PLATFORM FOR ROBOTICS EXPERIMENTS

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ABSTRACT: JAXA has developed the Japanese Experiment Module as a part of International Space Station. JEM has a unique platform which is called JEM Exposed Facility.
JEM-EF can provide the following services and environments for Robotics Experiments.

- Camera Views
- Robotics Compatible Berthing Mechanism
- Resources for EF Payload
- Payload View/Communication with other Satellite/Robotics Compatible Experiments

1. INTRODUCTION

Figure 1. shows the configuration of the International Space Station (ISS). Japanese Experiment Module (JEM) is attached to the front side of the ISS.(See Fig. 2.) Scientific experiments will be conducted both in the Pressurized Module (PM) and on the Exposed Facility (EF). JEM-EF has 10 interface ports to accept experiment payloads, four of which are on the front side of the ISS. The use of the interface ports is shared between Japan and the United States. Maximum envelope specified for a JEM-EF standard experiment payload is 0.8 m(W) x 1.0m(H) x 1.85m(L). Maximum allowable mass is 500[kg]. On the other hand, mass of large size experiment payload is allowed up to 2,500[kg], which can be attached to port #2, #9, and #10. Services such as electricity, liquid coolant, and data communications including the Ethernet are to be supplied through the EF interface ports. Details are shown in Section 5.

The ISS has a circular orbit with an inclination angle of 51.6[deg]. Most scientific experiments will be conducted while the ISS is in the inertial flight condition to meet microgravity requirements. It results in a steady decrease in altitude, and re-boosting is needed periodically.

The optimum operational altitude of the ISS and the re-boosting period depends on the solar activity, which affects the Earth atmosphere.

With respect to the attitude of the ISS, a set of Control Moment Gyros (CMG) works to keep the ISS in the Torque Equilibrium Attitude (TEA). No thrusters are operated while the ISS is in the microgravity mode. Maximum range of operational attitude, which is defined by deviations from the Local-Vertical-Local-Horizontal (LVLH) attitude, is specified as –20[deg] to +15[deg] in pitch, and within +/-15[deg] both in yaw and roll. Changes in the operational attitude during the orbital period of 93 minutes can be approximated by sinusoidal oscillations with amplitude less than 2[deg] (peak-to-peak) in each axis [*Treder*, 1999] [1].

Fig. 1. Artistic view of the International Space Station.

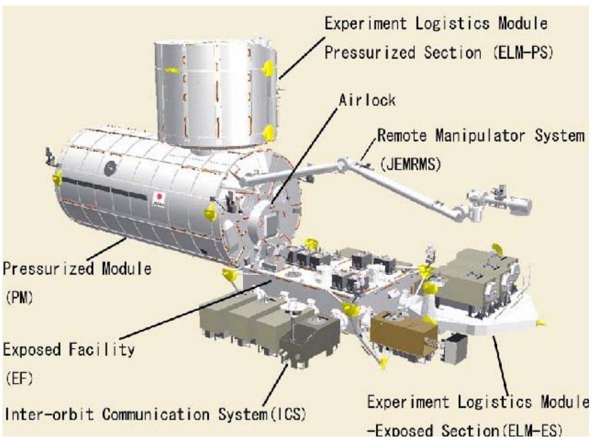

Fig.2. Japanese Experiment Module

Proc. of 'The 8th International Symposium on Artifical Intelligence, Robotics and Automation in Space - iSAIRAS', Munich, Germany.
5-8 September 2005, (ESA SP-603, August 2005)

2. JEM-EF PAYLOADS

The JEM-EF experiment payloads are classified into following two types by the difference of the mass.

- Standard Experiment Payload: up to 500[kg]
- Large Experiment Payload: up to 2,500[kg]

Allowable envelopes for both payloads are the same and they are 0.8m(W) x 1.0m(H) x 1.85m(L).

2.1 JEM-EF STANDARD PAYLOADS

The following JEM-EF standard experiment payloads for space observation mission are developed by JAXA and some universities in Japan. (See Fig. 3.)

- Space Environment Data Acquisition equipment-Attached Payload (SEDA-AP)

- Superconducting Submilimeter-Wave Limb-Emission Sounder (SMILES)

- Monitor of All-sky X-ray Image (MAXI)

Inter-orbit Communication System-EF (ICS-EF) is categorized as a standard payload.

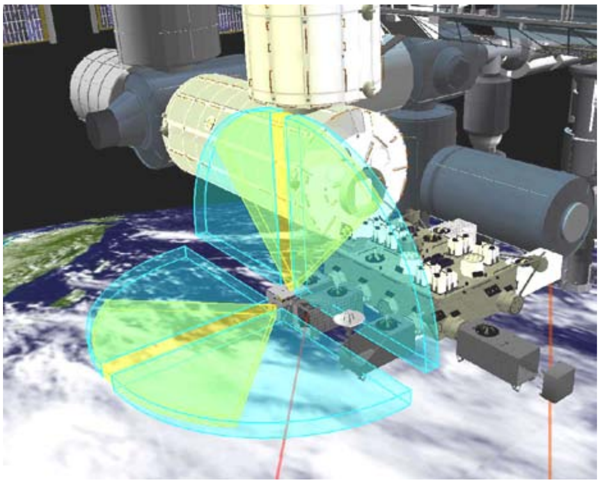

Fig. 3. Payloads attached on JEM-EF

2.1 JEM-EF STANDARD PAYLOADS

1) SEDA –AP (Fig. 4 & 9, will be attached to EFU#9)
SEDA-AP quantitatively measures the space environment (neutrons, high-energy light particles, heavy ions, cosmic dust, atomic oxygen, plasma, etc.) and environmental effects on materials and electronic devices to investigate the interaction with and from the space environment at Kibo's Exposed Facility. The data acquired by this mission will be useful for space equipment design, space-related scientific research, International Space Station operation and space weather forecasting.
SEDA-AP is composed of the Space Environment Data Acquisition equipment (SEDA) and APBUS. SEDA is a generic term for space environment sensors, such as the Neutron Monitor (NEM), Heavy Ion Telescope/Plasma Monitor (HIT/PLAM), Standard Dose Monitor (SDOM), Atomic Oxygen Monitor (AOM), Electronic Device Evaluation Equipment (EDEE), and Micro-Particles Capturer & Space Environment Exposure Device (MPAC &SEED). The NEM sensor extends about 1m from the structural body when it measures neutrons.

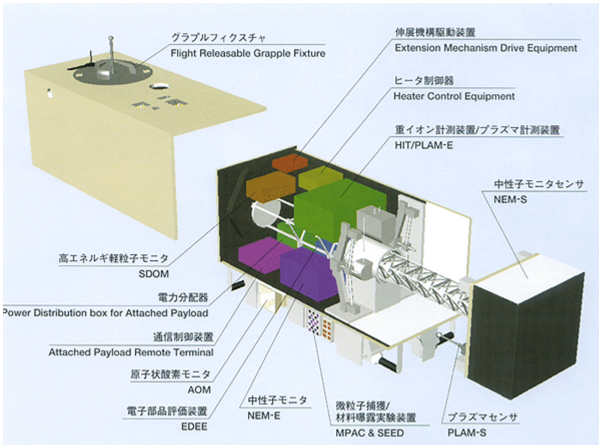

Fig.4. SEDA-AP

2) SMILES (Fig. 5 & 9, will be attached to EFU#3)
SMILES is a mission to demonstrate a new method of observing the Earth's atmosphere by receiving submillimeter signals. It aims at observing a number of molecules, such as ozone, chlorides and bromides in the Earth's stratosphere, which play decisive roles in global ozone-layer destruction. Such molecular information will disclose a complicated network of chemical processes in the stratosphere as well as its regional and seasonal variations. For these purposes, a high-sensitivity submillimeter receiver is being developed based on new space technology that includes a superconductivity submillimeter sensor and a 4-Kelvin mechanical refrigerator. This new technology and observational data will pave the way for more dedicated atmospheric research missions in the future.

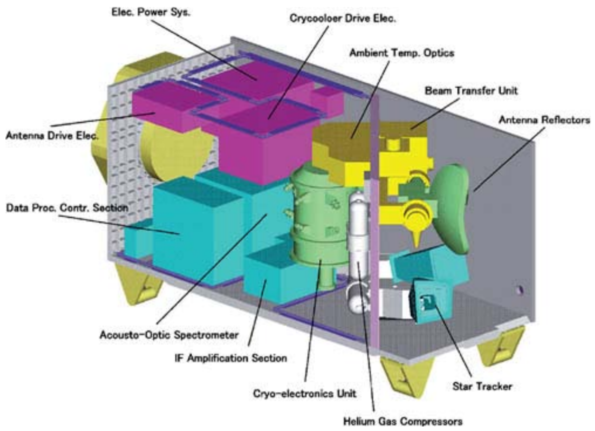

Fig. 5 SMILES

3) MAXI (Fig.6 & 9, will be attached to EFU#1)
MAXI is an X-ray camera with the widest field of view in the world designed to monitor active astronomical objects and the universe. MAXI will investigate the dynamic behaviour of the active sky outside our galaxy and the distribution of the active galaxy, in contrast to conventional x-ray observation satellites that have mainly observed the active sky inside our galaxy. MAXI will monitor X-ray intensity variations from the entire sky at the highest sensitivity achieved by an all-sky X-ray monitor. This observational data is also expected to solve questions on the space structure, its origin and evolution.

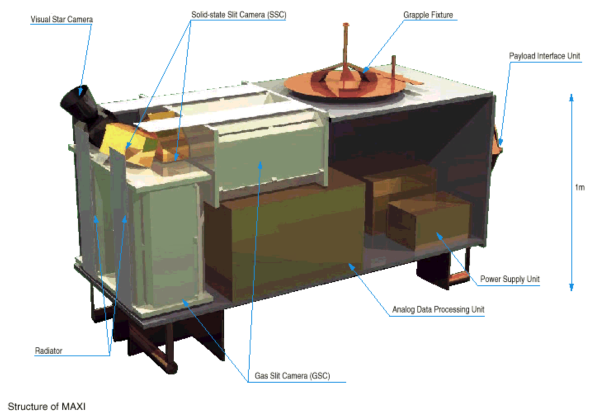

Fig. 6 MAXI

4) LTMPF (Fig. 7 & 9, was developed by NASA)
The LTMPF Facility Class Payload is a complete low temperature laboratory attached to the JEM-EF. There are two identical facilities, each weighing 500 kg or less and each supporting two experiments in parallel operations. An advanced superfluid helium Dewar maintains a base temperature pre-selected from 1.6K to 2.0K for a period of approximately five months.

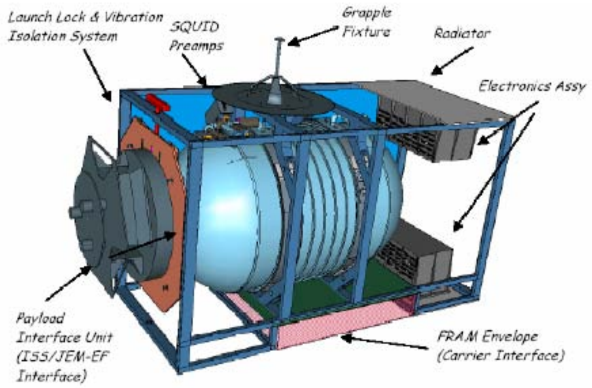

Fig. 7. LTMPF

5) ICS-EF (Fig 8 & 9, will be attached to EFU#7)
ICS provides the secondary JEM space communication link via JAXA Data Relay Test Satellites (DRTSs) to/from the ground. The NASA TDRSs link is the primary link of the ISS.
The data transmission rate and data items for JEM downlink and uplink via ICS are shown in Table-1.

Table-1 ICS Data Transmission Rate and Data Items

Data Direction	Data Rate or Capacity	Data Item
Downlink Data	Total 50Mbps (40Mbps without header/code)	- JEM System/RMS/ICS H&S data - File transfer data - High Rate data - Ethernet data (downlink) - Video data - ICS audio data - Playback data of above data
Uplink Data	Total 3Mbps (2.6Mbps without header/code)	- JEM System/RMS/ICS command - File transfer data - Ethernet data (uplink) - Payload command - ICS audio data - Forward bitstream data
Data Recording	20Gbits	Selected depending on operation

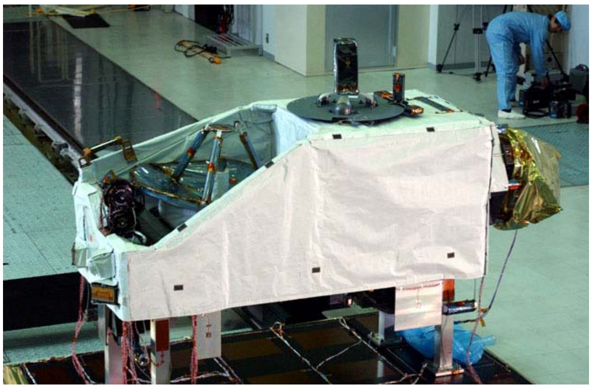

Fig. 8. ICS-EF

2.2 JEM-EF LARGE MASS PAYLOADS

At present, there is no JEM-EF large mass experiment payload though there are large mass JEM system modules attached to JEM-EF as below.

-Experiment Logistics Module-Exposed Section (ELM-ES)
-H-II Transfer Vehicle-Exposed Pallet (HTV-EP)

1) ELM-ES
ELM-ES will be launched in the flight 2J/A and attached to EFU#10 as primary port. Backup port is EFU#9. (See Fig. 9.) ELM-ES will be relocated to another port when HTV-EP will arrive. EFU#9 and EFU#10 have system local bus-2 line for ELM-ES communication and control.
In the flight 2J/A, ELM-ES is planned to carry the following payloads. (See Fig. 10.)

-ICS-EF: Inter-orbit Communication System-EF
-SEDA-AP
-STC: SFA Transfer Container
(SFA: Small Fine Arm)

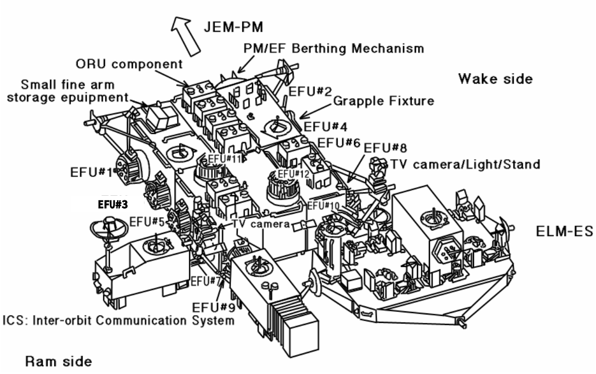

Fig. 9. ELM-ES on JEM-EF

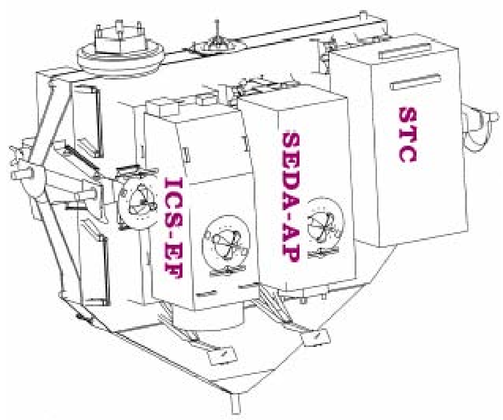

Fig. 10. ELM-ES with Payloads

2) HTV-EP
HTV-EP will be launched by HTV and attached to EFU#10 as primary port. Backup port is EFU#9. EFU#9 and EFU#10 have system local bus-2 line for HTV-EP communication and control as same as ELM-ES. HTP-EP will be able to carry three JEM-EF standard payloads. (See Fig.11 and Fig. 12)

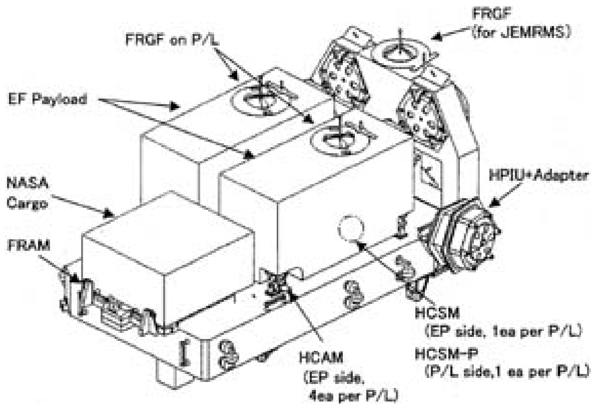

Fig. 11. HTV-EP with Payloads

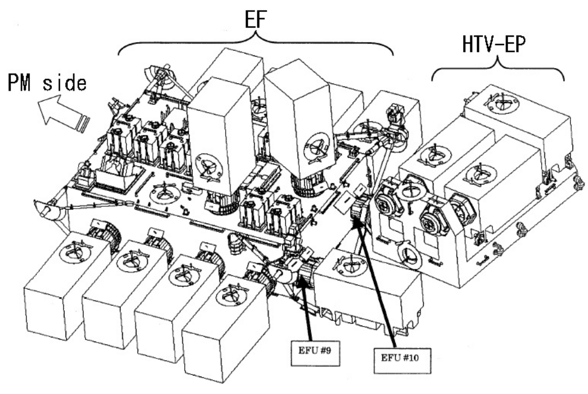

Fig.12. HTV-EP on JEM-EF

3. CAMERA VIEWS

Four TV cameras are located on the four corners of the JEM-EF and we can provide the view from each TV camera. In addition, there are two cameras on JEMRMS. Total six cameras view are available, and IVA crew in the JEM-PM and ground personnel can see views from these cameras. (See Fig. 13.)
When the experiments on JEM-EF is conducted, the appearance of experiments can be observed by using these six cameras view.

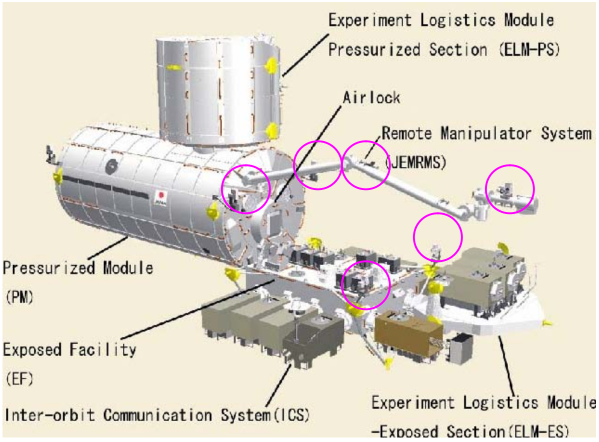

Fig. 13. Camera Location around JEM-EF

4. ROBOTICS COMPATIBLE BERTHING MECHANISM

JEM-EF has following berthing mechanisms to capture the experiment payloads or Orbital Replacement Units (ORUs) on JEM-EF. These experiment payloads or ORUs on JEM-EF have the interfaces and targets for robotics and can be exchanged by robotics arms (JEMRMS, SSRMS or JEMRMS with SFA).
JEM-EF experiment payload has the berthing mechanism to attach the JEM-EF, which is called Payload Interface Unit (PIU). The PIU is passive mechanism and is captured by Exposed Facility Unit (EFU), which is active mechanism. And JEM-EF experiment payload has Flight Releasable Grapple Fixture (FRGF) to be captured by robotics arms.
EF ORUs have the berthing mechanism to attach the JEM-EF, which called ORU attachment mechanism. And EF ORUs have two Tool Fixtures to be captured by Small Fine Arm (SFA). In case of failure of EF ORU, EF ORU can be replaced by SFA on JEMRMS. And also EF ORU has the interface with Extra-vehicular (EV) crew and can be replaced by EV crew.
(See Table-2 and Fig. 14.)

Table-2 Robotics Compatible Berthing Mechanism

Berthing Mechanism on JEM-EF	Equipment to be exchanged	Robotics I/F	Robotics Arm
EFU(Active)/ PIU(Passive)	EF experiment Payloads	FRGF	JEMRMS/ SSRMS
ORU Attachment Mechanism	ORUs	Tool Fixtures	JEMRMS with SFA

JEM-EF has 3 types ORUs as below.
- R-ORU: Robotics & EVA compatible (See Fig. 14)
- E-ORU: EVA compatible
- Vision Equipment(VE) and DC/DC converter Unit (DCU): EVA compatible

Details of these ORUs are shown in Table-3.

Table-3 JEM-EF ORUs

Type	Equipment	Quantity	Location
R-ORU	ESC	2	Upper Surface
	EF-PDB	2	
	SPB	1	
	FPP	2	
	VSW	1	
E-ORU	HCE	2	Lower Surface
	TIU	1	
	EDU	1	
VE and DCU	VE	2	Upper Surface
	DCU	2	

- ESC: EF System Controller
- EF-PDB: EF Power Distribution Box
- SPB: Survival Power Distribution Box
- FPP: Fluid Pump Package
- VSW: Video Switcher
- HCE: Heater Controller
- TIU: Thermal Interface Unit
- EDU: EEU Driver Unit

Fig. 14. R-ORUs on JEM-EF

JEM-EF itself has the berthing mechanism to attach the JEM-PM, which is called Exposed Facility Berthing Mechanism (EFBM) passive. EFBM active half is installed in JEM-PM and operated by Inter-vehicular (IV) crew in JEM-PM. EFBM has eight guides for alignment. JEM-EF is berthed to JEM-PM by SSRMS handling. (See Fig. 15.)

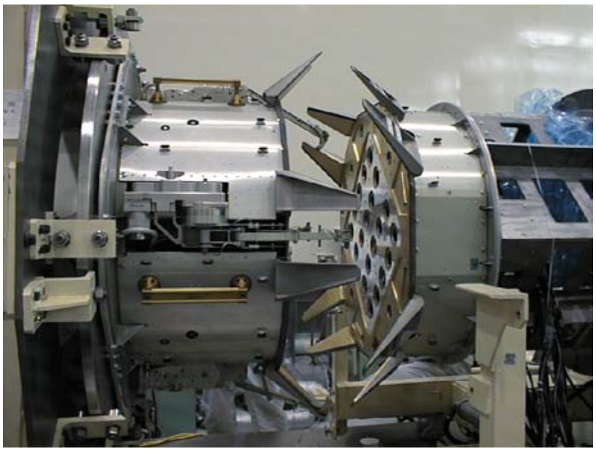

Fig. 15. EFBM Active and Passive

5. RESOURCES FOR EF PAYLOAD

JEM-EF has 10 ports (EFUs) to attach EF experiment payloads which can receive the resources such as electric power, fluid, communication and video through berthing mechanism (EFU and PIU) from JEM-EF. Details are described in following sections.

5.1 Electrical Power System (EPS)

JEM-EF provides the electrical power of 3kW for main power to the each experiment payload. To the EFU#1 and EFU#2, JEM-EF can provides the electrical power of 6kW for the large electrical power payloads.
And JEM-EF can provides the electrical power of 100W for the survival power.

5.2 Active Thermal Control System (ATCS)

JEM-EF also provides the active thermal control system (ATCS) for the experiment payloads via EFU/PIU and will be able to absorb the heat of the experiment payloads. Heat of 3kW – 6kW can be absorbed for each payload by JEM-EF ATCS.

FC-72 Fluorinert™ (produced by 3M) is used for coolant in the JEM-EF ATCS and its chemical formulae is C_6F_{14}.
The following shows physical and chemical properties of FC-72 Fluorinert [2].
-Specific Physical Form: Liquid
-Odor, Color, Grade: Colorless, odorless liquid.
-General Physical Form: Liquid
-Boiling point: 50 - 60 ºC
-Density: 1.7 g/ml
-Vapor Density: Approximately 11.7 [@ 20 ºC]
[*Ref Std:* AIR=1]
-Vapor Pressure: Approximately 232 mmHg [@ 20 ºC]
-Specific Gravity: Approximately 1.7
[*Ref Std:* WATER=1]
-Evaporation rate: > 1 [*Ref Std:* BUOAC=1]

5.3 Communication and Data Handling (C&DH)

JEM-EF has communication line to connect JEM-EF experiment payload with Payload Data Handling (PDH) installed in JEM-PM.

- Payload Bus(1553B): 2ch for each payload
- Local Bus Payload(1553B): 2 ch for each payload
- Video: 8ch
- Ethernet: 7ch
- High Rate Data: 8ch
- House Keeping Data: 2ch for each payload

6. FUTURE EXPERIMENTS ON JEM-EF WITH USING WIDE VIEW AND ROBOTICS

1) Experiments with Using Wide View
As described in section 2, some space (including the earth) observing mission payloads are already developed, but the JEM-EF experiment payloads such as space telescope, communication with other co-orbiting satellite and robotics compatible experiment, have not been developed yet.

For four JEM-EF experiment payloads located on forward side, we can provide the wide clear view and large space for works and experiments. So, it will be able to perform the communication experiment with other co-orbiting satellite or use JEM-EF for the Large Size Space Telescope such as Extreme Universe Space Observatory (EUSO). (See Fig. 16.)

EUSO: The concept of Orbiting Wide-angle Light collector, studied in the present research, obtained strong interests of European Space Agency and phase-A study has started from March 2000 in the name of EUSO to attach Columbus External Payload Facility on ISS. Although EUSO mission was proposed as a free flyer at first, it was suggested to attach ISS by ESA. This fact clearly shows the good foresight of the concept of the present study. The Japanese EUSO team directed by Dr. Toshikazu Ebisuzaki at RIKEN have joined the accommodation study of EUSO to Columbus External Payload Facility from March through December 2000. The result are presented in "Extreme Universe Space Observatory : Report on the accommodation of EUSO on the Columbus Exposed payload Facility".[3]

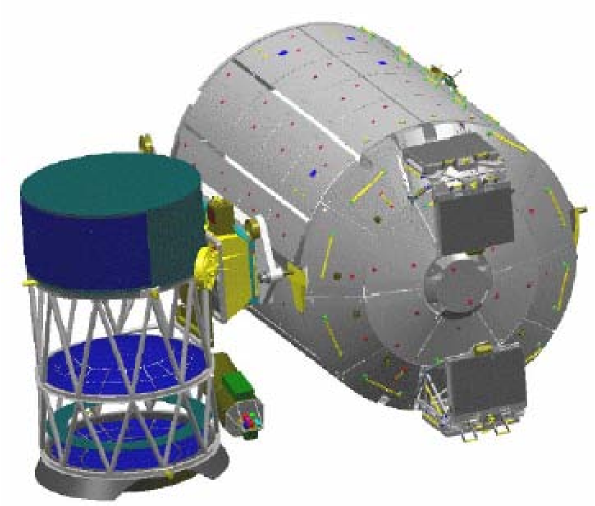

Fig. 16. EUSO attached to Columbus[3]

2) Experiments with Using Robotics
JEM-EF can provide the environment for Robotics Experiments, because both JEMRMS and SSRMS can access to around JEM-EF (See Fig. 17.) and JEM-EF has some mechanisms to have robotics interface described in section 4.
Followings are some example of proposal experiment with using Robotics.

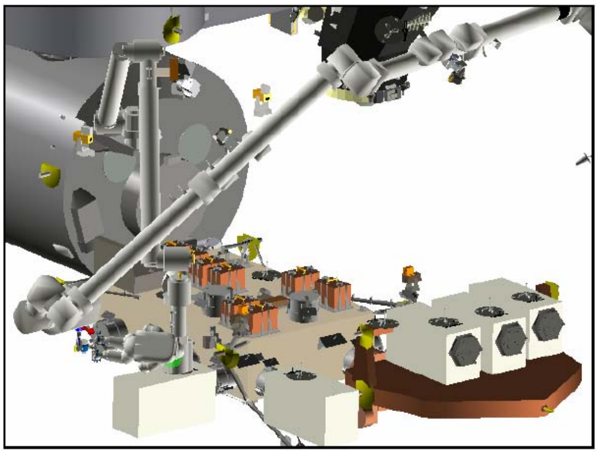

Fig. 17. JEMRMS and SSRMS access to JEM-EF

a) Small Experiment Equipment (SEE)
SEE such as a simple space environment monitor is installed in R-ORU type Box and will be launched. It will be grappled and moved to appropriate location by SFA on the JEMRMS, and experiment will be performed. (See Fig. 18.) After finishing of experiment, SEE will be located on temporary stowed position on JEM-EF and carried into JEM-PM through JEM Airlock. Monitoring data will return to ground by return cargo.

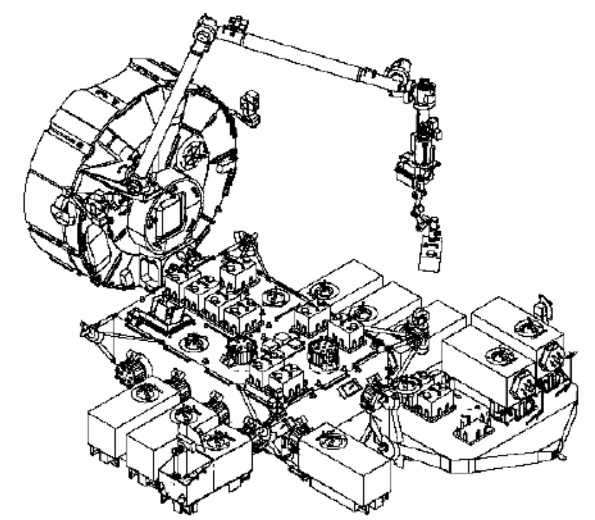

Fig. 18. Image of SEE Mission

b) Workbench for the assembly of the vehicles/ modules to the Moon/Planet and experiments for the Moon/Planet

In the near future, ISS could be a parking station or factory for the vehicles/modules to the Moon/Planet and also experiments for travelling to the Moon/Planets will be performed at ISS. At that time, JEM-EF could be used as a workbench for the assembly of the vehicles/modules to the Moon/Planet and these vehicles and modules could be assembled on the JEM-EF by JEMRMS and SSRMS. (See Fig. 19)

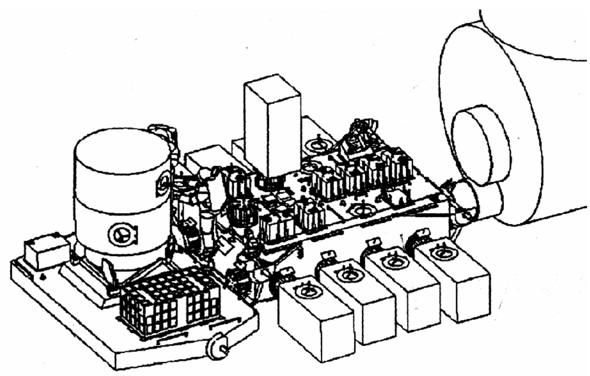

Fig. 19. Image of Workbench on JEM-EF

REFERNCES

1. Masato Shiotani and Harunobu Masuko, *JEM/SMILES Mission Plan,* Version 2.1, November 15, 2002.

2. *3M MATERIAL SAFETY DATA SHEET FC-72 FLUORINERT Brand Electronic Liquid*, 09/05/2002.

3. G. Gianfiglio, *EUSO MISSION OVERVIEW*, HTV-EUSO Working Group, TIM #1 27-28 May 2004