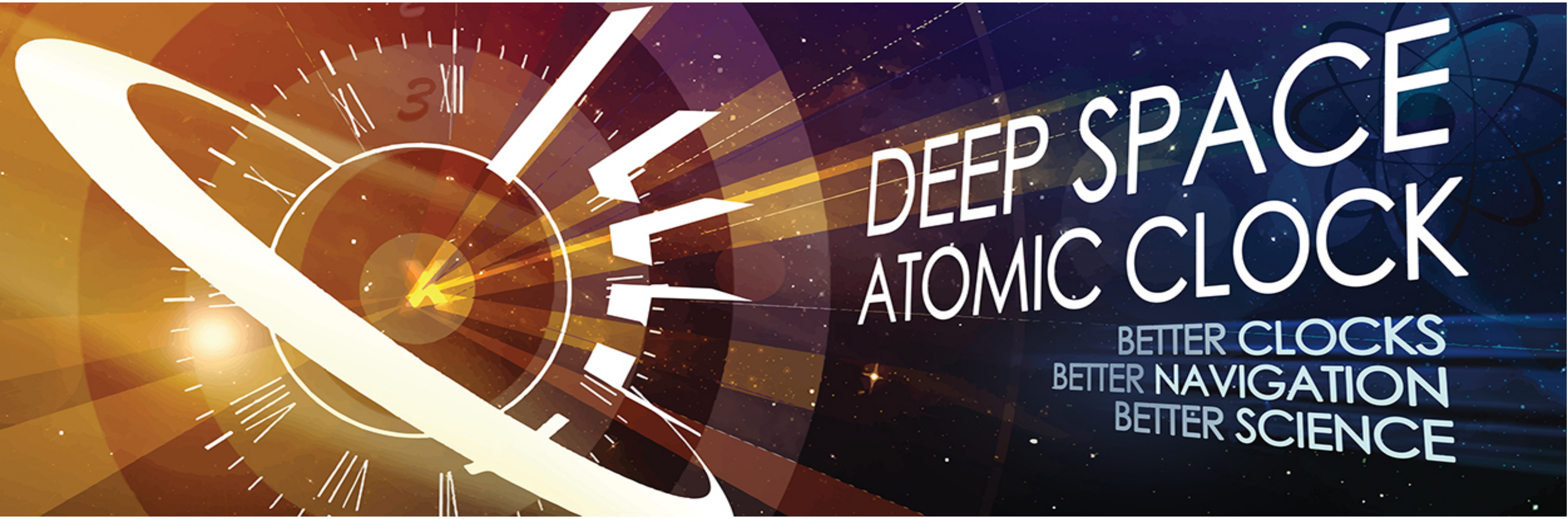


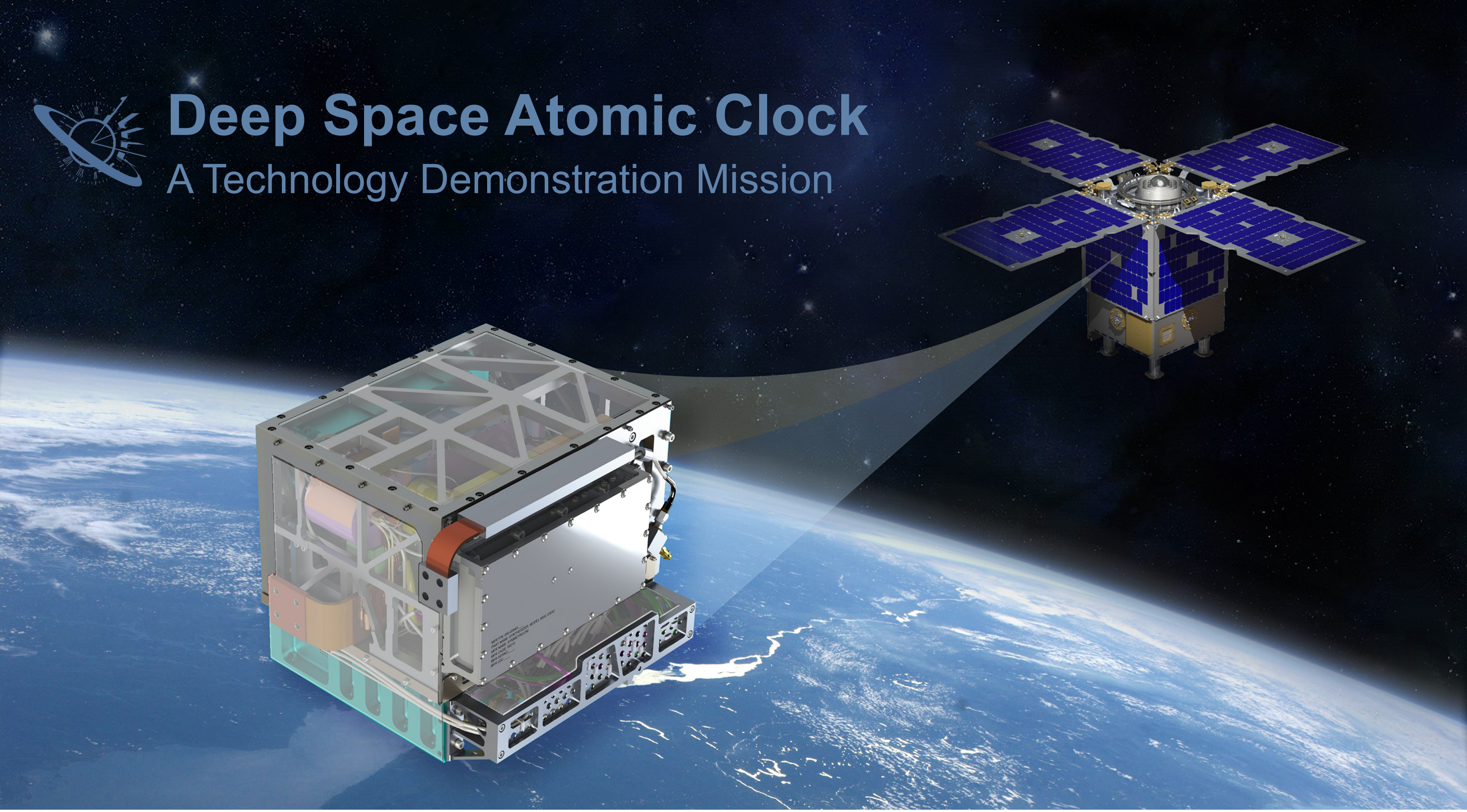
Mission Countdown for Deep Space Atomic Clock

Todd Ely

Principal Investigator/Project Manager

December 2018

Jet Propulsion Laboratory
California Institute of Technology



NASA

TDM

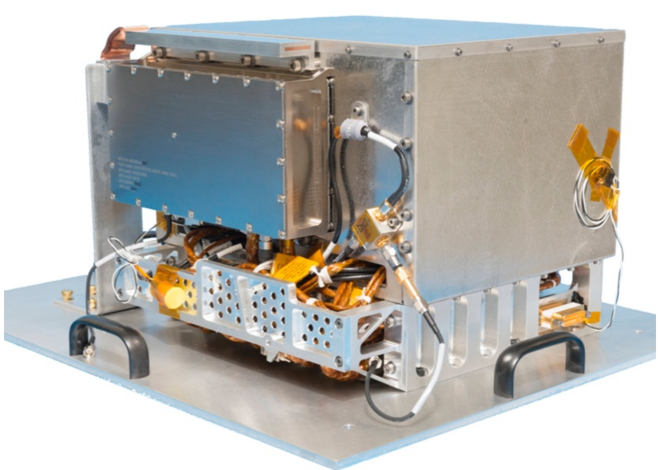
SPACE COMMUNICATIONS SCaN AND NAVIGATION

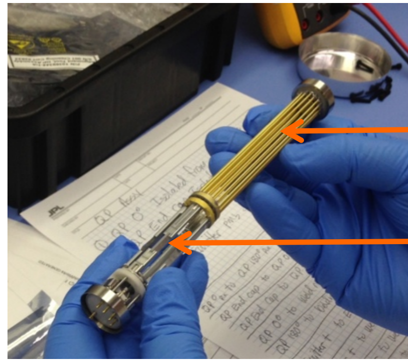
JPL
Jet Propulsion Laboratory
California Institute of Technology

GENERAL ATOMICS

DSAC Technology Demonstration Mission

DSAC Demonstration Unit

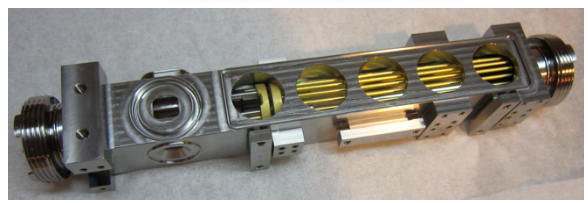




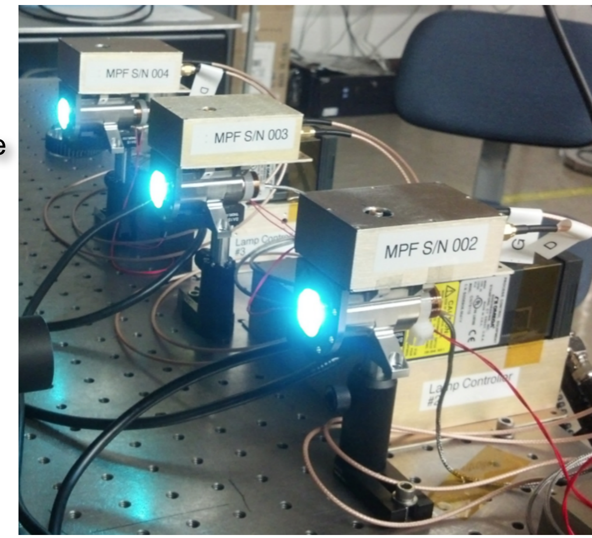
Multi-pole Trap

Quadrupole Trap

Titanium Vacuum Tube



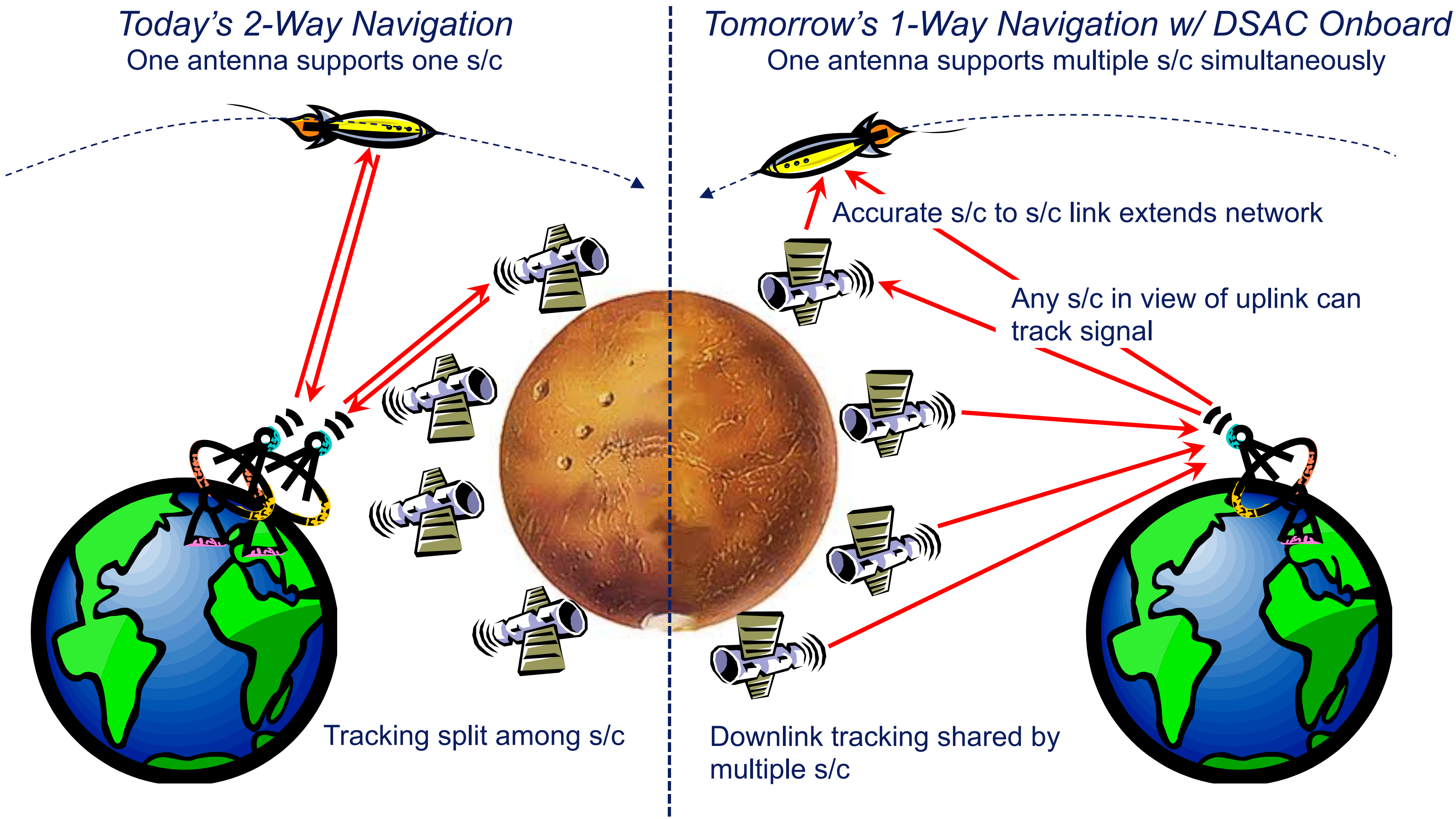
Mercury UV Lamp Testing



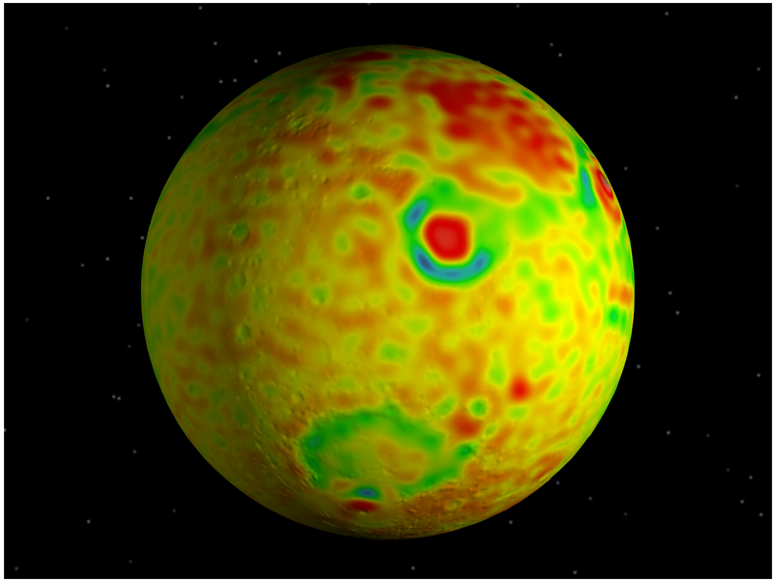
Develop advanced prototype ('Demo Unit') mercury-ion atomic clock for navigation/science in deep space and Earth

- Perform year-long demonstration in space beginning Spring 2019 – advancing 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

DSAC Enables a Scalable DSN Tracking Architecture



DSAC Enhances NASA Radio Science and Enables Robust Onboard Navigation

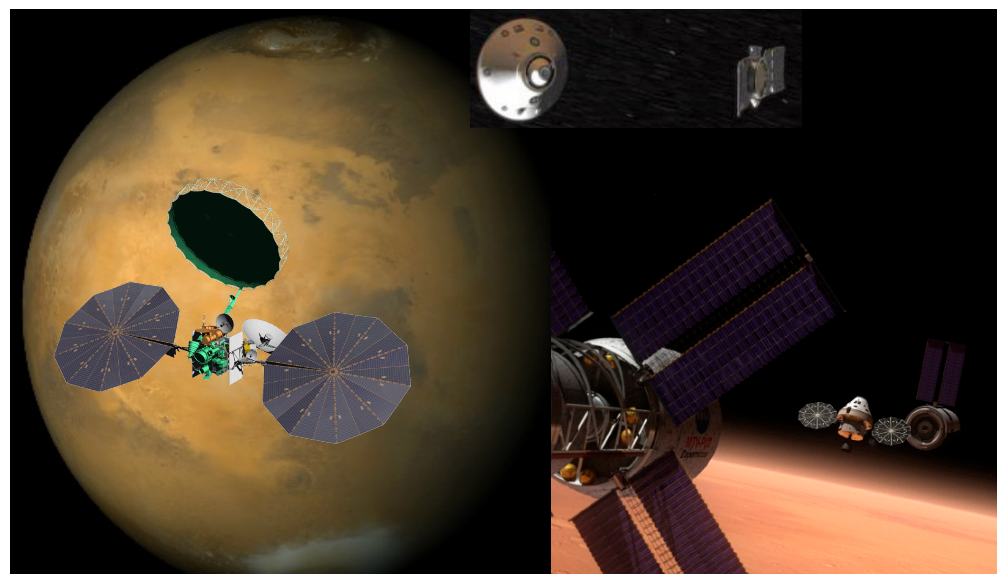


DSAC enables use of existing DSN Ka-band downlink tracking capability

- Ka-band data 10 x more accurate than X-band data
- Determine Mars long-wavelength, time variable gravity effects to GRACE-quality with single s/c
- Improve ring/atmosphere measurements by 100 x

Real time, onboard deep space radio navigation system with DSAC yields

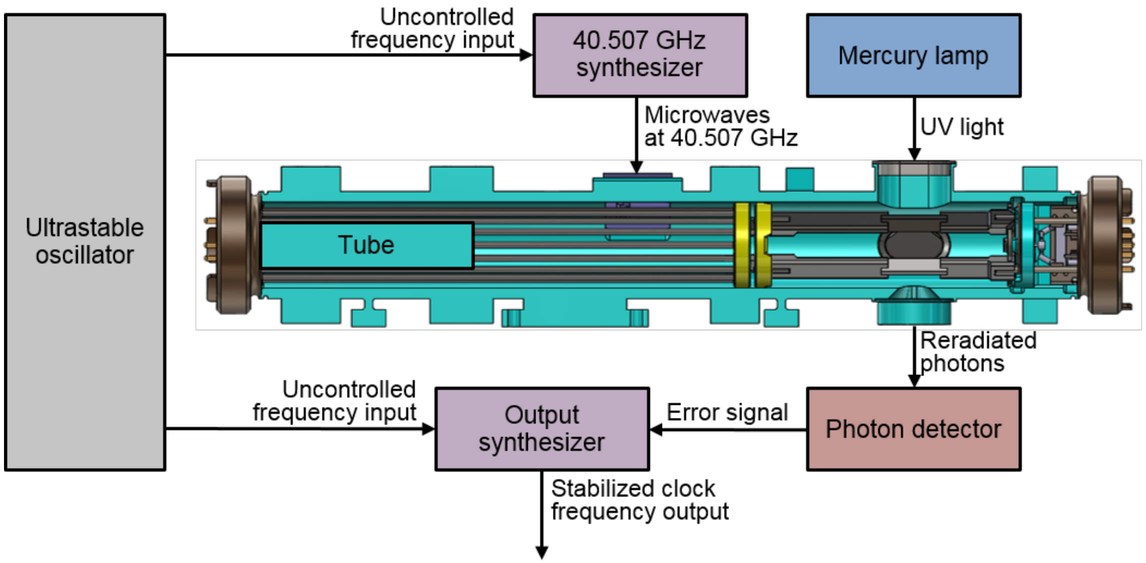
- 100 meter class trajectory knowledge at Mars atmosphere entry
- Enhanced navigation operations such as SEP spiraling into a low-altitude orbit
- Fault tolerant, robust navigation solutions required for safe human exploration



GPS and Other DOD Applications

- DSAC short and long term performance useful for future GPS uses (FAA & autonomy) – DSAC short term performance is 10X better than RAFS, and long term performance 50X better
- DSAC performance sufficient for future GPS III URE goals (improved clocks needed to shorten a ‘tent pole’ contributing to URE – ephemeris error is the other ’tentpole’)
- DSAC performance (considering no intrinsic drift) well suited for autonomous operations needed for secure command and control satellite systems (follow-on AEHF) and other government agencies

Technology & Operation



Ion Clock Operation

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

Key Features for Reliable, Long-Life Use in Space

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

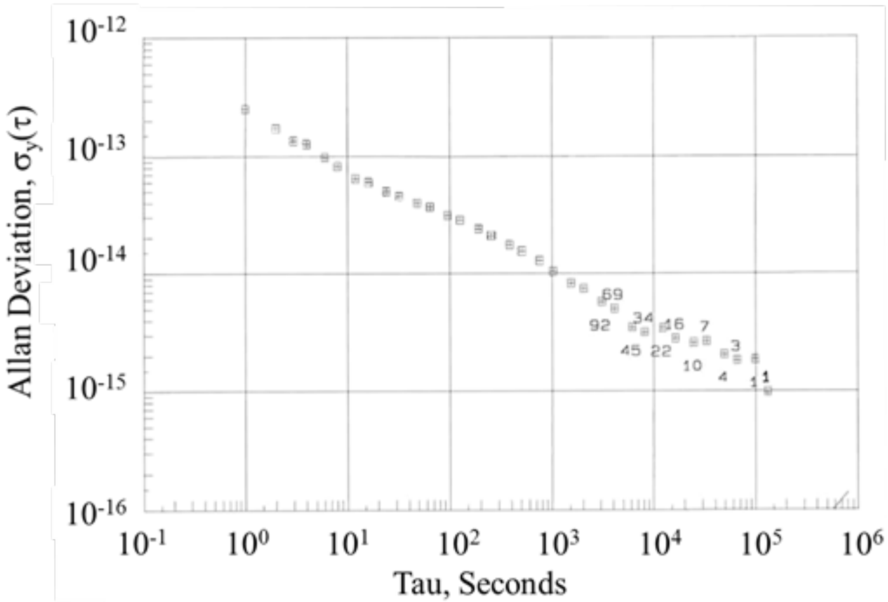
Ion Clock Technology Highlights

- State selection of 10^6-10^7 $^{199}Hg^+$ electric-field contained ions (no wall collisions) via optical pumping from $^{202}Hg^+$
- High Q microwave line allows precise measurement of clock transition at 40.5 GHz using DSAC/USO system
- Ion shuttling from quadrupole (QP) to multipole (MP) trap for best disturbance isolation

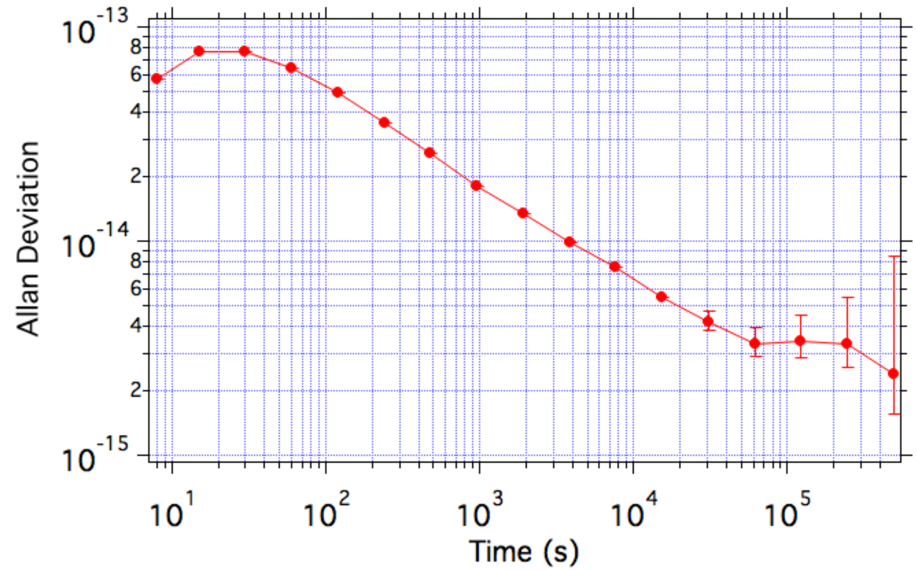
  MP Test Bed: $SNR \times Q < \frac{3\times10^{-13}}{\sqrt{\tau}}$ & $A.D. \sim 1\times10^{-15}$
- QP -Only implementation offers major simplification

  QP–Only DU: $SNR \times Q < \frac{5\times10^{-13}}{\sqrt{\tau}}$ & $A.D. < 3\times10^{-15}$

DSAC Demo Unit Ground-Based Measured Stability



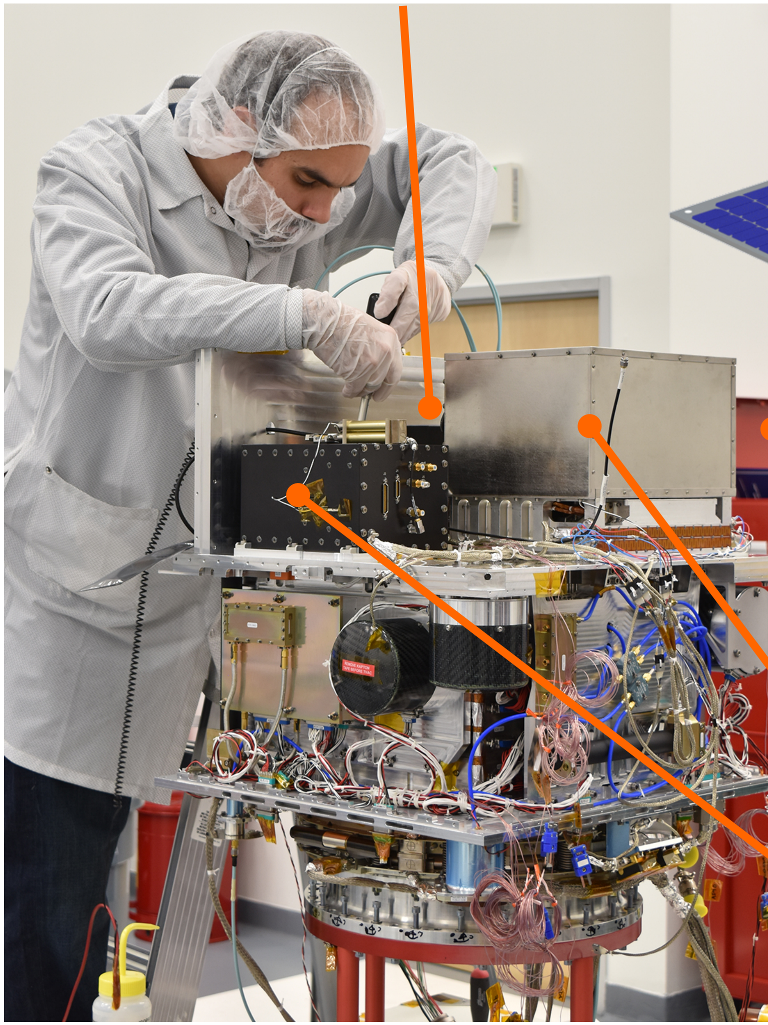
- DU in MP with Maser input at constant temperature
- Stability ~1e-15 @ 1-day in MP mode (*no drift removed*)
  → 87 ps/day or 26 mm/day

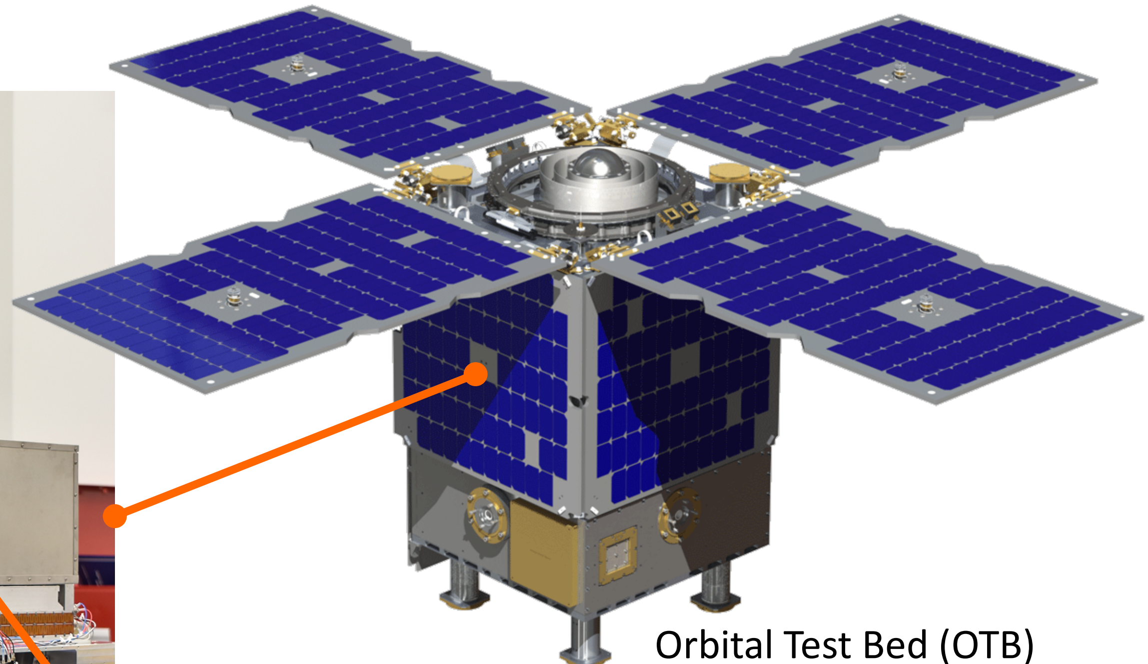


- DU in QP with Maser input at constant temperature
- DU/USO configuration tested with similar results
- Stability < 3e-15 @ 1-day in QP mode (*no drift removed*)
  → 0.26 ns/day or 8 cm/day

DSAC Payload Integrated on the Orbital Test Bed Spacecraft

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





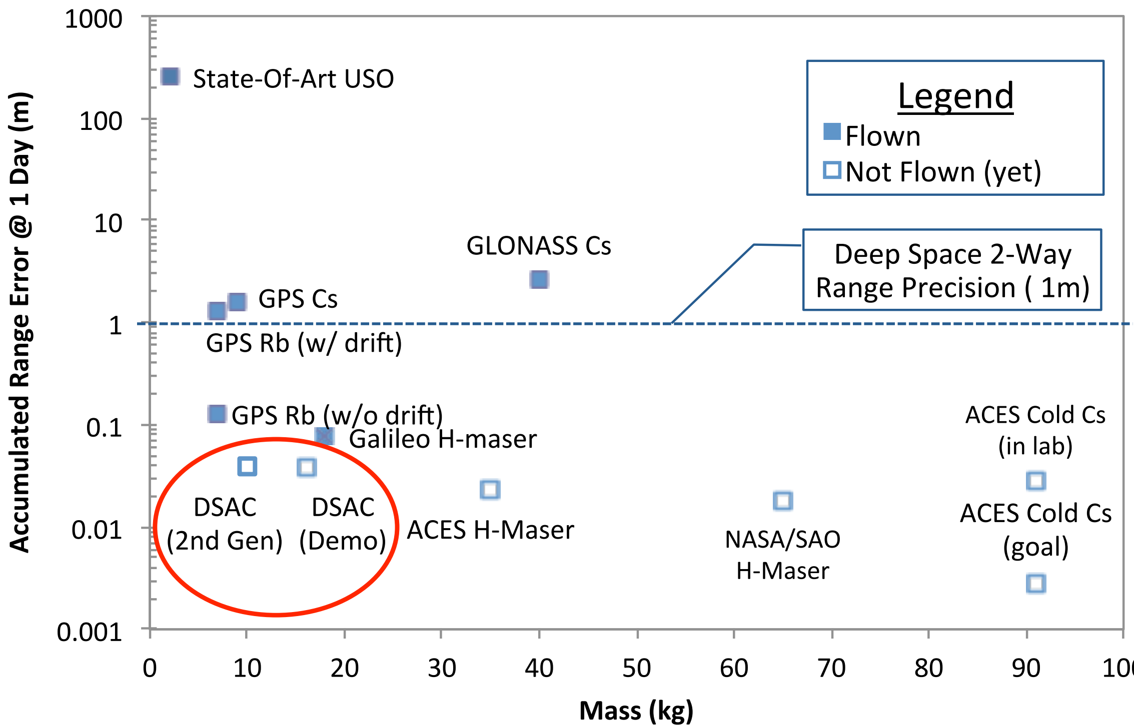
Orbital Test Bed (OTB)
Host Spacecraft (GA-EMS)

DSAC Demo Unit (DU)
Atomic Resonator (JPL)

GPS Receiver
Validation System (JPL-Moog)

Demo Unit designed for maximal instrument telemetry and prototyping flexibility and demonstration

DSAC Compared to Other Space Clocks

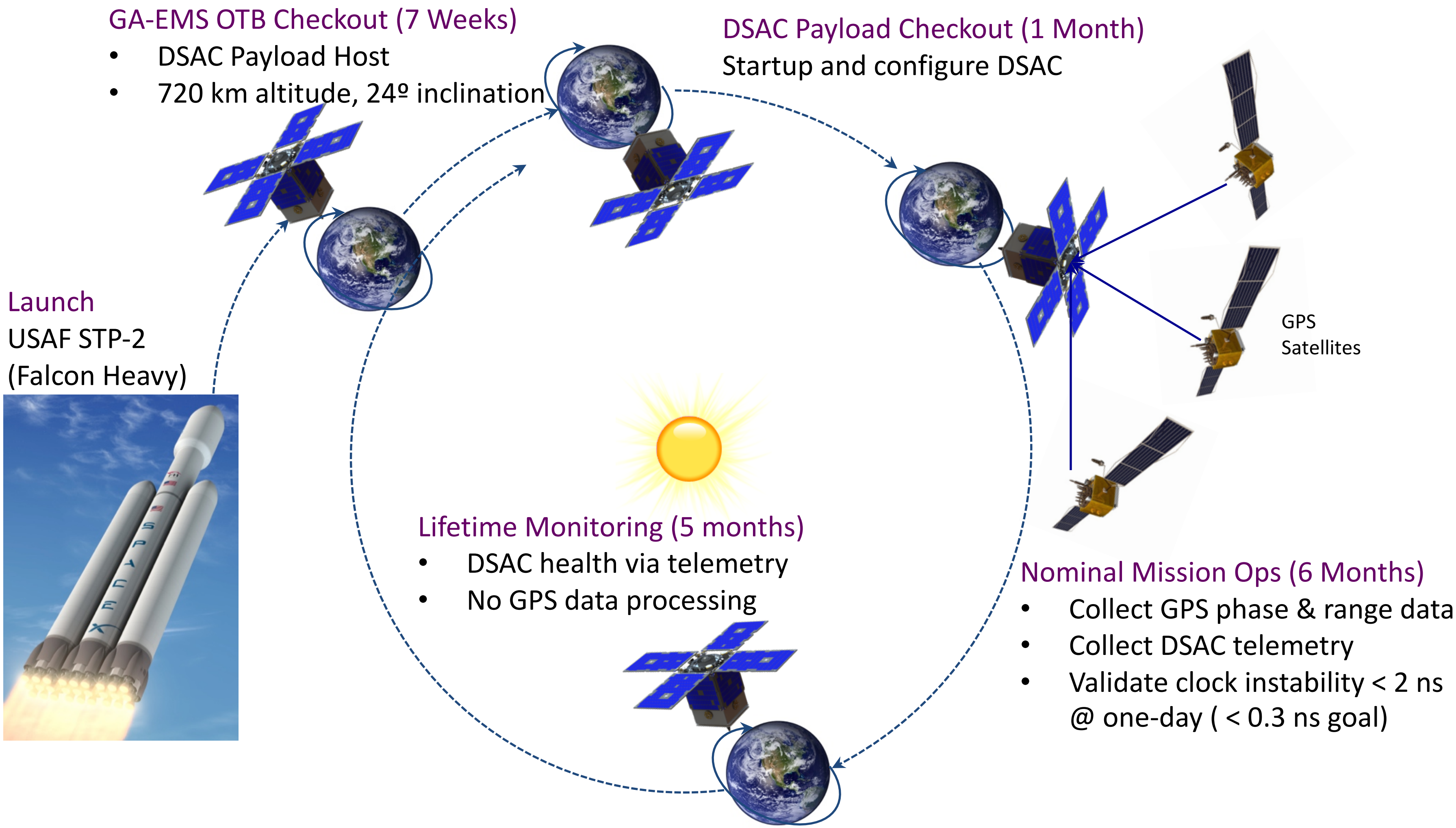


Atomic Frequency Standard	Mass	Average Power
DSAC Demo Unit (1st Generation)	16 kg	< 50 W
DSAC Future Unit (2nd Generation)	< 10 kg	< 30 W
GPS IIF Rb (5th Generation)	7 kg	< 40 W
Galileo H-Maser (2nd Generation)	18 kg	< 60 W

- Anticipated Allan Deviation (including drift) < 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

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

Mission Architecture and Timeline



Launch Spring 2019 for one-year demonstration

Schedule

• MDR & SRR	February 2012
• Preliminary Design Review	May 2013
• Key Decision Point–C	November 2013
• Clock Critical Design Review	May 2014
• Mission CDR & System Integration Review	Nov 2014
• Pre-Ship Review	Jan 2017
• System-End-to-End Test	Oct 2017
• Mission Readiness Review	June 2018
• Launch	Spring 2019
• Mission Operations	Launch + 1 Year

Towards a GPS ready version of DSAC

- Development of an operational mercury atomic frequency standard (MAFS) based on DSAC technology realizable in the near-term
  - Alternate technologies (optical Rb and cold atom Cs) at much lower readiness levels with TRL 7 not achievable for 10 years or more
    - Recent Aerospace report recommended DSAC as the only viable US technology for near term deployment on GPS
  - DSAC Demo Unit a point of departure with demo results feeding into MAFS design and development
- In discussions with the GPS program office on *potential* for a GPS-demo version of DSAC to fly in a GPS III spare clock slot
  - A smart approach is to pair with the right commercial partner and develop a clock that is easily adapted for multipurpose use – GPS, AEHF, NASA

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov