# DECIGO Pathfinder

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**Abstract**. DECIGO pathfinder (DPF) is a milestone satellite mission for DECIGO (DECi-hertz Interferometer Gravitational wave Observatory) which is a future space gravitational wave antenna. DECIGO is expected to provide us fruitful insights into the universe, in particular about dark energy, a formation mechanism of supermassive black holes, and the inflation of the universe. Since DECIGO will be an extremely large mission which will formed by three drag-free spacecraft with 1000m separation, it is significant to gain the technical feasibility of DECIGO before its planned launch in 2024. Thus, we are planning to launch two milestone missions: DPF and pre-DECIGO. The conceptual design and current status of the first milestone mission, DPF, are reviewed in this article.

## 1. Introduction

DECIGO, a DECi-hertz Interferometer Gravitational wave Observatory, is a space gravitational wave antenna planned to be launched in 2024 [1][2]. The purpose of DECIGO is to observe gravitational waves at the frequency band mainly between 0.1 Hz and 10 Hz, and thus, to open a new window of gravitational wave astronomy. Since the observation band of DECIGO is between LISA [3] and terrestrial detectors such as LCGT [4], it can be a follow-up of LISA by observing inspiral sources that have moved above the LISA band, and can also be a predictor for terrestrial detectors by observing inspiral sources that have not yet moved into the terrestrial detector band. Moreover, since DECIGO's observation band is free from foreground noises caused by unresolved gravitational-waves from many galactic binaries, it can play an important role in the observation of stochastic background gravitational waves from the early universe.

In the pre-conceptual design, DECIGO will be formed by three drag-free spacecraft which are separated by 1000km to one another. The gravitational-wave signals are detected by measuring the relative displacements with differential Fabry–Perot interferometers. The arm length was chosen so as to realize a finesse of 10 with a 1 m diameter mirror and 0.5 μm laser light. The mass of the mirror is 100 kg and the laser power is 10 W.

Since DECIGO will be an extremely large mission, it is significant to gain the technical feasibility before its planned launch in 2024. Thus, we have a roadmap to launch two milestone missions before DECIGO. DECIGO pathfinder (DPF) is the first milestone mission to test the key technologies with one spacecraft. Pre-DECIGO is supposed to detect gravitational waves with minimum specifications. In this article, we review the conceptual design and current status of DPF.

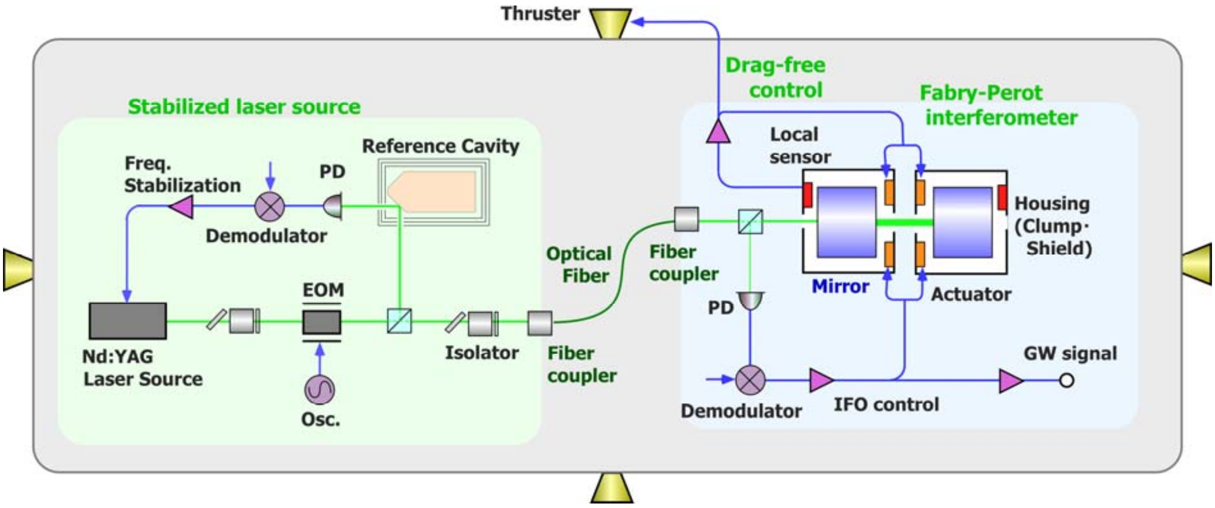


Fig.1. Conceptual design of the mission part of the DECIGO pathfinder (DPF).

## 2. Purpose and conceptual design of DECIGO pathfinder

The purposes of DPF are to test the key technologies and to make observations at 0.1-1Hz frequency band. The key technologies tested in DPF will be the followings: (1) low-noise operation and observation with a Fabry-Perot interferometer in space (2) operation of a laser source and its stabilization system, (3) demonstration of a drag-free control system (4) demonstration of a launch-lock system for the test-mass mirrors. All of these technologies are critical in the realization of DECIGO. As for the scientific purpose of DPF, DPF targets at 0.1-1Hz gravitational waves from intermediate-mass blackhole inspirals. If merger or ringdown events occur at around the center of our galaxy, DPF will have a sufficient sensitivity to detect them.

DPF will be a small satellite with weight of about 300kg, orbiting the earth along a sun-synchronous orbit with an altitude of 500km. The mission part of DPF is designed to be a prototype of DECIGO, being comprised of a short Fabry-Perot (FP) cavity, a stabilized laser source, and a dreg-free control system (Fig.1). The FP cavity is formed by two mirrors which act as free test masses. Each mirror is placed inside a module called housing. The housing has local sensors and local actuators, which are used to monitor and to control the relative motion between the housing and the mirror. In addition, the housing has a function of launch lock, which clumps the mirror at the launch of the satellite and releases it in the orbit with small initial velocity. The cavity has a baseline length of about 30cm and a finesse of about 100. The length change in the FP cavity, which would be caused by gravitational waves or external disturbances, is measured by means of a stabilized laser beam. In DPF, we use a Nd:YAG laser source in which the frequency is stabilized using an external reference. The requirement for the frequency stabilization is $1\mathrm{Hz/Hz}^{1/2}$. The laser source has an output power of 100mW at a wavelength of 1064nm. The drag-free control of the satellite position works as a shield against external forces such as solar radiations and air drags. The drag-free control is realized by measuring the relative fluctuations between the mirrors and the satellite, and feeding these signals back to the satellite position actuated by low-noise thrusters of the satellite.

With the configuration described above, DPF will have a sensitivity limit of about $h{\sim}10^{-15}$ at around the frequency band of 0.1-1Hz (Fig.2 left). The sensitivity is mainly limited by the laser frequency noise at the high-frequency band and acceleration noises from various kinds of external forces on the test-mass mirrors at the low-frequency band. From this noise curve, we estimated the observable range for blackhole inspirals and ringdowns of a blackhole quasi-normal mode as a function of blackhole mass (Fig.2 right). In this estimation of the observable range of DPF, we used

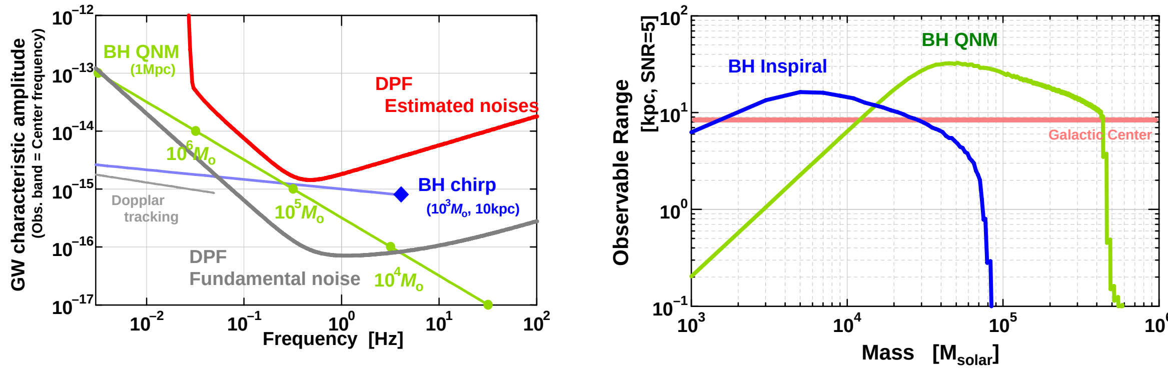


Fig.2. Sensitivity (left) and observable range (right) of DPF. The observable range of DPF for intermediate-mass blackholes will cover the center of our galaxy.

the calculated waveform of gravitational-wave signal by post-Newtonian approximation, and set the detection threshold to be a signal-to-noise ratio of 5. As shown in Fig.2, DPF has a sensitivity to detect gravitational-wave signals, if there is a blackhole inspiral event with $10^3$-$10^4$ solar-masses, or a ringdown event of a quasi-normal mode for $10^4$-$4x10^5$ solar-mass blackhole at the center of our galaxy.

## 3. Current status of DPF

Currently, DPF is selected as one of the candidates of small satellite missions of JAXA (Japan Aerospace Exploration Agency). JAXA have a program to launch at least 3 small satellites in this 5 years, using standard bus systems. The standard bus module has a 200kg weight and a 900mm cubic shape. It will provide a 900W power with 6 solar-cell puddles at maximum, and a 2Mbps downlink telecommunication ability. A Mission module is attached on the upside of the bus module. The bus and mission modules are connected with power lines and communication lines using the SpaceWire standard.

The first mission of the three missions has already decided to be TOPS, which is for the observation of inferior planets. TOPS will be launched in 2011. DPF is now one of the several high-ranked mission candidates for the second or third missions, and will be launched in 2012 in the best and earliest case.

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