*NASA Current and Planned ISS Research Activities on the Physics of Dusty Plasmas**

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14TH WORKSHOP ON THE PHYSICS OF DUSTY PLASMAS - AUBURN, AL

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Agenda

- Physics at NASA
- 2011 NASA Decadal Review
- NASA/JPL's Fundamental Physics Program Overview
- Current Research activities in Dusty Plasma
- Dusty Plasma NASA Research Announcement

Laboratory versus Observational NASA Physics

NASA OBSERVATIONAL PHYSICS – Science Mission Directorate

- **Studies are exclusively observational in nature with signals emanating in or beyond the solar system.**
- **Understanding the source and location of the signals is crucial.**
- **Domain of the current Beyond Einstein program**
  - **Gravity waves, strong gravity tests of GR, dark energy surveys, dark matter searches, CMB measurements, high energy cosmic rays,**
- **Also Lunar, solar, and planetary plasma studies**

NASA LABORATORY PHYSICS – Human Exploration Directorate

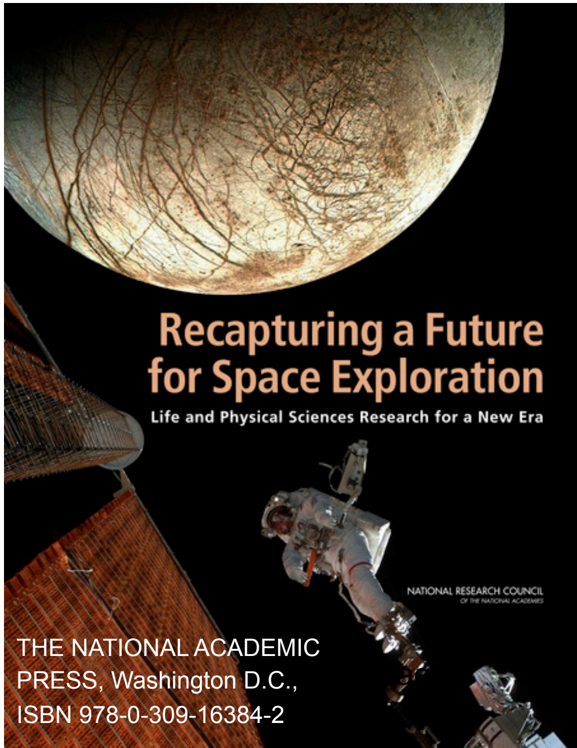
- **Studies of matter, space, and time using space laboratories.**
  - **Test mass or specimen under study resides in the laboratory**
  - **Gravitational Physics, Critical phenomena, Physics beyond the Standard model, Dusty Plasma.**

NASA 2011 Decadal Recommendations

- Fundamental Physics Recommendation FP1, page 261
  - Complex fluids and soft condensed matter are excellent candidates for study in the microgravity laboratory. Experiments on Earth are hampered by sedimentation, flows, and the suppression of thermodynamic fluctuations. Similar issues emerge for colloids, gels, and dusty plasmas, whose density and morphology under gravity are height dependent.

- Applied Physical Science Recommendation AP5, page 286
  - Complex fluid physics—NASA should conduct experiments on the ISS leading to an understanding of complex fluid physics in microgravity, particularly with regard to the behavior of granular materials, colloids, foams, nanoslurries, biofluids, plasmas, non-Newtonian fluids, critical-point fluids, and liquid crystals. (AP5)

- Applied Physical Science Recommendation AP4, page 286
  - Dust mitigation—NASA should develop fundamentals-based strategies and methods for dust mitigation during human and robotic exploration of planetary bodies. This should include experimental methods, the understanding of the fundamental physics of dust accumulation and electrostatic interactions, and methods for modeling dust accumulation. (AP4)



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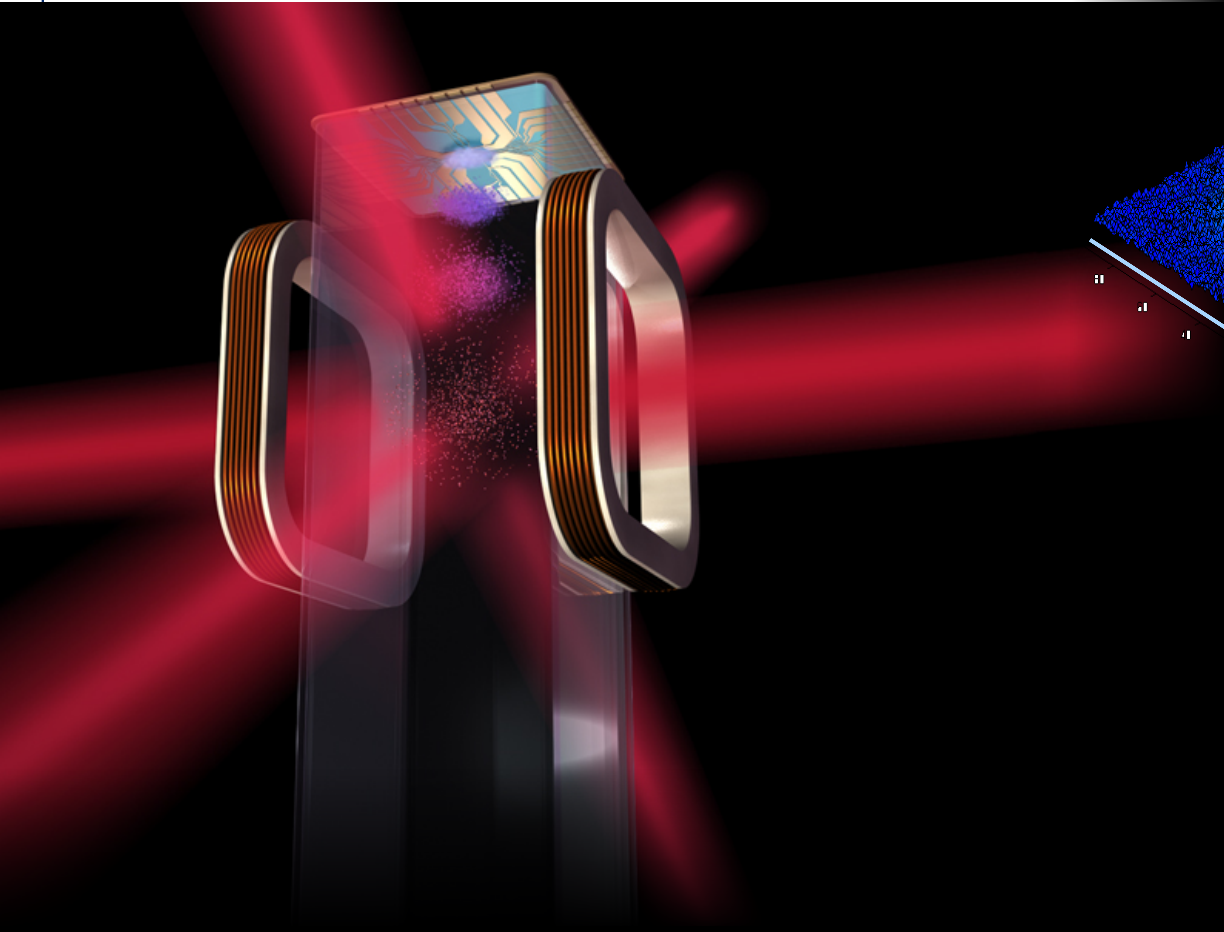
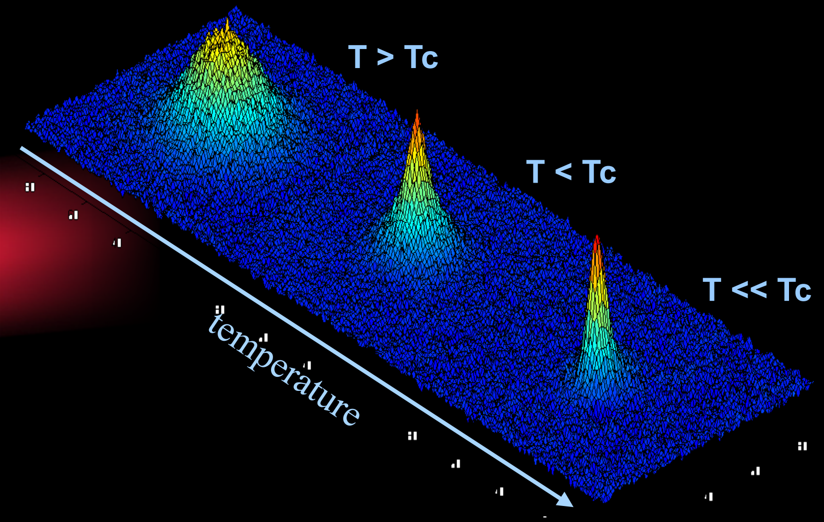
NASA 2011 Decadal Recommendations → CAL





- Fundamental Physics Recommendation FP3, page 261 → Cold Atom Laboratory
  - Research related to the Physics and Applications of Quantum Gases. Space Environment enables many investigations, not feasible on earth, of the remarkable unusual properties of quantum gases and degenerate Fermi gases.

NASA Fundamental Physics Investigators 1/2

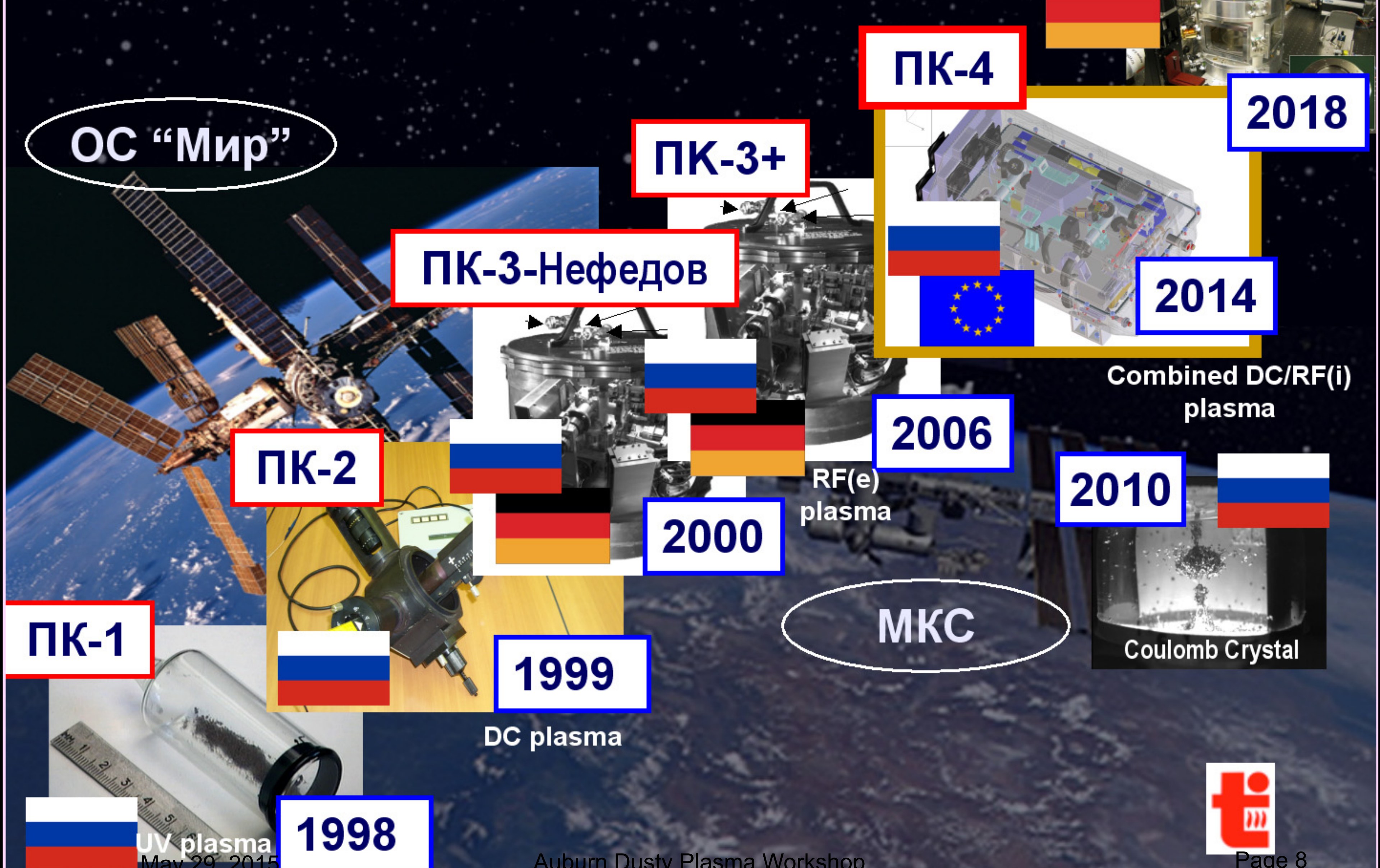
Fundamental Physics

NASA Fundamental Physics Projects and Investigators	
Plasma Krystal (PK4): Launch Oct, 2014	**ESA Led**
John Goree - The University of Iowa	**Self-Structuring in Dusty Plasmas**
DECLIC-ALI-R: Launch 2016	**CNES Led**
Inseob Hahn, Jet Propulsion Laboratory	**Investigation of equilibration near the liquid-gas critical point in microgravity utilizing DECLIC facility**
Atomic Clock Ensemble in Space (ACES): Launch 2017	**ESA Led (with CNES)**
Nan Yu - Jet Propulsion Laboratory	**JPL Participation in ESA ACES Worldwide Clock Comparison Campaign**
Kurt Gibble - Penn State University	**Contributions to the Evaluation of the ACES clock PHARAO**
Leo Hollberg - Stanford University	**Advancing Time Transfer and Optical Atomic Clocks for Space**
Tom O'Brian - National Institute of Science and Technology, Boulder	**NIST/ACES Collaboration: ACES Ground Station and Data Analysis Center in Boulder, Colorado**
Cold Atom Laboratory (CAL): Launch 2017	**NASA/JPL Led**
Nicholas Bigelow - University of Rochester	**Consortium for Ultracold Atoms in Space**
Wolfgang Ketterle - Massachusetts Institute of Technology	**Co-Lead with Bigelow**
David Pritchard - Massachusetts Institute of Technology	Co-investigator
Vladan Vuletic - Massachusetts Institute of Technology	Co-investigator
Mark Kasevich - Stanford University	Co-investigator
Mikhail Lukin - Harvard College	Co-investigator
Dan Stamper-Kurn - University of California, Berkeley	Co-investigator
Holger Mueller - University of California, Berkeley	Co-investigator
William Phillips - University of Maryland	Co-investigator
Jun Ye - University of Colorado	Co-investigator
Eric Cornell - University of Colorado, Boulder	**Zero-G Studies of Few-Body and Many-Body Physics**
Peter Engels - Washington State University	Co-investigator
Tin-Lu (Jason) Ho - Ohio State University	Co-investigator
Debbie Jin - University of Colorado, Boulder	Co-investigator
Nathan Lundblad - Bates College	**Microgravity dynamics of bubble-geometry Bose-Einstein condensates**
David Aveline - Jet Propulsion Laboratory	Co-investigator
Courtney Lannert - Smith College	Co-investigator
George Raithel - University of Michigan	**High-precision microwave spectroscopy of long-lived circular-state Rydberg atoms in microgravity**
Vladimir Malinovsky - Stevens Institute Of Technology	Co-investigator
Cass Sackett - University of Virginia	**Development of Atom Interferometry Experiments for the ISS' CAL**
John Burke - Air Force Research Laboratory	Co-investigator
Dan Stamper-Kurn - University of California, Berkeley	**Coherent magnon optics**
Holger Mueller - University of California, Berkeley	Co-investigator
Stuart Bale - University of California, Berkeley	Co-investigator
Steven Boggs - University of California, Berkeley	Co-investigator
Jason Williams, Jet Propulsion Laboratory	**Fundamental Interactions for Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment**

NASA Fundamental Physics Investigators 2/2

NASA Fundamental Physics Projects and Investigators	
Plasmalab: (Study)	ESA/DLR Led
John Goree - The University of Iowa	Plasmalab Experiments
Edward Thomas - Auburn University	Plasmalab Measurement
Marlene Rosenberg - University of California, Irvine	Plasmalab Theory
Space Optical Clock (SOC) (Study)	ESA Led
Chris Oates - National Institute of Science and Technology, Boulder	Development/Evaluation of a 10^-17 Yb Optical Clock For Space Applications
Scott Diddams - National Institute of Science and Technology, Boulder	Development of an optical microcomb system for fundamental physics research on ISS
Kerry Vahala, California Institute of Technology	Co-I to Diddams
Quantum Weak Equivalence Principle (QWEP) (Study)	ESA Led
Holger Mueller - University of California, Berkeley	QWEP Analysis and Optimization
Nan Yu - Jet Propulsion Laboratory	Co-I to Mueller
Quantum Test of Equivalence and Space Time (QTEST) (Study)	NASA/JPL led
Nan Yu - Jet Propulsion Laboratory	

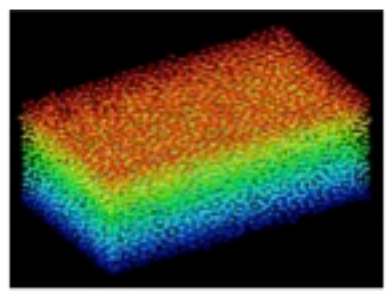
2.2 Космические плазменно-пылевые эксперименты при участии ОИВТ РАН:



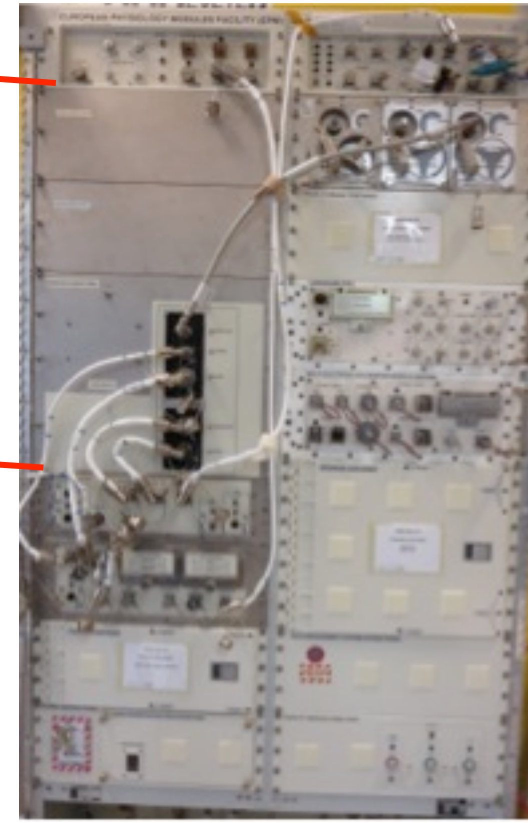
PK-4 International Collaboration

- ***ESA - Roscosmos project***
  - Following 9 years of development, the PK4 multi-user facility launched in Oct, 2014. PK-4 is a very large Class-II ISS payload.
  - ESA has invited U.S. scientists and other nations to participate in PK-4 on an equal footing with European scientists.
- ***Overall science objectives***
  - Study of the liquid phase of complex plasma such as flow phenomena
  - Study of non-Gaussian statistics of particle motion, diffusion, viscosity.
- ***NASA investigator – John Goree***
  - NASA support in Fundamental Physics
  - Science collaboration with ESA scientists
  - Studying mobility of a charged particle in a strongly coupled dusty plasma with gas

Photograph of the scientific elements of the PK-4 instrument.

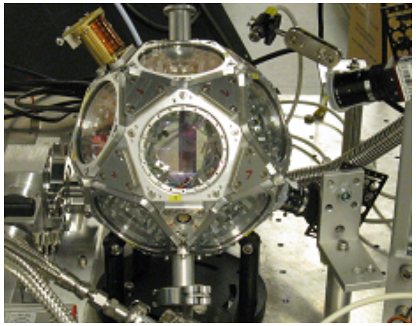


Simulation of 3D structure in a liquid-like dusty plasma, under PK-4 conditions.
B. Liu and J. Goree, Phys. Rev. E 89, 043107 (2014).



Photograph of the PK-4 Facility Ground Model, integrated into the European Physiology Module (EPM) rack. (source: J. Goree)

Plasmalab DLR – ESA - Roscosmos Study



Plasma chambers : Dodecahedron (left) & cylindrical (right) (images, MPE, Germany)

Objective:

- Use dusty plasmas to investigate self-organization of matter at the kinetic level. A dusty plasma is an ionized gas containing charged micron-size particles.
- Observe phase transitions, liquid-phase physics, and cooperative phenomena.

Relevance / Impact:

- In reduced gravity, particles fill a 3D volume, unlike lab experiments where gravity causes sedimentation into a 2D layer.
- Direct imaging allows experimenters to observe the structure and dynamics of 3D samples as they are formed and manipulated.
- An advance design for a plasma chamber will allow the study of phase transitions and critical-point phenomena.

Development Approach:

- ESA will form a Facility Science Team and select an industrial contractor .
- U.S. Team will participate with other teams, which will be funded by their respective agencies.

Status

ESA Proposal	PLASMALAB project was selected by ESA in response to AO-2009-PHYS-BIOSR
Testing	German team members are testing breadboards on ESA parabolic flights
U.S. Team	U.S. Team members began work in 2010 to establish experimental goals and methods for flight experiments: - Goree: PLASMALAB Experiments - Thomas: PLASMALAB Measurements - Rosenberg: PLASMALAB Theory

Dusty Plasma Physics Facility

Leads: Inseob Hahn JPL, John Goree, University of Iowa

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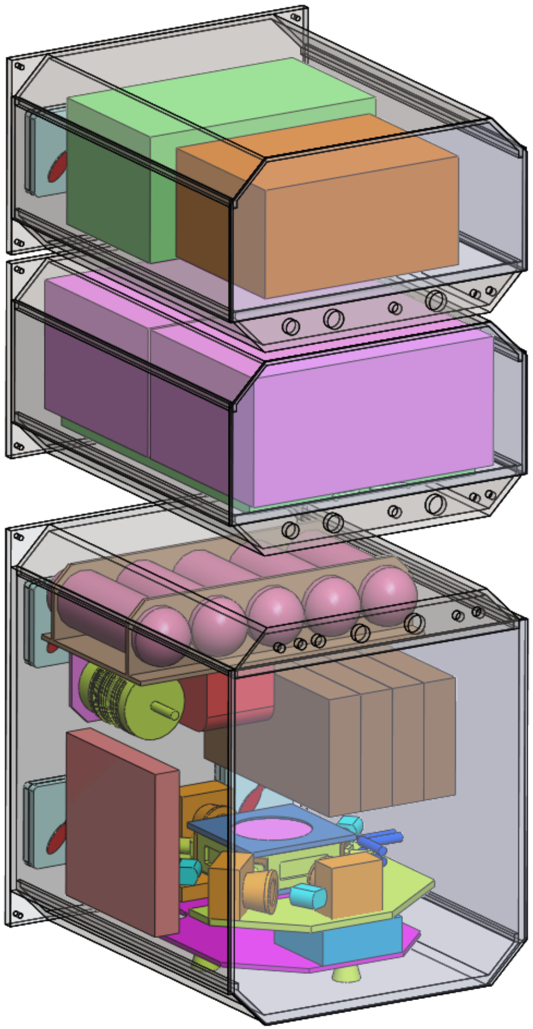

- Responding to Decadal Review, DPPF enables study of collective behavior of charged particles at a kinetic level not possible on Earth.
  - Shear induced melting
  - Statistical Physics
  - Wave synchronization
  - Viscoelasticity
- Express Rack mounted inside U.S. ISS module
- Disk shaped plasma region can accommodate multiple inert gases and various size seed particles.
- Modular, upgradeable design
- Multiple scientists and institutions
- EPO plan for student involvement

NASA Dusty Plasma Research Announcement

- Discussions held with ESA, Roscosmos and DLR about increasing the number of U.S. researchers participating in PK-4
- Based on positive outcome of these discussions, NASA will release a NASA Research Announcement in Physics of Dusty Plasma
  - Proposal release ~ Oct, 2015
  - Proposals due ~ Jan, 2016
  - Selections (up to 4 years of funding) ~ Apr, 2016
  - Funding available Jun, 2016
- Scope of NRA – Microgravity Relevance required
  - PK-4 participation.
  - Supporting theory and modeling
  - Ground based research leading to a potential PK-4 follow-on (Plasmalab, DPPF)
- Discussions held with the National Science Foundation – Slava Lukin about a potential joint solicitation.