GPS Carrier Phase Solution

R. Dach

rolf.dach@aiub.unibe.ch

Astronomical Institute, University of Bern,

Sidlerstrasse 5, CH-3012 Bern

Meeting of the CCTF Working Group on TWSTFT

NMi Van Swinden Laboratorium, Delft, Netherlands, November, 15–16, 2005

Outline

GPS Carrier Phase Solution:

1. Background and Motivation
2. Continuous Geodetic Time and Frequency Transfer
   Introduction and characterization of the method
3. GPS Carrier Phase Solution for the TW2005 Campaign
   Description of the solution and results
4. Summary and Conclusions

Astronomical Institute of the University of Bern:

- hosts one of the *Analysis Centers* of the IGS
  CODE in cooperation with SWISSTOPO, BKG, and IGN

Background and Motivation

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- contributions to IGS products:
  - GNSS satellite orbits, Earth orientation parameters
  - station coordinates and velocities $\longrightarrow$ reference frame
  - ionosphere models (because of dual frequency)
  - troposphere models (in particular water vapor content)
  - satellite clock corrections, receiver clock corrections

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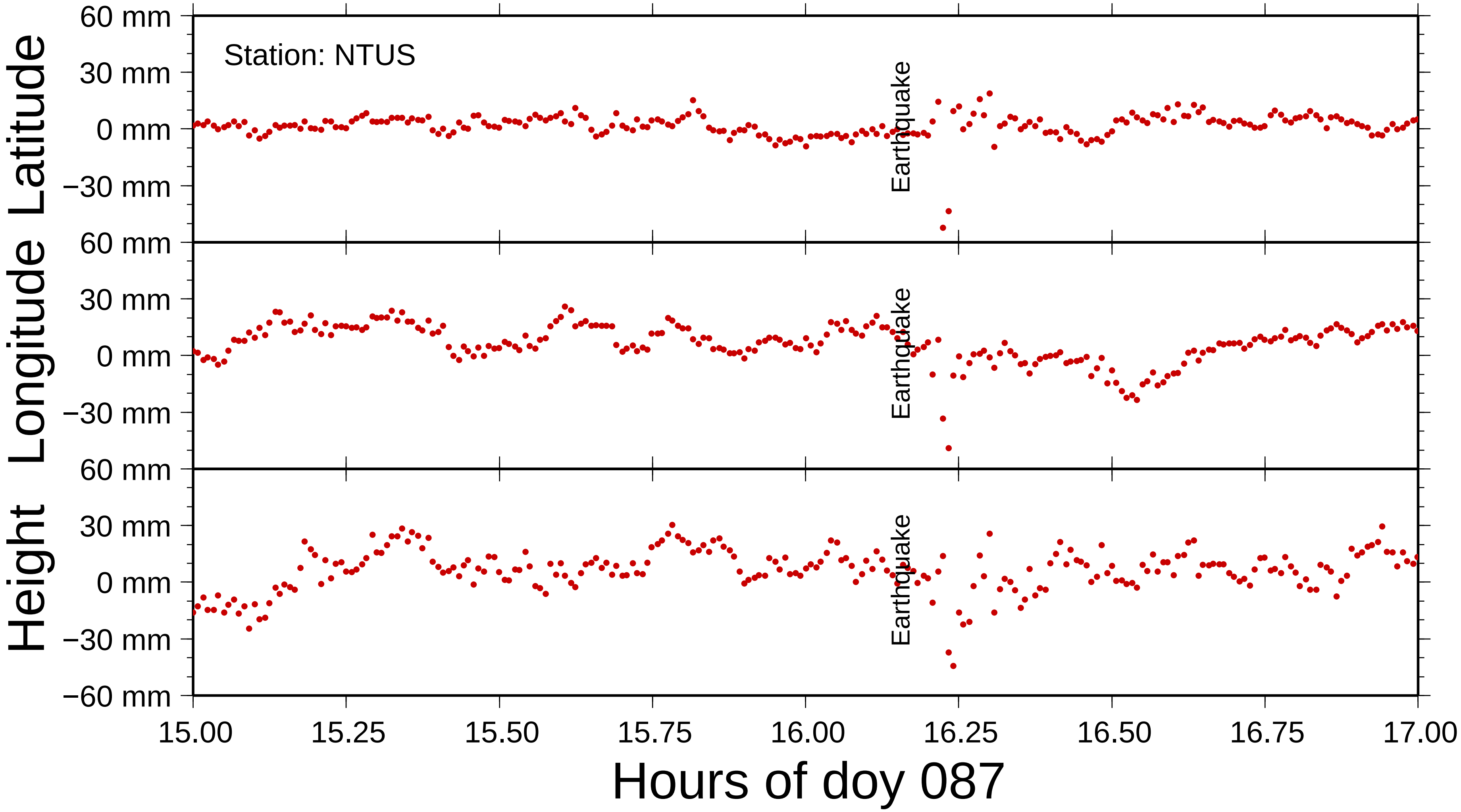
- develops the *Bernese GPS Software* package
  analysis of global scale networks for users with highest accuracy requirements

Background and Motivation

Kinematic Solution during an Earthquake



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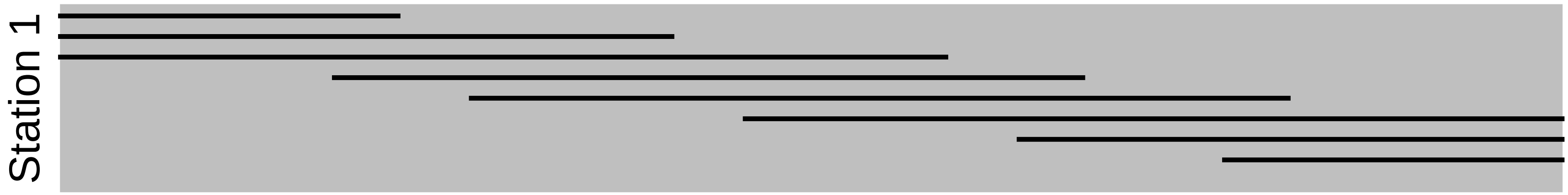
Principle of the Geodetic Time and Frequency Transfer



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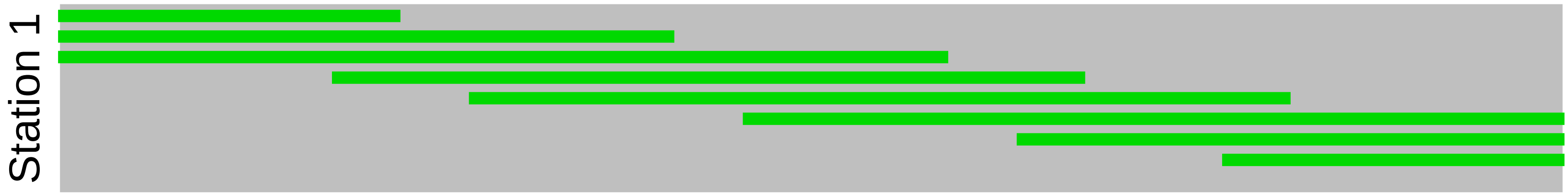

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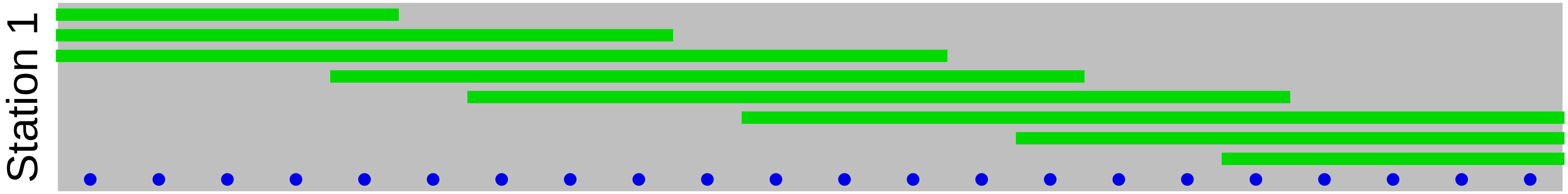
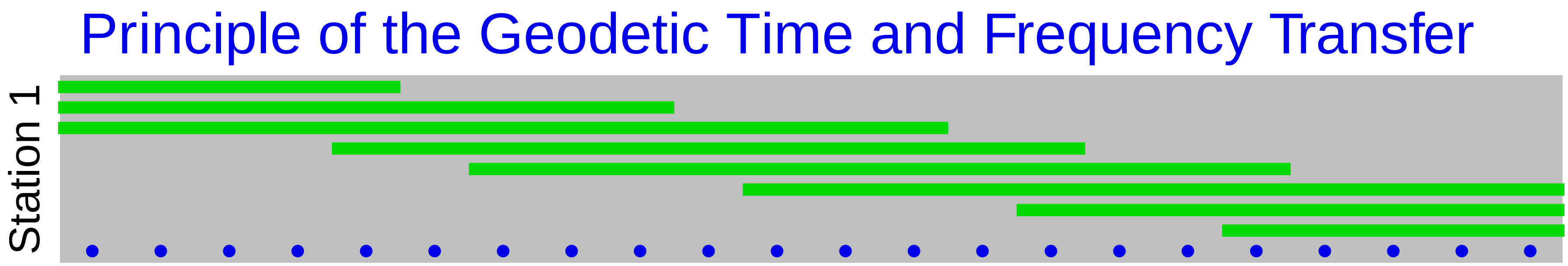
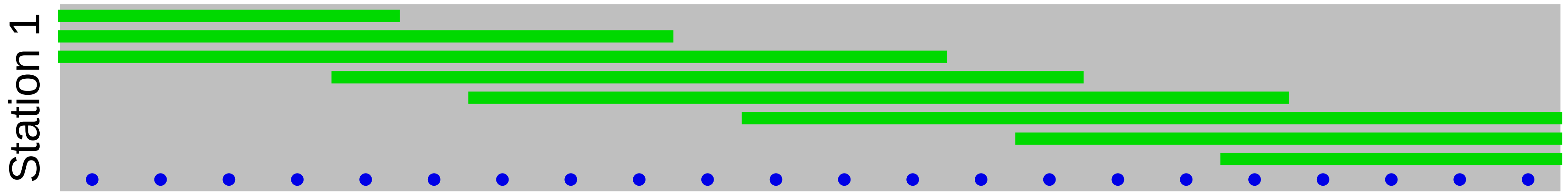


Geodetic Time and Frequency Transfer



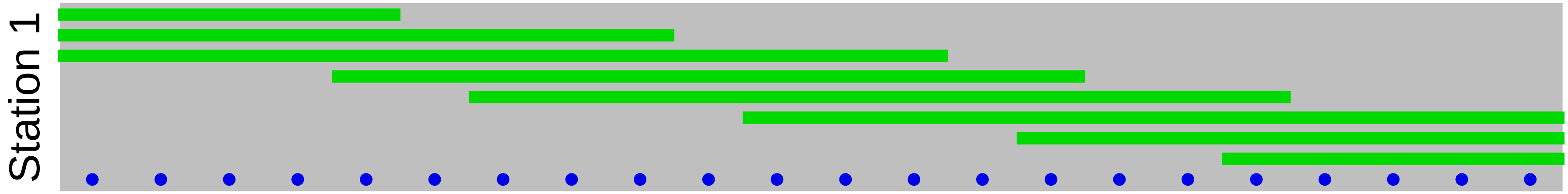
⇒ From carrier phase we can get only the change of the receiver clock in time.

Principle of the Geodetic Time and Frequency Transfer



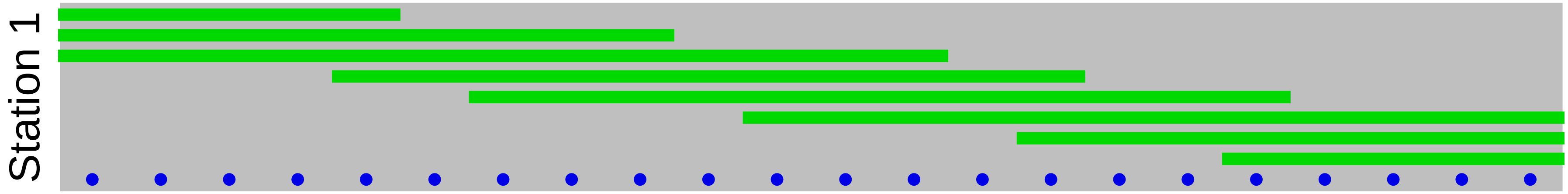
- Add pseudorange observations to have a direct access to the receiver clock parameters.

Principle of the Geodetic Time and Frequency Transfer



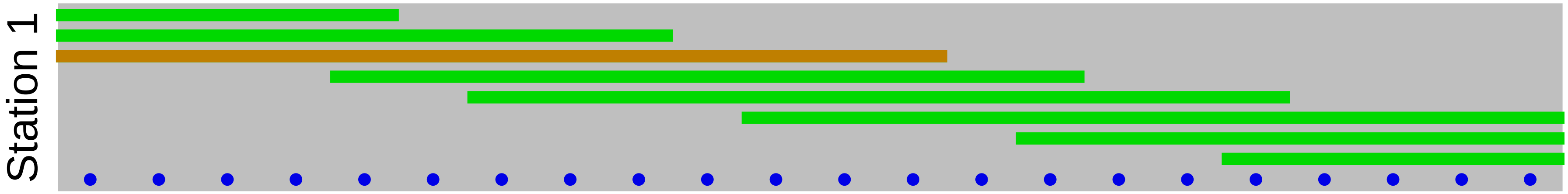
- Add pseudorange observations to have a direct access to the receiver clock parameters.
- Do not estimate one of the receiver clock parameters.

Principle of the Geodetic Time and Frequency Transfer



- Add pseudorange observations to have a direct access to the receiver clock parameters.
- Do not estimate one of the receiver clock parameters.
- Do not estimate one of the phase ambiguity parameters.

Principle of the Geodetic Time and Frequency Transfer



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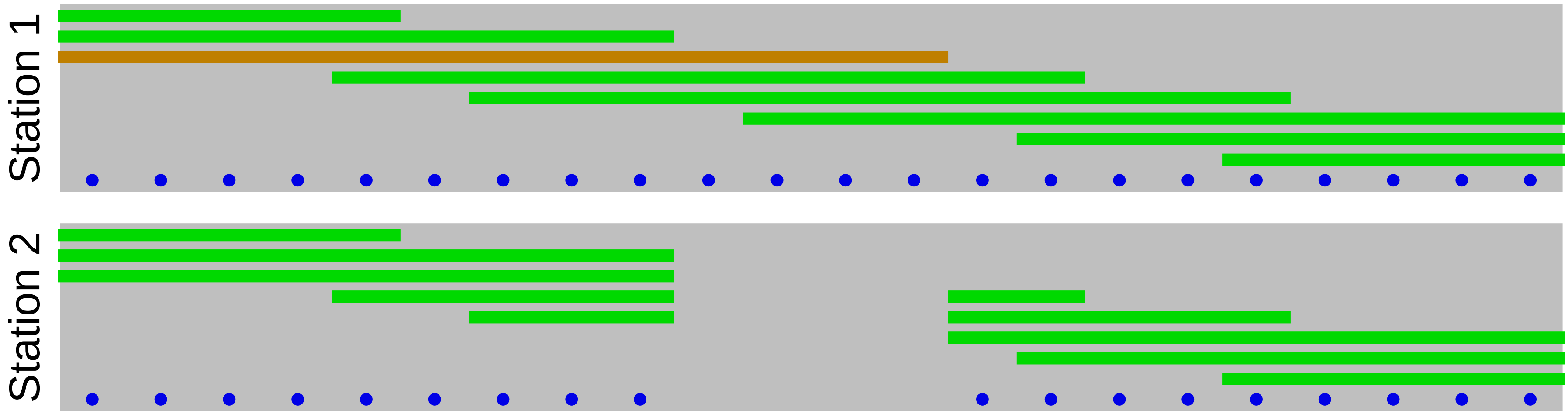

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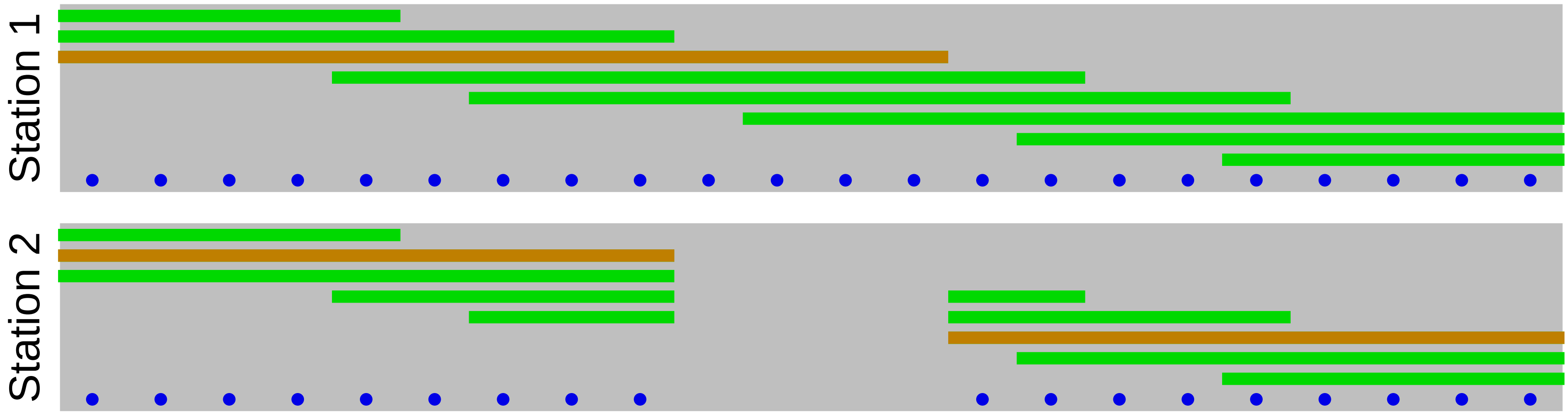
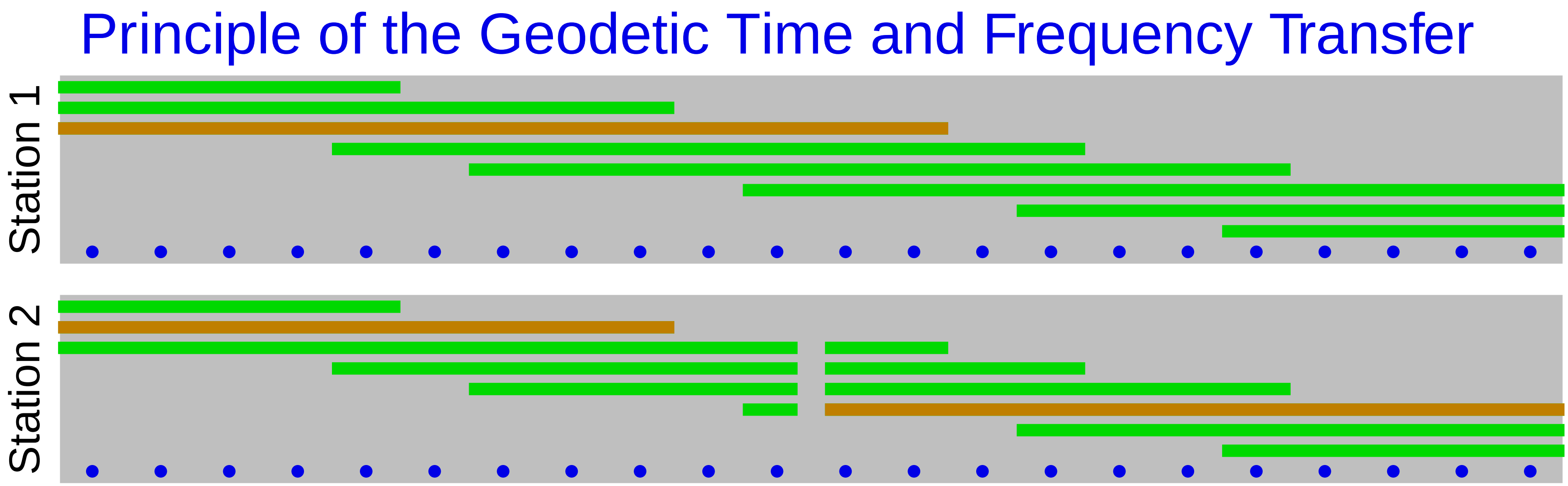


⇒ An interrupt in the ambiguities for all satellites leads to a discontinuity in the carrier phase solution.



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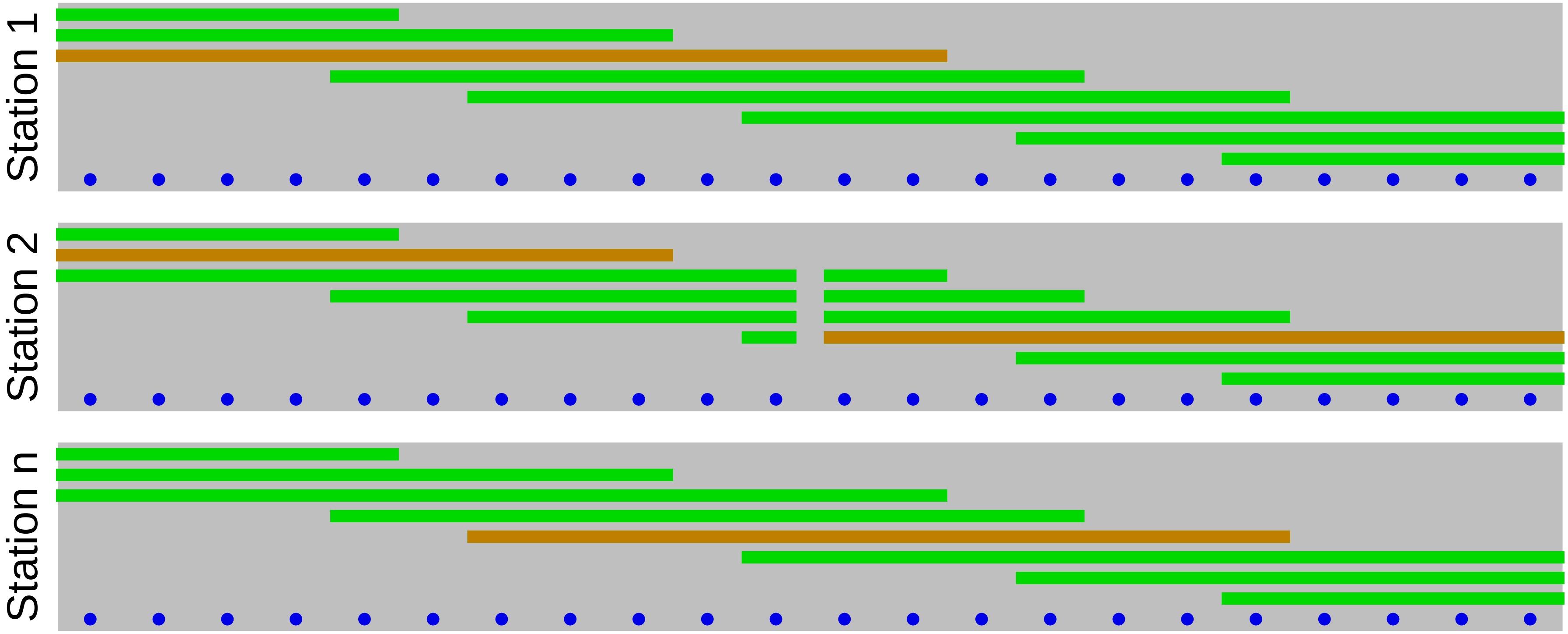
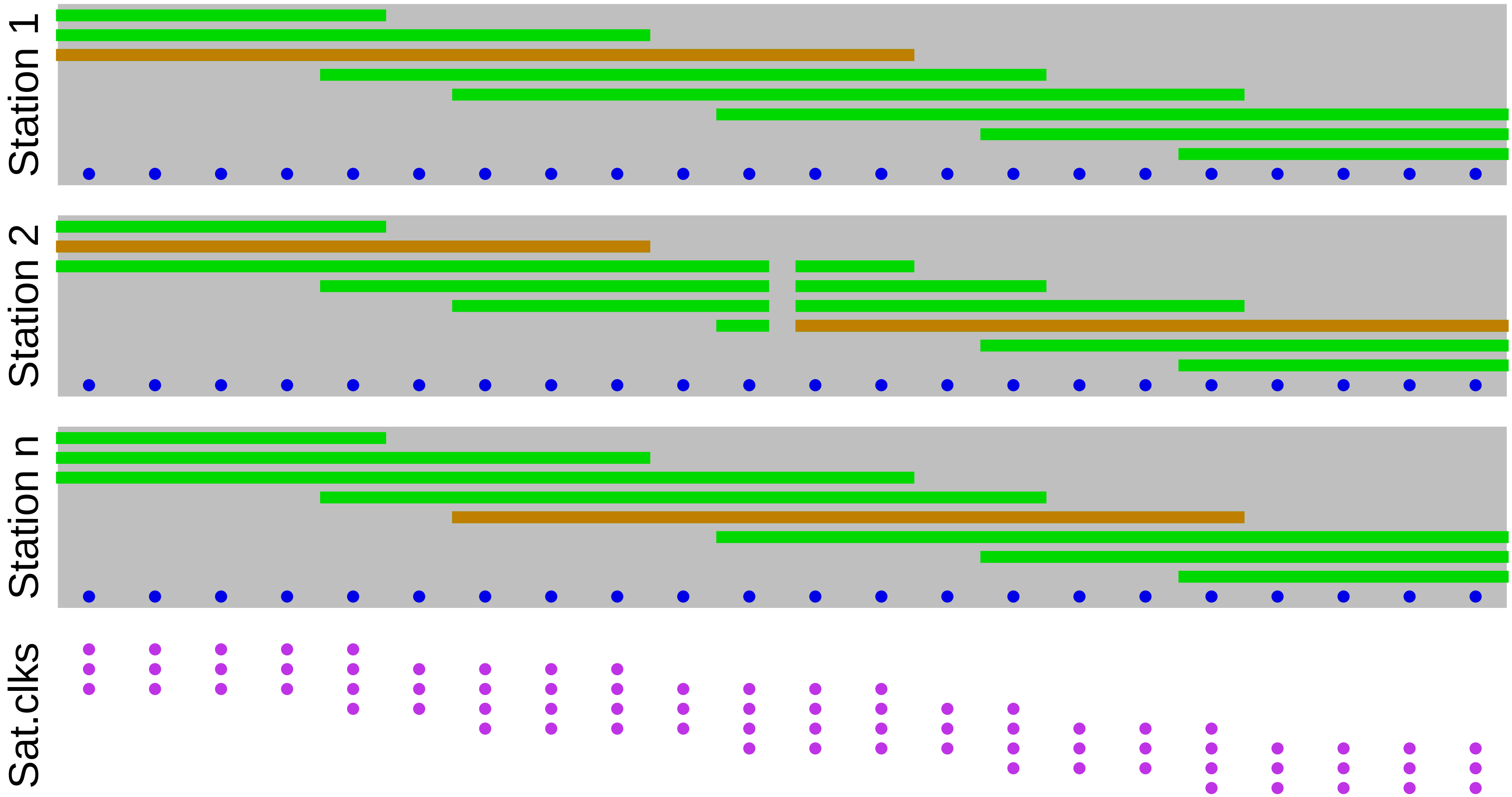
Geodetic Time and Frequency Transfer

Principle of the Geodetic Time and Frequency Transfer

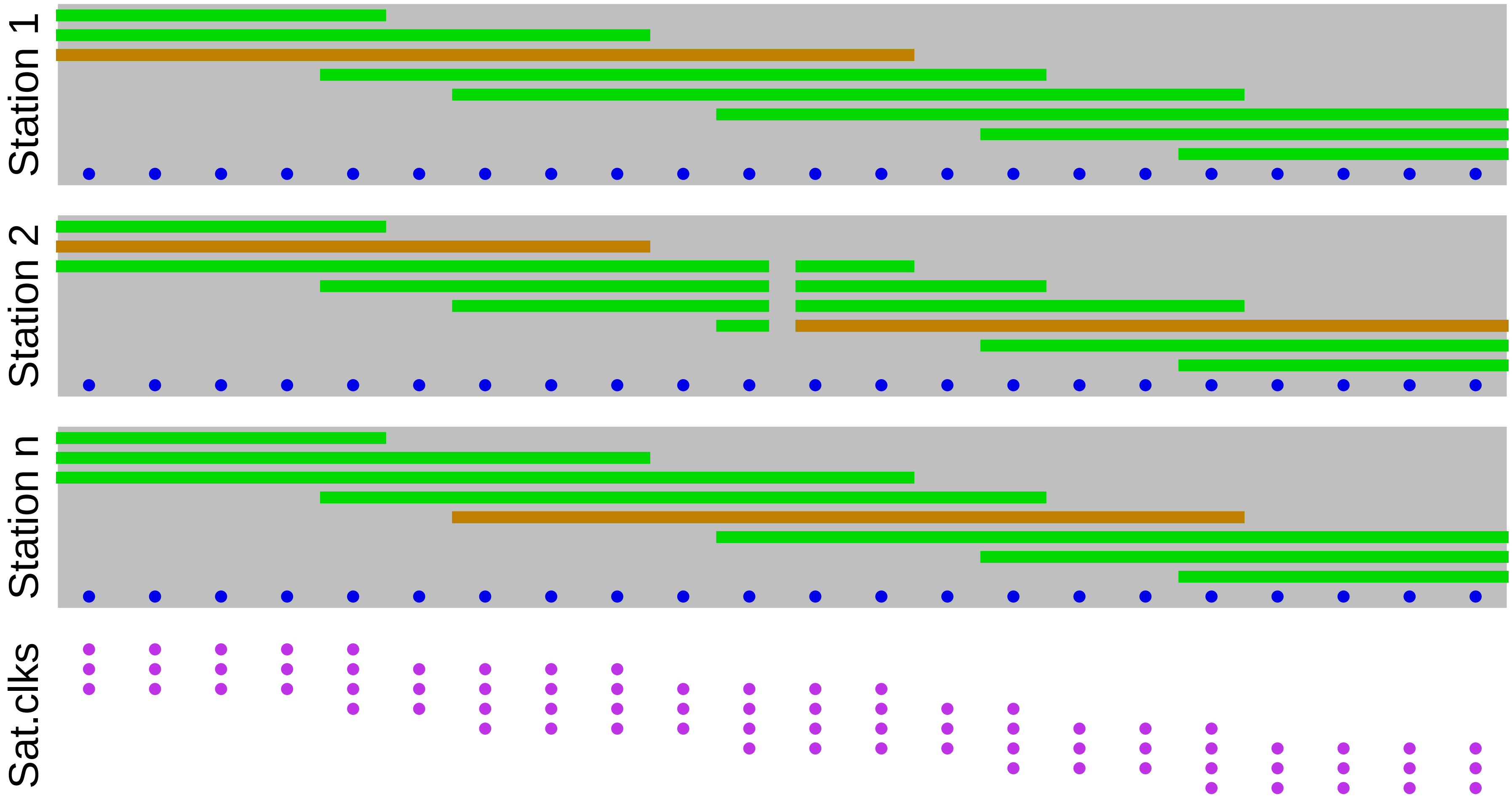


Principle of the Geodetic Time and Frequency Transfer



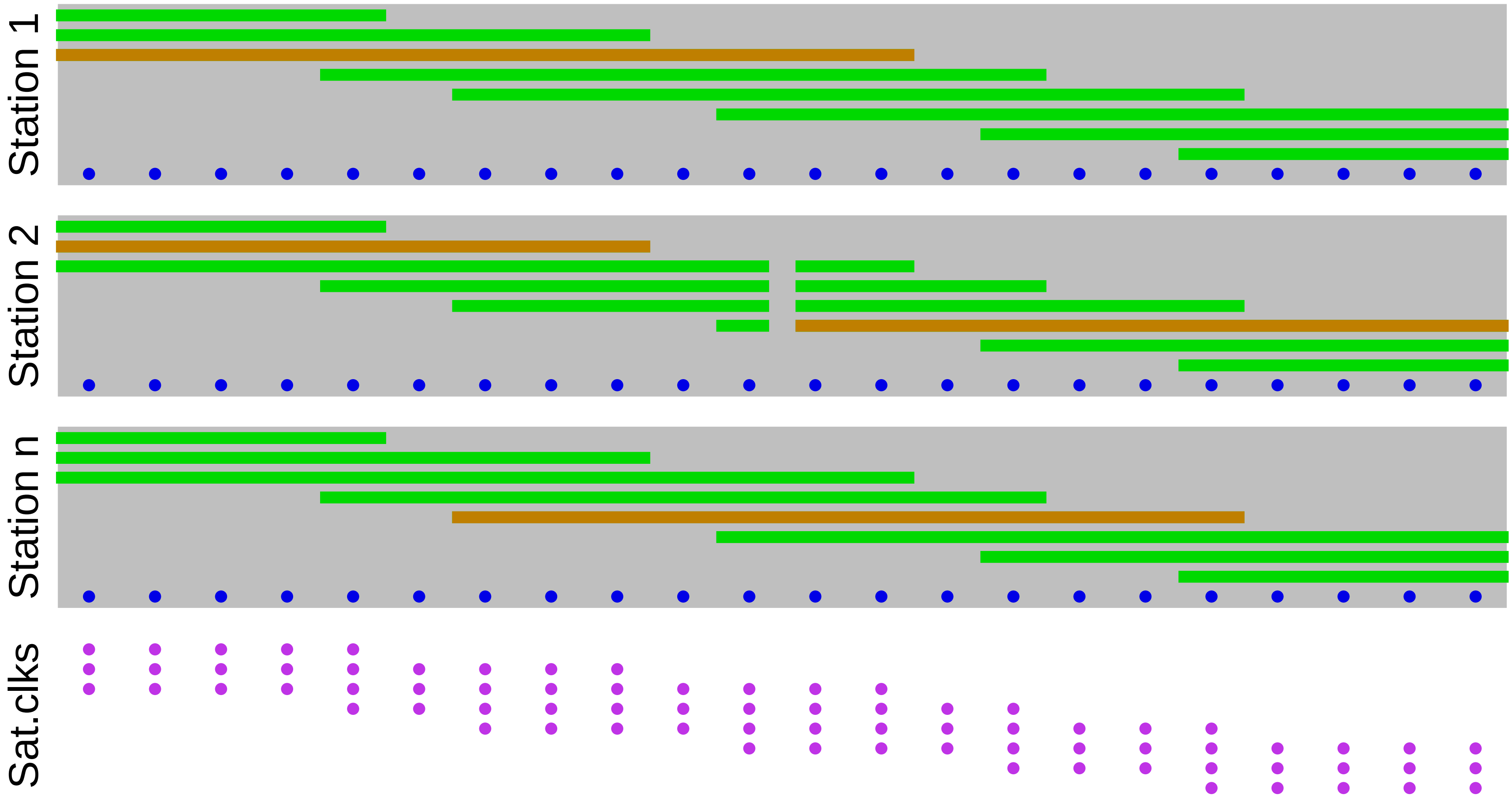
$\Rightarrow$ The satellite clock paramters are added to obtain a network solution.

Principle of the Geodetic Time and Frequency Transfer

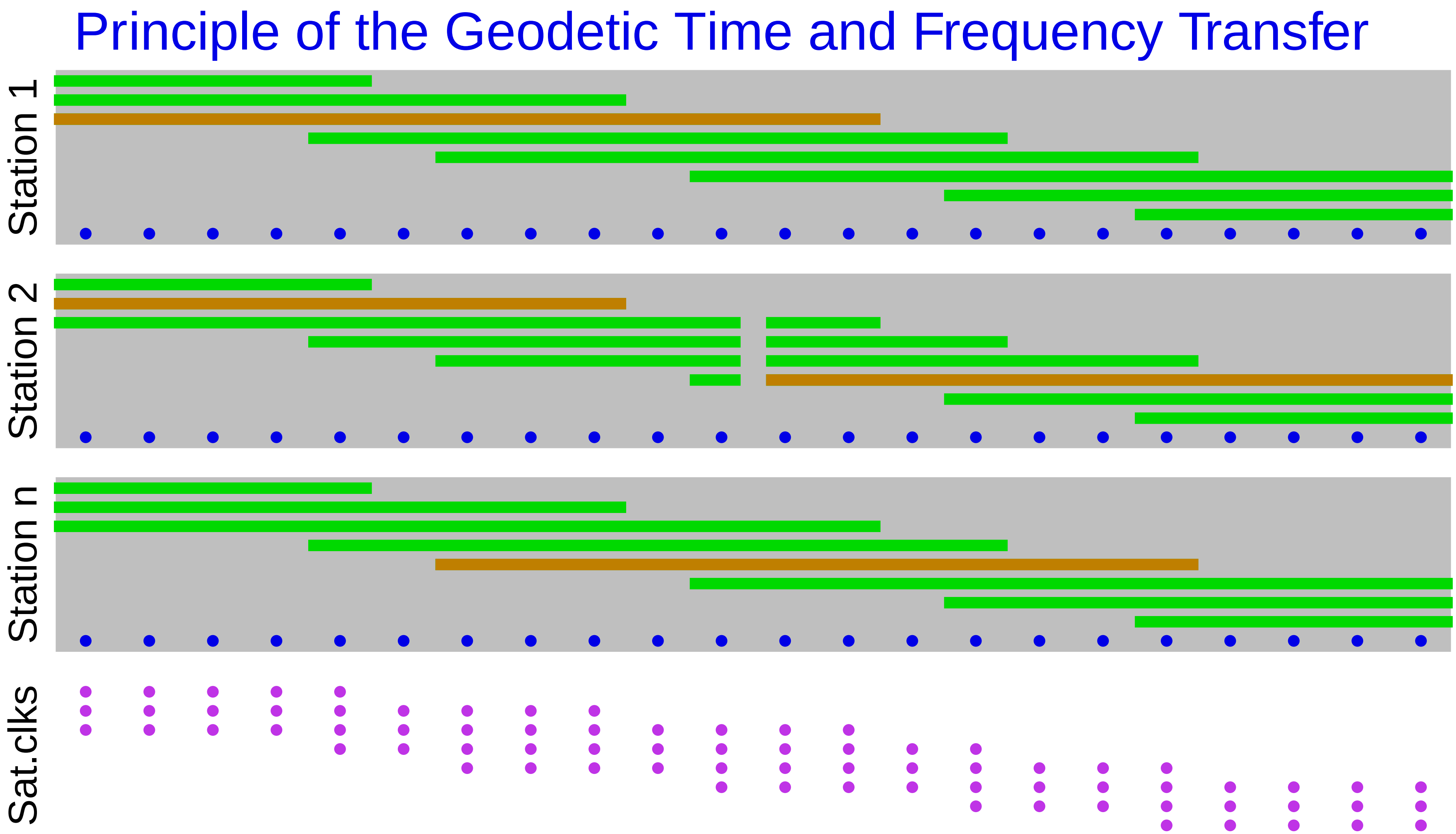


⇒ Only differences between (receiver) clocks can be interpreted.

Principle of the Geodetic Time and Frequency Transfer

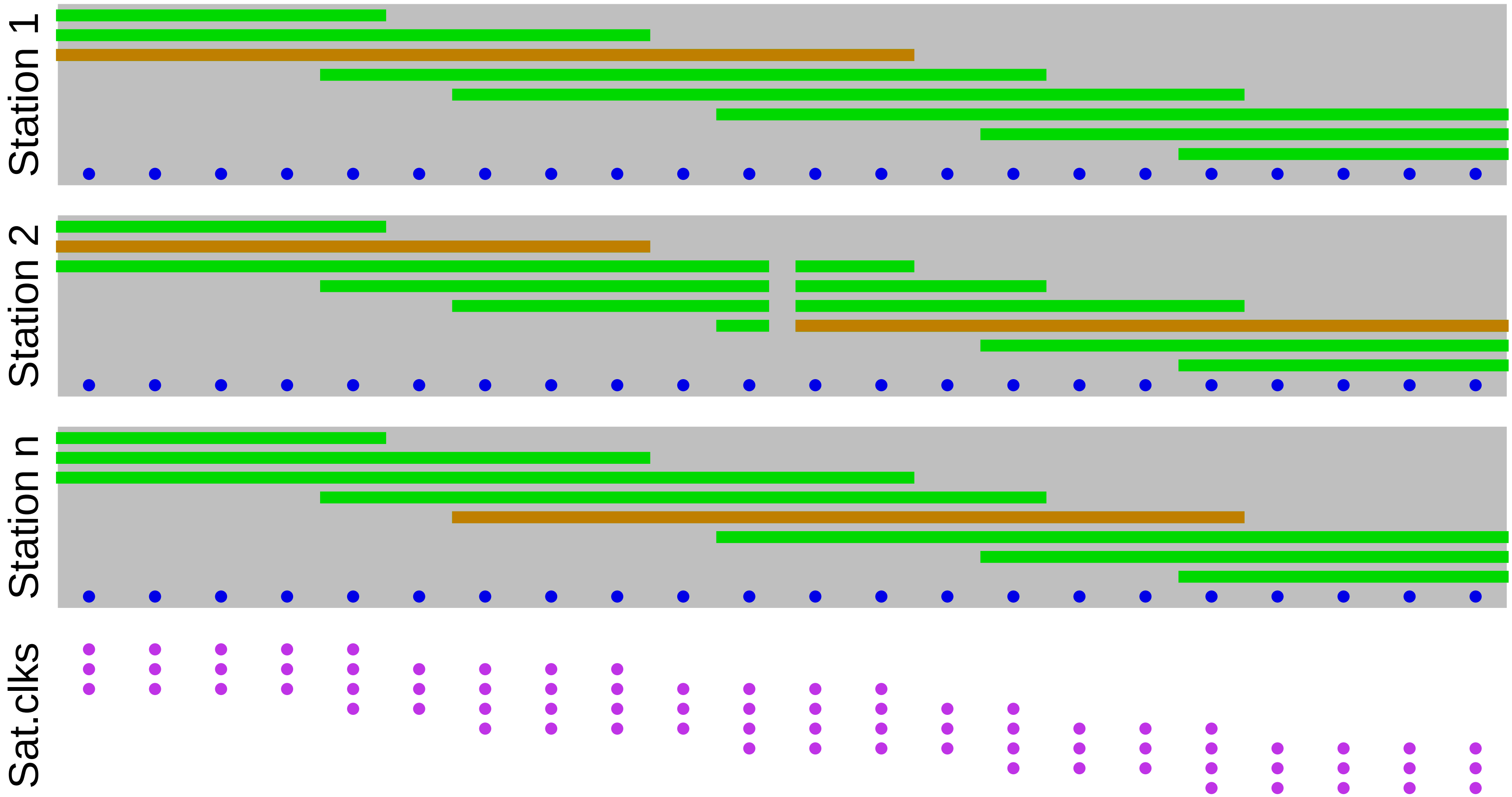


⇒ Any receiver clock difference can be extracted from the network solution.



⇒ All receiver clock values are available at one and the same epoch.

Principle of the Geodetic Time and Frequency Transfer



⇒ The method implies no presumptions for the receiver clocks.

Characteristics of the Geodetic Time and Frequency Transfer

- The complete set of receiver clock values refers to one and the same epoch.
- Only differences between estimated receiver clocks can be interpreted.
- Any simultanious receiver clock difference (baseline) can be extracted from the network solution.
- The method implies no presumptions for the receiver clocks.
- From carrier phase we can get only the change of the receiver clock in time.
- An interrupt in the ambiguities for all satellites leads to a discontinuity in the carrier phase solution.

Characteristics of the Geodetic Time and Frequency Transfer

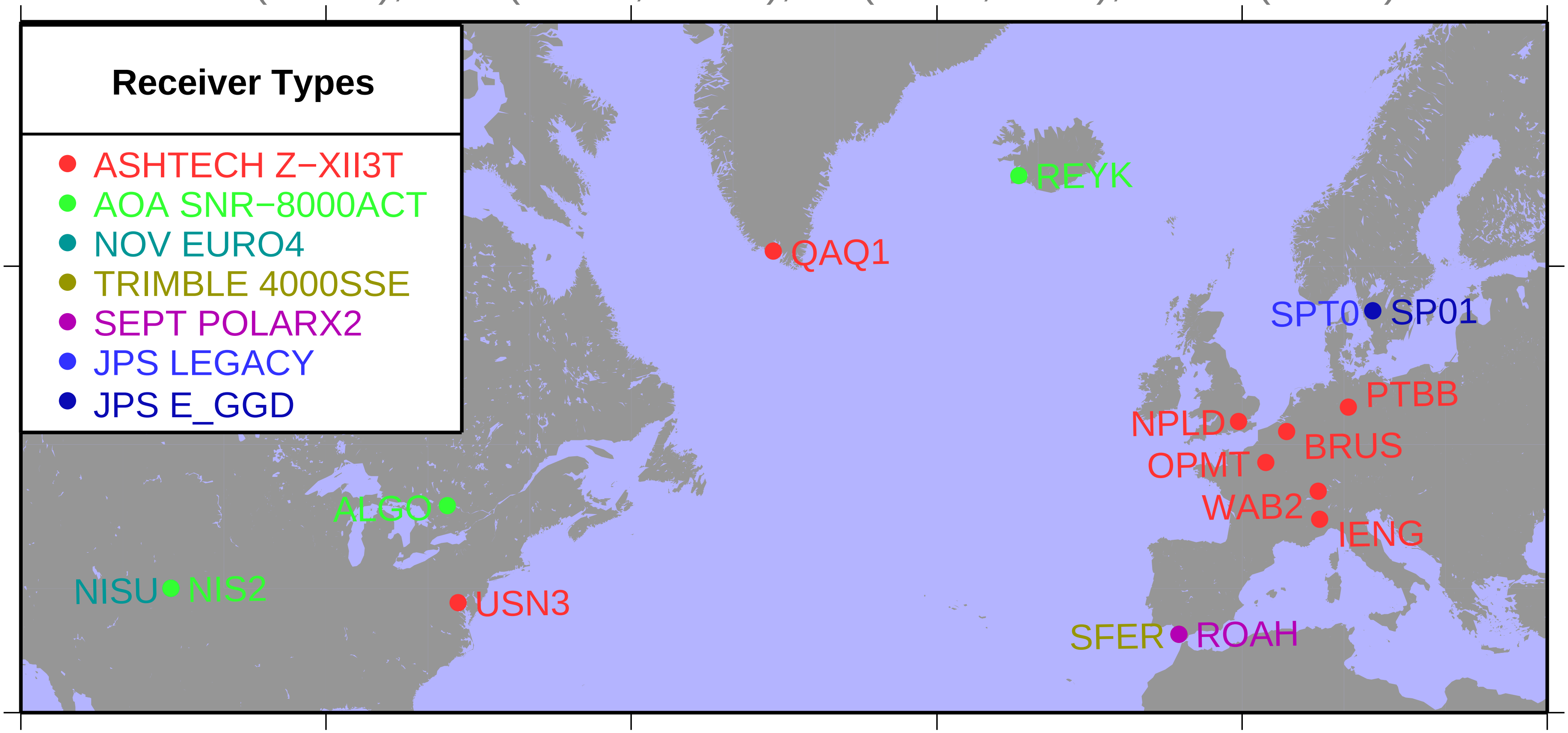
- The pseudorange observations may be added because they have a direct access to the receiver clock parameters.
  - Even in that case the loose of the ambiguity information at one epoch reflects in a discontinuity in the resulting time series or at least in the uncertainty for an obtained frequency.

- Benefit from a phase–only solution is obvious:
  - Geodetic receivers are primarily designed for using the phase observations.
  - Inconsistencies between the internal receiver clock for code and phase measurements have no effect on the solution.
  - Multipath and related effects in the phase data is much smaller than in the code data.

GPS CP Solution for TW–2005

Station Distribution

Participants: CH(WAB2), IEN(IENG), NIST(NISU,NIS2), NPL(NPLD), OP(OPMT), PTB(PTBB), ROA(SFER,ROAH), SP(SPT0,SP01), USNO(USN3)



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GPS CP Solution for TW–2005

Processing statistics

Total number of stations:	19	
institutions with two receivers:	5	pairs of stations
institutions with one receiver:	4	
additional (bridging) stations:	5	
Duration of the campaign:	MJD 53487–53502 (15 days)	
Sampling of the receiver clock solution:	300	seconds
Total number of observations:	639833	
Total number of parameters:	170016	
receiver clock parameters:	81523	($\leq$4320 per station)
satellite clock parameters:	66878	
ambiguity parameters:	15955	

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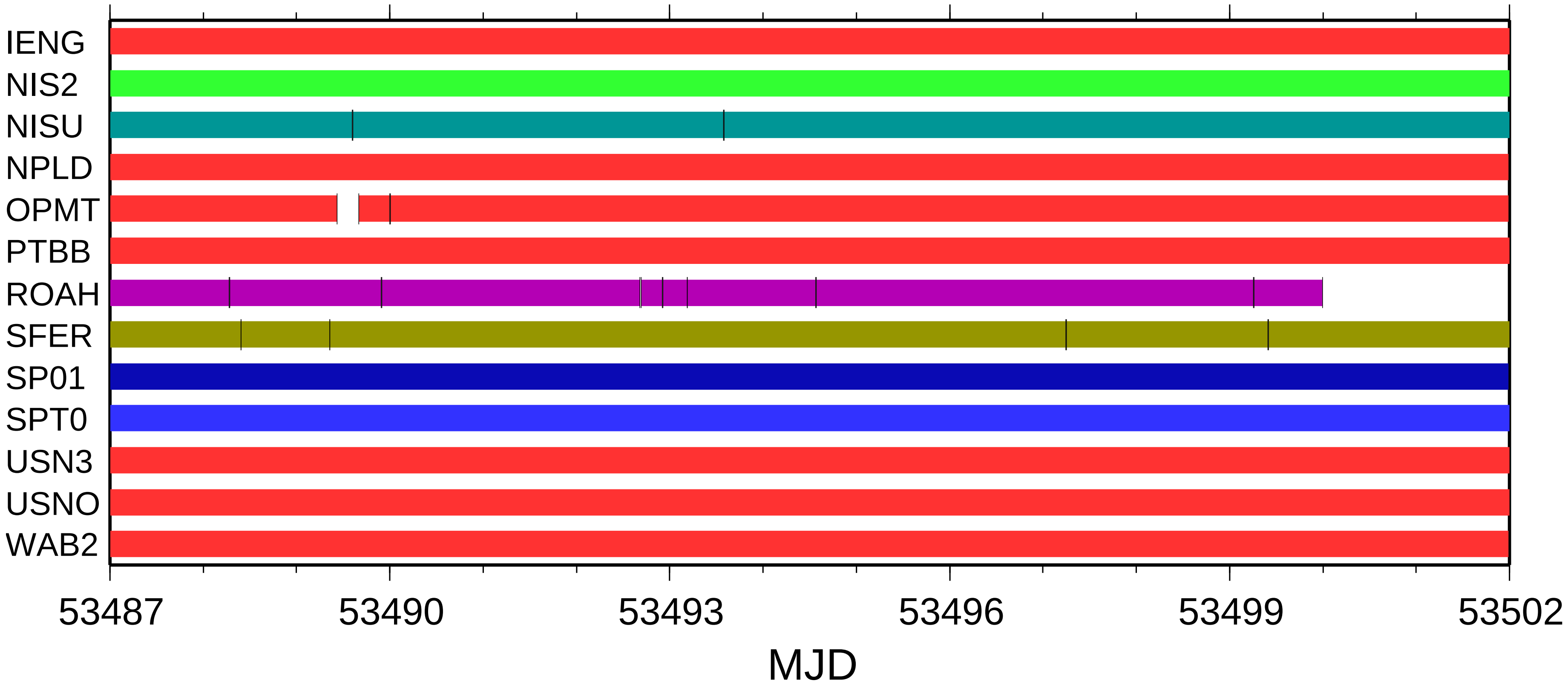
GPS CP Solution for TW–2005

Time intervals continuously connected by phase ambiguity parameters

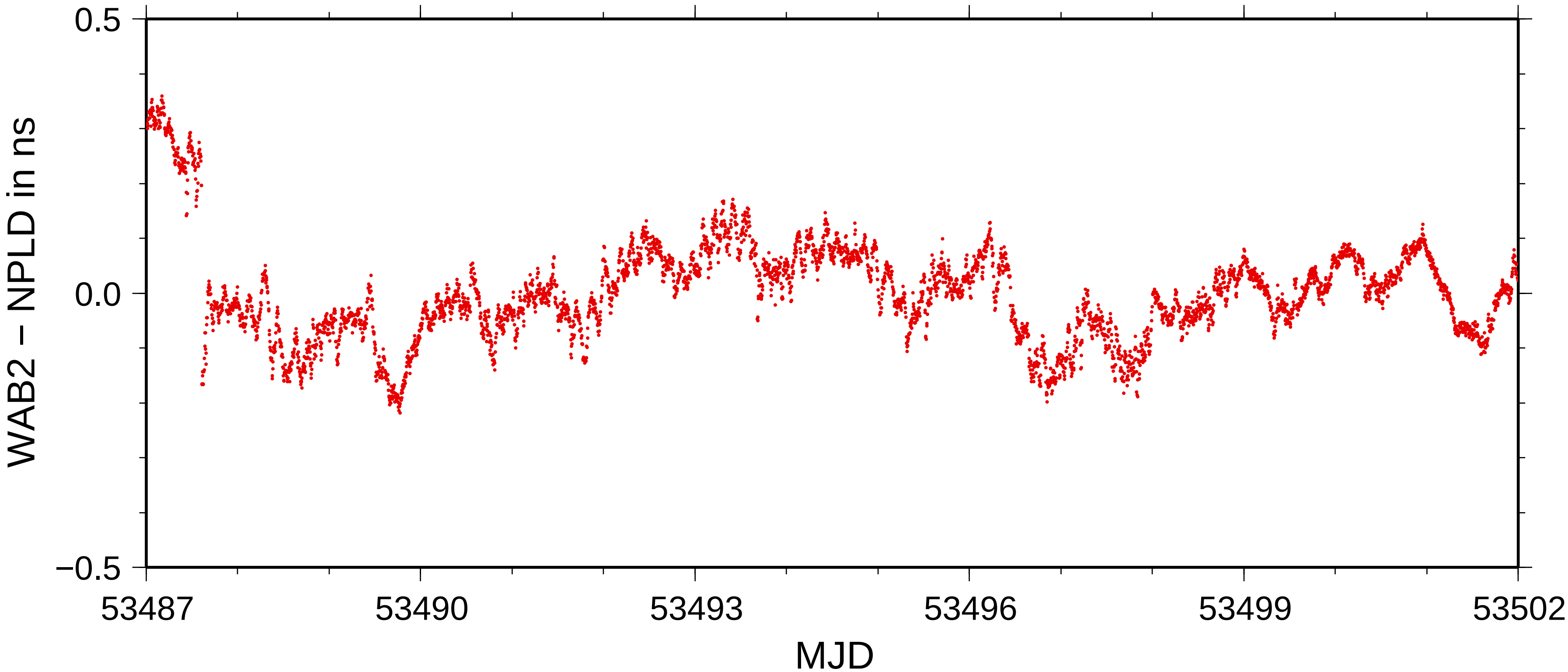


Events:	NISU, ROAH, SFER	Tracking problems
	OPMT	Gaps and unusable data in the RINEX file

TW–2005: Baseline NPLD → WAB2

Receiver clock difference between WAB2 and NPLD

Continuous solution only using phase data



A second order polynomial was substracted for plotting.

TW–2005: Baseline NPLD → WAB2

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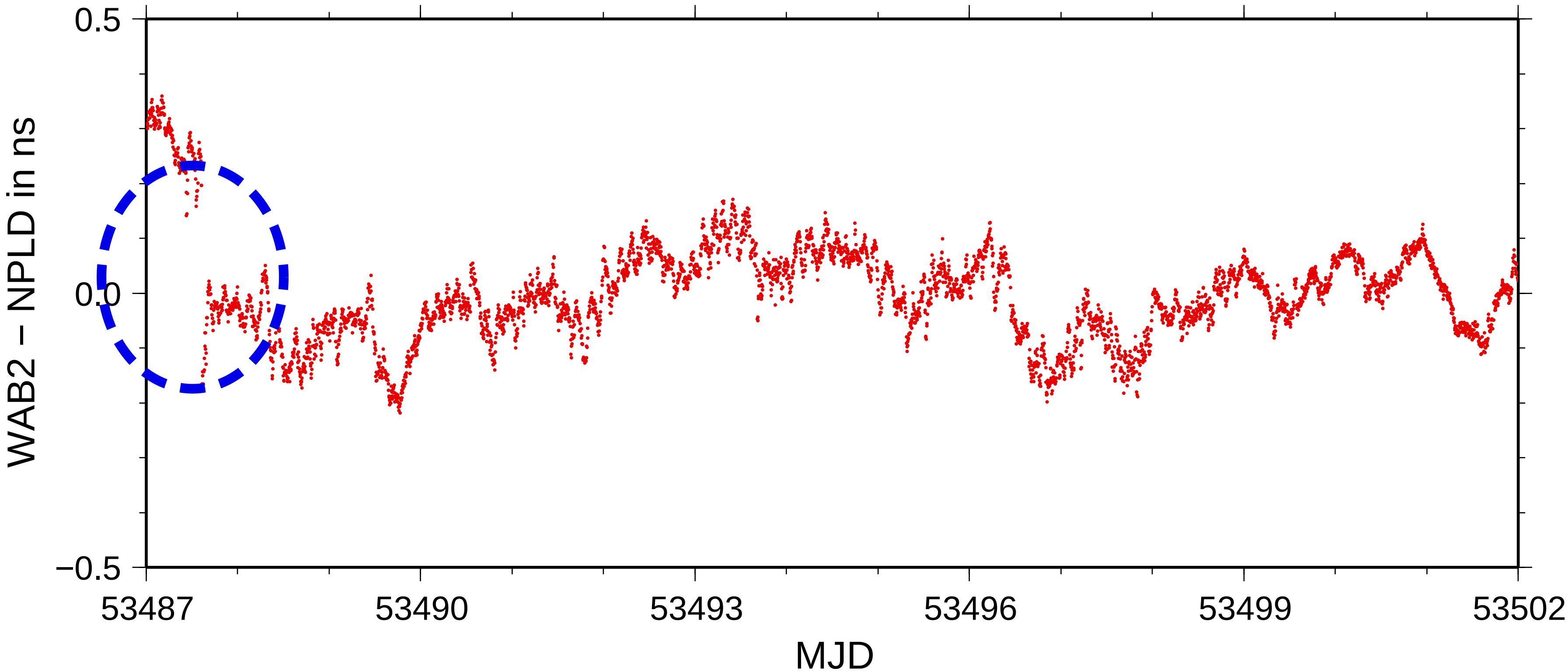

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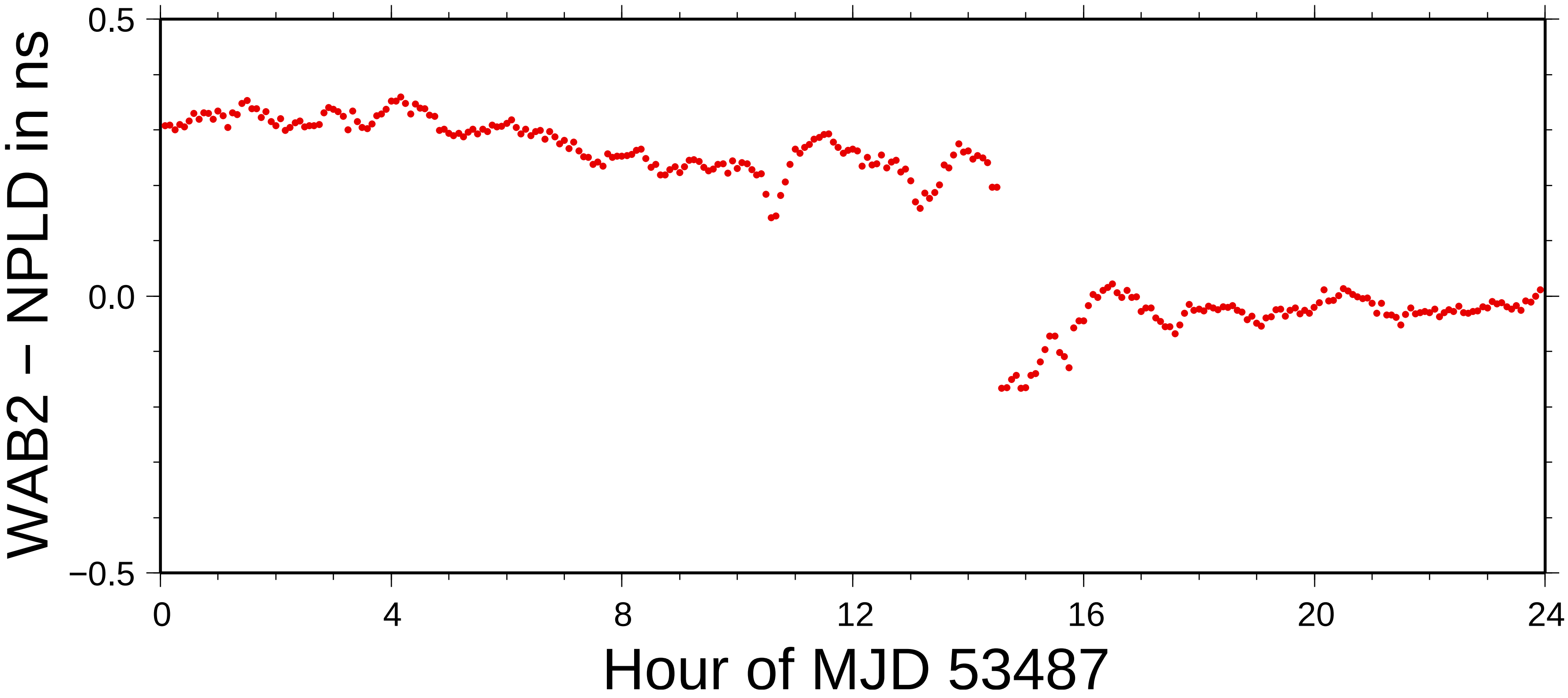


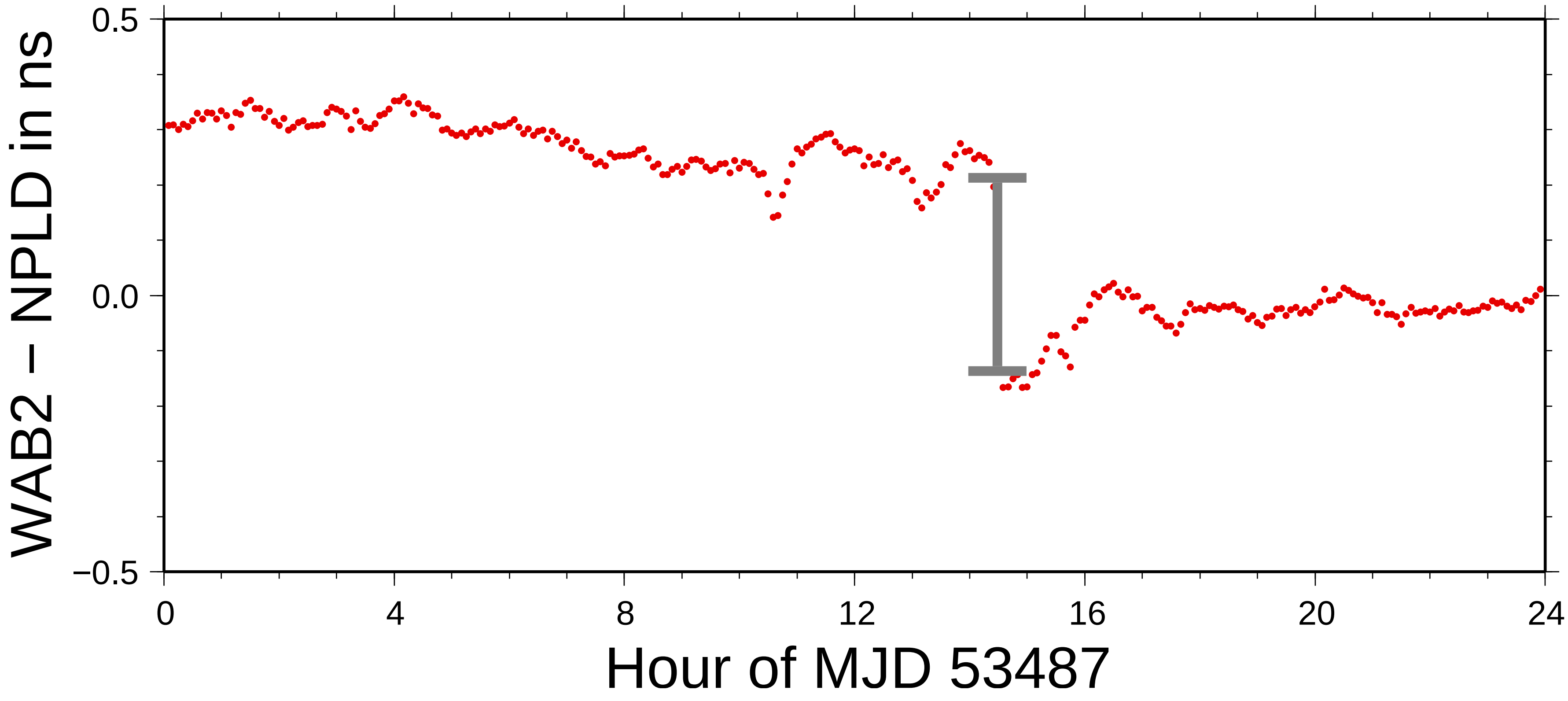
A second order polynomial was substracted for plotting.

TW–2005: Baseline NPLD → WAB2

Receiver clock difference between WAB2 and NPLD

Continuous solution only using phase data

Adding one cycle to all observations (both frequencies)

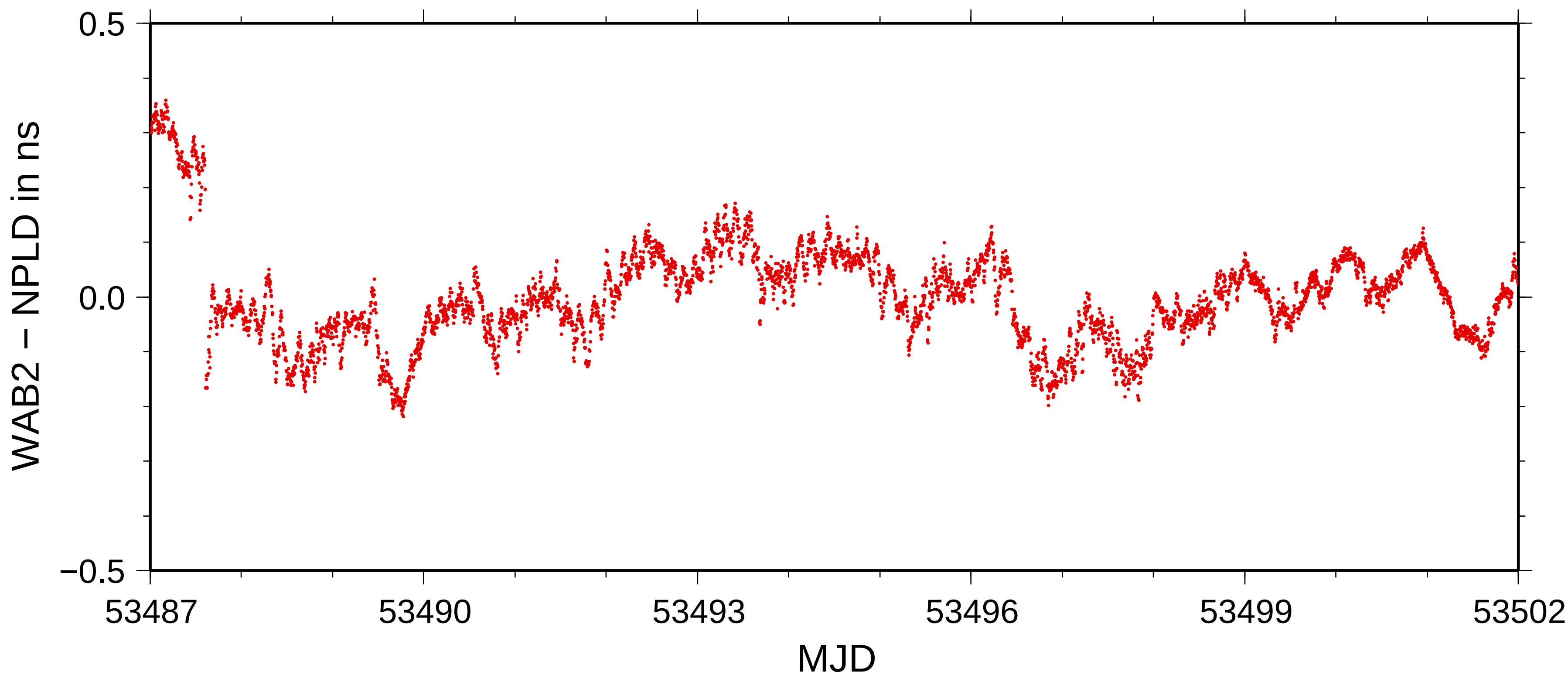


A second order polynomial was substracted for plotting.

TW–2005: Baseline NPLD → WAB2

Receiver clock difference between WAB2 and NPLD

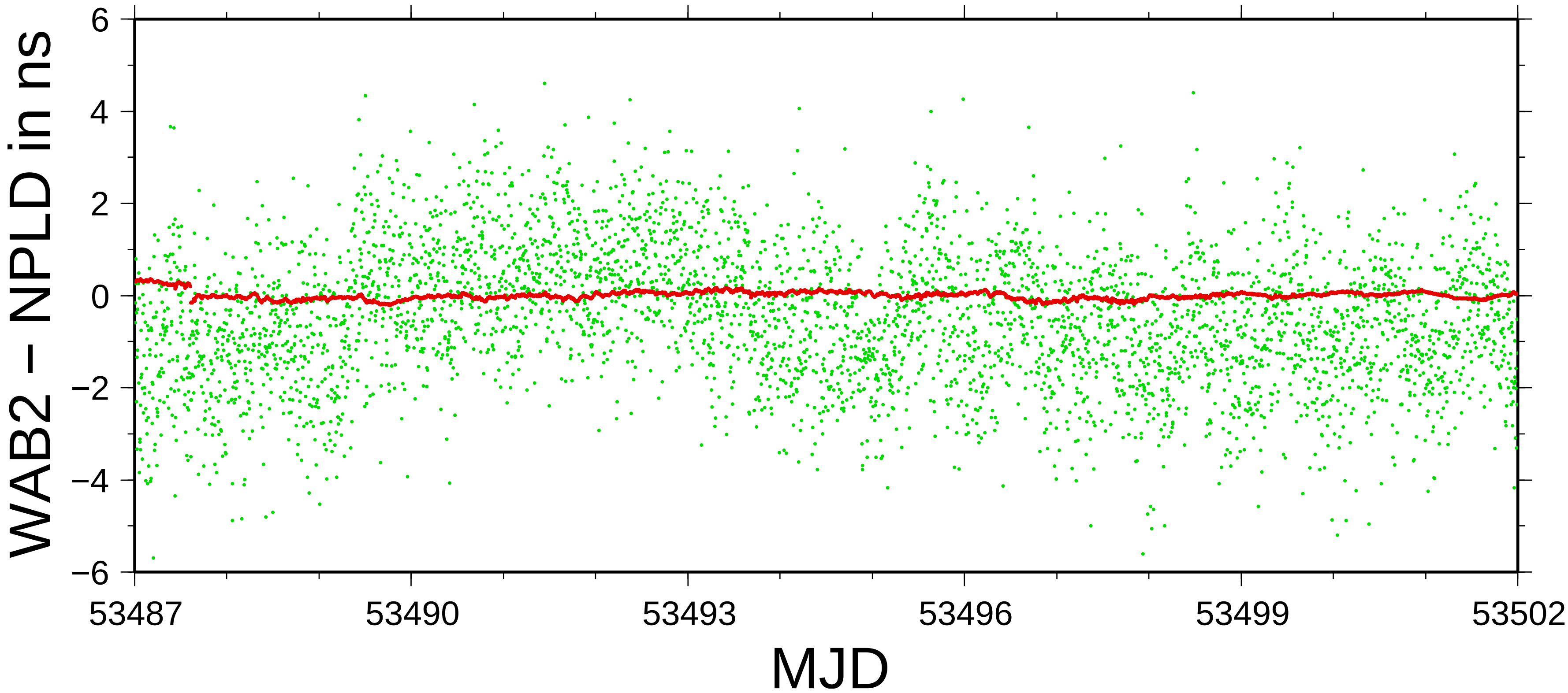
Continuous solution only using phase data



A second order polynomial was substracted for plotting.

TW–2005: Baseline NPLD → WAB2

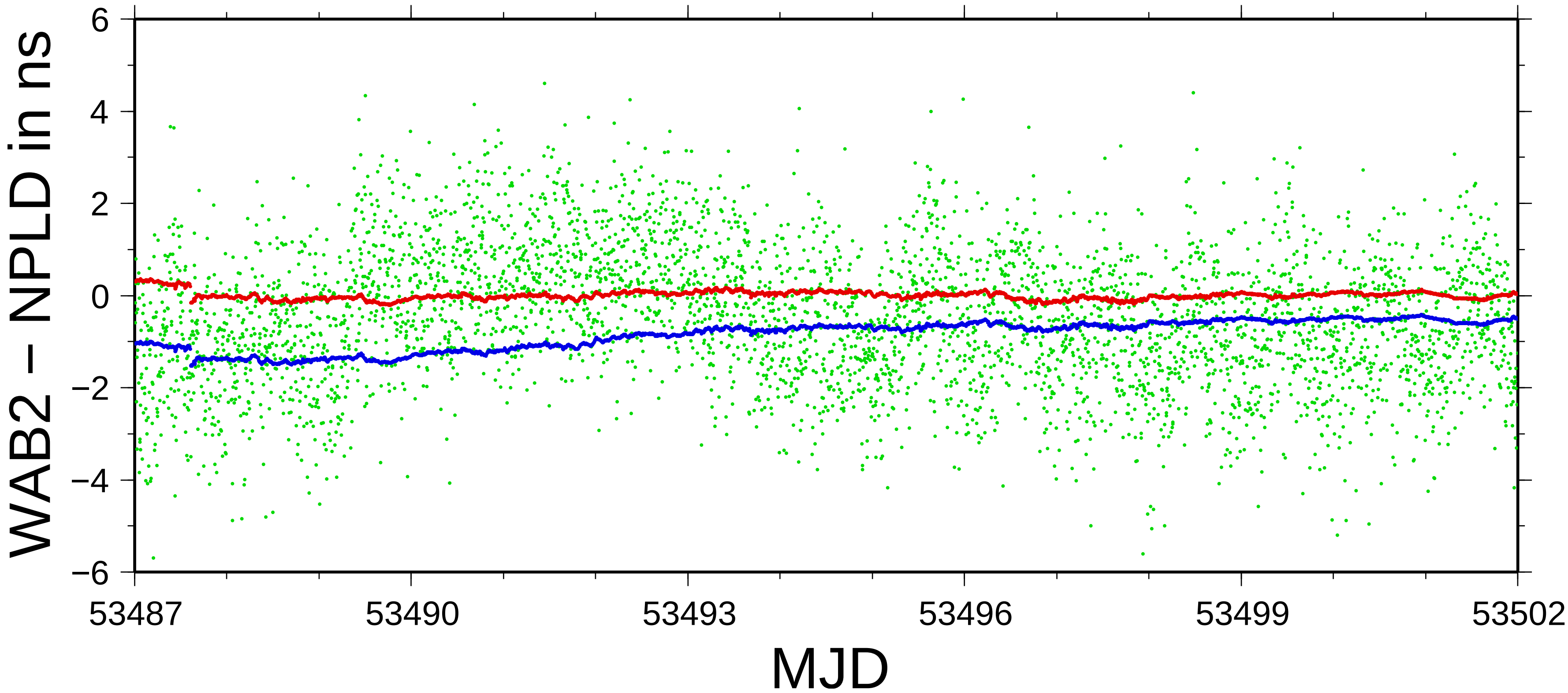
Receiver clock difference between WAB2 and NPLD
Continuous solution only using phase data
Epoch–wise solution only using code data



A common second order polynomial was substracted for plotting.

TW–2005: Baseline NPLD → WAB2

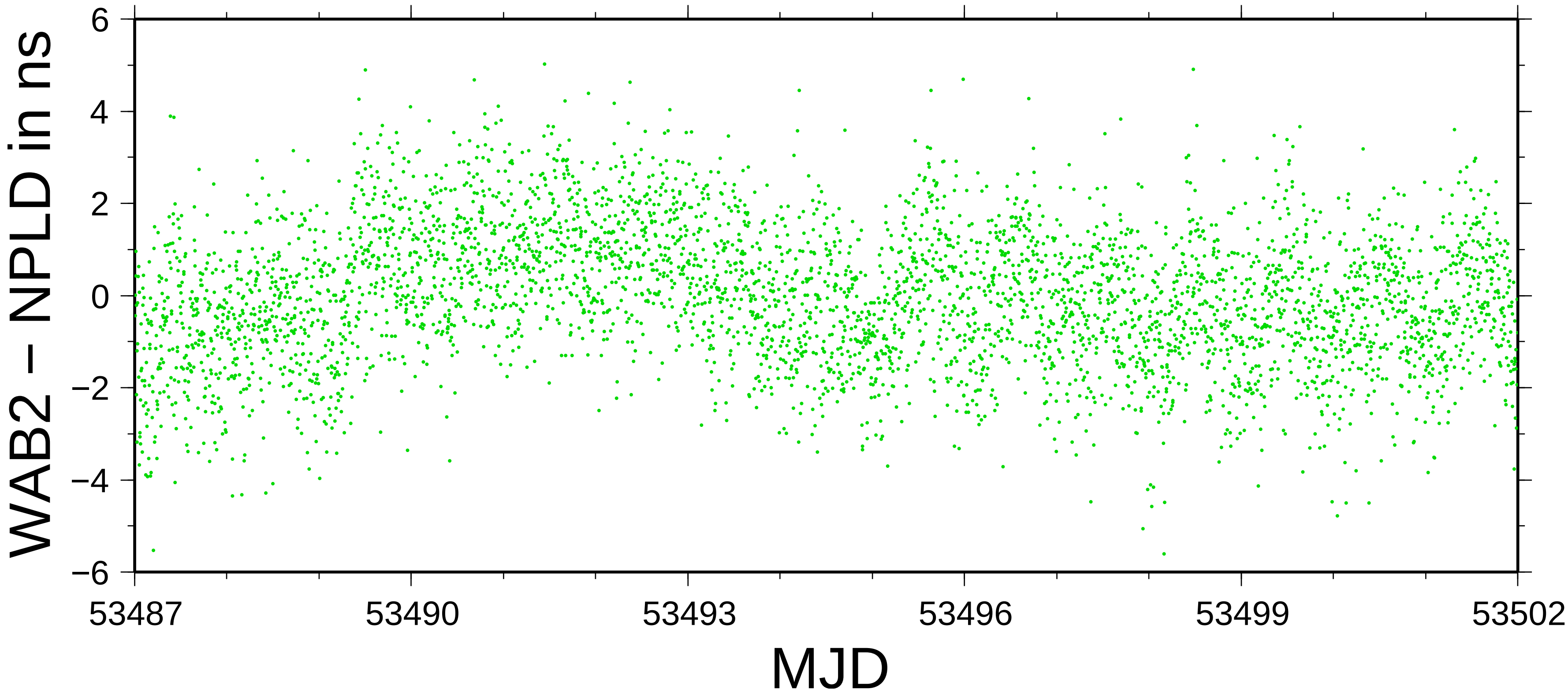
Continuous solution using code and phase data
Continuous solution only using phase data
Epoch–wise solution only using code data



A common second order polynomial was substracted for plotting.

TW–2005: Impact of Multipath

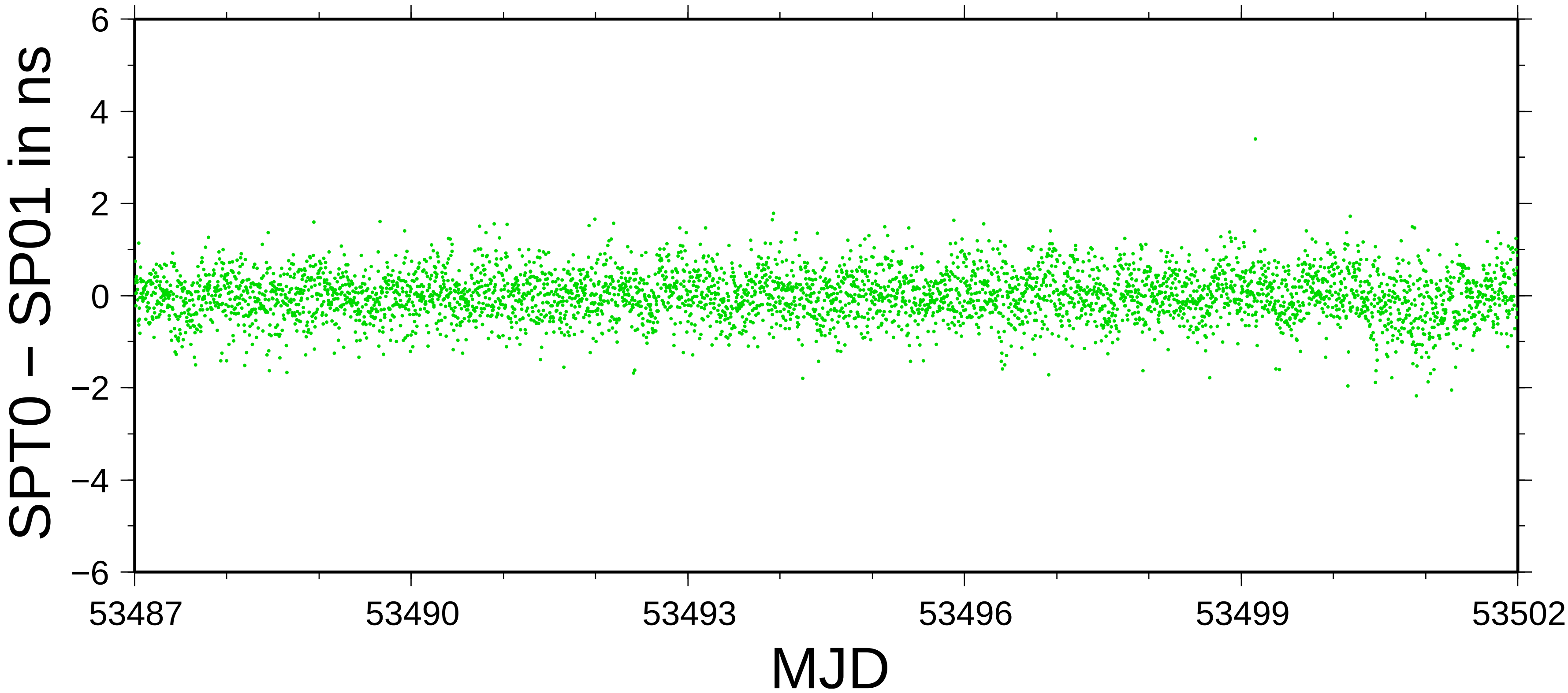
Differences for the baseline NPLD → WAB2 between
Epoch–wise solution only using code data
and continuous solution only using phase data



An offset was substracted for plotting.

TW–2005: Impact of Multipath

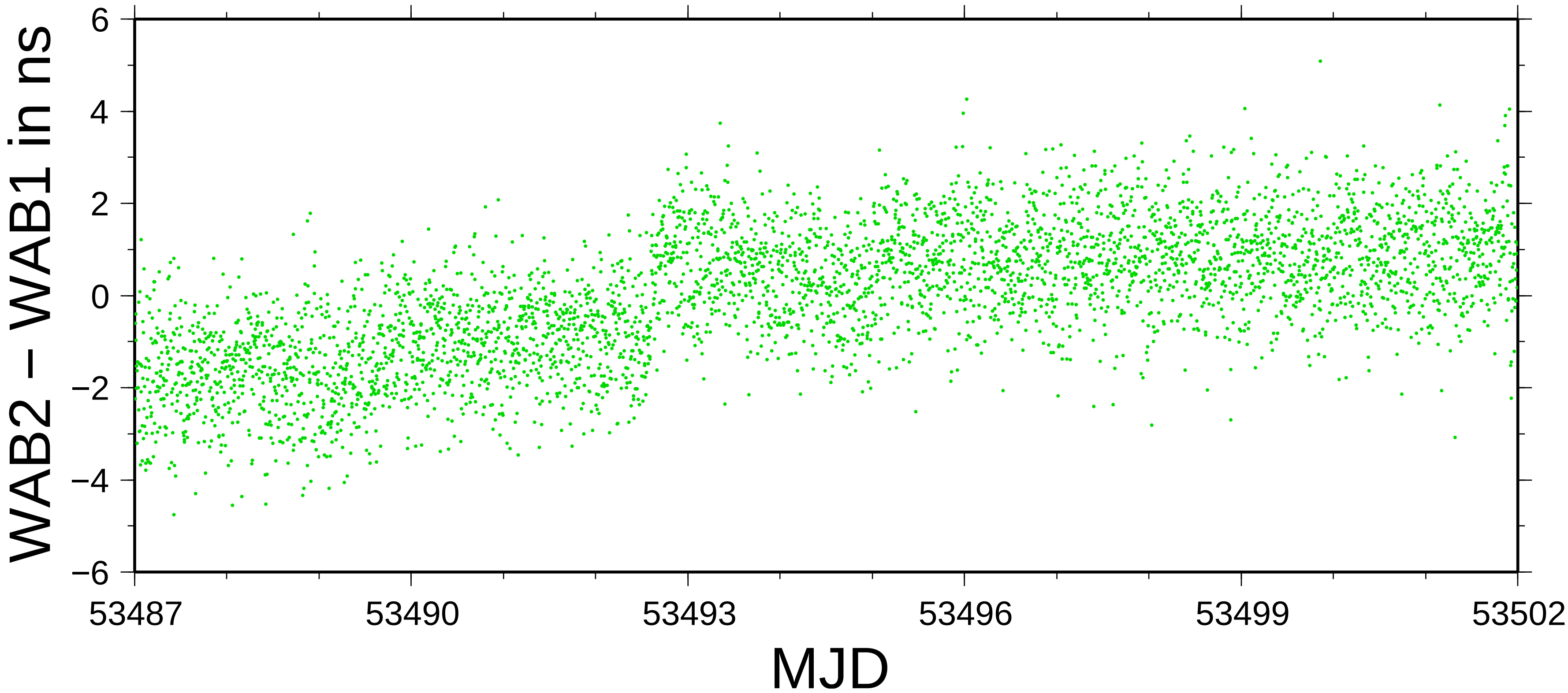
Differences for the baseline SPT0 → SP01 between
Epoch–wise solution only using code data
and continuous solution only using phase data



An offset was substracted for plotting.

TW–2005: Impact of Multipath

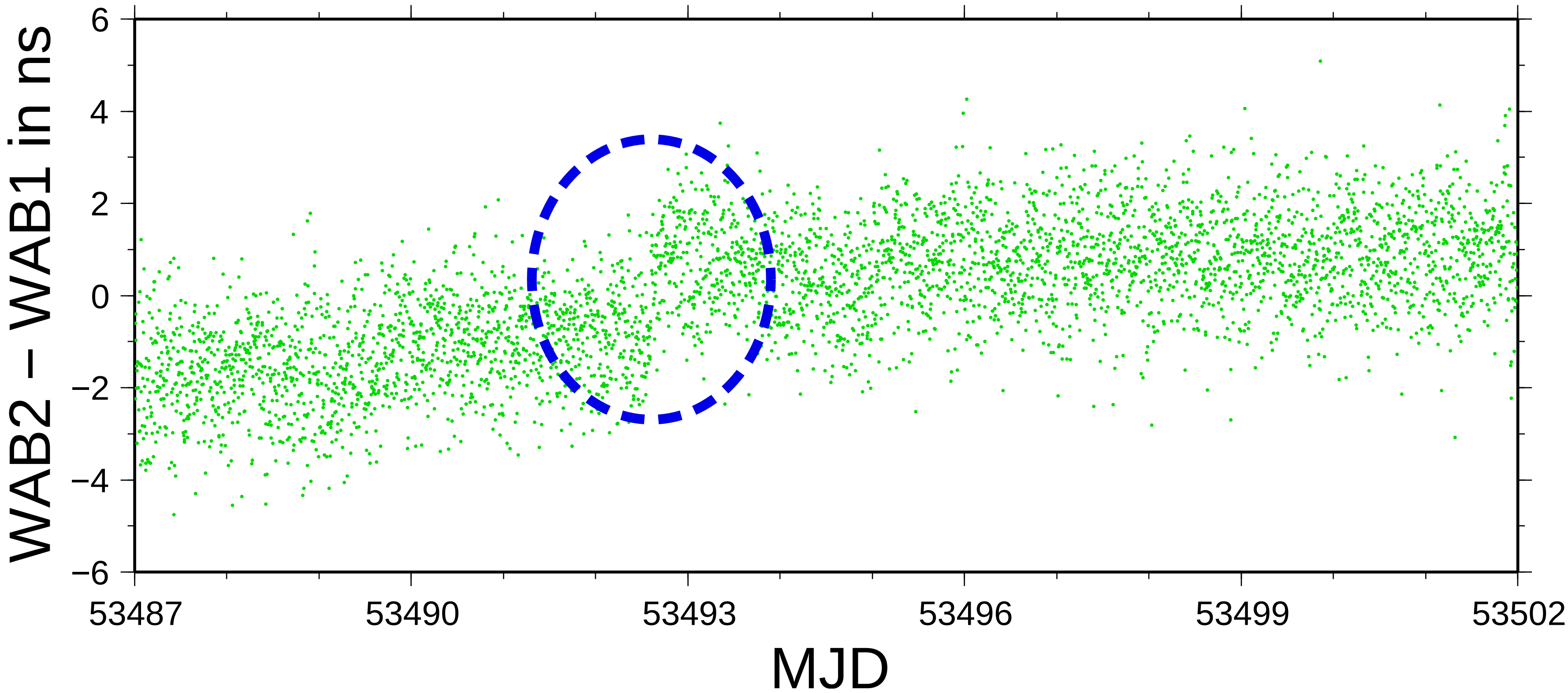
Differences for the baseline WAB1 → WAB2 between
Epoch–wise solution only using code data
and continuous solution only using phase data



An offset was substracted for plotting.

TW–2005: Baseline WAB1 → WAB2

Differences for the baseline WAB1 → WAB2 between
Epoch–wise solution only using code data
and continuous solution only using phase data



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TW–2005: Baseline WAB1 → WAB2

Differences for the baseline WAB1 → WAB2 between
Epoch–wise solution only using code data
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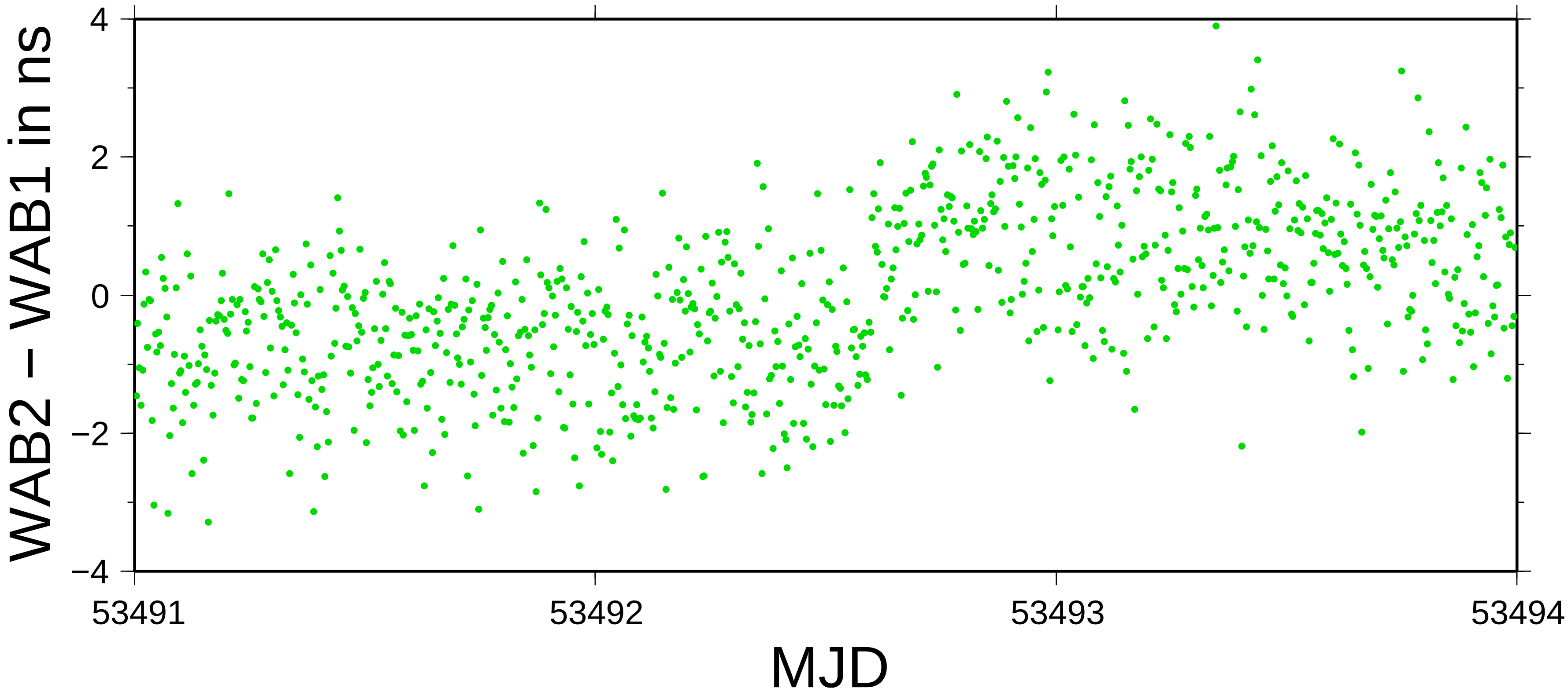

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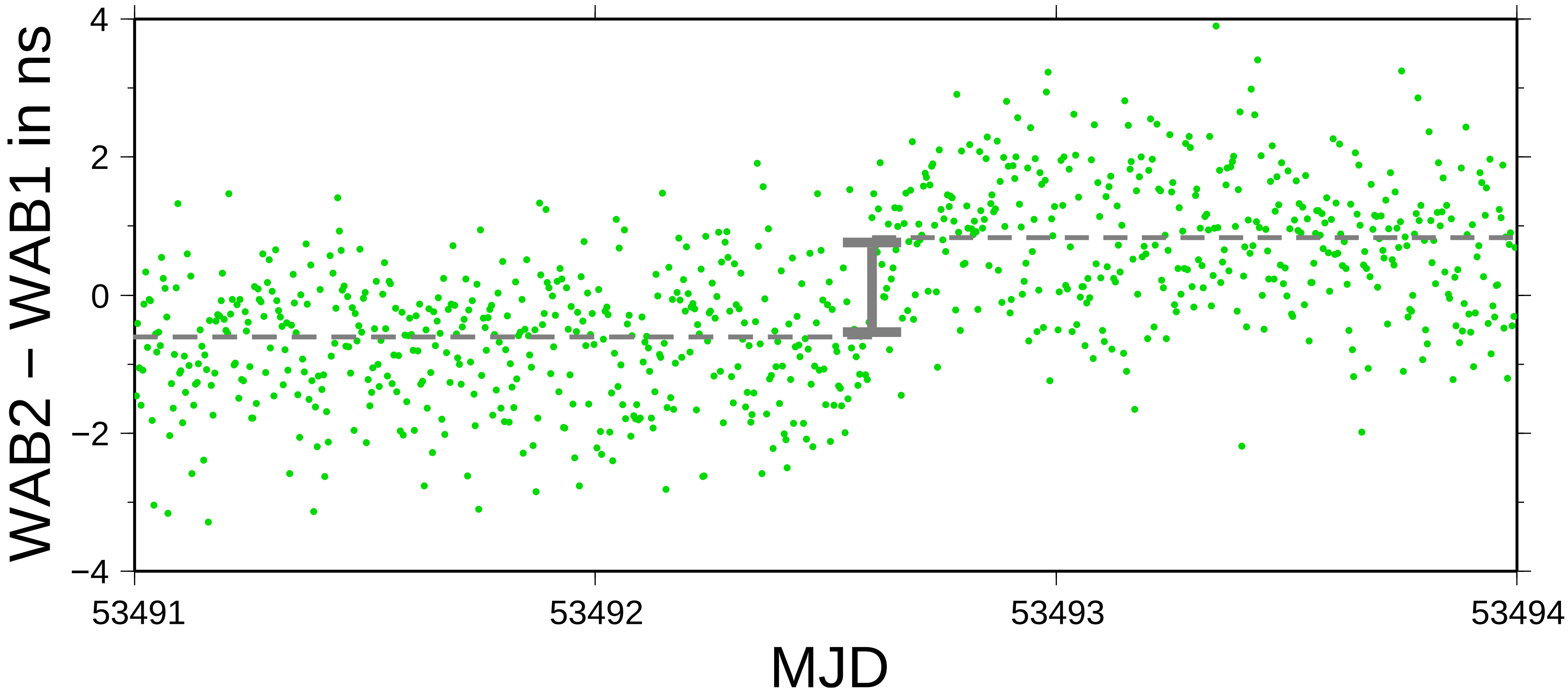
TW–2005: Baseline WAB1 → WAB2

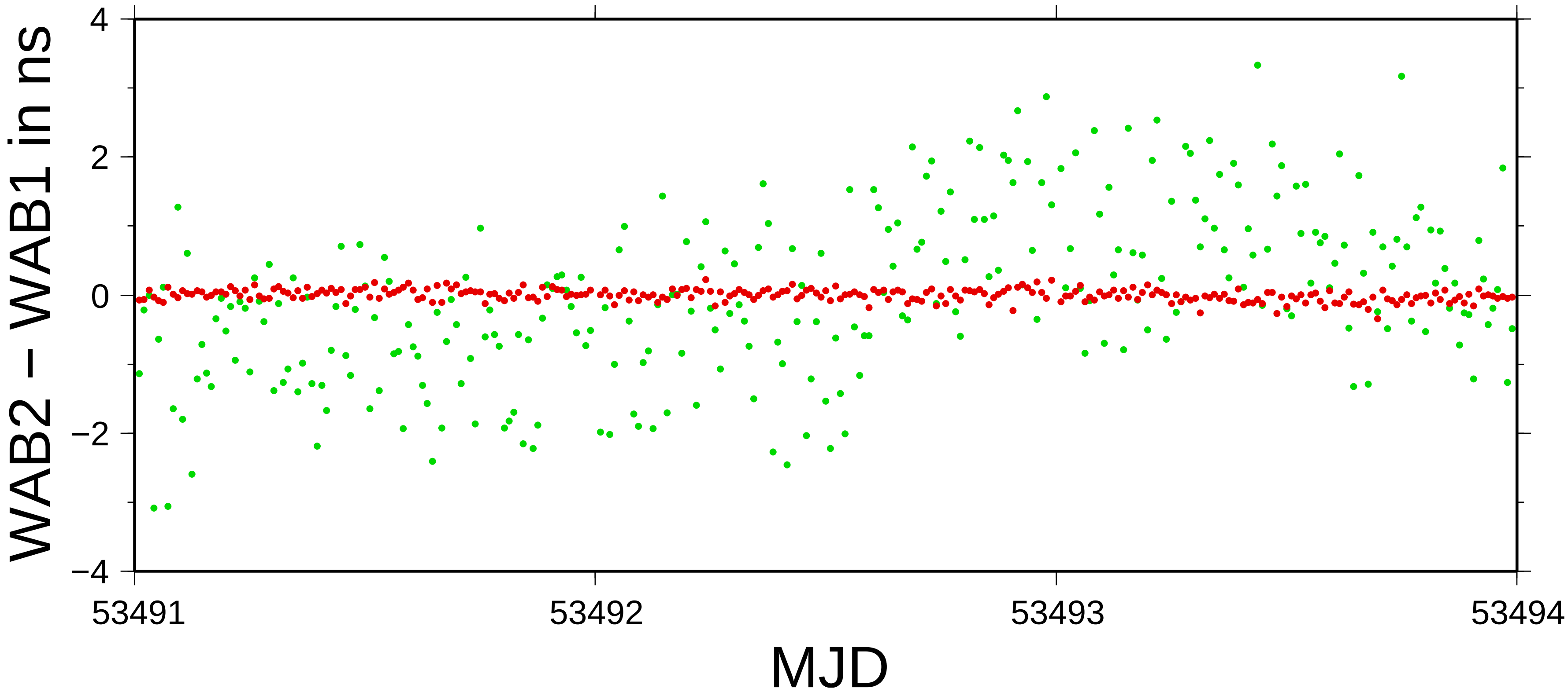
Differences for the baseline WAB1 → WAB2 between
Epoch–wise solution only using code data
and continuous solution only using phase data



An offset was substracted for plotting.

TW–2005: Baseline WAB1 → WAB2

Differences between epoch–wise solution only using code data
resp. continuous solution only using phase data
and the local measurements (every 15 minutes)



An offset was substracted for plotting.

Thanks to Laurent-Guy Bernier from METAS for providing the local measurements between WAB1 and WAB2 used for this plot.

Summary and Conclusions

- Multipath and related effects have less impact on phase than on code measurements.
- The internal receiver clock as it is seen by the code and phase data may become inconststent at a certain epoch.
- GPS carrier phase data may contain cycle slips that look like receiver clock discontinuities.
- Generation of continuous geodetic time/frequency transfer solutions with day boundary discontinuities is possible (e.g., using the ambiguity stacking method in the Bernese GPS Software).
- This allows a geodetic frequency transfer without using the code measurements at all (perferable when ever possible).