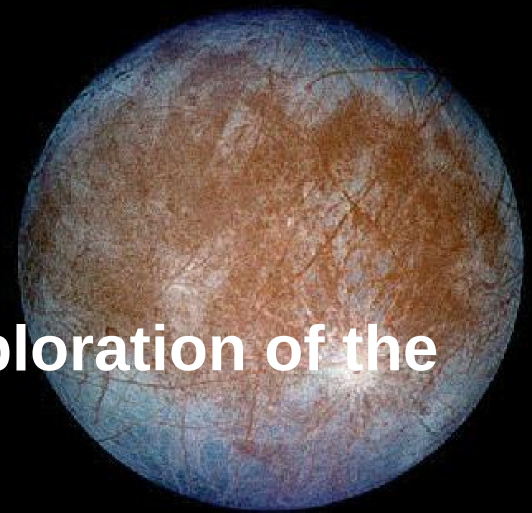
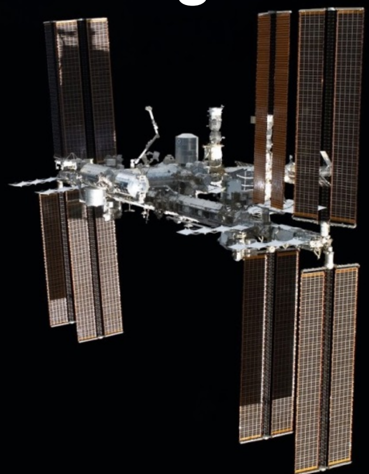
Space as a Tool for Astrobiological Exploration of the Solar System

Jean-Pierre de Vera and the BIOMEX and BIOSIGN-team

- 51st ESLAB Symposium Extreme Habitable Worlds, ESA/ESTEC, 06.12.2017

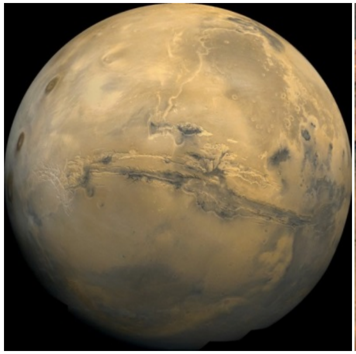


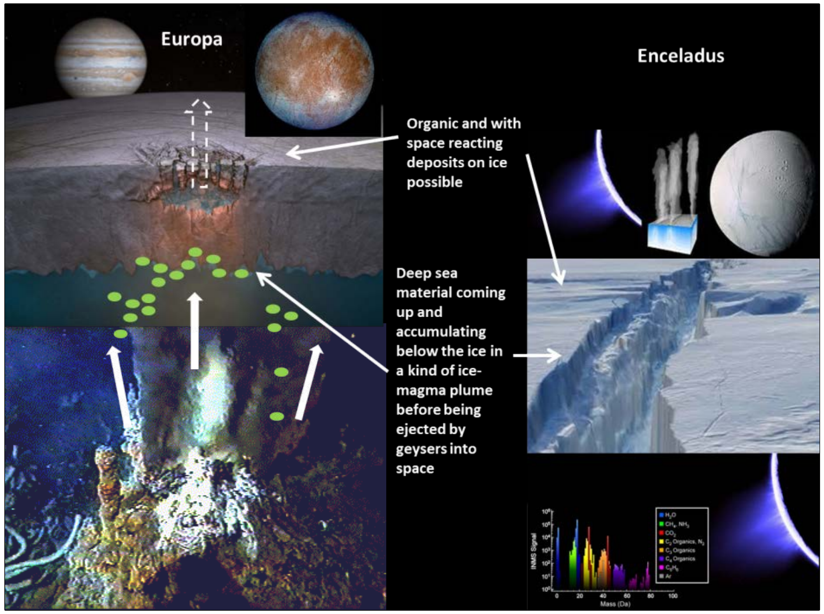


BIOMEX and BioSigN: support of future exploration missions to Moon, Mars, Enceladus and Europa

Motivation:

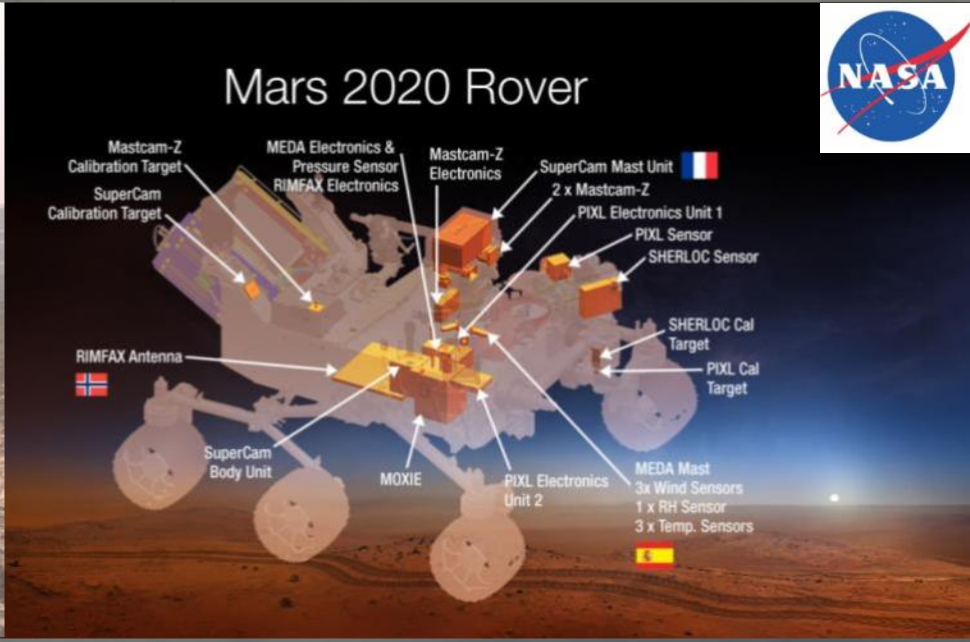
- the investigation of the resistance of potential biosignatures (from extremophiles such as: lichens, archaea, cyanobacteria, bacteria, snow alga, black fungi, bryophytes, pigments, cell wall components) to space / icy moon and Mars-like conditions
- the interaction of biological and Mars / Icy Moon analog material under space and Mars-like conditions
- database for life detection analysis on Mars and the icy moons
- Limits of Life (using organisms of all 3 domains of the tree of life)
- Habitability of Mars
- Lithopanspermia
- Support of immune system of astronauts
- Test instruments for future space exploration





New life detection instruments: next missions to Mars will carry Raman spectrometers

- Raman Laser Spectrometer (RLS) part of the Pasteur Payload on ExoMars with a 532nm laser excitation (e.g. Rull et al. 2013)
- Raman spectrometers on Mars2020: remote pulse-gated 532nm (SuperCam) and UV 248.6nm (SHERLOC) (e.g. Gasnault et al. 2015, Maurice et al. 2015, Beegle et al. 2014)



Necessity to create a database of Raman signatures from terrestrial organisms from Mars-analogue environments and/or after exposure to Mars-like conditions.

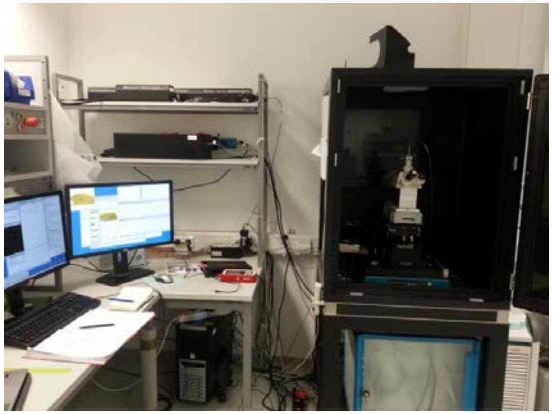
General parameters of the Raman setup at the DLR

Witec alpha300R Confocal Raman microscope

excitation wavelength:	532 nm
laser spotsize:	~ 1 µm
grating:	600 l/mm
laser power:	< 50 mW
spectral resolution:	< 16 cm^{-1}

cooling:	> 4 K
heating:	< 1773 K

Mars simulation:	composition of the atmosphere, mineralogical composition of the surface, pressure, temperature



For cyanobacteria algae, bacteria:
532 nm excitation
1mW laser power
10X objective
1s integration with 1 accumulation to avoid signal saturation from fluorescing pigments.
Laser spot on the sample <1,5µm

General Raman spectroscopy work at the DLR

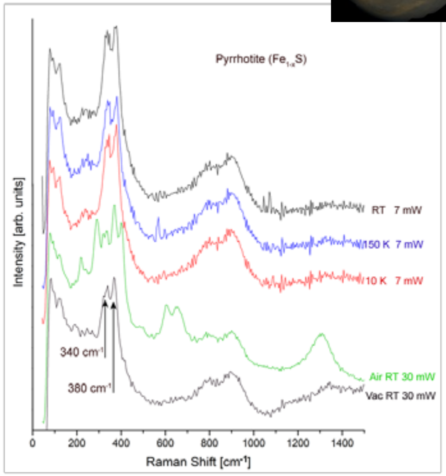
2013: Investigation of iron sulfides

Motivation:

- high amount of iron sulfides on Mars
- high sensitivity to laser irradiation in Earth atmosphere ⟶ behavior under Mars conditions and vacuum?

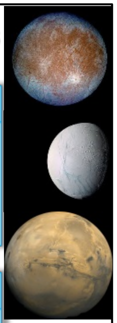
Results:

- Martian conditions: Raman spectra are not sensitive to laser irradiation
- Earth conditions: Pyrrhotite is highly sensitive to laser irradiation (reaction with oxygen results in the formation of hematite (green))



published in: U. Böttger, et al., *Laser-induced alteration of Raman spectra for micron-sized solid particles.* Planetary and Space Science, pp. 1-8, 2015.

2014: Investigation of frozen salt solutions



Motivation:

- liquid water is a necessary condition for the presence of life on Earth
- salts lower the freezing point of water ⟶ liquid phase (Mars)
- habitability ⟶ Search for signs of life (past or present)

Samples: binary system of H_2O and different salts

- diatomic salts: NaCl, KCl, LiCl, NaI, NaBr
- polyatomic salts (non-sulfates): $CaCl_2{\cdot}2H_2O$, $MgCl_2{\cdot}6H_2O$, $FeCl_3{\cdot}6H_2O$
- polyatomic salts (sulfates): Na_2SO_4, K_2SO_4, $CaSO_4{\cdot}2H_2O$, $MgSO_4{\cdot}H_2O$, $MgSO_4{\cdot}7H_2O$, $Fe_2(SO_4)_3{\cdot}xH_2O$

Methods:

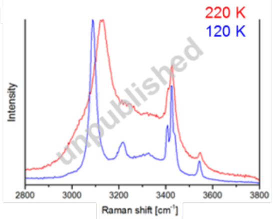
- Raman spectroscopy
- multivariate data analysis (PCA) + cluster analysis

Results:

- most of the frozen salt solutions could be identified using Raman spectroscopy
- The combination of Raman spectroscopy, PCA and cluster analysis is an appropriate method for the detection, differentiation and identification of these frozen salt solutions

binary system:

$H_2O + NaCl \rightarrow Ice + NaCl{\cdot}2H_2O$



2015 – 2017: BIOMEX and further preparation for BioSigN

BIOMEX – an European and World-wide space project

The Team

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34	Dr. Joachim Meeßen	DE	Co-I
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38	Prof. Dr. Dirk Schulze-Makuch	DE/USA	Advisor + Co-I
39	Dr. David Wolter	DE	Co-I
40	Dr. Andreas Lorek	DE	Co-I
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49	Prof. Lynn Rothschild	USA	Co-I
50	Dr. Michael Kliefoth	DE	Co-I
51	Prof. Natuschka Lee	S	Co-I
52	Prof. Leo Garcia Sancho	SP	Co-I
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54	Mrs. Claudia Fagliarone,	DE	PhD student
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57	Alessandro Napoli	IT	Master student
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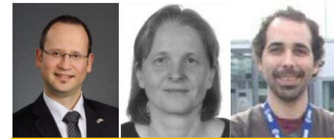
60	Casey Bryce	UK	PhD student
61	Sarah Phillips Brown	UK	PhD student
62	René Demets	NL	ESA-coordinator
63	Antje Hermelink	DE	Former Co-I (left 2015)
64	Marina Walther-Antonio	USA	Co-I
65	Andrea Ianneo	IT	PhD student
66	Victor Parro García	SP	Co-I
67	**Frédéric Foucher**	**F**	Co-I



P-I Team, DLR-Berlin:
P-I: Dr. J.-P. de Vera, Dr. U. Böttger, Dr. Mickael Baqué

EXPOSE-R2 ISS
BIOMEX

IN TOTAL
27 INSTITUTES

12 NATIONS
3 CONTINENTS

About 70 people working for the project!

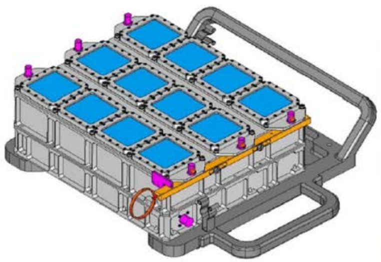
Maxim Suraev, Oleg Artemyev and Alexander Skvortsov

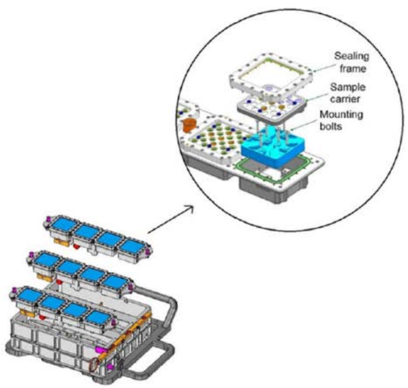
Including cosmonautes

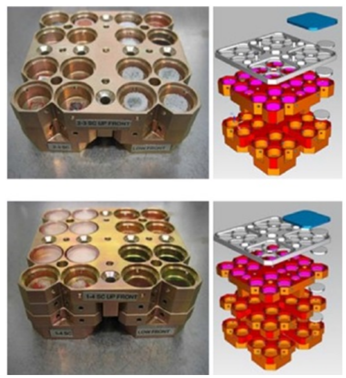
BIOMEX – an European and Worldwide Network

BIOMEX: Hardware

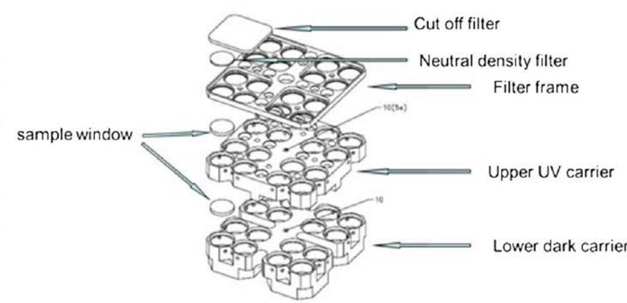
ESA/ROSCOSMOS-Exposure-Platform EXPOSE-R2 on the ISS:



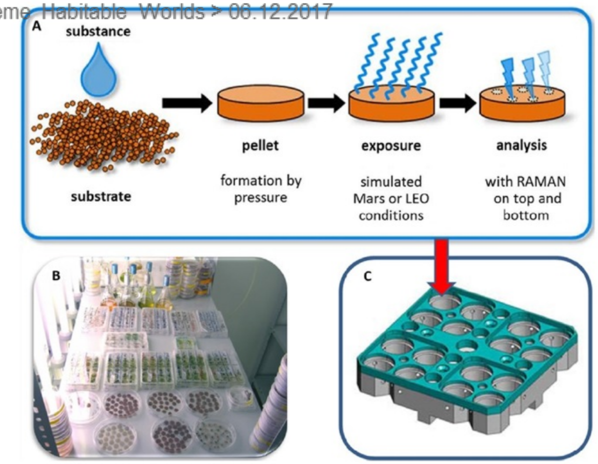




EXPOSE-R monoblock (480 × 520 × 327.5 mm) with 3 inserted trays with 4 compartments each (77 × 77 × 26 mm). The EXPOSE facility is made of three experiment trays into which four square sample carriers are fitted. (Pictures courtesy of RUAG/Kayser-Threde GmbH)



BIOMEX: Biological samples



Samples are chosen because of

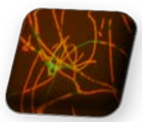
- survival of pre-flight tests
- because of being able to live under Mars-like conditions
- because of distinct detectable Raman sensitive biomolecules

Some examples of chosen most promising Mars-relevant microorganisms:

Archaea → methane producing Archaea / *Methanosarcina soligelidi*

Pre-flight tests published in Serrano et al. 2017

Bacteria → Cyanobacteria / *Nostoc, Chroococcidiopsis*



Bacteria → Iron bacteria /

Bacteria → radiation resistant bacterium / *Deinococcus radiodurans*

Pre- and Post-flight tests published in Leuko et al. 2017

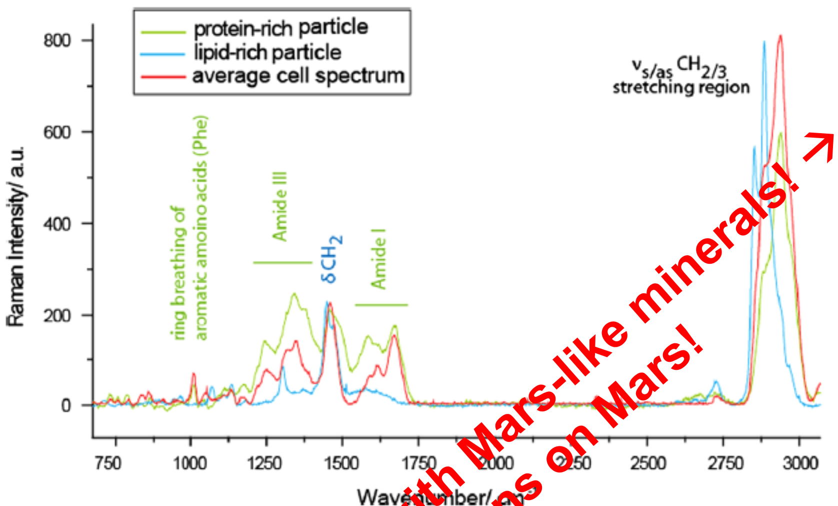
Different biomolecules mixed within Mars-analog minerals

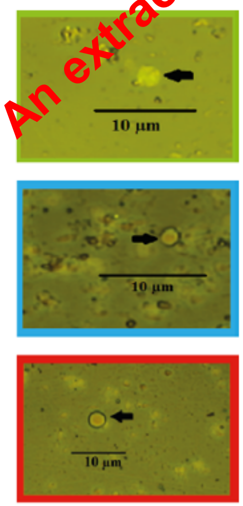
de Vera et al. 2017 in prep.

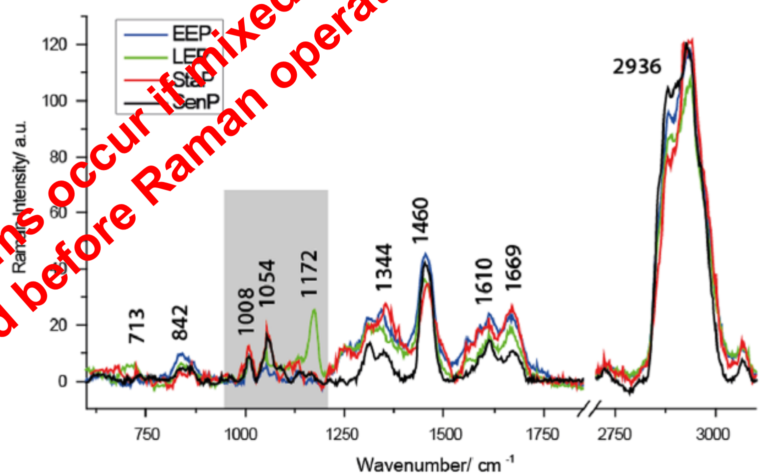
BIOMEX: some Pre-flight results – Methanosarcina soligelidi

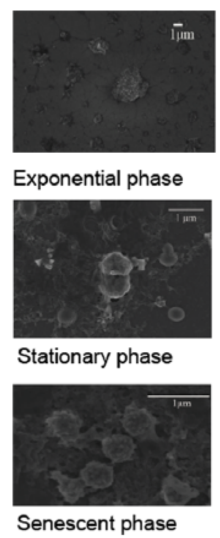
Together with Peter Lasch – Robert Koch Institute and Dirk Wagner – GFZ

The Raman biosignatures of M. soligelidi SMA-21 change over time as the archaeal cultures become older

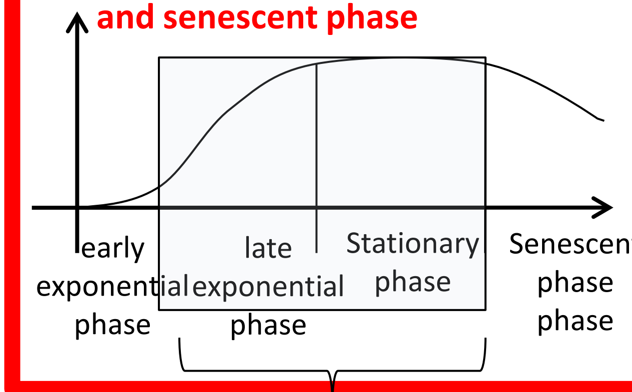


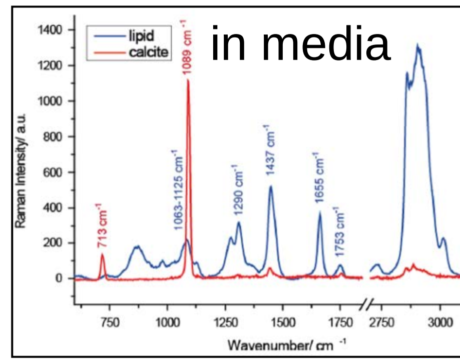


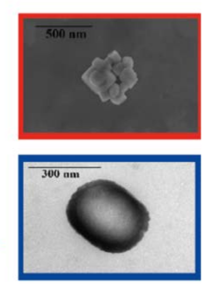




The life cycle of extant life can be monitored by Raman Spectroscopy → early and late exponential phase, stationary and senescent phase







Serrano et al. 2014, Planetary and Space Science 98 (2014), 191–197.

But problems occur if mixed with Mars-like minerals! → An extraction phase is needed before Raman operations on Mars!

DLR

BIOMEX: some Post-flight results – Deinococcus radiodurans

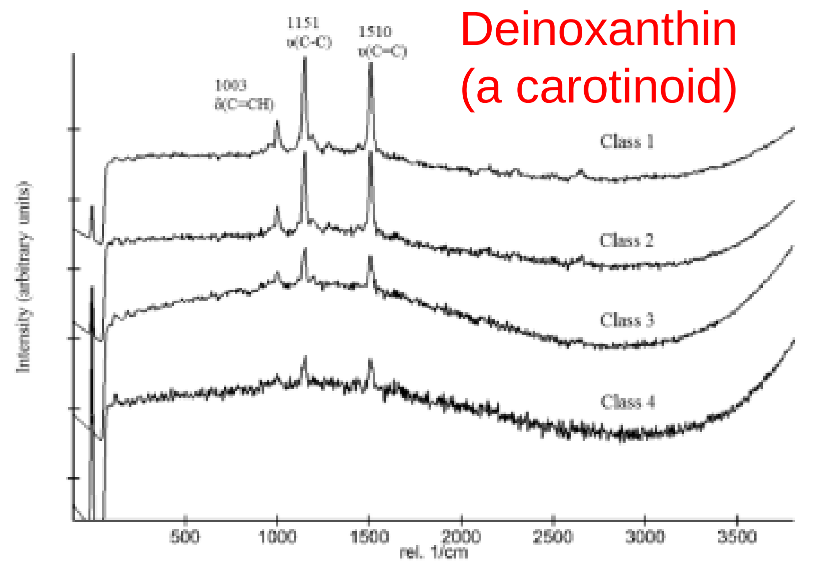


FIGURE 6 | Categorization of spectra and classification in different classes.

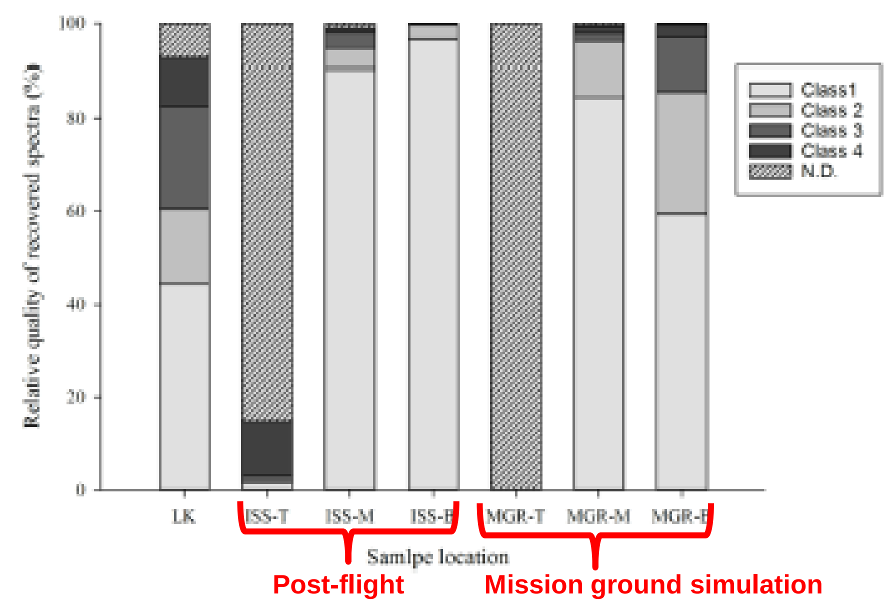


FIGURE 7 | Evaluation of the deinoxanthin signal intensity according to the defined classes (**Figure 6**) following ground simulations and samples exposed to outer space conditions during the EXPOSE-R2 mission. N.D. denotes that no signal could be determined. Eight hundred and seventy-five spectra were evaluated for each bar and scored according to the previously determined signal class (**Figure 6**). Sample location indicates whether samples were exposed to outer space (ISS) or part of the mission ground reference (MGR). LK denotes a laboratory control from the same batch that was sent to the ISS. T, M, and B describe the sample position within the tray as follows: T, top; M, middle; and B, bottom. Only the top samples were exposed to solar radiation.

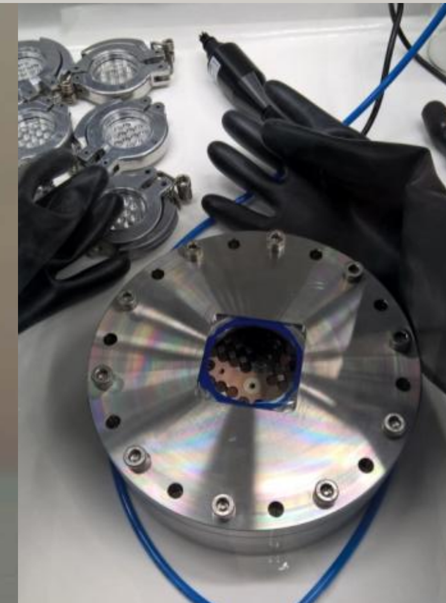
Deinococcus could be detected also if intermixed with Mars minerals and if embedded and protected by the soil!

Leuko et al. 2017, Frontiers in Microbiology

Analysis of biomolecules Flight samples without Earth's atmosphere exposure

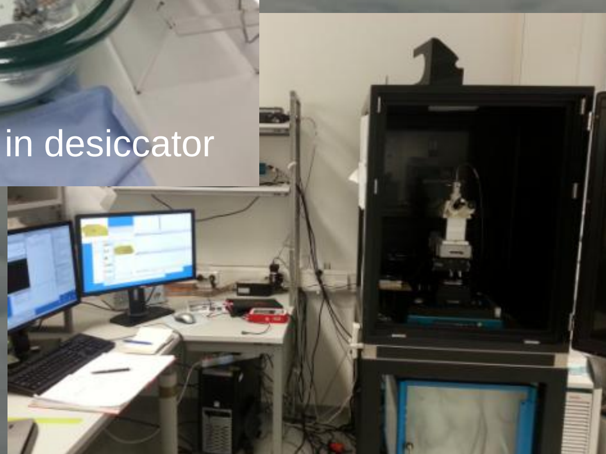
Samples kept after flight in O_2-free atmo. (anaerobic chamber) at DLR Cologne

Transferred in sealed container to DLR Berlin and to Robert Koch Institute



De-integration of samples in O_2-free conditions and transfer in Raman-capable sealed containers

Analyses under O_2-free conditions by Raman

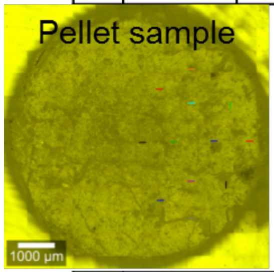


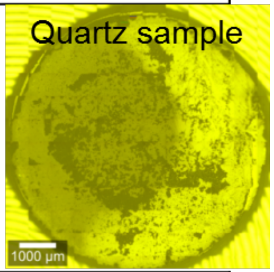
Finally stored in desiccator

BIOMEX: some Post-flight investigations are going on – biomolecules in Mars-analog minerals

	1	2	3	4	5	6	7	8
A	2-2-t-01 S-Mars ßC1	2-2-t-02 S-Mars Ca1	2-2-t-03 S-Mars Na1	2-2-t-04 S-Mars Qu1	2-2-t-05 P-Mars ßC1	2-2-t-06 P-Mars Ca1	2-2-t-07 P-Mars Na1	2-2-t-08 P-Mars Qu1
B	2-2-t-09 S-Mars Me1	2-2-t-10 S-Mars Pa1	2-2-t-11 S-Mars Ce1	2-2-t-12 S-Mars Ch1	2-2-t-13 P-Mars Me1	2-2-t-14 P-Mars Pa1	2-2-t-15 P-Mars Ce1	2-2-t-16 P-Mars Ch1
C	2-2-t-17 S-Mars ßC1	2-2-t-18 S-Mars Ca1	2-2-t-19 S-Mars Na1	2-2-t-20 S-Mars Qu1	2-2-t-21 P-Mars ßC1	2-2-t-22 P-Mars Ca1	2-2-t-23 P-Mars Na1	2-2-t-24 P-Mars Qu1
D	2-2-t-25 S-Mars Me1	2-2-t-26 S-Mars Pa1	2-2-t-27 S-Mars Ce1	2-2-t-28 S-Mars Ch1	2-2-t-29 P-Mars Me1	2-2-t-30 P-Mars Pa1	2-2-t-31 P-Mars Ce1	2-2-t-32 P-Mars Ch1
E	2-2-t-33 quartz ßC1	2-2-t-34 quartz Ca1	2-2-t-35 quartz Na1	2-2-t-36 quartz Qu1	2-2-t-37 S-Mars Ag1	2-2-t-38 P-Mars Ag1	2-2-t-39 S-Mars ---	2-2-t-40 P-Mars ---
F	2-2-t-41 quartz Me1	2-2-t-42 quartz Pa1	2-2-t-43 quartz Ce1	2-2-t-44 quartz Ch1	2-2-t-45 S-Mars Ag1	2-2-t-46 P-Mars Ag1	2-2-t-47 quartz Co1	2-2-t-48 quartz Ag1
G								
H								

	Pellets	
1	βC1	β-carotene
2	Ca1	chlorophyllin (Na salt)
3	Na1	naringenin
4	Qu1	quercitin (dihydrate)
5	Me1	melanin
6	Pa1	parietin
7	Ce1	cellulose
8	Ch1	chitin
9	Ag1	agar-agar
10	---	S-Mars pellet control
11	---	P-Mars pellet control



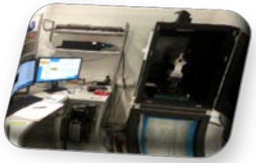


	Quartz	
1	βC1	β-carotene
2	Ca1	chlorophyllin (Na salt)
3	Na1	naringenin
4	Qu1	quercitin (dihydrate)
5	Me1	melanin
6	Pa1	parietin
7	Ce1	cellulose
8	Ch1	chitin
9	Co1	Control
10	Ag1	agar-agar

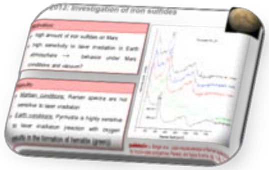
DLR

Conclusion

- Raman Spectroscopy is an excellent tool to be used in Planetary Research and in particular for Astrobiology (detection of life)

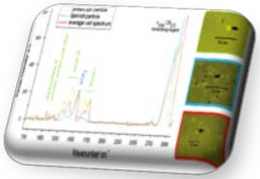


- Environmental conditions of the sample during measurements could change the spectra ranges and therefore a data base has to take thin into account these variables

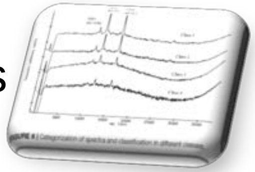


- A Life cycle of an organisms can show different Raman spectra → important for data base

- Depending on the investigated species, some organisms could not be detected if mixed in Mars-analog mineral mixtures → an additional extraction of the soil substrate would be needed to be certain there is life / no life



- Some biomolecules can even be detected in Mars-analog environments



- Further work is needed if testing organisms selected from ocean and deep sea sites (relevance for the icy moons of Jupiter and Saturn)

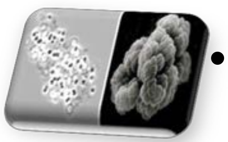
Further work – Experimental habitability / Limits of life studies

- Preflight results (Post flight analysis still under investigation)

Highlights

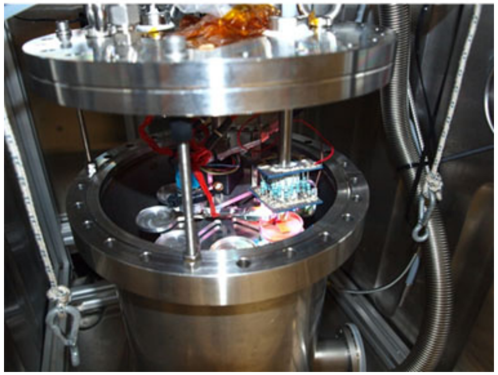
- Lichens survive and are photosynthetically active in Mars-like environments (de Vera et al. 2010, 2012, 2014, Brandt et al. 2014, Meeßen et al. 2015)

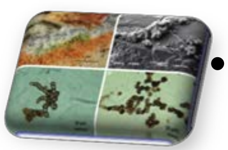
Perhaps relevant for soil formation



- Methanogens survive and are active in Mars-like environments (Schirmack et al. 2014)

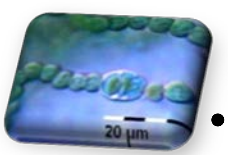
Perhaps relevant for warm climate and for use as fuel in a cold world



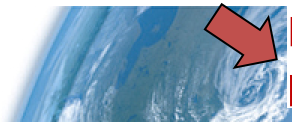


- Fungi survive and produce proteins in Mars-like environments (Zakharova et al. 2014, Onofri et al. 2015, Pacelli et al. 2016)

Perhaps relevant for soil formation and depending on species as food



- Cyanobacteria survive Mars-like environments (de Vera et al. 2014, Baqué et. al. 2013,)



Perhaps relevant for oxygen production and nitrogen fixation

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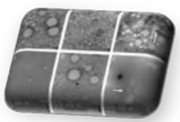
Further work – Stability of potential immune system triggering nutrient "Kombucha"
- Preflight- and Postflight results

Highlights

- Core community of bacteria and yeasts of the probiotic beverage Kombucha survived and provided protection against UV and simulated Mars-like conditions in the lab (O. Podolich et al. 2017a)



- Microbial density of Kombucha population was reduced after simulated Mars-like conditions in the lab (O. Podolich et al. 2017a)

- Reactivation of Kombucha community was possible after space exposure, but reduced diversity in the biofilm was observed (O. Podolich et al. 2017b submitted)

Results in Astrobiology are also relevant for Human Exploration of other Planets

Food production

Protection again harmful radiation

Manned Space Missions

Important gases for Life support systems

Trigger for human immune system

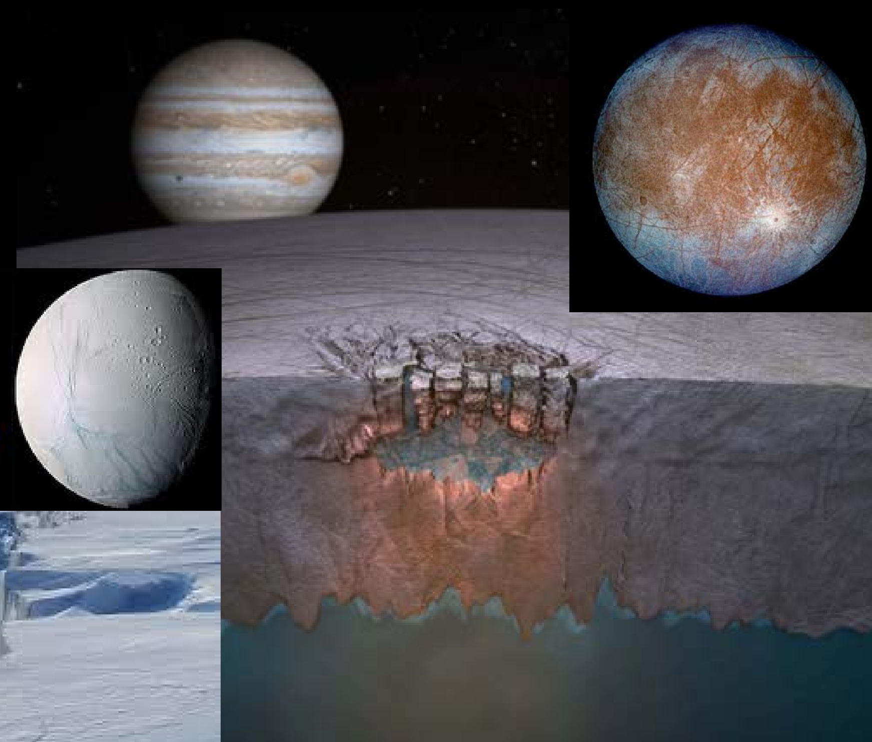
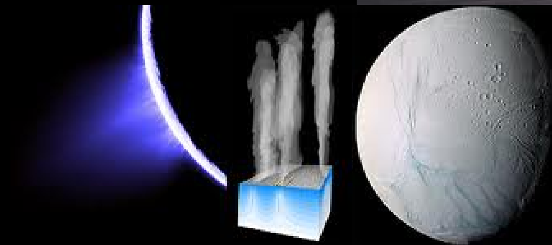
Fertilization of soils

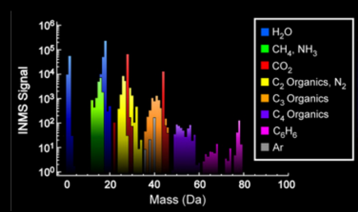
Production of Bio-fuel

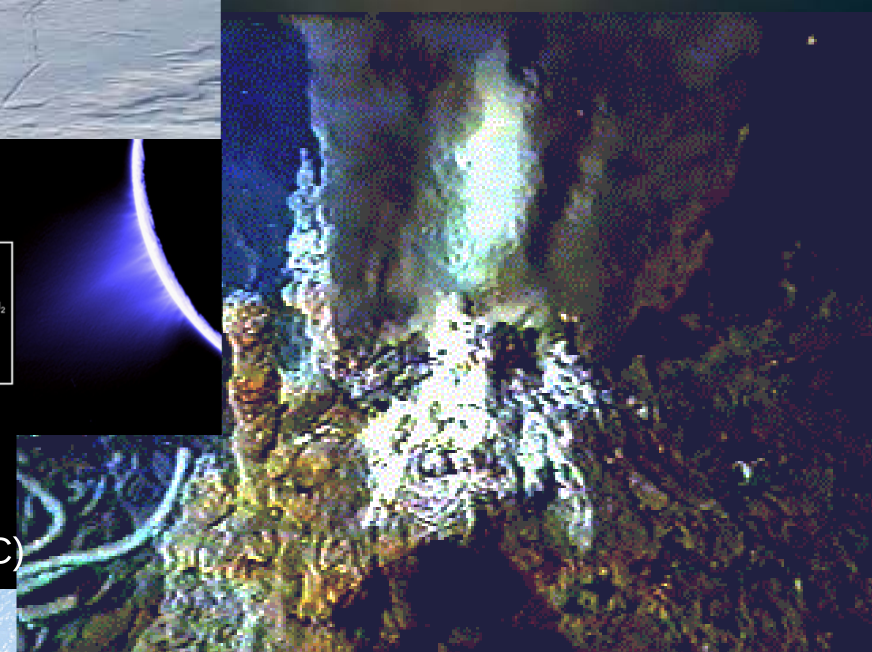

BIOSIGN – Biosignatures and habitable Niches
Jean-Pierre de Vera and Co-Is
Including ROBEX
Knowledge for Tomorrow

Science case

- **Habitability of icy moons**
- **Detection of Extant and extinct life**
- **Stability of Biomolecules / Biosignatures**
- **Origin of gases measured within plumes**
- **Interaction of radiation and water/ice, salts and organics**
- **Plume photo-chemistry**

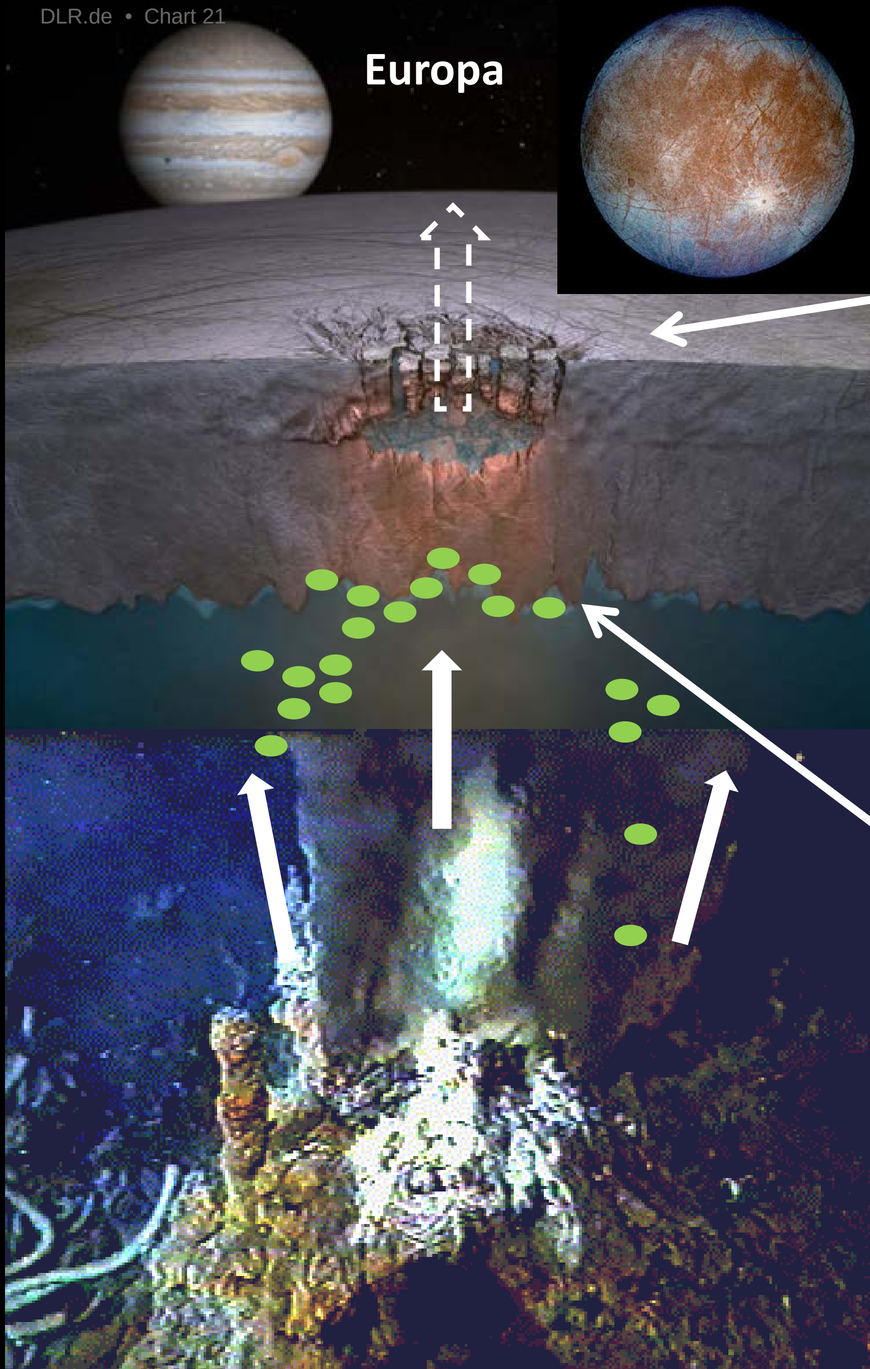




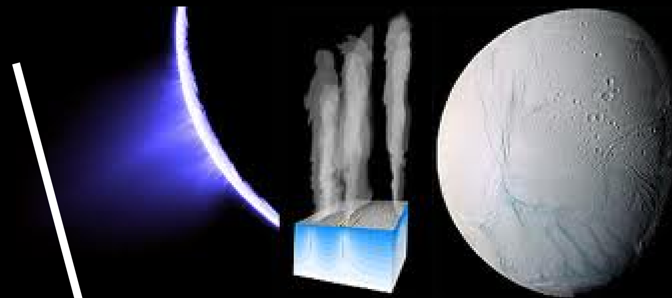
Surface110 K (ca. –160 °C) at Equator und 50 K (ca. –220 °C)

DLR

Europa

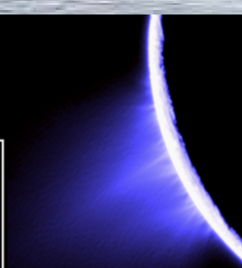


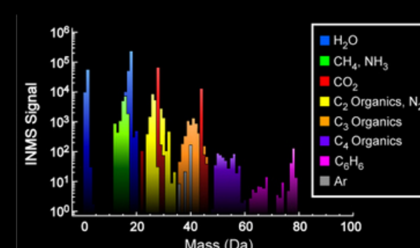
Enceladus



Organics: with space reacting Deposits on ice possible

Deep sea material coming up and accumulating below the ice in a kind of ice-magma plume before being ejected by geysers into space

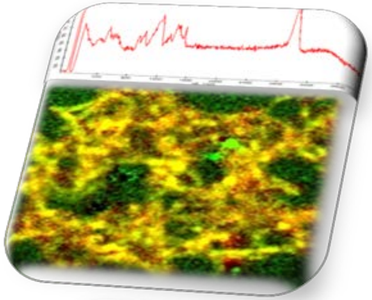


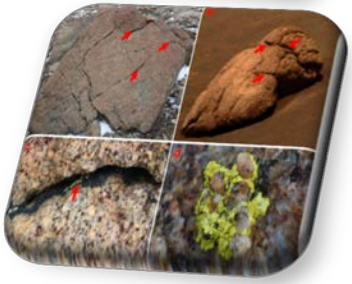


Main objectives

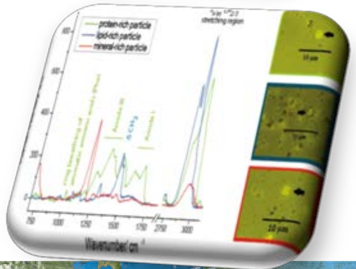
- The main objective of **BIOSIGN** is:
  to support **future planetary exploration missions** by a set of science experiments performed on the ISS

1. to analyze the extent to which selected **organisms** and **(micro-)fossils** from planetary / Mars- / Enceladus- / Europa-analog field sites (from the **deep sea** to **polar/alpine sites)** can survive/outlast the conditions of simulated planetary analog conditions and space exposure





2. Investigation of particular **planetary analog environments** and **niches** which can be most suitably simulated in space exposure experiments (ref. LIFE and BIOMEX)

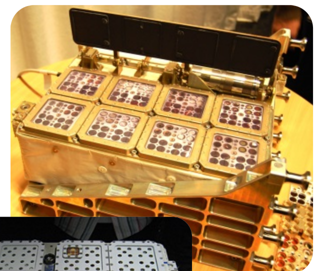


3. to analyze a **new set of bio-molecules** (other than previously tested in BIOMEX) on their stability as well as on their products and mechanisms of degradation.

DLR

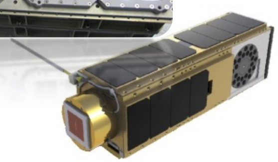
Methods / Techniques proposed

- Use of ISS-EXPOSE platforms (and satellites)
- EXPOSE-E

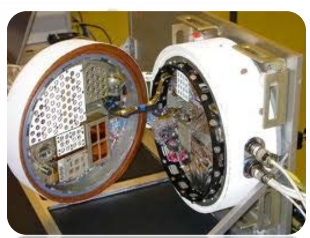


- EXPOSE-R

- CUBE-sat.

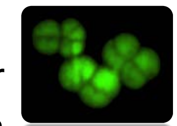


- BIOPAN-like-Sat.

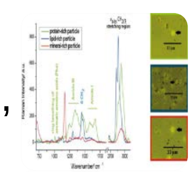


- Methods / analysis

1. **habitability**:
   vitality tests, (ultra-) structural analysis, screening methods for DNA-damage, investigations on photosynthesis and metabolic activity and growth rate assays of the organisms



2. **bio-signatures / traces**:
   fluorescence microscopy, Raman-, IR-spectroscopy, UV-, VIS-, and IR-spectrometry, as well as HPLC-mass spectroscopy.



Our team:

> 15 Institutes
8 countries

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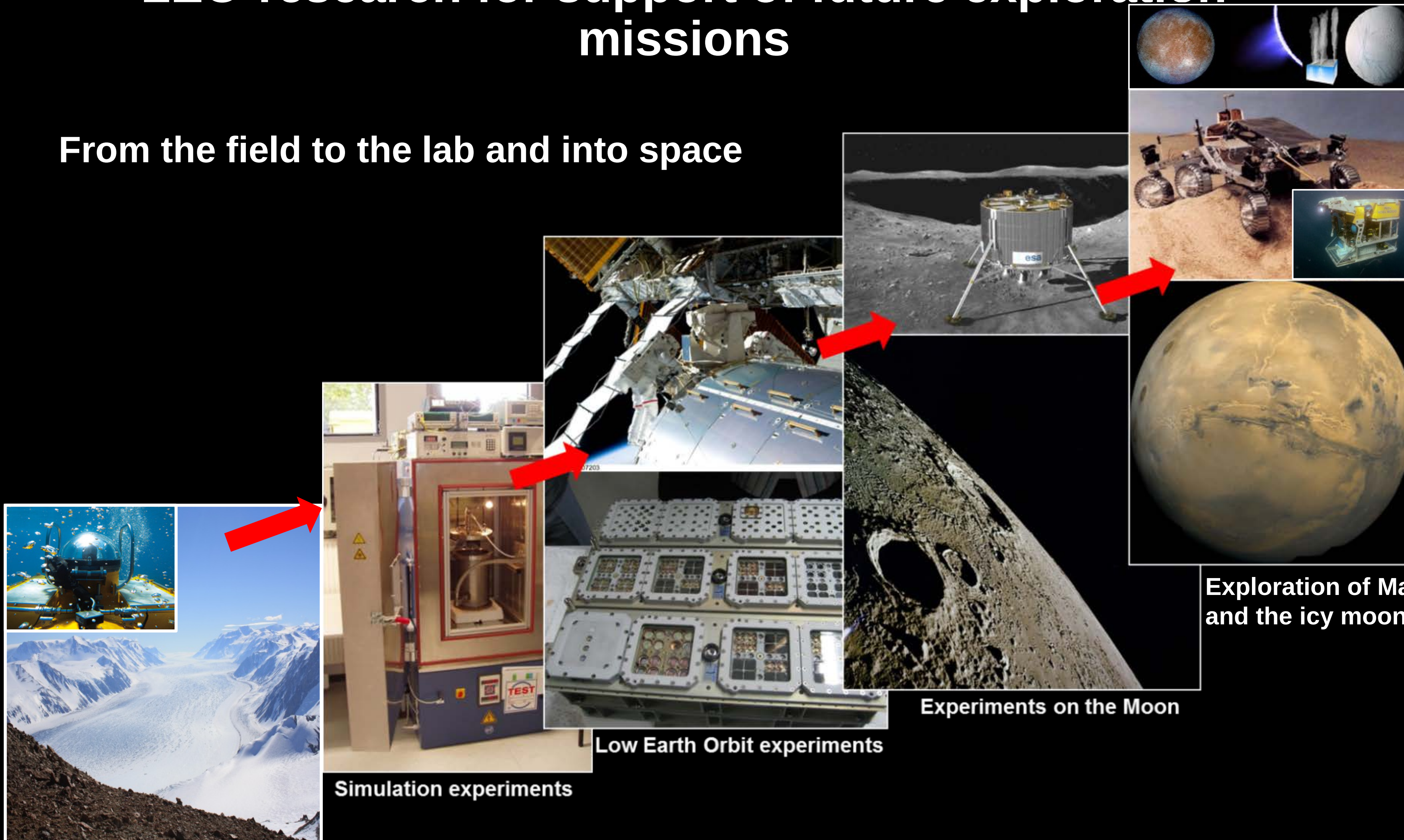
BIOMEX and BIOSIGN are combining field-, lab- and LEO-research for support of future exploration missions

From the field to the lab and into space



Field studies

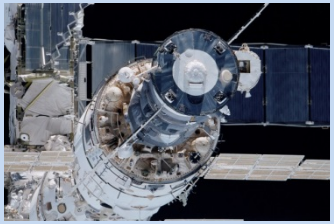
Simulation experiments

Low Earth Orbit experiments

Experiments on the Moon

Exploration of Mars and the icy moons

Acknowledgements



Astronauts / Cosmonauts

ESA

NASA

ROSCOSMOS

EANA

BMWi

Helmholtz-Alliance

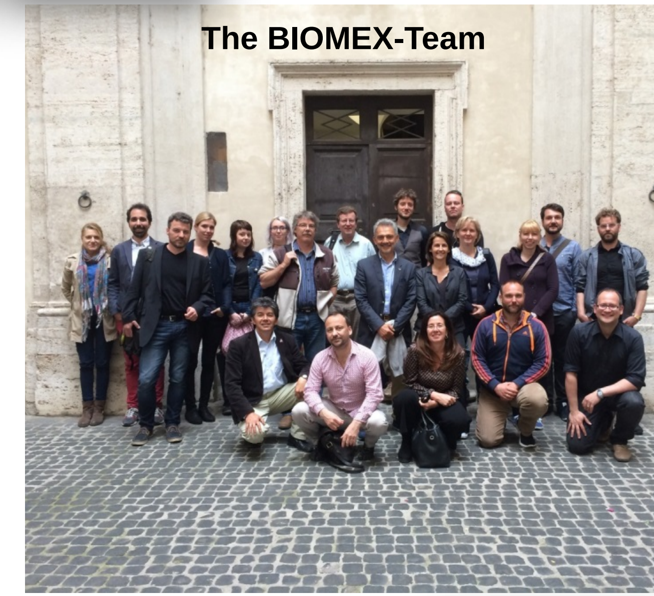
ASI

INTA

RKI

DLR + BGR + HNZ

DLR-Research Group Astrobiological Laboratories



The BIOMEX-Team

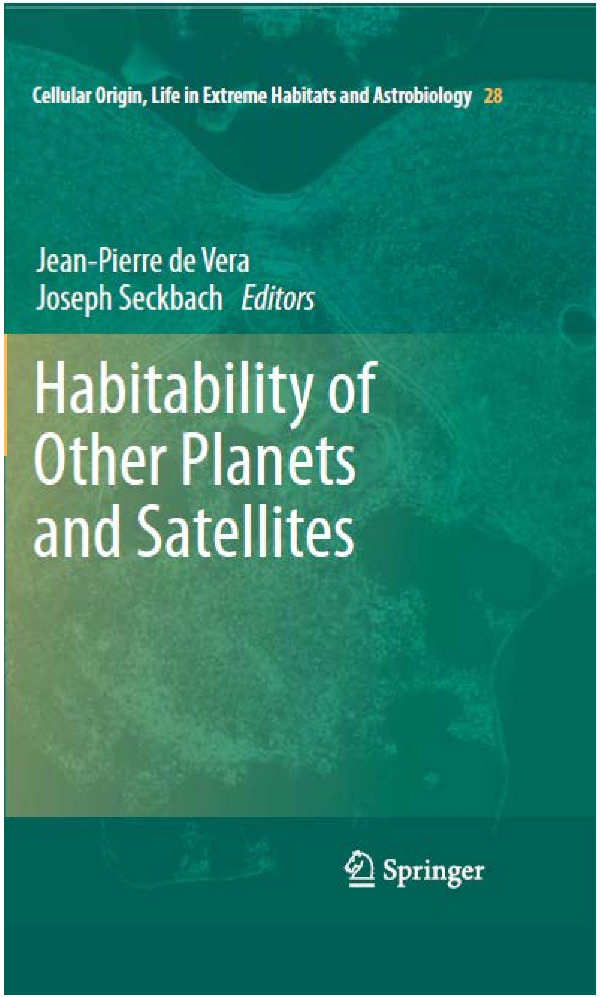
The GANOVEX-11 Team

Nicole Schmitz

Peter Lasch

Crew of Italica

Some Literature on Habitability



J.-P. de Vera, Institute of Planetary Research, Berlin, Germany; **J. Seckbach**, The Hebrew Univ. of Jerusalem, Jerusalem, Israel (Eds.)

Habitability of Other Planets and Satellites

Series: Cellular Origin, Life in Extreme Habitats and Astrobiology, Vol. 28

- Dedicated chapter illustrating alternative life compared to our Earth-centric considerations
- New mission concepts for remote studying of habitability of exo-planets
- In situ investigations of the Polar Caps of Mars and the icy Moons of Jupiter and Saturn
- State of the art collection from experts in relevant fields Systematic approach to define habitability of planets

Is Earth the right model and therefore our Earth-centric view the only universal key to understand habitability, the origin and maintenance of life? This book tries to give answers on this question. It gives insights into the nature of planets and their potential to harbor life as well as the role of life itself as an engine to increase the habitability of planets and satellites. Knowledge of different disciplines in Astronomy, Biology, Chemistry, Geology, Planetology and Physics are the driving force for the discussion what might be the clues to classify a planetary body as a habitable object. The role of the atmosphere, solar radiation, magnetism, tectonics, mineral composition, liquid water availability and the interactions with life are in the focus of the general discussion. Earth serves as the reference system to get an approximation of the factors which might be important for classification of a celestial body as a habitable object. Results from field studies and those obtained from laboratory studies in planetary simulation facilities will help to elucidate if some of the planets and satellites in our solar system are potentially habitable for terrestrial life forms. The discussion is also enlarged in particular to exo-planets and their potential to be habitable. Further, recent technologies are presented in this book which might be suitable for remote or in situ identification of habitable environments and life as we know it. Instrumentation, detection devices, space projects and space mission designs to search for habitable niches and life is part of this work and gives insights into the challenges we might confront if we pursue the main task to detect life. The initial step of these exploration endeavors might be to discover first habitable environments and then to look after life forms with life detecting instrumentation in the discovered habitable niches.

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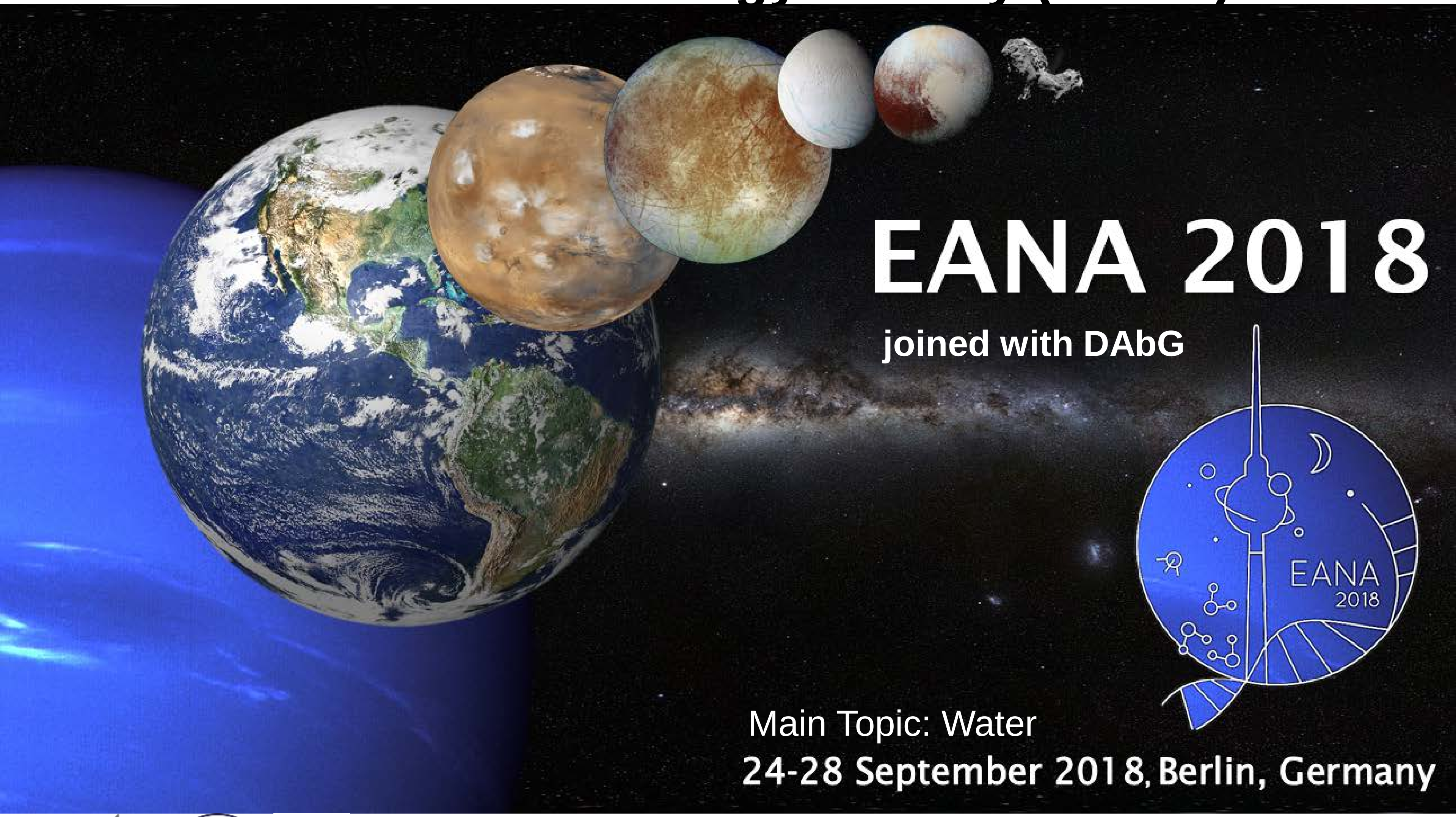
http://www.springer.com/life+sciences/ecology/book/978-94-007-6545-0

Joined Conference EANA 2018 together with the German Astrobiology Society (DAbG)



Thank you! – Time for questions!

BIOMEX-Meeting in Rome (10.05-12.05.2016)