Ring Laser „G“ for Monitoring Earth Rotation

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Introduction

The knowledge about the Earth rotation plays a fundamental role in the realization and maintenance of global reference frames.

Today VLBI-, SLR- and GPS- and DORIS techniques, coordinated through International Services of IAG provide the information via observations derived from global networks.

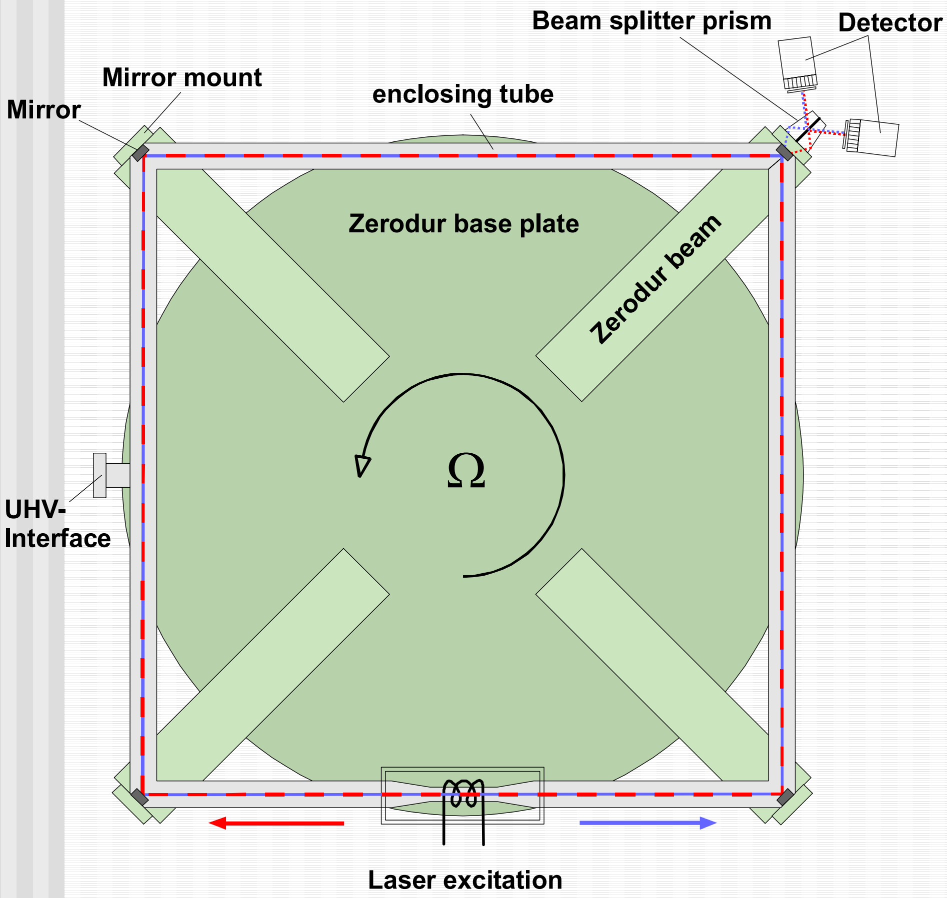
Large ring laser gyroscopes are sensitive to variations of Earth rotation. They are independent of global networks, because they measure with respect to an inertial reference frame.

The Research Group Satellite Geodesy namely the BKG (Bundesamt für Kartographie und Geodäsie) and the FESG (Forschungseinrichtung Satellitengeodäsie) in collaboration with the University of Canterbury (New Zealand) developed the „G“ ring laser.

The development of „G“

- Preparations to derive the required specifications
  - Study on the realization of ring lasers for monitoring Earth rotation (PhD thesis) in 1989
  - Inclusion of the development of „G“ in FGS research program 1990-1995 (Forschungsgruppe Satellitengeodäsie)
  - Cooperation with
    - Prof. H. Bilger, Oklahoma State University (USA)
    - Prof. G. Stedman, University of Canterbury (NZ)
  - Concept/realization of the prototype ,,Canterbury Ring'' C-II
  - January 1997 start of the operation of C-II in New Zealand
  - August 1997 Construction of G0 as large scale ring laser
- Realization of „G“
  - Construction of „G“ from September 1998 to July 2001
  - Start of operation and inauguration on October 5, 2001

Principle of Operation



Sensitivity to Earth rotation, described by the instantaneous angular velocity vetor Ω, is given by the Sagnac frequency Δf, which can be observed as the frequency difference between two counter rotating laser beams:

$$\Delta f = \frac{4A}{\lambda P} \vec{n} \cdot \vec{\Omega}$$

with

A area included by the laser beam
n normal vector of A
P perimeter
λ optical wavelength

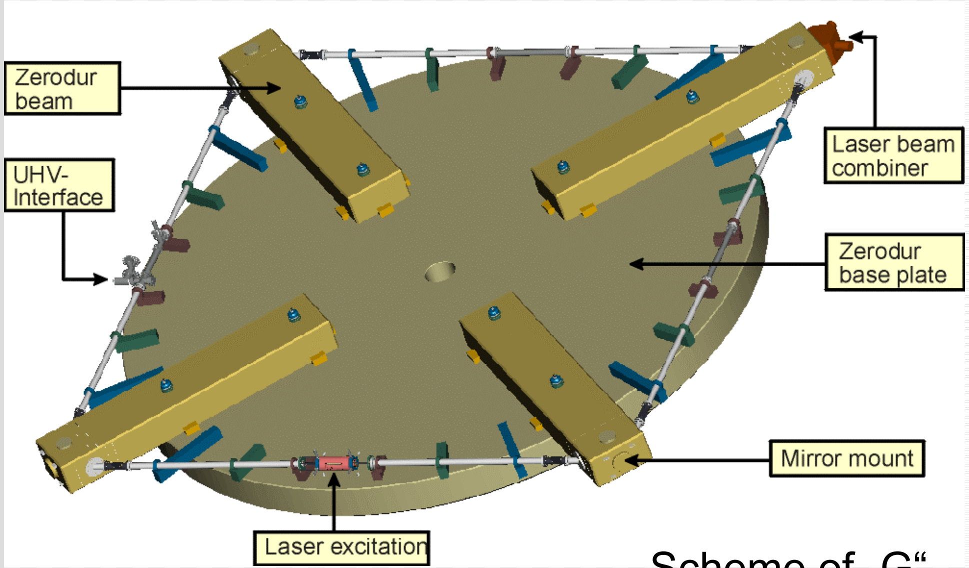
Reasons for Variations of the Sagnac Frequency

- Variations of Ω
  - Changes in the angular velocity of the Earth rotation
  - Changes in the position of the Earth rotation axis (polar motion)
  - Local rotations
- Variations of **n:**
  - Tilts from solid Earth tides
  - Tilts from ocean and atmospheric loading
  - Locally induced tilts
- Variations of A/P
  - Deformations of the ring laser body due to temperature and pressure changes
- Variations of λ
  - As a result of changing P
  - Changes in the effective refractive index in the laser cavity
  - Tiny cavity leaks

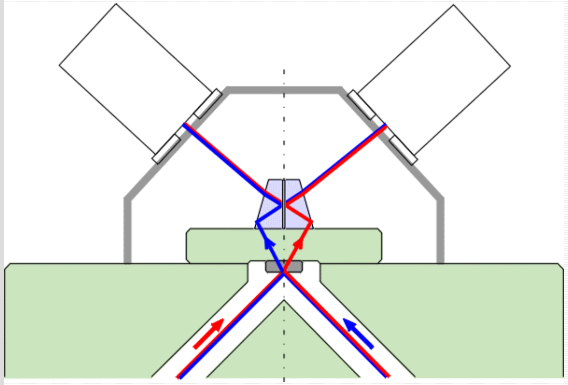
Advantages – Disadvantages

- Advantages:
  - Local sensor representing the inertial reference frame
  - No global network required
  - Direct access to the data
  - Real time availability
  - High temporal resolution (subdaily variations)
  - Open for new applications (seismic waves, free oscillations)
- Disadvantages:
  - Local disturbances (noise, temperature, pressure)
  - Local tilt effects
  - Observation of many local parameters required for data reduction
  - Absolute orientation not known a priori
  - Systematic effects

Technical Realization of „G“



Scheme of „G“

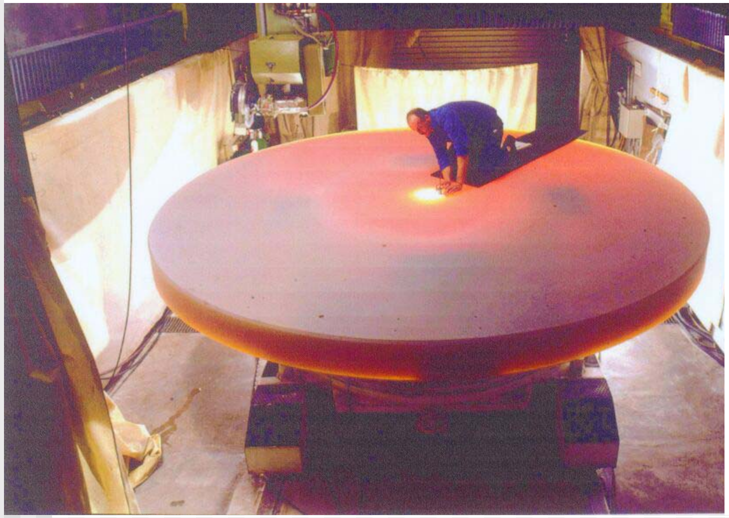


Beam combiner

- Zerodur used as base for the resonator plate: Thermal expansion $<1.4\times10^{-8}$
- Supermirrors with a total loss of 5 ppm
  - providing a cavity length of L=16m
  - inclosing an area of A=16m^2
- Ultrahigh vacuum stability
- HeNe laser operations
- RF-excitation of laser process
- Beam combiner for detection of the Sagnac frequency (348,6Hz)

Construction of „G“

Diameter: 4.30 m
Thickness: 0.25 m
Weight: 10 t
Therm. Expansion Coefficient: < 1.4×10^{-8}



Zerodur base plate manufactured at Schott AG/Mainz

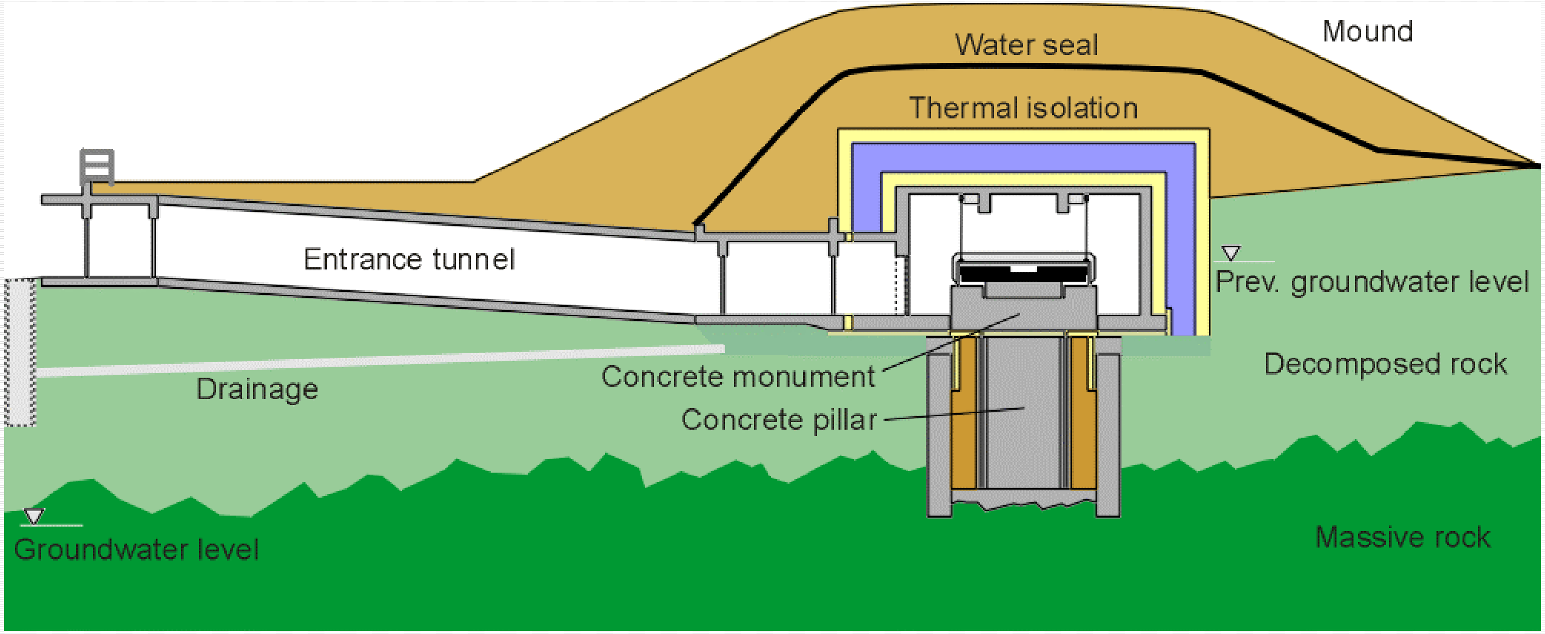
Assembled ring laser ,,G“

Site investigation

- Demand for instrumental stability requires underground installation
- Drilling of 6 boreholes of up to 36 m depth
- Fresh crystalline rock everywhere below 10 m
- Monitoring of groundwater level at 4 sites
- Long term monitoring of tilt and temperature variations at depths up to 17 m

Underground Laboratory

- Thermal isolation optimized by finite element calculations: 2 m thick styrofoam/clay/styrofoam layers covered by 4 m of soil
- Depth of laboratory limited by groundwater level
- Foundation on massive rock on a 5 m high, massive concrete pillar shielded against subsurface deformations by concrete rings



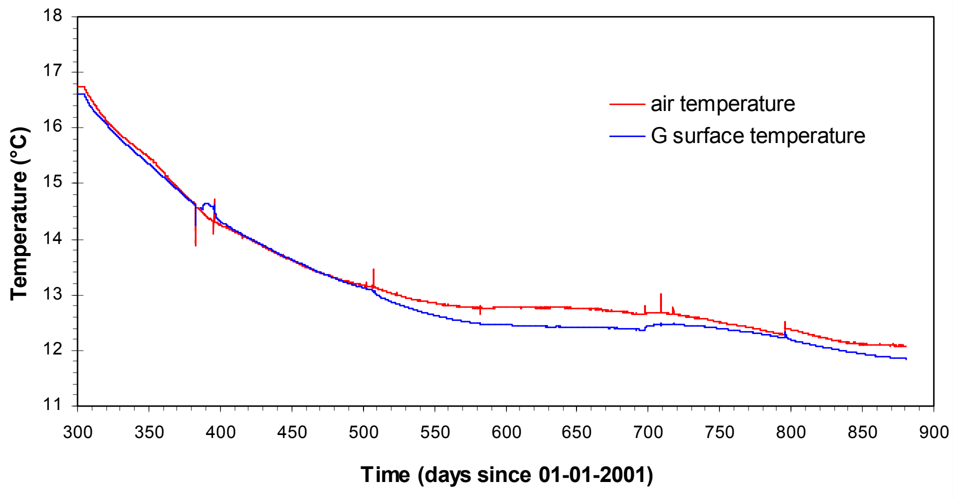
Installation in the Underground Laboratory

Installation of the Zerodur base plate

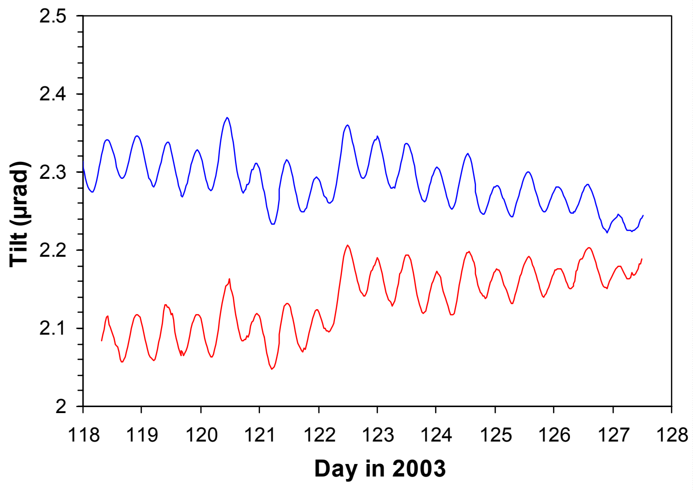
Base plate lowered into the underground laboratory

Thermal and mechanical stability

- T-variations: few mK/day, mainly caused by air pressure variations (adiabatic expansion, compression)
- Acclimatization towards thermal equilibrium takes years
- Local tilts cause orientation changes in the order of some μrad
- Monitoring of orientation by high resolution tiltmeters required

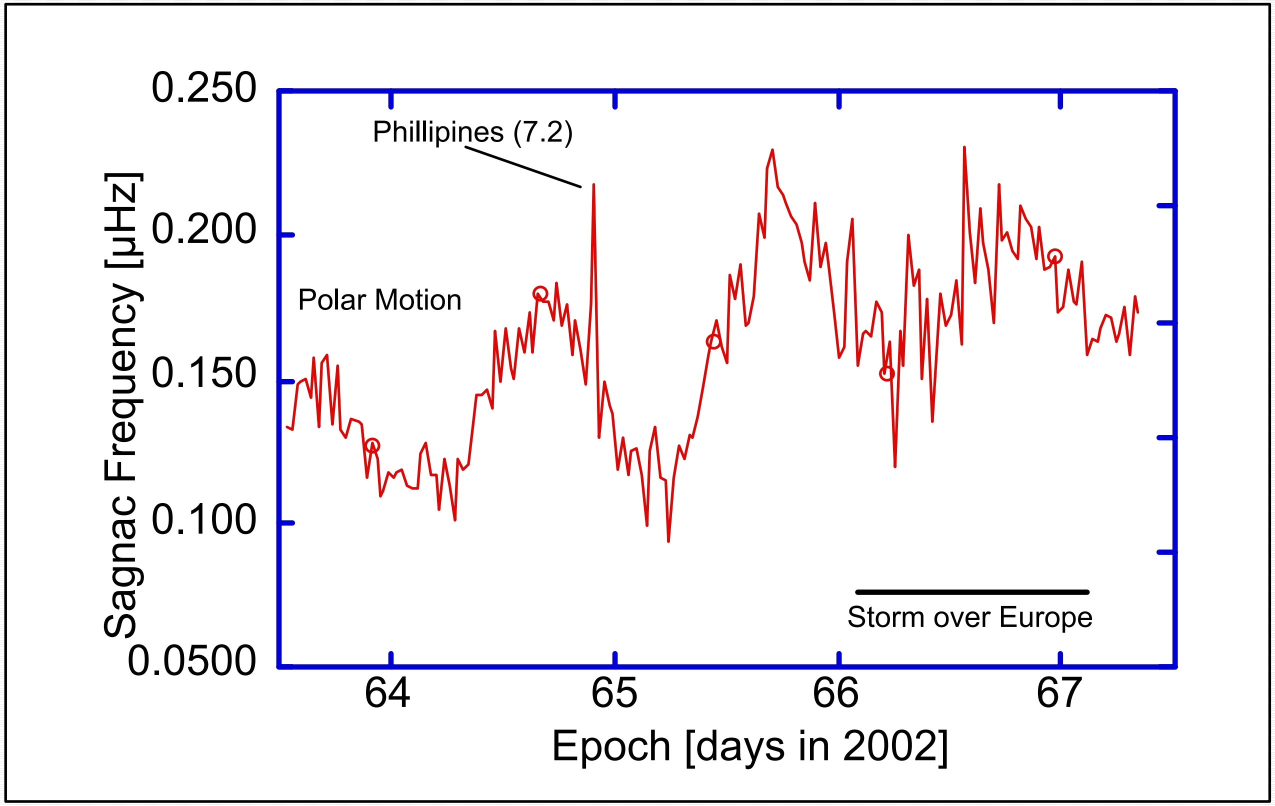


Temperature trend in the underground lab



Graphs of 2 parallel tiltmeters placed on top of „G"

Ring Laser Operation (1)



Ring Laser Operation (2)

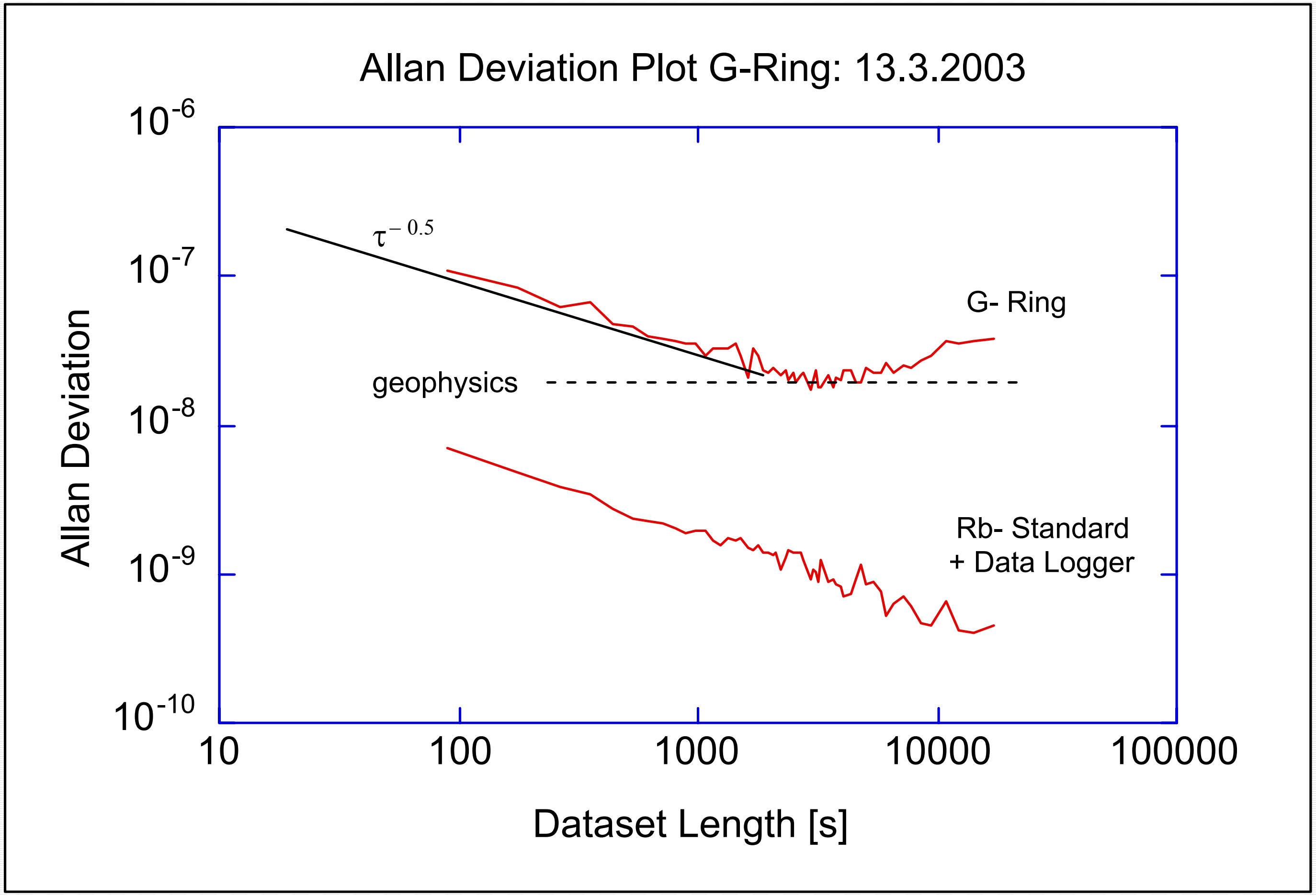
The diagram shows a timeseries of Sagnac frequency variations recorded at the beginning of march in 2002. A constant value of 348.643 Hz has been removed from each data point.

The left part of the plot shows the contribution of diurnal polar motion to the Sagnac frequency and illustrates the resolution of the instruments well.

On the right side of the diagram one can see an enhanced noise level caused by a storm passing over Europe.

The single spike towards the middle of the timeseries was caused by imposed rotations from an magnitude 7.2 earthquake at the Phillipines.

Ring Laser Stability (1)



Ring Laser Stability (2)

Allan deviation plots are characterizing the stability of precise generators. Therefore they are an ideal tool for evaluating the performance of a ring laser for the application in geodesy.

Geophysical signals such as solid Earth tides and diurnal polar motion are setting a lower limit to the obtainable instrumental raw data stability of,,G'', which is indicated by the dashed line in the diagram.

For comparison a Rubidium controlled reference oscillator recorded by the same data logging device is also shown in the plot. Since the stability of the reference generator is much higher than the ring laser this proofs that the data logging device does not affect the Allan Deviation estimates of the ring laser.