Planetary Evolution and Life
Proposal for a Helmholtz Alliance
Life Beyond Earth

- Finding life beyond Earth is one of the greatest challenges in science
- The task is extraordinarily demanding and has been embraced by space agencies in the International Space Exploration Initiative
- Finding extraterrestrial life is of fundamental philosophical relevance
  - It will complete the Copernican revolution
  - It will put our human existence into perspective and move us further from a geocentric concept of the world to a modern, knowledge-based one

Giordano Bruno (1548-1600) ExoMars Rover “Pasteur”
Understanding Extraterrestrial Life

- The search for extraterrestrial life rests on research to understand and to predict the whereabouts of extraterrestrial life.
- The new science of Astrobiology investigates the biological aspects of the topic.
- Planetary science studies the ability of planets to host life: their habitability.
Our Proposal

Our proposal thus centers on habitability. We will study the evolution of planets and their habitability and ask the questions of what role life has in planetary evolution and how planetary evolution will enable life?

We will pose the question of whether or not life can stabilize habitability!
H, C, and O

- Life as we know it requires liquid water. Physical habitability conditions are therefore often tied to the stability of water although it is speculated that other chemistries of life may exist.
- It is interesting to note that the elements forming the basis of terrestrial life (H, C, and O) are also key elements controlling large scale planetary processes.
- CO₂ is the major atmosphere greenhouse gas (together with H₂O and CH₄) and by interacting with water, crustal rock, and life regulates the temperature of the atmosphere.
- Water is the major compound controlling mass transport (convective flow and melting) in the rocky planetary interior.
Carbon Cycle, Impacts

- The carbon cycle buffers the atmosphere temperature through the concentration of CO₂ in the atmosphere.
- CO₂ is removed by precipitation and microbial activity and replenished by volcanism.
- Impacts can deliver volatiles and – perhaps – life (Panspermia hypothesis).
- Impacts can also remove the atmosphere or parts thereof.
Many believe that (complex) life requires plate tectonics to operate (e.g., the Rare-Earth Theory)

- Plate tectonics recycles near surface rock and volatiles with the planet’s interior through subduction. This helps
  - to cool the deep interior and to generate a magnetic field in the core
  - to create granitic cratons that will form continents
  - to replenish depleted surface rock
  - and to stabilize the atmosphere temperature
Questions

- Why does the Earth have plate tectonics while the others have not?
- How important is water?
- Does life help to stabilize plate tectonics by stabilizing water on the surface?
- Did e.g., Mars lose plate tectonics early on because life did not evolve rapidly enough? Because life lost the race against adverse effects, e.g., the erosion of the atmosphere?
- Or do we emphasize plate tectonics because we do not understand the other tectonic modes and their habitability well enough? Is this part of our geocentric thinking?
Biogeochemical interactions stabilize the surface temperature (carbon cycle)
Atmosphere

Biosphere

Hydrosphere

Crust

Space

Biogeochemical interactions stabilize the surface temperature (carbon cycle)

Erosion by solar wind; Impacts
Biogeochemical interactions stabilize the surface temperature (carbon cycle)
Subduction, regassing, and enhanced cooling

Space

Erosion by solar wind; Impacts

Subduction, regassing, and enhanced cooling

Biosphere

Atmosphere

Hydrosphere

Crust

Volcanism

Degassing

Mantle

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Mantle

Convective Cooling

Core

Dynamo Action

Space

Erosion by solar wind; Impacts

Erosion by solar wind; Impacts

Degassing

Space

Erosion by solar wind; Impacts

Degassing

Space

Erosion by solar wind; Impacts

Degassing
Magnetosphere

Subduction, regassing, and enhanced cooling

Atmosphere

Biosphere

Hydrosphere

Shielding

Crust

Volcanism

Degassing

Mantle

Convective Cooling

Core

Dynamo Action

Shielding

Subduction, regassing, and enhanced cooling
What will we do and what will we do better?

- Self consistent atmosphere models including atmosphere erosion and interaction with the biosphere
- Model constructive and destructive effects of impacts
- 3D mantle convection models to map the stability fields of the modes of mantle convection and to model the volatile exchange with the atmosphere
- Constraints on the degassing history of Mars from isotope geochemistry
- Numerical models of planetary dynamos
- Mapping the habitability of Mars as the prime candidate for extraterrestrial life to be found in-situ
- Studying the geology of Titan as a prime candidate for exotic habitability
Complements

- We will complement these studies by
  - studying a **potential habitat** of present Mars that is little explored: **thin films of water** (a few mono-layers) that can exist at subzero temperatures
  - deriving and studying **innovative concepts** for **instruments** and **missions** to search for life and explore habitability
Methods

- Advanced, state-of-the-art **numerical modeling** (we do have some of the best numerical modelers and codes in the field worldwide)
- Advanced **isotope cosmochemical measurements** in one of the best geochemical laboratories worldwide
- **Geological mapping** with unique space experiment data sets that we understand best because we took the data
- **Laboratory experiments** on water films and microbes also in a state-of-the-art Mars simulation chamber
- System analysis and testing for **innovative space mission** and **instrument** concepts. Use of a **concept car** approach.
Conclusion

- What we plan to do:
  - Study the evolution of planetary habitability and the role of life in it through an integrated approach using modeling and empirical studies
  - Complement this research by a study of a promising habitat for present Mars and novel mission approaches
  - The proposed research is of great societal interest and unique through its integrated approach
  - It fits well into the Helmholtz mission