Mercury Trapped Ion Frequency Standards and the Deep Space Atomic Clock (DSAC)

Future Directions

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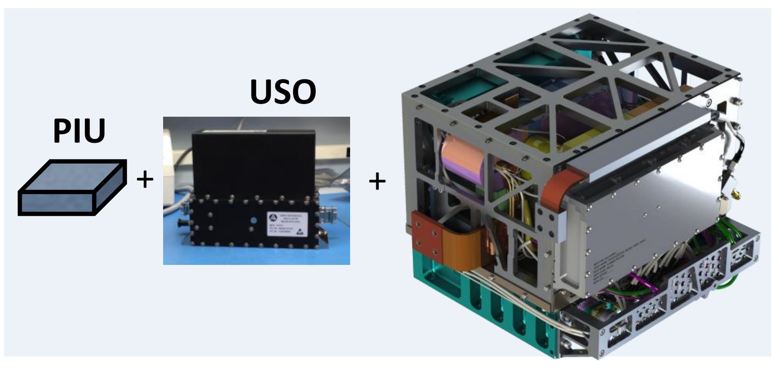
DSAC-2 Prototype

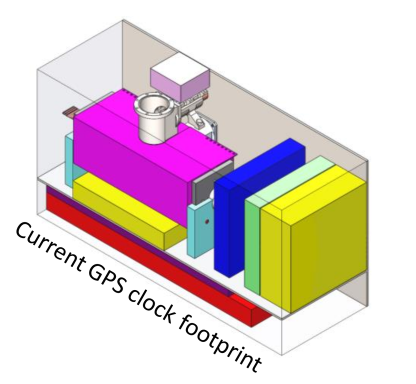
DSAC-2 will reduce size, mass & power, increase operational life, and improve stability relative to DSAC.
The manufacturable design integrates USO & clock control and fits in a GPS clock footprint or COTS chassis

DSAC-1

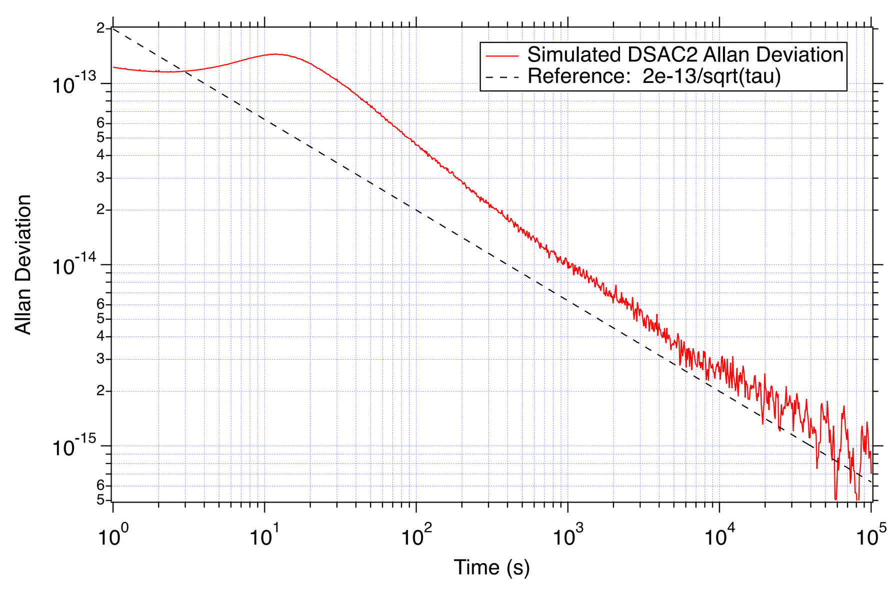


Power (actual): 56 W
Mass (actual): 19 kg

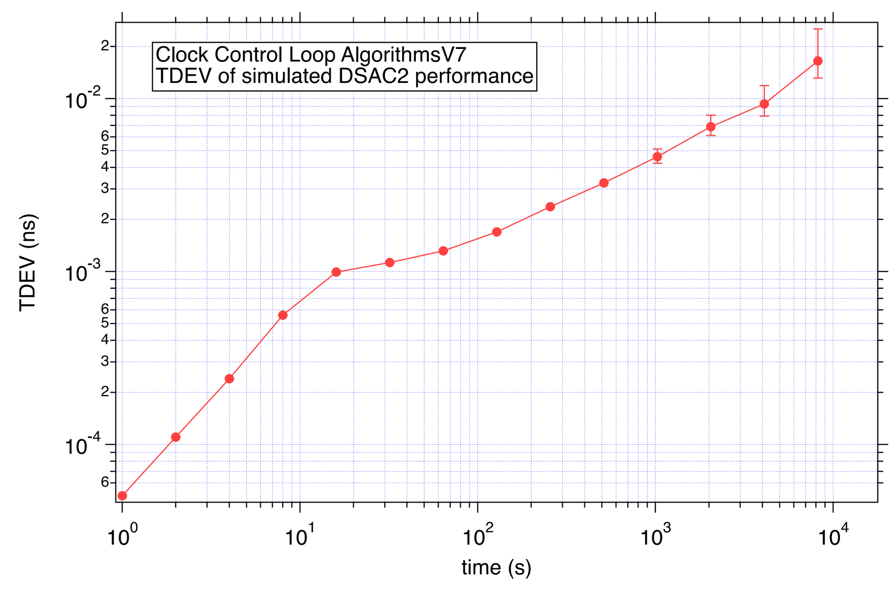
DSAC-2 Prototype Concept



Power (CBE): 34 W
Mass (CBE): 10 kg



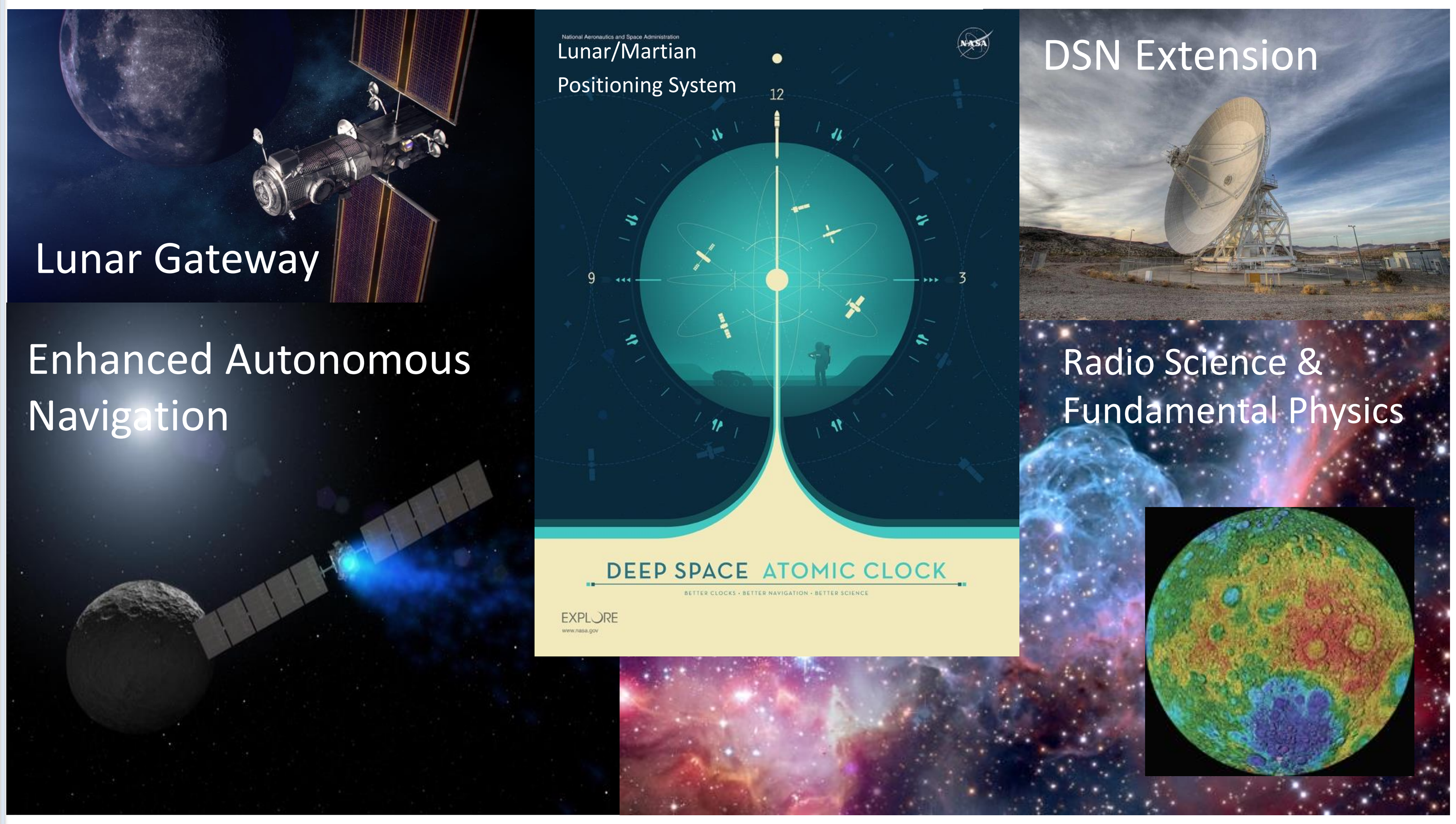
Stability of 1e-13 at 1 s, <1e-15 at a day



Time Deviation of ~ 10 ps at a day

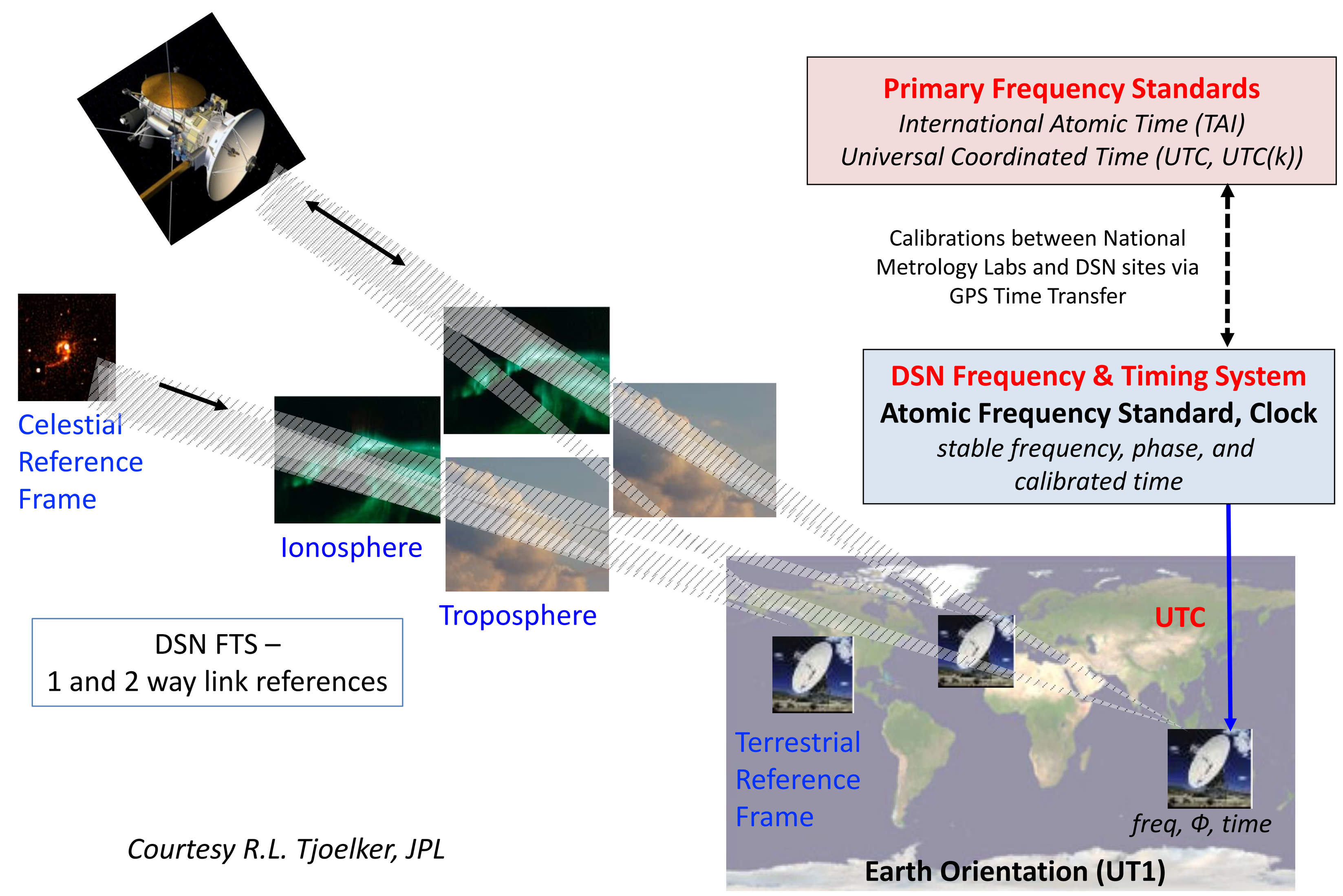
What Is Possible With DSAC-2

DSAC-2 is the right clock technology for realizing new ground and space based capabilities



Ground Example - DSN Frequency & Timing System (FTS) References

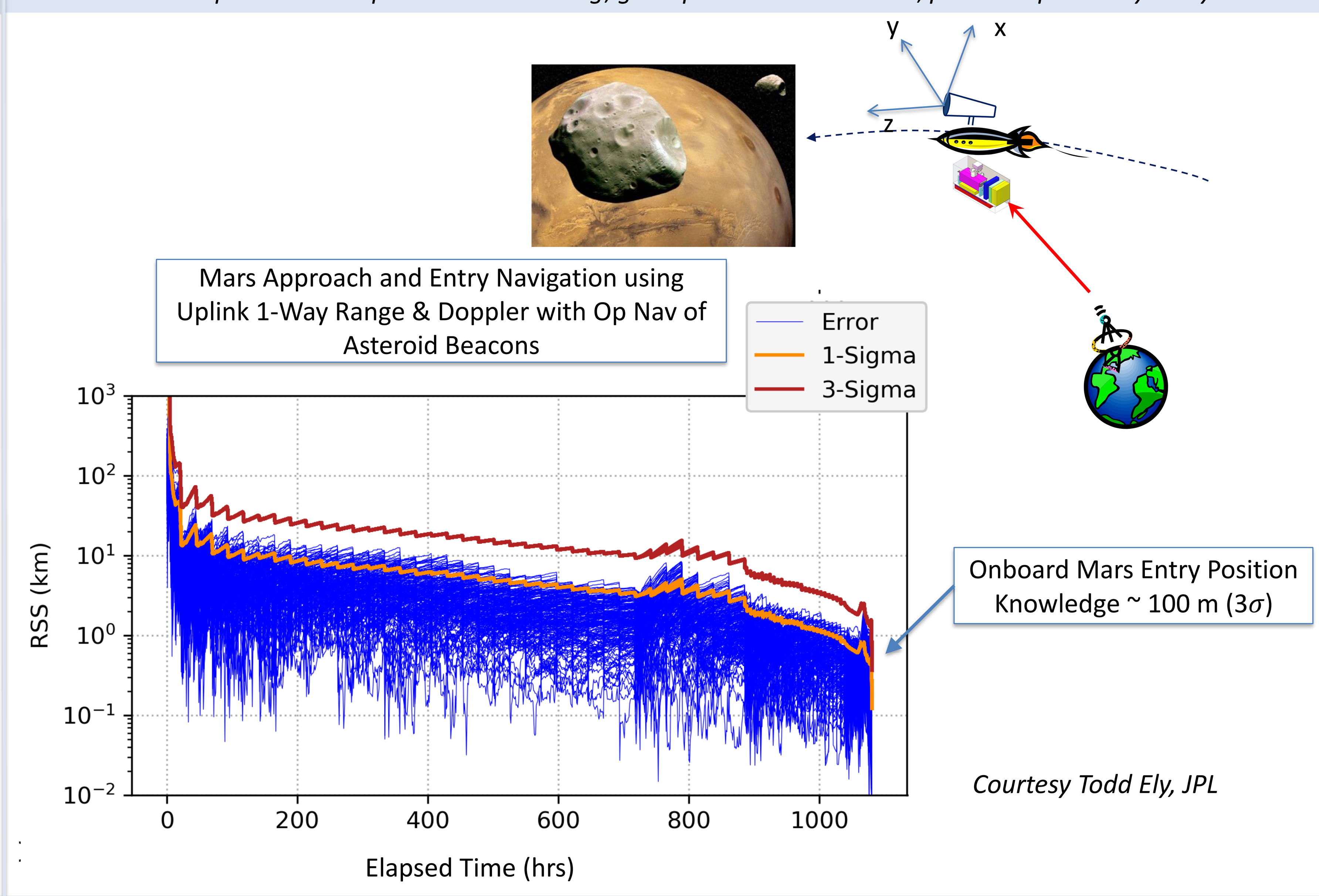
The DSN FTS enables NASA mission communications, tracking & navigation, and radio science.
Developing a ground version of DSAC-2 ensures the FTS can deliver these outcomes for years to come



Courtesy R.L. Tjoelker, JPL

Space Example - Autonomous Deep Space Navigation

DSAC produces 1-way *uplink* Doppler & range with 2-way accuracies ⟹ enabling for onboard, autonomous navigation (especially robust & accurate when paired with optical navigation) for applications such as
outer planet aerocapture & aerobraking, giant planet satellite tours, precision planetary entry

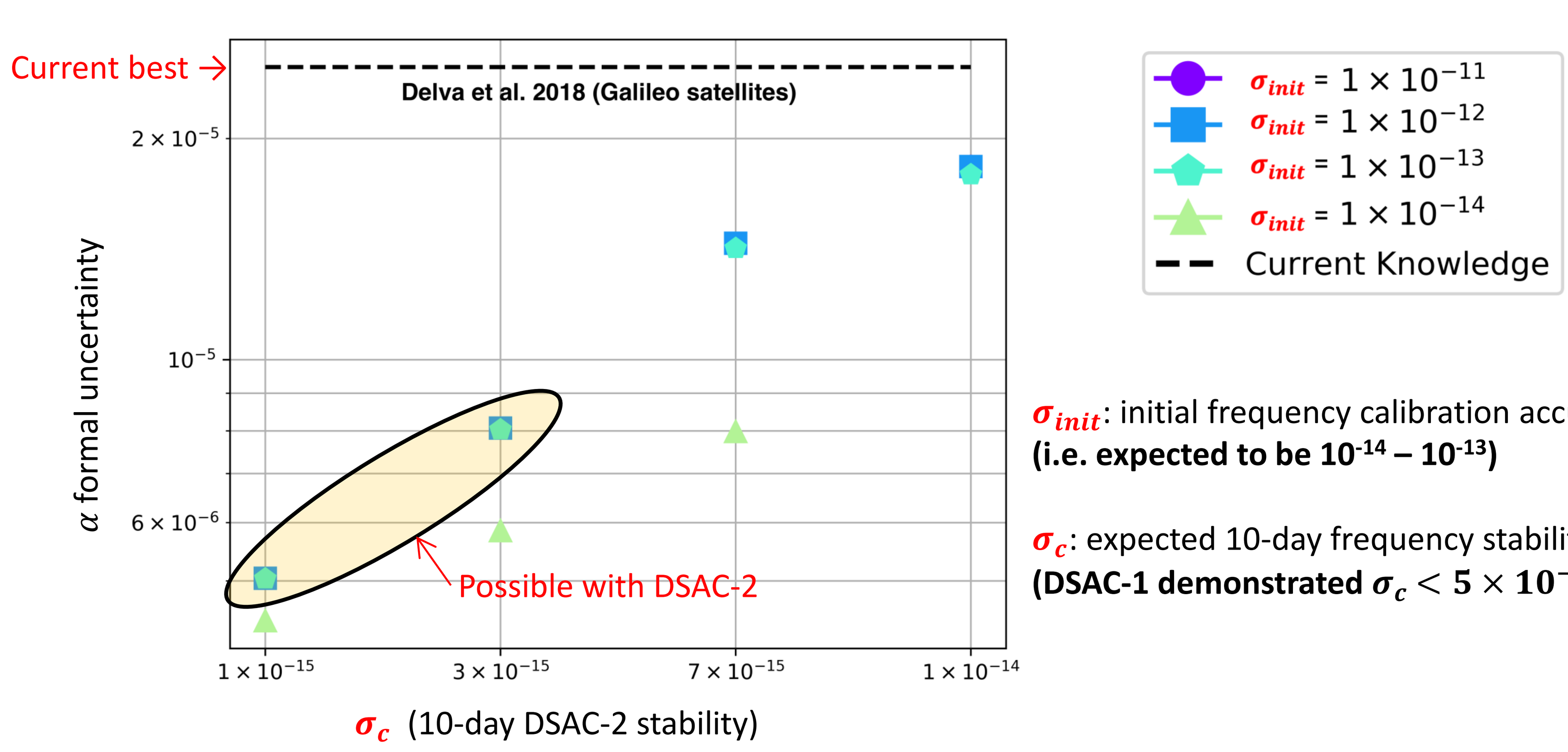


Courtesy Todd Ely, JPL

Space Example - Measuring the Gravitational Red Shift (General Relativity)

DSAC enables up to an order of magnitude improvement in verifying GR via LPI measurements.
Simulation results for Venus cruise LPI measurement

Parametrization: α. **LPI test with identical clocks (DSAC in space and on ground)**
Multi-arc covariance analysis (using NASA-JPL MONTE software):



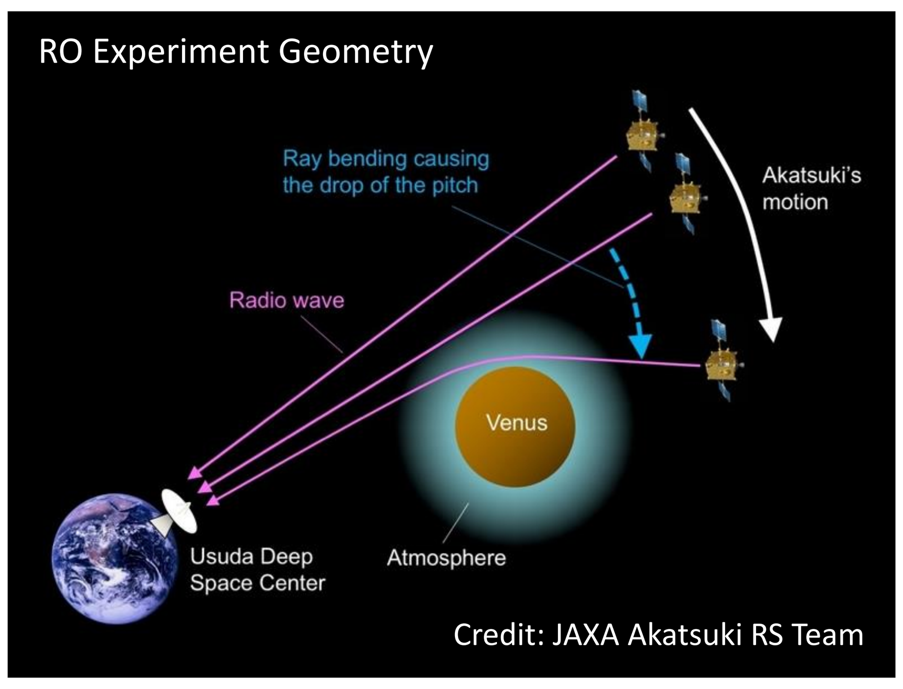
σ_{init}: initial frequency calibration accuracy **(i.e. expected to be 10^{-14} – 10^{-13})**

σ_c: expected 10-day frequency stability **(DSAC-1 demonstrated $\sigma_c < 5 \times 10^{-15}$)**

LPI/LLI simulation courtesy of G. Cascioli, F. de Marchi, and L. Iess
See F. De Marchi et al., arXiv:2211.08964 [gr-qc]

Space Example – Planetary Atmosphere Science using Radio Occultations

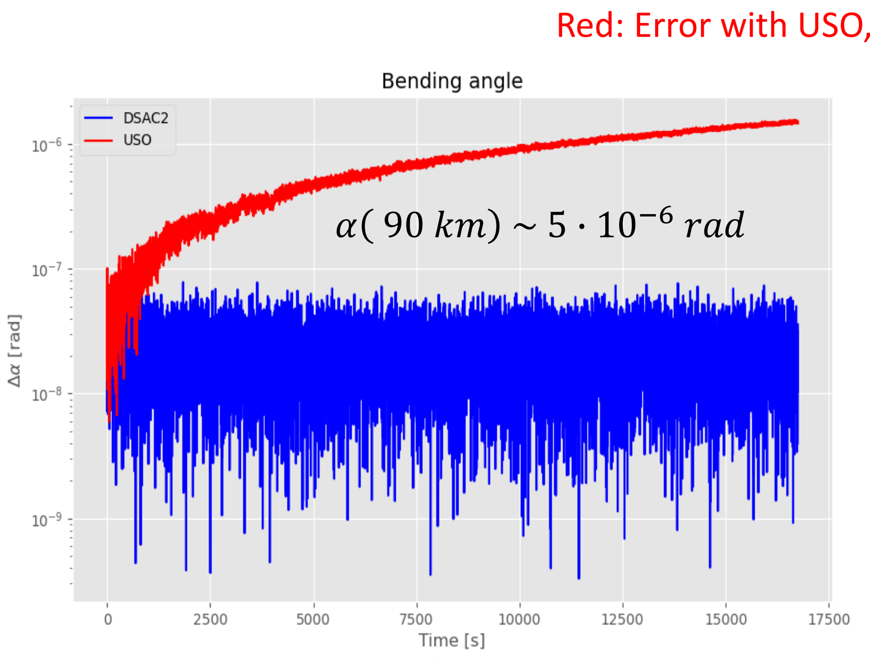
DSAC enables up to an order of magnitude improvement relative to a USO in characterizing relevant atmosphere characteristics



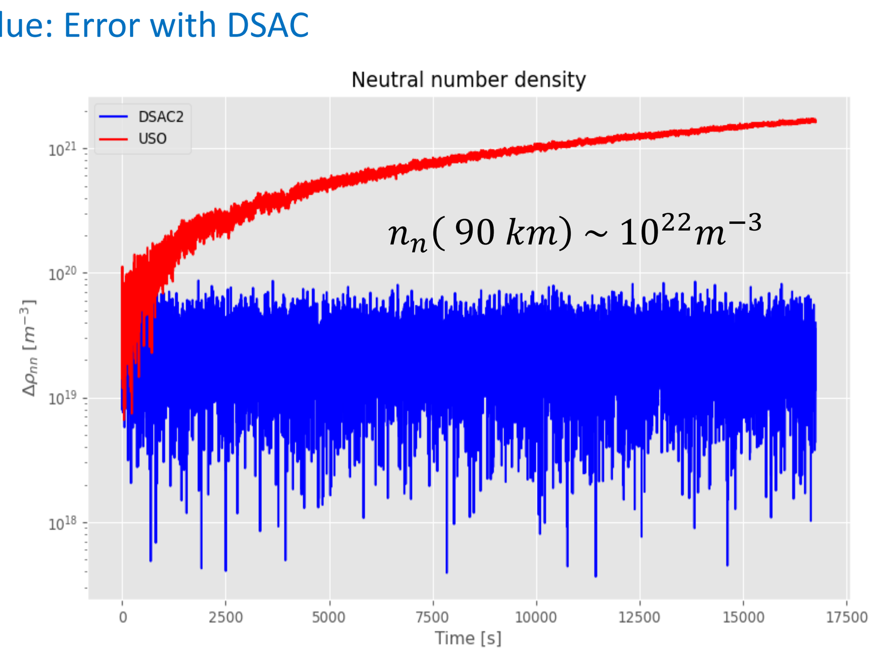
RO Simulation: DSAC vs. USO

- Neglecting OD and transmission errors
- Propagate σ_f through the multivariate and multistage occultation measurement model using Monte Carlo simulations.

Red: Error with USO, Blue: Error with DSAC



1% vs. factor of 2



Part per 1000 vs. 10%

Courtesy Tatiana Bocanegra-Bahamon, JPL

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