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The Plasma Crystal Research Program on the International Space Station (ISS)

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The International Space Station ISS is completely assembled with the main segments from Russia, America, Europe, Canada and Japan. It is fully operational now and provides the best infrastructure for microgravity research in life and physical sciences since the start of this branch of research end of 60ies of the last century. It complements research under gravity conditions and short term microgravity experiments in drop towers (up to 10 sec microgravity time), parabolic flights (up to ~20 sec microgravity time) and sounding rockets (up to 20 min microgravity time). It is the only platform which provides a laboratory character where long term programs can be performed and experiments can be repeated/adjusted accordingly to finally achieve best results for science in basic and application oriented fields. Now it is the time for the participating countries and agencies to harvest what have been seeded more than 20 years ago with the decision to start the biggest international project of mankind as a sign of peace in the world and funded with many tens of billions of dollars. With a comparable small amount of funding for existing and new laboratories/experiments this international program could be made a success story for the next decade.

The research on complex plasma is a relatively young field started in 1994 with the discovery of plasma crystals – the Coulomb crystallization of charged microparticles (historically called dust or fine particles) in physical plasma containing electrons and ions. The collection of the charged species from the plasma lead to the charge on the microparticles, typically a few thousands of negative charges on a micrometer sized particle. Their strong Coulomb interaction leads to a strong coupling of the microparticle component and therefore to the formation of liquid and crystalline structures. The major advantage of this model system for condensed matter is the direct observation of the particles (simulating the atoms in a liquid or solid) by laser light scattering allowing the full characterization of the dynamics at the most fundamental – the kinetic level – a dream for physicists since the full equation of motion of a many particle system showing strong coupling phenomena is available.

Already in the beginning it became clear that the sedimentation of the microparticles in the weakly ionized plasma and the necessity to levitate them with a strong electric field against gravity disturbs fundamental investigations and avoids exploring the full available parameter range available for complex plasmas. Especially the formation of large 3-D systems of liquid and crystalline complex plasmas was hampered. Therefore a long term microgravity program, the so called Plasmakristall (PK) program, was initiated from Russia and Germany. Jointly both countries started the first natural science lab on the ISS PKE-Nefedov, which was operational from 2001 to 2005. This first long term studies brought many new insights and interesting results were published in more than 30 scientific papers. This lab was followed by the second generation apparatus PK-3 Plus, which allowed the scientists to continue their research from 2006 to 2013 and to expand the broadness of it considerably. Both projects were joined by international partners e.g. from Japan, the US, or Europe. The above mentioned success story prognosed for the future research on the ISS came already true for the complex plasma research after more than ten years of continuous research in space.

The three papers presented here give an overview on the research capabilities and show the wide spectrum of phenomena which can be studied in complex plasma. These investigations

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provide interesting insights into processes like crystallisation and melting, laning and phase separation in binary mixtures, electrorheological effects due to ac electric fields, wave propagation, etc. (s. paper by Molotkov et al.). Even the topic of critical phenomena was addressed in experiments with PK-3 Plus on the ISS. Those experiments were performed after a proposal of a Japanese science team (s. paper by Adachi et al.) together with the Russian-German PK-3 Plus team. Although the critical point could not be reached in a serious of experiments, the approach to it could be clearly identified and the results might help to understand this interesting phenomenon in the near future on the most fundamental kinetic level.

The experiments under microgravity conditions are complemented by lab studies to provide important plasma parameters for understanding basic processes observed in space (s. paper by Takahashi et al.). For example, electron density and temperature were measured by different probe techniques not available in the lab on the ISS. Those are very important to calculate the charge on the microparticles, a basic parameter for the understanding of complex plasmas. The results from ground were used to explain e.g. wave propagation in complex plasma observed with the PKE-Nefedov laboratory on the ISS.

The end of the operational phase of PK-3 Plus on the ISS in 2013 fortunately was not the end of this long term program: This successful program continues with the European-Russian PK-4 lab! It was launched in October 2014 and installed into the Columbus module in the so-called European Physiology Module (EPM). Comparable to the former labs where cylindrical symmetric capacitively coupled radio frequency discharges where used a long direct current discharge tube is used. This allows mainly the investigation of fluid and flowing behavior of complex plasmas and expands the investigated parameter range accordingly. The research on the ISS is supported by a large international science team headed by the responsible Facility Science Team (FST) with members from Europe, Russia, USA and Japan. PK-4 is foreseen to be operational for more than four years on the International Space Station.