National Aeronautics and Space Administration

NASA BPS Fundamental Physics Program Update, Quantum Leaps Goal Update

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BPS

Biological & Physical Sciences

Program Update

- Fundamental Physics

Program Highlights: Fundamental Physics

Cold Atom Lab

- SM1 operating after SM3b failure
  - Rb BEC achieved and back to science, K in progress

BECCAL (DLR)

- Flight hardware availability expected Summer 2027

Direct Detection of Dark Energy in the Einstein Elevator (DLR)

- First launch in the Einstein Elevator expected this month (3D MOT)

Space Entanglement and Annealing Quantum Experiment

- Expected to launch on SpaceX 31

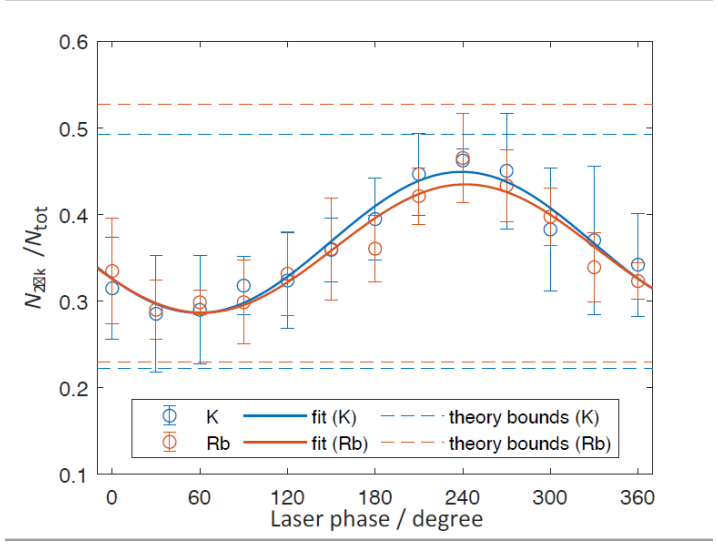
ACES (ESA)

- Expected to launch on SpaceX 32

Science Highlights: Fundamental Physics

Cold Atom Lab

- First dual species atom interferometry in space. Space based AIs have applications in geodesy, gravitational wave detection, precision navigation, tests of the equivalence principle, dark matter/dark energy searches
- First atom interferometer measurement as a quantum sensor in space
- Ethan Elliot compelling results ISS/RDC award



[NASA Demonstrates 'Ultra-Cool' Quantum Sensor for First Time in Space - NASA]

Solicitations: Fundamental Physics

Physical Sciences NRA expected ROSES24 soon

- Fundamental physics expected to be addressed

Publications: Fundamental Physics

Publications in the last year

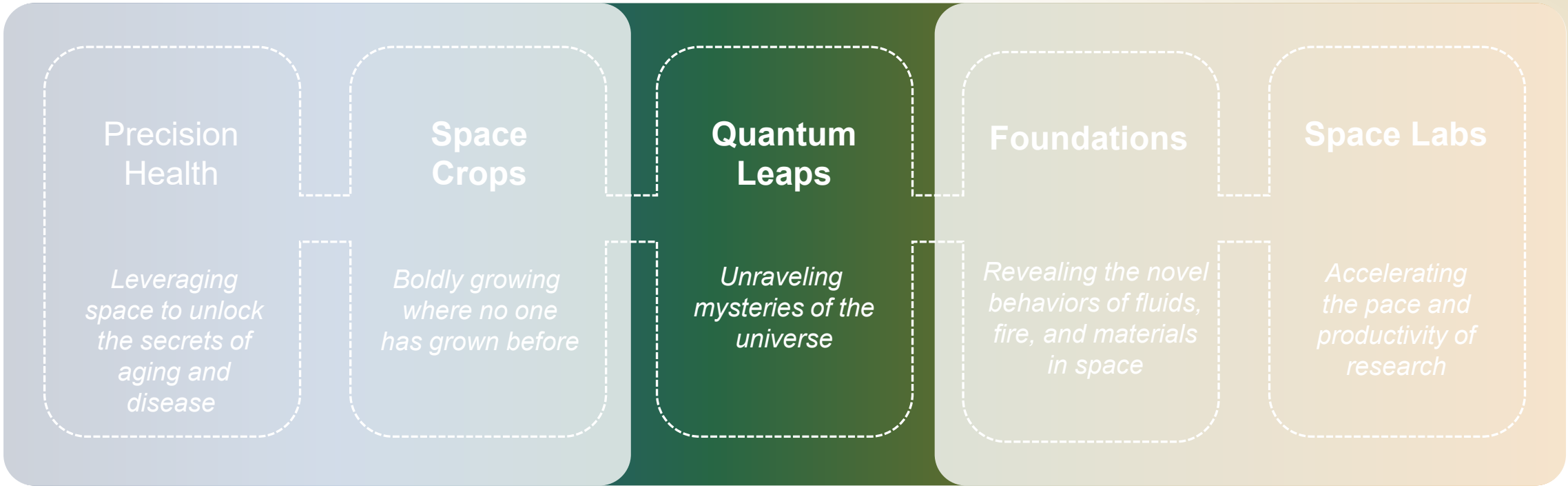
- Elliott ER, Aveline DC, Bigelow NP, et al. "Quantum gas mixtures and dual-species atom interferometry in space." Nature. 2023 Nov 16;623(7987):502-8., Nov-2023
- Alexander Lohrmann, Aileen Zhai, and Makan Mohageg, "Classical clock synchronization for quantum communications using the quantum channel," Appl. Opt. 62, 8567-8573 (2023)
- Parker TE, Brown RC, Sherman JA. "Statistics for quantifying aging in time transfer system delays." Metrologia. 2023 Nov 10;60(6):065011. https://doi.org/10.1088/1681-7575/ad088b , Nov-2023
- Beydler MM, Moan ER, Luo Z, Chu Z, Sackett CA. "Guided-wave Sagnac interferometer with large area and multiple orbits." AVS Quantum Science. 2024 Mar 1;6(1). https://doi.org/10.1116/5.0173769 , Mar-2024
- Neil Ashby and Bijunath R. Patla 2024 AJ 168 112 https://doi.org/ 10.3847/1538-3881/ad643a
- Williams, J.R., Sackett, C.A., Ahlers, H. et al. Pathfinder experiments with atom interferometry in the Cold Atom Lab onboard the International Space Station. Nat Commun 15, 6414 (2024). https://doi.org/10.1038/s41467-024-50585-6

Roadmap Update

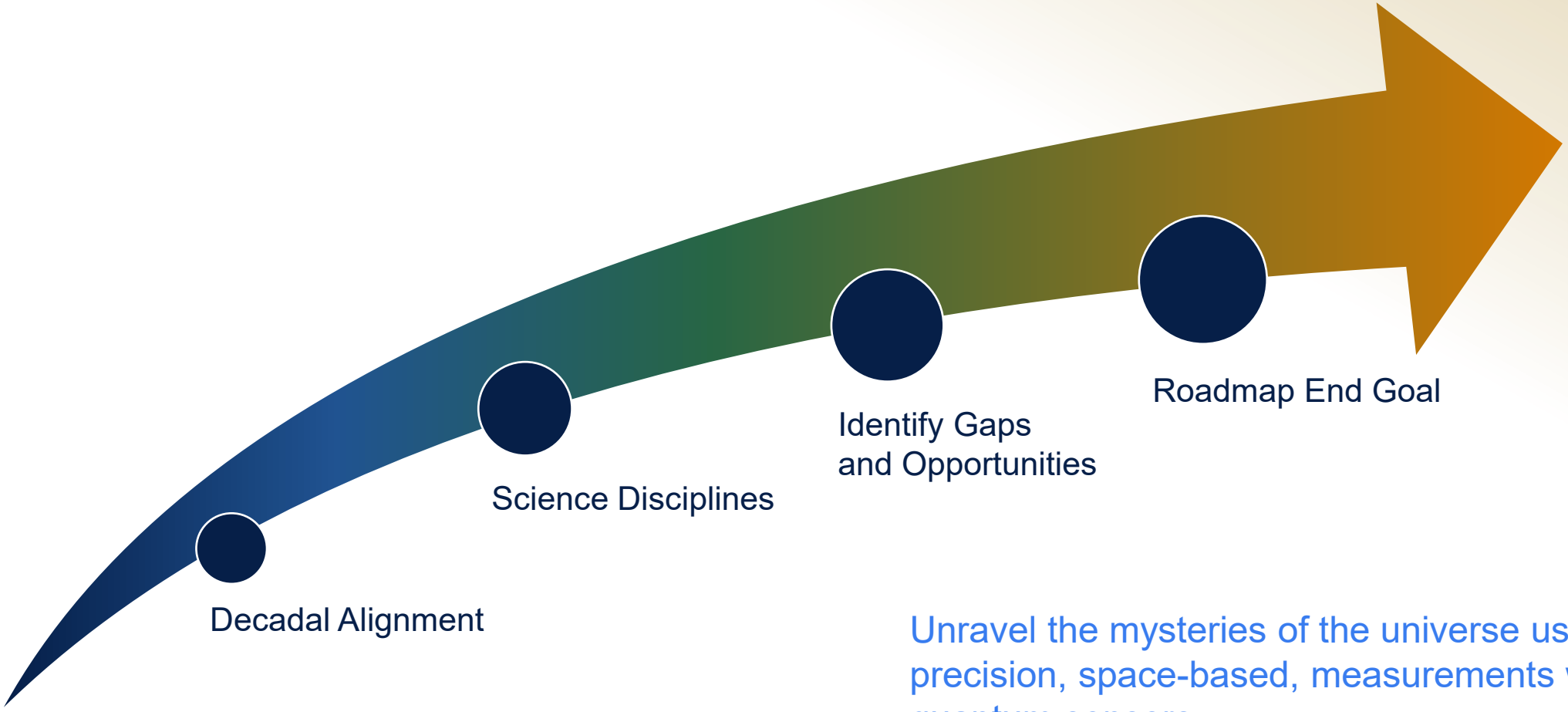
- Quantum Leaps

Thriving in Space

Revolutionary research in extraordinary places.

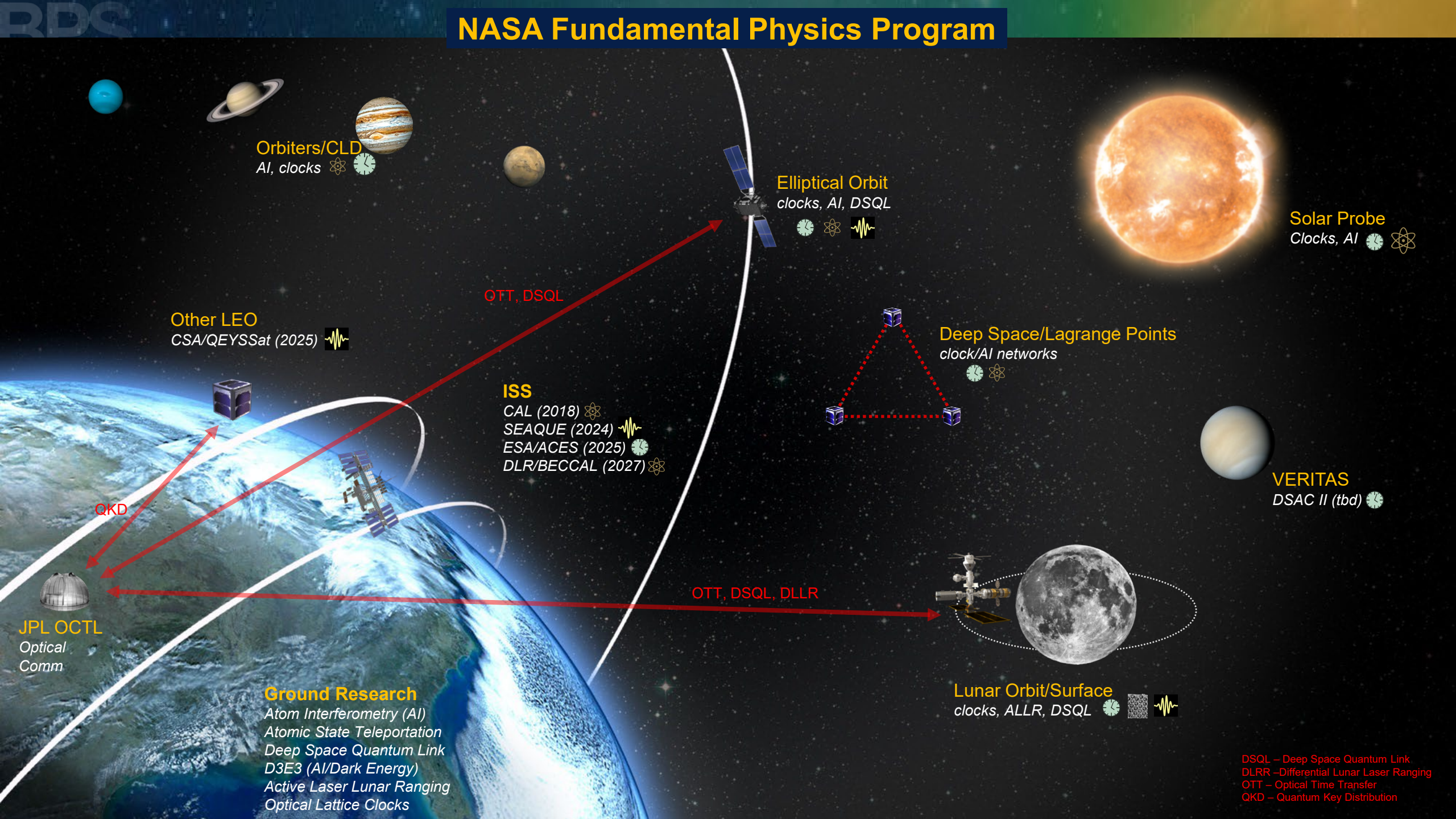


Goal Overview: Quantum Leaps



Unravel the mysteries of the universe using precision, space-based, measurements with quantum sensors

NASA Fundamental Physics Program



DSQL – Deep Space Quantum Link
DLRR –Differential Lunar Laser Ranging
OTT – Optical Time Transfer
QKD – Quantum Key Distribution

Decadal Alignment: Quantum Leaps

Probing Phenomena Hidden by Gravity or Terrestrial Limitations

- Key Science Question #11: What New Physics Can Be Discovered with Experiments That Can Only Be Carried Out in Space?

Quantum Leaps aims to probe the very nature of the universe using exquisitely precise space-based quantum sensors to test the Einstein equivalence principle, dark sector physics, and the nature of fundamental physical constants.

Multi-Agency Opportunity: Probing the Fabric of Space-Time (PFaST)

Science Disciplines: Quantum Leaps

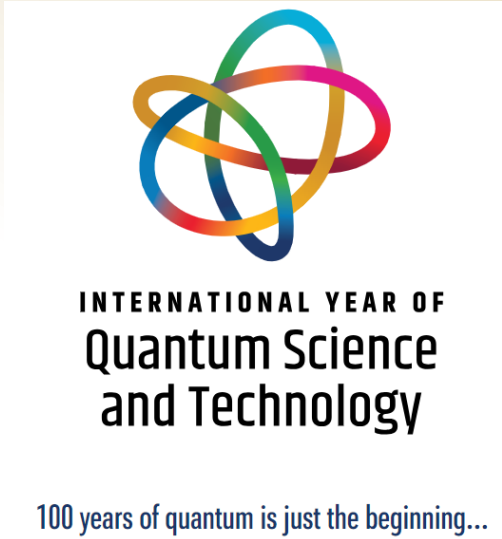
- Atomic Clocks
- Atom Interferometry
- Entanglement
- Cold atoms
- Lunar ranging

- What is Dark Matter?
- What is Dark Energy?
- Is the Equivalence Principle true?
- Are fundamental constants constant?
- Is there a quantum aspect to curved space-time?
- Can the matter-antimatter asymmetry be explained?
- What is the nature of the quantum vacuum?
- Can we explore physics at the Planck scale?
- Can we develop quantum technologies that will revolutionize navigation, timekeeping, planetary exploration, and Earth science?

*Unlike astronomical observations which can explore the **effects** of dark energy and matter, space-based measurements with quantum sensors may be able to **pinpoint signatures** of particular sources of these phenomena*

Identify Gaps & Opportunities: Quantum Leaps

- The United Nations has proclaimed 2025 the International Year of Quantum Science and Technology
- National Quantum Initiative re-authorization in process
- NESC Quantum Sensing study - fundamental physics
- On the cusp of precision space-based quantum sensing
  - Quantum sensing technologies have made rapid progress on the ground
    - Requires tech maturation to reduce SWaP and space qualify
  - Many interested in partnering
    - NSF, DOE, DoD, DOC, DLR, ESA
    - NASA ESD Quantum Gravity Gradiometer
- Opportunities to utilize ISS/CLDs, Gateway, Rideshares
- **Quantum technology performs better in space!** Quantum sensors can perform up to100 to 1000 times better in microgravity.



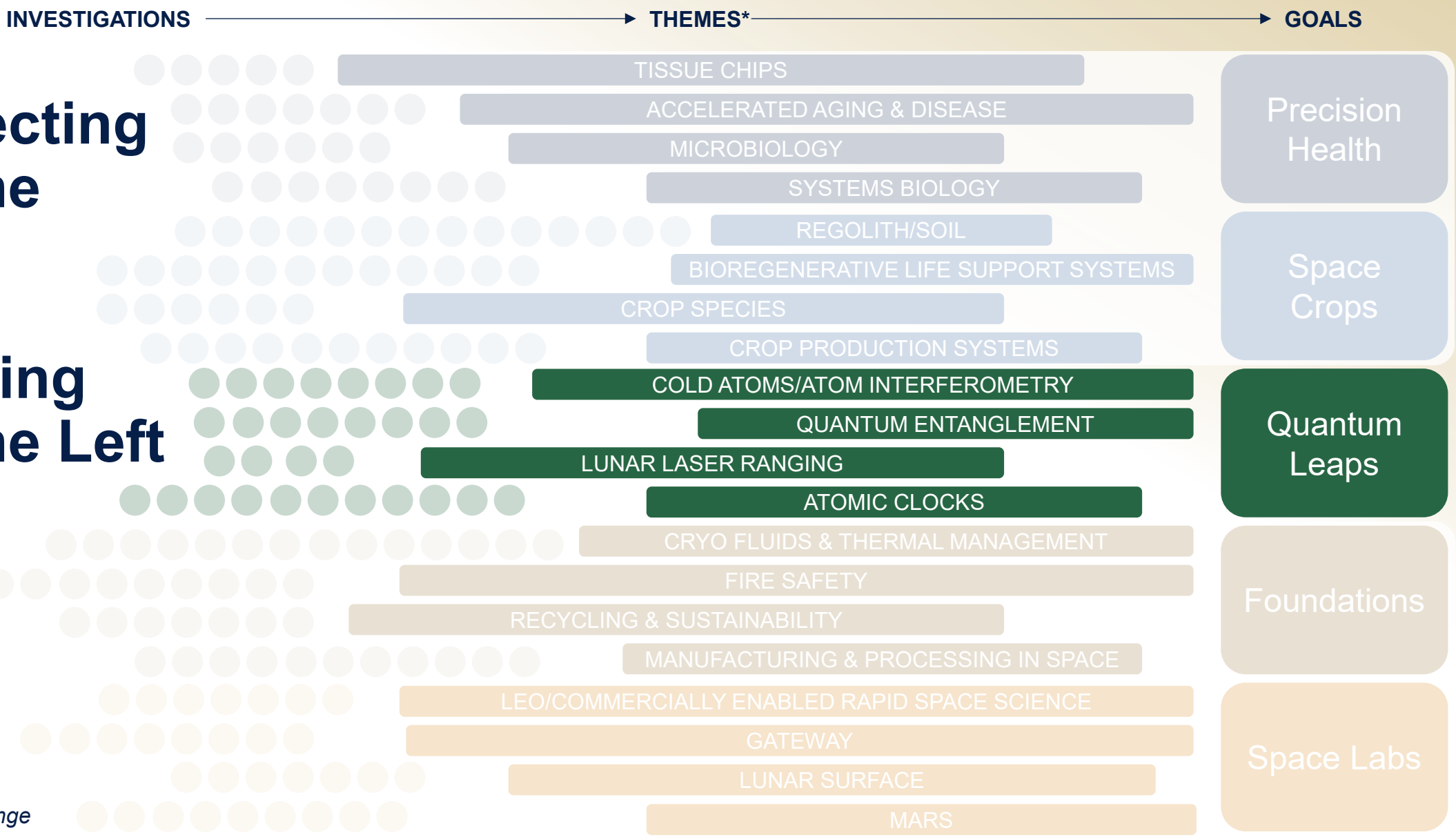
From: https://quantum2025.org/en/

Roadmap End Goals: Quantum Leaps

- Perform the definitive experiments that will guide theorists to a quantized theory of gravity, and from there to a unified understanding of the universe, including phenomena such as dark energy, dark matter and inflation
- Establish NASA at the forefront of contemporary physics, breaking the current paradigm of performing cutting-edge experiments in ever larger particle accelerators.

Architecting from the Right,

Executing from the Left



**Draft – subject to change*