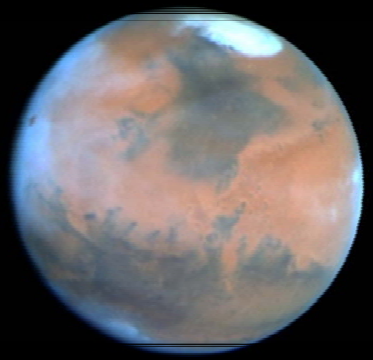
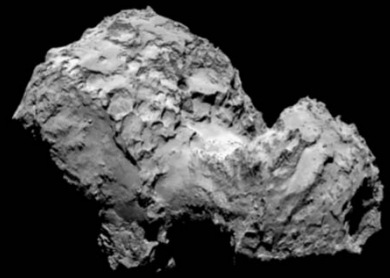
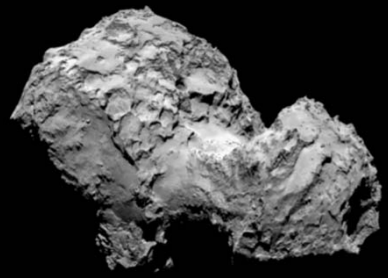
Mars, Rosetta, and the "emergence" of life. Genericities and Contingencies





51st ESLAB, ESTEC, 22/10/2017

Mars, Rosetta, and the "emergence" of life. Genericities and Contingencies



Jean-Pierre Bibring

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“Extreme habitable worlds”

How to characterize a “habitable world”, extreme or not ?

Is there a scientific approach to the search for “habitable worlds” ?

Is there a “normal habitability” opposed to “extreme habitability” ?

“Extreme habitable worlds”

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Is there a “normal habitability” opposed to “extreme habitability” ?

Habitability:

an ancient dogma, severely challenged by solar system space exploration, which is forcing an in-depth revisiting of major paradigms.

- infinity of inhabited worlds  Epicurus - 305

- infinity of inhabited worlds ← Epicurus - 305
- Earth, central, unique ← … + monotheisms

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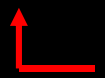

Earth, standard, generic

- infinity of inhabited worlds ← Epicurus - 300
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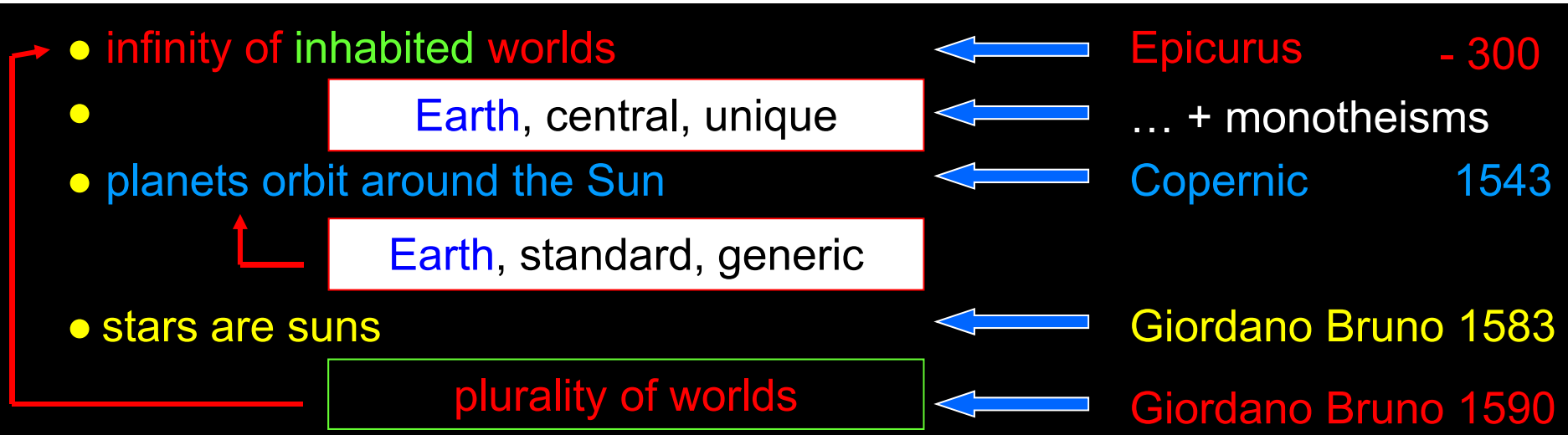
- stars are suns ← Giordano Bruno 1583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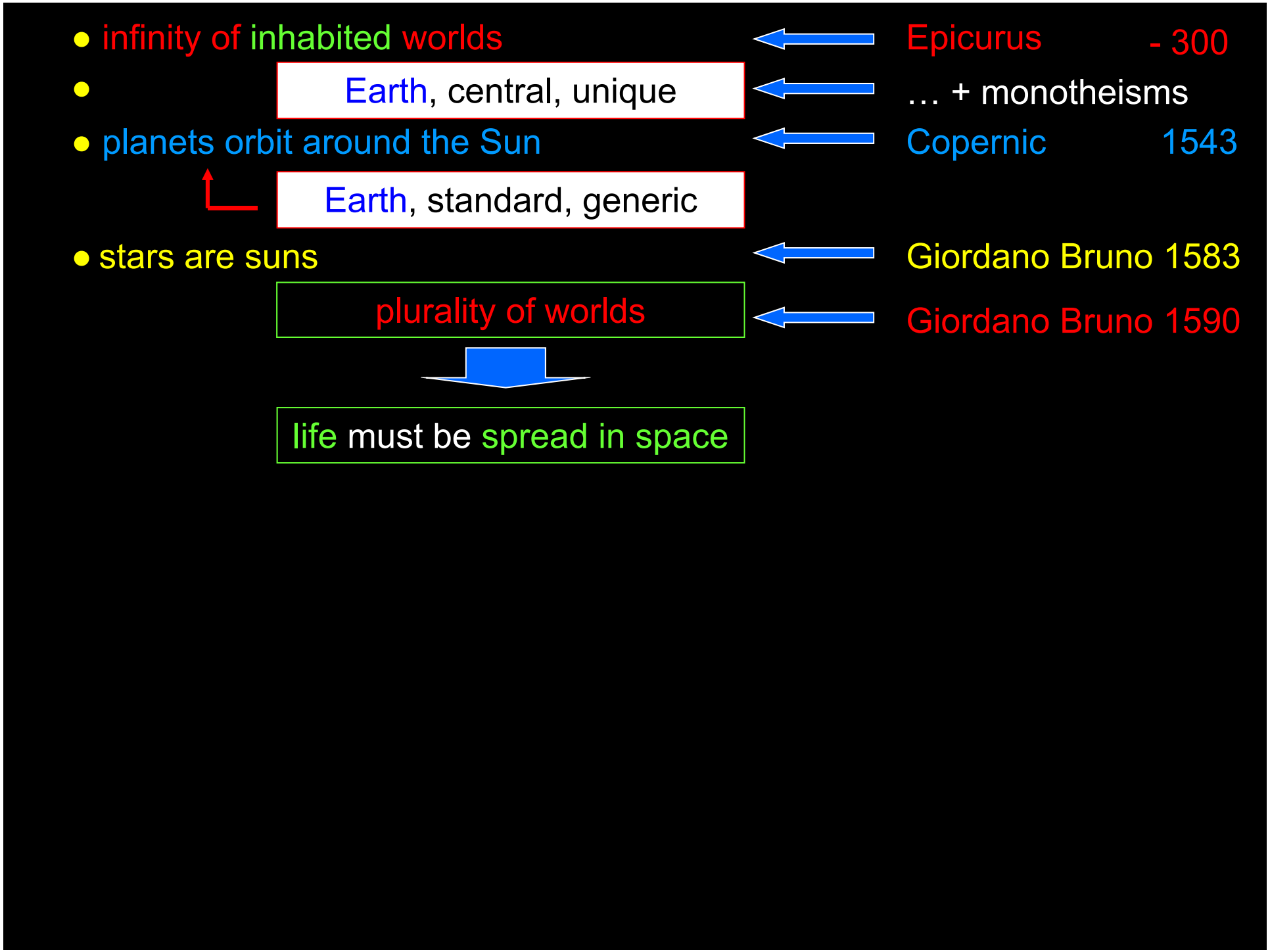
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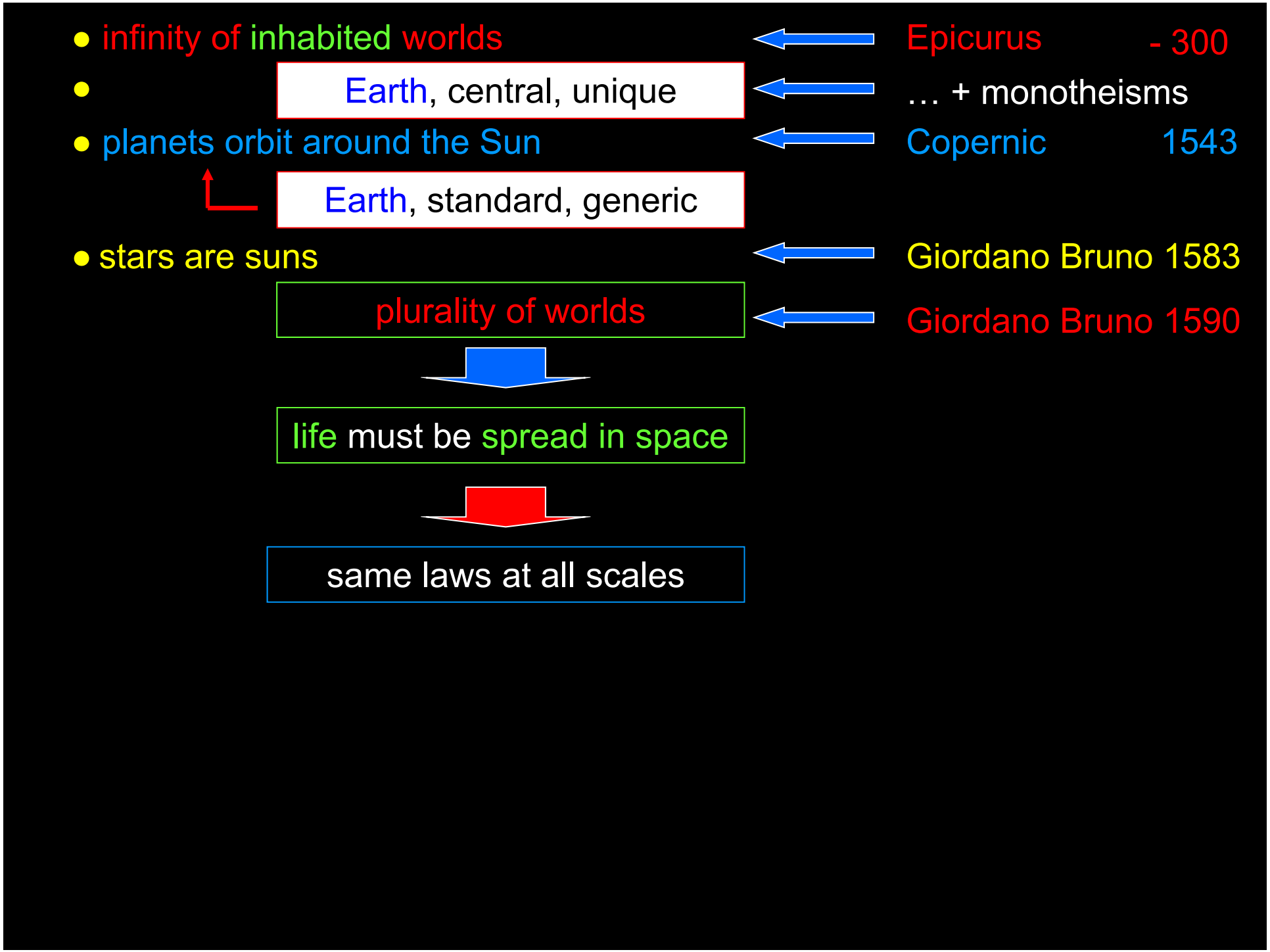
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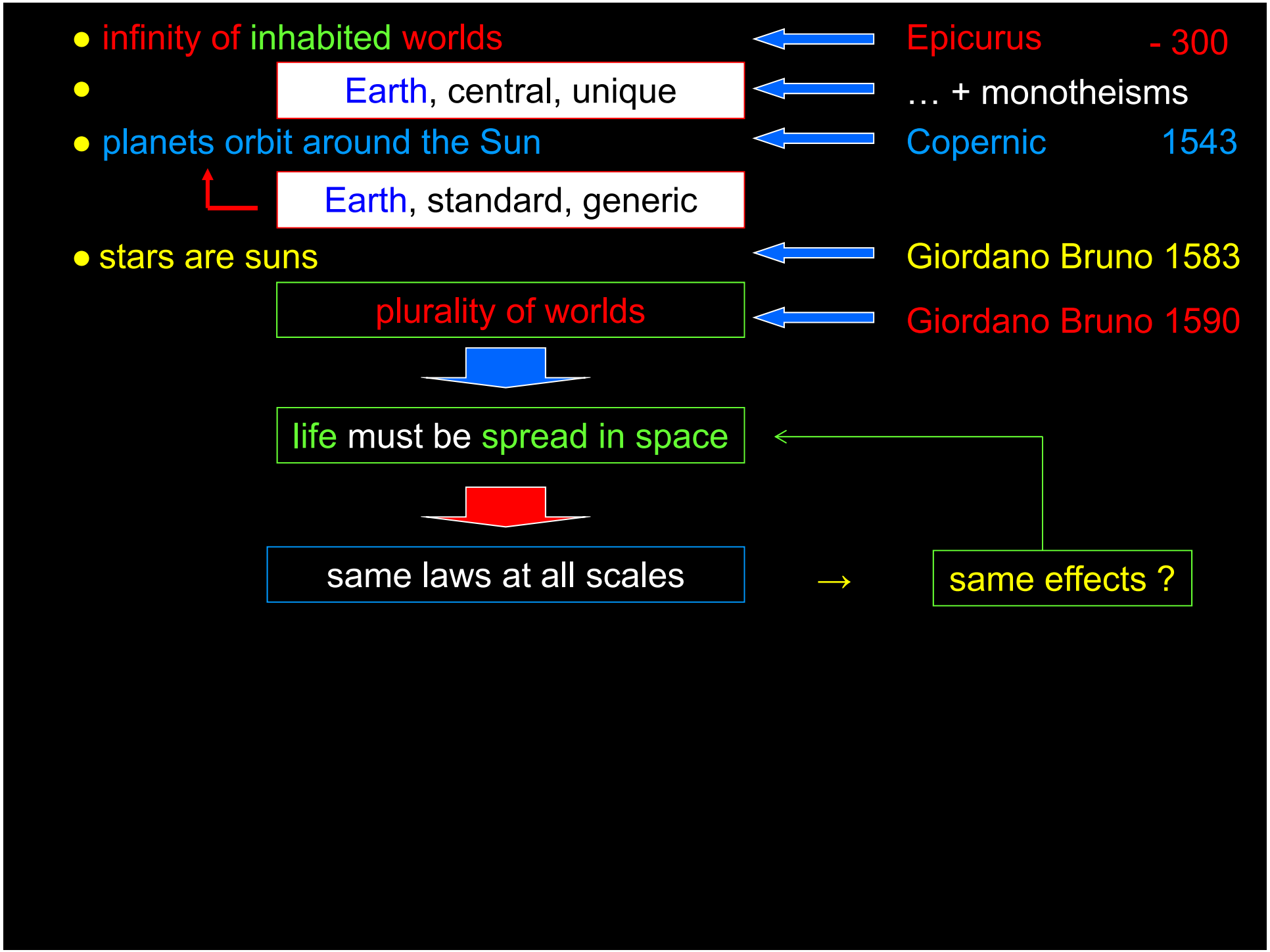
same laws at all scales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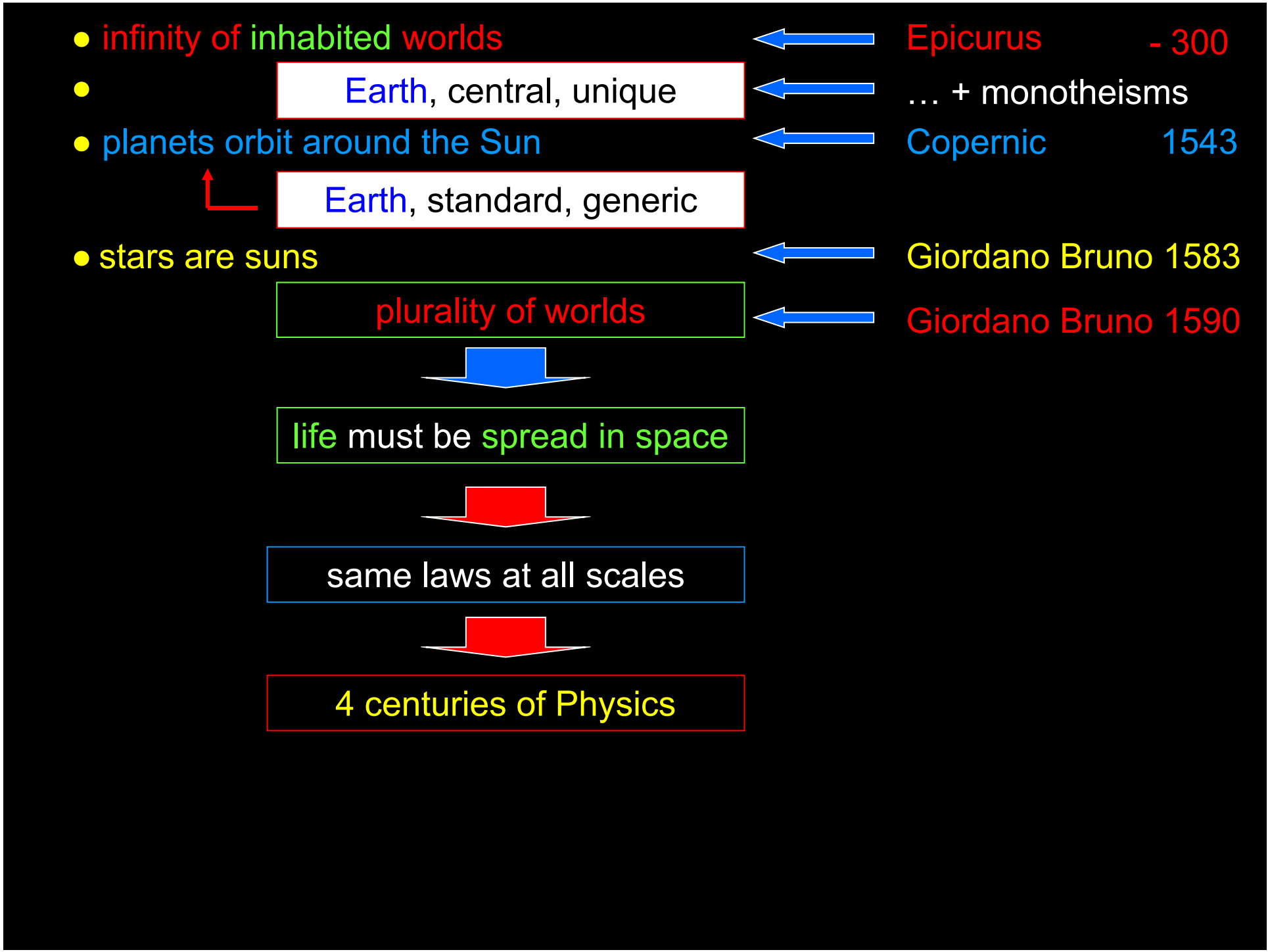
same effects ?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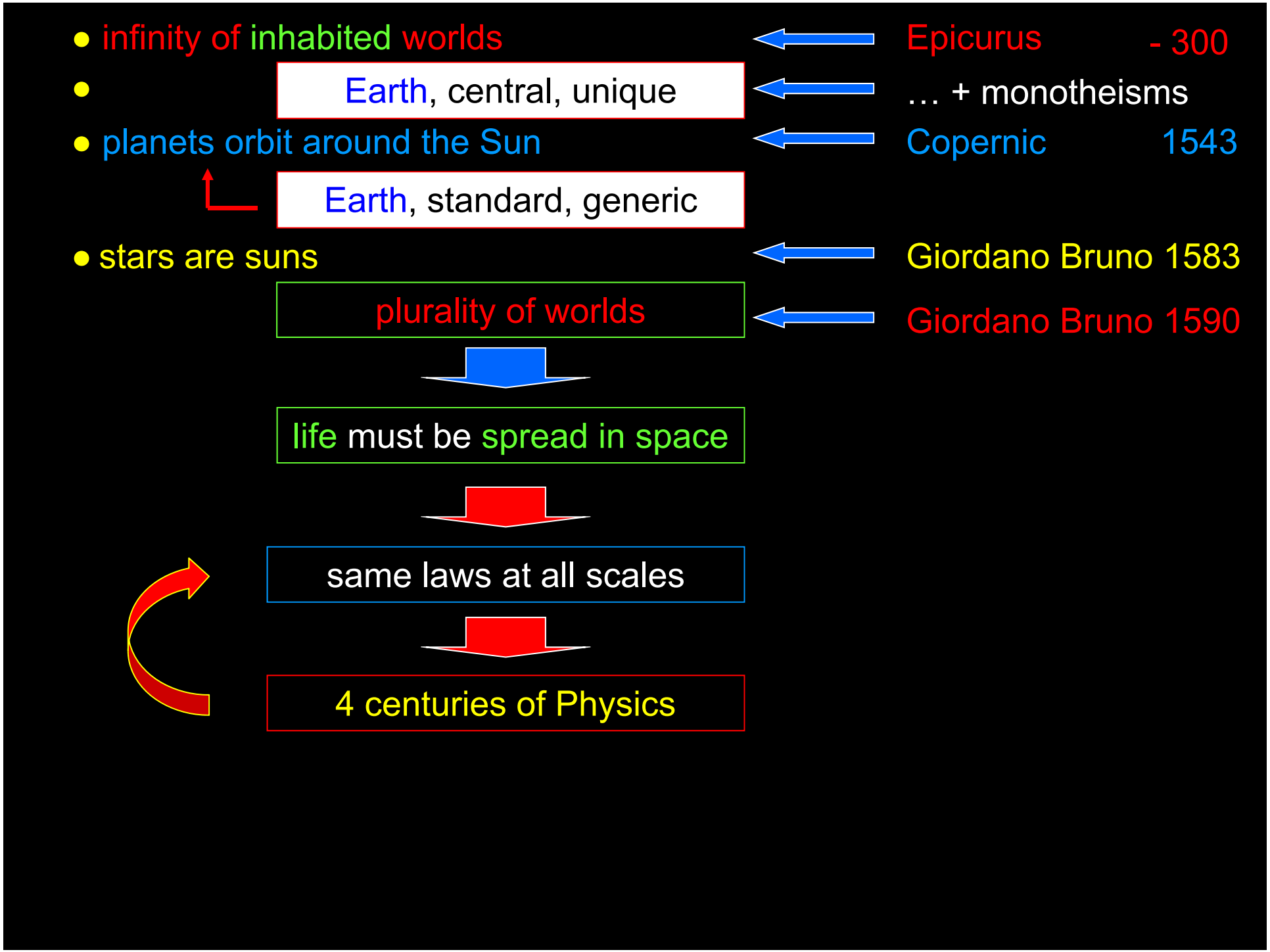
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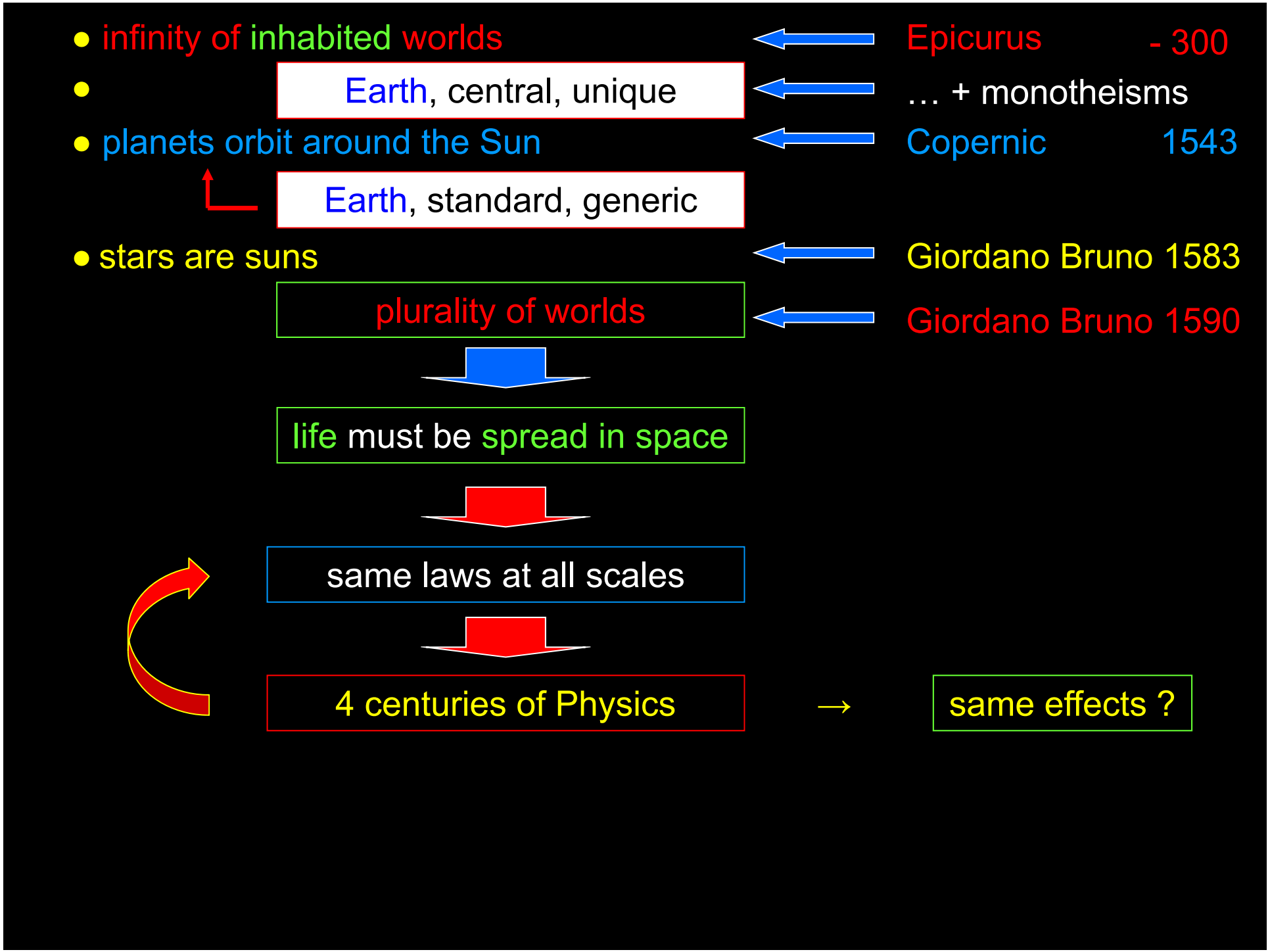
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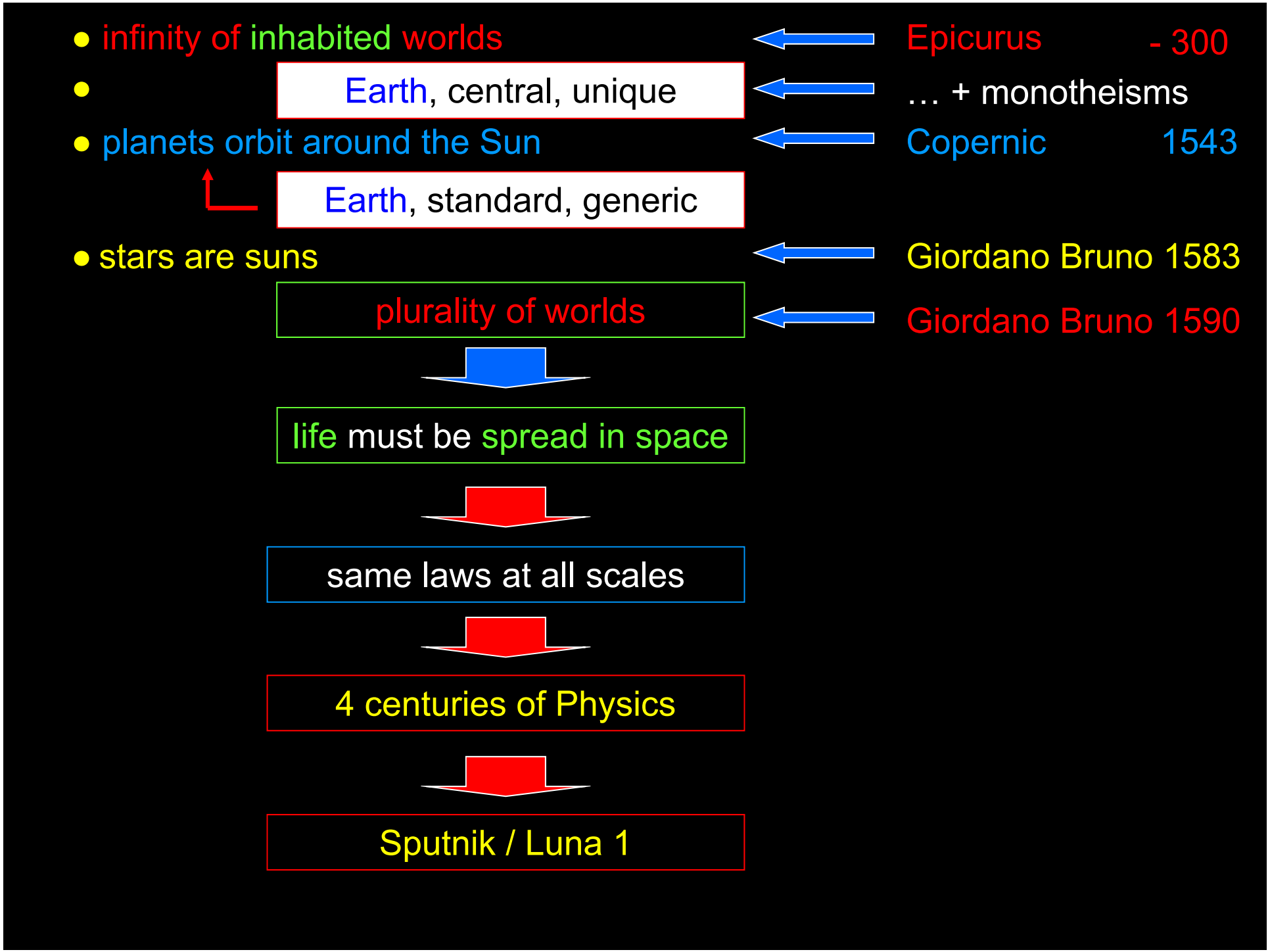
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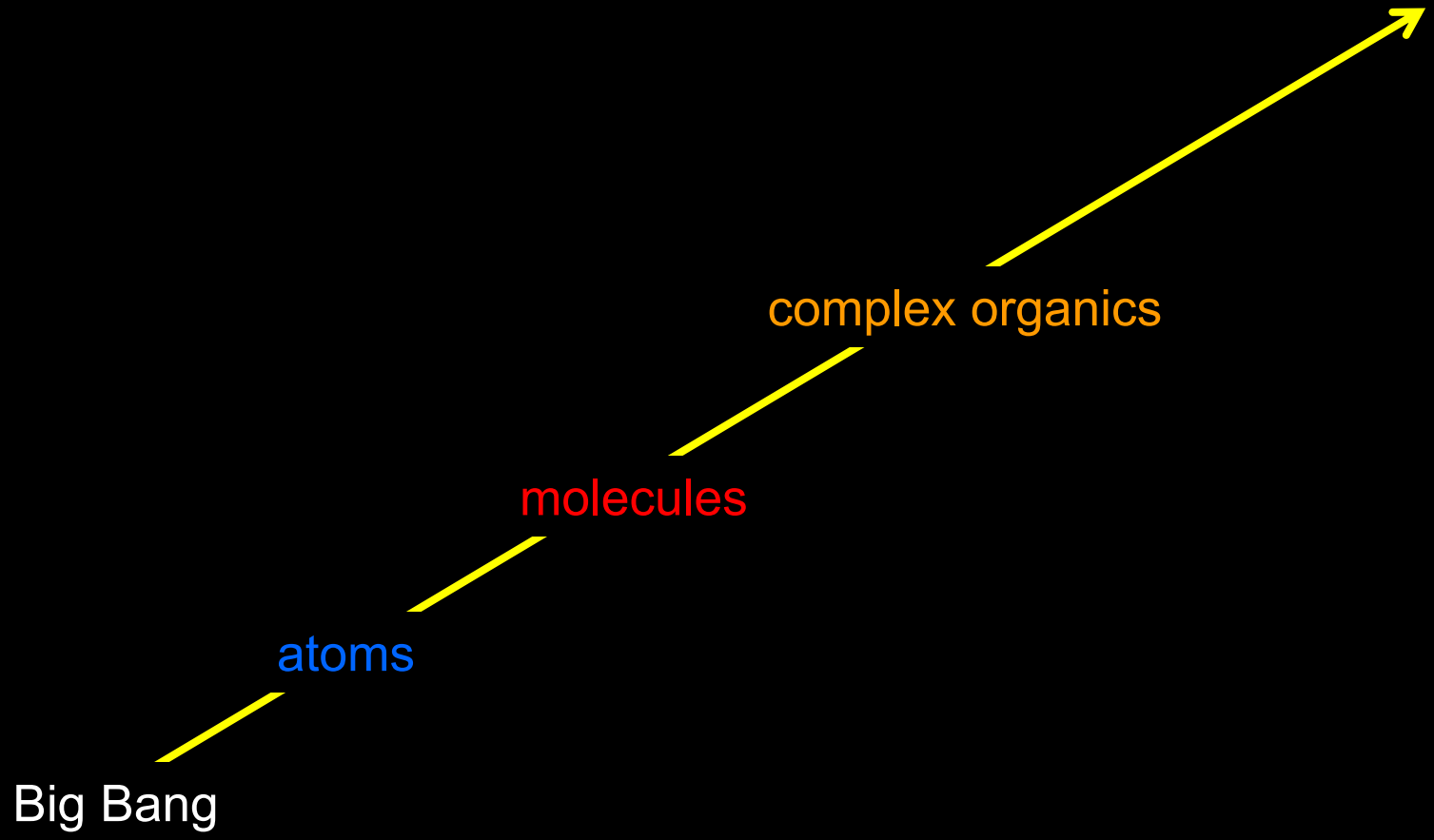
Sputnik / Luna 1

up to the space era, Earth was the sole planet within our scientific horizon.

evolution : envisioned via dogma



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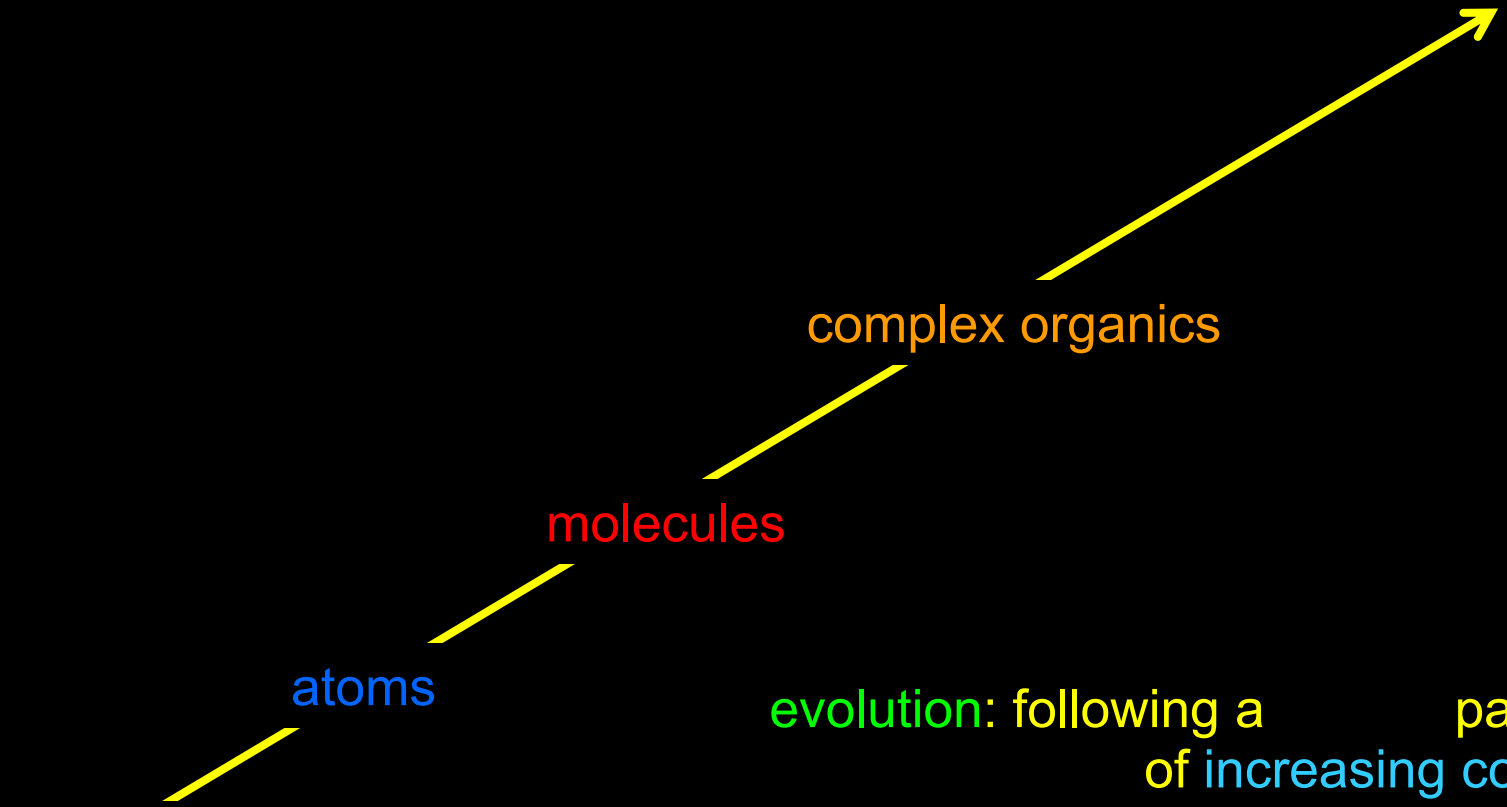
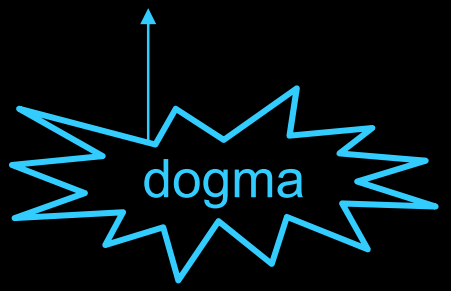


evolution: following a pathway of
of increasing complexity



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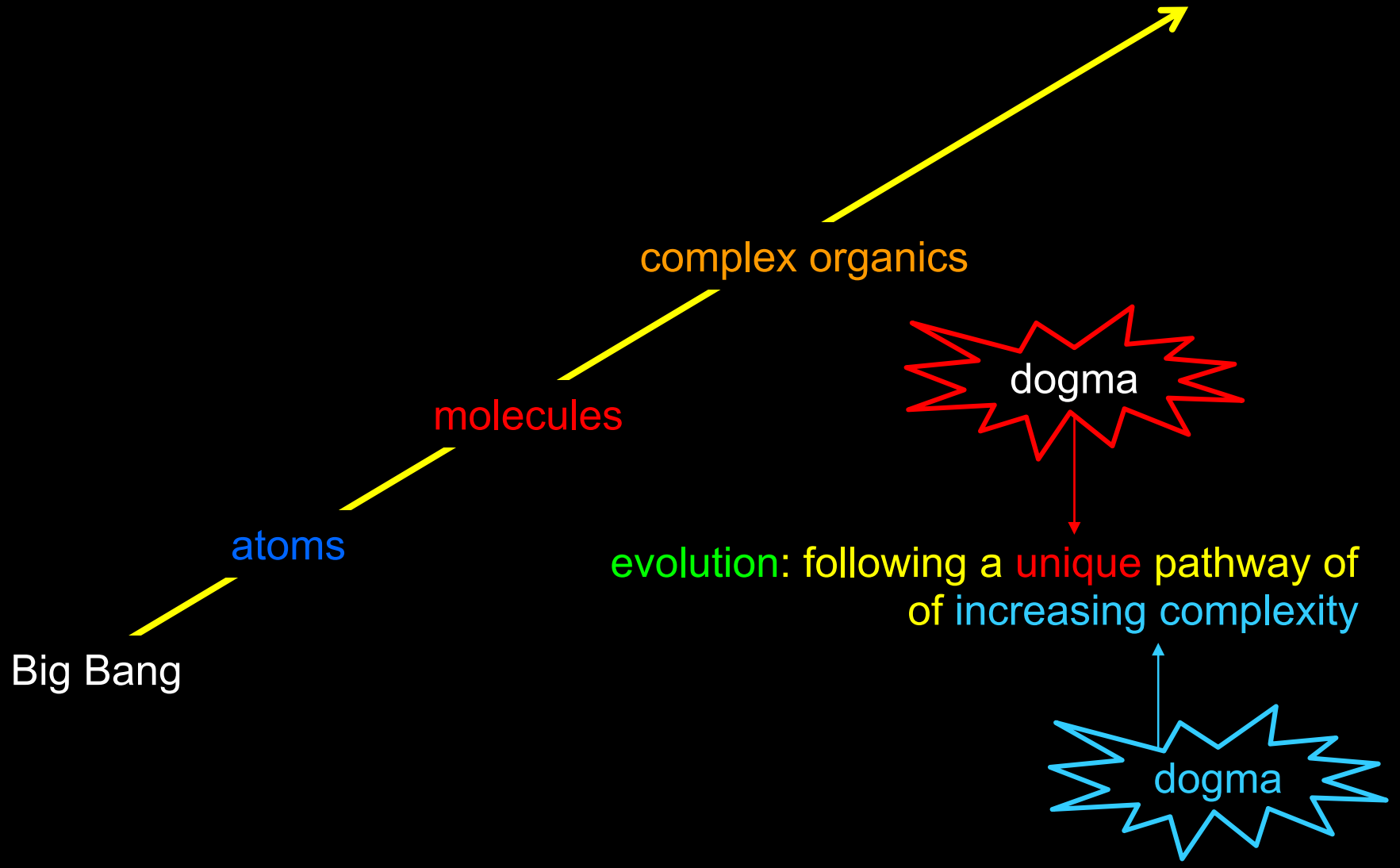
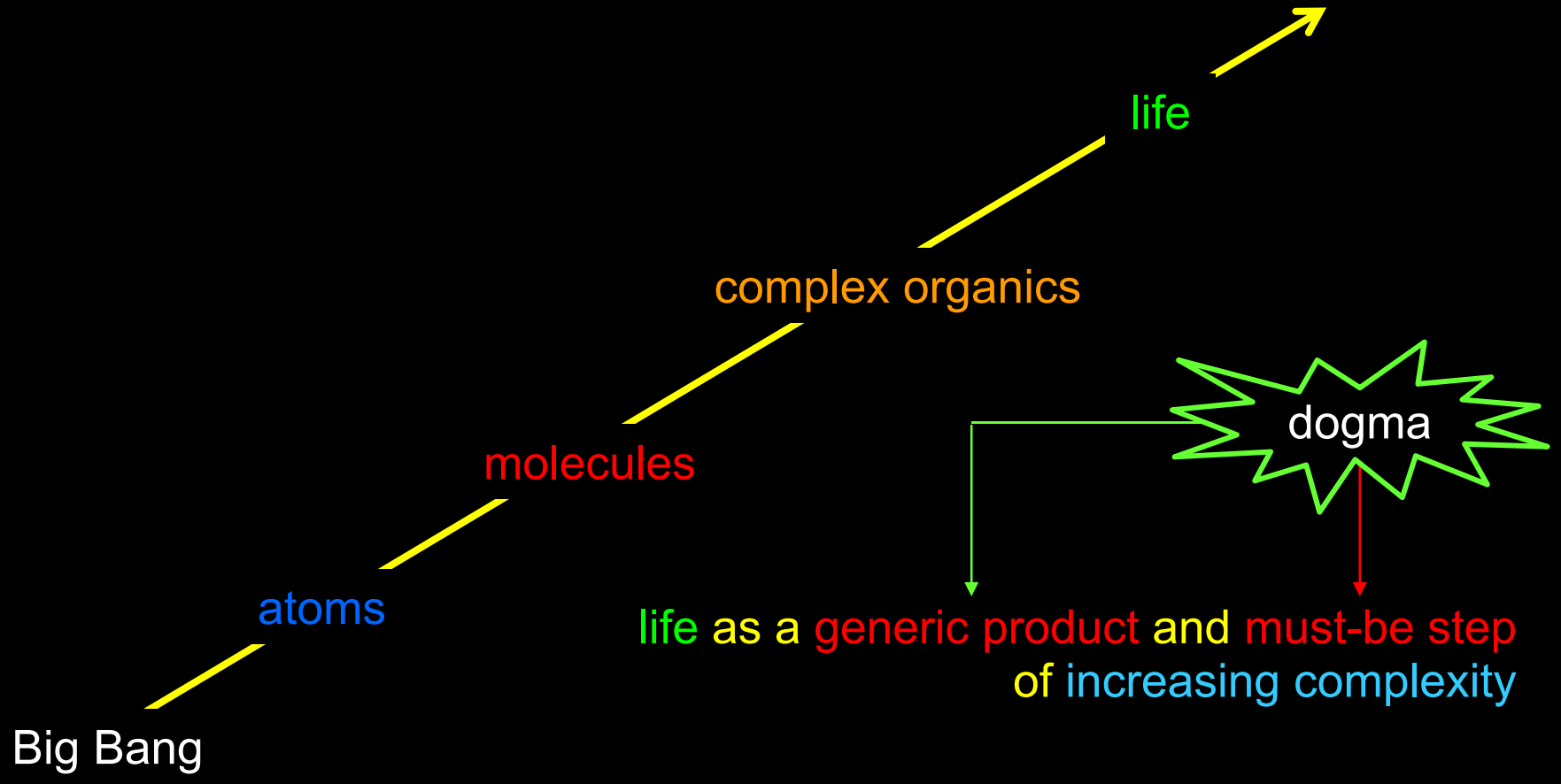


evolution / life: envisioned via dogma



evolution / life: envisioned via dogma

life

complex organics

molecules

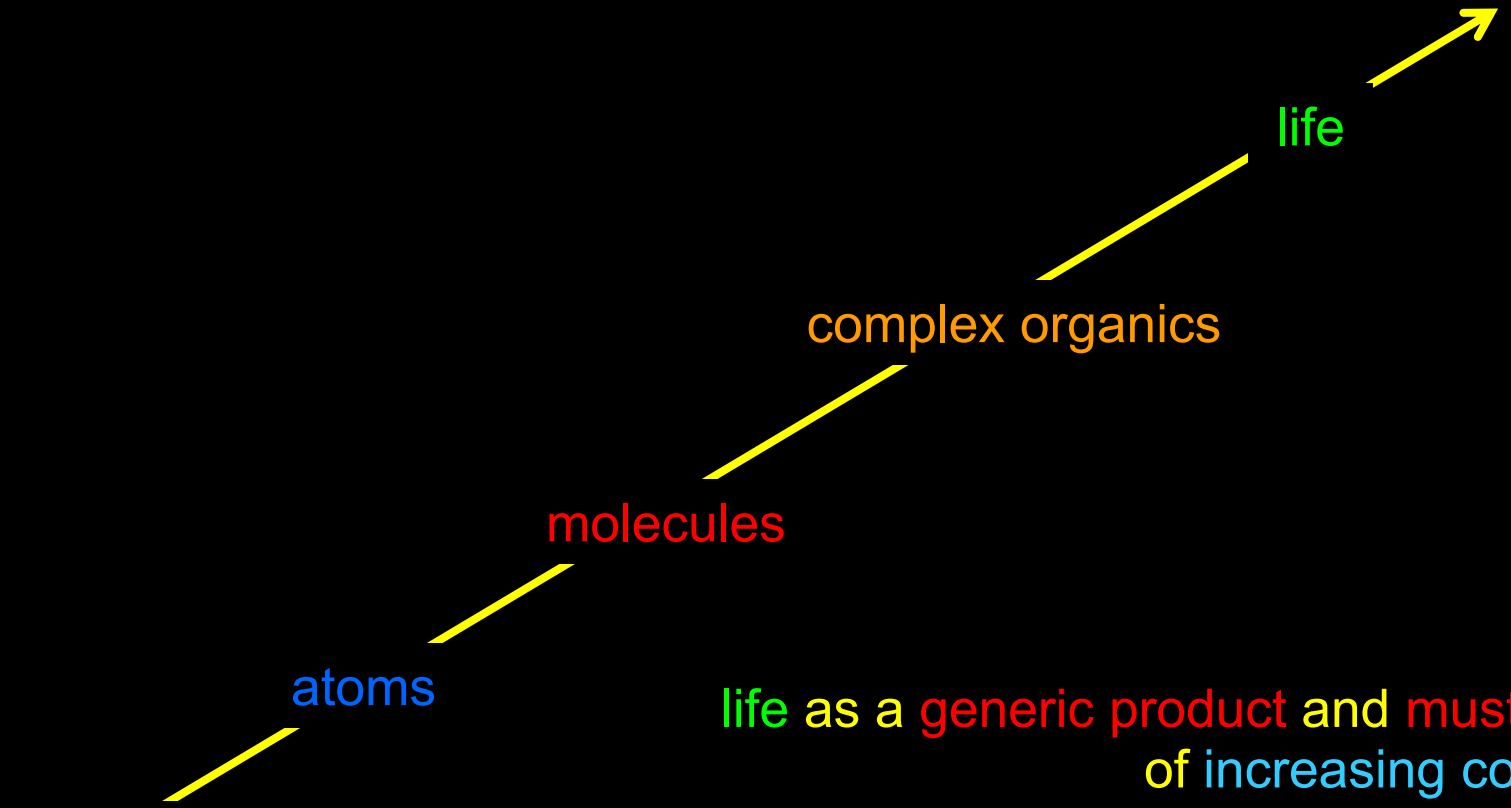
atoms

Big Bang

dogma

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

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



life as a generic product and must-be step
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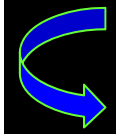
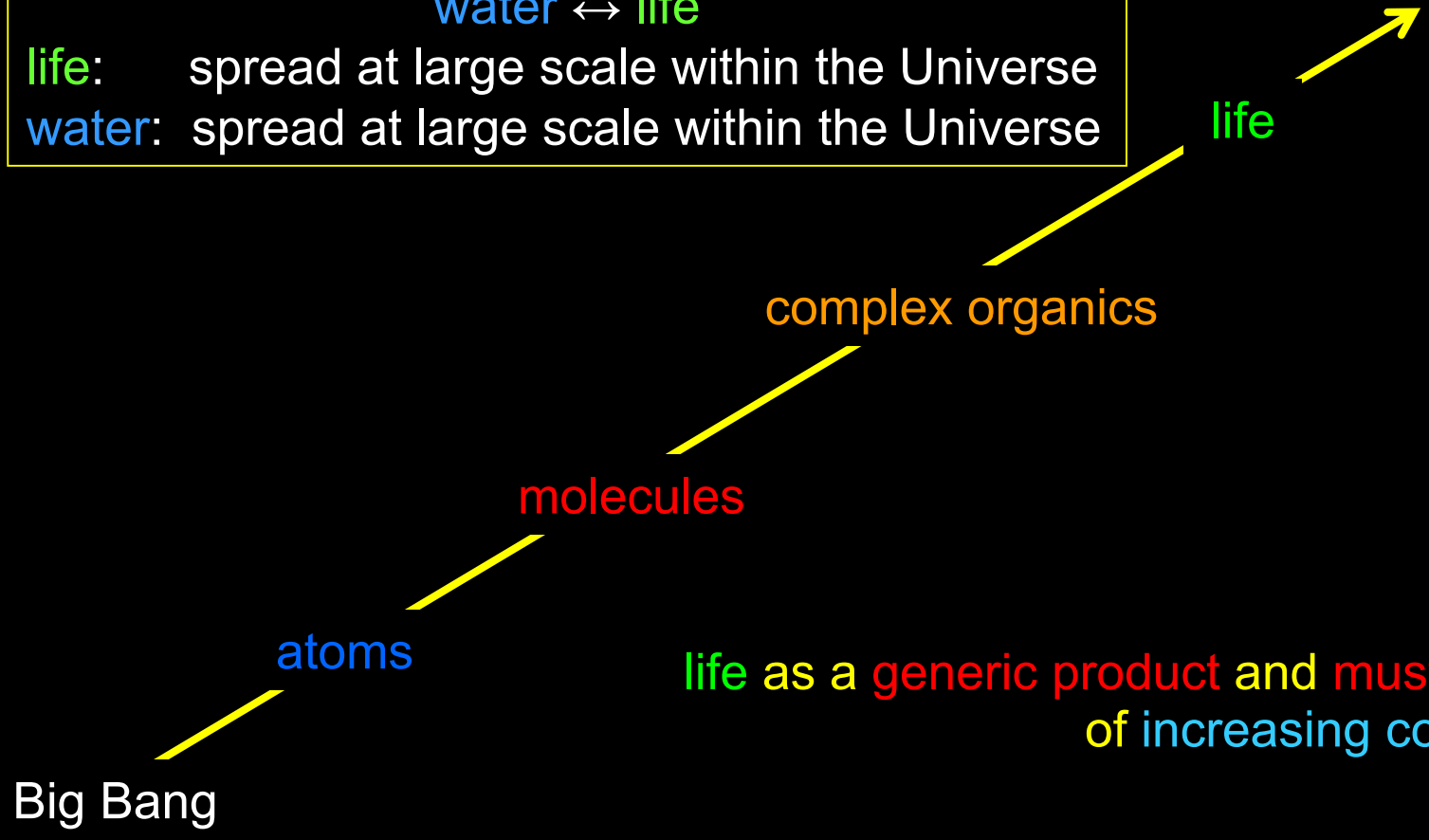
water ↔ life
life: spread at large scale within the Universe
water: spread at large scale within the Universe





life as a generic product and must-be step
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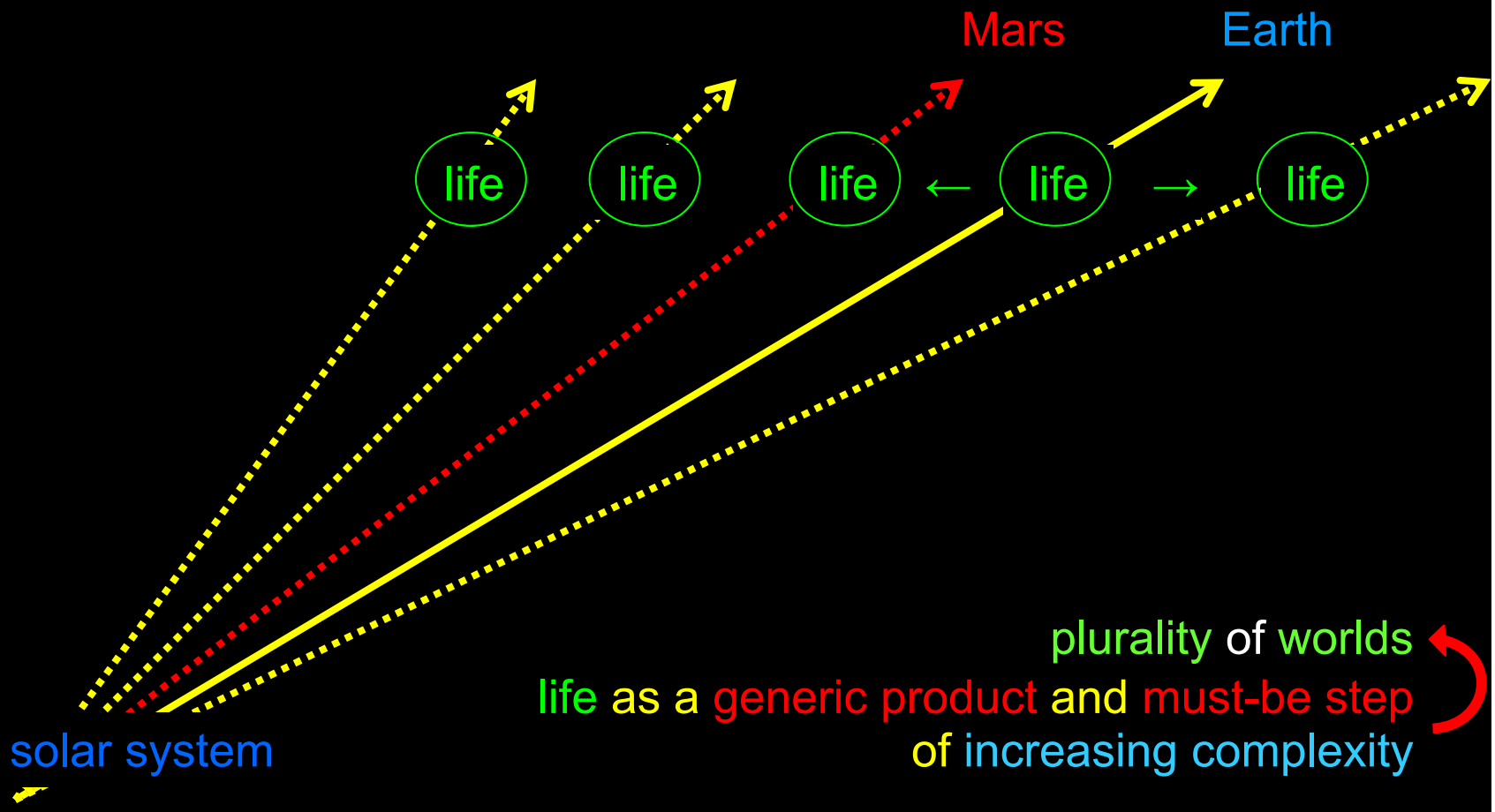

plurality of worlds
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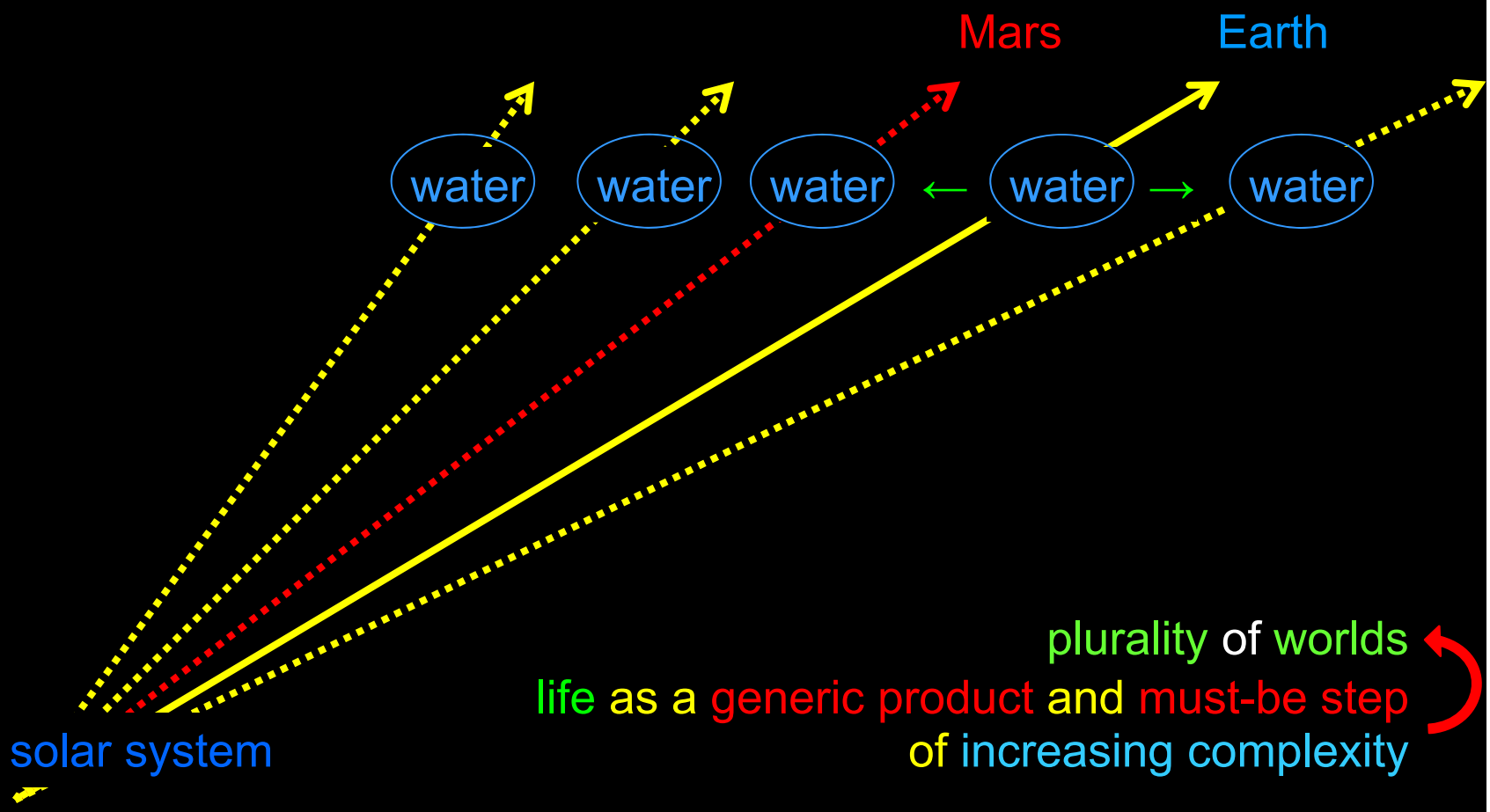
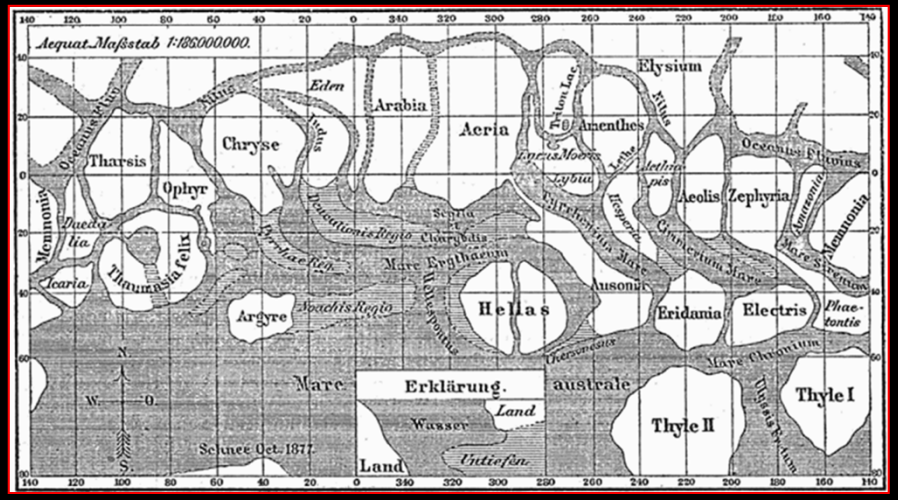


Mars

life water

Mars : a world not merely habitable, but inhabited…!



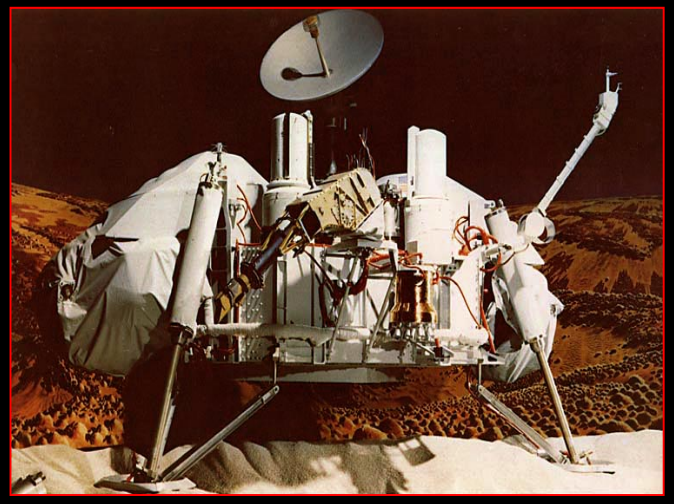
Lowell

Schiaparelli, *Canali*, 1877

Mars

life water

Viking prime goal: to
characterize Martian metabolism



Viking, 1976

Mars

life water

first astrobiological experiments

Viking, 1976

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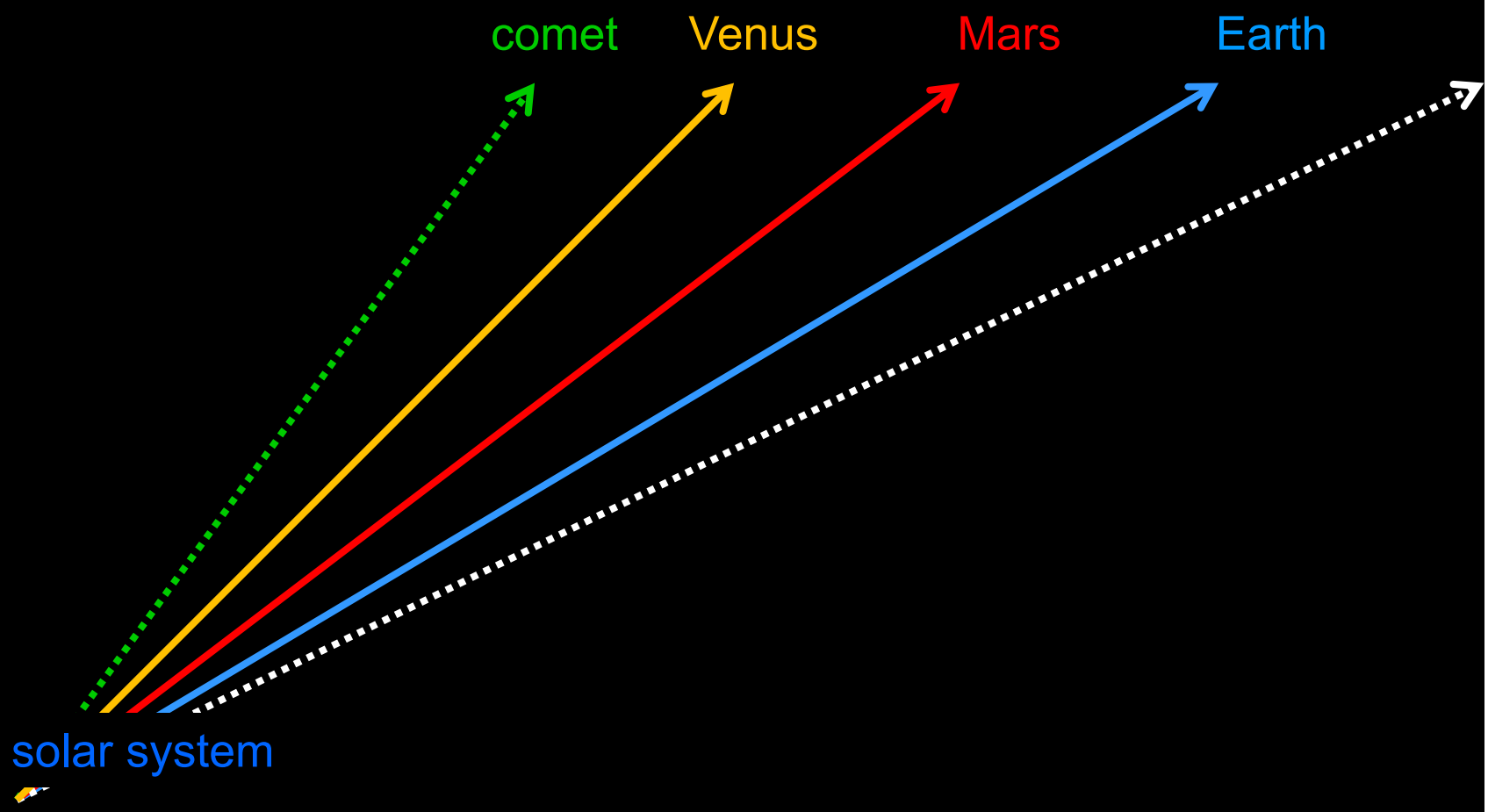
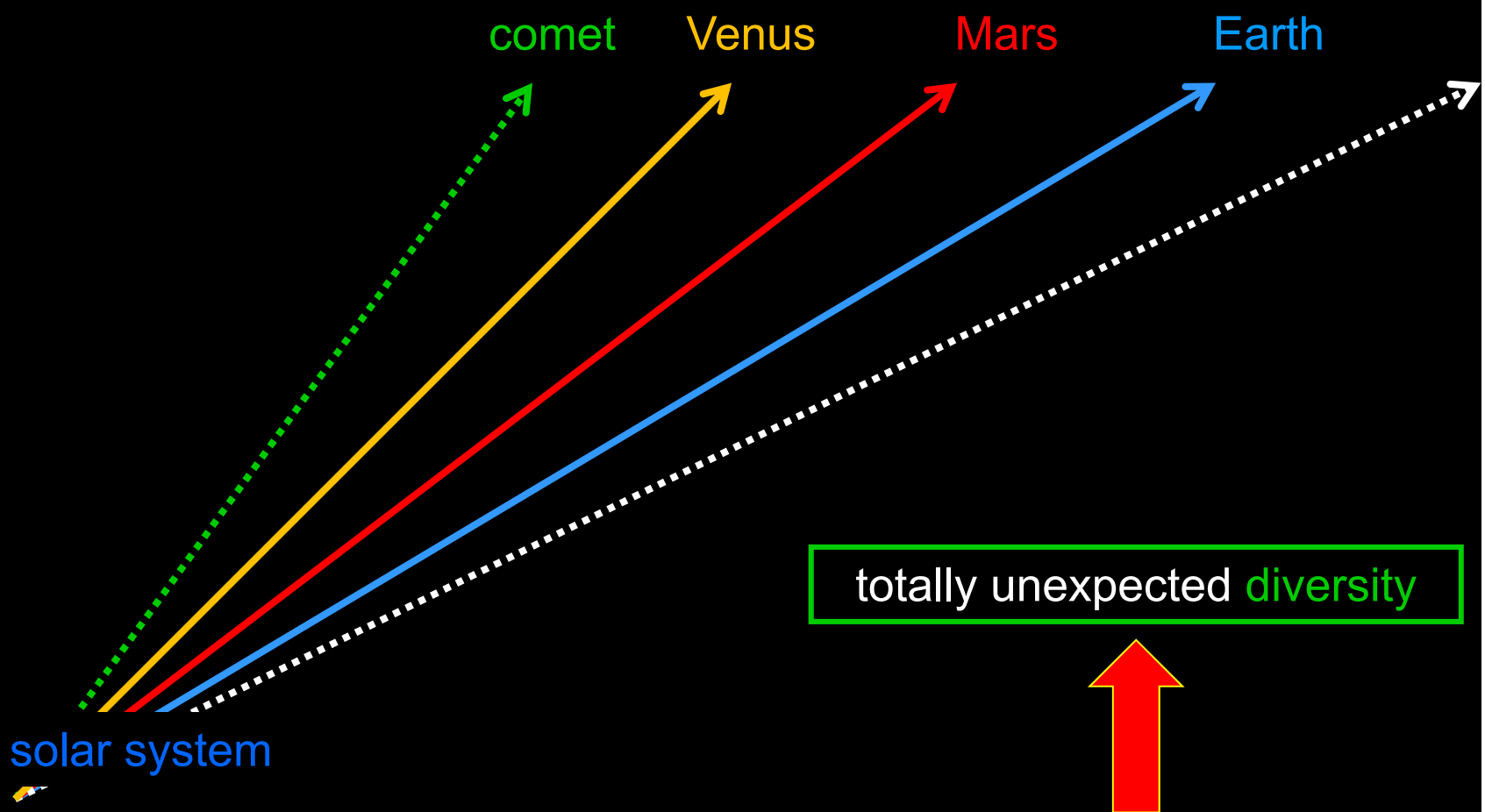
space exploration brings planets & small bodies within our science horizon



We belong to one specific evolution pathway,
but have now observational access to other planetary worlds

space exploration brings planets & small bodies within our science horizon



totally unexpected diversity

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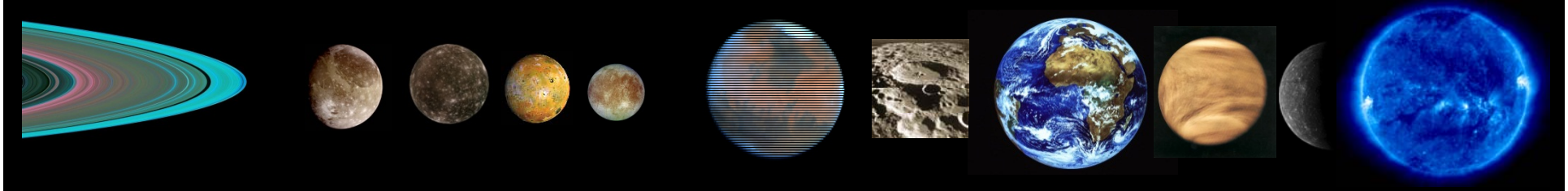
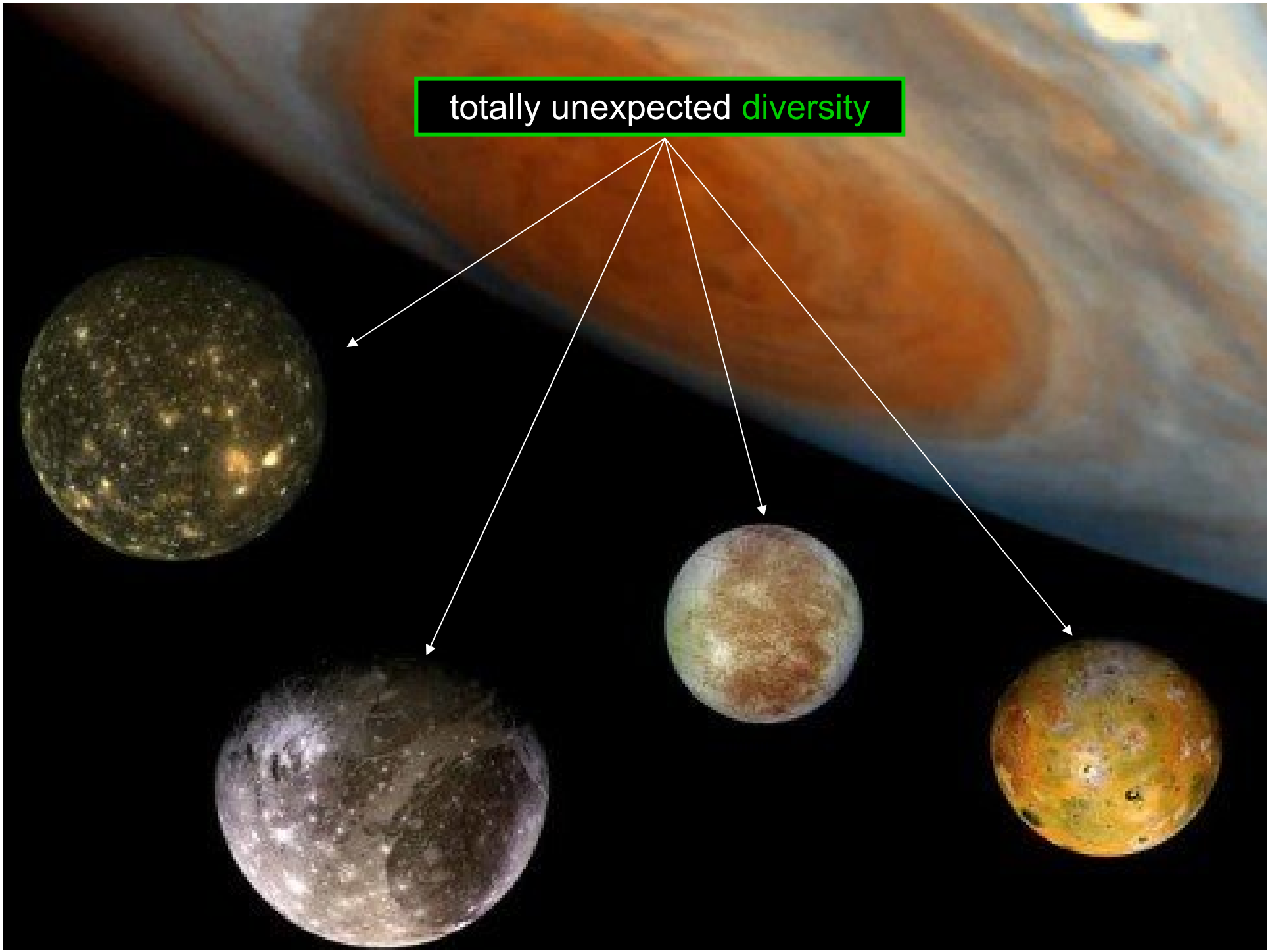
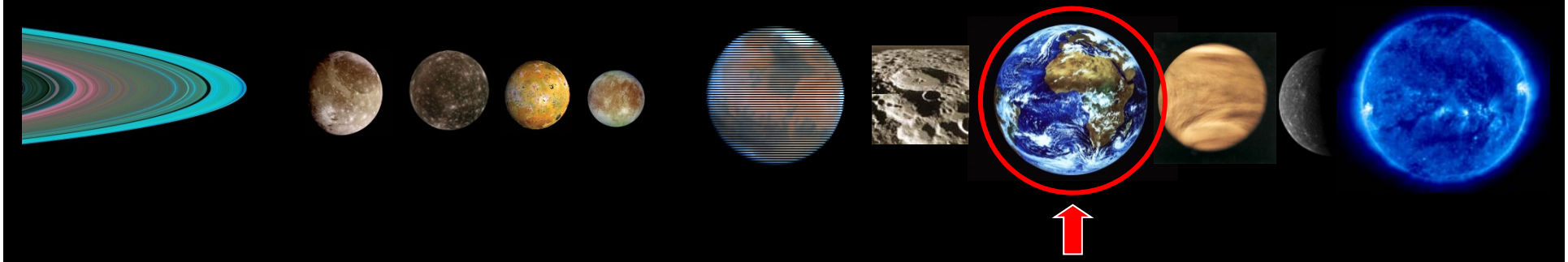
totally unexpected diversity




totally unexpected diversity

standard, generic ?

- unique ocean cover
- unique cloud cover
- unique atmospheric cover



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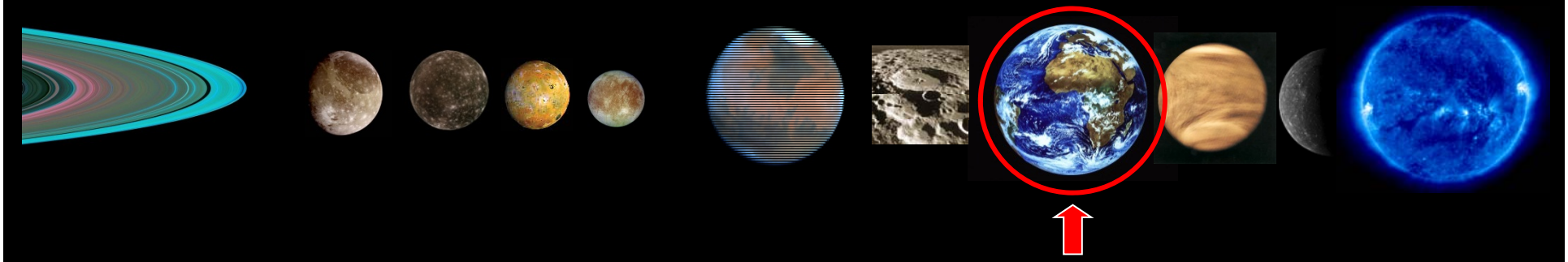
: at what time/space scale ?



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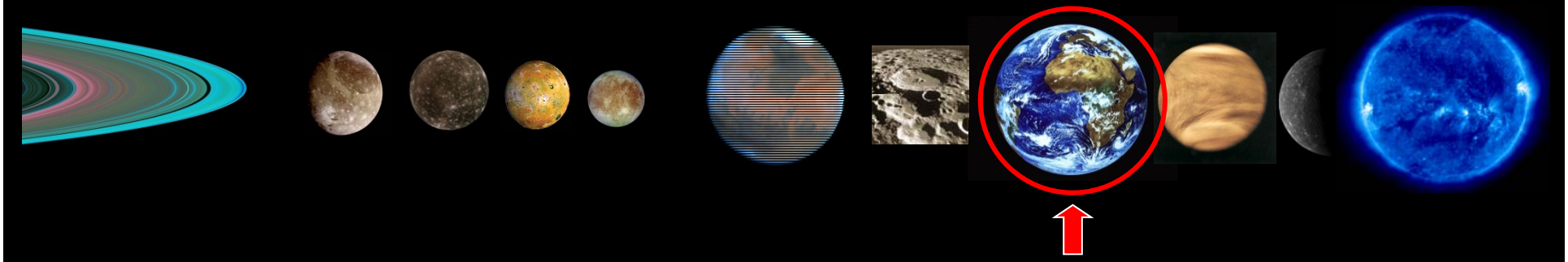
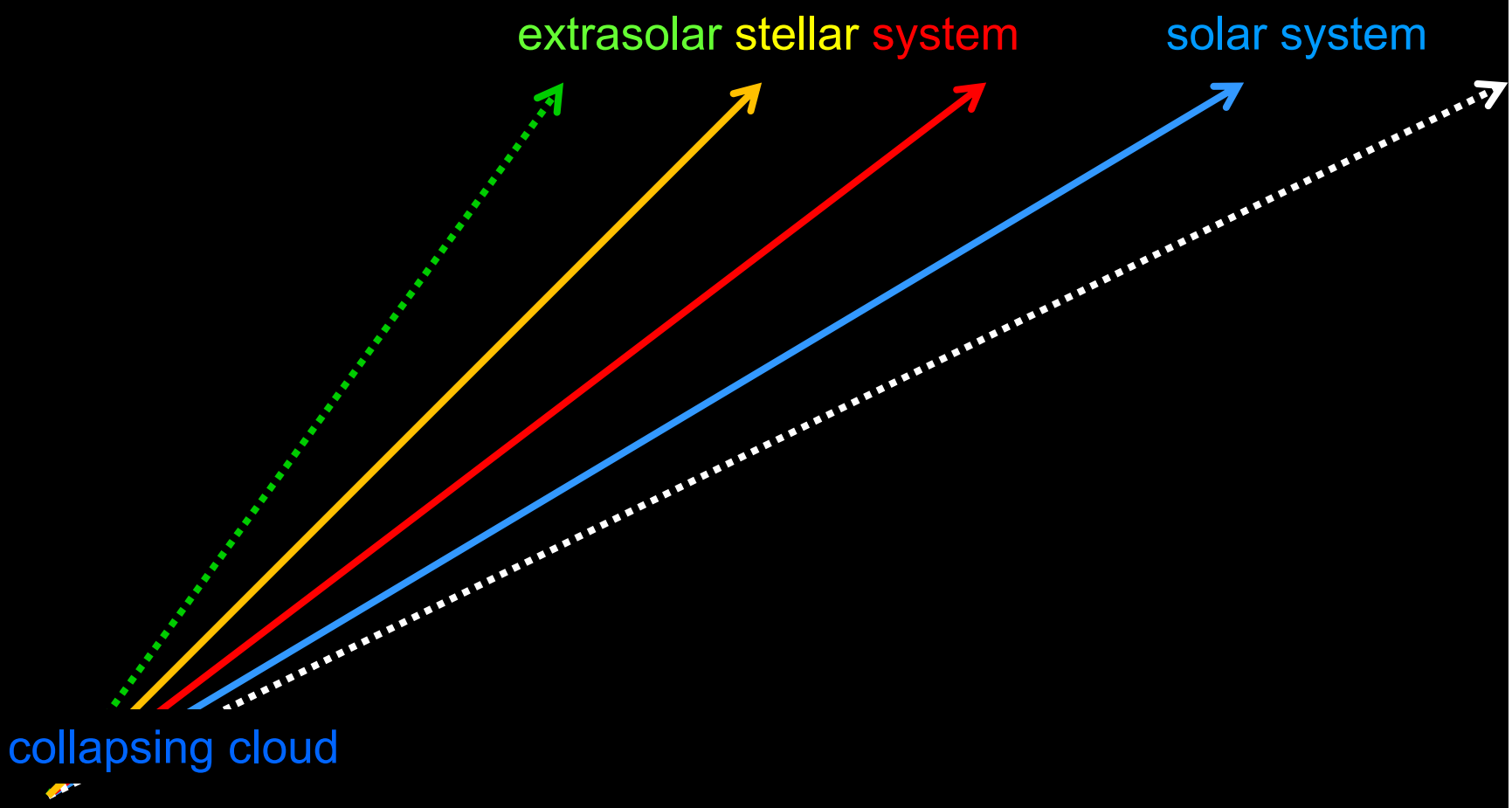
: at what time/space scale ?

is life unique ?



extrasolar stellar planets/systems are entering our science horizon



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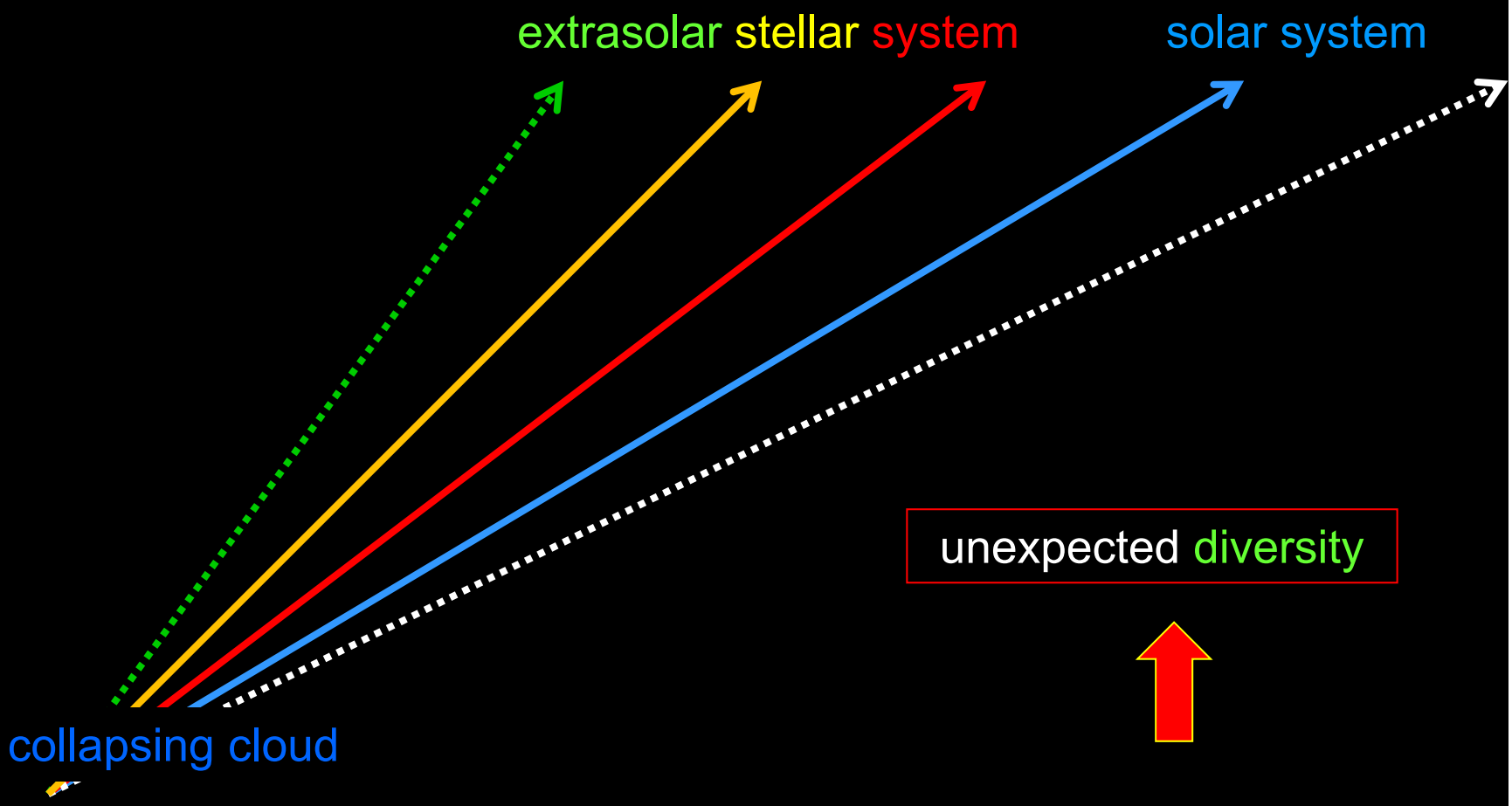

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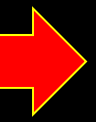
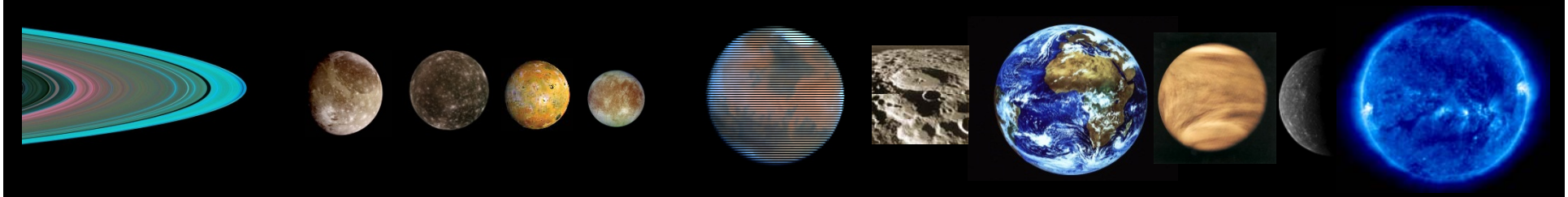
plurality of worlds



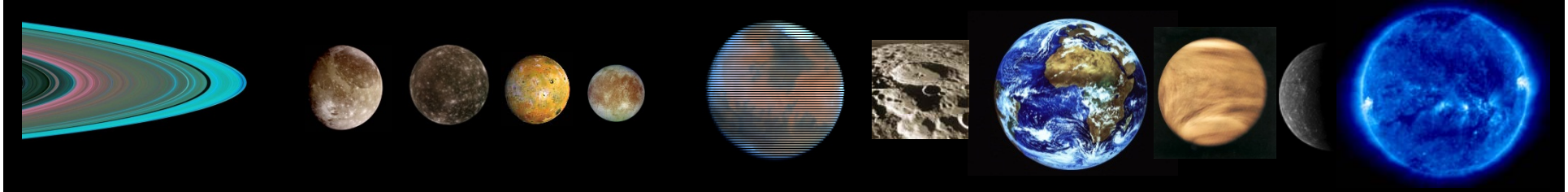
diversity of worlds

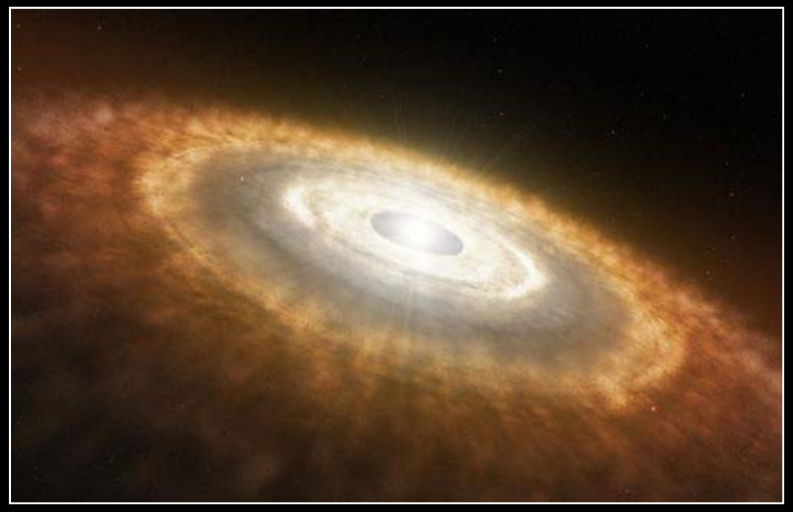


plurality of worlds → diversity of worlds

Is life a generic product of increasing complexity ?

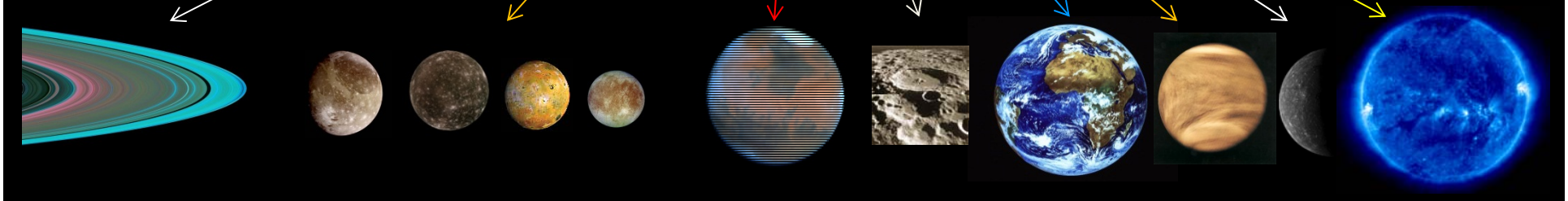
Has life ever "emerged" else than on Earth ?

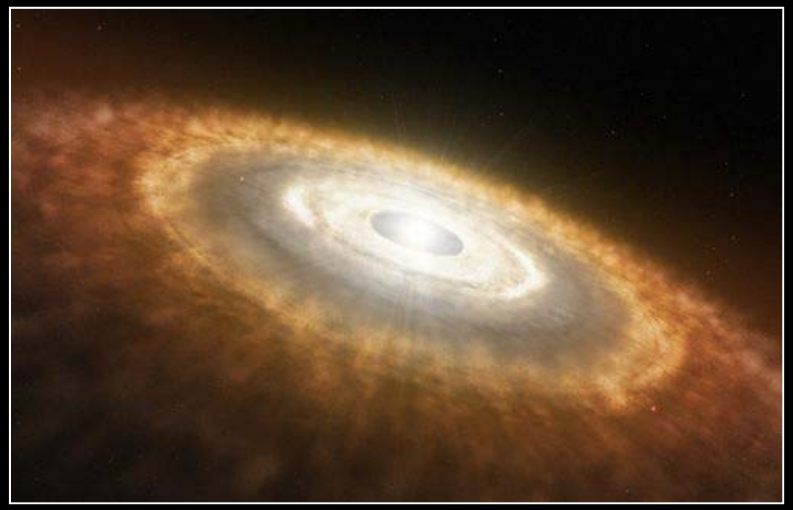




"common" origin

what drives the diversity of evolutions?

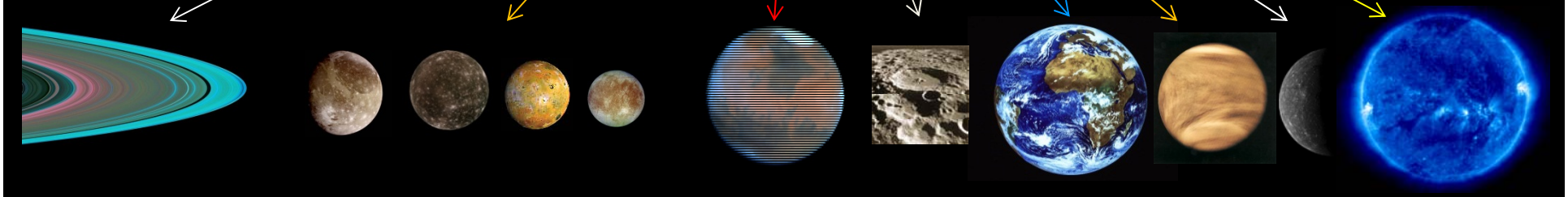


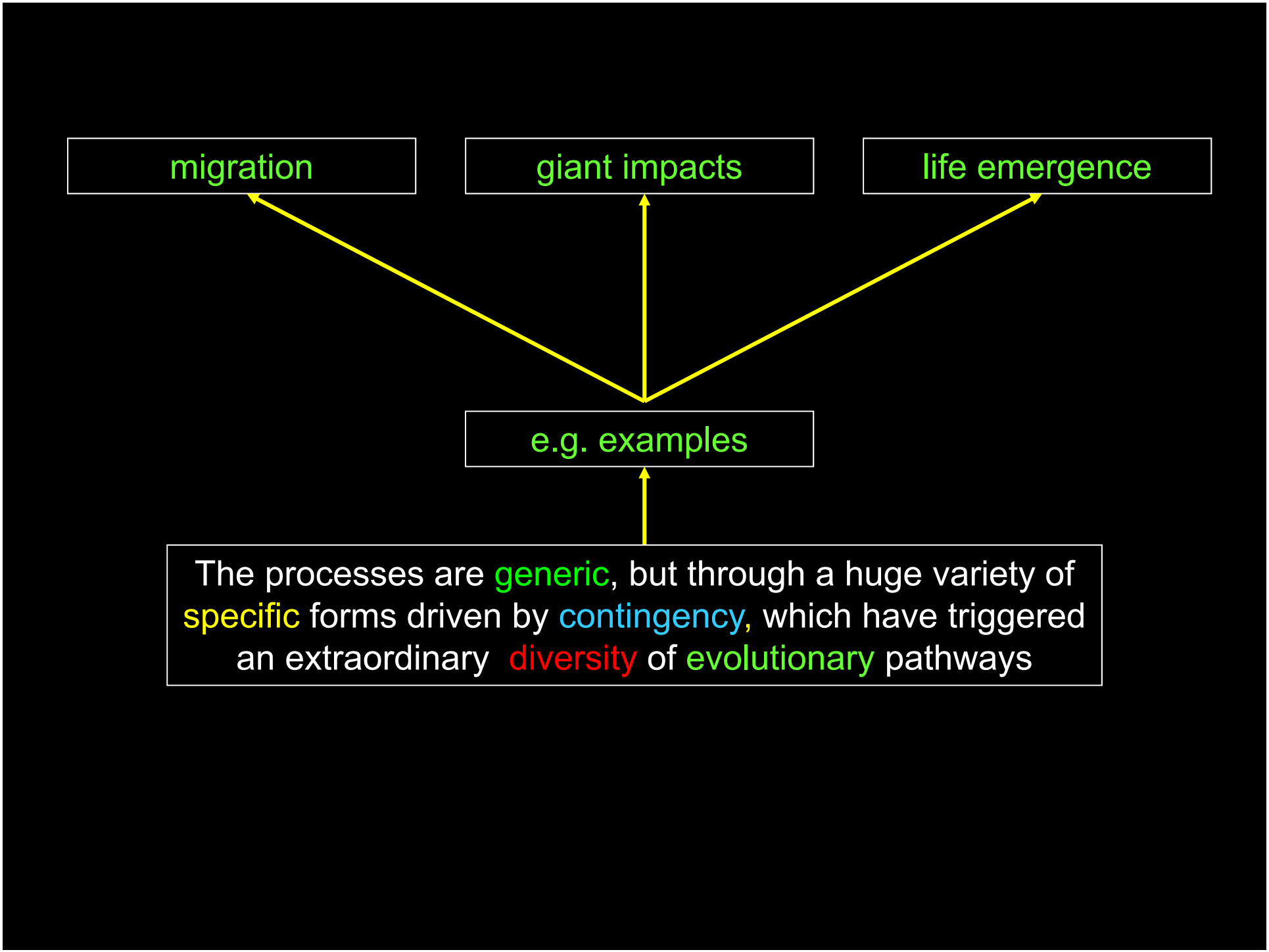


"common" origin

what drives the diversity of evolutions?

The processes are generic, but through a huge variety of specific forms driven by contingency, which have triggered an extraordinary diversity of evolutionary pathways




migration
giant impacts
life emergence
e.g. examples
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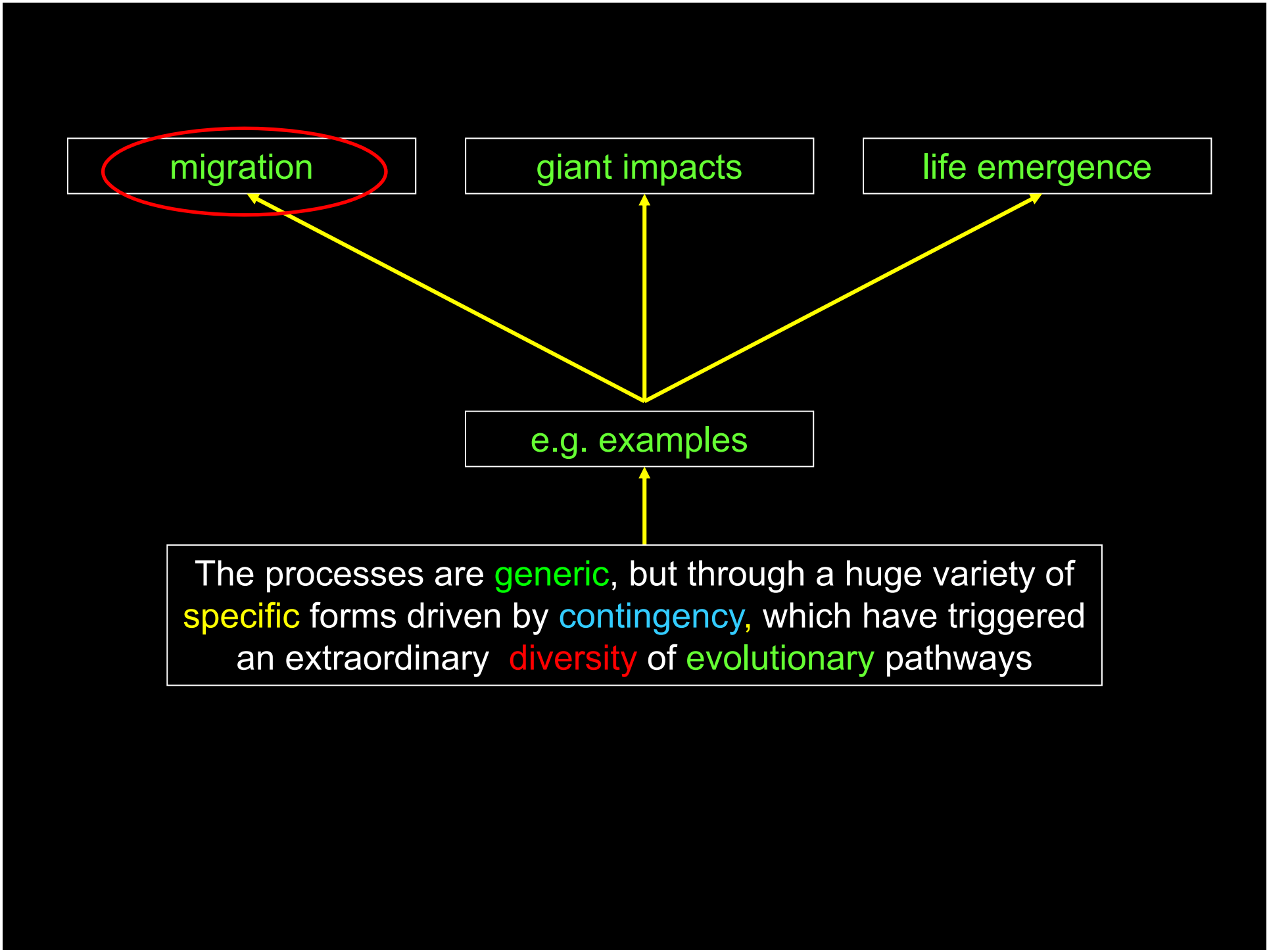
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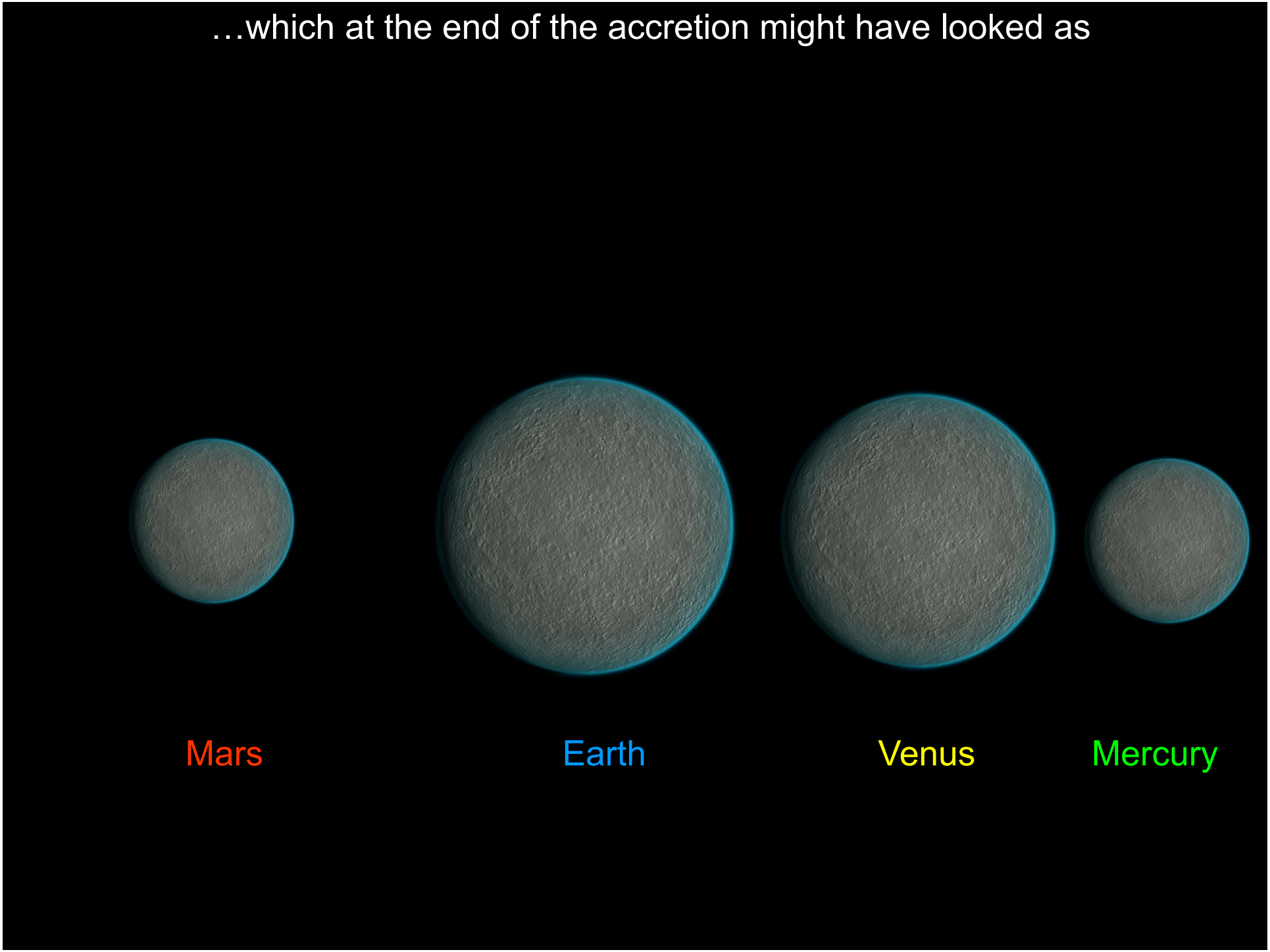
migration

The grand tack (Nice) and other similar models are based on the (recent) recognition that migration is a generic process of disk evolution, operating in essentially all observed stellar systems, and which also affected the solar system, but with a highly specific (contingent) pattern.

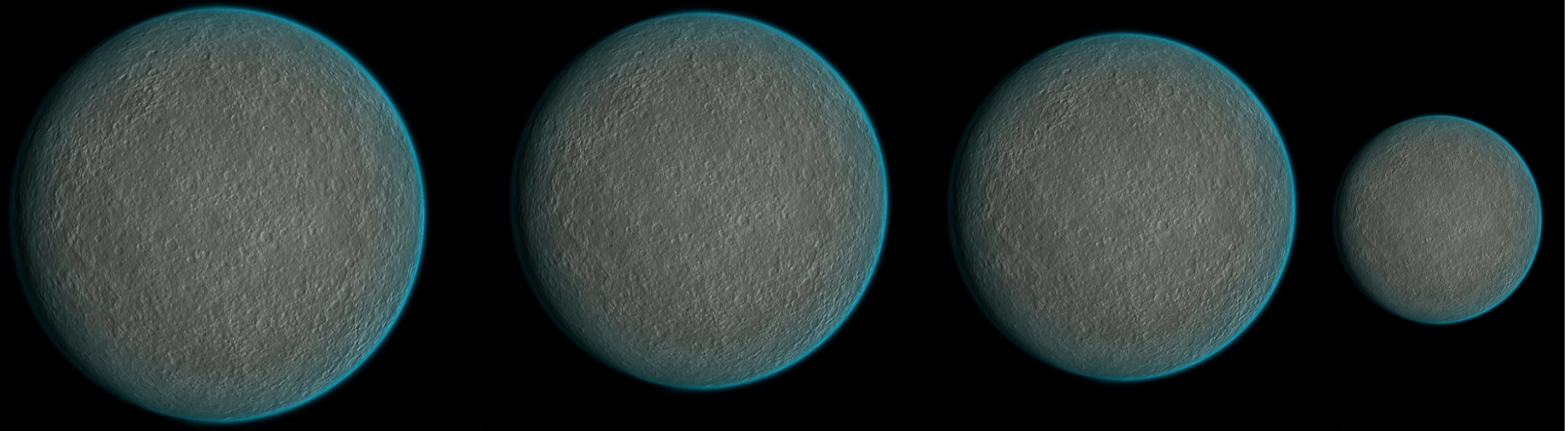
It is based on the relative mass (size) distribution of the inner planets

Mars Earth Venus Mercury

…which at the end of the accretion might have looked as



…which contrasts (for Mars) with the expected mass distribution derived from accretion in a full disk



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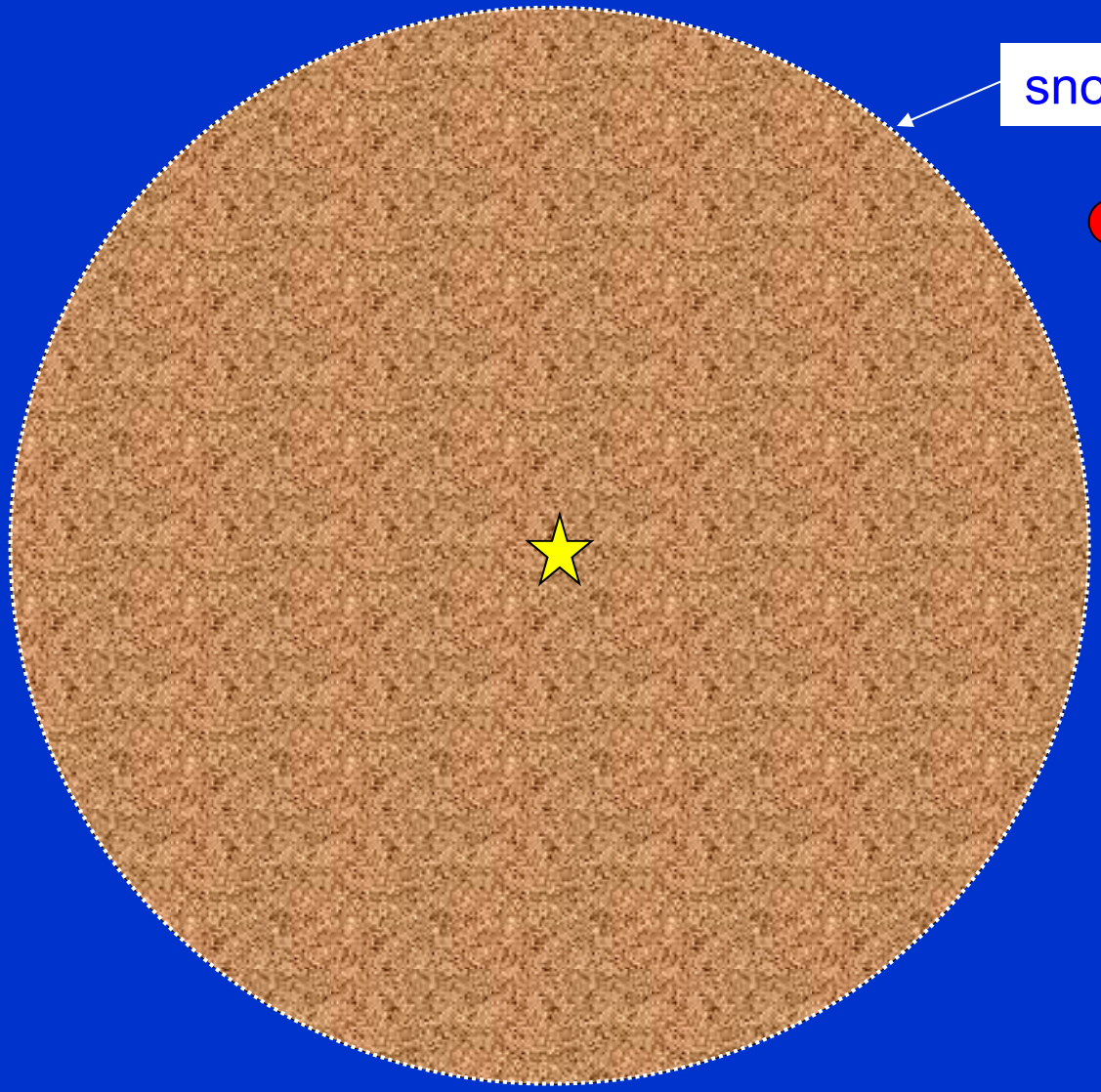
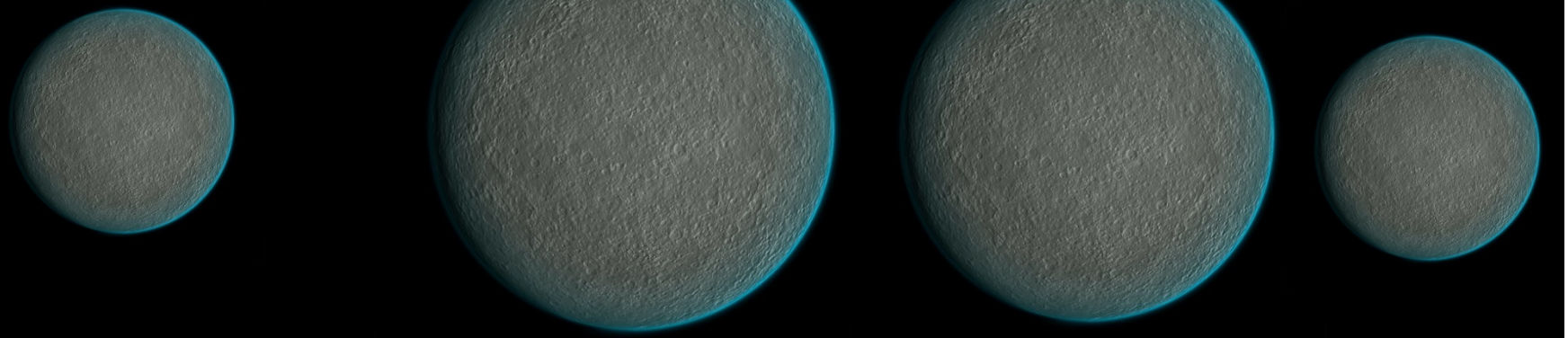
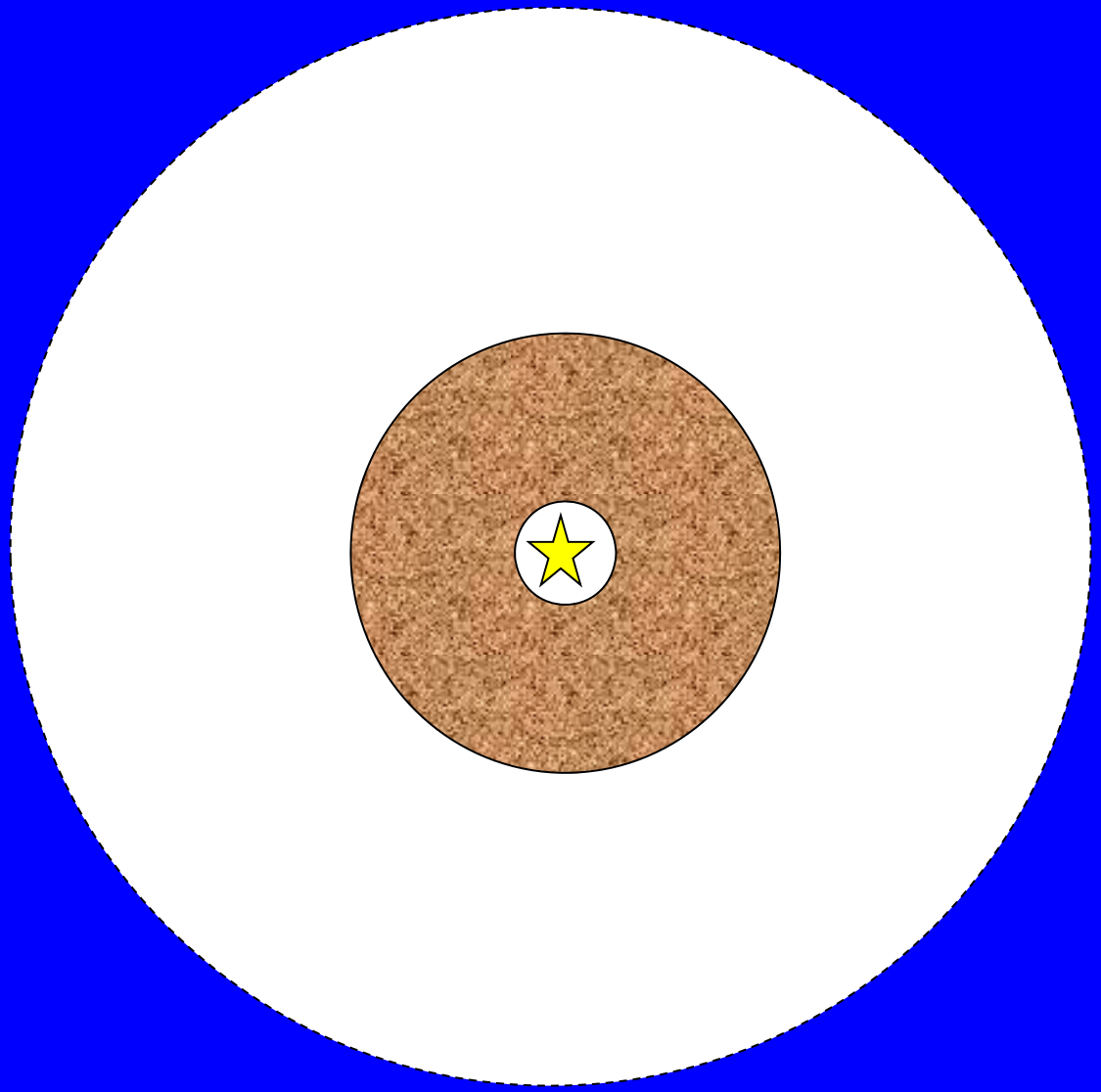


in order to get the observed mass distribution

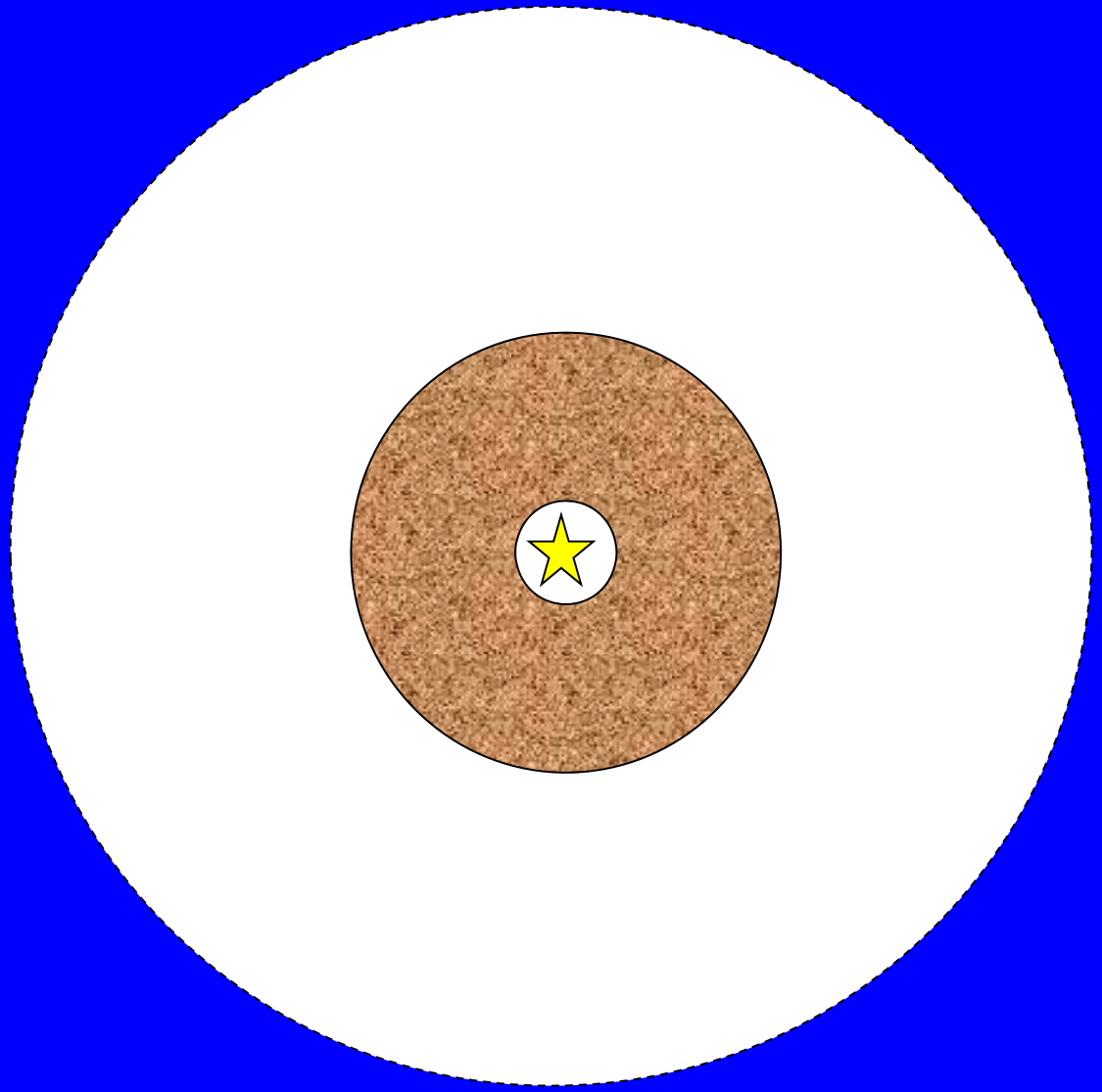


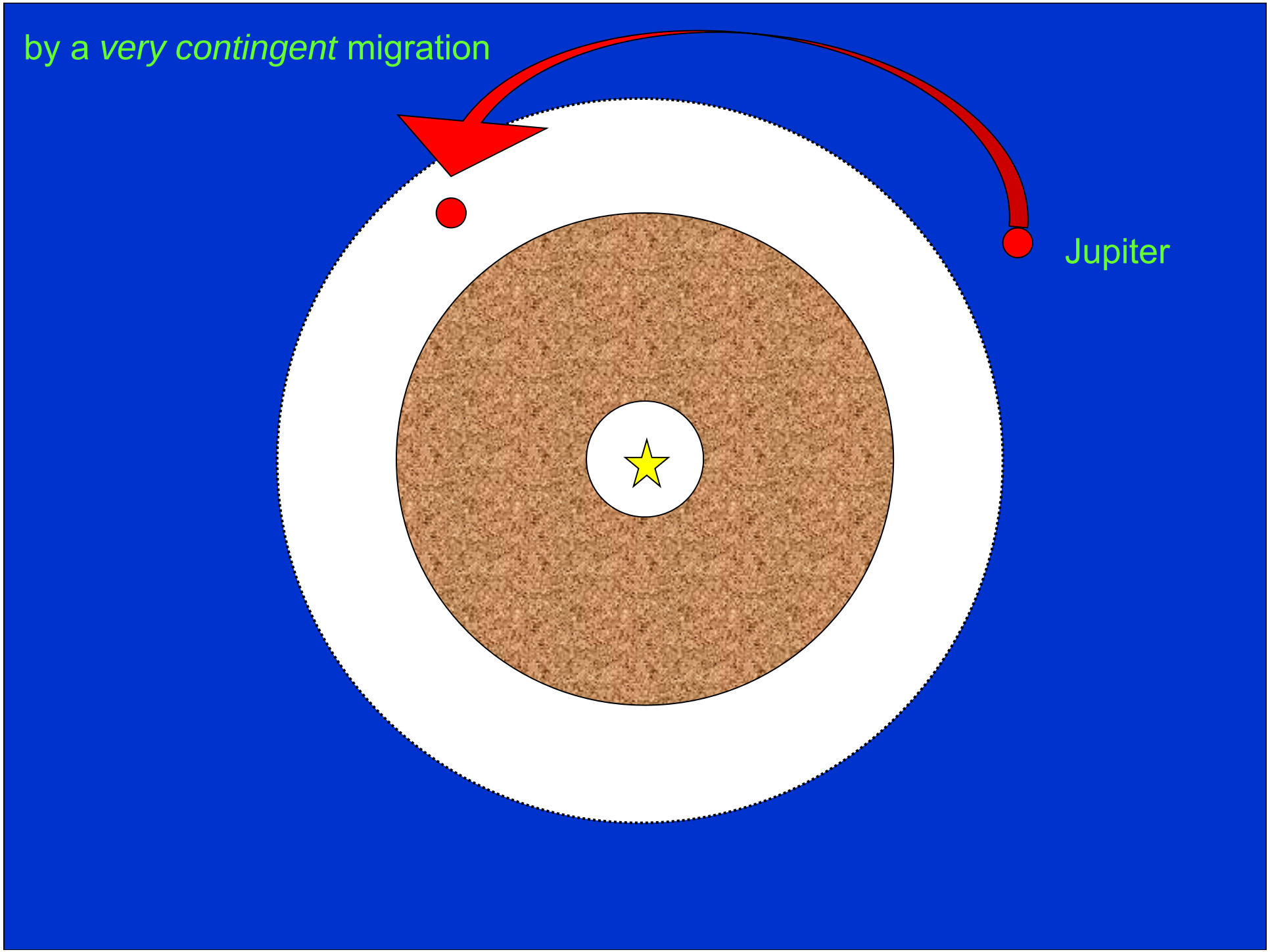
Mars Earth Venus Mercury

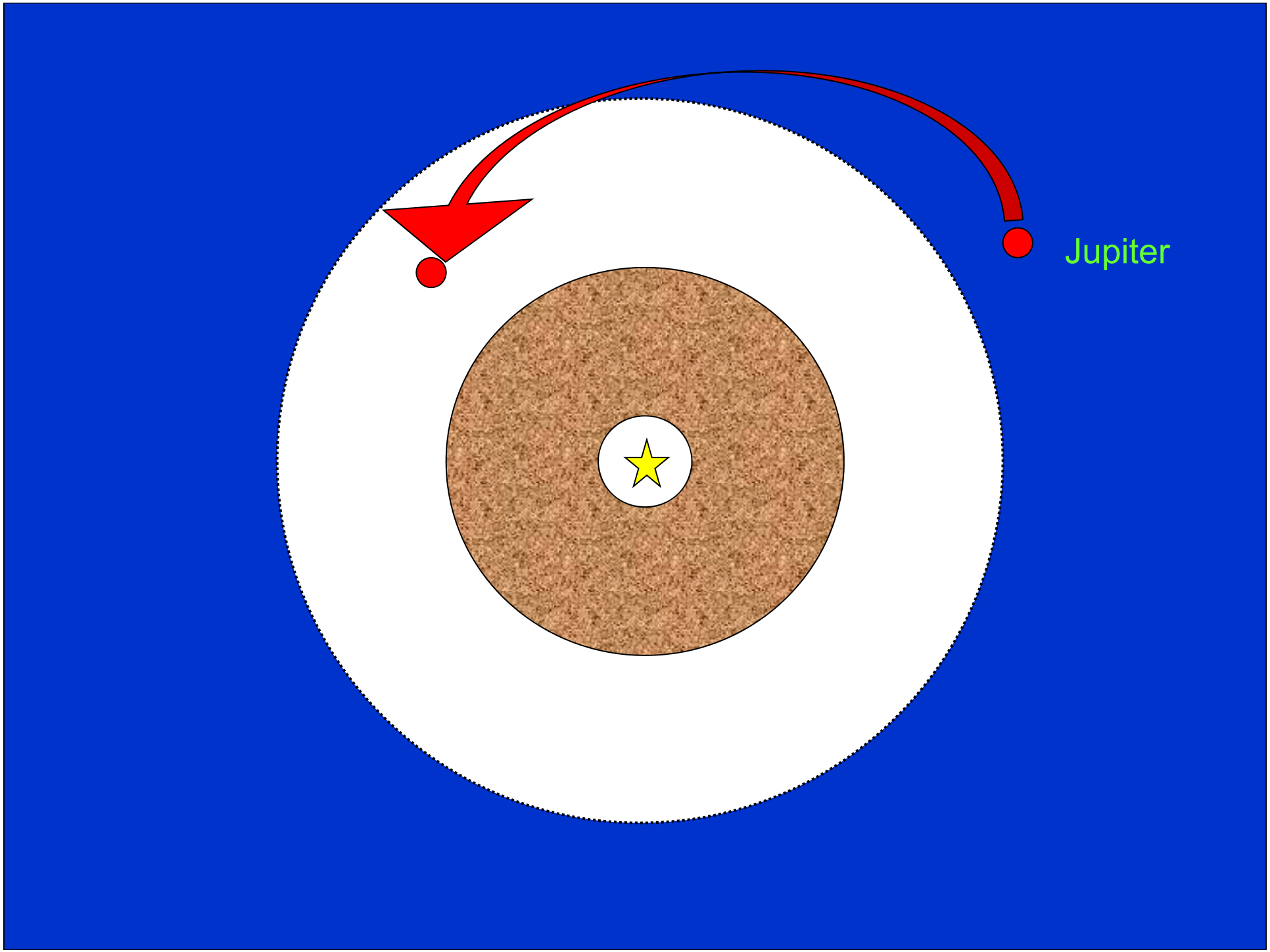
…the inner planets must have accreted within a disk confined within ~1 AU

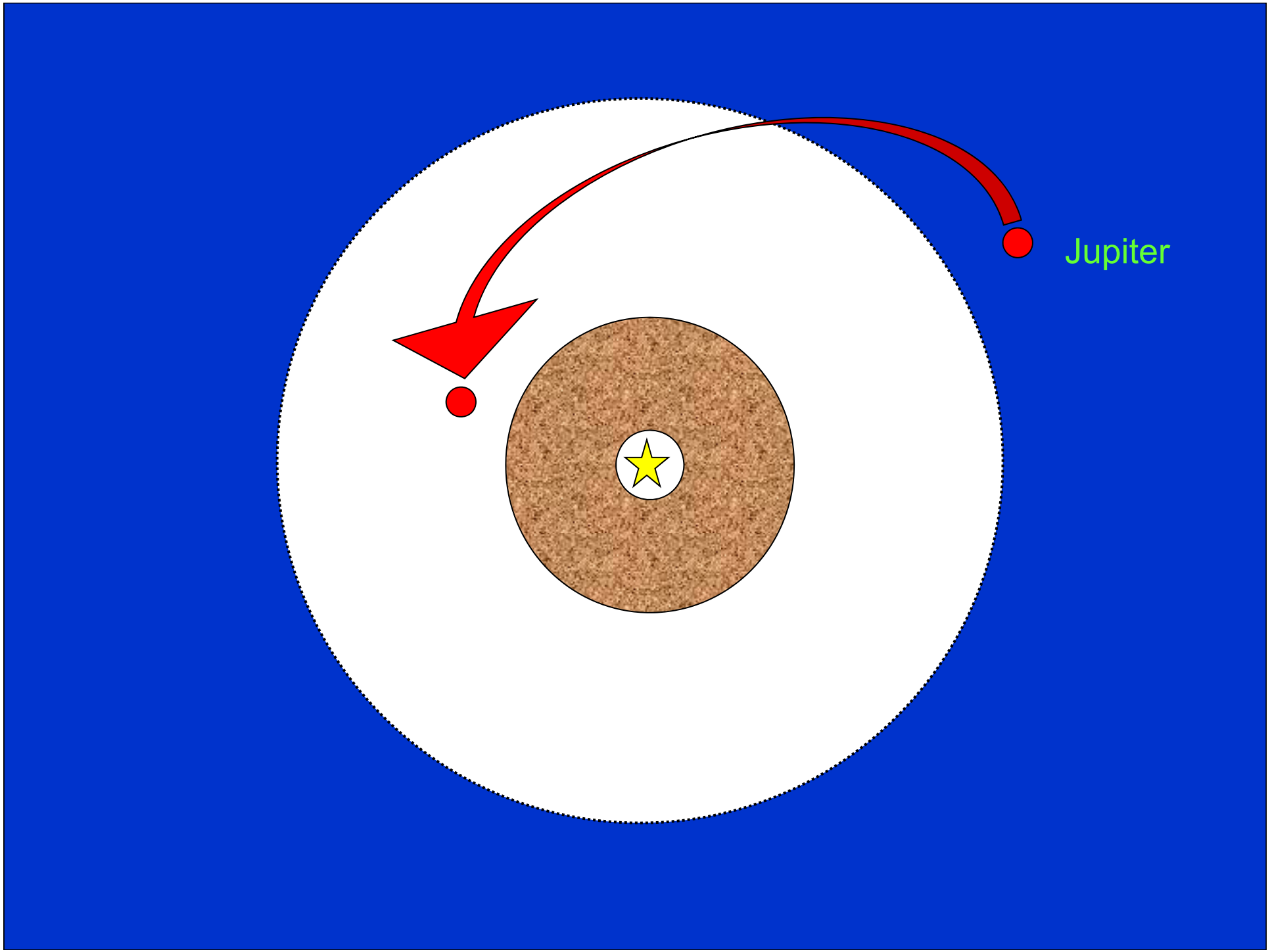


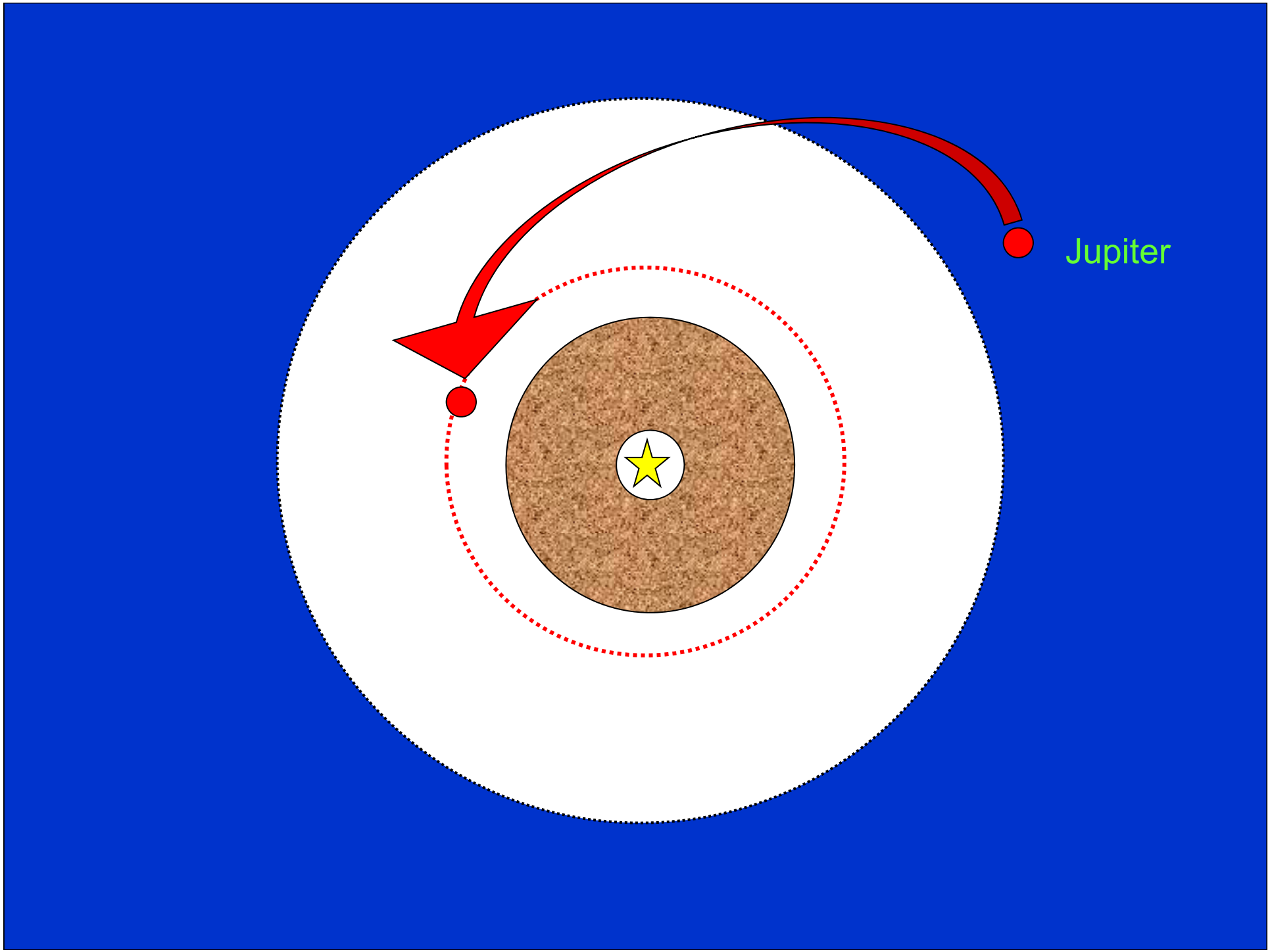
The Grand Tack model accounts for the disk to be partially emptied

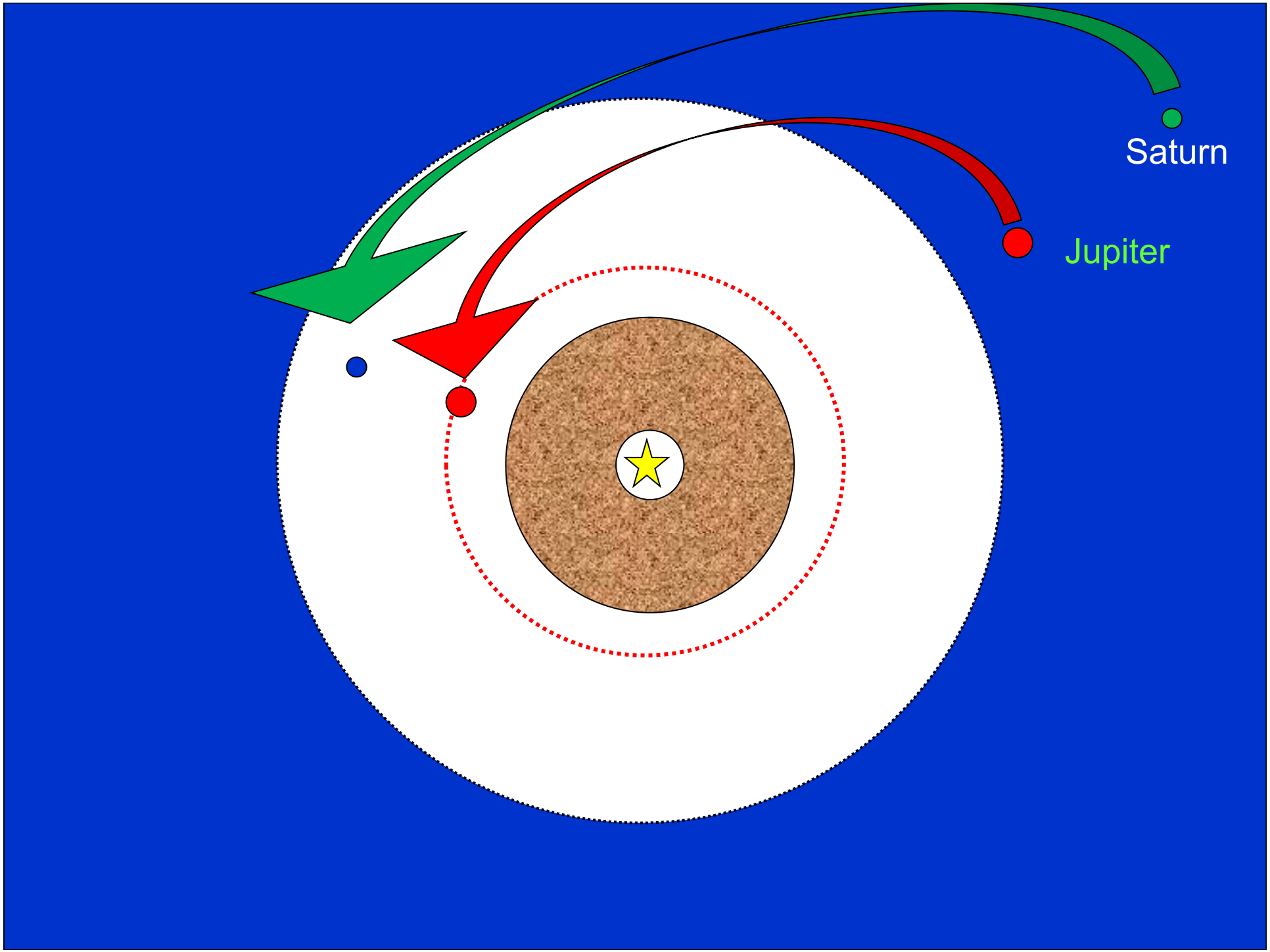


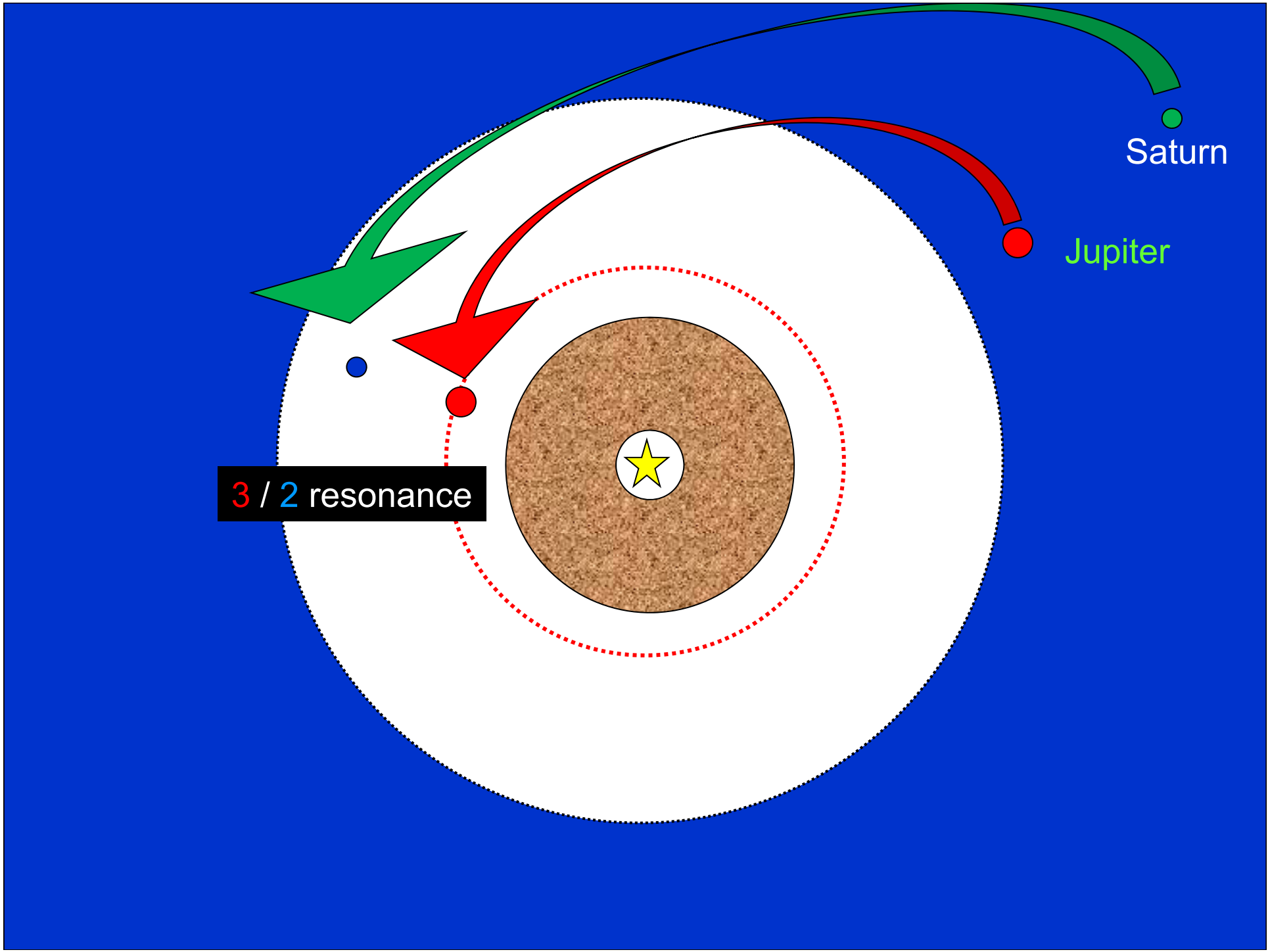

by a *very contingent* migration
Jupiter

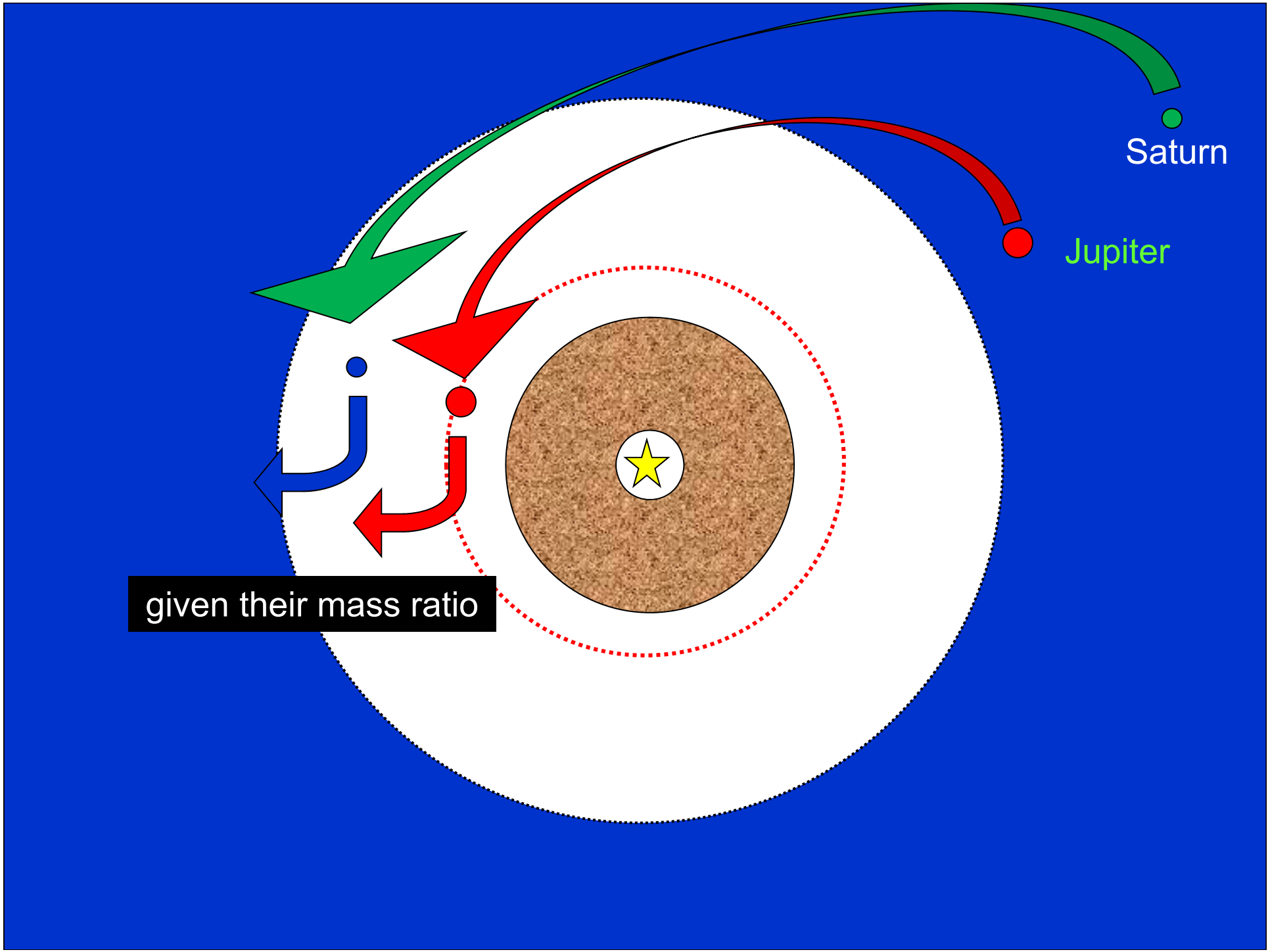

Jupiter

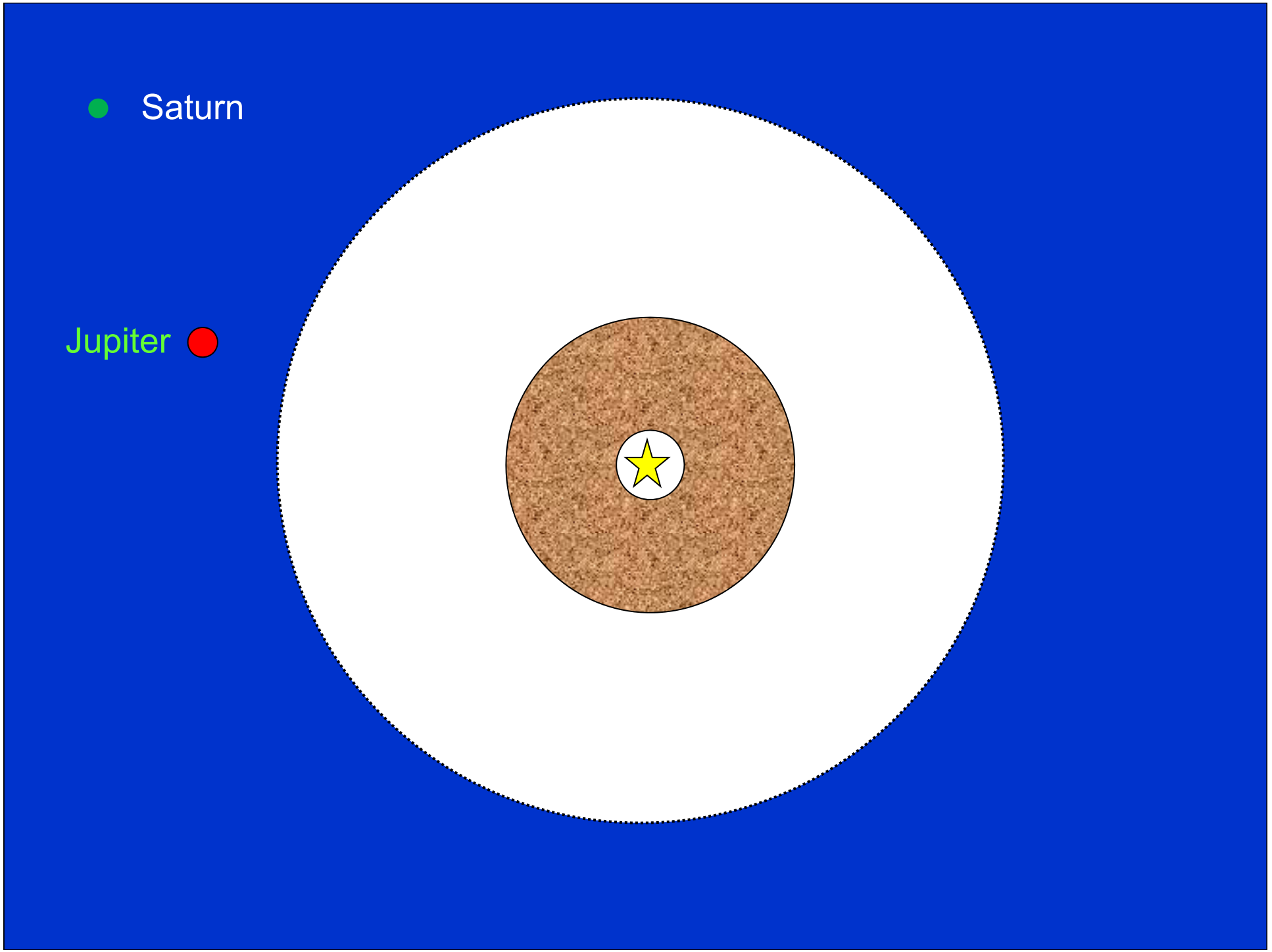

Jupiter

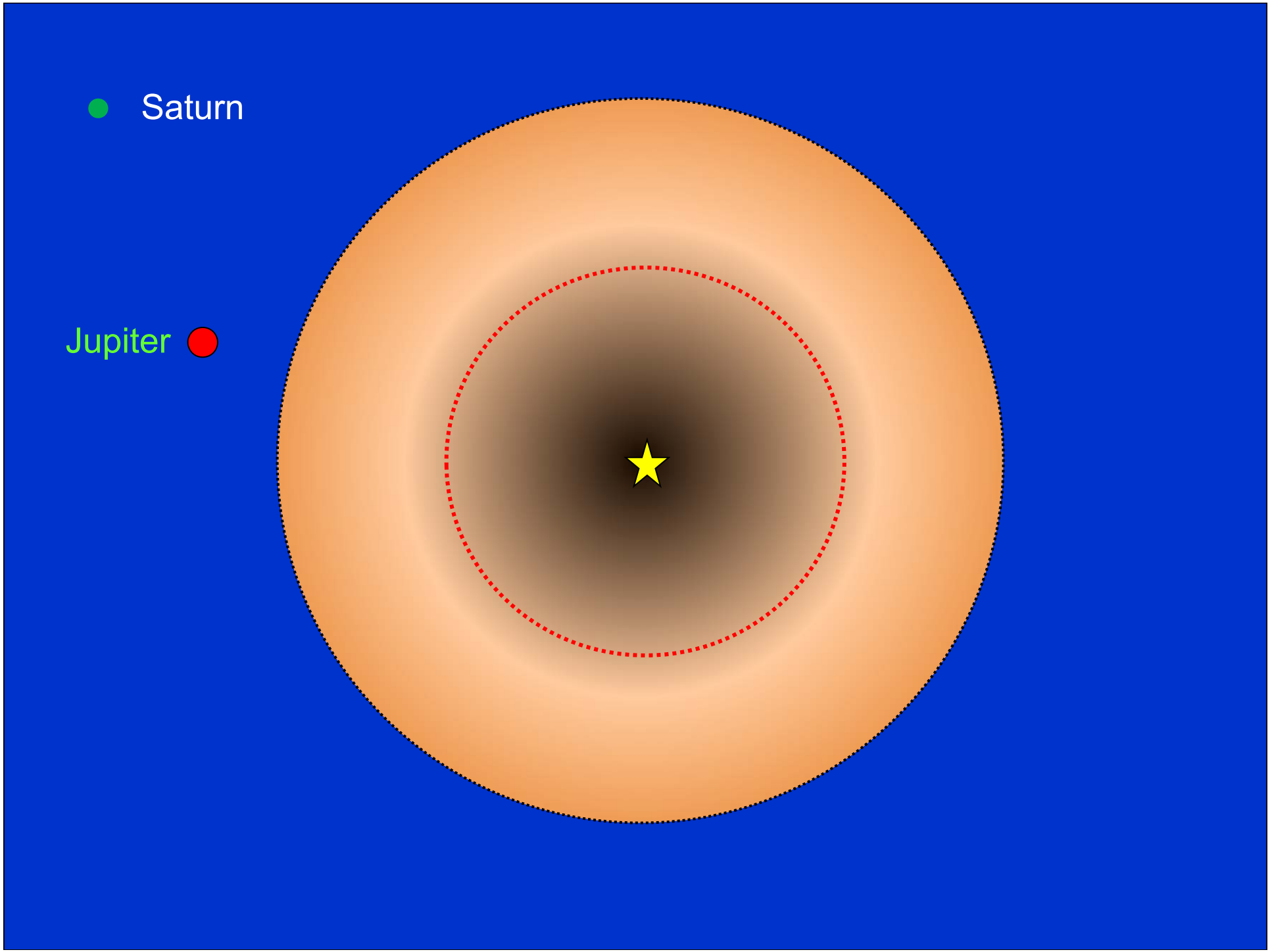

Jupiter

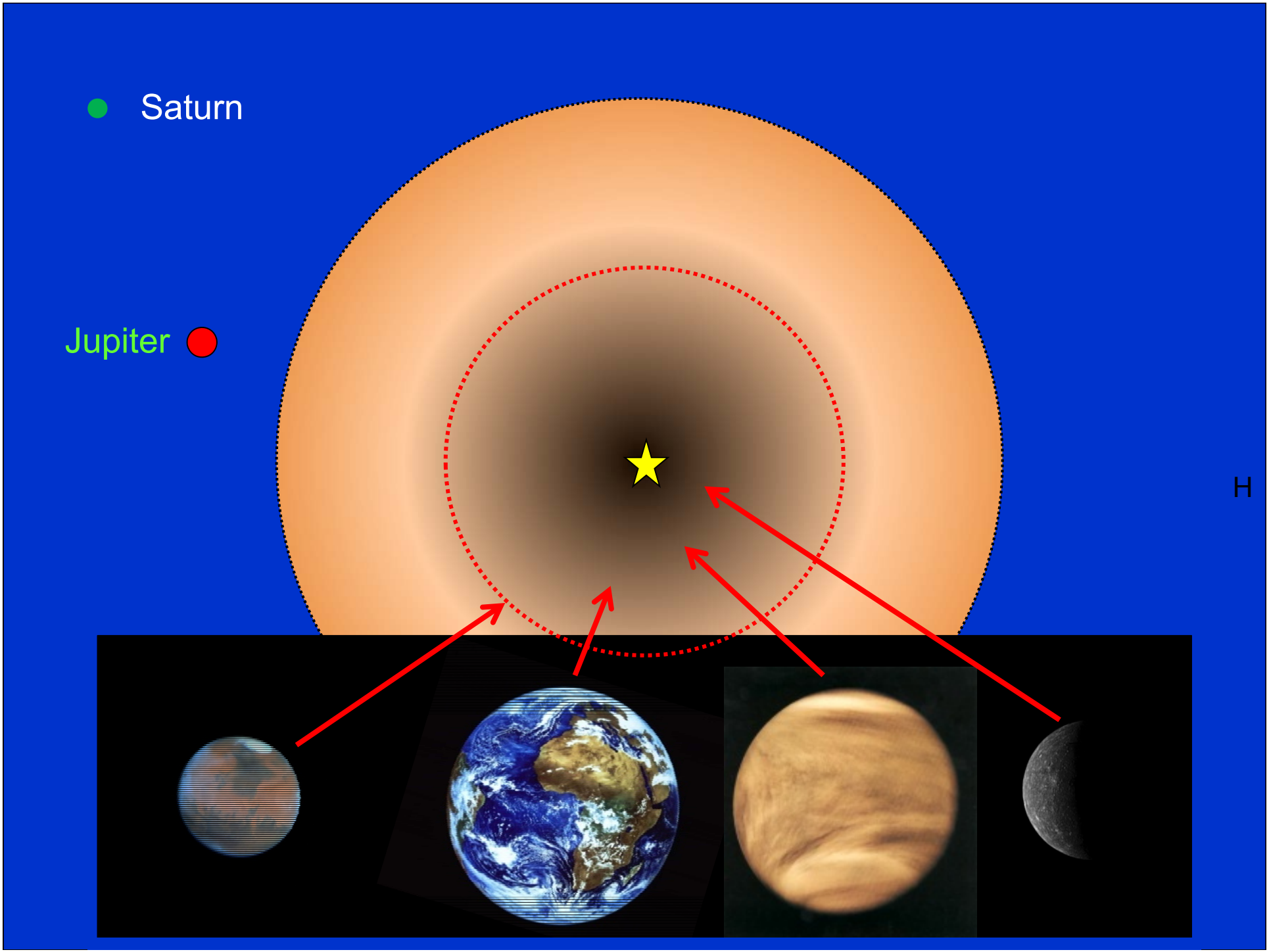

Saturn
Jupiter

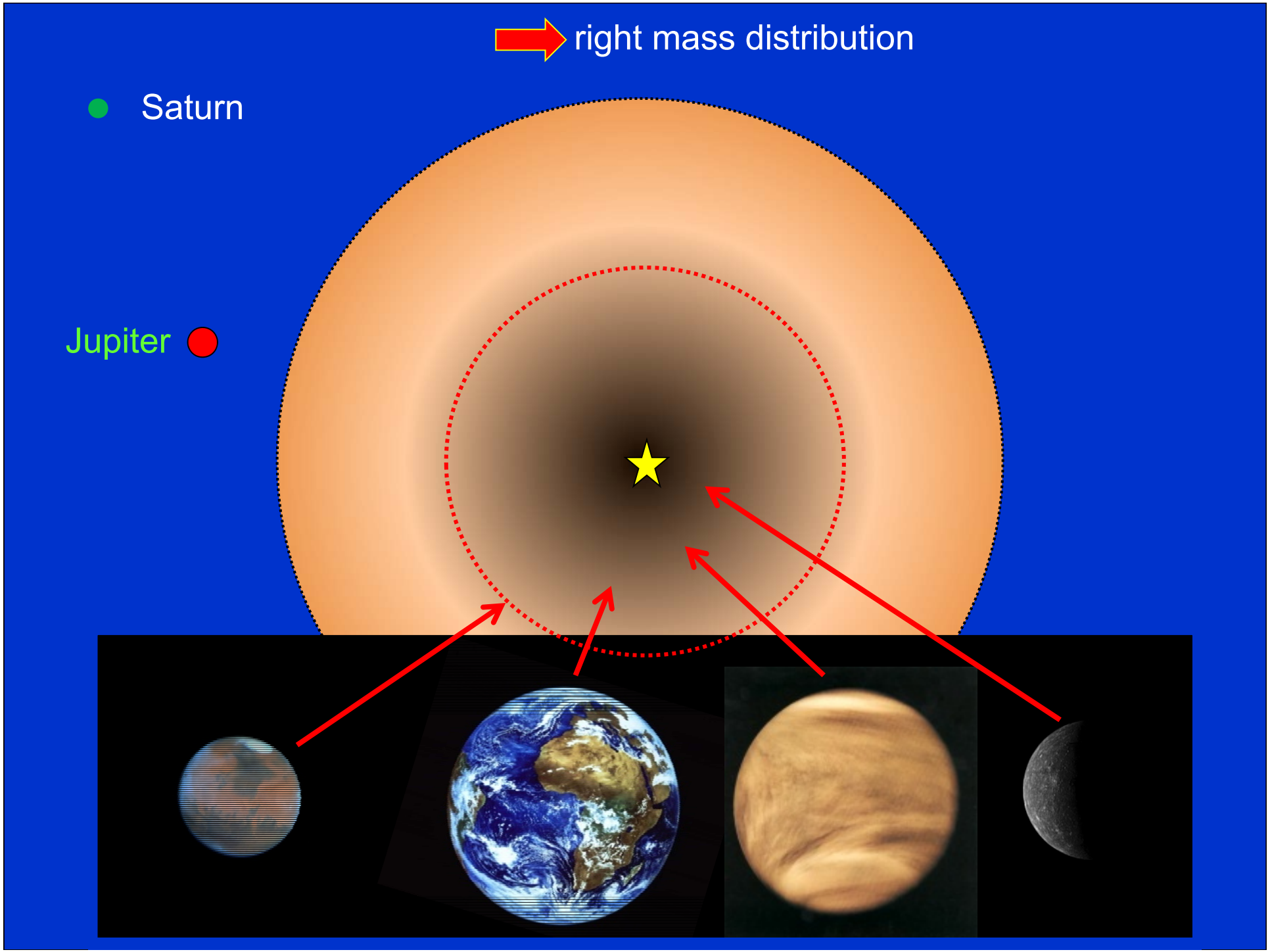

Saturn
Jupiter
3 / 2 resonance

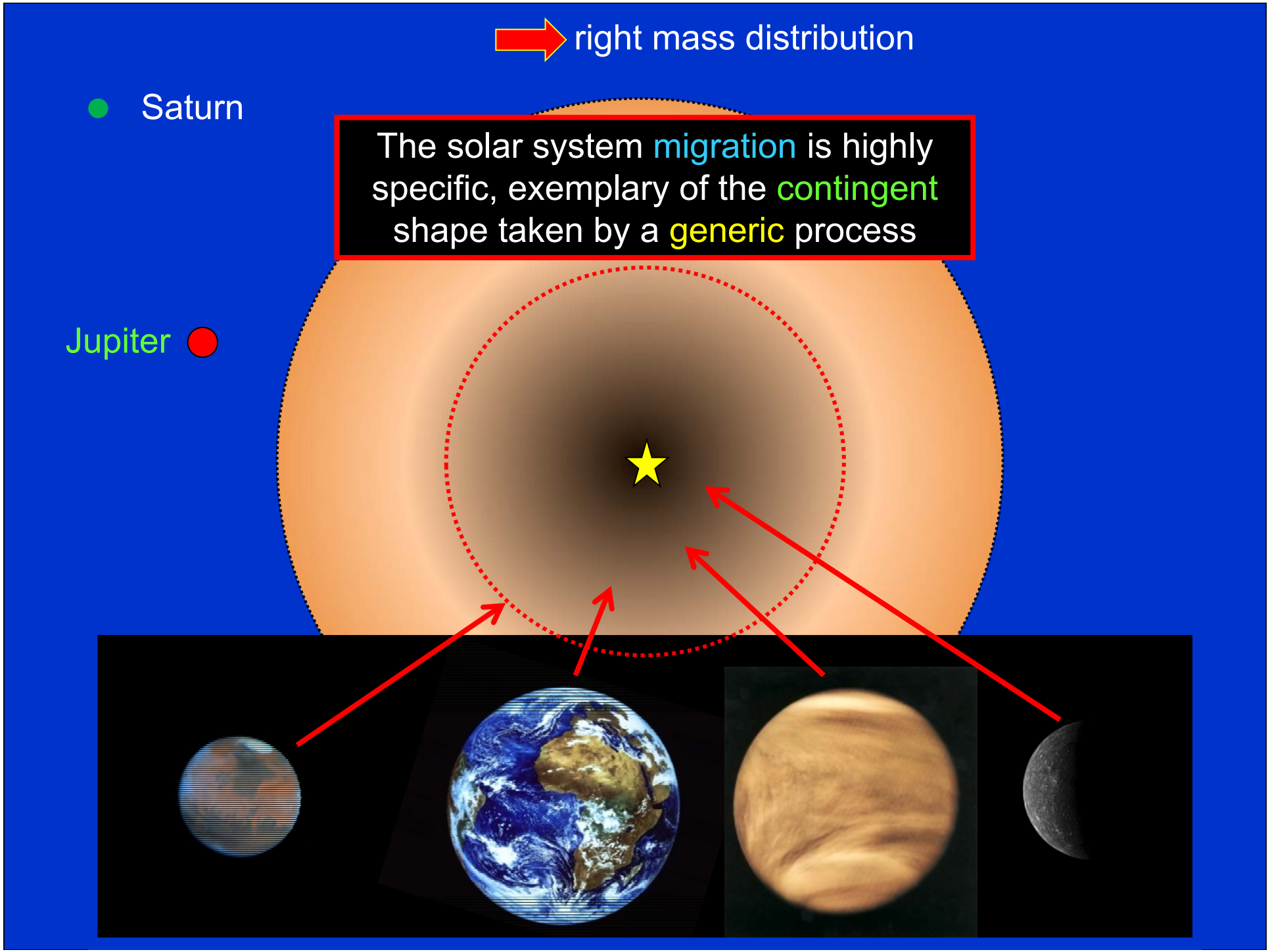

Saturn
Jupiter
given their mass ratio

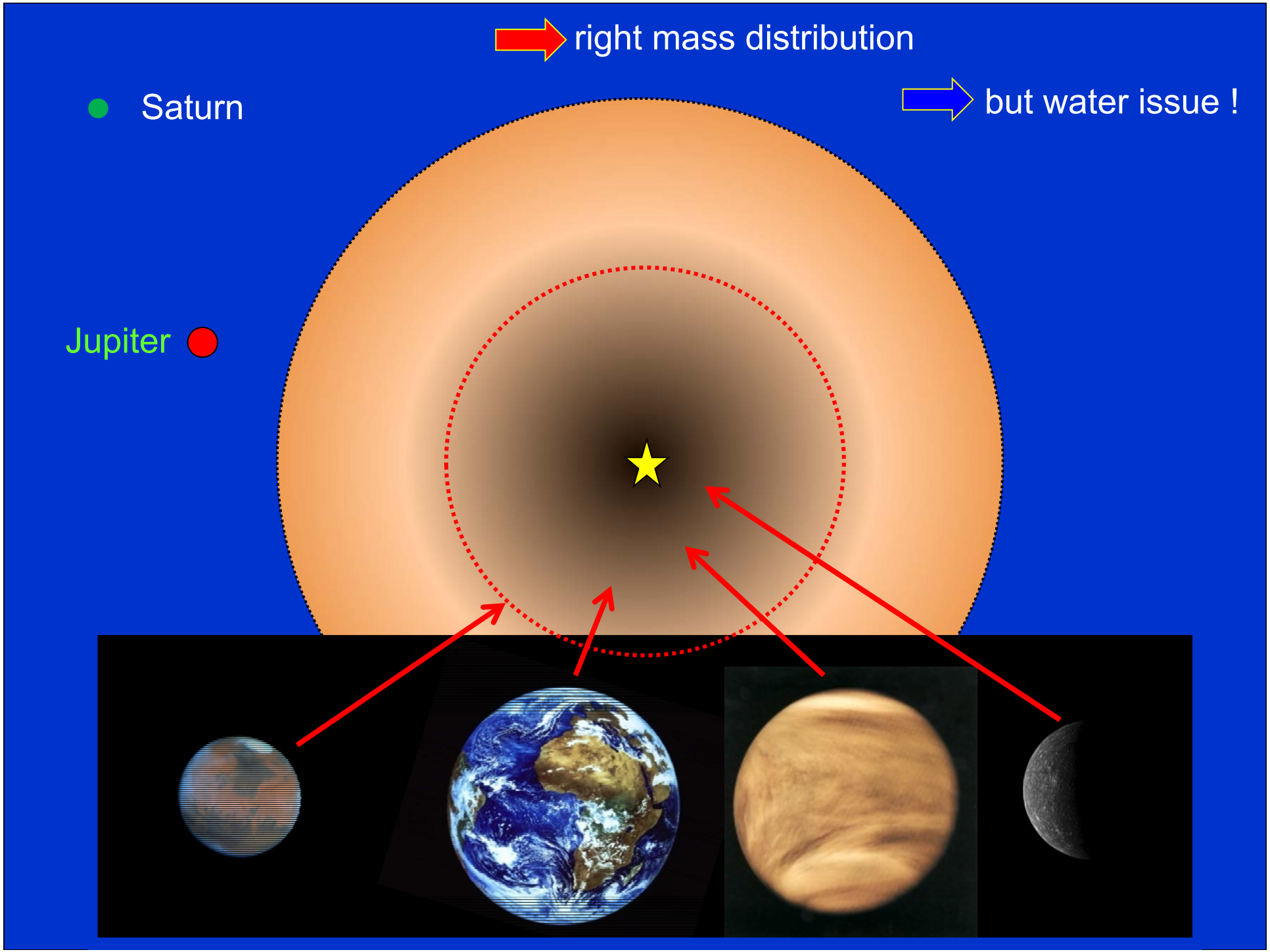

Saturn
Jupiter

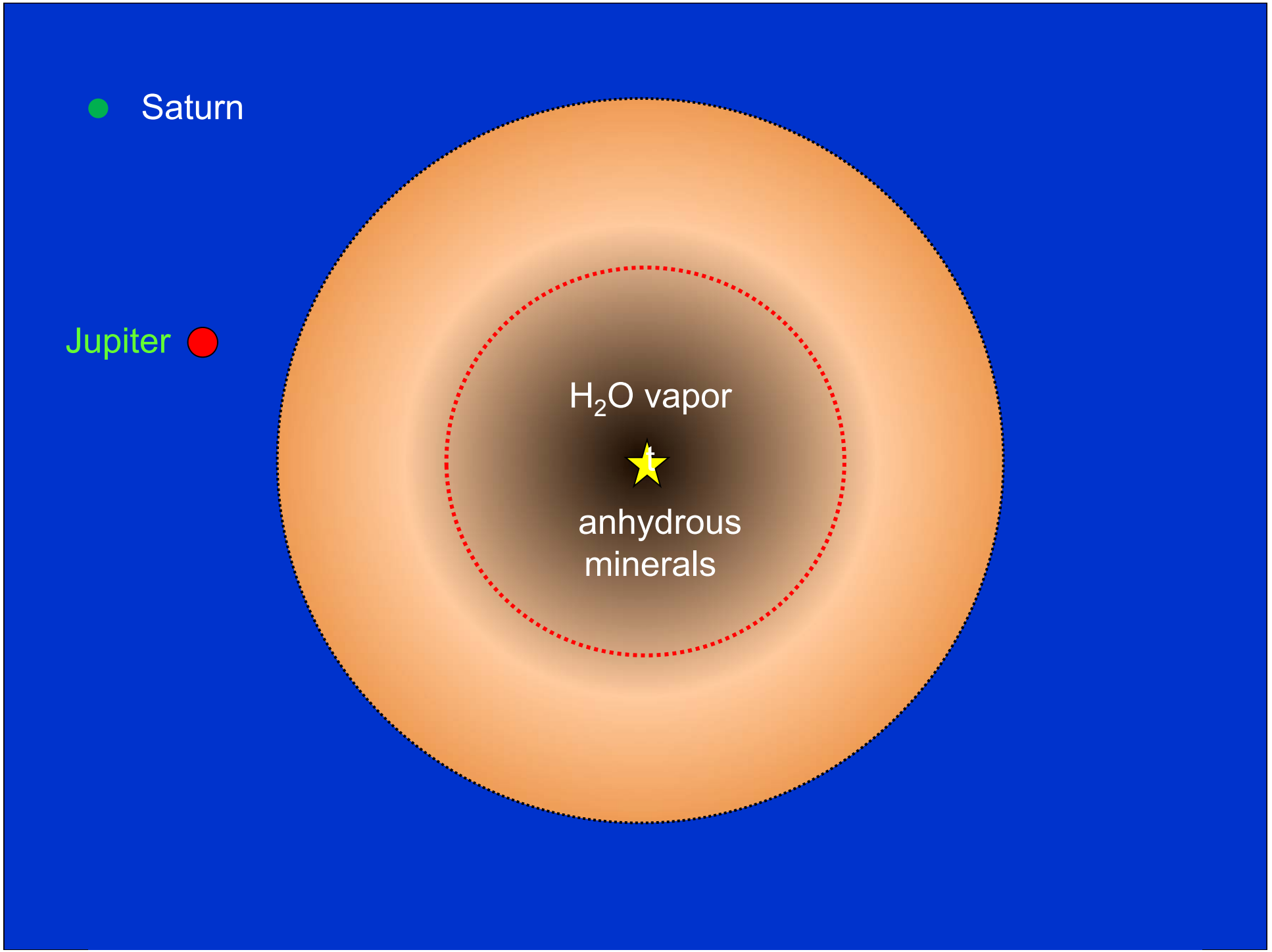

Saturn
Jupiter

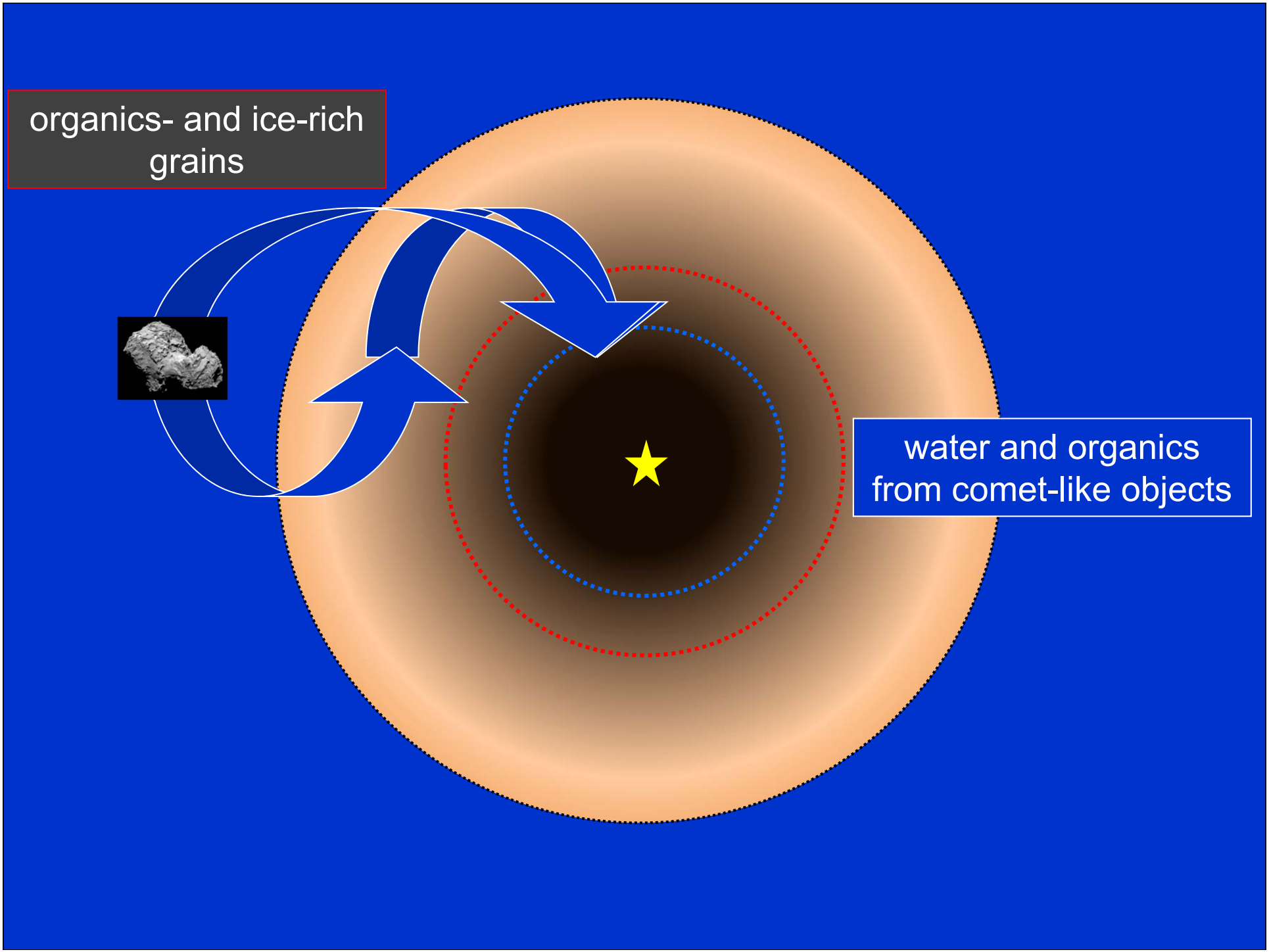

Saturn
Jupiter
H

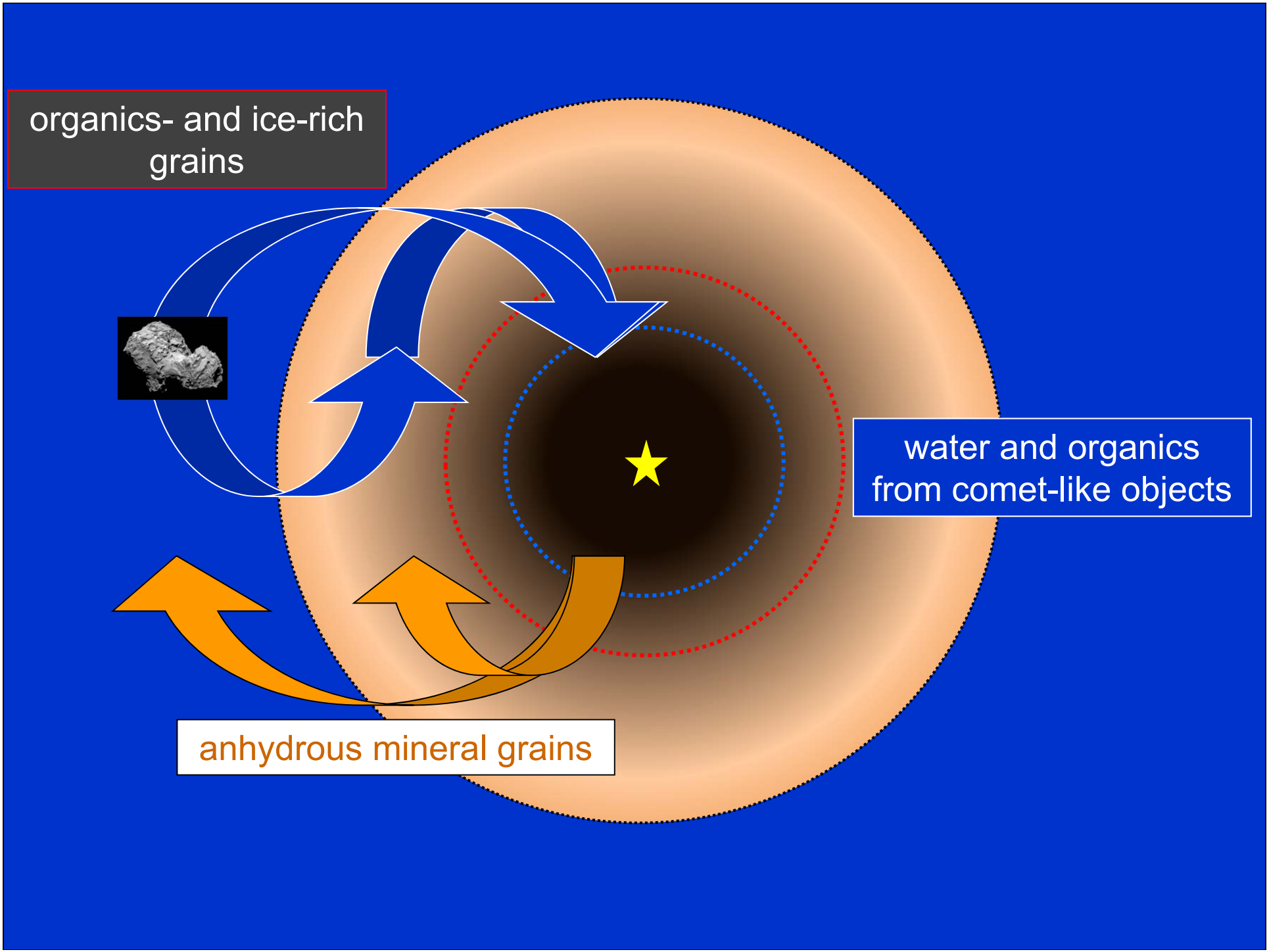

right mass distribution
Saturn
Jupiter


right mass distribution
Saturn
The solar system migration is highly specific, exemplary of the contingent shape taken by a generic process
Jupiter


right mass distribution
but water issue !
Saturn
Jupiter


Saturn
Jupiter
H_2O vapor
anhydrous
minerals


organics- and ice-rich grains
water and organics from comet-like objects


organics- and ice-rich grains
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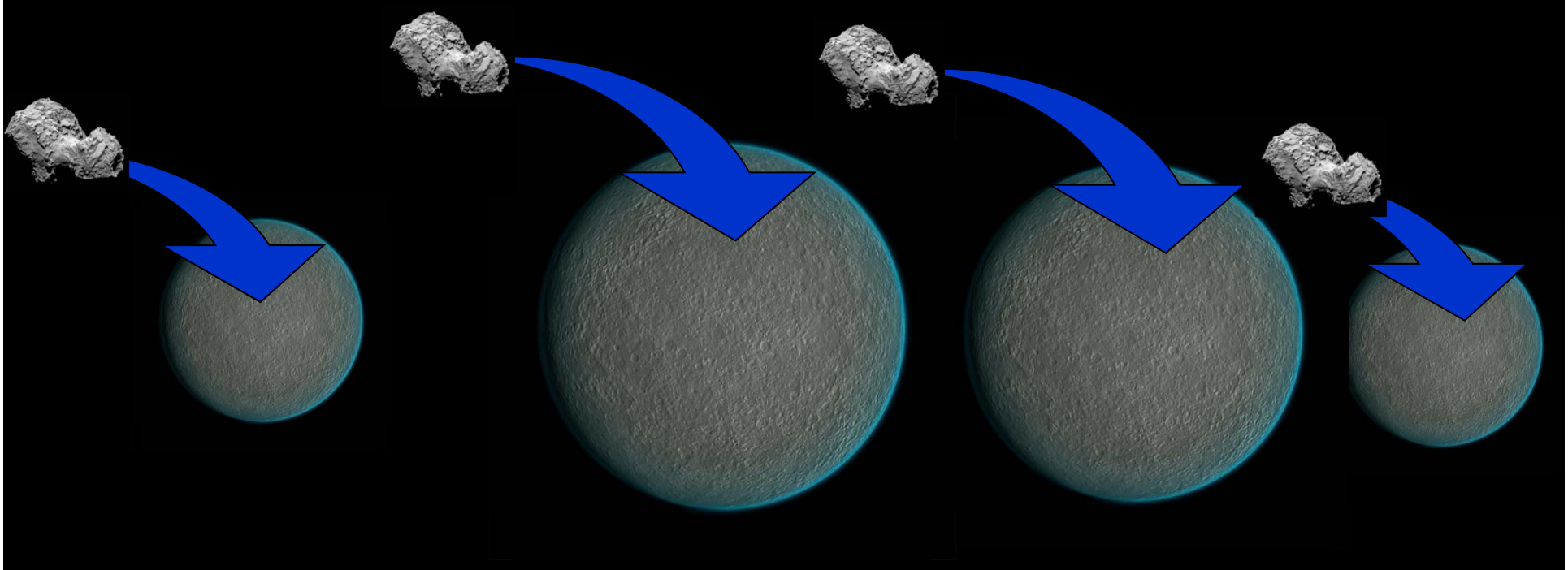
anhydrous mineral grains

accretion led to bodies with the right mass ration, with water trapped within their bulk, during accretion of outer ice-rich grains



Mars Earth Venus Mercury

…which further drove to:

Mars Earth Venus Mercury

accretion led to bodies with the right mass ration, with
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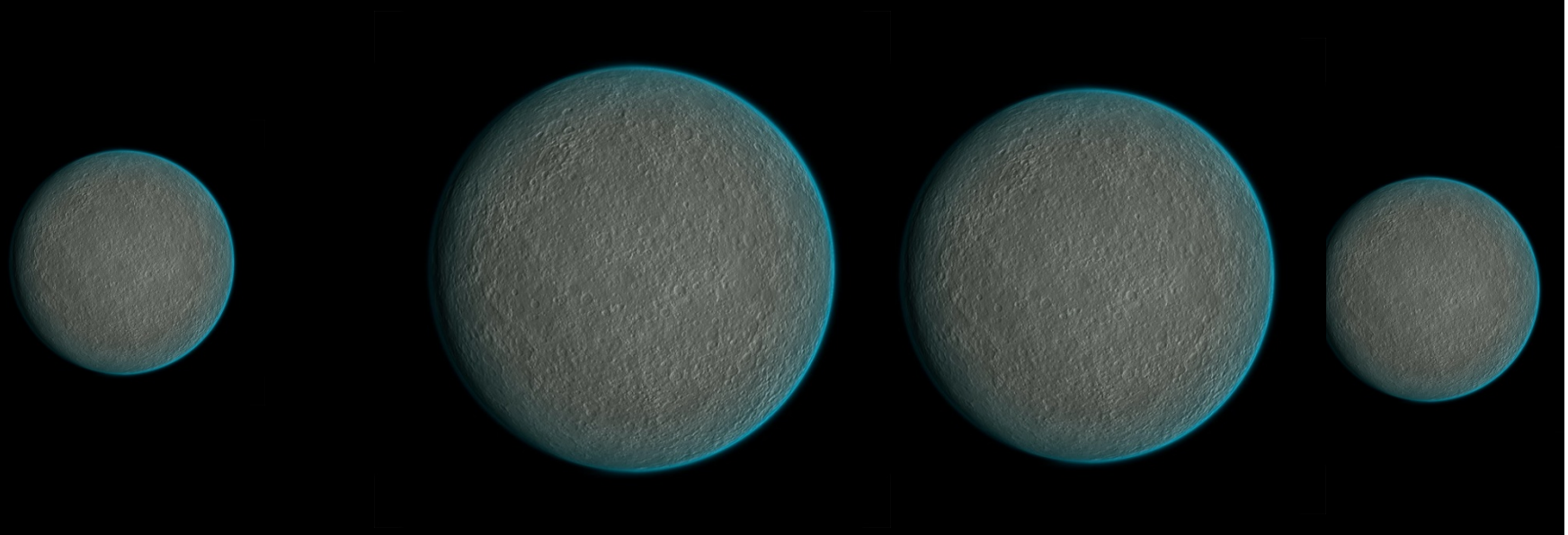

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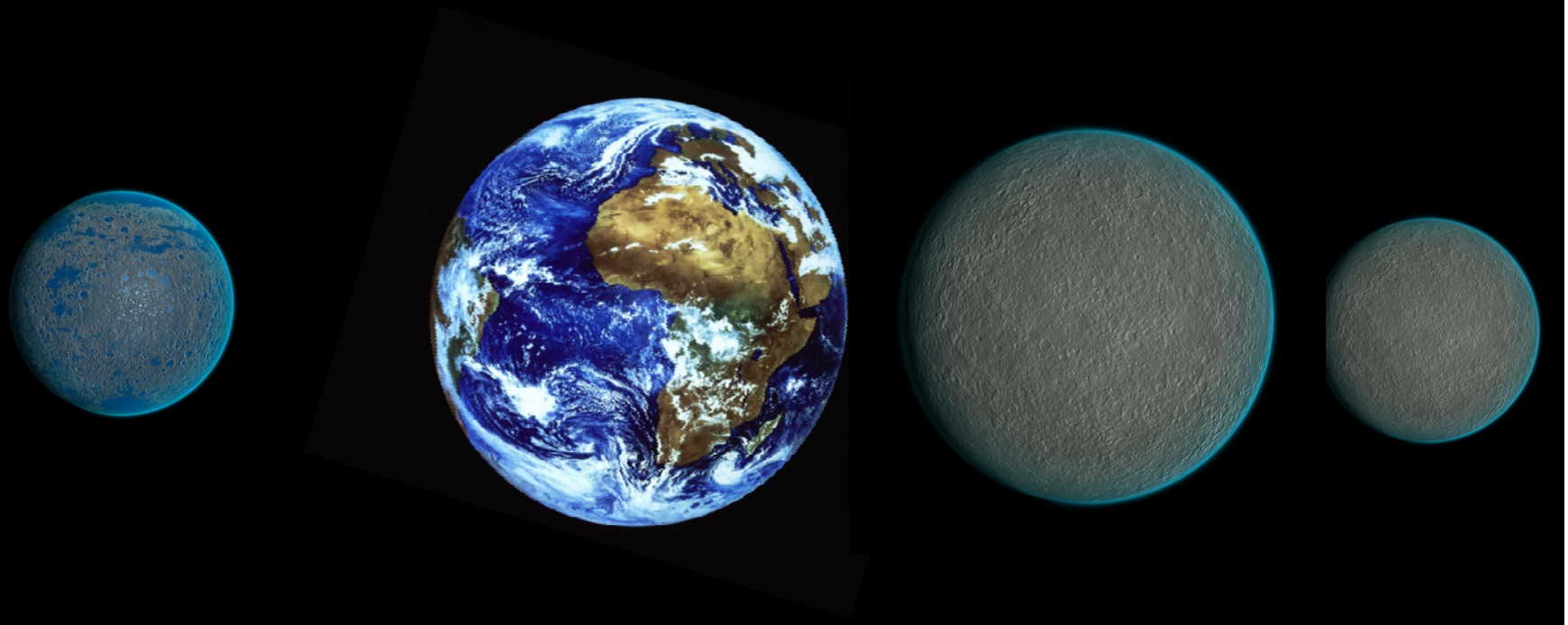
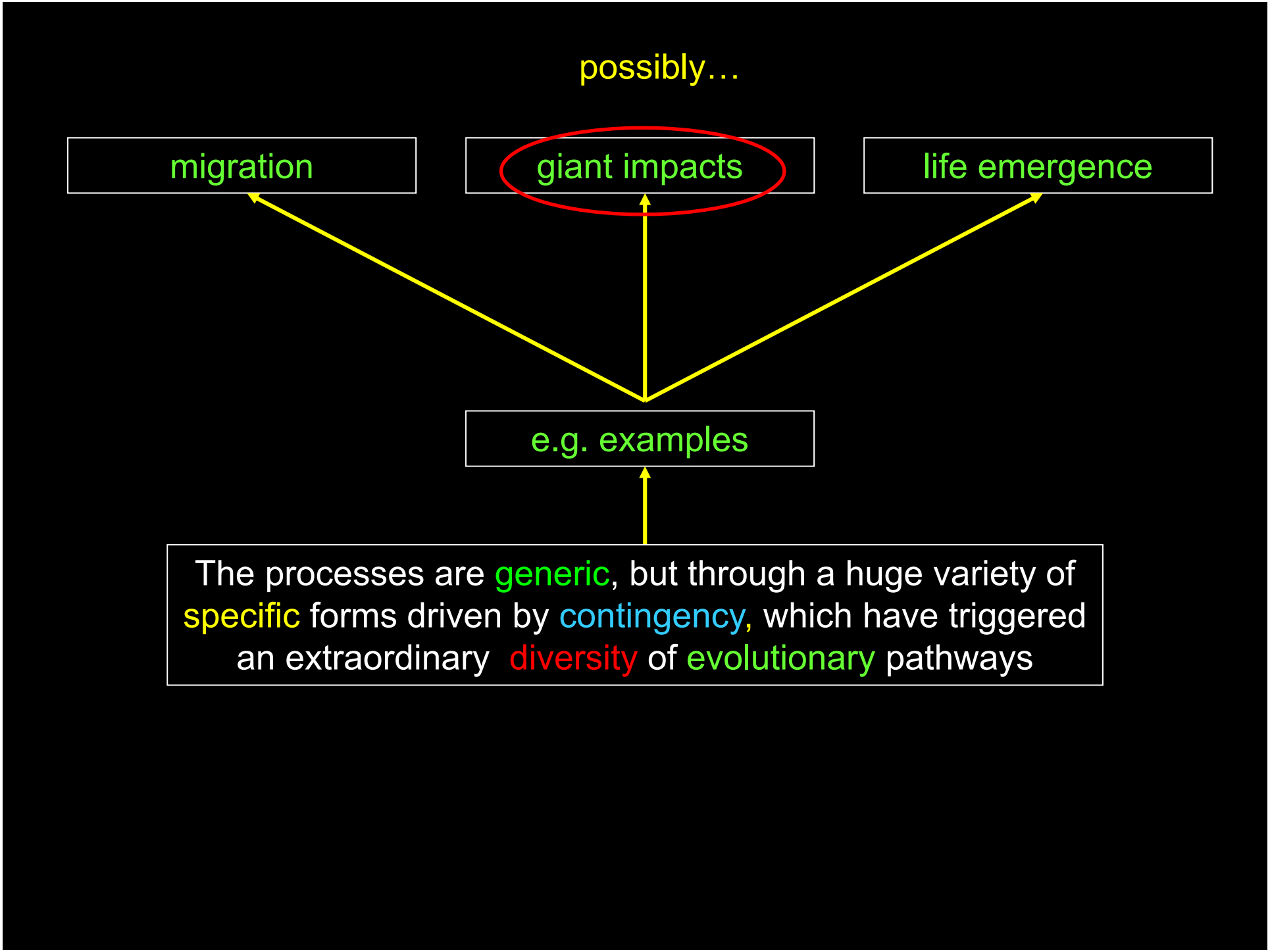
How has water been lifted towards the surface ?




possibly…
migration
giant impacts
life emergence
e.g. examples
The processes are generic, but through a huge variety of specific forms driven by contingency, which have triggered an extraordinary diversity of evolutionary pathways


the impact had a major effect on Earth (climatic) history, and possibly at Mars

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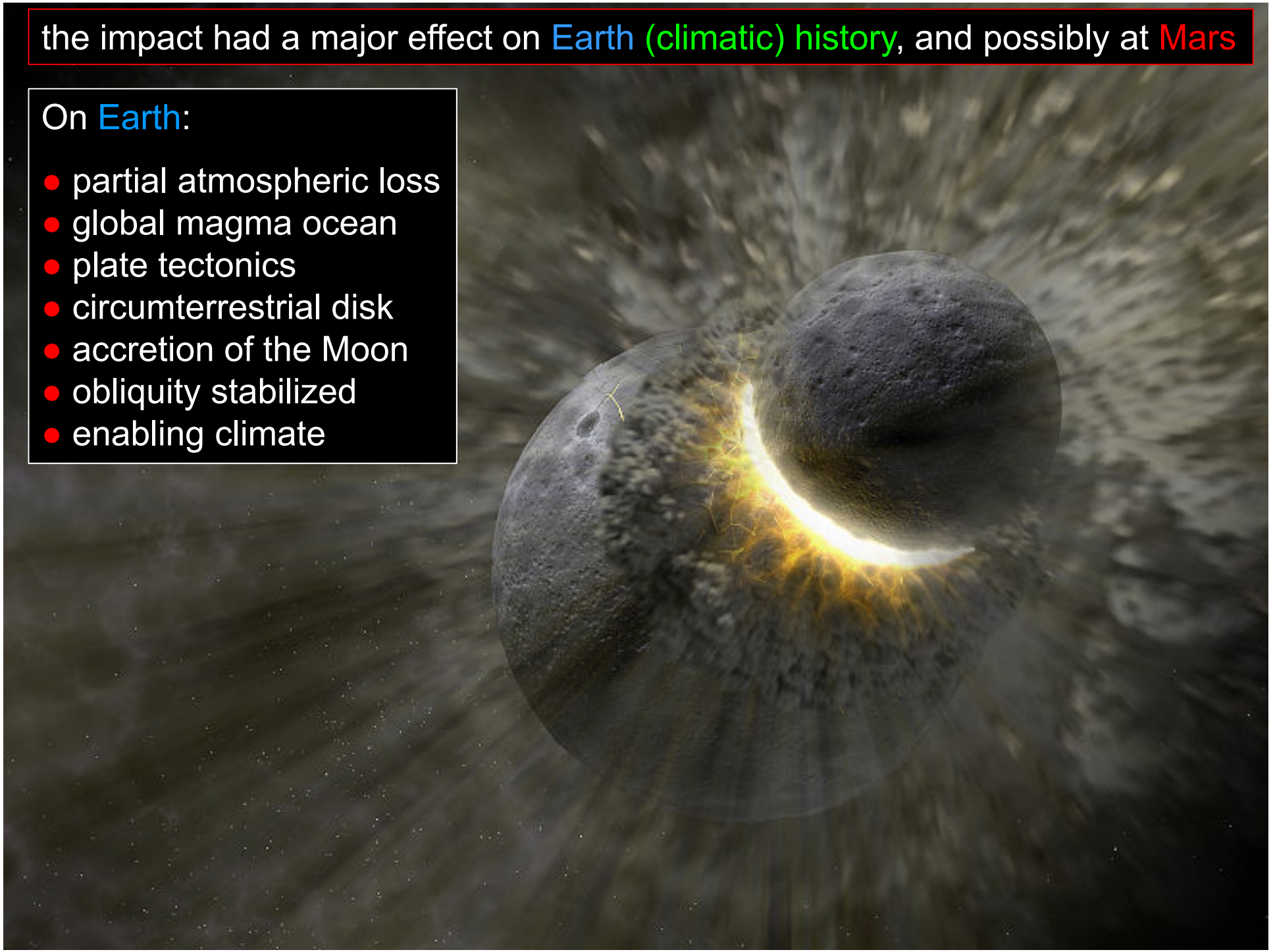
On Earth:

- partial atmospheric loss
- global magma ocean
- plate tectonics
- circumterrestrial disk
- accretion of the Moon
- obliquity stabilized
- enabling climate



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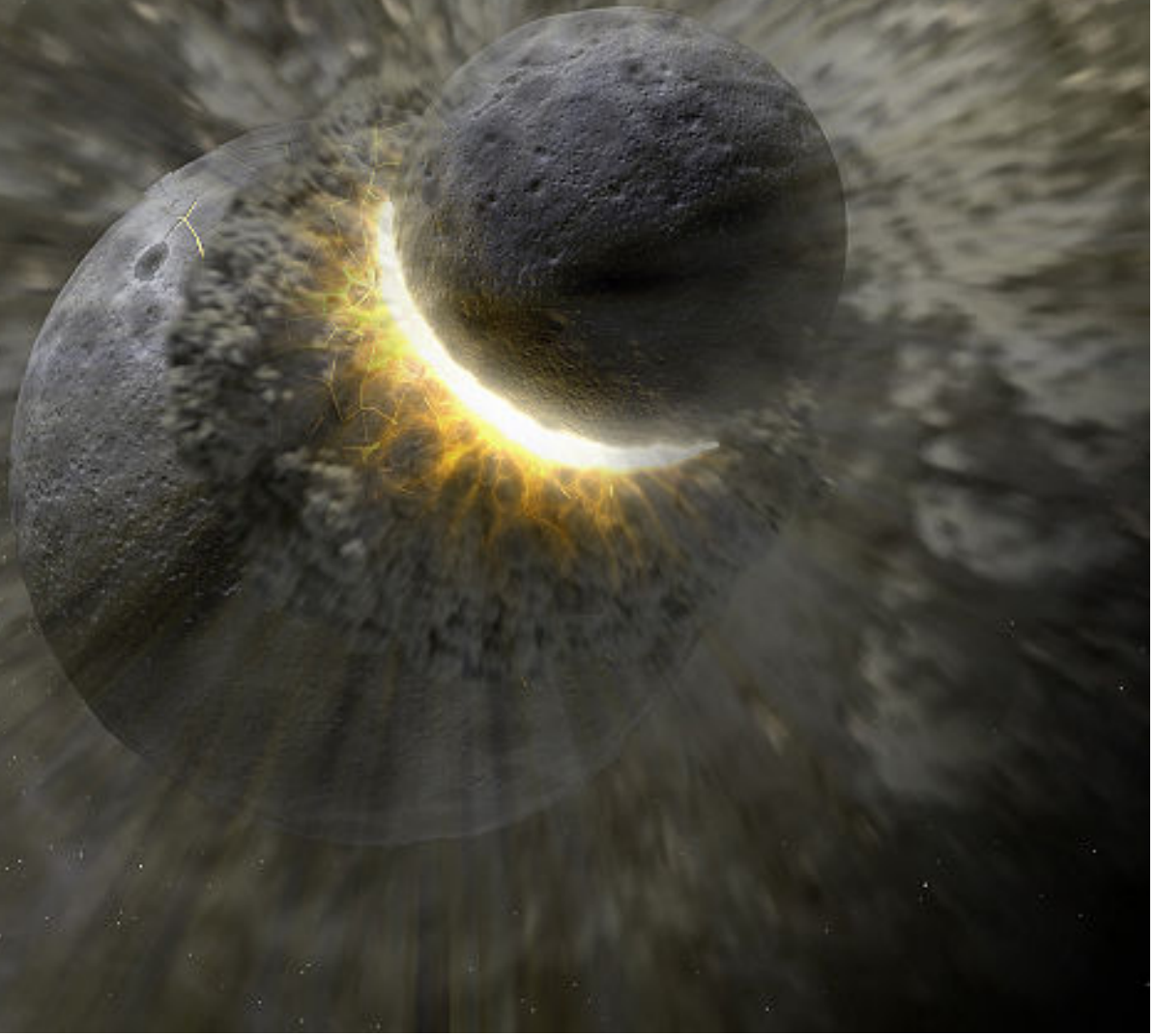
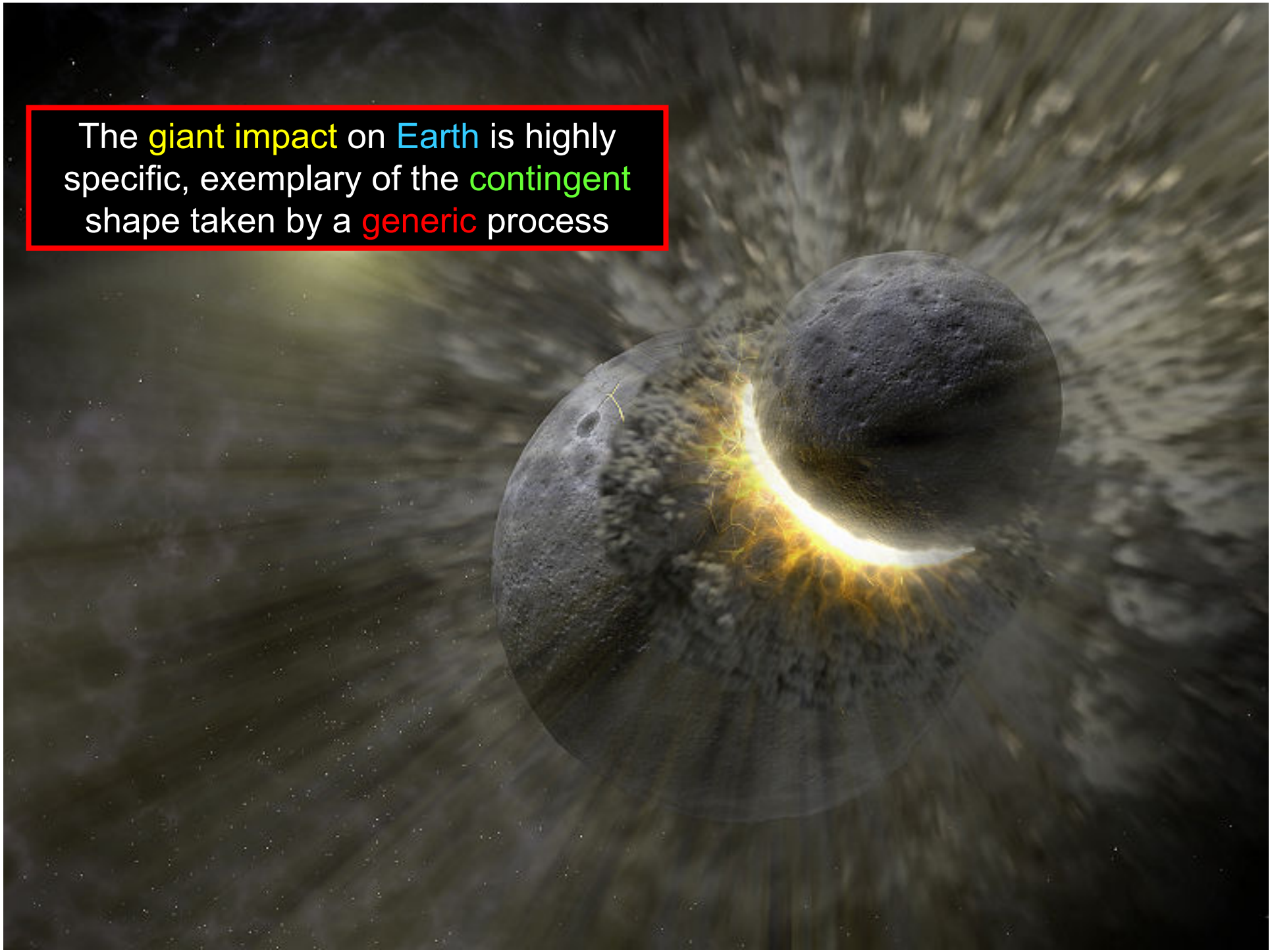
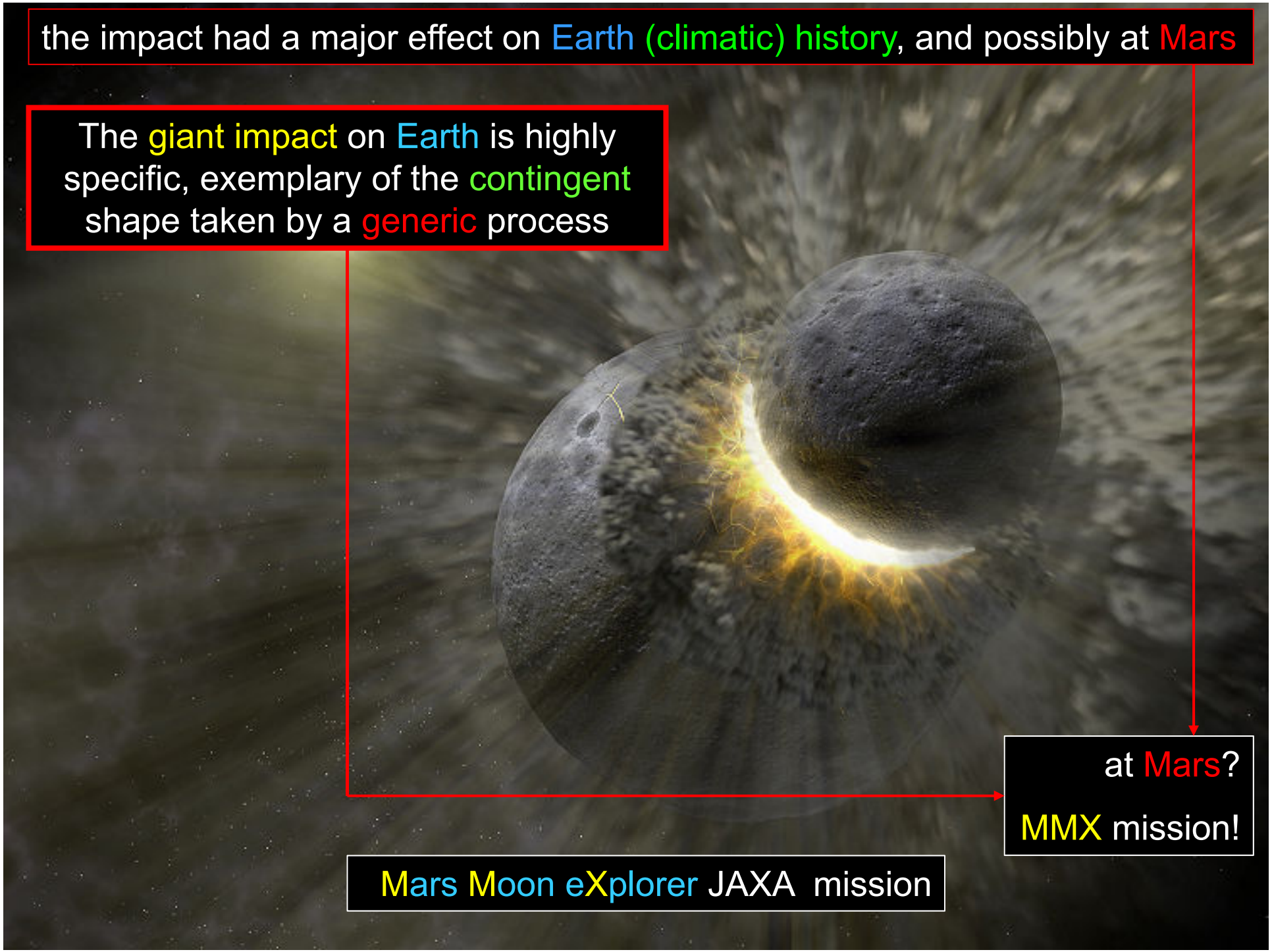
effects critically driven by the contingent pattern of the (specific) impact




The giant impact on Earth is highly specific, exemplary of the contingent shape taken by a generic process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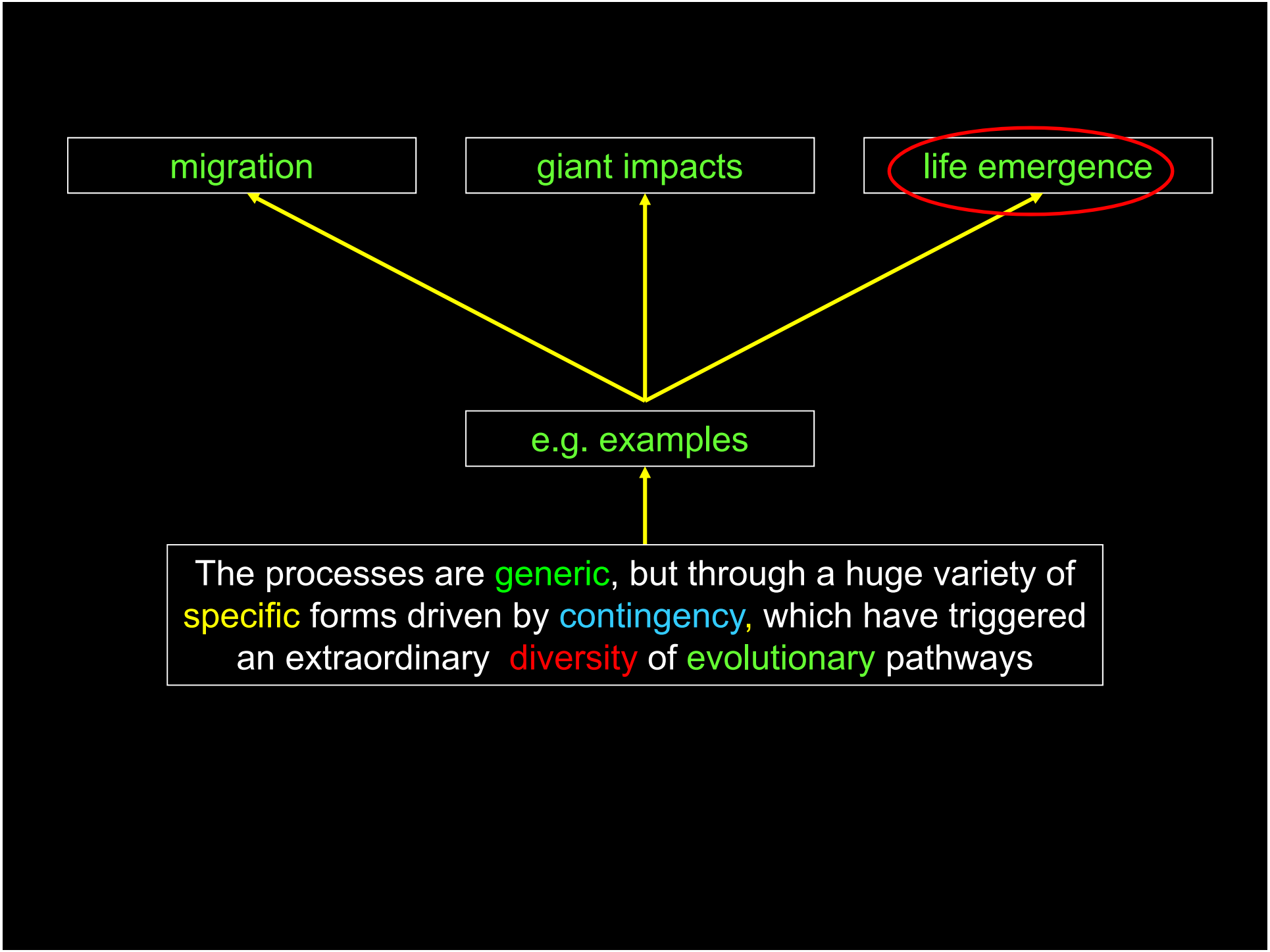
at Mars?
MMX mission!
Mars Moon eXplorer JAXA mission


migration
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Rosetta / Philae is trigerring an in-depth revisiting of life "emergence"

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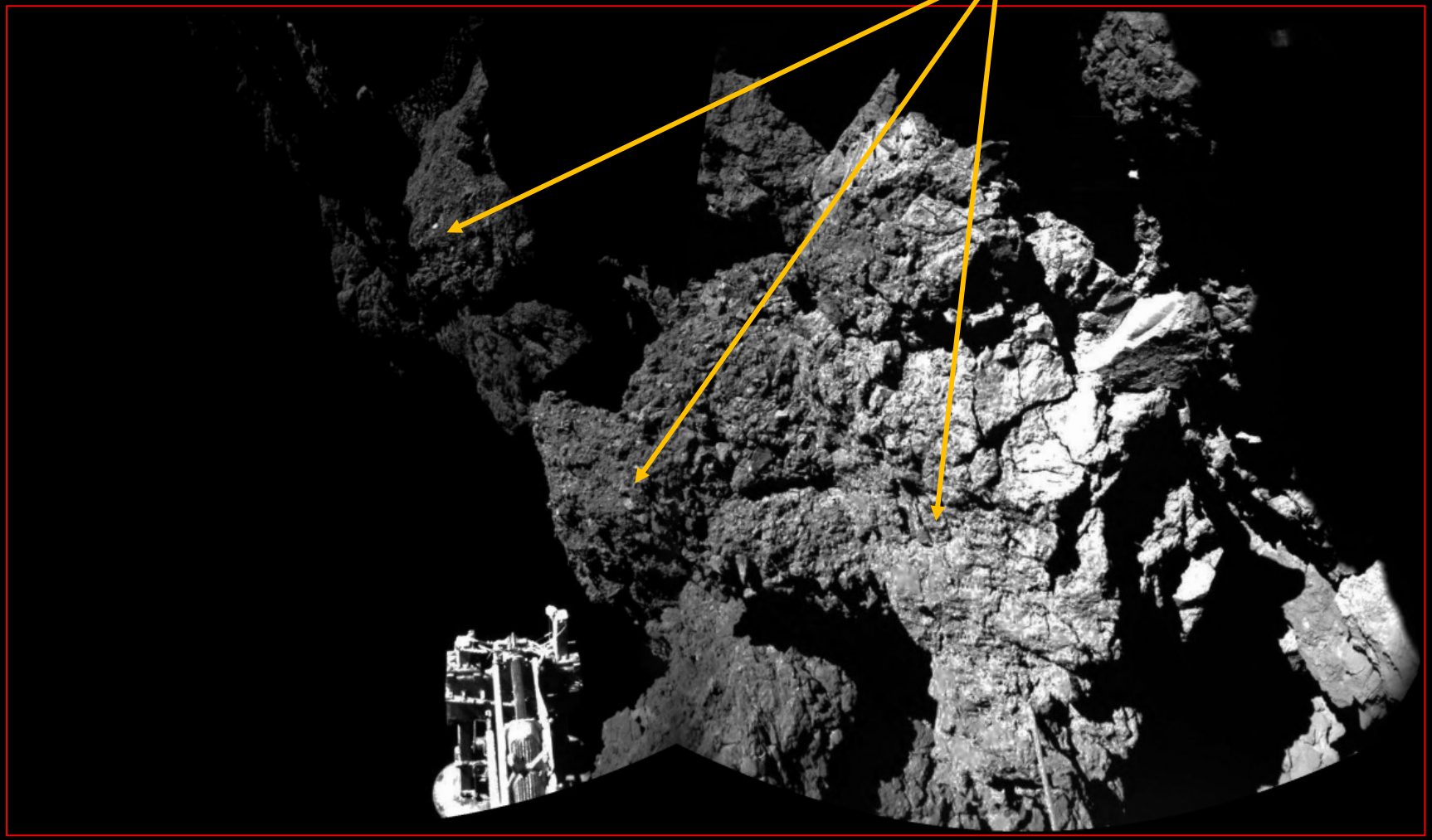
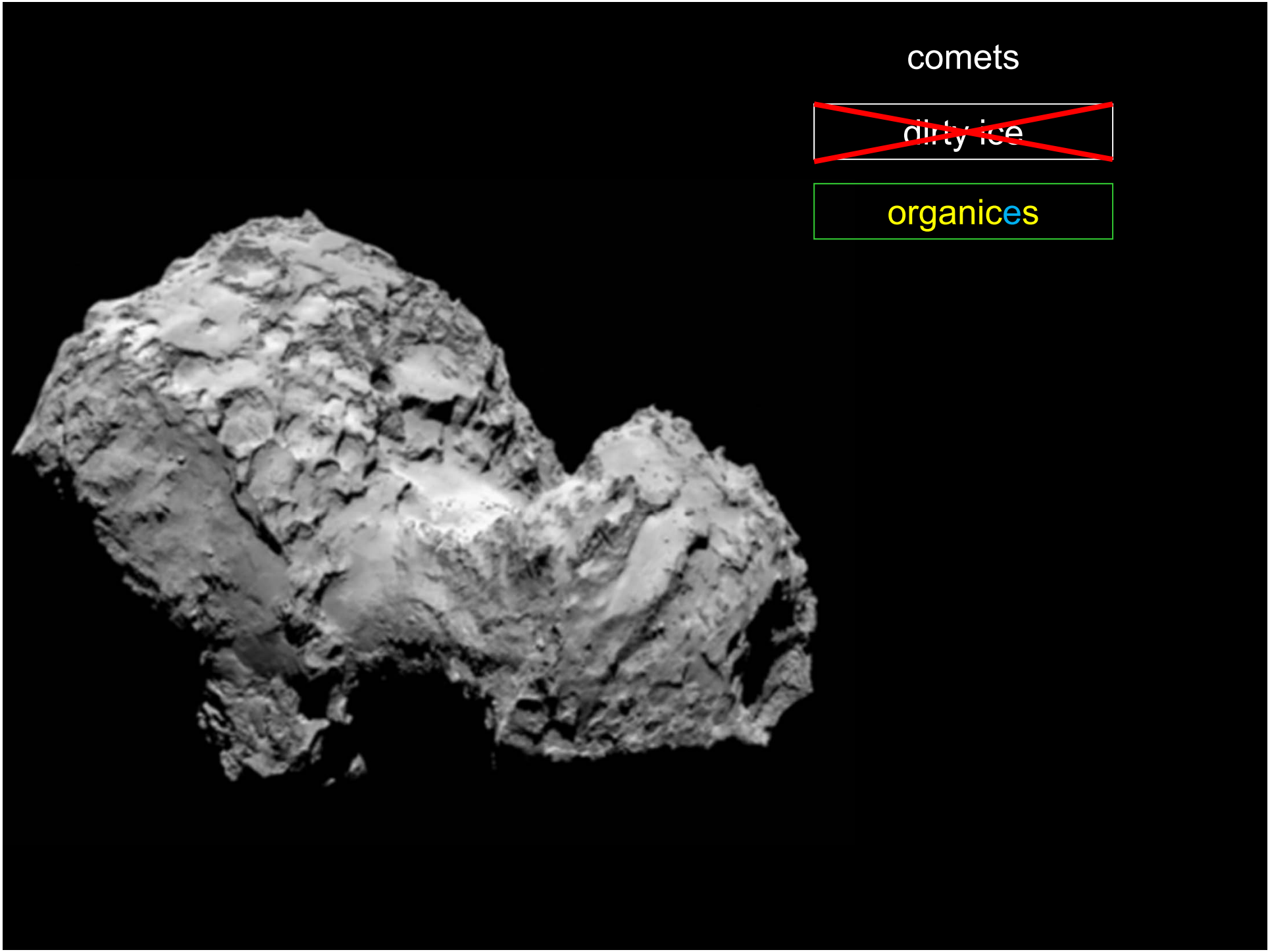
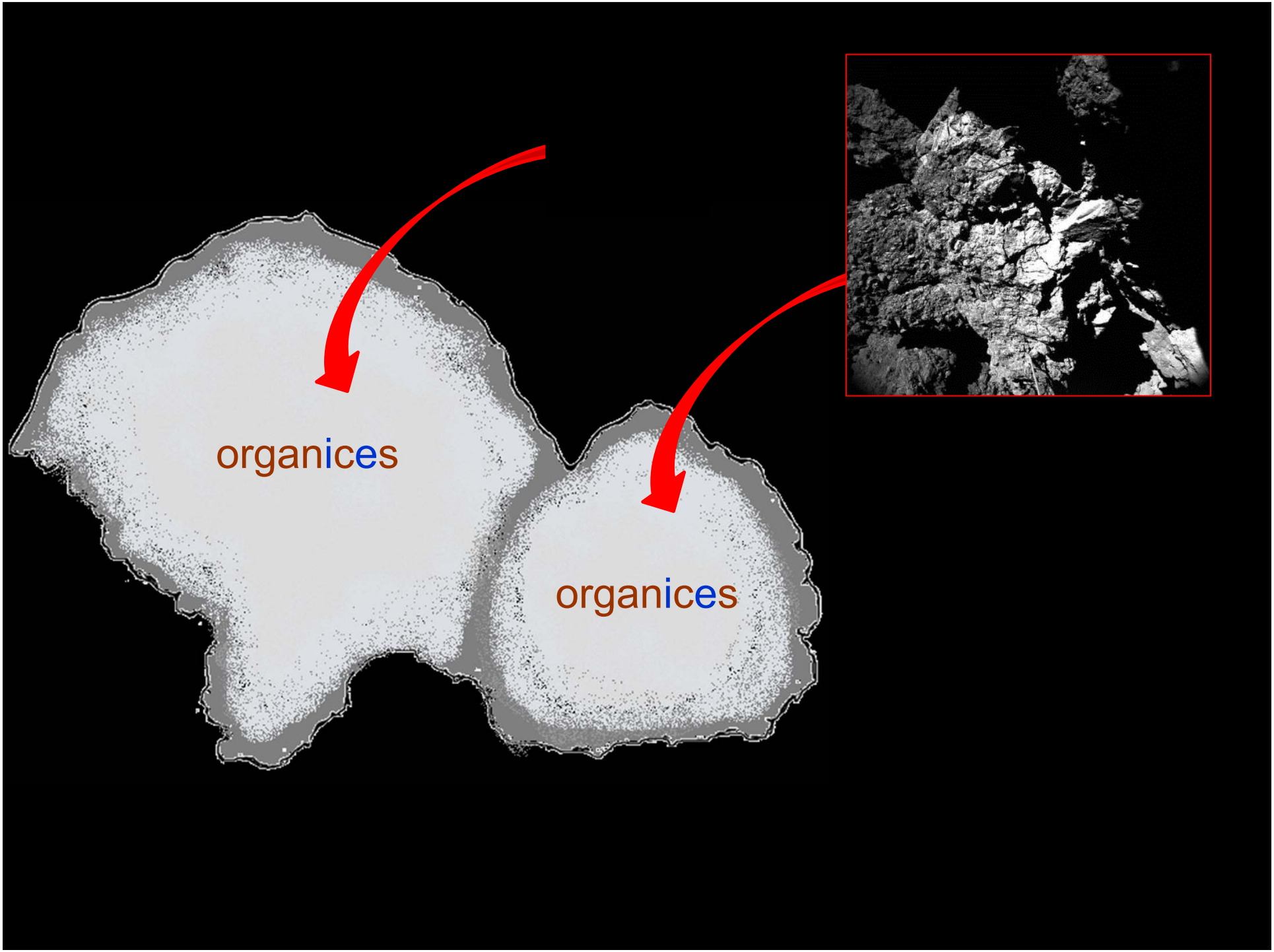
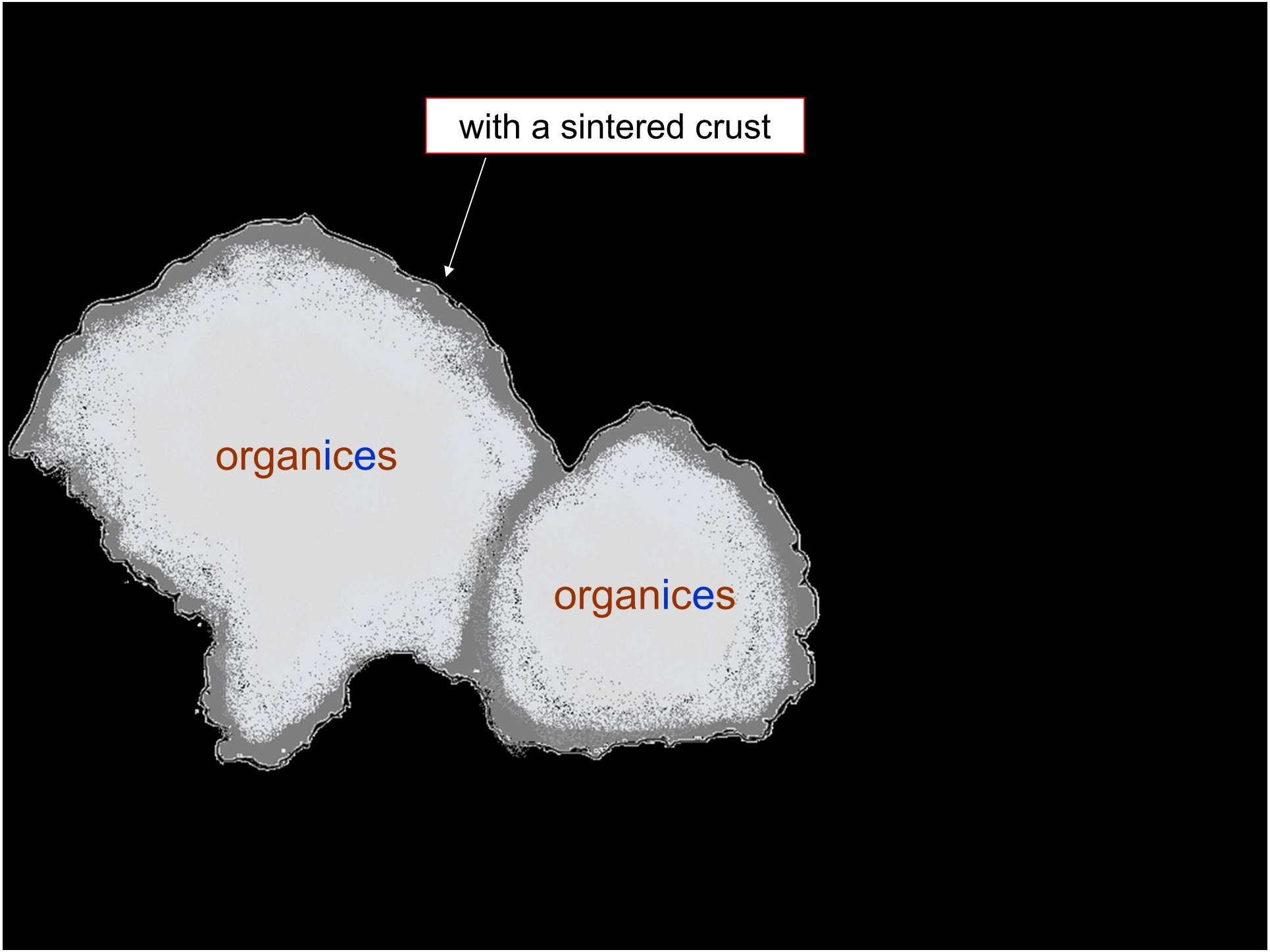
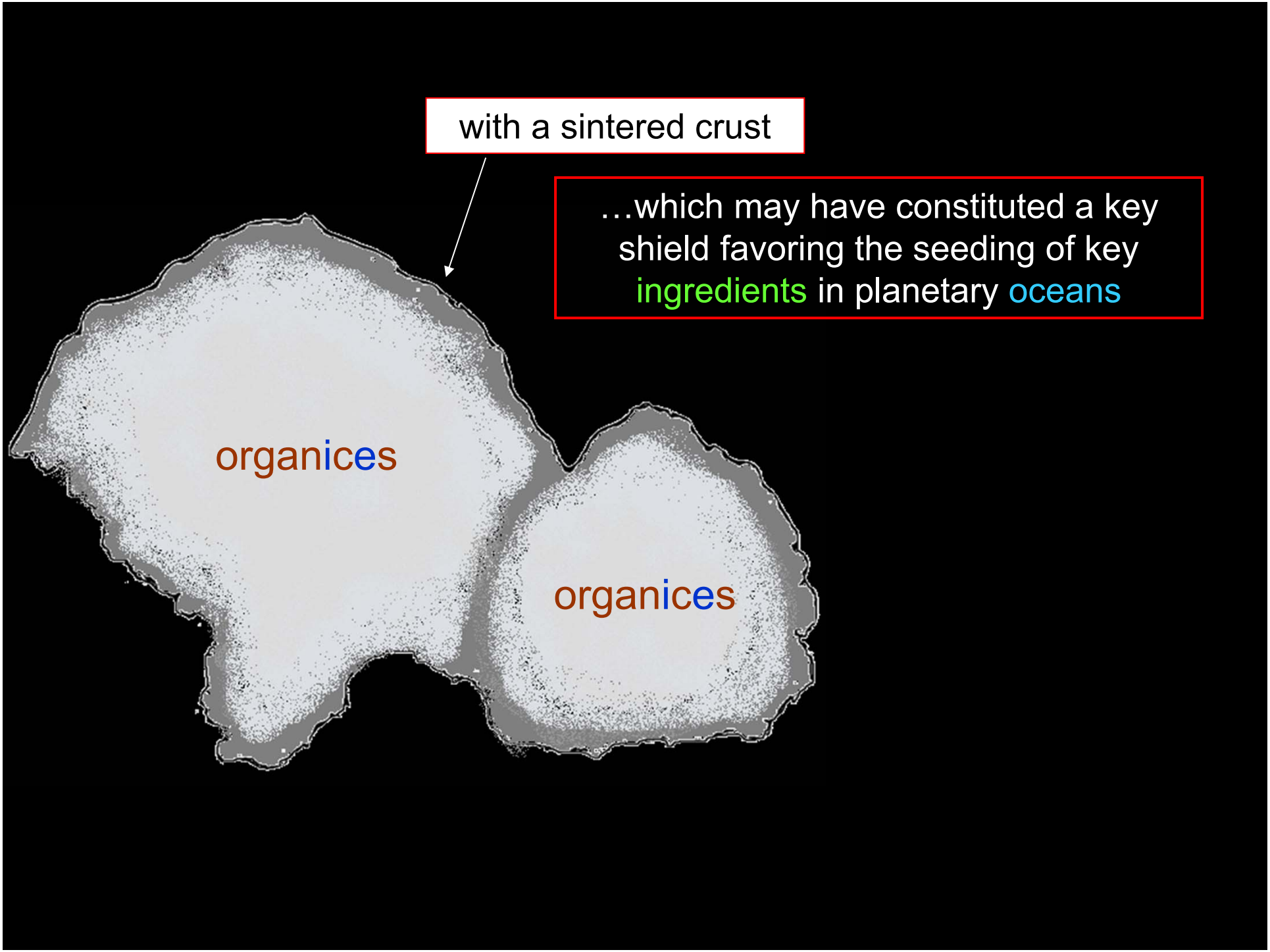
the bulk of the comet is made of ORGANIiCeS



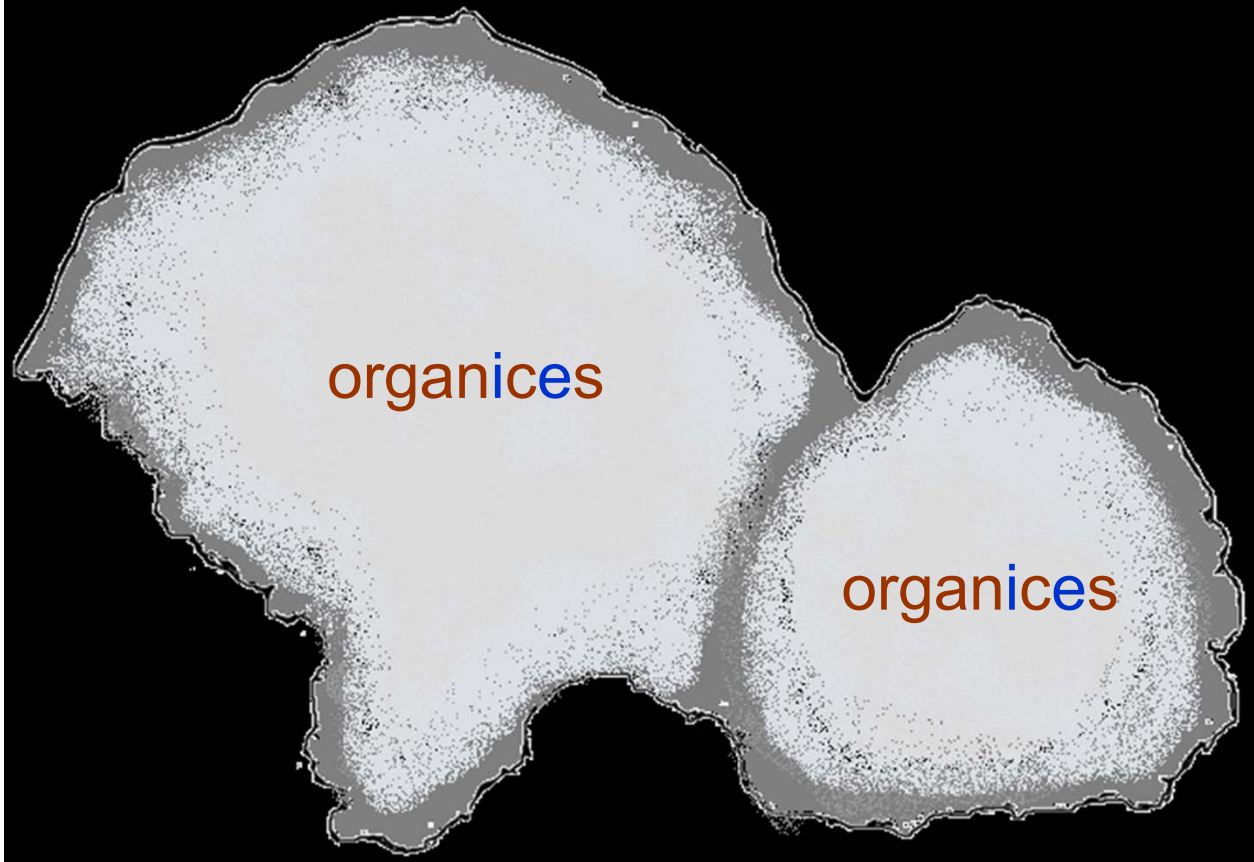

comets
dirty ice
organices


organices
organices


with a sintered crust
organices
organices


with a sintered crust
…which may have constituted a key shield favoring the seeding of key ingredients in planetary oceans
organices
organices

The "ORGANiCeS" possibly include all "life enabling" key ingredients, synthesized via a specific chemistry during the specific dynamical evolution of the protosolar disk; once immersed in water with specific properties (temperature, pH, cations, catalysts…) - multiple contingencies!



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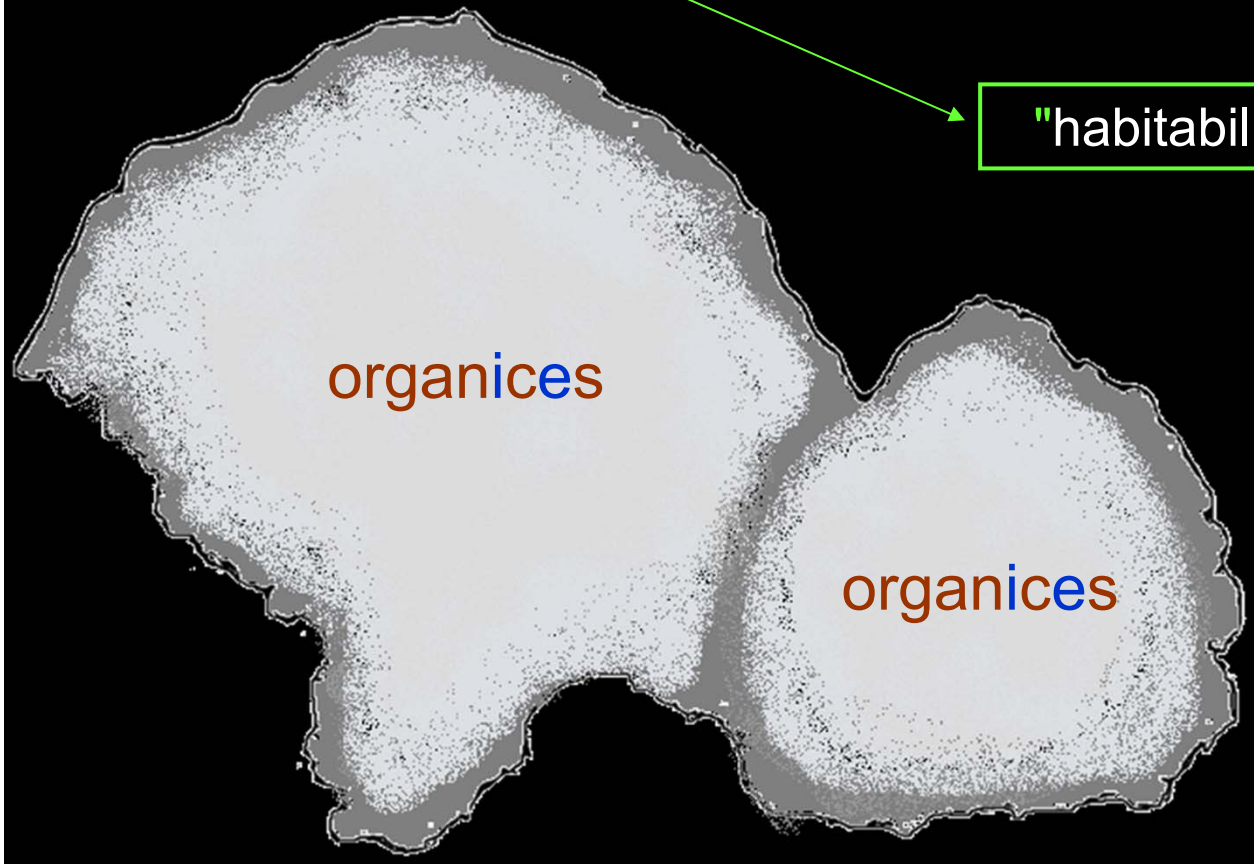
"habitability" critical parameters



Transition from inert to life would thus not require the synthesis of "living molecules", but would translate the building of structures, by contingent autocatalytic selection, from (complex, existing) molecules with adapted properties (e.g. with enantiomeric excesses).

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in particular to get protected against water!

Transition from inert to life would thus not require the synthesis of "living molecules", but would translate the building of structures, by contingent autocatalytic selection, from (complex, existing) molecules with adapted properties (e.g. with enantiomeric excesses). Their specific evolution would characterize Earth "life", without requiring the existence of "life principles".

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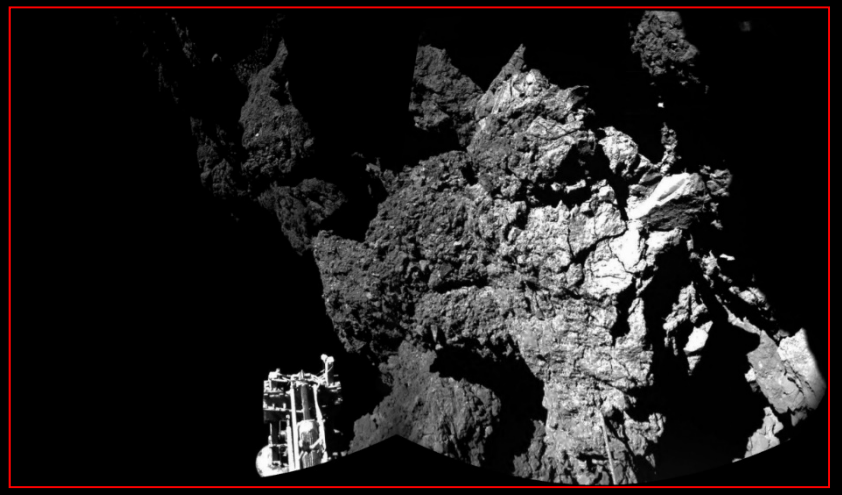
Hayabusa 2



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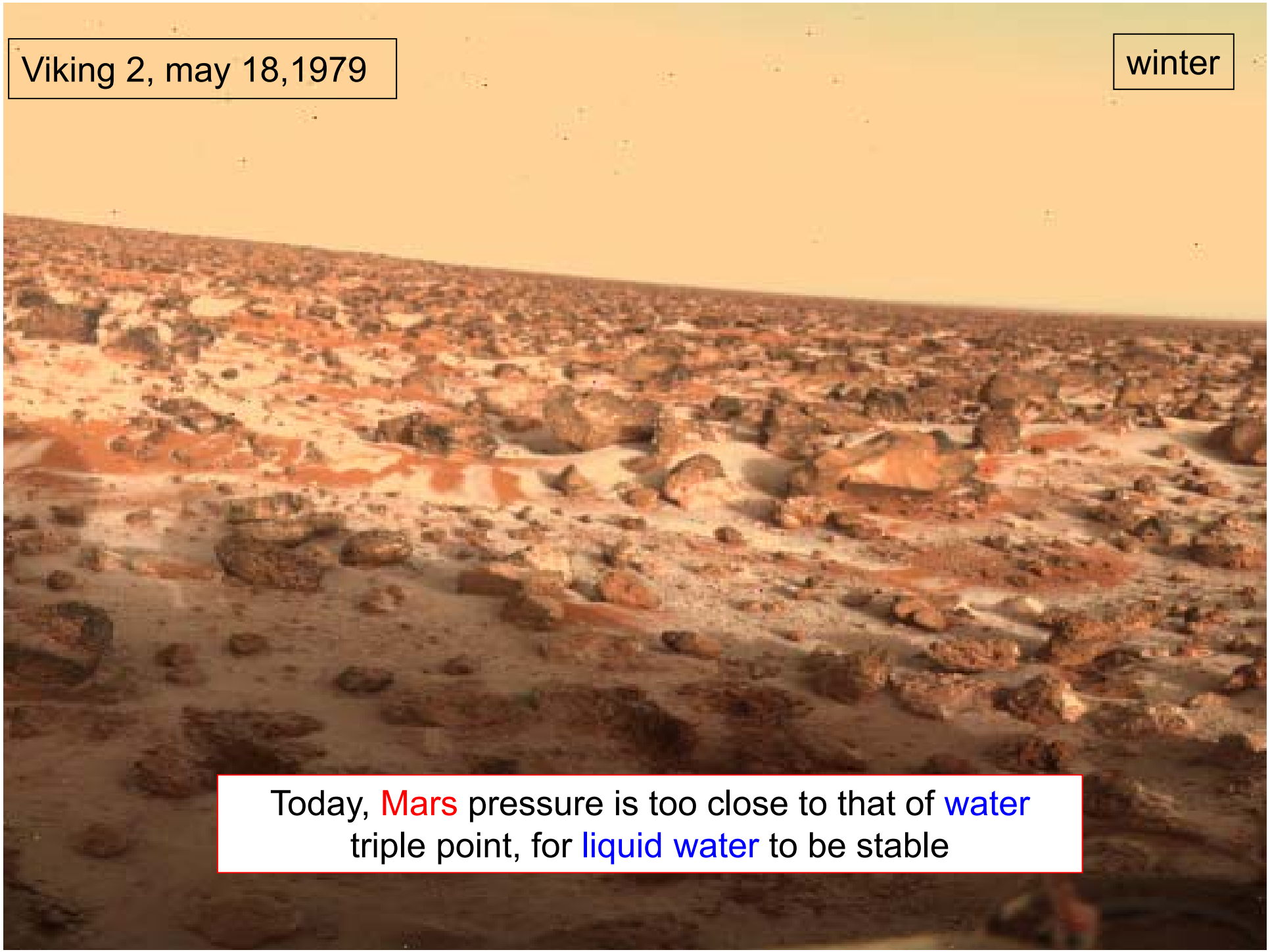
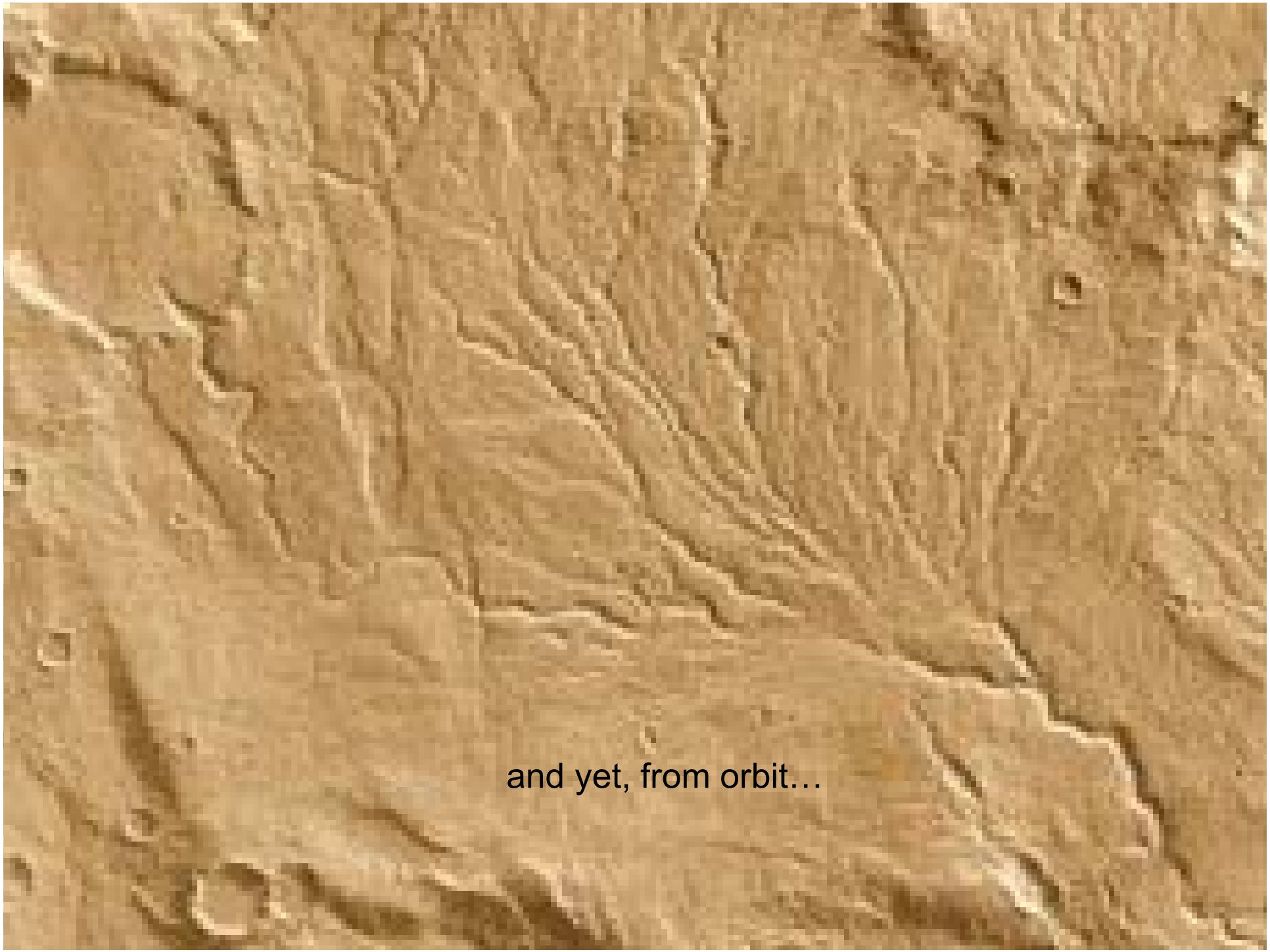
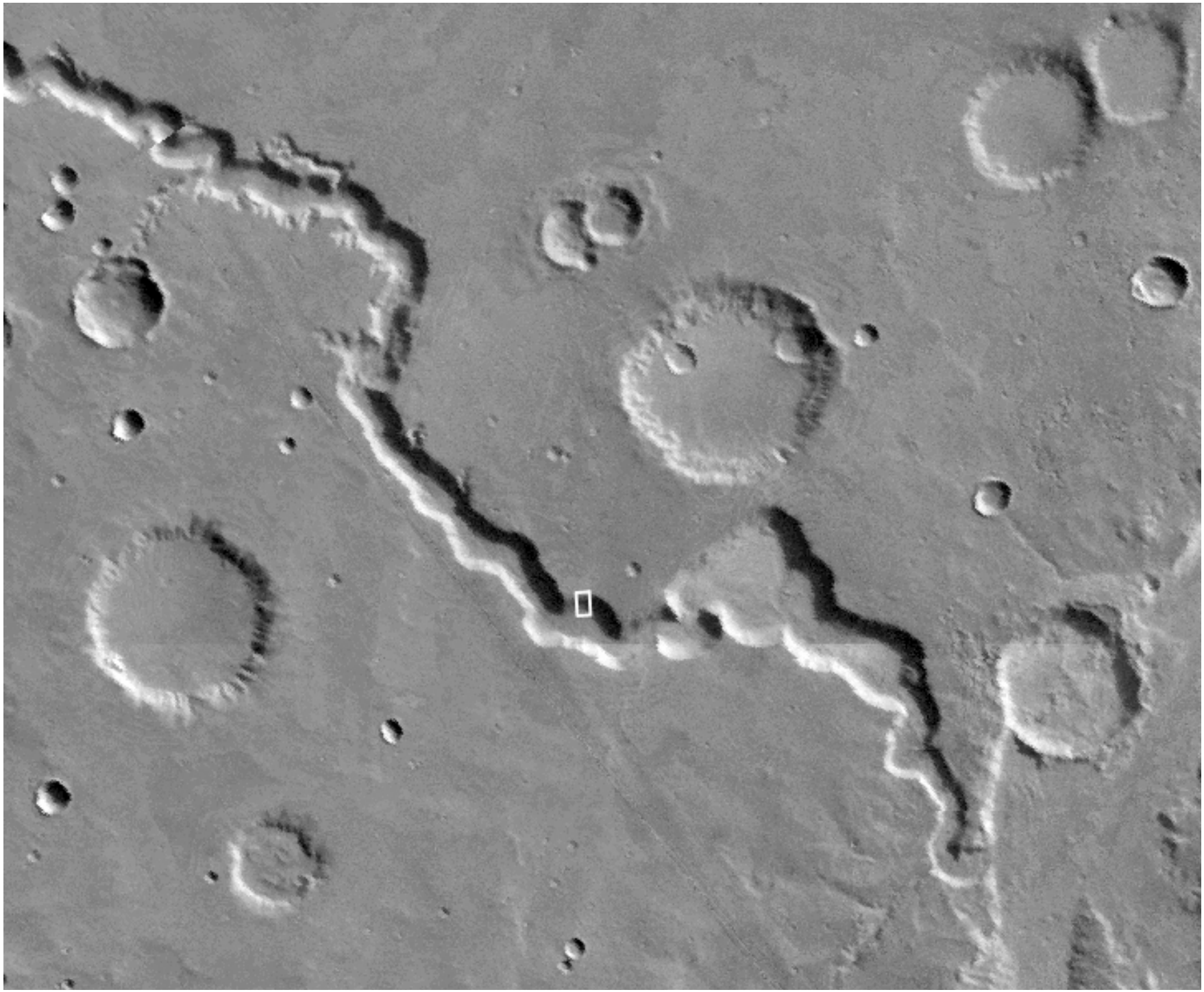
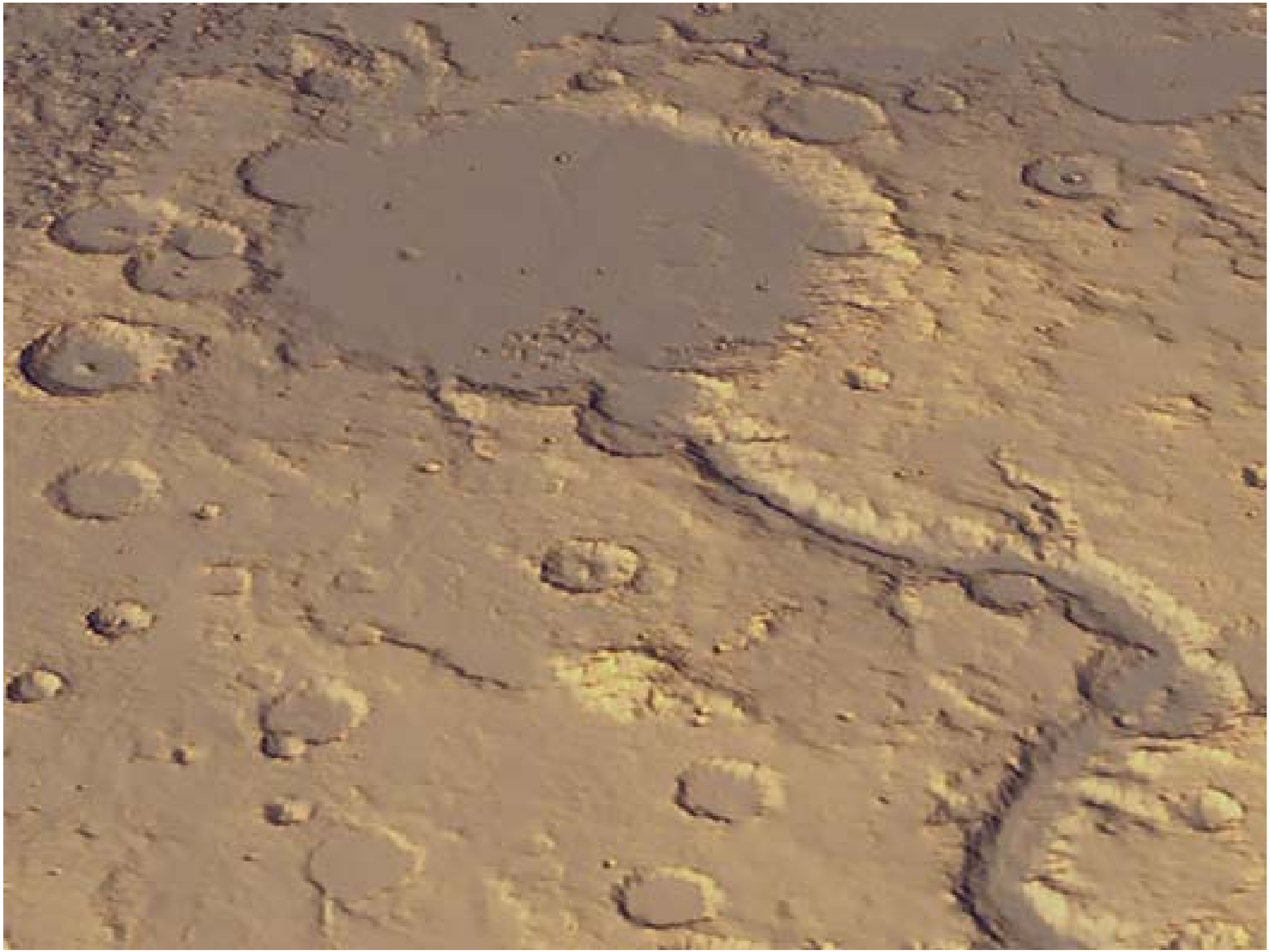
With respect to what drove living structures to be built on Earth, the most similar (favorable) environment seems to be Mars, in its ancient times.


Viking 2, may 18,1979
winter
Today, Mars pressure is too close to that of water
triple point, for liquid water to be stable


and yet, from orbit…



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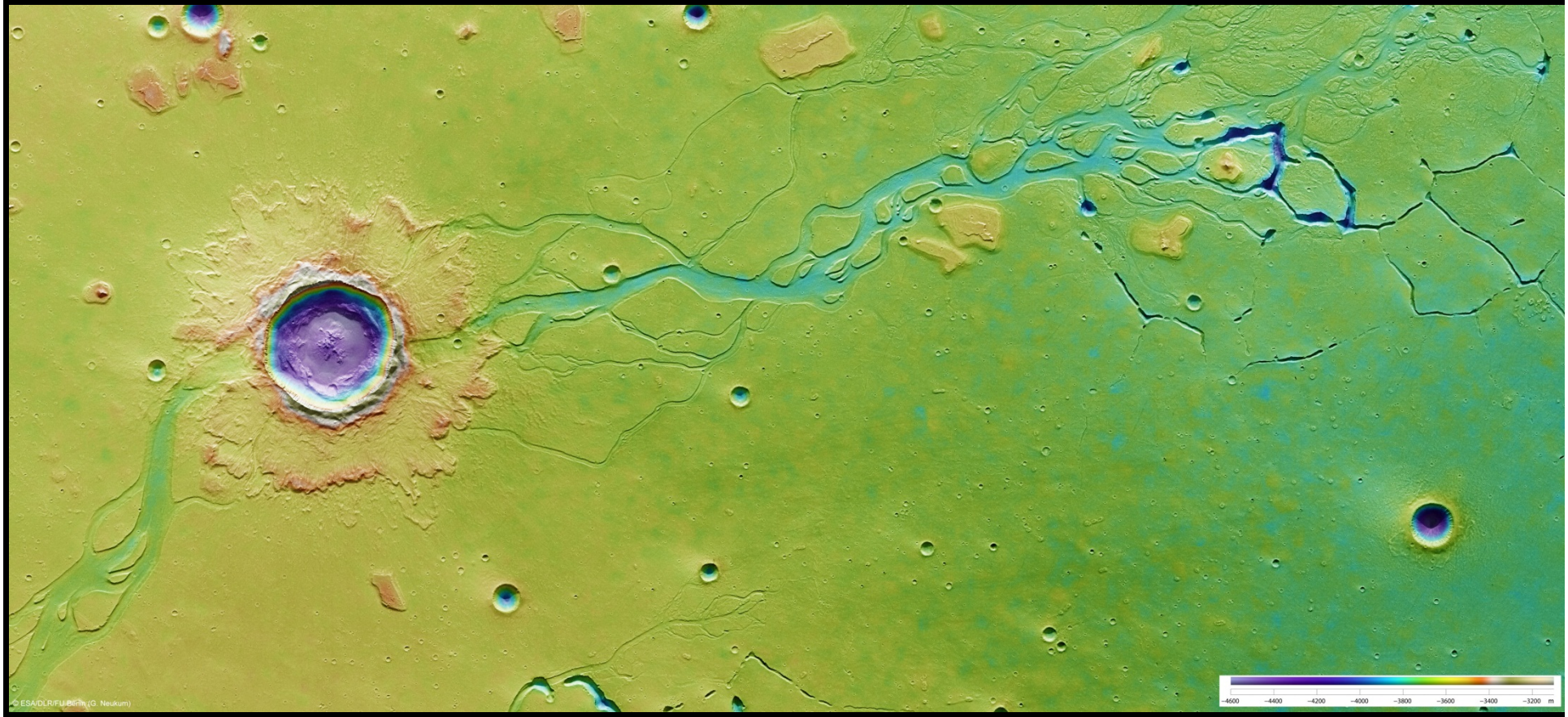
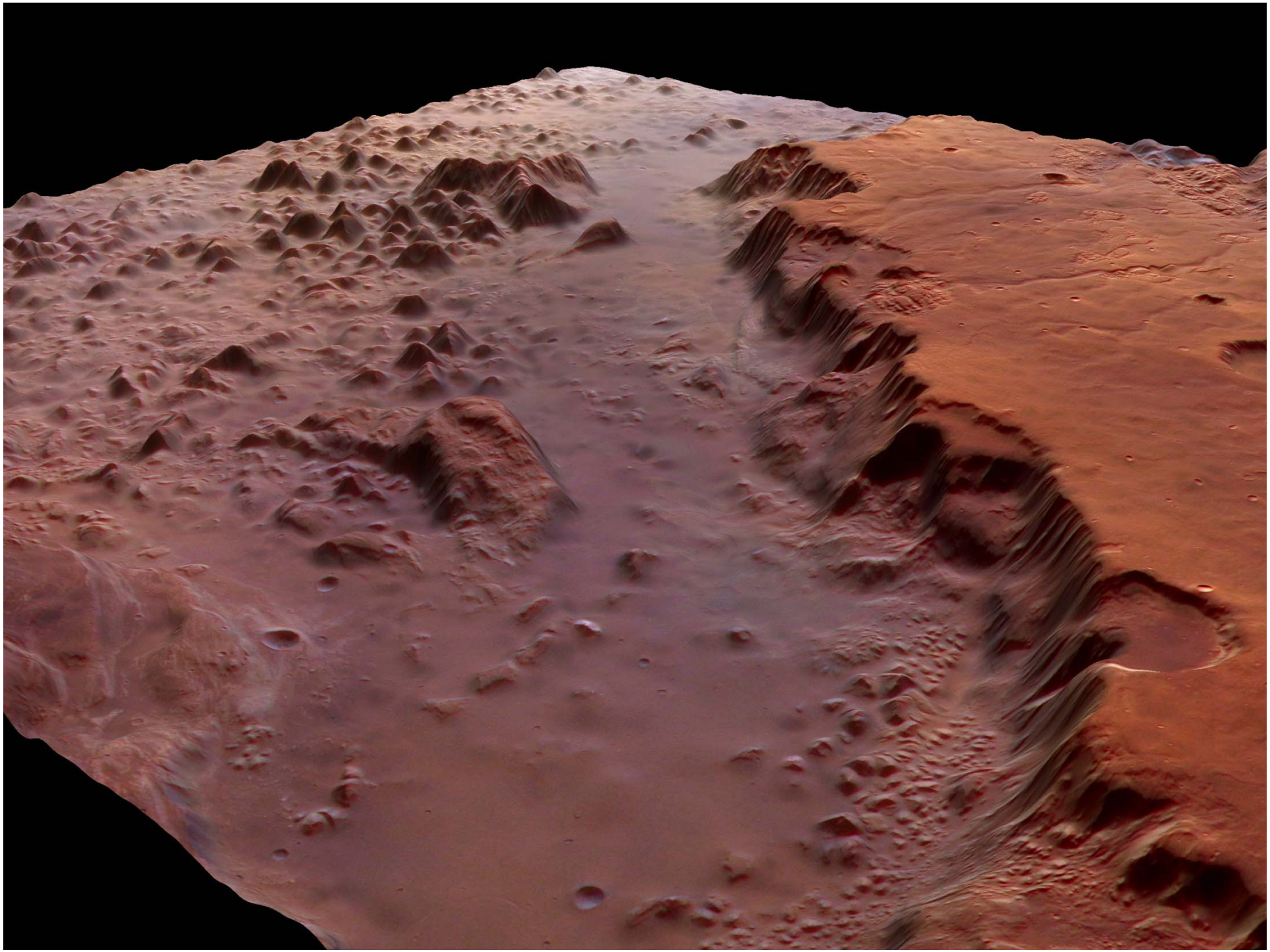
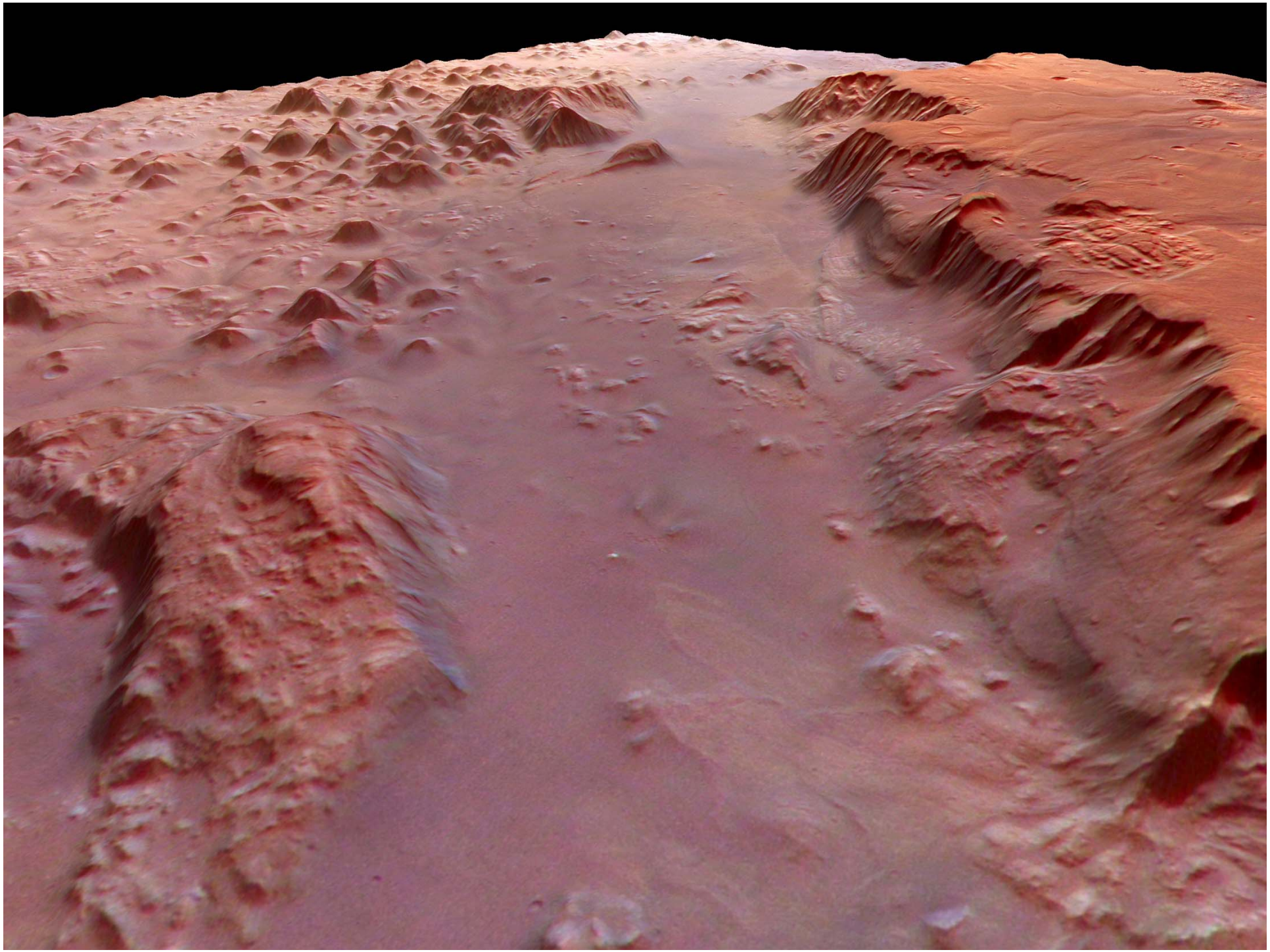
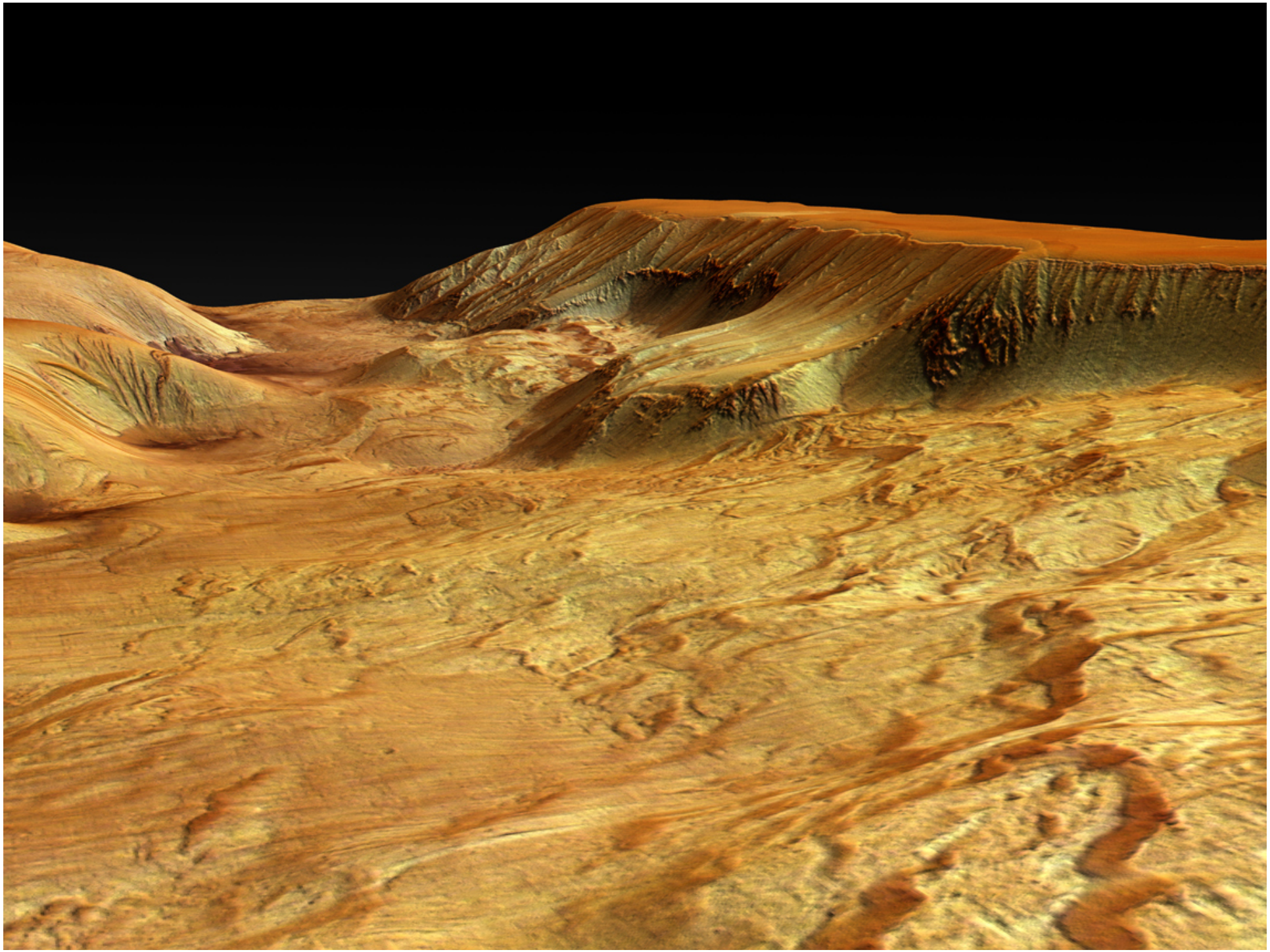
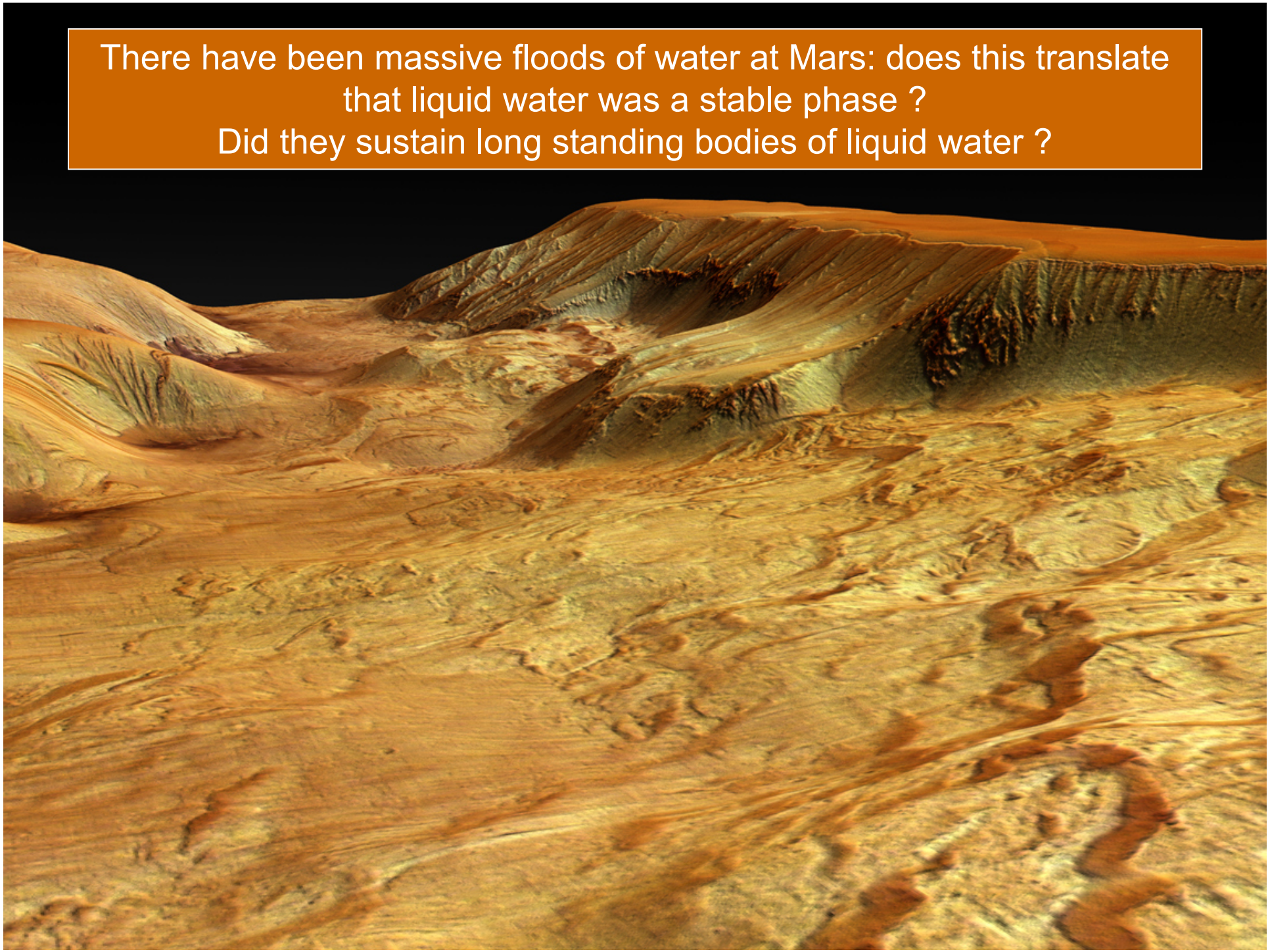

−4600 −4400 −4200 −4000 −3800 −3600 −3400 −3200 m
© ESA/DLR/FU Berlin (G. Neukum)



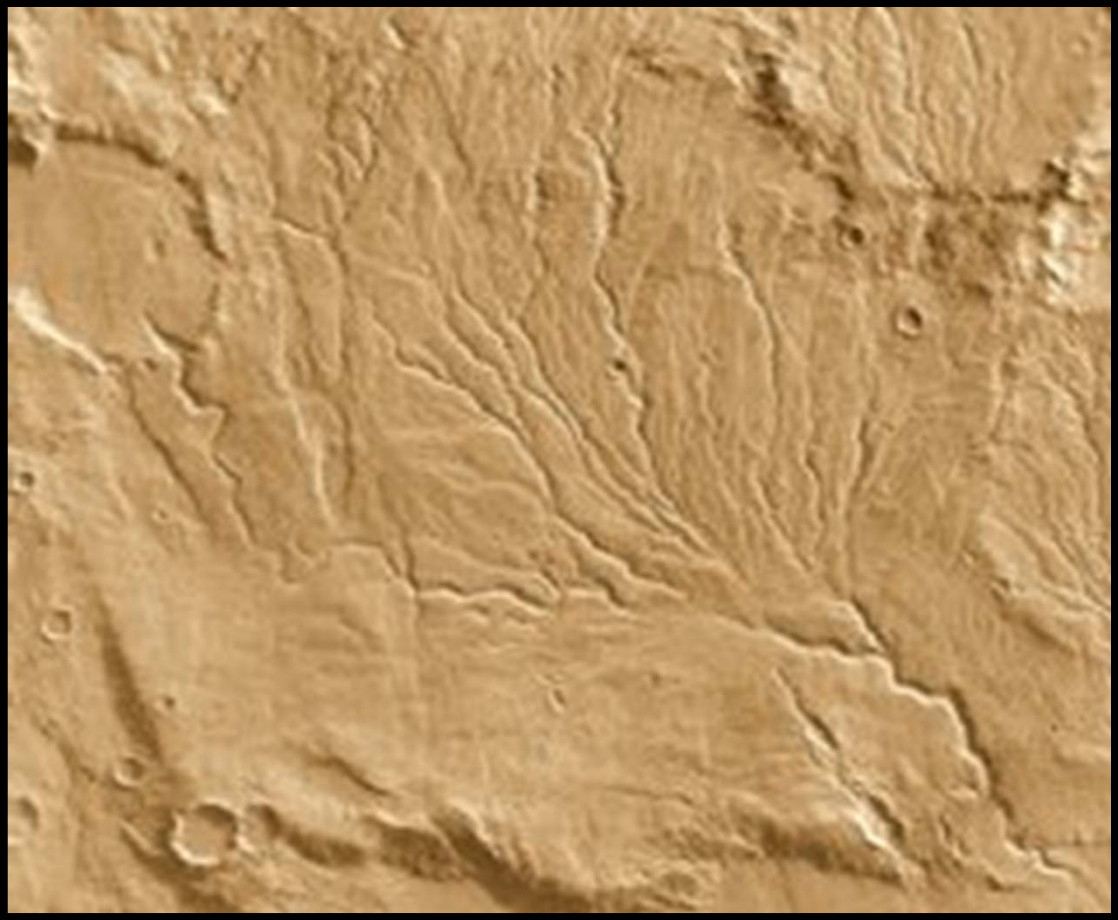




There have been massive floods of water at Mars: does this translate that liquid water was a stable phase ?
Did they sustain long standing bodies of liquid water ?

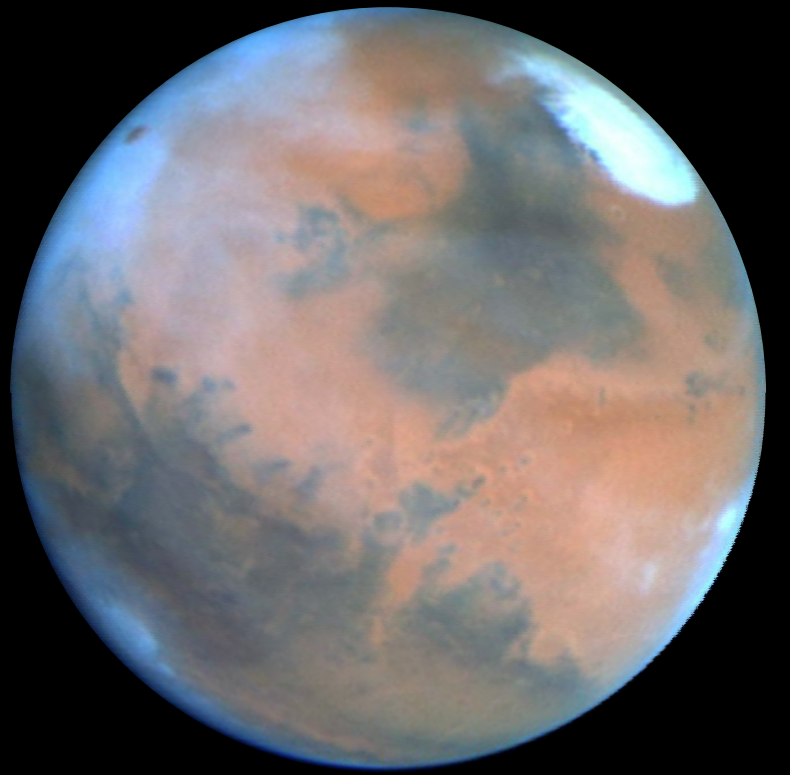


arid today



wet in the past?

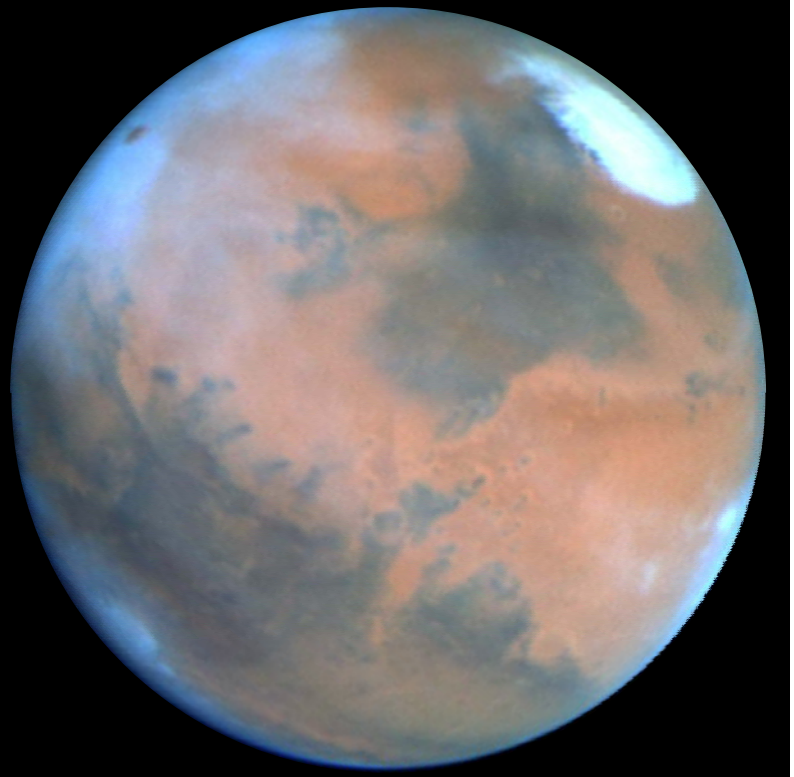
ancient ?



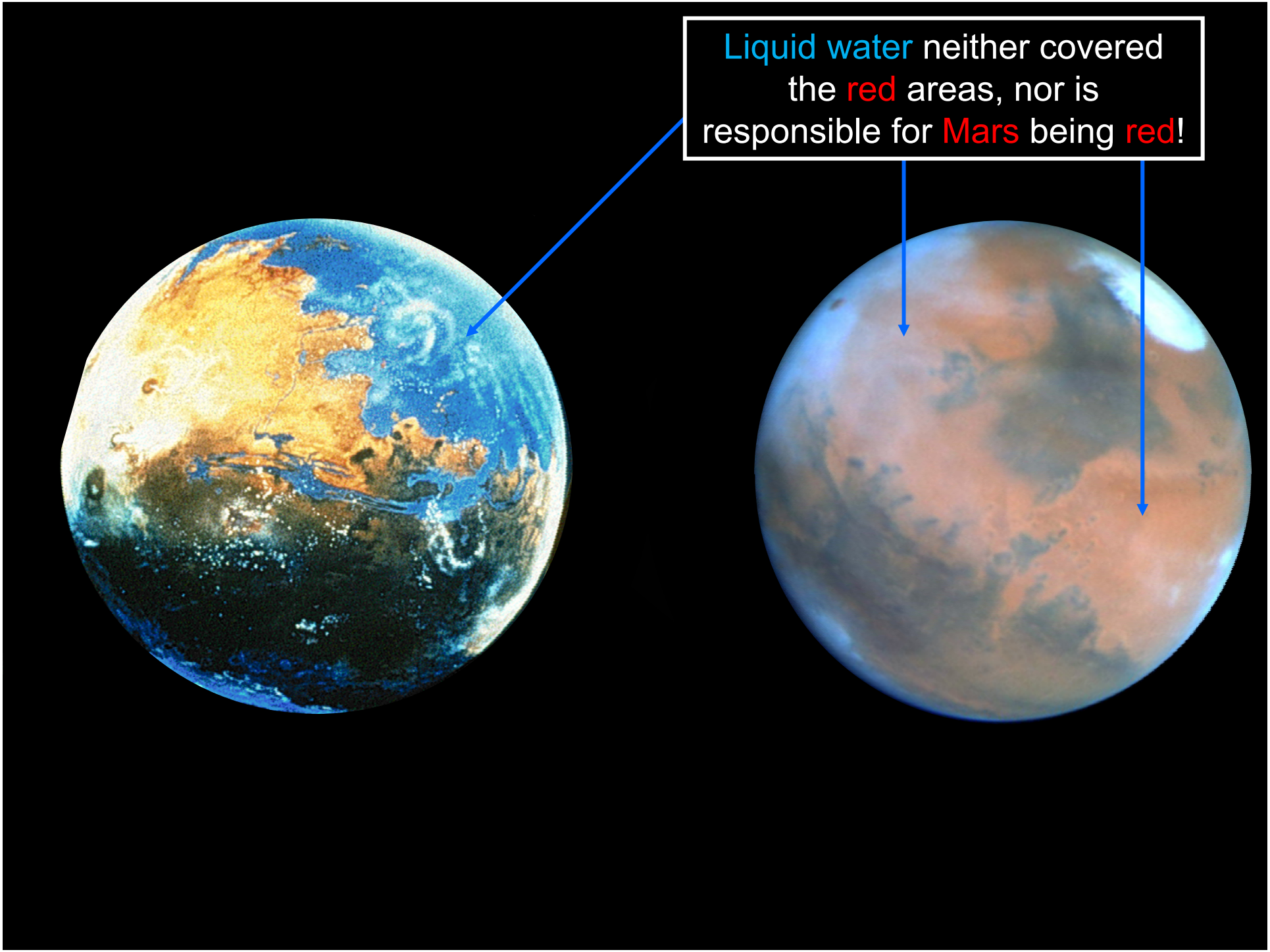
today

ancient ?

ESA / Mars Express data have triggered a profound revisiting of Mars History



today


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

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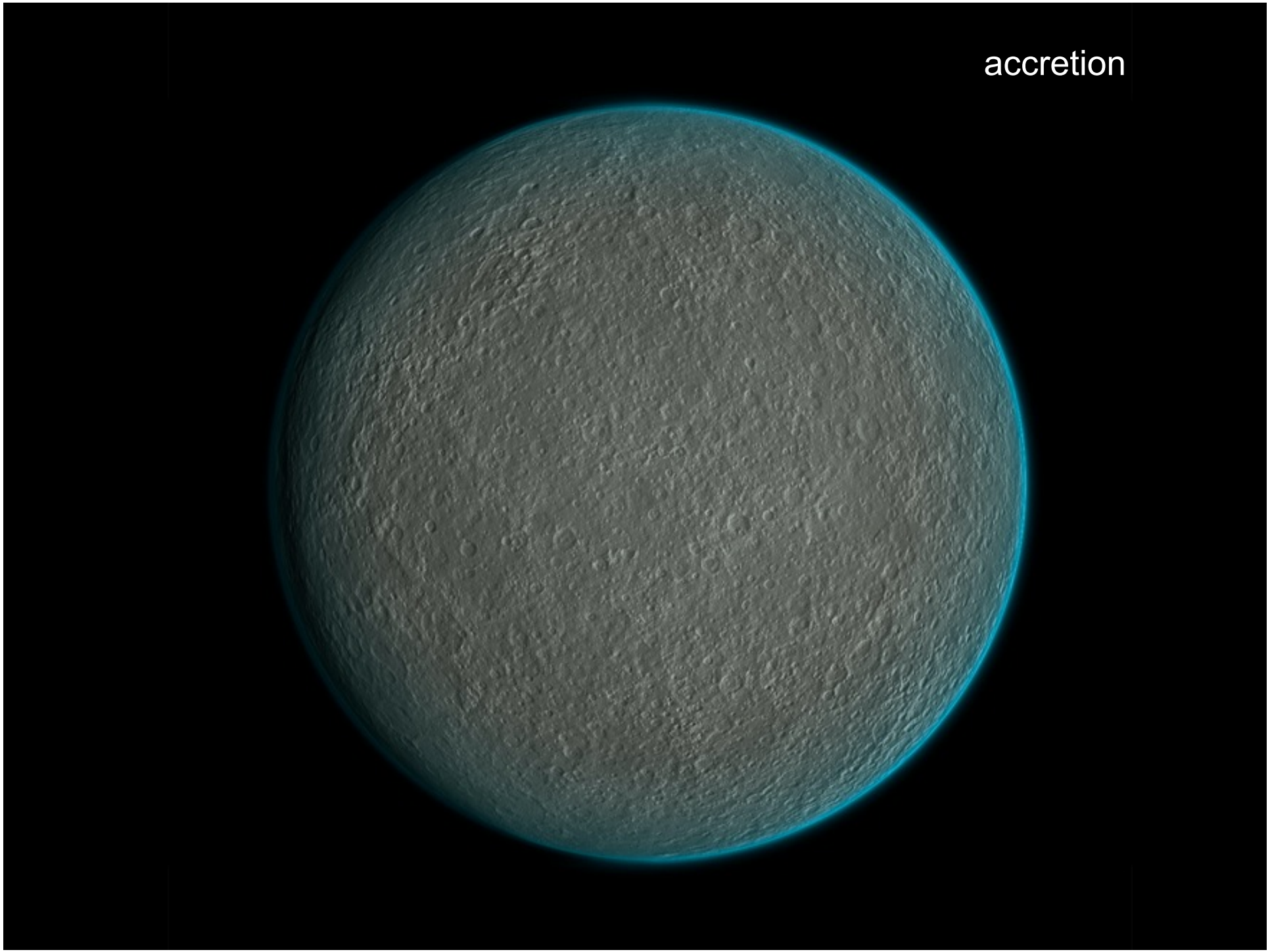
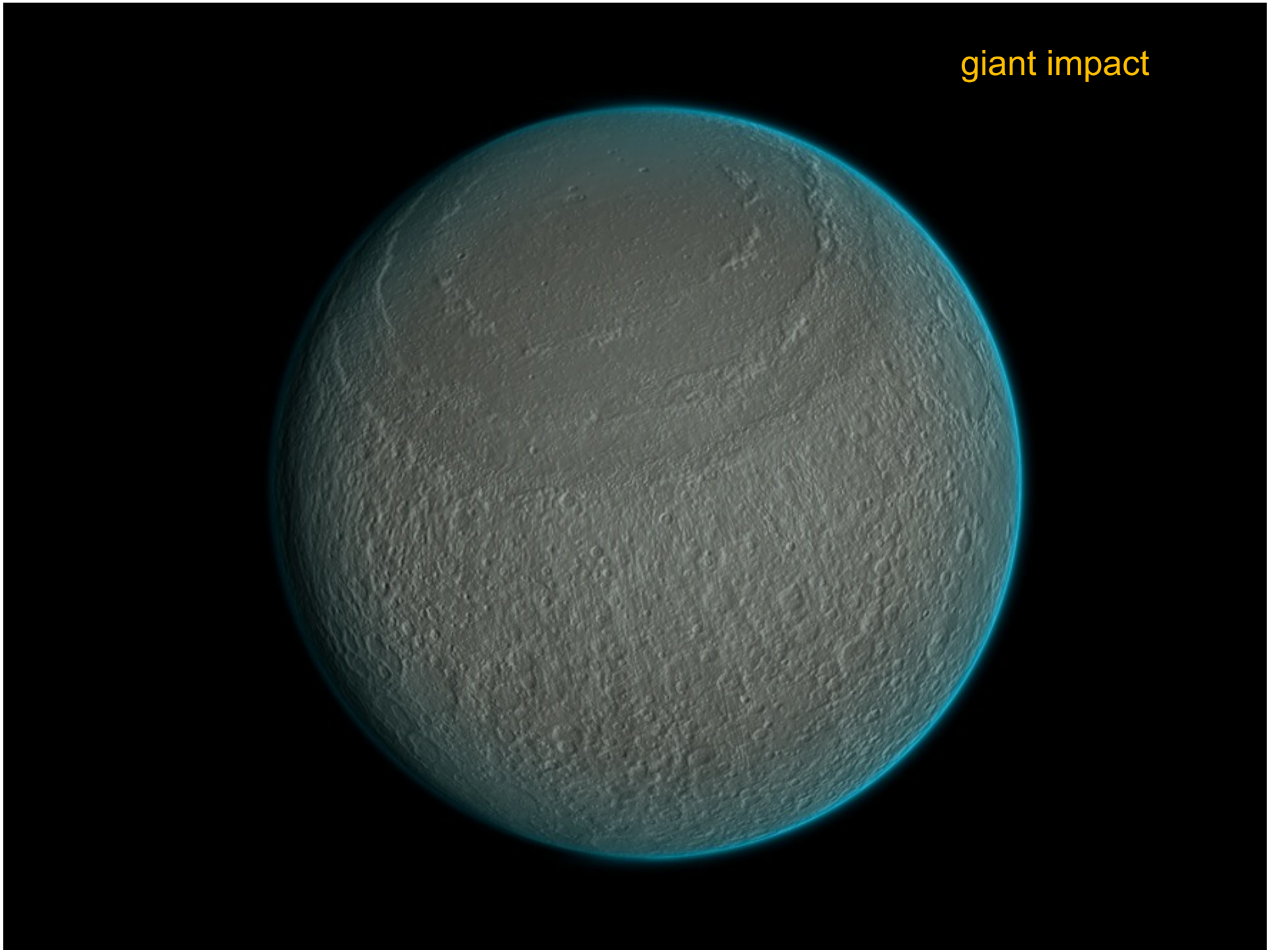
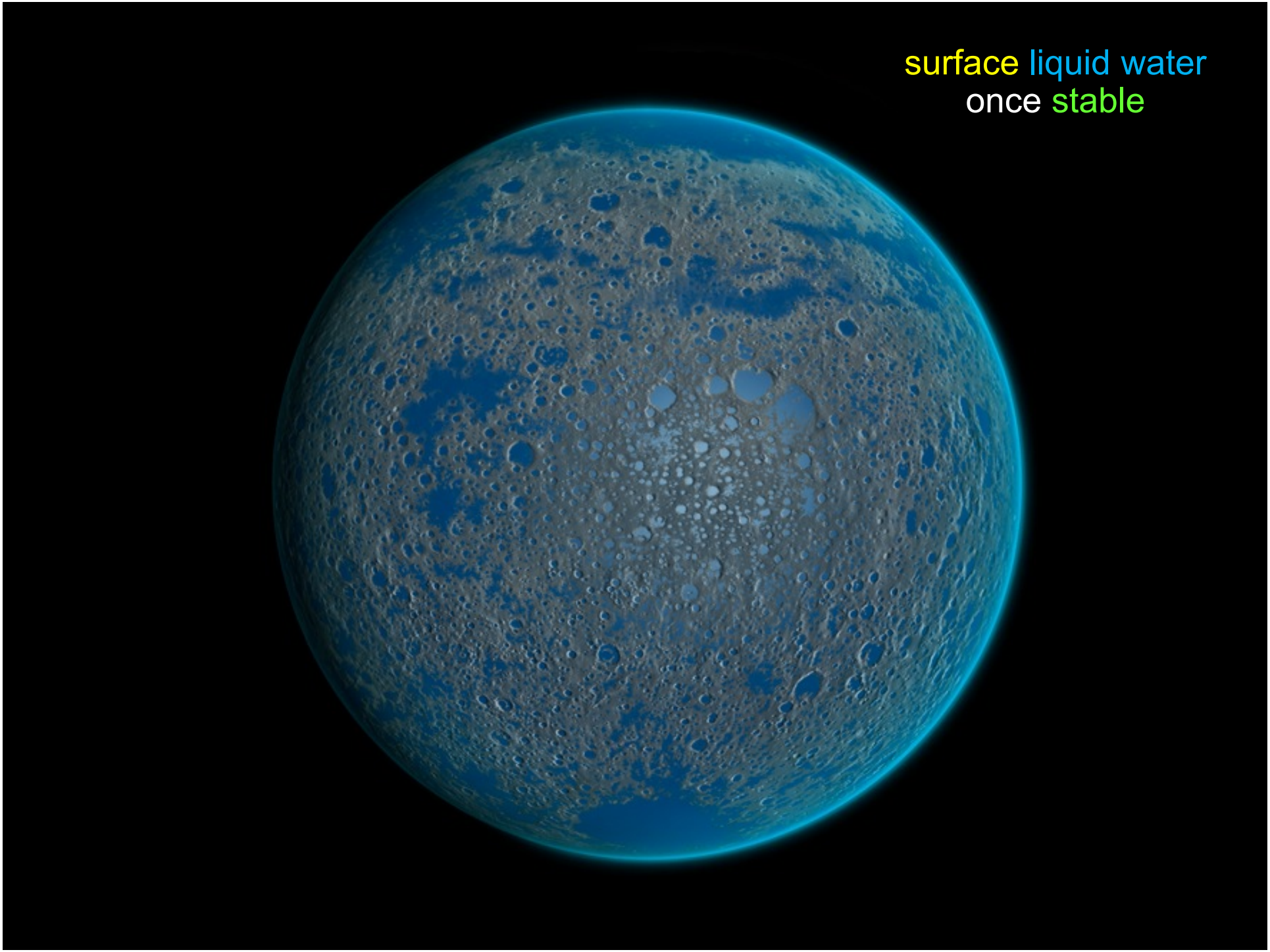
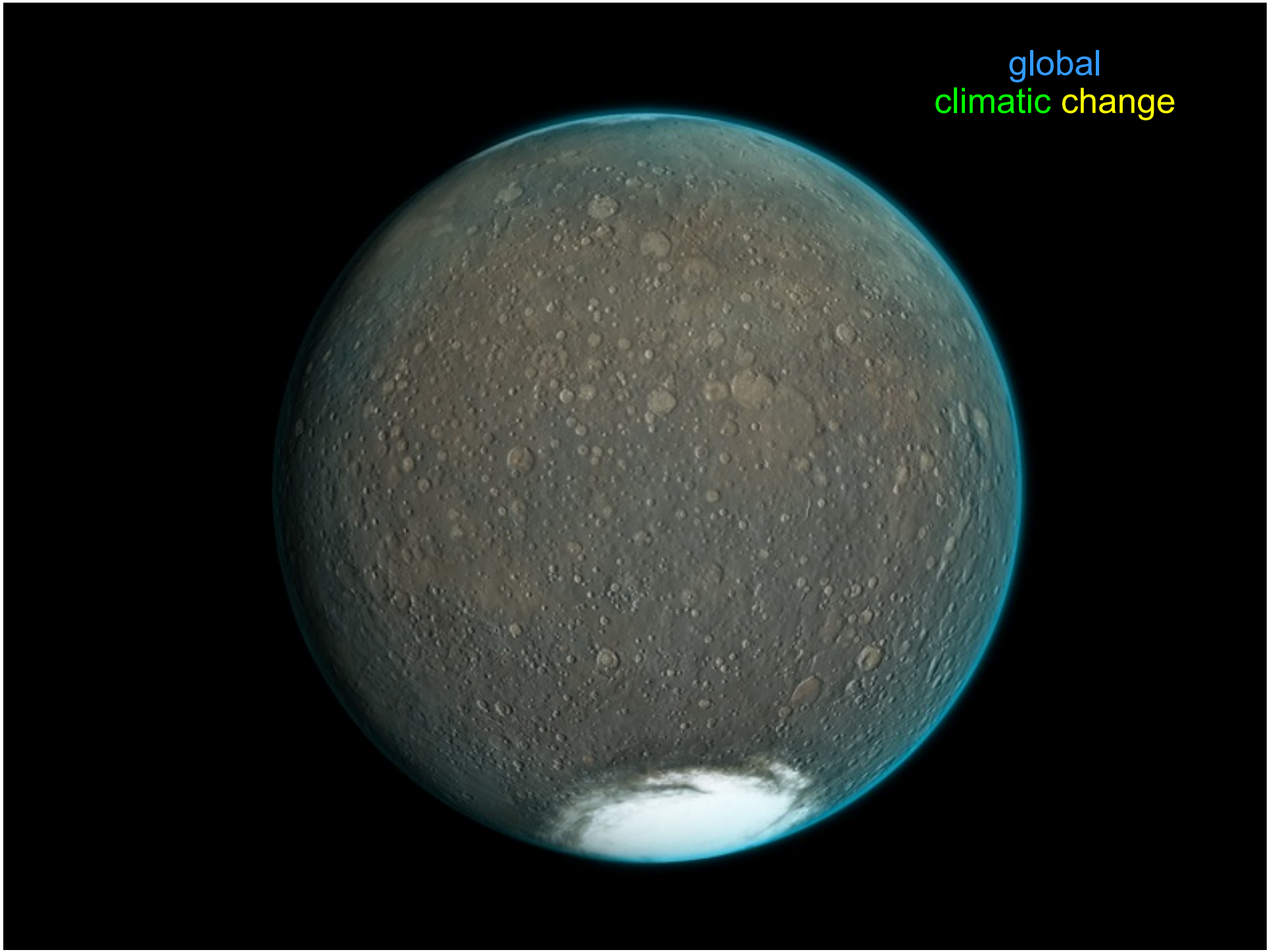
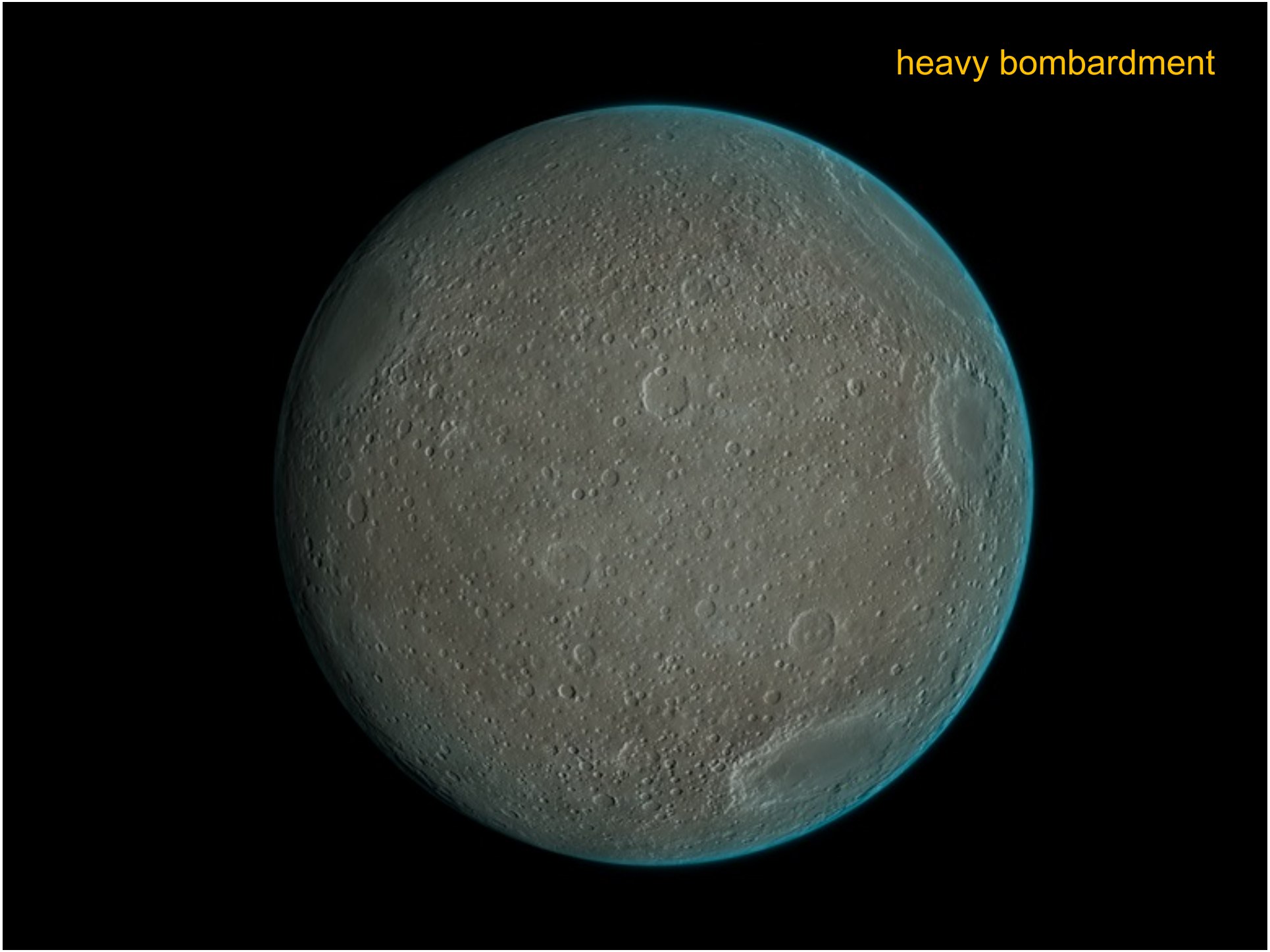

accretion

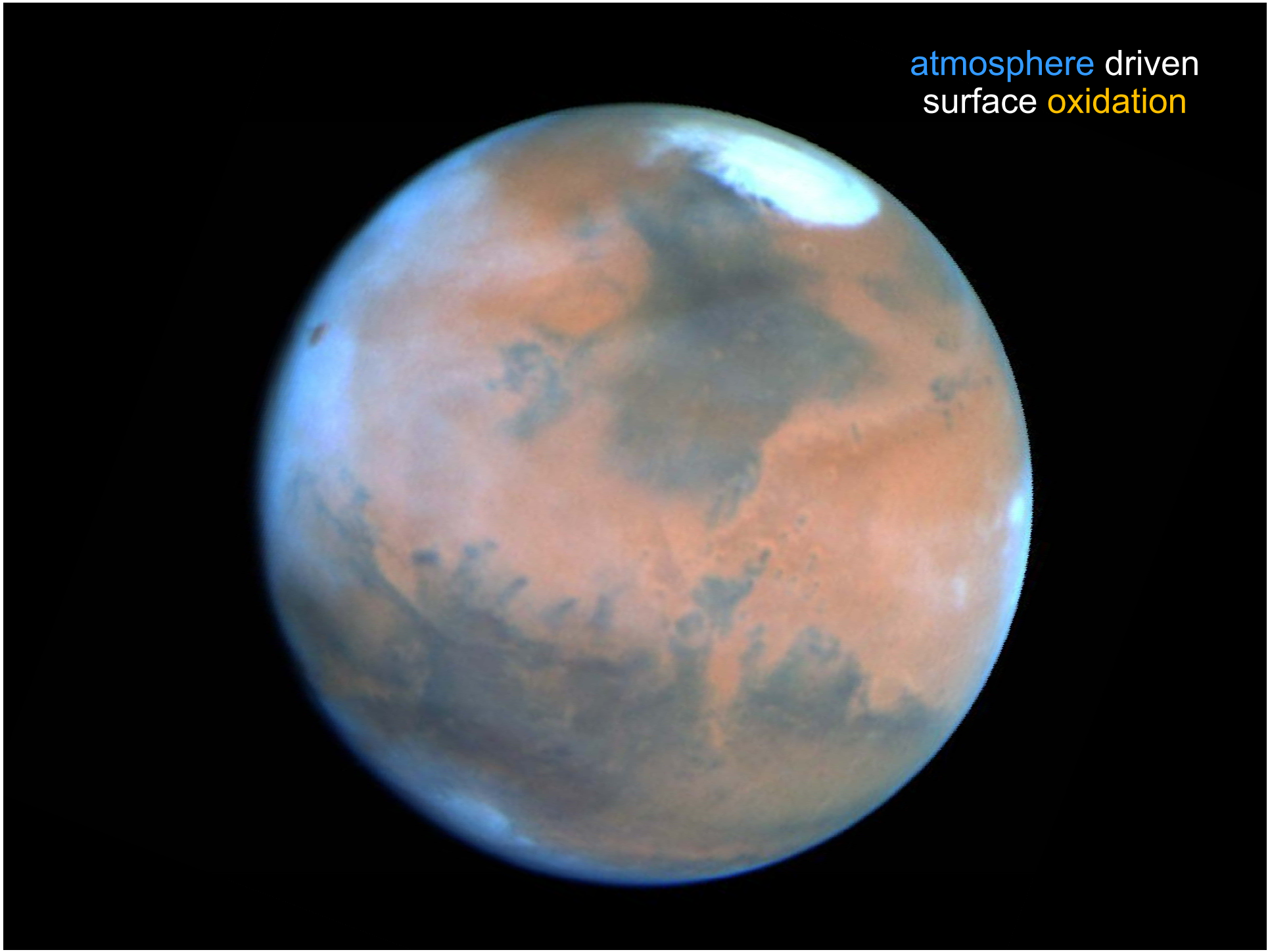

giant impact


giant impact

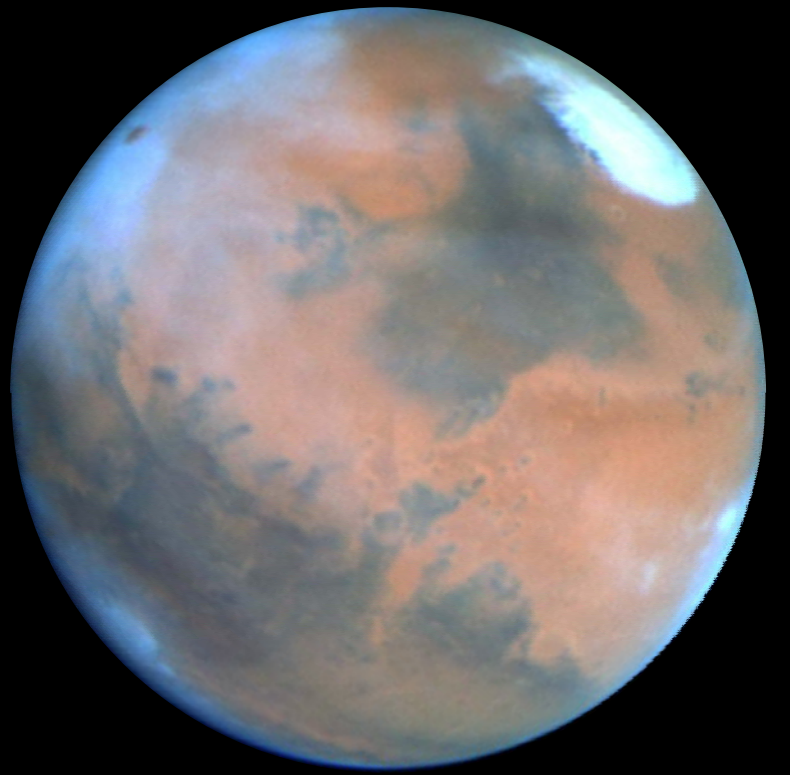

surface liquid water
once stable


global
climatic change


heavy bombardment

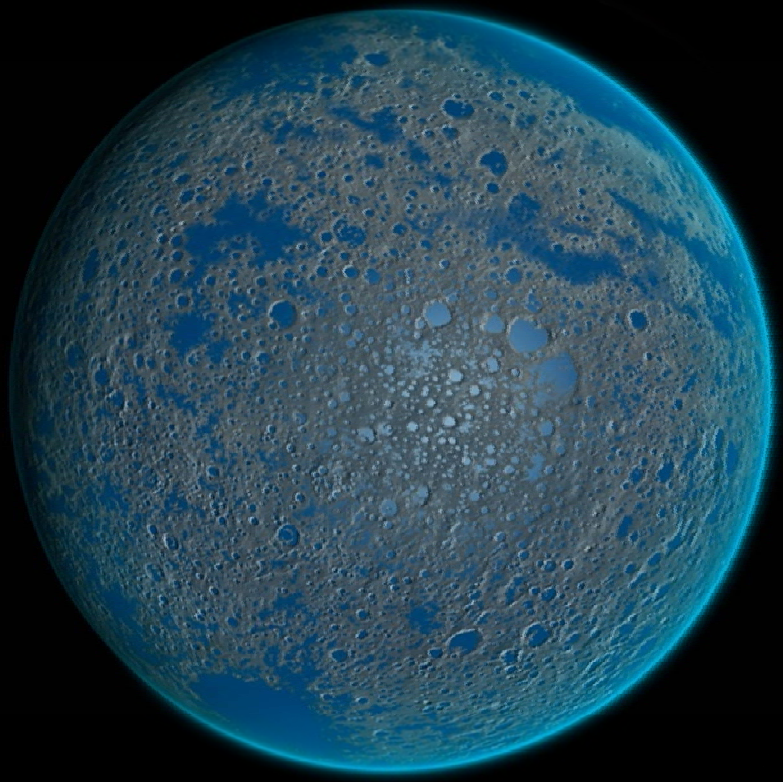

atmosphere driven
surface oxidation

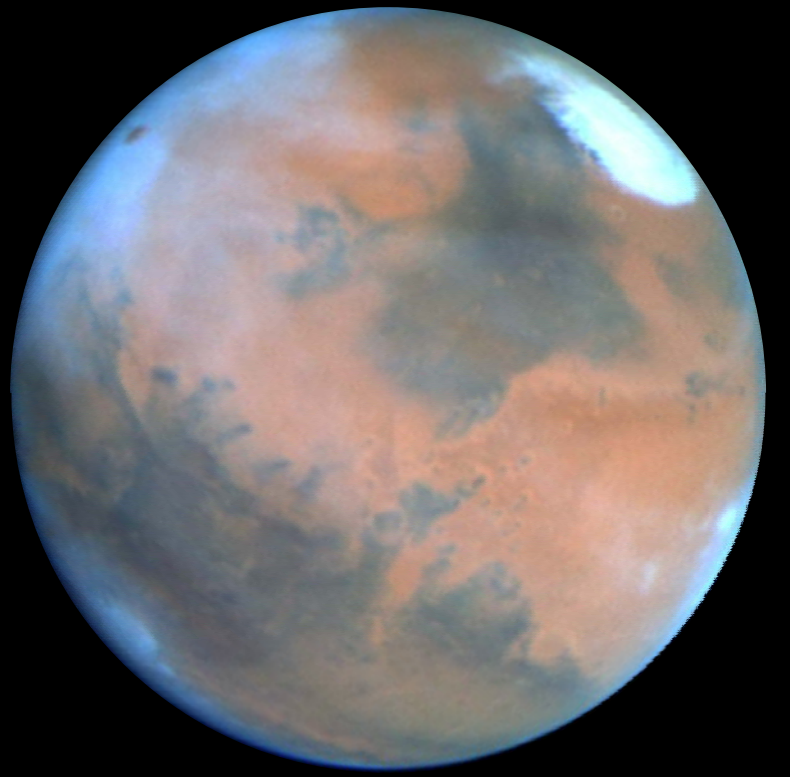
instead of…



today

… it could have been





in its ancient past

today

Mars

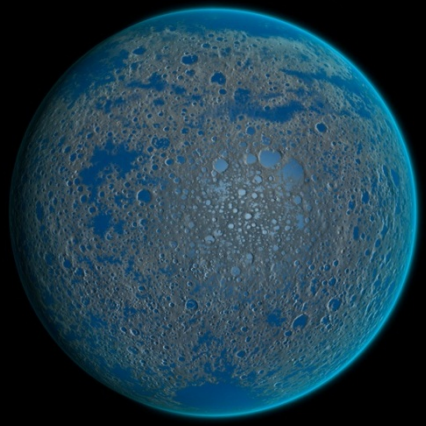
in the past ?

Earth

present

Mars

in the past ?



Earth

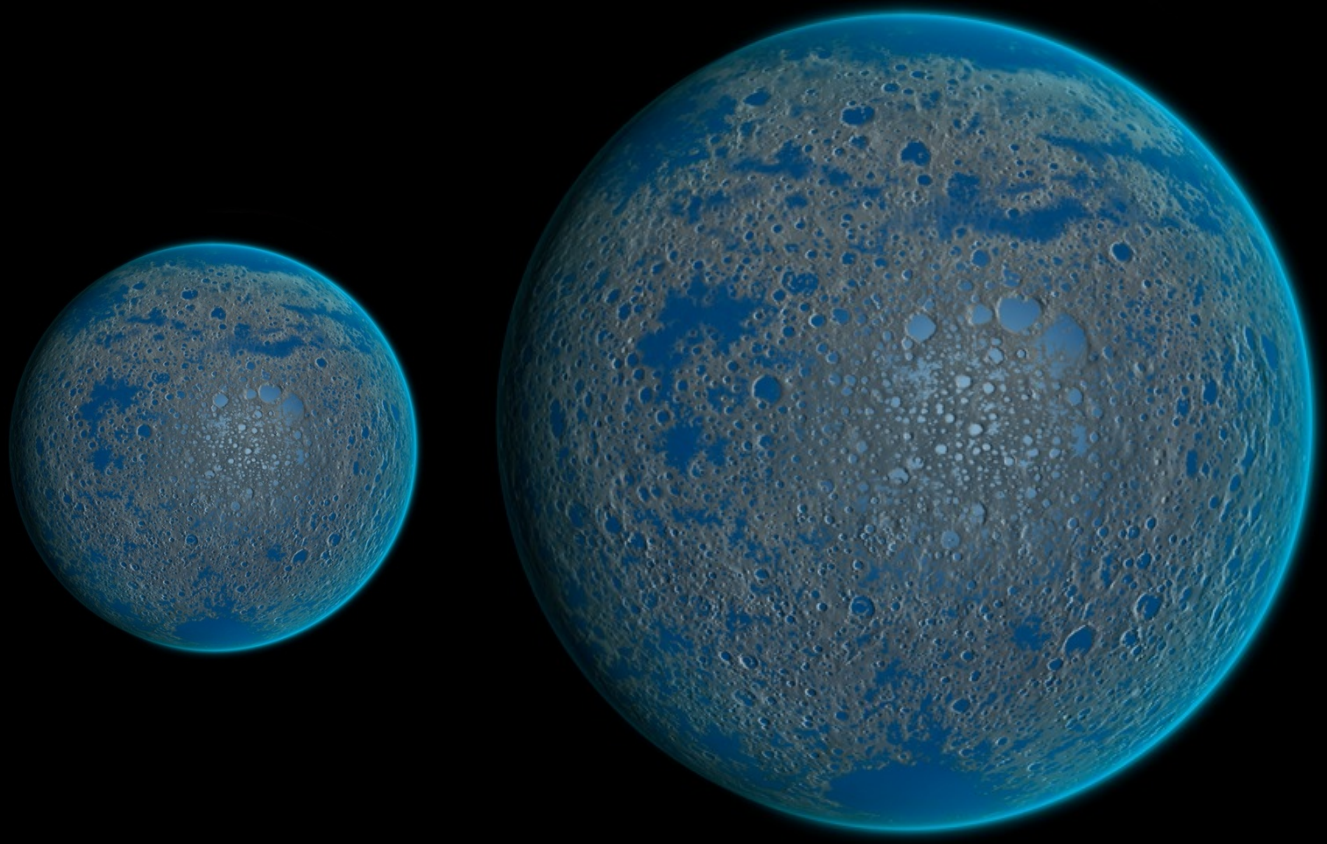
present

Mars

in the past ?

Earth

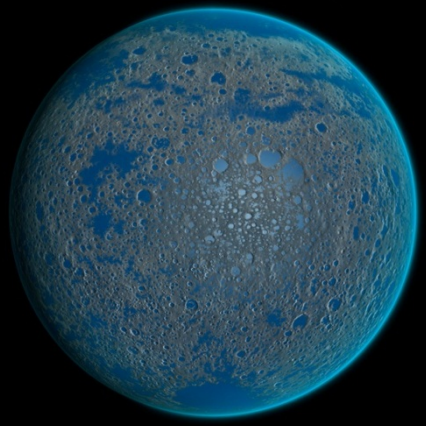
in the past ?



On Earth also surface liquid water might have been stable < 4.3 By

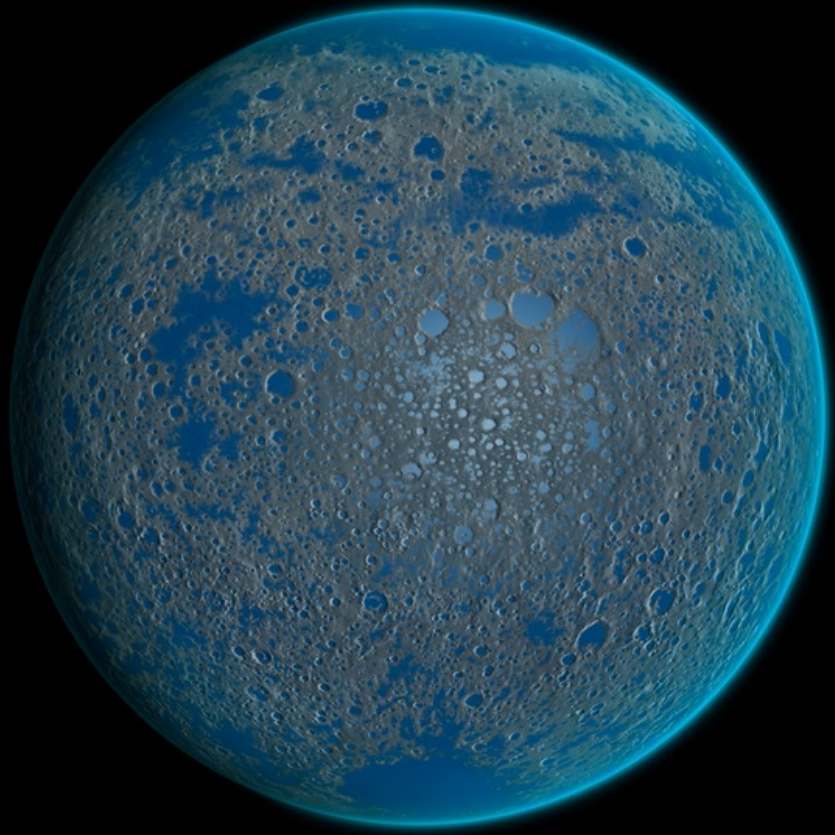
Mars

in the past ?

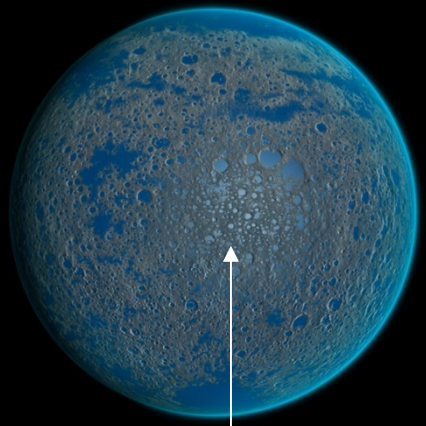


Earth

in the past ?

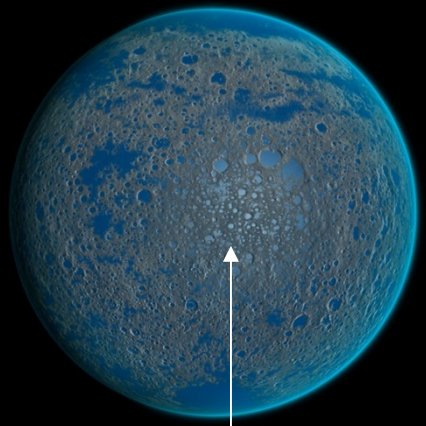


No preserved terrains exist
on Earth



There exist at Mars ancient preserved terrains

No preserved terrains exist on Earth



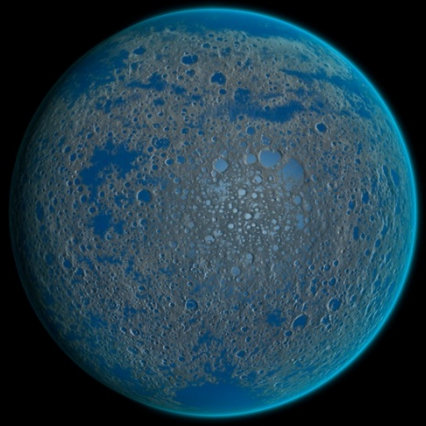
There exist at Mars ancient preserved terrains

No preserved terrains exist on Earth

They constitute unique sites, in the entire solar system.

in the past ?

today

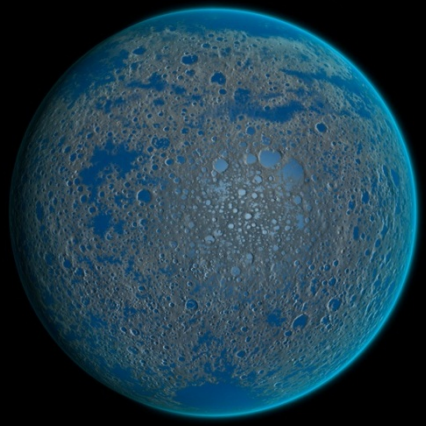


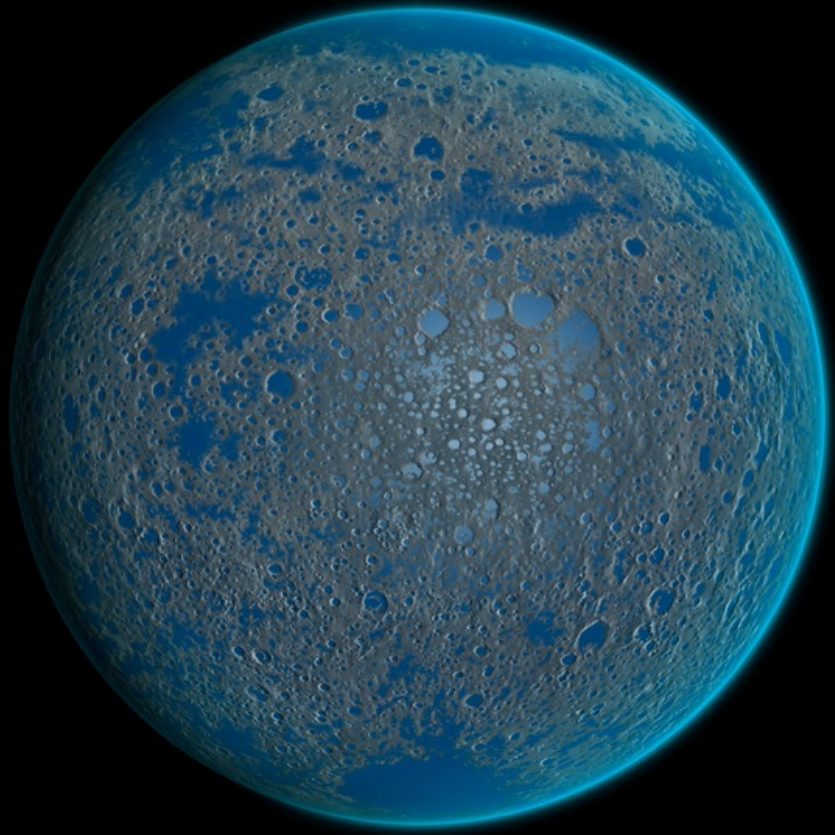
Mars
habitable ?

Earth
inhabited !

in the past ?

in the past ?





Mars
habitable ?

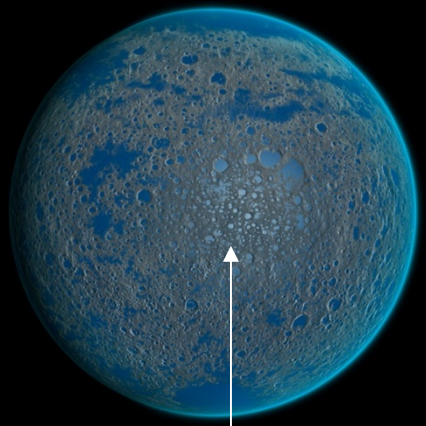
←

Earth
habitable !

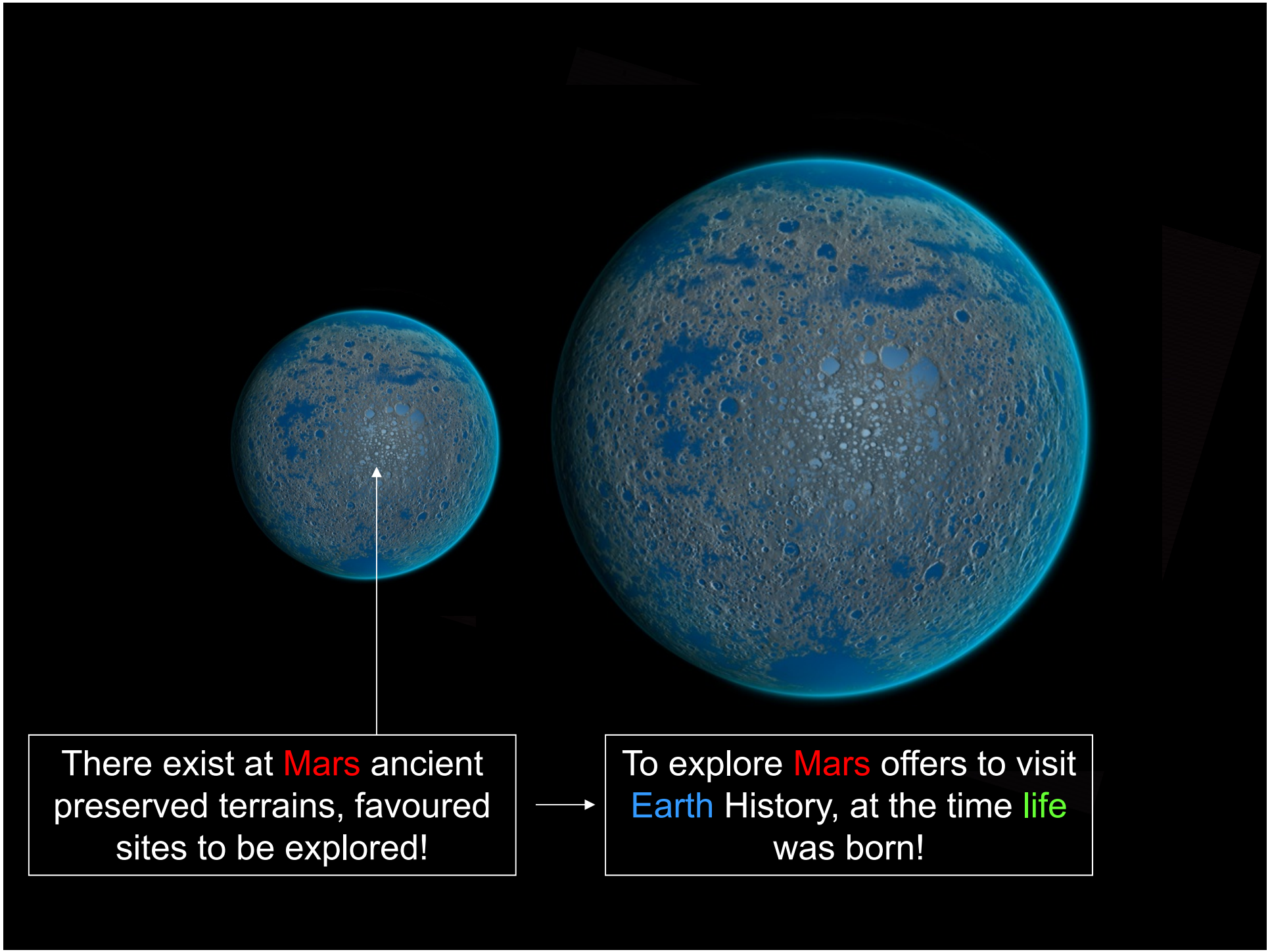
Mars

Earth

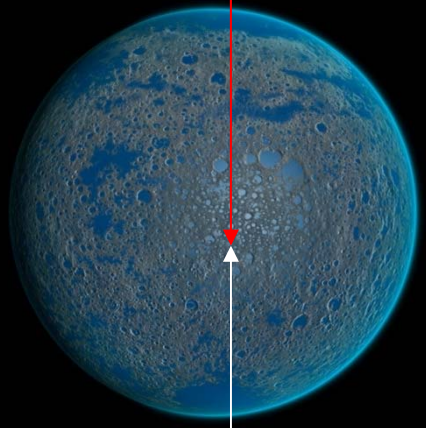
Is "life" robust enough to have "emerged" and adapted
in two similar, although distinct, envitronments ?

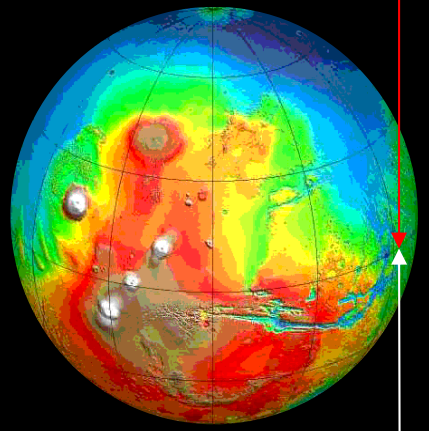


There exist at Mars ancient preserved terrains, favoured sites to be explored!


There exist at Mars ancient preserved terrains, favoured sites to be explored!
To explore Mars offers to visit Earth History, at the time life was born!

ExoMars





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TGO / ExoMars is already orbiting

The ExoMars 2020 rover will explore such a site

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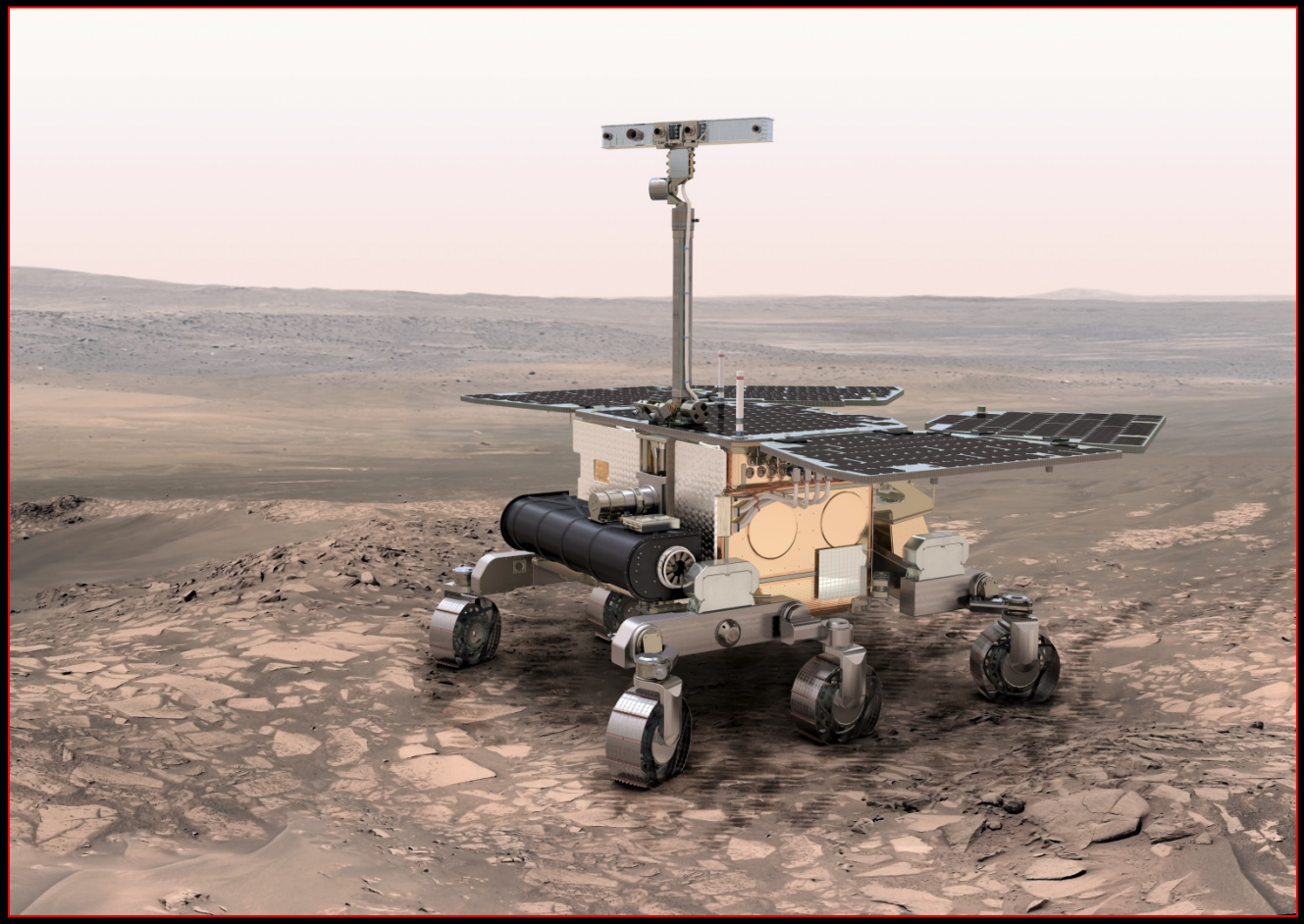

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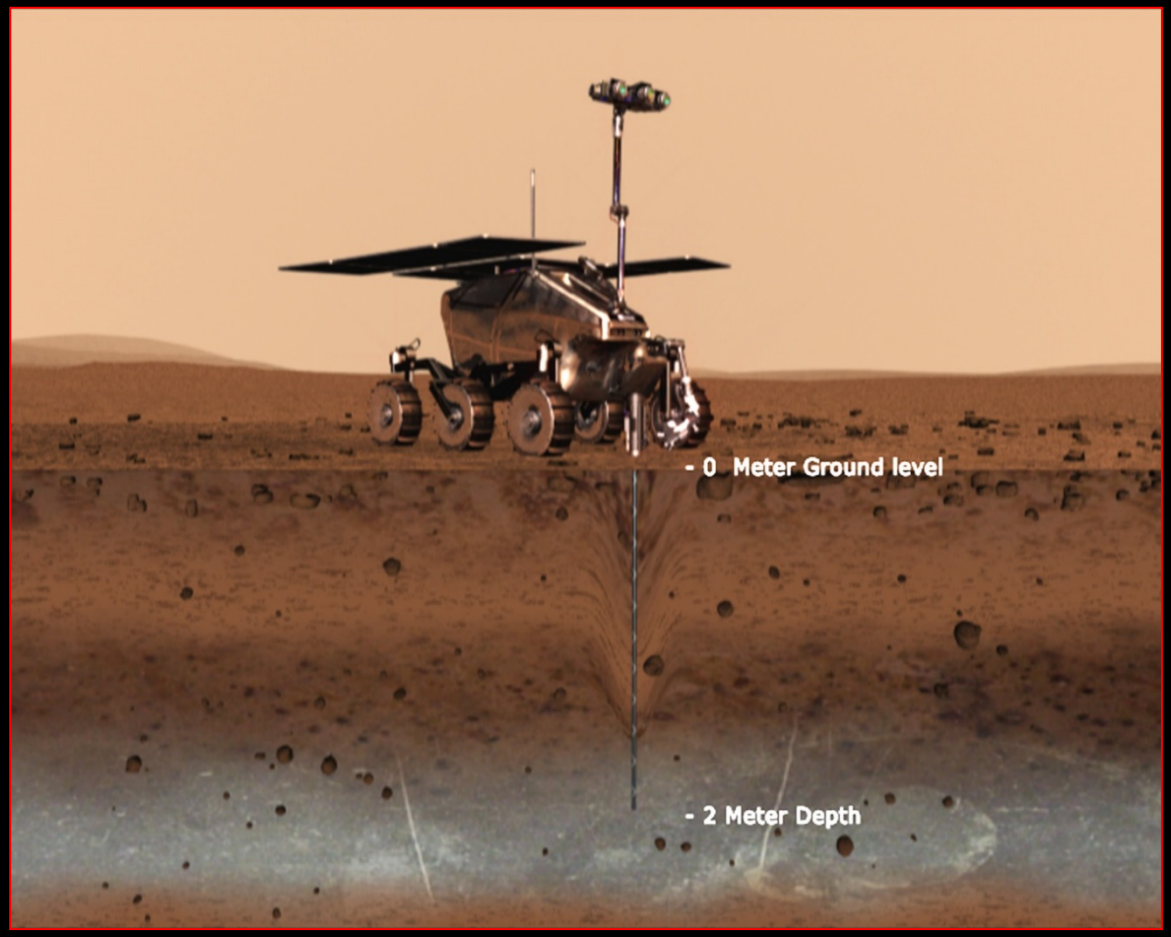

Some concluding suggestions

1. The "habitable" zone is certainly not sufficiently well described by the circumstellar region in which surface liquid water is stable. However, the reasons why life on Earth remained > 2 By in water before spreading on continents translate water properties which might justify the *a contrario* statement: a region where liquid water is not stable is likely "not habitable".

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2. The more we decipher the specificities of the Earth, the more we realize the key role of contingencies in its evolution: processes are generic, but evolution is shaped by the suite of contingent forms they harbor. Searching for “exoEarths“ tends to oppose to what the solar system community is being elaborating, as the evolutionary steps which uniquely shaped Earth History, as well as those relevant to other bodies.

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3. Among the key new addresses is the (highly controversial, if not provocative) possibility that life would be intimately coupled to the Earth specific evolution, in a specific solar system early evolution, including the dynamics of the protosolar disk.

4. Life on Earth is being demonstrated capable of developing/adapting/surviving in highly extreme environments. This cannot be translated into life capability to emerge in any extreme environment: Earth was habitable once, but no one knows how it was (what were the enabling properties). Then “life on Earth never died”: if life had stopped developing, would had it re-started ?