

Mars evolution and habitability: the evolution of paradigms

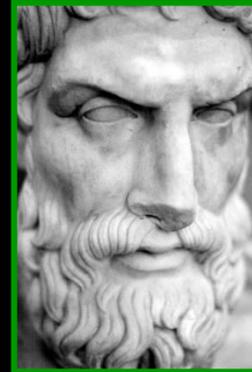
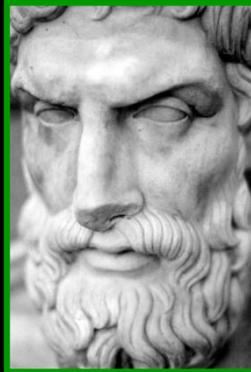
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Jean-Pierre Bibring
John Carter
François Poulet
IAS, Orsay, France

Ninth Mars Conference, Caltech, July 25, 2019

The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.



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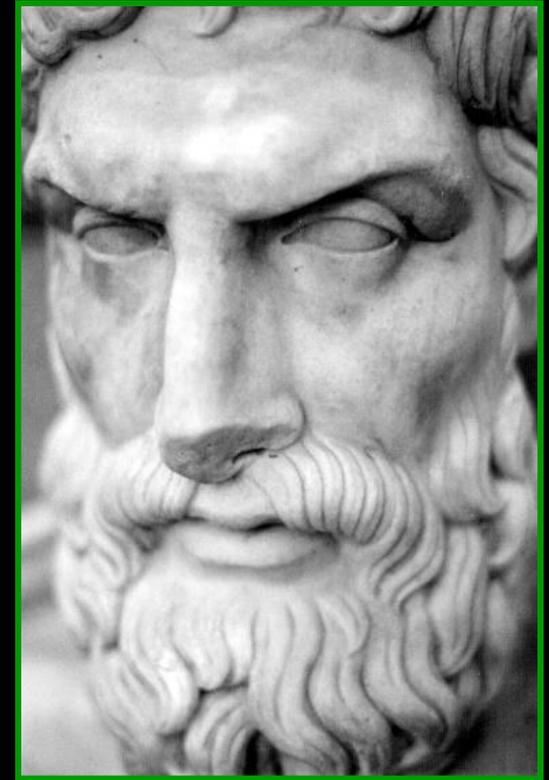
Changes of relevant **paradigms** have paved human History.
Space era, primary with **Mars** missions, is triggering a fundamental
revisiting, which challenges the (obsolete ?) concept of **life** itself.

Planning the future of **Mars space exploration** should be robustly based
on these **changes of paradigms**.



The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

Epicurus



~ 300 BC

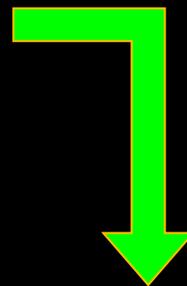
(letter to Herodotus)

infinite (static) cosmos



infinite number of "worlds"

↑
inhabited

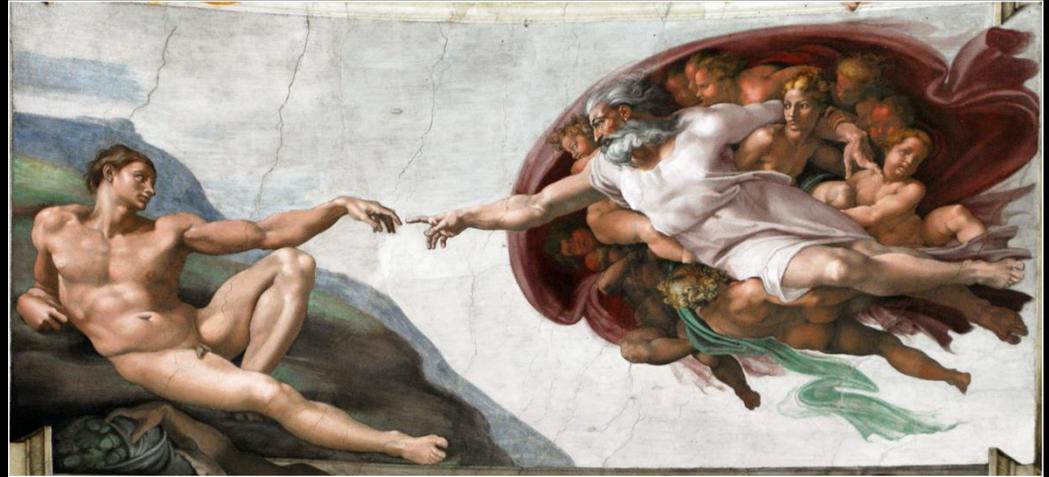


"plurality of worlds"

The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

launching 1.5 millennium of monotheisms

major change of
paradigm



0 BC 0 AC

Earth / life created **central, unique, immobile**

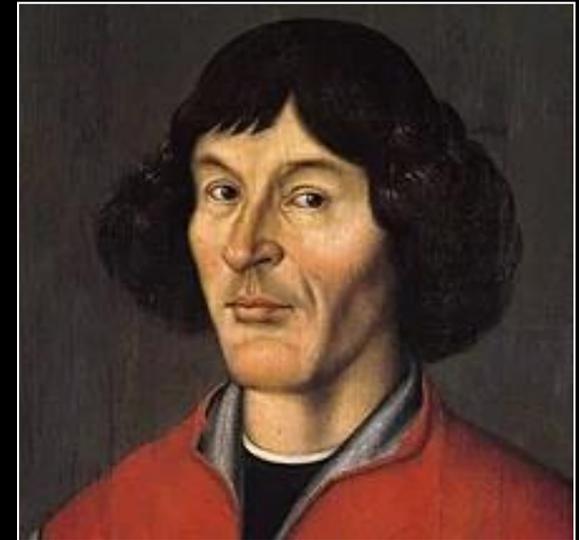
~~plurality of worlds~~

The farthest we access human records,
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major change of
paradigm

Copernicus

1543



Earth a **standard moving** planet

The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

major change of
paradigm

G. Bruno

1583



Earth a standard moving planet

Stars are **Suns** + Universe is **infinite**

The farthest we access human records,
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major change of
paradigm

G. Bruno

1583

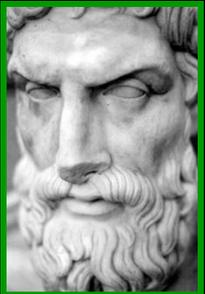


Earth a standard moving planet

Stars are Suns + Universe is infinite

back to

plurality of worlds



The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

after 1.5 millennium of monotheisms



G. Bruno

1583



1548 - 1600

↑
plurality of worlds

The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

4 centuries of Physics

1600 → ~ now

major change of
paradigm

laws are universal

same laws operate at all scales in the Universe

→ deep trend to “unify”

The farthest we access human records,
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4 centuries of Physics

1600 → ~ now

major change of
paradigm

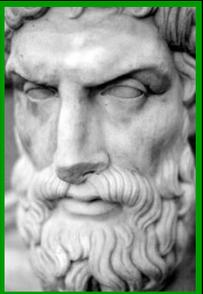
laws are universal

same laws operate at all scales in the Universe

+ syllogism: same causes drive same effects

justifies

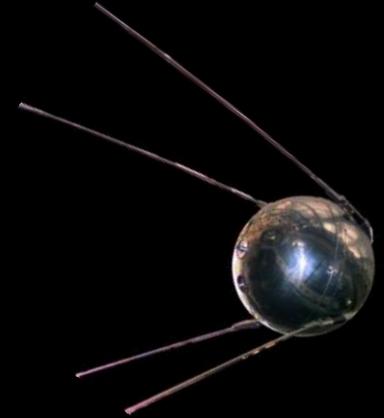
plurality of worlds



The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.



4 centuries of Physics



till the space age

(accepted dogma up to
essentially **now** !)



plurality of worlds

The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

(to be) presently violently
challenged



plurality of worlds

The farthest we access human records,
the **existence of life** beyond **Earth** is addressed.

together with the
drivers of **evolution**

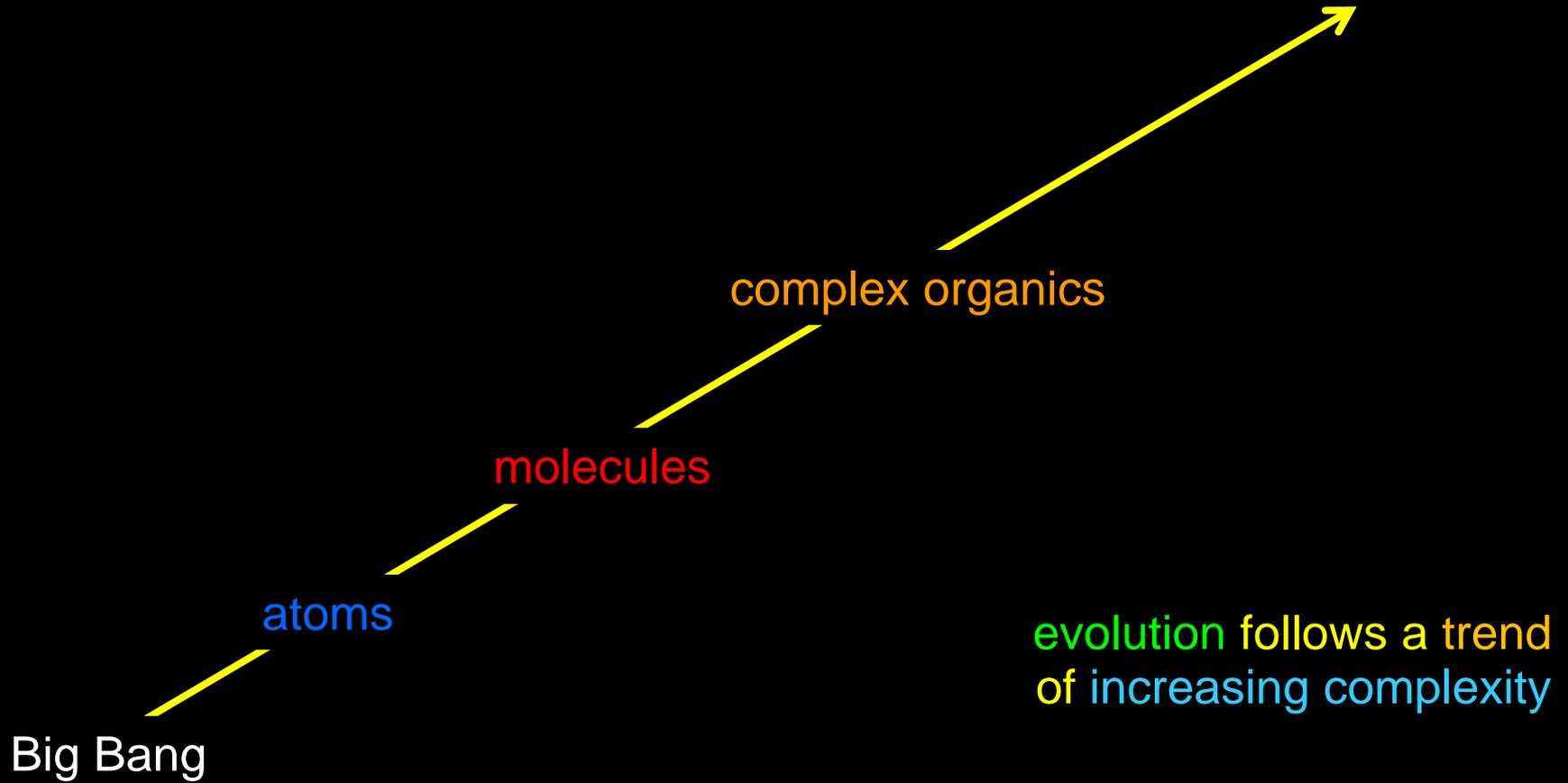


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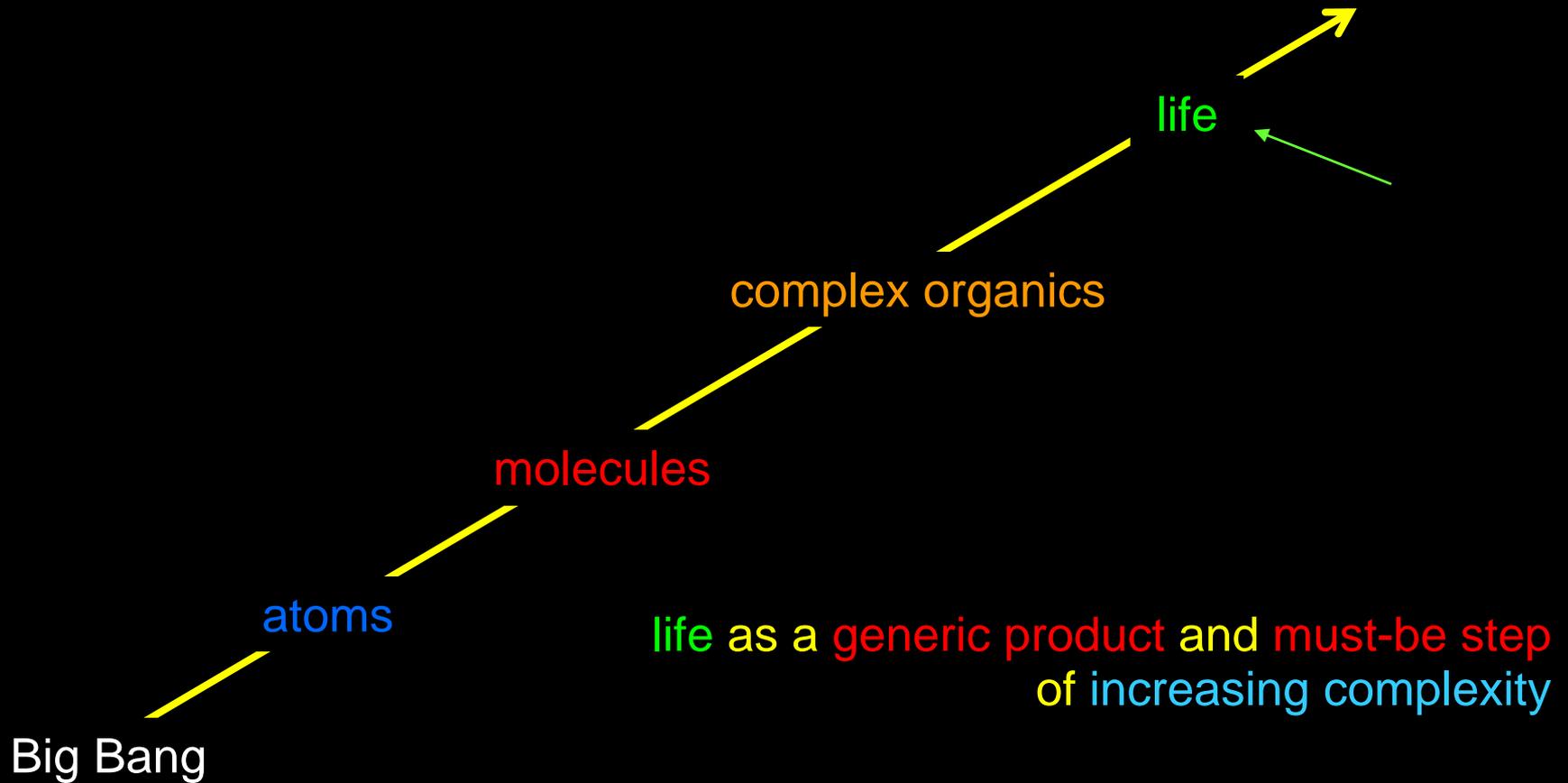


plurality of worlds

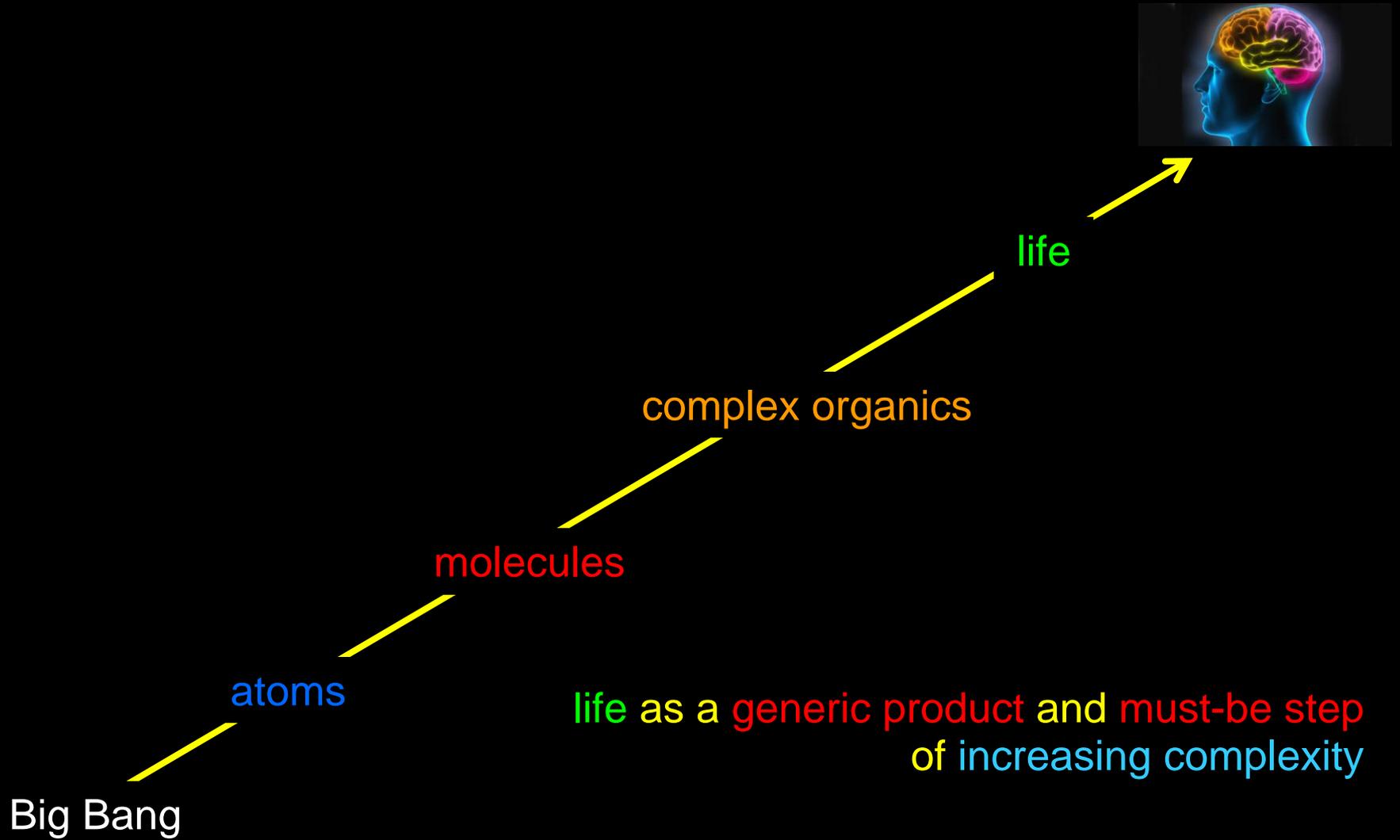
evolution : envisioned via dogma



evolution / life: envisioned via dogma



evolution / life: envisioned via dogma



evolution / life: envisioned via dogma

profoundly anti-Darwinian!

Big Bang

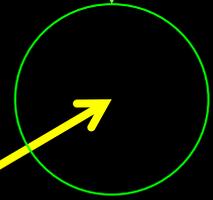
atoms

molecules

complex organics

life

life as a generic product and must-be step
of increasing complexity

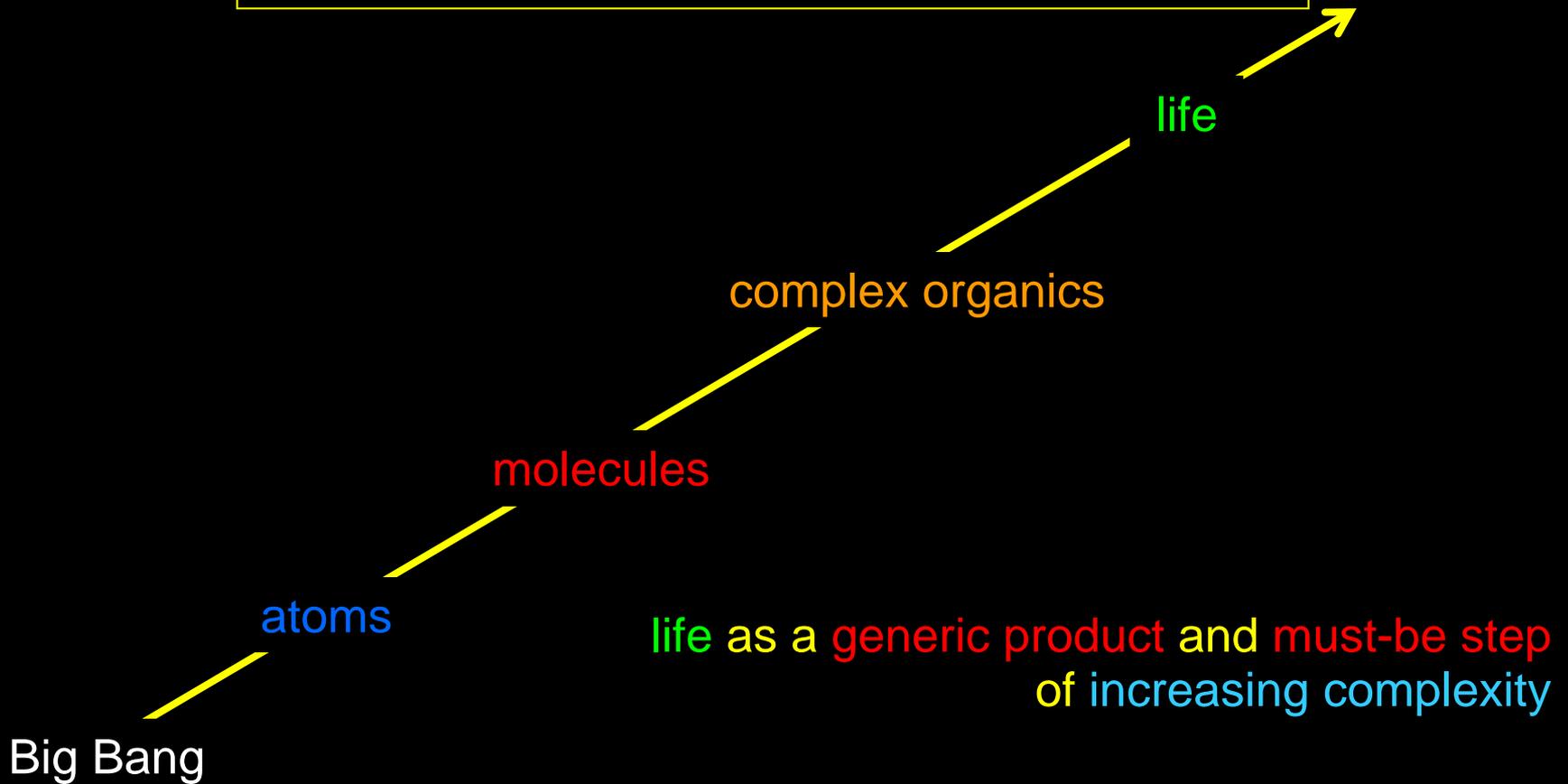


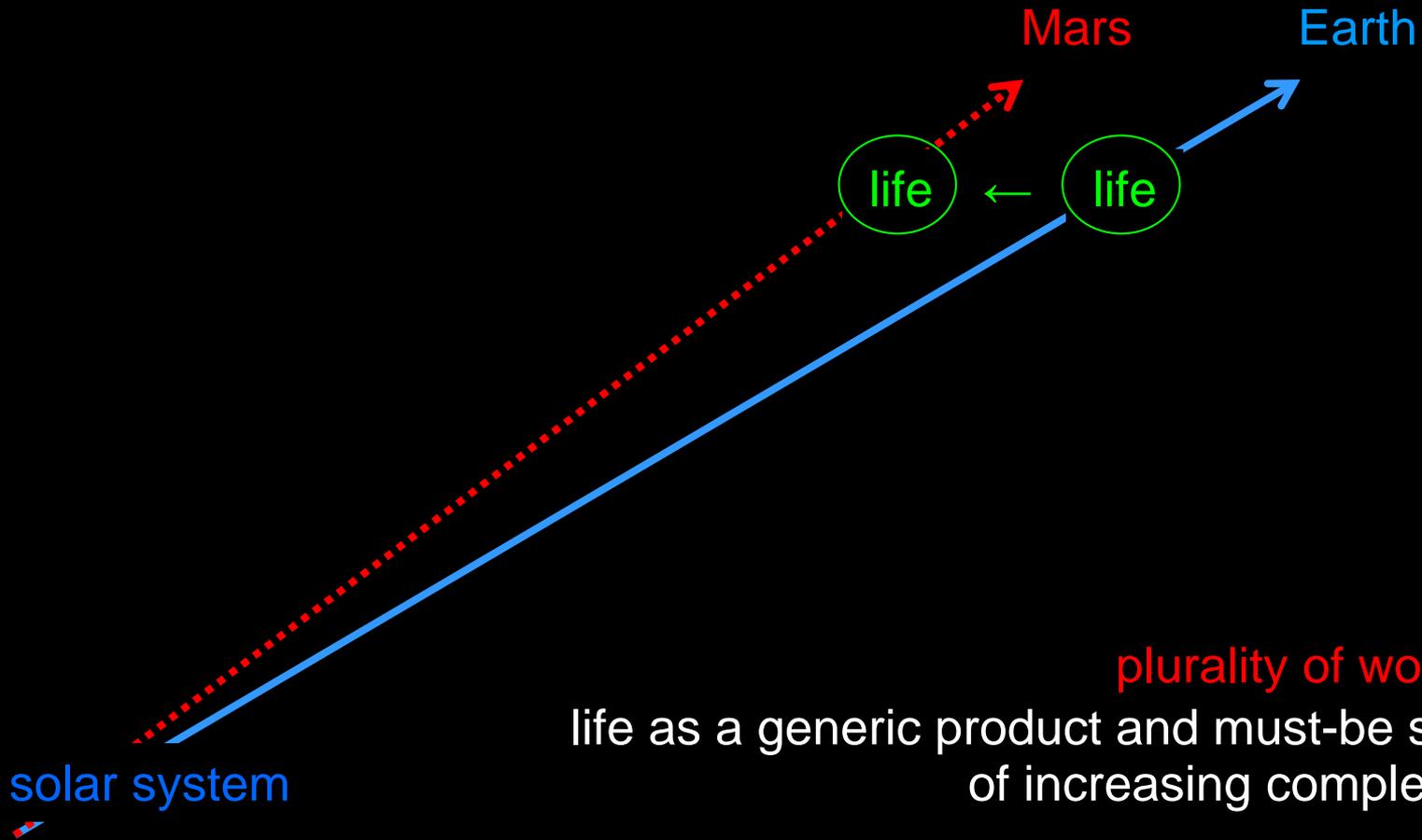
dogma

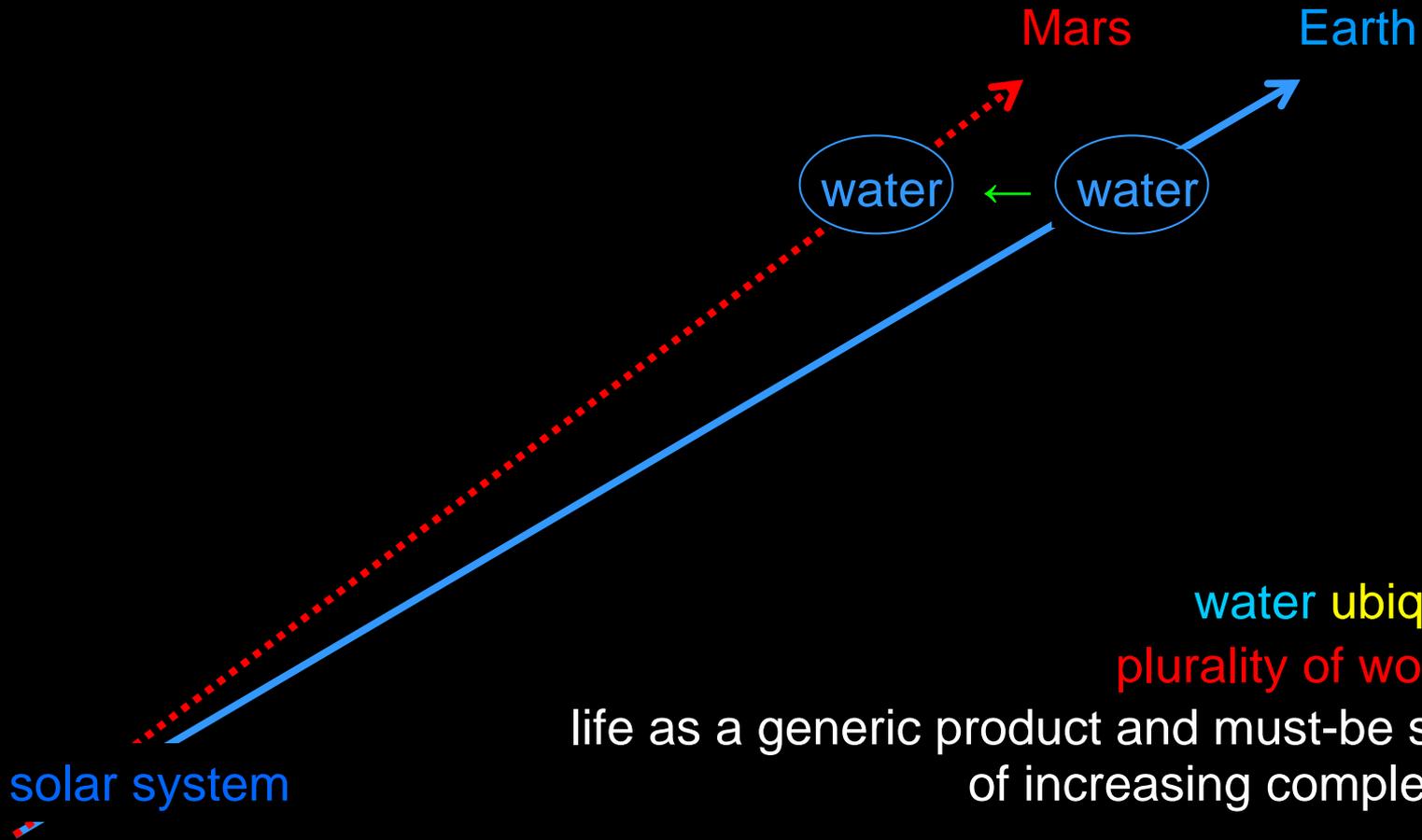
life: generic product of increasing complexity
life: spread at large scale within the Universe

dogma

water ↔ life
water: spread at large scale within the Universe







solar system

Mars

Earth

water

water

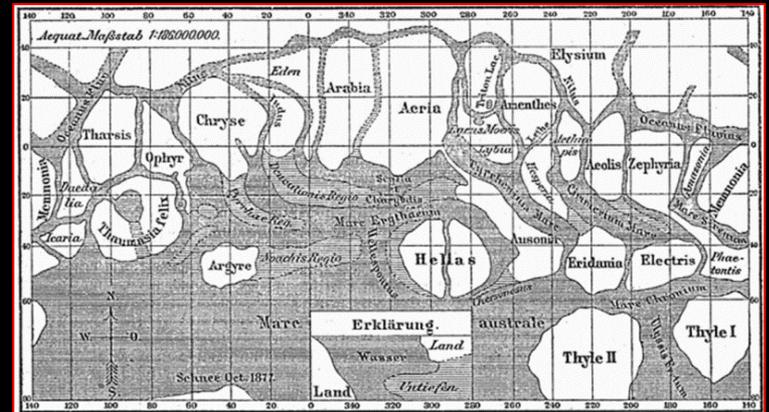
water ubiquity

plurality of worlds

life as a generic product and must-be step of increasing complexity

Mars

life water

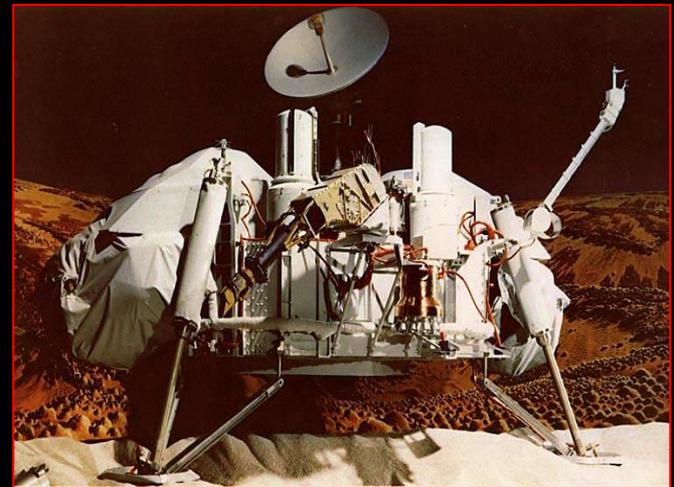


Schiaparelli, *Canali*, 1877

Mars

life water

Viking prime goal:
to characterize Martian metabolism



Viking, 1976

Mars

life water

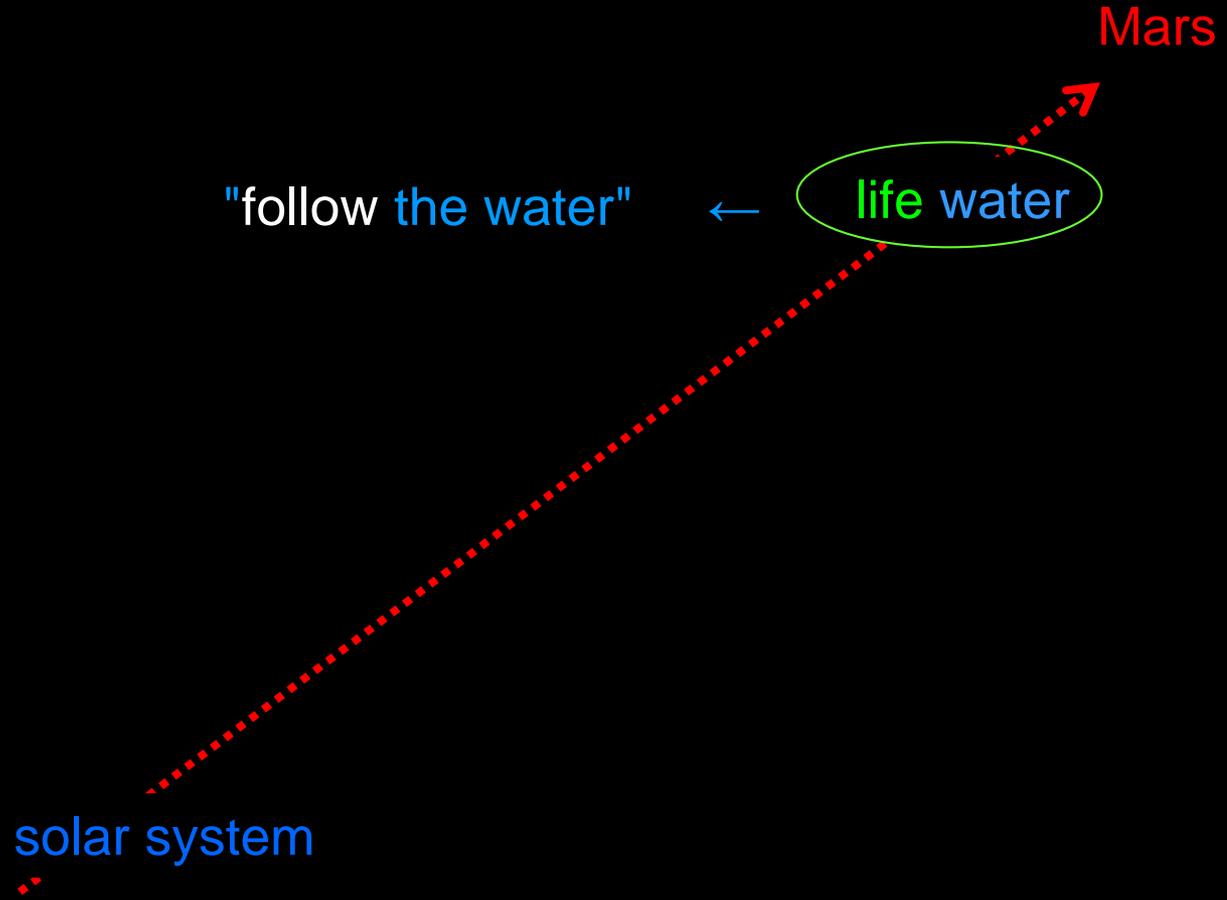
first astrobiological experiments

Viking prime goal:
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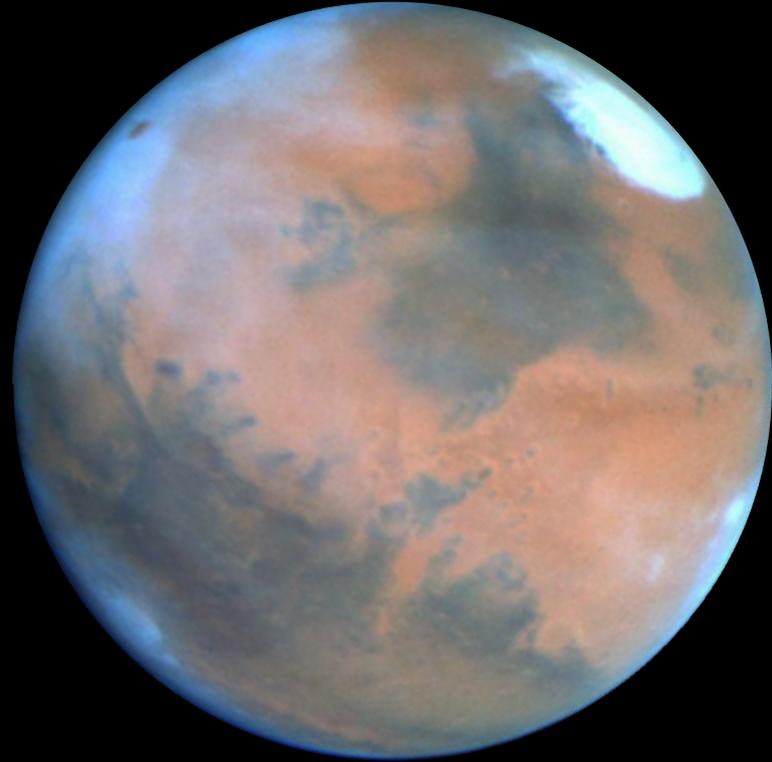
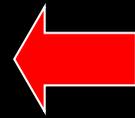
Viking, 1976

...till recently...





ancient ?



today

ancient
Mars

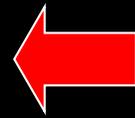


similar planets... both would have been habitable ?!

ESA / Mars Express data have triggered a profound revisiting of Mars History, based on mineralogy

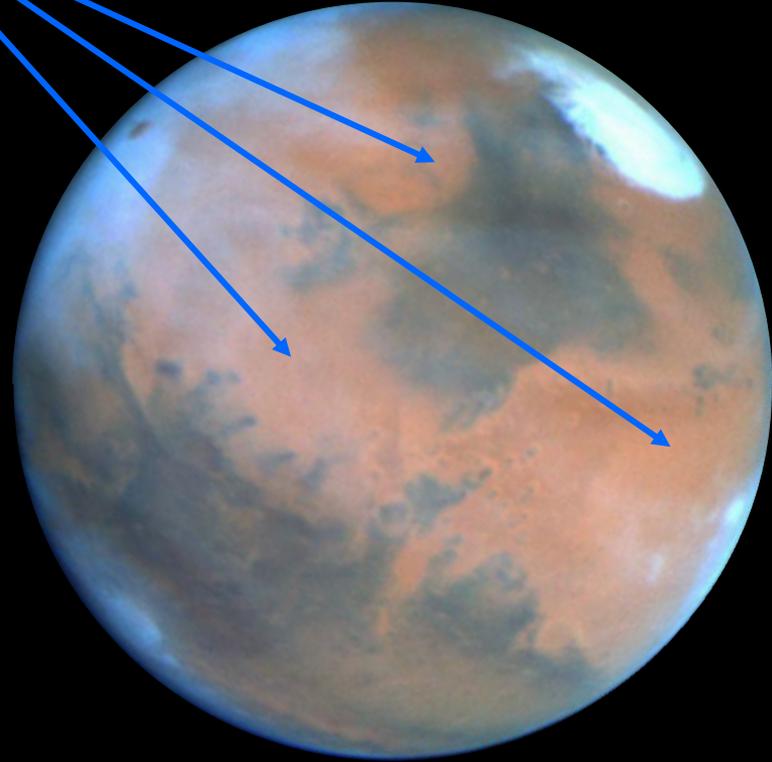
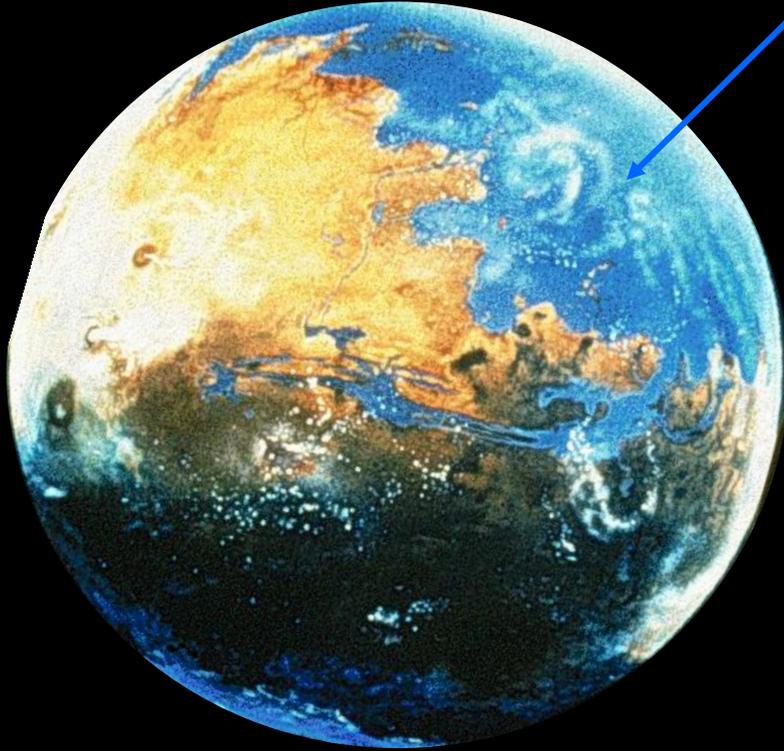


ancient ?



today

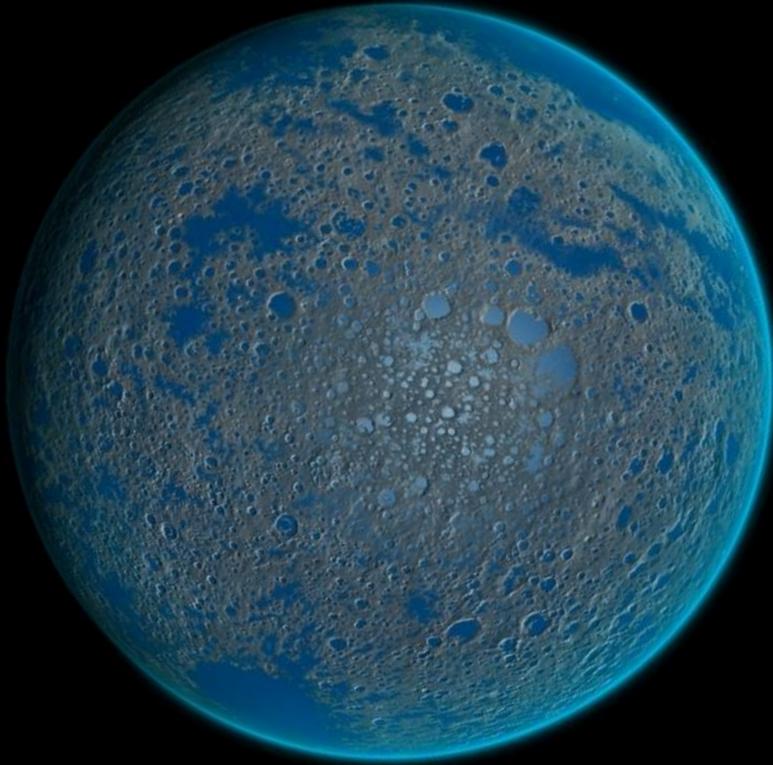
Liquid water neither covered
the red areas, nor is
responsible for Mars being red!



But: liquid water might have covered **Mars** in the **ancient** past, before a global climatic change, followed by its surficial reddening



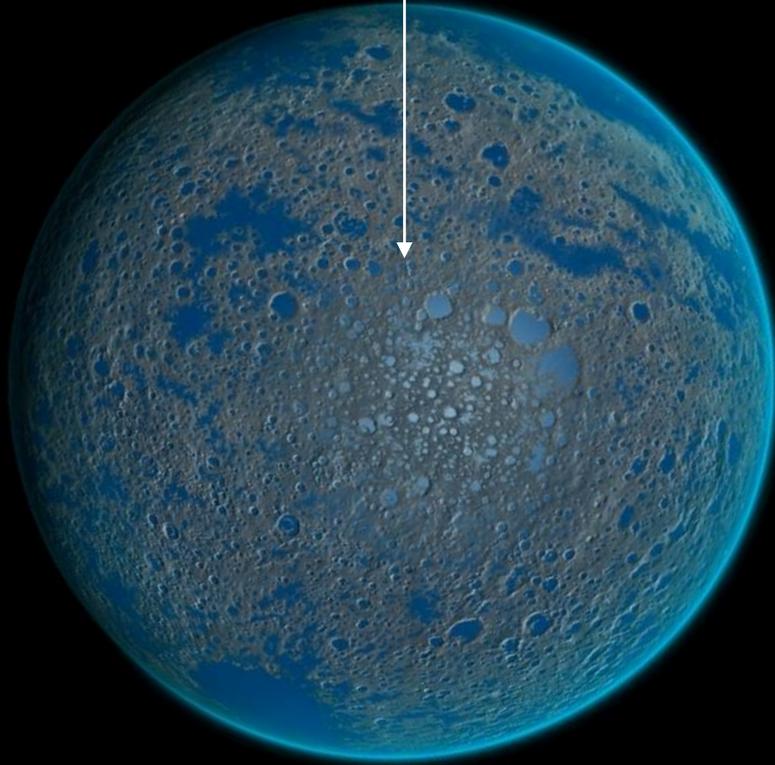
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in its ancient past



There still exist at **Mars** ancient terrains having **preserved** this record: **favoured** sites to be explored!
(proposal **now** percolating)

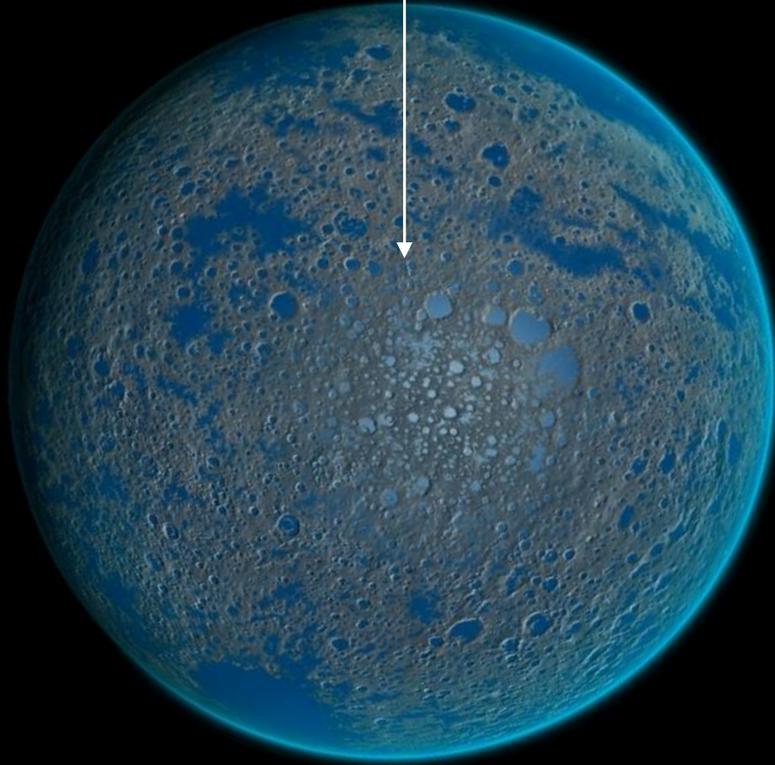


in its ancient past



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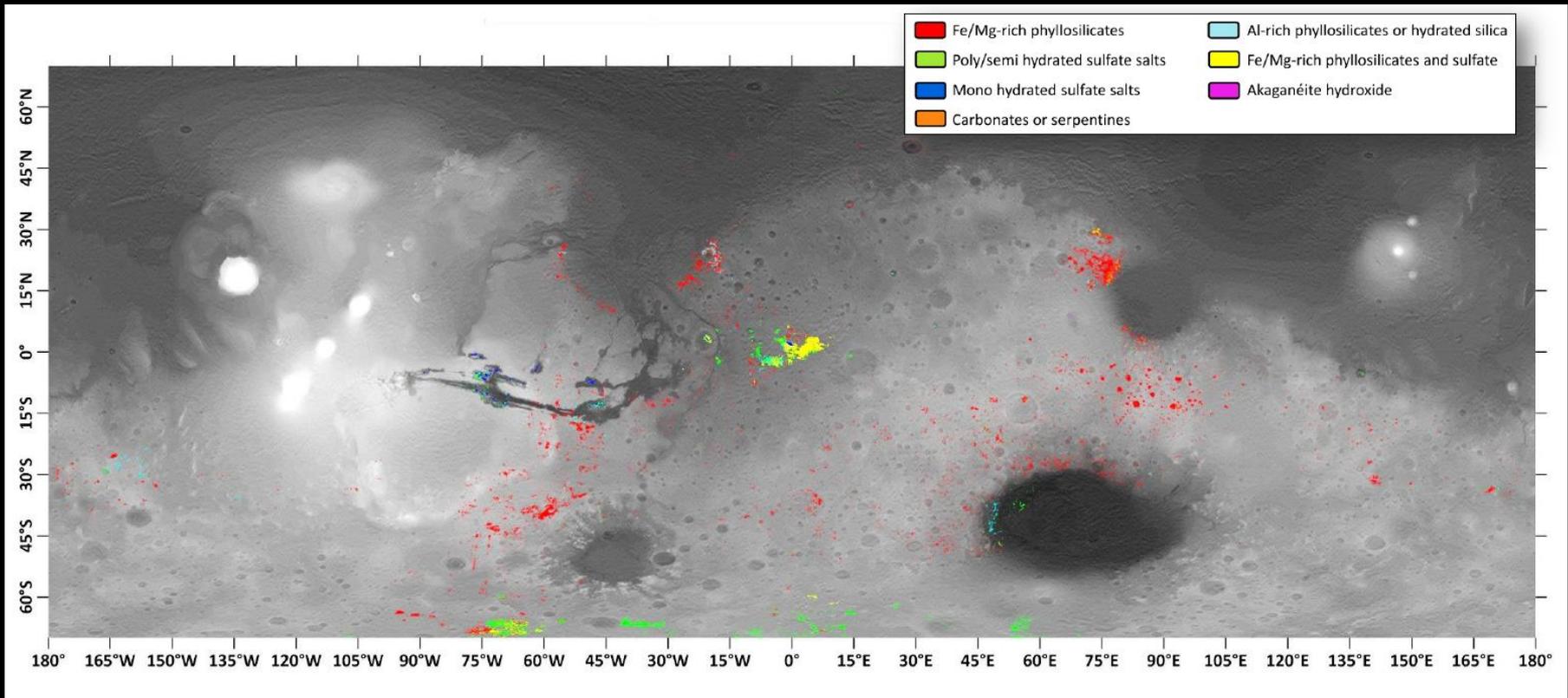
Go Phyllosian !



in its ancient past

major change of
paradigm

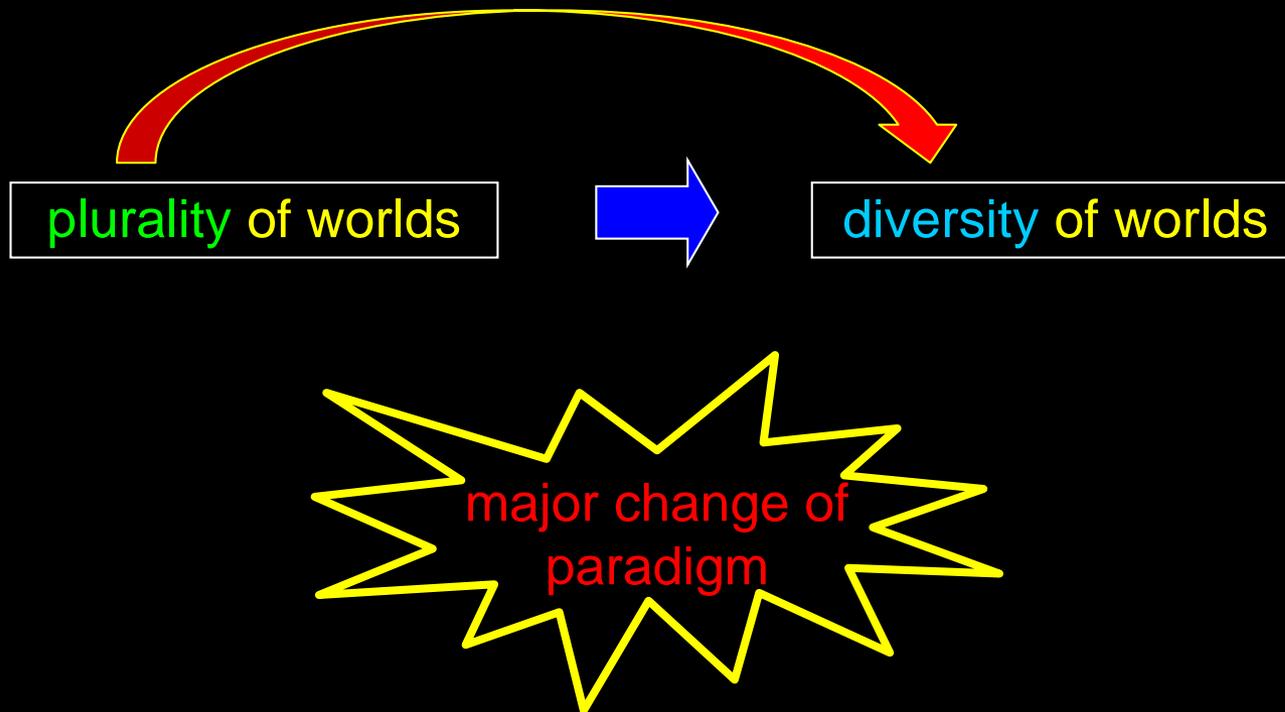
OMEGA/MEx and CRISM/MRO NIR hyperspectral coverage have enabled to identify 10^5 's spots with **aqueously** altered minerals



John Carter

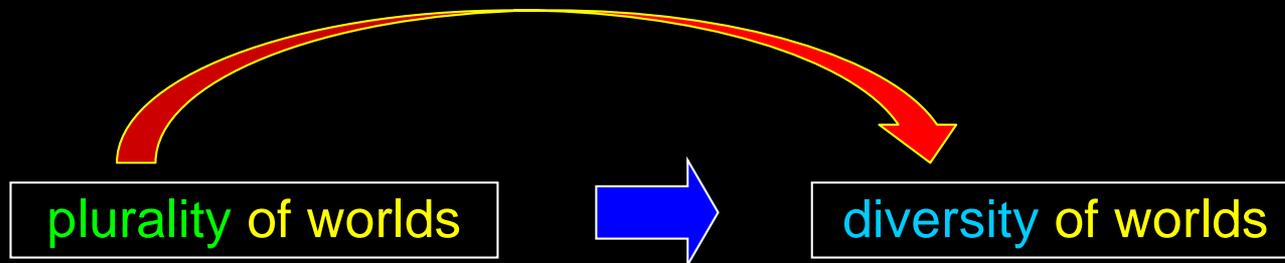
→ The **evolution** of **alteration** records that of **Mars** environment: does increased **diversity** translates an increased **habitability** ? ←

The **space exploration** of the solar system, coupled to the **identification of thousands of extra-solar planetary system**, is revealing the huge degree of **diversity** as the new feature characterizing the **evolution**, at all time/space scales.



What drives the **diversity** of **evolutionary** pathways ?

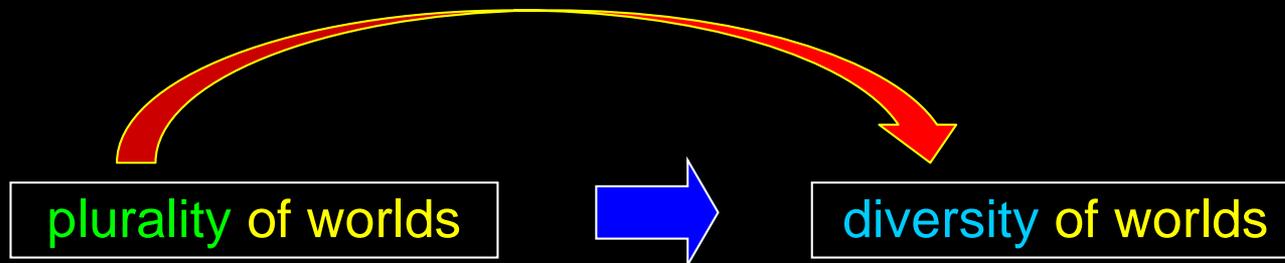
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Processes (laws) are indeed **generic**, but do not solely drive the **evolution**: the forms they take, in their huge variety of possibilities triggered by **contingencies**, drive the **huge diversity** of **evolutionary pathways**.

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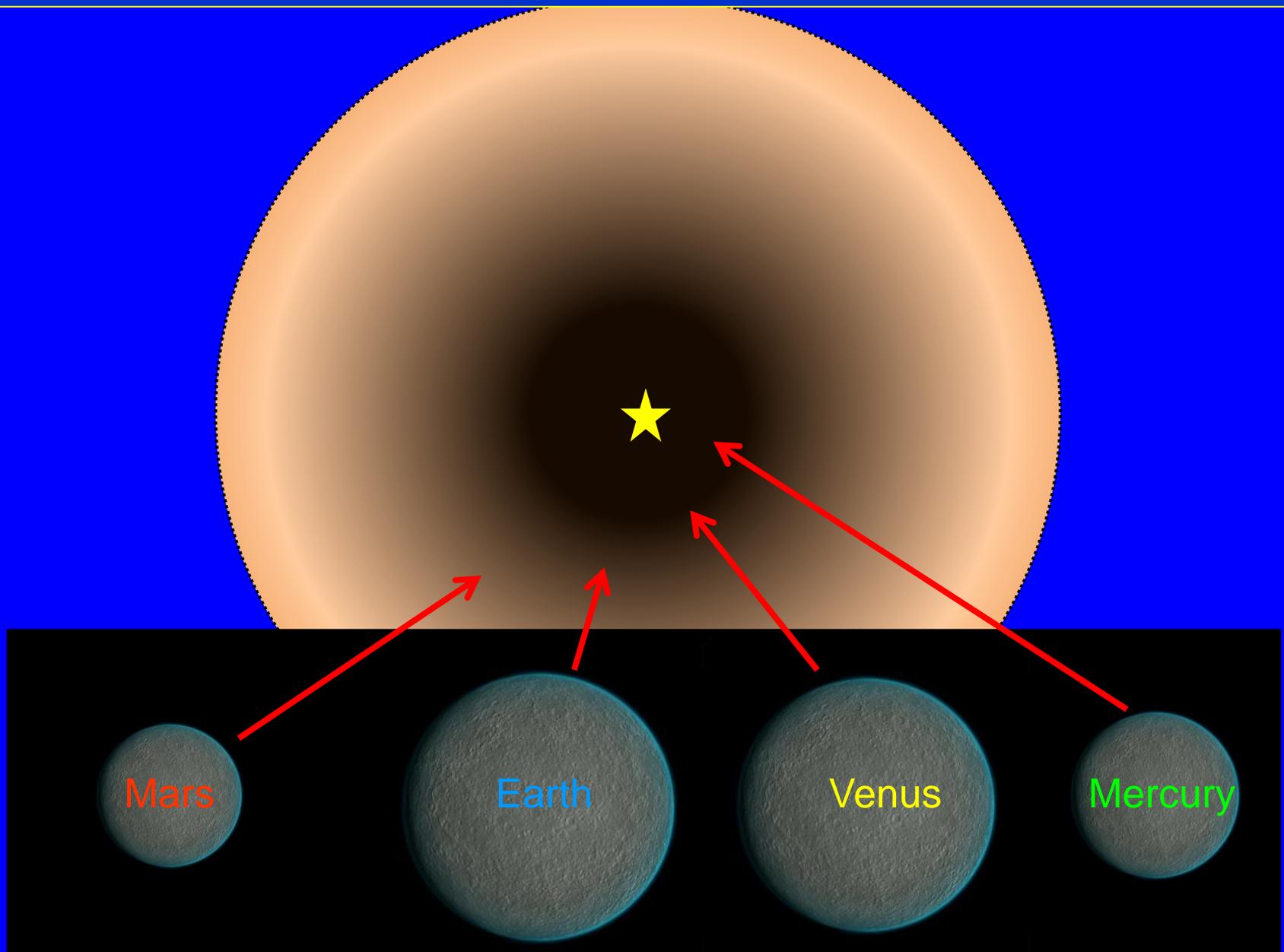


Processes (laws) are indeed generic, but do not solely drive the evolution: the forms they take, in their huge variety of possibilities triggered by contingencies, drive the huge diversity of evolutionary pathways.

For **Earth** and terrestrial planets, examples of their **contingent** triggers are (already) numerous:

highly specific **giant planet migration** (to account for mass distribution),
highly specific **giant impacts**, having triggered
highly specific **plate tectonics**, **water and CO₂** history, **atmospheric evolution**

To account for the specific mass distribution of inner planets, a specific migration has been proposed, to form a highly confined disk.



highly contingent
double migration

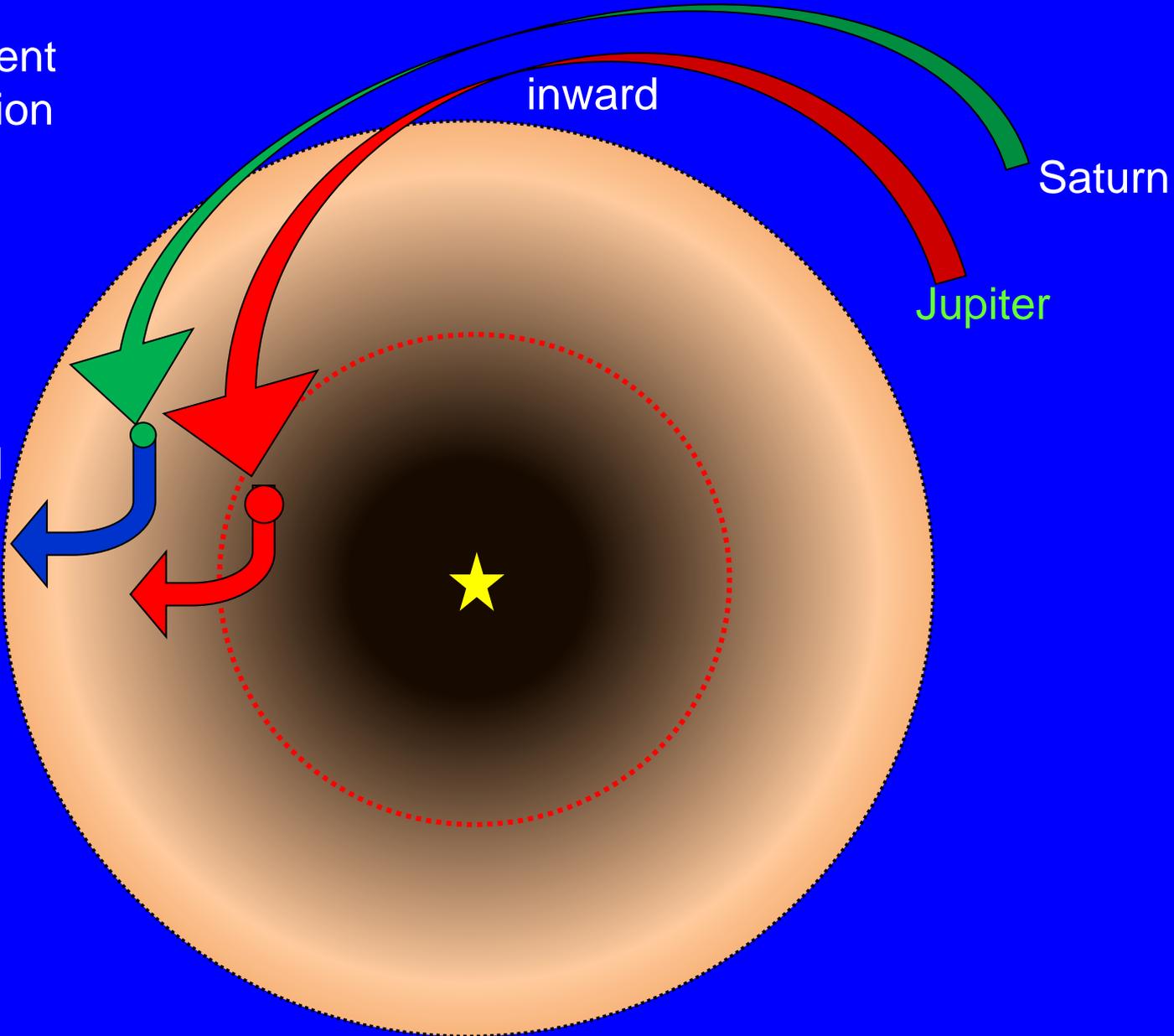
inward

Saturn

Jupiter

outward

given their
mass ratio

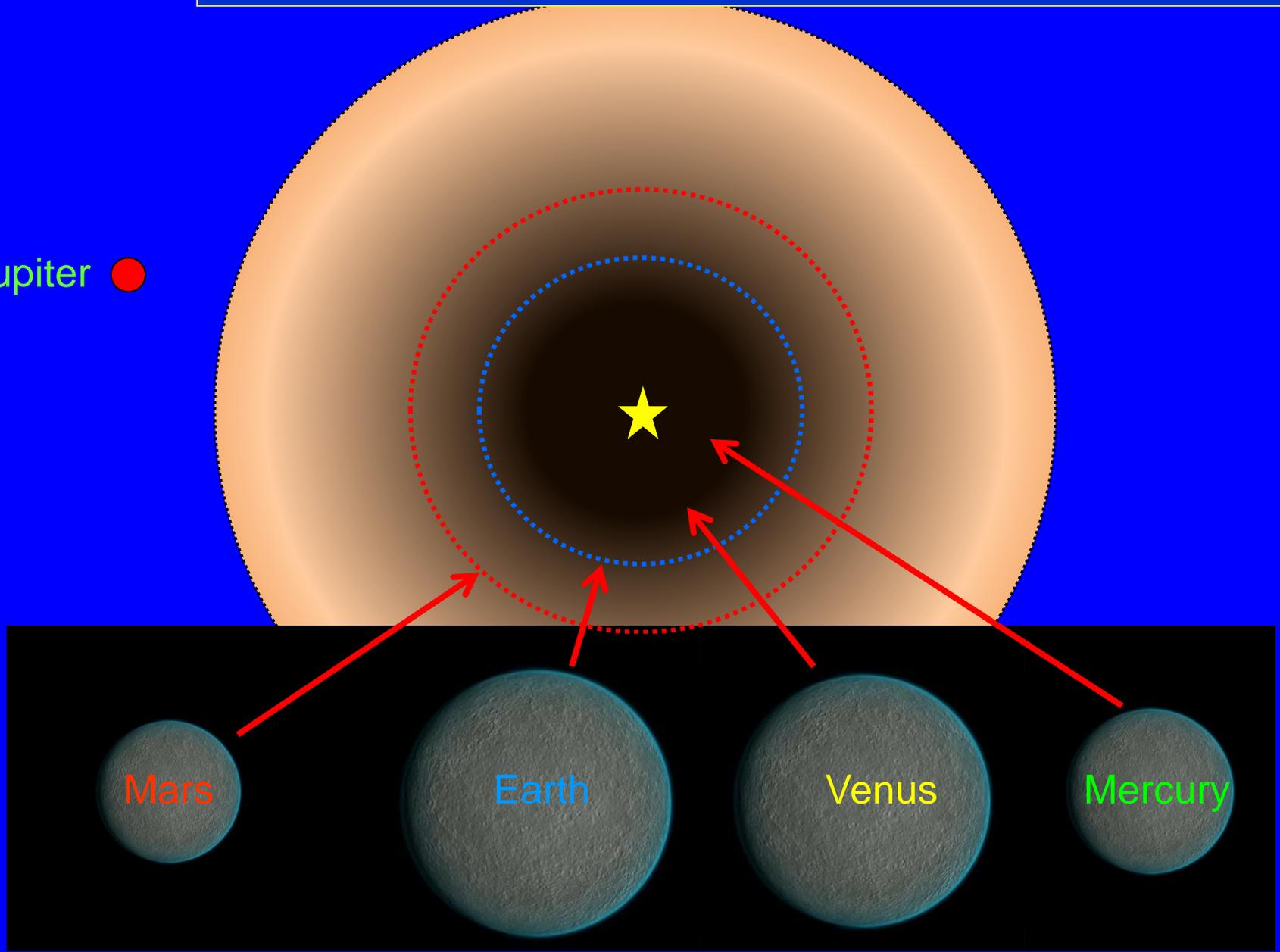


“grand tack” Nice model

● Saturn

The number, location, mass ratios of inner planets has been driven by the highly contingent planet migration

Jupiter ●



Mars

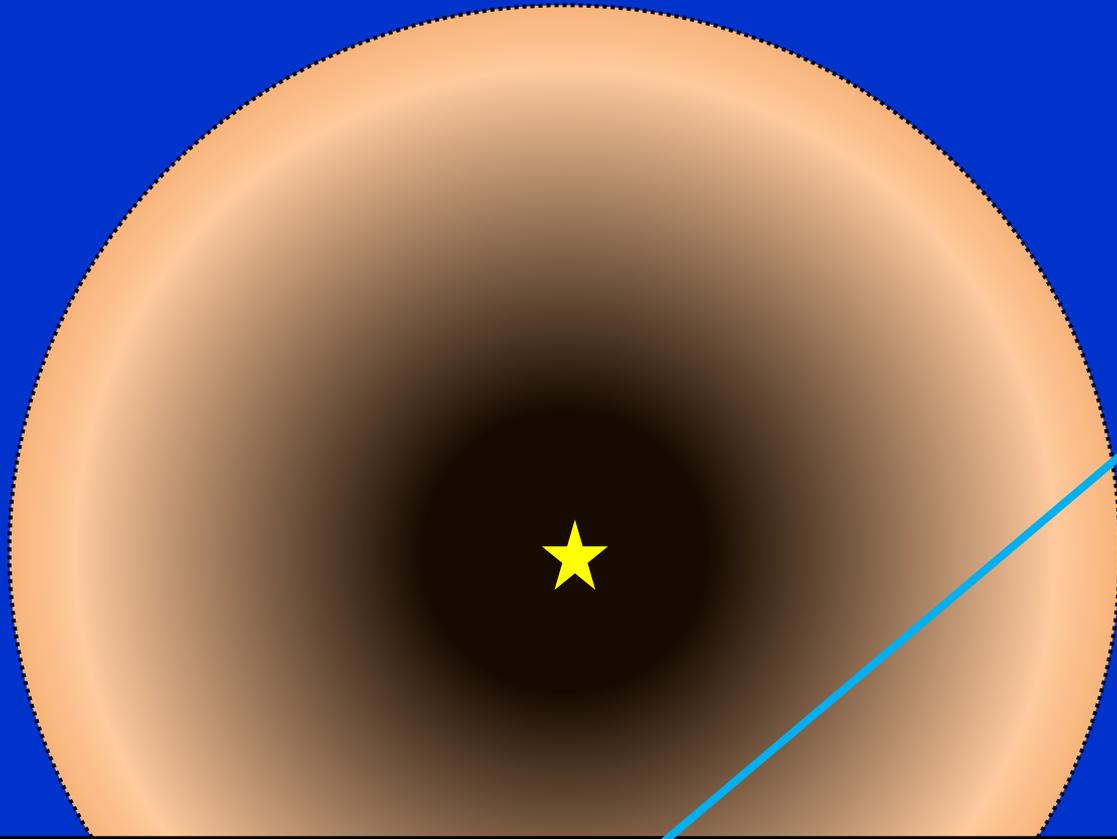
Earth

Venus

Mercury

● Saturn

Jupiter ●

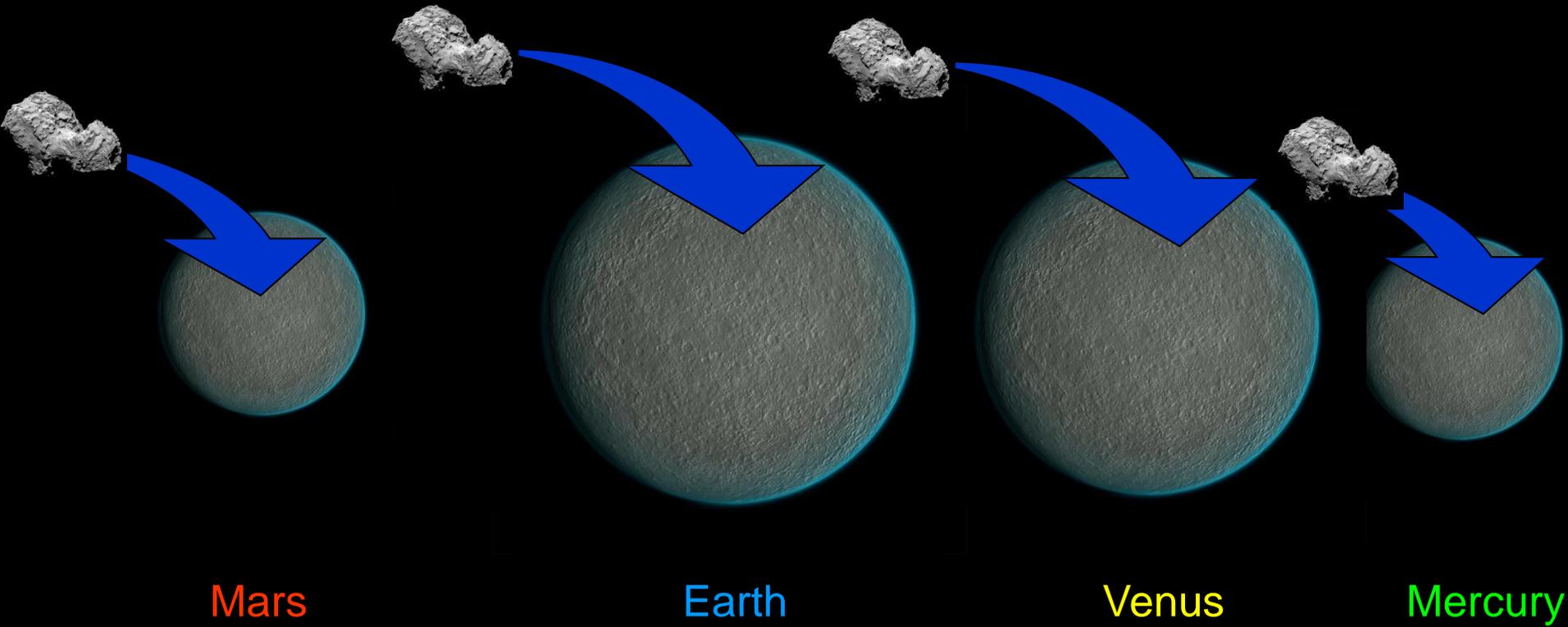


How to account for water on Earth, if accreted from inner anhydrate material ?





Most **water** was brought from outer small bodies during the protoplanet **accretion**, as a bulk component





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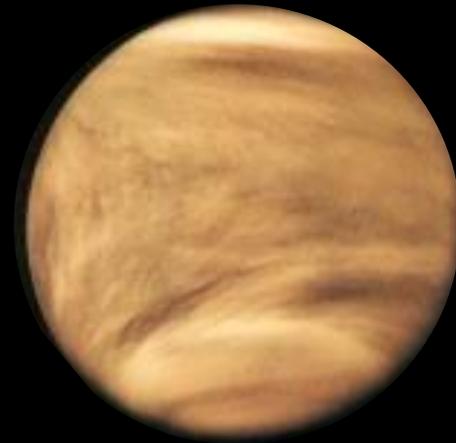
eventually brought to the surface as a result of a **giant impact**



Mars



Earth

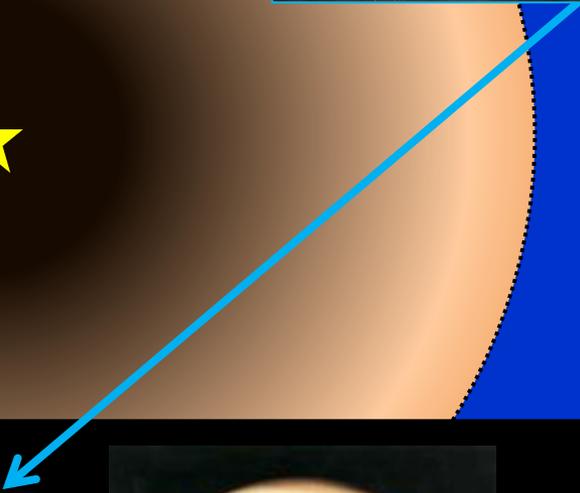
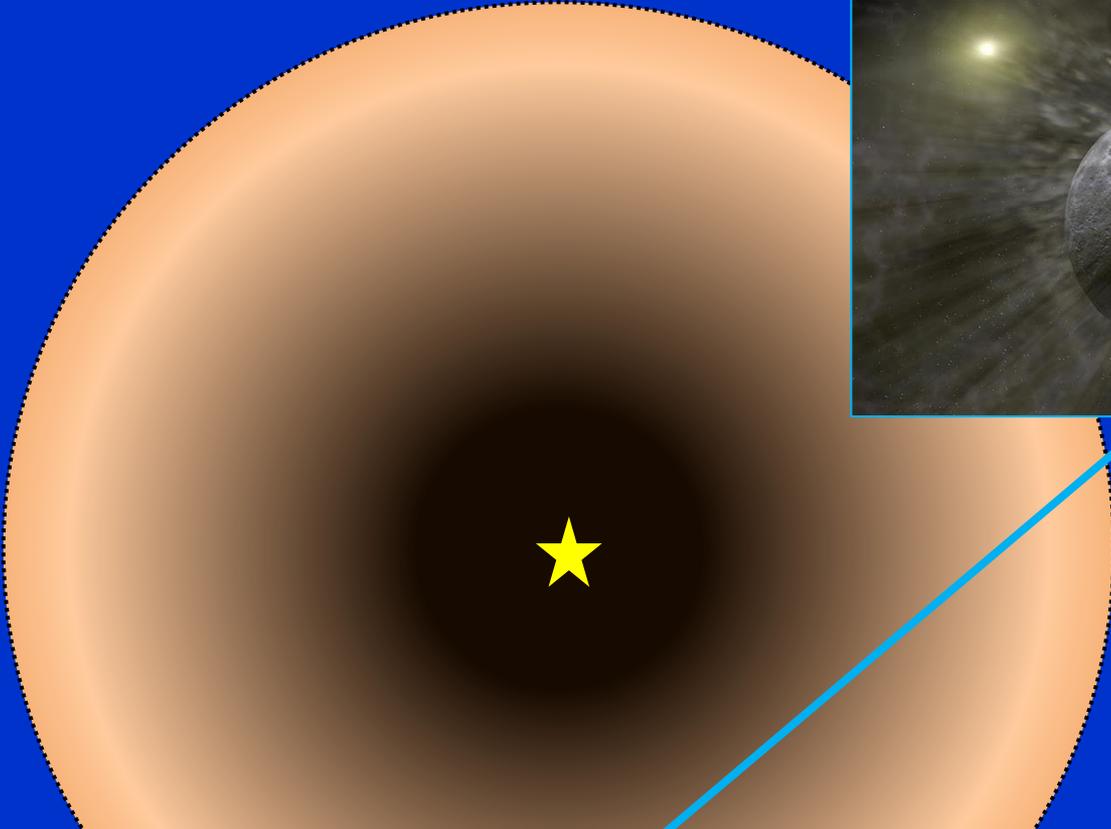


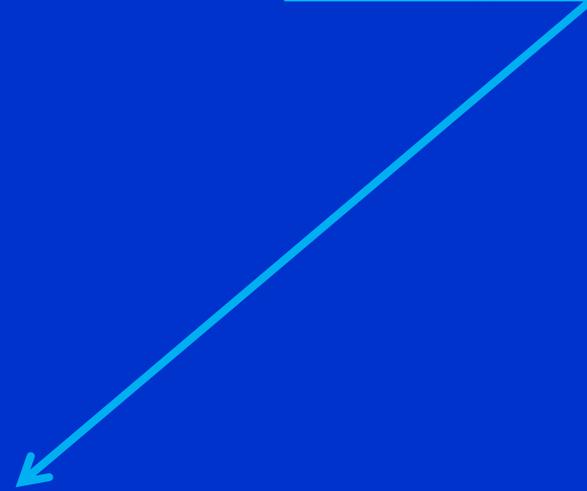
Venus



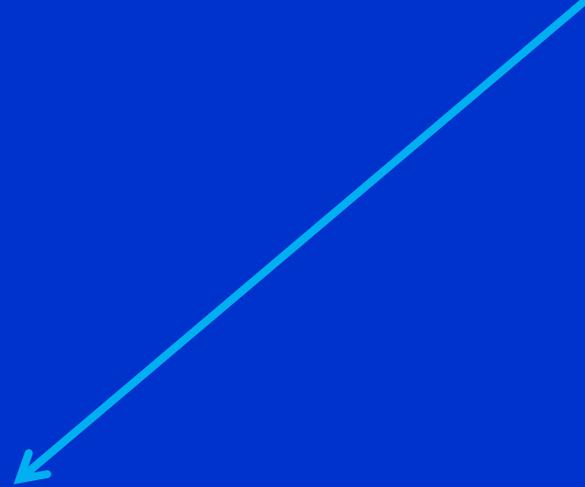
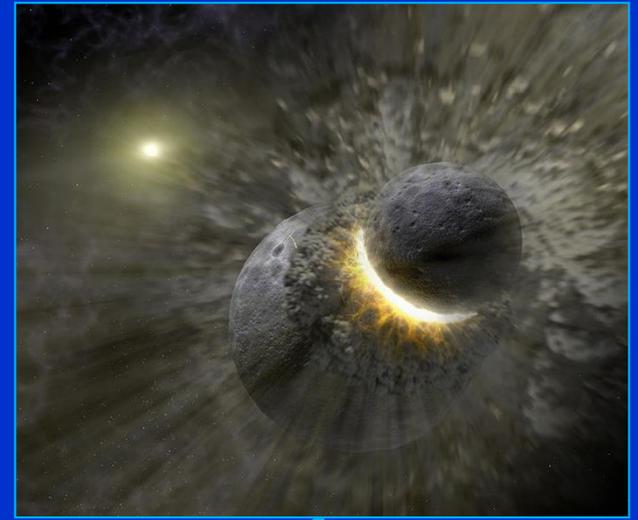
Mercury

suggestion !

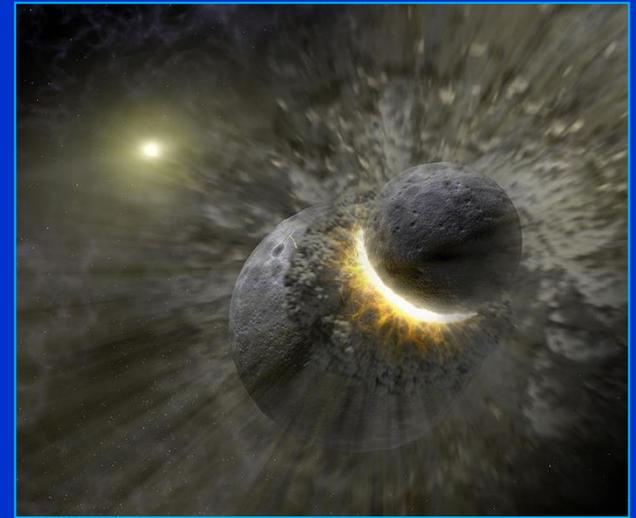




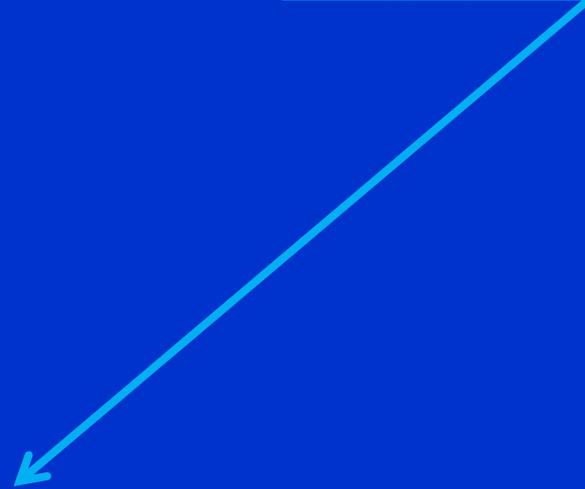
On **Earth**, the highly specific **giant impact** has triggered highly specific **water** and **CO₂** history, **plate tectonics**, **atmospheric evolution**



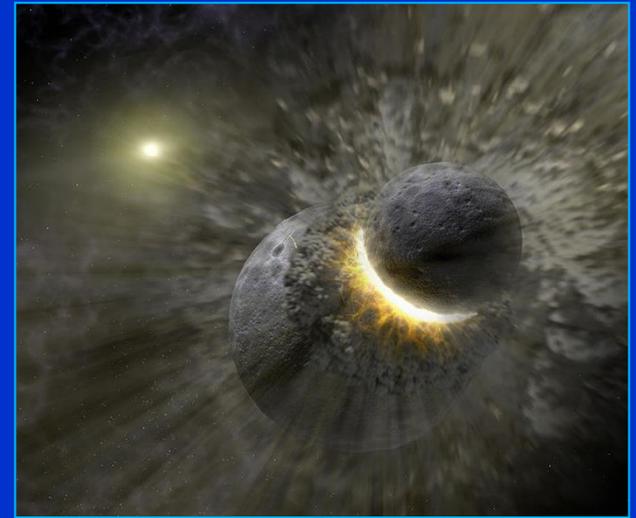
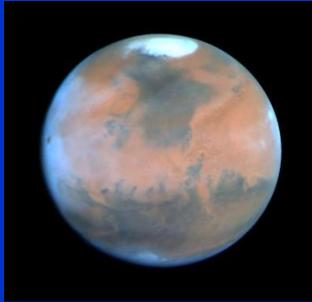
How sensitive is the **planet evolution** to the parameters of the **giant impact**
(mass ratio, composition, velocity, angle ...)



What, for Mars ?



How sensitive is the **planet evolution** to the parameters of the **giant impact**
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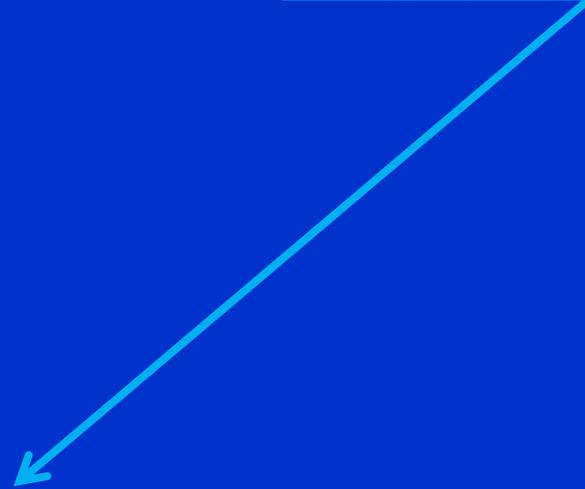
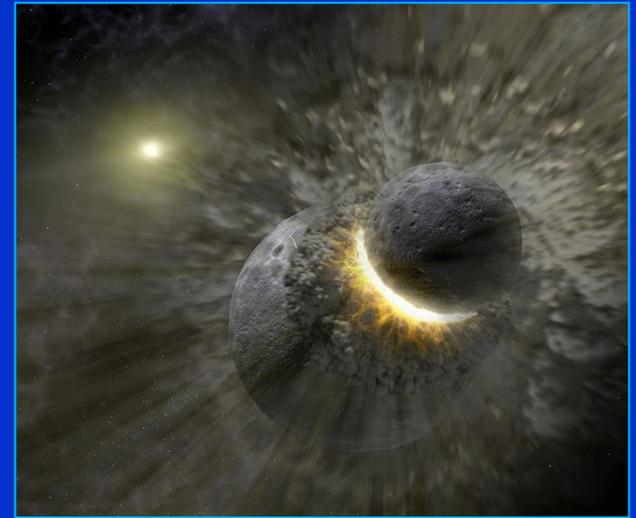


For Mars, the (quite distinct) impact induced magma ocean might have been mostly surficial, with weaker post effects such as: moon mass; raise of water (for ever, most deep inside, possibly still reacting - methane - ; volcanic activity ~ ceased, but gases still diffusing out); limited early aqueous surface alteration (Mg/Fe phyllosilicates); ~ no plate tectonics

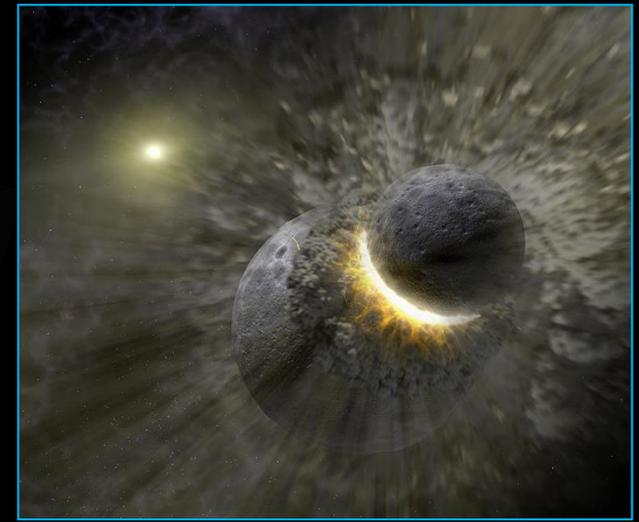
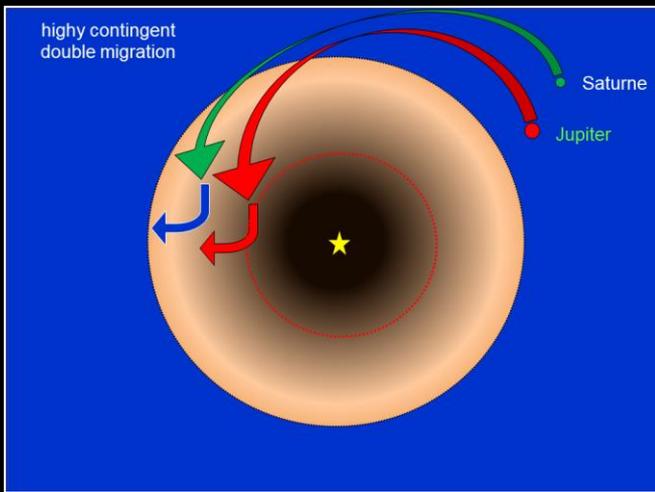
How sensitive is the **planet evolution** to the parameters of the **giant impact** (mass ratio, composition, velocity, angle ...)



MMX mission



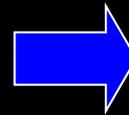
How sensitive is the planet evolution to the parameters of the giant impact (mass ratio, composition, velocity, angle ...)



Planet migration and giant impacts are exemplary of **generic** processes the **contingent** form of which, in their **diversity**, shapes each planet **evolution**.

evolution:

generic drivers



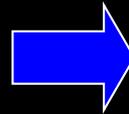
contingent drivers

major change of
paradigm



evolution:

generic drivers



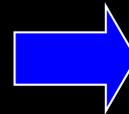
contingent drivers

so what, as to **life** ?



evolution:

generic drivers



contingent drivers

Life on Earth could/should be conceived as resulting from a continuous sequence of evolution, all steps and products being highly contingently shaped, by the specific dynamical evolution of the proto-solar cloud

Philae / Rosetta

“organics”

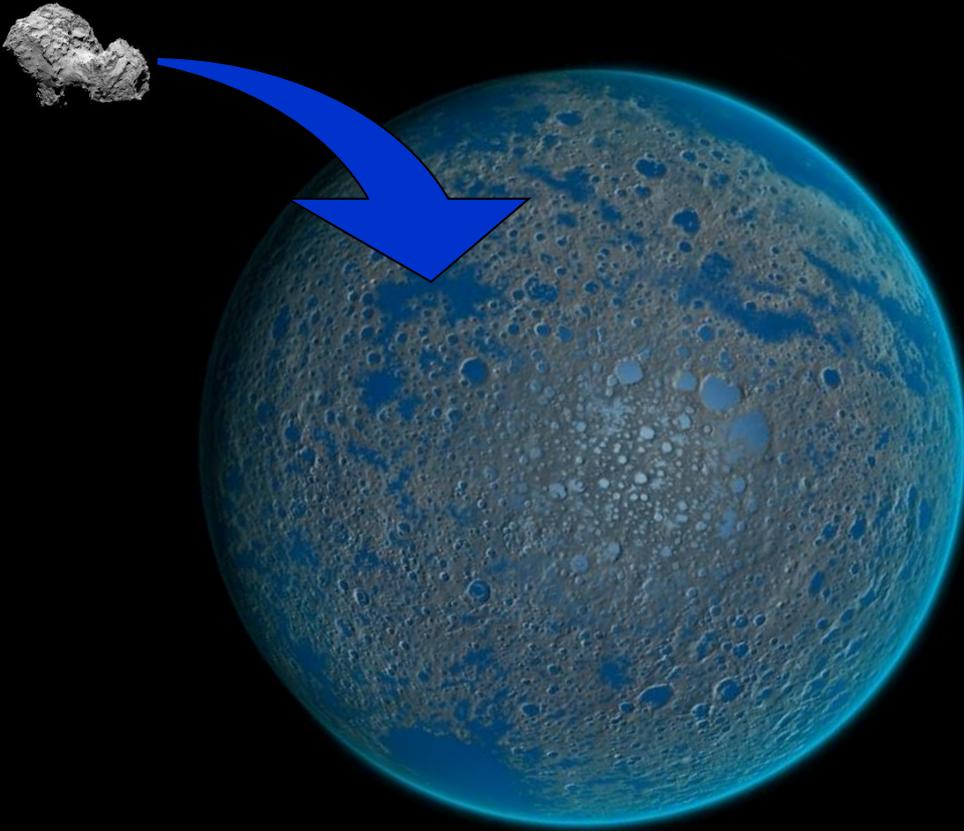


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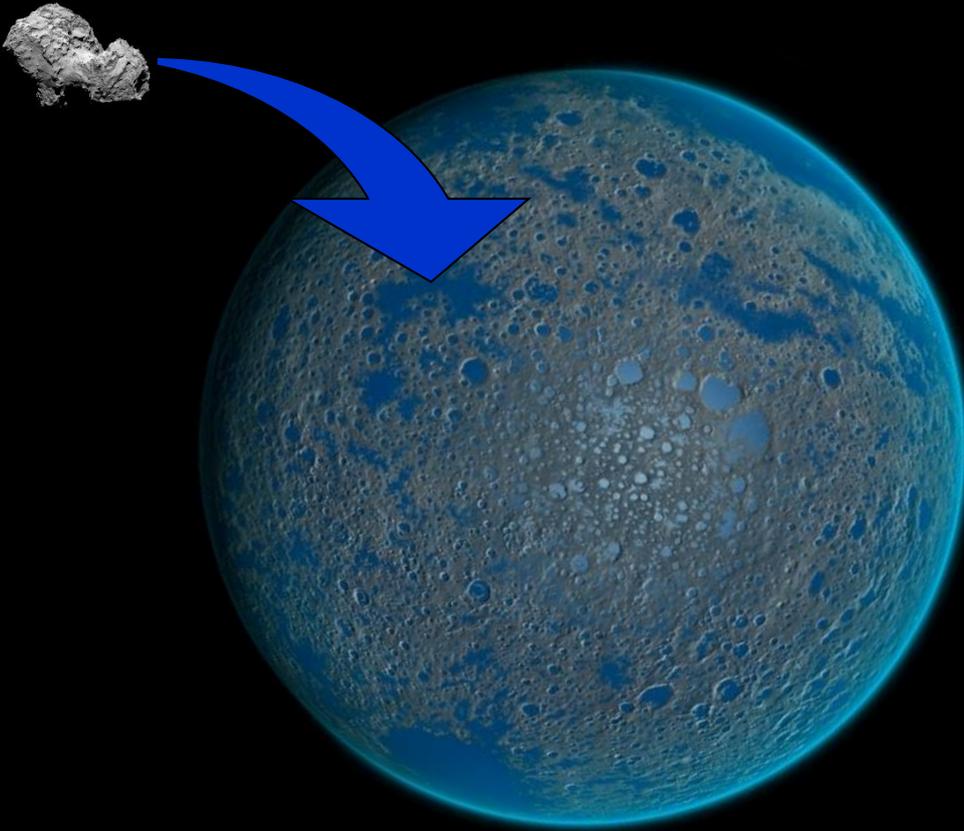
e.g. chirality excesses

Life on Earth could/should be conceived as resulting from a continuous sequence of evolution, all steps and products being highly contingently shaped, by the specific dynamical evolution of the proto-solar cloud through their seeding within the highly specific early Earth water beds.



Earth, in its ancient past

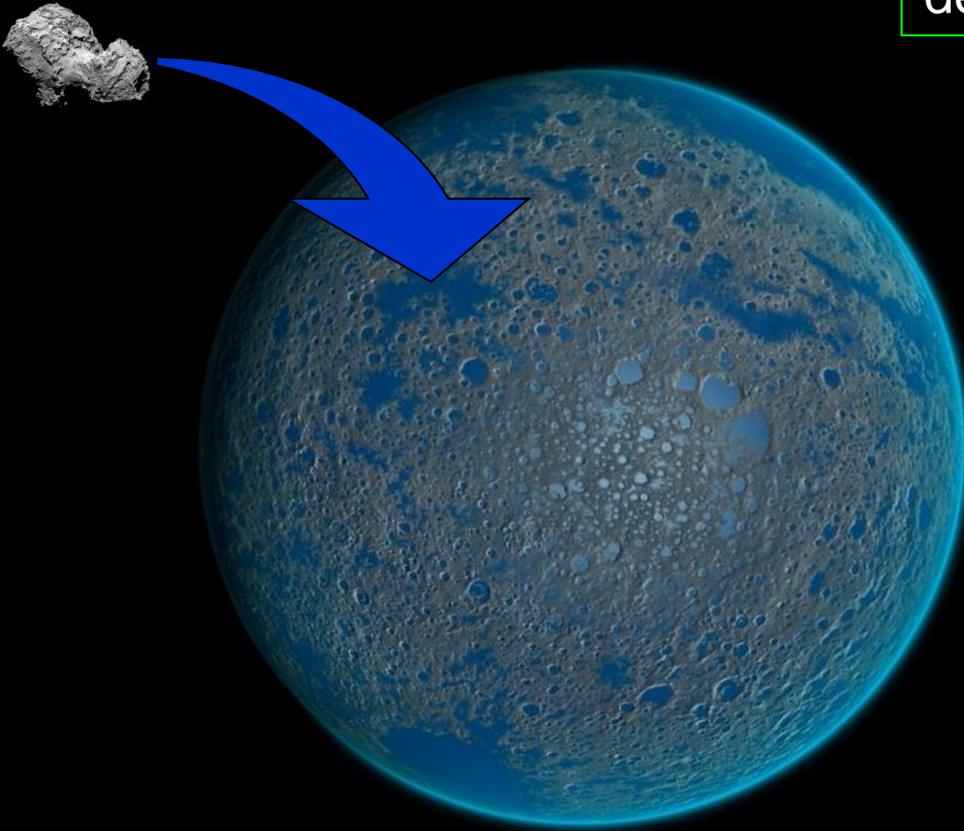
Ancient Earth has been habitable (possibly only once!) through a highly specific water properties (temperature, pH, cations & catalyser content...), favouring specific autocatalytic reactions towards “living structures”.



Earth, in its ancient past

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defining Earth (ancient) habitability

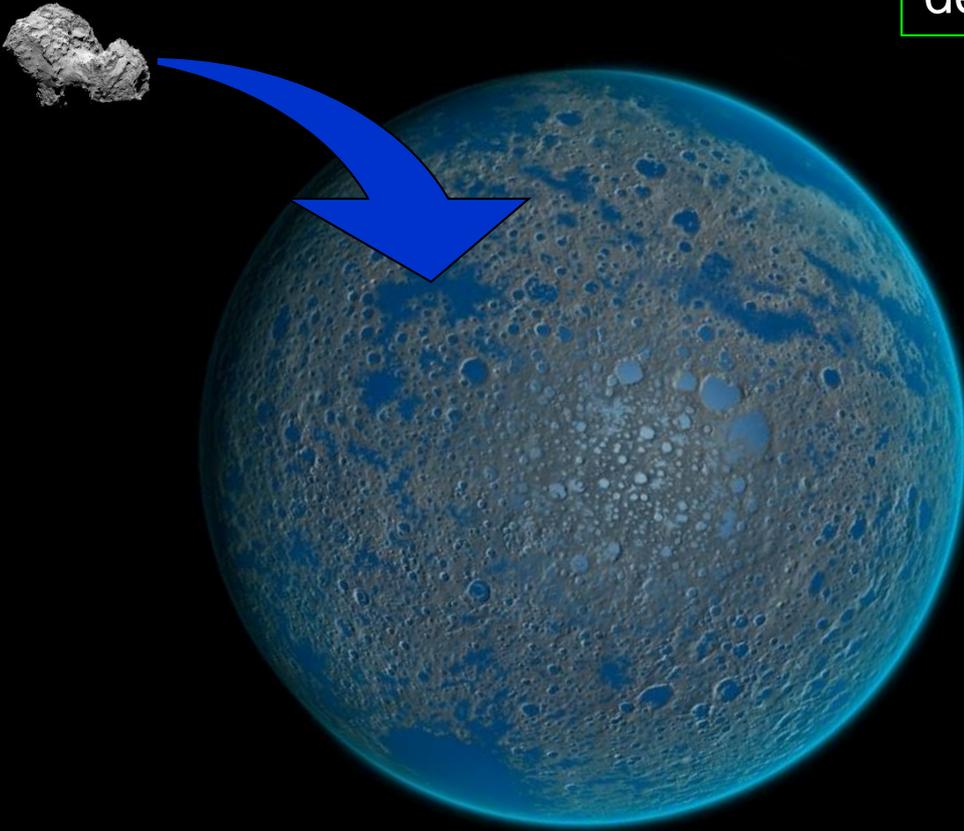


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defining Earth (ancient) habitability

no longer existing on Earth



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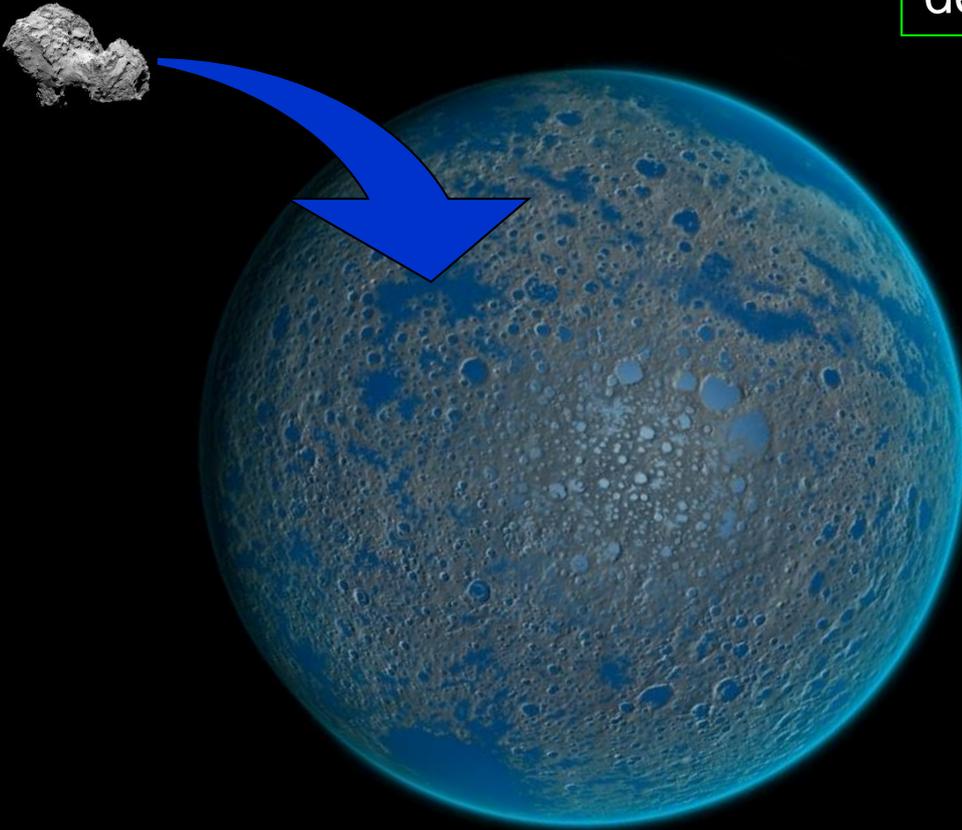
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defining **Earth** (ancient) **habitability**

no longer existing on Earth

Mars might have records

Key is not the mere (demonstrated) ancient stability of surface **liquid water**, but its **properties** and **content**



Earth, in its ancient past

Ancient Earth has been habitable (possibly only once!) through a highly specific water properties (temperature, pH, cations & catalyser content...), favouring specific autocatalytic reactions towards 'living structures'.

There is no “emergence of life” from “inert” species, but a continuum in the C evolution, following a specific pattern through specific contingencies.

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There is no "emergence of life" from "inert" species, but a continuum in the C evolution, following a specific pattern through specific contingencies.

Distinct conditions would have triggered distinct pathways.

Life is intimately coupled to the contingent evolution of its harboured Earth.

Life is one among the huge diversity of possible C-chemistry pathways, triggered by a number of contingencies all along cosmic evolution

major change of paradigm

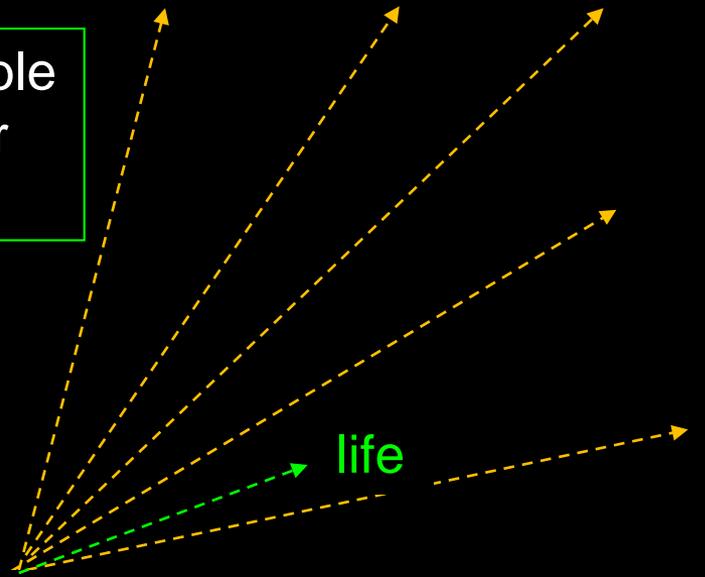
big bang

atoms

molecules

complex organics

life



Life is one among the huge diversity of possible C-chemistry pathways, triggered by a number of contingencies all along cosmic evolution

major change of paradigm

complex organics

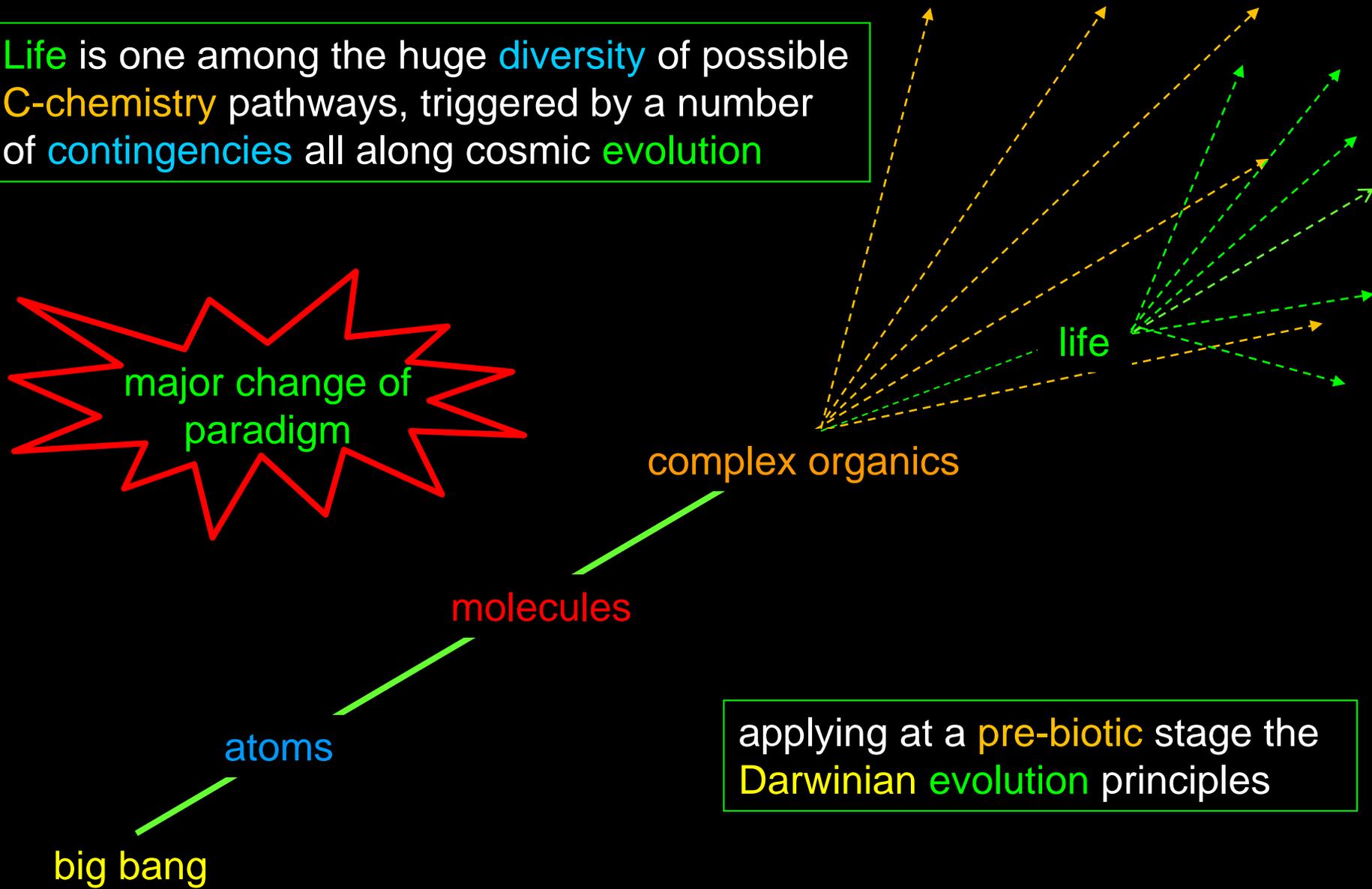
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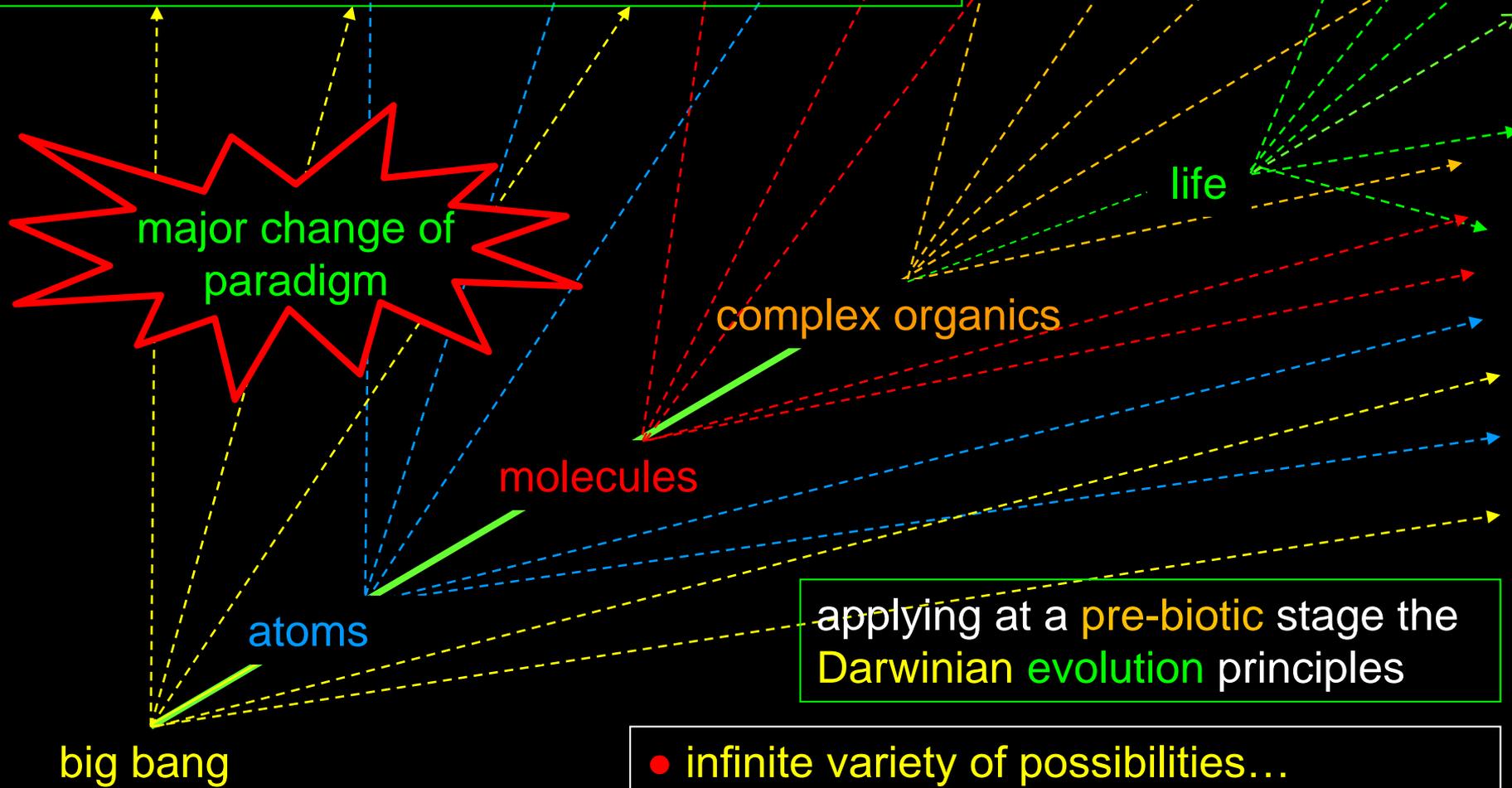
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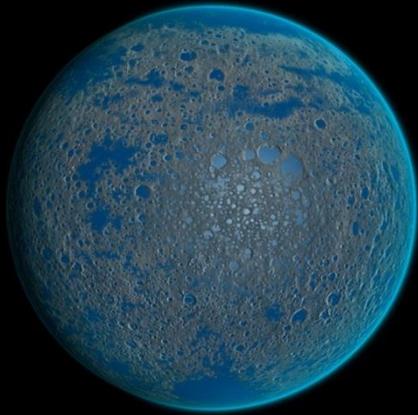
- infinite variety of possibilities...
- contingency not restricted to life...
- solve the issue of inert to life transition...

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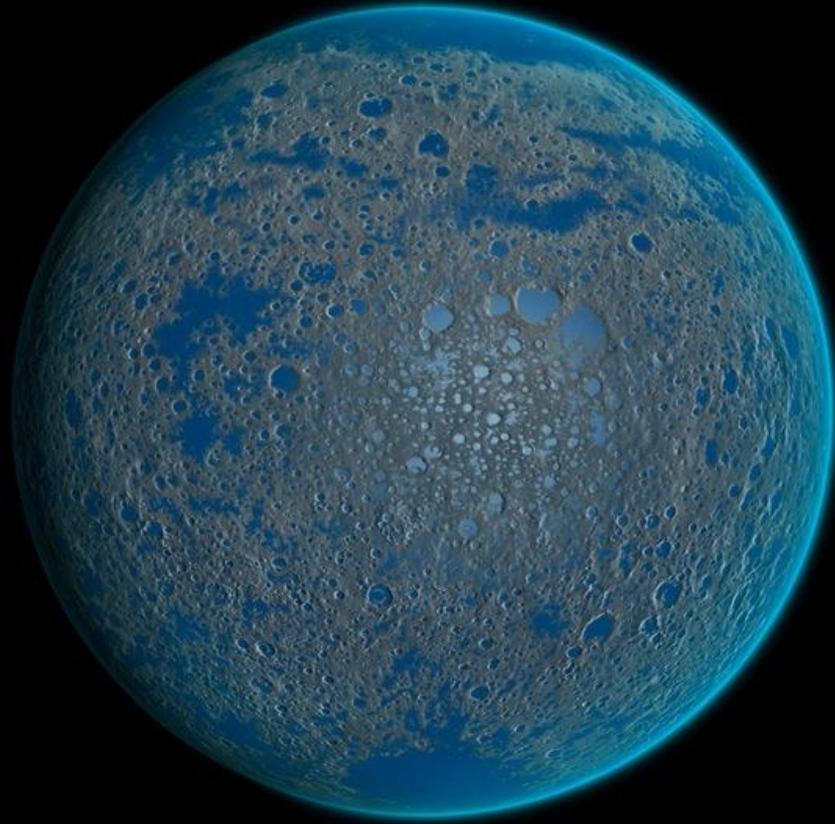


- infinite variety of possibilities...
- contingency not restricted to life...
- solve the issue of inert to life transition...

Was **early Mars** water habitable?



early Mars
was habitable?



early Earth
was habitable!



Ancient Earth has been habitable (possibly only once!) through a highly specific water properties (temperature, pH, cations & catalyser content...), favouring specific autocatalytic reactions towards ‘living structures’.

There is no “emergence of life” from “inert” species, but a continuum in the C evolution, following a specific pattern through specific contingencies.

Distinct conditions would have triggered distinct pathways.
Life is intimately coupled to the contingent evolution of its harboured Earth.

Water is not habitable per itself: similarly to UV photons, a few stimulates, too much destroys. The early chemistry had to build very rapidly shields (membranes) against the lethal water effects, while offering electric gradients favouring specific chemical evolution (“bio-chemistry”).

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These **autocatalytic reactions** favoured highly **specific chirality** properties, likely triggered by pre-existing **chiral excesses** (**proto-Sun** irradiation?).

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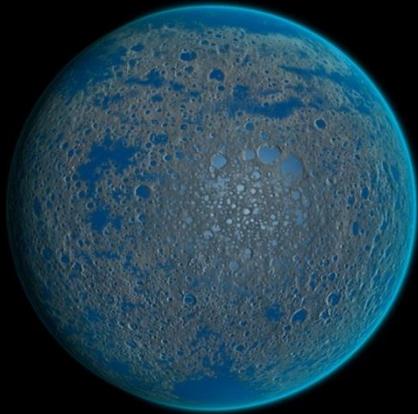
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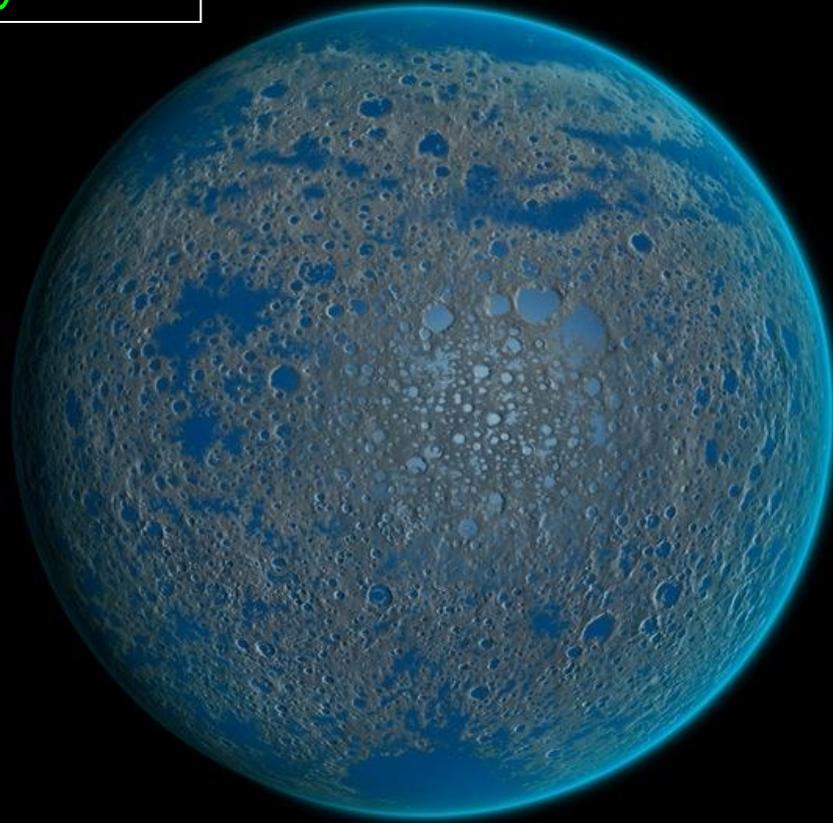
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Relics of **membranes** and **chirality**, are likely the most reliable **bio-relics**, witnesses of the early steps towards "living structures".

Was **early Mars** **water habitable**?
→ search for **bio-relics** as
membranes and **chirality**



early Mars
was habitable?



← **early Earth**
was habitable!

Was **early Mars** **water** **habitable**?

→ search for **bio-relics** as
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microscopic
examination

ExoMars
ALD

Was **early Mars** water habitable?

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critical need to **couple**
Mars 2020, **ExoMars**, **HX1**
operations & exploitation
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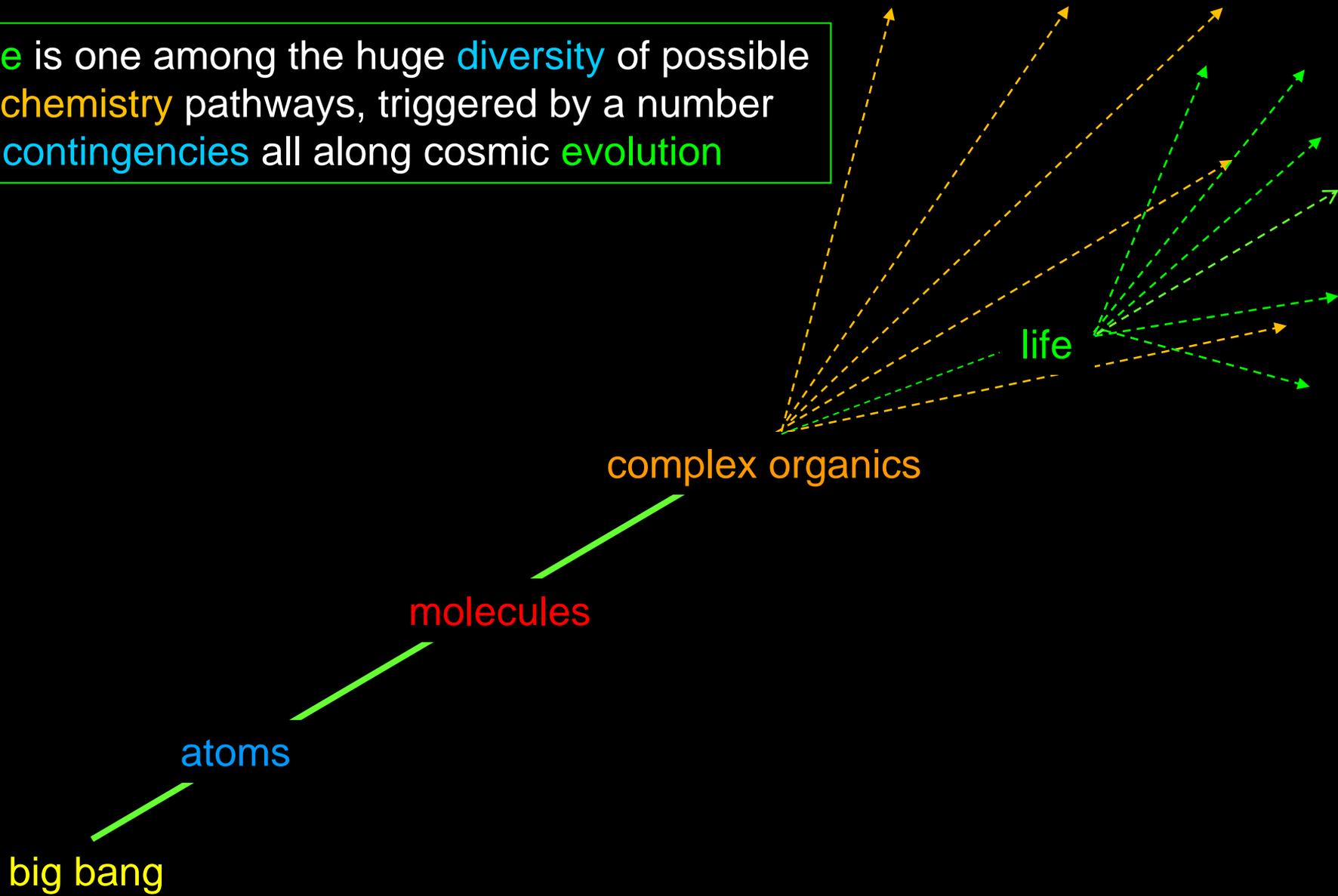
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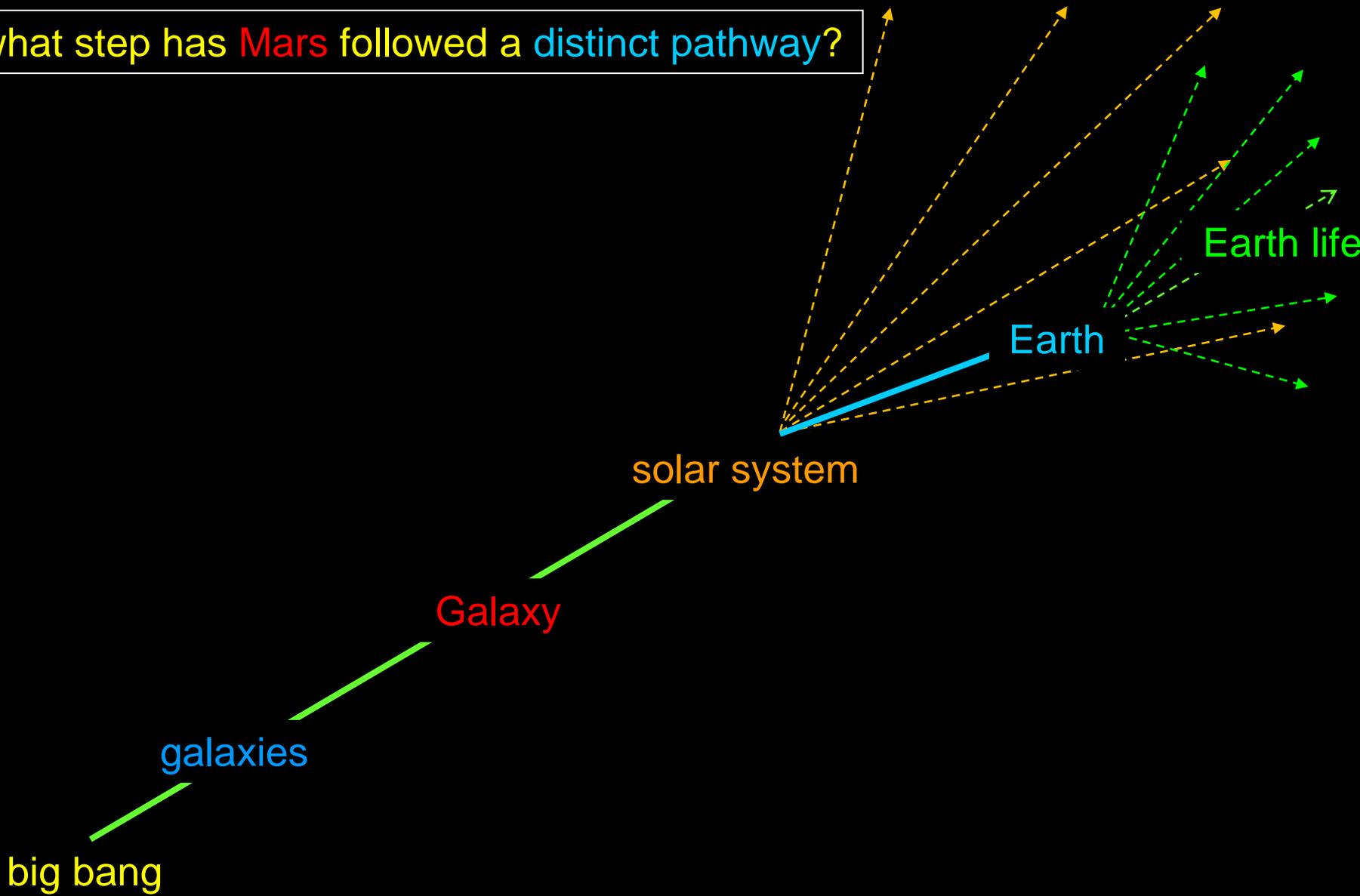
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MEPAG

Life is one among the huge diversity of possible C-chemistry pathways, triggered by a number of contingencies all along cosmic evolution



At what step has Mars followed a distinct pathway?



At what step has Mars followed a distinct pathway?

supposedly Mars and Earth evolution would have diverged from origin...

big bang

galaxies

Galaxy

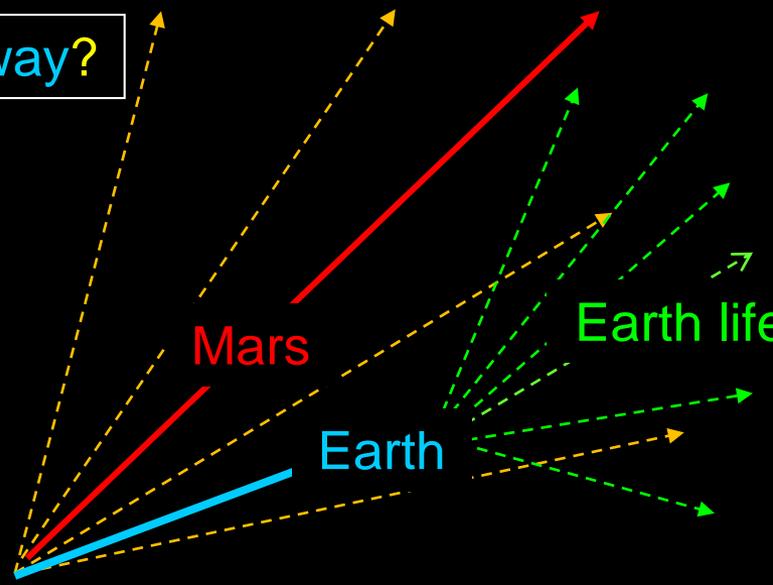
solar system

Mars

Earth

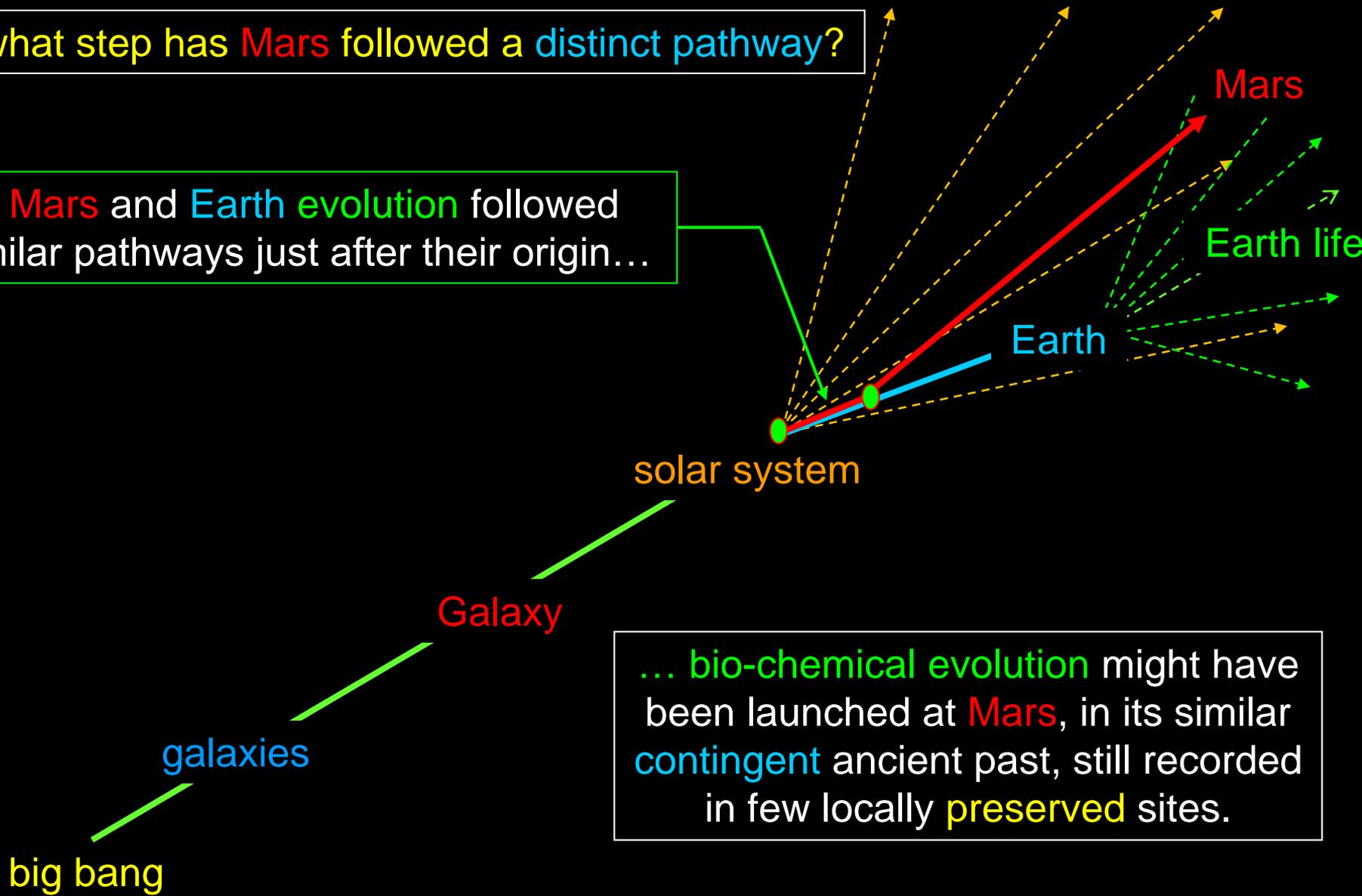
Earth life

... life would be uniquely coupled to Earth contingent evolution



At what step has Mars followed a distinct pathway?

if Mars and Earth evolution followed similar pathways just after their origin...



... bio-chemical evolution might have been launched at Mars, in its similar contingent ancient past, still recorded in few locally preserved sites.

At what step has Mars followed a distinct pathway?

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Phyllosian

Earth

Mars

Earth life

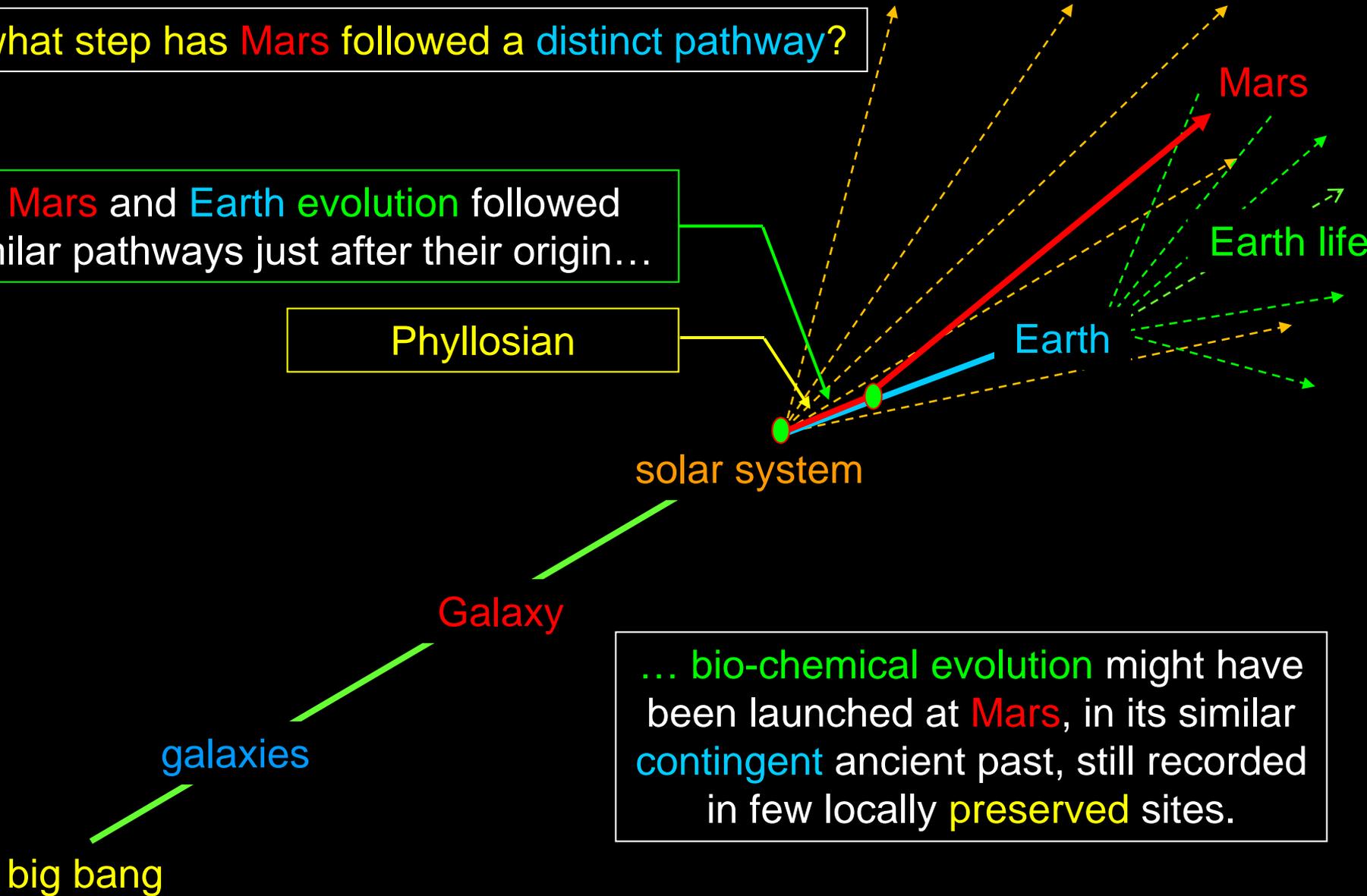
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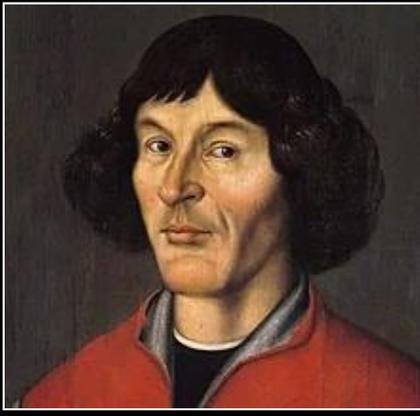
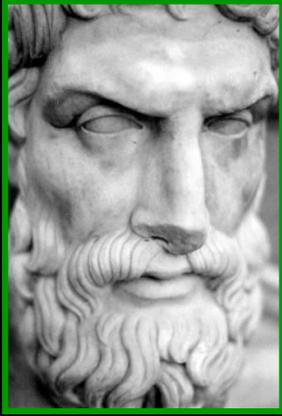
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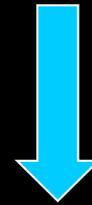
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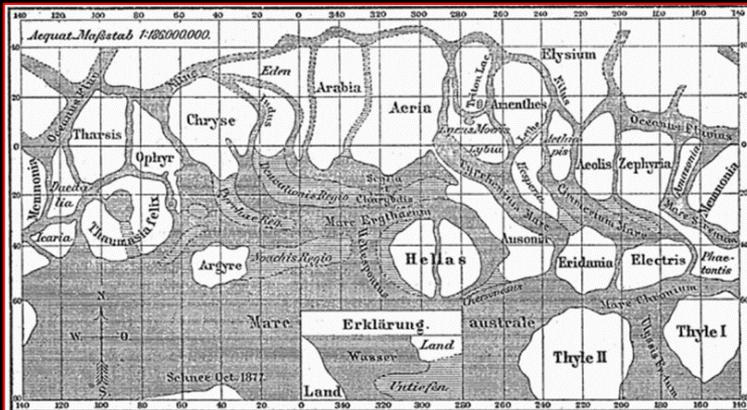
Mars evolution and habitability: the evolution of paradigms



plurality of worlds

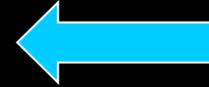


follow the water

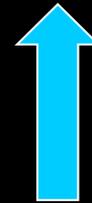


Mars evolution and habitability: the evolution of paradigms

diversity triggered by contingencies



diversity of worlds

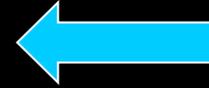


~~follow the water~~

Mars evolution and habitability: the evolution of paradigms

diversity triggered by contingencies

diversity of worlds



at what time/space scale is

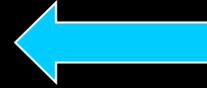


unique ?

Mars evolution and habitability: the evolution of paradigms

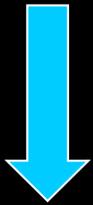
diversity triggered by contingencies

diversity of worlds



at what time/space scale is

unique ?



records

Mars evolution and habitability: the evolution of paradigms

diversity triggered by contingencies

diversity of worlds

at what time/space scale is

unique ?



records

requires



cooperation