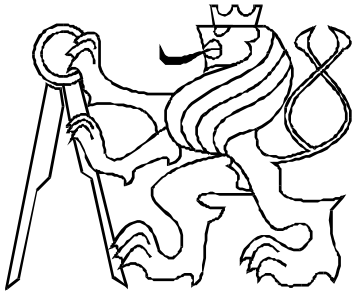


TECHNISCHE UNIVERSITÄT MÜNCHEN

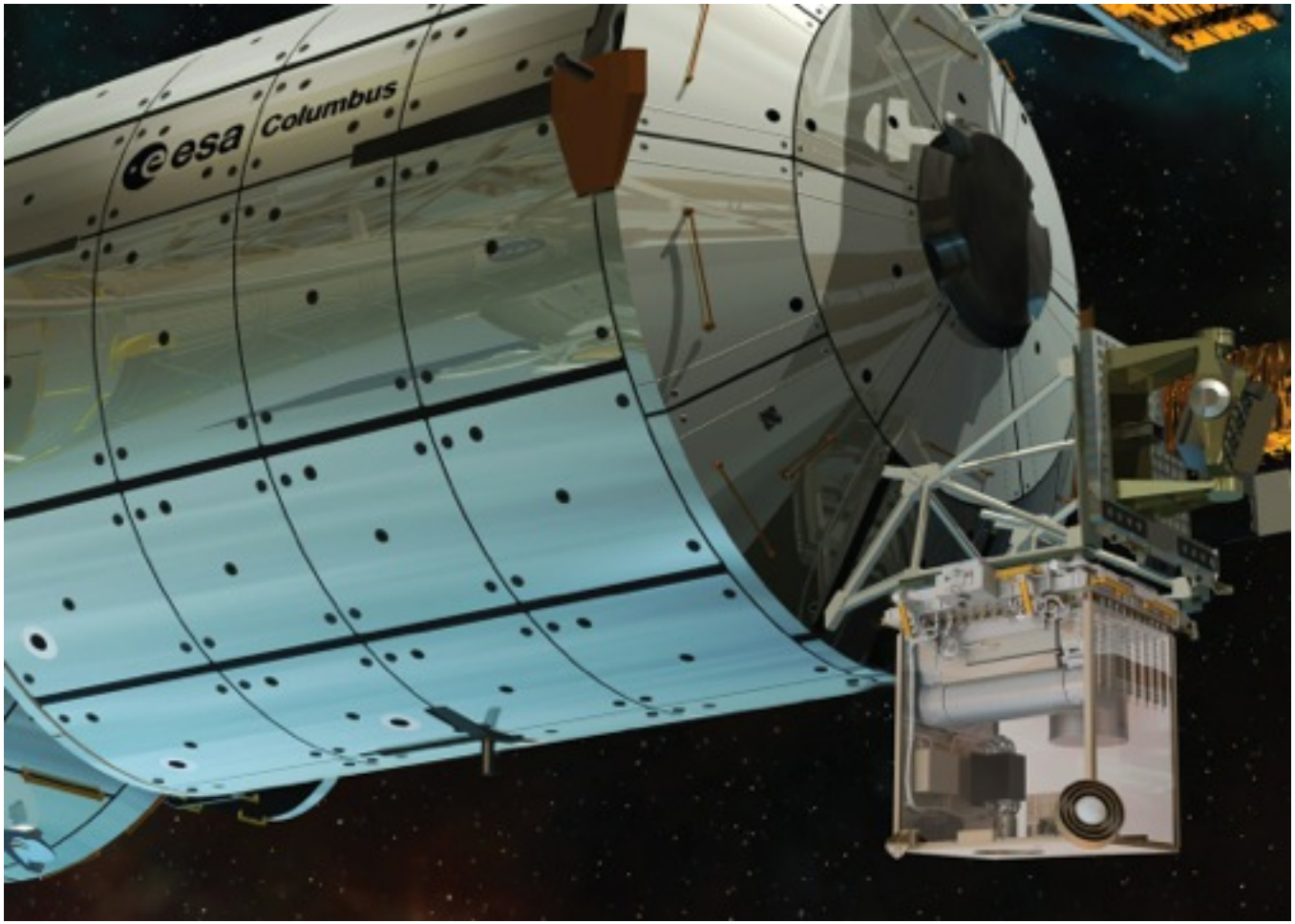
European Laser Timing (ELT)

Concept, Overview and Prospective

Atomic Clock Ensemble in Space (ACES) Payload

- (1,2,3) PHARAO (CNES): Atomic clock based on laser cooled Cs atoms
- (7) SHM (ESA): Active hydrogen maser
- (5,10) MWL (ESA): T&F transfer link
- (6) GNSS receiver (ESA)
- **(12) ELT (ESA): optical link**
- (4) XPLC: External PL computer
- (8) Mechanical, thermal subsystems
- (11) CEPA: Columbus External PL Adapter (ESA-NASA)

Atomic Clock Ensemble in Space (ACES) Payload



Operational Scenario

- Mission duration: 1.5 years to 3 years
- ISS orbit parameters:
  - Altitude: ~ 400 km
  - Inclination: ~ 51.6°
  - Period: 90 min
- Clock comparison
  - Time and Frequency transfer links
  - Microwave: MWL
  - Optical: ELT

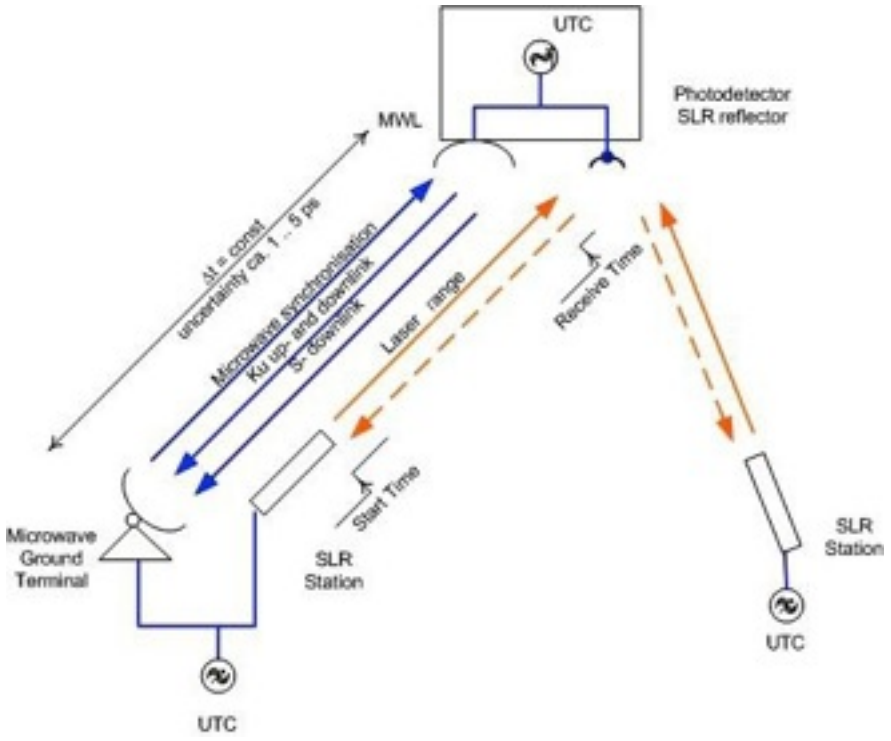
Basis of Ground Network Selection

- Clock performance
  - Ground clocks with stability and accuracy at the same level or better than the ACES clock signal
- Clock type
  - Microwave clocks (H-masers, atomic fountain clocks, etc.), optical clocks
  - As a minimum, 4 ground clocks (+1 redundancy) based on different atoms or atomic transitions (fountain clocks and optical clocks) connected to MWL
- Geographical distribution
  - At least two ground stations reasonably close (~1000 km baseline) to allow for CV comparisons (applicable to both MWL and ELT)
  - At least two ground stations separated by intercontinental distances for non CV comparisons (applicable to both MWL and ELT)
  - At least 1 station in the Southern hemisphere to contribute to LI tests

Applications

- Test Einstein’s general relativity and alternative theories of gravitation;
- Demonstrate a new type of 'relativistic geodesy' resolving differences in the Earth gravitational potential at the level of tens of centimeters;
- Contribute to the improvement of the global navigation satellite systems and their future evolutions;
- Contribute to the monitoring of the Earth atmosphere through radio-occultation experiments;
- Perform space-to-ground and ground-to-ground comparisons of best available atomic frequency standards.

ACES Microwave Link



- Two-way
- Additional down-link in the S-band:
  - Determination of the ionosphere TEC– Correction of the ionosphere time delay
- 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/son the S-band down-link to obtain clock comparison results in real time
- Up to 4 simultaneous space-to-ground clock

ELT Objectives

- Clock Comparisons and Time Transfer
  - Space-to-ground comparisons of clocks reaching a TDEV of 4 ps between 300 s and 10^4s of integration time, better than 7 ps on the long-term
  - CV comparisons below 6 ps per ISS pass
  - Non-CV comparisons below 6 ps after 2000 s of dead time
  - Space-to-ground and ground-to-ground synchronization of clocks
- Laser Ranging
  - Laser ranging performance at the centimetre level per single shot (50 ps one-way)
  - Comparison of ranging techniques: one-way optical ranging, two-way optical ranging, microwave ranging
  - Analysis of atmosphere propagation delays

WHY Single photon in metrology ?

- Quantum nature of light => two states detected 0 / 1
- NO analog signal processing => NO systematic errors
- Extremely weak signals => High dynamical range
- Measurement by-products
  - optical signal intensity
  - signal shape
  - measurement precision ~ N-1/2

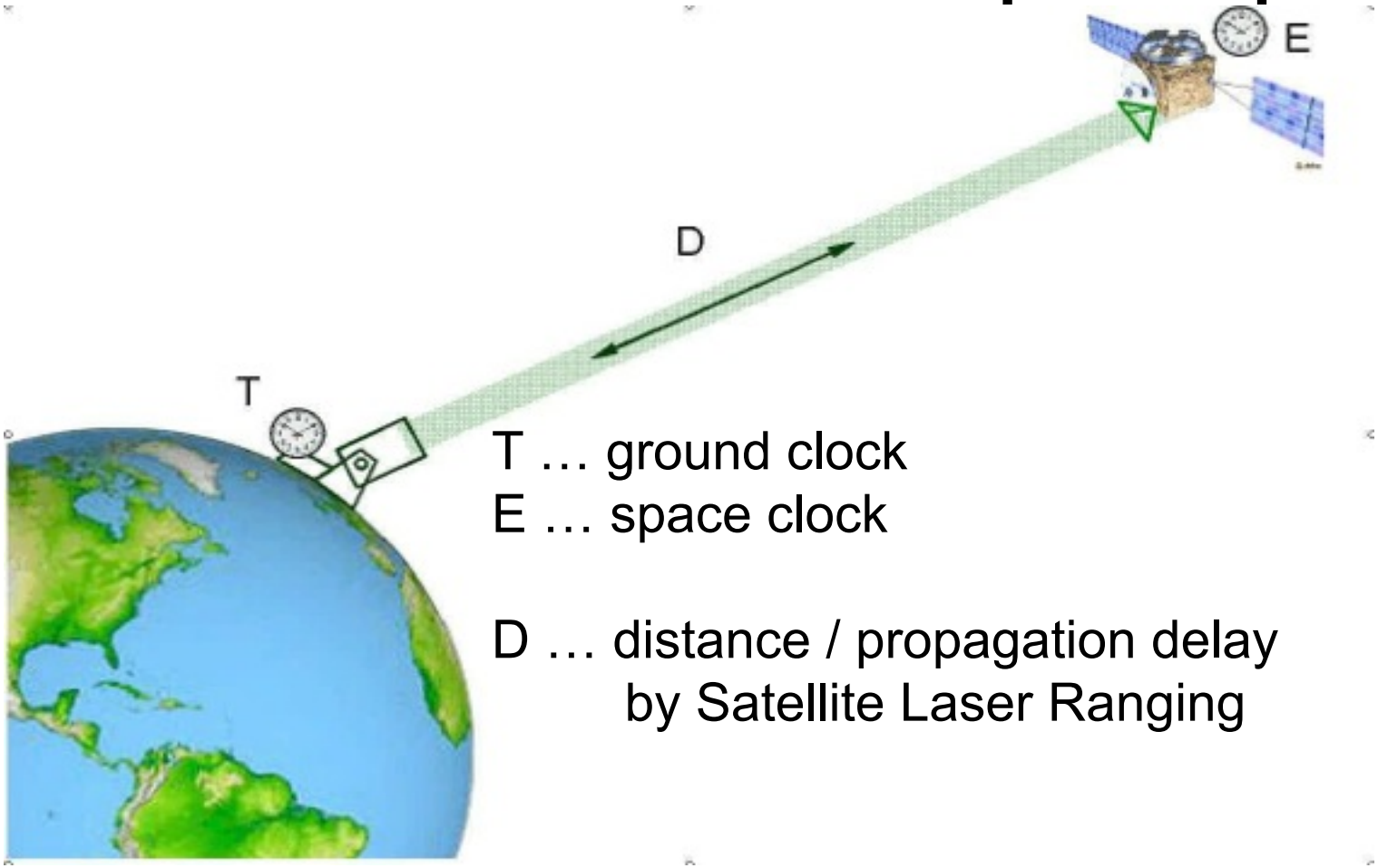
  => sub-ps precision, ps accuracy and ps stability
- Space qualified devices existing – see next …

Comparison ELT vs. T2L2

- Altitude 400 km km, i = 51.6°, P = 5400s
- Single pass: ~120s
- Time interval between pass ~1.5h
- Detector type – SPAD in single photon mode
- Event timer provided by TimeTech
- Frequency source ACES
  - $3 \cdot 10^{-15}$ at 300 s (ISS pass)
  - $3 \cdot 10^{-16}$ at 1 day
  - $1 \cdot 10^{-16}$ at 10 day

- Altitude 1336 km, i = 66°, P = 6800s
- Max distance in a common view mode : 6500 km
- Single pass: ~1000s
- Time interval between pass 2h < T < 14h
- Detector type – SPAD with laser energy measurement for time walk compensation
- Timing system – CNES
- Frequency source DORIS (USO) oscillator

Laser Time Transfer principle



T … ground clock
E … space clock

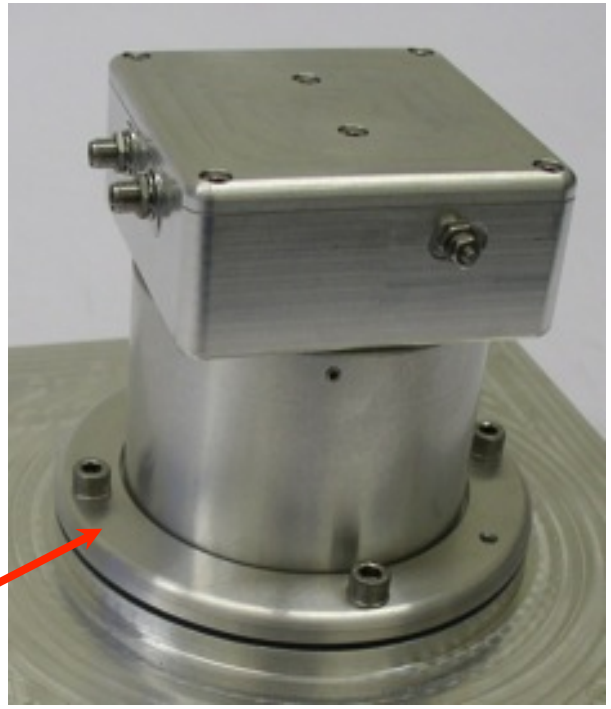
D … distance / propagation delay
by Satellite Laser Ranging

OPERATIONAL — on Compass LTT, T2L2 & Glonass-M

NEW CHALLENGE — to determine the **systematic** contributors on ~ 10 ps level

Conclusion of the ELT Design

- The detector package for the ESA ELT space mission has been designed, built and tested
- Detector parameters:
  - jitter 22 ps rms
  - dark count rate 200 kHz @ +25 C
  - delay drift +0.6 ps / K
  - delay stability Tdev ~ 400 fs / day
  - detection delay absolute measured +/-12 ps
- Radiation resistant, space qualified, safe for ISS



Detector package Engineering Model