UNIVERSITÄT BERN

13-Po43

Status of the Zimmerwald SLR Station

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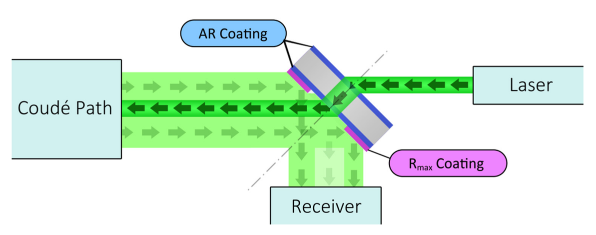
ZIMLAT

The 1-meter Zimmerwald Laser and Astronometry Telescope (ZIMLAT) was installed in 1997. It allows for state-of-the-art satellite laser ranging (SLR) and also serves as astronomical telescope for the optical observation of astrometric positions and magnitudes of near-Earth objects, such as space debris, using Charge Coupled Device (CCD) or Complementary Metal Oxide Semiconductor (CMOS) cameras. The telescope is monostatic w.r.t. SLR (transmit and receive paths are identical between the primary mirror and the transmit/receive mirror located at the lower end of the Coudé path). The detectors are protected from the backscatter of the transmit beam by a rotating shutter.

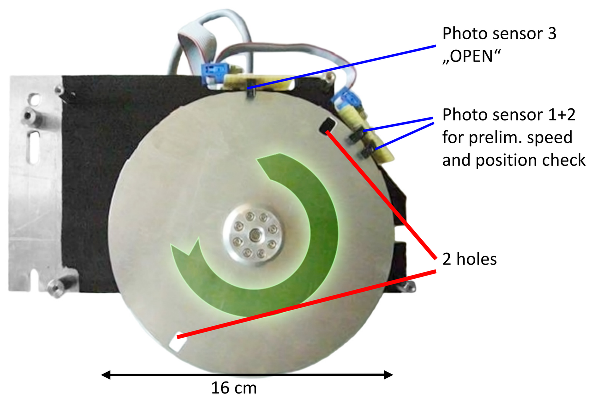
TRANSMIT/RECEIVE SWITCH

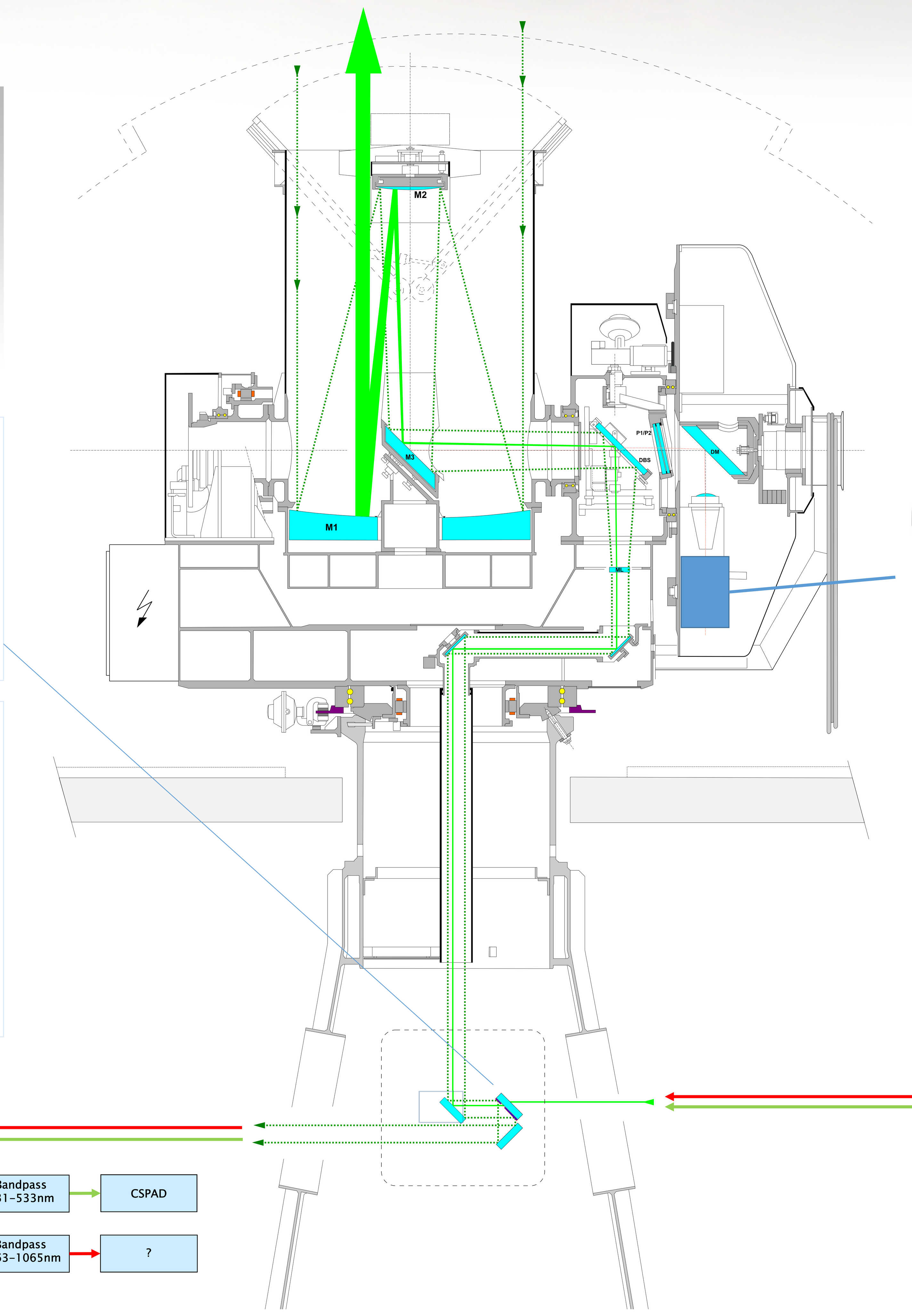
A specially coated mirror serves as switch between the transmit and the receive paths. This mirror has an anti-reflective coating on the back side (towards the laser). On the front face there is a reflective coating except at the place where the transmit beam passes the glass plate. This portion of the mirror has an anti-reflective coating and is also used to reflect a small percentage of the received calibration pulse into the receiving path.



ROTATING SHUTTER

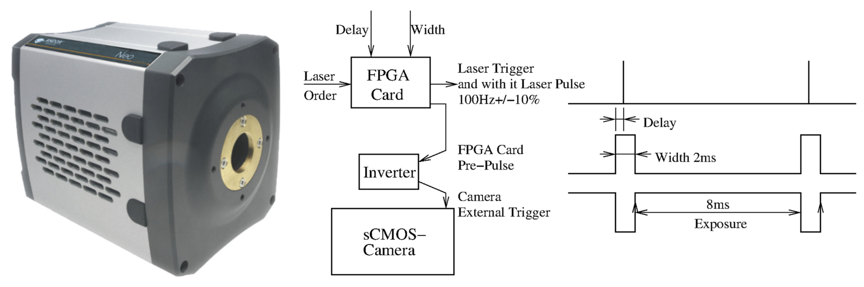
The rotating shutter opens the receiving path for the time of reception only. The shutter is implemented as a thin aluminum disk with two diametrically placed holes of 6 mm diameter each at a radius of 70 mm. It is driven by a DC servo motor with integrated controller operated in stepper mode at a speed of about 3000 rpm (->100 Hz optical chopper freq.) and is precisely synchronized with the actual firing rate of the laser. The shutter is open during about 300 µs with an uncertainty w.r.t. the expected time of reception of +/-50 µs. Frequency and phase are controlled by a PC via the FPGA card.





TRACKINGCAMERA

The dichroic mirror located in the fork of the mount allows for the use of tracking cameras simultaneously with SLR observations. The formerly used CCD Camera with an interline CCD was replaced in 2013 by a so-called scientific CMOS Camera manufactured by Andor. The maximum frame rate of 100 fps allows the exposure of the sensor between the transmitted laser pulses. The FPGA card, responsible for the timing of the laser, transmits a pre-pulse with variable delay and pulse width. This pulse can be used for triggering the exposure of the camera and for controlling the exposure time. It is not possible to make use of the full time span of about 10 ms for chip exposure due to fluorescence effects in the dichroic mirror after transmitting a laser pulse. The camera is well suited for bright objects like Low Earth Orbiters. For fainter objects, the exposure time must be increased by co-adding several short exposures. There is one remarkable disadvantage compared to the formerly used interline CCD camera manufactured by PCO where the photons of all sub-exposures were accumulated on-chip and read out only once. This is not possible with the new CMOS camera. The sub-exposures must be read out individually and co-added by software which degrades the signal-to-noise ratio.

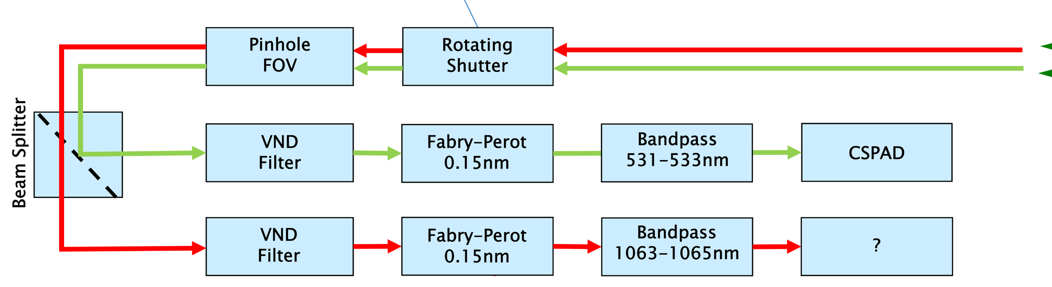


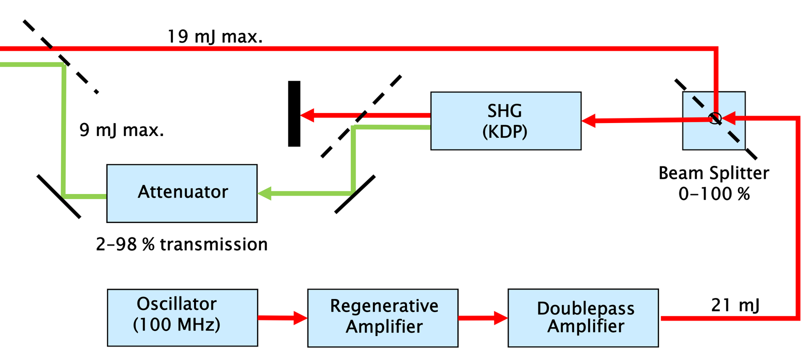
LASER

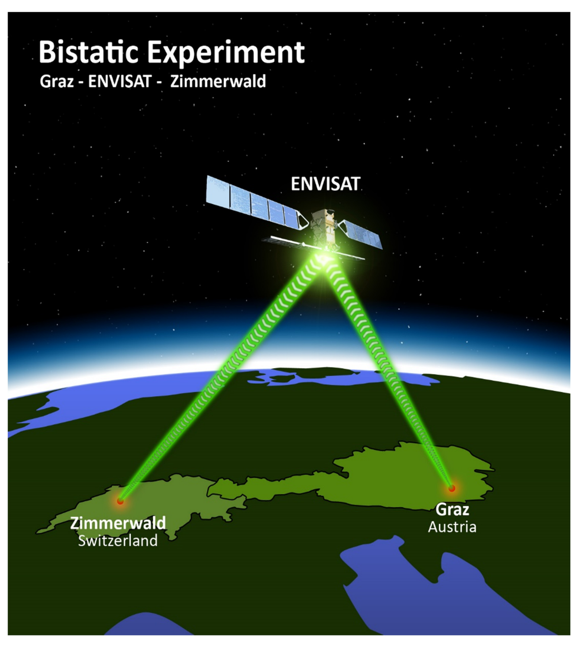
The laser system is a diode pumped solid state Nd:YAG laser manufactured by Thales Laser, France, with a primary wavelength of 1064 nm and a pulse rate between 90 – 110 Hz. The pulses with an energy of about 21mJ (before doubling) and a pulse width of 58 ps are generated by a 100 MHz oscillator, a regenerative amplifier and a double-pass amplifier. A KDP (Potassium Dihydrogen Phosphate) crystal in the second harmonic generator (SHG) produces a 9 mJ pulse at 532 nm. Theoretically the infrared beam after the SHG could be used for two-color ranging, but the quality of the infrared beam is insufficient. In case of two-color or infrared-only operation, the SHG can be bypassed with a selectable fraction of the infrared energy. Laser trigger signals for pump diodes and enabling/disabling signals for the pockels cell, as well as the signals for range gate generation and rotating shutter control, are generated by the Field Programmable Gate Array (FPGA) card prepared and programmed by the Technical University of Graz.

DETECTOR

The field of view (FOV) can be limited by various pinholes (diameters from 8 to 40 arcsec) in order to reduce the noise, especially during daytime operation. A beamsplitter separates the infrared and green light. A variable neutral density filter can be used to decrease the number of photons passing through a Fabry-Perot filter (FWHM of 0.15 nm) and a bandpass filter (531 nm – 533 nm) to the Compensated Single Photon Avalanche Diode (CSPAD) detector.





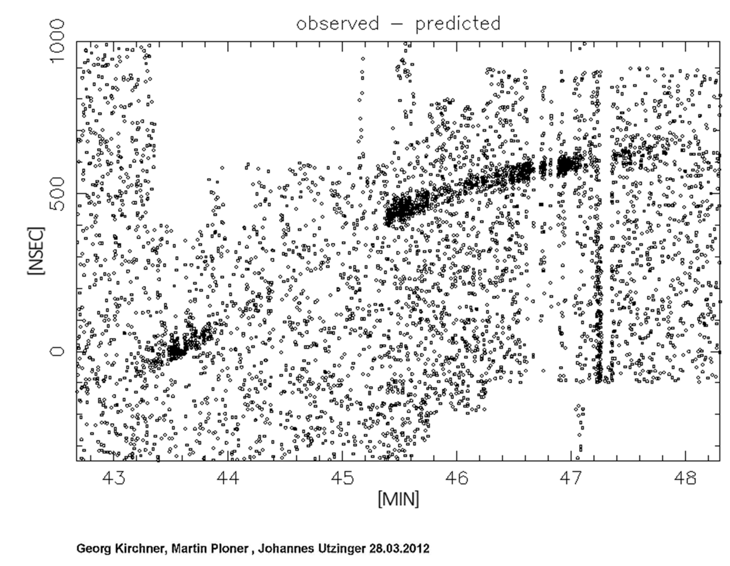


BISTATIC EXPERIMENT

In the so called 'bistatic' experiment the SLR station Graz is firing laser pulses to space debris objects using a powerful laser (200 mJ @ 532 nm, 3 ns pulse length, 80 Hz) provided by DLR (Deutsches Zentrum für Luft- und Raumfahrt) Stuttgart. On 28th March 2012 the diffusely reflected photons on the satellite ENVISAT were successfully detected and time-tagged at the Zimmerwald SLR station for the very first time. About one year later (18th June 2013) photons reflected on a space debris object (upper stage CZ-2C) with a considerably smaller radar cross section than ENVISAT could be detected. For bistatic range measurements the receiving components have to be synchronized to the Graz firing times within a few microseconds. Knowing the exact firing times of the Graz laser in advance, the expected arrival times of the Graz photons in Zimmerwald are calculated and the detector is activated accordingly. The collected data can be used to calculate improved orbits of the tracked debris objects. But this would ask for measuring the time stamps of the stop pulses with an absolute accuracy below 1 nanosecond. This is not possible so far due to the following unsolved issues. On the one hand, the time synchronization of the event timer with UTC is done by a GPS receiver with an accuracy of 100 ns. On the other hand, the delay between the reference point of the telescope (intersection point of the telescope axis) and the event timer is only estimated with an accuracy of a few nanoseconds.

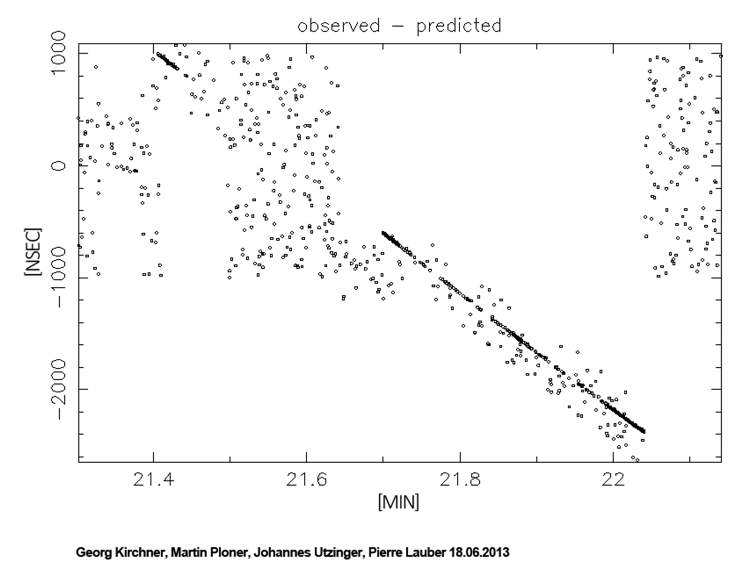
Bistatic Experiment Graz-ENVISAT-Zimmerwald

Envisat 28 March 2012, 20:40 – 20:50 UT: Returns measured at Zimmerwald



Bistatic Experiment Graz-"CZ-2C"-Zimmerwald

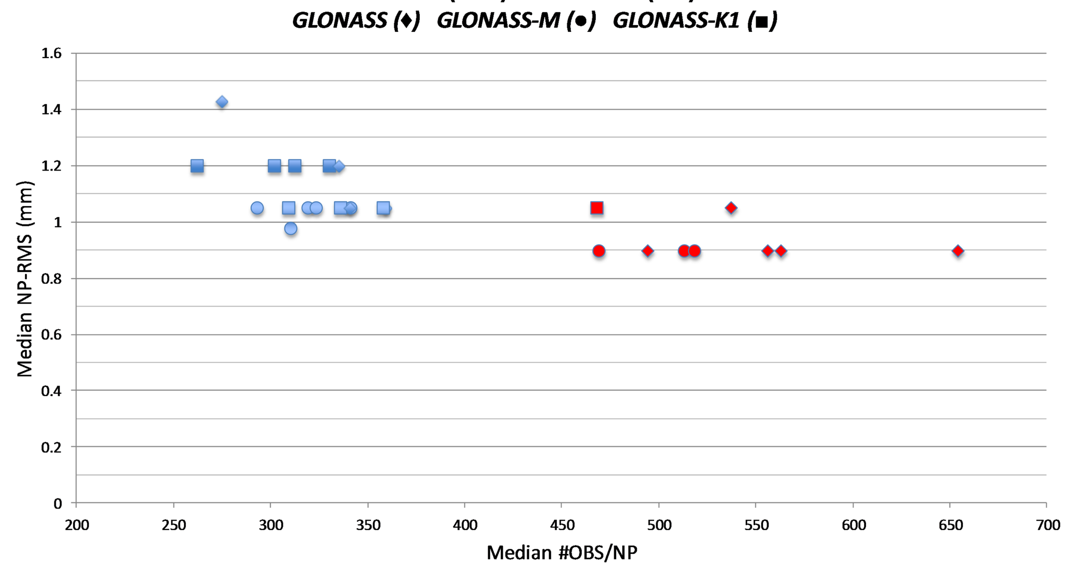
CZ-2C 18 June 2013, 21:17 - 21:25 UT: Returns measured at Zimmerwald



GNSS Constellation

Since summer 2010 the complete Glonass constellation (currently 24 satellites) is ranged from Zimmerwald. The number of observations per normal point (#OBS/NP) is almost a factor of two higher for Glonass satellites equipped with uncoated reflectors than for those with coated reflectors. The difference in #OBS/NP is a result of the higher return rate for satellites with uncoated reflectors. The lower RMS of the normal points for uncoated reflectors can be explained by the higher #OBS/NP. No significant differences can be seen between different types of Glonass satellites (Glonass, Glonass-M and Glonass-K).

GLONASS
coated (blue) vs. uncoated (red)
GLONASS (♦) GLONASS-M (●) GLONASS-K1 (■)



LRO

In case of range observations to the Lunar Reconnaissance Orbiter (LRO) the laser system has to operate in a special mode. At the spacecraft the observation window has a width of 8 ms and a frequency of 28 Hz. The pump diodes of the amplifiers can be triggered with a variable rate between approximately 9 and 11 ms in steps of 10 microseconds. By means of the pockels cell selecting the pulses to be amplified, the actual firing rate can be reduced by an additional integer factor. For the LRO one-way ranging experiment the laser fires at approximately 14 Hz, i.e. with a basic pump interval of 10.200 ms (corresponds to a frequency of 98 Hz) and a reduction factor of 7. The firing time can be empirically corrected in steps of 1 ms in case of unsuccessful observations. Especially during daytime operation the actual pointing offset of the telescope due to thermal effects is empirically estimated using GNSS satellites passing nearby. On 20th July 2009 the SLR station Zimmerwald was the first European SLR station that successfully carried out observations to LRO. Since this success more than 2300 observations minutes were collected at Zimmerwald.

Year	Observation minutes
2009 (from 20th July)	41
2010	164
2011	756
2012	399
2013 (until 25th October)	799

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