

ACES Mission Update: Scientific Objectives and Ground Station Requirements

DFG Research Unit FOR 5456/1

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Federal Agency for
Cartography and Geodesy

Atomic Clock Ensemble in Space ACES

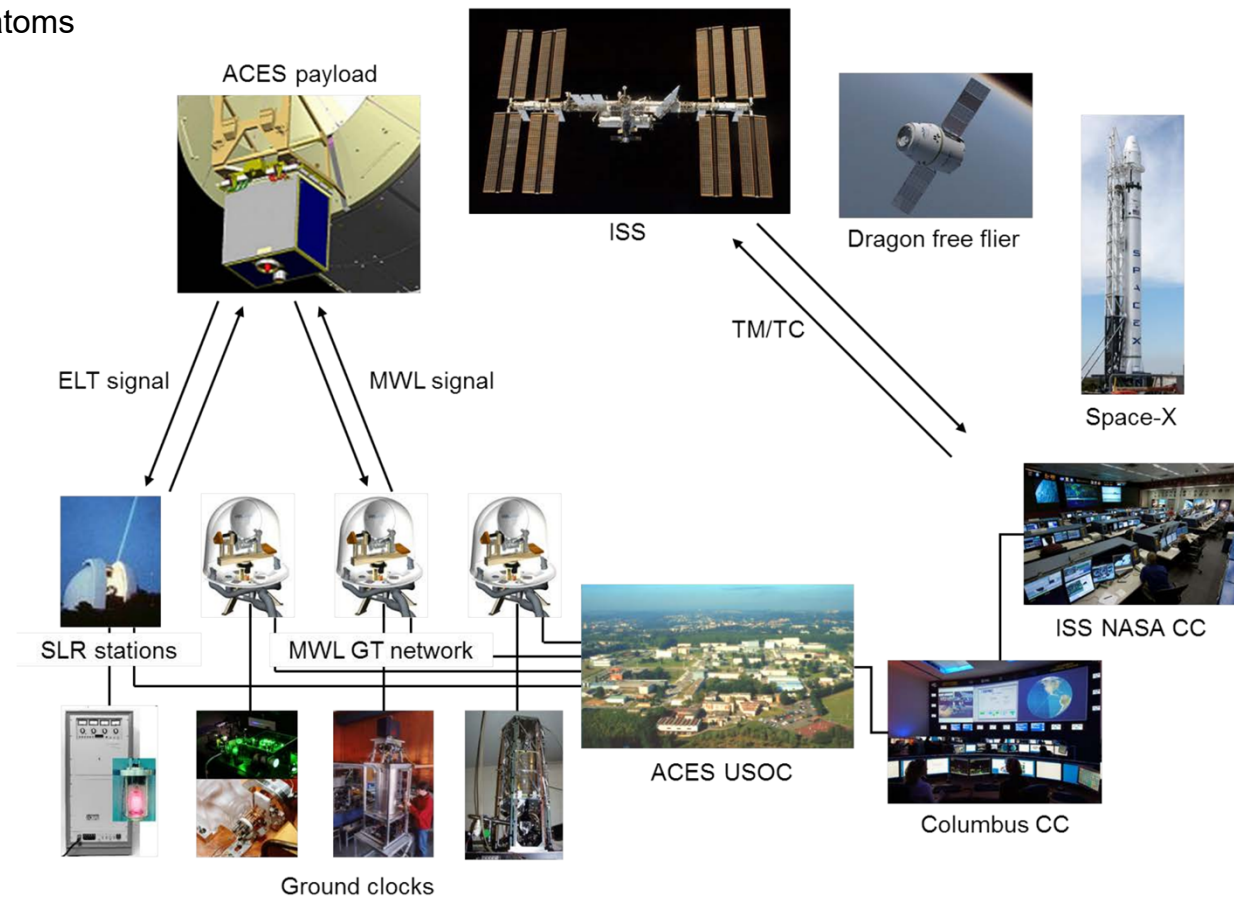


ACES Clock Payload:

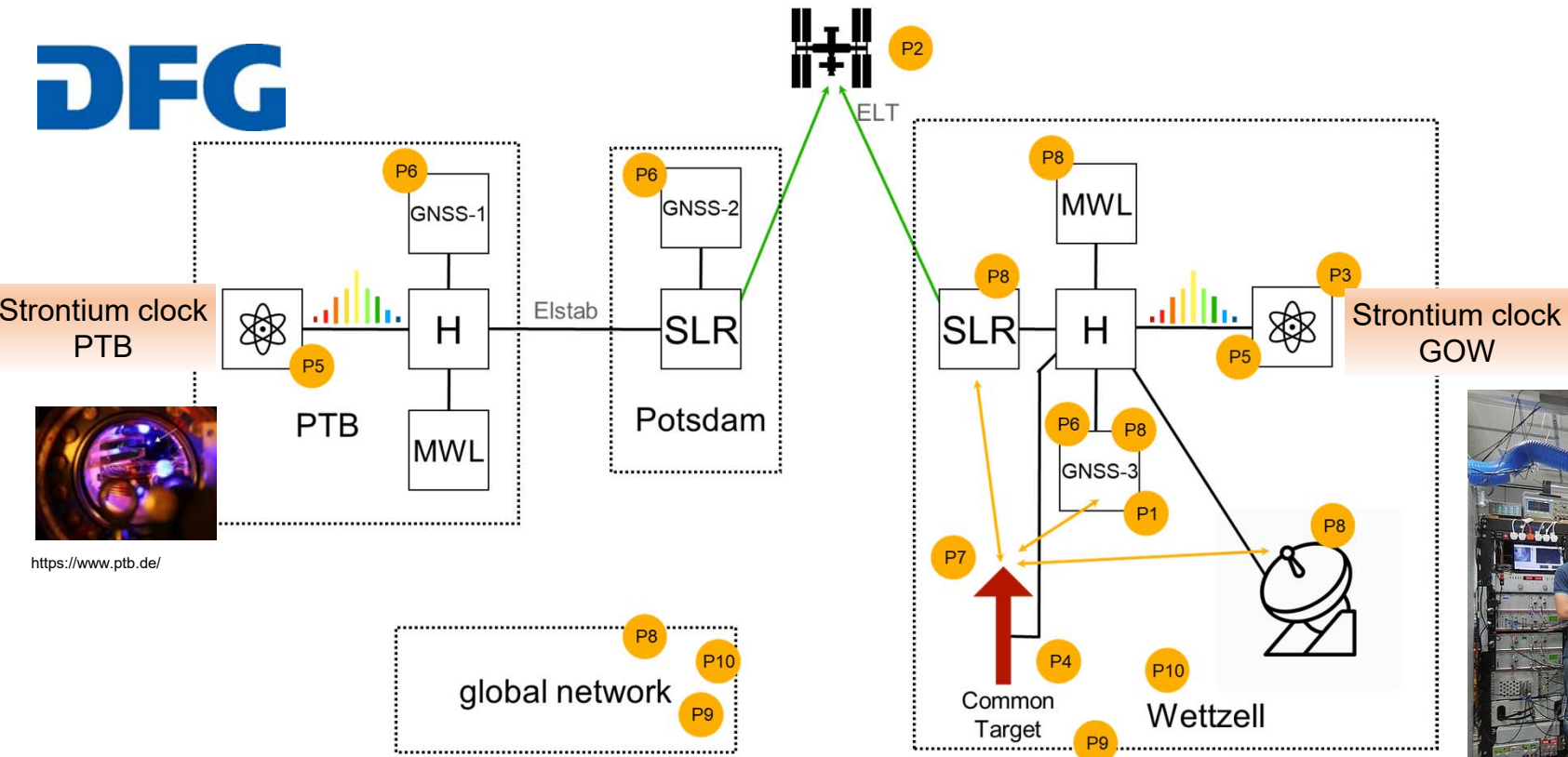
- PHARAO (CNES): Atomic clock based on laser cooled Cs atoms
- SHM (ESA): Active hydrogen maser

Mission Objectives:

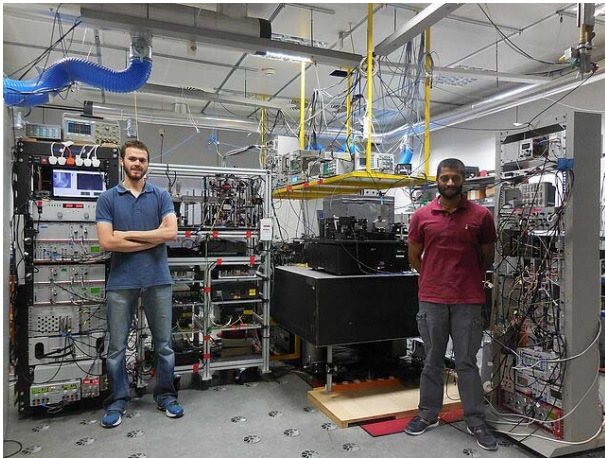
- Measurement of the gravitational redshift
- Search for time drifts of fundamental constants
- Search for violations of special relativity



Clock Metrology: A Novel Approach to TIME in Geodesy
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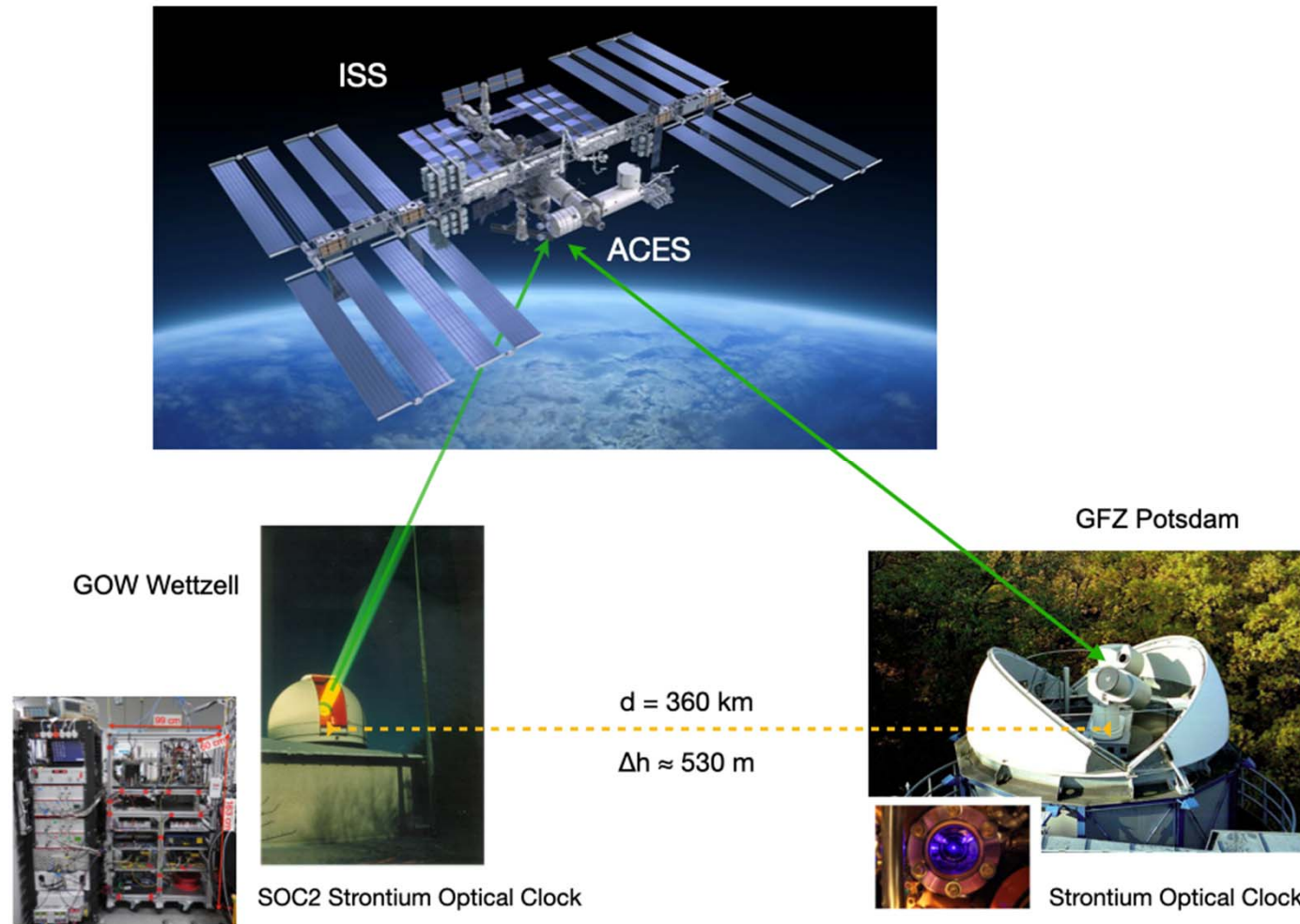
<https://www.ptb.de/>



Operation of optical clocks – P3 (HHU)

- We demonstrate the concept of clock ties (delay compensation)
- We introduce optical clocks to space geodesy
- We combine all space geodetic techniques on the observation level (proof of concept)
- We demonstrate physical height differences from optical time transfer (ACES)
- We provide the theoretical background for a relativistic geodesy

Clock Metrology: Leading experiment

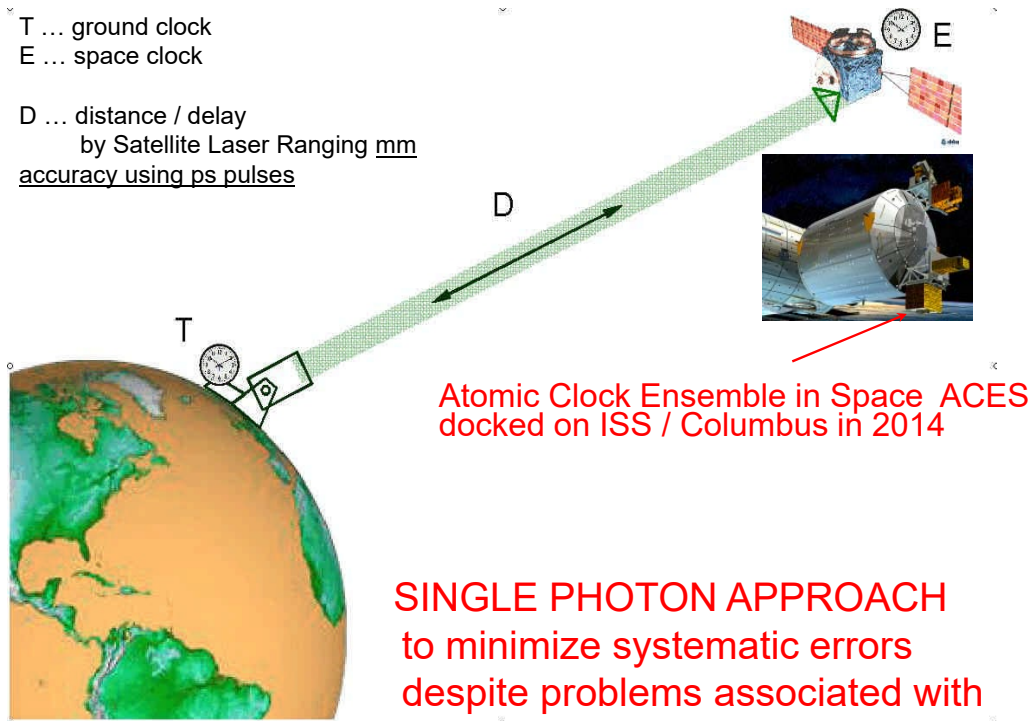


ELT principle and requirements



T ... ground clock
E ... space clock

D ... distance / delay
by Satellite Laser Ranging mm
accuracy using ps pulses



Requirements were defined in 2008

- Distances $\sim 400 \dots 500$ km
- Photon flux $\sim 10^{13}$ Ph /m²/ shot
- Timing resolution 25 ps rms
- **Timing stability ~ 1 ps/day**
- Absolute detection delay
- Operating temp. $-10 \dots +40$ °C
- 0.5 kg, 1 W max
- 3 years in space, no Sun protection
- **Robust, rugged, safe**

Clock Metrology: The objectives of optical time transfer

Time interval comparison GOW – PTB

→ difference of time intervals T_1 , T_2 measured locally by equal clocks → ΔU

Expected uncertainties (one comparison, $T = 2$ days):

ELT: $\sqrt{2} \times 3$ ps (common-view via ACES)

ELSTAB: ~ 1 ps

Strontium clock @ PTB: < 1 ps

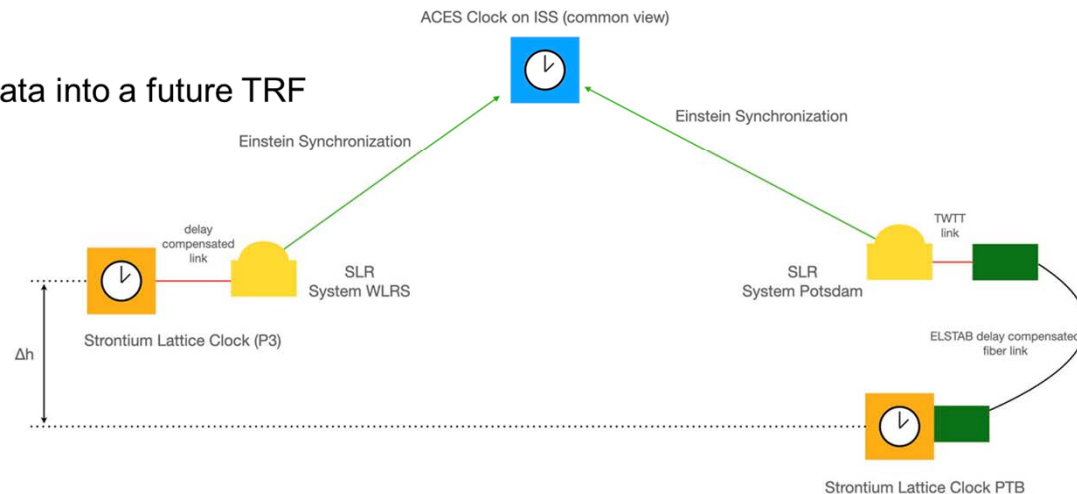
Strontium clock @ GOW: 2 ps

Total: ~ 5 ps

Goal (1st phase of FOR, 4 yrs.):

- (A) repeated determination of ΔU with uncertainty 0.3 m
(averaging → 0.2 m (limited by SOC2 clock);
→ time dependence detectable);
modeling of systematics

- (B) Integration of physical heights data into a future TRF



Clock Metrology: Preparation of ground stations for ELT tracking



- The requirements for participating stations are summarized in **Technical Note**
- Short laser pulses with a wavelength of 532 +/- 0.1 nm
- The ELT Data Center works closely with the Eurolas Data Center (EDC)

Involved Clocks:

- H-Maser / Cs / Opt. clocks

Ranging Data:

- Ranging data files: full-rate (fr2) and all laser-fire times (ff2)

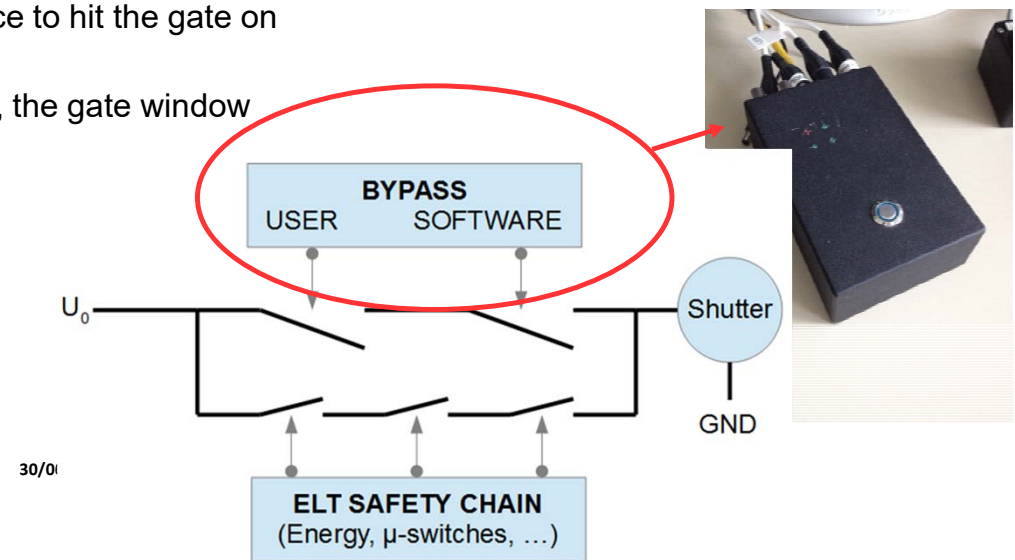
Prediction Data:

- Ranging prediction format (cpf) – prediction accuracy influences the chance to hit the gate on board ISS, Therefore predictions are updated every 90 minutes
- The background noise of the ELT detector is very high during the daytime, the gate window may not remain open for longer than 100 ns
- Additional header for transponder: offset and drift of the on-board clock

$$t_{UTC(k)} = t_{ACES} + (t_{ACES} - t_0) \cdot 10^{-15} \cdot drift + offset,$$

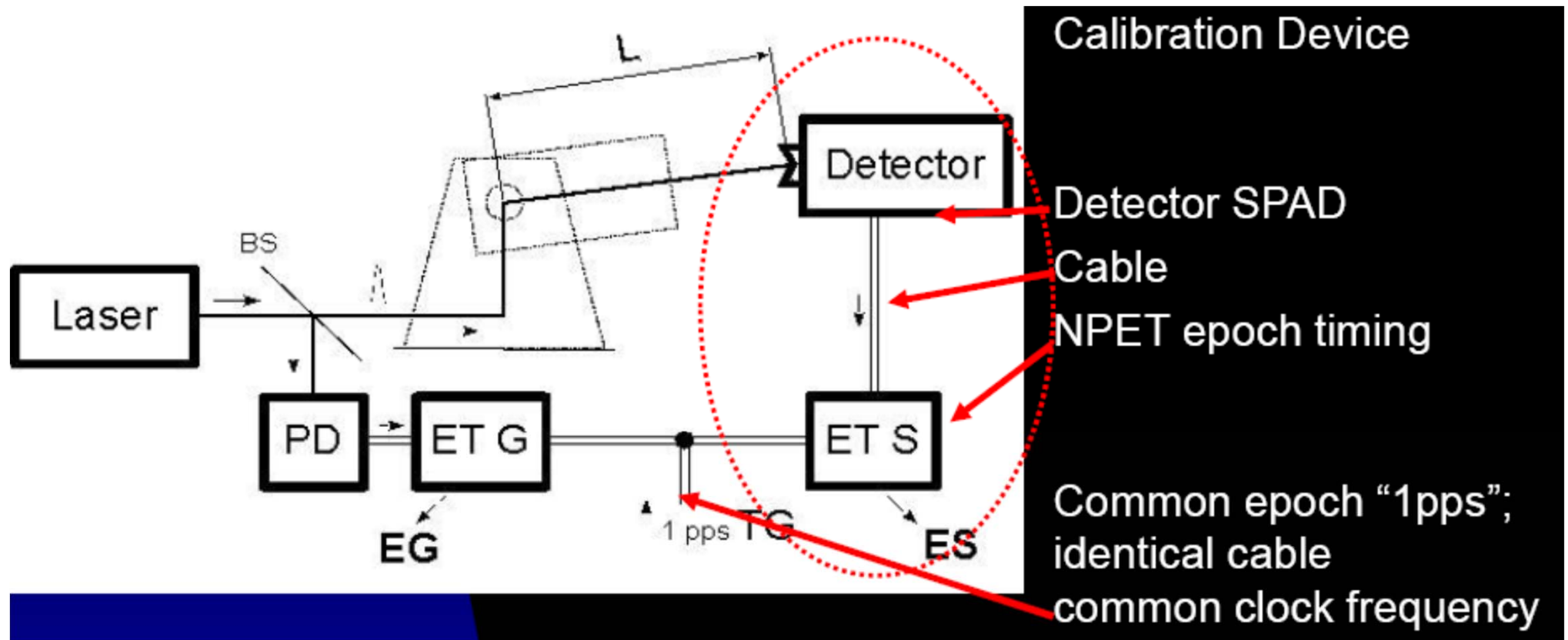
Laser Safety: ISS is manned object => restrictions for laser pulse energy

- go/nogo flag published by EDC - validity 5 minutes
- Stations which non eye safe operation
 - Safe switching between std. SLR- and ELT-mode



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Clock Metrology: ELT calibration

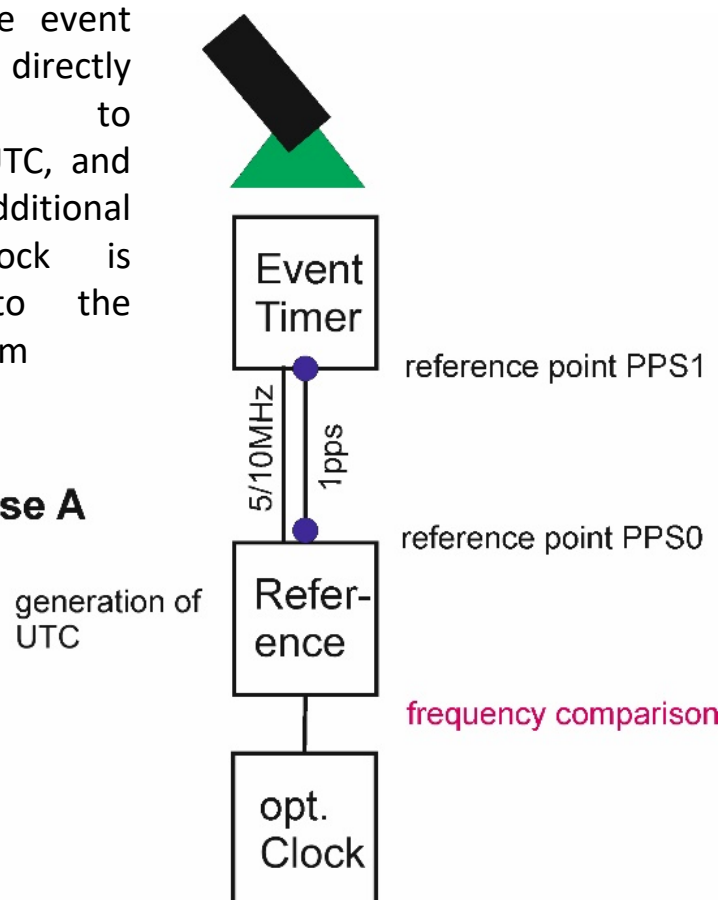


Clock Metrology: Clock Status Files



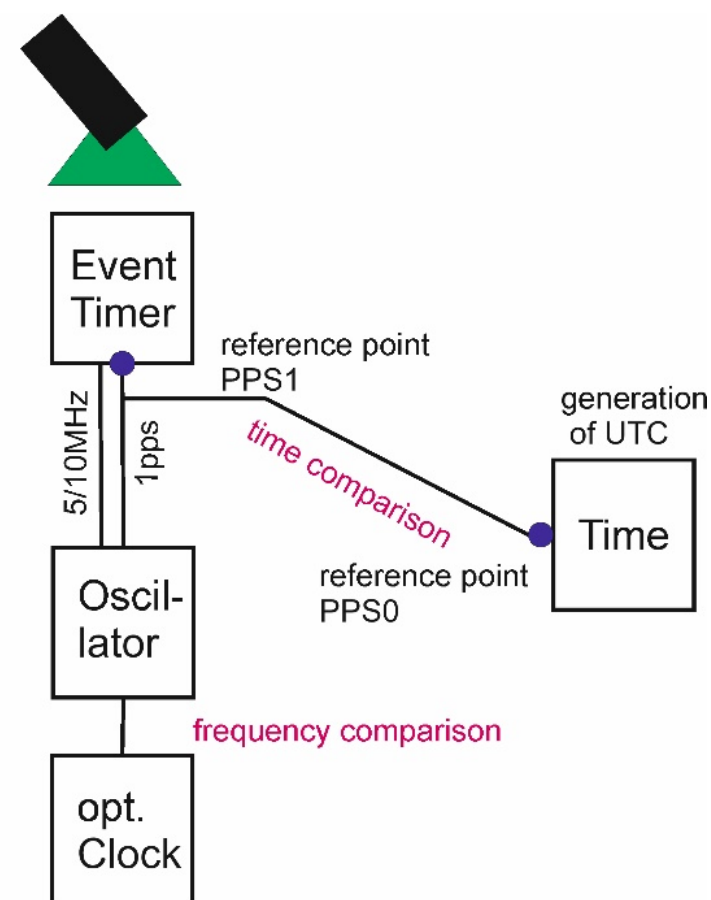
Case A: the event timer is directly connected to reference UTC, and an additional optical clock is placed into the timing system

Case A

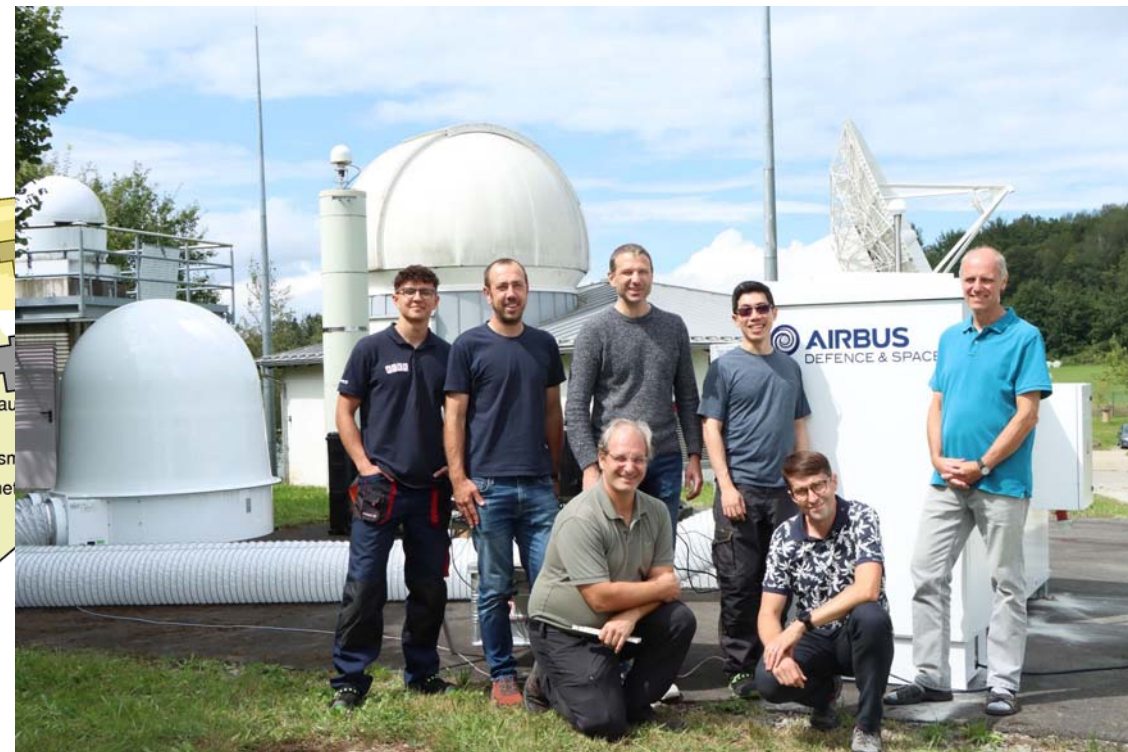
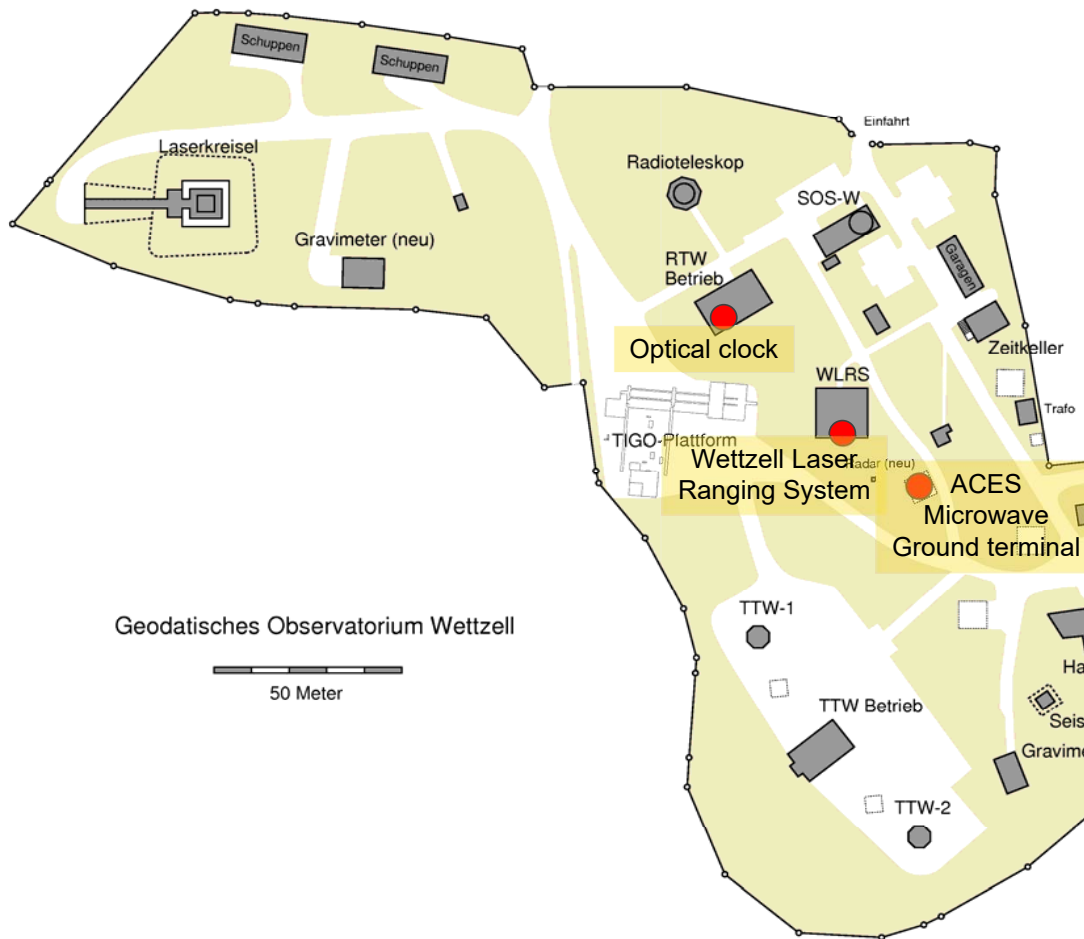


Case B: the event timer is connected to an oscillator not representing local UTC, and an additional optical clock is placed into the timing system

Case B



Clock Metrology: MWL terminal deployment





Thank you for your attention