Graz in Space 2014

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SLR Graz:

kHz Satellite Laser Ranging & Co

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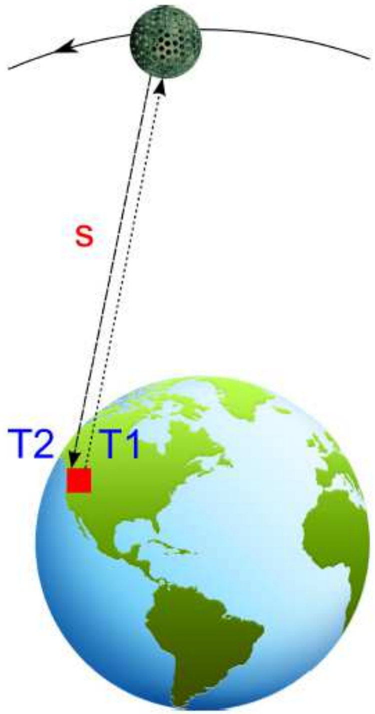
Outline

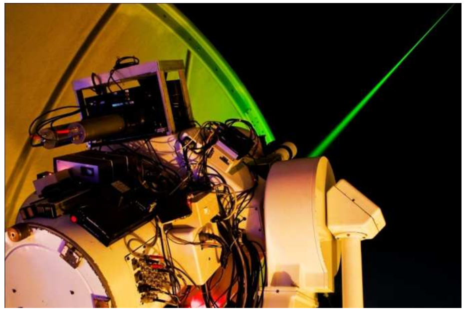
- What is SLR and how does it work?
- What is needed for SLR?
- What is done with the data?
- SLR and space debris?

What is SLR
and how does it work?

Satellite laser ranging

- Measurement of travel time Δt of a laser pulse from ground station to satellite and back
- Very short laser pulses (10 ps)
- Operating in the optical spectrum (532 nm)
- 0.4 mJ per pulse (about 10^{14} photons)
- 2 kHz: up to > 500 pulses simultaneously en route
- Basic observation equation (range): $s = c\,\Delta t / 2$
- Accuracy: 2-3 mm
- Satellites routinely equipped with Laser Retro-Reflectors (LRR)
- First satellite to carry a LRR: Beacon-Explorer B (BE-B) in 1964
- Dedicated SLR satellites (optimized in design and orbital parameters)





Satellite laser ranging

Dedicated SLR satellite design

- Spherical shape (simple non-gravitational forces modeling)
- Completely covered with reflectors (field of view 360°)

GFZ-1

WESTPAC-1

Alternative laser retro-reflector (LRR) designs

- LRR ring, LRR pyramid, LRR panel

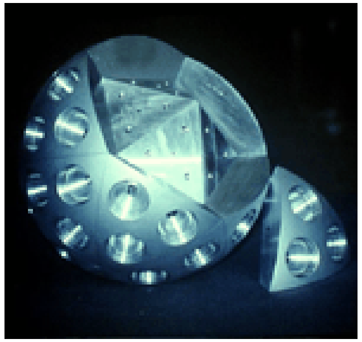
GOCE

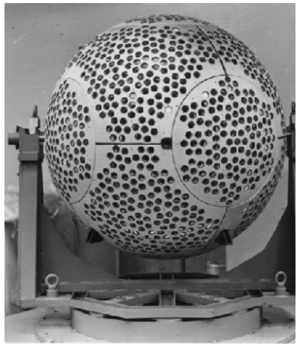
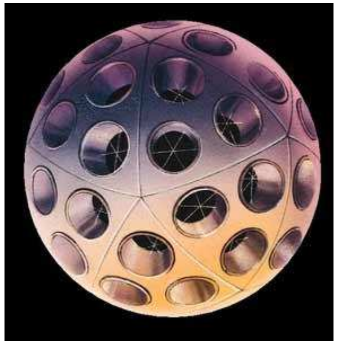
Swarm

COMPASS

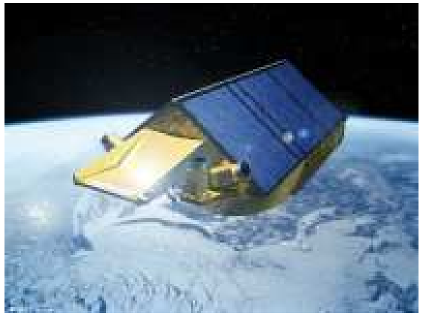
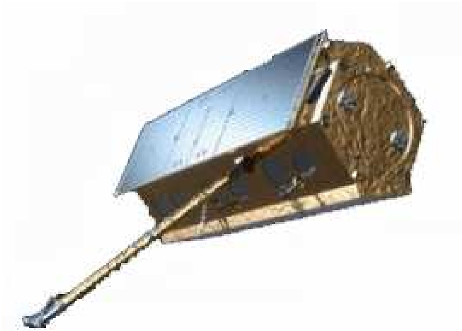
Passive (or geodetic) satellites: examples

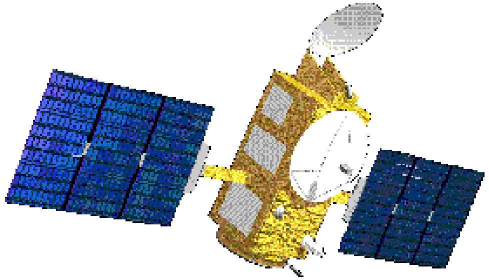
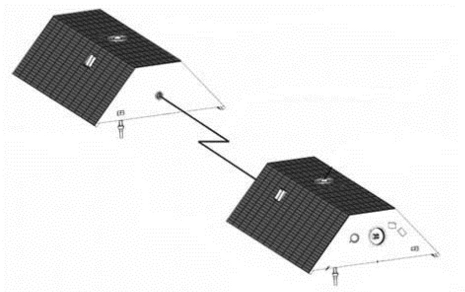
Satellite	Launch	Sponsor	Altitude (km)	Incl. (°)	Diameter (cm)	Mass (kg)	#LRR
STARLETTE	1975	CNES	800	50	24	47	60
LAGEOS-1	1976	NASA	6000	110	60	407	426
AJISAI	1986	JAXA	1500	50	215	685	1436
ETALON-1/2	1989	Russia	19000	65	1294	1415	2146
LAGEOS-2	1992	NASA/ASI	6000	53	60	405	426
STELLA	1993	CNES	800	99	24	48	60
LARES	2012	ASI/ESA	1450	69.5	36	387	92



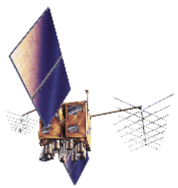




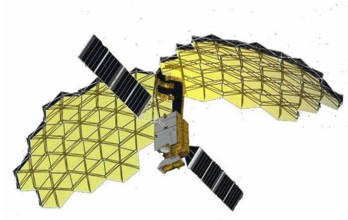
Active LEO satellites: examples

	Cryosat-2	Terra-SAR-X	Envisat
			
Inclination	92°	66°	98.5°
Altitude (km)	720	1350	800
Mass (kg)	711	2400	8211

	Swarm A/B/C	Jason-2	GRACE A/B
			
Inclination	88.3°	66°	89°
Altitude (km)	460	1336	450
Mass (kg)	472	500	432/sat

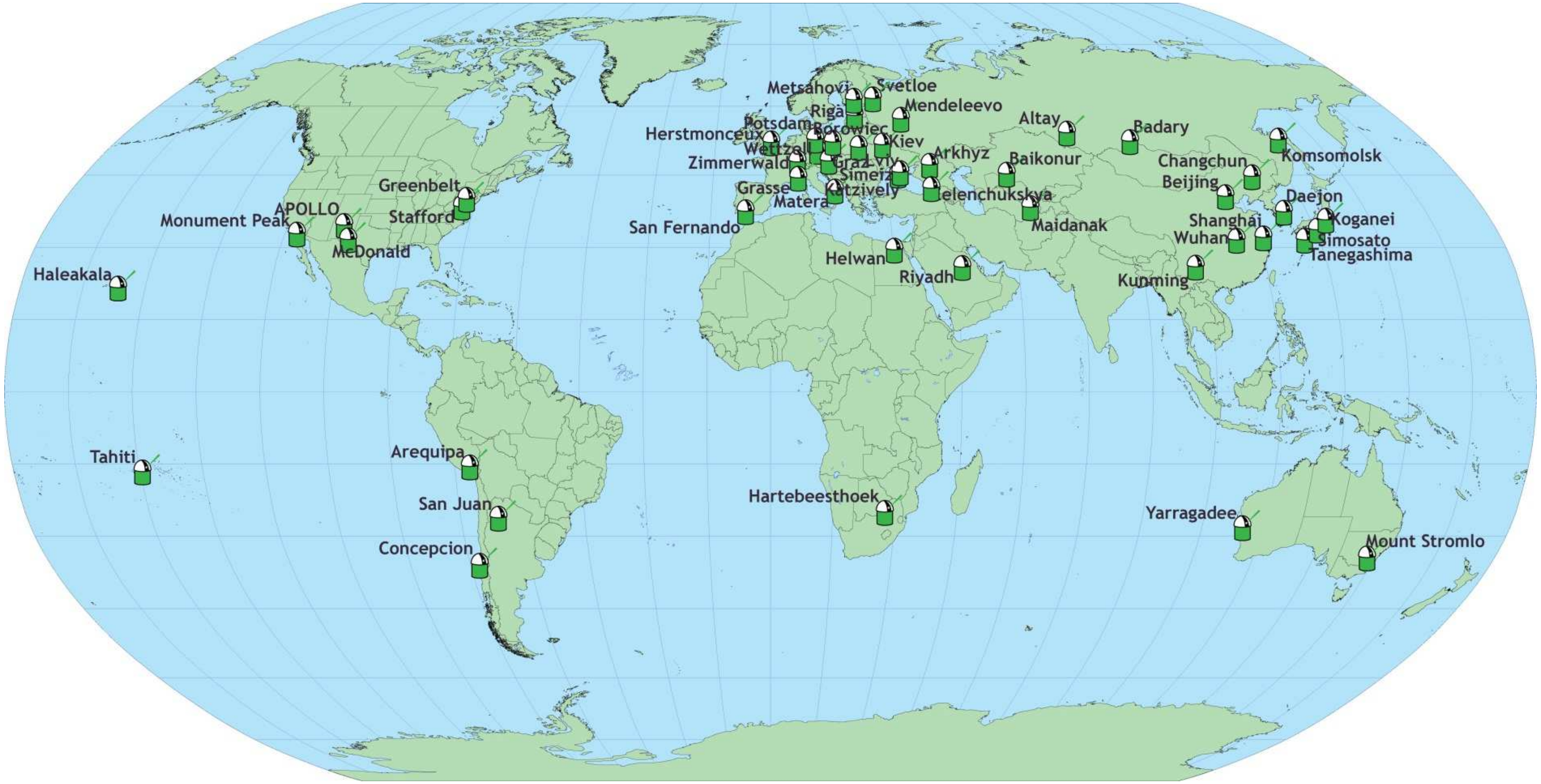
Navigation satellites: examples

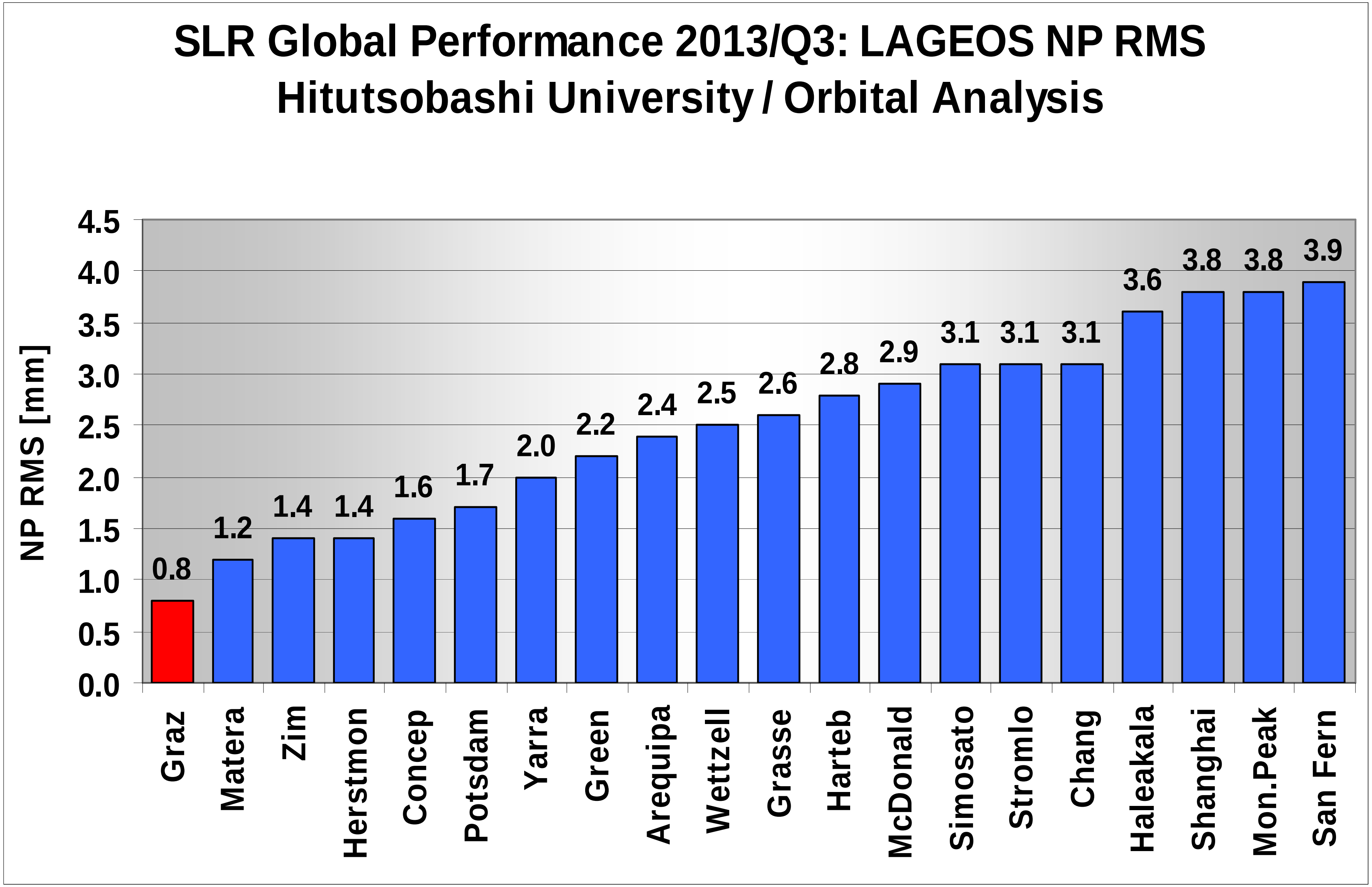
	GLONASS	GPS	COMPASS	GALILEO	ETS-8
Inclination	64°	55°	55.5°	56°	0°
Altitude (km)	19140	20100	21500	23920	36000
Mass (kg)	1400	930	1000	600	2800

Ground segment: network of SLR stations



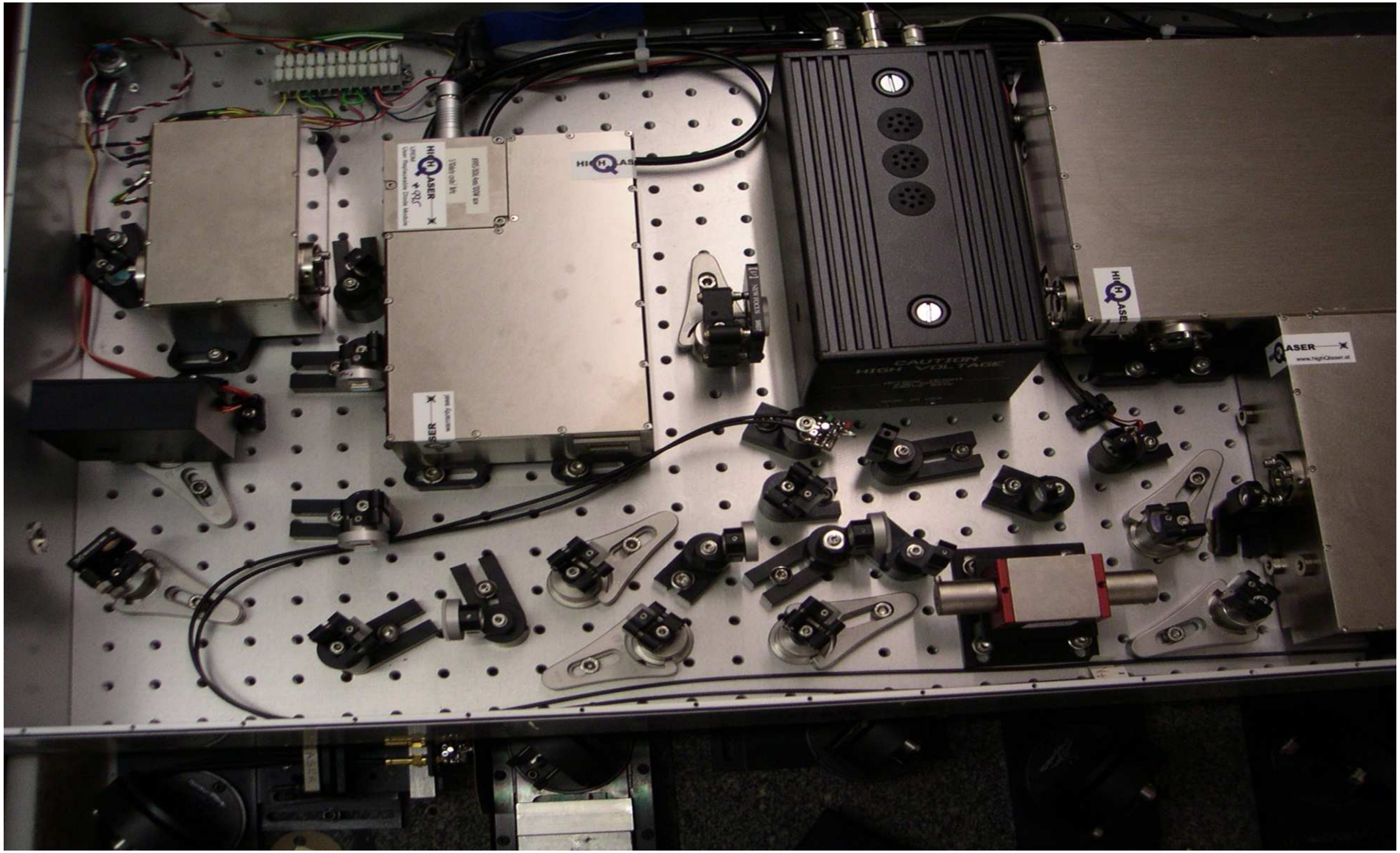
- About 30 SLR stations (inhomogeneously distributed around the globe)
- International Laser Ranging Service (ILRS)
- Graz currently tracks more than 80 different satellites
- Graz is one of the most accurate SLR stations

Graz performance



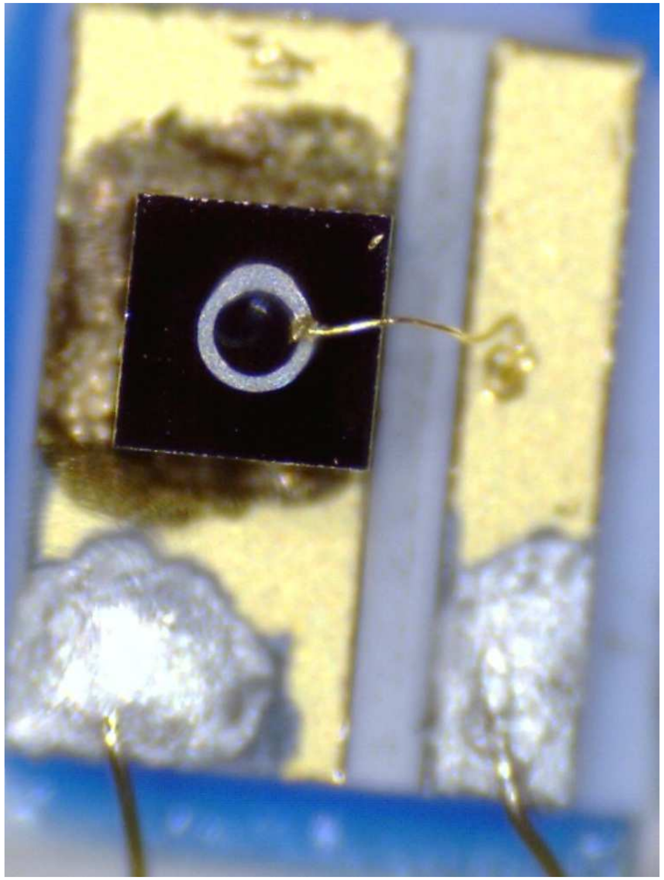
What is needed for SLR?

A laser



A telescope with a dome

A detector



The detector “sees” single photons, and time-tags their time of arrival with extremely high accuracy (few picoseconds)

… the displayed silicon diode has a diameter of only 200 µm

… each returning photon has to hit this surface ☺

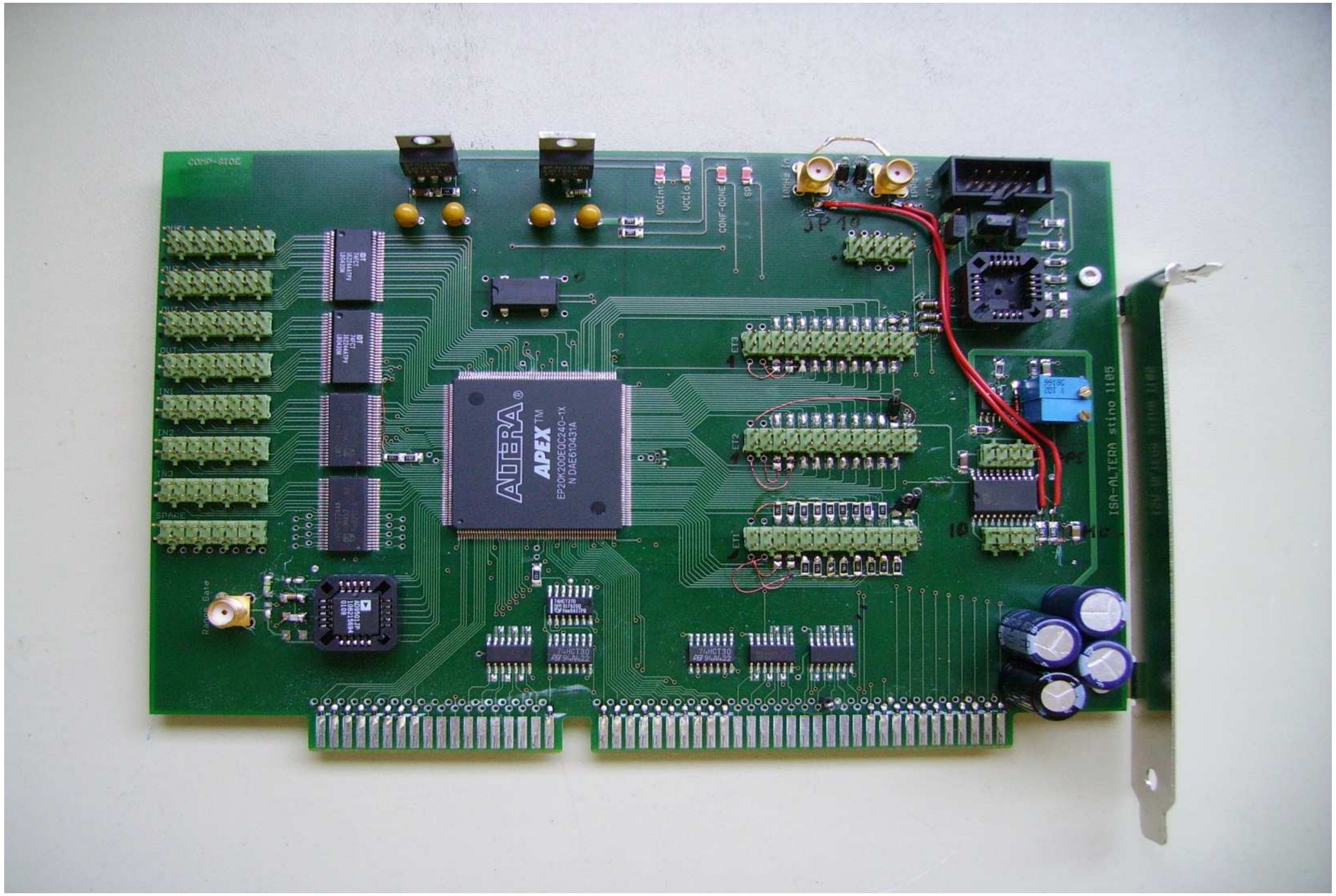
An Event Timer (E.T.)

The Event Timer determines the epoch time of an event; it measures:
start epoch times of all laser shots (down to 1 picosecond)
arrival epoch times of reflected photon(s) (down to 1 picosecond)

- At a repetition rate of 2 kHz, more than 500 shots are simultaneously on their way
- The PC/program has to combine start/stop epoch times accordingly, and calculates the time-of-flight
- Part of this E.T. has been developed and built in Graz

Our "Event Timer", E.T. ☺

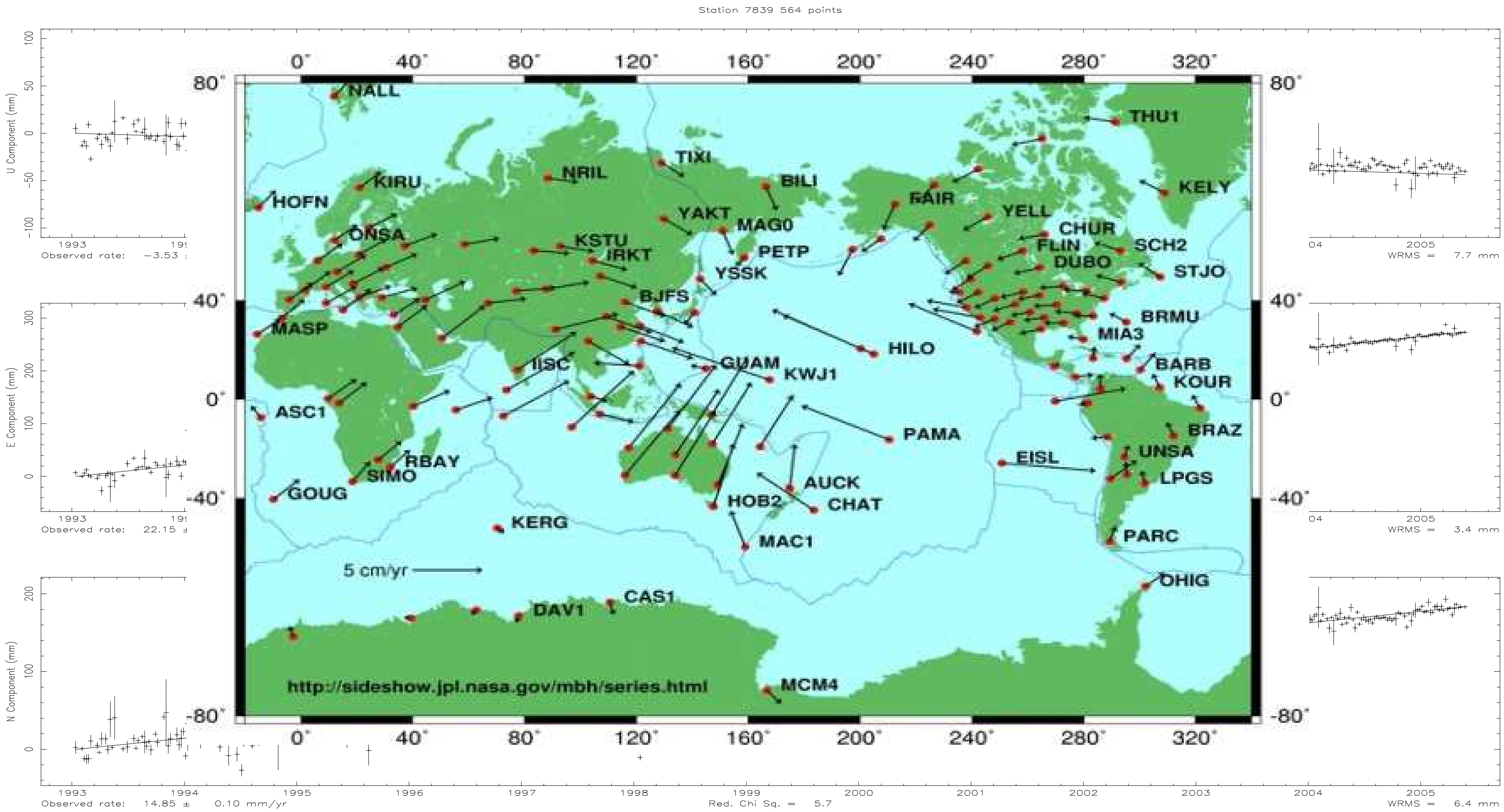
A FPGA card



The FPGA (Field Programmable Gate Array) card controls all real-time tasks: laser firing, range gates, etc.; the FPGA card built in Graz contains more than 1 million cells etc.

What is done with the data?

Reference frames, station displacements



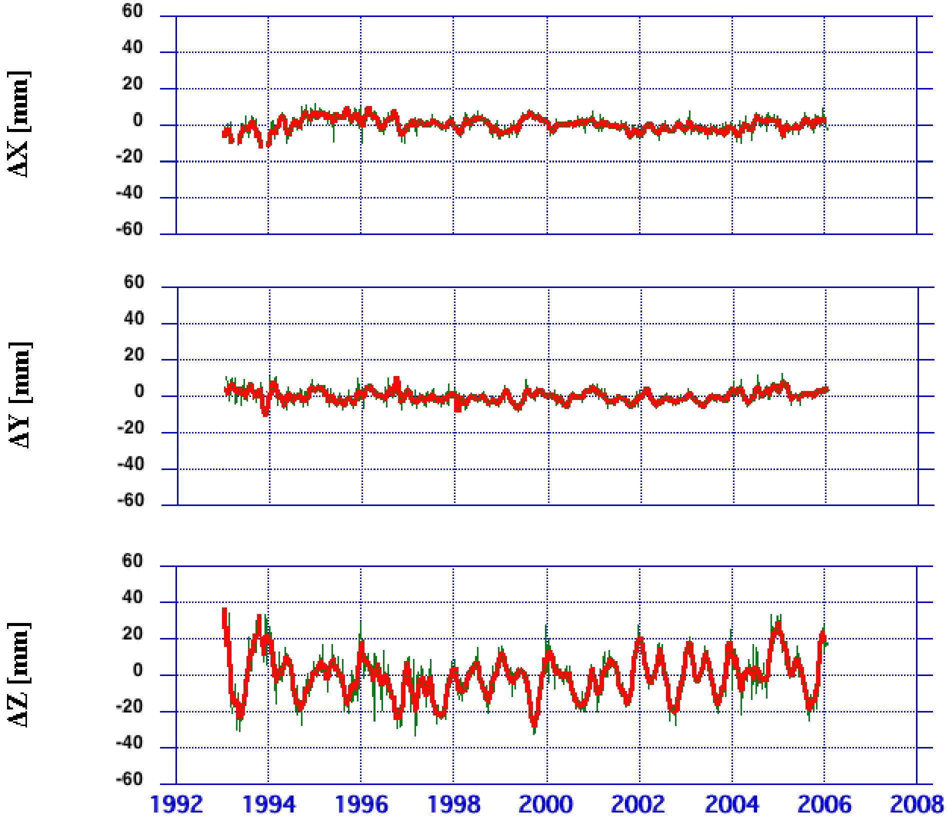
Up component: -3.53 ± 0.07 mm/year

East component: 22.15 ± 0.07 mm/year

North component: 14.85 ± 0.10 mm/year

Geocenter motion

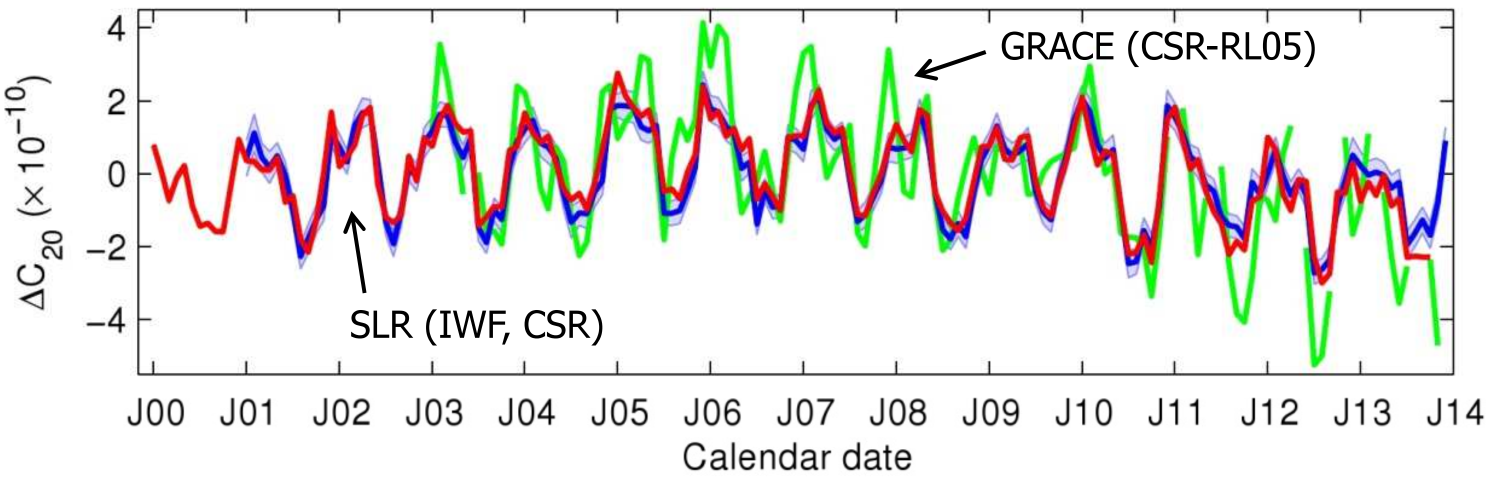
Earth's center of mass relative to the Earth's center of figure



Geocenter motion from weekly SLR solutions based on LAGEOS-1/2 tracking

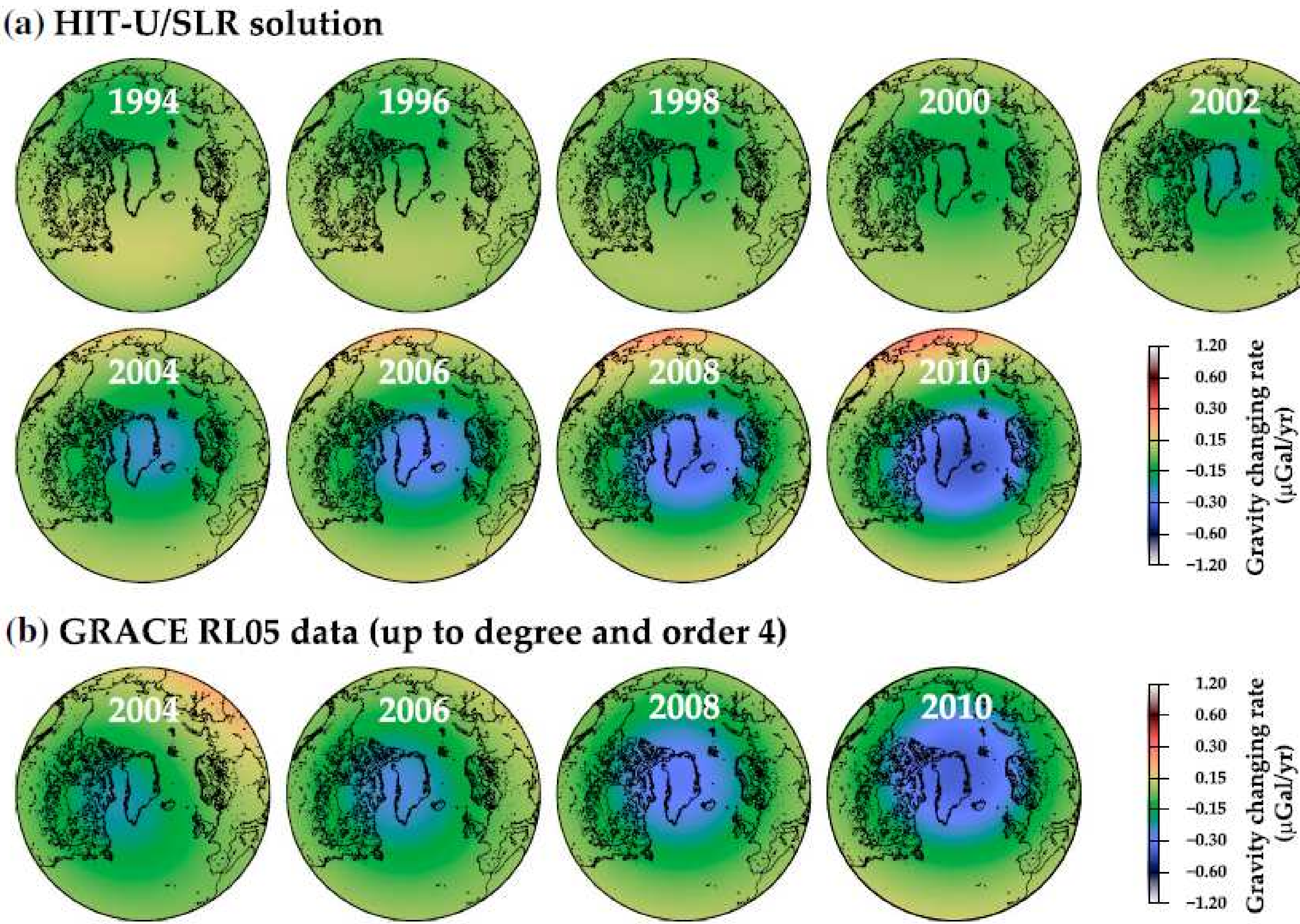
Geocenter motion projected into the equatorial plane

- Variability of C_{20} reflects changes in the Earth’s oblateness



- Dominated by an annual signal (mass redistribution in the atmosphere, in continental water reservoirs, and in the oceans); inter-annual variability (correlation with climate indices)
- Periodic effects superposed by secular trend (land uplift due to the post-glacial rebound, ablation of ice sheets/mountain glaciers, changes in water reservoirs, deceleration of the Earth’s rotation / tidal friction).

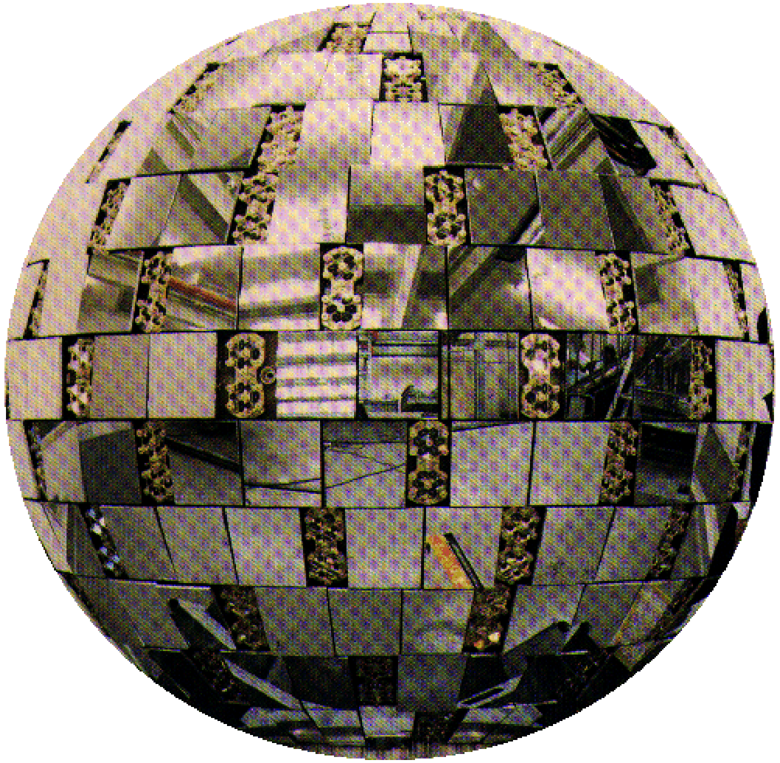
Gravity field / mass variation

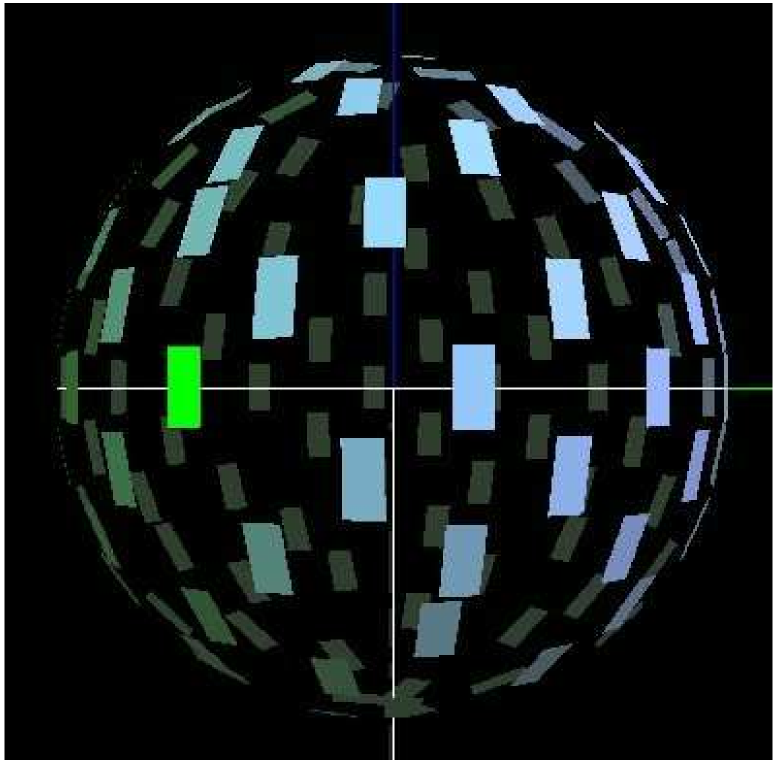


Matsuo et al. (2013)

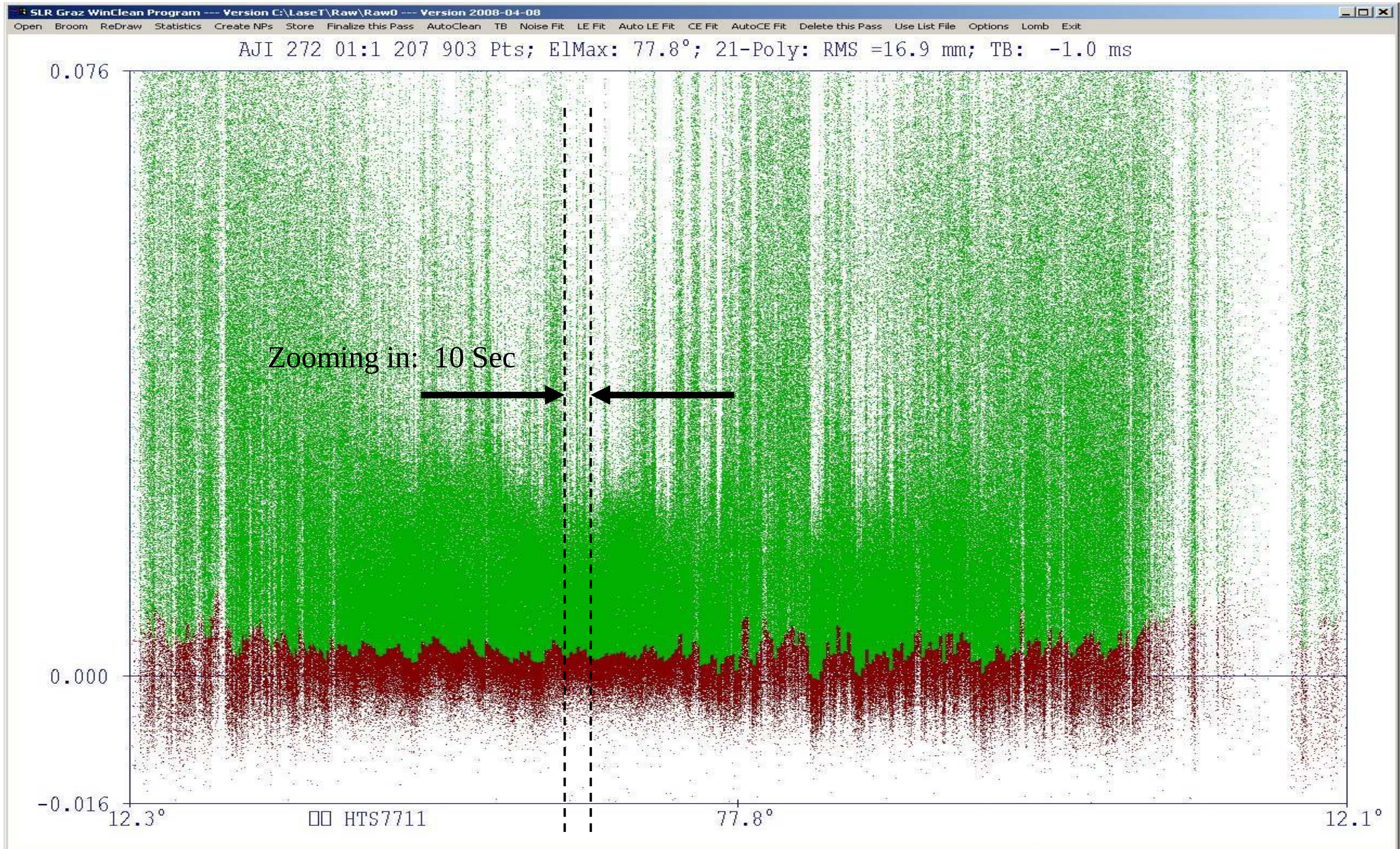
Satellite spin (kHz SLR) – AJISAI

- AJISAI rotates with ≈0.487 Hz
- Retro distances are changing
- At kHz: spin is visible ☺



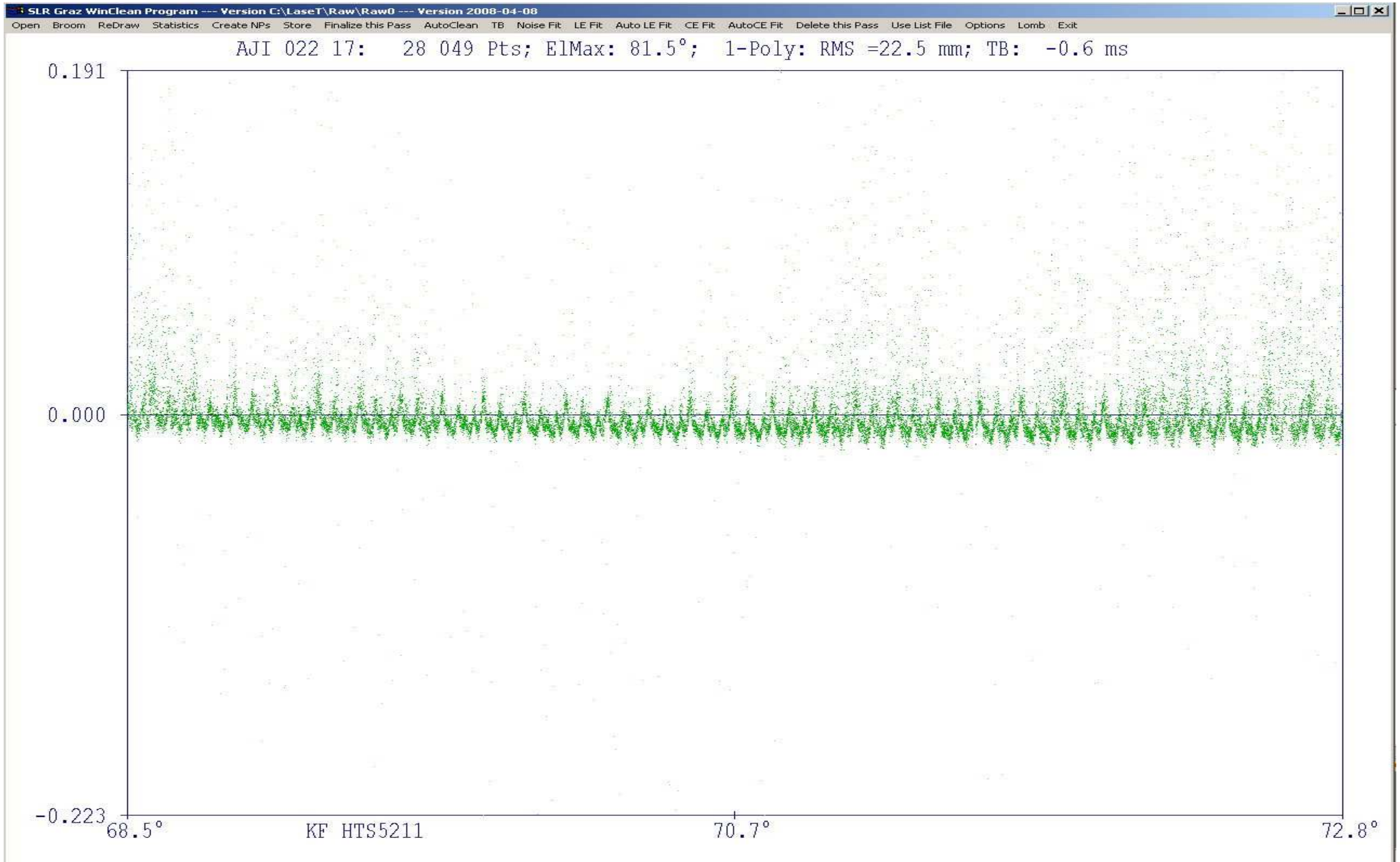


Satellite spin (kHz SLR) – AJISAI



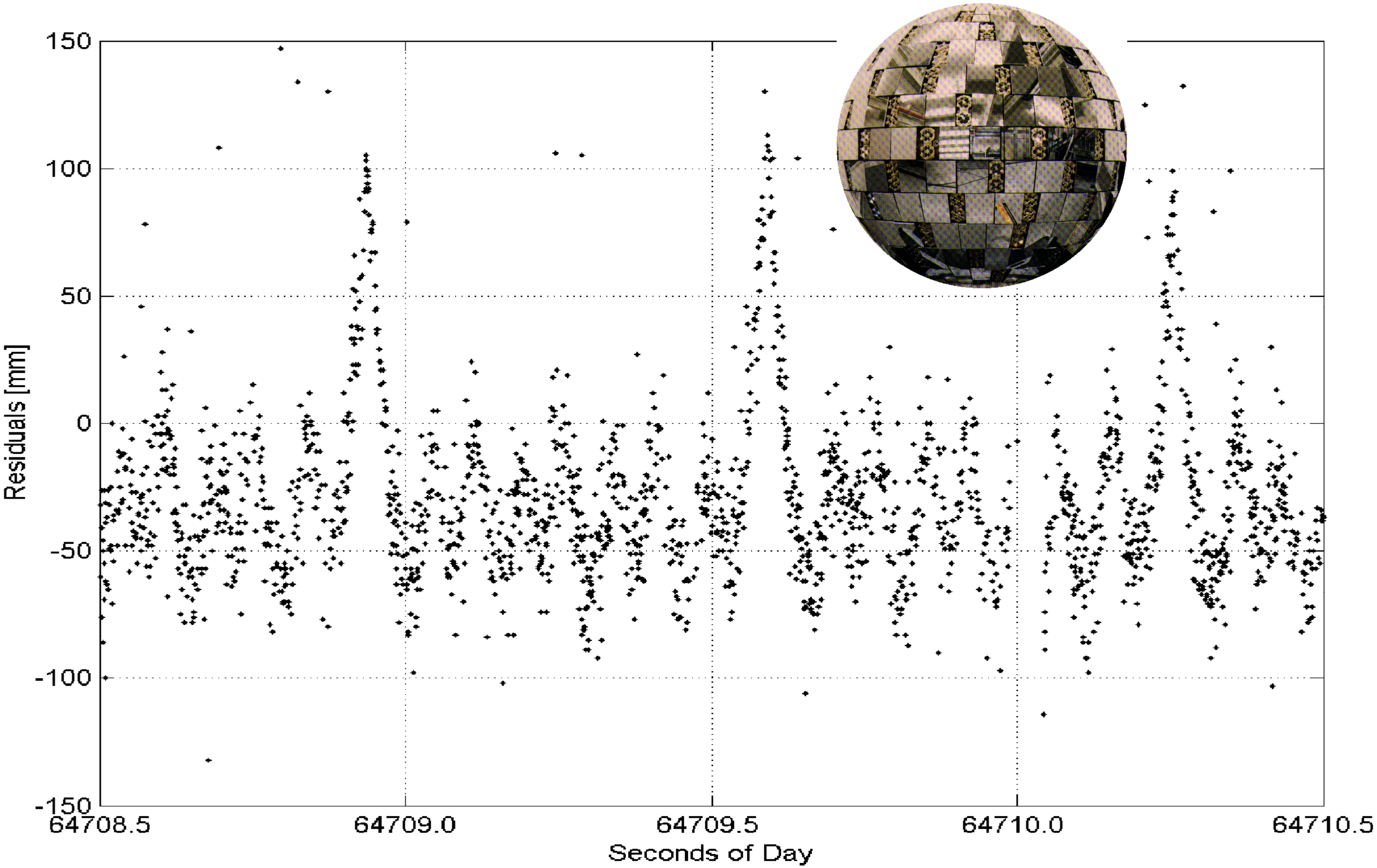
>1 million measurements in about 17 min (one pass); zooming into these data…

Satellite spin (kHz SLR) – AJISAI



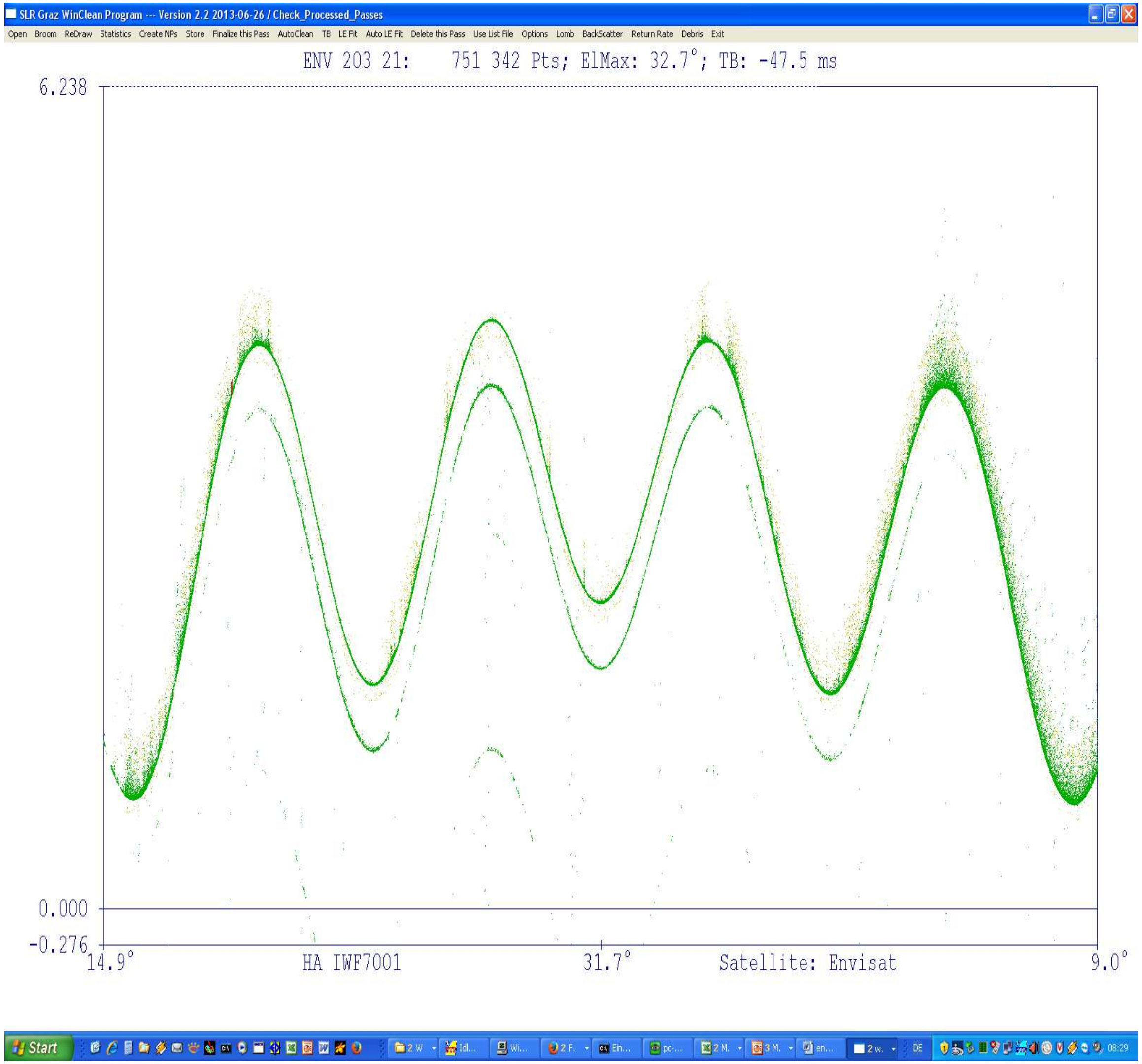
≈15.000 returns (10s): 5 rotations of the satellite, retro distances are varying; zooming into these data…

Satellite spin (kHz SLR) – AJISAI



≈3.000 returns (2s): 1 rotation of the satellite, retro distances are varying

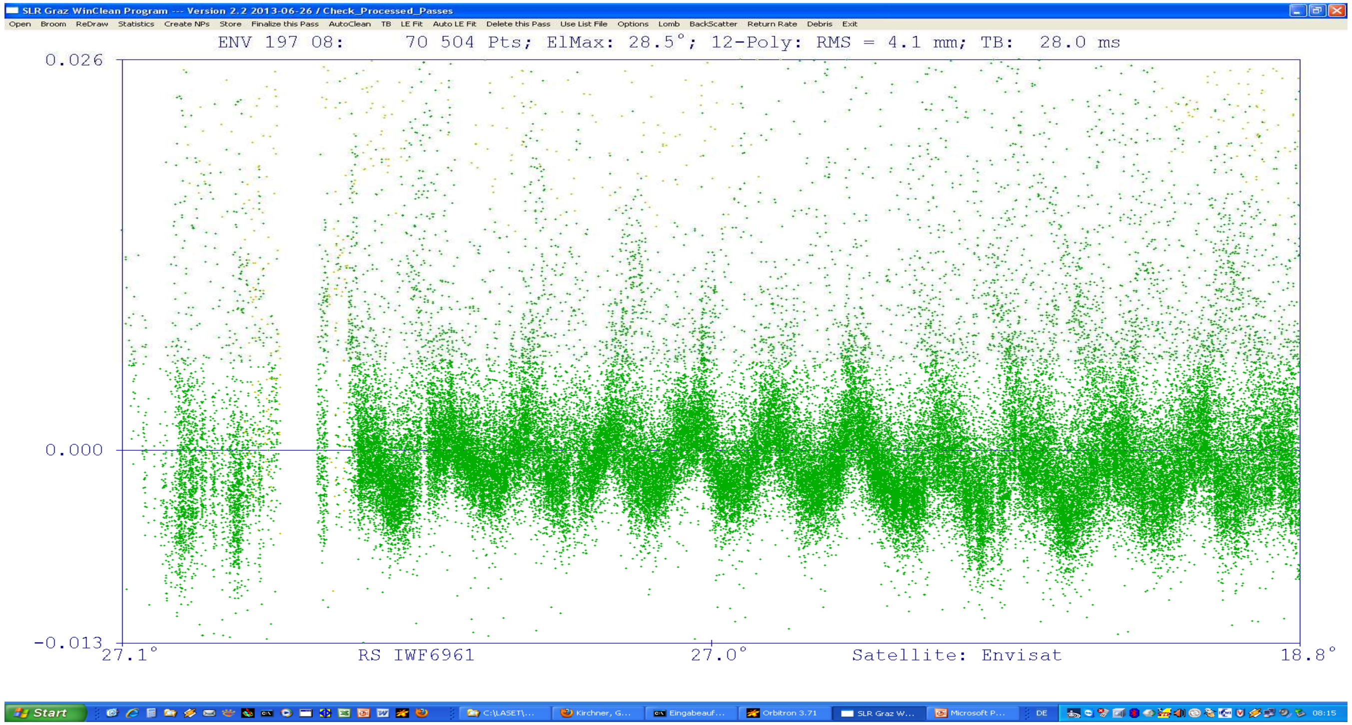
Satellite spin (kHz SLR) – ENVISAT



- Defunct since April 2012
- Tumbles in space
- Typical GRAZ ENVISAT pass using the 2 kHz/0.4 mJ laser
- Measurements when LRR "visible" from SLR station
- Satellite tumbles about "tilted" axis
- Large oscillations (±2 m) => spin

Satellite spin (kHz SLR) – ENVISAT

Retro-to-retro-oscillations



The detected few-mm oscillations allow very accurate spin parameter determination:

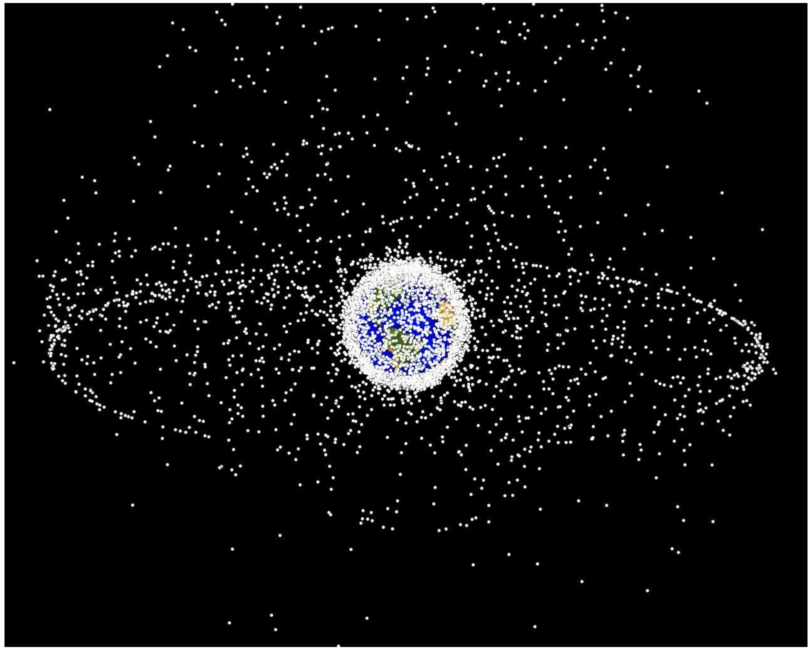
- Spin duration
- Spin axis orientation
- Spin direction

SLR and space debris?

Space debris

Wherever humans are:

They always leave a lot of garbage
☹ ☹ ☹



IWF

Space debris

ÖAW

A few numbers:

- About 1000 active satellites
- More than 1000 old/defunct satellites
- About 40.000 space debris objects are routinely tracked (by radar)
- About 500.000 small (<1 cm) debris particles exist
  (this is just an estimate; there might be more than 1 million)

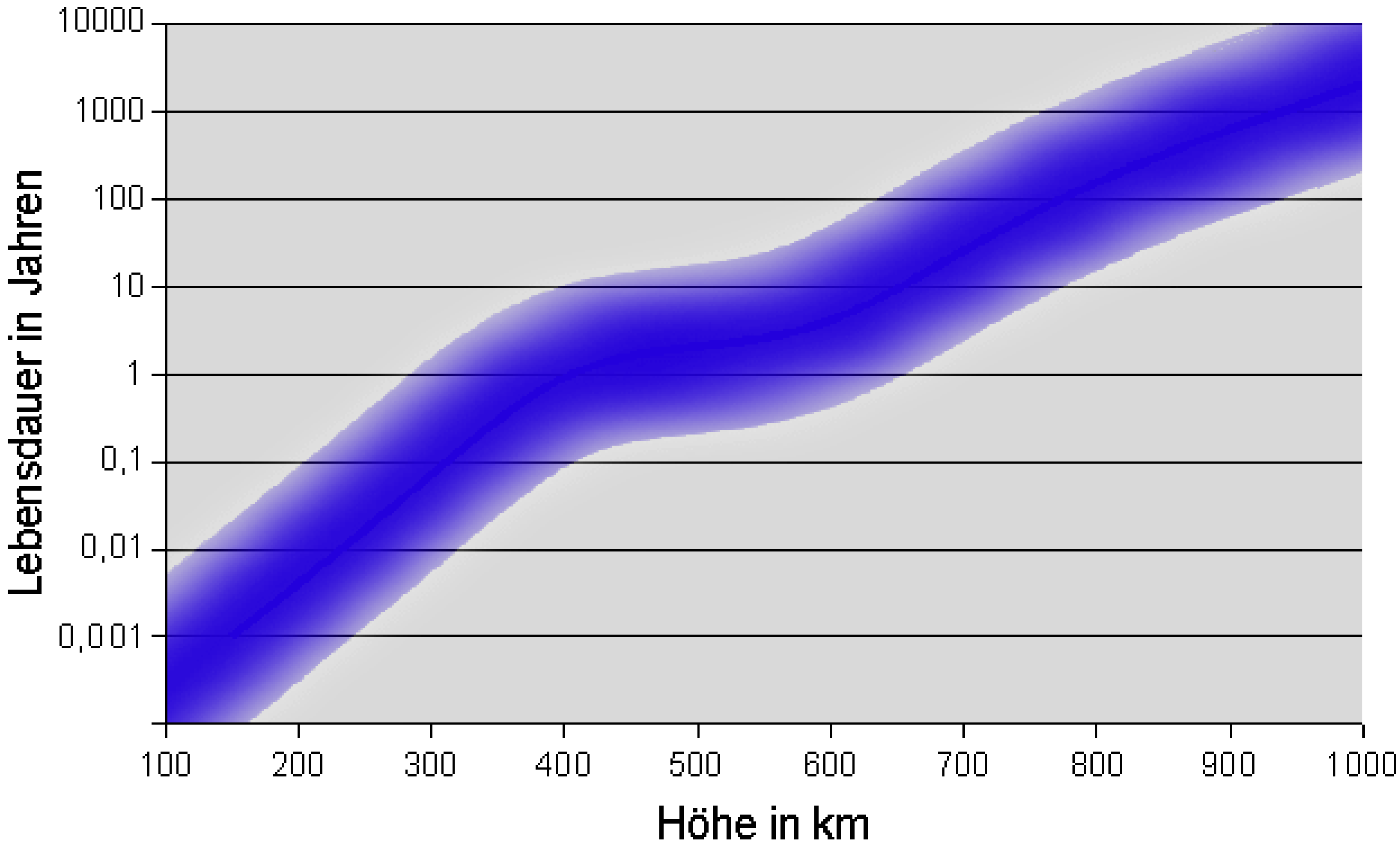
Consequences: several satellites already collided with debris parts, and have been damaged or destroyed completely; examples:

- Corot (2011), OICET (2005), JASON-1 (2002), BLITS (2013) etc. etc.
- Iridium 33 / Cosmos 2251 (2009); Fengyun 1C (2007): intentionally (!)

Note: the most important orbits (altitude around 800 km, near-polar) are the most crowded ones; it takes several 10 s up to several 100 s of years until re-entry

Space debris

Debris objects can stay up there for a looooooong time…



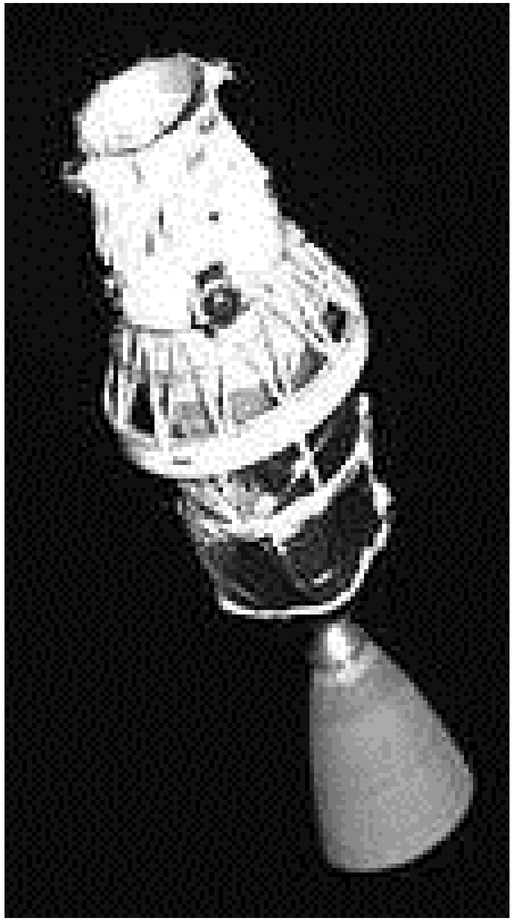
Space debris laser ranging in Graz

First space debris laser ranging in Graz: January 2012

stronger laser: 25 mJ / 1000 Hz / 10 ns pulse width
since 2013: 200 mJ / 100 Hz / 3 ns pulse width

…on loan from DLR Stuttgart (cooperation)

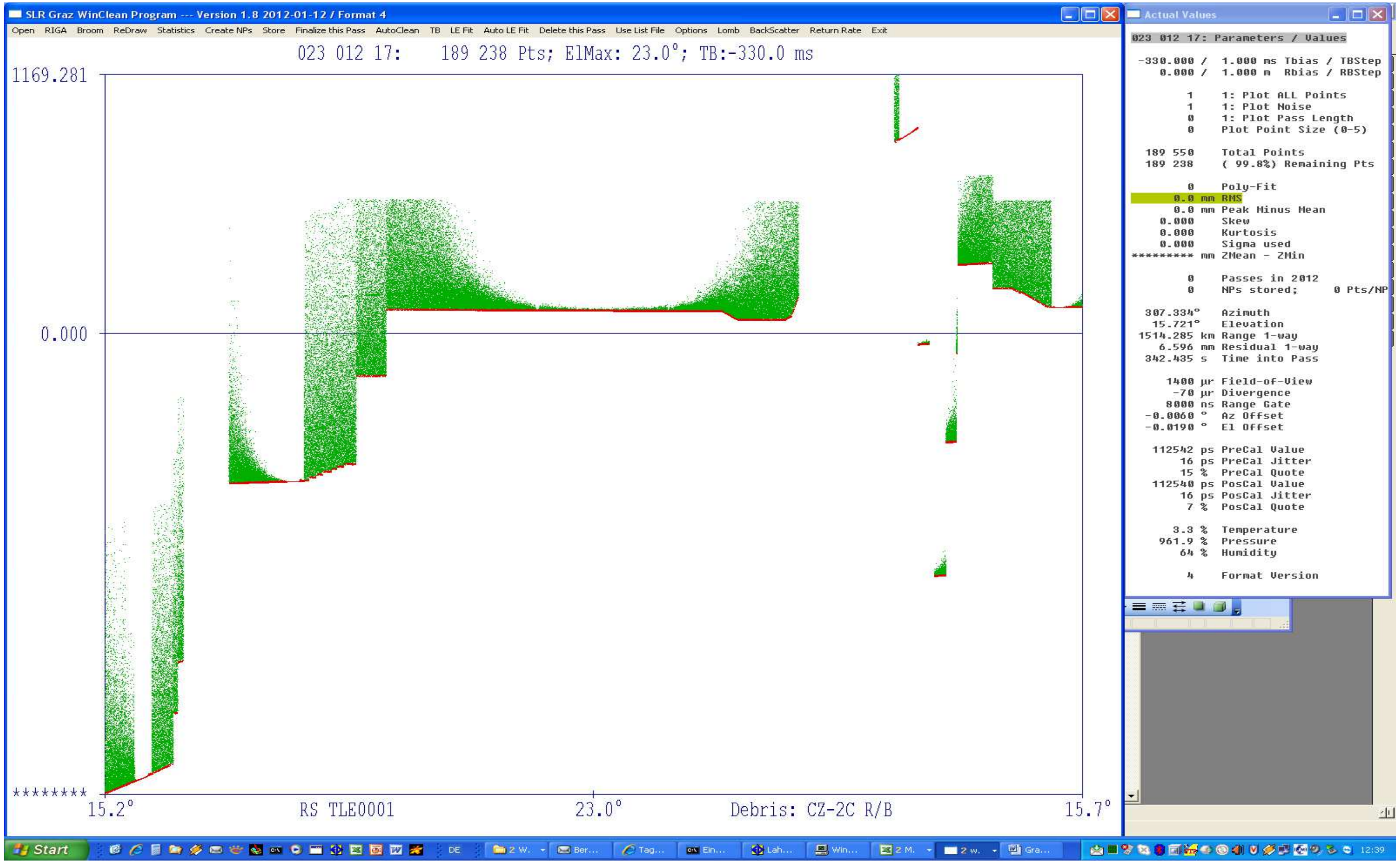
- Several hardware upgrades (mainly detector)
- >220 passes of ≈60 different objects measured
- Distances: 500 km to >3000 km
- Object size: 0.3 m^2 to 19 m^2
- Accuracy: ≈0.5 m RMS (dependent on size)
- Tracking difficult due to low-accurate orbit predictions



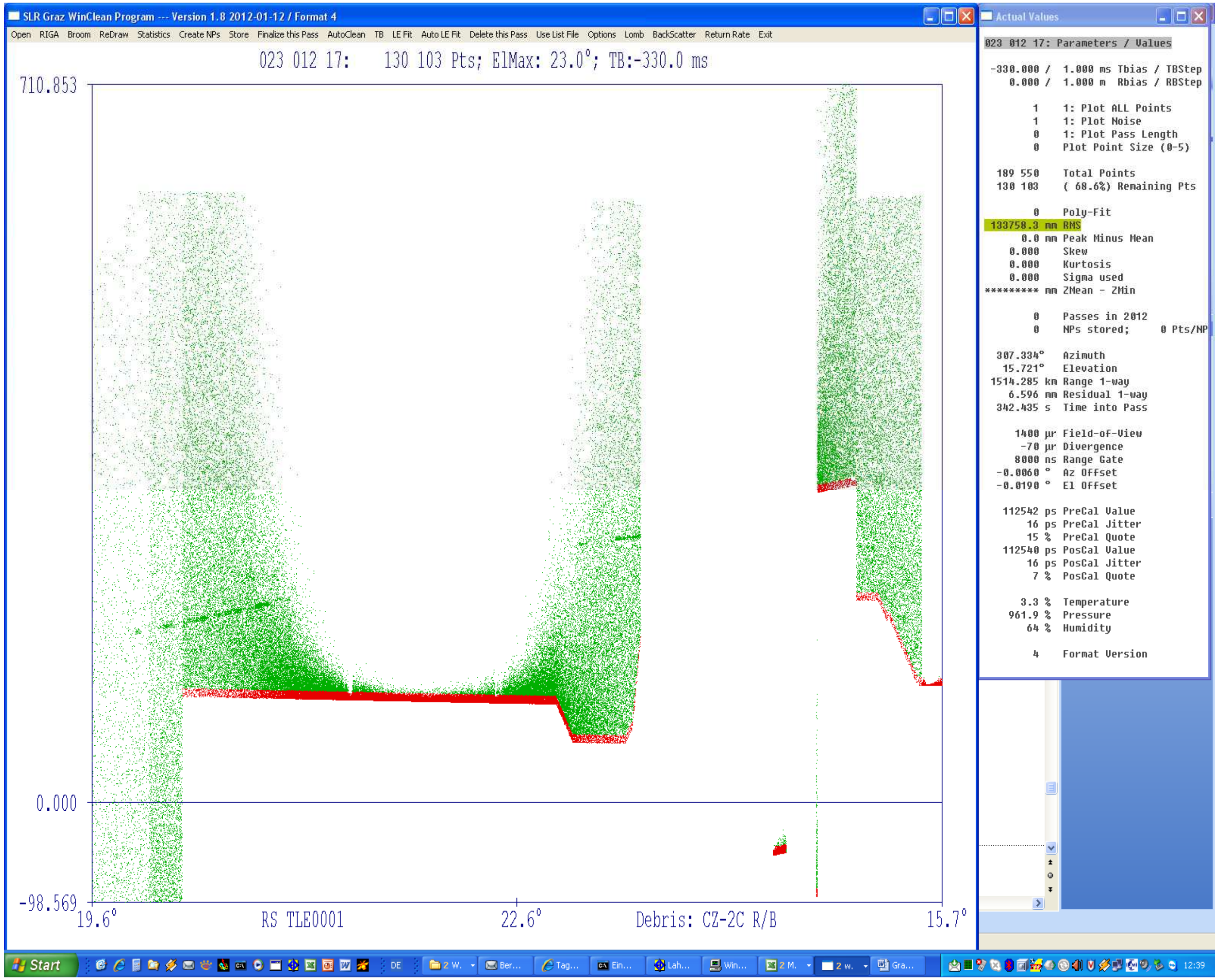
Space debris laser ranging in Graz

January 12, 2012: first echoes ever (from an old rocket body)…

…but: where are theses echoes ???

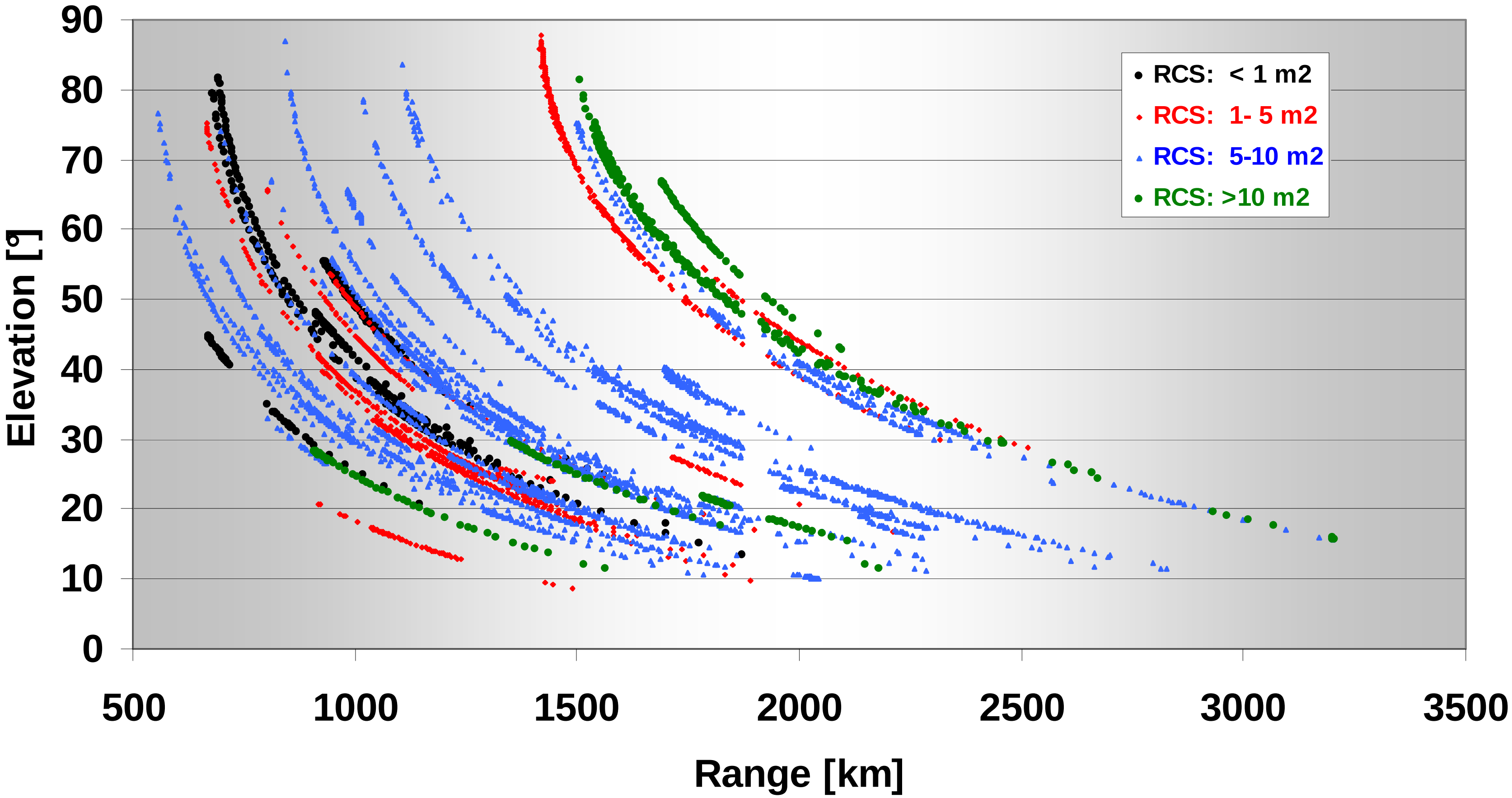


By zooming in the track becomes visible



Space debris laser ranging in Graz

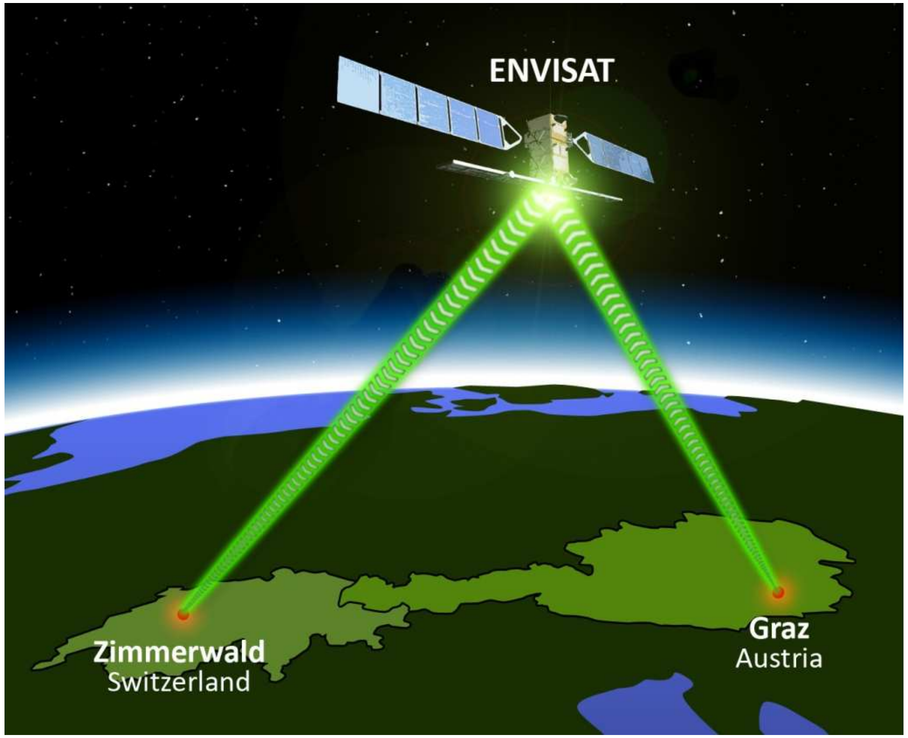
In 2013: 13 sessions (each 2-3 h the early evening)
>220 passes of about 60 objects
up to 3000 km distance



Bi-static experiment

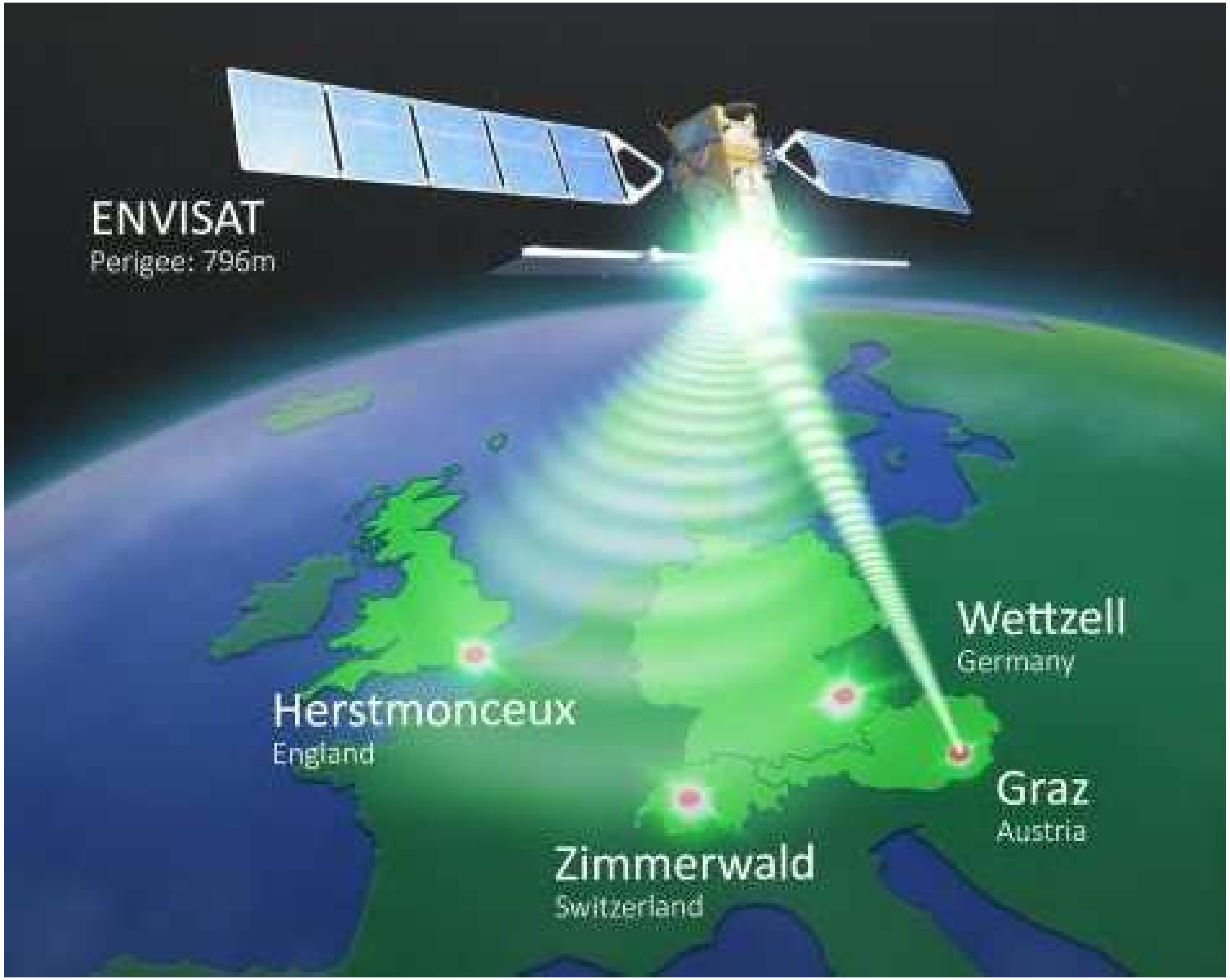
First bi-static experiment in 2012

- Graz fired with strong laser to ENVISAT
- SLR station Zimmerwald detected diffusely reflected photons
- Both distances measured with sub-meter accuracy



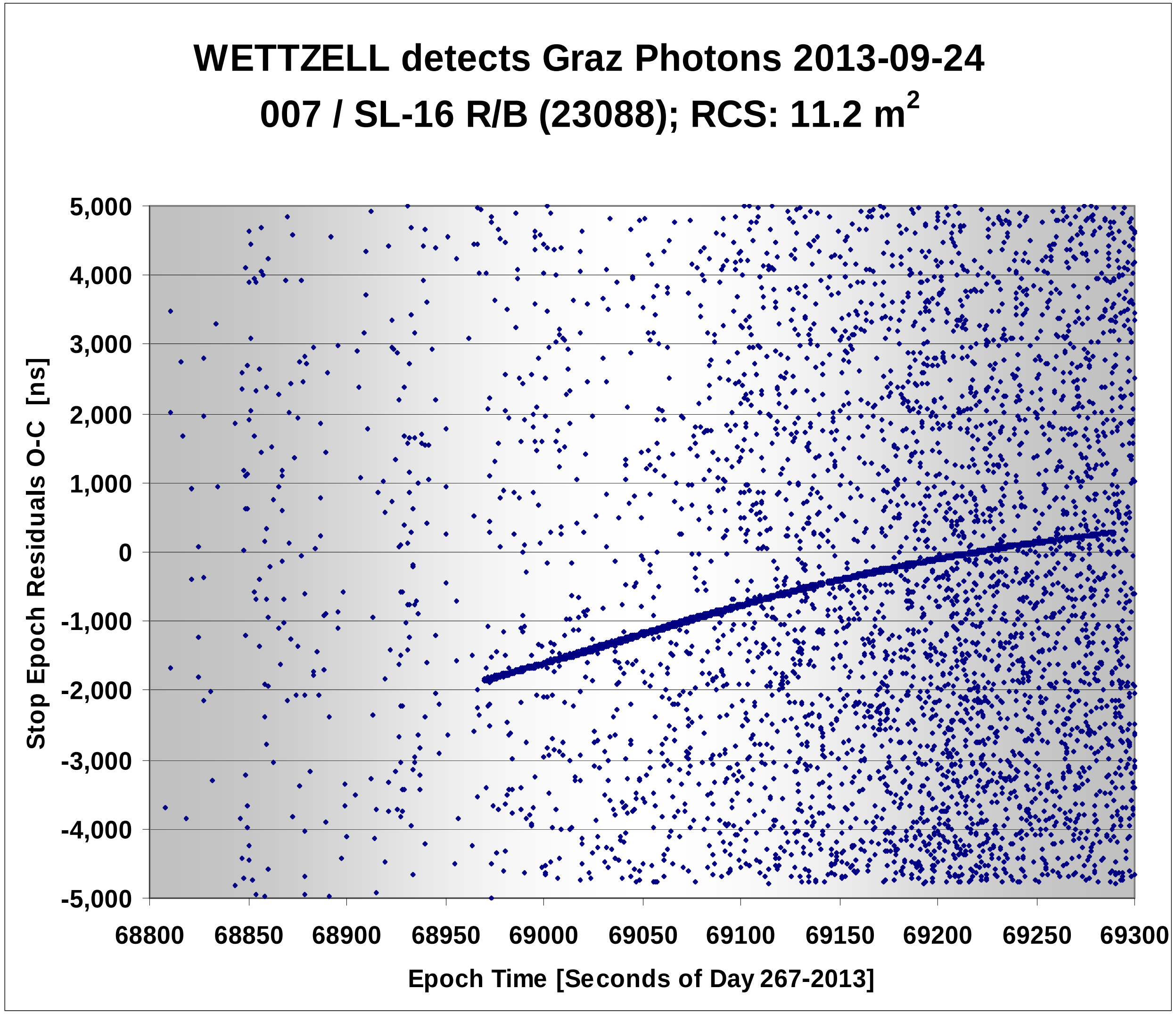
- New observation type (technological challenges, e.g. time synchronization)
- Low-cost network expansion (passive receiving stations)

Multi-static experiment



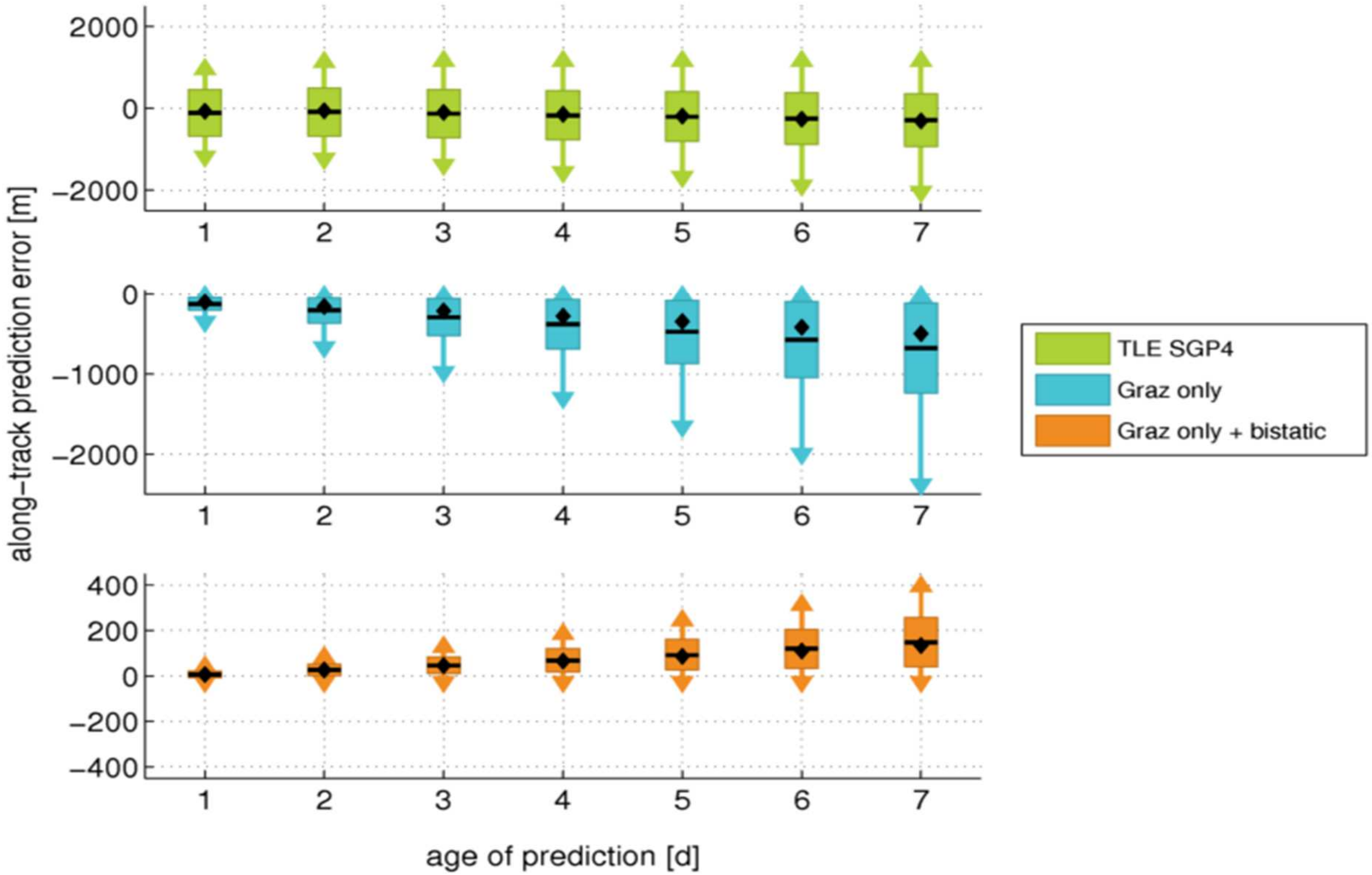
Multi-static experiment

Old rocket body passively tracked by Wettzell (distance 1800-2500 km)



Bi-/multi-static ranging

Orbit predictions (example: ENVISAT)



Thank you !

http://www.youtube.com/watch?v=5o6OtPJKRJ8
Video of Graz SLR station ranging to ILRS satellites