Geophysics interferometer installation and operation

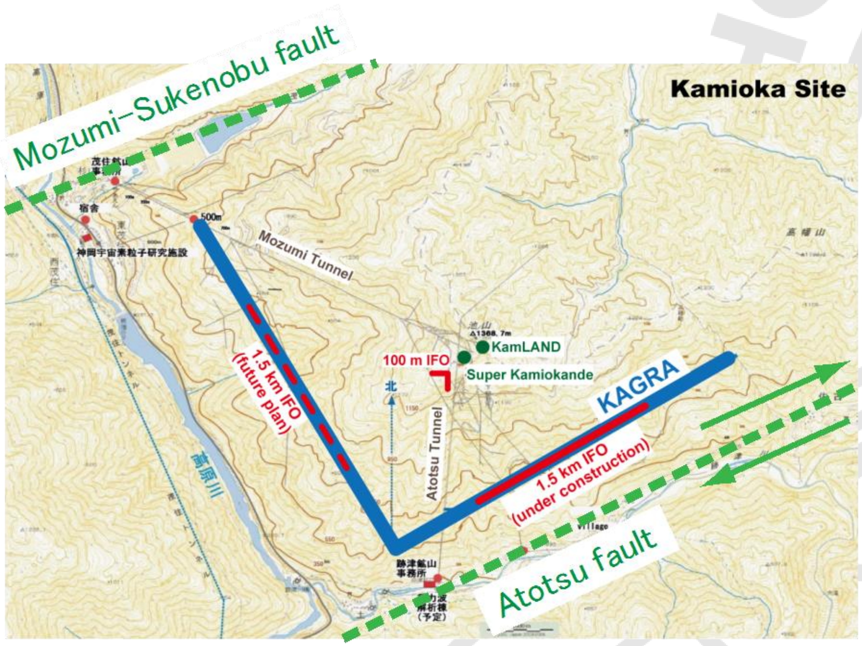
A. Takamori, A. Araya
(ERI, Univ. of Tokyo)
W. Morii (Recep, Kyoto Univ.)
K. Miyo, M. Ohashi (ICRR, Univ. of Tokyo)
and KAGRA Collaborators

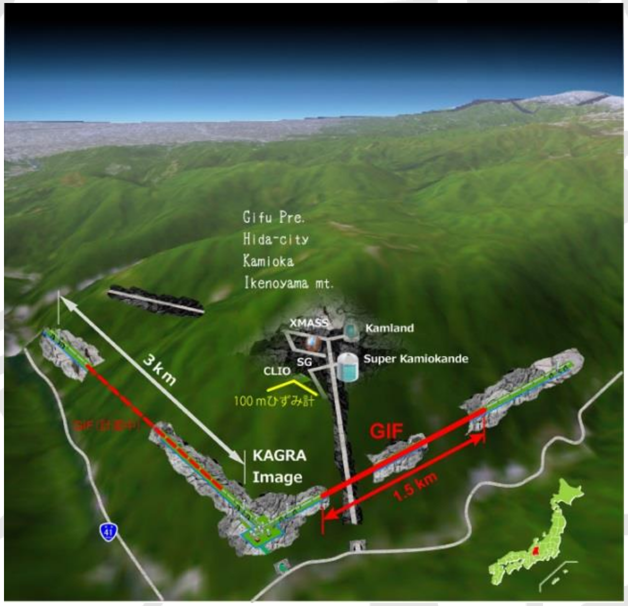
Contents

Introduction

□ Scope of project

- **Construction of Geophysics Interferometers (GIF) next to KAGRA**
- **GIF is used for geophysical observations and to provide baseline monitor for KAGRA**

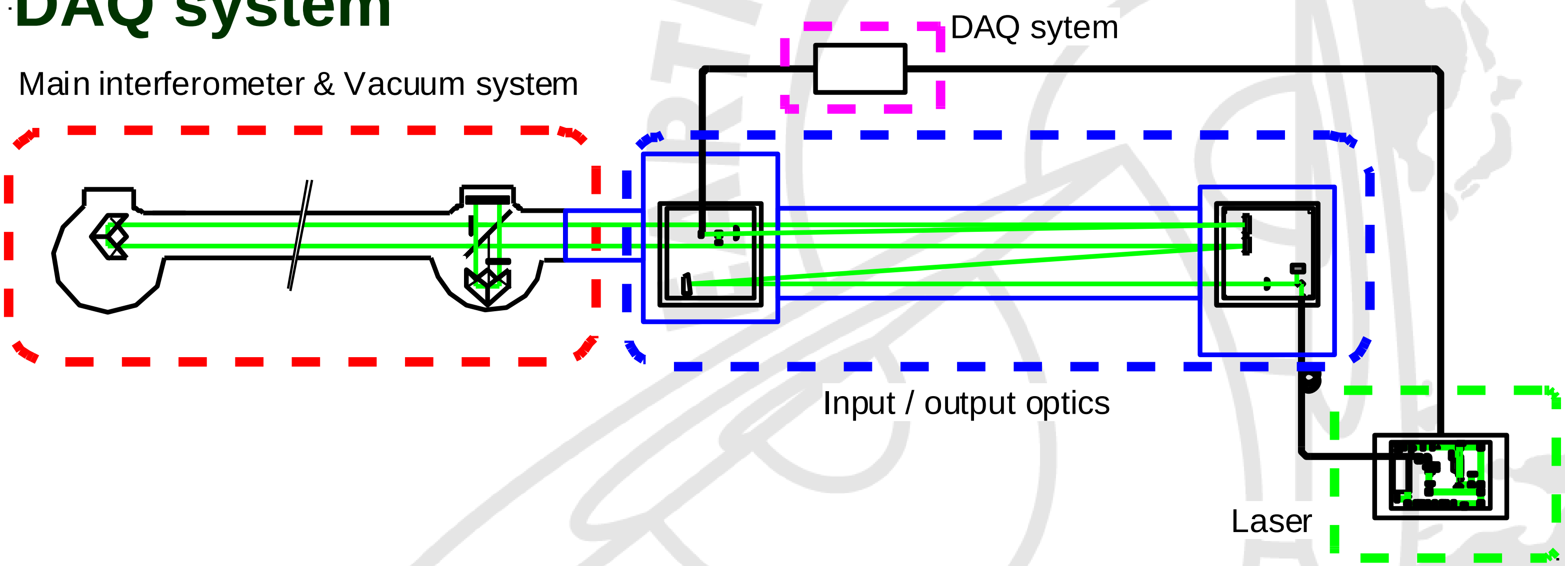




Geophysics interferometer (GIF)

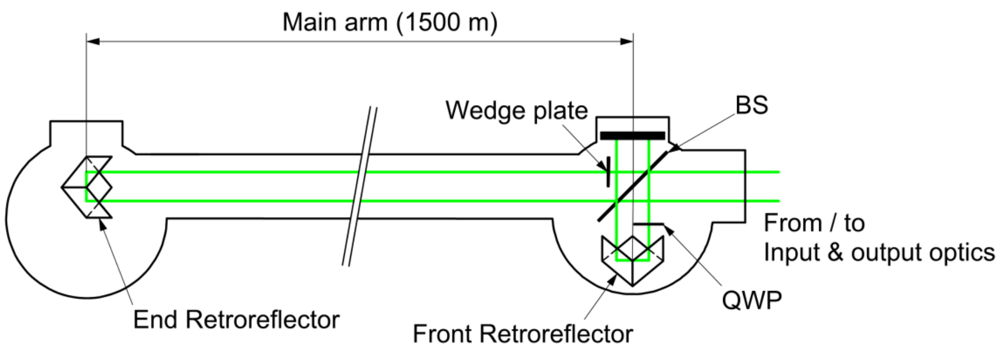
Subsystems

- Main interferometer
- Input & output optics
- Laser
- Vacuum system
- DAQ system



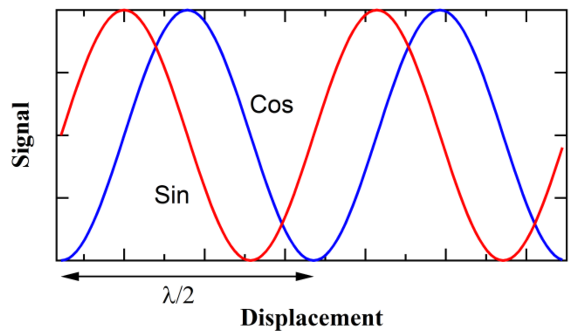
Main interferometer

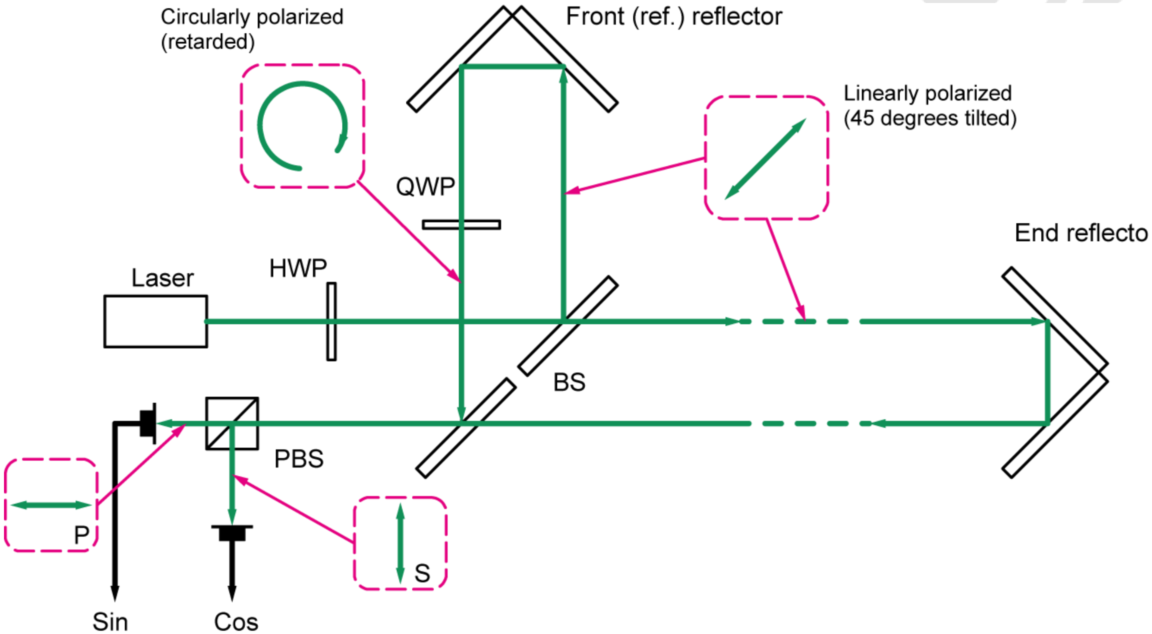
- **Asymmetric Michelson interferometer**
  - **1500 m (main arm) vs. 0.5 m (reference arm)**
    - **15" large retroreflectors for both ends**
    - **Reference arm built on a super-invar platform**
  - **Quadrature phase detection**
    - **Phase tracking without range limit**
    - **QWP inserted in reference arm**
  - **Wavefront correction**
    - **Wedge plate inserted in main arm**

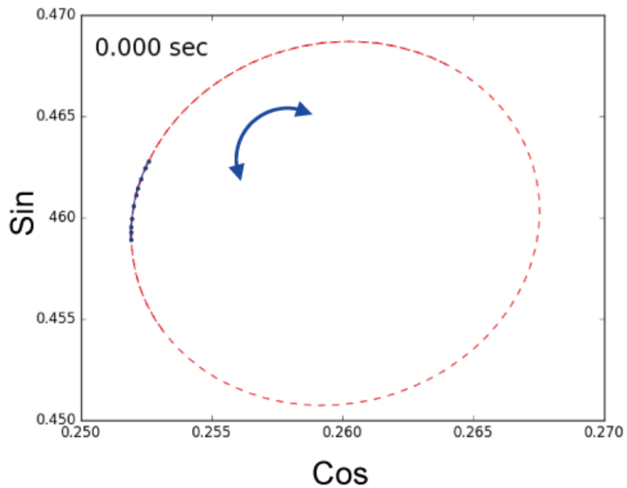


Main interferometer

- **Quadrature phase detection**
  - **Using polarized beam**
  - **No feedback to mirrors**
    - **No range limit for phase tracking**



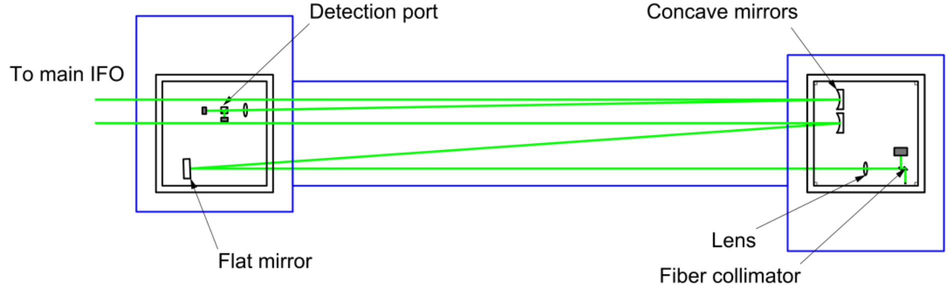




Input and output optics

Mode matching telescope

- **Reflecting telescope (10 m, folded)**
  - **Flat and concave mirrors (RC 10 m) and a lens**
  - **Installed in air (out of vacuum)**
    - Fully covered to eliminate air disturbances
- **Mode matching**
  - **Waist diameter at end reflector ~ 35 mm**
  - **Designed to minimize beam diameter at BS (~ 40 mm)**

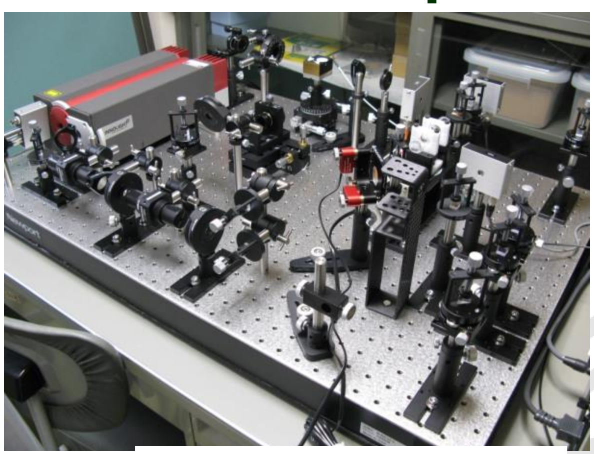


Beam cover

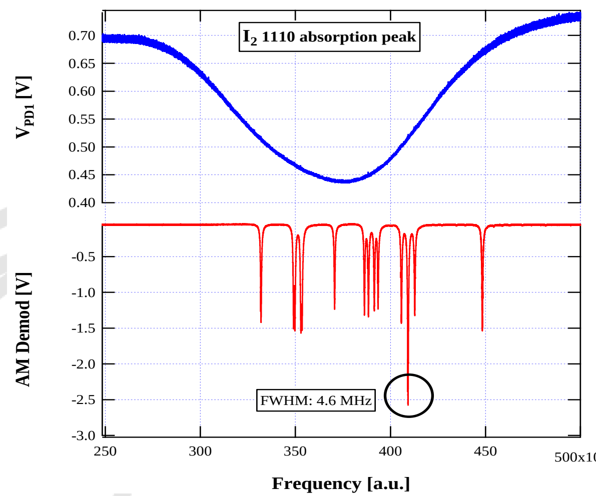
Laser

☐ Iodine stabilized laser

- **Frequency doubled Nd:YAG laser (532 nm)**
  - **Locked to I_2 absorption line**
    - Extremely stable quantum standard
    - Modulation transfer technique
- **Expected stability (strain resolution): 10^{-13}**
- **Delivered via optical fiber**



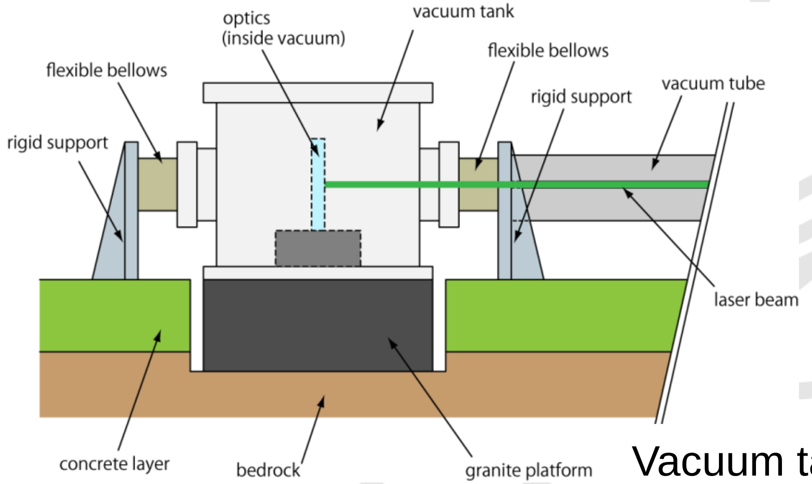
Laser optical system



I_2 absorption line

Vacuum system

- **Contains main interferometer**
  - **Vacuum tanks for main optics at both ends**
    - **Granite platforms directly attached to bedrock**
    - **Double-balanced bellows to eliminate stress**
  - **1500 m vacuum tube**
  - **Target vacuum pressure: 10^{-4} Pa**
    - **Maintained by TMPs**

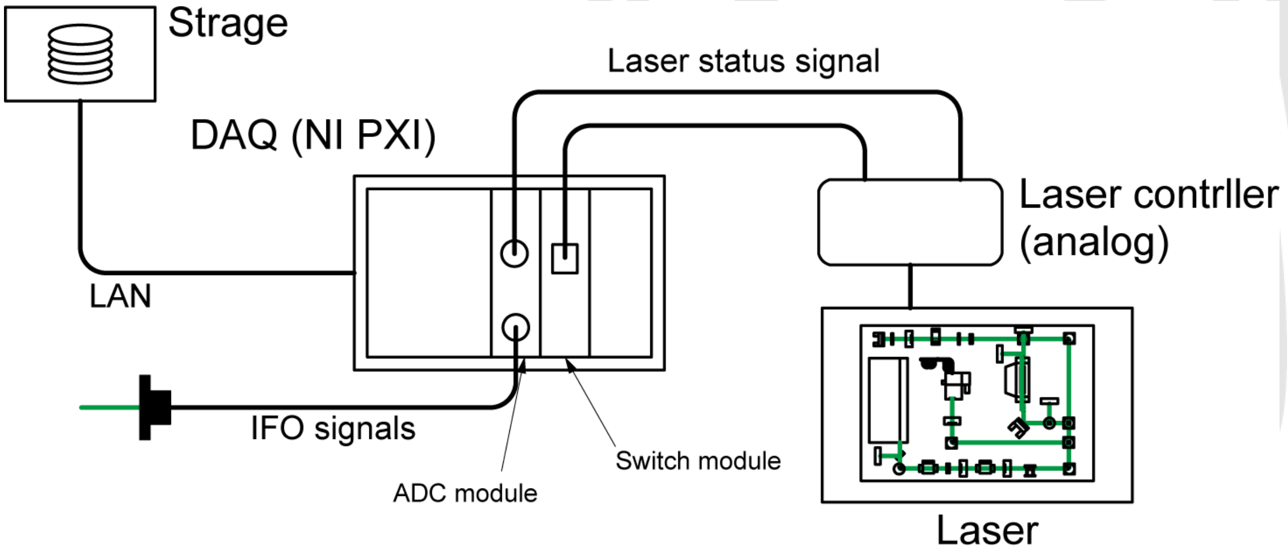


Vacuum tank

DAQ system

DAQ and system controller

- Based on NI LabVIEW and PXI
- Sampling at 50 kHz for fast phase tracking
- Monitors laser status and maintains locking
- Independent of KAGRA DAQ system

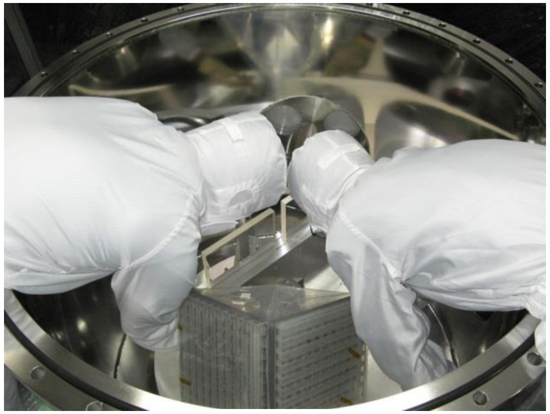


Development

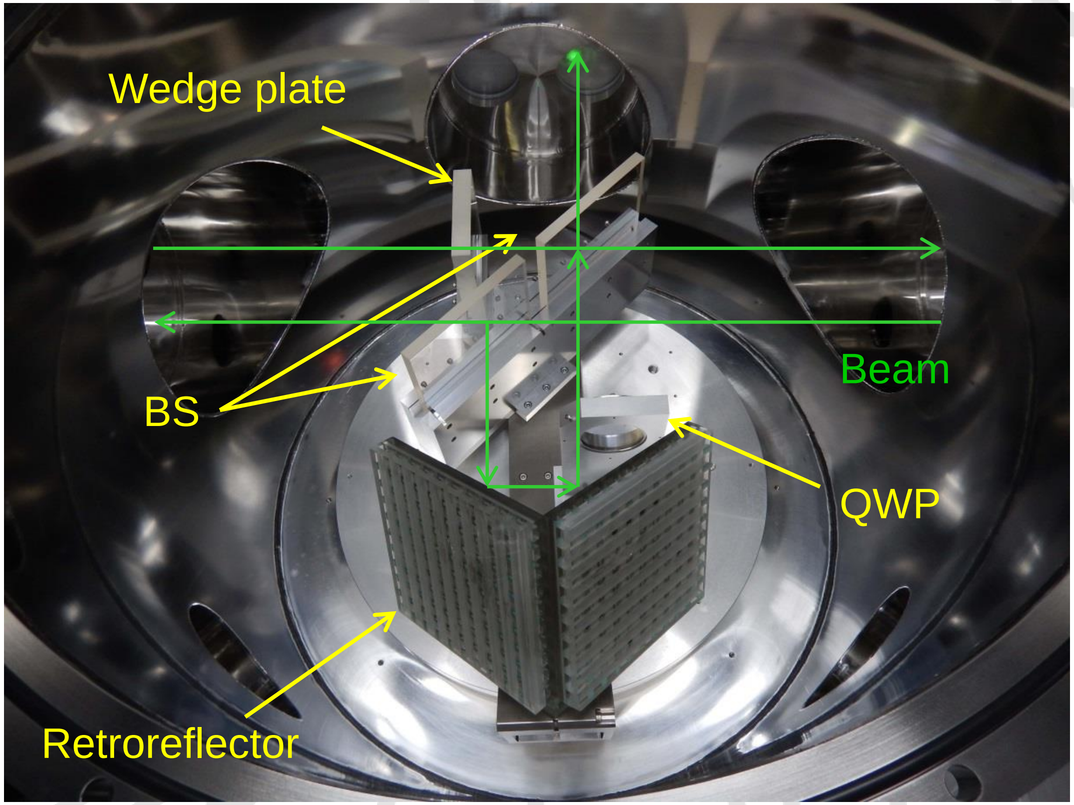
Year	Item / activity
2012	Vacuum pipes delivery Optics final design
2013	Vacuum chambers delivery Retro reflectors and other core optics delivery
2014	Valves and evacuation ducts delivery **KAGRA tunnel completed** Vacuum & granite platform installation
2015	Clean booths construction Optics installation Commissioning started **First alignment achieved** (Oct.)
2016	Beam cover upgrade **First fringe obtained** DAQ installed **Test observation**
2017	Wage plate installation Vacuum upgrade (in preparation) Laser stability evaluation (in preparation) **Long term observation**

Installation

◻ Main interferometer optics



Installation



Main optics in front tank

Commissioning

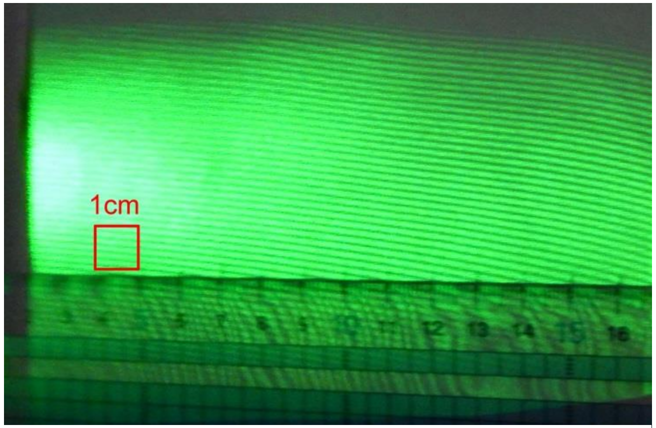
- **Adjusting optics**
  - **Mode matching**
    - **Re-designed mode matching telescope to adapt to actual focal length of concave mirror (3 % shorter)**
      - Beam waist located near end reflector
  - **Beam alignment**
    - **Adjusting concave mirror angle in mode maching telescope (Picomotor driven)**
    - **Very unstable at the beginning due to beam jitter**
    - **Tightly covered input & output beam path to obtain stable beam alignment (very crucial)**

Commissioning

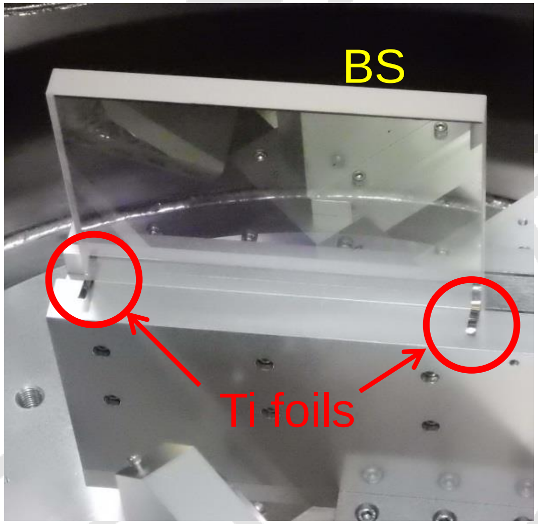
Wavefront optimization 1

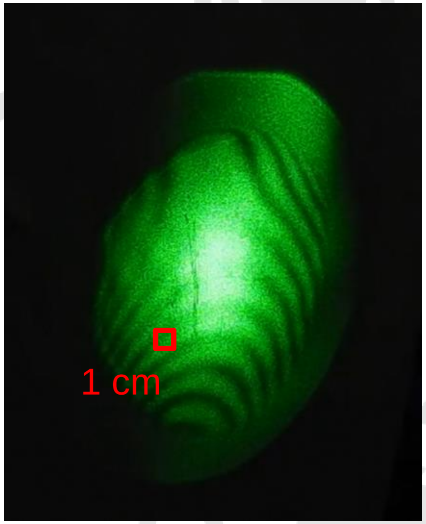
First fringe

- **Fine stripes in fringe pattern was observed**
  - Caused by Non-parallel (wedged) surfaces of BS
    specification: < 3' (best effort in manufacturing)
- **Coarsely corrected by tilting one BS**
  - Inserted Ti foils (1~3 μm thick) in BS clamp



First fringe
observed at Symmetric port



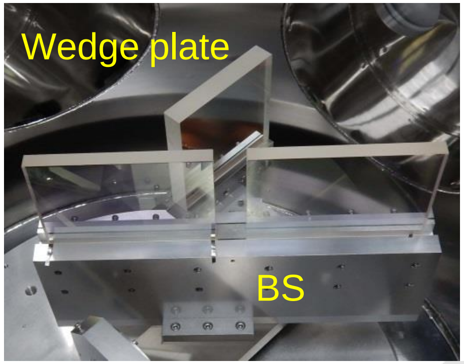


After correction

Commissioning

Wavefront optimization 2

- **After coarse correction**
  - **Very low visibility (almost useless)**
    - Tentative solution: masking output beam: visibility ~ 10 %
    - **Strain observation enabled**
    - Downside: alignment sensitivity, power loss
- **Fine adjustment**
  - **Inserted wedged glass plate in main arm**
    - Corrected in vertical direction
    - visibility ~ 9 % with no masking



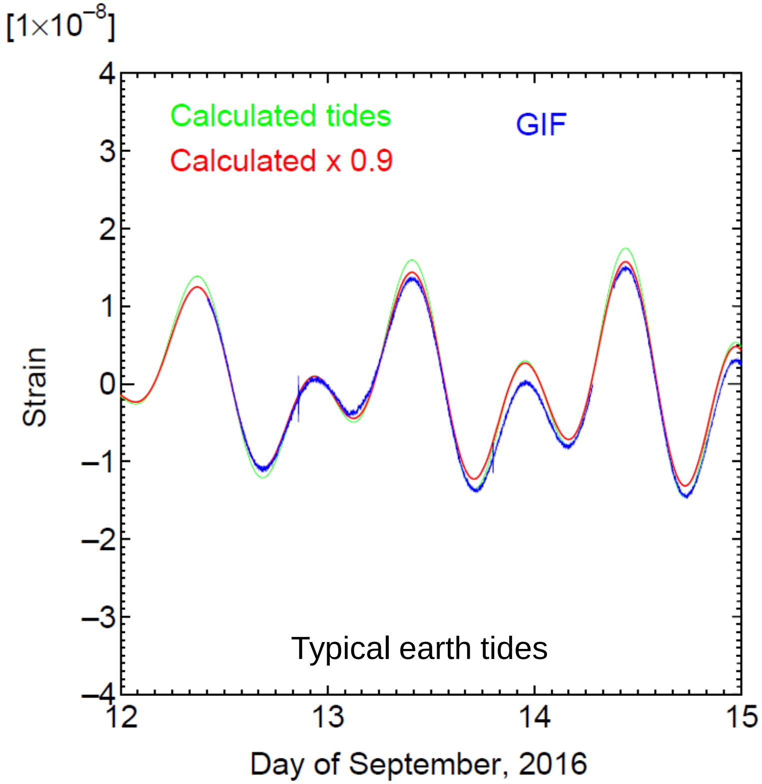
Front tank

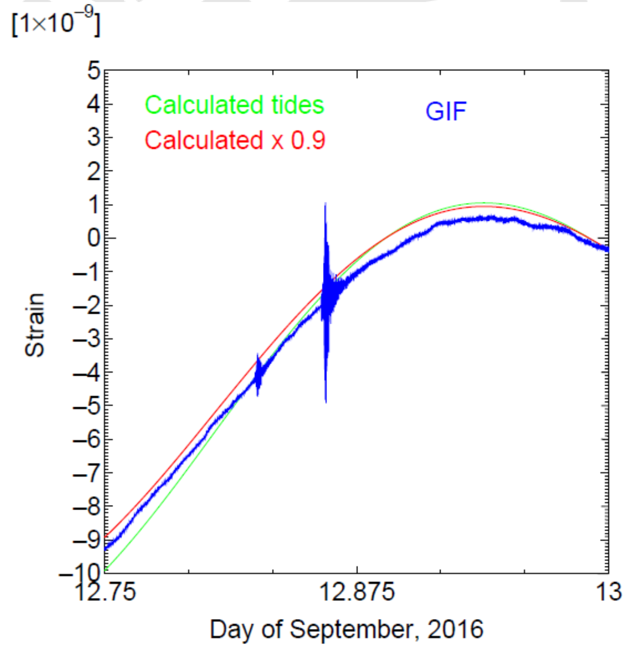
After fine adjustment

Observation

Earth tides and earthquakes

- **~ 10 % smaller amplitude than GOTIC2 theoretical model prediction**
  - **Considered as topographic effect**



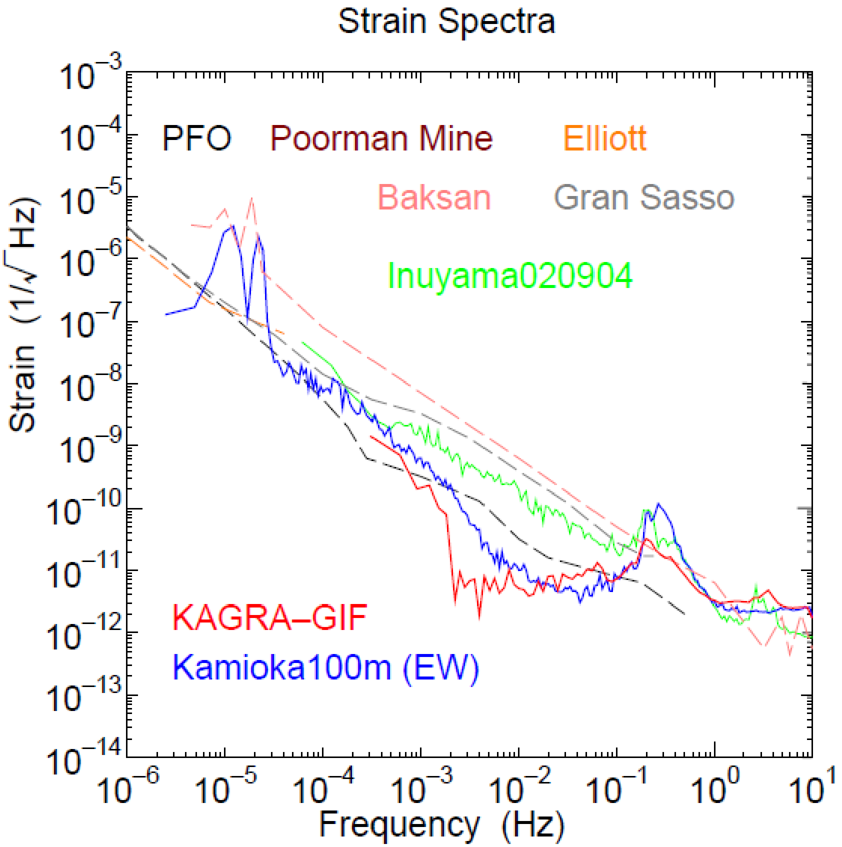


Seismic waves from
12-SEP-2016 10:44:33 M4.9 SOUTH KOREA
12-SEP-2016 11:32:54 M5.4 SOUTH KOREA

Observation

□ Back ground strain spectra

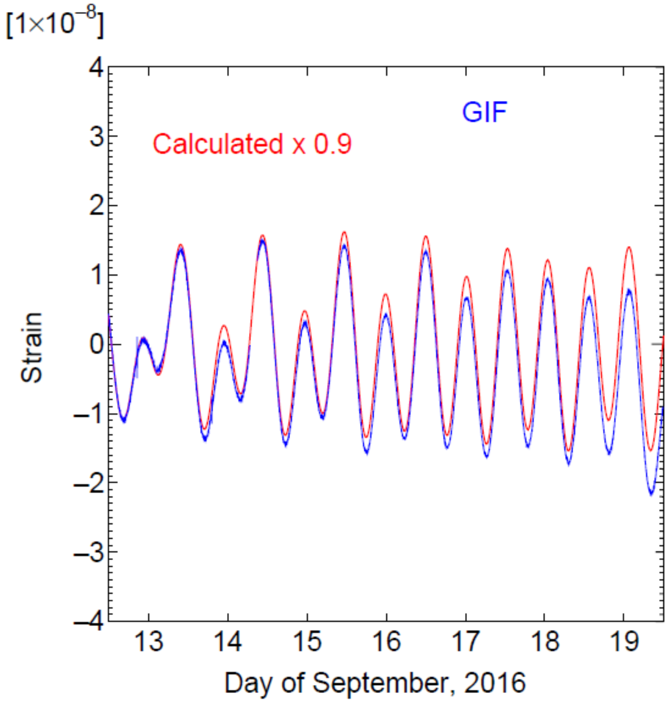
- **Lowest back ground, especially around 1-10 mHz**

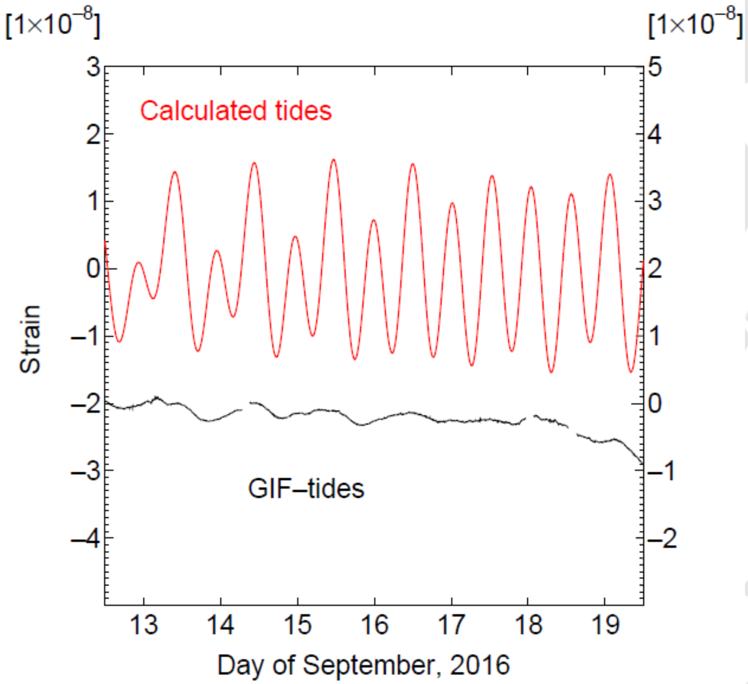


Observation

Trend (preliminary)

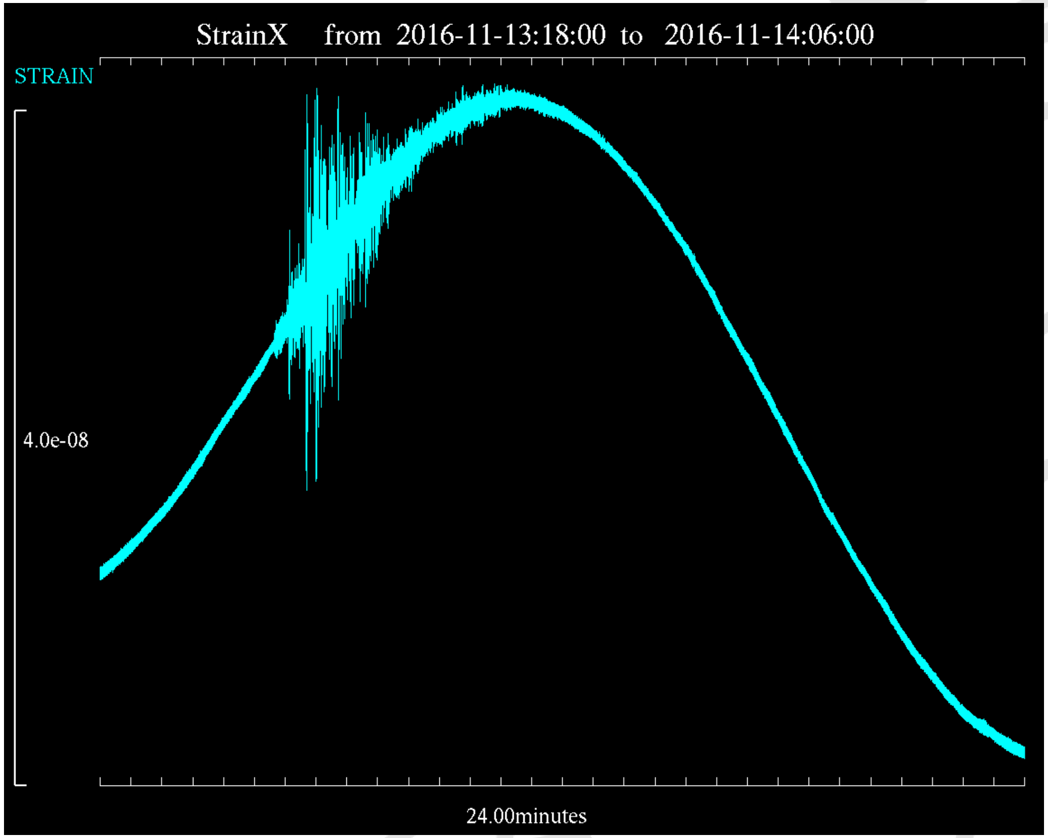
- ~ 6 x 10^{-9} / week (~ 3 x 10^{-7} /year)
- Trend rate slightly changes
- Laser stability is much smaller (~ 10^{-12})





Observation

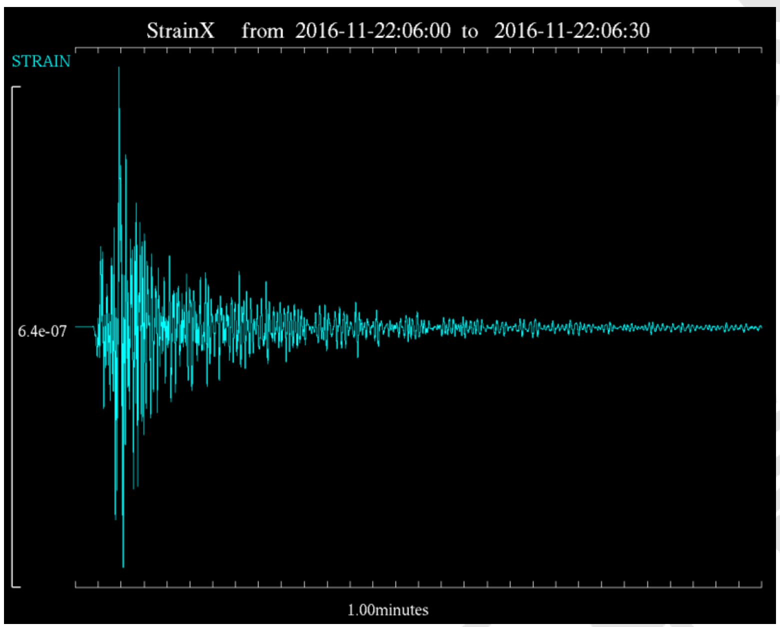
- **Large & far earthquake**
  - **New Zealand earthquake (strain amplitude ~ 10^{-8})**

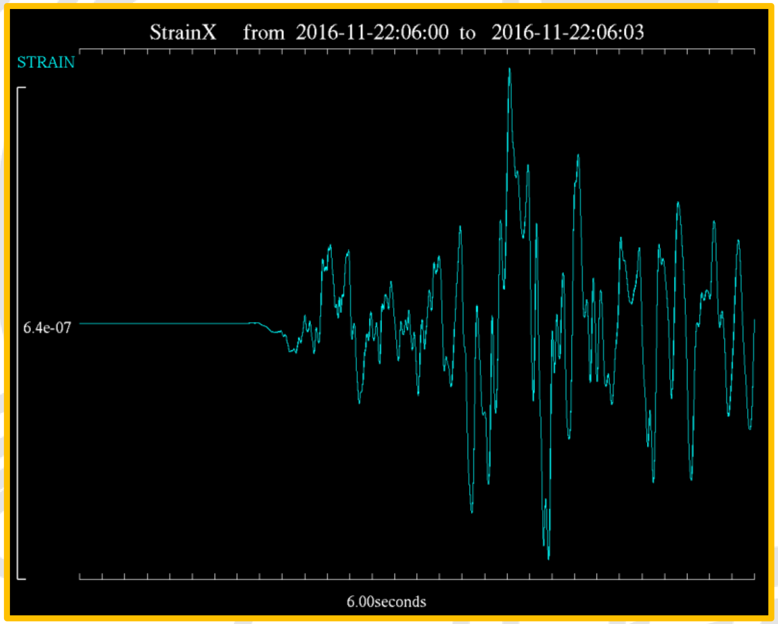


13-NOV-2016 11:02:56 M7.8 New Zealand

Observation

- **Large & close earthquake**
  - **Fukushima**
    - **Intensity 1 ~ 2 at Kamioka**
    - **Strain amplitude ~ 3 x 10^{-7}**
    - **No saturation, no phase step**





22-NOV-2016 6:59:49 Mw6.9 Fukushima

Summary

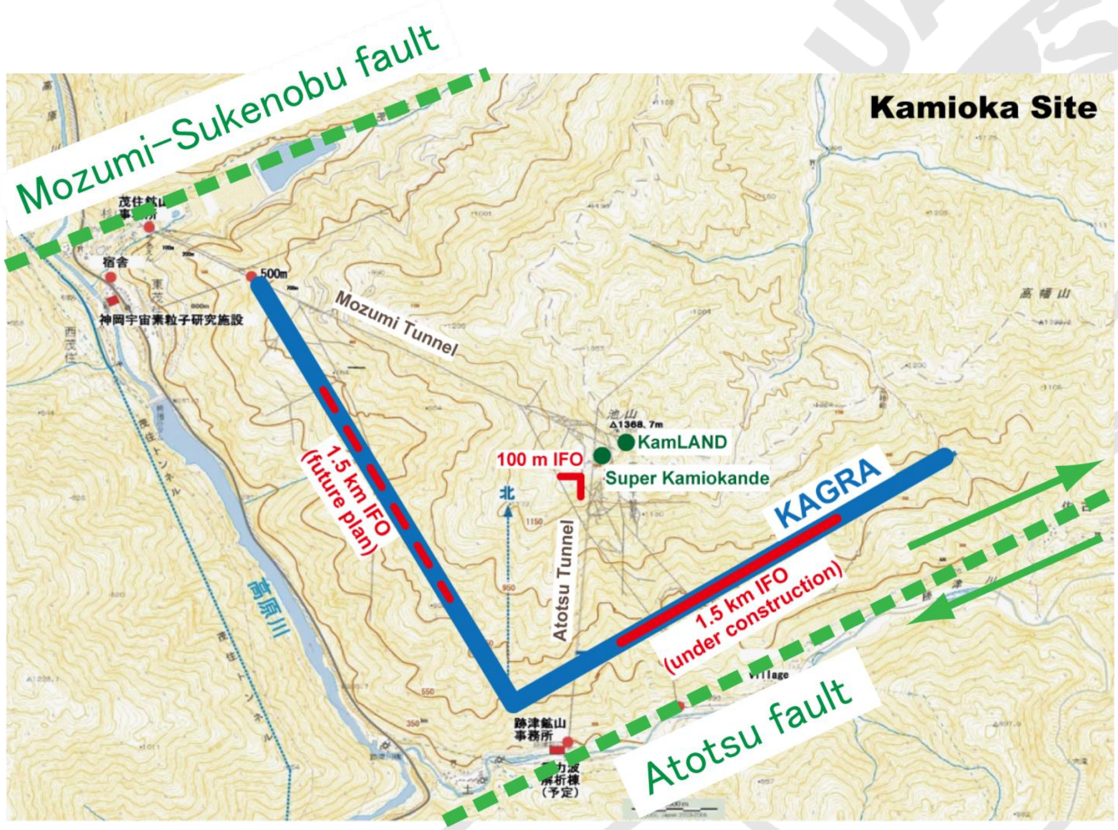
- **GIF development**
  - **GIF is a laser interferometer with 1500 m baseline length located in KAGRA underground tunnel.**
  - **GIF will be used for geophysical observations and as a baseline monitor for KAGRA.**
- **Installation & commissioning**
  - **GIF has been installed and commissioned since 2015.**
  - **Some technical issues have been encountered and resolved.**
    - **Air flow (beam jitter)**
    - **Wavefront distortion etc.**

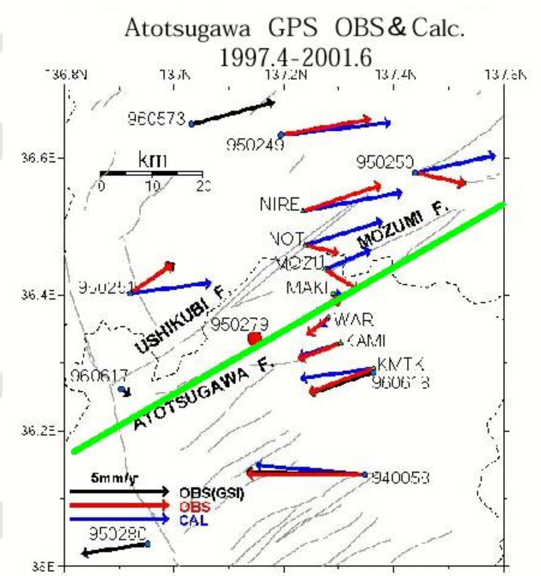
Summary

- **Observation results**
  - **Ground strain has been successfully recorded.**
    - Earth tides
    - Various types of earthquakes
    - Trend (preliminary, require further study)
  - **Achieved best strain sensitivity at low frequencies**
    - ~ 10^{-12} in 1-10 mHz
- **Planned works**
  - **Evaluation of laser stability**
    - Beat measurement with identical laser system
  - **Data sharing with KAGRA**
    - Real-time strain computation
    - Integration into KAGRA control system

KAGRA Site

- **Fault locations**
  - **Near two faults**
    - **Dislocations to be monitored by GIF**

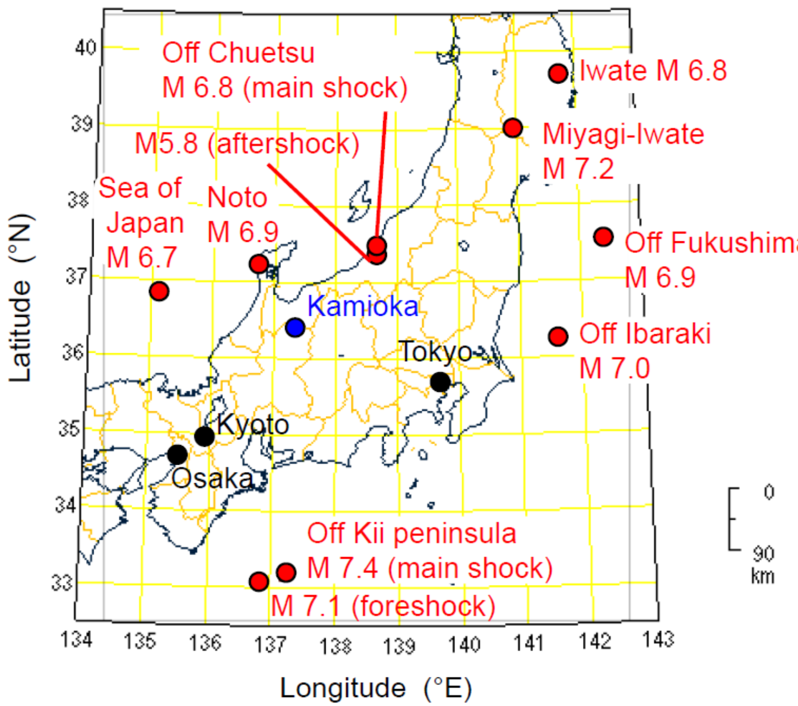




Dislocations observed by GPS network

KAGRA site

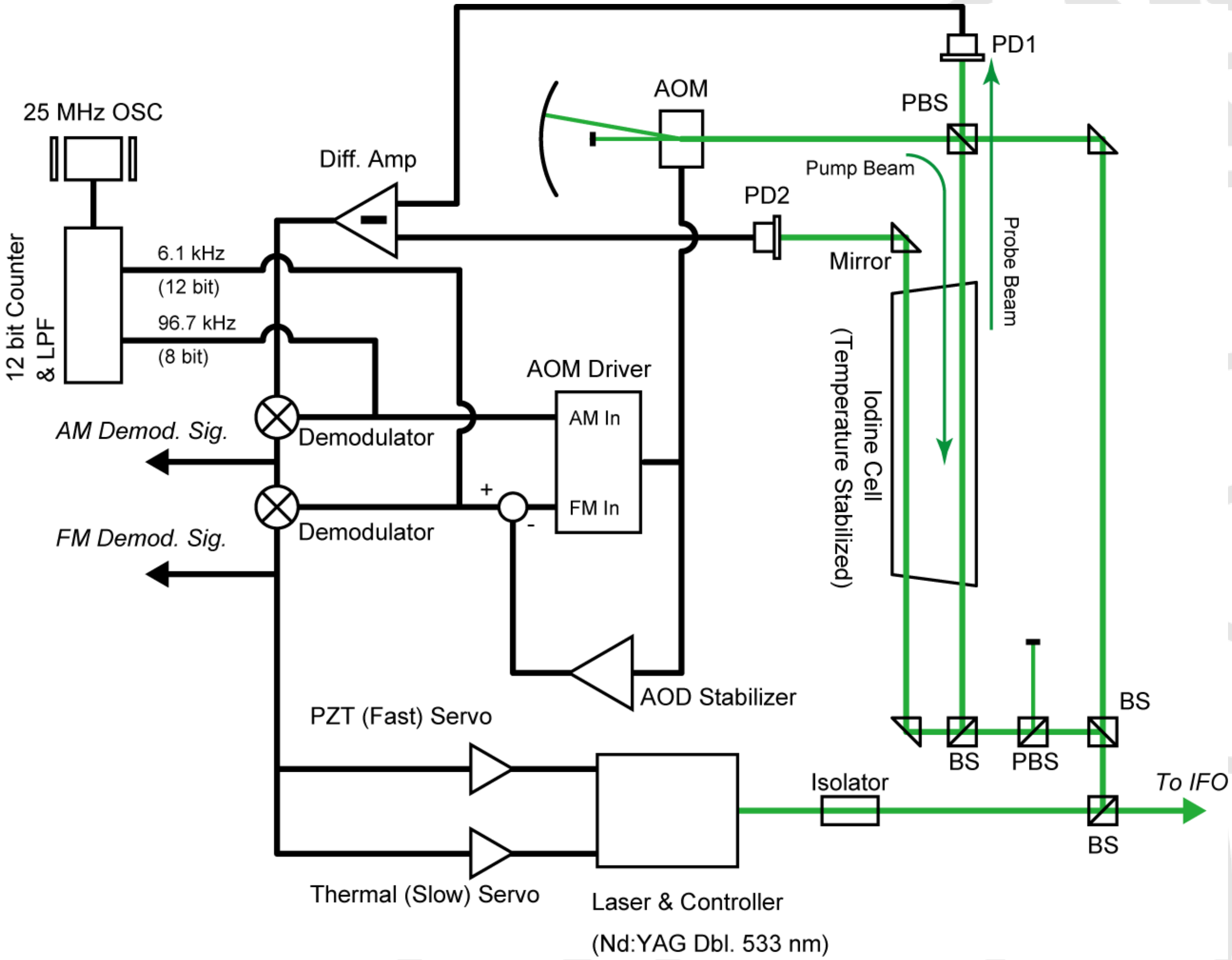
- **Seismic activities**
  - **Seismic events and associated strain steps**
    - **Observed with existing 100 m IFO, repeatedly**



Seismic events observed by 100 m IFO, 2004-2009

Laser stabilization system

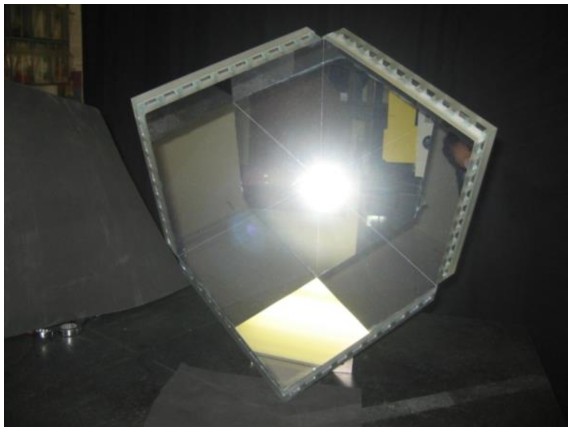
System diagram

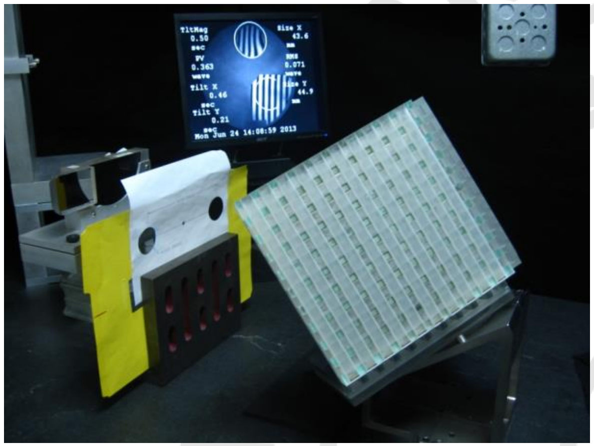


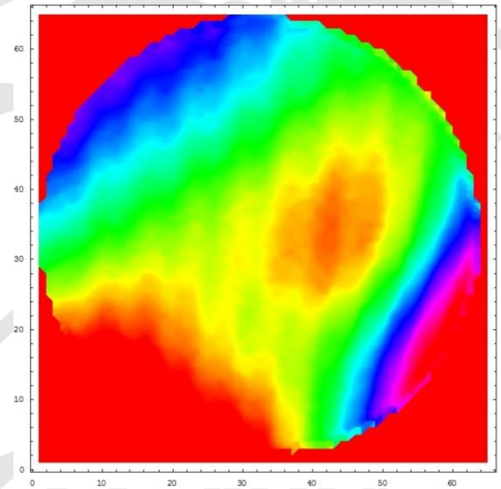
Core optics

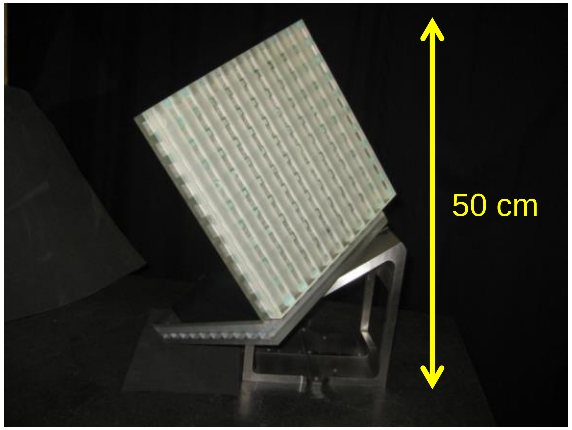
Retroreflector

Quality evaluation







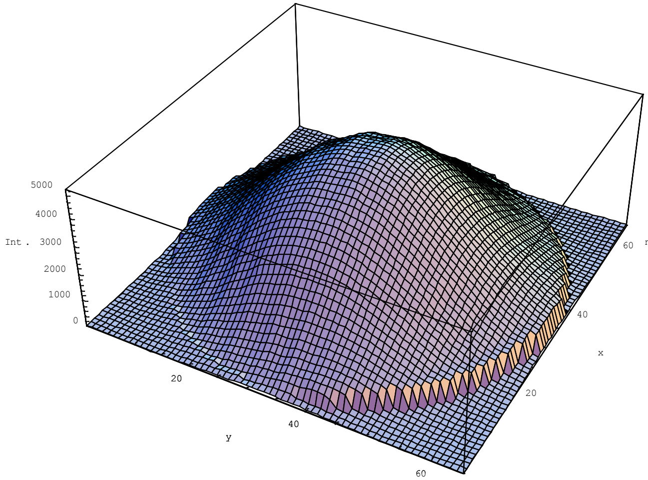


- **15” Retroreflector**
  - Surface distortion measured with Zygo interferometer: p.v. 0.353 λ / 0.070 λ rms
  - Interferometer visibility estimated:

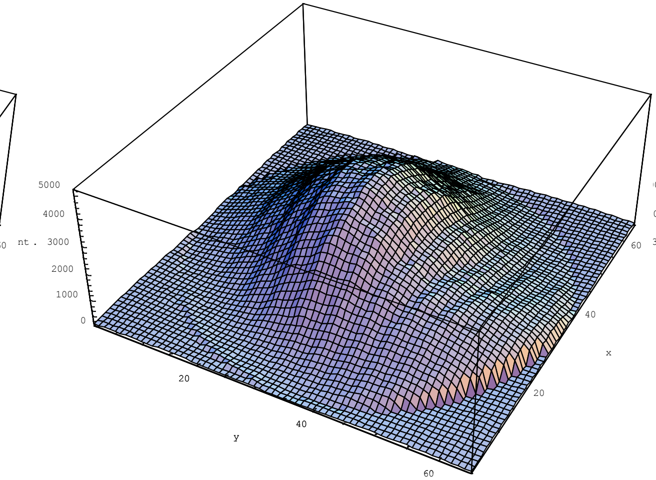
    0.53 (25% degradation) cf. actual visibility ~ 0.1

Visibility estimation

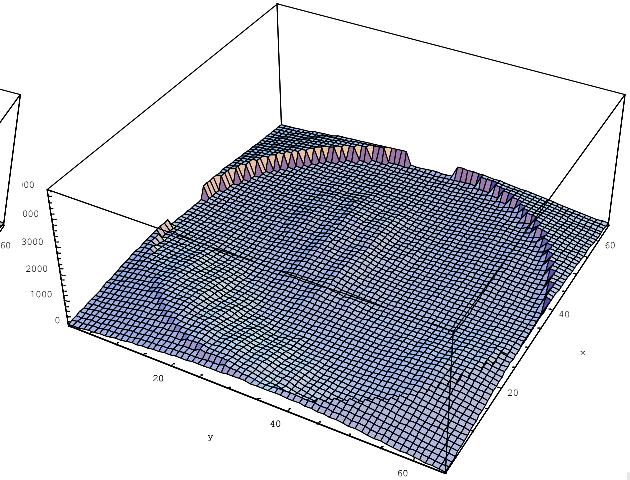
- **Finite element modeling**
  - **Using measured mirror surface information**
  - **Meshing mirror surface**
    - **100 x 100 (2 mm x 2 mm / element)**
  - **Compute spatial distribution of interfered beam intensity**
  - **Integration to calculate interferometer visibility**



Bright fringe



Intermediate fringe



Dark fringe