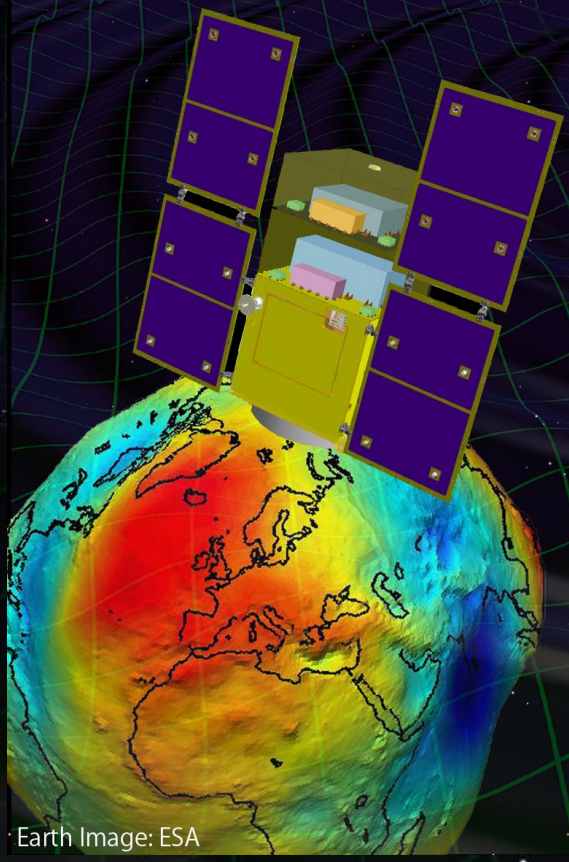
DECIGO



Masaki Ando

(National Astronomical Observatory of Japan)

On behalf of
DECIGO working group

DECIGO Working Group

Koh-suke Aoyanagi, Kazuhiro Agatsuma, Hideki Asada, Yoichi Aso, Koji Arai, Akito Araya, Masaki Ando, Kunihito, Ioka, Takeshi Ikegami, Takehiko Ishikawa, Hideharu Ishizaki, Hideki Ishihara, Kiwamu Izumi, Kiyotomo Ichiki, Hiroyuki Ito, Yousuke Itoh, Kaiki T. Inoue, Akitoshi Ueda, Ken-ichi Ueda, Masayoshi Utashima, Yumiko Ejiri, Motohiro Enoki, Toshikazu Ebisuzaki, Yoshiharu Eriguchi, Naoko Ohishi, Masashi Ohkawa, Masatake Ohashi, Kenichi Oohara, Yoshiyuki Obuchi, Kenshi Okada, Norio Okada, Nobuki Kawashima, Fumiko Kawazoe, Isao Kawano, Seiji Kawamura, Nobuyuki Kanda, Kenta Kiuchi, Naoko Kishimoto, Hitoshi Kuninaka, Hiroo Kunimori, Kazuaki Kuroda, Hiroyuki Koizumi, Feng-Lei Hong, Kazunori Kohri, Wataru Kokuyama, Keiko Kokeyama, Yoshihide Kozai, Yasufumi Kojima, Kei Kotake, Shiho Kobayashi, Motoyuki Saijo, Ryo Saito, Shin-ichiro Sakai, Masaaki Sakagami, Shihori Sakata, Norichika Sago, Misao Sasaki, Shuichi Sato, Takashi Sato, Masaru Shibata, Hisaaki Shinkai, Naoshi Sugiyama, Rieko Suzuki, Yudai Suwa, Naoki Seto, Kentaro Somiya, Hajime Sotani, Takeshi Takashima, Tadashi Takano, Kakeru Takahashi, Keitaro Takahashi, Tadayuki Takahashi, Hirotaka Takahashi, Fuminobu Takahashi, Ryuichi Takahashi, Ryutaro Takahashi, Takamori Akiteru, Hideyuki Tagoshi, Hiroyuki Tashiro, Takahiro Tanaka, Keisuke Taniguchi, Atsushi Taruya, Takeshi Chiba, Shinji Tsujikawa, Yoshiki Tsunesada, Kimio Tsubono, Morio Toyoshima, Yasuo Torii, Kenichi Nakao, Kazuhiro Nakazawa, Shinichi Nakasuka, Hiroyuki Nakano, Shigeo Nagano, Kouji Nakamura, Takashi Nakamura, Yoshinori Nakayama, Atsushi Nishizawa, Erina Nishida, Kazutaka Nishiyama, Yoshito Niwa, Kenji Numata, Taiga Noumi, Tatsuaki Hashimoto, Kazuhiro Hayama, Tomohiro Harada, Wataru Hikida, Yoshiaki Himemoto, Hisashi Hirabayashi, Takashi Hiramatsu, Mitsuhiro Fukushima, Ryuichi Fujita, Masa-Katsu Fujimoto, Toshifumi Futamase, Ikkoh Funaki, Mizuhiko Hosokawa, Hideyuki Horisawa, Kei-ichi Maeda, Hideo Matsuhara, Osamu Miyakawa, Umpei Miyamoto, Shinji Miyoki, Shinji Mukohyama, Mitsuru Musha, Toshiyuki Morisawa, Mutsuko Y. Morimoto, Shigenori Moriwaki, Kent Yagi, Hiroshi Yamakawa, Toshitaka Yamazaki, Kazuhiro Yamamoto, Chul-Moon Yoo, Jun'ichi Yokoyama, Shijun Yoshida, Taizoh Yoshino, Yaka Wakabayashi, Tomotada Akutsu, Nobuyuki Matsumoto, Ayaka Shoda, Yuta Michimura, Nobuyuki Tanaka, Sachiko Kuroyanagi, Dan Chen, Satoshi Eguchi, Rina Gondo, Kazunori Shibata, Takafumi Ushiba,

Collaboration and support

DECIGO

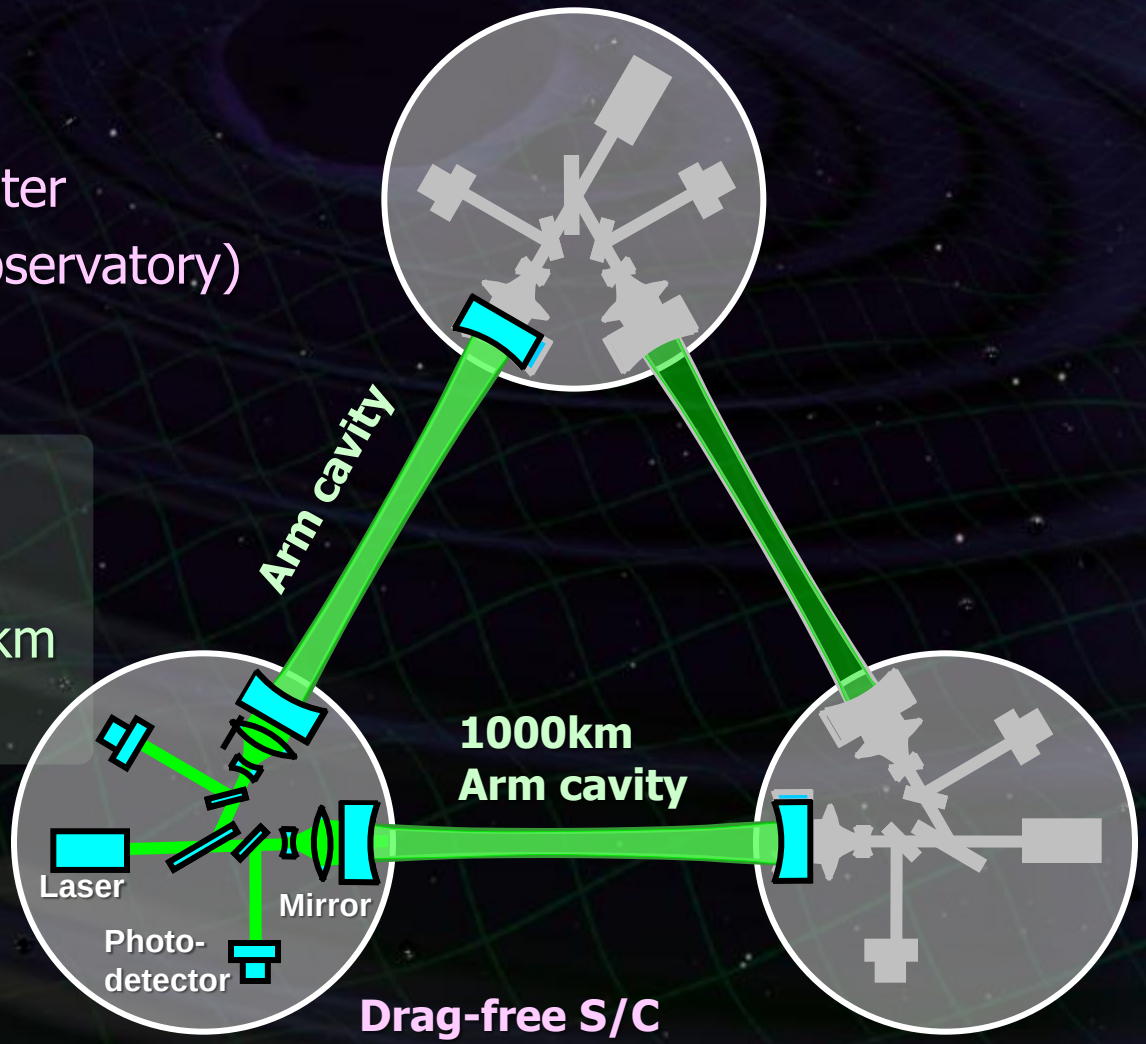
- **Supports from LISA**
  - Technical advices from LISA/LPF experiences
  - Support Letter for DECIGO/DPF, Joint workshop (2008.11)
- **Collab. with Stanford univ. group**
  - Drag-free control of DECIGO/DPF
  - UV LED Charge Management System for DPF
- **Collab. with JAXA Trajectory and Navigation group**
- **Advanced technology center (ATC) of NAOJ**
- **Geophysics group (Kyoto, ERI, UEC, NAOJ)**
- **Collab. with NASA/GSFC**
  - Fiber Laser, Earth's gravity observation
  - → Formation flight of DECIGO, DPF drag-free control
- **JAXA's fund for small satellite development**
- **Research Center for the Early Universe (RESCEU), Univ. of Tokyo**

DECIGO Interferometer

DECIGO

(Deci-hertz interferometer
Gravitational wave Observatory)

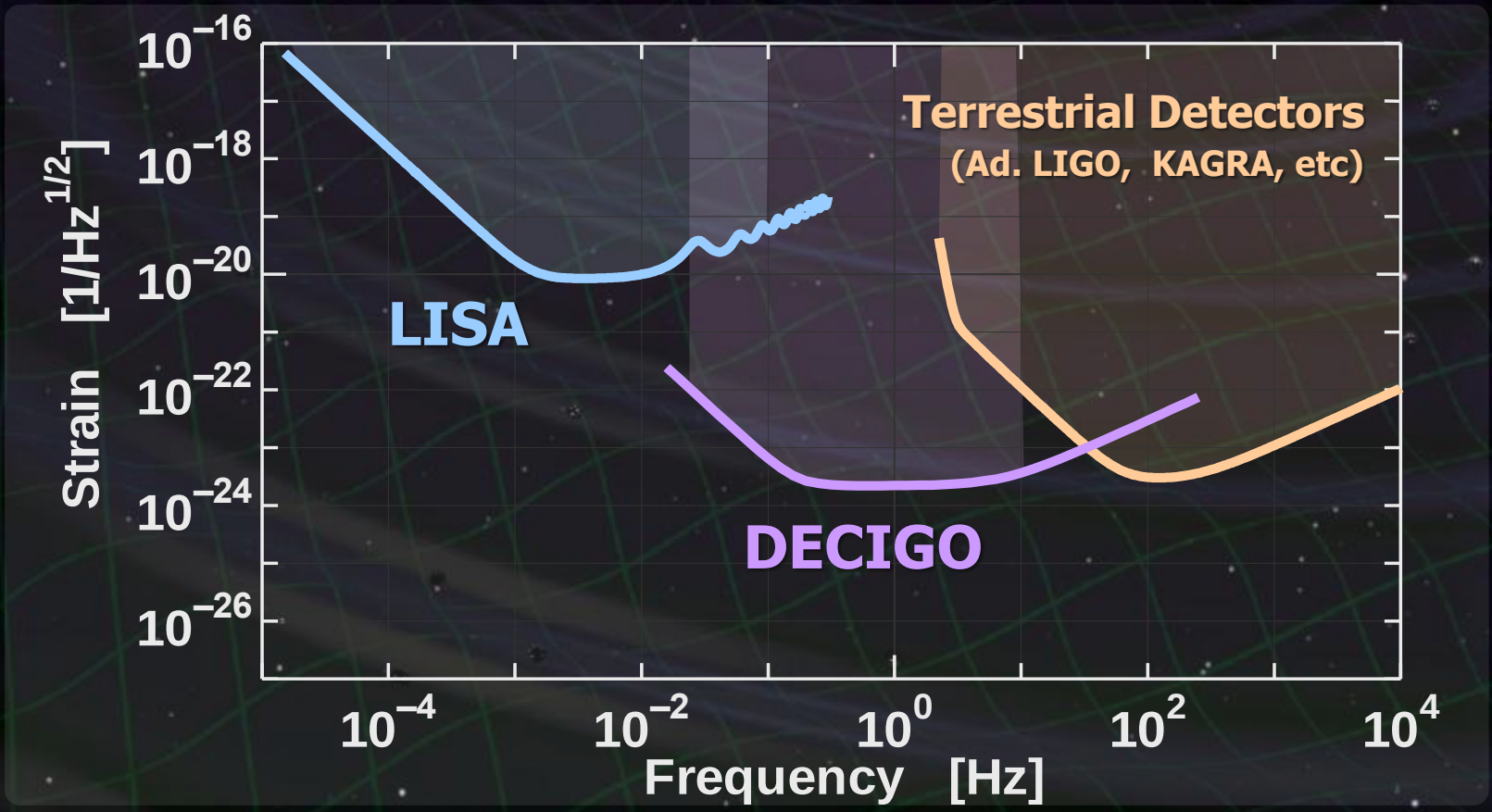
3 S/C formation flight
3 FP interferometers
Baseline length: 1000 km
Drag-free control



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

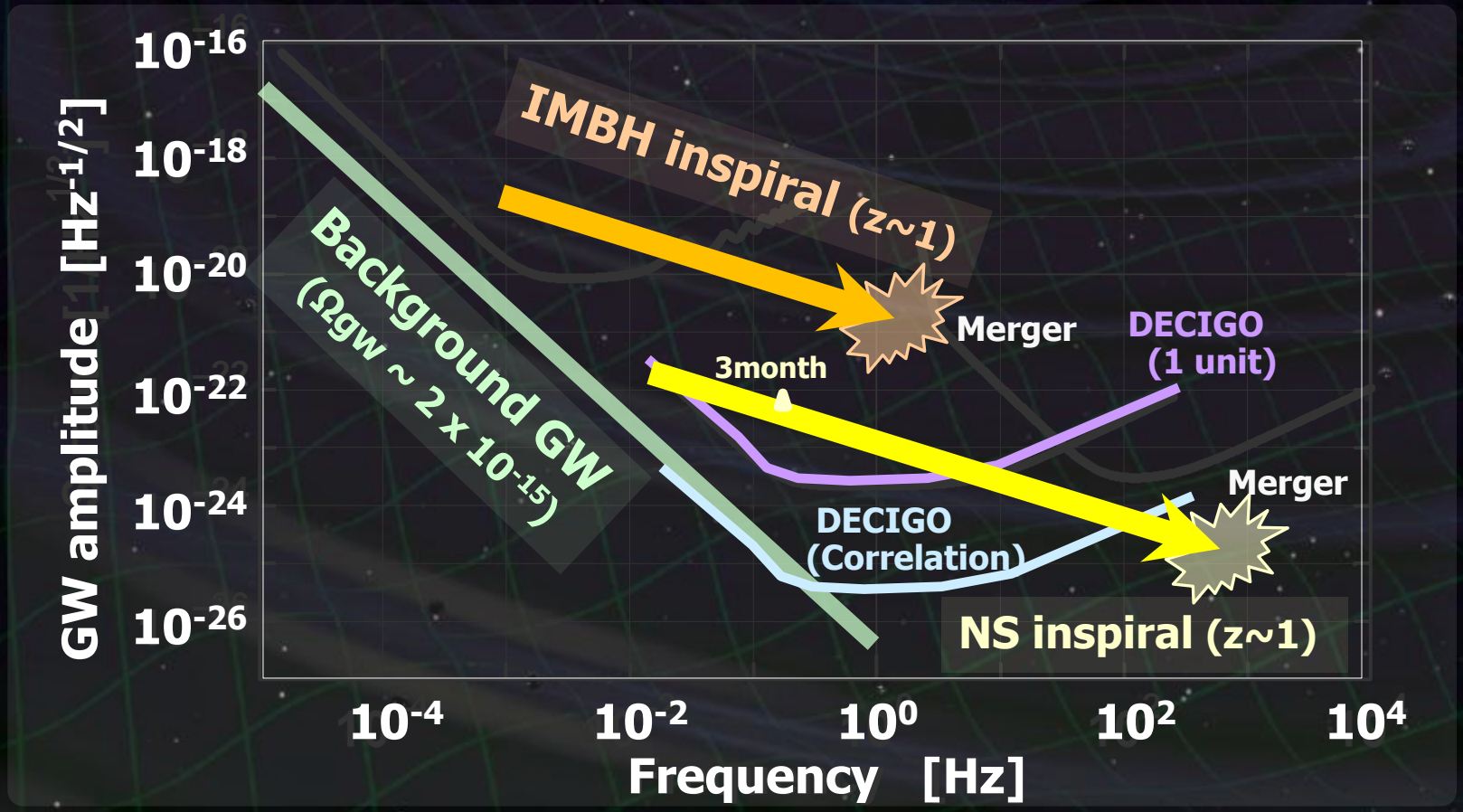


Targets and Science

IMBH binary inspiral
NS binary inspiral
Stochastic background

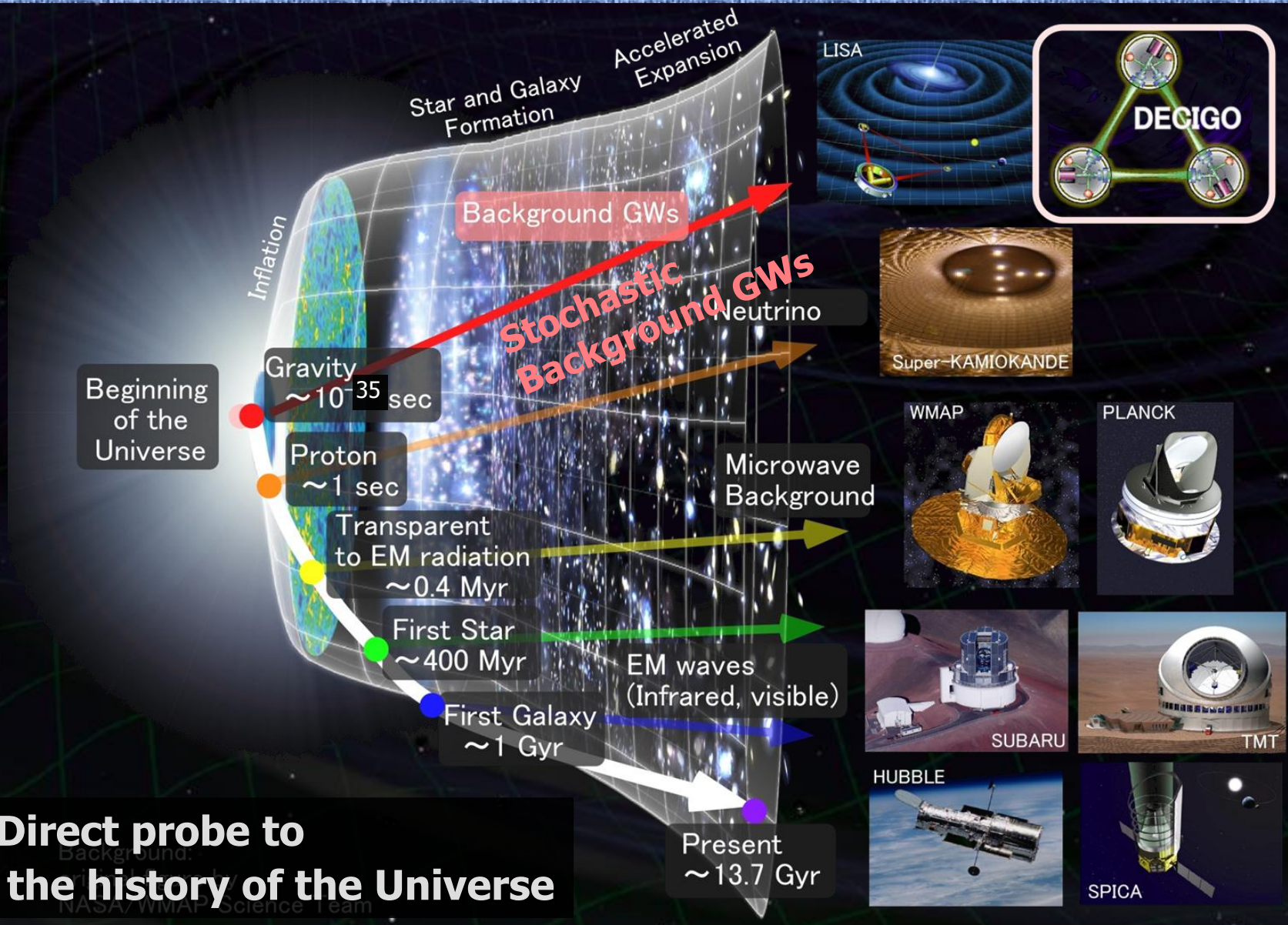
⇨

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



Characterization of inflation

DECIGO



Direct probe to the history of the Universe

KAGRA and DECIGO

KAGRA (~2016)

Terrestrial Detector

→ High frequency events

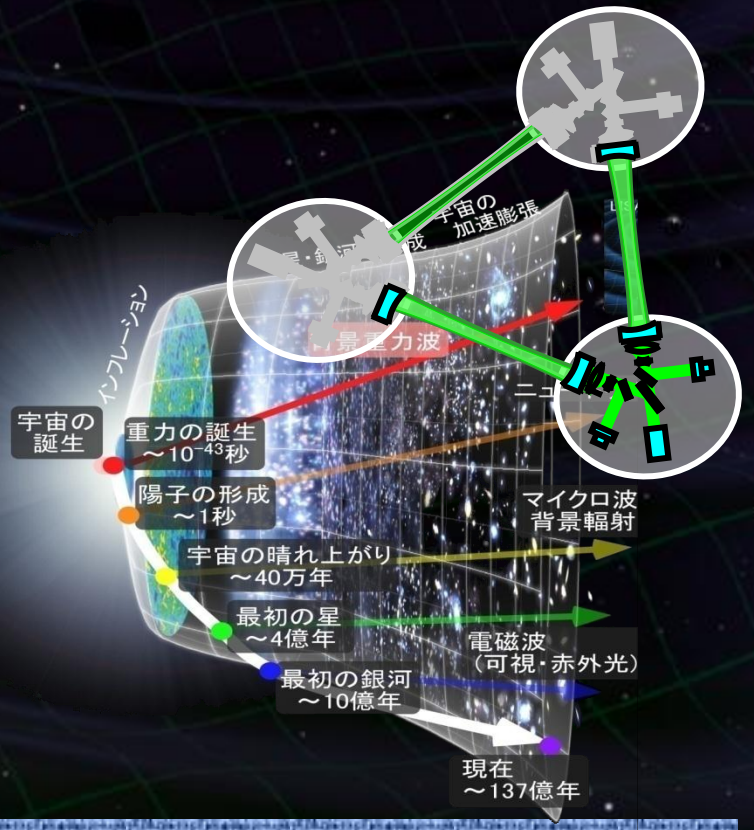
Target: GW detection

DECIGO (~2027)

Space observatory

→ Low frequency sources

Target: GW astronomy



Pre-Conceptual Design

DECIGO

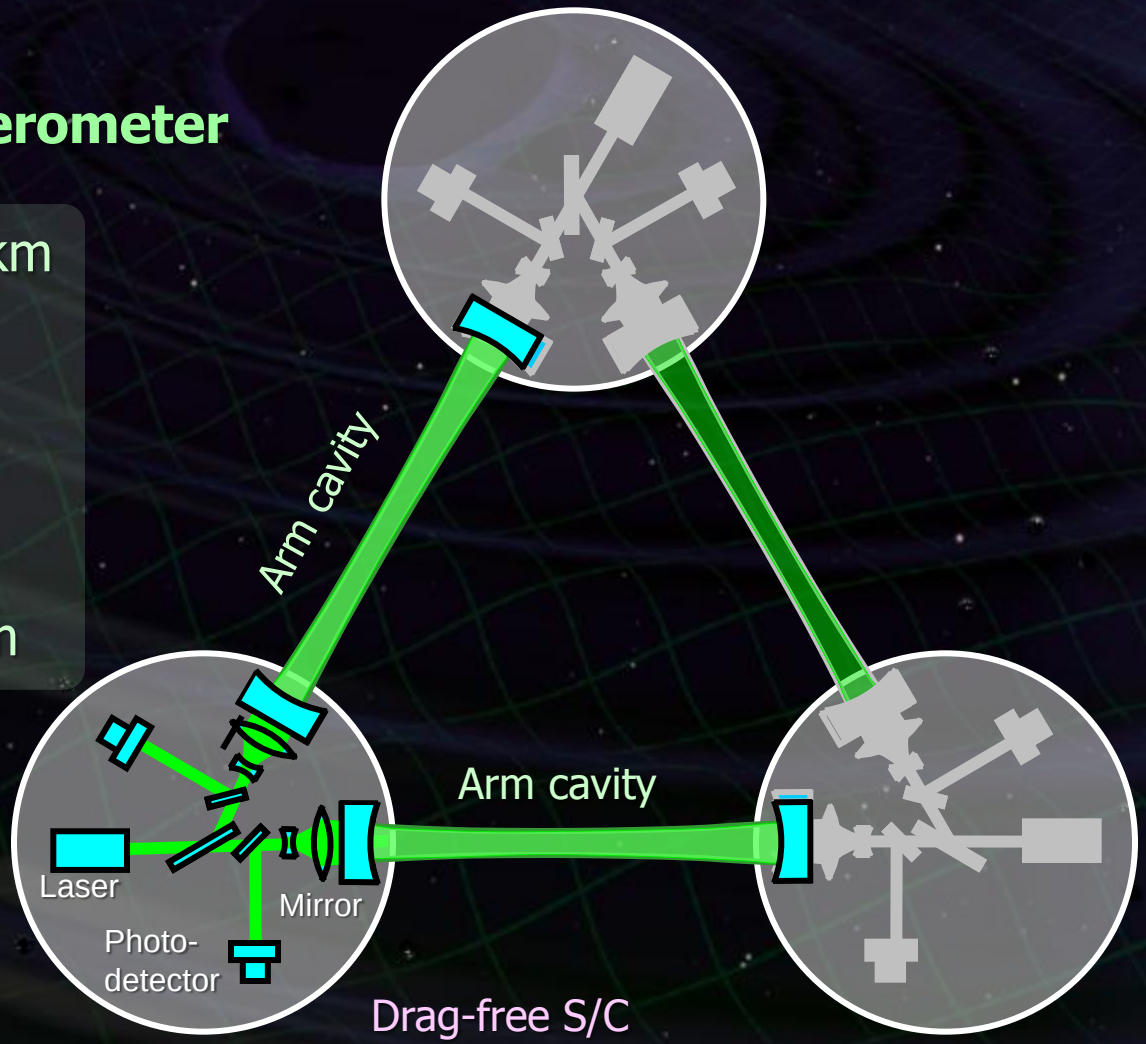
Interferometer Unit:

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

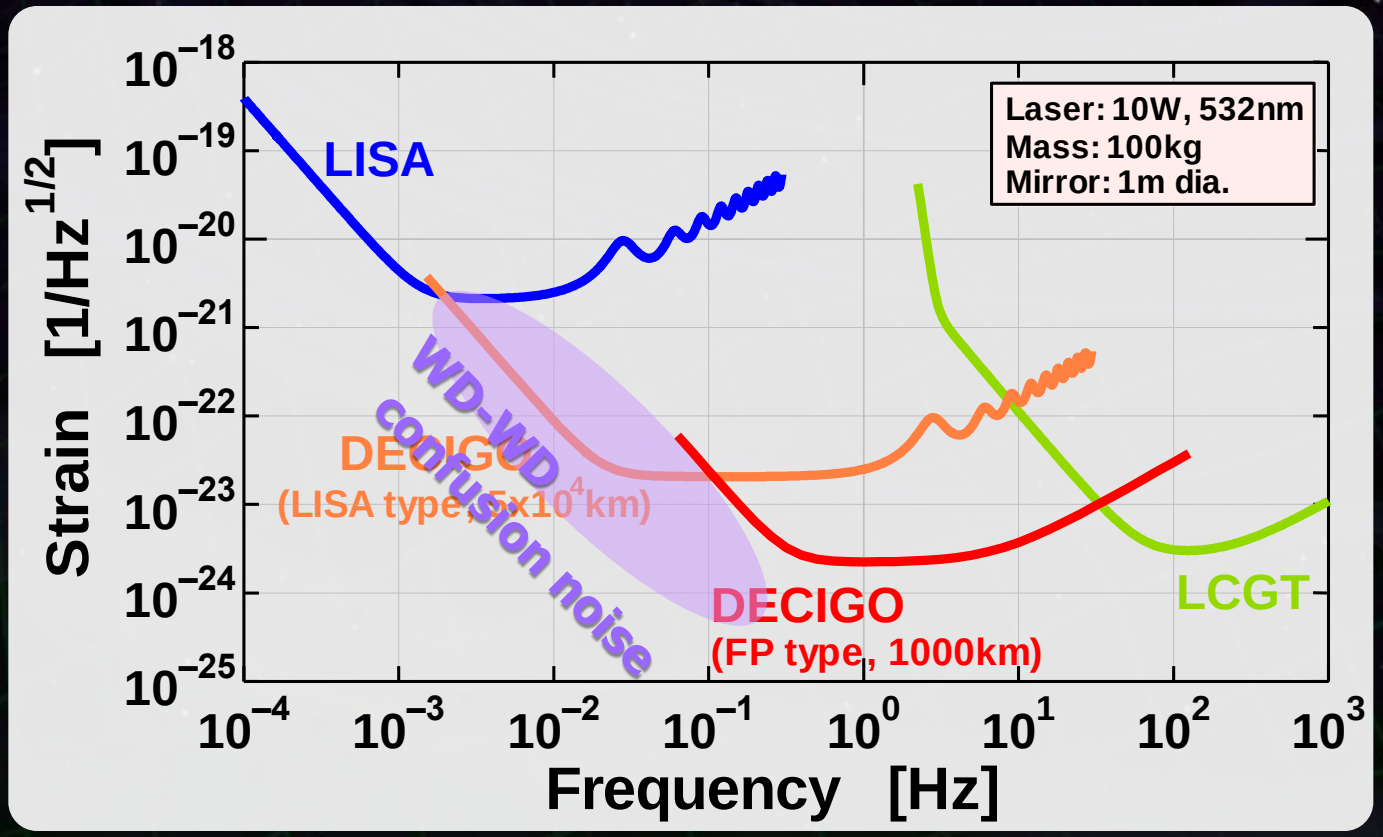


Interferometer Design

Transponder type vs Direct-reflection type

Compare : Sensitivity curves and Expected Sciences

⇨ Decisive factor: Binary confusion noise



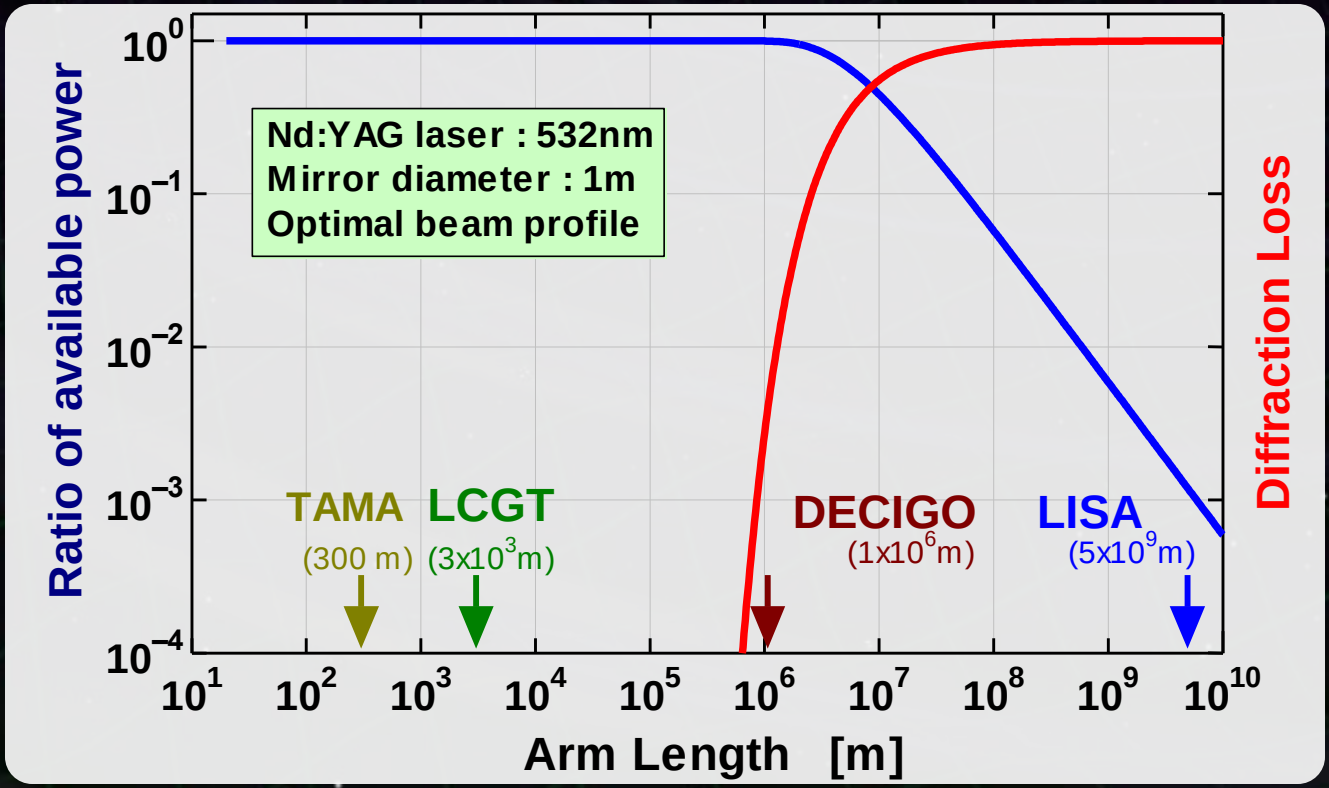
Arm length

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.



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

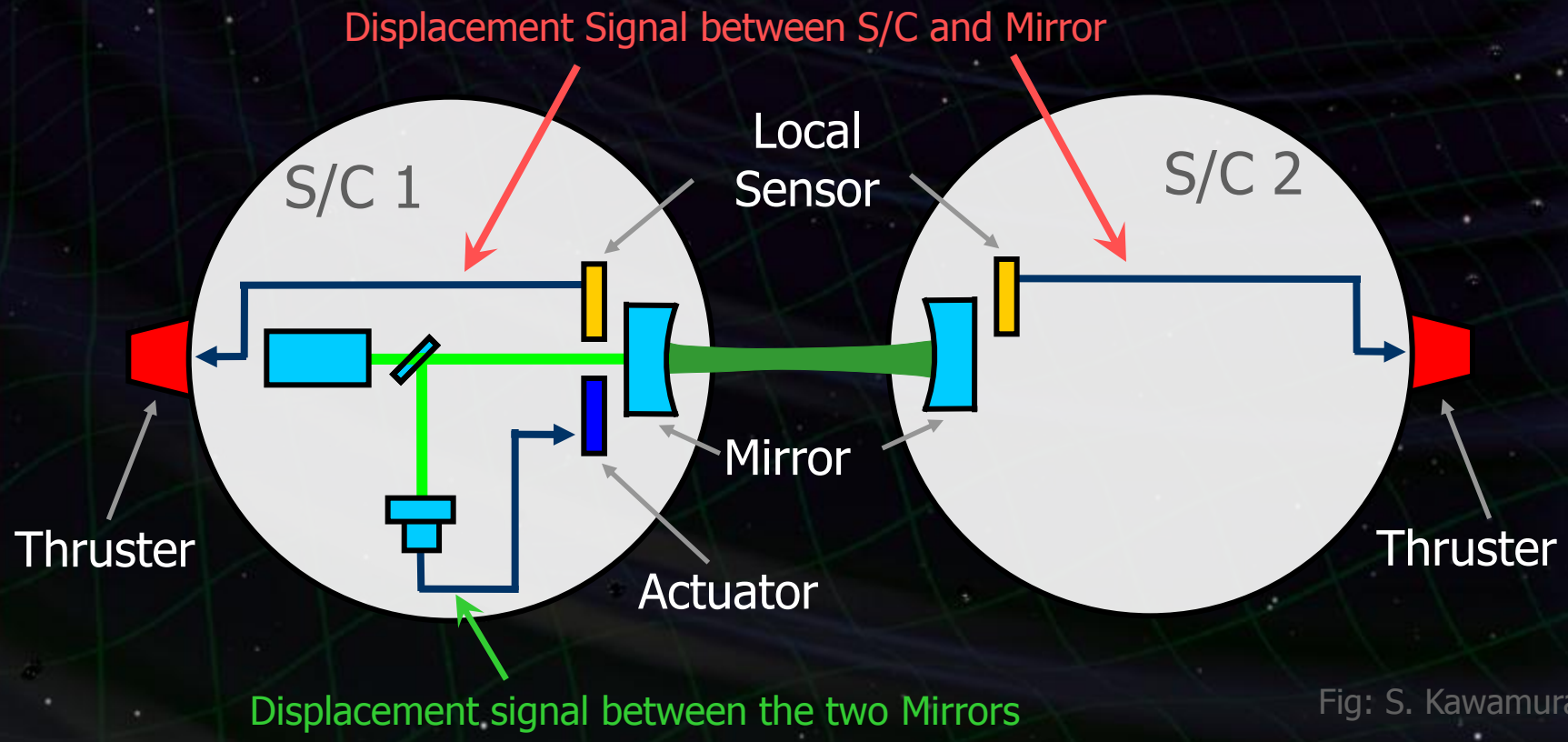


Fig: S. Kawamura

Requirements

DECIGO

Sensor Noise

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

⇨ **x 10 of KAGRA 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

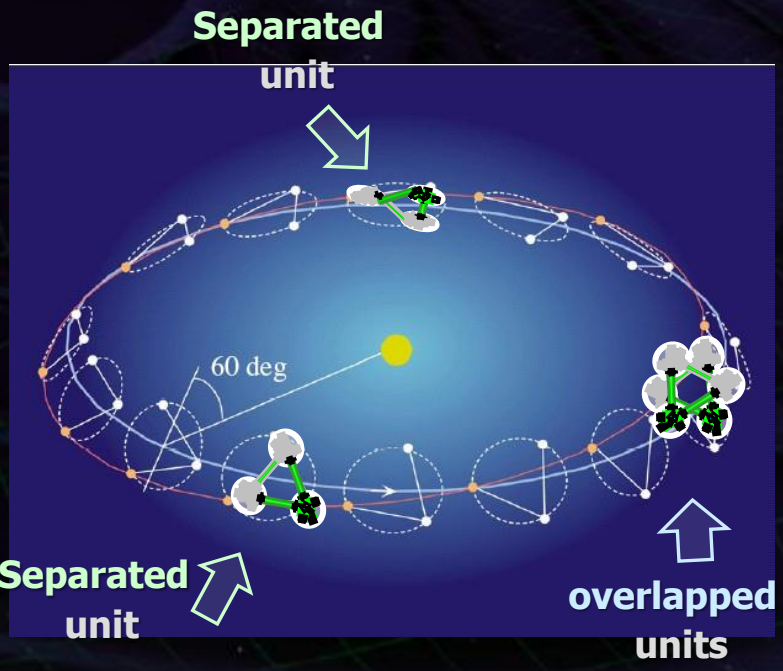
DECIGO

Candidate of orbit:

Record-disk orbit around the Sun

Relative acc. 4×10^{-12} m/s^2

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



Constellation

4 interferometer units

2 overlapped units → Cross correlation

2 separated units → Angular resolution

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
→ $\Delta m/m < \sim 10^{-7}$ %

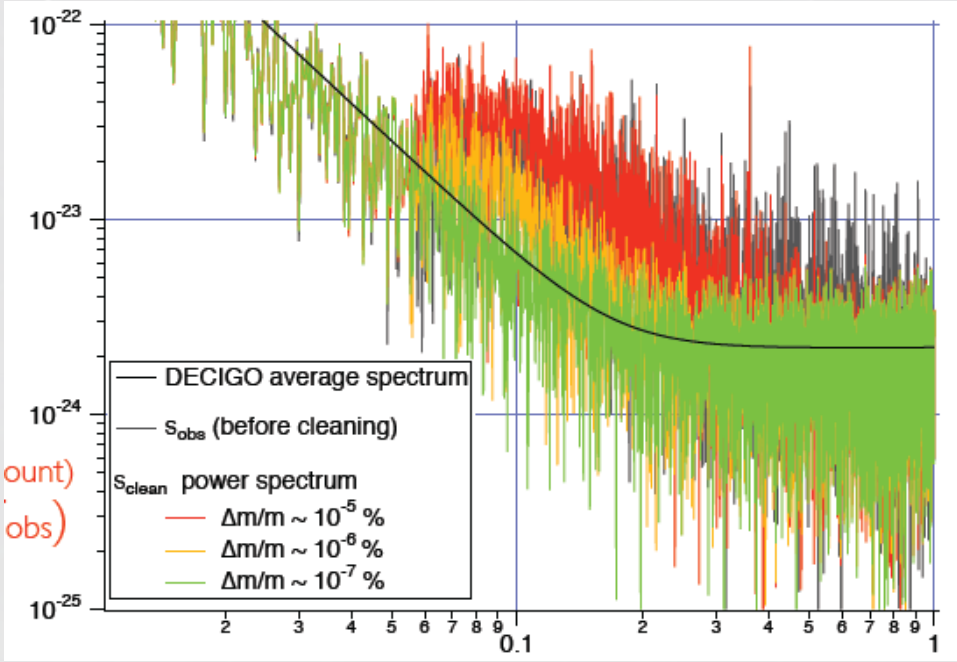


Fig: N. Kanda

Design Update

DECIGO

Considering "Conceptual design"

By T.Akutsu

- 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

Preliminary

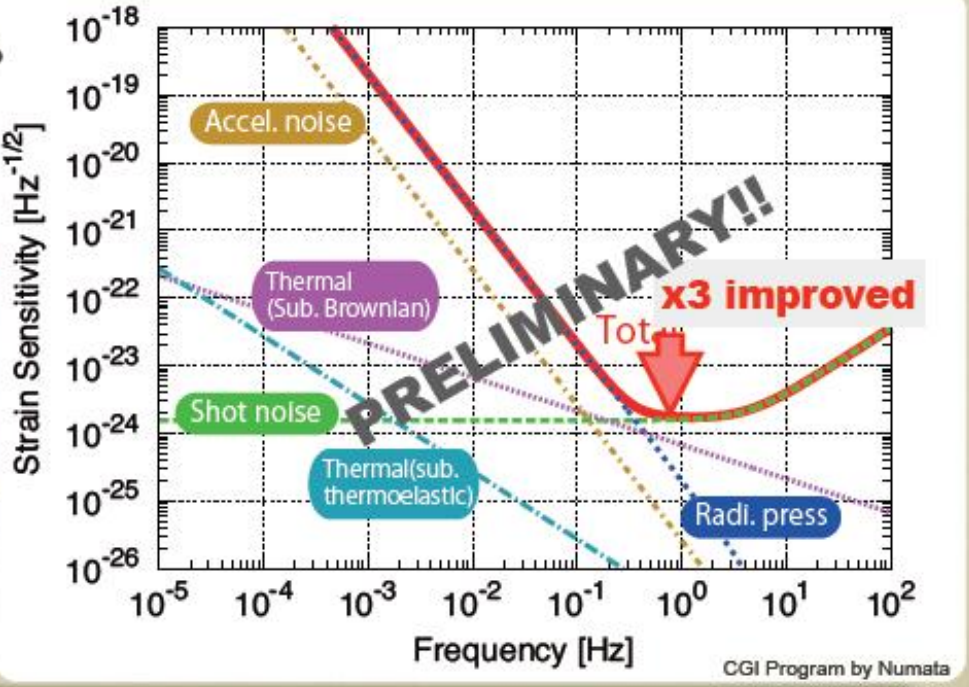
⇦ Parameters tuned

This is the first step to considering the conceptual design.

Next:

➡Confirm the calculations.

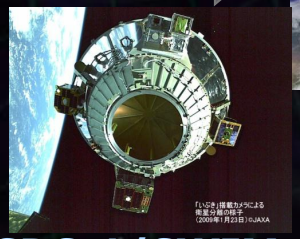
➡Find the realistic way to realize this!

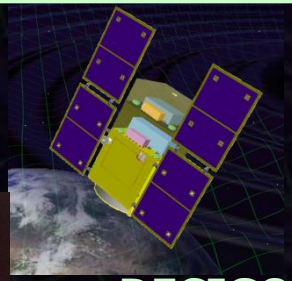


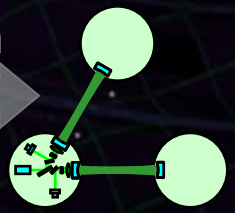
Roadmap

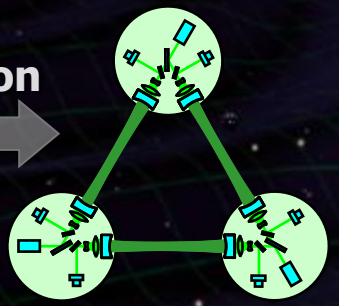
Figure: S.Kawamura

	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



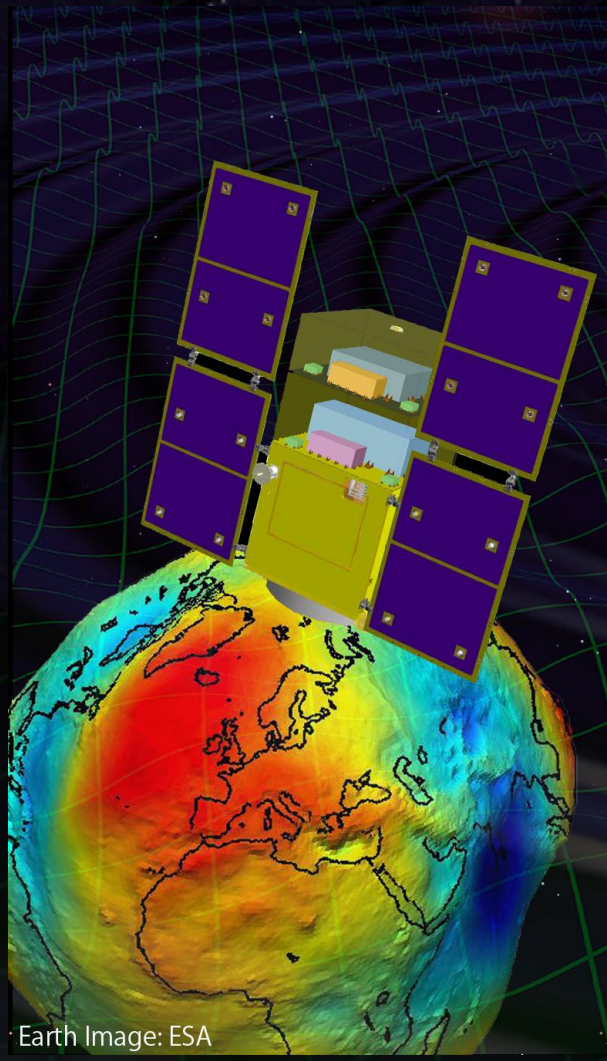






Targets of DPF

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

DECIGO

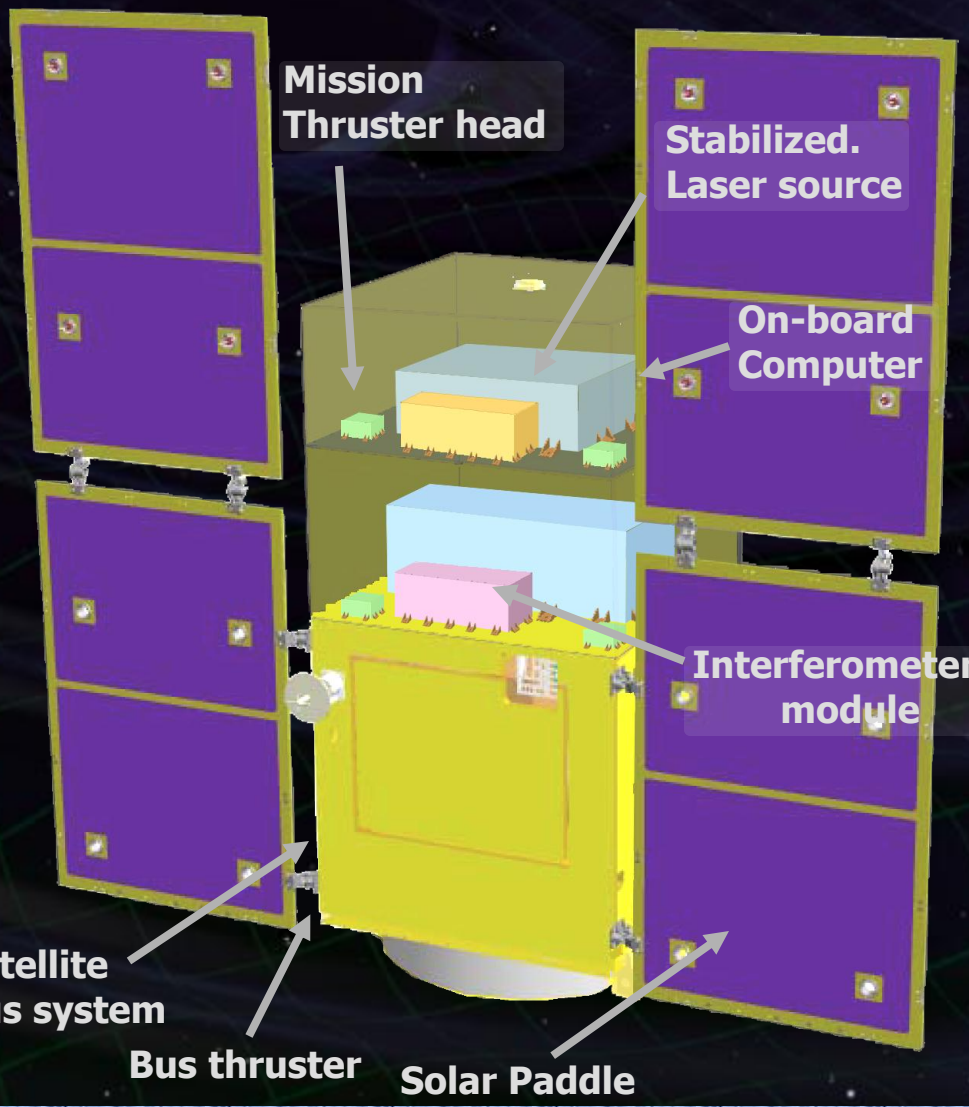
DPF Payload

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

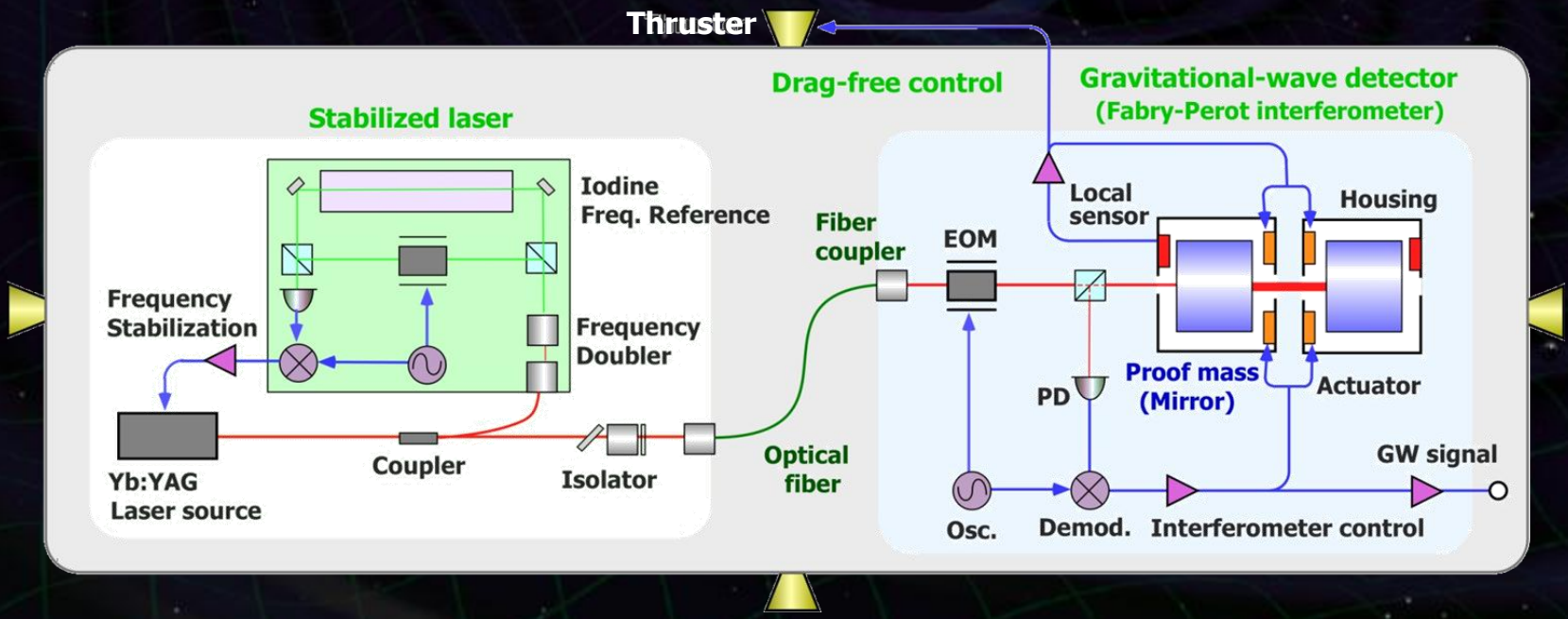


DPF mission payload

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 : ~a few kg
Signal extraction by P**DH**

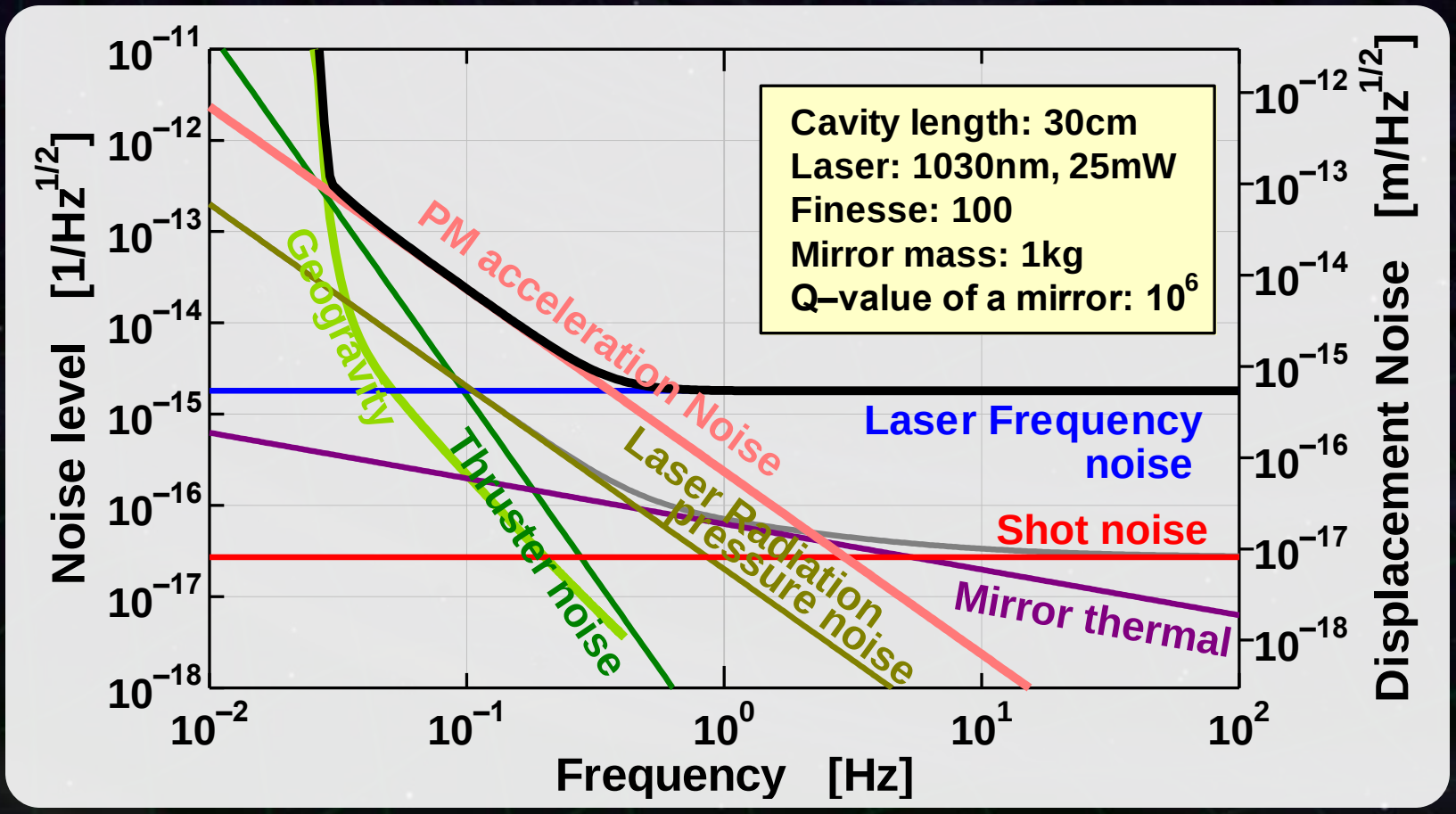
DPF Sensitivity

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 Science

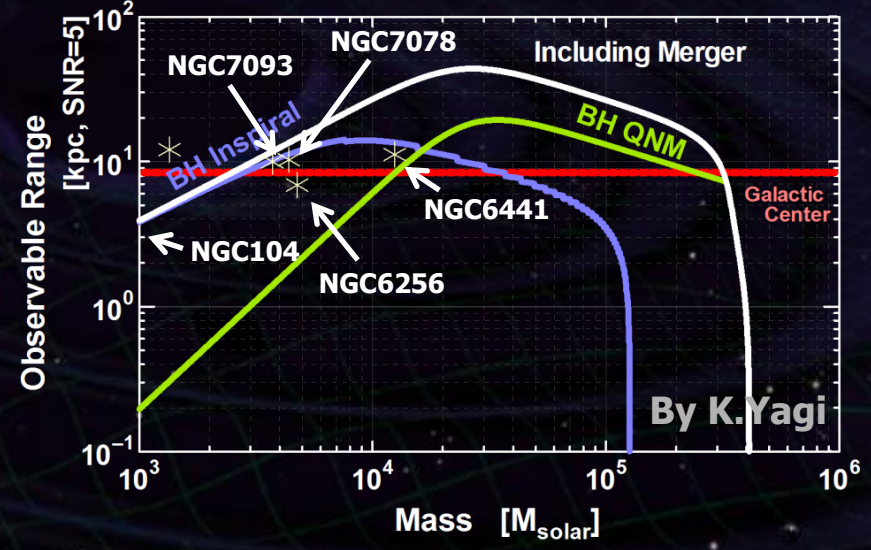
DECIGO

Astronomical observation

GW from merger of IMBHs

→ Formation mechanism of supermassive BHs

~30 GCs within DPF range



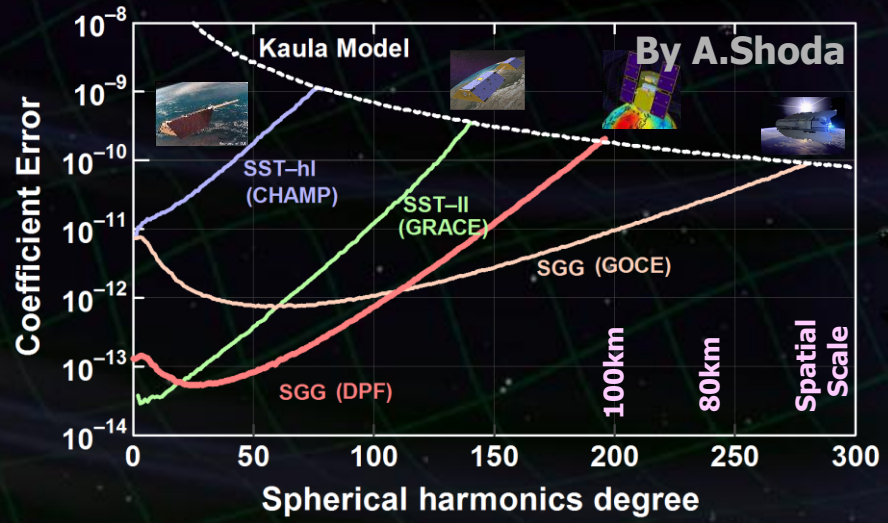
Observation of the earth

Gravitational potential

→ Shape of the earth

Environment monitor

Comparable sensitivity with other missions

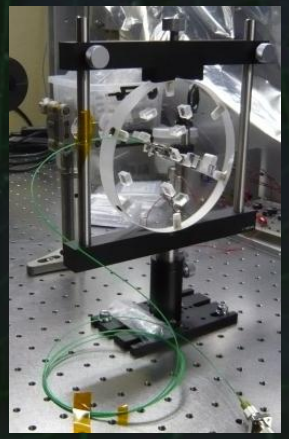


DPF-WG activities

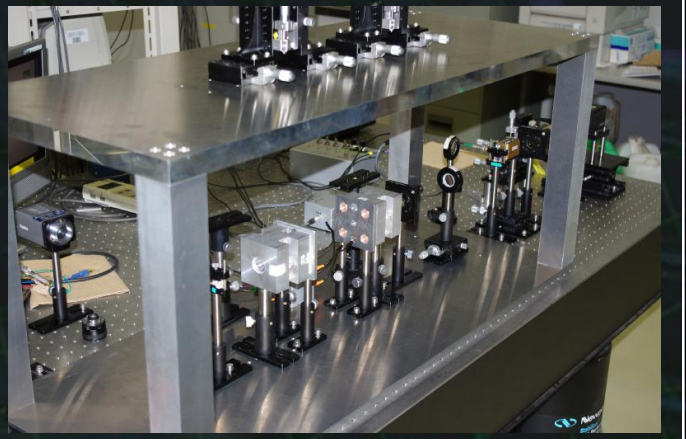
DECIGO

BBMs (Bread-board model) for Core Components

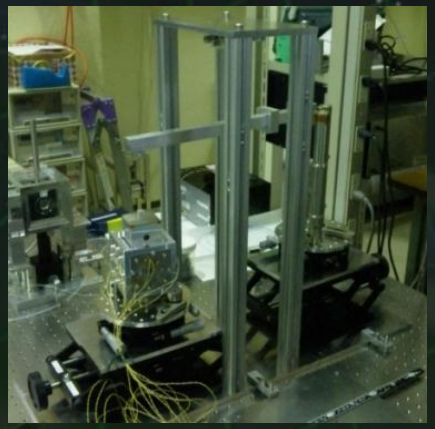
Interferometer and Test-mass Module



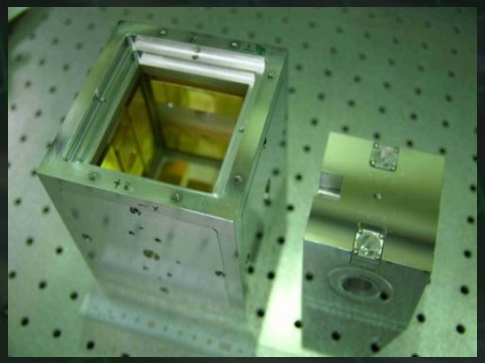
Monolithic input optics



Interferometer control Experiment

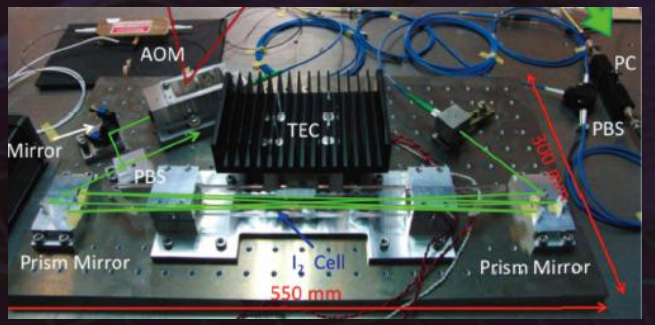


Two-dim Control Experiment



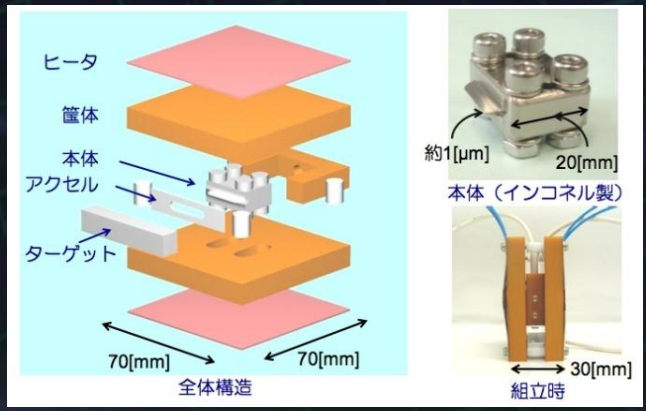
Test Mass Module

Laser stabilization module



Freq. stabilization with I_2 absorption line

Low-noise thruster module



Small low-noise thruster

Rotating TOBA : SWIMμν

DECIGO

Small Module SWIMμν on SDS-1

Launched Jan. 2009, Terminated Sept. 2010

→ Space test : Control, Signal processing

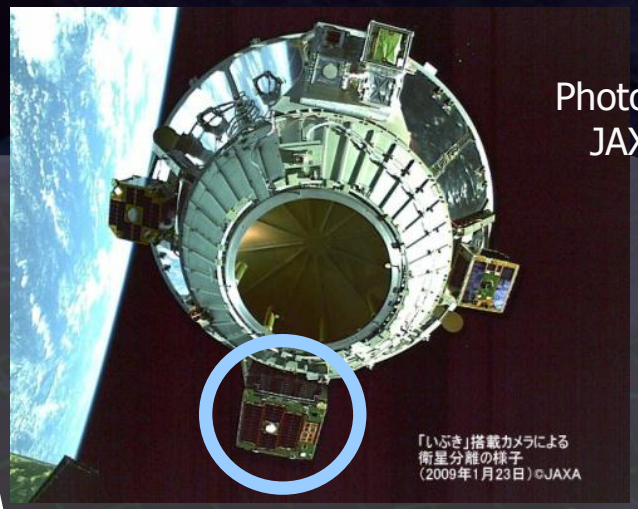
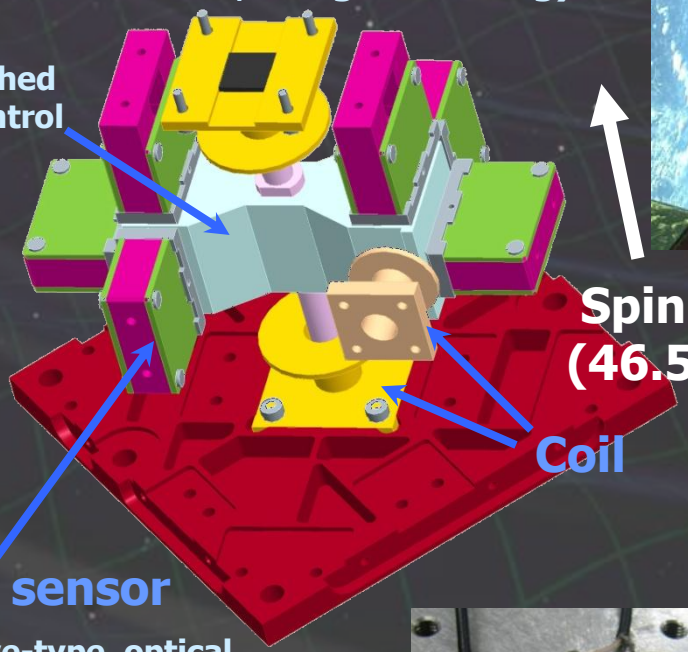


Photo: JAXA

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

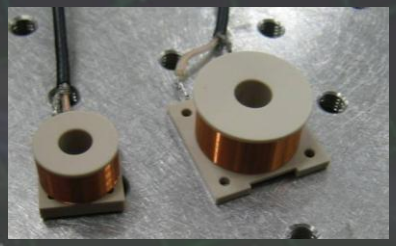


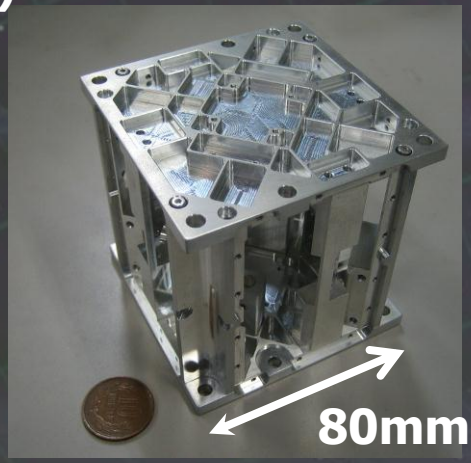
Spin Axis (46.5mHz)

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



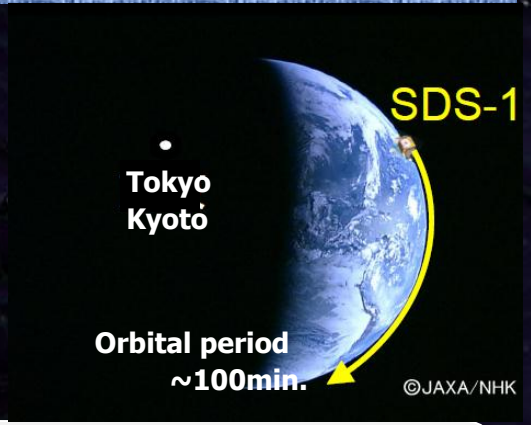


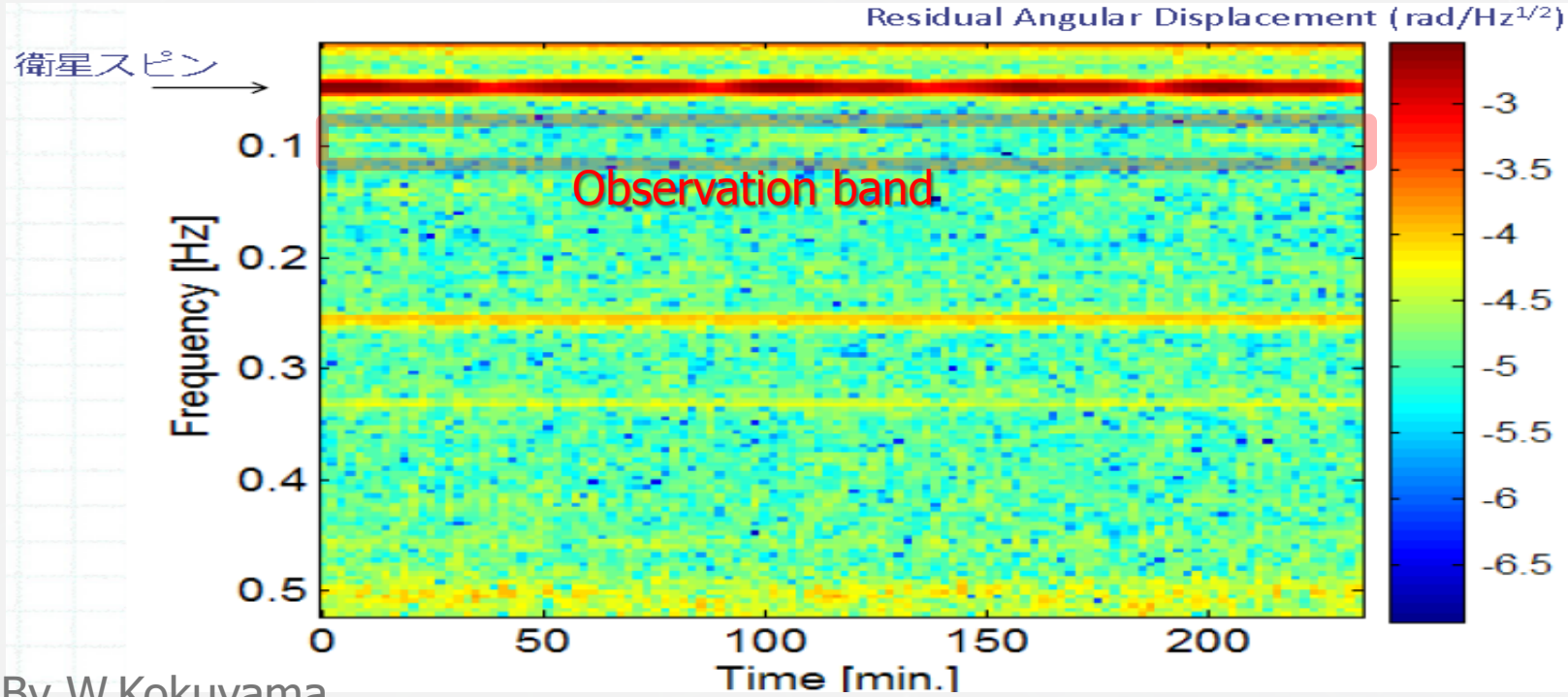
Observation by SWIM

DECIGO

Continuous data taking

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





By W.Kokuyama

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

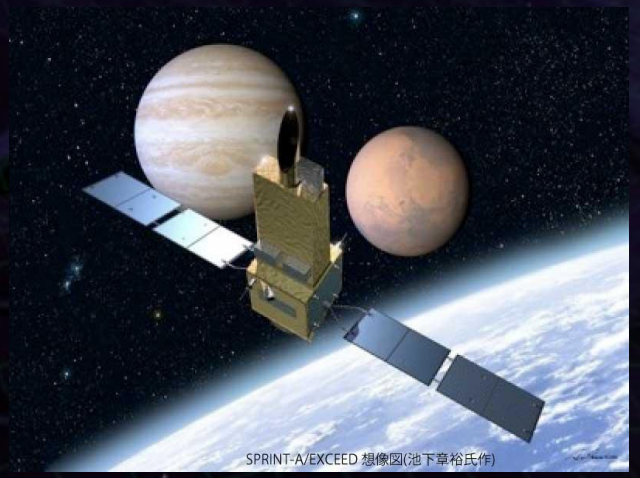
1st mission (2013): SPRINT-A/EXCEED

2nd mission (~2015) : SPRINT-B/ERG

DPF survived until final two

3rd mission (~2016/17) : TBD

Call for proposal : FY2012



SPRINT-A /EXCEED UV telescope mission

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

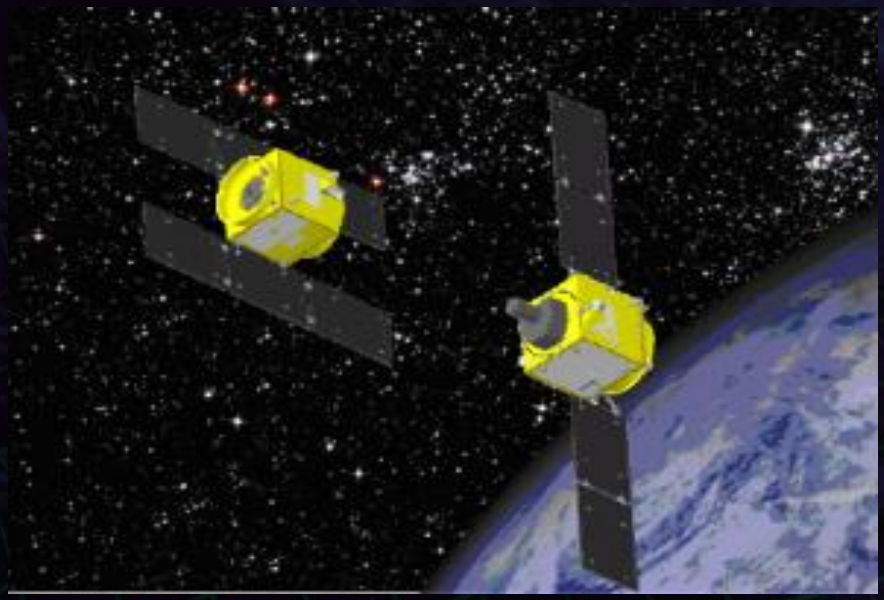
DPF is one of the strongest candidates of the 3rd mission

FRONT Mission

DECIGO

FRONT :

(Formation flight, Relative Orbit and Navigation Technology demonstration mission)

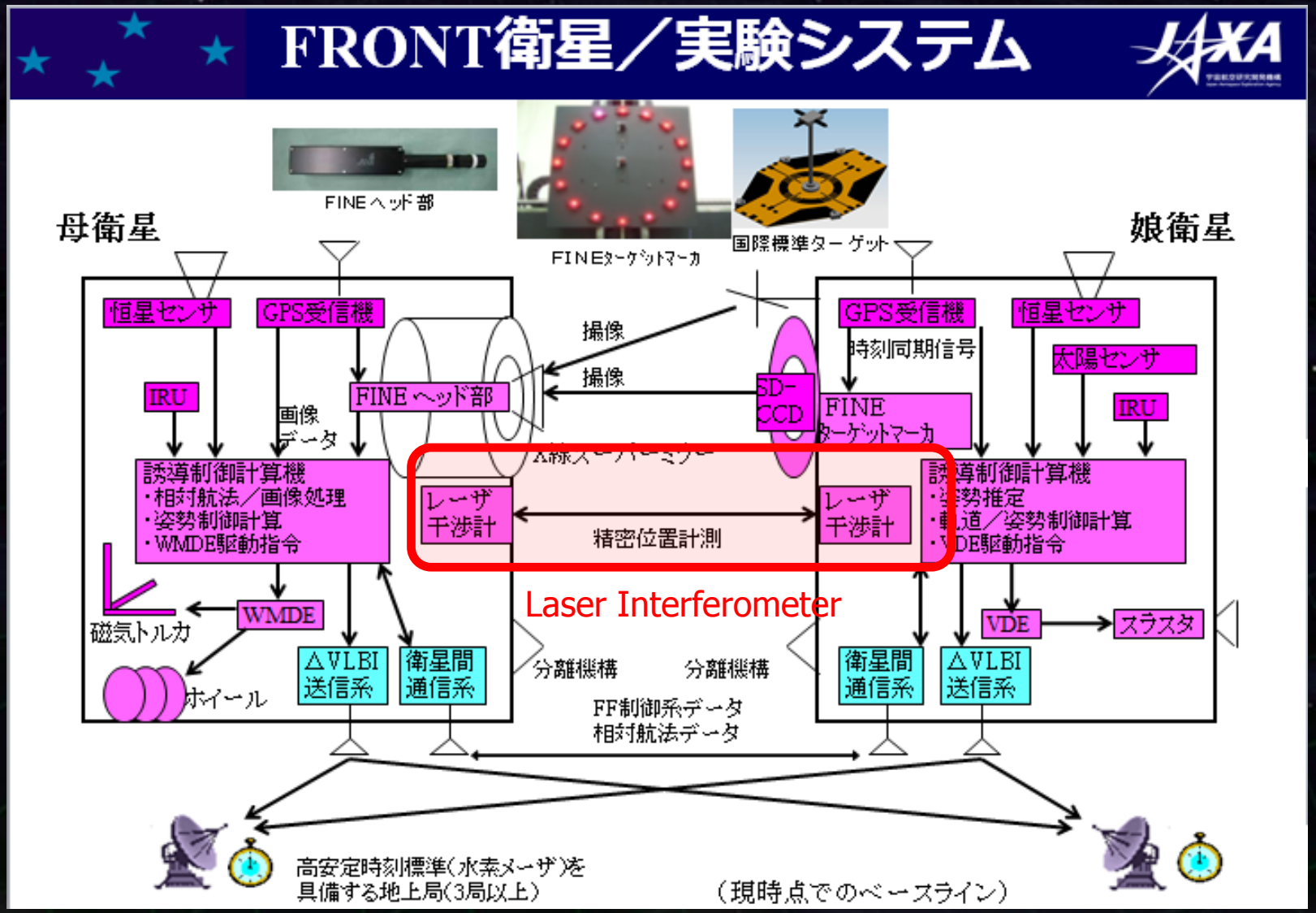


- Mission target
  - High-precision formation flight
  - Relative orbit determination
  - Relative navigation system

- Collaboration with science missions :
  - X-ray telescope,
  - InSAR (Synthetic Aperture Radar)
  - Gravitational-wave telescope

Under mission study in JAXA (Tsukuba)

FRONT Mission



By Kawano (56th Space Science and Technology conference, Nov.20, 2012 Beppu, Oita)

Summary

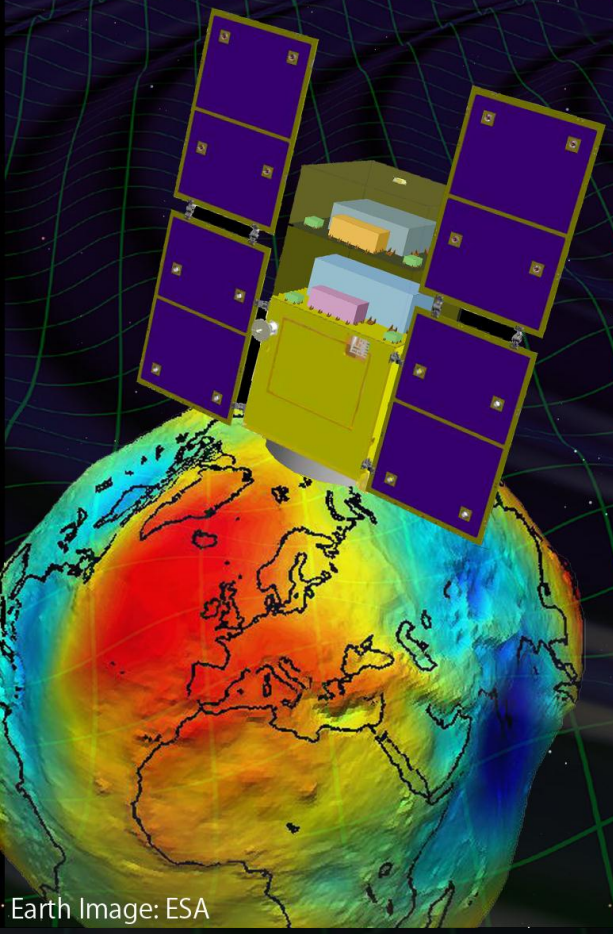
Summary

DECIGO : Fruitful Sciences

- Very beginning of the Universe
- Dark energy, Dark matter
- Galaxy formation
- Fundamental Physics

DECIGO Pathfinder

- Important milestone for DECIGO
- Observation of GWs and Earth's gravity
- Strong candidate of JAXA's satellite series



Earth Image: ESA

Original
Picture : Sora

End