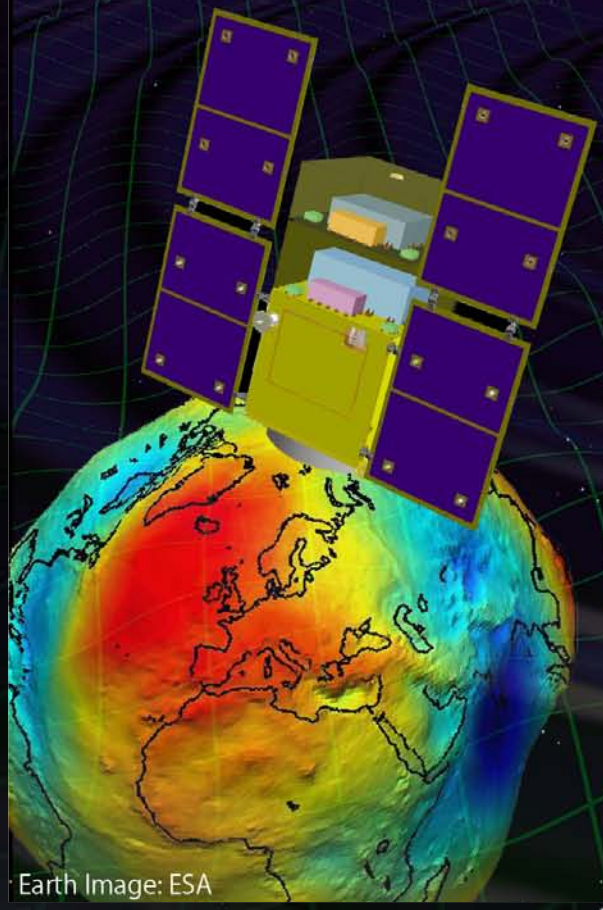
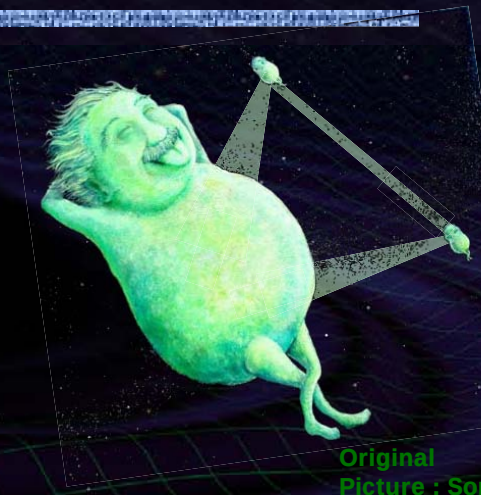
DECIGO and DECIGO Pathfinder





Original
Picture : Sora

Masaki Ando
(Department of Physics, Kyoto University)

On behalf of
DECIGO working group

1. DECIGO

- Overview and Science
- Pre-conceptual Design

2. DECIGO Pathfinder

- Overview and Science
- Design and Status
- Space Demonstration

3. Summary

1. DECIGO

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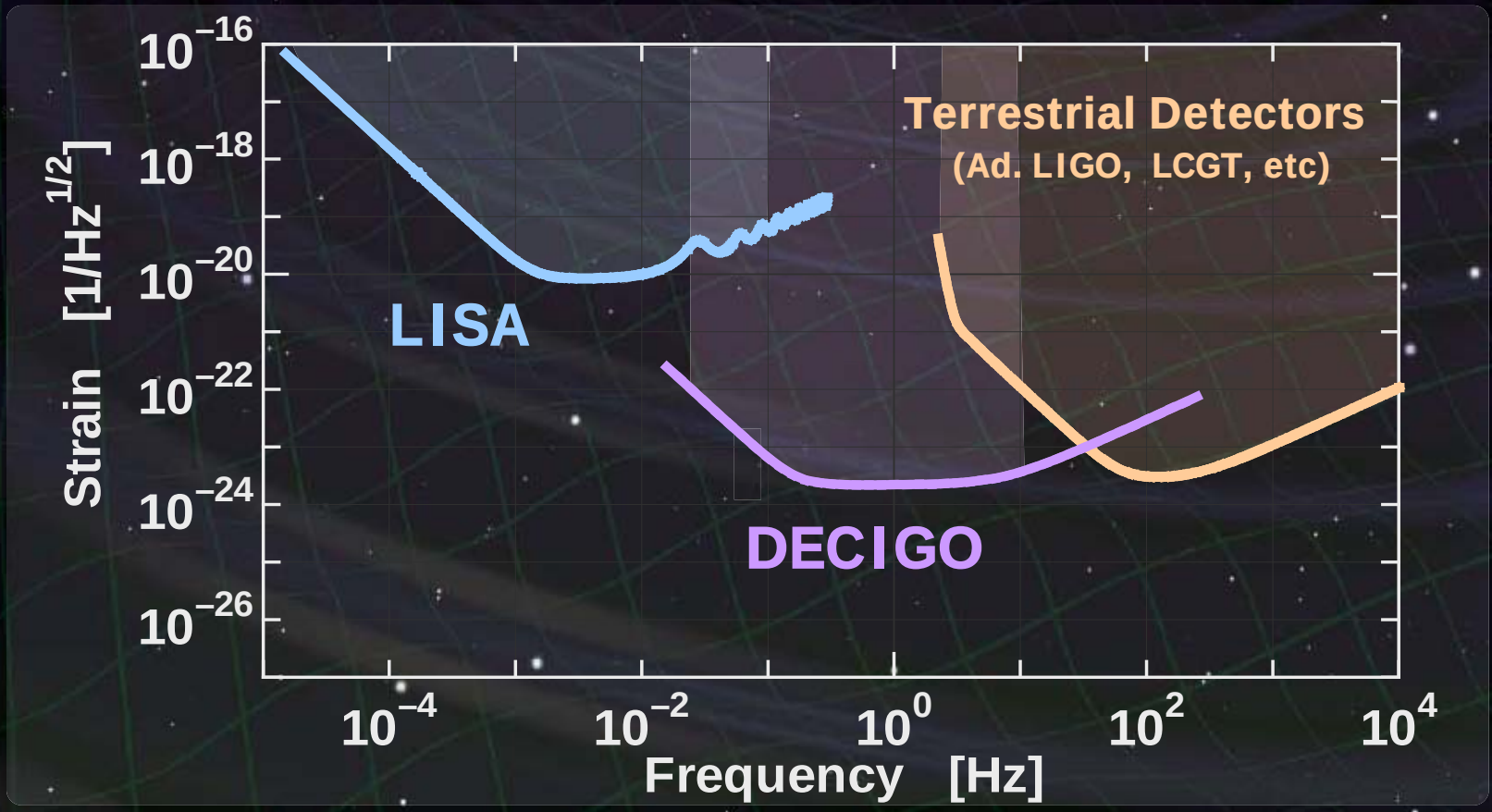
DECIGO

DECIGO (Deci-hertz interferometer Gravitational wave Observatory)

Space GW antenna (~2027)
Obs. band around 0.1 Hz

⇨ 'Bridge' the obs.gap between LISA and Terrestrial detectors

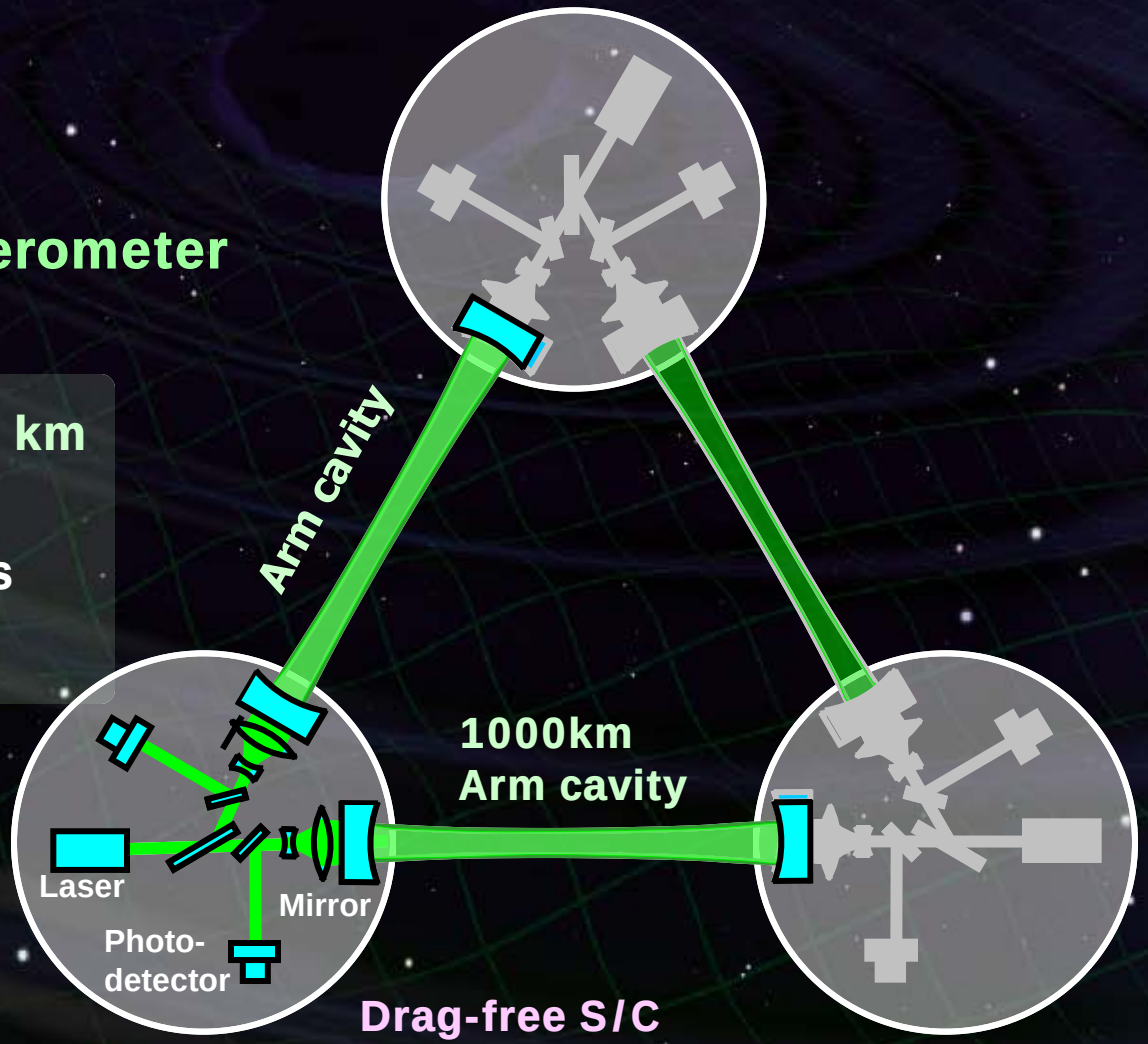


DECIGO Interferometer

Interferometer Unit:

Differential FP interferometer

Baseline length: 1000 km
3 S/C formation flight
3 FP interferometers
Drag-free control



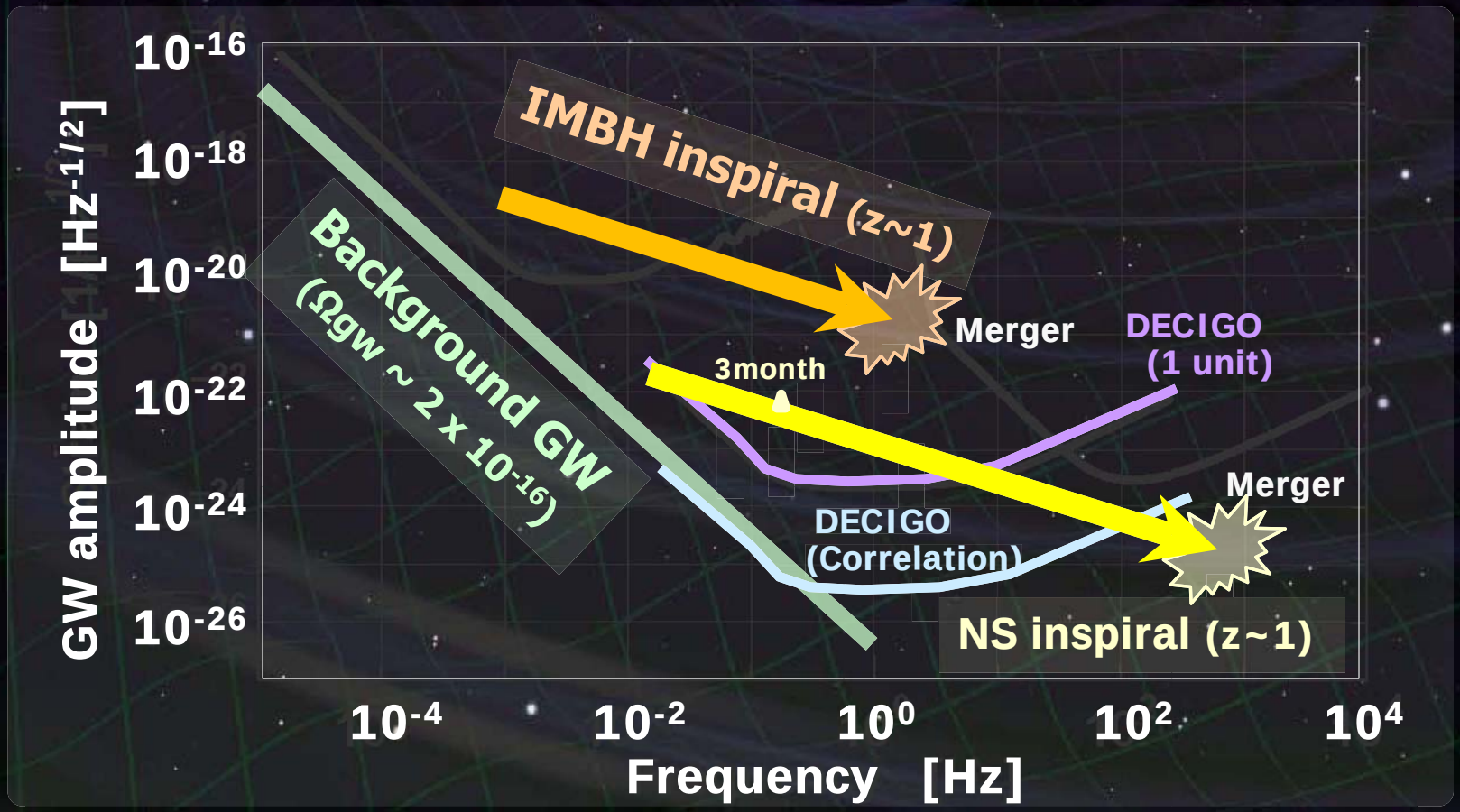
Targets and Science

DECIGO

IMBH binary inspiral
NS binary inspiral
Stochastic background

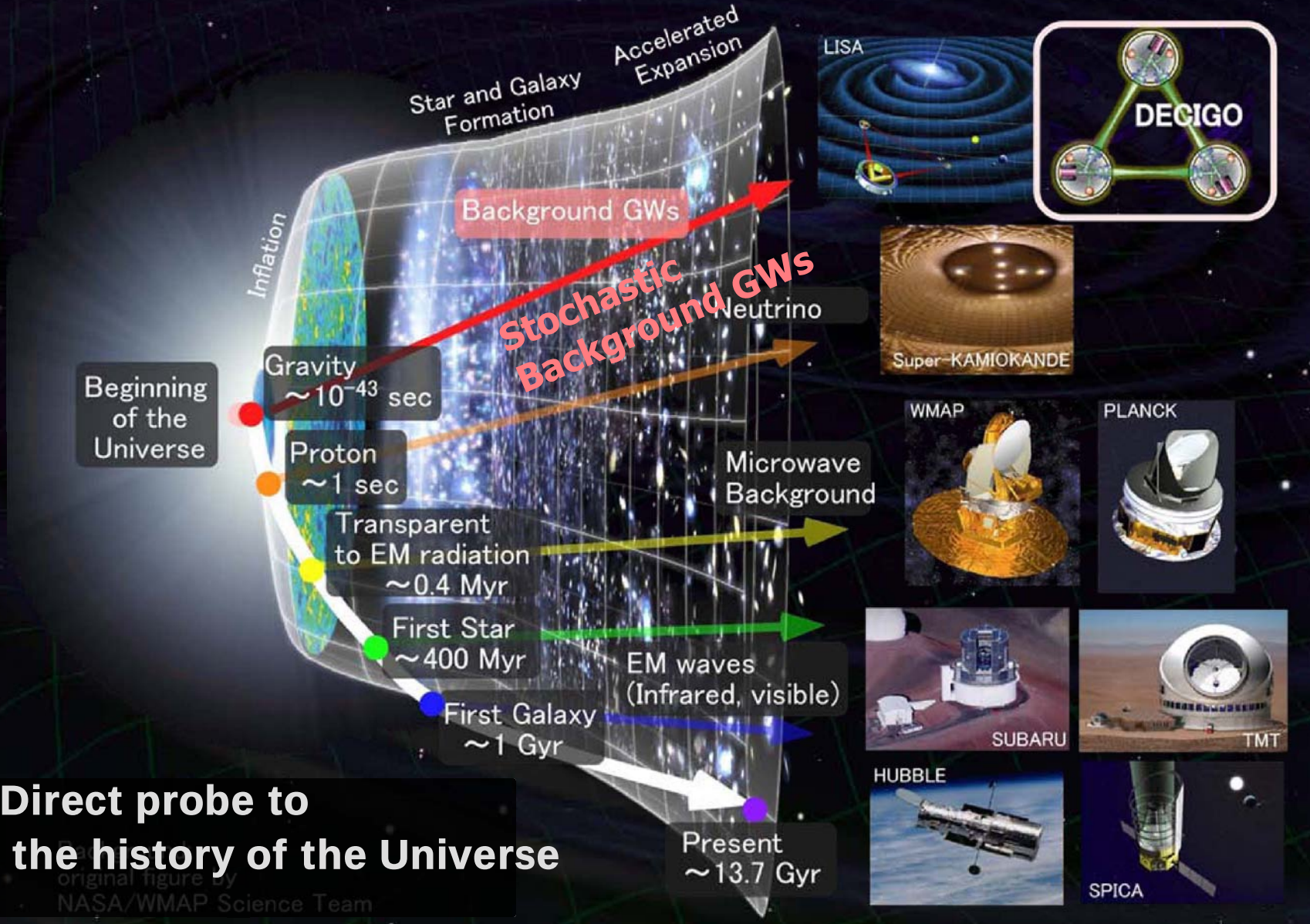
⇒

Galaxy formation (Massive BH)
Cosmology (Inflation, Dark energy)
Fundamental physics



Characterization of inflation

DECIGO



Direct probe to the history of the Universe

original figure by NASA/WMAP Science Team

Dark energy

DECIGO will observe

5×10^4 NS binaries for $z < 1$

↳ Precise 'clock' at cosmological distance

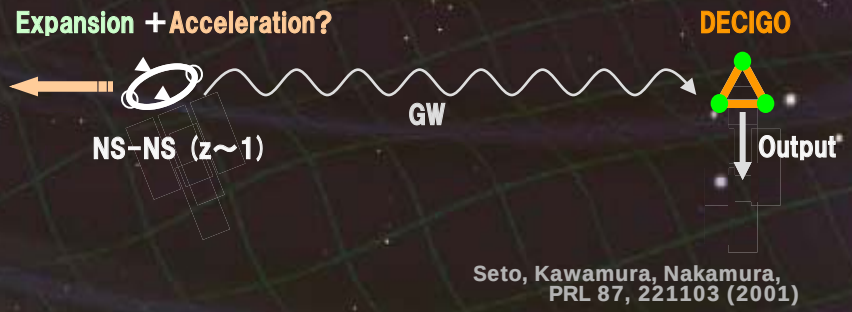
'Standard Siren'

Relationship between distance and redshift

Distance: chirp waveform

Redshift: host galaxy

→ Information on acceleration of expansion of the universe



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

Determine cosmological parameters

Absolute and independent measurement

Angular resolution

~10arcmin^2 (1 detector)

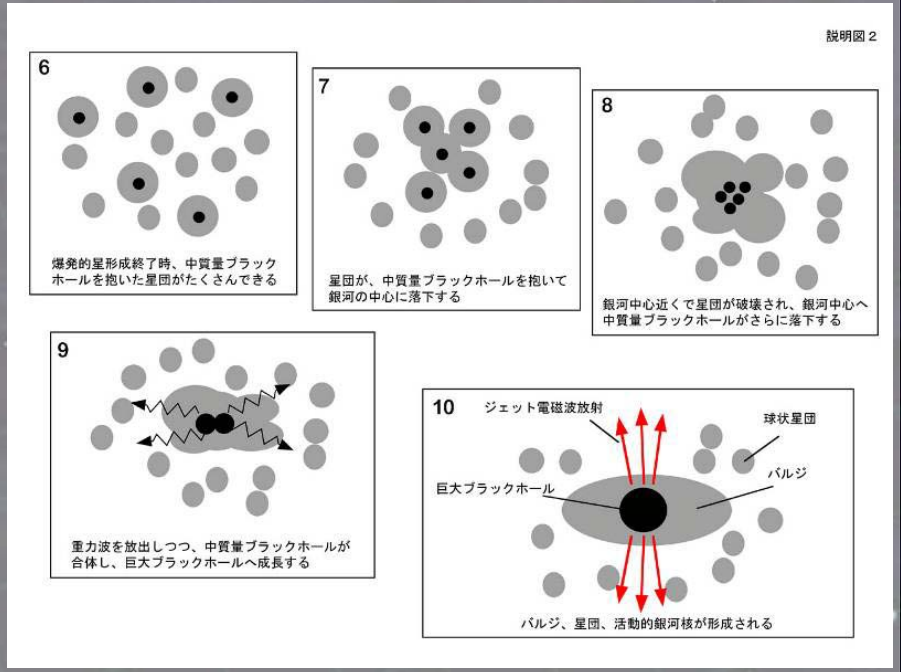
~10arcsec^2 (3 detectors)

at z=1

Galaxy formation

DECIGO will observe
Intermediate-mass BH (IMBH)
binary merger with
SNR>10^3 for z~10 source

Information on the
formation of
Supermassive BHs
at the center of galaxies



戎崎俊一(理化学研究所) 先生のwebページより引用
http://atlas.riken.go.jp/~ebisu/smbh.html

Astronomy and Cosmology

DECIGO

- **Verification of the alternative theories of gravity**
  Test Brans-Dicke theory by NS/BH binary evolution
  → Stronger constraint by 10^4 times

  K. Yagi and T. Tanaka, Prog. Theor. Phys. 123, 1069 (2010)

- **Black hole dark matter**
  Gravitational collapse of the primordial density fluctuations
  → Primordial black holes (PBHs)
  as a candidate of dark matter

  R. Saito and J. Yokoyama, Phys. Rev. Lett. 102 161101 (2009)

- **Neutron-star physics**
  Determine mass of 10^5 NSs per year
  → Constrain the EOS of NS
  Formation process of NS from the spectrum

1. DECIGO

Overview and Science

Pre-conceptual Design

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Pre-Conceptual Design

DECIGO

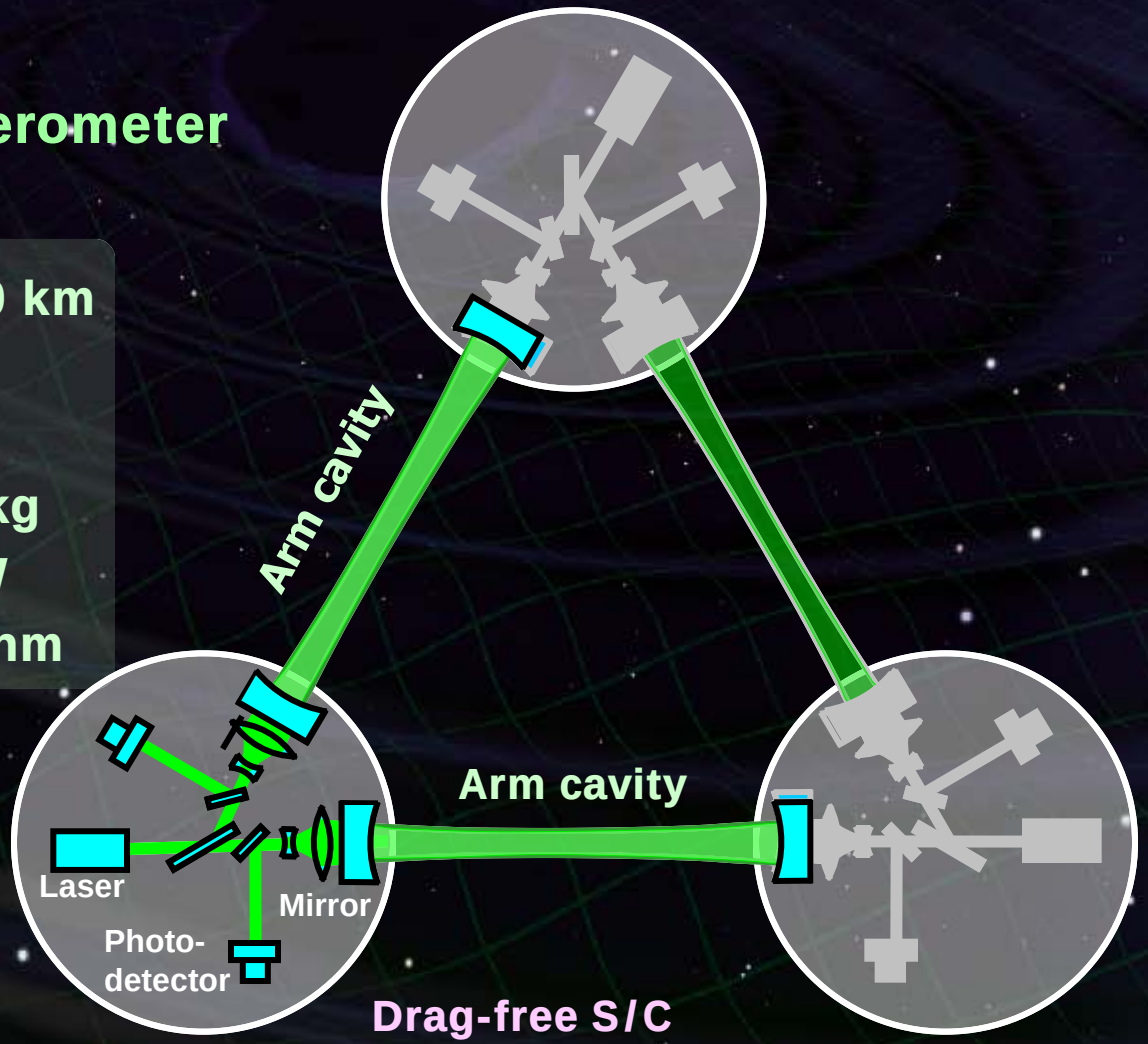
Interferometer Unit:

Differential FP interferometer

Arm length:	1000 km
Finesse:	10
Mirror diameter:	1 m
Mirror mass:	100 kg
Laser power:	10 W
Laser wavelength:	532 nm

S/C: drag free

3 interferometers



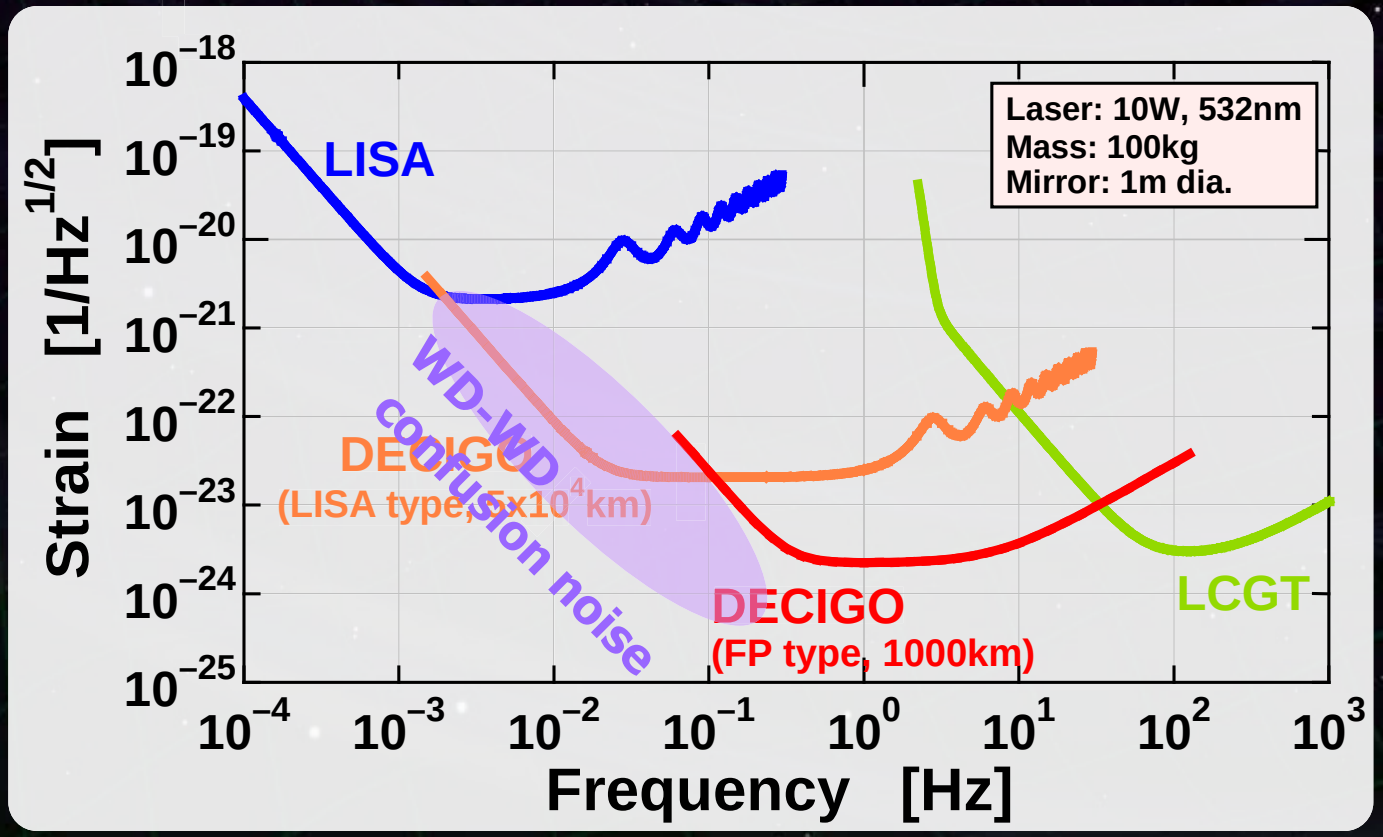
Interferometer Design

DECIGO

Transponder type vs Direct-reflection type

Compare : Sensitivity curves and Expected Sciences

Decisive factor: Binary confusion noise



Arm length

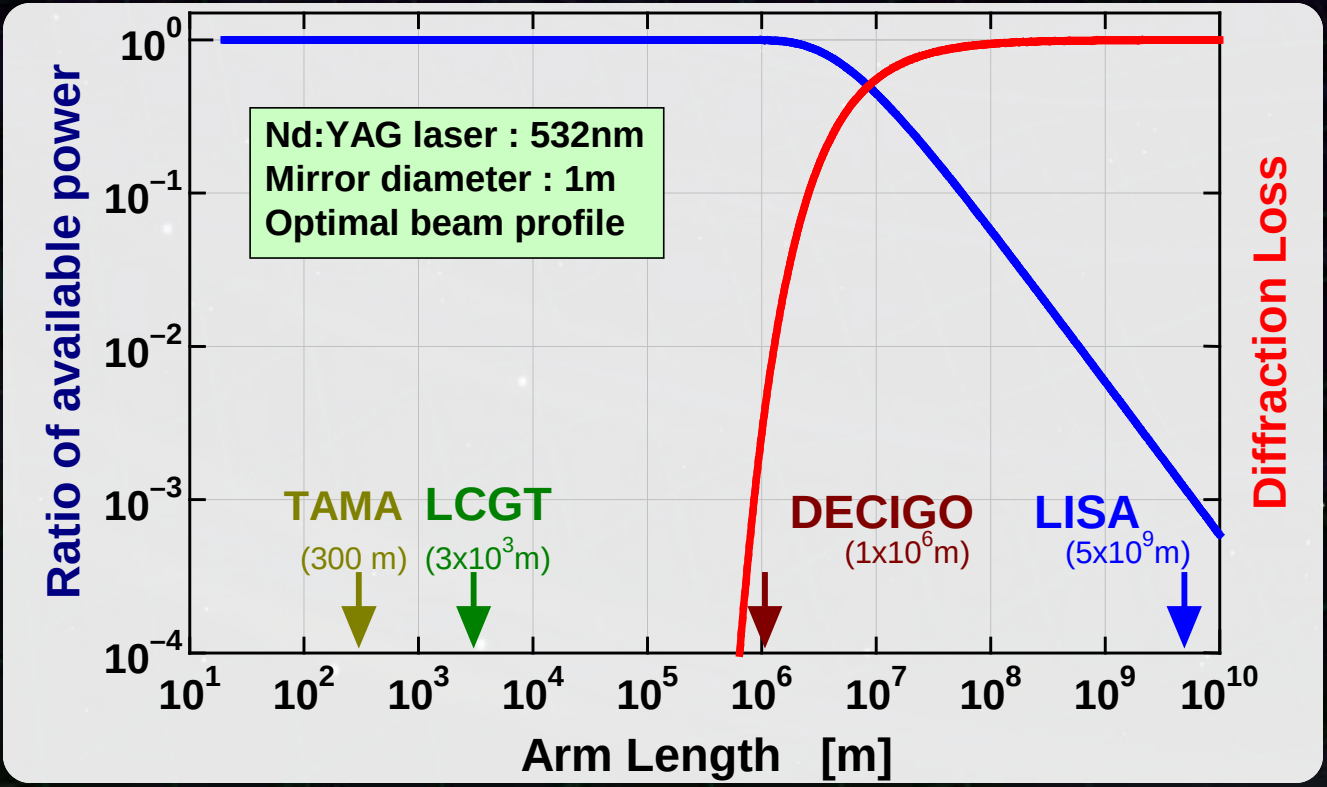
DECIGO

Cavity arm length : Limited by diffraction loss

Effective reflectivity ($TEM_{00} \rightarrow TEM_{00}$)

- Laser wavelength : 532nm
- Mirror diameter: 1m
- Optimal beam size

→ **1000 km is almost max.**



Foreground Cleaning

DECIGO obs. band: free from WD binary foreground
→ Open for cosmological observation

DECIGO will watch
~ 10^5 NS binaries

⇨ Foreground for GWB

In principle, possible
to remove them.

Require accurate waveform
→ $\Delta m/m < \sim 10^{-7}$ %

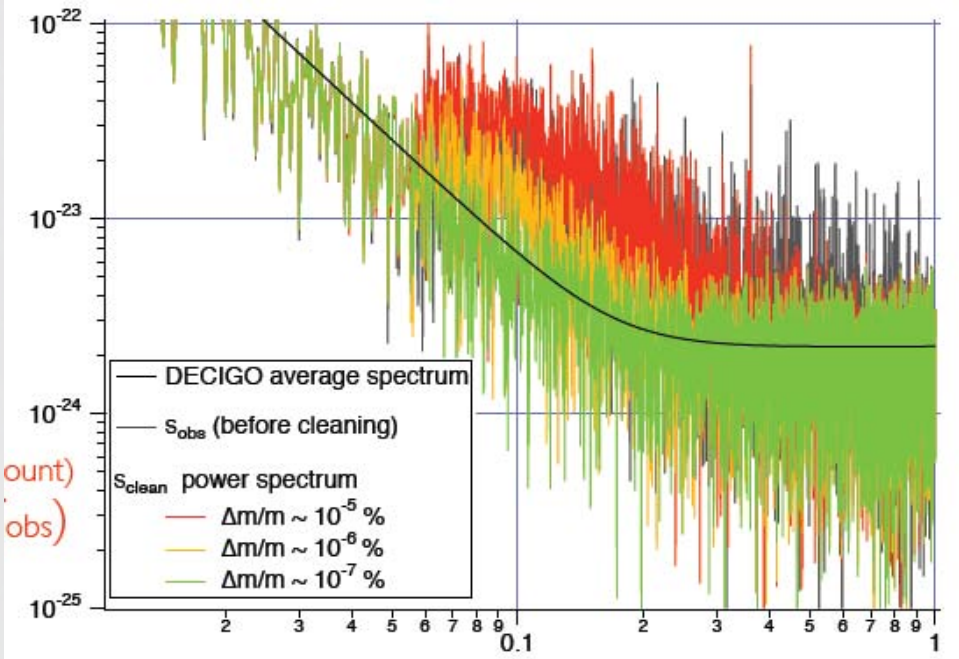


Fig: N. Kanda

Cavity and S/C control

DECIGO

Cavity length change

PDH error signal → Mirror position (and Laser frequency)

Relative motion between mirror and S/C

Local sensor → S/C thruster

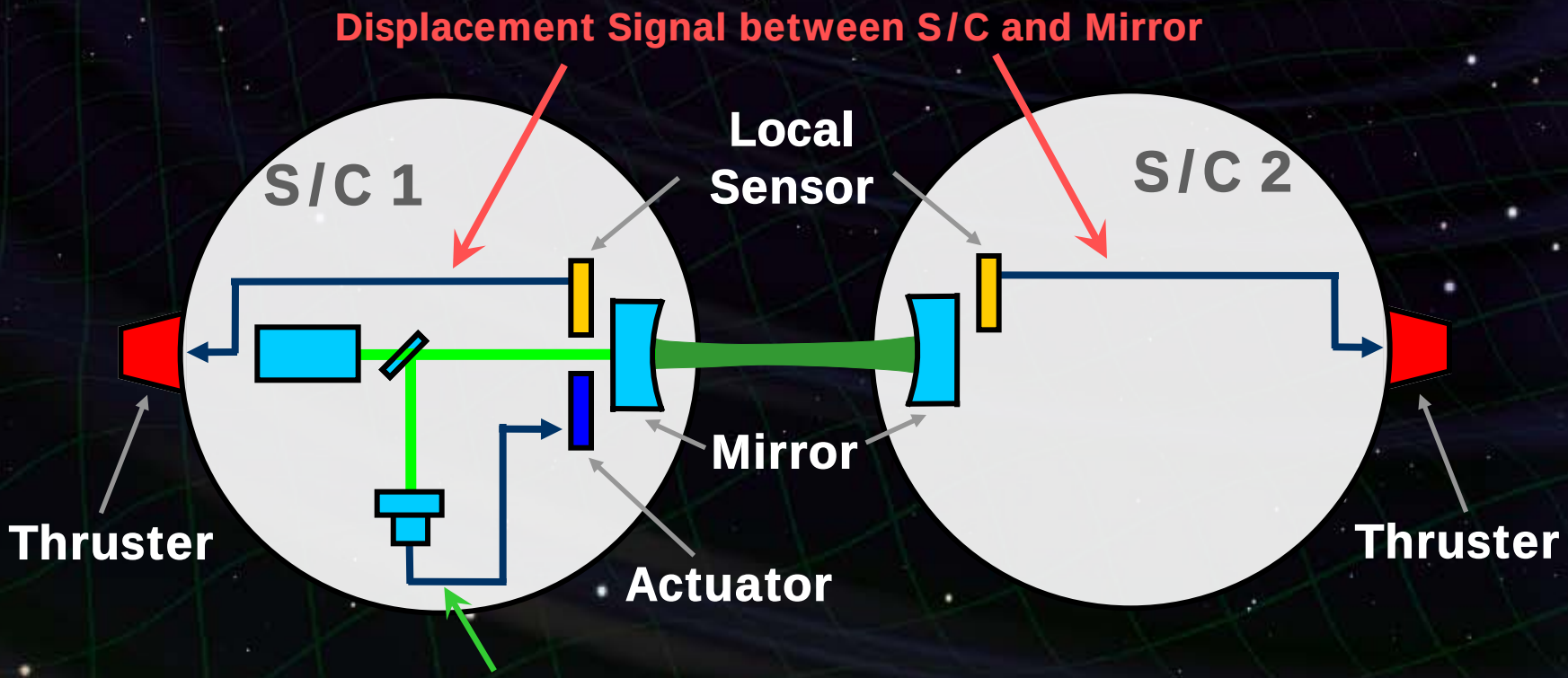


Fig: S. Kawamura

Requirements

DECIGO

Sensor Noise

Shot noise 3×10^{-18} m/Hz$^{1/2}$ (0.1 Hz)

⇨ x 10 of LCGT in phase noise

Other noises should be well below the shot noise

Laser freq. noise: 1 Hz/Hz$^{1/2}$ (1Hz)

Stab. Gain 10^5, CMRR 10^5

Acceleration Noise

Force noise 4×10^{-17} N/Hz$^{1/2}$ (0.1 Hz)

⇨ x 1/50 of LISA

External force sources

Fluctuation of magnetic field, electric field, gravitational field, temperature, pressure, etc.

Orbit and Constellation

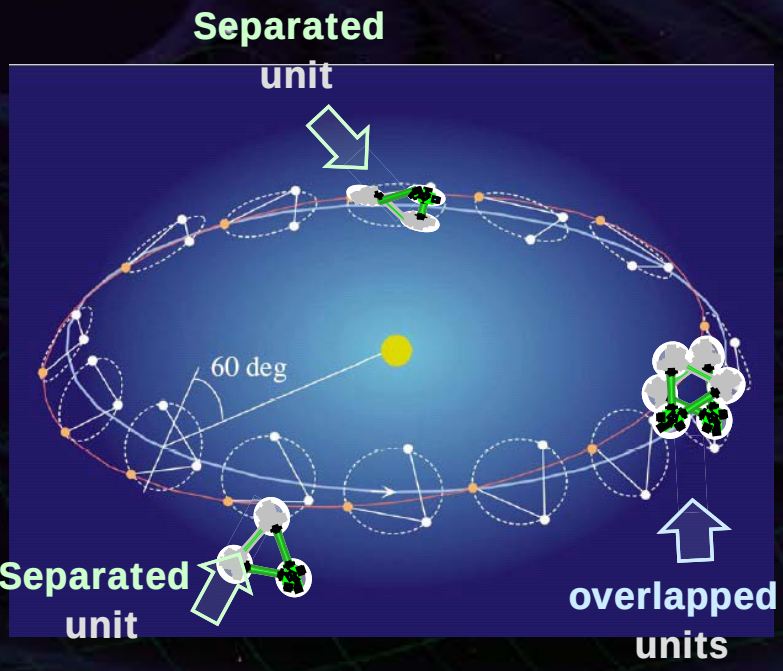
DECIGO

Candidate of orbit:

Record-disk orbit around the Sun

Relative acc. 4×10^{-12} m/s^2

(Mirror force ~10^{-9} N)



Constellation

4 interferometer units

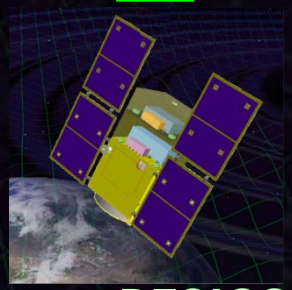
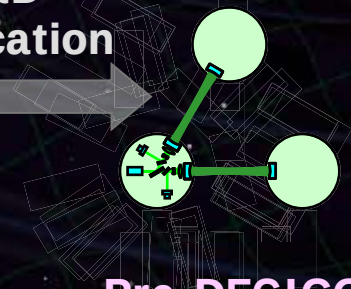
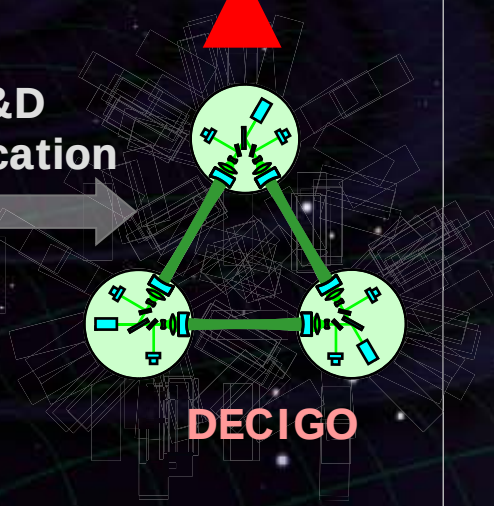
2 overlapped units → Cross correlation

2 separated units → Angular resolution

Roadmap

DECIGO

Figure: S.Kawamura

	2010 11 12 13 14 15 16	17 18 19 20 21 22	23 24 25 26 27 28 29
Mission	R&D Fabrication →  SDS-1/SWIM	R&D Fabrication →  DECIGO Pathfinder (DPF)	R&D Fabrication →  Pre-DECIGO →  DECIGO
Objective	Space test of key tech. GW observation	Detect GW with min. spec FP between S/C	GW astronomy
Design	Single small satellite Short FP interferometer	3 S/C 1 interferometer unit	3 S/C x 3-4 units

Organization

DECIGO

PI: Kawamura (NAOJ)
Deputy: Ando (Kyoto)

Executive Committee
Kawamura (NAOJ), Ando (Kyoto), Seto (Kyoto), Nakamura (Kyoto), Tsubono (Tokyo), Tanaka (Kyoto), Funaki (ISAS), Numata (Maryland), Sato (Hosei), Kanda (Osaka city), Takashima (ISAS), Ioka (KEK), Yokoyama (Tokyo)

Pre-DECIGO
Sato (Hosei)

Detector
Akutsu (NAOJ)
Numata (Maryland)

Science, Data
Tanaka (Kyoto)
Seto (Kyoto)
Kanda (Osaka city)

Satellite
Funaki (ISAS)

Design phase

DECIGO pathfinder
Leader: Ando (Kyoto)

Mission phase

Detector
Sato (Hosei)
Ueda (NAOJ)
Aso (Tokyo)

Laser
Musha (ILS)
Ueda (ILS)

Drag free
Moriwaki (Tokyo)
Sakai (ISAS)

Thruster
Funaki (ISAS)

Bus
Takashima (ISAS)

Data
Kanda (Osaka city)

Collaboration and support

- Supports from LISA
  - Technical advices from LISA/LPF experiences
  - Support Letter for DECIGO/DPF, Joint workshop (2008.11)
- Collab. with Stanford univ. group
  - Drag-free control of DECIGO/DPF
  - UV LED Charge Management System for DPF
- Collab. with NASA/GSFC
  - Fiber Laser , started discussion
- Collab. with JAXA navigation-control section
  - → formation flight of DECIGO, DPF drag-free control
- Research Center for the Early Universe (RESCEU), Univ. of Tokyo
  - Support DECIGO as ones of main projects (2009.4-)
- Advanced technology center (ATC) of NAOJ
  - Will make it a main nucleus of DPF

LCGT and DECIGO

LCGT (~2016)

Terrestrial Detector

→ High frequency events

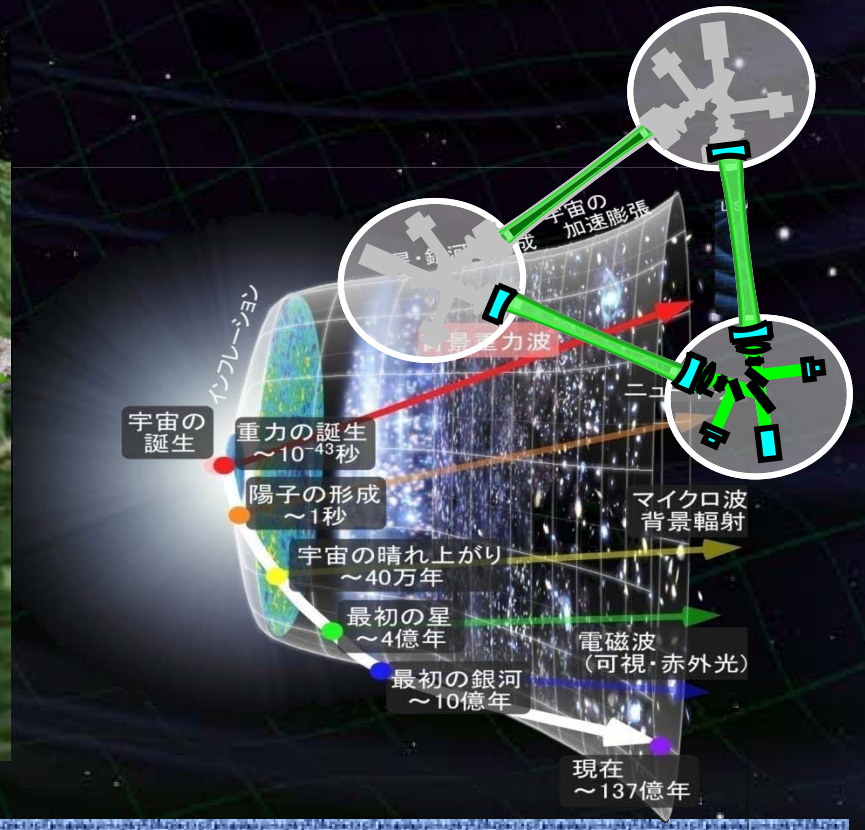
Target: GW detection

DECIGO (~2027)

Space observatory

→ Low frequency sources

Target: GW astronomy



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Roadmap

DECIGO

Figure: S.Kawamura

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DECIGO-PF

DECIGO Pathfinder (DPF)

- First milestone mission for DECIGO
- Shrink arm cavity
  - DECIGO 1000km → DPF 30cm

Single satellite
(Payload ~1m^3 , 350kg)

Low-earth orbit
(Altitude 500km, sun synchronous)

30cm FP cavity with 2 test masses

Stabilized laser source

Drag-free control

DPF satellite

DECIGO

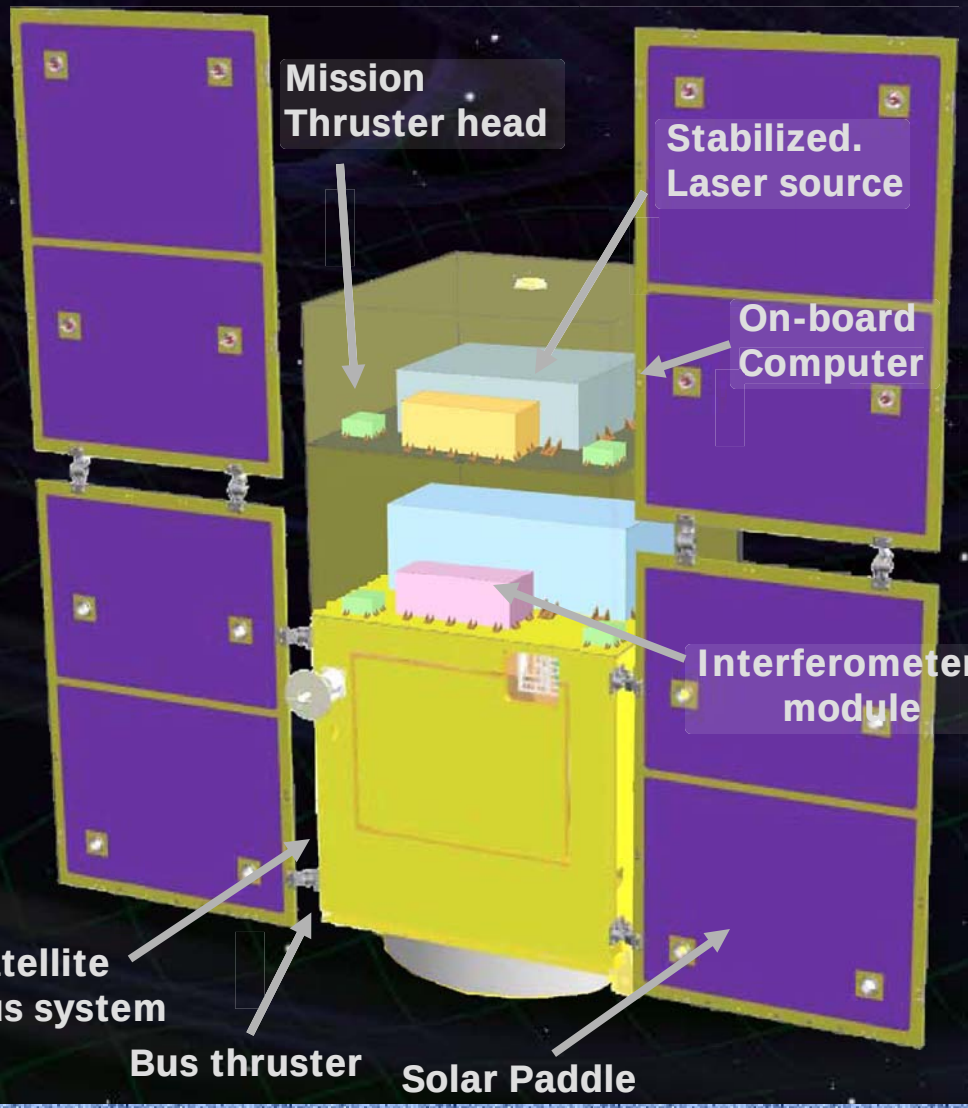
DPF Payload

Size : 950mm cube
Weight : 150kg
Power : 130W
Data Rate: 800kbps
Mission thruster x12

Power Supply
SpW Comm.

Satellite Bus

('Standard bus' system)
Size :
950x950x1100mm
Weight : 200kg
SAP : 960W
Battery: 50AH
Downlink : 2Mpbs
DR: 1GByte
3N Thrusters x 4

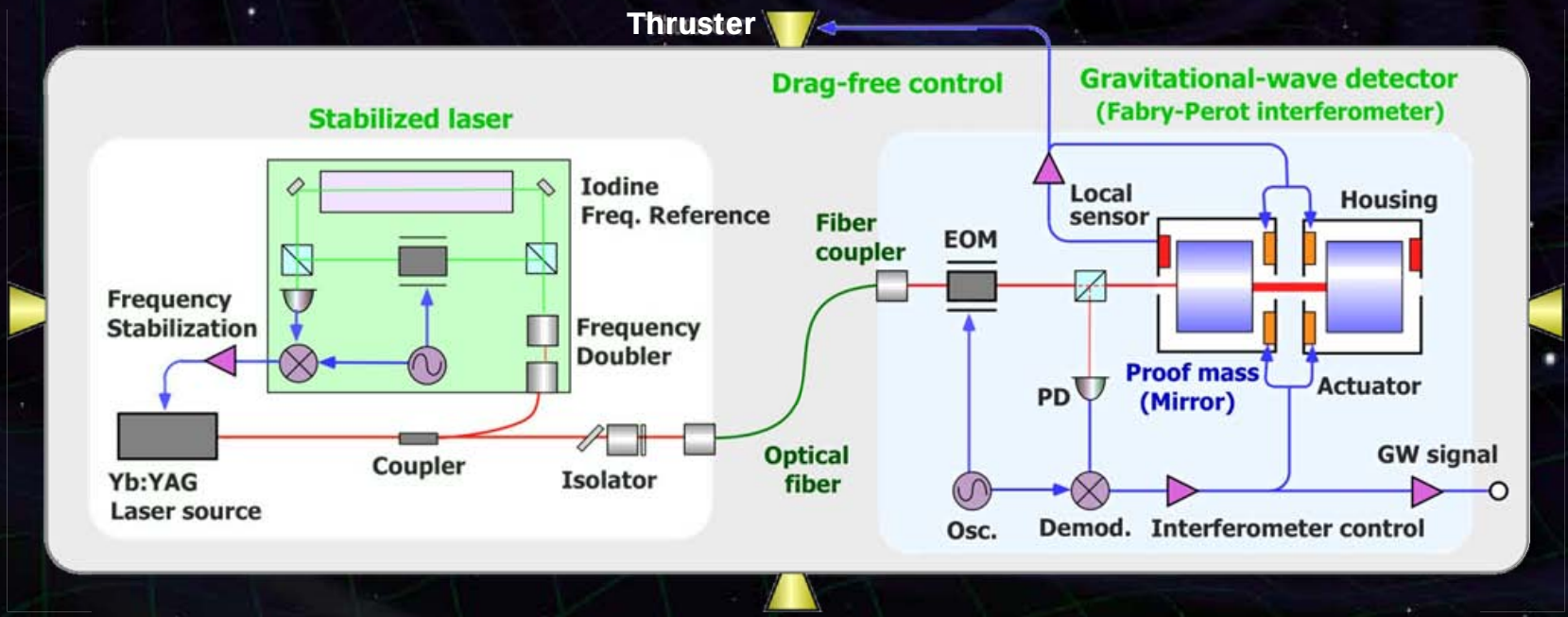


DPF mission payload

DECIGO

Mission weight : ~150kg
Mission space : ~95 x 95 x 90 cm

Drag-free control
Local sensor signal
→ Feedback to thrusters



Laser source
Yb:YAG laser (1030nm)
Power : 25mW
Freq. stab. by Iodine abs. line

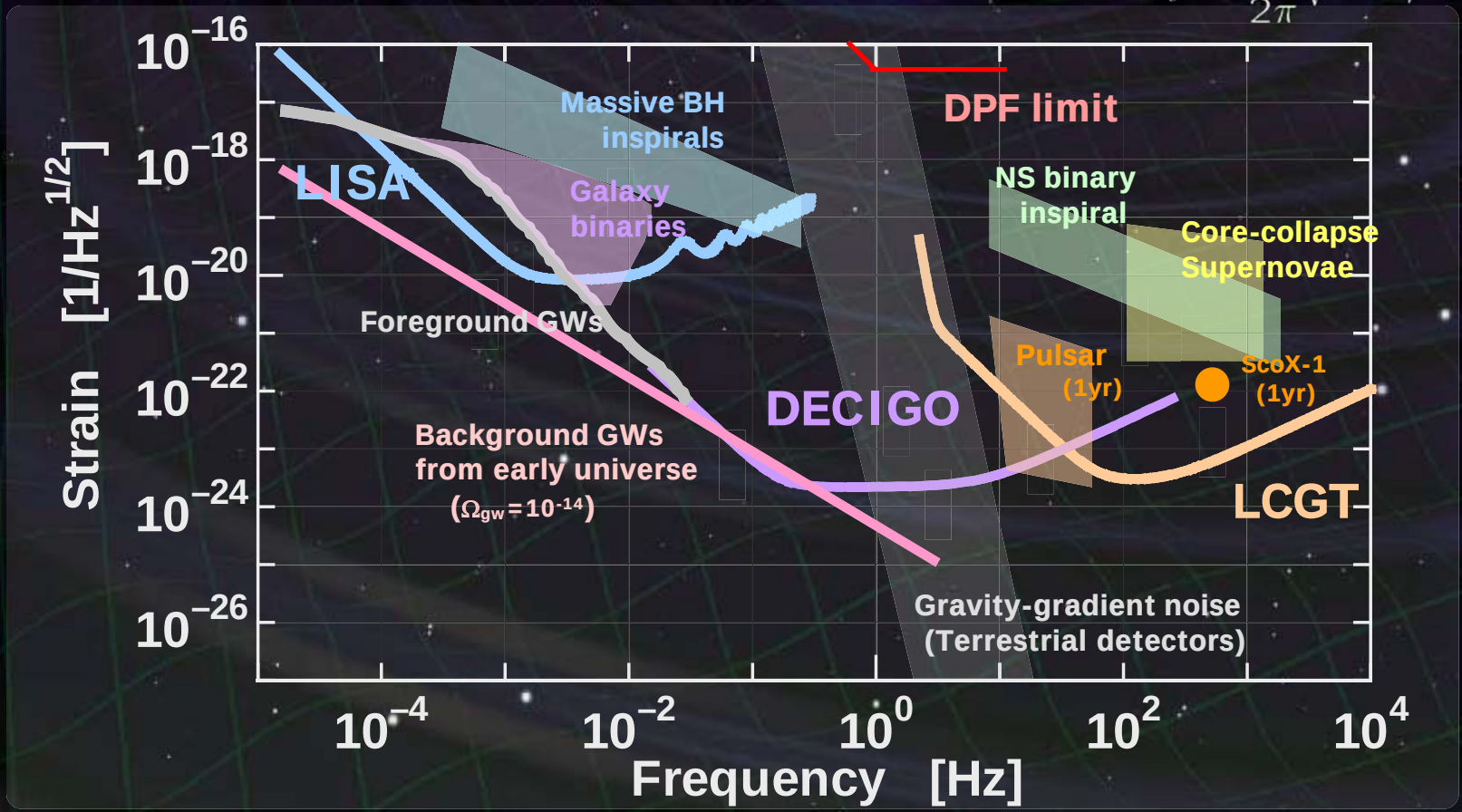
Fabry-Perot interferometer
Finesse : 100
Length : 30cm
Test mass : ~1kg
Signal extraction by PDH

DPF sensitivity

DPF sensitivity $h \sim 2\times10^{-15}\ \mathrm{Hz}^{1/2}$

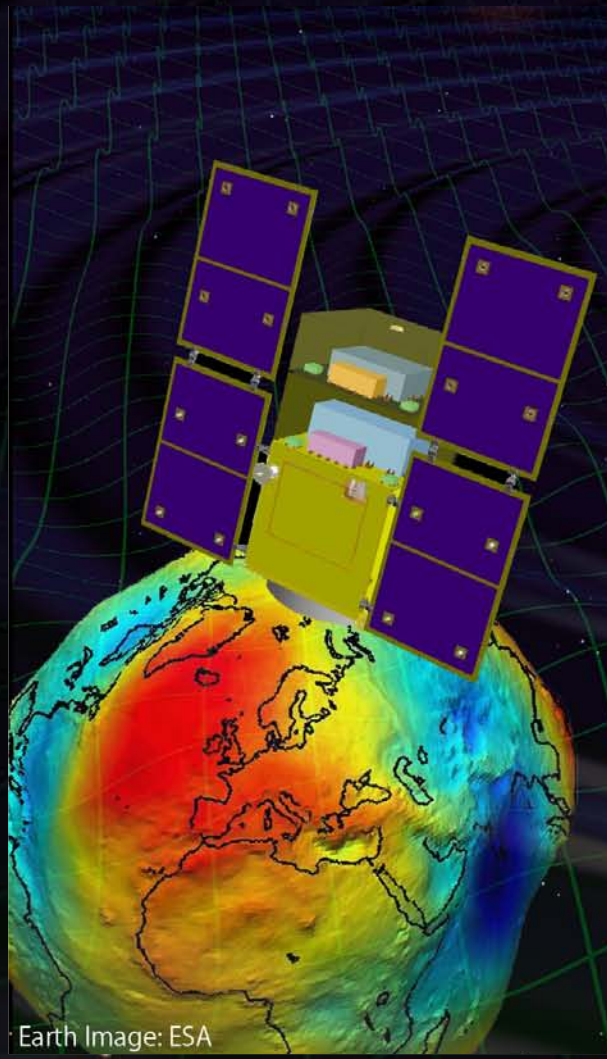
(x10 of quantum noises)

$$f \sim \frac{1}{2\pi}\sqrt{GM/R^3}$$



Targets of DPF

DECIGO



Scientific observations

Gravitational Waves form BH mergers

→ BH formation mechanism

Gravity of the Earth

→ Geophysics, Earth environment

Science technology

Space demonstration for DECIGO

→ Most tech. with single satellite

(IFO, Laser, Drag-free)

Precision measurement in orbit

→ IFO measurement

under stable zero-gravity

DPF Targets

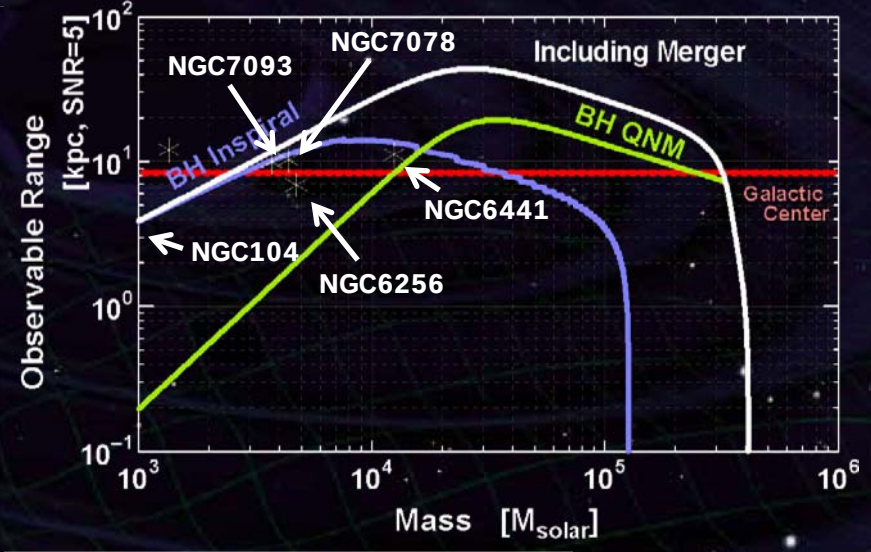
DECIGO

Astronomical observation

GW from merger of IMBHs

→ Formation mechanism of supermassive BHs

~30 GCs within DPF range

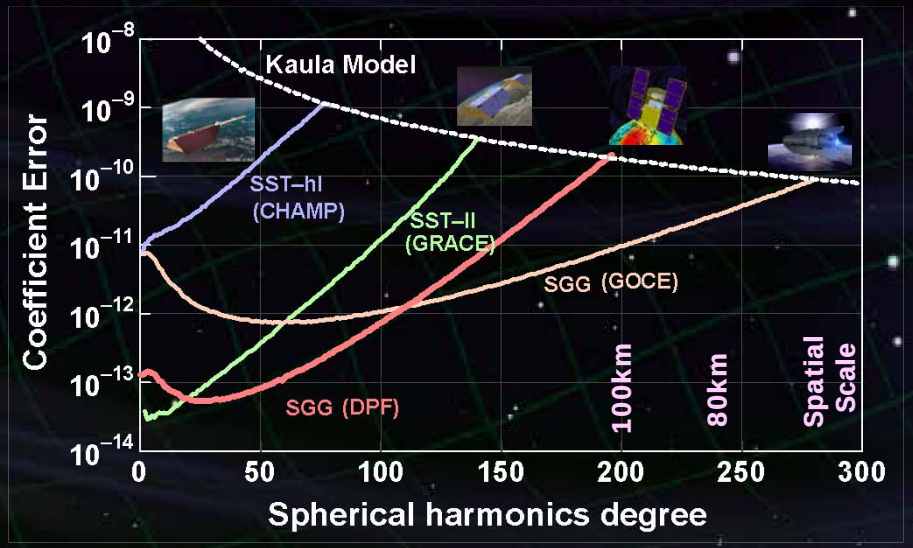


Observation of the earth

Gravitational potential

→ Shape of the earth Environment monitor

Comparable sensitivity with other missions



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DPF mission status

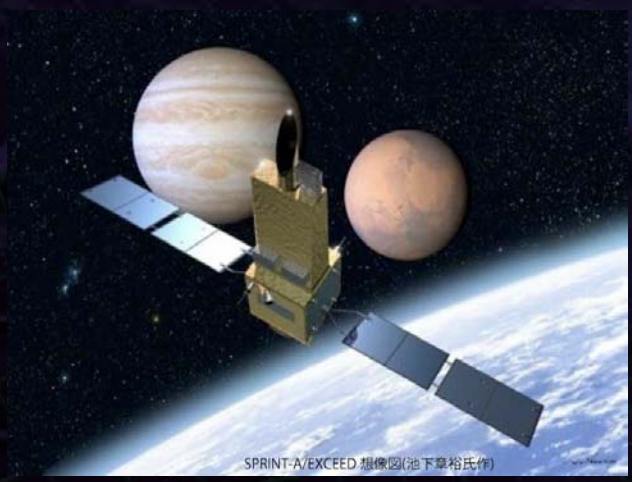
DECIGO

DPF : One of the candidate of
JAXA's small satellite series

At least 3 satellite in 5 years with
Standard Bus + M-V follow-on rocket

1st mission (2012): SPRINT-A/EXCEED
2nd mission (~2013/14) : ERG
DPF survived until final two
3rd mission (~2015/16) : TBD

DPF is one of the strongest candidates of the 3rd mission



SPRINT-A /EXCEED
UV telescope mission

Next-generation
Solid rocket booster (M-V FO)
Fig. by JAXA

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DECIGO

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SWIM launch and operation

DECIGO

Tiny GW detector module
Launched in Jan. 23, 2009

⇨ **In-orbit operation**

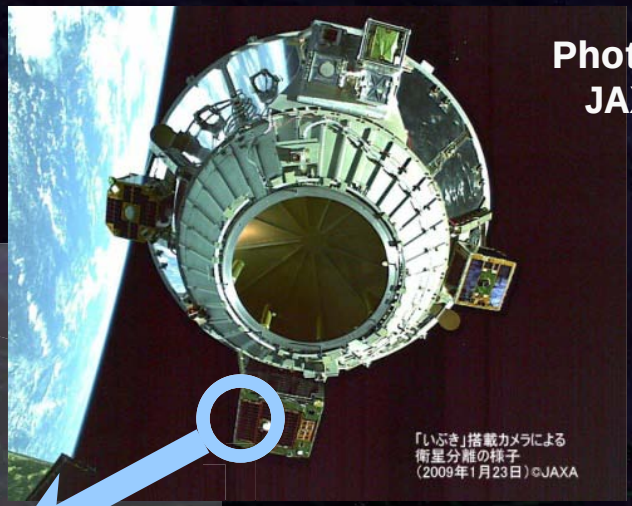


Photo: JAXA

TAM: Torsion Antenna Module with free-falling test mass
(Size : 80mm cube, Weight : ~500g)

Test mass

~47g Aluminum, Surface polished
Small magnets for position control

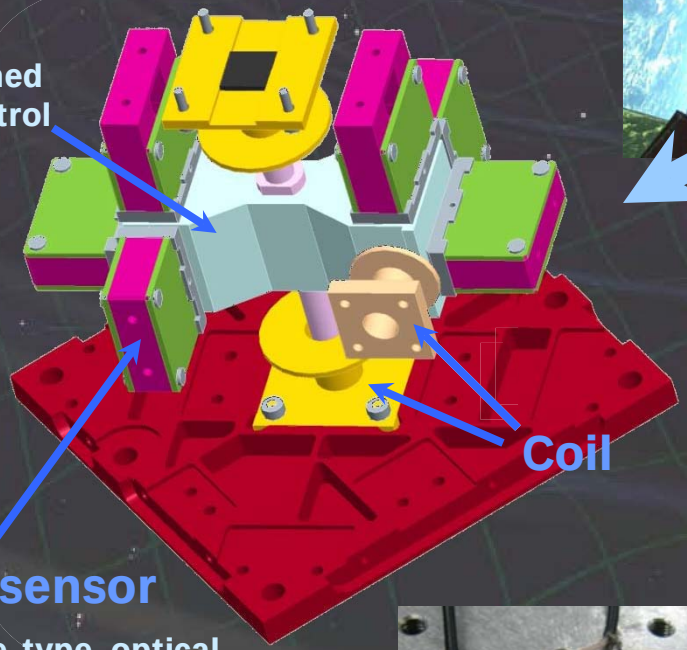
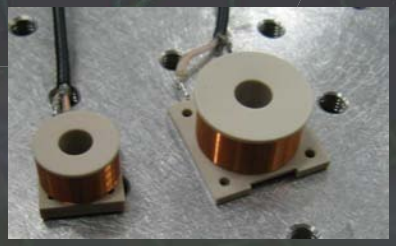


Photo sensor

Reflective-type optical
displacement sensor
Separation to mass ~1mm
Sensitivity ~ 10^{-9} m/$Hz^{1/2}$
6 PSs to monitor mass motion



SWIM observation

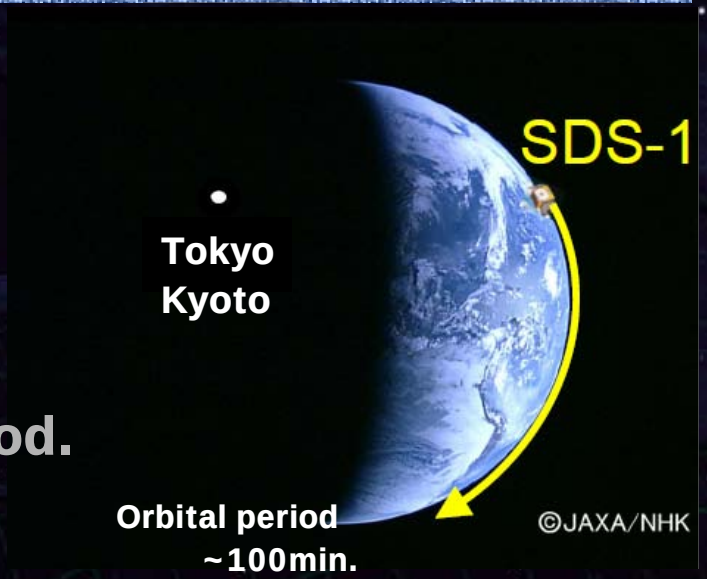
DECIGO

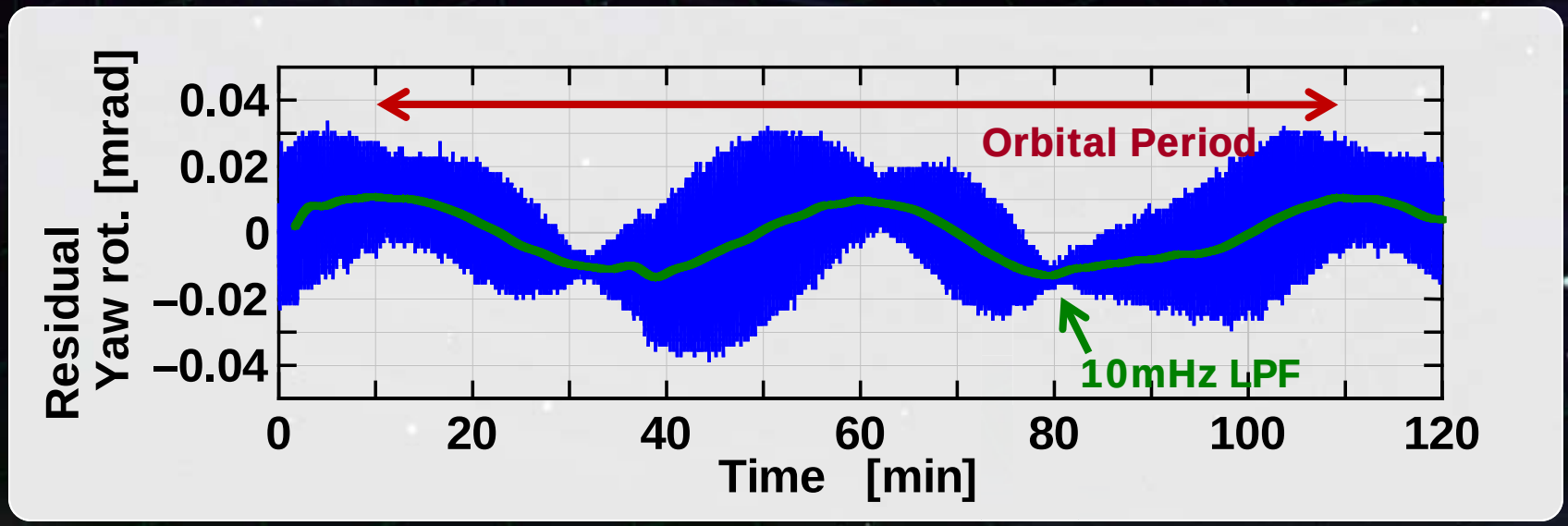
Observation by SWIM

Jun 17, 2010 ~120 min. operation
July 15, 2010 ~240 min. operation

Ground-based detectors were operated at the same period.

⇨ Data analysis





Supplementary topic

TOBA : Torsion-Bar Antenna

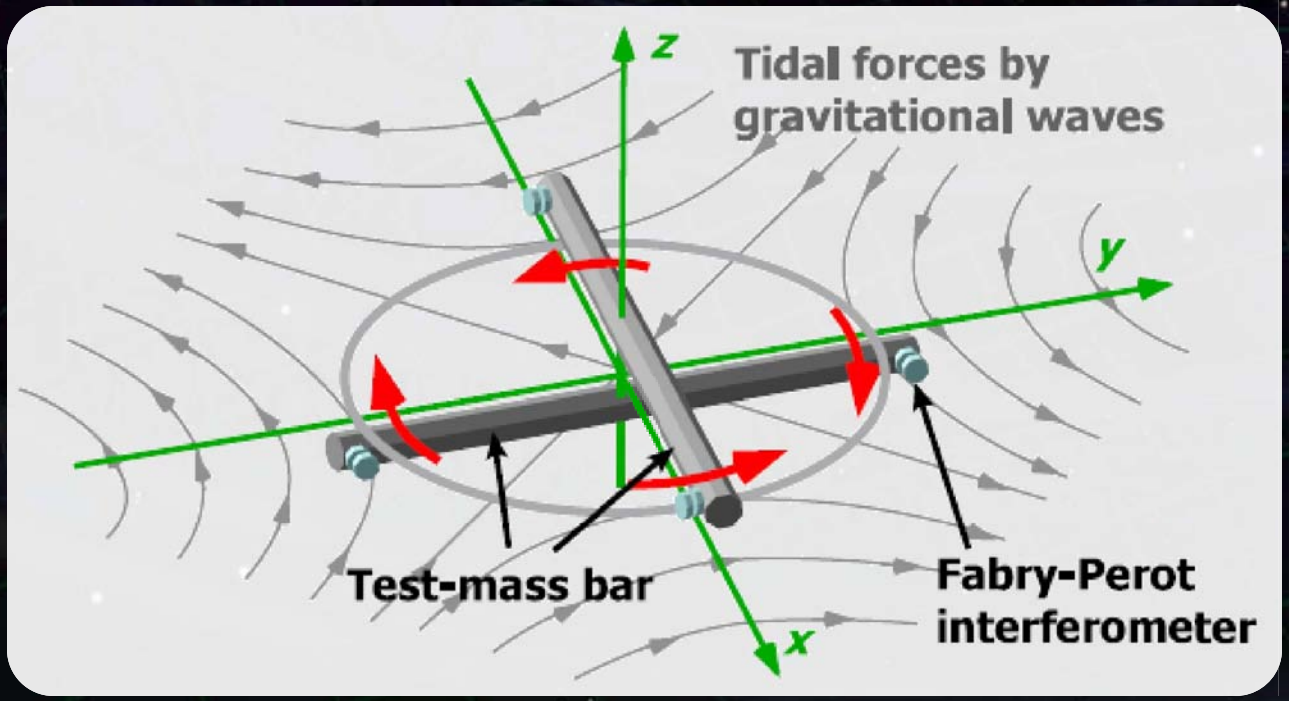
Two test-mass bars

Monitor differential angular fluctuation

⇒

Sensitive to low-freq. GWs even with ground-based config.

Much better in space



Current Issue!

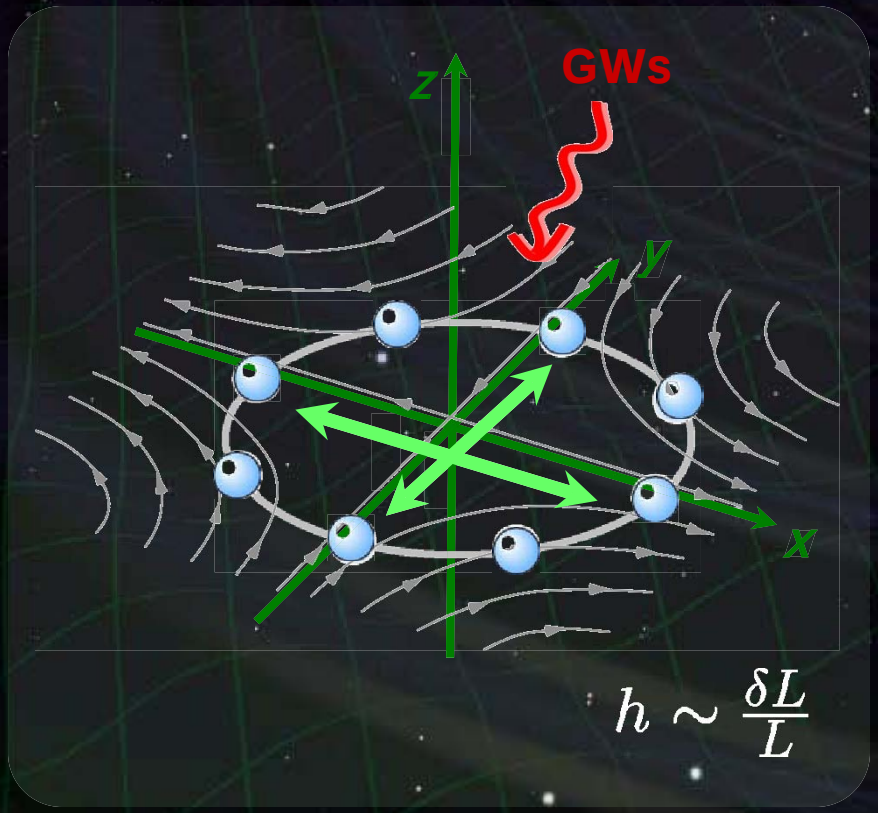
M.Ando, et. al, Phys. Rev. Lett. 105, 161101 (2010)

Strain and Torsion

DECIGO

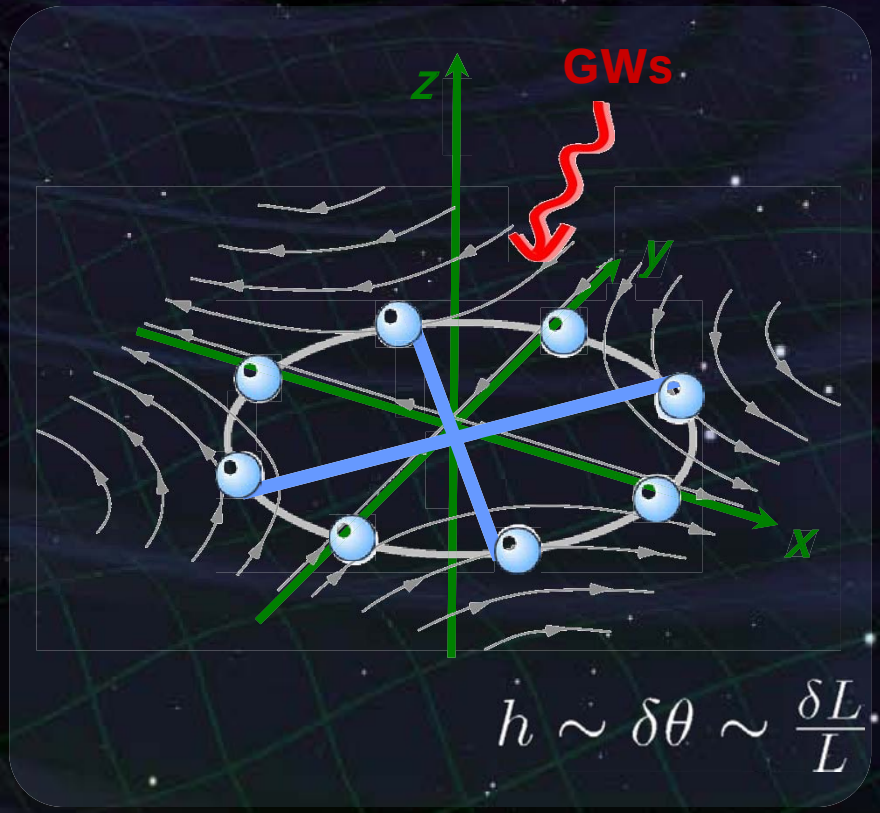
Conventional IFO antenna

Detect differential length change



Torsion-bar antenna

Detect differential rotation



Observe change in tidal forces using free test masses

Advantages

DECIGO

Conventional IFO

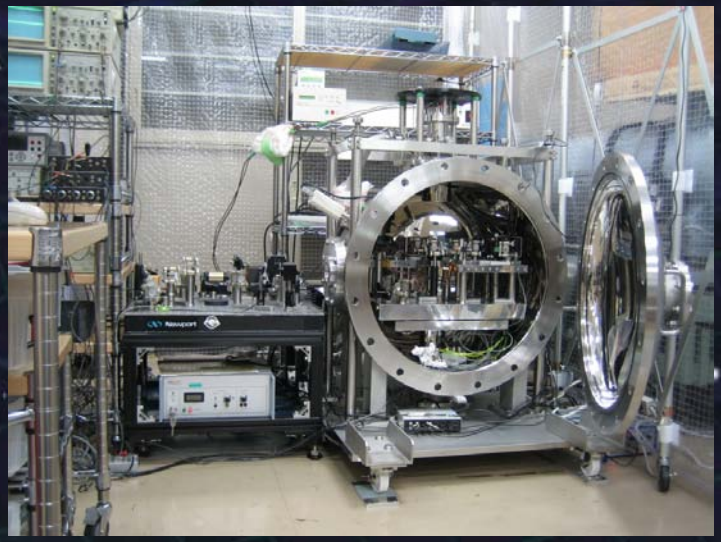
Obs. band 10Hz-1kHz

Suspended as pendulum
(Res. Freq. ~1Hz)

Long baseline
→Accumulation of signal,
High sensitivity

TOBA

Obs. band 10mHz-1Hz



Torsion pendulum
(Res. freq ~1mHz)

Shorter length
→ Simple config.
Common-mode rejection

TOBA Sensitivity

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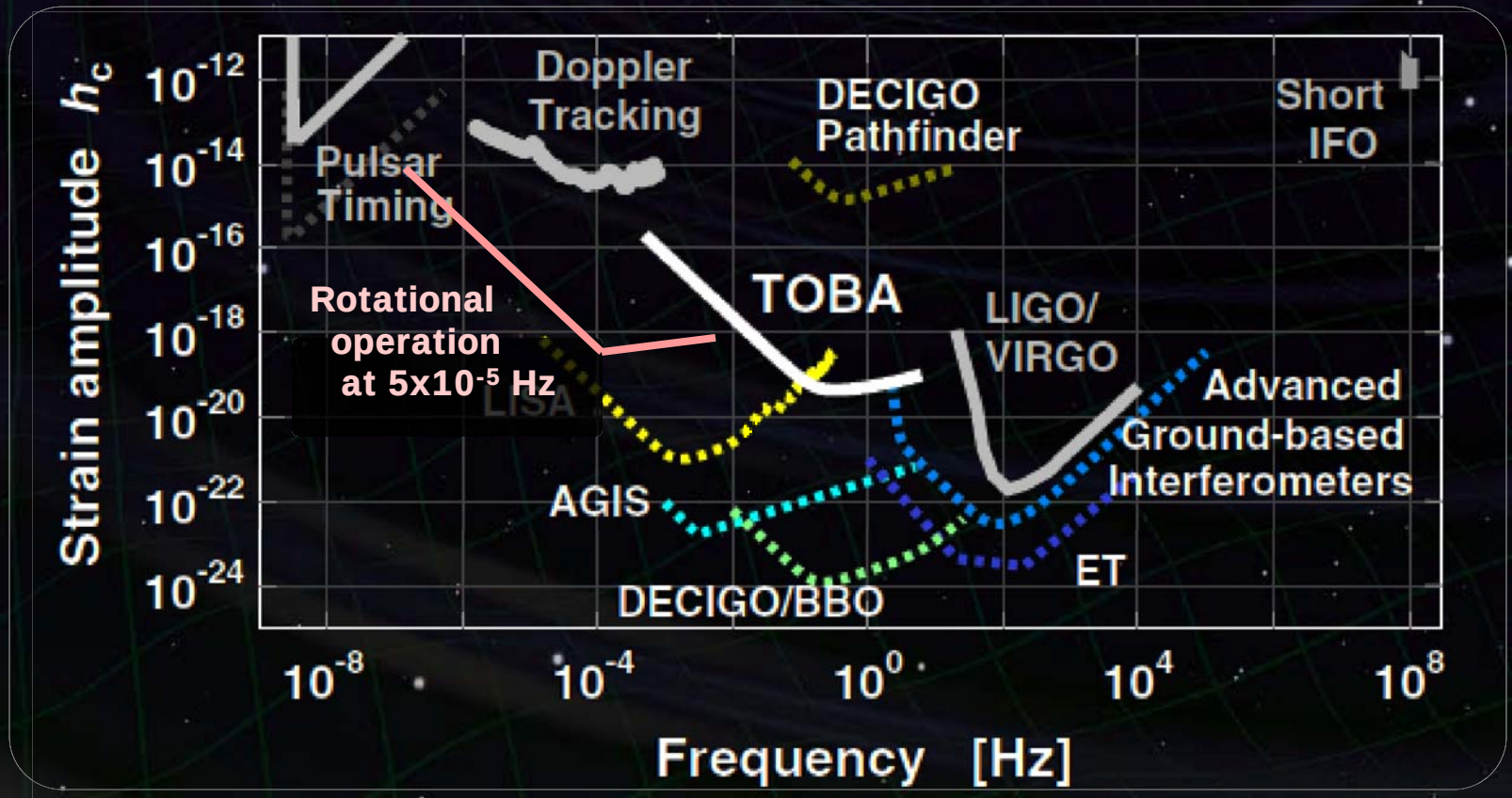
Assume realistic parameters

Test mass Aluminum 7,600kg, 10m

Laser source 10W

Temperature 4K

Bar length : 10m, Mass : 7600kg
Laser source : 1064nm, 10W
Cavity length : 1cm, Finesse : 100
Bar Q-value : 10^5 , Temp: 4K
Support Loss : 10^{-10}



Observable range

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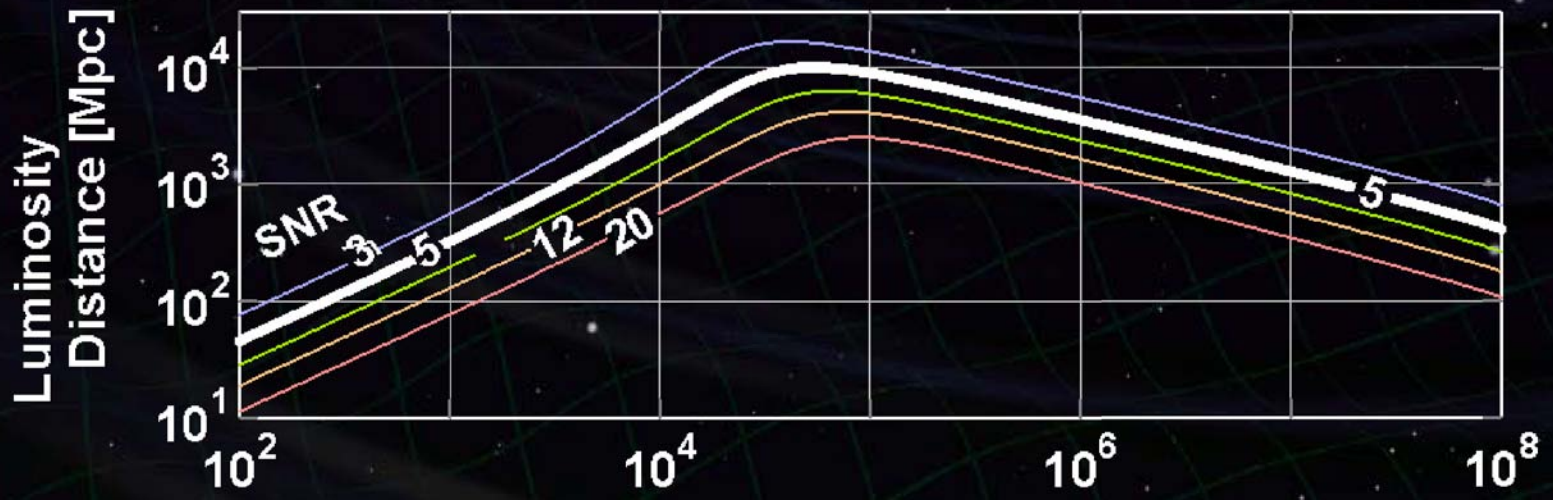
GWs from binary BH mergers

Obs. Range ~10Gpc ($\sim 10^5 M_\odot,\ \mathrm{SNR} = 5$)



Calculation by K.Yagi

Background GWs

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Observable GW energy density ratio

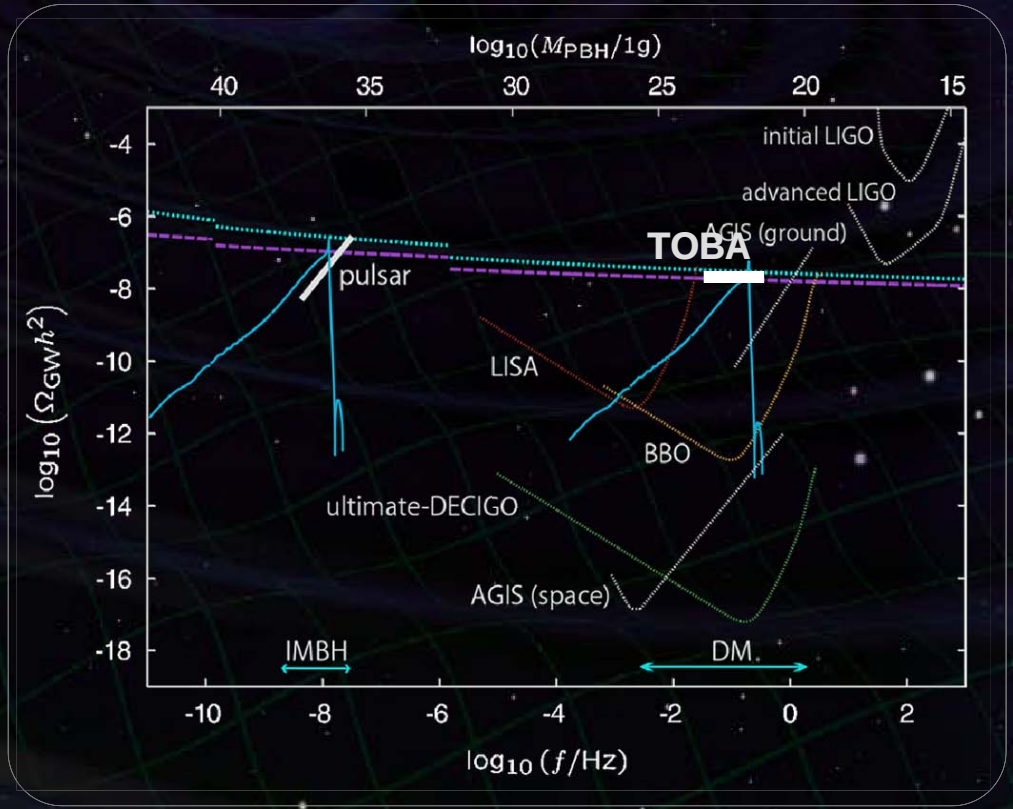
$$\Omega_{gw} \sim 10^{-7}$$

(1-yr observation)

Beat BBN upper limit

GW by primordial tensor perturbation

R.Saito and J.Yokoyama, PRL 102, 161101 (2009)



1. DECIGO

- Overview and Science
- Pre-conceptual Design

2. DECIGO Pathfinder

- Overview and Science
- Design and Status
- Space Demonstration

3. Summary

Summary

DECIGO : Fruitful Sciences

- Very beginning of the Universe
- Dark energy
- Galaxy formation

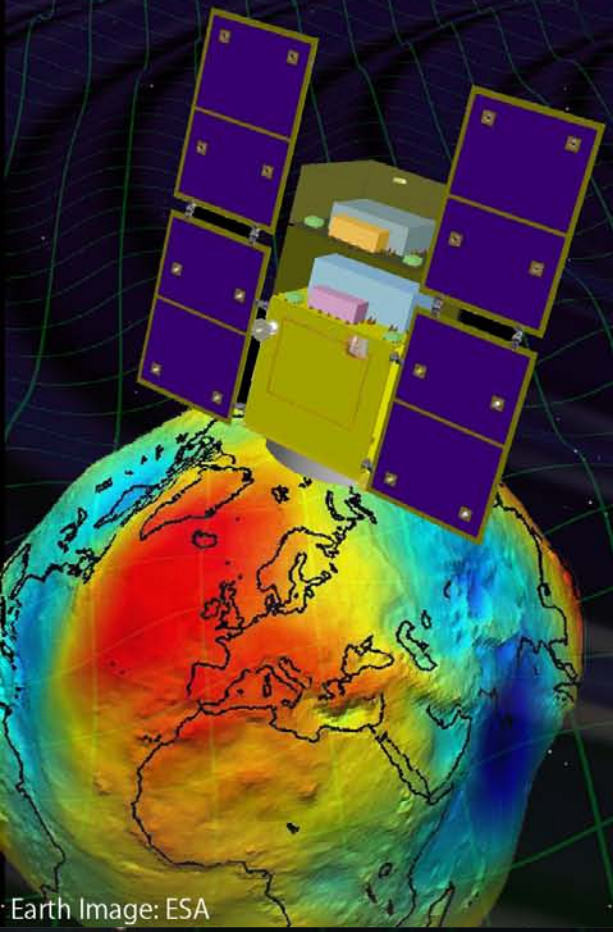
DECIGO Pathfinder

- Important milestone for DECIGO
- Strong candidate of JAXA's satellite series

SWIM – under operation in orbit

first precursor to space!

DECIGO



Original
Picture : Sora

End