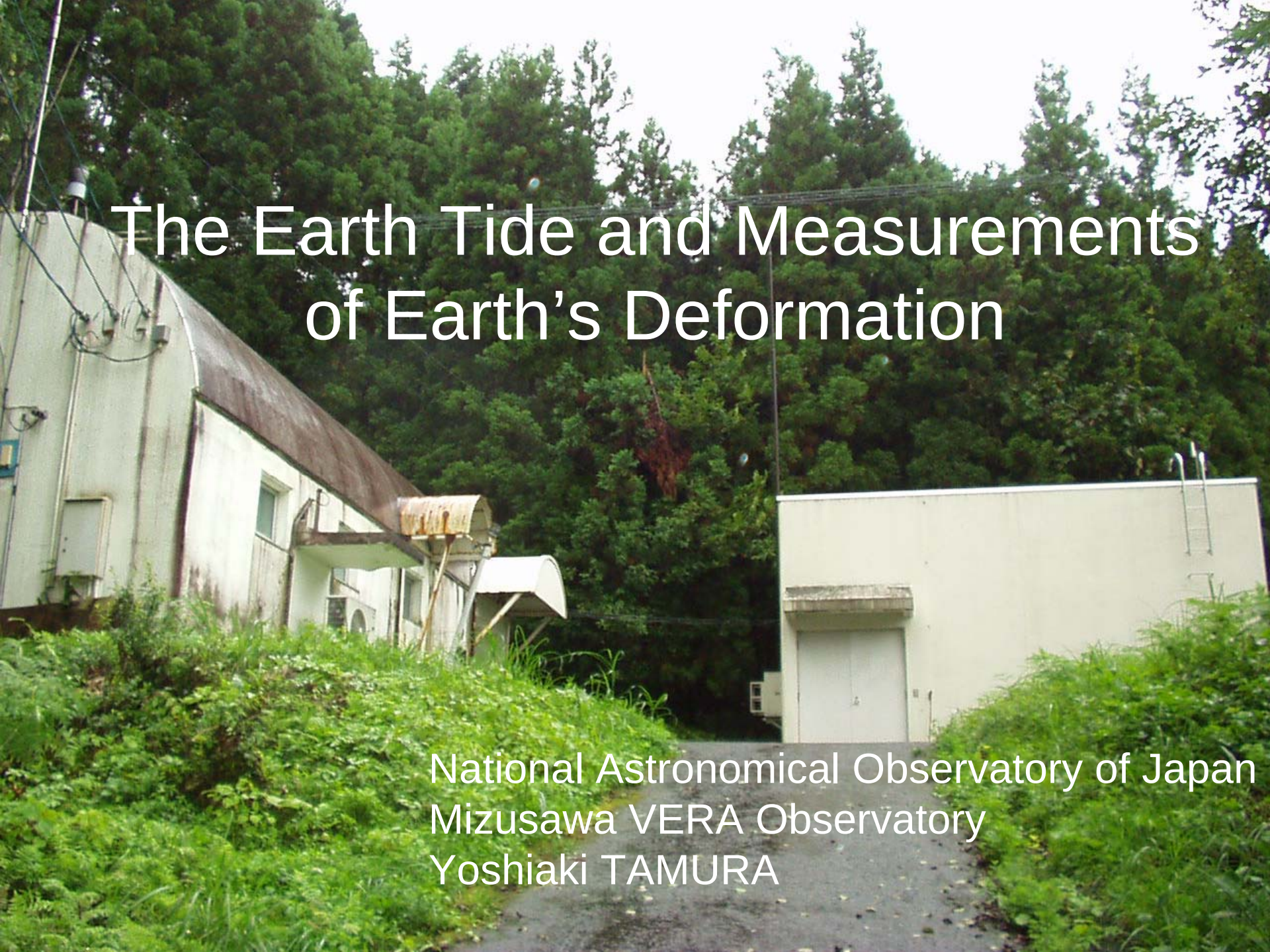
The Earth Tide and Measurements of Earth's Deformation



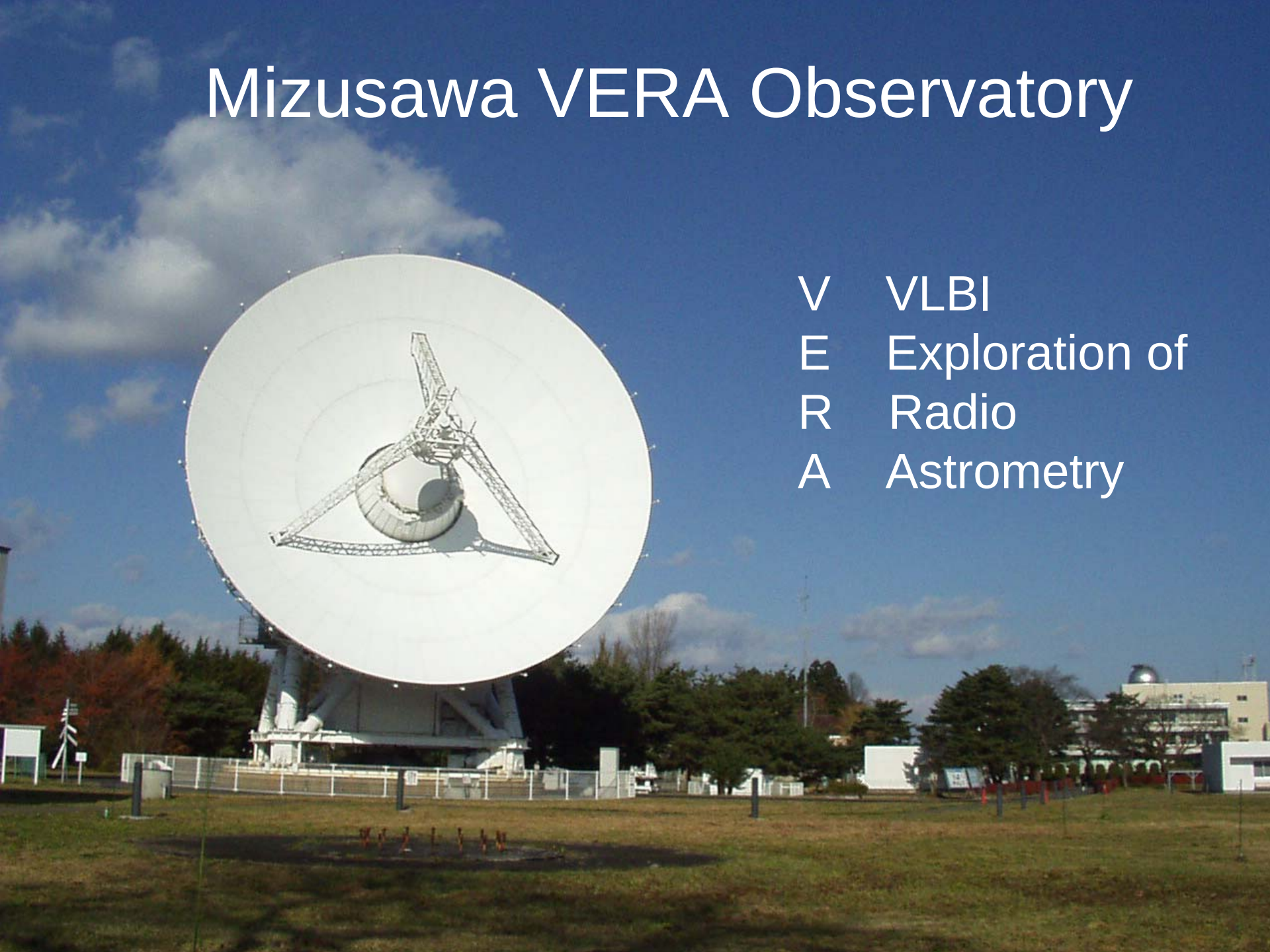
National Astronomical Observatory of Japan
Mizusawa VERA Observatory
Yoshiaki TAMURA

Introduction to Mizusawa VERA Observatory

Earth tides, Earth's deformations

- Earth's deformations, tides
- How to observe Earth tides
- Free oscillation of the Earth
- Ocean tide loading,
  atmospheric pressure loading

Mizusawa VERA Observatory



V VLBI
E Exploration of
R Radio
A Astrometry

Geodetic VLBI observation by VERA
Dec. 17, 2004

Iriki

Mizusawa

入来局

1266754122.1±1.9

1336884834.7±1.6

1018524230.4±2.3

2270415585.0±2.4

1251036587.5±1.9

Ishigakijima

Ogasawara

1826711055.0±2.4

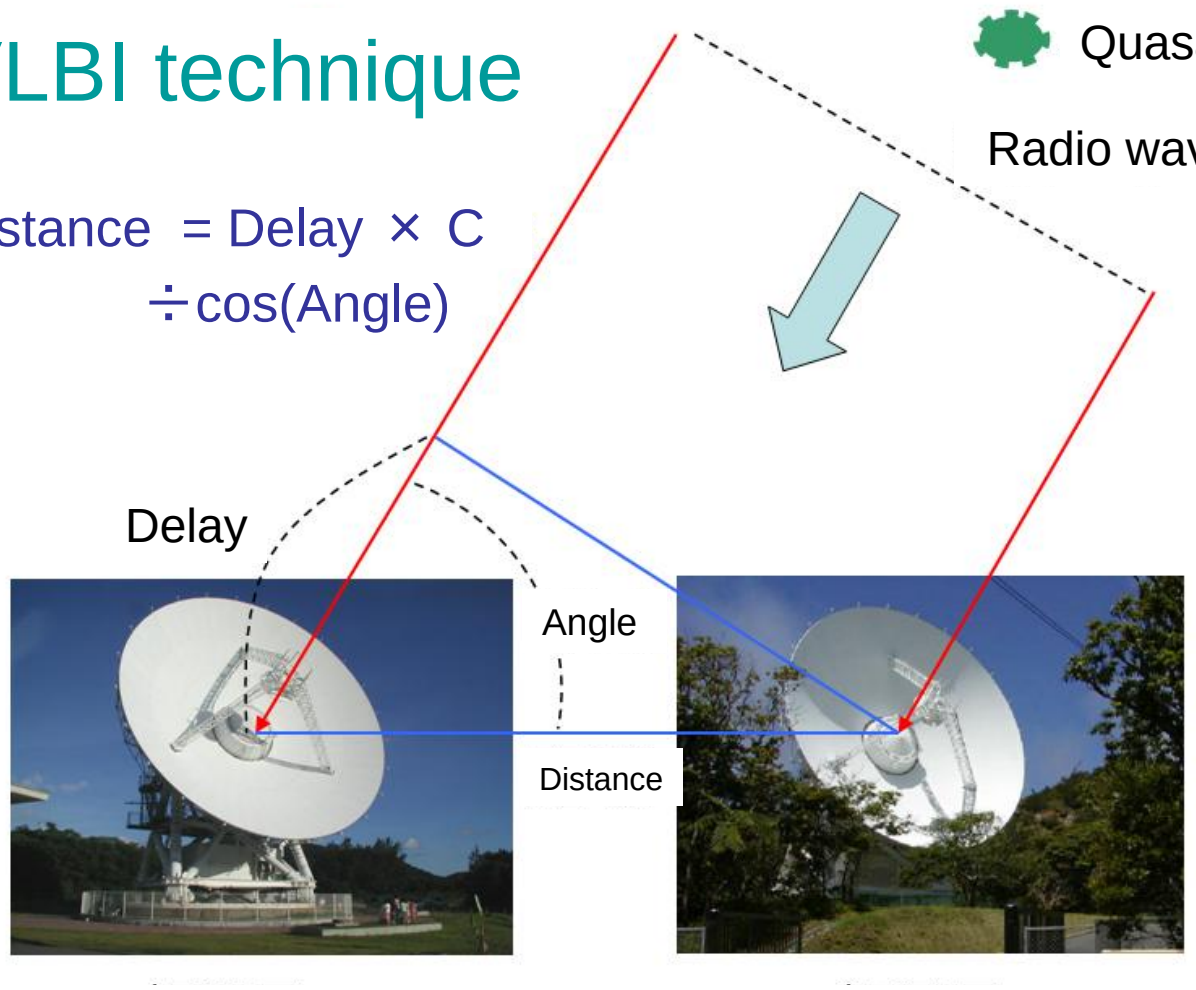
Unit mm

Illustration by KAGAYA

Principal of Geodetic VLBI

VLBI technique

Distance = Delay × C
÷cos(Angle)



Distance measurements of radio stars

- Position of radio stars changes by the motion of Earth's revolution.

→ The distance is measured directly from annual parallax.

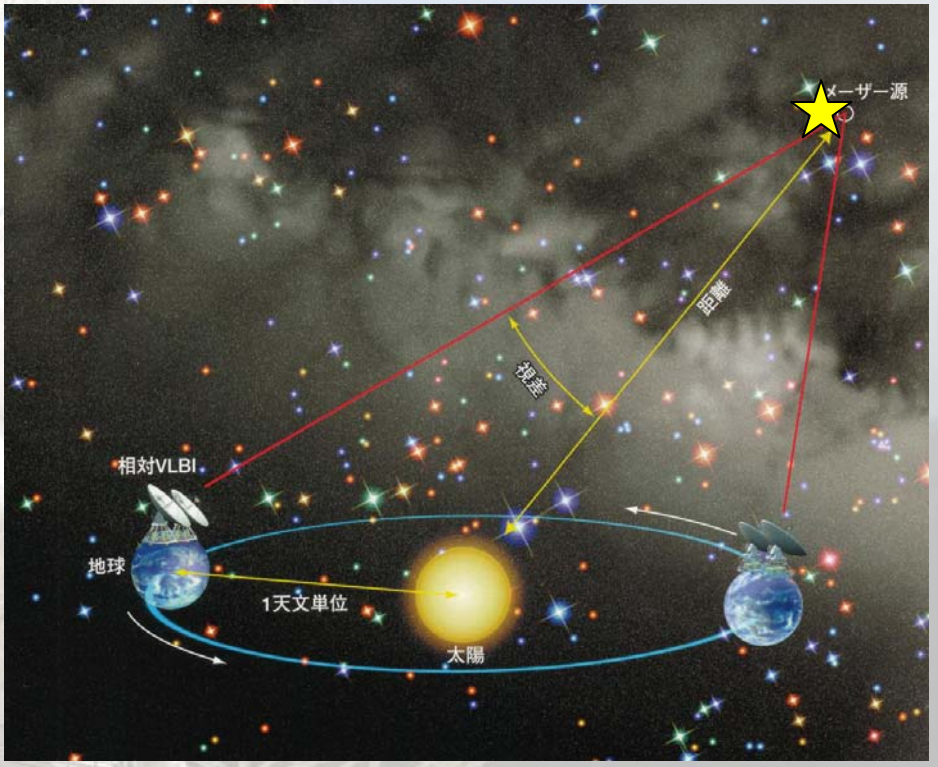
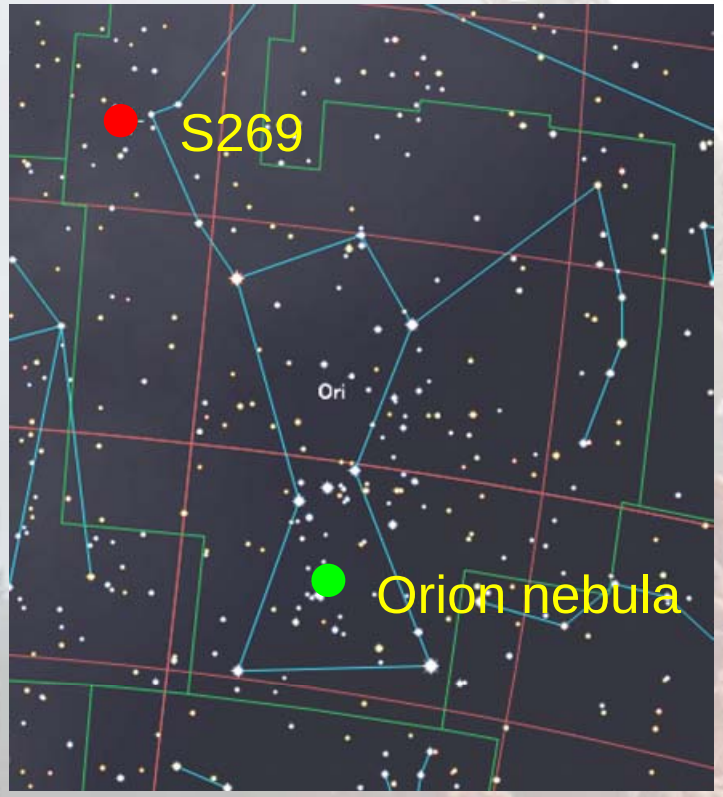


Illustration of annual parallax

Measurements of our Galaxy

- Orion KL maser 2.29±0.10mas 437pc
- S269 189±8 μas 5.28 kpc



Orion

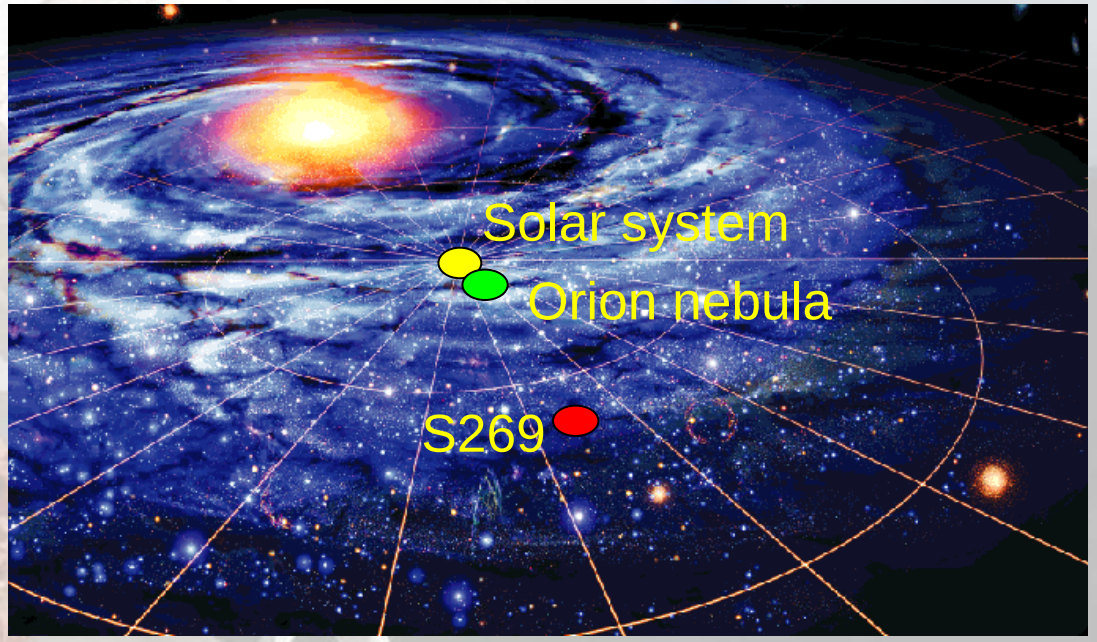


Image of our Galaxy

Geodetic VLBI observation by VERA
Dec. 17, 2004

Iriki

Mizusawa

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1266754122.1±1.9

1336884834.7±1.6

1018524230.4±2.3

2270415585.0±2.4

1251036587.5±1.9

Ishigakijima

Ogasawara

1826711055.0±2.4

Unit mm

Illustration by KAGAYA

Plate motion of VERA stations

Project VERA

Astrometry:
Precise positioning Radio Sources, ～10 μ as

↓

The coordinates of antennas should be kept with
10mm global accuracy, and
1～2mm internal accuracy.

It requires understanding of geophysical phenomena including Earth tides.

Earth tides, Earth's deformations

1) Earth's deformations, tides
2) How to observe Earth tides
3) Free oscillation of the Earth
4) Ocean tide loading,
   atmospheric pressure loading

5) Core mode oscillations
6) Other topics

1. Earth's deformations, tides

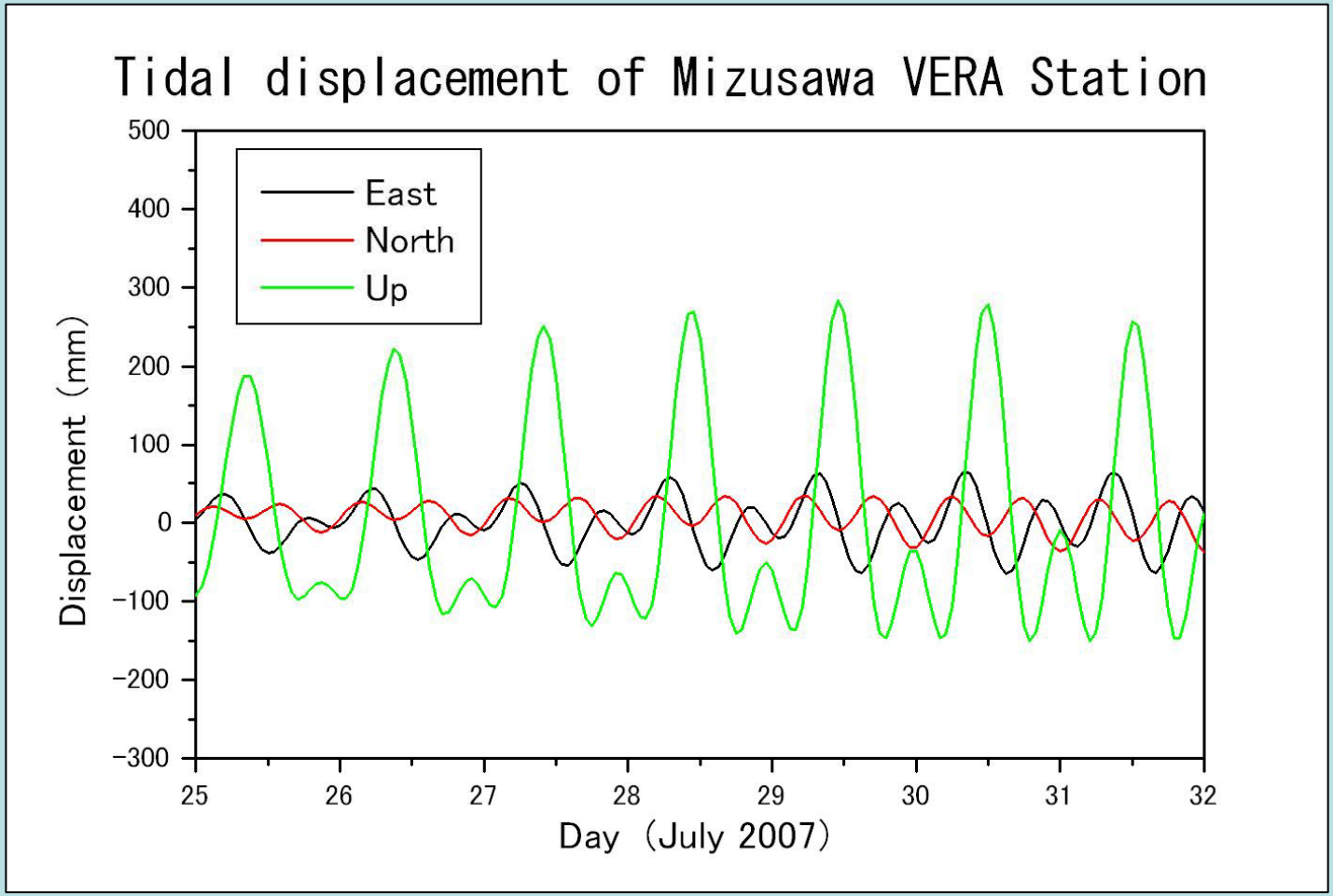
Phenomena	magnitude horizon	vertical	period	scale, note
Earth tide	150	300mm	diurnal, semidiurnal	global
Ocean loading	10	50mm	diurnal, semidiurnal	global
Pressure loading	1	5mm	day--annual	regional, global
Plate motion	70mm/year		secular	global
Co-seismic	10	10mm	step	M7, 100km distance
Slow event	5	5mm	～month	regional
Free oscillation	less 0.1mm		2-50 minute	global

Tidal Phenomena

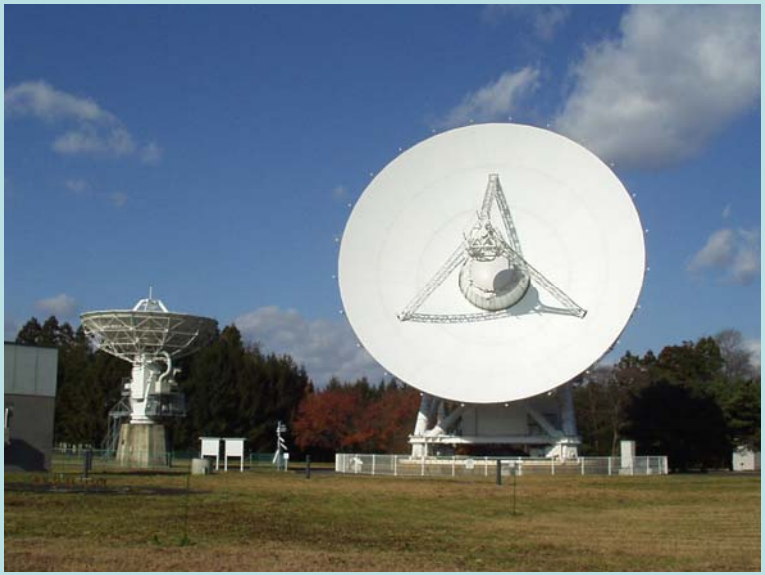
- Displacement 200 ～ 300mm
- Gravity change 150 ～200 μGal
  ($1\,\mu Gal = 10^{-9} ms^{-2}$)
- Strain $3 \sim 5 \times 10^{-8}$
- Tilt 10^{-7} rad

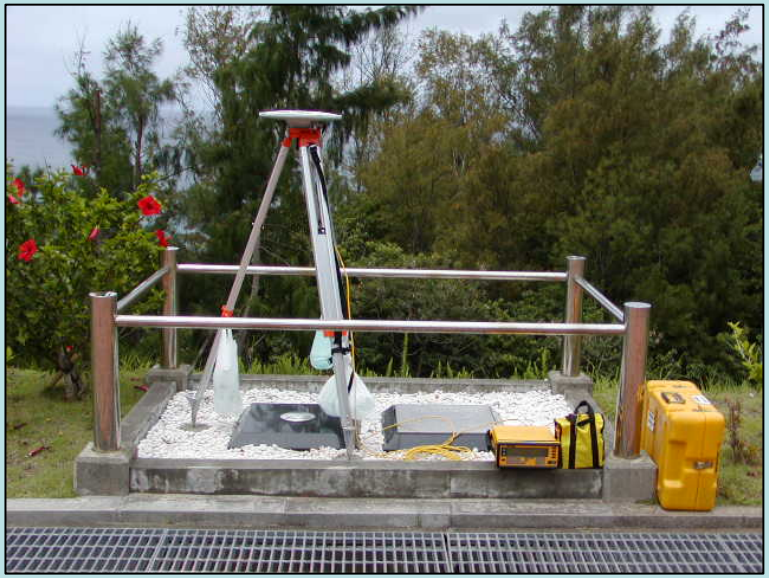
- Ocean Tide 0.5m ～ 2m
- Ocean Tide Loading 10～50mm

Tidal displacements (Theoretical)



Positioning by VLBI and GPS





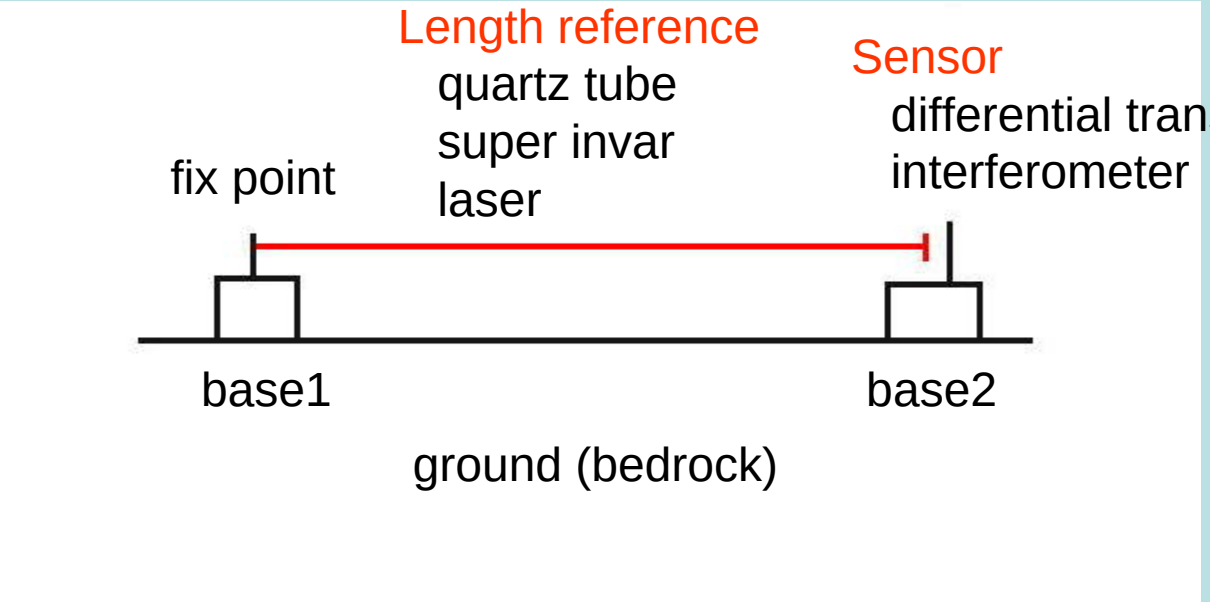
Measurements of tidal displacement is not easy.

The displacement is modeled, and the station coordinates are solved daily using 24 hour observation data.

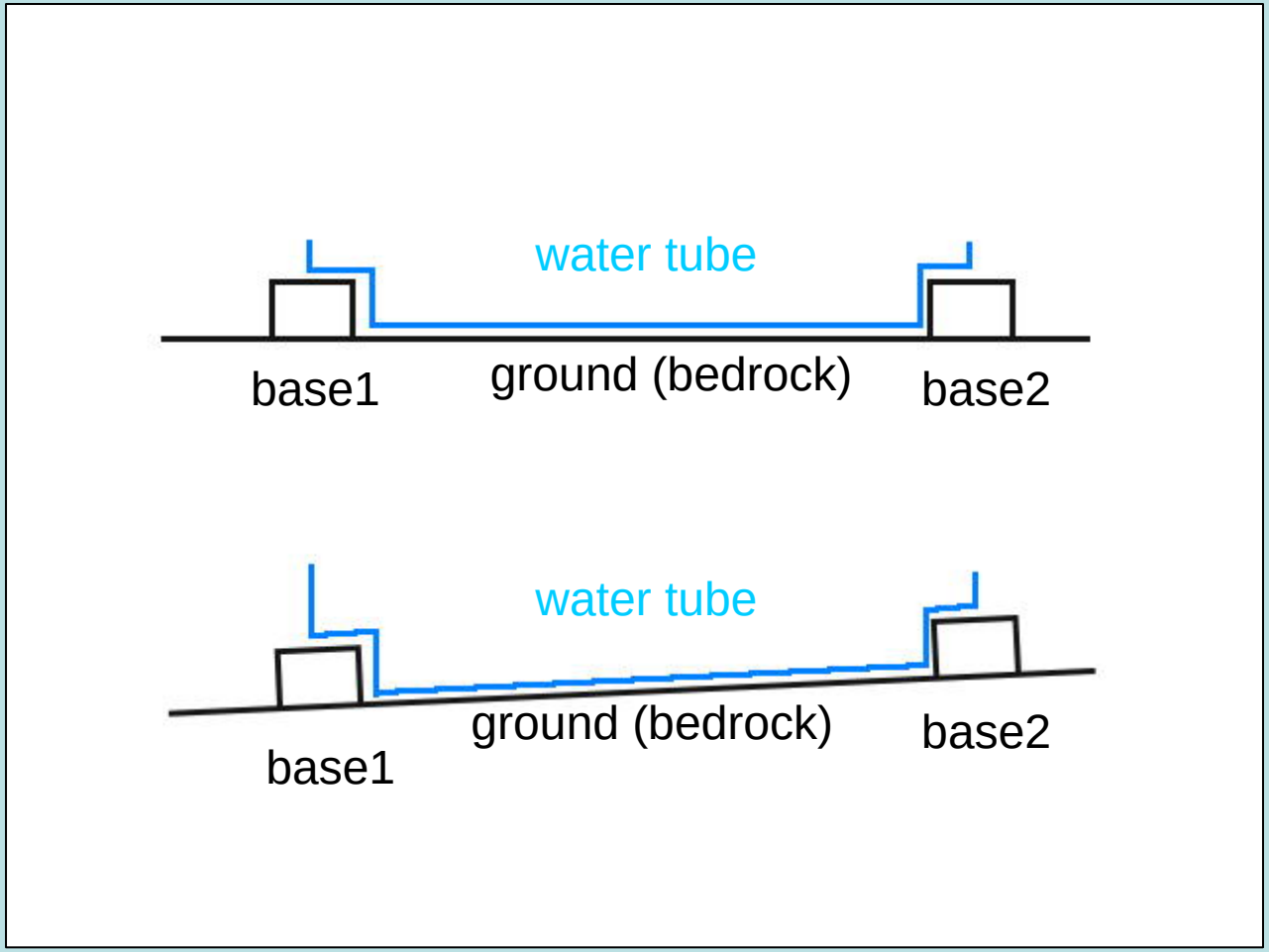
2. How to observe Earth tides

- Strain
- Tilt
- Gravity

Principal of strain measurement



Principal of tilt measurement



Position sensors

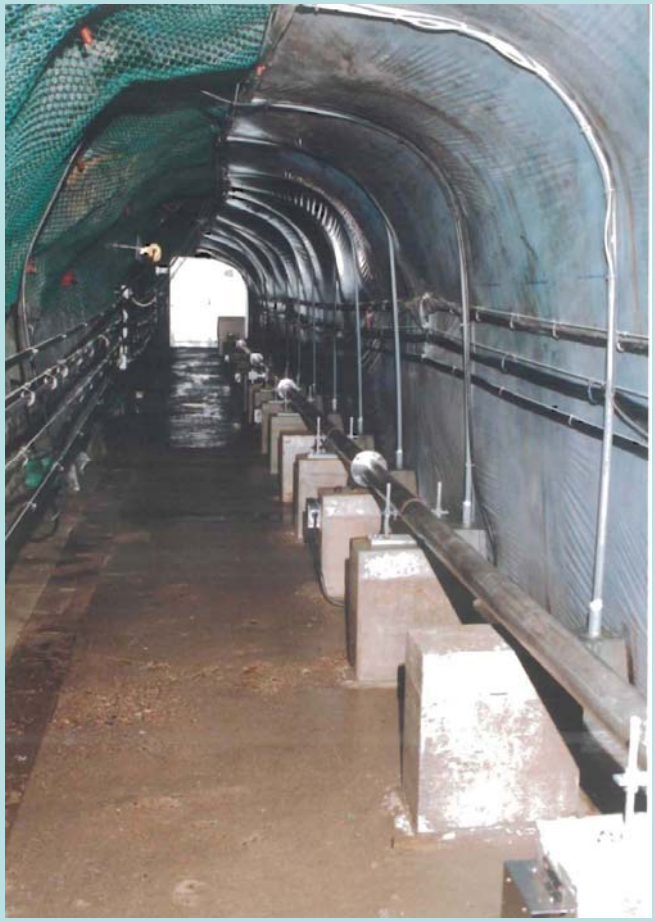
- Differential transformer
- Capacity bridge
- Optical interferometer

Order of Earth tide $\sim 10^{-7}$

$= \quad 10\text{m} \quad : \quad 1\,\mu\text{m}$

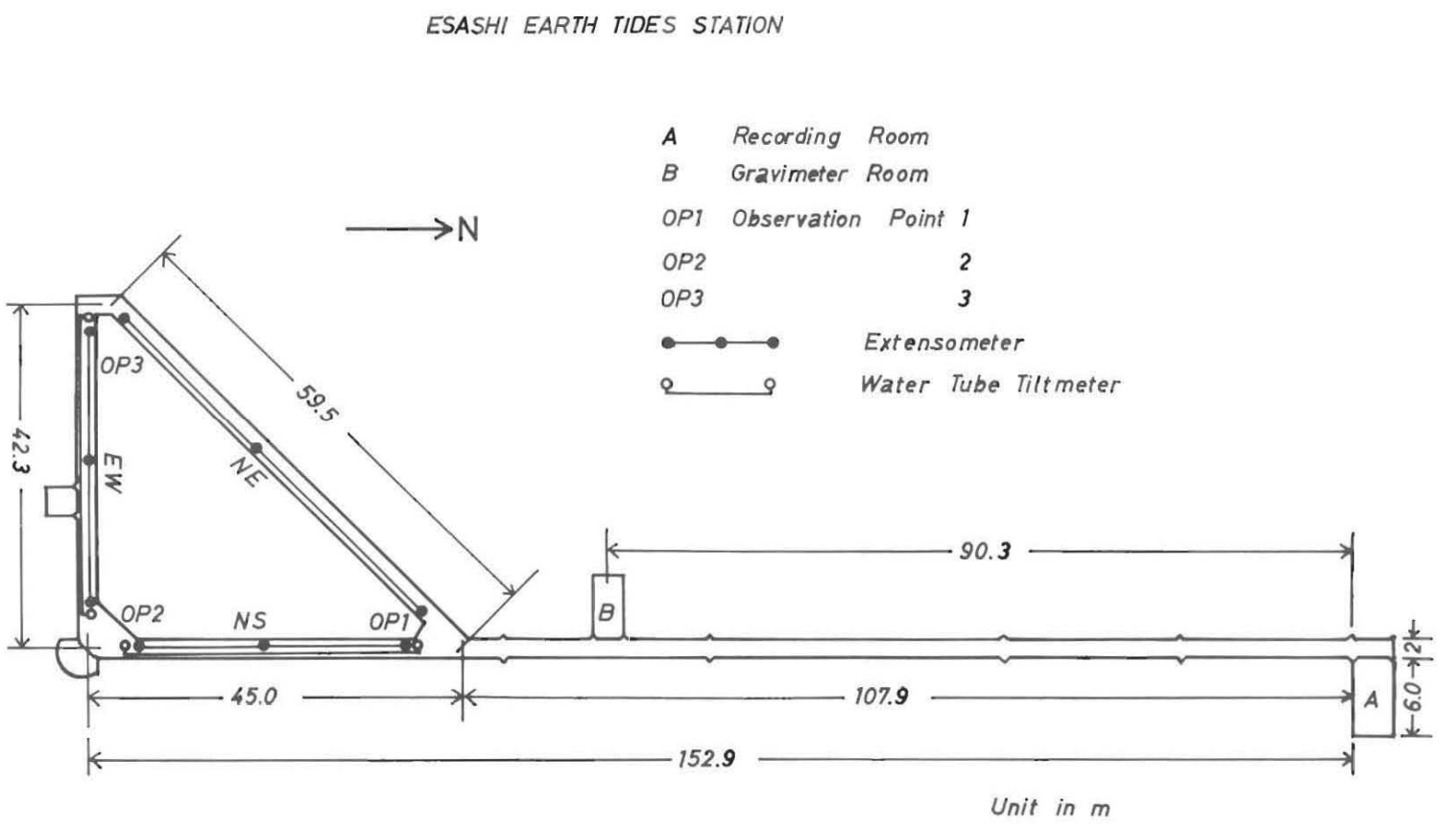
required resolution $\sim$ 0.01 μ m

Esashi Earth Tides Station, NAOJ

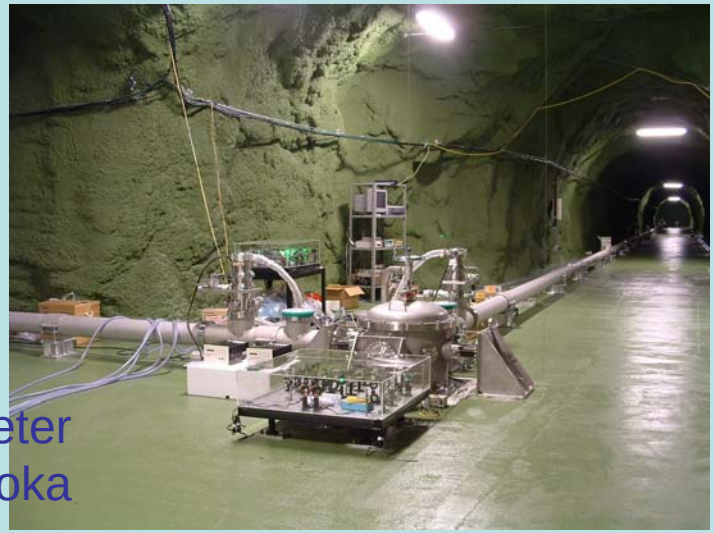


Observation tunnel of Esashi Earth Tides Station

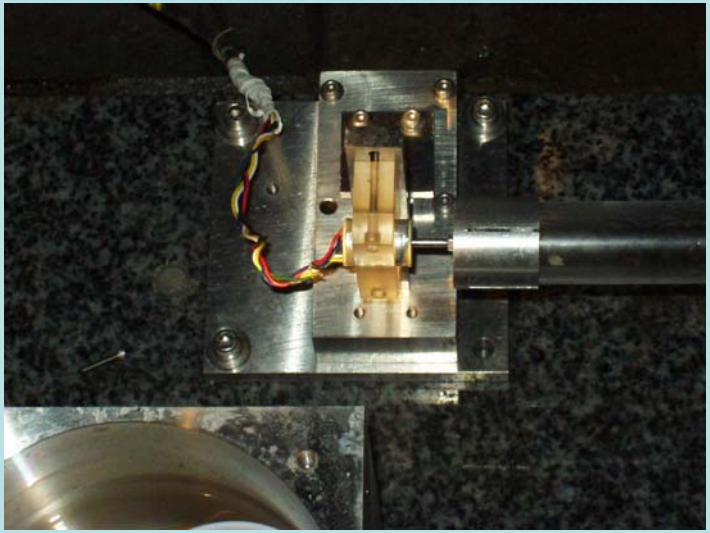
Figure 2 Plane figure of observation site and the recording room



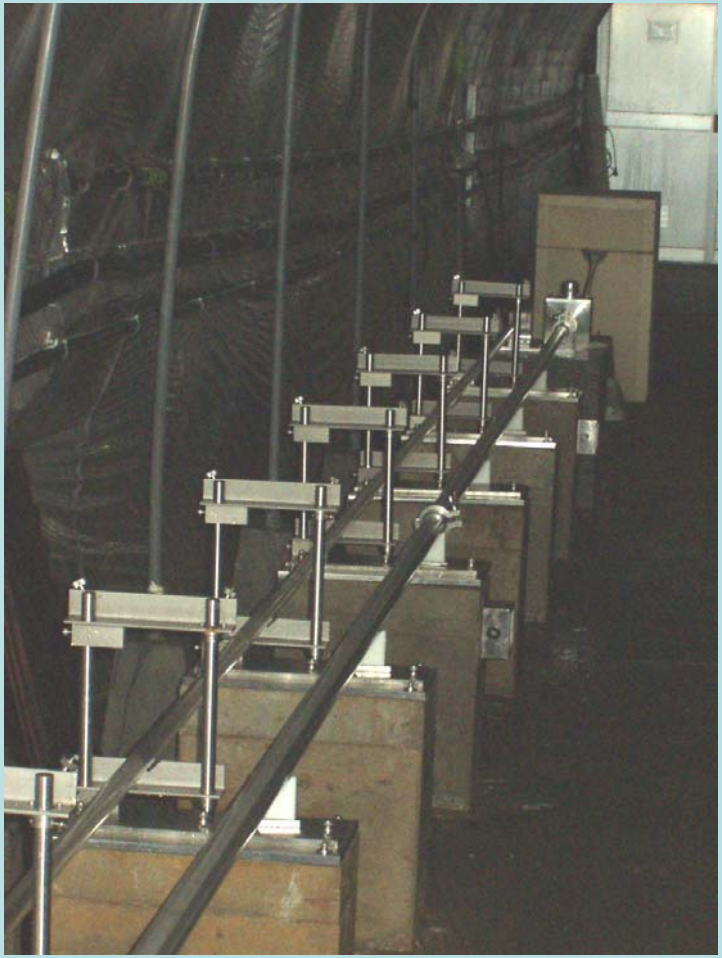
Strainmeters



Laser strainmeter at Kamioka by ERI

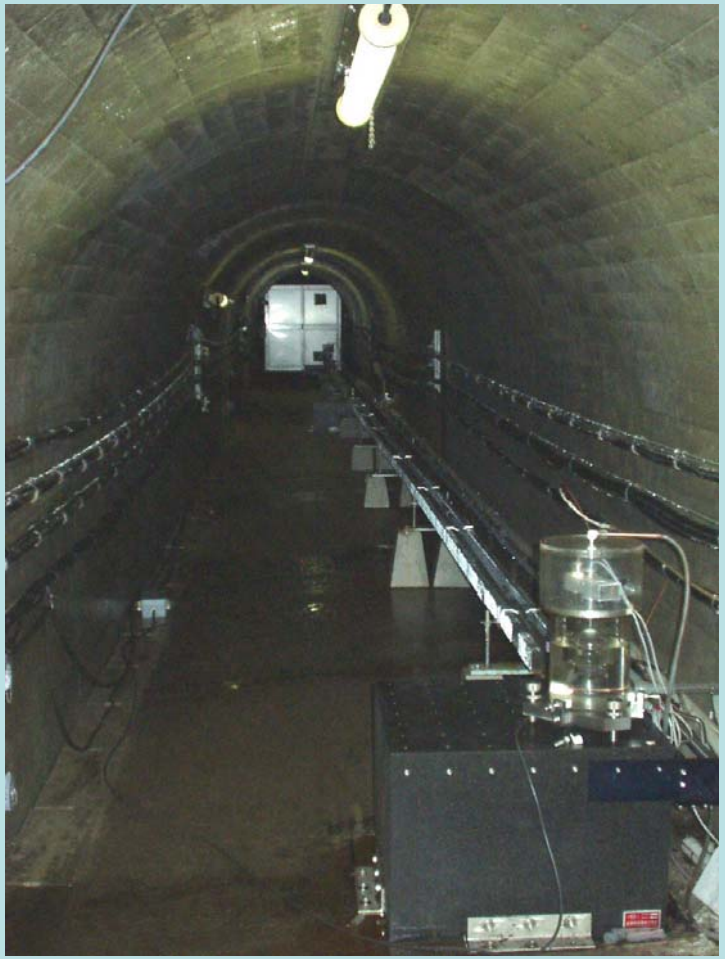


Sensor (differential transformer)

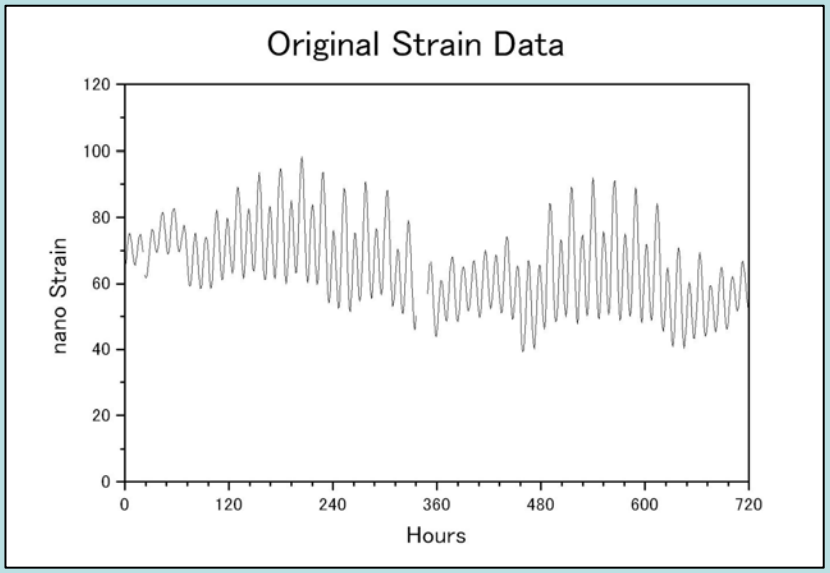


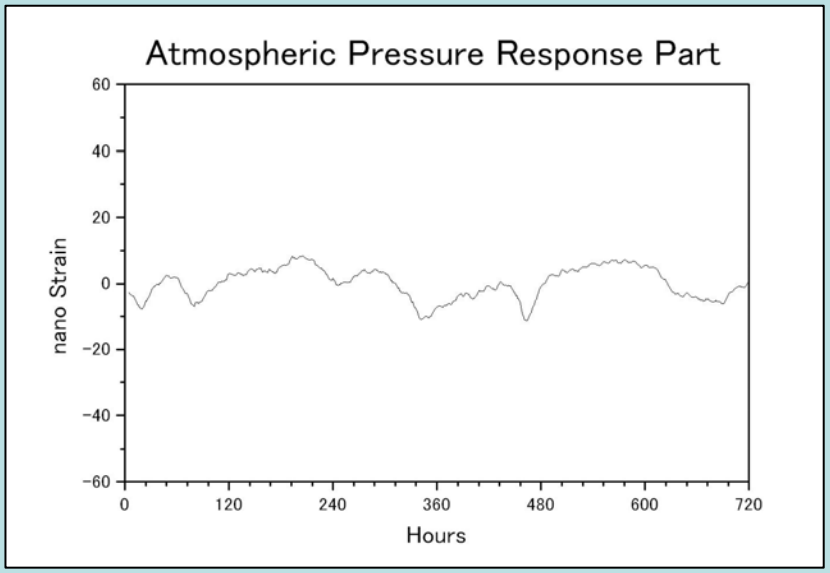
Quartz tube extensometer at Esashi

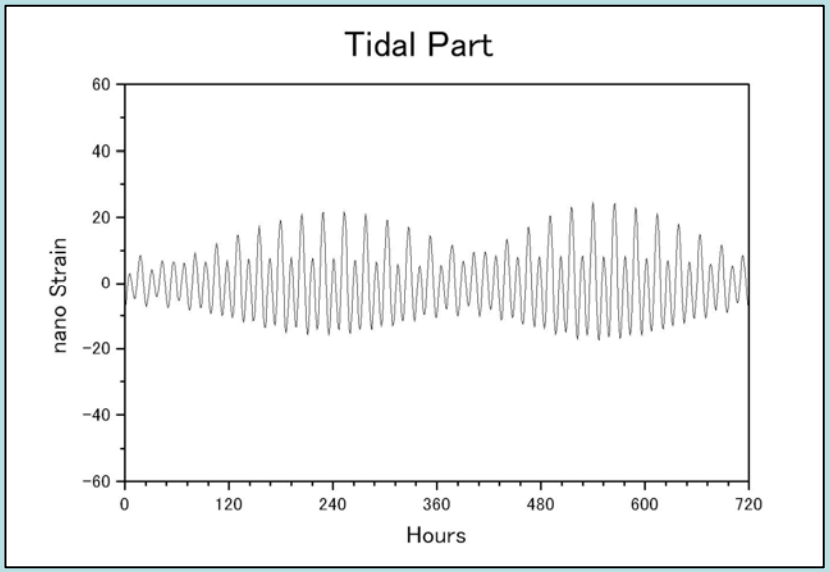
Water tube tiltmeter

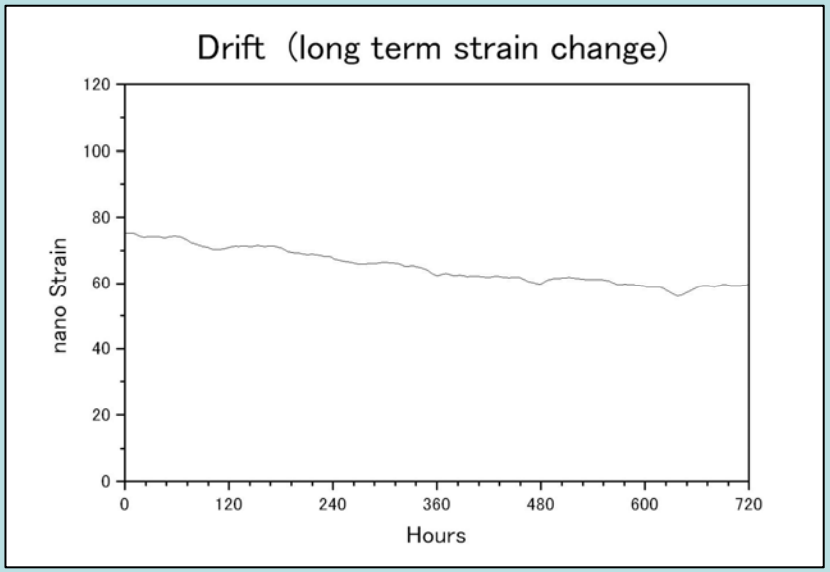


Sample of strain data

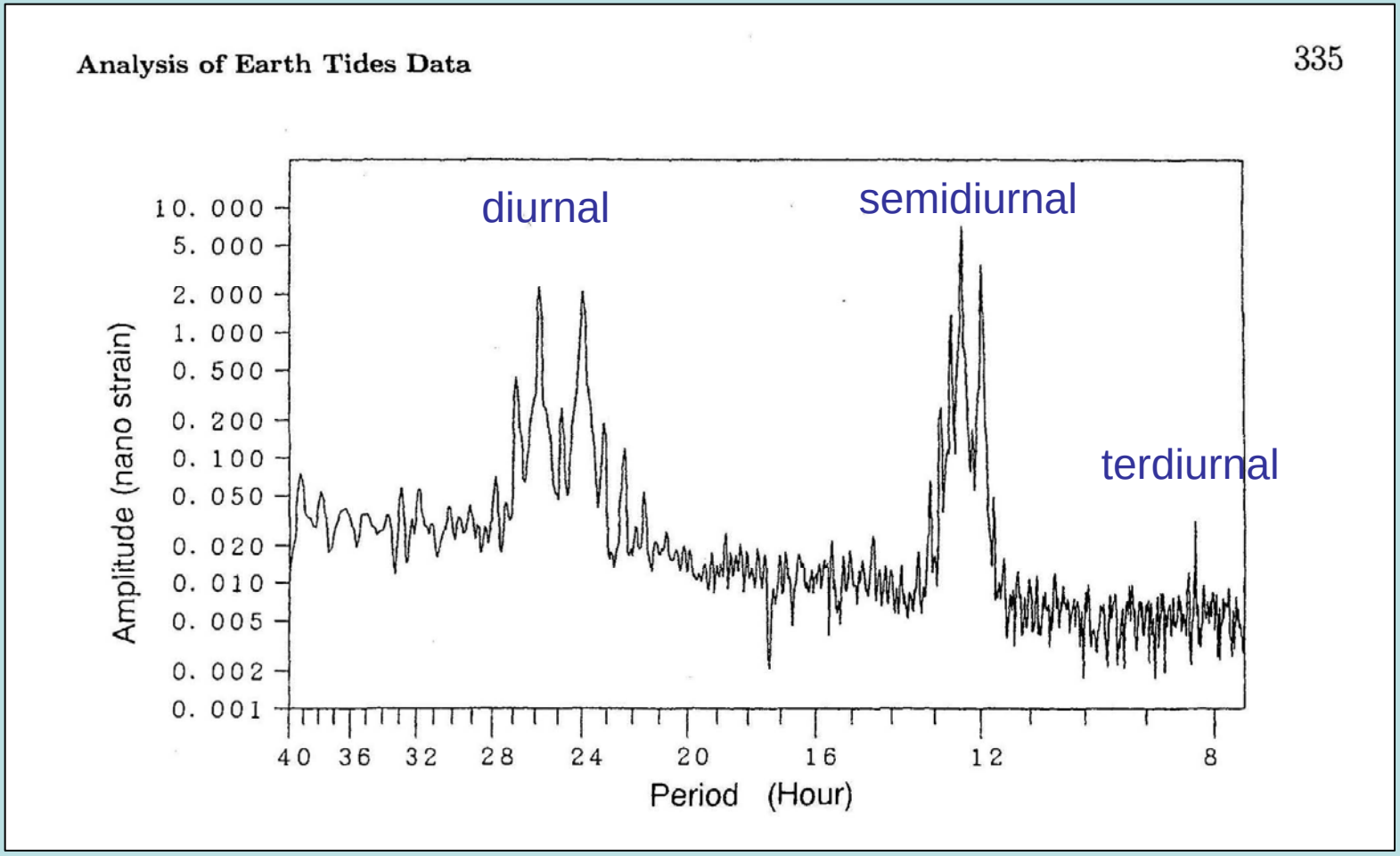




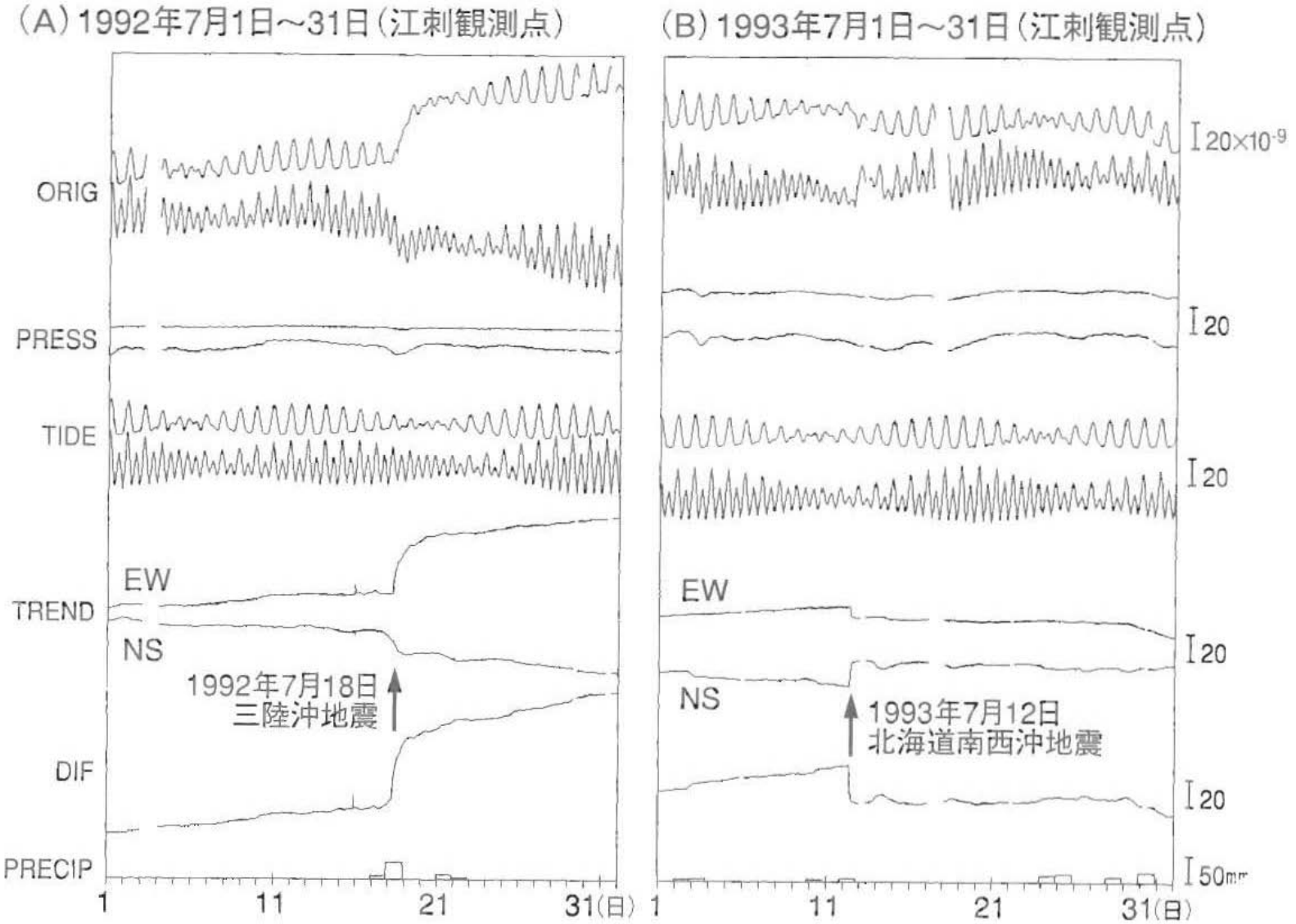




Spectrum of strain data

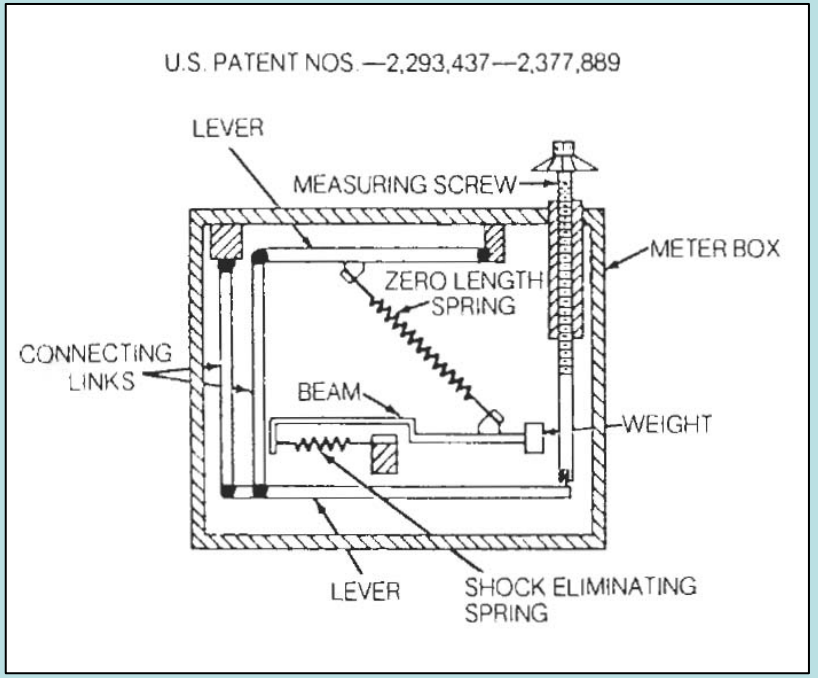


Strain changes at earthquakes

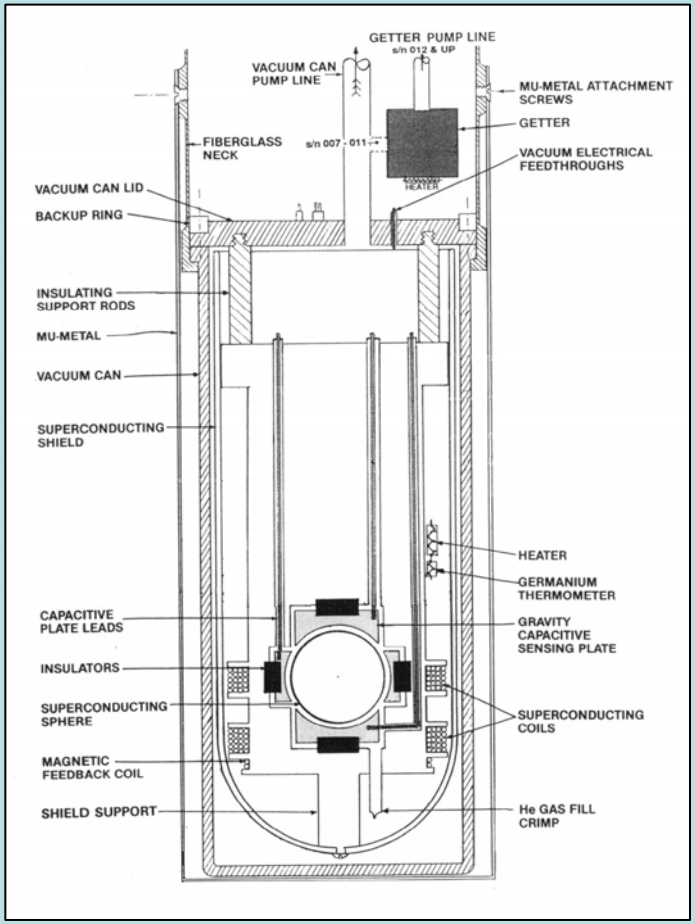


図Ⅲ－2　（A）国立天文台水沢観測センター（岩手県奥州市）の江刺観測点（同）の1992年7月1か月の伸縮計記録。横軸は時間の経過で、1目盛りが1日。縦軸は歪み。（B）1992年7月12日の北海道南西沖地震が発生した日を含む1か月分の原記録。ORIG

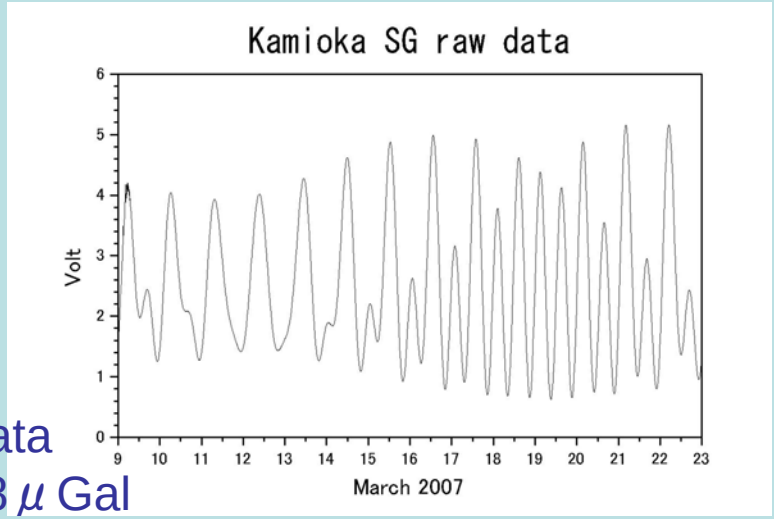
Spring type gravimeter



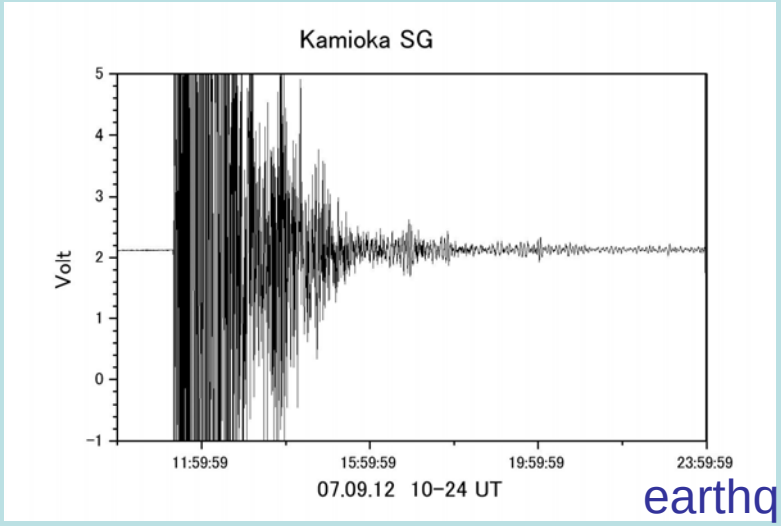
Superconducting gravimeter



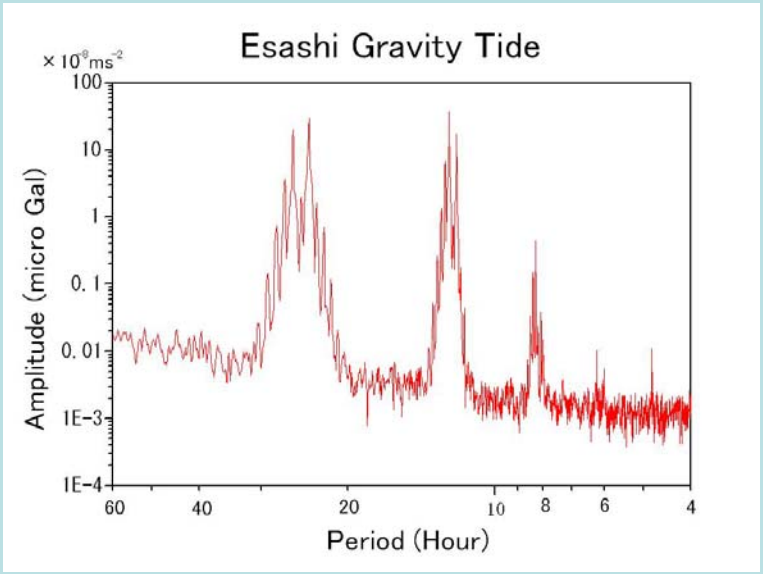
Sample of gravity data



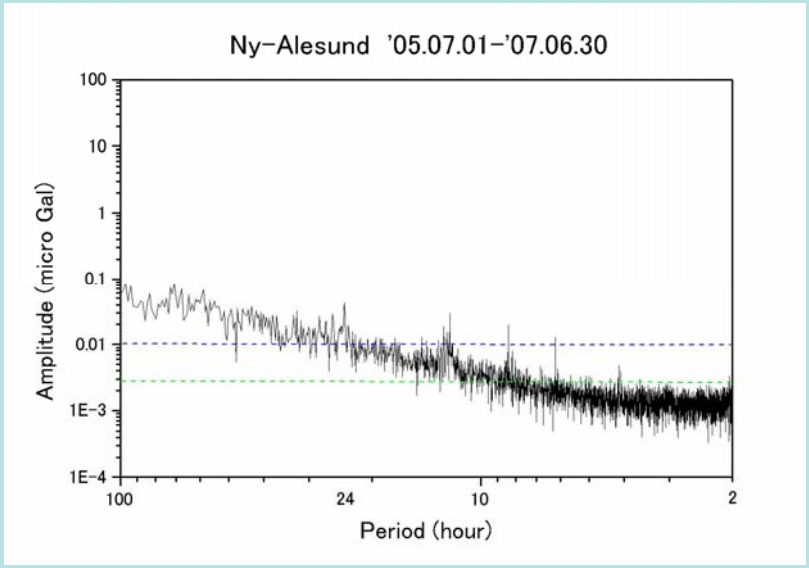
raw data
1V=58 μ Gal



earthquake

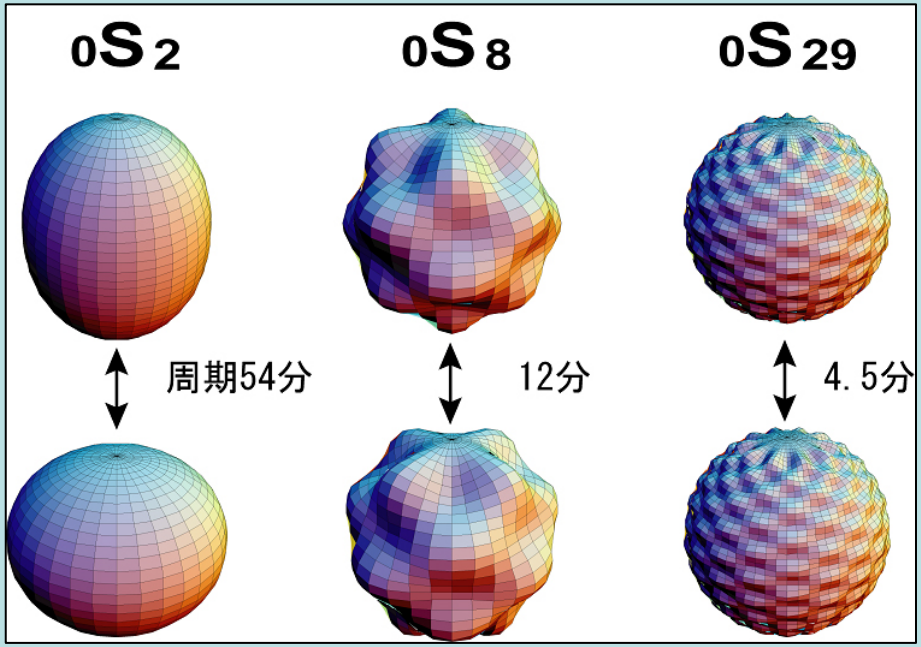


Spectrum of gravity data



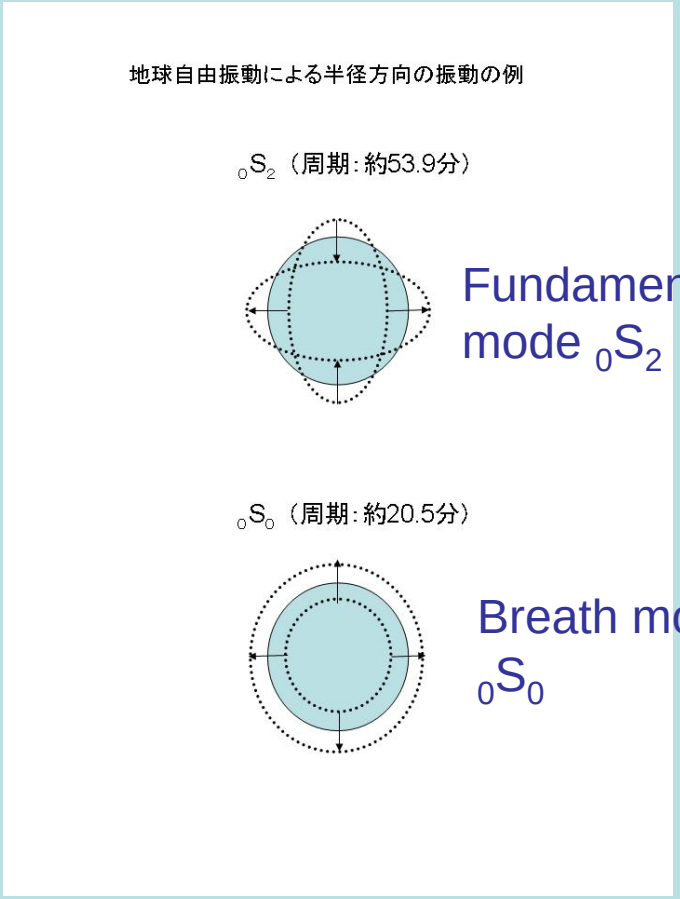
Spectrum of tidal residuals (noise level)

3. Free Oscillation of the Earth

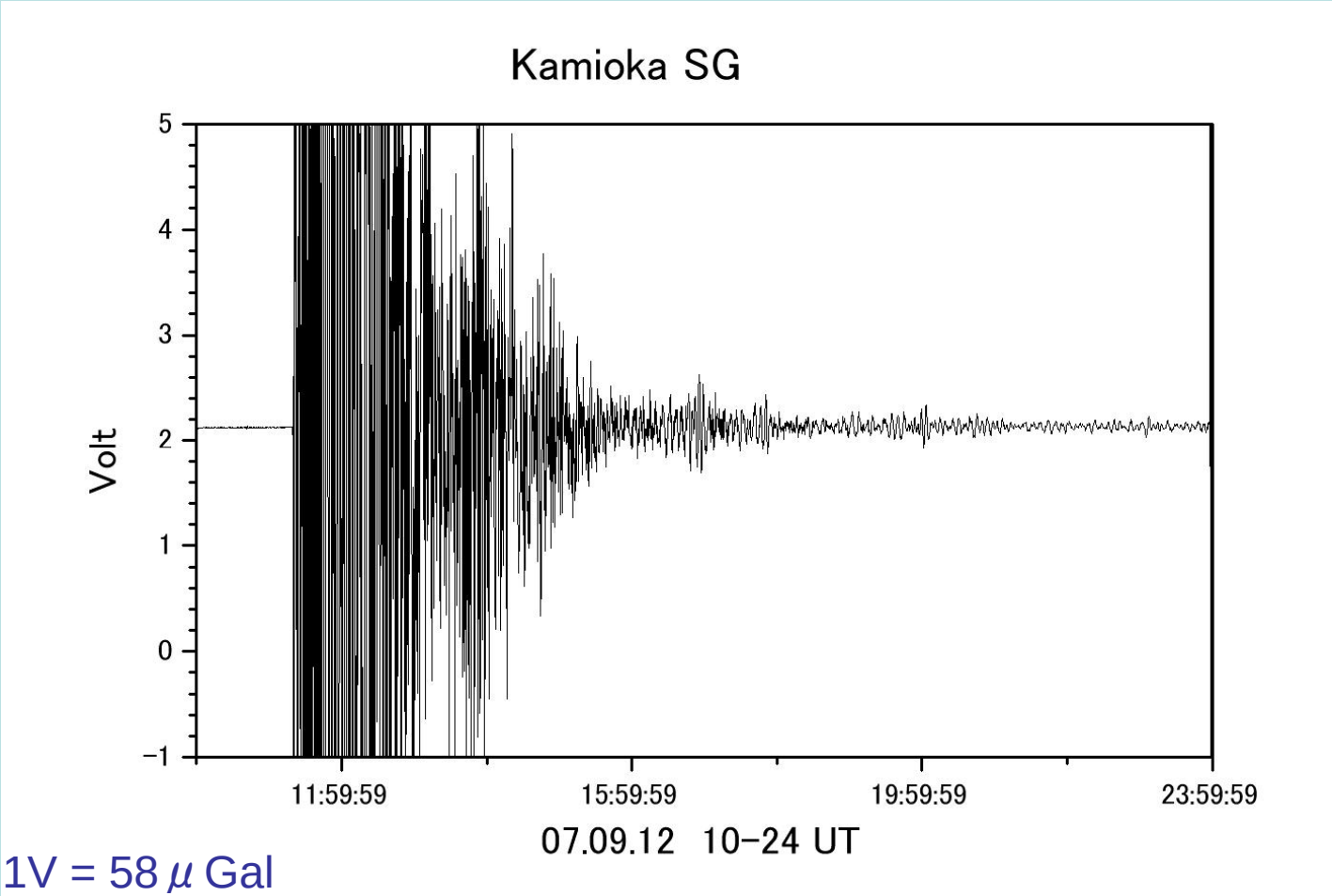


Spherical modes

Illustrated by N. Suda



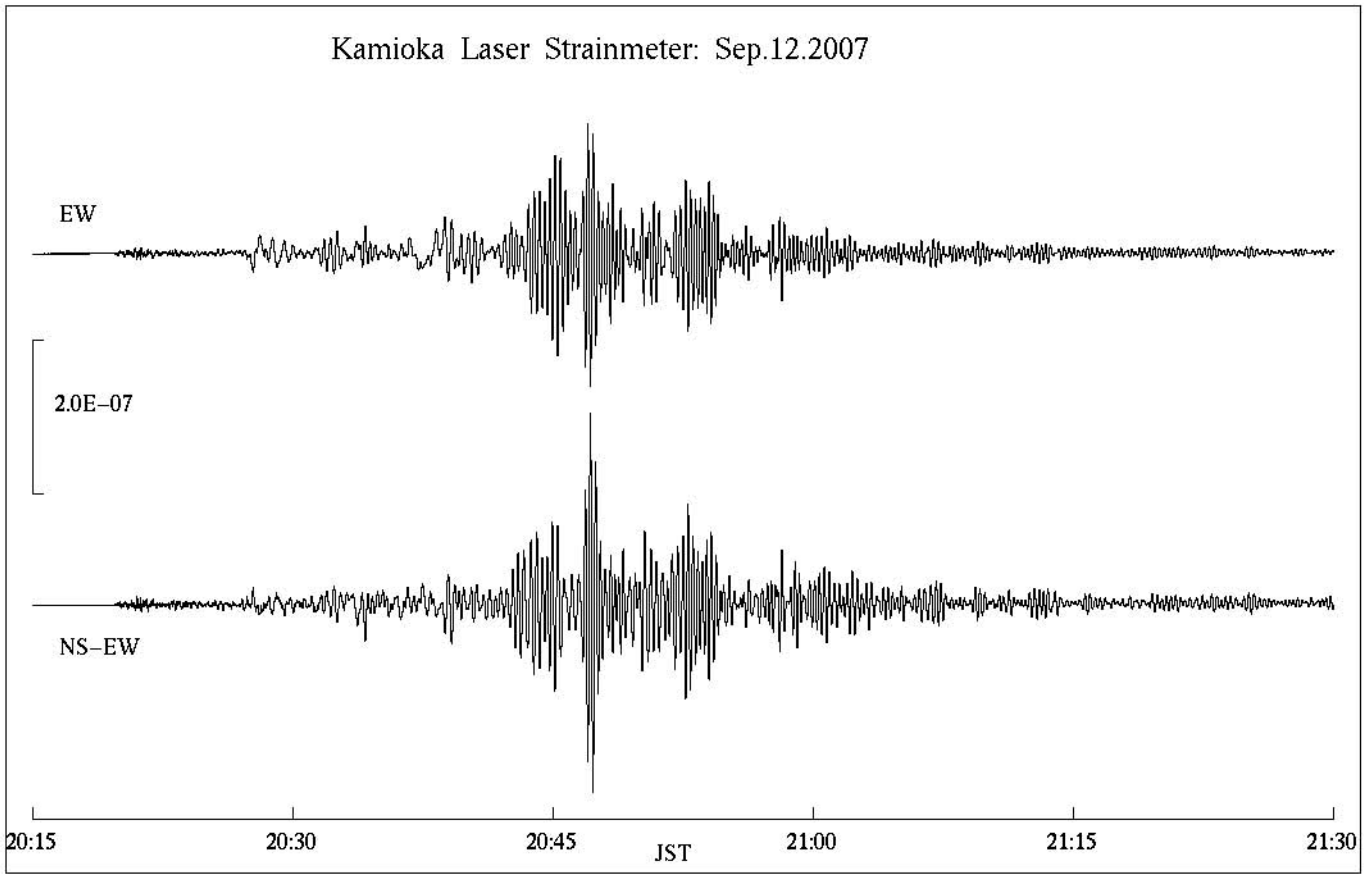
Sumatra earthquake (M8.4) Sep.12, 2007



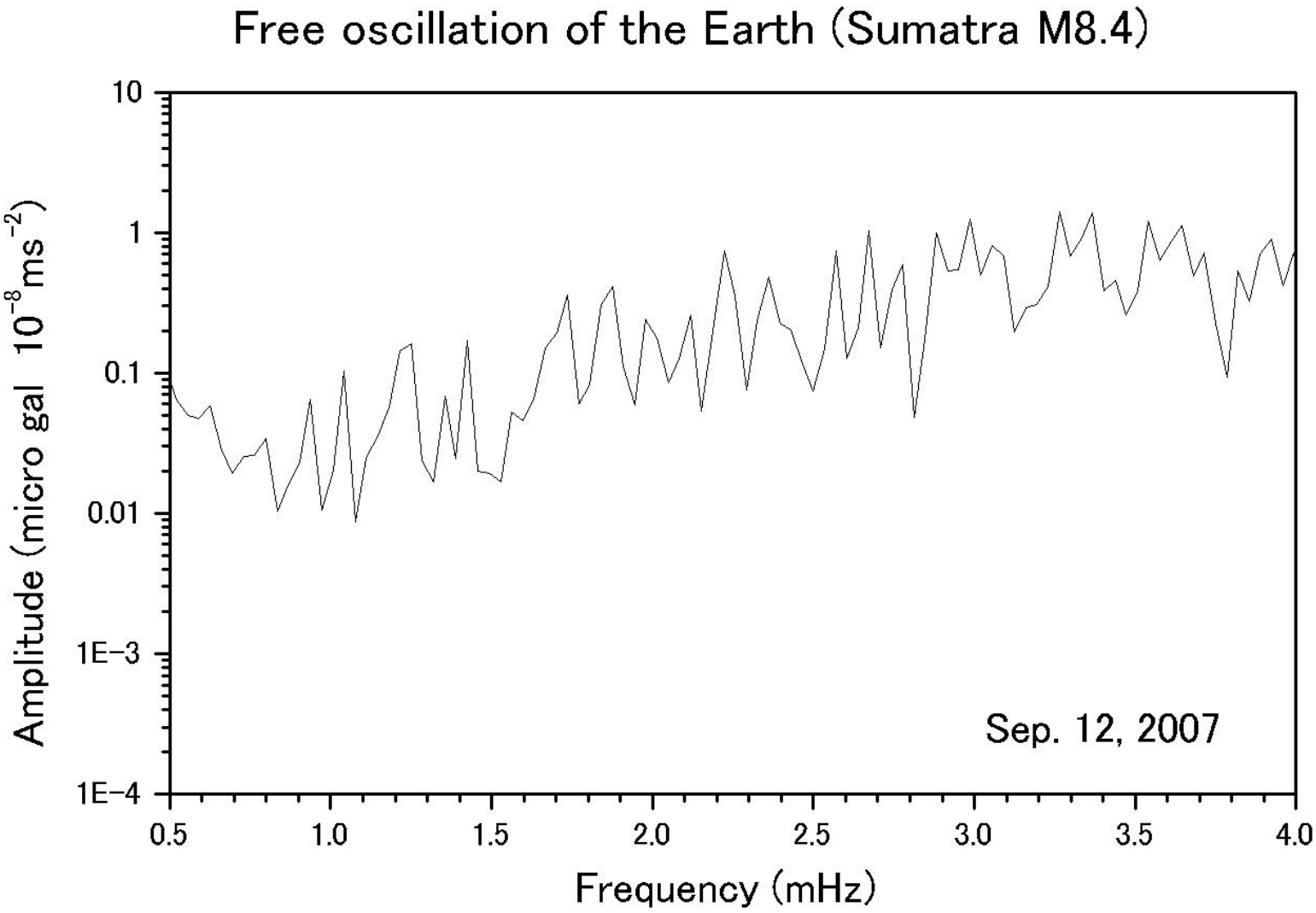
1V = 58 μ Gal

1 μ Gal=10^{-8}ms^{-2}

Sumatra earthquake 2007 observed by Kamika laser strainmeter of ERI

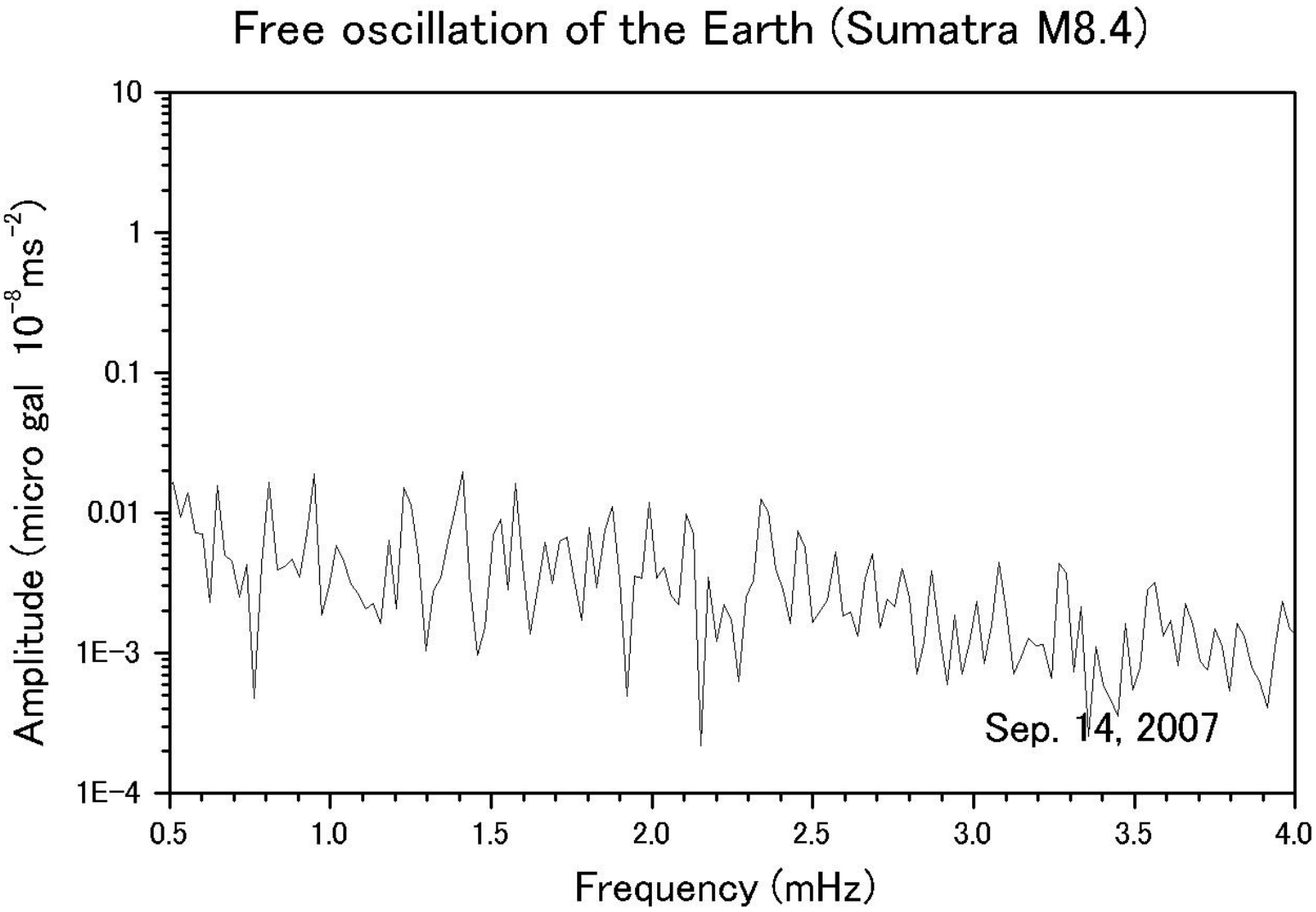


Spectrum of gravity data



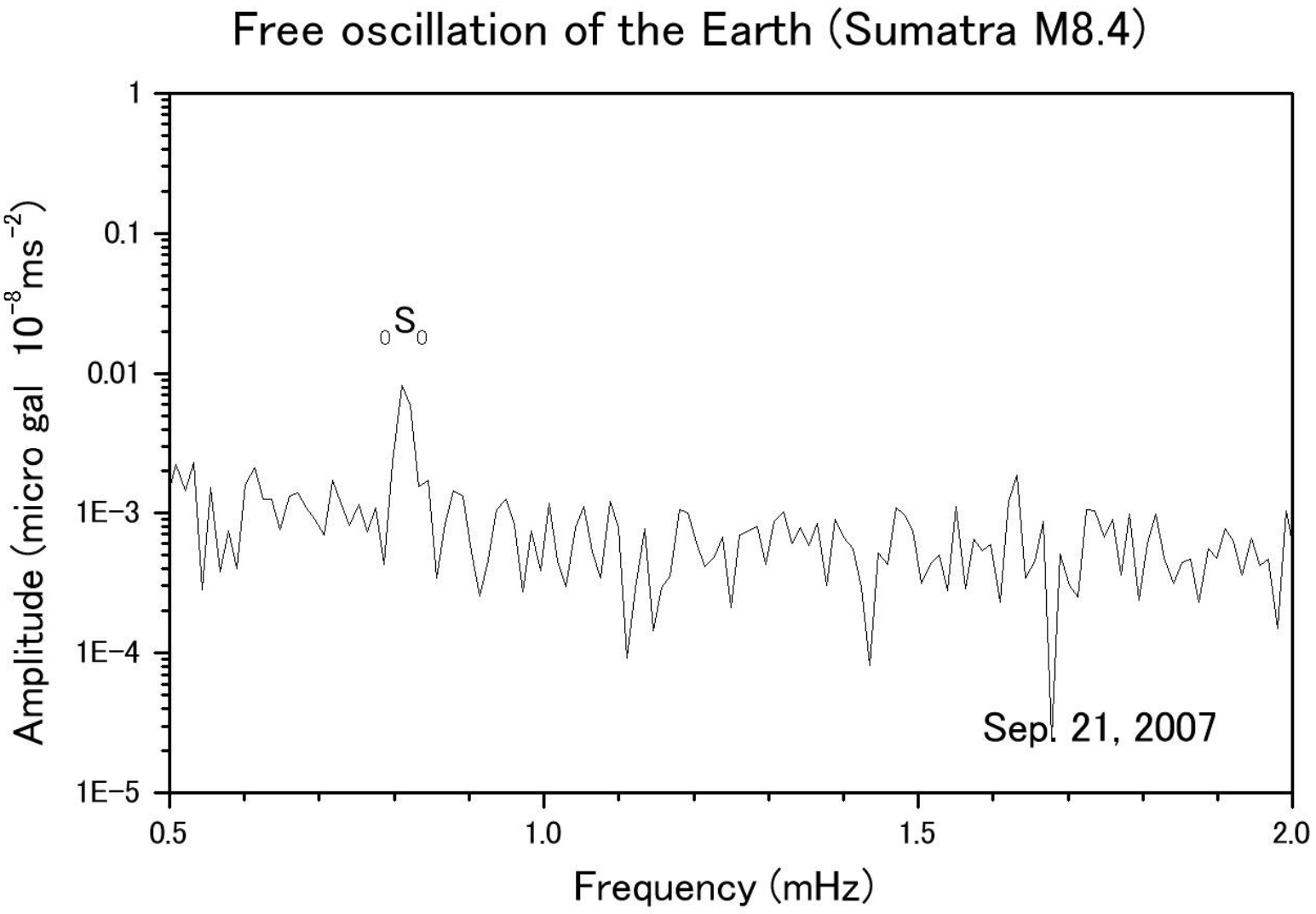
Several modes were exited by the earthquake.

Spectrum of gravity data

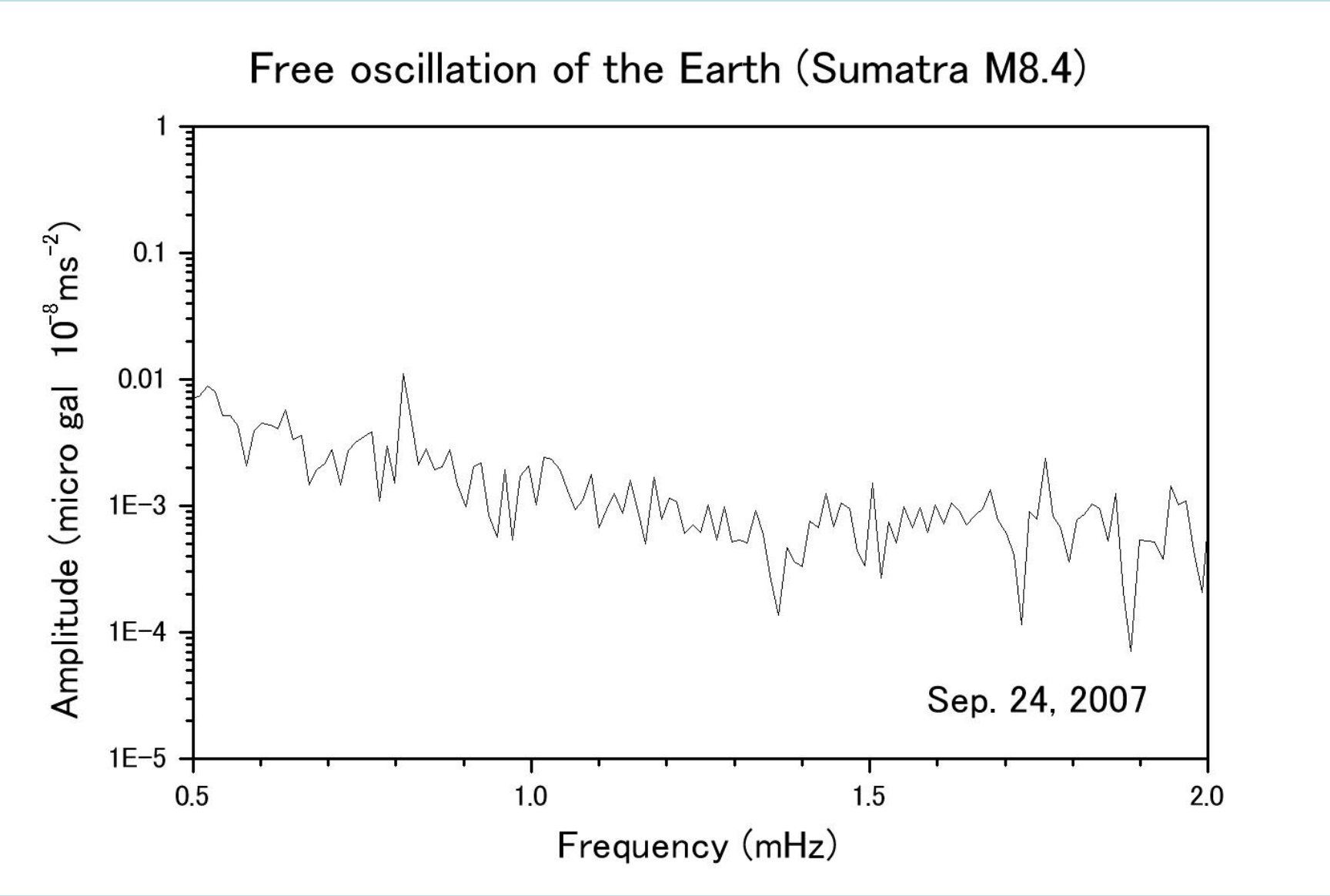


2days after : High frequency modes are decaying.

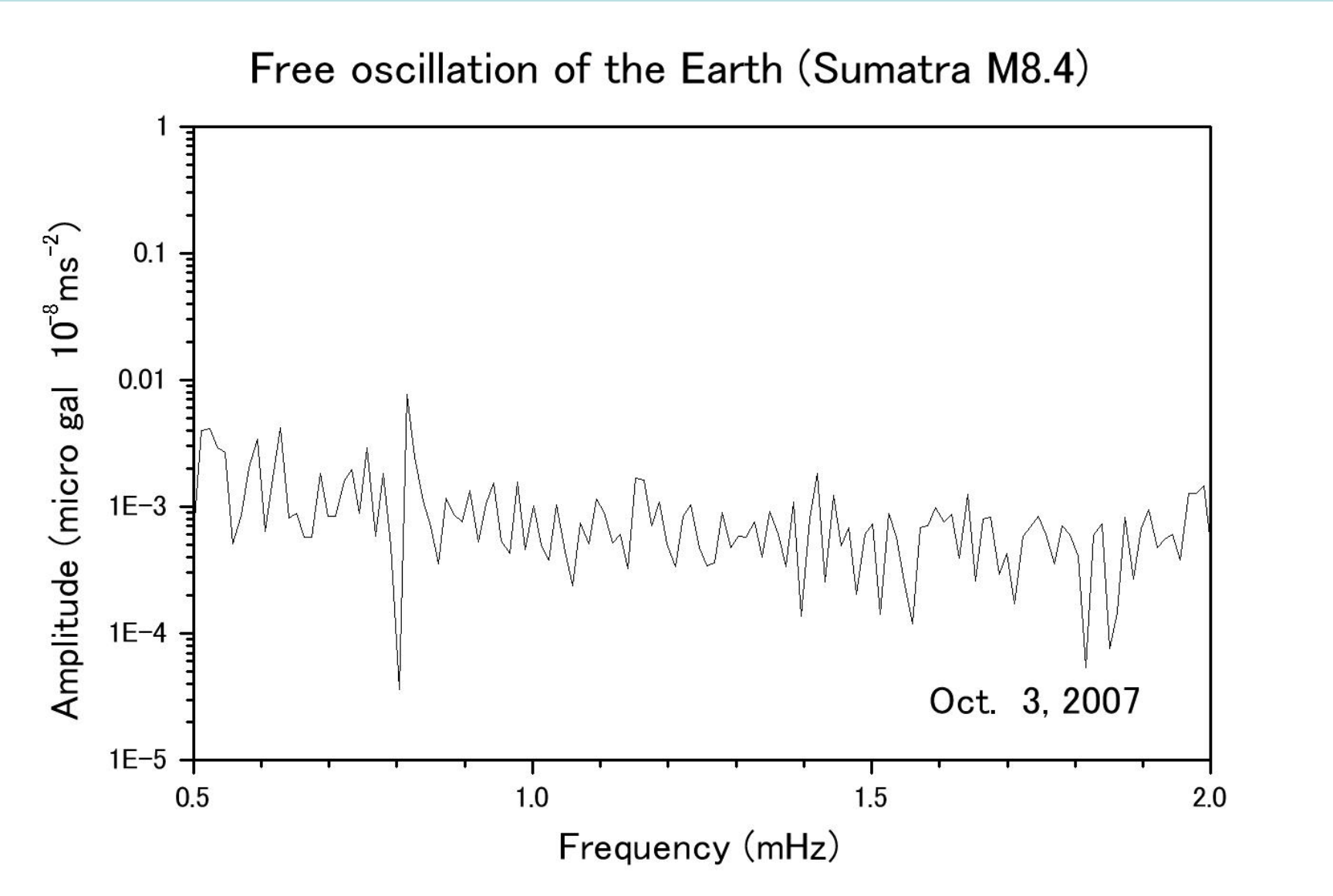
Low frequency part



9 days after: all modes decayed except $_0S_0$mode.

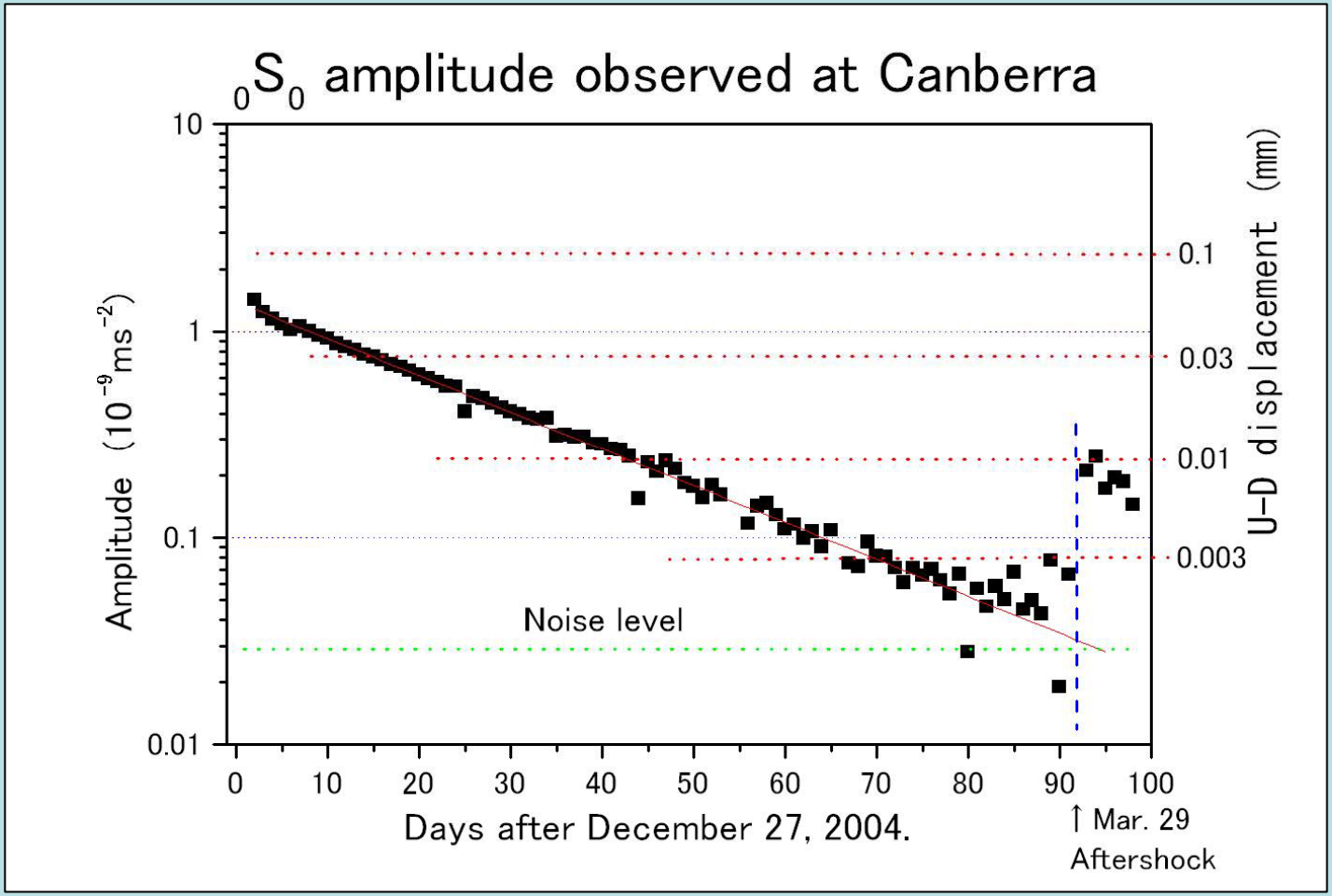


12 days after



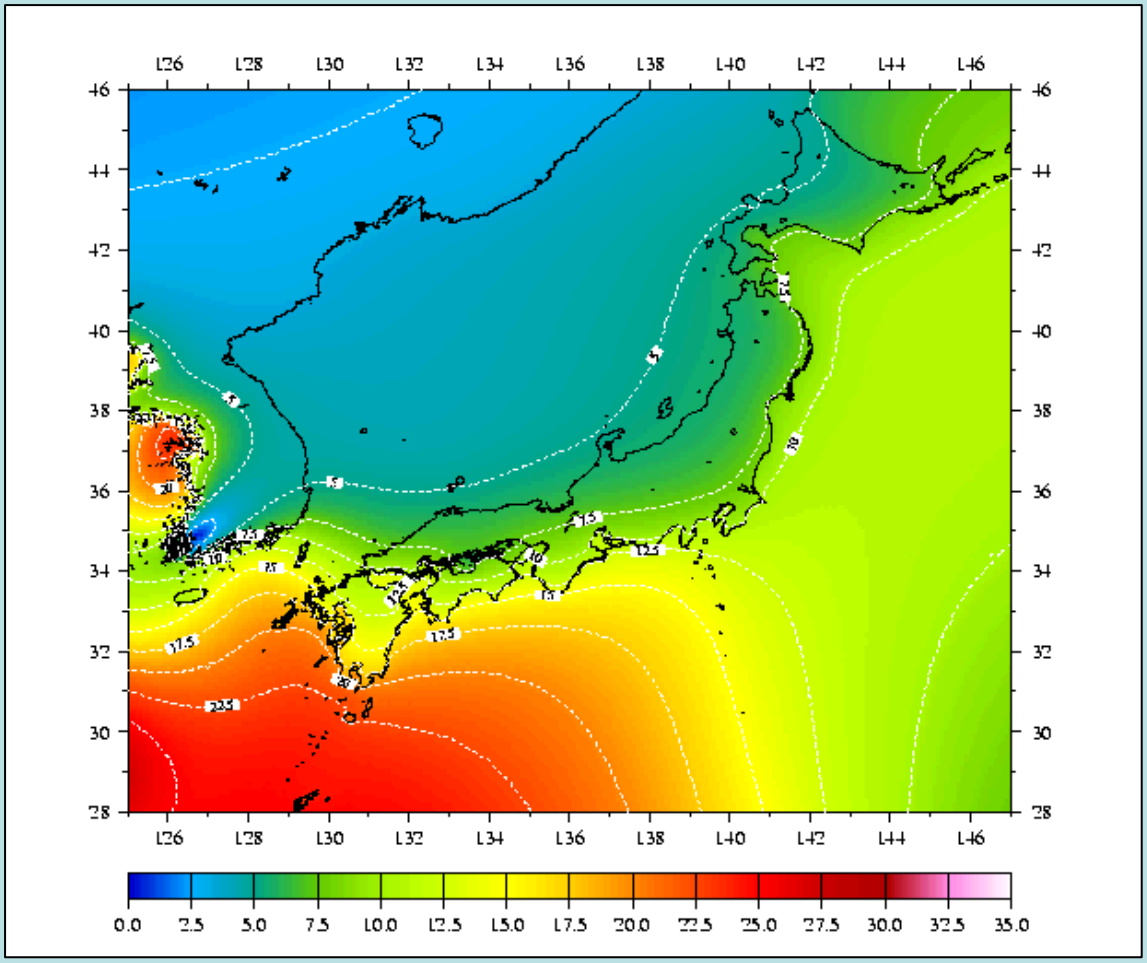
21 days after: ${}_0S_0$ mode is still visible.

Sumatra-Andaman Earthquake(Mw9.3) December, 2004



The amplitude of $_0S_0$ mode of 2004 Sumatra earthquake was 10 times larger than that of 2007.

4. Ocean tide loading



Ocean Tide loading, M2 (12.4h) component. Unit mm

5. Can we predict Earth tides?

Yes

- Predict from Earth model, physical model
- Predict from harmonic analysis results
  (empirical model)

- Feedback control
  major period: diurnal, semidirunal

Thank you for your attention