European External Payloads Selected for Early Utilisation on the International Space Station

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The external sites of the International Space Station (ISS) have huge utilisation potential for many different space disciplines. As a platform in a high-inclination, low Earth orbit and with a lifetime of 15 years or more, the ISS will provide payload mass, volume, power and communications capabilities far exceeding those of free-flying satellites. Every three months, the Space Shuttle and other servicing vehicles (ESA's Automated Transfer Vehicle, Progress, etc.) will take astronauts, new equipment and stocks of consumables up to the ISS.

The external payloads selected for the ISS assembly phase represent first-class science, as is demonstrated for example by the fact that two Nobel Prize winners are involved in two of the experiment teams (for ACES and AMS). Another payload (GTS) offers commercial services in the fields of protection against car theft, and wristwatch accuracy control.

Introduction

With the launch and subsequent coupling of the first two elements, 'Zarya' and 'Unity', at the end of 1998, the build-up of the International Space Station has begun in earnest. In all, more than 100 elements and 460 tonnes of structures, modules, equipment and supplies will be placed in orbit by the year 2004. Utilisation of ISS for different fields of research will already start in 1999, increasing year by year during the Station's assembly phase and keeping pace with the launch and assembly of the various modules and external structures designed for supporting and operating payloads.

The first externally mounted European payload will be launched this year as part of the Russian Service Module. Further European payloads have already been selected and are under development. The following paragraphs briefly describe the opportunities offered by the Station for mounting and operating payloads exposed to the external space environment, as well as those European payloads that have already been selected.

Opportunities being offered (Fig. 1)

The International Space Station is the largest international cooperative civil space programme ever undertaken. It is based on an Inter-Governmental Agreement (IGA) concluded in January 1998 between the Governments of five 'International Partners': the United States of America, Russia, Japan, Canada and Europe (11 States).

The European contributions to ISS include the 'Columbus' laboratory, the Automated Transfer Vehicle (ATV) to supply the Station and periodically raise its orbit, and several ground infrastructure elements. Through its contribution, Europe has acquired certain rights for Station utilisation, as well as participation in its management and operation. Based upon this formal right of access, it is possible to build up a strong, long-lasting ISS utilisation programme for the European user communities.

The International Space Station will provide broad opportunities for researchers in the life and physical sciences, remote sensing, technology and commercial applications sectors to exploit the unique attributes of space. These include prolonged exposure to microgravity, near-vacuum, and the space-radiation environment, but also those opportunities provided by exploiting the Station as an observation platform for celestial- or Earth-viewing payloads.

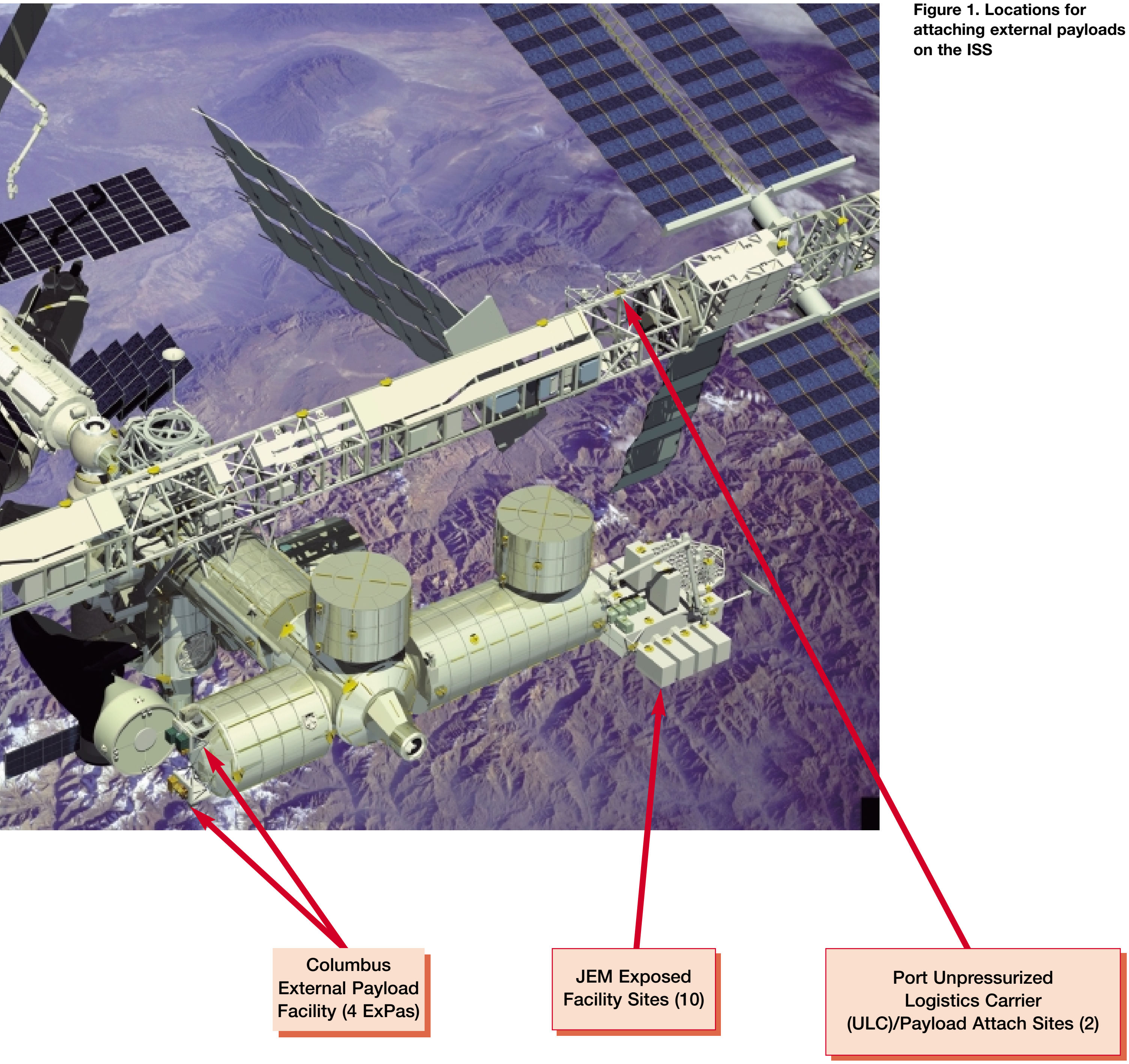


Figure 1. Locations for attaching external payloads on the ISS

The ISS offers a choice of several external sites for mounting payloads to be exposed to the surrounding space environment:

– 4 locations on the S3 segment of the US-provided 107 m-long Station Truss
– 10 locations on the Japanese-provided JEM
– 4 locations for Express Pallet Adapters on the Columbus laboratory's External Payload Facility
– mounting locations on the Russian segment.

A number of experiments can already be performed during the Assembly Phase when the Space Shuttle and Russian launchers visit the Station, and between flights when the on-board crew is available as experiment operators or as research subjects.

Sets of research hardware will be transported to the Station primarily on dedicated Shuttle Utilisation Flights (Fig. 2). These flights will start with UF1 in 2000 and end, according to the present build-up schedule, with UF7 in 2003, by which time the laboratories and external-payload sites will have been outfitted with the first generation of research equipment. From then onwards, five Shuttle flights and additional logistics flights by the Partners' mixed fleet of vehicles are planned each year for taking the astronauts to and from the Station and re-supplying ISS logistics and payload items.

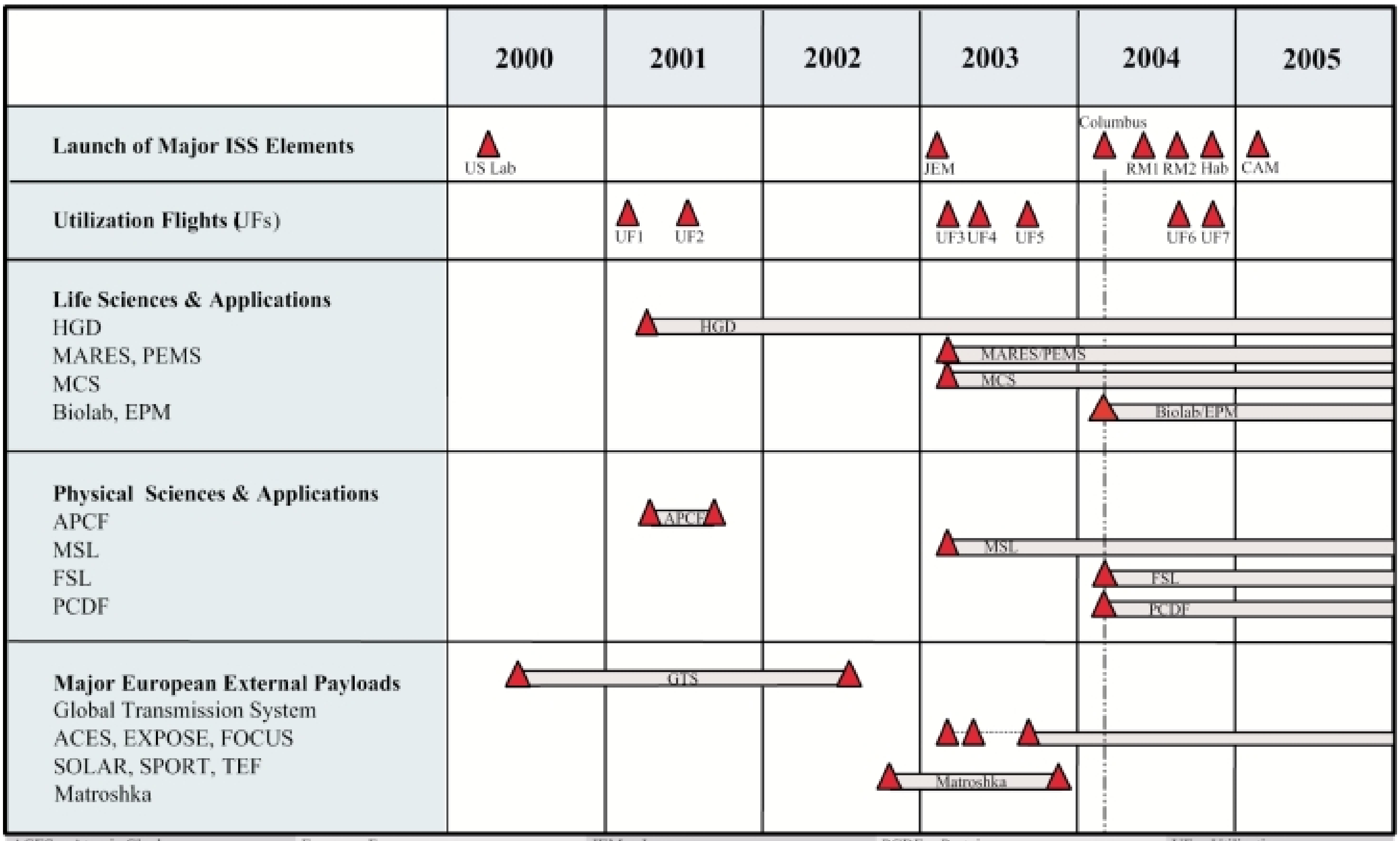
The ESA AO

In December 1996, ESA issued an Announcement of Opportunity (AO) for Externally Mounted Payloads during the Early Space Station Utilisation Period (ESA SP-1201). This AO was based on an ESA/NASA Agreement that affords European payloads access to the US-provided external Truss attach sites during the period 2002-2005. The AO was mailed using user-programme distribution lists and was also posted on the ESA Web Site. 102 proposals had been received by the April 1997 closing date, with the following distribution by discipline:

– Space Technology 48
– Space Science 23
– Life Sciences 14
– Physical Sciences 11
– Earth Observation 6

Some 350 investigators from 23 countries were involved in these proposals.

Figure 2. The milestones for major utilisation-related launches



ACES = Atomic Clock Ensemble in Space	Expose = Exposure Unit for Exobiology Samples	JEM = Japanese Experiment Module	PCDF = Protein Crystallisation Diagnostics Facility	UF = Utilization Flight
APCF = Advanced Protein Crystallisation Facility	Focus = Fire Detection Infrared Sensor Payload	MARES = Muscle Atrophy Research & Exercise System	PEMS = Percutaneous Electrical Muscle Stimulator	
CAM = Centrifuge Accommodation Module	HAB = US Habitation Module	MCS = Modular Cultivation System	RM = Russian Research Module	
EPM = European Physiology Modules	HGD = Hand Grip Dynamometer	MSL = Material Science Laboratory	TEF = Technology Exposure Facility	

The evaluation of the science and technology proposals was organised by each ESA user programme, using external peer review groups, and applying the evaluation criteria defined in the AO. The results of the peer review were presented to the existing ESA User Advisory Bodies for each discipline, and ultimately to the relevant User Programme Boards. In parallel, a technical team, including industrial contractors, began to assess the technical aspects of the proposals.

Based on the list of peer-recommended and technically feasible experiments, the Executive presented the European Utilisation Board (EUB) with a list of 10 discipline-oriented groupings, each of which comprised a complement of instruments per Express Pallet Adapter. From these 10 groupings, a final selection of 5 had to be made. This was achieved through several iterations, taking the following aspects into consideration:

– funding support by Member States for the experiments proposed
– compatibility with accommodation and/or operational constraints imposed by the Space Station
– expected readiness of payloads to meet the delivery dates for flight
– interdisciplinary aspects, the ESA Space Station User Panel (SSUP) having recommended a fair balance between the different disciplines.

The final payload complement was selected by the Manned Space Programme Board in December 1997 and consists of the following five Express Pallet payloads: ACES, EUTEF, EXPORT, FOCUS and SOLAR.

The Express Pallet System

The Express Pallet System (Figs. 3a,b) allows payloads to be mounted at external sites on the ISS Truss structure. This US-provided Pallet System will be launched and retrieved by the Space Shuttle.

The Pallets, which will be attached at specific locations on the Truss, can be zenith- or nadir-facing, allowing them to carry instruments requiring solar or celestial viewing (zenith) or Earth viewing (nadir). The Express Pallet will house six Adapters, each capable of carrying up to 225 kg of payload on a 1 m^2 mounting surface. ESA's instruments will be grouped to fully occupy Adapters: the SOLAR, EXPOSE/

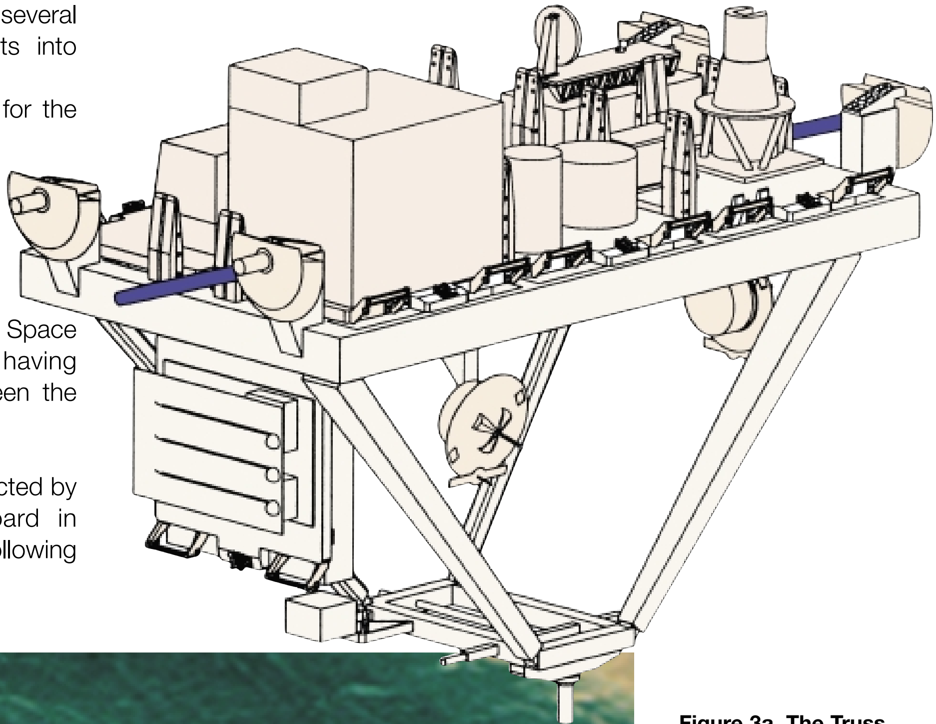


Figure 3a. The Truss Express Pallet can carry six ExPAs

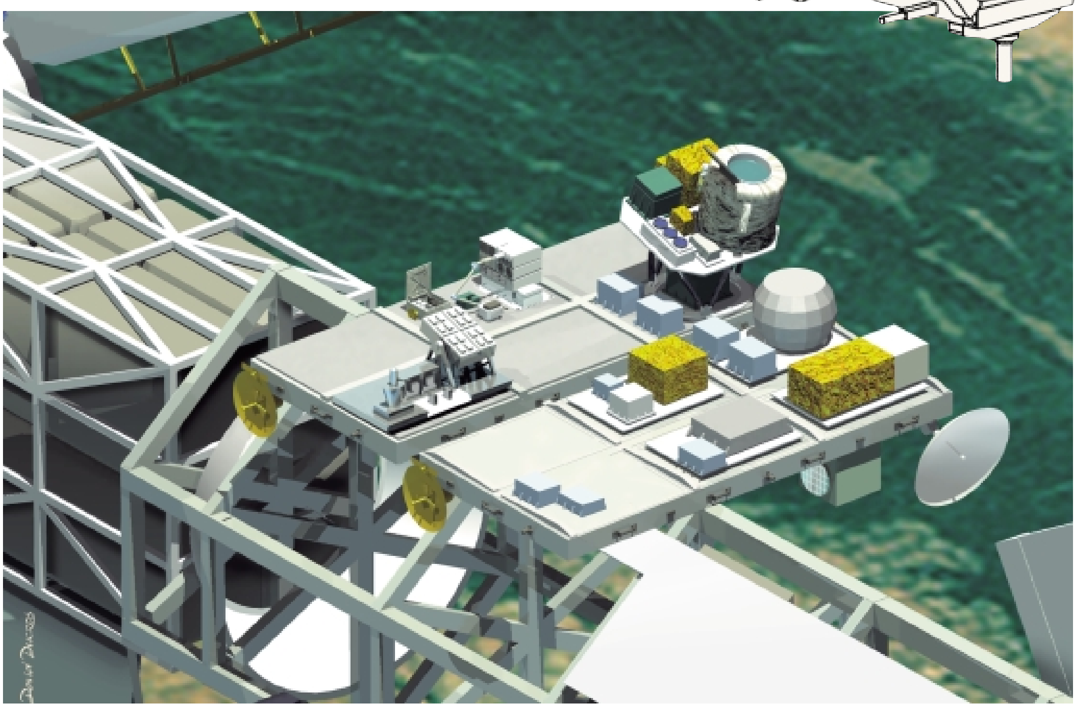


Figure 3b. The Express Pallet, carrying six ExPAs, mounted on the ISS Truss (ESA/D. Ducros)

SPORT (EXPORT) and EUTEF packages are zenith-oriented, while ACES and FOCUS are nadir-oriented. It is planned that two of the three Adapters will be exchanged during the three-year mission.

The first five European payloads

1. ACES – An Atomic Clock Ensemble in Space (Fig. 4)

The core of this project is a laser-cooled caesium atomic clock ('Pharao'), which exploits the microgravity conditions onboard the Space Station. The investigator team includes researchers belonging to the group that received the Nobel Prize for Physics in 1997.

Pharao will improve clock frequency stability and accuracy by a factor of 100 compared with the best measurements currently achievable on Earth, opening up new opportunities in various fields of fundamental research and applications. This ultra-precise measurement of time will allow relativistic measurements and tests, applications in atmospheric physics and geodesy, navigation and advanced telecommunications.

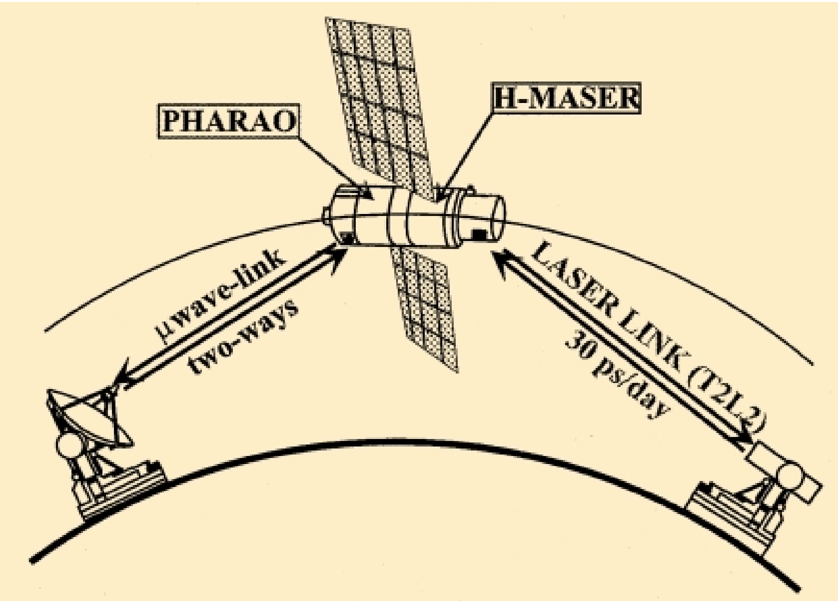


Figure 4. The ACES concept; Pharao is the laser-controlled atomic clock and the hydrogen maser serves as the reference clock

The ACES Principal Investigators (PIs) are Prof. C. Salomon from the Ecole Normale Supérieure, Paris and Prof. A. Clairon of the Laboratoire du Temps et des Fréquences, Paris. A Swiss hydrogen-maser clock provided by Dr. L.G. Bernier, also a PI, from the Observatoire Cantonal de Neuchatel, Switzerland, will serve as a reference clock. The important time transfer by laser link will be realised from the Observatoire de la Côte d'Azur in Grasse, France, with PIs Dr. E. Samain and Dr. P. Fridelance.

2. EUTEF – The European Technology Exposure Facility (Fig. 5)

EUTEF is a multi-user support facility that will be developed under the auspices of ESA's Manned Spaceflight and Microgravity Directorate, located at ESTEC in Noordwijk. It will provide modular accommodation for a variety of technology payloads requiring space exposure. It incorporates a material-properties laboratory allowing periodic onboard measurements of surface degradation, and a comprehensive environment-monitoring package to characterise the ISS space environment, including high-energy cosmic radiation, the natural and ISS-induced plasma environment, atomic-oxygen concentration, etc. An ASI-provided robot arm, to be incorporated with a tele-operated intelligent gripper for payloads, will allow the servicing of payloads, the exchange of exposed material within EUTEF modules, or the pointing of samples to a specific environment.

Several proposed EUTEF experiments — from France, Germany, the United Kingdom, the Netherlands, Italy and Spain — have already been selected. Industrial initiatives to qualify advanced and innovative sensors, components or subsystems have been selected with the highest priority. One example in this respect is the testing of a high-temperature super-conductor for advanced satellite communications.

3. EXPORT – consisting of EXPOSE and SPORT (Fig. 6a,b)

Eight exobiology experiments have been selected for accommodation on an exposure

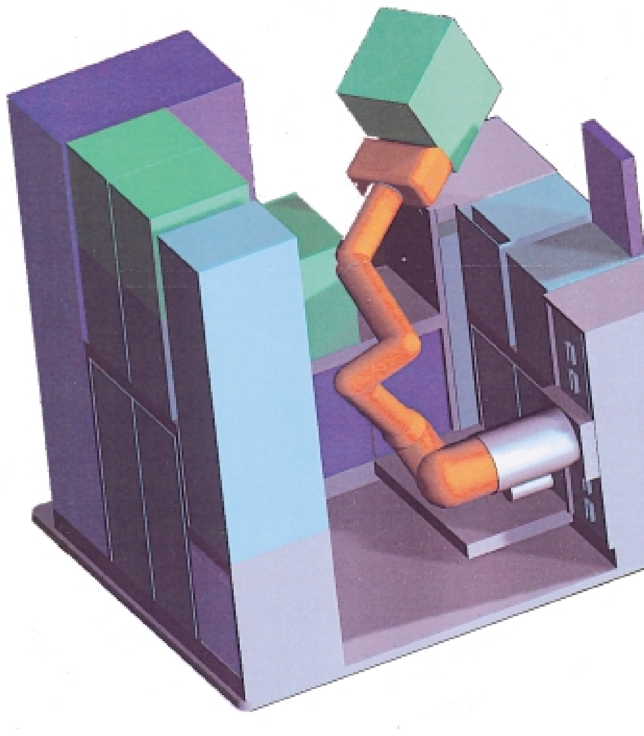


Figure 5. The Technology Exposure Facility (TEF) supports space technology research and development

Table 1. Instruments and experiments selected for EUTEF

Acronym/ Name	Ref. No.	Ctry	Principal Investigator	Description
PLEGPAY	16	I	A. Matucci	Plasma contactor electron gun
FIPEX	47	D	S. Fasoulas	Gas sensor for atomic-oxygen flux
	51	ESA	M. v. Eesbeck	Effect of space exposure of materials on thermo-optical and mechanical properties
	54	F	J.C. Mandeville	Monitoring and detection of micrometeoroids and space debris
	55	F	A. Paillous	Calorimetric/dynamic measurement of thermo-optical property degradation
	56	ESA	M. v. Eesbeck	Effects of contamination/radiation on optical surfaces
	57	UK	A.R. Chambers	Atomic-oxygen experiment
	58	D	B. Schaefer	Manipulator system identification and dynamic model validation
	59	I	P.G. Magnani	Intelligent axis for A & R
	60	I	E. Re	Tactile sensor-based robot control
DEBIE	62	ESA	G. Drolshagen	Active meteoroid/debris impact detector
	64	NL	C. Heemskerk	Robot inspection and measurement of LEO environment on solar cells
	66	NL	W. Jongkind	Teleoperated intelligent gripper for handling tasks
	68	UK	R.A. Rowntree	Tribology laboratory for bearing cage stability/wear and loss of fluid lubricants testing
CREEP	81		E. Daly & A. Zehnder	Columbus Radiation Environment and Effects Package
HTSC	18	D	M. Klanda	High-Temperature-Superconductor Demonstrator
HEPTES	88	D	S. Krause	Heat-Pipe/Thermal-Energy-Storage Receiver Element

unit oriented towards the Sun (Table 2). A range of organic molecules and micro-organisms will be exposed unshielded to solar ultraviolet radiation and the space environment (vacuum, cosmic radiation). This study of photochemical processes will support conclusions as to the origin and evolution of life, and on the survival capability of micro-organisms in space.

SPORT, with Principal Investigator Prof. S. Cortiglioni from the Istituto di Technologie e Studie Della Radiazioni Extraterrestri, CNR, Bologna, Italy, and further Co-Investigators from Italy and Russia, will measure the polarisation of the sky diffuse background radiation in the unexplored wavelength range between 20 and 70 GHz. In this spectral range, the galactic synchrotron radiation is the strongest source of polarised emission; however, the detection of small contributions from the linear polarisation of the cosmic

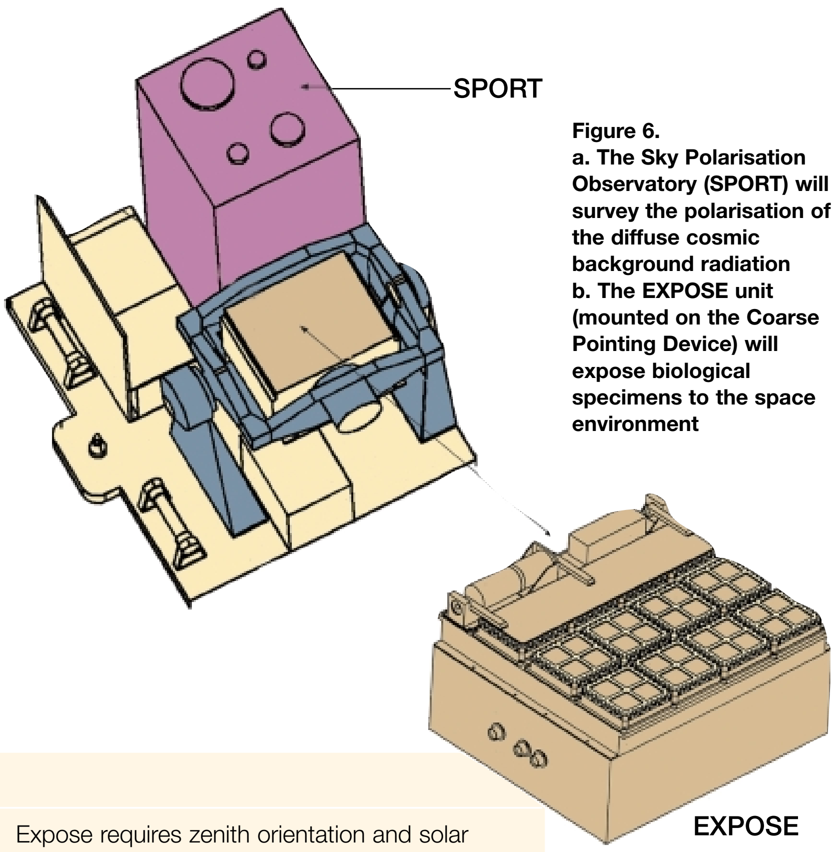


Figure 6.
a. The Sky Polarisation Observatory (SPORT) will survey the polarisation of the diffuse cosmic background radiation
b. The EXPOSE unit (mounted on the Coarse Pointing Device) will expose biological specimens to the space environment

Table 2. EXPOSE characteristics

Pointing requirements	Expose requires zenith orientation and solar pointing
Pointing	Coarse Pointing Device
Sample exposure variable control	Motorised lids/shutters
EXPOSE features:	
Sample containers	12
Selectable open/close lids	8
Permanently open	4
Atmosphere	Vacuum or inert gas
Temperature control	Heating (only)
Sensors	UV, radiation, temperature and pressure
Active signals	Real-time telemetry

microwave background radiation would be of great interest for modern cosmology.

4. FOCUS – Intelligent Fire Detection Infrared Sensor System (Fig. 7)
FOCUS will detect, from the ISS orbit, and analyse high-temperature events such as vegetation fires and volcanic eruptions. Large forest and savannah fires, as well as volcanic activities, have global atmospheric consequences (e.g. greenhouse effect, cloud generation, climate change) and the measurements onboard the Station will contribute to the classification, atmospheric composition determination and geocoding of the data, which will be transmitted to a worldwide scientific, application-oriented and pre-operational user community.

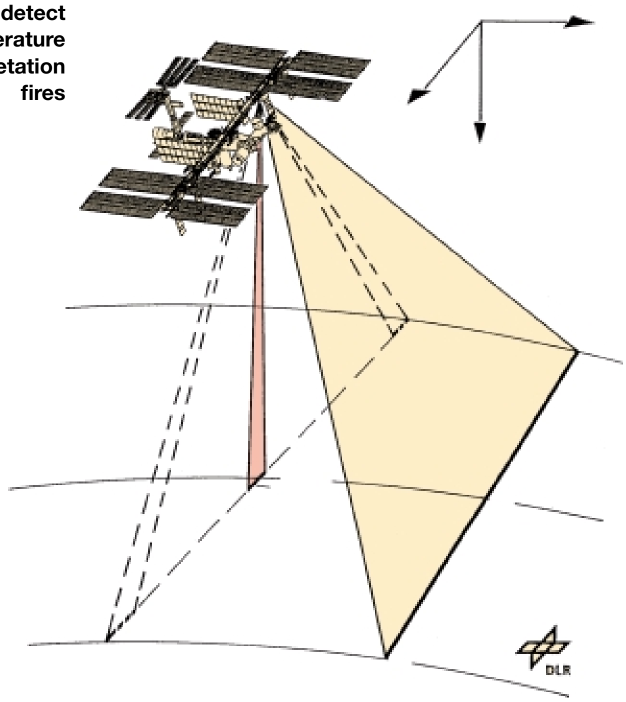


Figure 7. FOCUS will detect terrestrial high-temperature events such as vegetation fires

The Principal Investigator for FOCUS is Prof. H.P. Röser from the DLR Institute für Weltraumsensorik, in Berlin (D). Further important contributions are being made by various institutes in Spain, Italy, Germany, France, Greece and Russia.

5. SOLAR – A Solar Monitoring Observatory (Fig. 8)
The main objective of this experiment is to measure the solar spectral irradiance with unprecedented accuracy. Apart from the scientific contributions for solar and stellar physics, knowledge of the 'solar constant' and its variations is of great importance for atmospheric modelling, atmospheric chemistry and climatology.

The SOLAR observatory consists of three instruments, which complement each other and together cover the wavelength range 17 - 3000 nm in which 99% of solar energy is radiated. They are:

- *SOVIM (Solar Variable & Irradiance Monitor):* The Principal Investigator is Prof. C. Fröhlich from the World Radiation Centre in Davos (CH), who has teamed up with several co-investigators from Belgium, France, ESTEC, Switzerland and the USA. A similar instrument (SOVA) has already been flown on ESA's Eureca retrievable carrier.
- *SOLSPEC (Solar Spectral Irradiance Measurements):* The Principal Investigator is Dr. G. Thuilllier from the Service d'Aeronomie/CNRS, Verrières le Buisson (F). The co-investigators come from Belgium, France, Germany, Switzerland, the United Kingdom, the USA and Switzerland. SOLSPEC has already been flown on various Spacelab missions and on Eureca.
- *SOL-ACES (Solar Auto-Calibrating EUV/UV Spectrophotometers):* The Principal Investigator is Dr. G. Schmidtke from the Fraunhofer Institut für Physikalische Messtechnik in Freiburg (D), with co-investigators from Germany and the USA. SOL-ACES is a new instrument that is still to be developed and covers the solar spectral irradiance range from 17 to 220 nm.

The three instruments are mounted on a Coarse Pointing Device, which provides Sun-pointing for about 13 minutes per orbit.

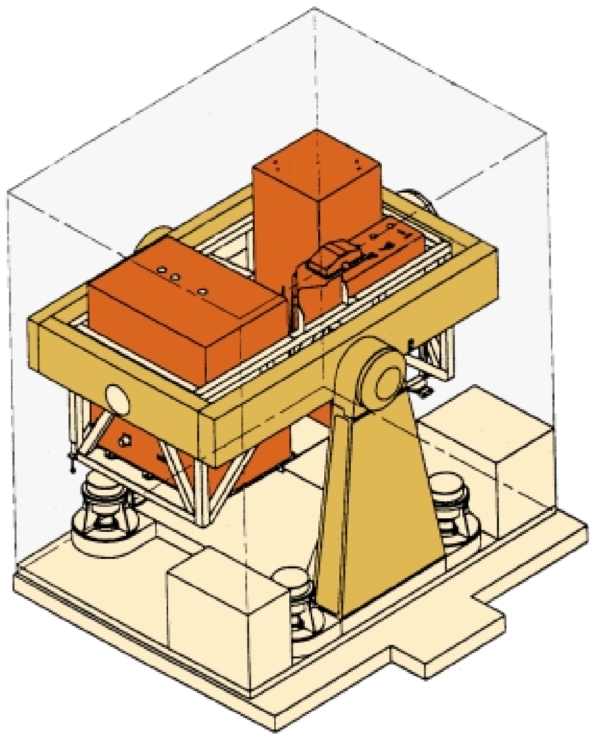


Figure 8. The Solar Monitoring Observatory (SOLAR) will measure the Sun's total and spectral radiance

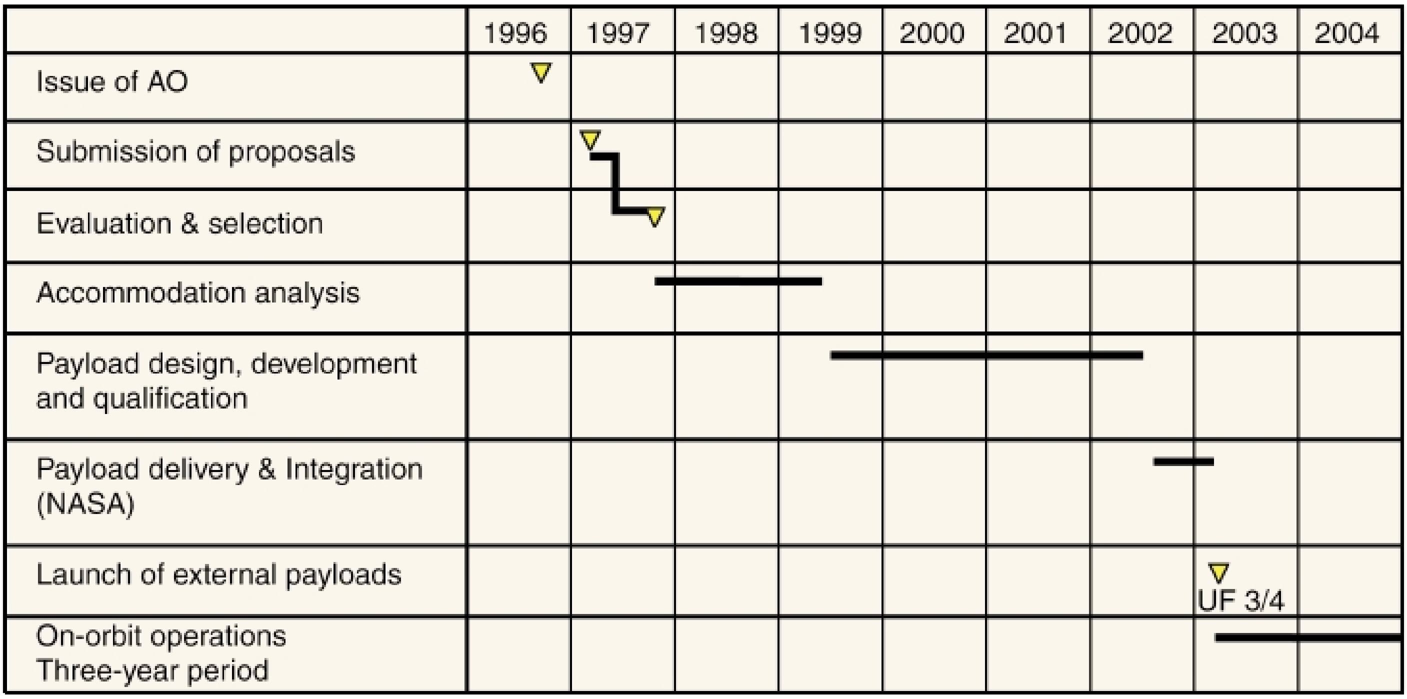


Figure 9. The overall schedule for ESA's Express Pallet Project

Overall schedule for ESA's Express Pallet project

As can be seen in Figure 9, approximately one year elapsed between the issuing of the Announcement of Opportunity and the selection of a feasible payload complement. Last year (1998) was used mainly for accommodation analyses for the five different adapters. The main development effort (Phase-C/D) is due to start in May 1999, in order to meet the projected Shuttle launch dates for UF3/4 at the end of 2002.

ESA's use of the Russian Segment

The Russian Segment of ISS is an attractive place to fly external payloads, and two European payloads are already selected, the 'Global Transmission Services System' (Fig. 10) and 'Matroshka' (Fig. 11a, b).

The Global Transmission Services (GTS) System

As a continuation of the recent successful cooperation between ESA and Russia on the Mir station, both sides have agreed to

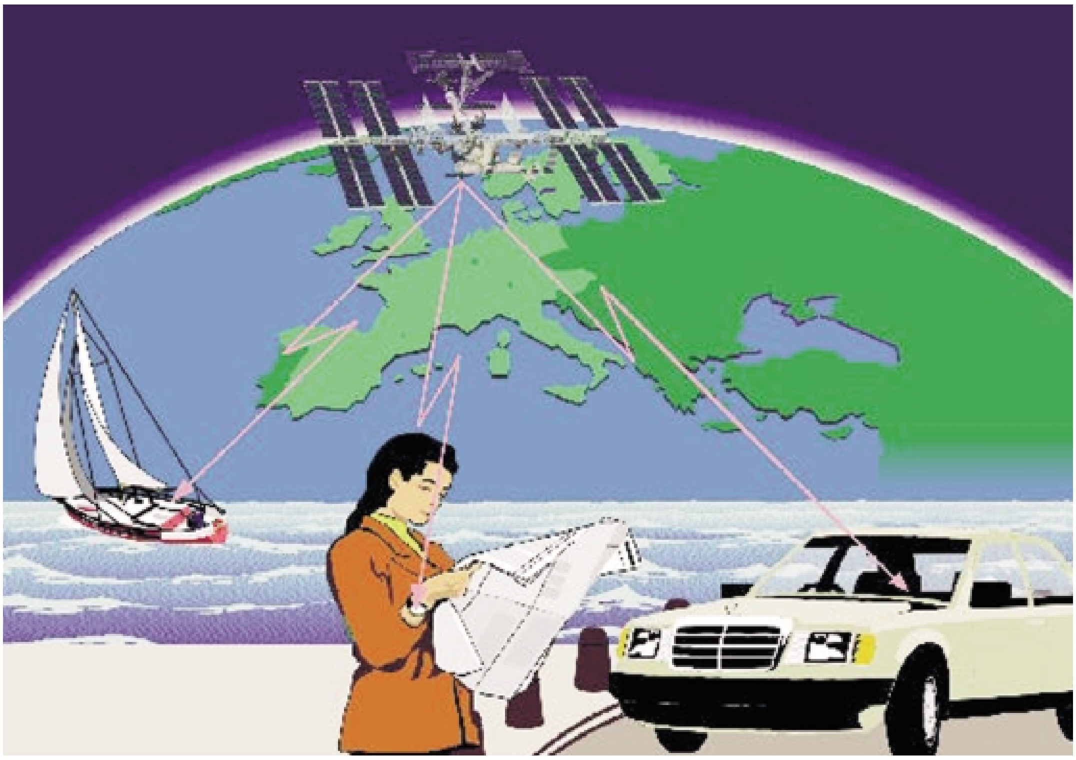


Figure 10. The Global Transmission Services (GTS) system, which will broadcast data and high-accuracy time signals

implement GTS as a Euromir-E replacement activity. GTS is a relatively small payload that will transmit highly accurate time and coded data signals for dedicated receivers on the ground.

The GTS experiment uses a transmitter accommodated onboard the ISS for signal distribution via an externally mounted antenna (with a transmission cone half-angle of approx. 70 deg) on the Russian Service Module. The signals transmitted – at two dedicated frequencies in the 400 MHz and 1.4GHz ranges – can be received for 5 -12 min several times per day by ground receivers with sufficient sensitivity.

The same services – specifically the highly accurate time signal – will be available through dedicated connections to users accommodated on-board the Russian Segment. Applications foreseen include:
- accurate time receipt and automated local time conversion for mobile users on the ground (e.g. wrist watches)
- car theft-protection (electronic car keys)
- coding and re-coding of electronic cards (chip cards, smart cards, credit cards).

Figure 11a. Matroshka will be mounted on the outside of the Russian Service Module

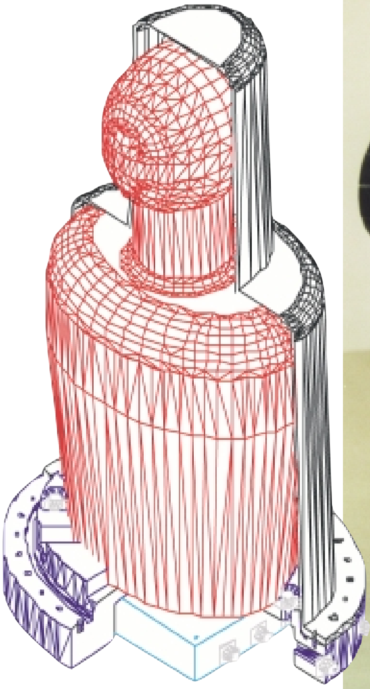


Figure 11b. Mathematical model of the Matroshka human torso/head dummy

The GTS experiment, which will begin operating approximately six months after launch of the Russian Service Module, will last at least two years.

The Matroshka payload

The Matroshka experiment (Fig. 11) aims to measure the radiation that an astronaut faces during Extra Vehicular Activity (EVA). Knowledge of the radiation doses to which sensitive body organs are exposed during long EVAs is an important prerequisite for radiation risk assessment.

The Matroshka payload consists of a human torso/head dummy, composed of various tissue substitutes simulating the human body in terms of size, shape, orientation, mass density and nuclear interactions. At the sites of the body organs of interest, spaces are provided at the surface and at different depths within the phantom to accommodate dosimeter packages to measure any ionising radiation received.

The key milestones for the Matroshka project are currently:
- launch with Progress 268 in mid-2002
- external operation on the Russian Service Module from mid-2002 (installation during EVA No. 37) to mid-2003 (retrieval during EVA No. 47)
- sample return with the eighth Soyuz flight to the ISS.

The data gathered will be used to reduce uncertainties in risk estimates for radiation-induced cancer, and for the refinement of the shielding needs for transport facilities for future long-duration missions. They also have important implications for ISS crew health and for mission planning, and thereby contribute to the ISS environmental monitoring effort.

The AMS Experiment

A further important external payload, selected by NASA, but with an important European scientific contribution, is the Alpha Magnetic Spectrometer (AMS) experiment (Fig. 12). This payload is designed for the study of antimatter and missing matter. To be located on an ISS Express Pallet in a zenith-pointing position, the AMS is an international collaboration between China, Finland, Germany, Italy, Russia, Switzerland, Taiwan and the United States. The team is led by Nobel Prize winner Prof. S.C. Ting.

The key scientific objective is to search for antimatter, basically anti-helium and anti-carbon, with a detector sensitivity 10^4 to 10^5 times better than current limits. The Big Bang

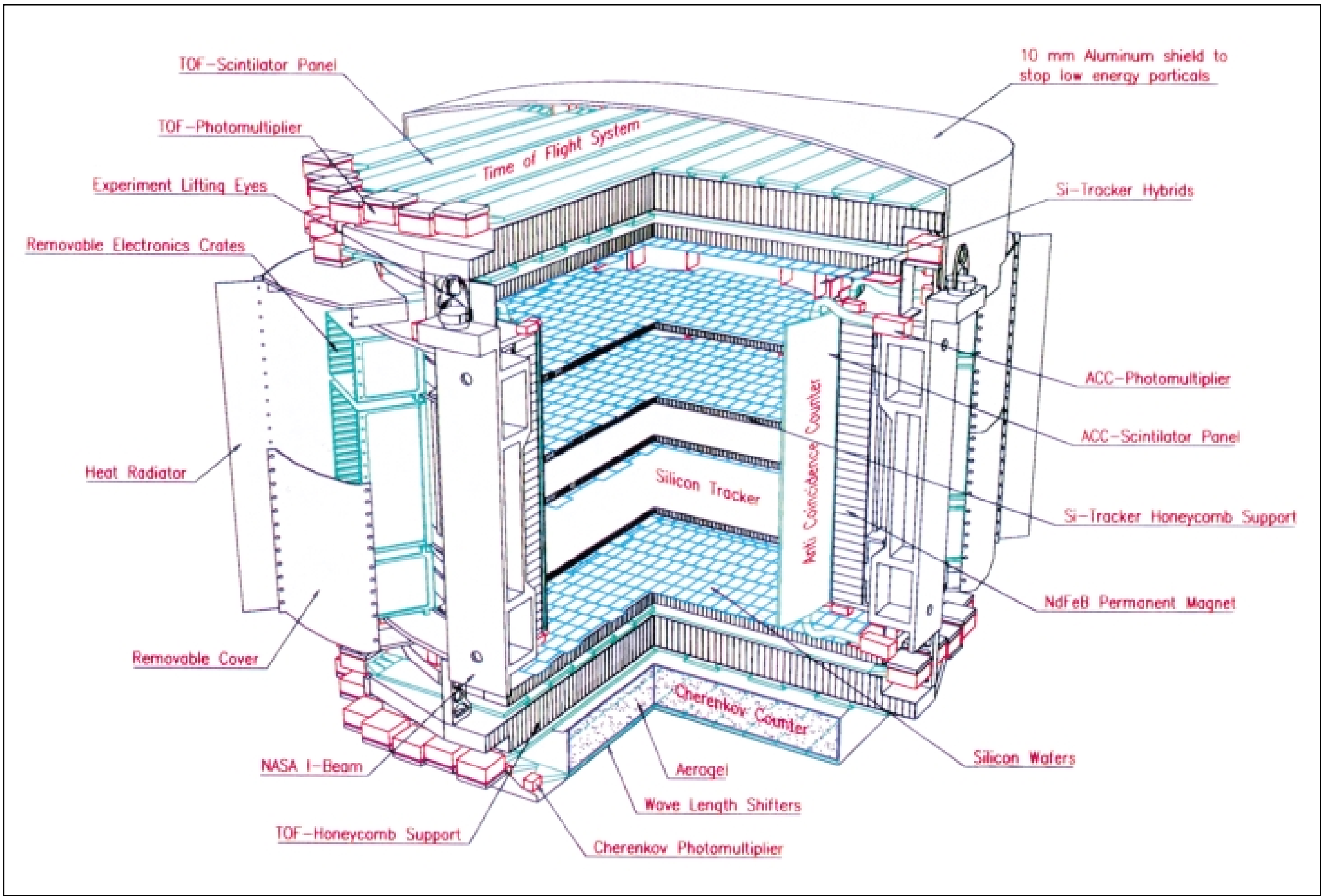


Figure 12. The detector arrangement for the Alpha Magnetic Spectometer (AMS), designed to measure anti-matter particles

theory of the origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning. The AMS payload is expected to detect a few anti-carbon nuclei per week if the present theory of the Big Bang is correct.

Conclusion

ESA is committed to fly the payloads that have been selected on the external sites of the ISS to which it has negotiated access. Detailed accommodation analyses have been carried out and the implementation phase will start this year. A wide range of first-class science and earth-observation studies, industrial space-technology tests and the provision of new services can be achieved using the ISS external sites. As the quality of the more than one hundred responses received to the Announcement of Opportunity has amply demonstrated, the European research community and European aerospace industries are more than ready to exploit these new opportunities that the International Space Station will provide.

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