High bandwidth ring laser observations in geodesy and geophysics

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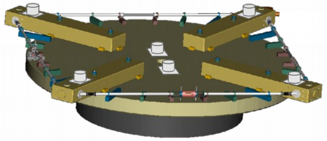
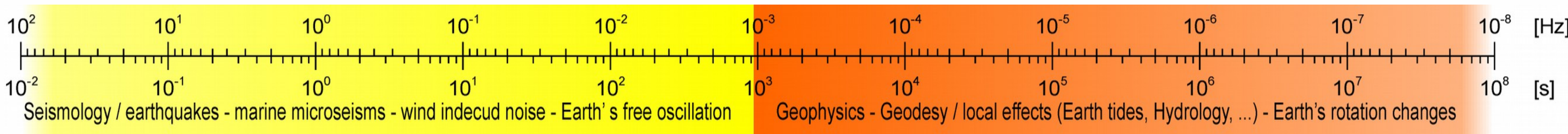
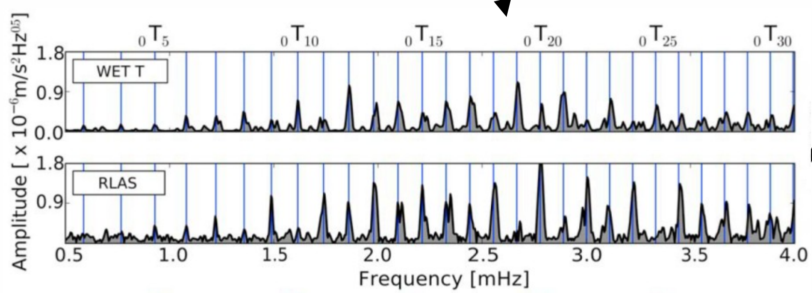
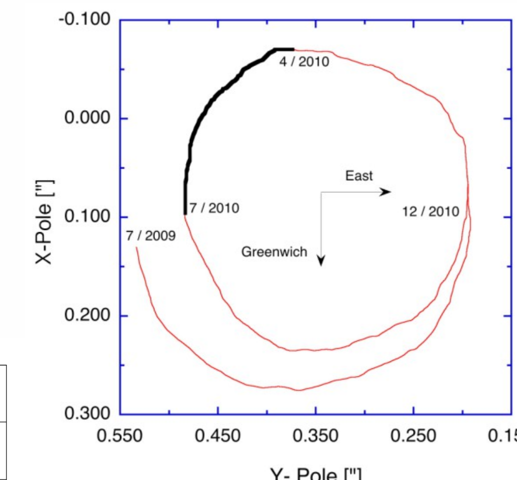


High bandwidth observation

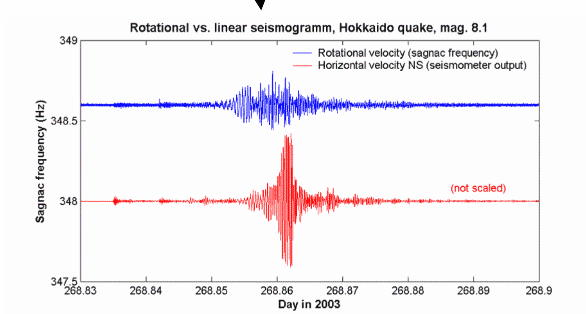




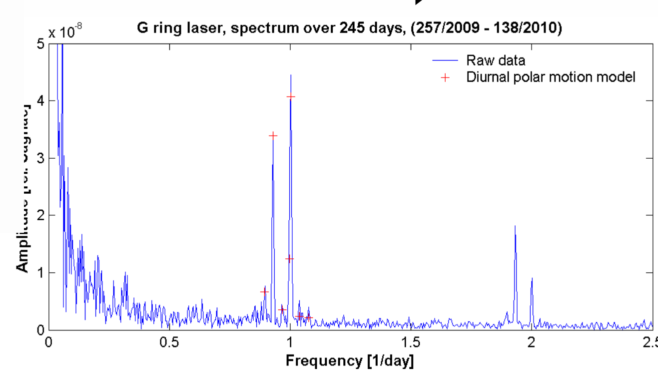
Earth free oscillation ...



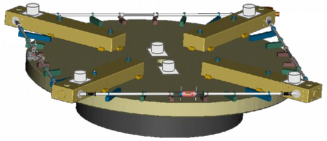
Pol wandering ...



Earth quakes ...



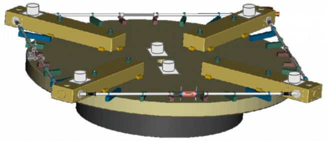
Diurnal polar motion ...



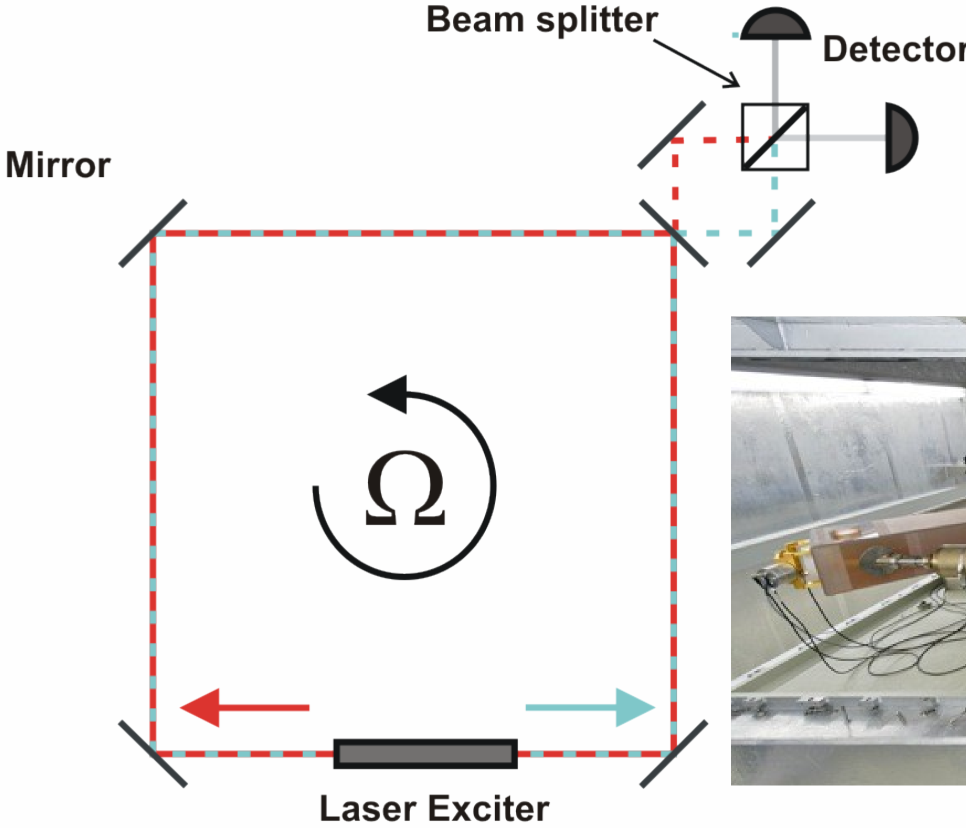
Introduction – Geodetic Observatory Wettzell

- VLBI
- SRL
- Cesium clocks
- H-Maser
- SG (Gravimeter)
- Seismometer
- Tiltmeter
- Weather station
- GNSS
- **Ring laser**

➔ Collocation of several instruments and techniques

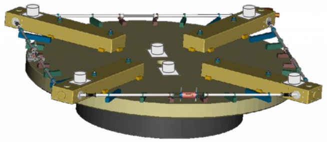


Introduction – ring laser - interferometer

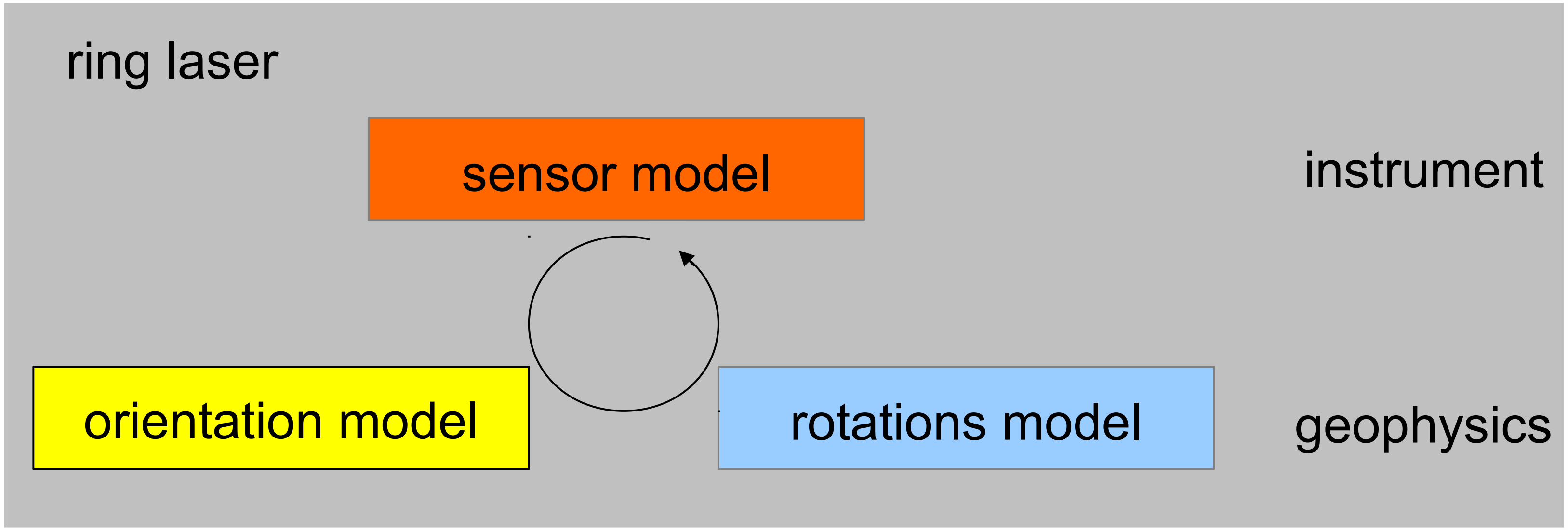


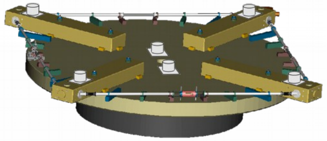
- Light is reference
- No masses → no transfer function
- Insensitive to translations

→ Observation occurs in inertial frame



Introduction – ring laser





Introduction

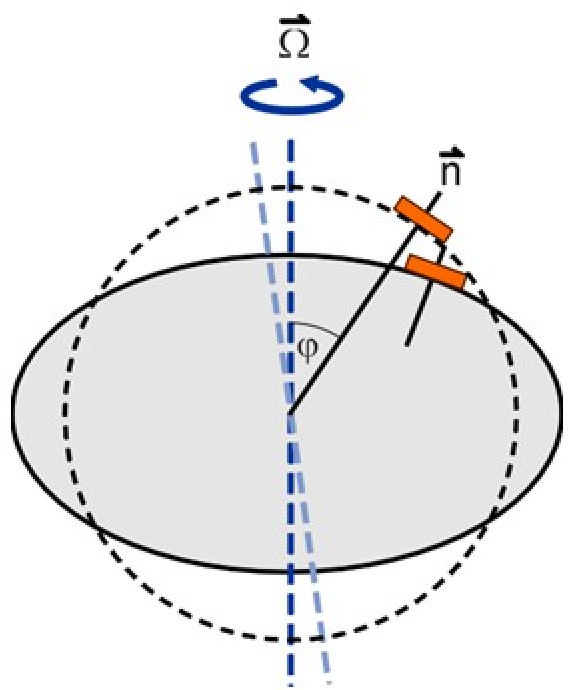
orientation of the rotation axis

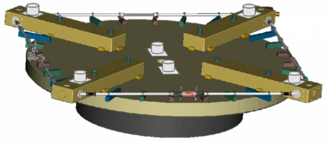
platform orientation

Sagnac formula: $$\Delta f = \frac{4A}{\lambda L}\, \vec{n} \cdot \vec{\Omega} + \Delta f_0 + \Delta f_{bs}$$

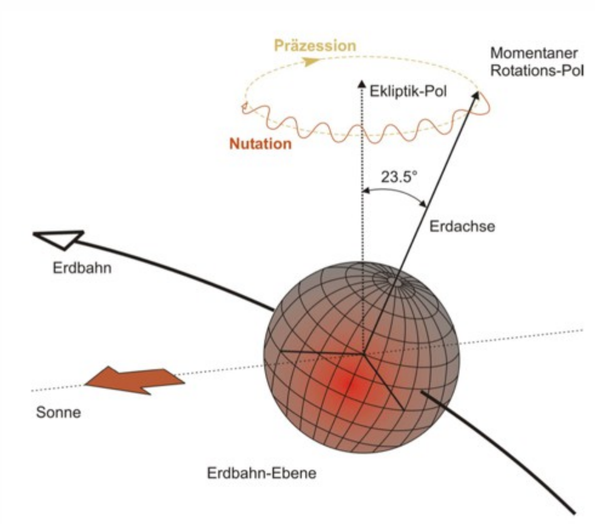
norm of rotation

$10^{-9}\Omega_E \approx$ 0.07 picorad/s



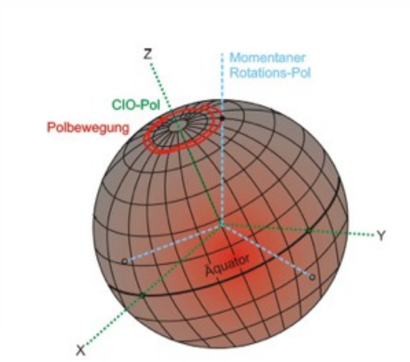


Earth rotation

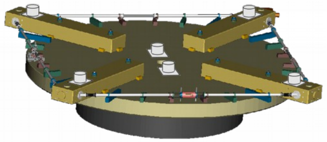


a) the rotation rate of the Earth is not constant. Deceleration by dissipation and variation by momentum exchange. Free oscillations excited by ocean, atmosphere.

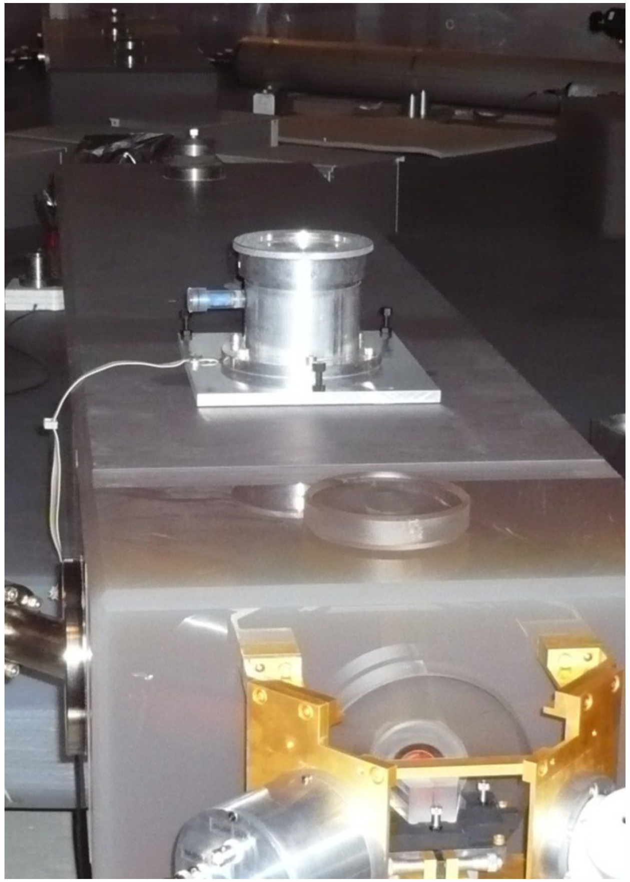
b) gravitational attraction of sun and moon on a near spherical object give rise to precession and nutation.



c) mass redistribution on Earth and the fact that the figure axis and the axis of Inertia are not coinciding, give rise to polar motion.



Local tilt correction



Plattform-Tiltmeter Typ Lippmann

- Tiltmeter: Attraction + Deformation
- Ring laser: only Deformation

Tiltmeter:

$b_h = (1 + k - h) * \delta V / r\, \delta\psi$

previous attraction correction:

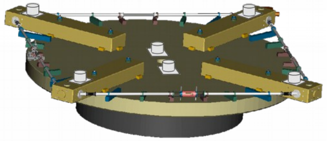
$b_{h(attr)} = (1 + k) * \ldots$

$b_{h(def)} = -h * \ldots$

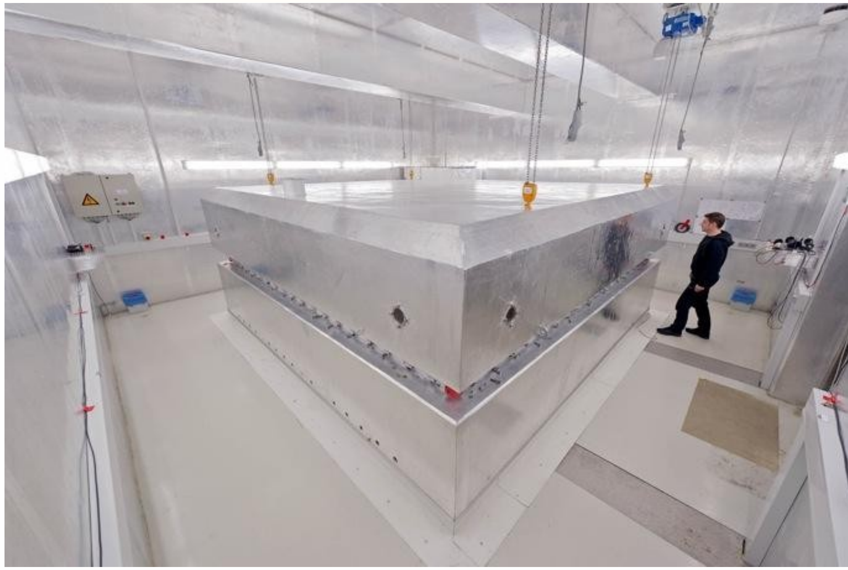
Consideration of latitude variation (Wei Tian)

$b_{h(attr)} = (1 + k - l) * \ldots$

$b_{h(def)} = (-h + l) * \ldots$



Long term stability



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

= const. (4A=const.)
pressure regulation

prohibit changes caused by air pressure and temperature

f_{nr1} = const
digital intensity control

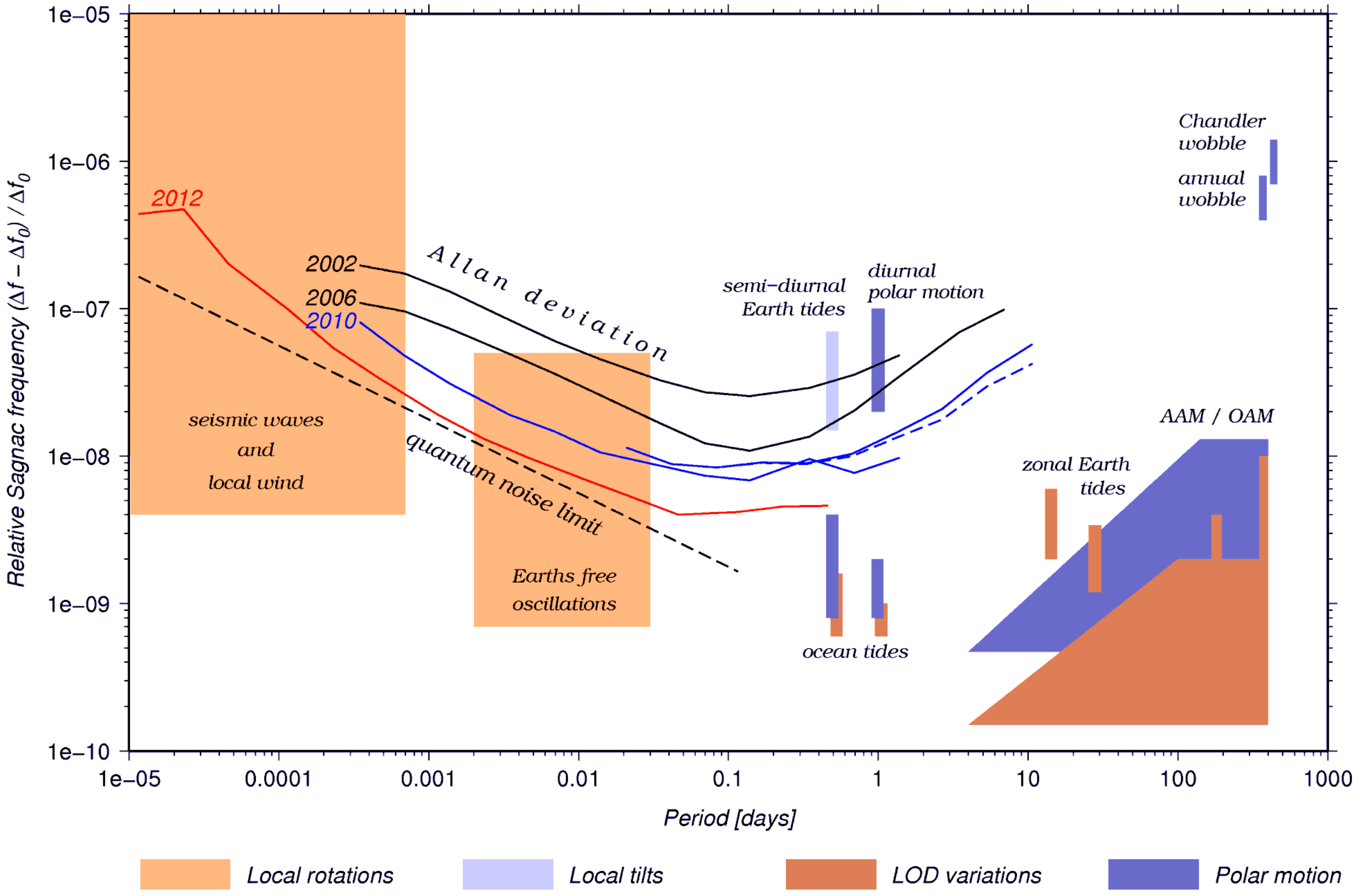
prohibit drift in Sagnac-frequency

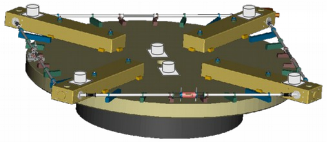
$f_{nr2} \neq$ const
Backscatter

→ Actual Stability ~ 10^{-8}–10^{-9}

→ intended Stability in scale factor 10^{-10}

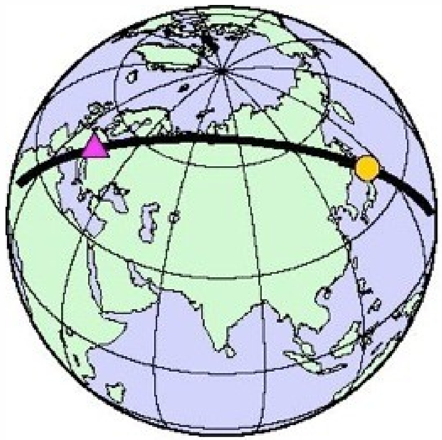
Stability – observable signals



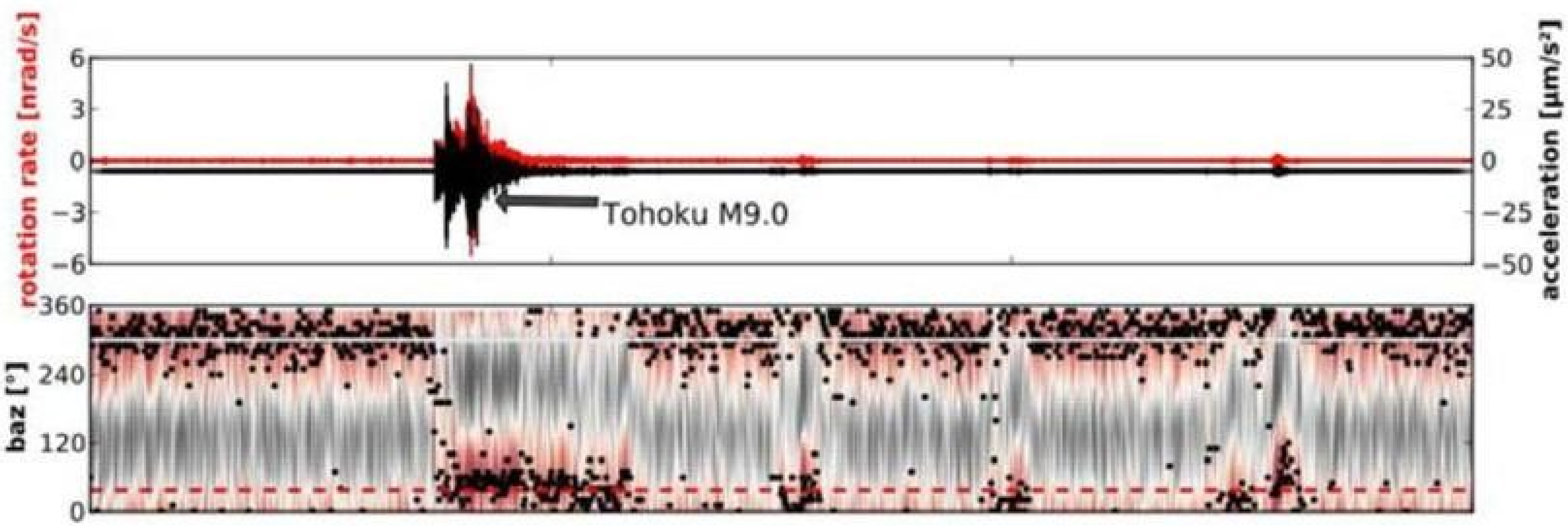


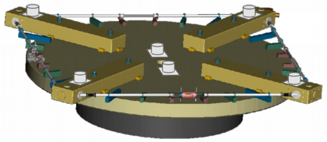
Noise investigations

In order to get the transversal acceleration, one has to rotate the signal of the two horizontal seismometer components to the correct back azimuth.

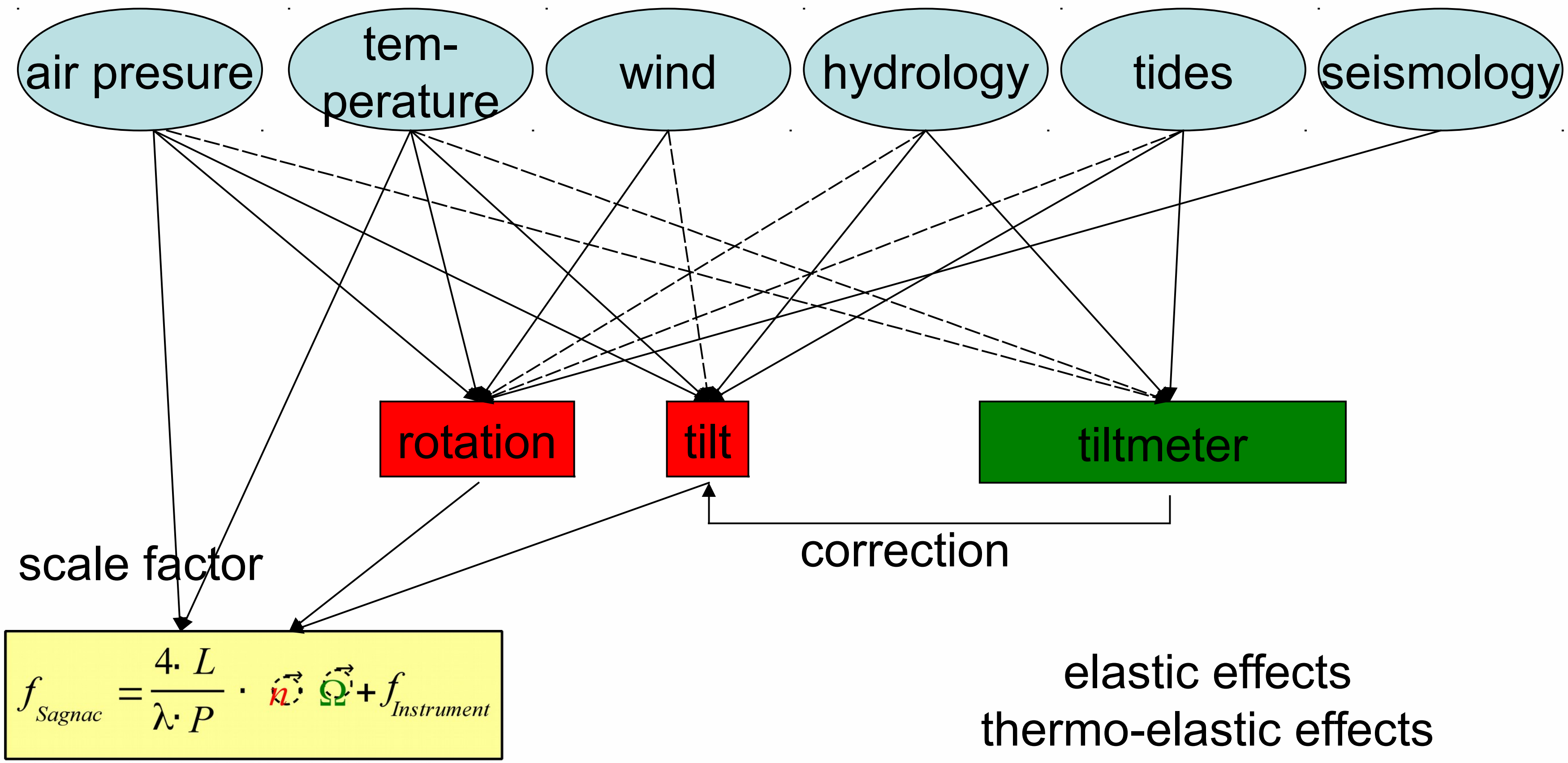


$$\varepsilon = a\,x \cos\varphi + a\,y \sin\varphi$$

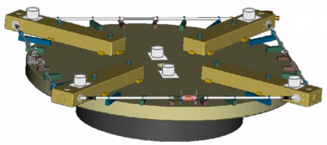




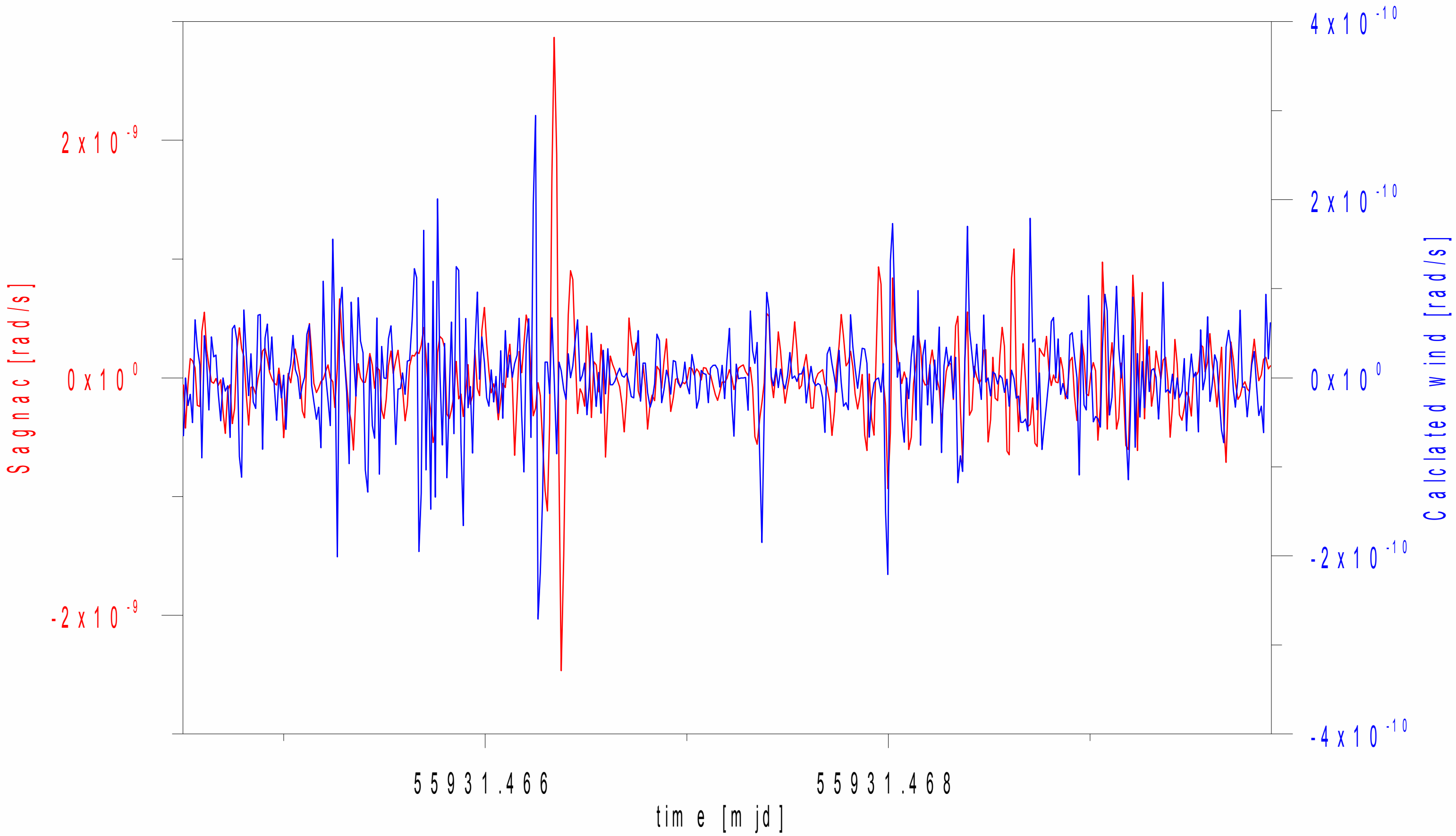
Local (disturbing) effects

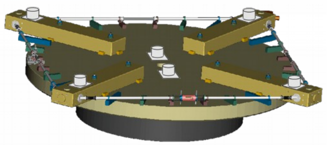


elastic effects
thermo-elastic effects
cavity effect
geological effects
tilt-strain-coupling

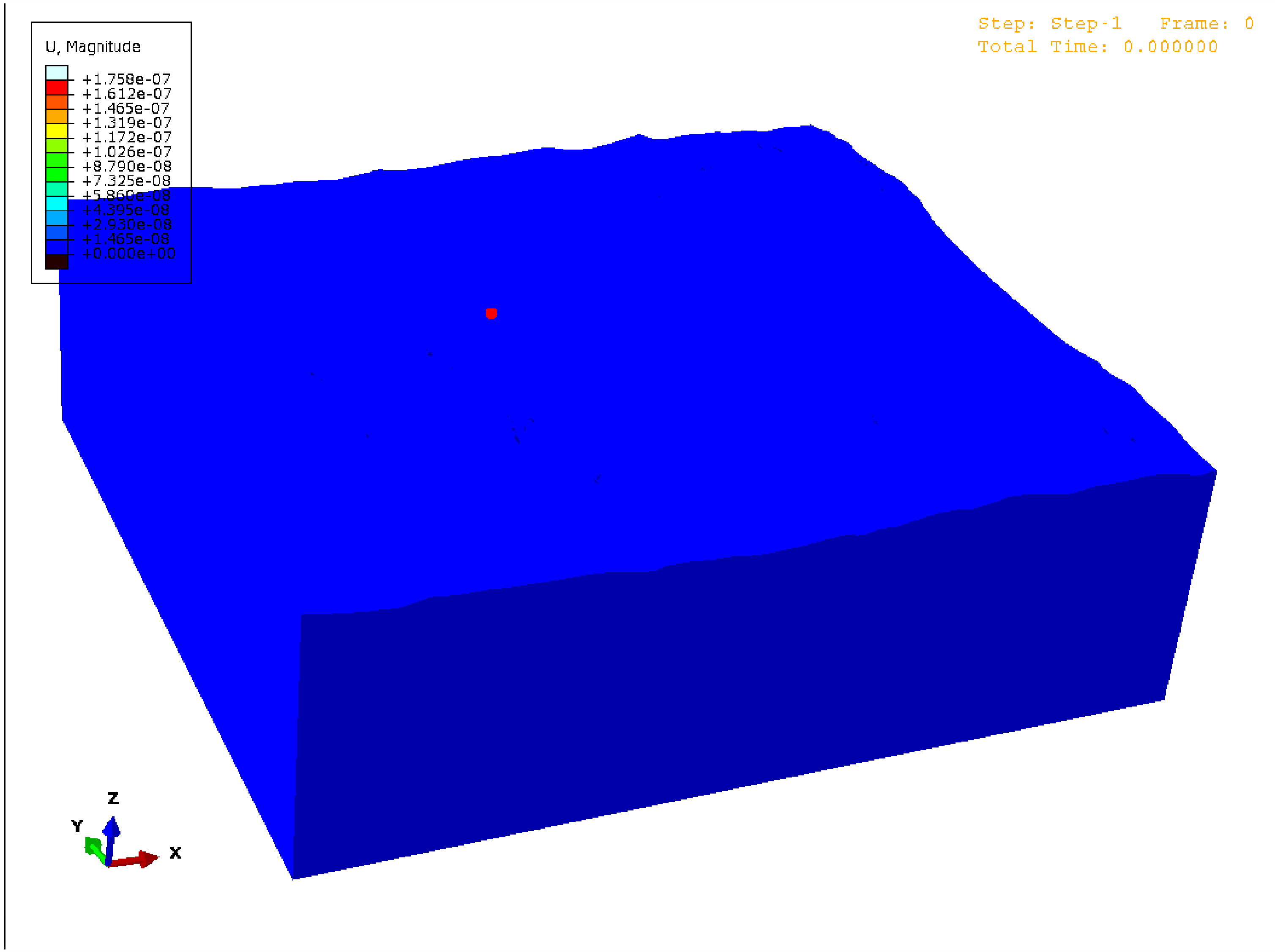


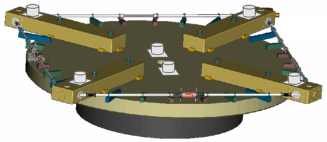
Observed – computed wind effects



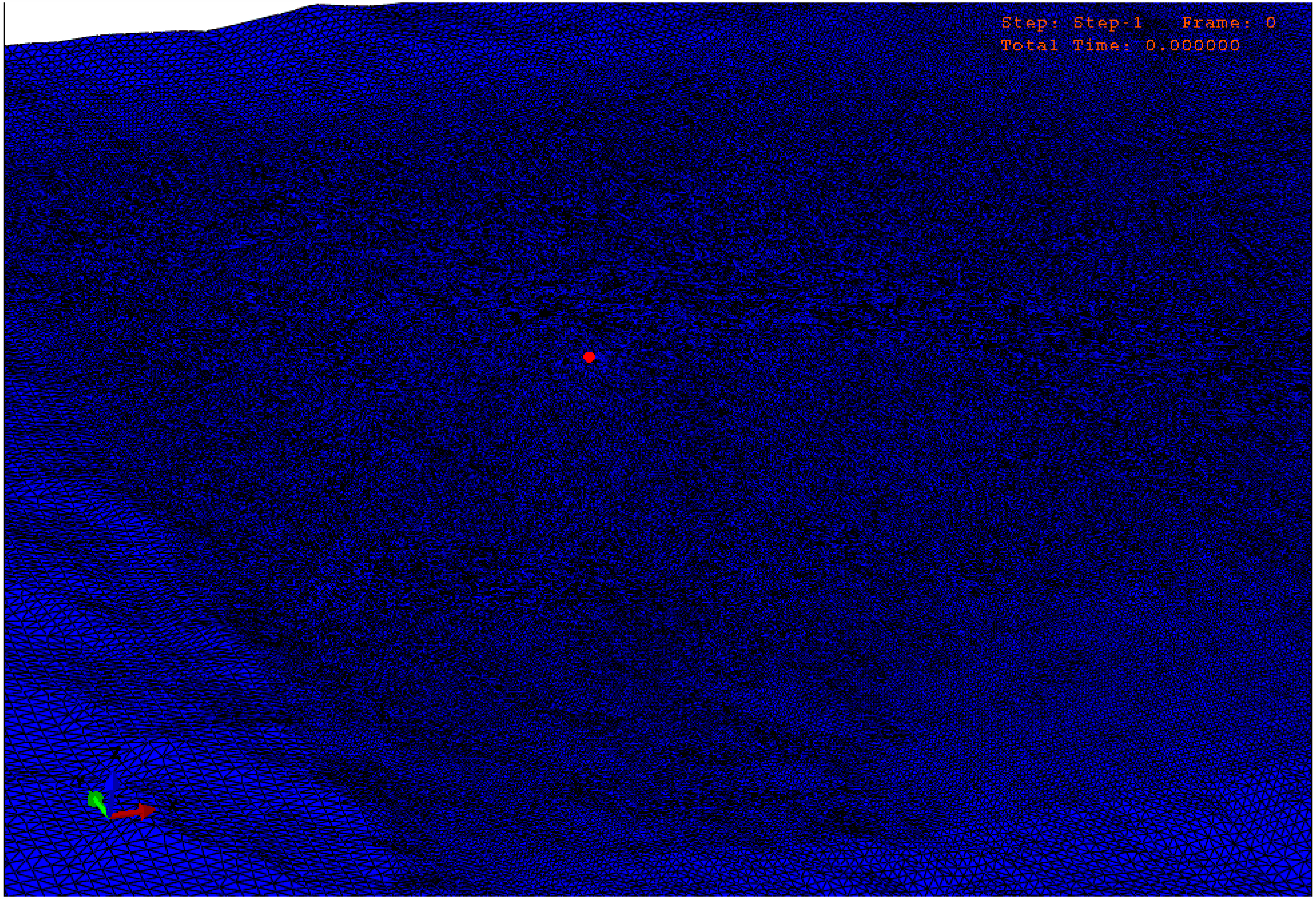


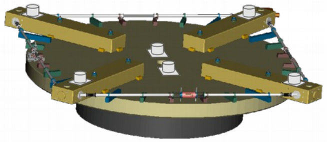
Local wind effects





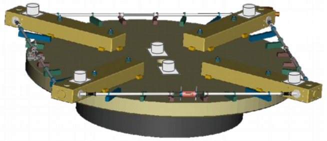
Local wind effects



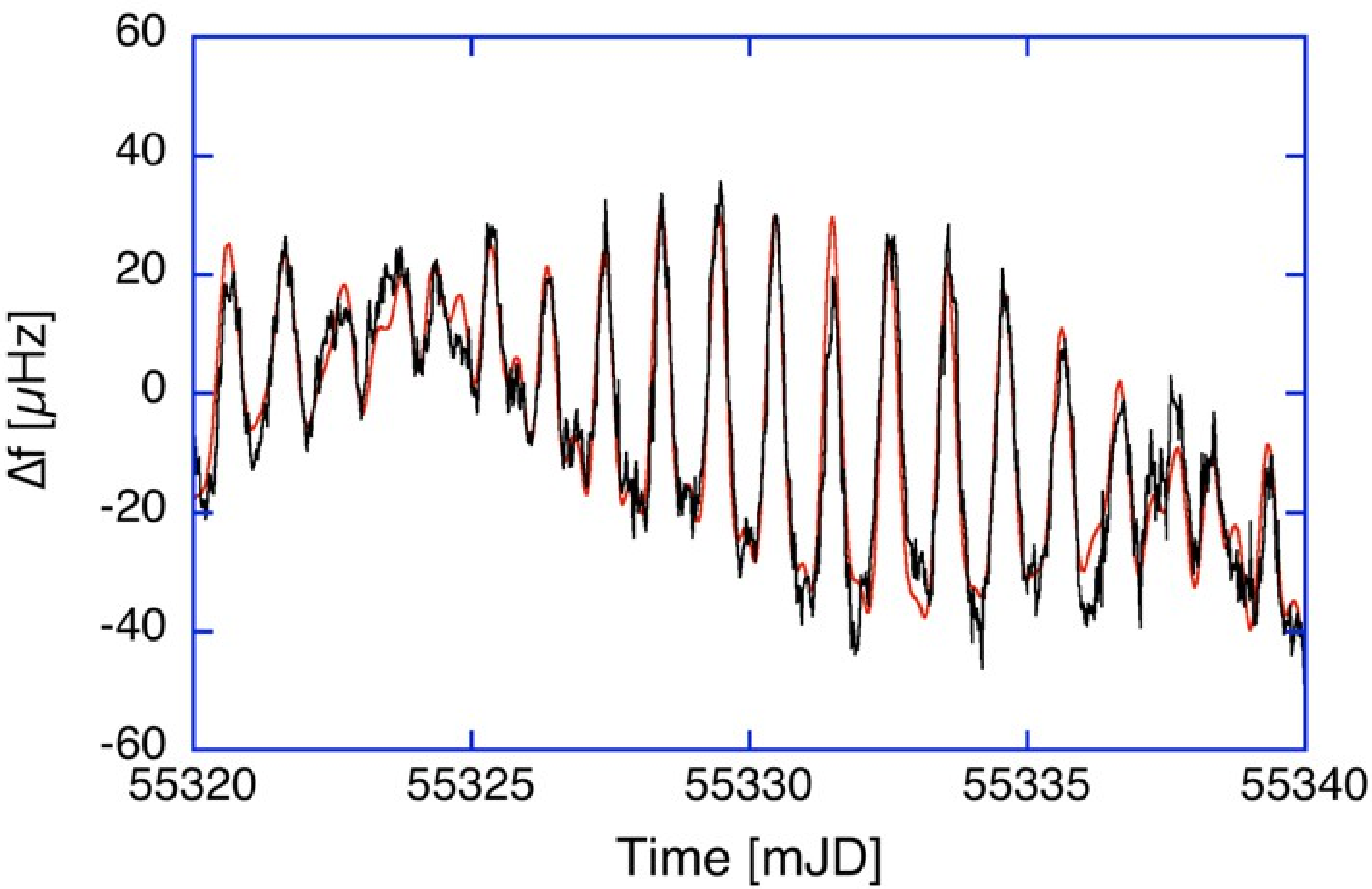


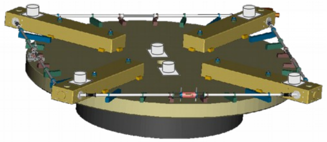
Local wind effects

- wind acts very locally (~250 m)
- influencing factors:
  - cultivation
  - topography
  - wind field
  - additional deformation (moving trees)
- soil acts as ‚bad' low pass

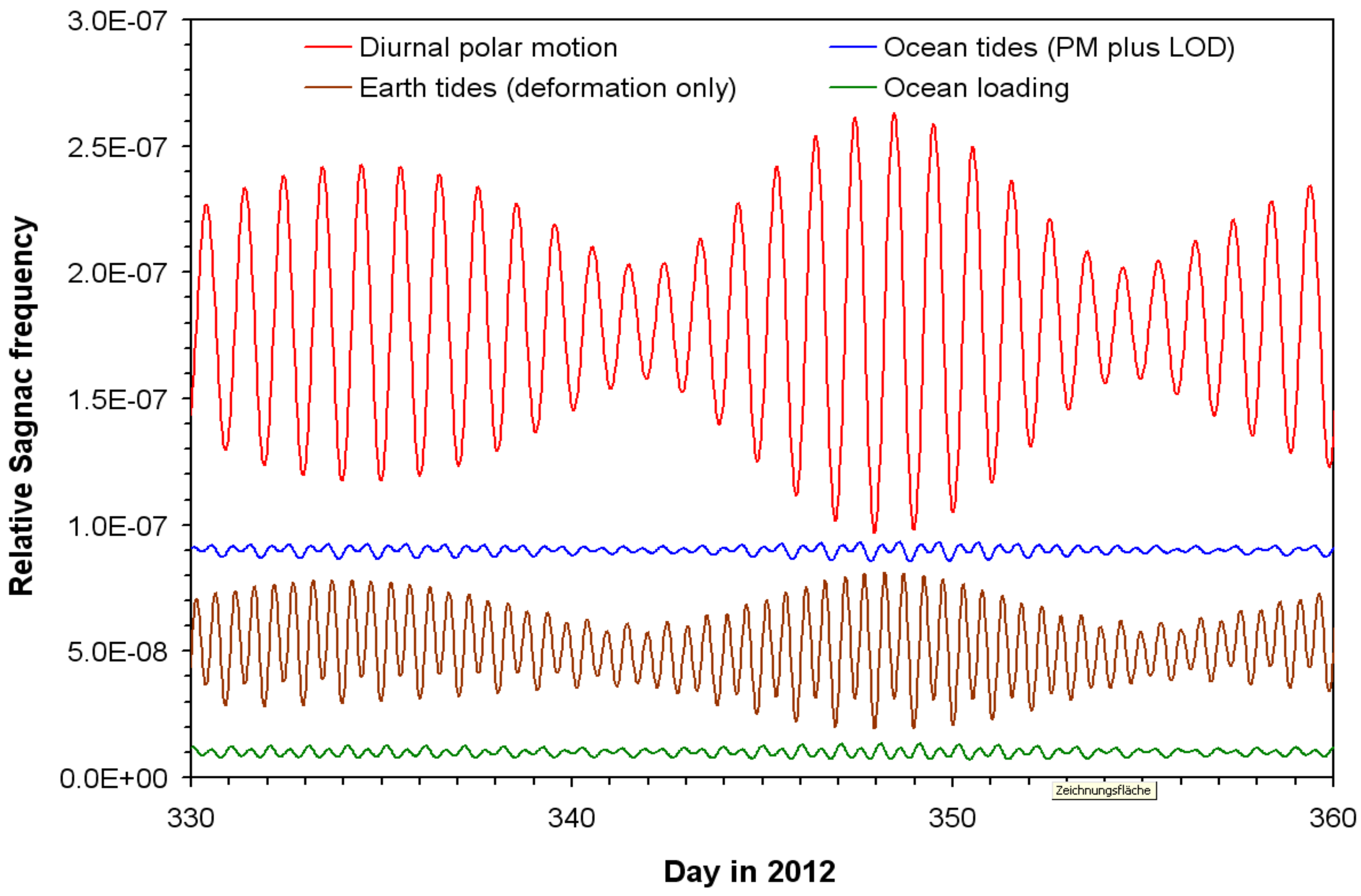


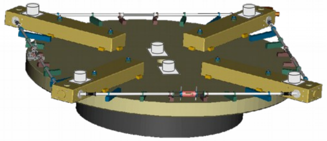
Signals in ring laser observations



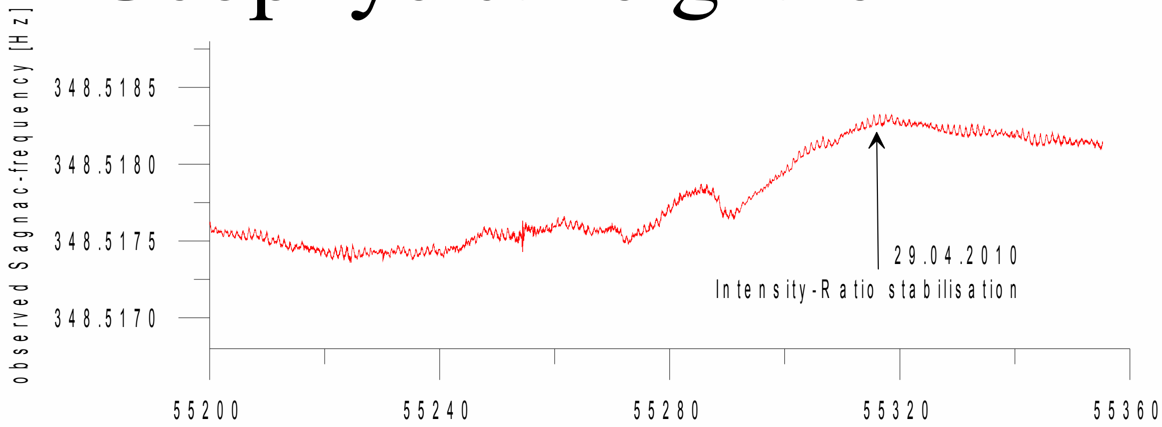


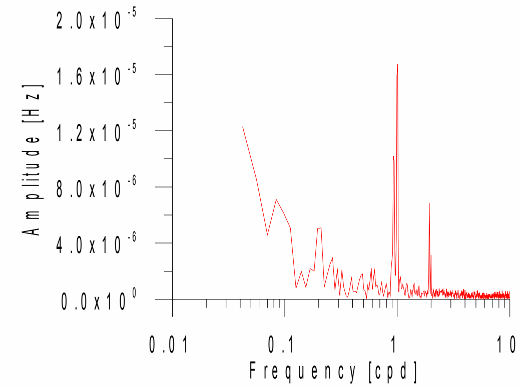
Effect and used models (IERS2003)

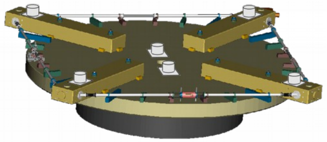




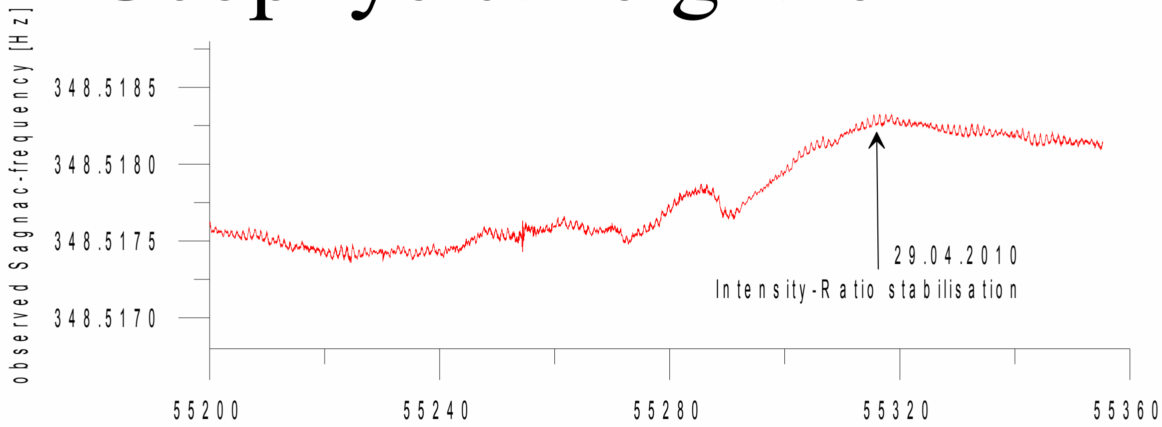
Geophysical signals

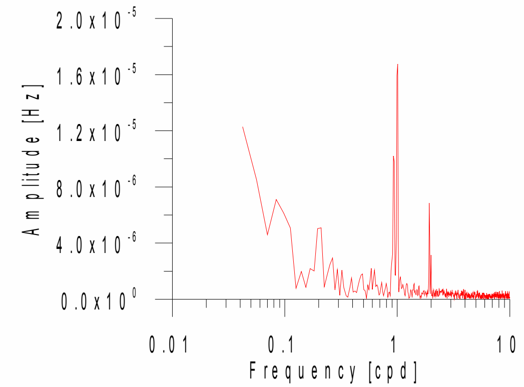


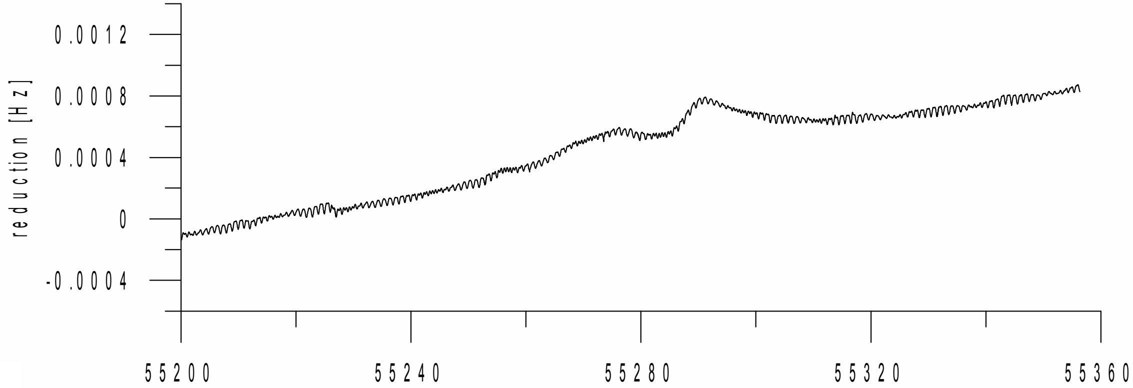


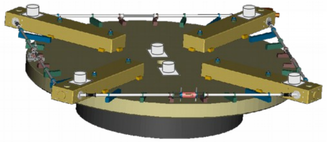


Geophysical signals









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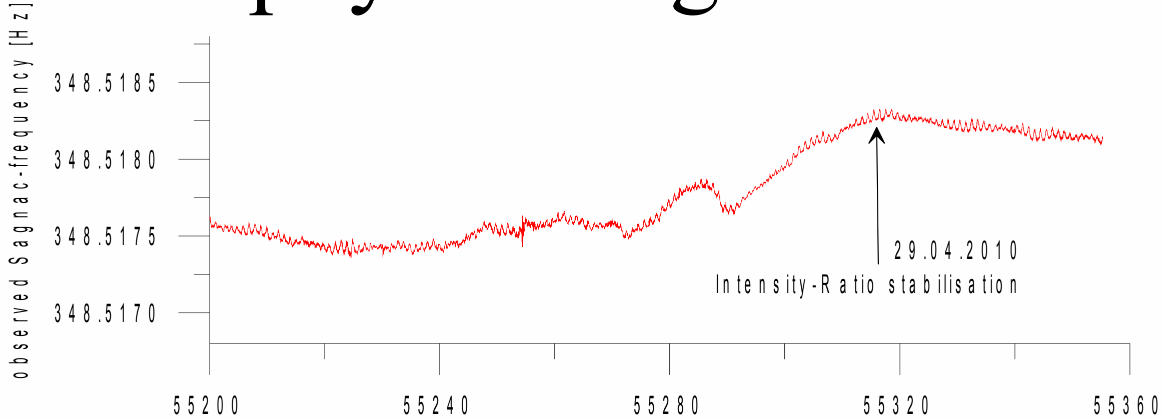
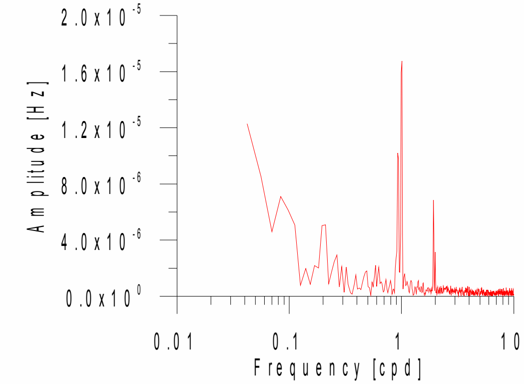
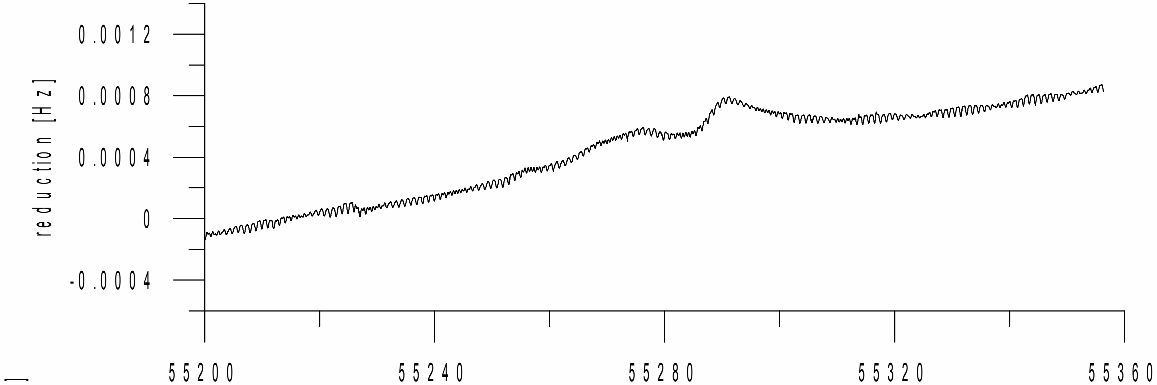
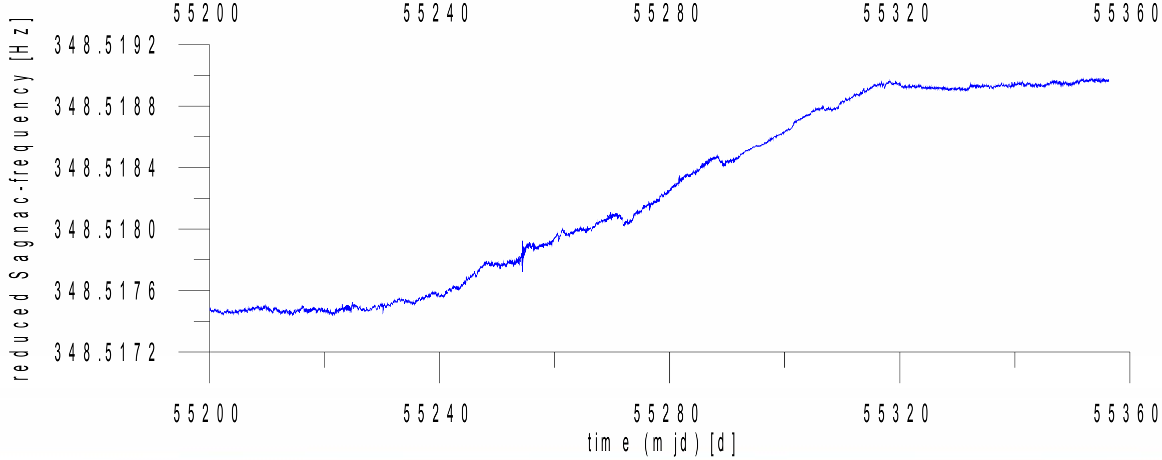
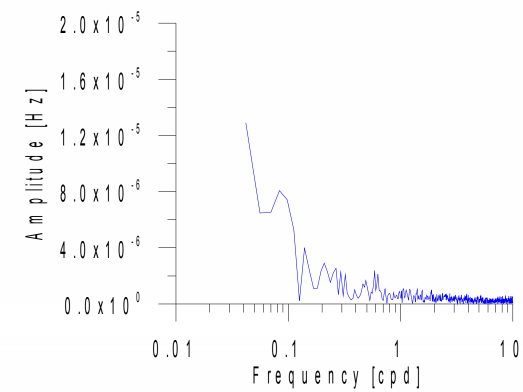


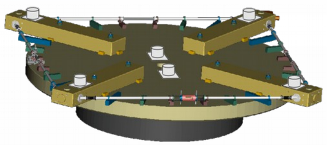




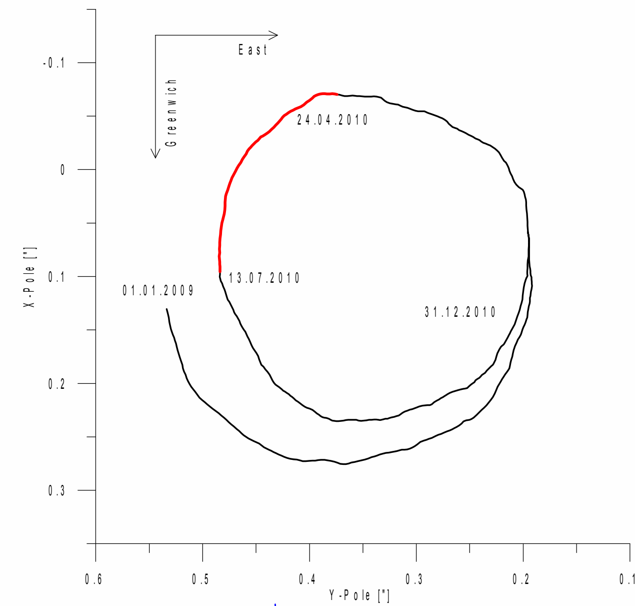


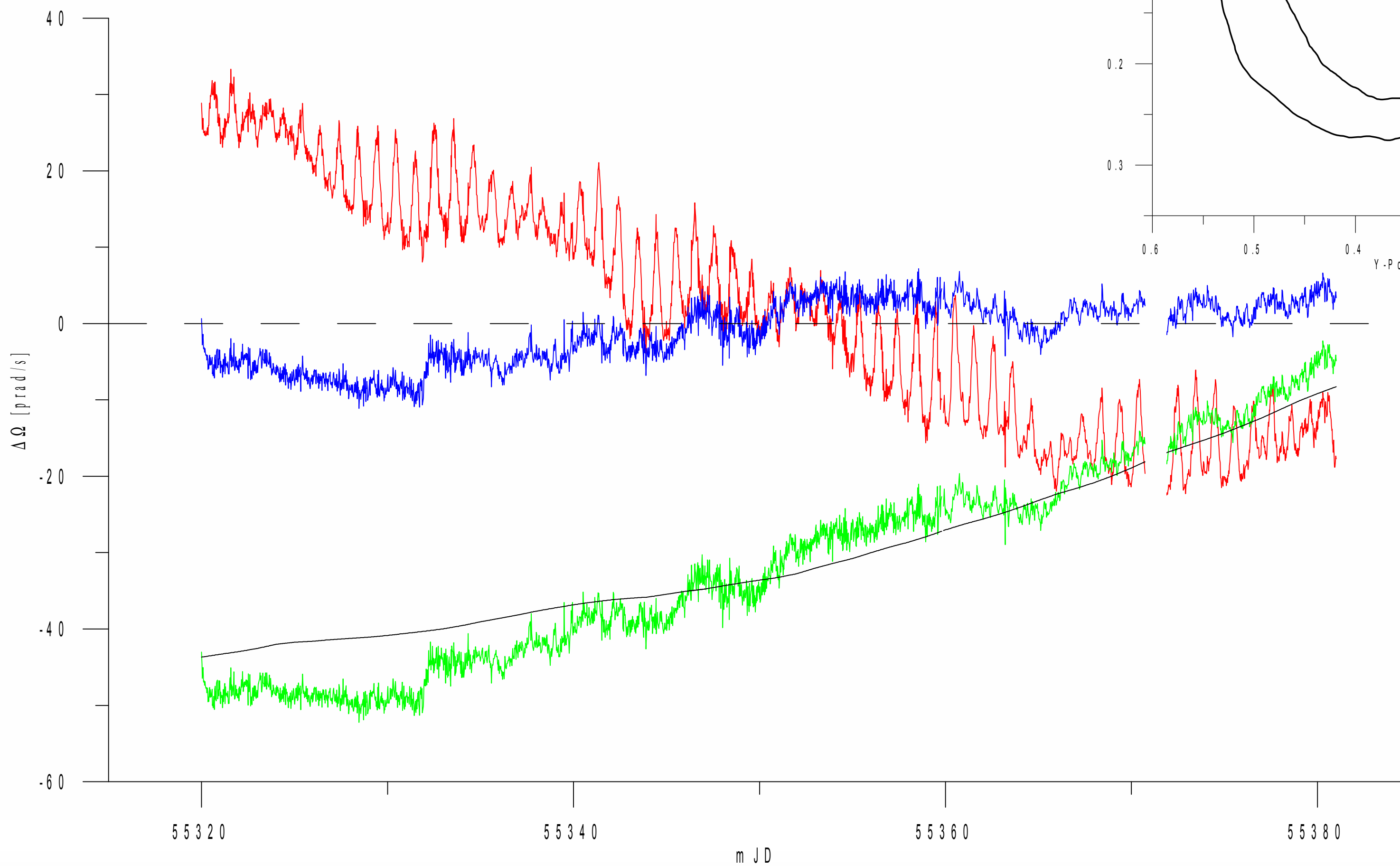


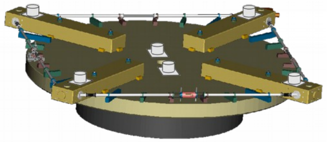
- High bandwidth observations
- Introduction
- Earth rotation
- Local tilt effect
- Long term stability
- Stability
- Noise investigations
- Local wind effect
- **Geophysical signals**
- Backscatter effects
- Conclusion
- Outlook



Chandler/Annual Wobble







Backscatter effect

Backscatter coupling between the clockwise and counterclockwise beams is usually the largest source of systematic error.

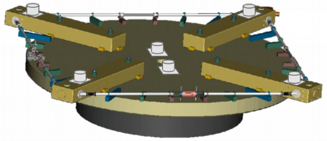
$$\Delta f_s \approx \frac{1}{2} f_s m_1 m_2 \cos\phi$$

where m 1 and m 2 are the fractional beam modulations, and φ is the phase angle between them.

For given mirror quality, cavity of linear size m 1 and m 2 scale approximately as $L^{-2.5}$ for L .

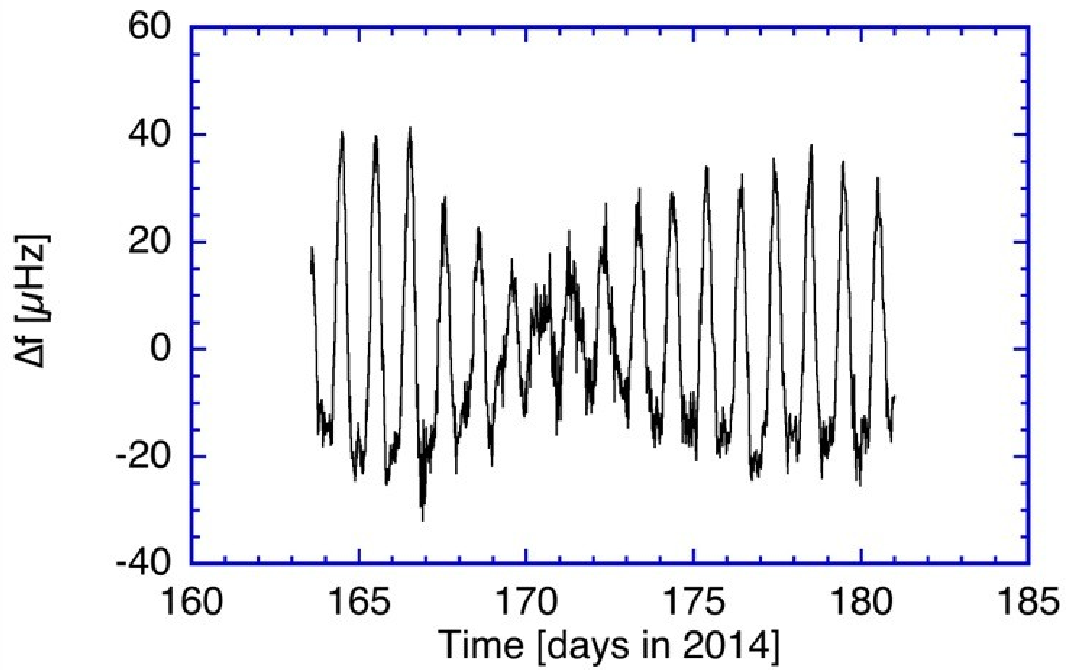
$\dfrac{\Delta f_s}{f_s}$ scales approximately as L^{-5} !!!

It is extremely important to maximize the size of the laser.

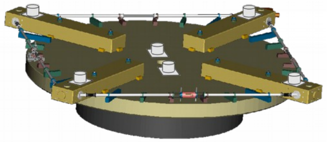


Backscatter effect

- Currently under investigation
- (Obvious first step) Select best available mirrors
- Most promising approach then appears to be a calculated correction based on modulation of the clockwise and counterclockwise beams.

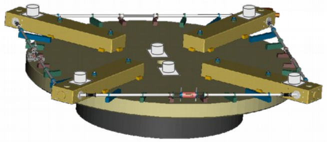


Can we obtain the necessary quantities m_1 and m_2 well enough?



Conclusion

- If the sensitivity and stability of the ring laser is within the needed range for Earth rotation observation, seismology wins anyway …
- Several signals of the ring laser identified (polar motion, earthquakes, free oscillations, Chandler wobble, ambient noise, etc)
- wind / meteorological effects have no consequence for Earth rotation, but might affect long-period seismology



Outlook

- data analysis (models, …)
- revision of the signal preparation
- increase long term stability (instrumental effects) → frequency comb
  - mirrors
  - Backscatter
  - Laser
  - Piezo actuator (first tests successful)
  - …
- new concepts for future ring lasers in geophysical applications → ROMY