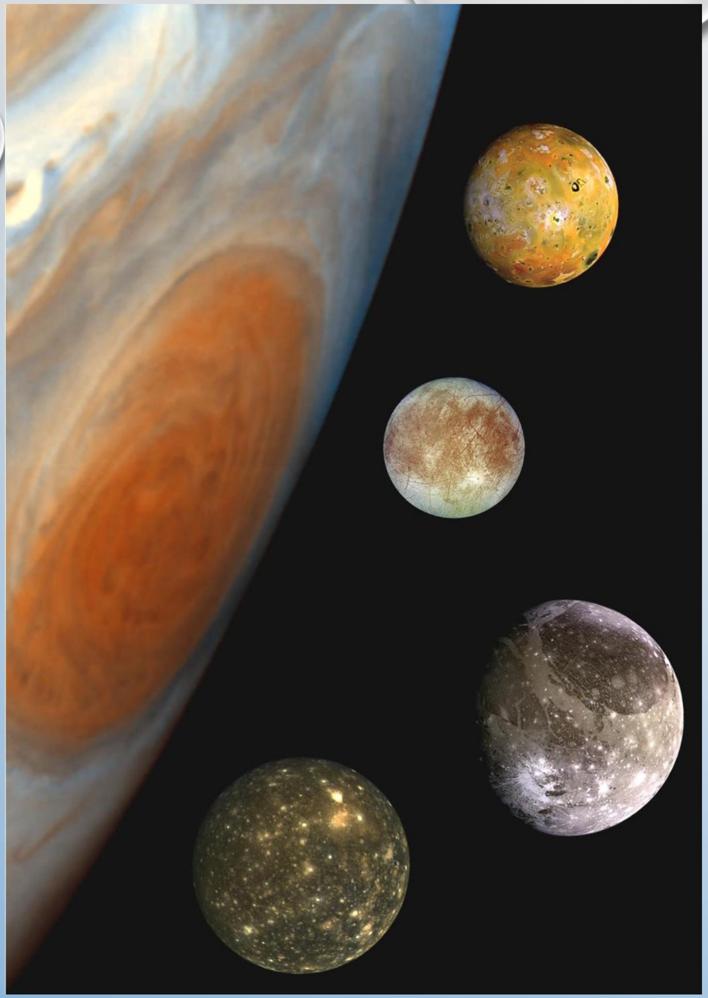


JUICE-ESA MISSION,

CHALLENGE FOR JUPITER SYSTEM EXPLORATION

HANNA ROTHKAEHL

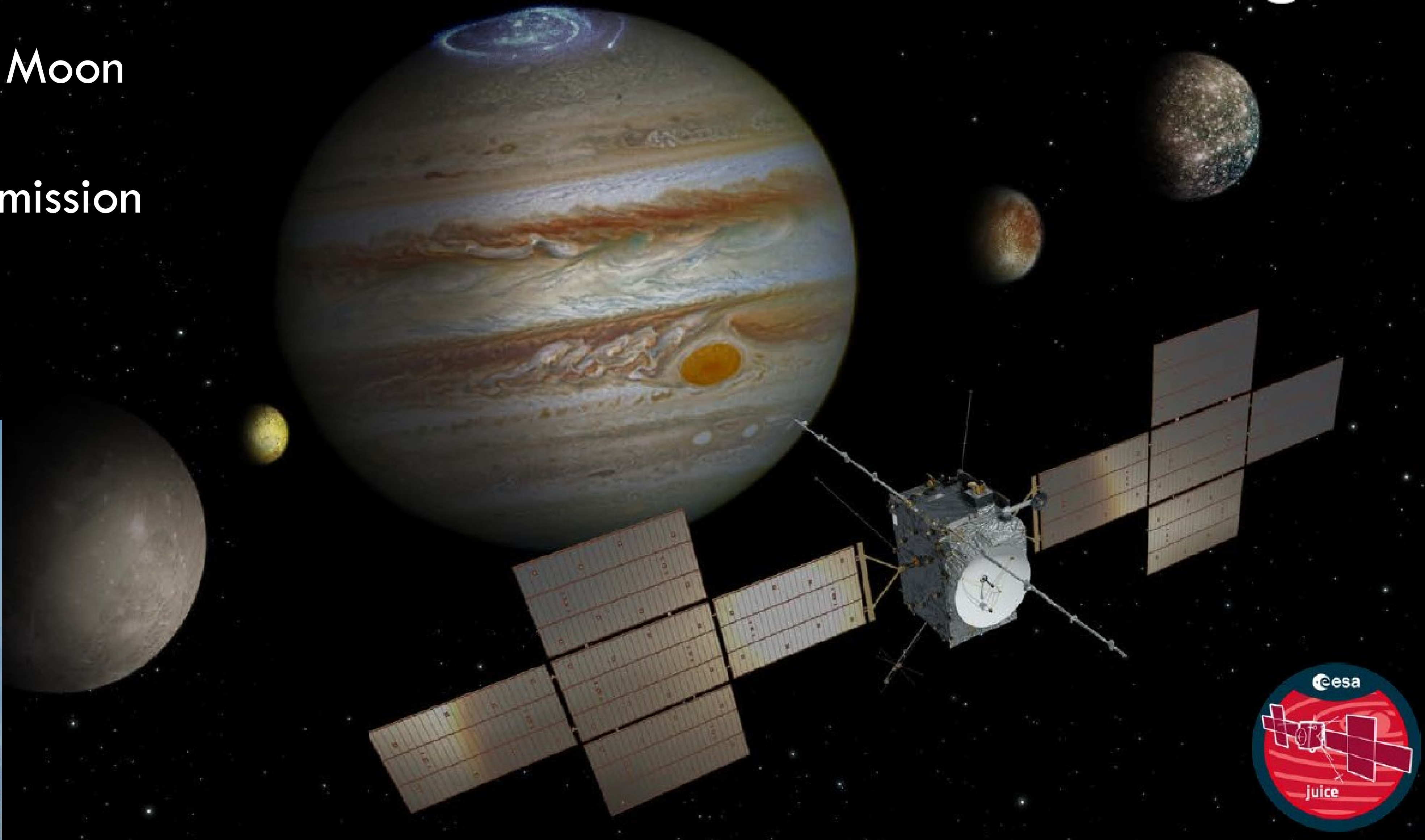
12 09 2023 PTA TORUŃ

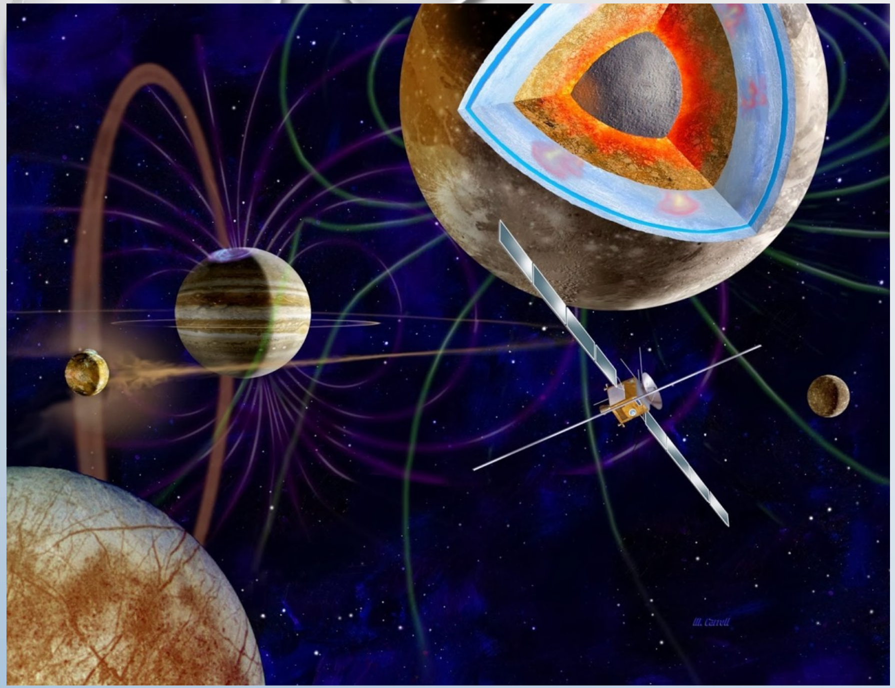
14 04 2023 14:14 CET

JUICE

JUpiter ICy Moon Explorer

ESA L class mission





The JUICE mission will address two themes of ESA's Cosmic Vision programme:

1.What are the conditions for planet formation and emergence of life?

2. How does the Solar System work?

The JUpiter ICy moons Explorer (JUICE) will perform detailed investigations of Jupiter and its system in all their inter-relations and complexity with particular emphasis on Ganymede as a planetary body and **potential habitat.**

Investigations of Europa and Callisto would complete a comparative picture of the Galilean moons.

Dimensions (stowed for launch): 4.09 x 2.86 x 4.35 m
Dimensions (deployed in orbit): 16.8 x 27.1 x 13.7 m
Dry mass (without fuel): 2420 kg. This includes the 'payload adapter' that connects the satellite to the launcher.
Amount of propellant (full tank): 3650 kg.

Instrument payload mass: 280 kg

RPWI 15.2 KG

Solar panels: Juice has a distinctively shaped solar array – two ‘wings’ of panels in a cross-like formation. Overall, these wings are made up of ten **2.5 x 3.5 m** panels (five on each side) with a total area of 85 m^2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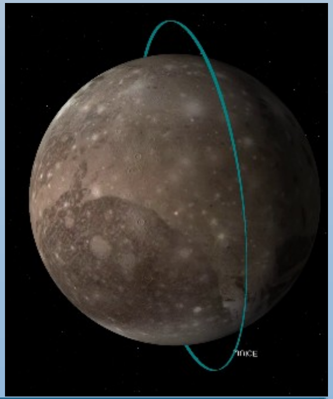
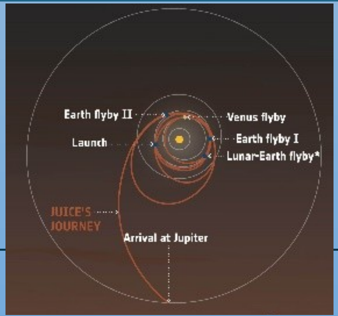
JUICE PROJECT OVERALL TIMELINE

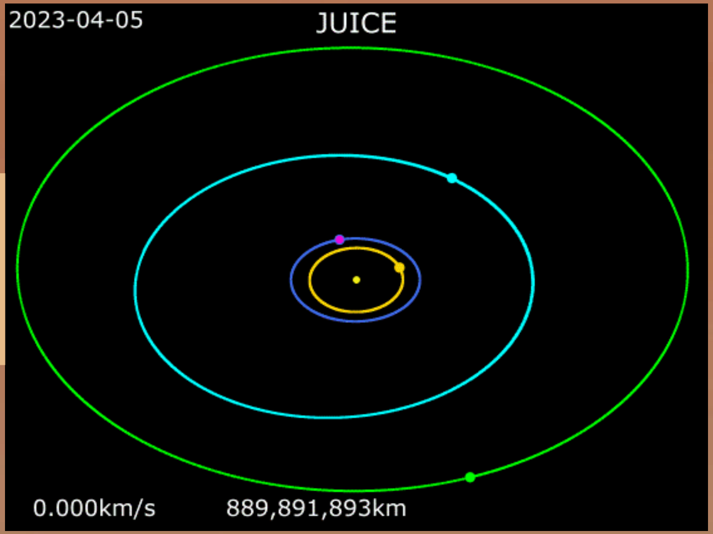
2007-2014	2015-2023	2023-2031	2031-2037
Call, proposal, study, mission and instrument selection	Development phase Launch campaign	Cruise phase	Nominal mission + possible extension

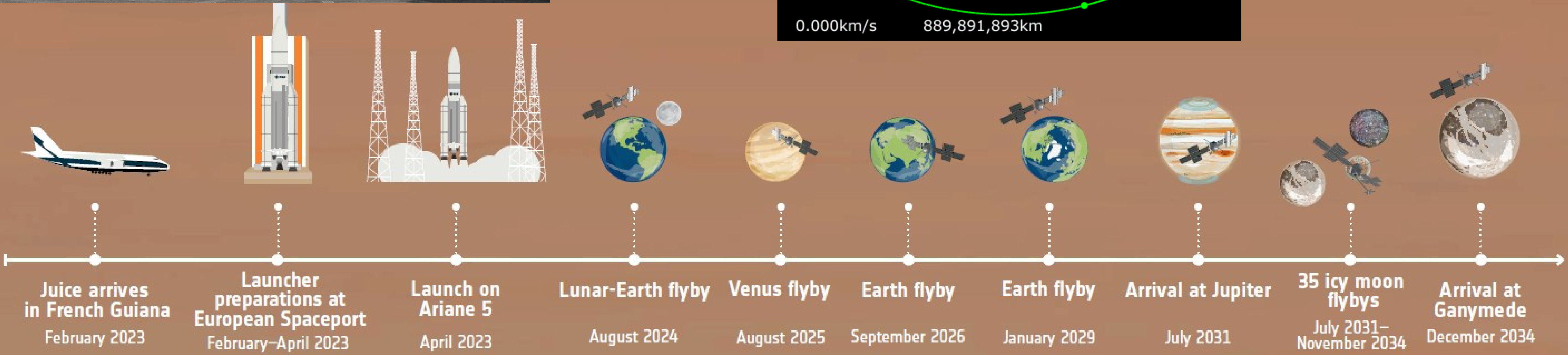




Credit ESA

Cayenne Airport.
marzec 2023

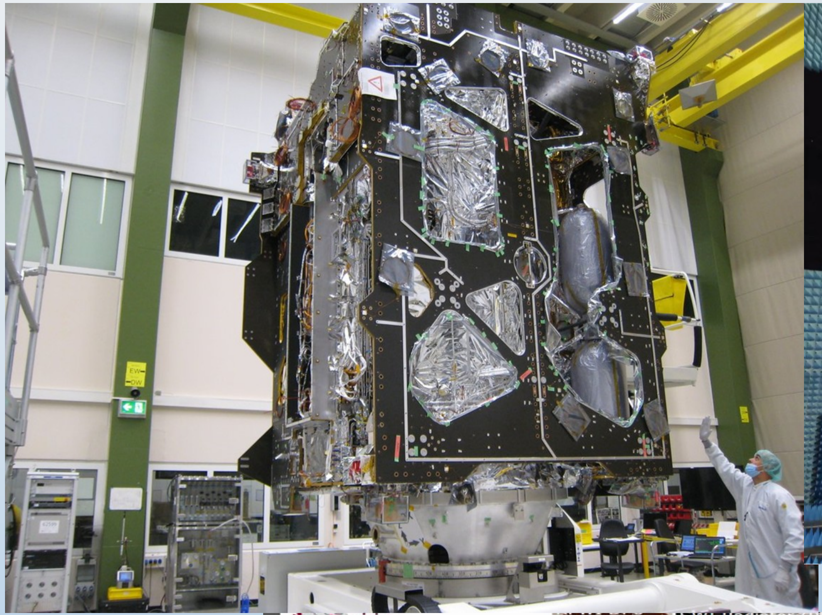




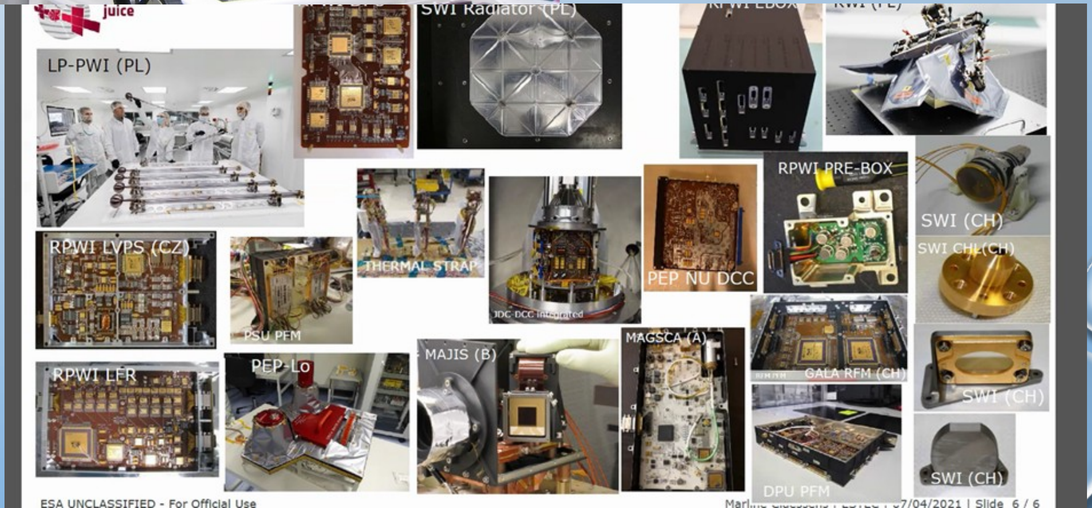
JUICE

JUpiter ICy Moon Explorer
ESA L class mission 2023

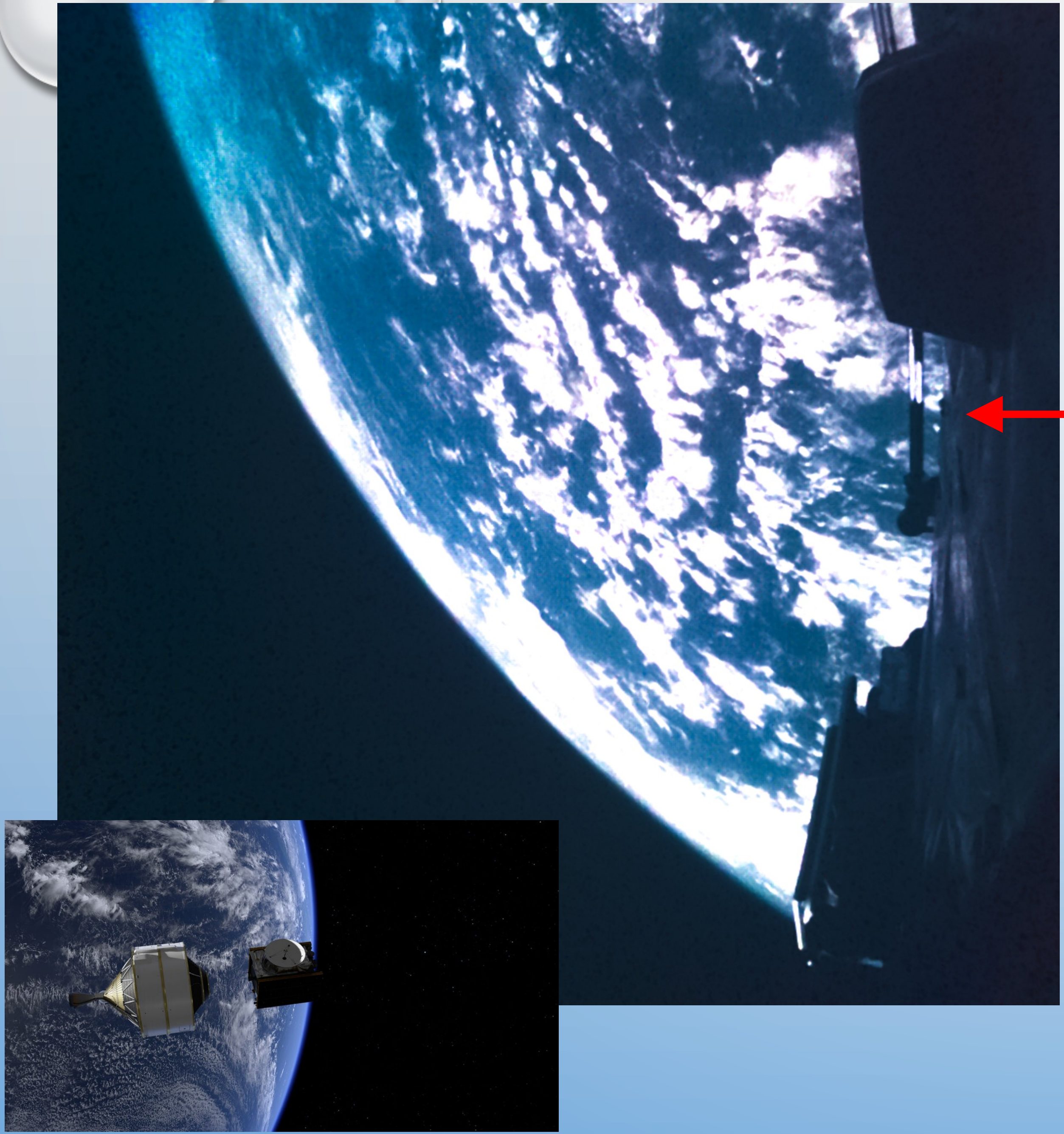
5 04 -25 04 2023 lauched window



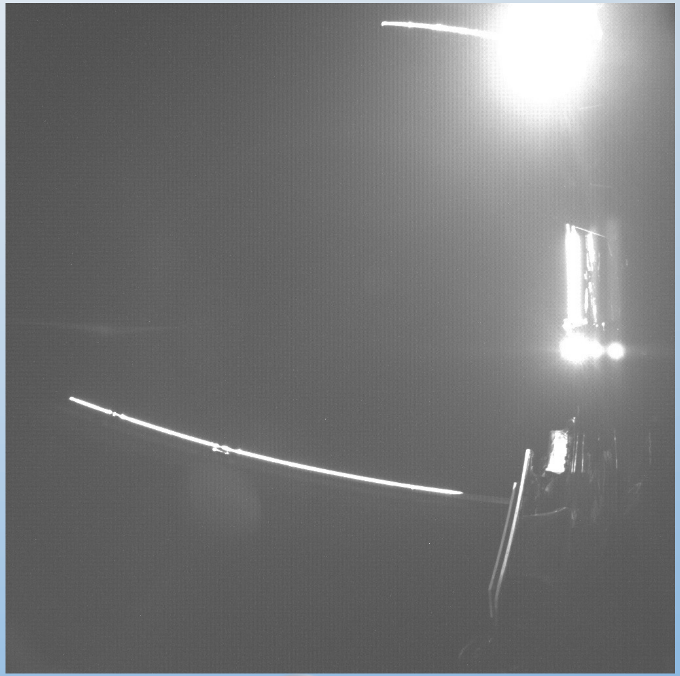
JANUS - Camera system
MAJIS - Moons and Jupiter Imaging Spectrometer
UVS - UV imaging Spectrograph
SWI - Sub-millimeter Wave Instrument
GALA - GAnymede Laser Altimeter
RIME - Radar for Icy Moons Exploration
J-MAG - A magnetometer instrument for JUICE
RPWI - Radio & Plasma Wave Investigation
3GM - Gravity & Geophysics of Jupiter and Galilean Moons
PRIDE - Planetary Radio Interferometer & Doppler Experiment



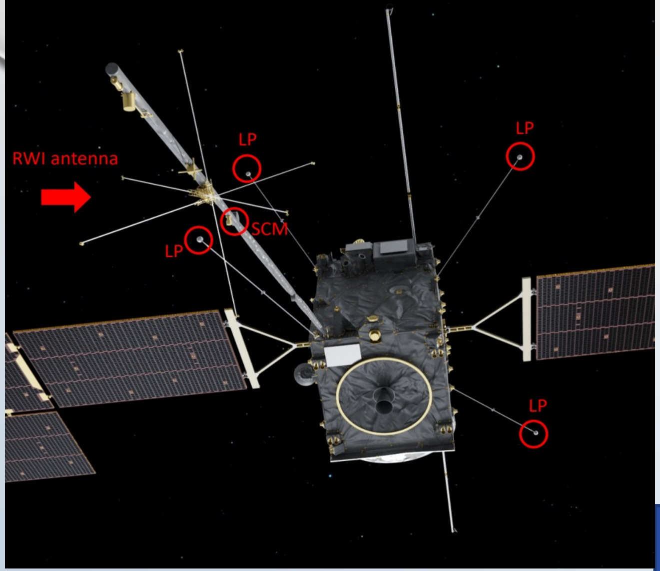
First photo



RPWI - Radio & Plasma Wave Investigation



19-23 April
RPWI Sensors release and first signals detected, FFT – Full Functional Tests



RPWI makes use of several different sensors and receivers. Altogether, the instrument uses sensors and 3 receivers, which cover a wide frequency range, from DC up to 45 MHz.
There are 4 Langmuir probes (LP-PWI) for plasma and electric field measurements, a search coil magnetometer (SCM) with 3 coils for magnetic fields measurement, and 3 radio antennas (RWI).
Thus, the RPWI sensors provide complete measurements of the electric and magnetic field vectors.

Jan-Erik Wahlund (PI)
Swedish Institute of Space Physics

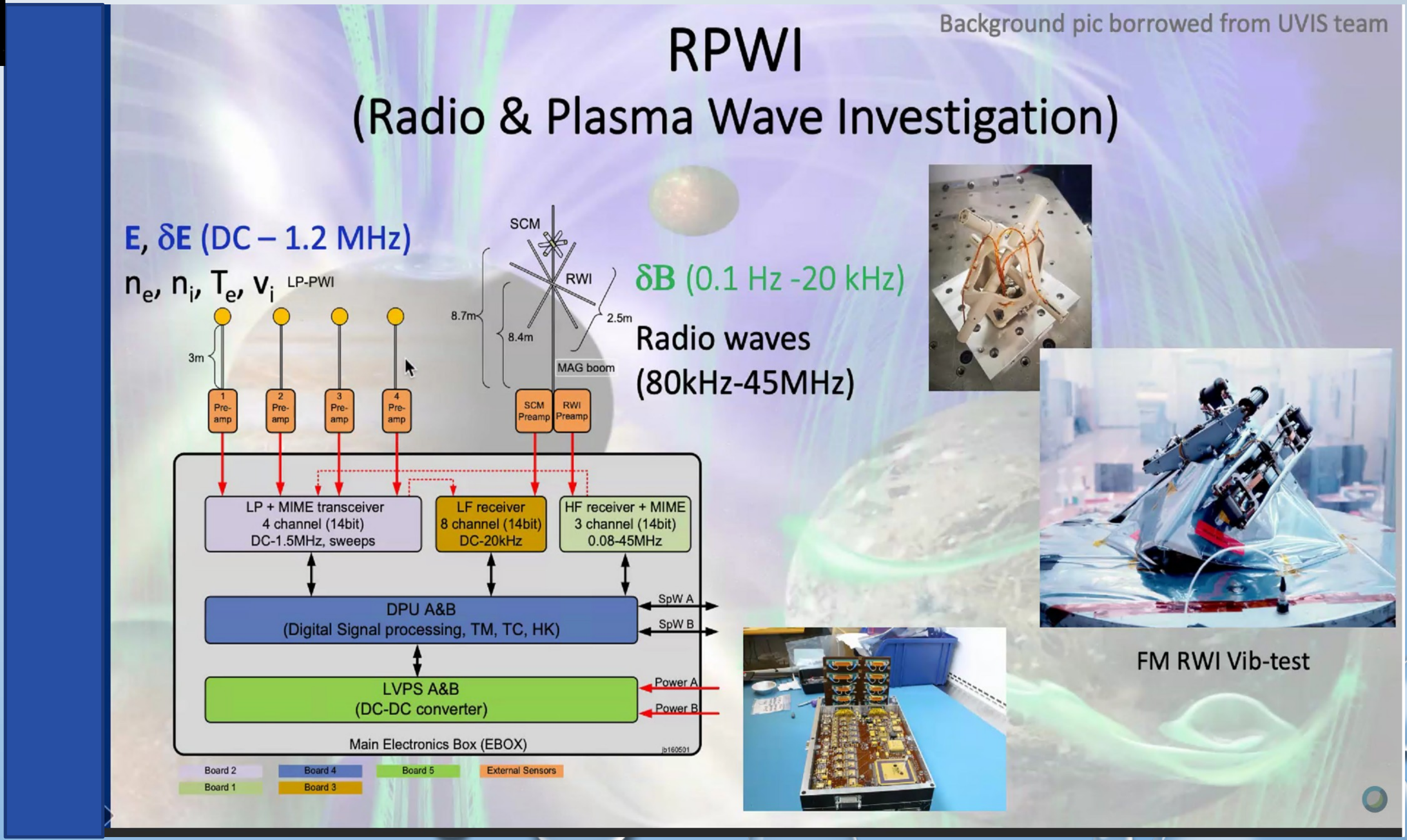
Baptiste Cecconi (Co-PI)
LESIA-Observatoire de Paris, 5 place Jules

Yasumasa Kasaba (Co-PI)
Department of Geophysics, Tohoku University

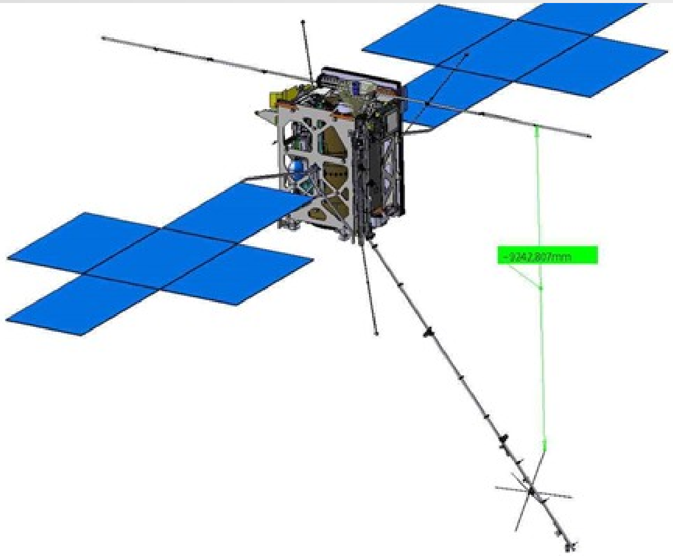
Hanna Rothkaehl (Co-PI)
Space Research Centre PAS

Ondrej Santolik (Co-PI)
Institute of Atmospheric Physics

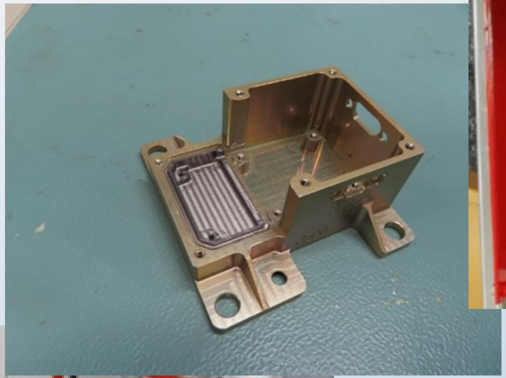
Ingo Müller-Wodarg (Co-PI)
Space and Atmospheric Physics group
Imperial College London, London, UK

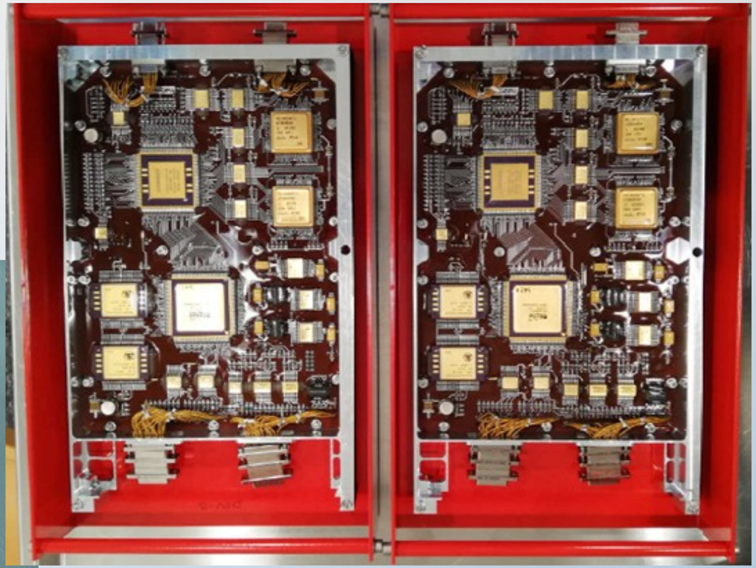


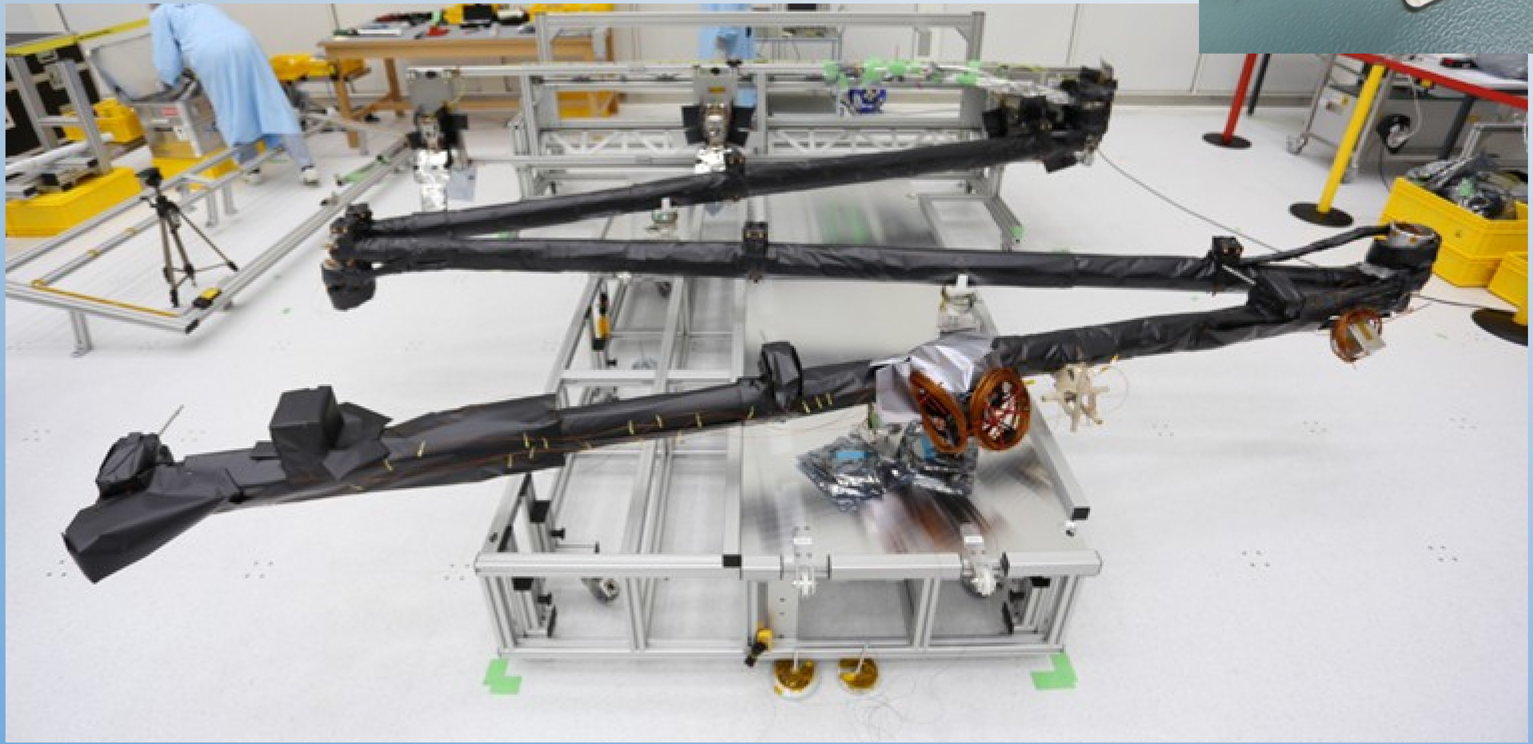
RPWI CBK contribution

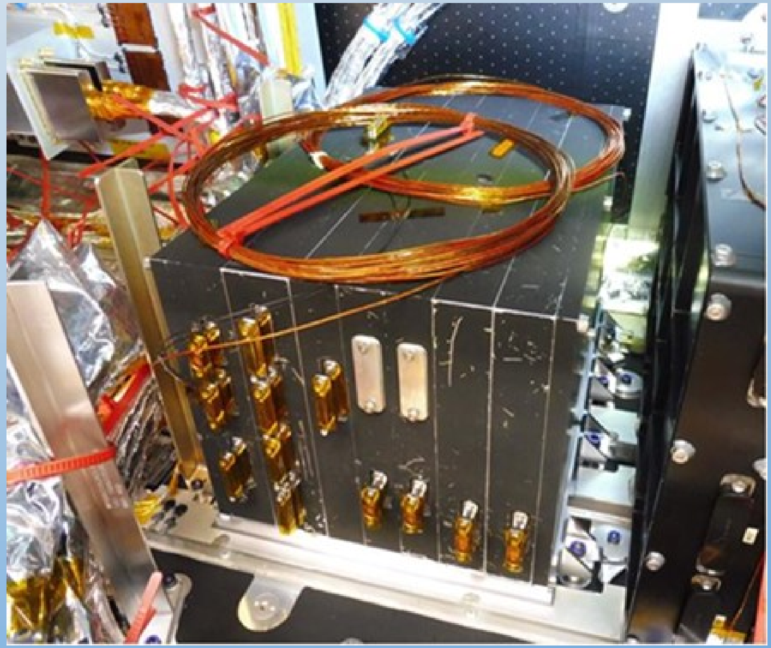


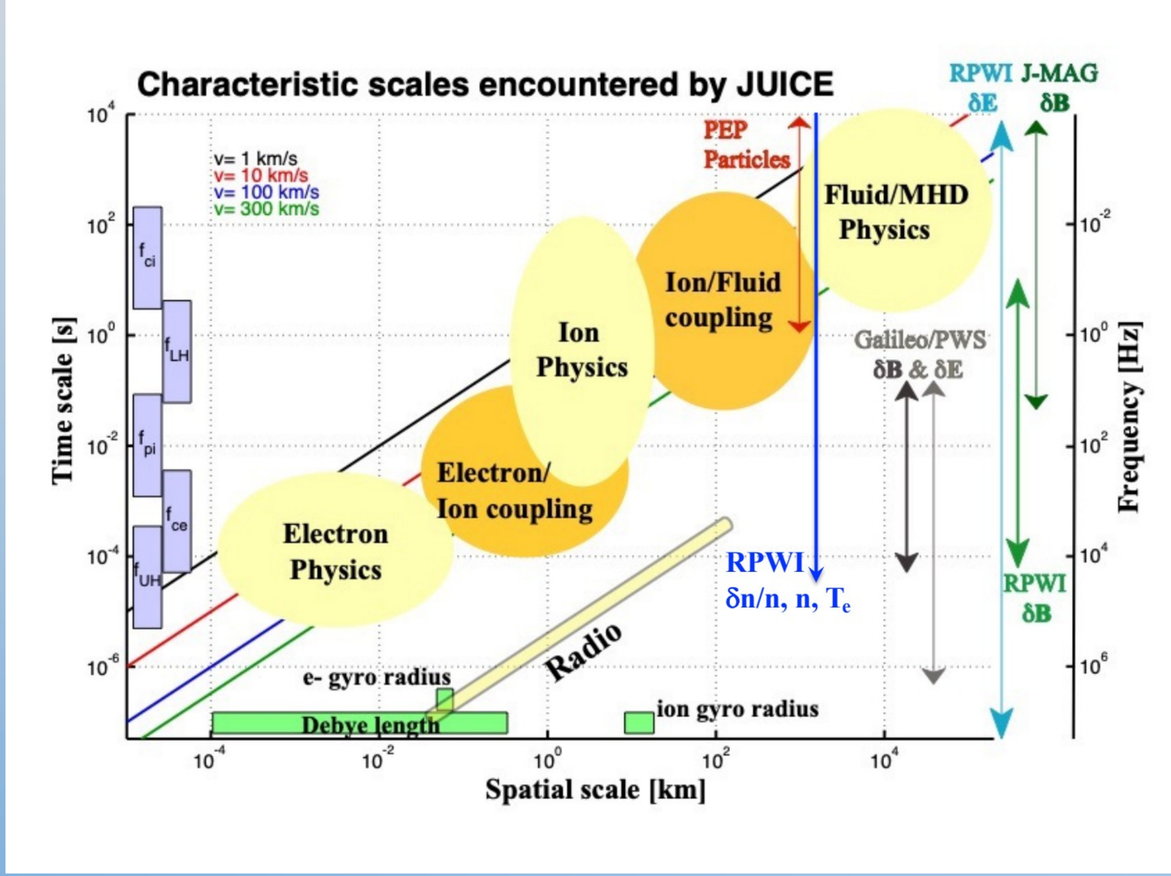
1. DPU
2. EBOX
3. PREBOX







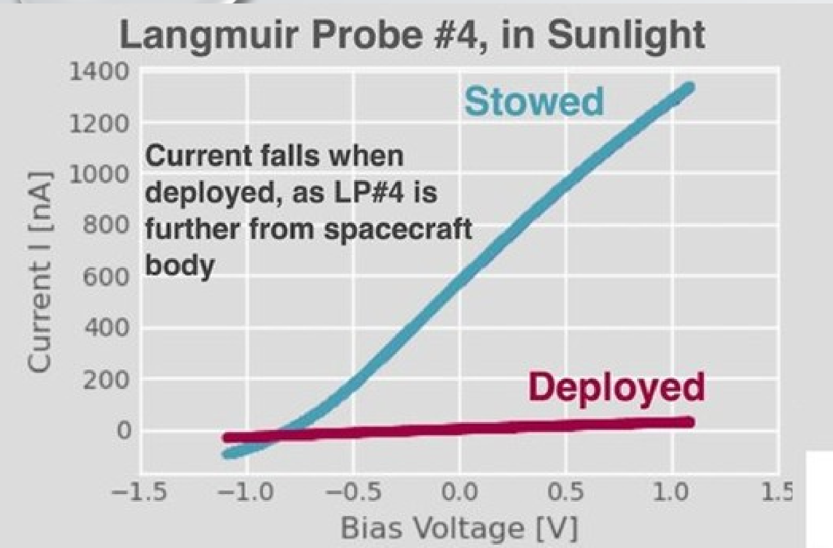


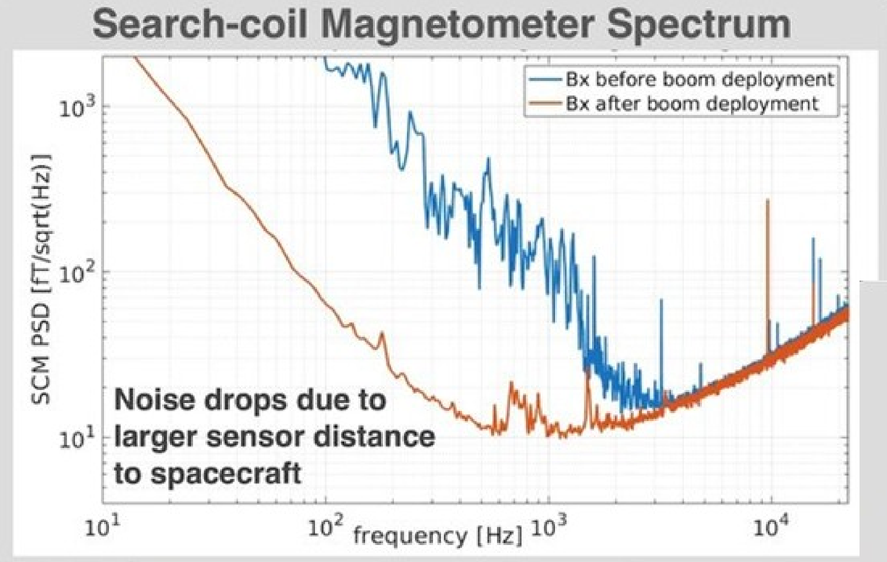


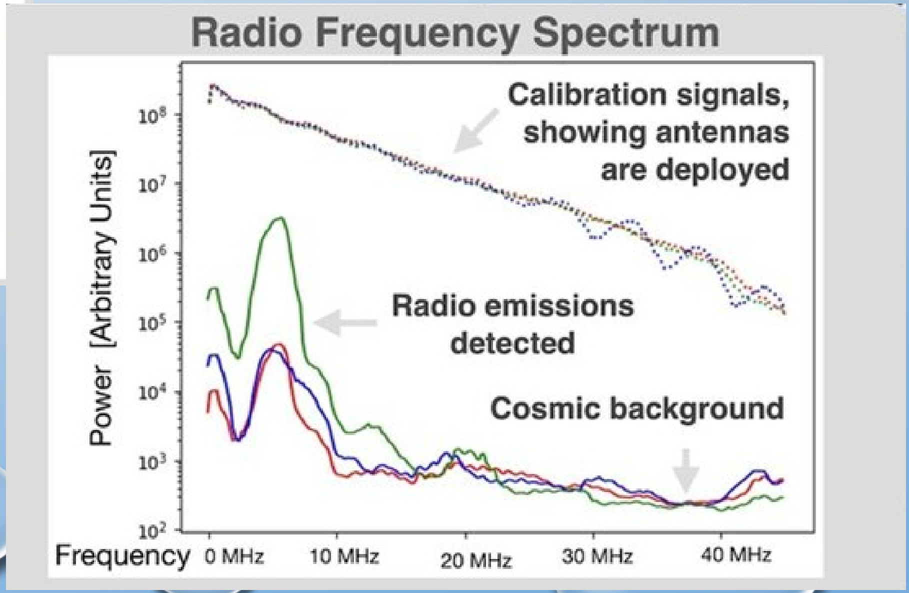
PWI Measured Quantity	Range/Product	Error/Sensitivity
Electric field vector, δ**E**(f)	DC – 1.5 MHz Dust detection. Polarization with δ**B**(f). Poynting flux with δ**B**(f).	DC: ≈ 0.9 μV/m (instrument) (Calibration for S/C influence needed in flight) Spectral (differential): <1μV/m/√Hz (>500Hz)
Electric field vector, δ**E**(f)	80 kHz – 45 MHz Wave vector (δ**k**) Polarization	10 nV/m/√Hz (at 10 MHz) ~1° (at 5 MHz) ~10% (at 5 MHz) (Direction finding calibration needed in-flight)
Magnetic field vector, δ**B**(f)	0.1Hz – 20 kHz Polarization with δ**E**(f). Poynting flux with δ**E**(f).	8 pT/√Hz (at 1 Hz) 0.6 pT/√Hz (at 10 Hz) 0.06 pT/√Hz (at 100 Hz) 20 fT/√Hz (500Hz-10kHz)
Electron density (Ne)	10^{-4} – 10^{5} cm^{-3}	<10% (>10cm^{-3}) Leak current ≈0.5pA <100Hz
Density fluctuations (δn/n)	DC – 10kHz	<5% below 1kHz
δ**E** or δn interferometry	<1000 km/s	Phase accuracy <1° for <20kHz. Phase response correctable.
Ion density (Ni)	1–10^{5} cm^{-3}	<20%
Electron temperature (Te)	0.01 – 20 eV	<20%
Ion drift speed (Vdi)	0.1–200 km/s	<20%
Ion temperature (Ti) upper constraints	0.02 – 20 eV	Constrained by <$mV_{di}^2/2e$
Spacecraft potential (Usc)	±80 V	<10%
Integrated solar EUV flux	<1 Hz	Res. 0.003 Gphotons/cm^2/s
PSSR: Dynamic range incl. processing gain	85 dB	
PSSR: Max Ice depth / Resolution	<20 km (depend on ice conductivity/salinity)	<1km

Instrument RPWI (Instrument Radio & Plasma Wave Investigation)

Pierwsze pomiary dokonane w przestrzeni kosmicznej daleko poza magnetosferą Ziemi, pokazały że przyrząd działa dobrze !.

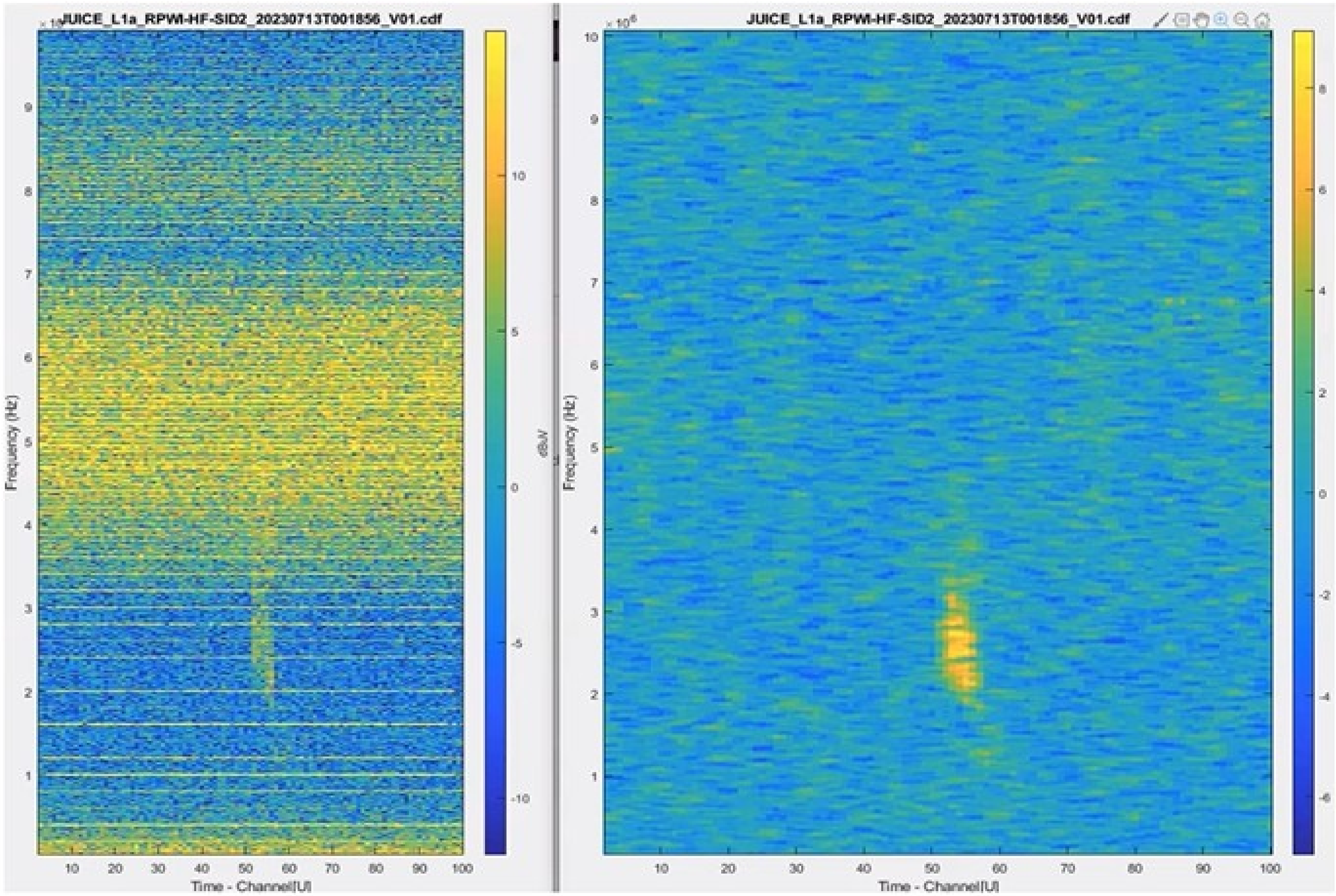






In prep, The Radio & Plasma Wave Investigation (RPWI) for the JUpiter ICy moons Explorer (JUICE) w Space Sci Rev 2023

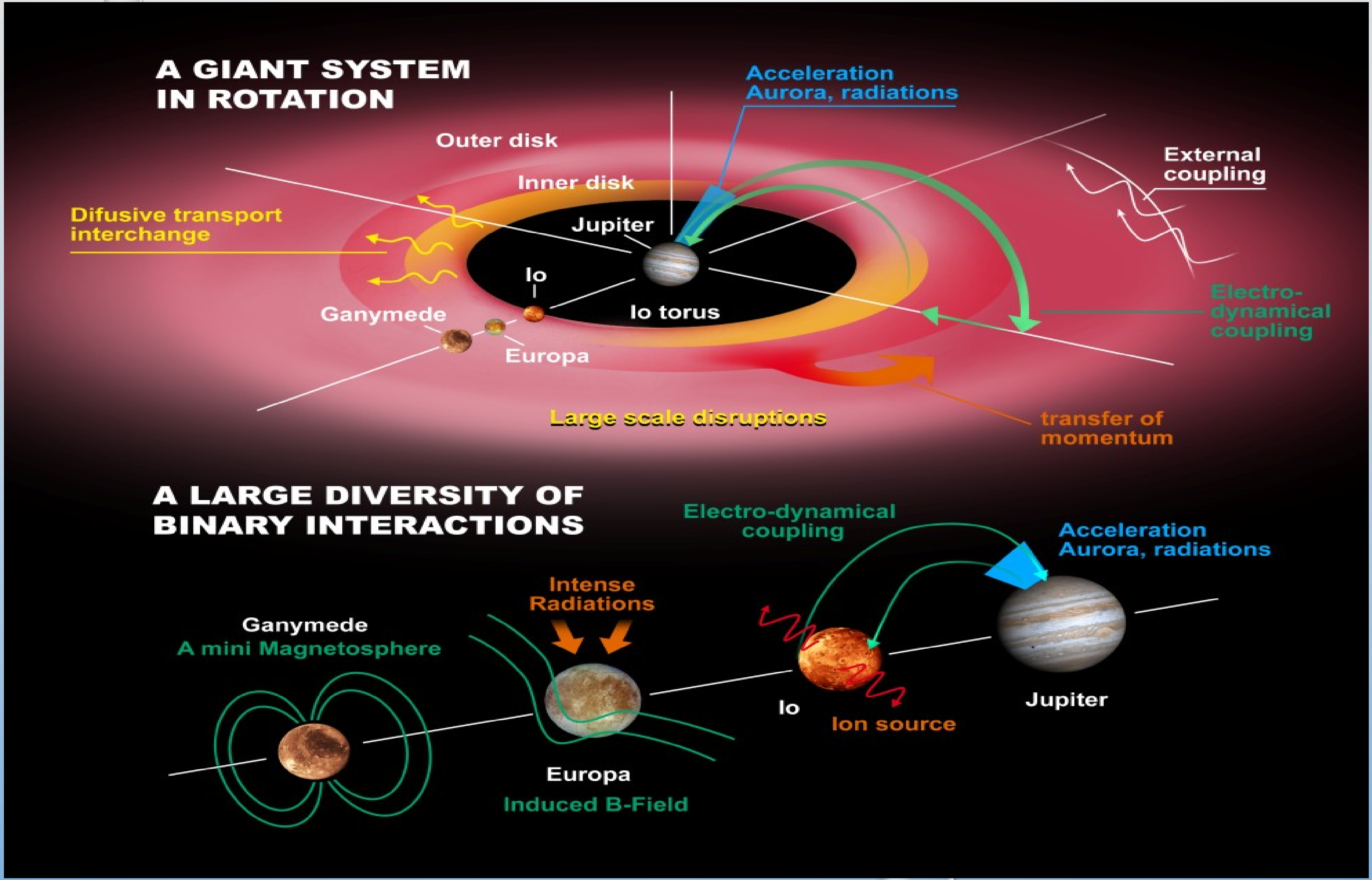
First evidence of a solar radio emission 13 July



Left: Raw data from RWI
Right: Filtered data

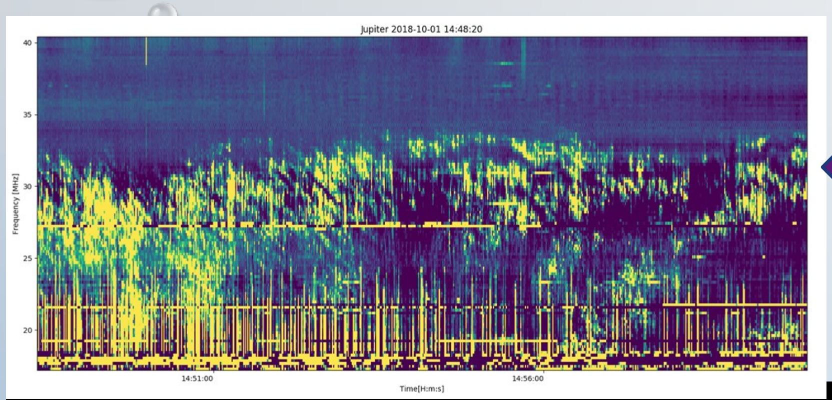
- The time axis is about minutes. RWI takes 5 spectra every 63 seconds. Each set takes 8 seconds.

- 32 samples/bin (4kHz)
- 512 samples/bin (250Hz) would have been desirable

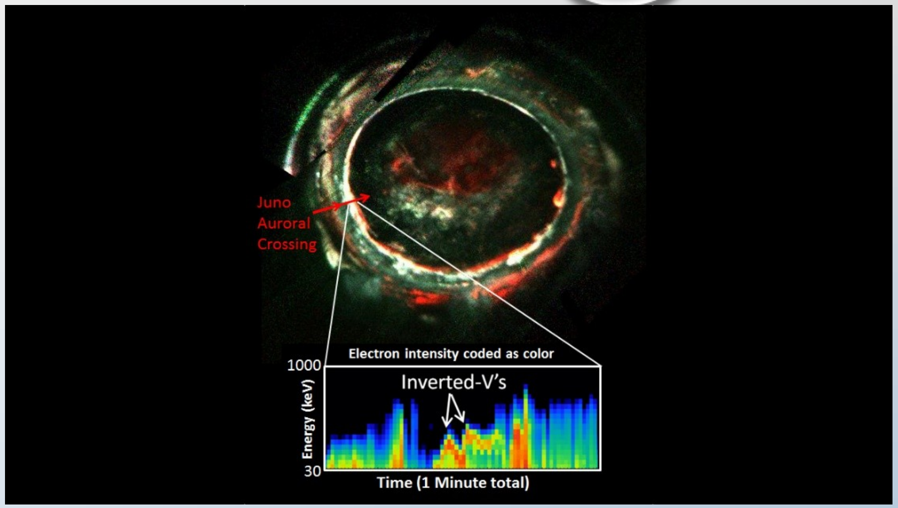


A GIANT SYSTEM IN ROTATION
Acceleration Aurora, radiations
Outer disk
Inner disk
Jupiter
External coupling
Difusive transport interchange
Io
Io torus
Ganymede
Europa
Electro-dynamical coupling
Large scale disruptions
transfer of momentum
A LARGE DIVERSITY OF BINARY INTERACTIONS
Electro-dynamical coupling
Acceleration Aurora, radiations
Intense Radiations
Ganymede
A mini Magnetosphere
Io
Ion source
Jupiter
Europa
Induced B-Field

JOVIAN RADIO EMISSIONS
JUICE AND LOFAR SUPPORT

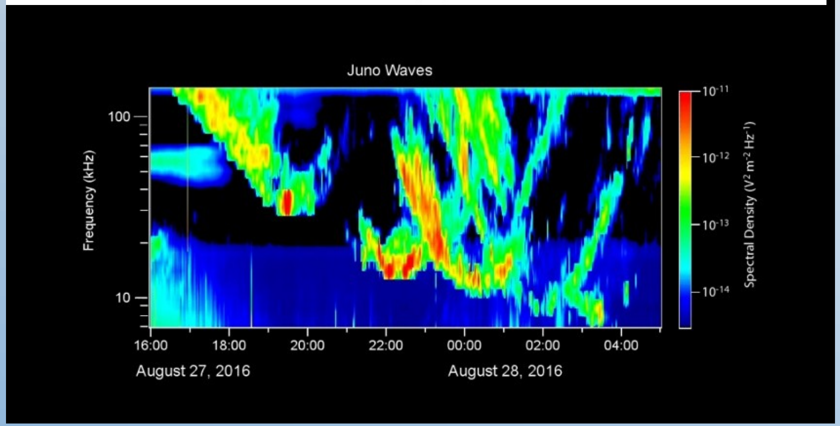


JUNO

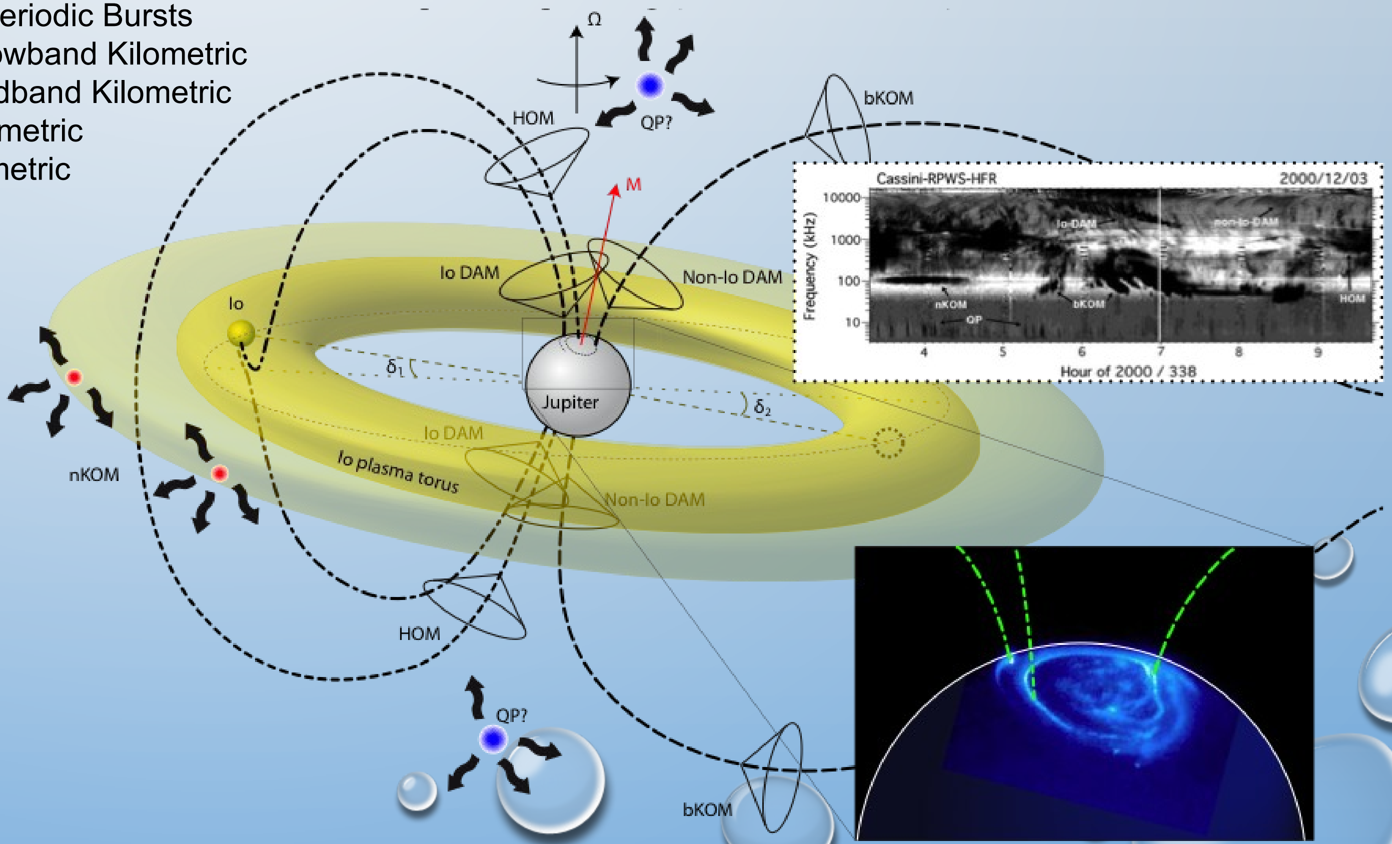


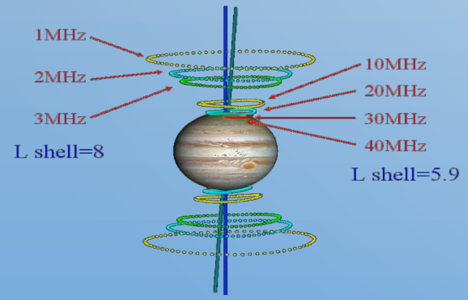
LOFAR
BORÓWIEC

VESPA VO

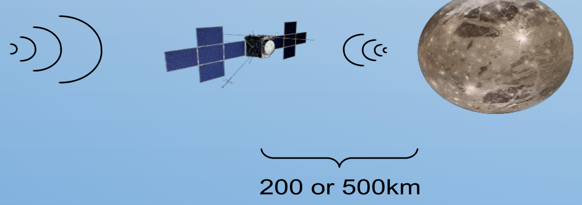


QP = Quasi-Periodic Bursts
nKOM = narrowband Kilometric
bKOM = broadband Kilometric
HOM = Hectometric
DAM = Decametric

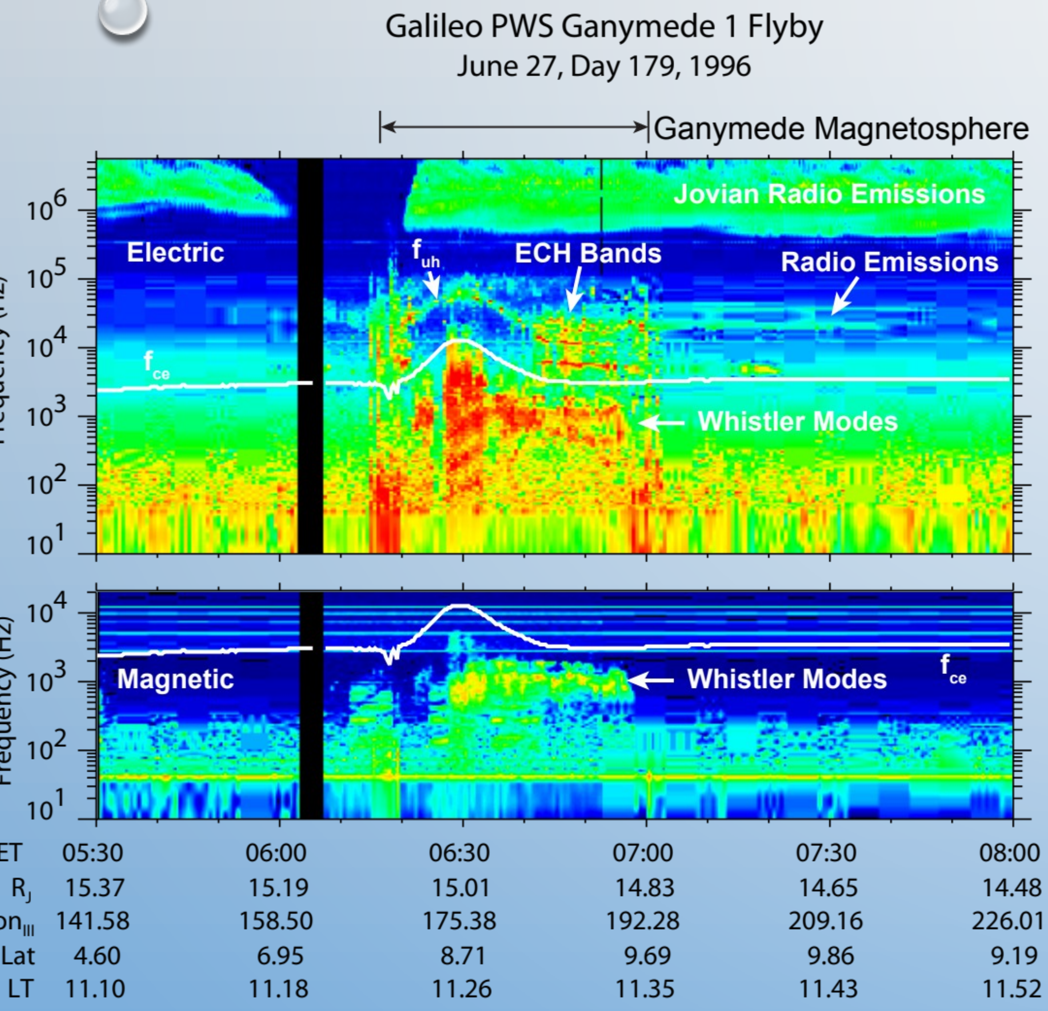




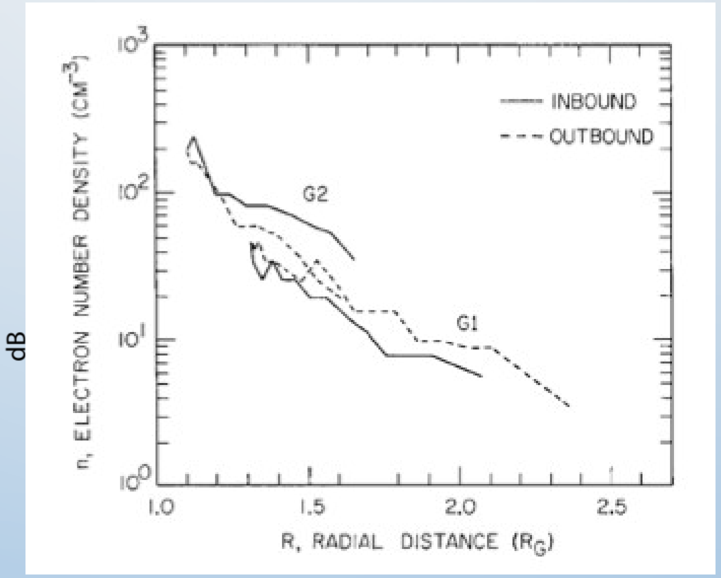
Passive radar

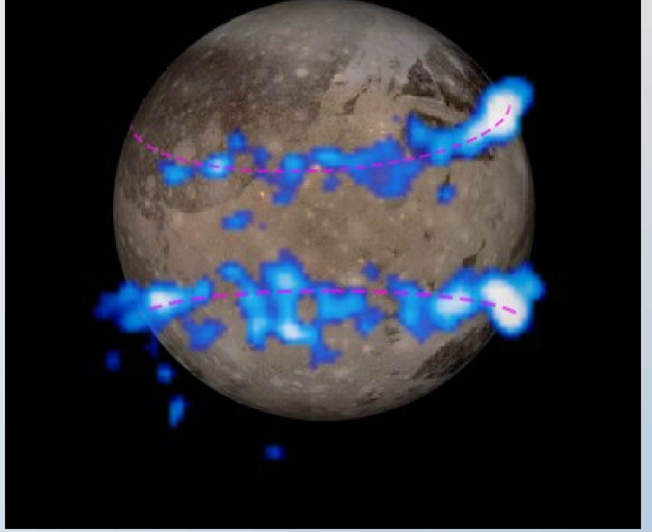


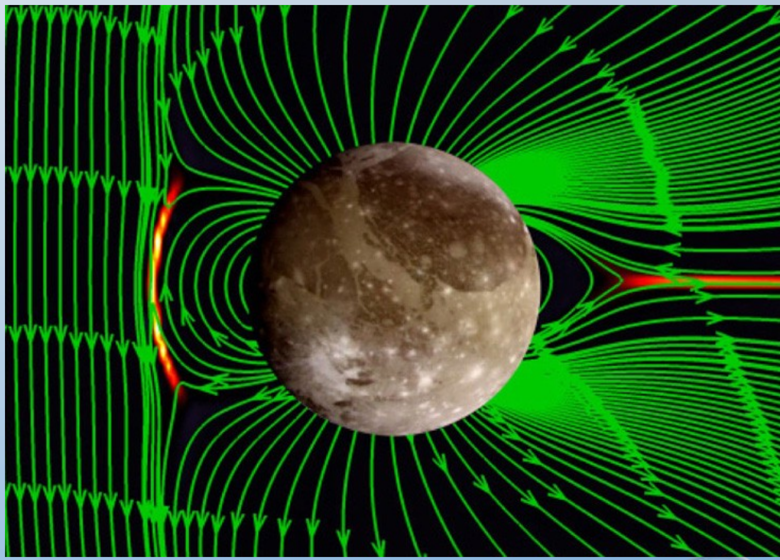
DETECTION OF GANYMEDE MAGNETOSPHERE & IONOSPHERE



dB







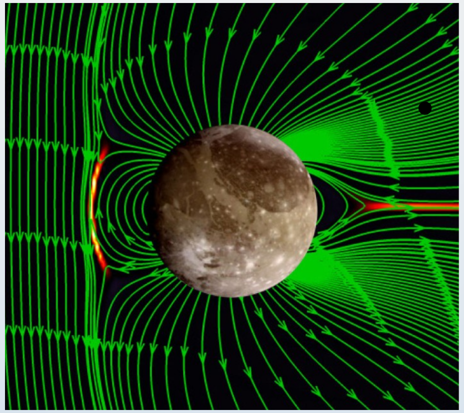
$N_e \approx$ 200-300 cm^{-3} @ 260 km
[Gurnett et al., 1996]

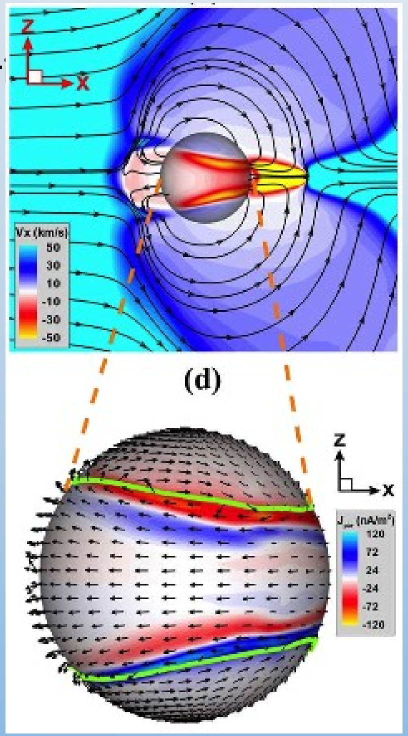
$T_i \approx$ 1-3 eV
[Frank et al., 1997]

ICY MOON CONDUCTIVITIES & ELECTRIC CURRENTS

- Determine the **electric conductivity of the ionospheres**
  - Assess their **role in supporting MHD-dynamo generated current systems** induced by the rotating and variable Jovian magnetosphere
  - Assess how these currents may **couple inductively to sub-surface oceans**
- Monitor **electric acceleration structures** at magnet flux tubes connected to **Ganymede's auroral regions.**

- $\sigma_H \approx - \sigma_P \sim en_e/(2B) \sim 10^{-4}\text{-}10^{-3}$ mho near surface
- $j \geq \sigma E \sim 0.1\ \mu A/m^2$
- $I \geq 100$ kA through ionosphere?
- Or through salty sub-surface ocean?



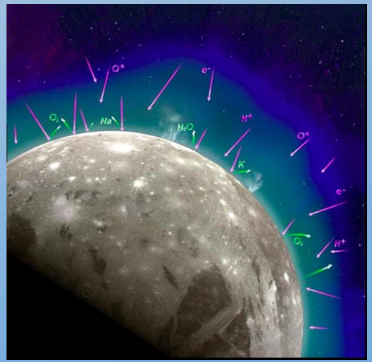


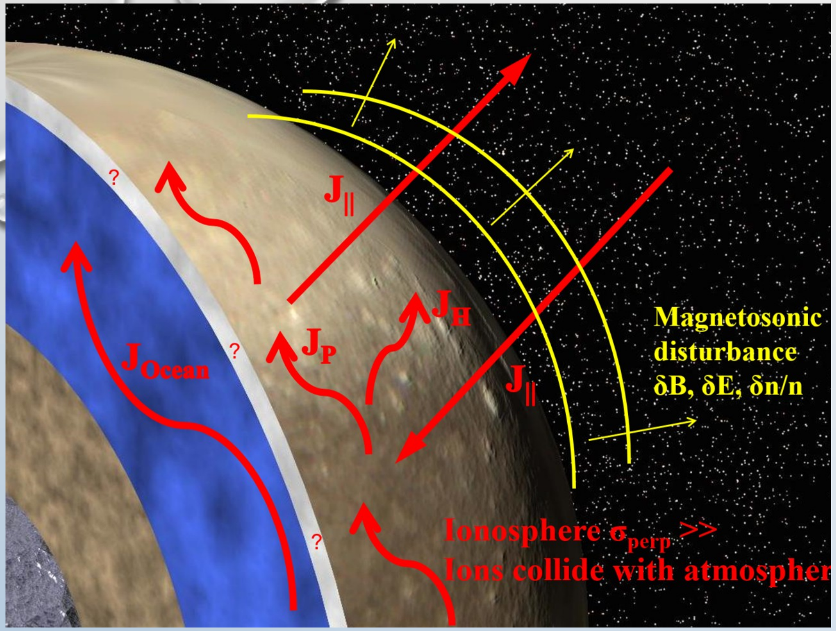
Upward/Downward
$j \approx 0.05\text{-}0.1\ \mu A/m^2$

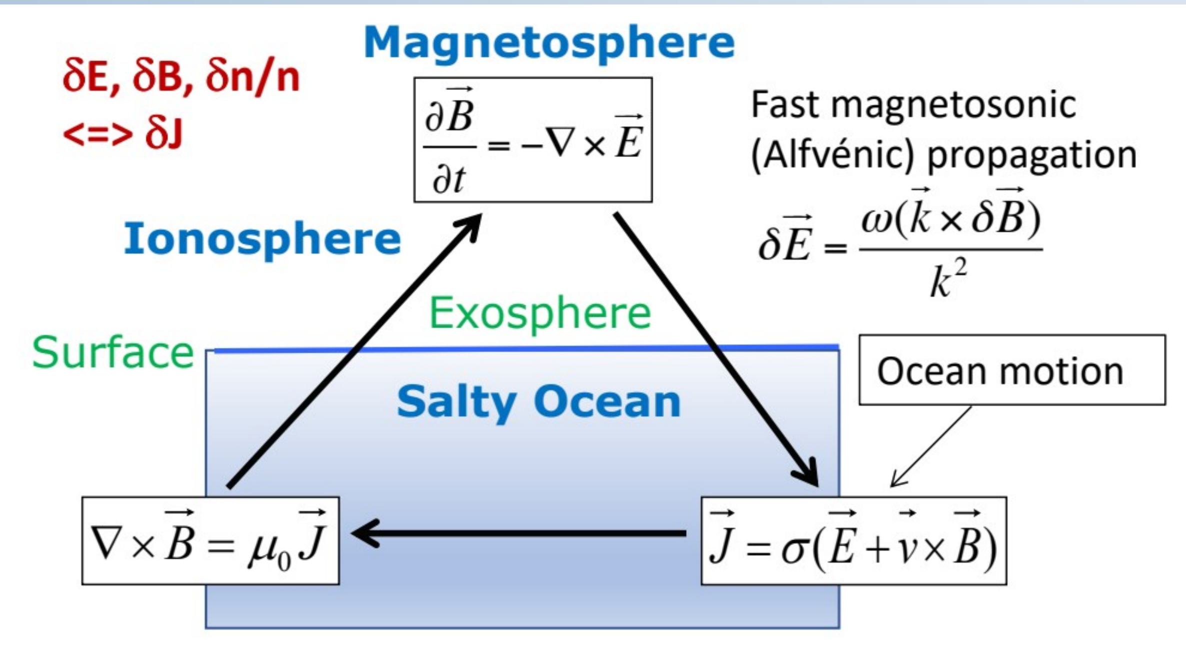
IONIZATION, HEATING AND DYNAMICS OF EXOSPHERES/IONOSPHERES

RPWI WILL:

- MONITOR PLASMA DENSITIES $10^{-4} - 10^{5}$ CM^{-3} (MS RESOLUTION)
- LOCATE (ELECTRON) HEATING REGIONS IN THE DENSE PLASMA (>0.1 CM^{-3})
- DETERMINE **EXB** CONVECTION AND BULK ION DRIFT SPEED
- MONITOR THE SIZE AND MASS DISTRIBUTION OF A POSSIBLY EXISTING CHARGED DUST COMPONENT
- MONITOR **DUST-PLASMA** INTERACTIONS





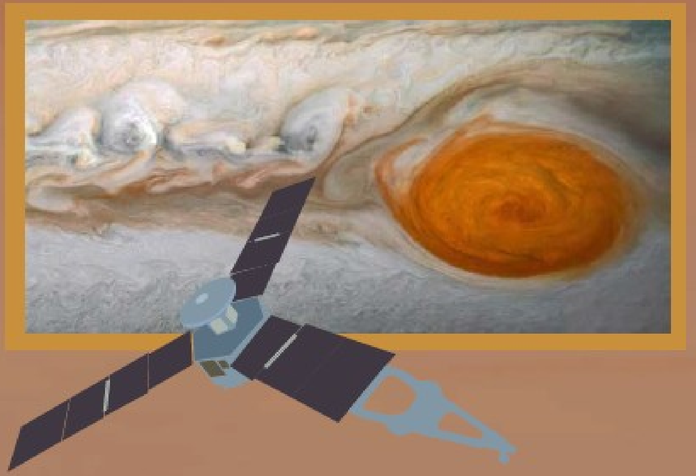


The induction process coupling the local space plasma where the spacecraft is situated to the electric currents in a conductive sub-surface ocean. The red parameters are measured in orbit (or during flybys) of the icy moons by RPWI and J-MAG onboard JUICE. The quasi-periodic magnetospheric induction disturbance dominantly from Jupiter's magnetodisc propagates down to the sub-surface ocean in an Alfvénic manner, and there generates an induction current. The ocean (e.g., tidal) motion also contributes to an electric current. The total induction response in the ocean propagates outward through the ionosphere to the magnetosphere, where the JUICE spacecraft measures the disturbed electric and magnetic fields at many frequencies (days, hours). Various other electric current sources, such as ionospheric electric currents, also contribute to the measured electric and magnetic fields and must be separated out from the contribution of the sub-surface ocean. For instance, the induction response itself generates electric currents in the ionosphere, and for Callisto, this ionospheric induction response can dominate the measurements.

esa

A TRIO OF MISSIONS: JUNO, JUICE AND EUROPA CLIPPER

Their destination may be the same, but Juno, Juice and Europa Clipper are all unique missions with different goals and instruments. Juno's discoveries are being used to optimise plans for Juice and Europa Clipper.

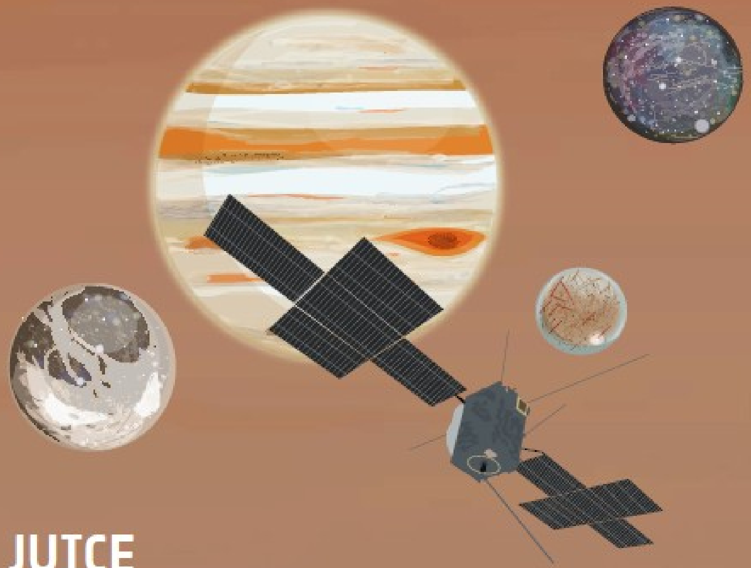


JUNO

Target: Jupiter

Arrival: 2016

Special skill: a polar orbit that goes very close to Jupiter, allowing deep mapping of its gravity and magnetic fields

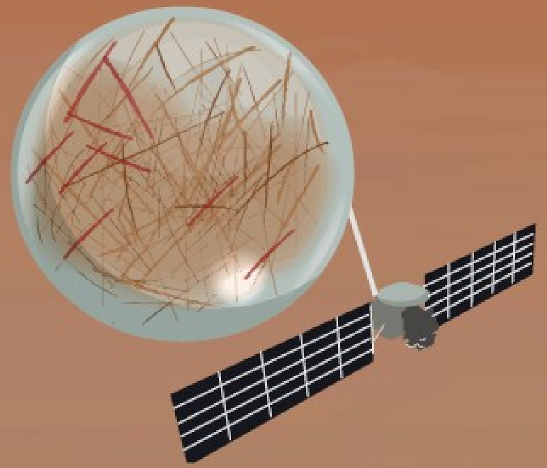


JUICE

Targets: Jupiter, Ganymede, Europa, Callisto

Arrival: 2031

Special skill: observing Jupiter and its icy moons to provide a complete view of habitable conditions in the Jovian system



EUROPA CLIPPER

Target: Europa

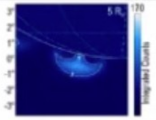
Arrival: 2030

Special skill: investigating the potential for life on Europa; helping select a landing site for a future Europa lander

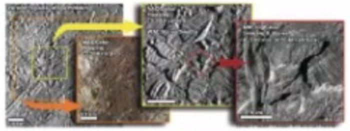
Start 10 2024 Jupiter 04 2030

Europa Clipper Remote Sensing Investigations

- **Ultraviolet Spectrograph/Europa (Europa-UVS)**
  - *Principal Investigator:* Dr. Kurt Retherford, Southwest Research Institute, San Antonio
  - Detect the likely presence of water plumes erupting from Europa's surface, including small plumes, and to provide valuable data about the composition and dynamics of Europa's rarefied atmosphere.

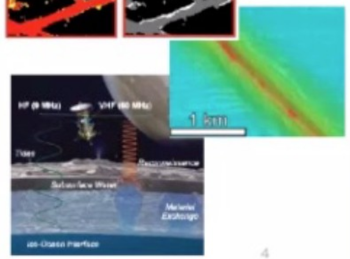


- **Europa Imaging System (EIS)**
  - *Principal Investigator:* Dr. Elizabeth Turtle, Johns Hopkins University Applied Physics Laboratory
  - Wide and narrow angle cameras to map most of Europa at better than 100 m resolution, and to provide images of areas of Europa's surface at up to 100 times higher resolution.



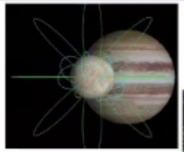
- **Mapping Imaging Spectrometer for Europa (MISE)**
  - *Principal Investigator:* Dr. Diana Blaney, Jet Propulsion Laboratory, California Institute of Technology
  - Probe the composition of Europa, identifying and mapping the distributions of organics, salts, acid hydrates, water ice phases, and other materials to determine the habitability of Europa's ocean.

- **Europa Thermal Emission Imaging System (E-THEMIS)**
  - *Principal Investigator:* Dr. Philip Christensen, Arizona State University, Tempe
  - Provide high spatial resolution, multi-spectral thermal imaging of Europa to help detect active sites, such as potential vents erupting plumes of water into space.
- **Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)**
  - *Principal Investigator:* Dr. Donald Blankenship, University of Texas, Austin
  - Characterize and sound Europa's icy crust from the near-surface to the ocean, revealing the hidden structure of Europa's ice shell and potential water within.

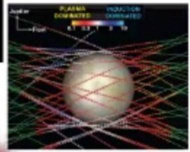


Europa Clipper *In Situ* Investigations

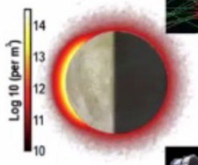
- **Europa Clipper Magnetometer (ECM)** – *Project provided instrument*
  - *Team Leader:* Dr. Margaret Kivelson, University of Michigan, Ann Arbor
  - To measure the magnetic field near Europa and infer the location, thickness and salinity of Europa's subsurface ocean using multi-frequency electromagnetic sounding.



- **Plasma Instrument for Magnetic Sounding (PIMS)**
  - *Principal Investigator:* Dr. Joseph Westlake, Johns Hopkins University Applied Physics Laboratory
  - In conjunction with a magnetometer, is key to determining Europa's ice shell thickness, ocean depth, and salinity by correcting the magnetic induction signal for plasma currents around Europa.



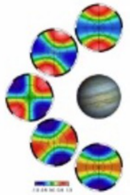
- **MAss SPectrometer for Planetary EXploration/Europa (MASPEX)**
  - *Principal Investigator:* Dr. James Burch, Southwest Research Institute, San Antonio
  - To determine the composition of the surface and subsurface ocean by measuring Europa's extremely tenuous atmosphere and any surface material ejected into space.

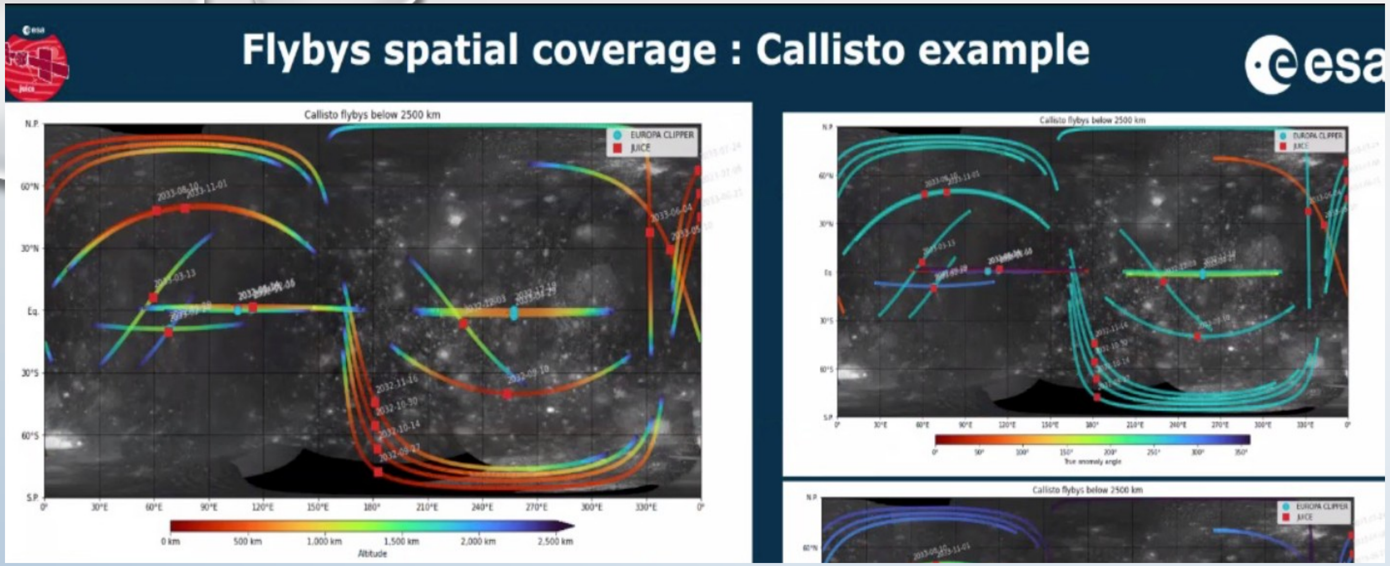


- **SUrface Dust Mass Analyzer (SUDA)**
  - *Principal Investigator:* Dr. Sascha Kempf, Univ. Colorado, Boulder
  - To measure the composition of small, solid particles ejected from Europa, providing the opportunity to directly sample the surface and potential plumes on low-altitude flybys.

- **Gravity and Radio Science (G/RS)** – *Project provided instrument*
  - *Team Leader:* Dr. Erwan Mazarico, GSFC, Greenbelt, MD
  - Using the telecommunications system to perform gravity and radio science experiments to enhance the science return of the Europa Clipper mission.

NEW

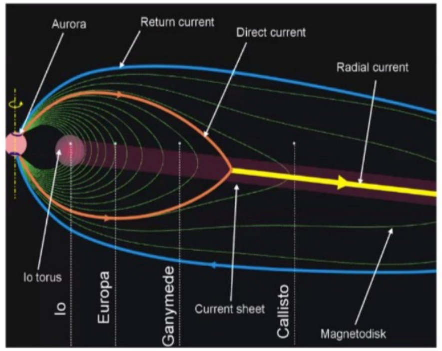


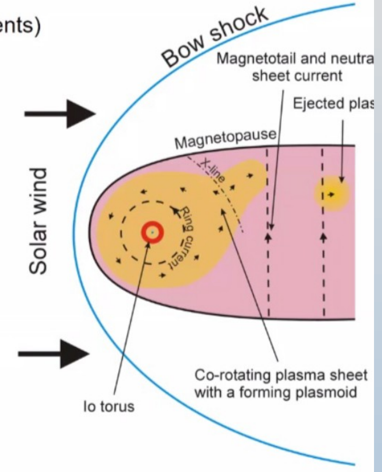


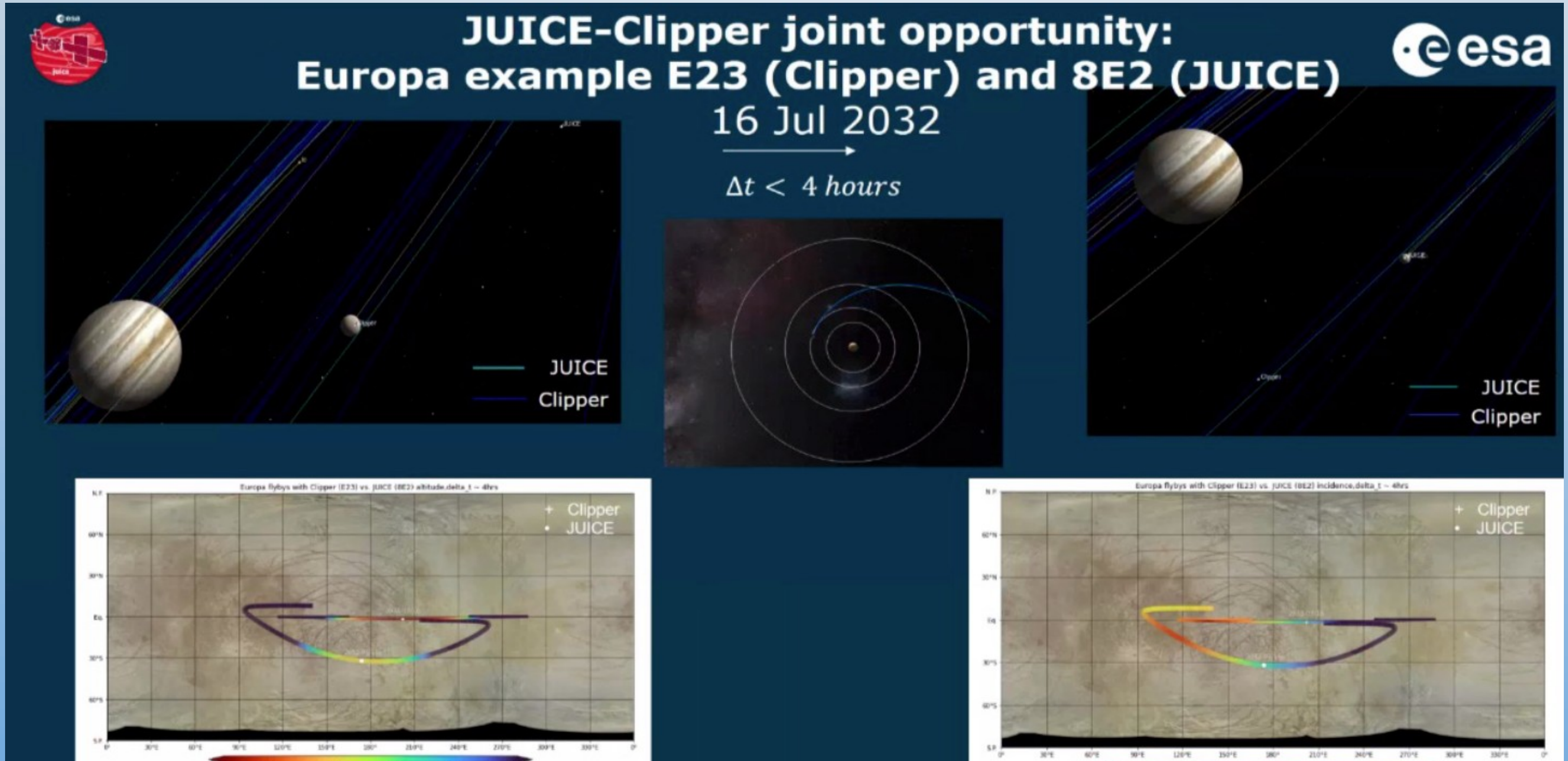
Dual-spacecraft Magnetospheric Dynamics

Physics of potential interest (among others):

- Radial transport (outward from Io, inward from injection events)
- Azimuthal transport (ring current, energy dispersion)
- Field-aligned transport (FACs, auroral connection)







18 institutions

23 countries

83 companies

116 industry contracts

>2000 people

~1.6 billion euros (mission cost)

esa

EUROPEAN PARTNERS

Many agencies, organisations and companies have contributed to the development of Juice. This map highlights the main contributing ESA Member States and their funding agencies. Prime contractor for the building of Juice is Airbus.

Austria
Austrian Research Promotion Agency

Belgium
Belgian Science Policy Office

Czech Republic
Department of Research and Development, Ministry of Education

France
National Centre for Space Studies (CNES)

Germany
German Space Agency at DLR

Greece
Academy of Athens

Hungary
Centre for Energy Research

Italy
Italian Space Agency (ASI)

Poland
Ministry of Entrepreneurship and Technology

Spain
Ministry of Economy and Competitiveness

Sweden
Swedish National Space Agency

Switzerland
Swiss Space Office

United Kingdom
UK Space Agency

Beyond Europe:

United States
National Aeronautics and Space Administration (NASA)

Japan
Japan Aerospace Exploration Agency (JAXA)

Israel
Israel Space Agency (ISA)