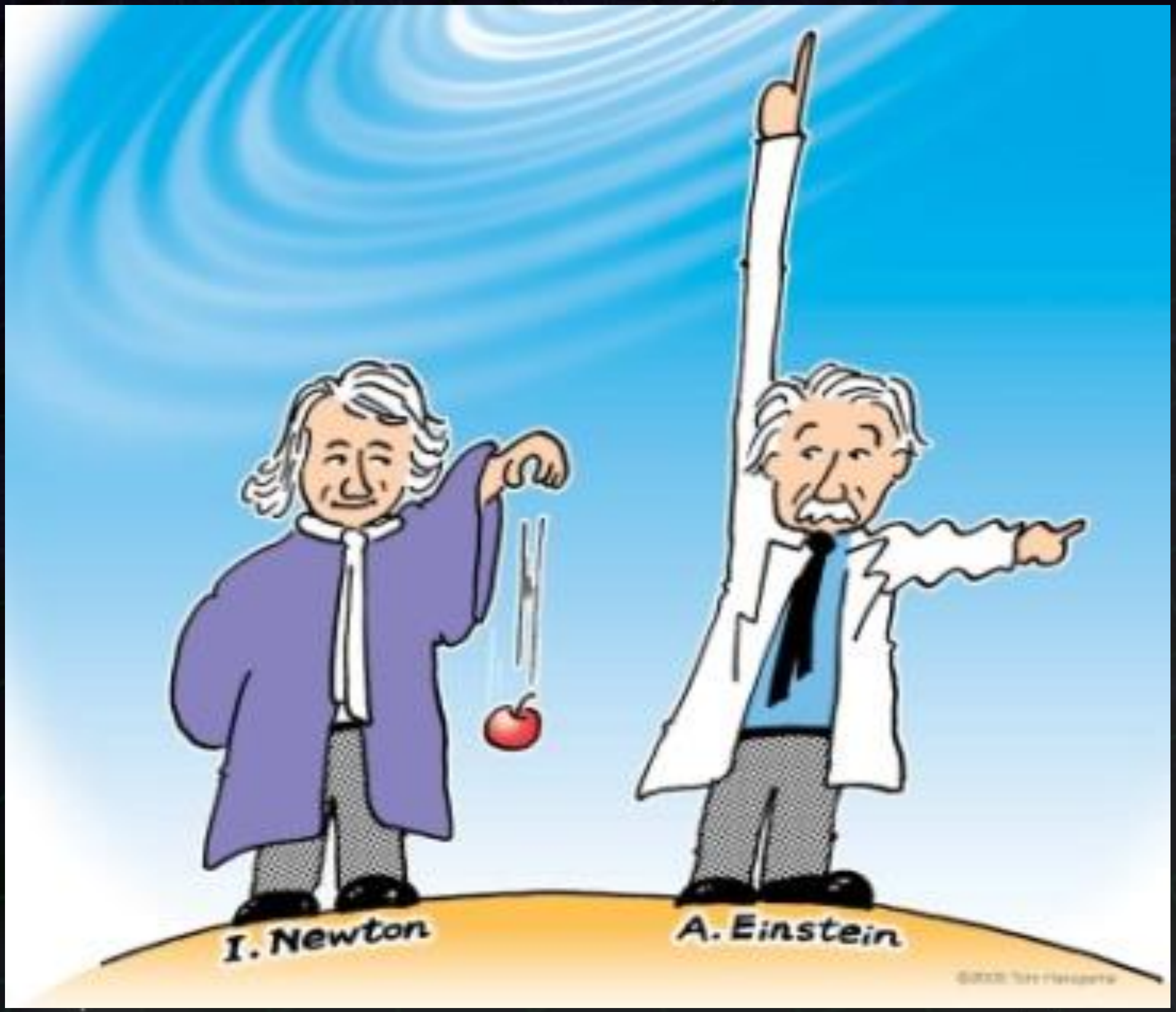
Gravity and Gravitational-Wave Physics



Masaki Ando
(National Astronomical Observatory of Japan)

Global COE Symposium 'Development of Emergent New Fields' (Feb. 13, 2013, Kyoto University, Kyoto)

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)

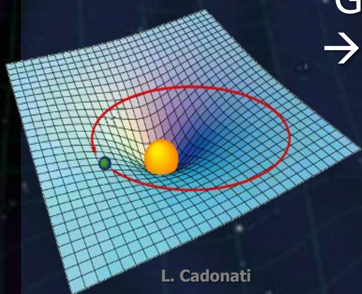
Gravitational-Wave Project office

- 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)

Gravity and Gravitational waves

General Relativity


L. Cadonati

Gravity
→ Nature of space-time

Einstein equation

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Curvature
Of space time

Mass
(Energy Momentum)

AC component

DC component

Gravitational wave

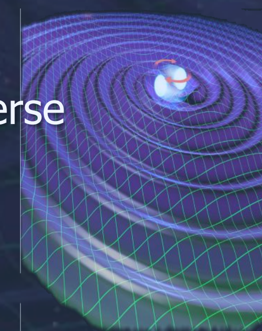
GW astronomy

New probe for the Universe

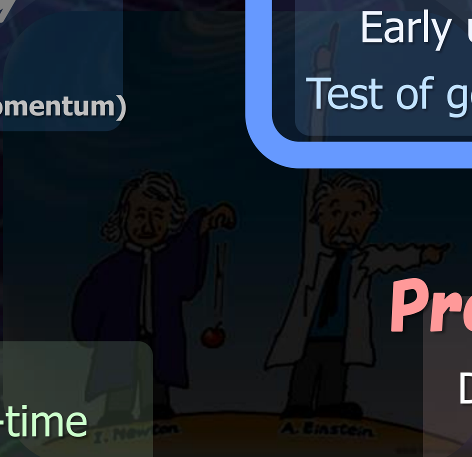
Violent phenomena,

Early universe, …

Test of general relativity



Obs.



Tom Haruyama

Gravity

Direct Probe of space-time

Prospects on problems
in modern physics

Fundamental Physics

ISL, EP

Measurement

Precise Measurement

Displacements of
Macroscopic objects

Laser interferometer

Quantum optics, …

Fundamental noises

Thermal fluctuation, …

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,

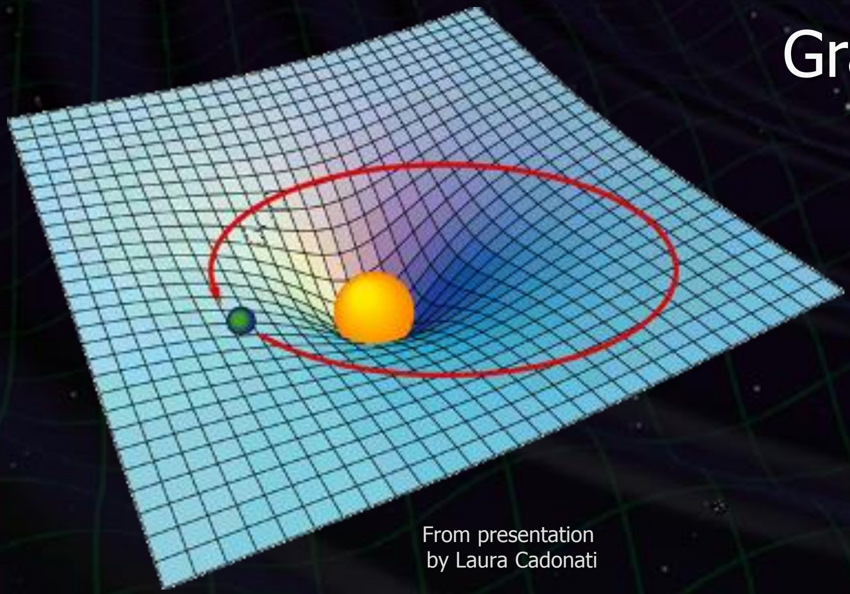
1000m underground

Outline

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

Gravitational Wave Astronomy

Gravitational Wave



From presentation by Laura Cadonati

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

General Relativity

Gravity : Curvature of space-time

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

⇩

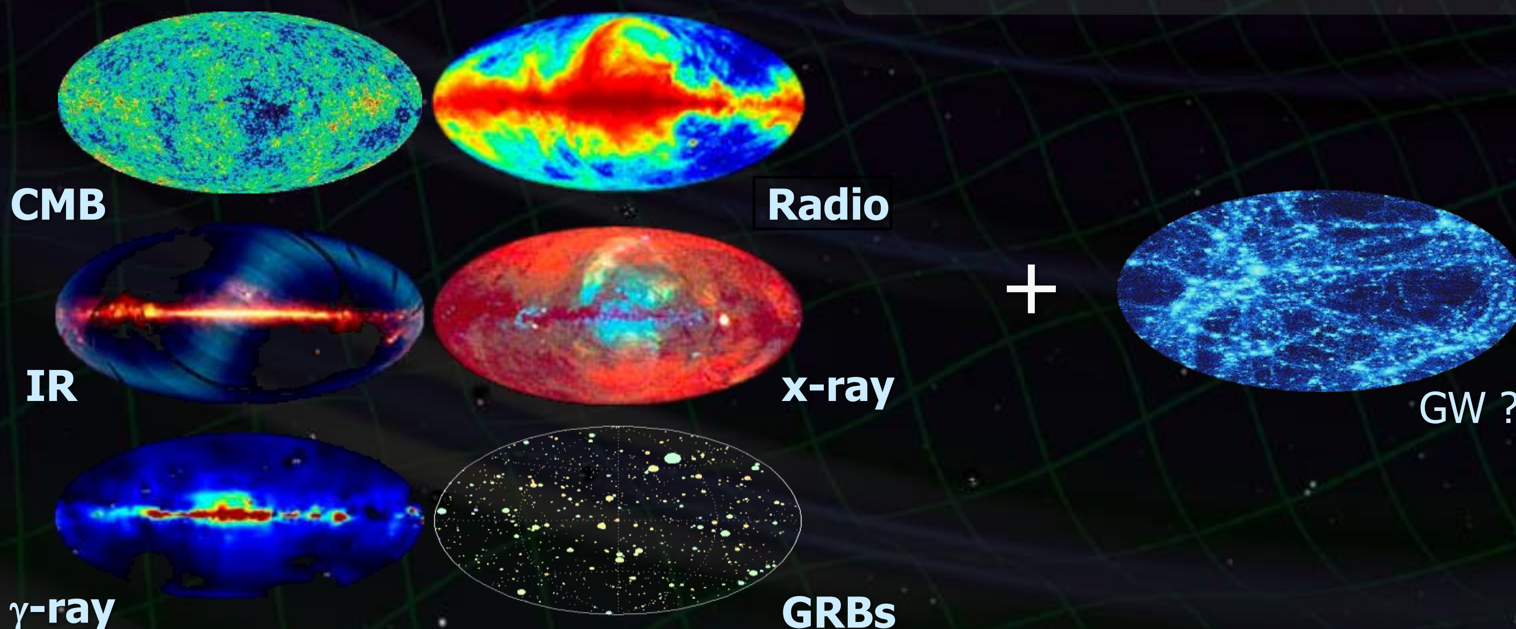
Gravitational Waves

Gravitational-Wave Astronomy

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



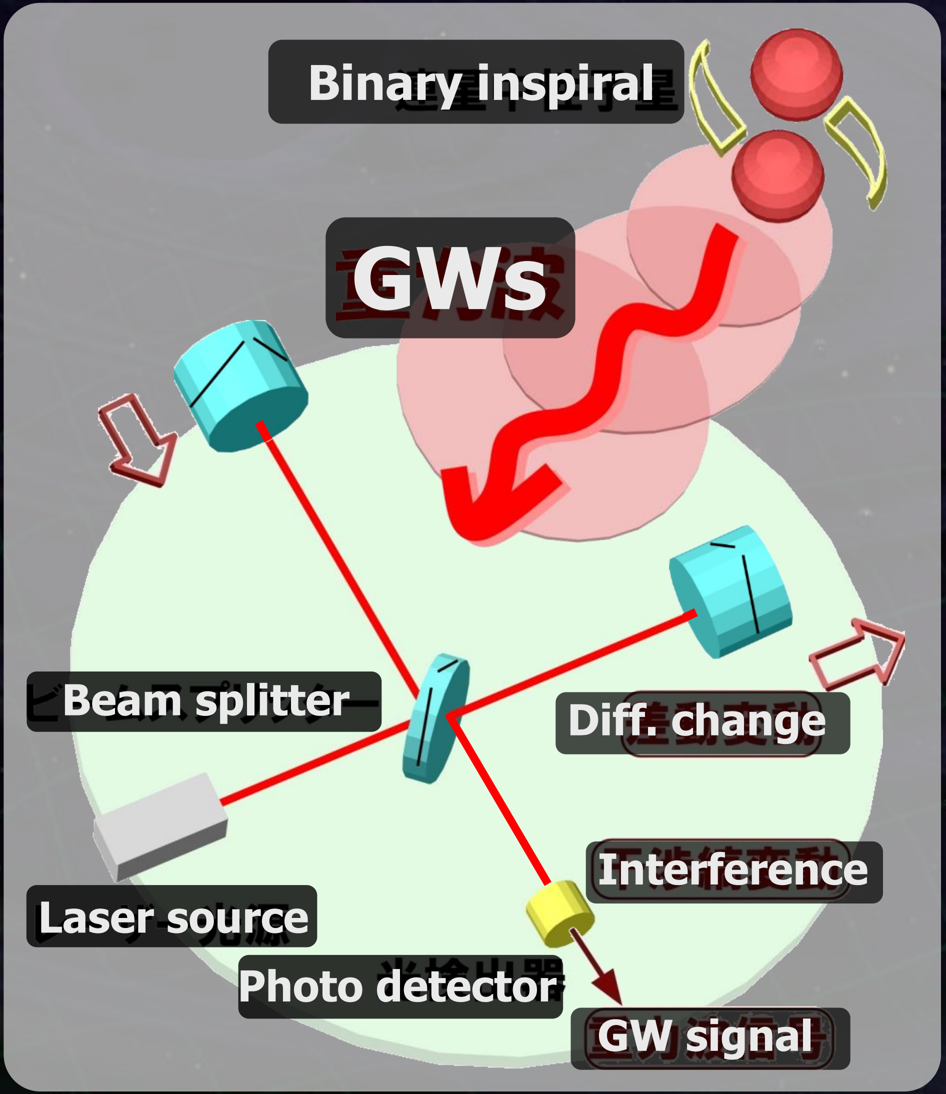
Laser Interferometric Detector

Laser Interferometer

(Michelson interferometer)

When GW comes…

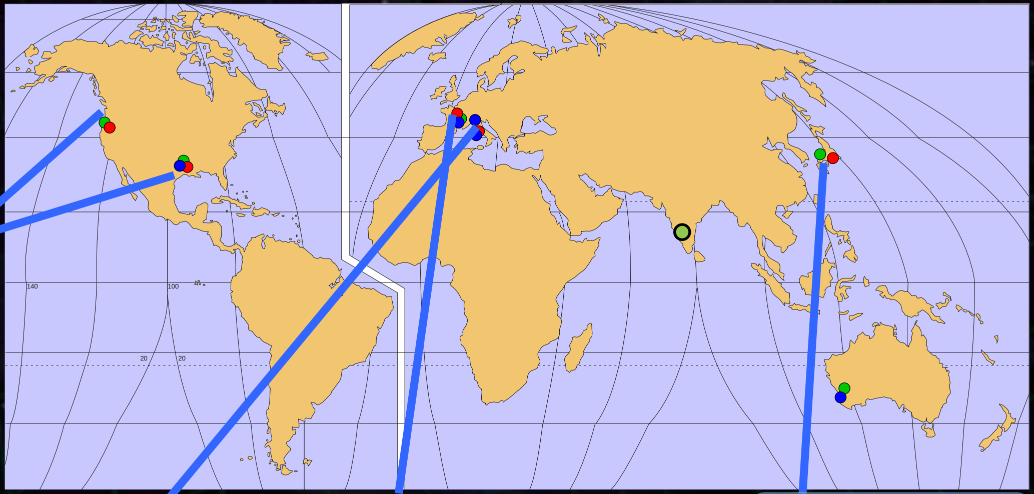
Differential length (strain) changes in two arms
↓
Detected at photo detector



2^{nd}-Generation GW Antennas

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)



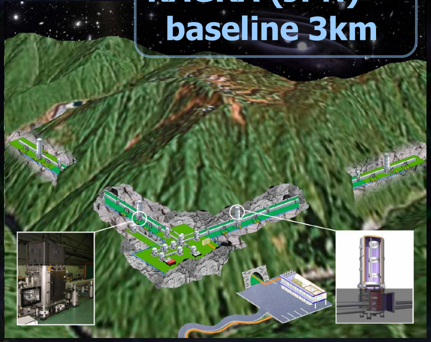
LIGO-Austreria

LIGO-India
in proposal

Adv.VIRGO (ITA-FRA)
baseline 3km

GEO-HF (GER-UK)
baseline 600m

KAGRA (JPN)
baseline 3km



Target of Ground-based Detectors

KAGRA

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

⇨ Compact and high-energy astronomical phenomena

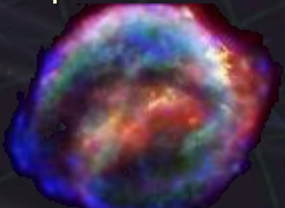
Neutron Star

Black Hole

Early Universe

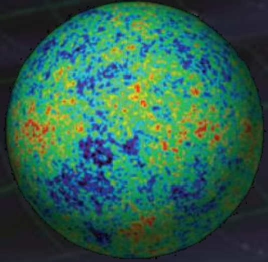
Pulsar

Supernova

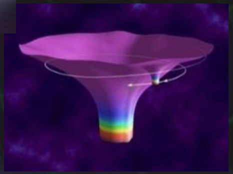


Binary merger

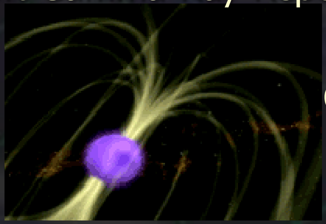
Stochastic Background



EMRI



Soft Gamma-Ray Repeater



Star Oscill ation

Long GRB

Short GRB

Quasi-normal Oscillation

EM Waves
Neutrino
High-energy CR

Follow-up observation
Numerical Relativity

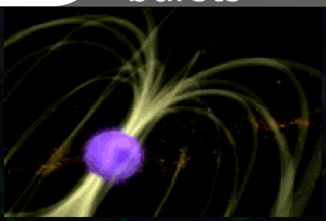
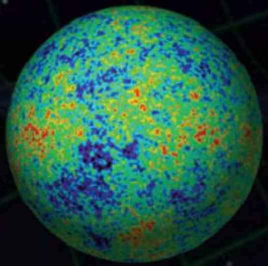
Understandings on High-E phenomena

EoS of high-density Matter → Nuclear Phys.

Test of Relativity Physics in Strong Gravity

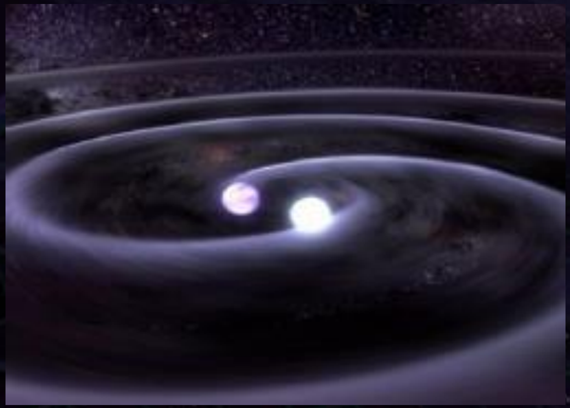
GW targets and data analysis

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

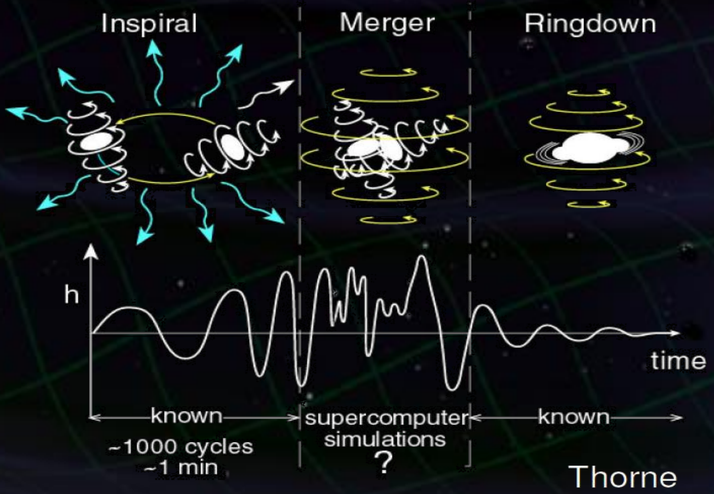
Primary target :
Inspiral and merger of NS binary



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

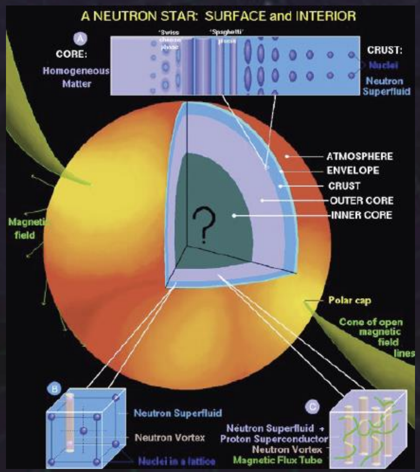
⇩

Promising for first detection



EoS of Neutron Stars

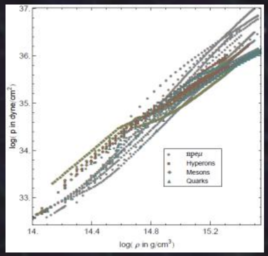
KAGRA



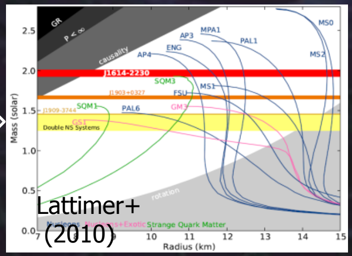
Neutron-star EoS

(Density $2 \sim 15\rho_0$)

Density-Pressure



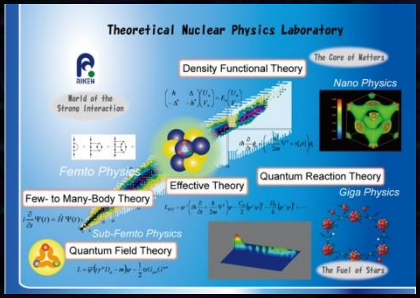
Radius-Mass of NS



Lattimer+ (2010)

Nuclear Physics

Natural Laboratory for high-density nuclear physics



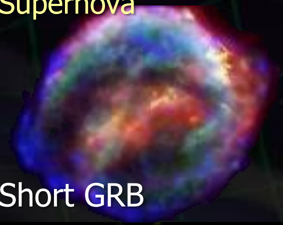
理研Web pageより

High-energy Phenomena

→ Astrophysics, Frontier Physics

Radio Pulsar

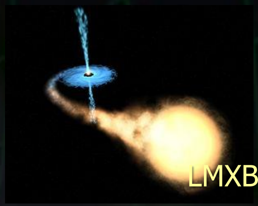
Supernova



Short GRB

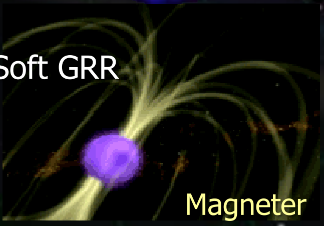
Binary Merger

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

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

Type Ⅰ

Collapse to BH

Type Ⅱ
Lifetime < 5ms

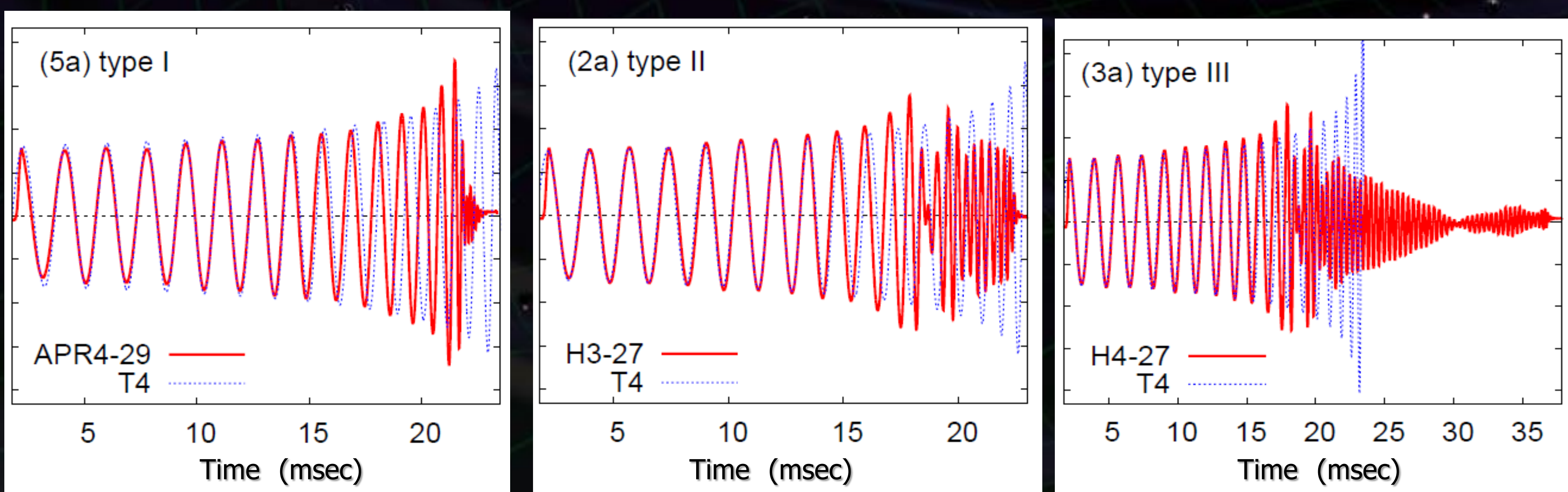
Short lived

Collapse to BH

Type Ⅲ
Lifetime > 5ms

Long lived

Collapse to BH



KAGRA Project

KAGRA

KAGRA（かぐら）

- LCGT

Large-scale Cryogenic Gravitational-wave Telescope

2nd generation GW detector in Japan

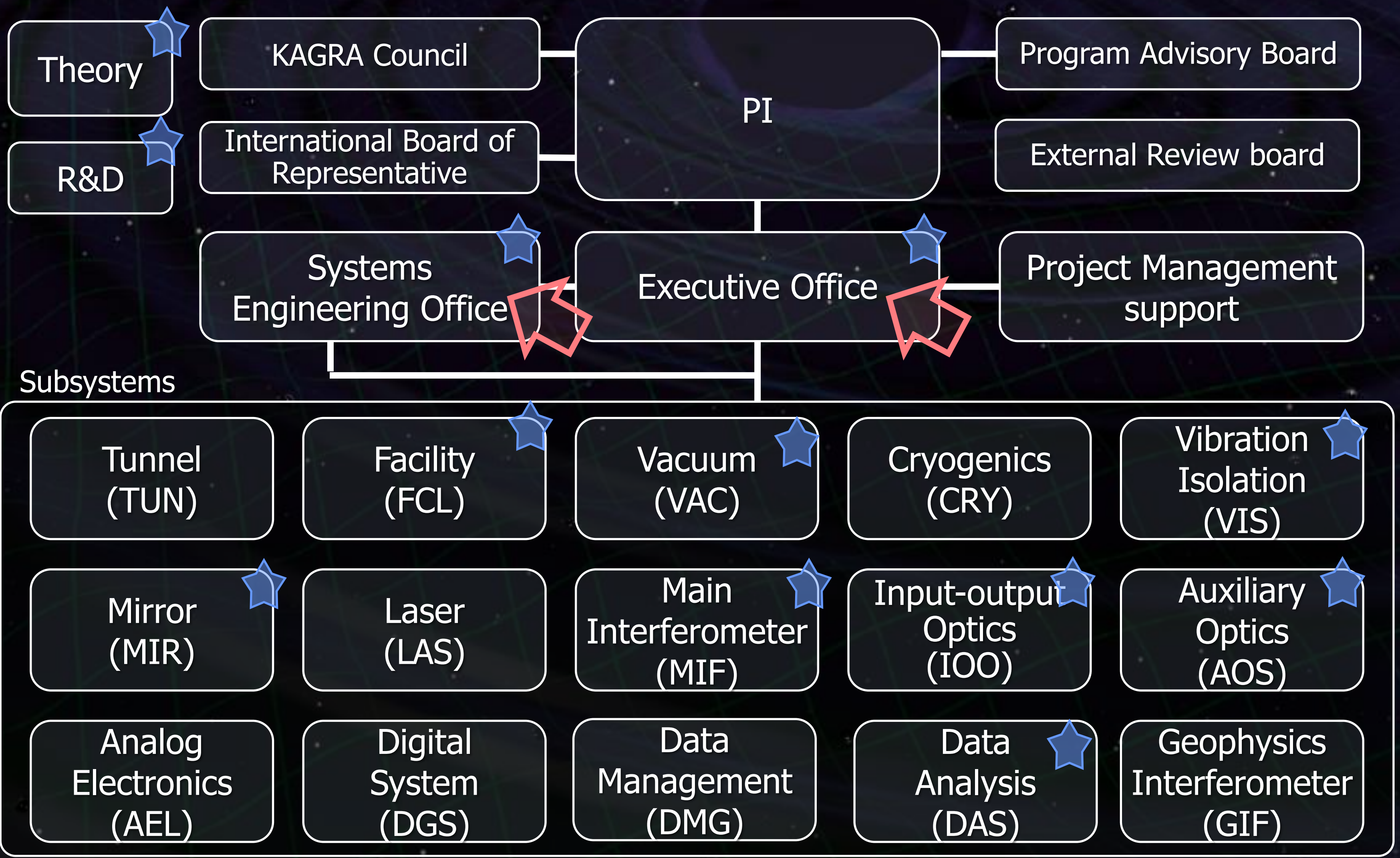
Large-scale Detector
- Baseline length: 3km
- High-power Interferometer

Cryogenic interferometer
- Mirror temperature: 20K

Underground site
- Kamioka mine,
  1000m underground

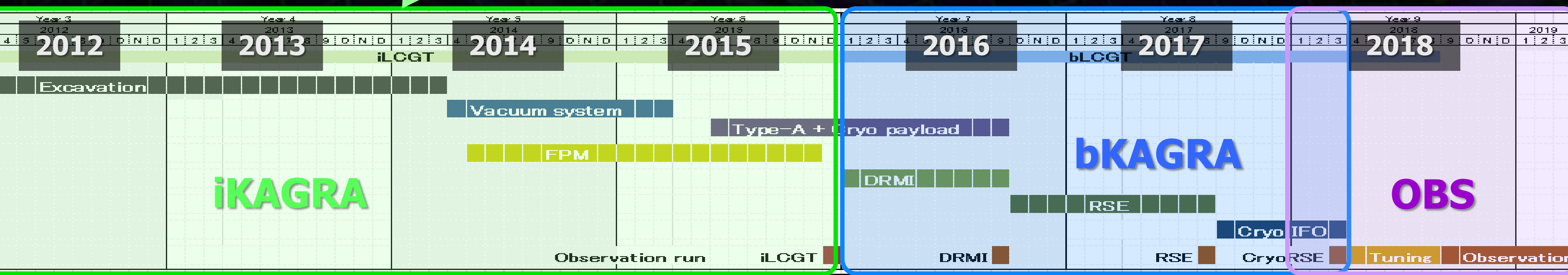
Organization of KAGRA

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

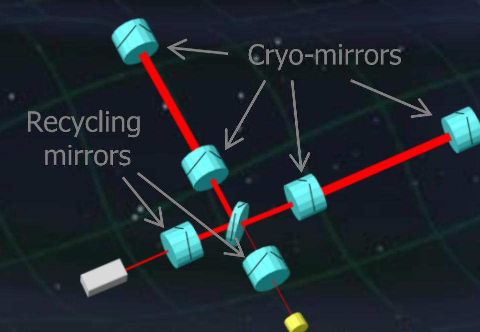


KAGRA Schedule

- **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

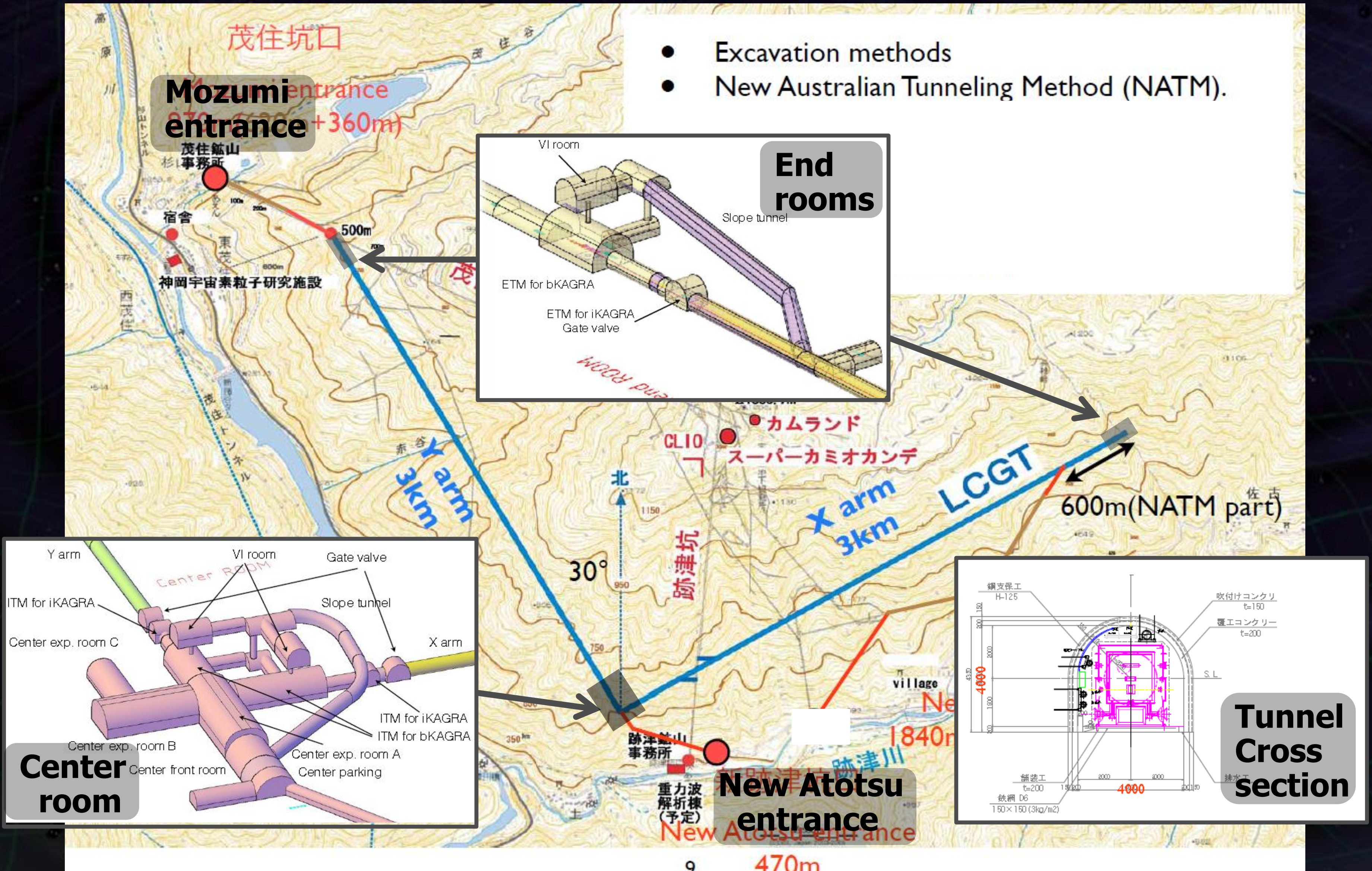
Underground site at Kamioka, Gifu prefecture

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

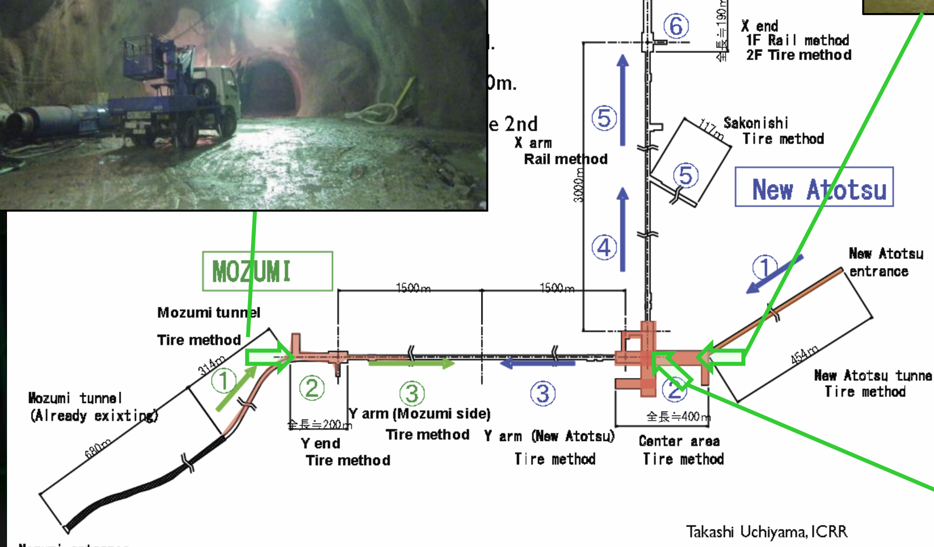


9

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

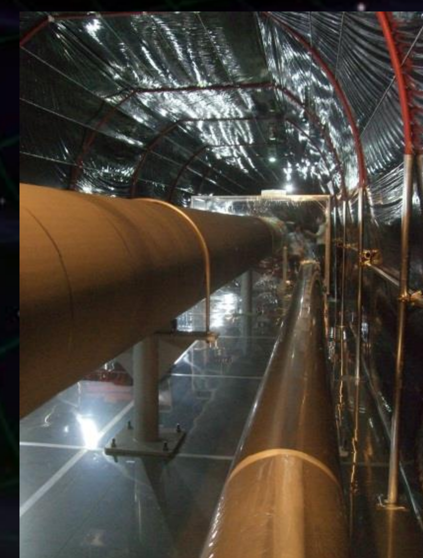
Transportation to Kamioka

Installation Test Facility

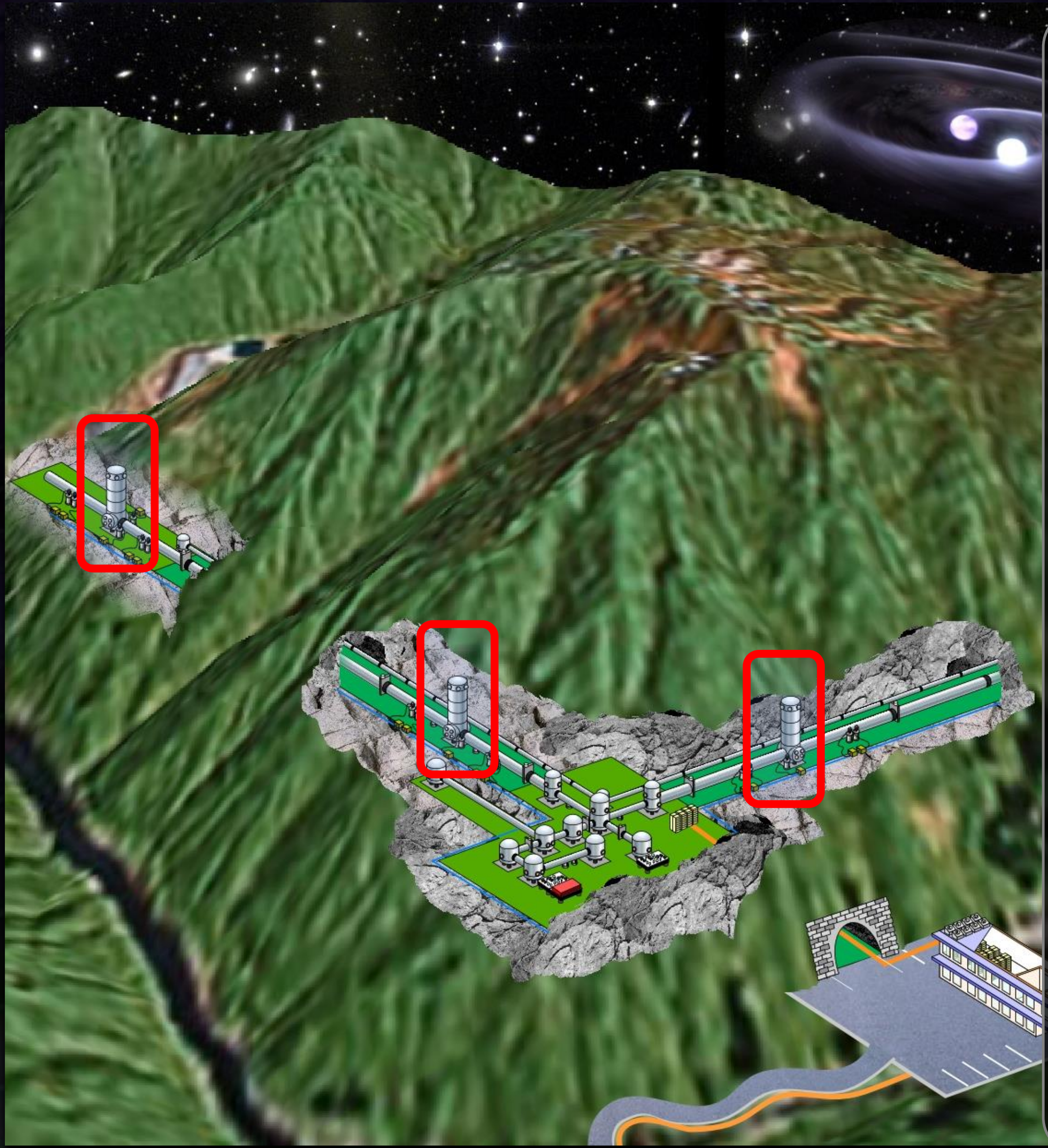
KAGRA tunnel simulator for installation test

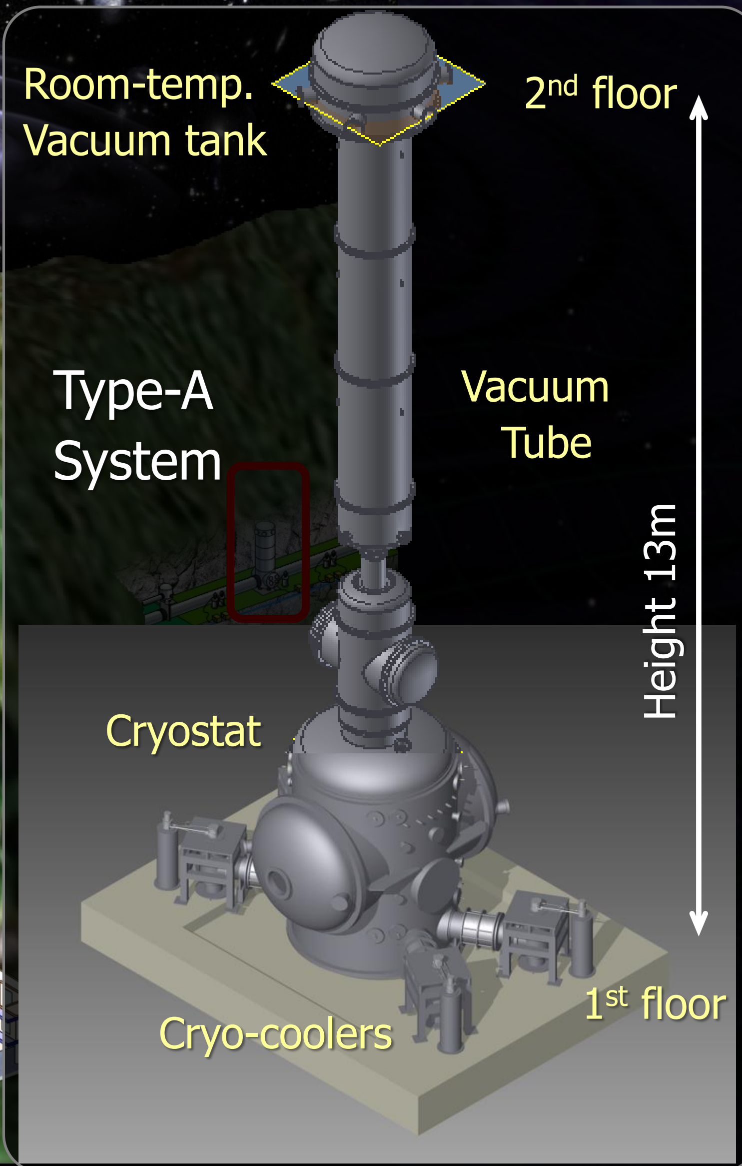
(MIRAPRO, Noda factory)

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



Cryogenic Isolator

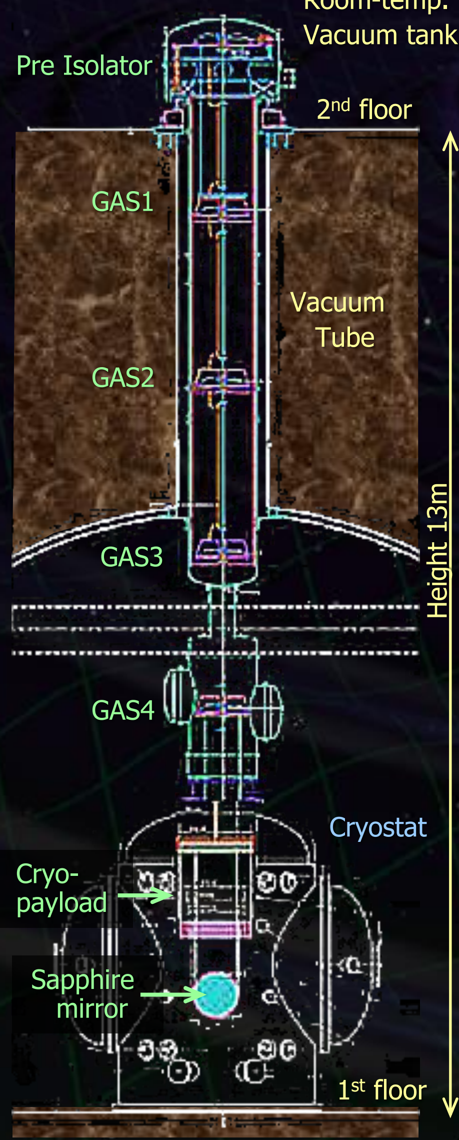


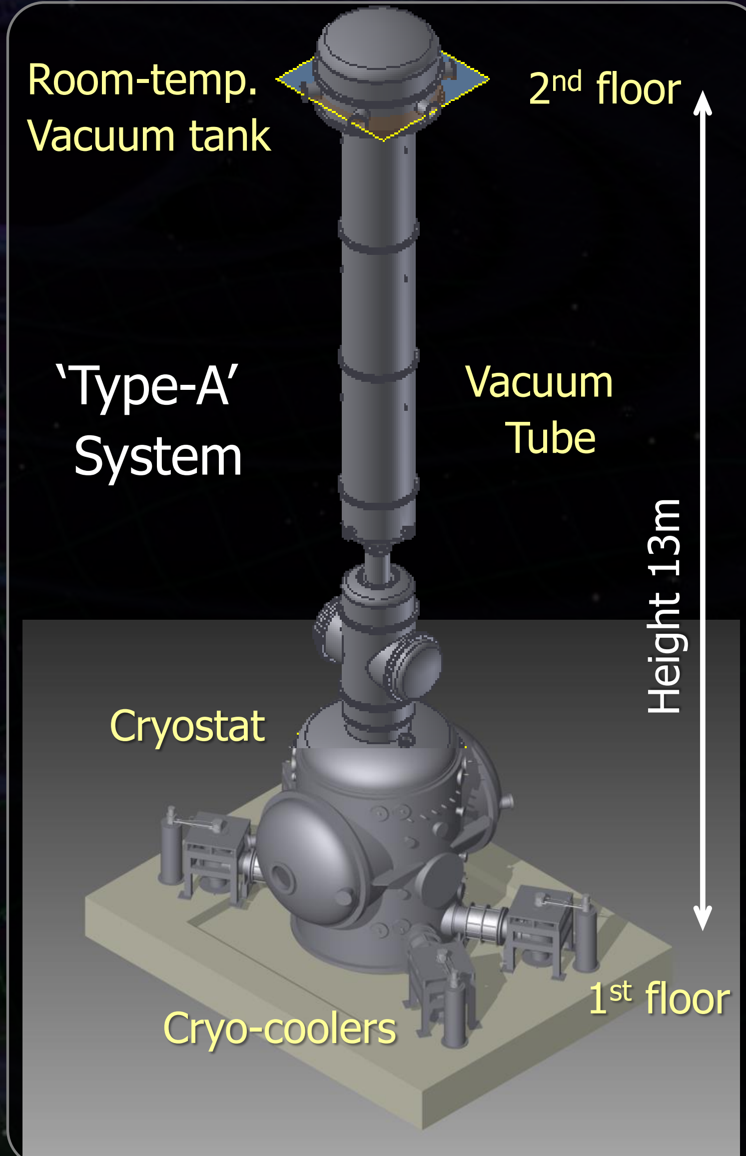


Cryogenic Mirror Isolator

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

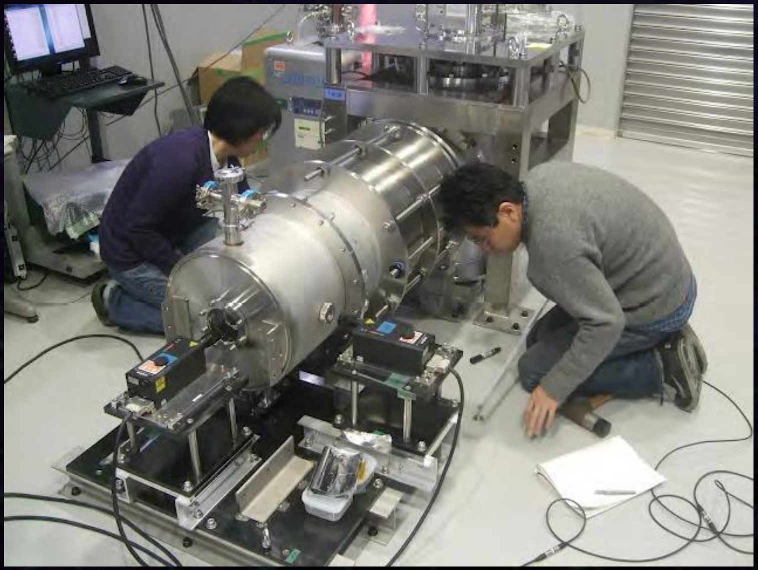
Radiation shield

Toshiba Keihin Factory (Oct 31, 2012)

Cryo-cooler Construction

Cryo-cooler units at ICRR (Kashiwa)

Vibration measurement



Storage at
ICRR (Akeno)

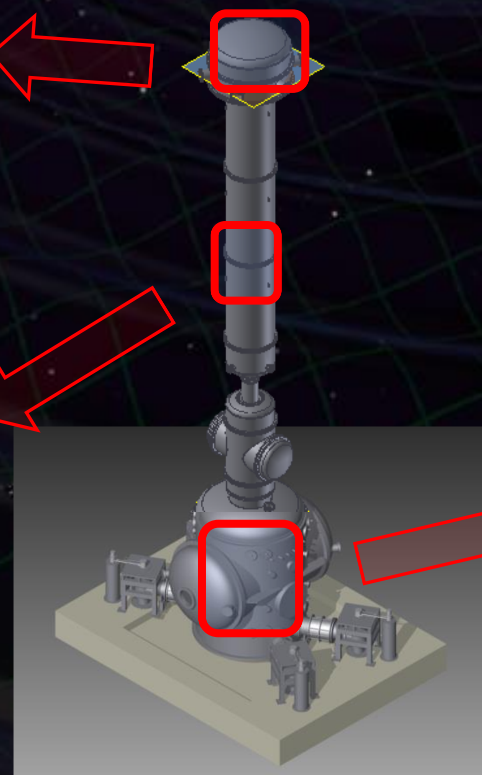
T.Suzuki at
External Review
(April 2012)

Sapphire Mirror Isolator

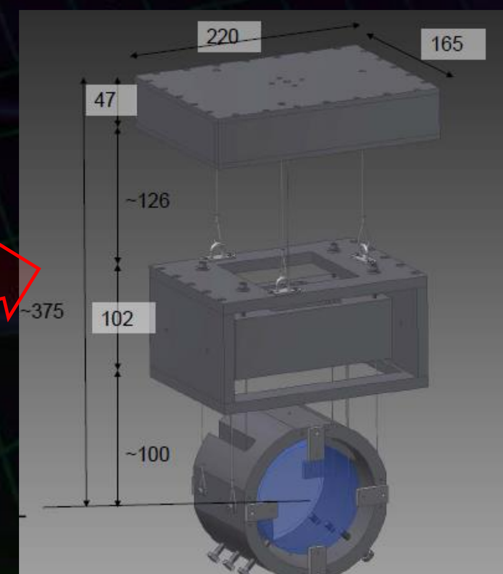

Pre Isolator prototype at Lucca(Pisa)


GAS filter prototype

'Type-A' system

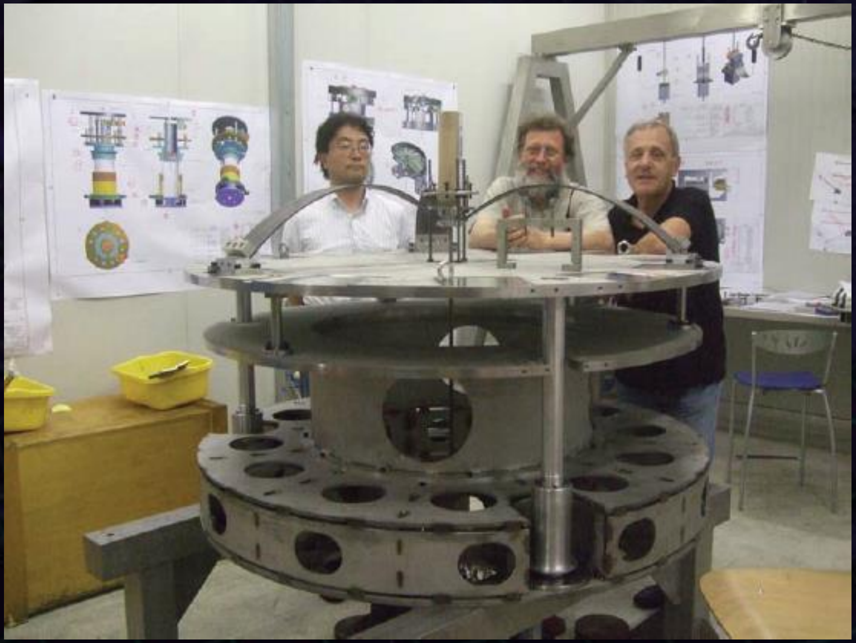


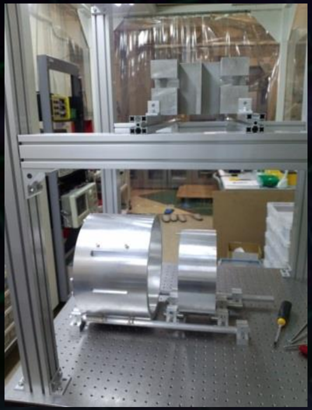
Cryogenic payload
½-scale prototype



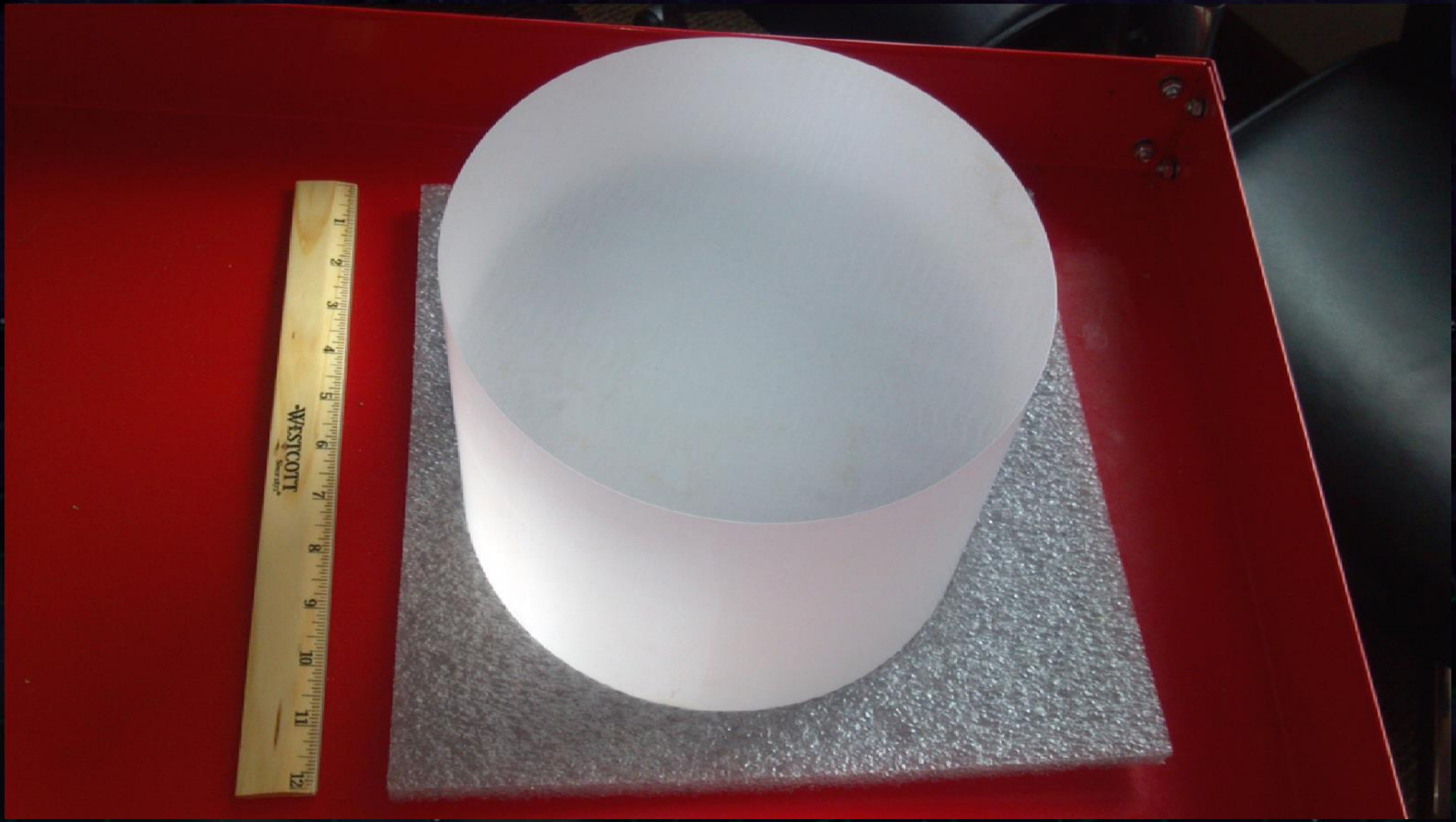
Isolator Prototypes


Pre-Isolator Prototype test (Kashiwa)





Sapphire Mirror



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 2^{nd}-gen. detectors

⇨ Aim to detect GW, and to open new astronomy

- KAGRA will demonstrate 3^{rd} 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.

Experiences in GCOE

For me...

- Enjoyed life in Kyoto.
- Research experiences in Kyoto was vary fruitful.
  - 'Tentaikaku' astrophysics theory group:
    → Interactions with theorists
  - Quantum Optics group.
    → Precise atomic spectroscopy for fundamental phys.

⇩

Opportunities to tackle on new fields

Thank You Very Much!!!

End