Particle Environment Package (PEP) for the ESA JUICE mission

S. Barabash (PI)[1], P. C. Brandt (USA Lead)[2], P. Wurz (Co-PI)[3], and PEP Team
[1] *Swedish Institute of Space Physics, Kiruna, Sweden*
[2] *The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA.*
[3] *University of Bern, Bern, Switzerland*

PEP is a suite of six (6) sensors to measure charged and neutral particles in the Jupiter magnetospheres and at the moons to answer four overarching science questions:

1. How does the corotating magnetosphere of Jupiter interact with the complex and diverse environment of Ganymede?
2. How does the rapidly rotating magnetosphere of Jupiter interact with the seemingly inert Callisto?
3. What are the governing mechanisms and their global impacts of release of material into the Jovian magnetosphere from seemingly inert Europa and active Io?
4. How do internal and solar wind drivers cause such energetic, time variable and multi-scale phenomena in the steadily rotating giant magnetosphere of Jupiter?

PEP measures positive and negative ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms present in all domains of the Jupiter system over nine decades of energy from < 0.001 eV to > 1 MeV with full angular coverage.

PEP provides instantaneous measurements of 3D flow of the ion plasma and composition to understand the magnetosphere and magnetosphere-moon interactions. It also measures instantaneously 3D electron plasma to investigate auroral processes at the moon and Jupiter. Measurements of the angular distributions of energetic electrons at sub-second resolution probe the acceleration mechanisms and magnetic field topology and boundaries.

PEP combines global imaging via remote sensing using energetic neutral atoms (ENA) with in-situ measurements and performs global imaging of Europa/Io tori and magnetosphere combined with energetic ion measurements. Using low energy ENAs originating from the particle – surface interaction PEP investigate space weathering of the icy moons by precipitation particles. PEP will first-ever directly sample of the exospheres of Europa, Ganymede, and Callisto with extremely high mass resolution ($M/\Delta M > 1100$).

PEP consists of three units (Fig. 1) with resource-optimized modular design hosting sensors and electronics, and provides for well-defined, minimal interfaces to the spacecraft. Table 1 sums up the PEP sensor performance.

The Zenith Unit, accommodated on the spacecraft zenith plane, includes the JDC and JoEE sensors plus redundant DPU (Digital Processing Unit), dedicated power converters, and a spacewire spacecraft interface. The Nadir Unit, accommodated on the spacecraft nadir plane, includes the JEI, NIM, JENI, and JNA sensors, plus redundant DPU (Digital Processing Unit), dedicated spower converters, and a spacewire spacecraft interface; the JENI sensor is independently mounted to the nadir deck.

The PEP sensors are designed and optimized to mitigate both high radiation doses and high instantaneous fluxes of the penetrating radiation. PEP radiation mitigation strategy includes *(1)* passive shielding to reduce total dose and backgrounds, *(2)* coincidence schemes up to triple to increase signal-to-noise ratio, *(3)* reduction of the detector sensitive area to reduce background rates keeping foreground sensitivity same by employing focusing electrostatic optics, *(4)* reduction of the sensor volumes to decrease the internal surface areas emitting not-valid secondary electrons, *(5)* monitoring instantaneous background rates to be subtracted, *(6)* replacement of microchannel plates (MCP) by radiation insensitive Ceramic Channel Electron Multipliers (CCEM), where feasible.

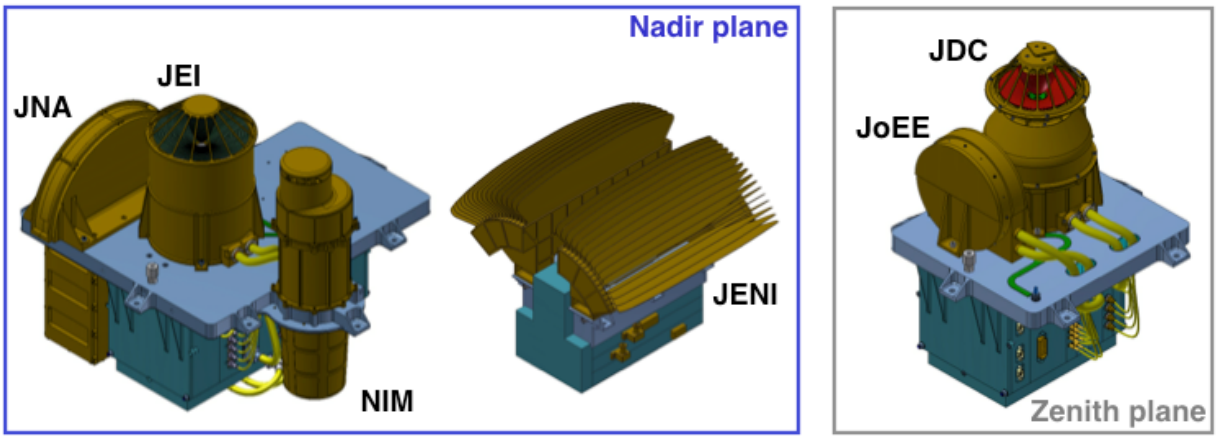

Fig. 1. PEP mechanical configuration including Nadir Unit, JENI (Jovian Energetic Neutrals and Ions) and Zenith Unit. JNA – Jovian Neutrals Analyzer, JEI – Jovian Electrons and Ions analyzer, NIM – Neutral gas and Ion Mass spectrometer, JoEE – Jovian Energetic Electrons, JDC – Jovian plasma Dynamics and Composition analyzer.

PEP sensors and subsystems have a high technology readiness level and are built on direct flight and team heritage from Galileo, Cassini, Juno, Mars Express (ASPERA-3), Venus Express (ASPERA-4), Rosetta, SOHO, New Horizons, Chandrayaan-1, IMAGE, & RBSP. The PEP team is listed in Table 2.

Table 1. PEP sensors performance

PEP sensor	**Key Performance**
JDC - Jovian plasma Dynamics and Composition: Design using reflectron and reflecting surface. Instantaneous 3D distributions of positive and negative ions, constraining charge-states, electron measurement capability	Plasma ions and electrons 1 eV – 41 keV, ΔE/E=12% M/ΔM=30 Hemispheric FoV with 5.5˚x19.5˚ ang. resolution
JEI - Jovian Electrons and Ions: Instantaneous 3D distributions of plasma electrons, ion measurement capabilities	Plasma electrons and ions ~1 eV – 50 keV, ΔE/E=4.9% Hemispheric , 20˚x10˚ resolution
JoEE - Jovian Energetic Electrons: Ultra-lightweight energetic electron sensor built on the Galileo energetic particle detector technique. Instantaneous pitch-angle distributions and spectra.	Energetic electrons 25 keV – 1 MeV, ΔE/E≤20% FoV:12˚x180˚, 12˚x22˚ resolution
NIM - Neutral gas and Ion Mass spectrometer: Compact design based on TOF and reflectron. First-ever exospheric neutral gas and thermal plasma mass spectroscopy at Jupiter's moons.	Thermal neutrals and ions (<5 eV) Mass range: 1-1000 amu M/ΔM=1100 Sensitivity: 2 cm^{-3} (~10^{-16} mbar)
JNA - Jovian Neutrals Analyzer: ENA camera based on successful instrument on the Lunar Chandrayaan-1 mission. Imaging of Io plasma torus, backscattered and sputtered surface products.	Low-energy ENA 10 eV – 3 keV (H) 7˚x10˚ ang. resolution
JENI - Jovian Energetic Neutrals and Ions: Combined energetic ion and ENA camera based on Cassini, IMAGE and Juno. Global imaging of magnetosphere and neutral gas tori.	ENA and ions ~0.5 – 300 keV (ENA), 5 MeV (ions) ΔE/E=14% 90˚x120˚, 2˚ ang. resolution (>10 keV H)

Table 2. PEP Team (SL – sensor Lead)

M. Wieser (SL: JDC, JNA), M. Holmström, Y. Futaana, G. Stenberg, H. Nilsson A. Eriksson (Science with RPWI)		Swedish Institute of Space Physics, Box 812, SE-98128, Kiruna, Sweden (IRF) Swedish Institute of Space Physics, Box 537, SE-751 21, Uppsala, Sweden (IRFU)
P. Wurz (SL: NIM), M. Tulej, A. Vorburger, N. Thomas		University of Bern, Physikalisches Institut, CH-3012 Bern, Switzerland (UBe)
C. Paranicas (SL: JoEE), D. G. Mitchell (SL: JENI), G. Ho, B. H. Mauk, D. Haggerty, J. H. Westlake Krishan Khurana (Science) Xianzhe Jia (Science) C. Paty (Science)		Applied Physics Laboratory, Johns Hopkins Univ., Laurel, MD, 20723-6099, USA (JHU/APL) Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA, 90095, USA (UCLA) Dept. of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI 48109-2143, USA (U-M) School of Earth and Atmospheric Science, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, GA 30332-0340, USA (GaTech)
M. Fränz (SL: JEI), N. Krupp, E. Roussos **R. F. Wimmer-Schweingruber** B. Heber		Max Planck Institute for Solar System Research, 37191 Katlenburg-Lindau, Germany (MPS) Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität Kiel, Leibnizstraße 11, 24118 Kiel, Germany (CAU)
Asamura Kazushi (JNA electronics)		Institute of Space and Astronautical Science 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan (ISAS)
E. Kallio, W. Schmidt (DPU)		Finnish Meteorological Institute, Box 503 FIN-00101 Helsinki, Finland (FMI)
K. Szego, S. Szalai (Power system, EGSE)		Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Konkoly Thege Miklós út 29-33, H-1121 Budapest, Hungary (WRCP)
M. Grande (Radiation analysis) A. Coates, G. Jones (h/w)		University of Wales Aberystwyth, Penglais, Aberystwyth, Ceredigion, SY23 3BZ, Wales (UA) Mullard Space Science Laboratory, University College London, and The Centre for Planetary Sciences at UCL/Birkbeck (MSSL)
H. Lammer T. Zhang (Science)		Space Research Institute, Schmiedlstraße 6, 8042 Graz, Austria (IWF)
S. McKenna-Lawlor (h/w)		Space Technology Ireland, National University of Ireland, Maynooth, Co. Kildare, Ireland (STIL)
S. M. Krimigis (Science) Th. Sarris (Science, h/w)		Academy of Athens, Soranou Efesiou 4, 115 27, Athens, Greece (AA),Democritus University of Thrace, Xanthi, Greece (DUTh)
D. Grodent (Science)		Université de Liège, Institut d'Astrophysique et de, Géophysique, Allée du 6 Août, 17 (B5c), B-4000 LIEGE, Belgium (LPAP)
N. André, A. Fedorov (h/w)		Institut de Recherche en Astrophysique et Planétologie 9, avenue du Colonel ROCHE, B.P. 4346, 31028 TOULOUSE Cedex 4, France (IRAP)