

Broadband Observations of Rotational Ground Motions: Observations and Modelling

H. Igel¹, A. Cochard^{1,4}, A. Flaws^{1,2}, W. Suryanto¹, B. Schuberth¹, U. Schreiber³, D.N. Pham¹, A. Velikoseltsev³

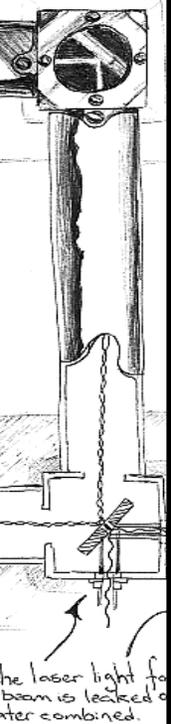
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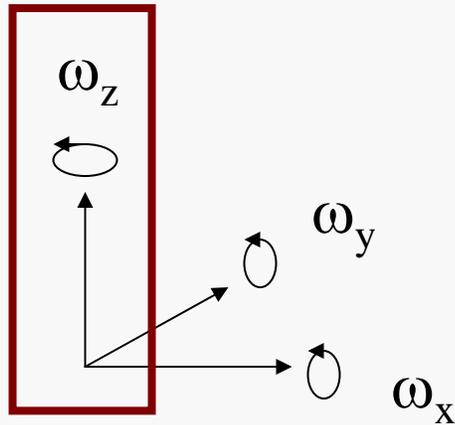
- **Array-derived vs. directly measured rotations**
- **Broadband observations of rotations vs. transverse accelerations**
 - Peak rotation rates
 - Waveform comparison with translations
 - Horizontal phase velocities
 - Love wave dispersion
 - P-coda signals
- **Conclusions and future**



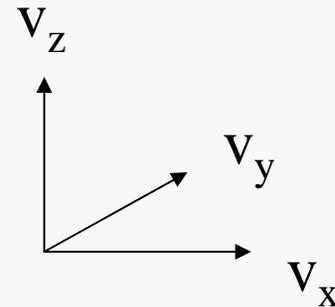
Rotation is the **curl** of the wavefield

... it separates P- and S-wave in isotropic media

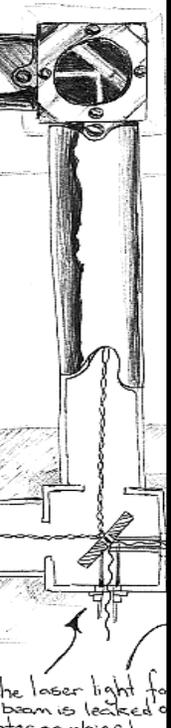
$$\begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} = \frac{1}{2} \nabla \times \underline{\mathbf{v}} = \frac{1}{2} \begin{pmatrix} \partial_y v_z - \partial_z v_y \\ \partial_z v_x - \partial_x v_z \\ \partial_x v_y - \partial_y v_x \end{pmatrix}$$



Rotation rate
Rotation sensor



Ground velocity
Seismometer



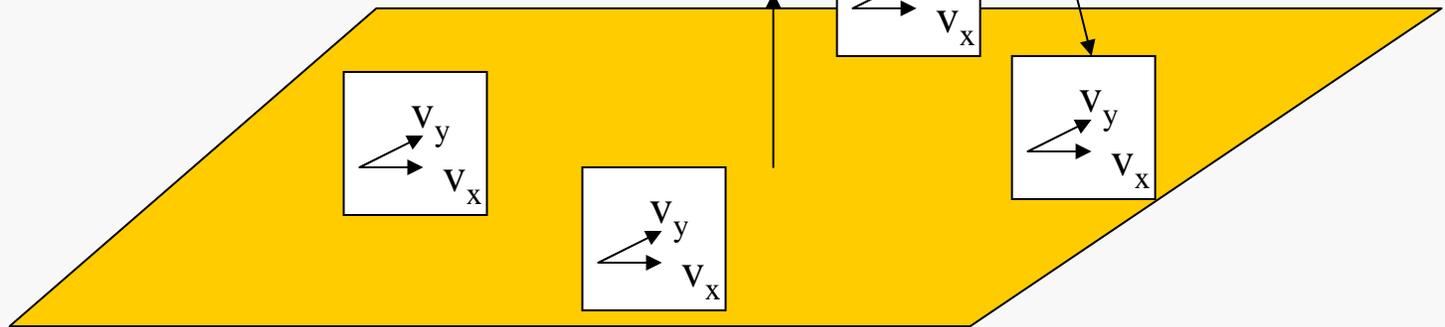
Rotation from seismic arrays?

... by finite differencing ...

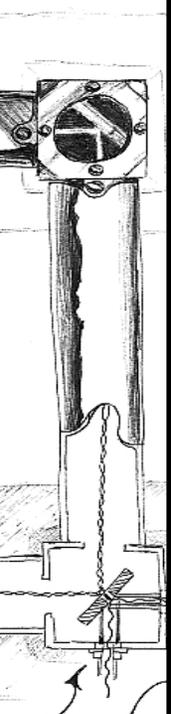
$$\omega_z \approx \partial_x v_y - \partial_y v_x$$

seismometers

ω_z



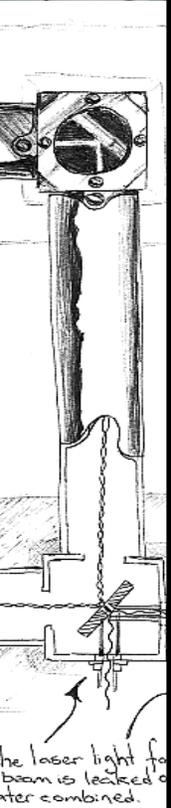
Rotational motion
estimated from
seismometer recordings



the laser light for
beam is leaked o
inter combined.

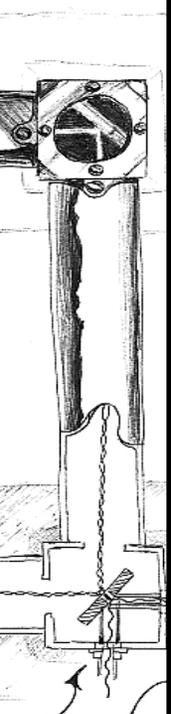
Initial Questions

- How do **direct** observations compare with **array-derived** rotations?
- Are the direct observations **consistent** with broadband translations?
- Can we extract any **useful information** from **collocated** recordings of translations and rotations?

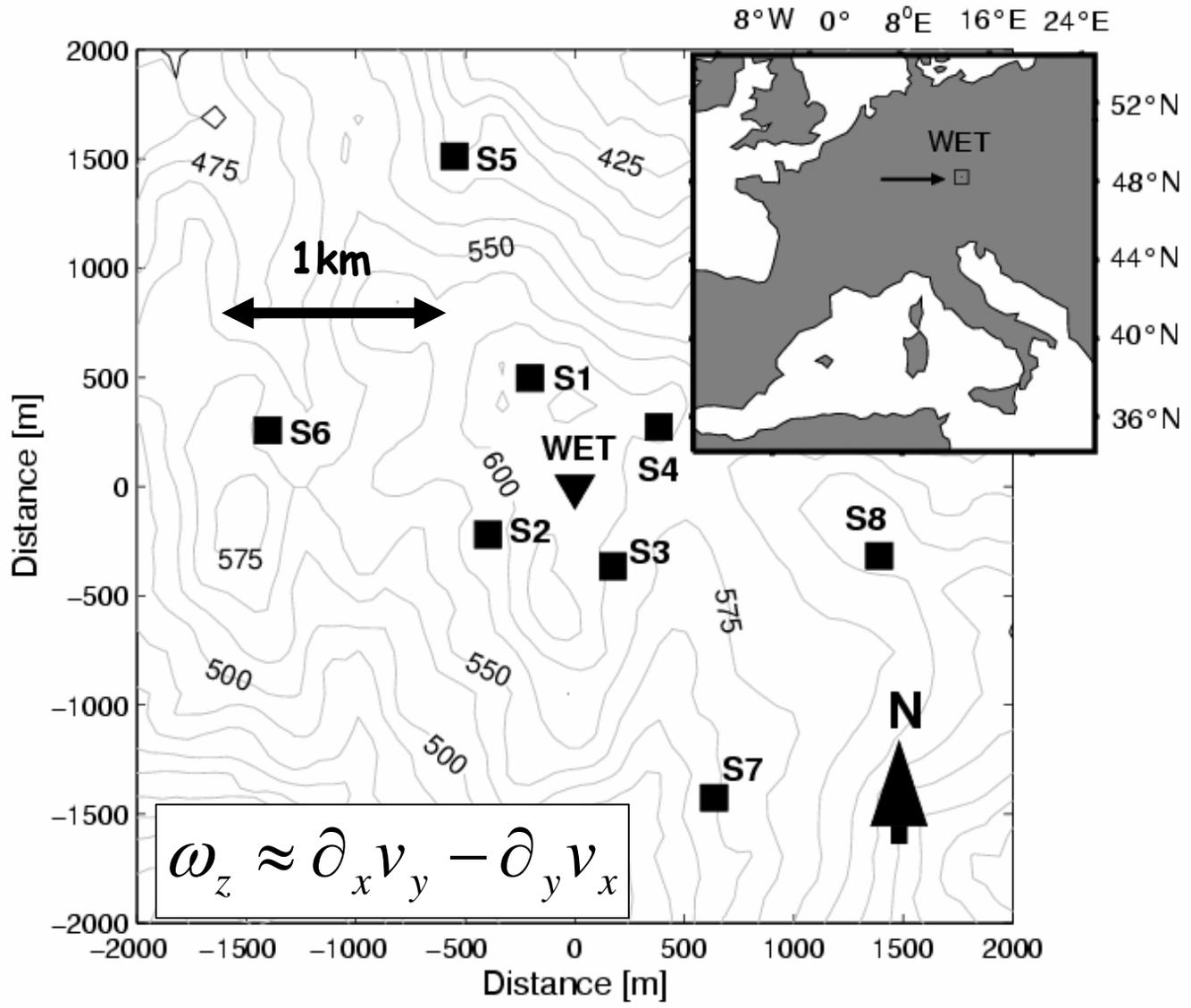


Array Experiment

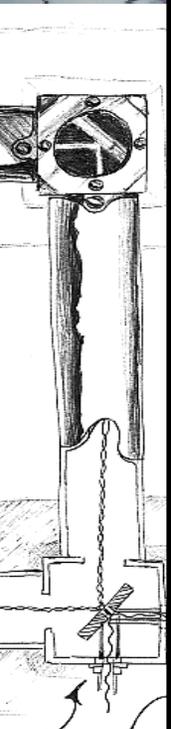
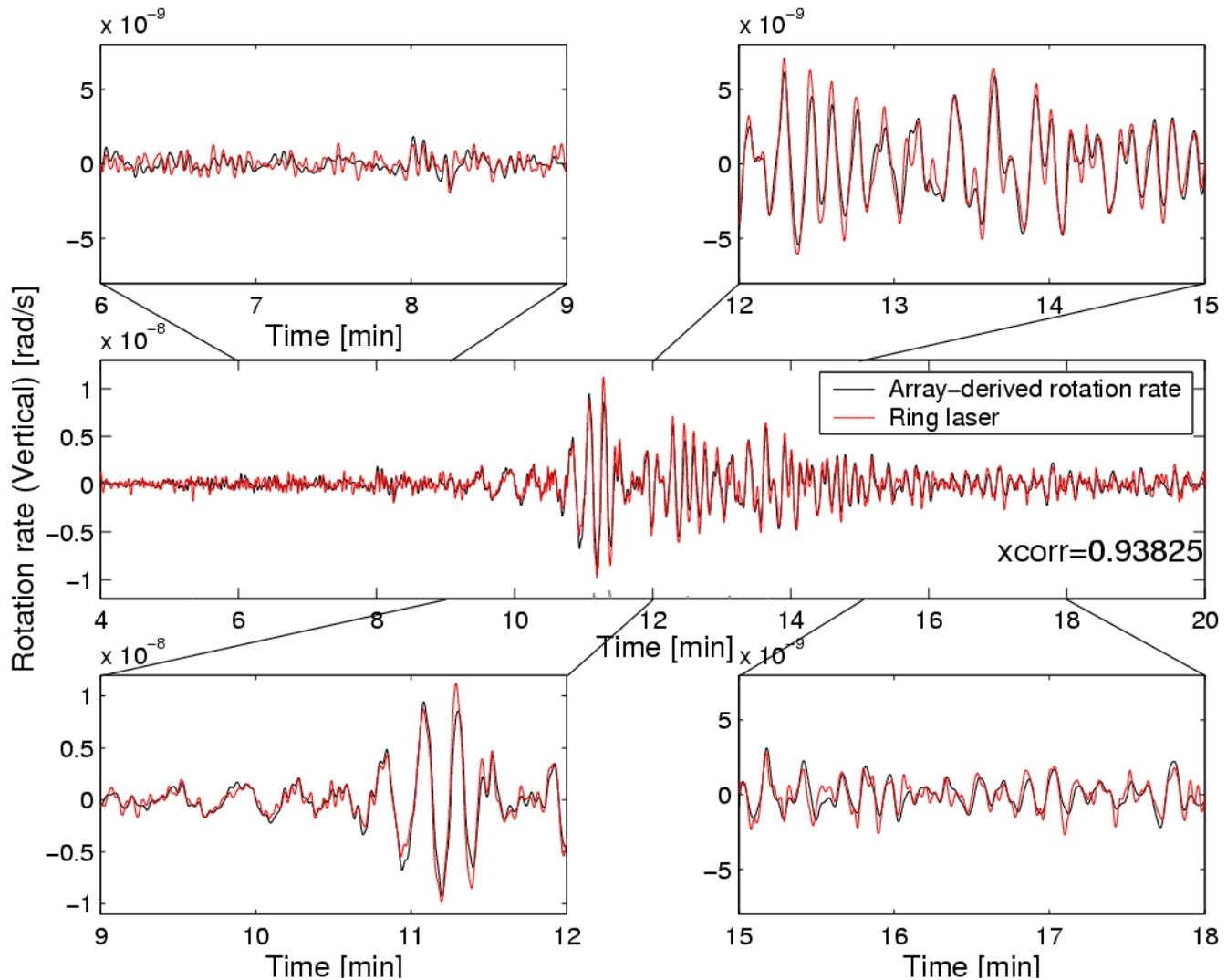
Dec 2003-Mar 2004



the laser light for
beam is leaked &
inter combined.

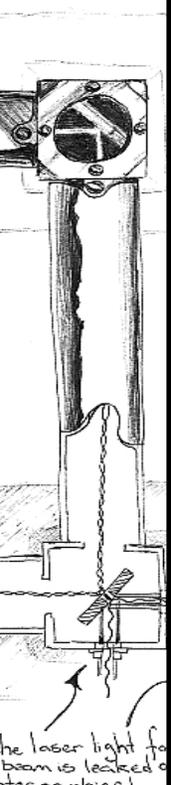


First comparison of array-derived rotations (black) and direct ring laser measurements (red)



the laser light for beam is leaked after combined.

From Suryanto et al (2006, BSSA, in print)



Theoretical relation

rotation rate and transverse acceleration
plane-wave propagation

Plane transversely polarized wave propagating in x-direction with phase velocity

$$u_y(x, t) = f(kx - \omega t) \quad c = \omega / k$$

Acceleration

$$a_y(x, t) = \ddot{u}_y(x, t) = \omega^2 f''(kx - \omega t)$$

Rotation rate

$$\Omega(x, t) = \frac{1}{2} \nabla \times [0, \dot{u}_y, 0] = \left[0, 0, -\frac{1}{2} k \omega f''(kx - \omega t) \right]$$



$$a(x, t) / \Omega(x, t) = -2c$$

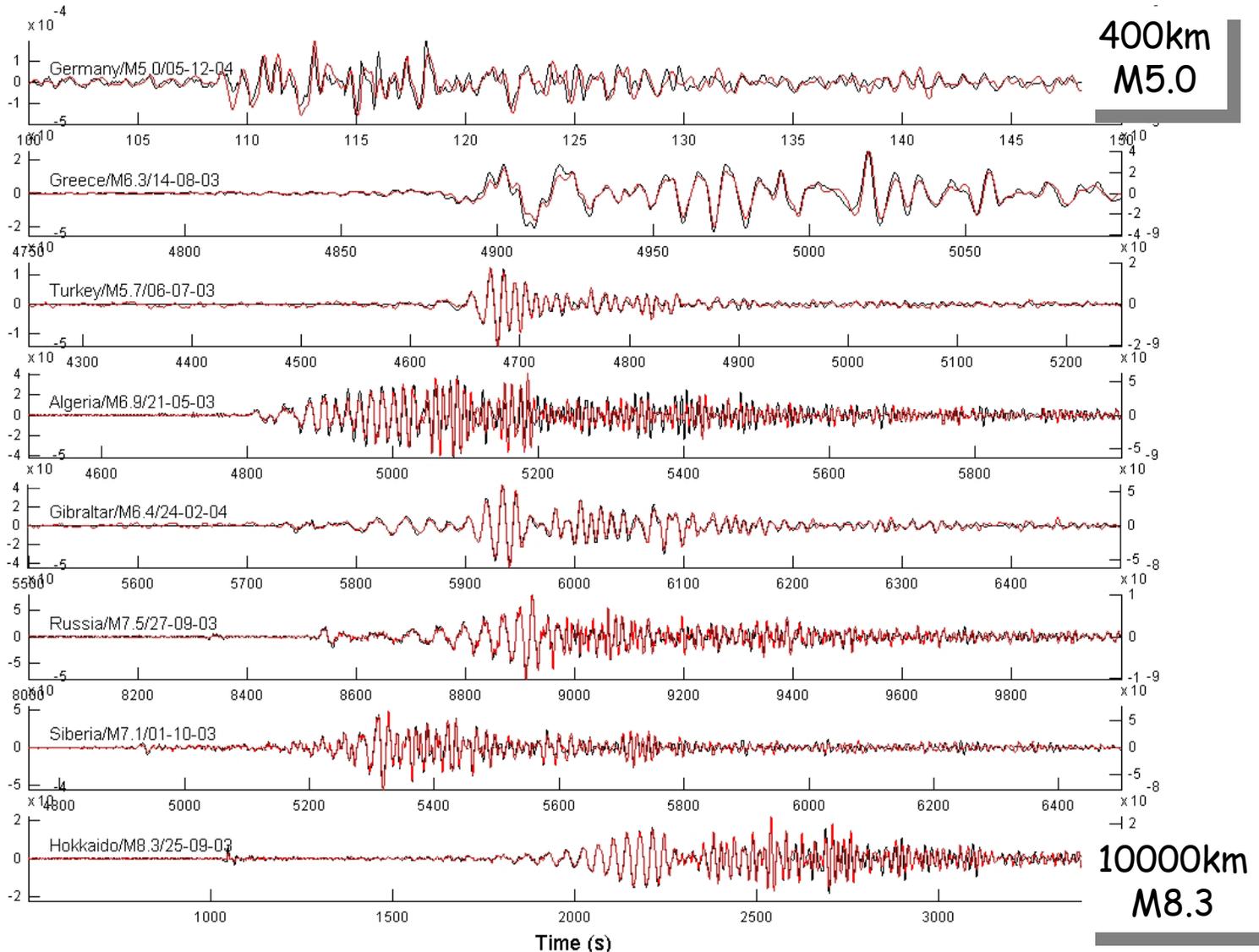
Rotation rate and acceleration should be **in phase** and the **amplitudes scaled by two times the horizontal phase velocity**

the laser light for
beam is leaked o
ater combined.

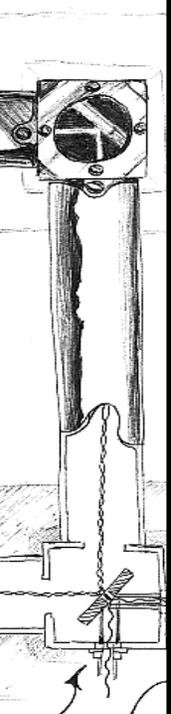
Rotational data base

events with varying distance
transverse acceleration - rotation rate

increasing epicentral distance



From Igel et al., *GJI*, 2007



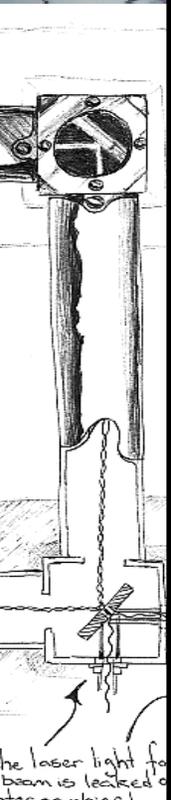
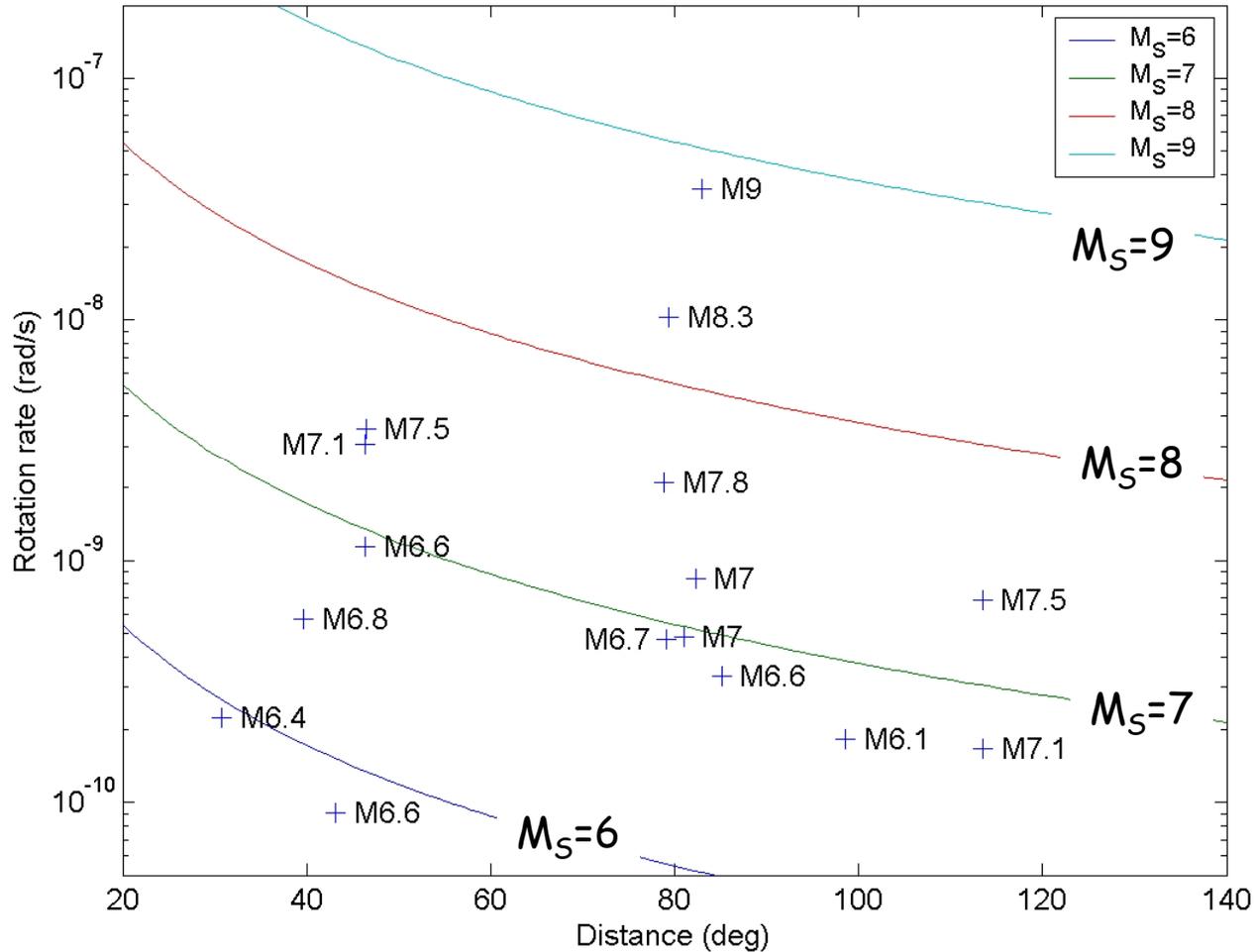
the laser light for beam is leaked after combined.

Compatibility with MS (surface wave magnitude)

$T=30s, c=4300m/s$

$$M_S = \log_{10} \frac{A}{T} + 1.66 \log_{10} D + 3.3$$

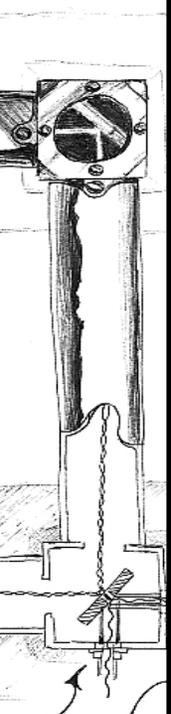
$$\Omega_z = 2 \frac{\pi^2}{cT^2} A(M_S, D) = 2 \frac{\pi^2}{cT} 10^{M_S - 1.66 \log_{10} D - 9.3}$$



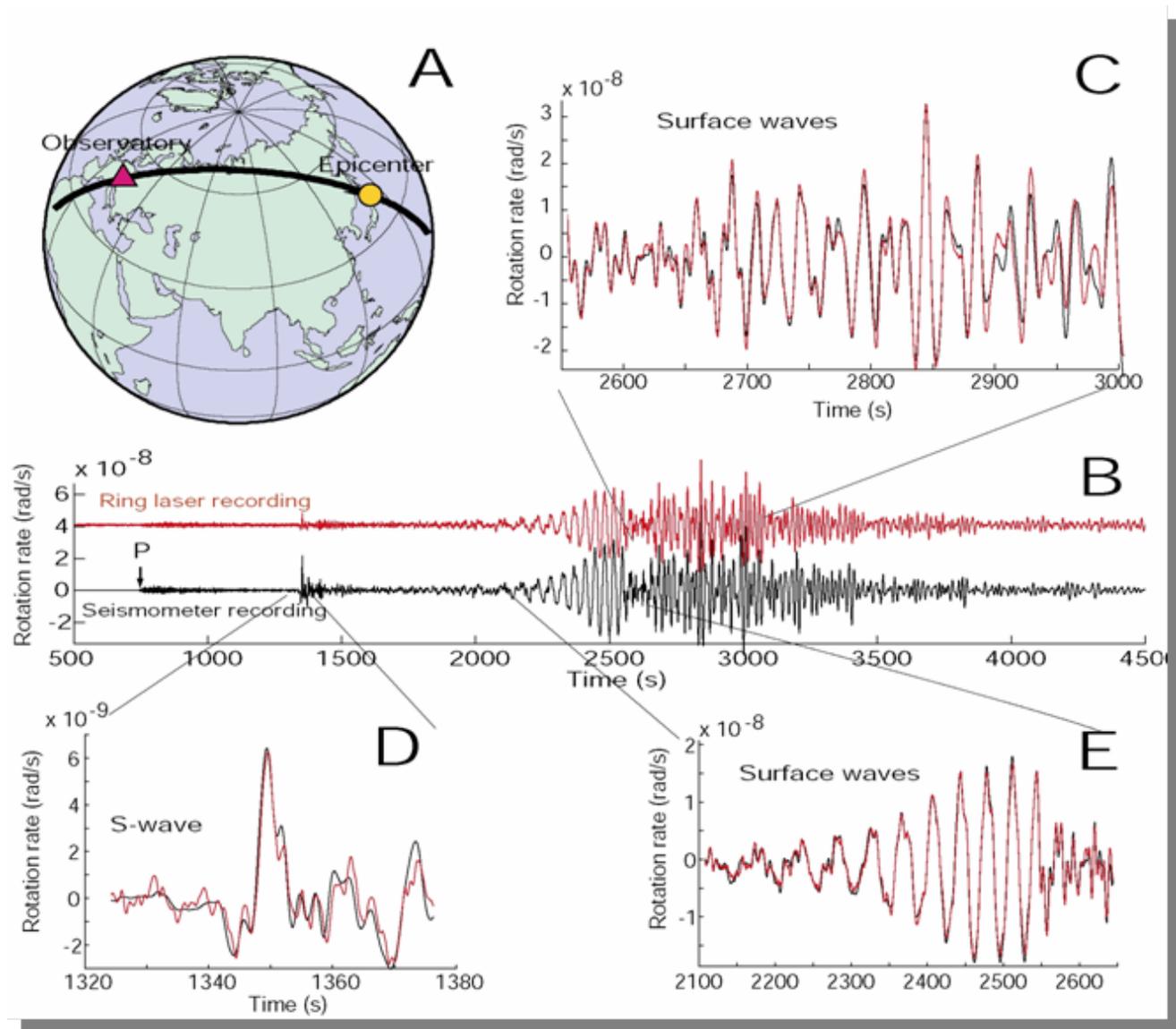
the laser light for beam is leaked or after combined.

Mw = 8.3 Tokachi-oki 25.09.2003

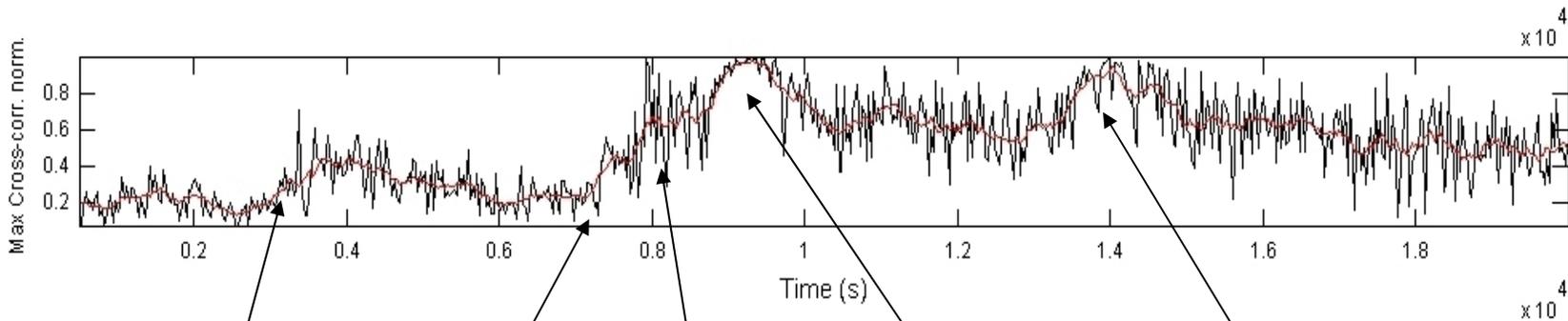
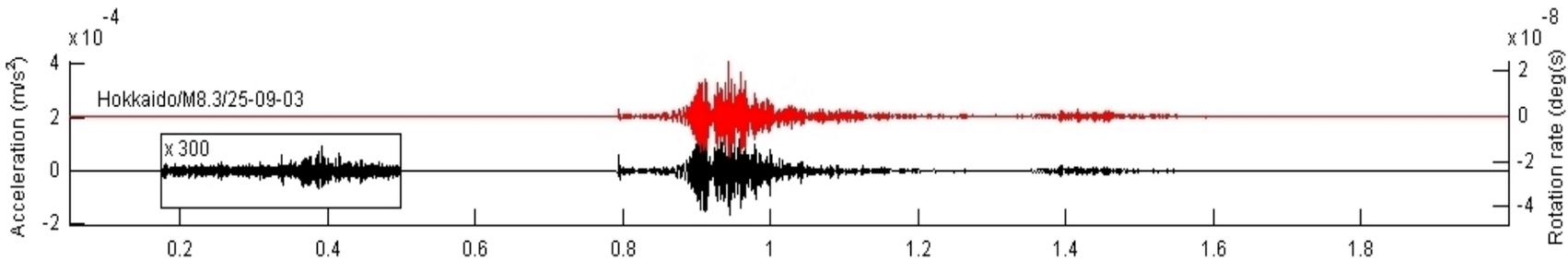
transverse acceleration - **rotation rate**



the laser light for the beam is leaked after combined.



Max. cross-corr. coefficient in sliding time window transverse acceleration - rotation rate



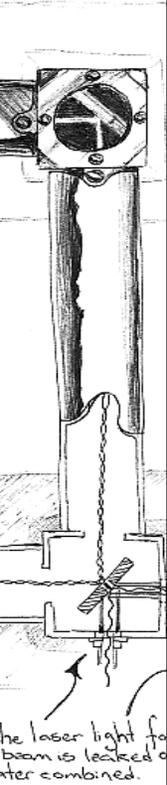
P-onset

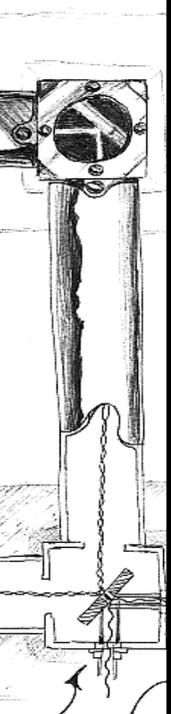
S-wave

Love waves

Aftershock

Small tele-seismic event

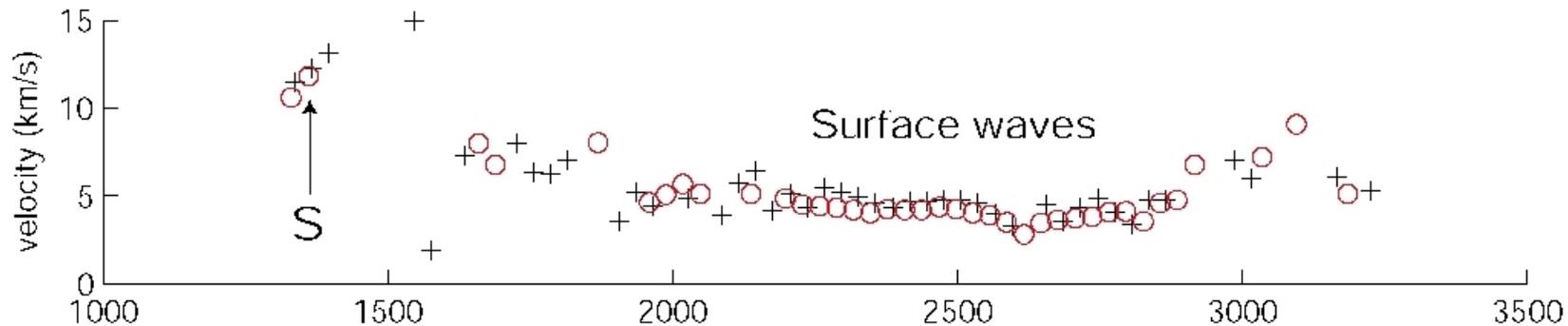
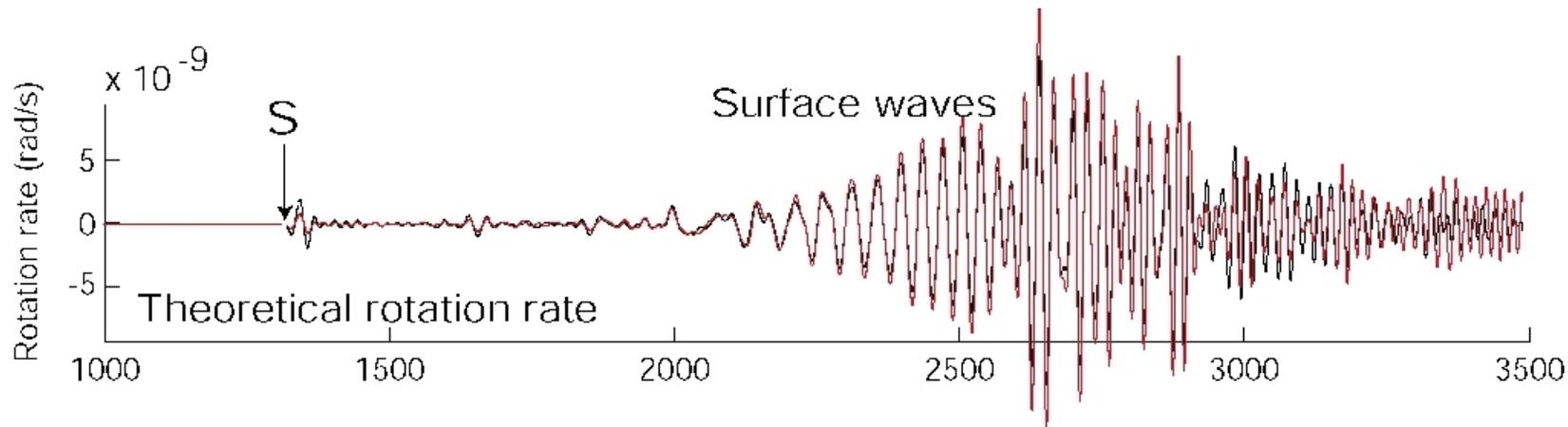




the laser light for beam is leaked after combined.

M8.3 Tokachi-oki, 25 September 2003

phase velocities (+ observations, o theory)



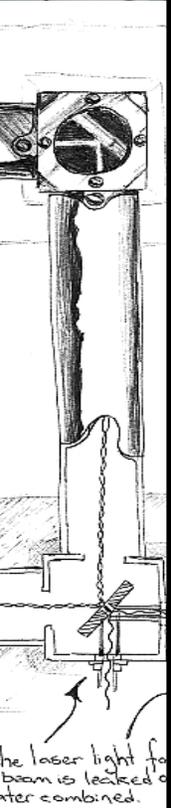
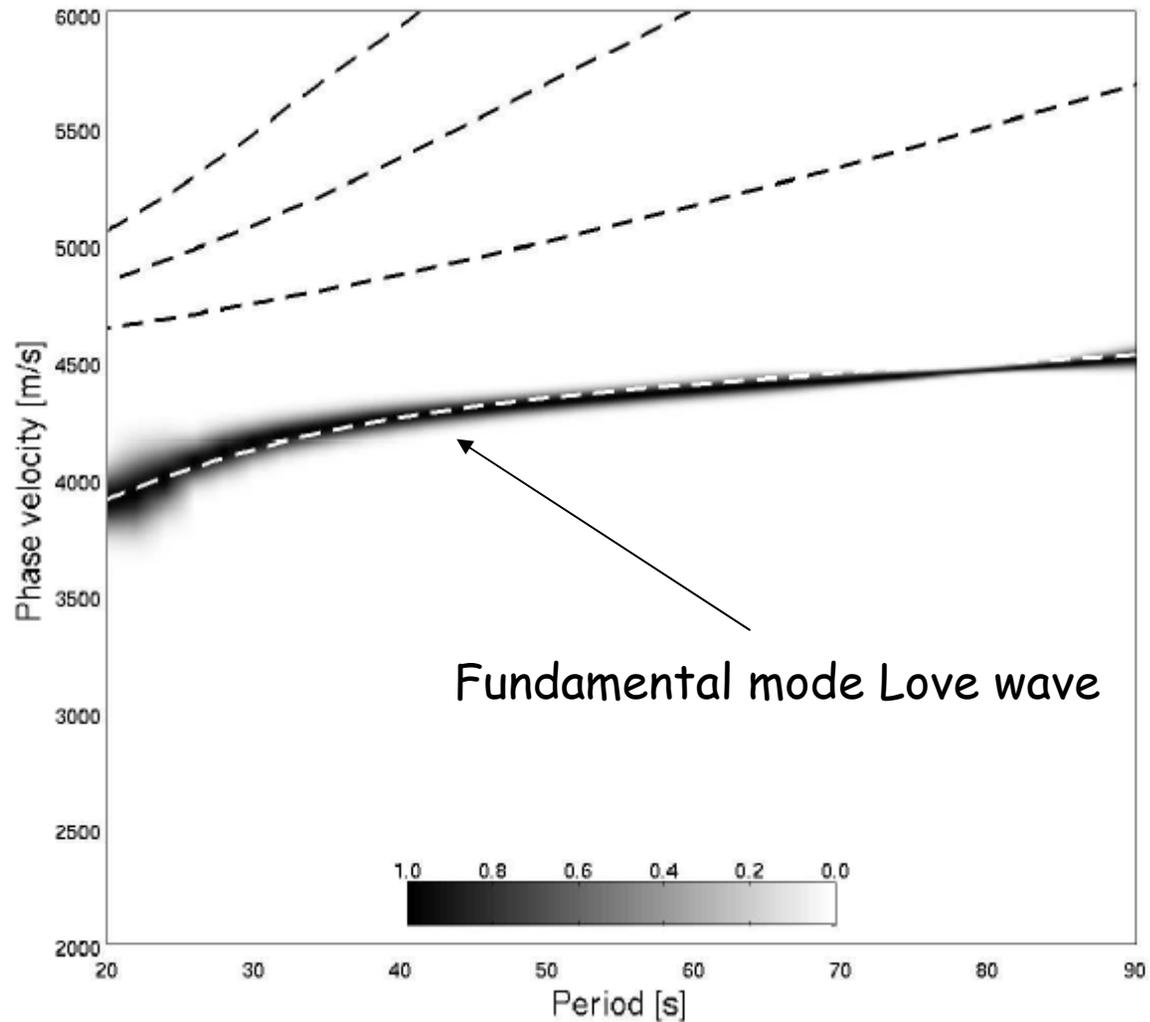
Horizontal phase velocity in sliding time window

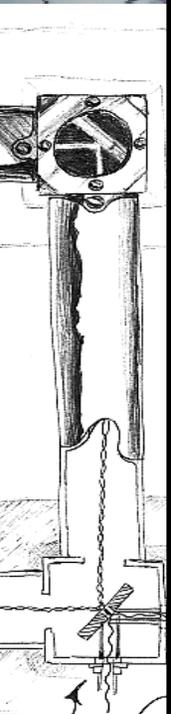
From Igel et al. (GRL, 2005)

Stacked spectral ratios ...

Synthetic example

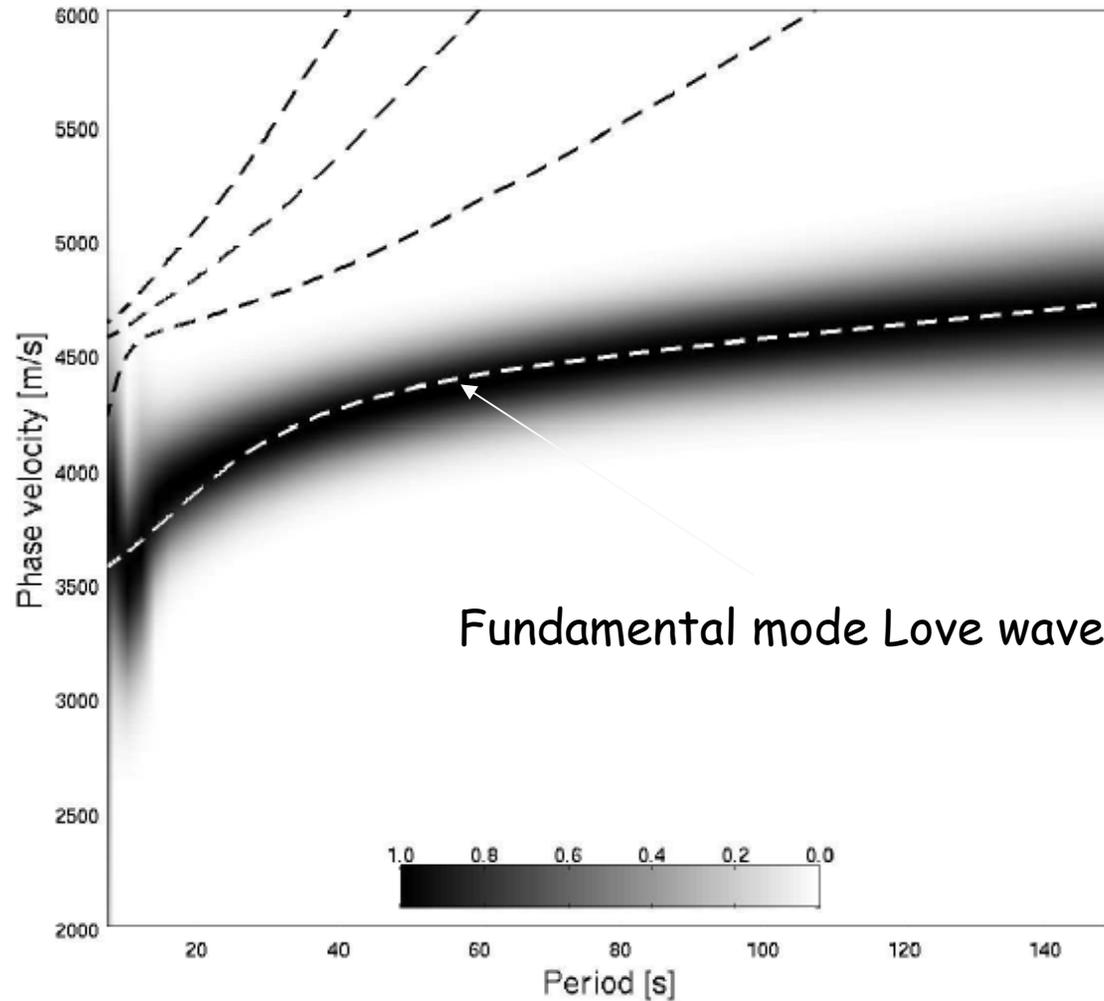
Four spectral ratios averaged - theoretical dispersion for ak135



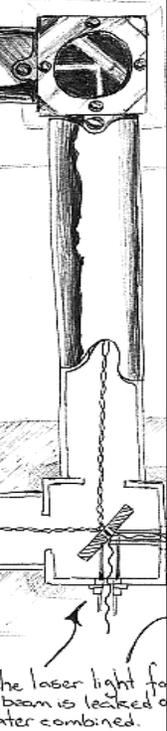
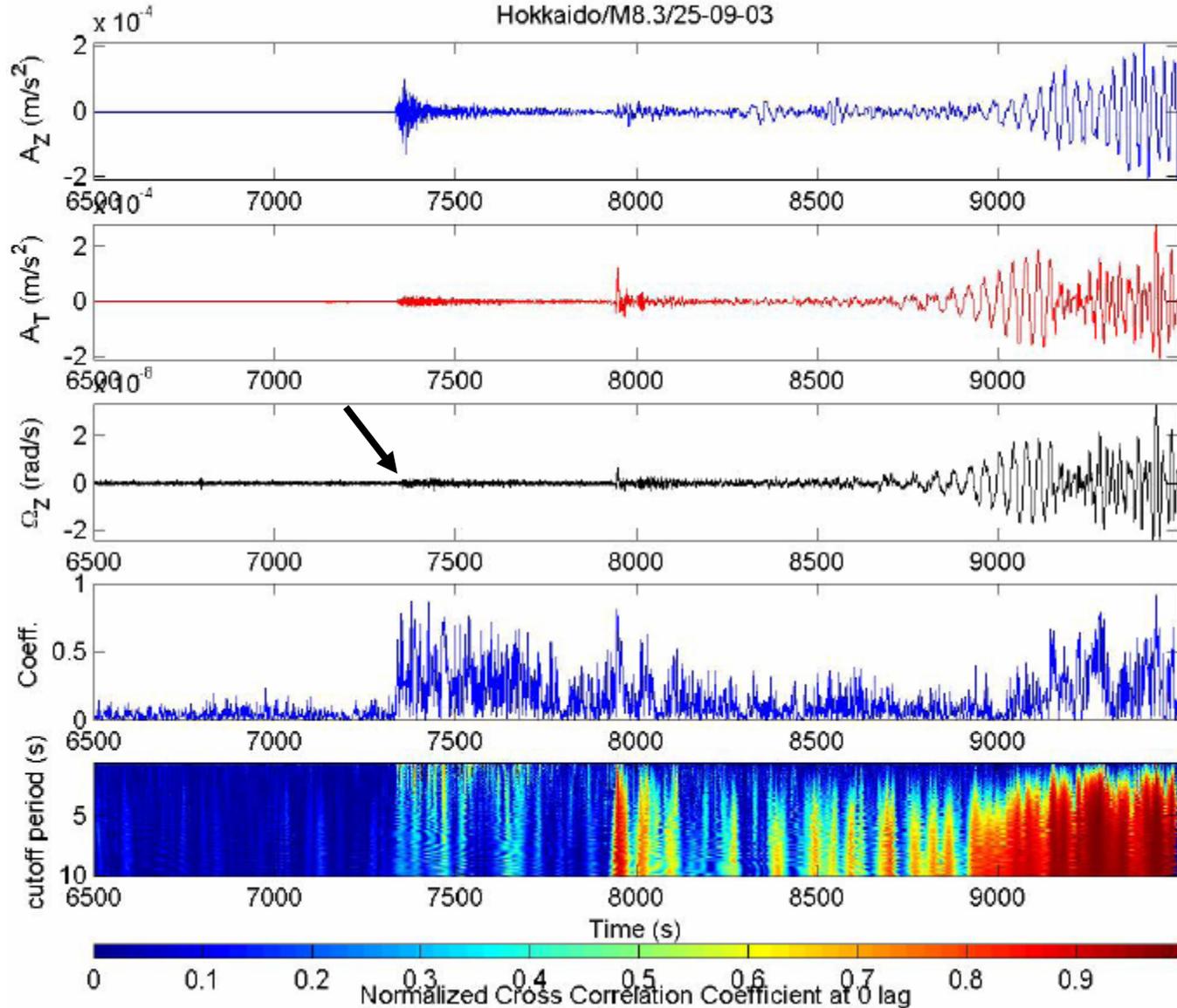


the laser light for beam is locked after combined.

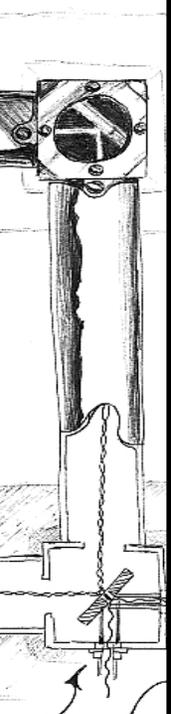
Stacked spectral ratios ... observations - nine teleseismic events



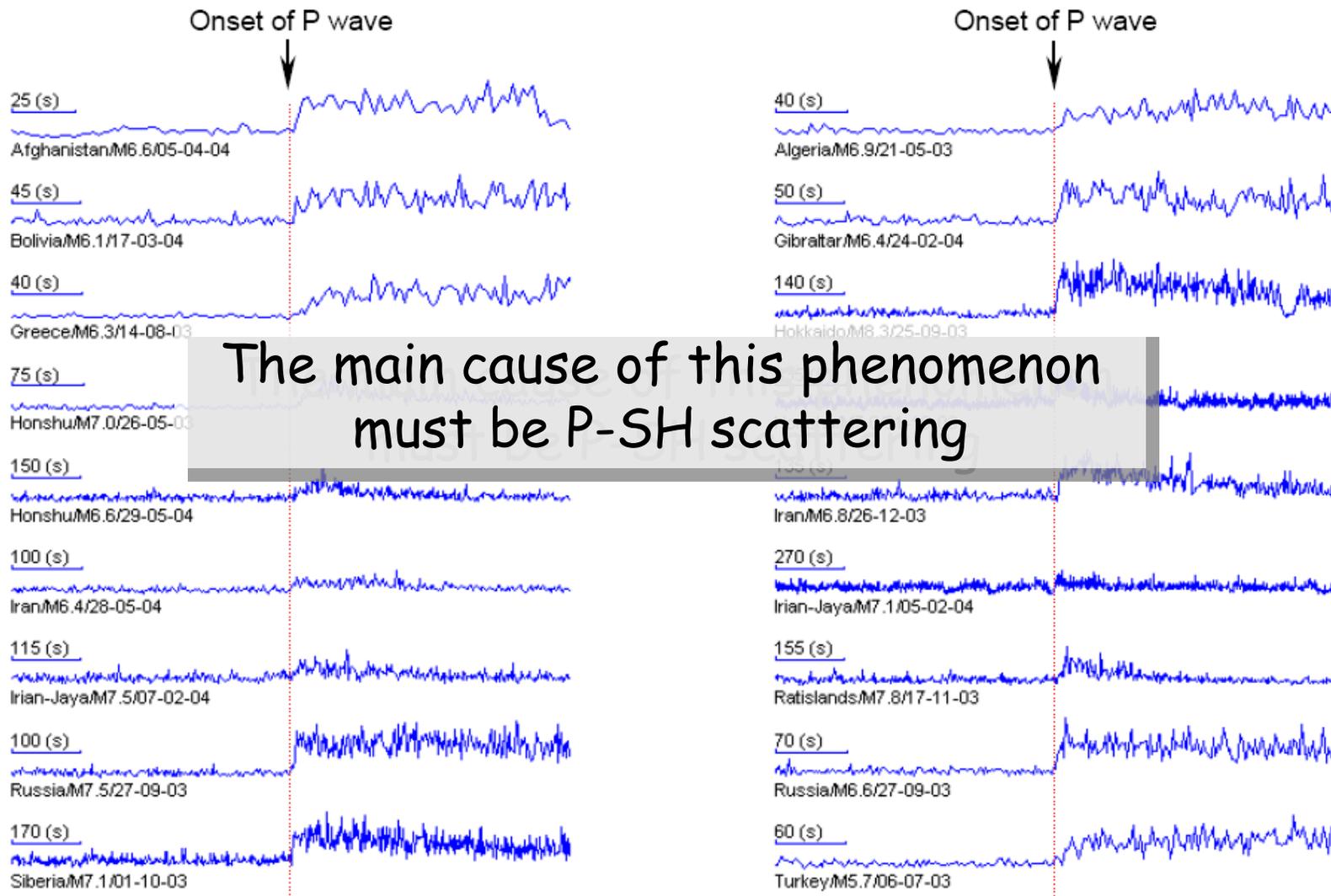
Rotational signals in the P-coda???



Increase in **correlation** (rotation rate vs. transverse acceleration) at P-onset ... observable for all events!



the laser light for beam is leaked after combined.



The main cause of this phenomenon must be P-SH scattering

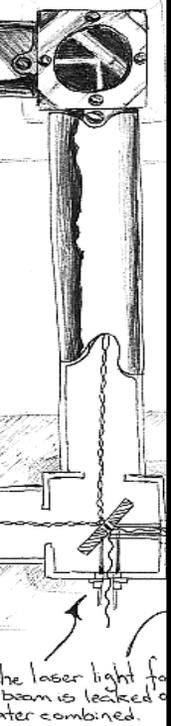
Rotations - why bother?

- Standard seismological observations are polluted by rotations
- Tiltmeters (rotation around horizontal axes) are polluted by translations
- 6C sensor may allow integration to displacements
- Rotations may contribute to co-seismic structural damage
- Rotational measurements may provide additional wavefield information (phase velocities, etc)
- ... and may allow further constraints on rupture processes ...

Instruments

Earthquake
engineering

Waves
and
rupture



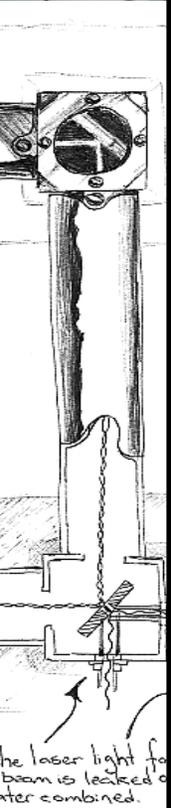
Summary

seismic ground rotations

- We do have a new observable for broadband seismology, that is **consistent in phase and amplitude** with collocated recordings of translations
- The joint observations allow seismic array-type (but array-free!) processing steps
- A prototype sensor designed for seismology has been installed at **Piñon Flat Observatory, CA**

Open questions:

- **Love-wave dispersion**, how accurate? -> Tomography? -> What volume does it represent?
- Understanding observations in data base in terms of **structure, anisotropy, scattering, source, etc.**
- How to improve **S/N ratio** of ring laser records?
- What technology is best for **strong motions**?
- Would observations of rotations allow tighter constraints on **finite source parameters**?



International Working Group on Rotational Seismology

Welcome to the IWoRS Home page! – IWoRS Homepage -Netscape

http://www.rotational-seismology.org/

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- TG Broadband Observations
- TG Processing
- TG Sensors

Welcome to the IWoRS Home page!

The purpose of the **International Working Group on Rotational Seismology (IWoRS)** is to promote investigations of all aspects of rotational motions in seismology and their implications "for related fields" such as, earthquake engineering, geodesy, strong-motion seismology, tectonics, etc., and to share experience, data, software, and results in an open Web-based environment. In addition, to disseminate information on all matters pertaining to rotational motions through publications and by holding meetings and workshops, and to interact with professional bodies in engineering and science. A provisional **Charter** containing the goals, structure, and task groups of IWoRS is available.

Why and how to join a **mailing list**? If you are interested in receiving information on any issues happening in the task groups or the working group as a whole you can click on the specific mailing lists and join directly.

If you want to become an **active member** (providing information on projects, events, news, etc) you can request a login for immediate access.

by **Heiner Igel** — last modified 2006-12-06 16:16

news

- Postdoc position in rotational seismology, LMU Munich
2006-12-04
[More news...](#)

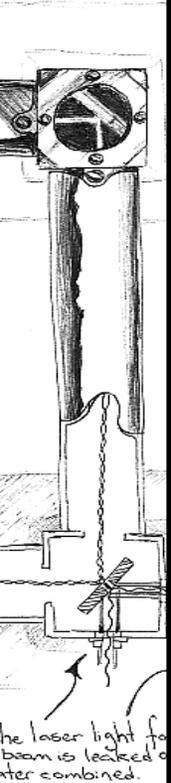
upcoming events

- AGU06 Session on Rotational seismology
San Francisco, 2006-12-11
- IWoRS Inauguration Meeting
San Francisco, 2006-12-12
[Upcoming events...](#)

December 2006

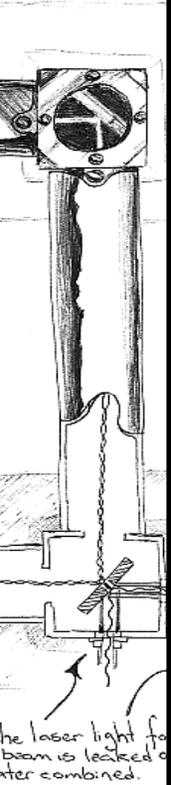
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www.rotational-seismology.org



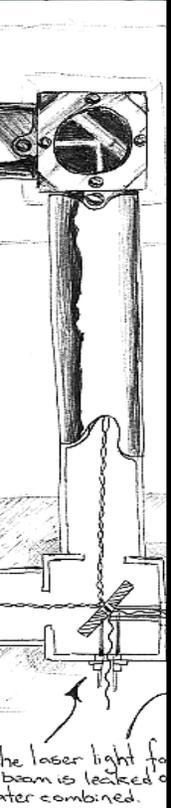
International Working Group on Rotational Seismology **aims at**

- **promoting investigations of all aspects of rotational motions in seismology** and their implications for „related fields“ such as, earthquake engineering, geodesy, strong-motion seismology, tectonics, etc.
- **sharing experience, data, software, and results** in an open Web-based environment.
- **disseminating information** on all matters pertaining to rotational motions through publications and by holding meetings and workshops
- **interacting with professional bodies** in engineering and science.
- **seeking funding** for research projects



Provisional Sub-Groups

- Processing of rotational motions
- Strong motion
- Theory
- Sensors
- Broadband observations



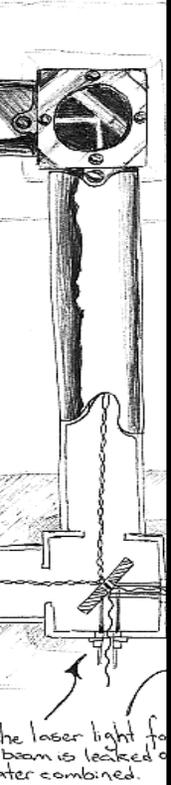
Sub-Group: Processing of rotational motions

Chair: Joachim Wassermann, LMU Munich.

Goals: Development and provision of processing and modelling tools for rotational motions

Current project:

- Developing a new Web-based methodology to **archive and process multi-component data with six-degree-of-freedom (6DOF) data** (specifically, but not exclusively, included).
- 3-year project, funded by German Research Foundation, Project scientist: Robert Barsch

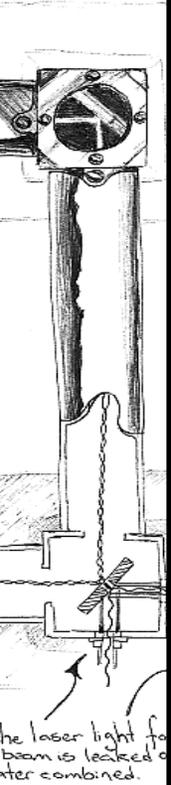


Sub-Group: Strong Motions

Chair: Misha Trifunac and Maria Todorovska, USC, Los Angeles.

Goals:

- Guidelines and recommendations for **how and where to record rotational strong motions**.
- Promoting establishment of several **full-scale laboratories for measurement of rotational strong motions in buildings** and on bridges, dams, and lifelines, as well as in the free field (near and far).
- Developing data processing methods for **processing 6DOF strong-motion records**.
- Developing software for **synthetic generation of realistic rotational accelerograms**, to facilitate engineering studies of the associated structural response.

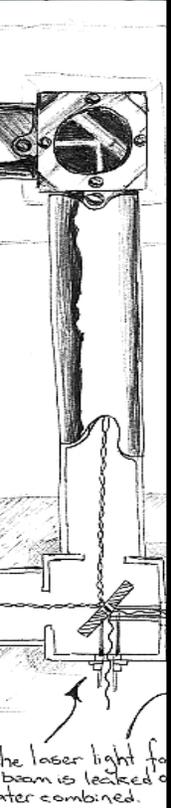


Sub-Group: Theory

Chairs: Alain Cochard, Strasbourg, and Eugeneiusz "Eugene" Majewski, Poland.

Goals:

- The relevance of rotational motions for **source inversion**.
- Rotational motions in **various rheologies** (anisotropic, viscoelastic, viscoplastic).
- Understanding the **difference between direct rotation and acceleration-derived rotation**
- **Physics of rotations in rock-forming minerals:** dislocations and disclinations.
- Generation, propagation, and attenuation of **seismic rotational waves**.
- **Dispersion** of seismic rotational waves.
- **Solitary rotational waves** as a fracture mechanism.



Sub-Group: Sensors

This task group will be divided into **strong** and **weak** motion sensors.

Chairs: Robert Nigbor, UCLA, John R. Evans, USGS, and Robert Hutt, USGS.

Strong-motion rotational sensors

Test sensitivity, linearity, 6DOF cross-axis sensitivity, and self noise of various strong-motion rotational sensors.

Work with the USGS Albuquerque Seismological Laboratory to procure and validate improved testing apparatus and to perform precision tests of at least strong-motion rotational sensors.

Chairs: Ulrich Schreiber, Wettzell, and B. Hurst, Christchurch.

Weak-motion rotational sensors

Improving the performance of large ring lasers for seismic studies

Verification of rotational sensor data by collocation of alternative techniques

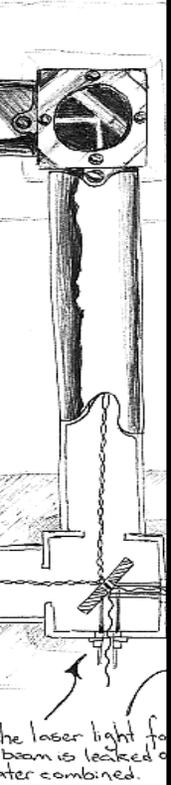
Improve existing detection concepts

Explore and evaluate **alternative sensor concepts** (FOG, IMU, Superfluid helium, electro-chemical) for teleseismic and strong motion application

Develop a full **highly sensitive 6-degrees of freedom sensor** to be tested at Pinon Flat Observatory and verify the performance (investigate implications of alignment errors)

Develop and evaluate sensor concepts to **monitor rotations in civil eng. structures**

Enhance productivity by interacting with other development groups



Sub-Group: Broadband Observations

Chairs: Heiner Igel, Munich, and Frank Vernon, SCRIPPS.

Goals:

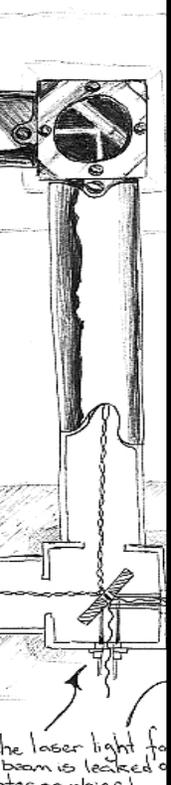
- **Develop infrastructure for data transfer** and availability of high-resolution broadband sensors (Wettzell, Germany; Christchurch, New Zealand; Pinon Flat Observatory, California).
- **Defining formats for storage** and transfer of multi-component ground motion data (e.g., translations, rotations, tilt, strain, etc.).
- **Data analysis, interpretation and modeling** of observations.

Current projects:

Array-derived rotations and tilt (PhD project Wiwit Suryanto, finished in a few weeks).

Analysis of broadband data (N.D. Pham, PhD project, currently working on **P-coda**).

2 year postdoctoral position in broadband rotational motions (open and advertised)



The web-interface

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Schreiber, Ullrich	schreiber@wettzell.ifag.de	✓				✓

news

Postdoc position in rotational seismology, LMU Munich
2006-12-04
More news...

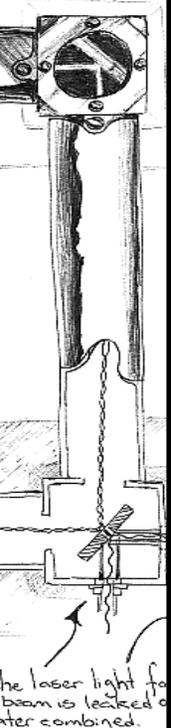
upcoming events

AGU06 Session on Rotational seismology
San Francisco, 2006-12-11

IWoRS Inauguration Meeting
San Francisco, 2006-12-12
Upcoming events...

Get login for active membership

Join mailing lists (global or subgroup)



Inauguration Lunch

The Garden Terrace
Restaurant on the Second
Floor of the **San Francisco
Marriott Hotel**, 55 Fourth
Street

Today 12:30

