Three "Top" Columbus Laboratory Scientific Results after 10 Years in Orbit
Joachim J. Kehr, Editor SpaceOps News

The remarkable year 2018 marks the 20th anniversary of the launch of ISS' first element Zarya (20. November 1998) and also marks the 10th anniversary of the launch of the European ISS laboratory Columbus (7. February 2008) - reason enough to take a closer look at the scientific results of ISS and Columbus.
The following summary was compiled and selected from NASA, DLR and scientific Internet publications. [1-5]
The judgment of the selected "top" results is rather subjectively driven by the taste and evaluation of the author – the real value of the results might not be known yet because, on the one hand follow-up long term experiments are needed and on the other hand evaluating scientists and industry might be reluctant to publish break-through findings before they are absolutely sure about the final confirmation within their research community. The preference of the author was focused on experiment results having potential practical value for the "tax payer" i.e., the population at large and are pointing to follow-on developments in the future.

A total of 161 ESA/DLR experiments have been conducted so far within Columbus and additional 67 experiments in cooperation with international partners and commercial users. More than 100 astronauts have been working on the ISS since ESA astronaut Hans Schlegel commissioned the Columbus laboratory after in February 2008. In June 2018 ESA astronaut Alexander Gerst will continue experimentation activities in Columbus and as ISS commander of the ISS mission , "New Horizons".[6]

Columbus operations are coordinated by DLR's Columbus control center (Col-CC) at Oberpfaffenhofen (Bavaria). Approximately 80 scientists and engineers at DLR's German Space Operations Control Center (GSOC) supervise and coordinate the European activities on the ISS: GSOC has been monitoring and coordinating operation in the Columbus module for more than 87,600 hours since its launch on February 7th 2008.

In addition to the experimentation and proofing of new technologies, ISS research also covers basic and application-oriented research areas such as life sciences, materials science, physics, biology, medicine and earth observation. The topic of education has also become more and more a new focus. The three selected experiments are from the categories technology (ColAIS), Physics (PK-3) and Gravitational Biology (Cell-Box 2)

1. ColAIS Secure Maritime Traffic from Space [7]

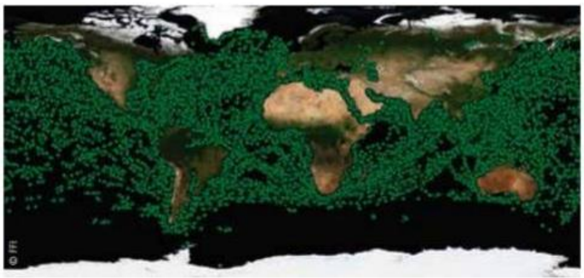

Fig. 1: ColAIS sample from June 1, 2010: From 19:00 to 9:00, the NORAIS receiver collected more than 90,000 Class A ColAIS messages.

Background.
Mankind's largest moving structures are ships. You can carry large quantities of goods with little staff and little effort. Around 45,000 merchant ships currently ply the oceans, transporting nearly seven billion tons of goods per year. Over 90% of total world trade and almost 70% of German imports and exports are handled by sea. Ensuring the safety of this fleet helps to secure the global trade. Satellite systems offer

new possibilities for surveillance, especially surveillance of the high seas. Ships and their exact positions are recognized and mapped from space. The Columbus Automatic Identification System (ColAIS) on ISS receives the signals sent by the ships, thus determining their position and sending the data back to earth. Until the commissioning of ColAIS, the automatic identification system (AIS) was only applied in coastal areas. It is now to be extended together with other orbital systems and thus increase the range and enable the reception of the signal types outside the earth's atmosphere. This is how ColAIS should make our sea-transport routes even safer in the future. The experiment facility is part of the Vessel ID system, which was operated from the space station during the "Blue Dot" mission of German ESA astronaut Alexander Gerst in 2016 also.

Hermann Oberth already postulated in his book "The Rocket into Planetary Space" (1923): "If we let such large rockets circle the Earth, they would provide a small moon, so to speak. They would no longer needs to be configured for descent. Traffic between them and Earth could be maintained with smaller apparatuses so that these large rockets (we will call them observation stations) can be converted more and more for their original purpose ... With their percise instruments, they could recognize details on Earth and send light signals with appropriate mirrors [antennas] to Earth ... the station could detect icebergs and warn ships either indirectly by reporting the iceberg to a marina observatory, which would then provide a the telegraphic notification of its location or directly if its mirrors are powerful enough that ships can detect them through mostly foggy air. The Titanic disaster of 1912 could have been prevented in this way, for example. The stations could also contribute a lot to the rescue of castaways, to news services etc. "

Results

ColAIS is still in a validation phase. The functionality of the system has been proven. In four months, 30 million messages were received by AIS transponders on more than 60,000 different ships of all classes and sizes.

Perspectives for research and application:

Sweden, Norway but also the EU, the UN and international shipping authorities show interest in ColAIS. After a sufficient test phase on the ISS, a private system for worldwide monitoring of shipping traffic could become a reality in the near future. ColAIS transmitters could be used as certified personal emergency transmitters. Activated by castaways, the sender could send an emergency message and at the same time send the position of the built-in GPS receiver via AIS. With several days of broadcasting life-time, the device could speed up the rescue and save lives. Ships involved in the rescue can accurately locate people in distress on their chart-plotters. The AIS data, which are inserted into the electronic nautical chart, are currently superimposed on the registered sea markings of today's identification standards. At present, there is no standardized representation of AIS navigation marks because these signals are available all over the world, international efforts to standardize these data would be desirable and an important step to make our "seaways" even safer in the future. Since AIS works in a similar wavelength range as mobile phones, a further development of modern AIS receivers is necessary.

Experiment Components:

ERNObox (Computer), NORAS-Receiver, LUXAIS-Receiver; Institutions/Partners : FFI, Seatex, ESA, Airbus Defence in Norway, Bremen, ESA)

2. PK-3 Investigating Complex Plasmas [7]

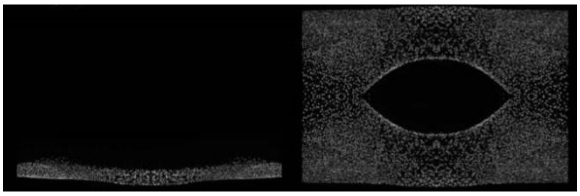

Fig. 2: A complex plasma is compressed under the influence of gravity towards the center of the earth (left). In weightlessness, on the other hand, a large, three-dimensional, complex plasma structure can arise (right).

Background and scientific goals

Plasmas are actually considered the most disordered state of matter. The visible matter in the universe is about 99% of plasma - including the sun, lightning and northern lights. A complex plasma, such as in the Saturn rings or comet tails, consists of a low-temperature plasma - an electrically charged gas with free electrons and ions such as the gas filling in a fluorescent tube - and small particles (dust) of a few microns in size.

The particles are electrostatically charged in the gas and interact with each other. Both reactants behave like a substance. Depending on the experimental conditions - varying the plasma generating electric field and the gas pressure - such a complex plasma changes its structure and behaves like a liquid, a gas or, in the case of three-dimensional regular arrangement of the particles, like a crystal. This ordered structure is therefore also called a plasma crystal.It was first detected experimentally in 1994. In addition to their importance in astronomy, plasmas are of great importance in many fields, such as illumination technology, surface engineering, materials processing, hygiene or medicine. Plasma crystals, like a normal material, can behave in a gaseous, liquid, solid state, but have special properties: the particles are large enough to let follow their dynamics with simple microscope techniques. The processes can be observed well because they run slowly because of the large particle mass and the plasma-forming noble gas is very thin. So the particles are not damped in their movement. For ordinary plasma, gravity is of secondary importance. Complex plasma, however, is very sensitive to gravity because of the 100 billion times larger mass of micro-particles than electrons and ions: the particles sink and compress the complex plasma in the direction of gravity. Therefore, a plasma crystal is limited to only a few lattice planes. Only under weightlessness can large, three-dimensional structures be created undisturbed and explored.

Results

More than 70 publications using ISS PK-3 experiment data are available so far. Most of them have appeared in scientific journals. This balance has not been achieved by any other space station experiment so far. Due to the breadth of the research field, the experimental results on the ISS are also very diverse. They have enriched plasma physics (improving the ion friction theory), provided the basis for new theories on early phases of plasma formation (accumulation of micro particles, charge-induced gel formation) and reveal new details on phase transitions (direct analysis of a crystallization front and its dynamics, segregation of binary fluids, formation of electrorheological fluids). In addition to basic research, new technologies developed for the research equipment on the ISS already provides the basis for the application in the field of plasma hygiene and plasma medicine (spin-offs for bacteria killing the effect of plasmas, treatment of chronic wounds in clinics) ,

Perspectives for research and application

The gained knowledge and fundamental insights have far-reaching, interdisciplinary application potentials. Examples include the development of designer materials in the field of soft matter (colloids, gels, granules) as well as industrial plasma technology (coating process of flat screens, solar cells, microchips), where dusty impurities have a disturbing effect. The next experiment generation PK-4 was developed within the ESA program and was transported to the ISS in the summer of 2014. The operation, which is carried out cooperatively with Roskosmos, is running in the Columbus module now since 2015. While the PK-3 device generation focused on the study of crystalline complex plasmas, PK-4 is especially suited for liquid-state experiments of such a type of plasma.

Experimentator: Prof. Dr. Gregor Morfill (MPE-Garching), Prof. Dr. Vladimir E. Fortov (JIHT, RAS, Moskau).

3. Cell-Box 1: New Approaches to Cancer Therapy and Tissue Engineering? [7]

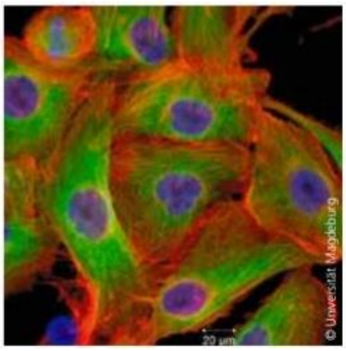

Fig. 3 Thyroid cancer cell line FTC-133 after four hours of simulated weightlessness. Nuclei are blue, components of the cytoskeleton are green and red.

Background and scientific goals:

The immune system of astronauts is weakened in space. So far we do not understand the exact causes or the mechanisms. This is certainly due to the fact that a highly efficient interaction of different organs, cell types and molecules is necessary for a healthy immune system in vertebrates - including humans. In addition to the skin, which in a sense acts as the first barrier against invading pathogens, there are two other protectors: on the one hand, our body has the innate, nonspecific immune system, which developed very early in the evolution process and since then remained largely unchanged. On the other hand, the vertebrates also developed a complex, adaptive immune defense, which protects us even more intelligent and effective against pathogens. It recognizes the attackers and is independently able to develop specific cellular defense mechanisms and molecular antibodies. To find out about the causes of the weakened immune system of astronauts, DLR's space research management currently pursues two approaches: on the one hand, scientists are studying the changes in components of the immune system in the blood of astronauts. Secondly, the effects of weightlessness on the cellular level in different organisms and cell cultures are analyzed. This is where the Cell-Box 1 experiment sets in. It will study the influence of weightlessness on human thyroid cancer cells. These cells grow in weightlessness into large globular clusters of thousands of tumor cells - the so-called three-dimensional multicellular tumor spheroids - which resemble the original tumor. Understanding the mechanisms of this spheroid formation, one could use this knowledge to breed multicellular tumor spheroids. If these tumors could artificially create cell clusters on earth, then pharmaceutical companies and anti-tumor drugs could test against many cancers without resorting to animal testing - a revolution in cancer research.

Results

Detailed results of the ISS experiment are not yet available. However, one knows from previous space experiments such as the German-Chinese Simbox-Shenzou project from 2011, that in the thyroid tumor cells, the expression of various genes and proteins from different physiological processes in weightlessness is changed. Thus, the control of cancer cell proliferation and metastasis as well as cell death (apoptosis), cytoskeleton, adhesion /

extracellular matrix, proliferation, stress response, migration, angiogenesis and signal transduction are influenced by space conditions. The increase in gene expression of certain growth factors such as Epidermal Growth Factor (EGF) and Connective Tissue Growth Factor (CTGF) was consistent with the formation of tissue-like structures and may therefore be crucial for the control of spheroid formation. These promising results will be underpinned and extended in the follow-up Cell-Box experiments.

Perspectives for research and application:

The tendency of the cells to grow in microgravity as multicellular spheroids is also interesting in the context of the production of three-dimensional tissue (tissue engineering). In preliminary experiments, it was already possible to grow vessel-like structures in weightlessness - an important goal of this research in the future. Therefore, in the medium term, it is planned to offer pharmaceutical companies to test new drugs using these three-dimensional structures. If further space experiments and accompanying ground studies succeed in decoding the signaling pathways leading to sudden cell death in the tumor cells, a new opportunity for the development of innovative anticancer drugs would emerge.

Experimentator: Professor Doktor Daniela Grimm, Universität Magdeburg

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joachimkehr@aol.com
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