Bundesamt für
Kartographie und Geodäsie

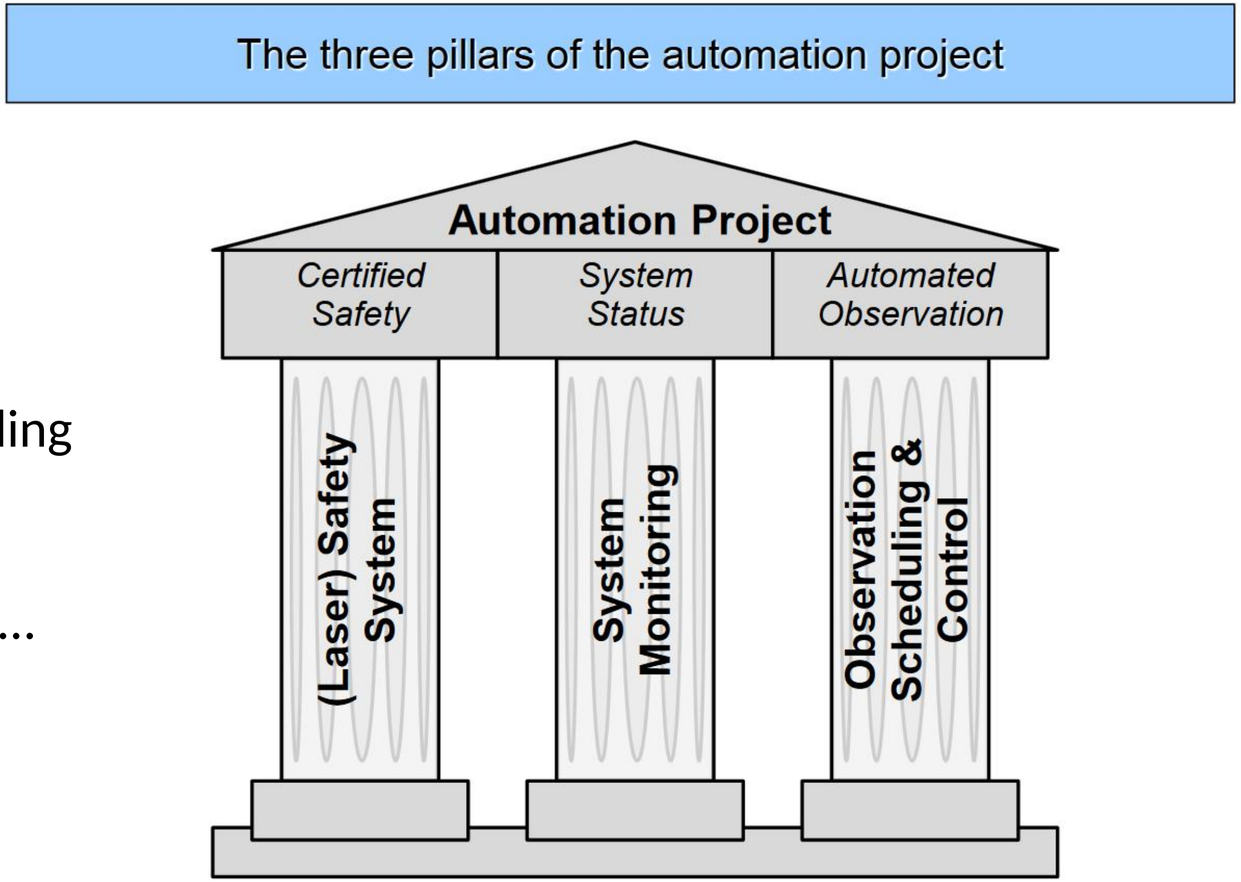
BKG
Wir geben Orientierung.

NESC Meeting – System Automation @ Wettzell

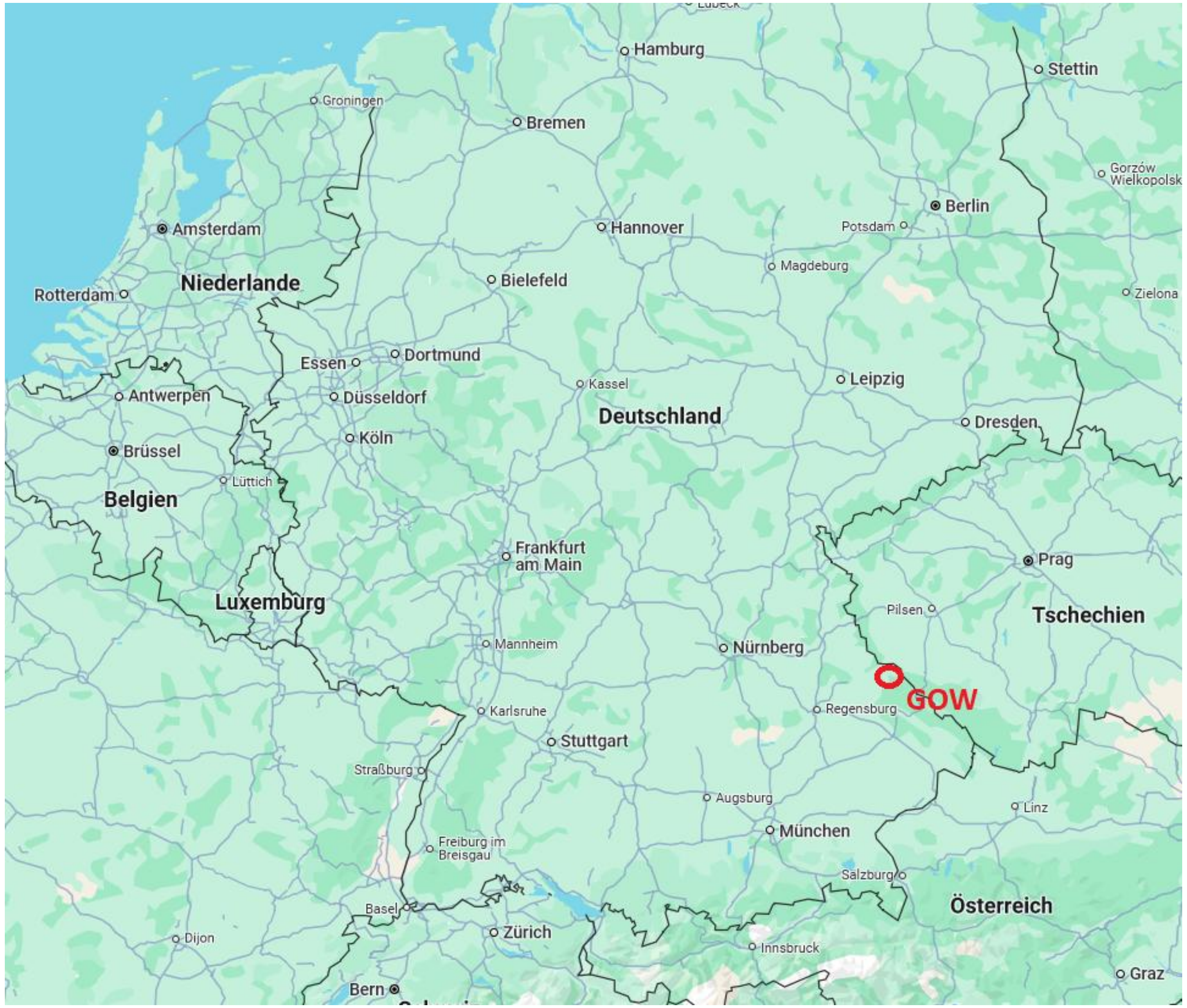
2025-07-10

Safety:

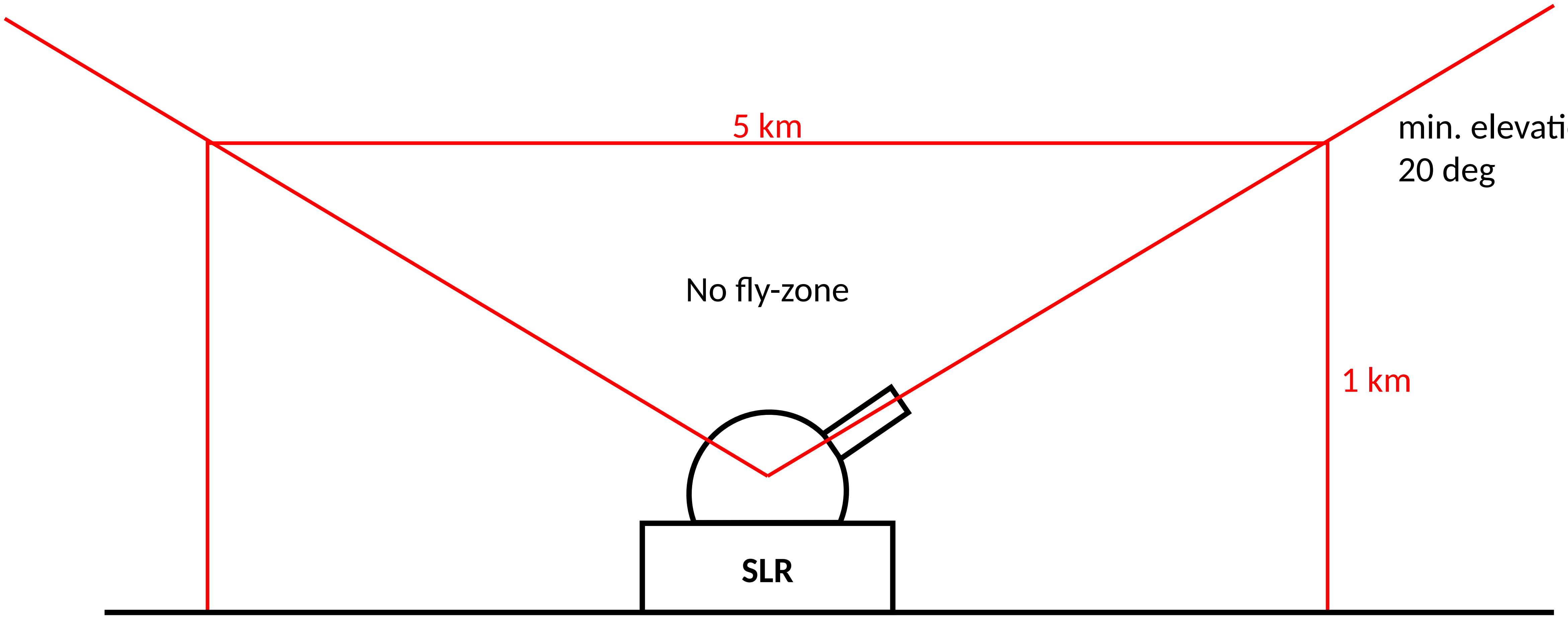
- Risk analysis according to standards
- Risk assessment
- Operating manual, …
- CE Conformity



Geodetic Observatory Wettzell



GOW no fly-zone



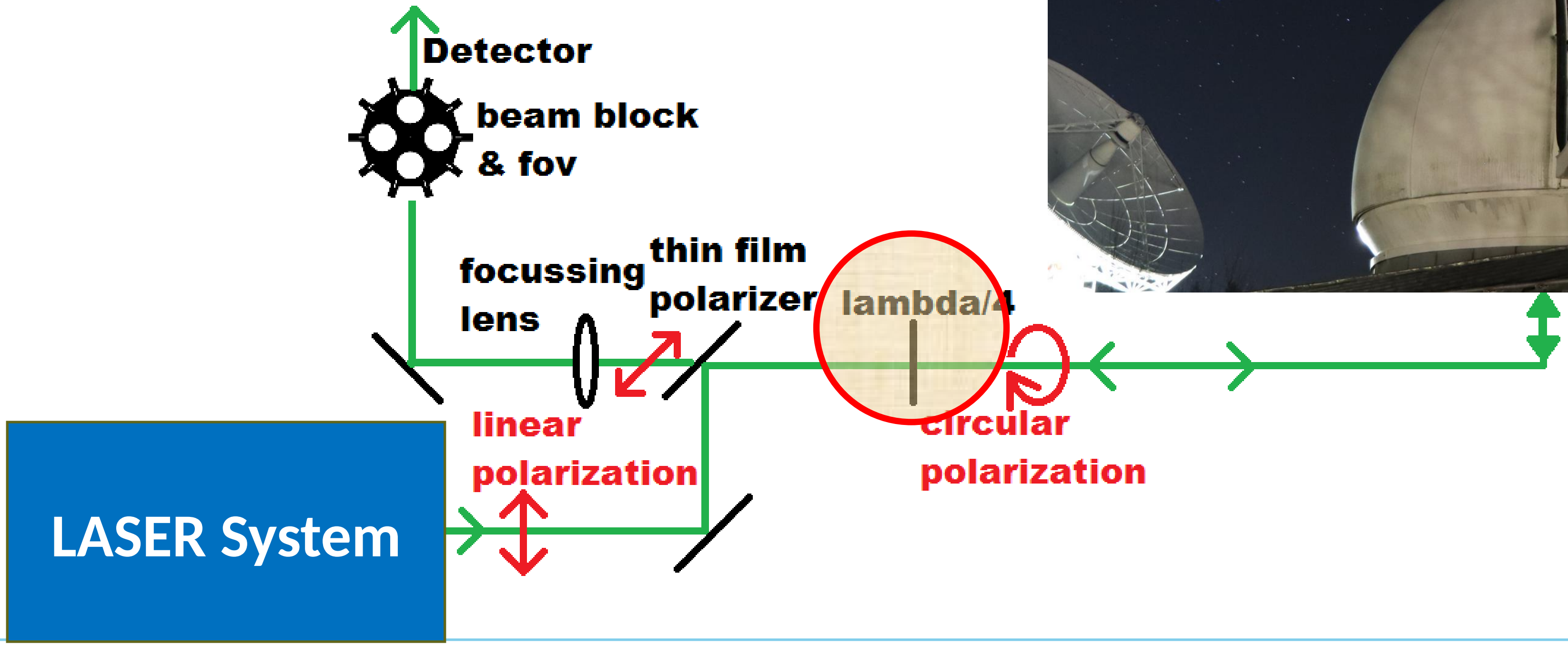
Observer Instructions …

Personell of other disciplines (VLBI, Facility management, …) shared with SLR observations.

WLRS T/R switch

- Thin Film Polariser in combination with Lambda/4-plate (passive)
- Rotating beam block

-> 667 Hz Repetition Rate



Improvements of the SOS-W automatic scheduler for special campaign support

S.Riepl, A. Böer, C.Schade, T.Schüler

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Geodätisches Observatorium Wettzell

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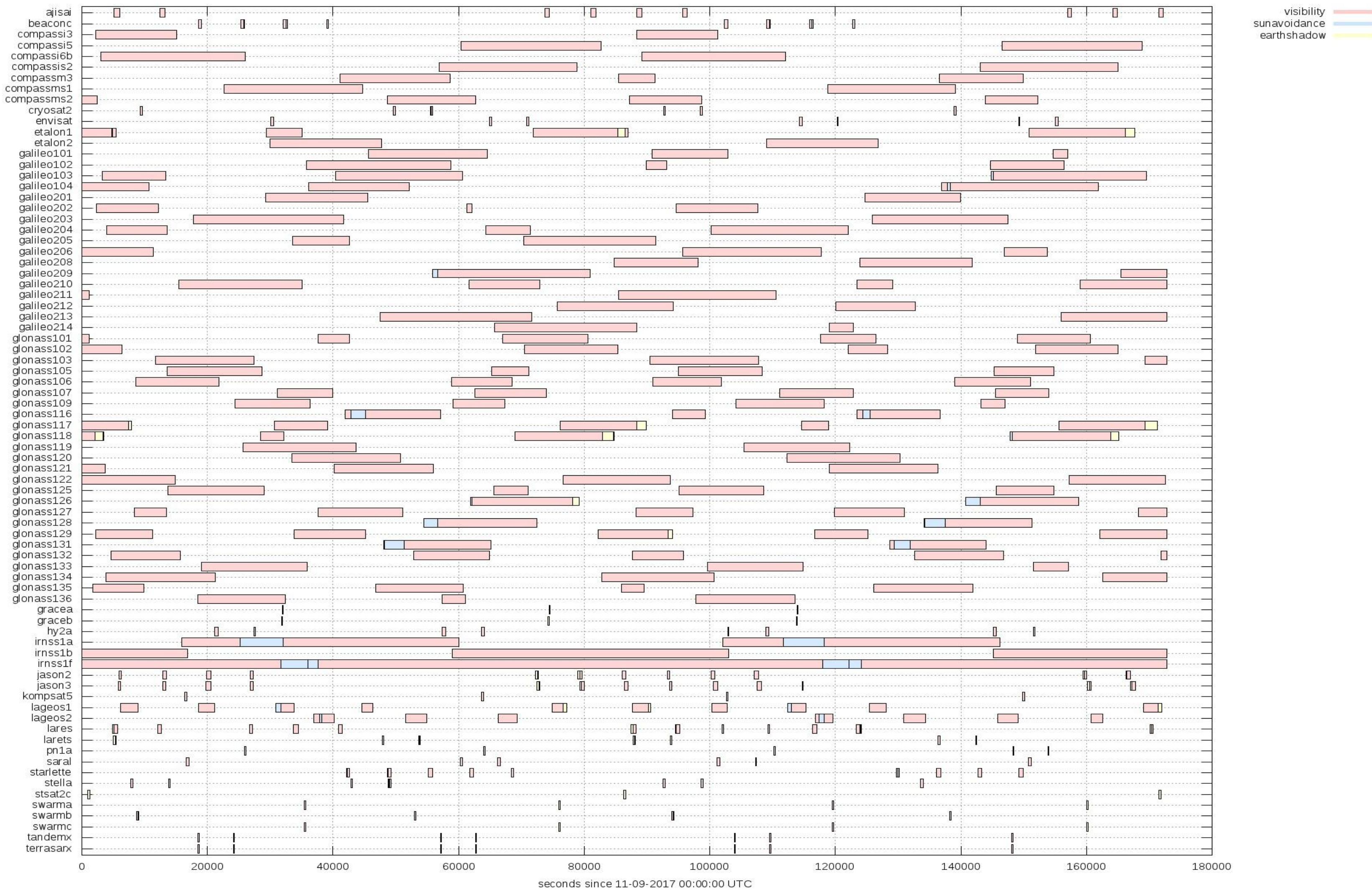
Why automated pass scheduling ?

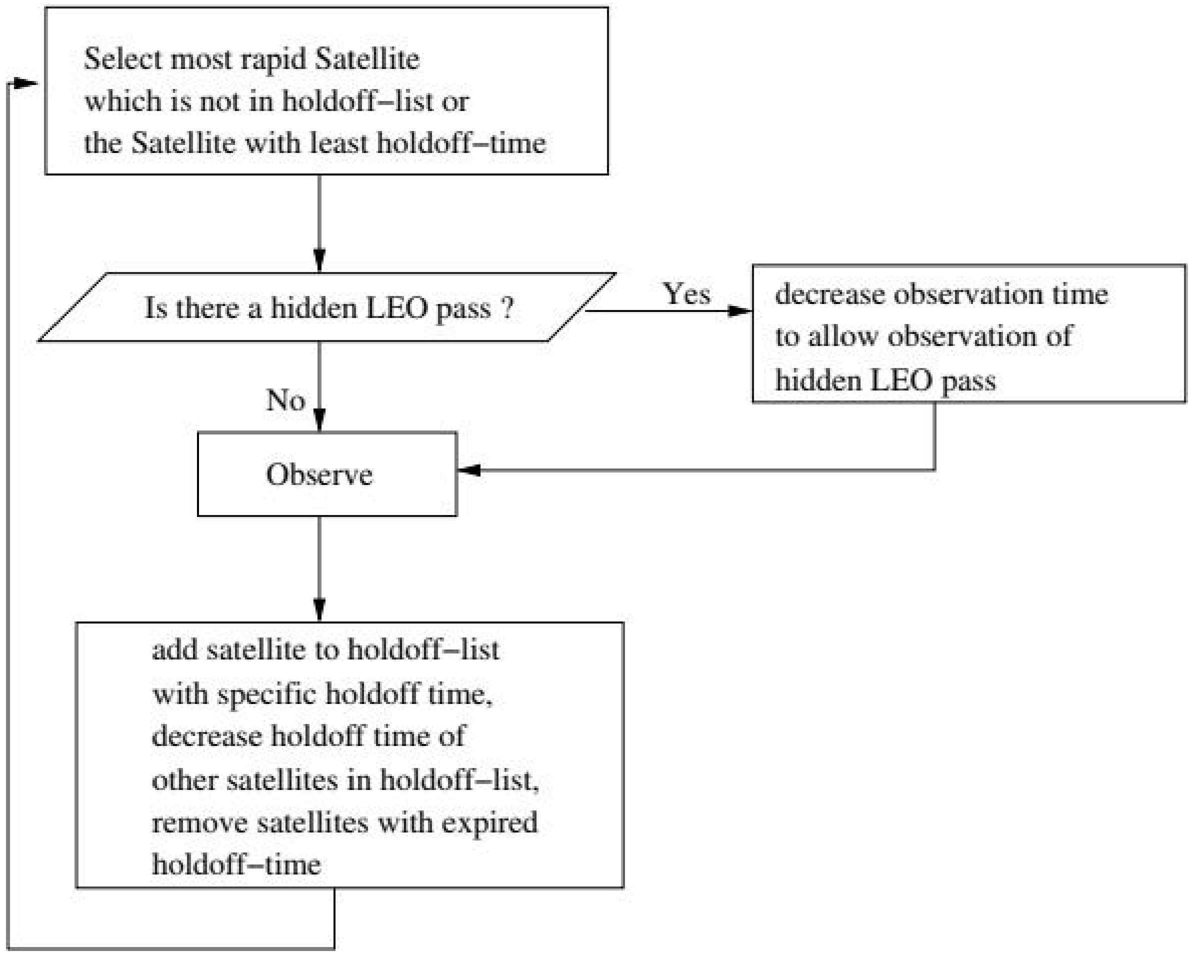


- Besides satellite acquisition, pass scheduling is the most tedious job

Pass scheduling parameters

- Minimum observation time (for SOS-W 60 seconds, including pass switch time)
- Minimum elevation angle (20 degree)
- Sun avoidance and earth shadow encounters (for scheduling of light curve measurements)
- Target specific observation time (normal point window)
- - for geodetic targets 6 normal point windows per pass are allocated,
- observing session is terminated if maximum number of observations
- is reached
- - LEO targets have highest priority to avoid hidden passages
- System performance is governed by minimum observation time

Pass scheduling algorithm



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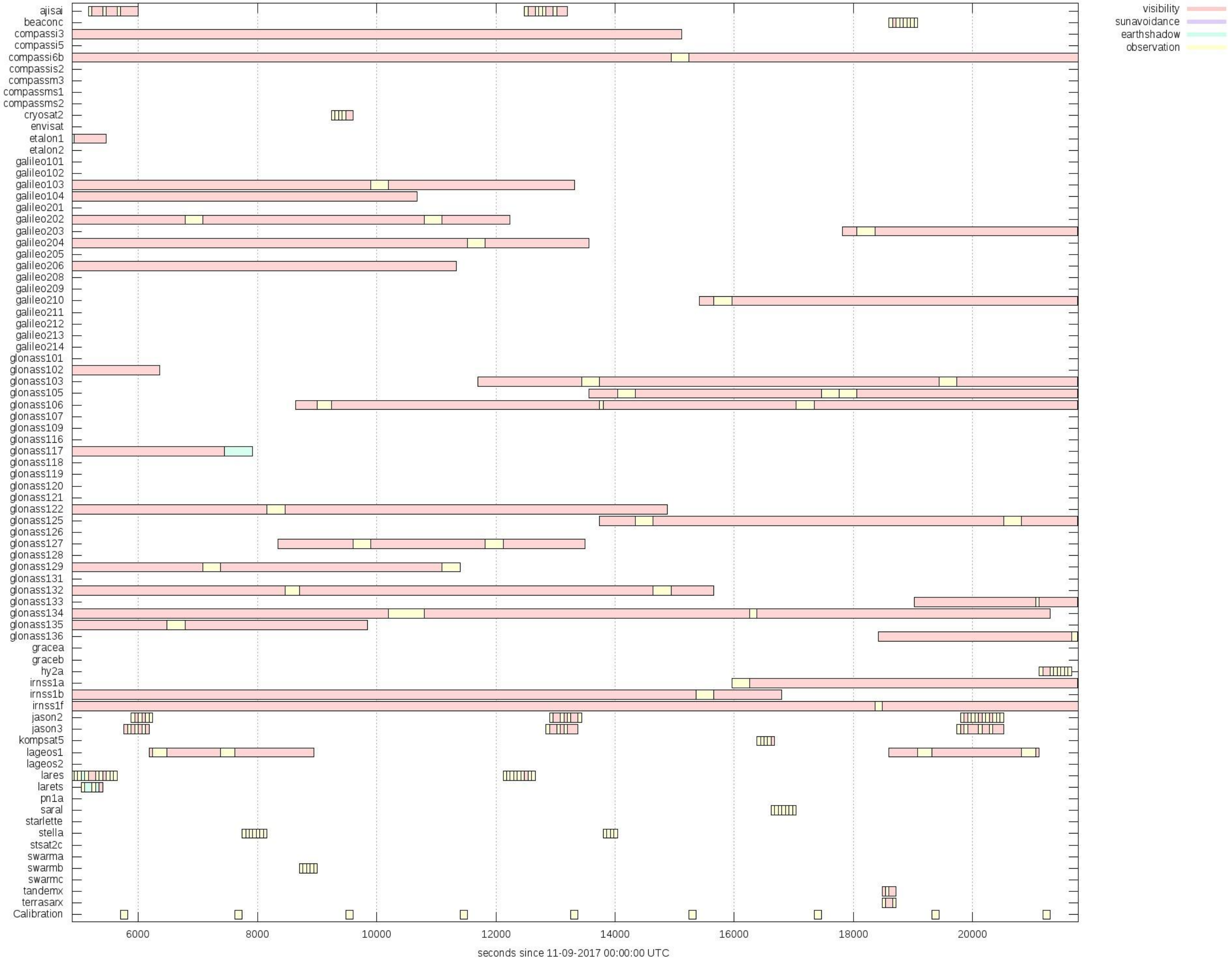
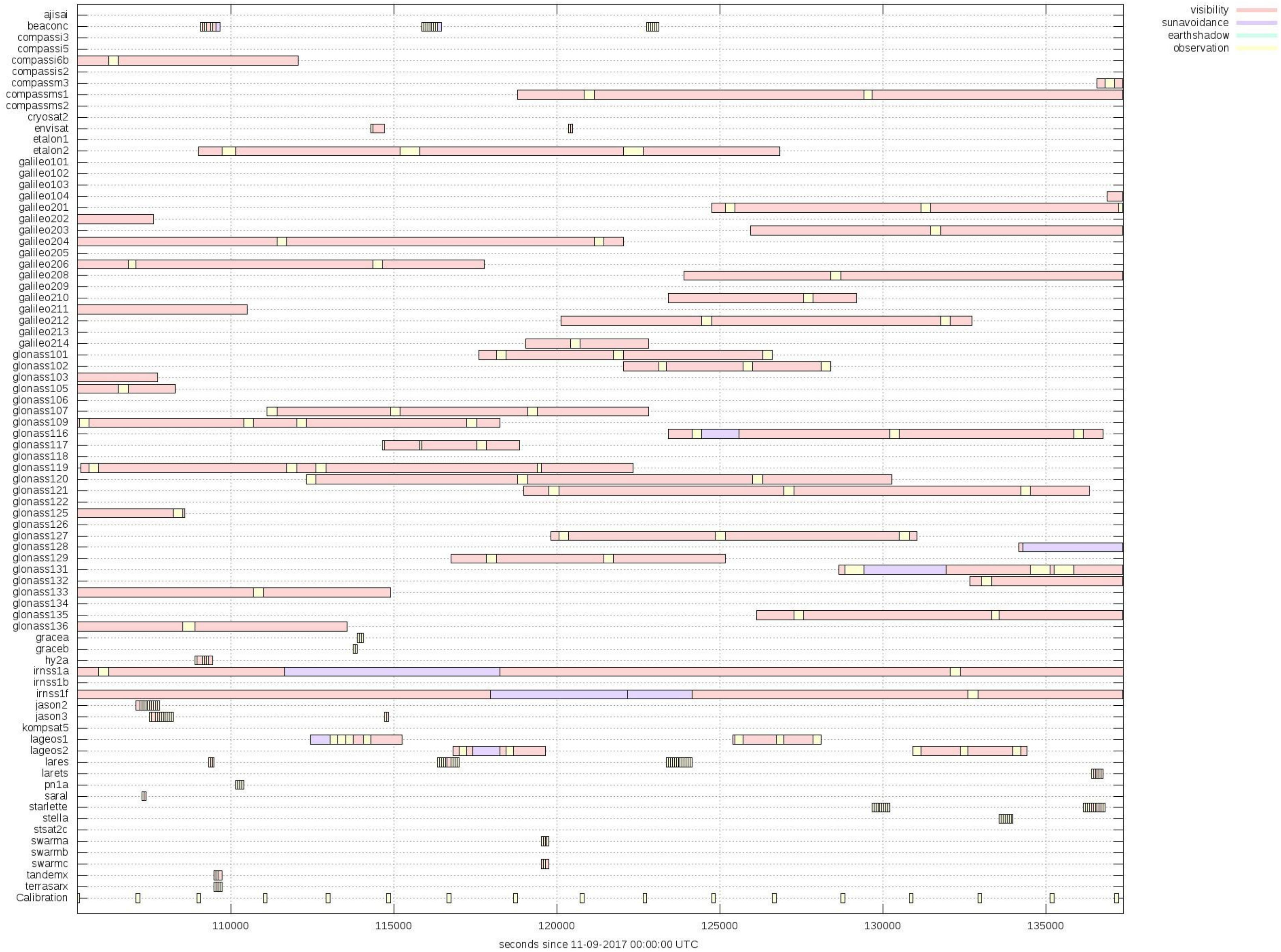
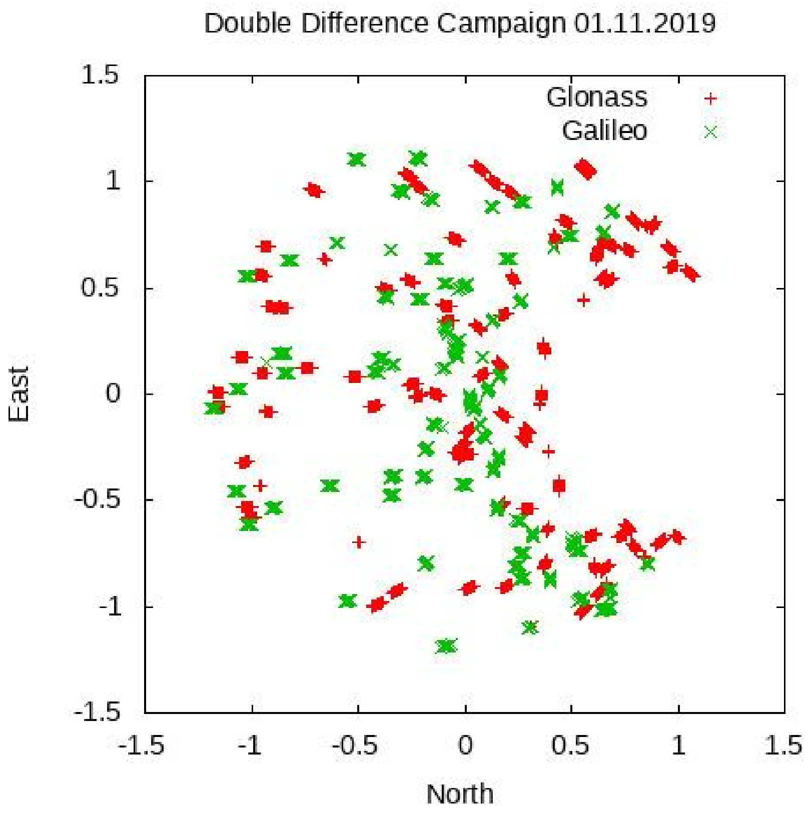
Interleaving features

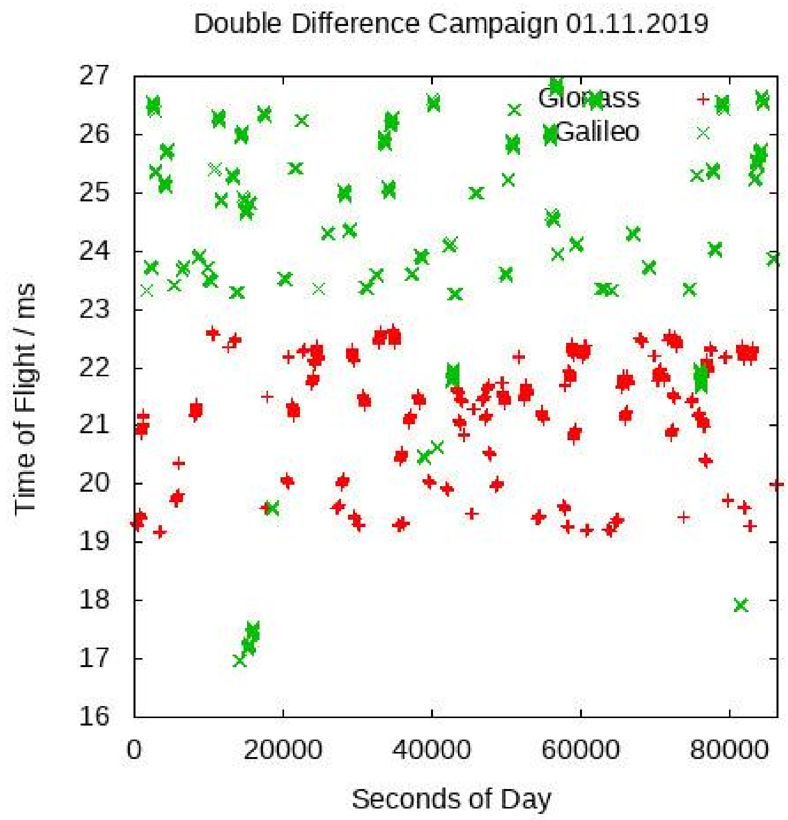


Interleaving features (2)



Pass scheduling algorithm – typical distribution of GNSS observations

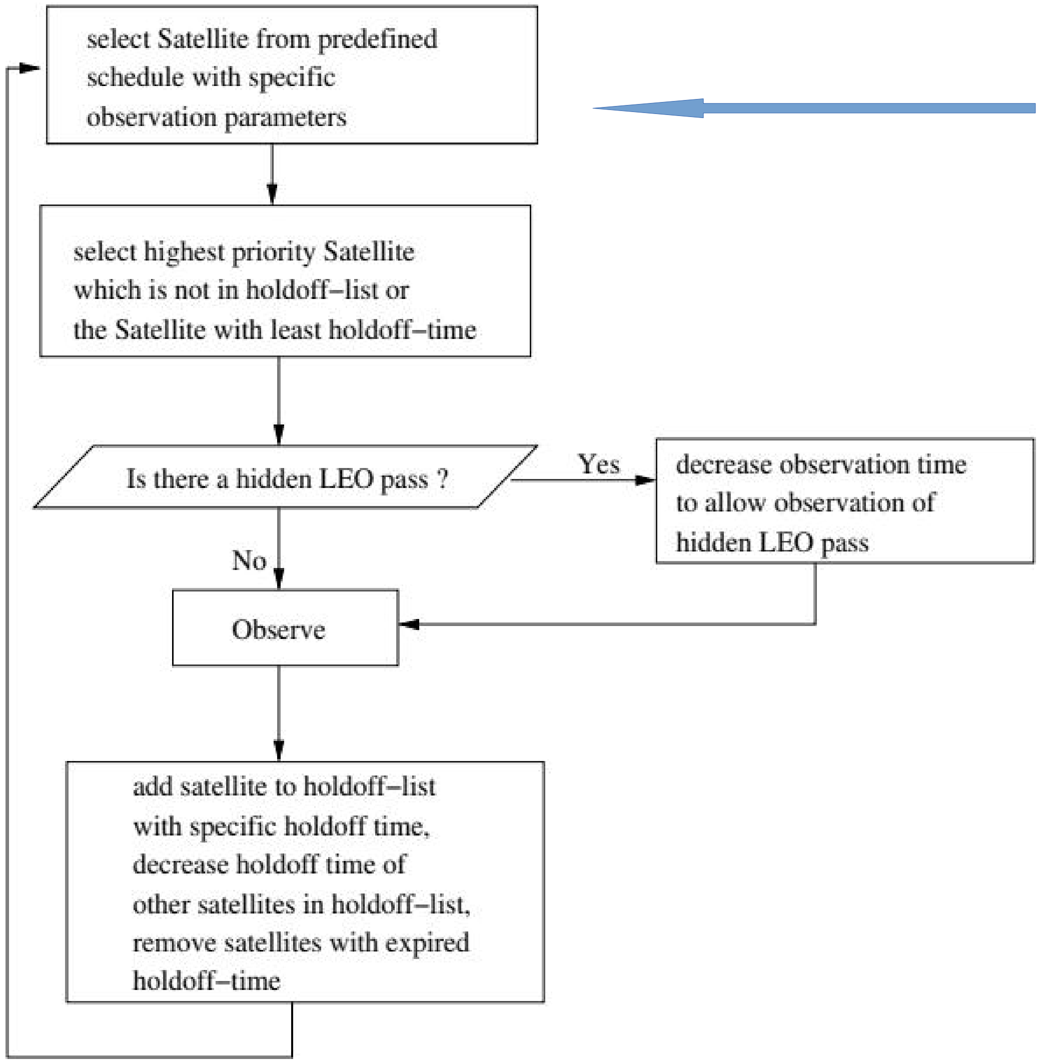




SUCCESS Campaign Requirements

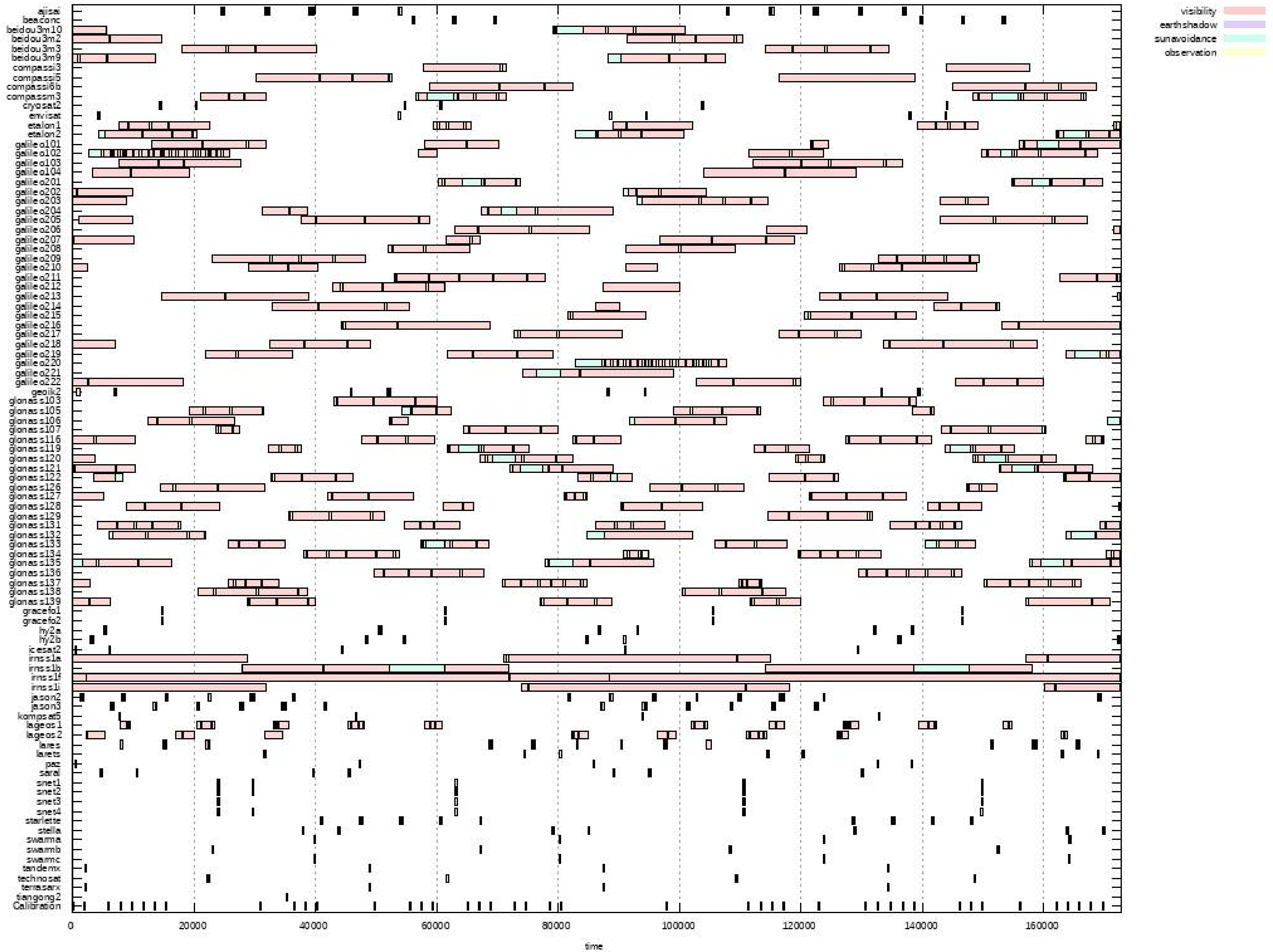
Campaign duration: 2019/05/12-2019/06/02
Main Tasks:
- Eclipsing satellite passes: Observations of Galileo 102 and 220 satellites during eclipse. Continuous observation during eclipse phases is encouraged (collection of NPTs with low sample rate is also possible). Furthermore it is suggested to start ranging at least 5-10 minutes before the eclipse. If possible, collect a long pass segment of the pass during which the eclipse is taking place (description see below, selected eclipse passes are 5 -7 hours long).
- Long pass segments: Collect one normal point of the above Galileo satellites every 15 minutes, for the whole pass (as long as possible).
- Simultaneous observations: Two or more stations observe the same Galileo satellite simultaneously for e.g. 15-30 minutes continuously.

Pass scheduling algorithm with predefined schedule

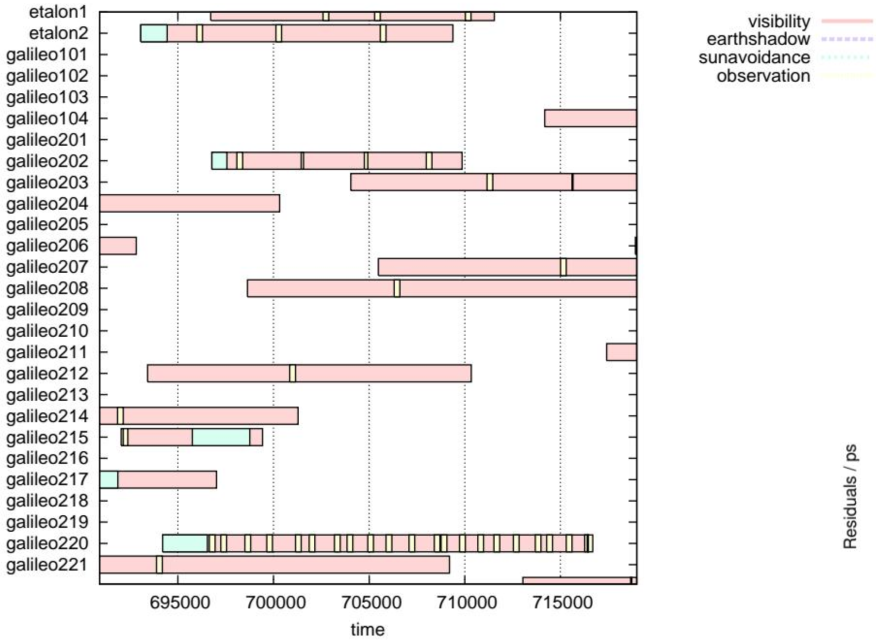


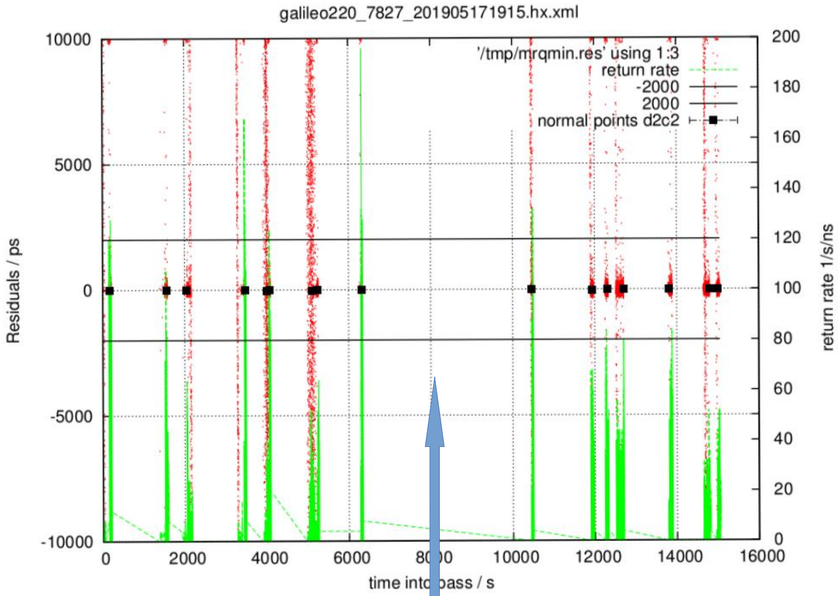

```
2019-05-12 17:20:00 2019-05-12 23:04:09 galileo102 10 300 900 600
2019-05-12 23:04:09 2019-05-12 23:07:00 galileo102
2019-05-13 16:14:00 2019-05-13 21:52:00 galileo220 10 300 900 600
2019-05-15 14:19:00 2019-05-15 14:28:00 galileo102 10 300 900 600
2019-05-15 15:45:00 2019-05-15 21:15:00 galileo102 10 300 900 600
2019-05-17 19:12:00 2019-05-18 00:27:18 galileo220 10 300 900 600
2019-05-18 00:27:18 2019-05-18 00:29:00 galileo220
2019-05-19 18:35:00 2019-05-19 23:57:15 galileo102 10 300 900 600
2019-05-19 23:57:15 2019-05-20 00:02:00 galileo102
2019-05-20 17:30:00 2019-05-20 22:51:52 galileo220 10 300 900 600
2019-05-20 22:51:52 2019-05-20 22:59:00 galileo220
2019-05-22 17:01:00 2019-05-22 22:22:34 galileo102 10 300 900 600
2019-05-22 22:22:34 2019-05-22 22:27:00 galileo102
2019-05-23 14:21:00 2019-05-23 14:27:00 galileo220 10 300 900 600
2019-05-23 15:53:00 2019-05-23 21:12:00 galileo220 10 300 900 600
2019-05-25 13:39:00 2019-05-25 13:58:00 galileo102 10 300 900 600
2019-05-25 15:24:00 2019-05-25 20:35:00 galileo102 10 300 900 600
2019-05-27 18:41:00 2019-05-27 23:49:00 galileo220 10 300 900 600
2019-05-29 18:12:00 2019-05-29 23:21:00 galileo102 10 300 900 600
2019-05-30 17:05:00 2019-05-30 22:18:00 galileo220 10 300 900 600
2019-06-01 16:36:00 2019-06-01 21:46:00 galileo102 10 300 900 600
2019-06-02 13:41:00 2019-06-02 14:01:00 galileo220 10 300 900 600
2019-06-02 15:27:00 2019-06-02 20:31:00 galileo220 10 300 900 600
```

Partial Schedule Gantt Graph for SUCCESS Campaign



SUCCESS Campaign Observations





overcasted sky

Conclusion

- Automatic Scheduling optimizes observing geometry
- Automatic Scheduling provides objective target selection
- Automatic Scheduling does very nice pass interleaving
- Implementation of predefined schedule permits realisation of arbitrary tracking scenarios
- Special observation campaigns can be programmed in advance
- Predefined Scheduling will be used intensively in upcoming double difference campaigns

NESC

July 2025

GENESIS Mission Objectives

Contribute to improve ITRF accuracy and stability by providing in-orbit colocation and necessary combined processing for the four space-based geodetic techniques that contribute to its realization. The goal is to contribute to the achievement of the Geodetic Global Observing System (GGOS) objectives for the ITRF realisation, aiming for a parameter **accuracy of 1 mm and a stability of 0.1 mm/year**, in order to provide significant scientific benefits in Earth modelling, and to support a wide range of societal applications (as endorsed by the United Nation resolution A/RES/69/266).

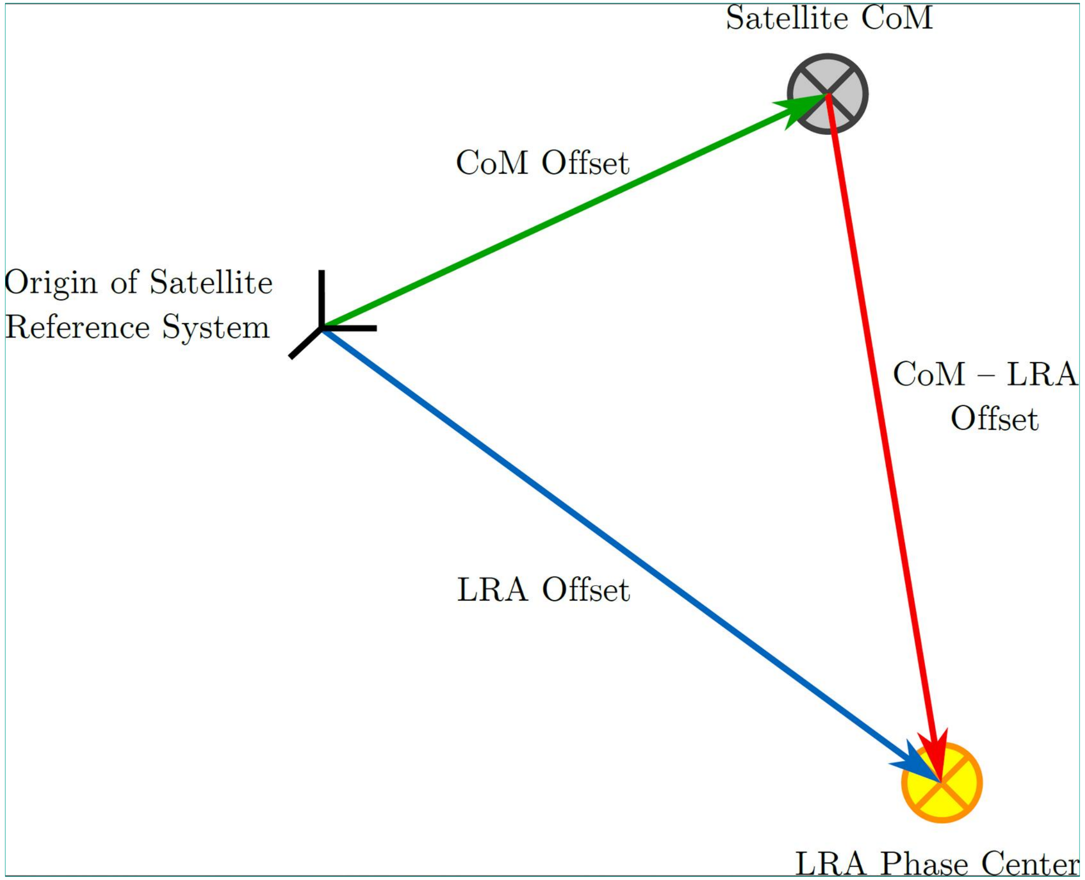
Targets:
Accuracy: 1 mm
Stability: 0.1 mm per year

Contribute to improve the link between the ITRF and the ICRF, thanks to the increased consistency of the Earth Orientation Parameters (EOP). In particular, this mission shall allow for the first time a link between the orbit reference frame, ITRF and ICRF.

Measuring the Laser ranging correction with level of accuracy required by Genesis

- <u>Measure/calibrate the optical center of the LRR</u>
  - <u>w.r.t. the center of mass of the LRR</u>
  - w.r.t. the other technics
  - w.r.t. the center of mass of the satellite after all the integration
- Important:
  - Origin of the SRF must be known better than 1mm
  - Satellite CoM must be known better than 1mm
  - LRA optical phase center must be known better than 1mm

→ All points should be calibrated on the fully mounted/equipped satellite, preferably with electronic devices switched on!



Zeitlhöfler, 2019

- **Requirement in *4.3.5. Satellite Laser Ranging (SLR) Instrument (p48/67)*, PLD-SLR-060 Position Vector Knowledge**

Initial Requirement: The position vector of the LRR centre of phase relative to the internal satellite reference frame shall be known with accuracy better than 0.5 millimetres (1 sigma).

⇒ Question: We question whether this is a sufficiently stringent requirement. If the target accuracy for the products is about 1 mm, a 2- and 3-sigma error here would already compromise said target. Hence, 1 mm at 3-sigma appears to be the bare minimum for this requirement. Ideally more, as the uncertainty in the knowledge of the reference positions of the different payloads (LRA, VLBI, GNSS, DORIS) will be compounded.

⇒ In the updated SRD2.0 dated 31/01/2025, the requirement reads as follows: "The position vector of the LRR centre of phase relative to the LRR Reference Point shall be known with accuracy better than 1mm (3D, 2 sigma)."

This applies also to **PLD-SLR-090 Range Correction**

Outputs from the ESA GENESIS Science meeting in Matera

Extreme 1σ (optical) challenges for the Genesis LRR

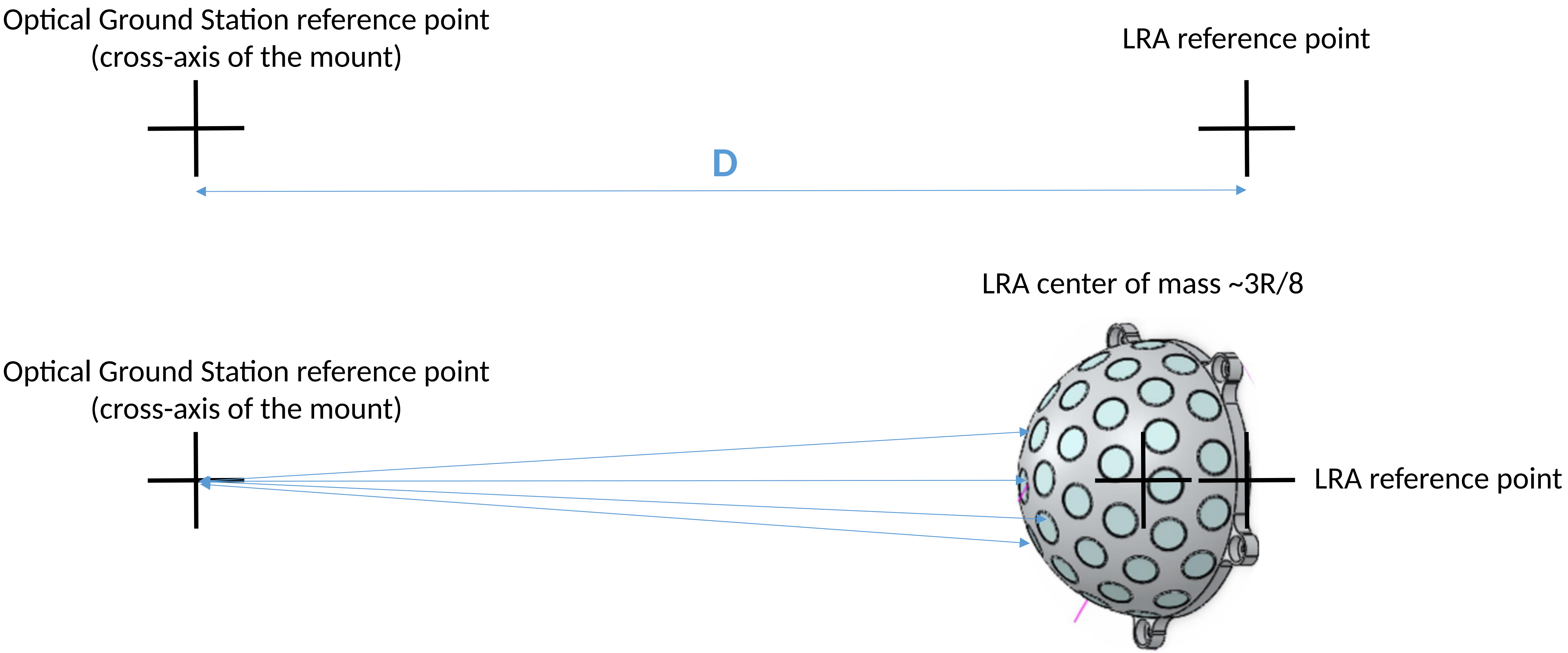
- Requested accuracy of calculated (purely optical) laser range correction is:
- **0.5 mm @1-sigma for Genesis, to be compared to**
  5 mm @1-sigma for LAGEOS (source: David Arnold)
  2 mm @1-sigma for LARES-2 (source: LARES-2 mission support req. form)
  - **Who has better definitive numbers for LAG / LS2 ?**
  - **Very challenging/critical, who knows/wants to compute @0.5mm 1σ ?**

- Compare requested laser ranging accuracy to accuracies of atmosph. corrections:
- **10/15/20° elevations, accuracies 5/2/1 mm at 1-sigma**
  - **ILRS requested x2 OCS increase for low elevations, where limit is 2-5 mm.**

- **Why 0.5 mm if there is (at least) another limitation of 2-5 mm?**
- **Other multi-mm limitations (at stations, for ex.)?**
- **Final (optics plus mechanics …) accuracy goal of LaRCo is 1 mm.**
- **Achievable with optics [0.5-1.0] mm ⊕ mech/else [0.0-0.5] mm:**
  - **0.75 ⊕ 0.25 = 0.8 mm, 0.8 ⊕ 0.3 = 0.85 mm, 0.9 ⊕ 0.4 < 1 mm, …**
  - **Numerically, optical LaRCo accuracy can be relaxed keeping final goal.**

What is the laser range correction ?

describes the difference between the distance of the SLR station from a predefined LRA reference point (D) and the actual range measurement.



What is the laser range correction ?

O. Montenbruck, R. Neubert, Range correction for the CryoSat and GOCE Laser Retroreflector Arrays

Range Correction

Following [6], the range correction for a single prism takes into account two contributions:

- The measured range is larger than the geometric distance of the input face center from the station by a contribution related to the light path inside the prism (taking into account the reduced group velocity in the refractive medium)
- The distance of the reference point and the input face center differ by an amount that equals the projection of the input face center position on the line-of-sight vector.

Defining the range correction $\Delta\rho$ as the difference of the measured range and the geometric distance of the reference point from the station[1], the following expression is obtained for the individual prisms ($i = 0,\ldots,6$):

$$\Delta\rho_i = \left[L\sqrt{n_g^2 + (\mathbf{e}^T\mathbf{n}_i)^2 - 1}\right] - \left[\mathbf{e}^T\mathbf{r}_i\right] \qquad (1)$$

Here, L and n_g denote the vertex height and the group refractive index of the prism, $\mathbf{e}$ is the line-of-sight unit vector (directed from the LRA to the station), $\mathbf{n}_i$ is the optical axis unit vector (i.e. the vector perpendicular to the surface of the prism) and $\mathbf{r}_i$ is the position of the input face center relative to the reference point. Eqn. (1) is generically valid for an arbitrary choice of the reference point (e.g. MRP or ORP) provided that the proper coordinates of the input face centers are used. Other than for the GFZ reflector, which exhibits a constant distance of the input face center from the ORP for all prisms, an ORP-related range correction does not provide specific advantages or simplifications. For ease of use and comparison with IPIE results, only the MRP-related range correction is considered in the sequel.

The effective range correction for a single photon detecting system working at low return rate is the weighted average

$$\Delta\rho = \left(\sum_{i=0}^{6} S_i \cdot \Delta\rho_i\right) \Big/ \left(\sum_{i=0}^{6} S_i\right) \qquad (2)$$

of all contributing cube corner prisms. The weighting factors S_i depend on the location of the receiving station in the far field of the return beam. Because of manufacturing errors and

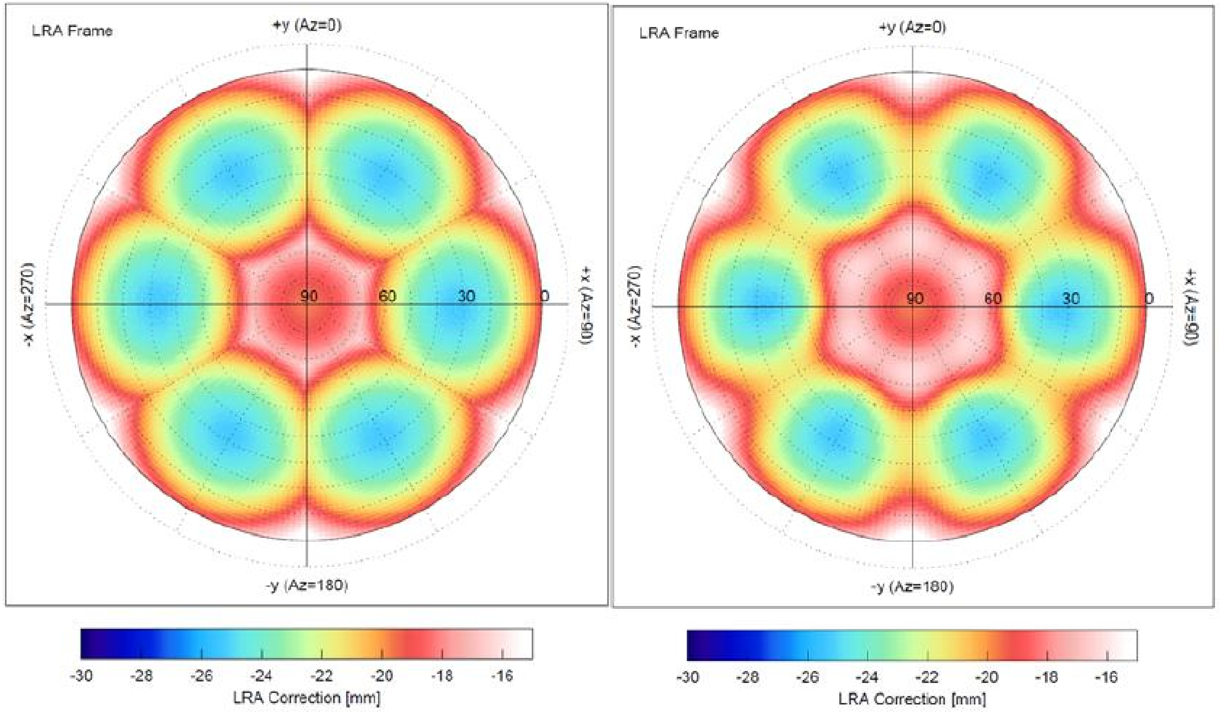


Fig. 2 Range correction of the IPIE Type 1 LRA of CryoSat as obtained from the nearest- (*left*) and multi-prism approximation (*right*).

What is the laser range correction ?

O. Montenbruck, R. Neubert, Range correction for the CryoSat and GOCE Laser Retroreflector Arrays

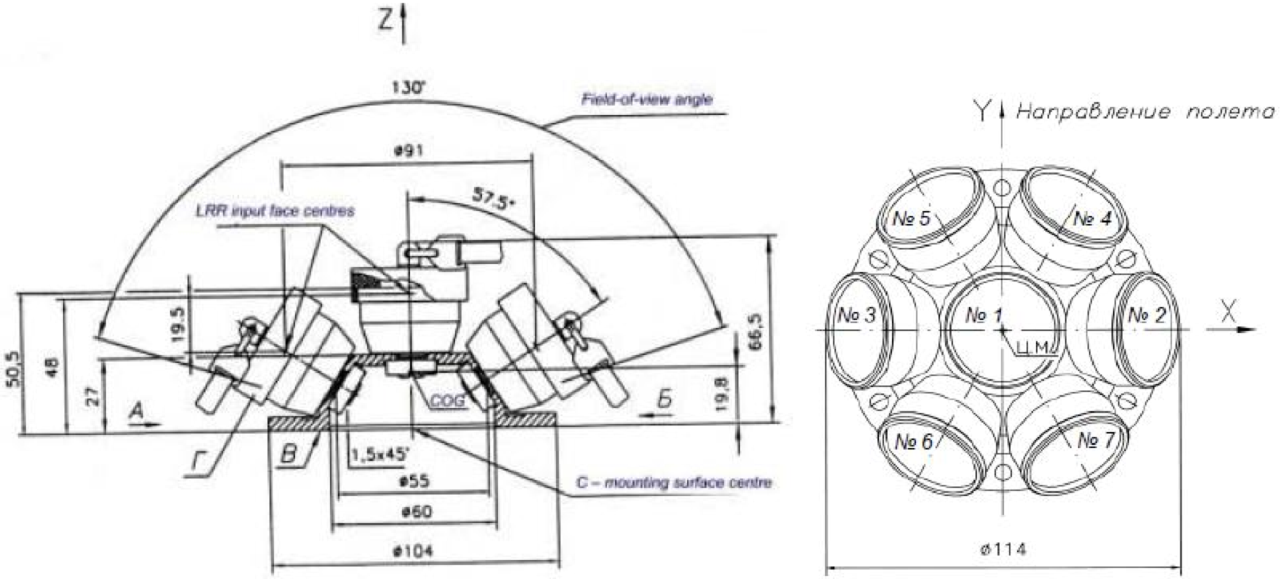


Fig .A1 CryoSat-1/2 laser retroreflector array (from [1])

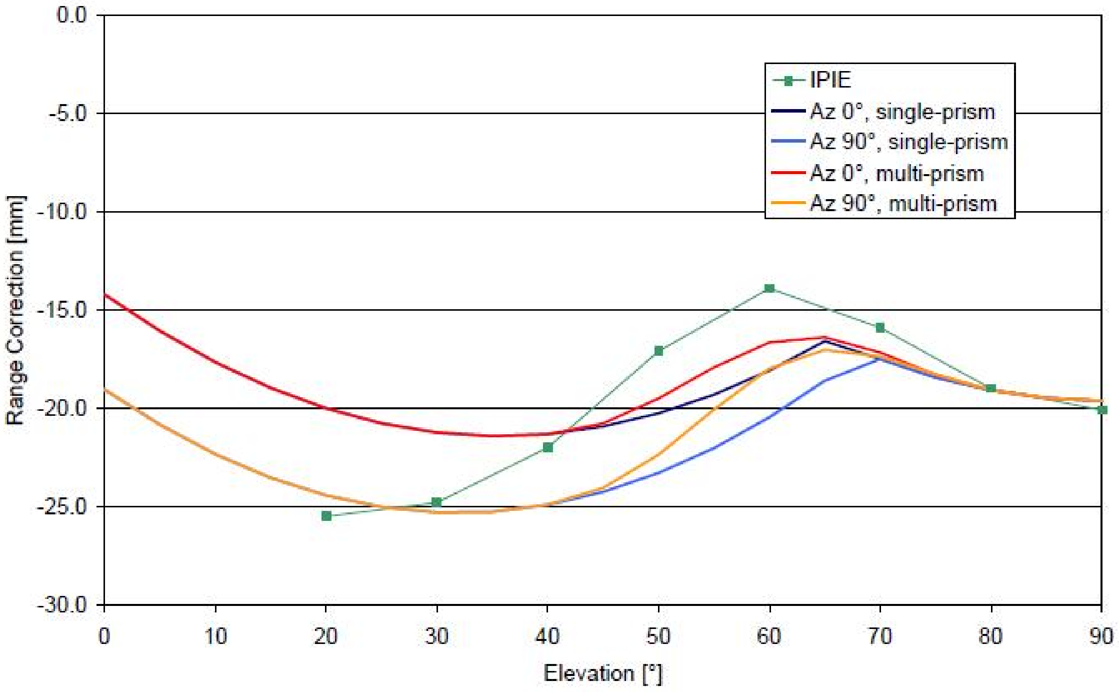


Fig. 4 Comparison of elevation dependent range corrections for IPIE Type 1 LRA of CryoSat.

Position Vector Knowledge & Range Correction

- ESA is requesting a consolidation of the requirement

  - How can we consolidate the Laser Range correction requirement at the level required for GENESIS ?
    - Computation of the uncertainty budget from a pre-design ?
    - Find an instrumental solution ?
      - Feedback of the network regarding on the Simone's proposal on LarCo?
      - Calibration with other instrument (i.e, NMI absolute distant meter)

LaRCo = Laser Range Correction

- Service facility to measure in the lab the laser range correction.

- Sort of ultimate laser ranging calibration, relating geometrical centers of LRR hemi/spheres, spherical domes to the measured laser time-of-flight (ToF), **and reach/break the barrier of 1 mm of laser range accuracy.**

- **But for Genesis the optical barrier is actually at 0.5 mm at 1-STD / 1-sigma.**

- Measurement done twice in 60 years of laser ranging, for LAGEOS-1/2 in ~1974/1994. Now only calculated.

- At INFN-Frascati we have a suited Clean Room, the SCF_lab2, co-funded by ASI & INFN, with a massive optical granite table, suitable for heavy 'cannon-ball' type of stand-alone satellites, like LAGEOS-1/2 and LARES-1/2).

Ideas for implementation of LaRCo

- <u>Direct involvement of the ILRS stations / SLR analysis Community !</u>

We think that, in addition to the ILRS endorsement, an appropriate direct form of involvement in the project of some *<u>representative, voluntary</u>* ILRS *'partner'* stations would be crucial, not only useful. The range correction is FOR ILRS stations + SLR analysts. We also believe that this involvement in the project needs to be built together, getting feedback from stations' operators, analysts and taking time to discuss critical technical and programmatic details of the project. ILRS cannot get funding, but the single stations may and do get national, European funding, some also ESA funding. We foresee specific and focussed purchased support services not for ILRS as an organization (not possible), but for some *partner* ILRS stations and for some *partner* SLR analysts.

Ideas for implementation of LaRCo

- Facility instrumentation:
  - Technique of detection of the return signal?
    - Single photon, Multi photon; CFD? ...
  - What detector?
    - Streak camera, MC PMT, C-SPAD … What other detector or detector combinations (for start time) to measure the ToF?
  - What laser WL / repetition rate?
    - 532, 1064 nm / kHz ?
  - Laser pulse width and / or polarization type
  - Do all of the above categories map directly into separate corrections to be delivered to the funding agency / ILRS?
  - Flat LRRs: check range correction vs laser incidence angle
  - Clock options, …
- HW procurement and verification/validation
  - Share work (and associated funding) with *partner* stations
  - More sharing to be decided together. And come to Frascati, please.

Ideas for implementation of LaRCo

- <u>Execution of the measurements:</u>
  - ➢ Ask personnel of *partner* stations (representing detection techniques and/or detectors and/or laser characteristics of the previous points) to participate in the range correction measurements.
  - ➢ Participating means travel to Frascati, work there together, even in the preparation and then analysis of the results (this also remotely).
  - ➢ This will be TBD weeks of work for 1-2 people, which needs to be supported financially with LaRCo funding (if/when approved). It would be not only fair to the *partnering* stations, but also pragmatically effective.

Absolute Distant Meter from National Metrological Institute

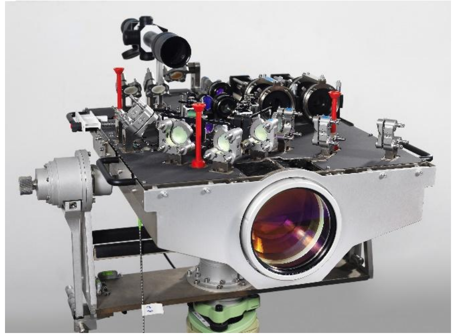
GENESIS LRR range correction measurement:
NMI Absolute Distant Meter

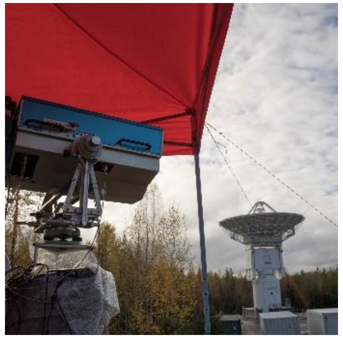
- Calibration with NMI (National Metrological Institute) instrument:
  - calibration with measurements better than 0.5 mm @ 1sigma
  - Measurement linked to the SI-traceability of SLR
  - Mobile instrument: possibility to link the calibration in clean room to measurement outside (comparison with Optical Ground Station)

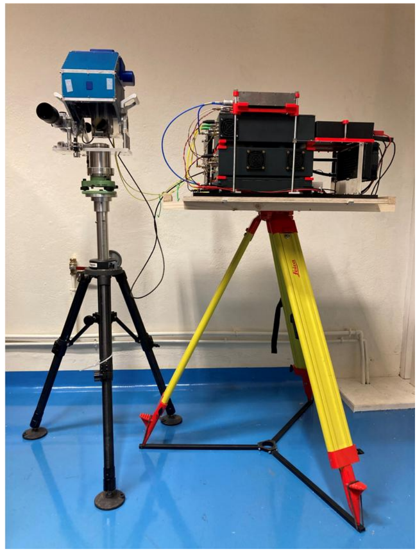
GENESIS LRR range correction measurement:
NMI Absolute Distant Meter

During the GEOMETRE Project:

- Development of Si-traceable long distance range meters with low uncertainty
- Exploiting intrinsic refractivity compensation







le cnam

Arpent system:

- RF modulation
- 780 and 1560 nm
- All-fibred design
- Flexible in use, well portable

PTB
Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut

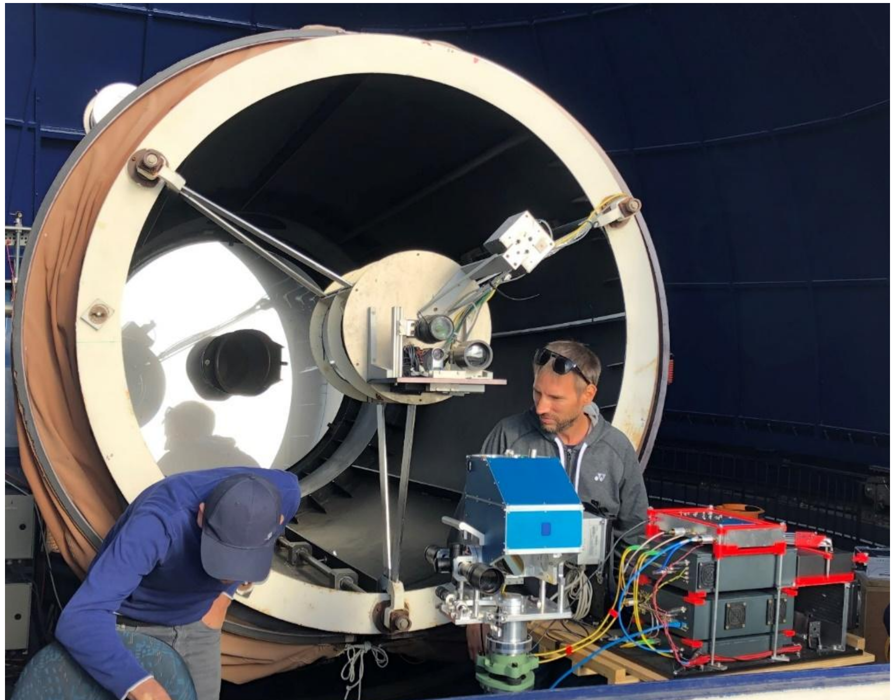
TeleYAG-II system:

- Absolute interferometry
- 532 and 1064 nm wavelength
- Complex set-up

Absolute Distance Meter (ADM) of CNAM: ARPENT

Guillory, J., de La Serve, M. T., Truong, D., Alexandre, C., & Wallerand, J. P. (2019). Uncertainty assessment of optical distance measurements at micrometer level accuracy for long-range applications. IEEE Transactions on Instrumentation and Measurement, 68(6), 2260-2267.

ARPENT-CNAM two-wavelength absolute distance meter @Grasse during the GEOMETRE (EURAMET) project



GENESIS LRR range correction measurement

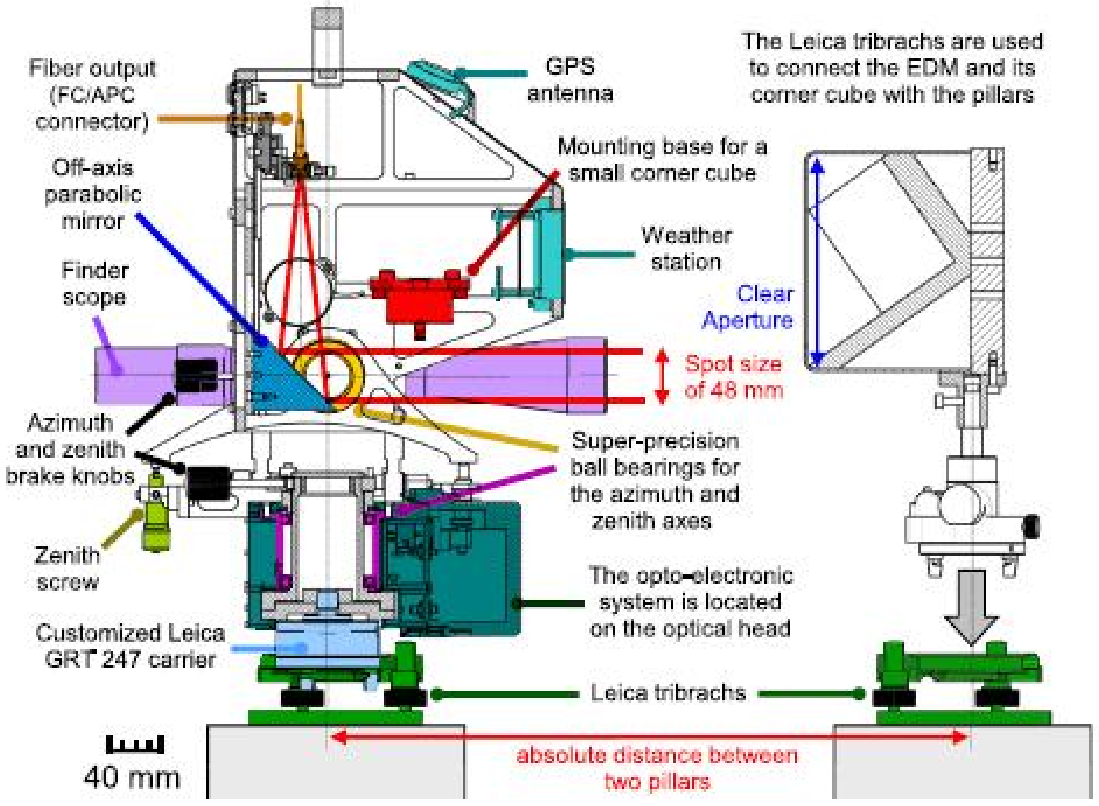


Fig. 2. Cross section view of the optical head and of a hollow corner cube with a clear aperture of 127 mm.

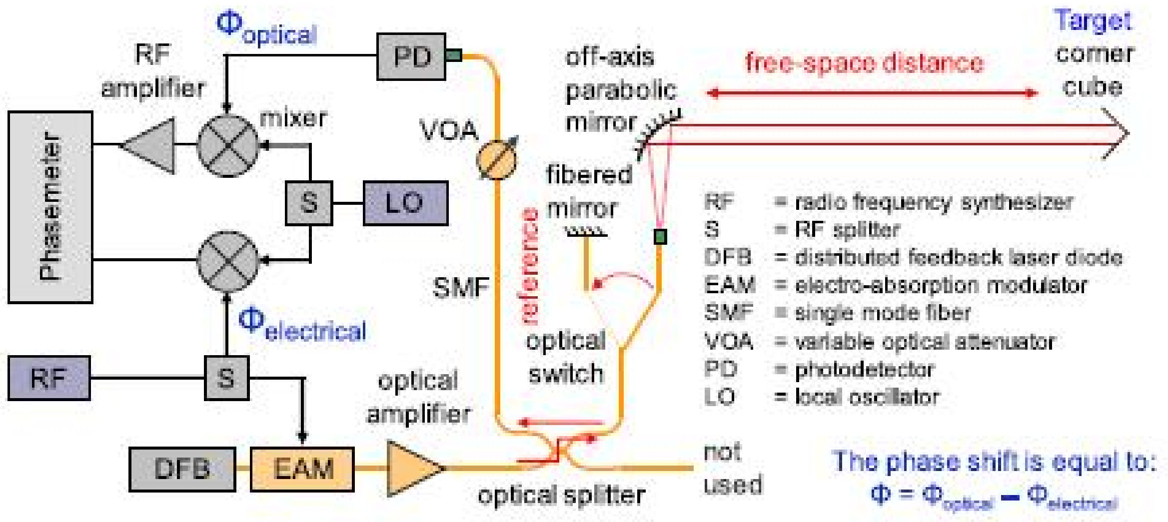


Fig. 3. Functional setup of the ADM.

GENESIS LRR range correction measurement

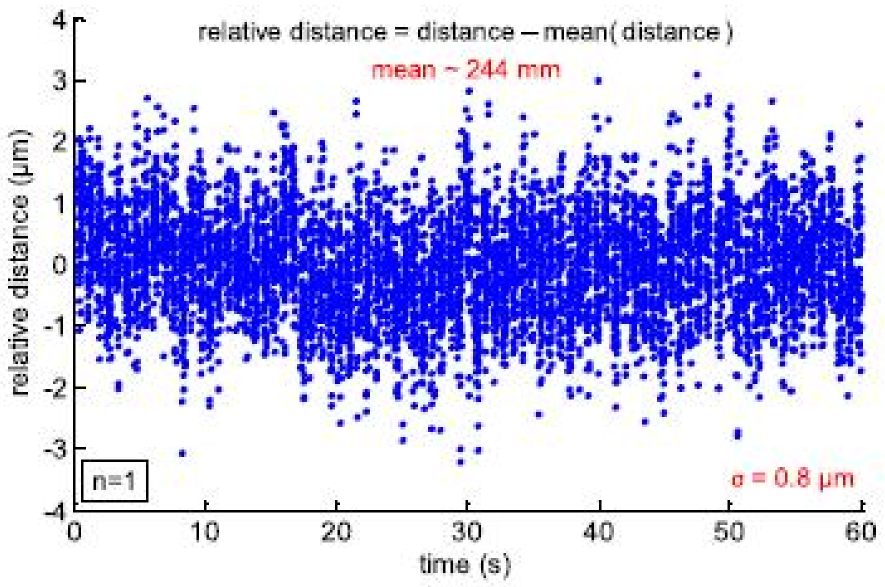


Fig. 7. Relative distance as a function of time. $n = 1$ means that no air refractive index correction was applied.

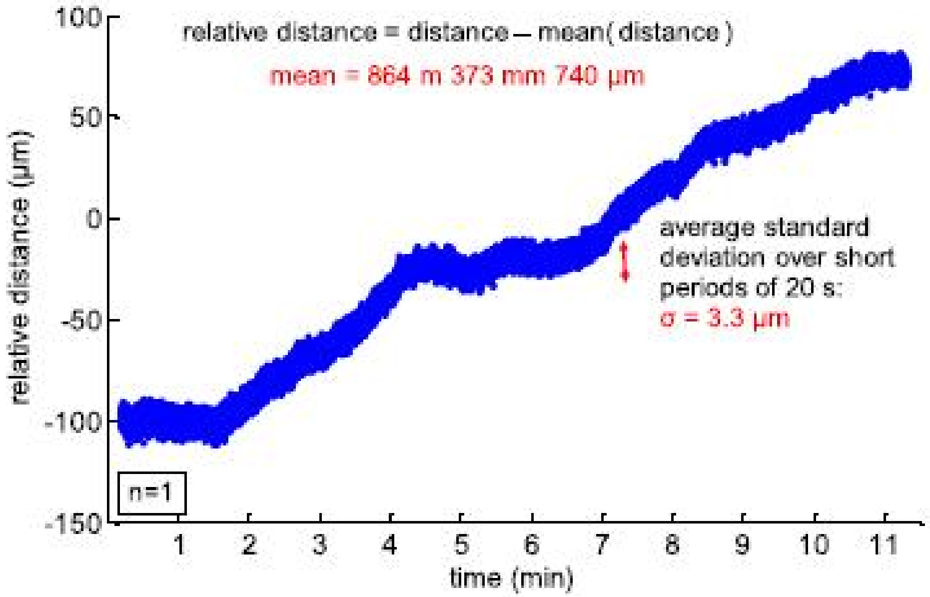
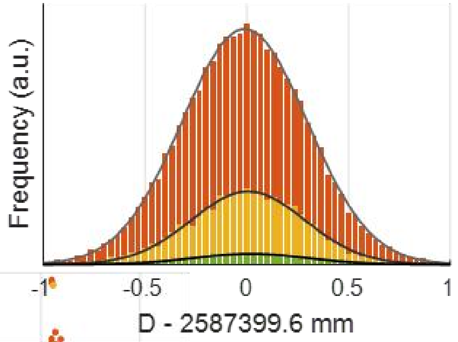


Fig. 8. Data points obtained over 864 m at FGI baseline (Nummela, Finland).

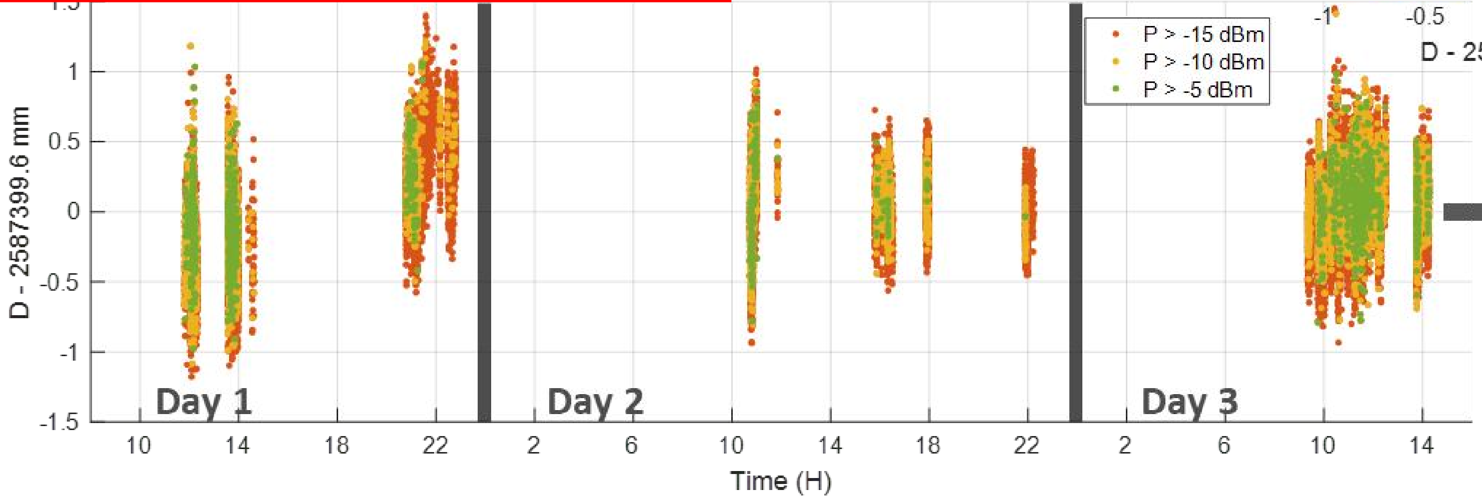
Geometre: verification of SLR versus Arpent/EDM

Comparison of the distance difference between two corner cubes separated by about 2.6 km

- Two-colour ADM Arpent from Cnam, at 780 nm and 1560 nm.
- Two-colour SLR from Observatoire de la Côte d'Azur, at 532 nm and 1064 nm.



Result of the 2-colour ADM from Cnam:
average distance of 2587399.6 mm ± 0.3 mm



normal distribution with $\sigma \sim 300$ µm