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Bepi Colombo: the mission, the instruments

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Abstract. Despite the fact the Mercury is a small, rocky, burned planet, so close to the Sun that it is hard to be seen from Earth except during twilight, it has played a very important role in the history of astronomy and fundamental physics and plays a crucial role in the understanding of the formation and evolution of our Solar System.

1. Introduction

Some major facts may be cited to explain how Mercury observations had influenced the understanding of our world. In 1631 Pierre Gassendi, French philosopher, priest, scientist, astronomer, and mathematician, discovered solar side passage of Mercury. This observation led to the evidence that "Planets are much smaller than Sun!" inducing a great shock to the classic concept of those days. Later, in 1845, Le Verrier, the French mathematician who specialized in celestial mechanics and is best known for his part in the discovery of Neptune, published his work observing that the anomalous advancement of 43 arcseconds per century of the Mercury perihelion cannot be explained only on the base of Newton dynamics.

Only seventy years later, in 1915, this problem was properly addressed by Albert Einstein with the general relativity. Until 1889 it was believed that Mercury rotation had the same duration of the Martian and Terrestrial. This believe was finally discredited by Schiaparelli's observations. Despite the fact that Schiaparelli is by far most famous for is observations and maps of Mars, his contribution to the discovery of the Mercury orbital characteristics was exceptional. In fact observing at the Brera Observatory from 1881 to 1888 (see Fig 1), he deduced that Mercury should have spinning on its axis once every ~88 days, the same time it takes to go around its orbit, therefore Mercury was always keeping one face toward the Sun. He also outlined that Mercury showed librations of 47° implying a broad, temperate "twilight" zone between perpetual day and perpetual night. Finally he also argued that Mercury could have an atmosphere and the overall environment conditions should not be impossible for life.

Schiaparelli's observations and measure of the rotation period remained unchanged until recent times, 1965, when the rotational period of Mercury was determined from radar Doppler-spread measurements to be 59±5 days (Pettingill & Dyce 1965). Then Giuseppe Colombo, nicknamed Bepi (Fig. 2), provided the explanation of the spin-orbit resonance in Mercury's orbit. Mercury is locked in the 3:2 (not 1:1) spin orbit resonance, hence its period 58.65 days (consistent with 59 ± 5 days radar measurements) due to the combination of two torques due to the Sun: a tidal torque and a torque due to a permanent dipole-like deformation. Colombo had also the fundamental

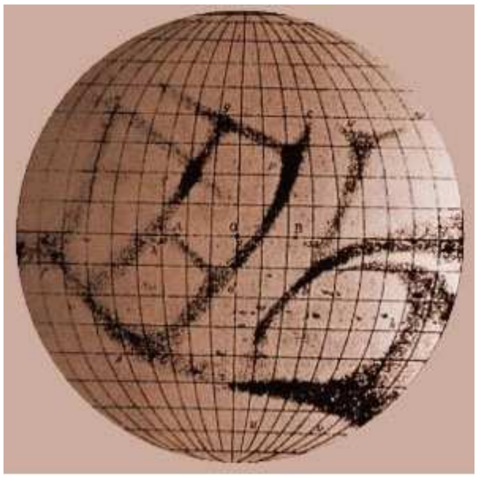

Fig. 1. One of the many maps that Schiaparelli drafted after his observation of Mercury at the Brera Observatory.

merit to provide an orbital solution to allow the Mariner 10 spacecraft, originally designed to reach only Venus, to arrive at Mercury providing the first, and since 2009, the only images of the Hermean surface. The flyby technique it is used since then for almost all the planetary missions allowing to reach the farthest planets with large mass missions maintaining the compatibility with the available launchers.

2. Mercury's key questions

Mercury, Venus, Earth, and Mars are terrestrial (rocky) planets. Among these, Mercury is an extreme: the smallest, the densest (after correcting for self-compression), the one with the oldest surface, the one with the largest daily variations in surface temperature - and the least explored. The outstanding questions to understand Mercury as a planet are:
Why it is so dense?
What is its gravity field?
What is the structure of Mercury's core?
What is the geologic history of Mercury?
What is the nature of Mercury's magnetic field?
There is water at Mercury's poles?
What volatiles are important at Mercury?

Apparently, Mercury's surface resembles the Moon. However, there are many unique features: there are only small differences between highlands and seas. Although volcanic planes are found, there are little traces of volcanos. There are large-scale geographical features which could be related to cooling process in the early stages of formation. There is the huge Caloris basin (the diameter of 1300km) and, located in the opposite side of the planet, peculiar geographical features possibly caused by the gigantic impact that originated Caloris. Moreover, the radar observation from the Earth has suggested some important features such as the possible presence of ice at the bottom of the polar craters. It has to be recalled that Mercury surface imaged by Mariner10 is only about 45%, and the surface composition is not known well. The NASA mission Messenger, which on March 18, 2011 will become the first satellite to orbit Mercury, is already providing new images and data. However its optical instruments and the particular orbit geometry does not allow to image the surface at very high resolution. The design requirements of the BepiColombo optical suite have been chosen in order to provide the higher spatial resolution needed to achieve the information level for discriminate the detailed geographical features and the mineralogy composition of all the Mercury surfaces, hence it will lead to the understanding of the initial formation process of this planet.

Mariner 10 data revealed for the first time the existence of a magnetic field. This was quite surprising, considering Mercury's dimensions and the lack of evidence of recent internal activity linked to a melted interior. Mariner 10 also measured the presence of a magnetosphere, and observed the explosive high energy electron flow, which is similar to the one observed in the terrestrial magnetosphere. However, the encounters occurred 30 years ago provided a low amount of data and no hints on the stability in time: most of the details have not been solved. The measure of the Mercury magnetosphere considering that apparently it represent a sort of "minimum scale", it is im-

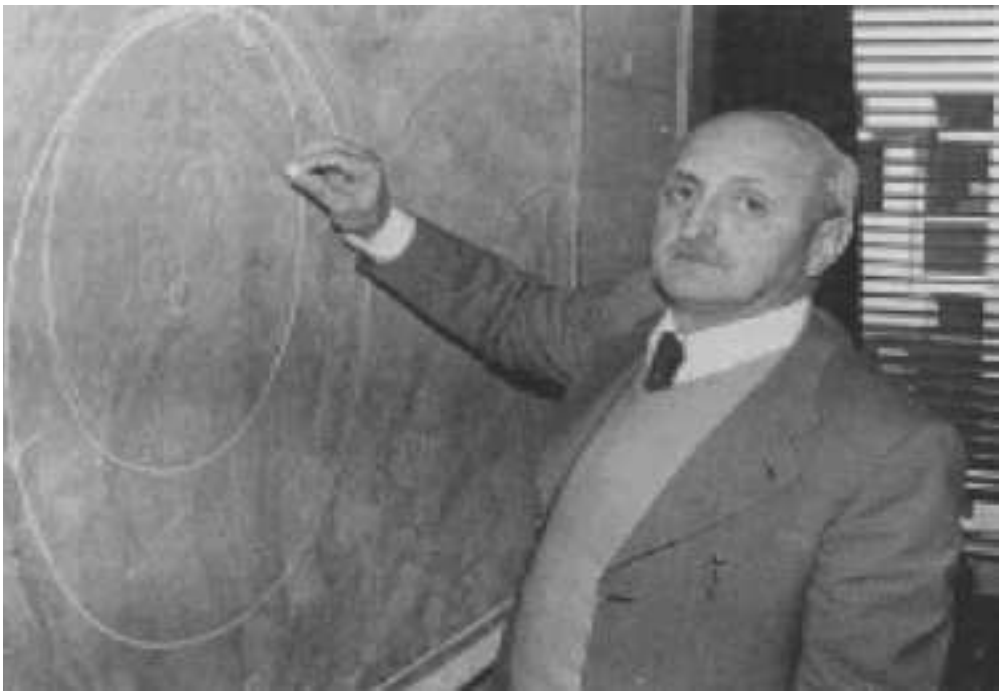

Fig. 2. Prof. Giuseppe Colombo.

portant for the study of the terrestrial and astronomical magnetospheres. In fact, presence of magnetospheres are seen on various scales, such as planets, the Sun and stars, pulsars, and galaxies. Mercury has so far the smallest Magnetosphere in the known universe Mercury does not have sufficient atmosphere, so that the magnetosphere directly connects to the surface. On the Earth the ionosphere plays an important role in the electromagnetic processes. Another relevant condition as to be understood, in fact the conditions of a solar wind are quite different from the terrestrial situation, because the Mercury is closer to the Sun. Other open question are: is such a magnetosphere be stable enough? What and how energy processes are expected? The presence of a magnetic field may be related to the planet high-density. However in the situation in the other terrestrial planet is ambiguous. There is no intrinsic magnetic field in Venus, even if recent data seems to indicate the presence of volcanic activity. Earth has a magnetic field as well an internal differentiation and melted core. Mars does not have a global magnetic field although the trace of the magnetic field in the old crust was recently discovered. Then, why does the smaller planet Mercury has a magnetic field? The question does not have an answer yet. In the standard theory, the melted core is needed for the magnetic field. Is it possible for Mercury? To understand the origin of the hermean magnetic field it is necessary to have more accurate measures of its spatial distribution, but mainly it is needed to determine if Mercury has an internal differentiation with a high density core and a melted interior. Finally, the comparison with the detailed information on the magnetosphere, magnetic field and the interior between Mercury and Earth is required. Another peculiar feature of Mercury is the presence of a thin sodium atmosphere (exosphere) discovered with the terrestrial telescope. In a exosphere the average distance of the atoms and molecules is such that the probability of a collision due to thermal effect is negligible, while the Brownian model is dominant in an atmosphere. Mercury exosphere is thought to be made from the elements from the surface by the evaporation heated by sunlight, or scattered by the collision of high energy particles coming form the solar wind, magnetospheric ions and interplanetary dust. The observations done on ground have shown that the "atmosphere" spreads by several times the Mercury radius, and it is becoming clear to change its quantity and distribution sharply in about one day. This effect could be triggered by the magnetosphere activity, but the details are far to be understood yet. Moreover, the composition of the exosphere is useful as a unique observation method which leads to detection of important elements, such as noble gas related to the history of Mercury.

3. The BepiColombo mission

The role of Colombo in the understanding of the planet was the reason to name the first European mission to Mercury mission after him. To be precise Bepicolombo is a European-Japanese mission, it is composed by two distinct spacecrafts, MMO and MPO, and a cruise stage assembled together in order to be launched by a single launcher. MPO (Mercury Planetary Orbiter, realized by ESA) and MMO (Mercury Magnetospheric Orbiter, realized by JAXA) will then travel together and will separate only when approaching Mercury. This configuration well suited to allow a single launch and a solid architecture and reduced operations during the cruise, however do not allow to operate the on board instrument almost until arriving at Mercury with the noticeable exception of the radioscience experiment. Once at Mercury, MPO will enter in a polar orbit at 400×1500 km with 2.3 hr period, and MMO in more elliptic polar orbit at 400×12 000 km and 9.2 hr period. The main objectives of the mission are:

- Understanding of the origin and evolution of a planet close to the parent star
- Study Mercury as a planet: form, interior, structure, geology, composition and craters
- Determine Mercury's vestigial atmosphere (exosphere): composition and dynamics
- Mesure Mercury's magnetized envelope (magnetosphere): structure and dynamics
- Discover the origin of Mercury's magnetic field
- Determine composition and origin of the polar deposits:
- Test of Einstein's theory of general relativity

The set of instrument composing the MMO and MPO payload have been selected to achieve these objectives. Most of the instruments are innovative either in the design and technology. All of them are very compact and lighter with respect to similar instruments previously embarked on other planetary missions. The Mercury Planetary Orbiter will carry a highly sophisticated suite of eleven scientific instruments, ten of which will be provided by Principal Investigators through national funding by ESA Member States and one from Russia. There is a strong synergy among the various instruments on board MPO. The experience of the last decades of exploration of the planets clearly shows that only a multi-sensor analysis allows to discriminate the various effects that may hidden the real cause of a certain feature or effect. A planet is a complex body where many different forces may act together over long periods masking the fossil evidence of the mechanism working at the time of its formation. On the other side the current status is continuously evolving and all the factors have to be studied to understand how. In Figure 3 the concurrence of the various instruments of the BepiColombo MPO orbiter, with respect to the science goals, are depicted.

The instrument forming the BepiColombo MPO payload have been selected after a long study phase and very selective competition. MPO has on board the following 10 instruments:

1. BELA (BepiColombo Laser Altimeter). BELA it is designed to characterize the topography and surface morphology of Mercury. It will also provide a digital terrain model that, compared with the data from the MORE instrument, will allow to obtain information about the internal structure, the geology, the tectonics and the age of the planet's surface. Co-

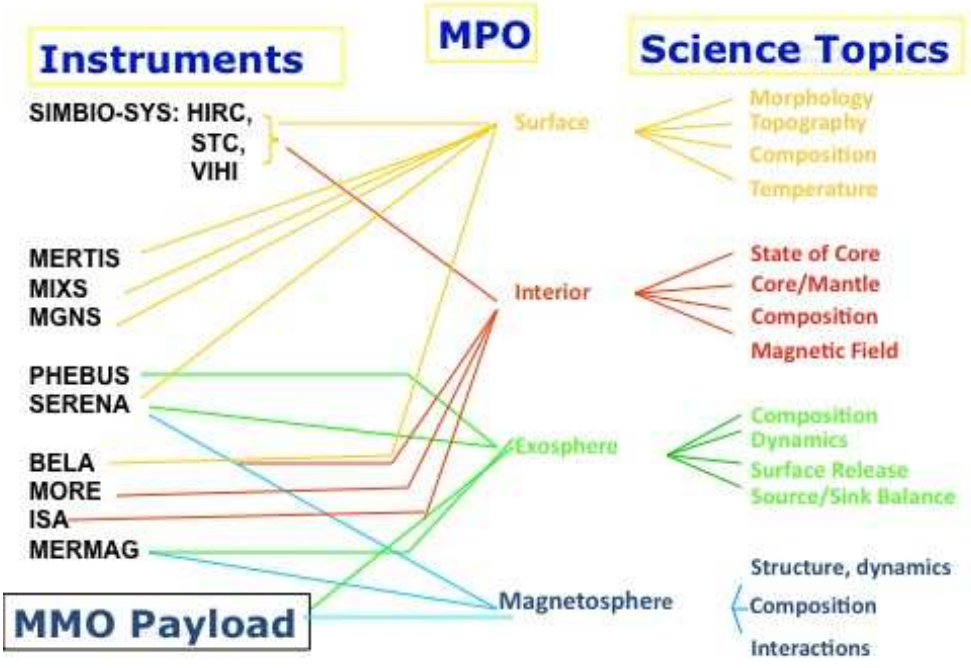

Fig. 3. The MPO instrument synergy

Principal Investigators: N. Thomas, University of Bern, Switzerland, and T. Spohn, DLR, Germany.

2. ISA (Italian Spring Accelerometer). It is designed to measure the inertial accelerations acting on the MPO. The objectives of the ISA accelerometer are to measure •the global gravity field of Mercury and its temporal variations; •the local gravity anomalies; •the rotation state of Mercury ; •the orbit of Mercury's center-of-mass around the Sun. These objectives are strongly connected with those of the MORE experiment. Together the two experiments can give information on Mercury's interior structure as well as test Einstein's theory of the General Relativity. Principal Investigator: V. Iafolla, CNR-IFSI, Italy.

3. MERMAG (Mercury Magnetometer). MERMAG will measurement accurately the Mercury's planetary magnetic field and its source, to better understand the origin, evolution and current state of the planetary interior, as well as the interaction between Mercury's magnetosphere with the solar wind. This measures will contribute to the study of the interaction of the solar wind with the hermean magnetic field and the planet itself, the formation and dynamics of the magnetosphere as well as to the processes that control the interaction of the magnetosphere with the planet. Principal Investigator: K.H. Glassmeier, Technical University of Braunschweig, Germany.

4. MERTIS (Mercury Thermal Infrared Spectrometer). MERTIS will provide detailed information about the mineralogical composition of Mercury's surface layer with a high spectral resolution, crucial for selecting the valid model for origin and evolution of the planet. Principal Investigator: H. Hiesinger, University of Münster, Germany.

5. MGNS (Mercury Gamma ray and Neutron Spectrometer). MGNS will determine the elemental compositions of the surface and sub-

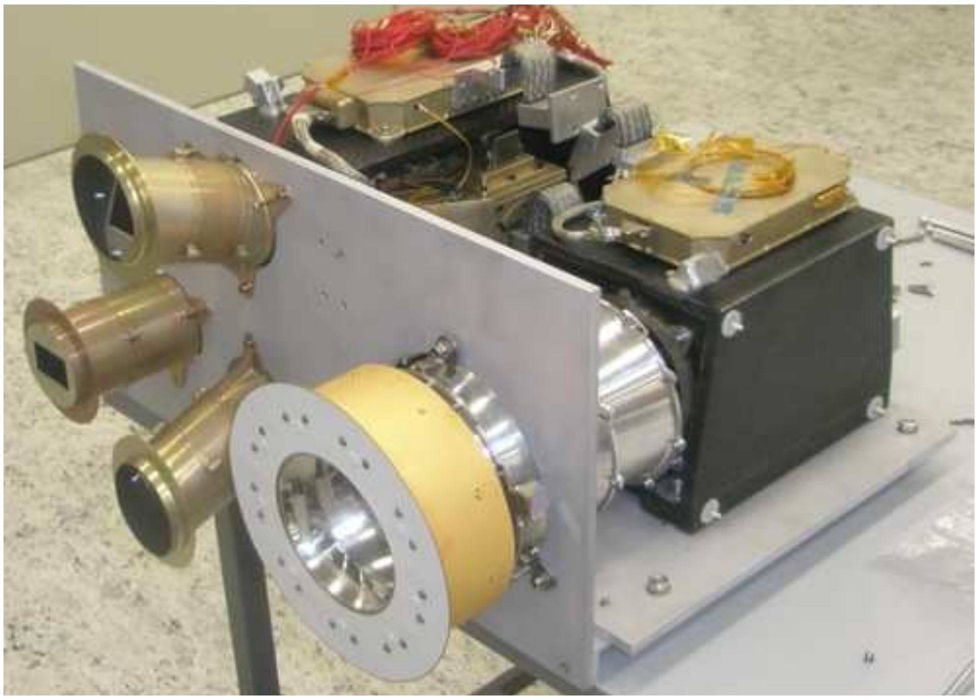

Fig. 4. The BepiColombo optical suite. It includes a stereo mid-resolution camera, high resolution camera and a mapping spectrometer.

surface by the measurements of nuclear lines of major soil-composing elements. It will also contribute to determine the elemental compositions by the measurements of the leakage flux of neutrons and of the lines of natural radioactive elements and the regional distribution of volatile depositions on the polar areas of Mercury which are permanently shadowed from the Sun, and to provide a map of column density of this depositions. Principal Investigator: I. Mitrofanov, Institute for Space Research, Russia.

6. MIXS (Mercury Imaging X-ray Spectrometer). MIXS will use the “X-ray fluorescence” analysis method to produce a global elemental maps of key rock-forming elements by analyzing atomic composition at high spatial resolution. It will be also provide observations to confirm that the auroral zone is an intense source of continuum and line X-rays. Principal Investigator: G. Fraser, University of Leicester, UK.

7. MORE (Mercury Orbiter Radio science Experiment)
MORE, based on the simultaneous use of two frequency bands, will determine the gravity field of Mercury, the size and physical state of its core, provide crucial experimental constraints to models of Mercury’s internal structure , test theories of gravity, measure the gravitational oblateness of the Sun,test and characterize the most advanced interplanetary tracking system ever built and assess the performances of the novel tracking system in precise orbit determination and space navigation. Principal Investigator: L. Iess, University of Rome “La Sapienza”, Italy.

8. PHEBUS (Probing of Hermean Exosphere by Ultraviolet Spectroscopy). The PHEBUS spectrometer is devoted to the characterization of Mercury’s exosphere composition and dynamics. It will also search for surface ice layers in permanently shadowed regions of high-latitude craters. VIts goals are : the vertical,

geographic and seasonal mapping of already detected elements (H, He, O, Na, K, Ca), the search for still non-detected compounds (Si, Mg, Al, Fe, S, C, N, OH, H2), the search and mapping for noble gases other than He (Ne, Ar, Xe, Kr) and ion species (He+, Na+, O+, Mg+, Al+, Ca+, C+, N+, S+,), measurement of surface reflectance at 121.6 nm in polar craters in order to search for surface ice layers. Principal Investigator: E. Chassefière, Université P&M Curie, France.

9. SERENA (Search for Exosphere Refilling and Emitted Neutral Abundance). SERENA will study the gaseous interaction between surface, exosphere, magnetosphere and solar wind. The major objectives of the esxperiment are: to measure chemical and isotopic composition of the exosphere, investigate the exo-ionosphere, derive the gas density profile as a function of the altitude, estimate the particle loss rate from hermean environment, measure the plasma precipitation rate and the surface emission rate.
SERENA is a suite of sensors each devoted to a specific task: ELENA: Emitted Low-Energy Neutral Atoms
STROFIO: Start from a ROtating FIeld spectrOmeter
MIPA: Miniature Ion Precipitation Analyser
PICAM: Planetary Ion CAMera
Principal Investigator: S. Orsini, CNR-IFSI, Italy.

10. SIMBIO-SYS (Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System) is a compact suite of 3 integrated sensors :
STC: Stereo Channel with spatial resolution (at 400 km altitude): 50 m/pixel filters: 550, 700, 880 nm stereo vertical resolution: 84 m at periherm&equator
HIRC: High Resolution Channel with spatial res. (at 400 km alt.de): 5 m/pix at periherm filters: 1 panchromatic, 3 broad band filters (550, 700, 880 nm)
VIHI: Visible and near IR Hyperspectral Imager with spectral sampling: 6.25 nm Spectral range: 400 2000 nm(with option to 2200 nm) spatial res.: 100 m @periherm
SIMBIO-SYS will provide global surface imaging coverage with color capabilities; local mapping at high resolution with color capabilities; global mineralogical and compositional mapping, global stereo mapping and Digital Terrain Model reconstruction and exosphere observation of Na and K (optionally) supporting the understanding of the surface geology, volcanism, global tectonics, surface age and composition, and geophysics. Principal Investigator: E. Flamini, ASI, Italy.

The instruments on board the JAXA provided MMO spacecraft are devoted to the study of the space environment surrounding Mercury. They are:

– Solar Intensity X-ray Spectrometer (SIXS) SIXS will perform measurements of X-rays and particles of solar origin at high time resolution and a very wide field of view. Principal Investigator: J. Huovelin, Observatory University of Helsinki, Finland.

– Mercury Magnetospheric Orbiter (JAXA) MMO will carry five advanced scientific experiments that will also be provided by nationally funded Principal investigators, one European and four from Japan. Significant European contributions are also provided to the Japanese instruments:

– Mercury Magnetometer (MERMAG) MERMAG will provide a detailed description of Mercury's magnetosphere and of its interaction with the planetary magnetic field and the solar wind. Principal Investigator: W. Baumjohann, Austrian Academy of Sciences, Austria.

– Mercury Plasma Particle Experiment (MPPE) MPPE will study low- and high-energetic particles in the magnetosphere. Principal Investigator: Y. Saito, ISAS, JAXA, Japan.

– Mercury Plasma Wave Instrument (PWI) PWI will make a detailed analysis of the structure and dynamics of the magnetosphere. Principal Investigator: H. Matsumoto, RISH, University of Kyoto, Japan.

– Mercury Sodium Atmospheric Spectral Imager (MSASI) MSASI will measure the abundance, distribution and dynamics of sodium in Mercury's exosphere. Principal Investigator: I. Yoshikawa, University of Tokyo, Japan.

– Mercury Dust Monitor (MDM) MDM will study the distribution of interplanetary dust in the orbit of Mercury. Principal Investigator: K. Nogami, Dokkyo Medical University, Japan.

4. Conclusion

The two spacecrafts composing the BepiColombo missions will carry the most complete and advanced set of instruments that will ever orbit around Mercury. BepiColombo will provide and unsurpassed amount of data that will set the state of Mercury knowledge for decades, providing to generations of scientist essential information on the planet, its environment and key elements for the understanding of the formation and evolution of the Solar System.

References

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