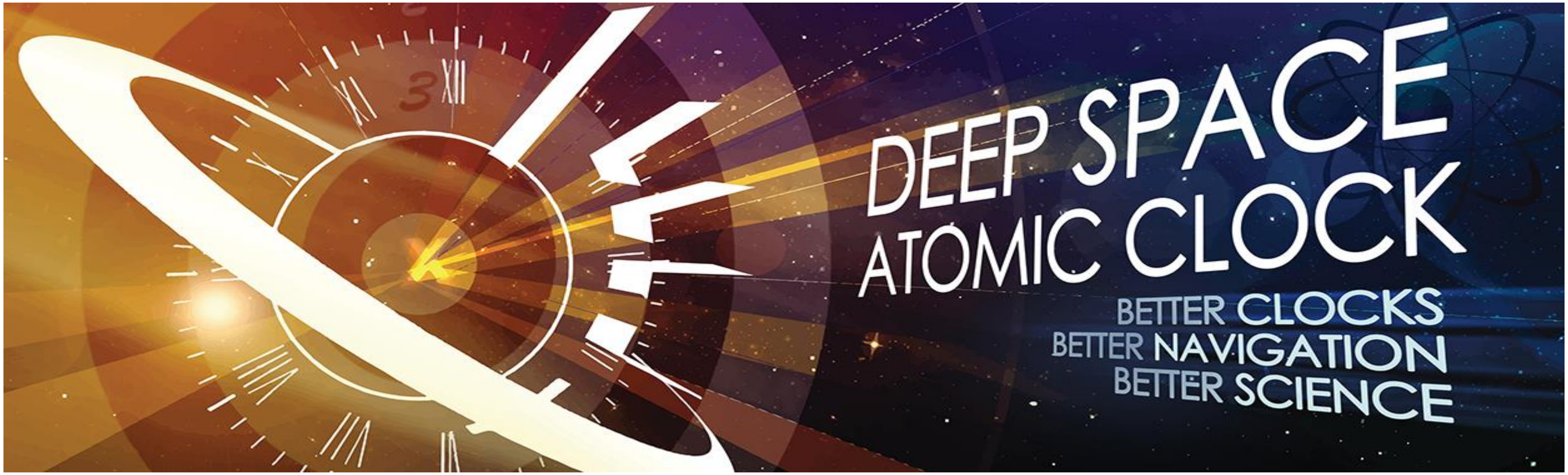
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology



Deep Space Atomic Clock Mission Overview

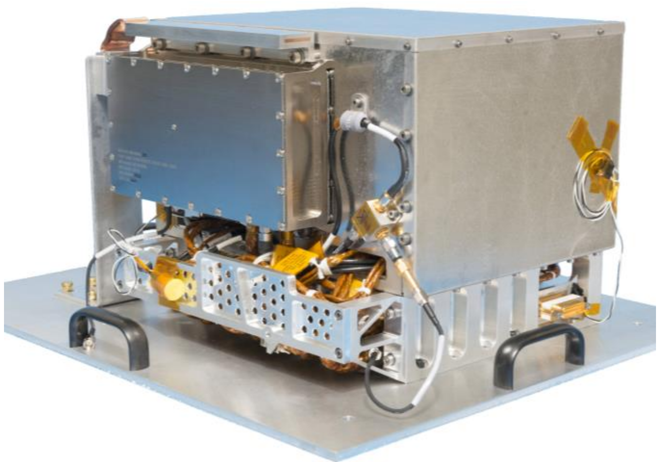
Todd Ely
Principal Investigator

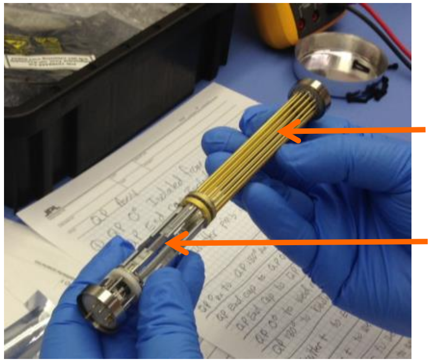
Allen Farrington
Project Manager

July 2015

NASA's DSAC Technology Demonstration Mission

DSAC Demonstration Unit



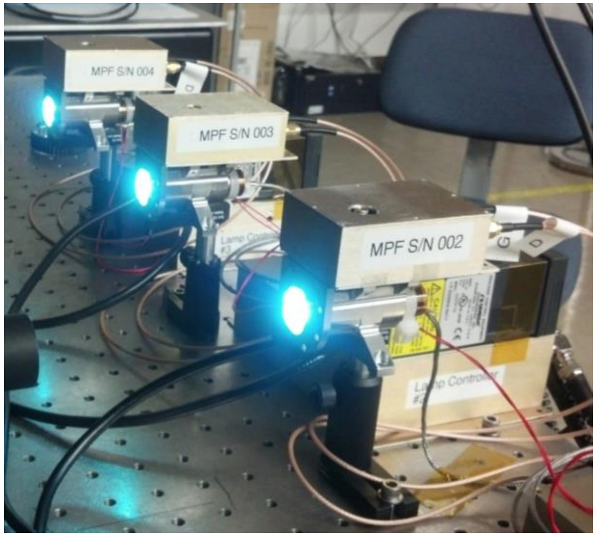


Multi-pole Trap

Quadrupole Trap

Titanium Vacuum Tube

Mercury UV Lamp Testing

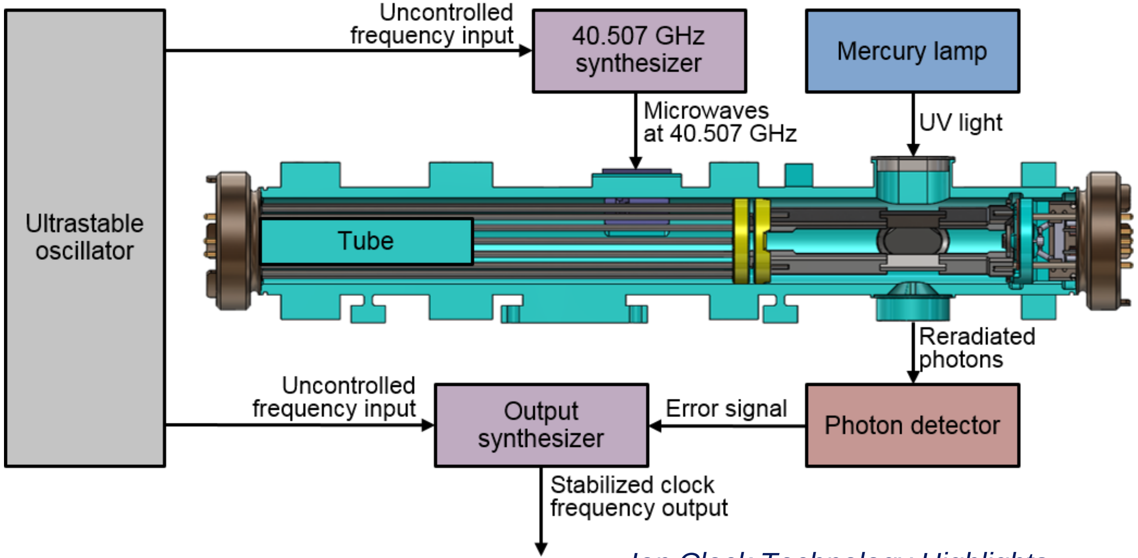


Develop advanced prototype ('Demo Unit') mercury-ion atomic clock for navigation/science in deep space and Earth

- Perform year-long demonstration in space beginning mid-2016 – advancing the technology to TRL 7
- Focus on maturing the new technology – ion trap and optical systems – other system components (i.e. payload controllers, USO, GPS) size, weight, power (SWaP) dependent on resources/schedule
- Identify pathways to 'spin' the design of a future operational unit (TRL 7 → 9) to be smaller, more power efficient – facilitated by a detailed report written for the next DSAC manager/engineers

For More Information, Contact: Todd.A.Ely@jpl.nasa.gov, Website: http://www.nasa.gov/mission_pages/tdm/clock/

Technology & Operation



Ion Clock Operation

- Short term (1 – 10 sec) stability depends on the Local Oscillator (DSAC selected USO 2e-13 at 1 second)
- Longer term stability (> 10 sec) determined by the “atomic resonator” (Ion Trap & Light System)

Key Features for Reliable, Long-Life Use in Space

- No lasers, cryogenics, microwave cavity, light shift, consumables
- Low sensitivity to changing temperatures, magnetics, voltages
- Radiation tolerant at levels similar to GPS Rb Clocks

Ion Clock Technology Highlights

- State selection of 10^6-10^7 $^{199}Hg^+$ electric-field contained (no wall collisions) ions via optical pumping from $^{202}Hg^+$
- High Q microwave line allows precision measurement of clock transition at 40,507,347,996.8 Hz using DSAC/USO system

$$SNR \times Q < \frac{3e-13}{\sqrt{\tau}} \quad \& \quad A.D. < 3 \times 10^{-15} \text{ @ 1-day}$$

- Ion shuttling from quadrupole to multipole trap to best isolate from disturbances
- Ions are in an uncooled Neon buffer-gas

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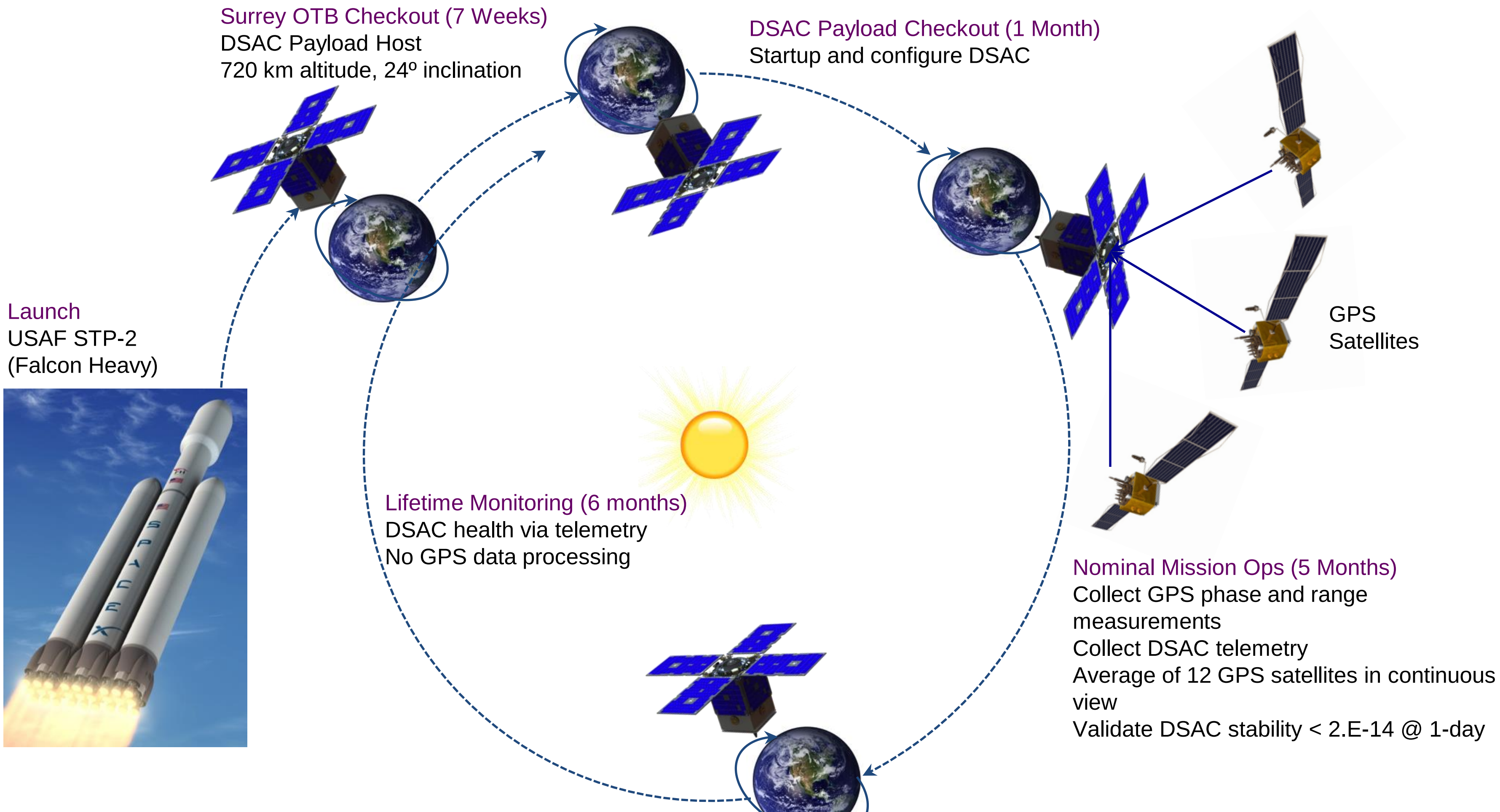
Mission Architecture and Timeline

Launch September 2016 with one-year demonstration



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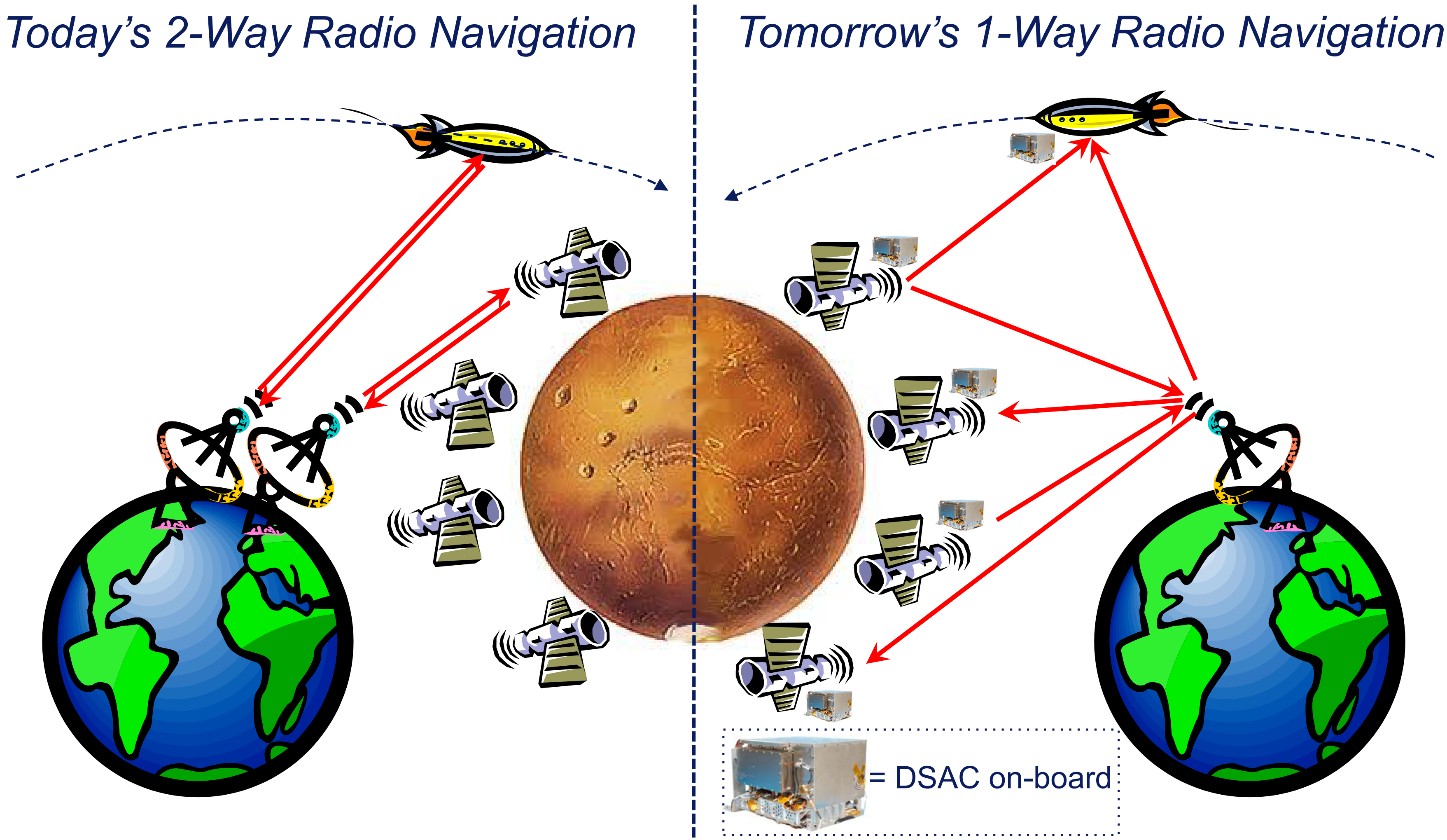
Broad Benefits for Enhanced Exploration
Enables Multiple Space Craft Per Aperture Tracking at Mars



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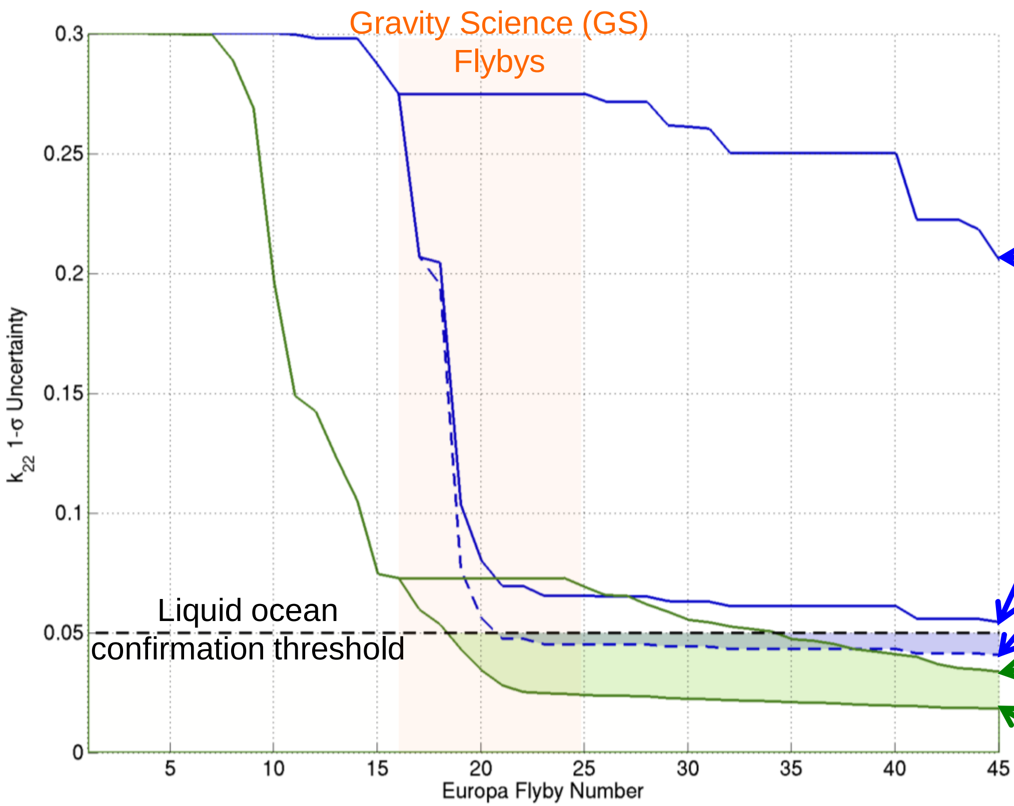
Broad Benefits for Enhanced Exploration
Europa Gravitational Tide Recovery is more Robust

- Europa gravitational tide parameters can confirm subsurface liquid ocean existence
- Solution quality inherently limited by quantity/quality of available tracking data
- DSAC-enabled LGA solution satisfies science requirement early in primary mission – robust to missing key flybys and/or trajectory redesign



Solutions obtained using solar powered configuration with current trajectory (as of June 2015) with following results:

2-Way, DSN, No GS Flybys
✕ No confirmation

2-Way, DSN, All GS Flybys
✕ No confirmation

2-Way, DSN+ESA, All GS Flybys
✓ Confirmed, no flyby margin

1-Way w/ DSAC, DSN, No GS Flybys
✓ Confirmed w/ flyby margin

1-Way w/ DSAC, DSN, All GS Flybys
✓ Confirmed w/ flyby margin

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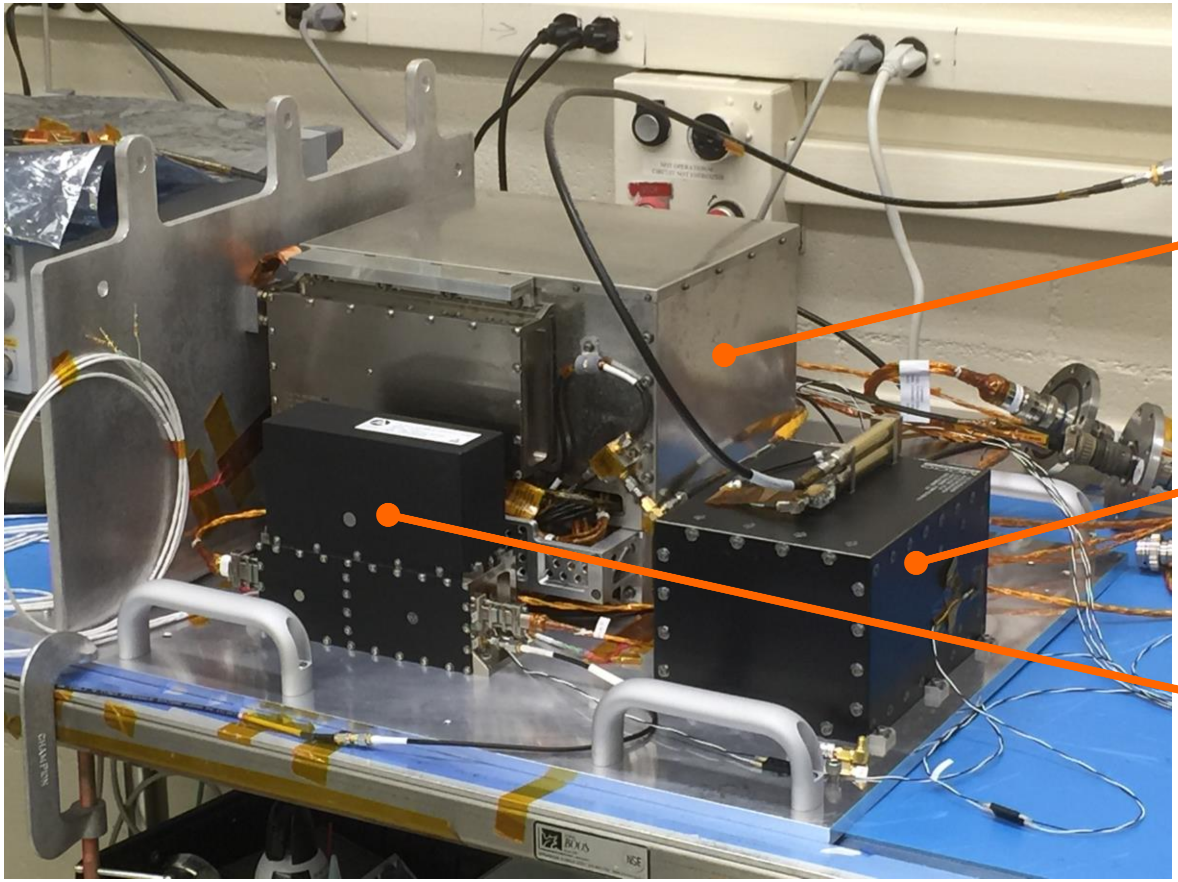
Payload Integration & Test on Flight Hardware



DSAC Demo Unit (DU)
Atomic Resonator (JPL)
V: 285 x 265 x 228 mm
M: 16 kg, Physics Pkg – 5.7 kg
P: 45 W, Physics Pkg – 24 W

GPS Receiver
Validation System (JPL-Moog)

Ultra-Stable Oscillator (USO)
Local Oscillator (FEI)

The DSAC Demonstration Unit was designed for prototyping flexibility and has significant room for mass, power, and volume optimization.

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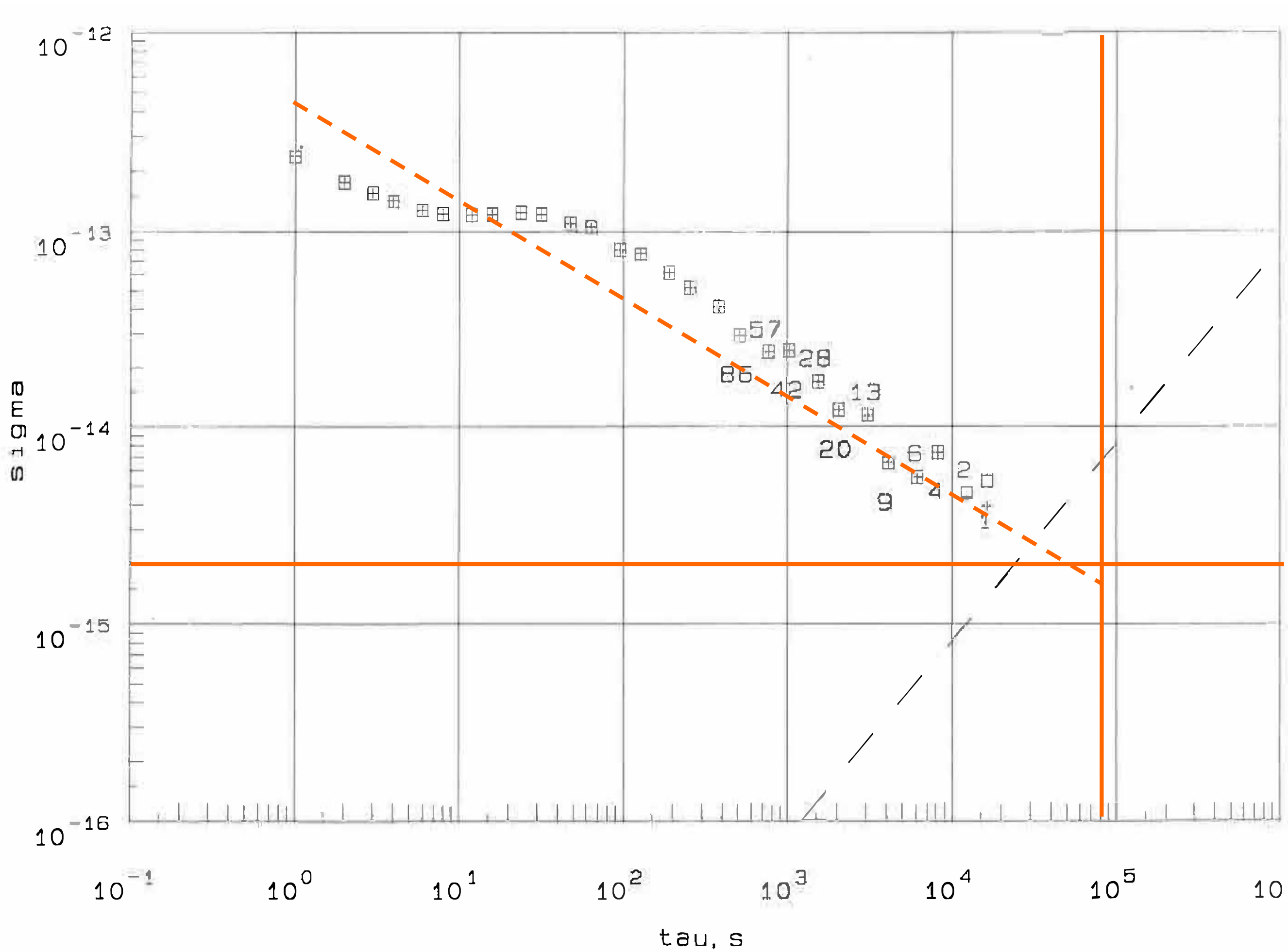
Payload I&T Initial Results - Short Term Stability of DU/USO



- First AD results of DU/USO combination taken in air, at room temperature, and unregulated environment
- Only 12 hrs of data processed and compared to Maser
- DU/USO configuration is not optimized
- Stability *trending* towards < 2e-15 @ 1-day
- Long term optimized performance will be determined this fall

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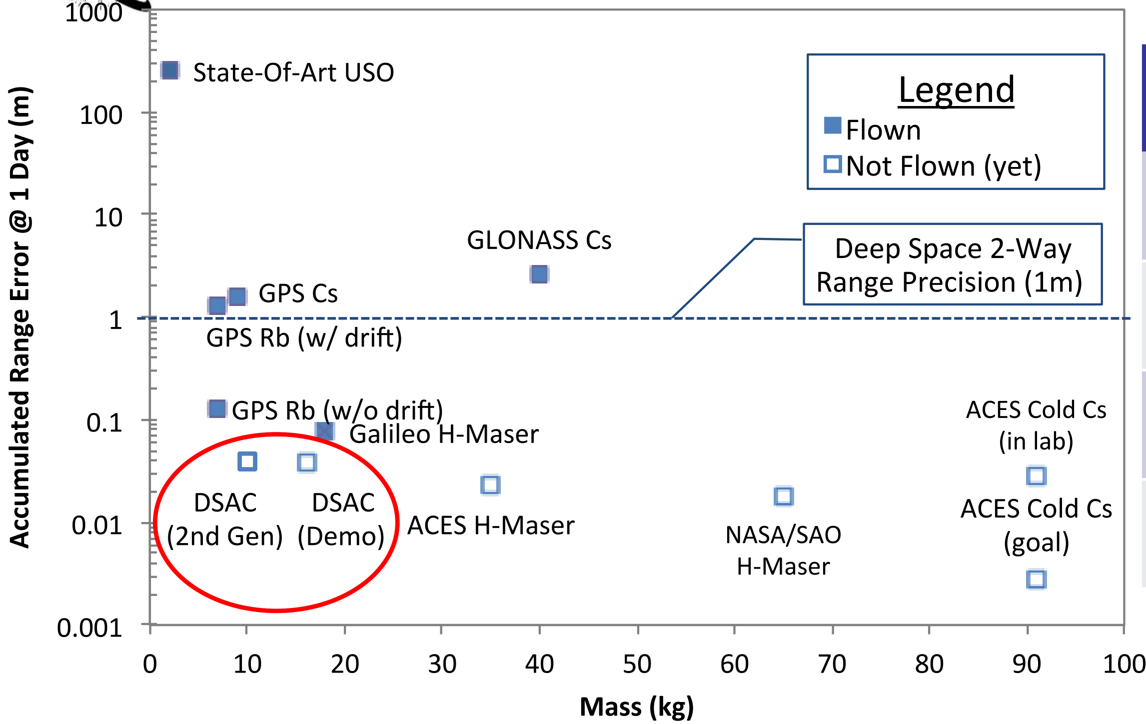
DSAC Compared to Other Space Clocks



Atomic Frequency Standard	Mass	Average Power
DSAC Demo Unit (1st Generation)	16 kg	< 50 W
DSAC Future Unit (2nd Generation)	< 10 kg	< 30 W
GPS IIF Rb (5th Generation)	7 kg	< 40 W
Galileo H-Maser (2nd Generation)	18 kg	< 60 W

- Anticipated Allan Deviation (including drift) of < 3e-15 at one-day will outperform all existing space atomic frequency standards
- Mass and power of DSAC Demo Unit competitive with existing atomic frequency standards – future version could be < 10 kg and < 30 W with modest investment primarily on the electronics design

DSAC is an ideal technology for infusion into deep space exploration and national security systems

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Technology Advancement Report

High-level briefing packages/memos
- Programmatic information
- Discussion of how mission success criteria were met

Summary

- The DSAC mission will demonstrate unprecedented performance of a highly accurate and stable, yet small and low-mass mercury ion atomic clock in the low Earth orbit environment

- DSAC's current expected Allan Deviation is < 3.e-15 at 1 day - equivalent to DSN ground clock performance and better than any existing space clocks

- DSAC-enabled high-quality one-way signals for deep space navigation and radio science can
  - Improve data quantity and quality, including during low SNR scenarios
  - Enhance tracking architecture flexibility and robustness
  - Enhance radio science at Europa, Mars, and extensible to any solar system body
  - Enable fully-autonomous onboard absolute radio navigation

- DSAC has the potential to transform the traditional two-way paradigm of deep space radiometric tracking to a more flexible, efficient and extensible one-way tracking architecture

- DSAC is a viable new technology clock that could be used to enhance national security systems

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