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
Institut d’Astrophysique Spatiale
IAS, Orsay, France
bibring @ ias.u-psud.fr
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”
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”?

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
- infinity of inhabited worlds
- Earth, central, unique

Epicurus - 305

... + monotheisms
- infinity of inhabited worlds
- Earth, central, unique
- planets orbit around the Sun

Epicurus - 300

... + monotheisms

Copernic 1543
- infinity of inhabited worlds
- **Earth**, central, unique
- planets orbit around the Sun

**Earth**, standard, generic

- Epicurus - 300
- Copernic 1543

... + monotheisms
- infinity of inhabited worlds
- Earth, central, unique
- planets orbit around the Sun
- stars are suns

Epicurus: -300
Giordano Bruno: 1583
Copernic: 1543
• infinity of inhabited worlds

• Earth, central, unique

• planets orbit around the Sun

• stars are suns

plurality of worlds

Epicurus - 300

… + monotheisms

Copernic 1543

Giordano Bruno 1583

Giordano Bruno 1590
• infinity of inhabited worlds  
  Epicurus - 300
  … + monotheisms

• Earth, central, unique

• planets orbit around the Sun  
  Copernic 1543

• stars are suns  
  Giordano Bruno 1583
  Giordano Bruno 1590

plurality of worlds

life must be spread in space
- infinity of inhabited worlds
- Earth, central, unique
- planets orbit around the Sun
- Earth, standard, generic
- stars are suns
- plurality of worlds
- life must be spread in space
- same laws at all scales

Epicurus (-300)
... + monotheisms
Copernic 1543
Giordano Bruno 1583
Giordano Bruno 1590
- infinity of inhabited worlds
- Earth, central, unique
- planets orbit around the Sun
- Earth, standard, generic
- stars are suns
- plurality of worlds
- life must be spread in space
- same laws at all scales
- same effects?
- infinity of inhabited worlds
  - Earth, central, unique
  - planets orbit around the Sun
    - Earth, standard, generic
- stars are suns
  - plurality of worlds
    - life must be spread in space
    - same laws at all scales
  - 4 centuries of Physics

Epicurus - 300
... + monotheisms
Copernic 1543
Giordano Bruno 1583
Giordano Bruno 1590
- **infinity of inhabited worlds**
  - Epicurus - 300
  - ... + monotheisms

- **Earth, central, unique**
  - Copernic 1543

- **planets orbit around the Sun**
  - Earth, standard, generic

- **stars are suns**
  - Giordano Bruno 1583
  - Giordano Bruno 1590

  - **plurality of worlds**

  - **life must be spread in space**

  - **same laws at all scales**

  - **4 centuries of Physics**
• infinity of inhabited worlds

• Earth, central, unique

• planets orbit around the Sun

• Earth, standard, generic

• stars are suns

plurality of worlds

life must be spread in space

same laws at all scales

4 centuries of Physics

same effects?
• infinity of inhabited worlds  
  Epicurus  - 300

• Earth, central, unique  
  ... + monotheisms

• planets orbit around the Sun  
  Copernic  1543

• stars are suns  
  Giordano Bruno 1583
  Giordano Bruno 1590

  plurality of worlds

  life must be spread in space

  same laws at all scales

  4 centuries of Physics

  Sputnik / Luna 1
up to the space era, Earth was the sole planet within our scientific horizon.

evolution : envisioned via dogma

Big Bang

atoms

molecules

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

evolution: envisioned via dogma

Big Bang

atoms

molecules

complex organics

evolution: following a pathway of increasing complexity

dogma
evolution: envisioned via dogma

atoms

molecules

complex organics

evolution: following a unique pathway of increasing complexity

Big Bang

dogma
evolution / life: envisioned via dogma

atoms → molecules → complex organics → life

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

dogma
evolution / life: envisioned via dogma

Big Bang

atoms

molecules

complex organics

life

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

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

Big Bang
atoms
molecules
complex organics
life as a generic product and must-be step of increasing complexity
up to the space era, Earth was the sole planet within our scientific horizon.

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

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

plurality of worlds

life as a generic product and must-be step of increasing complexity
Mars: a world not merely habitable, but inhabited...!

Schiaparelli, Canali, 1877
Viking prime goal: to characterize Martian metabolism.
Viking prime goal: to characterize Martian metabolism

Mars

life water

first astrobiological experiments

Viking, 1976
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

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

totally unexpected diversity
totally unexpected diversity
totally unexpected diversity
- unique ocean cover
- unique cloud cover
- unique atmospheric cover
- unique ocean cover
- unique cloud cover
- unique atmospheric cover

: at what time/space scale?
- unique ocean cover
- unique cloud cover
- unique atmospheric cover

is life unique?

: at what time/space scale?
extrasolar stellar planets/systems are entering our science horizon

collapsing cloud

electsolar stellar system

We belong to one specific evolution pathway,
but have now observational access to other stellar systems
We belong to one specific evolution pathway, but have now observational access to other stellar systems.

Extrasolar stellar planets/systems are entering our science horizon.

Unexpected diversity.
Is life a generic product of increasing complexity?

Has life ever "emerged" else than on Earth?
"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.
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 processes are *generic*, but through a huge variety of *specific* forms driven by *contingency*, which have triggered an extraordinary *diversity* of *evolutionary* pathways.
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.
...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.
…which contrasts (for Mars) with the expected mass distribution derived from accretion in a full disk.
in order to get the observed mass distribution
...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
Saturn
Jupiter

Saturn

3 / 2 resonance
given their mass ratio
right mass distribution

Saturn

Jupiter
The solar system \textit{migration} is highly specific, exemplary of the \textit{contingent} shape taken by a \textit{generic} process.
organics- and ice-rich grains

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

water and organics from comet-like objects

anhydrous mineral grains
accretion led to bodies with the right mass ratio, with water trapped within their bulk, during accretion of outer ice-rich grains
...which further drove to:

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

**How has water been lifted towards the surface?**
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**
the impact had a major effect on Earth (climatic) history, and possibly at Mars

On Earth:
- partial atmospheric loss
- global magma ocean
- plate tectonics
- circumterrestrial disk
- accretion of the Moon
- obliquity stabilized
- enabling climate
the impact had a major effect on Earth (climatic) history, and possibly at Mars

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

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

The giant impact on Earth is highly specific, exemplary of the contingent shape taken by a generic process.

Mars Moon eXplorer JAXA mission at Mars? MMX mission!
The processes are **generic**, but through a huge variety of **specific** forms driven by **contingency**, which have triggered an extraordinary **diversity** of **evolutionary** pathways.
Rosetta / Philae is trigerring an in-depth revisiting of life "emergence"
the bulk of the comet is made of ORGANICeS

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

dirty ice

organics
organices

organices

with a sintered crust
with a sintered crust

...which may have constituted a key shield favoring the seeding of key ingredients in planetary oceans.
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!
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!

"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).
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).

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”.
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”.

For life “emergence” also, contingent properties have to be considered within generic processes, to explore the possibility that it ever happened other than on Earth.
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".

For life "emergence" also, contingent properties have to be considered within generic processes, to explore the possibility that it ever happened other than on Earth.
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”.

For life “emergence” also, contingent properties have to be considered within generic processes, to explore the possibility that it ever happened other than on Earth.

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.
Today, Mars pressure is too close to that of water triple point, for liquid water to be stable.
and yet, from orbit...
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
ESA / Mars Express data have triggered a profound revisiting of Mars History.
Liquid water neither covered the red areas, nor is responsible for Mars being red!
Liquid water neither covered the red areas, nor is responsible for Mars being red!
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
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. They constitute unique sites, in the entire solar system. No preserved terrains exist on Earth.
in the past?  
Mars 
habitable?

today
Earth
inhabited!
in the past?

Mars
habitable?

Earth
habitable!
Is "life" robust enough to have "emerged" and adapted in two similar, although distinct, environments?
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!

There exist at Mars ancient preserved terrains, favoured sites to be explored!
There exist at Mars ancient preserved terrains, favoured sites to be explored!
TGO / ExoMars is already orbiting
The ExoMars 2020 rover will explore such a site
The ExoMars 2020 rover will explore such a site
The ExoMars 2020 rover will explore such a site.
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".

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".
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".

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.
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".

2. The more we decipher the specifities 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 specific forms they harbor. Searching for "exoEarths" tends to ignore what the solar system community is being elaborating at depth, as the evolutionary steps which uniquely shaped Earth History, as well as those relevant to other bodies.

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.
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".

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 specific forms they harbor. Searching for "exoEarths" tends to ignore what the solar system community is being elaborating at depth, as the evolutionary steps which uniquely shaped Earth History, as well as those relevant to other bodies.

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?