Effects of the atmosphere on the SLR precision

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Introduction

- Goals:
  - precise measurement of range by using a laser beam and a retro-reflector
  - prediction of the influence of atmospheric effects on the precision of the measurement
  - using an atmospheric model for correction of the measurement results
- My task:
  - study of known atmospheric effects and theoretical background of laser ranging
  - writing a computer model of the atmosphere and checking its results experimentally

Theoretical background

- atmosphere - optical set of layers which vary with time and geographical position
- measured length is affected by such a set
- optical effect of the whole layer of the atmosphere = effect of a 6 km horizontal path
- optical behaviour of the atmosphere is predictable from:
  - weather
  - elevation angle
  - wavelength of used laser

Used formula

- integration of the Gardner's formula for Le (the effective path length) both analytically and numerically

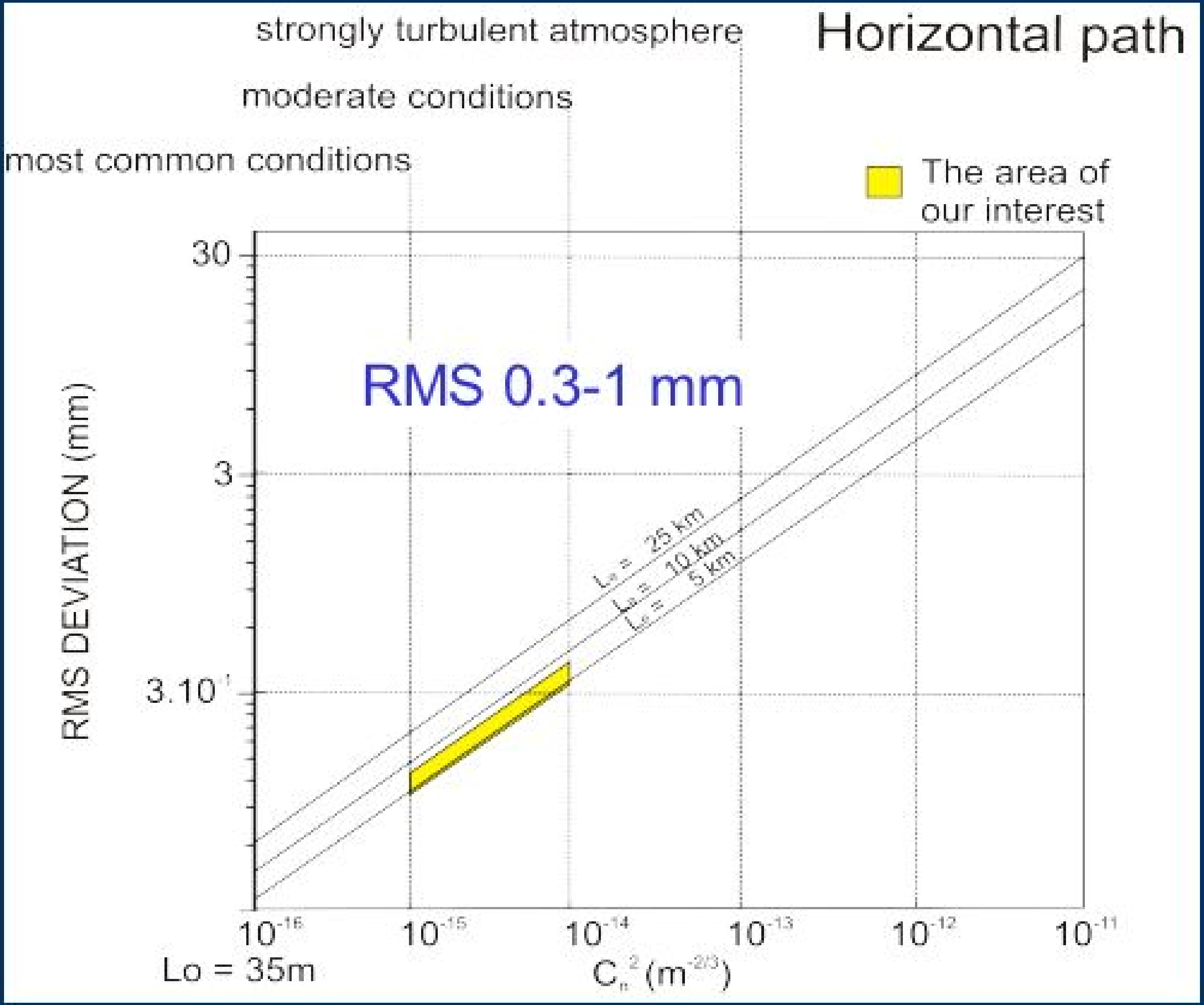
Gardner Greenwood-Tarazano model:

- $Le = 1/C_n^2 \int_0^L C_n^2(x)\,dx$, where:

- x is path through atmosphere $x = (h - h_0)/\cos(j)$
- $C_n^2(h) = 3{,}59.10^{-3}.(h.10^{-5})^{10}.e^{(-h/1000)} + 2{,}7.10^{-16}.e^{(-h/1500)} + 1{,}7.10^{-14}.e^{(-h/100)}$
- for horizontal path
  - the C_n^2 is constant
  - L_e equals the beam path length
  - L_o (outer scale of turbulence) matches H, the average height of the beam above ground
  - $RMS = sqrt(26.31\ C_n^2\ L_0^{5/3}\ L_e)$

- where Le is the effective path length, C_n^2 is the refractive index structure constant, h is the height of the target above the sea level, h_0 is the height of the measuring point above the sea level, and j is the zenith angle of the shot beam

Gardner Greenwood-Tarazano model



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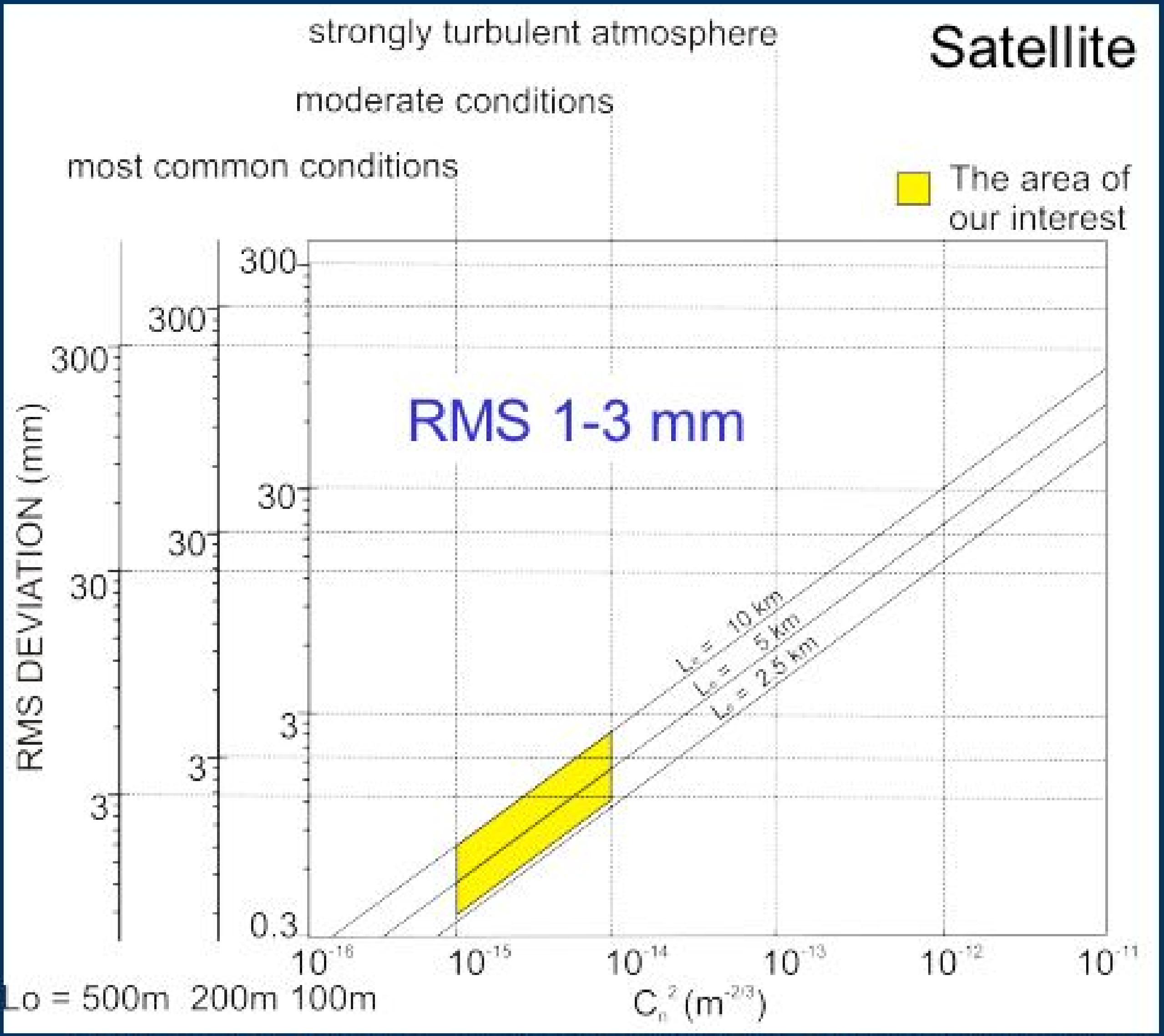
Gardner Greenwood-Tarazano model



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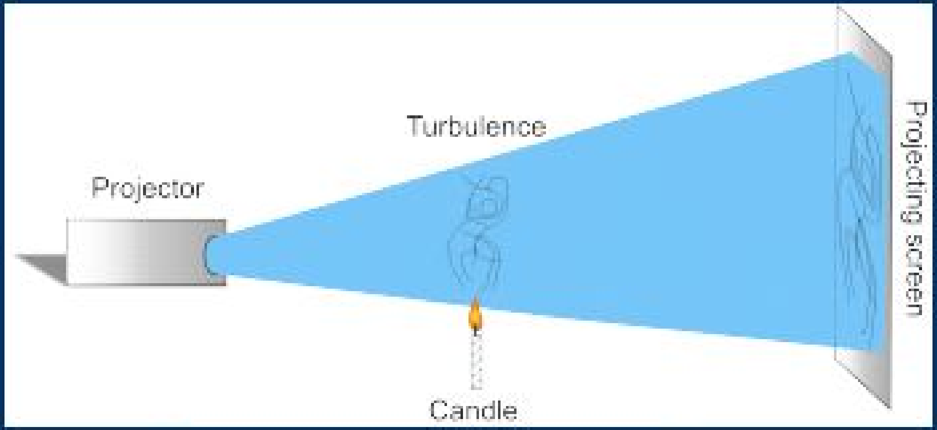
Clear Air Turbulence

Prague Indoor Tests, June 2004



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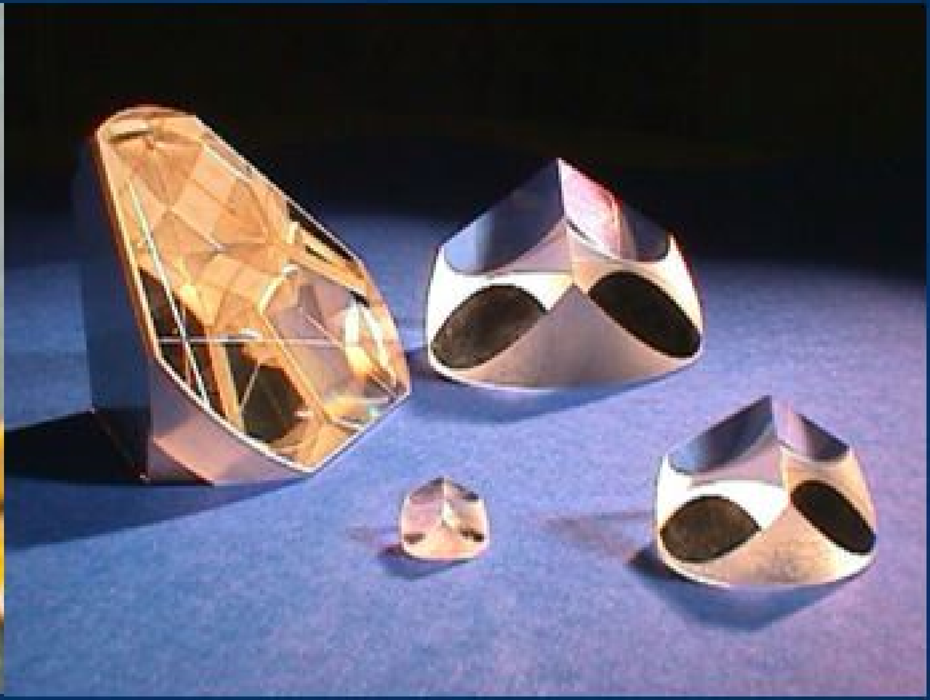
Clear Air Turbulence

San Fernando Indoor Tests, June 2004

Retroreflector

- Corner cube
- cross-section ~ 10^5 m^2



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Retroreflector

- „Shiny ball"
- a silver coated Christmas sphere, Ø 10 cm

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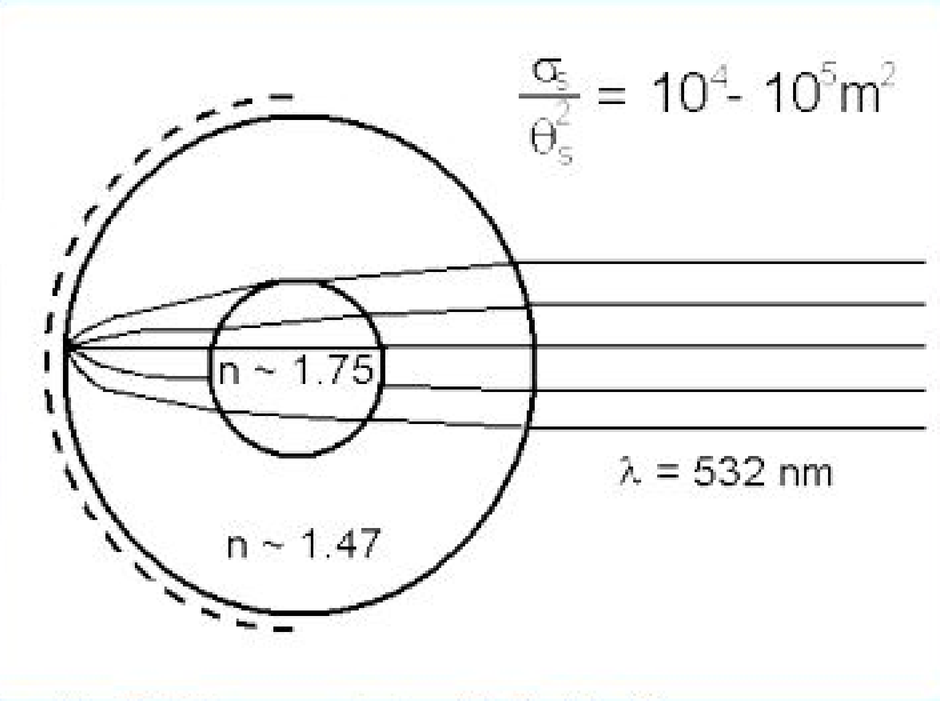
Retroreflector

- Spherical retro
- cross-section ~ 10^4-10^5 m^2



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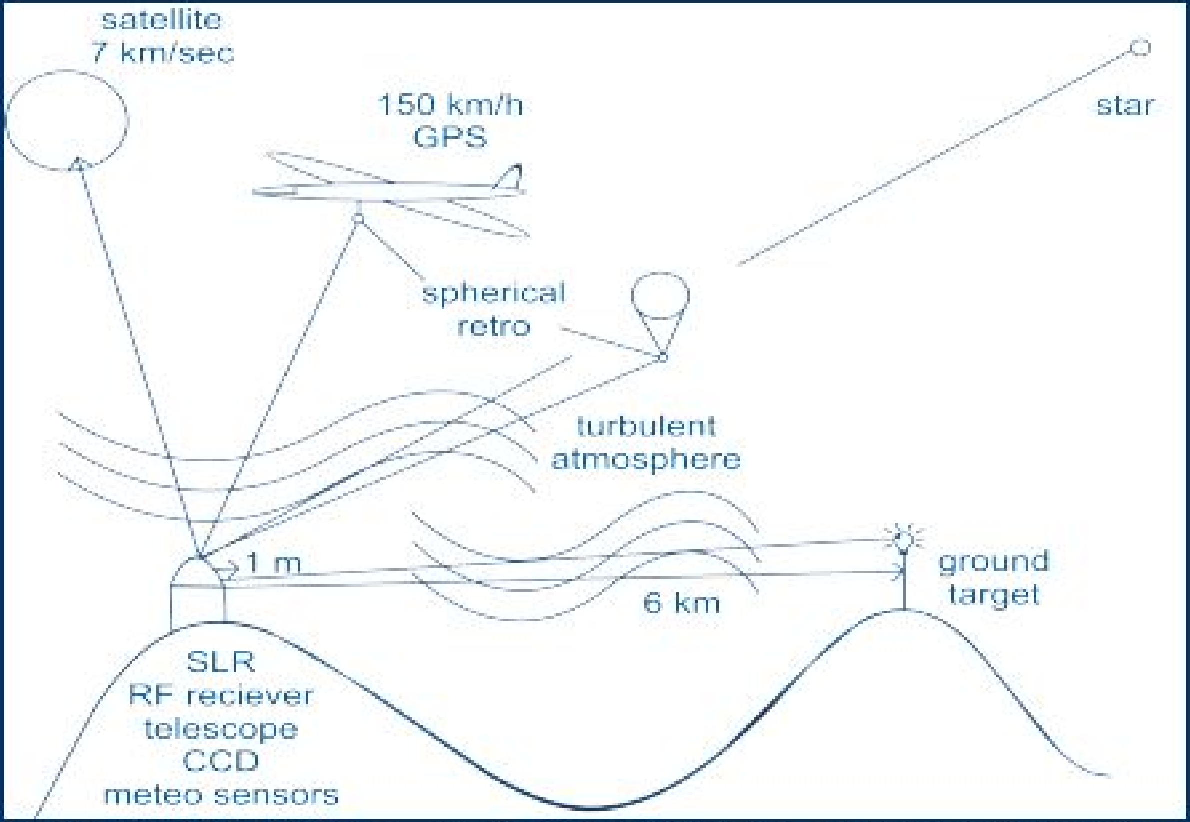
Graz observatory

- Graz, Steiermark, Austria
- 47°04' N , 15°30' E , 495 m above sea
- SLR station: 532 nm Nd:YAG laser, 2kHz, 10 ps, 10^{15} photons per pulse, beam divergence ~ 30 arcsec, Single Photon Avalanche Detector SPAD

Introduction to the experiments

- measured on the Graz observatory, using all the retros



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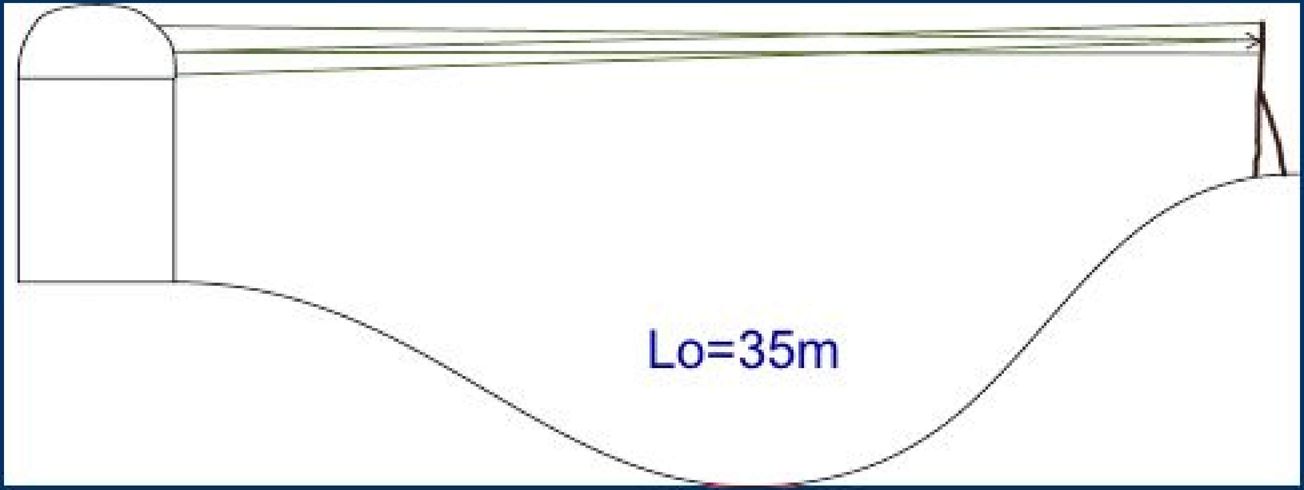
6 km ground corner retro

- 6 km of the atmosphere in the horizontal direction correspond with the whole layer of atmosphere in the slant path in the way of the passage of light beam
- in comparison with a close target (1 meter) can be useful for research of the part of the pathlength deviation, caused by the hardware



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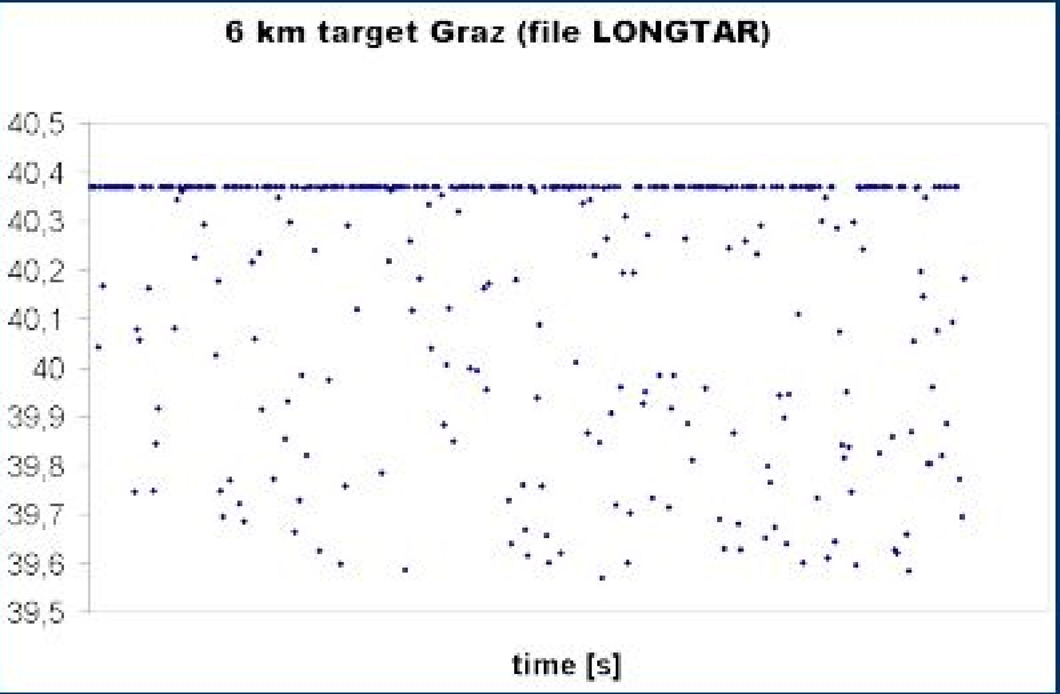
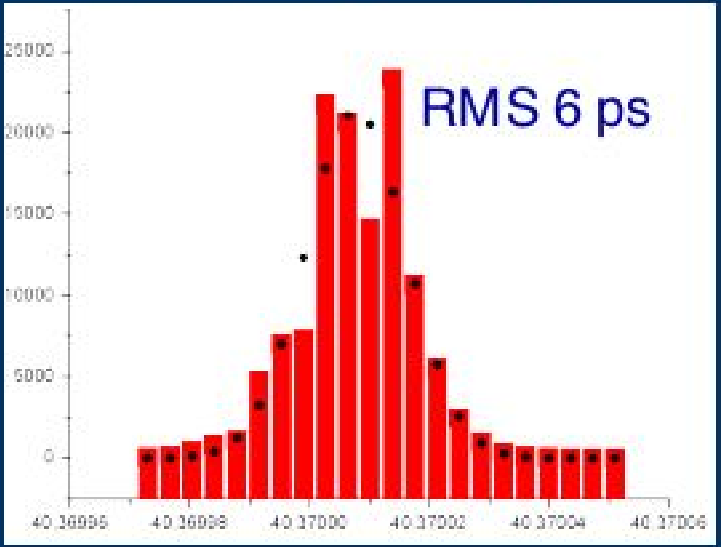
6 km target results
Graz, 30. 9. – 2. 10. 2003

- for the horizontal path the RMS w as predicted and measured 1 mm (6.6 picoseconds)



6 km processed results - RMS



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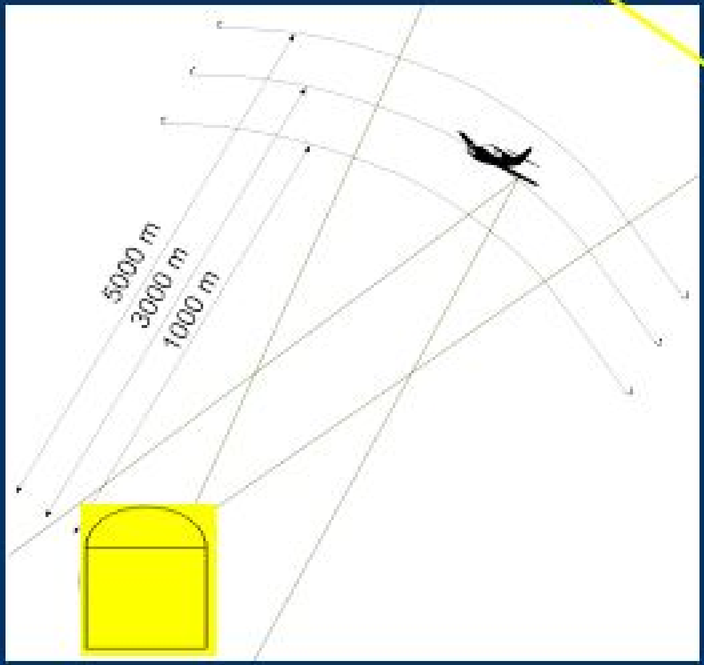
Motoglider mission 1
Graz, 30. 9. – 2. 10. 2003

- to check the theoretical prediction of RMS for non-horizontal path also not to space
- first attempt: a corner retro on the wing of a motoglider



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Motoglider mission 1 results

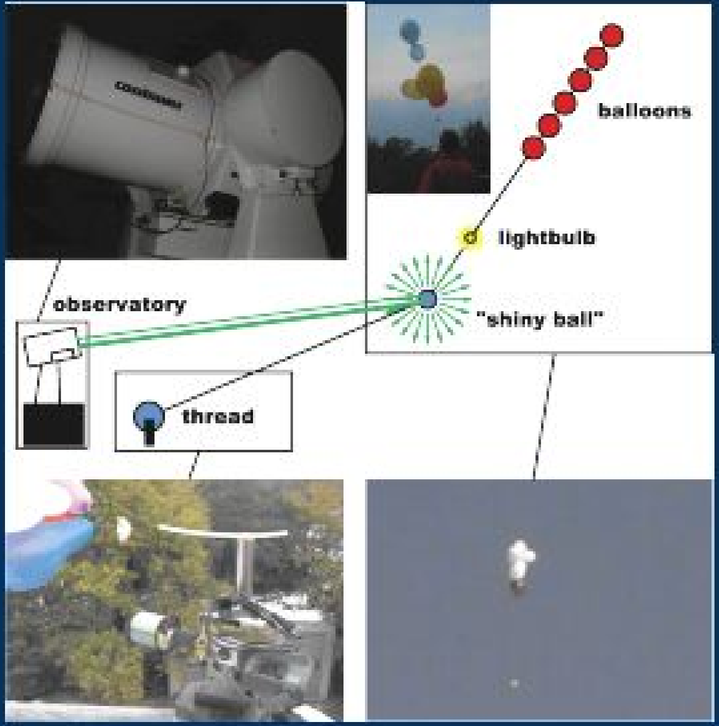
- the motoglider had only a corner retro on its wing and so the probability of hitting it in the right direction was too small
- also the only way of targeting the motoglider was manual manipulation with the whole telescope and visual contact
- the next attempt was planned very carefully, a few options were discussed, for example a GPS client device on board, connected to the wireless serial port on the observatory computer
- Mr. Kirchner and Mr. Koidl thought out another solution

- NO SUCCESS

Balloons carrying “shiny ball”

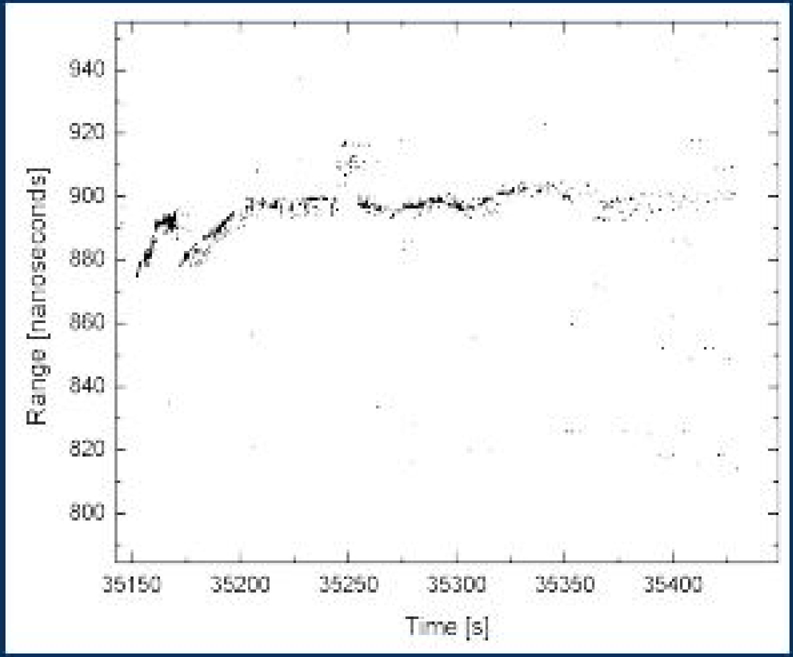
Graz, 25. 10. -27. 10. 2003

- the next experiment was based on the same purpose - to check the predicted value of pathlength deviation on the slant path to closer target experimentally
- the balloons were bound on thread, equipped also by a searchlight for easier targeting
- the whole set was light and cheap, which allowed us to launch more of them
- the shiny ball = silver coated sphere for Christmas trees
- range 0 – 300 m

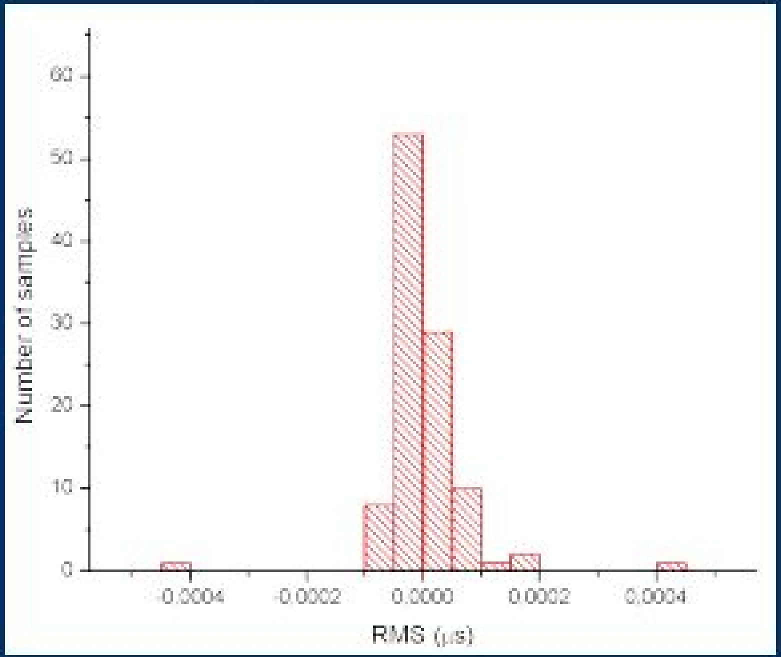


Balloons & “shiny ball” results

- for the balloons carrying a Christmas shiny ball the RMS measured was 26 ps



Balloons processed results - RMS



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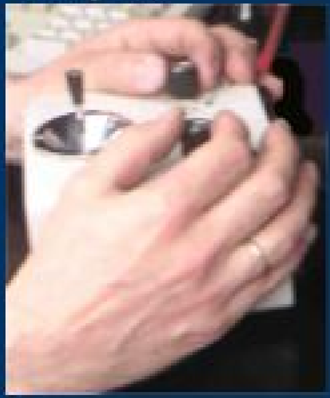
Motoglider mission 2
Graz, 3. 5. – 7. 5. 2004

- the principle of this experiment was the same as in the previous motoglider case
- another retro (sphere) was attached to the glider
- the Graz observatory team constructed a joystick for targeting the motoglider
- a video camera was added to the telescope to watch the target



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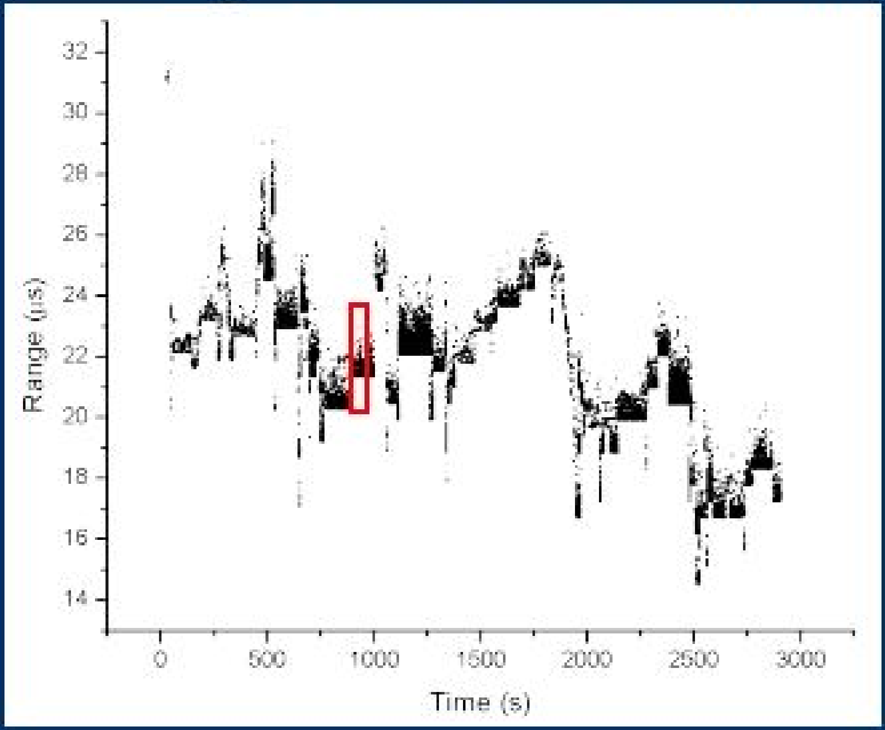
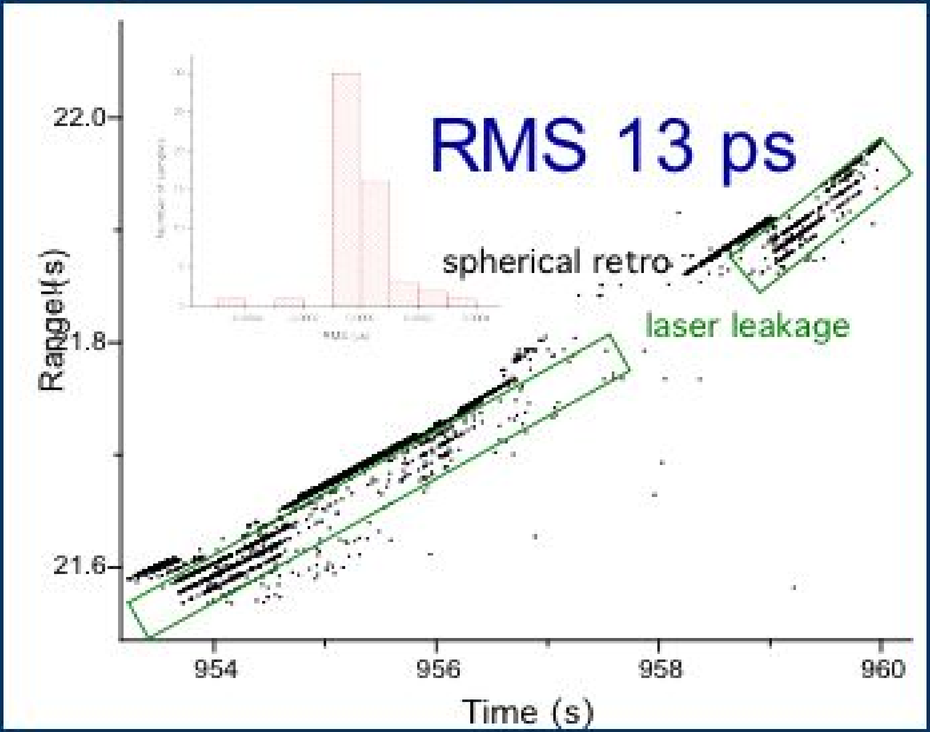
Motoglider mission 2 results

- a few results of 13 ps for pathlength deviation RMS were measured
- depicted the reflection from the spherical retro result





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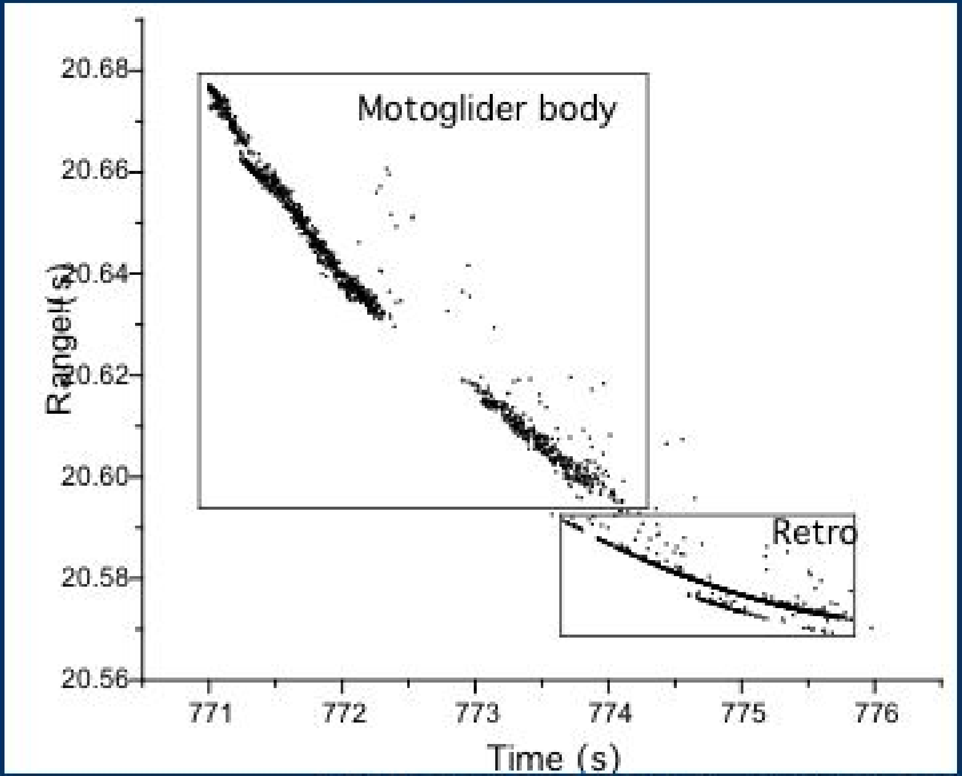
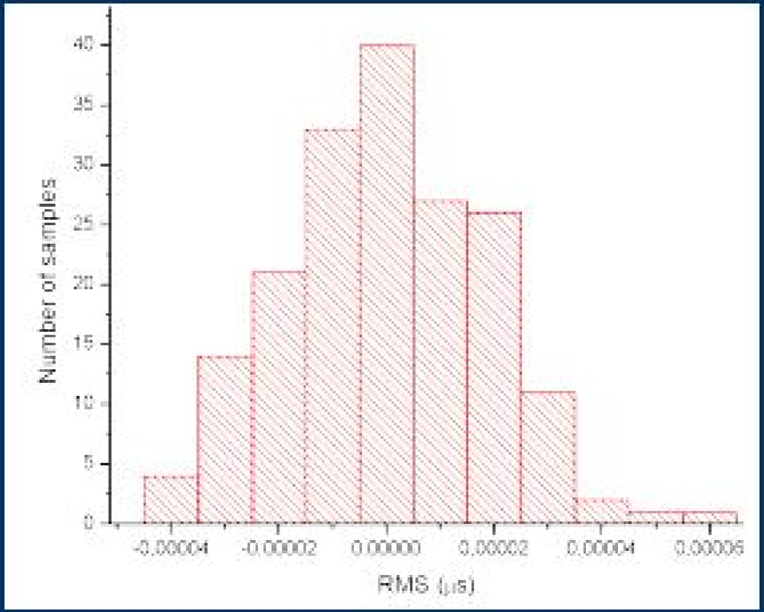
Motoglider 2 results

- Reflections from the sphere, corner cube and even the body of the glider were recognized
- depicted the reflection from the comer cube retro result



Corner cube retro 18 ps results



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Measured RMS

6 km target	7 ps
Motoglider 1	none
Balloons & „shiny ball“	27 ps
Motoglider 2 corner cube retro	18 ps
Motoglider 2 spherical retro	13 ps

Predicted number of photons

6 km target	1
Motoglider 1	$1.3 \cdot 10^3$
Balloons & „shiny ball“	$4.3 \cdot 10^2$
Motoglider 2 corner cube retro	$1.3 \cdot 10^3$
Motoglider 2 spherical retro	$1.3 \cdot 10^3$

Conclusion

- Long term Graz and perhaps the other millimeter ranging stations show a discrepancy between the ground target RMS 1 mm and SLR 3 mm.
- Clear Air Turbulence CAT modeled by Gardner and Greenwoon-Tarazano might explain contribution to the overall SLR RMS.

Conclusion

- Our experiments (2 kHz laser) using several retros: “Shiny ball” equipped balloons, the Roof Prism and Spherical Retro equipped motorglider, show 2-4 mm RMS consistent with the Gardner and T-G model.
- 6 km – 4 km horizontal path shows routinely 1 mm RMS consistent with the Gardner and G-T model close to the machine RMS.
- Due to the signal strength RMS dependence more info might be expected from the Signal Strength Monitor built in Pico Event Timer 2k.

Thank you for your attention!

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