Exoplanets, Bacteria and Mars

– a series of on-line "corona-lock-down meetings" during the summer of 2020

Shortly before the close down of the university in March 2020 due to the Corona pandemic, I had been lucky to receive a synergy grant from the Novo Nordisk Foundation to study the "Effects of bacteria on the atmospheres of Earth, Mars and exoplanets". At the same time I was participating in the selection process of PhD fellows for our newly granted Marie Curie ITN network "CHAMELEON – virtual laboratories for exoplanets and planet forming disks", which was to start in June 2020. The two projects together involves 19 new PhD students, 2 new post.docs. and 15 staff members from Denmark and 4 other European countries. To keep the interaction with the existing and coming students during the lock-down, we quickly initiated regular zoom-meetings. Soon the discussions we had during these meetings attracted interest from other of our colleagues too, and grew into regular workshops with enthusiastic discussions about the science projects we were to embark into once the universities would open up again. It is the power points from 8 of these meetings that are collected below as a lasting inspiration for ourselves and others about what we have now been given the possibility to work on thanks to the synergy that has already grown out of these two projects – not as an official start, but rather as an excitement about what is soon to be.

The Novo Nordisk supported synergy project involves three different institutes at University of Copenhagen; the department of Chemistry, the department of microbiology, and two different sections of the Niels Bohr institute (NBI). My own group at the astrophysics section of NBI is involved in the study of exoplanets; we are doing computer simulations of the atmospheric structure of stellar and exoplanetary atmospheres, and the section also includes Morten Bo Madsen who has been involved with experiments onboard the bulk of NASA's landings on Mars. The part of the biocomplexity section at NBI included in our grant is lead by Jan Härter with his group of students and post.docs. who have specialized in understanding the microphysics of the cloud formation process. The group at microbiology is lead by Anders Priemé and he and his students are involved in studies of bacteria living under extreme conditions on Earth, and finally the group around Henrik Grum Kjærgaard at the institute of Chemistry is studying the chemical processes of Earth's atmosphere and has also been involved in the chemistry of Venus.

Together our groups from the 3 institutes is now given the posibility to study the limits of life on Earth, experiment on how extreme life forms can potentially be transformed to survive on Mars and help facilitate the coming human colonization of the planet, and to simulate how this new knowledge can help us identify and understand potential lifeforms on the nearest exoplanets through observation of their spectra. In the simulation chamber that Morten has build and we are now expanding to accommodate the new bacteria experiments, we will collect the metabolic gasses from microorganisms exposed to various conditions that could exist on Mars as well as on exoplanets that it will soon become possible to take high-resolution spectra of. In the chemistry lab we will measure the monochromatic absorption coefficient of these gasses, and with our computer simulations we will model how the spectrum of different exoplanets would look like if microbiology with some similarities to the kind we grow and identify in the lab experiments exist out there on foreign worlds. In this way we will be able to not only identify, but also quantify, the biological activity we may soon identify on exoplanets by use of upcoming instruments such as the spectrographs of the European Extremely Larege Telescope (ELT).

The presentations below begin with the power points from May 15 by four master students of Morten, Anders and me, who have been doing laboratory experiments in the Mars simulation chamber and have done modelling of the associated exoplanetary atmospheres. The contribution from May 29 are by Henrik's students and post.doc. about the projects related to the chemistry side, while the power points from the meeting on July 10 presents the work done in Jan Härter's group. During the meeting on August 7, Morten gave a presentation of the Mars simulation chamber itself, as well as an introduction to the coming landing on Mars by the MARS 2020 Perseverance mission.

The CHAMELEON project, reveivew on July 24, focuses on the theoretical understanding and development of the complex physics and chemistry that goes into the numerical modelling of the structure (and spectrum) of an exoplanet as well as the dust-gas structure of a protoplanetary disk where new planets are formed. In this sense it both overlaps and complement the aim of the Novo Nordisk project, and it forms a modern basis for successful interpretation of the spectra of foreign worlds and quantification of their potential traces of extraterrestrial lifeforms. The meeting on July 24 was devoted to discussions of the work performed at the leading node of the network, in St Andrews, by Christiane Helling (PI of the network) and Peter Woitke and their group of students. Their 5 presentations are discussing aspects of generalized cloud formation in exoplanets and protoplanetary disks as well as the role of liquid water and how lightening can tricker prebiotic chemistry. In a direct extension of the theoretical studies of the role of lightning and high-energetic radiation on the cloud nucleation process and its potential role for the formation of pre-biotic material, two of the CHAMELEON students will spend part of their time doing experiments in the cloud formation chamber at the Technical University of Denmark (DTU) in Lyngby near Copenhagen, under the supervision of Martin Enghoff and Henrik Svensmark who discussed the abilities of the cloud chamber in their presentation on August 7.

The grant we received from the Novo Nordisk Foundation was part of their call for "Interdisciplinary Synergy programme 2019". One of the other projects that received support from this same call was the project "Deciphering the Role of Atmospheric Microbial Aerosols" (DRAMA) at Århus University with Kai Finster as PI. This project builds on the idea that a large fraction of the nucleation seeds for cloud formation on Earth actually isn't solid mineral grains as often assumed, but microscopic living bacteria. Maybe as much as one out of every five raindrops in the clouds on Earth are formed by water condensing on a free floating bacteria. One effect of the bacteria nucleation is that it affects the condensation temperature. When I heard about this brilliant idea, there was of course immediately a bell that rang, saying that then the whole energy balance in exoplanet atmospheres of a given chemical composition is different dependent on whether microbial lifeforms floats in the exoplanet atmosphere, as on Earth, or not, and we will be able to see that in the spectra of exoplanets hundreds of light years away. We now aim at including these effects into our numerical modelling of exoplanets with and without biology. The presentation and discussion on June 12 was devoted to this subject, and we are now planning a common workshop between the two synergy groups once the corona viruses allow us to meet again in person.

Yet another new Novo Nordisk supported project that overlap with our Bacteria-Exoplanet-Mars project is the Emerging Investigator support the foundation granted to Johan Andersen-Ranberg at the department of plants and environment at University of Copenhagen. This project aims at studying whether algae can be modified to use perchlorate in their metabolism, and thereby potentially help facilitate the coming colonization of Mars. This is the same idea as goes behind some of the experiments we do in our Mars simulation chamber to study how perchlorate using bacteria can potentially do the trick. The implication for human colonisation of Mars as well as identification of lifeforms in the coming spectroscopic observations of the nearest Earth-like exoplanets (and biological cleaning of perchlorat poluted environments on Earth) is obvious, and the meeting on June 26 was devoted to this discussion.

We decided to end this series of on-line discussion-meetings as the university finally open up again for physical presence during September 2020. It has been a terrifying experience to see how voulnerable humanity and our modern civilisation are toward the Earth's microbia, but it has also been assuring for me to see how the necessary lock-down combined with modern technology and the curious minds of the many inspiring colleagues and students I am priviliged to interact with, in the end lead to an enhanced synergy and eyeopening new insight into new possibilities of understanding of the world around us — in Danish there is a saying that "nothing is so bad that it is not good for something else"; it is my hope that the information stored in the presentations below will contribute to increase the synergy between the many different fields and persons involved, and inspire also others outside our small circle of friends and colleagues.

Uffe Gråe Jørgensen, professor in astrophysics & planetary sciences,
(now back at) the Niels Bohr Institute, University of Copenhagen, September 2020.

The program and the speakers:

May 15:
The Mars chamber and exoplanets
by master students Angeliki Christakopoulou, Cecillie P. Knudsen, Nanna Bach-Møller, Poul Kari Madsen

Ongoing projects on studying the growth-rate of bacteria exposed to variations in temperature, atmospheric composition, and level of UV radiation. Simulation of martian guilles and their relation to liquid water on Mars. Computation of non-equilibrium atmospheres exposed to biological activity.
Supervisors: Professors Morten Bo Madsen, Uffe Gråe Jørgensen, Niels Bohr Institute,
and professor Anders Priemé, Institute of Biology, University of Copenhagen.

May 29:
The atmospheric chemistry
by master, PhD and postdocs Emil Vogt, Kristian H. Møller, Pablo B. Valls
Computation and measurements of the chemical composition and reactionrates in Earth's and Venus' atmospheres. Development of the instruments. Organic and non-organic molecules in exoplanet atmospheres.
Supervisor: Professor Henrik Grum Kjærgaard, Department of Chemistry, University of Copenhagen

June 12:
The influence of bacteria on cloud formation
Professor Kai Finster, Institute for Bioscience, Århus University
Kai's research has span questions from freezing-point lowering proteins in bacteria, over habitability conditions of Mars, to the search for biotechnology signs on exoplanets. With start in 2020, Kai has received a grant from the Novo Nordisk synergy program 2019 to set up an experiment to study how microbiology

influences the cloud formation, and hence drastically can modify the exoplanetary (and Earth's) energy balance. He will indtroduce this project, which he calls DRAMA, in the presentation, and discuss the role of microbial aerosols on cloud formation and how it can be experimentally simulated.

June 26:
Algae and perchlorate, and potential applications for the coming colonisation of Mars.
Assoc. prof. Johan Andersen-Ranberg, department for plants & environment, Univ. Copenhagen
Together with colleague Sillas Busck Mellor, Johan presents how algae might utilize perchlorate to form oxygen, and hereby potentially clean the martian soil for perchlorate. Mars has a relatively high abundance of reactive perchlorate (it is a salt, ClO_4) in the surface soil, which may be a challenge for the first steps of the coming colonization of Mars. It is today believed that the high reactivity of ClO_4 was the reason behind the reactions in the Viking experiment that initially looked like a signature of life.

July 10:
Cloud formation and convection.
PhD students and postdocs Bettina Meyer, Gorm Gruner Jensen and Sillas Boye Nissen
Supervisor: Assoc. prof. Jan Härter, Niels Bohr Institute, University of Copenhagen
The "Atmospheric complexity" group (www.nbi.ku.dk/english/research/biocomplexity/atmospheric complexity/) is part of the section for biocomplexity at the Niels Bohr Institute. Here the group present an overview of their work on convection modeling and cloud formation in Earth's atmosphere. Clouds may form high or low in the atmosphere, and they affect the energy balance radically different dependent on where they form, and chaotic processes may lead to sudden and violent rain fall. Exoplanets will widely expand the parameter space and types of convection, cloud, and energy budget we will be able to study.

July 24:
The CHAMELEON project – understanding exoplanet atmospheres and protoplanetary disks.
PhD students Oliver Herbort, Dominic Samara, Patrick Barth
Supervisors: Ass. profs. Christiane Helling and Peter Woitke, University of Sct Andrews.
Five presentations by Christiane Helling and Peter Woitke's group in St Andrews, which include the subjects of cloud formation, mantel compositions and biosignatures. Christiane is PI of our ITN double PhD degree network CHAMELEON. She will introduce us into the ideas of the network. Peter is likewise one of the central initiative takers of the CHAMELEON project, and he will talk about the protoplanetary disk part of the network. The three students will talk about water and cloudformation on exoplanets, as well as abot how lightning and high energetic radiation can tricker formation of pre-biologic molecules in exoplanet atmospheres as well as in the protoplanetary disks where planets are formed.

August 7:
The Mars simulation chamber and the Perseverance mission to Mars in 2020.
Assoc. prof. Morten Bo Madsen, Niels Bohr Institute, University of Copenhagen
Morten's group has been involved in instruments for the bulk of all NASA's Mars landings, including studies of the magnitic properties of martian dust, camera calibrations, Moesbauer spectroscopy, and site selections. It is also one of Morten's former students that build the first version of the Mars simulation chamber which we are now expanding to be able to manipulate bacteria that may one day help us living on Mars and which may reveal the presence of life on remote exoplanets. Here he tells the story of how the Mars chamber came about and what to expect from the ongoing Mars 2020 probe Perseverancee.

August 21:
High-energetic radiation, cloud formation, and pre-biology in the cloud simulation chamber
Assoc. prof. Martin Enghoff, DTU Space, the Technical University of Denmark.
Together with his colleague Henrik Svensmark, Martin will tell about how cloud formation is affected by high-energetic radiation and how this radiation might trigger the formation of pre-biologic molecules. In collaboration with the CHAMELEON project, experiments will be set up to measure how lightning, which might be identified observationally in brown dwarfs and protoplanetary disks, facilitates the dust condensation and growth, and potentially can contribute to the first pre-biological molecule formation.