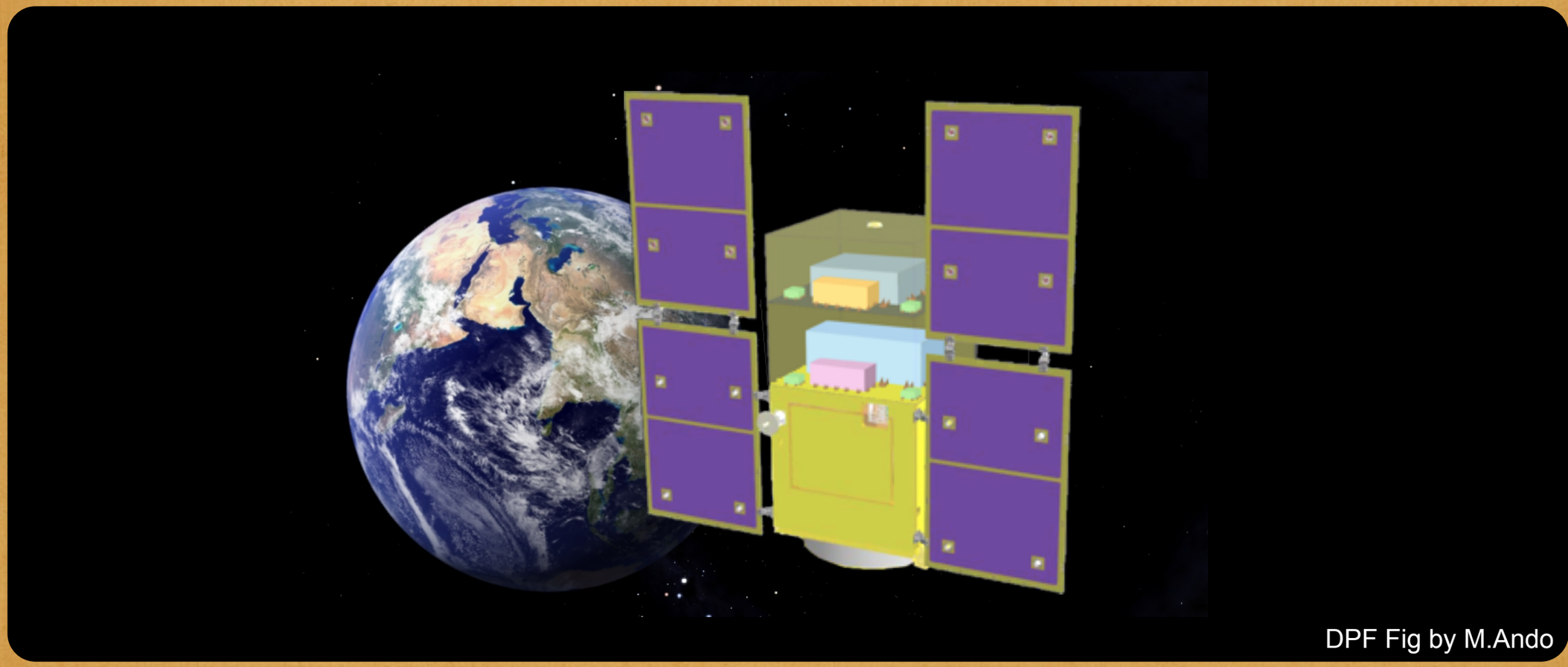
DECIGO and DECIGO Pathfiner



Tomotada Akutsu
National Astronomical Observatory of Japan
on behalf of DECIGO Working Group

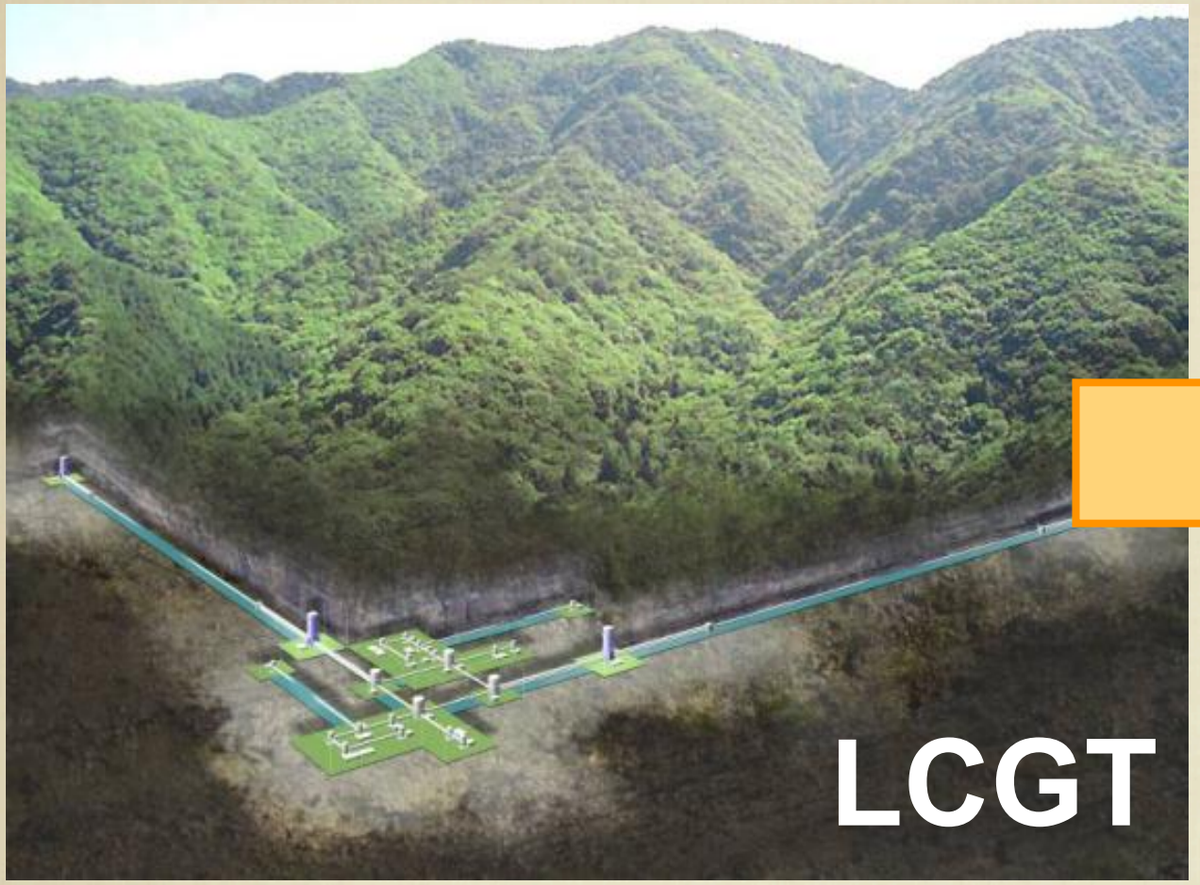
GWADW2011 in Isola d'Elba, Italy (24 May 2011)

Contents

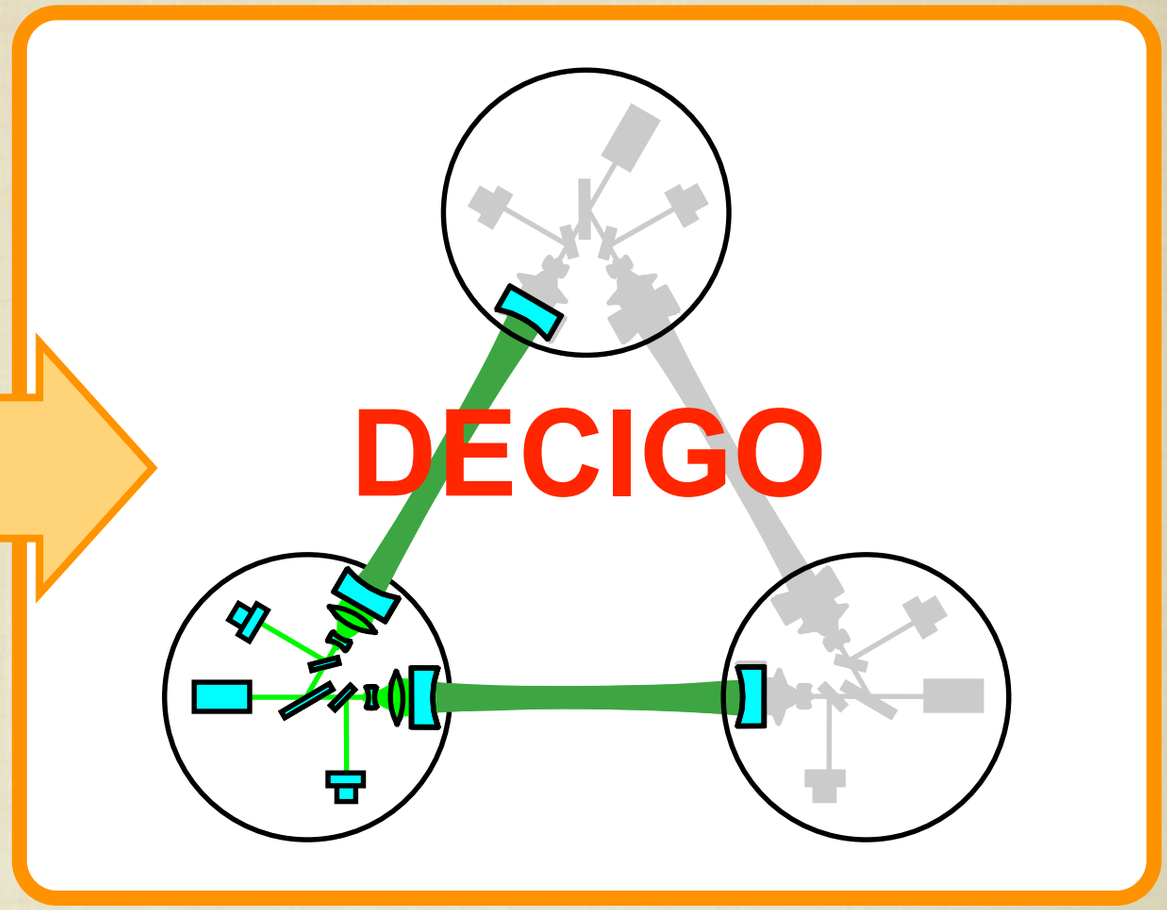
1. DECIGO
2. DECIGO Pathfinder (DPF)
3. Summary

Some of the viewgraphs are owing to S. Kawamura, M. Ando, and other members of DECIGO Working Group.

Roadmap to GW astronomy of Japan



Detecting GW
International network

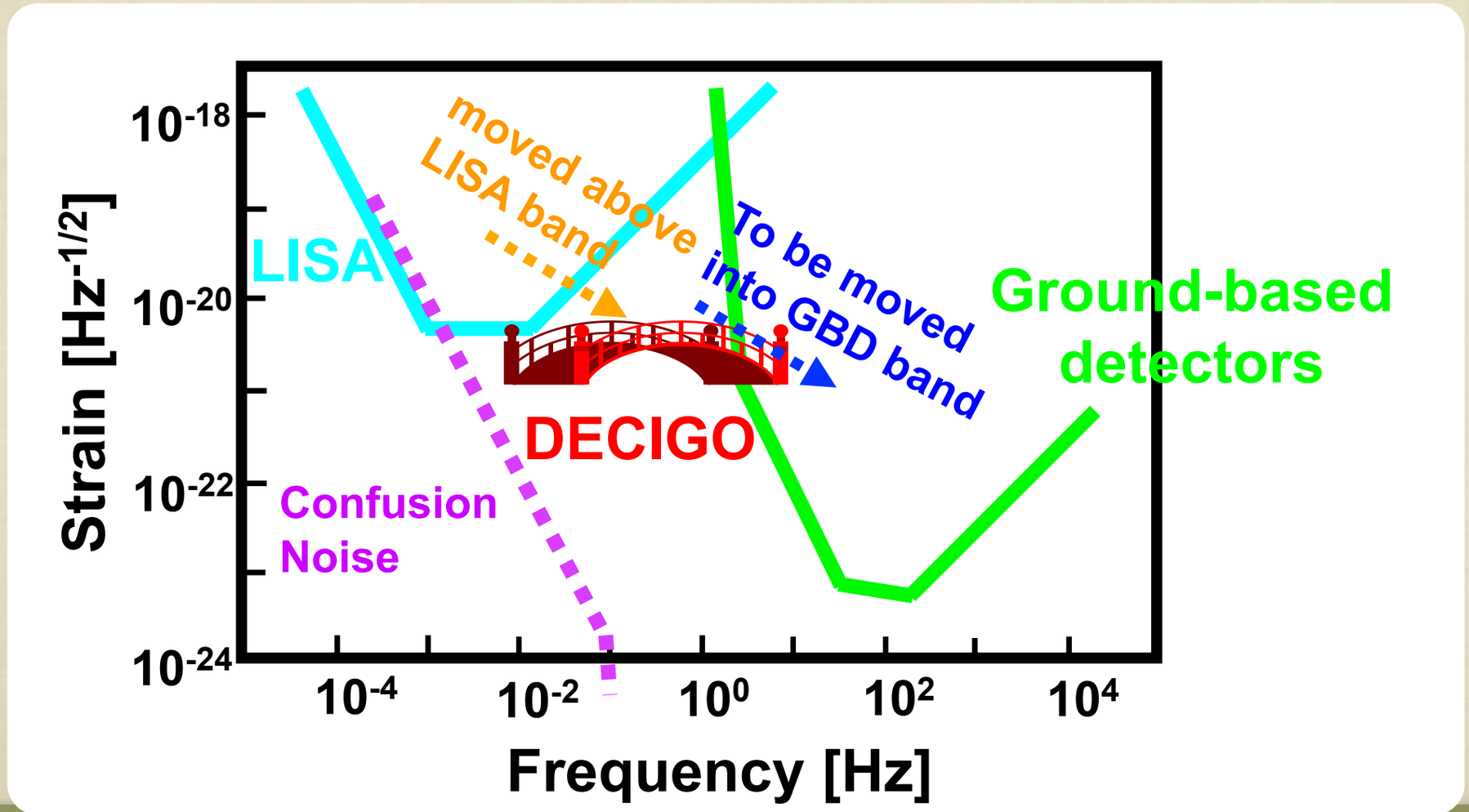


Opening a new window
(*after LISA*)

1. DECIGO
2. DECIGO Pathfinder (DPF)
3. Summary

DECIGO

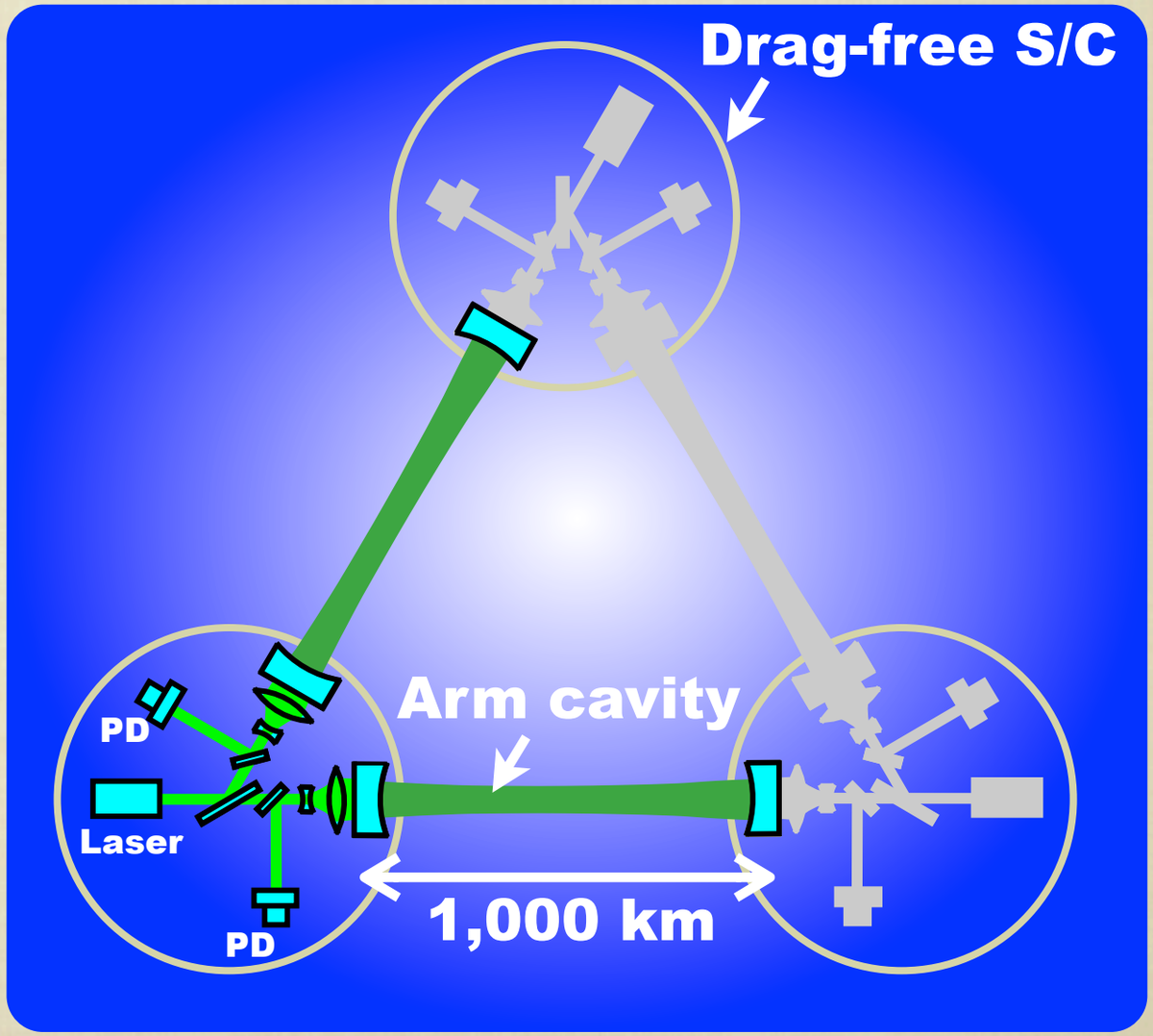
- Deci-hertz interferometer gravitational-wave observatory
  - “bridge” the gap between LISA and terrestrial detectors
  - Observation band: 0.1~10Hz
  - Space GW antenna



Design (pre-conceptual)

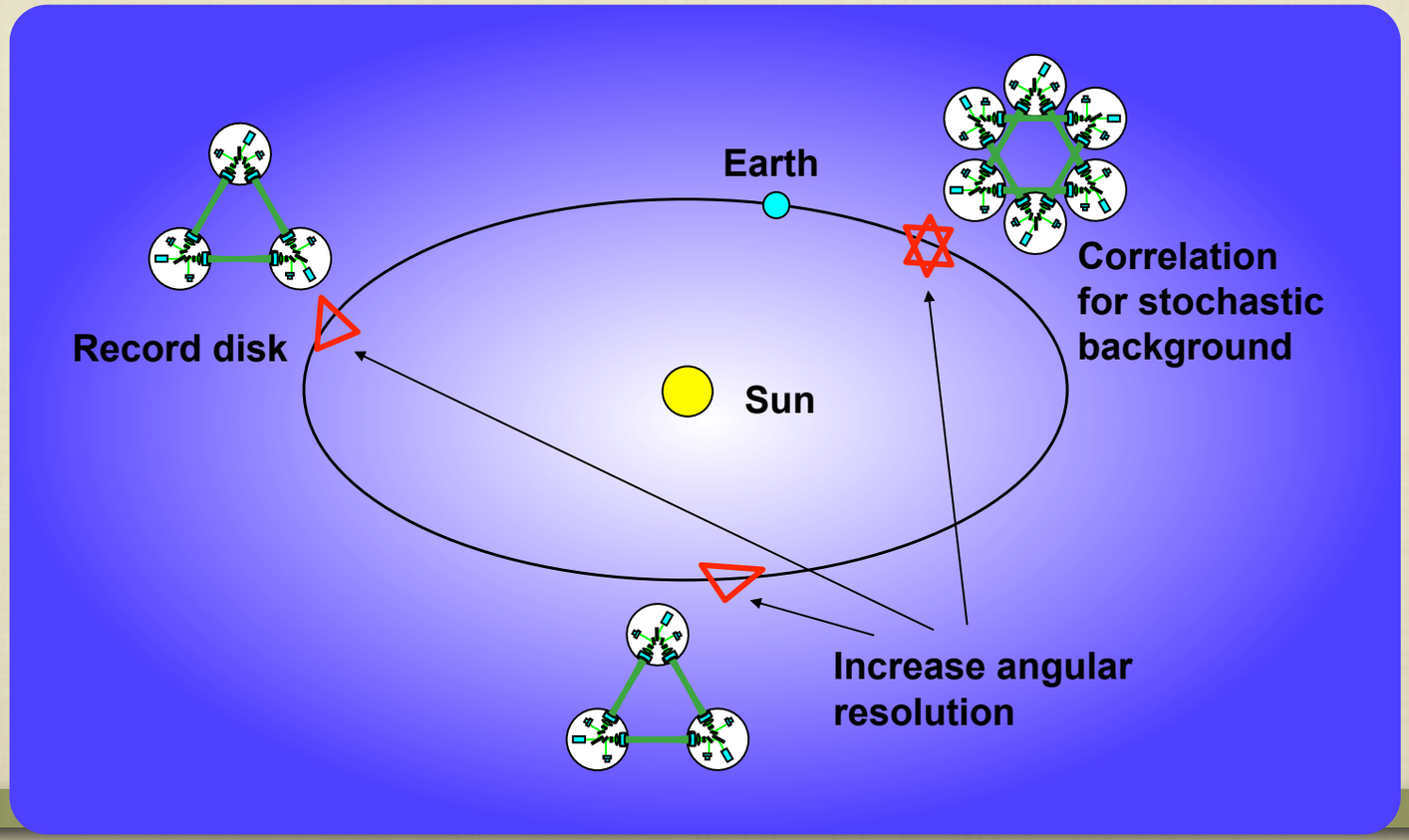
- Interferometer Unit
  - Differential Fabry-Perot interferometer
    - Baseline length: 1000km
    - 3 S/Cs formation flight
    - 3 FPs (finesse: ~10)
    - Drag-free control

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

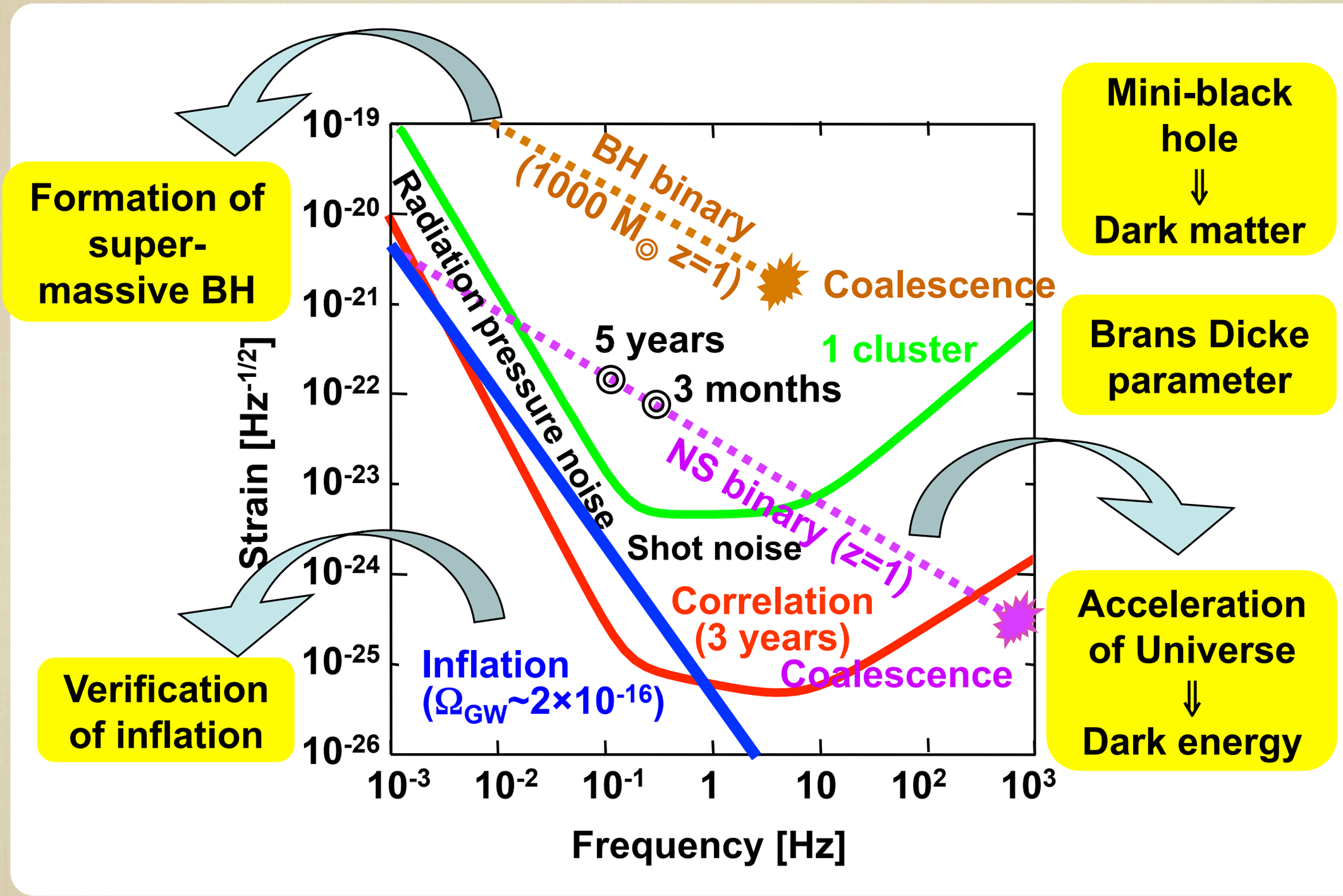


Orbit and constellation

- Candidate Orbit
  - Record disk around the sun
- Constellation
  - 4 interferometer units
    - 2 overlapped units ⇒ Cross correlation
    - 2 separated units ⇒ angular resolution



Science by DECIGO



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

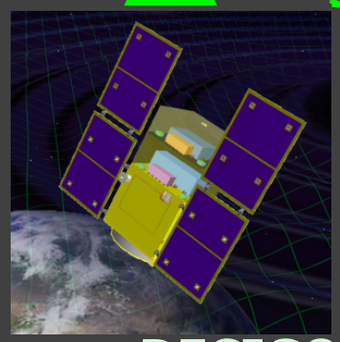
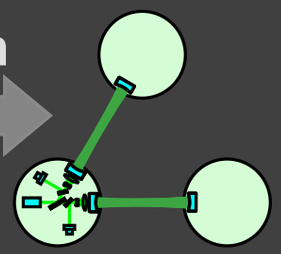
Force noise 4×10^{-17} N/Hz$^{1/2}$ (0.1 Hz)

⇨ x 1/50 of LISA

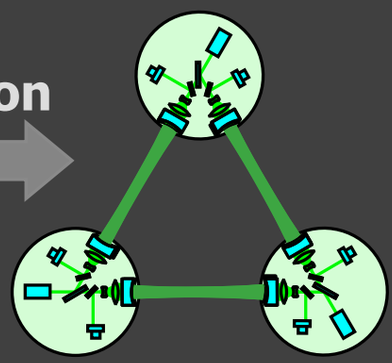
External force sources

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

Roadmap

	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. 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

R&D Fabrication



DECIGO

DECIGO interim organization

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

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

Pre-DECIGO
Sato (Hosei)

Detector
Akutsu (NAOJ)
Numata (Maryland)

Science & Data
Tanaka (Kyoto)
Seto (Kyoto)
Kanda (Osaka City)

Spacecraft
Funaki (JAXA/ISAS)

Design Phase

DECIGO Pathfinder
Leader: Ando (Kyoto)

Mission Phase

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

Laser
Musha (E.C.)
K. Ueda (E.C.)

Drag-free
Moriwaki (Tokyo)
Sakai (JAXA/ISAS)

Thruster
Funaki (JAXA/ISAS)

Signal Process
Akutsu (NAOJ)

Bus
Takashima (JAXA/ISAS)

Data
Kanda (Osaka City)

Collaborations and supports

- Supports from LISA
  - * Technical advices from LISA/LPF experiences
  - * Support Letter for DECIGO/DPF, Joint workshop (2008.11)
- Stanford univ. group
  - * Discharge system for DPF, other R&D for DECIGO
- NASA
  - * Fiber laser, Joint observation with GRACE
- JAXA Navigation-control section
  - * Formation flight of DECIGO, DPF drag-free control
- Research Center for the Early Universe (RESCEU), Univ. of Tokyo
  - * supports DECIGO as ones of main projects (2009.4-)
- Geo-gravity field group (Kyoto, ERI, UEC, NAOJ)
  - * Geophysics by DPF obs. data
- Advanced Technology Center (ATC) of NAOJ

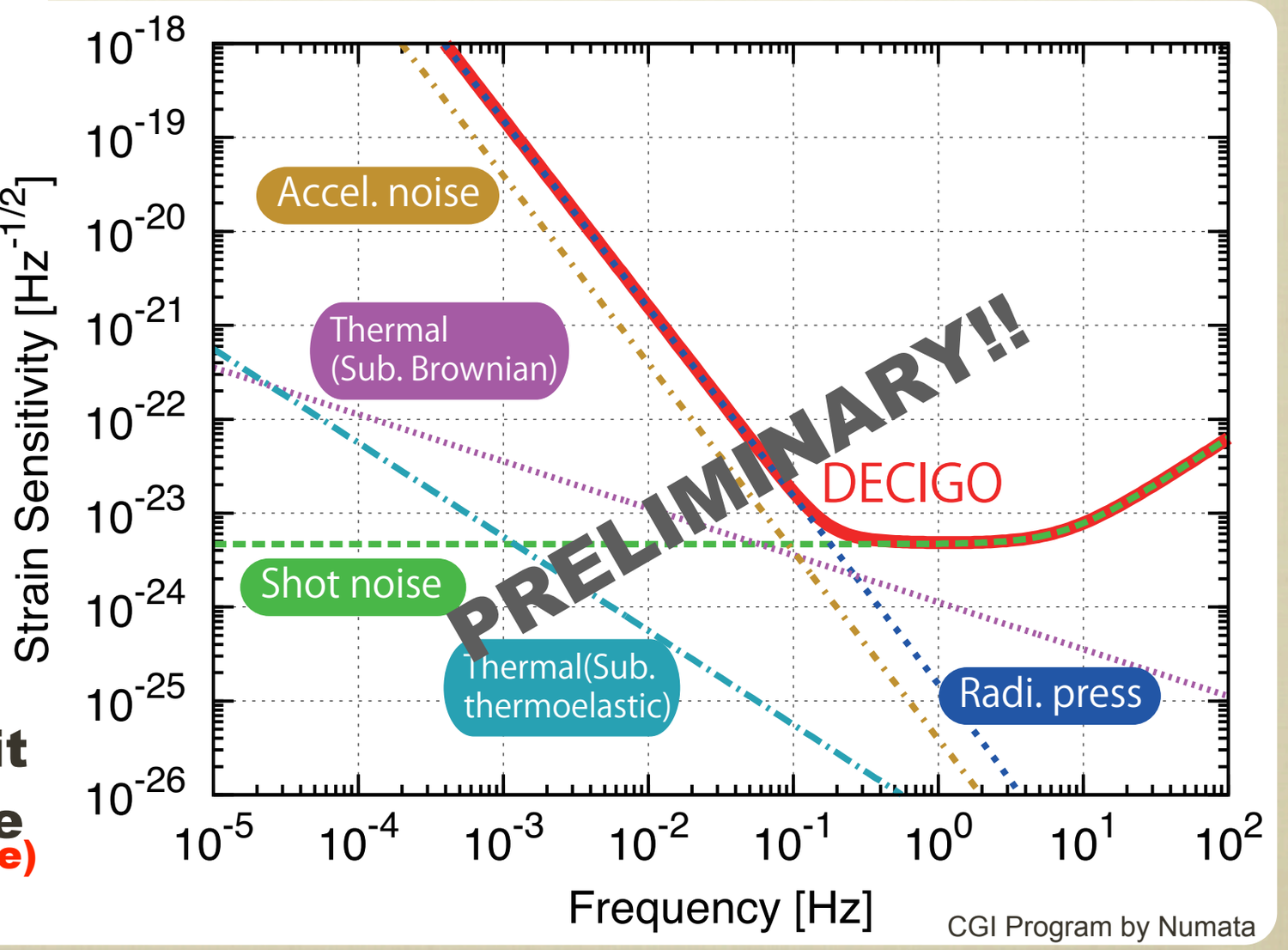
New!

New!

Calculating the sensitivity

- Arm length: 1,000 km
- Laser power: 10 W
- Laser wavelength: 532 nm
- Mirror diameter: 1.0 m
- Mirror mass: 100 kg
- Mirror reflectivity: 77.3%
- Cavity g-param: 0.1

⇐ **"pre-conceptual design"**



To detect stochastic GWs and observe *the early universe*, we should clean off any "foreground GW sources."

Tune the parameters a little bit to improve the sensitivity more (~ 3 times more) in the obs. freq. band.

Considering “Conceptual design”

- Arm length: 1,500 km
- Laser power: 30 W
- Laser wavelength: 532 nm
- Mirror diameter: 1.5 m
- Mirror mass: 100 kg
- Mirror reflectivity: 77.3%
- Cavity g-param: 0.1

This is the first step to considering the conceptual design.

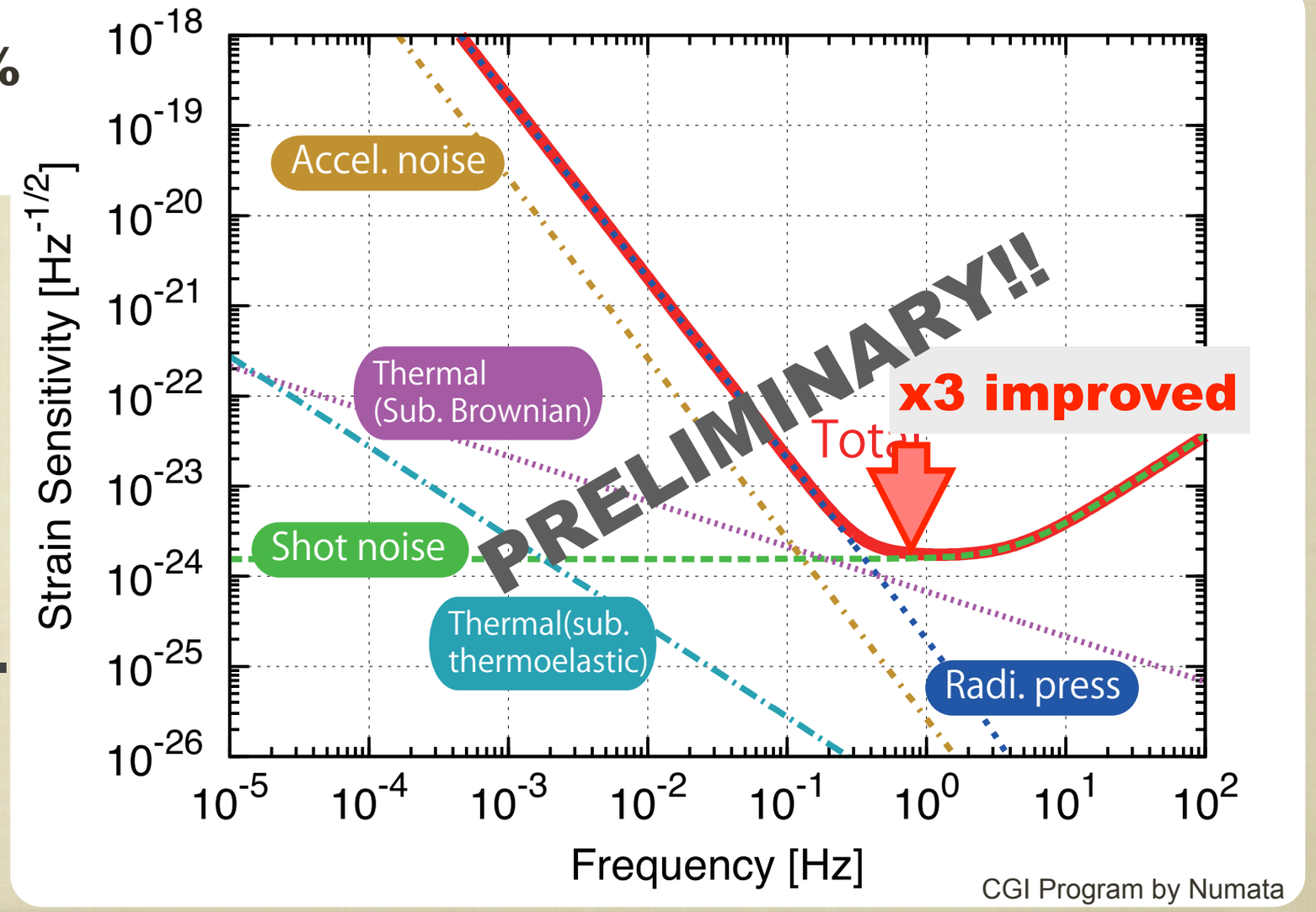
Next:

➡Confirm the calculations.

➡Find the realistic way to realize this!

Preliminary

Parameters tuned

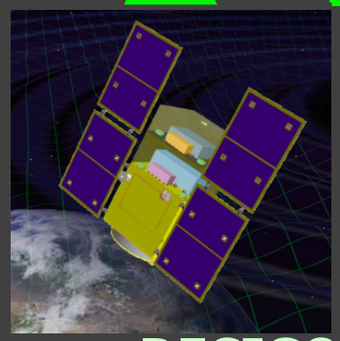


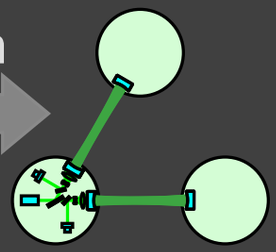
1. DECIGO
2. DECIGO Pathfinder (DPF)
3. Summary

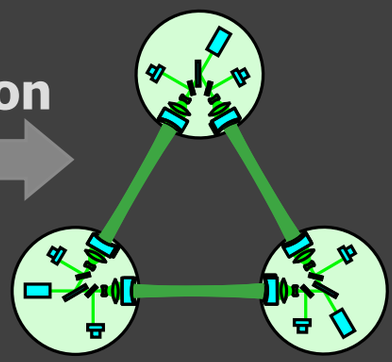
DECIGO Pathfinder in the roadmap

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

SDS-1/SWIM


DECIGO Pathfinder (DPF)


Pre-DECIGO


DECIGO

DECIGO Pathfinder

DECIGO Pathfinder (DPF)

First milestone mission for DECIGO

Shrink arm cavity

DECIGO 1000km → DPF 30cm

Single satellite

(Payload ~1m³ , 350kg)

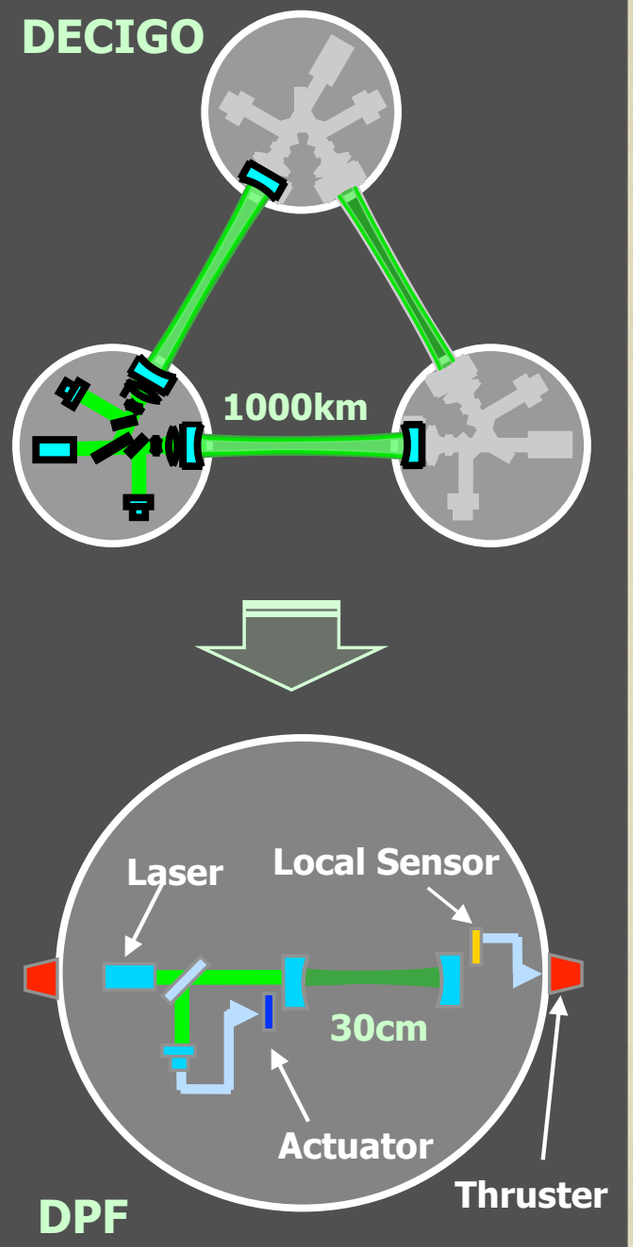
Low-earth orbit

(Altitude 500km, sun synchronous)

30cm FP cavity with 2 test masses

Stabilized laser source

Drag-free control



DPF Satellite design

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

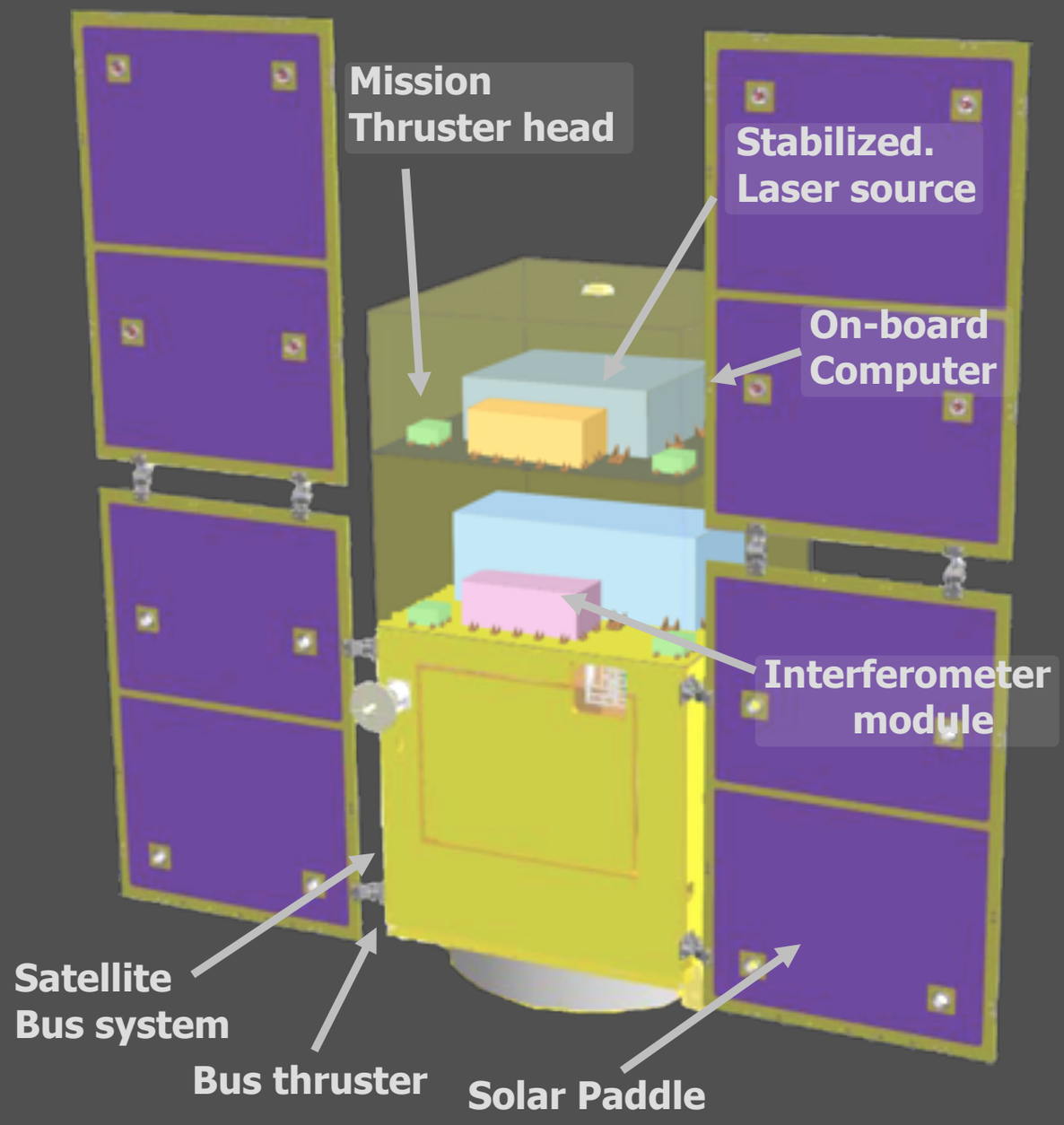
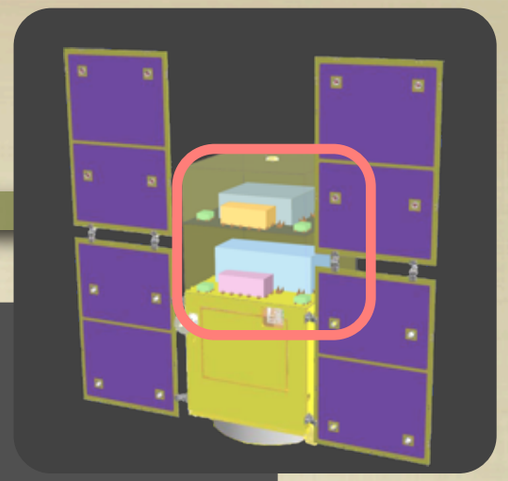


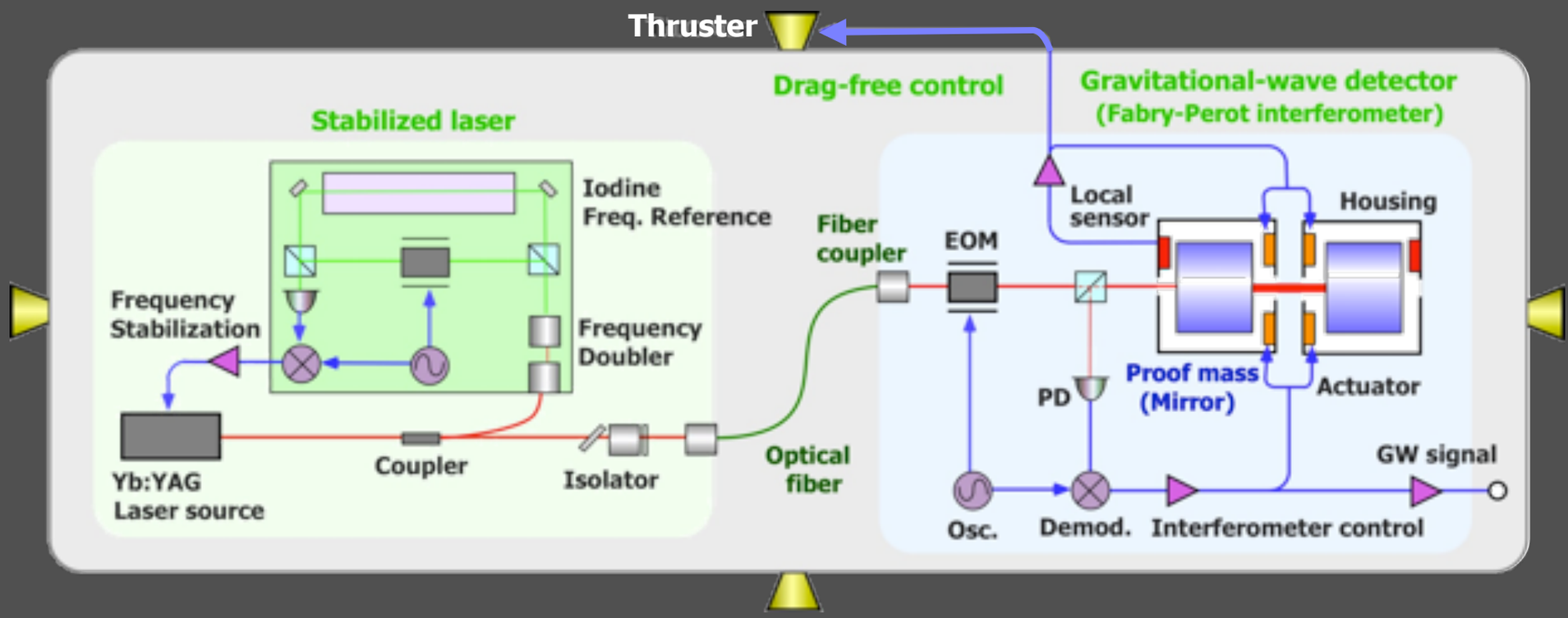
Fig. by Ando

DPF mission payload



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

Drag-free control
Local sensor signal
→ Feedback to thrusters



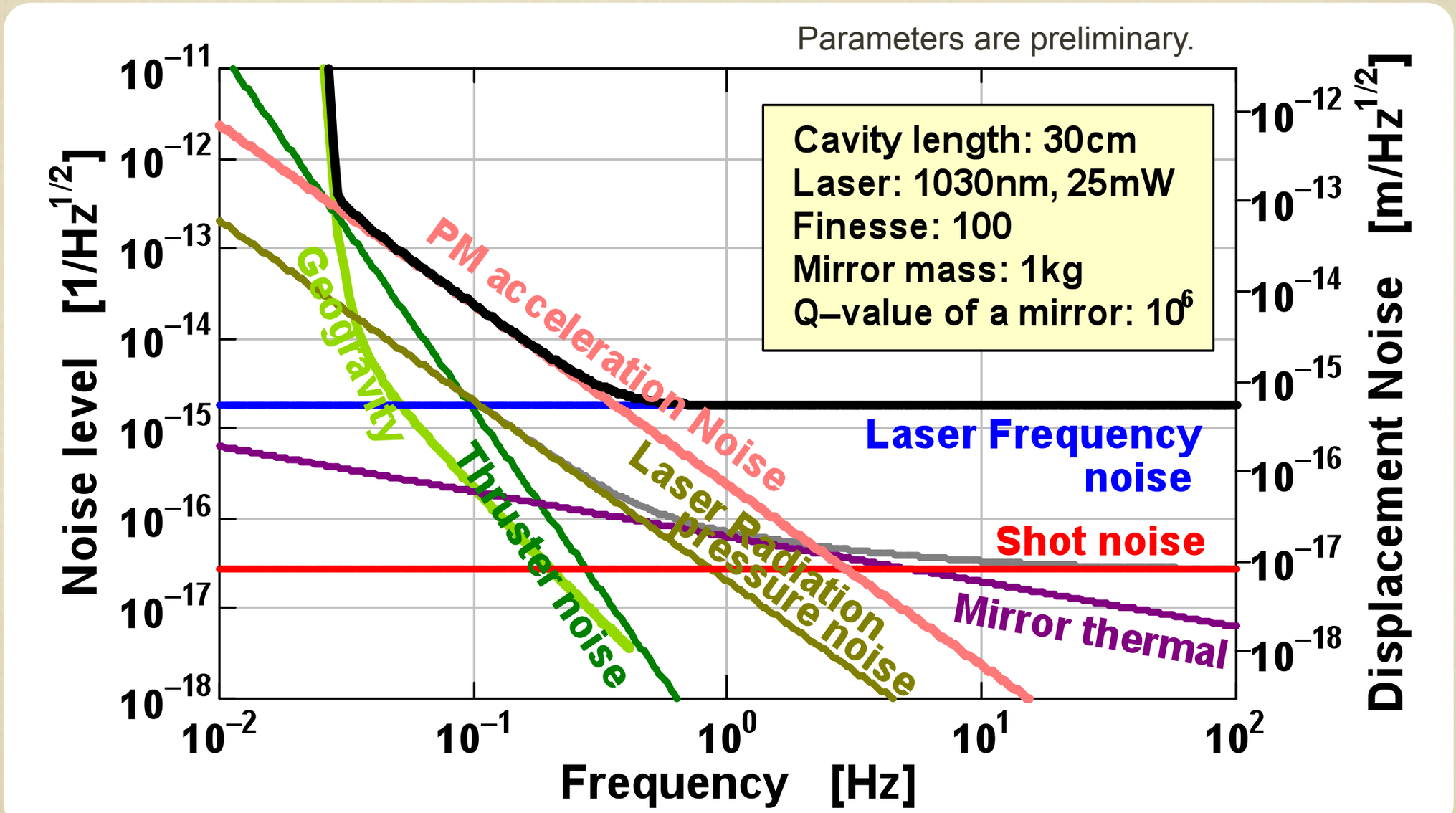
Laser source
Yb:YAG laser (1030nm)
Power : 25mW
Freq. stab. by Iodine abs. line

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

Fig. by Ando

DPF sensitivity

- Noise level : h ~ 2e-15 strain/rtHz
  - Limited by laser frequency noise and acceleration noise



DPF Requirements

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.

DPF Science --- 1. gravitational wave

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

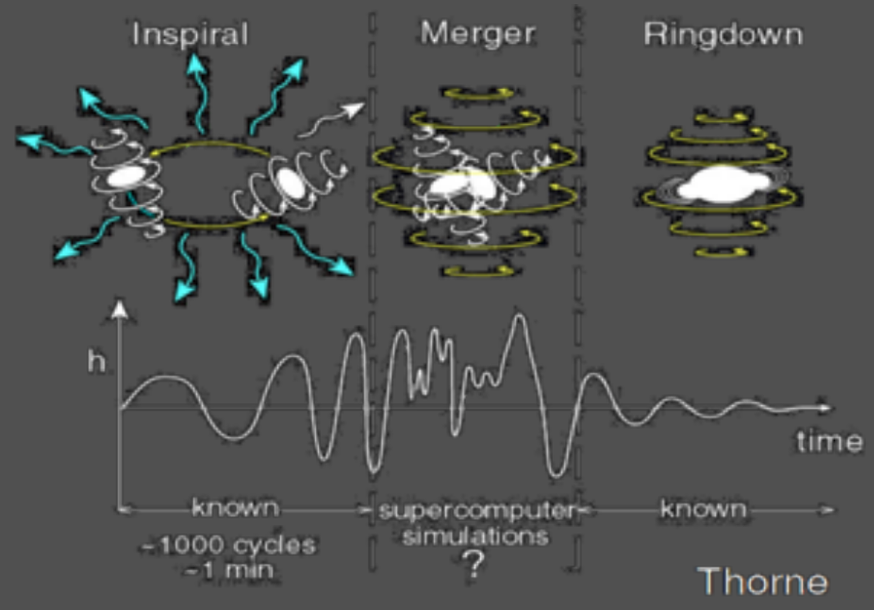
$h \sim 10^{-15}$, $f \sim$ 0.3 Hz

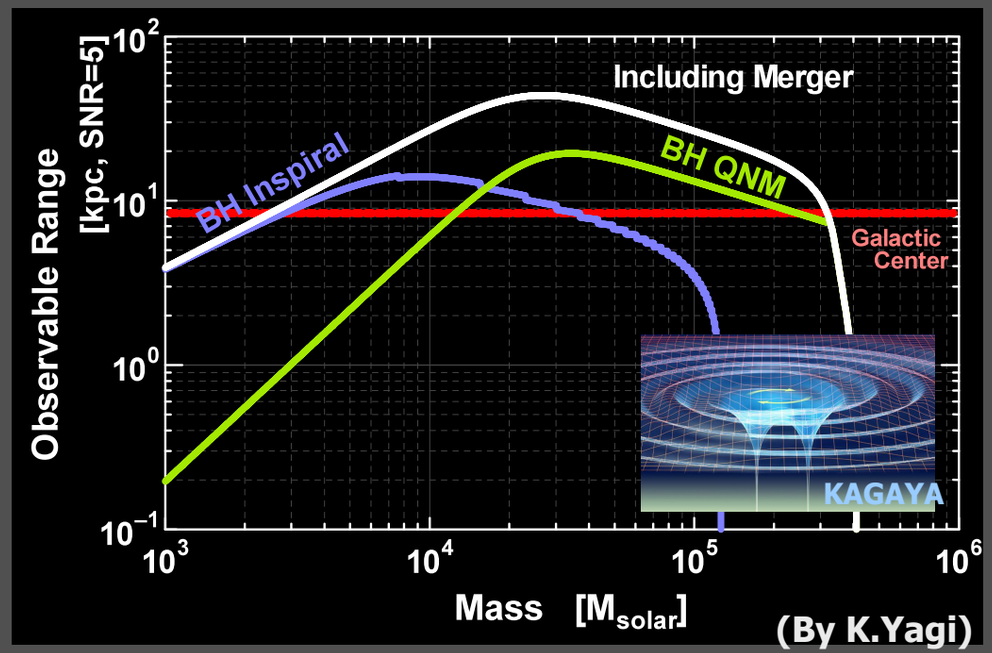
Distance 1Mpc, $m = 10^5 M_{sun}$

Observable range covers our Galaxy (SNR~5)

Hard to access by others

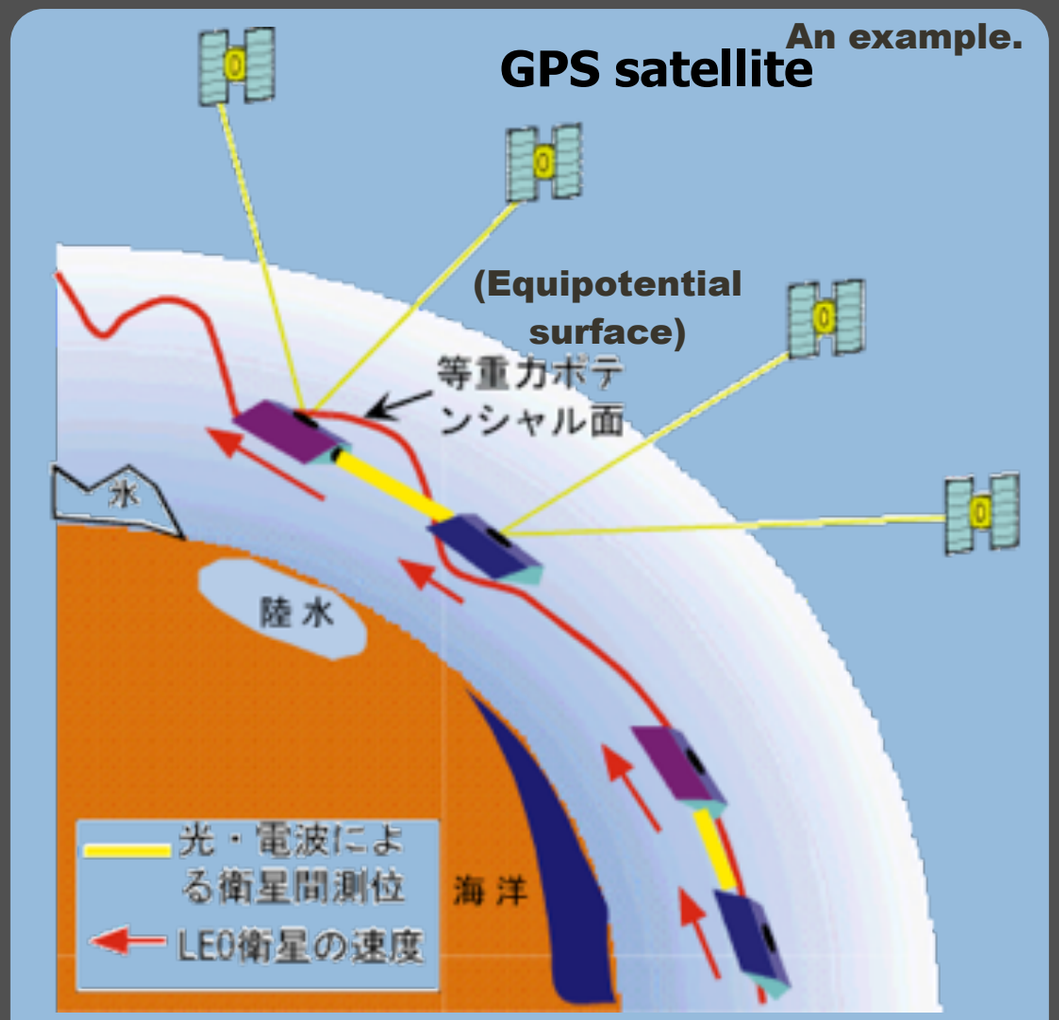
→ Original observation





DPF Science --- 2. gravity of the earth

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



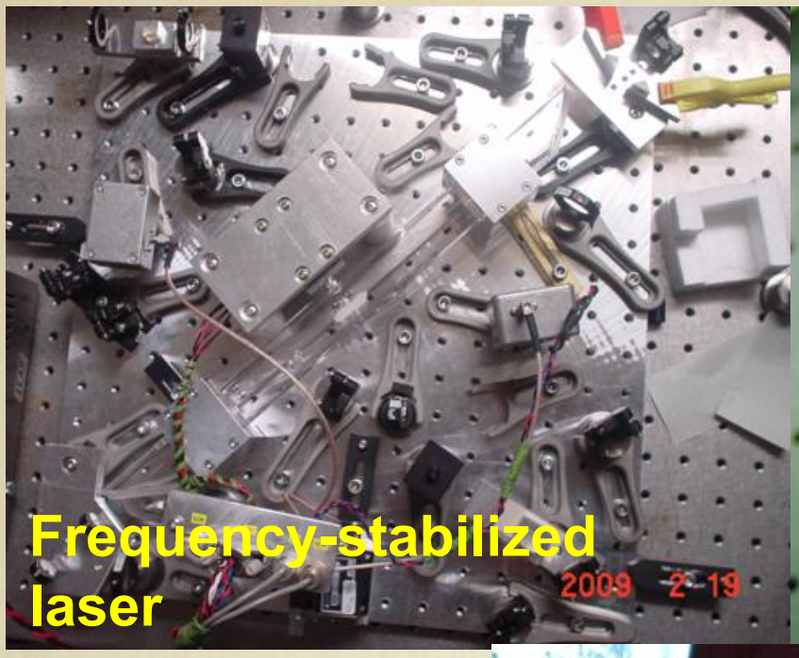
By Araya and Fukuda

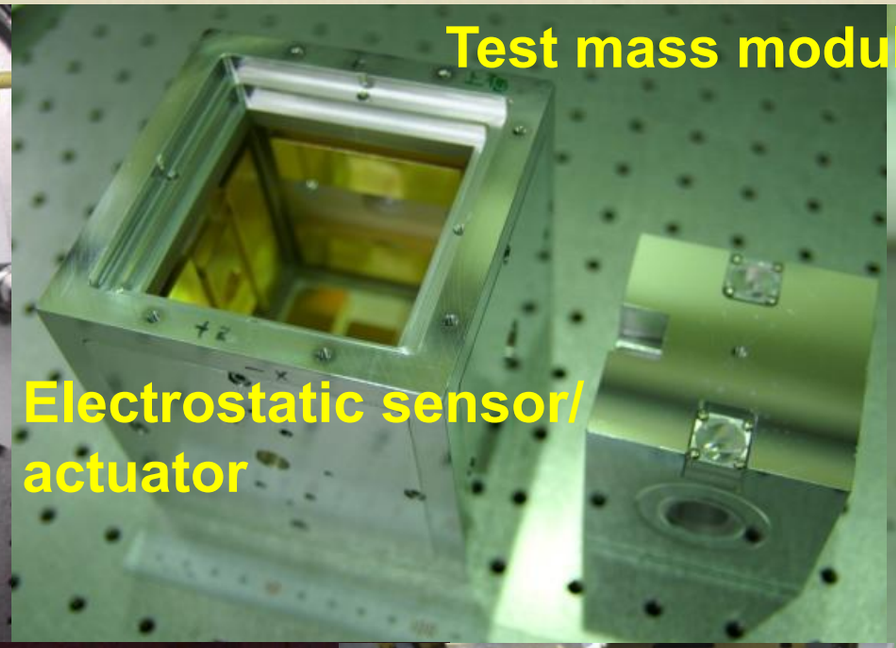
Determine global gravity field
→ Density distribution
Monitor of change in time
Ground water motion
Strains in crusts by earthquakes and volcanoes

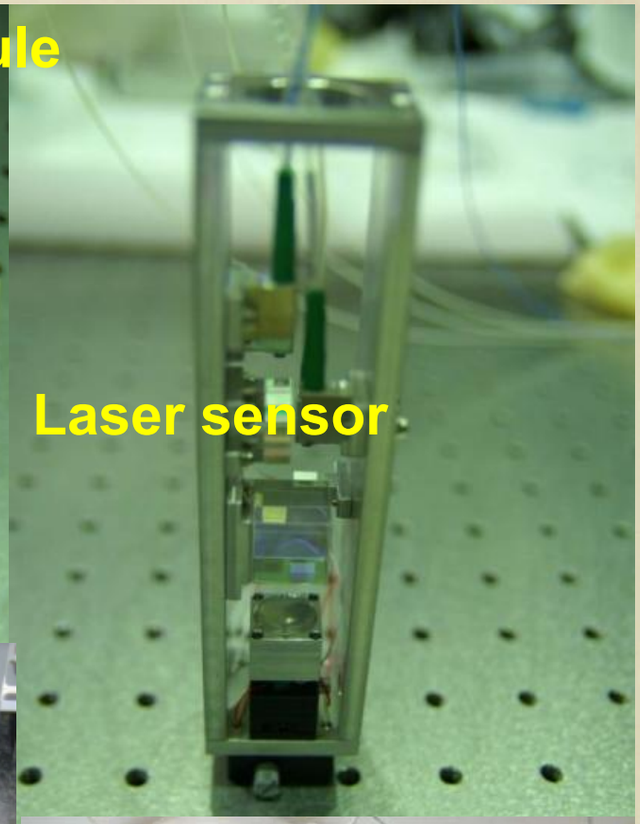
NASA's mission
GRACE FO (2016-2021?)

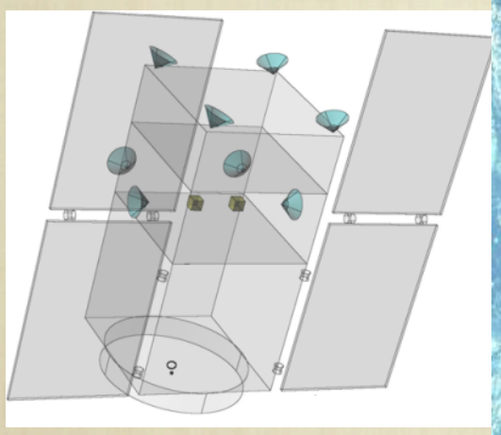
➡DPF contribution (2017?)
in international network

R&D for DPF subsystems

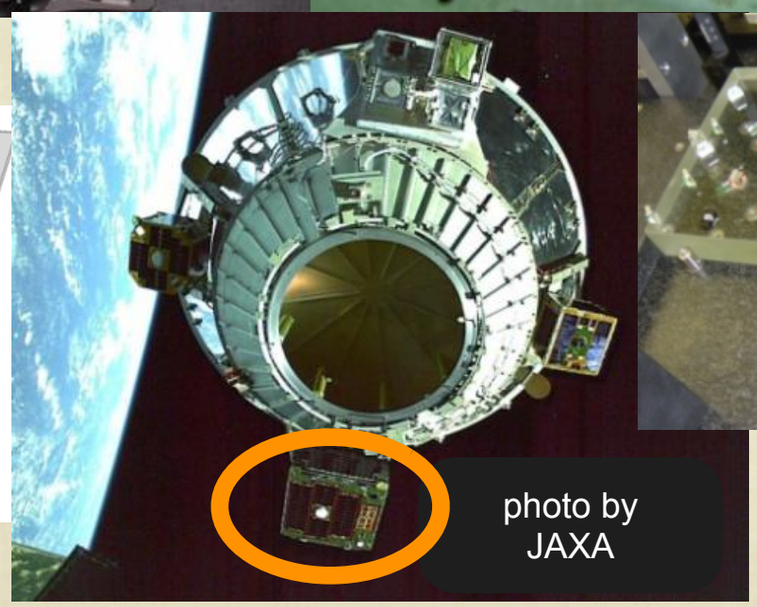




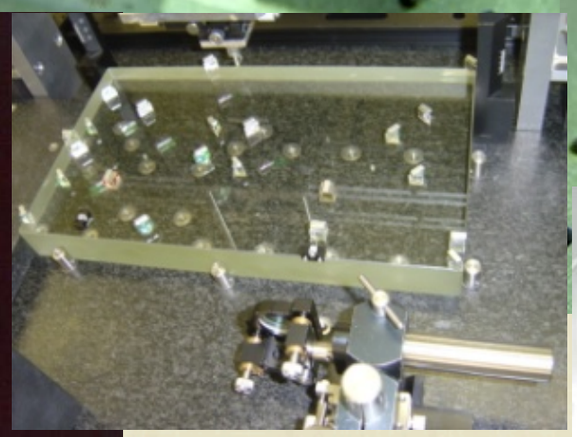




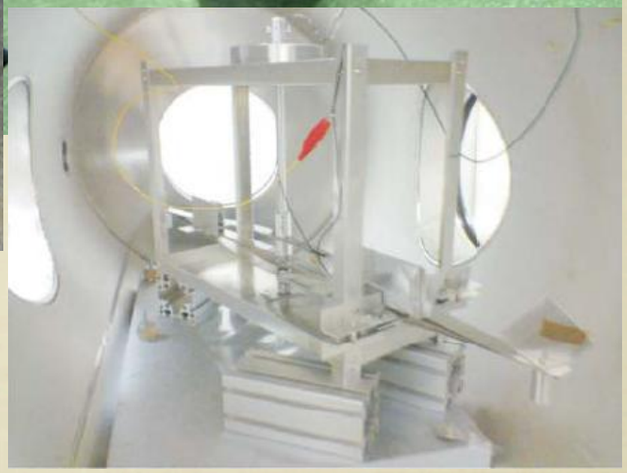
Drag-free model



Signal processing and control in space



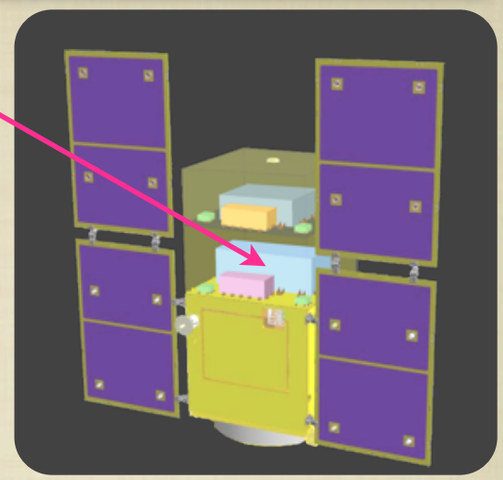
Interferometer (monolithic optics)



Low noise thruster

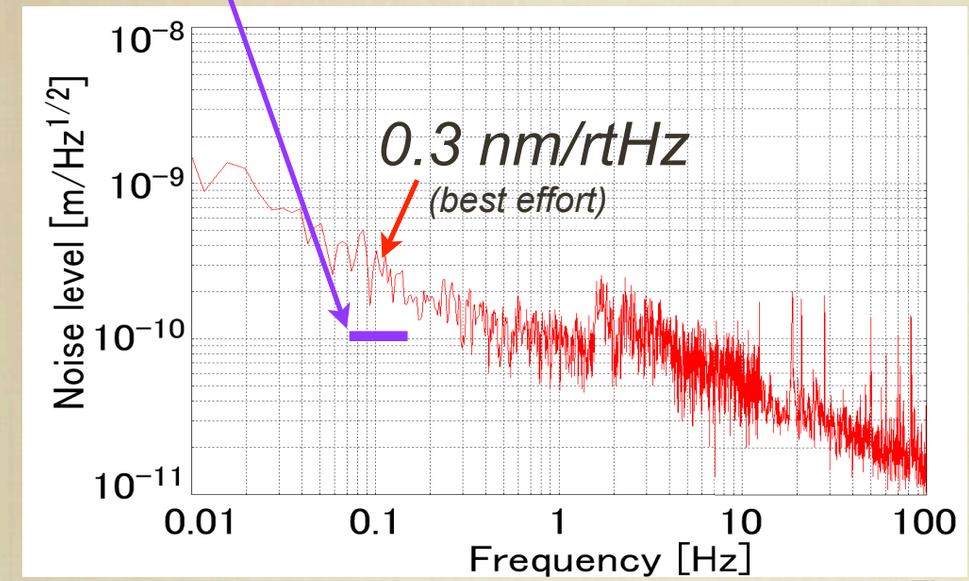
Test mass module (Inertial sensor)

Subsystem of Interferometer module

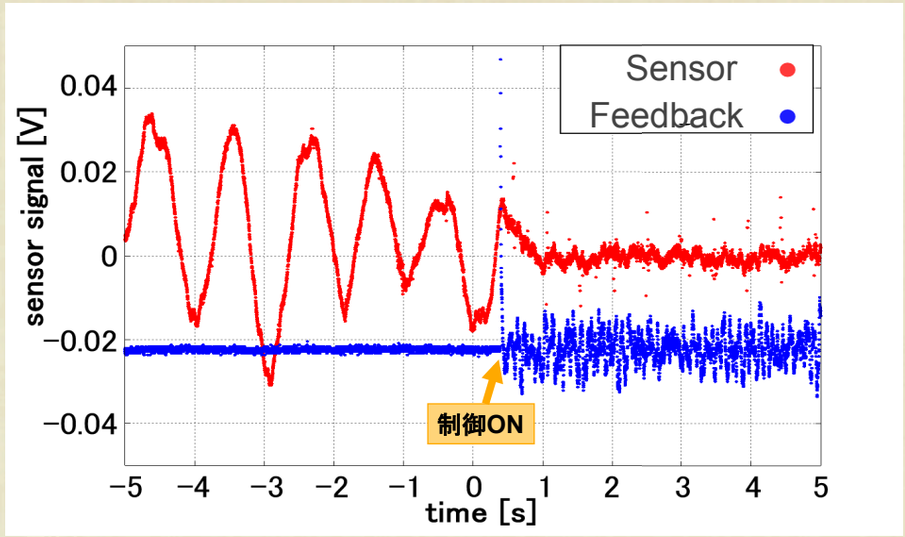


❖Prototype experiment of individual functions

Req. of local sensor noise
(capacitive sensor)



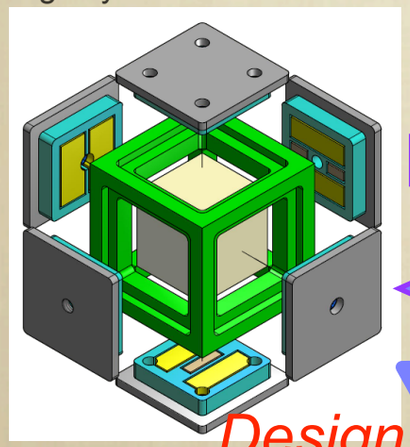
Controlling motions of a suspended test-mass
with ***electrostatic actuators***



Figs by Ejiri

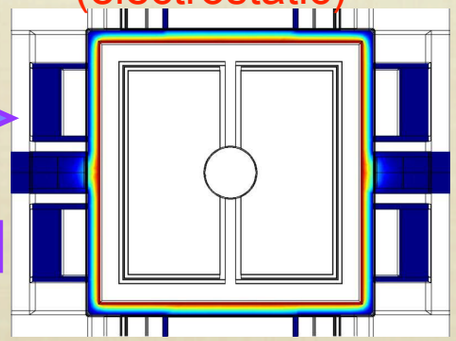
❖Design & Analysis

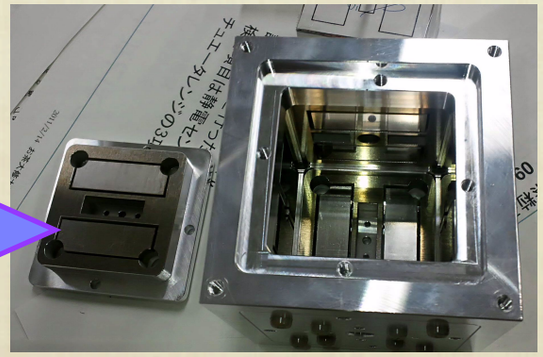
Figs by R.Suzuki



Design

FEM analysis
(electrostatic)





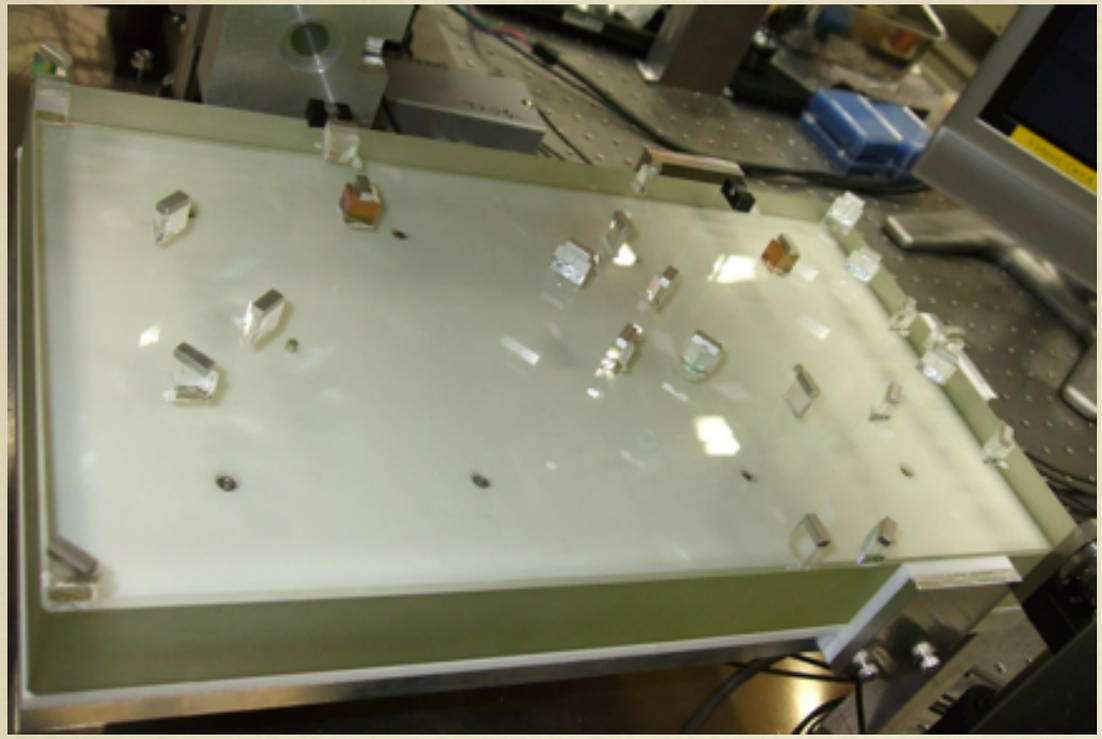
Manufacture &
Functional test

To meet the requirements of:
Noise of **Capacitive sensors,**
Range of **Electrostatic Actuators,**
and **Electrostatic Stiffness**

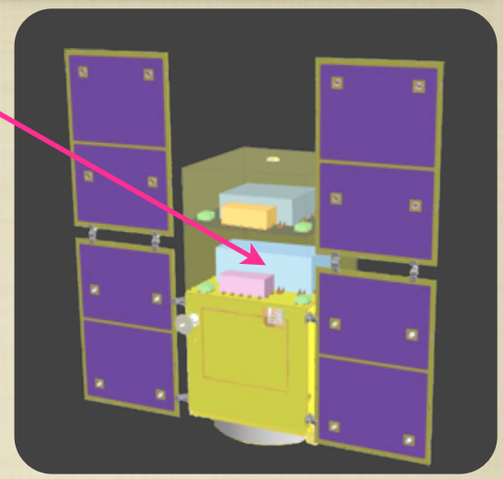
Interferometer module

❖Monolithic optics

(as input optics)



Interferometer module



Why monolithic?

➡To survive the shocks during launch.

➡To prevent optical path from fluctuating in space

➡etc...

Demonstration:

➡With the optics,

a FP cavity can be in operation

(30cm long, same as DPF's)

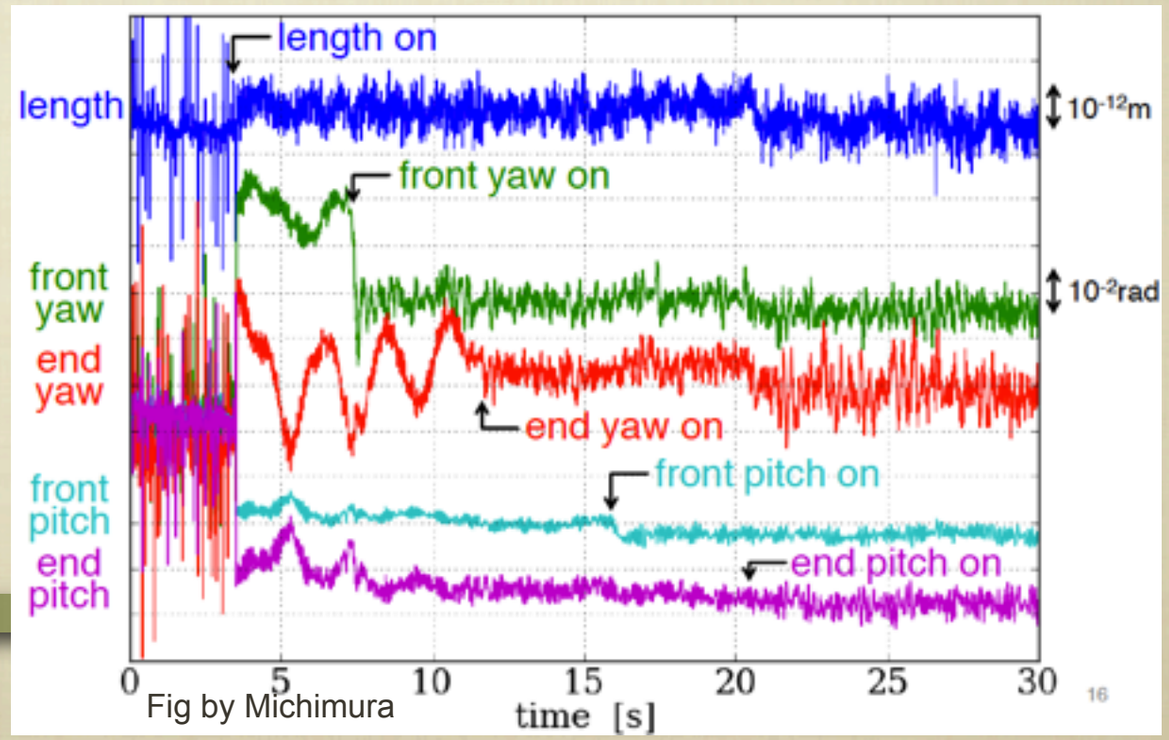
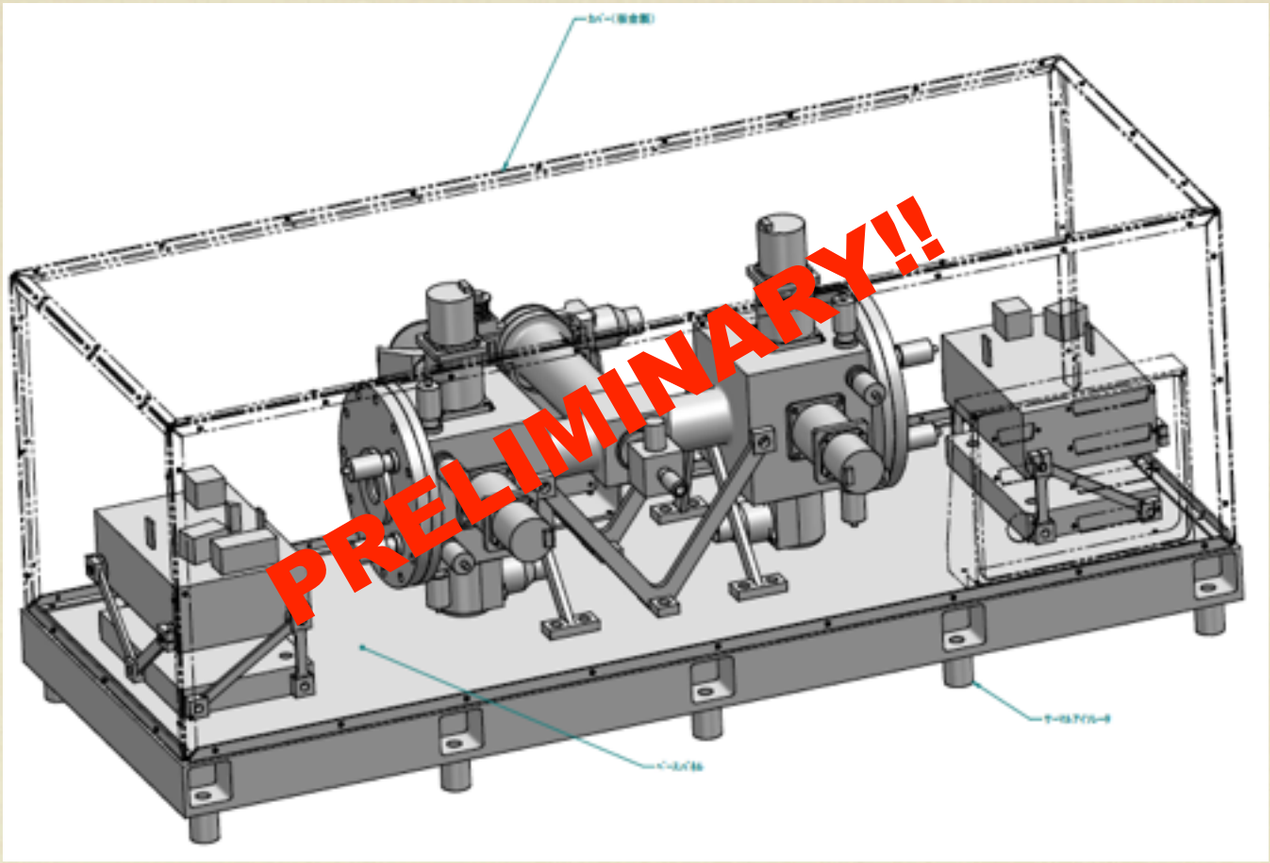


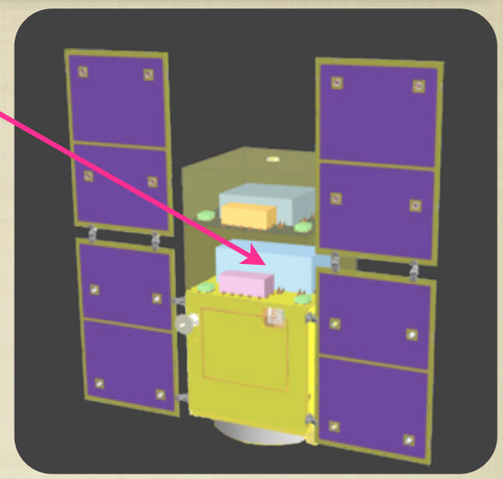
Fig by Michimura

Interferometer module (contd.)

❖Structure



Interferometer module

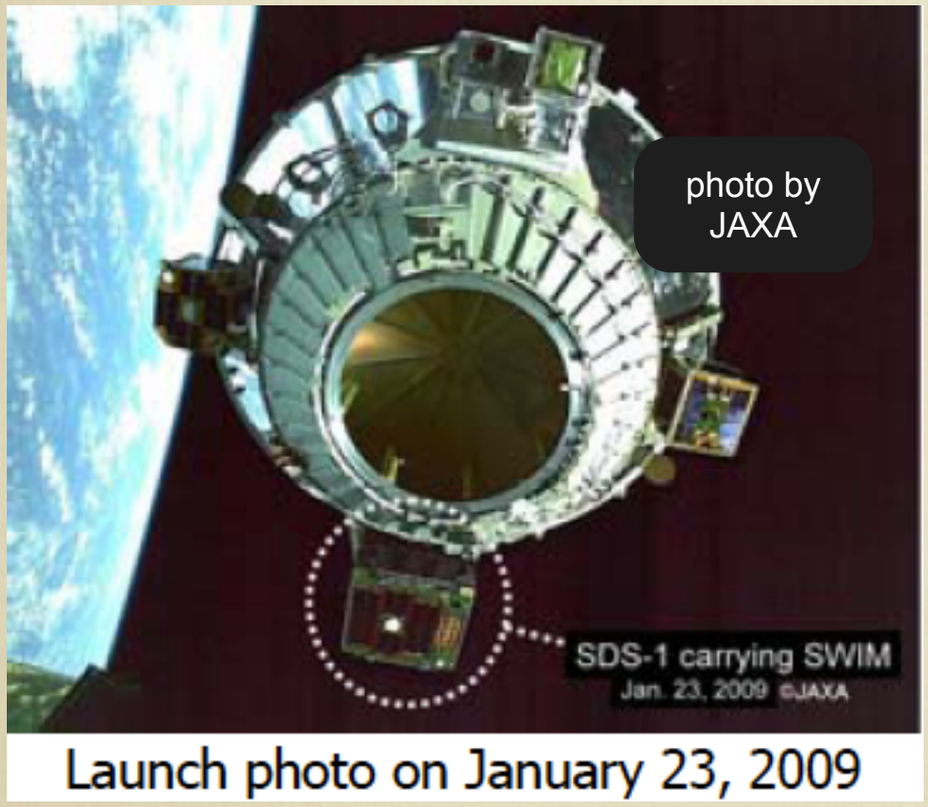


Assemble every component to one module

➡ **Components: test-mass modules, optics, electronics, optical fibers and metal wires, dynamic mechanisms, robust chassis,...**

SWIMμν --- *Mission Successfully Completed!!*

- SWIMμν: tiny space GW sensor (torsion type)
- * SWIM (one of the missions of JAXA's Small Demonstration Satellite-1)
  = SWIMμν + new satellite technology
  space-qualified computers, signal processing systems etc.
- * Design sensitivity: 1e-6 rad/rtHz (0.1-1Hz) in space



Launch photo on January 23, 2009

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

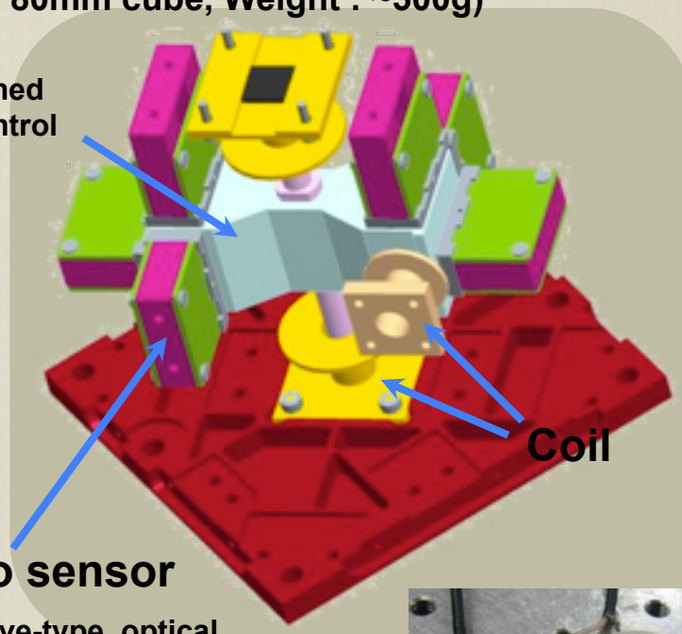
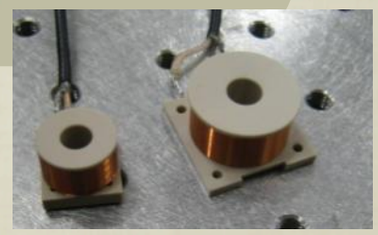


Photo sensor

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



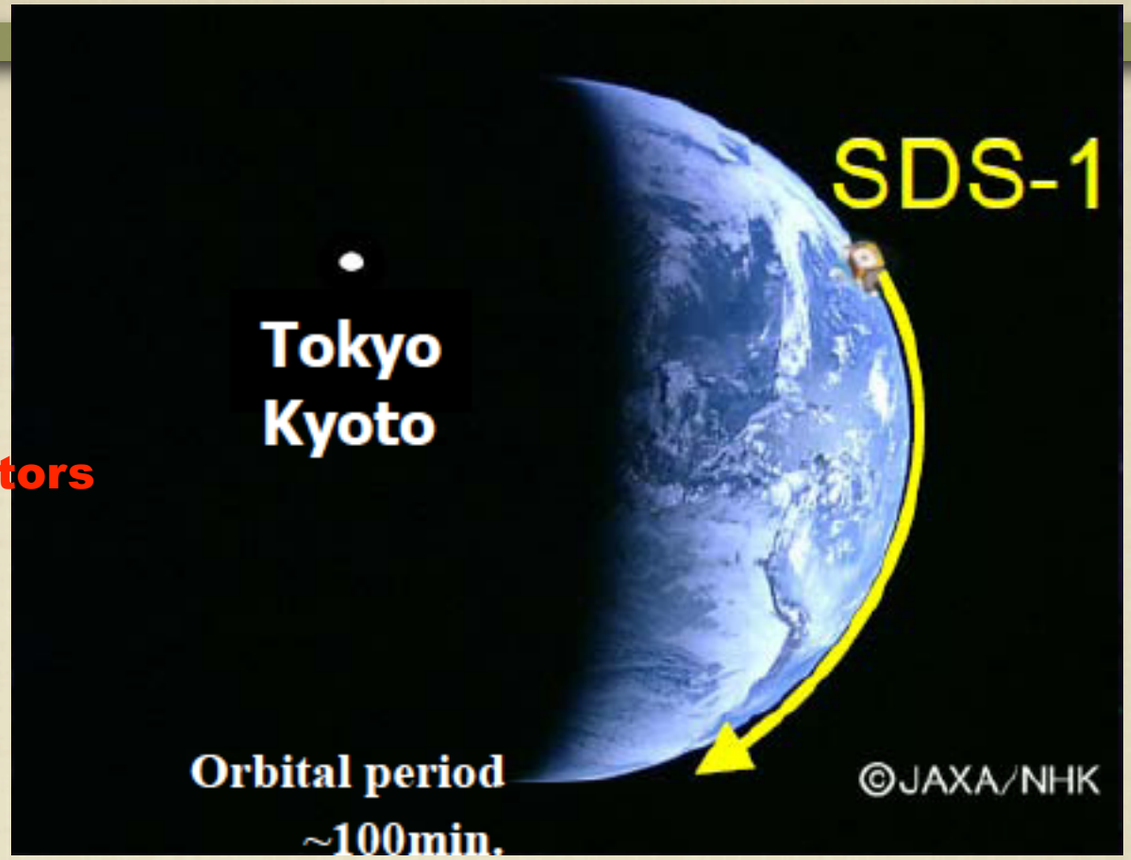
SWIMμν (contd)

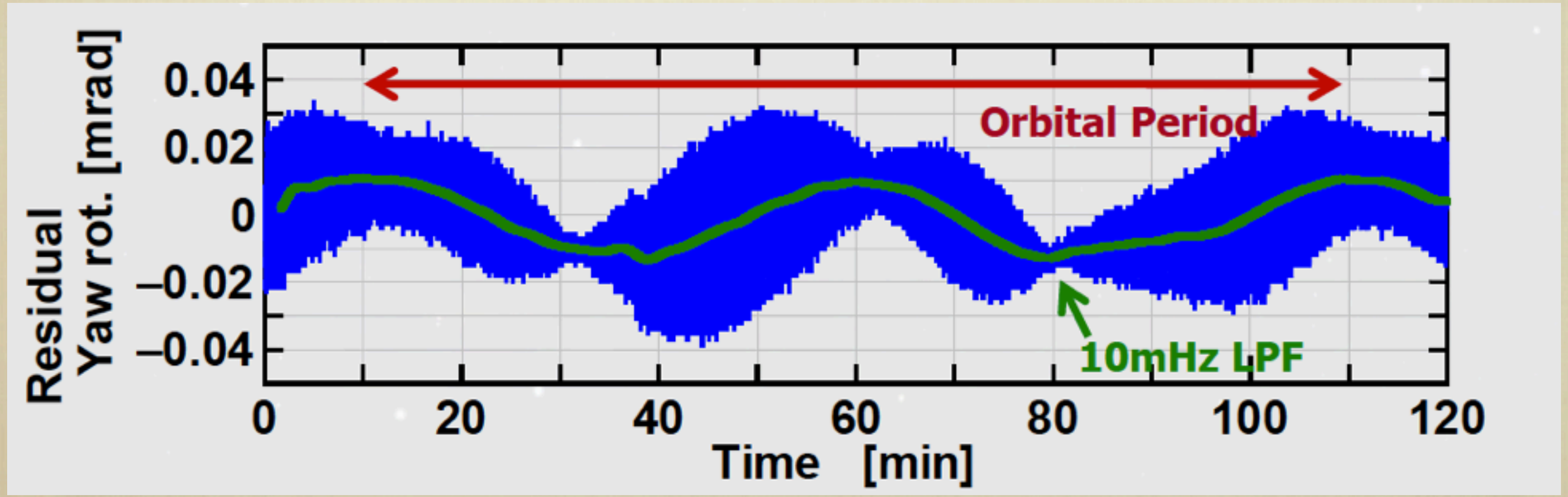
- Data Taking
  - ~120 min (17 Jun 2010)
  - ~240 min (15 Jul 2010)

Taking data together with terrestrial detectors

Now data analysis is ongoing!!

Details:
Ando's talk tomorrow (May 25)

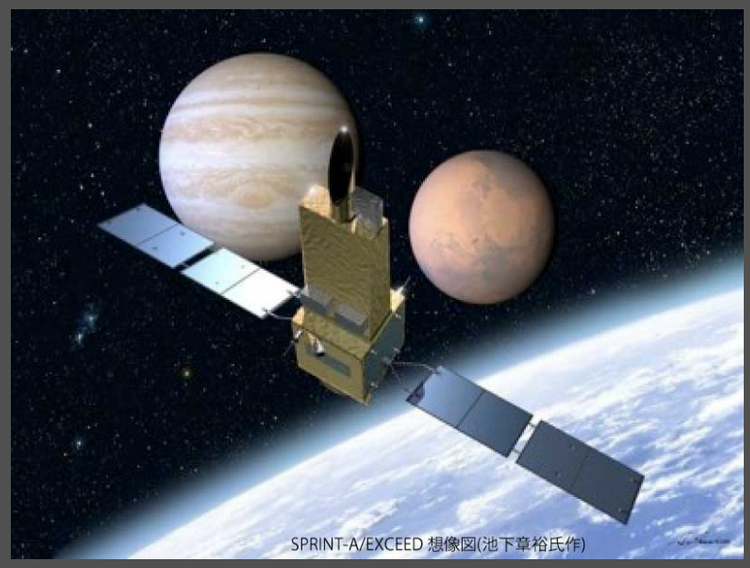




Funding status of DPF

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

At least 3 satellites 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 (2016/17?) : TBD

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

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

1. DECIGO
2. DECIGO Pathfinder (DPF)
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 – Mission successfully completed!!
first precursor to space!

END