

# Concept for a new minimal SLR system

Daniel Hampf

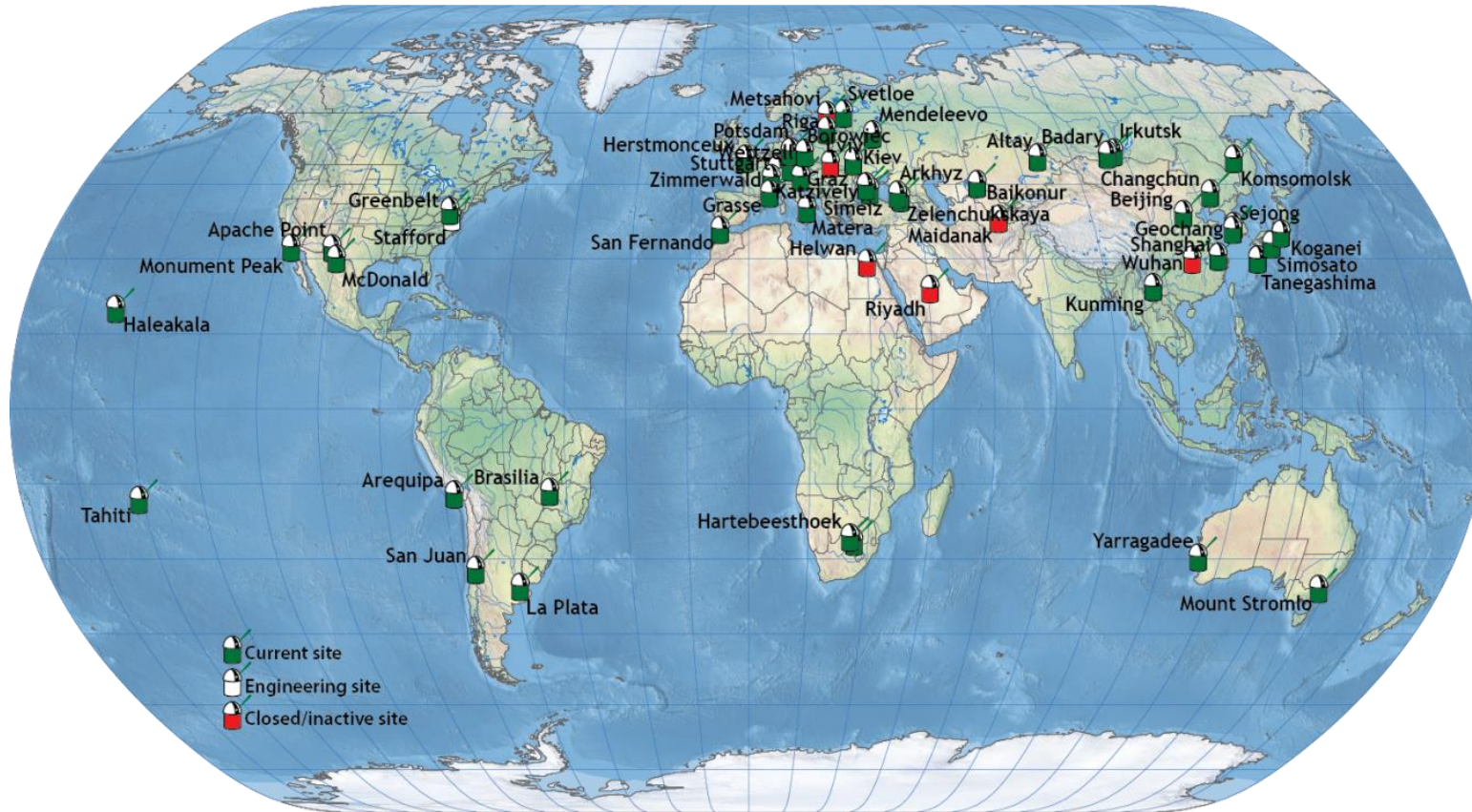
German Aerospace Center, Institute of Technical Physics, Stuttgart



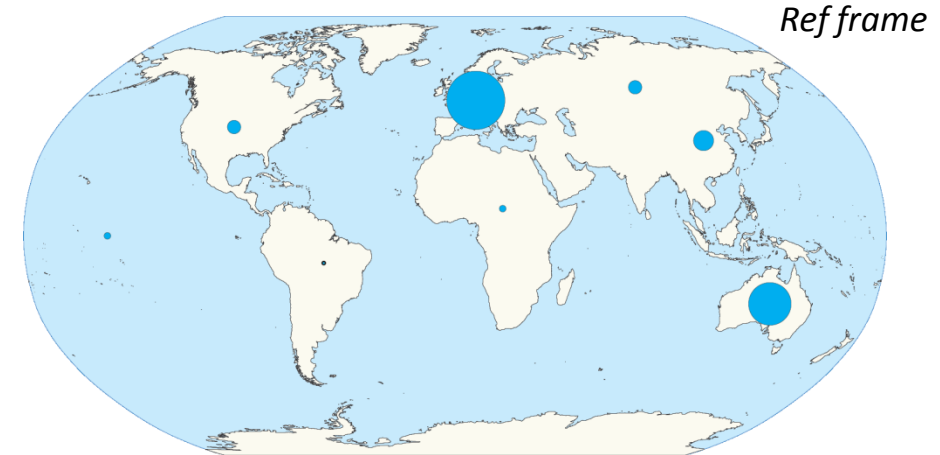
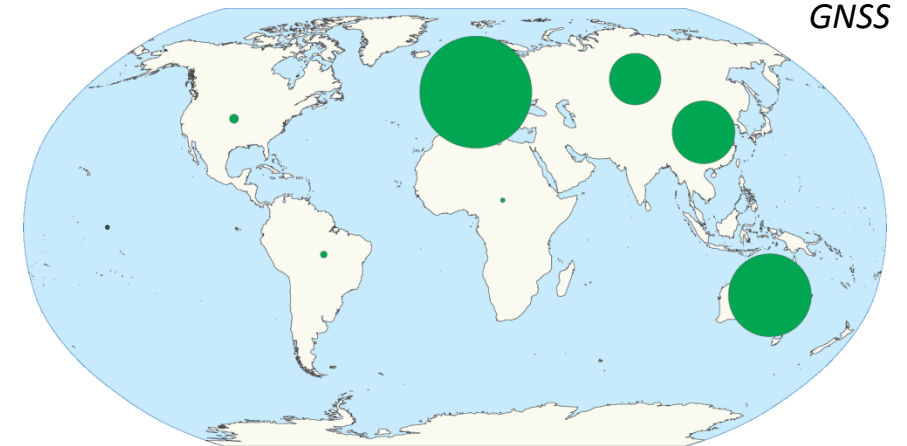
Knowledge for Tomorrow



# The need for new SLR stations



ILRS stations (from: ILRS website)

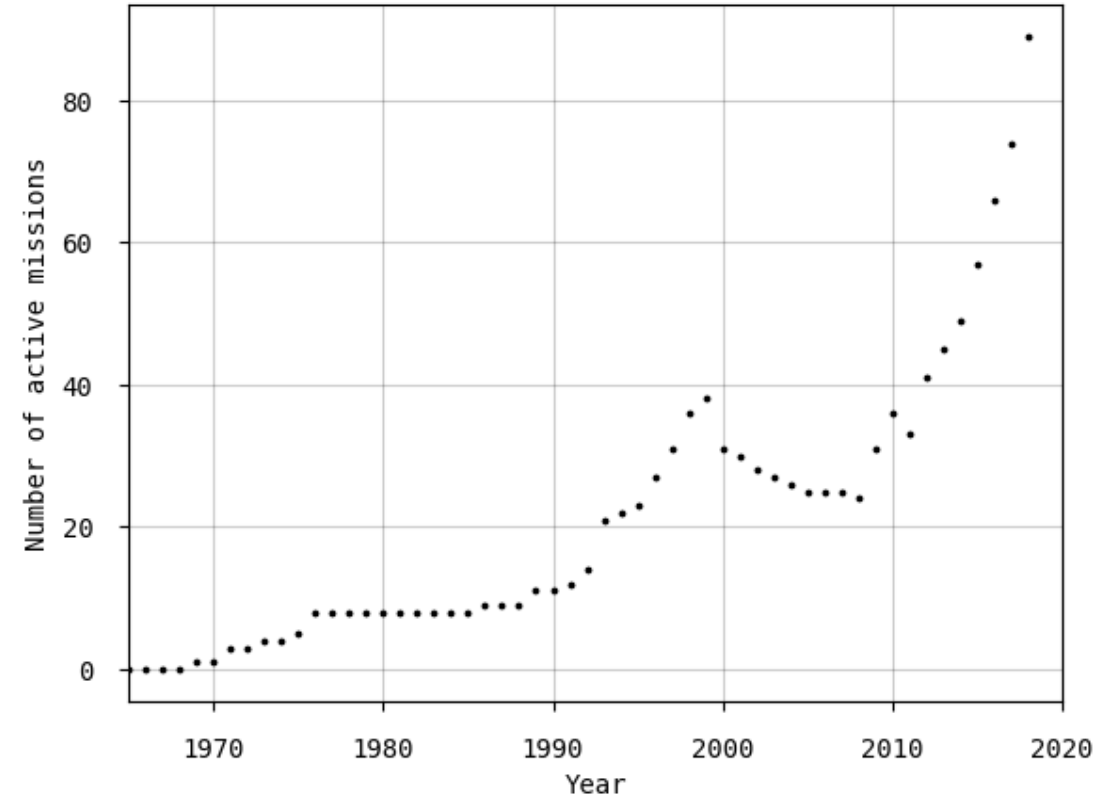


Passes tracked per continent (Pearlman 2017)

# More to come...

- More navigation satellites
- More Earth observation satellites
- Space Traffic Monitoring
- ...

Satellite Name	Sponsor	Exp. Life Time	Purpose	Launch Date
<b>Approved by ILRS for Future SLR Tracking</b>				
Astrocast	ETH Zurich and Astrocast SA	1-2 yrs	Positioning information, precise orbit determination	November 15 to November 21, 2018
COSMIC-2	UCAR	5 yrs	Atmospheric research, validation of GNSS orbits	NET June 13, 2018
HY-2B	CNES, CNSA		Earth observation	October 25, 2018
ICESat-2	NASA		ice-sheet elevation change, sea-ice freeboard, and vegetation canopy height	September 15, 2018
Lightsail-2	The Planetary Society	30 days	Orbit determination	NET June 13, 2018
NISAR	NASA/JPL, ISRO	3 yrs	Earth observation	2020
PN-1B, -1C, -1D	Beijing Aerospace Control Center	1 yr	Precise orbit determination	Sep-2015
RANGE	Georgia Institute of Technology	1 yr	Positioning information, precise orbit determination	Jul/Aug 2018
<b>Future Satellites with Retroreflectors</b>				
GPS-III (n=??)	DoD, DoT		Positioning, navigation, timing, geodesy	
GRASP	NASA		Positioning, geodesy	TBD
HY-2C	CNES, CNSA		Earth observation	2015
HY-2D	CNES, CNSA		Earth observation	2019
IRS-P5 (CARTOSAT-1)	ISRO	5 yrs	Earth observation	May-2005
Sentinel-6	NASA, NOAA, ESA, EUMETSAT	5.5 yrs	Ocean altimetry	2020
SWOT	NASA, CNES		SAR altimeter	2020



Number of SLR missions (Data: ILRS website)



# Minimal SLR - Design goals

- Minimal...
  - Small
  - Inexpensive
  - Few components (COTS where possible)
  - Modular
  - Easy to maintain
  - Eye-safe?
- ...yet powerful
  - From LEO up to GNSS orbits
  - 1 cm NP accuracy
  - Day and night ranging
  - Automated operation

Make it as simple as possible – but not simpler

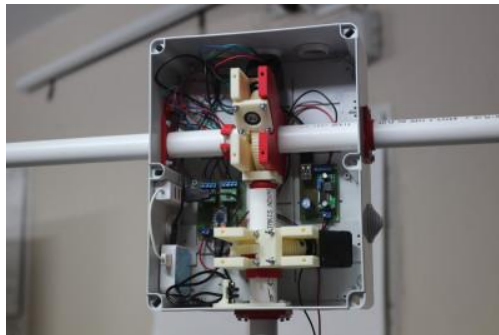


# A unified minimal SLR system – open source

- Together...
  - Share efforts in development
  - Share experiences in operation
  - Share software and hardware designs
- ...and alone
  - Funded and built by individual agency
  - Operated locally
  - Enhancements / modifications encouraged



Arduino Uno R3  
(From: Wikimedia / user "Clic17")



SatNOGS



White Rabbit time-synchronisation  
(Image from: Sevensolutions)



Linux

# OOOS: Orbital Objects Observation Software

- Supports full SLR operation
- Modular hardware layer

Released as open source (GPL v3)

The screenshot shows the OOOS software interface. At the top, there are tabs for Planning, Hardware, Control, Automation, SkyView, and Calibration. Below the tabs is a 'Target List' table with columns for ID, Name, Epoch, Radar CS, Mass, Apogee, Altitude, Range, Priority, Retro, and Campaign. Below the target list is a 'Queue (47)' table with columns for ID, Name, Epoch, Campaign, Observation start, Observation stop, and Passes. A small circular diagram on the right shows the Earth's orbit and the telescope's position. At the bottom, there is a log window showing system messages.

ID	Name	Epoch	Radar CS	Mass	Apogee	Altitude	Range	Priority	Retro	Campaign
1328	EXPLORER 27	2018-09-26 12:02:24	2,0809	55	1303	-57,8	12 276	4	13,0 km <sup>2</sup>	ILRS Targets in LEO
2674	DIADEME 1	2018-09-26 08:12:55	0,5003	23	899	-38,5	9 132	4	<none>	ILRS Targets in LEO
2680	DIADEME 2	2018-09-26 13:38:50	0,6213	23	1653	-60,4	11 894	4	<none>	ILRS Targets in LEO
7646	STARLETTE	2018-09-26 14:32:30	0,1687	46,58	1107	-34,4	8 739	4	1,8 km <sup>2</sup>	ILRS Targets in LEO
7734	GEOS 3	2018-09-26 12:28:45	1,2801	238,85	850	-40,7	9 480	4	20,0 km <sup>2</sup>	ILRS Targets in LEO
8820	LAGEOS 1	2018-09-26 11:21:24	0,3981	411	5948	-70,4	18 130	4	15,0 km <sup>2</sup>	ILRS Targets in LEO

ID	Name	Epoch	Campaign	Observation start	Observation stop	Passes
43215	PAZ	2018-09-26 13:59:36	ILRS Targets in LEO	2018-09-28 17:49:08	2018-09-28 17:54:26	1 / 1
39451	SWARM B	2018-09-26 14:49:09	ILRS Targets in LEO	2018-09-28 17:50:48	2018-09-28 17:58:20	1 / 1
26997	JASON	2018-09-26 11:55:47	ILRS Targets in LEO	2018-09-28 17:51:16	2018-09-28 18:04:04	1 / 4
8830	LAGEOS 1	2018-09-26 11:21:24	ILRS Targets in LEO	2018-09-28 17:55:15	2018-09-28 18:53:41	1 / 1
28931	ALOS	2018-09-26 11:38:54	Bright Torches	2018-09-28 17:59:25	2018-09-28 18:06:32	1 / 1
39086	SARAL	2018-09-26 13:35:54	ILRS Targets in LEO	2018-09-28 18:06:12	2018-09-28 18:16:36	1 / 2

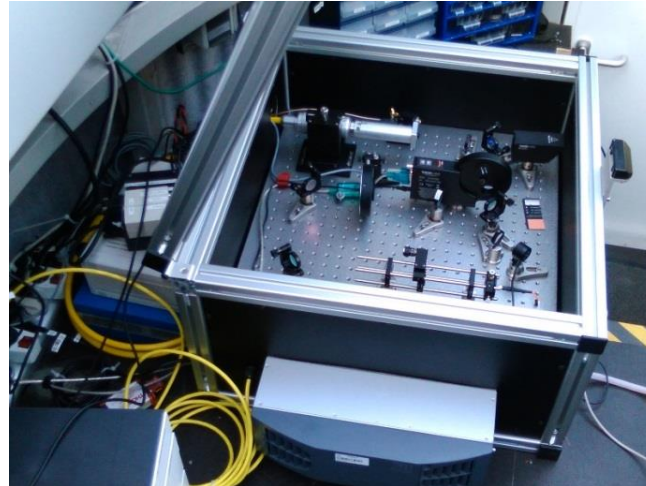
The screenshot shows the OOOS software interface in 'SkyView' mode. The main window displays a plot of 'RA (h:m:s)' vs 'Dec (d:m:s)'. A blue line represents the telescope's path, and a red dot represents the target object. The plot is titled 'TOPEPOGEODON (22176)' and '2792.0 km'. To the right of the plot are control panels for 'RA / DEC offsets', 'Camera presets', and 'Laser control'. The 'RA / DEC offsets' panel shows RA = -0.1717" and Dec = +0.0128". The 'Camera presets' panel shows ROI x, ROI y, and Blanking values. The 'Laser control' panel shows Filter, Shutter, and buttons for Previous, Next, Open, and Close.

See also: [spacedebris.dlr.de/OOOS\\_software](http://spacedebris.dlr.de/OOOS_software)



# Uhlandshöhe SLR station

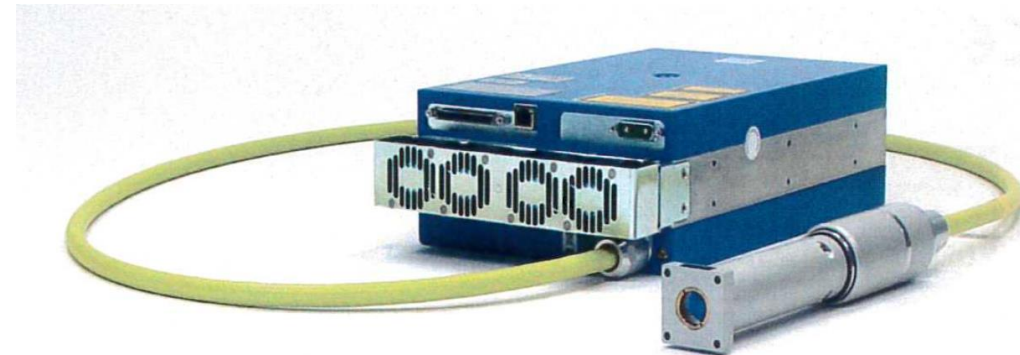
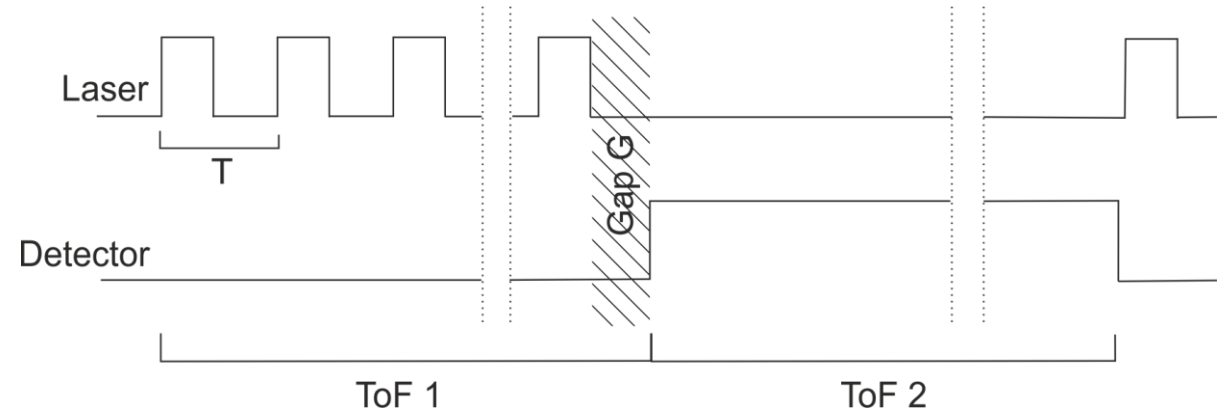
- Location: Historic observatory in Stuttgart, Germany
- First returns 2016
- ILRS Engineering station since 2017
- Specs:
  - 100 kHz repetition rate
  - 50  $\mu$ J pulse energy
  - 42 cm receiver telescope
  - 10 cm transmitter
  - Fibre coupling
  - Ranging at 1064 nm



# 100 kHz laser ranging

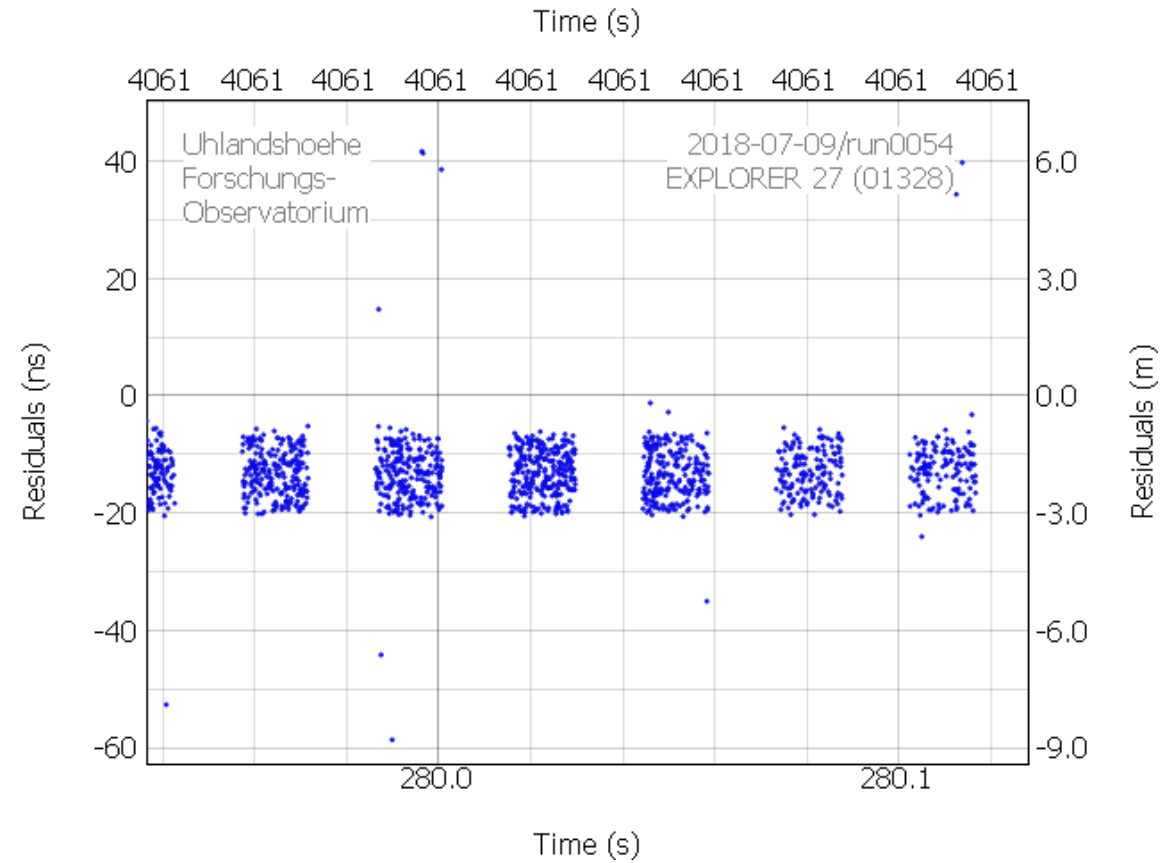
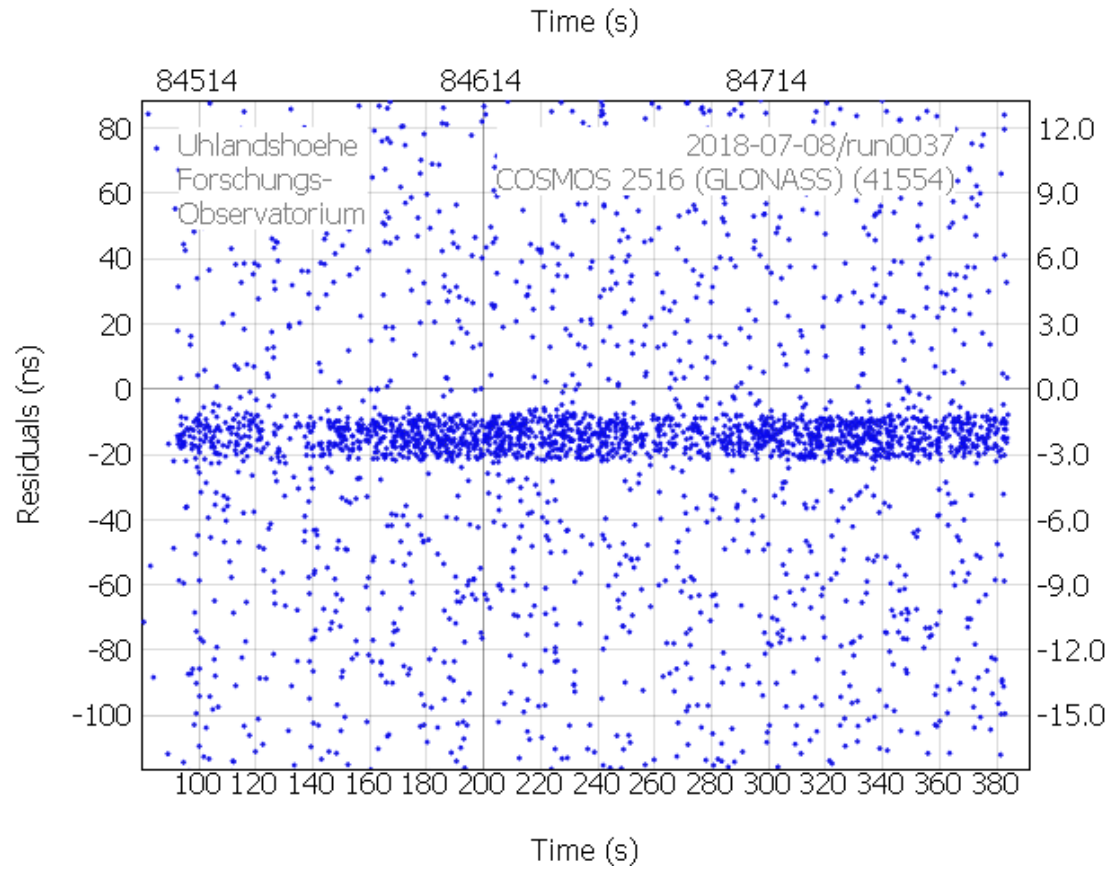
- Why?
  - Low pulse energy (50  $\mu\text{J}$ )
  - Long pulses ( $\sim 10$  ns)
- How?
  - Burst mode pulse collision avoidance
  - Fast event timer
  - Multithreading
- Results?
  - Ranging up to GNSS targets
  - NP scatter  $\sim 1$  cm

See also: D. Hampf et al: *Satellite Laser Ranging at 100 kHz repetition rate* (submitted to CEAS space journal)

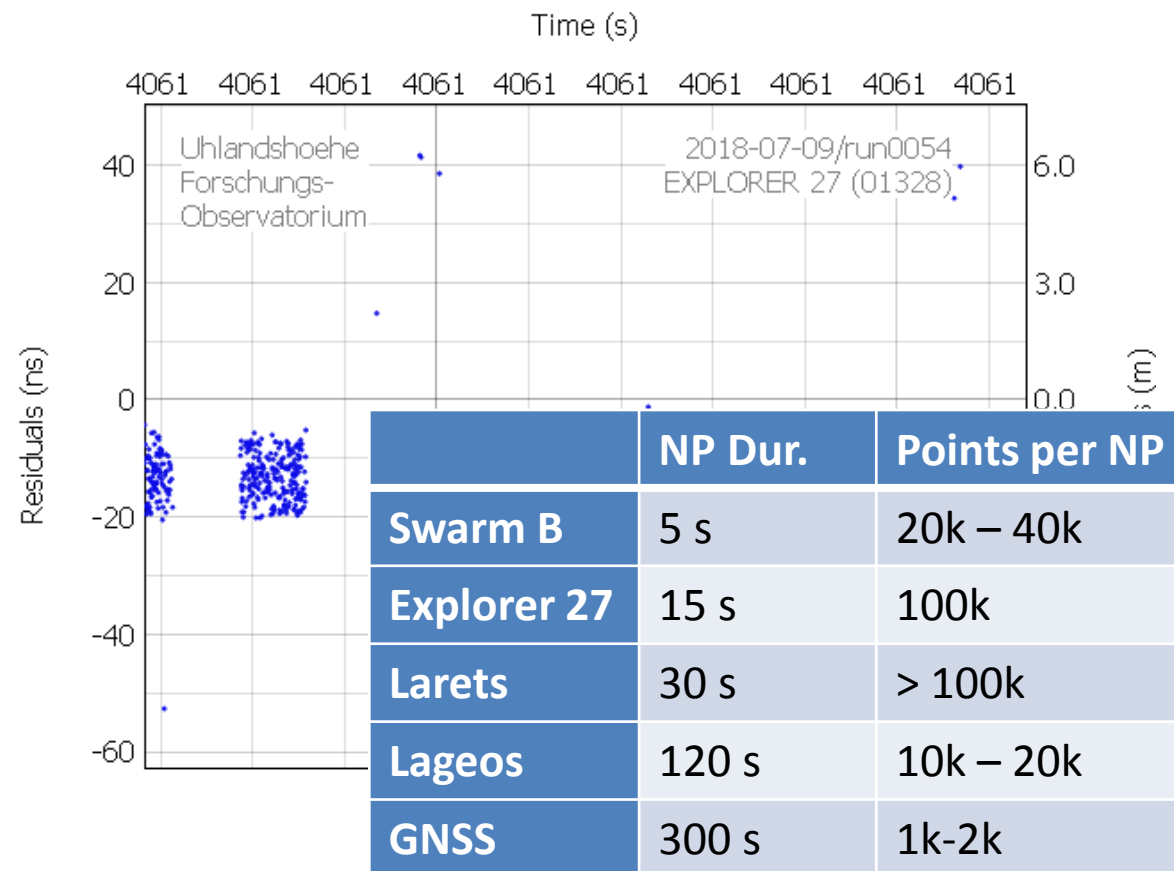
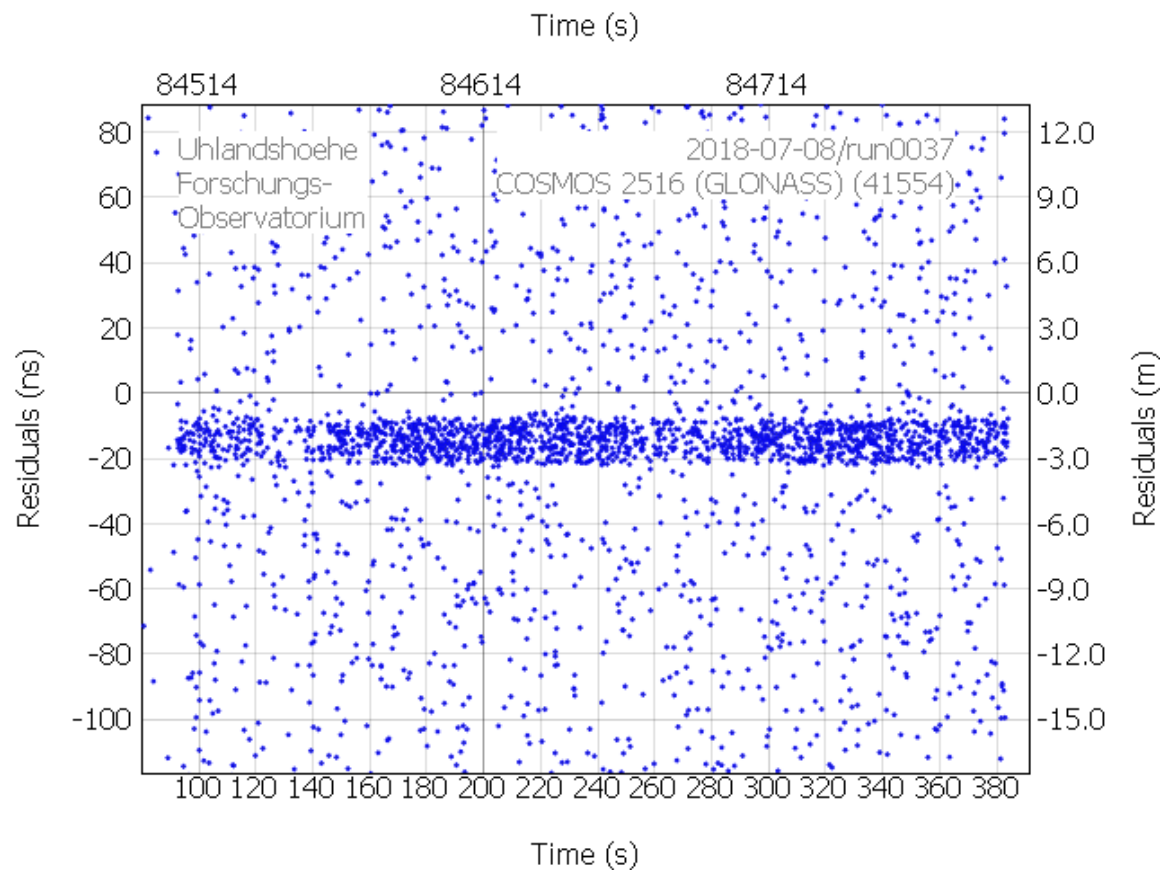




# 100 kHz laser ranging: Results



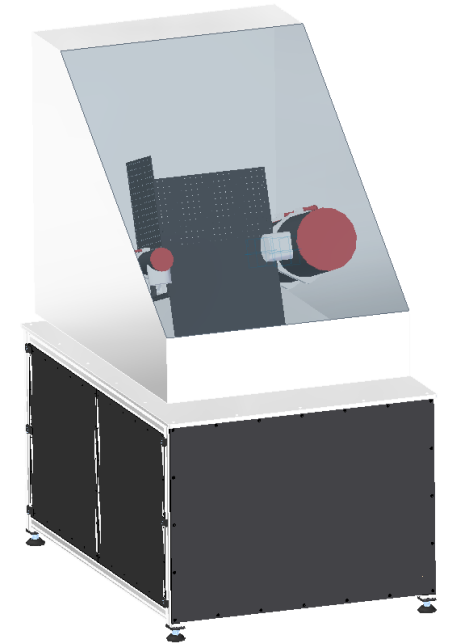
# 100 kHz laser ranging: Results



# miniSLR

- Complete SLR system “in-a-box”
- Transportable
- Fully automated
- Sealed and air-conditioned
- Easy maintenance

	UFO	miniSLR
Energy	50 $\mu$ J	200 $\mu$ J
Divergence	100 $\mu$ rad	50 $\mu$ rad
Aperture	42 cm	20 cm
Photons / Puls	0,02	0,08
Rep-Rate	100 kHz	30 kHz
Return-Rate	2 kHz	2 kHz



# Summary

- New technology opens up interesting new possibilities for SLR (fibre coupling, 100 kHz, ...)
- Open source software and hardware foster cooperation
- Let's build a minimal SLR station!

**We invite for collaboration!**

