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Micro-Thruster System Development for the DECIGO/DPF missions

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Outline

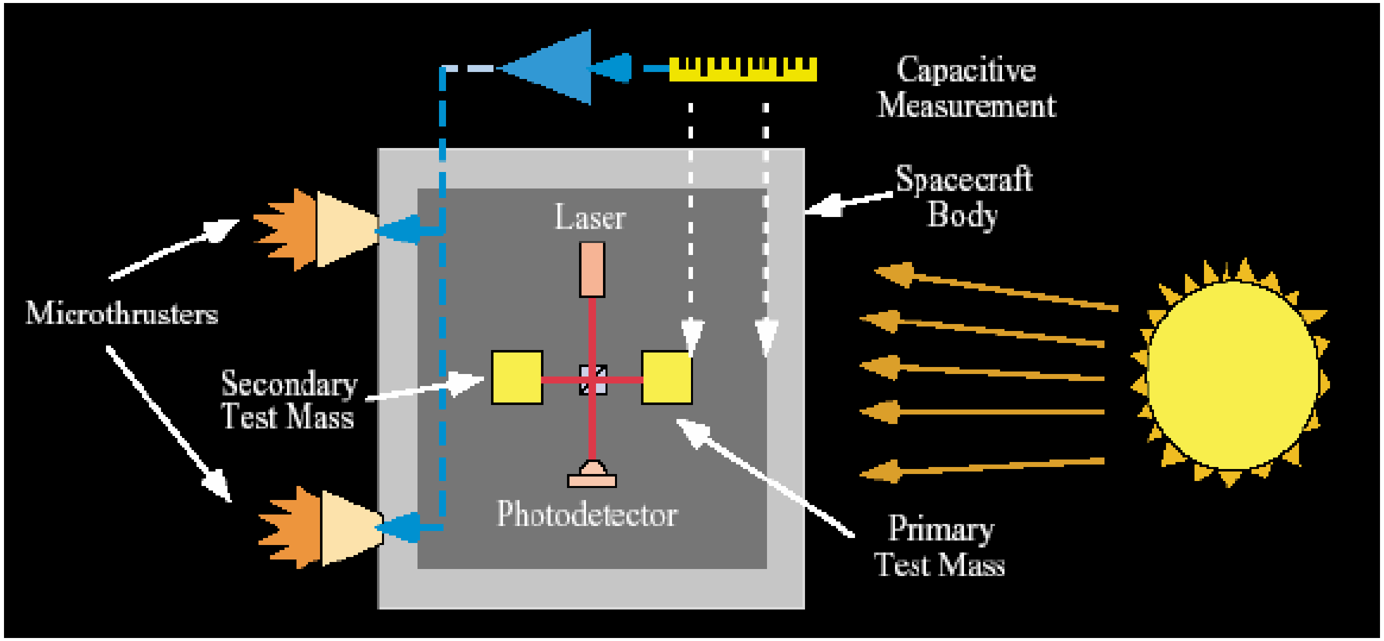
R&D status of DPF's Micro-Thruster System is provided.

1. Introduction
    - DPF Spacecraft
2. Objectives
3. System Requirement
    - Drag-Free System
    - Requirement/Spec. for Micro-Thrusters
4. System Design and Development Status
    - Thruster Sub-System
    - FEEP
    - Microwave Ion Propulsion
    - Neutralizer
5. Summary and Future Plan

1. Introduction

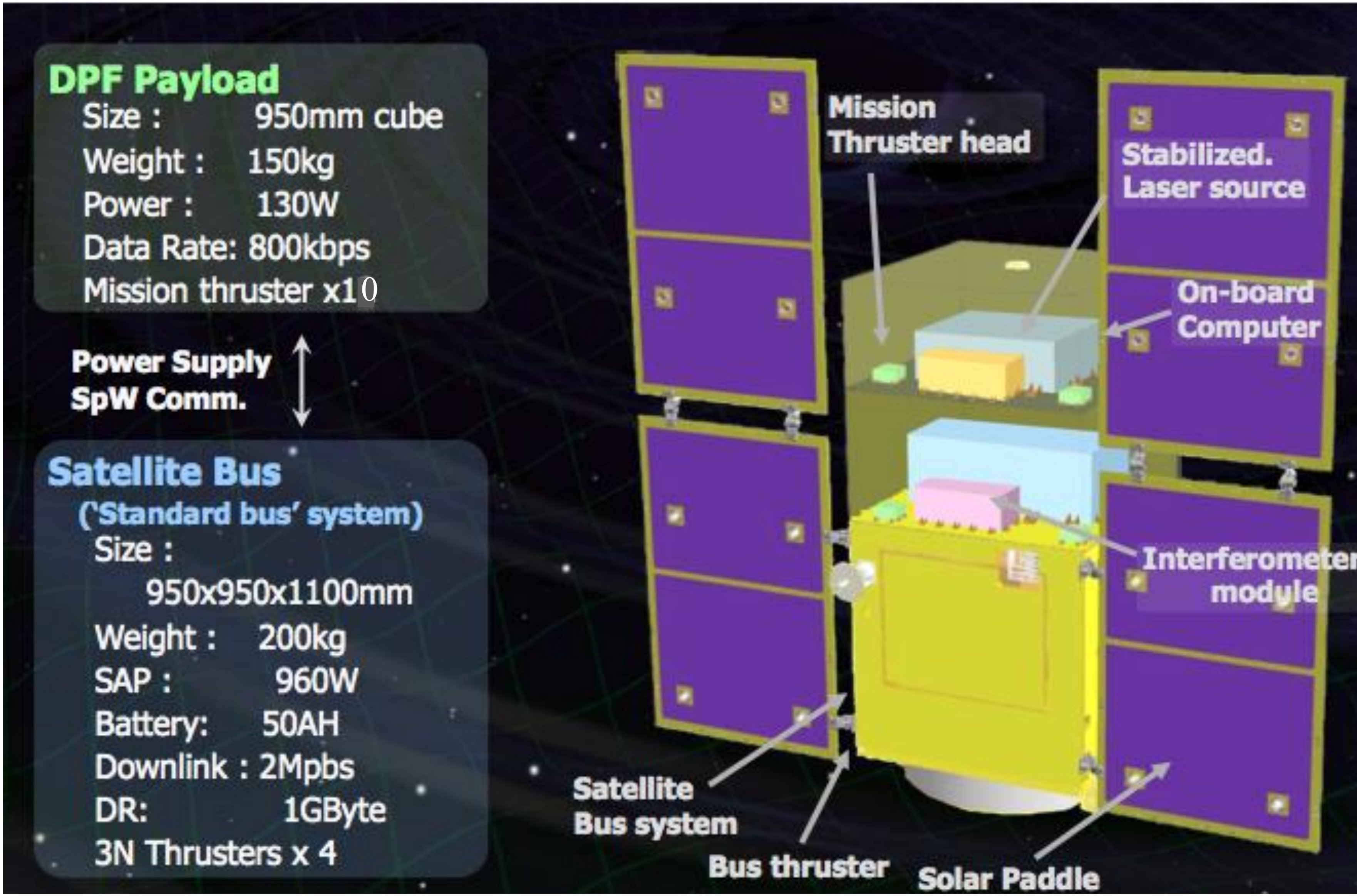
Drag-Free Spacecraft

- put spacecraft in purely gravitational orbits for precise gravity measurement or gravitational wave measurement
- non-gravitational forces (radiation pressure, etc.) must be attenuated
- typical thrust level required for drag-free control: 10~100μN



Principle of Drag-Free Controlled Spacecraft

DPF Satellite

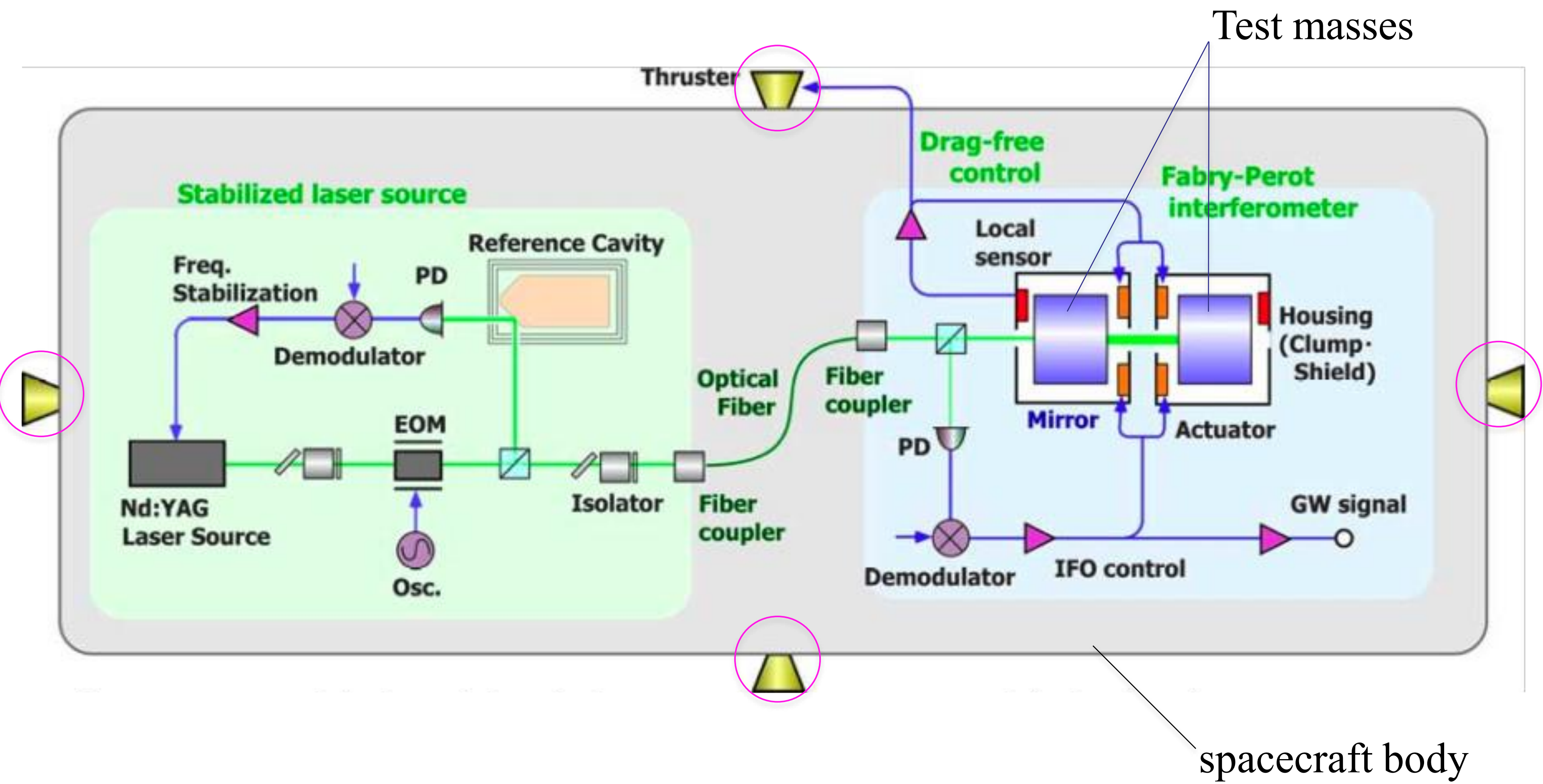


2. Objectives

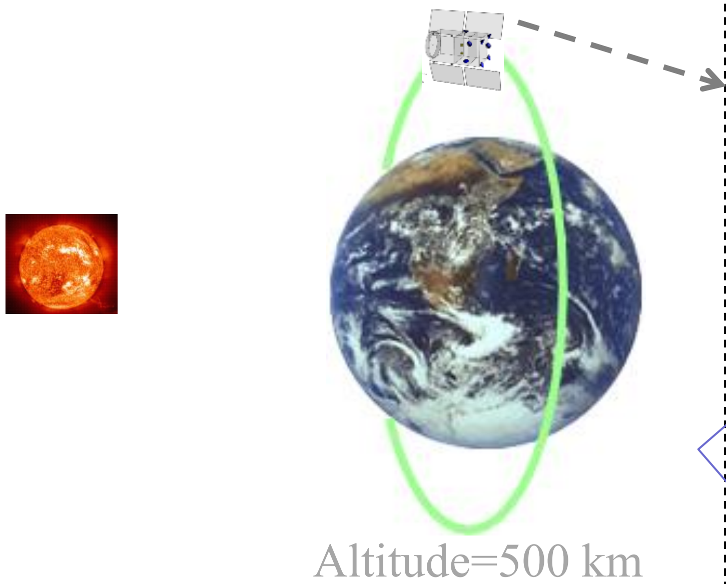
- to specify the requirement of a micro-thruster system for the DPF's drag-free system
- to provide a design of a micro-thruster system for DPF
- to summarize the development status of micro-thrusters for DPF

3. Requirement for DPF's Micro-Thruster System

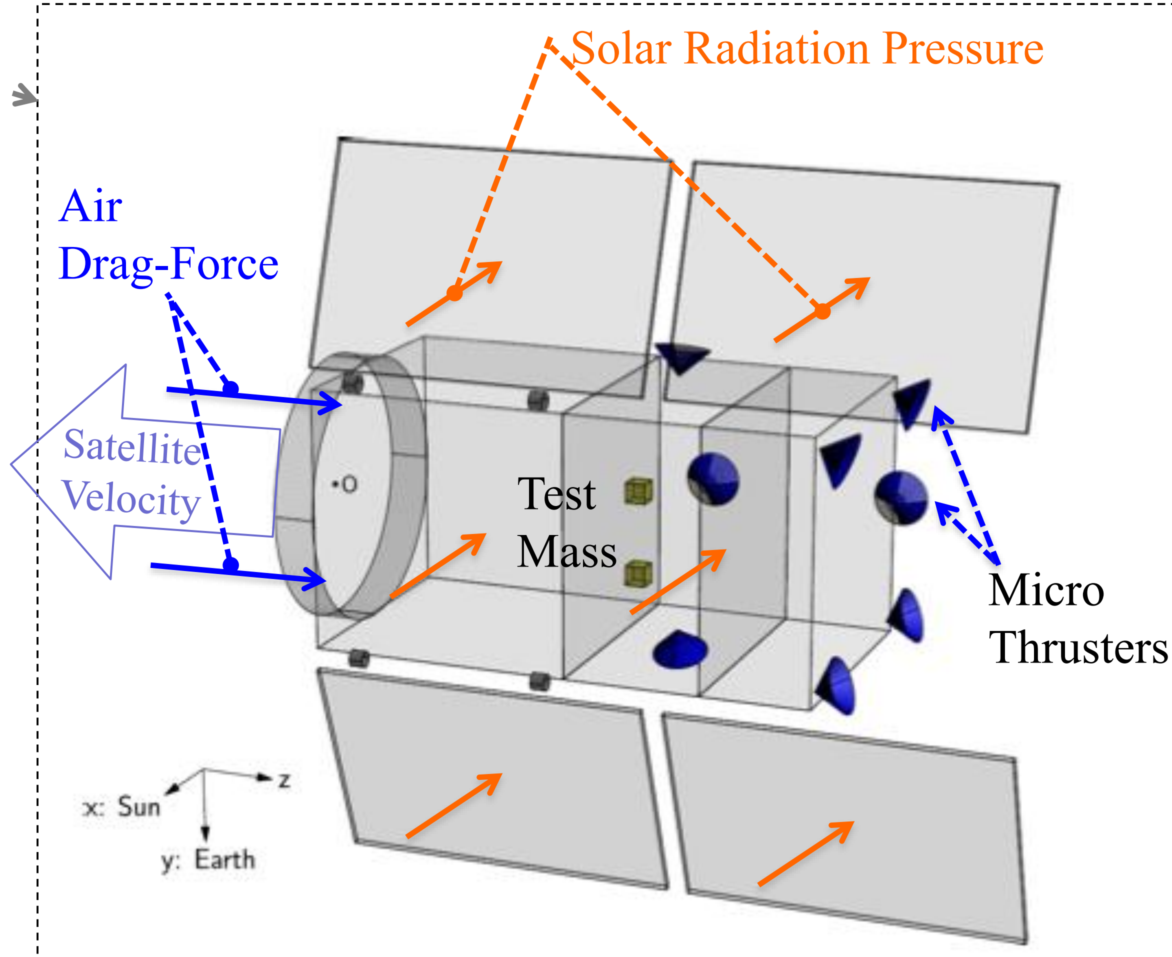
Drag-Free System of DPF Satellite



Orbit and Attitude Control of DPF Satellite



Sun Synchronous Polar Orbit



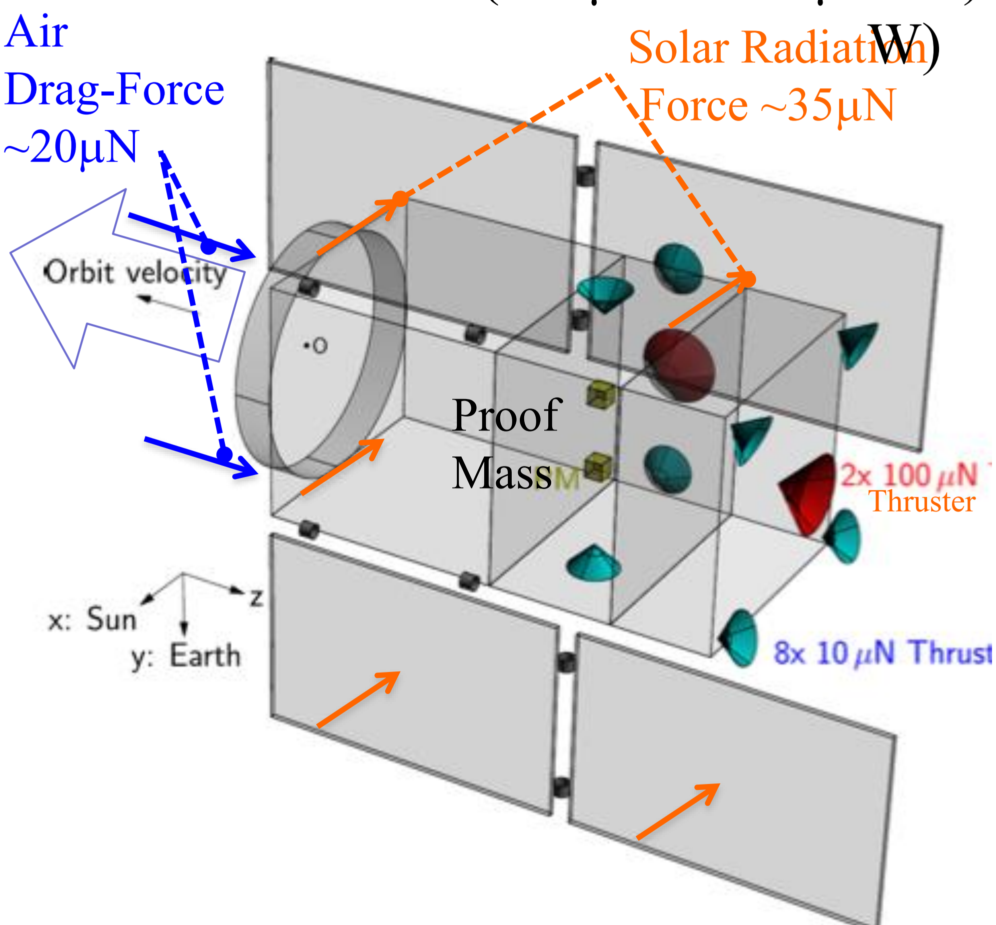
Disturbance Forces on DPF and Cancellation by Micro Thrusters

Requirement for DPF's Micro-Thrusters

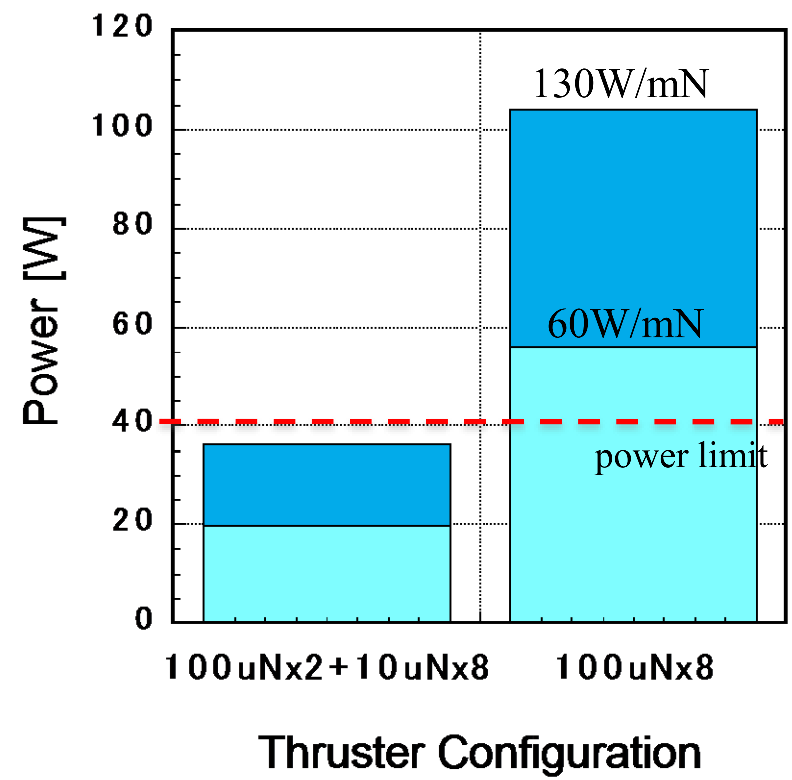
1. very low thrust level (up to 100 μN) in comparison with standard RCS thrusters (1~10 N)
2. wide-range throttling capability (0.5-100 μN)
3. fine (0.1 μN) and fast (10 Hz) control of thrust level
4. low thrust noise in a GW observation frequency range of *0.1 to 10 Hz*
5. long life (~ 0.5 year)
6. limited resources (both power and weight) due to the design of small scientific satellite

Low-power Configurations

Lower-thrust level (100μNx2+10μNx8) allows low power operation (<50 W)



DPF Disturbance Forces and Micro-Thruster Configuration



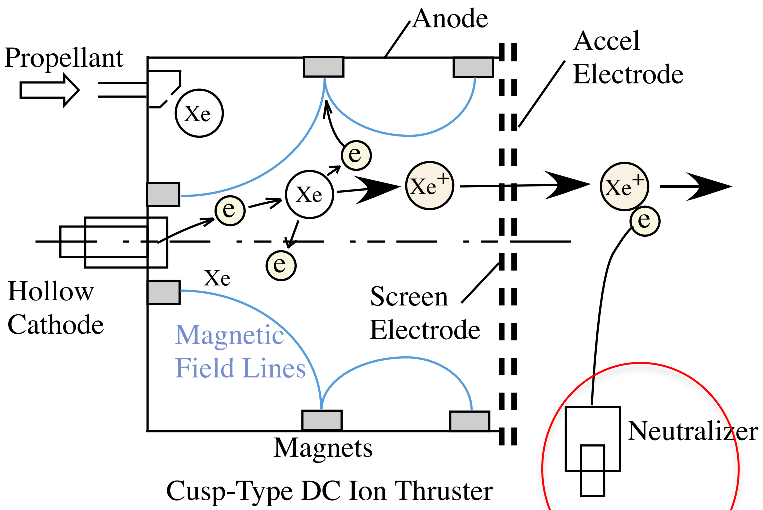
Power Necessary for 10 Micro-Thruster Units

Specification of DPF's Micro-Thruster

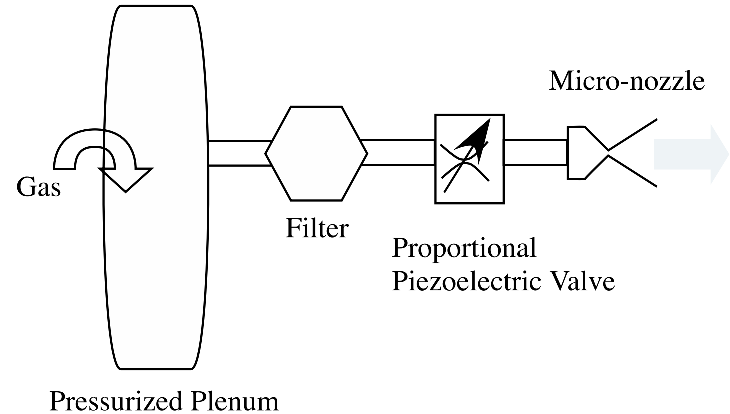
Item	Requirement
Thrust	5-100 μN x 2 units 0.5-10μN x8 units
Thrust resolution	0.1 μN
Loop control time	10 Hz
Thrust noise	0.1μN/√Hz
Isp	T.B.D. (>1,000s)
Weight	<40 kg
Power	<58 W
Ope. Time	4,300hrs
Total Unit	10

4. DPF's Micro-Thruster System and Development Status

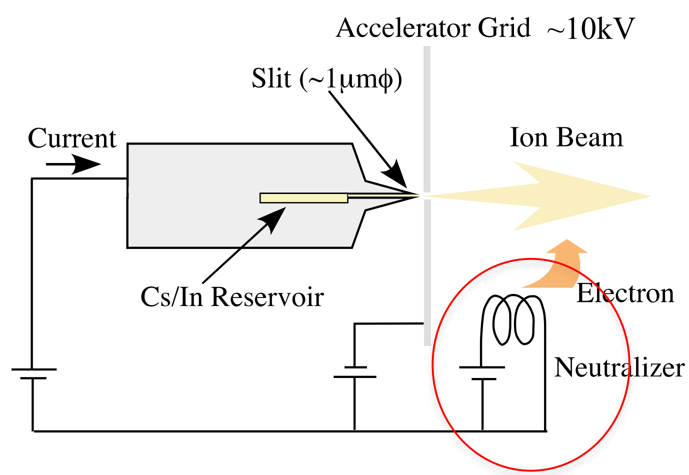
Candidate Micro-Thrusters



a) Ion Thruster



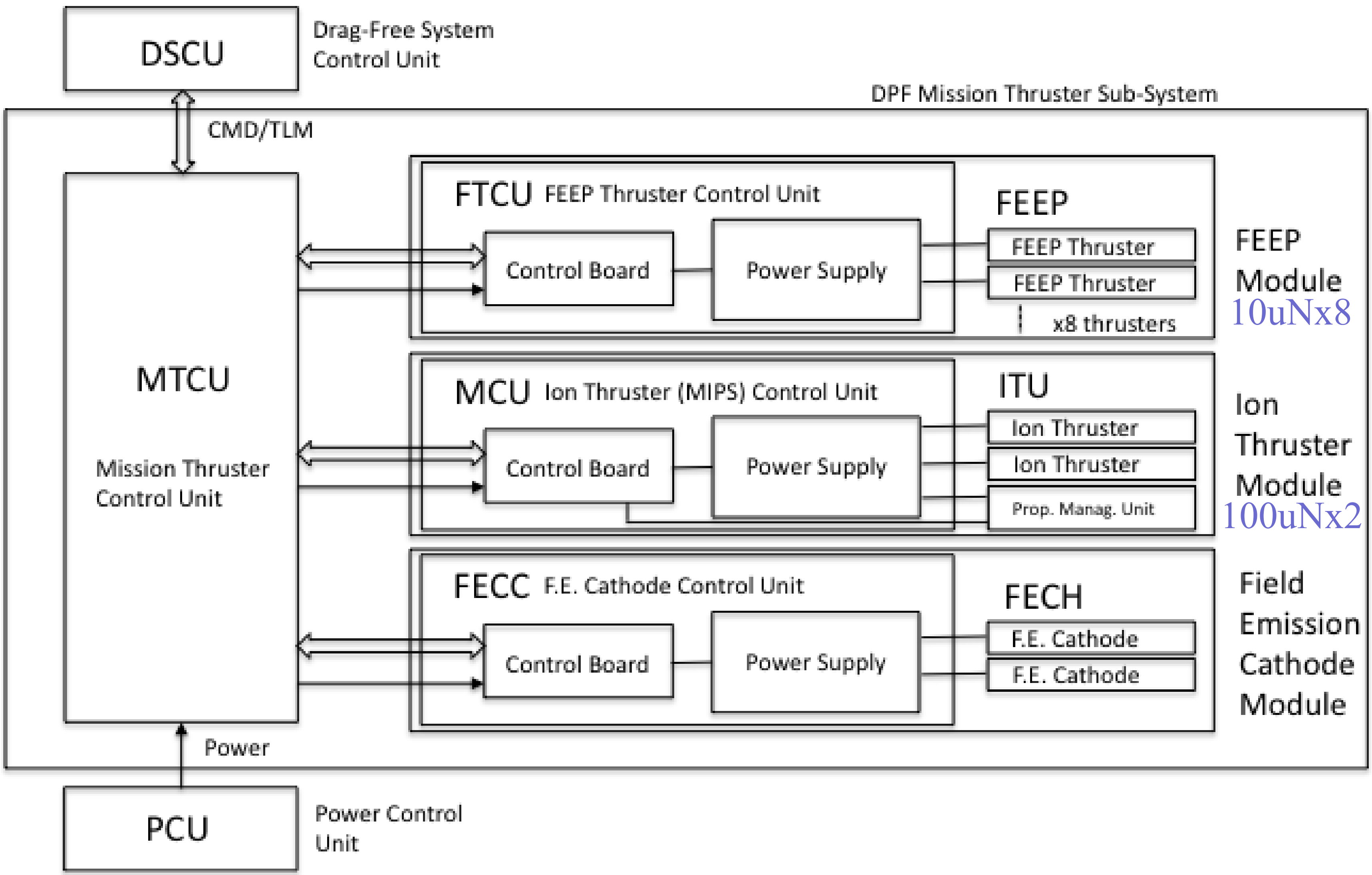
b) Cold Gas Jet (N_2)



c) FEEP

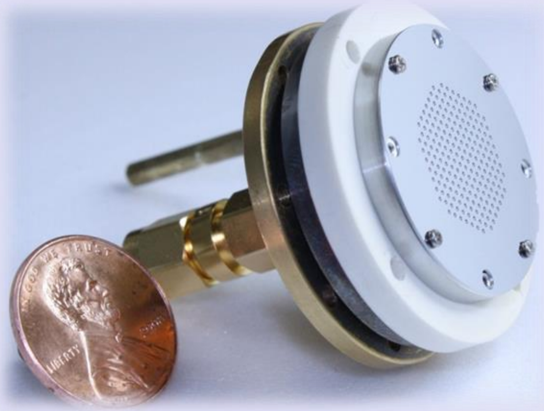
Field Emission Electric Propulsion

DPF's Micro-Thruster System



Micro Thruster Candidates for DPF

Needle Type FEEP (~10μN)
: flight proven



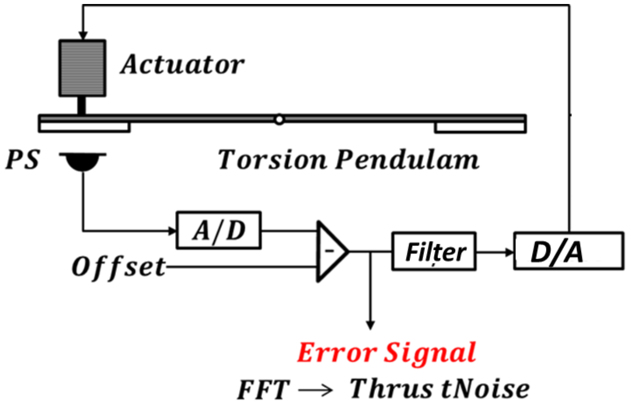
Tokyo Univ.'s Ion (>100μN)
:under development

R&D Status of Micro-Thrusters

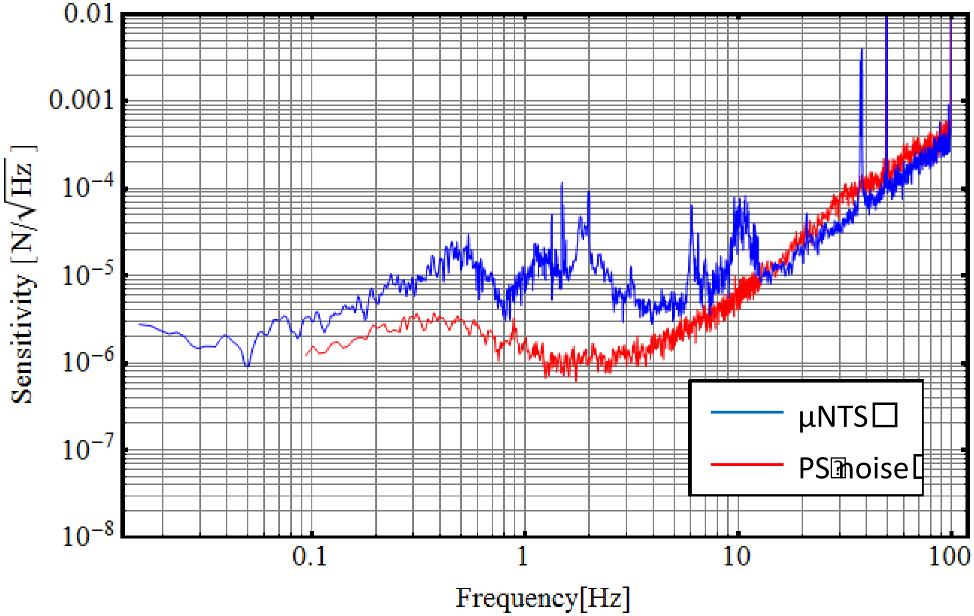
スラスタ種類		FEEP	Xeイオンスラスタ	電界放出カソード
TRL		9	4	4
主要緒元	推力(1機あたり)	0.1−10μ N	5−100μ N	−
	電流値	<1mA	<2mA	<5mA
	推進剤	インジウム, セシウム	キセノン	−
	推力分解能	0.1μ N	0.1μ N	−
	推力応答性	0.1ms	0.1s	−
	推力ノイズ	<0.1μ N/√Hz	<0.1μ N/√Hz	−
	Isp	4000−8000s	>1000s	−
	基数	8	2	2
	サブシステム重量（推定値）	16.5kg	20kg	3.5kg
	消費電力	16W	38W	4W
	寿命	>4,000h	N/A（>4000hを予測）	>4000h
	推力制御方法	加速電圧	加速電圧,電力,推進剤流量	−
海外での開発状況		ARC−Sr (Austria), ALTA(Itally)にて開発 ST7(LISA−Pathfinder)搭載,2014年以降打ち上げ	Astrium (Germany), NASA JPL等にて開発中	Busek (U.S.A.)にて開発
国内での開発状況		N/A（民生用イオン源としては多数の開発実績）	東大で研究開発中	JAXAで研究開発中

Thrust Stand Development for Qualif. Test

Torsion Balance Thrust Stand



Thrust Stand Sensor System



Preliminary Evaluation of Thrust Stand Sensitivity

5. Summary and Future Plans

Summary

A micro-thruster system for the Japanese formation flying spacecraft (Deci-hertz Interferometer Gravitational Wave Observatory Spacecraft, DECIGO) are being developed.

•A small (~450 kg) scientific satellite to demonstrate drag-free technology in an Sun-synchronous orbit around the earth (altitude ~ 500 km) was conceptually design for the future gravitational wave mission, DECIGO. For drag-free system, thrusters up to 100 μN with a thrust precision of 0.5 μN, low thrust noise (0.1 $\mu N/Hz^{1/2}$), and fast response (> 10 Hz) are required.

•Electrostatic micro-thrusters (FEEP, colloid, and ion thrusters) may satisfy the above requirement. For the DPF mission, because available electric power is very severe, two 100 μN thrusters and eight 10 μN thrusters will be employed for the drag-free control.

5. Summary and Future Plans (Cont.)

Future Plan (until Feb. 2014)

- Complete Sub-System Design (including power source etc.)
- Establish Back-up Plan for Thruster

  - 100μN Thruster : FEEP (cluster or original), Cold jet

  - 10μN Thruster: Cold jet

- Update Thrust Stand Design and its Exp. System

Acknowledgements

Contribution by the DPF thruster team is appreciated:

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FEEP	**Prof. Nakayama (NDA)**
Gas Jet	**Prof. Horisawa (Tokai Univ.)**
Field Emission Cathode	**Dr. Ohkawa (JAXA)**
Thrust Stand	**Prof. Sato (Hosei Univ.)**
	Mr. Higashiura (Hosei Univ.)

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