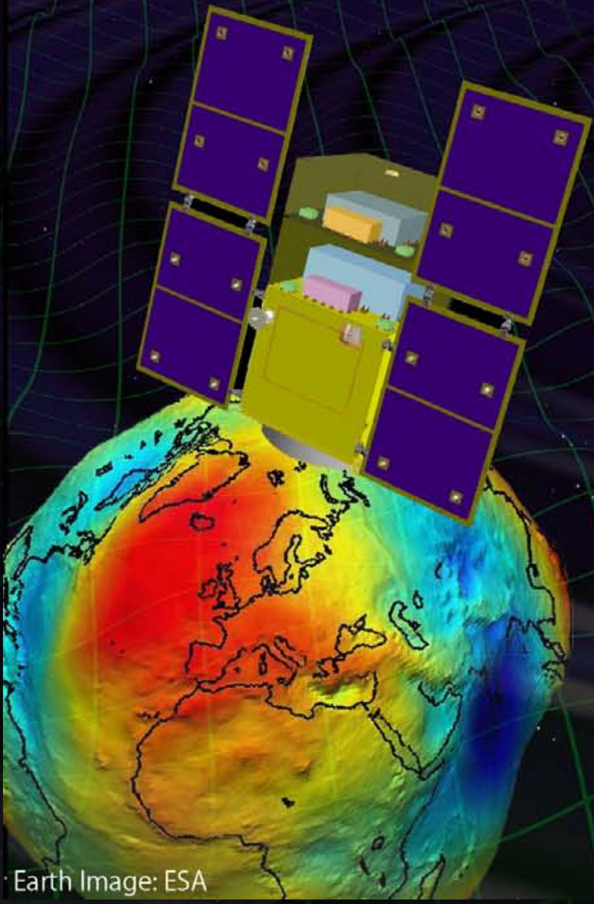
Satellite Design of DECIGO Pathfinder



Original
Picture : Sora

Masaki Ando
(Department of Physics, Kyoto University)

On behalf of
DECIGO working group

8th LISA symposium (July 1, 2010, SLAC, Stanford)

1. DECIGO Pathfinder

Overview, Design

2. Science

GW, Gravity of the Earth

3. Status

R&Ds, Mission selection

4. Summary

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Roadmap

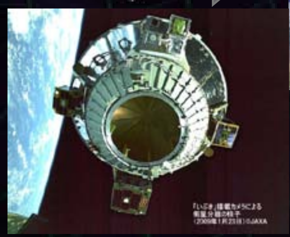
DECIGO

Figure: S.Kawamura

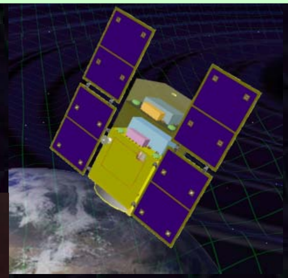
2010 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

Mission

R&D Fabrication

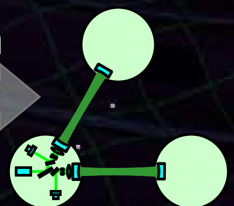


SDS-1 / SWIM



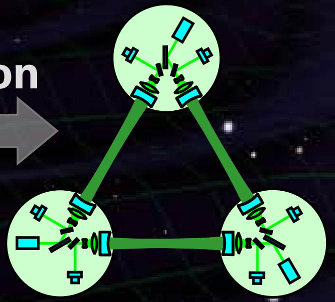
DECIGO Pathfinder (DPF)

R&D Fabrication



Pre-DECIGO

R&D Fabrication



DECIGO

Presentation by Seiji 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

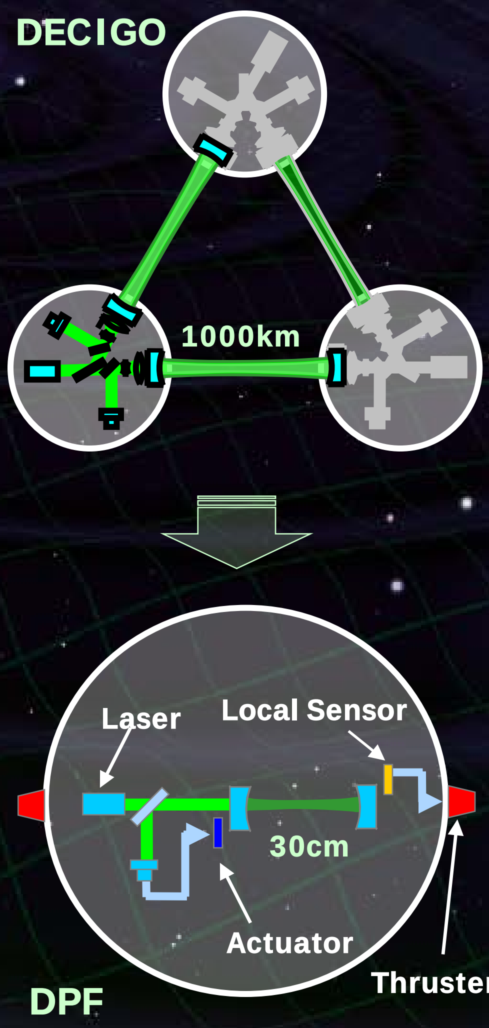
DECIGO-PF

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)

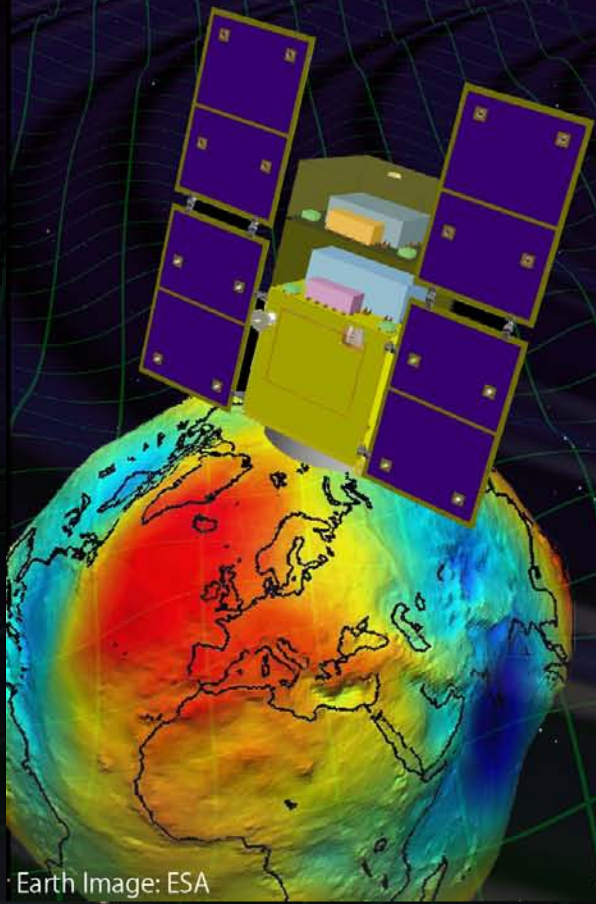
30cm FP cavity with 2 test masses

Stabilized laser source

Drag-free control

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 satellite

DPF Payload

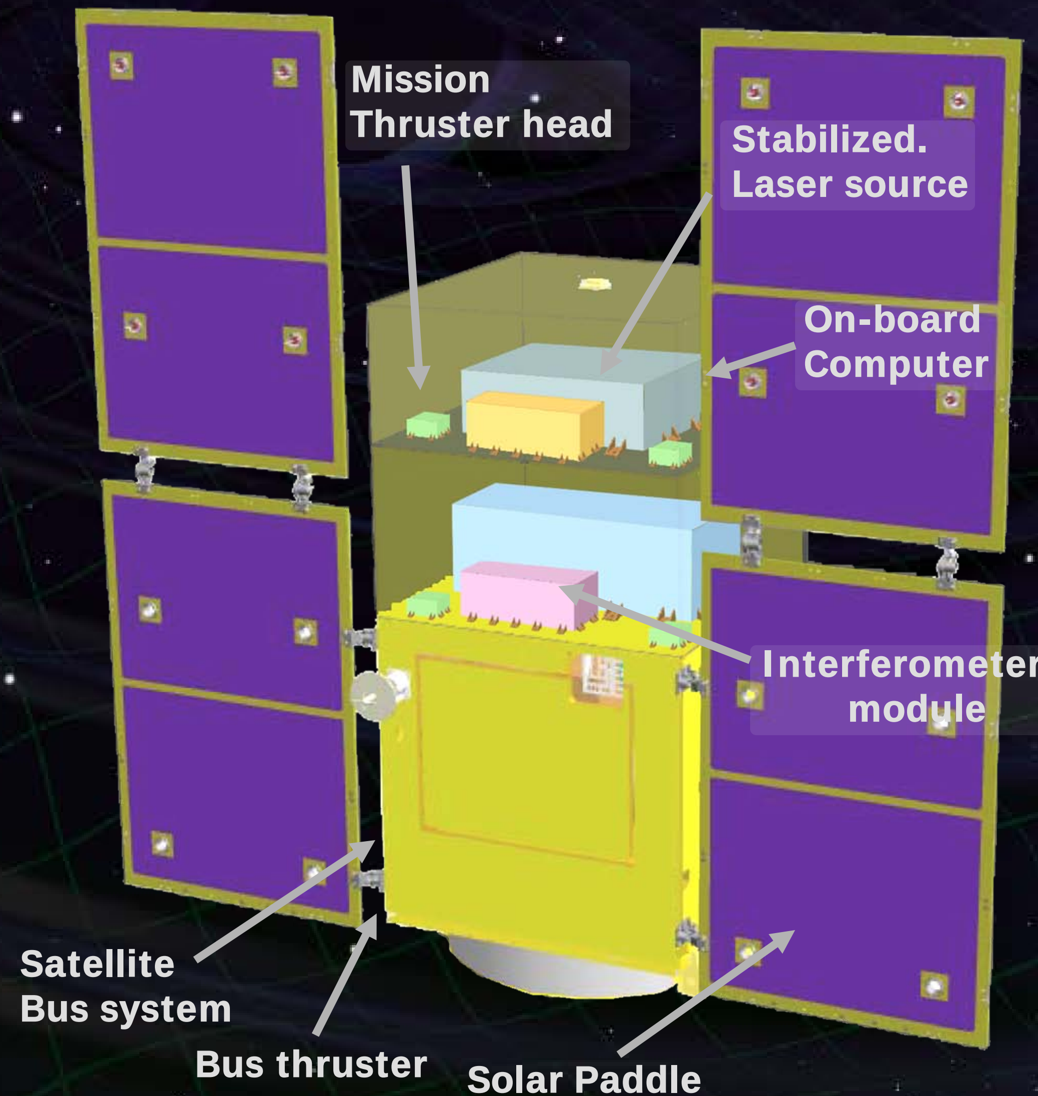
Size : 950mm cube
Weight : 150kg
Power : 130W
Data Rate: 800kbps
Mission thruster x12

Power Supply
SpW Comm.

Satellite Bus

('Standard bus' system)

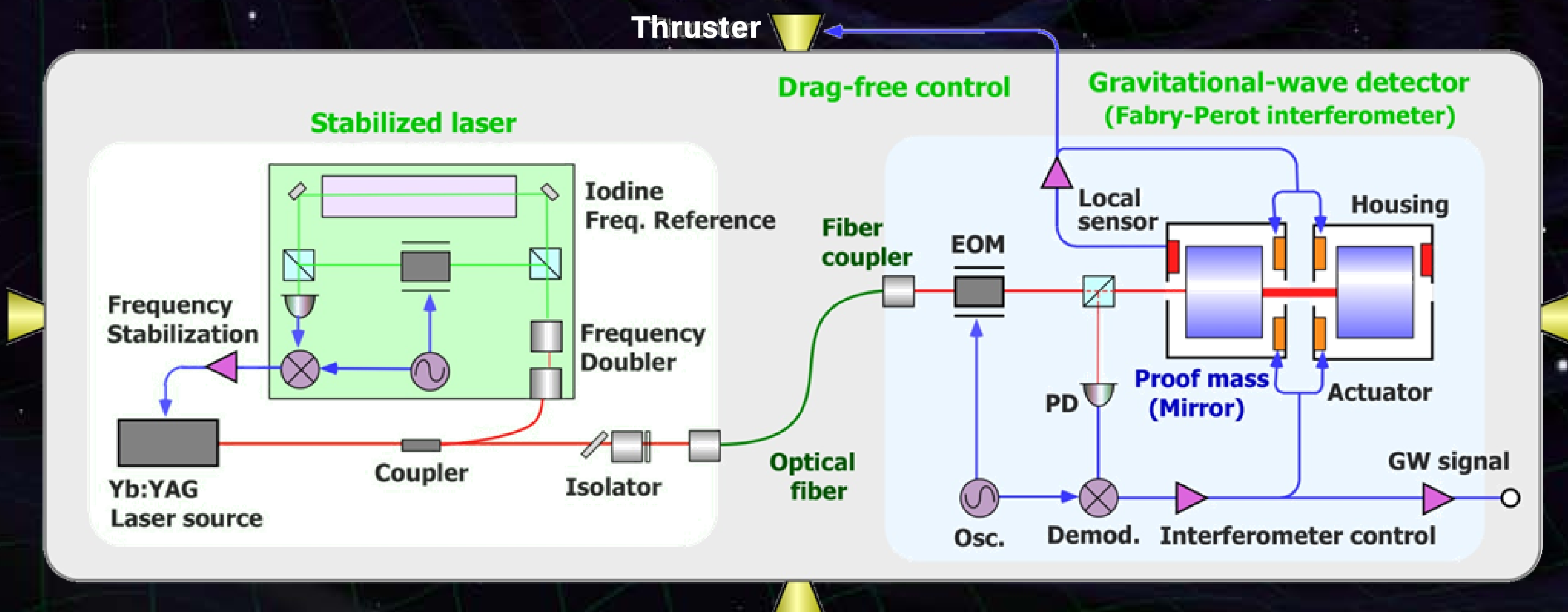
Size :
950x950x1100mm
Weight : 200kg
SAP : 960W
Battery: 50AH
Downlink : 2Mpbs
DR: 1GByte
3N Thrusters x 4



DPF mission 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

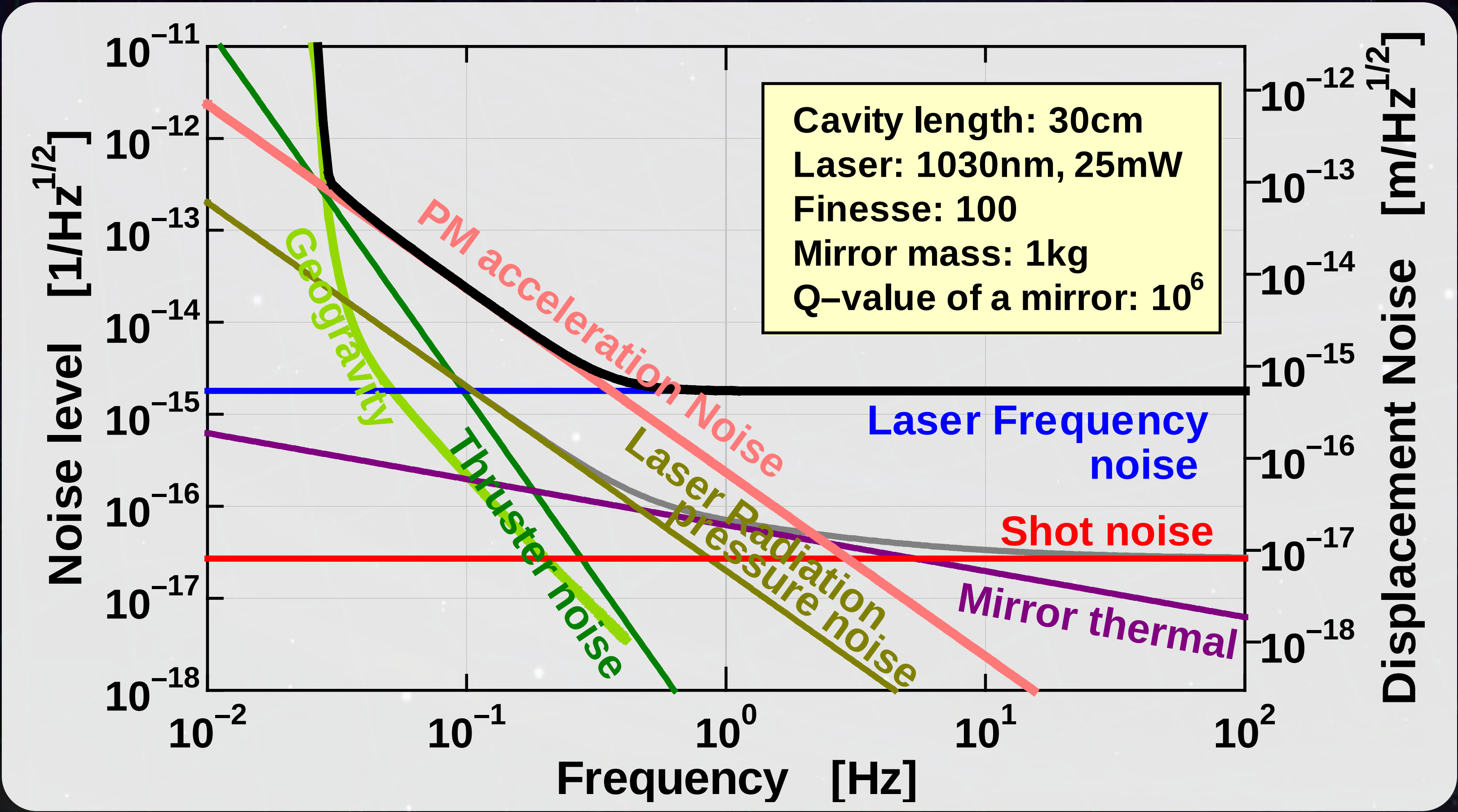
DPF Sensitivity

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)



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: Residual gas damping, Fluctuation of magnetic field, electric field, gravitational field, temperature, pressure, etc.

1. DECIGO Pathfinder

Overview, Design

2. Science by DPF

GW, Gravity of the Earth

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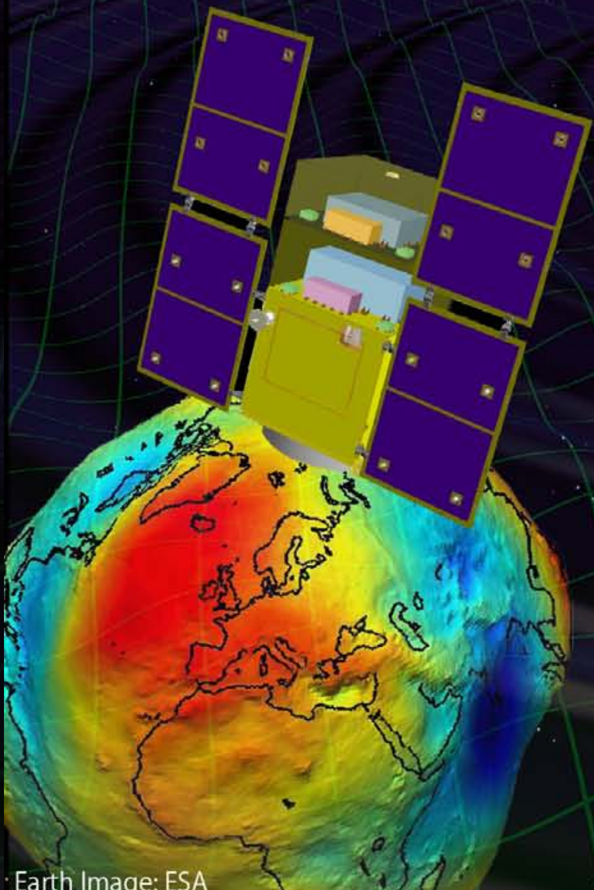
Scientific observation by DPF



Astrophysical observation

Gravitational Waves form BH mergers
→ BH formation mechanism

Geophysical observation

Gravity of the Earth
→ Geophysics, Earth environment

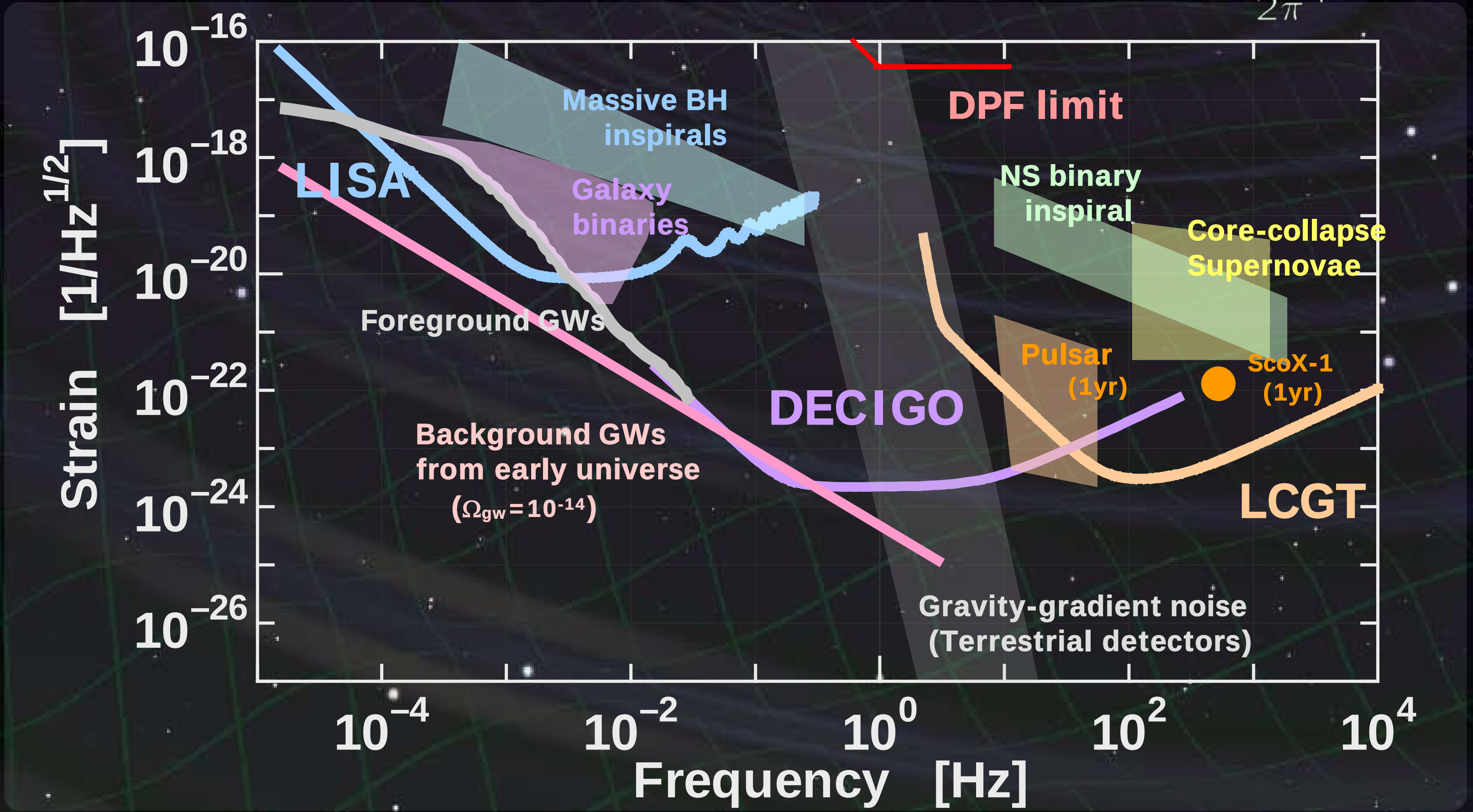
DPF sensitivity

DECIGO

DPF sensitivity $h \sim 2x10^{-15}$ $Hz^{-1/2}$

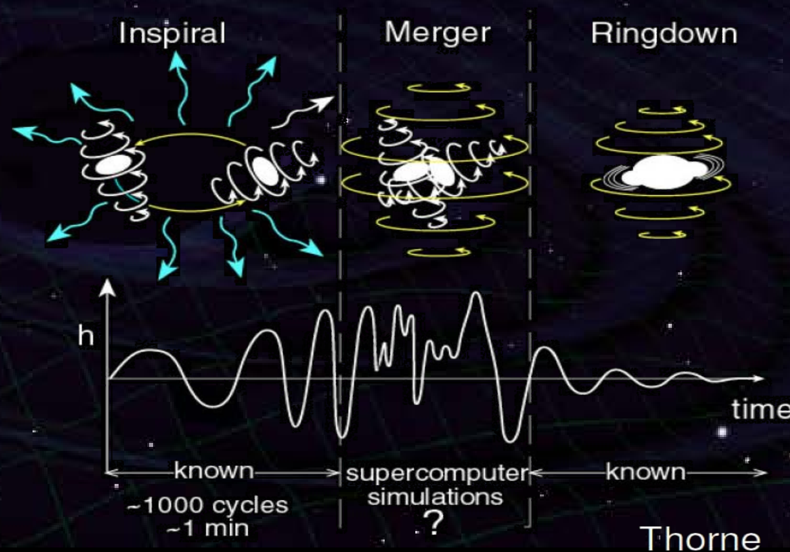
(x10 of quantum noises)

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



GW target of DPF

DECIGO



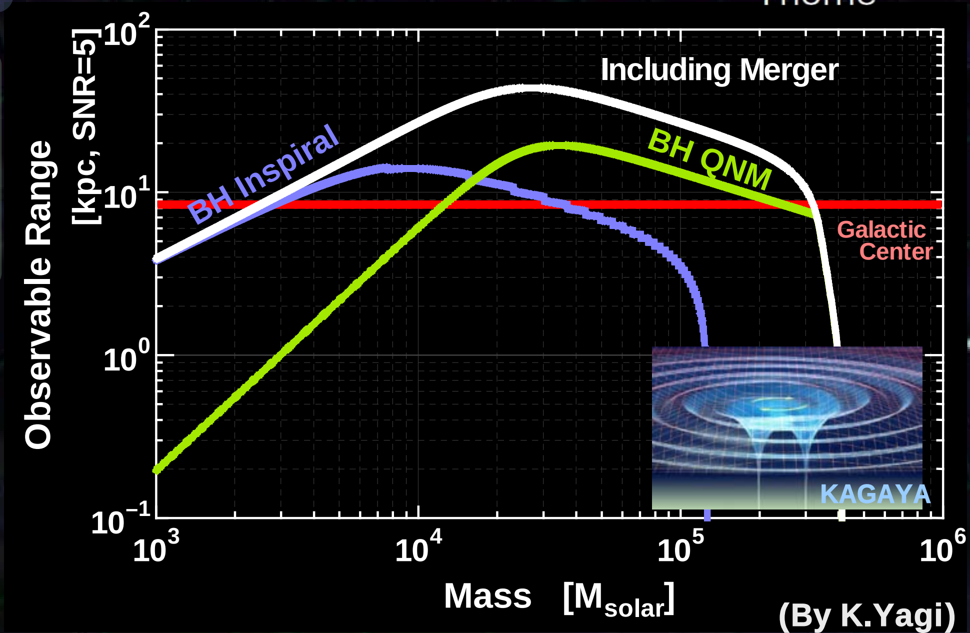
Blackholes events in our galaxy

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, $m = 10^5 M_{sun}$

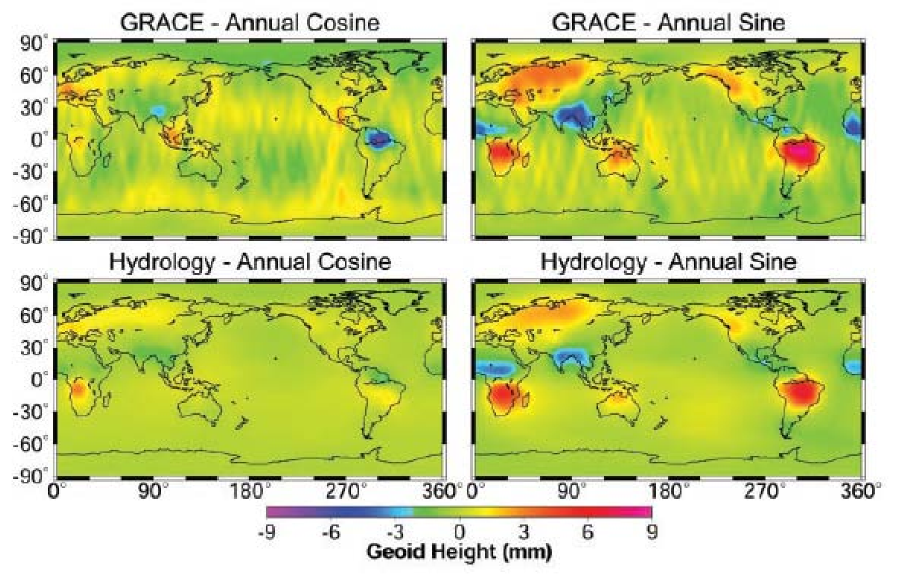


Observable range covers **our Galaxy** (SNR~5)

Earth's Gravity Observation

DECIGO

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

Satellite Gravity missions

DECIGO

3-types of satellite gravity missions

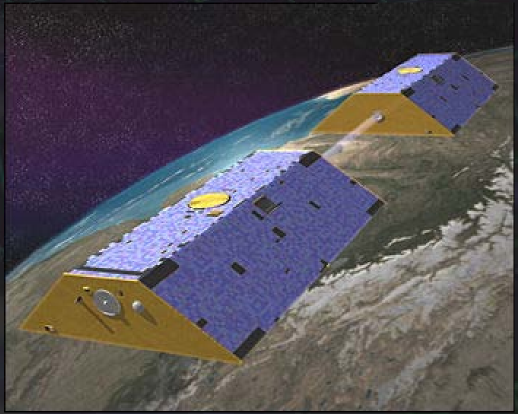
Satellite-to Satellite tracking High-Low

- 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

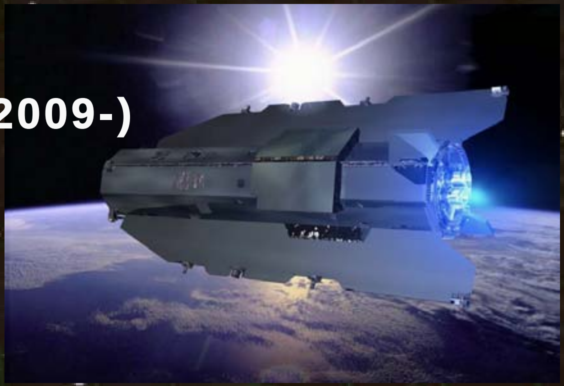
GOCE (ESA, 2009-)

GOCE and DPF

Satellite Gravity Gradiometry

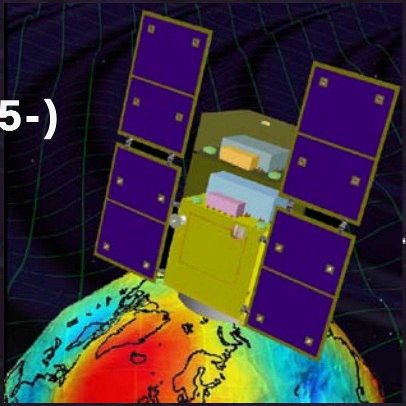
GOCE

(ESA, 2009-)



DPF

(JAXA, 2015-)



Earth observation by gravity gradiometer
Drag-free control of satellite

	GOCE	DPF
Altitude	295km, 3-axis GG	500km, 1-axis GG
Sens.	5×10^{-12} m/s^2/Hz$^{1/2}$	1×10^{-15} m/s^2/Hz$^{1/2}$
Baseline	0.5m	0.3m
Weight	1,200 kg	350 kg

Earth Gravity model

Describe gravity potential by
Spherical harmonic functions

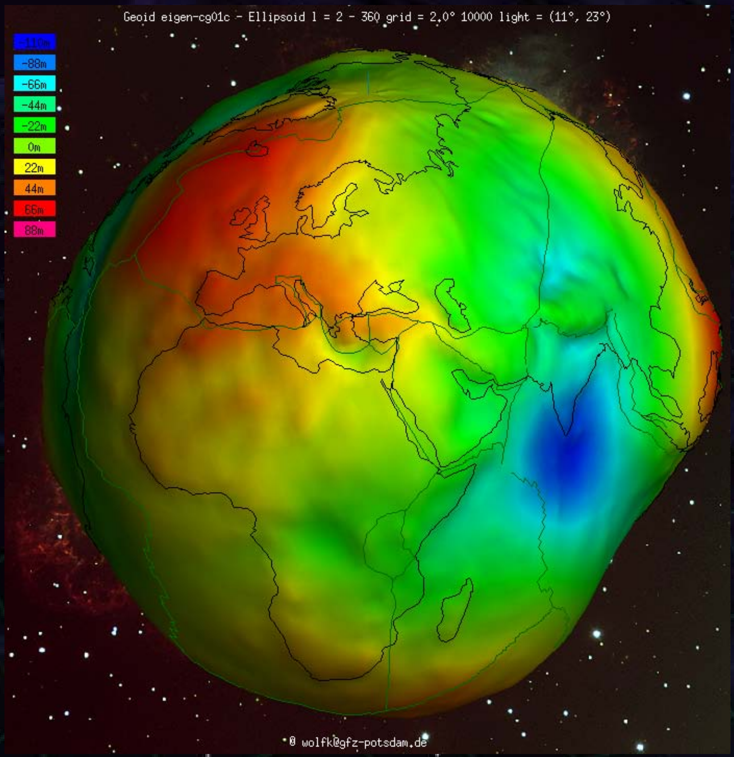
$$U(r,\lambda,\phi) = \frac{GM}{r}\sum_{l=0}^{\infty}\sum_{m=0}^{n}\left(\frac{R}{r}\right)^{l} P_{lm}(\sin\phi) \times [C_{lm}\cos(m\lambda) + S_{lm}\sin(m\lambda)]$$

$G,\ M,\ R$: 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

DPF sensitivity

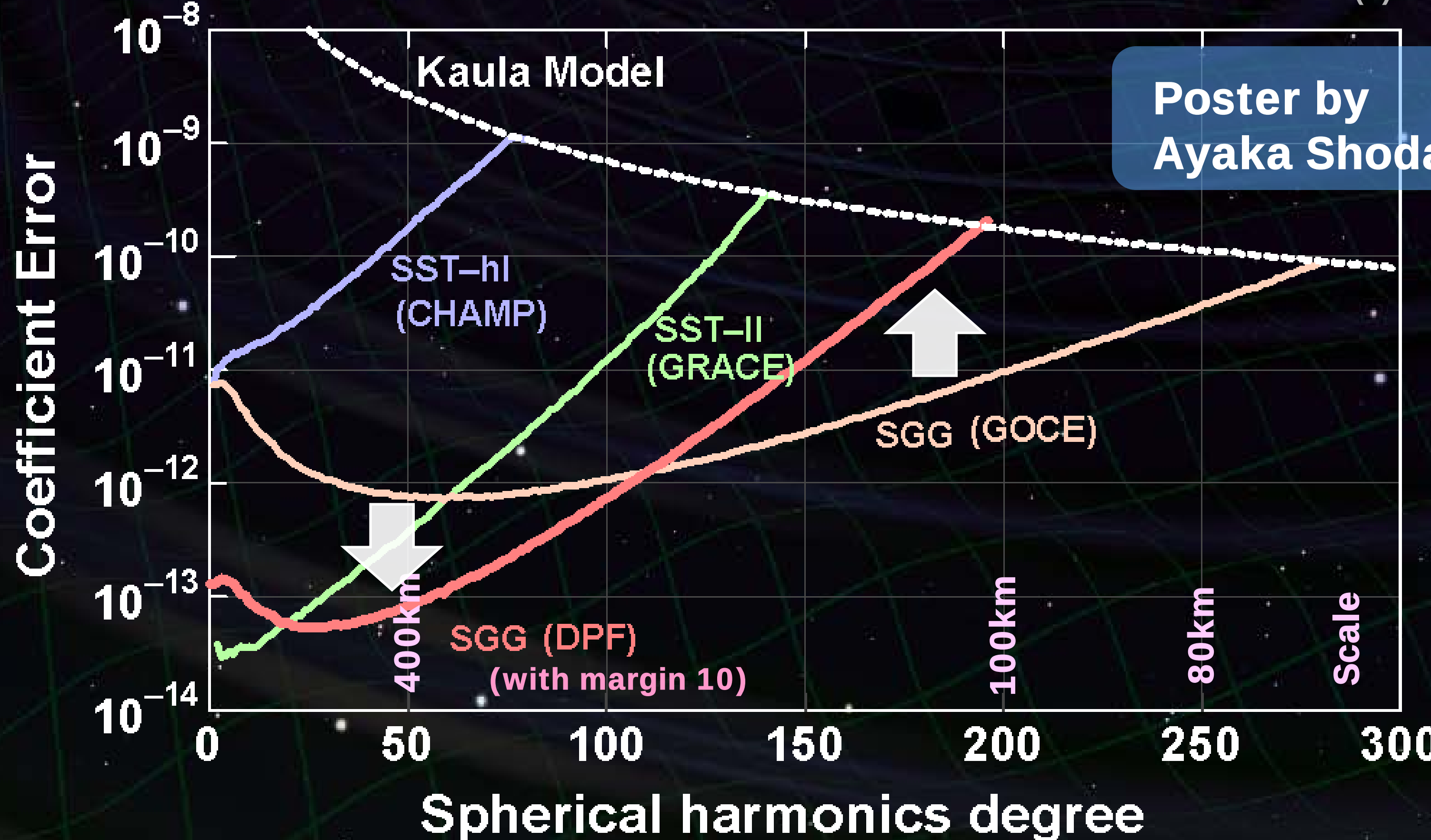
DECIGO

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.

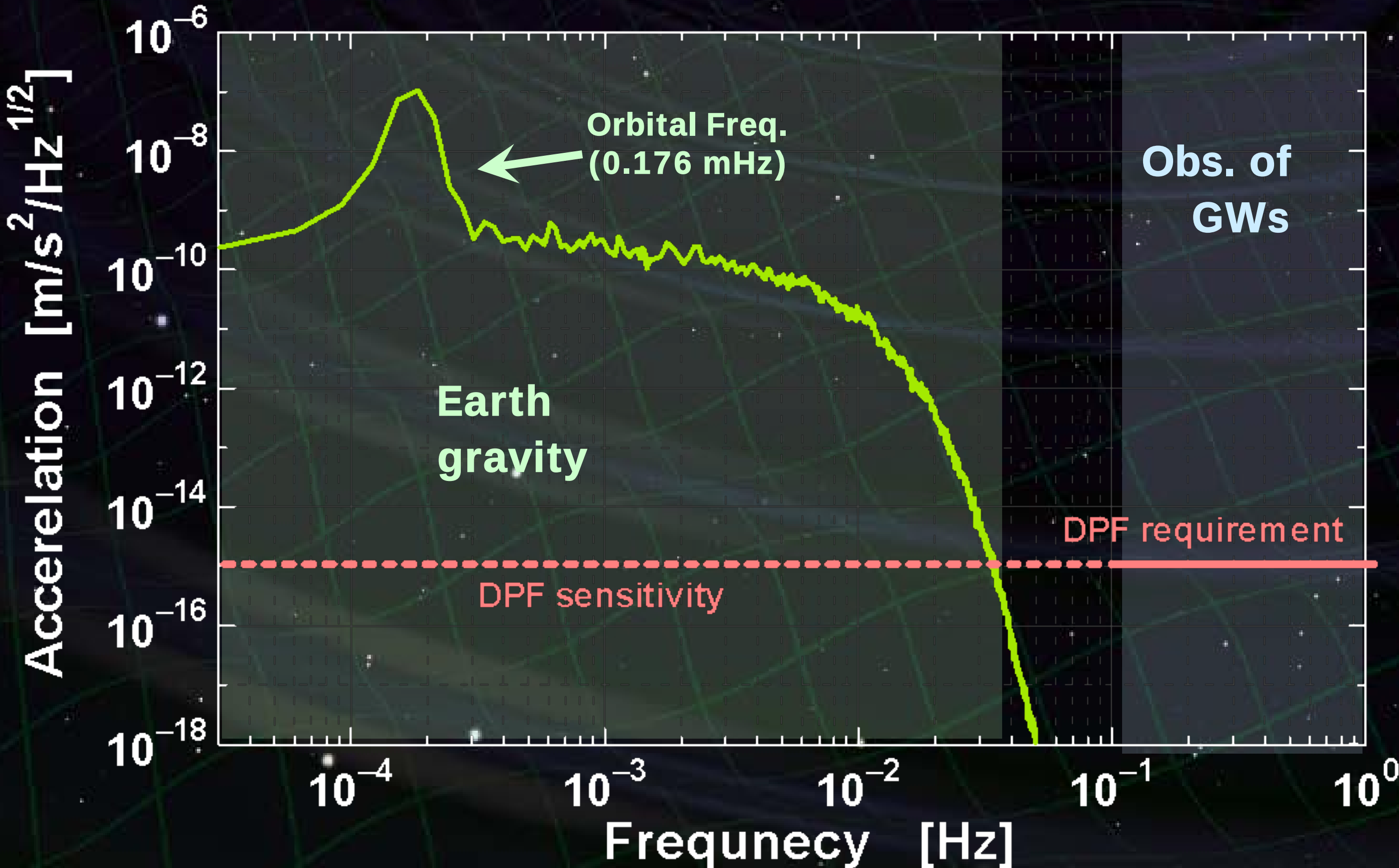


Poster by
Ayaka Shoda

GW and Earth observations

DECIGO

DPF orbit: altitude 500km, polar-orbit
Earth model : EGM2008 (order 2190)
→ Estimate observed signals



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Overview, Design

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GW, Gravity of the Earth

⇨ 3. Status of DPF

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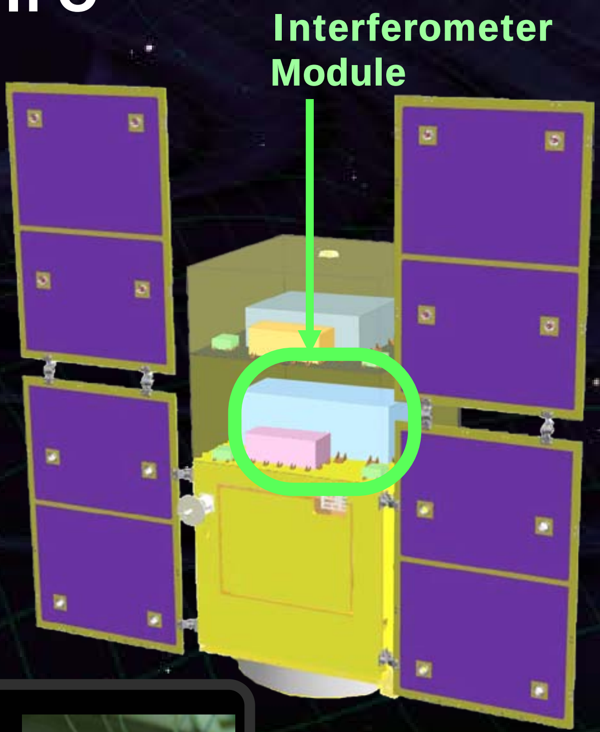
4. Summary

Interferometer Module

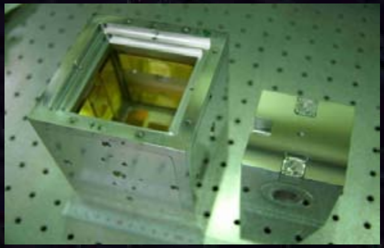
DECIGO

Interferometer Module : Test mass + IFO



Test-mass module
→ Gravity reference

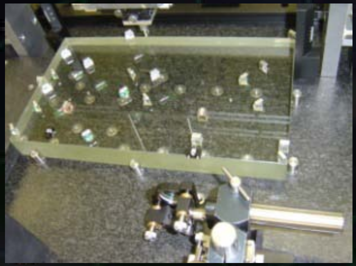
- BBM of Module, Sensor, Actuator, Clump/Release
- μ-Grav. Exp.



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

Presentations by
S. Sato
Y. Michimura
A. Shoda

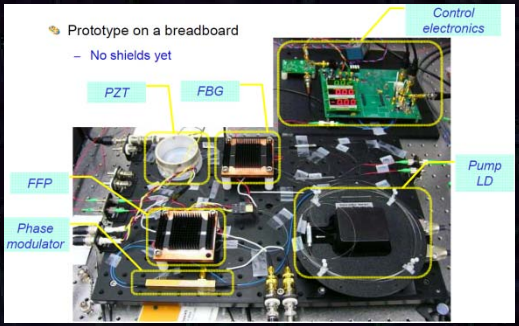
Stabilized Laser Module

DECIGO

Stabilized Laser : Laser source + Stabilization system

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

- BBM development

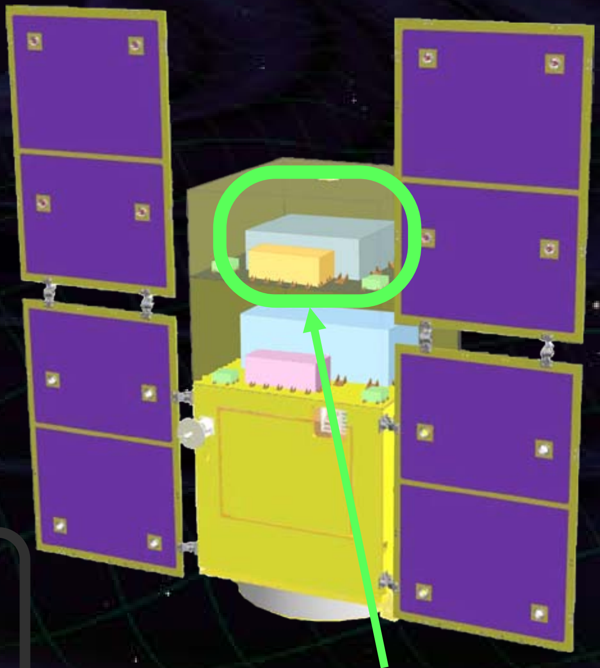


UEC, NASA/GSFC

I_2 absorption line
→ Frequency reference

- BBM development
- Stability meas.

UEC, NICT



Stabilized Laser Module

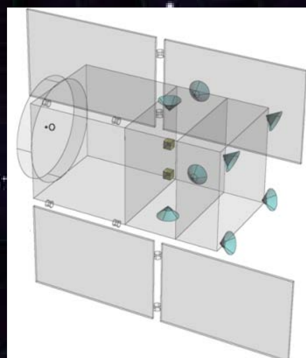
Presentations by K.Numata

Attitude and Drag-free control

DECIGO

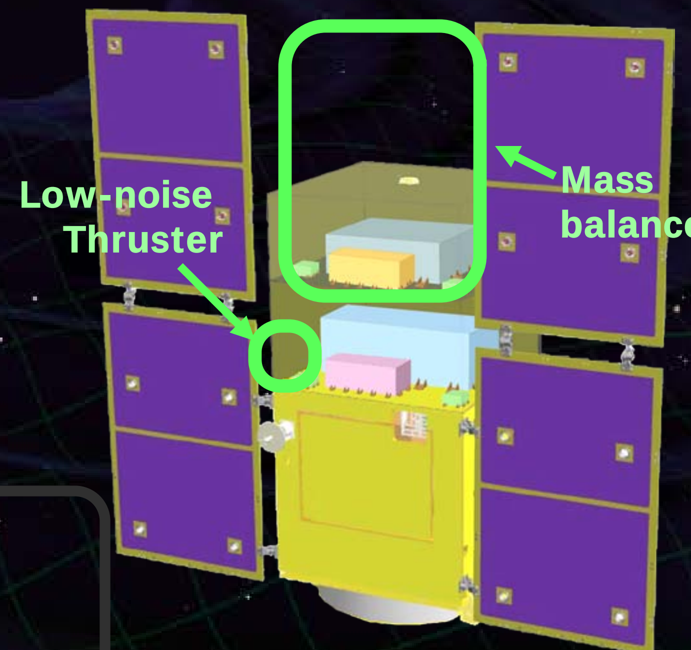
Attitude and Drag-free control : Structure, Thrusters, Control

Structure, thermal stability



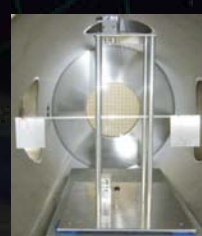
- Passive
  attitude stability
- Drag-free control

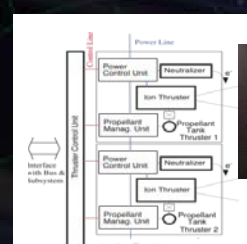
U-Tokyo, JAXA



Low-noise Thruster

→ Actuators for satellite control





- BBM and system design

JAXA, NDAJ, Tokai-U

Signal processing and Control

Signal Processing and Control : SpaceWire-based system

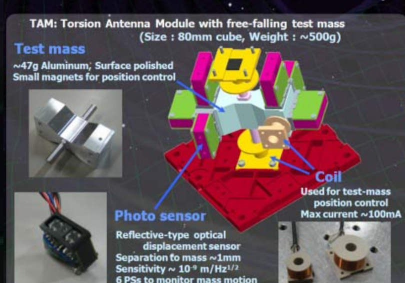
SpC2 + SpW system
→ Signal processing and install. ctrl

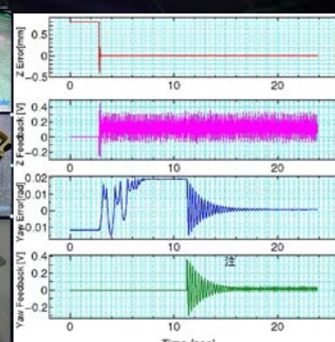
Space demonstration
bySDS-1/SWIM

SDS-1
(Jan. 2009)

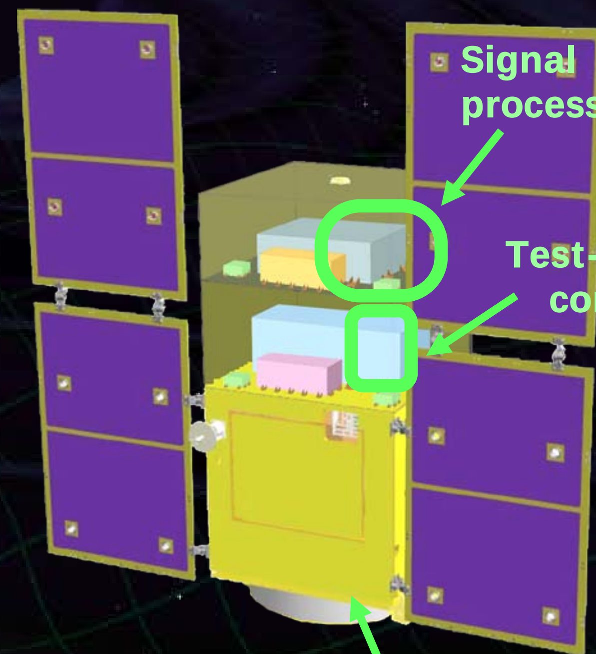
JAXA, U-Tokyo, Kyoto

SWIMmn demonstration
→ Test mass control in orbit





JAXA, U-Tokyo, Kyoto

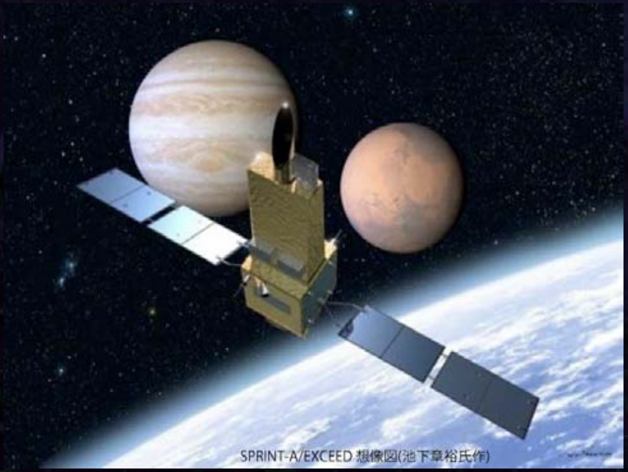


**Poster by
Wataru Kokuyama**

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

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Summary

DECIGO Pathfinder

Important milestone for DECIGO

Strong candidate of JAXA's satellite series

Science

GWs from galactic BHs

Gravity of the Earth

R&Ds

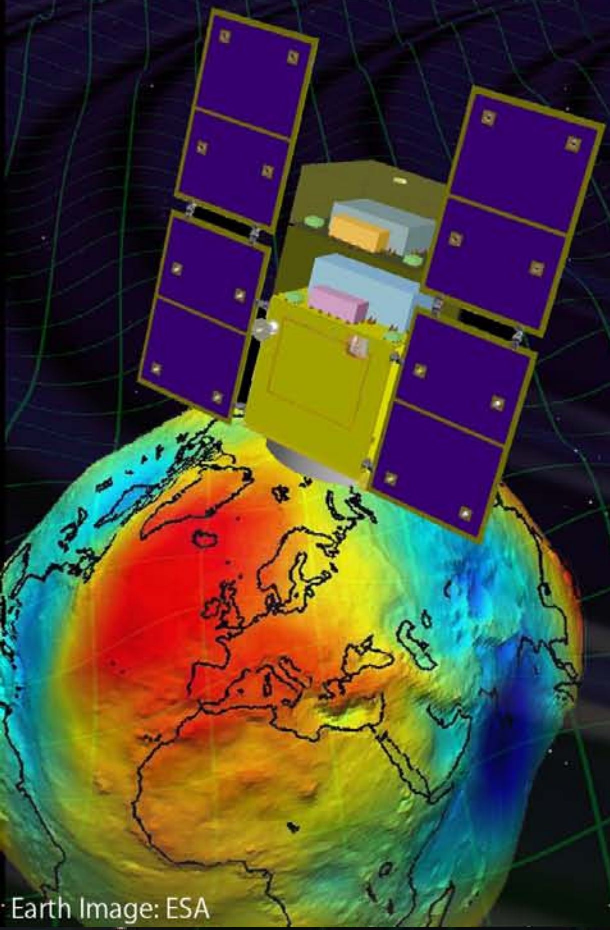
BBM tests

SWIM – under operation in orbit

first precursor to space

Related Presentations

DECIGO



Plenary Session

- Seiji Kawamura — DECIGO

Parallel Session

- Shuichi Sato — DPF interferometer module
- Yuta Michimura — BBM test for DPF interferometer

Poster

- Wataru Kokuyama — In-orbit operation of small module SWIM
- Ayaka Shoda — Observation of Earth's gravity by DPF

End