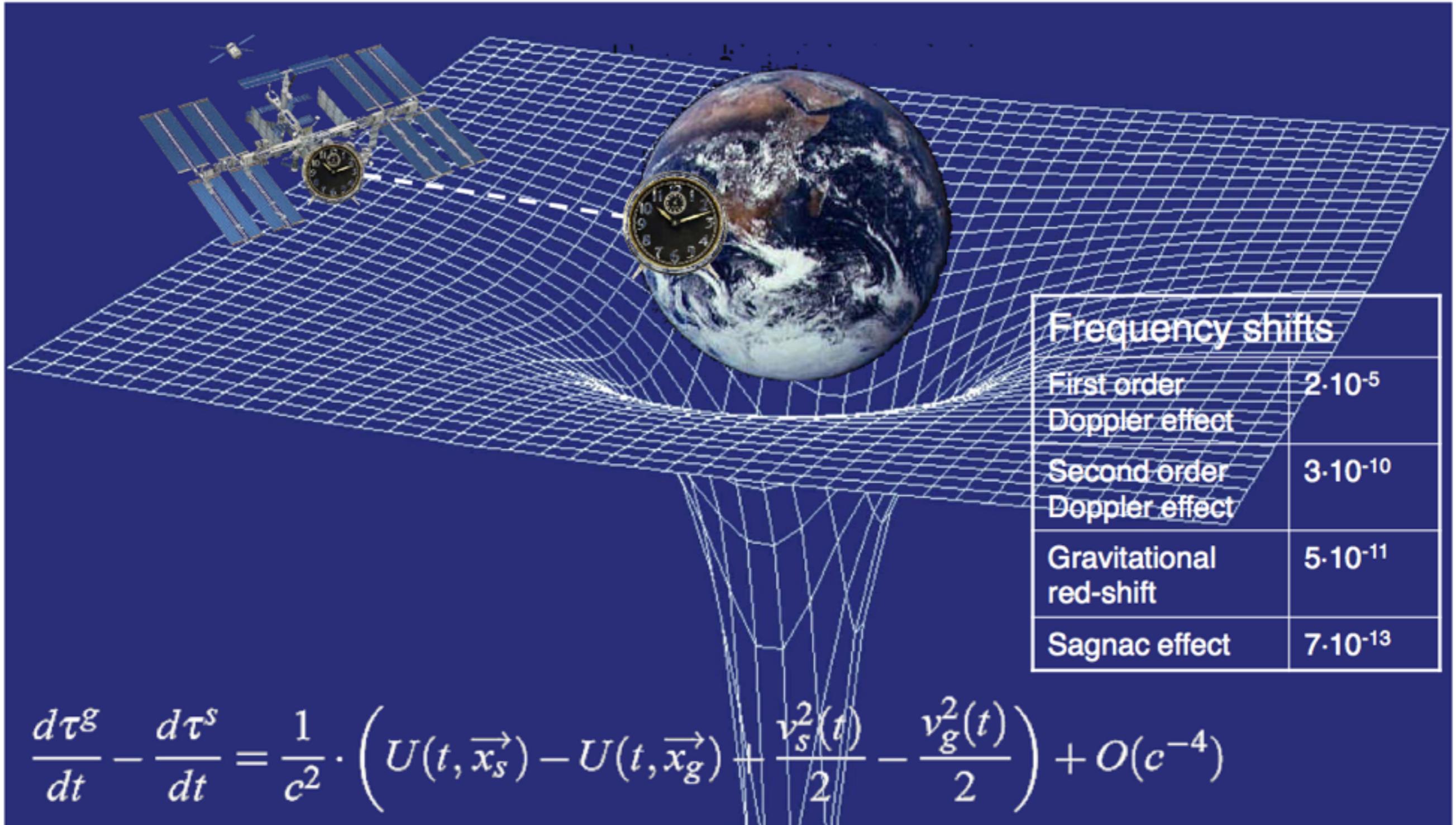


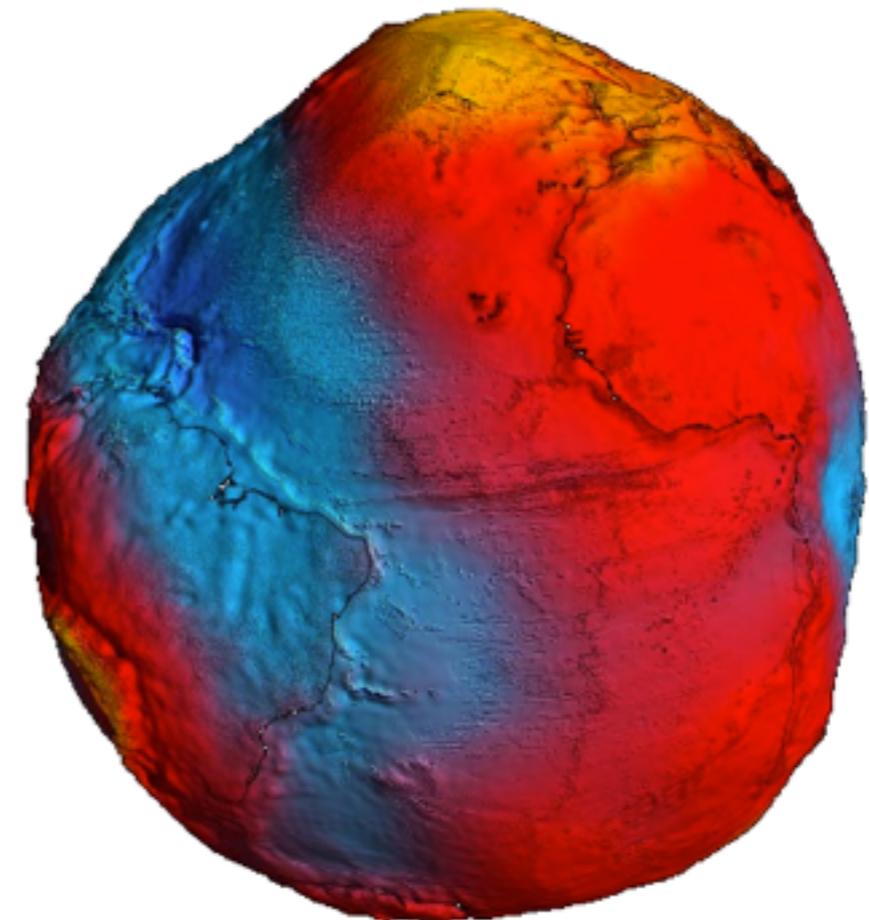
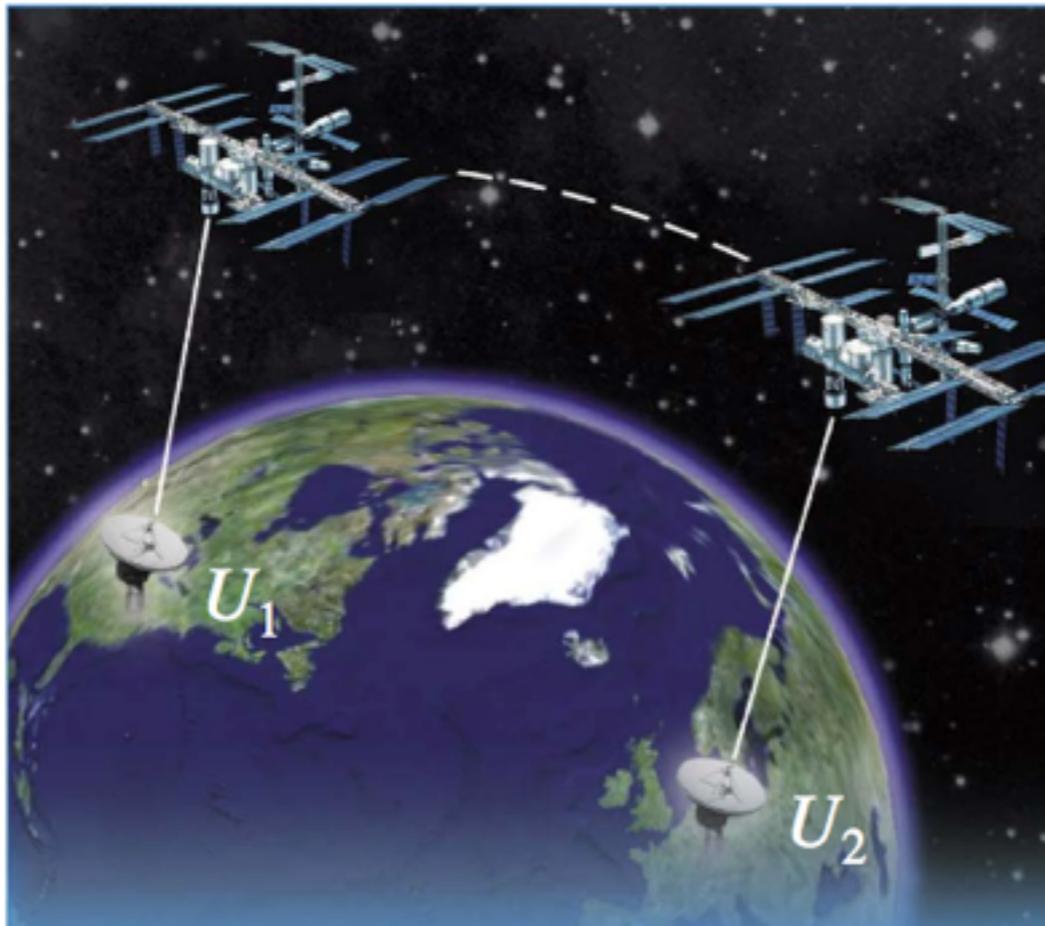
Testing Fundamental Physics with Clocks in Space: **The ACES Mission**

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M. P. Hess (Airbus D&S), D. Goujon (SpectraTime), W. Schaeffer (TimeTech) and
D. Massonnet (CNES)

Atomic clocks and high-performance links are used to measure time and frequency to accuracy levels never reached before. When operated in a space-based laboratory, the large variations of the gravitational potential, the large velocities and velocity variations, as well as the worldwide access to ground clocks become key ingredients to measure tiny deformations in space-time that might bring the signature of new physics and new fundamental constituents. From the International Space Station, the ACES payload will distribute a clock signal with fractional frequency stability and accuracy of $1 \cdot 10^{-16}$. The comparison of distant clocks via ACES will be used to test Einstein's theory of general relativity. The ACES mission elements are now close to flight maturity. The flight model of the cold cesium clock PHARAO has been tested and delivered for integration in the ACES payload. Tests on the active hydrogen maser SHM and the microwave link MWL have been completed and manufacturing of the flight models is ongoing. The time transfer optical link ELT is also well advanced. This paper presents the progress of the ACES mission elements.

ACES Mission Objectives	ACES performances	Scientific background and recent results
<i>Fundamental physics tests</i>		
<i>Measurement of the gravitational red shift</i>	Absolute measurement of the gravitational red-shift at an uncertainty level $< 50 \cdot 10^{-6}$ after 300 s and $< 2 \cdot 10^{-6}$ after 10 days of integration time.	Space-to-ground clock comparison at the 10^{-16} level, will yield a factor 35 improvement on previous measurements (GPA experiment).
<i>Search for time drifts of fundamental constants</i>	Time variations of the fine structure constant α at a precision level of $\alpha^{-1} \cdot d\alpha / dt < 1 \cdot 10^{-17} \text{ year}^{-1}$ down to $3 \cdot 10^{-18} \text{ year}^{-1}$ in case of a mission duration of 3 years	Optical clocks progress will allow clock-to-clock comparisons below the 10^{-17} level. Crossed comparisons of clocks based on different atomic elements will impose strong constraints on the time drifts of α , m_e / Λ_{QCD} , and m_u / Λ_{QCD} .
<i>Search for violations of special relativity</i>	Search for anisotropies of the speed of light at the level $\delta c / c < 10^{-10}$.	ACES results will improve present limits on the RMS parameter α based on fast ions spectroscopy and GPS satellites by one and two orders of magnitudes respectively.

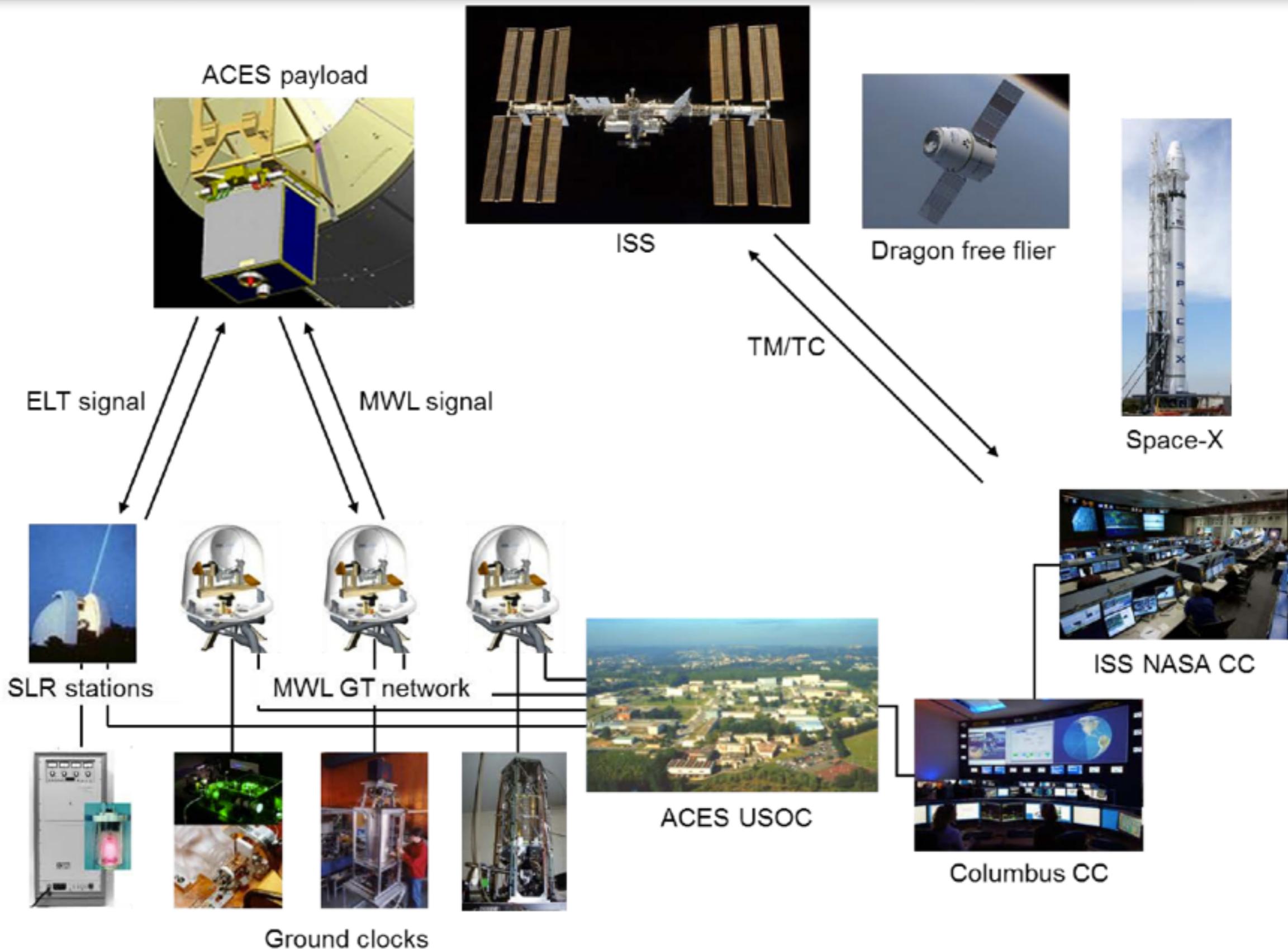




Relativistic geodesy: mapping of the Earth gravitational potential based on the precision measurement of the red-shift experienced by two clocks at two different locations

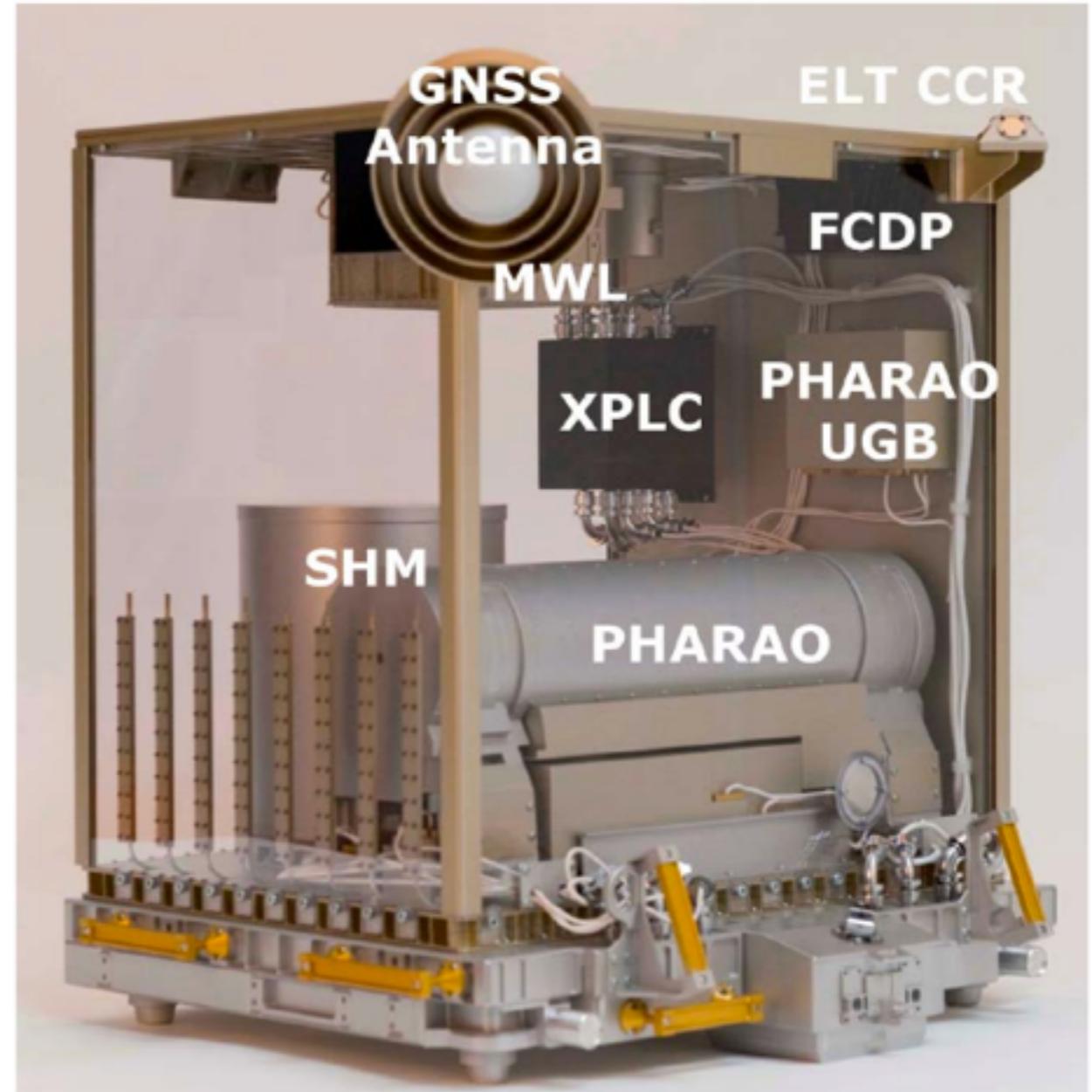
- ACES will perform intercontinental comparisons of optical clocks at the 10^{-17} level after 1 week of integration time, measuring the local height of the geoid at the 10 cm level.
- The global coverage offered by ACES will complement the results of the CHAMP, GRACE, and GOCE missions.

Atomic Clock Ensemble in Space



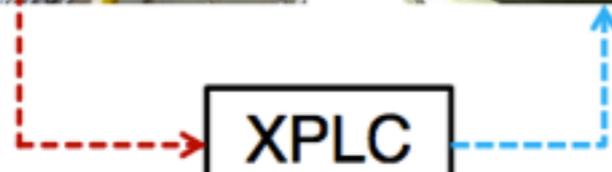
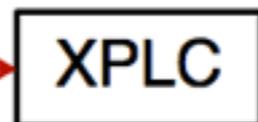
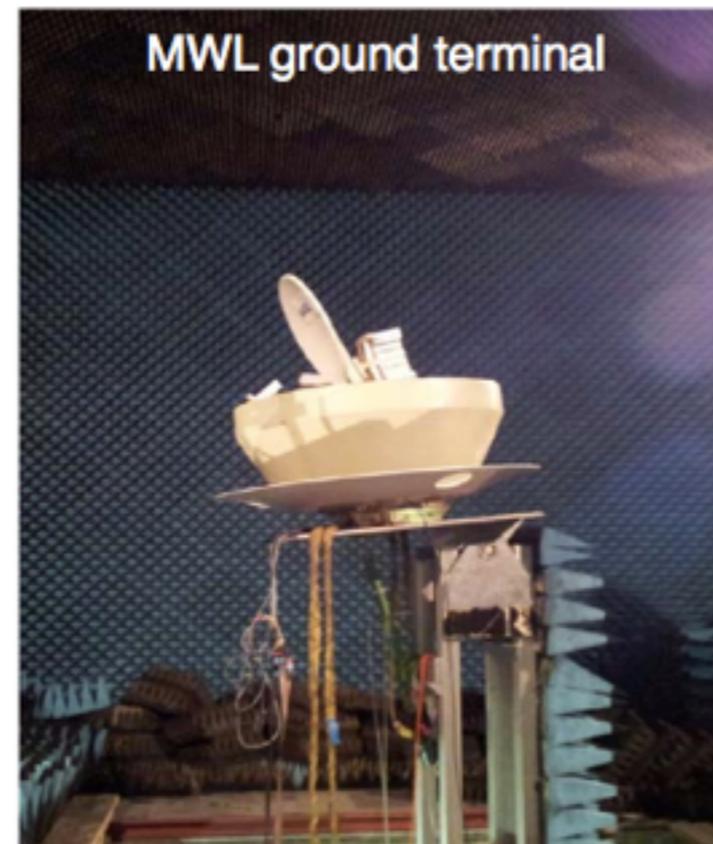
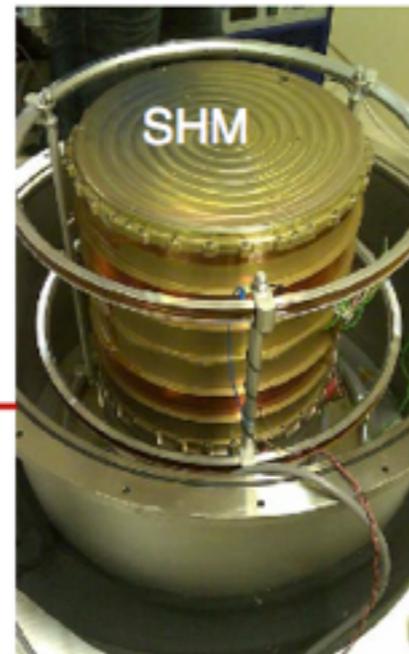
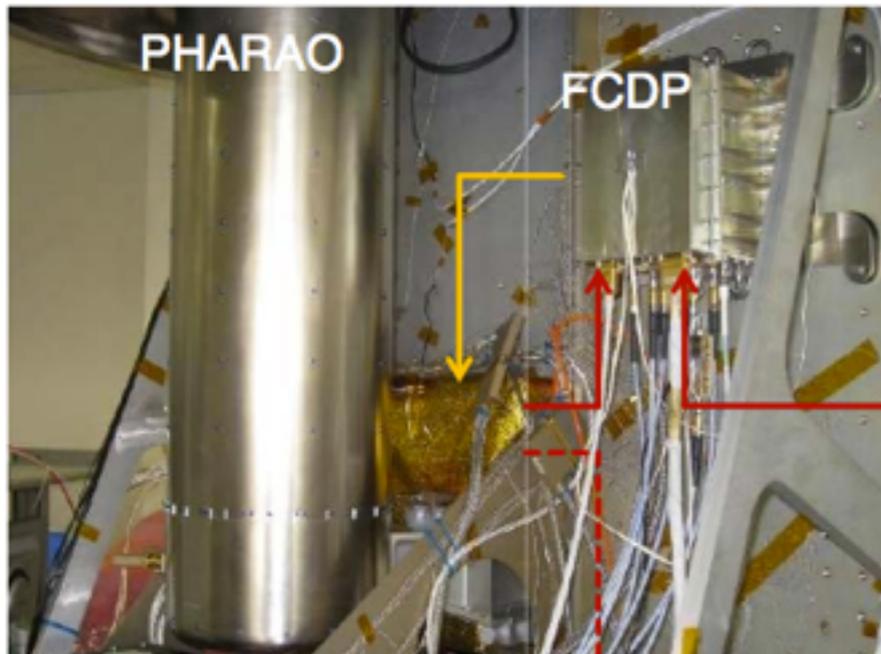
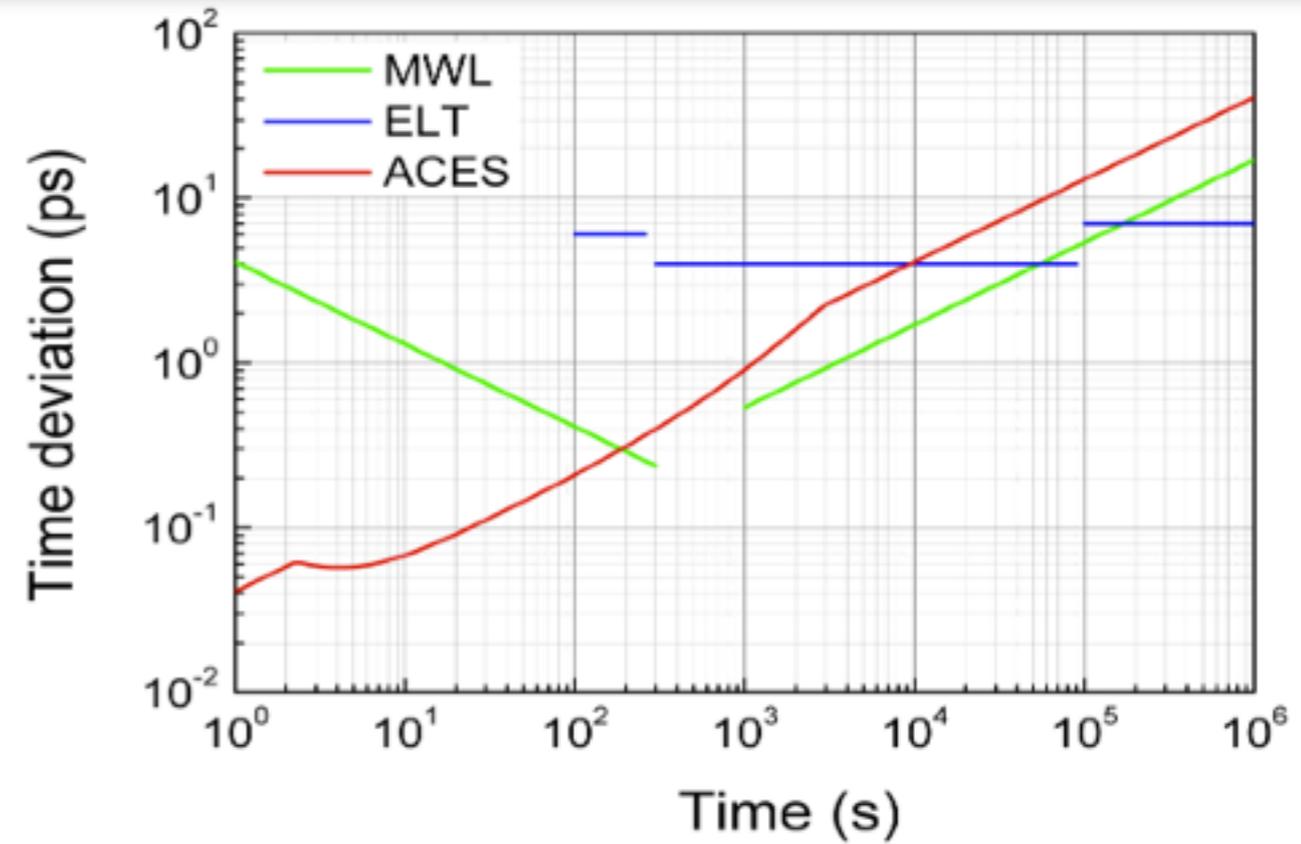
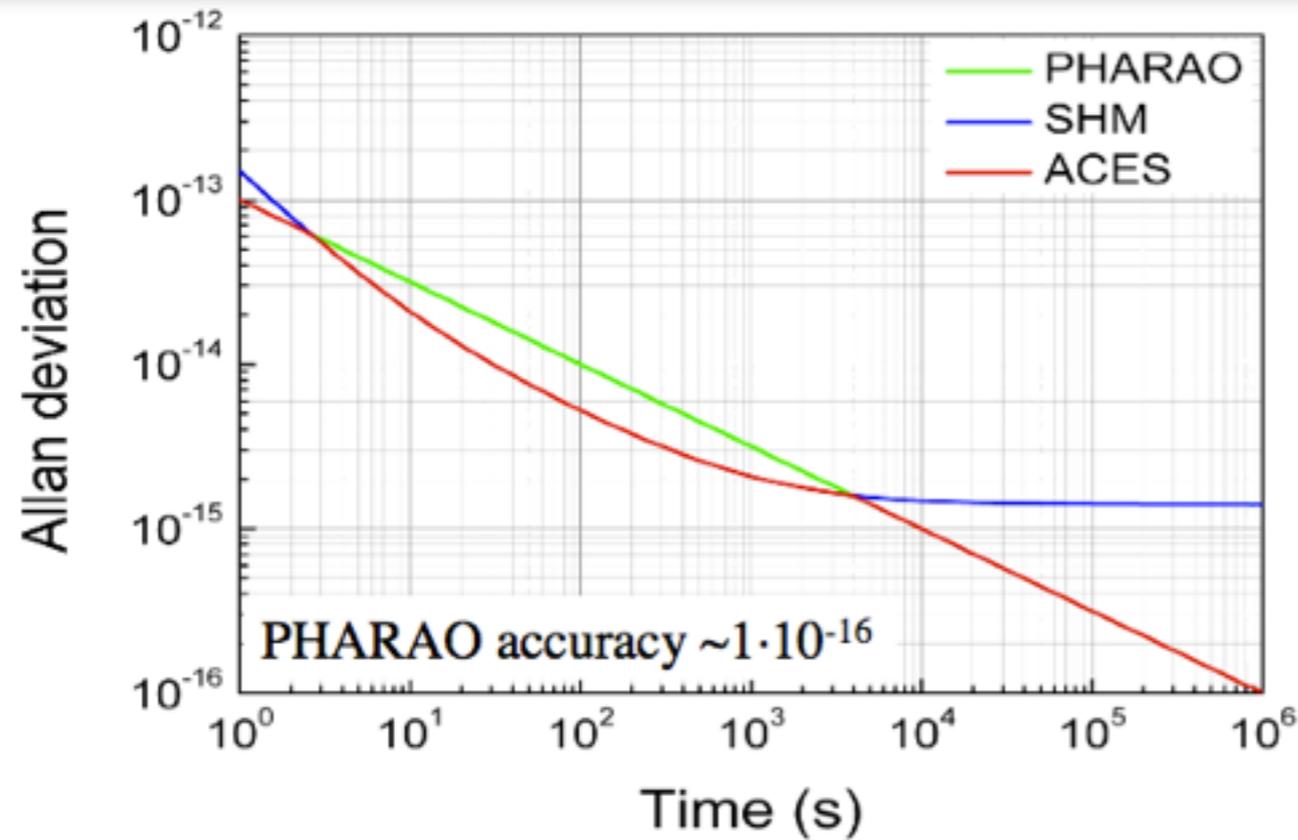
The ACES Payload

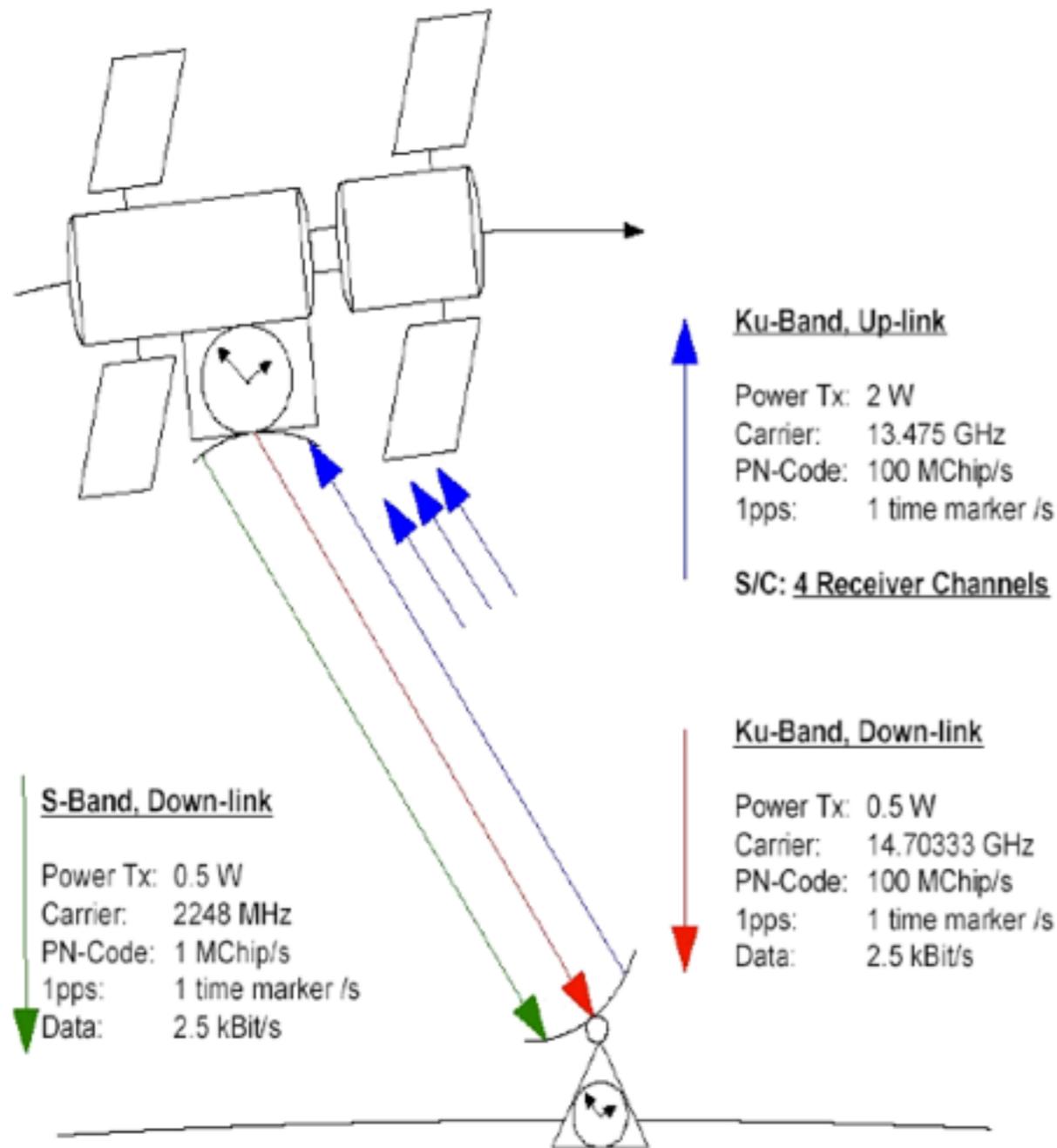
- **PHARAO (CNES):** Atomic clock based on laser cooled Cs atoms
- **SHM (ESA):** Active hydrogen maser
- **FCDP (ESA):** Clocks comparison and distribution
- **MWL (ESA):** T&F transfer link
- **GNSS receiver (ESA)**
- **ELT (ESA):** Optical link
- **Support subsystems (ESA)**
 - XPLC: External PL computer
 - PDU: Power distribution unit,
 - Mechanical, thermal subsystems
 - CEPA: Columbus External PL Adapter (ESA-NASA)



Volume: 1172x867x1246 mm³
 Mass: 227 kg
 Power: 450 W

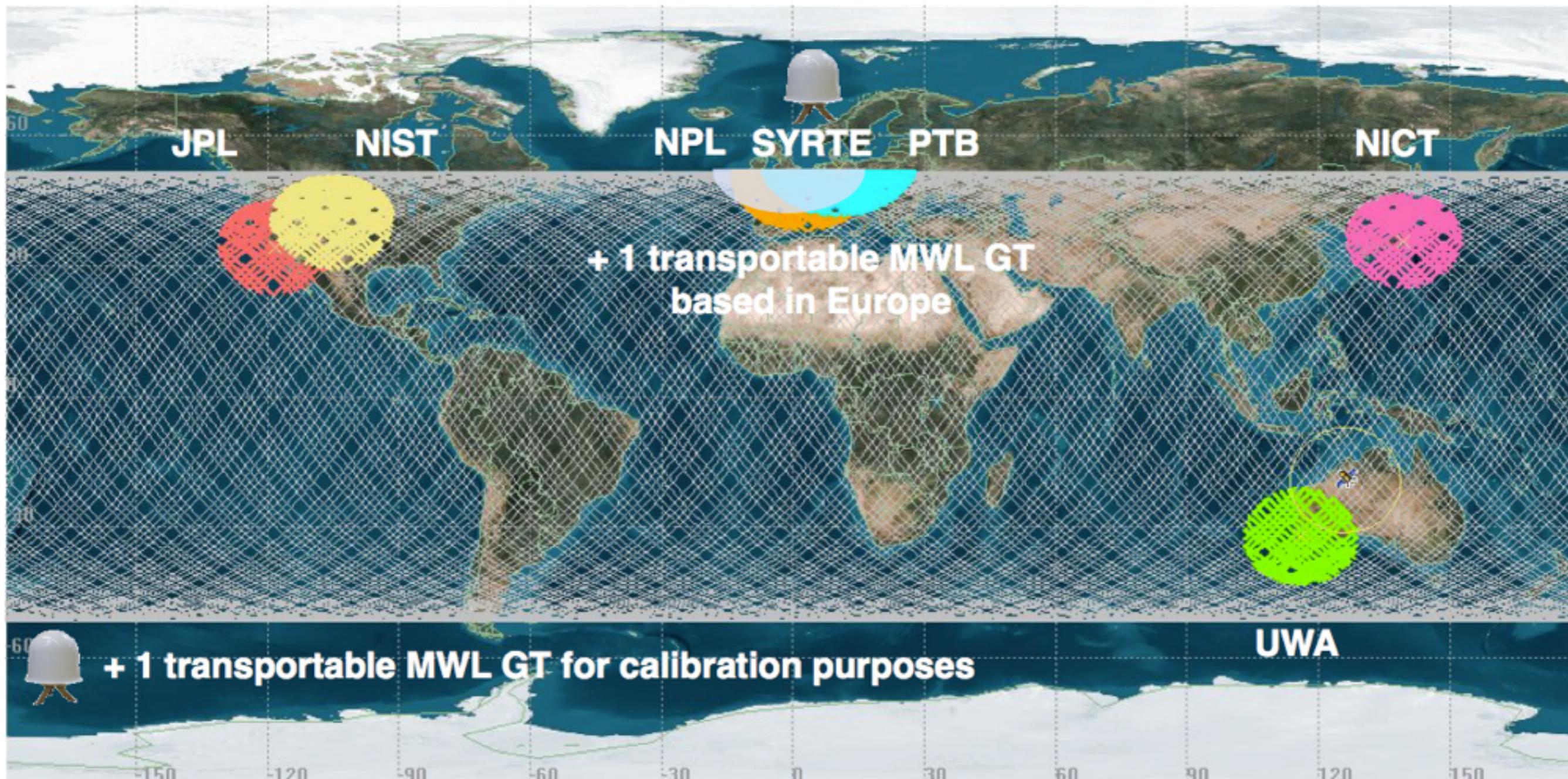
ACES Clocks and Links Performance



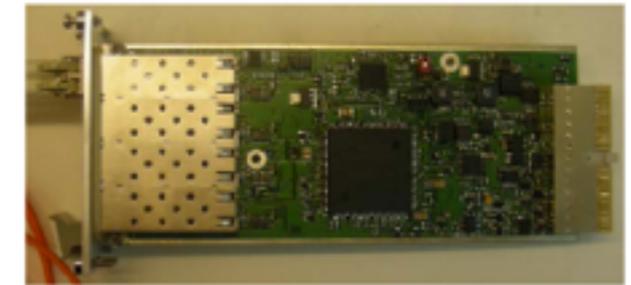
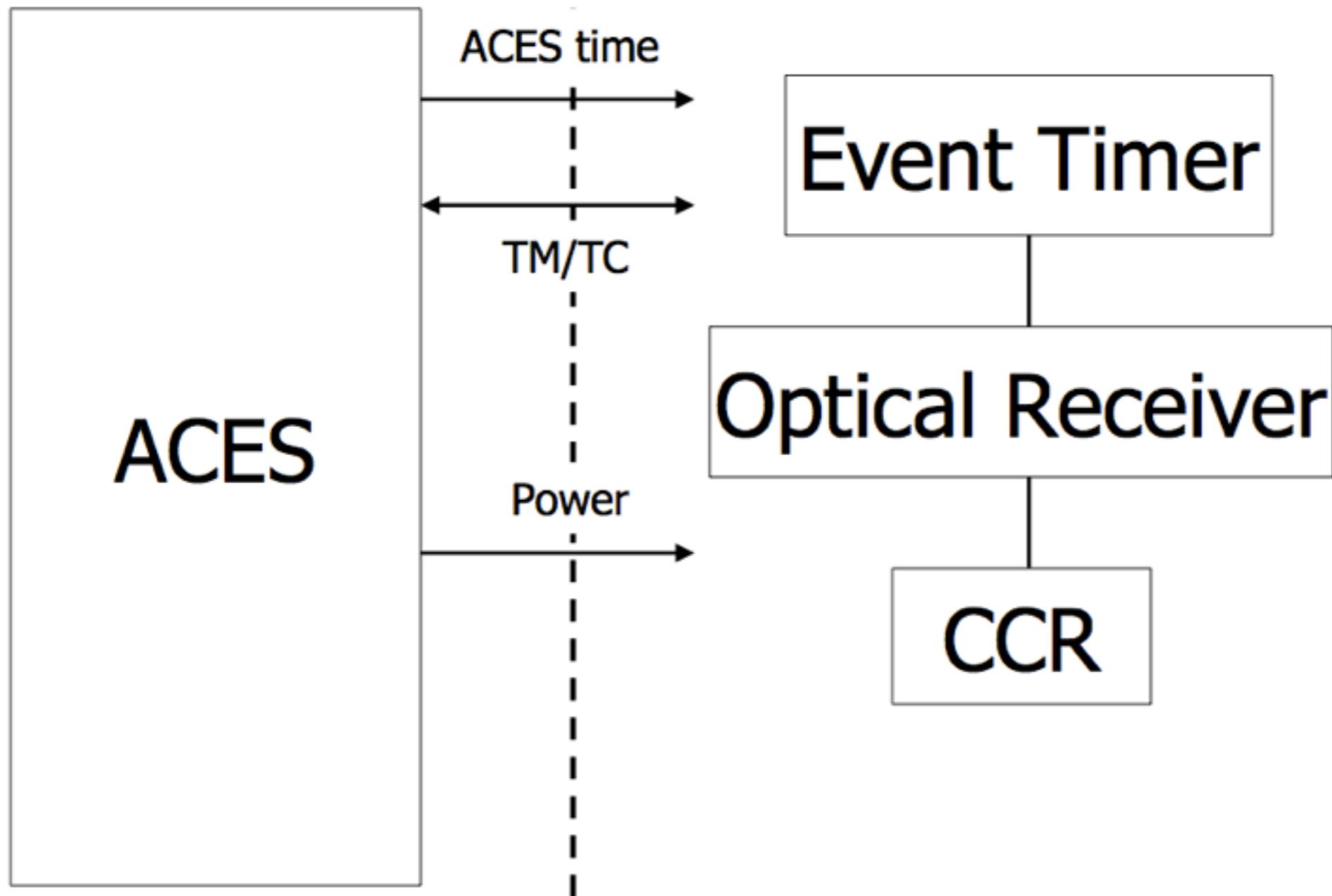


- **Two-way link:**
 - Removal of the troposphere time delay (8.3-103 ns)
 - Removal of 1st order Doppler effect
 - Removal of instrumental delays and common mode effects
- **Additional down-link in the S-band:**
 - Determination of the ionosphere TEC
 - Correction of the ionosphere time delay (0.3-40 ns in S-band, 6-810 ps in Ku-band)
- **Phase PN code modulation: Removal of 2π phase ambiguity**
- **High chip rate (100 MChip/s) on the code:**
 - Higher resolution
 - Multipath suppression
- **Carrier and code phase measurements (1 per second)**
- **Data link: 2 kBits/s on the S-band down-link to obtain clock comparison results in real time**
- **Up to 4 simultaneous space-to-ground clock comparisons**

Core Network of MWL GTs



+ METAS (CH) + INRIM (IT)+ Wetzell (DE)



Detector package
500 grams
0.6 Watt

ELT SPAD Detector – Timing Stability



Date: 06/13/11 Time: 12:00:51

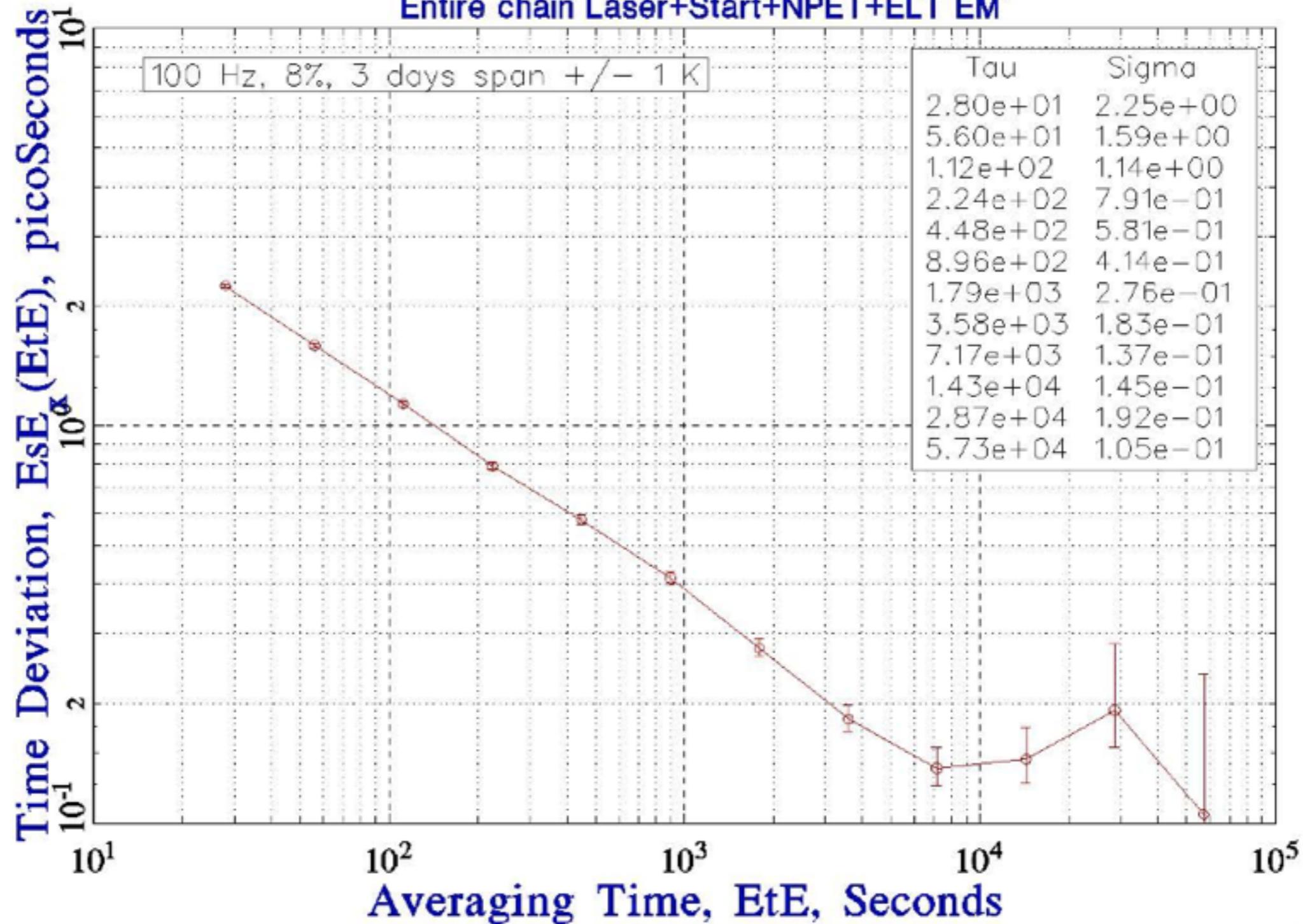
Data Points 1 thru 8929 of 8929

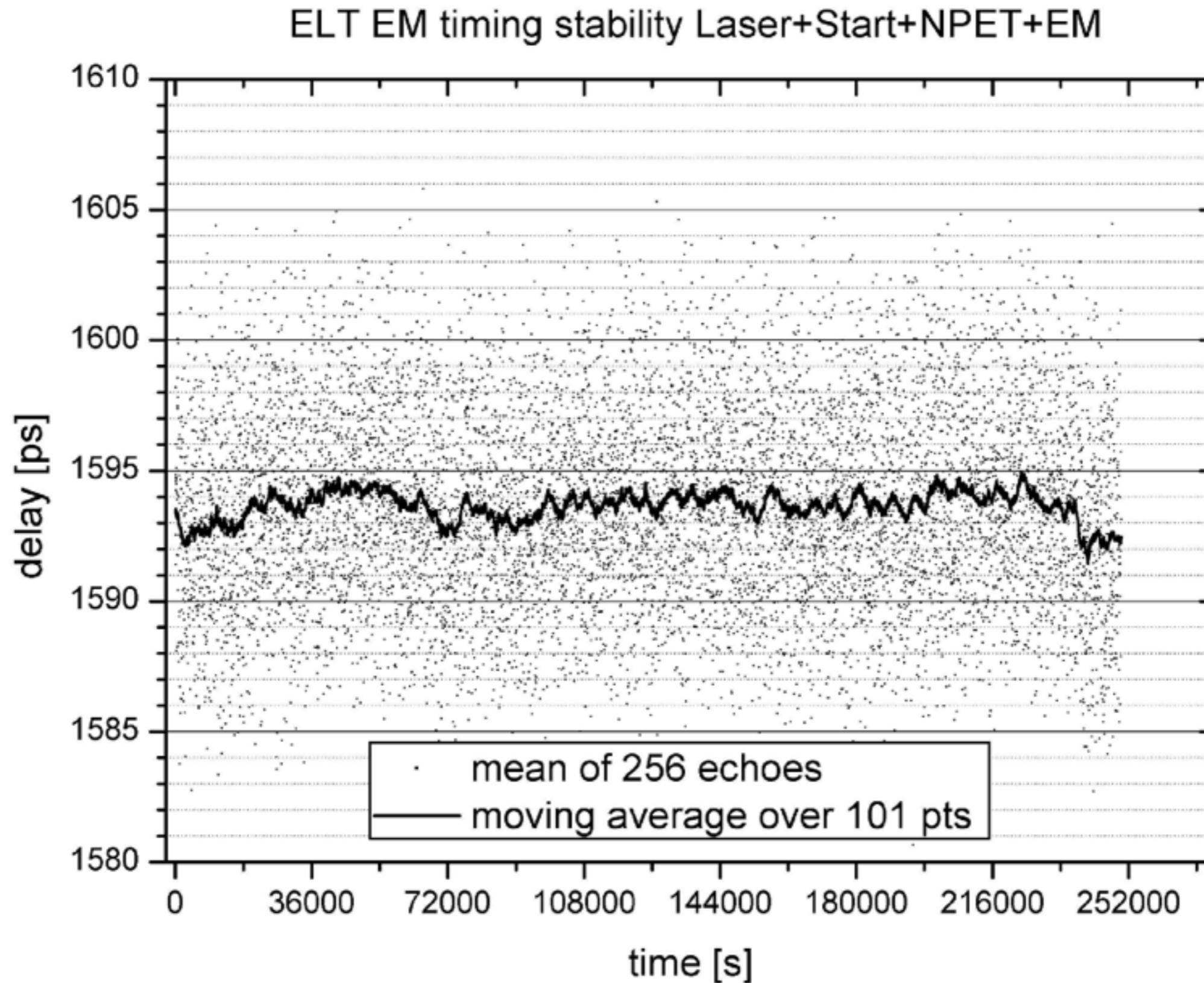
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File: stat101.txt

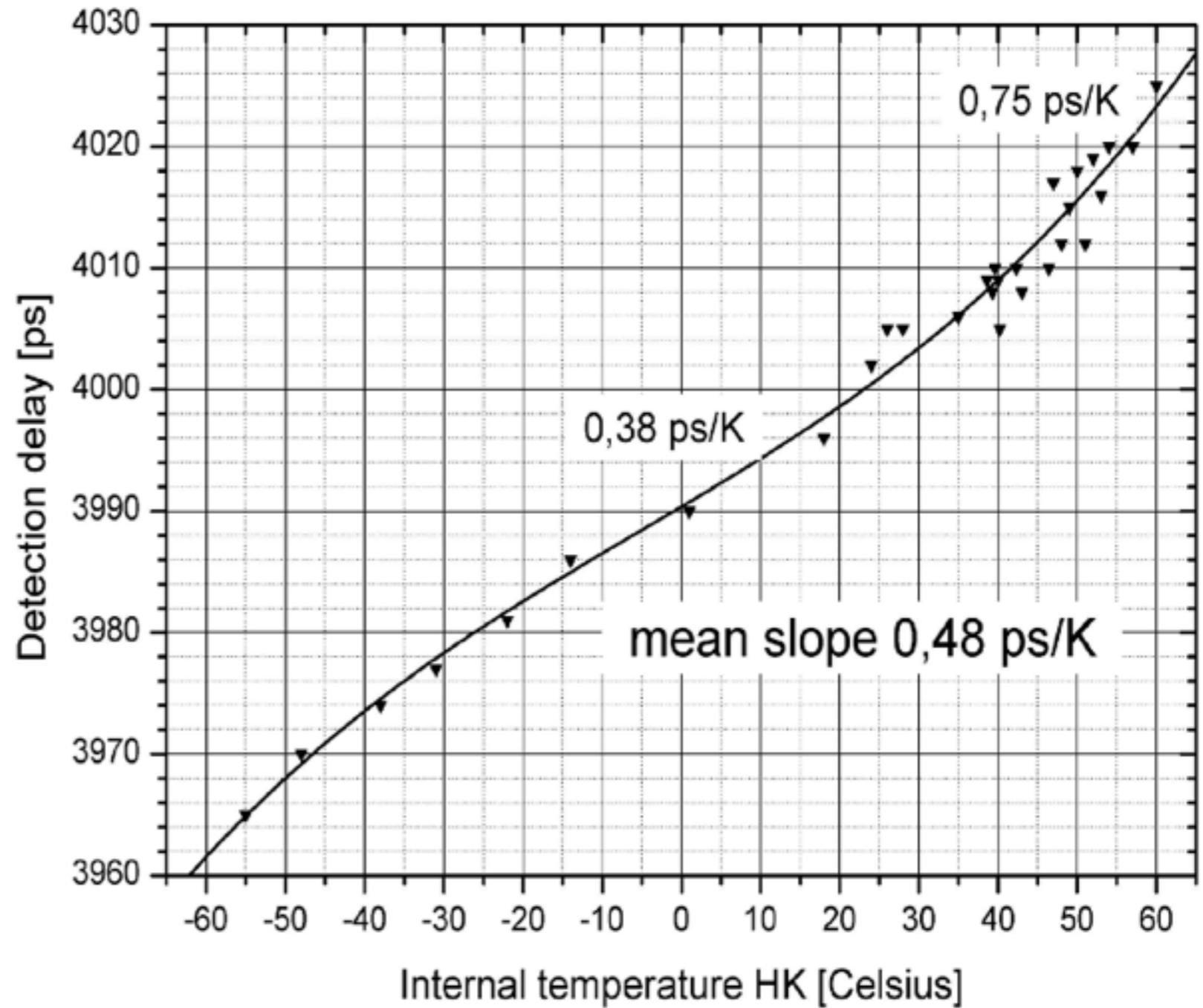
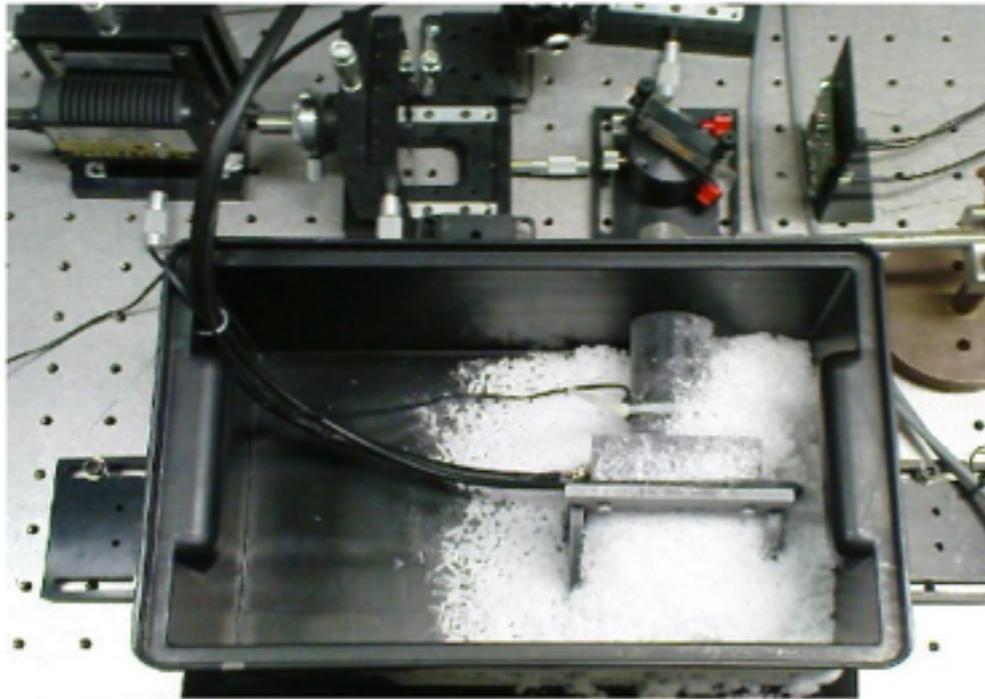
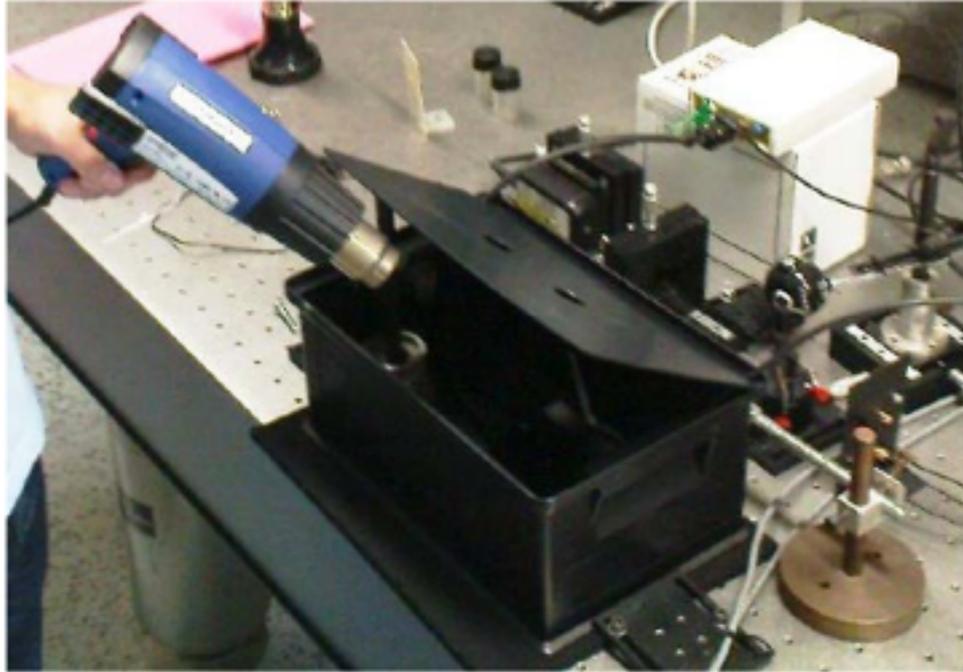
ELT EM Time stability

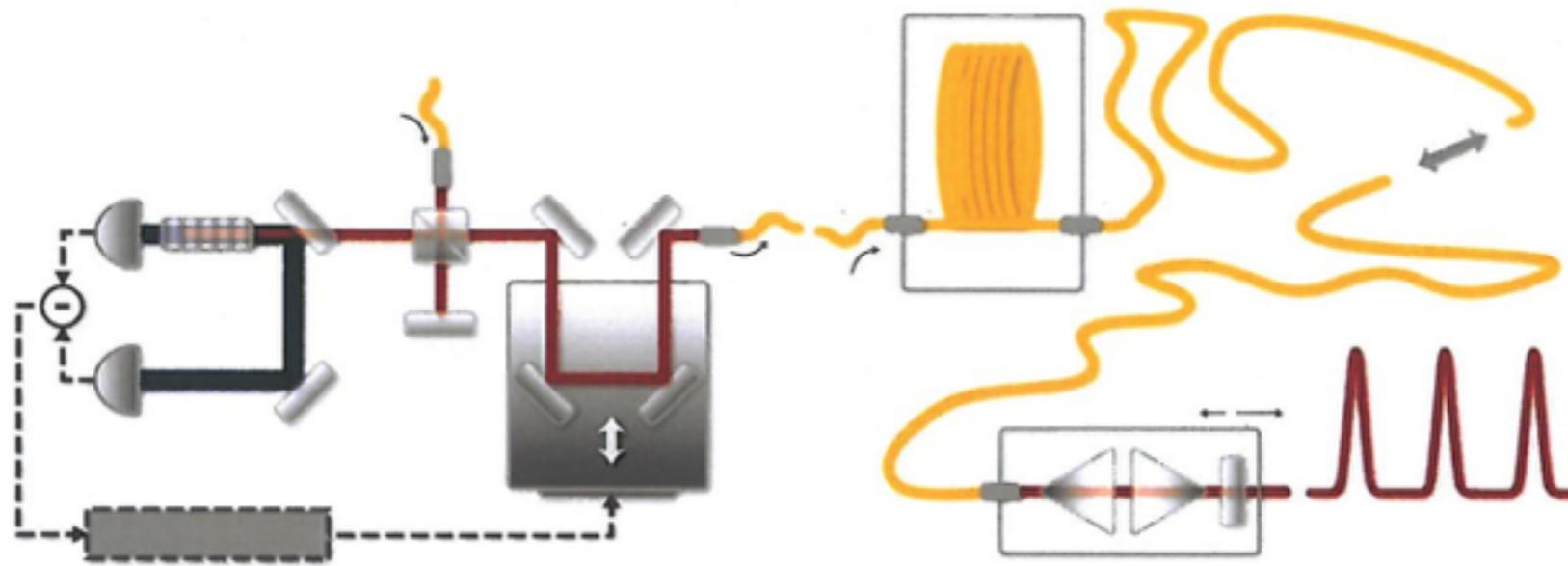
Entire chain Laser+Start+NPET+ELT EM





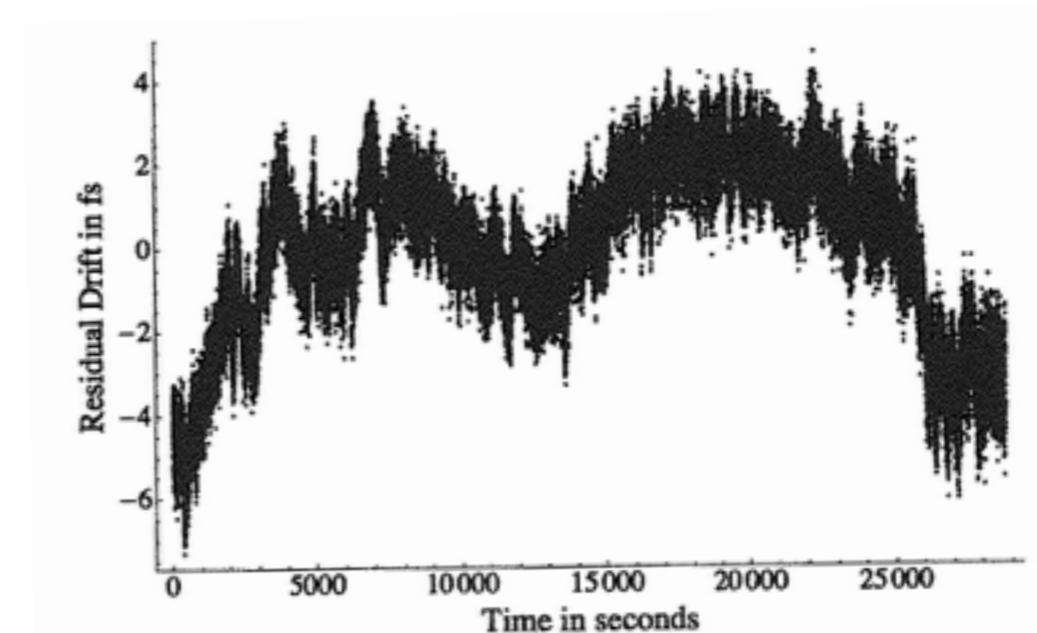
ELT SPAD Detector – Temperature Stability



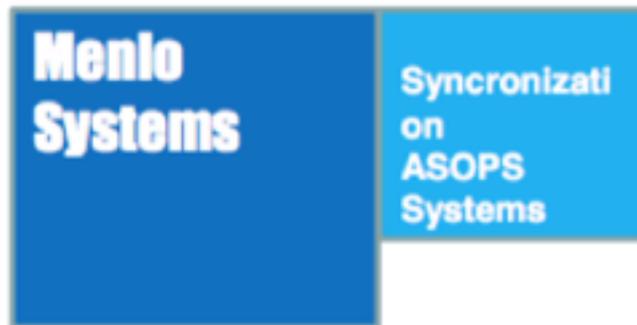


Example: FEL in Trieste

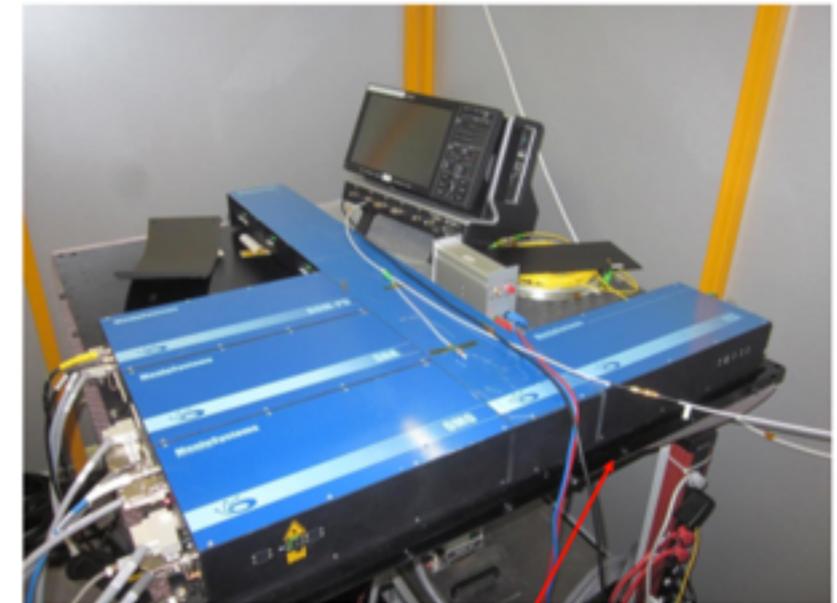
- 2-Way compensation technique only possible in the optical domain
- required broadband signal available from fs-pulse lasers only
- Inherent uncertainty < 100 fs: ≈ 5 orders of magnitude gain over current situation
- Consequences for Local Survey: $1 \text{ mm} = 3 \text{ ps}$



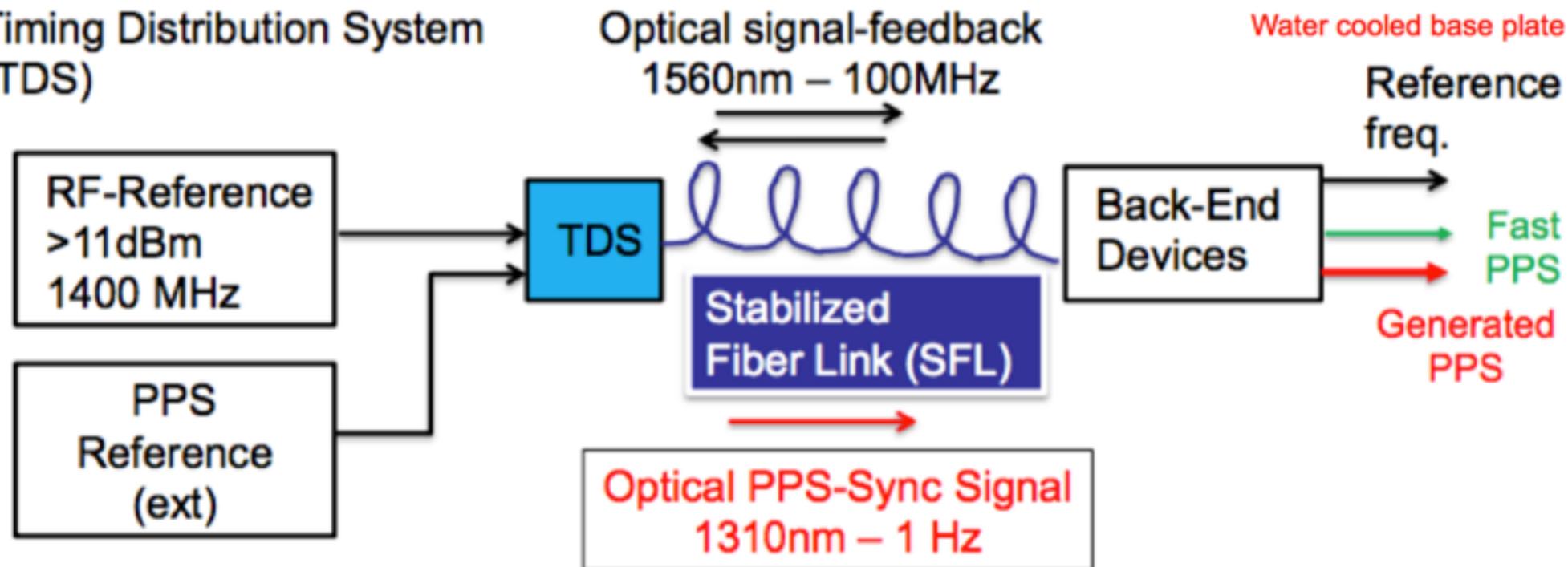
Two-Way Time + Frequency (on Ground)



Timing Distribution System (TDS) (Wettzell)



Timing Distribution System (TDS)



Water cooled base plate



- ACES is taking clock comparisons to the next level. SLR is a natural technique of choice for that purpose
- ELT + TWSTFT are essential parts of the mission objective (ELT provides a clear geometric reference)
- Payload awaits launch vehicle: Launch in early 2018
- WLRS is technically ready, awaiting ESA and NASA clearance for laser safety
- Once Laser safety clearance is obtained, the concept is transferred to the partner stations (without extra pain)