Measuring [sub-] mm range differences caused by polarization effects

or

What can we expect from GNSS ?

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Kötzting, May 2011

What can we expect from GNSS ?

Overview

- Improvements for HEO satellite tracking in Graz
  - #1: Filter removed for night time HEO tracking (2010)
  - #2: dichroic mirror replacement (March 2011)

    Tracking software improvements

- Compass M1 Polarization tests
  - Tracking full CompassM1 passes (> 4 hours, high elevation)
  - Switching polarization plane during tracking in 1 minute intervals
  - Forming 1-minute NPs
  - Measuring effects of polarization plane orientation

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What can we expect from GNSS ?

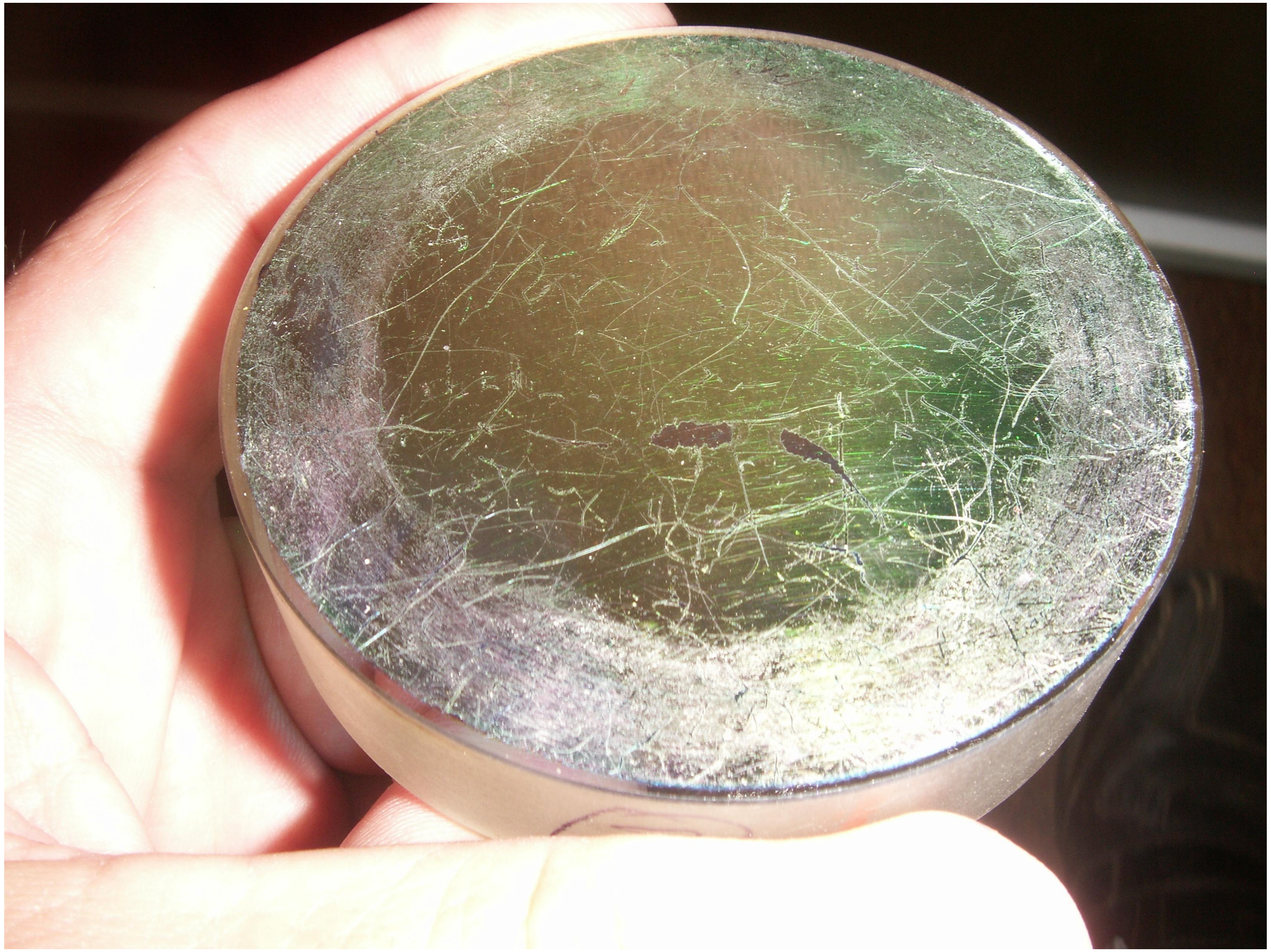
- Since 2010 we are removing the 0.3 nm filter for night time HEO passes
  - This daylight filter has about 35% transmission
  - This improved HEO return rates already by a factor of 3

- In March 2011 we replaced our old (1982!!!) dichroic mirror
  - NERC colleagues found (and tested) an excellent new dichroic
  - This new dichroic transmits > 95% at 532 nm
  - Almost ZERO polarization dependence

- Software / Tracking routines: Minor improvements

- All together: About 10 times higher return quotes from HEO satellites

Our old [from 1982…] dichroic…



„Chris suggested you might have been using it as an ice hockey puck ☺…“

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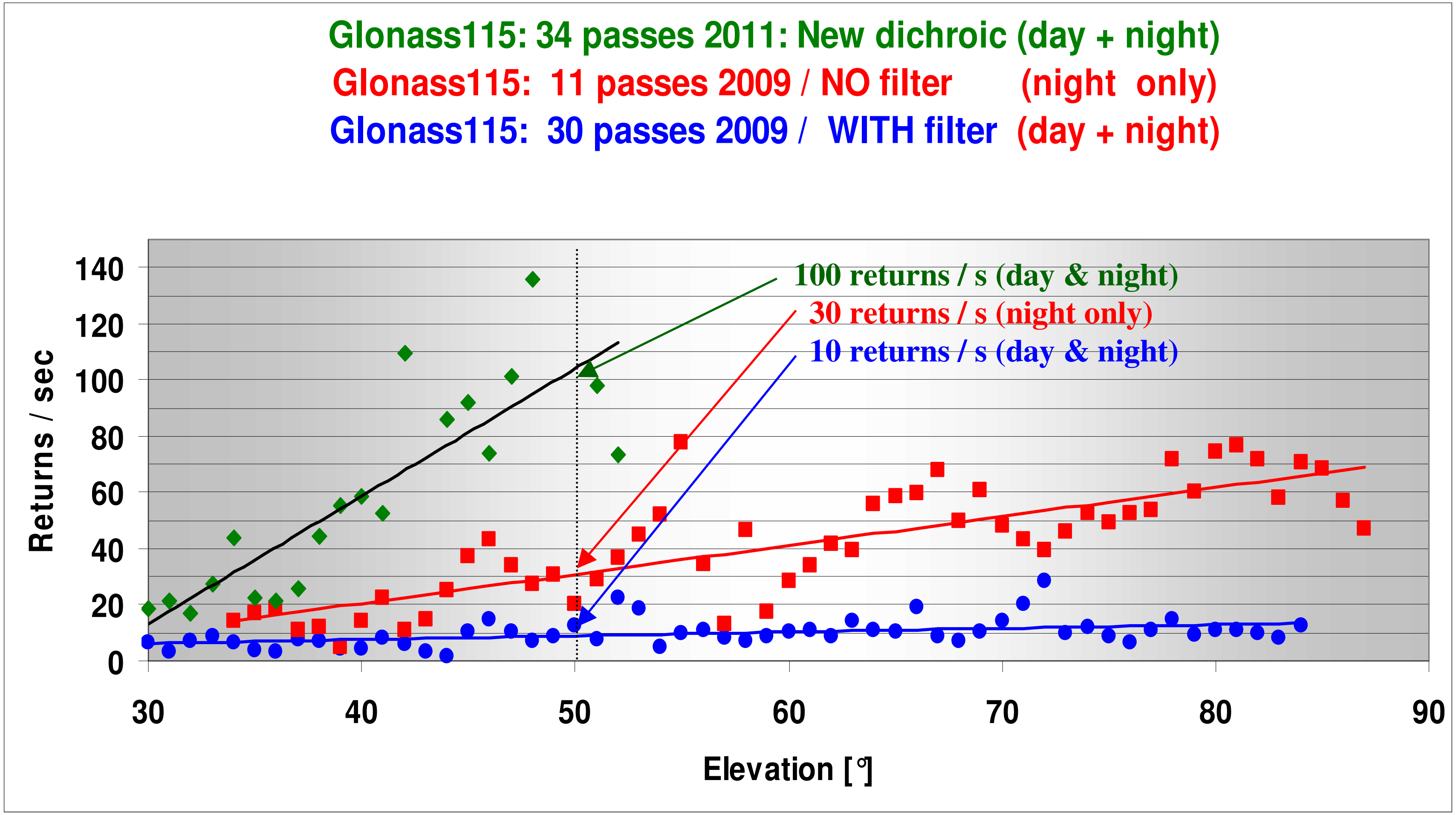
How many returns/s can we expect from GNSS ?

IWF ÖAW



Graz kHz SLR: HEO Return Quotes for 2 kHz, and 400 µJ/shot

Small improvements can have big effects (sometimes ☺ …)

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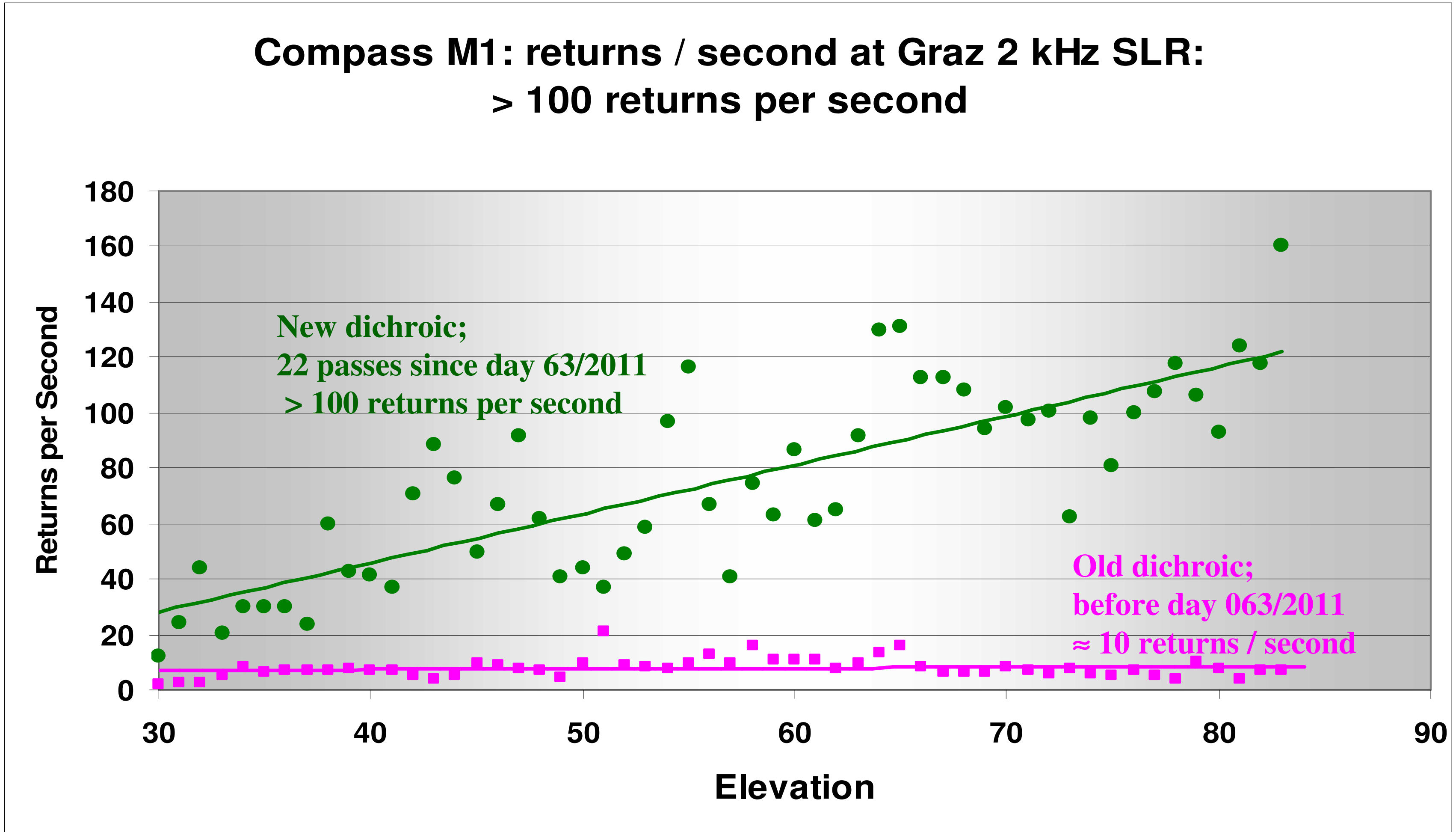

Graz kHz SLR: HEO Return Quotes for 2 kHz, and 400 µJ/shot

Factor of 10 Improvement …

Polarization Effect

- Dave Arnold has said at several recent ILRS meetings that there may be differences in target signatures due to the state of polarization of the beam incident on the target.
- Effects only on uncoated retros – e.g. Lageos 1 & 2 and ETS 8.
- For **LINEAR** polarization on LAGEOS, cross section varies between 10 and 21×10^6 m^2, and range correction by 3.2 mm, depending upon angle between polarization and velocity aberration vectors. (Arnold, private comm., 15 Sep 2007)
- For **CIRCULAR** polarization, there is little such variation.
- Are differences between linear and circular polarization of incident laser beam measurable in practice?

John Luck, Victoria Smith, Chris Moore: „Circular Polarization Experiment“
ILRS Fall 2007 Workshop Grasse

What can we expect from GNSS ?

- Now a new satellite Compass M1 has been launched: UNCOATED retros !
- We tracked a few full passes of CompassM1 (about 4 hours);
  - This gives about 2 Million points (2 kHz, 400 μJ pulses)
- We switched polarization plane during tracking in 1 minute intervals;
  - 1 Minute with POL plane ALONG orbit of CompassM1 (even minutes)
  - 1 Minute with POL plane ACROSS orbit of CompassM1 (odd minutes)
- We formed 1-minute NPs (about 250 NPs for 1 pass)
- We see the effects of POL plane orientation at least on part of the passes

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Polarization Effect: Update 2011

Satellites with uncoated CCR:	LAGEOS-1, LAGEOS-2:	Satellite signature is too big
	ETS-8:	Not visible from Graz
NEW:	CompassM1:	Uncoated CCR; good efficiency

31.6 x 28 cm hexagonal array; 2.5 kg;
42 CCR; each 33 mm diameter;
fused silica;

UNCOATED ☺

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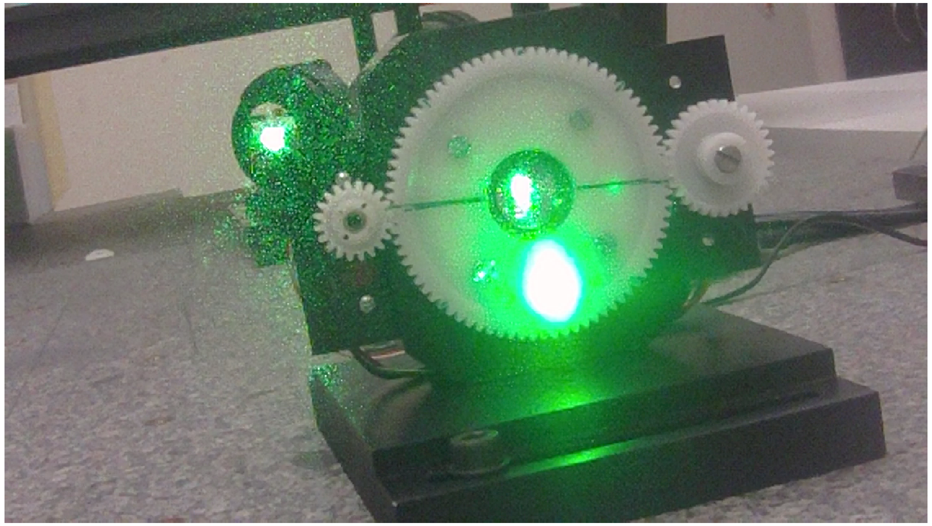
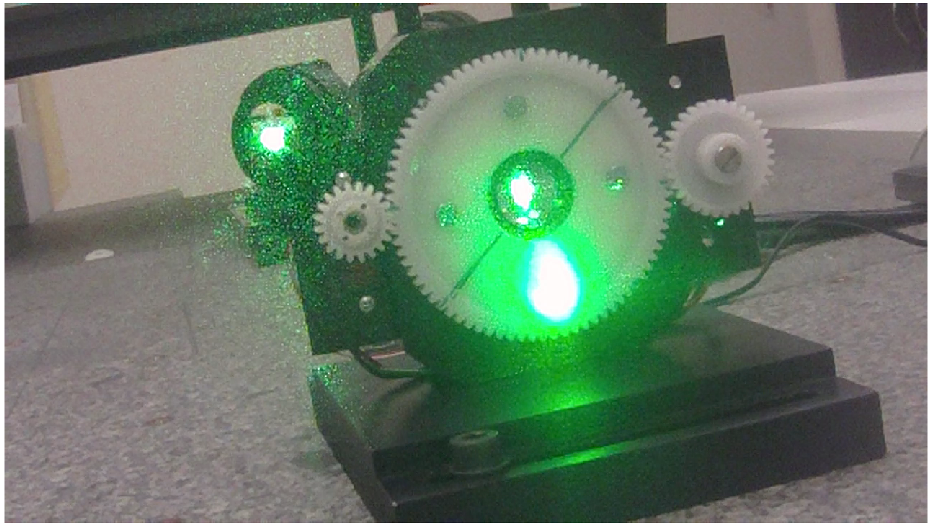
How to set orientation of POL plane?

- We installed a $\lambda/2$ waveplate on the laser table: rotation by α rotates POL plane by **2α**
- Rotation is PC controlled; POL plane orientation can be chosen:
    - To compensate for mount / telescope motion; and/or
    - To adjust for the satellite orbital motion, resp. its velocity aberration vector

- For the ‚Arnold' experiment, the plate was rotated each minute by 45° (back and forth);
- This rotated the linear POL plane by 90°; Goal:
    - In each ODD minute: POL plane orientated ACROSS orbit (‚Arnold' angle ☺: 90°)
    - In each EVEN minute: POL plane orientated ALONG orbit (‚Arnold' angle ☺: 0°)





$\lambda/2$ waveplate at 0° (on laser table);

$\lambda/2$ waveplate at 45°

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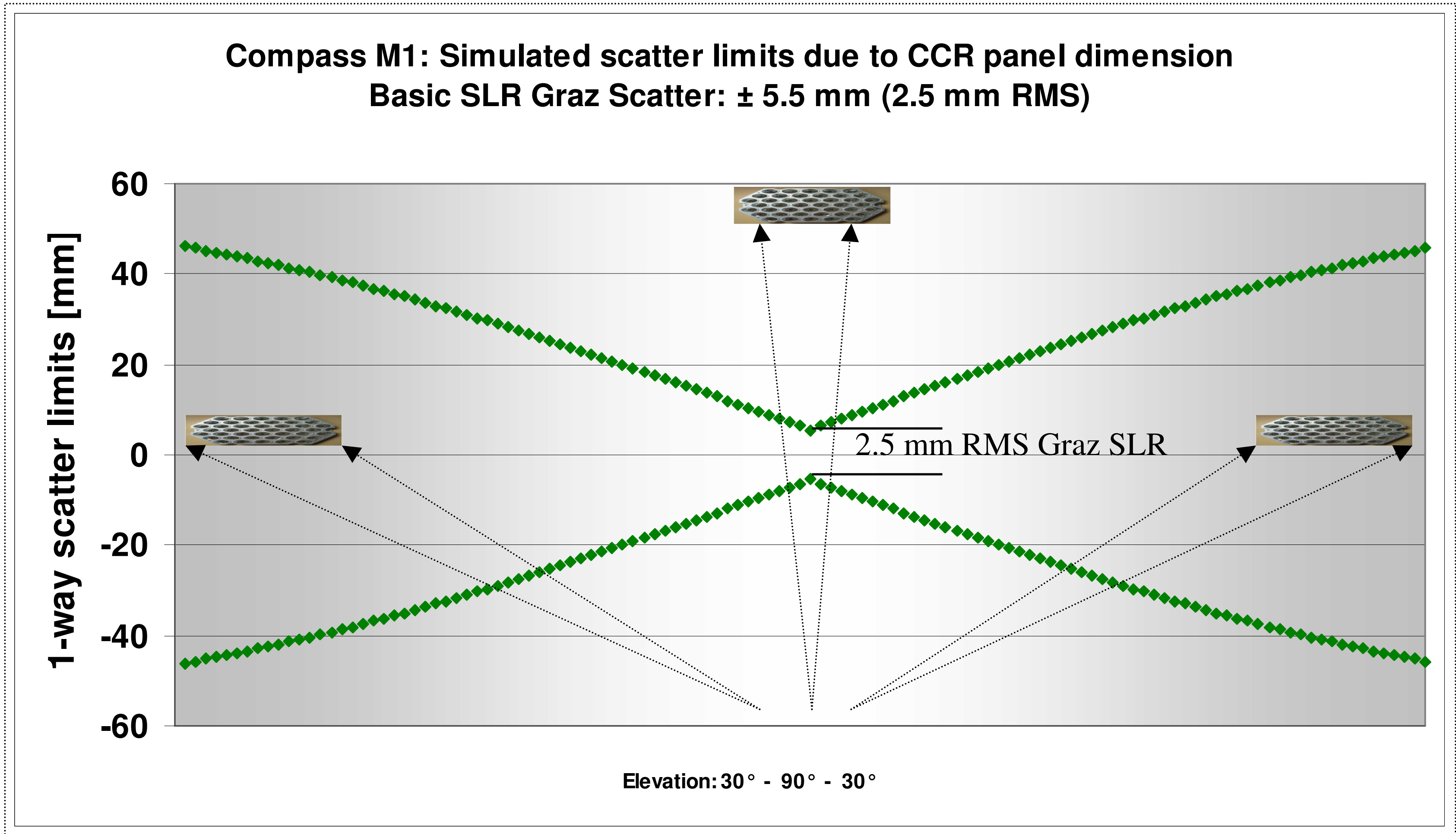
Satellite Signature: What do we expect ?



- At 90° Elevation: Minimum scatter of 2.5 mm RMS
- At lower elevation: Increasing scatter due to panel geometry / dimensions

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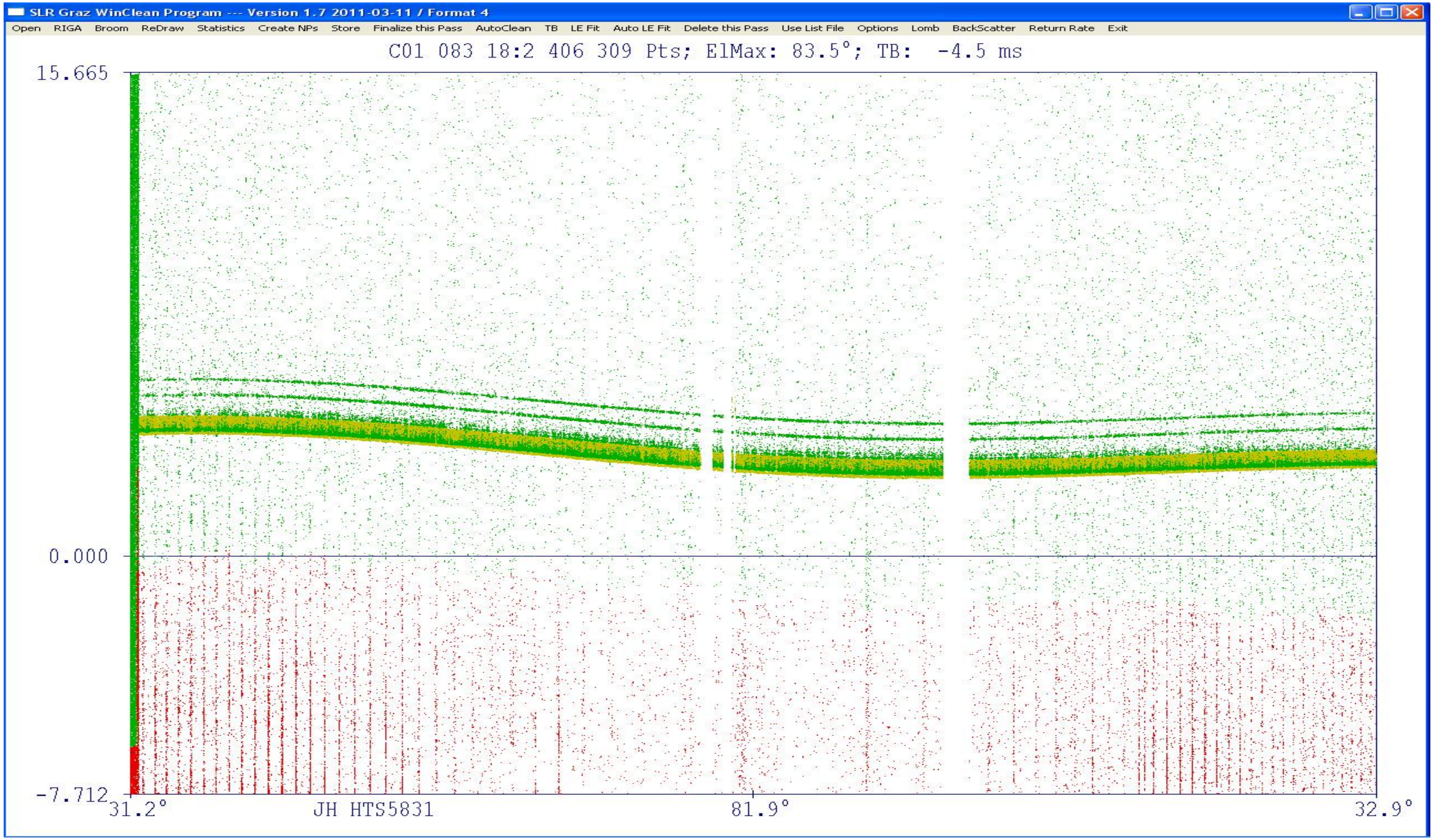
A full Compass-M1 pass: > 2 Million returns



- About 4 hours of a Compass-M1 pass; max elevation: 83.5°
- < 3% post train (due to slight leakage of laser regenerative amplifier)
- Still some – slight – overlaps visible

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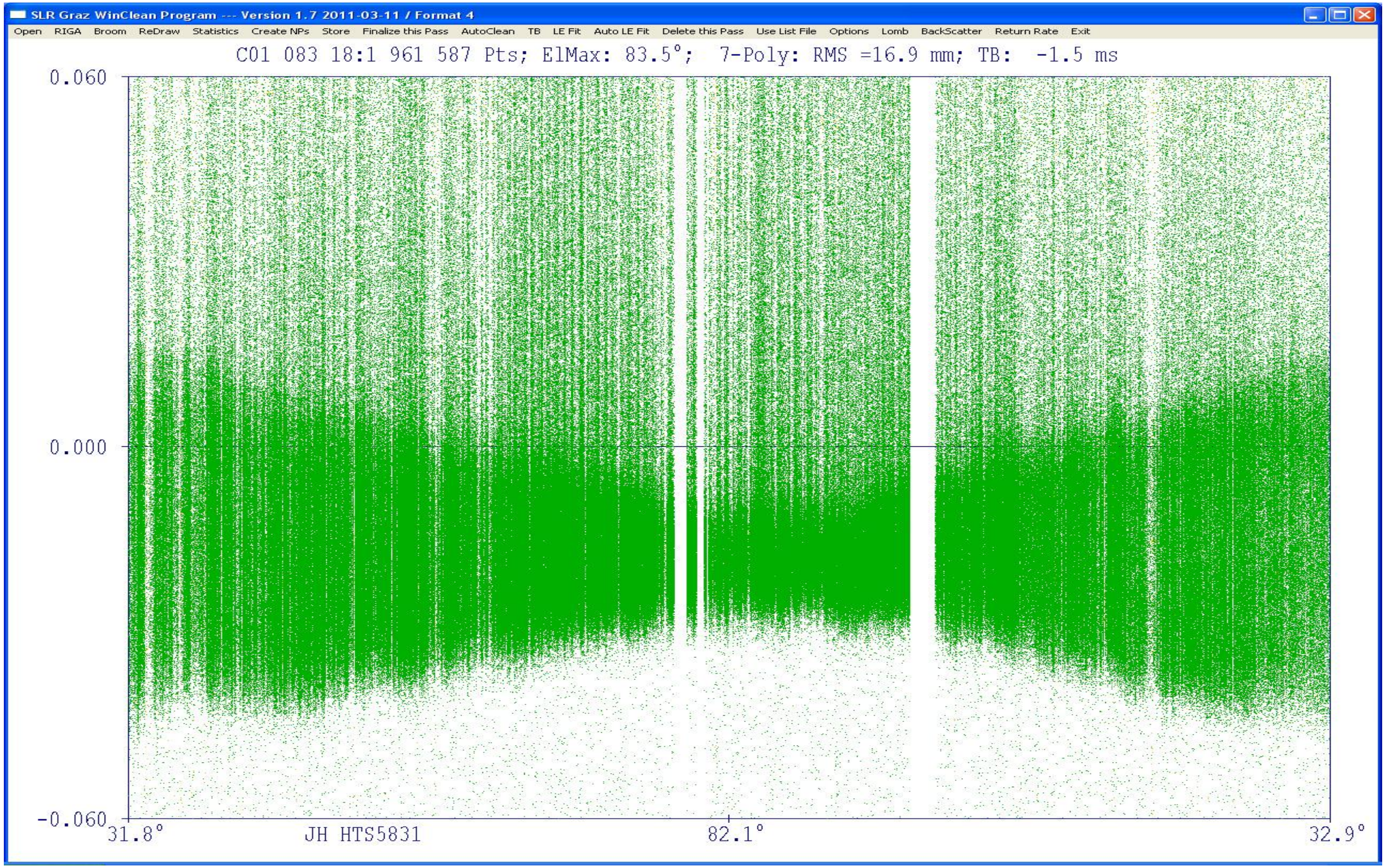
Looking at the main return track …



- Main Return Line clearly visible; C-SPAD after-pulsing: Increased noise AFTER main track
- Panel geometry becomes visible; still almost 2 million points

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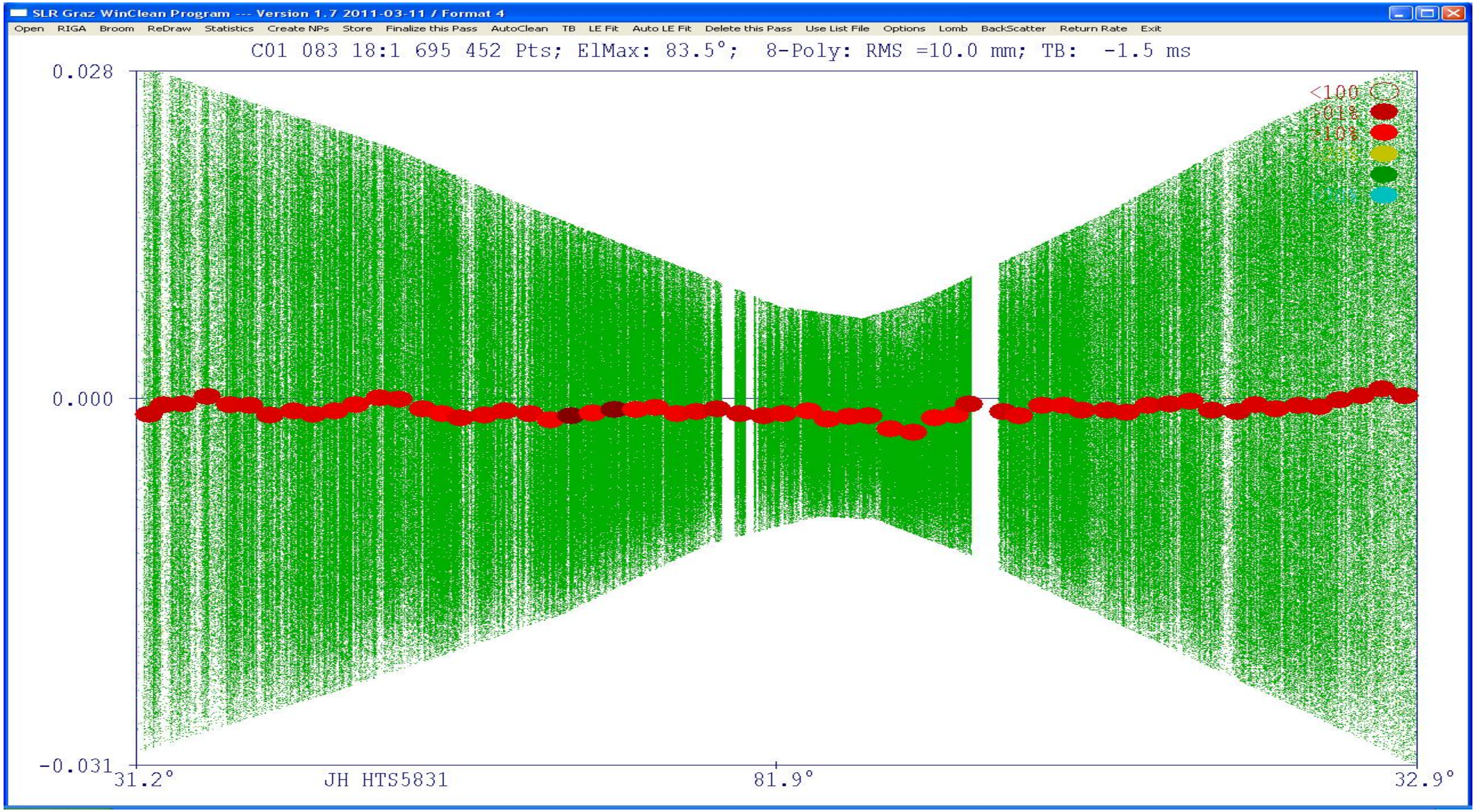
Standard handling: 5-minute NPs



- Standard / routine handling: Removing noise, sending 5-minute NPs to ACs
- Although significant satellite signature: NPs are VERY accurate with the 2 - kHz system …

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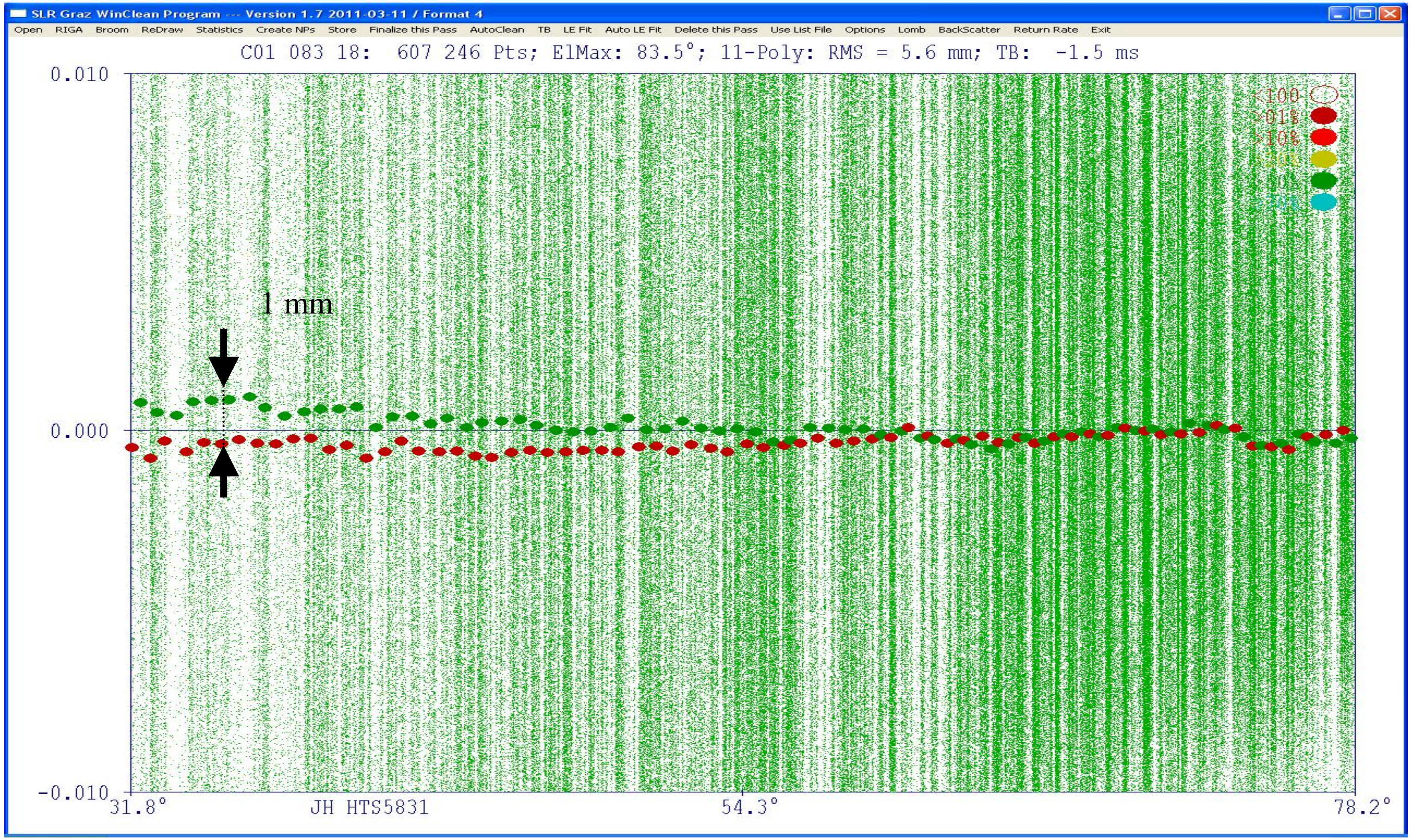
CompassM1 / POL handling: 1-minute NPs



- Green NPs: ODD minutes, POL plane ***across*** orbit; red NPs: EVEN minutes; POL plane ***along*** orbit
- Unfortunately, the effect disappeared towards CA: (error in our ‚Arnold'-angle calculations ☹ ??)

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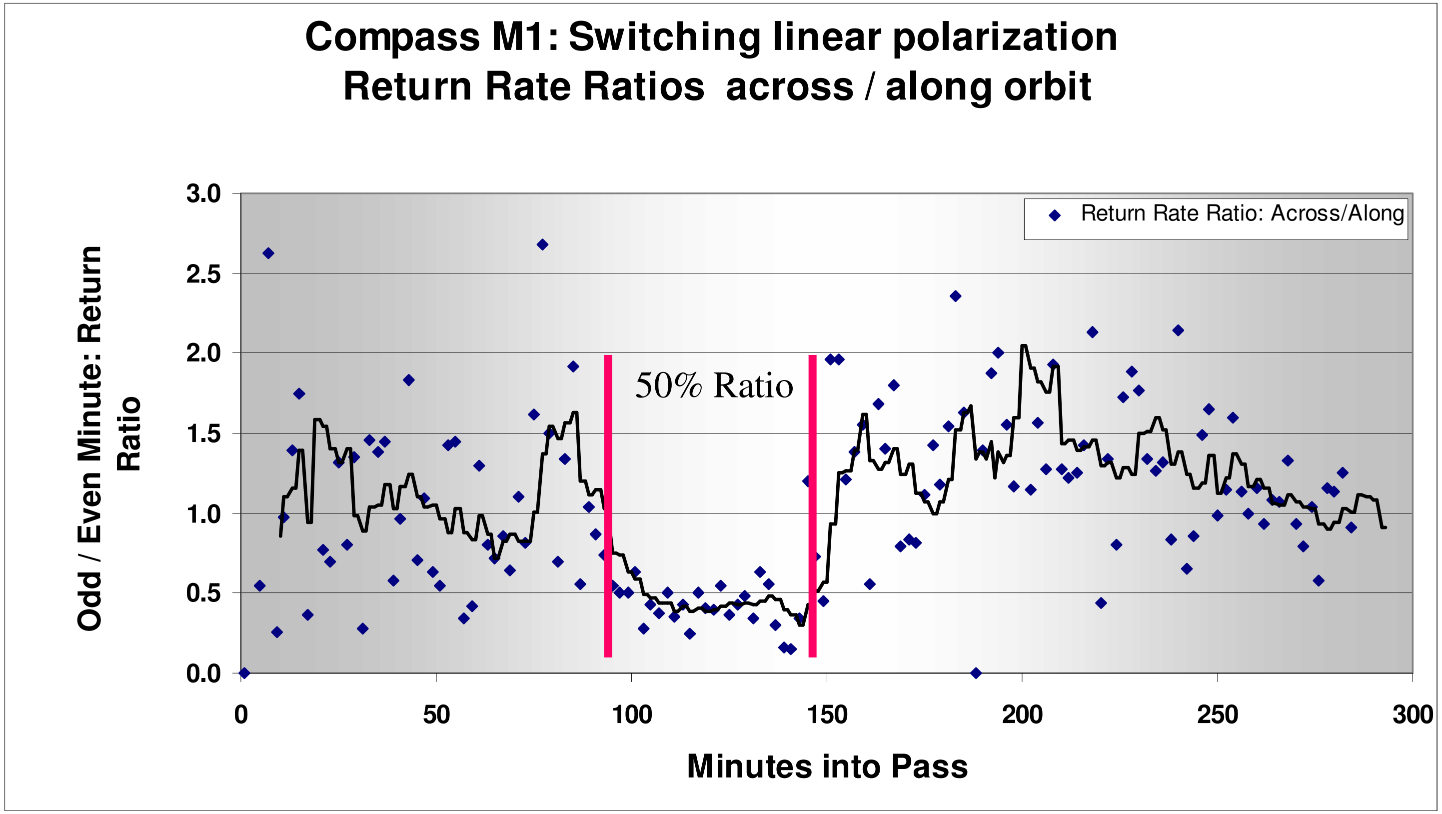
Factor 2 in Cross Section due to Polarization

Another prediction: *„ [Lageos] cross section will vary between 10 x 10^6 and 21 x 10^6 m^2, depending upon angle between polarization and velocity aberration vectors (‚Arnold angle‘)“*

We calculated the return ratio between ***odd*** (=ACROSS) and ***even*** (=ALONG) minutes; the results are not complete, but during the 50‘ around CA the ratio is rather constant at 0.5



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Conclusions

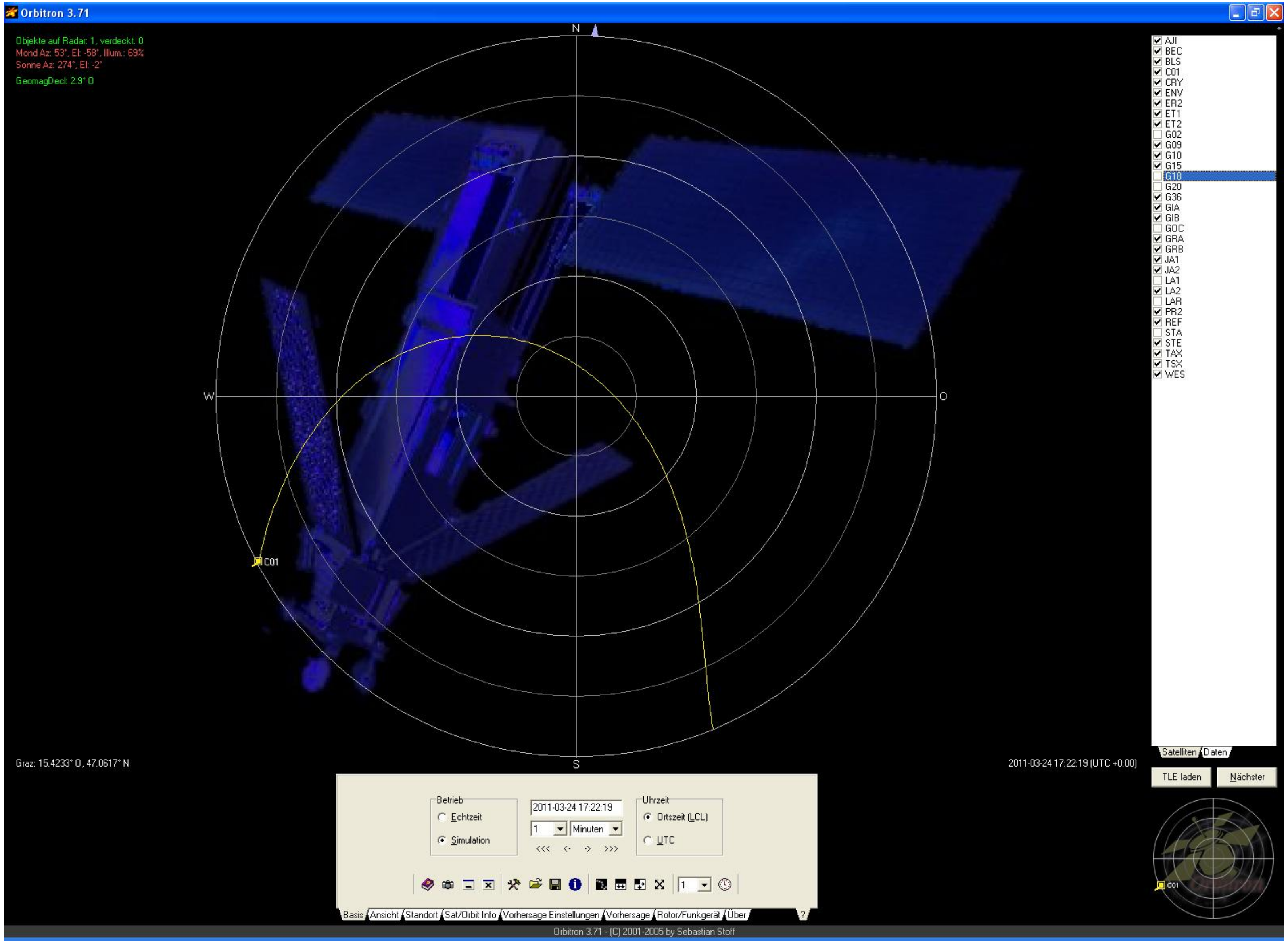
- *Conclusion 1:*

  - GNSS Satellites allow sub-mm NPs with kHz SLR techniques
  - With a 2 kHz / 400 µJ system, some 10 to > 100 returns / s can be achieved
  - With fast switching between satellites, this will allow tracking of ALL GNSS satellites (including future Galileo etc.)

- *Conclusion 2* (only CompassM1 – und future Compass satellites – and Lageos 1&2):

  - Linear polarized laser pulses on *uncoated* retro-reflectors affect the measured ranges;
  - This effect is up to a few mm
  - It can be avoided by inserting a λ/4 waveplate on the laser table:
    This changes linear polarization into circular polarization (will be tested in Graz)

New Dome in Graz – but still 2 kHz…



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