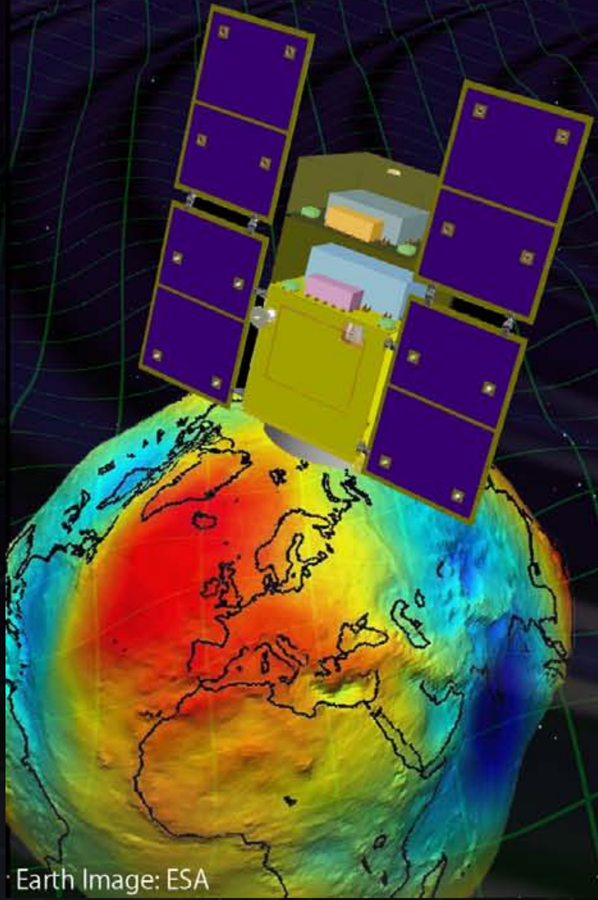
DECIGO and DECIGO Pathfinder

Original
Picture : Sora



Earth Image: ESA

Masaki Ando

(Department of Physics, Kyoto University)

On behalf of
DECIGO working group

Gravity of the Earth (October 18, 2010, NASA/Goddard SFC, Greenbelt, USA)

1. DECIGO

- Overview and Science
- Pre-conceptual Design

2. DECIGO Pathfinder

- Overview and Science
- Design and Status
- Space Demonstration

3. Summary

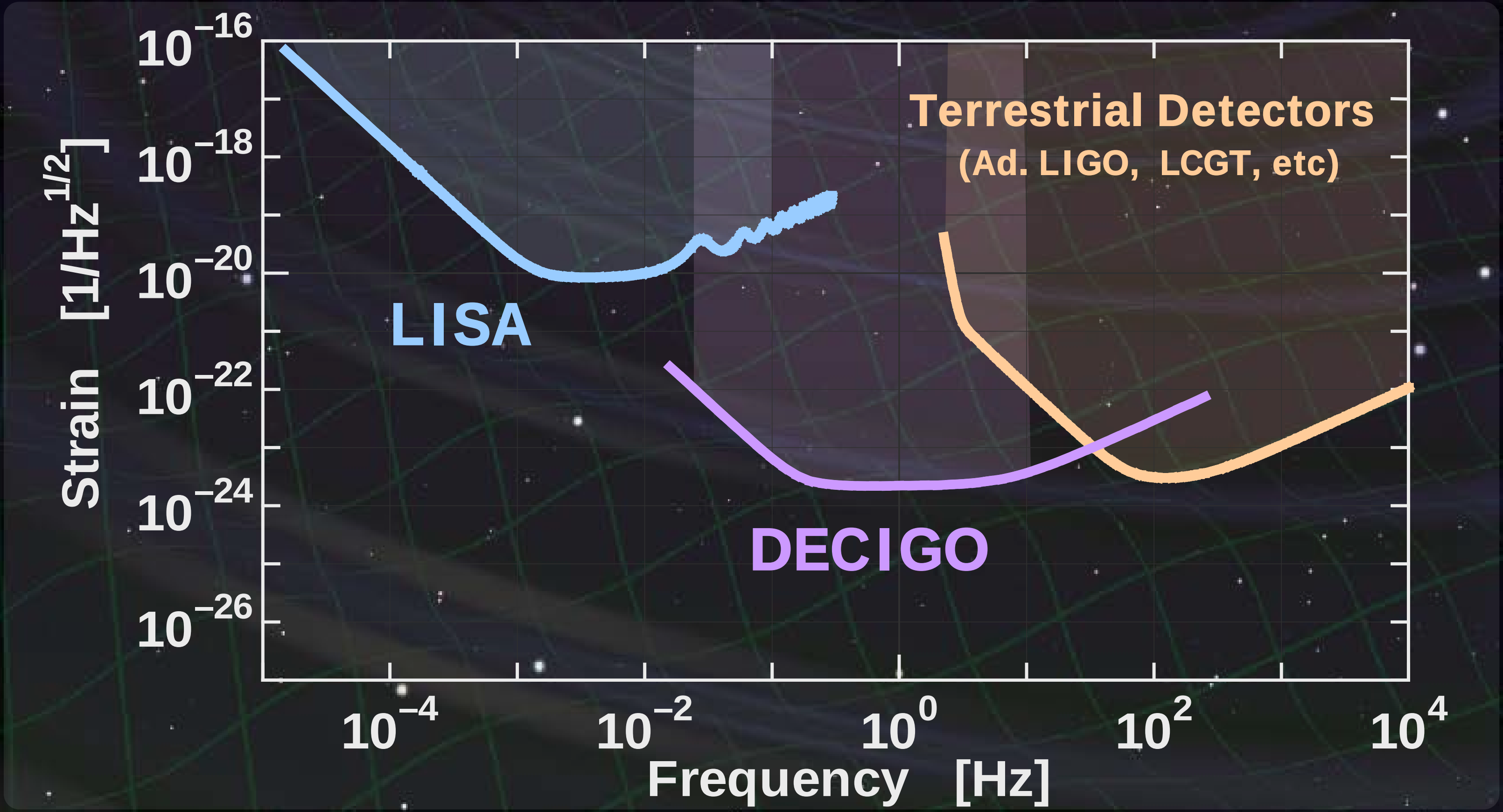
DECIGO

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:

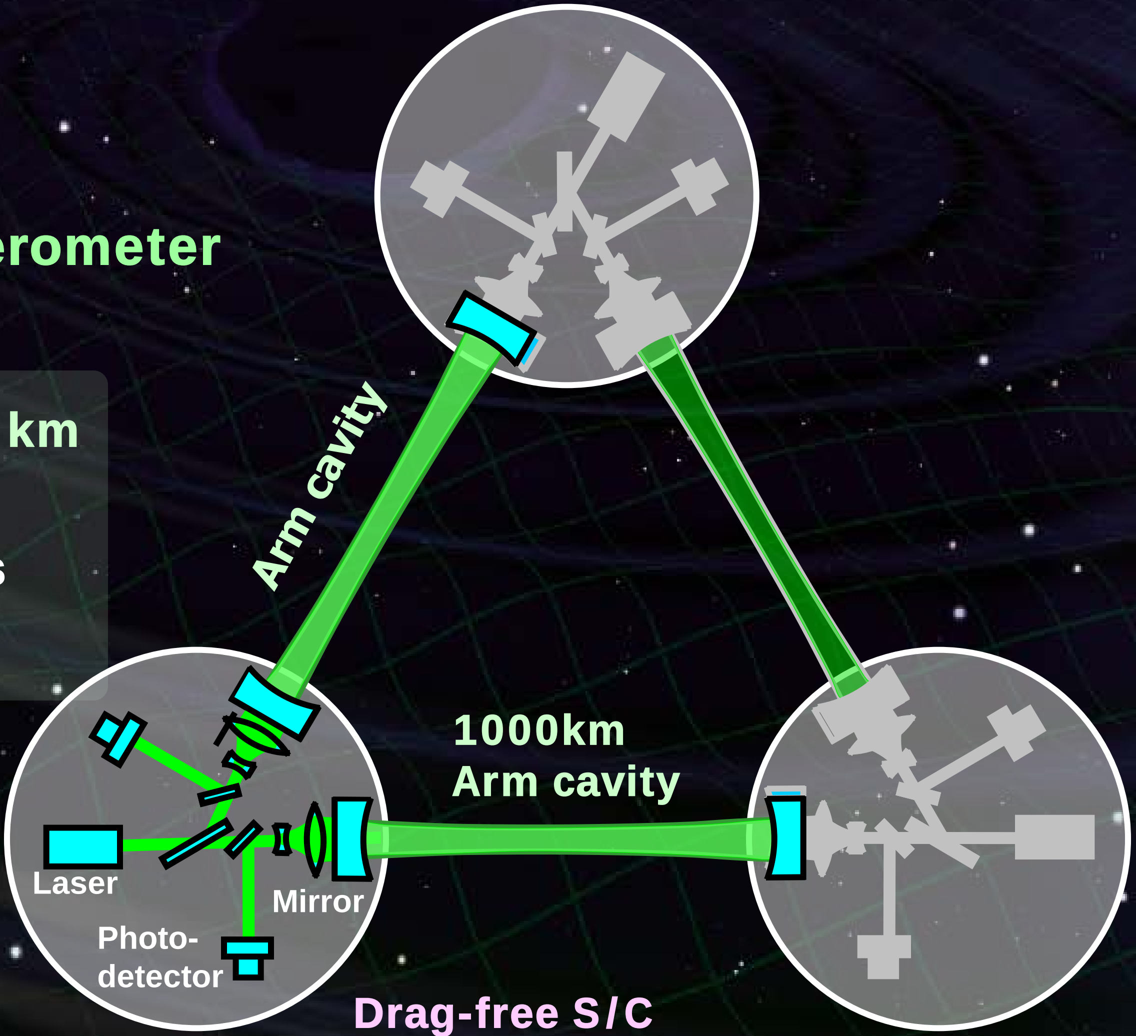
Differential FP interferometer

Baseline length: 1000 km

3 S/C formation flight

3 FP interferometers

Drag-free control



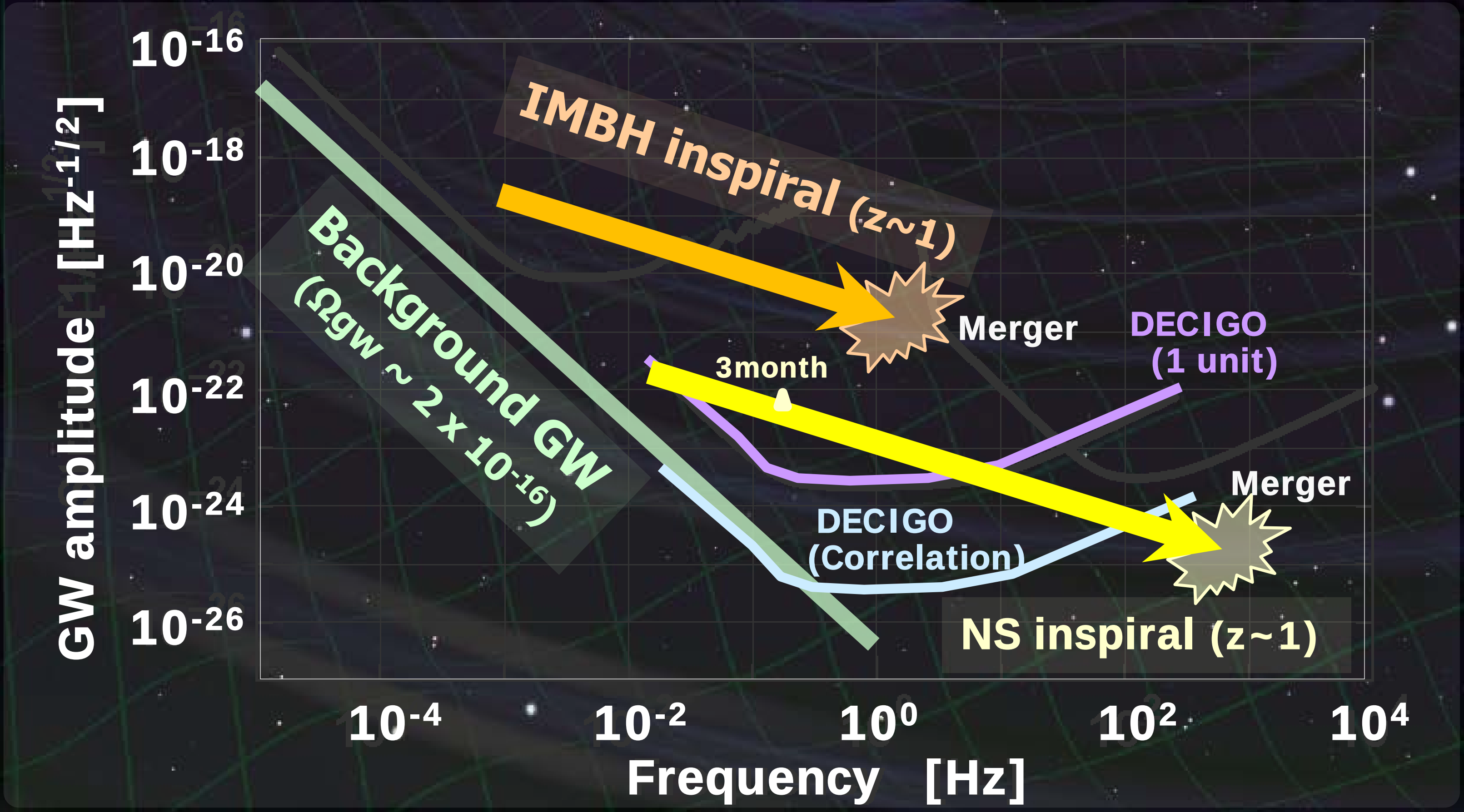
Gravity of the Earth (October 18, 2010, NASA/Goddard SFC, Greenbelt, USA)

Targets and Science

IMBH binary inspiral
NS binary inspiral
Stochastic background

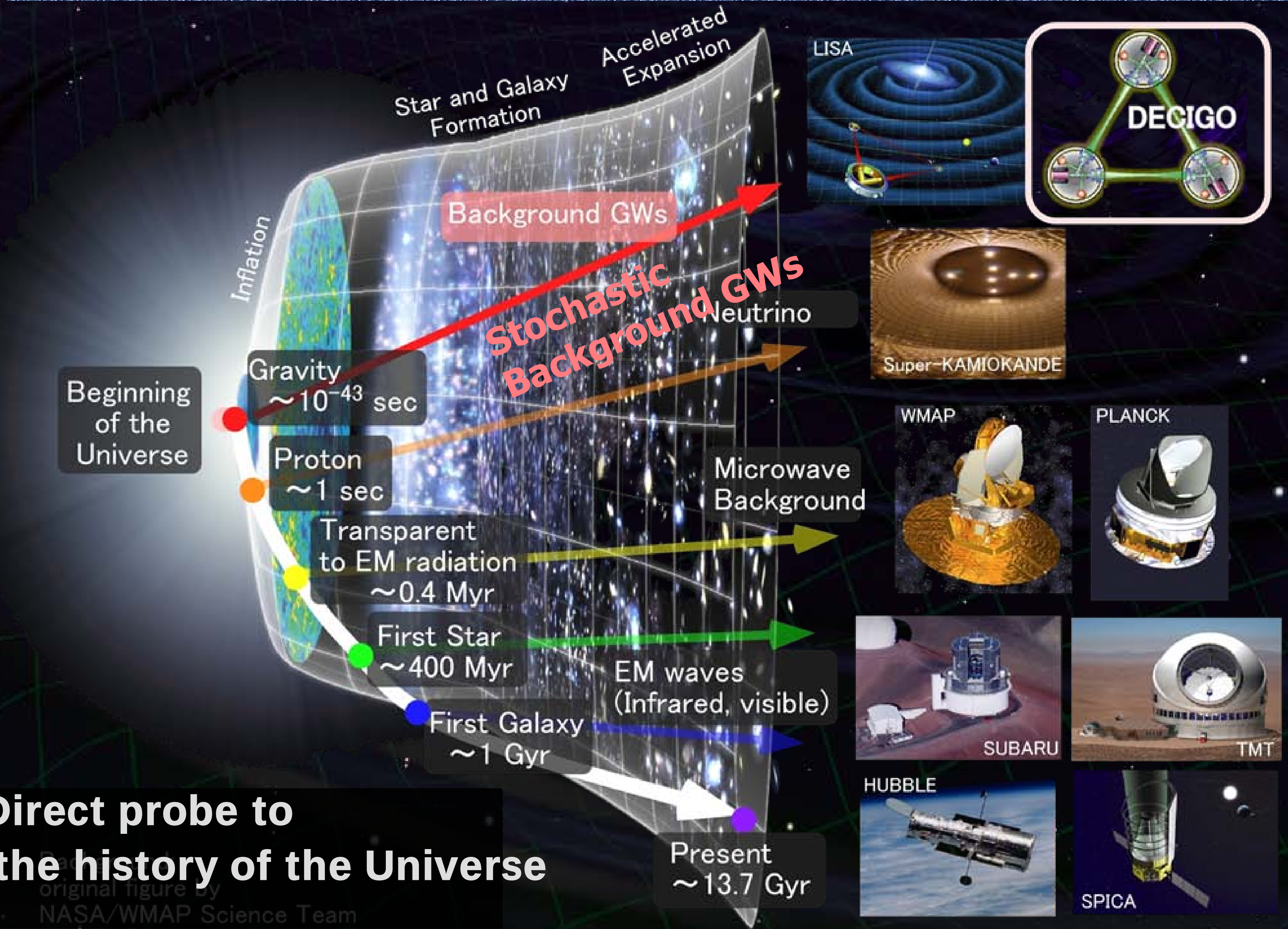
⇨

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

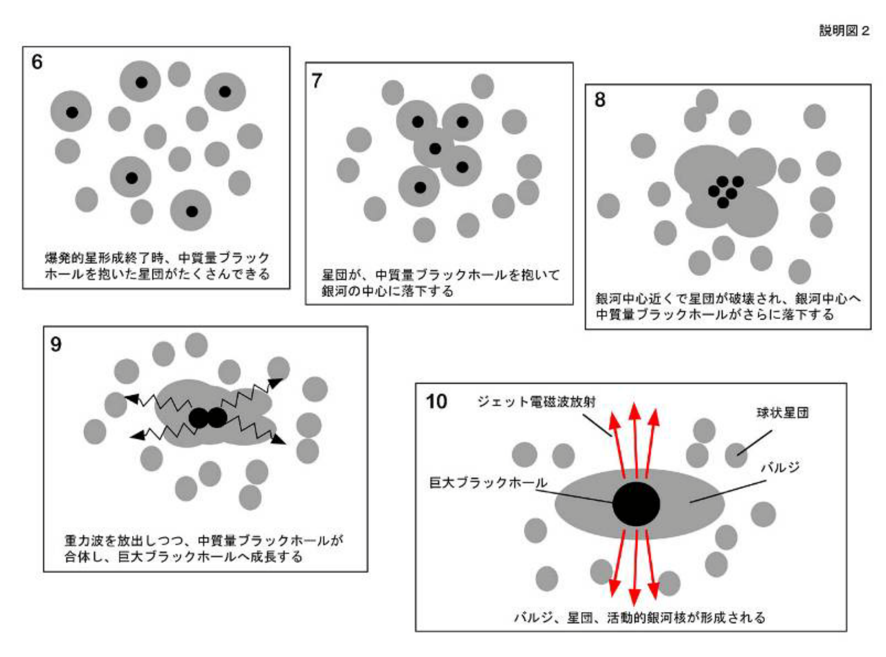
Gravity of the Earth (October 18, 2010, NASA/Goddard SFC, Greenbelt, USA)

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



爆発的星形成終了時、中質量ブラックホールを抱いた星団がたくさんできる

星団が、中質量ブラックホールを抱いて銀河の中心に落下する

銀河中心近くで星団が破壊され、銀河中心へ中質量ブラックホールがさらに落下する

重力波を放出しつつ、中質量ブラックホールが合体し、巨大ブラックホールへ成長する

バルジ、星団、活動的銀河核が形成される

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

- **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

2. DECIGO Pathfinder

Overview and Science

Design and Status

Space Demonstration

3. Summary

Pre-Conceptual Design

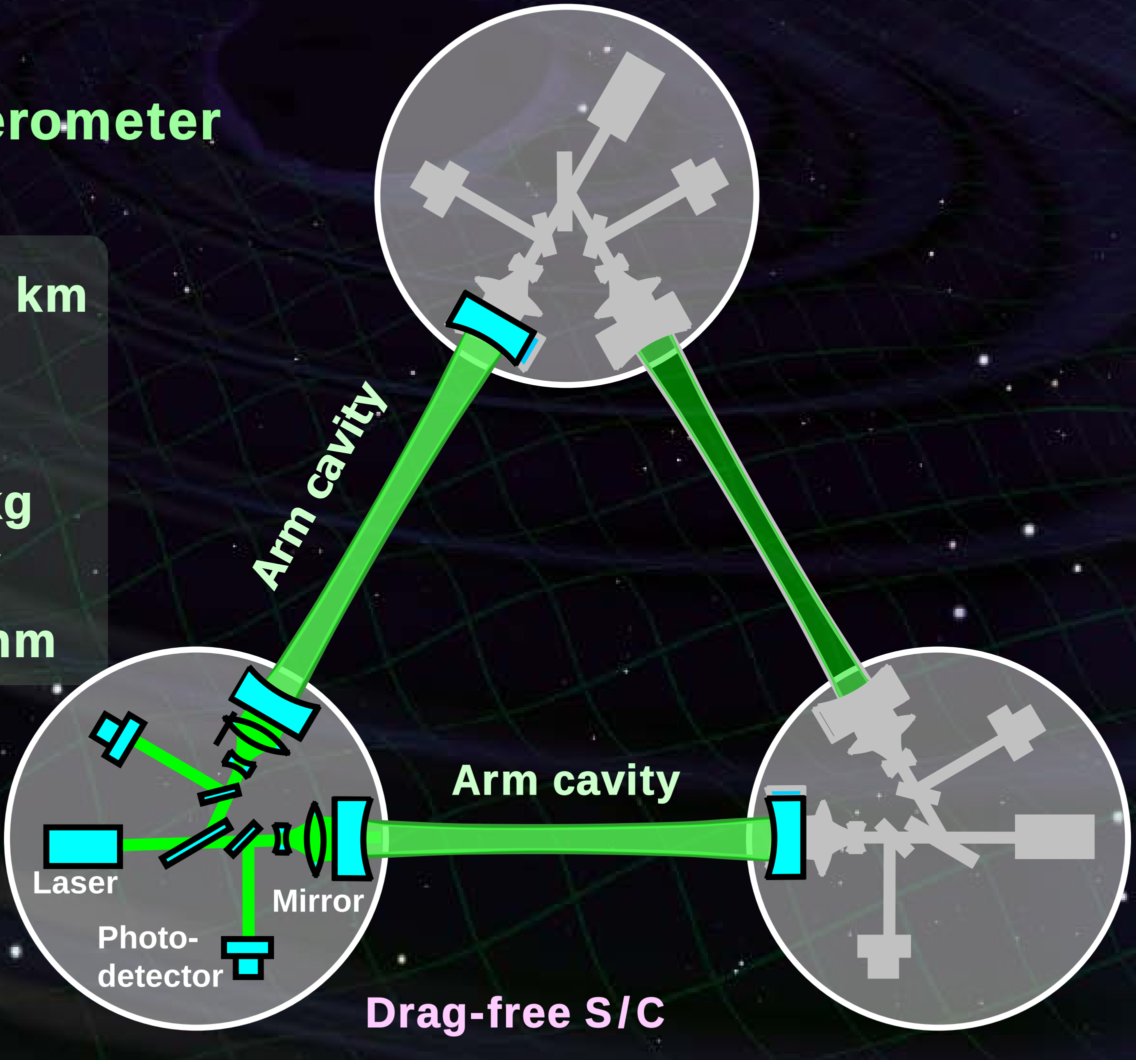
Interferometer Unit:

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

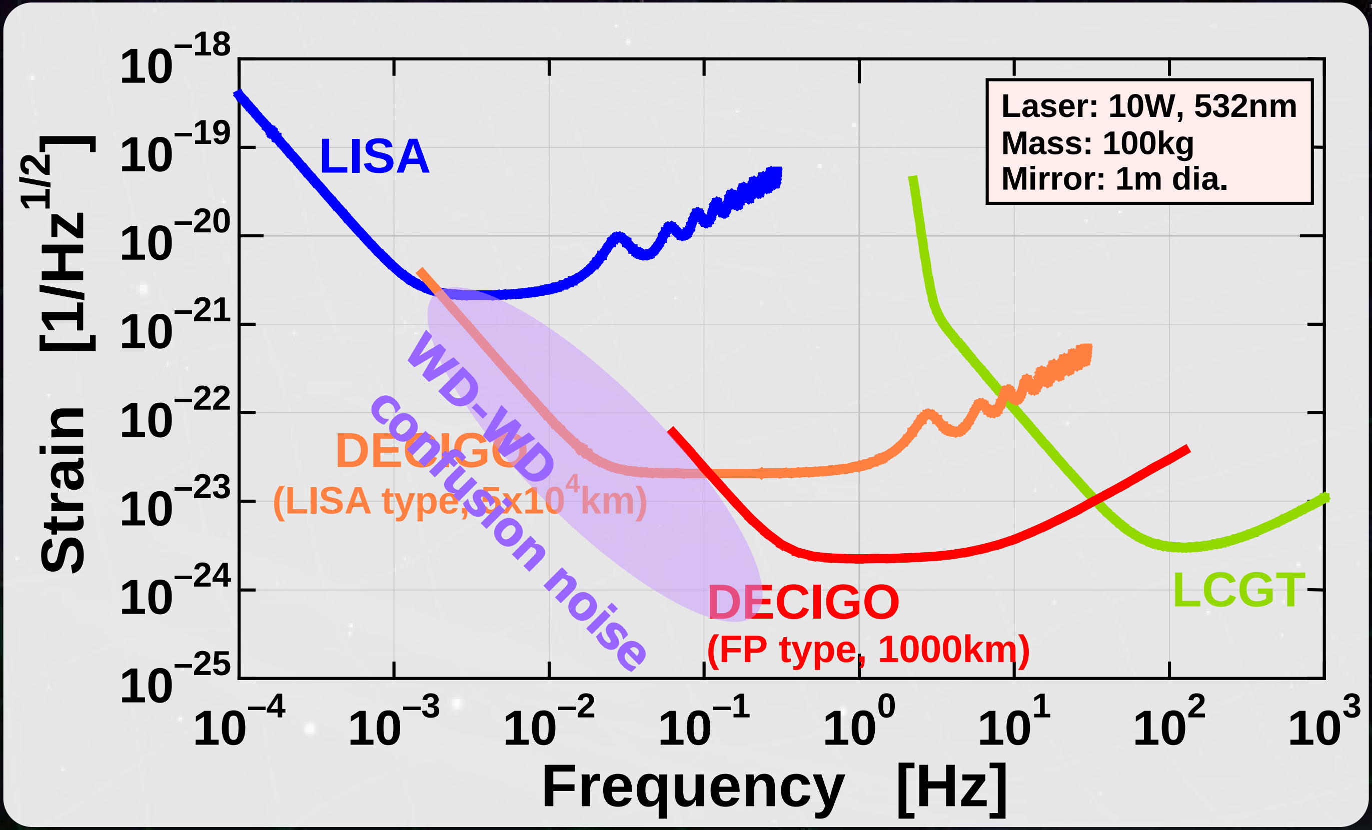


Interferometer Design

Transponder type vs **Direct-reflection type**

Compare : Sensitivity curves and Expected Sciences

⇨ **Decisive factor: Binary confusion noise**



Arm length

Cavity arm length : Limited by diffraction loss

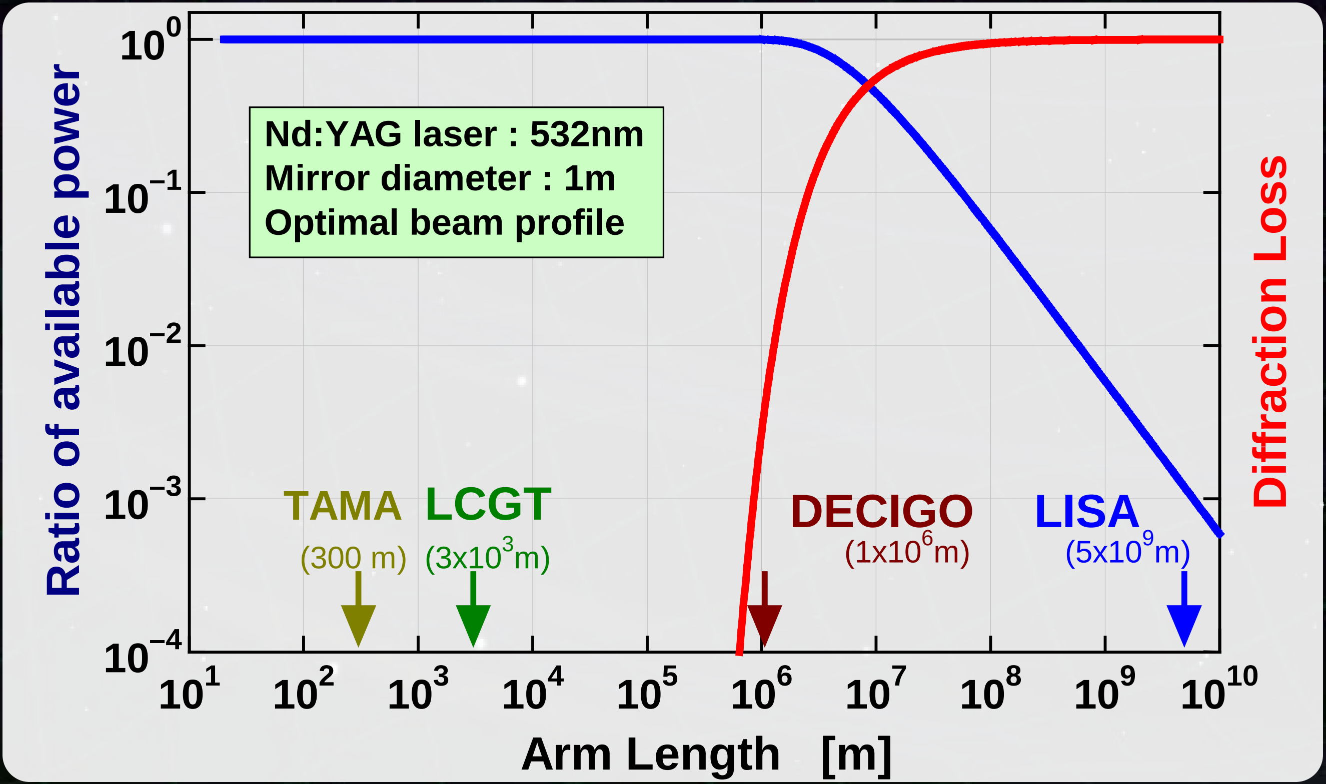
Effective reflectivity ($TEM_{00} \rightarrow TEM_{00}$)

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
→ $\Delta m/m < \sim 10^{-7}$ %

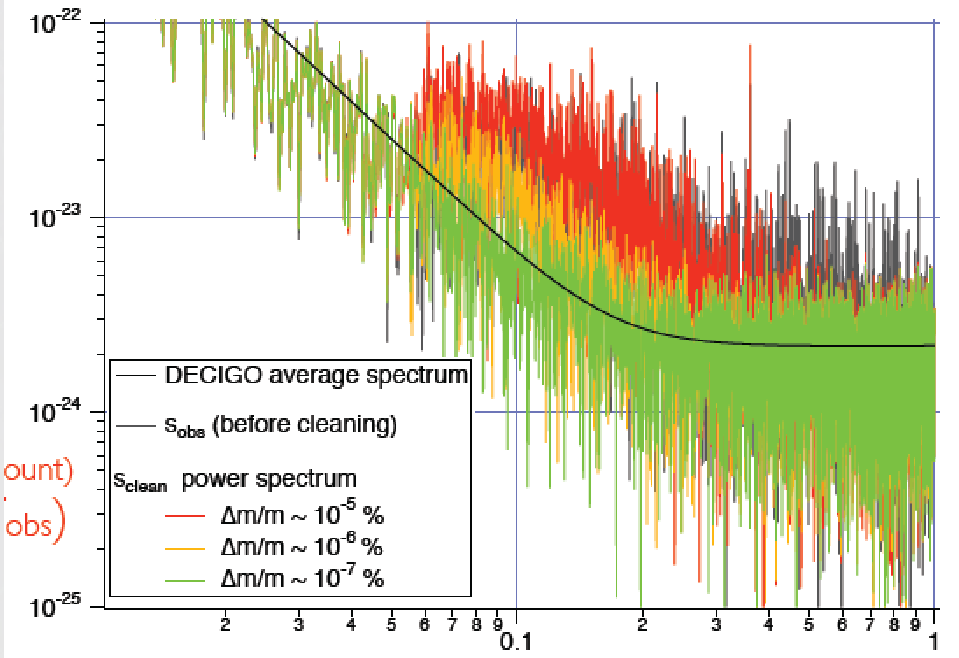


Fig: N. Kanda

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

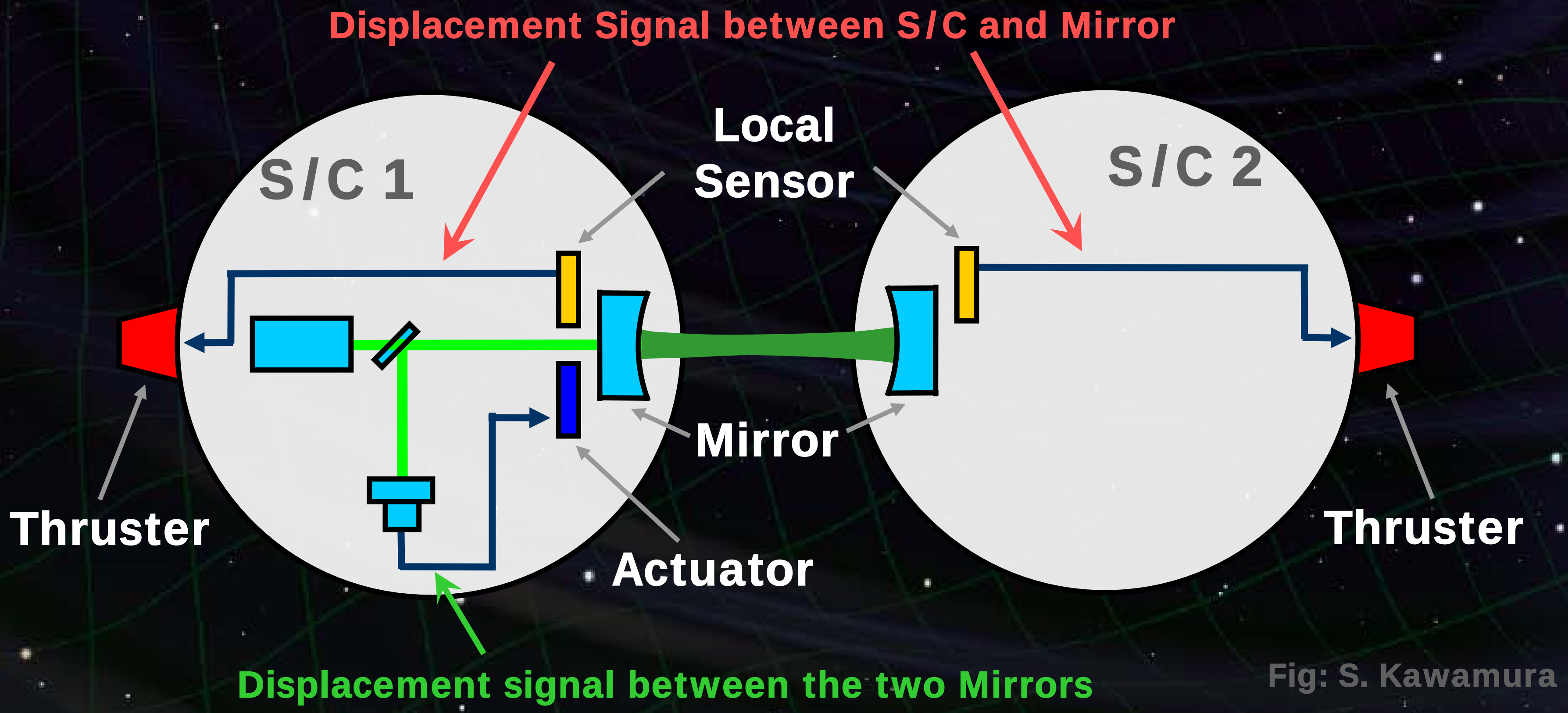


Fig: S. Kawamura

Requirements

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.

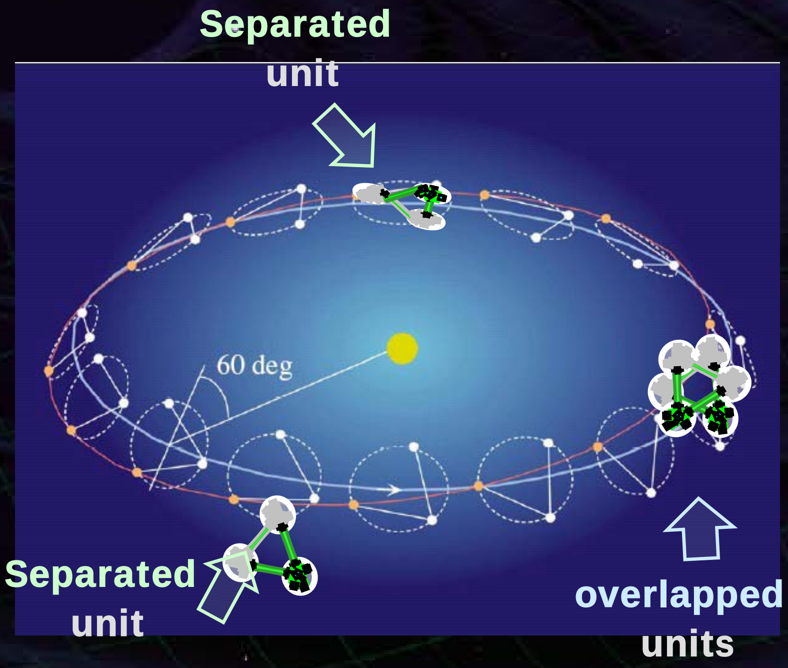
Orbit and Constellation

Candidate of orbit:

Record-disk orbit around the Sun

Relative acc. 4x10^{-12} m/s^{2}

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



Constellation

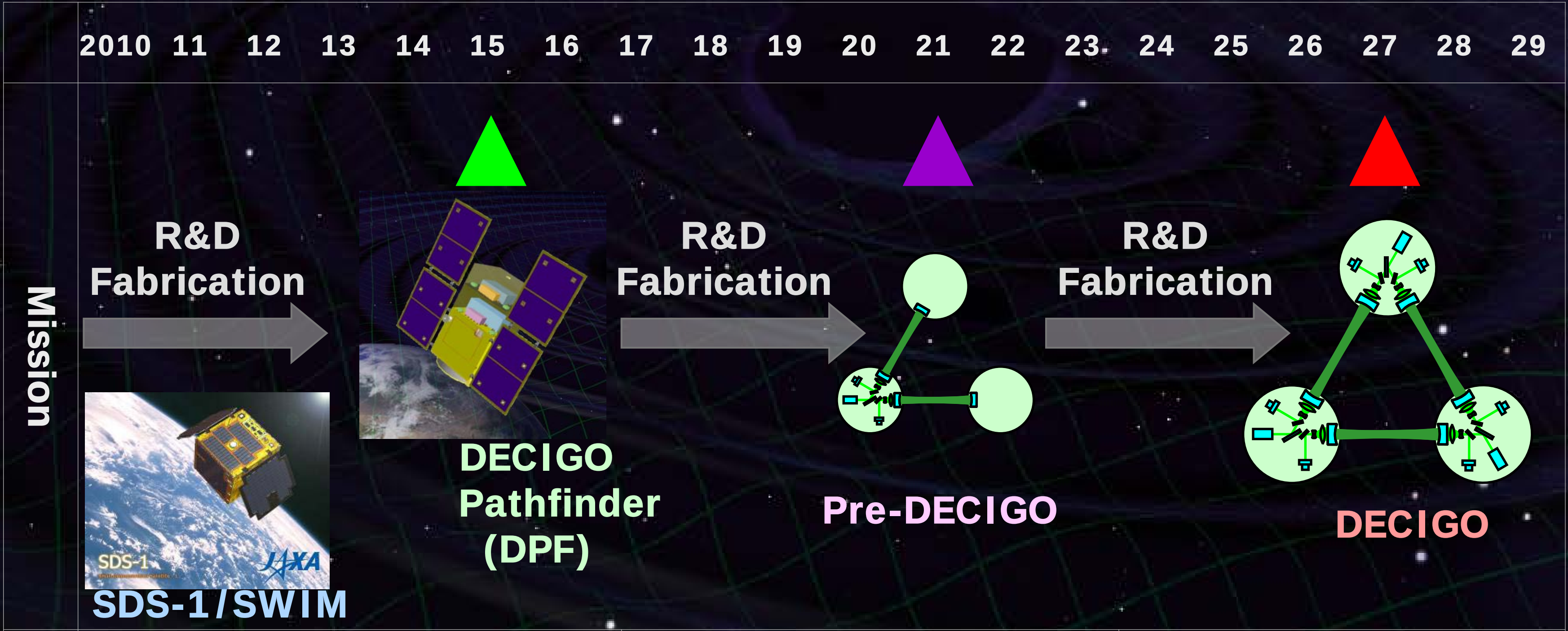
4 interferometer units

2 **overlapped** units → Cross correlation

2 **separated** units → Angular resolution

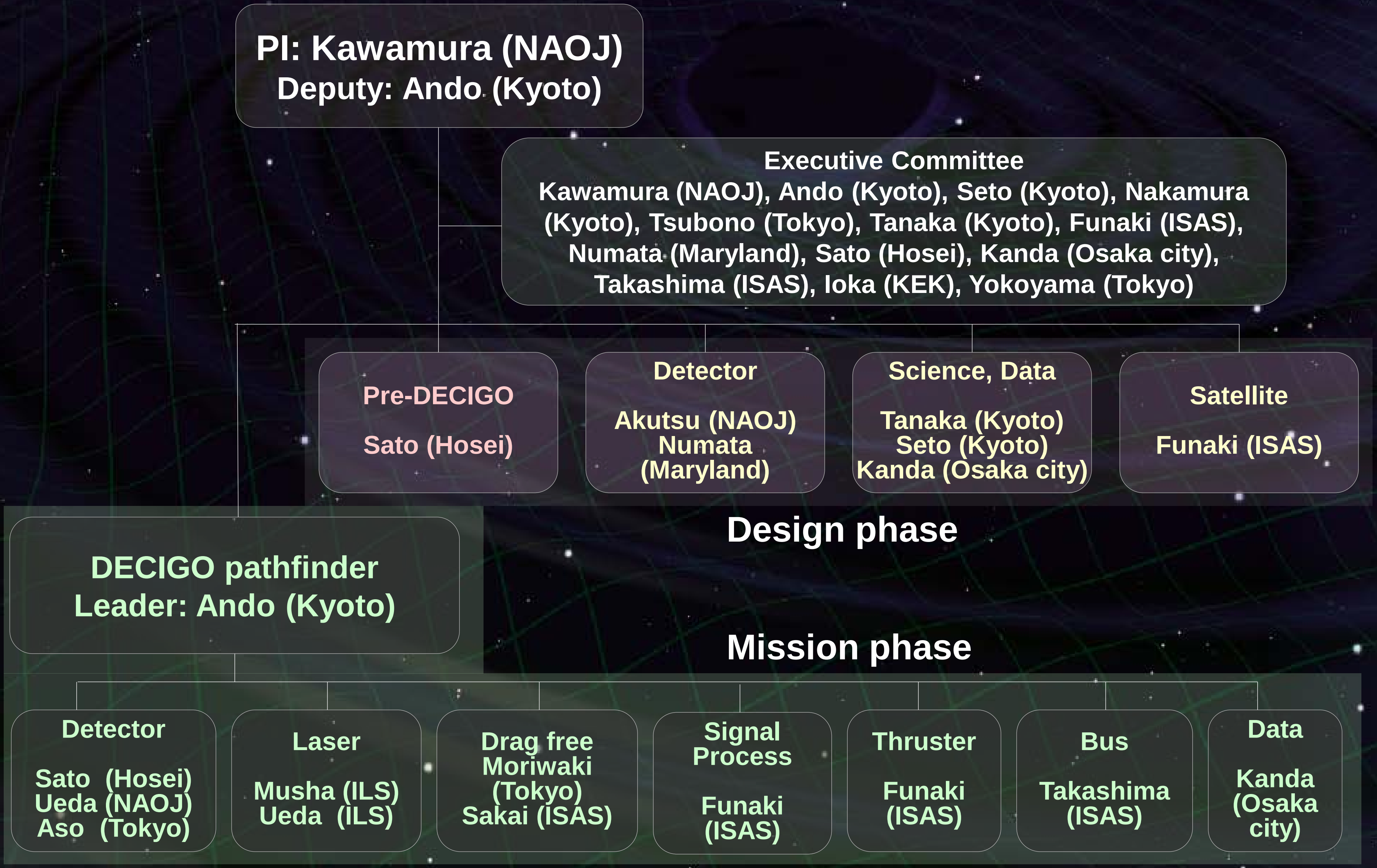
Roadmap

Figure: S.Kawamura



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



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)

Signal Process
Funaki (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

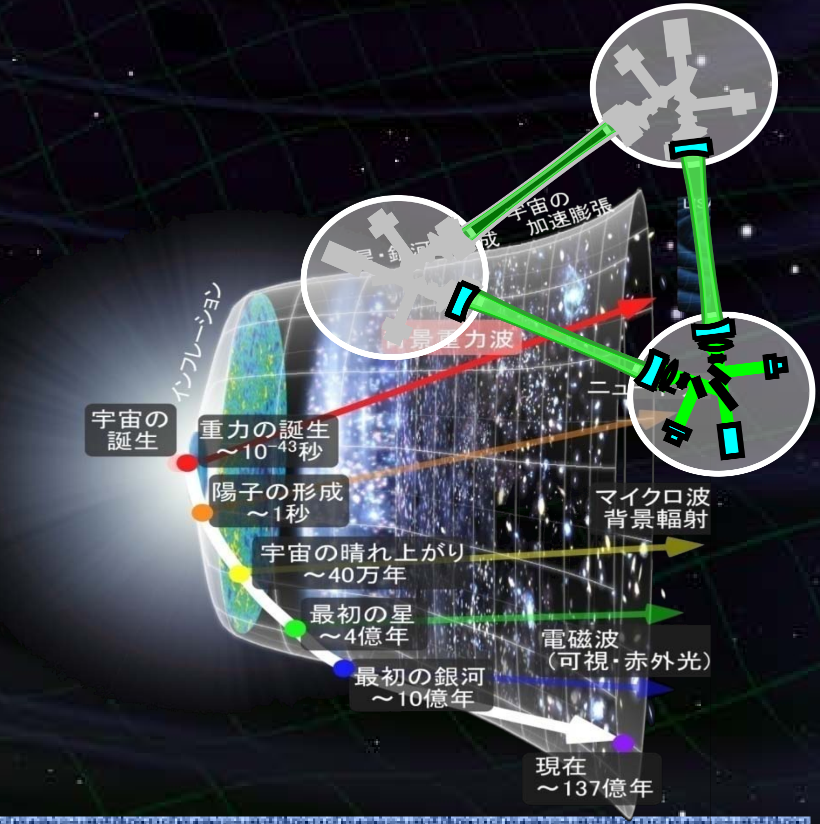
Target: GW detection

DECIGO (~2027)

Space observatory

→ Low frequency sources

Target: GW astronomy



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Overview and Science

Pre-conceptual Design

⇨ 2. DECIGO Pathfinder

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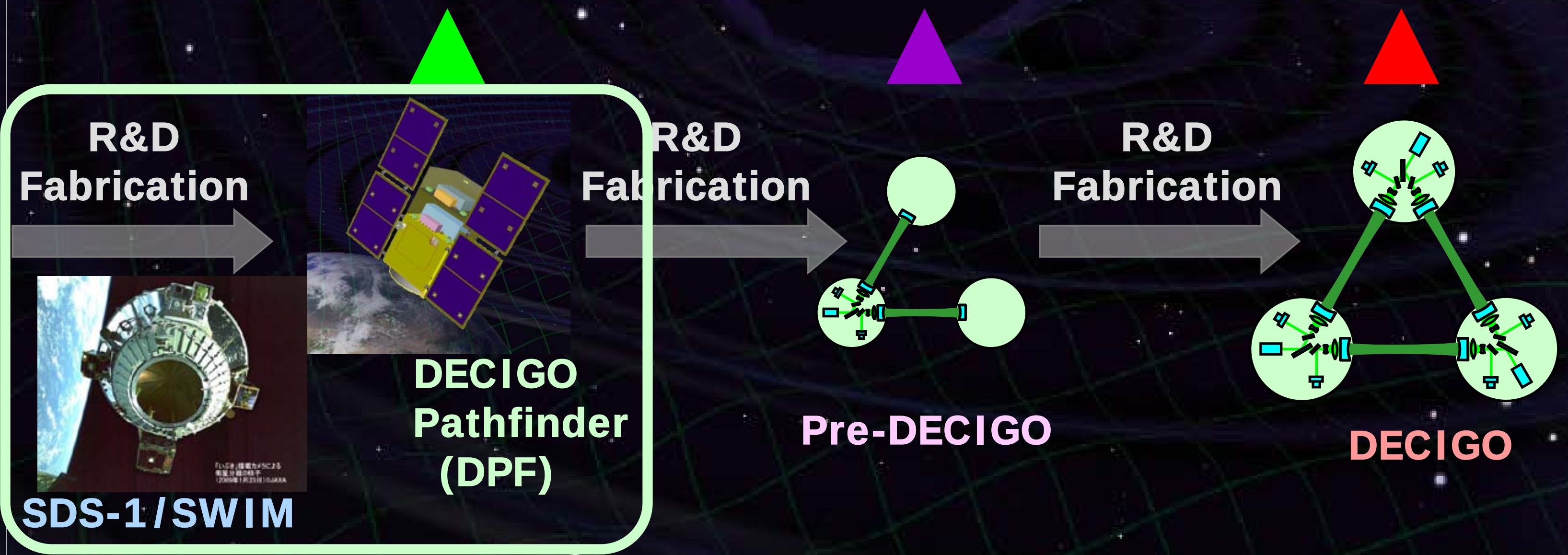
3. Summary

Roadmap

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. 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

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

DPF Payload

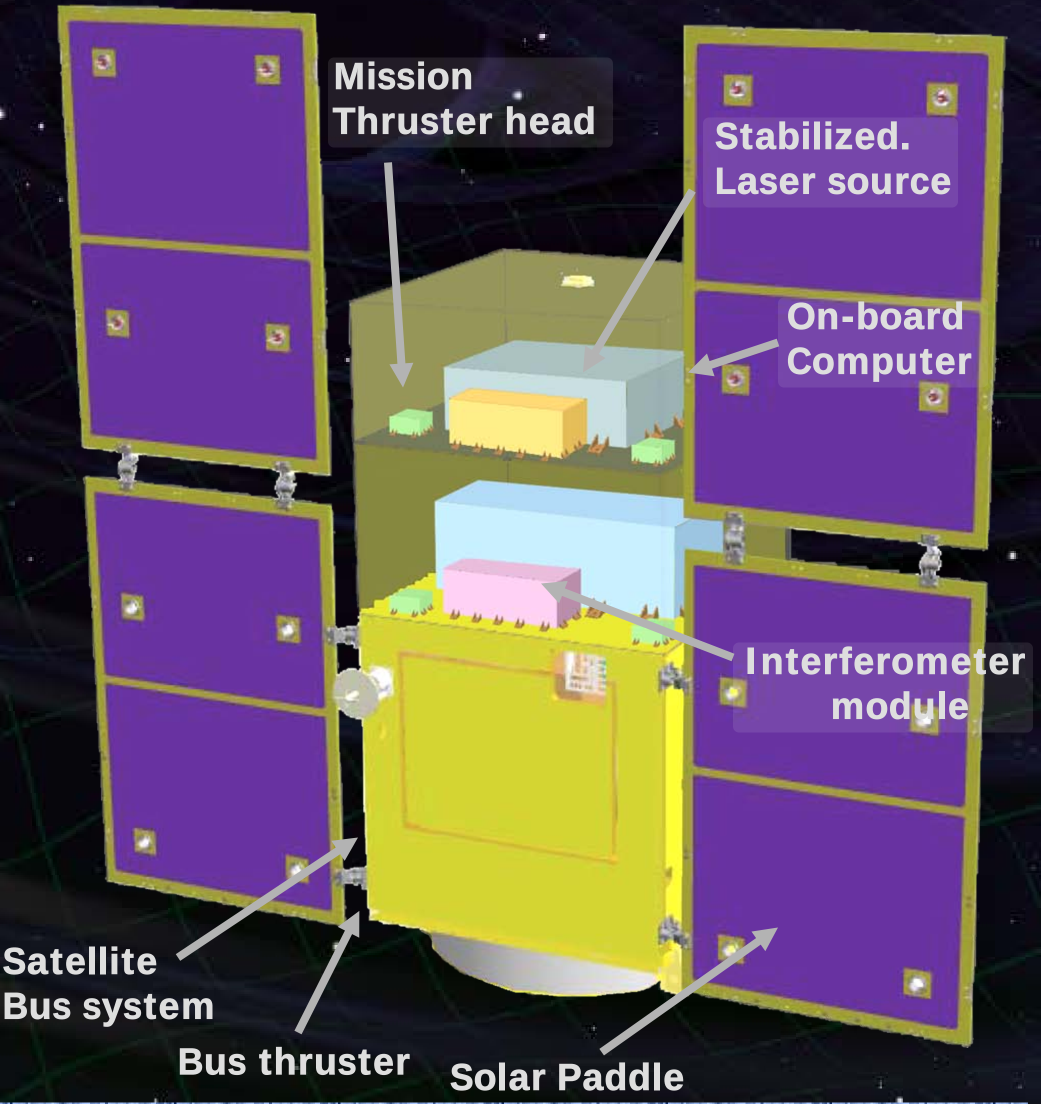
Size : 950mm cube
Weight : 150kg
Power : 130W
Data Rate: 800kbps
Mission thruster x12

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

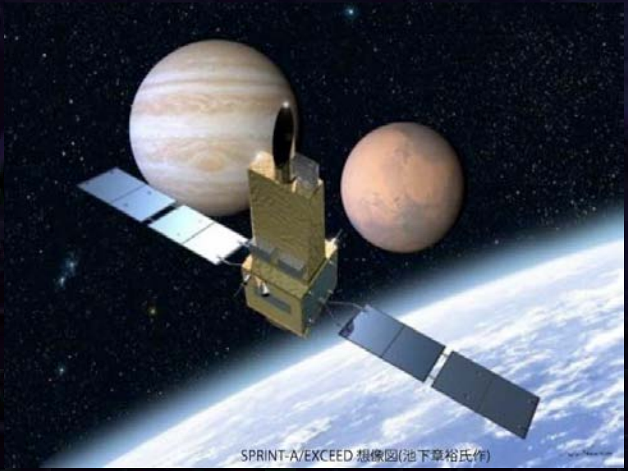


DPF mission status

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



SPRINT-A /EXCEED
UV telescope mission

1st mission (2012): SPRINT-A/EXCEED

2nd mission (~2013/14) : ERG

DPF survived until final two

3rd mission (~2015/16) : TBD

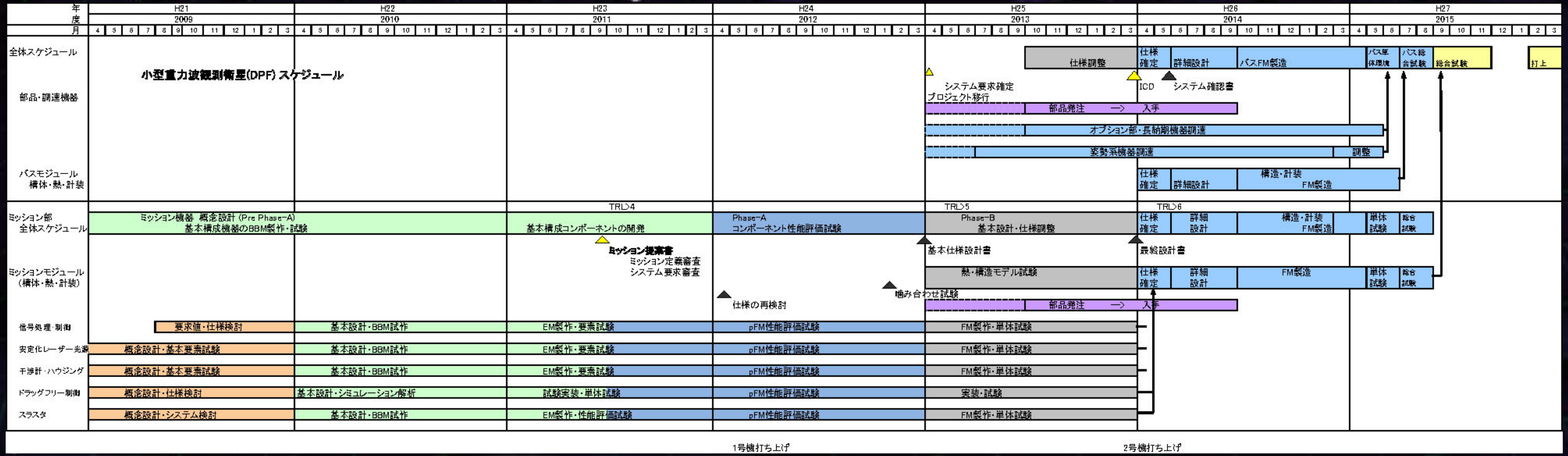
Next-generation
Solid rocket booster (M-V FO)
Fig. by JAXA

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

DPF Schedule

DECIGO

2009 2010 2011 2012 2013 2014 2015



小型重力波観測衛星(DPF) スケジュール

年	H21	H22	H23	H24	H25	H26	H27
度	2009	2010	2011	2012	2013	2014	2015
月	4 5 6 7 8 9 10 11 12 1 2 3	4 5 6 7 8 9 10 11 12 1 2 3	4 5 6 7 8 9 10 11 12 1 2 3	4 5 6 7 8 9 10 11 12 1 2 3	4 5 6 7 8 9 10 11 12 1 2 3	4 5 6 7 8 9 10 11 12 1 2 3	4 5 6 7 8 9 10 11 12 1 2 3
全体スケジュール					仕様調整 △ システム要求確定 プロジェクト移行	仕様確定 / 詳細設計 / バスFM製造 △ ICD ▲ システム確認書	バス単体環境 / バス総合試験 / 総合試験 / 打上
部品・調達機器					部品発注 —>	入手	
					オプション部・長納期機器調達	オプション部・長納期機器調達	
					姿勢系機器調達	姿勢系機器調達 / 調整	
バスモジュール 構体・熱・計装						仕様確定 / 詳細設計 / 構造・計装 FM製造	
			TRL>4		TRL>5	TRL>6	
ミッション部 全体スケジュール	ミッション機器 概念設計 (Pre Phase-A) 基本構成機器のBBM製作・試験		基本構成コンポーネントの開発	Phase-A コンポーネント性能評価試験	Phase-B 基本設計・仕様調整	仕様確定 / 詳細設計 / 構造・計装 FM製造	単体試験 / 総合試験
			△ ミッション提案書 ミッション定義審査 システム要求審査		▲ 基本仕様設計書	▲ 最終設計書	
ミッションモジュール（構体・熱・計装）				▲ 仕様の再検討 ▲ 噛み合わせ試験	熱・構造モデル試験	仕様確定 / 詳細設計 / FM製造	単体試験 / 総合試験
					部品発注 —>	入手	
信号処理・制御	要求値・仕様検討	基本設計・BBM試作	EM製作・要素試験	pFM性能評価試験	FM製作・単体試験		
安定化レーザー光源	概念設計・基本要素試験	基本設計・BBM試作	EM製作・要素試験	pFM性能評価試験	FM製作・単体試験		
干渉計・ハウジング	概念設計・基本要素試験	基本設計・BBM試作	EM製作・要素試験	pFM性能評価試験	FM製作・単体試験		
ドラッグフリー制御	概念設計・仕様検討	基本設計・シミュレーション解析	試験実装・単体試験	pFM性能評価試験	実装・試験		
スラスタ	概念設計・システム検討	基本設計・BBM試作	EM製作・性能評価試験	pFM性能評価試験	FM製作・単体試験		
				1号機打ち上げ		2号機打ち上げ	

Conceptual design **BBM** **EM / pFM** **Component FM** **Satellite FM** **Tests and Launch**

Mission proposal
Require >TRL 4

Complete component FM

Orbit and attitude

Satellite Orbit

Low-earth orbit

- Altitude 500km, Inclination 98 deg
- Eccentricity < 10^{-3} (accuracy of the launcher)
- Orbital period ~100min
- Sun-synchronous, dusk-dawn orbit for thermal stability
- (eclipse ~100days/yr, 25 min max)

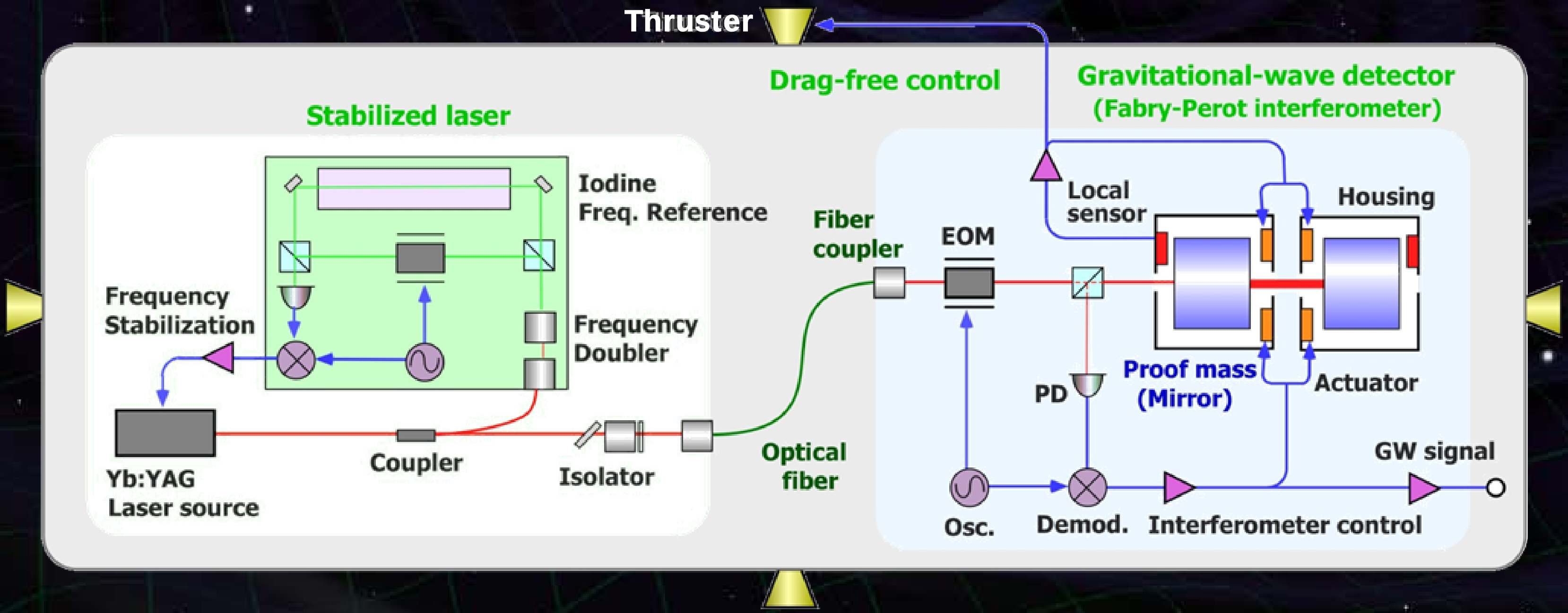
Satellite Attitude (under discussion)

- Sun and Earth synchronous attitude
- IFO optical axis parallel to the earth-vertical line

DPF mission payload

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

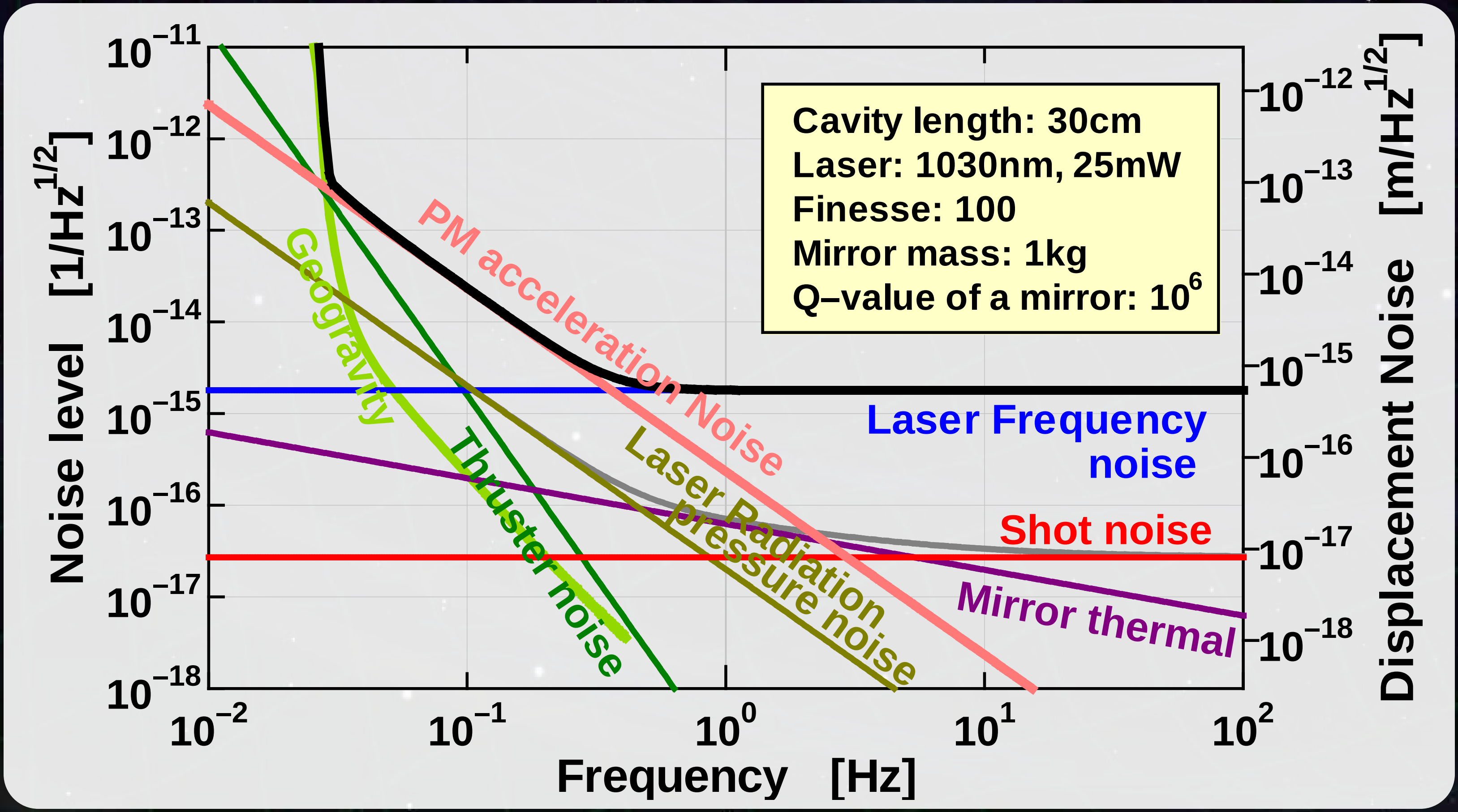
Fabry-Perot interferometer
Finesse : 100
Length : 30cm
Test mass : ~a few kg
Signal extraction by PDH

DPF Sensitivity

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)



Gravity of the Earth (October 18, 2010, NASA/Goddard SFC, Greenbelt, USA)

Key requirements

DECIGO

Sensor Noise

Disp. noise 6×10^{-16} m/Hz$^{1/2}$ (0.1 Hz)

⇨ x 200 of DECIGO in disp. noise

Other noises

Laser freq. noise: 0.5 Hz/Hz$^{1/2}$ (1Hz)

Acceleration Noise

Force noise 1×10^{-15} m/s^2/Hz$^{1/2}$ (0.1 Hz)

⇨ x 250 of DECIGO

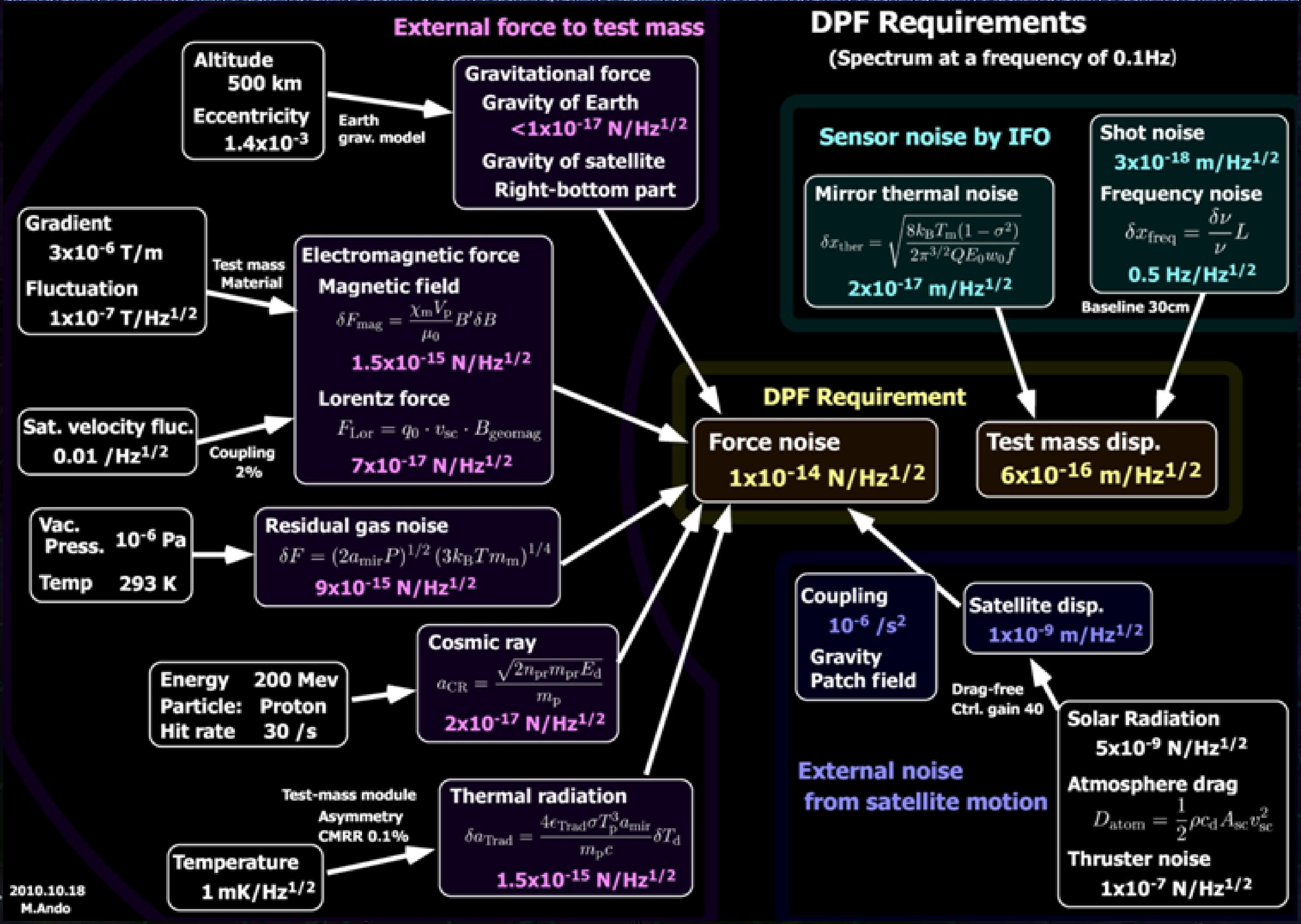
Satellite motion

Disp. noise 1×10^{-9} m/Hz$^{1/2}$ (0.1 Hz)

External force sources

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

DPF Requirements



External force to test mass

DPF Requirements

(Spectrum at a frequency of 0.1Hz)

Altitude 500 km

Eccentricity 1.4×10^{-3}

Earth grav. model

Gravitational force

Gravity of Earth

$<1\times10^{-17}$ N/Hz$^{1/2}$

Gravity of satellite

Right-bottom part

Gradient 3×10^{-6} T/m

Fluctuation 1×10^{-7} T/Hz$^{1/2}$

Test mass Material

Electromagnetic force

Magnetic field

$$\delta F_{\rm mag} = \frac{\chi_{\rm m} V_{\rm p}}{\mu_0} B' \delta B$$

1.5×10^{-15} N/Hz$^{1/2}$

Lorentz force

$$F_{\rm Lor} = q_0 \cdot v_{\rm sc} \cdot B_{\rm geomag}$$

7×10^{-17} N/Hz$^{1/2}$

Sat. velocity fluc. 0.01 /Hz$^{1/2}$

Coupling 2%

Vac. Press. 10^{-6} Pa

Temp 293 K

Residual gas noise

$$\delta F = (2 a_{\rm mir} P)^{1/2} (3 k_{\rm B} T m_{\rm m})^{1/4}$$

9×10^{-15} N/Hz$^{1/2}$

Energy 200 Mev

Particle: Proton

Hit rate 30 /s

Cosmic ray

$$a_{\rm CR} = \frac{\sqrt{2 n_{\rm pr} m_{\rm pr} E_{\rm d}}}{m_{\rm p}}$$

2×10^{-17} N/Hz$^{1/2}$

Test-mass module Asymmetry CMRR 0.1%

Temperature 1 mK/Hz$^{1/2}$

Thermal radiation

$$\delta a_{\rm Trad} = \frac{4 \epsilon_{\rm Trad} \sigma T_{\rm p}^3 a_{\rm mir}}{m_{\rm p} c} \delta T_{\rm d}$$

1.5×10^{-15} N/Hz$^{1/2}$

Sensor noise by IFO

Mirror thermal noise

$$\delta x_{\rm ther} = \sqrt{\frac{8 k_{\rm B} T_{\rm m} (1-\sigma^2)}{2\pi^{3/2} Q E_0 w_0 f}}$$

2×10^{-17} m/Hz$^{1/2}$

Shot noise

3×10^{-18} m/Hz$^{1/2}$

Frequency noise

$$\delta x_{\rm freq} = \frac{\delta\nu}{\nu} L$$

0.5 Hz/Hz$^{1/2}$

Baseline 30cm

DPF Requirement

Force noise 1×10^{-14} N/Hz$^{1/2}$

Test mass disp. 6×10^{-16} m/Hz$^{1/2}$

Coupling 10^{-6} /s^2

Gravity Patch field

Satellite disp. 1×10^{-9} m/Hz$^{1/2}$

Drag-free Ctrl. gain 40

External noise from satellite motion

Solar Radiation 5×10^{-9} N/Hz$^{1/2}$

Atmosphere drag

$$D_{\rm atom} = \frac{1}{2} \rho c_{\rm d} A_{\rm sc} v_{\rm sc}^2$$

Thruster noise 1×10^{-7} N/Hz$^{1/2}$

2010.10.18
M.Ando

Gravity of the Earth (October 18, 2010, NASA/Goddard SFC, Greenbelt, USA)

Some examples

Fluctuation (spectrum) is important
at observation band (0.1-1 Hz)

Mechanical fluctuation

Satellite 1×10^{-9} m/Hz$^{1/2}$

Test mass fluctuation by coupling by electromagnetic field, gravity, etc.

Magnetic field

Fluctuation 1×10^{-7} T/Hz$^{1/2}$

Divergence 3×10^{-6} T/m

Test mass fluctuation by magnetic field

Temperature

Fluctuation 1×10^{-3} K/Hz$^{1/2}$
(Inner surface of TMM)

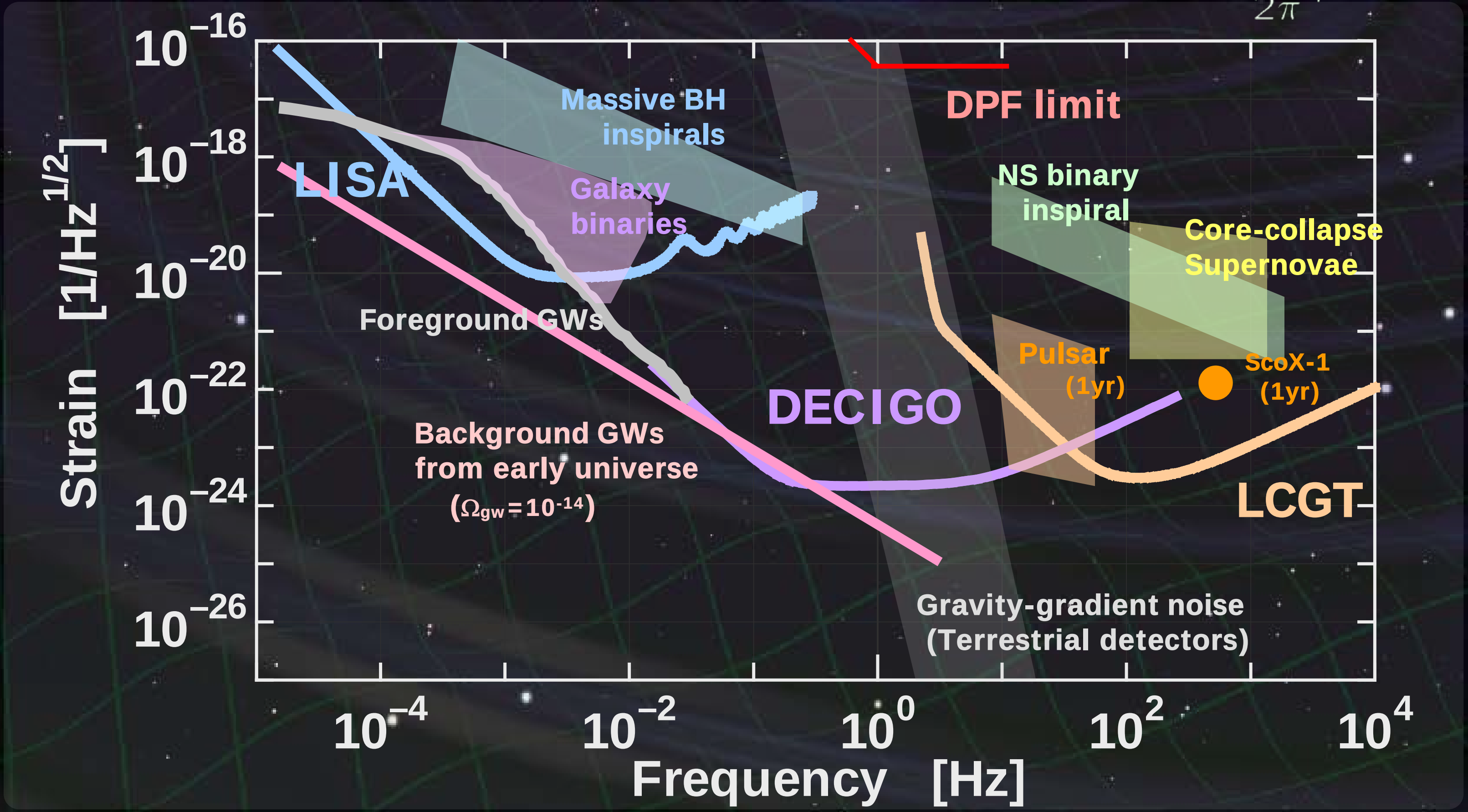
Test mass fluctuation by thermal radiation

DPF sensitivity

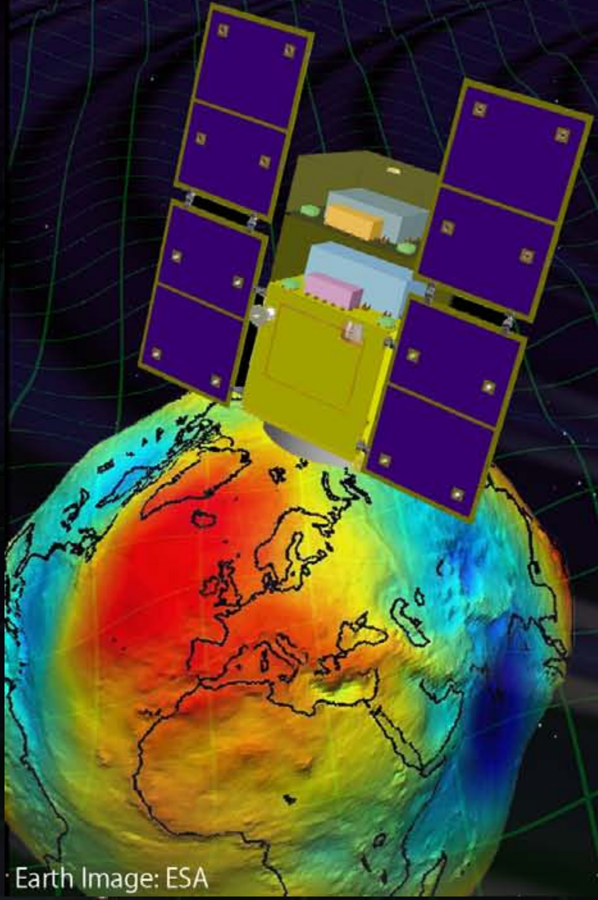
DPF sensitivity $h \sim 2\mathrm{x}10^{-15}\ \mathrm{Hz}^{1/2}$

(x10 of quantum noises)

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



Targets of DPF


Earth Image: ESA

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

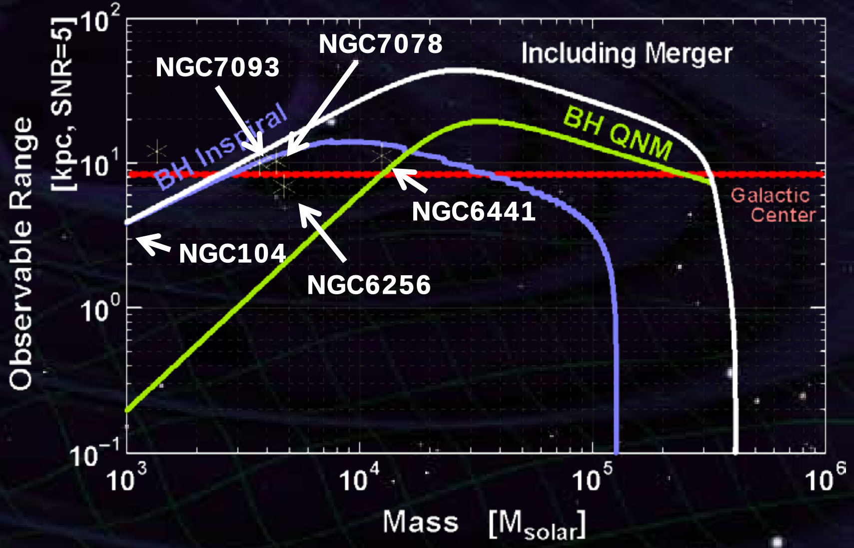
DPF Targets

Astronomical observation

GW from merger of IMBHs

→ Formation mechanism of supermassive BHs

~30 GCs within DPF range



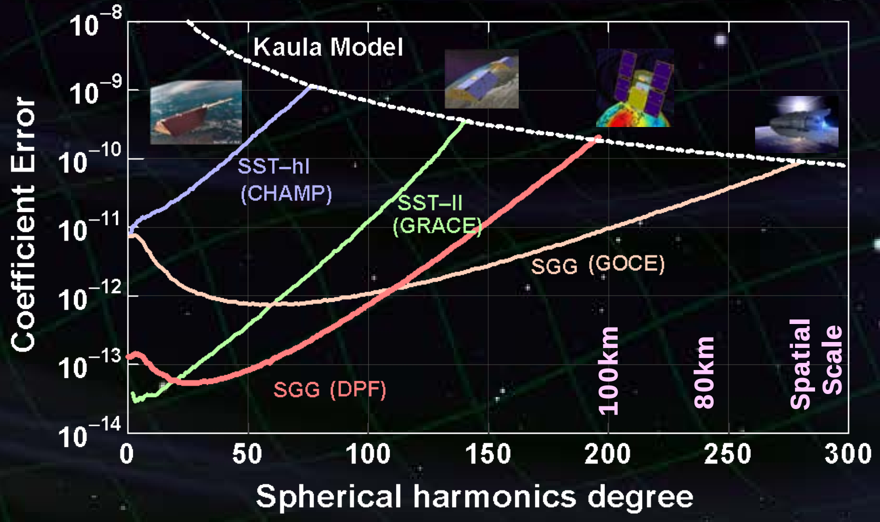
Observation of the earth

Gravitational potential

→ Shape of the earth

Environment monitor

Comparable sensitivity with other missions



GW target of DPF

Blackholes events in our galaxy

IMBH inspiral and merger

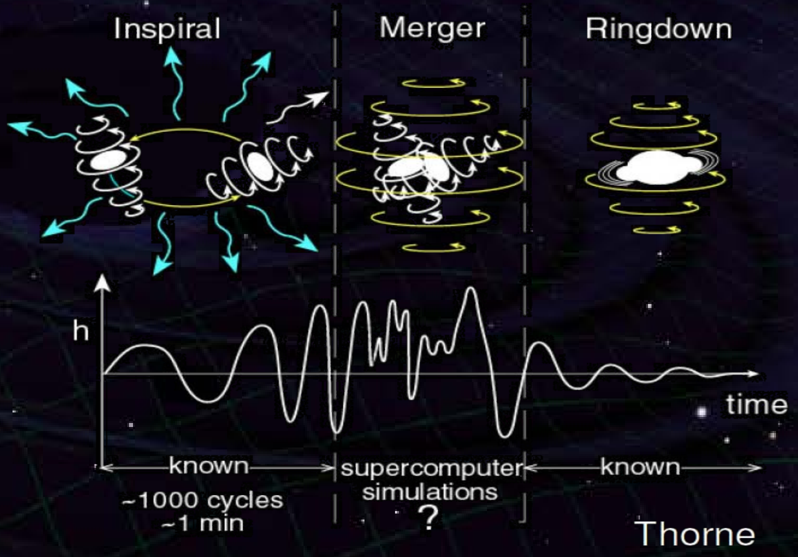
$h \sim 10^{-15}$, $f \sim$ 4 Hz
Distance 10kpc, $m = 10^3 M_{sun}$
Obs. Duration (~1000sec)

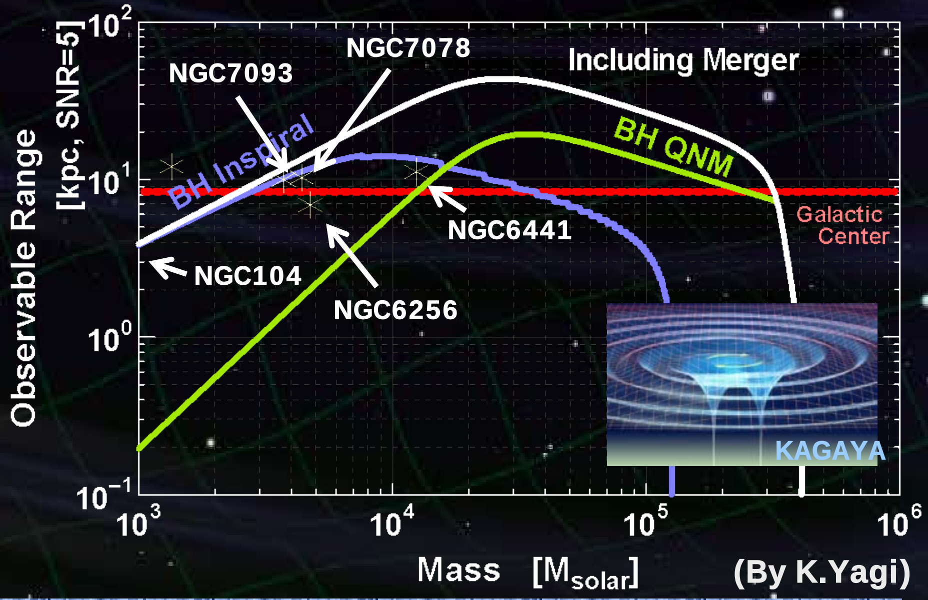
BH QNM

$h \sim 10^{-15}$, $f \sim$ 0.3 Hz
Distance 1Mpc, $m = 10^5 M_{sun}$

Observable range covers our Galaxy (SNR~5)

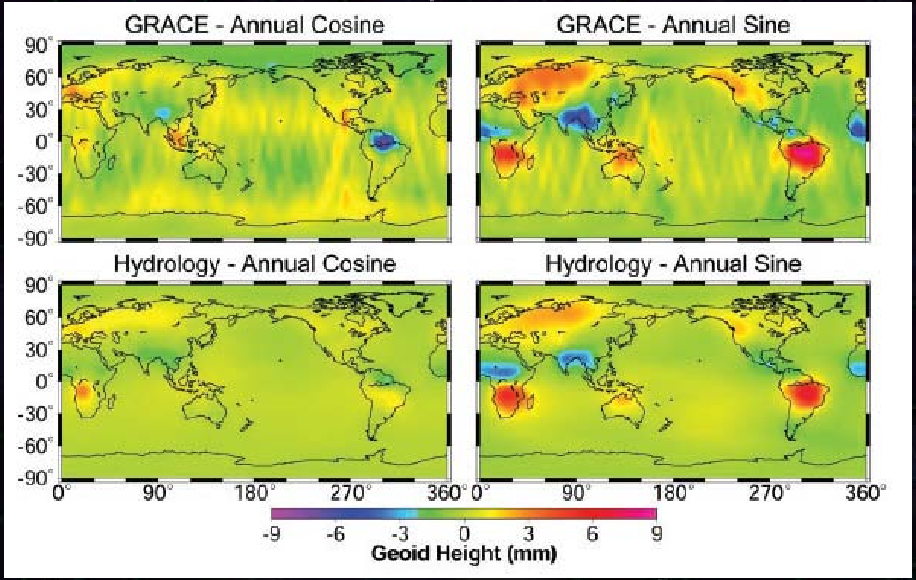
Hard to access by others
→ Original observation





Earth's Gravity Observation

Measure gravity field of the Earth
from Satellite Orbits, and gravity-gradiometer
⇨ comprehensive and homogeneous-quality data



Seasonal change of the gravitational potential observed by GRACE

Determine global gravity field
→ Basis of the shape of the Earth (Geoid)

Monitor of change in time
→ Result of Earth's dynamics
Ground water motion
Strains in crusts by earthquakes and volcanoes

Observation Gap between
GRACE and GRACE-FO (2012-16)

→ DPF contribution
in international network

Gravity of the Earth (October 18, 2010, NASA/Goddard SFC, Greenbelt, USA)

Satellite Gravity missions

3-types of satellite gravity missions

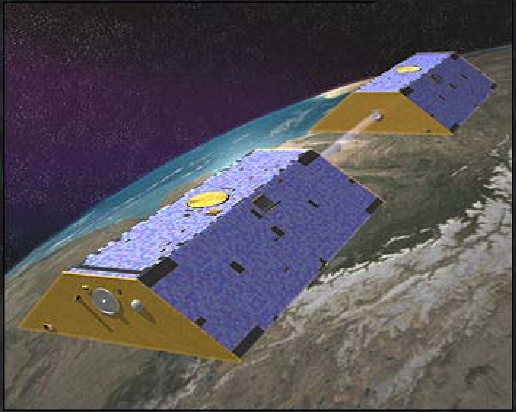
Satellite-to Satellite tracking High-Low

- Observe satellite orbit by global positioning system (GPS,…)
- Cancel drag-effects by accelerometer

CHAMP (GFZ, 2000-)

Satellite-to Satellite tracking Low-Low

- Distance meas. by along-track satellites
- Cancel drag-effects by accelerometer



GRACE (NASA, 2002-)

Satellite Gravity Gradiometry

- Observe potential by gravity gradiometer
- Drag-free control for cancellation of drags

GOCE (ESA, 2009-)

Results and plans

CHAMP,GRACE, GOCE in operation

- Shape of the Earth

  Coefficients up to 2190 orders

  (GRACE etc., 2008)

  ⇨ Earth standard with high precision and resolution
- Changes in time

  Seasonal movement of waters

  Crust deformation by earthquakes

  (Sumatera 2004)

Will be ended by around by 2012

GRACE-FO (NASA)

Based on GRACE,

Add laser interferometer

To be launched in2016

The Future of Satellite Gravimetry

Report from the

Workshop on The Future of Satellite Gravimetry

12-13 April 2007, ESTEC, Noordwijk, The Netherlands

Radboud Koop and Reiner Rummel (Eds.)

IAS

Earth Gravity model

Describe gravity potential by
Spherical harmonic functions

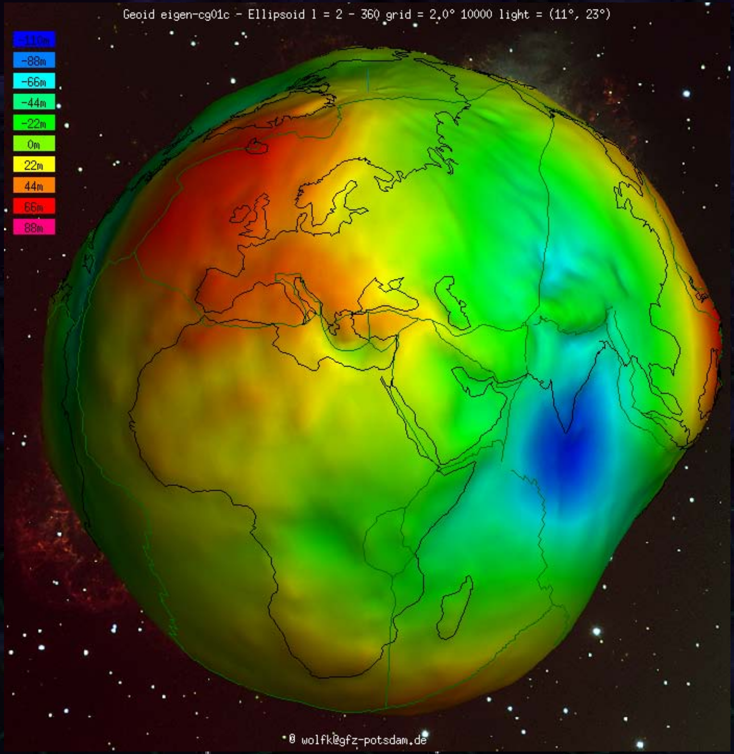
$$U(r,\lambda,\phi) = \frac{GM}{r}\sum_{l=0}^{\infty}\sum_{m=0}^{n}\left(\frac{R}{r}\right)^{l} P_{lm}(\sin\phi) \times [C_{lm}\cos(m\lambda) + S_{lm}\sin(m\lambda)]$$

$G, \ M, \ R$: Grav. Const., Mass and radius of the Earth

$r, \ \lambda, \ \phi$: Orbital radius, longitude, altitude

P_{lm} : Associated Legendre functions

Coefficients C_{lm} , S_{lm} :
Describe the mass distribution
Determined by satellite missions, etc.



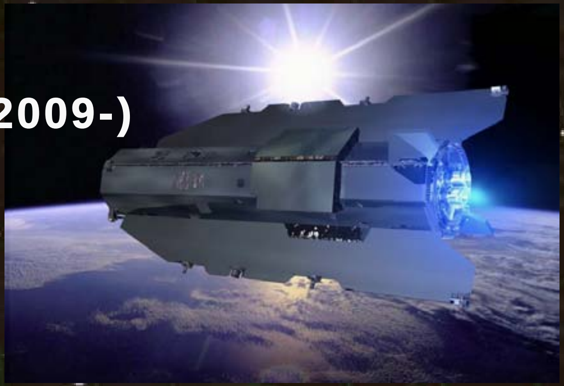
International Centre for Global Earth Models (ICGEM)
http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html

GOCE and DPF

Satellite Gravity Gradiometry

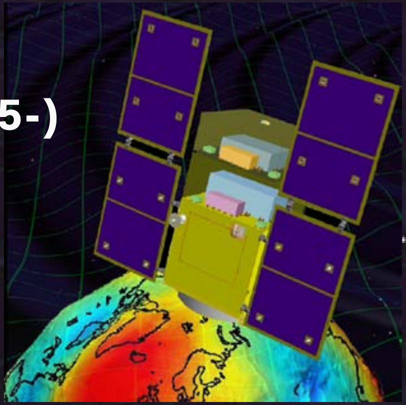
GOCE

(ESA, 2009-)



DPF

(JAXA, 2015-)



Earth observation by gravity gradiometer

Drag-free control of satellite

Altitude	295km, 3-axis GG
Sens.	5×10^{-12} m/s^2/Hz$^{1/2}$
Baseline	0.5m
Weight	1,200 kg

Altitude	500km, 1-axis GG
Sens.	1×10^{-15} m/s^2/Hz$^{1/2}$
Baseline	0.3m
Weight	350 kg

DPF sensitivity

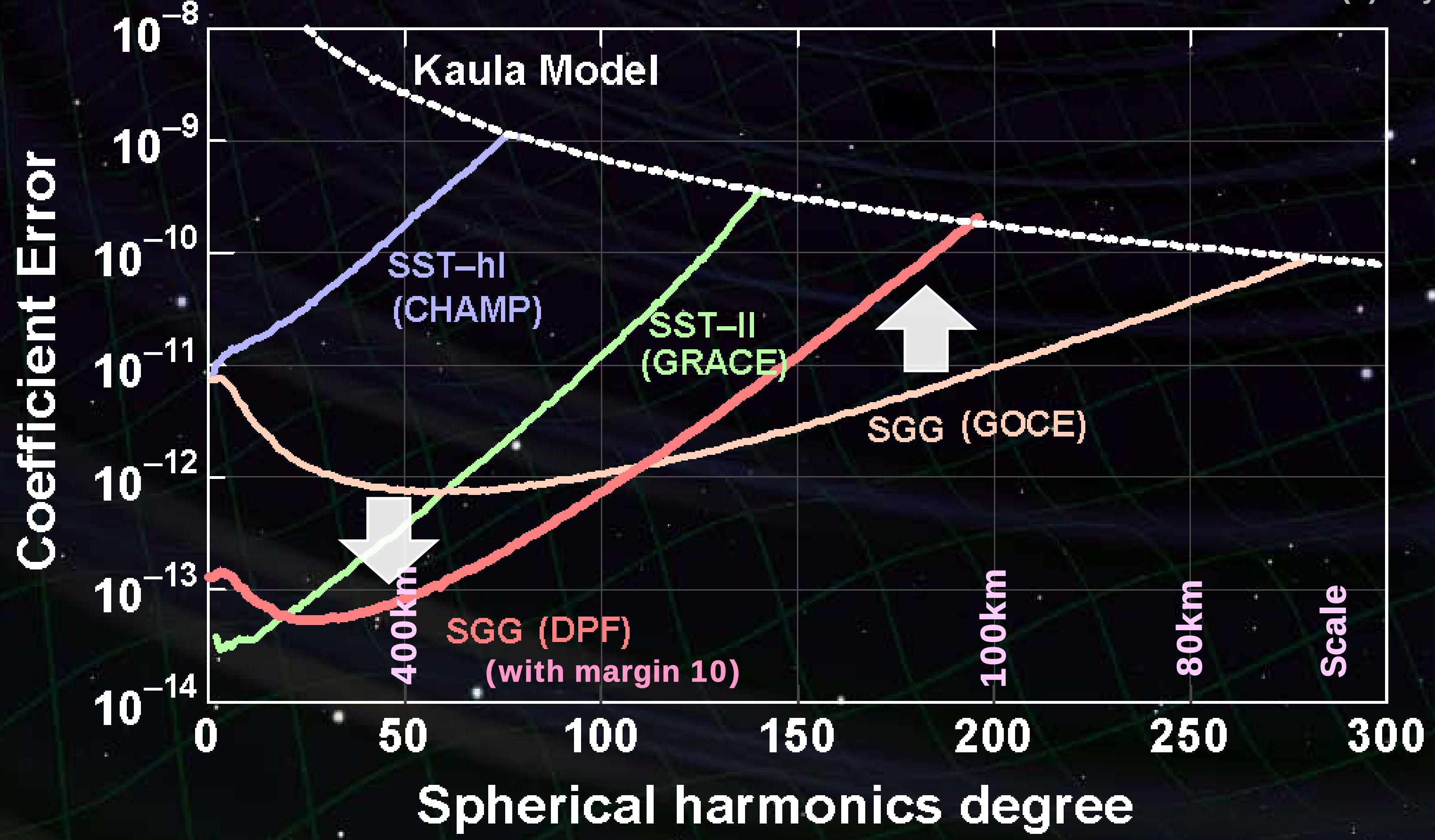
DECIGO

Comparison of sensitivities

Better in low orders (large scale) ← Sensors

Worse in high orders (small scale) ← Altitude

Report for Mission Selection
Gravity Field and Steady-State
Ocean Circulation Mission
ESA SP-1233(1) July 1999.



Acceleration spectrum

Estimation of observed acceleration

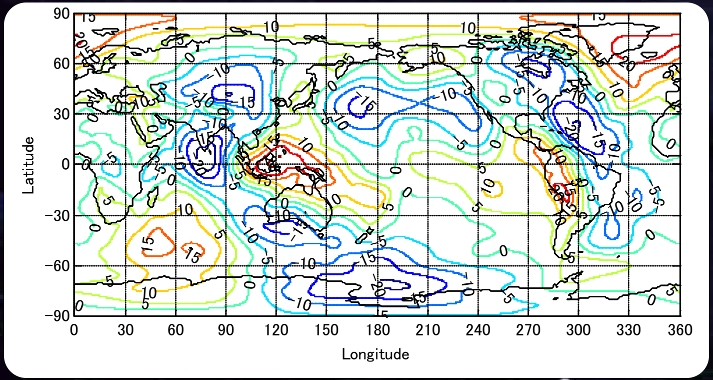
EGM2008 (order 2190) data

→ Calculate potential

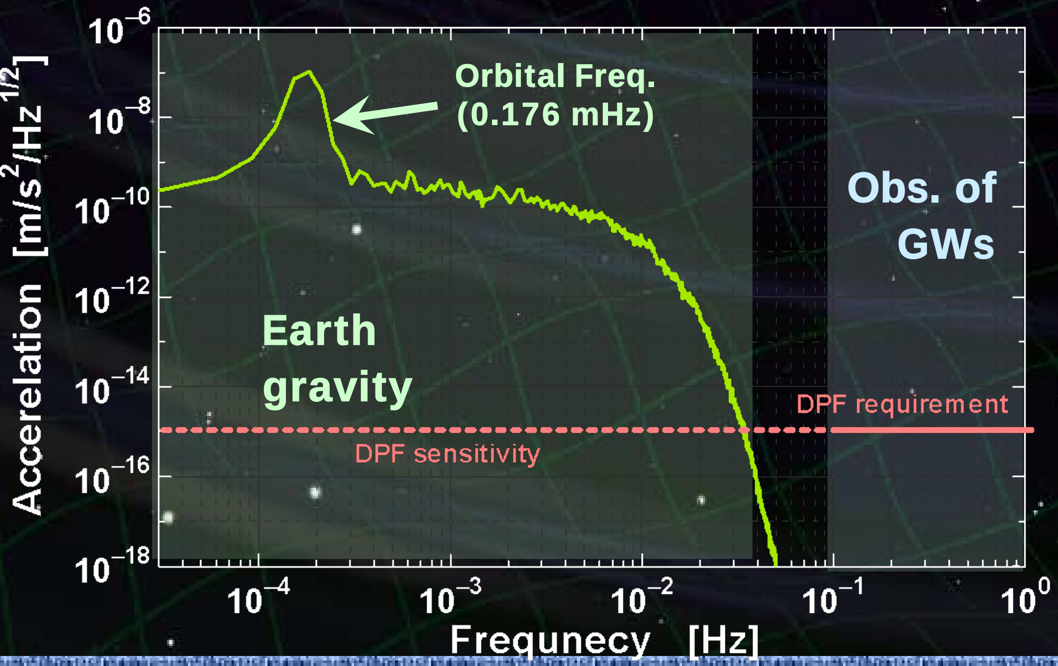
DPF orbit

altitude 500km, polar-orbit

→ Estimate observed acceleration



Gravity acceleration in mgal
(l>2 500km altitude)



1. DECIGO

- Overview and Science
- Pre-conceptual Design

2. DECIGO Pathfinder

- Overview and Science
- ⇨ Design and Status
- Space Demonstration

3. Summary

Interferometer Module

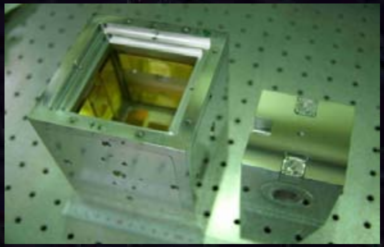
Interferometer Module : Test mass + IFO

Test-mass module

→ Gravity reference

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

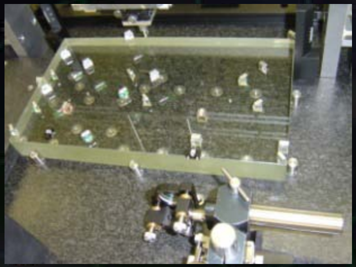
Hosei, NAOJ, Ochanomizu, Stanford



Interferometer

→ GW, Gravity observation

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



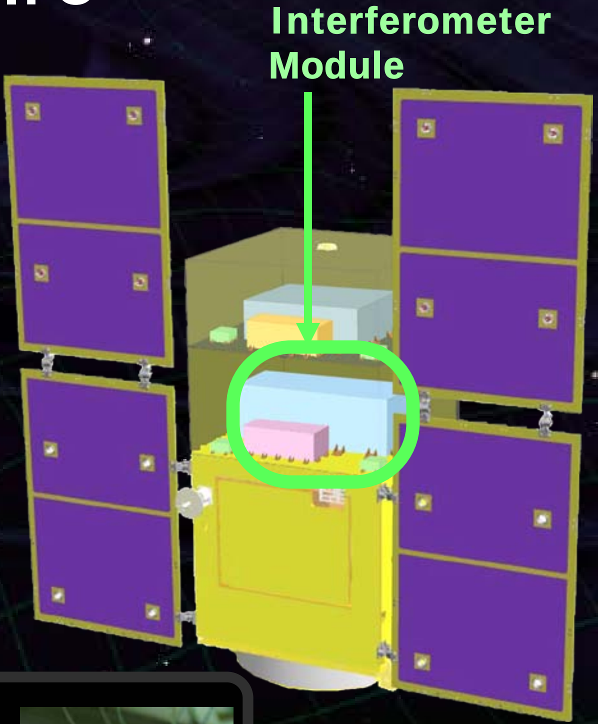
NAOJ, U-Tokyo

Laser sensor

→ Small MI

- BBM test
- Sensitivity meas.

ERI, U-Tokyo



Interferometer Module

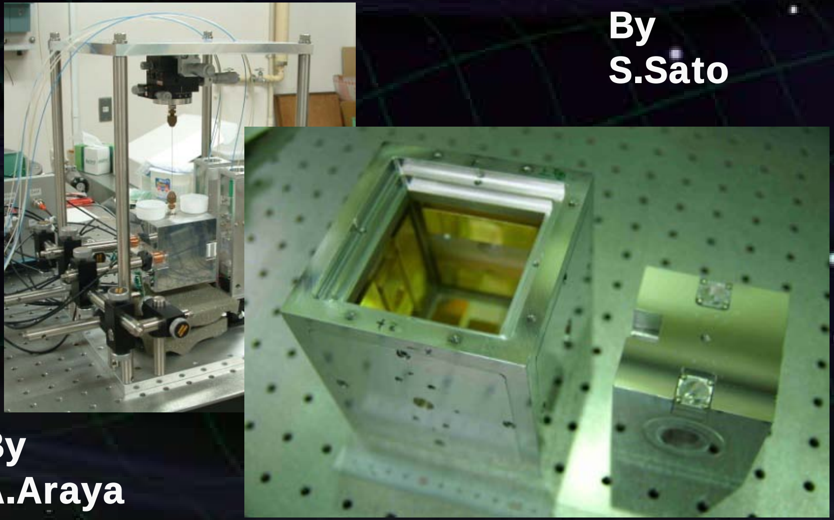
By
M.Michimura

Main interferometer

30cm Fabry-Perot interferometer
Finesse ~100, Two test masses
Monolithic input bench
PDH and WFS for length and alignment signal extraction

Test-mass module

Reference for geodesy
- Test mass ~1kg ~50mm cubic
- Mirrors will be glued
- ES sensor-and-actuators
- Laser sensors
- Launch lock, clump/release
- Discharge with UV LED



By
S.Sato

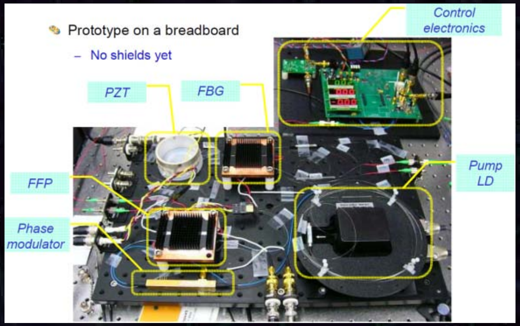
By
A.Araya

Stabilized Laser Module

Stabilized Laser : Laser source + Stabilization system

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

- BBM development



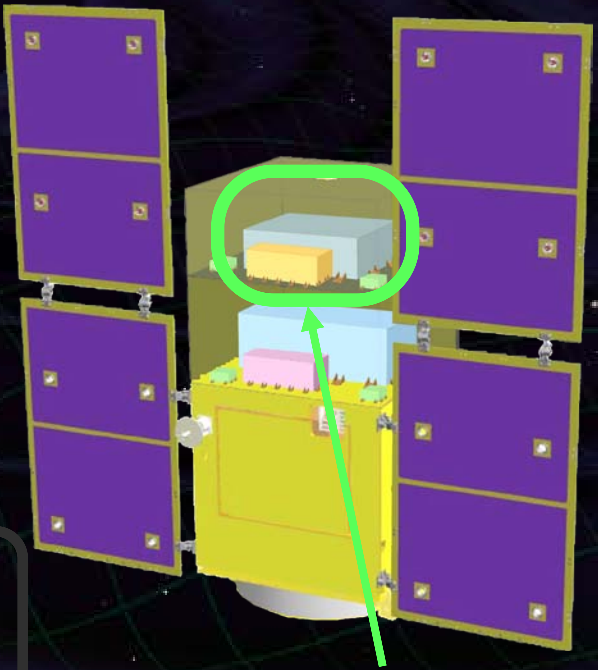
Prototype on a breadboard
- No shields yet

UEC, NASA/GSFC

I$_2$ absorption line
→ Frequency reference

- BBM development
- Stability meas.

UEC, NICT



Stabilized Laser Module

Stabilized Laser Module

Laser source

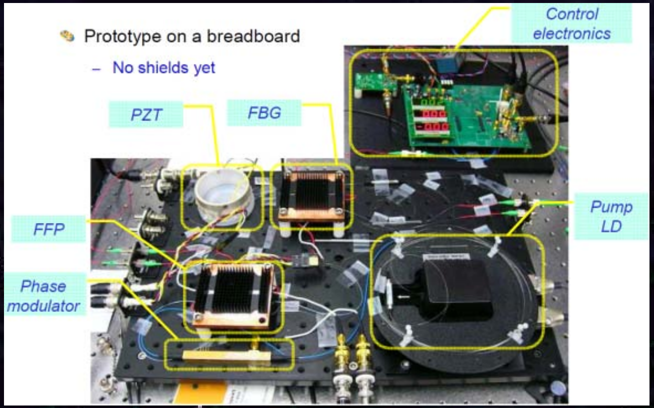
Yb:YAG laser

wavelength 1030nm

output 100mW

Candidates

NPRO, fiber laser



- Prototype on a breadboard
  - No shields yet

By
K.Numata

Stabilization

Freq. Stabilization

by Saturated absorption with I_2

Requirement: 0.5 Hz/Hz$^{1/2}$

Required freq.-doubled beam (515nm)

Multi-path in 40cm-length cell

Option: monolithic reference cavity

Intensity stabilization

Requirement: 10^{-8} Hz$^{-1/2}$

2009 2 19

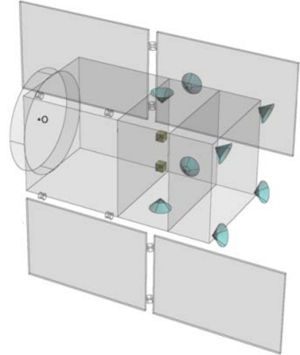
By
M.Musha

Attitude and Drag-free control

DECIGO

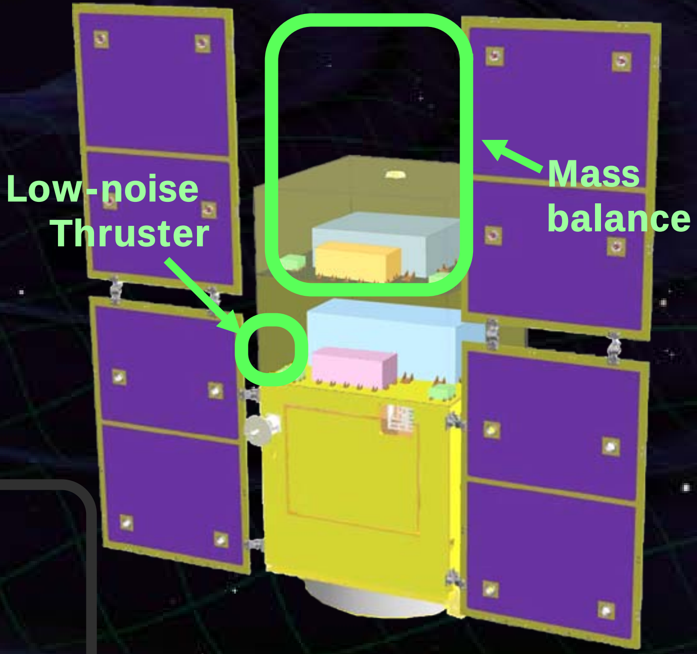
Attitude and Drag-free control : Structure, Thrusters, Control

Structure, thermal stability



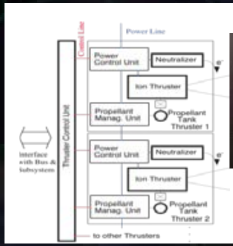
- Passive attitude stability
- Drag-free control

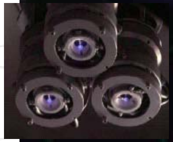
U-Tokyo, JAXA



Low-noise Thruster

→ Actuators for satellite control





- BBM and system design

JAXA, NDAJ, Tokai-U

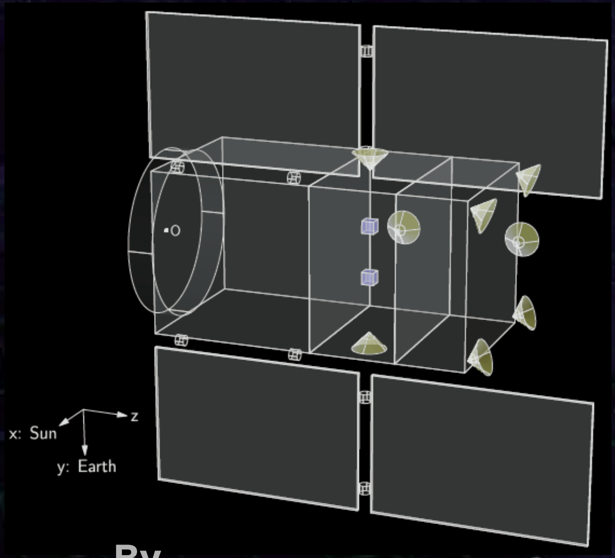
Attitude and Drag-free control

Attitude control and Drag-free

Satellite structure (mass distribution)

Passive attitude stabilization by gravity gradient

Thruster position and control topology: under consideration



By S.Moriwaki

Thruster (tentative)

12 (TBD) mission thrusters

Low-noise small thruster

- Max. thrust 10μN (tunable)
- Noise 0.1 μN/Hz$^{1/2}$
- >10Hz response

- FEEP system, Gas jet backup

By I.Funaki

1. DECIGO

Overview and Science

Pre-conceptual Design

2. DECIGO Pathfinder

Overview and Science

Design and Status

⇨ Space Demonstration

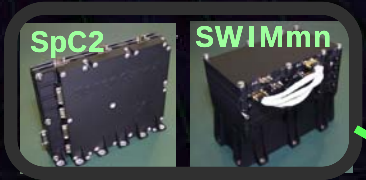
3. Summary

Signal processing and Control

Signal Processing and Control : SpaceWire-based system

SpC2 + SpW system

→ Signal processing and install. ctrl

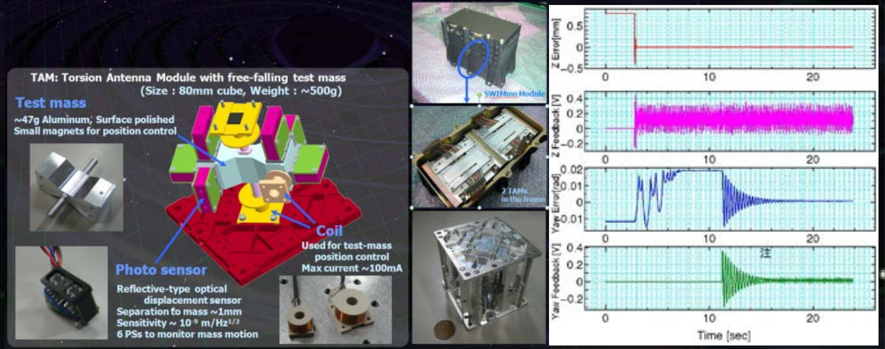


Space demonstration bySDS-1/SWIM

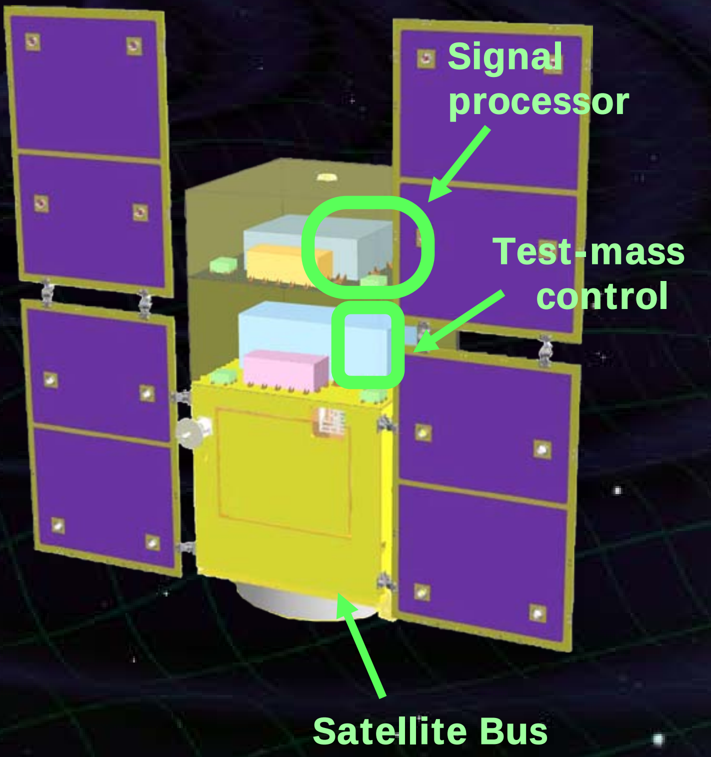
JAXA, U-Tokyo, Kyoto

SWIMmn demonstration

→ Test mass control in orbit



JAXA, U-Tokyo, Kyoto



SWIM launch and operation

Tiny GW detector module
Launched in Jan. 23, 2009
⇨ In-orbit operation

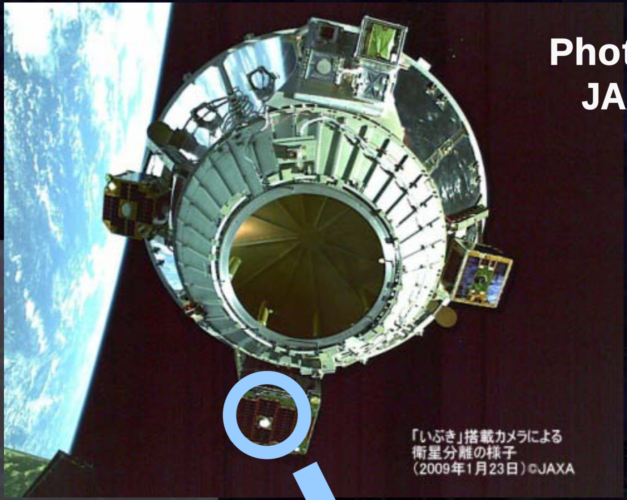
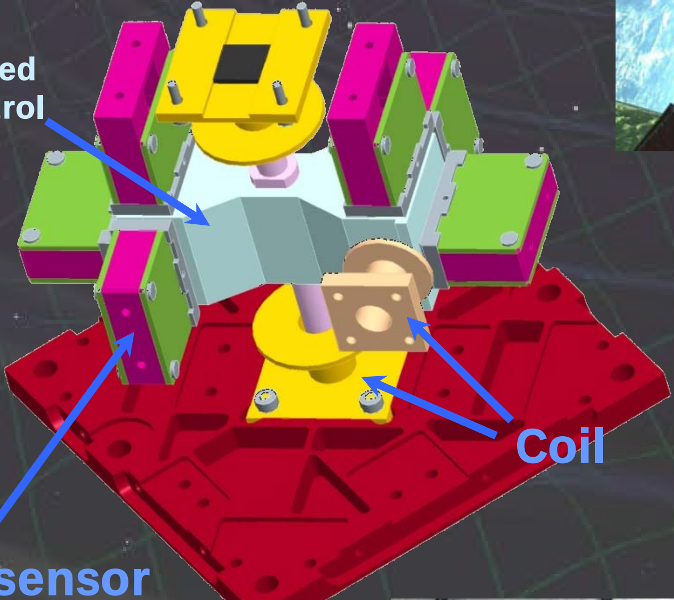


Photo:
JAXA

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

Test mass

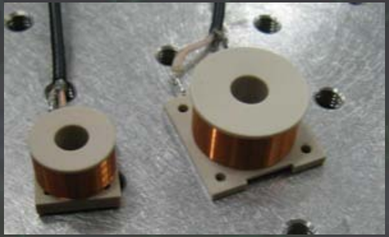
~47g Aluminum, Surface polished
Small magnets for position control



Coil

Photo sensor

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



Successful control

SWIM

In-orbit operation

Test mass controlled

Error signal → zero

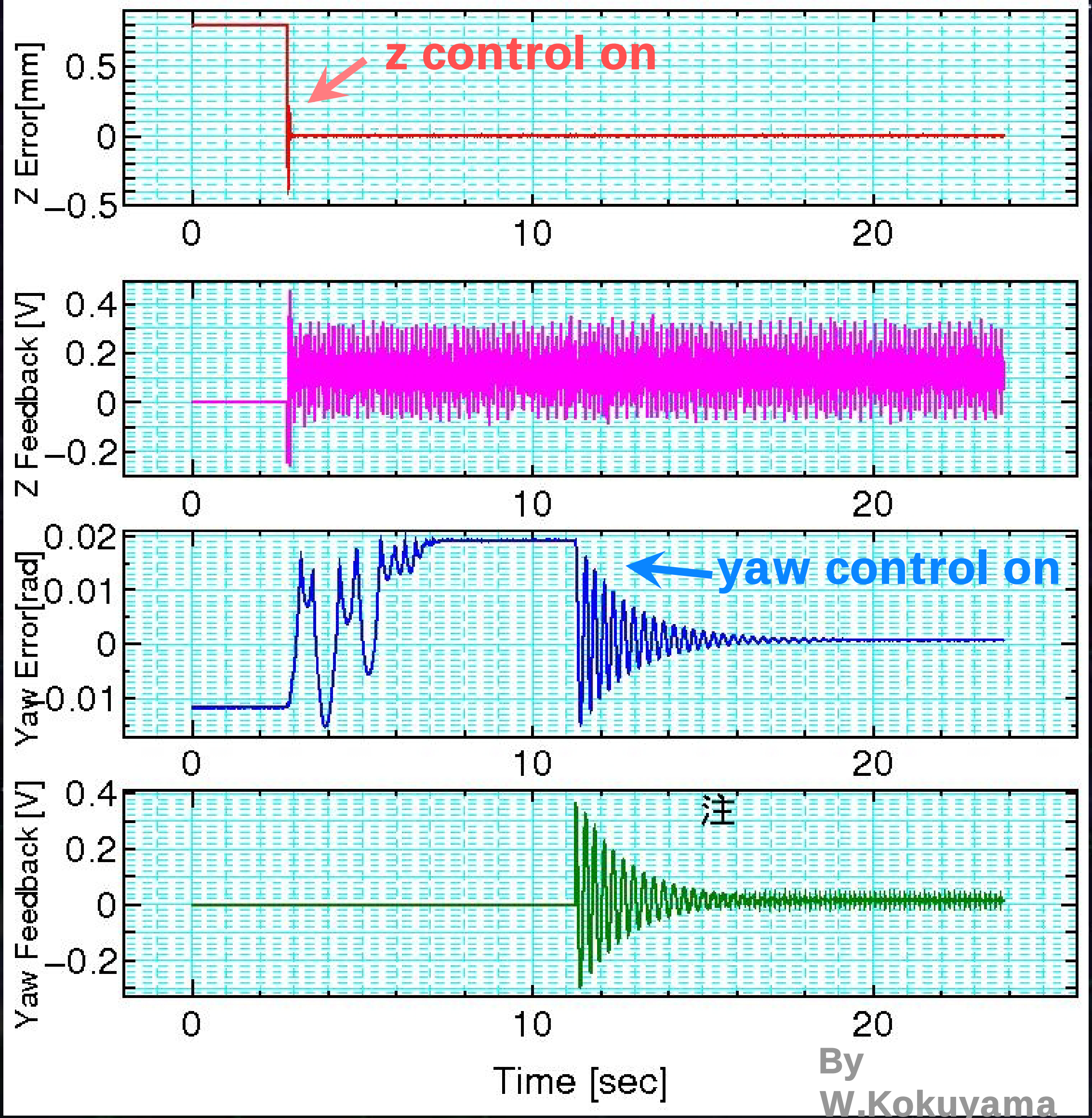
Damped oscillation (in pitch DoF)

Free oscillation in x and y DoF

Signal injection → OL trans. Fn.

Operation: May 12, 2009

Downlink: ~ a week



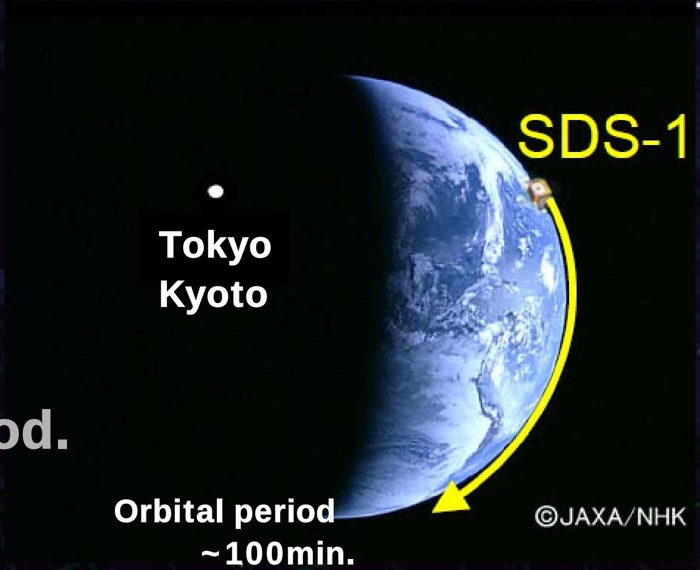
SWIM observation

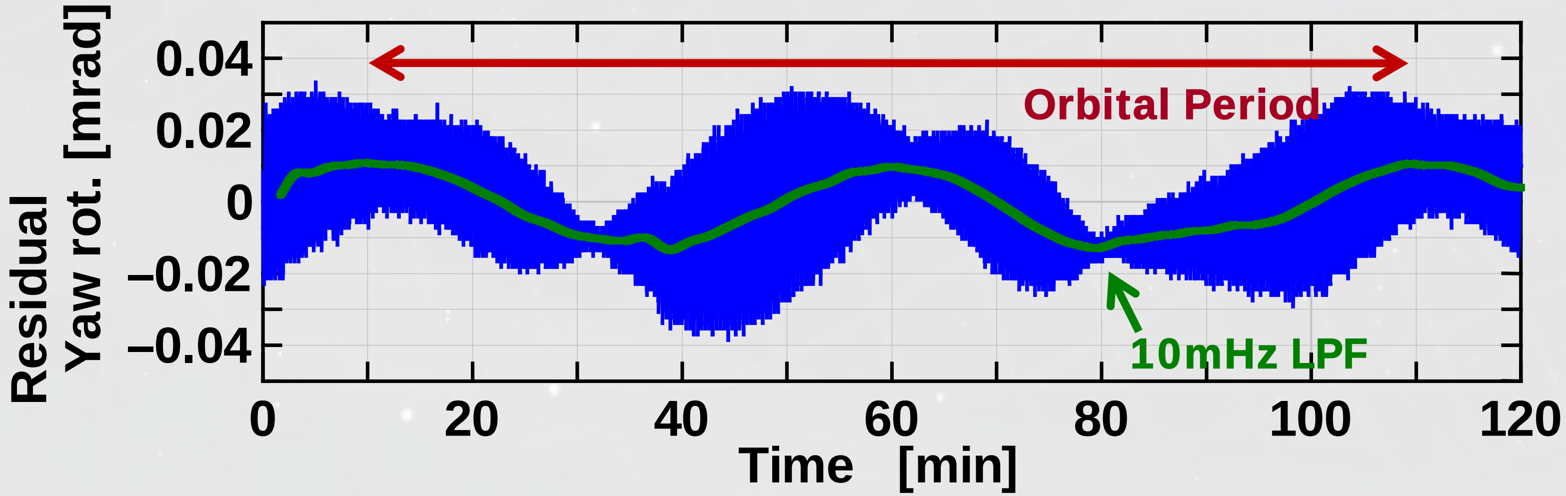
Observation by SWIM

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

Ground-based detectors were operated at the same period.

⇨ **Data analysis**





Roadmap

Figure: S.Kawamura

	2010	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

Mission

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

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

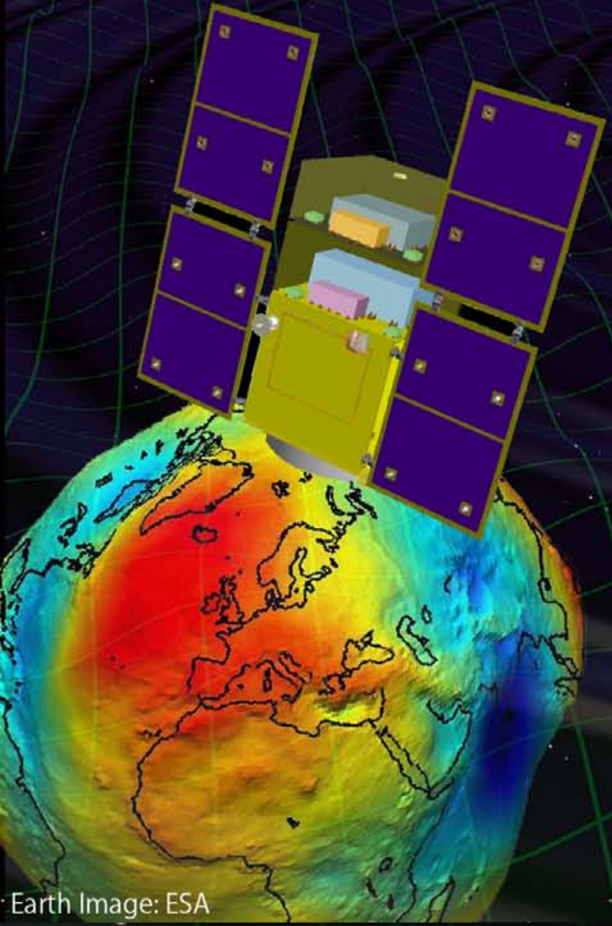
DECIGO Pathfinder

Important milestone for DECIGO

Strong candidate of JAXA's satellite series

SWIM – Operation in orbit

first precursor to space!



Earth Image: ESA

End

Original Picture : Sora