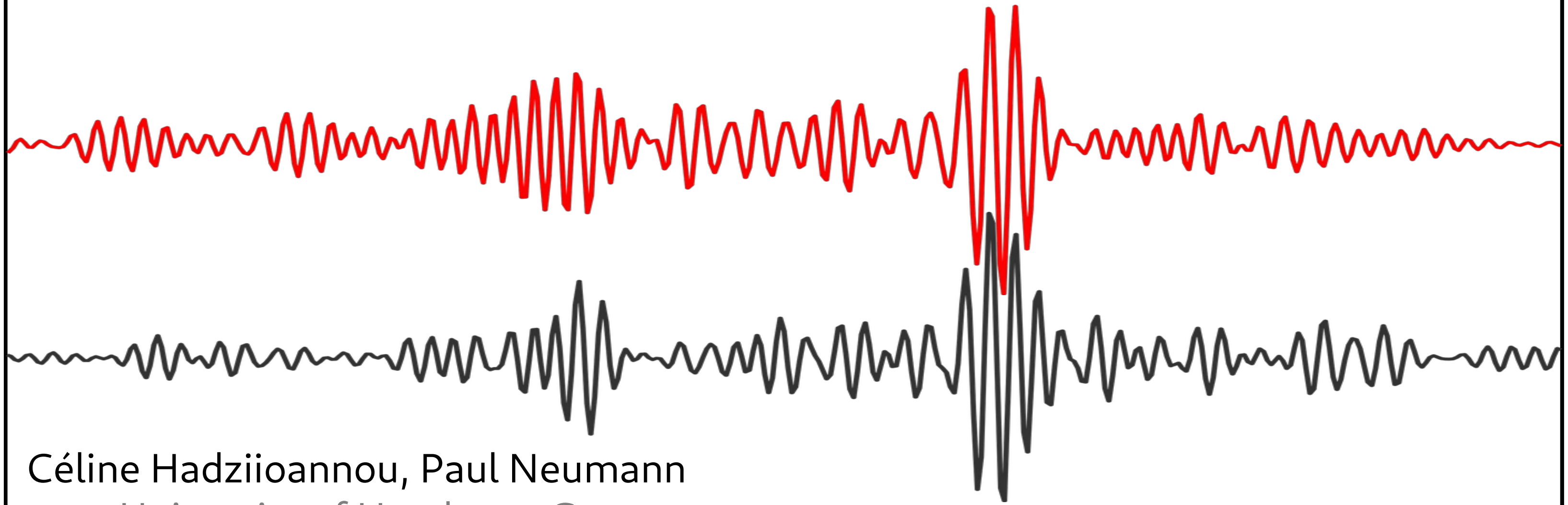
# Ambient seismic noise interferometry using rotational ground motion



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

New sensing technologies → beyond conventional seismic translation measurements.

**Here:** rotational ground motion

Can we detect the weak **ocean-generated seismic noise**?

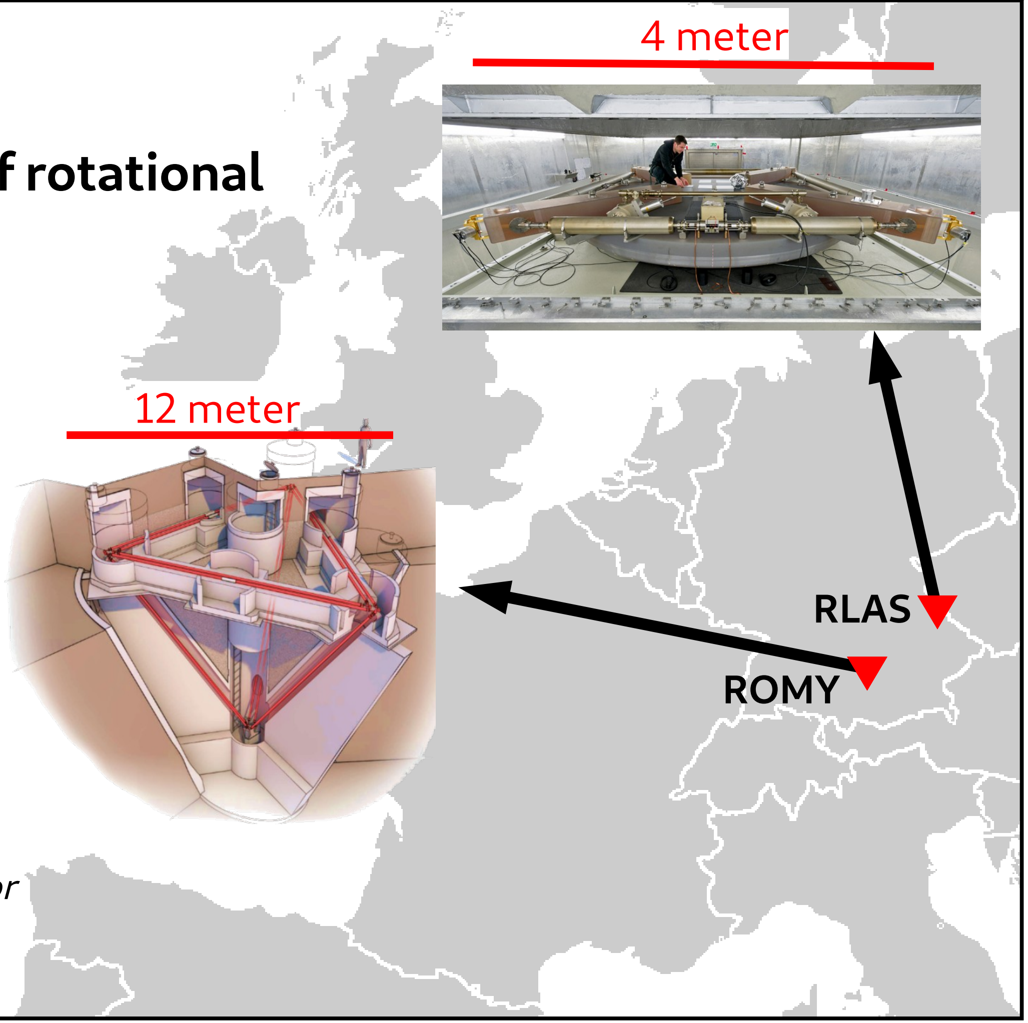
Can we perform **ambient noise interferometry** with rotational motions?

*Interferometry with rotations & strain:*
*Paitz, Sager, Fichtner; GJI 2019*

# 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




ROMY
ROtational Motions in seismologY

*"ROMY: A Multi-Component Ring Laser for Geodesy and Geophysics", earthArxiv*
*"Lord of the Rings", Science, 2017*

# Observing rotations: Ring lasers

**Observatory instruments:** Ring lasers

+ **RLAS in Wettzell, Germany:**
  vertical component rotation
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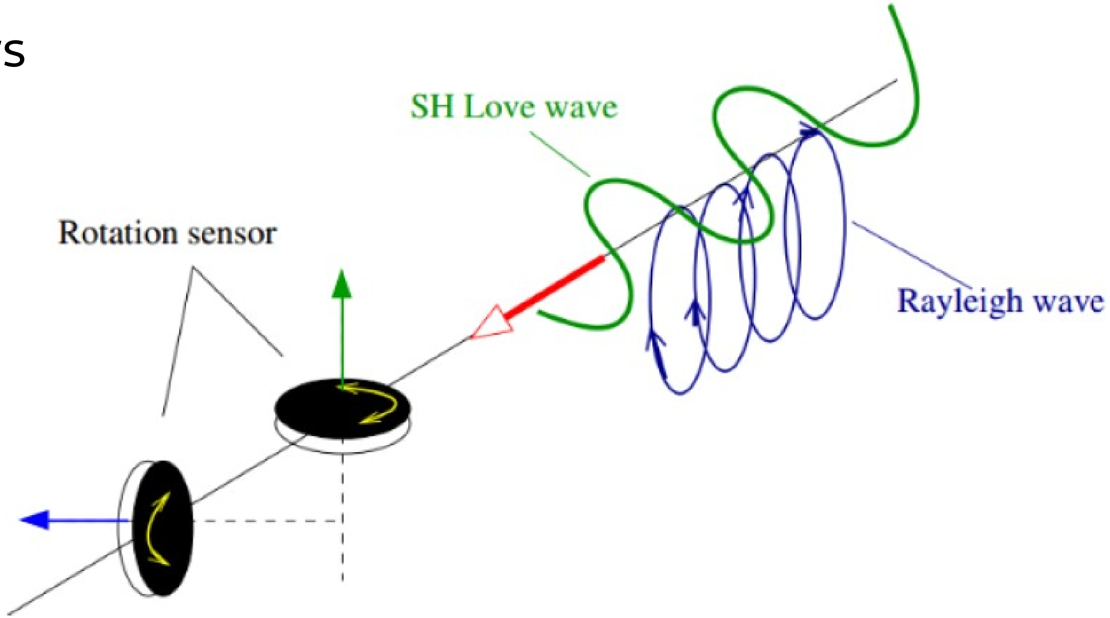
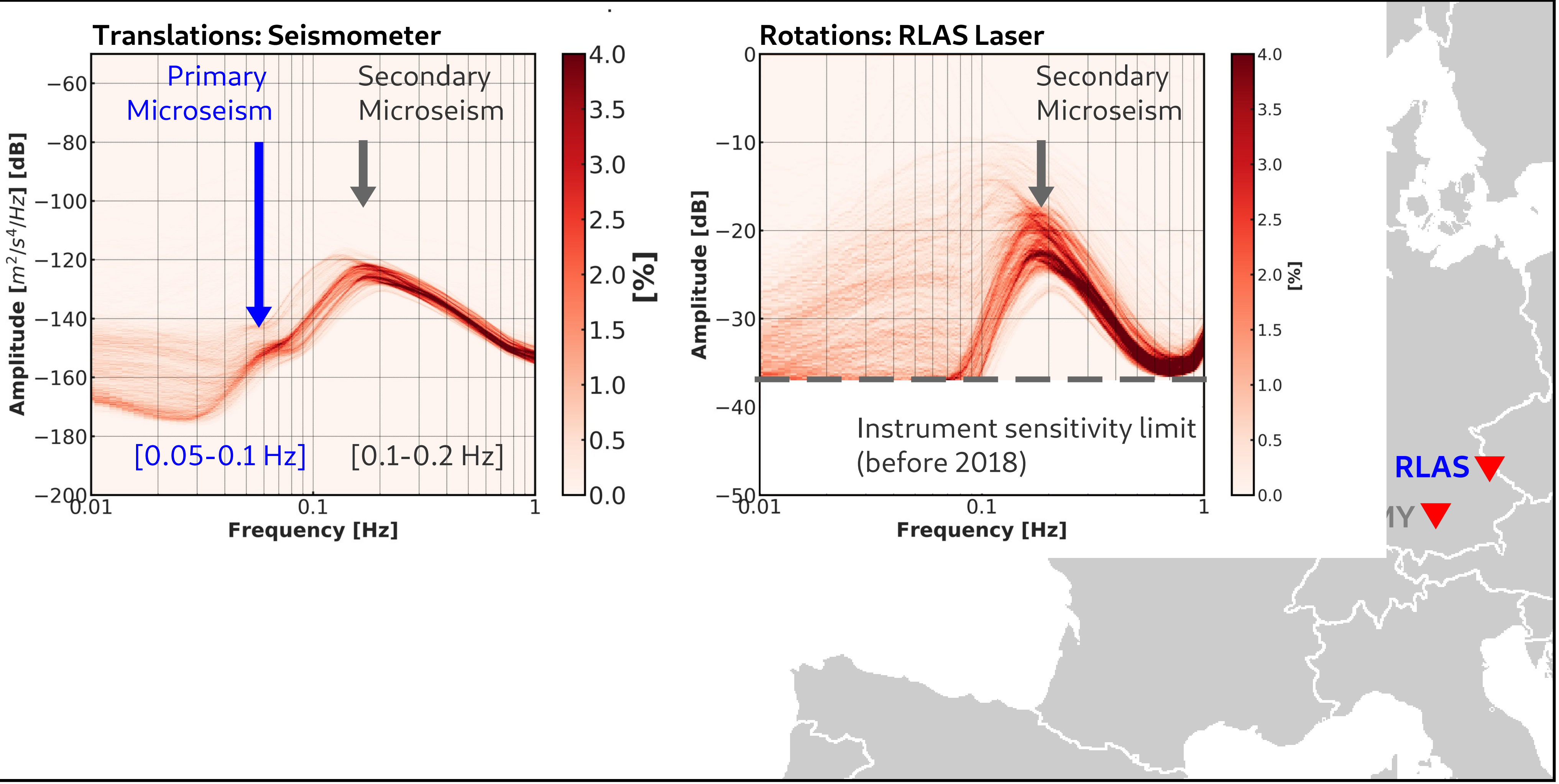
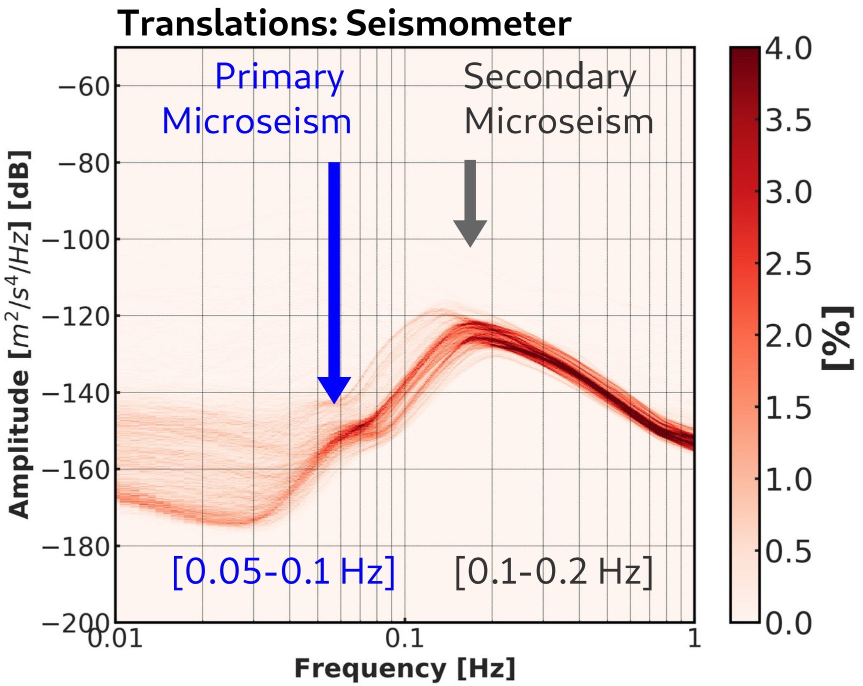
**Here: focus on vertical component:**
SH- and Love waves

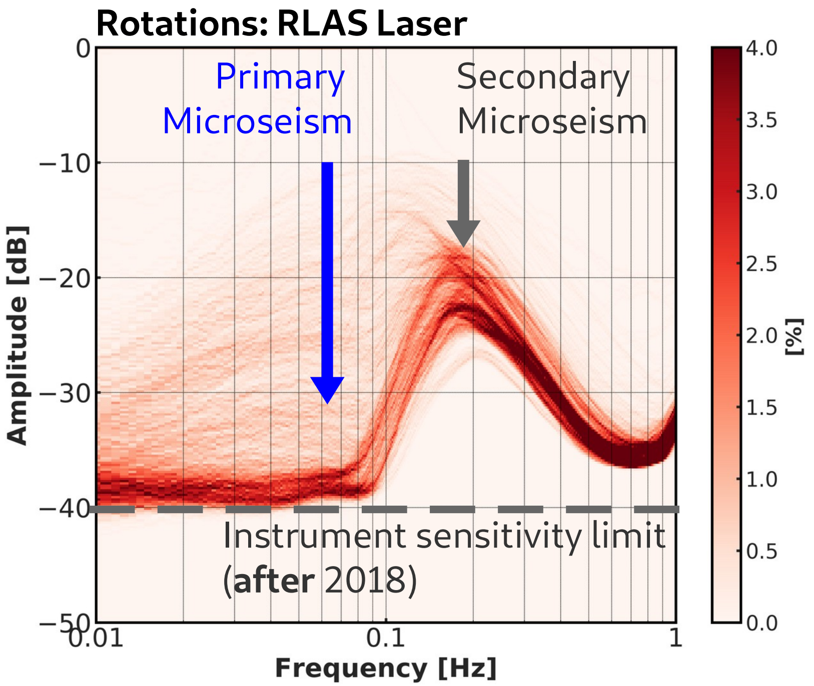


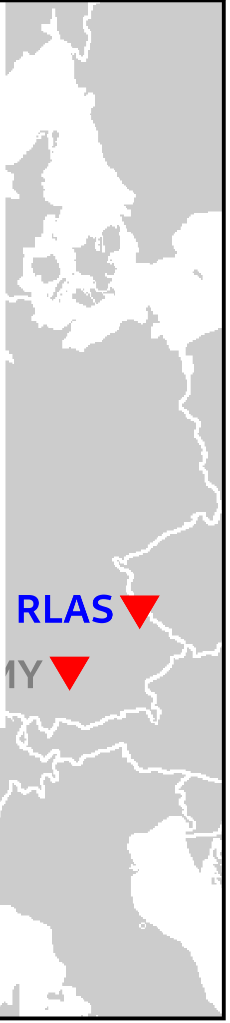
# **Can we pick up the ocean microseism?** PPSD for seismometer vs. ring laser



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



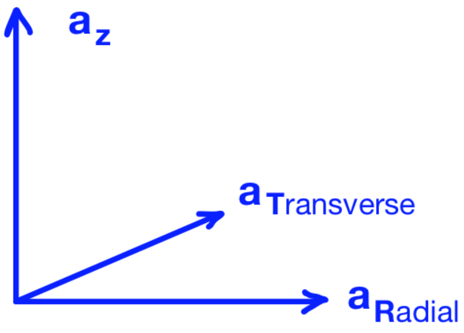

RLAS ring laser in Wettzell improved in 2017

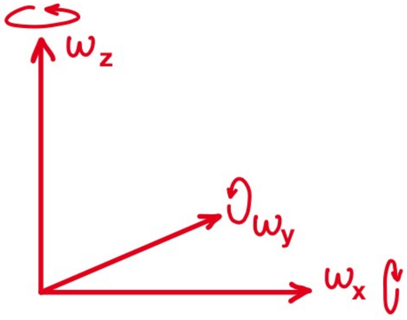
Here: Primary microseism detected in January 2018

Is it *really* the primary microseism?

# Combining Rotation and Translation

3C Translation + 3C Rotation




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

Ground acceleration
**Seismometer**

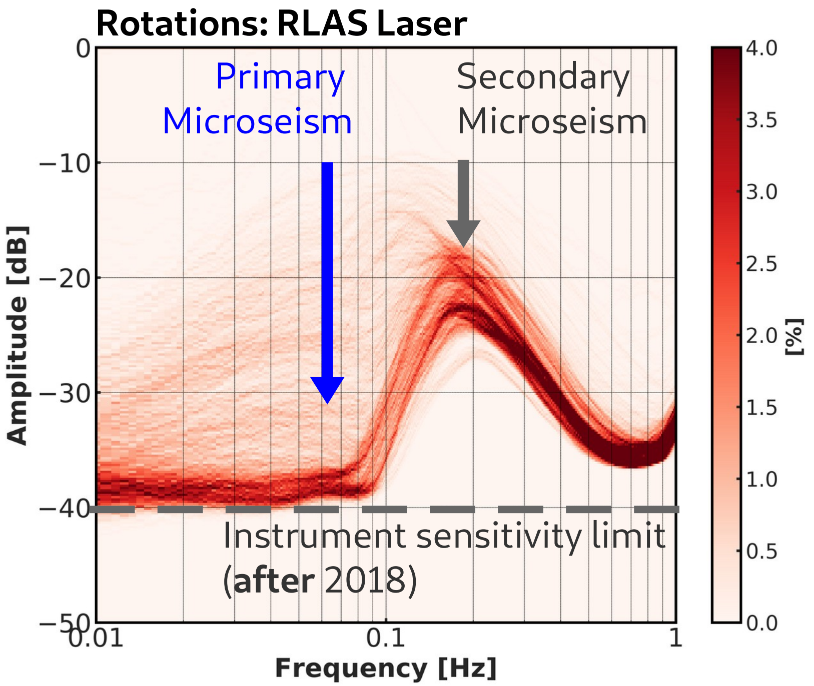
Rotation rate
**Rotation sensor**

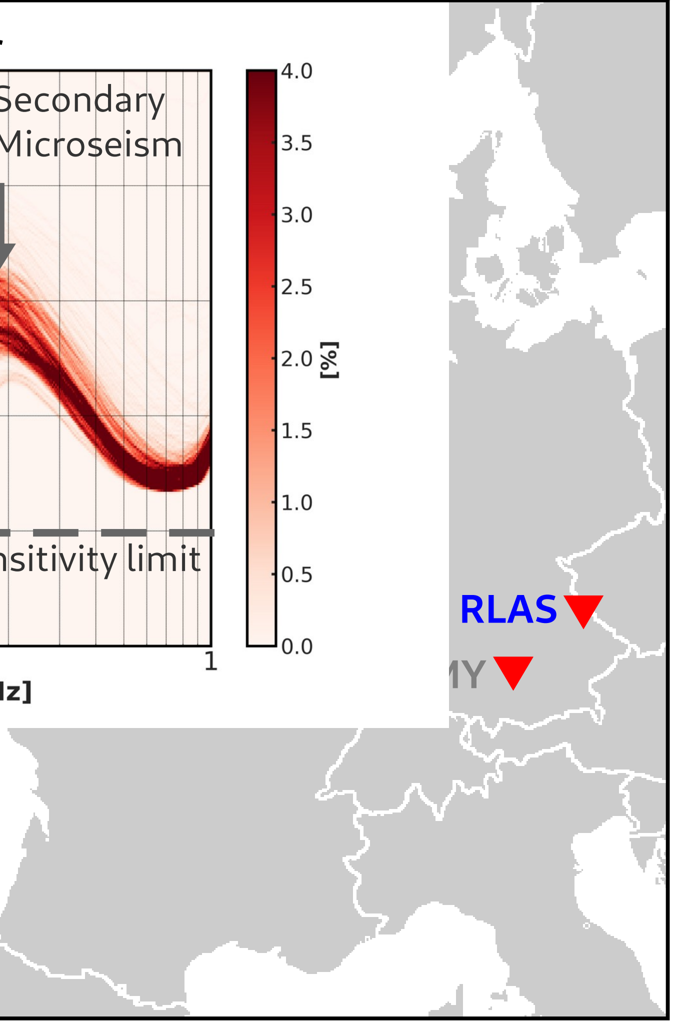
+ Rotation rate and acceleration should be **in phase**
+ amplitudes scaled by **two times the horizontal phase velocity.**

**Phase velocity** → using single measurement of 6C

**in phase** → waveforms similar → can find source direction

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




RLAS ring laser in Wettzell improved in 2017

Here: Primary microseism detected in January 2018

Is it *really* the primary microseism?

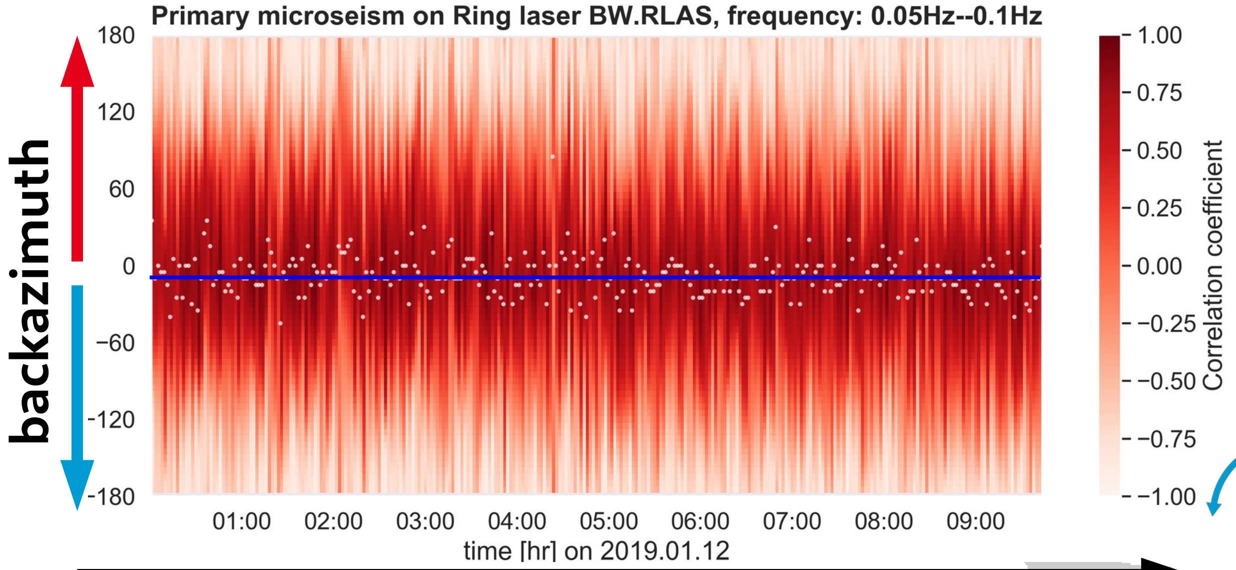
Is it coming from a specific direction?

# Single-point **backazimuth determination**

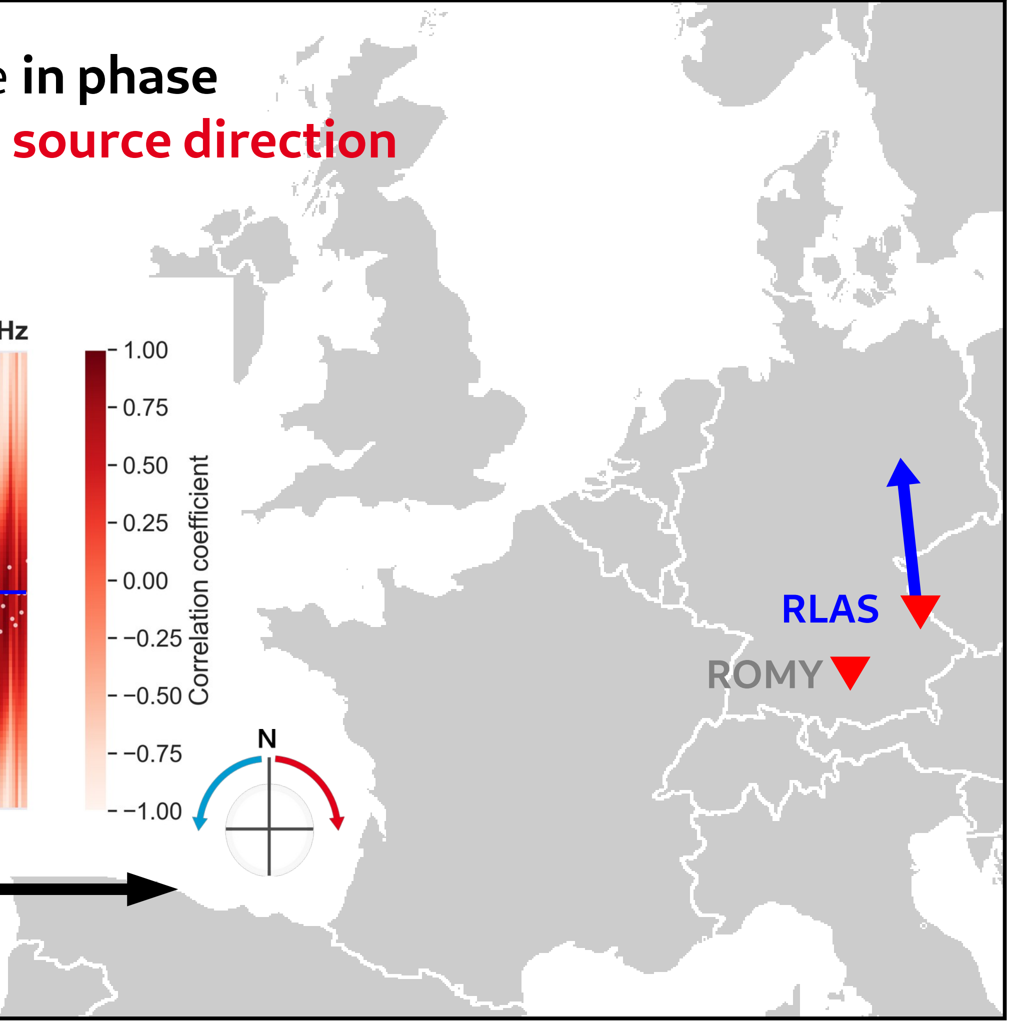
Rotation rate and acceleration should be **in phase**

**in phase → waveforms similar → can find source direction**

**Primary microseism:** 0.05 – 0.1 Hz




**10 hours**

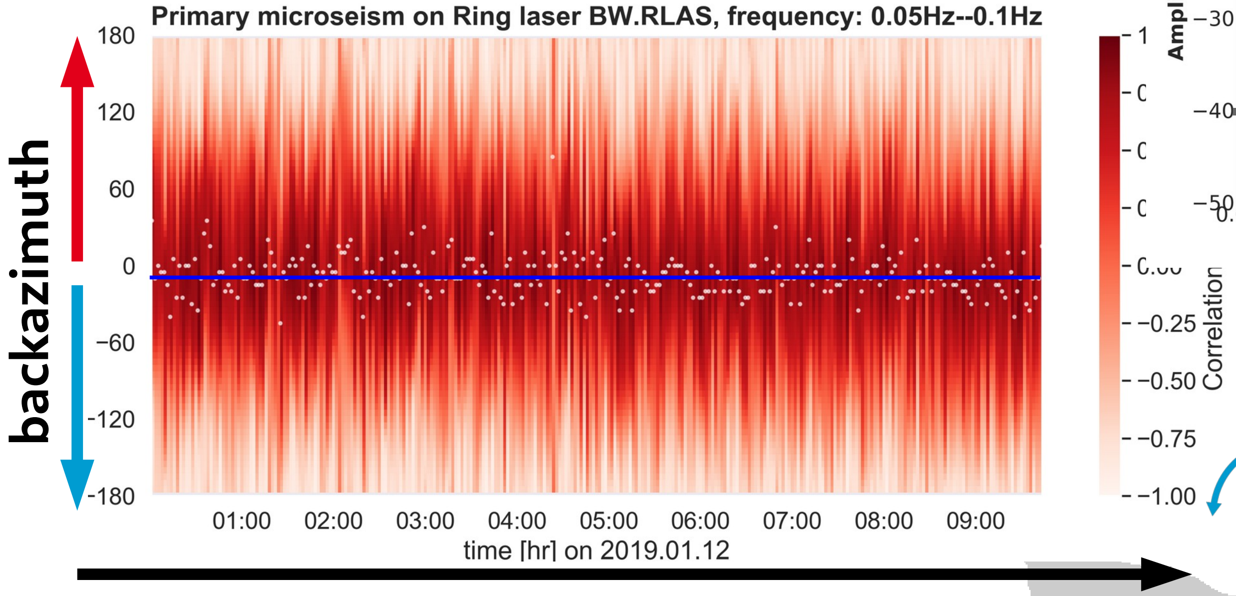



*Approach described: Hadziioannou et al. 2012, JoS*

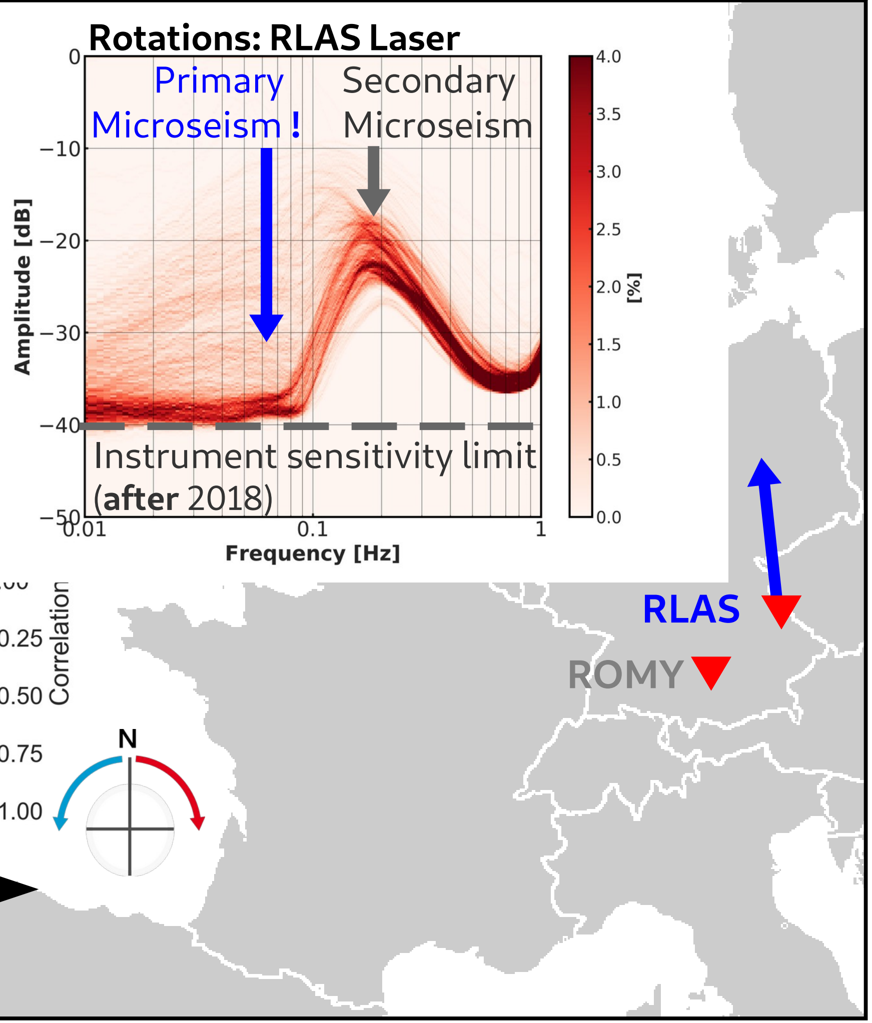
# **Sensitivity** of ring laser sufficiently improved to detect **primary microseism**

Coherent wavefield coming from North:

**Primary microseism detected!** 0.05 – 0.1 Hz




**10 hours**




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

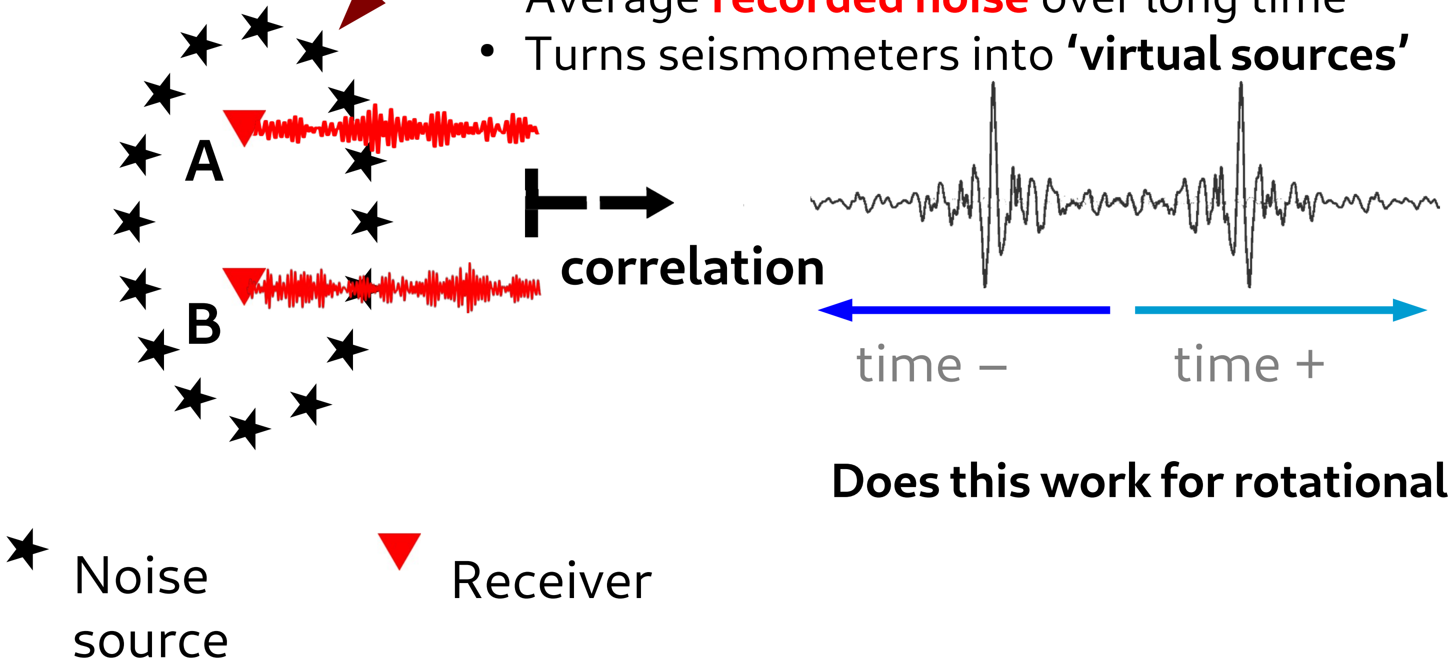
Can we perform **ambient noise interferometry** with rotational motions?

# Ambient noise interferometry

From seismic noise to useful signal: noise interferometry

**Ideal case:**

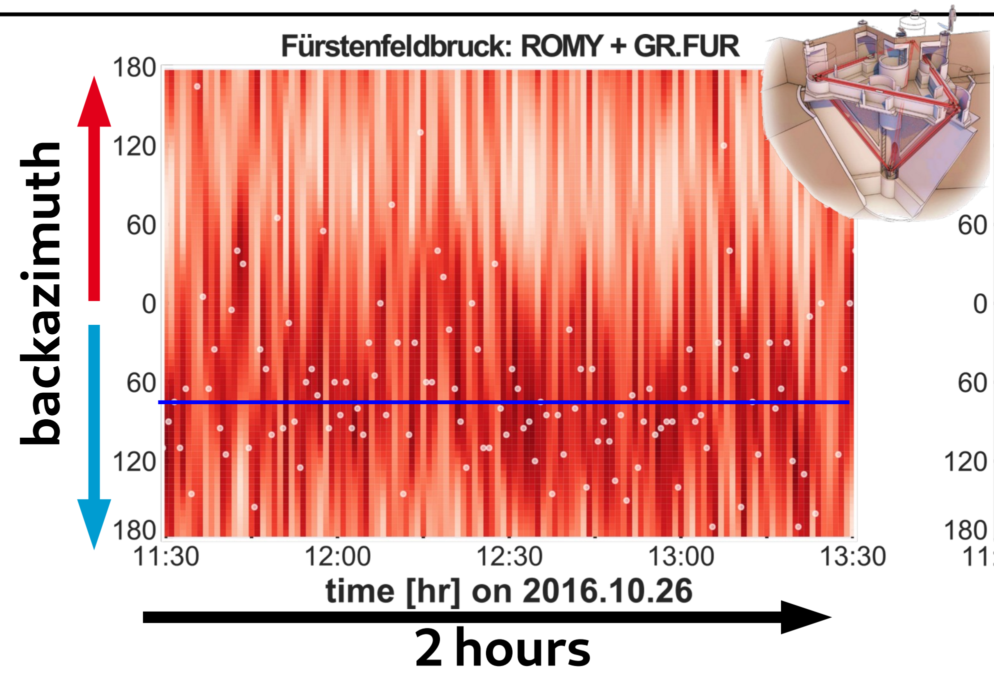
- **noise sources** illuminating medium from all sides
- Average **recorded noise** over long time
- Turns seismometers into **‘virtual sources’**

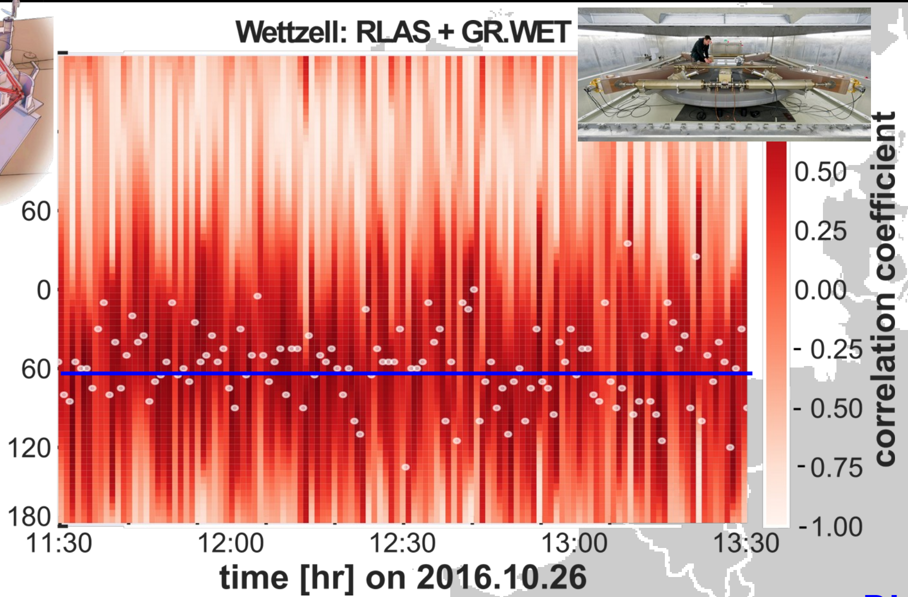



**Does this work for rotational motion?**

Want to know more?
*“Tutorial on seismic interferometry”, Wapenaar et al, Geophysics 2010*

# **Seismic noise interferometry** with rotational ground motion?

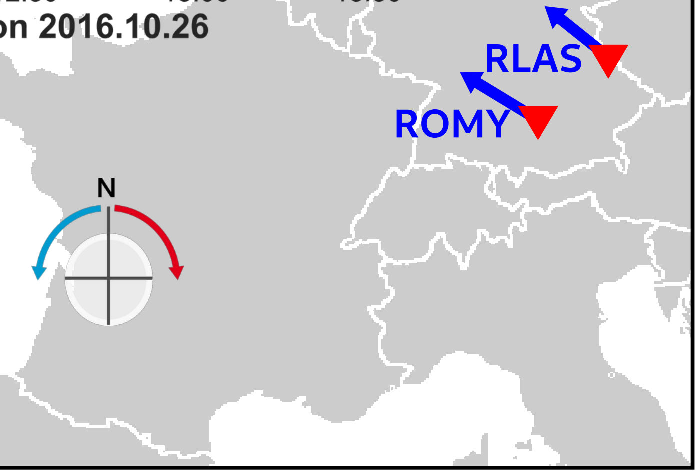



**0.1 – 0.2 Hz**

**Secondary microseism** available on both sensors

Dominant source toward NW consistent with beamforming

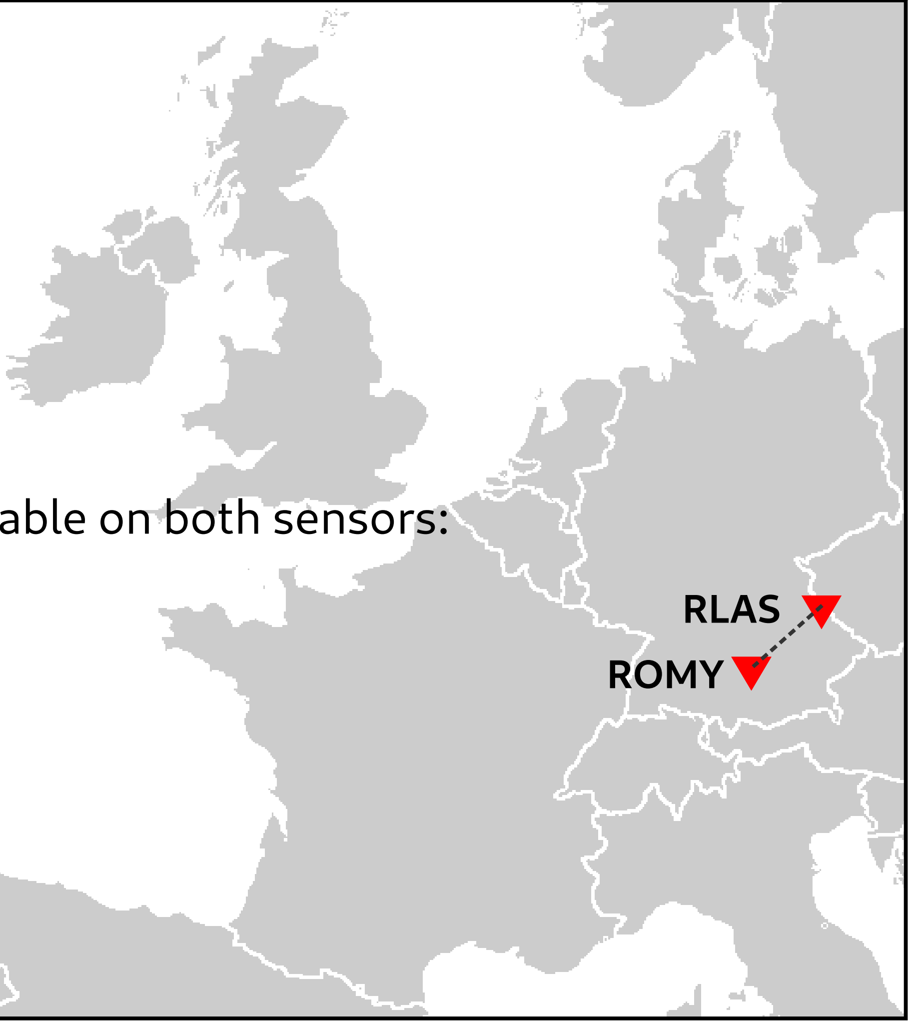



*"Where do ocean microseisms come from?"*
*Juretzek & Hadziioannou, JGR 2016*

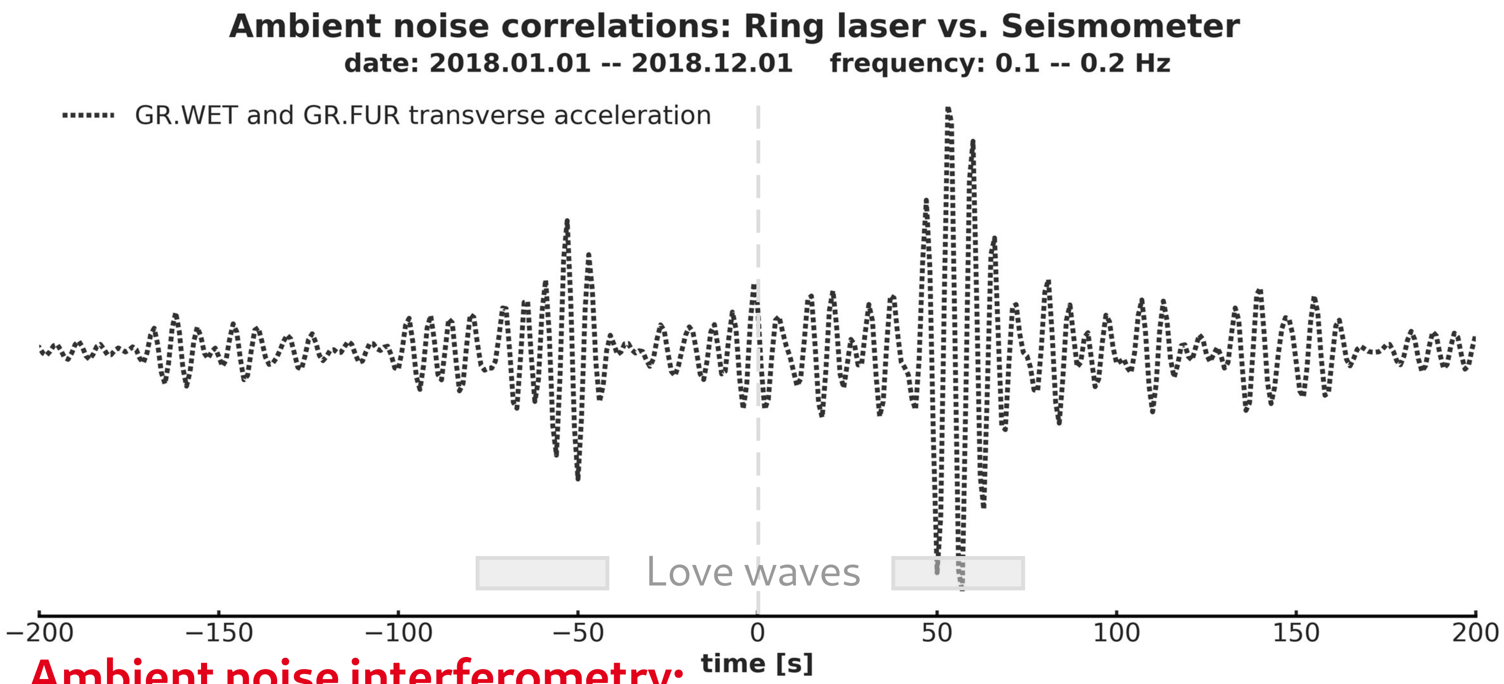
# **Seismic noise interferometry** with rotational ground motion?

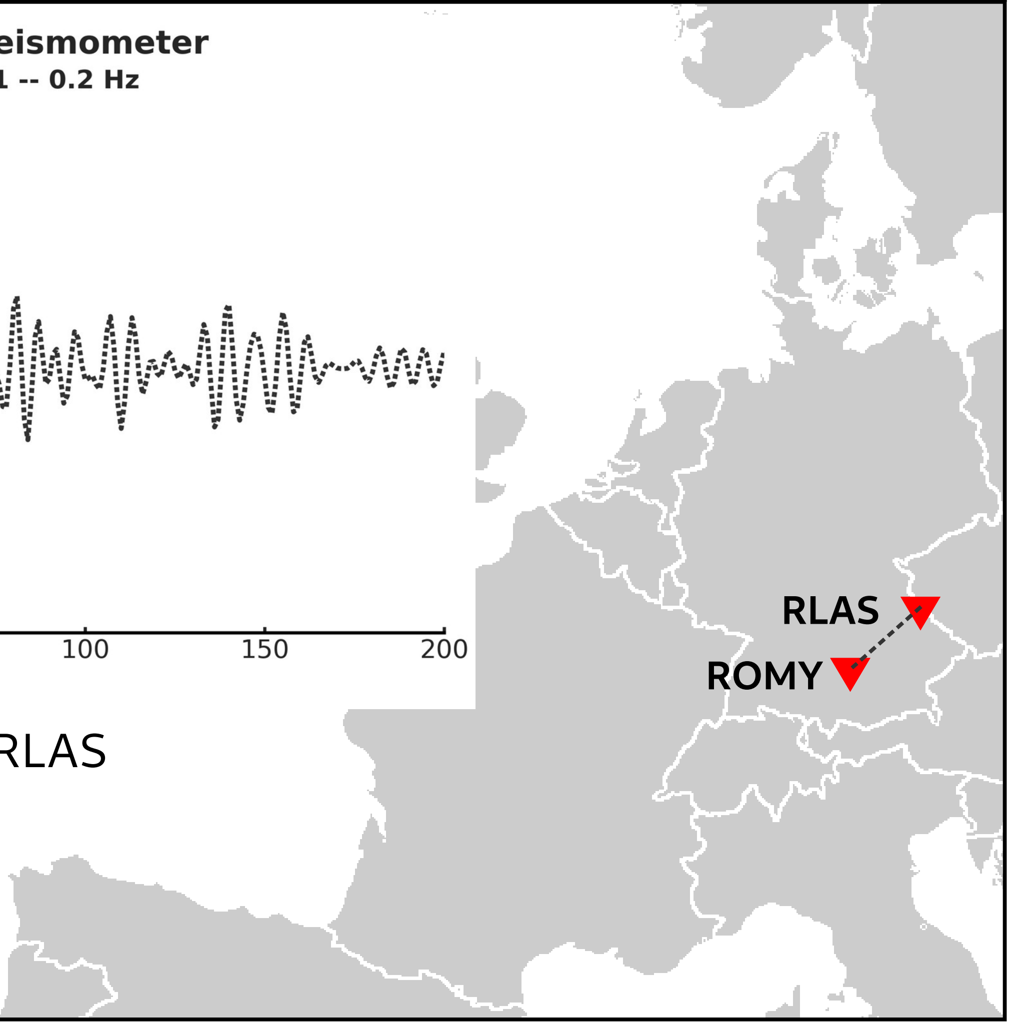
Need **long enough stacking time**:
→ ± one year of noise, 01.01.2018 – 01.12.2018

Ambient noise from the **secondary microseism** available on both sensors:
→ filter between 0.1 – 0.2 Hz



# **Seismic noise interferometry** with rotational ground motion?

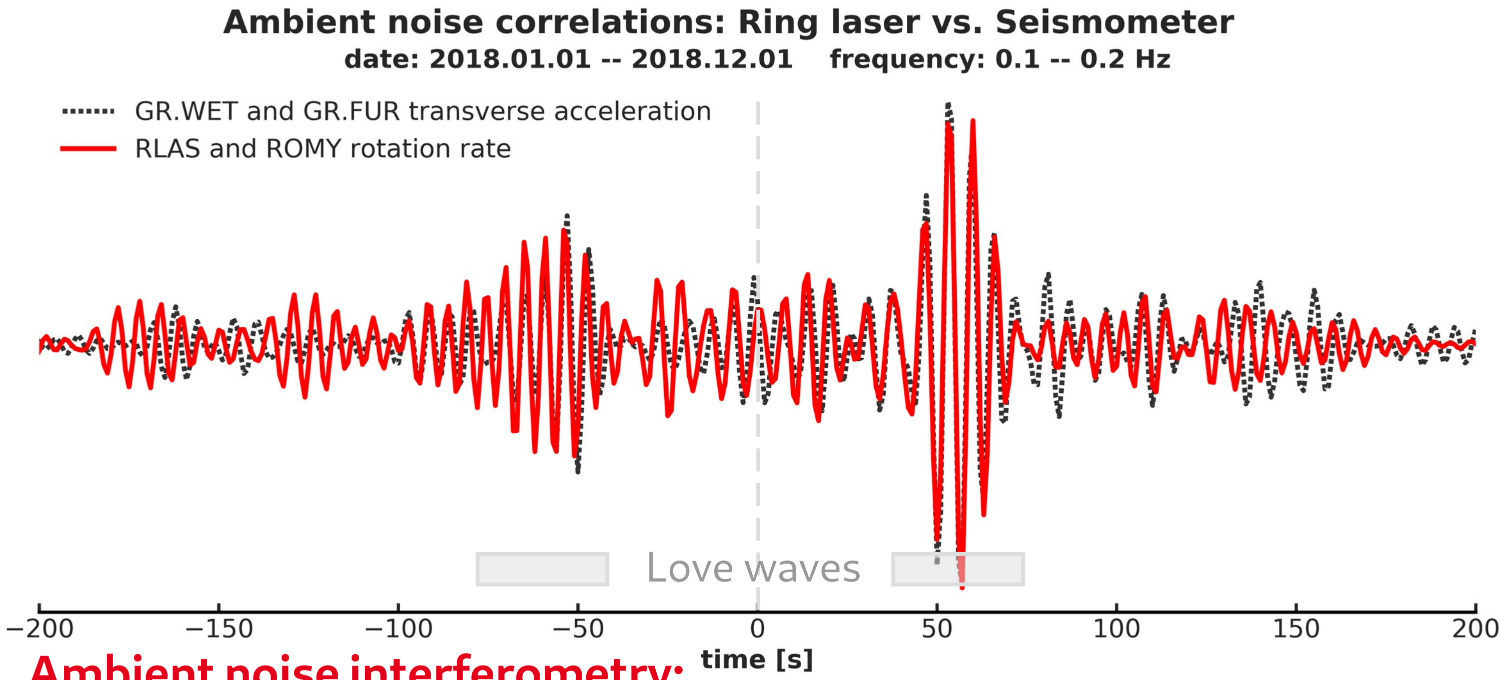


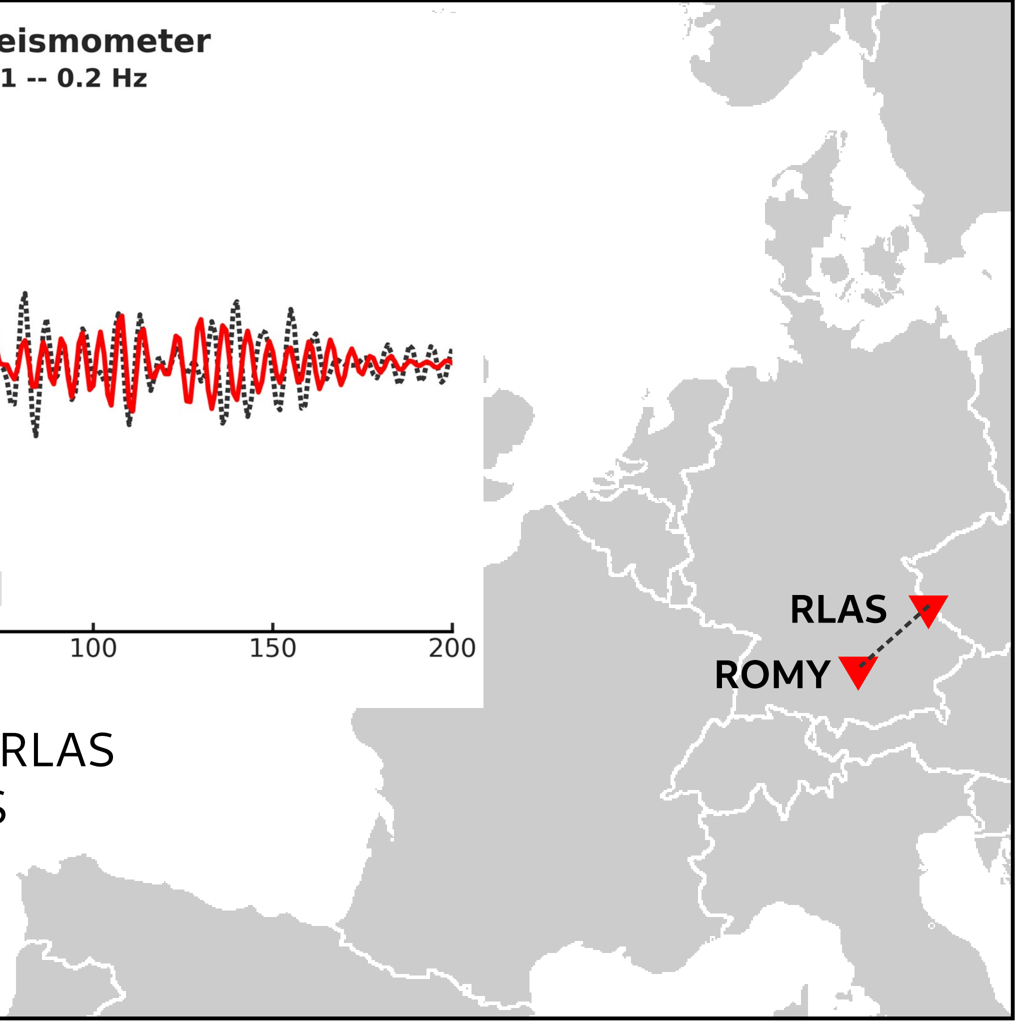




**Ambient noise interferometry:**

+ between **two seismometers** near ROMY and RLAS

# **Seismic noise interferometry** with rotational ground motion?

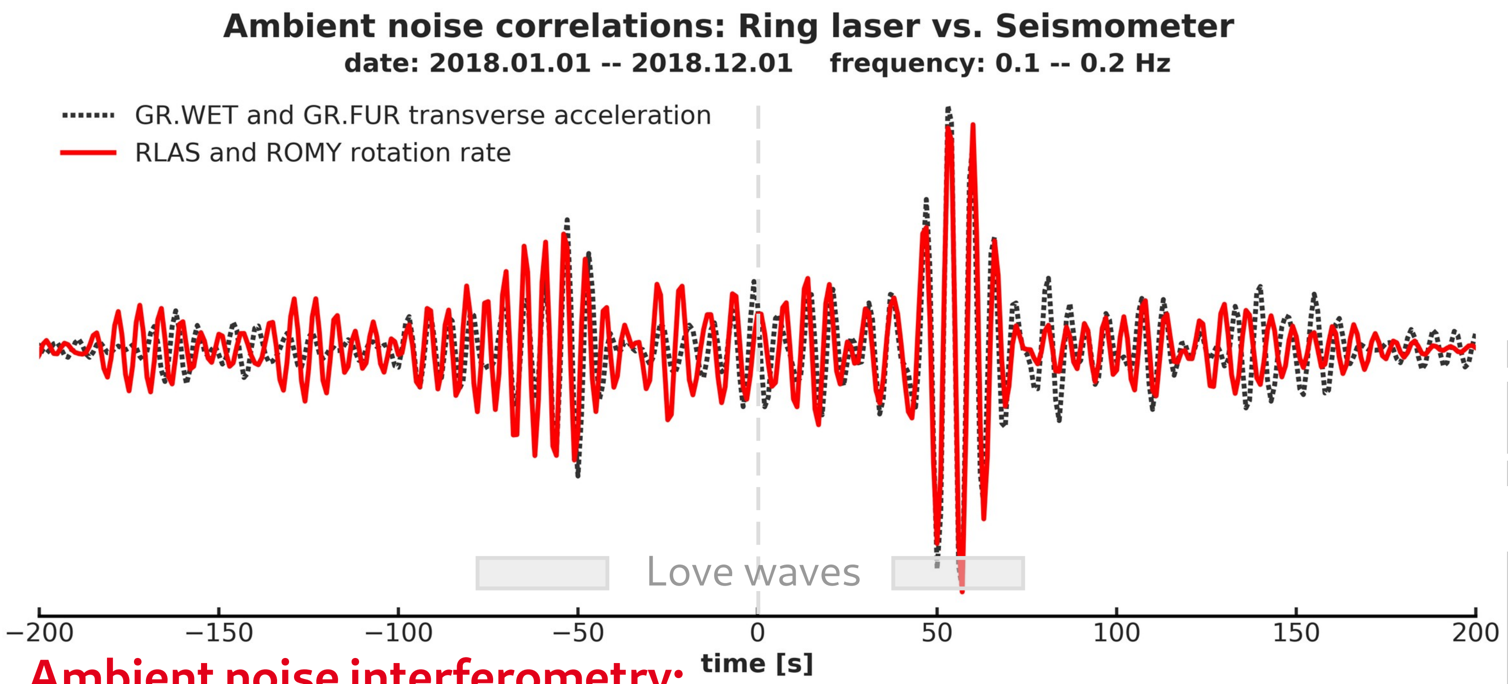


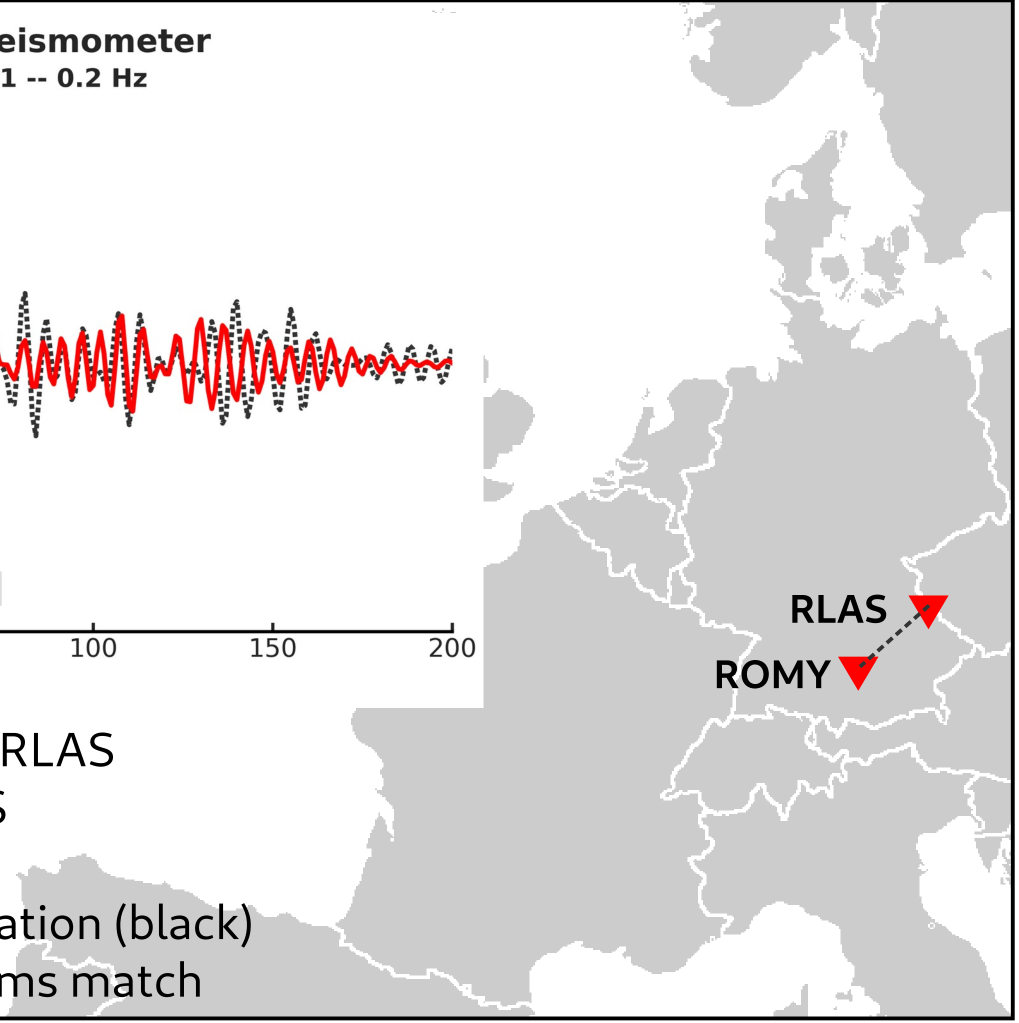




**Ambient noise interferometry:**

+ between **two seismometers** near ROMY and RLAS
+ between **the two ring lasers** ROMY and RLAS

# Seismic noise interferometry with rotational ground motion?

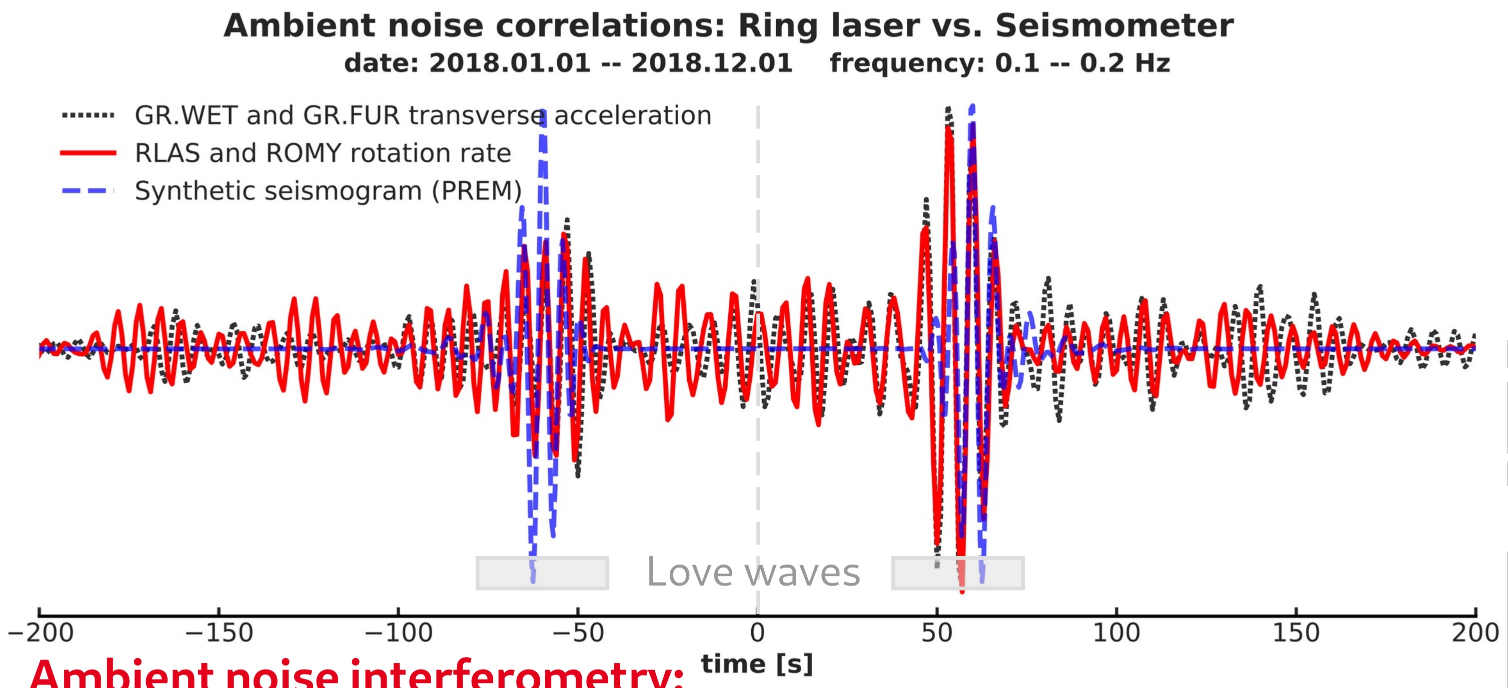



**Ambient noise interferometry:**

+ between **two seismometers** near ROMY and RLAS
+ 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

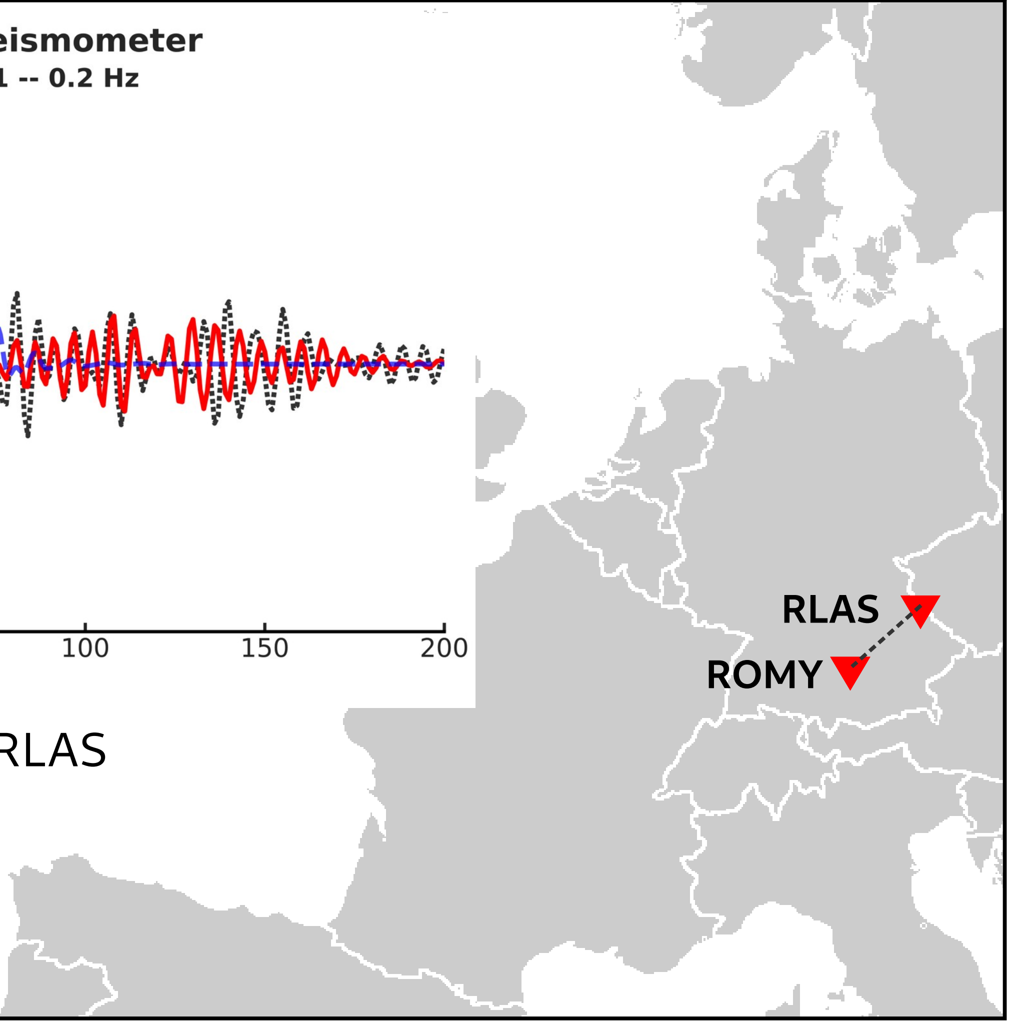
# **Seismic noise interferometry** with rotational ground motion?




**Ambient noise interferometry:**

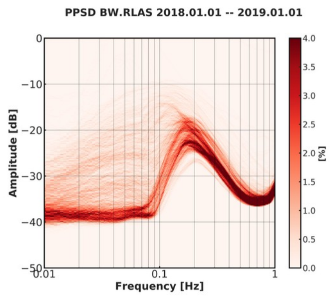
+ between **two seismometers** near ROMY and RLAS
+ between **the two ring lasers** ROMY and RLAS
+ **synthetic signal** for 1D model (PREM)

source at RLAS recorded at ROMY

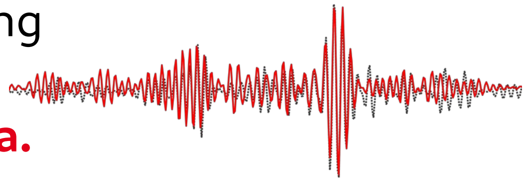


# Seismic noise analysis with rotational ground motion

**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 Framework Programme of the European Union

- **Innovative Training network funded by EU H2020 programme Starting march 2021.**
- integrate emerging ground-motion sensing technology into seismological practice
- Effect of small-scale structure and changes on the seismic wave field
- **Train** a new generation of researchers: **15 PhD positions across Europe**

| | |
|---|---|
| **Germany** | University of Hamburg (Coordinator) |
| | LMU Munich |
| | GFZ Potsdam |
| **Switzerland** | ETH Zürich |
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| | Université Grenoble Alpes |
| **Ireland** | DIAS Dublin |
| **UK** | University of Edinburgh |
| | British Geological Service |

More about SPIN: spin-itn.eu

Slides & more: celine.hadzii.com

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  DOI: 10.1126/science.356.6335.236
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# References

**Rotational seismology database**


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**Get started with rotational data**

- seismo-live.org → rotational seismology
  → 3 introductory notebooks to reproduce some figures from the rotational database

# Other References (not exhaustive!)


**General Rotational seismology**

- Review article: Schmelzbach, C. *et al.,* (2018). Advances in 6C seismology: Applications of combined translational and rotational motion measurements in global and exploration seismology, Geophysics, 83(3)
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**Wavefield separation**

- Sollberger, David, et al. "6-C polarization analysis using point measurements of translational and rotational ground-motion: theory and applications." Geophysical Journal International 213.1 (2017): 77-97.

**Structure**

- Wassermann, J., Wietek, A., Hadziioannou, C., & Igel, H. (2016). Toward a Single - Station Approach for Microzonation: Using Vertical Rotation Rate to Estimate Love-Wave Dispersion Curves and Direction Finding. Bulletin of the Seismological Society of America.
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# Other References (not exhaustive!)


**Instrumentation**

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- www.romy-erc.eu
- www.rotational-seismology.org (with mailing list!)