Gravitational Wave Detection

Seminar @Sogang University, Oct. 17, 2013

JGW-G1301934-v1

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Outline

- Gravitational wave
- Detection
- KAGRA
- DECIGO
- Summary

Gravitational wave

- **Einstein Equation**

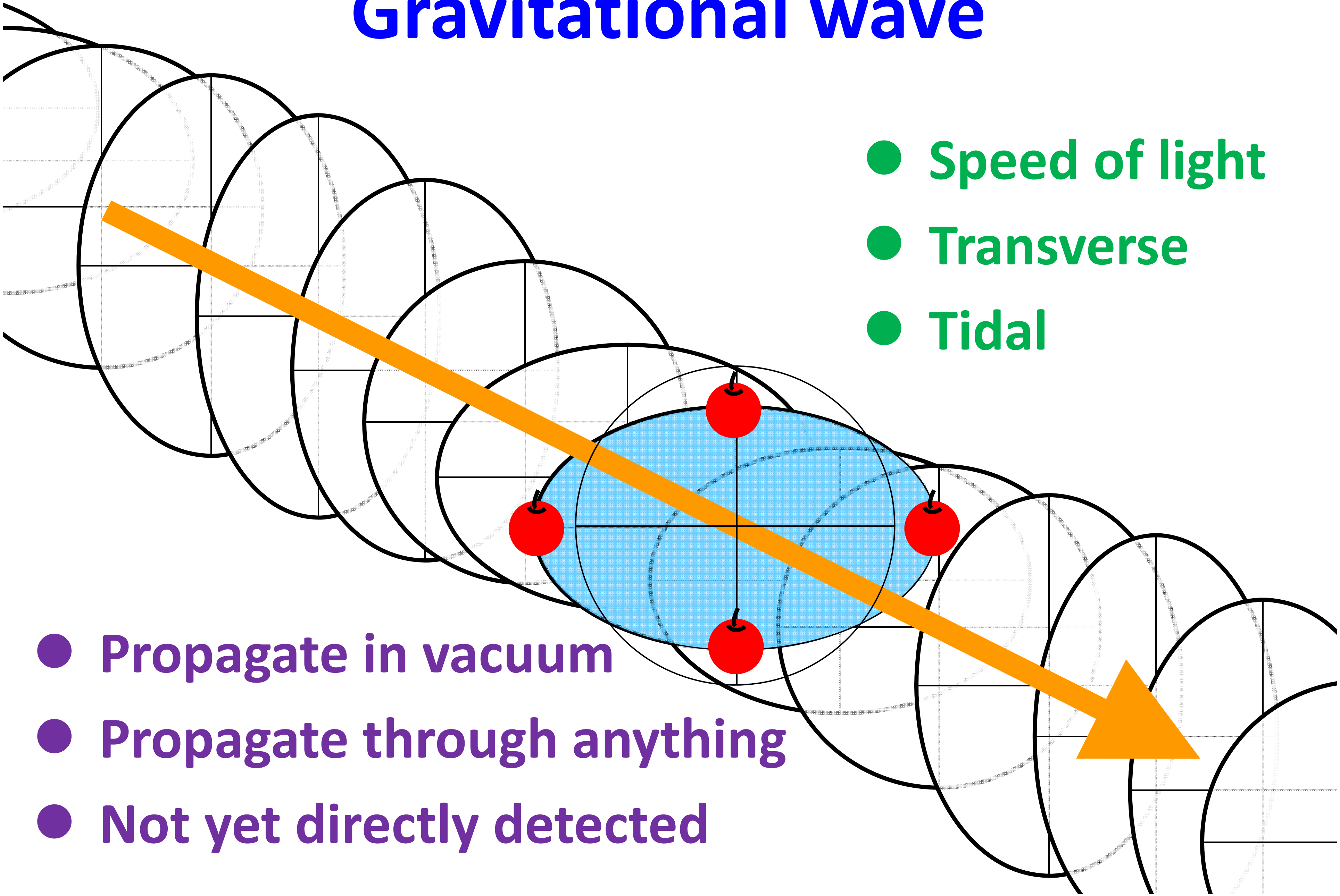
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\kappa T_{\mu\nu}$$

- **For a small perturbation 'h', a wave equation is derived**

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) h_{\mu\nu} = 0$$

Gravitational wave

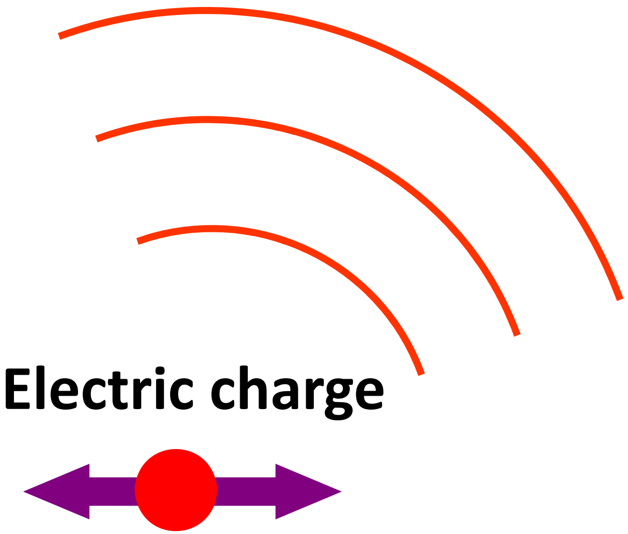


- Speed of light
- Transverse
- Tidal

- Propagate in vacuum
- Propagate through anything
- Not yet directly detected

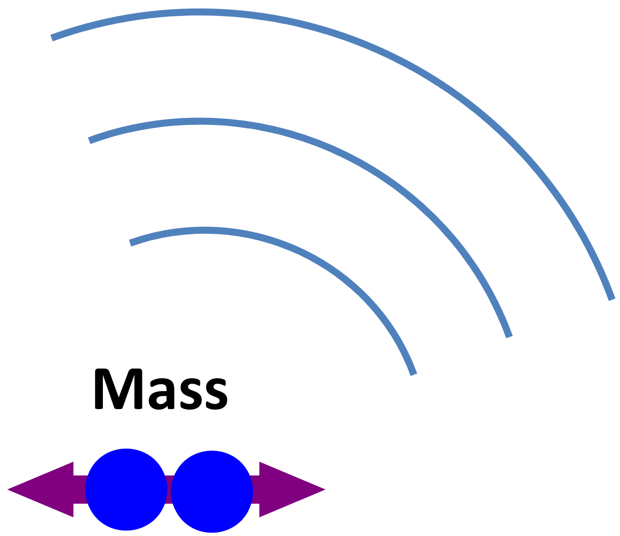
What produces GWs?

Electromagnetic wave



Dipole radiation

Gravitational wave



Quadrupole radiation

GW exists!

- Hulse & Tayler's observation on PSR 1913+16
- Orbit period decreased due to GW emission
- Nobel prize in1993

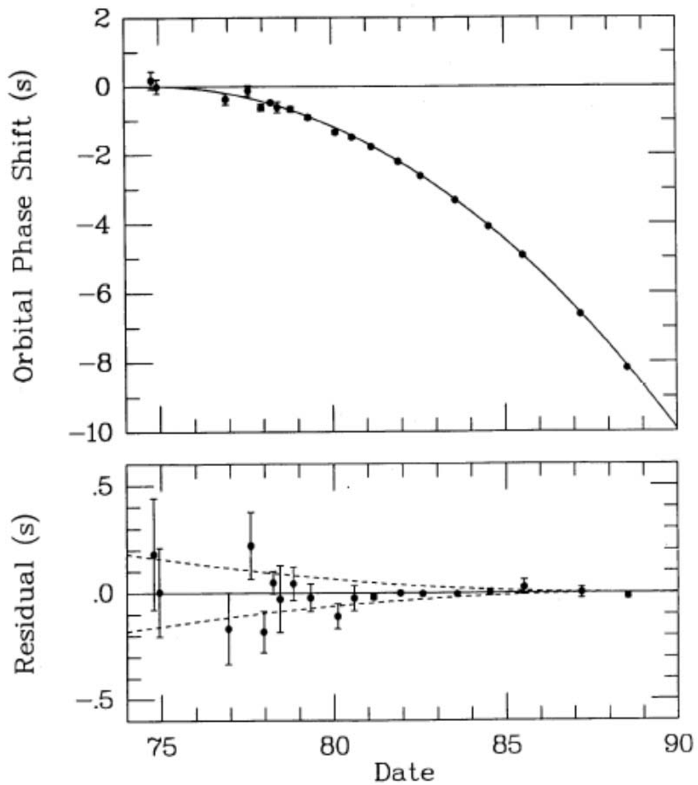


FIG. 5.—*Top:* Cumulative shift of the times of periastron passage relative to a nondissipative model in which the orbital period remains fixed at its 1974.78 value. *Bottom:* Differences between the locally measured periastron times and those expected according to the DD(1) parameter set. Dashed curves illustrate differential trends that would be expected (relative to epoch 1988.54) if the rate of orbital decay $\dot{P}_b$ were 2% larger or 2% smaller.

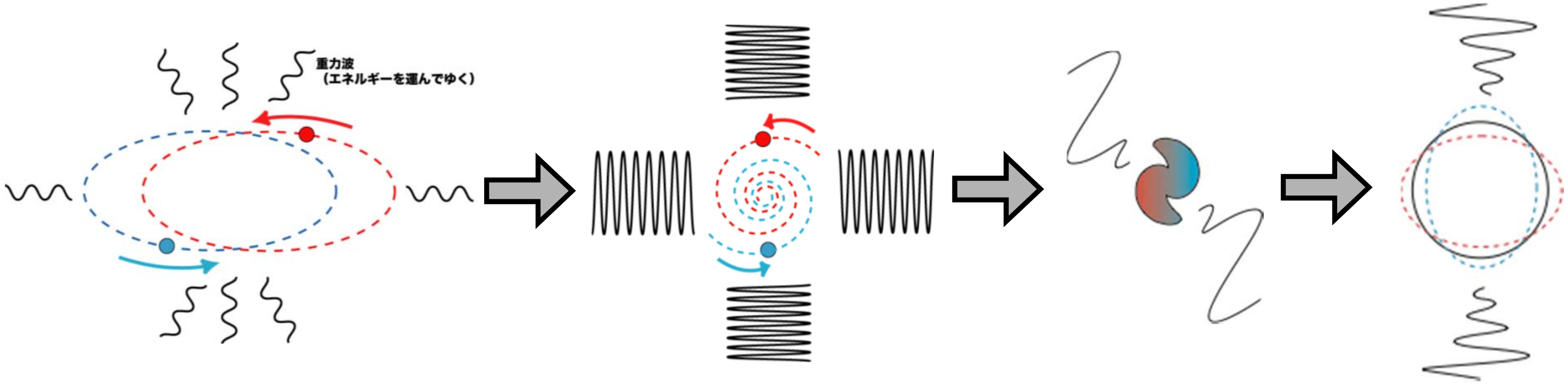
Taylor et al., ApJ.345(1989) p435

Emission of gravitational wave

1. Coalescence of binary neutron star
2. Supernova
3. Coalescence of binary black hole

CG／KAGAYA

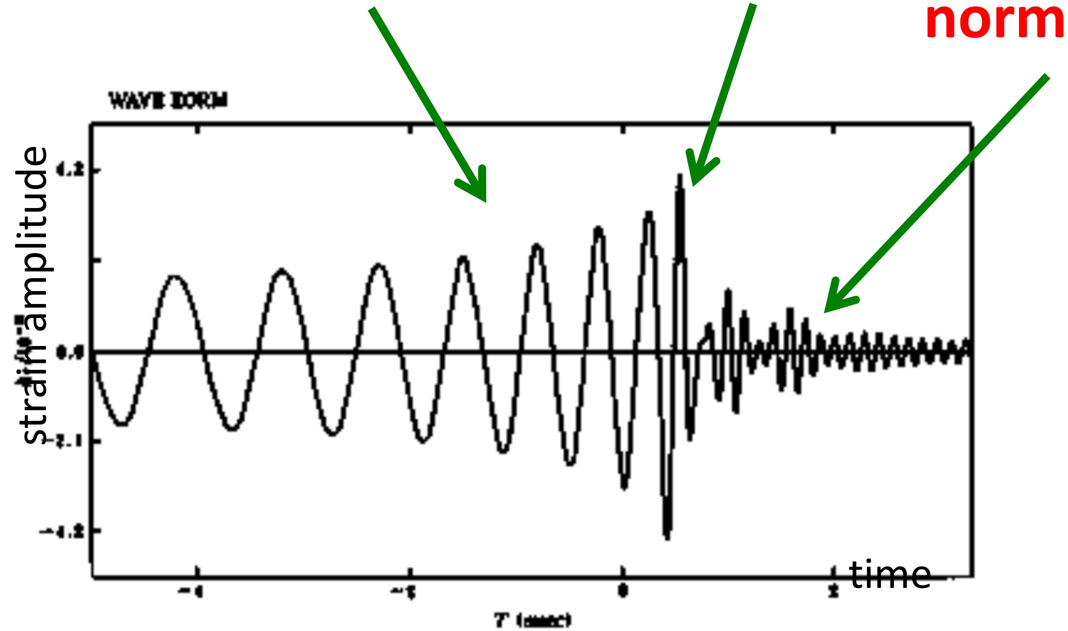
Neutron star binary coalescence

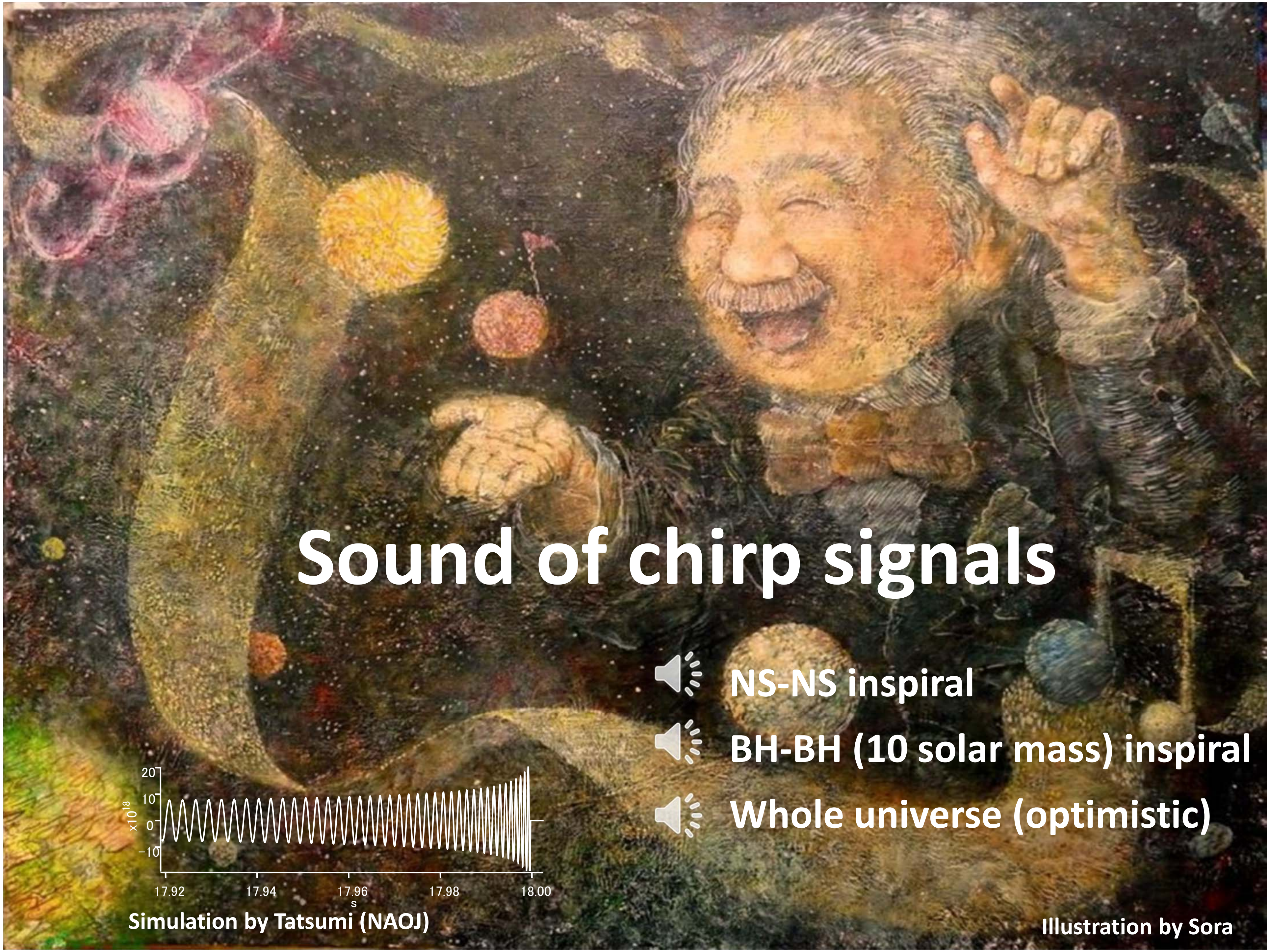


inspiral phase

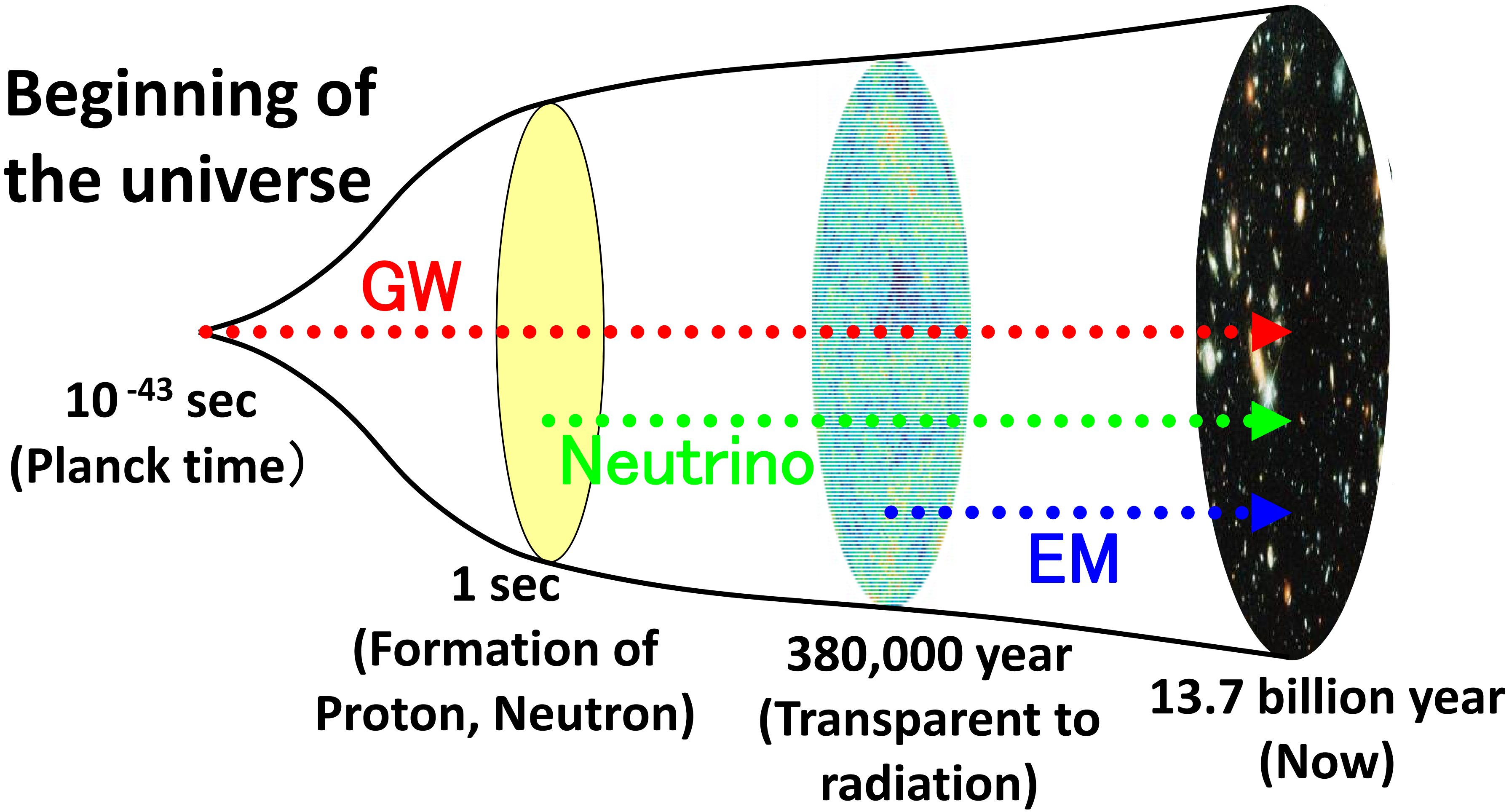
merger

Black hole quasi-normal mode

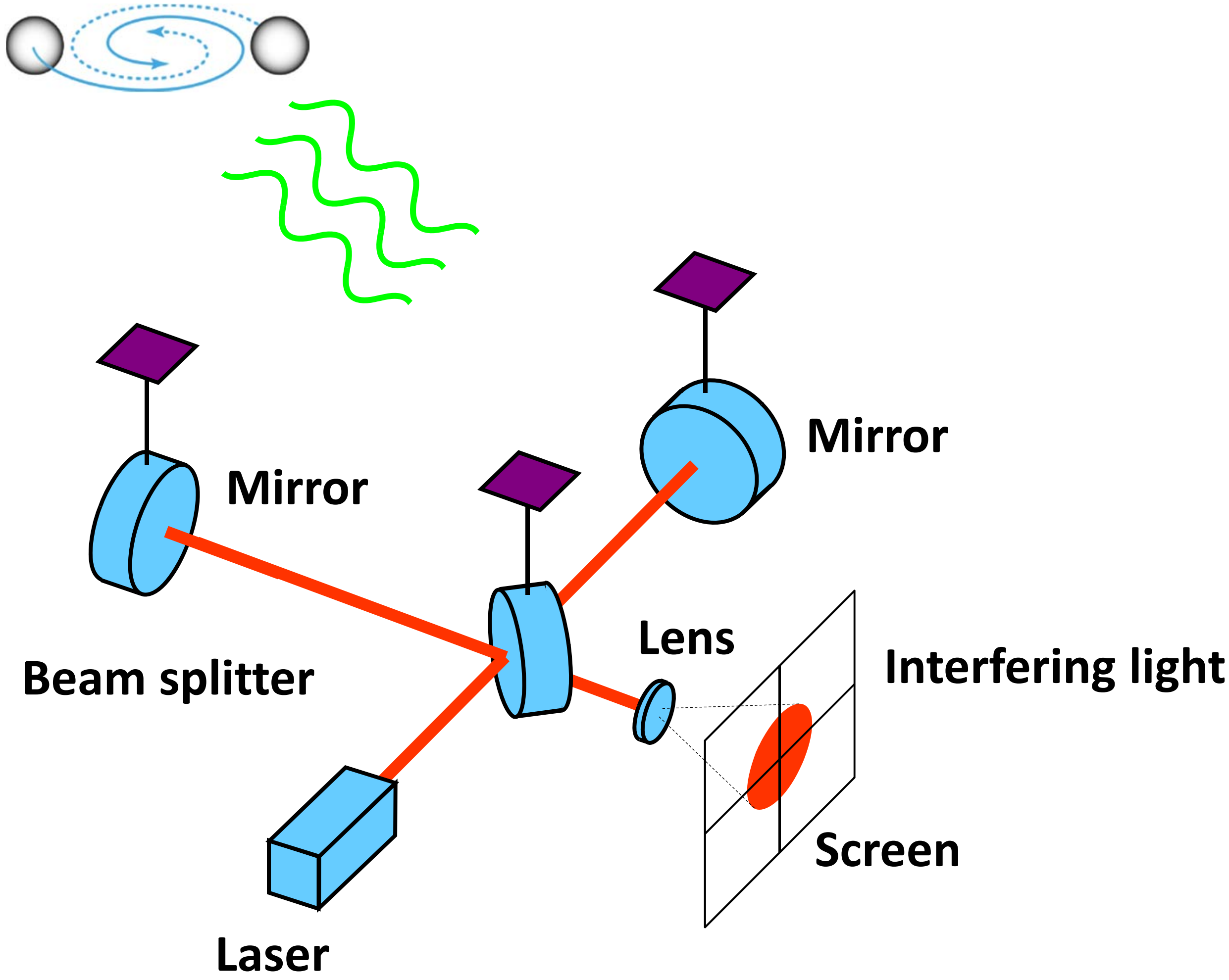



Sound of chirp signals
NS-NS inspiral
BH-BH (10 solar mass) inspiral
Whole universe (optimistic)
20
10
0
−10
x10^18
17.92
17.94
17.96
17.98
18.00
s
Simulation by Tatsumi (NAOJ)
Illustration by Sora

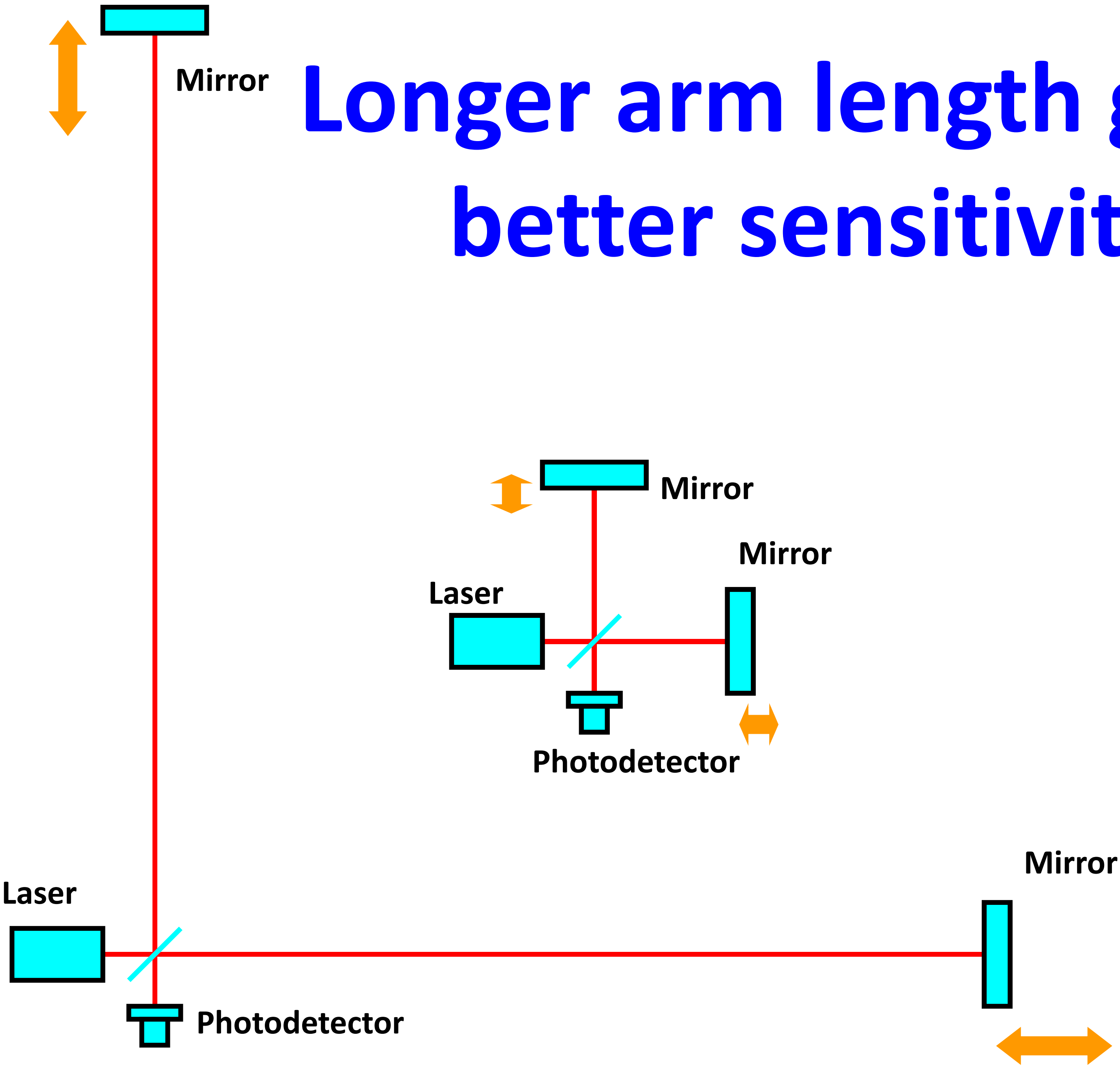
Beginning of the Universe



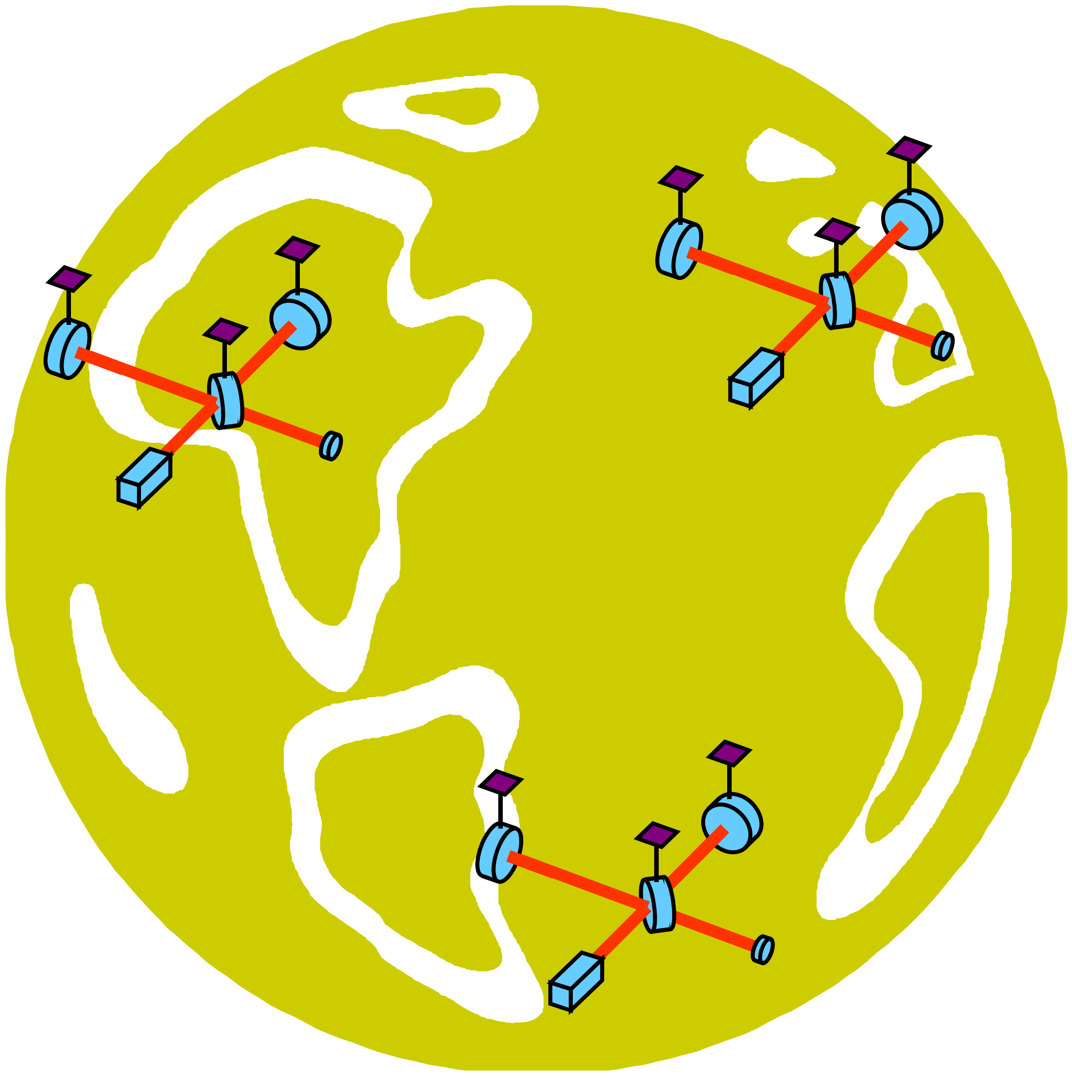
Michelson interferometer



Longer arm length gives better sensitivity

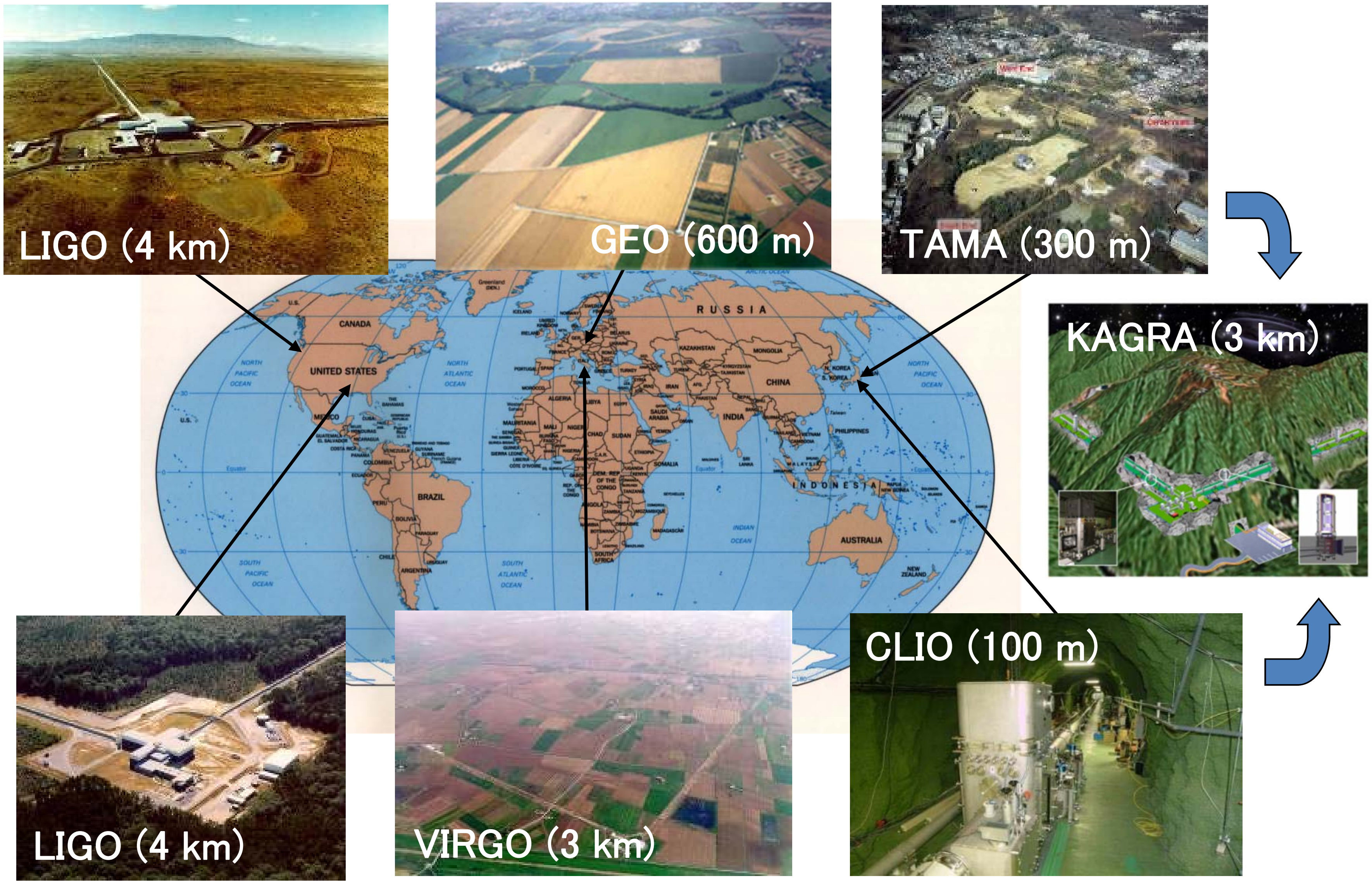


Direction of source



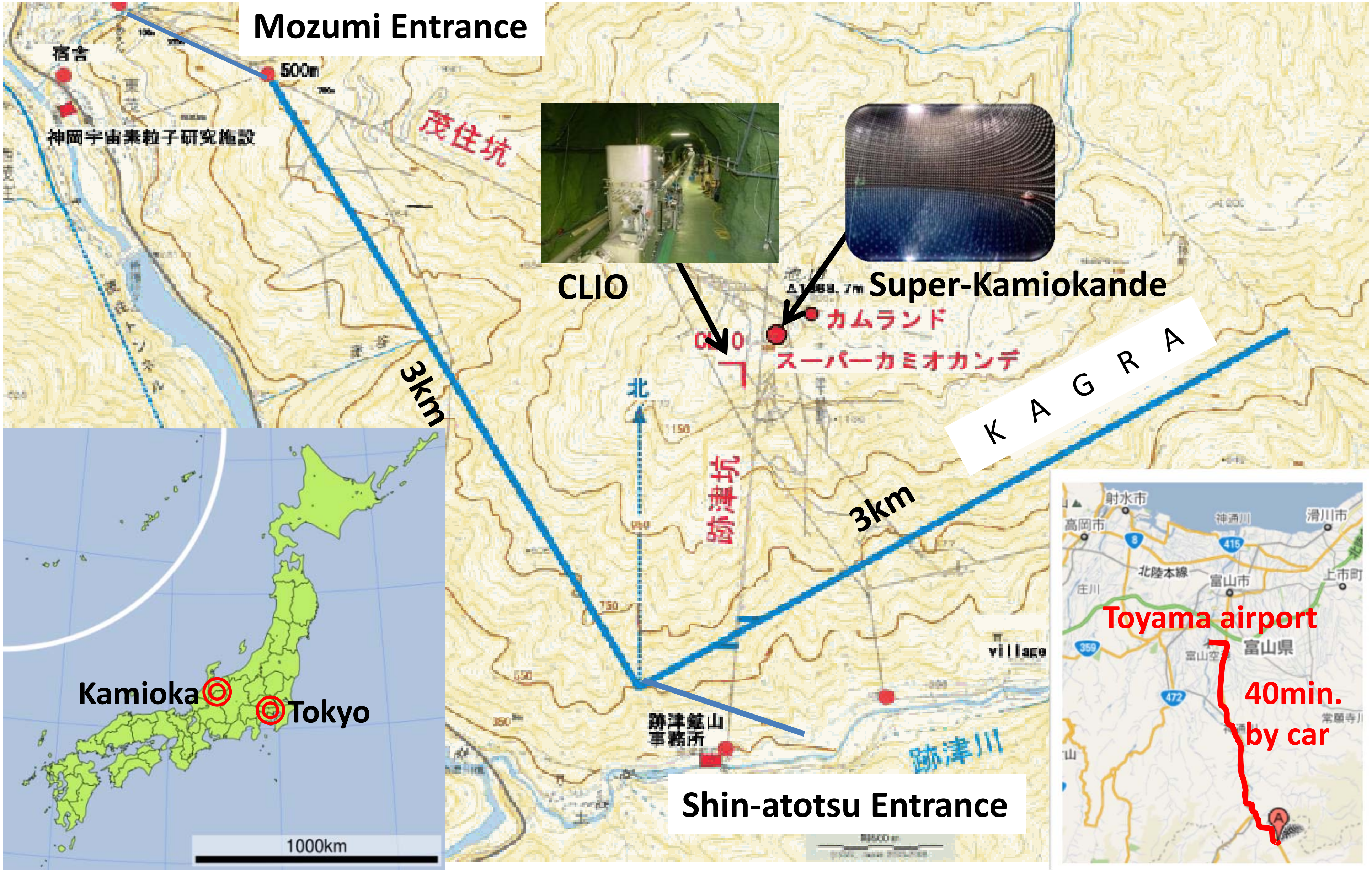
Difference in
arrival time

Detectors in the world

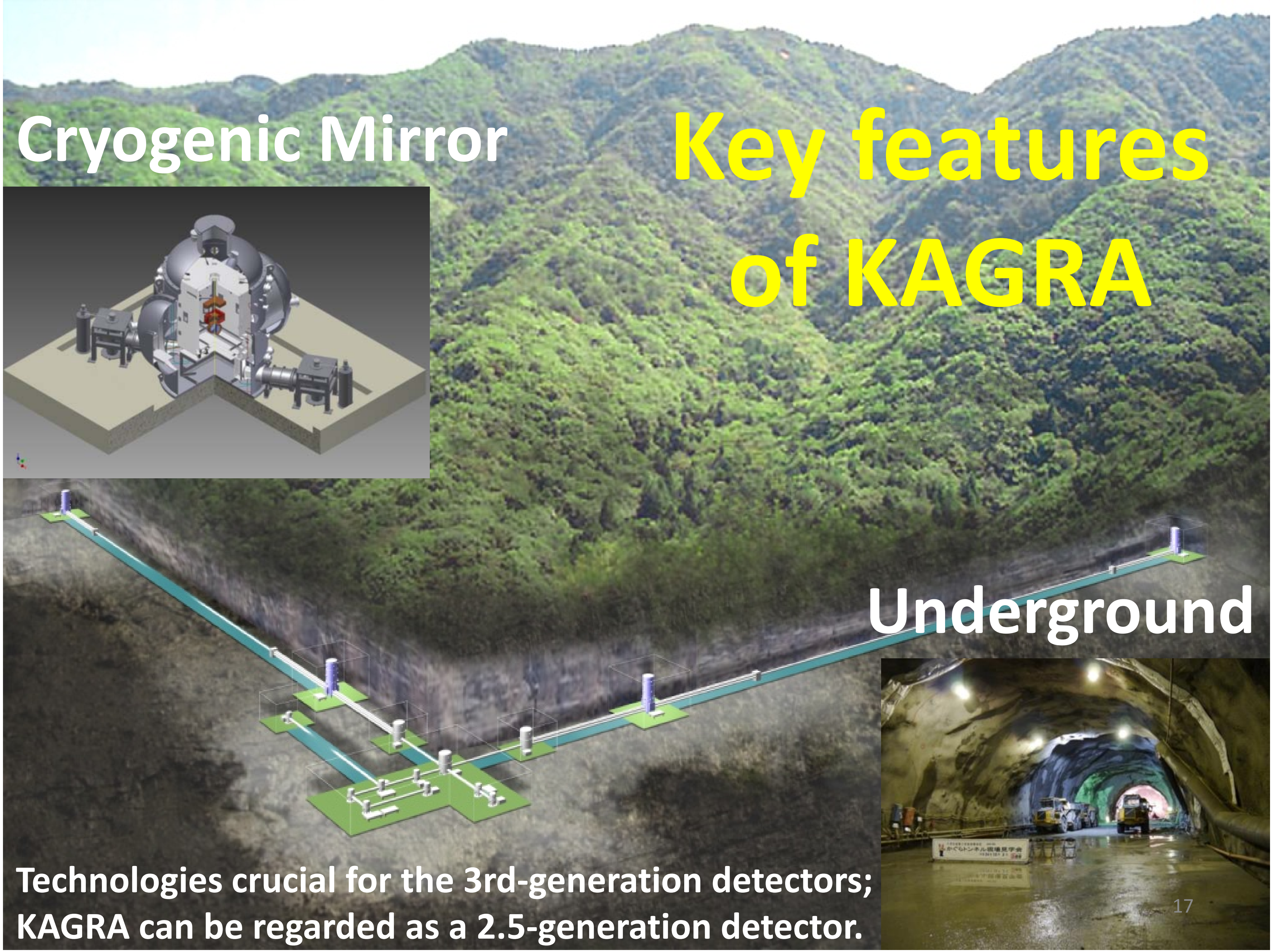



KAGRA

Location (Kamioka)



Key features of KAGRA

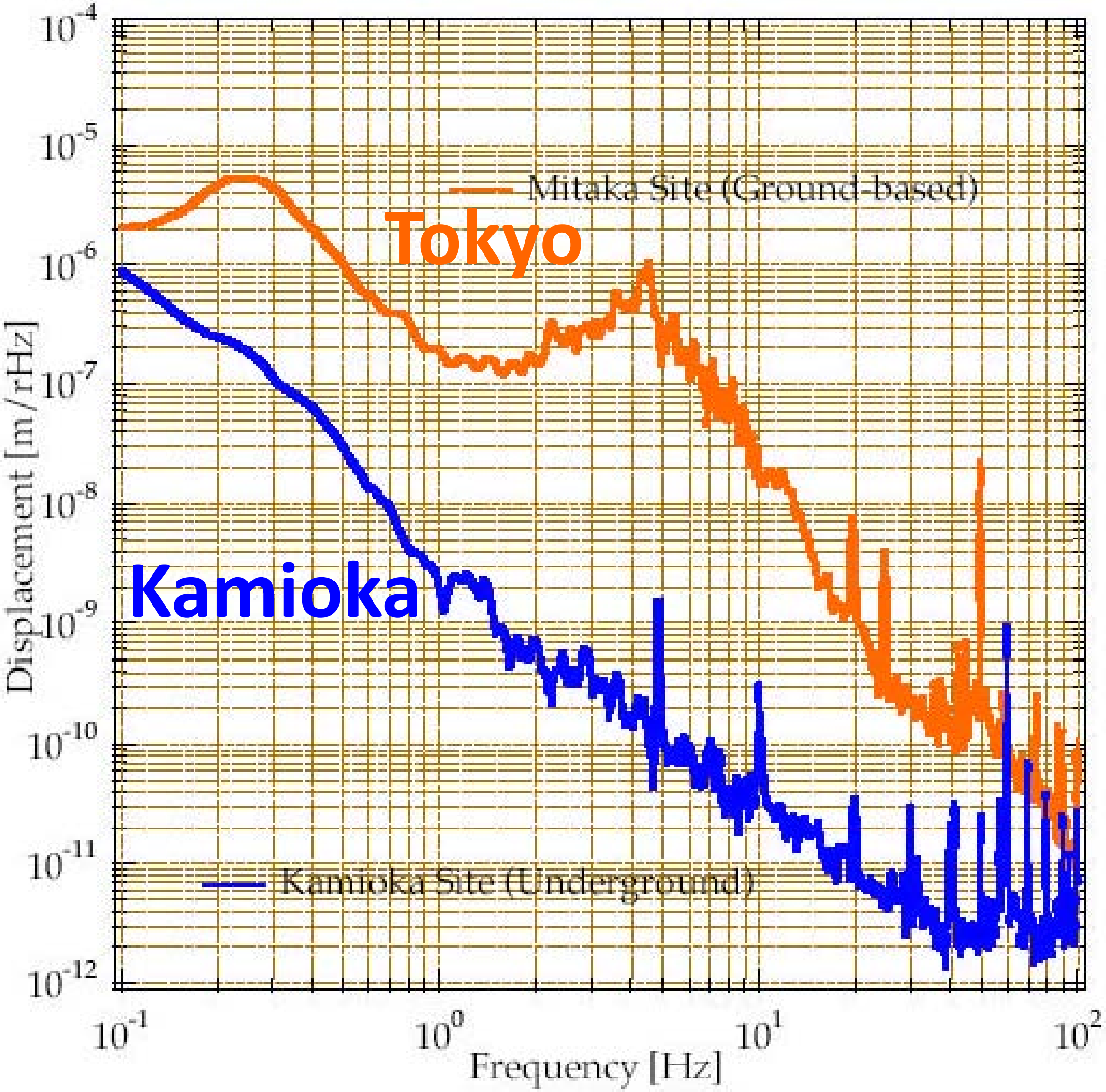


Cryogenic Mirror

Underground

Technologies crucial for the 3rd-generation detectors; KAGRA can be regarded as a 2.5-generation detector.

Ground motion in Kamioka mine



Hard rock of Hida gneiss
(5 [km/sec] sound speed)

Vibration isolation system

Two-layer structure was chosen to avoid the resonances of the structure.

2nd floor

Chamber

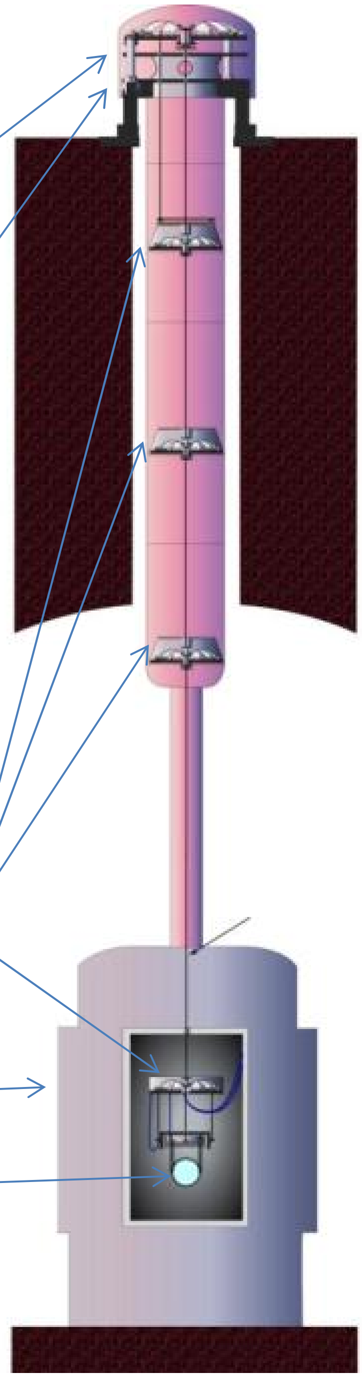
Inverted pendulum

Geometrical antispring filter

Cryostat

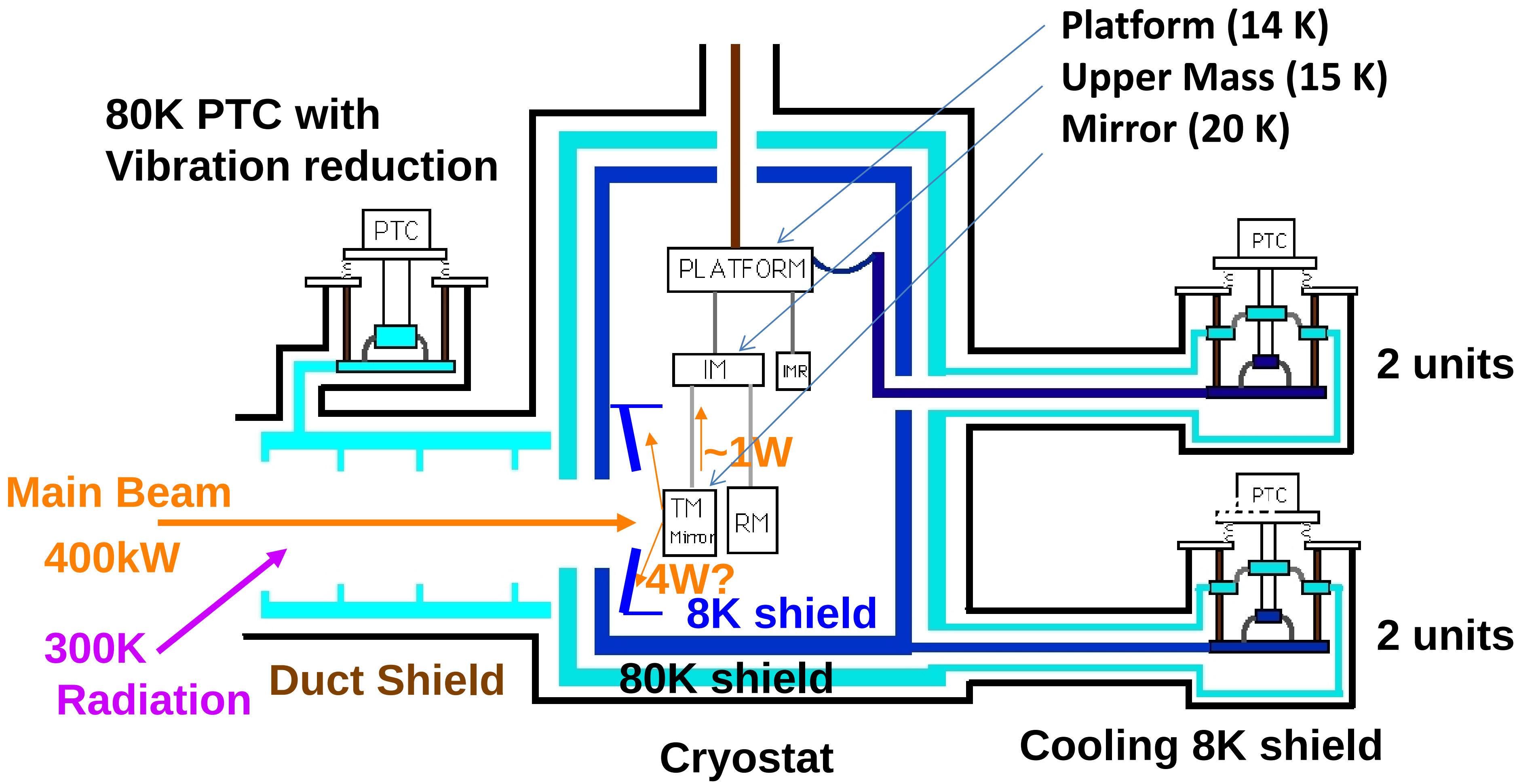
Mirror

1st floor

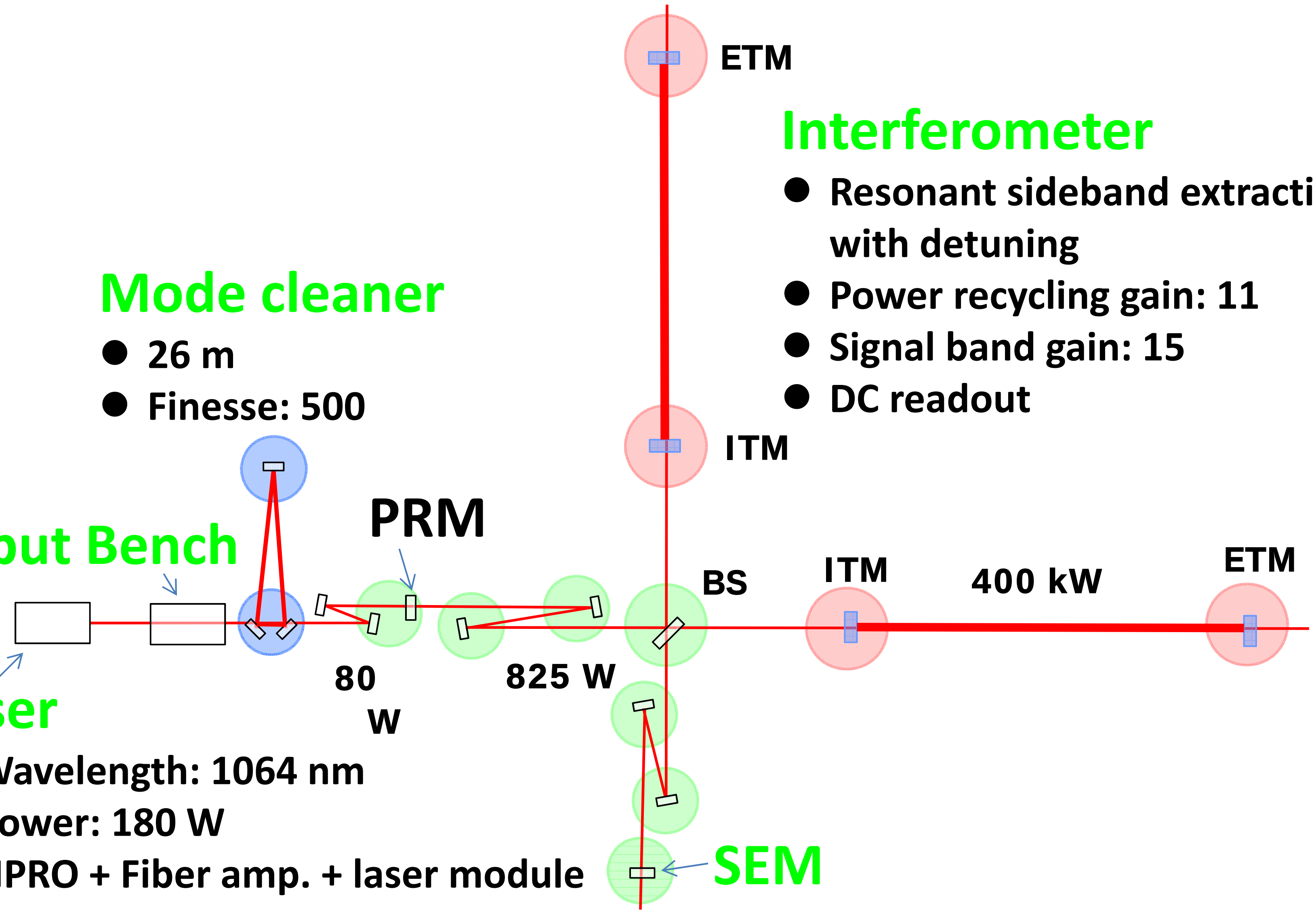


Tunnel (3D movie)

Cryogenics System



Optical configuration



Interferometer

- Resonant sideband extraction with detuning
- Power recycling gain: 11
- Signal band gain: 15
- DC readout

Mode cleaner

- 26 m
- Finesse: 500

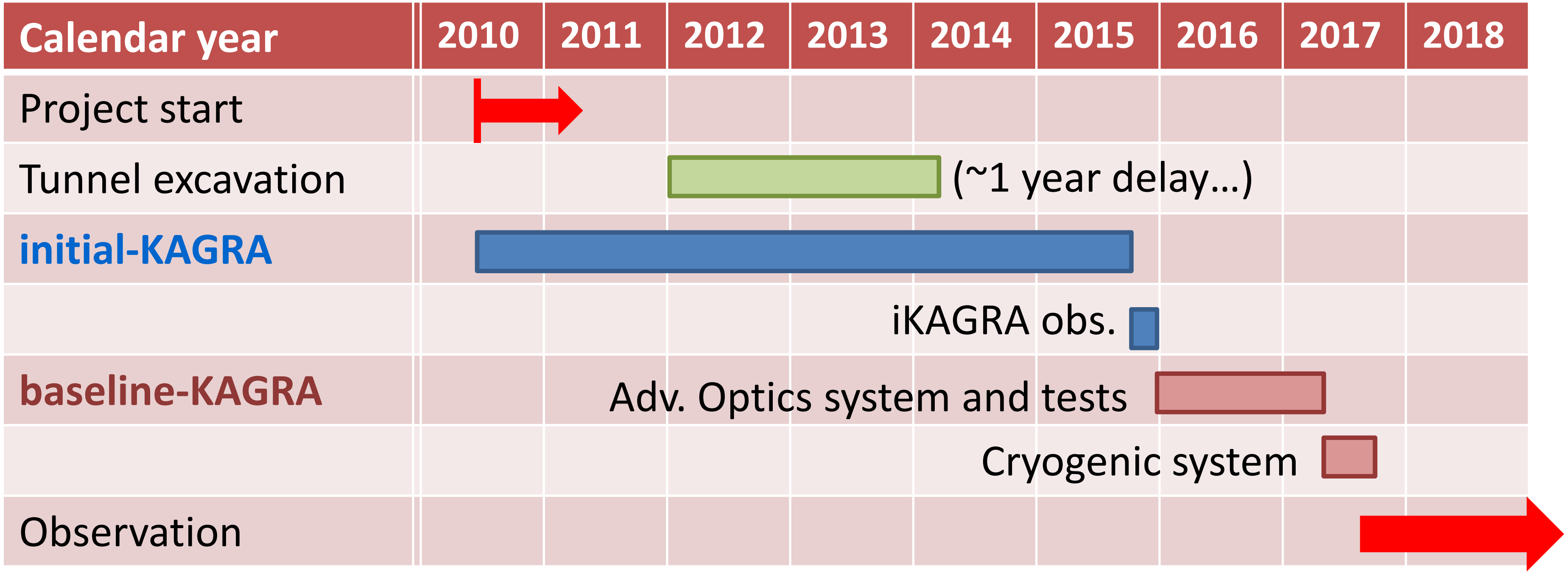
Input Bench

Laser

- Wavelength: 1064 nm
- Power: 180 W
- NPRO + Fiber amp. + laser module

Output mode cleaner

Schedule of KAGRA



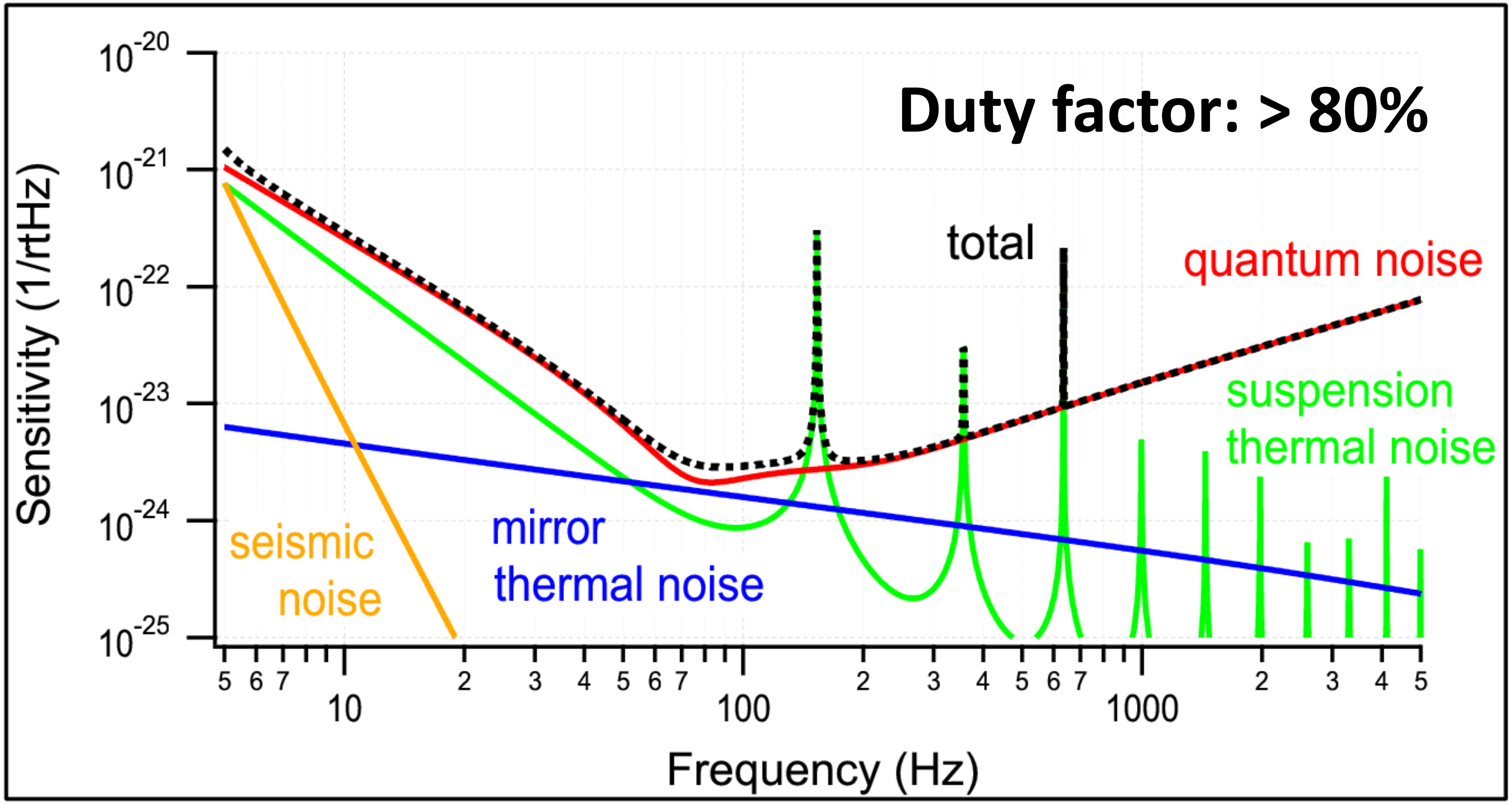
iKAGRA

- **Fabry-Perot Michelson interferometer**
- **Room temperature**
- **Simple seismic isolation system**

bKAGRA

- **Resonant sideband extraction with detuning**
- **Cryogenic temperature**
- **Advanced seismic isolation system**

Target sensitivity of bKAGRA



Inspiral range: 173 Mpc, Mirror mass: 30 kg

Expected event rate for NS-NS coalescence

Inspiral range: 173 Mpc
(the same definition as LIGO/Virgo)

Assuming Inspiral rate per galaxy

$$118^{+174}_{-79}\,\mathrm{Myr}^{-1}$$

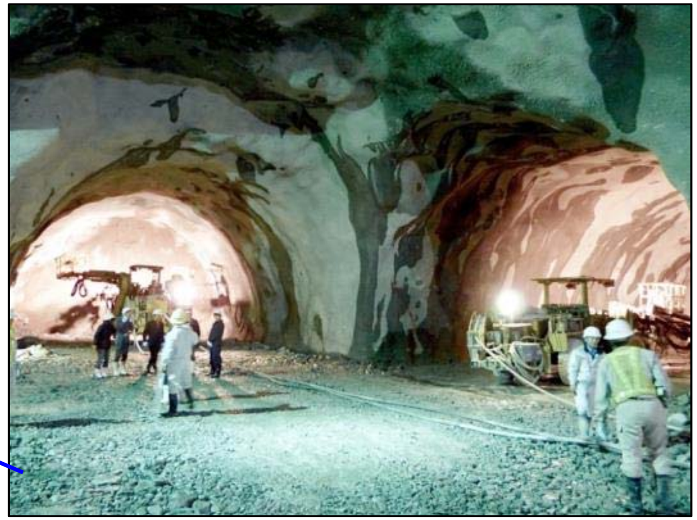
$$\Downarrow$$

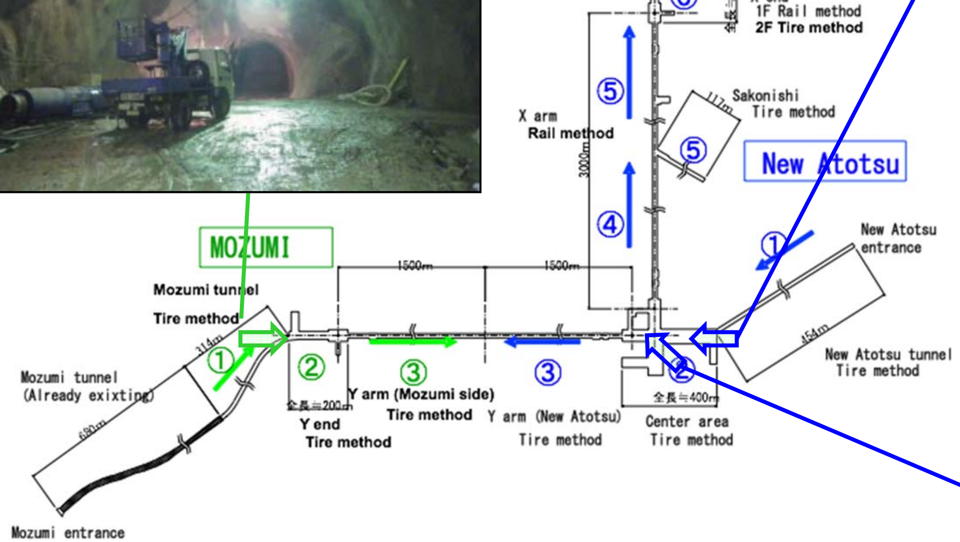
Expected event rate $9.8^{+14}_{-6.6}\,\mathrm{yr}^{-1}$

Tunnel excavation

Mozumi Entrance

New-Atotsu Entrance



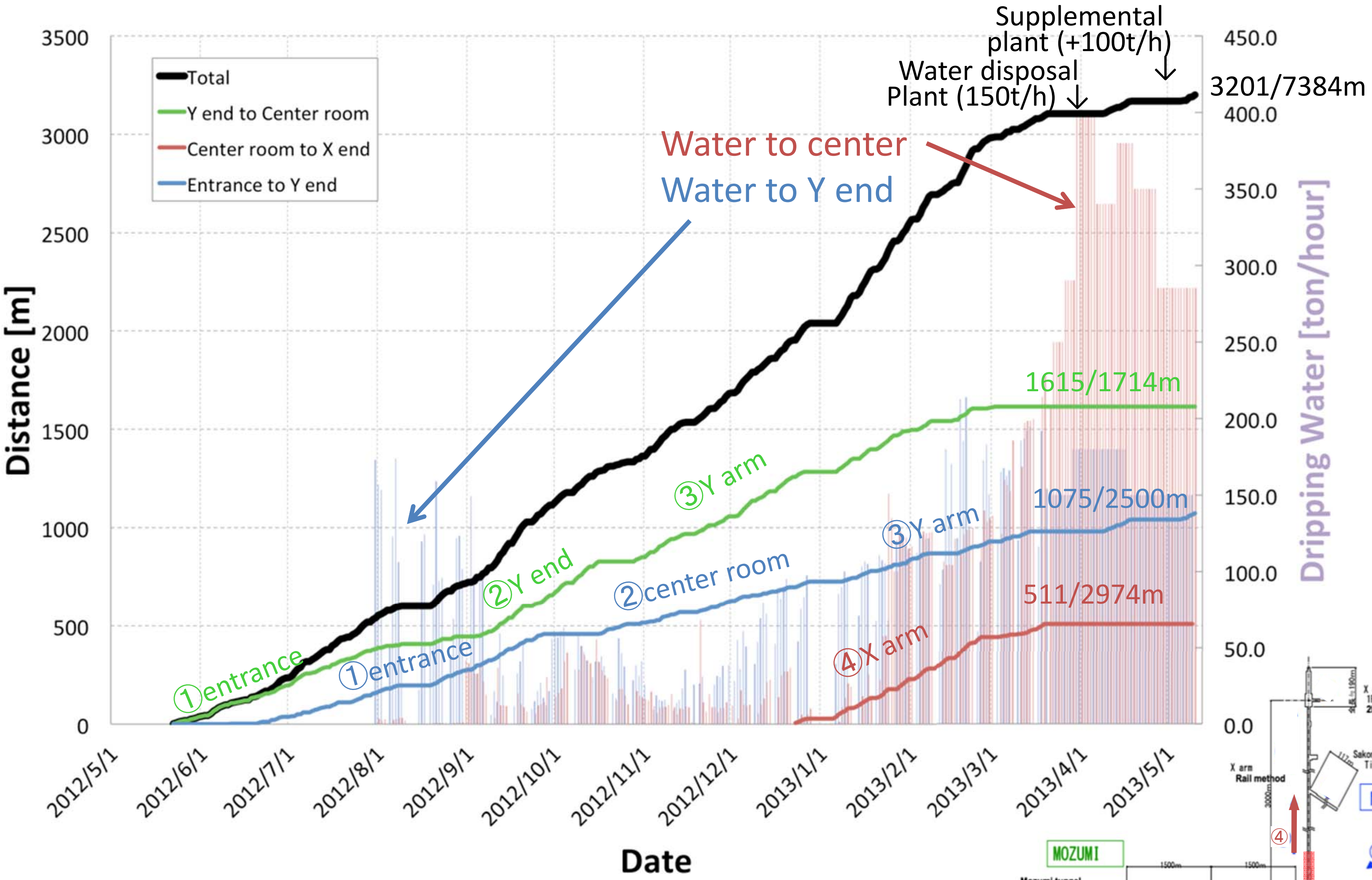


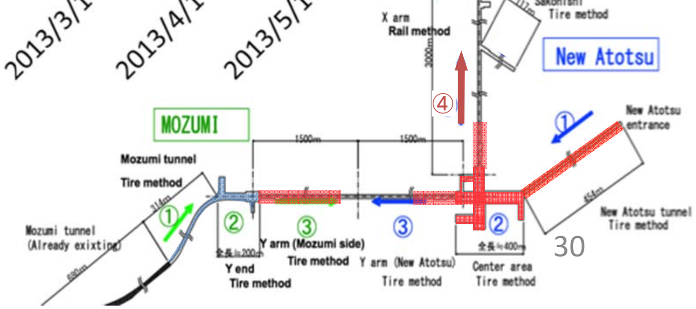
Blasting (Movie)

Water (Movie)

Water (Movie)

Water





Distance: 43.4% (3201m/7384m)

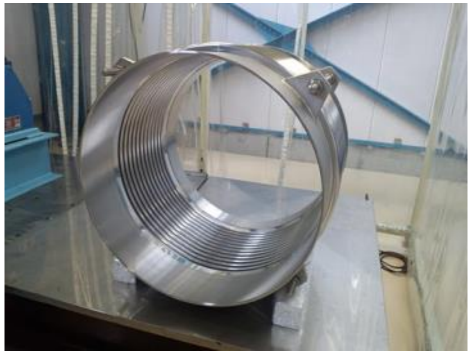
Volume: 51.9% (72000m^3/138700m^3)

Beam tubes

12m, Φ800mm beam tubes for 3km x 2 arms:

Delivered in 2012

Press to form a beam tube



Bellows for each beam tube

Baking at MIRAPRO Co. Noda/MESCO, Kamioka

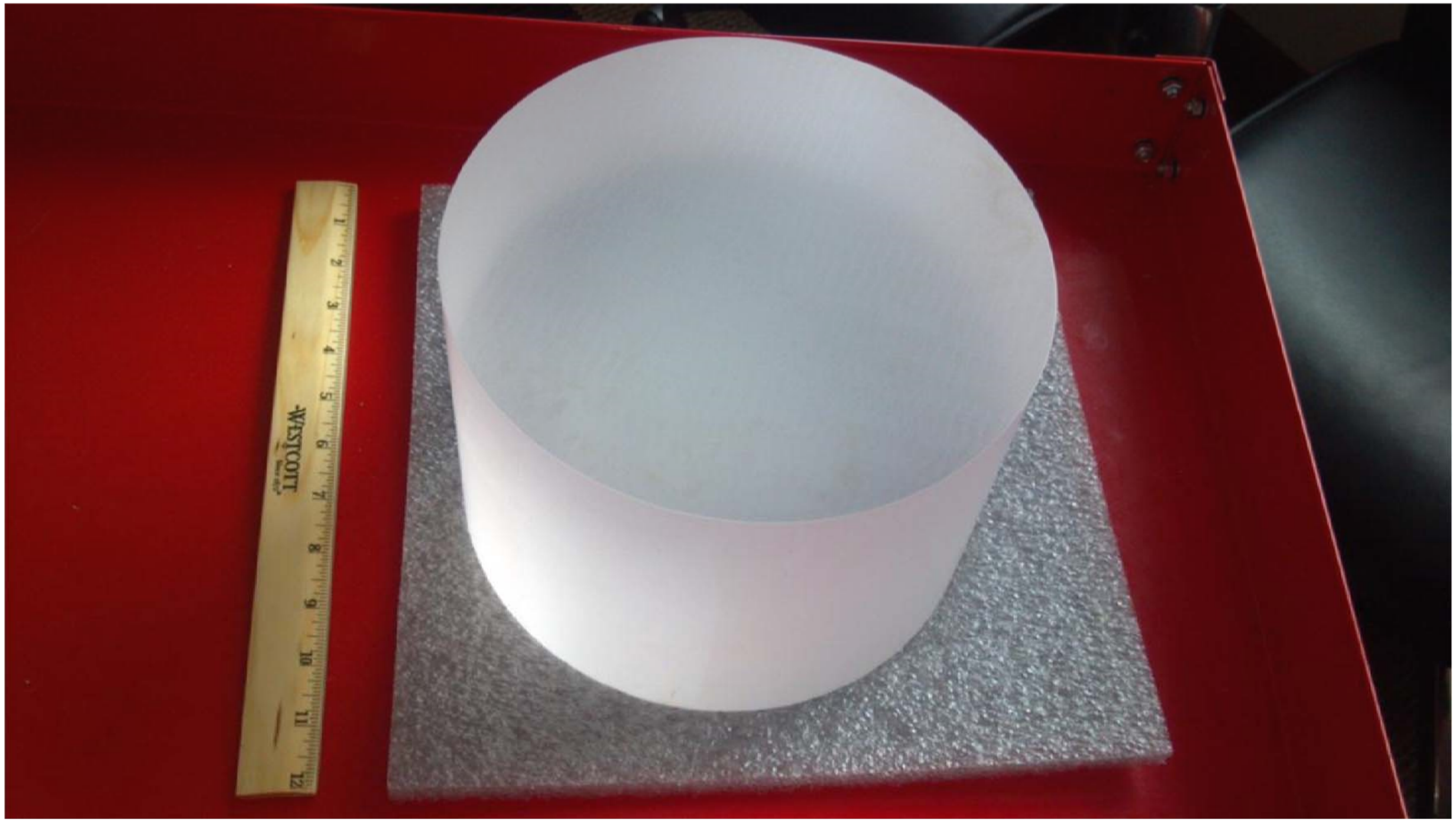
Test at MIRAPRO Co. Noda

Transportation to Kamioka

Cryostat construction and test

Construction and cooling tests were finished!

Sapphire Mirror



Two Sapphire substrates have been delivered.
(Φ220mm, t 150mm, c-axis)

Cryogenic suspension

We are developing the technique to suspend Sapphire mirror with Sapphire fiber.

Sapphire fiber with a nail head (MolTech GmbH): Length = 350 mm diameter = 1.8 mm

Quality factor

- Measured at Glasgow and Jena
- Satisfied the requirement

Thermal conductivity

- Measured at Jena
- Satisfied the requirement

Strength

- To be measured

Prototype test of the suspension

- To be performed soon

Apparatus to measure Q-values at ICRR

Collaboration with the Korean GW group

- We had a meeting to discuss the possibility of collaboration in January 2011 at Seoul National Univ.
- Some KGWG members joined KAGRA in August 2011, then collaboration started.
- Later more KGWG members joined KAGRA.
- Four joint workshops have been held so far.
- Collaboration on Laser, interferometer, data analysis, and data characterization are going on.
- Tai Hyun Yoon (Korea Univ.) visited ICRR for two months in summer 2013 to work on fiber laser as an ICRR visiting Professor.

Korea-Japan workshop on KAGRA

1st workshop (Jan. 2012 @ Korea Univ.)

2nd workshop (May 2012 @ ICRR)

3rd workshop (Dec. 2012 @ Sogang Univ.)

4th workshop (June 2013 @ Osaka Univ.)

KAGRA collaboration

190 members from the following institutes/universities

The University of Tokyo, National Astronomical Observatory of Japan, the Graduate University for advanced studies, High Energy Accelerator Research Organization , Tokyo Institute of Technology, Osaka City University, Kyoto University, University of Electro-Communications, Hosei University, National Institute of Advanced Industrial Science and Technology, Osaka University, Ochanomizuu University, Nihon University, Niigata University, Yamanashi Eiwa College , Nihon University, Hirosaki University, Tohoku University, Rikkyo University, Hiroshima University, University of the Ryukyus, Waseda University, Teikyo University, Japan Student Service Organization, Institute for Molecular Science, Max-Planck-Institut, California Inst. Technology, University of Western Australia, Louisiana State University, Beijing Normal University, Inter University Center for Astronomy & Astrophysics, Moscow University, LATMOS, CNRS, University of Science and Technology of China, Tsinghua University, Industrial Technology Research Institute, University of Maryland, Columbia University, University of Glasgow, University of Sannio, Fulbright Fellow, INFN Student Fellow, Univ. of Basilicata, Univ. of Salerno, Shanghai Normal University, National Tsing Hua University, Korea University, Inje University, Seoul National University, Myongii National University, Korea Atomic Energy Research Institute, Hanyang University, Pusan National University, Korea Institute of Science and Technology Information, National Institute for Mathematical Sciences, Kyungpook National University, Gunsan National University, Korea Institute for Advanced Study, Sogang University, Chinese Academy of Sciences, The Pennsylvania State University, Montana State University

MoU with LSC and VIRGO

- **MOU signed**
  - **General part (K-L-V)**
  - **Attachment A (K-L)**
    Technical collaboration
  - **Attachment B (K-L-V)**
    Data sharing and analysis
- **MOU to be signed very soon**
  - **Attachment C (K-V)**
    Technical collaboration

KAGRA-M1201313-v1
LIGO-M1200326-v1
VIR-0371A-12

Memorandum of Understanding

between

KAGRA, LIGO and Virgo Scientific Collaborations

A. Purpose of the agreement:

The purpose of this Memorandum of Understanding (MOU) is to establish a collaborative relationship between the signatories who are seeking to discover gravitational waves and pursue the new field of gravitational wave astronomy. The main scientific motivation is that the maximum return from gravitational wave observations is through simultaneous joint measurements by several instruments.

This MOU provides for joint work between the scientific collaborations of KAGRA, LIGO and Virgo. We enter into this agreement in order to lay the groundwork for decades of world-wide collaboration. When sensitive detectors are in operation, we intend to carry out the search for gravitational waves in a spirit of teamwork.

Details and extensions to this MOU will be provided in Attachments agreed by the parties.

B. Parties to the agreement:

1. KAGRA

KAGRA, previously called LCGT (Large-scale Cryogenic Gravitational-wave Telescope), is a 3-km laser interferometric gravitational wave antenna built at Kamioka underground site in Japan. One of its characteristic features is to be a cryogenic interferometer; the test-mass mirrors that form 3-km Fabry-Perot arm cavities are cooled down to cryogenic temperature of around 20K, so as to reduce the effect of thermal noises. Stable environment of the underground site and

EliTES

- ET-KAGRA collaboration program
  mainly on underground site and cryogenics.
- 1st general meeting in Oct. 2012 at Tokyo

JSPS core-to-core program

- Five year program
- 16,000,000 yen ($160,000) for FY2013

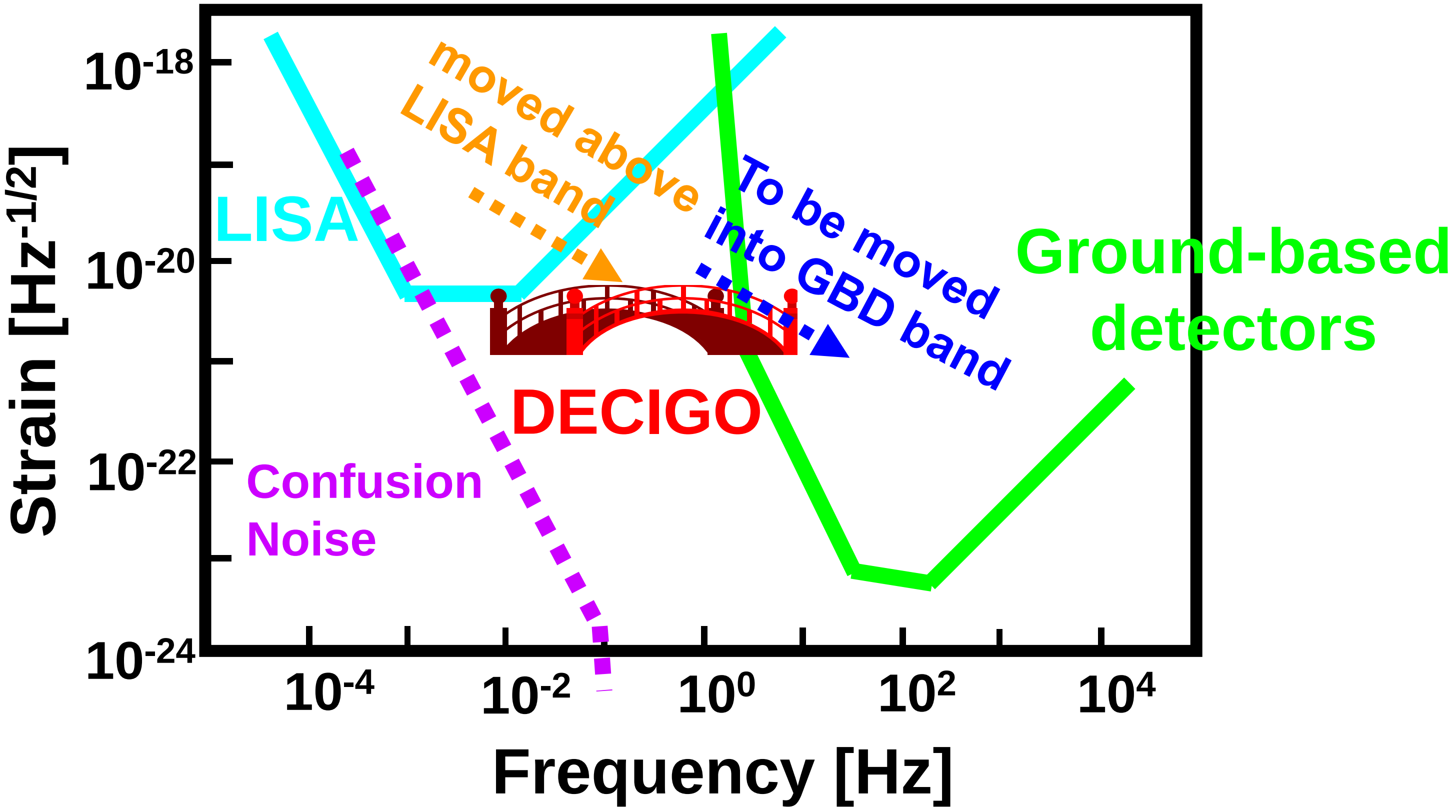
Country	Core Institute	Coordinator
USA	Louisiana State University	Warren Johnson
Italy	European Gravitational Observatory	Michele Punturo
Germany	Albert Einstein Institute	Harald Lueck
UK	University of Glasgow	Sheila Rowan
Netherlands	NIKHEF	Jo van den Brand
Australia	University of Western Australia	David Blair
Korea	Korea University	Tai Hyun Yoon
China (1)	Beijing Normal University	Zong-Hong Zhu
China (2)	Shanghai Normal University	Xiang-Hua Zhai
Taiwan	National Tsing-Hua University	Shiuh Chao
India	IUCAA	Sanjeev V. Dhurandhar


DECIGO
Illustration Sora

What is DECIGO?

Deci-hertz Interferometer Gravitational Wave Observatory

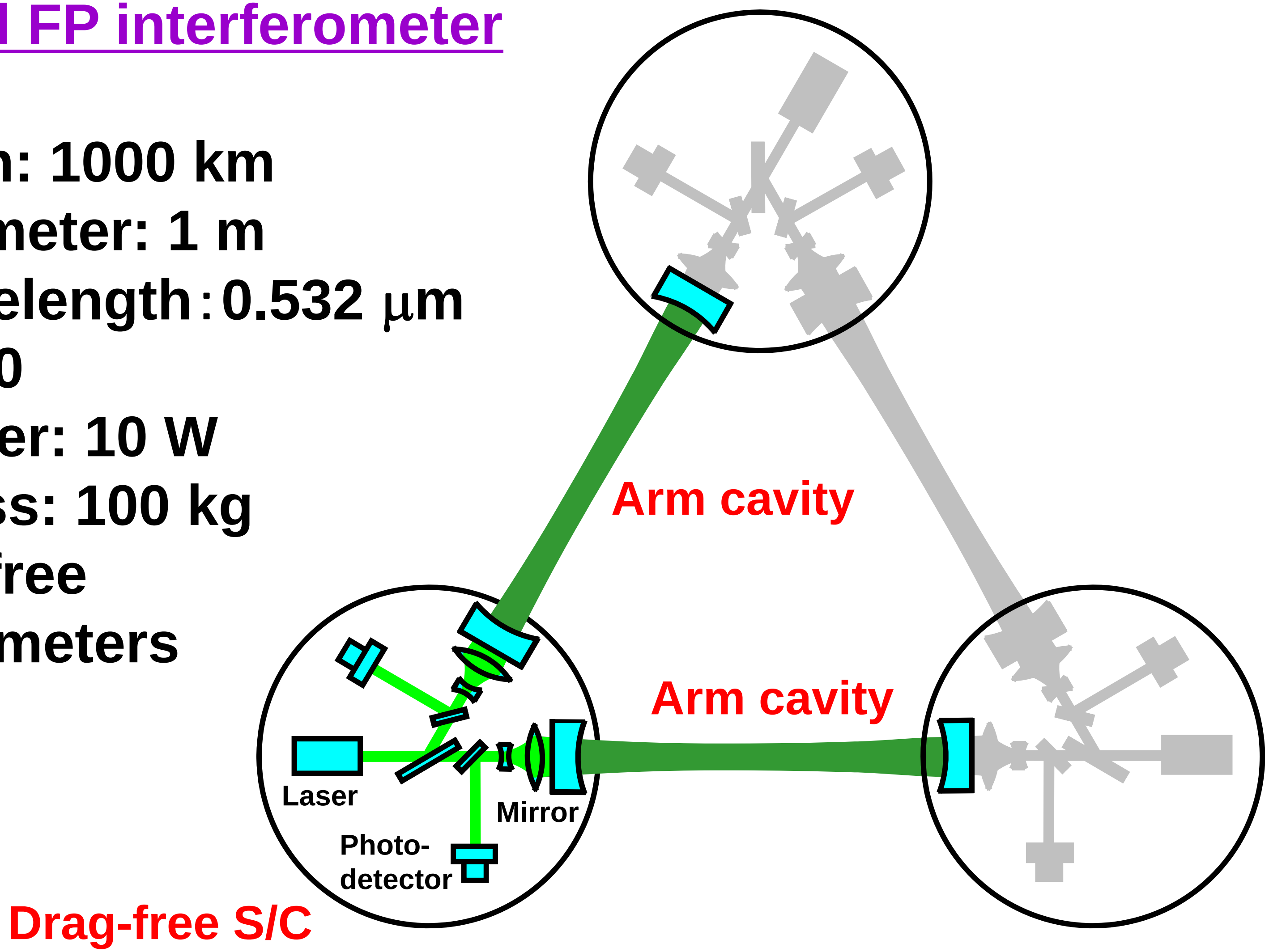
- **Bridges the gap between LISA and ground-based detectors**
- **Low confusion noise -> Extremely high sensitivity**



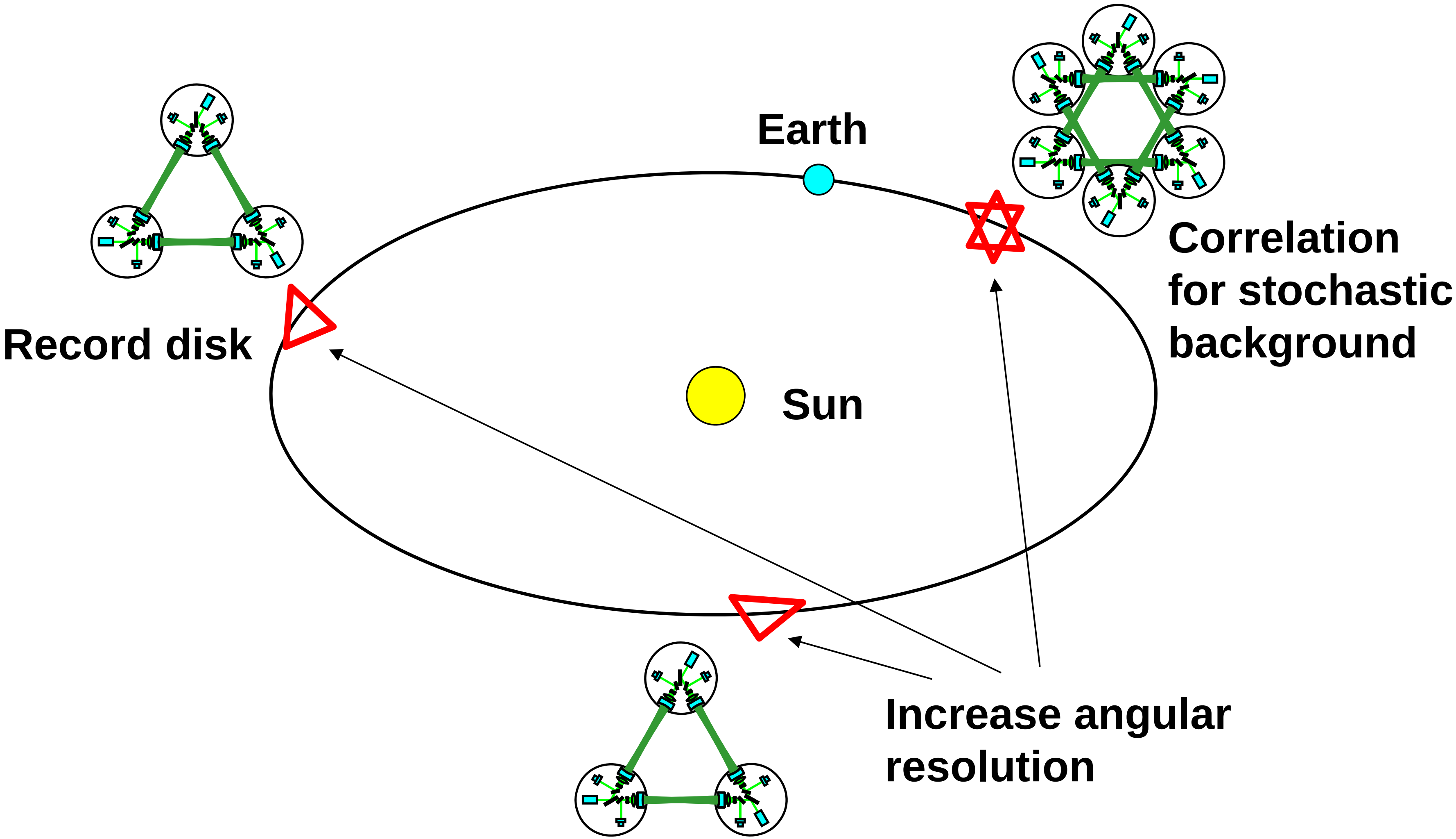
Pre-conceptual design

Differential FP interferometer

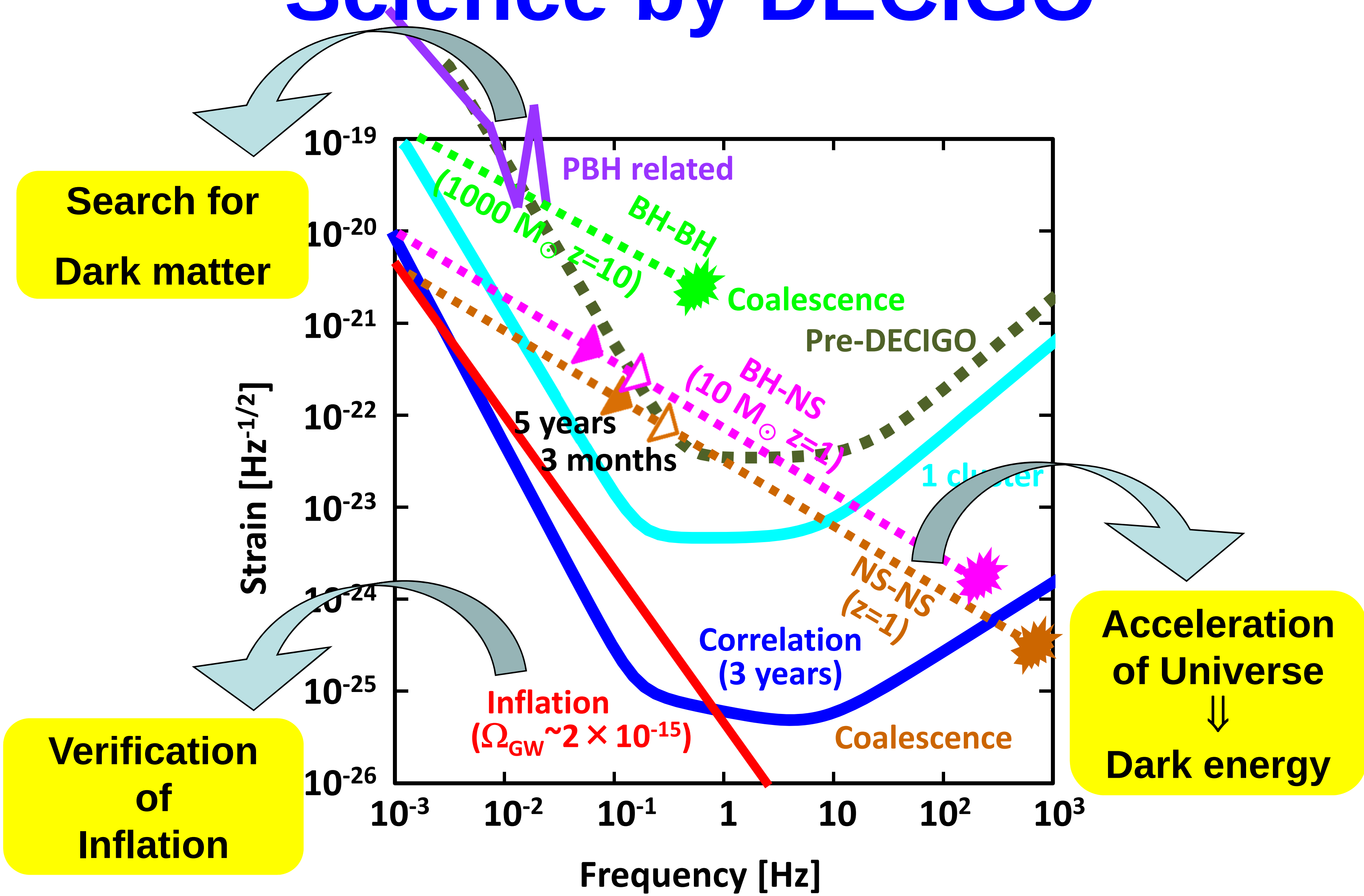
Arm length: 1000 km
Mirror diameter: 1 m
Laser wavelength：0.532 μm
Finesse: 10
Laser power: 10 W
Mirror mass: 100 kg
S/C: drag free
3 interferometers



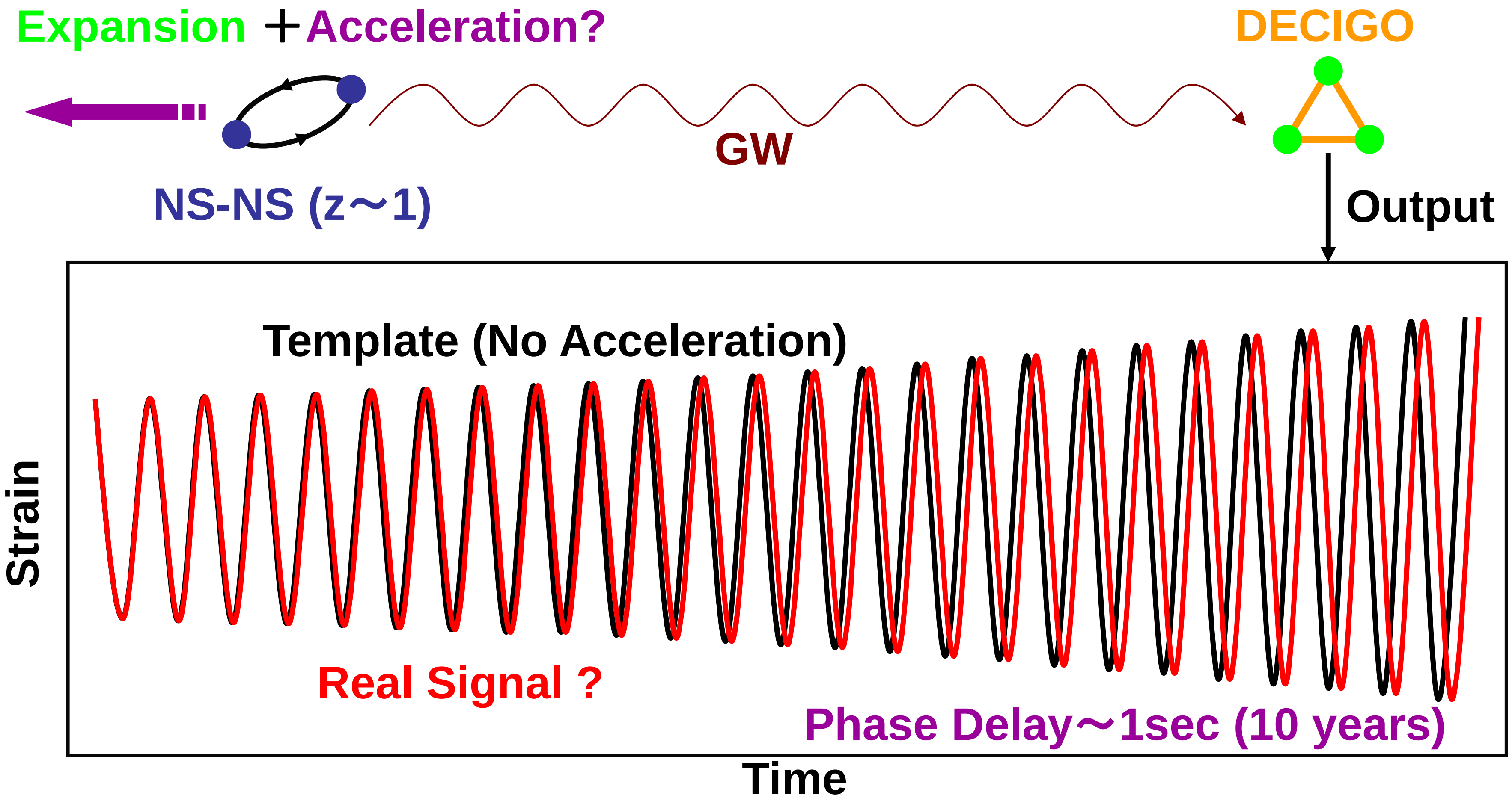
Orbit and constellation (preliminary)



Science by DECIGO



Acceleration of Expansion of the Universe

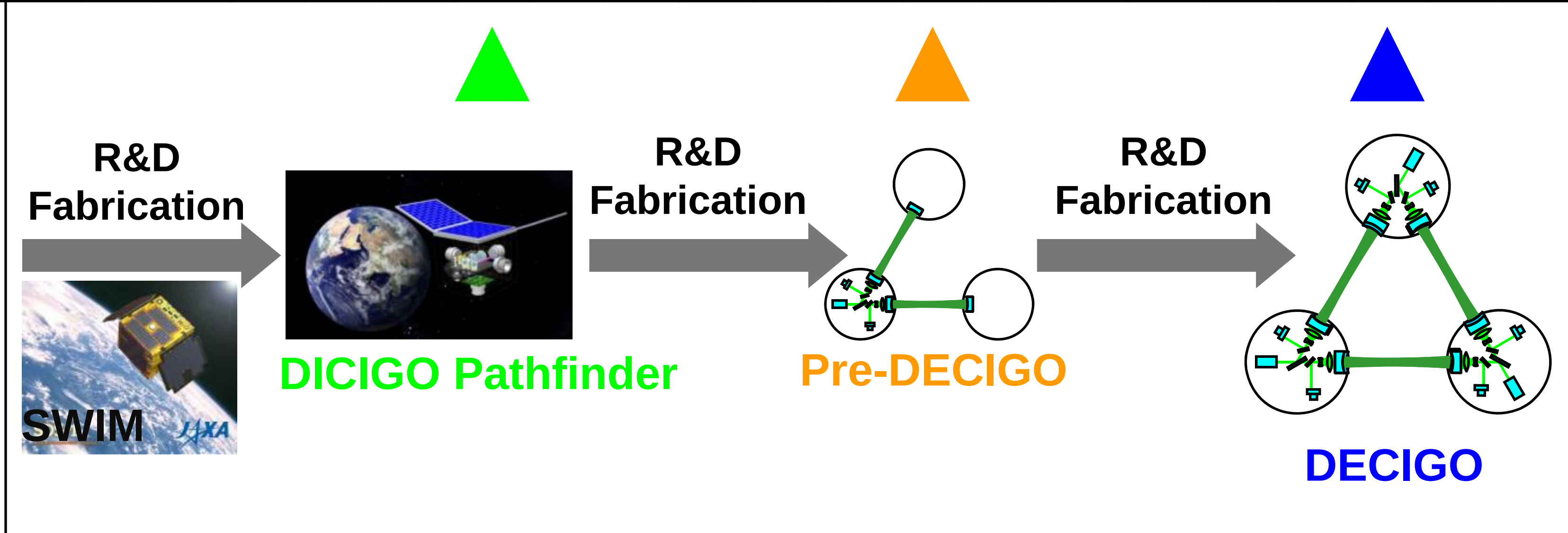


Seto, Kawamura, Nakamura, PRL 87, 221103 (2001)

Roadmap

	2009	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

Mission



Objectives	Test of key technologies	Detection of GW w/ minimum spec. Test FP cavity between S/C	Full GW astronomy
Scope	1 S/C 1 arm	3 S/C 1 interferometer	3 S/C, 3 interferometer 3 or 4 units

Dawning of Gravitational Wave Astronomy is near!

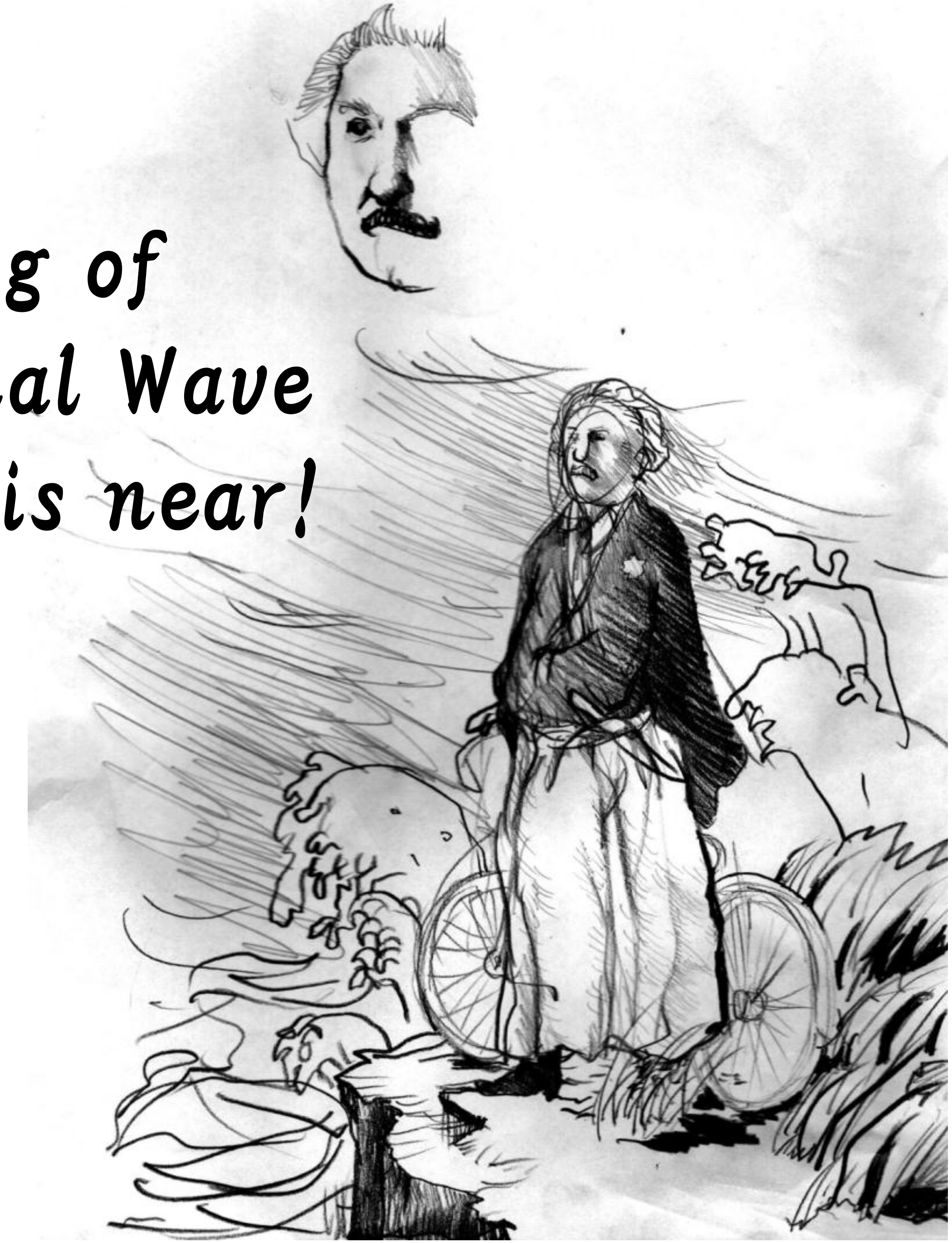


Illustration: Sora