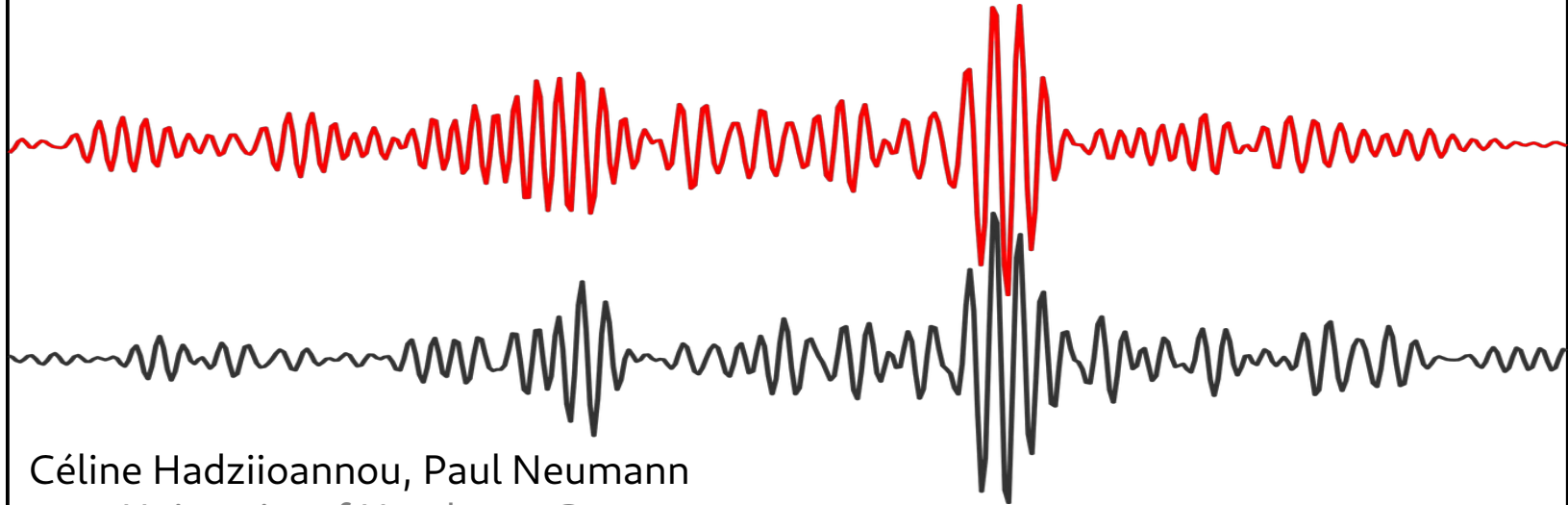


Ambient seismic noise interferometry using rotational ground motion



Céline Hadziioannou, Paul Neumann
University of Hamburg, Germany



Joachim Wassermann, Heiner Igel
Ludwig-Maximilians-University Munich, Germany

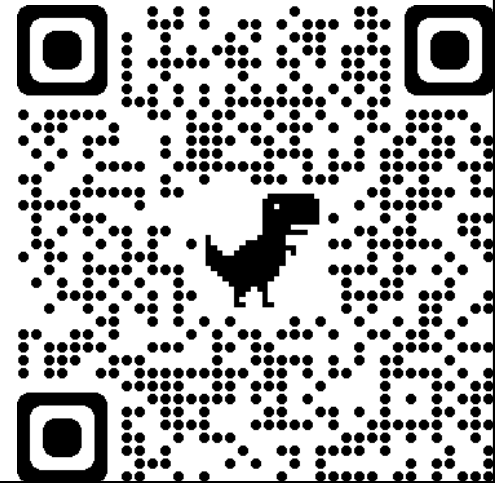


Ulrich Schreiber
Technical University Munich, Germany
... and the ROMY team



Video recording of presentation **here** (or scan the QR code!)

Note: most references are links to the publications!



New sensing technologies → beyond conventional seismic translation measurements.

Here: rotational ground motion

Can we detect the weak **ocean-generated seismic noise** with the existing rotation sensors?

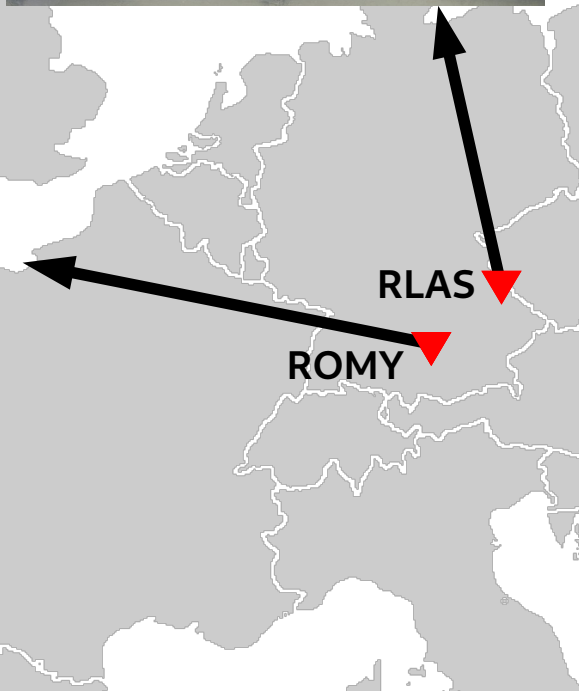
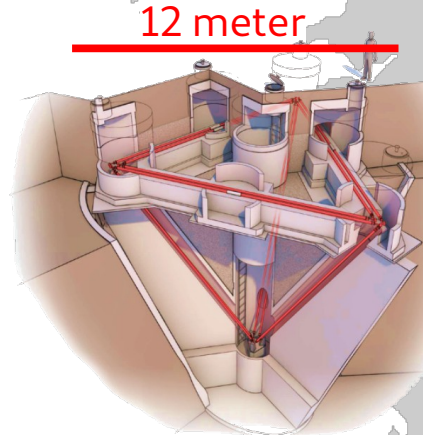
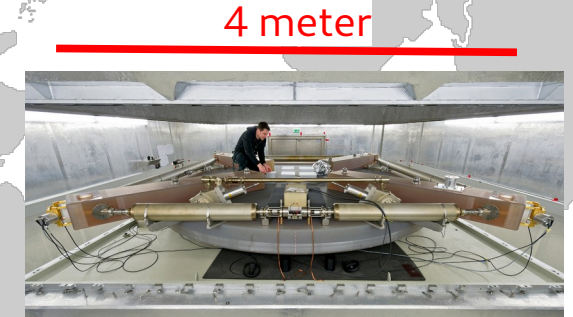
Can we perform **ambient noise interferometry** with rotational motions?

Observing rotations: Ring lasers

Observatory instruments: Ring lasers

Ring lasers offer a **point measurement of rotational ground motion**

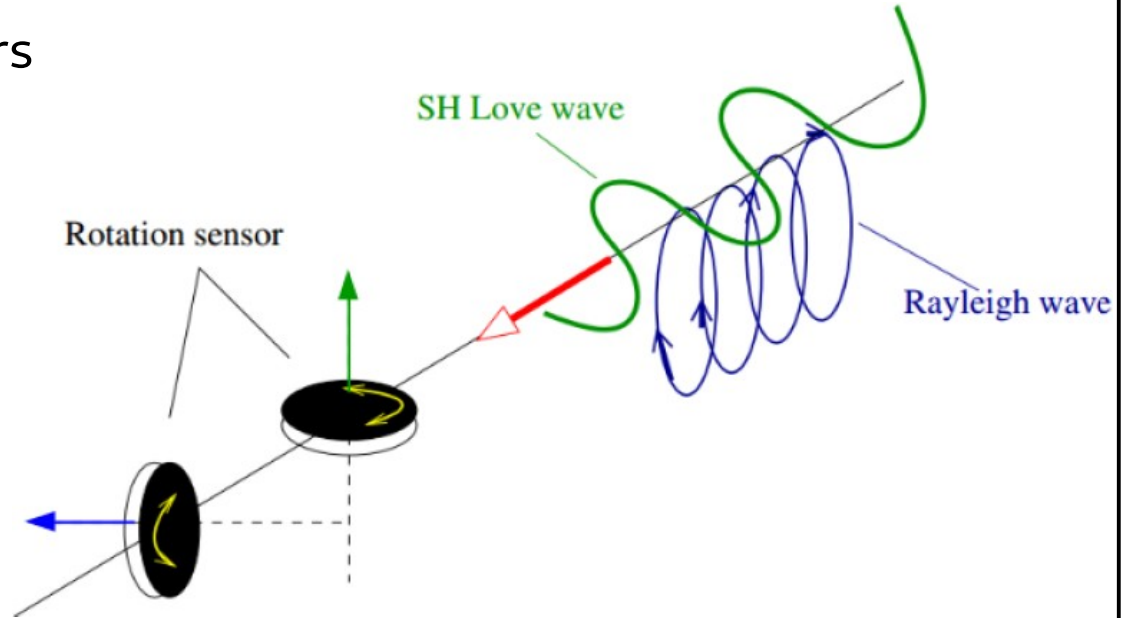
- + **RLAS in Wettzell, Germany:**
vertical component rotation
most sensitive worldwide
co-located seismometer: WET
- + **ROMY near Munich, Germany:**
first 3-component rotation
co-located seismometer: FUR



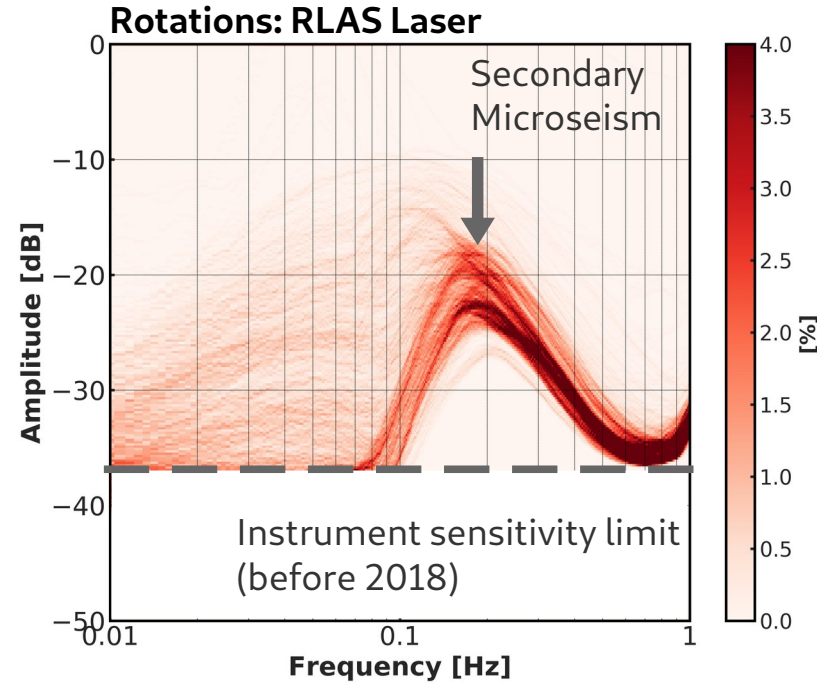
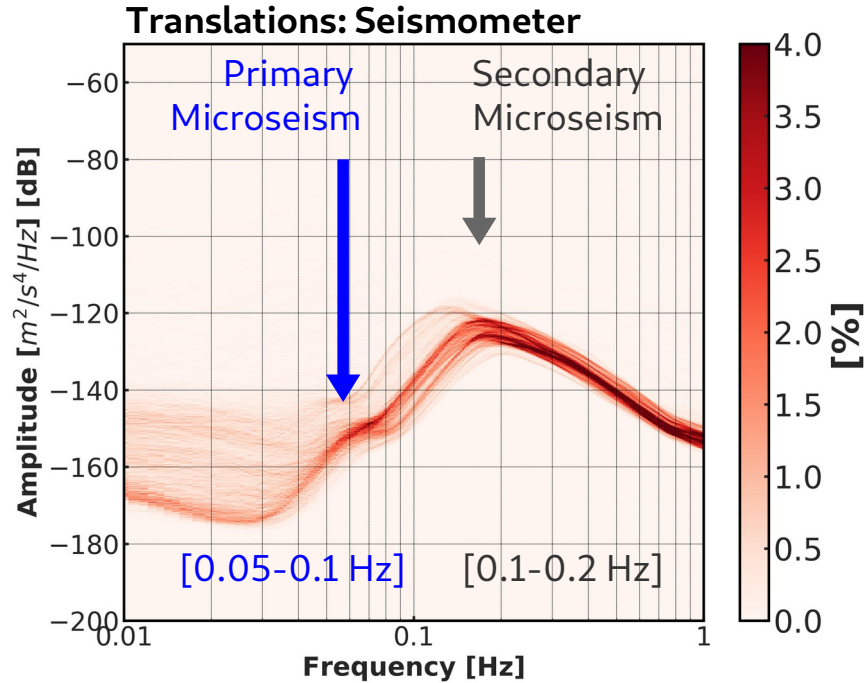
Observatory instruments: Ring lasers

- + **RLAS in Wettzell, Germany:**
vertical component rotation
most sensitive worldwide
co-located seismometer: WET
- + **ROMY near Munich, Germany:**
first 3-component rotation
co-located seismometer: FUR

Here: focus on vertical component:
SH- and Love waves



Can we pick up the ocean microseism? PPSD for seismometer vs. ring laser

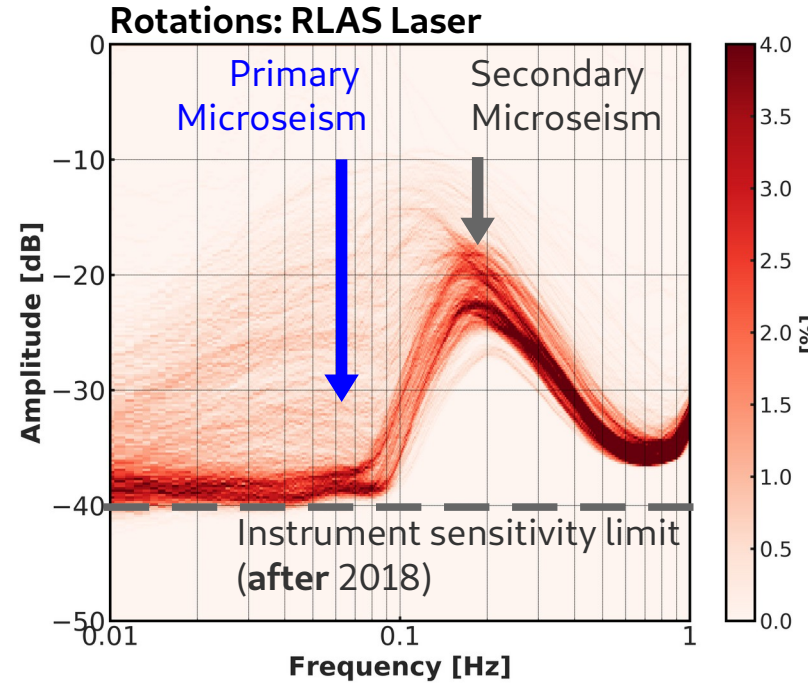
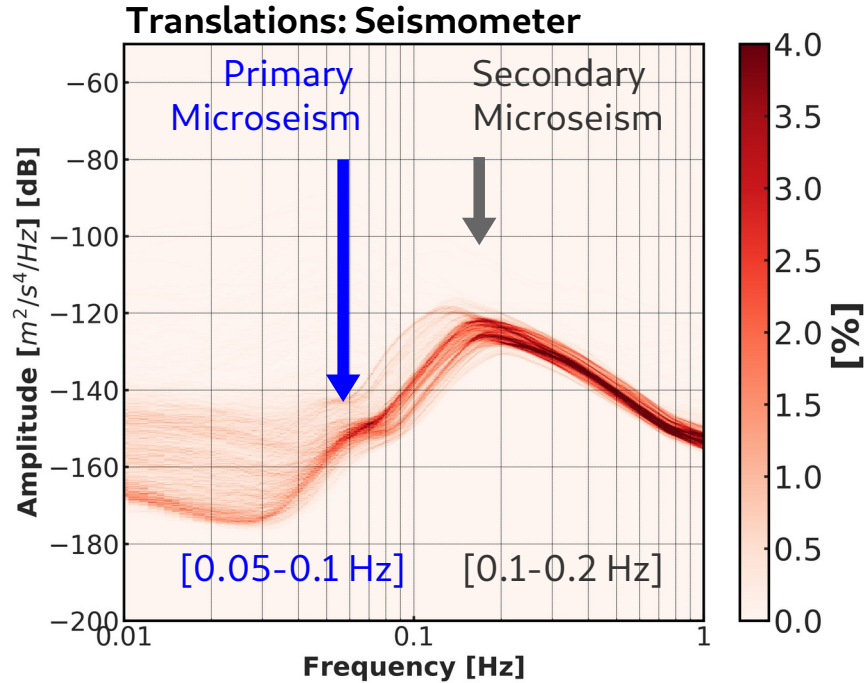


RLAS ▼

ROMY ▼

Detailed description: A map of Europe is shown in the background, with the locations of the instruments marked by red downward-pointing triangles. 'RLAS' is located in the North Atlantic, and 'ROMY' is located in the Mediterranean Sea.

Can we pick up the ocean microseism? PPSD for seismometer vs. ring laser



RLAS

ROMY

RLAS ring laser in Wettzell improved in 2017

Here: Primary microseism detected in January 2018

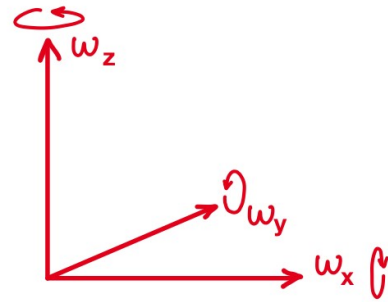
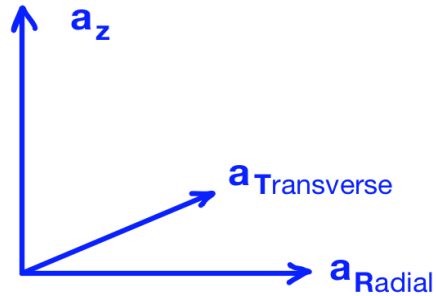
Is it *really* the primary microseism?

Combining Rotation and Translation



3C Translation

+ 3C Rotation



$$\frac{a_T}{\dot{\omega}_z} = \frac{-k^2 c^2 A \sin(kx - kct)}{\frac{1}{2} k^2 c A \sin(kx - kct)} = -2c$$

Ground acceleration
Seismometer

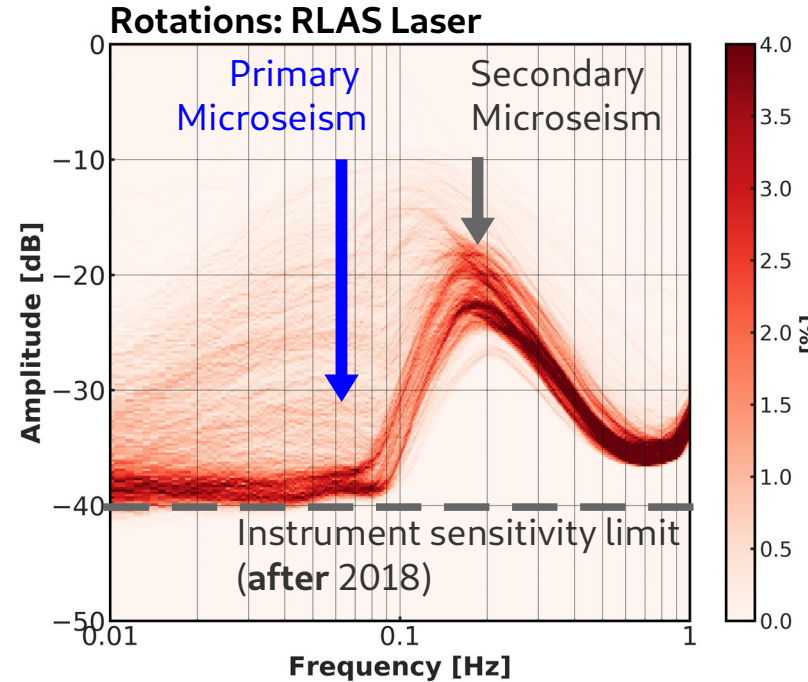
Rotation rate
Rotation sensor

- + Rotation rate and acceleration should be **in phase**
- + amplitudes scaled by **two times the horizontal phase velocity**.

Phase velocity → using single measurement of 6C

in phase → waveforms similar → can find source direction

Can we pick up the ocean microseism? PPSP for seismometer vs. ring laser



RLAS ▼
ROMY ▼

RLAS ring laser in Wettzell improved in 2017

Here: Primary microseism detected in January 2018

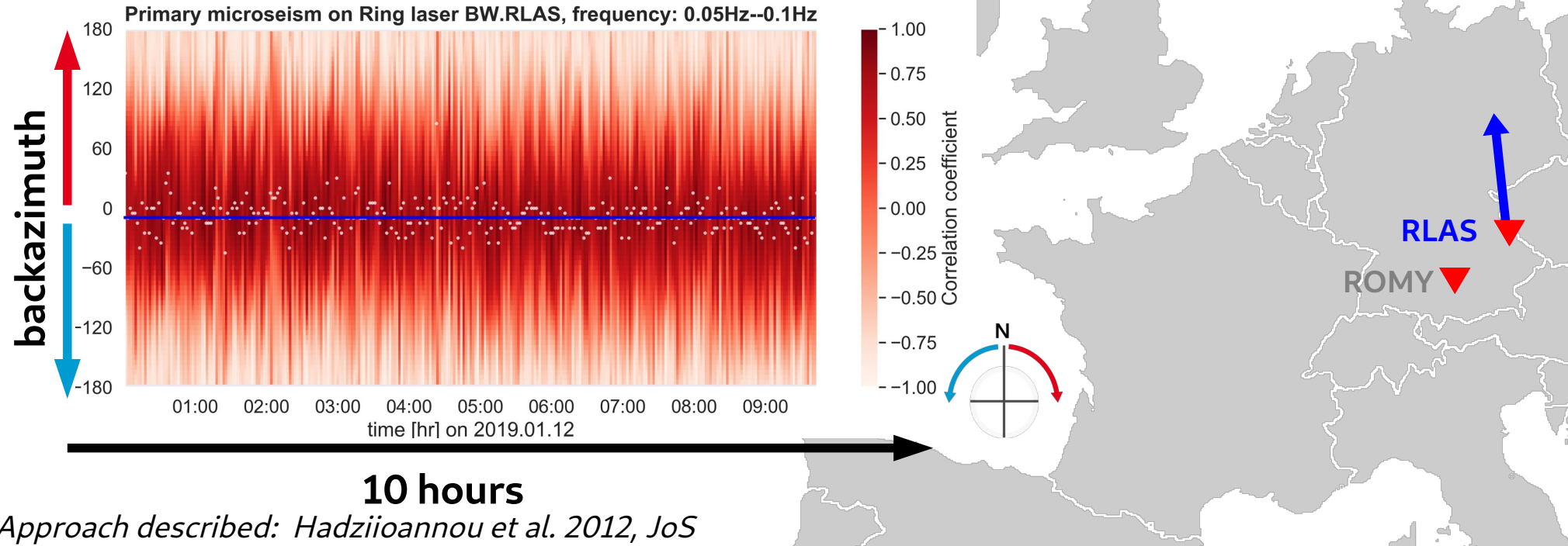
Is it *really* the primary microseism?

Is it coming from a **specific direction**?

Single-point backazimuth determination

Rotation rate and acceleration should be in phase
in phase $\rightarrow$ waveforms similar $\rightarrow$ can find source direction

Primary microseism: 0.05 – 0.1 Hz

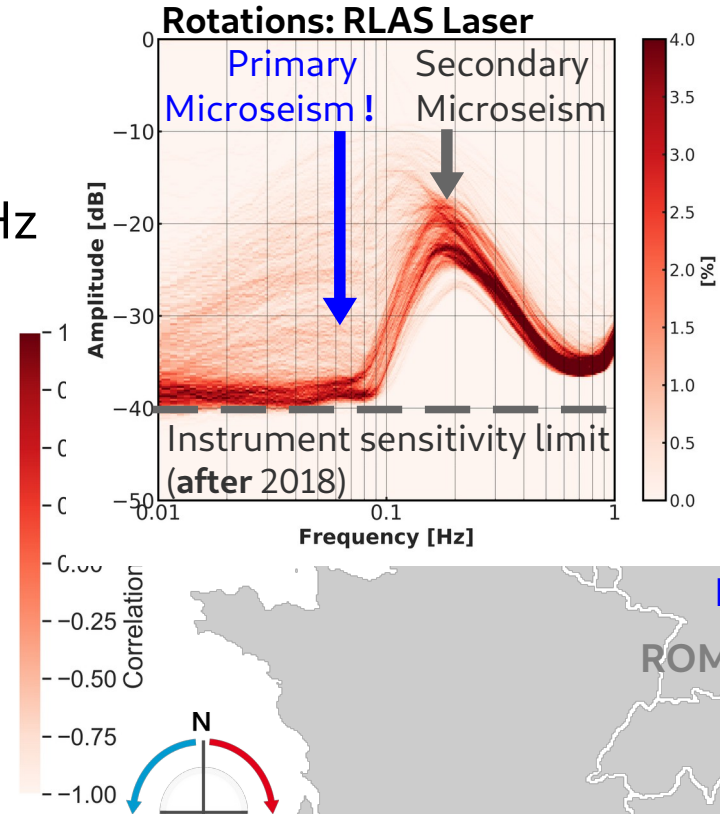
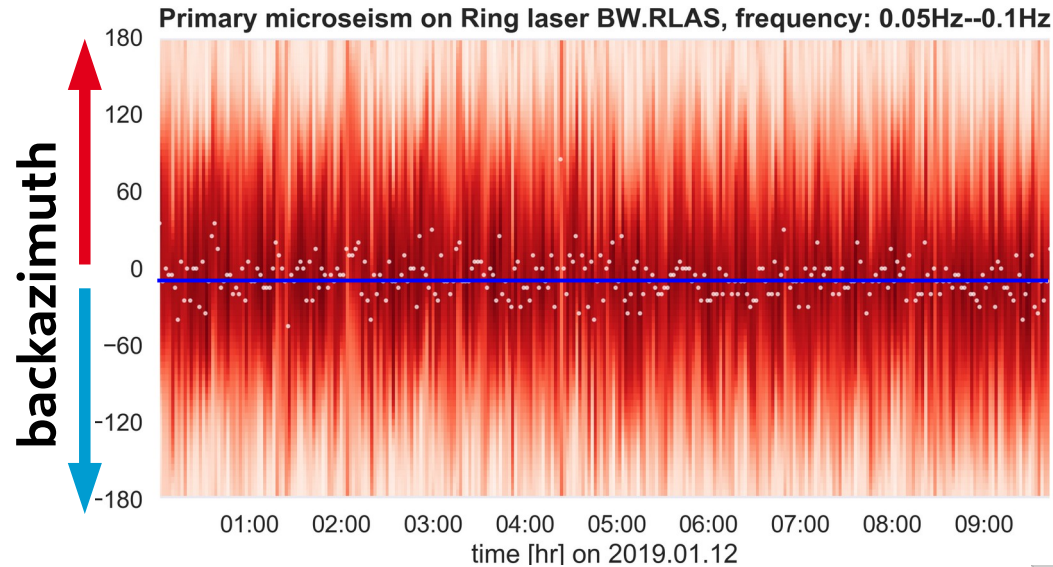


Sensitivity of ring laser sufficiently improved to detect **primary microseism**



Coherent wavefield coming from North:
(consistent with e.g. Juretzek & Hadziioannou, GJI 2017)

Primary microseism detected! 0.05 – 0.1 Hz



Approach described: Hadziioannou et al. 2012, JoS

New sensing technologies → beyond conventional seismic translation measurements.

Here: rotational ground motion

Can we detect the weak **ocean-generated seismic noise** with the existing rotation sensors? **Yes!**

→ **Sensitivity** of ring laser sufficiently improved to detect **primary microseism**

Can we perform **ambient noise interferometry** with rotational motions?

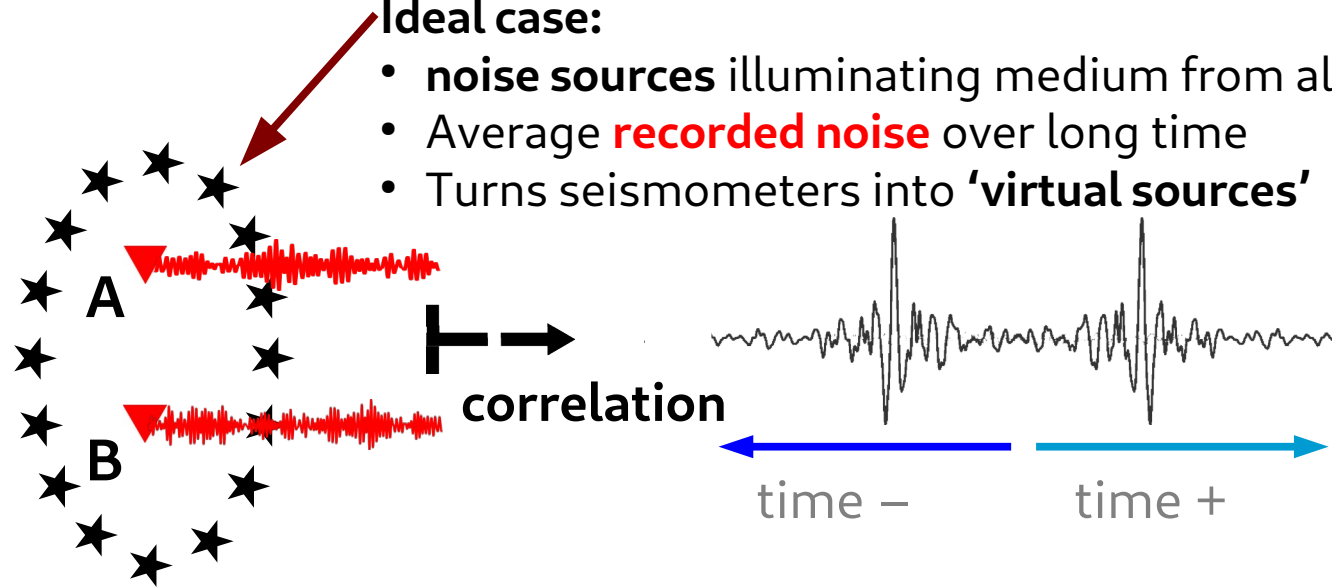
Ambient noise interferometry



From seismic noise to useful signal: noise interferometry

Ideal case:

- **noise sources** illuminating medium from all sides
- Average **recorded noise** over long time
- Turns seismometers into '**virtual sources**'



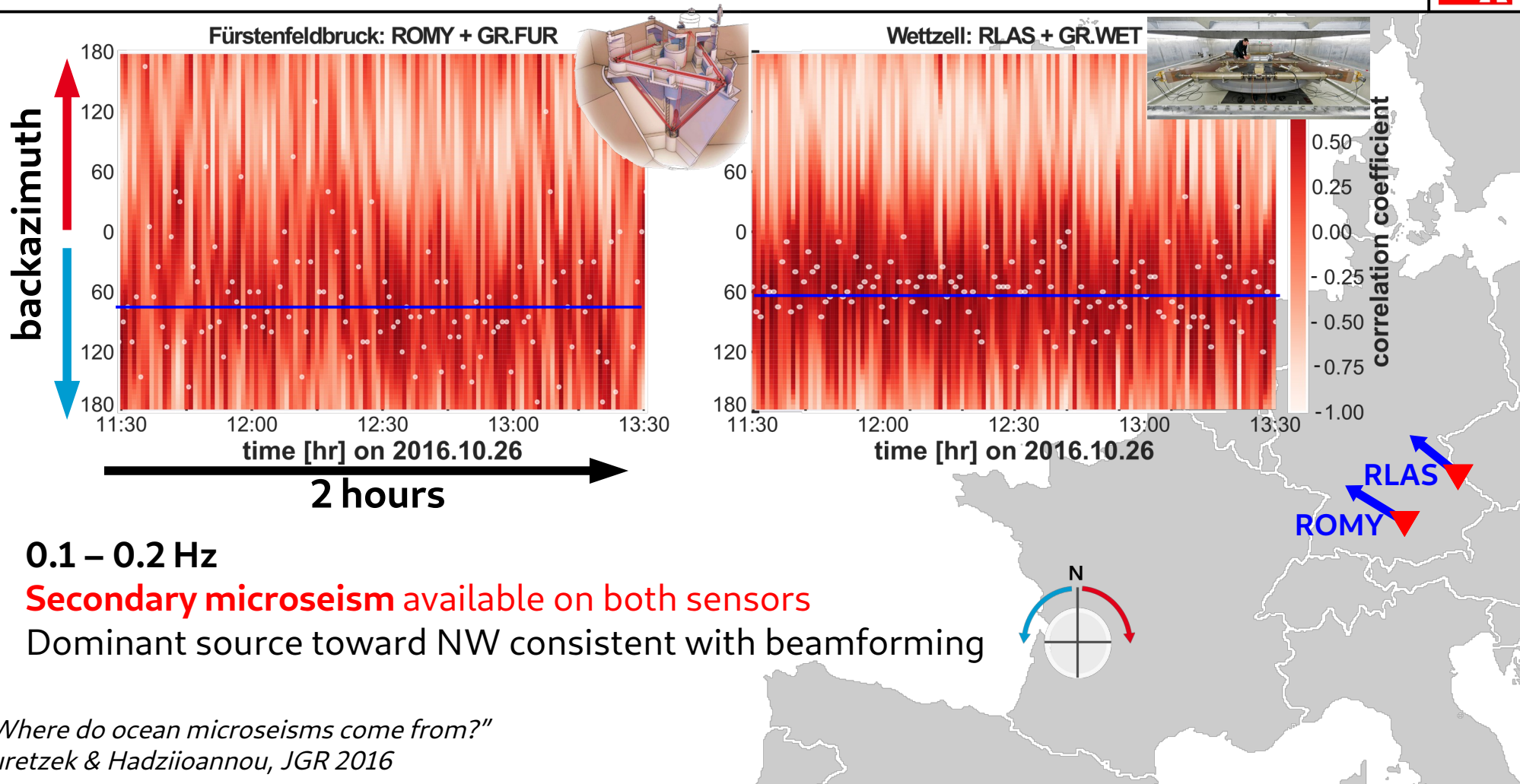
Does this work for rotational motion?

★ Noise source
▼ Receiver

Want to know more?

"Tutorial on seismic interferometry", Wapenaar et al, Geophysics 2010

Seismic noise interferometry with rotational ground motion?



Seismic noise interferometry with rotational ground motion?

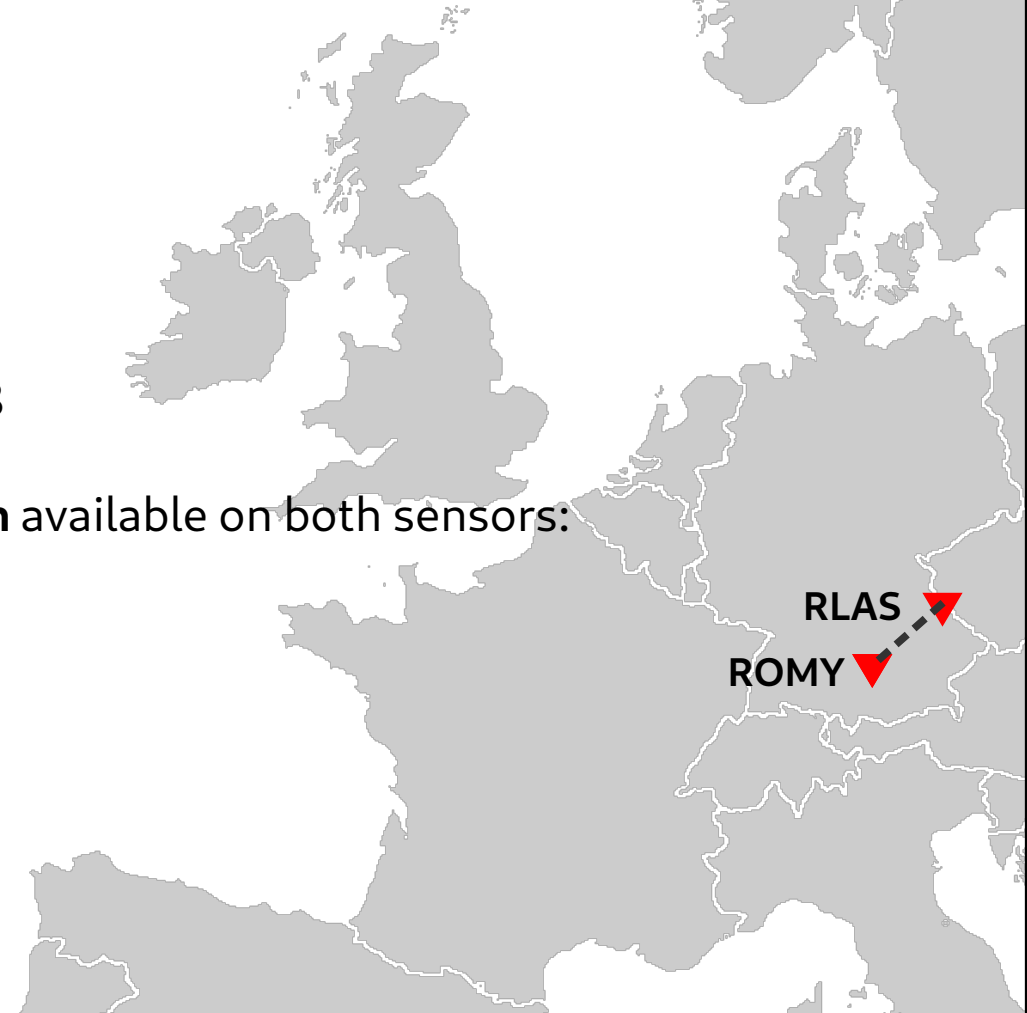


Need **long enough stacking time**:

→ $\pm$ one year of noise, 01.01.2018 – 01.12.2018

Ambient noise from the **secondary microseism** available on both sensors:

→ filter between 0.1 – 0.2 Hz



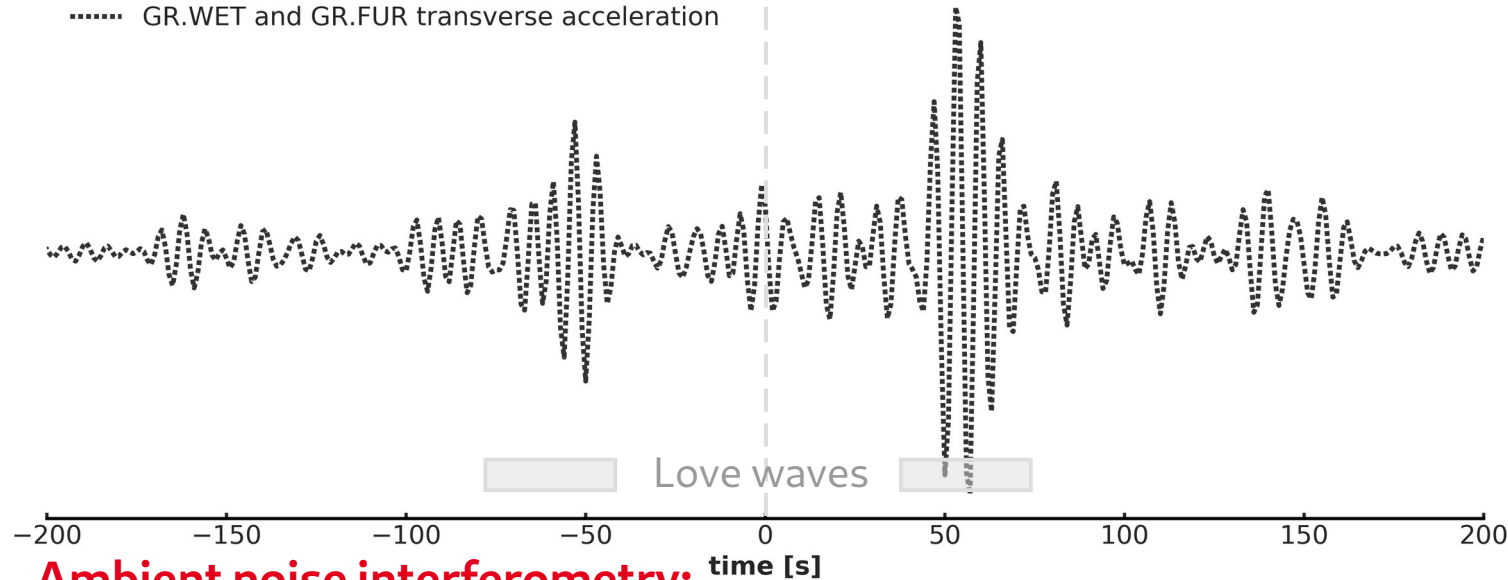
Seismic noise interferometry with rotational ground motion?



Ambient noise correlations: Ring laser vs. Seismometer

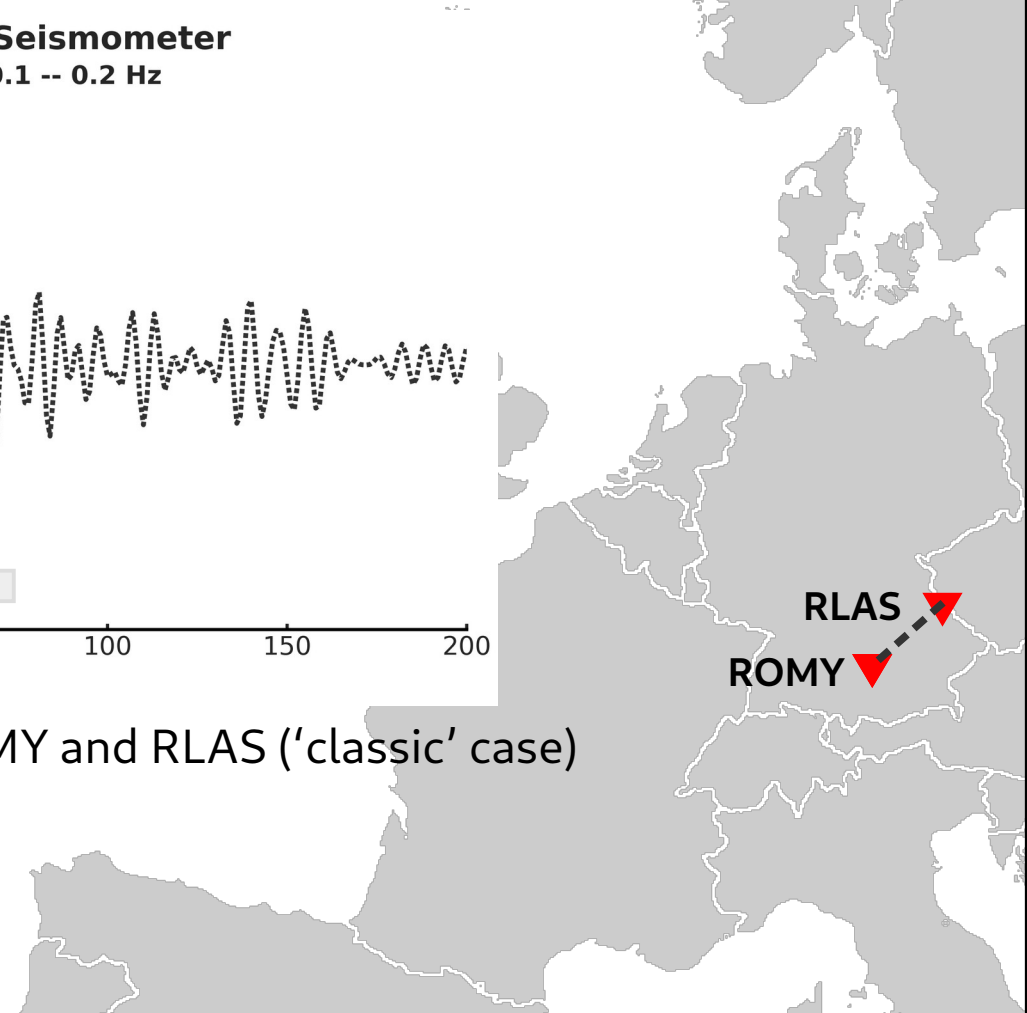
date: 2018.01.01 -- 2018.12.01 frequency: 0.1 -- 0.2 Hz

..... GR.WET and GR.FUR transverse acceleration



Ambient noise interferometry:

+ **black**: between **two seismometers** near ROMY and RLAS ('classic' case)

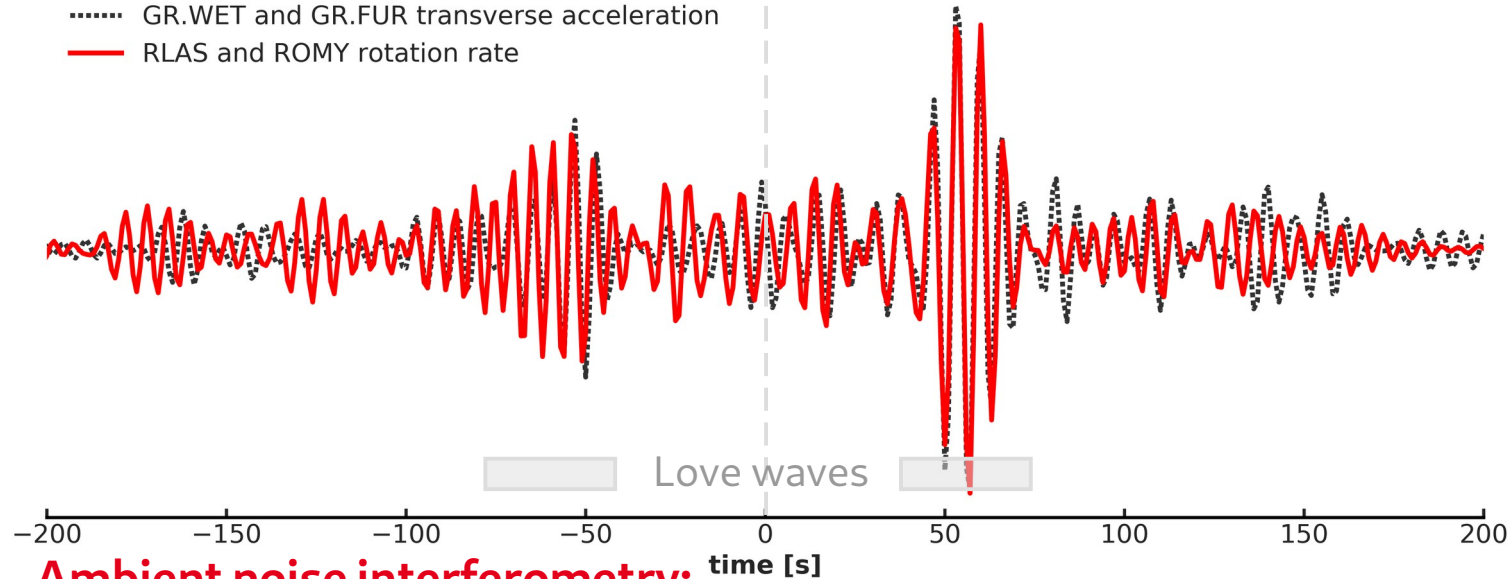


Seismic noise interferometry with rotational ground motion?

Ambient noise correlations: Ring laser vs. Seismometer

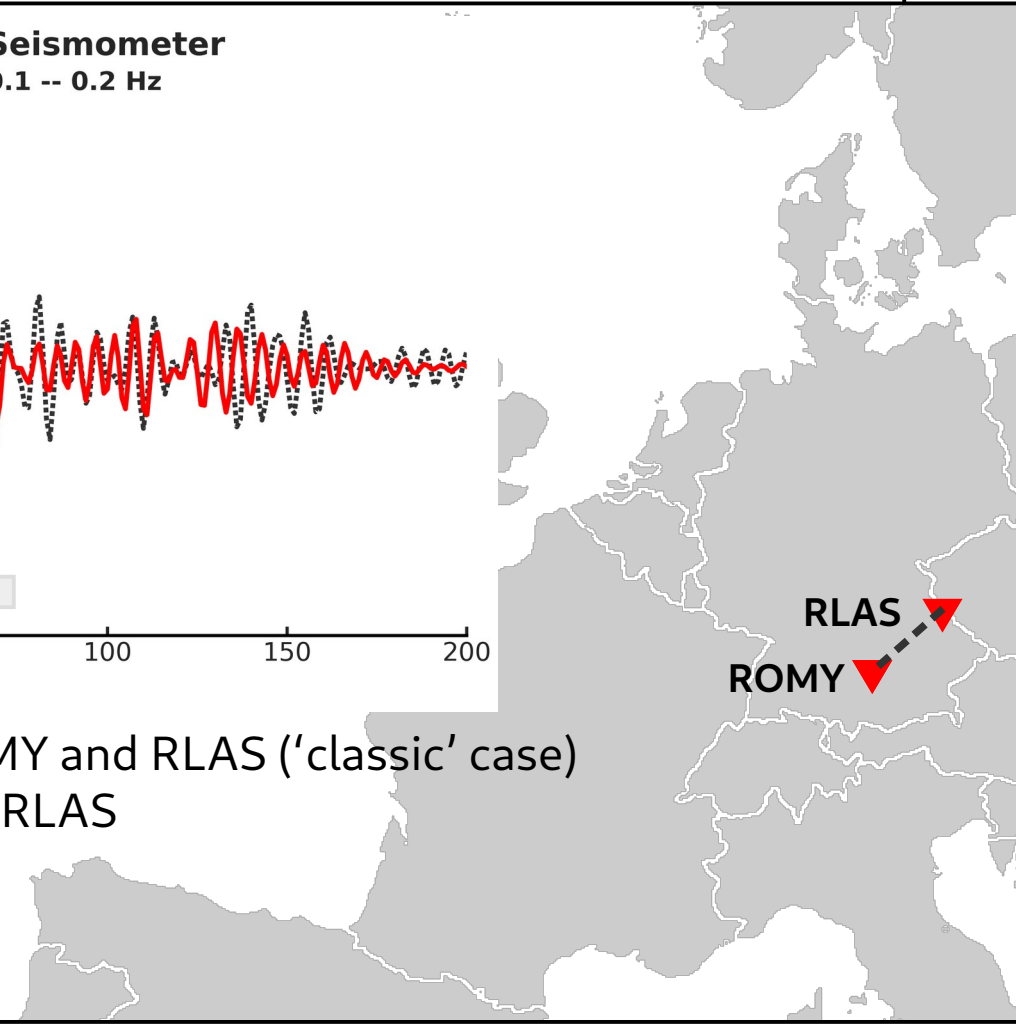
date: 2018.01.01 -- 2018.12.01 frequency: 0.1 -- 0.2 Hz

..... GR.WET and GR.FUR transverse acceleration
— RLAS and ROMY rotation rate



Ambient noise interferometry:

- + **black**: between **two seismometers** near ROMY and RLAS ('classic' case)
- + **red**: between **the two ring lasers** ROMY and RLAS



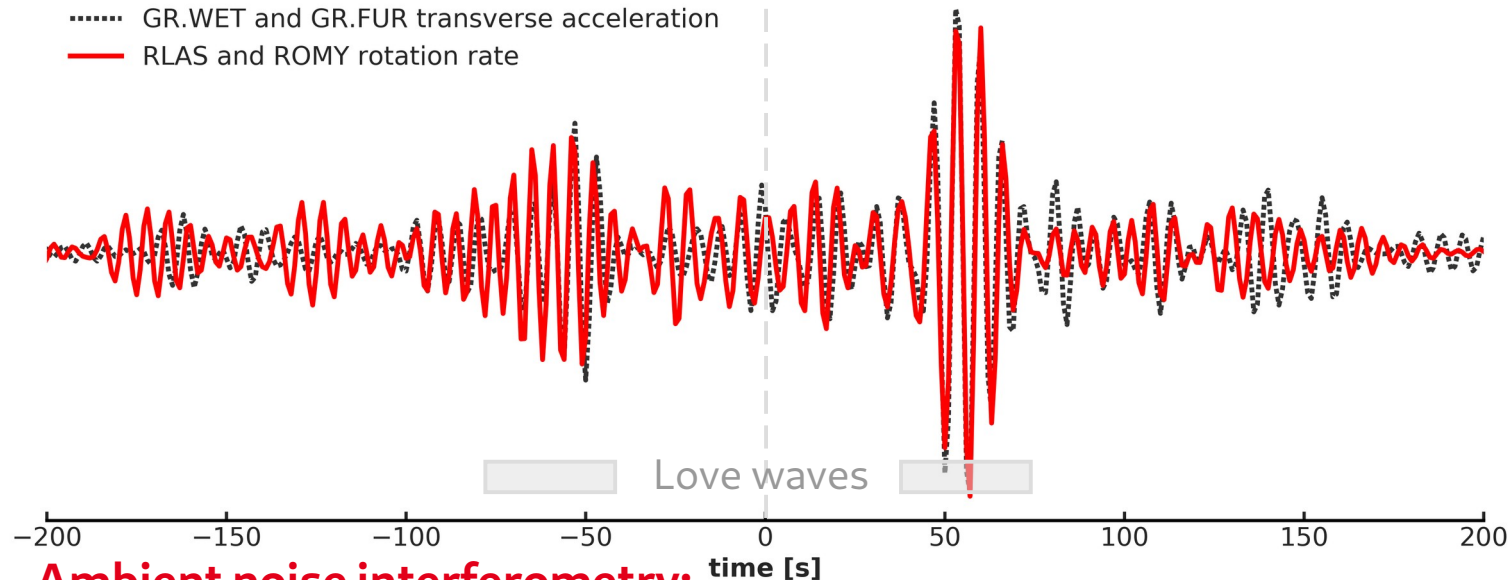
RLAS
ROMY

Seismic noise interferometry with rotational ground motion?

Ambient noise correlations: Ring laser vs. Seismometer

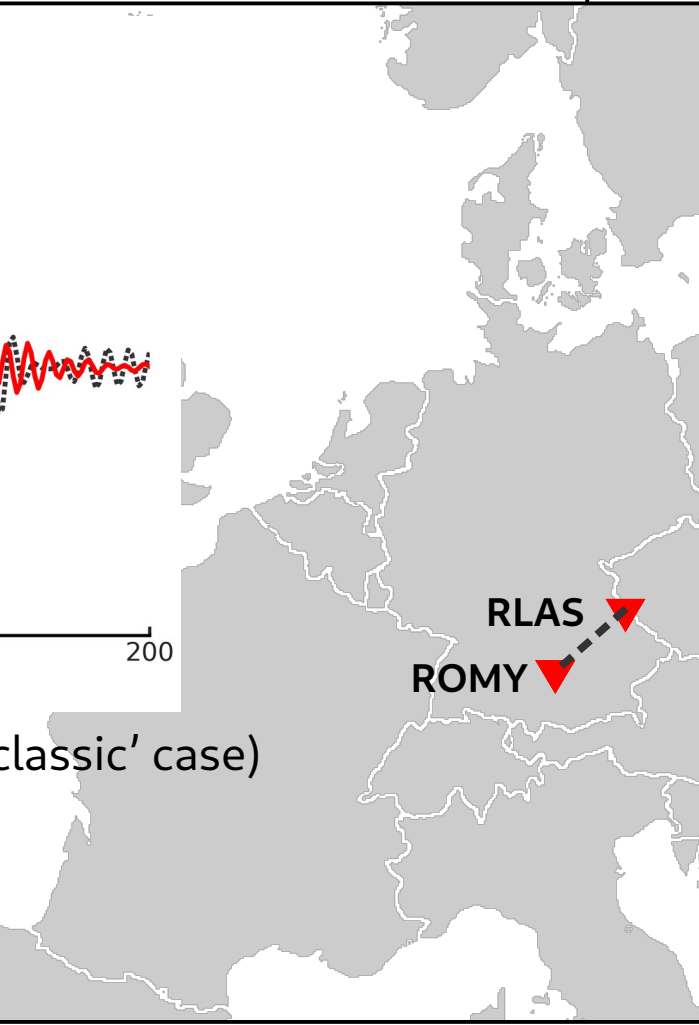
date: 2018.01.01 -- 2018.12.01 frequency: 0.1 -- 0.2 Hz

..... GR.WET and GR.FUR transverse acceleration
— RLAS and ROMY rotation rate



Ambient noise interferometry:

- + **black**: between **two seismometers** near ROMY and RLAS ('classic' case)
- + **red**: between **the two ring lasers** ROMY and RLAS
- + **waveform** of vertical rotation rate (**red**)
should be similar to the transverse acceleration (**black**)
- + with **long enough stacking time**, the waveforms match!



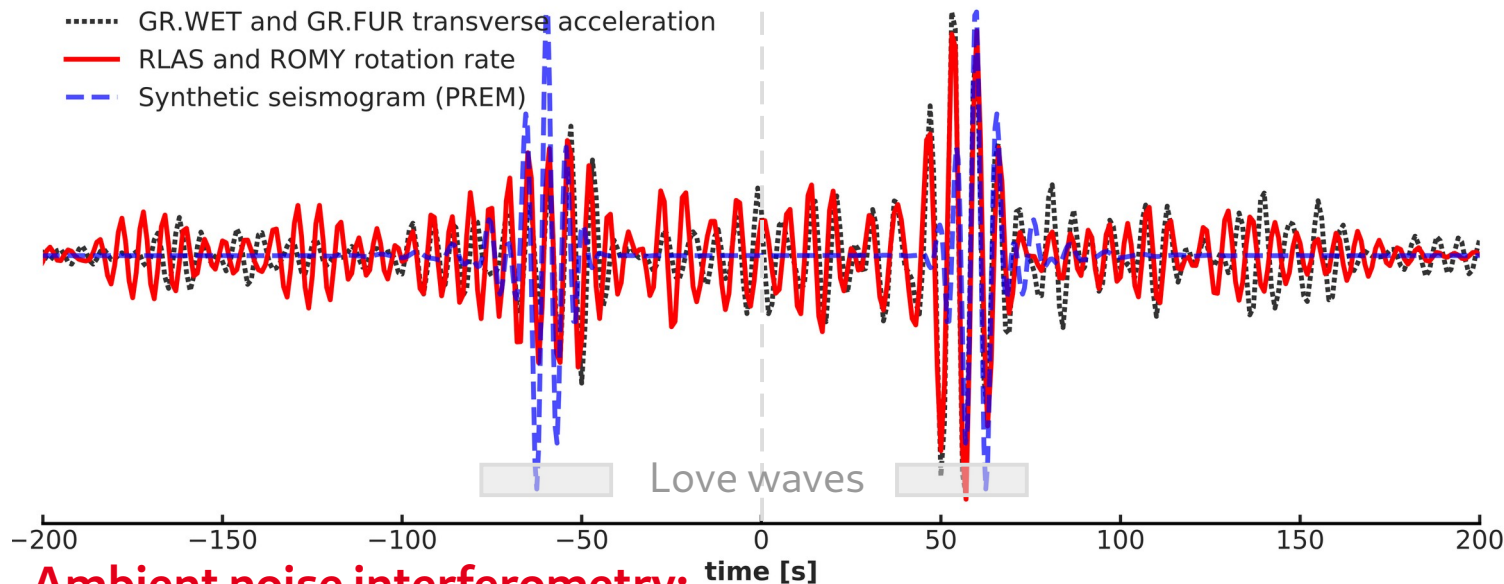
RLAS
ROMY

Seismic noise interferometry with rotational ground motion?

Ambient noise correlations: Ring laser vs. Seismometer

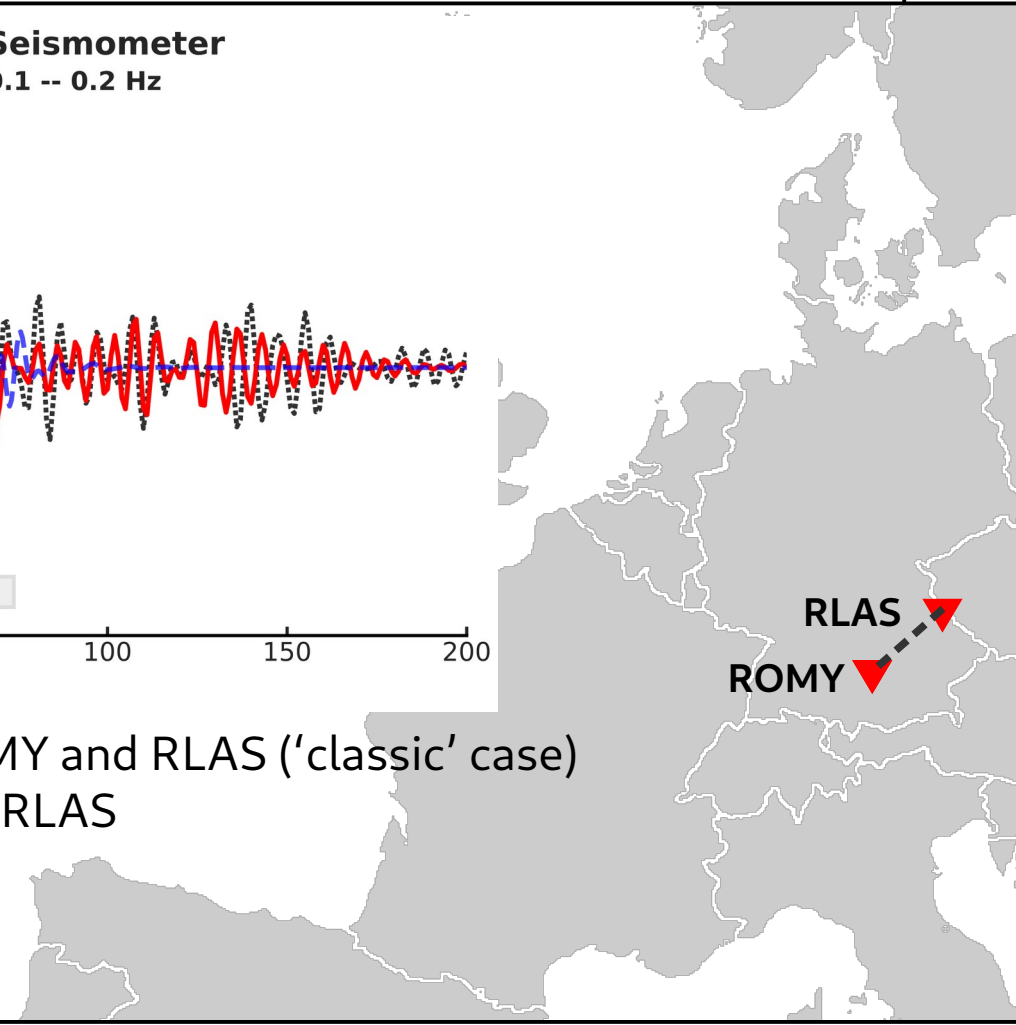
date: 2018.01.01 -- 2018.12.01 frequency: 0.1 -- 0.2 Hz

- GR.WET and GR.FUR transverse acceleration
- RLAS and ROMY rotation rate
- Synthetic seismogram (PREM)



Ambient noise interferometry:

- + **black**: between **two seismometers** near ROMY and RLAS ('classic' case)
- + **red**: between **the two ring lasers** ROMY and RLAS
- + **blue**: **synthetic signal** for 1D model (PREM)
source at RLAS recorded at ROMY

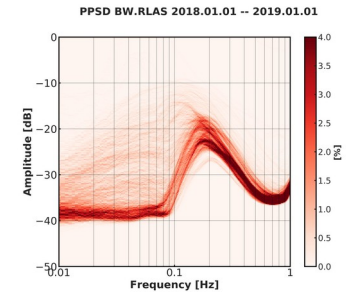


RLAS
ROMY

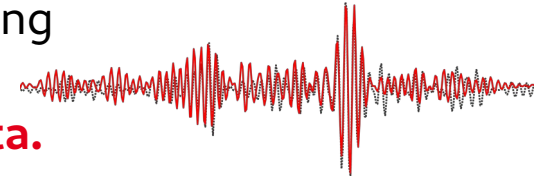
Seismic noise analysis with rotational ground motion



Ocean-generated noise can be detected at two ring laser sites: beside the **secondary** microseism, now also the **primary microseism**
→ **push limit towards weak motions**



Proof of concept: first case of '**rotational**' **noise interferometry** using ocean-generated noise recorded at two ring lasers
→ **towards noise interferometry of 6-component displacement data.**



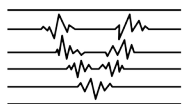
General:

→ **ambient noise applications with rotational motion**

What's next?

Slides & more: celine.hadzii.com

What does the **future** bring?



SPIN MONITORING A
RESTLESS EARTH

Funded by the Horizon 2020
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- "Lord of the Rings",
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DOI: 10.1126/science.356.6335.236
- Paitz, P., Sager, K., & Fichtner, A. (2019).
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Geophysical Journal International, 216(3), 1938-1952. <https://doi.org/10.1093/gji/ggy528>
- Wapenaar, K., Draganov, D., Snieder, R., Campman, X., & Verdel, A. (2010).
Tutorial on seismic interferometry: Part 1—Basic principles and applications.
Geophysics, 75(5), 75A195-75A209. <https://doi.org/10.1190/1.3457445>

Rotational seismology database

- Salvermoser, J., Hadziioannou, C., Hable, S., Krischer, L., Chow, B., Ramos, C., Wassermann, J., Schreiber, U., Gebauer, A & Igel, H. (2017). An event database for rotational seismology. Seismological Research Letters.
<https://rotations-database.geophysik.uni-muenchen.de/>

Get started with rotational data

- seismo-live.org → rotational seismology
→ 3 introductory notebooks to reproduce some figures from the **rotational database** presented in the link above