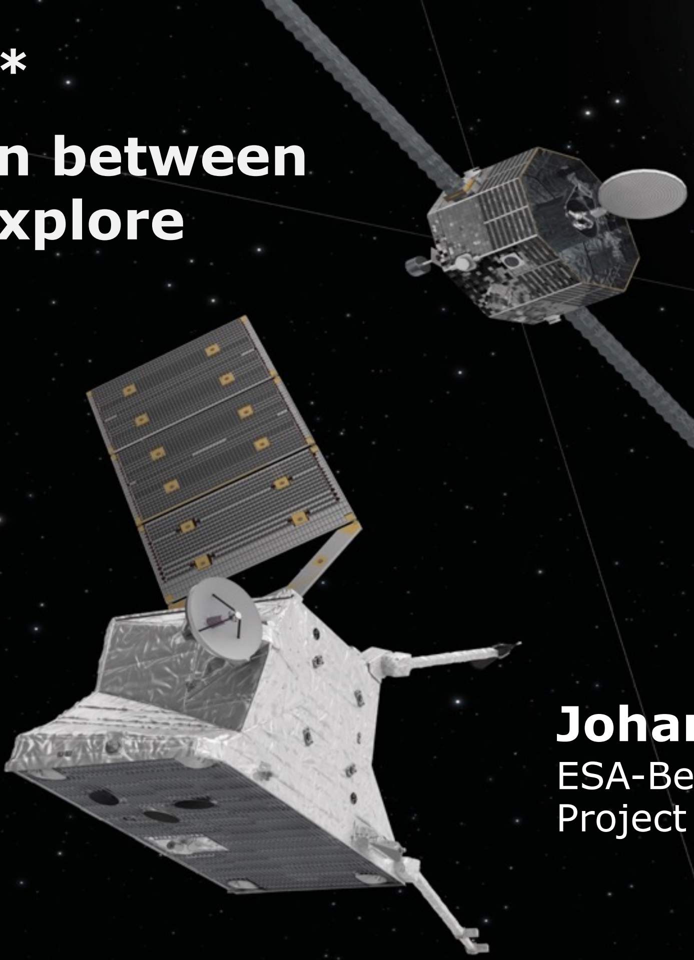
BepiColombo*

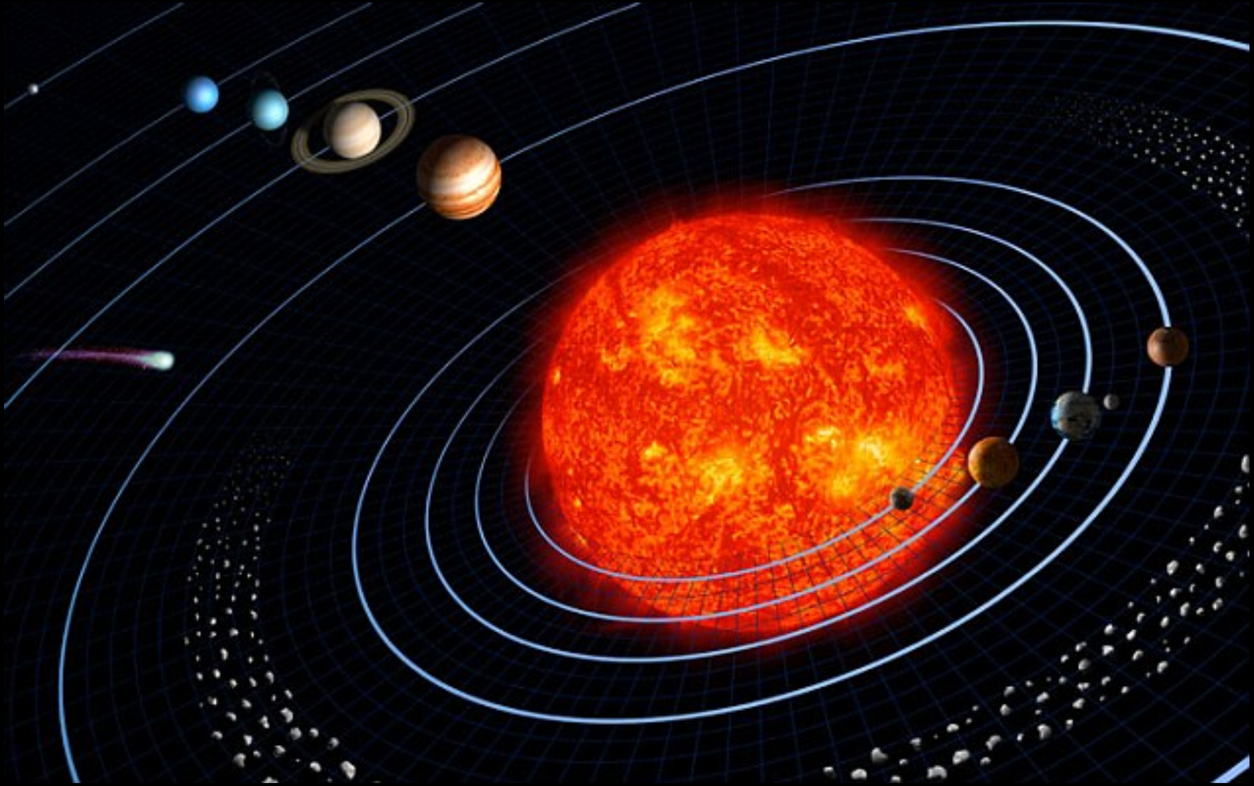
Joint Space Mission between ESA and JAXA to explore planet Mercury



Johannes Benkhoff

ESA-BepiColombo
Project Scientist

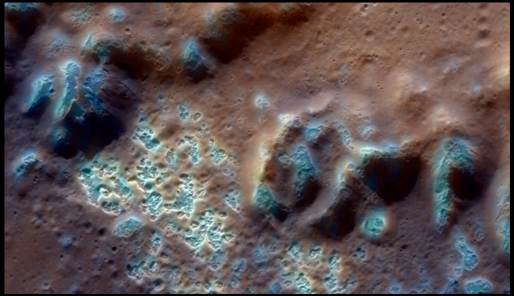
*) named after Prof. Giuseppe (Bepi) Colombo



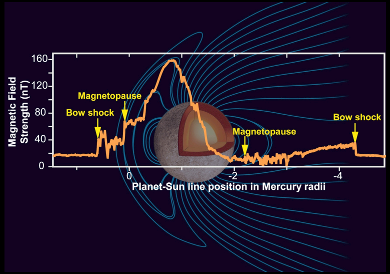
→ To study Mercury it is essential to understand the formation history of our Solar System

→ Mercury is a key element because of its position so close to the Sun

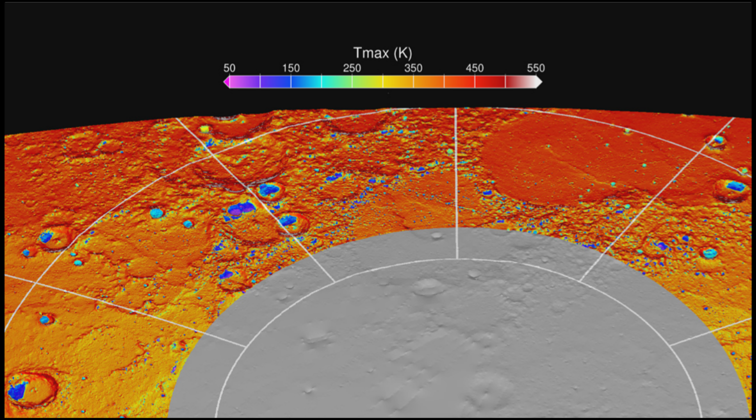
Mercury mysteries



Not seen on other planets: Hollows



Mercury has an Earth like Magnetic Field

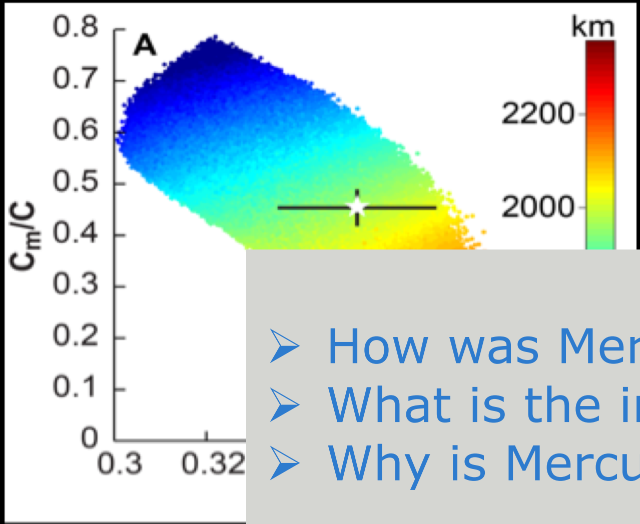


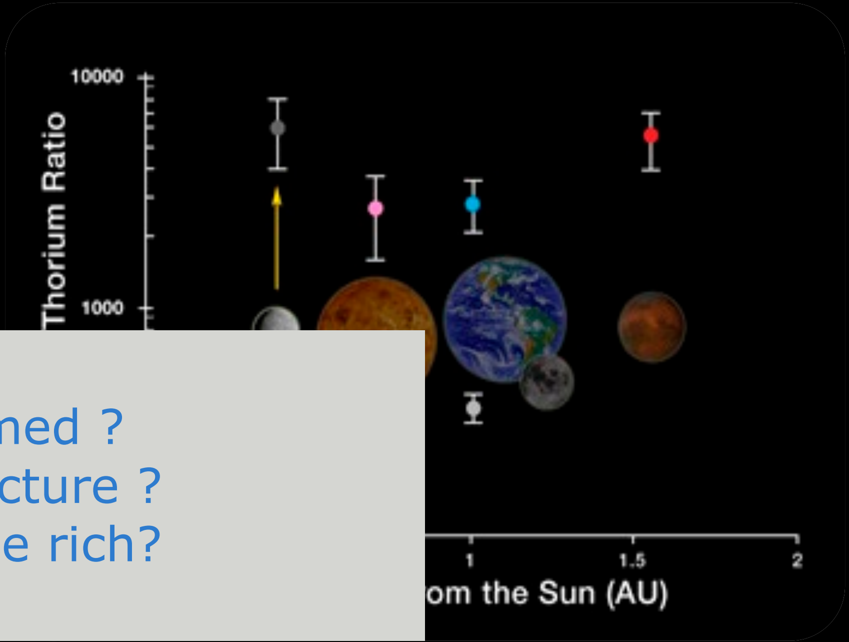
Water ice in deep polar craters expected

- ➢ What is the origin of the polar ice ?
- ➢ How was Mercury formed
- ➢ What cause the formation of hollows ?

Image Credit: NASA/The Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Mercury mysteries



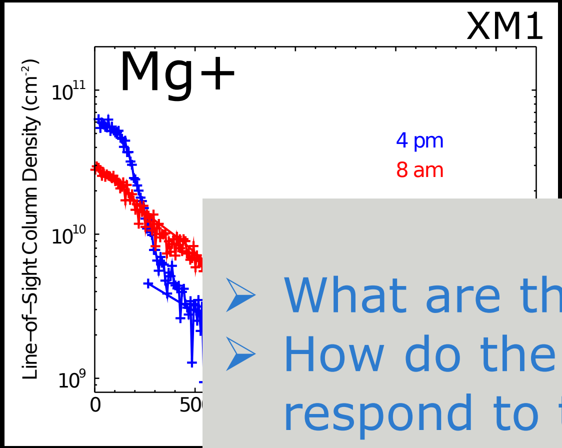


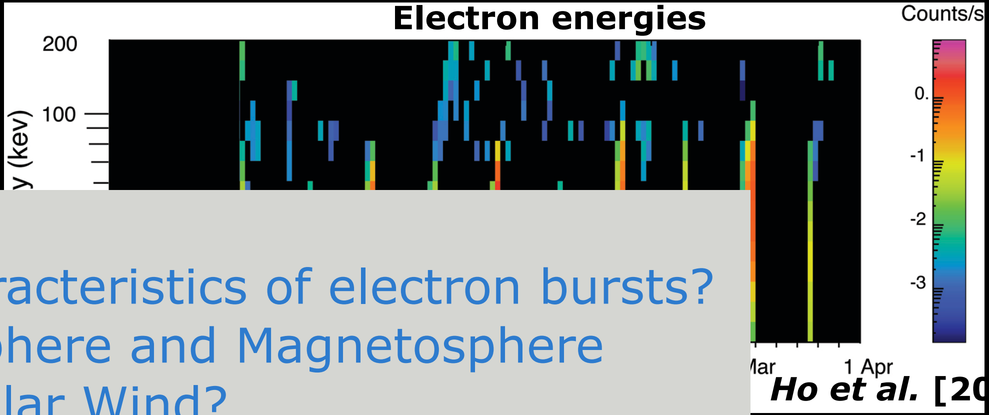
- ➢ How was Mercury formed ?
- ➢ What is the inner structure ?
- ➢ Why is Mercury volatile rich?

MESSENGER observations of the gravity field components C_{20}, and C_{22} together with earthbound observations of the libration and obliquity have been used determine the interior structure. Core radius of 2000 – 2050 km, mantle thickness of ca 400 km (Hauck et al, 2013)

MESSENGER showed that Mercury is volatile richer than previously thought and then perhaps not consistent with some formation scenarios e.g., giant impact or series of giant impacts

Mercury mysteries





- ➢ What are the characteristics of electron bursts?
- ➢ How do the Exosphere and Magnetosphere respond to the Solar Wind?
- ➢ What are the implications ?

Distribution of variations in d densities

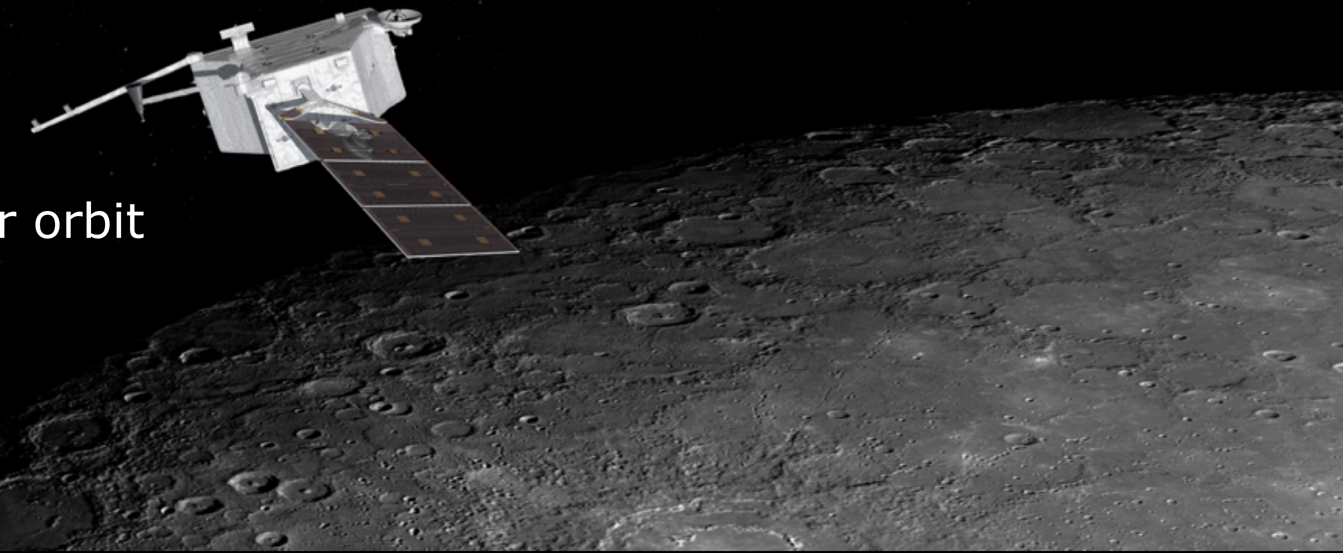
ns ENGER

Science objectives

- the origin and evolution
- Mercury's figure, interior structure, and composition
- Interior dynamics and origin of its magnetic field
- Composition, origin and dynamics of Mercury’s exosphere and polar deposits
- Structure and dynamics of Mercury's magnetosphere
- Test of Einstein's theory

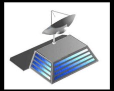
Launched on 20 October 1:45 UT

MPO –Mercury Planetary Orbiter

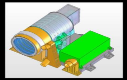


- Low-eccentricity polar orbit (480x1500 km)
- 2.3 hours period
- Mainly nadir pointing

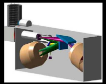
MORE
Radio Science
Ka-band Transponder
L. Iess



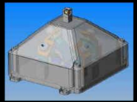
SIMBIO-SYS
High Res.+ Stereo Cameras
visual + NIR Spectrometer
G. Cremonese



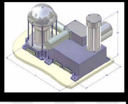
PHEBUS
UV
Spectrometer
E. Quémerais

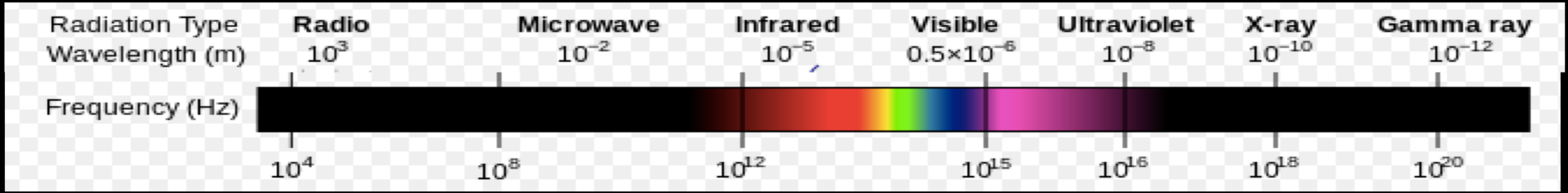


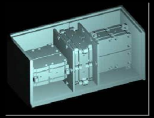
SIXS
Solar Monitor
J. Huovelin



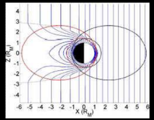
MGNS
Gamma Ray/
Neutron Spect.
I. Mitrofanov



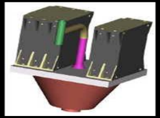




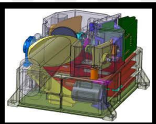
ISA
Italian Spring
Accelerometer
V. Iafolla



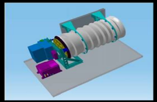
MERMAG
Magnetometer
D. Heyner



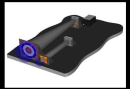
SERENA
Neutral Particle Analyser
Ion Spectrometers
S. Orsini



MERTIS
Thermal IR
Spectrometer
H. Hiesinger



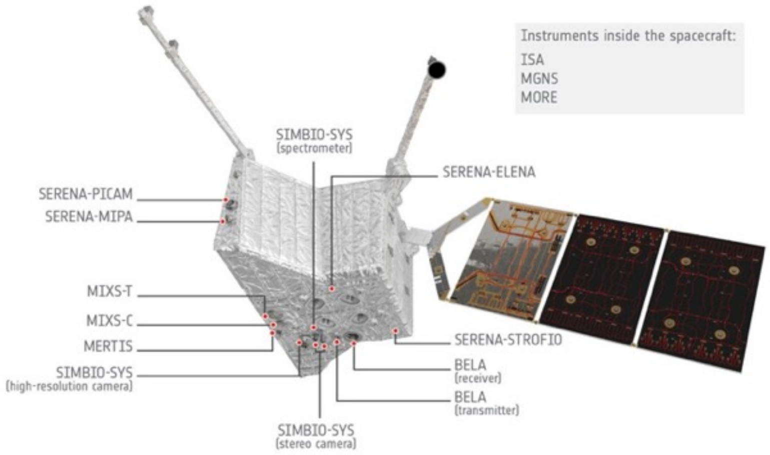
BELA
Laser Altimeter
N. Thomas
T. Spohn

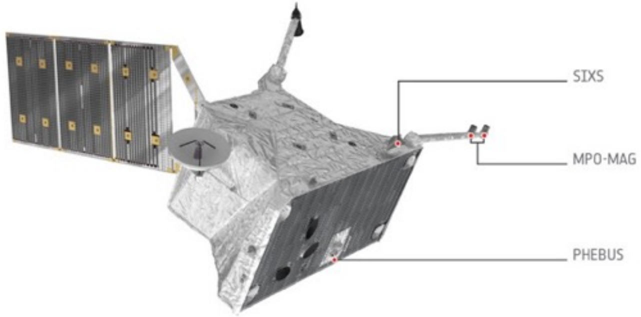


MIXS
X-ray
Spectrometer
E. Bunce

MPO Payload

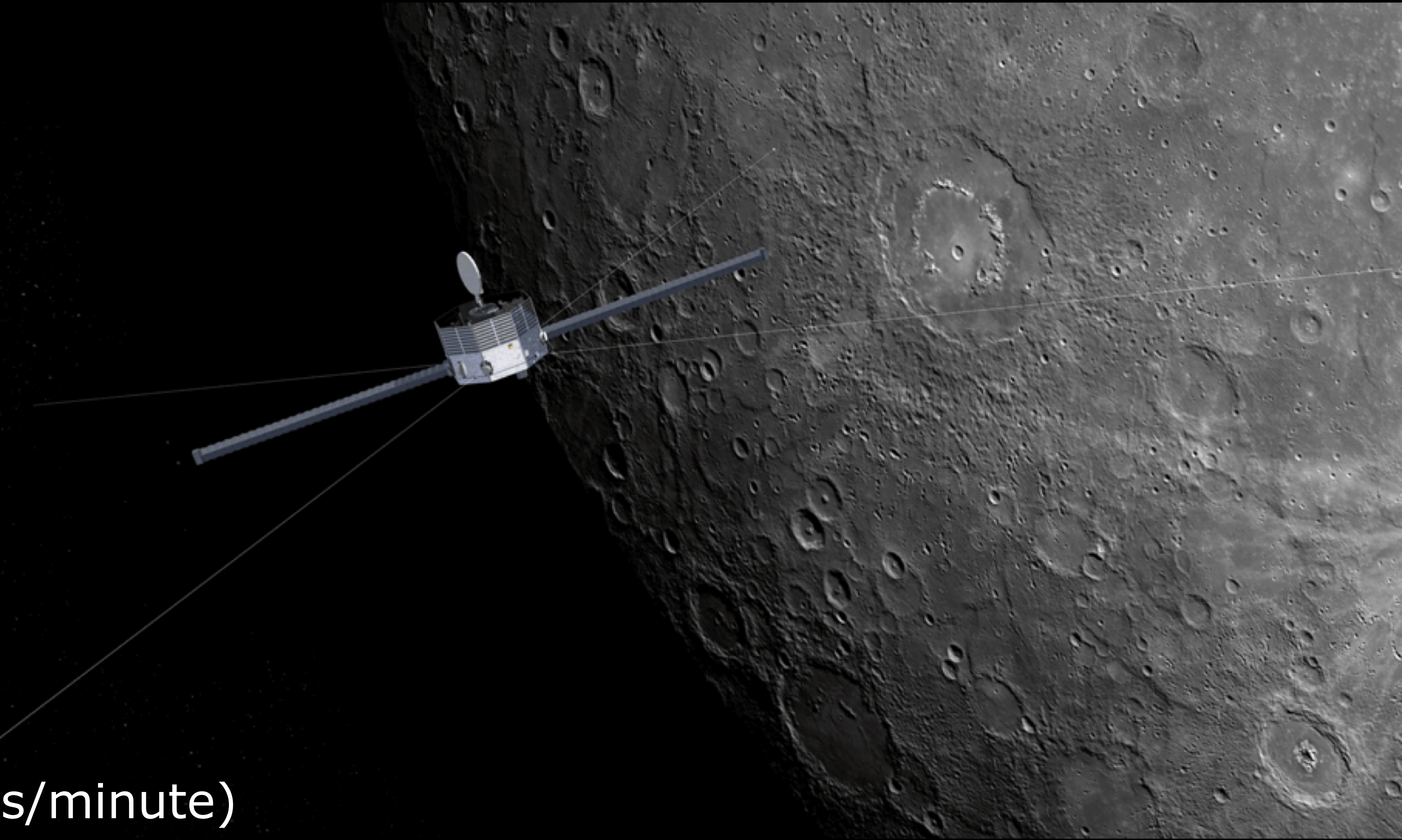
MPO – Instruments



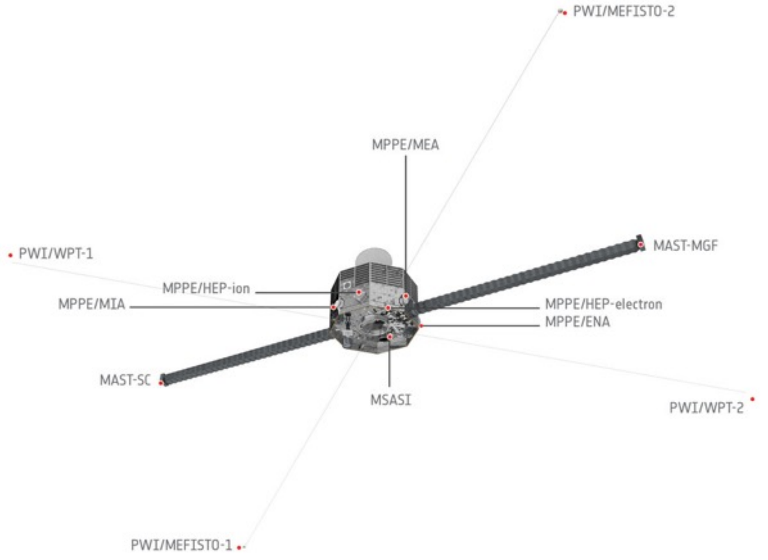


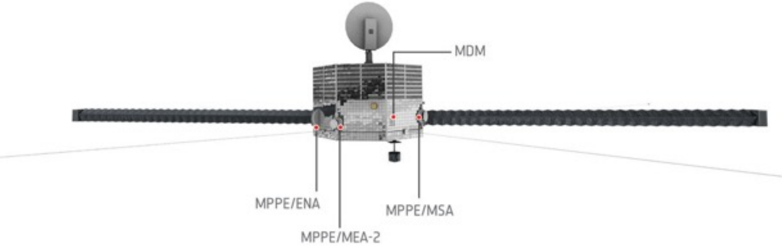
	Instrument description
BELA	Characterise the topography and surface morphology of Mercury.
MORE	Determine Mercury’s gravity field as well as the size and physical state of its core.
ISA	Study Mercury’s interior structure and to test Einstein’s Theory of Relativity.
MPO-MAG	Describe Mercury’s magnetic field and its source.
MERTIS	Study of Mercury’s mineralogical composition, global temperature maps.
MGNS	Elemental composition of Mercury’s surface distribution of volatiles in polar areas
MIXS	Use X-ray fluorescence analysis a global map of the surface atomic composition.
PHEBUS	Characterisation of the composition and dynamics of Mercury’s exosphere.
SERENA	Study the interactions between the surface, exosphere, magnetosphere & the solar wind.
SIMBIO-SYS	Provide global, high-resolution, and IR imaging of the surface
SIXS	Perform measurements of solar X-rays and particles at high time resolution.

Mio – Mercury Magnetospheric Orbiter



- polar orbit (590x11640 km)
- 9.2 hours period
- Spinning (15 orbits/minute)

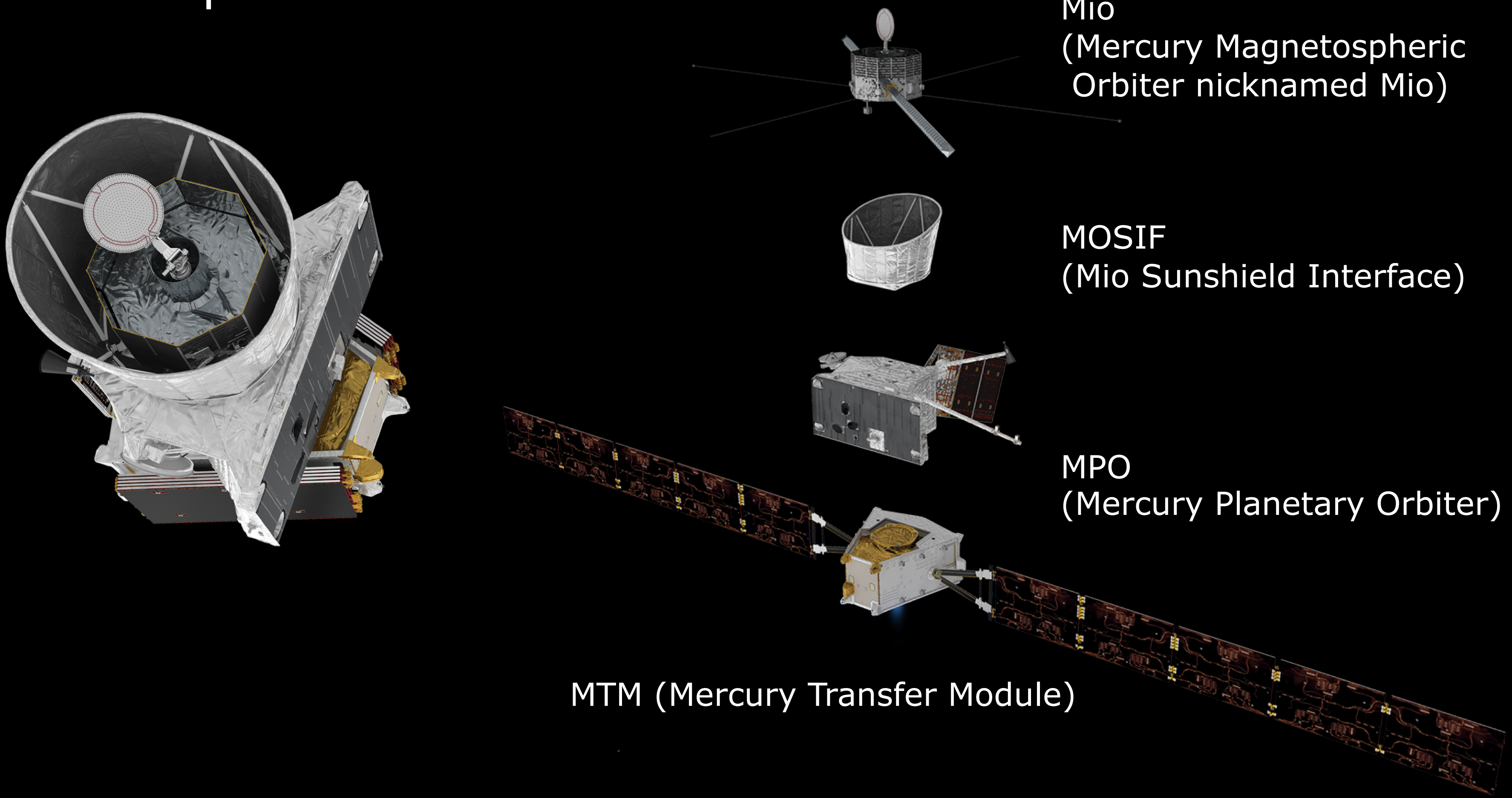




Mio – Instruments

	Instrument description
MGF	Provide a detailed description of Mercury's magnetosphere and of its interaction with the planetary magnetic field and the solar wind.
MPPE	Study low- and high-energetic particles in the magnetosphere. MEA- Electron Analyzer MIA – Ion Analyzer HEP-ion – High Energy Particles HEP-electron – High Energy Particles ENA – Energetic Neutrals Analyzer MSA – Mass Spectrum Analyzer
PWI	Make a detailed analysis of the structure and dynamics of the magnetosphere. MEFISTO, WPT – two sets of electric field sensors LF-SC and DB-SC -- two kinds of magnetic field sensors
MSASI	Measure the abundance, distribution, and dynamics of sodium in Mercury's exosphere.
MDM	Study the distribution of interplanetary dust in the orbit of Mercury.

Spacecraft Overview



How does BepiColombo get to Mercury ?

Launch: 20 October 2018

Mercury arrival: December 2025

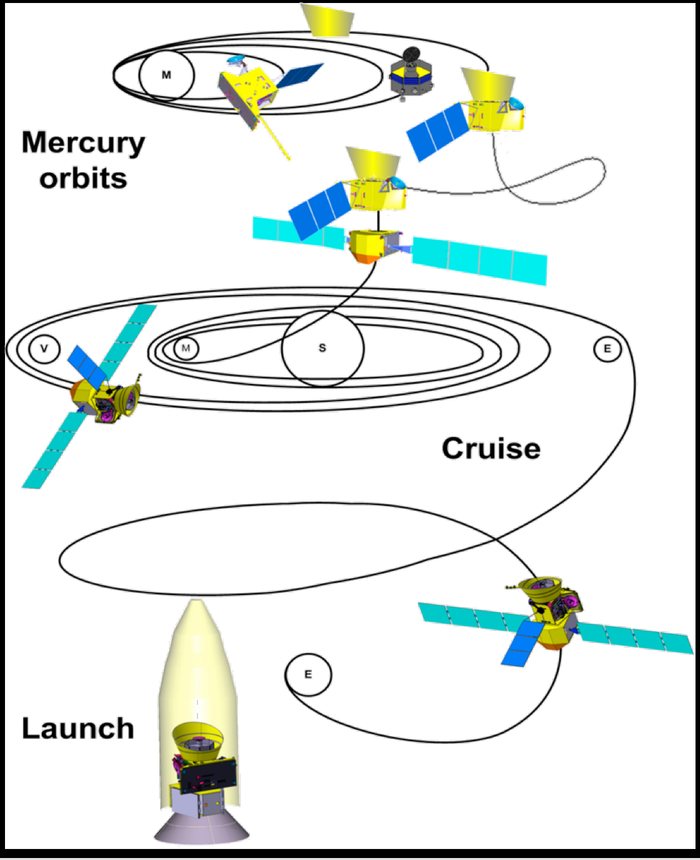
Cruise phase:

- 1 Earth flyby
- 2 Venus flybys
- 6 Mercury flybys

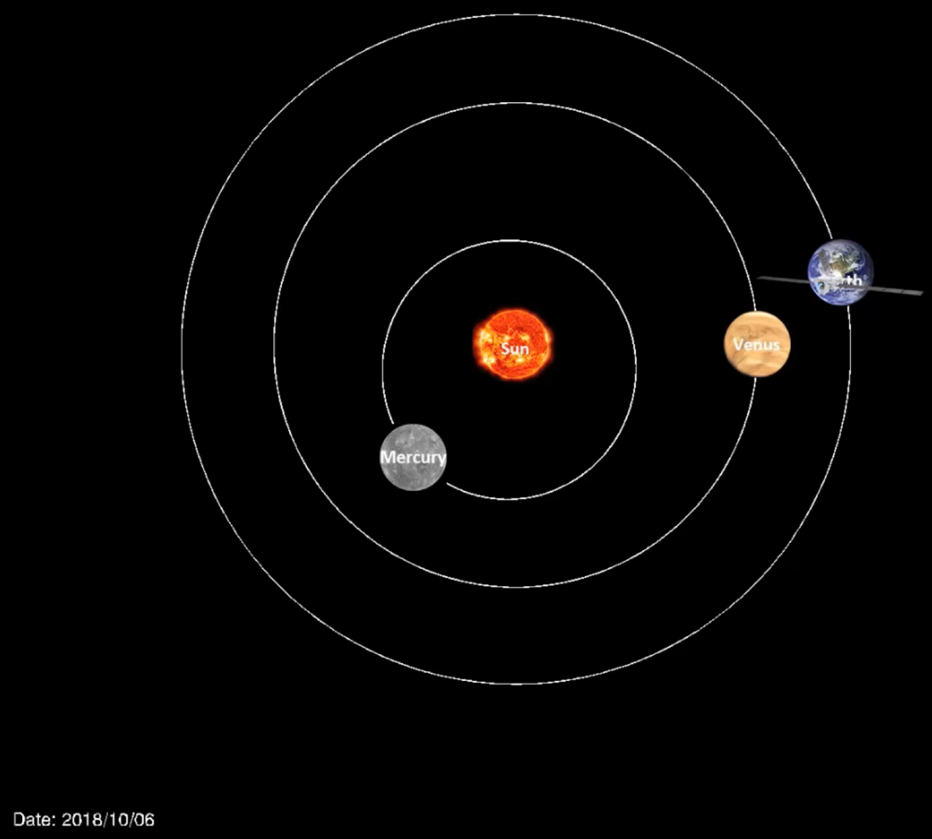
Science phase:

Start: April 2026

Duration: 1 + 1 year



Cruise to Mercury



20 Oct 2018: Start
10 Apr 2020: Earth flyby

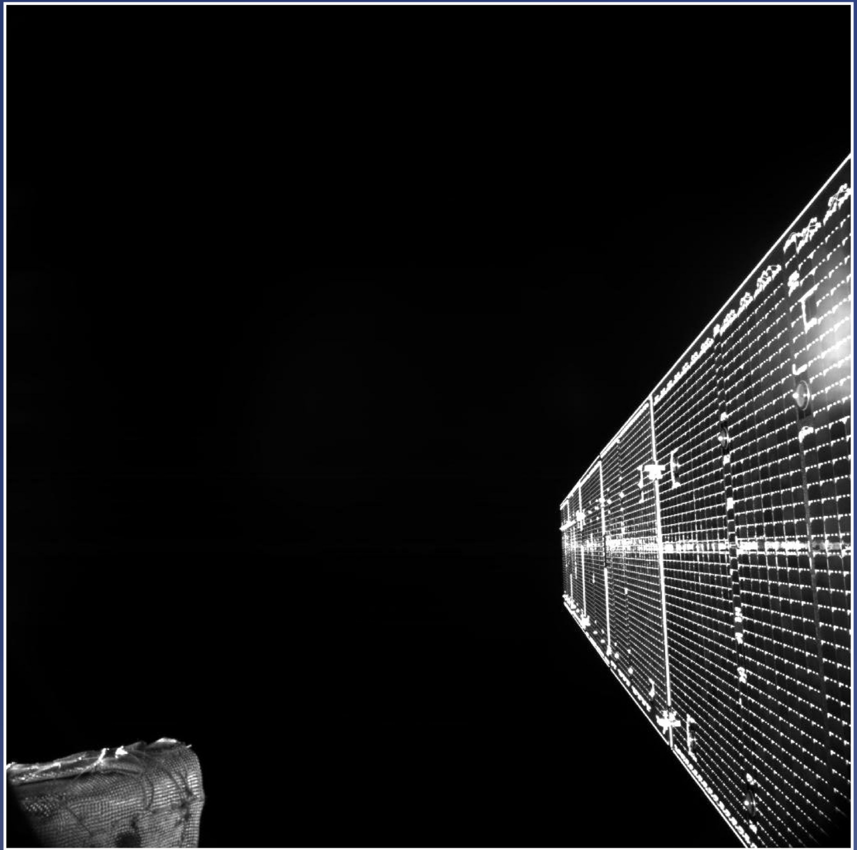
15 Oct 2020: Venus flyby #1
10 Aug 2021: Venus flyby #2

1 Oct 2021: Mercury flyby #1
Jun 2022: Mercury flyby #2
Jul 2023: Mercury flyby #3
Sep 2024: Mercury flyby #4
Dec 2024: Mercury flyby #5
Jan 2025: Mercury flyby #6

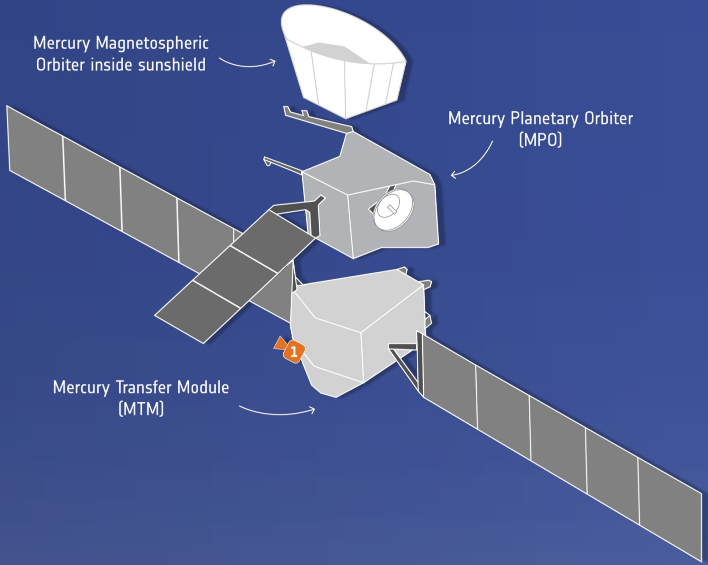
Dec 2025: Mercury orbit insertion

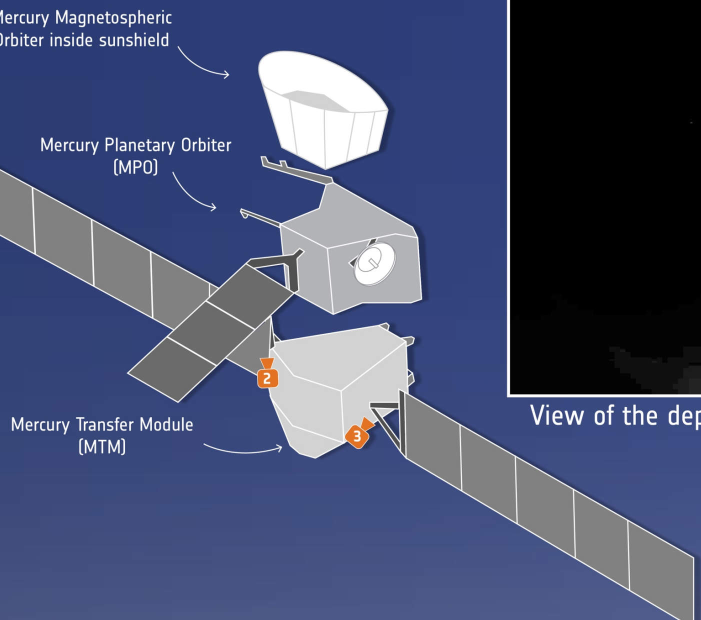
Launch 20 October 2018

1 M-CAM 1



View of the deployed MTM solar array

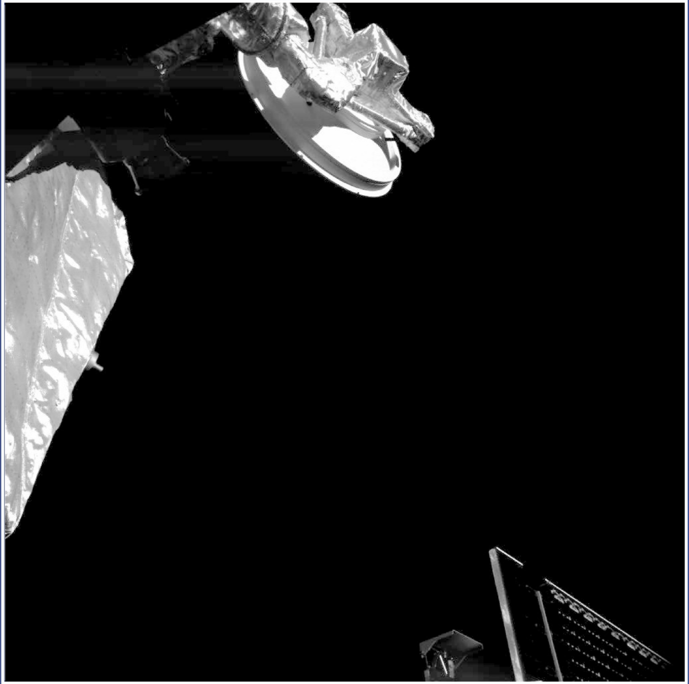




M-CAM 2

View of the deployed medium-gain antenna on the MPO

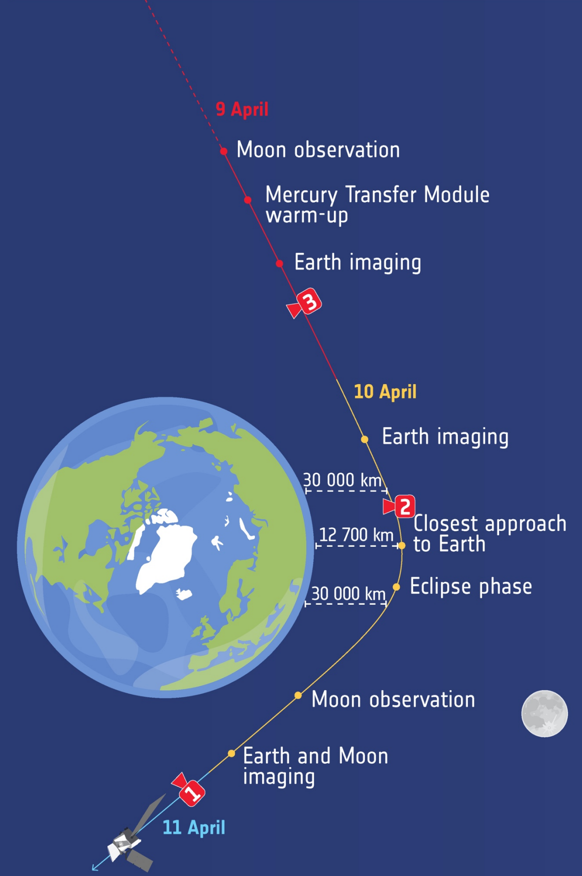
M-CAM 3



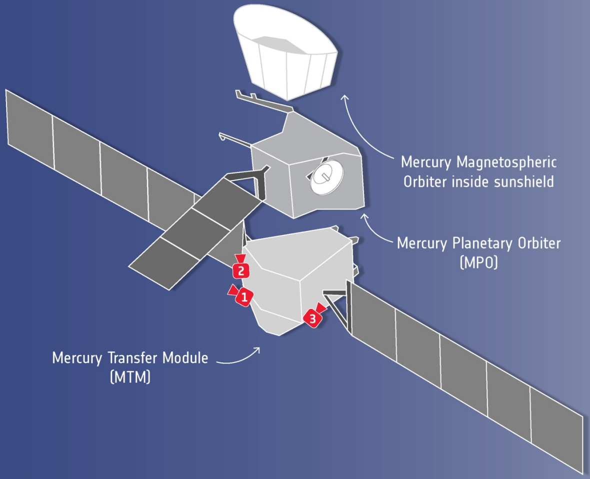
View of the deployed high-gain antenna on the MPO

Earth Flyby 10 April 2020

BEPICOLOMBO IMAGES EARTH DURING FLYBY

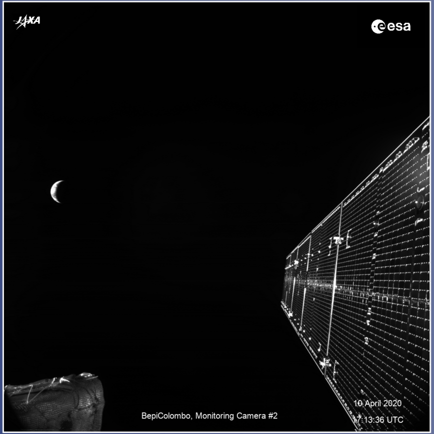


3 9 April - MTM monitoring camera 3 128 000 km



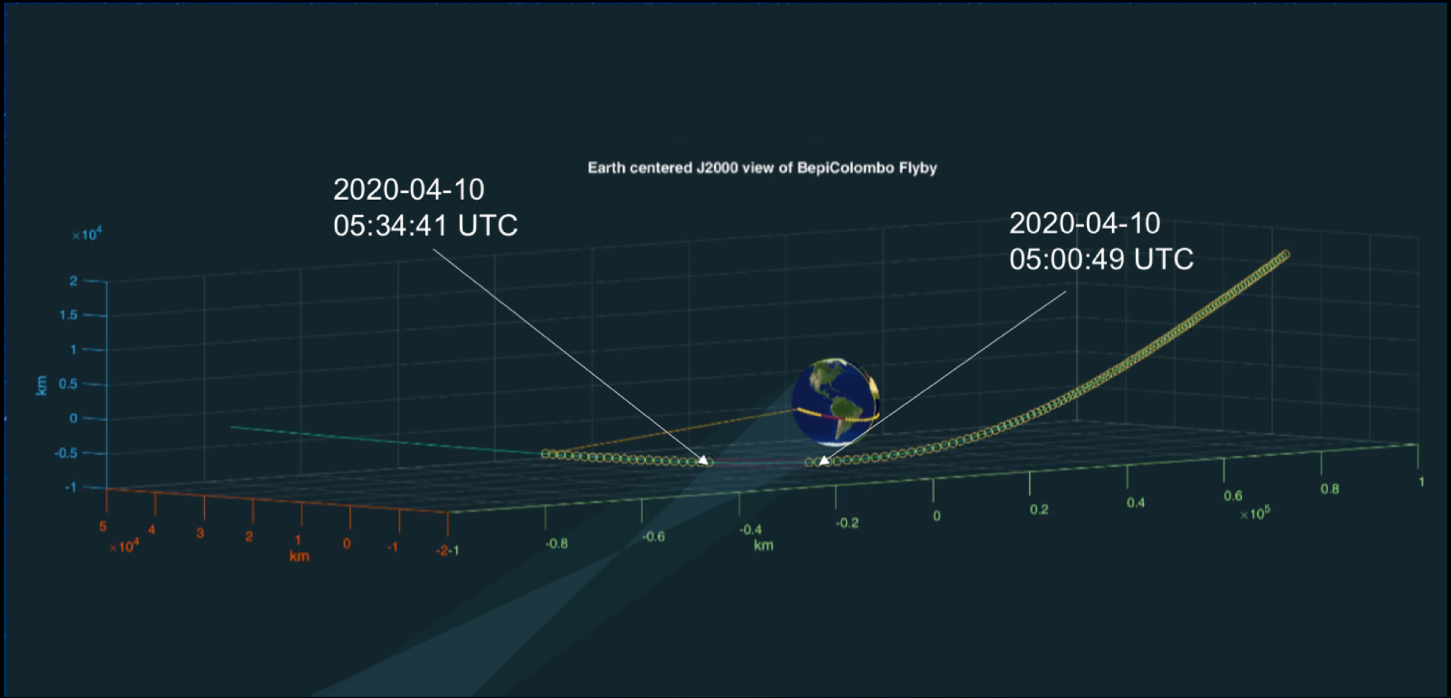
2 10 April - MTM monitoring camera 2 17 500 km

1 11 April - MTM monitoring camera 1 540 400 km



#bepicolombo

33:55 minutes Eclipse during Flyby

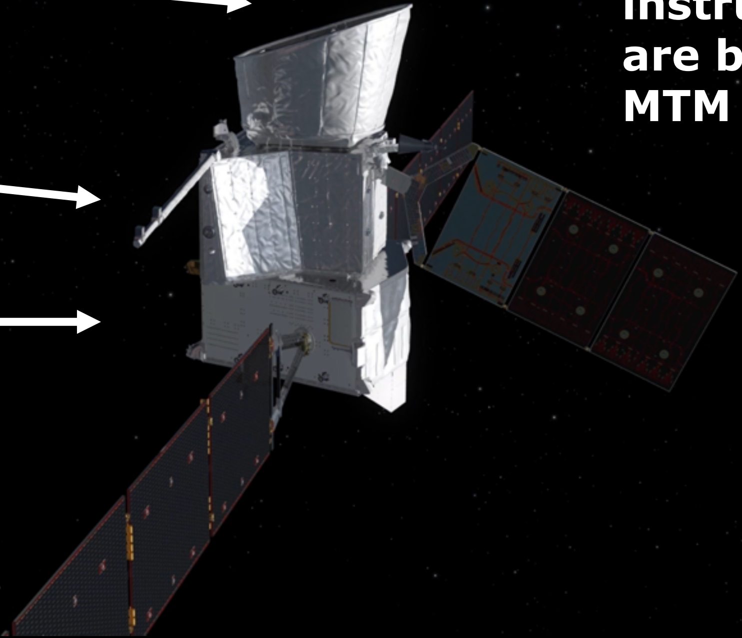


BepiColombo: cruise configuration

Mio

MPO

MTM

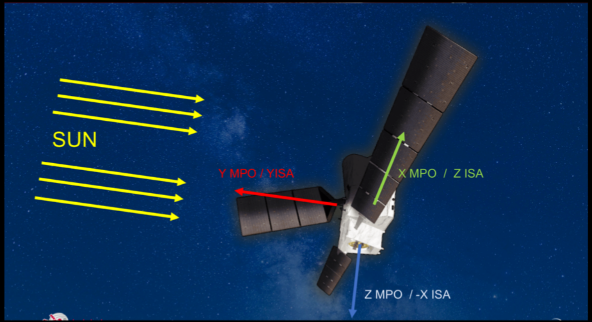


MPO remote sensing instruments on Nadir Panel are blocked (covered) by MTM

BELA, SIMBO-SYS, MIXS, MERTIS*

*) MERTIS has a space-view for calibration

First results from ISA and MGNS:



ISA, INAF Rom
Acceleratio ments during
eclipse xis

Unpublished, confidential results

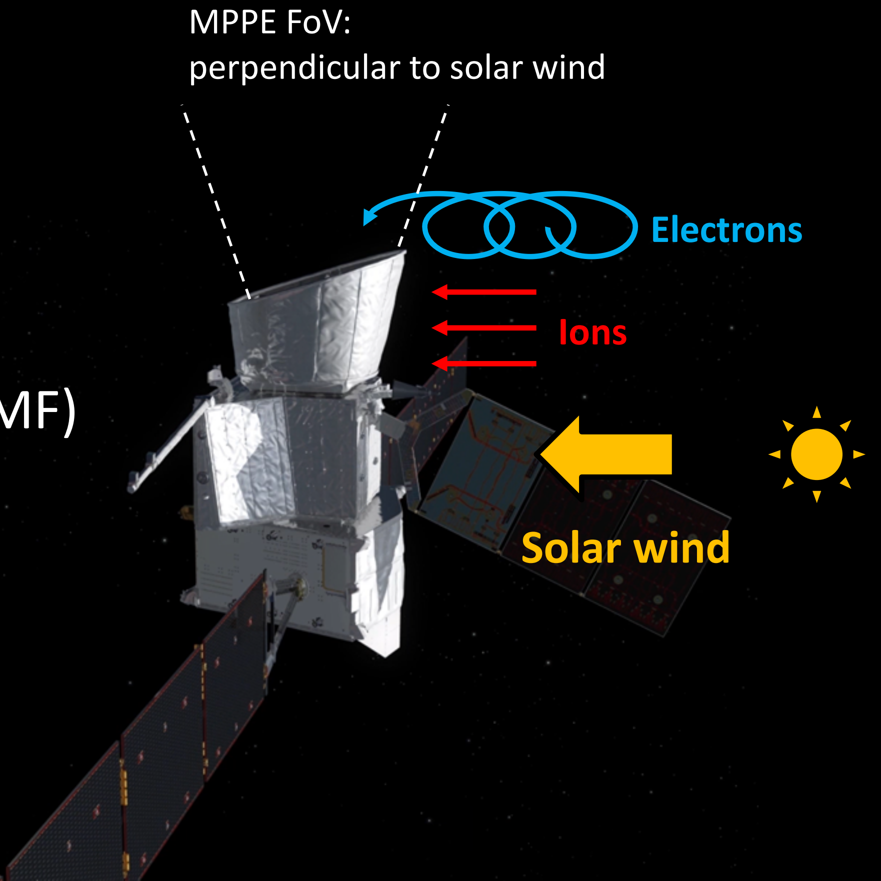
M ussia, gamma-rays time
or possible terrestrial ^{16}O
lear line detected at Earth fly-by
flight of BepiColombo

PICAM/ MPO MAG comparison

Unpublished, confidential results

BepiColombo: Mio cruise science

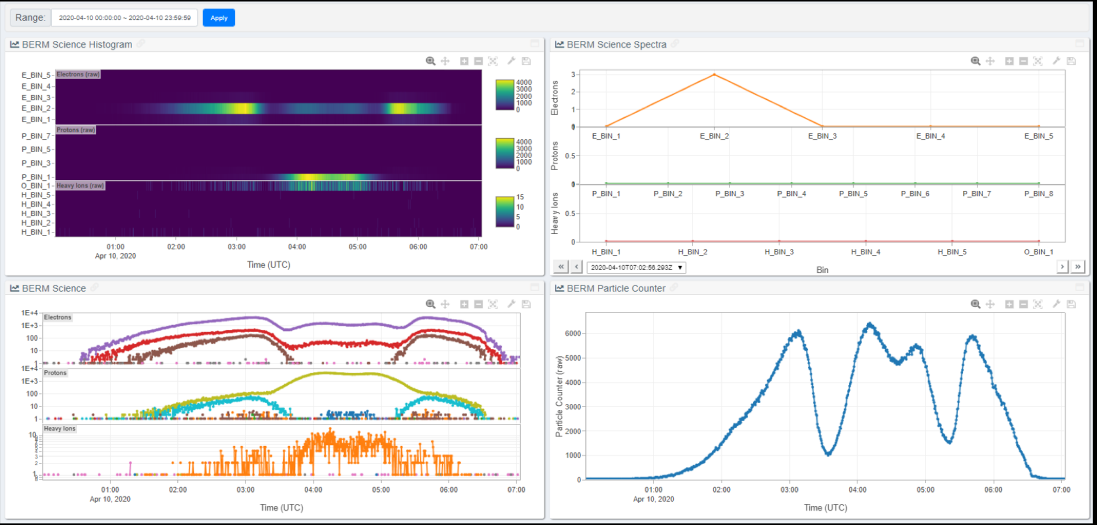
- **MPPE/MEA**: solar wind electron temperature
- **MPPE/HEP-e**: solar energetic particles (SEP)
- **MGF**: interplanetary magnetic fields (IMF)
- **PWI**

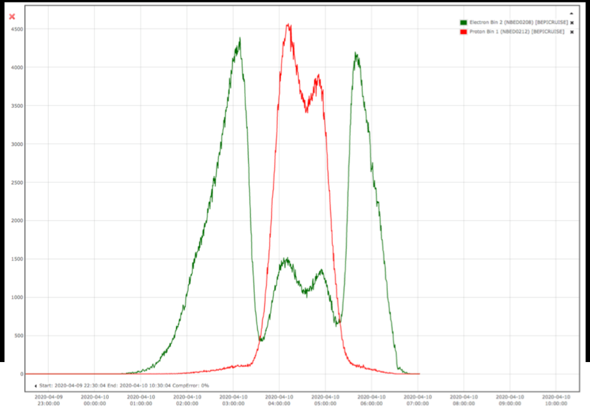


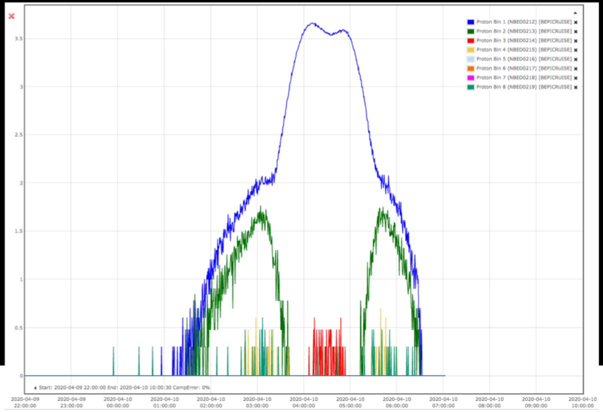
Mio: fist results

Unpublished, confidential results

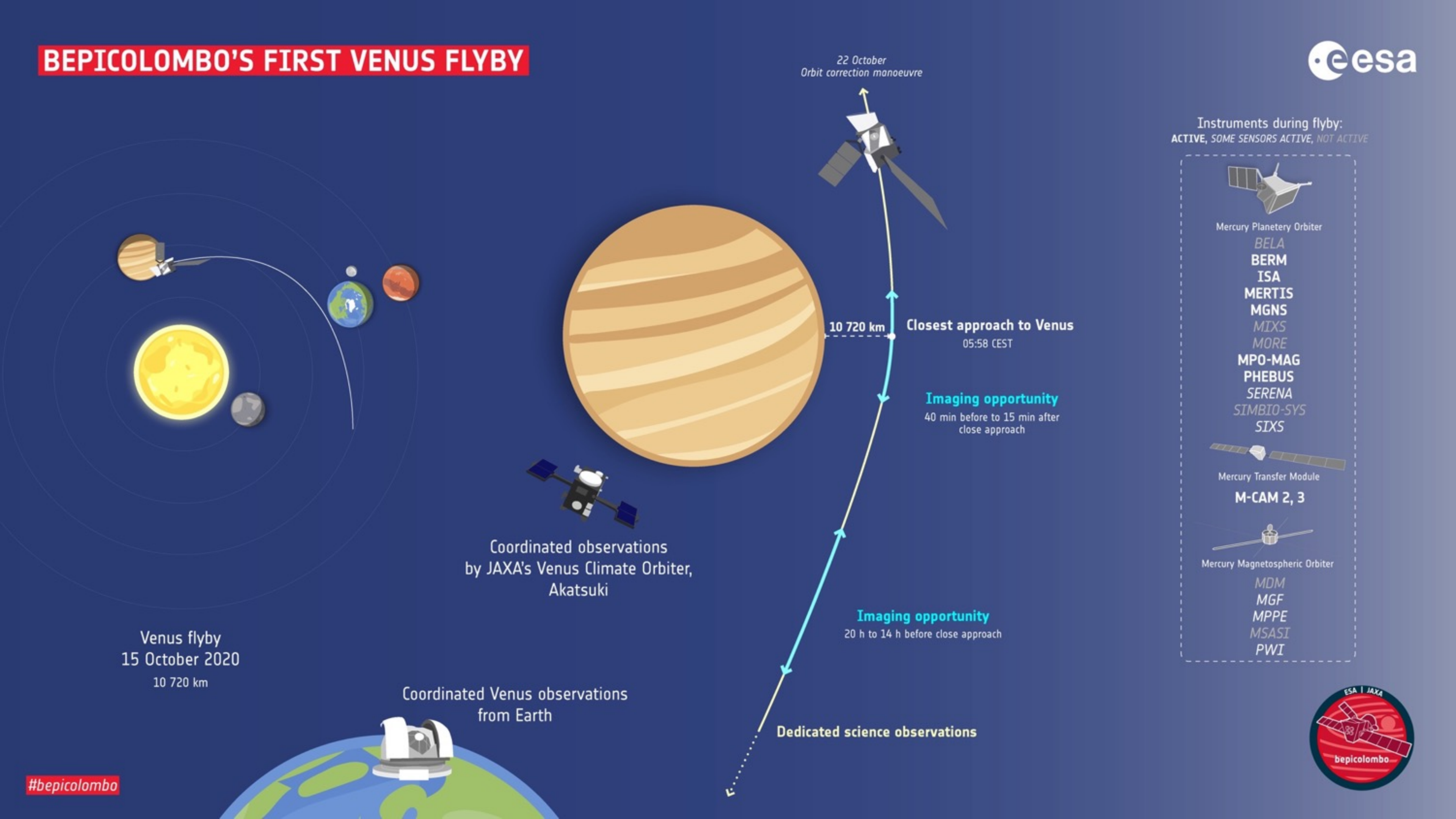
Radiation Monitor: BERM







1st VENUS Flyby 15 October 2020



BEPICOLOMBO'S FIRST VENUS FLYBY
22 October
Orbit correction manoeuvre
Instruments during flyby:
ACTIVE, SOME SENSORS ACTIVE, NOT ACTIVE
Mercury Planetery Orbiter
BELA
BERM
ISA
MERTIS
MGNS
MIXS
MORE
MPO-MAG
PHEBUS
SERENA
SIMBIO-SYS
SIXS
Mercury Transfer Module
M-CAM 2, 3
Mercury Magnetospheric Orbiter
MDM
MGF
MPPE
MSASI
PWI
10 720 km
Closest approach to Venus
05:58 CEST
Imaging opportunity
40 min before to 15 min after close approach
Coordinated observations by JAXA's Venus Climate Orbiter, Akatsuki
Imaging opportunity
20 h to 14 h before close approach
Venus flyby
15 October 2020
10 720 km
Coordinated Venus observations from Earth
Dedicated science observations
#bepicolombo
ESA | JAXA
bepicolombo

Venus flyby 15 October 2020

Operating instruments at Venus

MPO:

BERM

ISA

MERTIS

MGNS

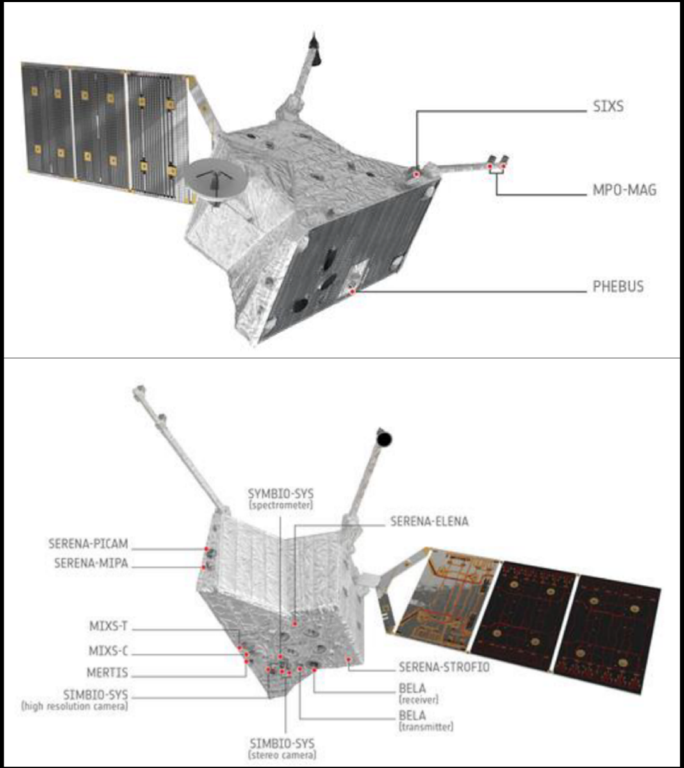
MORE

MPO-MAG

PHEBUS

SERENA

SIXS

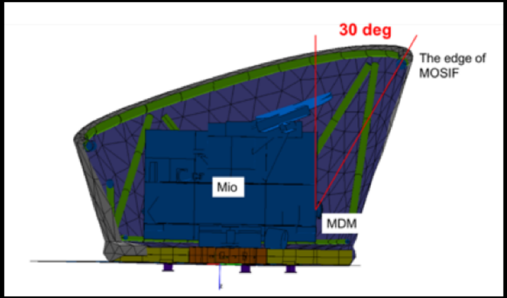


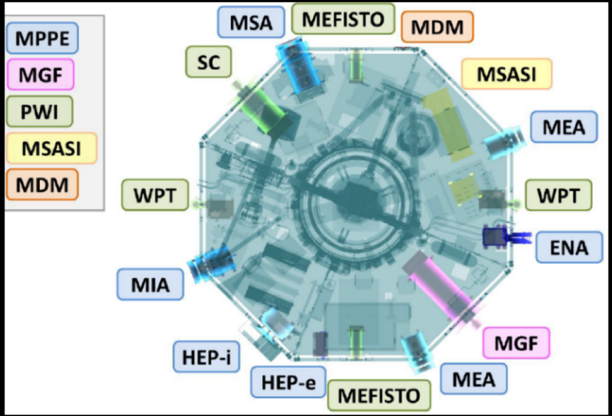
MMO:

PWI

MPPE

MGF





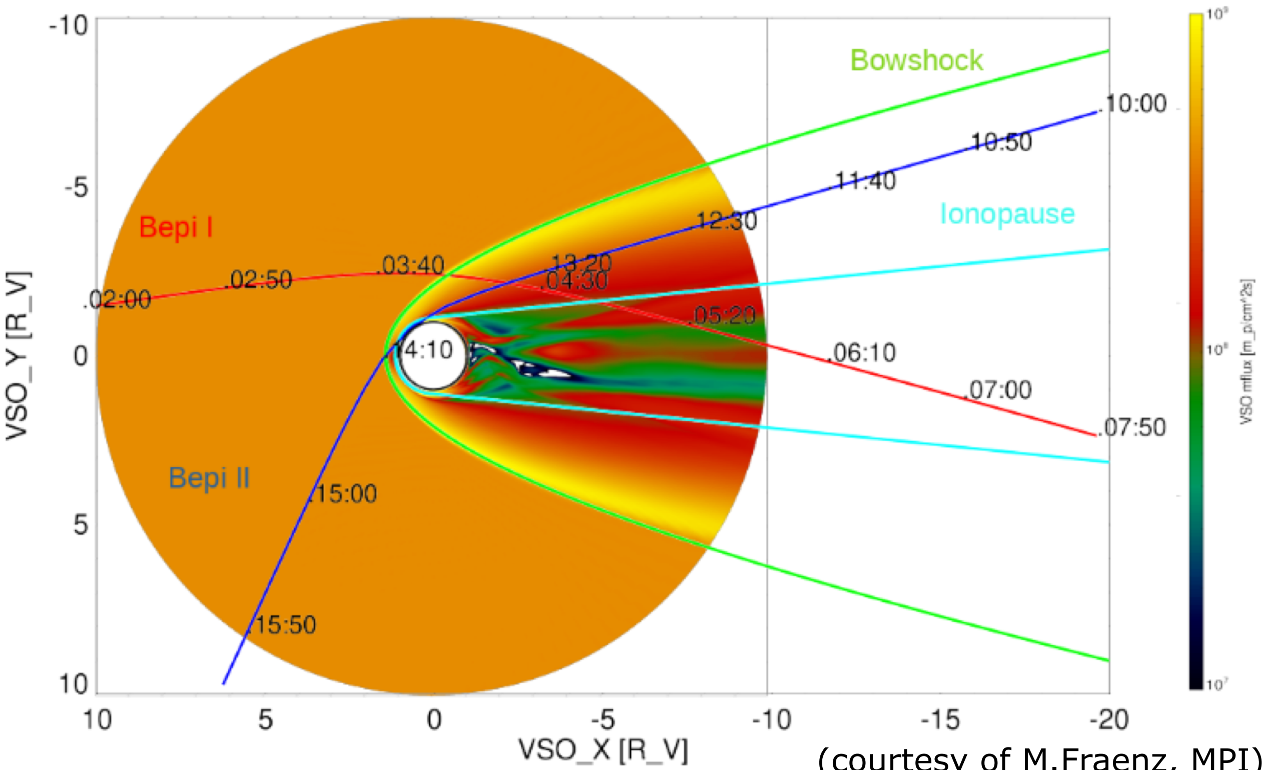
Flybys geometry (X-Y plane)

First flyby (Bepi I)

- October 15th 2020
- Closest approach: 10720 km
- Time of CA: ***03:58 UTC***
- Approaching from dayside

Second flyby (Bepi II)

- August 10th 2021
- Closest approach: 552 km
- Approaching from nightside



(courtesy of M.Fraenz, MPI)

Scientific objectives at Venus

#1 Atmosphere:

MERTIS → radiometer TIR (7-14 µm) + spectrometer TIS (7-40 µm)

- Upper-cloud SO2, cloud aerosol properties, temperature

+ research for phosphine signatures at IR

PHEBUS → spectrometers NUV (55-155 nm), FUV (145-315 nm) + 2 NUV (404 and 422 nm)

- global average cloud top SO2 abundance, bulk and trace gas species profiles, NO emission (in occultation)

+ Dayside disk integrated albedo (faraway from Venus)

MGNS → neutron (10-3 eV – 10 MeV) and gamma-ray (100 keV-10 MeV) spectrometers

- Identification of C, O, N and H2O profiles through the neutron escape

Scientific objectives at Venus

#2 Ionosphere & Induced Magnetosphere:

MPO:

MER-MAG → magnetometer (16-128 Hz)

- discontinuities of bow shock and other boundaries crossings; measurements of draped dayside magnetic field, low frequency wave activity inside the ion composition boundary; potential measurements of flux ropes, possible confirmation of the tail lobes with opposite magnetic field polarity;

SERENA → ion monitors (few eVs - 15 keVs) with mass, direction and energy range detection

- density and velocity of the ions populating the different regions crossed

SIXS-X → X-ray sensors (~1s @ 1- 20 keV)

- monitor the flare activity on the Sun, weak charge exchange induced X-ray emission from the interaction between the solar wind and the Venus exosphere

Scientific objectives at Venus

#2 Ionosphere & Induced Magnetosphere:

MIO:

MPPE → ion electron sensors (5 of 7 operating)

PWI → plasma wave sensors (2 operating)

MGF → magnetometer

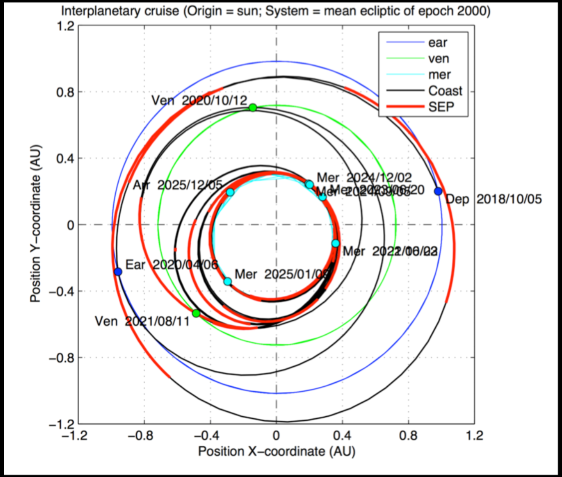
- electron shielding effects, atmospheric pick-up ions and energetic neutral atoms as derived from solar wind backscattering and/or ion sputtering over the exobase;

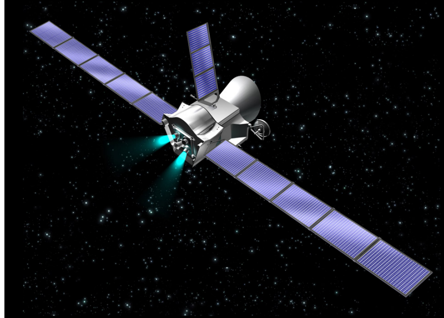
- magnetic and electric fields around Venus (with possible detection of upstream foreshock waves, proton cyclotron waves, magnetosheath turbulence…)

+ ISA accelerometer → may measure possible acceleration effects derived from the crossing of bow shock and other boundaries

3rd November 2020

BepiColombo's Cruise





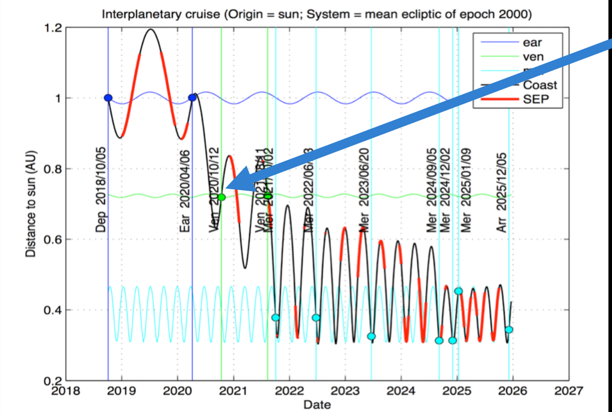


Figure 13: Distance of BepiColombo spacecraft, Earth, Venus and Mercury to the Sun. Thrust arcs are plotted with red thick lines.

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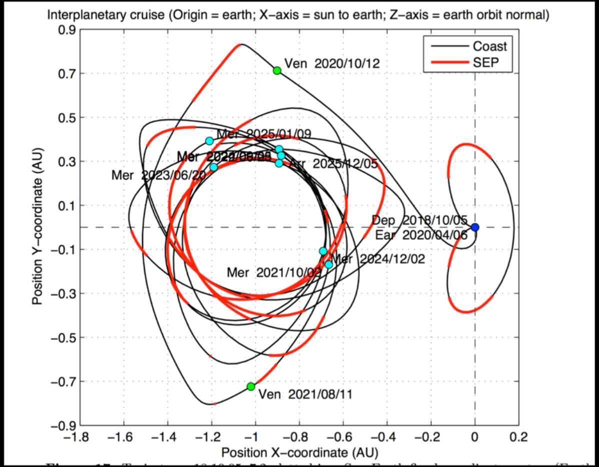
BepiColombo Mercury Cornerstone
Consolidated Report on Mission Analysis

by

R. Jehn and A. Rocchi



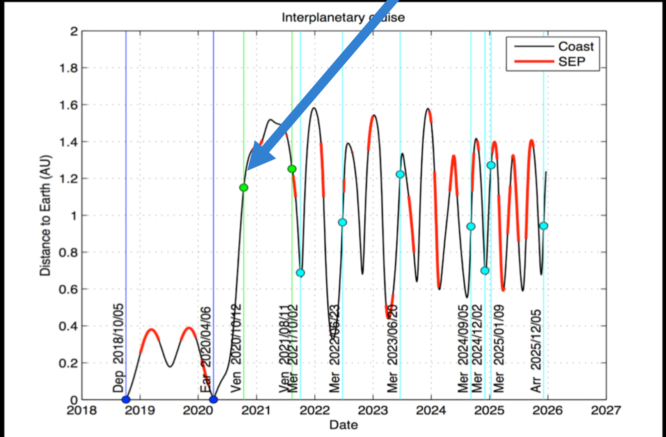


Figure 14: Distance of BepiColombo spacecraft to the Earth.

Conclusion

- BepiColombo is going to send two spacecraft to Mercury for comprehensive investigation of the planet and its environment
- BepiColombo will increase our knowledge of the "planet of Mysteries" and will provide clues to a better understanding of its formation history
- BepiColombo will follow up on MESSENGER results
- BepiColombo is performing as expected
- Enthusiastic Science Team - outstanding cooperation of Japanese & European scientists!

Backup - slides

Scientific Objectives 1/3

- **Mercury as a planet:**
  - surface morphology and topography (< 10m accuracy)
  - surface age (observation of craters > 500m diameter)
  - mineralogical and Elemental Composition (thermal IR spectral range 7-14μm, spectral resolution 200nm; near IR 0.4 - 2μm)
  - determination of abundance of key elements (X-ray telescope better than 200km spatial resolution; MGNS)
  - search and identify signatures of unexpected species
  - study mass, figure and moment of inertia (moment of inertia factor C/MR2 with accuracy better 0.003; second degree tidal Love number k with Signal/Noise ~ 50)
  - chemistry of the surface
  - surface heat flow

Science Objectives 2/3

- **Origin of Mercury's magnetic field:**
  - map magnetic field
  - separation of internal/external sources

- **Exosphere:**
  - composition and vertical structure
  - search for noble gases, isotopes, molecules, atoms from crustal origin, composition and dynamics (UV range 50-300nm)
  - surface release processes
  - search for Ionosphere, Exosphere/Magnetosphere exchange and transport processes

Science Objectives 3/3

- **Magnetosphere:**
  - structure, dynamics, interaction with planet
- **Relativity and Gravitational Physics:**
  - test general relativity and alternative theories of gravity

BepiColombo after MESSENGER

- MESSENGER and BepiColombo are complementary
- repeating of some measurements almost a decade later
    - a chance of getting time as a variable into the picture
- new or improved observations
    - Observing the southerly hemisphere from a significantly lower distance
    - Observing the magnetic field with two spacecraft on significantly different orbits
    - Payload elements that BepiColombo has but that MESSENGER did not have such as the thermal infrared spectrometer, the magnetospheric payload, second spacecraft at the same time, plasma wave studies, dust monitor, sodium imager

Mission Timeline

Date	Event	Distance
20 October 2018	Launch	
10. April 2020	Earth Swing-by	12570km
15. October 2020	Venus Swing-by I	10721km
11. August 2021	Venus Swing-by II	552km
1. October 2021	Mercury Swing-by I	200km
June 2022	Mercury Swing-by II	200km
June 2023	Mercury Swing-by III	200km
September 2024	Mercury Swing-by IV	200km
December 2024	Mercury Swing-by V	40000km
January 2025	Mercury Swing-by VI	345km
December 2025	Orbit Insertion into Mercury	

Launch Configuration

Launch Mass: 4.100 kg

- MPO P/L: 80kg
- MMO P/L: 45kg
- MPO: 1.150kg
- MMO: 285 kg
- MTM: 1.160 kg
- Xenon fuel: 580 kg
- MTM Chemical fuel: 160 kg
- MPO Chemical fuel: 670 kg

Data

- 1550 Gbits/year
- 22kbits/s downlink
- 384 Gbit memory EOL
- X and Ka-band

Dimensions:

- Overall height: 6.3 m
- Span: 40.4 m

Launch Configuration

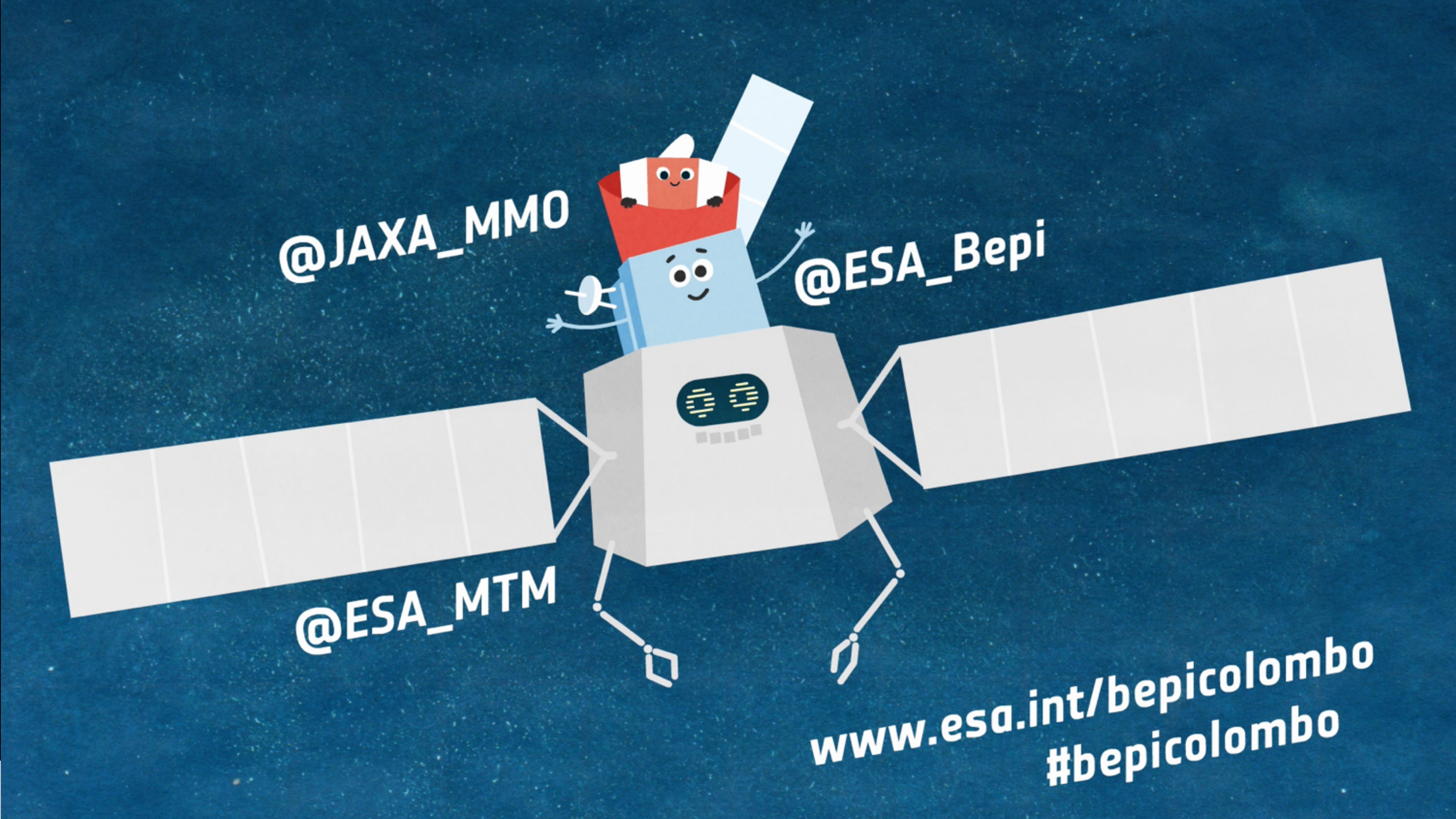
MPO Radiator: 3.8 m^2 with vanes

MPO Propulsion
- 8 x 5 N thrusters
- 8 x 22 N thrusters

MTM-Propulsion:
- 4x145 mN ion engines
  - Isp = 4200 s
  - 290 mN max
- 16 x 10N thrusters

Delta-V:
- 4000 m/s electrical cruise
- 80 m/s chemical cruise
- 1000 m/s chemical orbit descent

Solar Arrays:
- MTM: 13,200 W on 2x21m^2
- MPO: 2,000 W on 8.2 m^2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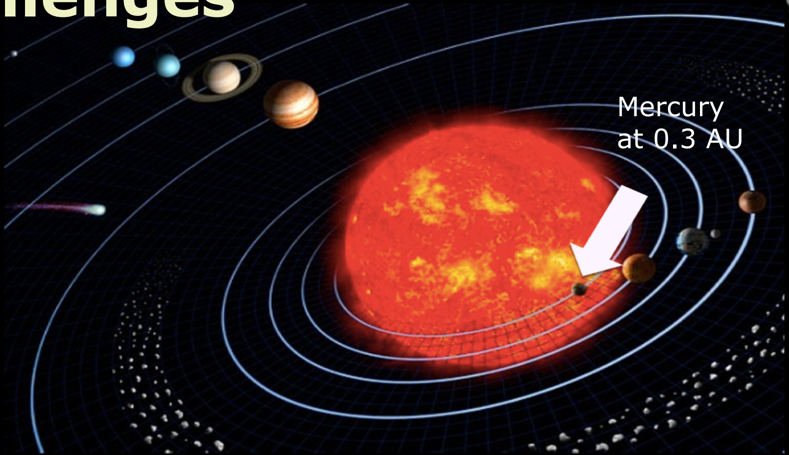
@ESA_Bepi
@ESA_MTM
www.esa.int/bepicolombo
#bepicolombo

Technological Challenges



Main driving requirements:

- Dual spacecraft mission to Mercury
- Global coverage => nadir pointing
- High resolution => low orbit altitude

Main challenges:

- 10 times Solar radiation and surface temperatures up to 450° C
- 5 of 6 spacecraft sides and antennas in full Sun and Mercury infra-red
- Large amount of energy required, requiring gravity assists and electric propulsion
- High percentage of hardware is a specific BepiColombo development
- Complex configuration and tight mass constraint