White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 18, 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:	Physics of Magnetized Dusty Plasmas
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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.**

Ionized gas (i.e., plasma), magnetic fields, and charged particulate matter (i.e., "dust") are ubiquitous in the visible universe. Combined with the gravitational force, these components form the building blocks of stars and planets. As early as 1956, Mestel and Spitzer noted the important role that charged dust could play in the processes that lead to star formation.[1] The exploration of the solar system with telescopes and interplanetary probes support these ideas through examples such as the detailed observations of the rings and spokes at Saturn,[2,3] the discovery of dust streams being ejected from Jupiter,[4] and the recent detection of charged ice particles near the moon Enceledus.[5,6] These observations show the strong coupling between charged dust particles and the magnetized plasma environment that exists in the solar system.

While there is an extensive range of laboratory studies of dusty plasma phenomena, the majority of these studies are performed without a magnetic field. This is reasonable because microparticles suspended in the plasma due to a balance between gravitational and electrostatic forces already show a broad variety of phenomena even without magnetic fields. However, to extend laboratory dusty plasma studies to regimes relevant to space and astrophysical systems, it is necessary to perform experiments that include magnetic fields.[7,8,9] Obtaining the experimental conditions necessary to achieve a plasma in which all of the charged particle components – the electrons, ions, and the dust – are magnetized is technically challenging. To date, no experiment has definitively shown that full magnetization of the microparticles (e.g., observation of dust gyro-orbits) has been achieved.

Therefore, a critical challenge for dusty plasma research is to **study the structural, thermal, and stability properties of a dusty plasma in which the magnetic force acting upon each of the charged plasma components is comparable to the electrical, gravitational, or inter-particle forces.**

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

Approach: To address this challenge, the newly commissioned, mid-scale, high magnetic field, research device – the Magnetized Dusty Plasma Experiment (MDPX) will be used.[10] For this project, the goal is to explore a new regime of plasma conditions under which the magnetic force must be a significant contributor to the overall force balance for each charged species in the plasma. This research will address two major themes:

1) Investigate how the structural, thermal, charging, and stability properties of a dusty plasma evolve as the system is taken from an unmagnetized state through a progression of regimes where first the electrons, then the ions, and then charged microparticles become magnetized.
2) Investigate how the properties of a dusty plasma composed of microparticles that have paramagnetic or ferromagnetic properties evolve in the presence of uniform and non-uniform magnetic fields.

An organized research program has been developed to perform specific activities within these two themes. This overall research plan is shown in Figure 1. These activities are based upon our current understanding of the physics of magnetized dusty plasmas. This list of activities is expected to grow and evolve as we gain more experience and a better understanding of the properties of a magnetized dusty plasma. For example, the area identified as "driven organization" in Figure 1 has been added to the research program based upon a newly discovered and previously unknown phenomenon in a dusty plasma in high magnetic fields ($B > 1$ T).[11]

Because the addition of the magnetic field adds a new degree of freedom, this enables a wider range of dusty plasmas studies. Furthermore, because the magnetic field will also modify the background plasma and it will be necessary gain a better understanding of the parameters that will be achievable in the plasma. Important issues that must be addressed include:

- Can a stable, uniform, neutral-dominated plasma be created at high magnetic field strengths?
- How will ion and electron $E \times B$ drifts affect the behavior of the plasma and dusty plasmas as the magnetic field strength increases?
- Can a robust, three-dimensional numerical model of DC and RF devices with high magnetic field and with/without the presence of dust be developed?

Therefore, a research activity in the area of magnetized dusty plasmas must take an approach that couples the study of both plasma and the dusty plasma phenomena.

Resources: In the US dusty plasma research portfolio, the Magnetized Dusty Plasma Experiment (MDPX) facility at Auburn University is uniquely suited to address this research area.[12] As a 4-Tesla, split-bore, superconducting, variable magnetic field system with a 50-cm bore and excellent diagnostic access from both the top/bottom and sides – the MDPX device is a highly flexible research instrument that can serve a variety of missions from exploring the basic physics of dusty plasmas to providing a test-bed for high magnetic field diagnostics, long-duration plasma experiments, and superconducting technologies. The MDPX device is the only device in the US, and one of only five around the world, that are configured to study magnetized dusty plasmas.

Moreover, since the MDPX device was conceived, built, and is operating as a collaborative partnership among several institutions and beginning its operations using a collaborative model, it has the technical and scientific infrastructure to service the dusty plasma community. However, to leverage the full potential of the MDPX device – and to remain competitive in an environment where international competitors are have access to signficant resources – additional support in terms of personnel and diagnostic development are needed in order to ensure signficant and productive collaborative activities.

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

Impact: With the addition of the magnetic field, dusty plasma research will have even stronger connections to other areas of the plasma research community. The formation and transport of dust is well-known as a important source of contamination in both industrial[1314,15,16] and fusion[17,18,19] plasmas. The development of a dedicated and sustained research effort to understand the behavior of charged microparticles in magnetized plasmas has the potential to impact these important technological areas. Additionally, a magnetized dusty plasma represents a system that is more closely tied to astrophysical phenomena.[20,21,22]

Finally, the development of experimental facilities to study the physics of magnetized dusty plasmas will lead to new resources for the entire plasma physics community. An experimental platform that provides access to superconducting magnets and high magnetic field can be used for a variety of fundamental studies of plasma processes, e.g., cross-field diffusion in strongly magnetized plasmas, plasma-surface interactions, E x B flows, etc., that will supplement and enhance the scientific benefits of a research program on magnetized dusty plasmas.

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Figures

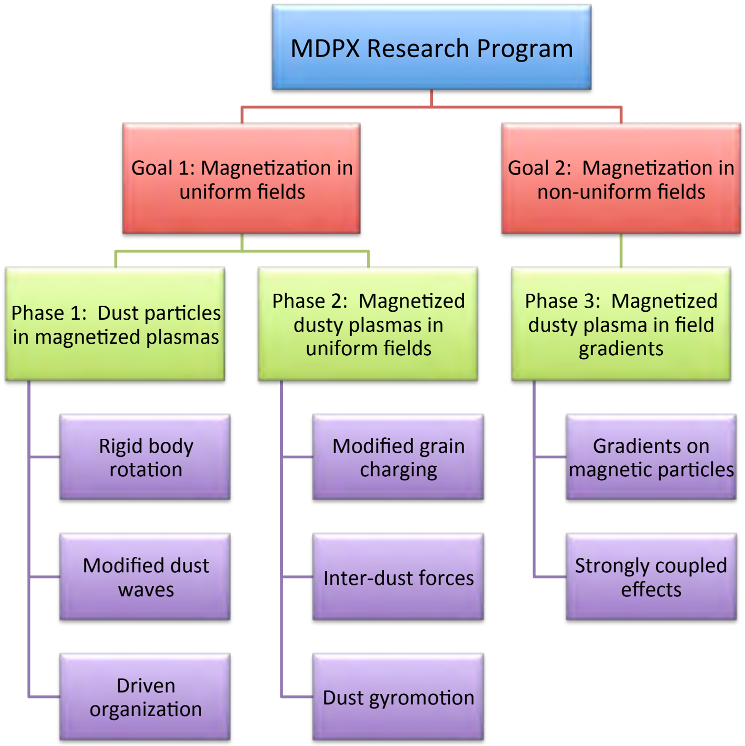

Fig. 1: Summary of the Magnetized Dusty Plasma Experiment research program.

Fig. 2: Photograph of the assembled Magnetized Dusty Plasma Experiment (MDPX) device at Auburn University. The superconducting coils are located inside of the black-painted cryostat. The split-bore between the two halves of the cryostat can be seen. Radial structures from the magnet support diagnostics systems such as probes, cameras, and lasers.