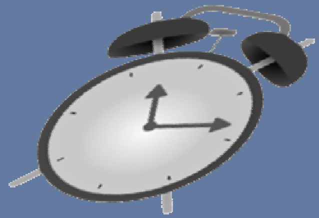


MULTI-GNSS TIME TRANSFER

Pascale Defraigne

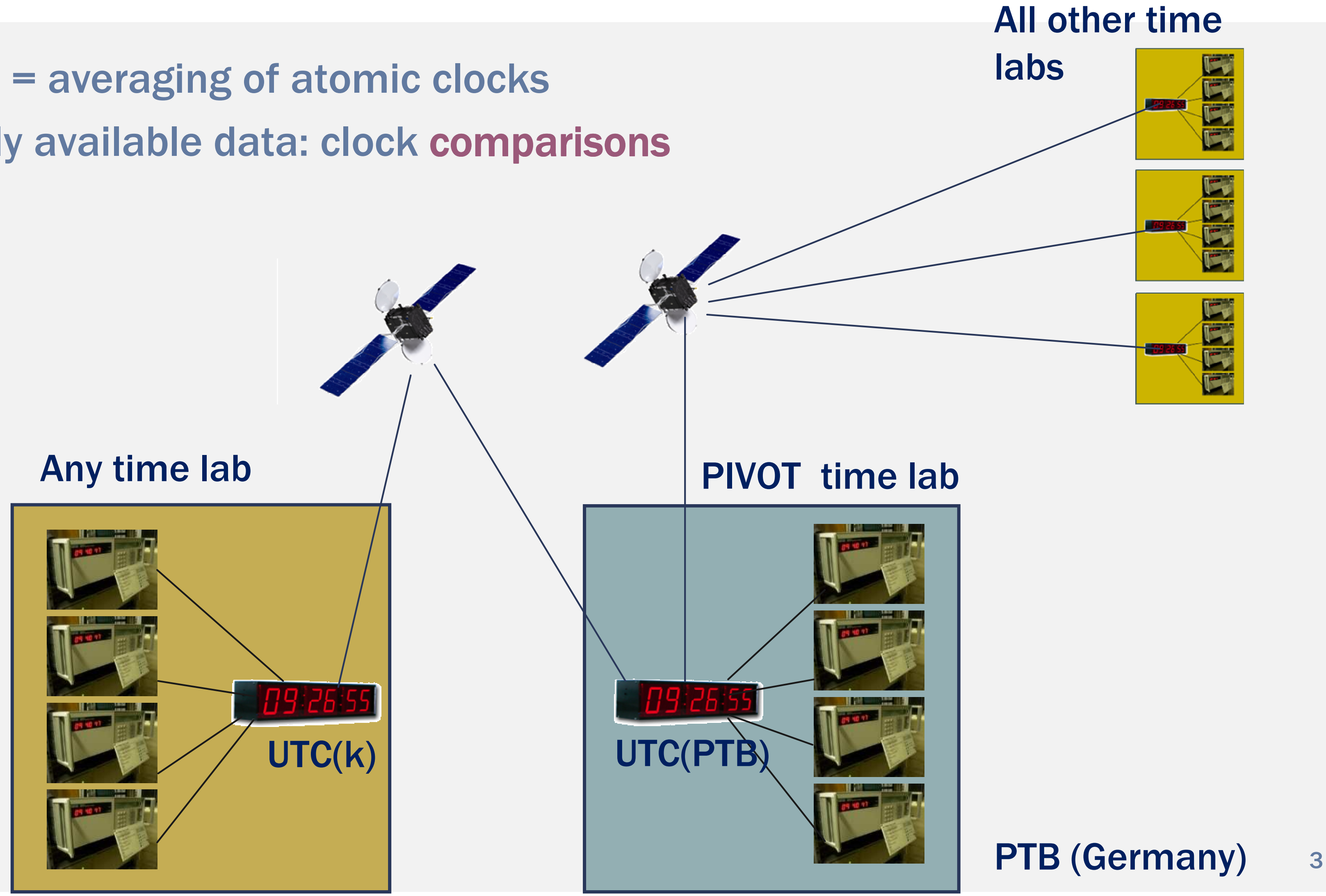
Royal Observatory of Belgium

OUTLINE

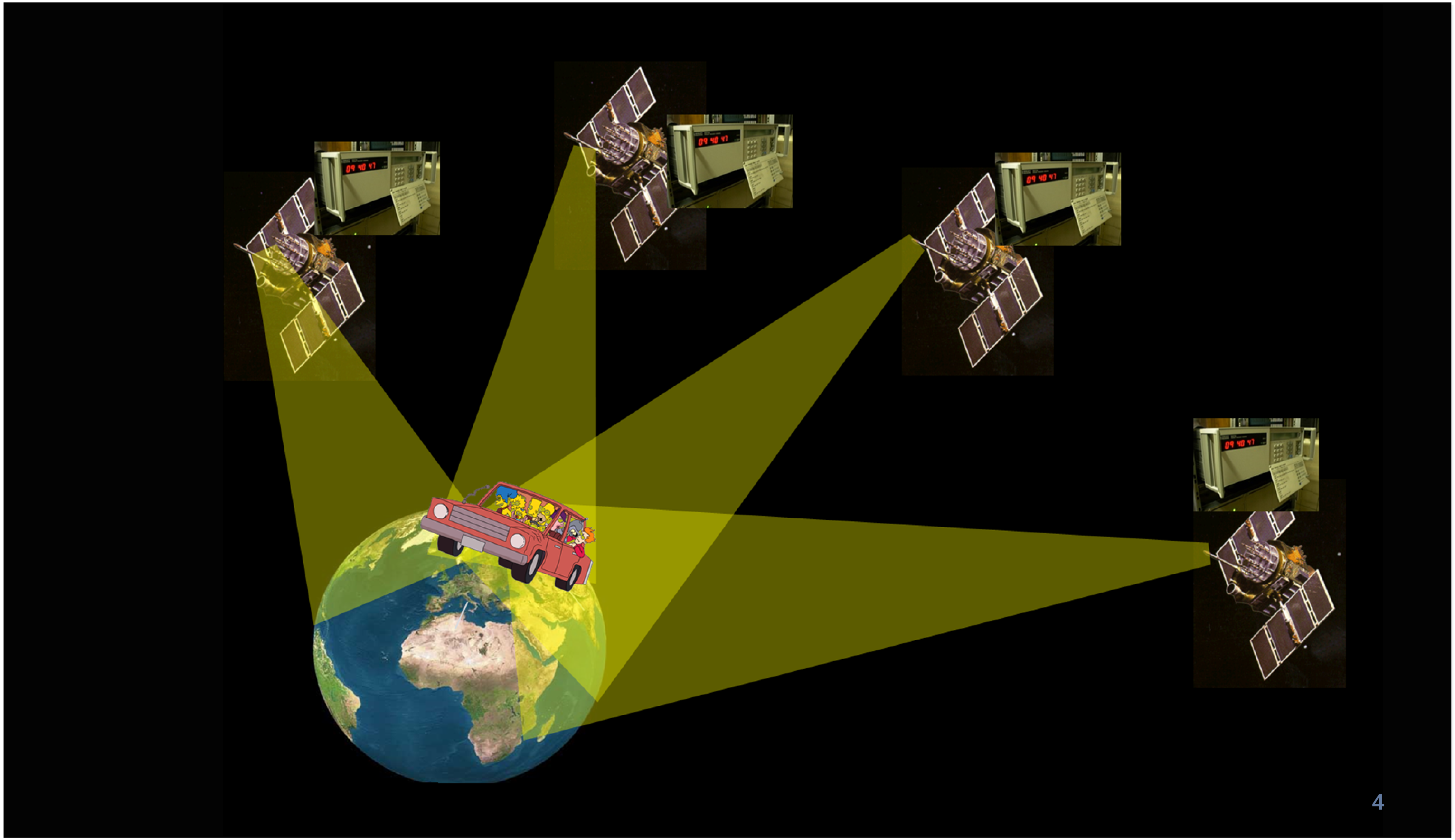
- Introduction
- GNSS Time Transfer
  - Concept
  - Instrumental aspect
  - Multi-GNSS
  - Requirements
  - GPS-GLONASS experiment
  - Galileo, Beidou: where we are
- Conclusion

INTRODUCTION

- TAI = averaging of atomic clocks
- Only available data: clock **comparisons**

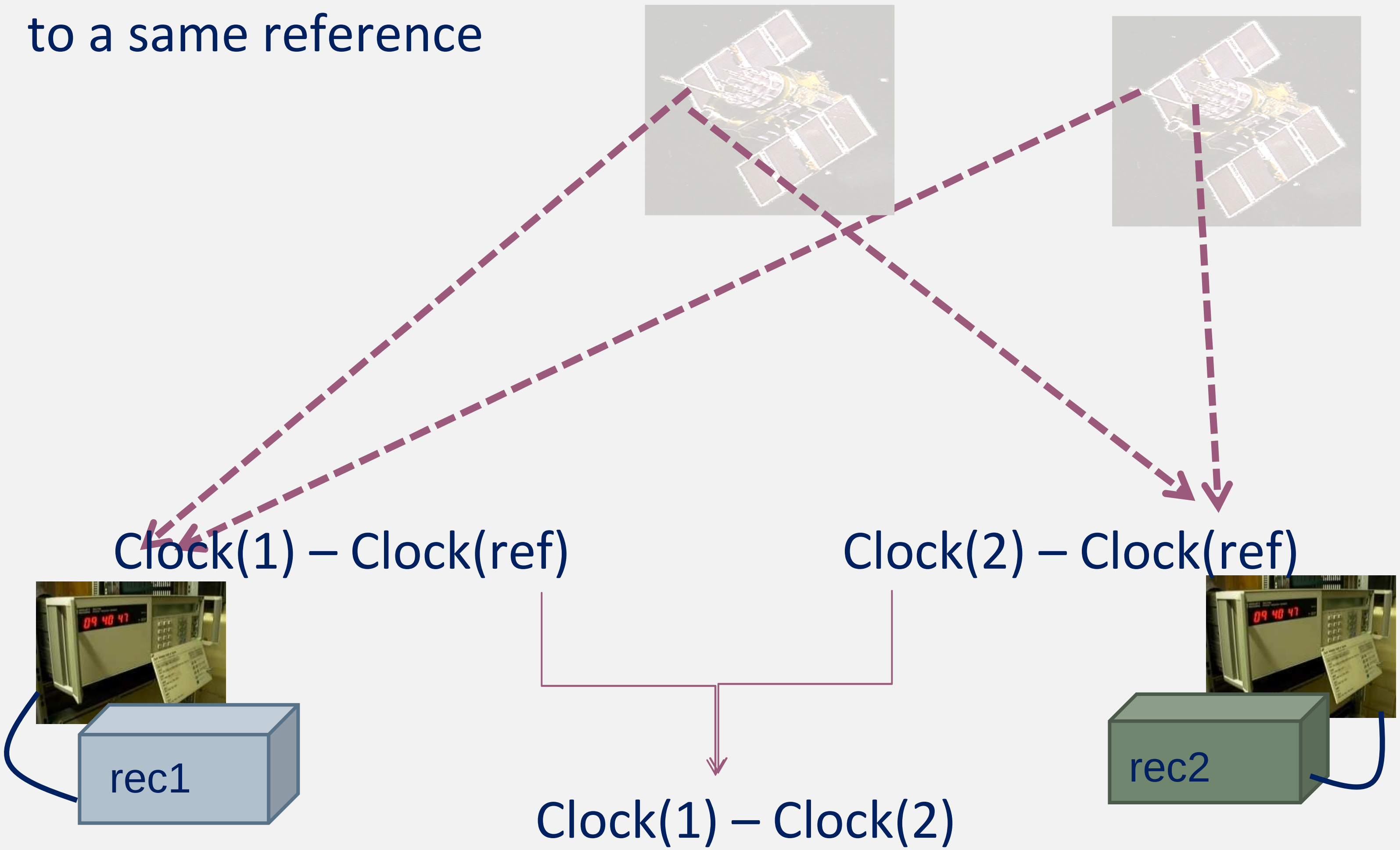


GNSS TIME TRANSFER

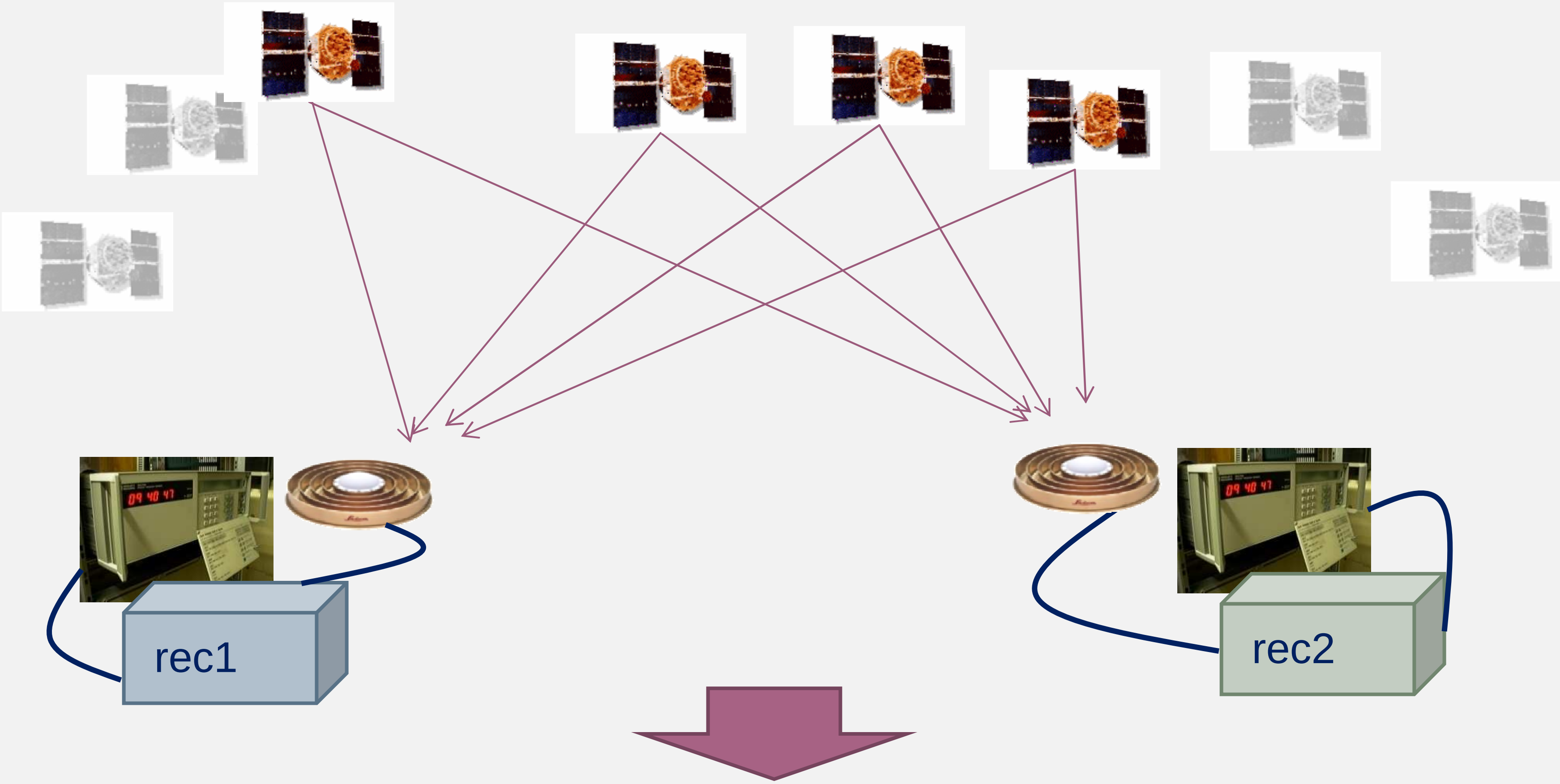


CONCEPT OF GNSS TIME TRANSFER

Compare two remote clocks
to a same reference



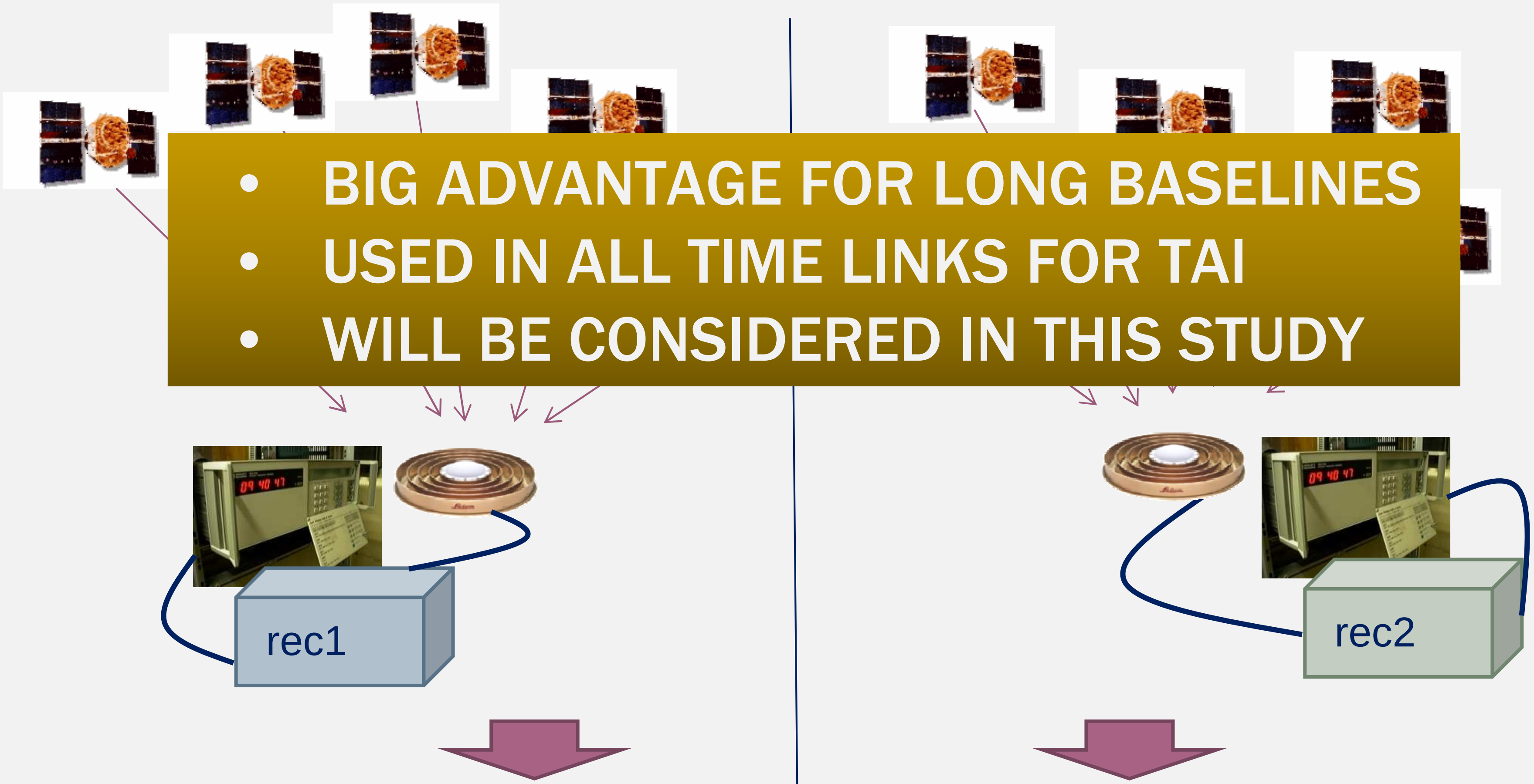
COMMON VIEW



→ For each satellite track: Clock1-Clock2 (t,sat)
Make an average at each epoch → Clock1-Clock2 (t)

ALL IN VIEW

- BIG ADVANTAGE FOR LONG BASELINES
- USED IN ALL TIME LINKS FOR TAI
- WILL BE CONSIDERED IN THIS STUDY



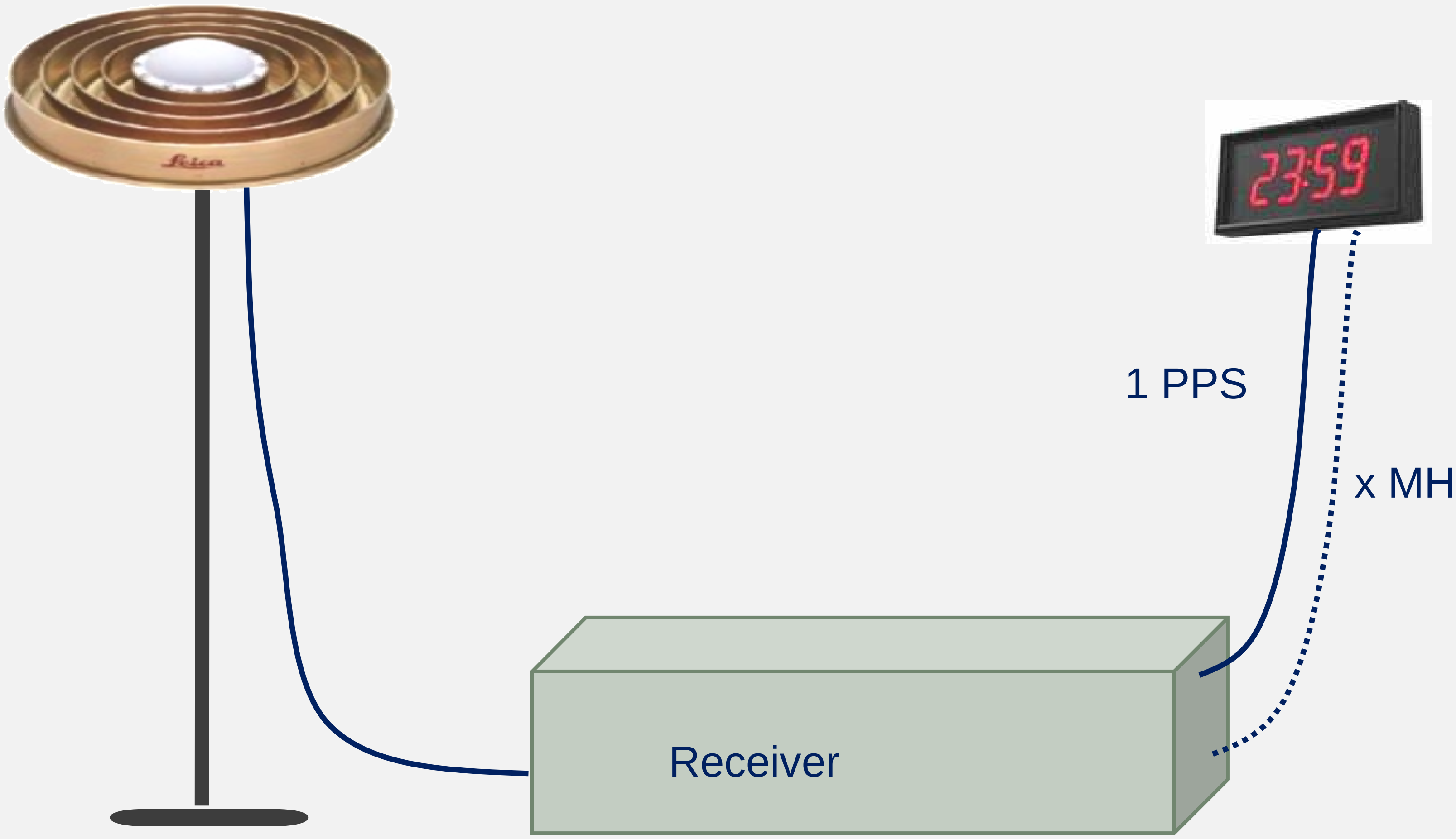
At each epoch, average of satellites
→Clock1-REF (t)

At each epoch, average of satellites
→Clock2-REF (t)

EXAMPLE OF CLOCK SOLUTION

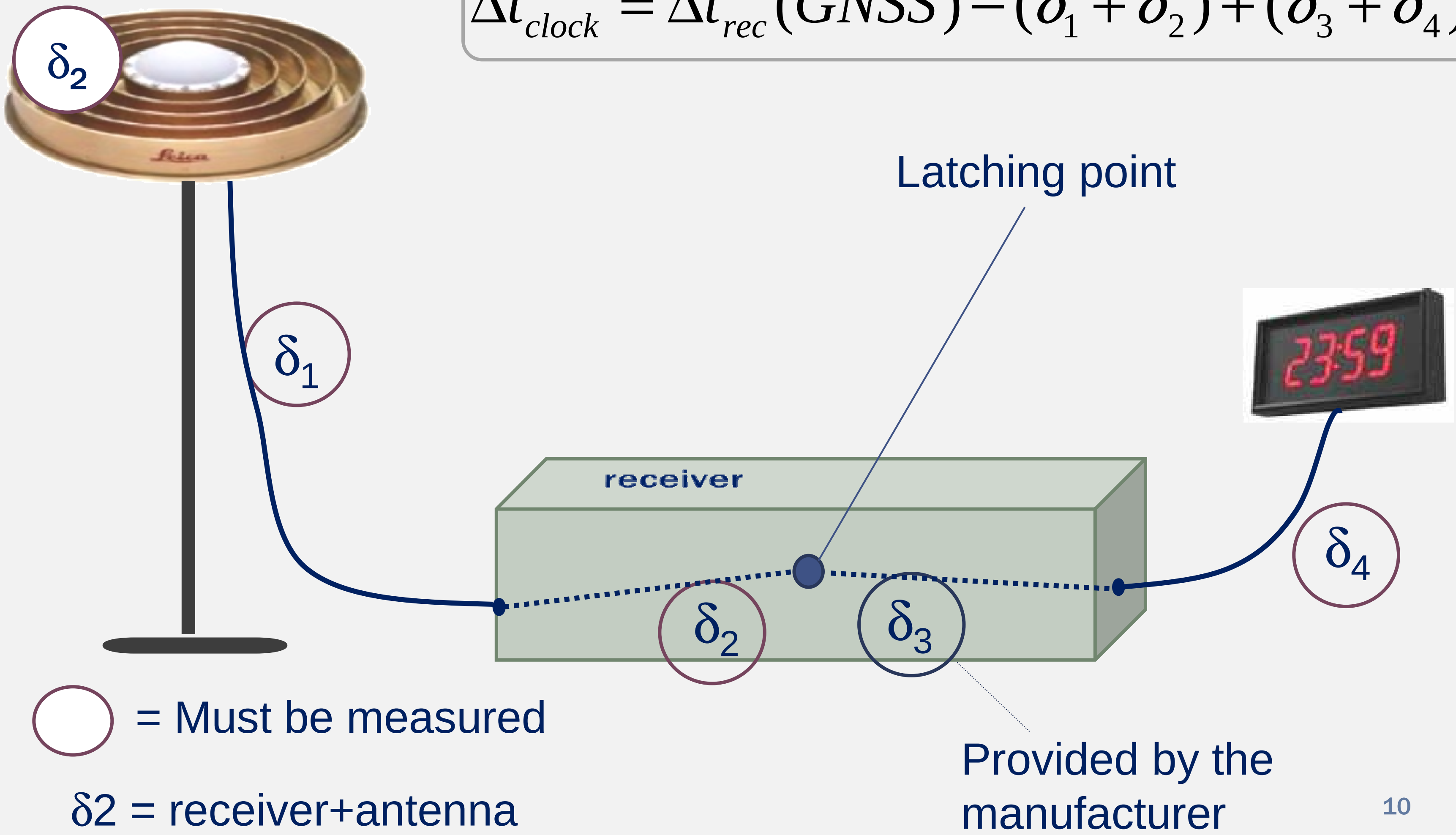
Comparison of clocks in Poland and Australia:

SETUP FOR GNSS TIME TRANSFER



DELAYS TO BE CALIBRATED

$$\Delta t_{clock} = \Delta t_{rec}(GNSS) - (\delta_1 + \delta_2) + (\delta_3 + \delta_4)$$



HARDWARE DELAYS

•

able delays : same for all the codes/frequencies

•

eceiver + antenna delay :

different for each code / each frequency

•

PS : same frequency for all the satellites

delays: P1 (≈C/A), P2

•

alileo : delays for E1, E5, E5a, E5b

MULTI-GNSS TIME TRANSFER

REQUIREMENTS :

1. Receiver internal clock the same for all the measurements from all the constellations

2. Receiver + antenna calibrated for all the codes and frequency used for each constellation

3.

REFERENCE TIME SCALE

$$
\begin{cases}
c(t_r - t_e)^{sat\_1} = \| x_s - x_r \| - c(t_{rec} - t^{sat\_1}) + errors \\
\vdots \\
c(t_r - t_e)^{sat\_k} = \| x_s - x_r \| - c(t_{rec} - t^{sat\_k}) + errors
\end{cases}
$$

different for each satellite

$(3 + k)$ unknowns for k observations

x_r = receiver position

x_s = satellite position

t_{rec} = receiver clock

t_{sat} = satellite clock

known

$$
\begin{cases}
c(t_r - t_e)^{sat\_1} = \| x_s - x_r \| - c(t_{rec} - ref) - (t^{sat\_1} - ref) + errors \\
\vdots \\
c(t_r - t_e)^{sat\_k} = \| x_s - x_r \| - c(t_{rec} - ref) - (t^{sat\_k} - ref) + errors
\end{cases}
$$

same 4 unknowns for all the satellites

MULTI-GNSS TIME TRANSFER

$$\begin{cases} P^{sat\_1} = \| x_s - x_r \| - c((t_{rec} - ref_A) - (t^{sat\_1} - ref_A)) + errors \\ \dots \\ P^{sat\_k} = \| x_s - x_r \| - c((t_{rec} - ref_A) - (t^{sat\_k} - ref_A)) + errors \end{cases}$$

$$\begin{cases} P^{sat\_1} = \| x_s - x_r \| - c((t_{rec} - ref_B) - (t^{sat\_1} - ref_B)) + errors \\ \dots \\ P^{sat\_k} = \| x_s - x_r \| - c((t_{rec} - ref_B) - (t^{sat\_k} - ref_B)) + errors \end{cases}$$

COMBINATION FOR MULTI-GNSS ALL IN VEIW

2 SOLUTIONS :

- **COMBINATION A T THE LEVEL OF THE SOLUTIONS**
  determine separately $(t_{rec-1} - t_{rec-2})$ via ref_A and ref_B
  And make an average of the two time transfer solutions
  as Presently for TAI with GPS and GLONASS.

- **COMBINATION AT THE LEVEL OF THE OBSERVATIONS** requires
  - ~~Either the accuracte knowledge of $(ref_A - ref_B)$~~ Not available
  - Or: a same reference for the clocks $(t_{sat} - ref_{GNSS})$

    → The combined solution will be $(t_{rec} - ref_{GNSS})$

REQUIREMENT 3

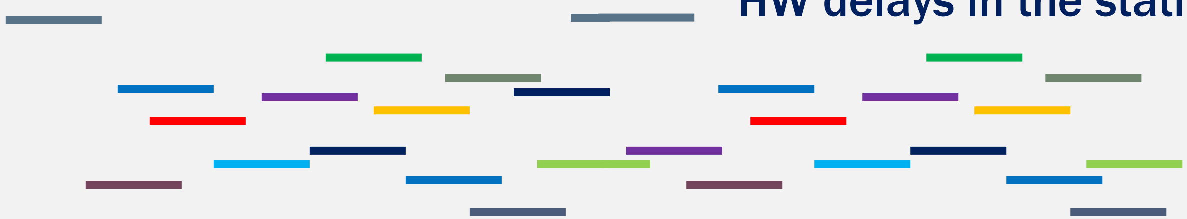
DIFFERENCE GPS / GLONASS

GPS: same frequency for all the satellites
GLONASS : satellite-dependent frequencies

And impact on time transfer results:

GPS : all the satellites give the (nearly) same results

GLONASSS : all the satellites give different results due to the different HW delays in the station.



GPS+GLONASS COMBINATION

For any receiver, we have to introduce and determine DAILY receiver-satellite biases

AV GPS

Calibrated solution

GPS $$P3(sat,rec) = (t_{rec} - ref) - (t_{satGPS} - ref) - CAL(rec)$$

GLONASS $$P3(sat,rec) = (t_{rec} - ref) - (t_{satGLO} - ref) - BD\,(rec, sat, \mathbf{day})$$

From ESOC products

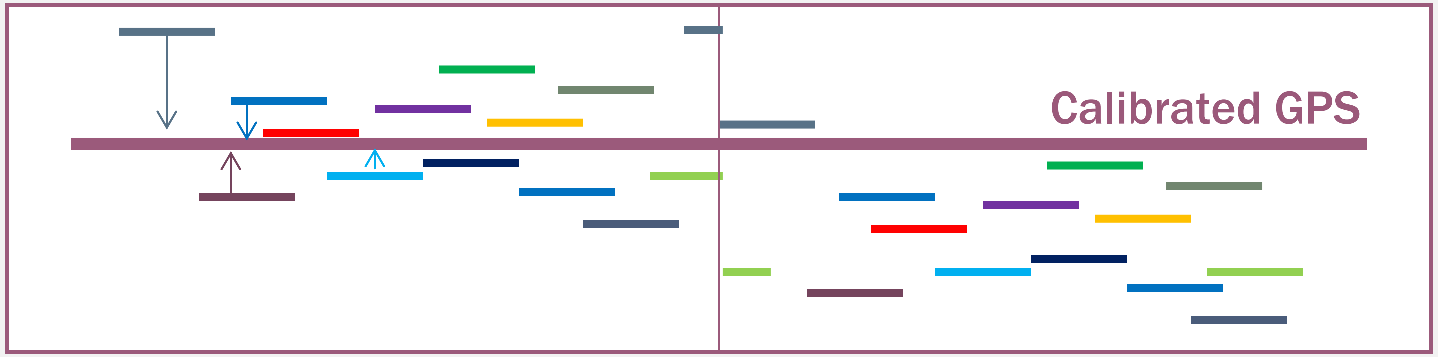
Determined as additional unknwon

→ GLONASS data use the GPS calibration

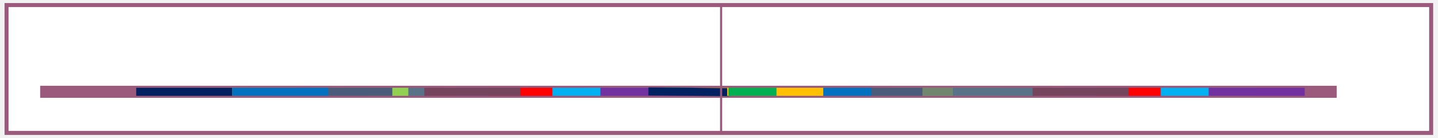
PROCEDURE TO GET COMBINED GPS+GLONASS AV USING ONLY GPS CALIBRATION

1. Compute AV_GPS
2. Determine the $BD\ (rec, sat, \mathbf{day})$ = meas_P3 – sat_clock – AV_GPS
3. Compute a new AV_GPS+(GLONASS- $BD\ (rec, sat, \mathbf{day})$)

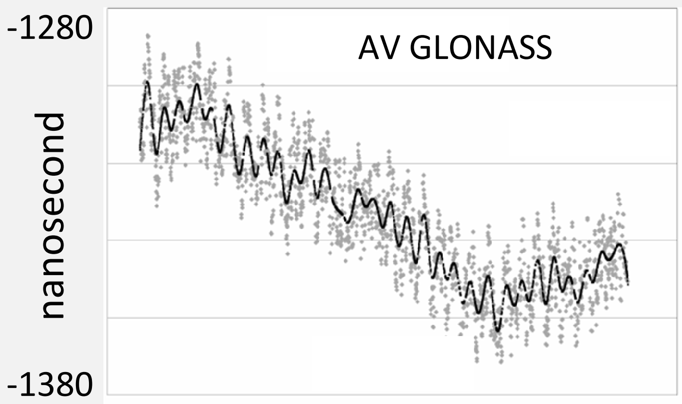
(See Harmegnies et al. (Metrologia 50, 2013))



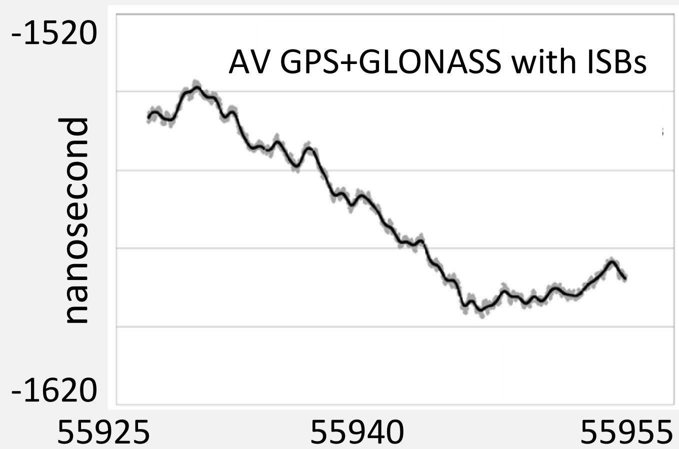
Data used for the combined GPS+GLONASS AV:



AV SOLUTION
DAILY GLONASS BIASES HAVE BEEN DETERMINED



LINK AOS (Poland) – AUS (Sydney)



From Harmegnies et al. (Metrologia 50, 2013)

USING GLONASS CALIBRATION

$$P3(sat, rec) = (t_{rec} - ref) - (t_{satGPS} - ref) - CAL(rec)$$

$$P3(sat, rec) = (t_{rec} - ref) - (t_{satGLO} - ref) - BD\,(rec, sat, day)$$

From ESOC products

$$BD(rec, sat, day) = B(day, sat) + D(rec, f_{sat})$$

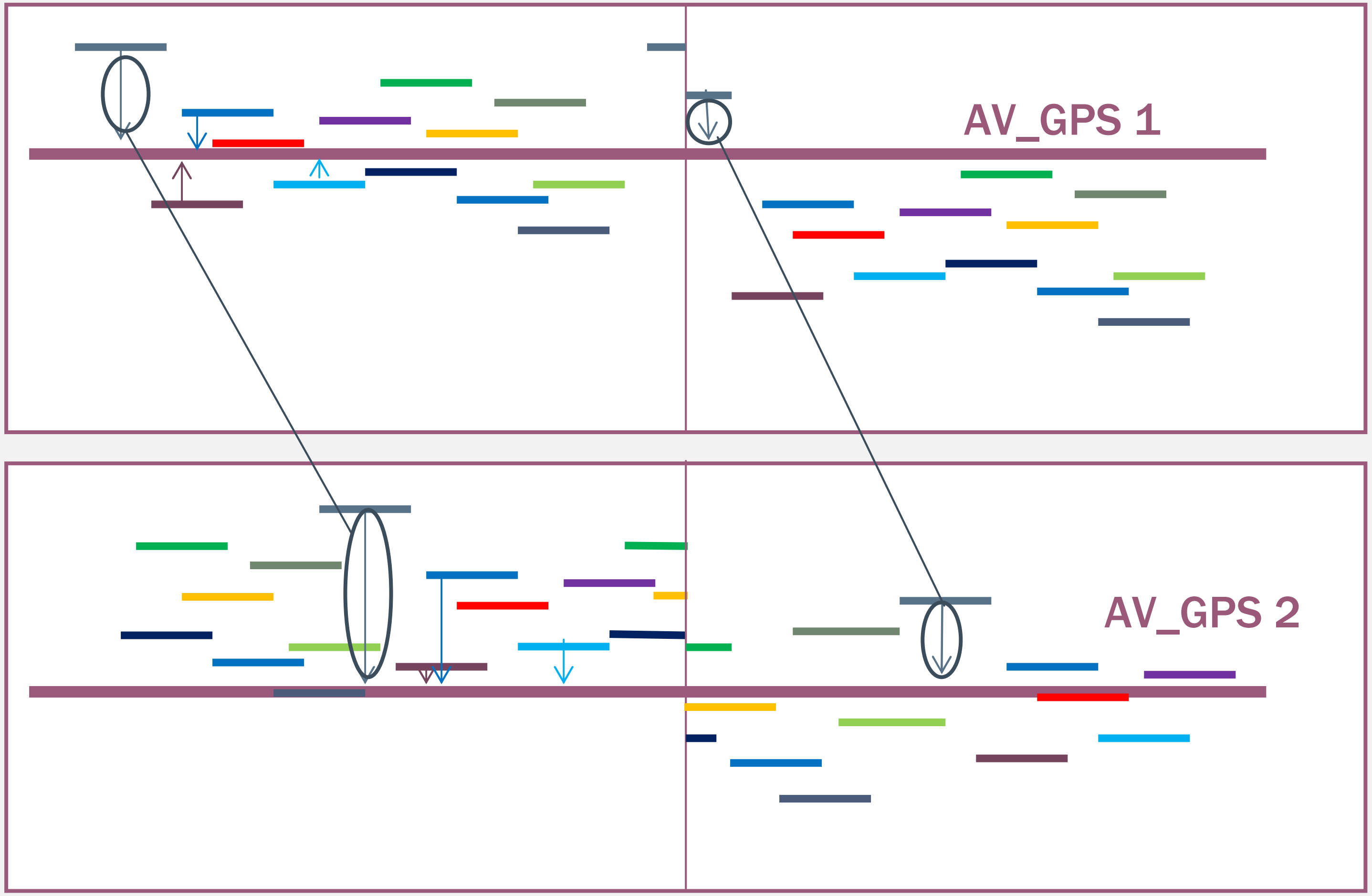
Unknown
Same for all receivers

Can be calibrated
Constant over time

$$BD(rec\_1, sat, day) - BD(rec\_2, sat, day) = D(rec\_1, f_{sat}) - D(rec\_2, f_{sat})$$

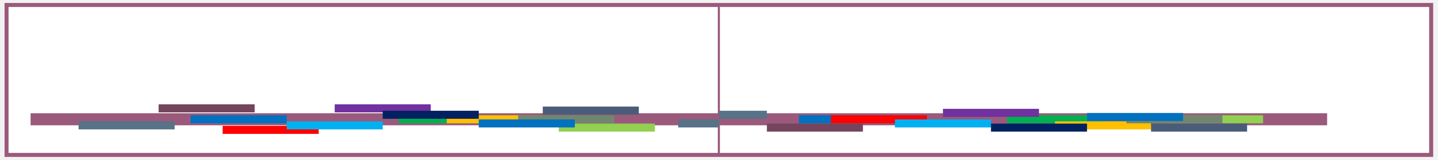
= differential hardware delays for the GLONASS frequencies between rec1 and rec2

USING GLONASS CALIBRATION DATA

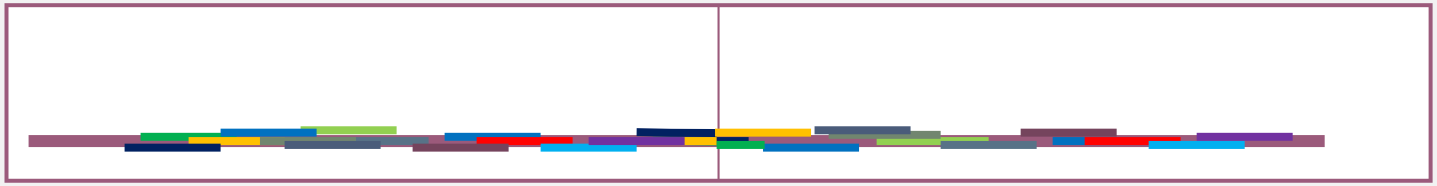


USING GLONASS CALIBRATION DATA

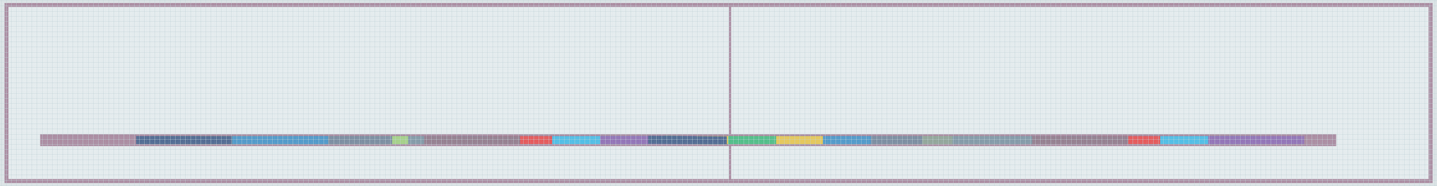
Data used for AV_GPS+GLONASS 1



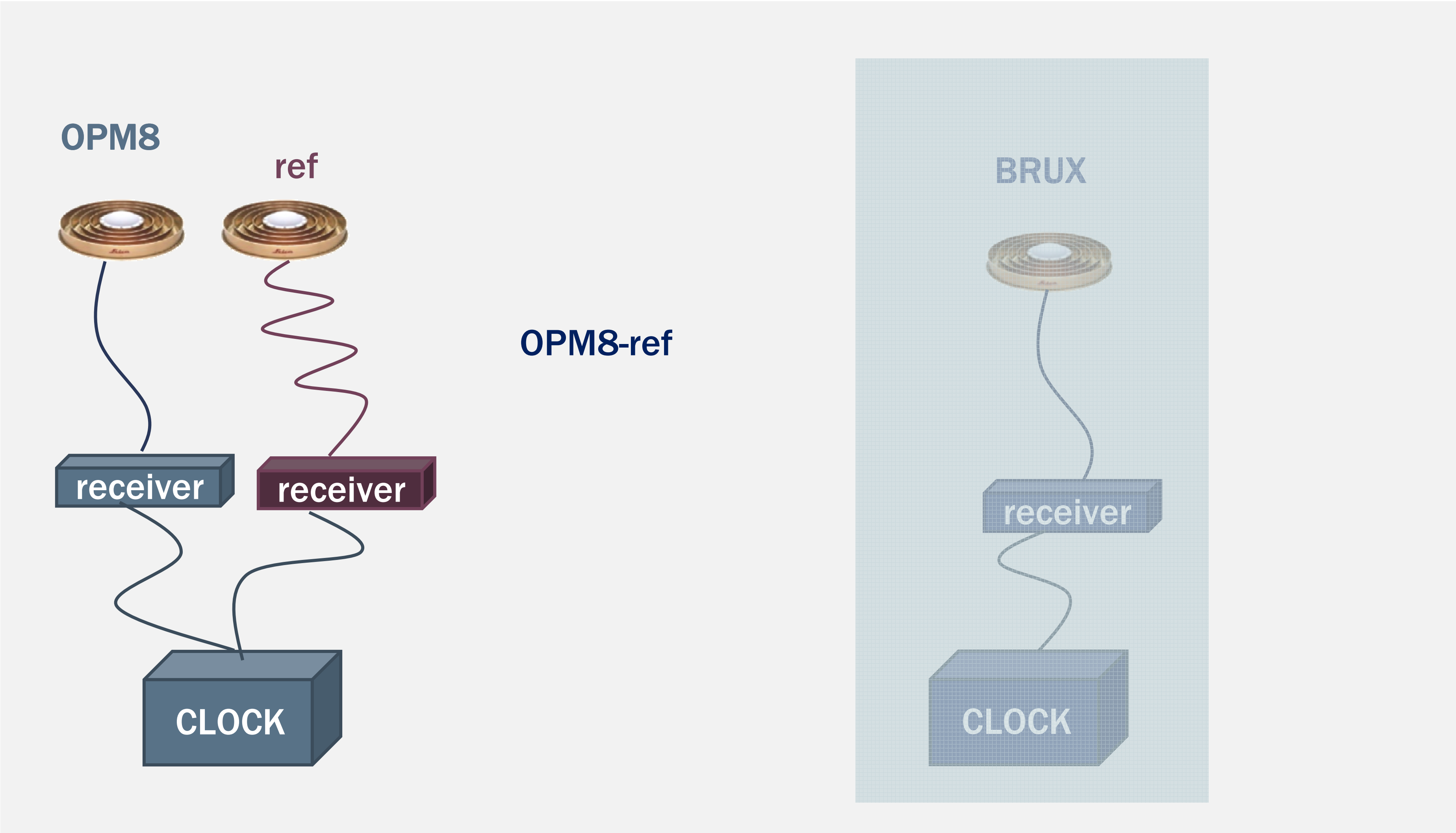
Data used for AV_GPS+GLONASS 2



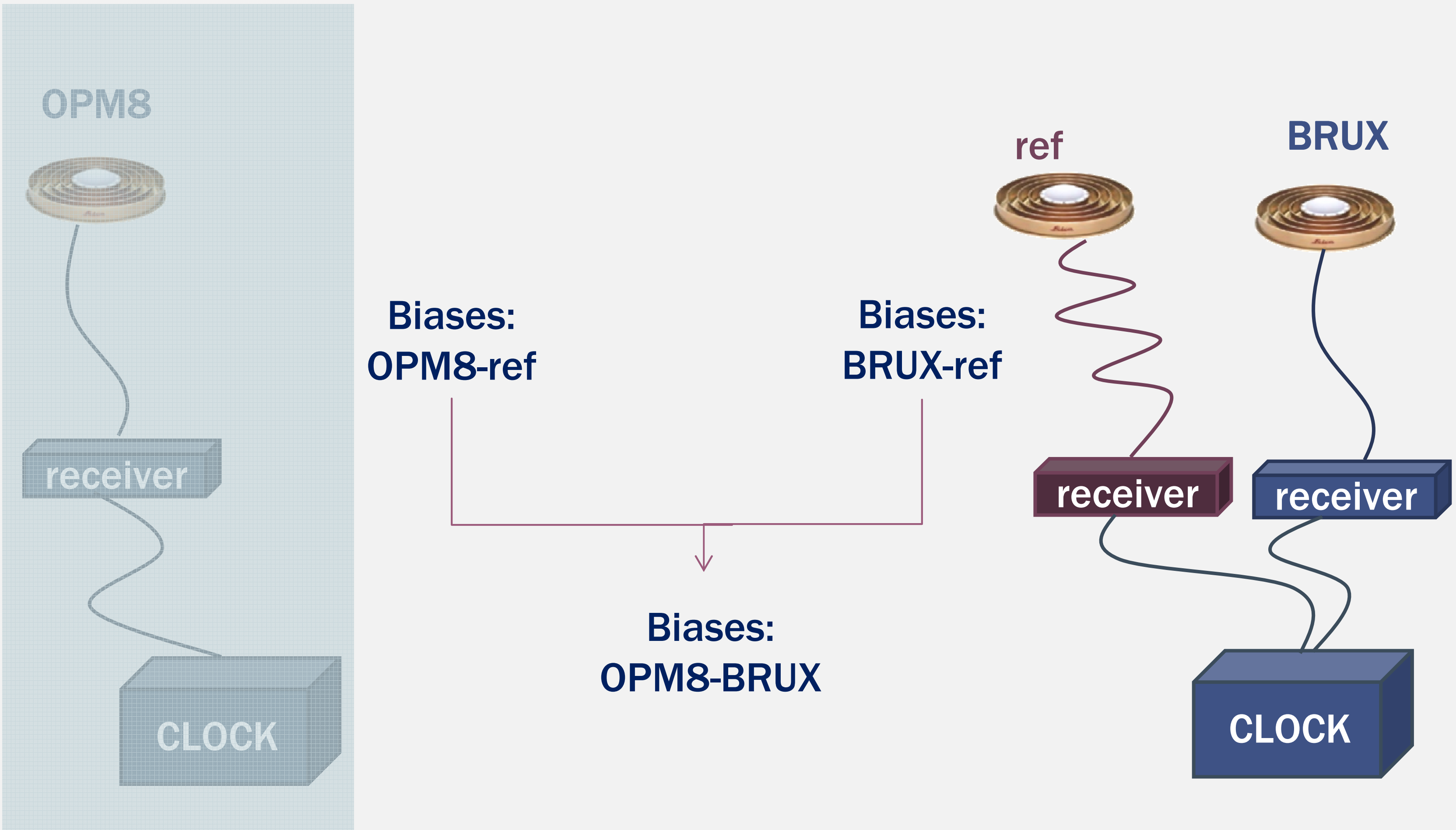
While Data used for AV_GPS+GLONASS without GLONASS calibration



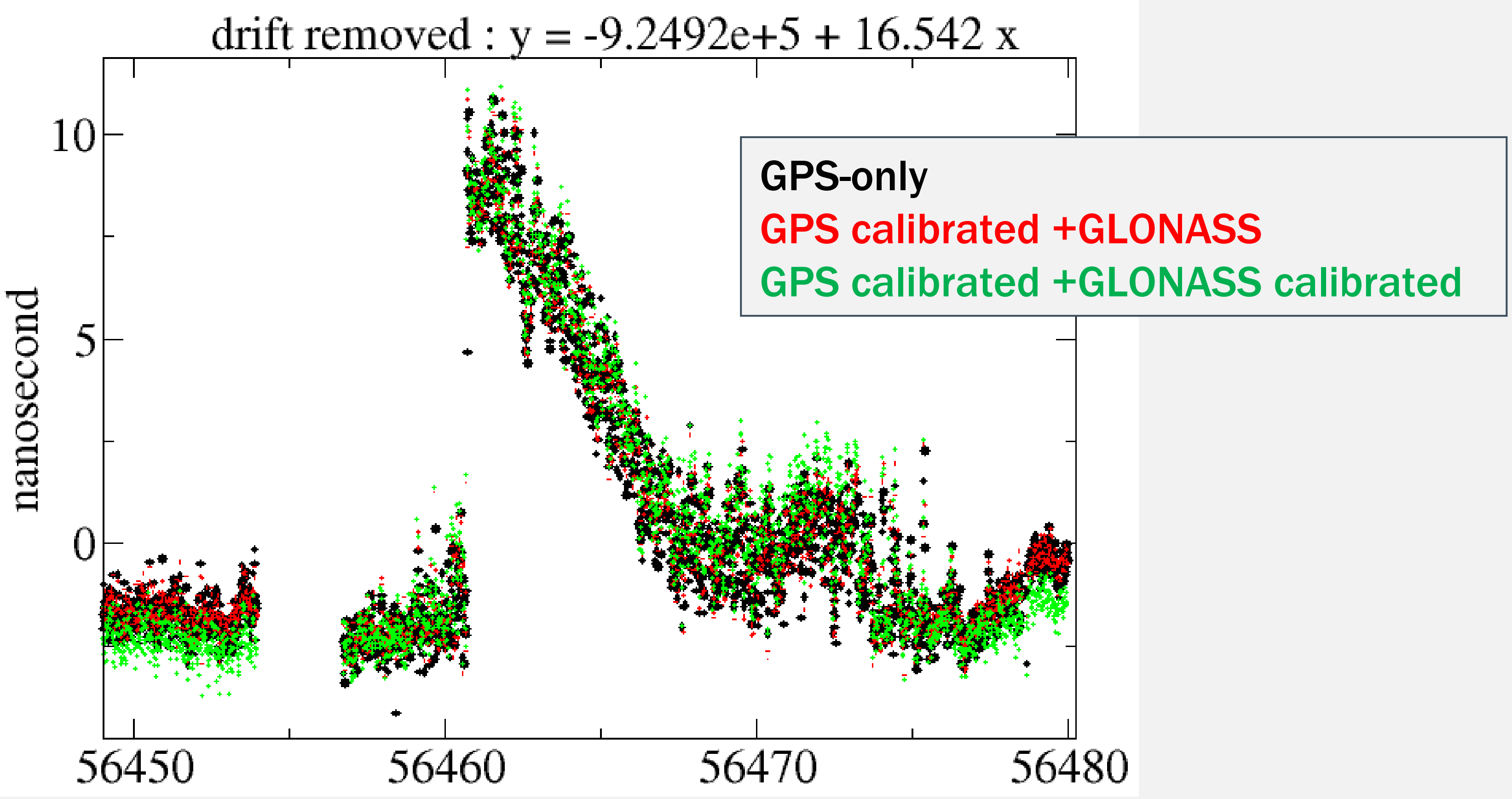
DEMONSTRATION WITH BRUX-OPM8
1. GLONASS CALIBRATION OF THE LINK



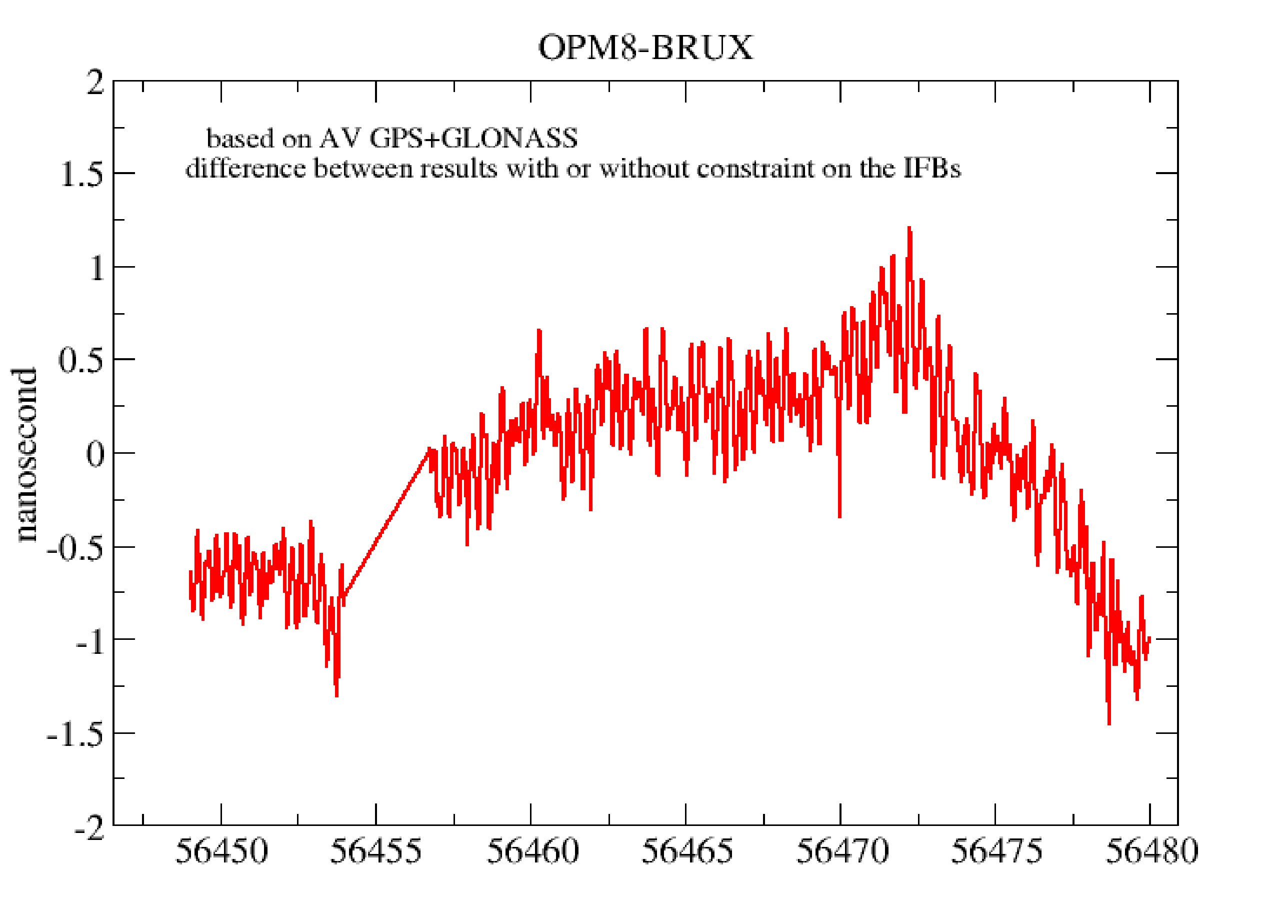
RELATIVE GLONASS CALIBRATION



AV SOLUTIONS OPM8-BRUX



DIFFERENCES
= EFFECT OF USING GLONASS CALIBRATION DATA



GALILEO

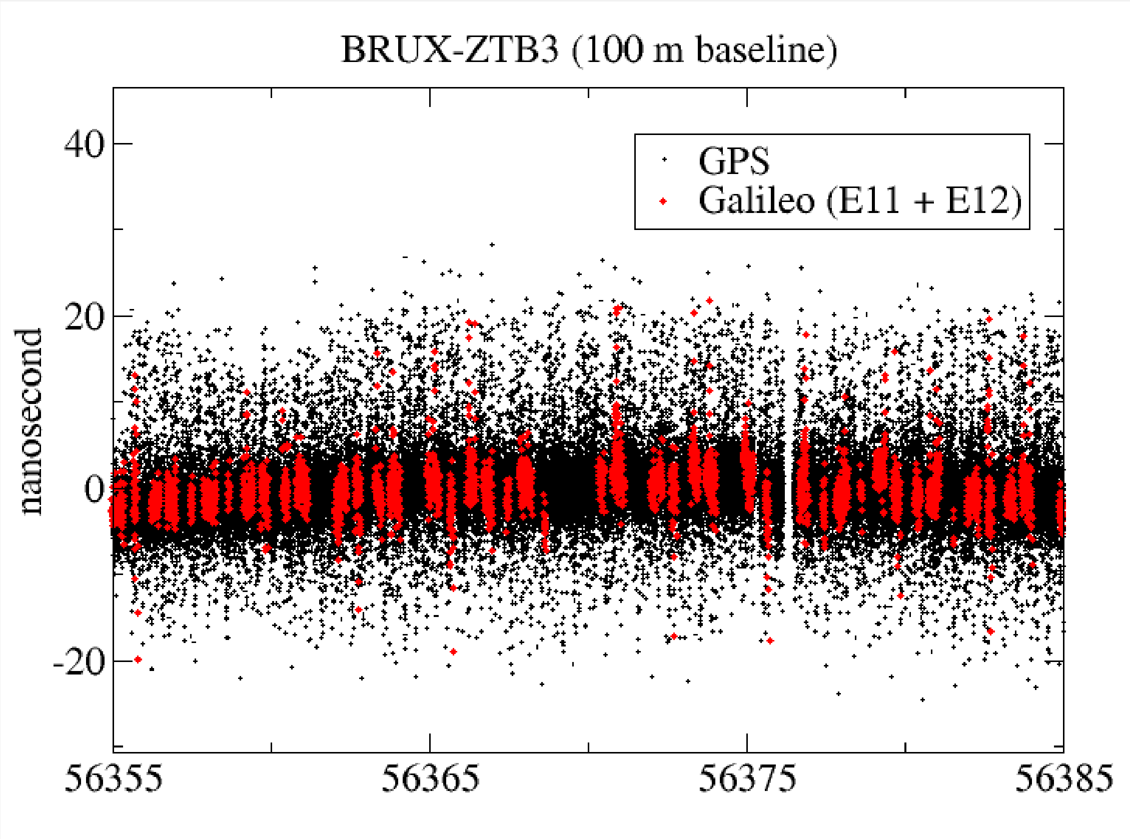
- 4 satellites
- Navigation data since March 21, not continuoulsy
- IGS : IGS Multi-GNSS Experiment (MGEX) provides orbits/clocks at 5 min
  - not always, not for all the satellites
  - quality?
- Only a few time labs are equipped with Galileo-able receivers.

Here use BRUX and ZTB3 (Brussels)

GALILEO

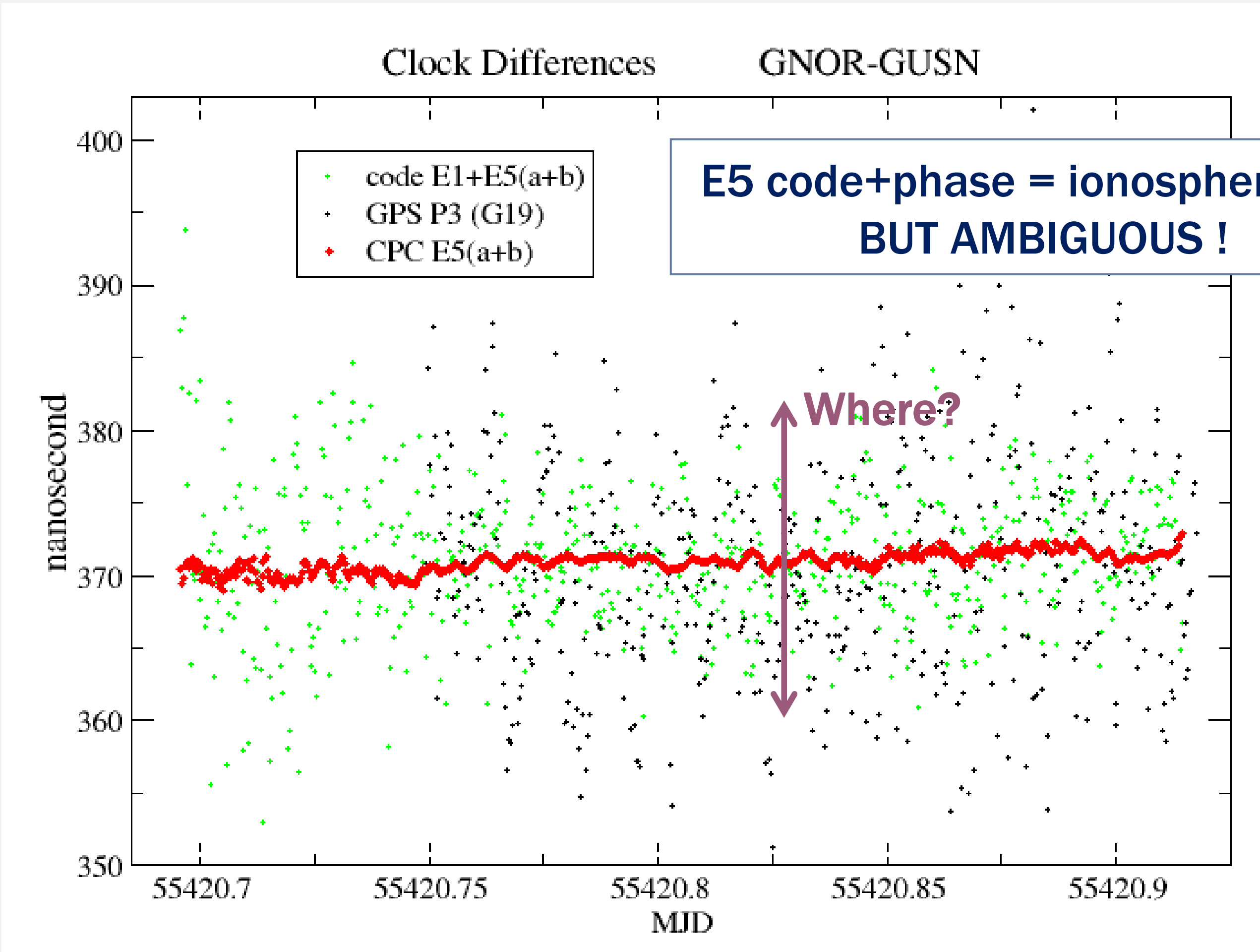
First results between UTC(ORB) and the H-maser in ORB
Using the IGS-MGEX products delivered by TUM

CGGTTS-like results, over 5 minutes tracks.



Same results for GPS and Galileo
Maybe noise (Galileo) < noise (GPS) but TBC

E5 : VERY PRECISE BUT… HOW USE IT?



E5 code+phase = ionosphere-free
BUT AMBIGUOUS !

CONCLUSIONS

- TOWARDS multi-GNSS time transfer : combined the observations (not the solutions): 3 requirements

1. Same receiver internal clock for all constellations
2. Each of the observations should be calibrated
3. Products for satellite clocks, all with a same reference, should exist

GLONASS + GPS:

- GLONASS calibration data can only be introduced in the computation of a LINK, i.e. a difference of 2 AV solutions.
- These calibration data should be introduced as constraints in the determination of inter-satellite biases
- The method can also be applied to combined GPS+GLONASS PPP

GALILEO, BEIDOU → future

THE END

Thank you for your attention !