THE BMSTU RESEARCH AND EDUCATIONAL CENTRE FOR PLASMA SCIENCE AND TECHNOLOGY

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The BMSTU Research and Educational Centre for Plasma Science and Technology was officially opened on April 10th 2013. During the preparation stage of the laboratories already a series of lectures was started in order to prepare the students for the new opportunities which the Centre will offer. Plasma Science and Technology — and this may come as a surprise to some – has become a major growth area, mainly through new discoveries (such as plasma crystals), new frontiers (such as high power lasers), interdisciplinary applications (such as plasma-biology, plasma-medicine and plasma-colloid physics) and technological advances (such as mono- and multilayer surface applications) as well as progress in plasma-chemistry, novel materials and plasma source design. The Centre for Plasma Science and Technology focuses on these modern and innovative aspects of plasma research and aims to play a major role in these fields. Economically, some of these topics have the potential to become major "disruptive technologies" with the corresponding impact on society. Thus the Centre – in its current form and the planned additions — will play an important role in shaping this future. In the following, a brief summary of the activities, now and in future, will be presented.

Introduction. ***Current Status of the Centre.*** After more than a year of intense planning and preparations the ***Centre for Plasma Science and Technology*** was officially opened on April 10th 2013. Its role in BMSTU is to highlight new and emerging fields of plasma science and to educate students towards understanding the physics, chemistry and technology aspects which "plasmas" open up in the future. This is achieved in a trilogy of approaches: teaching, experiments and theory.

Why the focus on plasma? When just over a decade ago many "experts" were convinced that the only topics still unexplored in this field were "plasma fusion — mainly a large energy engineering project, possibly of doubtful value" and "plasma surface treatments — primarily etching and vapour deposition, all well established in multi-billion industrial settings". Basic research aspects seemed to be exhausted. But, as it happens so often in science, these "experts" were well and truly wrong!

Laser plasmas (which are able to reach ultra-high energies), *complex plasmas* (which are able to explore something nobody had believed possible — plasma crystallization), *plasma chemistry* (which through non-equilibrium reactions is able to produce new species and materials), *plasma medicine* (which has great potentials in hygiene, cancer therapy, skin diseases, environment protection and agriculture) — these are some of the emerging young fields that have revolutionized the way we currently think of plasma research. They are also the fields through which major new developments, even whole new industries, may emerge — as a result of the introduction of new disruptive plasma technologies.

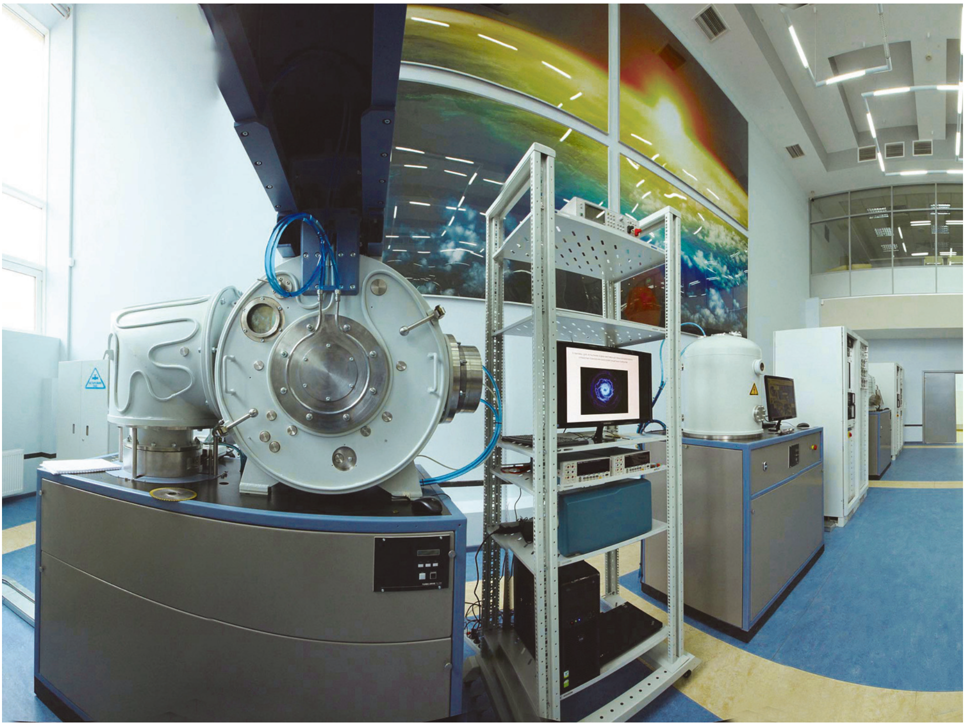

Fig. 1. The laboratory of the Centre for Plasma Science and Technology

An innovative, forward-looking and advanced institution like BMSTU cannot ignore these developments and therefore it has decided to remain competitive and invest in some of these emerging plasma research areas. The topics chosen reflect in part existing research areas at BMSTU, in part new fields are included that had no research history at BMSTU. The Centre currently houses three laboratories, equipped to the most competitive international standards (see fig. 1):

1. Complex Plasma Laboratory (see fig. 2, fig. 3). Complex Plasmas consist of electrons, ions and charged microparticles. The microparticles are illuminated with a laser and can be visualized individually with e.g. a CCD camera. Because of their comparatively large mass (hundreds of billions times heavier than atoms) they move much more slowly and physical processes occur practically as if in "slow motion". The microparticles can interact with one another and self-organise, forming liquid and even crystalline states.

The research, combining experimental activity with theoretical investigations, is focused on two major directions: Studies of basic properties of complex plasmas, and interdisciplinary research of generic phenomena occurring in classical liquids and solids. The aim of basic studies of complex plasmas is to better understand their physics, while the principal objective of the interdisciplinary research is to use complex plasmas as a

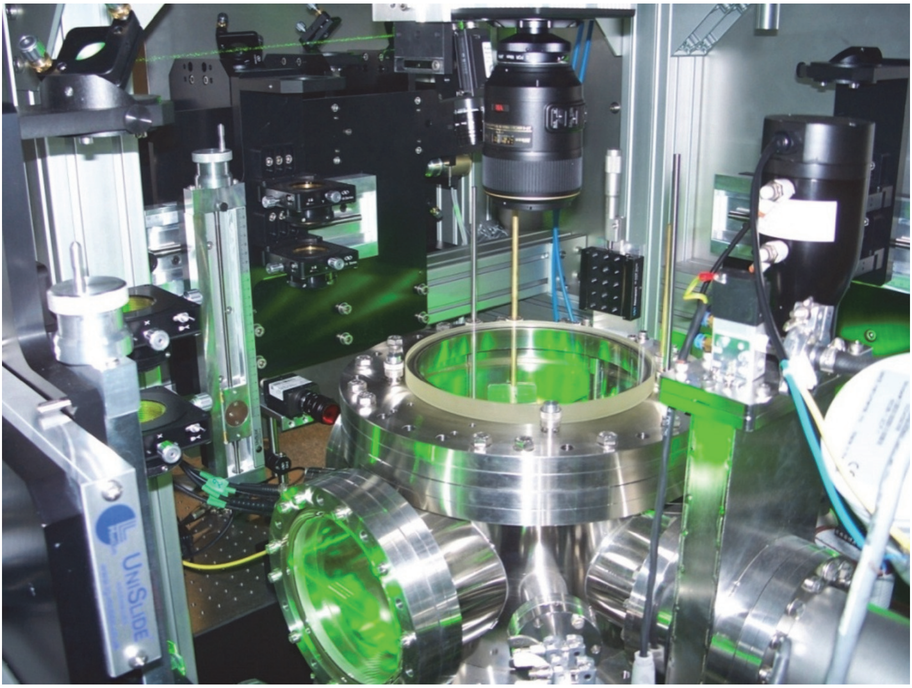

Fig. 2. A detailed view of the complex plasma laboratory equipment. The picture shows the plasma chamber with the view ports

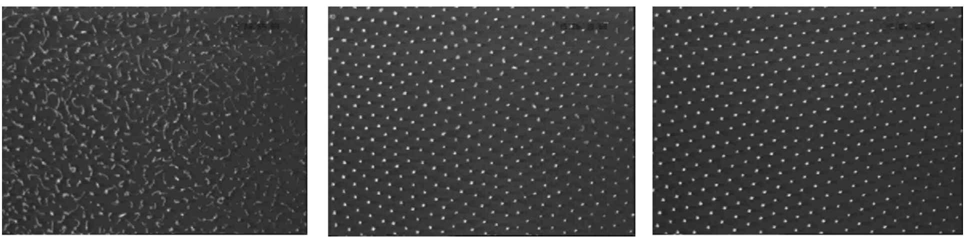

Fig. 3. Complex plasma states: gaseous (left), liquid (centre), crystalline (right). The picture shows the (individually resolved) microparticles. In the gaseous state the particle motion is rapid and the photo (at 1/50th % second) shows many particle tracks, rather than points

natural model system and to understand classical properties of matter at the most fundamental — individual particle — level. Such investigations, with a resolution covering all the physically interesting length and time scales, have not been possible before. In addition, the study of complex plasma also allows us to bridge the gap to complementary research conducted in colloid and soft matter science. Particular research topics are:

- Probing the onset of cooperative phenomena — self organization and structure formation in physical systems;
- Tribology at the single particle level;
- Transition from laminar to turbulent flow;

- Dynamics of dislocations and grain boundaries in 2D and 3D crystals;
- Phase transitions — melting resolved in time and space;
- Solitary waves and shock waves at the kinetic level;
- Phase separation at the "nano-level".

2. Plasma Coating and Sources (see fig. 4). The principal aim of the laboratory is to develop novel methods and tools of ion-plasma surface processing. Particular development directions are:

- Optimized methods of vacuum arc evaporation, development of facilities characterized by low droplet-phase concentration;
- Technologies to form nanostructured coating;
- Methods of ion-stimulated thermodiffusion and surface implantation;
- Development of ion and plasma thrusters for nano-scale processing of optical parts;
- Methods of ion polishing to surface roughness of less than 1 nm.

3. New Materials (see fig. 5, fig. 6, fig. 7). New materials produced using plasma technology already demonstrate fascinating properties, and we are only at the beginning of their studies. The development of new nanostructured materials in the laboratory will include the following principal directions:

- Study of multilayer monocrystalline and polycrystalline nanostructures;

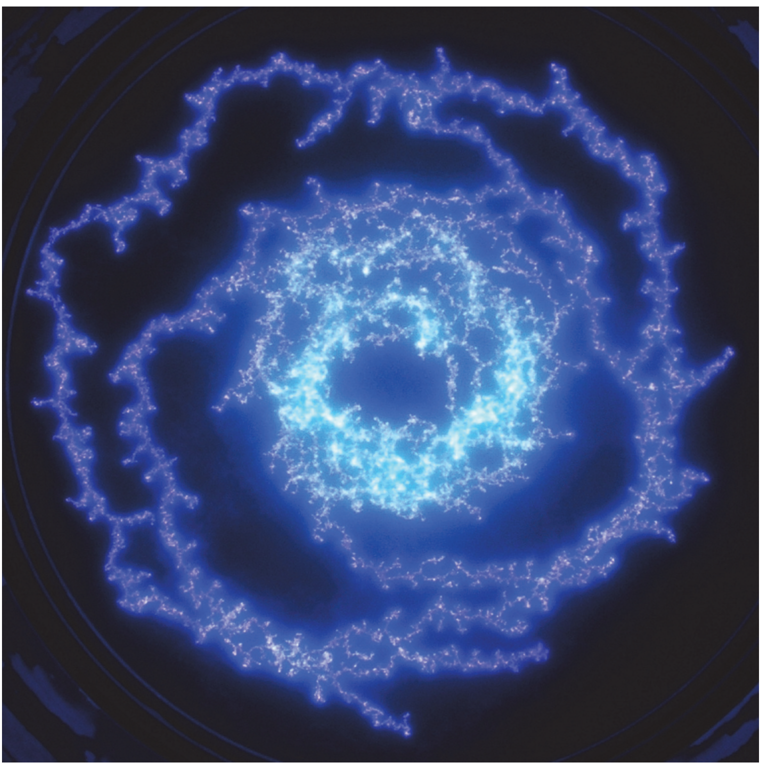

Fig. 4. View of a focused plasma beam travelling across a surface

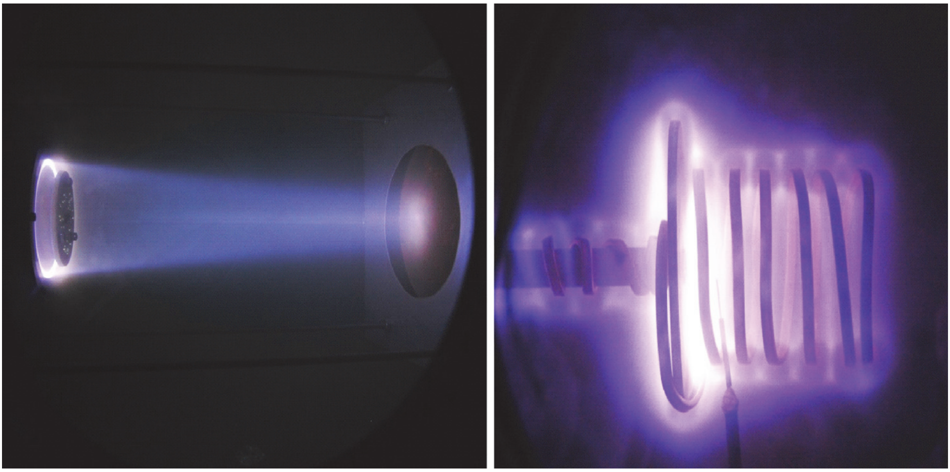

Fig. 5. Examples of plasma sources and new materials on surfaces

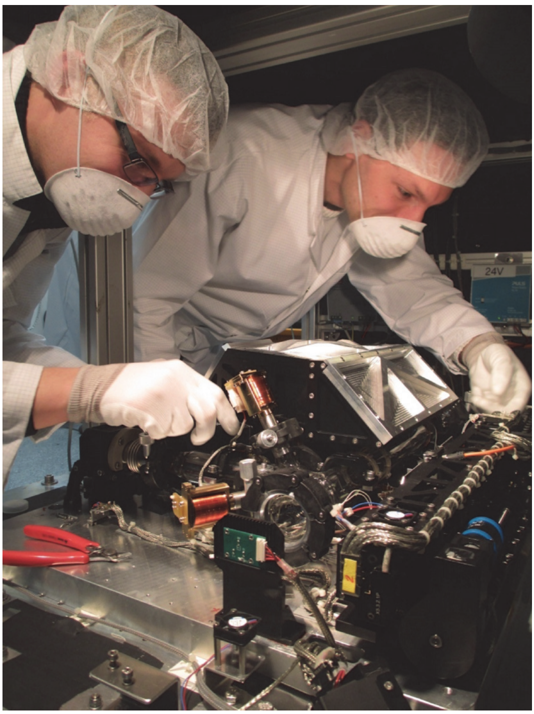

Fig. 6. Space Prototype of PK-4 in assembly at MPE

- Development of thin multilayer films for different purposes;
- Research into the physics of interlayer diffusive interactions;
- Investigation of physical and technological principles of multilayer film diagnostics;
- Study of energetics aspects of thin-film explosion;
- Development of micro- and nanopowder plating technologies.

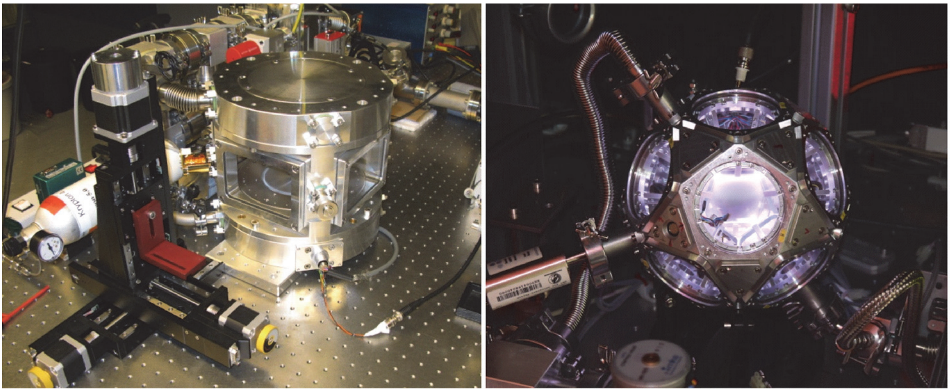

Fig. 7. Laboratory prototypes of two developments for the next generation Space Laboratory Plasma Lab. A cylindrical plasma chamber (left) and a multi-electrode near-spherical chamber (right)

These and most certainly many other topics will occupy the researchers of the new Centre for Plasma Science and Technology in the years to come.

Looking ahead. There are other major new developments in plasma science and technology, which we plan to embark on (in addition to the three topics started this year) in the years to come. These are:

4. New Space Laboratories (see fig. 8). Unlike “regular” plasma species — electrons and ions, microparticles in complex plasmas are strongly affected by gravity. A vertical dc electric field generated near the lower plasma electrode is usually employed to provide a force that compensates gravity and allows the microparticles to levitate. This provides favorable conditions to study 2D systems — this is utilized in the *GEC* setup already installed in our Centre. However, in order to perform precision

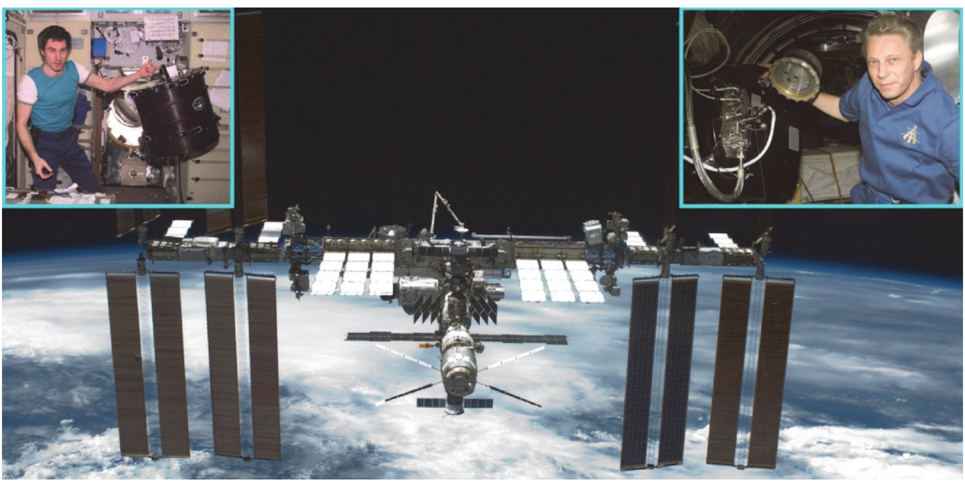

Fig. 8. Previous Plasma Laboratories on the ISS: PKE-Nefedov (2001-2005, left insert), PK-3plus (2005-2013, right insert)

measurements with large isotropic 3D systems, microgravity conditions are absolutely necessary.

The complex plasma space program has been continuous since the first experiments were carried out on the Mir station — by cosmonauts trained by scientists from JIHT of the Russian Academy. Over 50 cosmonauts have already conducted complex plasma experiments to this day. Soon (in 2014) it will be time to install the next complex plasma space laboratory — *PK-4*. With this new technological development the quality of the next-generation microgravity experiments will be further improved, experiments will be much more flexible, diagnostics is better and — most important — the laboratory is the first which has been designed to specially facilitate interdisciplinary research. This crucial strategic step could be achieved with plasma discharge chambers utilizing novel principles of plasma generation and manipulation. The *PK-4* laboratory, which has been developed in a close collaboration between JIHT and MPE, is scheduled for launch to the International Space station in 2014. It is perfectly suited for particle-resolved studies of flow phenomena occurring in liquid plasmas. In our strategic plans *PK-4* will be followed by the *Plasma Lab* setup, which is currently undergoing first laboratory tests at MPE. This setup should provide us with the unique opportunity to manipulate interparticle interactions, which will expand the frontiers of the particle-resolved studies of condensed matter dramatically.

5. Plasma Medicine Laboratory (see fig. 9, fig. 10, fig. 11). Plasma medicine is an "emerging new topic" in plasma science. To understand the full scope it is perhaps better to use the term "Plasma Health Care", since the envisaged applications range from food hygiene and sterile packaging to water treatment, plant growth, environmental protection, and medicine. The latter includes, in particular, treatment of bacterial, viral and fungal skin diseases, wound infection and wound healing, cancer, artificial joints and dental medicine — to name the most prominent examples.

Fig. 9. Microwave plasma device, which has been used in clinical trials, so far over 3500 applications (developed together with Adtec Plasma Technology Ltd.)

Fig. 10. Three more developments: self-sterilising surfaces (completely encapsulated work surface, which can self-sterilize with plasma — left), battery-operated design for surface treatment to remove malodour (centre), piezo (mechanically) operated plasma device (right)

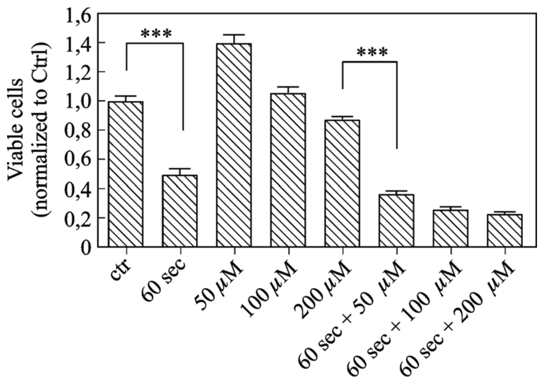

Fig. 11. Viable LN18 cells (cell line which is resistant against TMZ) for a CAP treatment of 60 s, for a treatment with 50 μM/100 μM TMZ and for the combined treatment 60 s CAP + 50 μM/100 μM/200 μM TMZ. The data clearly shows, that the combined treatment revealed synergistic non-additive effects.(Köritzer et al. 2013)

Plasma is a new medium that has remarkable properties in health care:

- it is a broadband germicidal agent;
- it inactivates bacteria, viruses, fungi and spores — ideal for hygiene;
- it kills resistant bacteria in seconds;
- it reduces the risk of infections;
- it has regenerative properties — wounds heal faster;
- it is cell selective — cancer cells are inactivated, healthy cells are unaffected;
- it soothes and heals many skin disorders;
- there are no known detrimental side effects;
- it even accelerates plant growth...

The big breakthrough for plasma medicine came with the development of “Cold Atmospheric Plasmas”, which can be safely applied to human skin and which have no known negative side effects.

The important current issues in plasma medicine are:

- identify the processes that make plasma such a formidable germicidal agent;
- understand in detail the mode of action of plasma-cell interaction;
- optimize plasma source and transport design for specific applications;
- improve plasma chemistry for biological/medical applications;
- investigate combined plasma-topical/systemic drug effects;

- research the causes of cell selectivity and identify "therapeutic windows";
- control plasma and monitor its properties continuously;
- develop scaling techniques for manufacture.

How do we plan to do this?

Research and development in interdisciplinary teams — involving physics, chemistry, engineering, biology, microbiology and medicine — a network composed from different expert institutes. The crucial role of BMSTU will be to provide the technology and the understanding of plasmas — i.e., the "plasma design" in a new *Plasma Medicine Laboratory*. We plan to start this by using plasma technologies developed in house as well as at our cooperation partner, the Max Planck Institute for Extraterrestrial Physics. Some examples of MPE technology are shown below.

To illustrate the possible impact that plasma application may have in combination with other drugs — here one example. It involves in vitro studies of glioblastoma cells (incurable brain cancer). The figure shows the survival of these cells after exposure to different doses TMZ (the standard chemotherapy treatment) and the survival of the same cell lines after plasma exposure and after combined plasma-TMZ treatment. For example, at 100 M TMZ alone there was no effect on the cancer cells. With a combined treatment, however, e.g. 60sec Plasma + 100 μM TMZ only 25 % of the cancer cells remained viable.

6. Colloidal Physics Laboratory (see fig. 12). Many fundamental issues in classical condensed matter physics can be addressed experimentally using model systems of individually visible mesoscopic particles playing the role of "proxy atoms". The interaction between such "atoms" is determined by the properties of the surrounding medium and/or by external tuning. Along with complex plasmas, the best known example of such model systems are colloidal dispersions.

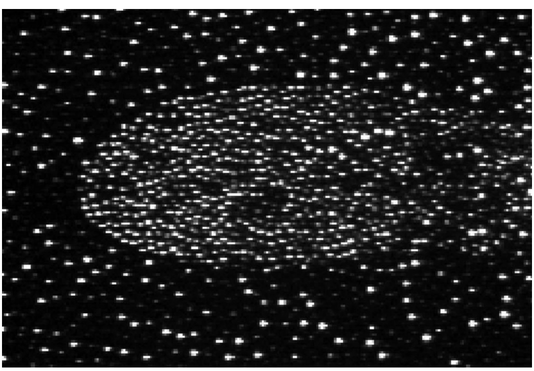

Fig. 12. Example of a physical process that can be studied at the particle level for small systems all the way to the limits of cooperative and self-organised behavior — *phase separation*. The oil-water effect. Shown here is a complex plasma system (data from ISS experiments — Ivlev et al., 2012). Complementary studies on equilibrium phenomena can be made more suitably with colloidal suspensions. Such studies give useful information about the behavior of systems as we approach further into the nano-world

Complex plasmas and charged colloidal dispersions represent two domains of *soft matter* with huge methodological and conceptual overlap, which opens up the possibility to perform joint research of numerous fundamental problems. This wonderful similarity and, at the same time, the mutual complementarity of the two systems in terms of the individual-particle dynamics would make the combined studies enormously important for the comprehensive understanding of “atomistic” physics underlying the processes in strongly correlated media.

Introducing the new *Colloidal Physics Laboratory* to the Centre will enable us to employ complementary approaches from the two different domains of soft matter, and thus to perform interdisciplinary studies that promise huge synergy and hence should bring us more than the sum of the parts. The principal scientific aim of such combined research is to investigate generic dynamical and self-organization processes occurring in classical liquids and solids – covering the whole range of non-equilibrium and equilibrium phenomena – at a detail not possible in the past.

Final Remarks. By continuously advancing and extending the scope we plan to maintain a Research and Educational Centre of exceptional quality — always at the pulse of new developments in science and even leading some of the research that we feel will play a big role in shaping the economics and well-being of our society. Our choice — *plasma science and technology* — was very carefully executed, and the current topics on which we concentrate our research efforts within this field were chosen with the same diligence. The plans for the future are subject to the same careful scrutiny and will ensure that the Centre will have a sustained leading role. That is our aim — and given the right support we will succeed. Certainly, the start of the Centre with the state-of-the-art equipment which we were able to procure and the perfect infrastructure, has provided a tremendous boost – one that we will use to maintain the highest possible standards of research and education now and in future.

Let me close by thanking all my colleagues at BMSTU, JIHT and MPE who have helped to build up the Centre and who will continue to provide their expertise to maintain highest standards of education and research.

Received June 1, 2013

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