The **ROMY** project: **RO**tational ground **M**otions: a new observable for seismolog**Y**



Werner Bauer, Felix Bernauer¹, Moritz Bernauer¹, Bryant Chow¹, Stefanie Donner¹, Sven Egdorf, Celine Hadziioannou¹, Heiner Igel¹, Chin-Jen Lin¹, Andreas Fichtner², Andre Gebauer^{2,1}, Frederic Guattari⁷, Fabian Lindner¹, Maria-Fernanda Nader-Nieto¹, Michael Reinwald¹, Johannes Salvermoser¹, Karl Ulrich Schreiber², Andrea Simonelli^{6,1}, Toshiro Tanimoto⁵, Frank Vernon⁴, Joachim Wassermann¹, and others

ROMY funded

¹ LMU Munich, Germany
 ² TU Munich, Germany
 ³ ETH Zurich, Switzerland

⁴ UCSD, La Jolla, CA
⁵ UC Santa Barbara, CA
⁶University of Pisa, Italy
⁷iXBlue, St. Germain-en-Laye



ROMY - facts

- Funded by the European Research Council
- > Duration (5+1) years, 2014-2020
- 2.5 million Euro (plus support for ring laser construction by LMU)
- ➤ 12 postdoctocal years
- > Approx. 1 million for instruments, hardware
 - ➢ Ring laser
 - Portable sensors
 - Seismic arrry
 - Field studies



Current ROMY activities

[Instrumentation]

- ring lasers the ROMY ring (talk Schreiber)
- array rotations vs. direct rotations (ROMY)
- fibre-optic gyros (talk, poster Bernauer, Guattari)
- ocean bottom seismometry (paper Lindner)

[Observations]

- ring laser event data base (poster Salvermoser, Chow)
- understanding ocean-generated seismic noise (talk Tanimoto, poster Hadziioannou)
- array-derived rotation and strain (talk Lin)

[Theory]

- earthquake source inversion (poster Donner)
- wavefield separation (poster Nakata)
- tomography with rotations

[Outlook]

Multi-component ring laser for geodesy and seismology

High resolution >=3-component observations of rotational motions for Earth's free oscillations, ocean generated seismic signals, Earth rotation, space geodesy



The ROMY ring – the first 4C ring laser



ROMY ring - Construction



Construction - side view





Expected sensitivity



Sagnac frequencies:

RL-horitzontal: 593Hz RL-S1 (az 60° clockwise, dip 70.5°): 448Hz RL-S2 (az 180° clockwise, dip 70.5°): 302Hz RL-S3 (az 300° clockwise, dip 70.5°): 448Hz

Sensitivity: 0.02-0.05 prad/s

3D – 3C Array Observations



Event Data Base (G-Ring + ROMY)



Observations – Earth's free oscillations

M9.1. Tohoku-Oki earthquake March 11, 2011





Nader-Nieto et al., 2015

Rotations and ocean bottom observations - the experiment



Experiment site

OBS System

Fiber-optic gyro

Rotations and ocean bottom observations - data



14

Theory – Earthquake Model Parameters

Finite Source

_		¢	>	

- Rupture velocity
- > Rise time
- Static slip

Point Source



- Source location
- Moment tensor components

Theory – Point source inversion



Information gain

Donner et al., GJI, submitted

Tomographic inverse problem



Let s define a new observable...

$$\boldsymbol{\beta}_{a}(\mathbf{x}^{r}) = \frac{\|\mathbf{V}(\mathbf{x}^{r})\|_{2}}{\|\boldsymbol{\omega}(\mathbf{x}^{r})\|_{2}}$$

... and call it **apparent shear velocity** (the same principle works with translations and strain) ...

... and calculate sensitivity kernels ...



ROMY Outlook

- ROMY construction finished August 2016
- ROMY 4 ring laser components operational ... sometime after
- Realtime data aquisition and display (translations, direct rotations, array-derived rotation, strain)
- Cross-correlation of rotational motions (G-Ring ROMY)
- Analysis of free oscillations, ocean-generated noise, earthquakes etc etc
- Prototype Blueseis September 2016
- Labtests, field tests (volcano, near field, active seismology, etc)
- OBS prototype with 6C -> ocean noise model
- Blueseis pool of sensors -> extensive field studies

Papers, more info on www.romy-erc-eu



BlueSeis-3A

Broaband & High-Grade 3-component Rotational Seismometer for land applications

XBlue offers now to geosciences the possibility to explore rotational ground motion. Recognized throughout the industry for its mastery of Fiber Optic Gyroscope (FOG), the IXBlue group stands as a global leader in several high-grade applications such as inertial navigation. hydrography and satellite gyroscopes. Based on its 30 years' unchallenged expertise, IXBlue revolutionizes geosciences by offering a brand-new product that seismology has always been looking for. BlueSeis-34 is today the best and most reliable answer to the rotational seismometer need. "axis, broadband low-noise, high dynamic range and flat passband solution with "geosciences-ready" interfaces including digitizer and time stamping.

BENEFITS

FEATURES • 3 Interferometric Fiber Optical Gyroscope (I-FOG) for

High dynamic range

Field-proven technology

low self-noise and broadband measurement

DC signal for absolute rotation measurement

· Embedded digitizer and GNSS time stamping

- Rotation as a new observable in seismology!
- Easy to deploy: no calibration, no tilt range limitation,

Rotational Seismometer

- insensitive to enviromental conditions • Heading provided by the system
- Heading provided by the system
 2-in-1: "weak motion" low-noise + "strong motion" dynamic
- Plug and play interfaces

 ${\sf APPLICATIONS} \bullet {\sf Seismic tomography} \bullet {\sf Volcanology} \bullet {\sf Earthquake physics} \bullet {\sf Geophysical exploration}$



