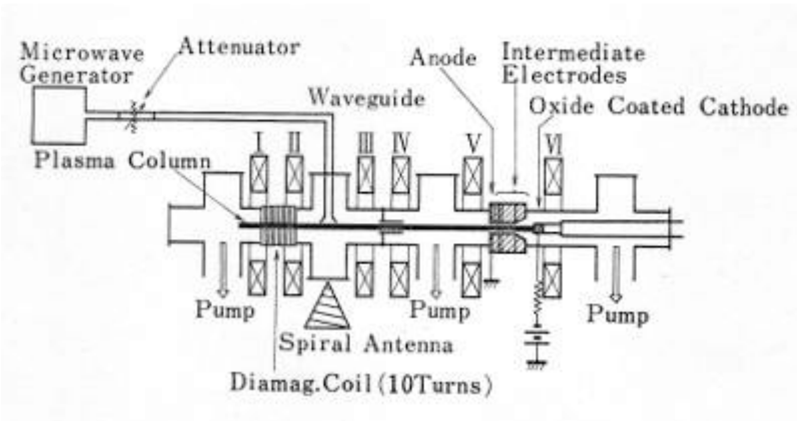
# *Study of Space Plasma Physics and Spacecraft Environment*

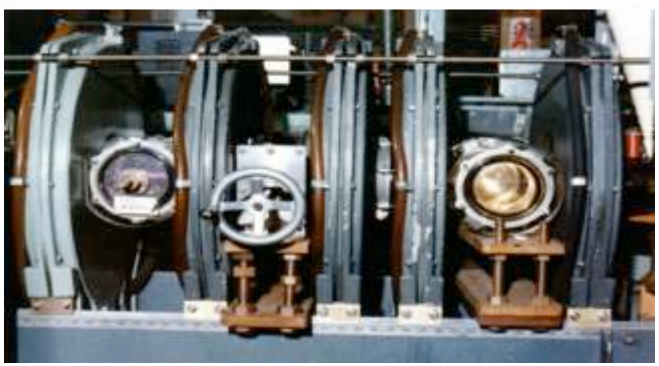
- *Laboratory Experiments on Non-linear Wave/Particle Interaction*
- *Study of Electrodynamic Tether by Sounding Rockets*
- *Space Experiments with Particle Accelerators (SEPAC) on Spacelab-1/Space Shuttle STS-9*
- *Study of Spacecraft Environment on Space Flyer Unit (SFU)*

*March 2012*

# Laboratory Experiments on Non-linear Wave/Particle Interaction

## "Delayed Emissions" from plasma excited by a high-power microwave pulse

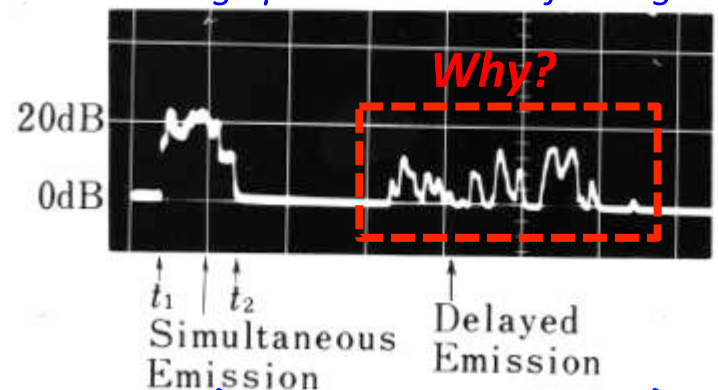


*Experimental apparatus*

*Delayed emission excited by a high power microwave pulse, S.Sasaki, et.al., Phys. Fluids 19, 906 (1976)*

*Strange phenomenon at first sight*




*Microwave injection*

*Emissions after termination of microwave injection*

*Mechanism for the delayed emissions was finally clarified.*

*1. Microwave pulse excites electrostatic waves in plasma via the parametric instability.*

*2. The electrostatic waves heat the plasma electrons.*

*3. The heated electrons are trapped in the magnetic mirror field for a while and then excite the electron cyclotron waves via the electrostatic instability, which are often observed in space.*

# Study of Electrodynamic Tether by Sounding Rockets

**Sounding rocket experiment in the conductive tethered mother/daughter payload system with an electron beam injector. It was intended to use the space as a large plasma laboratory.**

*Sounding rockets used for this research:*
*Japanese: K-9M-57, K-9M-69, S-520-2*
*U.S.: Black-Brant V(1), Black-Brant V(2)*

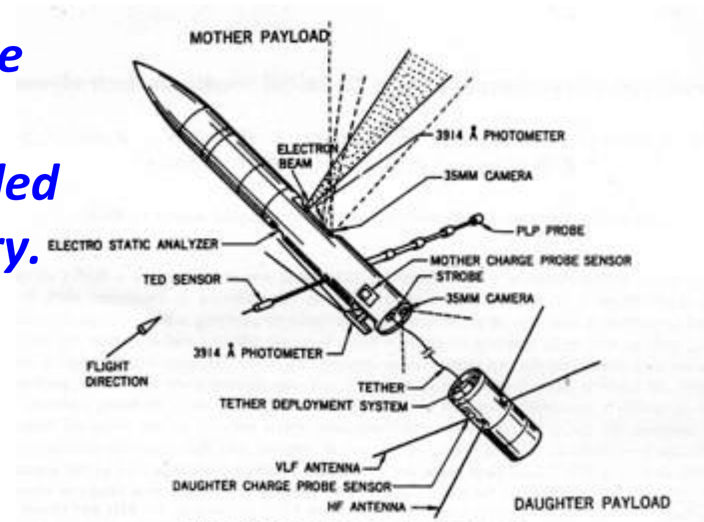
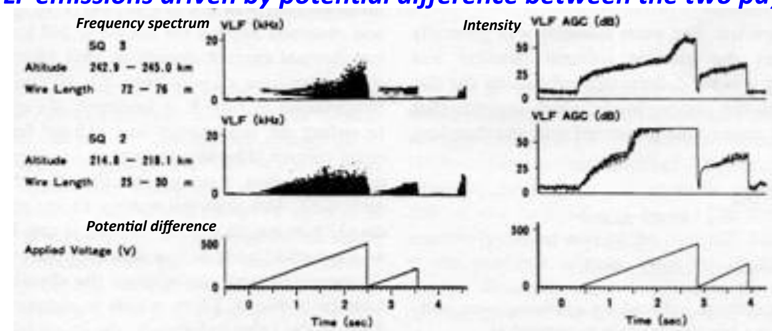



Fig. 1. Configuration of payload instruments.

*Configuration of Tether Rocket Experiment in 1983 that marked the longest tether length in space by that time.*

***VLF emissions driven by potential difference between the two payloads***




*Time (sec/div)*

*One of the important findings:*
*The lower-hybrid resonance waves were excited by ion motion driven by the electric field near the electrodynamic tether system.*


*Tethered Rocket Experiment(CHARGE-2):Initial Results on Electrodynamics, S.Sasaki, et.al., Radio Science, 23, 975 (1988)*

# *Space Experiments with Particle Accelerators (SEPAC) on Spacelab-1/Space Shuttle STS-9*

*SEPAC was an active experiment to use space as a gigantic plasma laboratory for studying plasma physics. SEPAC carried electron beam/plasma accelerators, diagnostic instruments, and a low light level TV camera.*

*The objectives were to study;*
*1.vehicle charge build-up and its neutralization,*
*2.beam plasma physic, and*
*3.beam atmosphere interaction (artificial aurora).*

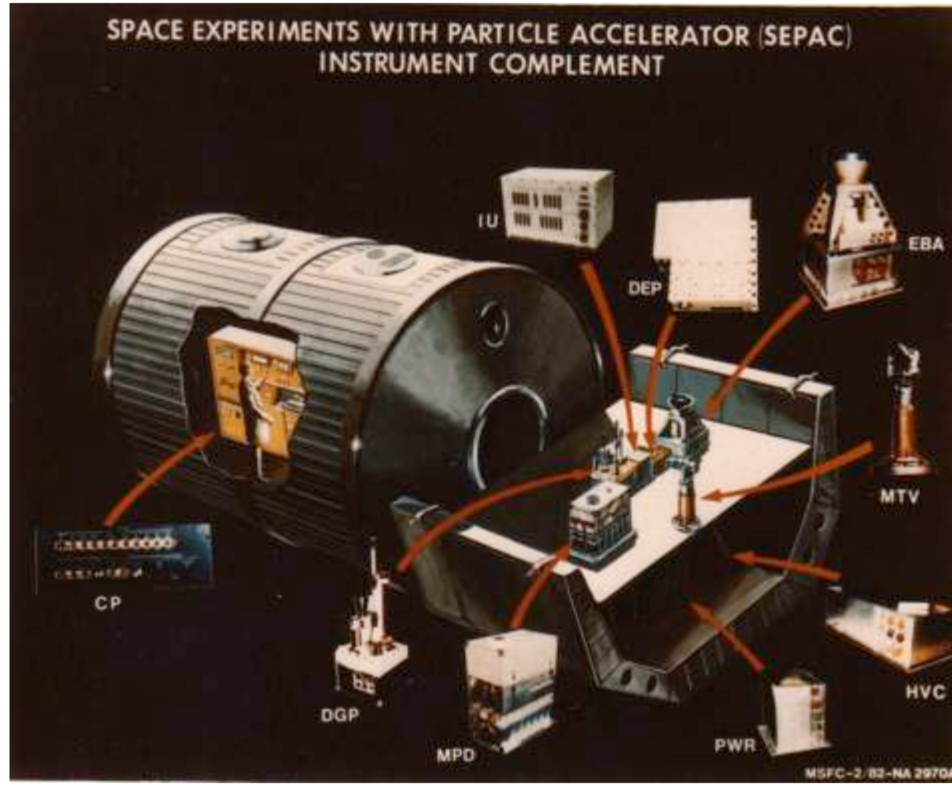
*SEPAC experiment was conducted as a first large-scale joint space program between Japan and U.S. It started in 1978. The experiment was conducted in 1983. The follow-on experiment was performed in 1992.*

*Space Experiments with Particle Accelerators, T.Obayashi, et. al., Science, Vol.225, No.4658, 195, July (1984)*

# SEPAC Instruments

***Japanese Onboard Instruments***
***Accelerators and Diagnostics***
***(1 ) Electron Beam Accelerator:***
***7.5kV, 1.6 A, 10ms~1sec***
***(2) Magneto-Plasma-Dynamic Arcjet:***
***2kJ/pulse, 1ms, Ar***
***(3) Neutral Gas Plume Generator:***
***Nitrogen***
***(4) Diagnostic Equipment:***
***Photometer, Energetic particle analyzer, Plasma probe, Pressure gauge, and Wave and field probes***
***(5) Low Light Level TV Camera***

***U.S. Onboard Instruments***
***Control and Data Management Equipment***
***(1) Control Panel***
***(2) Dedicated Experiment Processor***
***(3) Interface Unit***



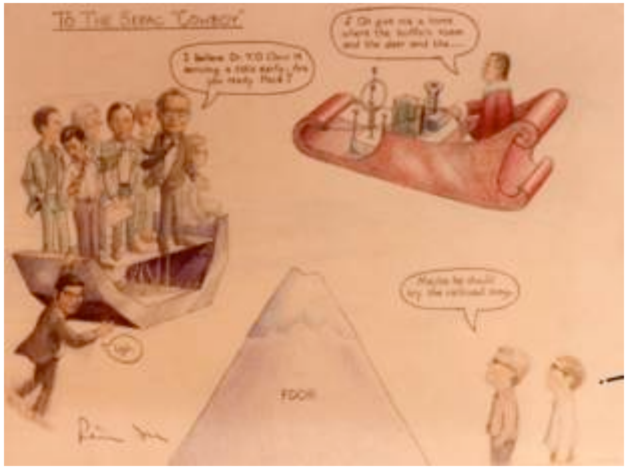

***SEPAC On-board Instruments***

***SODA-QL (Scientific On-line Data Analysis Quick Look System )***

# SEPAC Team and Operation

## Japanese Team:

***T.Obayashi (ISAS), N.Kawashima (ISAS), K.Kuriki (ISAS), M.Nagatomo (ISAS), K.Ninomiya (ISAS) M.Ejiri (ISAS, NIPR), S.Sasaki (ISAS), M.Yanagisawa (ISAS), I.Kudo (ETL)***




*Launch in 1983*

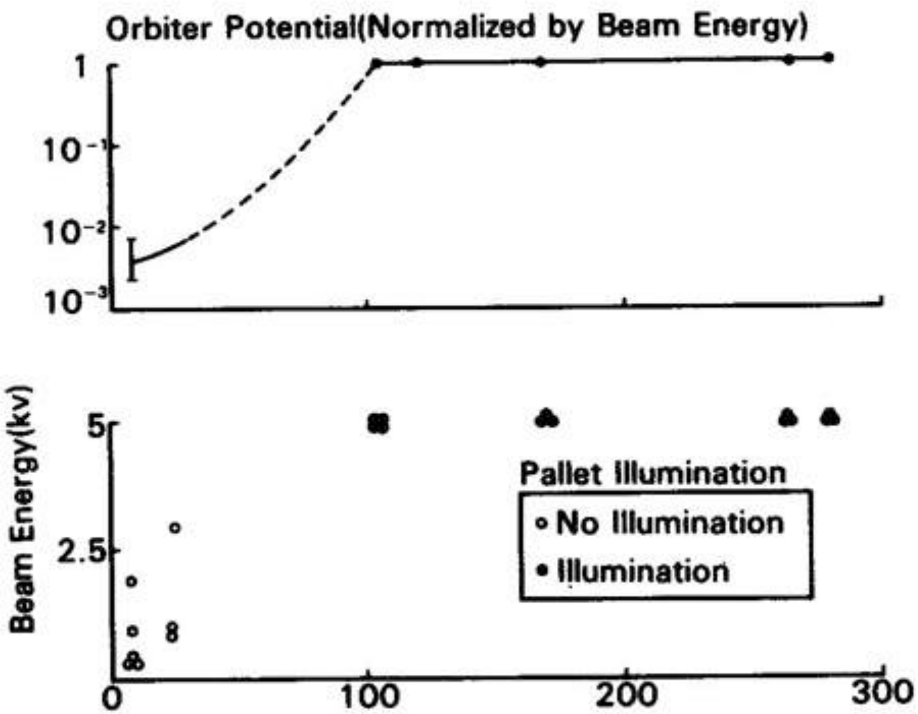
## U.S. Team:

***W.T.Roberts (MSFC), C.R.Chappell (MSFC) D.L.Resoner (MSFC), J.Burch (SWRI) W.L.Taylor (TRW), P.M.Banks (Stanford Univ.) P.R.Williamson (Stanford Univ.) , O.K.Garriott (JSC)***

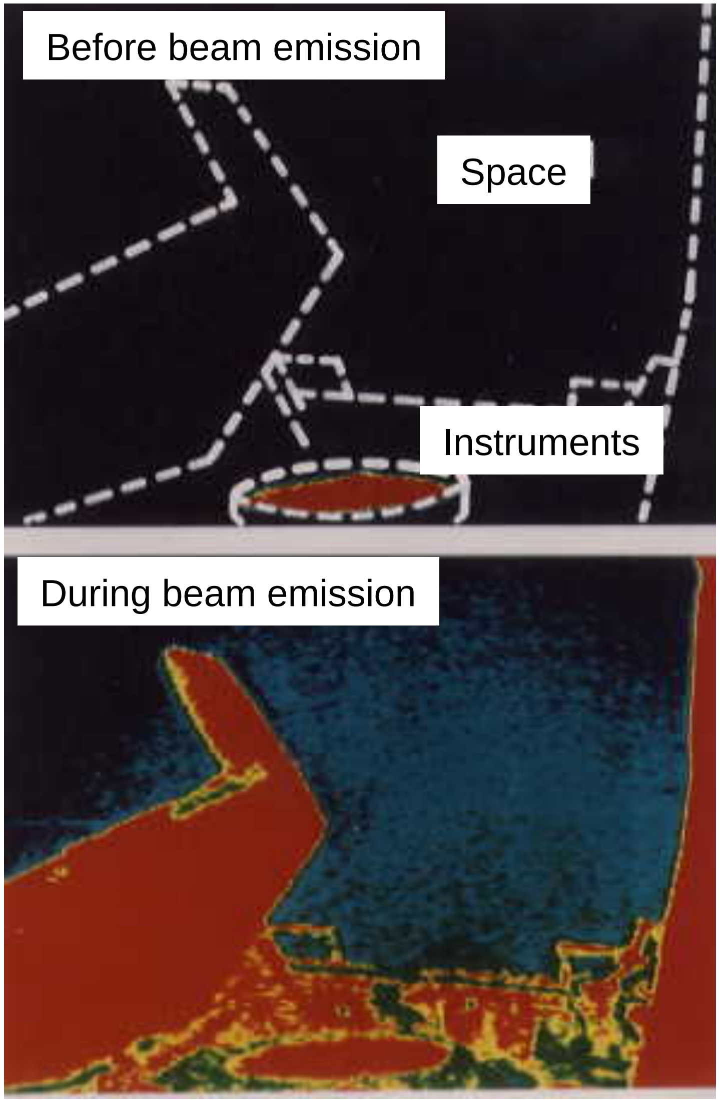
*Ground operation by Japan/U.S. joint team (3 shifts)*

# *Orbiter was Charged up to Several Thousand Volts !*

*The potential of the orbiter with respect to the space potential was measured during the electron beam injection. It was found that the orbiter was occasionally charged up to the beam acceleration voltage (several thousand volts).*



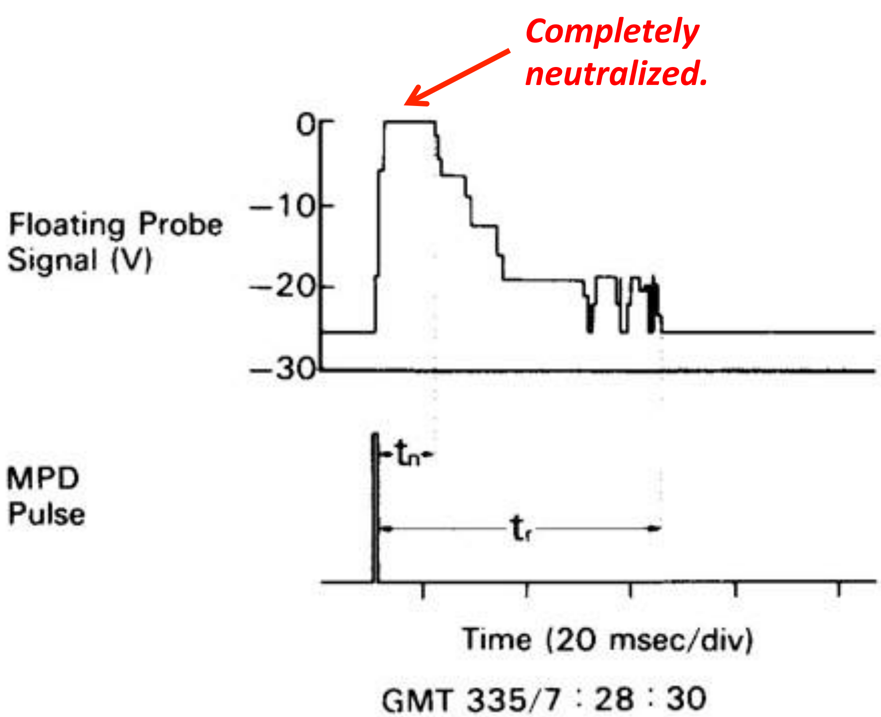

*Vehicle Charging Observed in SEPAC SPACELAB-1 Experiment, S.Sasaki, et. Al., AIAA J. Spacecraft and Rockets 23, 194 (1986)*

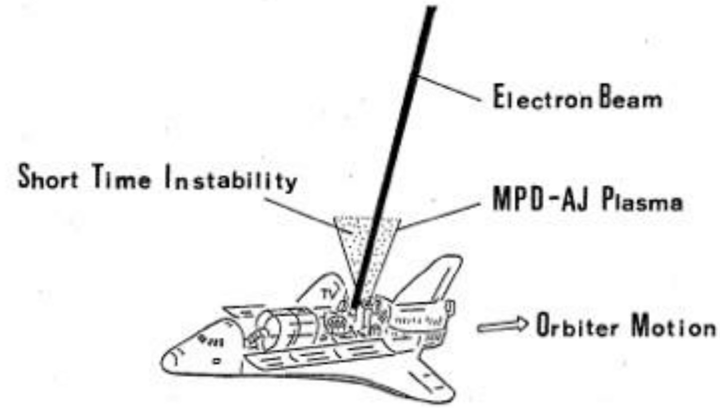


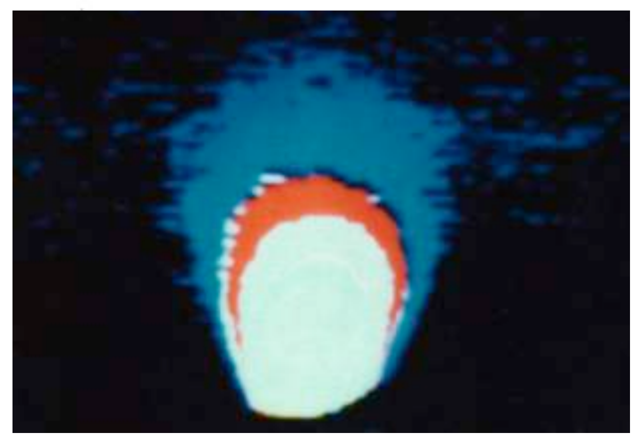

*The instruments on the orbiter pallet were strongly illuminated (pseudo color) by retuning energetic electrons.*

# *Neutralization of the Orbiter Charging by Simultaneous Injection of Gas or Plasma*

***Charge-neutralization by plasma injection (1 msec) was first demonstrated and analyzed.***



*Plasma plume injected from MPD arc-jet (pseudo color)*

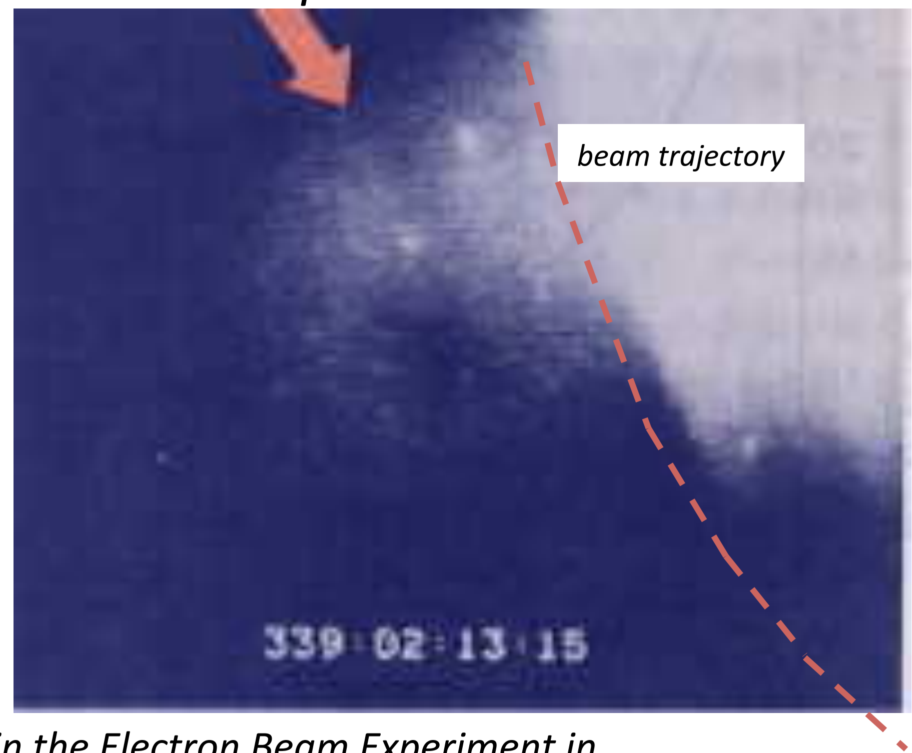
*Neutralization of Beam-Emitting Spacecraft by Plasma Injection, S.Sasaki, et. al., AIAA J. Spacecraft and Rockets, 24, 227 (1987)*

# *Demonstration of Beam Plasma Discharge (BPD)*

*Beam Plasma Discharge is an ionization by energetic electrons generated by beam plasma interactions in a gas-beam system. It had been demonstrated in laboratory experiments on ground. SEPAC first demonstrated the ignition of BPD in space without walls.*

***BPD surrounding a spiral electron beam observed in laboratory***

***Local BPD near the electron beam observed in SEPAC experiment***



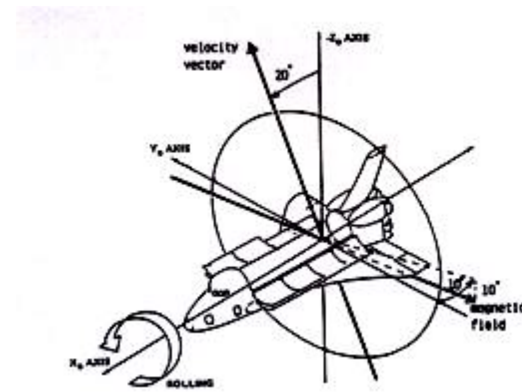

*Ignition of Beam Plasma Discharge in the Electron Beam Experiment in Space, S.Sasaki, et. al., Geophys. Res. Letts., 10, 647 (1985)*

# Verification of Critical Velocity Ionization (CVI)

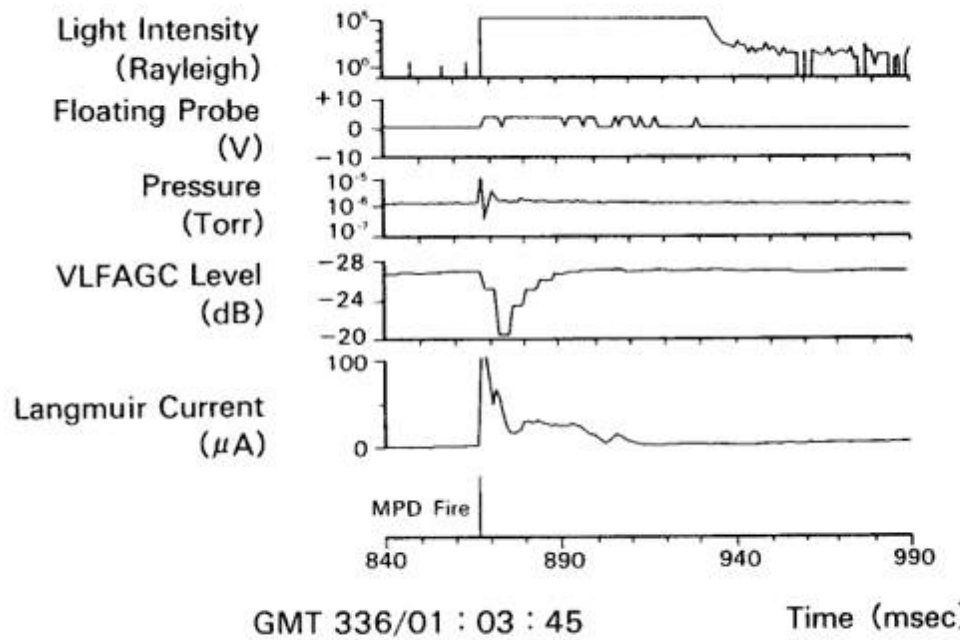
*The concept of Critical Velocity Ionization was first proposed by Alfve'n, related to the formation of the solar system. The hypothesis is that a gas plume propagating in a magnetic field at more than a critical velocity will be rapidly ionized.*

| *Experiment* | *Year* | *Increase Ionization* |
|---|---|---|
| SEPAC | 1983 | yes |
| XANI | 1989 | yes |
| STS 39 | 1991 | no |
| ATLAS 1 | 1992 | yes |
| APEX | 1993 | yes |
| North Star | 2000 | yes |
| ARGOS | 2000 and 2001 | no |

*Verification of CVI in space.*




*Phenomena induced by gas injection from the orbiter, suggesting the ignition of CVI.*




*An Enhancement of Plasma Density by Neutral Gas Injection Observed in SEPAC Spacelab-1 Experiment, S.Sasaki, et. al., J. Geomag. Geoelectr., 37, 883 (1985)*

# SEPAC Contribution to Space Science and Space Development

1. There were a lot of new findings and surprises in space plasma physics, especially in particle-particle and particle-wave interactions.
2. SEPAC demonstrated the controlled space experiment as a powerful tool to study space physics and play a role of the forerunner to the following active space experiments such as 20 –km tether experiment and gas release experiments in space.
3. It was conducted as the first large scale international collaboration in space program between Japan and the U.S., that educated many scientists and engineers who have lead projects in space science and even wider fields in Japan and the U.S.

Completion of SEPAC first experiment in 1983

# Lessons Learned and Some Personal Impressions from SEPAC

1. ***Since the electron gun failed during the mission, the high power experiment to produce the artificial aurora was cancelled. The scientific achievements were significantly obtained as a whole, but the failure was strictly criticized by the media and the government. Whether right or wrong, any failure even in challenging projects is hardly allowed in Japan, which is a little bit different from the society's eye in the U.S.***

2. ***The re-flight was planned soon after the first experiment, but it was considerably delayed due to the "Challenger accident". The artificial aurora was successfully generated in the follow-on mission in 1992, 9 years after the first attempt. However, it did not attract the scientists' attention so much. For scientific research, there is a "season".***

たかがナット、されどナット――1回目の失敗

いろいろと幸運も重なり、大林の実験計画はいわゆるアクティブ実験として、スペースラブの最初の飛行で行われることになった。日本側は主要機器である電子ビームとプラズマの加速

れた気持ちでジョンソン宇宙センターの管制室から解放され、宇宙ステーションのワークショップが開かれるワシントンDCに移動した。

ホテルの部屋で、テレビに映し出されるスペースラブの様子を見つめていた長友は、画面が時々明るくなるのを見て、「あ、これはMPDアークジェットの光だな。いいぞ、いいぞ」と思いつつも、電子ビームが出てくる様子がないので、「電子ビームはテレビには映りにくいのだ」と勝手に判断していた。まさかその時すでに電子銃の電源が故障していたことは知る由もなかったのである。

シャトルが地球に帰還して、電源の中にナットが1個見つかった。これが宇宙で浮遊して悪さをしてフューズがとび、人工オーロラの生成を含む高エネルギーの実験は実施できなかったのである。実験は失敗と評価され、計画は事実上打ち切りとなった。

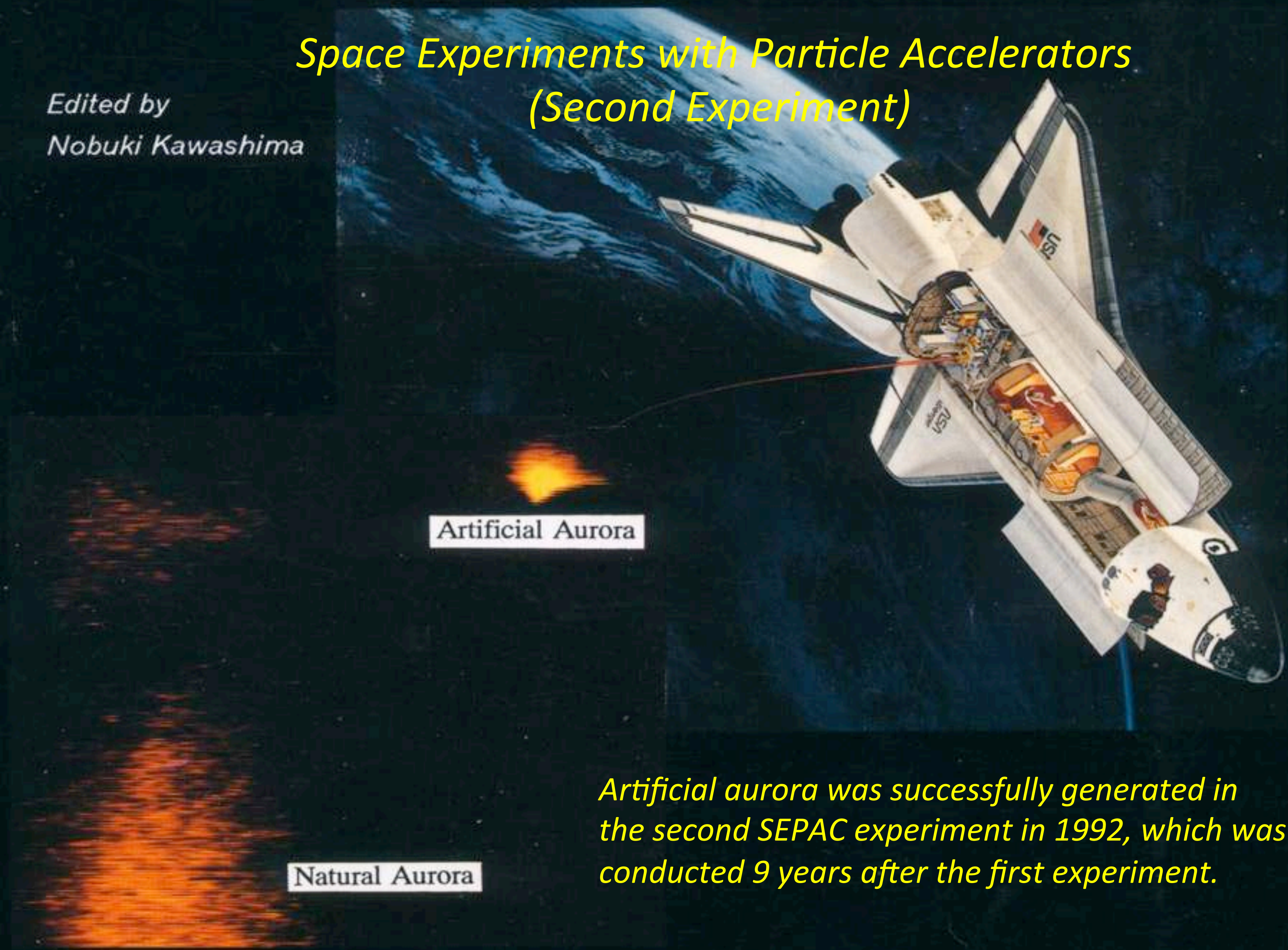
SEPACのオーロラ生成実験イメージ図

SEPAC実験装置配置図

SEPAC実験装置

*A Japanese article, "History of Space Development（ISAS Story）". The title is "<u>It's only a nut, but a nut.</u>", explaining that the failure was caused by one nut which was unintentionally left in the flight instrument, and SEPAC was labeled as failing because the high power experiments including artificial aurora generation were cancelled.*

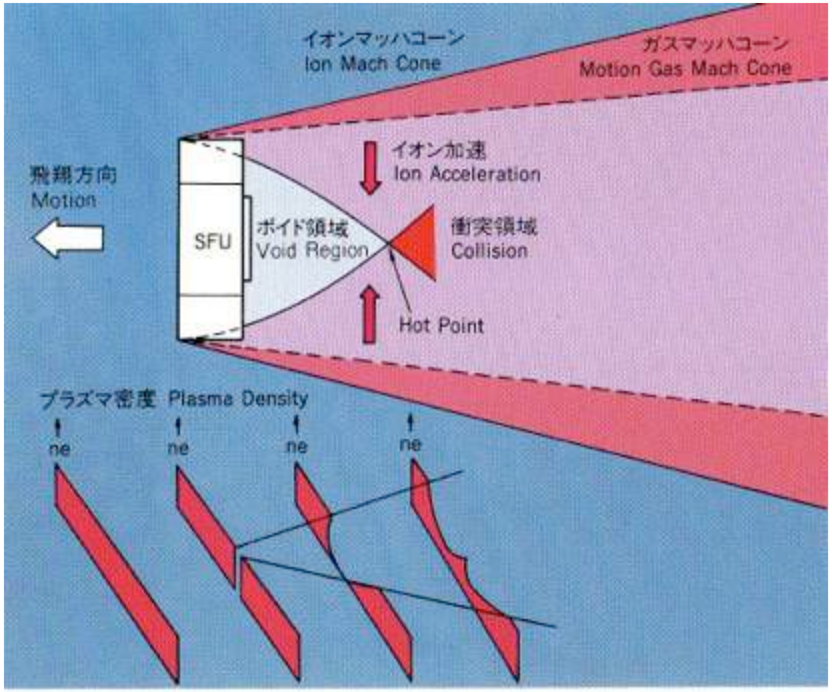
# *Space Experiments with Particle Accelerators (Second Experiment)*

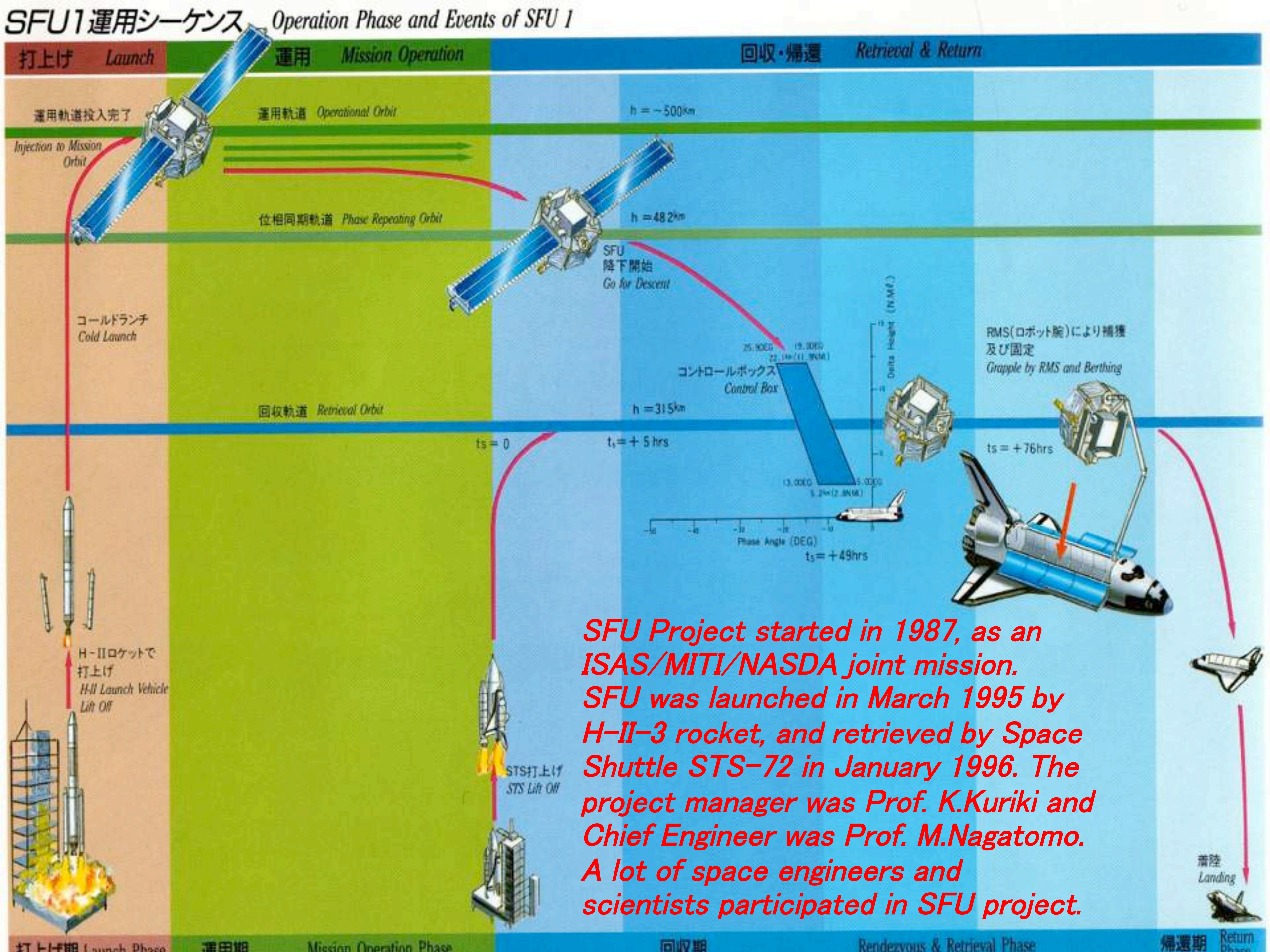



*Artificial aurora was successfully generated in the second SEPAC experiment in 1992, which was conducted 9 years after the first experiment.*

# Study of Spacecraft Environment on Space Flyer Unit (SFU)

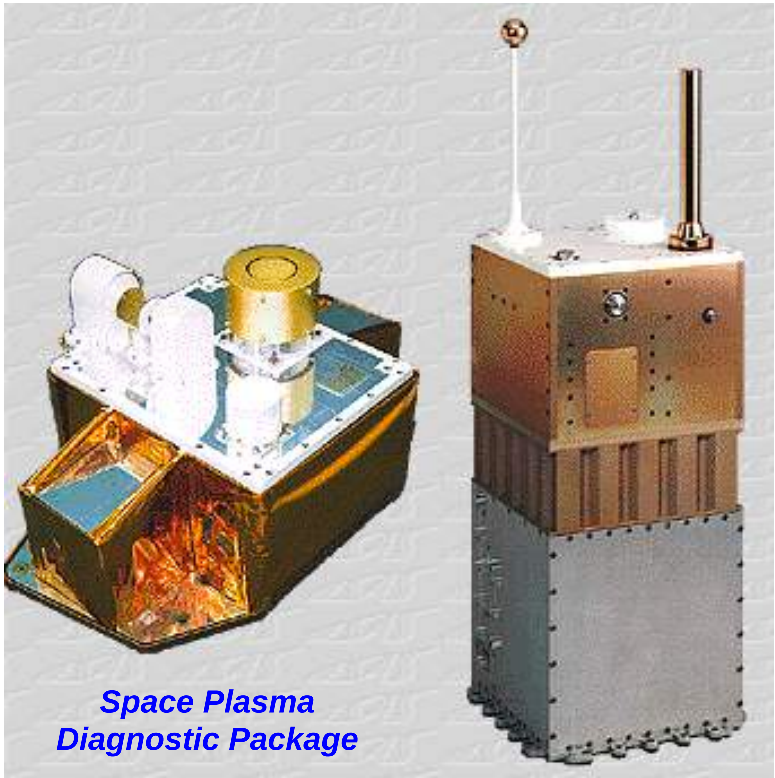
*When we live on an orbiting large space structure (or space colony), we will experience a unique environment (spacecraft environment) surrounding the structure.*
*The spacecraft environment is generated by the interaction between the structure and space medium.*
*The spacecraft environment was extensively studied by diagnostic packages on the SFU（Space Flyer Unit） launched in 1995.*






*SFU Project started in 1987, as an ISAS/MITI/NASDA joint mission. SFU was launched in March 1995 by H-II-3 rocket, and retrieved by Space Shuttle STS-72 in January 1996. The project manager was Prof. K.Kuriki and Chief Engineer was Prof. M.Nagatomo. A lot of space engineers and scientists participated in SFU project.*

# SFU Environment Monitor/Diagnostic System




Environment
Monitoring System

### Environment Monitoring System

*Ionization Gauge (2 sets)*
*Pirani Gauge (4 sets)*
*Mass Spectrometer*
*Plasma Probe (4 sensors)*
*Floating Probe*
*Impedance Probe*
*Wave Receivers（VLF and HF bands）*
*Micro-g Meter（3-axis）(4 sets)*
*Exposed material samples (for analysis after retrieval）*

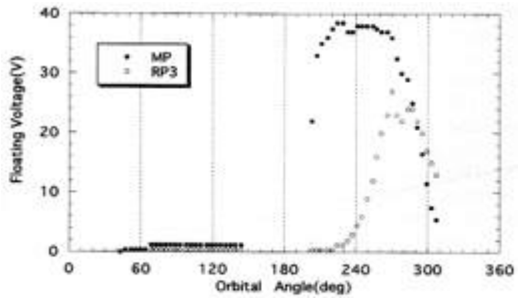
### Space Plasma Diagnostic Package

*Spectrometer with exposed sample materials (for real time analysis)*
*Exposed material samples (for analysis after retrieval）*
*Magnetometer (3-axis)*
*Electron Density Fluctuation Detector*

*Study of Spacecraft-generated Environment on Space Flyer Unit, S.Sasaki, et. al., Proc. of the 19th ISTS, Yokohama, 769-774(1994)*

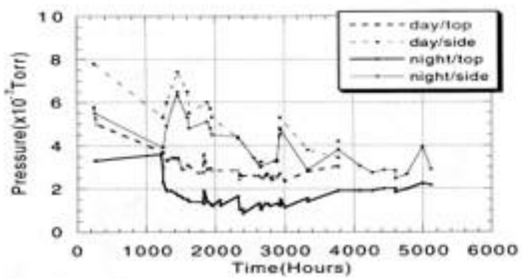
# *Major Results Obtained in the Research of SFU Spacecraft Environment*

*Spacecraft Potential*



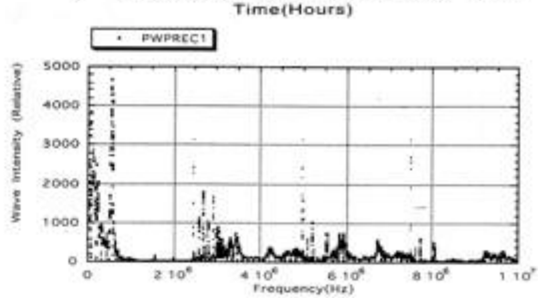

*During the daytime, the potential of spacecraft with respect to the ambient plasma is determined by the solar array voltage(*1).*

*Change of Pressure in a Long Period*



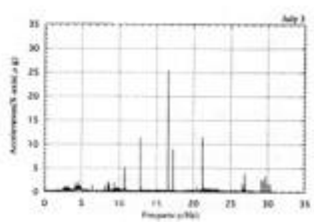

*The pressure near the surface of spacecraft is dominated by the outgassing effect for about 6 months after launch. Water is the principal constituent .*

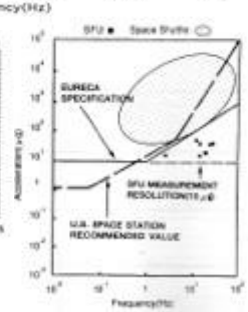
*Electromagnetic Environment*




*Surrounding large space structures, there always exist low frequency broad band noises, possibly excited by the density gradient of the surrounding plasma.*

*Micro-g Environment*






*The micro-g environment is much better than the manned space station, but there are always low level vibration near the characteristic frequencies of the spacecraft structure.*

**1 Plasma Effects Driven by Electromotive Force of Spacecraft Solar Array, S.Sasaki, Geophys. Res. Letts., Vol.26, No.13, 1809-1812 (1999)*

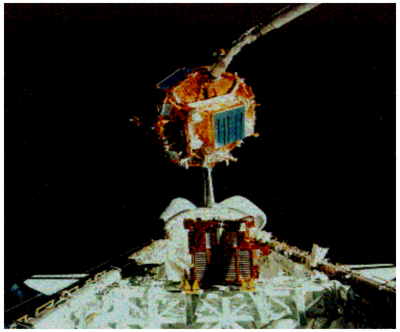
# *Lessons Learned and Some Personal Impressions from SFU Project*

***1. For the experiment planning, "Time Line Generator" was used to automatically arrange the complicated experiment requests from the 10 PI teams. This technique originally came from NASA, but was modified for SFU project. It worked quite effectively.***

***2. During the standby operation to wait for retrieval (after the nominal mission) , the frequency of ground tracking operation was reduced to save operation cost. It turned out to be a bad decision. Since we could not timely notice the spacecraft problem, SFU fell into a dangerous situation for a while. Avoid easy compromise any time during the flight operation.***

***3. During the retrieval phase by the Shuttle, we had to separate the solar paddles just before the berthing (contingency operation) because we failed to retract them. The paddles were separated in time perfectly. That emergency had been considered a very low probability case, but the separation procedure was repeatedly tested in the operator's training session. It is important to make sufficient training for critical operation to avoid total loss even if the probability for such situation is extremely low.***

***SFU operation room***



***Berthing after critical operation (paddle separation)***

***Operation team at completion of mission success***