Space Life and Physical Sciences Research and Applications Division

National Aeronautics and
Space Administration

NASA Fundamental Physics 2019 Status

presented to

The Committee on Biological
Physical Sciences in Space

29 October 2019

Agenda

- **Overview**
- **Self-Assessment**
- **Decadal Recommendations**
- **Fundamental Physics Then and Now**
- **Current Content**
- **Conclusions**

Fundamental Physics

- **Fundamental Physics research has two organizing goals**
  - **Discover new understanding beyond today's knowledge of fundamental laws governing matter, space, and time.**
  - **Understand organizing principles of nature from which structure and complexity emerge.**
- **Fundamental Physics often has a long time horizon to economic return**
- **In Fundamental Physics, space-based research is explicitly and quantitatively measured against the best Earth-based experiments**
- **Discipline evolves with physics priorities**
- **Requires constant improvement in measurement precision and technologies, and generates technological advances of broad applicability**

Fundamental Physics – a self-assessment

Strengths - 1. A significant, quantifiable advantage for space experiments in cold atom and quantum research

- **Long observation times and low trap energies**
- **Free space transmission of photons over long distances**
- **Gravity field variations, deep space vacuum**

2. Wide recognition of the timeliness of "quantum science"

- **National Quantum Initiative**
- **One of NSF's "10 Big Ideas"**
- **Focus of International Initiatives**

3. Community support

- **Fundamental Physics Science Standing Review Board**
- **Internationally recognized researchers**

Fundamental Physics – a self-assessment

Weaknesses - 1. We're on the wrong side of the ISS program life cycle

Management focus now is on cost control and efficient use of existing resources

2. Lack of a grant program with regular solicitations

3. FP flight projects are expensive

4. ISS is at research operational capacity

5. Fragmented NASA and Federal programs and interests

- **NASA SMD technology interest in watchful waiting mode**
- **NASA communications and navigation not a physics program**
- **AFRL, NRL, DARPA not budgeting for space experiments**

NRC 2011 FP Decadal Recommendations

Fundamental Physical Sciences in Space (Chapter 8)

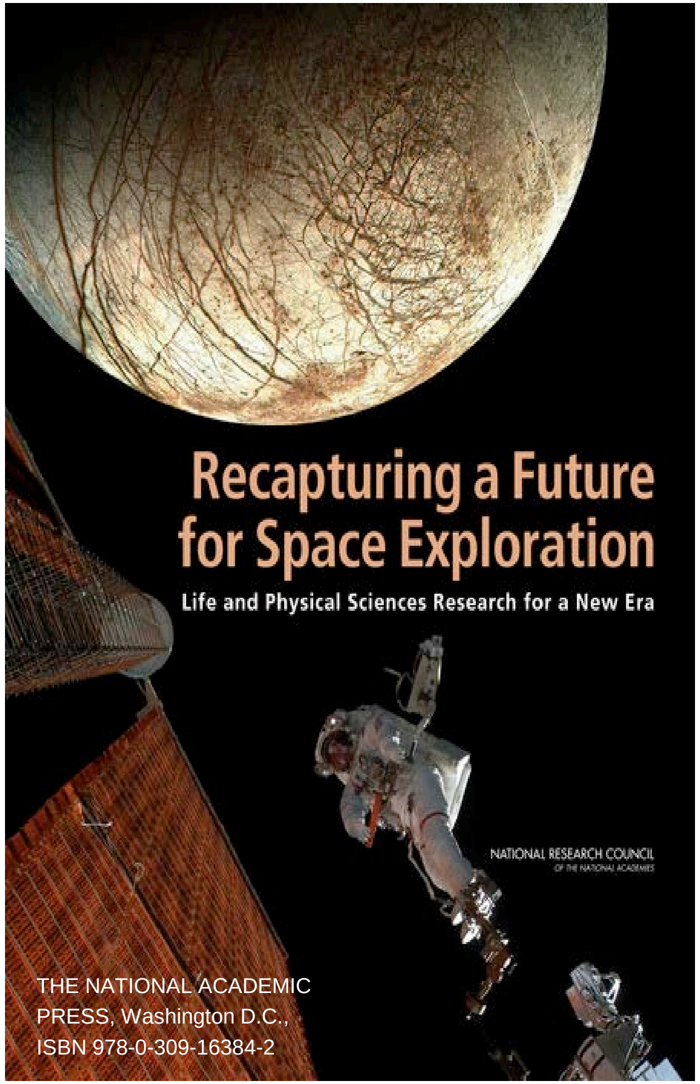
FP1	Research on complex fluids and soft matter. Microgravity provides a unique opportunity to study structures and forces important to the properties of these materials without the interference caused by Earth-strength gravity.	**PK4** **Ekoplasma**
FP2	Understanding of the fundamental forces and symmetries of nature. High-precision measurements in space can test relativistic gravity, fundamental high-energy physics, and related symmetries in ways that are not practical on Earth. Novel effects predicted by new theoretical approaches provide distinct signatures for precision experimental searches that are often best carried out in space.	**ACES** **MICROSCOPE** **DSQL** **AI in EE**
FP3	Research related to the physics and applications of quantum gases. The space environment enables many investigations, not feasible on Earth, of the remarkably unusual properties of quantum gases and degenerate Fermi gases.	**CAL** **BECCAL**
FP4	Investigations of matter near a critical phase transition. Experiments that have already been designed and brought to a level of flight readiness can elucidate how materials behave in the vicinity of thermodynamically determined critical points. These experiments, which require a microgravity environment, will provide insights into new effects observable when such systems are driven away from equilibrium conditions.	**DECLIC-ALI-R**

Applied Physical Sciences in Space (Chapter 9)

AP4	Development of fundamentals-based strategies and methods for dust mitigation during advanced human and robotic exploration of planetary bodies.	**Lunar Dust Mitigation**

Translation to Space Exploration Systems (Chapter 10)

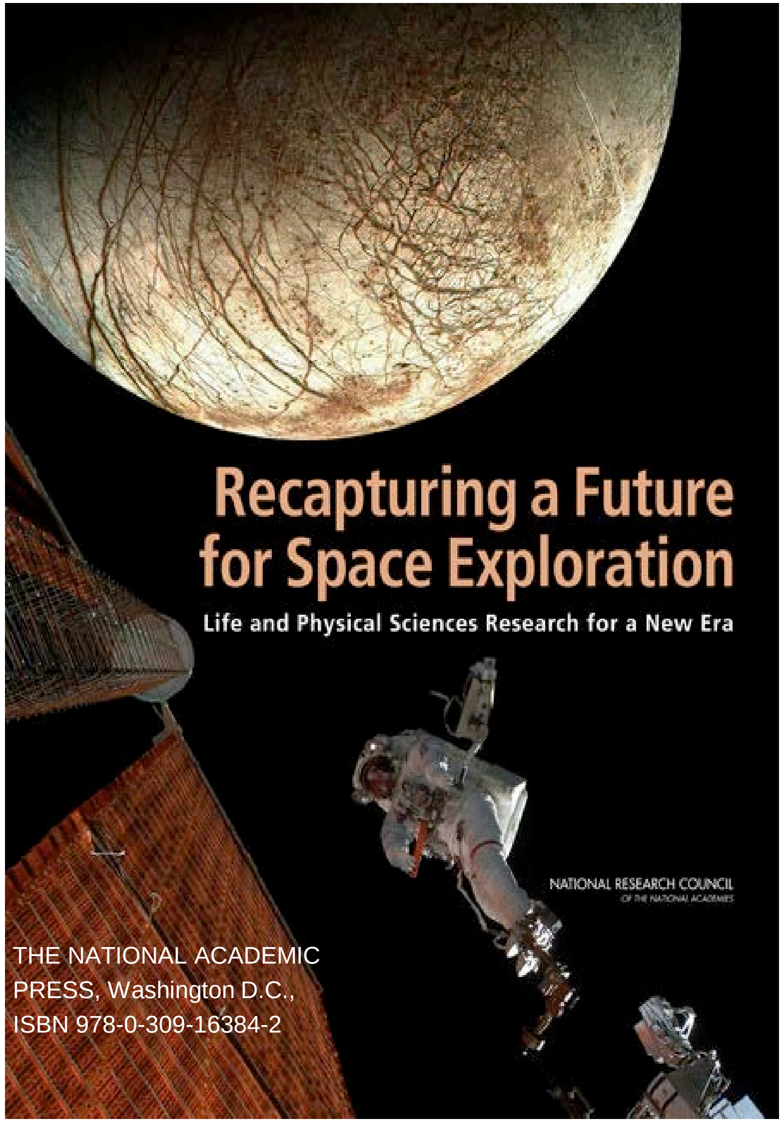
TSES4	NASA should develop and demonstrate technologies to mitigate the effects of dust on extravehicular activity (EVA) systems and suits, life support systems, and surface construction systems. Supporting research includes impact mechanics of particulates, design of outer-layer dust garments, advanced material and design concepts for micrometeoroid mitigation, magnetic repulsive technologies, and the quantification of plasma electrodynamic interactions with EVA systems (T5); dynamics of electrostatic field coupling with dust (T23); and regolith mechanics and gravity-dependent soil models (T27).	**Lunar Dust Mitigation**



NRC 2011 FP Decadal Recommendations continued

TABLE 10.3 Current Research and Technologies Required to Support Objectives and Operational Systems up to 2020

Recommendation	Research Topic	Current Gap	Critical Technology	Enabling Research	Environmental Constraints	Crosscutting Applications
T1	Space power and thermal management	Inability to utilize multiphase flow systems to increase performance	Two-phase flow thermal management technologies	Harness ability to use active two-phase flow thermal management in reduced gravity fields	Partial and microgravity	Space and surface operations, propellant systems, EVA, life support, habitats, power, ISRU
T2	Space propulsion	Inability to limit boiloff of cryogenic propellants to extend storage	Zero-boiloff propellant storage systems	Research in such areas as advanced insulation materials, active cooling, multiphase flows, and capillary effectiveness	Full gravity range	Space and surface operations, ISRU
T3	Space propulsion	Lack of knowledge of cryogenic propellant flow, handling, and gauging in microgravity	Cryogenic fluid management technologies	Research to enable microgravity propellant flow, handling, and gauging	Partial and microgravity	Enables propellant depots, ISRU
T4	EVA	Inadequate mobility for suited crew	EVA suit mobility enhancements	Research in suit comfort, trauma countermeasures, and joint mobility to provide crew the mobility to perform tasks over extended periods without injury	Partial and microgravity	Space and surface operations
T5	EVA	Lack of suit durability in on-orbit, lunar, and martian environments	Dust and micrometeroid mitigation systems	Research and test beds to deal with durability and maintainability issues of suits stemming from micrometeoroid and orbital debris damage, dust exposure, and plasma	Partial and microgravity, temperature extremes	Space and surface operations
T23	EVA and life support systems	Dust mitigation techniques and technologies do not exist	Dust mitigation technologies	Development and testing of dust countermeasures to mitigate the effects of dust coating, contamination, and abrasion and to prevent thermal control problems, seal failures, and inhalation/irritation	Partial gravity	Habitat and rovers, ISRU
T27	Planetary surface construction	Lack of information regarding regolith mechanics and properties	Regolith- and dust-tolerant systems	Research to describe the physical and mechanical properties of regolith to facilitate surface operations, construction, and ISRU	Partial gravity, extreme temperatures	Surface operations

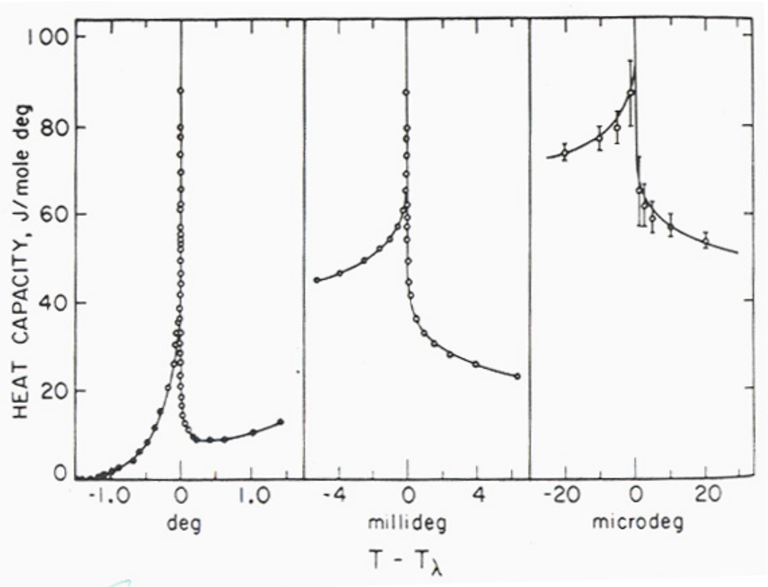


THE NATIONAL ACADEMIC PRESS, Washington D.C., ISBN 978-0-309-16384-2

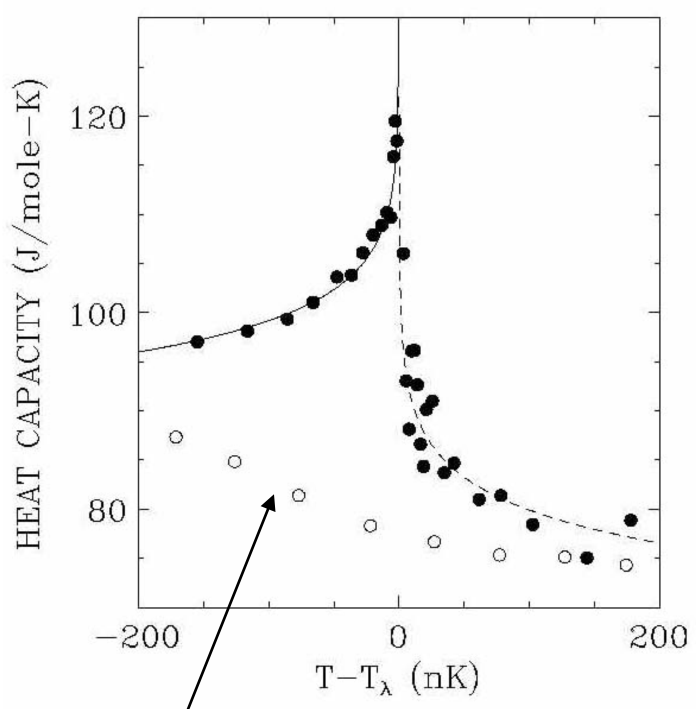
1990's Fundamental Physics

Lambda Point Experiment – Heat Capacity of ^{4}He at the Lambda Transition

- The sharpness of the transition reveals the very nature of collective behavior of the atoms.
- Measure specific heat and test detailed theoretical prediction in :
  - critical exponents
  - amplitude ratios
  - scaling laws



Physical Review Letters, **76**, 944 (1996)



data under gravity

1990's Fundamental Physics

Phase transitions

Superfluid Transition of 4He in the Presence of a Heat Current (Prof. Guenter Ahlers)
Microgravity Test of Universality and Scaling Predictions Near the Liquid-Gas Critical Point of 3He (Dr. Martin B. Barmatz)
New Phenomena in Strongly Counterflowing He-II near Tl (Dr. Stephen T. Boyd)
Prediction of Macroscopic Properties of Liquid Helium from Computer Simulation (Prof. David M. Ceperley)
Measurement of the Heat Capacity of Superfluid Helium in a Persistent-Current State (Dr. Talso C. Chui)
Nonequilibrium Phenomena Near the Lambda Transition of 4He (Dr. Talso C. Chui)
The Lambda Transition Under Superfluid Flow Conditions (Dr. Talso C. Chui)
Nucleation of Quantized Vortices from Rotating Superfluid Drops (Prof. Russell J. Donnelly)
Critical Dynamics in Microgravity (Prof. Robert V. Duncan)
Kinetic and Thermodynamic Studies of Melting-Freezing of Helium in Microgravity (Prof. Charles Elbaum)
Critical Dynamics of Ambient Temperature and Low Temperature Phase Transitions (Prof. Richard A. Ferrell)
Dynamics of Superfluid Helium in Low Gravity (Mr. David J. Frank)
Critical Fluid Light Scattering Experiment - ZENO (Prof. Robert W. Gammon)
Condensate Fraction in Superfluid Helium Droplets (Prof. J. Woods Halley)
Ultra-Precise Measurements with Trapped Atoms in a Microgravity Environment (Dr. Daniel J. Heinzen)
Collisional Frequency Shifts near Zero-Energy Resonance (Prof. Randall G. Hulet)
Dynamic Measurement Near the Lambda-Point in a Low-g Simulator on the Ground (Dr. Ulf E. Israelsson)
High Resolution Pressure Transducer and Controller (Dr. Ulf E. Israelsson)
Dynamic Measurements Along the Lambda Line of Helium in a Low-Gravity Simulator on the Ground (Dr. Ulf E. Israelsson)
Static Properties of 4He in the Presence of a Heat Current in a Low-Gravity Simulator (Dr. Melora E. Larson)
Second Sound Measurements near the Tricritical Point in 3He - 4He Mixtures (Dr. Melora E. Larson)
Confined Helium Experiment (CHeX) (Prof. John A. Lipa)

1990's Fundamental Physics

Phase Transitions, continued

Effect of Confinement on Transport Properties by Making use of Helium Near the Lambda Point (Prof. John A. Lipa)
A New Test of Critical-Point Universality by Measuring the Superfluid Density Near the Lambda Line of Helium (Prof. John A. Lipa)
Theoretical Studies of the Lambda Transition of Liquid 4He (Prof. Efstratios Manousakis)
Dynamics and Morphology of Superfluid Helium Drops in a Microgravity Environment (Prof. Humphrey J. Maris)
Equilibration in Density and Temperature Near the Liquid-Vapor Critical Point (Prof. Horst Meyer)
Indium Mono-ion Oscillator II (Prof. Warren Nagourney)
Nonlinear Relaxation and Fluctuations in a Non-Equilibrium, Near-Critical Liquid with a Temperature Gradient (Prof. Alexander Z. Patashinski)
Superfluid Density of Confined 4He near Tl (Dr. David Pearson)
Finite Size Effects near the Liquid-Gas Critical Point of 3He (Dr. Joseph Rudnick)
Dynamics and Morphology of Superfluid Helium Drops in a Microgravity Environment (Prof. George M. Seidel)
Precise Measurements of the Density and Thermal Expansion of 4He Near the Lambda Transition (Dr. Donald M. Strayer)

Everything Else

Satellite Test of the Equivalence Principle (STEP) (Prof. C. W. F. Everitt)
Precision Measurements with Trapped, Laser-Cooled Atoms in a Microgravity Environment (Dr. Daniel J. Heinzen)
Red-Shift Test of General Relativity on Space Station Using Superconducting Cavity Oscillators (Prof. John A. Lipa)
Investigation of Future Microgravity Atomic Clocks (Prof. Kurt Gibble)
Atom Interferometry in a Microgravity Environment (Dr. Mark A. Kasevich)

Current Program Content

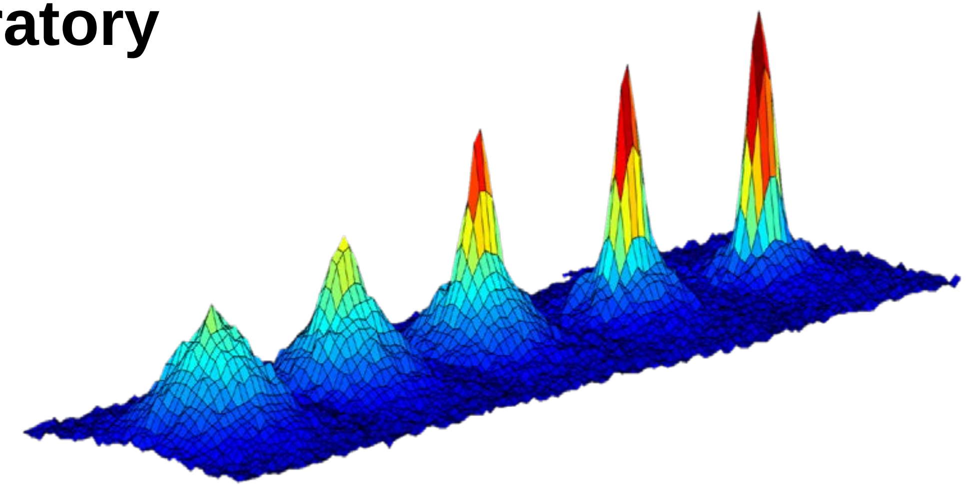
NASA Fundamental Physics Projects and Investigators		Decadal Link
Plasma Kristall 4 [PK4] Launch Oct, 2014	**ESA/ROSCOSMOS Led**	
John Goree - University of Iowa	Nonlinear wave experiments in dusty plasmas	**FP1**
Uwe Konopka - Auburn University	Complex Plasma under Microgravity, Utilizing the ISS Experiment "PK-4" and Beyond	**FP1**
Bin Liu - Unviersity of Iowa	Three-dimensional dusty plasma experiments	**FP1**
Garudas Gangoli - Navy Research Lab	Understanding the Frequency Synchronization Physics in PK-4 Experiment	**FP1**
Paul Bellan, Caltech	Development of Laser Induced Fluorescence as a Diagnostic for Measuring Neutral, Ion, and Molecular Particle Fluxes in the PK-4 Experiment	**FP1**
Truell Hyde - Baylor University	PK-4: Self-Ordering of Interacting Complex Plasma Particles in Microgravity	**FP1**
Microscope : Launch April 2016	**CNES Led**	
Slava Turyshev - Jet Propulsion Laboratory	Data analysis and orbit determination support	**FP2**
DECLIC-ALI-R: Launch Aug 2017	**CNES Led**	
Inseob Hahn, Jet Propulsion Laboratory	Investigation of equilibration near the liquid-gas critical point in microgravity utilizing DECLIC	**FP4**
Cold Atom Laboratory (CAL): Launch May 2018	**NASA/JPL Led**	
Nicholas Bigelow - University of Rochester	Consortium for Ultracold Atoms in Space	**FP3**
Eric Cornell - University of Colorado, Boulder	Zero-G Studies of Few-Body and Many-Body Physics	**FP3**
Nathan Lundblad - Bates College	Microgravity dynamics of bubble-geometry Bose-Einstein condensates	**FP3**
George Raithel - University of Michigan	High-precision microwave spectroscopy of long-lived circular-state Rydberg atoms in μg	**FP3**
Cass Sackett - University of Virginia	Development of Atom Interferometry Experiments for the ISS' CAL	**FP3**
Dan Stamper-Kurn - UC Berkeley	Coherent magnon optics	**FP3**
Jason Williams, Jet Propulsion Laboratory	Fundamental Interactions for Atom Interferometry with Ultracold Quantum Gases in μg	**FP3**
Atomic Clock Ensemble in Space: Launch 2020	**ESA Led (with CNES)**	
Nan Yu - Jet Propulsion Laboratory	JPL Participation in ESA ACES Worldwide Clock Comparison Campaign	**FP2**
Kurt Gibble - Penn State University	Contributions to the Evaluation of the ACES clock PHARAO	**FP2**
Leo Hollberg - Stanford University	Advancing Time Transfer and Optical Atomic Clocks for Space	**FP2**
Chris Oates - NIST, Boulder	NIST/ACES Collaboration: ACES Ground Station and Data Analysis Center in Boulder, Colorado	**FP2**
Bose Einstein Condensate CAL: Launch 2025	**DLR Led**	
4 SDT members currently; NRA planned 2021		**FP3**
Study Activities	**NASA/JPL Led**	
Sheng-Wei Chiow	Microgravity Atom Interferometry and Dark Energy	**FP2**
Inseob Hahn	Lunar and Mars Dust Mitigation	**FP1**
Makan Mohageg	Deep Space Quantum Link	**FP2**

Color Code

- FP1: Complex Fluids and Soft Matter
- FP2: Fundamental Forces and Symmetries in Nature
- FP3: Physics and Applications of Quantum Gases
- FP4: Critical Phenomena

Cold Atom Laboratory

- Flight Pis: Nick Bigelow, Rochester, Jason Williams, JPL, Cass Sackett, U Virginia, Nathan Lundblad, Bates College, Eric Cornell, U Colorado/JILA.



- ***Objective:***
- Establish ultra-cold atomic physics in space and provide a cutting edge research facility for the NASA science community.
- *Experimental Approach:*
- Study evaporatively cooled atomic samples of 87Rb, 39K, and 41K
- Provide researchers with a state of the art suite of tools for ultra-cold atom studies including advanced state selection; Feshbach control of atomic interactions and precision atomic interferometry
- ***Relevance/Impact:***
- First multi-user research facility in space
- Exceptionally diverse and prestigious team of PI 's
- Decadal FP3 – Cold Atom Research & FP3: Fundamental Forces, EEP violation, Standard Model extension.
- Science Instruments Roadmap: Quantum Interferometry.
- Identified need in 5 of 38 exploration quantifiable capabilities quad charts, including precision landing, GW detection, and In-situ resource utilization (detection).
- ***Project Development Approach:***
- JPL continues remote operation of CAL and maintains testbeds
- New atom interferometer enabled science module is being developed at JPL

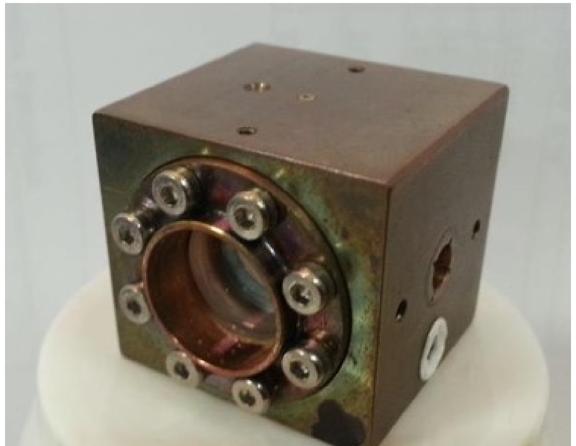
Space Resource Requirements

Accommodation (carrier)	US Module Express Rack
Upmass (kg) (w/o packing factor)	300
Volume (m^3) (w/o packing factor)	0.4
Power (kw) (peak)	.85
Crew Time (hrs) (installation/operations)	TBD
Autonomous Operation	3 years
Launch	May 2018

Project start	CDR	Launch	Sci Ops Start	Return	CAL-2 launch	CAL 2 Ops
Sep-12	Feb-15	May-18	Oct-18	Jan-20	Nov-20	10/20 – 9/22

DECLIC-ALI R

CNES PI Team: Yves Garrabos, Daniel Beysens, Carole Lecoutre
JPL Principal Investigator: Dr. Inseob Hahn


ALI R cell providing near exact criticality

Objective:
- Study temperature and density relaxation near a critical point in single and two-phase regions.

Experimental Approach:
- Study SF6.
- Measure thermal diffusivity, heat capacity, turbidity, and density in two-phase region.
- Experiments to be performed in the ISS DECLIC Facility (CNES)

Relevance/Impact:
- Studies of critical phenomena in well-defined test beds can help us understand the behavior of two-phase fluids used in ground and space applications.
- Ultimately tests the Nobel prize winning RG theory of critical phenomena which is applicable to numerous complex systems.

Project Development Approach:
- DECLIC and ALI R Hardware developed by CNES.
- Utilize interferometric capability of the instrument to perform the NASA investigation.
- Partner with CNES investigators on all ALI R investigations.
- Initial data gathered in Feb 2018. Due to a DECLIC facility laser diode failure, final operations will be performed in 2021 after the facility is changed out to DECLIC EVO.

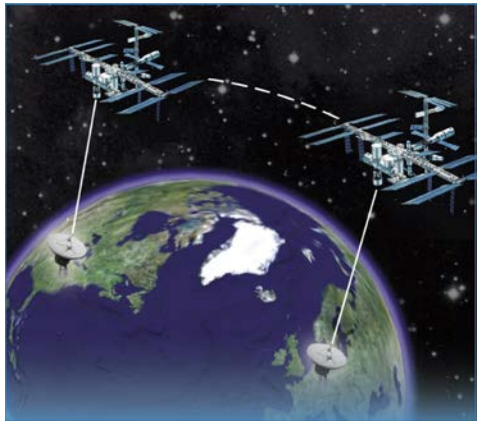
ISS Resource Requirements

Accommodation (carrier)	DECLIC EVO Facility
Upmass (kg) (w/o packing factor)	~ 5
Volume (m^3) (w/o packing factor)	.05
Power (kw) (peak)	TBD
Crew Time (hrs) (installation/operations)	Only for insert change-out
Autonomous Operation	Autonomous operations with ground command (CADMOS)
Launch/Increment	Nov 2020

Award	SCR	RDR	PDR	CDR	FHA	Ops
Oct 2015	N/A	N/A	N/A	N/A	Nov 2020	1/21 – 7/21

Atomic Clock Ensemble in Space

Principal Investigator: Christophe Salomon, Ecole Normale Superieure, France



ACES Micro Wave Link Ground Terminal

- ***Objective:***
- Validate cold atom space clock technology to the 10^-16 level
- Perform time and frequency transfer to the Earth
- Test general and special relativity to high precision
- Use relativistic geodesy to map the Earth's gravitational potential.
- ***Experimental Approach:***
- Cesium laser cooled atomic fountain clock.
- Hydrogen maser flywheel oscillator provide accurate short time stability.
- Microwave and Optical time transfer from ACES to a constellation of ground clocks for clock comparison activity.
- ***Relevance/Impact***
  - Decadal FP2: – Einstein's Equivalence Principle is the foundation of Einstein's General Theory of Relativity. Uncovering a violation would indicate additional forces beyond the 4 currently known and require modifications to the Standard Model of Physics.
  - Global and National time & frequency reference, relativistic geodesy.
  - LOP-G: Verify laser ranging technique
- ***Project Development Approach:***
  - CNES provides Pharao Cs Clock.
  - ESA is mission implementer using EADs Astrium.
  - ESA to deliver MWL to NIST and JPL teams for use in global frequency comparison effort.

ISS Resource Requirements

Accommodation (carrier)	External to Columbus Module
Upmass (kg) (w/o packing factor)	227
Volume (m^3) (w/o packing factor)	1.0
Power (kw) (peak)	0.45
Crew Time (hrs) (installation/operations)	Installation only
Autonomous Operation	18 months
Launch	Spring 2020 (Space X-21)

Award	SCR	RDR	PDR	CDR	FHA	Ops
Jun 2012	N/A	N/A	N/A	N/A	Feb 2020	6/20 – 12/21

PK-4 NASA/NSF Support

PK4 Facility Science Team Chair: Prof. John A. Goree, Univ. of Iowa
NASA PIs: J Goree & B Liu, University of Iowa; U Konopka, Auburn University; G Ganguli, NRL;
NSF Pis: P Bellan, Caltech; T Hyde, Baylor University.

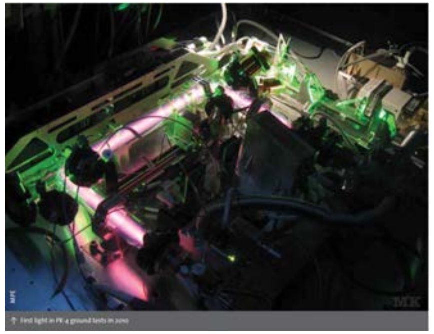


Image Credit: +European Space Agency, ESA / +ROSCOSMOS RUSSIA)

- ***Objective:***
- Study of the liquid phase of complex plasma such as flow phenomena
- Study of non-Gaussian statistics of particle motion, diffusion, viscosity.
- ***Experimental Approach:***
- Control variables: Particle size, plasma gas, DC discharge field.
- Diagnostics: High speed camera.
- ***Relevance/Impact:***
- NASA's decadal survey recommendation for FP in microgravity: dusty plasma, condensed matter physics analog.
- Understanding astrophysics phenomena
- Dust mitigation physics needed for exploration
- Earth Based applications in Semiconductor, Manufacturing, and Clinical Industries.
- ***Project Development Approach:***
- Hardware built by DLR contractor OHB System AG (Kayser-Threde
- PK4 is the culmination of a sequence of prior flight experiments with the collaborating partners starting on the Russian MIR station.

ISS Resource Requirements

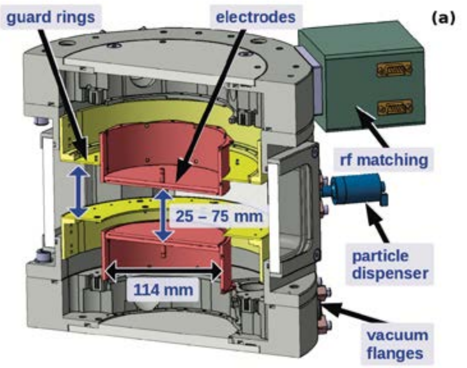
Accommodation (carrier)	ISS Columbus Module
Upmass (kg) (w/o packing factor)	25
Volume (m^3) (w/o packing factor)	0.24
Power (kw) (peak)	0.3
Crew Time (hrs) (installation/operations)	TBD
Autonomous Operation	6 years, not continuous
Launch	10/2014

Award	SCR	RDR	PDR	CDR	FHA	Ops
4/1/2017	N/A	N/A	N/A	N/A	Jul 2014	1/15 – 9/19

Ekoplasma NASA/NSF Support

ESA/ROSCOSMOS/DLR Project installed in the ISS Columbus Module
German Lead Scientist: Dr. Hubertus Thomas, MPE, Garching, Germany
Russian Lead Scientist: Dr. Andrey Lipaev, JIHT, Moscow, Russia
ESA Coordinator: Astrid Orr, ESTEC, Netherlands
NASA PIs: TBD
PS/PM: Dr. Inseob Hahn, JPL

- WBS



- ***Objective:***
  - Study of the liquid phase of complex plasma in 3-D such as flow phenomena
  - Study of 3-D non-Gaussian statistics of particle motion, diffusion, viscosity.
- ***Experimental Approach:***
  - Control variables: Particle size, plasma gas, DC discharge field.
  - Diagnostics: High speed camera.
- ***Relevance/Impact:***
  - NASA's decadal survey recommendation for FP in microgravity: dusty plasma, condensed matter physics analog.
  - Understanding astrophysics phenomena
  - Dust mitigation physics needed for exploration
  - Earth Based applications in Semiconductor, Manufacturing, and Clinical Industries.
- ***Project Development Approach:***
  - NRA for US science community to utilize the planned DLR/ESA ECOPLASMA follow-on to PK4 to investigate the motion and organization of charged micro-particles
  - Charged particle motion in a spherical chamber and quasi-isotropic interaction potential will be used.

ISS Resource Requirements

Accommodation (carrier)	ISS Columbus Module
Upmass (kg) (w/o packing factor)	25
Volume (m^3) (w/o packing factor)	0.24
Power (kw) (peak)	0.3
Crew Time (hrs) (installation/operations)	TBD
Autonomous Operation	6 years, not continuous
Launch	10/2014

Award	SCR	RDR	PDR	CDR	FHA	Ops
10/1/2022	N/A	N/A	N/A	N/A	Jul 2022	10/22-9/26

BECCAL

DLR Principal Investigator: Wolfgang Schleich, University of Ulm, Germany
NASA Science Team Lead: Dan Stamper-Kurn, UC Berkeley

- ***Objective:***
- Provide a research facility for the German and NASA science communities that enhances the CAL capabilities by providing higher atom flux, colder atom ensembles, more capable atom interferometry, and painted box trap.

– *Experimental Approach:*

- Study laser cooled atoms ensembles of 85Rb, 87Rb, 39K, 40K and 41K prepared in precise external and internal states.
- Light pulse atom interferometry and quantum optics techniques are employed with detection of both absorption and fluorescence.
- Relevance/Impact:
  - Decadal FP3 – Cold Atom Research & FP3: Fundamental Forces, EEP violation, Standard Model extension.
  - Science Instruments Roadmap: Quantum Interferometry.
  - Identified need in 5 of 38 Exploration quantifiable capabilities quad charts, including precision landing, GW detection, and In-situ resource utilization (detection).

Project Development Approach:

- DLR will develop, deliver, and operate the hardware. DLR will use heritage from the MAIUS rocket experiments and CAL.
- JPL will support DLR's development, verify feasibility of new capabilities requested by the US Science Definition Team, provide CAL information and lessons learned, and support US investigators.
- NASA investigators will be selected from a NRA with funding to start in Apr 2023.
- JPL will maintain and operate BECCAL ground testbed in support of PI science investigations.

Space Resource Requirements

Accommodation (carrier)	US Module Express Rack
Upmass (kg) (w/o packing factor)	350
Volume (m^3) (w/o packing factor)	0.4
Power (kw) (peak)	.9
Crew Time (hrs) (installation/operations)	TBD
Autonomous Operation	2 years
Launch	Oct 2024

SDT Award	SCR	RDR	PDR	CDR	FHA	Ops
Aug-17	Feb-18	Feb-18	May-19	May-20	Aug-24	10/24 – 9/27

Dust Mitigation: Plasma Dry Cleaning

Principal Investigator: Prof. Xu Wang, LASP, University of Colorado, Boulder
Co- Investigator: Prof. John Goree, University of Iowa
Project Manager and Project Scientist: Inseob Hahn, JPL

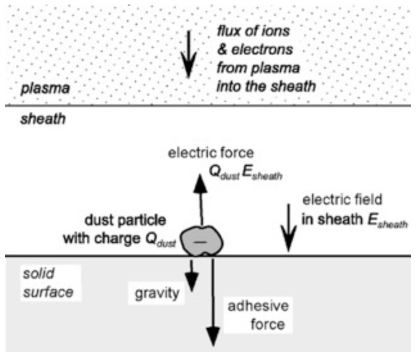
Objective:
- Developing open, portable plasma cleaning tool and demonstrate superiority over other techniques in Moon/Mars like environment.

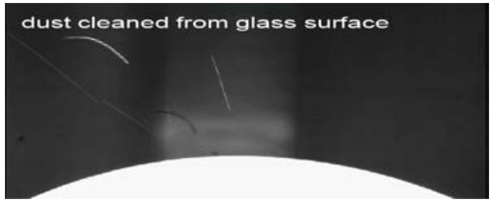
Experimental Approach:
- Develop a portable plasma generator using CO2 and demonstrate plasma cleaning of representative dust particles in lunar habitat conditions.
- Study particle lofting physics for various surfaces (radiators, solar panels, visors, EVA suit, etc)
- Collect data by video imaging

Relevance/Impact:
- ”Dust mitigation systems” is the highest priority (midterm report decadal survey)
- Dust mitigation is an unresolved issue identified in Decadal review TSES4 and listed as critical in 5 of 38 exploration quantifiable capabilities requirements.

Project Development Approach:
- Develop requirements and concept
- Acquire relevant dust simulants
- Study particle lofting physics under realistic conditions.
- Verify proof of concept in realistic system against a full 1-g to demonstrate margin against lunar and Mars operation.
- Develop TRL5 concept with matching STMD funds

Breadboard tests show cleaning JSC-1 simulant from surfaces





ISS Resource Requirements

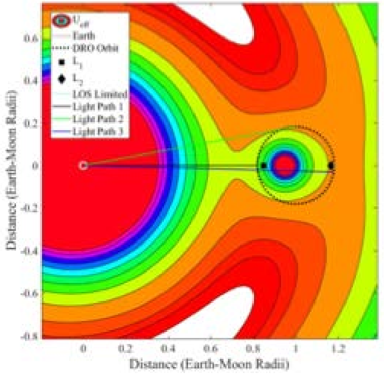
Accommodation (carrier)	Ground Demo
Upmass (kg) (w/o packing factor)	N/A
Volume (m^3) (w/o packing factor)	N/A
Power (kw) (peak)	N/A
Crew Time (hrs) (installation/operations)	N/A
Autonomous Operation	N/A
Launch/Increment	N/A

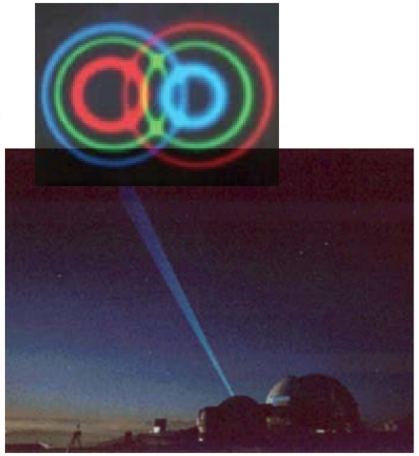
Award	SCR	RDR	PDR	CDR	FHA	Ops
Mar 2019	N/A	N/A	N/A	N/A	N/A	N/A

Deep Space Quantum Link

NASA Project Manager: Ulf Israelsson, JPL
NASA Principal Investigator and Project Scientist: Dr, Makan Mohageg, JPL

- ***Objective:***
- Demonstrate high-rate entangled photon source systems for near earth and deep space quantum experiments
- Assess the feasibilities of science and a mission concept for deep space quantum link experiments from LOP-G and other opportunities
- Provide quantum communication capabilities to other US space quantum QKD and communication endeavors with substantive SLPSRA contributions
- ***Experimental Approach:***
- Focus on the key quantum technology component in space quantum communication – a high-rate entangled photon source
- Leverage JPL's capabilities in quantum science, quantum optics, and optical communication
- ***Relevance/Impact:***
- Develop capability for quantum communication experiments at long distance and secure communications network in particular
- Enable relativistic confirmation (both special and general) of quantum mechanics / quantum field theory
- Establish new and improved long distance communication capabilities
- ***Project Development Approach:***
- Two-year plan for a laboratory demonstration and another two year for technology maturation ready for flight system development.
- Start flight development in 2022 with PDR in 2024.
- Actively engage SCaN and seek collaboration with International Partners
- Establish Gateway requirements and seek matching funds.





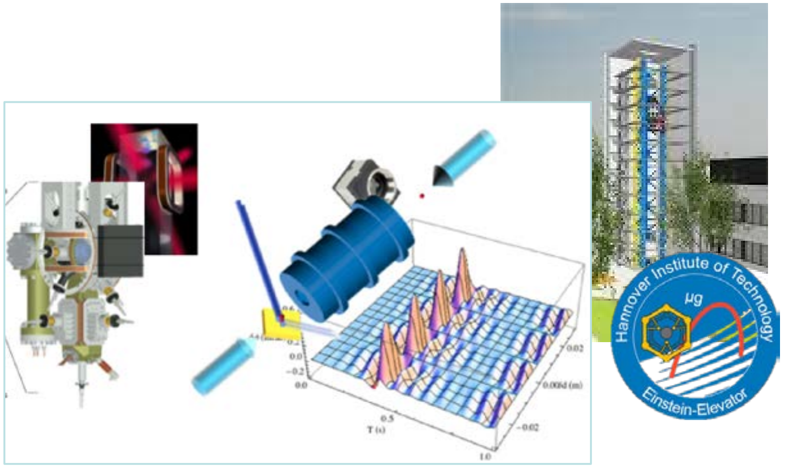
Space Resource Requirements

Accommodation (carrier)	Deep Space Gateway
Upmass (kg) (w/o packing factor)	TBD
Volume (m^3) (w/o packing factor)	TBD
Power (kw) (peak)	TBD
Crew Time (hrs) (installation/operations)	TBD
Autonomous Operation	TBD
Launch	TBD

Award	SCR	RDR	PDR	CDR	FHA	Ops
Mar-19	NA	NA	Apr-23	NA	NA	NA

Micro Gravity Atom Interferometry on EE for Hunting Dark Energy

NASA Project Manager: Ulf Israelsson, JPL
NASA Project Scientist: Nan Yu, JPL
German collaborator: Prof. Wolfgang Ertmer, Prof. Ernst Rasel



- ***Objective:***
- To conclusively verify or refute if the chameleon field is responsible for the dark energy which represents 68% of the energy content in the Universe.
- Demonstrate AI precision measurements in micro gravity
- ***Experimental Approach:***
- Reuse the MAIUS cold atom module through collaboration with Germans
- Use specially designed periodic dark energy source mass for environment gravity interference and systematic reduction
- Perform multiple atom Interferometers with repeated drop experiment runs afforded by the Hannover Einstein Elevator
- ***Relevance/Impact:***
- :
- Address important science question of the century
- Use and demonstrate precision measurement tools in microgravity
- Mature atom interferometer technology and science measurement concepts for future space experiments
- ***Project Development Approach:***
- Build on SLPSRA funded dark energy study and results already published.
- Establish collaborations with DLR and German science foundation
- Initiate a joint Phase A implementation feasibility study for reusing MAIUS
- JPL build and evaluate the dark energy source mass structure and its integration interface.
- German team integrates the experiment drop payload and operate experiments
- US and German scientists share data and perform joint analysis and investigate science

ISS Resource Requirements

Accommodation (carrier)	Ground based
Upmass (kg) (w/o packing factor)	N/A
Volume (m^3) (w/o packing factor)	N/A
Power (kw) (peak)	N/A
Crew Time (hrs) (installation/operations)	N/A
Operation	1 year
Launch	N/A

Award	SCR	RDR	PDR	CDR	FHA	Ops
Jun 2019	N/A	N/A	N/A	N/A	N/A	2024

Fundamental Physics – here are your conclusions

1. What an interesting program

2. This program really needs a grants budget

3. With an adequate budget, this program could play a meaningful role in an important national initiative for science and technology