重力波望遠鏡が拓く新しい天文学

Masaki Ando
(National Astronomical Observatory of Japan)

京都大学 基礎物理学研究所 談話会 (2013年3月8日, 京都大学)

Self Introduction

•Was a Special Associate Professor of this GCOE program for 3.5 years (2009.1 – 2012.5)

→ Special Research Unit for 'Gravity and Gravitational-Wave Physics'
(Belonging to 'Tentaikaku' astrophysics theory group)

•From June 2012, an Associate Professor of NAOJ (National Astronomical Observatory of Japan)

Gravitational-Wave Project office

- Host for TAMA300 GW detector
- Co-host for KAGRA GW antenna

~20 members (1 Prof. to come, 1 Assoc. Prof., 5 Research Associates, 3PDs, 3 Engineers, 2 Secretaries, and 4 Grad. Students)

•Will move to the University of Tokyo in April.

Outline

Part I : KAGRA

- Gravitational-Wave Astronomy
- Overview KAGRA GW Antenna
- Current Status of KAGRA

Part II : TOBA

- Principle of TOBA
- Prototype Tests
- Medium-scale TOBA

KAGRA

KAGRA（かぐら）

- LCGT

2nd generation GW detector in Japan
Obs. Start ~2017 → Direct detection of GW

Large-scale Detector
- Baseline length: 3km
- High-power Interferometer

Cryogenic interferometer
- Mirror temperature: 20K

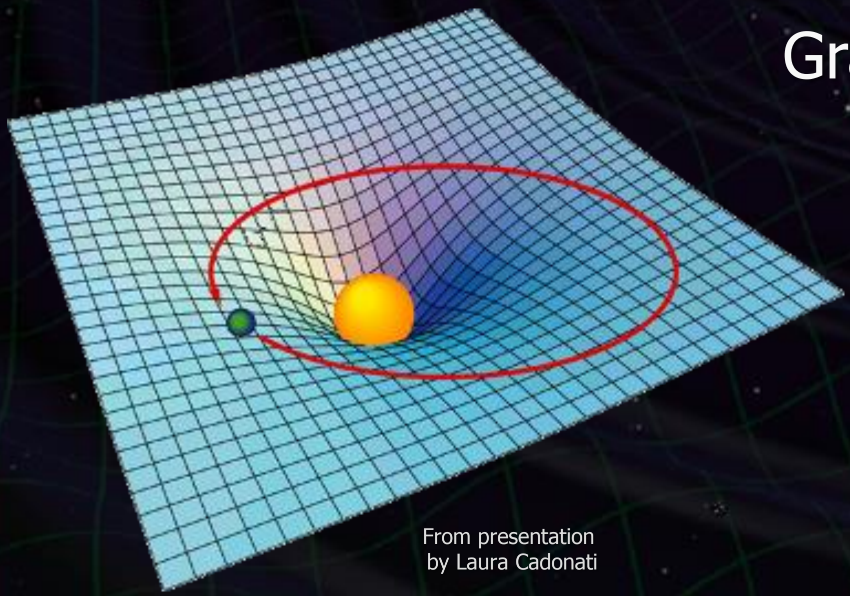
Underground site
- Kamioka mine,
  1000m underground

Gravitational Wave Astronomy

Gravitational Wave

General Relativity

Gravity : Curvature of space-time



From presentation
by Laura Cadonati

Acceleration of Mass
→ Fluctuations in space-time
→ Propagates as
'Ripples in space-time'

↓

Gravitational Waves

*"Mass tells space-time how to curve,
and space-time tells mass how to move."
John Archibald Wheeler*

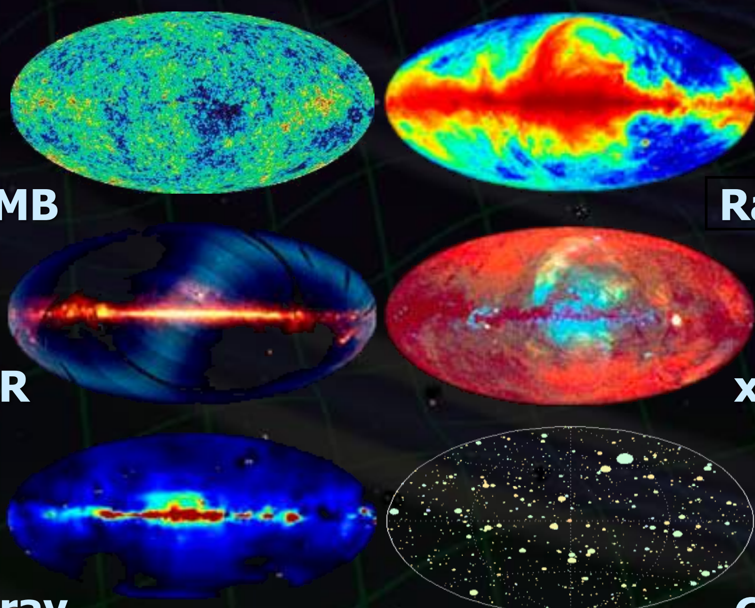
Gravitational-Wave Astronomy

KAGRA

Reveal the universe by Gravitational Waves.

Nature of GWs
- Radiated by accelerated masses
- Strong transmissivity

New probe to the universe
- Complementary with EMWs.
- Unique sciences
  - Early universe before CMB era
  - High-energy phenomena



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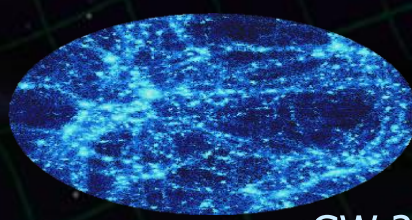


Laser Interferometric Detector

Laser Interferometer

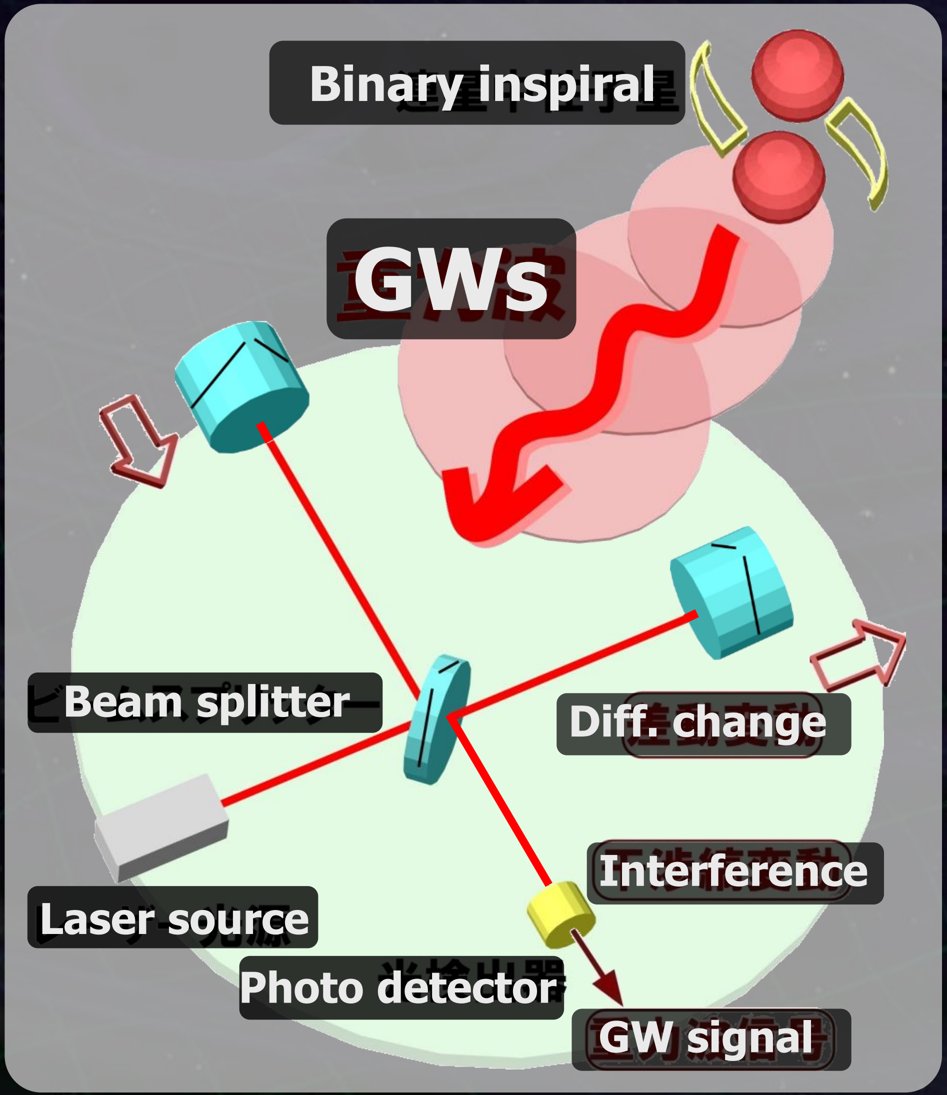
(Michelson interferometer)

When GW comes…

Differential length (strain) changes in two arms

↓

Detected at photo detector

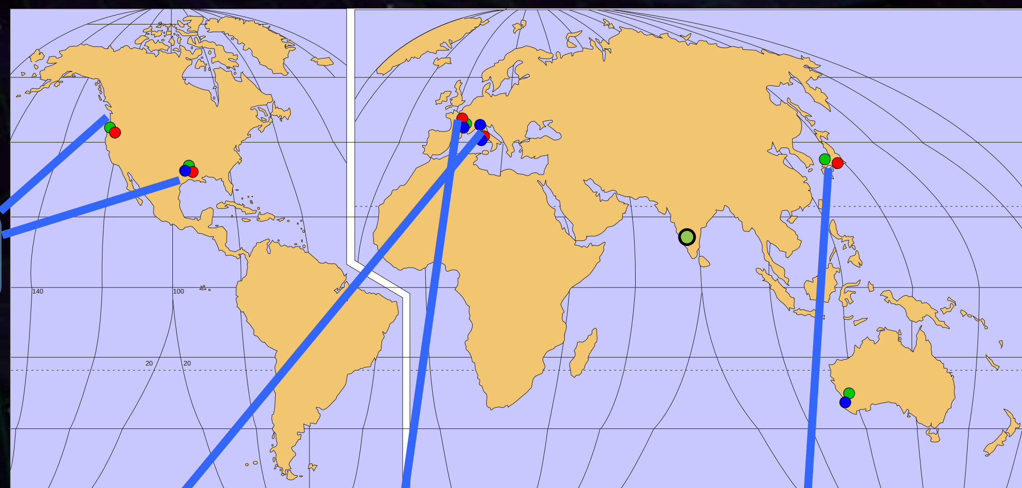


2nd-Generation GW Antennas

KAGRA

International observation network
for GW astronomy will be on-line in ~5 years.
>200Mpc range →Event rate ~10 events/year

aLIGO (USA)
4km x 2 (or3)



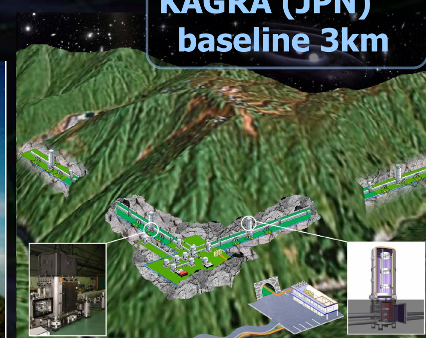
LIGO-Austreria

LIGO-India
in proposal

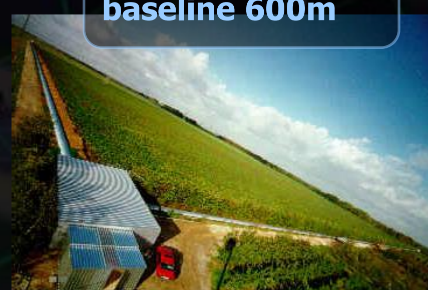
indigo

GEO-HF (GER-UK)
baseline 600m

KAGRA (JPN)
baseline 3km



Adv.VIRGO (ITA-FRA)
baseline 3km



Target of Ground-based Detectors

Terrestrial Detectors – Obs. Band ~10Hz – 1kHz

⇨ Compact and high-energy astronomical phenomena

Neutron Star

Black Hole

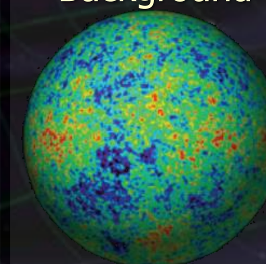
Early Universe

Pulsar

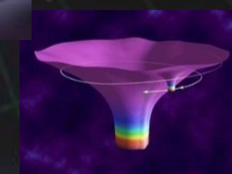
Supernova

Binary merger

Stochastic Background

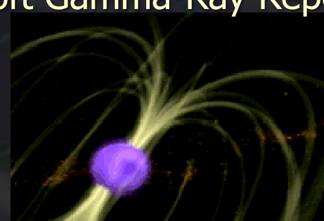


EMRI



Quasi-normal Oscillation

Soft Gamma-Ray Repeater



Star Oscill ation

Long GRB

Short GRB

EM Waves
Neutrino
High-energy CR

Follow-up observation
Numerical Relativity

Understandings on High-E phenomena

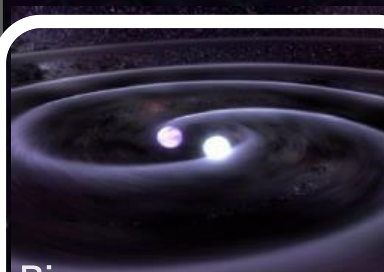
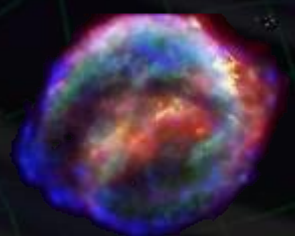
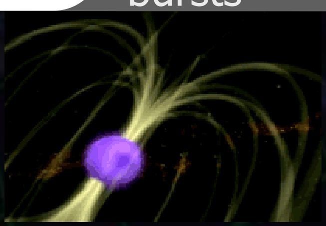
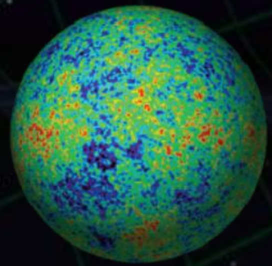
EoS of high-density Matter → Nuclear Phys.

Test of Relativity Physics in Strong Gravity

GW targets and data analysis

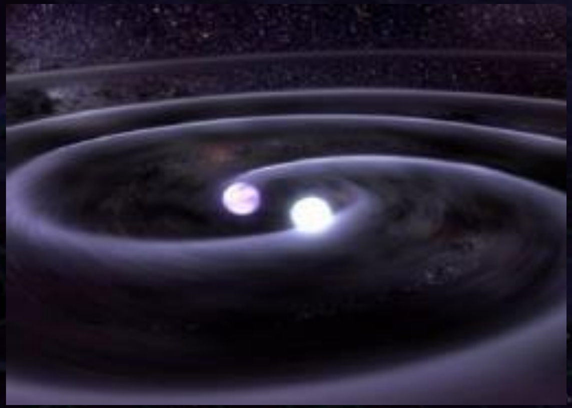
KAGRA

Signal duration

Waveform	Short (bursts)		Long (stationary)
Known	 Binary merger → Chirp wave, Ringdown wave	Gamma-ray bursts	 Pulsar, LMXB → Continuous
Unknown	 Stellar core collapse → burst wave	 Soft gamma-ray repeater	 Stochastic background → Random wave

Neutron-star inspiral

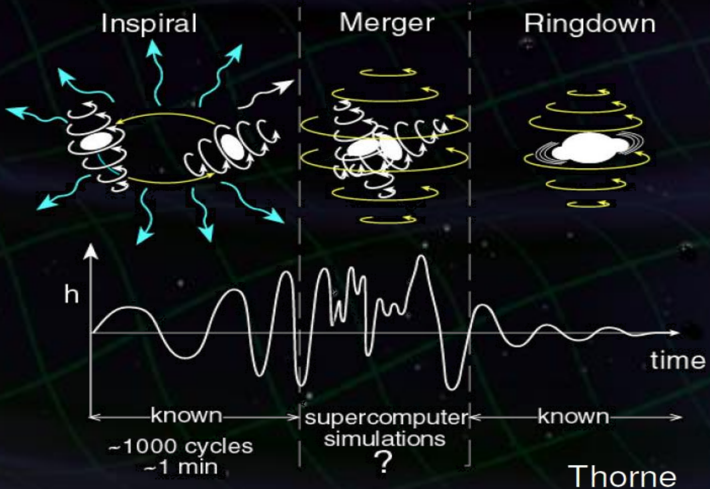
Primary target :
Inspiral and merger of NS binary



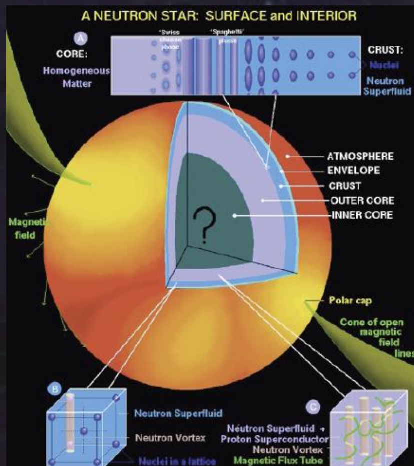
- Quantitative estimation of event rate from pulsar observations.
- Precise waveform is predicted.
  → Sophisticated analysis method using an optimal filter.

⇩

Promising for first detection



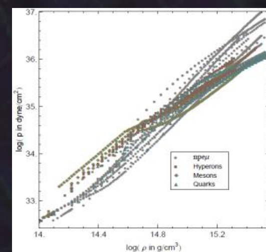
EoS of Neutron Stars



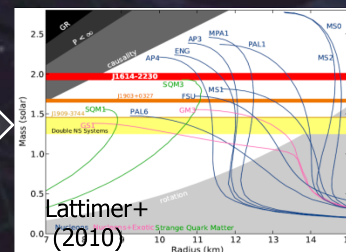
Neutron-star EoS

(Density $2 \sim 15\rho_0$)

Density-Pressure

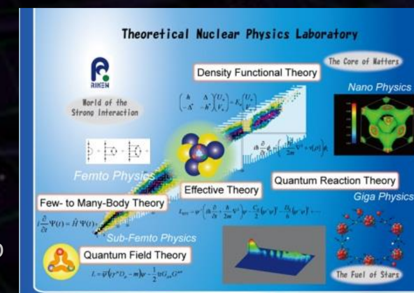


Radius-Mass of NS



Nuclear Physics

Natural Laboratory for high-density nuclear physics



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High-energy Phenomena

→ Astrophysics, Frontier Physics

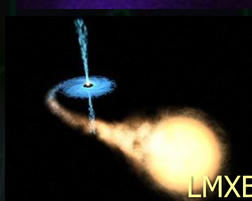
Radio Pulsar

Supernova

Long GRB

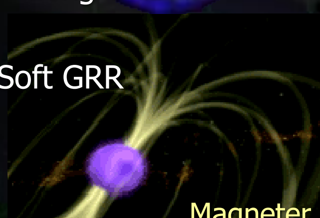
Binary Merger

Short GRB



LMXB

Soft GRR



Magneter

Black-hole formation

Relativity and Cosmology

Compact Binary

→ Standard Siren

Physics in Strong Gravity

Cosmological Parameters

Messenger and Read, arXiv:1107.5725

Numerical Simulation

KAGRA

Hotokezaka+, PRD (2011)

Equal-mass NS merger

HMNS

$M > M_{\rm max}$
Supported by centrifugal force

Type Ⅰ

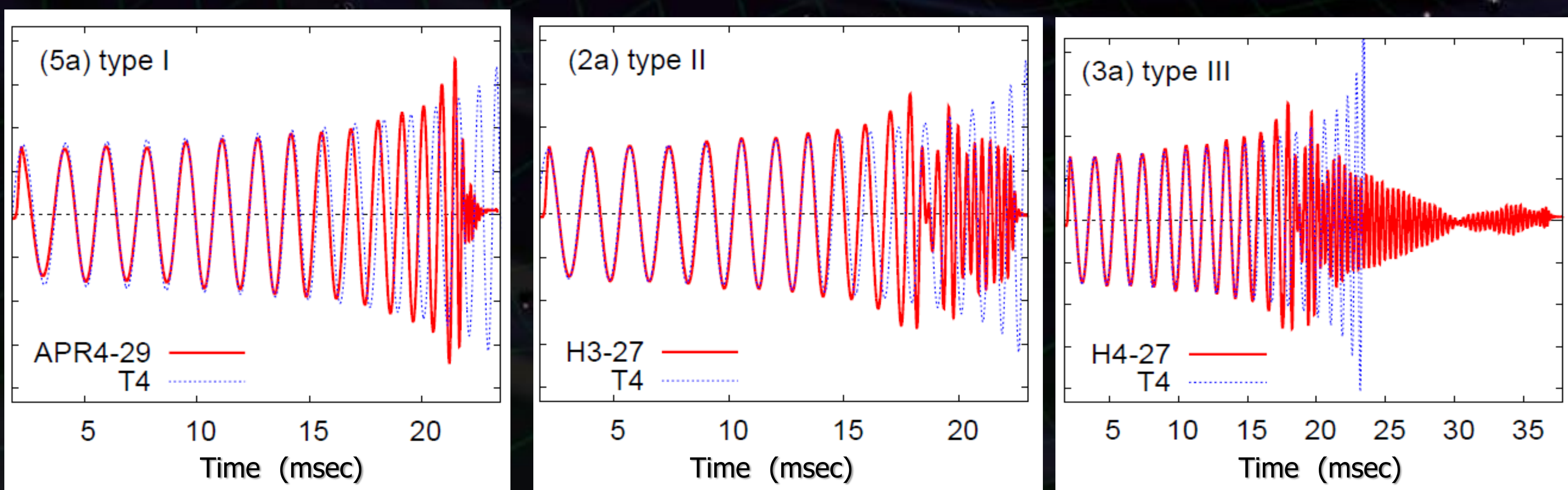
Collapse to BH

Type Ⅱ
Lifetime < 5ms

Short lived → Collapse to BH

Type Ⅲ
Lifetime > 5ms

Long lived → Collapse to BH



KAGRA

KAGRA Project

KAGRA

KAGRA（かぐら）

- LCGT

Large-scale Cryogenic Gravitational-wave Telescope

2nd generation GW detector in Japan

Large-scale Detector

Baseline length: 3km

High-power Interferometer

Cryogenic interferometer

Mirror temperature: 20K

Underground site

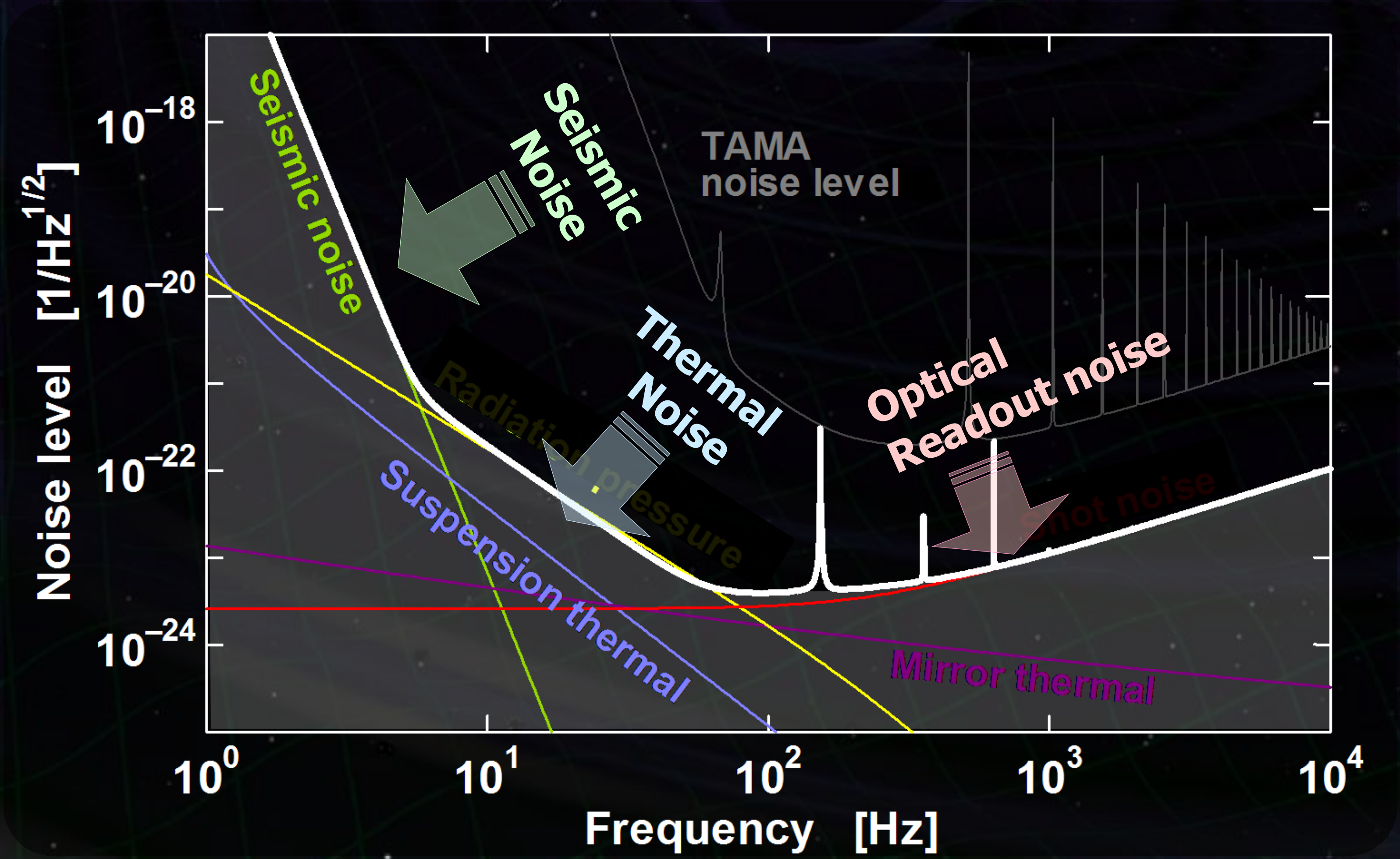
Kamioka mine,

1000m underground

Sensitivity Curve

KAGRA

Comparable with Ad.LIGO Ad.VIRGO
→ Global network observation

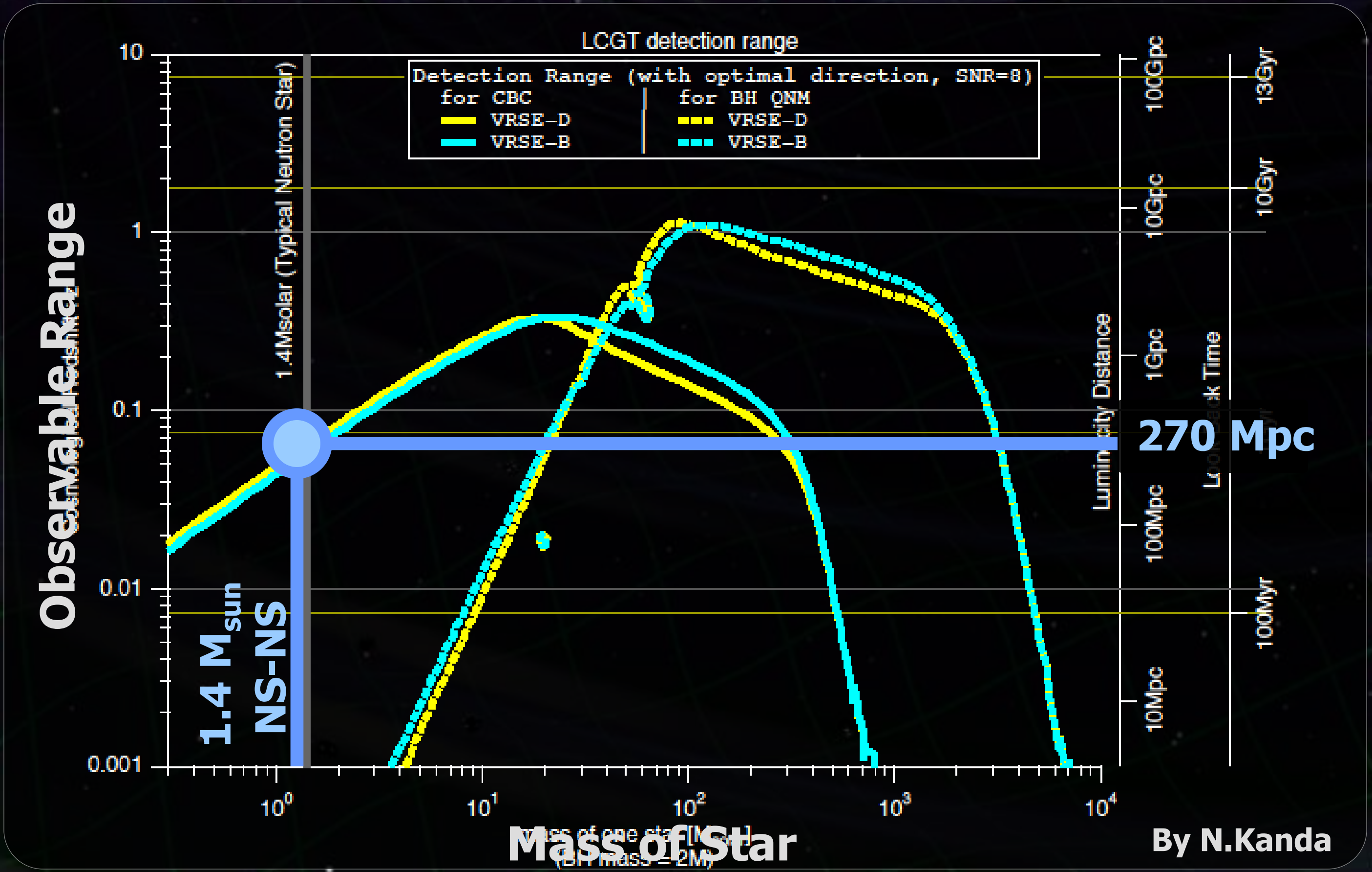


Observable range

Primary purpose of LCGT : Detection of GW

→ **First target : Neutron-star binary inspirals**

⇨ **Obs. Range 270Mpc** (SNR=8, Optimal sky pos. an pol.)



Detection rate of LCGT

KAGRA

Neutron-star binary inspirals events

Observable range

sensitivity curve → 270 Mpc

Galaxy number density :

$$\rho = 1.2 \times 10^{-2} \quad [\mathrm{Mpc}^{-3}]$$

R. K. Kopparapu et.al., ApJ. 675 1459 (2008)

Event rate :

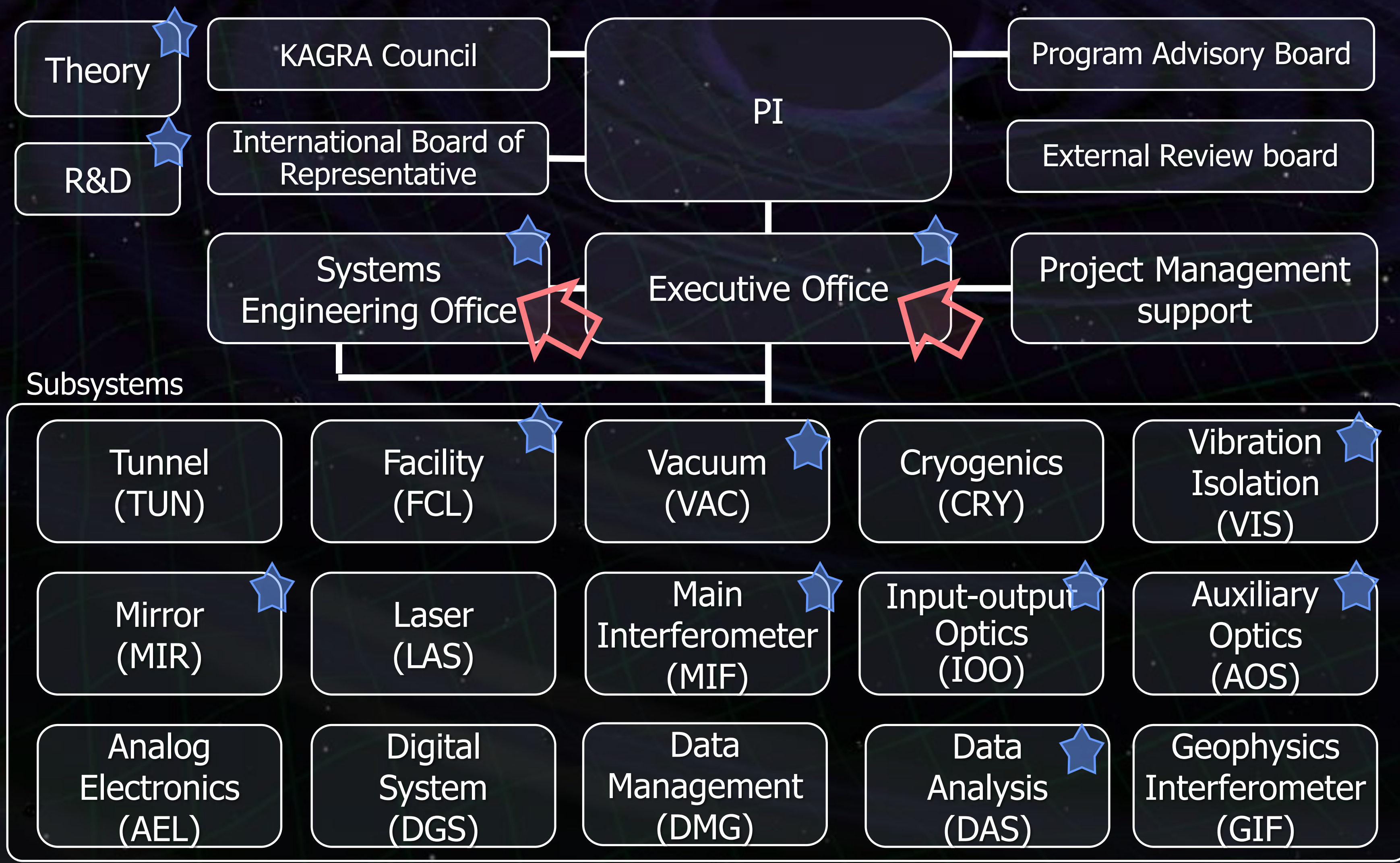
$$\mathcal{R} = 118^{+174}_{-79} [\mathrm{events/Myr}]$$

V. Kalogera et.al., ApJ, 601 L179 (2004)
Kim et al. (2008)

⇨ **LCGT Detection rate 9.8 events/yr**

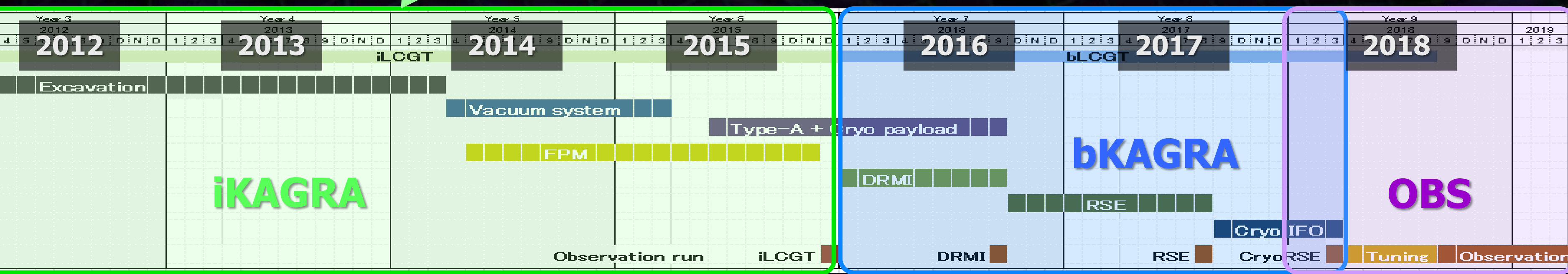
Organization of KAGRA

~150 Collaborators (Host : ICRR, Co-hosts: NAOJ, KEK)

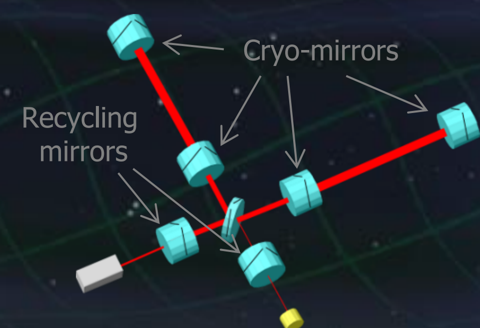


KAGRA Schedule

- **iKAGRA** (2010.10 – 2015.12)
  3-km FPM interferometer
  - Baseline 3km room temp.
  - Operation of total system with simplified IFO and VIS.



- **bKAGRA** (2016.1 – 2018.3)
  Operation with full config.
  - Final IFO+VIS configuration
  - Cryogenic operation.



Schedule and Budget

FY2010 FY2011 FY2012 FY2013 FY2014 FY2015 FY2016 FY2017

Budget

‘Leading-edge Research Infrastructure’ program (~98M$) for iKAGRA

‘Specially Promoted Research’ program (~5M$) for detector upgrade

Budget from MEXT (~33M$) for excavation

Budget from MEXT (~20M$) for detector upgrade

KAGRA configuration

iKAGRA

- KAGRA facility
- 3km simple room-temp. interferometer

Upgrade

bKAGRA

- Cryogenic mirrors
- Full-power RSE configuration

Purpose

Preparation of infrastructure

GW detection and astronomy

KAGRA Site

Underground site at Kamioka, Gifu prefecture

Facility of the Institute of Cosmic-Ray Research (ICRR), Univ. of Tokyo.

Neutrino
- Super Kamiokande, Kamland

Dark matter
- XMASS

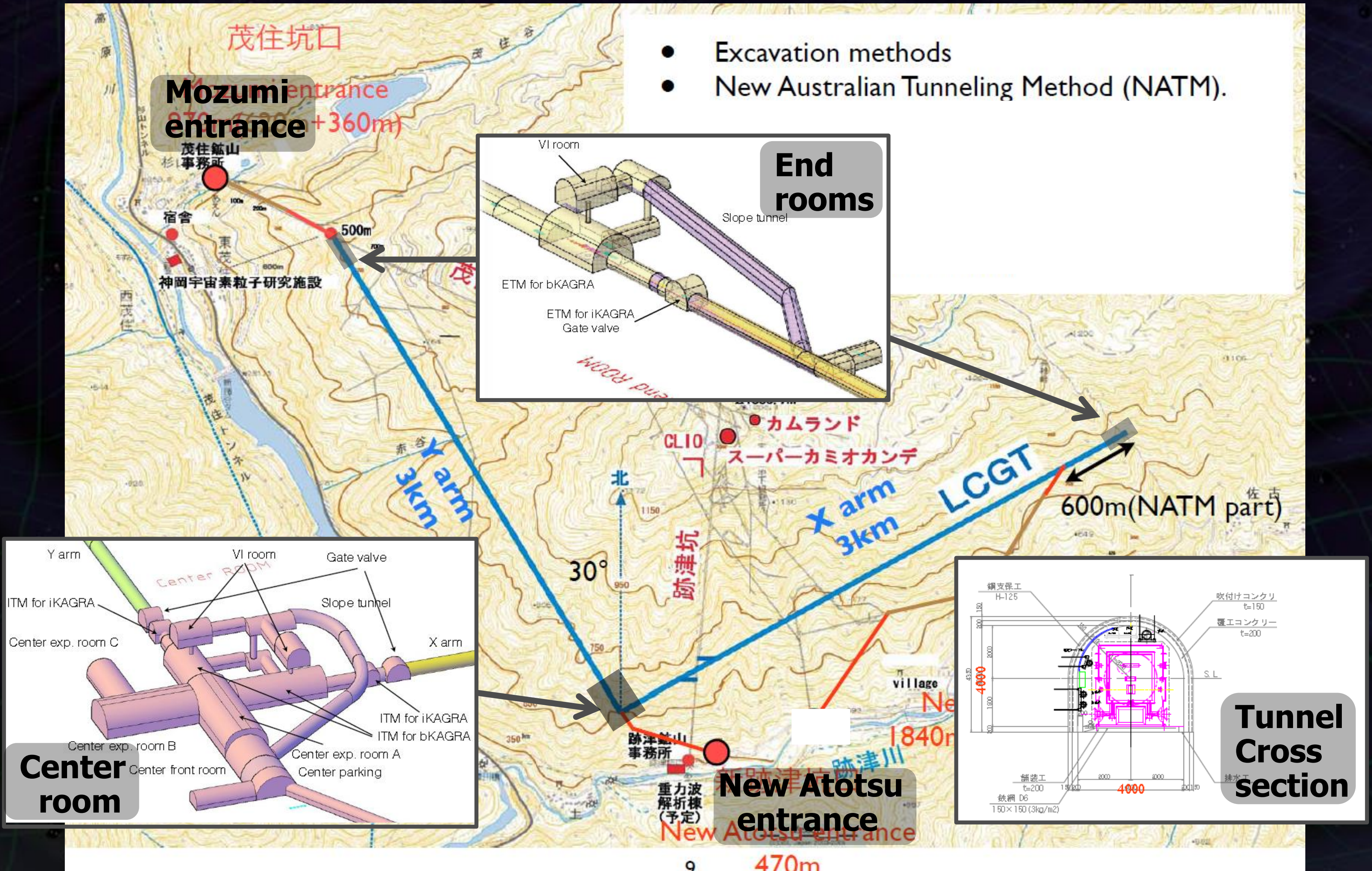
Gravitational wave
- CLIO, KAGRA

Geophysics
- Strain meter

- 220km away from Tokyo
- 1000m underground from the top of the mountain. (Near Super Kamiokande)
- 360m altitude
- Hard rock of Hida gneiss (5 [km/sec] sound speed)

Tunnel Design

- Excavation methods
- New Australian Tunneling Method (NATM).



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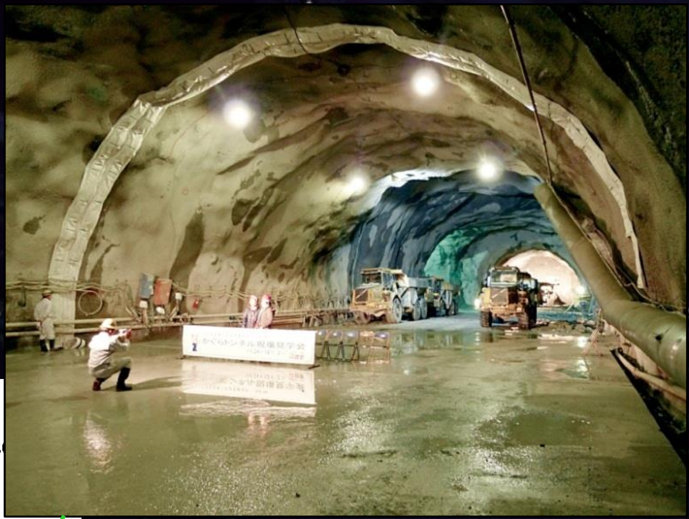
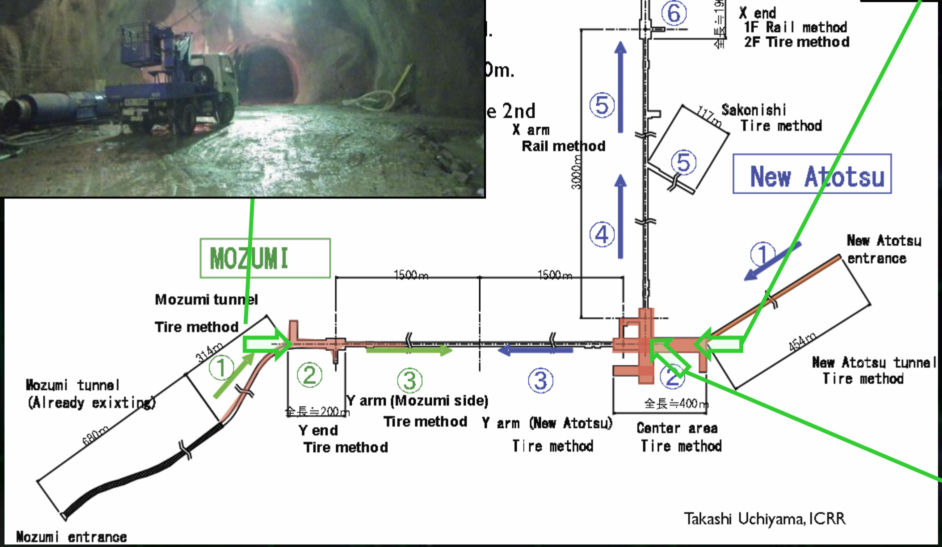
Status of Tunnel Excavation

Mozumi ：
Y-arm tunnel
(~1000m)

New Atotsu：Center room





Surface Facility at Kamioka

Rent and remodel a public building (140m^2) for free.
→ On-site office and laboratory for GW group.

Aug. 29, 2012
Announcement for local people
→ Open as office in Nov.

KAGRA Vacuum duct

- 12m, Φ800mm ducts for 3km x 2 arms.
  → ~90% of 478 ducts have been delivered.


Press to form a duct


Bellows for each duct

Presentation
By Y.Saito (KEK)


Baking at MIRAPRO Co.
Noda/MESCO, Kamioka


Test at MIRAPRO Co. Noda

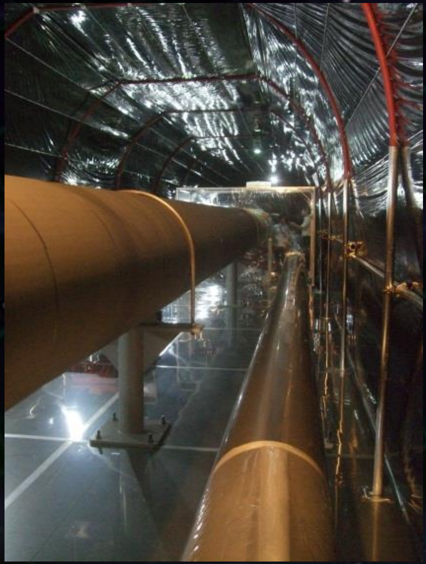

Transportation to Kamioka

Installation Test Facility

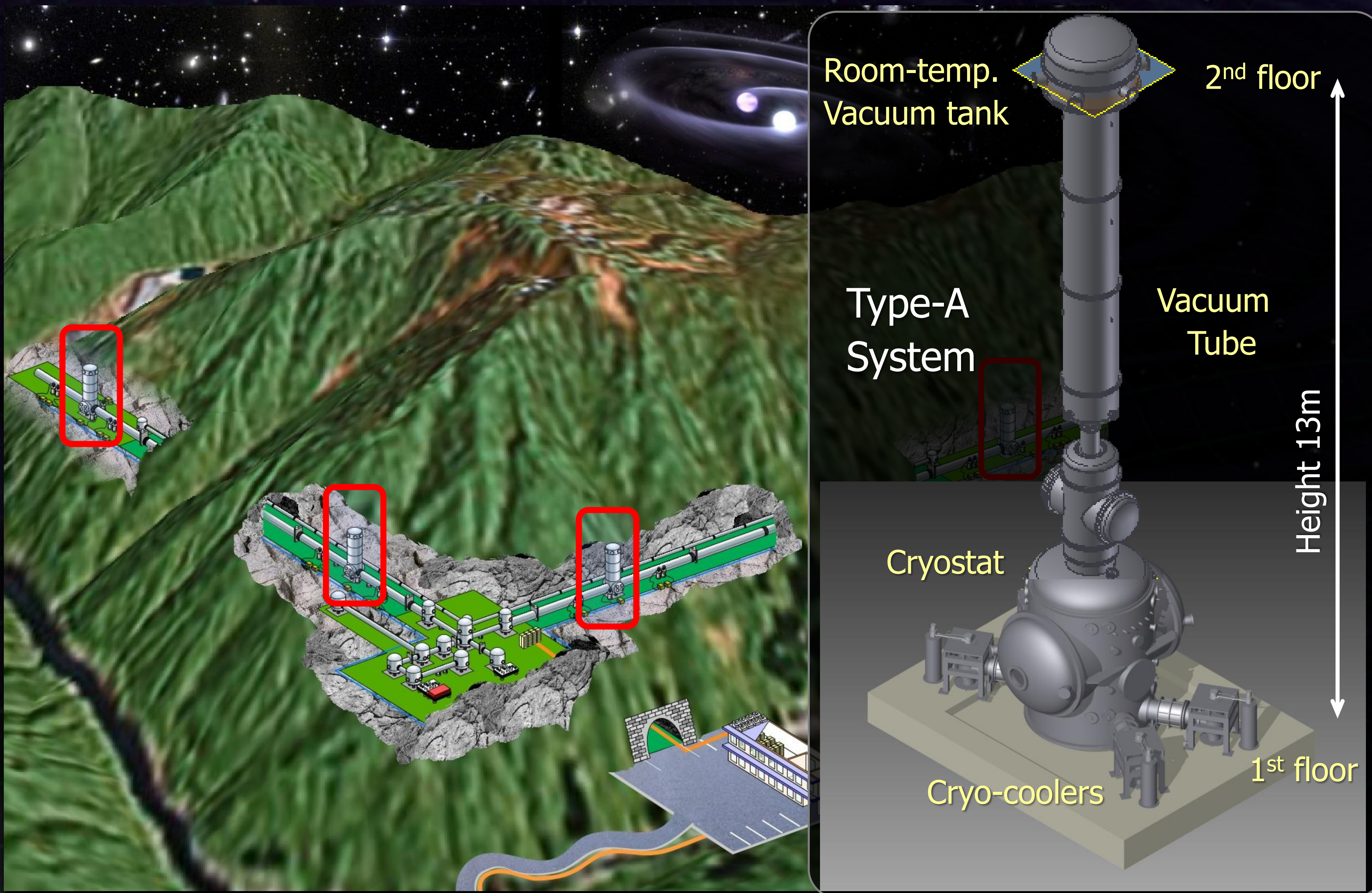
KAGRA tunnel simulator for installation test

(MIRAPRO, Noda factory)

June 28, 2012, Photo by Kamiizumi and Iwasaki (ICRR)



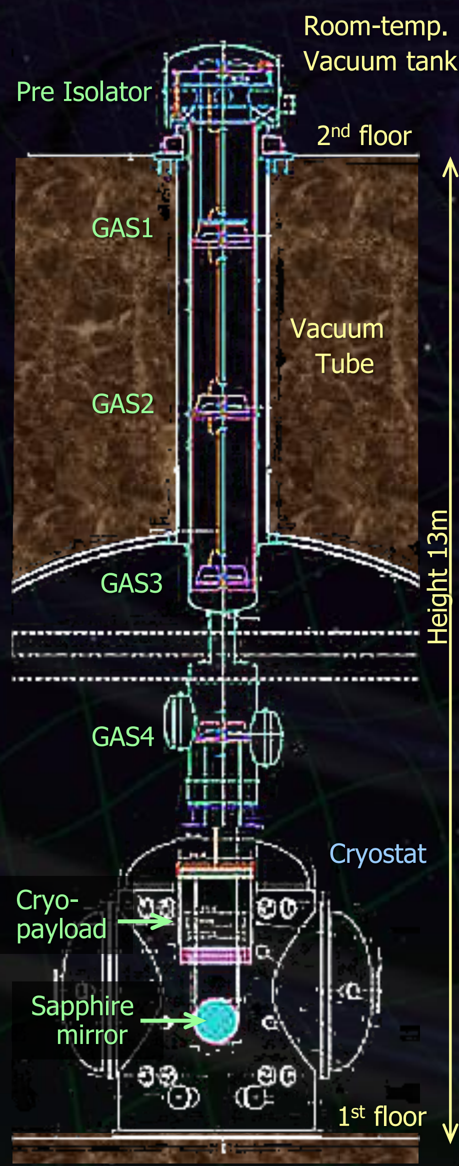
Cryogenic Isolator

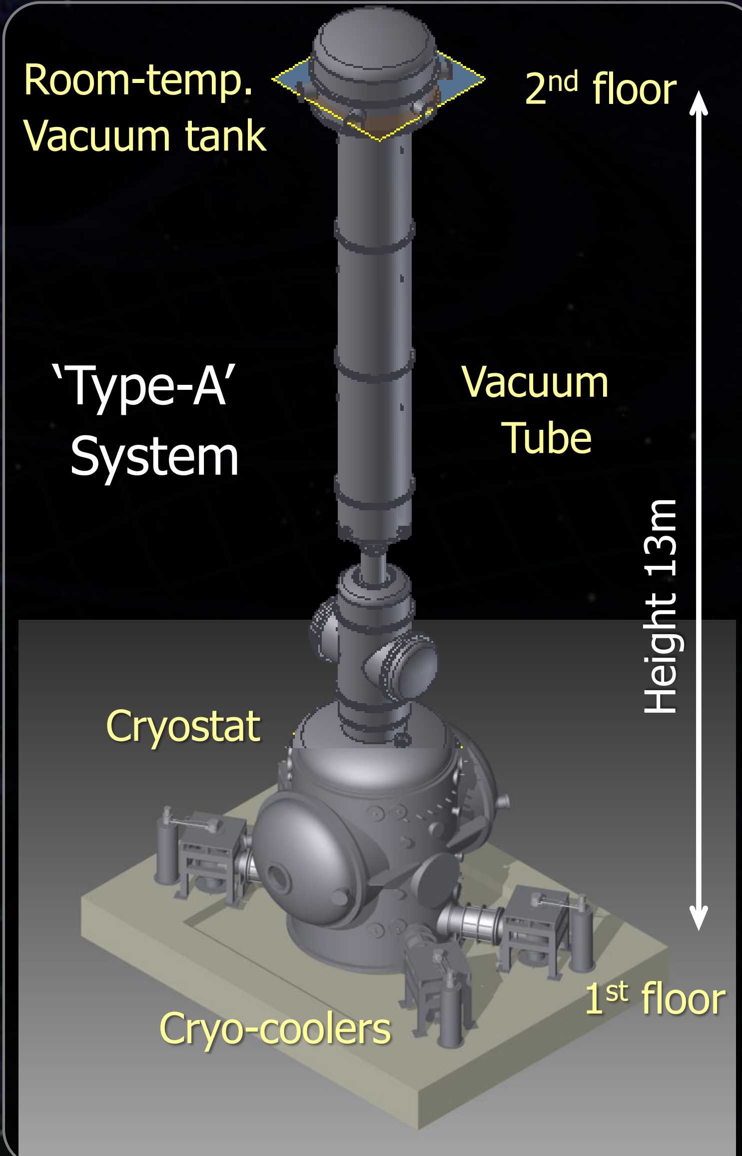


Cryogenic Mirror Isolator

Room-temp.
Filter chain

Cryogenic
Payload





Cryostat Construction

Cryostat #1 in preparation for installation of radiation shield.

Cryostat #2 in leak test.

3rd and 4th cryostats under construction

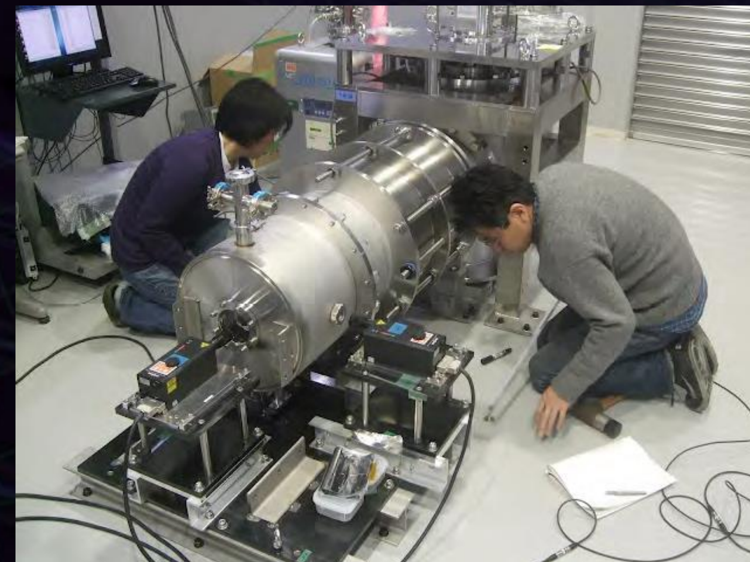
Radiation shield

Toshiba Keihin Factory (Oct 31, 2012)

Cryo-cooler Construction

Cryo-cooler units at ICRR (Kashiwa)

Vibration measurement



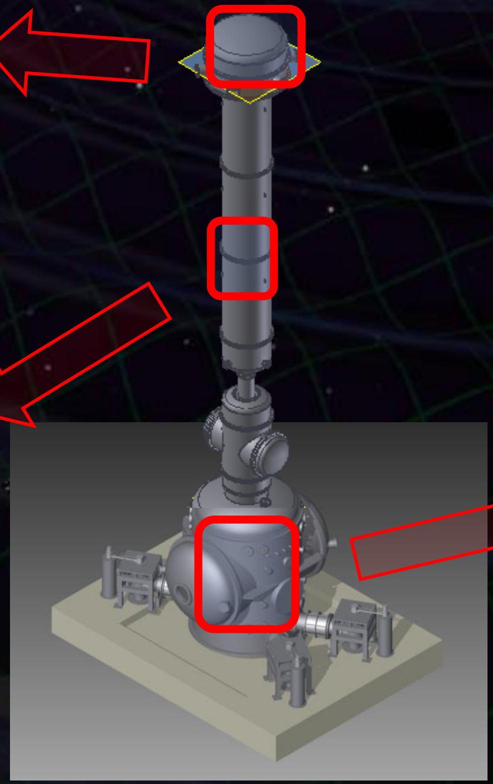
Storage at ICRR (Akeno)

T.Suzuki at External Review (April 2012)

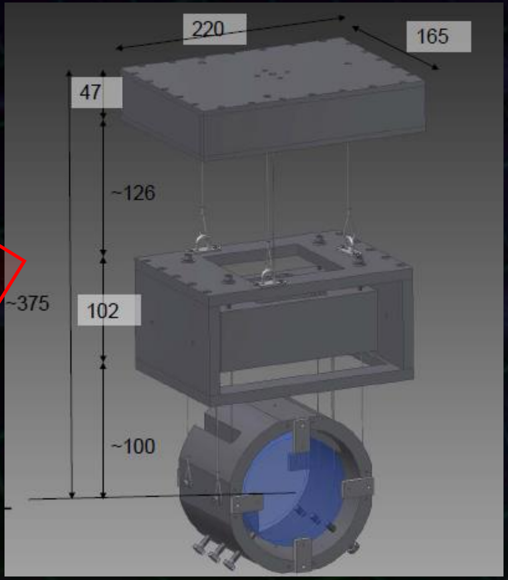
Sapphire Mirror Isolator


Pre Isolator prototype at Lucca(Pisa)

'Type-A' system



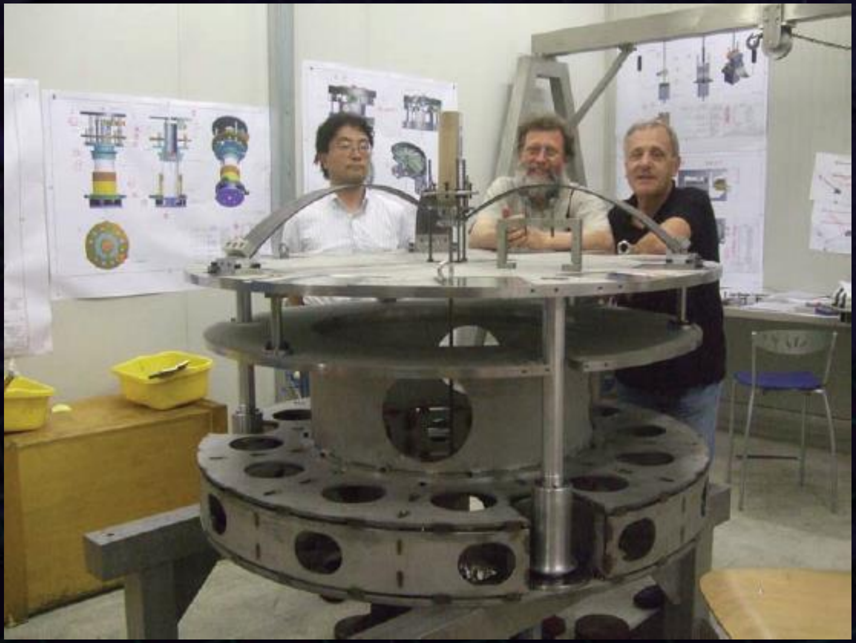
Cryogenic payload
½-scale prototype

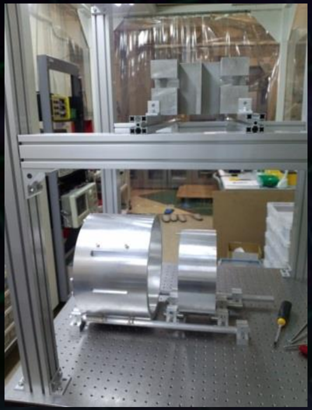



GAS filter prototype

Isolator Prototypes

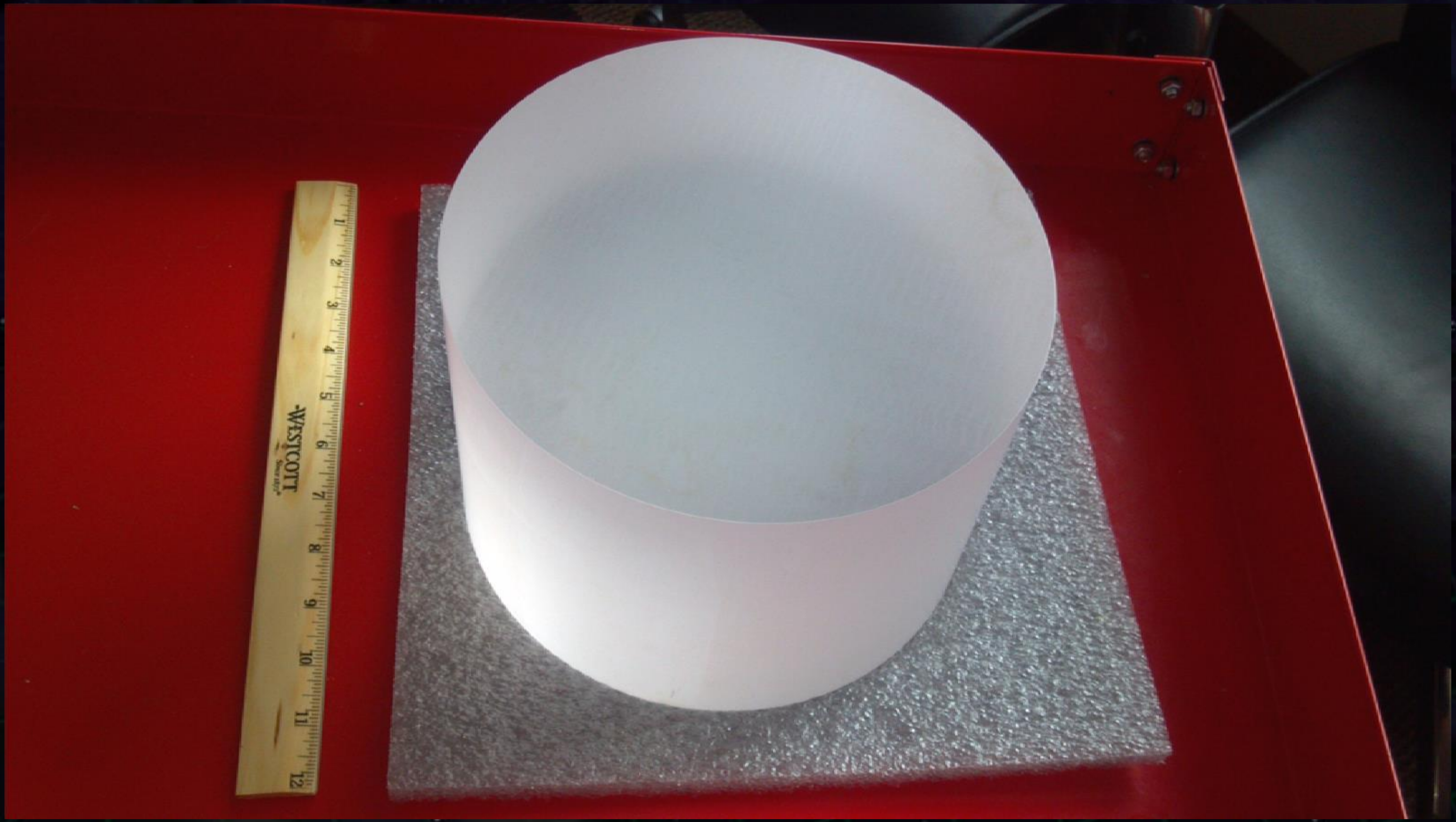

Pre-Isolator Prototype test (Kashiwa)





Sapphire Mirror

KAGRA



2 Sapphire substrates were delivered
(Φ220mm, t 150mm, c-axis)

Summary

Summary

KAGRA : Under Construction

- Sufficient sensitivity for direct GW detection
- Form global network as one of the 2nd-gen. detectors

⇨ Aim to detect GW, and to open new astronomy

- KAGRA will demonstrate 3rd generation detector techniques: cryogenics and underground

Status

- Technology based on TAMA and CLIO experiences
- Tunnel and facilities are becoming real.
- Prototype developments : SAS, Cryostat, Control Sys.

End