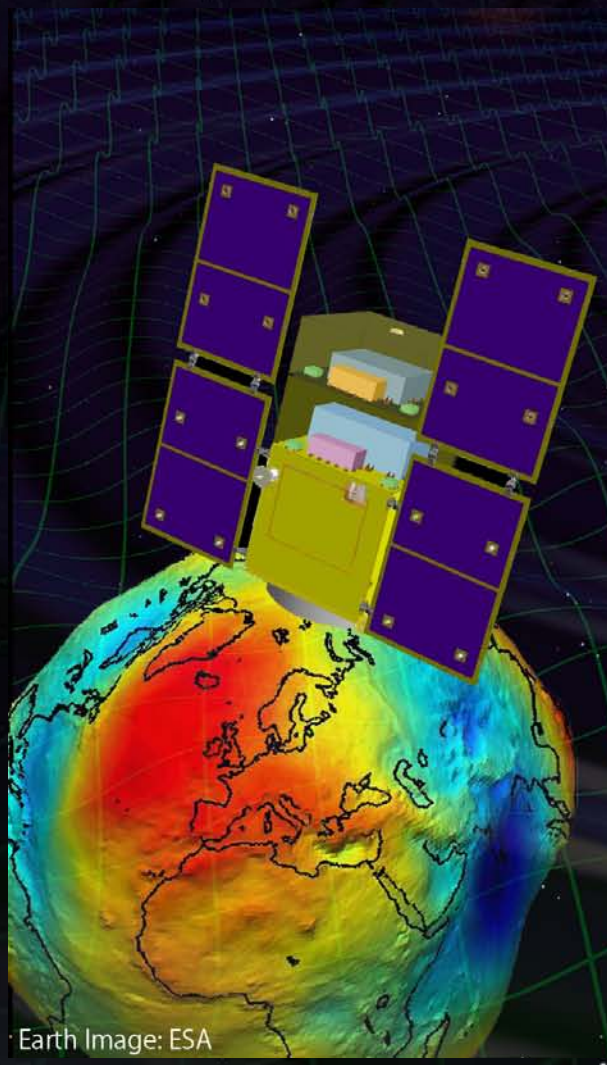
# Space Gravitational-Wave Antenna DECIGO




Original
Picture : Sora

**Masaki Ando**
(Department of Physics, Kyoto University)

**Wataru Kokuyama**
(Department of Physics, University of Tokyo)

On behalf of
DECIGO working group

GWADW2010 (May 20, 2010, Kyoto, Japan)

# 1. DECIGO

- Overview and Science
- Pre-conceptual Design

# 2. DECIGO Pathfinder

- Overview and Science
- Design and Status
- Space Demonstration ← Wataru ← Kokuyama

# 3. Summary

# 1. DECIGO

## Overview and Science

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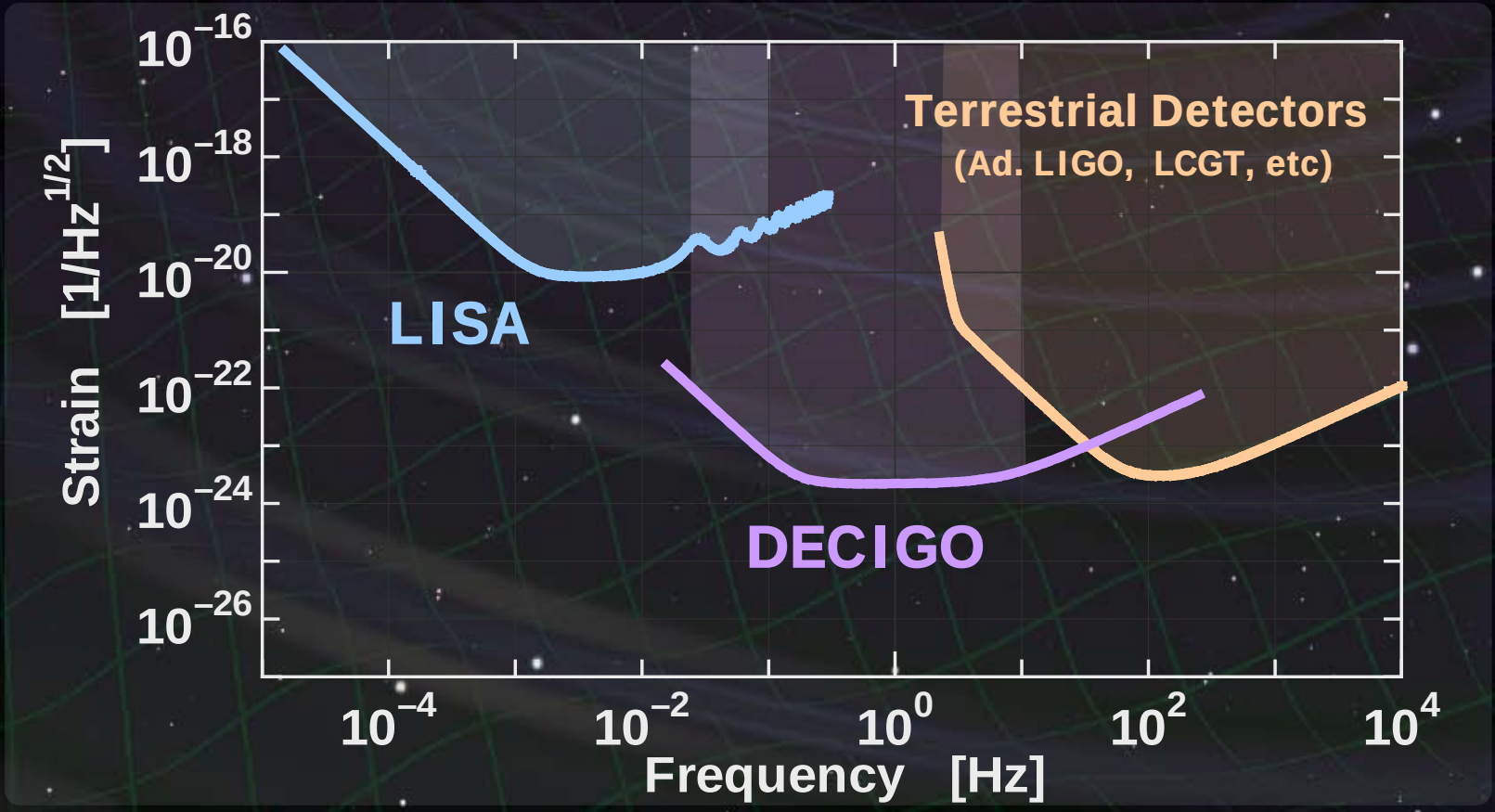
# DECIGO

**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



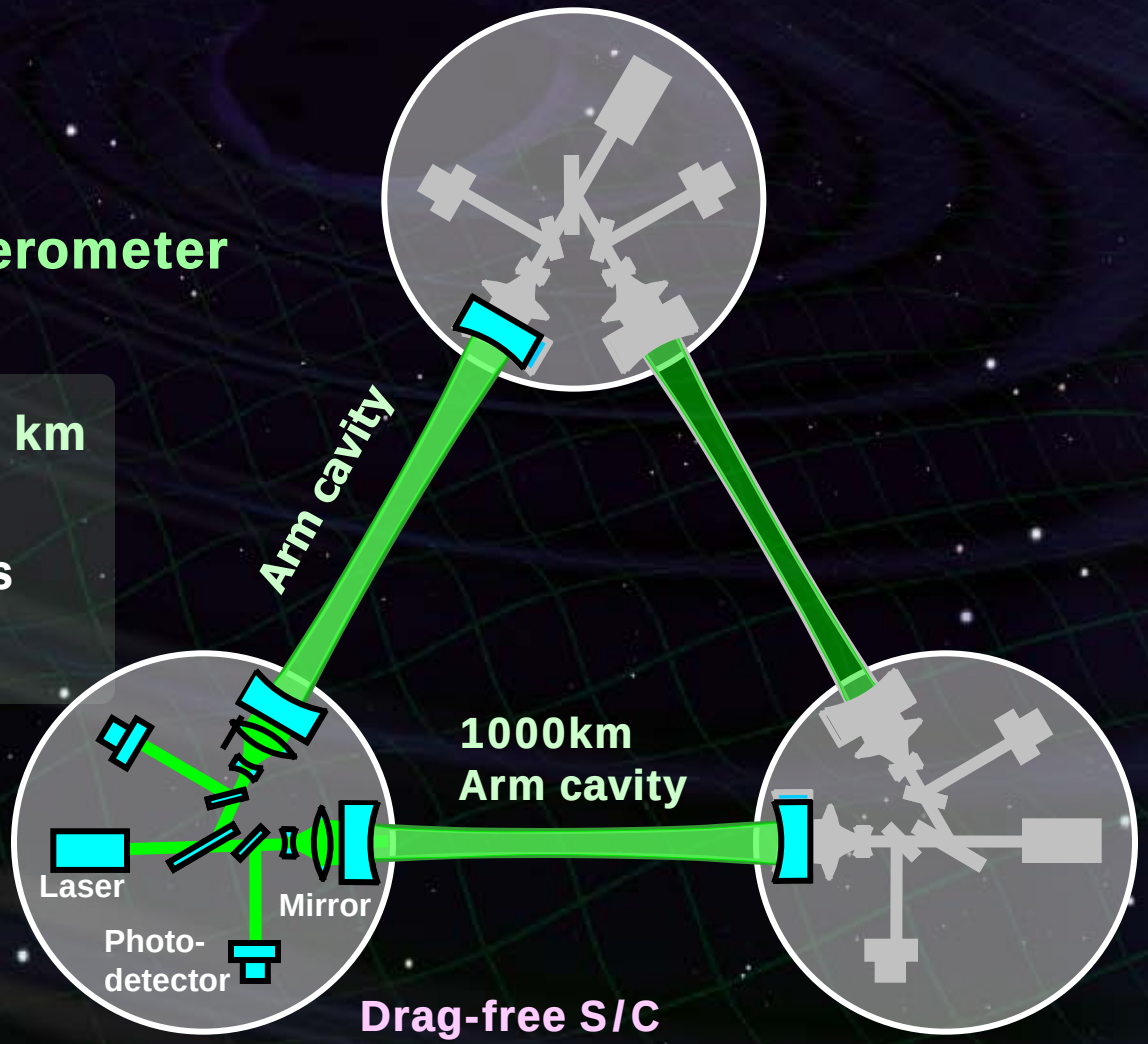
# DECIGO Interferometer

DECIGO

**Interferometer Unit:**

**Differential FP interferometer**

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

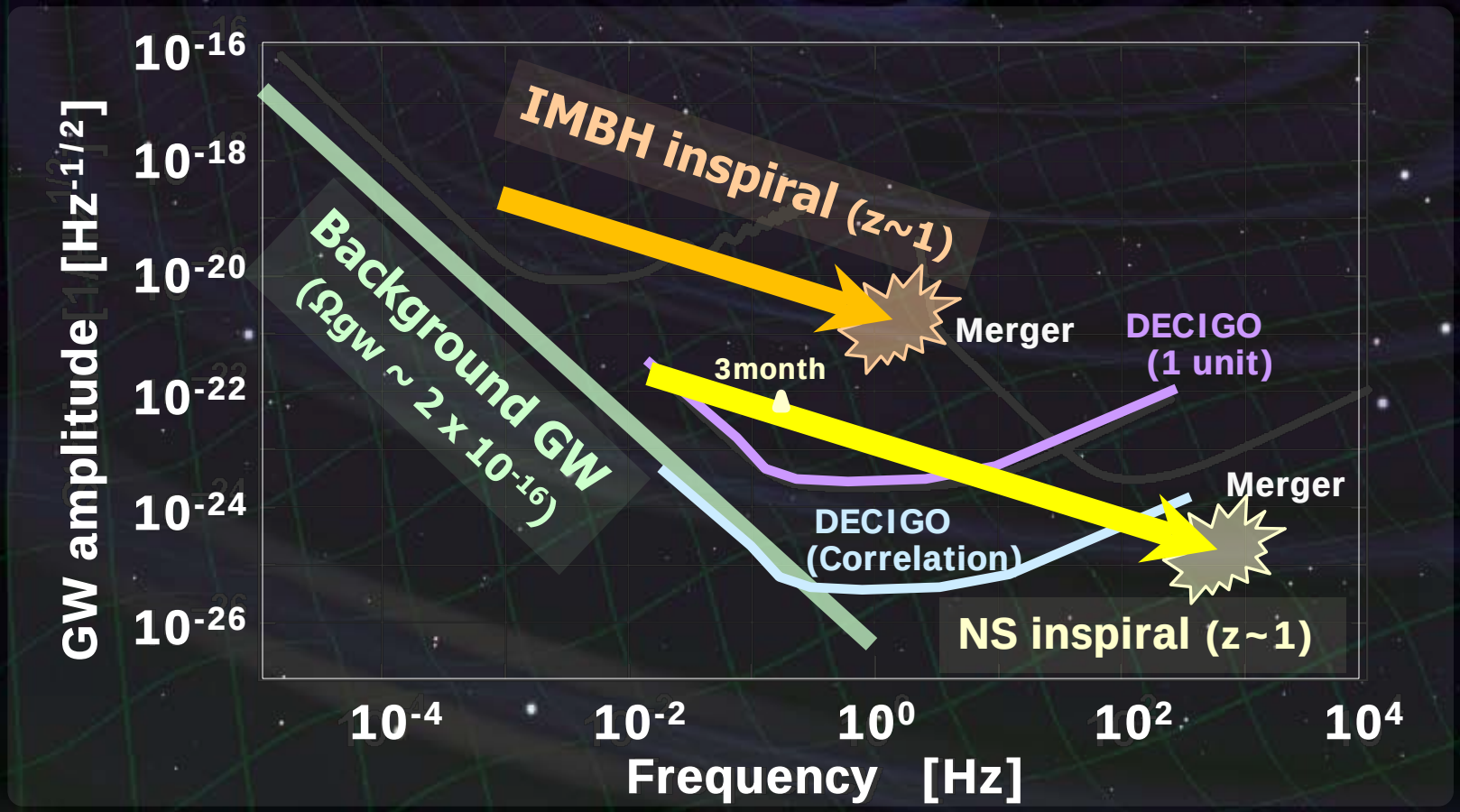


# Targets and Science

DECIGO

**IMBH** binary inspiral
**NS** binary inspiral
**Stoch**astic background

⇨ Galaxy formation (Massive BH)
Cosmology
(Inflation, Dark energy)



# Constraint on dark energy

DECIGO will observe

$10^{4\text{-}5}$ NS binaries at z~1

↳ Precise 'clock' at cosmological distance

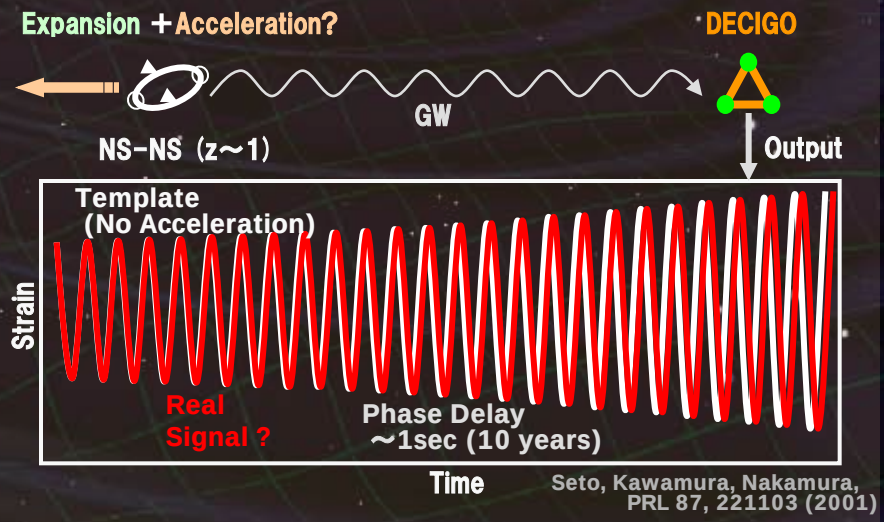
## 'Standard Siren'

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)

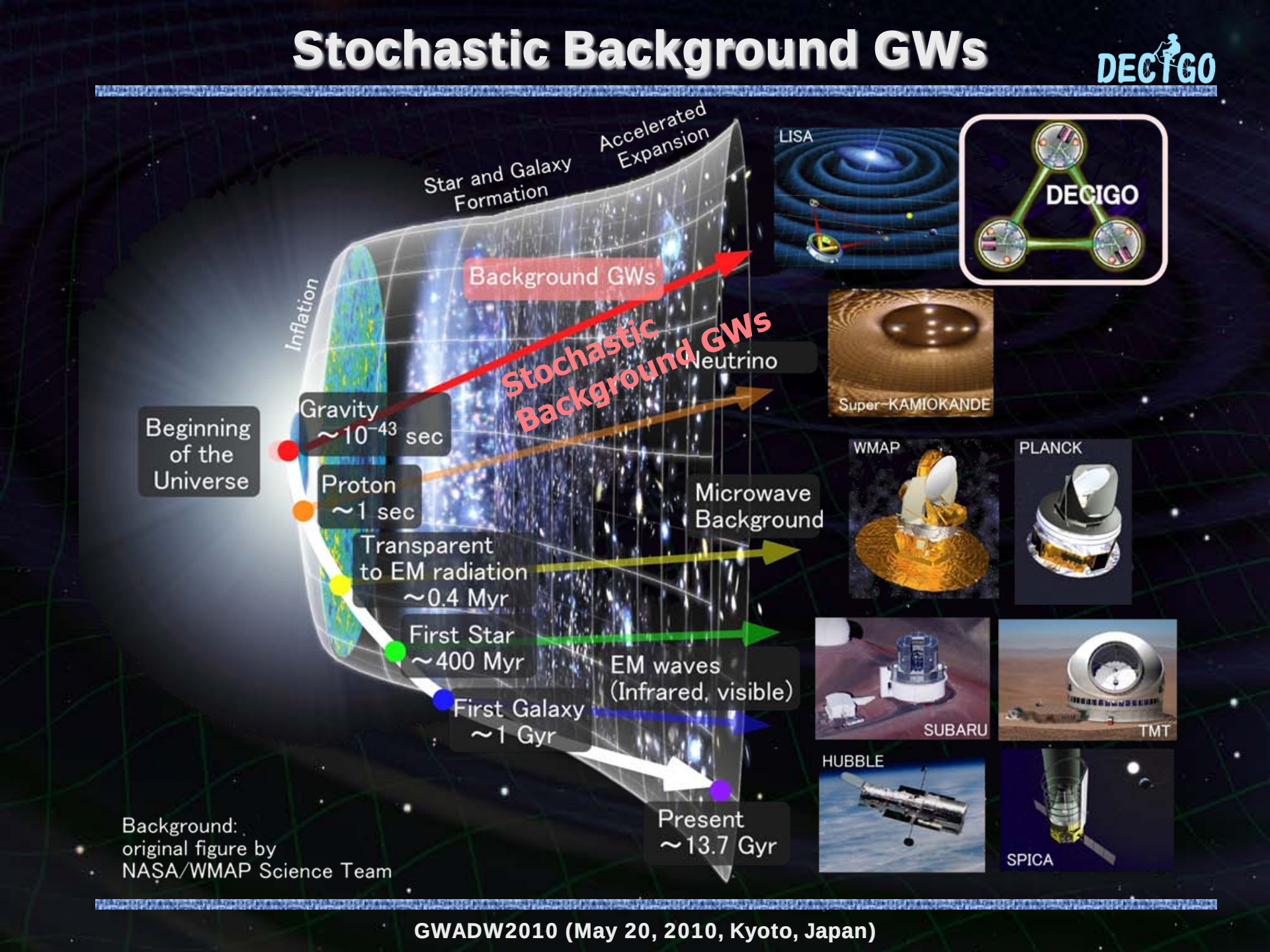
Determine cosmological parameters

$$\Delta\Omega_m, \Delta\Omega_w, \Delta w \approx 1\%$$

Absolute and independent measurement

Angular resolution
~10arcmin (1 detector)
~10arcsec (3 detectors)
at z=1

# Stochastic Background GWs



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# Pre-Conceptual Design

DECIGO

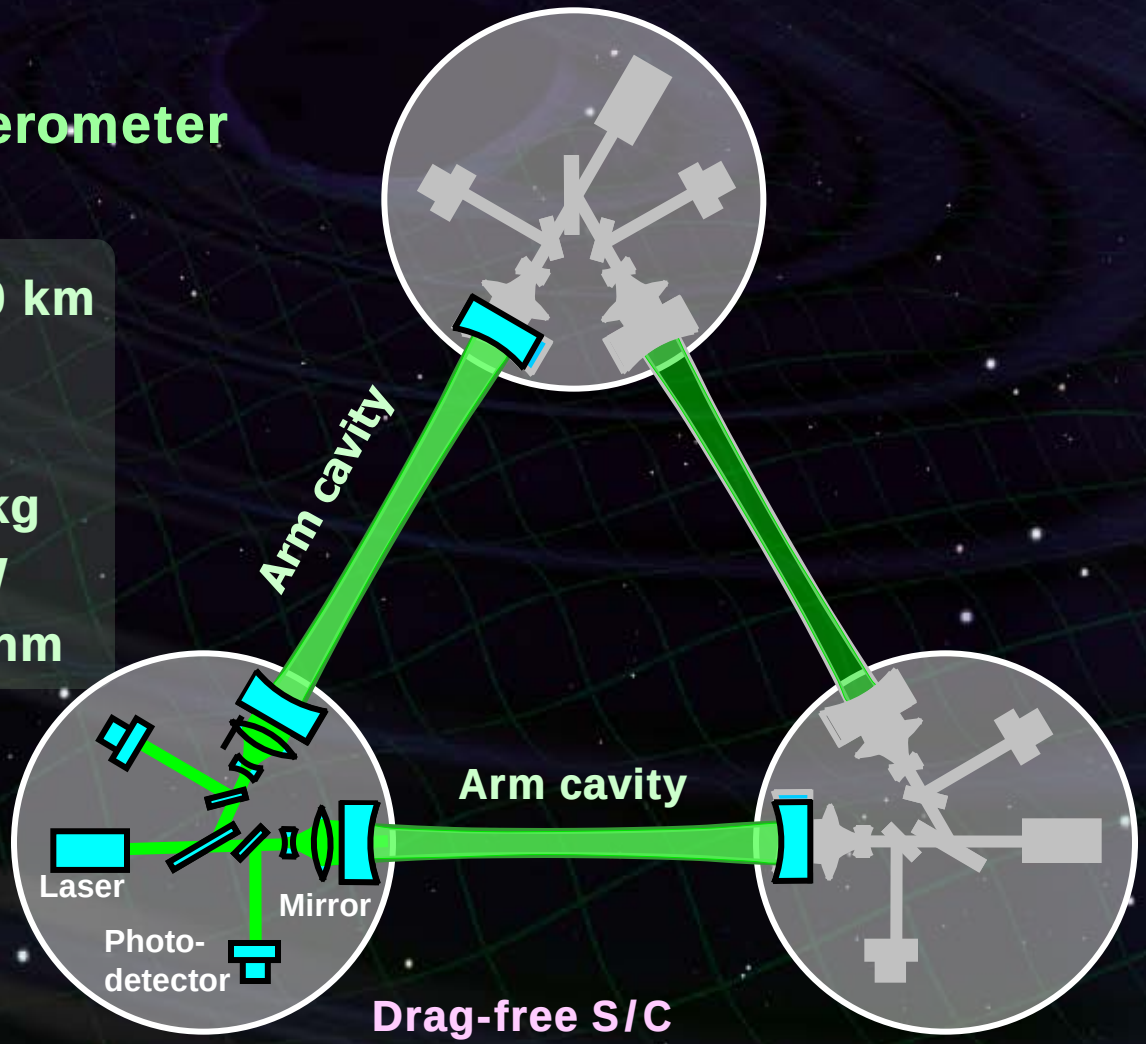
**Interferometer Unit:**

**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**



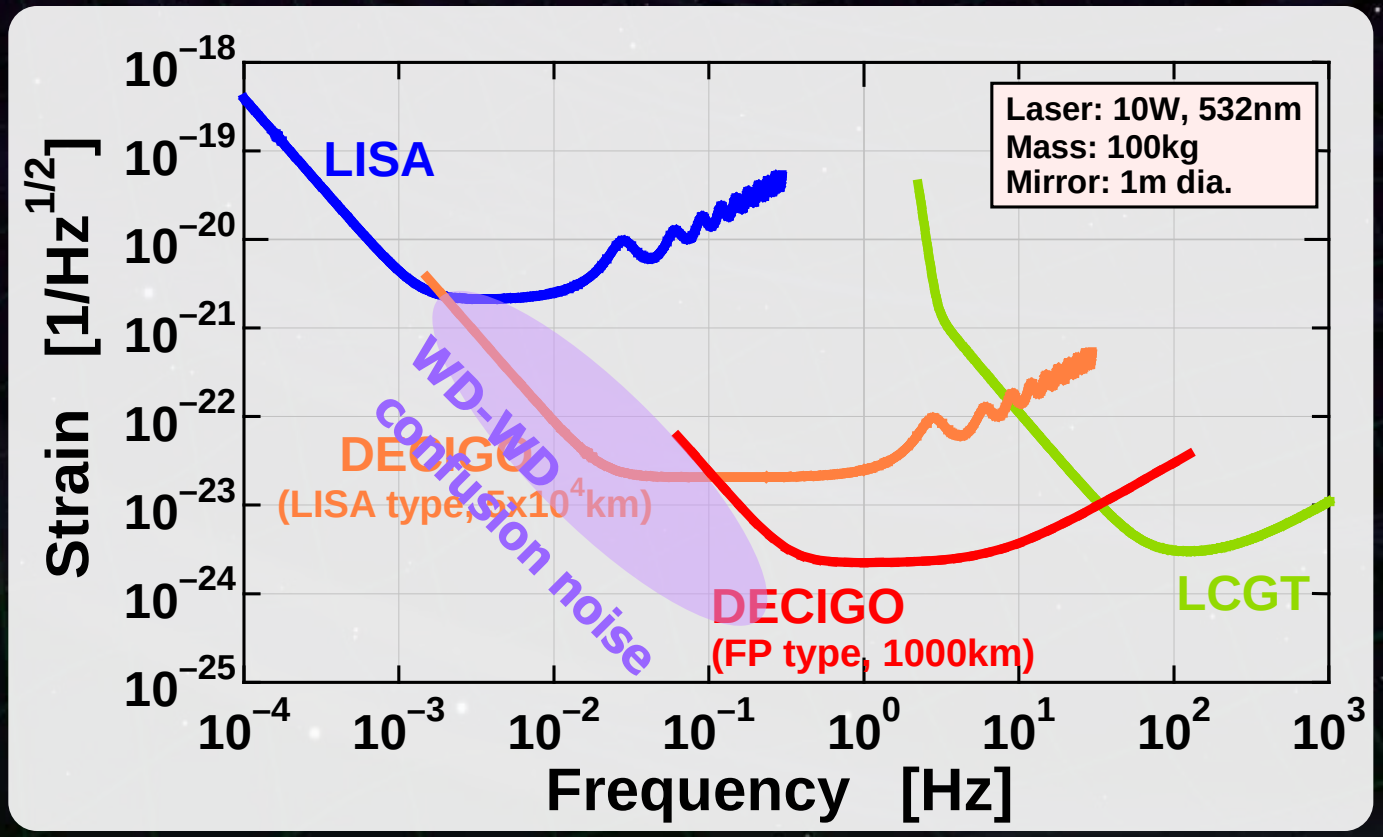
# Interferometer Design

DECIGO

**Transponder type vs Direct-reflection type**

**Compare : Sensitivity curves and Expected Sciences**

**Decisive factor: Binary confusion noise**



# 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

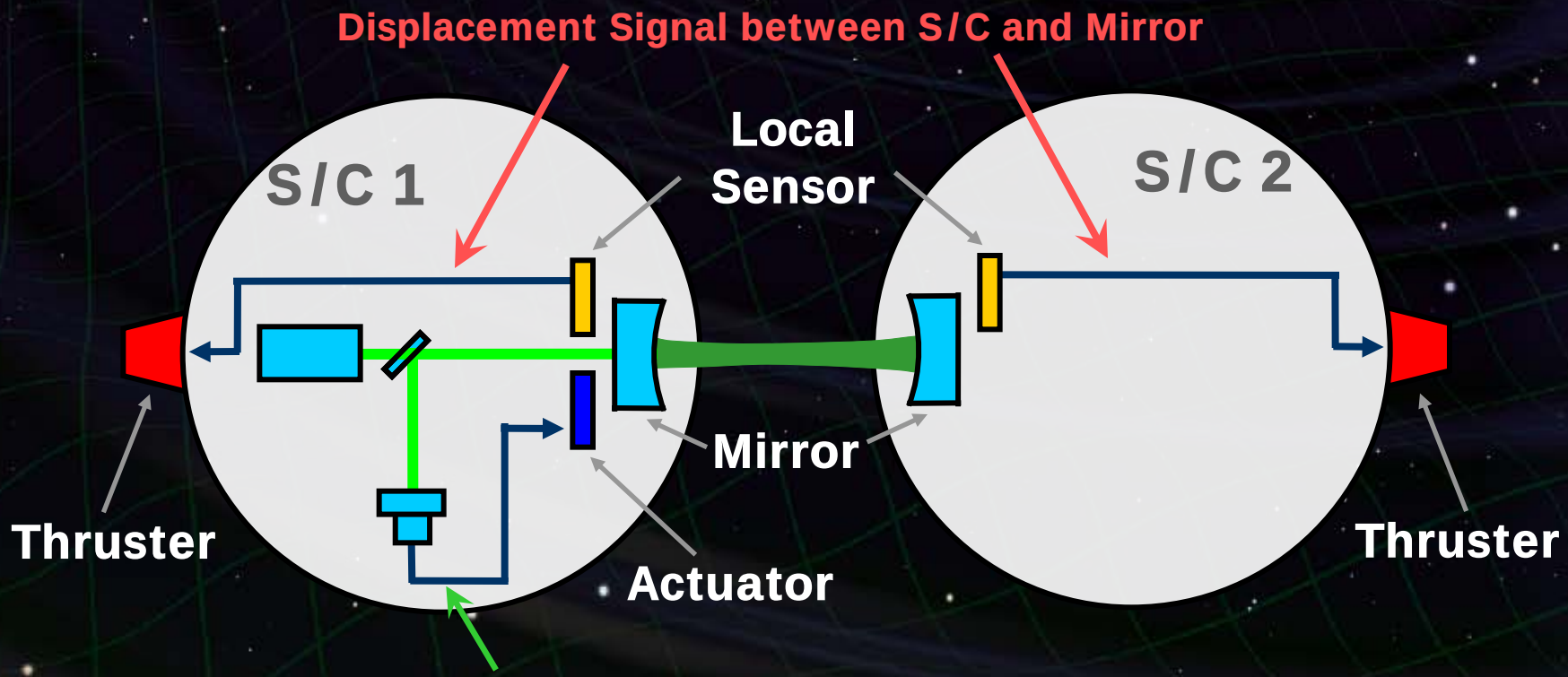



Fig: S. Kawamura

# Requirements

DECIGO

**Sensor Noise**

Shot noise $3 \times 10^{-18}$ 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 $4 \times 10^{-17}$ 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**

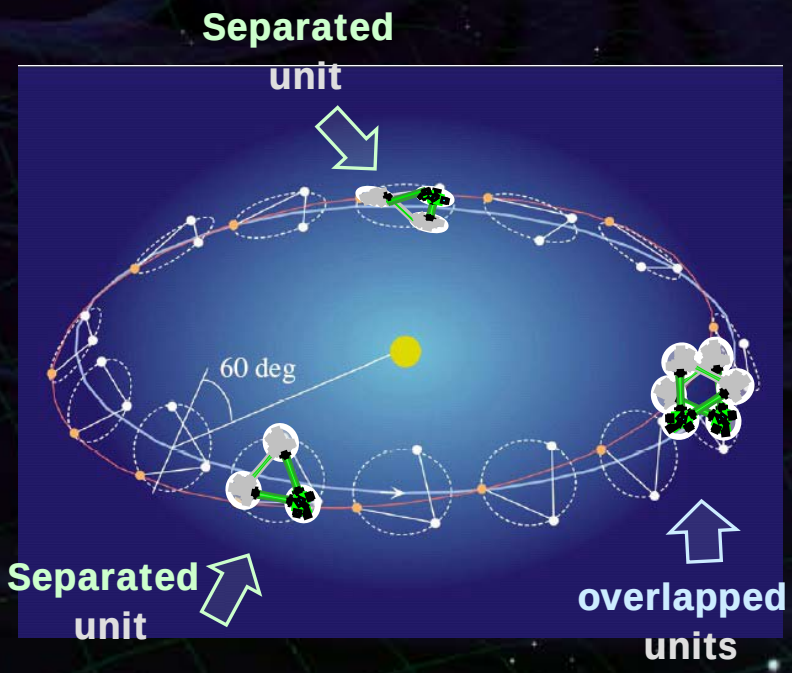
Relative acc. $4\times10^{-12}$ m/s$^2$

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

**Halo orbit around L2 (or L1)**

Relative acc. $4\times10^{-7}$ m/s$^2$

(Mirror force ~$10^{-4}$ N )




**Constellation**

4 interferometer units

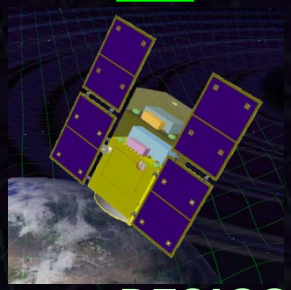
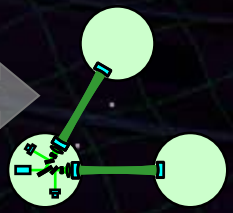
2 overlapped units → Cross correlation

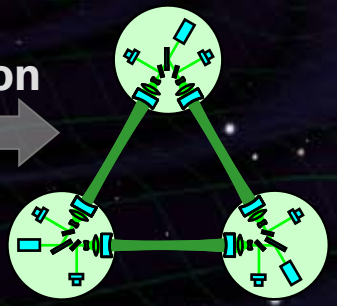
2 separated units → Angular resolution

# 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 |  DECIGO Pathfinder (DPF) | R&D Fabrication →  Pre-DECIGO |
| Objective | Space test of key tech.<br>GW observation | Detect GW<br>with min. spec<br>FP between S/C | GW astronomy |
| Design | Single small satellite<br>Short FP interferometer | 3 S/C<br>1 interferometer unit | 3 S/C<br>x 3-4 units |

R&D Fabrication →  DECIGO

# 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

DECIGO

- 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

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# 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; DECIGO Pathfinder (DPF) | R&D Fabrication → Pre-DECIGO | R&D Fabrication → DECIGO |
| Objective | Space test of key tech.<br>GW observation | Detect GW<br>with min. spec<br>FP between S/C | GW astronomy |
| Design | Single small satellite<br>Short FP interferometer | 3 S/C<br>1 interferometer unit | 3 S/C<br>x 3-4 units |

# 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

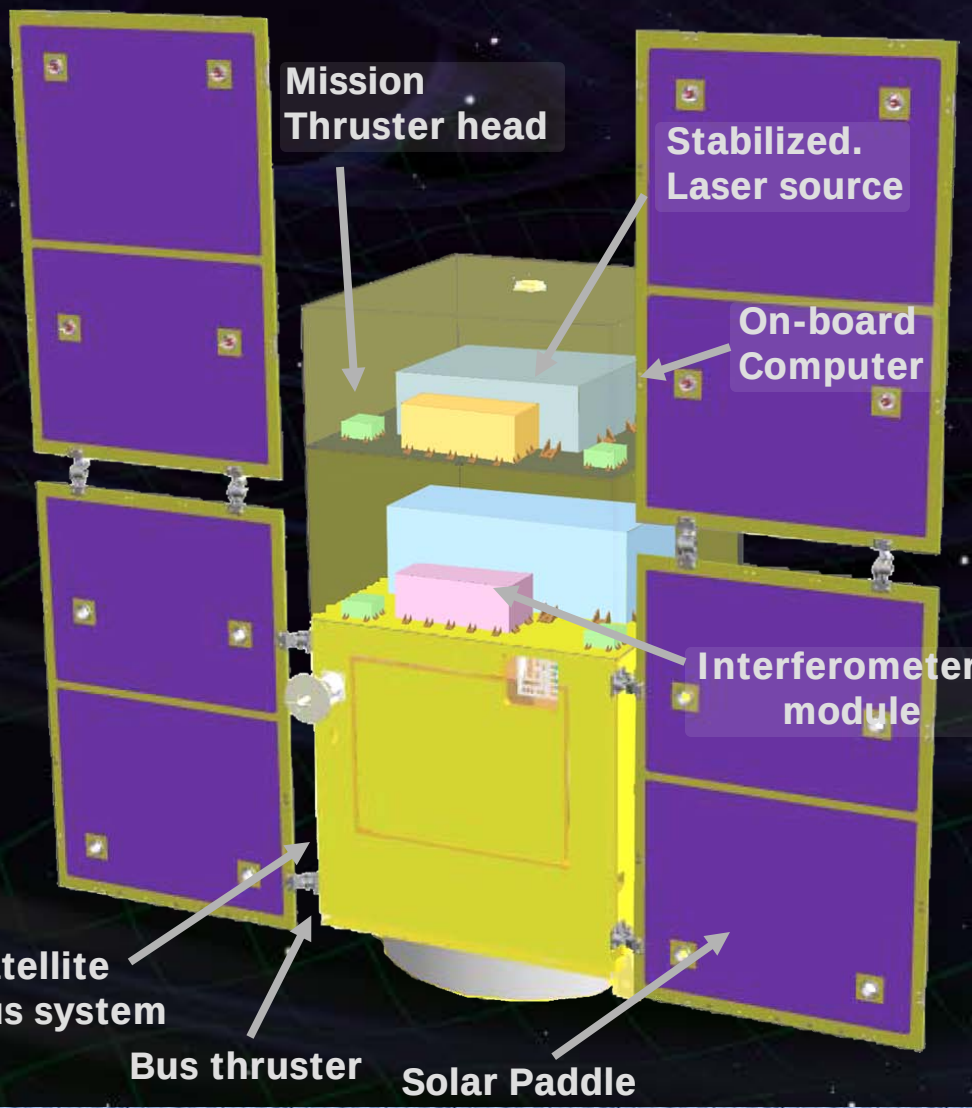
## DPF Payload

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

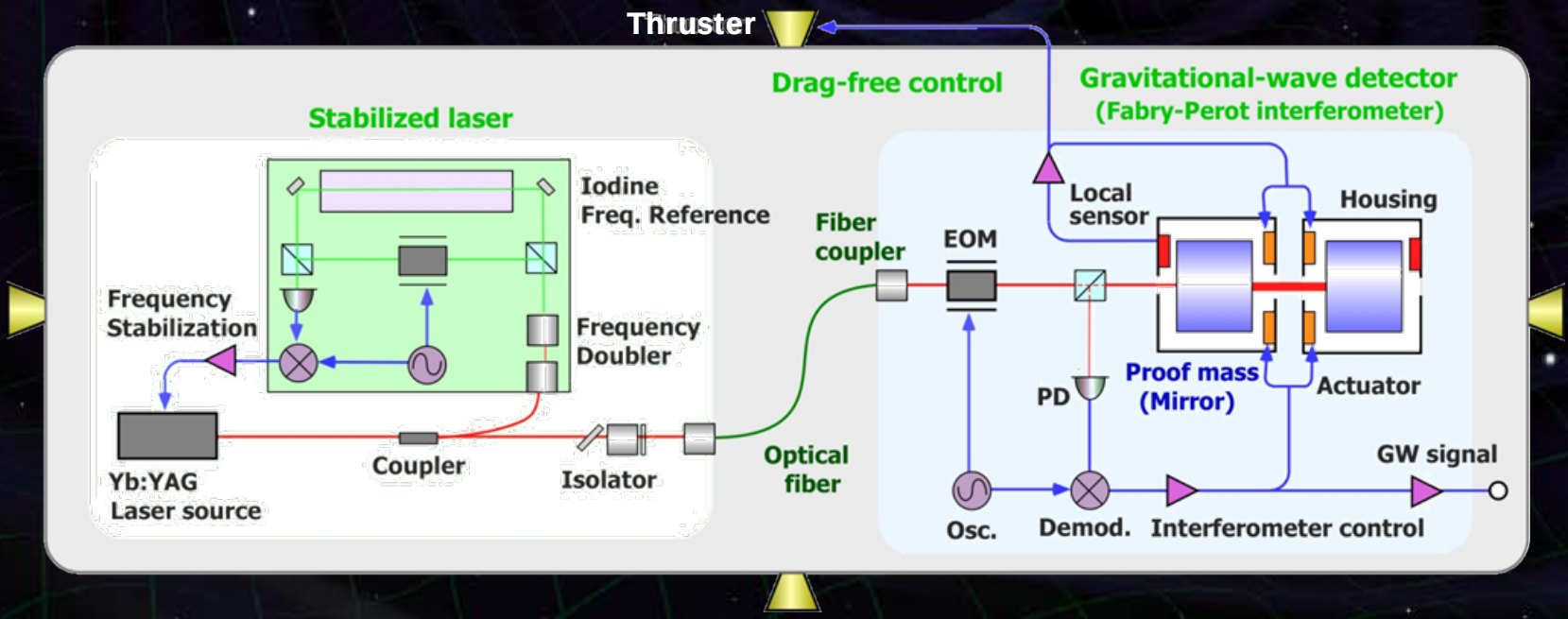


# DPF mission payload

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

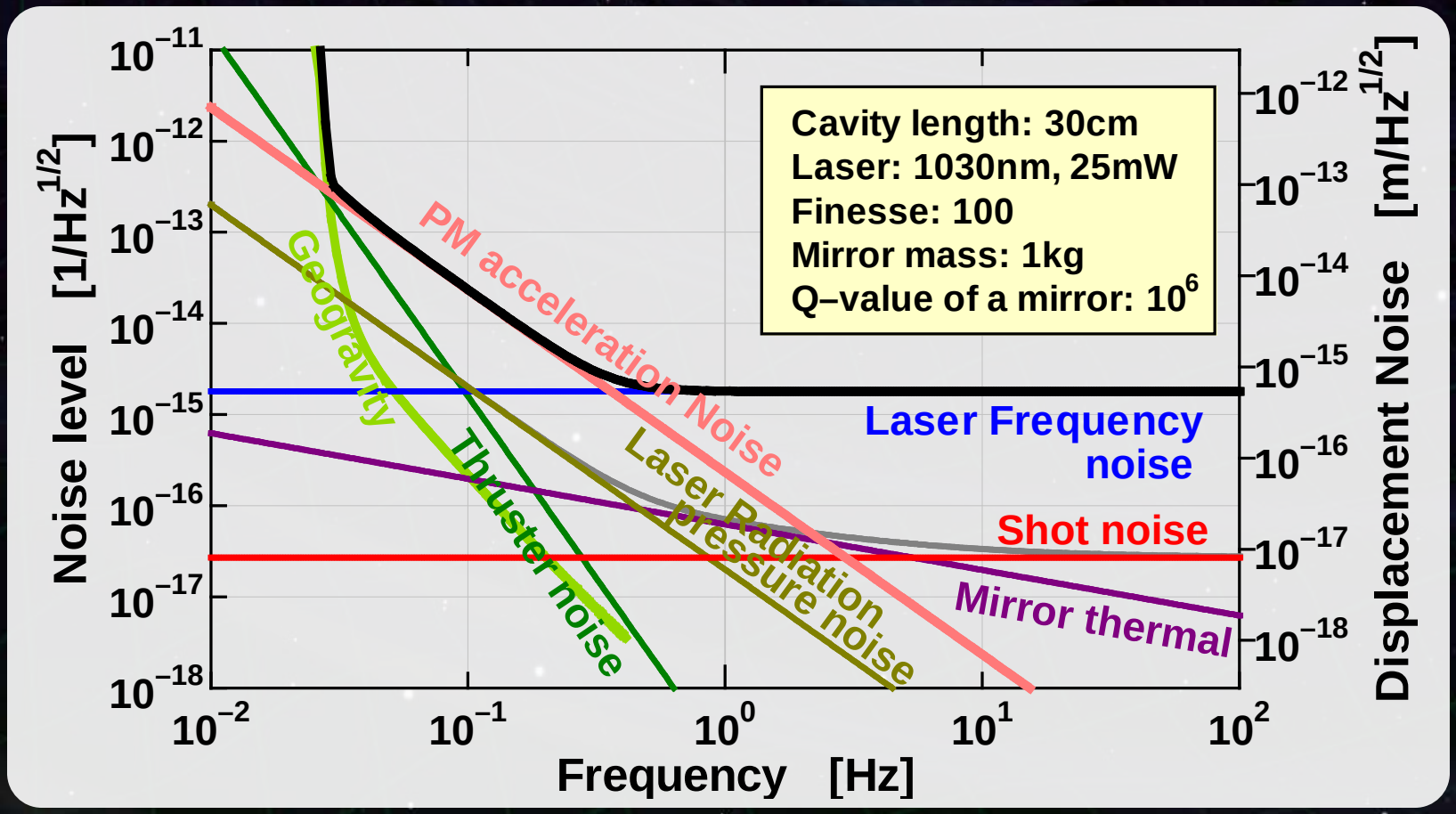
# DPF Sensitivity

DECIGO

Laser source : 1030nm, 25mW
IFO length : 30cm
Finesse : 100, Mirror mass : 1kg
Q-factor : $10^5$, Substrate: TBD
Temperature : 293K

Satellite mass : 350kg, Area: $2m^2$
Altitude: 500km
Thruster noise: $0.1\mu N/Hz^{1/2}$

(Preliminary parameters)

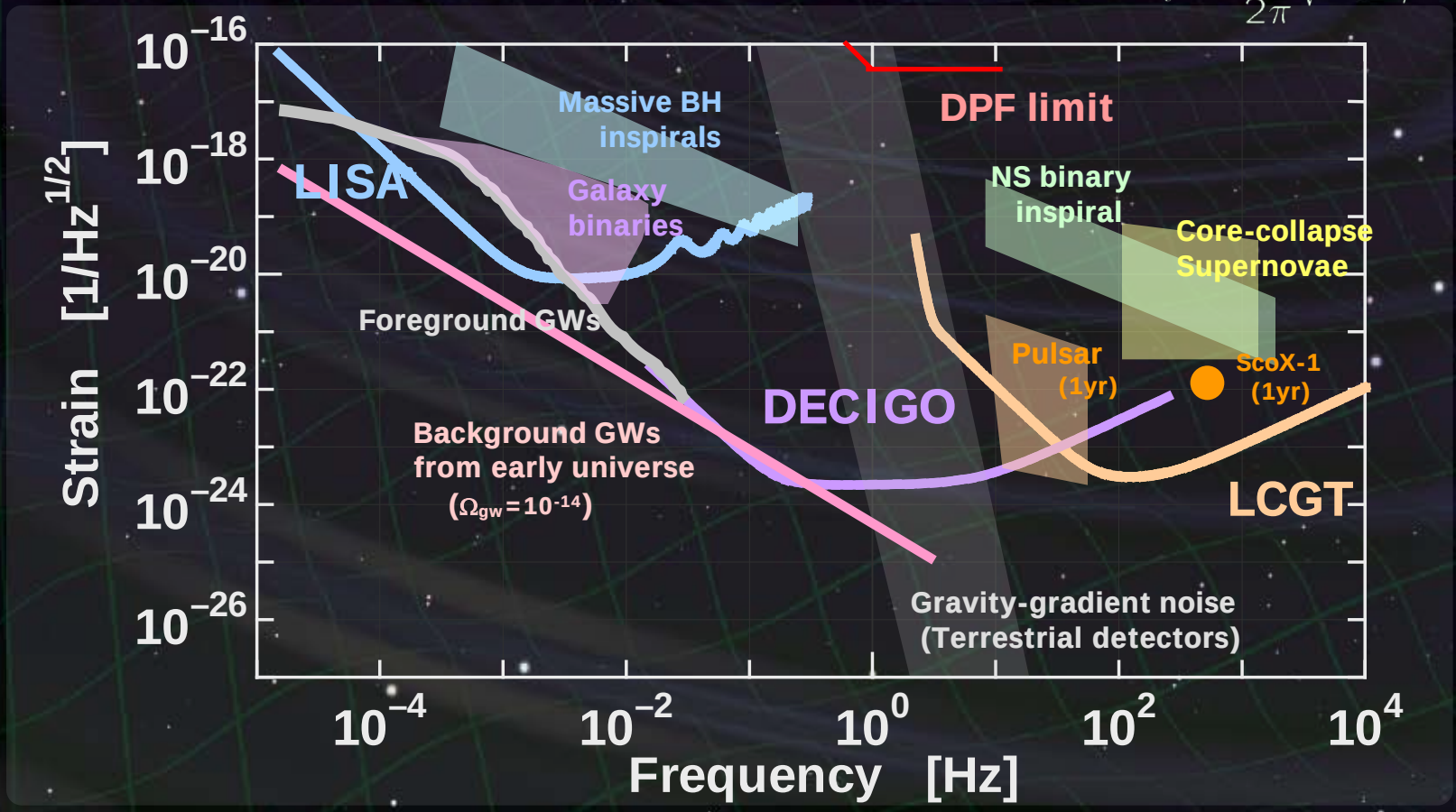


# DPF sensitivity

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

**(x10 of quantum noises)**

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



# GW target of DPF

DECIGO

**Blackholes events in our galaxy**

**IMBH inspiral and merger**

$h \sim 10^{-15}$ , $f \sim$ 4 Hz

Distance 10kpc, $m = 10^3 M_{sun}$

Obs. Duration (~1000sec)

**BH QNM**

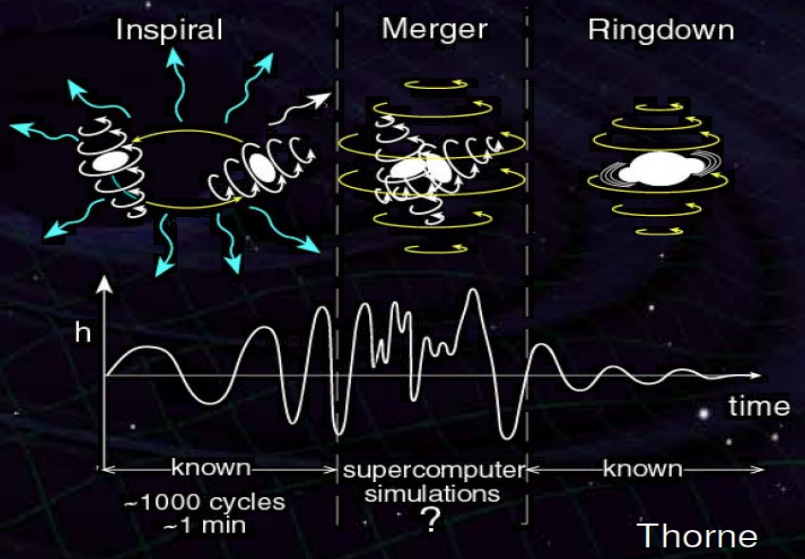
$h \sim 10^{-15}$ , $f \sim$ 0.3 Hz

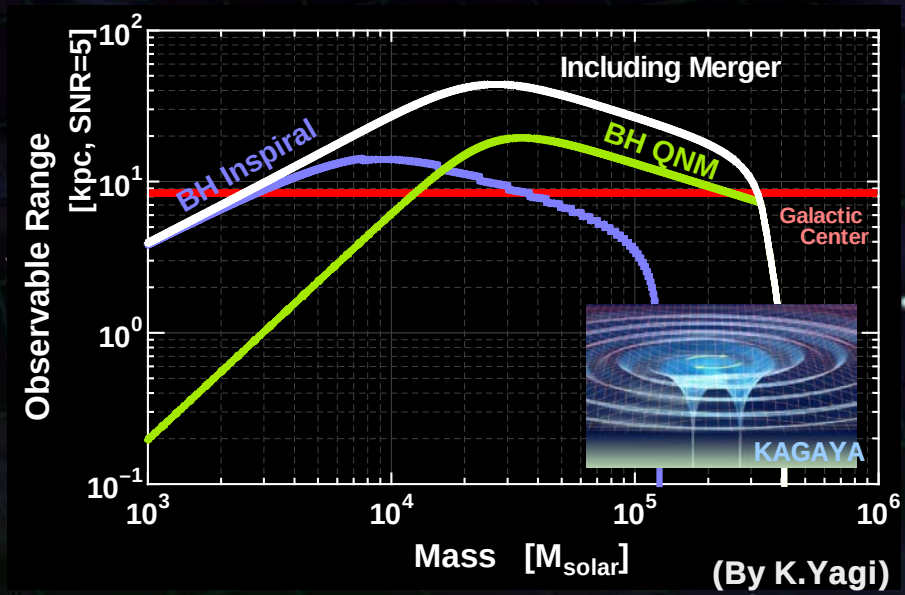
Distance 1Mpc, $m = 10^5 M_{sun}$

**Observable range covers our Galaxy (SNR~5 )**

**Hard to access by others**

**→ Original observation**

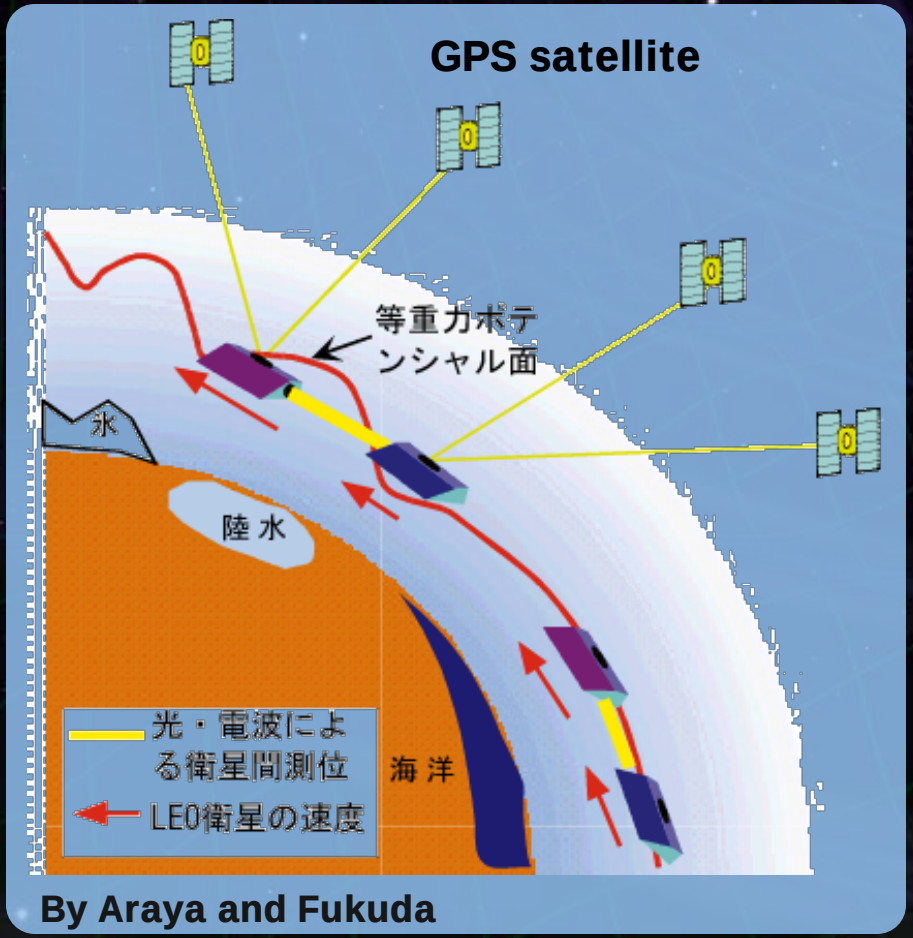


# Gravity of the Earth

DECIGO

**Measure gravity field of the Earth from Satellite Orbits, and gravity-gradiometer**




By Araya and Fukuda

Determine global gravity field
→ Density distribution

Monitor of change in time
Ground water motion
Strains in crusts by earthquakes and volcanoes

Observation Gap
between GRACE and GRACE-FO (2012-16)
→ DPF contribution in international network

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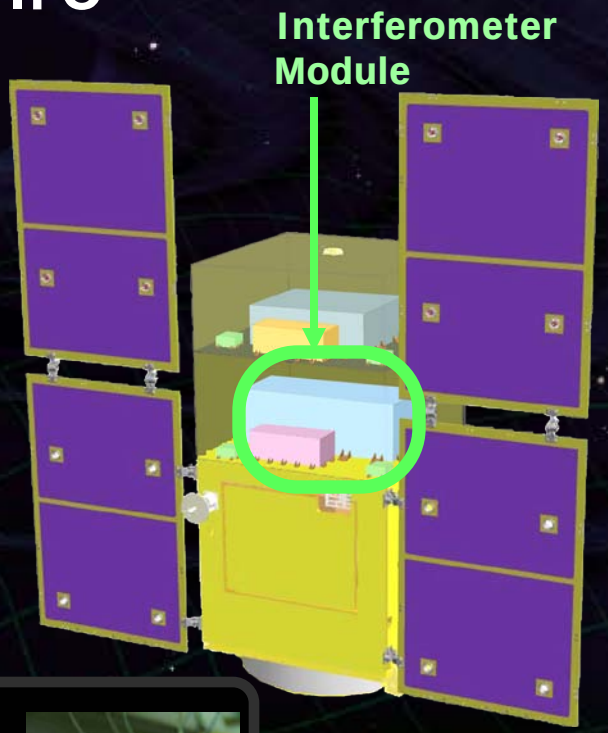
# Interferometer Module

DECIGO

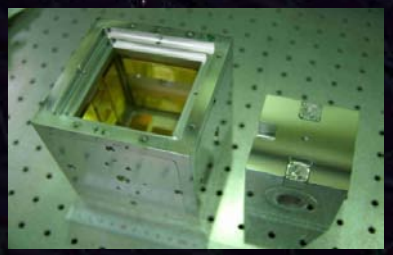
## Interferometer Module : Test mass + IFO




### Test-mass module
→ Gravity reference

- BBM of Module, Sensor, Actuator, Clump/Release
- μ-Grav. Exp.

Hosei, NAOJ, Ochanomizu, Stanford



### Interferometer
→ GW, Gravity observation

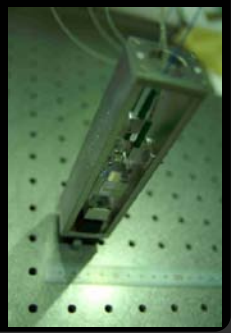
- 30cm IFO BBM Digital control
- Packaging
- Monolithic Opt.

NAOJ, U-Tokyo

### Laser sensor
→ Small MI

- BBM test
- Sensitivity meas.

ERI, U-Tokyo



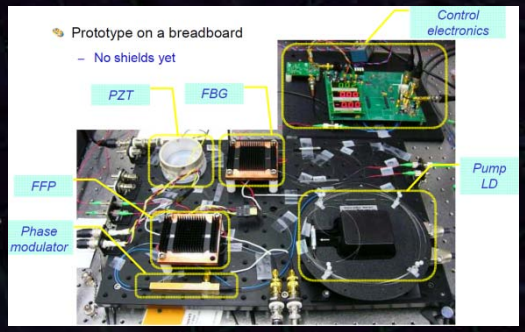
# Stabilized Laser Module

DECIGO

**Stabilized Laser : Laser source + Stabilization system**

## Yb:YAG (NPRO or Fiber laser) → Laser source

- BBM development

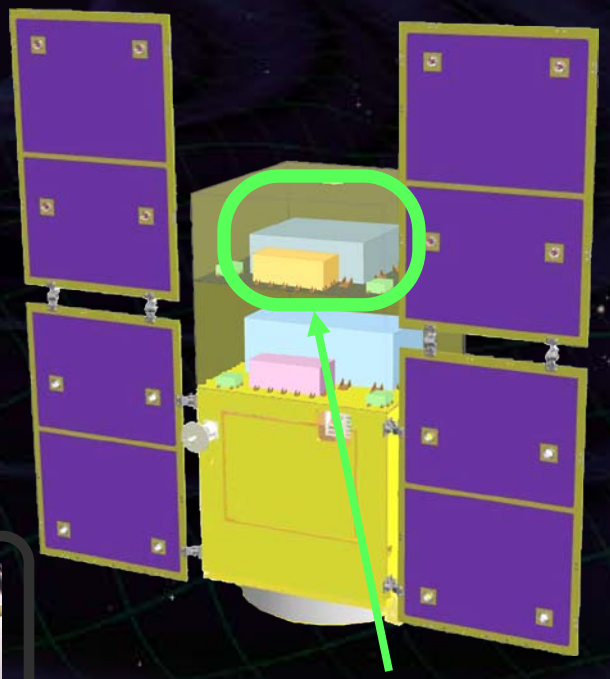



UEC, NASA/GSFC

## $I_2$ absorption line → Frequency reference

- BBM development
- Stability meas.


UEC, NICT



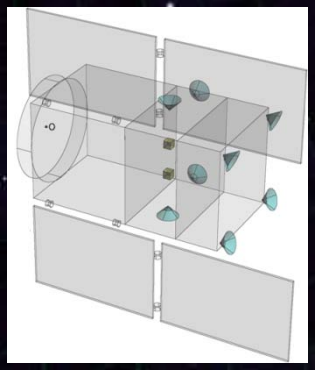
Stabilized Laser Module

# Attitude and Drag-free control

DECIGO

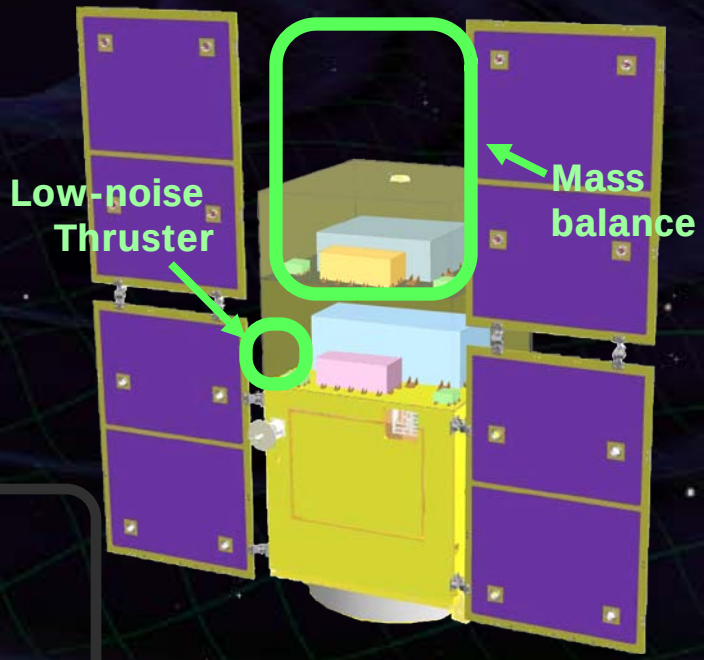
## Attitude and Drag-free control : Structure, Thrusters, Control

### Structure, thermal stability



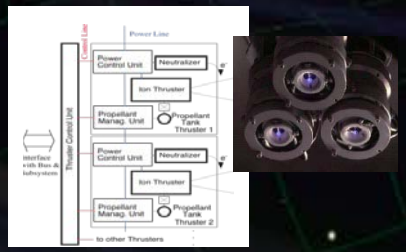
- Passive attitude stability
- Drag-free control

U-Tokyo, JAXA




### Low-noise Thruster

→ Actuators for satellite control




- BBM and system design

JAXA, NDAJ, Tokai-U

# Signal processing and Control

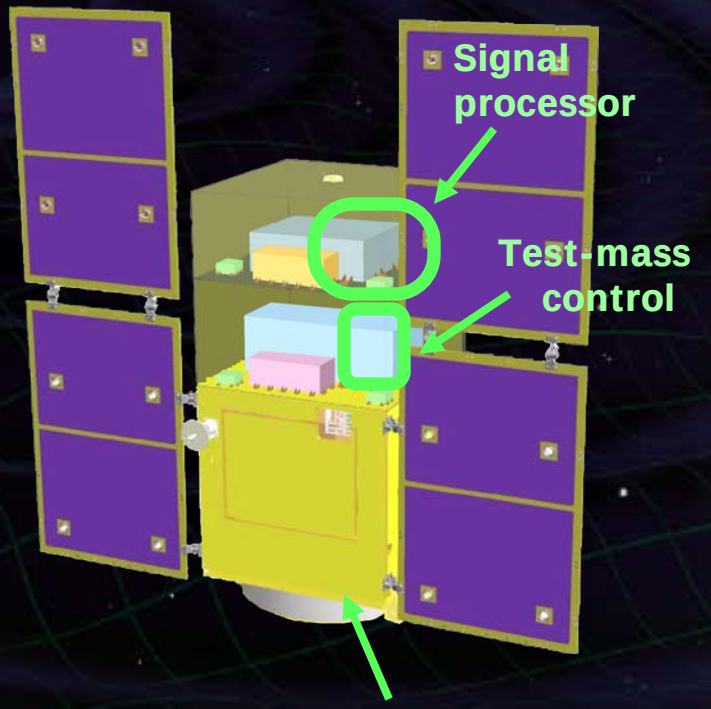
DECIGO

## Signal Processing and Control : SpaceWire-based system

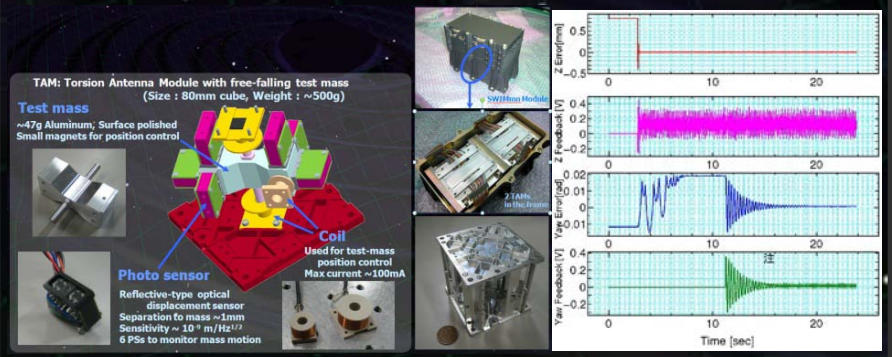
SpC2 + SpW system
→ Signal processing and install. ctrl


Space demonstration
bySDS-1/SWIM


JAXA, U-Tokyo, Kyoto




SWIMmn demonstration
→ Test mass control in orbit




JAXA, U-Tokyo, Kyoto

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# DPF mission status

DECIGO

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

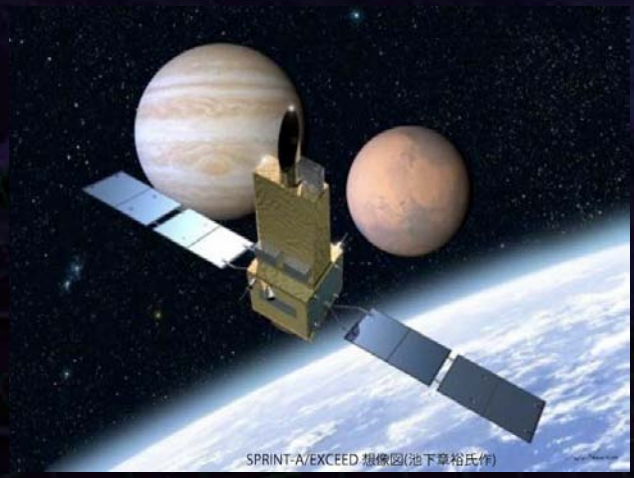
At least 3 satellite in 5 years with
Standard Bus + M-V follow-on rocket

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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# Summary

DECIGO : Fruitful Sciences

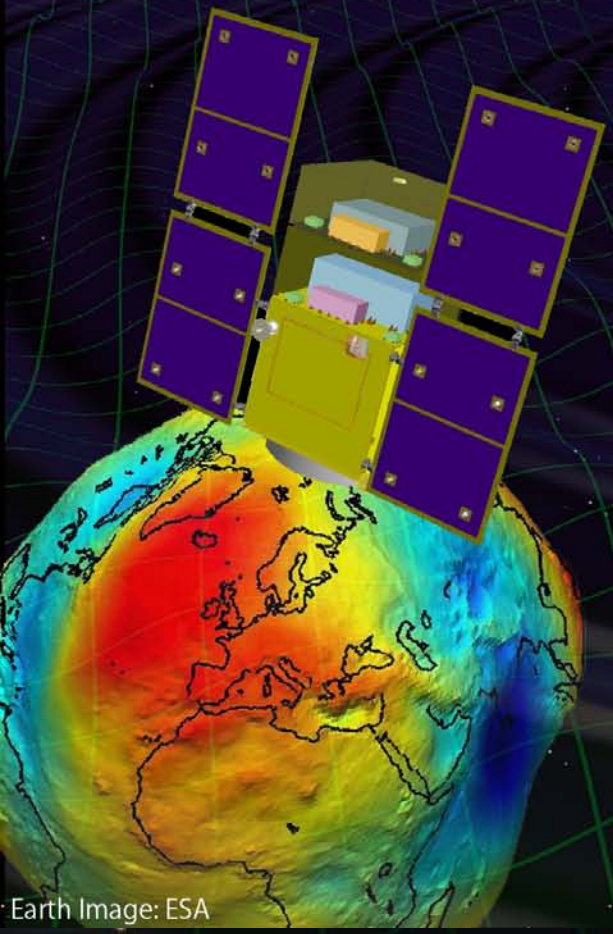
- Very beginning of the Universe
- Dark energy
- Galaxy formation

DECIGO Pathfinder

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

SWIM – under operation in orbit

first precursor to space!




# End

Original
Picture : Sora