The quest for life in extrasolar planets

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On the existence of life in other worlds

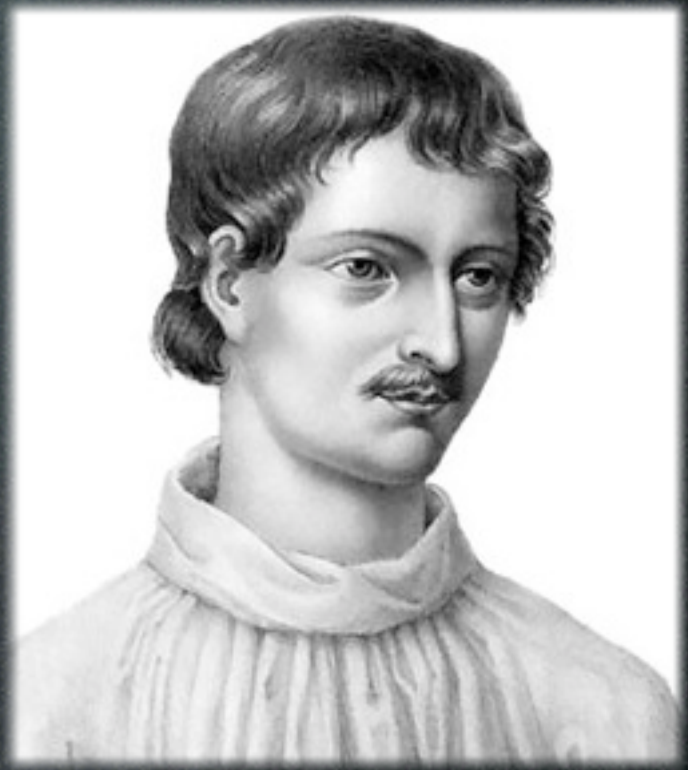
Democrito (ca 460 - ca 370 aC)

- Rationalistic philosophy
- Other worlds similar to ours may exist

Lucrezio (94 aC - 50 aC)

- "De Rerum Natura"

Giordano Bruno (1548-1600)

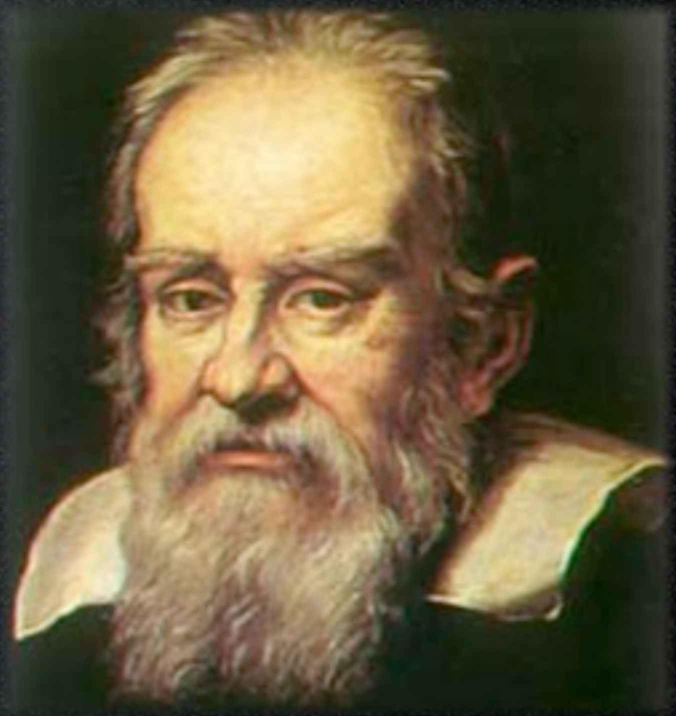


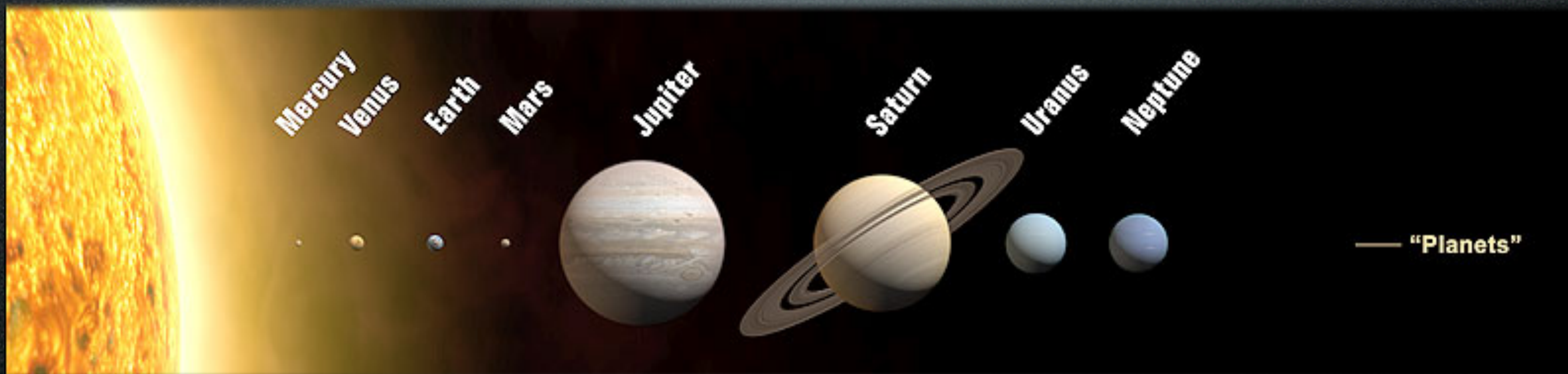
"De l'Infinito, Universo e Mondi"

Galileo Galilei (1564-1642)

On the nature of the Solar System planets

The planets in the sky obey the same laws of material bodies that we know on Earth





The planets of the Solar System

The only known planets until 20 years ago

The regular architecture of the Solar System

relatively small rocky planets, close to the Sun

giant gaseous/icy planets, far away from the Sun

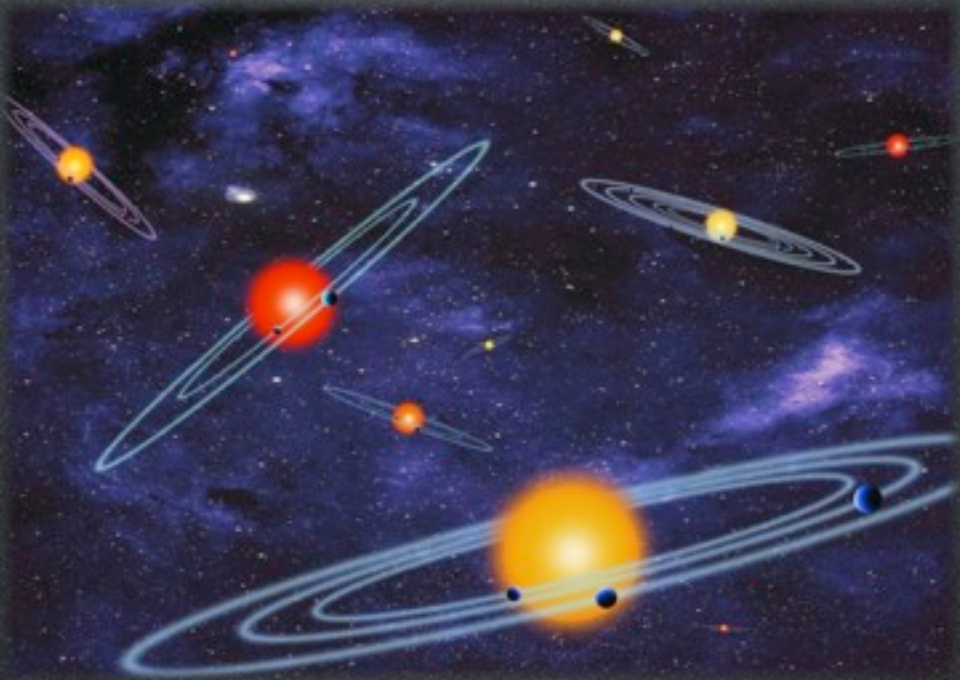
One of the small, rocky planets, the Earth, hosts life

Are there planetary systems around other stars ?

Do they have an architecture similar to that of the Solar System ?

Do they have planets similar to the Earth ?

Are there other planets with life ?



Extrasolar Planets
(Exoplanets)

Extremely difficult to detect

- luminosity contrast with its own star, can be a factor of a billon

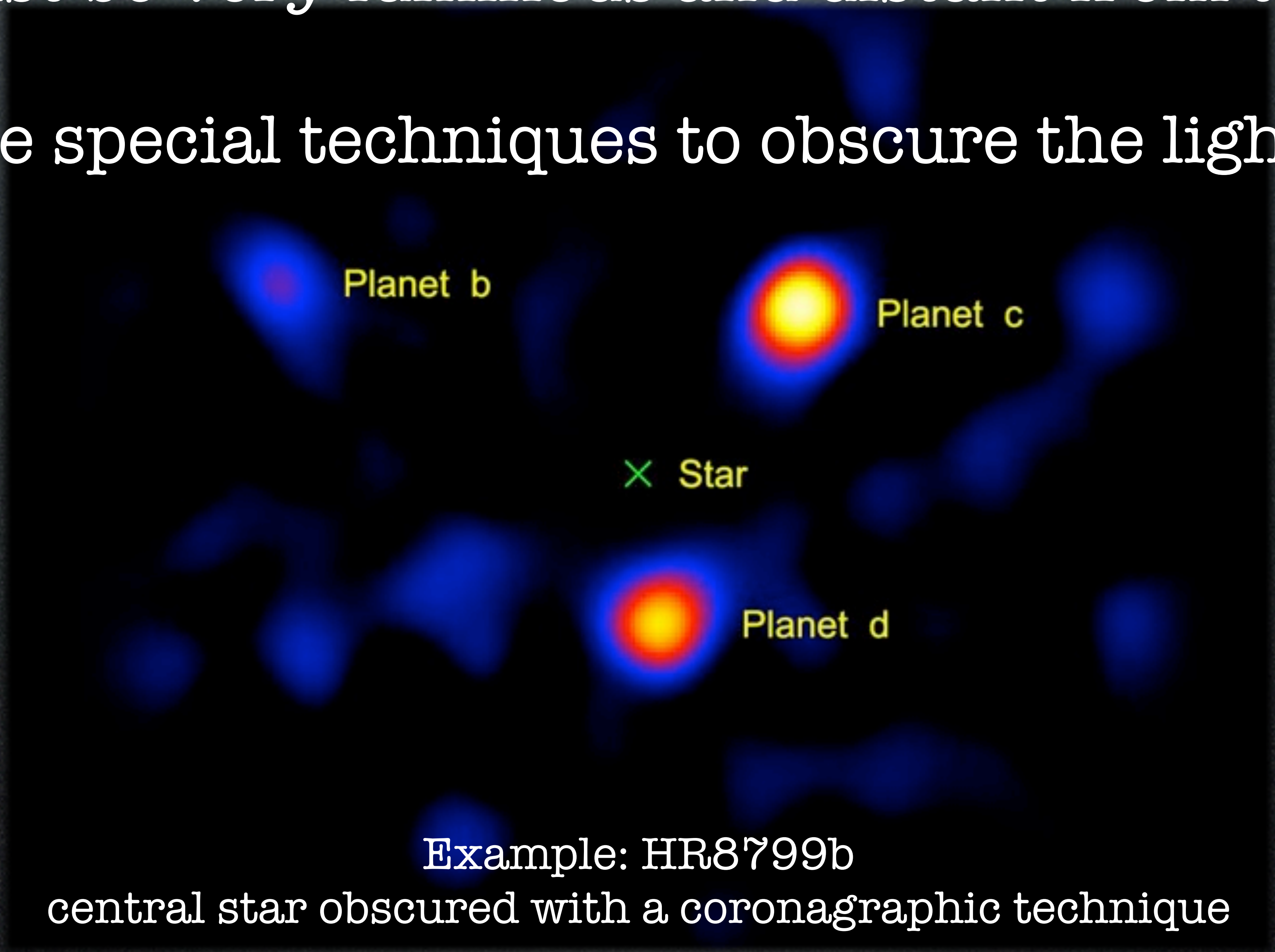
- hard to separate the planet from the star due to their extreme vicinity in the sky

Direct Imaging

In some cases it is possible to directly see the exoplanets

They must be very luminous and distant from their star

We must use special techniques to obscure the light of the star



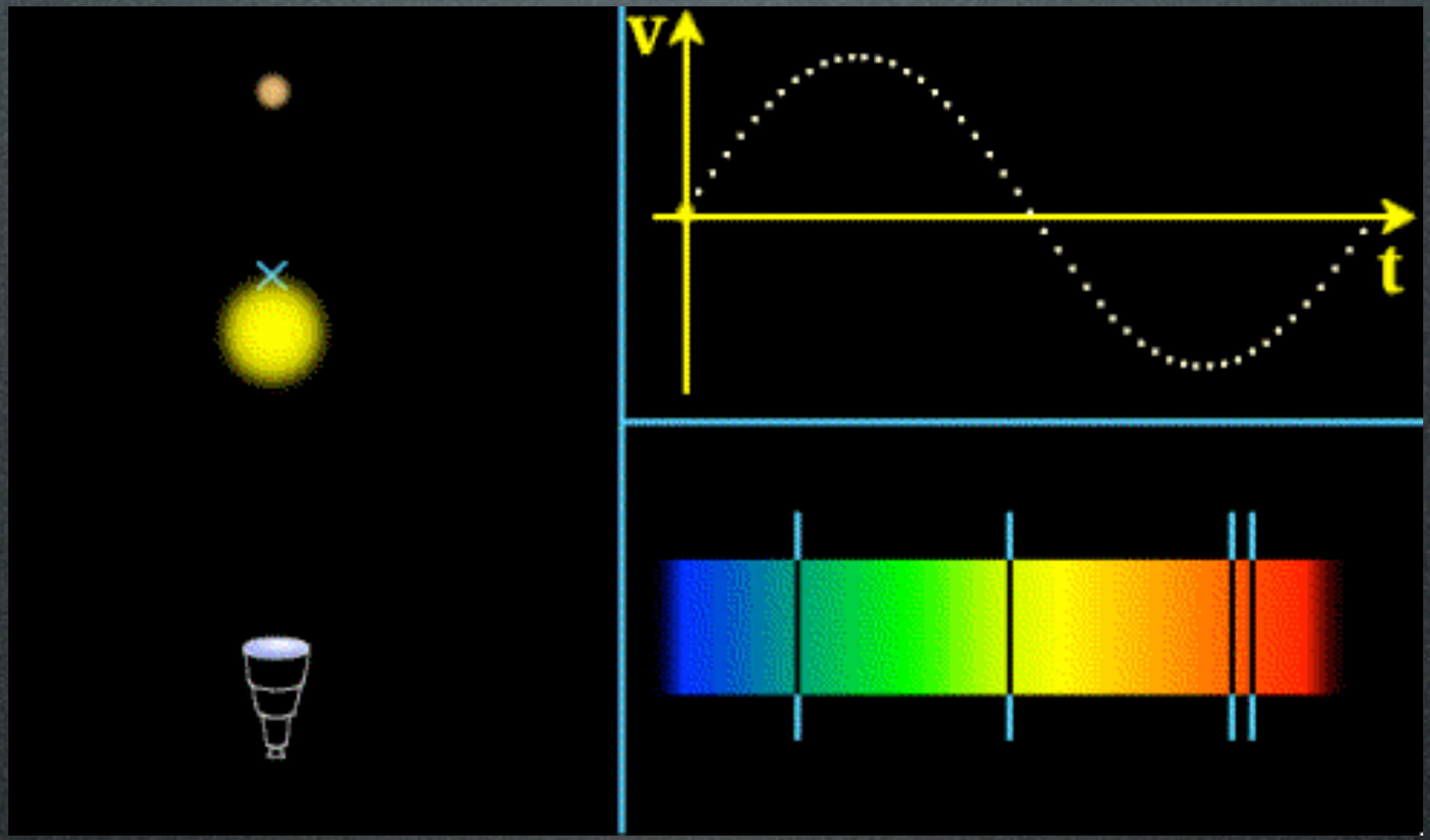
Example: HR8799b
central star obscured with a coronagraphic technique

Due to the difficulty of directly observing exoplanets

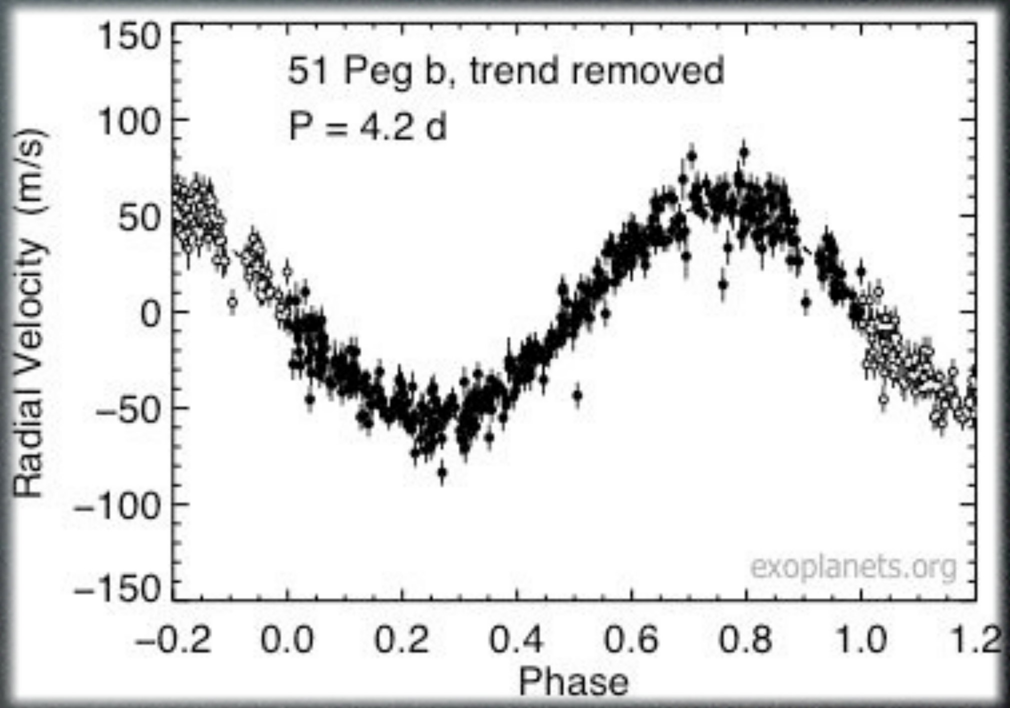
we use

indirect observational techniques

Doppler Method
(Radial Velocity Method)



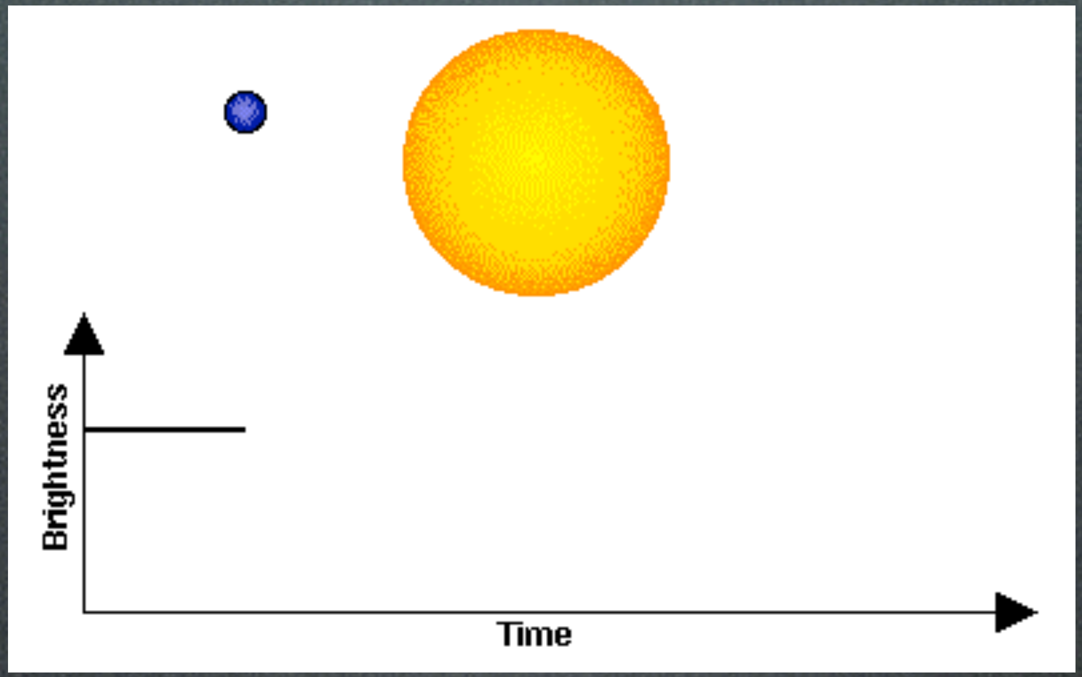
Doppler Method
(Radial Velocity Method)



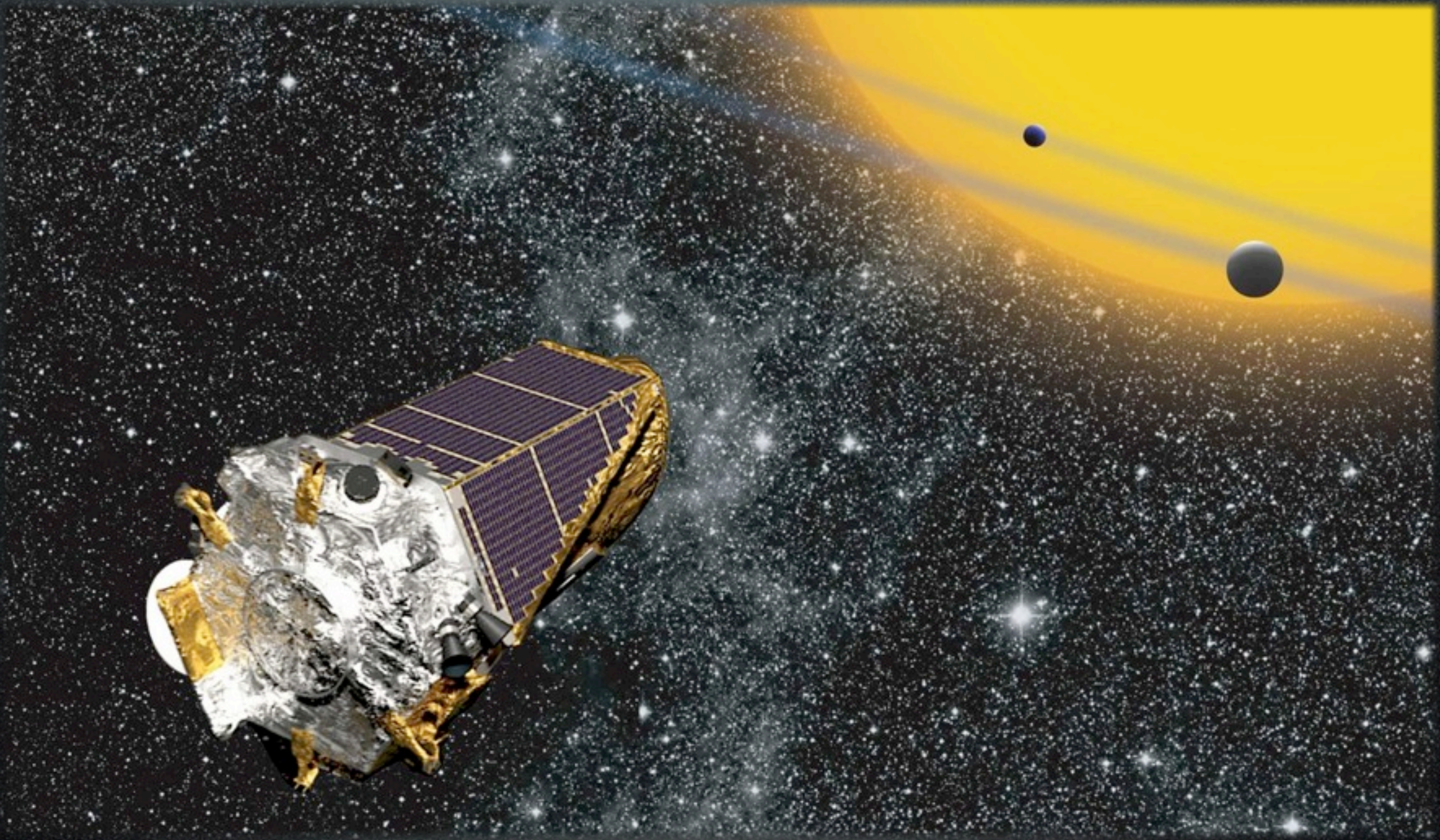
Doppler Method
(Radial Velocity Method)

With the Doppler method
we can measure the orbital period
and the mass of the planet

Transit Method



Transit Method

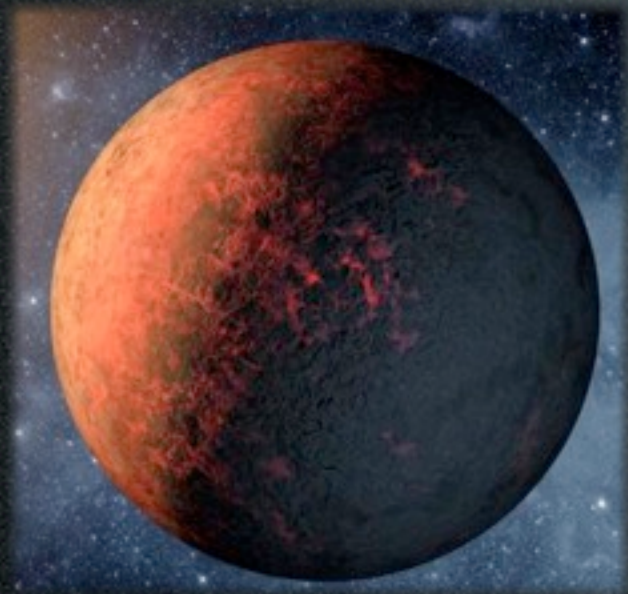


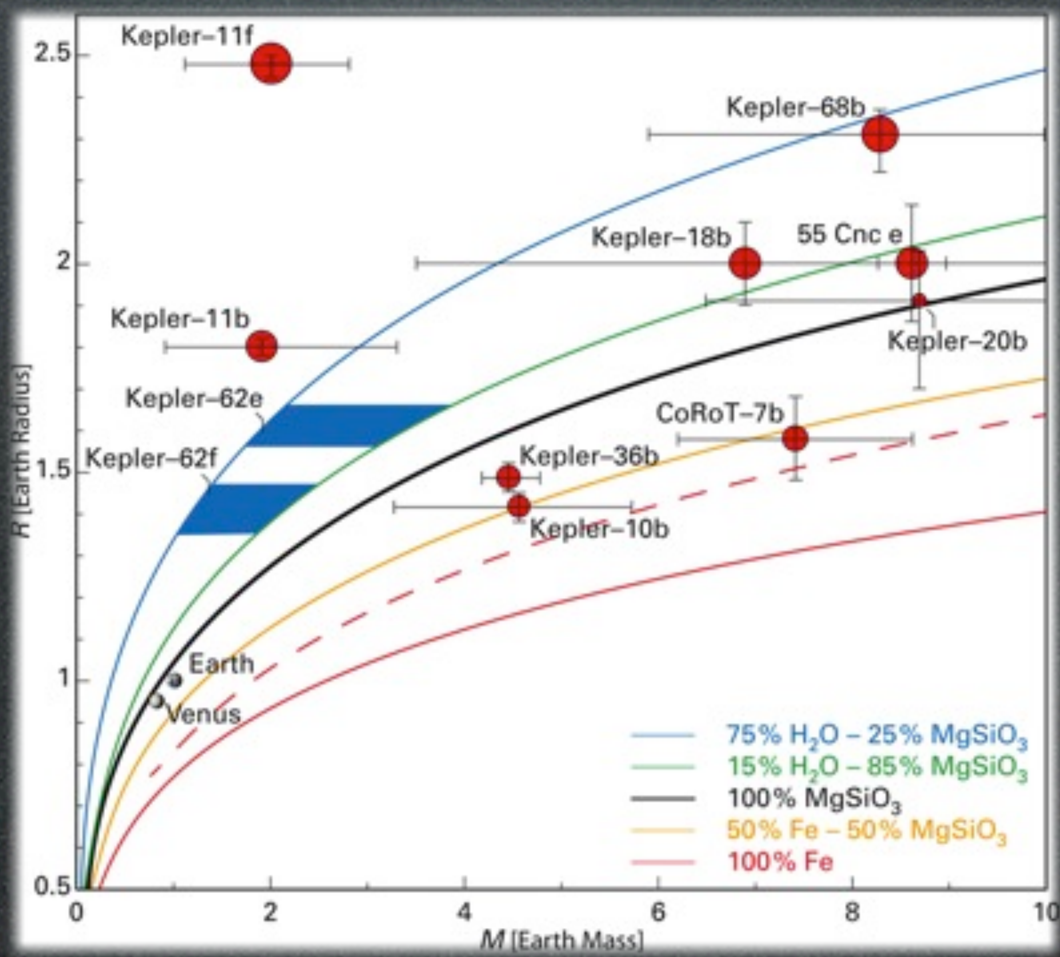
Transit Method

With the transit method
we can measure the orbital period
and the radius of the planet

From the mass (Doppler Method)
and the radius (Transit Method)
we compute the density

We can distinguish rocky planets
from gaseous planets





A few thousands of exoplanets have been discovered so far, mostly with the indirect methods of detection

Main results

New classes of planets have been discovered

Great diversity of planetary systems

Unexpected discoveries

“Hot Jupiters”

gaseous giants very close to their star

They do not exist in the Solar System
Not suitable for hosting life

Unexpected discoveries

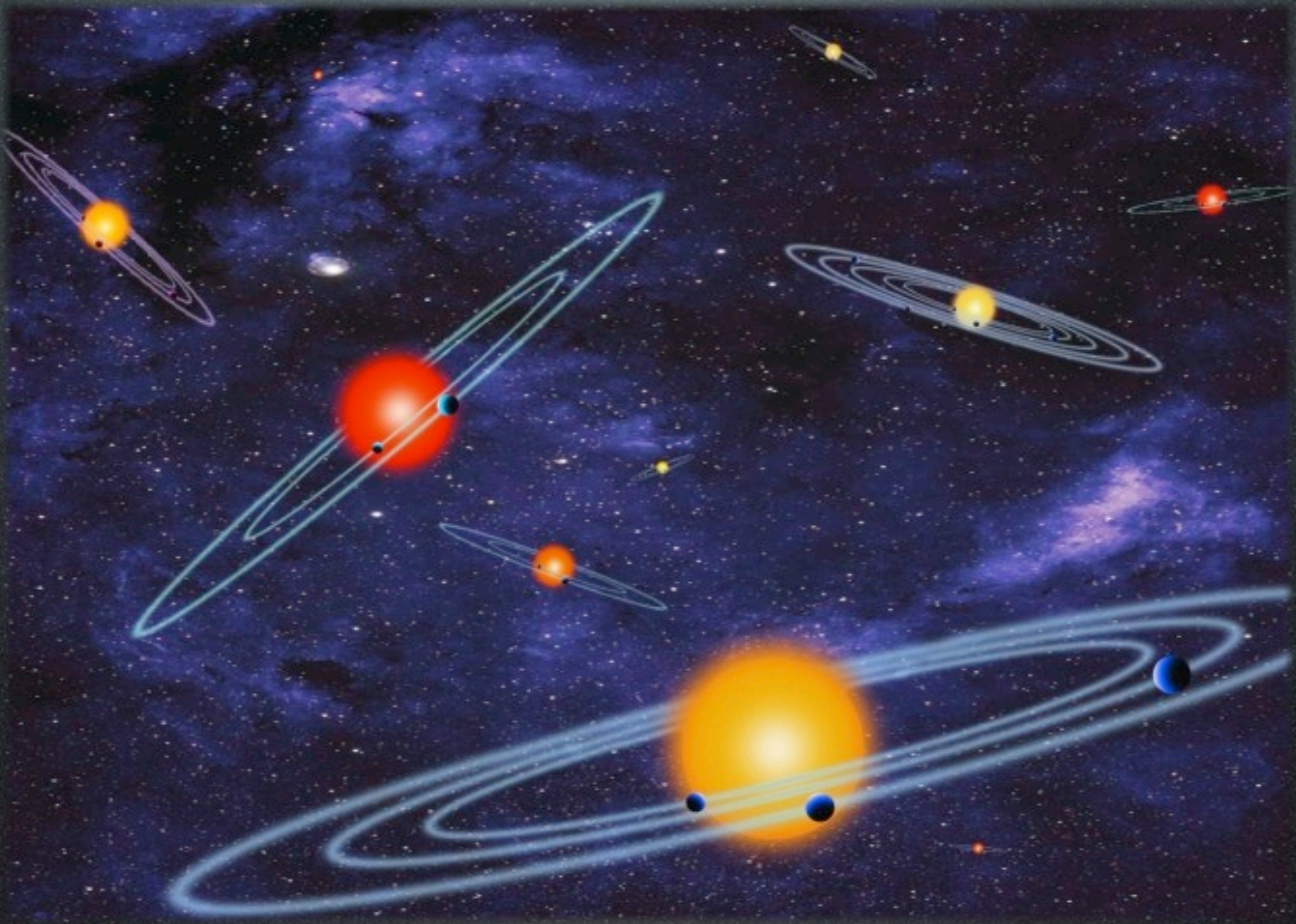
“Super-Earths”

mass intermediate between Earth and Neptun

They do not exist in the Solar System

Might be suitable for hosting life

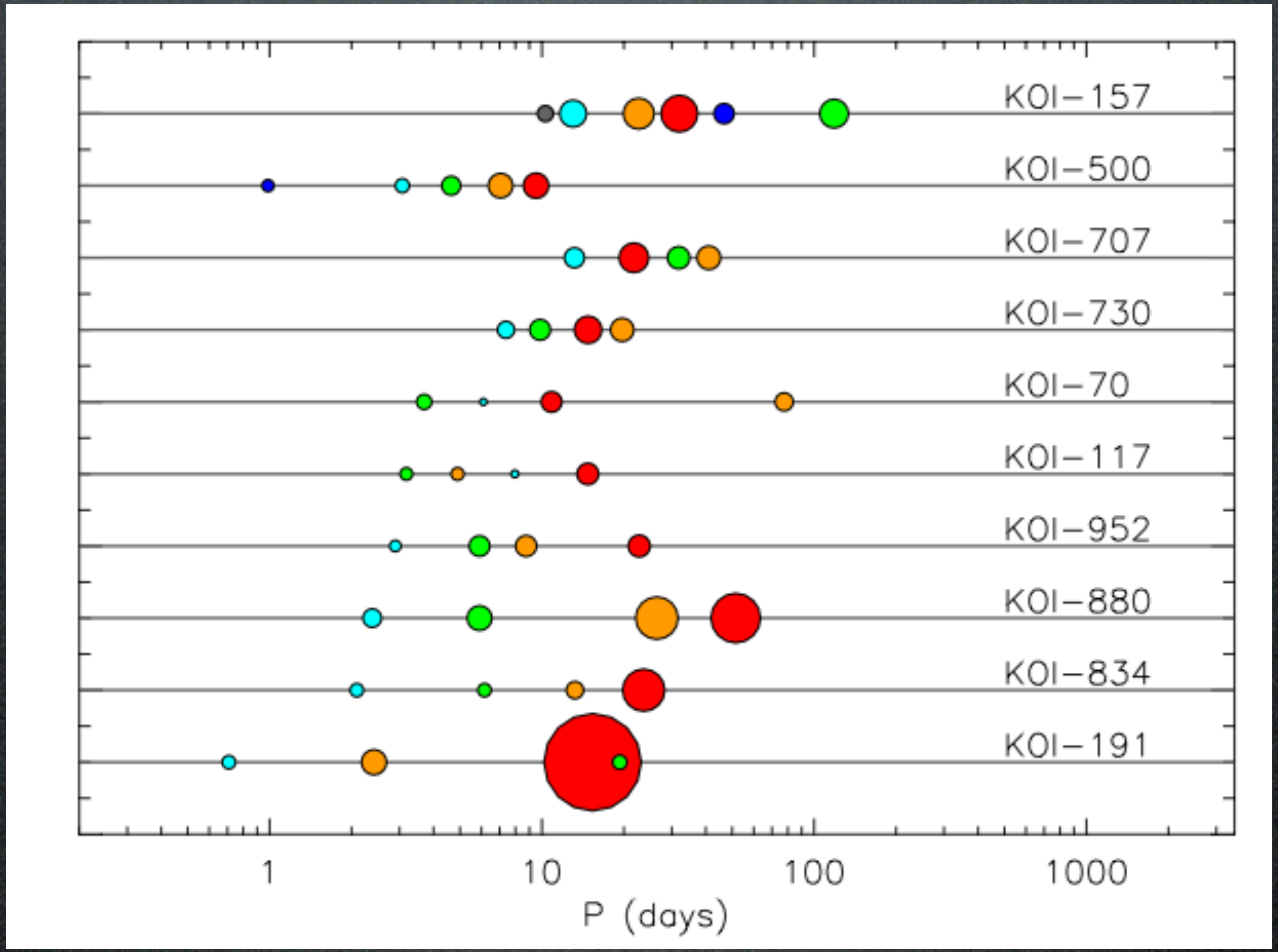
Extrasolar planetary systems

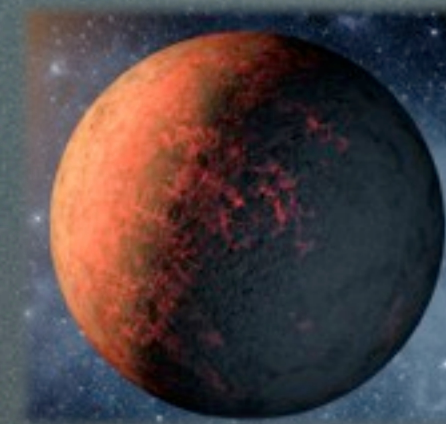


Diversity of extrasolar planetary systems

Different architectures

The Solar System is not a typical case





Based on the example of the Earth,
the only planet that is known to host life,
the quest for inhabited worlds
is mostly focused on

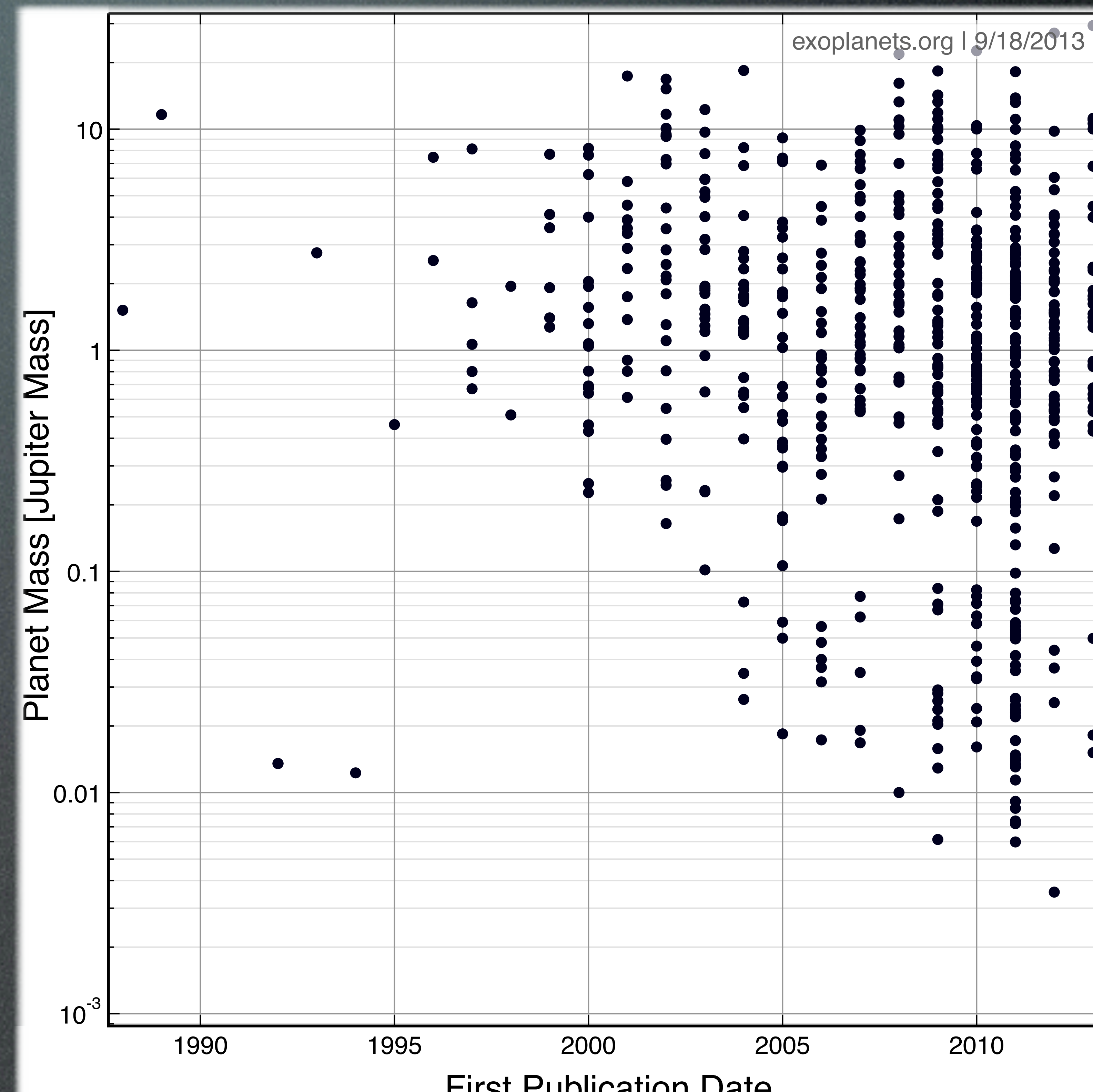
rocky planets of terrestrial type

Progress in the search for terrestrial planets

Massive exoplanets are easier to detect than terrestrial ones

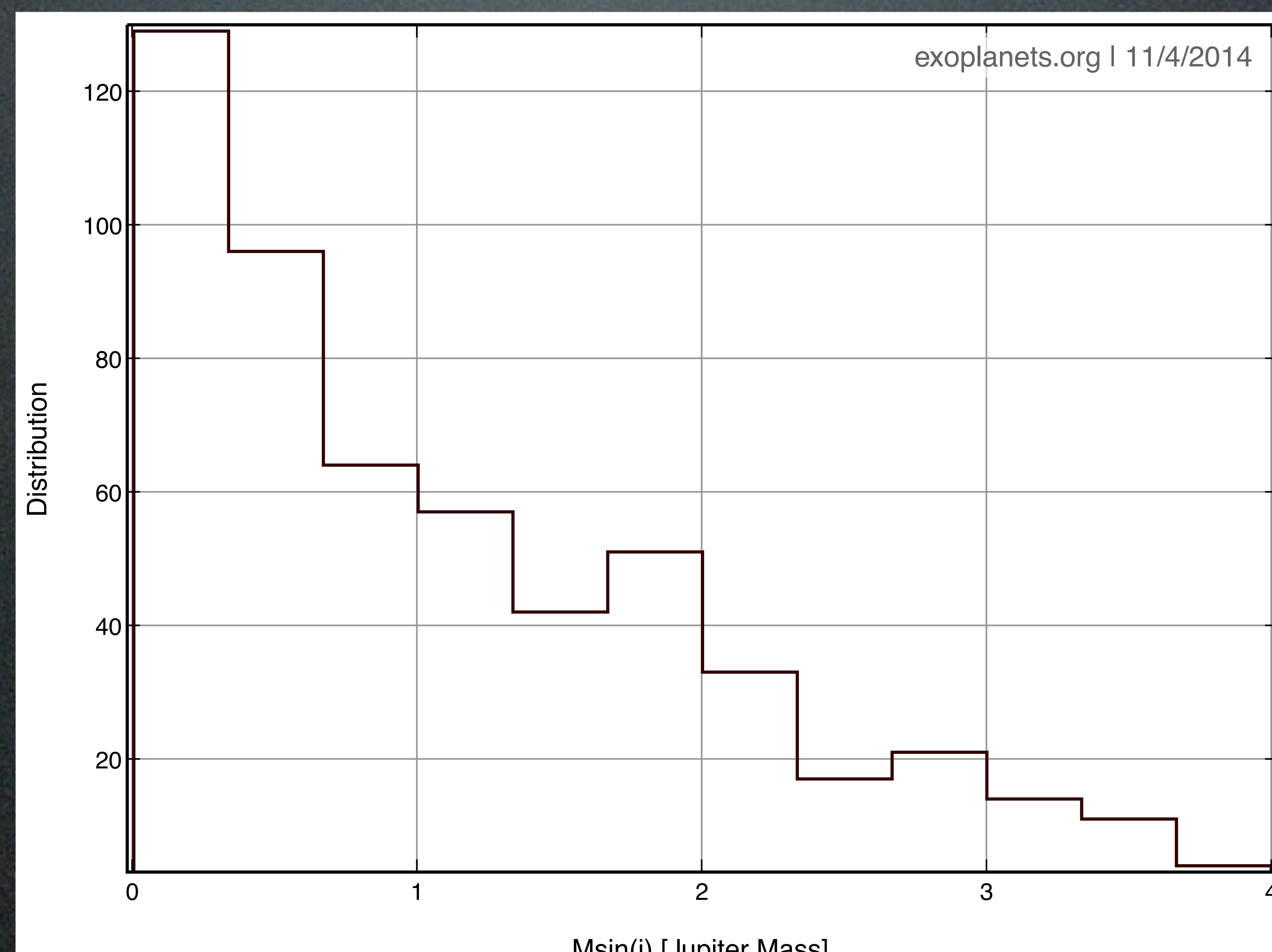
The first exoplanets, discovered in the mid of the 90's, were quite massive, more massive than Jupiter

As the observational techniques become more efficient we are starting to detect exoplanets with masses as small as that of the Earth



How numerous are terrestrial-type planets?

In spite of the fact that they are difficult to detect,
the evidence is growing that they are very numerous

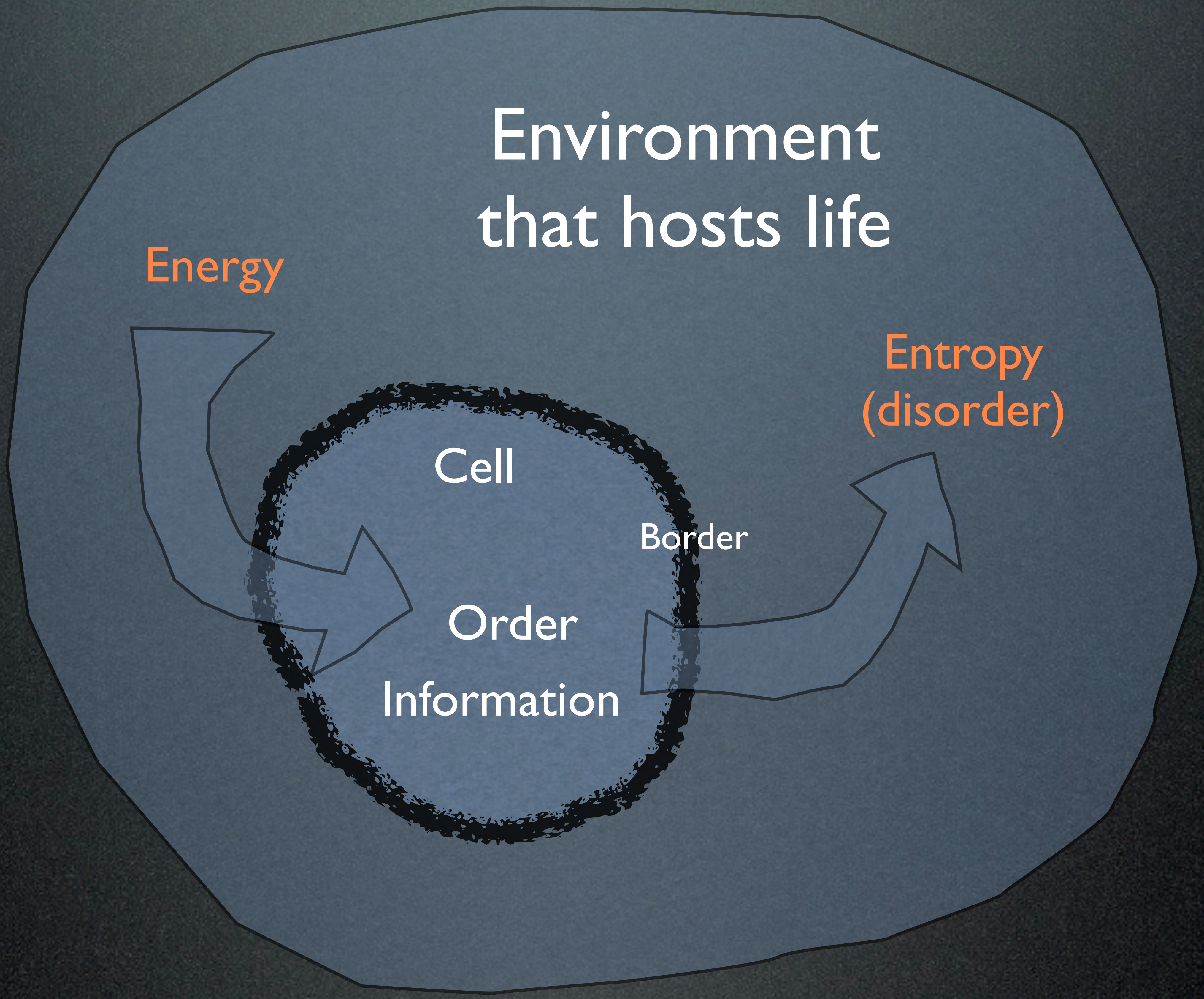


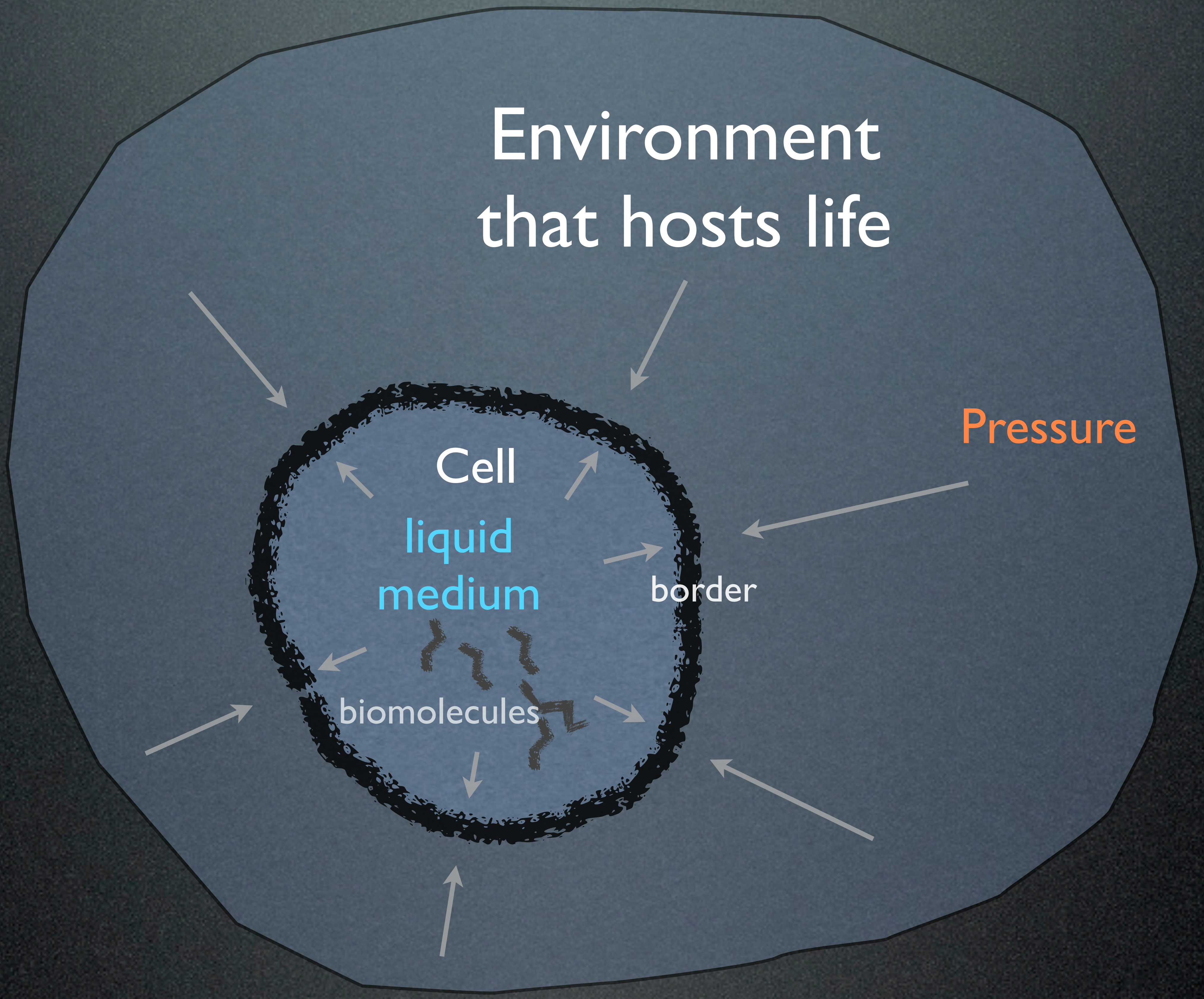
Terrestrial-type planets are likely to be very numerous in the Galaxy

Can they host life ?

Are they inhabited ?


Life
Habitability


Environment
that hosts life
Energy
Entropy
(disorder)
Cell
Border
Order
Information


Environment
that hosts life
Pressure
Cell
liquid
medium
border
biomolecules

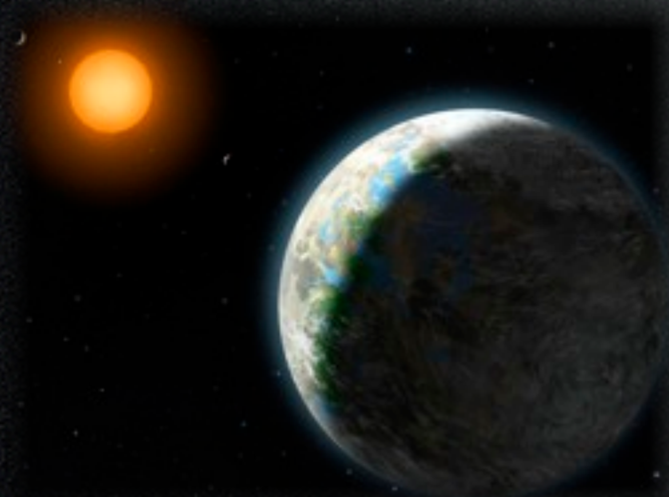
Requirements of planetary habitability

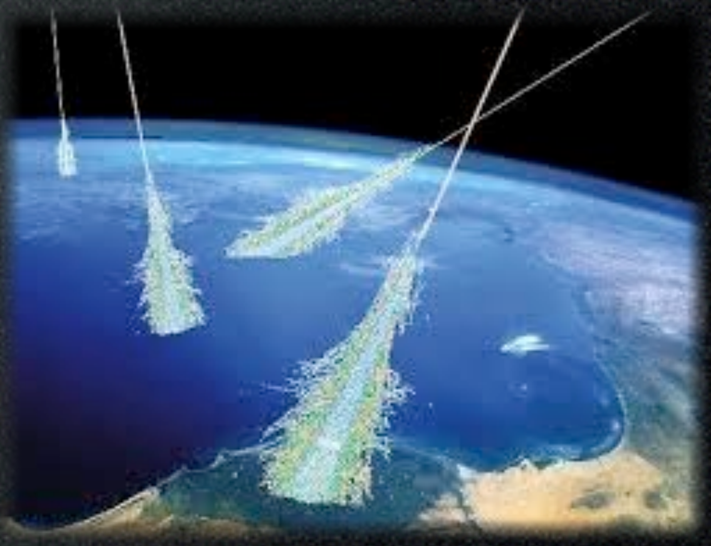
Examples:

Energy sources

Planetary atmosphere

(external pressure and protection from ionizing radiation)





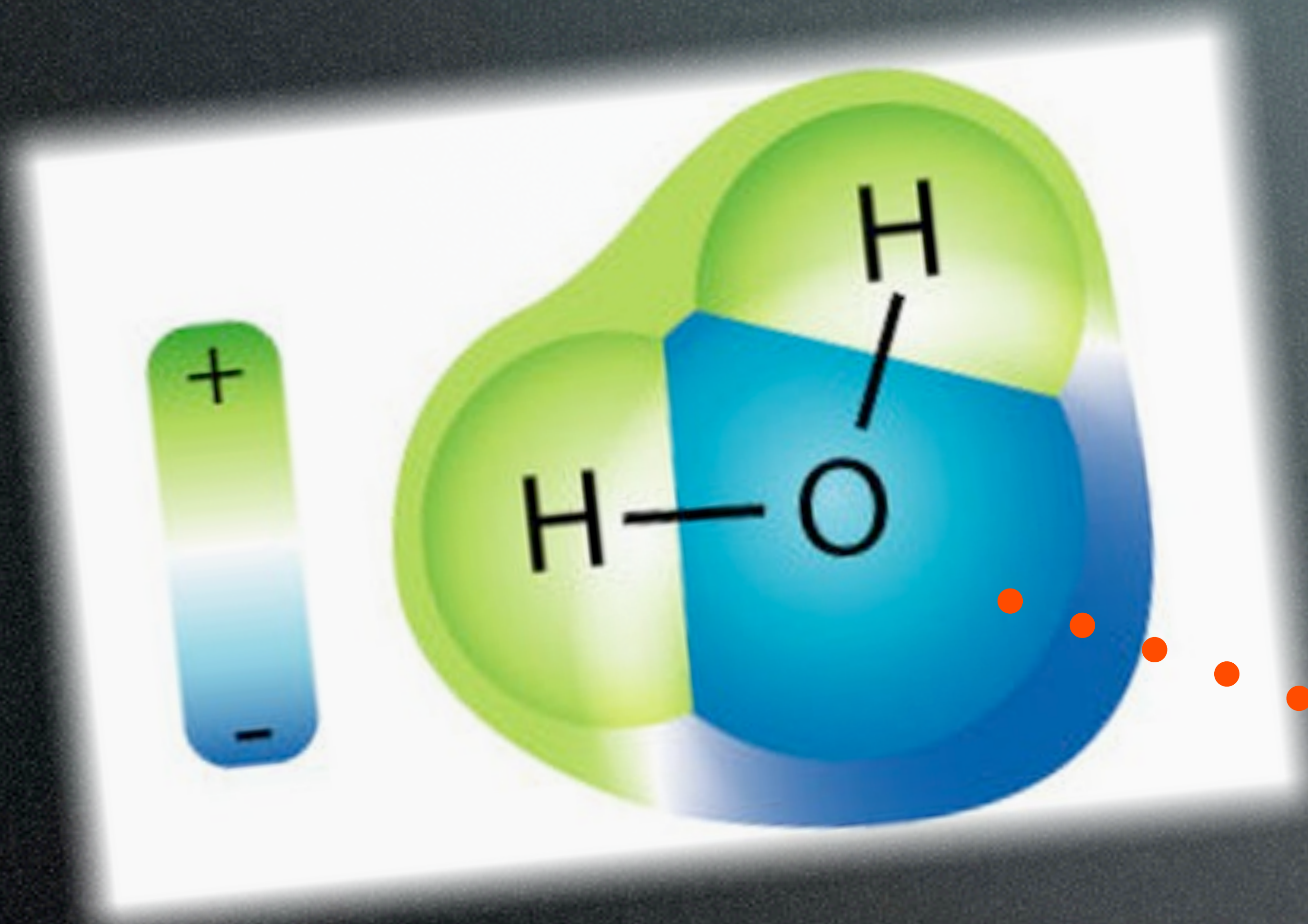
The liquid water criterion

A commonly adopted requirement of planetary habitability

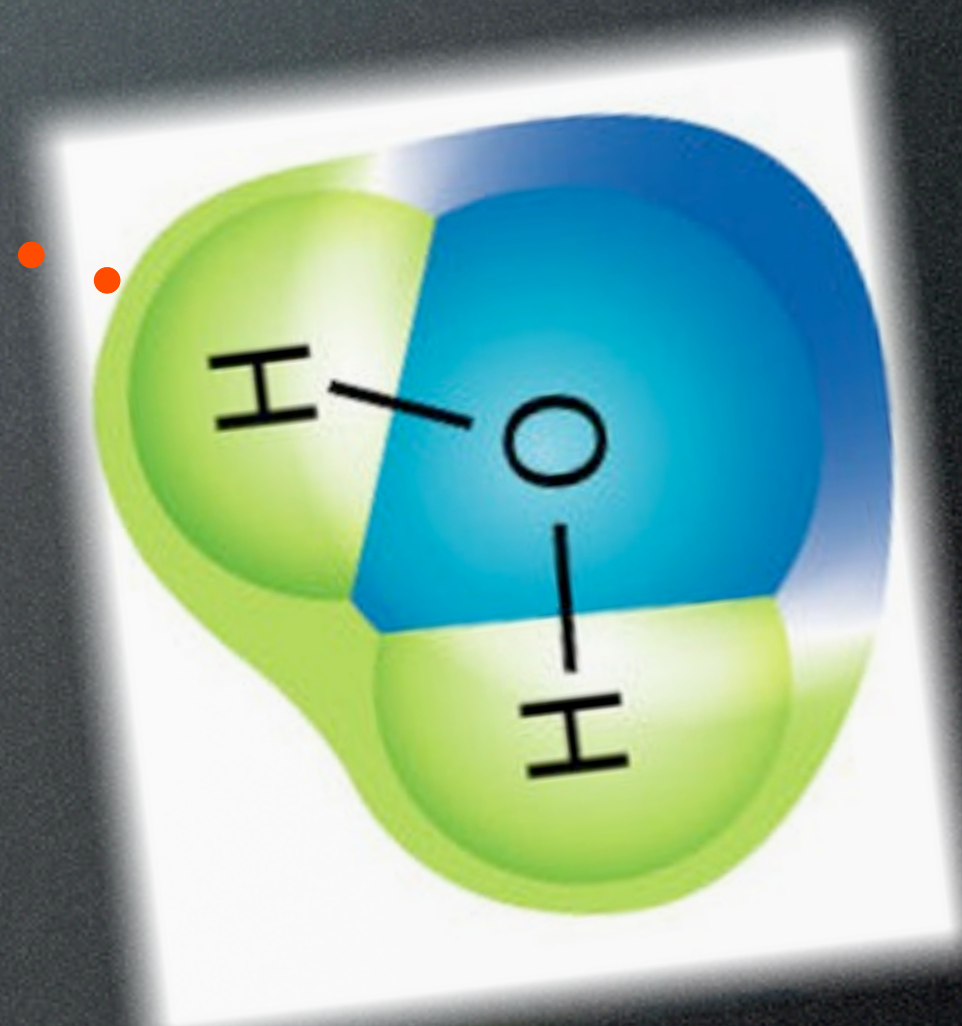
The planet should be able have liquid water on its surface

Why is water so important ?

Water and Life

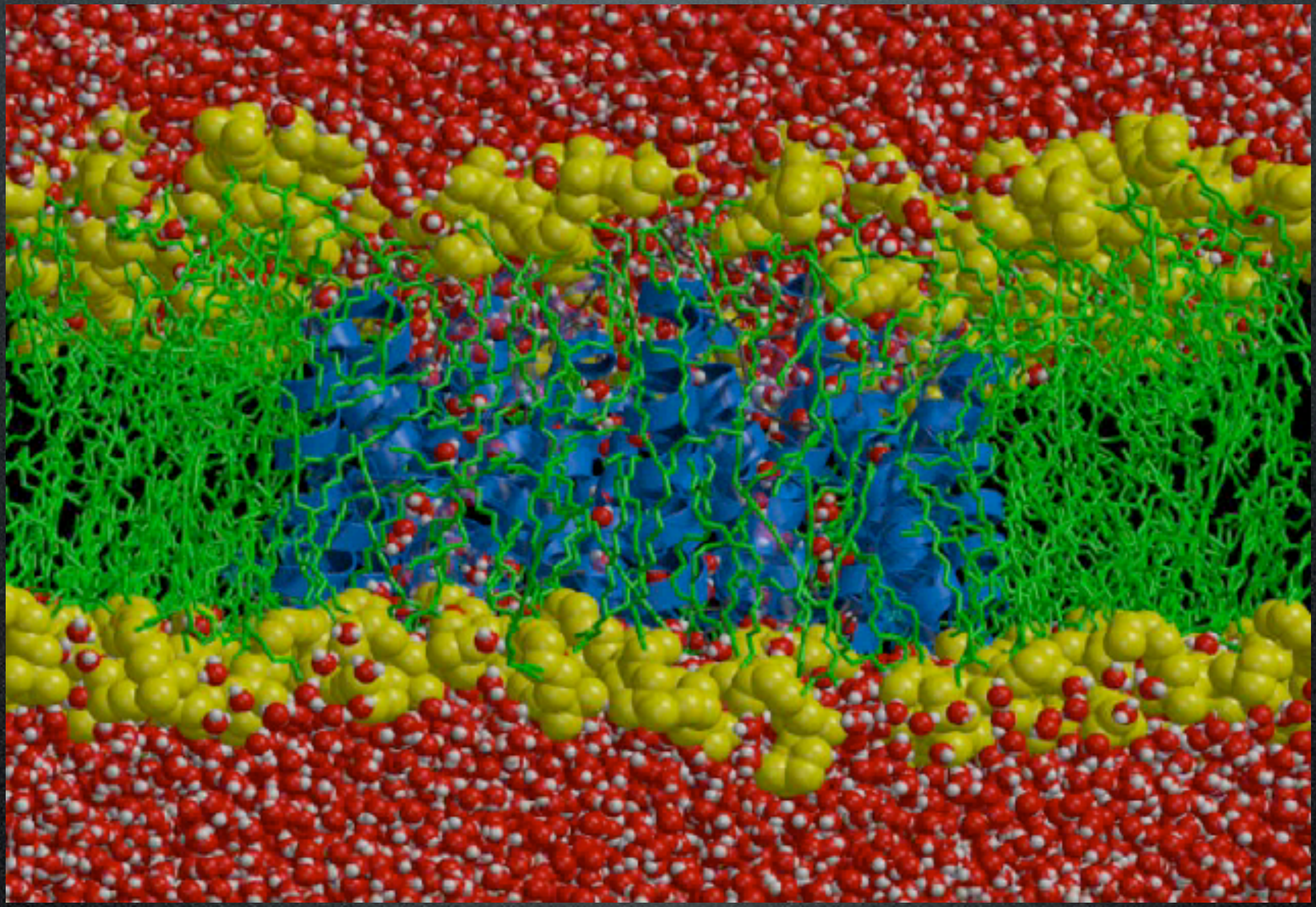


Water has many special properties



Many properties of water are due to the polarity of the water molecule

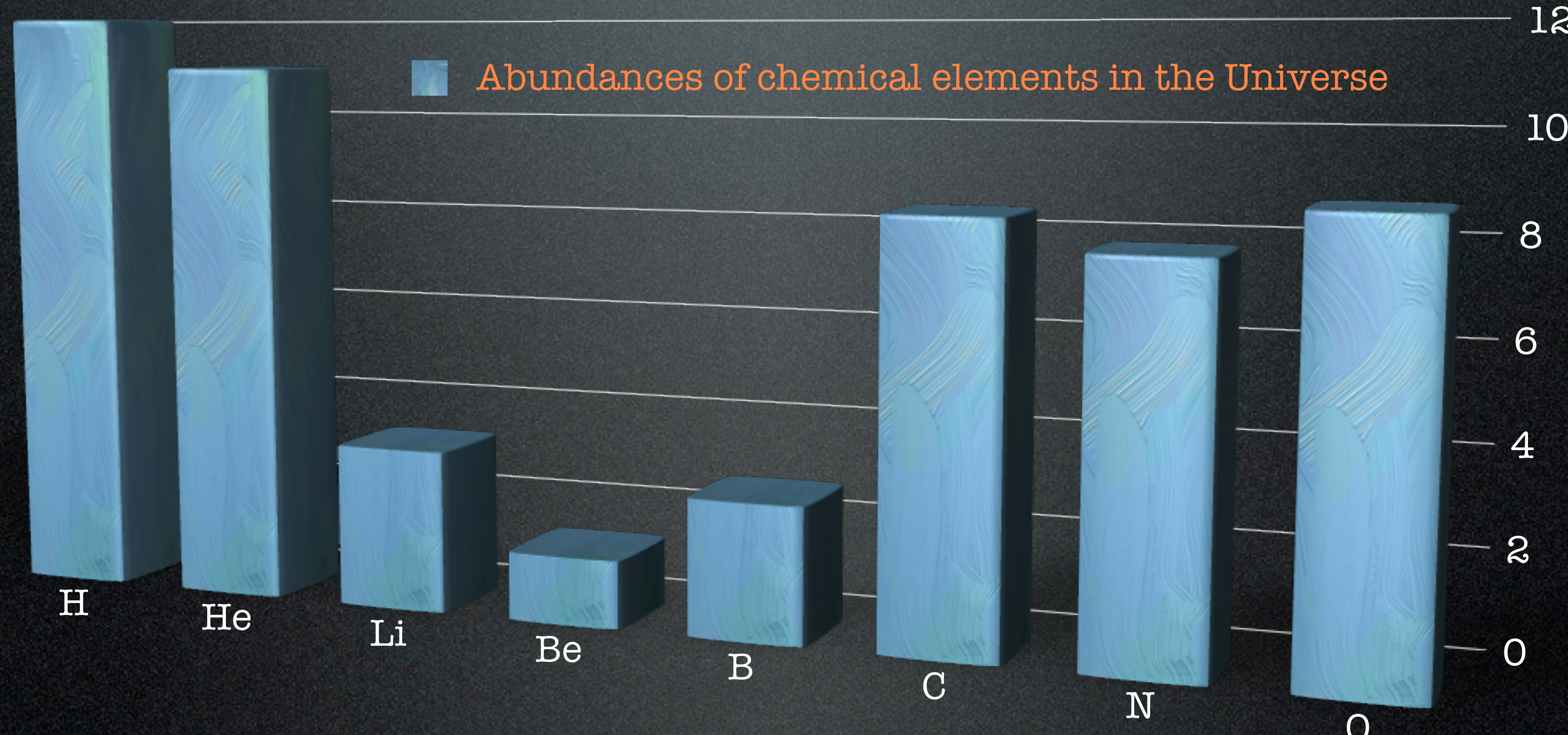
Water and Life



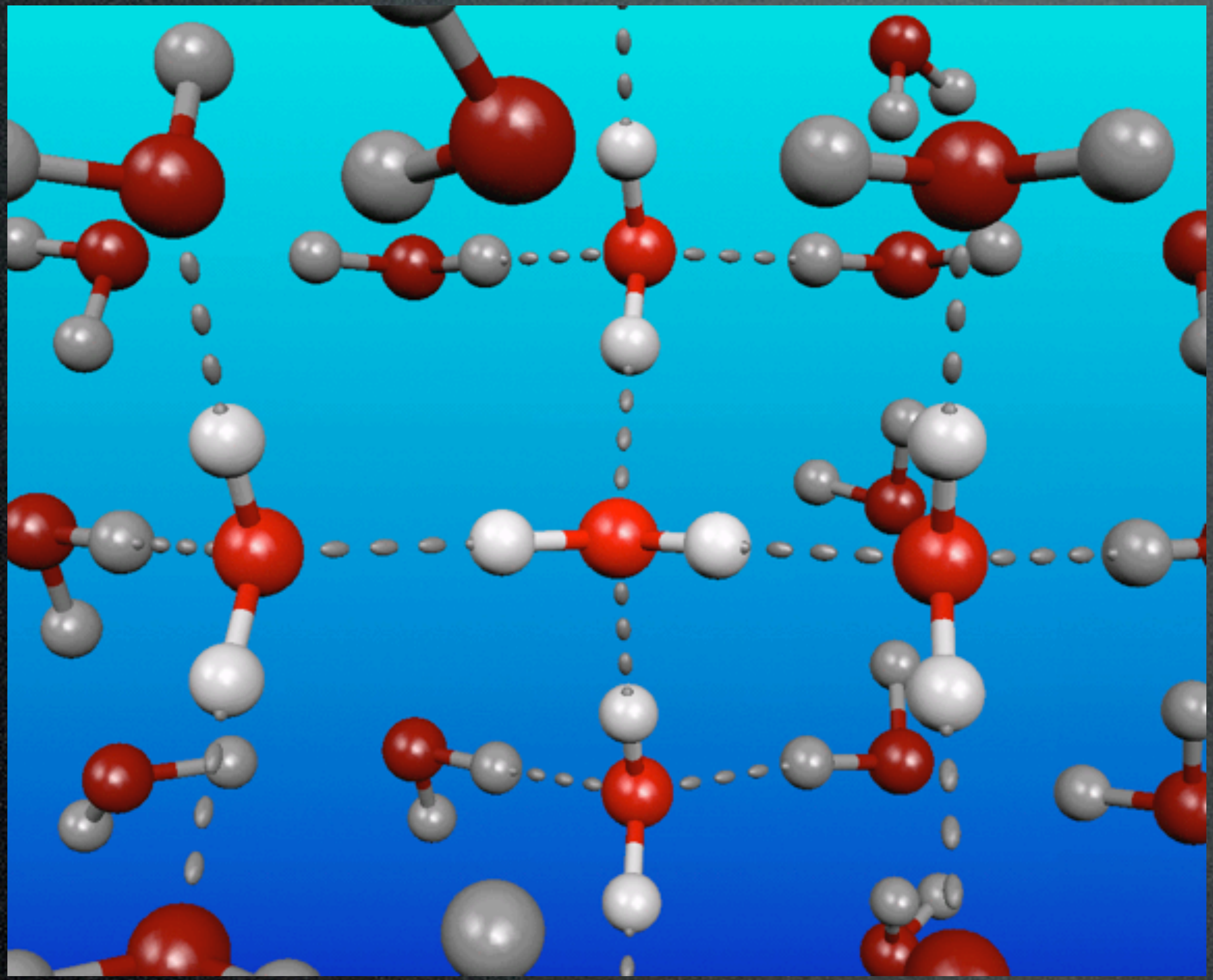
How common is the water in the Universe?

Water is formed by hydrogen and oxygen,
which are abundant elements in the Universe

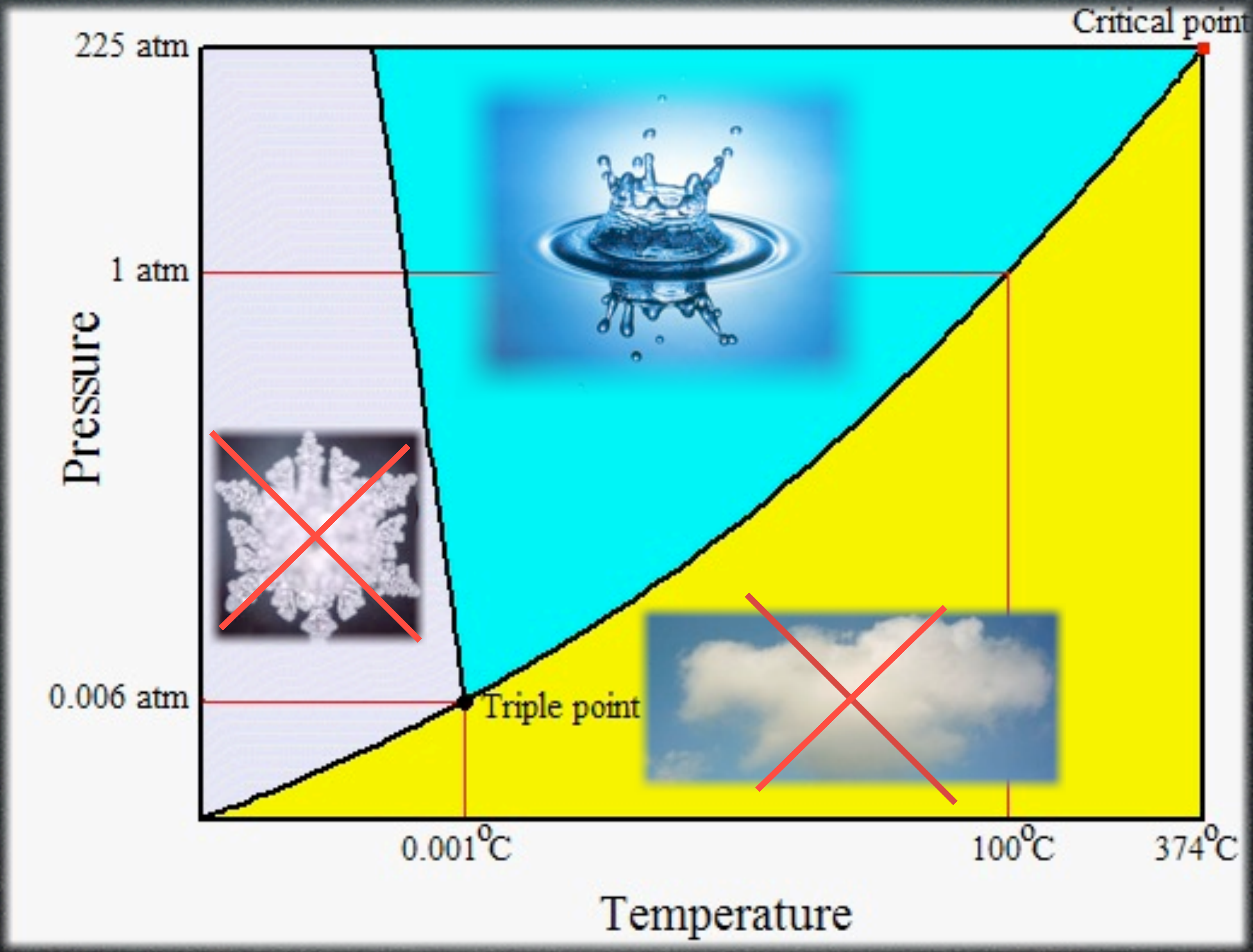
With suitable conditions,
water could be abundant in other planets



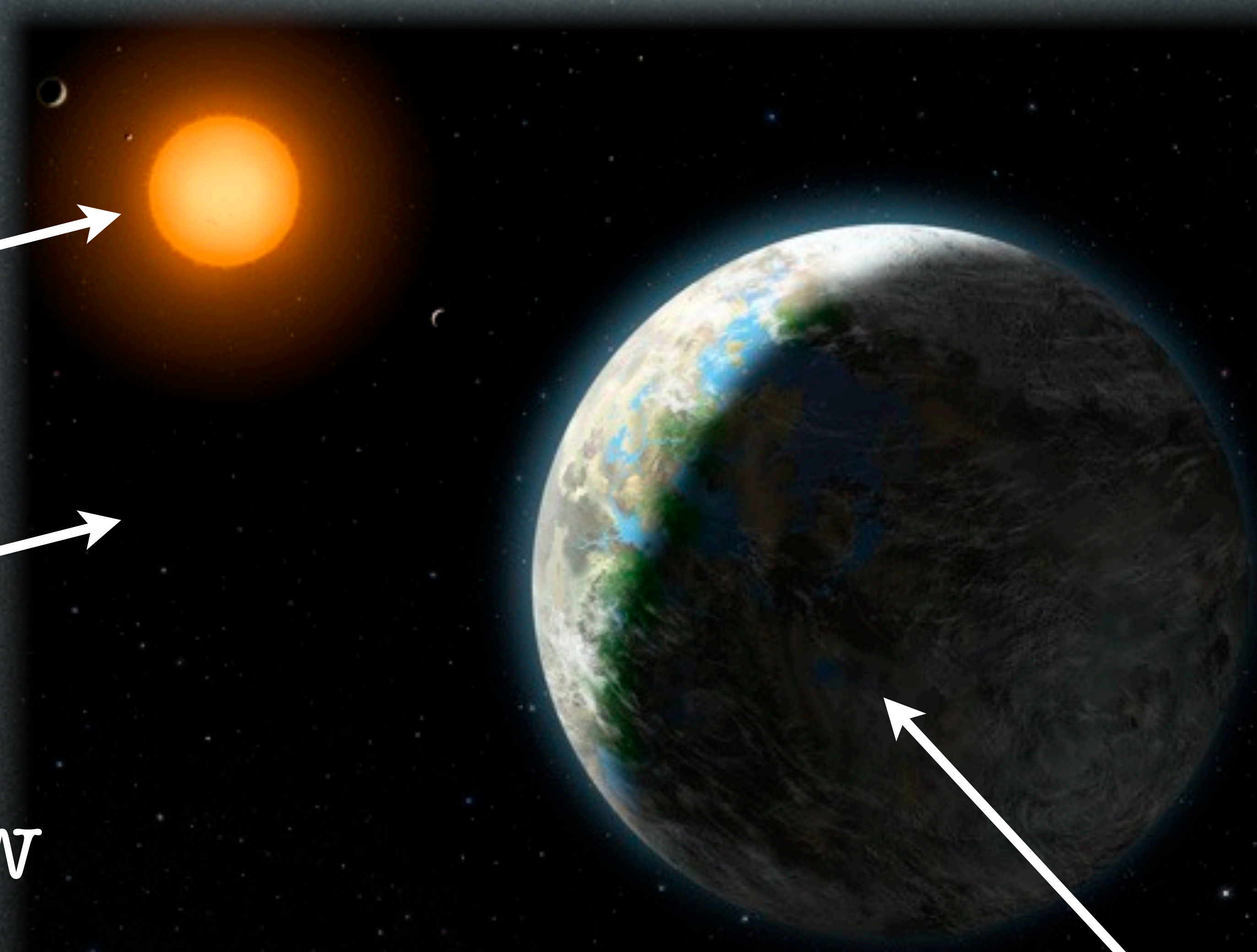
Water in biological processes must be in liquid phase rather than in ice or vapor form



For water to be in liquid phase the temperature and pressure must lie in well defined intervals



In the Universe only planets (or satellites) can have temperature and pressure suitable for liquid water



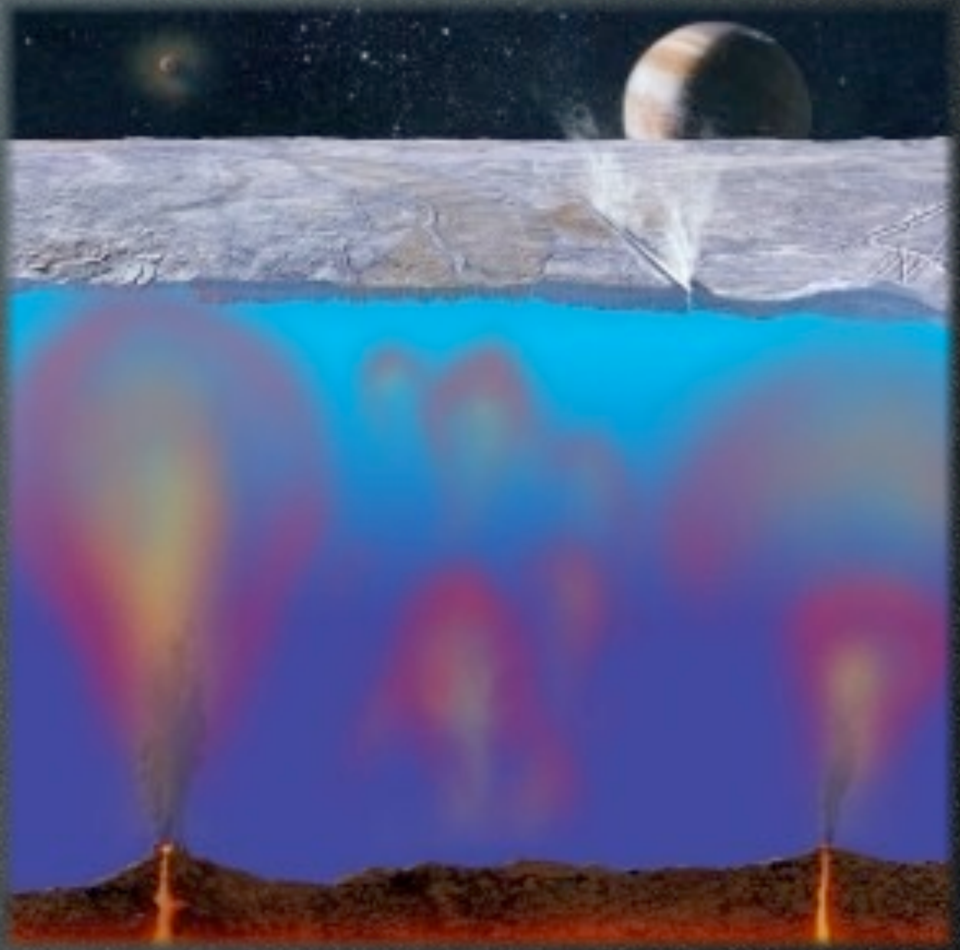
Stars are too hot

The pressure of the interstellar medium is too low

Planets (or satellites) can have suitable conditions if they lie at a proper distance from the star

Liquid water could be present
below the surface of the planet (or satellite)

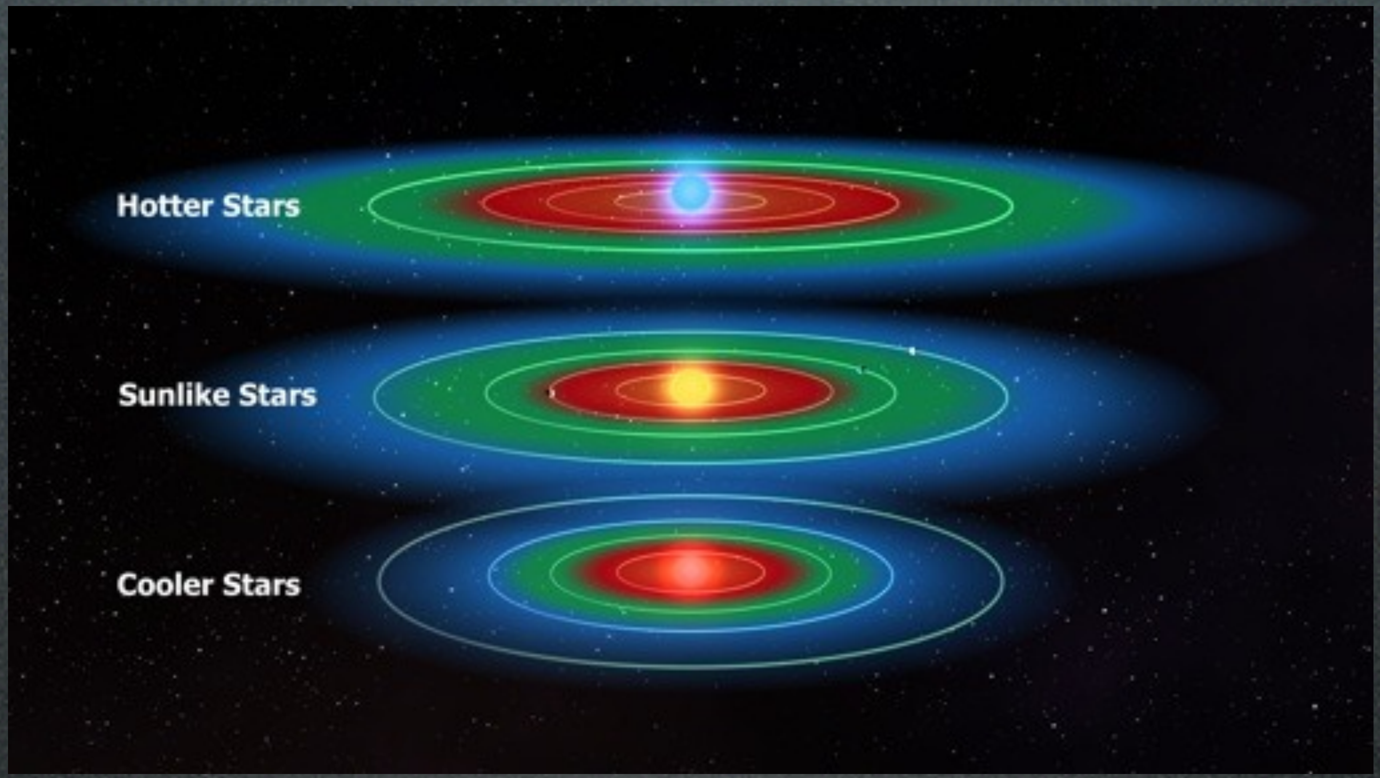
Example:
Water oceans are present
below the surface of Europa
(one of Jupiter's satellites)



In exoplanets we are mostly interested
in the presence of water on the <u>planet surface</u>

Circumstellar habitable zone

defined according to the habitability of the planet surface

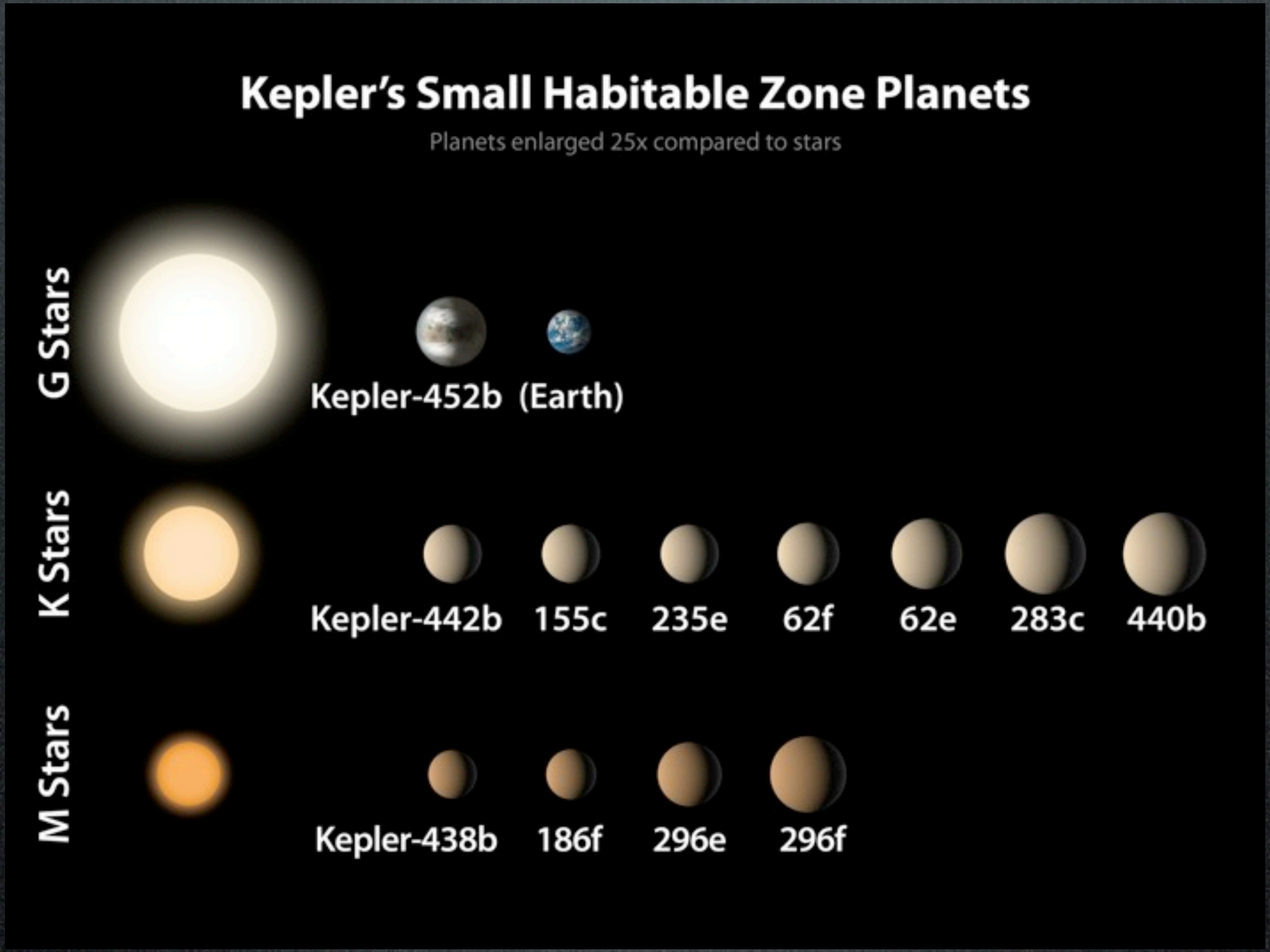


The location of the habitable zone depends on the level of insolation and other planetary properties, mostly the greenhouse effect

The Earth is inside the habitable zone of the Solar System

Venus and Mars are slightly outside
The other planets are distant from the habitable zone

Most detected exoplanets are too close to the central star, but we are starting to find exoplanets in the habitable zone



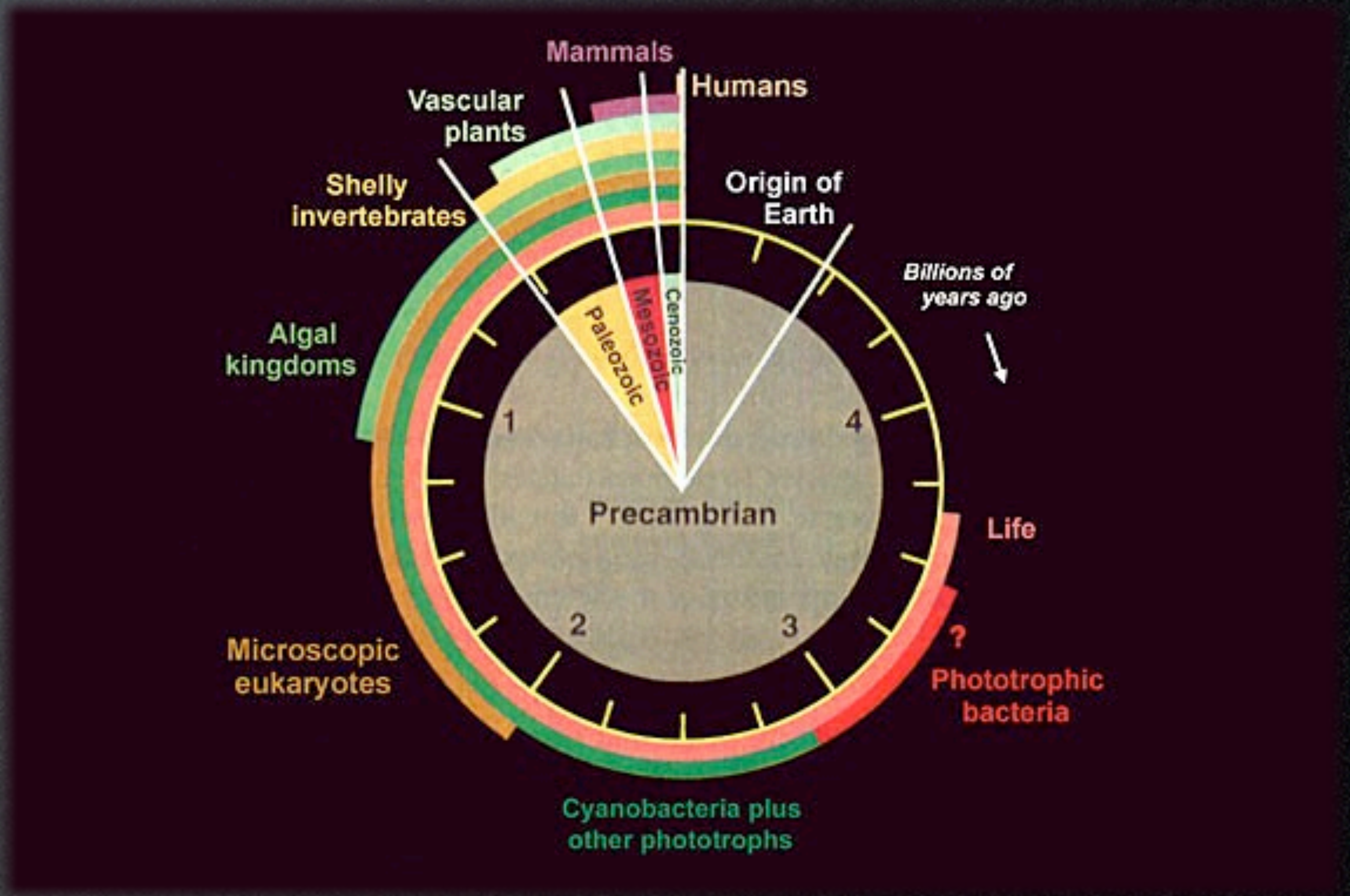
Habitable planets around hot stars

Distant from the star

More difficult to detect with indirect methods

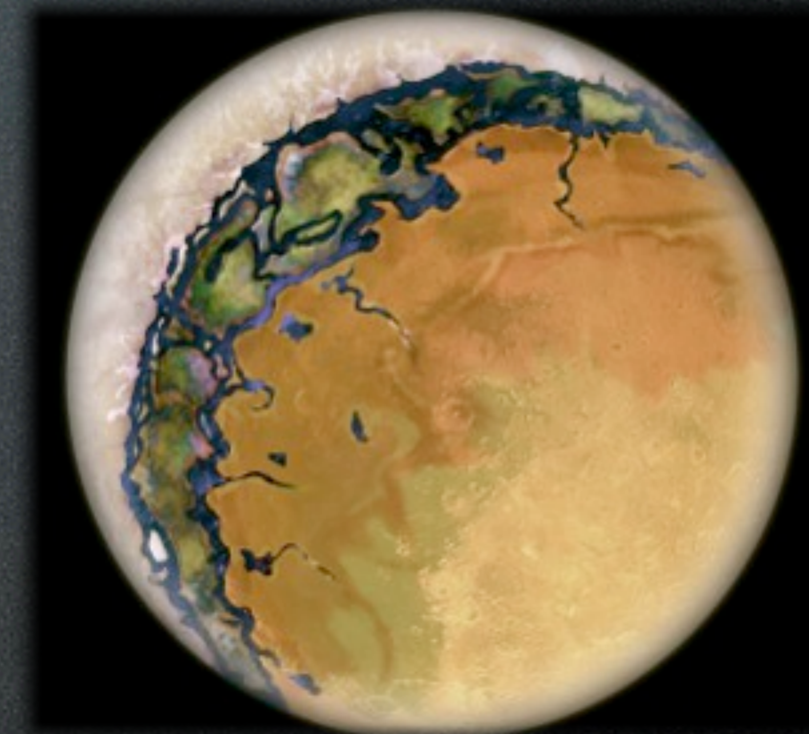
Hot stars have short life times compared to the time scales of life evolution

Planets around hot stars are not suitable to host life forms as evolved as ours



Habitable planets around cool stars

Easier to detect with indirect methods because the habitable zone lies close to the central star



The vicinity of the habitable zone poses several challenges:

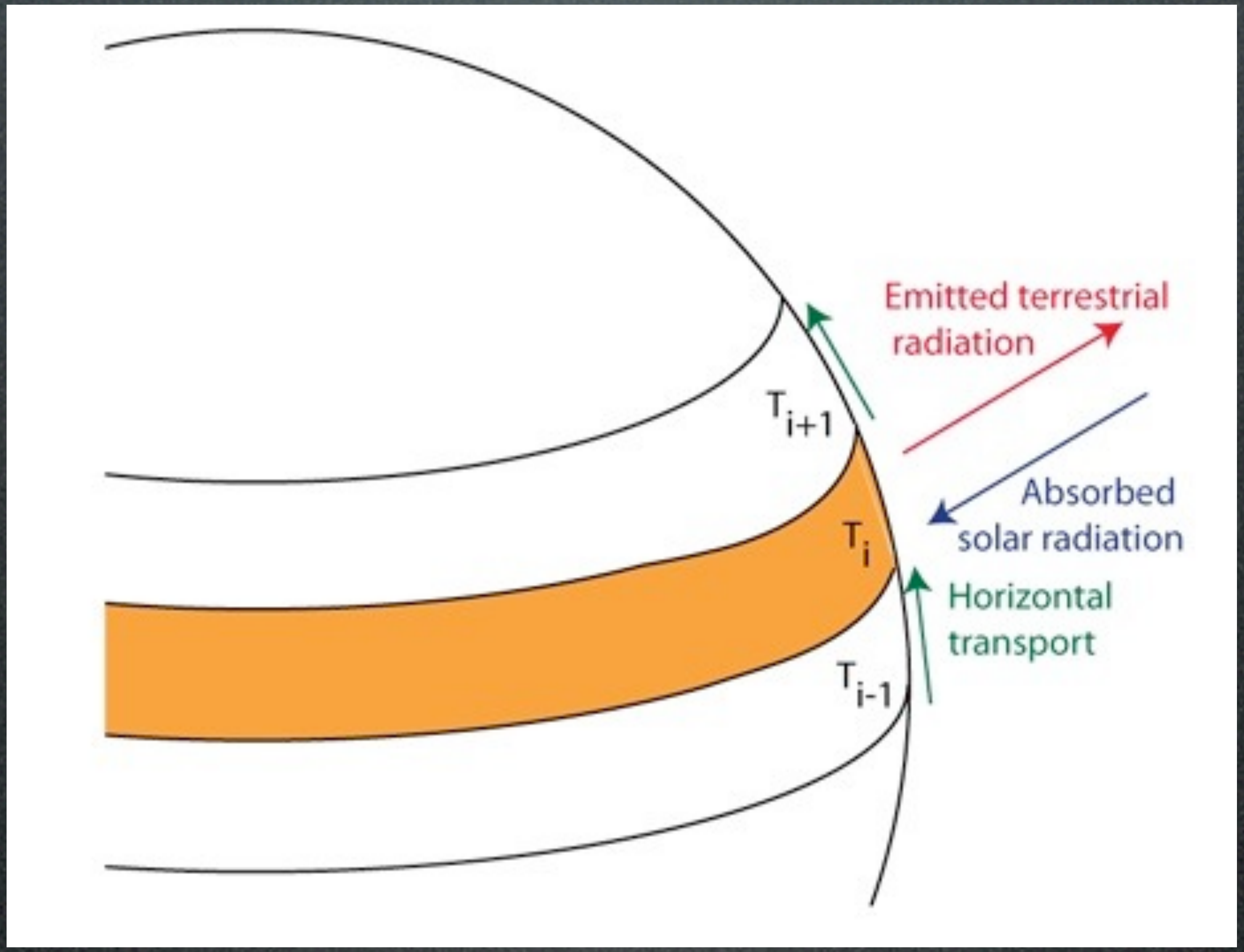
1) stellar eruptions

2) tidal locking -> “Eyeball planets”

3) dry planets (?)

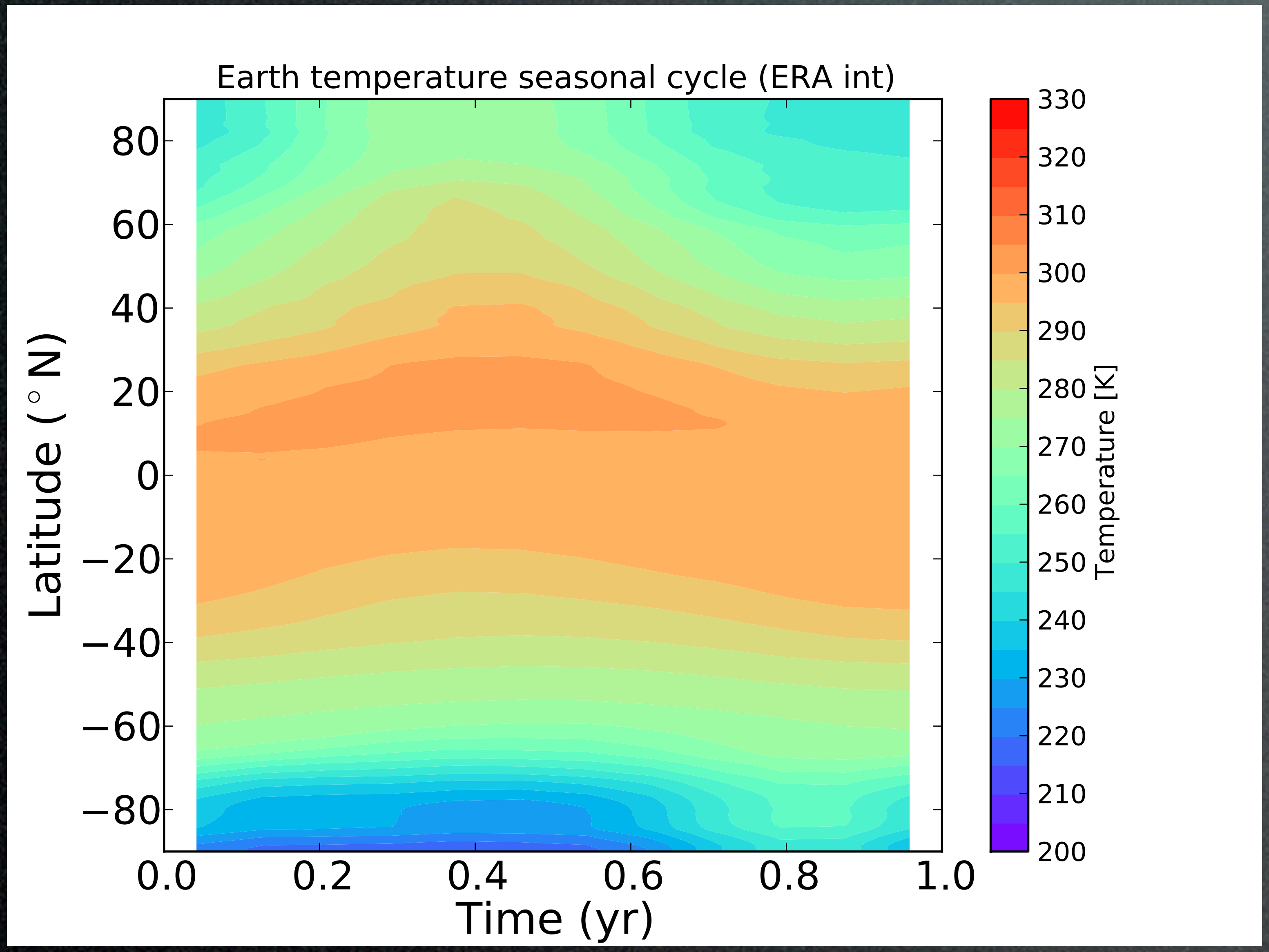
To assess the habitability via the liquid water criterion we need to know the surface temperature

We use climate models to estimate the surface temperature

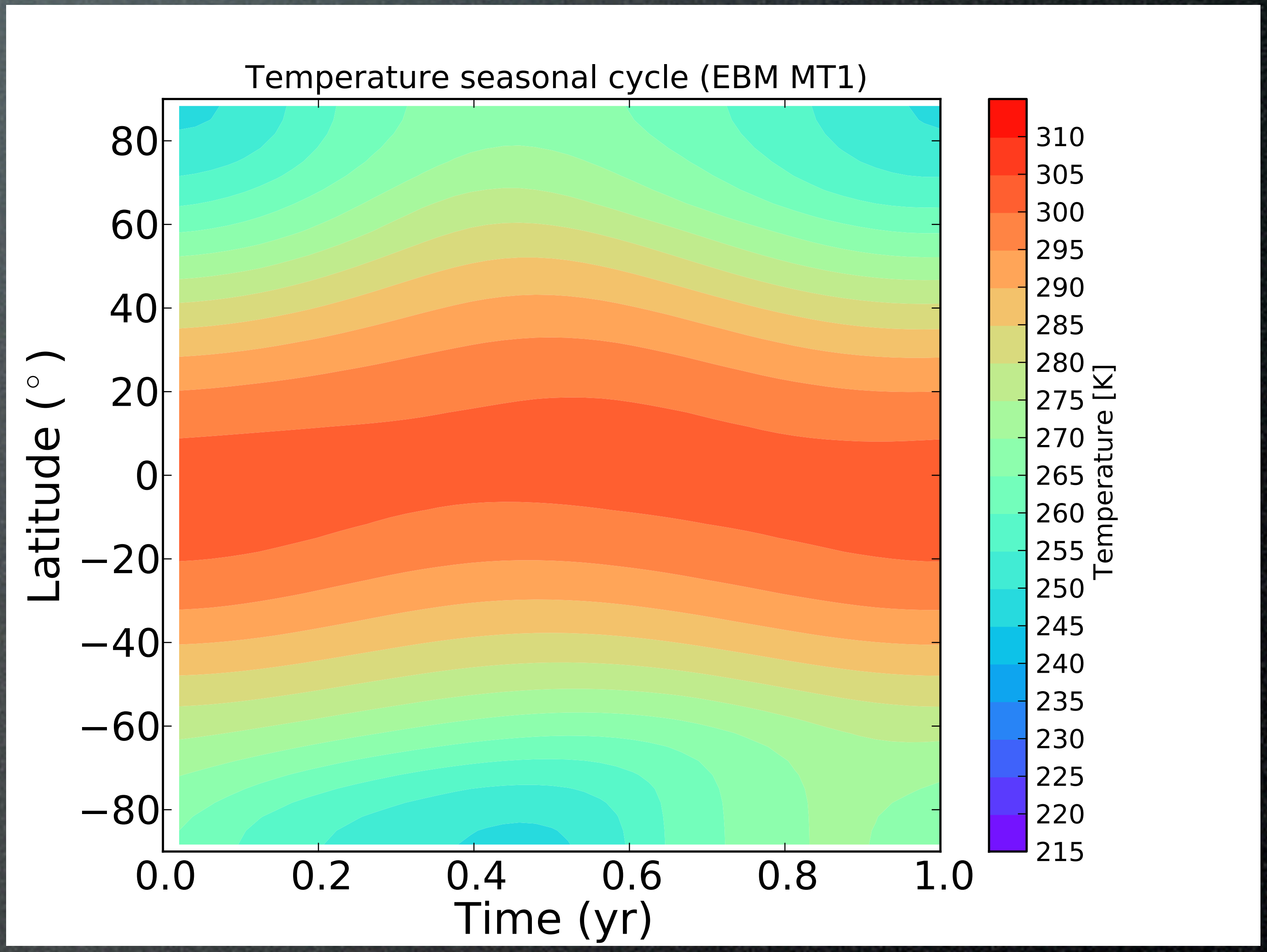


Seasonal and latitudinal variations of surface temperature on the Earth

Data



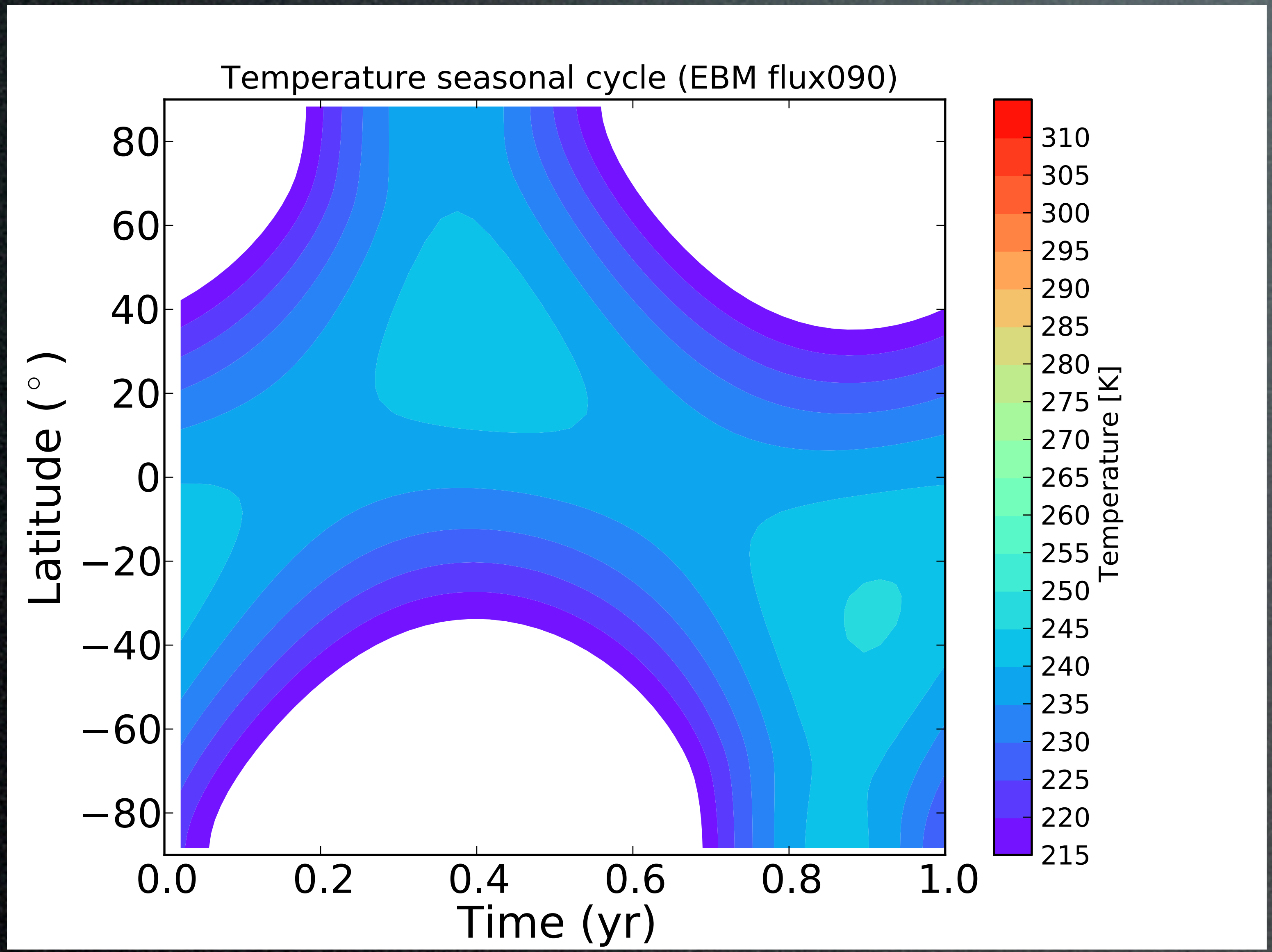
Climate model



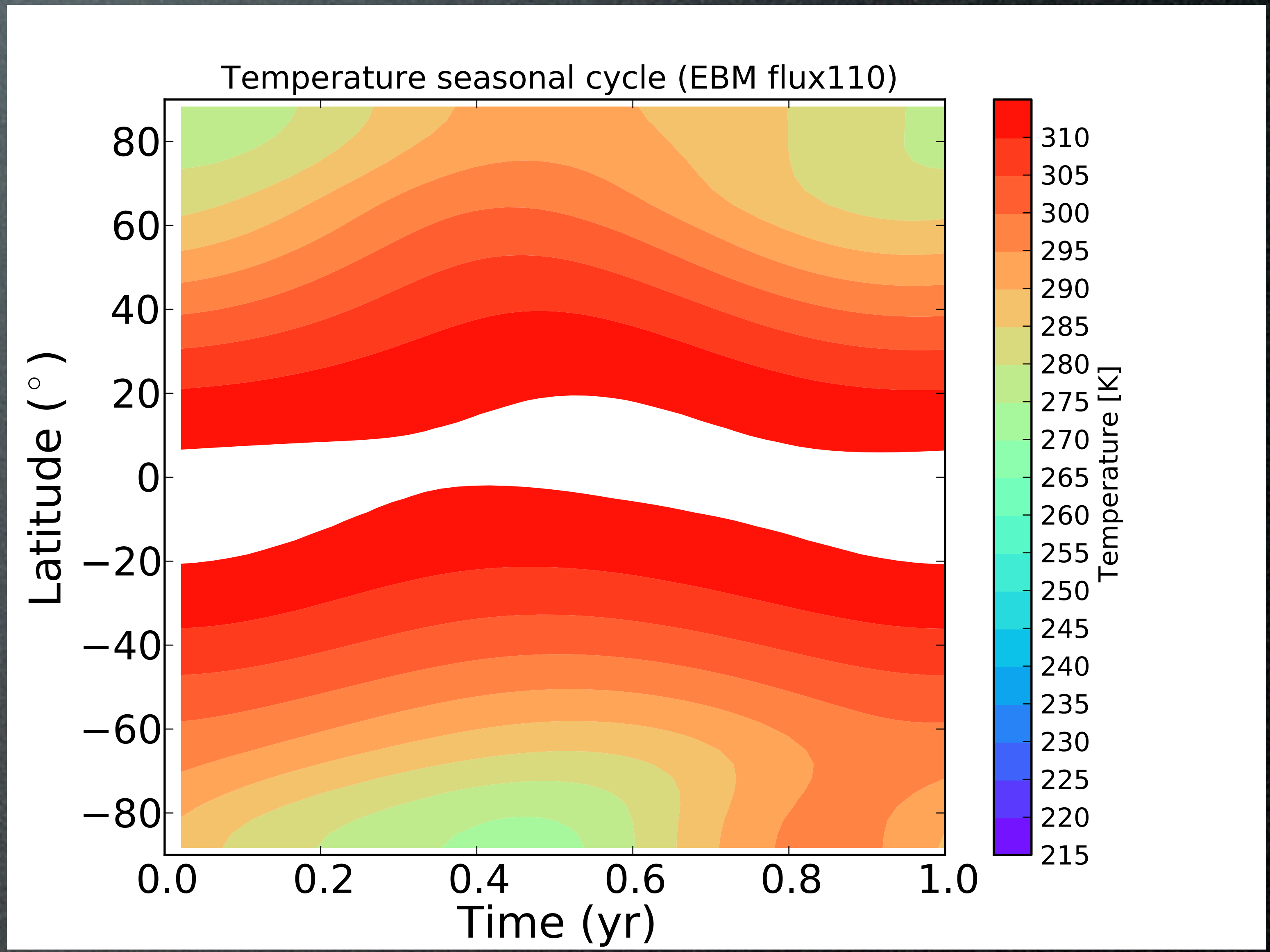
What happens to the surface temperature if we change the planetary parameters ?

Insolation
Surface pressure
Rotational velocity
Inclination of the rotation axis
Location of the continents
...

Insolation

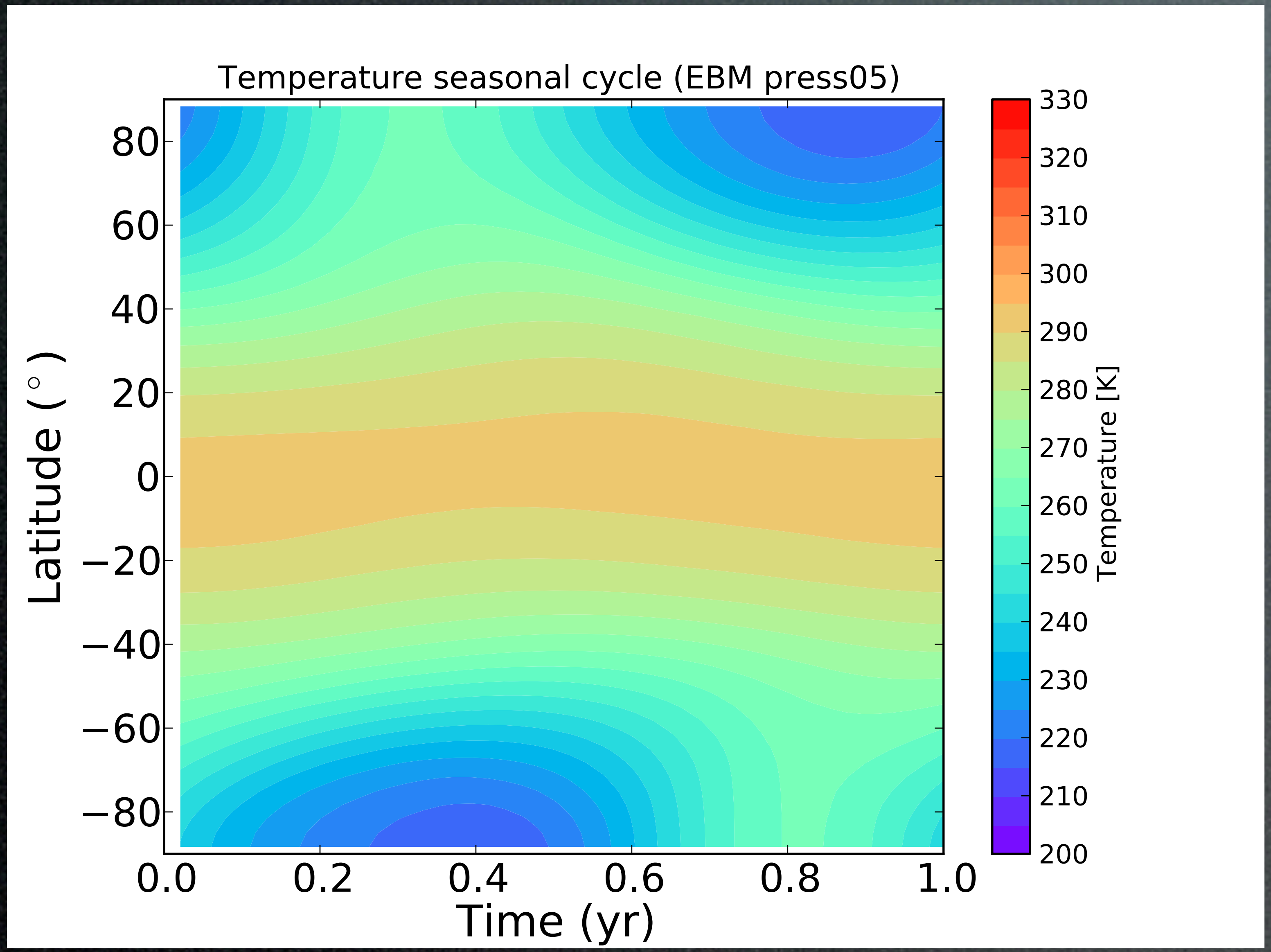


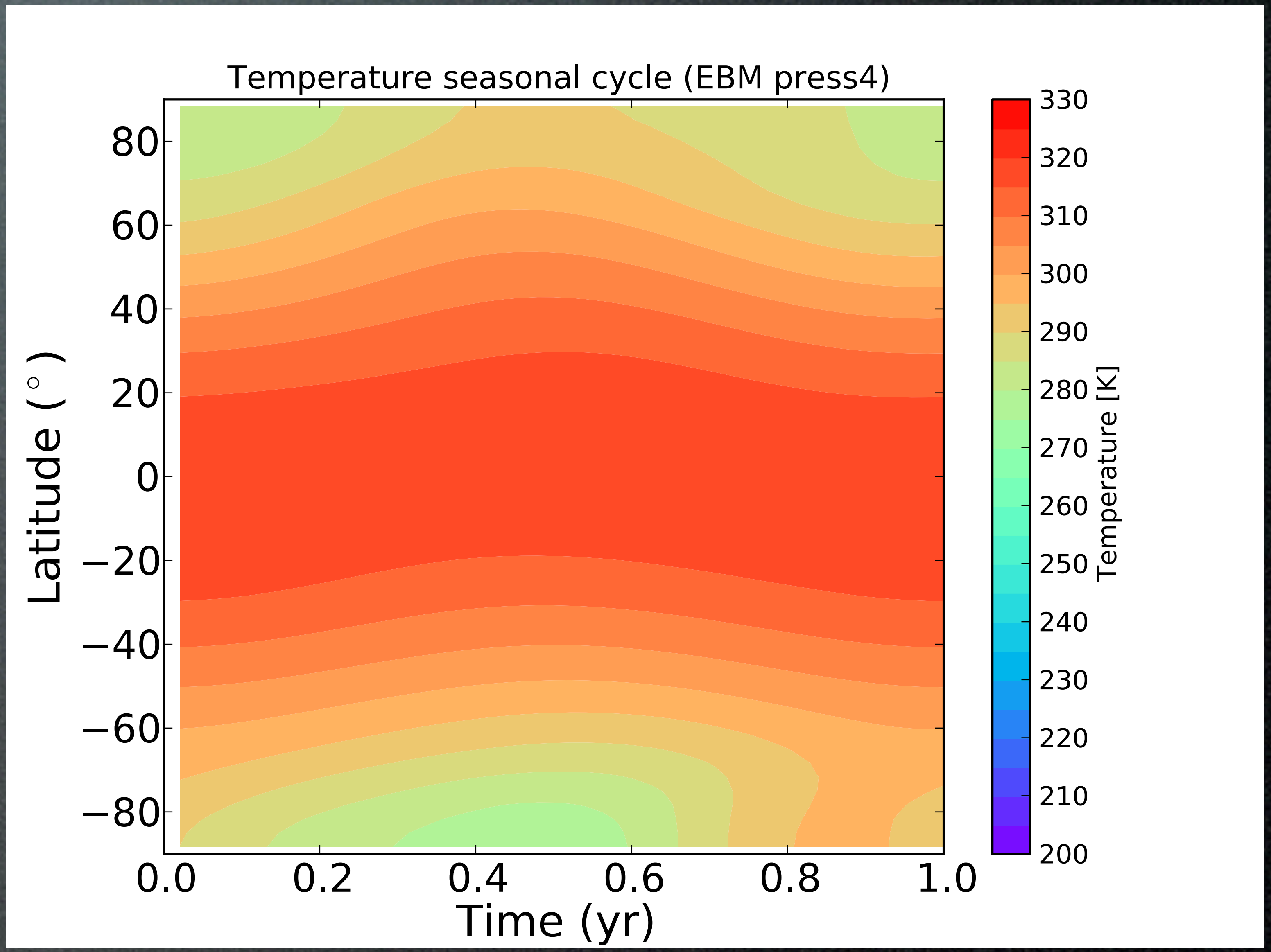
Temperature seasonal cycle (EBM flux090)
Latitude (°)
Time (yr)
Temperature [K]
80
60
40
20
0
−20
−40
−60
−80
0.0
0.2
0.4
0.6
0.8
1.0
310
305
300
295
290
285
280
275
270
265
260
255
250
245
240
235
230
225
220
215



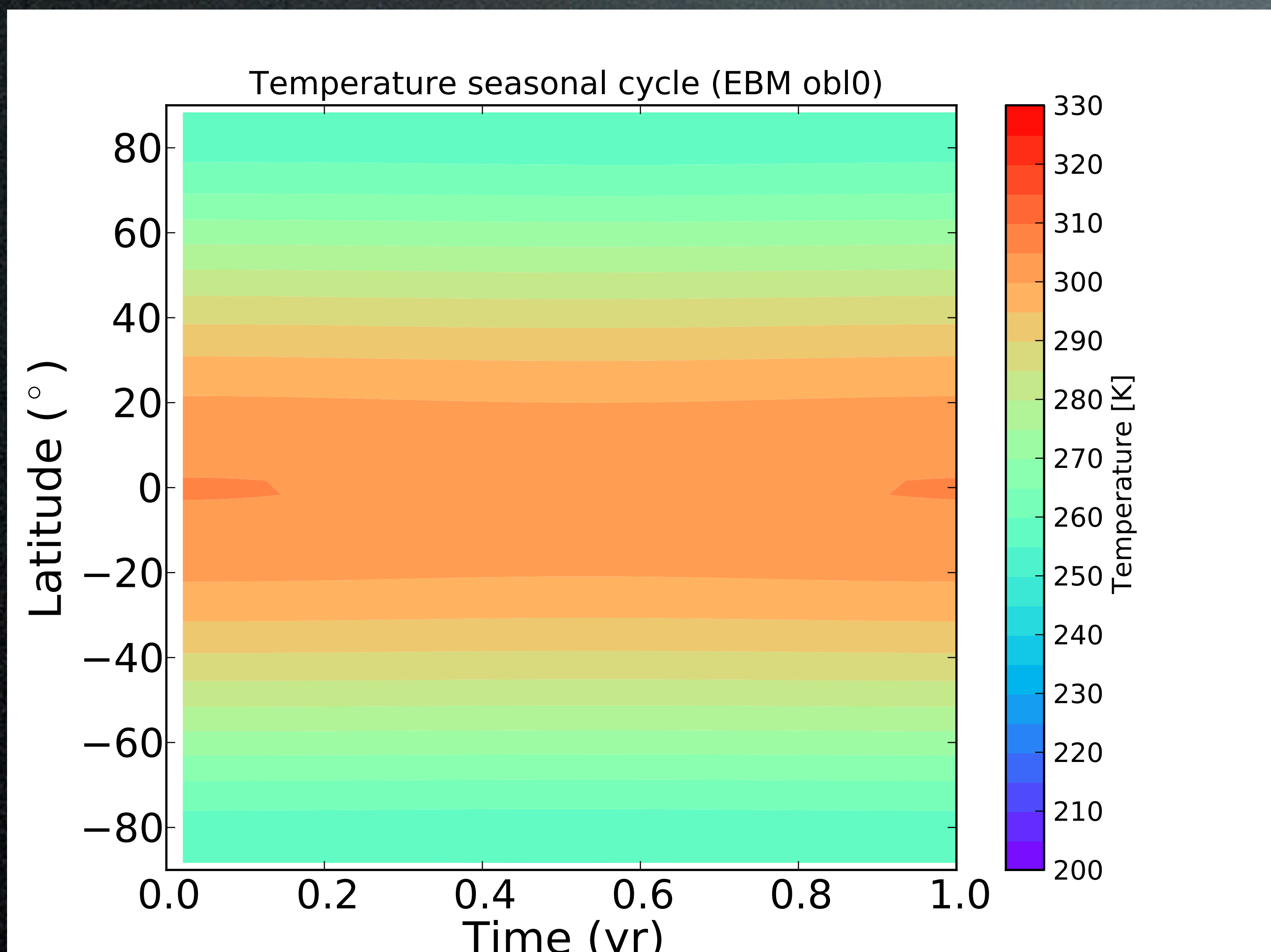
Temperature seasonal cycle (EBM flux110)
Latitude (°)
Time (yr)
Temperature [K]
80
60
40
20
0
−20
−40
−60
−80
0.0
0.2
0.4
0.6
0.8
1.0
310
305
300
295
290
285
280
275
270
265
260
255
250
245
240
235
230
225
220
215

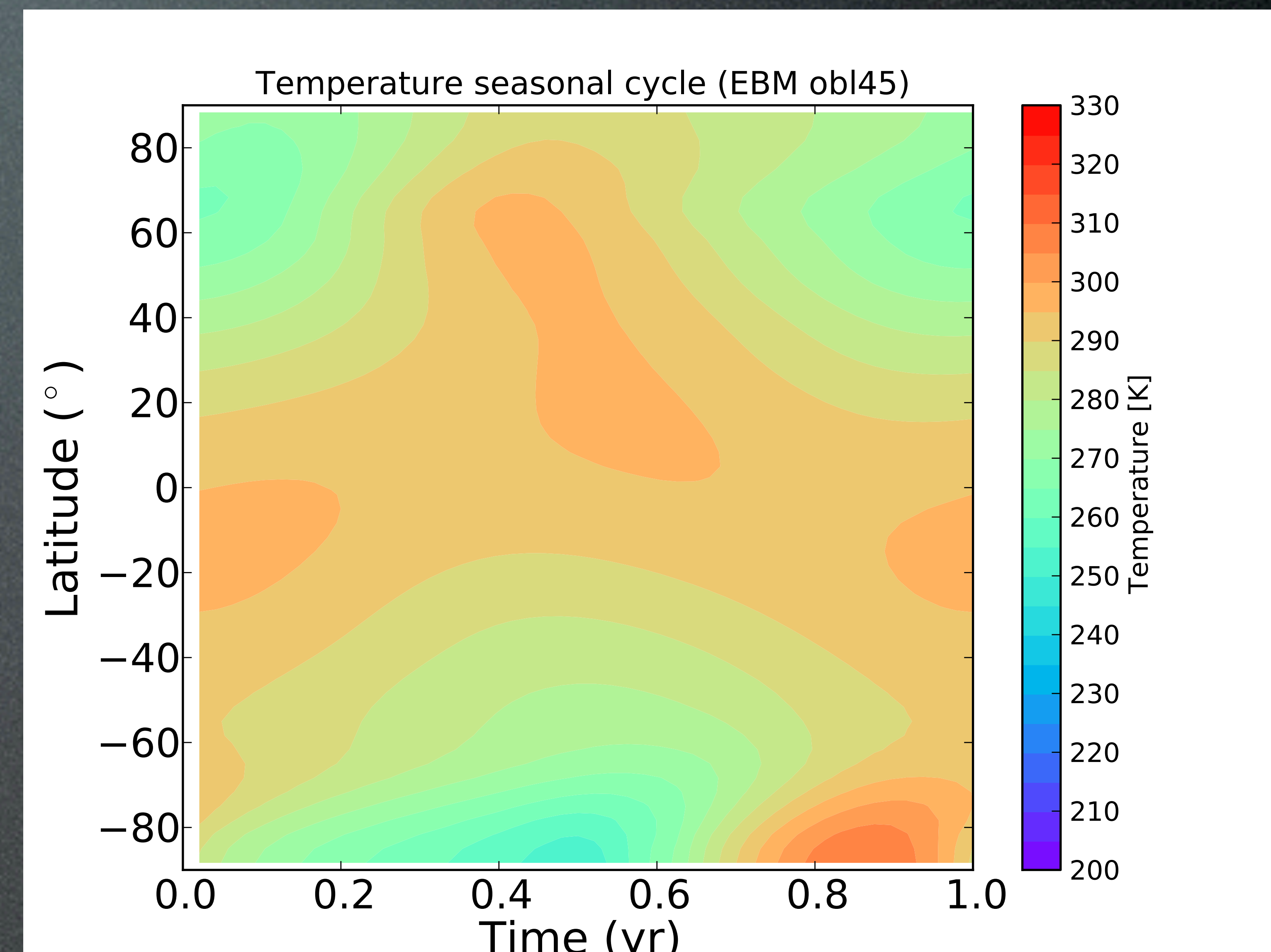
Surface pressure



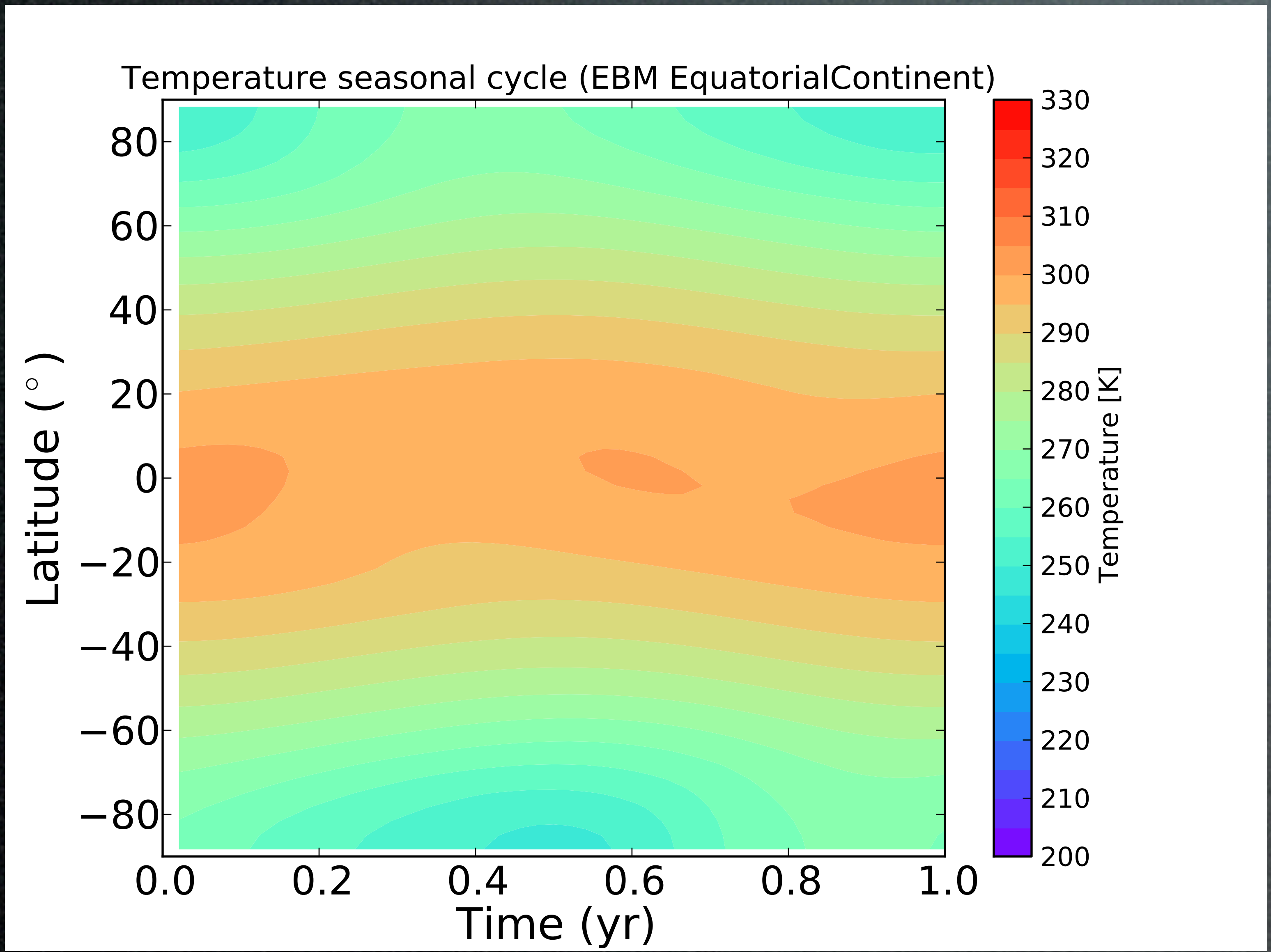


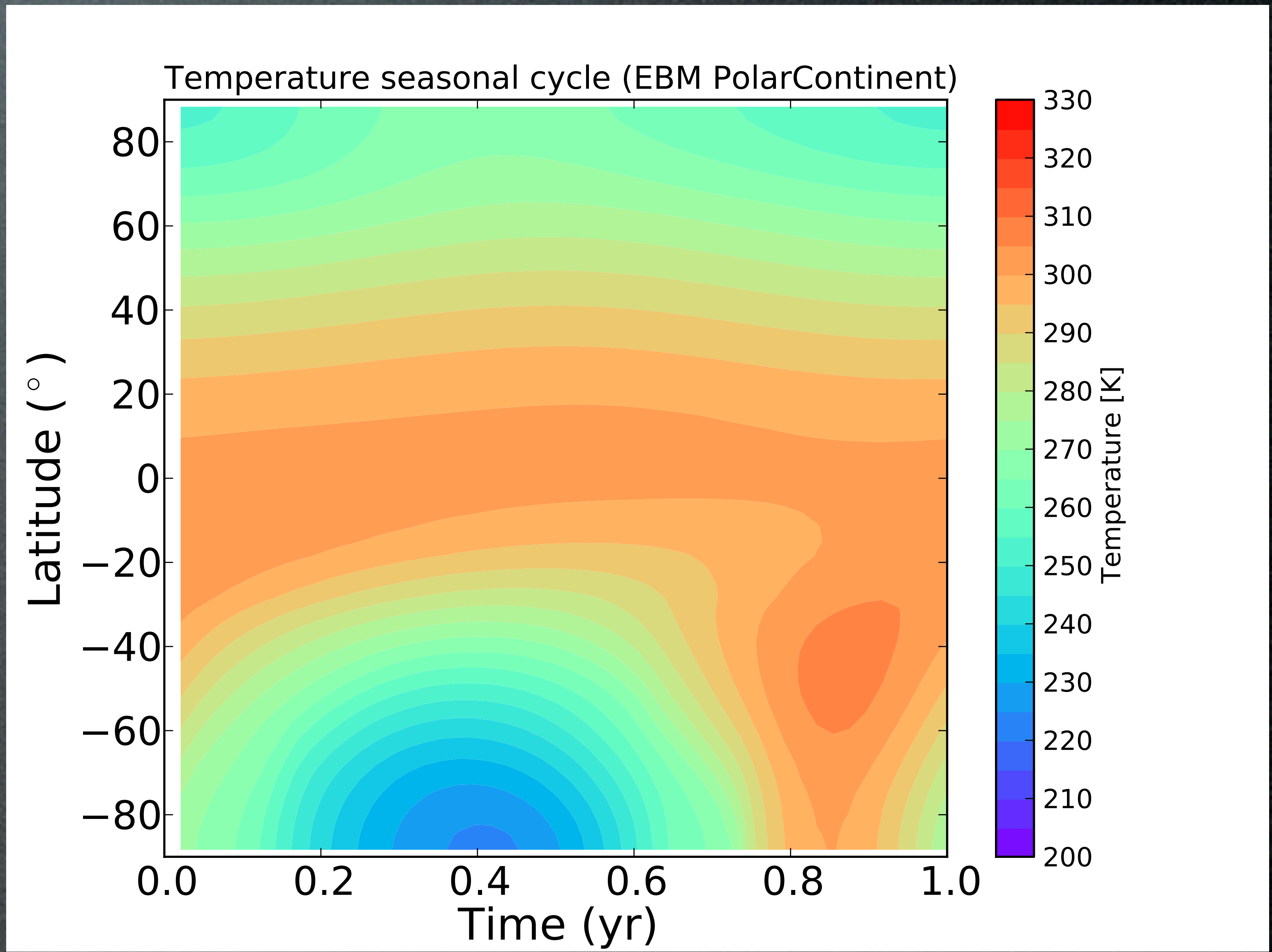
Tilt of the rotation axis



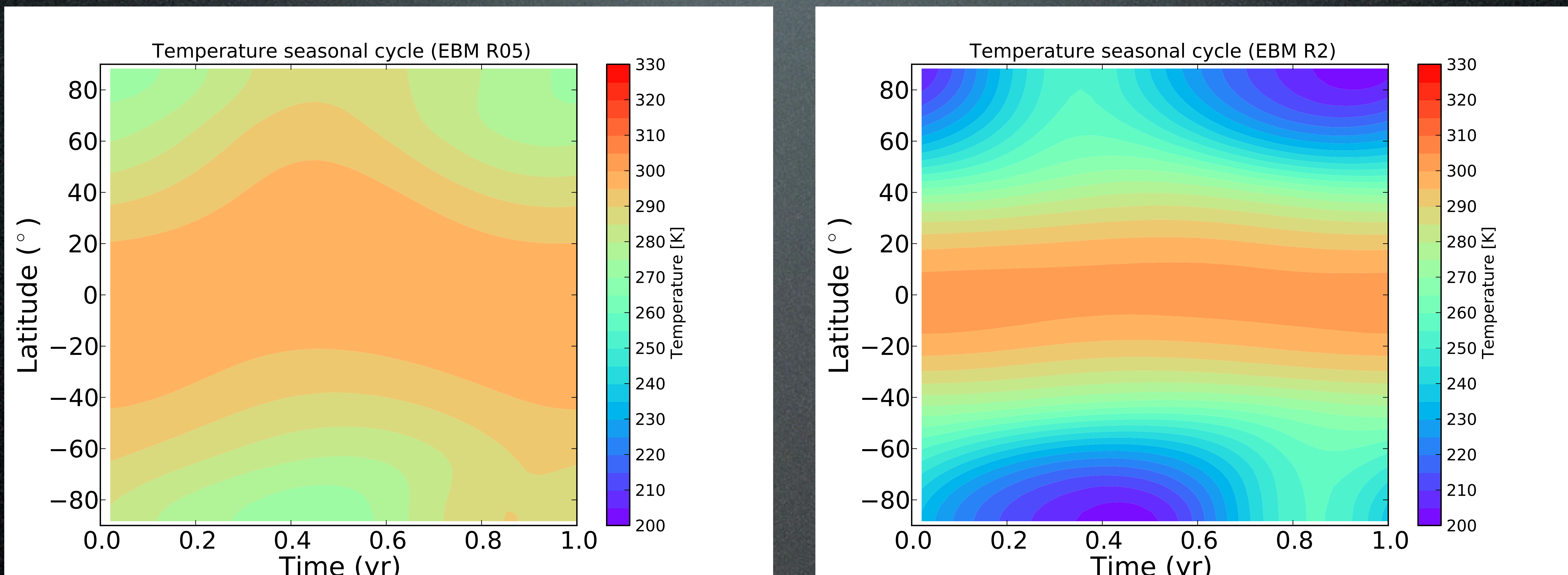


Location of the continents

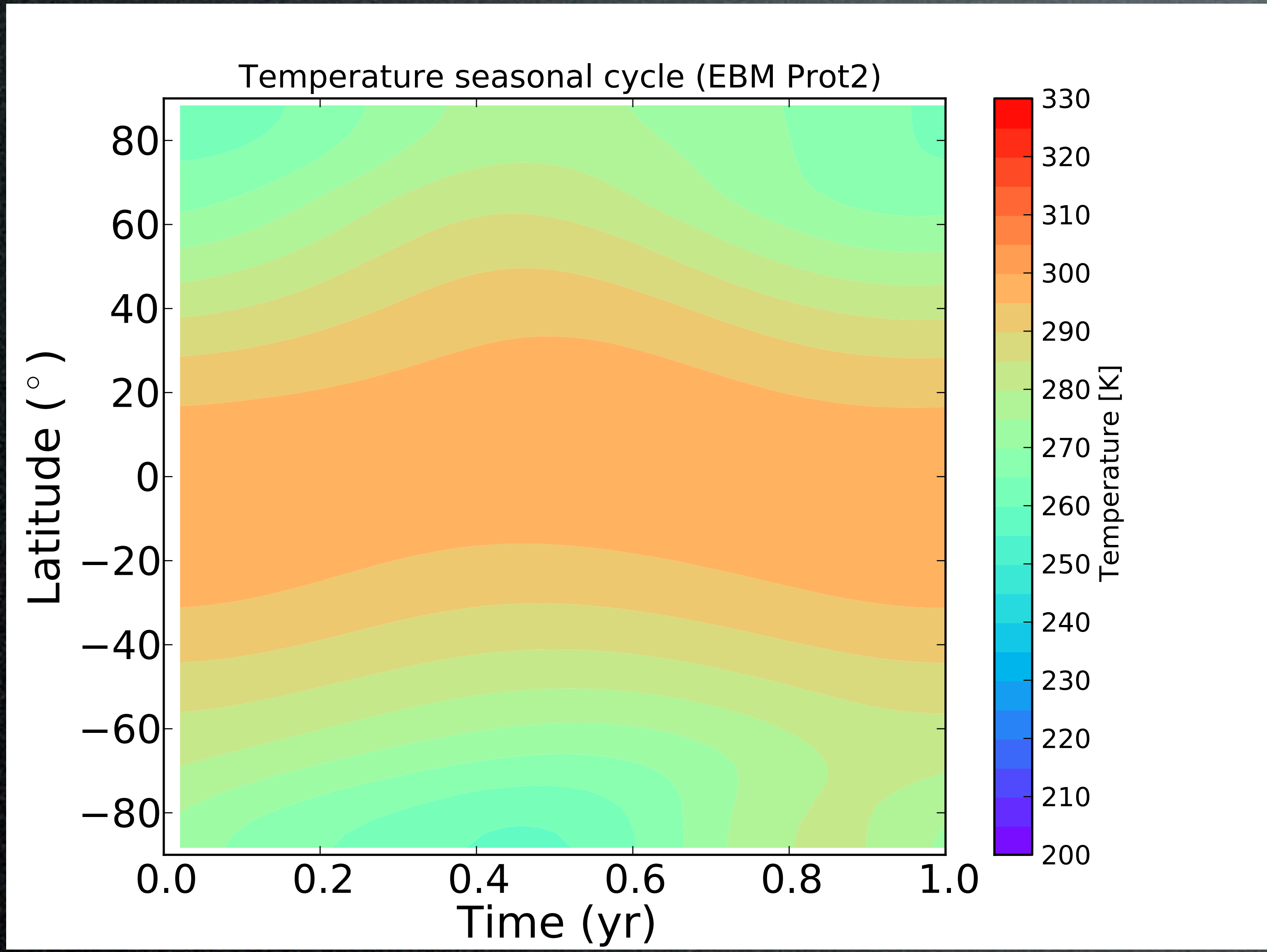


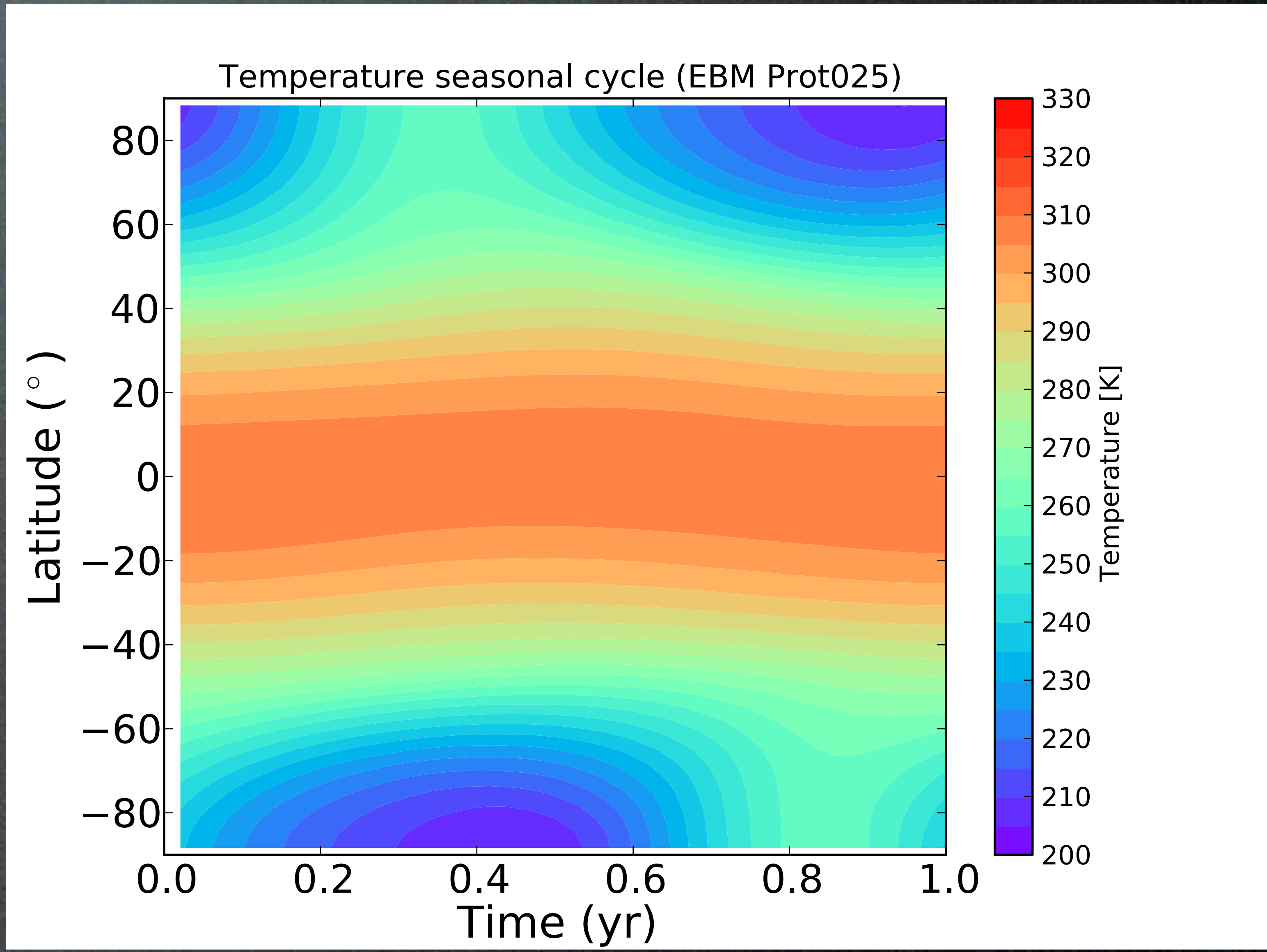


Planetary radius

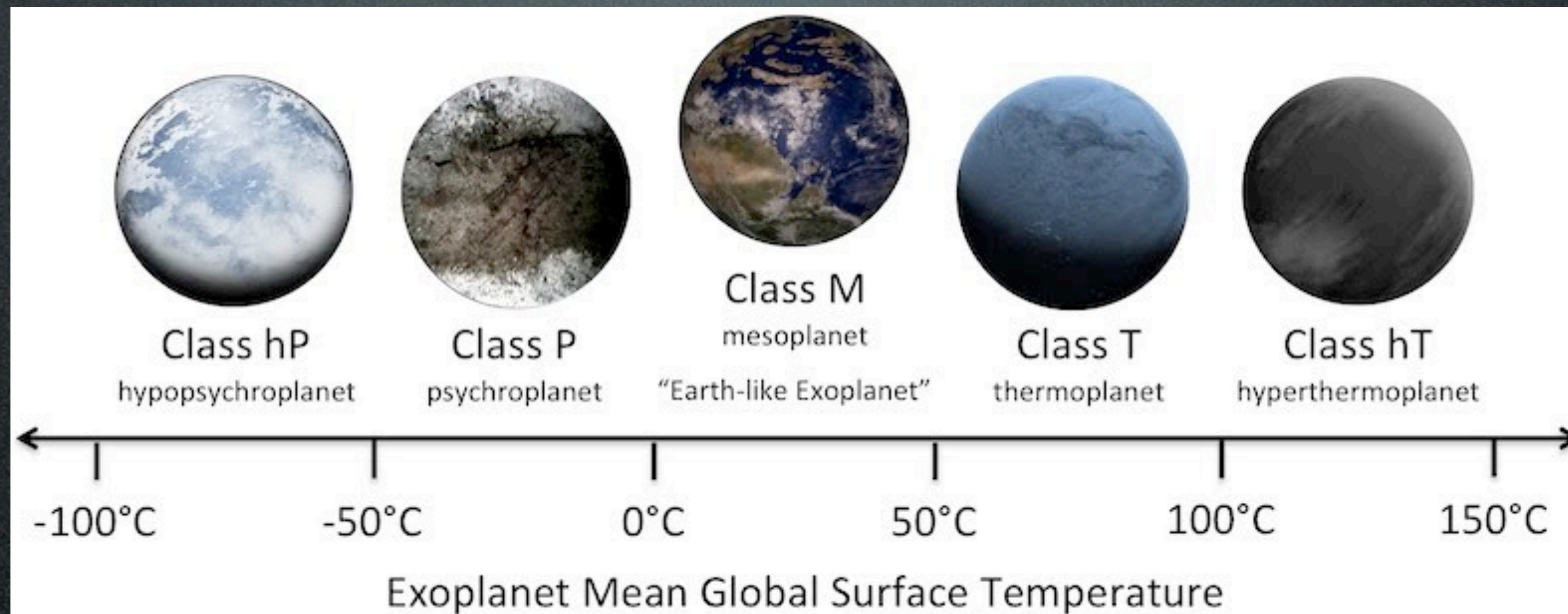


Rotation period





From surface temperature to habitability



Different types of life form may be present depending on the surface temperature

Is there life in habitable planets ?

The habitability does not guarantee
the actual presence of life

The requirements for the origin of life
could be more stringent, or even different,
compared to the requirements of habitability

The origin of life

The most difficult challenge in science

We must cast light on the origin of life
in order to understand which planets
could have the right conditions for the emergence of life

Studies on the origin of life:
two different approaches based on Earth life

Prebiotic chemistry ⟶ Proto-cell

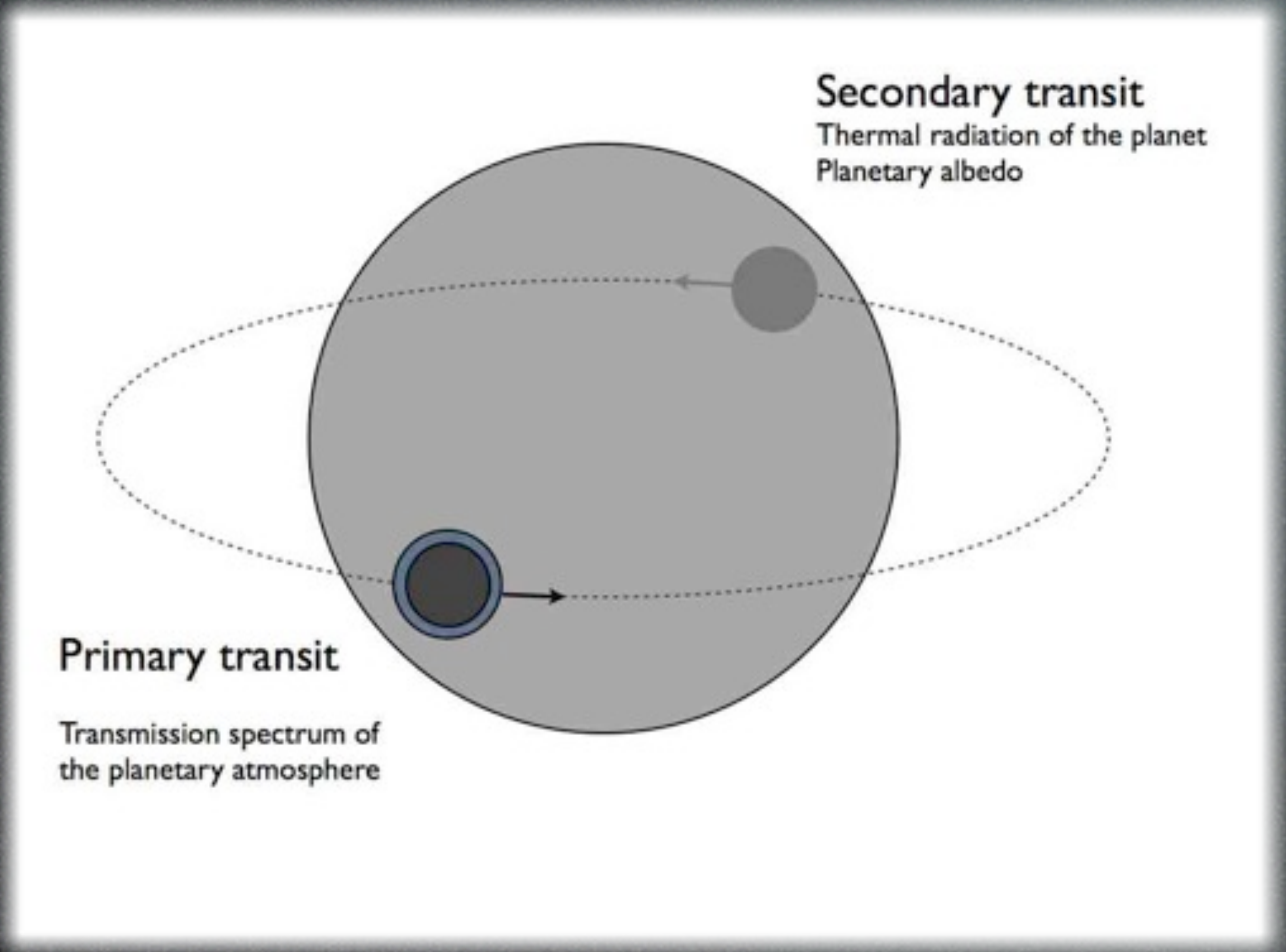
Proto-cell ⟵ Phylogenetic studias/minimal cell

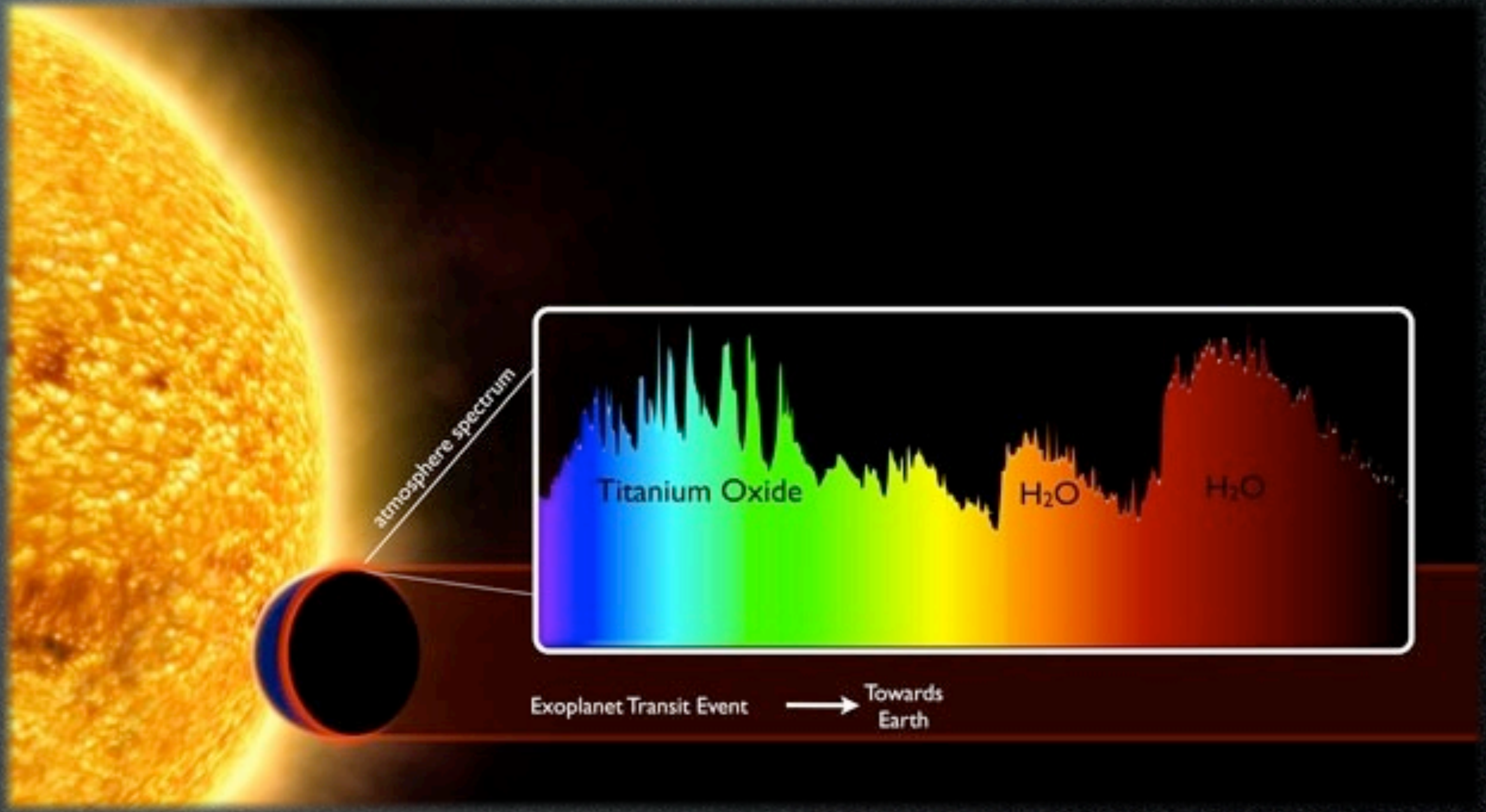
Alternative approach to understand if life can originate in different types of environments

Search for life in the Solar System

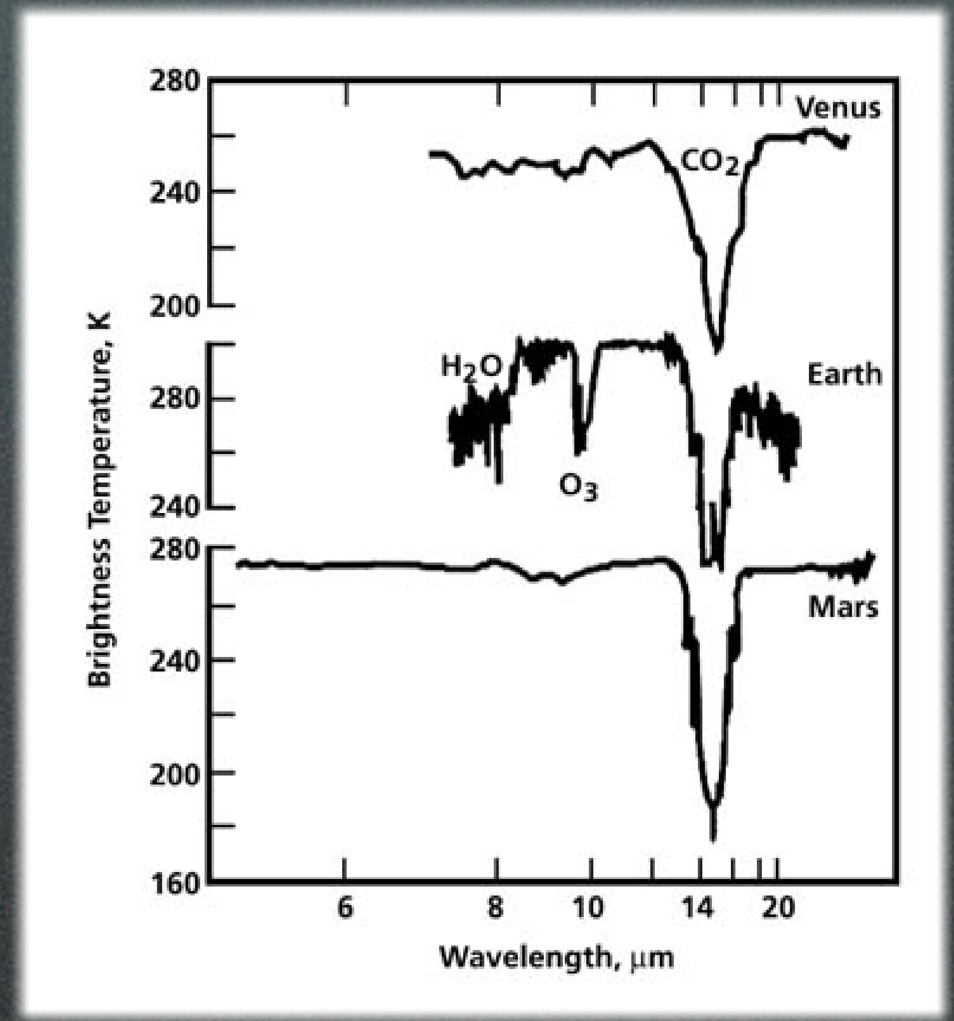
Can we find signatures of life
from the observations of exoplanets ?

Study of the planetary atmospheres of transiting planets



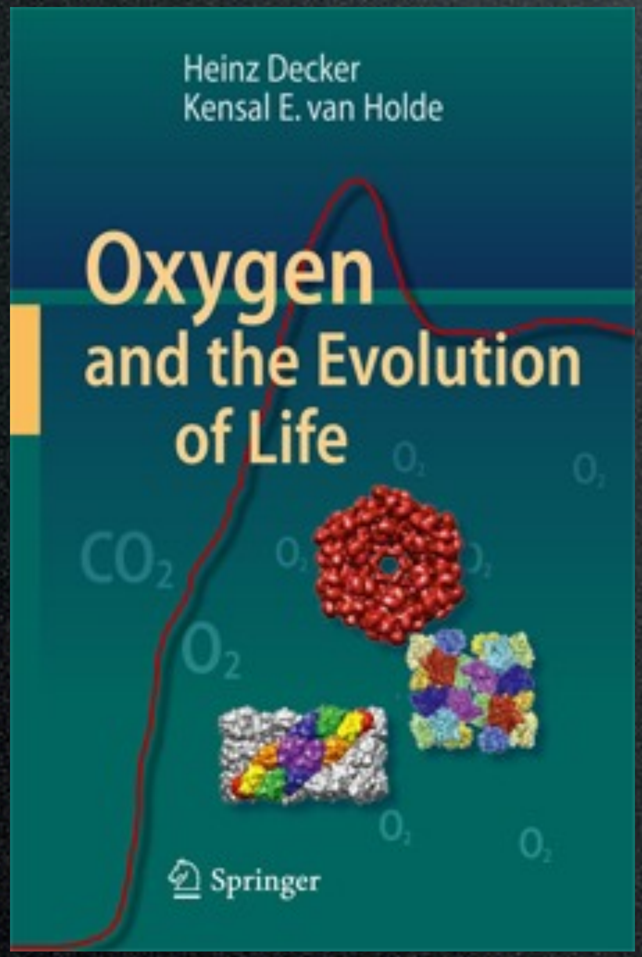


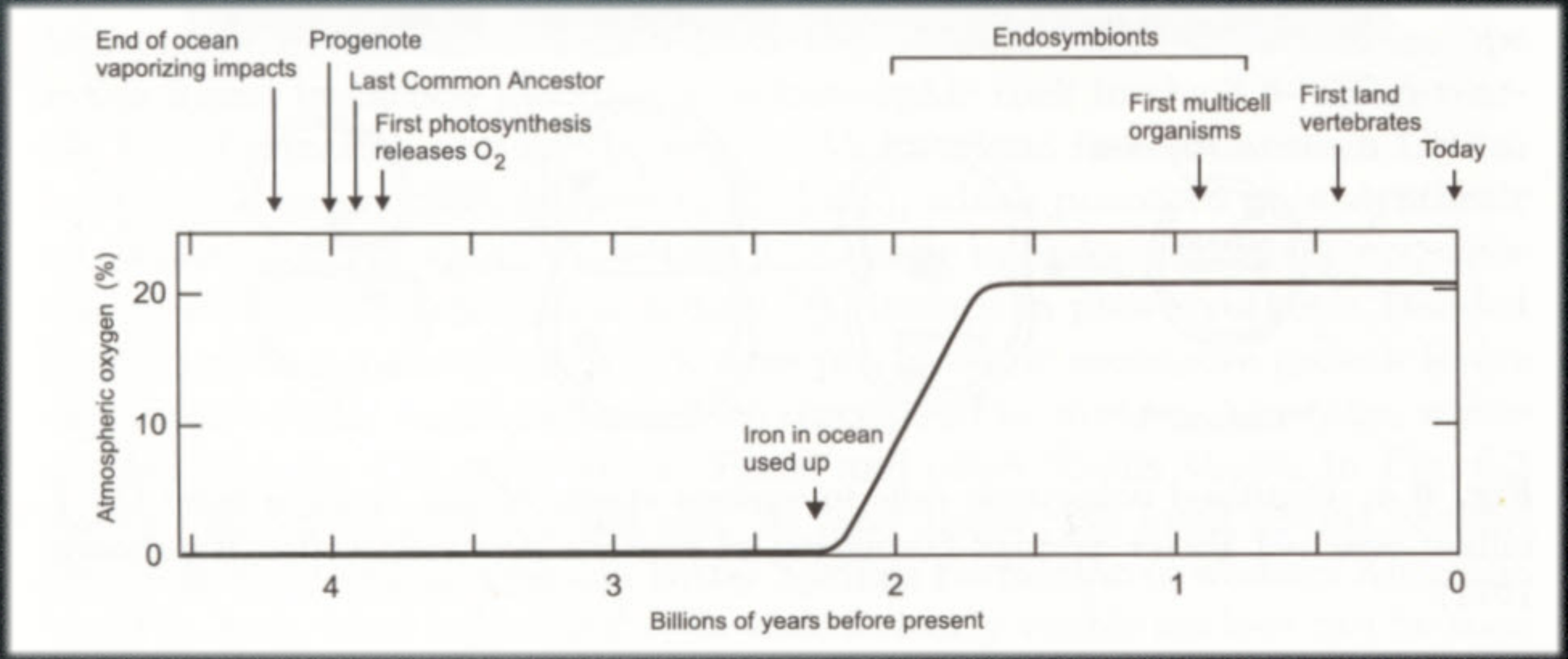
Search for water and biomarkers in planetary atmospheres



Terrestrial atmospheric oxygen is sustained by life

Oxygen as an atmosphericbiomarker





Conclusions

We are gradually proving that there are many planets similar to the Earth

Only a fraction of such planets is habitable

Life could have emerged only in a fraction of habitable planets

The study of planetary atmospheres could provide signatures for the presence of life in exoplanets

It is very important to cast light on the origin of life by means of laboratory experiments and space missions in the Solar System