Session 15

kHz Ranging and Its Impact

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kHz SLR in Graz

Now operational ...

Georg Kirchner

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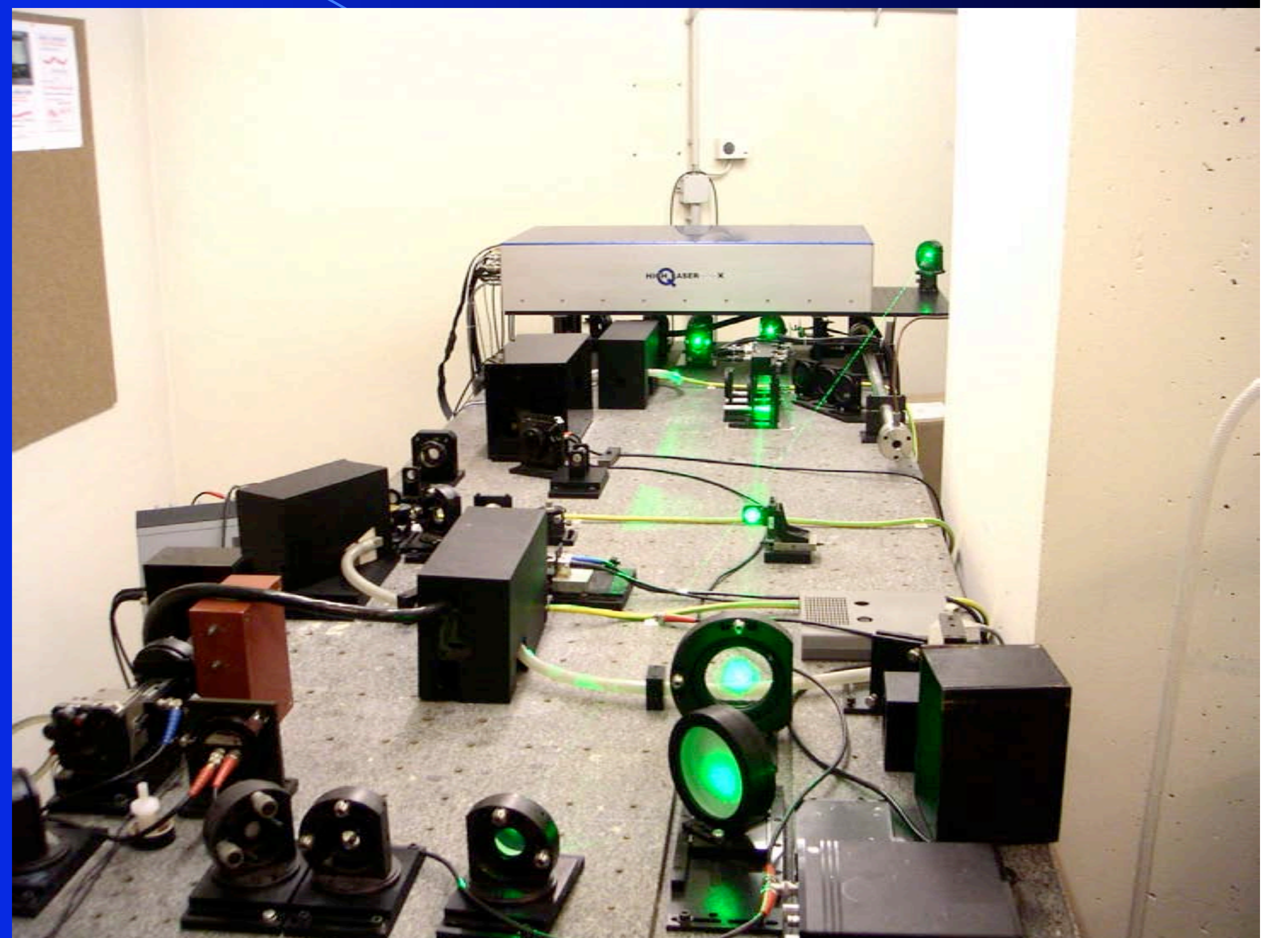
kHz SLR at Graz

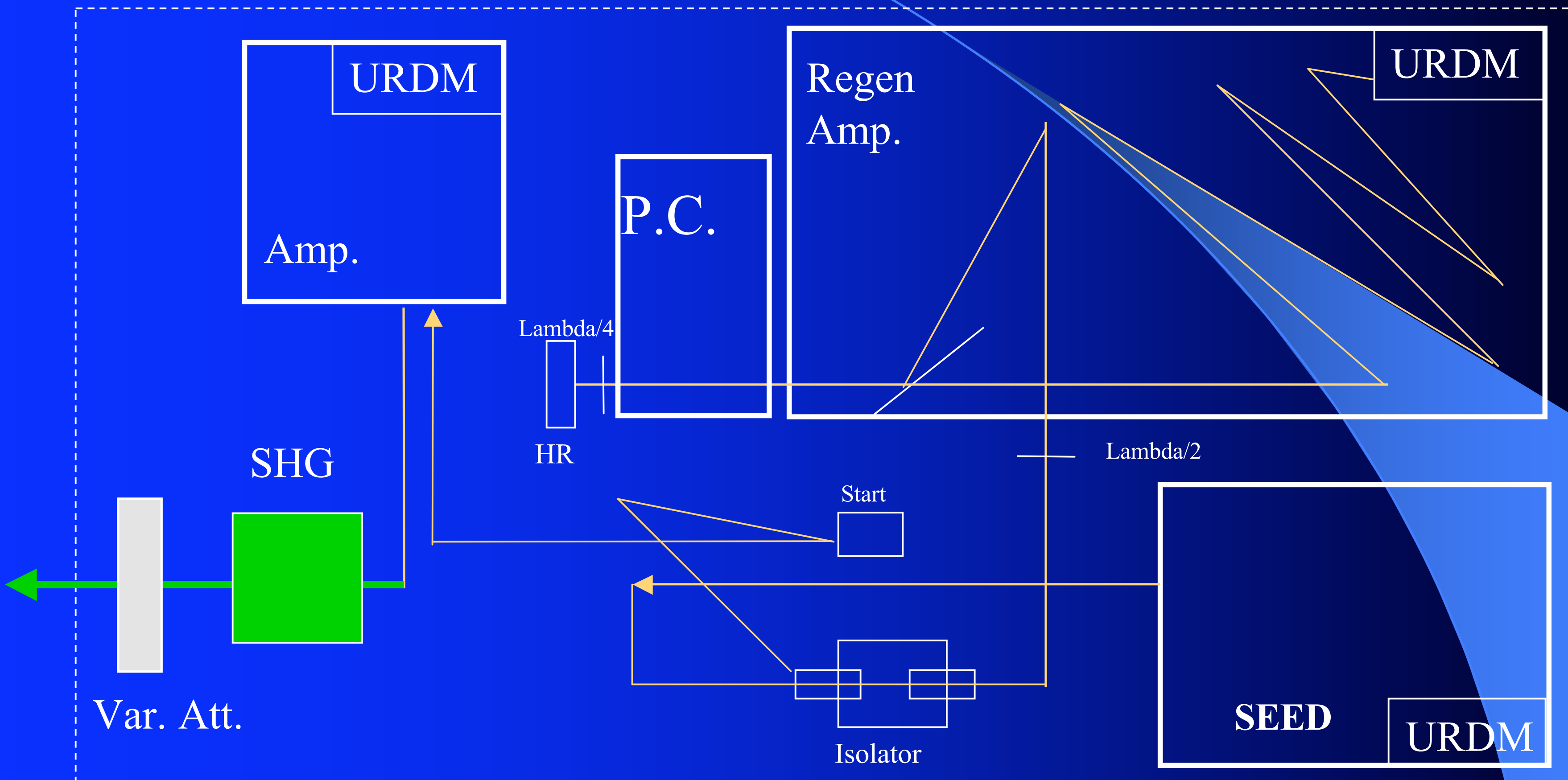
kHz Laser Specs:

- Nd:Vanadate
  - Diode Pumped
  - Seed: SESAM
  - Regen. Amp
  - Post Amp
- 10 Hz – 2000 Hz
- <10 ps Pulse Width
- 0.4 mJ / Pulse @ 532 nm

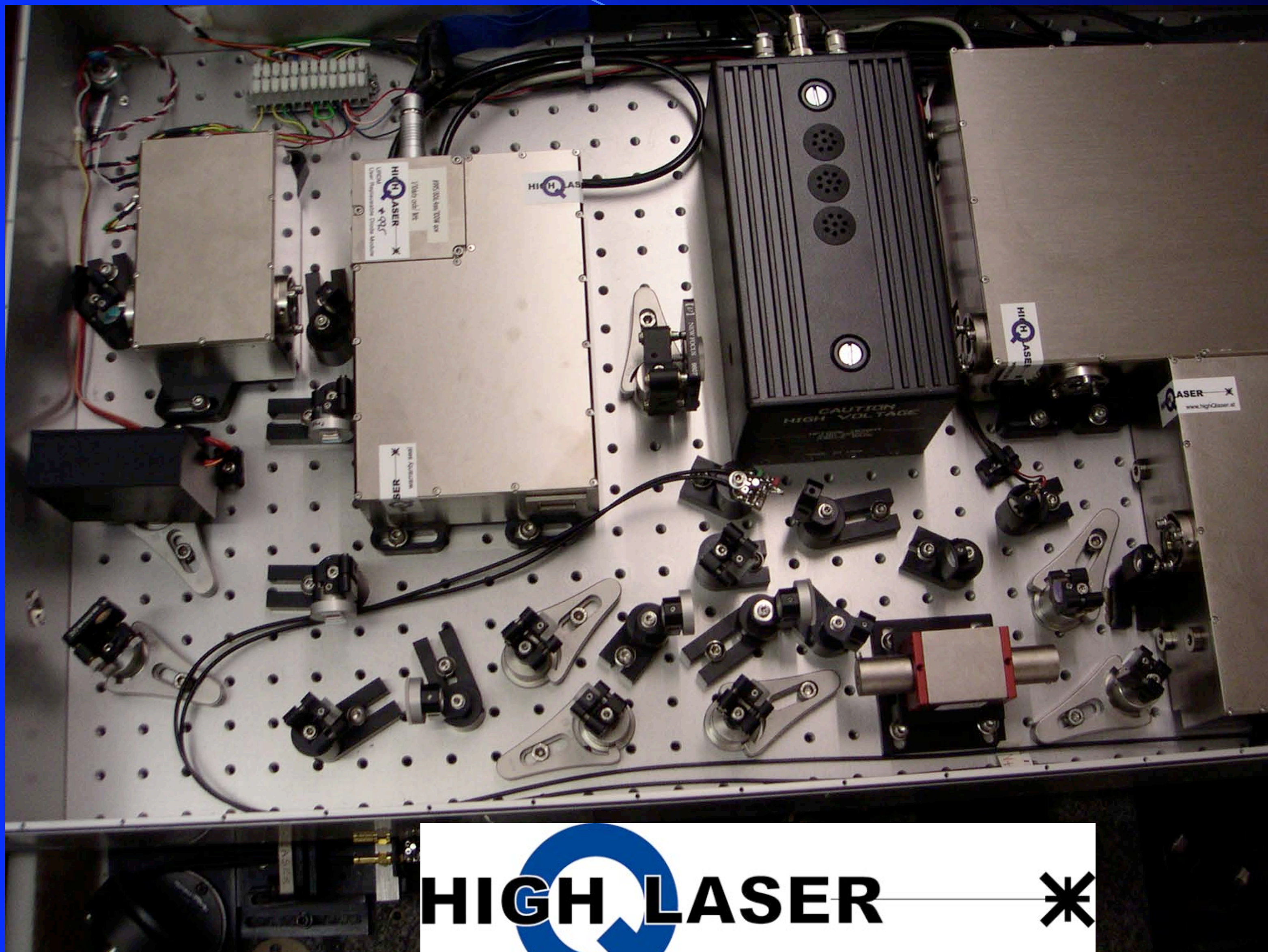


New kHz Laser on top of 10 Hz Quantel Laser ...

kHz SLR at Graz



kHz SLR at Graz



HIGH Q LASER

kHz SLR at Graz

New / adapted / necessary Items for kHz Laser Ranging:

- The kHz Laser itself;
- Event Timers: Graz E.T., using Dassault Modules;
- Range Gate Generator: FPGA Device, built in Graz; with < 500 ps Resolution
- 2.4 GHz PC as Real Time Controller;
- We use the „Stone-Age“ DOS (but it is fast ...)
- Software to handle everything within 500 µs cycles

kHz SLR at Graz

Statistics (2 weeks after start of kHz):

- 10 Hz Laser, first 279 days in 2003:
  - 6361 Passes, with 9.635.964 Returns
- kHz Laser, first 10 days after start (Day 281/2003):
  - 120 Passes, with 10.005.816 Returns

kHz SLR at Graz

Statistics (2 weeks after start of kHz):

- LAGEOS: Up to 200.000 Returns / Pass
- ENVISAT etc: Up to 350.000 Returns / Pass
- TOPEX: Up to 500.000 Returns / Pass
- AJISAI: > 1.000.000 Returns / Pass
- GPS 36: About 10.000 Returns / Hour ...

(remember: 0.4 mJ/shot !)

kHz SLR at Graz

Statistics (2 weeks after start of kHz):

- LAGEOS: Up to 20.000 Returns / NP
- STARLETTE: Up to 38.000 Returns / NP
- AJISAI: Up to 45.000 Returns / NP

- In NP File: We state „9999“ if actual number exceeds that ....

kHz SLR at Graz

Statistics (2 weeks after start of kHz):

- We now submit only NPs with > 100 Pts / NP
- We might change that to > 600 Pts / NP for LEOs
  - This will increase NP stability again;
  - This eliminates NPs with „poor“ return rate;
- We will check also possible use of Single Photons only for specific / all satellites;
  - But presently everything points to MultiPhotons

kHz SLR at Graz

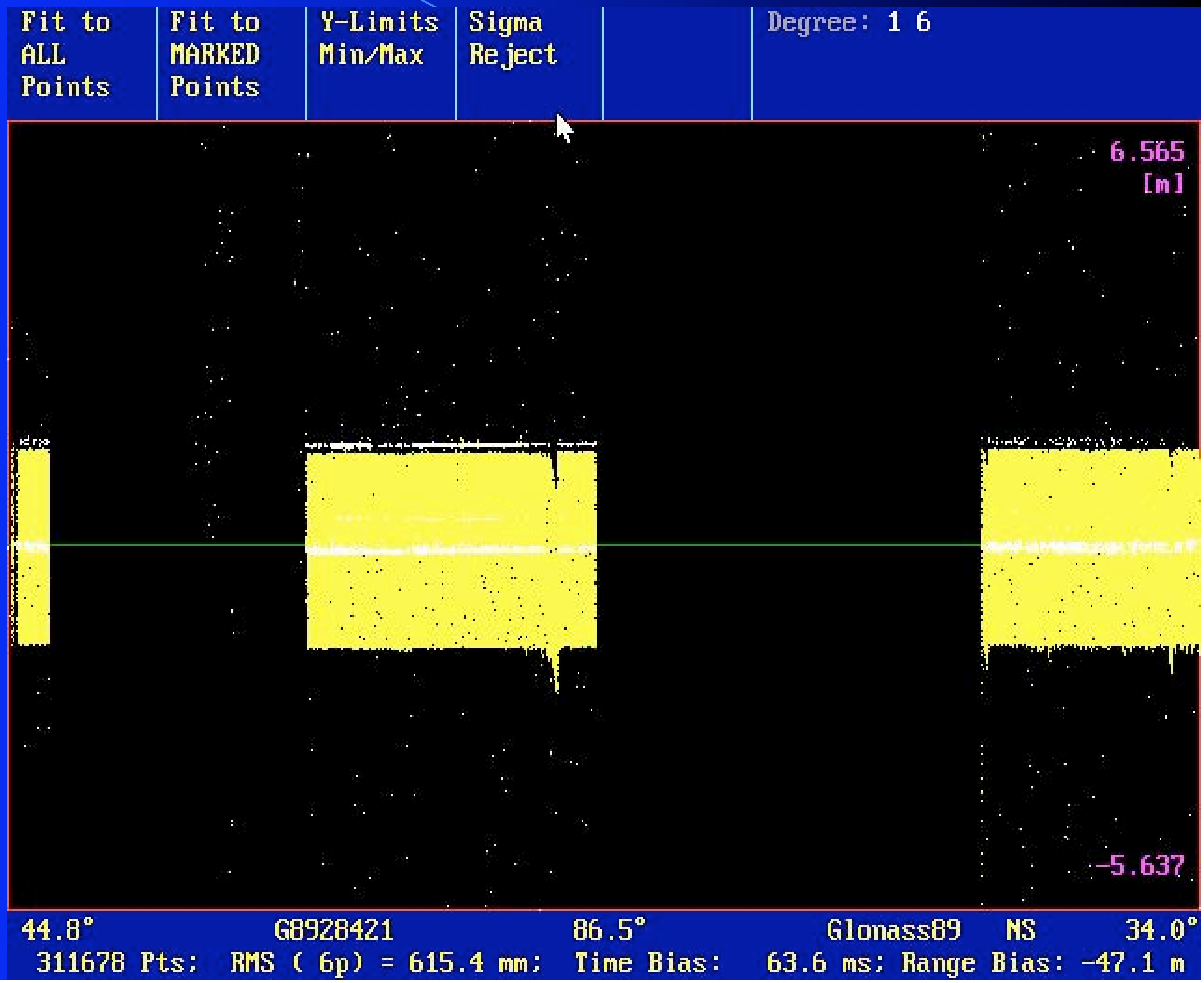
Additional Remarks:

- Day and Night: Similar Amount of Results
- Single Shot Accuracy: Similar as for the 10 Hz Laser:
  - Better due to < 10 ps pulses;
  - Better due to pulse uniformity of DPSSL;
  - Worse due to low return energy (IF Sat signature)
  - ERS-2, Envisat: 3 - 4 mm; GraceA/B: 2 - 4 mm

kHz SLR at Graz

G89 284 21:

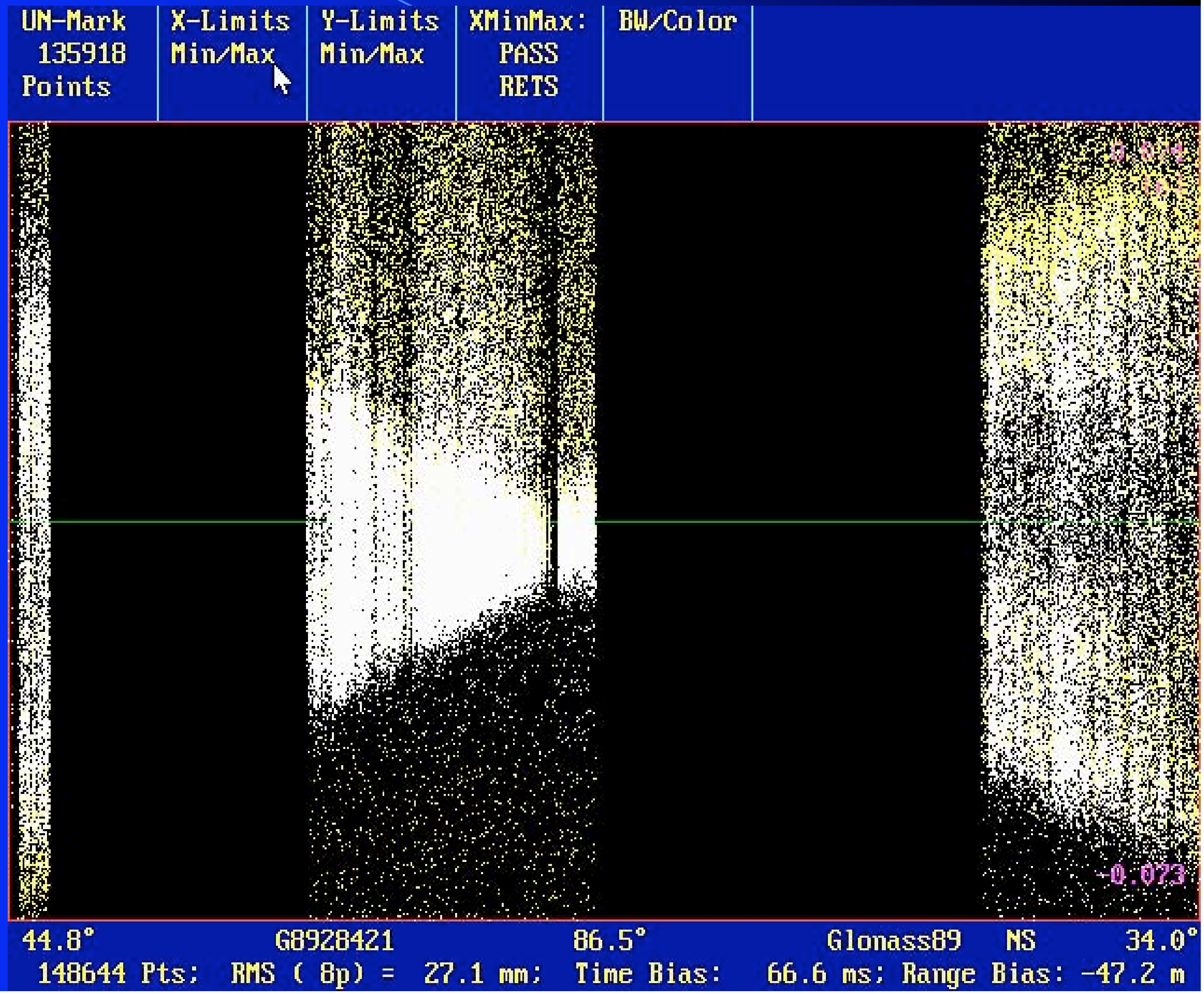
- 311 k Pts
- 135 k Rets
- White: ID
- Yell.: Noise
- No other Noise stored



kHz SLR at Graz

G89 284 21:

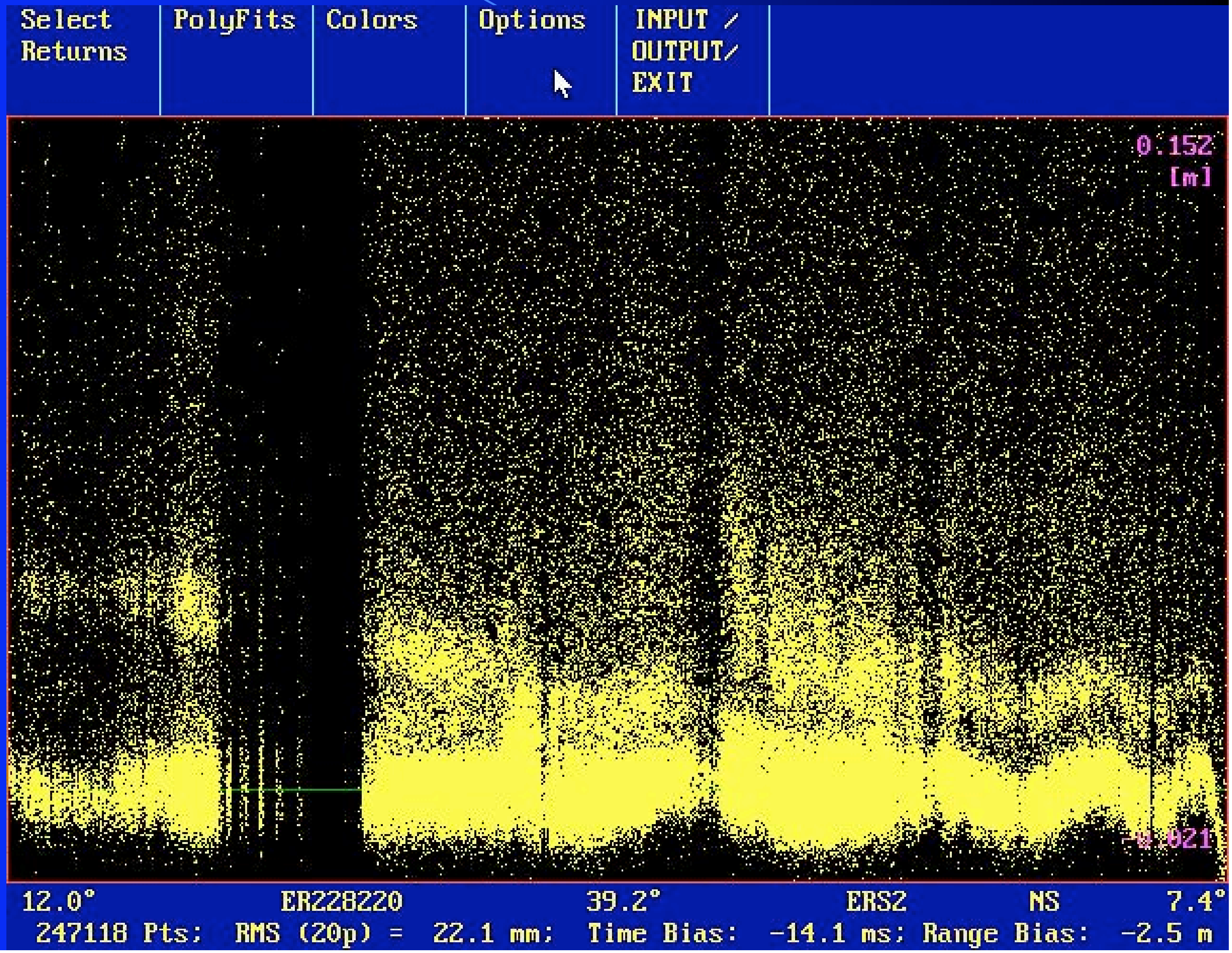
- 311 k Pts
- 135 k Rets
- White: ID
- Yell.: Noise
- Shows Retro Panels



kHz SLR at Graz

ER2 282 20:

- 247 k Pts
- 179 k Rets
- Single Retros Visible ...
- Low Elev: < 8° with 0.4 mJ ...
- Only first track used

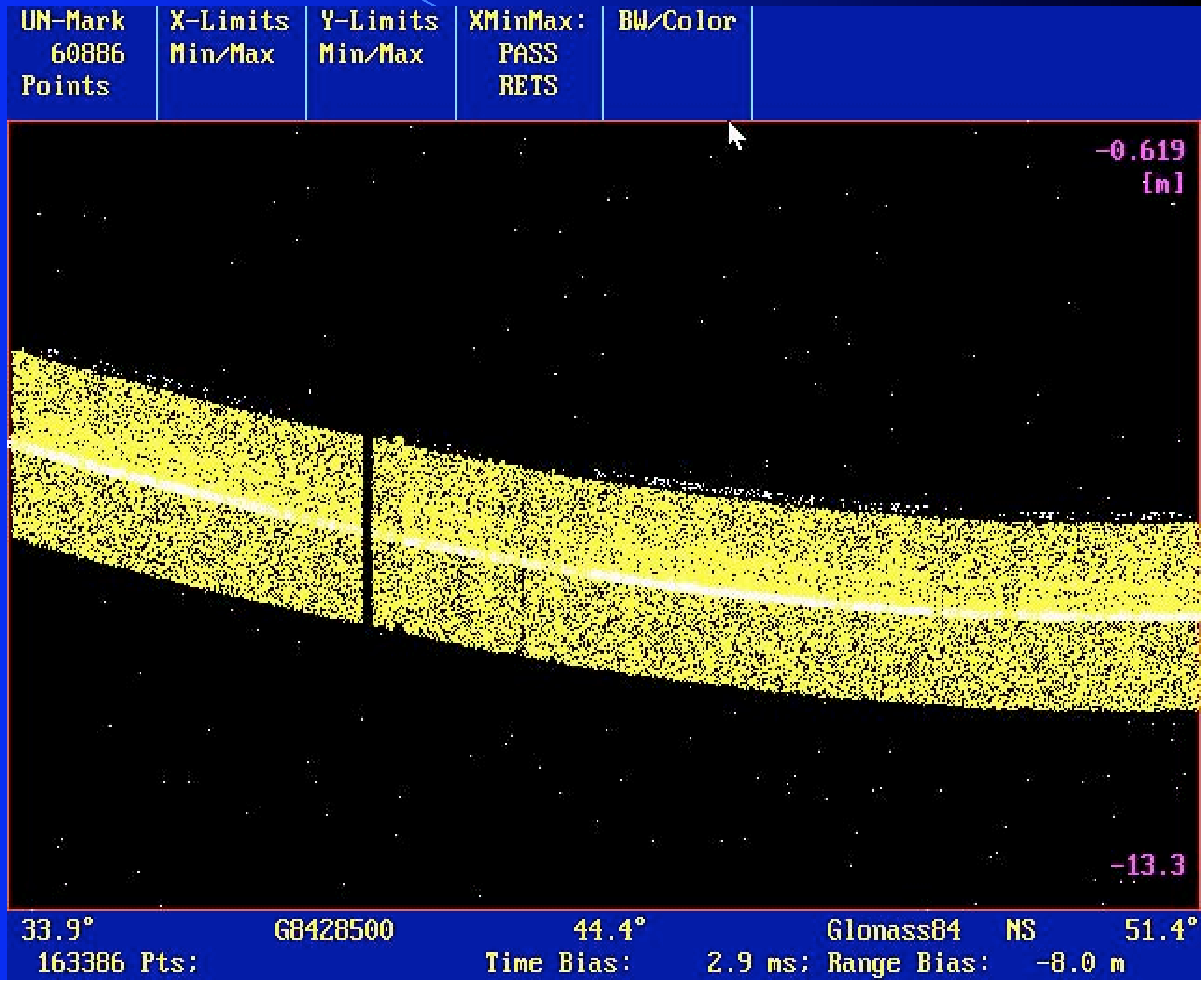


kHz SLR at Graz

G84 285 00:

Storage:

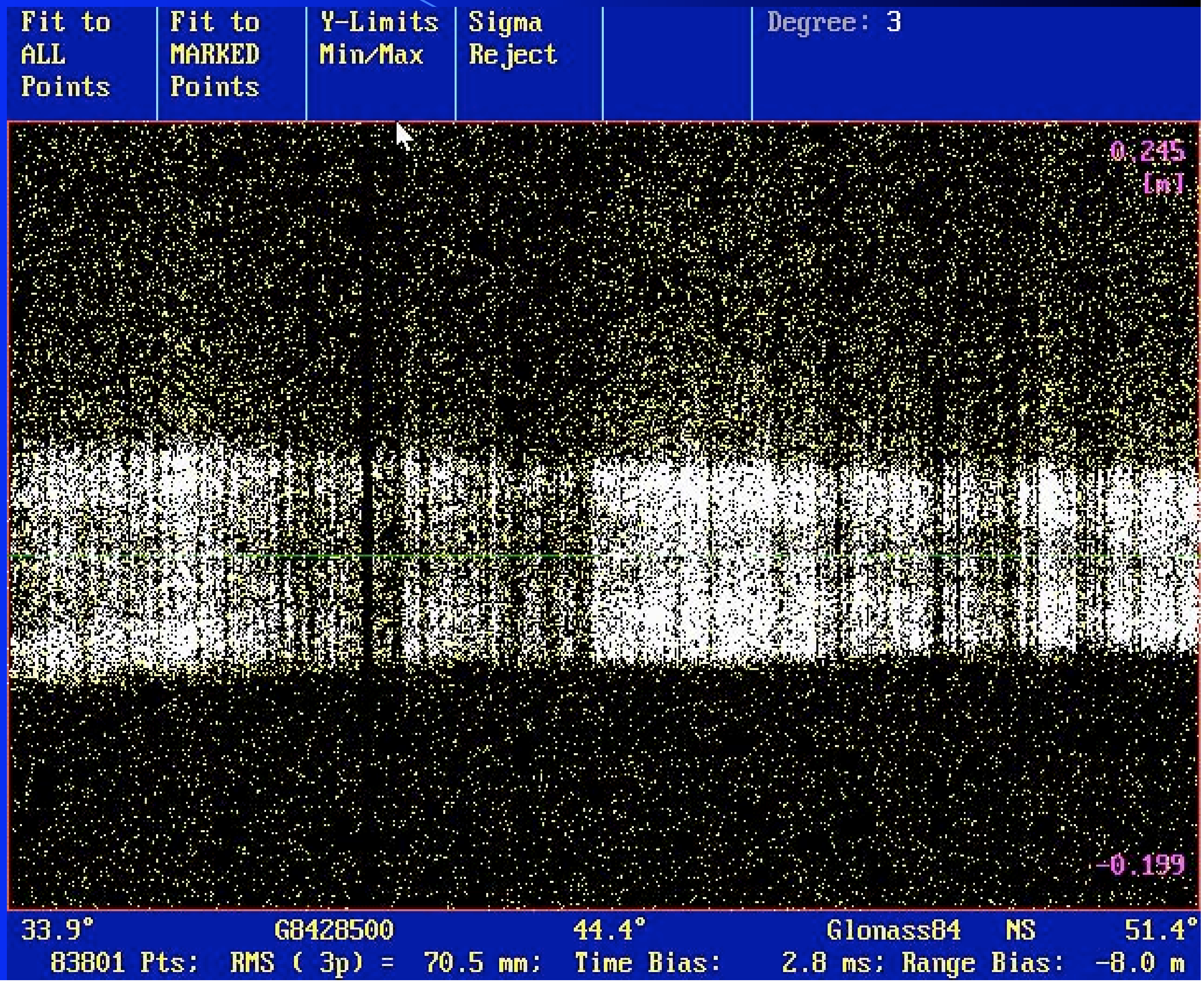
- Only ID Returns
- PLUS Pts around ID Returns
- 163 k Pts;
- 67 k Rets



kHz SLR at Graz

Glonass 84 / Same Pass:

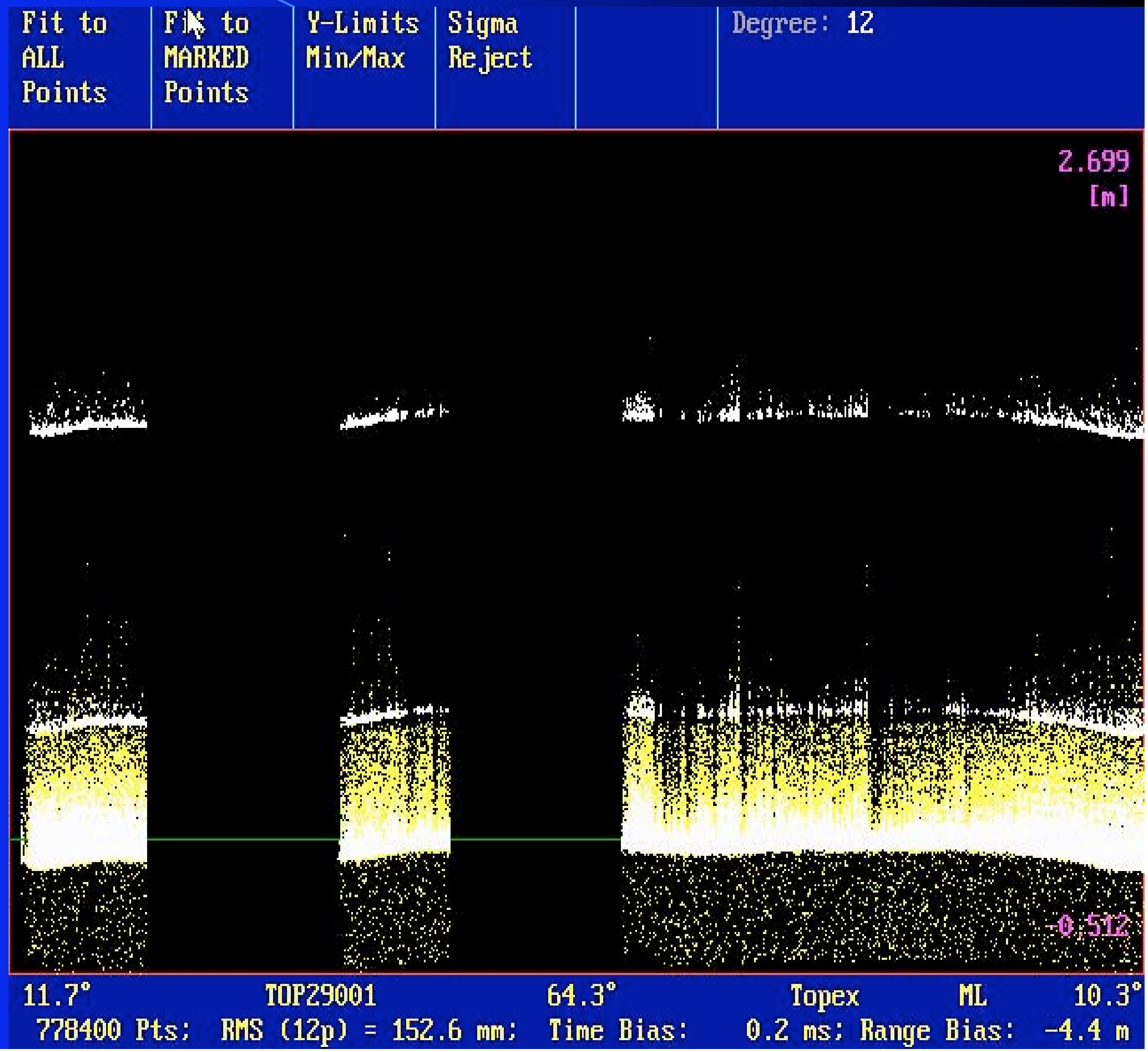
- Returns as identified in Real Time
- Various Retro Tracks
- About 67 k Returns;
- 35 mm RMS



kHz SLR at Graz

TOP 290 01

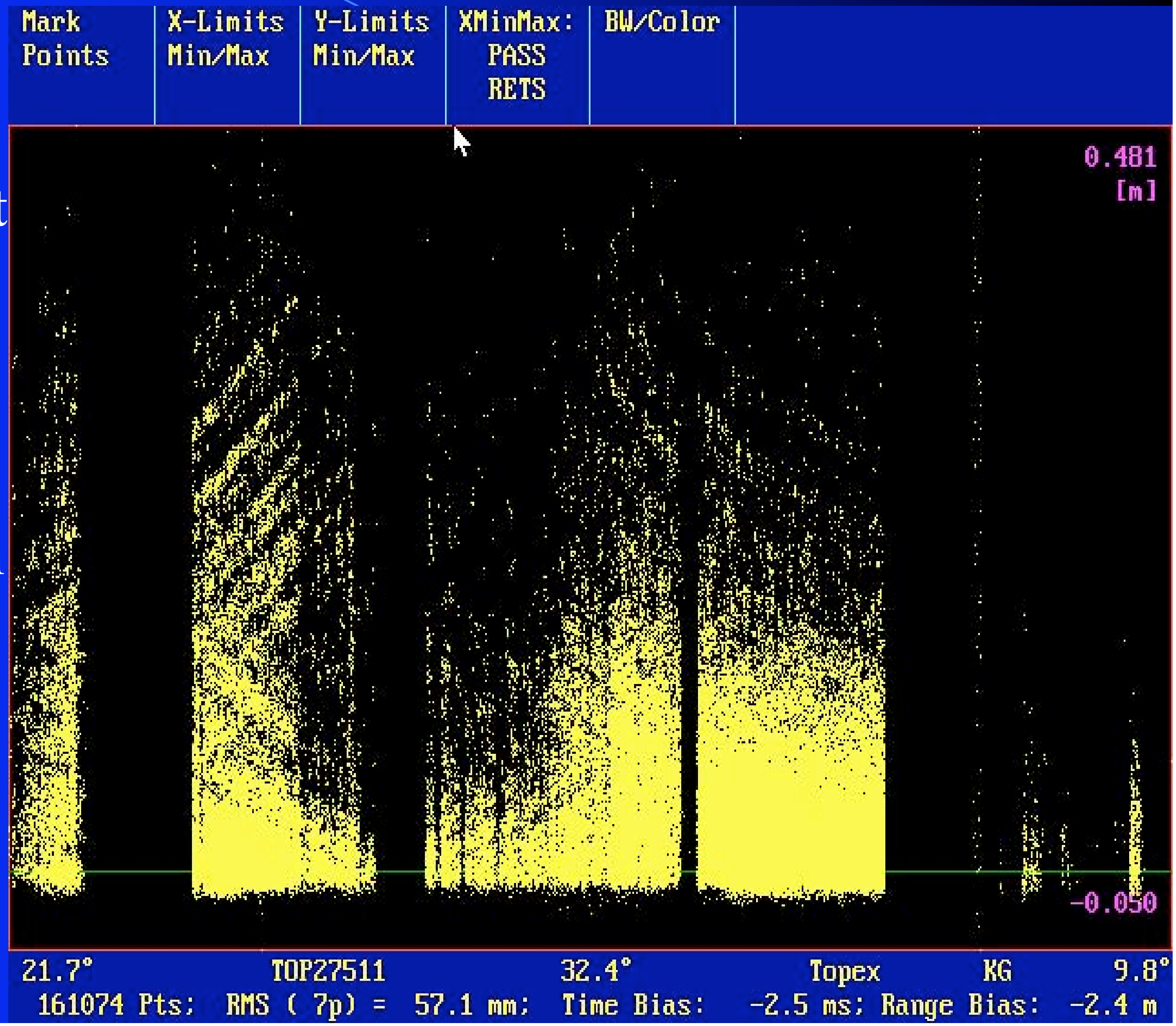
- Elevation: Down to 10 °
- Post Tracks from Laser
- 778.400 Pts
- 501.000 Rets, 5.4 mm RMS



kHz SLR at Graz

TOP 275 11

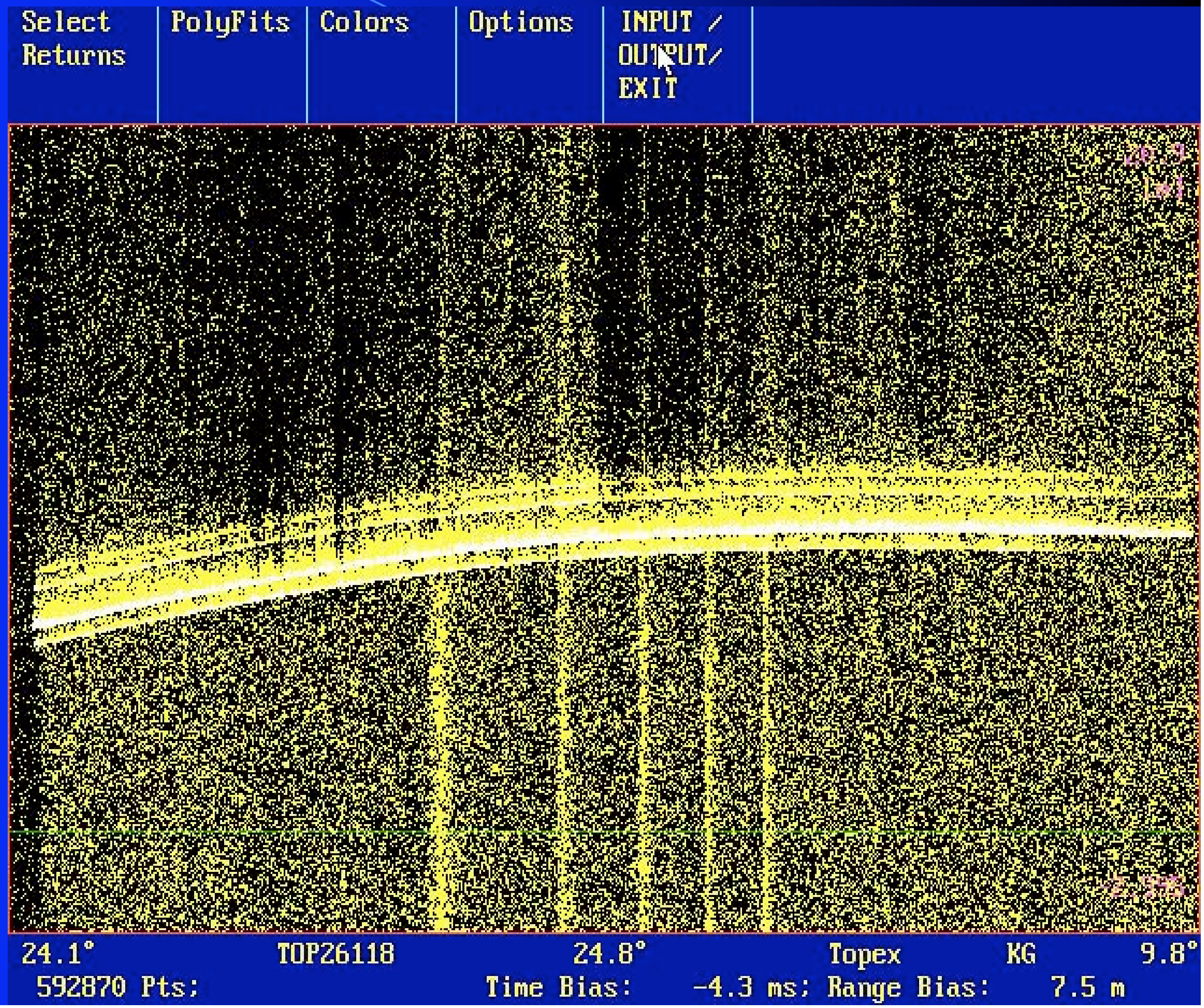
- Full Daylight
- Low Elev.
  Down to 10°
- Retro Pattern



kHz SLR at Graz

TOP 261 18:

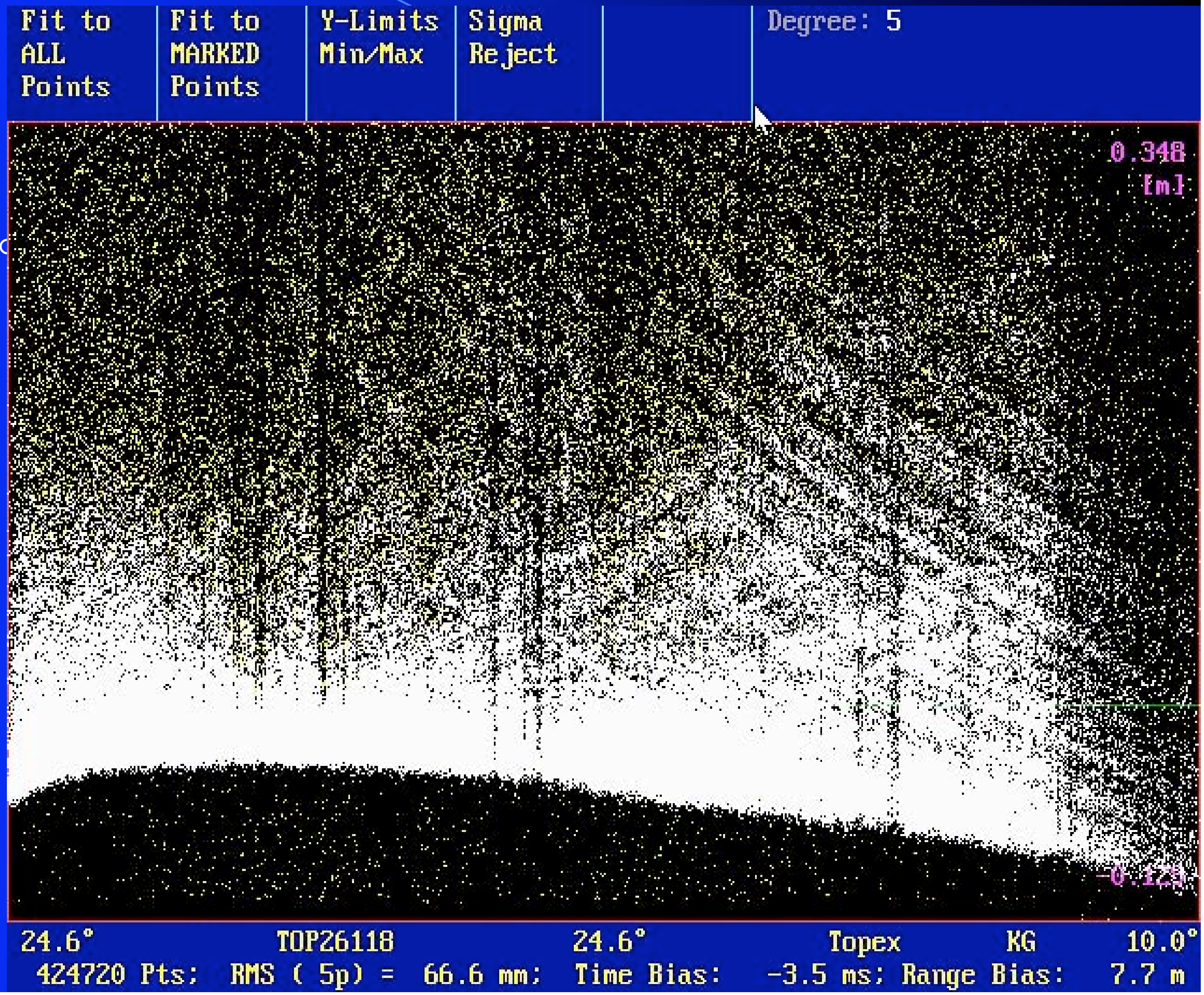
- NO Shift of Laser Firing;
- Periodically Noise Increase
- 600 k Pts recorded;
- 424 k Rets remaining



kHz SLR at Graz

TOP 261 18:

- 25° max El;
- Tracked to 10° elevation
- 424 k Rets remaing;
- Traces of Retros
- Only „First“ Track used for NPs



kHz SLR at Graz

kHz Advantages: *OPERATIONAL ITEMS*:

- Tracking and Acquisition: Much faster, easier;
- All Automatic Routines: Faster, better determined, more possibilities:
  - Auto Gate; Auto Track, Auto Time Bias, Auto Search etc.
- Difficult targets: Significantly easier to track !!!
  - GPS, Glonass, ETALONs: MORE Returns (even with 0.4 mJ);
  - Daylight tracking now easier !!!
- DPSSL: Much more stable, more uniform pulses, much less HF noise;
  - No more water leakage problems; no more flash lamp problems,
  - Easier alignments with kHz; etc.

kHz SLR at Graz

kHz Advantages: *Results:*

- NPs: Very High Data Density; from 25 to 5000 Pts/NP average (STA);
- Much higher stability / significantly less NP Jitter
  - Already seen in first LAGEOS passes;
- Accuracy: Single Shot => Similar to 10 Hz Laser; NPs: Much better ...
- Resolution: Does resolve single Retros;
- Calibrations: Much better RMS, better stability:
  - 10.000 returns for standard CAL, within 10 secs (50% Return Rate);
  - Allows fast and easy checks for Skew, Peak minus Mean etc.
  - RMS: 12-14 ps (2 mm)

kHz SLR at Graz

First Insights and Findings:

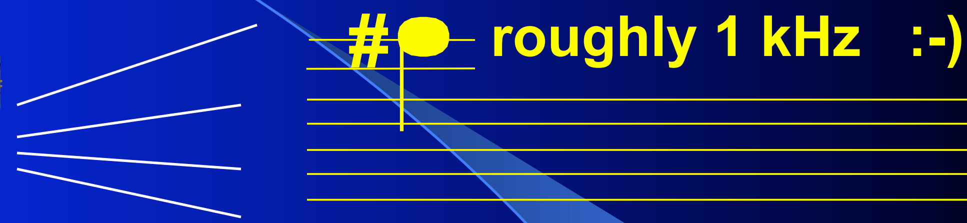
- Laser Pulse Shifting REQUIRED due to excessive noise in case of overlap with incoming returns;
- Satellite Signature becomes more important:
  - Single Retroreflectors visible on various satellites: TOPEX, ENVISAT, ERS-2, STARLETTE ....
- Inspite of low energy (< 0.4 mJ/Shot):
  - Huge Increase of Data for ALL satellites possible !

kHz SLR at Graz

First Insights and Findings (2):

- LAGEOS: Naturally MOST returns are in SP region; Maximum observed return rate up to now was about 25 %;
  - Even for these „High Return Rate“ Passes, the majority of returns will be Single Photon anyway;
- LEOs: Difficult to maintain SP region reliably;
  - For ERS-2 and similar: MultiPhotons seem to be the much better choice at the moment (low sat signature, no CoM problem, much better statistics etc.);

kHz SLR at Graz



The Graz kHz Laser whistle has started ...

(Now even with 2 kHz ...)

IS kHz the **FUTURE OF SLR ???**

Multi kilo Hertz laser ranging for deep space missions

I.Procházka, K.Hamal, P. Jirousek, M.Kropik

Czech Technical University in Prague,

U. Schreiber

Technical University Munich

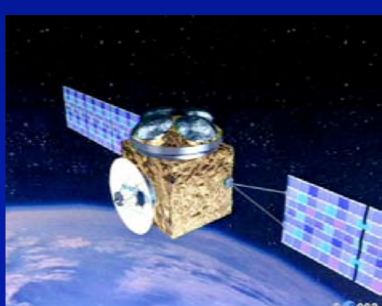
presented at

International Laser Ranging Service Meeting, Koetzting, October 28-30, 2003

GOALS

- multi kilo Hertz laser ranging
  for ESA deep space missions (Mercury..)
- laser ranging to non cooperative targets

- ranges 0 → > 1000 km
- range resolution < 1 m / shot (6 cm)
- /deep/ space qualified:
  radiation, heat flux, lifetime..
- photon counting concept
- high repetition rate microlasers

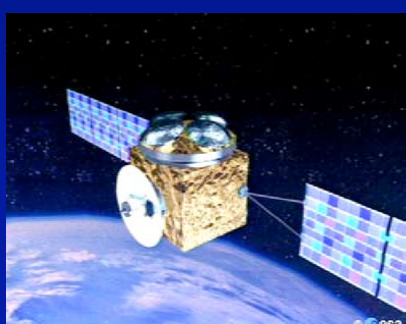


Technology demonstrator

Phase A (2003-2004)

- microlaser “NanoLas”
- 16 kHz , 1 uJ, < 1 ns, 532 nm
- Si SPAD , 40 um, CW
- Modular electronics
  - programmable gate arrays (100 MHz)

- optics - refractive
  - scaled to preserve
    - energy budget
    - high back ground count rate

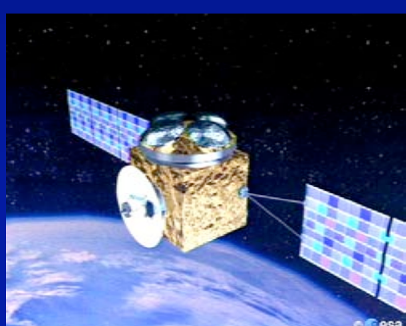


Technology demonstrator

Phase A (2003-2004)

- timing electronics
  - 100 nsec counter
  - 8 bit TDC -> 0.5 nsec resolution

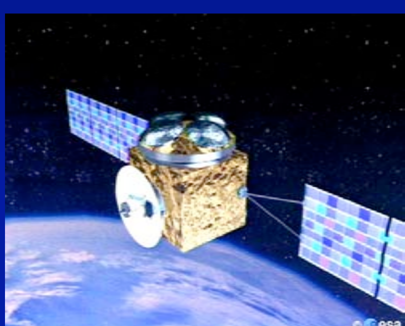
- adaptive range gate
  - gate delay programmed via orbit parameters and terrain profile
  - gate strategy can be modified within the experiment



Technology demonstrator

Phase A (2003-2004)

- control electronics
  - Z80 based
  - real time & parallel processing OS
  - range gate position calculation
  - data flow control
  - data accumulation
  - echo signal identification



Technology demonstrator milestones

• concept design/decision	Oct. 2003
• budget collection	Oct. 2003
• laser, filter, SPAD	Dec. 2003
• mechanics & optics design	Jan. 2004
• breadboard electronics&control	Dec. 2003
• mechanics and optics	May 2004
• programming	Jan. June 2004
• first echoes	June 2004

Photon-Counting Kilohertz Laser Ranging

John Degnan

Sigma Space Corporation

Lanham, MD 20706 USA

2003 ILRS Workshop, Koetzting, Germany

October 28-31, 2003

Who is building kHz systems?

- **USA**
  - NASA SLR2000 system proposed at 1994 Canberra Workshop
  - Development begun in late 1997
  - Field testing of prototype underway. No satellite ranging attempts yet
  - 2 kHz, 300 psec, 130 □J transmitter; microchip laser oscillator plus multipass amplifier
- Austria
  - Presented at 2002 Washington DC Workshop
  - Uses existing Graz SLR station
  - 1-2 kHz, 10 psec, 500 □J transmitter planned; SESAM oscillator plus multiple amplifiers
  - Near 100% return rate from LEO’s with 80 □J at 125 Hz (computer-limited)
- Australia, Japan, and Russia are experimenting with 100 Hz systems

Advantages of kHz Systems

- **Can take advantage of microchip and SESAM laser technologies**
  - Simpler, more compact, and less expensive than modelocked lasers for picosecond pulse generation
  - Transmitter requires fewer amplifiers due to higher oscillator energies (up to tens of □J for microchips vs nJ for modelocked lasers)
  - No electro-optic pulse selection or high voltages required
- **Increases number of range returns per normal point by about two orders of magnitude**
  - Can improve normal point precision by over an order of magnitude relative to current 5 or 10 Hz systems
  - May allow meaningful two color measurements of differential atmospheric delay using high speed PMT's or SPADS
- **Improves single photon ranging statistics**
  - higher repetition rate compensates for single pulse photon deficit
  - Allows single pulse output flux to be reduced to eyesafe levels thereby eliminating the need for safety observers or aircraft radars
  - Single photon range measurements are free of signal amplitude biases
  - Orbit range residuals can reproduce the impulse response of the overall system (laser, satellite,detector) within a single normal point period

Special requirements of kHz systems

- KHz gating circuits and range gate generators
- Use of event timers rather than time interval units due to multiple pulses in flight
- More sophisticated ranging software required to extract the signal from the background noise and to link the proper return signal to each start pulse and compute the pulse time of flight
- Faster interfaces between the ranging hardware and system CPU
- More aggressive background noise reduction and fast receiver recovery times in the case of photon-counting systems

Computation of normal points from kHz photon-counting data

1. Create station impulse response *h(t-t')* histogram using most recent single cube calibration target data where t is the independently measured roundtrip transit time to the target (tracks changes in system calibration)
2. Convolve cal data with theoretical averaged impulse response of target (relative to the satellite CofM) to form Poisson generating function for each station/satellite combination, i.e.,

$$g(t) = h(t) \quad s(t)$$

3. Maximize convolution integral with the normal point residuals *r(t)* from the nominal orbital fit to compute the displacement of the normal point relative to the fit, i.e.,

$$\Delta t_{opt} = \max\left[r(t) \quad g(t)\right]$$

4. **or** compute centroids for 2 and 3 using current normal point algorithms and difference the results to obtain the displacement.

Impact on ILRS Data System

- The computation of the normal point can be carried out at the stations or by the analysts (TBD)
- The proper satellite center-of-mass correction to be applied by the analysts is the distance between the computed ground system-dependent centroid of *g(t)* and the satellite center of mass plus Δt_{opt}.
- If N is the number of ranges per normal point, the RMS uncertainty in the normal point should be given by

$$RMS_N = \frac{RMS[g(t)]}{\sqrt{N}}$$

- To the analyst, normal points from kHz systems should look identical to those from lower rate systems, but we may want to redefine the normal point integration times for each satellite to better support atmospheric modeling studies and multi-wavelength systems.

Example: SLR2000 Ranging to LAGEOS

- **There are 240,000 (120 sec x 2 kHz)ranging attempts in a two minute LAGEOS normal point.**
- **For standard clear atmosphere (visibility = 23 km) and no cloud cover, about 5,000 ranges per normal point (2% return) are expected during acquisition at 20° elevation and rising to a maximum of about 60,000 ranges (25% return) near zenith**
- **Since RMS of LAGEOS impulse response is about 15 mm, the RMS precision of the centroid (normal point) would have a lower limit of 0.2 mm during acquisition and 0.05 mm near zenith.This calculation ignores any statistical broadening due to the system impulse response or the minimum timing resolution of the receiver.**