White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 19th 2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	
• Interactions of plasmas and waves	
• Plasma self-organization	**P**
• Statistical mechanics of plasmas	**S**

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	
Poster	
Either Oral or Poster	
Will not attend	**X**

Title:	Control of the particle interaction in quasi spherical symmetric complex plasmas utilizing a dodecahedron shaped plasma device
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format.*)**

- ***Describe the research frontier* and importance of the scientific challenge.**

The complex (dusty) plasma consists beside the usual electrons and ions of a third component, the "dust" particles. The "dust" can be a result of chemical reactions and agglomeration as in industrial plasma processing[1,2], it can be due to particle growth or disruptive processes as in astrophysical environments like in planetary accretion discs[3], due to ablation of material from plasma chamber walls as observed in fusion reactors[4,5] or just be introduced on purpose by the researcher in form of precise defined microspheres. As a result of the interaction with the plasma background the particles get charged, and by rearrangement of electrons and ions also mostly screened. Unlike the other plasma species the dust component has a variable charge and an inertia that is more than ten orders of magnitude higher. This leads to dynamical timescales in the regime of millisecond to seconds. Standard plasma dynamics as waves, flows or just simple things as particle scattering can now be studied on easily accessible spatial and time scales[6,7]. On the other hand, because of the rather high particle charge, the ratio of the dust particle interaction to their kinetic (thermal) energy, which is often of the order of the environmental temperature, can range from values much less than 1 (weak coupled system as in usual plasmas) up to very high values much greater than 1 (very strong coupled systems as in solids). The dusty plasma therefore allows the study of fluid behavior, phase transitions as well as crystalline structures[8]. Since the

background plasma is bound to the dust component the plasma background spatial structures follow the same transitions.
The field of complex (dusty) plasma has undergone an inflationary growth after the discovery of the plasma crystal[9] even though the forces in between the microparticles have been barely controllable. The particle charge, which is mainly a function of electron temperature, particle size and less dependent on plasma densities, is a result of the chosen discharge type, gas pressure and discharge power. The screening is influenced by the same parameters and thus not independently controllable. A complication for the particle control exists for earth bound experiments with larger, micrometer-sized particles, because they have to be levitated against their weight force by an electric field. These electric fields cause plasma flows, inhomogeneities and introduce preferred directions. Combined with the sedimentation effects, introduced by the weight forces that is in general dominating the system in earth bound experiments, the dusty plasma system often is strongly inhomogeneous, anisotropic and accompanied by undesired particle flows. These disturbing effects can partly be overcome by performing microgravity-based experiments utilizing for example, parabolic flight opportunities or using dedicated setups aboard the International Space Station[10]. Even though the sedimentation effect can be suppressed under microgravity (free fall) conditions, the challenge to overcome the anisotropy and with it the plasma background plasma flows, as well as to control of the particle pair interaction has not been successfully met.
The problem of the isotropy has been partly addressed during a parabolic flight campaign by the authors and co-workers using a spherical shaped glass discharge chamber as sketched in Figure 1. In this experiment the discharge was generated by alternatively addressing pairs of opposing electrodes mounted along the mayor three spatial, orthogonal directions. The first results on achieving a time averaged isotropic plasma environment were promising. Though, until now no deeper investigations has been done with this setup. The particle interaction was investigated extensively in theory[11,12]. It was found, that a directed ion flow and its deflection by a dust particle can cause an attractive space charge region, known as ion wake field, that can potentially be used to actively manipulate the particle pair interaction. This ion wake field effect has often been experimentally observed, for example, when particle in plasma sheath regions undergo a vertical alignment. During a space station experiments this effect was used to demonstrate the possibility to create a time average attraction between particles. This was realized by driving alternating currents through the plasma along the devices symmetry axis[13] leading to positive space charge regions on both sides of each particle and thus creating the desired particle attraction. A theoretical model further predicts that the time average of directional ion flows with random directional distribution can even lead to a spherically symmetric attractive time-averaged particle interaction[14.]

The challenge what we want to meet is, to generate user defined plasma fluxes (incl. random fluxes as necessary for the spherically symmetric attraction) to actively control the particle pair interaction. We also want to control the particle charge by means of electron temperature control and to control the overall isotropy and homogeneity of the plasma background. Meeting this challenge means opening up new frontiers in dusty plasma research for studies on large particle systems, their static and dynamic properties under variation of the fundamental interaction.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

In our project we would like to address both issues, creating a time averaged, quasi-spherical symmetric plasma discharge and second, investigate possible mechanisms to actively control the particle pair interaction.
As an approach to meet the challenge we would like to setup a multi electrode plasma device with equally shaped electrodes. As the most preferable solution we identified the dodecahedron geometry that supports twelve identical five-folded electrodes. As starting point on this development we can build on the recent design and construction of a suitable dodecahedron shaped plasma chamber. This chamber was build by the authors as part of a DLR (German Aerospace Center) financed project to investigate new plasma

vessels for future microgravity complex experiments aboard the International Space Station[15]. A picture of the DLR prototype is displayed in Figure 2. One prototype of this plasma vessel has been build at DLR and an additional vacuum vessel has partly been setup at Auburn University.
For both systems the complete plasma generation system still has to be developed, the setup in detail characterized and finally optimized to our needs. The electrodes of the experimental chamber are transparent, giving us optical access to the interior of the device, which is necessary to follow the motion of the dust in the plasma. The electric connection is realized by coating the glass plates with a transparent but electrically conducting film like Indium Tin oxide (ITO) or Fluoride doped Tin oxide (FTO). Each electrode will be connected to its own radio frequency generator and will be individually be biased. This seems necessary to manipulate the plasma homogeneity and isotropy and also drive the required currents through the system to generate the ion wake fields in the vicinity of the dust particles to realize the particle attraction. Since the particles have a high inertia, they cannot follow high frequency varying forces induced by oscillating electric fields or ions flows. Thus the plasma generation as well as the bias switching will be realized at timescale higher than the particle dynamic reaction time. Additional, pulsing the plasma generation at very high frequencies can potentially also be used to gain some independent control on the electron temperature and therefore the particle charge, which we might want to test at a later stage.
After completion of the system we will characterize it using different techniques for plasma diagnostics. Possible diagnostic tools include Langmuir probes, impedance analyzer or spectrometers. To study the dust behavior and the efficiency on to what extend we can control the particle interaction, we will use the usual combination of a laser sheet particle illumination and observation by computer controlled fast cameras. We will analyze the particle spatial structure and potentially appearing waves and flows in the system. Because of the disturbing influence of the gravitational force some of this measurements will be studied using very small particles (nano- to micrometer sized particles) where the gravitation influence is less dominant. But, since the ion wake field strongly depends on particle size and thus large particle would be preferable, experiments under free fall conditions might be necessary too. It has to be mentioned that the authors have extensive experience performing microgravity related research both using parabolic flights and utilizing the ISS (experiments PK-3, PK-3 plus, PK-4). At a later stage, after we could proof the performance of the system, even experiments with small satellites, as cube-sats, which Auburn is also involved in for the study of different topics, might be an excellent test bed for this research.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit***.

This research will extend the possible dusty plasma research to isotropic systems and is should give the experimenter, at least to some extend, control over the inter-particle forces, a parameter that has up to now barely been controllable. A user defined attractive forces in complex plasmas would allows to study new systems that are more common to other physical disciplines. This can trigger interdisciplinary research and lead to significant contribution to the research in fields as solid state, fluid or astrophysics. The development of active particle manipulation techniques can further help in future fusion devices or semiconductor processing environments to keep potential existing dust contamination problems under control. Developing this devices also for microgravity research, miniaturizing plasma diagnostic tools, help educating next generation engineers and plasma scientist and would strengthen the US microgravity complex plasma research competence.

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Figures

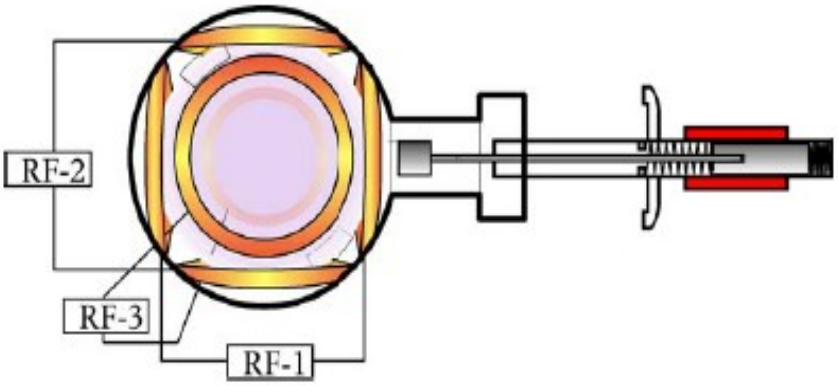

Fig. 1: Sketch of the plasma chamber as used during a DLR/ESA operated parabolic flight campaign to investigate the possibility of generating time-averaged homogeneous, isotropic plasma backgrounds. Each electrode pair is connected to its own radio frequency generator and switched randomly at high frequencies (~1kHz to 10kHz) to average-out the naturally preferred cylindrical symmetry.

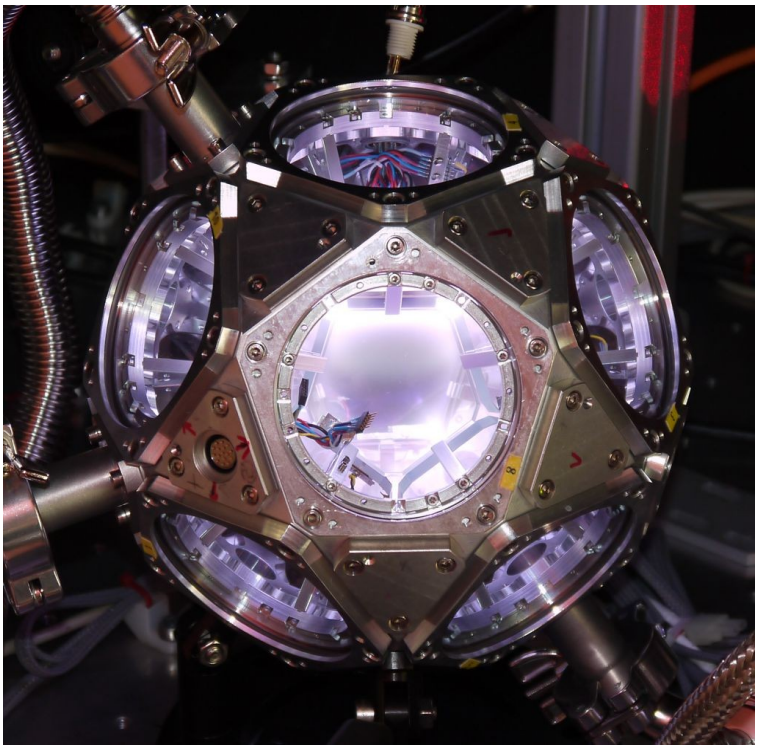

Fig. 2: The “Dodecahedron” prototype plasma chamber, recently developed by the author and former co-investigators at DLR. The dodecahedron shaped electrode system is based on twelve transparent five-folded glass electrodes that are introduced in the system through the vacuum ports to build a dodecahedron in the interior of the vessel. The electrodes are partly visible through one of the vacuum view-ports. In this demonstration only the top electrode was driven to produce a plasma.