Clock Metrology:

A Novel Approach to TIME in Geodesy

Overview over the Research Unit FOR 5456/1

Speaker: **Ulrich Schreiber** (TUM)
Co-Speakers: **Manuela Seitz** (DGFI-TUM), **Stephan Schiller** (HHU)

The Members of the Research Unit

Anja Schlicht

Claus Lämmerzahl

Christian Lisdat

Urs Hugentobler

Susanne Glaser

Alex Neidhardt

Ulrich Schreiber

Mathis Bloßfeld

Jürgen Müller

Manuela Seitz

Harald Schuh

Thomas Pany

Eva Hackmann

Jan Kodet

Clovis Maia

Florian Seitz

Stephan Schiller

Thomas Klügel

Johann Eckl

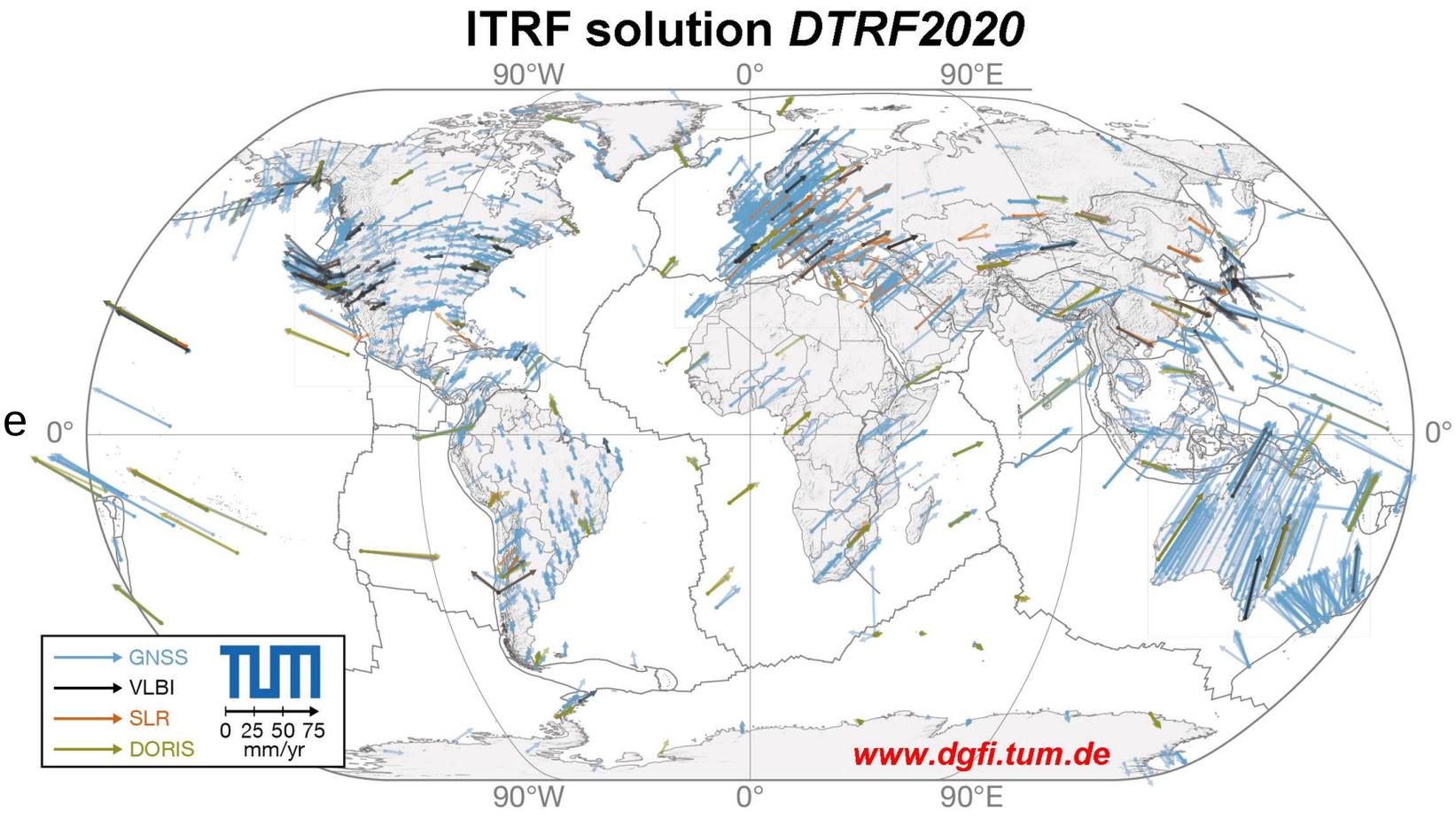
Kyriakos Balidakis

Mathias Palm

Benjamin Männel

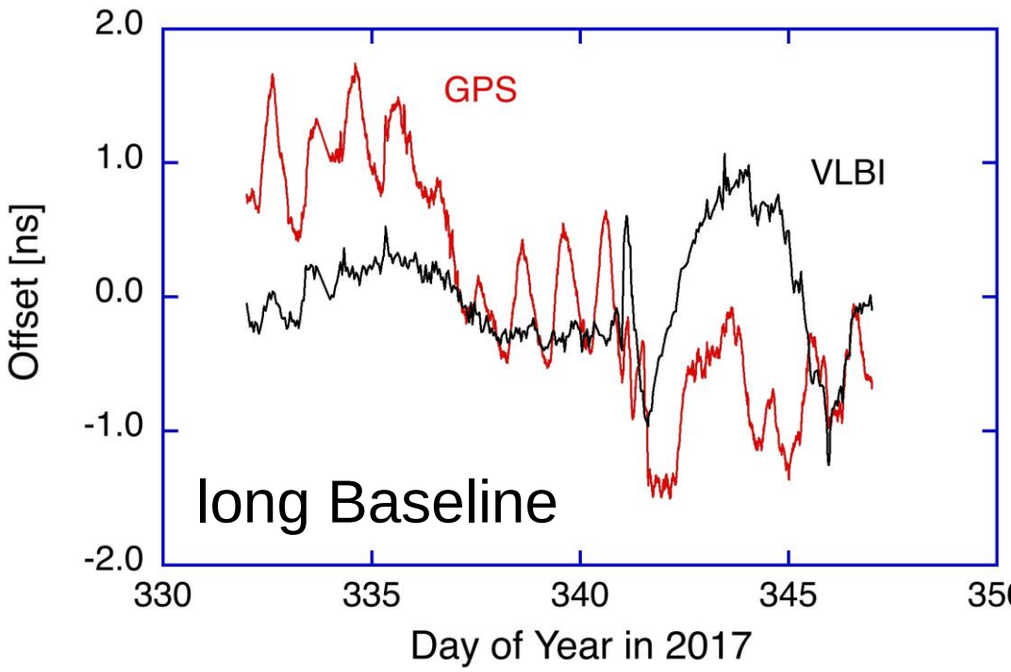
The Terrestrial Reference Frame

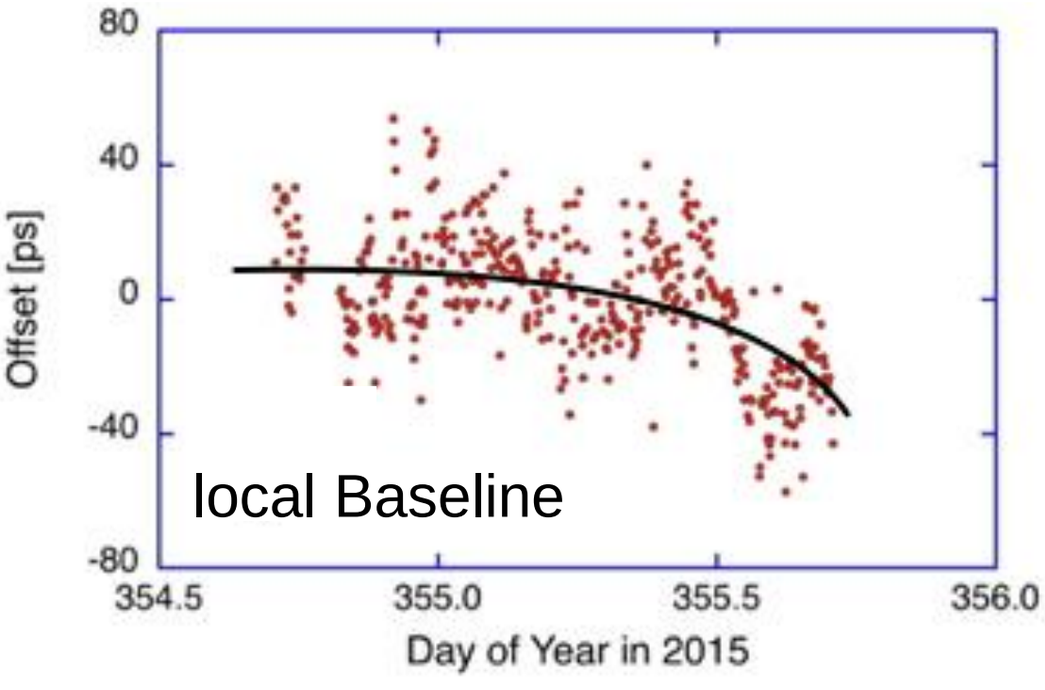
- The terrestrial reference frame (TRF) is the physical realization of a terrestrial reference system (TRS)
- The quantification of global change and applications of positioning and navigation are based on the TRF
- Only the combination of the 4 techniques of space geodesy provides all parameters
- Ties are provided by the local geodetic surveys
- Systematic errors are limiting the achieved accuracy to about a factor of 5 above the desired GGOS value of 1 mm (position) and 0.1 mm/year (velocity)



We illustrate this fact by an example on the next slide!

Clock Comparison by two Techniques





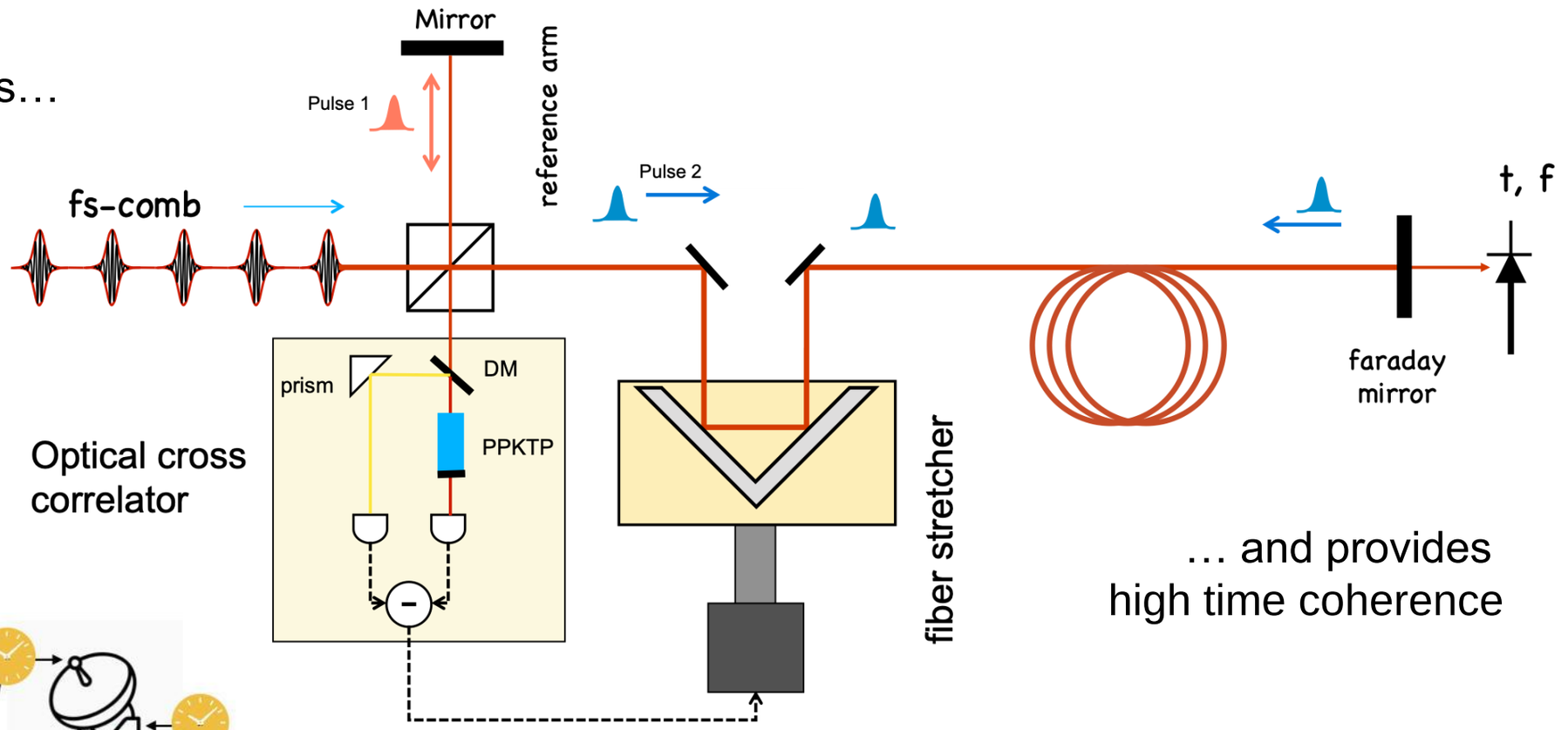
- During the CONT17 campaign we compare the masers of **Matera** and **Wettzell**
- Clock absorbs delays
- Systematic errors contaminate the clock offsets
- This means coordinates are also contaminated

Closed-loop delay compensation is a promising approach

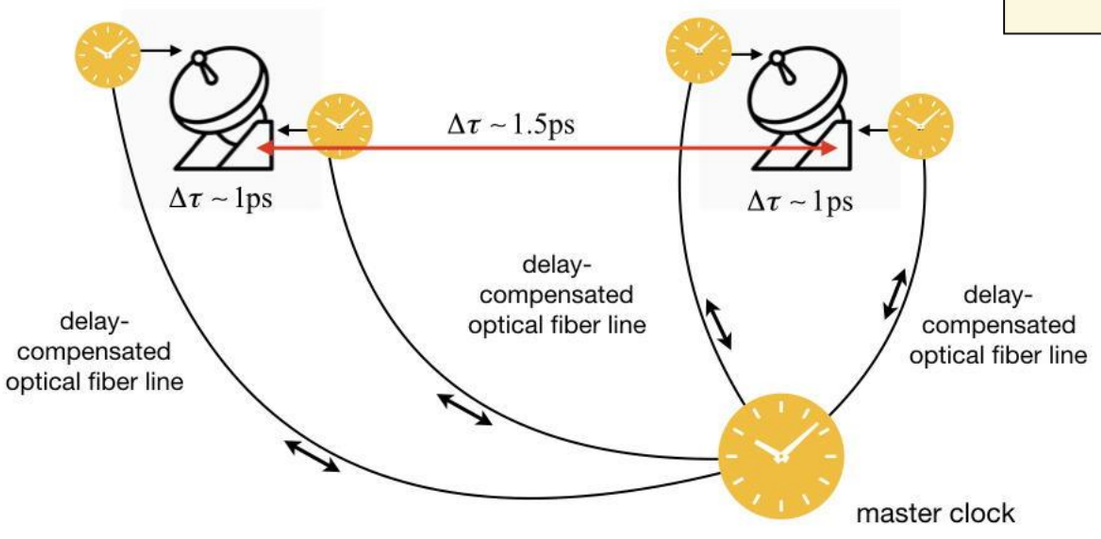
- R-Session Wettzell: Common clock, fixed baseline
- Non-normal noise distribution + drift of delay
- Requirement: Variable “electronic” delays have to be captured

Closed - Loop Delay Compensation

mode-locked laser have
excellent low noise properties…



… and provides
high time coherence



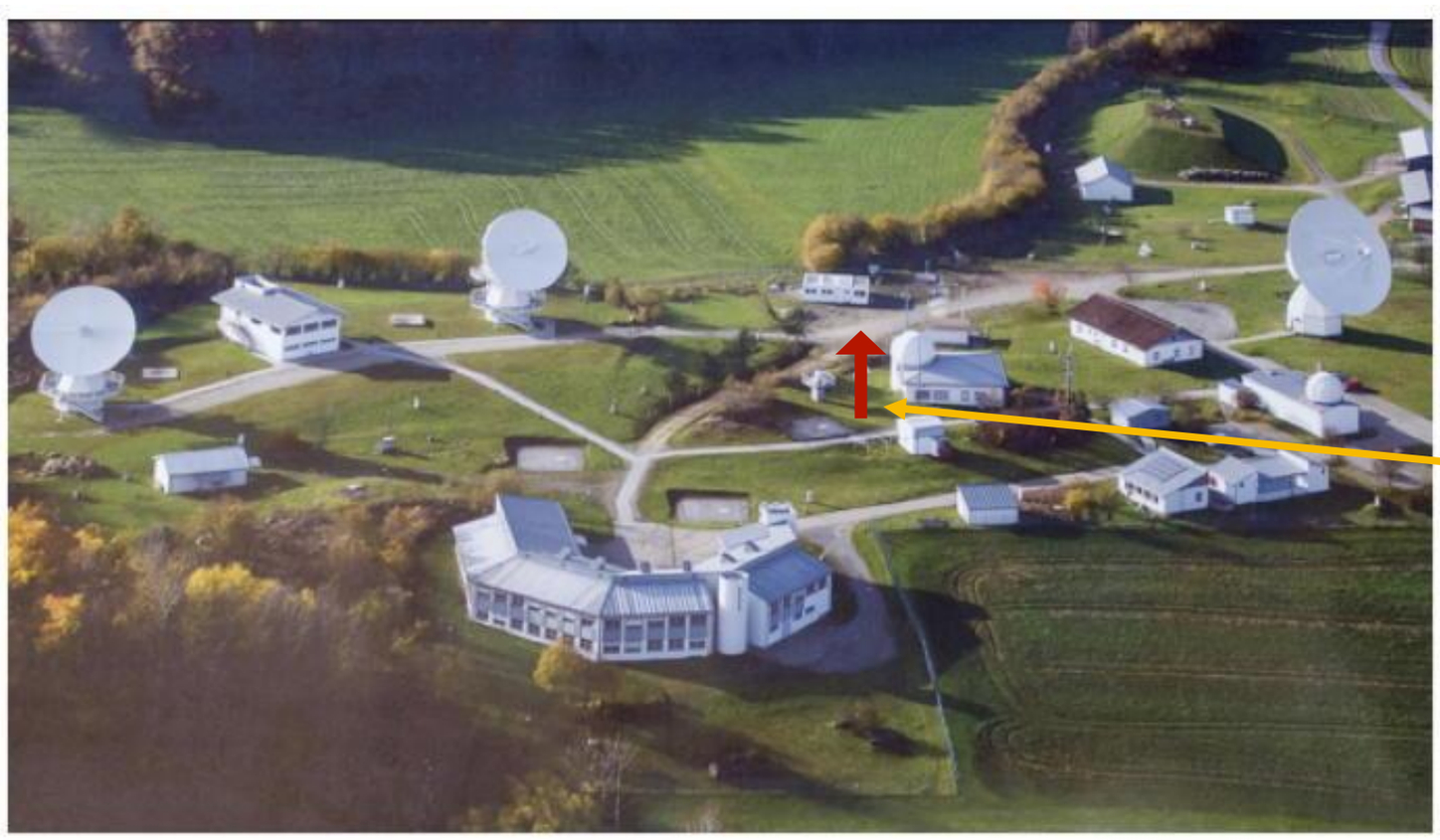
This allows us to utilize exact phase comparisons for the delay compensation

Phase stability is vital for closure measurements

The Geodetic Observatory Wettzell - a Testbed

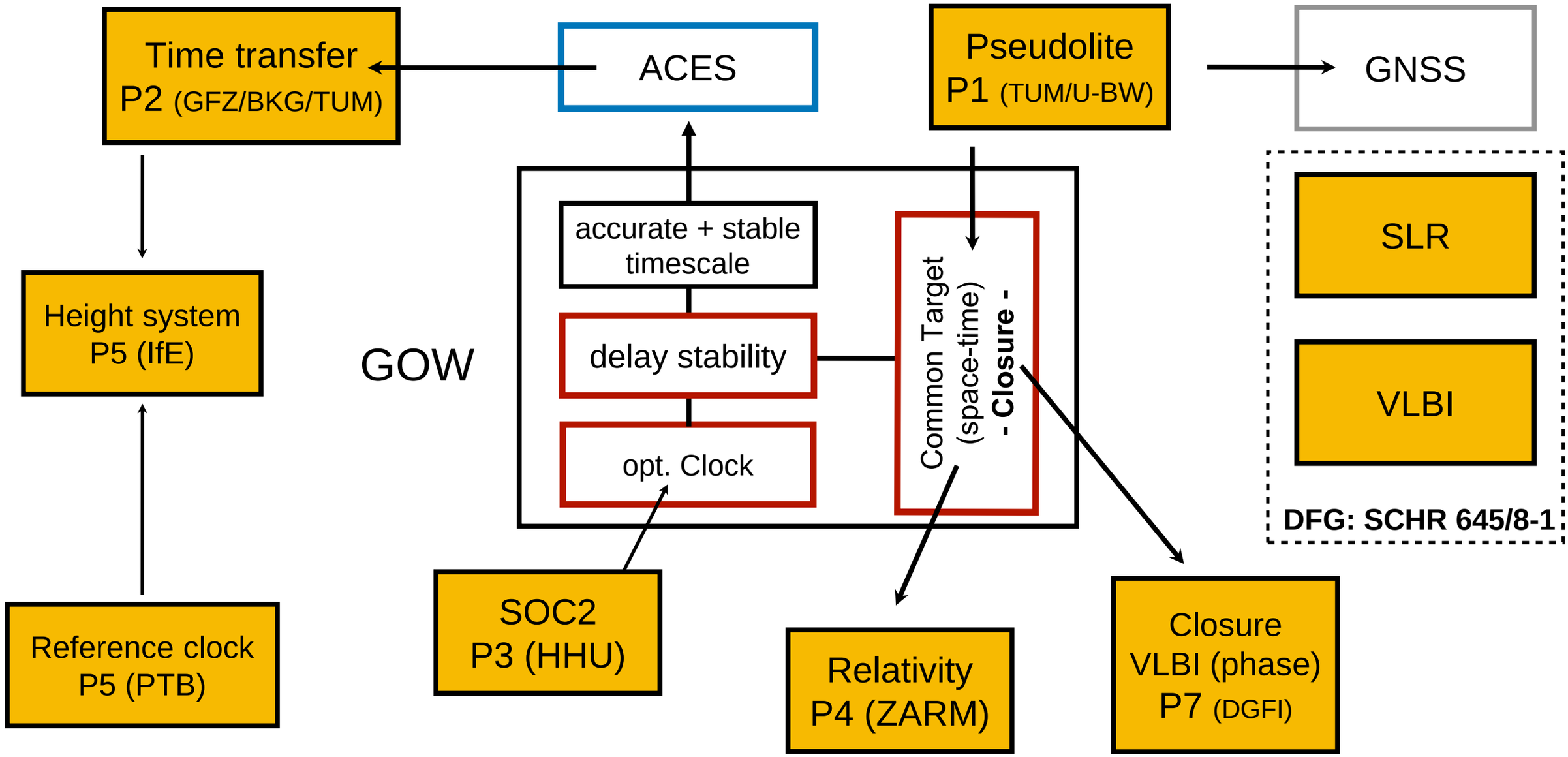
In this research unit…

- 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



Common target (early version)

The Research Unit (Local Component)



Local demonstration that we can provide “clock ties” to the measurement techniques of space geodesy

The Research Unit (Global Component)

Closure on common target
(VLBI phase observation)

P7 (DGFI)

A better handle on
“Time” in GNSS

P6 (GFZ/TUM)

accurate clock

stable clock

clock ties

delay compensation

closure technique

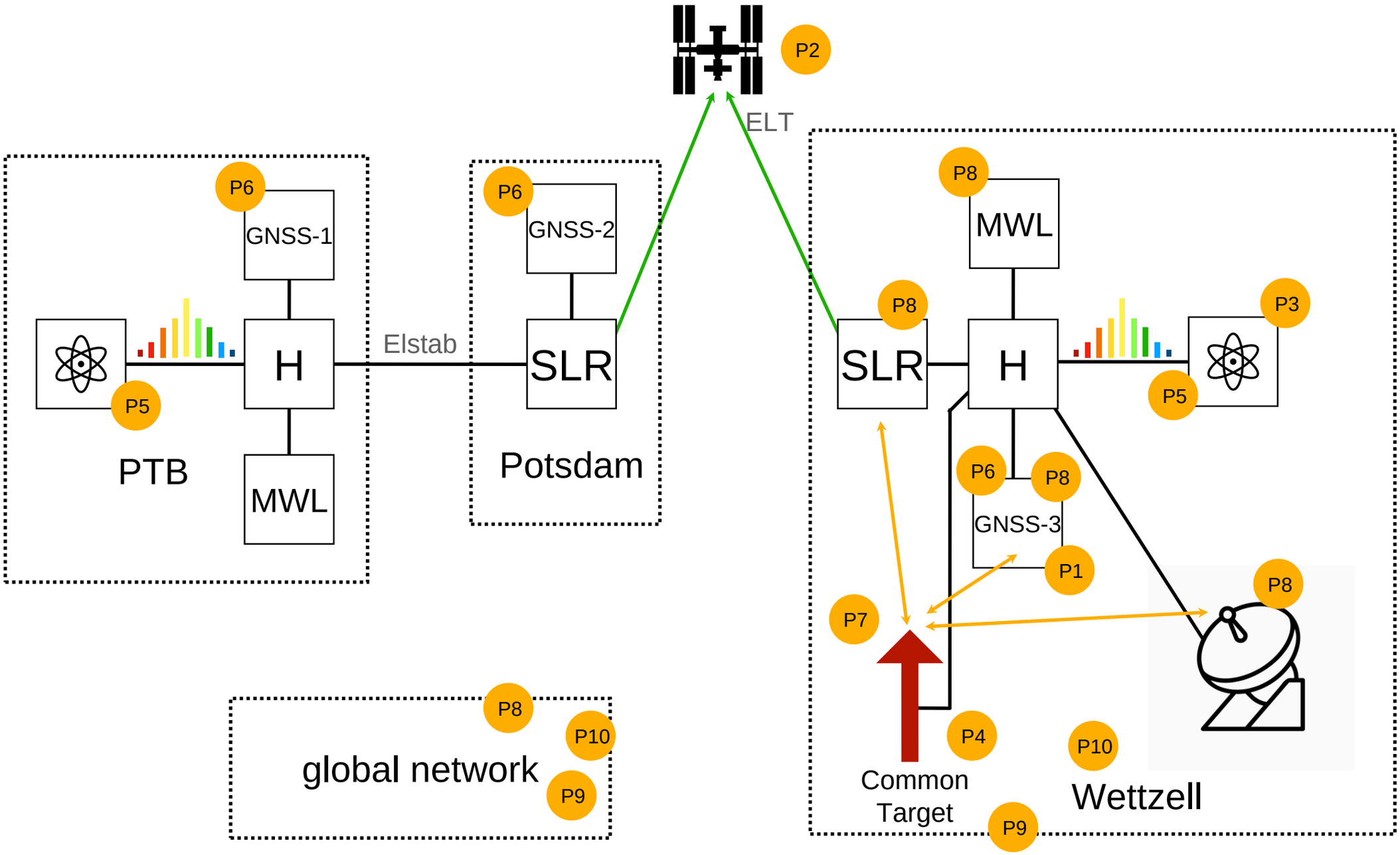
A tighter grip on
atmosphere

P8 (DGFI/IUP)

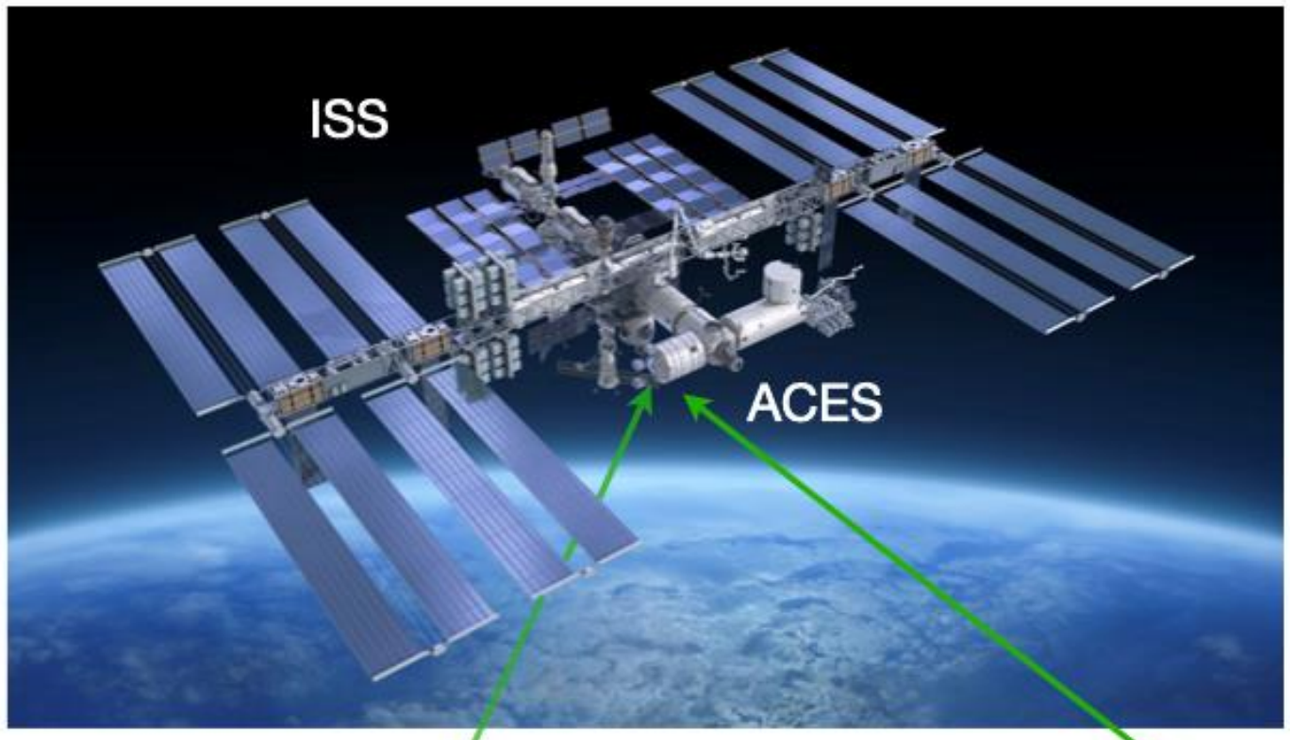
Consistent
inter-technique
combination
P9 (DGFI, GFZ)

Constraints from
clock ties
P10 (TUB/GFZ)

Condensed Summary: All Projects



P2: Example



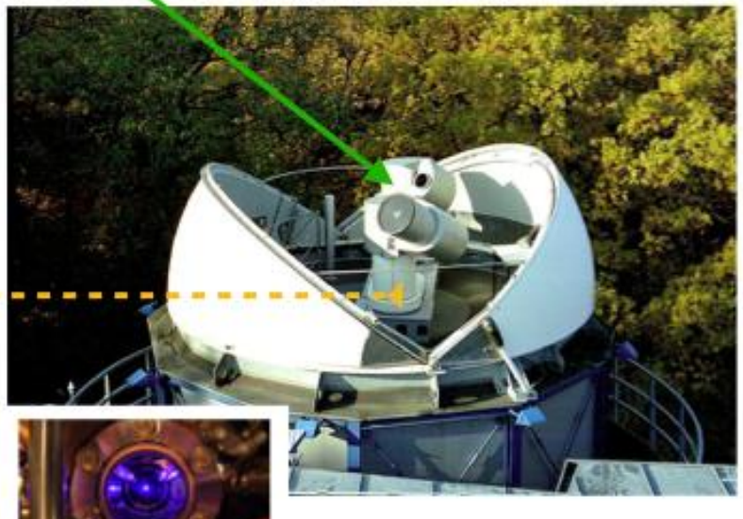
GOW Wettzell

SOC2 Strontium Optical Clock

d = 360 km

Δh ≈ 530 m

GFZ Potsdam



Strontium Optical Clock

The full experiment (P2, P3, P5)

Time interval comparison GOW – PTB
→ difference of time intervals T_1 , T_2 measured locally by equal clocks → Δ U

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

ELT: √2×3 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