Spacecraft Propulsion using the Solar Wind:
Numerical Simulation and Experimental Simulation in Laboratory

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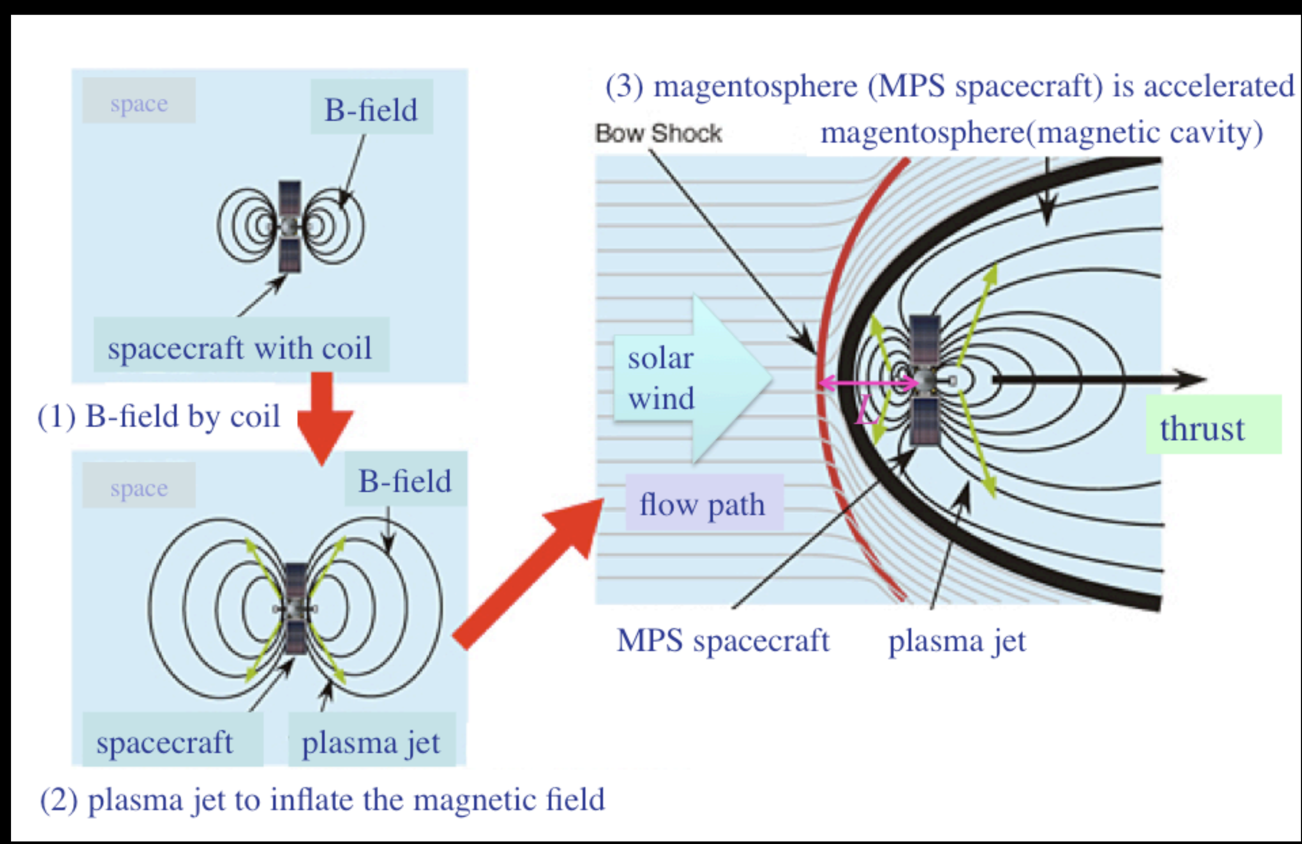
A new spacecraft propulsion concept using the solar wind is studied. When a low-velocity plasma is released near the spacecraft with onboard coil, it was found that plasma equilibrium is established to form a larger artificial magnetosphere. By receiving solar wind momentum with this inflated magnetosphere, thrust force is ~10 times increased in comparison without plasma release in numerical simulation, and ~2 increase was demonstrated in laboratory experiment.

1. Introduction: Magnetic Sail and Magnetoplasma Sail

- Magnetic sail is a deep space propulsion system, in which an artificial magnetic cavity (magnetosphere) captures the energy of the solar wind to propel a spacecraft in the direction leaving the sun.
- To produce a significant thrust level by a magnetic sail, we must create a considerably large artificial magnetosphere (>10 km) by a large (for example, kilometer size) hoop coil onboard a spacecraft, but this is difficult to deploy in space.
- Magnetoplasma sail concept inflates magnetosphere by releasing artificial from spacecraft so that large thrust level is achieved with small electromagnet (coil).
- However, study of MPS so far cannot provide only small amount of thrust increment when releasing artificial plasma from spacecraft.



Concept of Magnetoplasma Sail

2. Objectives

- To provide effective thrust gain of Magnetoplasma sail by improving the magnetosphere inflation process.

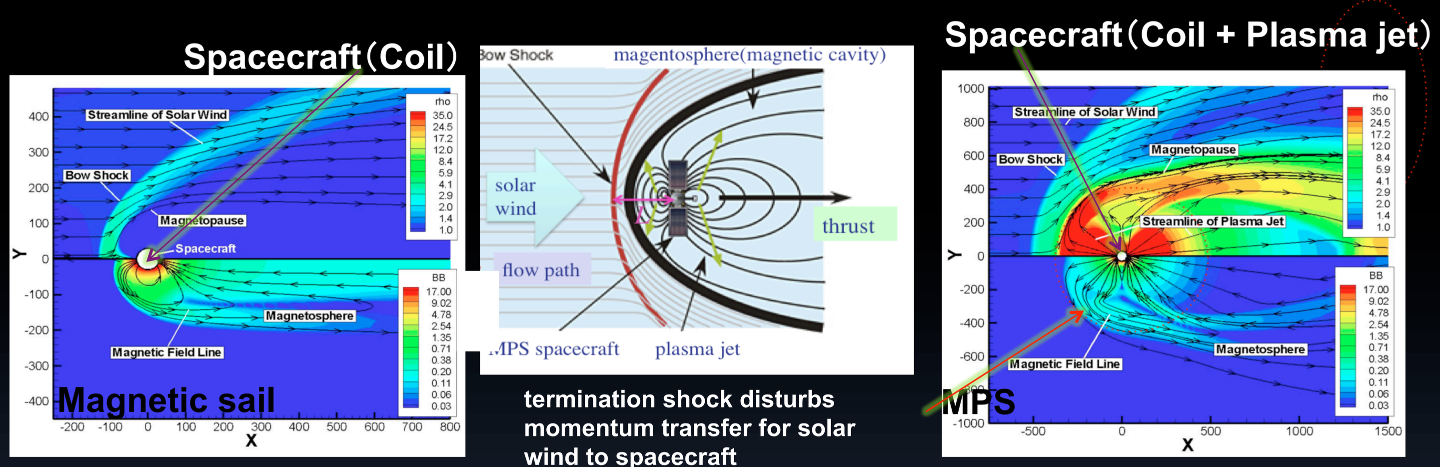
3.Concept of Magnetoplasma Sail (MPS) with Equatorial Ring Current

MPS with equatorial ring-current method obtains larger thrust than M2P2 method.

Old (M2P2) method :

B-field inflation by high velocity flow (β_k>1)

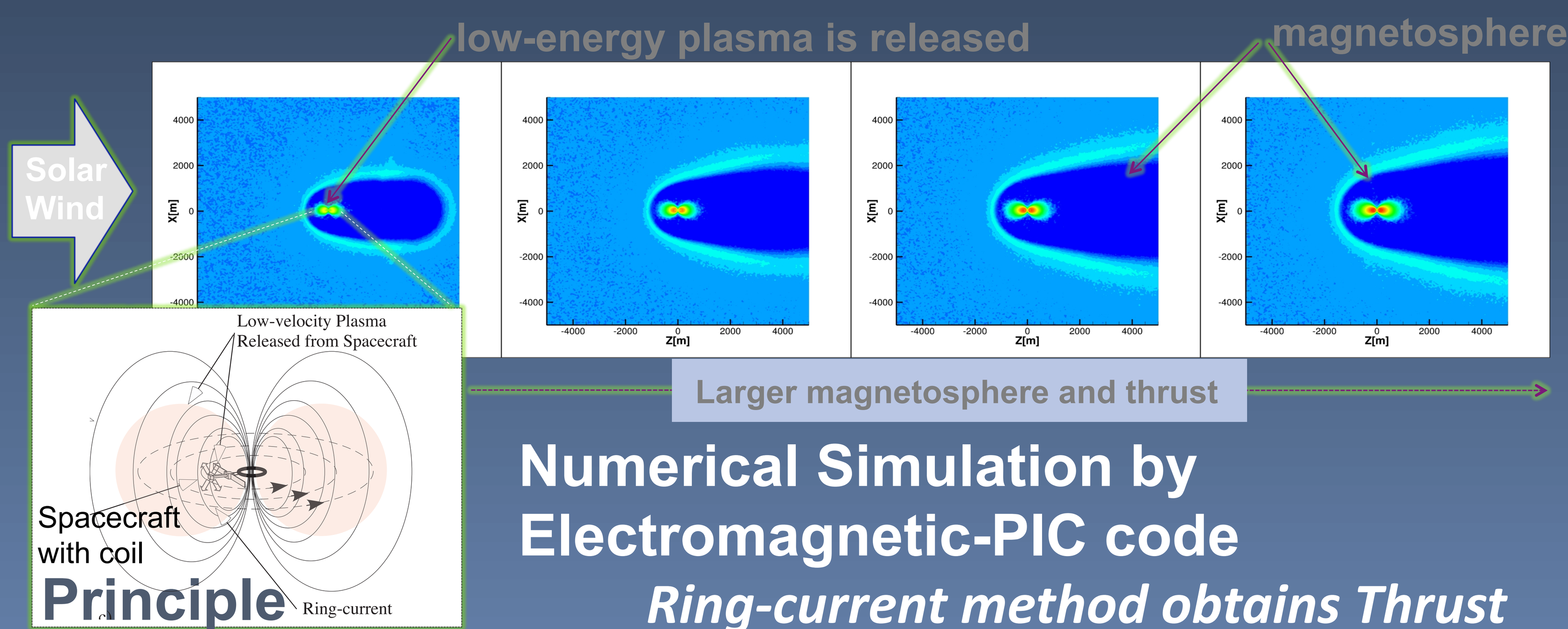
- **Large magnetosphere is possible**
- **But thrust is restricted as thrust gain <2**



MHD Simulation with M2P2(old)method

Ring-current(plasma equilibrium)method(new method) :

- **trapped charged particles (β_{th}<1) induce j_θ and enlarge magnetospheric size**
- **$F \propto S$ (Magnetospheric area) is expected.**



Numerical Simulation by Electromagnetic-PIC code

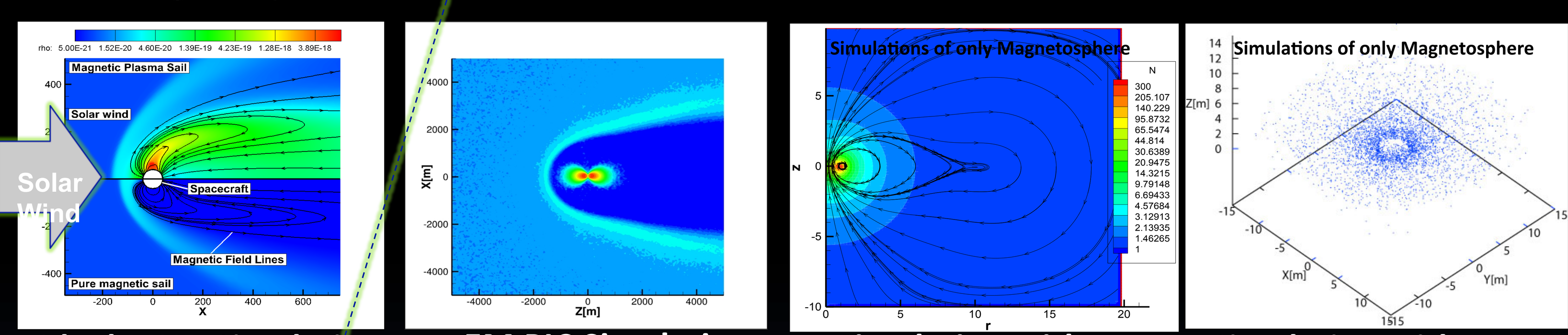
Ring-current method obtains Thrust gain＞2

4. Characteristics of MPS by Numerical and Laboratory Simulations

Thrust gain ~10 obtained numerically and ~2 obtained in laboratory experiment.

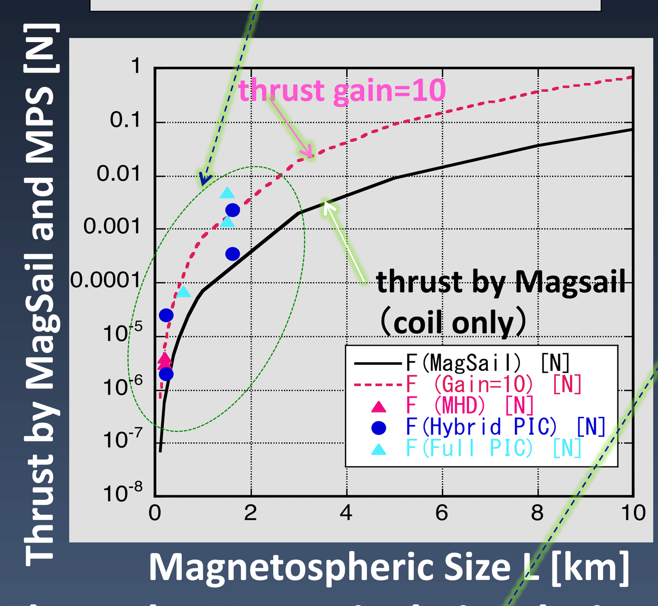
Numerical Simulation

- **Various physical modeling was used depending on magnetospheric size (thrust level).**
- **Thrust gain up to 10 was obtained**

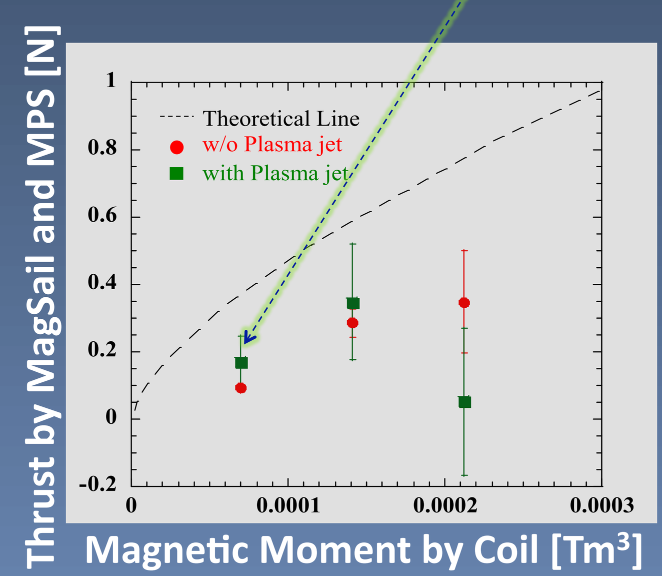


Ideal MHD Simulation (~100km magnetosphere) | EM PIC Simulation (~10km magnetosphere) | Simulation with Grad-Shafranov eq. with diffusion | Simulation with Ion Particle (one-component) model

$$\text{Thrust gain} = \frac{F_{MPS}}{F_{Magsail} + F_{jet}}$$



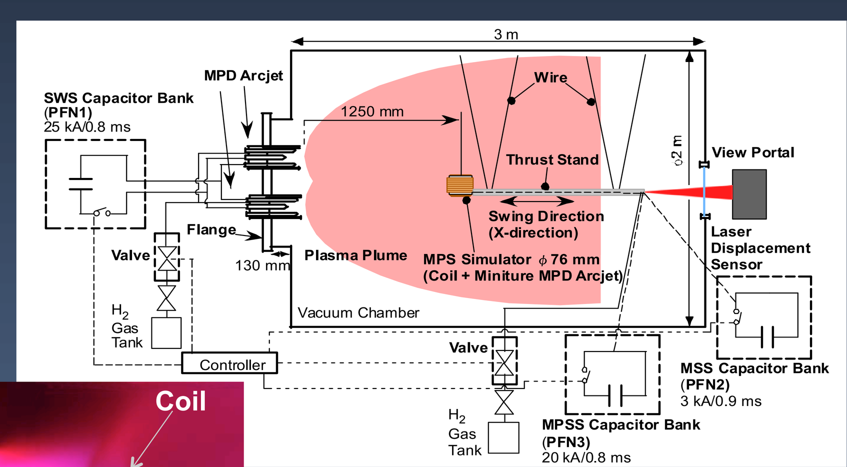
Thrust by Numerical Simulation



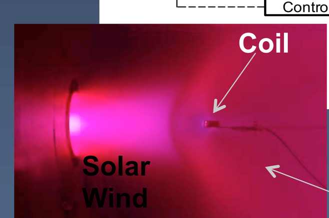
Thrust by Experiment

Laboratory Simulation

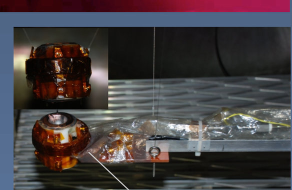
- **Scale-model experiment of Magnetoplasma Sail using solar wind simulator in 2m-diam. chamber.**
- **Magnetosphere inflation was observed and thrust gain up to 1.9 was obtained.**

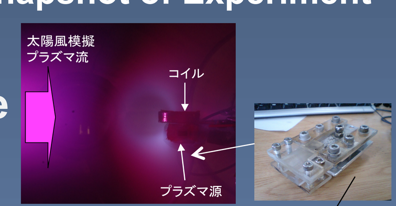


Exp. System and Thrust Stand

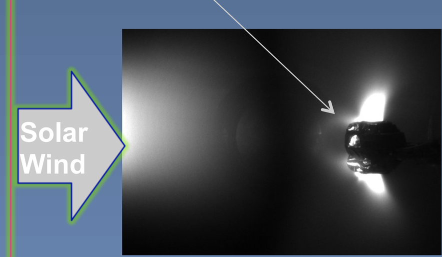


Typical Snapshot of Experiment





Miniature MPSs



M2P2 type

Ring-current type