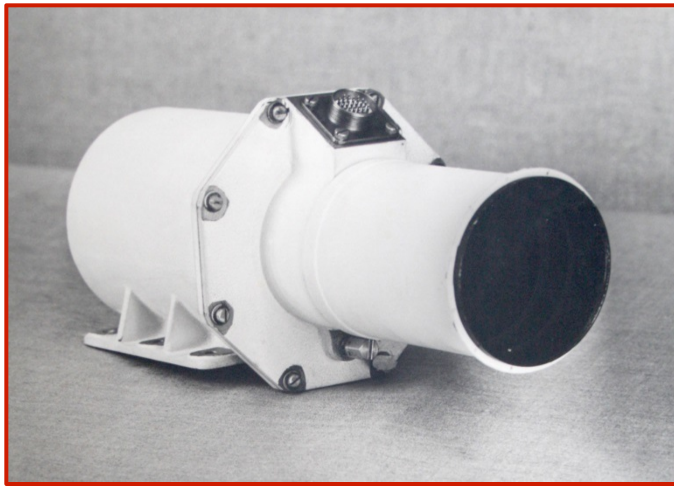
DEVELOPMENT STAGES OF STATIONS, NETWORKS AND METHODS OF SLR APPLICATION FOR GLOBAL SPACE GEODESY AND NAVIGTION SYSTEMS

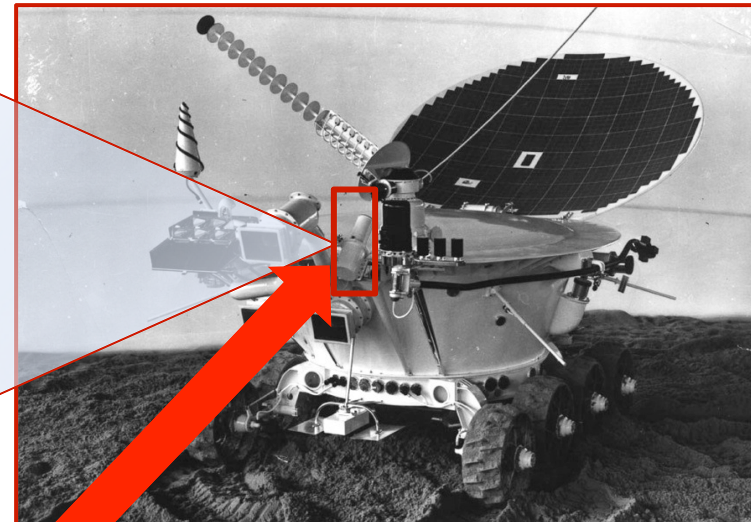
The presentation discusses main stages of development of Russian SLR stations, networks and methods of their application for geodetic, ephemerides-time and metrological support of various space systems, first of all navigation-geodetic one

M.A. Sadovnikov, V.D. Shargorodskiy

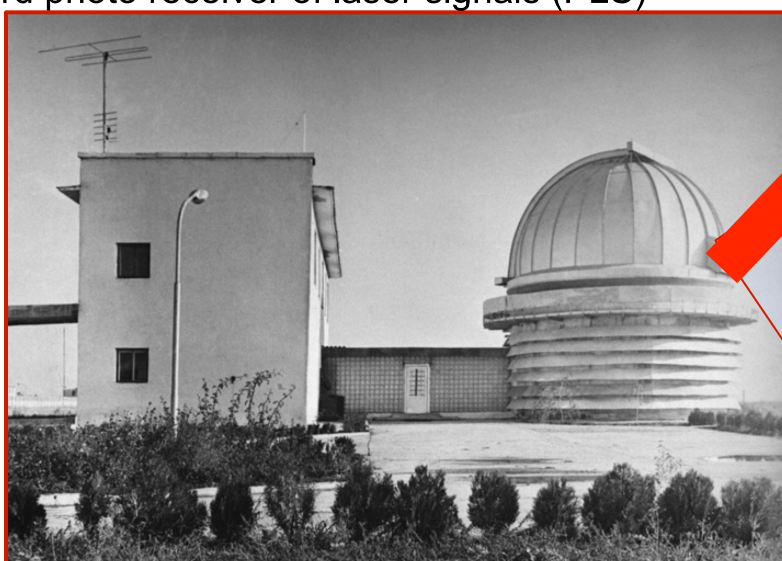
Laser location of “Lunokhod-2” with accuracy of 0.1 arc sec (200 m on the Moon). First transmission of a message in laser line “Earth-Moon”. 1973г.



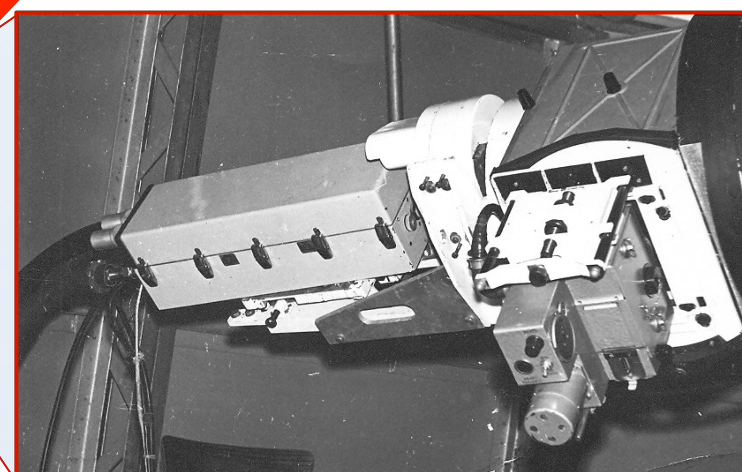
On-board photo receiver of laser signals (PLS)



Lunokhod-2 with PLS

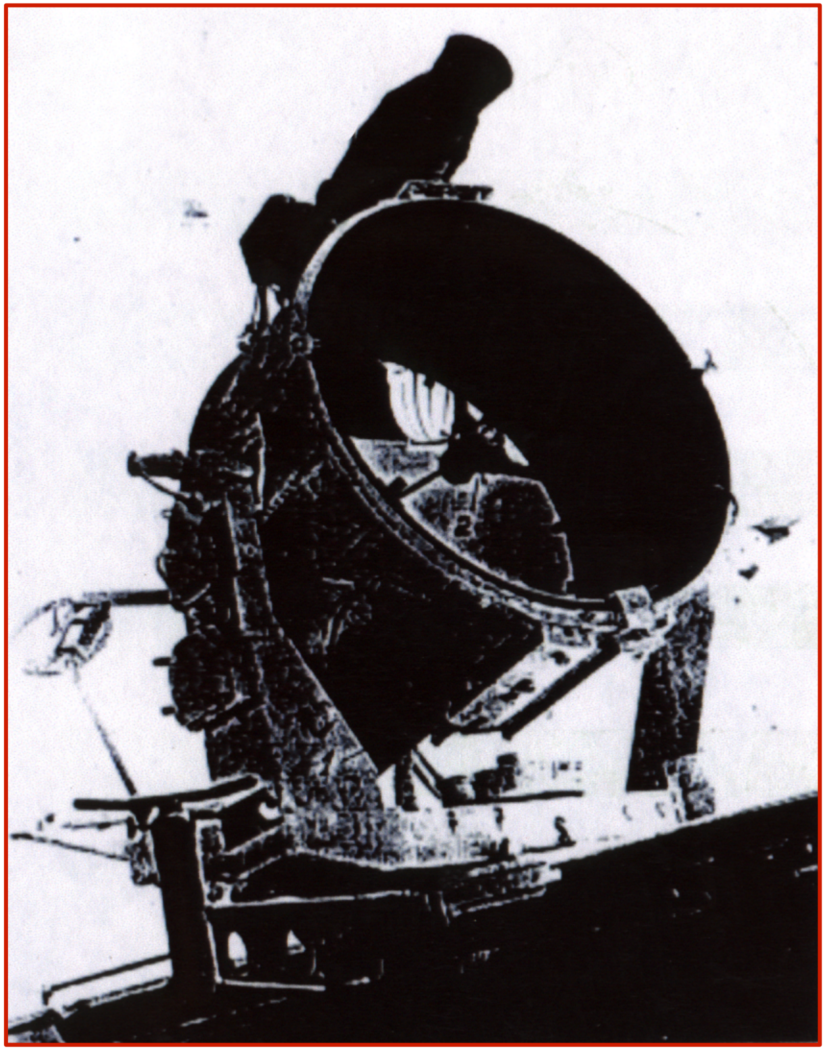


Telescopes with diameter 0.7 m (Eupatoria – pictured) and 0.5 m in Zailiysk Alatau (Alma-Ata)

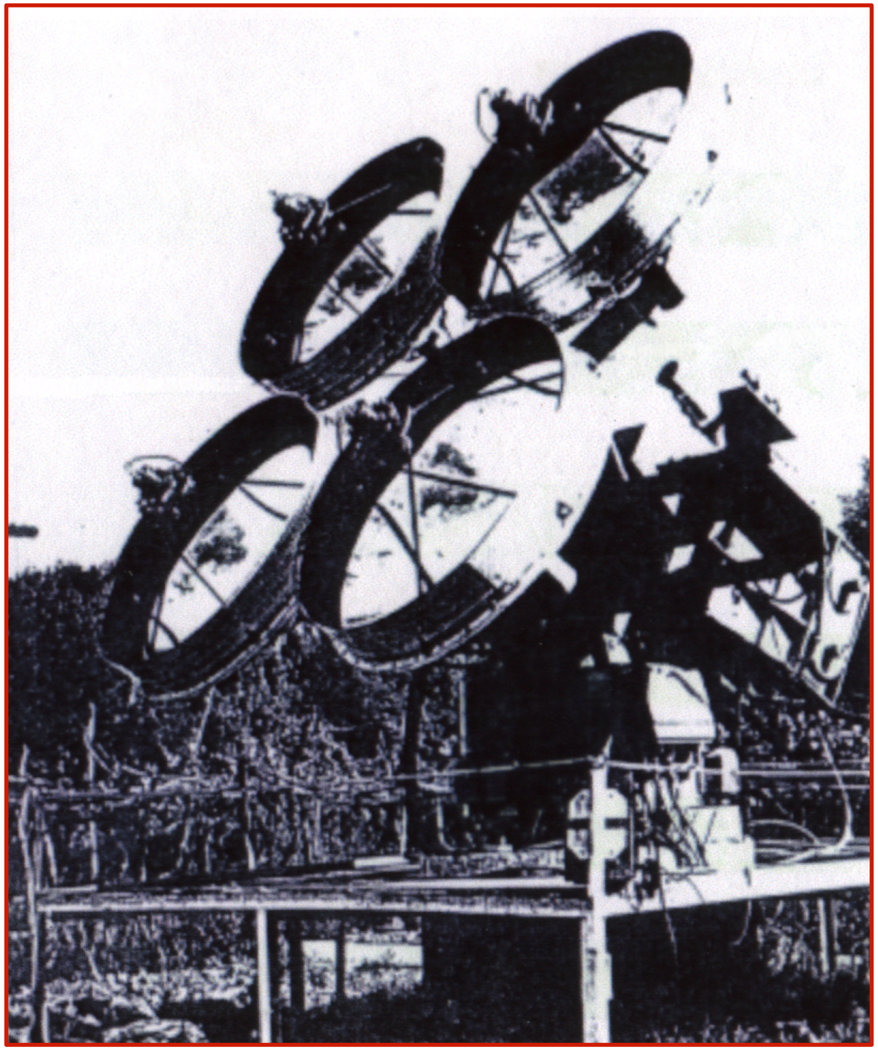


Ground module with ruby laser placed on telescope tube.

Experimental laser rangers

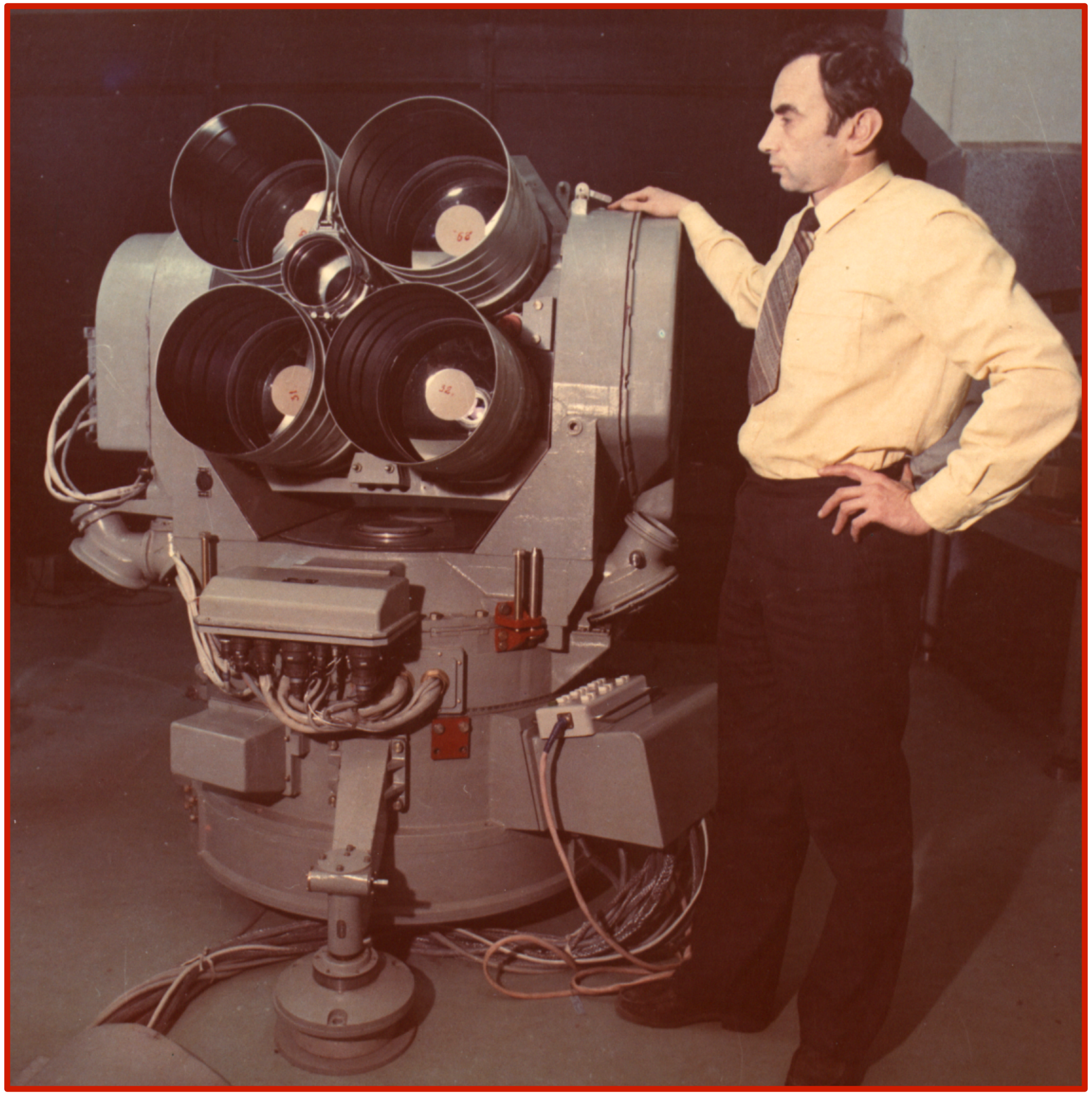


First stationary
satellite laser ranger SKOL-1 (Eupatoria)
Laser ranging of orbital space station Salyut-4 (1975)



Laser ranger SKOL-2 (Kitab)
World's first laser ranging of
geostationary S/C "Raduga" (1976)

Laser ranger «Sazhen-2»



First Russian serie produced satellite laser ranger for space geodesy.

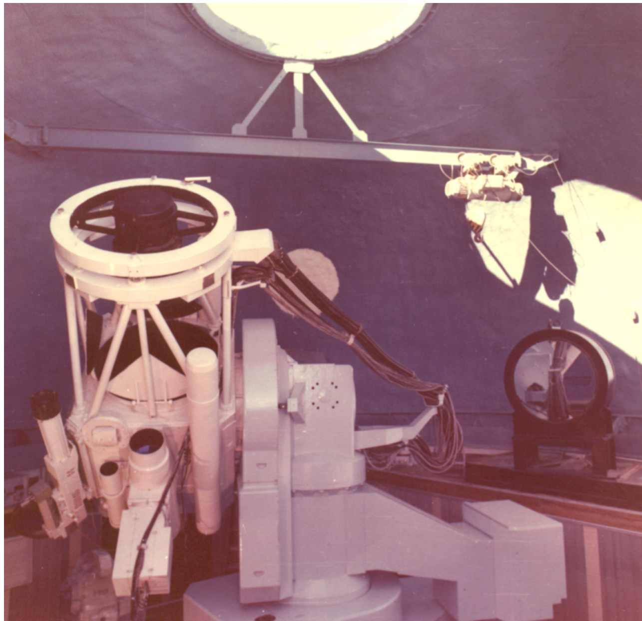
Developed in 1981.

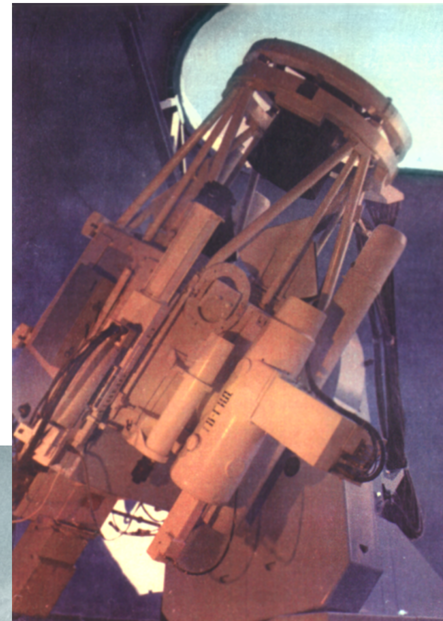
Accepted for permanent operation with geodetic S/C “GEO IK”.

25 sets were manufactured.

Accuracy of range measurements – 20 cm.

Quantum-optical system "Sirius"





SLR "Sirius" test commission was lead by cosmonaut № 2 German Titov.

SLR «Sirius»
brought to operation:
1st stage – in 1980
2nd stage – in 1985

Equipped with two 1.1 m telescopes with equatorial and altazimuth mounting

SLR station «Sirius» on Maidanak mountain h=2700m

World's 1st laser ranging of GNSS GLONASS S/C was done in 1982, at the distance of about 20000 km.

SLR «Sazhen-S»

A network of 4 SLR “Sazhen-S” (YAG lasers, two 0.5 m telescopes for transmission and reception) was established for calibration of two-way radio systems of GLONASS’ first stage:

At sites:

Dunaevtsy 1987

Eupatoria 1988

Balkhash...............................1988

Komsomolsk-On-Amur 1990

ILRS participation started in 1991

Operational satellite laser rangers "Sazhen-T"

SLR station near Moscow, operational since 2000

SLR station at Altai optical-laser center, operational since 2006

Baikonur Cosmodrome, SLR «Sazhen-TOS», since 2006

Mobile station

Altai optical laser center named after G.S. Titov

Altai Region, Zmeinogorsk Area, Savvushka vilage, near Big Kolyvanskoe Lake.
Average number of clear nights: 178.
AOLC location is one of the best in Russia in respect to cloudless time.
Lower site, located at 300 m. It has the SLR station with
60 cm Telescope for Trajectory Measurements (TTM).

AOLC lower site

0.6 m Telescope for Trajectory Measurements

Commercial SLR system «SAZHEN-TM», developed in 2005.

Range	Angular coordinates	Photometry
S/C orbital altitude: up to 23000 km t of laser pulse ………….200 ps RMSE np …………….5 – 10 mm	Visible star magnitude not weaker than: 12^m RMSE of measurements……….1 – 2 arc sec. Angular velocities……........... up to 40 arc sec.	Visible star magnitude….................. ….not weaker than 11^m RMSE of brightness determination: ……… not greater than 0.2^m

Collocation node "Badary" (Siberia)

Three such stations were deployed at three VLBI stations of the Institute of Applied Astronomy RAS and they form collocation nodes together with GLONASS, GPS and DORIS receivers.

Russian SLR network

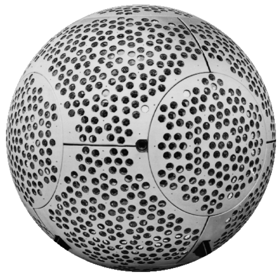
Commercial SLR station «SAZHEN-TM» in Brasilia, Brazil.

Range	Angular coordinates	Photometry
S/C orbital altitude: up to 23000 km RMSE of normal point….5 – 10 mm	Visible star magnitude not weaker than: 12^m RMSE of measurements……….1 – 2 arc sec. Angular velocities……............ up to 40 arc sec.	Visible star magnitude….................. ….not weaker than 11^m RMSE of brightness determination: ……… not greater than 0.2^m

Operational since June 2014 г.

Domestic and foreign retroreflector systems and satellites

AJISAI / Japan

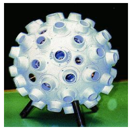


ETALON/Russia

LAGEOS/USA

LARES/
Italy

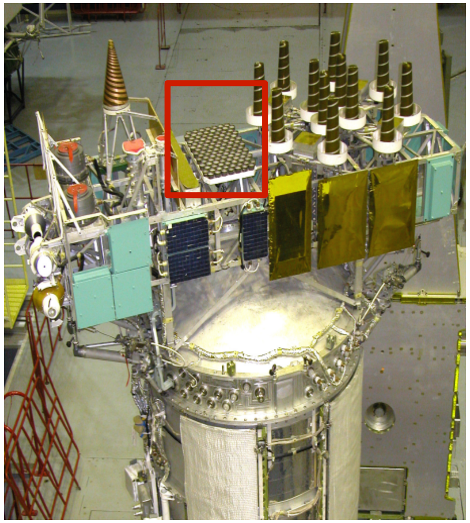
GFZ-1/
Russia



WESTPAC/
Australia
Russia

Larets /
Russia

CRYOSAT
/ Russia/
ESA

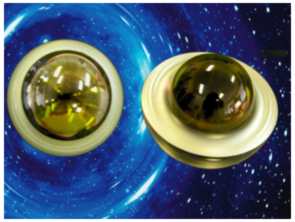


GLONASS-M /
Russia

GALILEO /
ESA/Russia

GPS #35,36 /
USA/
Russia

Meteor /
Germany/Russia



BLITS /
Russia

Laser retroreflector systems designed by RPC PSI for Russian spacecraft.

Тип КА	Высота орб., км	Год запуска	Кол. КА	Кол. СВ на КА	Размер системы ретрорефл., мм
Салют – 4 (Россия)	350	1975	1	42	184x168x47
Цикада – 11,-13 (Россия)	1 000	1976	2	280	235x145x110
Метеор – 1 (Россия)	950	1976	2	70	∅585x210
Молния – 1С (Россия)	36 000	1974	1	70	504x318x510
Радуга (Россия)	36 000	1976	2	50	306x255x248
ГЕОИК (Россия)	1 500	с 1981 по 1990	11	692	$\varnothing_1$1960 - $\varnothing_2$1410 (кольц. зона)
ГЛОНАСС (Россия)	19 100	с 1981 по 2000	>50	396	1330x1010
Эталон - 1, -2 (Россия)	19 100	1989	2	2142	∅1294
Ресурс – 0 (Россия)	620	1992	1	2	200x160x90
Метеор – 2 (Россия)	950	1993	1	3	196x66x96
Метеор-3 (Россия - Германия)	1 200	1994	1	24	∅280x100
Зея (Россия)	475	1997	1	20	∅968
ГЛОНАСС (Россия)	19 100	с 2000 по 2005	11	132	$\varnothing_1$660 - $\varnothing_2$380
Метеор-3М-1 (Россия)	1 020	2002	1	1 сфера ∅60 мм	∅88x64
ЛАРЕЦ (Россия)	690	2003	1	60	∅215
Можаец (Россия)	690	2003	1	6	∅115x46
ГЛОНАСС-М (Россия)	19 100	с 2003 по н.в.	*45	112	511x311
BLITS 2009 (Россия)	832	2009	1	автоном. сфера	∅170
ГЕО-ИК (Россия)	1000	февраль 2011 неудачный запуск	1	30	∅300x96,5
Спектр-Р (Россия)	Эллипт-ическая	2011	1	100	500x406x80
ГЛОНАСС-К (Россия)	19 100	2011	1	123	$\varnothing_1$626 - $\varnothing_2$340 кольцевая зона

Total 147 Russian S/C are equipped with laser retroreflectors.

Laser retroreflector systems designed by RPC PSI for foreign spacecraft

Тип КА	Высота орб., км	Год запуска	Кол. КА	Кол. СВ на КА	Размер системы ретрорефл., мм
GPS - 35, - 36 (США)	20 150	1993, 1994	2	32	239x194x50
GFZ-1 (Германия)	400	1995	1	60	∅215
WESTPAC (Австралия)	835	1998	1	60	∅245
REFLECTOR (Россия - США)	1 020	2002	1	32	1445x620x560
GIOVE-A (EKA)	23 916	2006	1	76	308x408x42
GIOVE-B (EKA)	23 916	2008	1	67	305x305x42
GOCE (EKA)	295	2009	1	7	∅125x57
Proba-2 (EKA)	757	2009	1	7	∅114x51
CrioSat (EKA)	720	2005	1	7	∅114x51
CrioSat (EKA)	720	2010	1	7	∅114x51
Proba-V (EKA)	820	2011	1	7	∅114x51
Sentinel-3	718,5	план 2014	3	7	∅114x51
Galileo	23 222	планируется	22	60	350x253x48,5

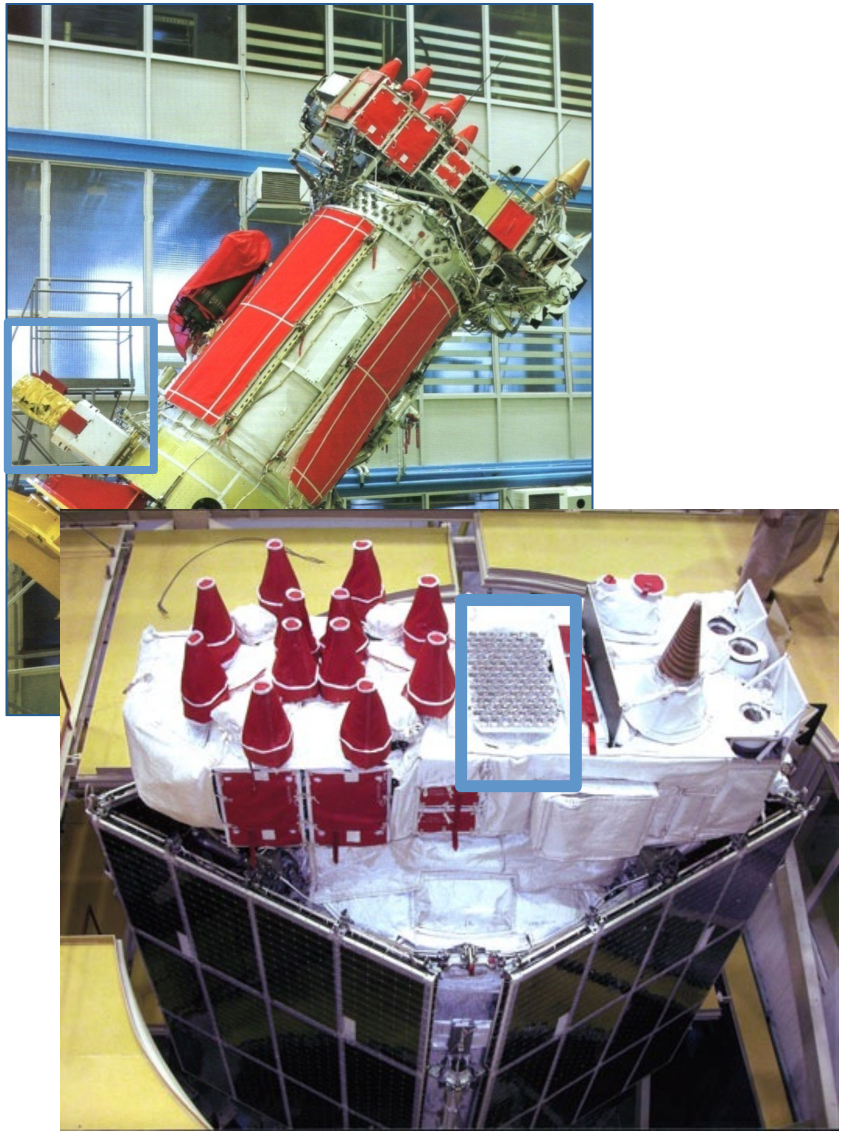
Total 37 foreign S/C are equipped with laser retroreflectors

RPC PSI designs for GLONASS

To increase competitiveness of GLONASS,

RPC PSI develops:

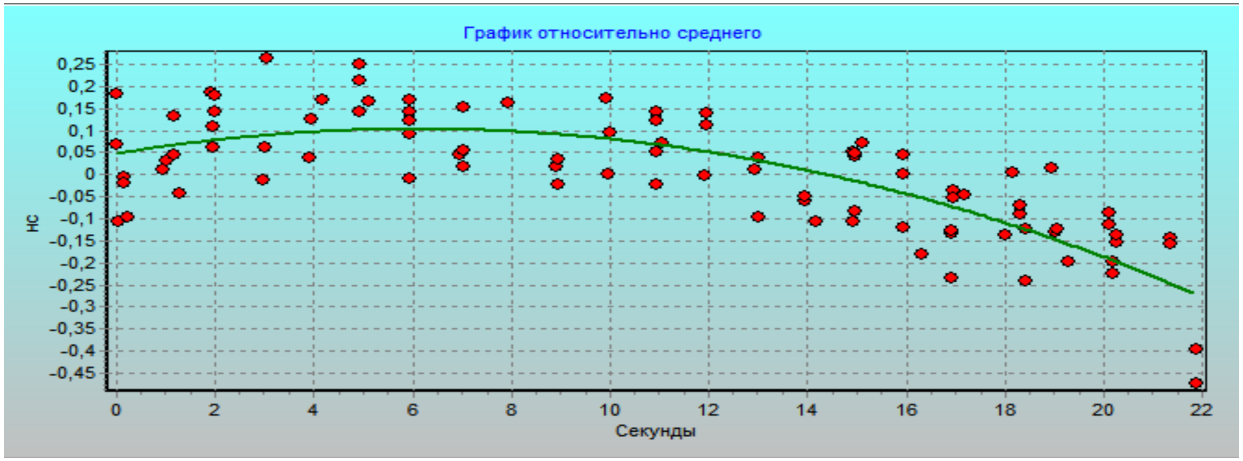
- system for high-accuracy determination of ephemerides and time corrections of time scales
- network of ground SLR stations working with S/C GLONASS onboard retroreflectors
- inter-satellite laser navigation and communication system (ISLNCS)
- one- and two-way SLR system for precise check of time-frequency parameters of GNSS GLONASS



Evaluation of time scales difference between S/C “Glonass-M” # 747 and GLONASS central synchronizer

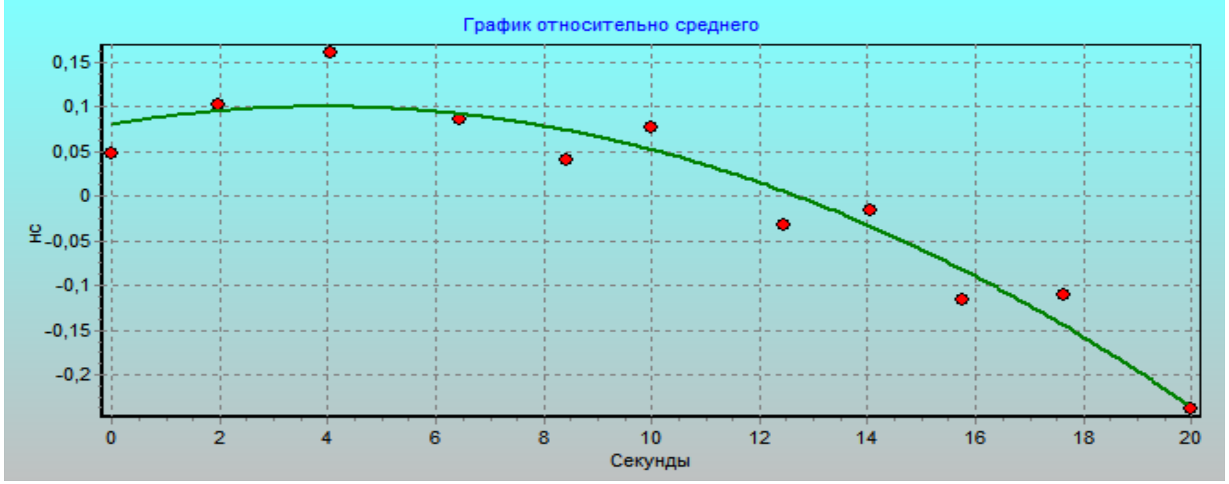
Session “On-board one-way SLR – Central Synchronizer». Evaluation of scales difference (raw measurements) RMSE 82 ps

S/C: 747 Date: 06.10.2013 Start Time: 20.15.41.305 Stop Time: 20.16.03.955



Session “On-board one-way SLR – Central Synchronizer». Evaluation of scales difference with 2 s averaging RMSE 36 ps

S/C: 747 Date: 06.10.2013 Start Time: 20.15.43.73 Stop Time: 20.16.03.66



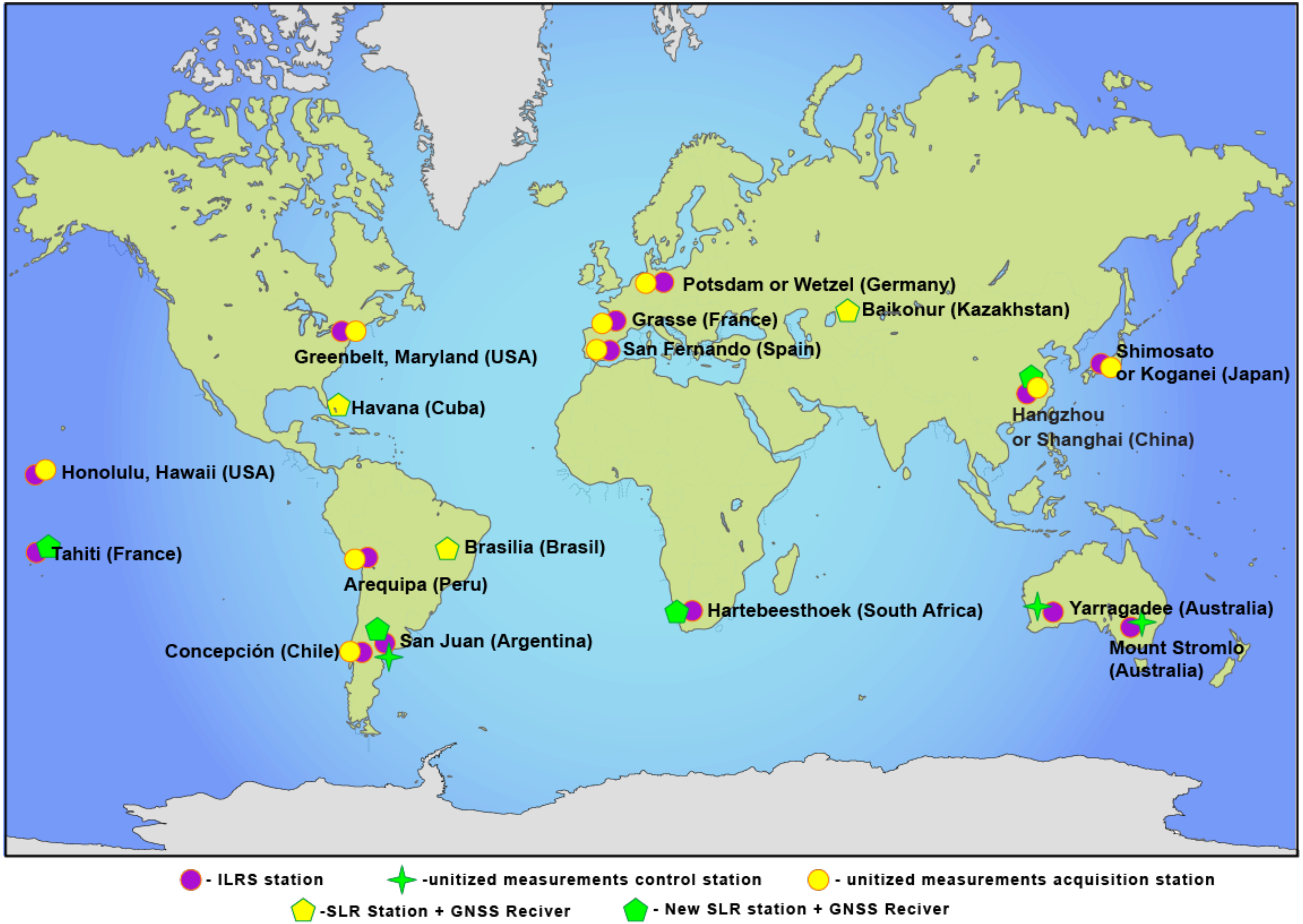
One can define calibration data with approximately this error using:

- difference between time scales of each S/C and GLONASS central synchronizer;

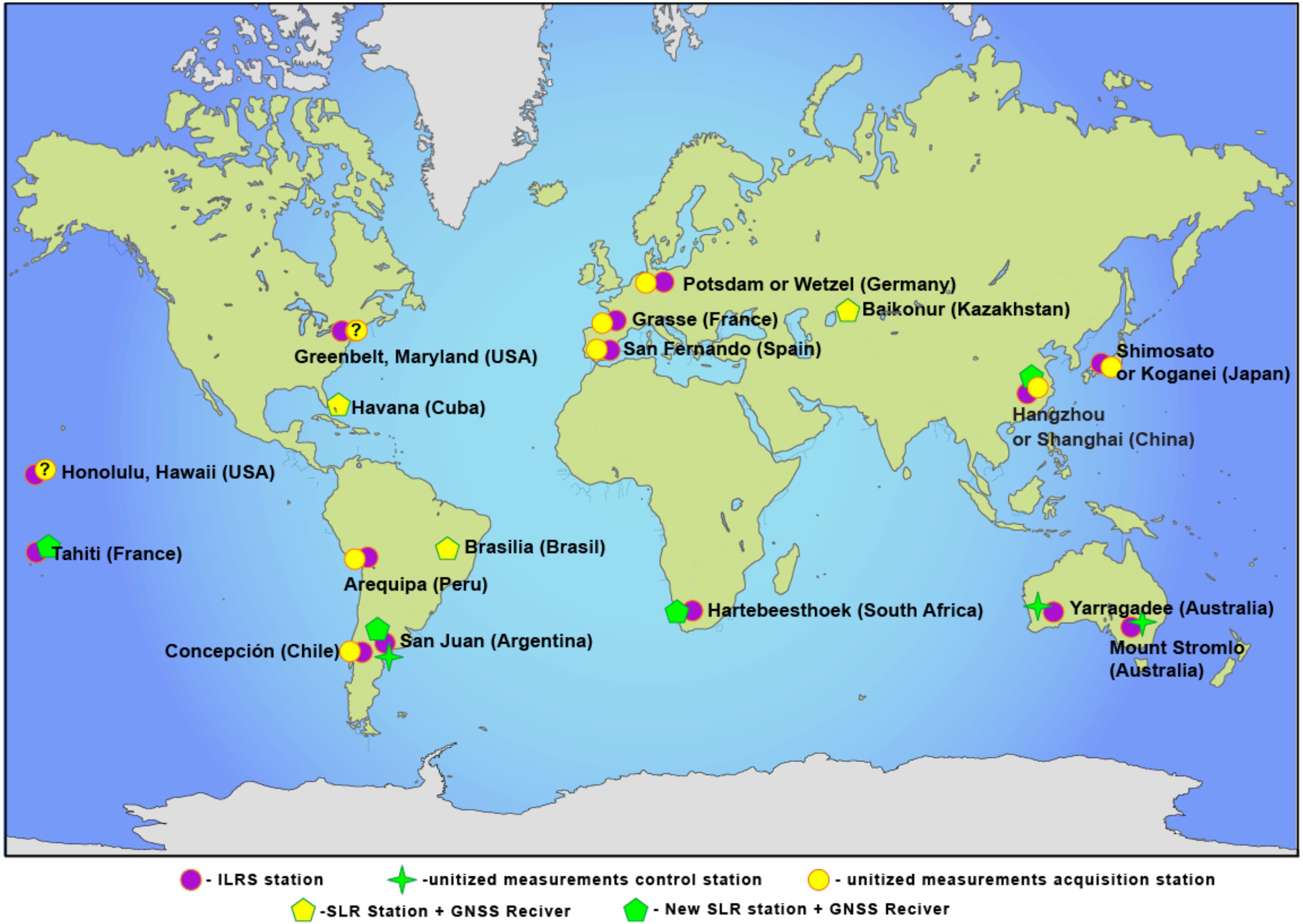
- difference between time scales of the central synchronizer and remote time and frequency standards (time transfer to remote sites);

- difference of time scales between S/C with onboard laser terminals that provide measurements and exchange of pseudoranges with all S/C in the global navigation system constellation.

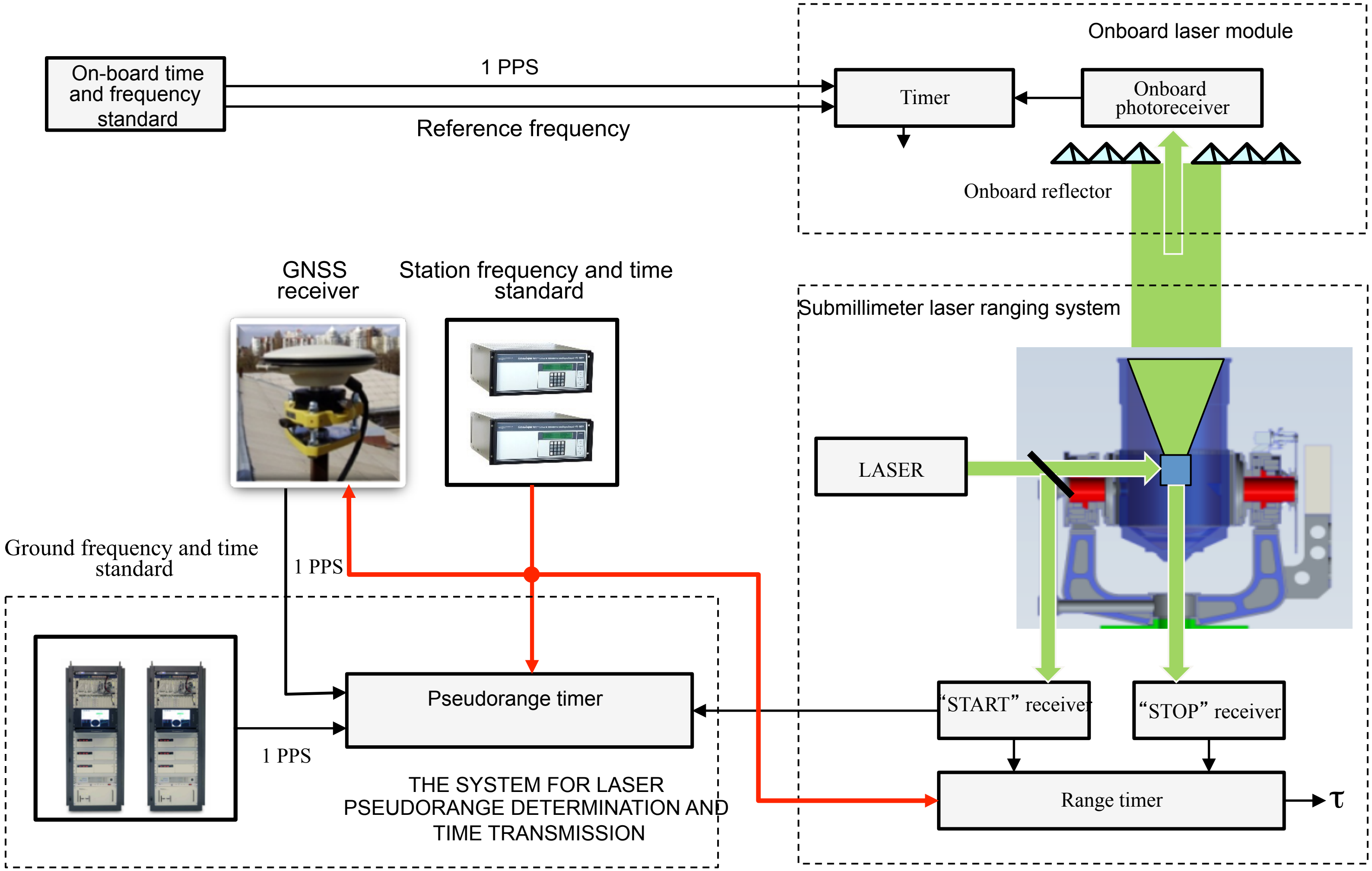
Plan for placement of GMS and SLR stations abroad



Plan for placement of GMS and SLR stations abroad

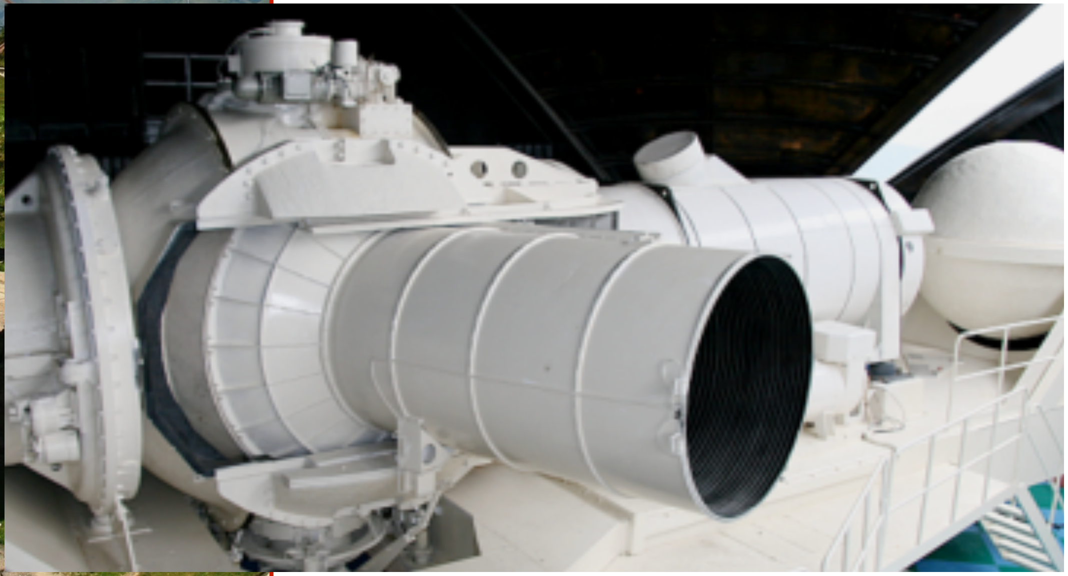


Sub-millimeter round-the-clock station for high-frequency SLR «Tochka»



Main technical specifications of SLR station "Tochka":
- random and systematic error of laser ranging ……………………………………………..not more than 1 mm;
- error of laser pseudorange measurements relative to time scales of GLONASS central synchronizer and State Time, Frequency and National Time Scale Standard …. not more than 50 ps.

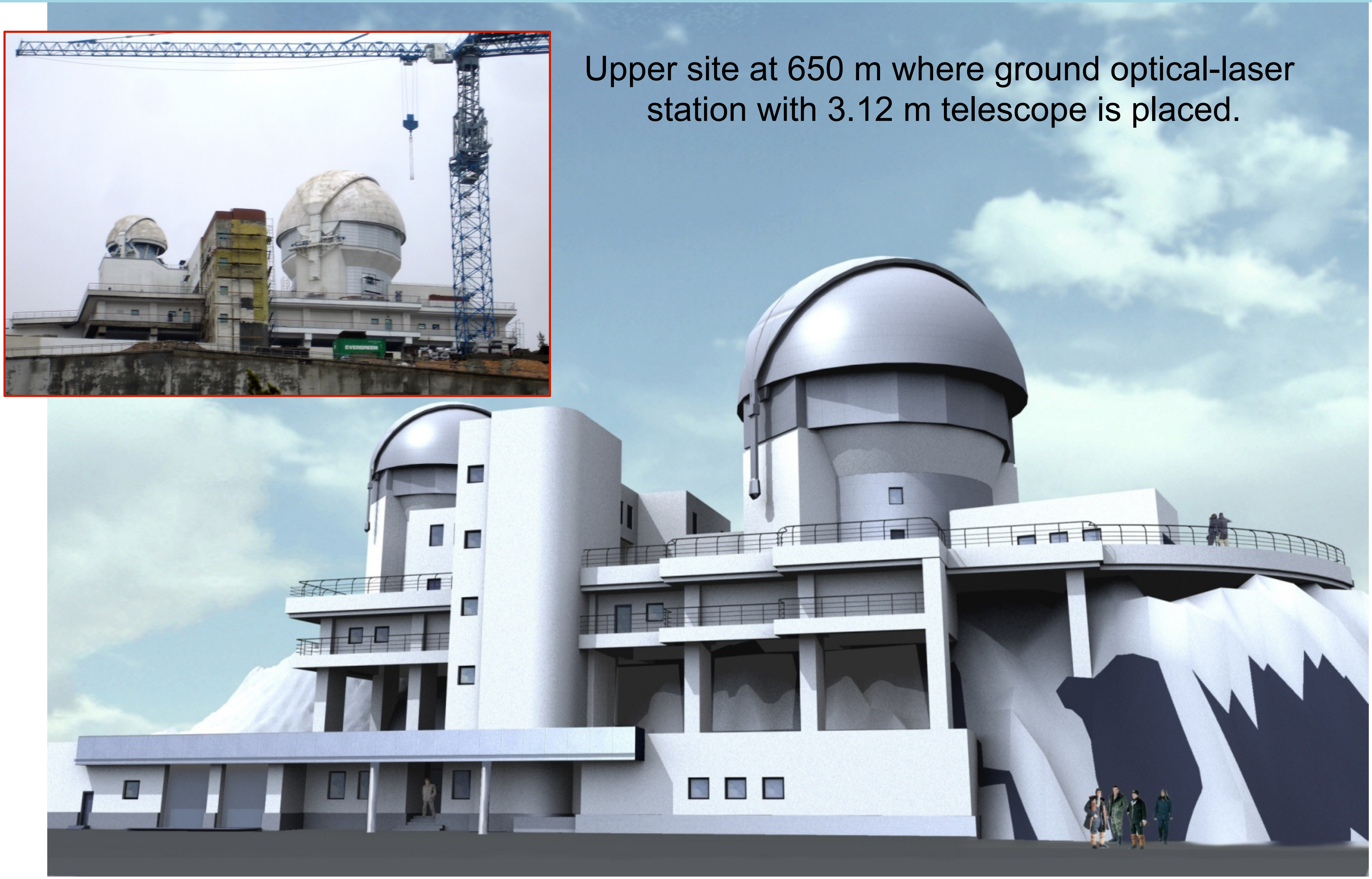
Laser Optical Ranger of the System for Monitoring of Space (LOR SMS)



Designed for:

- laser ranging of space objects and space debris elements using reflection from diffusive-reflective surfaces of space objects
- range measurements of distant S/C with laser reflectors (for example, S/C “Spektr” with GLONASS-type reflectors at the distance of 330,000 km)

General view of the second stage of AOLC (design)



Upper site at 650 m where ground optical-laser station with 3.12 m telescope is placed.

Purpose: detailed imaging with resolution of < 0,1 arc sec and acquisition of other information for S/C monitoring, laser ranging of the Moon and distant S/C with reflectors.

Thank you for your attention!