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From the Editors

Mercury 2001 conference Field Museum, Chicago, Illinois 2001 October 4–5

Mercury, the planet, is named after the divine messenger of Antiquity, but what information the wing-footed god has provided to planetologists has been cryptic and incomplete. The exceedingly difficult ground-based observations of a planet that is never separated by more than 28° from the Sun and three close encounters by the *Mariner 10* spacecraft in 1974/75 have told us just enough to know how interesting it would be to go back and study the elusive planet in more detail.

This goal is to be accomplished during the next decade by two space missions, NASA's Messenger (**M**ercury **s**urface, **s**pace **en**vironment, **ge**ochemistry, and **r**anging mission) and BepiColombo, which is a joint project of the European Space Agency and the Japanese Institute of Space and Astronomical Science. In order to summarize the current state of knowledge and introduce the two upcoming missions to the wider community, a conference entitled "Mercury 2001: Space Environment, Surface, and Interior" was held at the Field Museum in Chicago, 2001 October 4–5. With the exception of some NASA scientists, who were prevented by a budget-related travel ban, practically all research groups involved in the scientific exploration of Mercury were represented. In all about 100 scientists attended the conference.

Messenger, named for Mercury the envoy of the gods, is due to launch in March or April 2004 and go into a 12-hour highly eccentric orbit around Mercury in April 2009. The much more ambitious BepiColombo mission, named for Giuseppe "Bepi" Colombo (1920–1984), who played a pivotal role in planning the *Mariner 10* trajectory, is due to launch in 2009 and arrive in 2012. As currently designed, the spacecraft will consist of three components, two orbiters and a lander, but its definitive configuration is not yet finalized. According to their separate missions, the orbiters are referred to as planetary orbiter and magnetospheric orbiter.

Putting a spacecraft in orbit around Mercury requires considerable energy, and Messenger uses multiple gravity assist encounters to bring the spacecraft into position. BepiColombo relies on new propulsion technology for this task, which is both costlier and riskier, but cuts the transfer time to two-and-a-half years as compared to Messenger's five years.

The biggest challenge to spacecraft design is the thermal environment at a location where the Sun is up to 11× more intense than on Earth, and the sunlit side of the planet heats up to over 400 °C. In addition to the general stress on equipment caused by the high temperatures, geochemistry is apparently the main casualty of these conditions. Infrared bands >1.4 μm are obscured by thermal noise, limiting the mineralogical information that can be obtained by Messenger. An actively cooled IR spectrometer has been proposed for BepiColombo, which would extend the spectral range to 2.8 μm. The use of conventional solid-state detectors is likewise impossible without power-hungry active cooling. Unfortunately the efficiency of solar panels also degrades at high temperature, limiting the energy available for refrigeration. In spite of these limitations the photon (gamma, x-ray, and optical) and neutron spectrometers on both spacecraft will provide an impressive amount of geochemical information, although the spatial resolution that can be obtained is not as good as it would be in a less harsh environment.

Getting this data bonanza back to Earth poses problems as well. Mercury and the Sun interfere with radio transmissions during part of the spacecraft's duty cycle, but the main limitation on data return comes from antenna design. Weight considerations limit the size of the antenna, and the severe thermal cycling makes any pointing mechanism prone to eventual failure. Messenger will therefore use two fixed phased array antennas rather than a gimbaling antenna design, with a consequent penalty in the attainable data rate. The BepiColombo planetary orbiter is likewise expected to be limited by data rate.

Any mission to an unexplored part of space involves evaluation of existing data, framing questions on the basis of what is already known, and selecting methods that are likely to provide answers to them, as well as being prepared for potential surprises. In the case of Mercury we know less than about most other planets, instrument selection is constrained by environmental conditions as well as weight limitations, and *Mariner 10* has certainly encountered more than its fair share of surprises. All that adds special urgency to the planning process for Messenger and BepiColombo.

The *Mariner 10* images, which cover ~40% of Mercury's surface, show a very Moon-like landscape. However, with Mercury's specific gravity of 5.44 as compared to the Moon's 3.34, the similarity can be no more than skin-deep. In the 1970s the Moon, as the most explored planetary body, became the paradigm for understanding other planets. This has turned out to be misleading. Today it looks much more likely that there is a regular progression among the terrestrial planets, from Mercury to Mars, in several of their fundamental geochemical properties (*e.g.*, volatile and refractory inventory, FeO content in the crust, reduced density), whereas the Moon is an anomaly. Among the major rocky bodies in the solar system, Mercury has the highest metal/silicate ratio and the Moon the lowest.

At the surface the two most obvious differences to the Moon are the lack of a strong albedo contrast on Mercury and the presence of features called lobate scarps, which most investigators interpret as thrust faults due to thermal contraction of the whole planet.

The albedo contrast on the lunar surface is caused by the color difference between the Fe-rich mare basalts and the feldspathic and thus Fe-poor highlands. Rocks on Mercury are generally Fe-poor, and therefore light-colored, although the petrologic nature of the Mercurian equivalent of lunar maria is uncertain. Infrared spectra of the Mercurian surface do not show the FeO band at 1 μm. There are several phenomena that could conceivably obscure the band, but together with other spectral features the absence of the 1 μm band puts the upper limit of bulk FeO at <6 wt%. On the other hand, the IR spectrum does show the characteristic reddening due to nanophase Fe° produced by space weathering, which requires that FeO must be >2 wt%. A consensus emerged at the Mercury 2001 conference that ~3 wt% FeO is the most reasonable value for the crust of Mercury.

The weathering process itself is thought to be somewhat different from the lunar case. The higher flux of particles close to the Sun and their higher energy combine to increase the energy deposition due to (micro-)impacts by a factor of 20. On the other hand, because of the magnetic field ion sputtering, if it occurs at all, is limited to near-equatorial latitudes. At lower latitudes significant annealing takes place on the sunlit side, but this effect should decrease toward the poles.

Current thermal models indicate that the planet should have shrunk by at least 4–6 km in radius. If the interpretation of lobate scarps is correct, then only a small fraction of the total shrinkage has been taken up by thrust faulting. More subtle shrinkage features may have been missed by *Mariner 10*, but might be detected by precision radar altimetry from Messenger. Moreover, there is no guarantee that geological features on the unimaged side are similar to the ones recorded by *Mariner 10*. As one speaker warned, one ought to be very cautious about claiming to understand a planet if one has seen less than half of it.

An unexpected discovery of *Mariner 10* was the presence of a magnetic field. Its strength of ~1% of the Earth's field is just enough to indicate the existence of a core dynamo. Only the strength of the dipole component is known at present, which does not allow any inferences about the state of the core. Current models suggest that the evolution of a planetary dynamo requires the presence of a solid inner core and a liquid outer core; as the inner core grows, convection in the outer core becomes more complex, and higher order components of the magnetic field become more important relative to the dipole. A set of experiments is planned to determine whether Mercury contains an inner core decoupled from the rest of the planet. This should be detectable from a combination of precise spacecraft tracking and laser altimetry.

If there is a liquid outer core, thermal models suggest that it cannot be pure metal. A considerable content of non-metals (probably mostly sulfur) would not only lower the crystallization temperature, but also the density of the core. The inner structure is therefore of interest in connection with the thermal history, the source and shape of the magnetic field, the volatile inventory (since S is a volatile element), as well as the geophysical properties of the planet.

This kind of interaction between diverse fields of science often leads to unanticipated needs for new interdisciplinary connections in planetary research. It is in this context that conferences such as Mercury 2001, where scientists can come together in person, are most useful. A case in point is the interaction of solar wind and planetary magnetic field, which leads to complex induced current patterns in a planet's vicinity. The only other planet where this occurs is Earth, which has a highly conductive ionosphere, and therefore scientists concerned with magnetospheric interactions tend to specialize in understanding rarefied plasmas. On Mercury, however, it is likely that some of the current closure takes place in the regolith. Understanding the details of this process requires collaboration between scientific disciplines, the study of magnetospheres and of regoliths, that so far have had no reason to talk to each other.

Two noteworthy puzzles raised by terrestrial observations are likely to be resolved by the upcoming missions. One concerns the possibility of water in craters near the poles, the other the mechanisms governing the composition of the tenuous exosphere.

Material of high radar reflectivity was discovered near the poles of Mercury by ground-based radar in 1991 and interpreted as ice, possibly mantled by dust. Since then improved observations have verified that the material does indeed occur inside craters at high latitudes, where it is shielded from direct solar heating, although some occurrences are seemingly inconsistent with thermal models of ice stability. Unfortunately the BepiColombo lander can not be aimed with sufficient precision to target one of the presumed ice fields, but the neutron spectrometers on both missions will be able to detect the presence of hydrogen at the planetary surface. Other proposals for the composition of the radar-bright areas exist, and spacecraft observation is expected to give a conclusive answer.

Both Moon and Mercury are surrounded by an exosphere of neutral atoms among which Na and K are the easiest to detect by ground-based optical spectroscopy. But whereas the Na/K ratio in the Moon's exosphere reflects the ratio in the surface rocks of 6–7, the Na/K ratio in Mercury's exosphere is very large and highly variable. In addition one research group has detected a strong diurnal variation in Na and K abundance. The high Na/K ratio is presumably related in some way to the magnetic field rather than the composition of the surface rocks. Unfortunately instrumental limitations will prevent Messenger from obtaining the Na concentration of the surface rocks by direct measurement.

There is considerable overlap in the objectives of the two missions, but the approximately three-year time lag will allow the detection of short-term changes on the planet. This is especially important for the presumed ice fields inside high latitude craters and a possible time-dependent component of the magnetic field. Another bonus from having two missions is much better total coverage. For thermal reasons the orbit of any Mercury probe has to be highly eccentric, with the periapsis over one of the "cooler" poles rather than near the subsolar point. The Messenger periapsis will be near the north pole, which means that the spatial resolution of measurements in the southern hemisphere will be considerably worse than in the northern. The logical complement is to put the planetary orbiter of BepiColombo in an orbit with a periapsis near the south pole, so that the two spacecraft in between them can obtain data at comparable resolution over the entire planet.

Mercury will still be the "winged messenger" in 2013, but by then we hope to understand its message much more clearly than we do today.

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New views on the Moon–Europe: Future lunar exploration, science objectives and integration of datasets DLR-Berlin, Germany 2002 January 14–16

The two and half days workshop, convened by Dave Heather (ESA-ESTEC) and Ralf Jaumann (DLR), was divided into eight main sections including a poster session, and also a series of print-only abstracts: lunar volcanism and the internal/thermal evolution of the Moon; lunar chronology; remote sensing perspectives—*Clementine* and *Lunar Prospector*; the crustal and internal structure of the Moon; upcoming lunar missions—SMART-1, Lunar-A and Selene; and future lunar exploration: science and missions. This meeting was attended by over 60 people from Europe, Asia and the USA, 88% were male and 12% female. The majority of the participants were associated to one of the three near-future lunar missions (SMART-1, Luna-A and Selene), together with excellent presentations on lunar science and the integration of different datasets. The student participation was reduced which reflects the fact that most of lunar science is done in the USA and the current financial difficulty in supporting students to travel overseas.

The main objective of this meeting was to encourage international collaboration and to stress the need for the focusing on the strategy for lunar science and mission preparation for the next decade and beyond. The workshop also underscored the need for improved dialogue between technology-developing groups and science groups. Also, it was emphasized the need for the elaboration of strong and coherent recommendations regarding lunar science and the making aware of the rest of the Planetary Science community that lunar scientists "do not know it all"! For this, it was suggested that during the next months, and in preparation for upcoming meetings, and *via* the Lunar-L e-mail list, different researchers come together with suggestions in response to "Decadal Study for Planetary Sciences" and preparation for the European Space Agency (ESA) Aurora program.

After a general introduction and welcoming to the participants, the first day and a half were dedicated to an overview of the current lunar science understanding (a good representation of laboratory, remote sensing and modeling work) and the list of outstanding questions and respective exploration goals: the identification of the basic processes involved in the evolution of the Moon (geochemical remote-sensing and geophysical networks); the disentangling of the complex record of early lunar crustal formation and evolution and relating this to the thermal evolution of the Moon and to the one-plate planets in general; to establish a better perspective of the initial events prior to the formation of the Moon and the history of the precursor material? And that of the impactor? Is the lunar volatile depletion a result of the impact or was it inherited from the impactor? Priority areas on the Moon were suggested as important targets for next missions: South-Pole Aitken Basin, the South Pole and west Proccelarum basalts. The second day and a half was dedicated to the upcoming missions and future lunar exploration with discussions primarily based on strategies for dealing with remote-sensing data: from software problems, to where to point the detectors on board the orbiters, to how to plan the next decade and beyond.

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