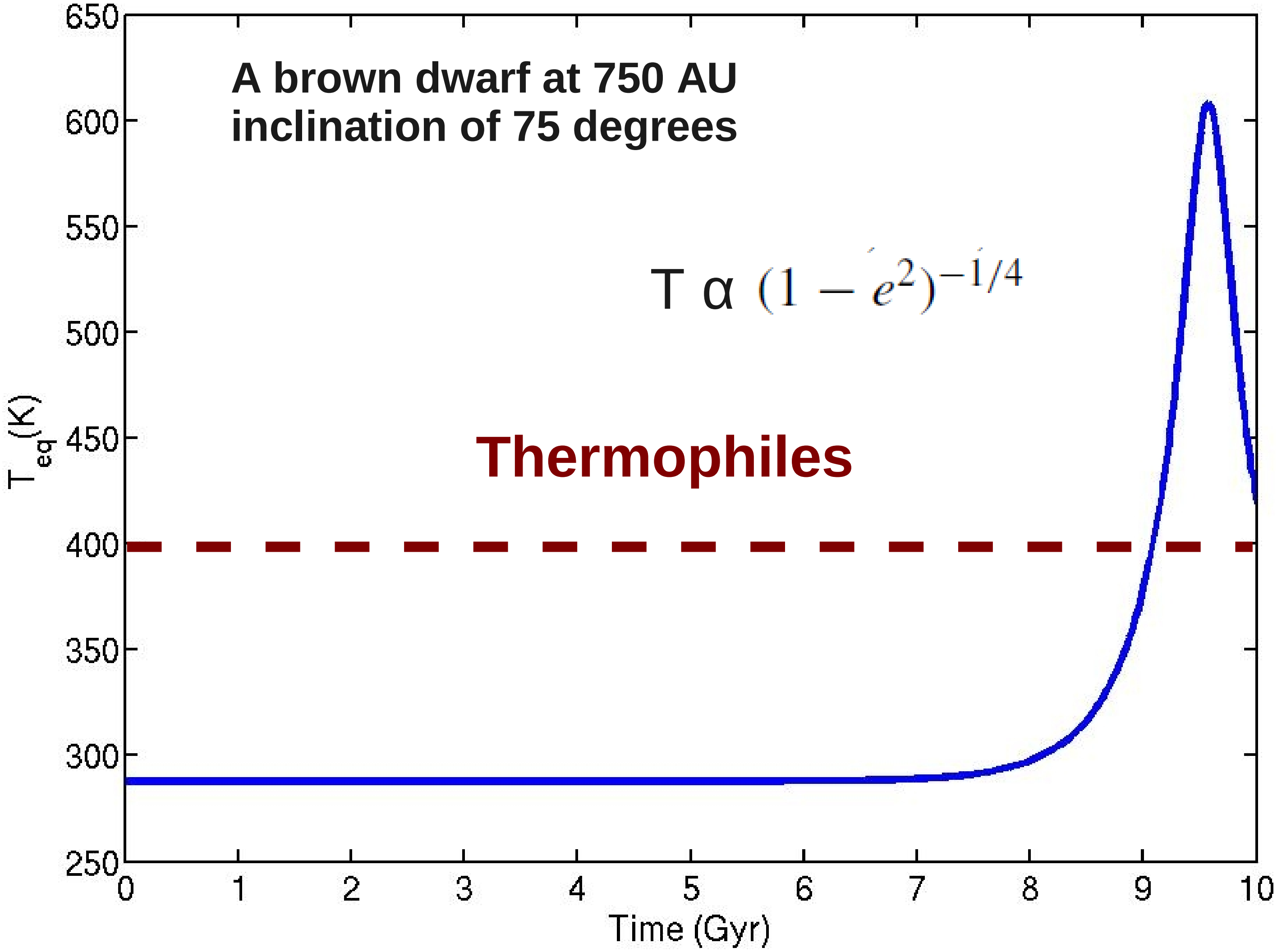


See also Spiegel et al. 2010

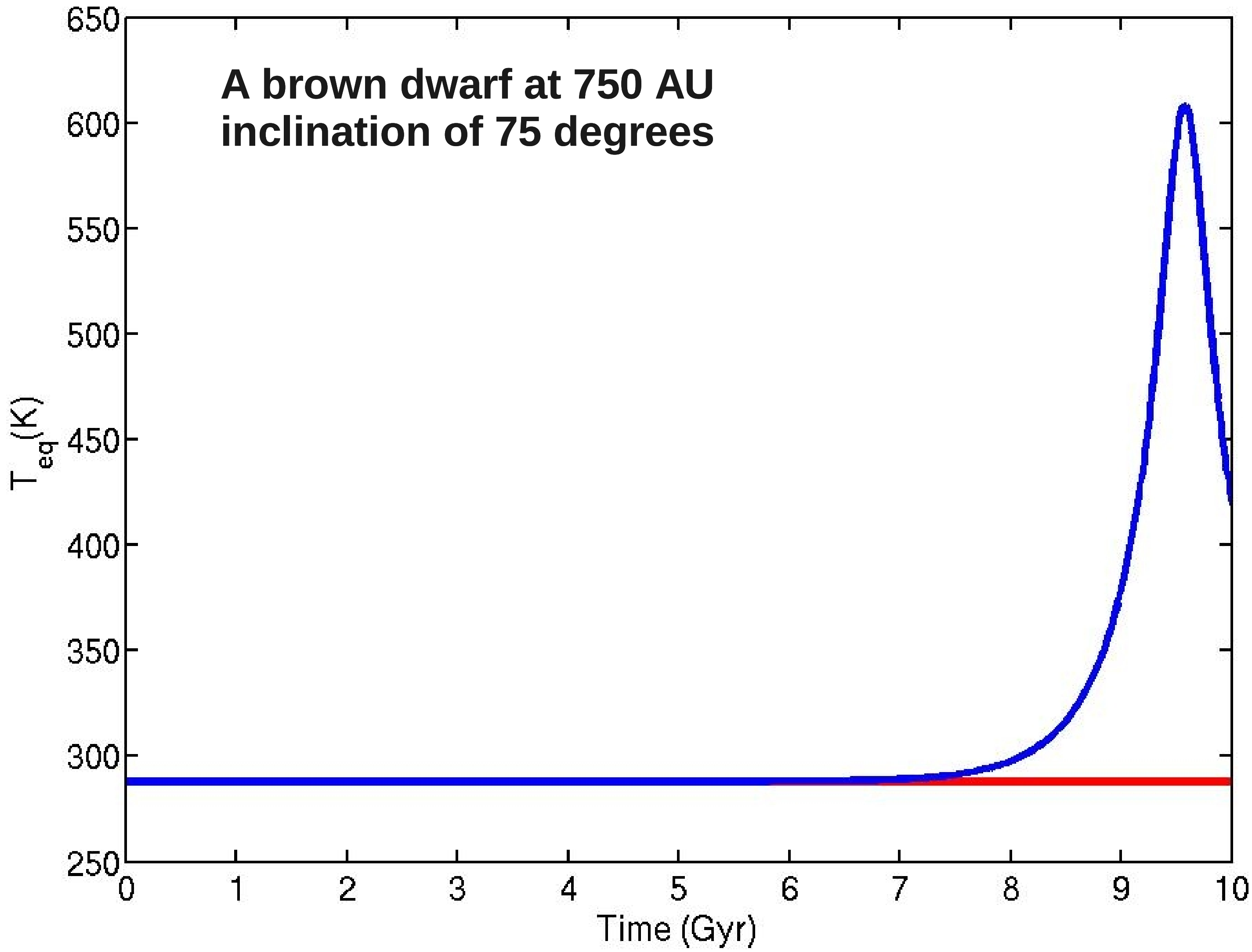
Example:
Secular Kozai evolution can



Long term change may allow for life to adapt... up to a limit



Habitability cares about general relativity !



Other examples

- Planet migration (Kyrs-Myrs)
- Stellar evolution (Myrs-Gyrs)
  - Pre-MS evolution
  - X-ray variability evoltuion
  - Post-MS evolution
- ...

Planetary niche filling:
Late-stage organism population can fill a wide variety of environmental niches

- Planetary organism population at the late stage can extend its effective environmental variability through niche filling
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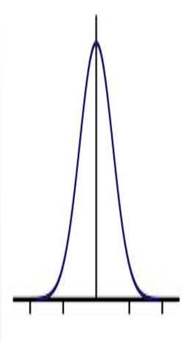

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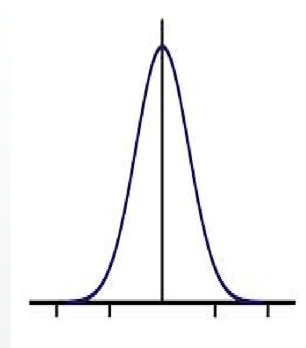

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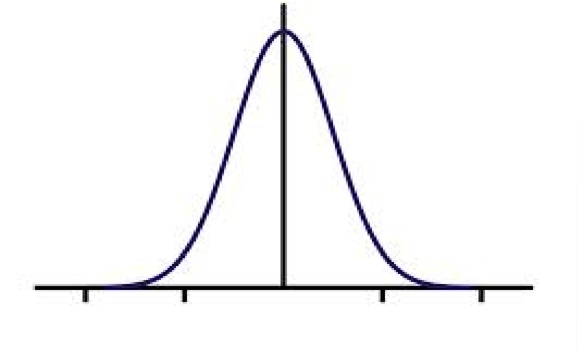

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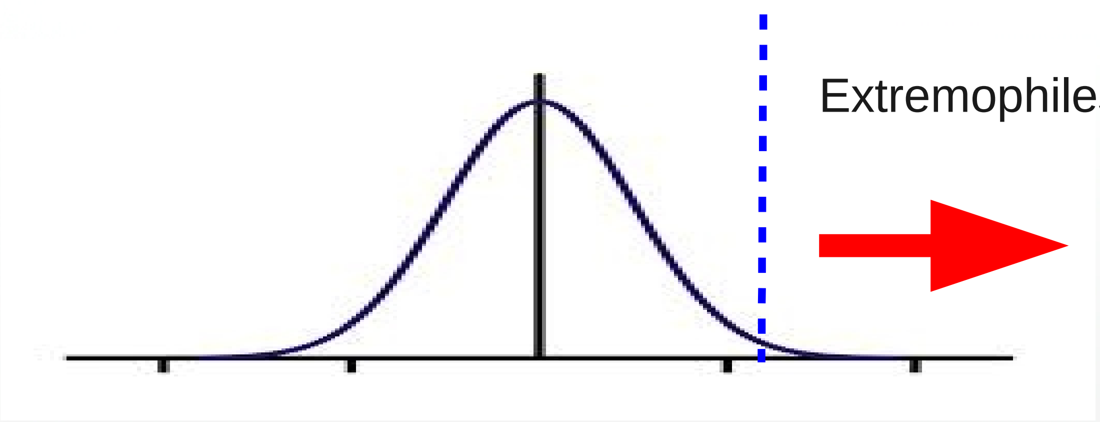
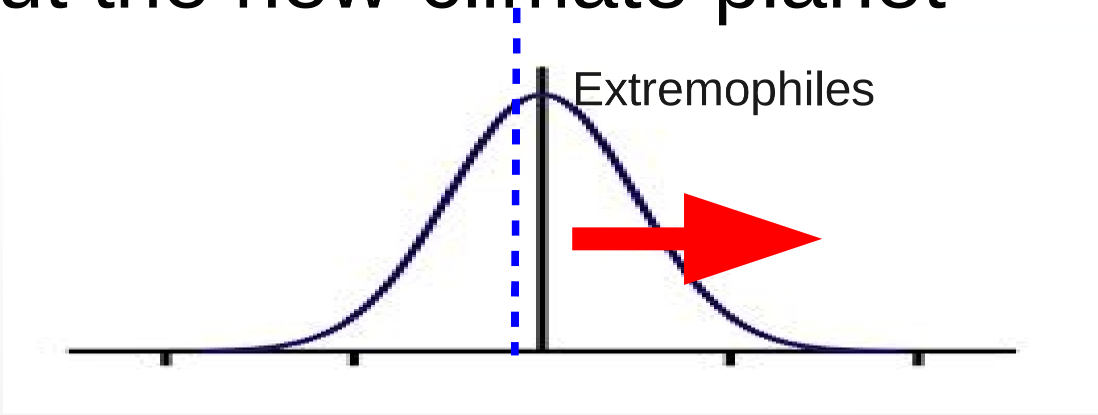


Planetary niche filling:
Late-stage organism population can fill a wide variety of environmental niches

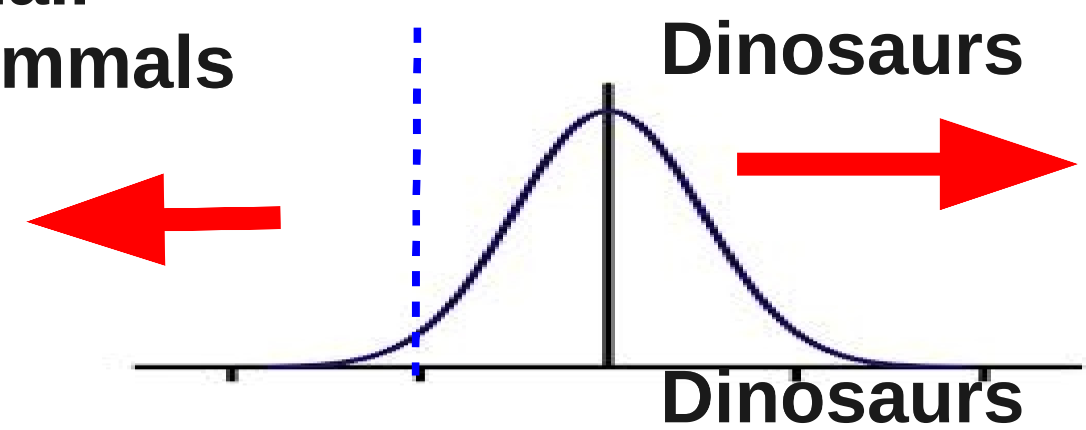
- Planetary organism population at the late stage can extend its effective environmental variability through niche filling
- Through exo-climate change extremophiles of such planets rescue planet habitability and become the dominant species throughout the new-climate planet



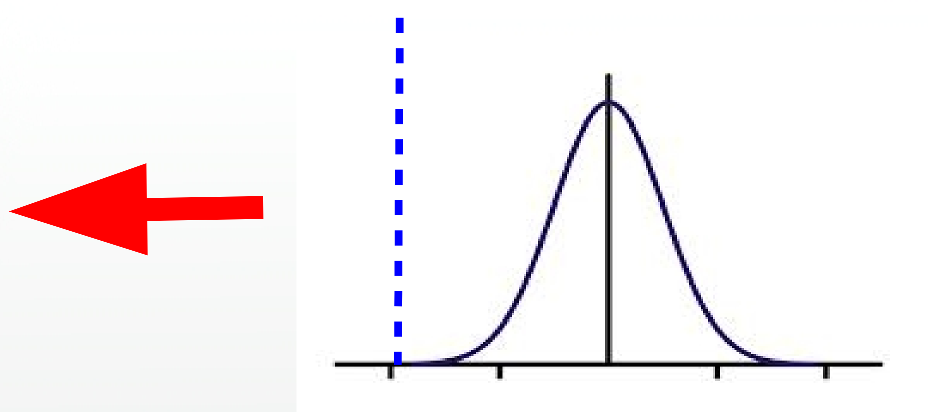
Example:
Prompt climate change
KT asteroid impact

- KT - survival

Small mammals



Late heavy bombardment – extinction ?



Summary

- Complex life evolves though several stages with different timescales
- As a population of organisms evolve they populate a larger range of their potential traits
- At the planetary level life evolve to fill potential niches
- Life can adapt to environmental pressures, if the timescale for change is sufficiently long and/or if the population is large enough and/or large range of extreme niches are filed
- Exo-climate change is a natural phenomena that affect habitability over time
- The rate of change compared to the adaptiveness of life determines the adaptable habitability
- Habitability cares about general relativity