National Aeronautics and Space Administration

EXPLORE SCIENCE

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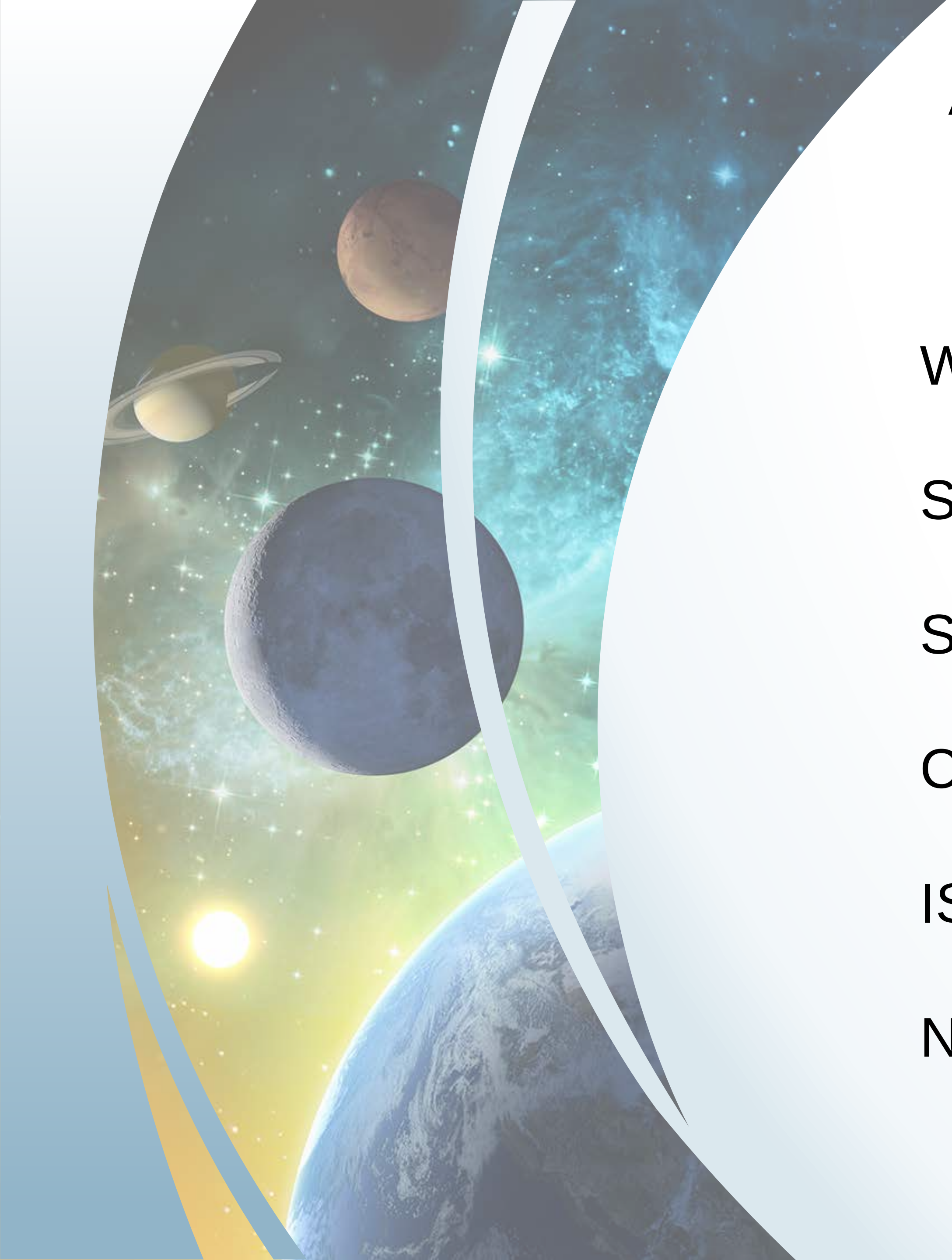
Biological and Physical Sciences Division

Committee on Biological and Physical Sciences in Space
28 October 2020



Agenda

What is Fundamental Physics?

Status and developments in Fundamental Physics

Science Highlights

Cold Atom Lab status

ISS Utilization

Next generation planning

What exactly is Fundamental Physics?

- “I know it when I see it” – Potter Stewart, 1964
- Working Definition - Experimental Physics in Space
- First generation (1980-2000) Fundamental Physics – Cooperative phenomena in phase transitions and experimental tests of renormalization group theory
- Current generation (2000-) Fundamental Physics – Properties of quantum matter; Use of quantum properties in research; Physics of dusty plasmas

Fundamental Physics has potential for great potential for growth in the next decade

- National Quantum Initiative
- Quantum science is the NSF “10 Big Ideas” for physical science
- Recommendations in 2019 AMO Decadal and 2020 Plasma Science Decadal for space research

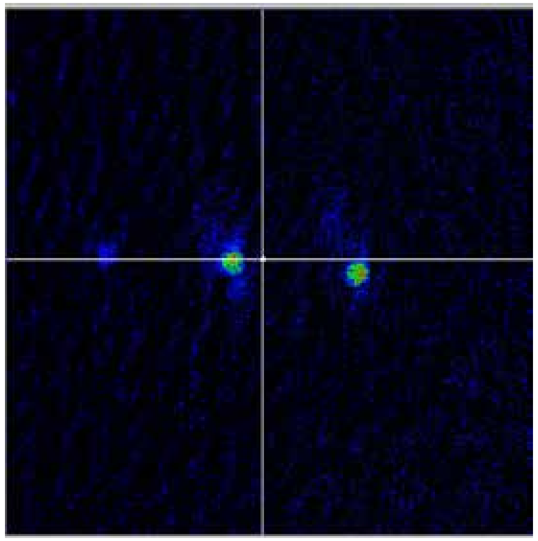
Fundamental Physics Status and Developments

- One major flight project in operation – Cold Atom Laboratory (CAL). CAL is the largest NASA investment in ISS research in the last 10 years. HEOMD approval 2011, initiation 2012. Delivered to ISS 2018.
- Next generation flight research is dependent on international instruments. BECCAL is the follow-on to CAL, expected delivery 2025-2026. COMPACT is the expected follow-on to PK-4 for dusty plasma research, hoped-for delivery in 2025-2026. Both are DLR projects.
- Future NRA releases currently linked to flight project schedules
- Move to SMD is promising. Focus on scientific excellence and transformative science is a huge positive for us.

Fundamental Physics Highlights

CAL Science Highlights

- Instrument checkout of the new Science Module has gone very well
- The CAL team demonstrated the first atom interferometer in space
- A paper describing the initial checkout of the original system was published in *Nature*
- A further six papers are in the preparation phase based on the output of CAL's phase one science. (2-3 from JPL, along with 4-5 from CAL PI's).

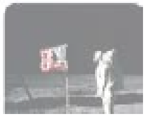


Atom Interferometer output

Lunar Dust Research and Mitigation

- University of Colorado Web release of Acta Astronautica *Dust Mitigation* publication picked up by *Science News*.
- Abstract titled “A New Technique for Lunar Dust Mitigation Utilizing an Electron Beam” submitted by Xu Wang to Lunar Surface Innovation Consortium Fall meeting
- BPS funded technology development activities continue on FY21 to evaluate/improve the technology
  - Use of UV light
  - Improvement of efficiency
- A multi-NASA center team proposal to STMD has received FY21 funding
  - “Plasma Lofting Technique” (JPL) received dust mitigation technology maturation funding
  - A JPL solar cell coupon is currently installed in the vacuum chamber for the test

Space.com
Everyday Tech From Space: How Moon Science Gave Us the DustBuster



Economic Times
All set to move to the moon? Lunar dust is going to be a bigger problem than you think
And the dustbuster prototype created by researchers at the University of Colorado that dislodges regoliths by emitting astrong beam of electrons ...
1 month ago

SciTechDaily
Pioneering a New Solution to a Lunar Problem: A Dustbuster ...

physicsworld.com
Dust buster for the Moon, curious pattern appears on ...
The team tested their lunar “dust buster” in a vacuum chamber using dust

c|net COVID-19 BEST REVIEWS NEWS HOW TO CARS DEALS
Scientists develop moon 'dustbuster' to clean lunar gunk off astronaut gear

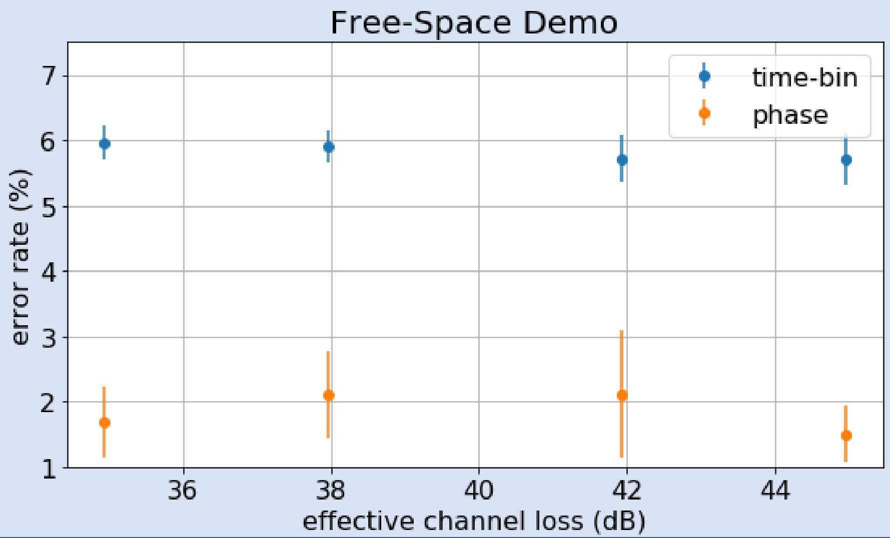
The Weather Channel
Lunar Dustbuster: Researchers Develop Electron Beam to Get Rid of Moon Dust
Researchers from the US have created a brand new dust mitigation

Deep Space Quantum Link

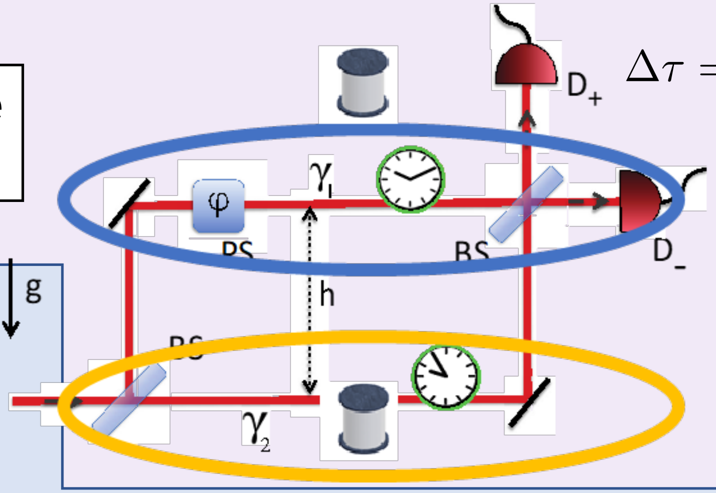
Successful lab demo in partnership with Caltech & JPL Advanced Concepts Program: highest rate quantum communications channel ever measured à

- Successful links (error rate < 11%) in lab for 12.25 GHz clock rate quantum channel
  - Current SoA: 5 GHz [1, 2]
- Using current low-DCR detectors (0.03 cps) expect a maximum channel loss of ~81 dB
  - Current SoA: 71.9 dB [3]

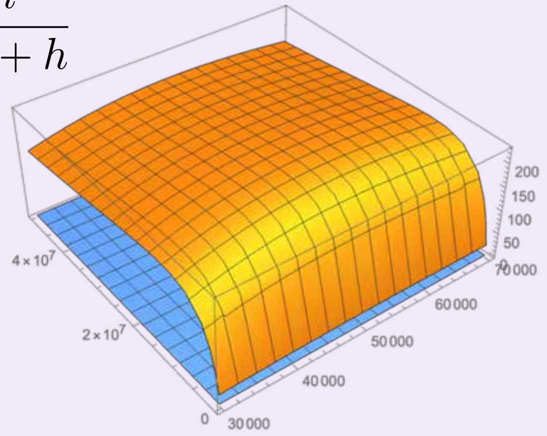
[1] N. T. Islam, et al., *Science Advances,* 3(11), e1701491 (2017)
[2] A. Boaron, et al., *Appl. Phys. Lett.*, 112, 171108 (2018)
[3] A. Boaron, et al., *Phys. Rev. Lett.*, 121, 190502 (2018)

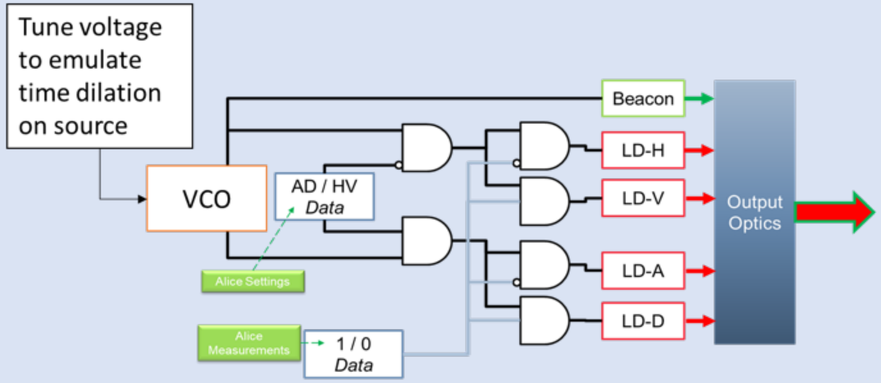


Optimization of spacecraft orbital profile for single photon interferometer/quantum "COW" test à



$$\Delta\tau = \frac{l}{2c}\frac{r_S}{r_E}\frac{h}{r_E + h}$$





ß Modulator design for emulating time dilation on quantum channels in the laboratory

CAL Status

Cold Atom Lab Science Status

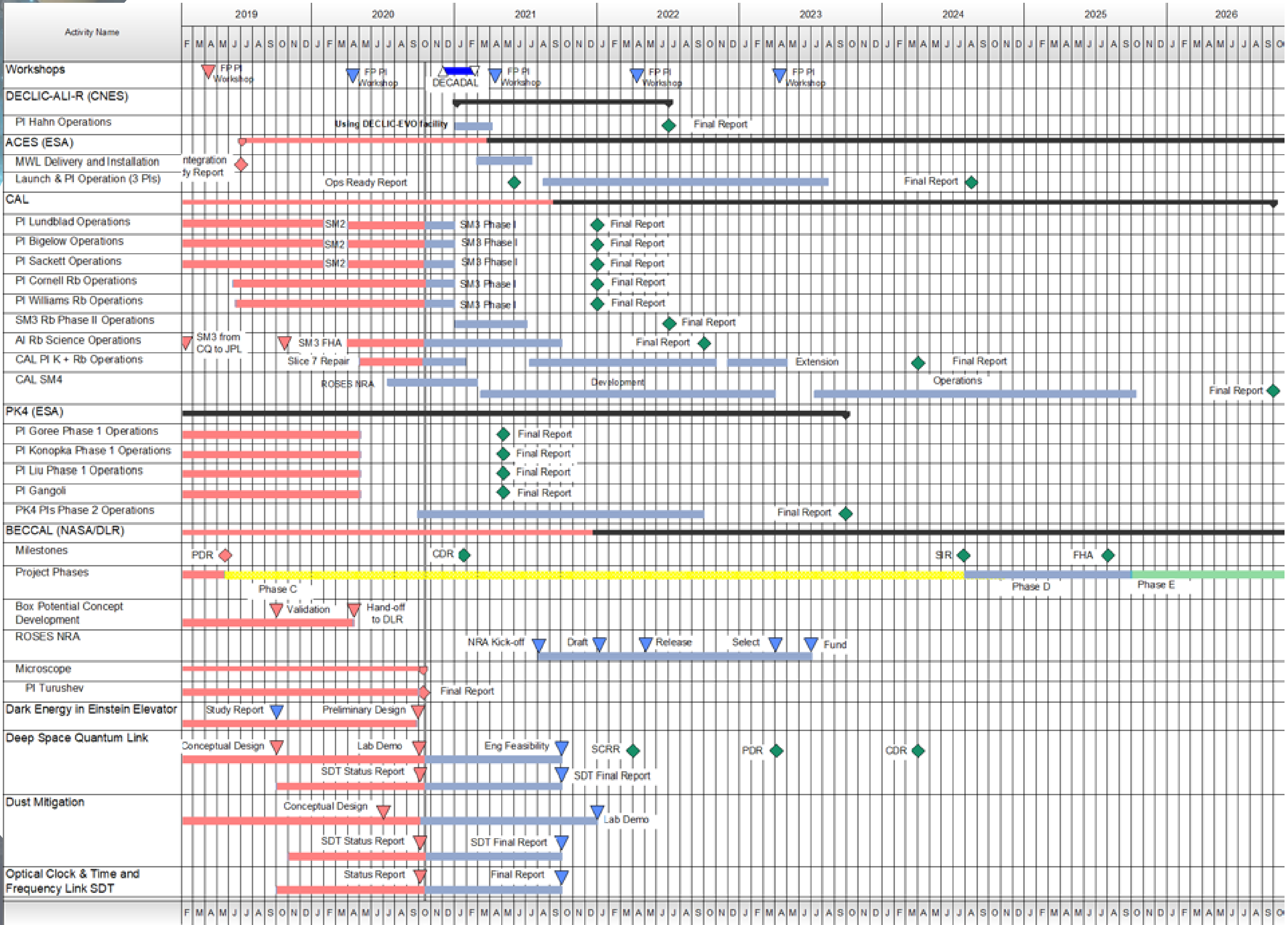
- The science team has overcome limitations on the availability of the Bragg laser for science and continued to perform pioneering research in this area. Issues with atom dispensers had only a low impact on science, as we were able to prioritize science that didn't require Bose condensates. While the Bragg issue is still pending, the instrument continues to perform very well, typically delivering well over a hundred data runs/day to PI's; with very robust condensates over the past month.

- The AI science team (PI's Williams, Bigelow, and Sackett, along with the JPL team) has worked to optimize the original AI results, and explore atom interferometry in new geometries and quantum states, as discussed on the next page.

- Paper status:
  - We are compiling and analyzing information for first paper detailing the first demonstration of atom interferometry in space.
  - A paper entitled "Quasi-adiabatic external state preparation of ultracold atoms in microgravity" by A. Pollard, E. Moan, Cass Sackett, Ethan Elliot and R. Thompson has been accepted by *Microgravity Science and Technology*
  - Two other papers are in the final stages of preparation
- Cold Atom Lab results were presented in a plenary lecture at the ISS R&D conference by K. Oudhiri and R. Thompson, as well as in talks given by several PI's

Utilization Plans

Schedule


Activity Name
2019
2020
2021
2022
2023
2024
2025
2026
Workshops
FP PI Workshop
DECADAL
DECLIC-ALI-R (CNES)
PI Hahn Operations
Using DECLIC-EVO facility
Final Report
ACES (ESA)
MWL Delivery and Installation
ntegration
ty Report
Launch & PI Operation (3 PIs)
Ops Ready Report
Final Report
CAL
PI Lundblad Operations
PI Bigelow Operations
PI Sackett Operations
PI Cornell Rb Operations
PI Williams Rb Operations
SM3 Rb Phase II Operations
AI Rb Science Operations
CAL PI K + Rb Operations
CAL SM4
SM2
SM3 Phase I
Final Report
SM3 from CQ to JPL
SM3 FHA
Slice 7 Repair
Extension
ROSES NRA
Development
Operations
PK4 (ESA)
PI Goree Phase 1 Operations
PI Konopka Phase 1 Operations
PI Liu Phase 1 Operations
PI Gangoli
PK4 PIs Phase 2 Operations
BECCAL (NASA/DLR)
Milestones
PDR
CDR
SIR
FHA
Project Phases
Phase C
Phase D
Phase E
Box Potential Concept Development
Validation
Hand-off to DLR
ROSES NRA
NRA Kick-off
Draft
Release
Select
Fund
Microscope
PI Turushev
Dark Energy in Einstein Elevator
Study Report
Preliminary Design
Deep Space Quantum Link
Conceptual Design
Lab Demo
Eng Feasibility
SCRR
PDR
CDR
SDT Status Report
SDT Final Report
Dust Mitigation
Conceptual Design
Lab Demo
SDT Status Report
SDT Final Report
Optical Clock & Time and Frequency Link SDT
Status Report
Final Report

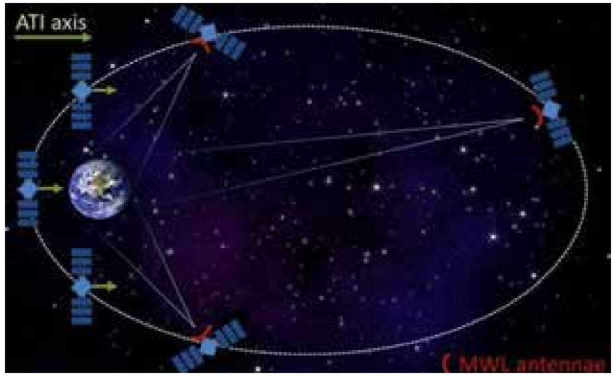
Next Generation Planning

Optical Clock in Space Science Definition Team Report

Science Definition Team:

Dr. Christopher Oates (Chair), NIST; Prof. Kurt Gibble, Penn State; Prof. Leo Hollberg, Stanford; and Dr. Nathan Newbury, NIST

Supported by Dr. Nan Yu, JPL



Mission concept: an SOA optical lattice clock at $1x10^{-19}$ precision orbiting in a highly elliptical orbit with near optimal visibilities at Boulder, CO.

Implementation roadmap

Science	Expected results	Significance
Relativistic gravity Redshift (EEP-LPI)	30,000´ improvement over existing limit	New limit on the very foundation of GR. A deviation from the GR theory will signal the dawn of new era in modern physics, discovering new physics sand helping understanding dark matter.
Local Lorentz Invariance	100´ improvement over existing limit	Search for a preferred frame, perhaps the isotropic 3K microwave background radiation; search for the Lorentz violating coupling of Standard Model Extension.
Combined relativistic effects on the clock frequency and satellite orbit	Beyond the SOA relativistic effect analysis and corrections	Relativistic-consistent treatment of reference frames (Geocentric and Barycentric), Earth, solar and lunar tidal effects, as well as non-gravitational perturbations to the orbit.
Parameterized Post Newtonian Gravity	Orders of magnitude improvement over existing limits	Search for deviation from General Relativity and tests for alternative gravity metric theories.
Dark matter searches	100-1000´ higher sensitivity, new mass-environment-dependent unknown force	Direct detection of dark matter possibly as ultra-light scalar field, help understanding the nature of dark matter.
Worldwide time synchronization	10,000x improvement over the current SOA	Connecting clocks world-wide, enabling a revolutionary new network for time, lay foundation for future GNSS.
International clock network	Currently only through GPS. e.g. 10 – 100 x improvement in drift rate of fundamental constants	Enable utilization of all high performance works participating and contributing to fundamental physics experiments such as time-dependence of fundamental constants and dark matter wave detection.
Relativistic geodesy	mm-level geodesy	Help improve and verify geodetic referencing and Terrestrial Reference Frames, continental scale leveling, and potential new method for earth static gravity field measurements.
Primary frequency standard and clock	Feasibility of national time standard in space	Lay basis for future space-based time standard, free from local gravity perturbations.

Lunar Dust Research and Mitigation Science Definition Team Report

Christine Hartzell, University of Maryland, USA
Paul Bellan, California Institute of Technology, USA
Dennis Bodewits, Auburn University, USA
Gian Luca Delzanno, Los Alamos National Laboratory, USA
Masatoshi Hirbayashi, Auburn University, USA
Truell Hyde, Baylor University, USA
Uwe Konopka, Auburn University, USA
Edward Thomas, Auburn University, USA
Hubertus Thomas, German Aerospace Center DLR

Program Officers:
Inseob Hahn, Jet Propulsion Laboratory
Ulf Israelsson, Jet Propulsion Laboratory

Funded by the NASA Division for Biological and Physical Sciences and the Space Technology Mission Directorate.

Payload Recommendations for a Multi-User Facility to Investigate Dust-Plasma Interactions and Dust Remediation Technologies on the Moon

- A shorter version will become a Decadal Whitepaper.
- A manuscript is being prepared for a submission to a peer-review journal.
- Prof. Hartzell will present at the ASGSR meeting

		Instruments/Technologies and Chapter of Detailed Description							
		Chap 2: Langmuir Probe	Chap 3: Dust Coupons	Chap 4: Dust Charge Meas.	Chap 5: Horizon Glow Obs.	Chap 6: Dust Loading	Chap 7: ES Dust Shields	Chap 8: Dust Attractor	Chap 9: Plasma Beam
Near-Term Science Objectives	Sci Obj 1: Measure the plasma properties near the lunar surface.	✓							
	Sci Obj 2: Determine whether or not electrostatic lofting occurs naturally.	✓	✓	✓	✓				
	Sci Obj 3: Determine whether or not electrostatic levitation occurs.	✓			✓				
Later Science Objectives	Sci Obj 4: Measure cohesion/adhesion of regolith.					✓	✓	✓	✓
	Sci Obj 5: Evaluate whether electrostatically lofted/levitating dust poses a hazard to exploration vehicles.		✓		✓				
	Sci Obj 6: Characterize the effects of plume impingement on dust properties related to interactions with plasmas.					✓			
	Sci Obj 7: Measure the triboelectric charging of lunar regolith.			✓					
	Sci Obj 8: Characterize the size and shape of lunar regolith particles.		✓			✓			
Plasma-Based Remediation Technologies	Rem Tech 1: Electrostatic Dust Shields		✓			✓	✓		
	Rem Tech 2: Attractive surface-induced electrostatic lofting		✓			✓		✓	
	Rem Tech 3: Plasma beam-induced electrostatic lofting		✓			✓			✓
	Rem Tech 4: Tribocharging-induced electrostatic lofting		✓			✓			

Deep Space Quantum Link Science Definition Team

SDT Objectives

- ***Refine*** **Mission Statement for DSQL**
- ***Define*** **Potential Science Experiments**
  - Generate list of proposed science experiments
  - Prioritize experiments based on scientific impact and feasibility
  - Working with JPL staff and advisors, develop mission architecture to support science objectives
- ***Identify*** **Potential Technology Demonstration Opportunities**
  - Define technology development requirements (ie, Should NASA invest in a specific component or subsystem to mature it prior to deploying it on DSQL?, or, should NASA launch a precursor flight mission?)
  - Identify in-flight technology demonstrations that support the science objectives of DSQL
  - Map the technology demonstrations to future science and technology capabilities
- ***Evaluate*** **Link Scenarios**
  - Determine optimum link scenario to achieve science objectives
  - Rank link scenarios based on scientific opportunities each one offers
- ***Publish*** Science Envelope Requirements Document

Role	Last Name	First Name	Affiliation
SDT Chairman	Kwiat	Paul	University of Illinois Urbana-Champaign
SDT Member	Gallichio	Jason	Harvey Mudd College
SDT Member	Jennewein	Thomas	University of Waterloo
SDT Member	Worner	Lisa	University Bremen
SDT Member	Hu	Bei-Lok	University of Maryland

JPL support team: Makan Mohageg, Nan Yu, Luca Mazzarella

- **SDT Schedule/ Activities**
  - Nov 2019 - Jan 2020: Multiple teleconferences held
  - Dec 2019: SDT Chairman Paul Kwiat elected
  - Jan 2020: 6 additional SDT advisors identified. Total team now 14 people from 5 different countries.
  - Feb 20-21: SDT Face-to-Face meeting at JPL
  - Mar: Prepare PPBE materials
  - May 2020: Writing assignments (Telecom)
  - Jul 2020 – SERD review (Telecom)
  - Sep 2020 – Delivery of SERD document to NASA BPS
  - Sep 2020 – Planning for second year study