



# The Mercury MESSENGER



Issue 8

The newsletter concerned with exploration of the planet Mercury

September 1997

## Mercury: Planet of Fire and Ice

### Part 1

Not so long ago, Mercury was considered to be a rather boring version of the Moon, a view based on limited information and data from *Mariner 10* gathered at visible and near-visible wavelengths. Over the last decade, this view has changed dramatically, largely as a result of the wide range of groundbased observations taken at visible, near-infrared, midinfrared, and microwave wavelengths. These observations have demonstrated that real differences exist in the atmospheres and surface rocks of Mercury and the Moon. Issues 8 and 9 of *The Mercury Messenger* will focus on how these striking observations and the models that result from or corroborate them reveal Mercury's unique character as the Planet of Fire and Ice.

### T H E   A T M O S P H E R E

**Mercury's Exosphere:** Mercury's atmosphere, really an exosphere, is tenuous: The total mass of all known constituents is approximately 15 orders of magnitude less than Earth's. An exosphere is an atmosphere that has such a low density that collisions between constituents are negligible. Thus, according to Smyth and Marconi, "Mercury has multiatmospheres, with each separate atmosphere forming independently and hence each having the capacity of being very different. These differences are determined by the unique properties of each particular gas, the nature of the sources and sinks for that gas, and the interactions of that gas with the surrounding environment" [1].

Atoms of each constituent are liberated from a source, interact with the surface by moving through a series of ballistic hops, eventually become adsorbed on the surface, and are liberated to begin the process again. Constituents are continually removed from local environments, generally to be transported and implanted elsewhere, through processes involving magnetospheric recycling on a global scale. The probability and duration of implantation depends on temperature, which determines the average kinetic energy of the constitu-

ent, and chemical composition, which determines the bonding potential. Smyth and Marconi have developed models of spatial distribution for two known atmospheric constituents, Na and K [1]. Their work has shown that each of these constituents has "a sunward neutral pause and an antisunward tail structure similar to that of a comet coma" and that the details of this structure vary systematically with radiation pressure, as solar distance and subsolar point position vary solar irradiance during the course of a mercurian year (see Fig. 1).

**History:** Early groundbased searches for CO<sub>2</sub> resulted in determining upper limits for atmospheric density. On *Mariner 10* flybys of Mercury, both an occultation experiment, which measured four passbands in the UV, and a 10-passband UV airglow spectrometer provided the first data on atmospheric constituents. The observations established the atmosphere as exospheric, and the upper limit for gas density of the dayside atmosphere was deduced as 10<sup>6</sup> cm<sup>3</sup> [2]. Hydrogen and He were positively identified and their distributions shown to be thermal. Oxygen was tentatively identified. Upper limits were determined for abundances of a number of atmospheric gases, including Ar, Ne, Xe, N<sub>2</sub>, H<sub>2</sub>O, CO<sub>2</sub>, O<sub>2</sub>,

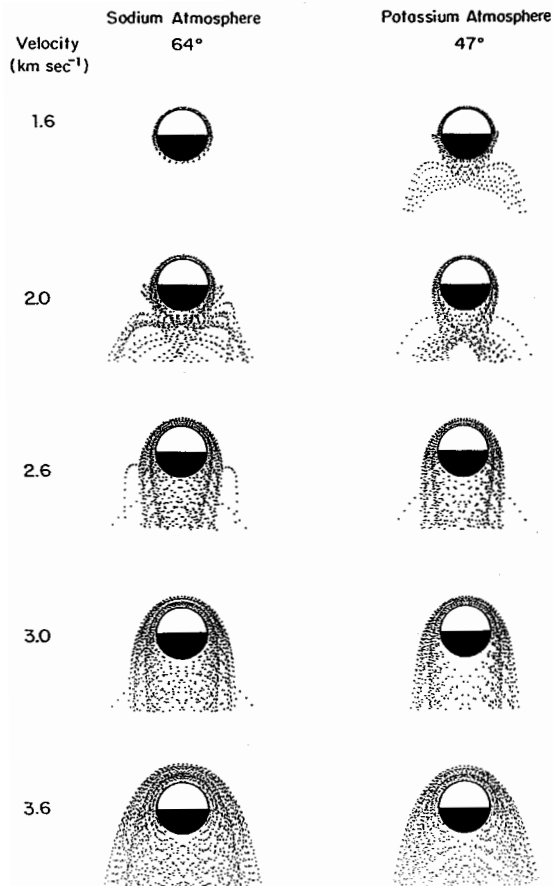


Fig. 1. From Smyth and Marconi [1].

$N_2$ , and  $H_2$  [2]. The poor coverage along with the low spatial resolution of *Mariner 10* resulted in an inability to determine significant spatial differences.

**New Observations:** A decade ago, groundbased observations by Potter and Morgan resulted in the discovery of Na and K in the atmosphere of Mercury [3,4]. Sodium and K emissions were observed to be a factor of 3 brighter (in kilorayleighs) than such emissions on the Moon. Sodium was observed to be 2 orders of magnitude more abundant (in terms of column density) than K and comparable to O in abundance. Despite a far greater abundance of O than Na anticipated in the regolith, a principal source of atmospheric constituents, Cheng et al. [5] point out that the upward transport of O in the regolith is much less because of a smaller concentration gradient, and thus it has a proportionately smaller atmosphere/regolith ratio. More recently, Sprague et al. [6,7] determined upper limits for Ca and Li in Mercury's atmosphere.

Substantial evidence for variations in the distribution of atmospheric constituents has been found. Potter and Morgan observed, using a north-south slit, both higher Na [8] and higher K [9] emission at higher latitudes and localized highs that vary on a daily basis, a pattern consistent with sputtering by magnetospheric particles from the polar cusps (see Fig. 2) [10]. They observed an increase in Na/K abun-

TABLE 1. Column and surface number densities of measured exospheric species.

Species	Wavelength (Å)	Column Density ( $cm^2$ )	Surface Density ( $cm^2$ )	Reference
H	1216	$3 \times 10^9$	23–230	[17]
He	584	$2 \times 10^{11}$	$6 \times 10^3$	[17]
O	1304	$3 \times 10^{11}$	$4 \times 10^4$	[17]
Na	5890,5896	$1-5 \times 10^{11}$	$1 \times 10^5$	[9]
K	7664,7699	$1-3 \times 10^9$	$6 \times 10^2$	[9]
Ar	867	$<1-4 \times 10^{13}$	$<7 \times 10^6$	[17]
Ca	4227	$<0.5-1 \times 10^9$		[6]
Li	6708	$<8.4 \times 10^7$		[7]

dance as the solar radiation pressure increased, which is consistent with the differences in chemical properties of the two elements and an indication that suprathermal Na is present [11]. In fact, Potter and Morgan observed Na at a range of temperatures, including “hot” Na at considerable distance from the planet's surface [10]. They propose that the lower-temperature portion results from chemical sputtering that occurs when solar protons are neutralized at the surface to form atomic H, which then reacts with surrounding minerals to form Na and even water vapor. A correlation between this component and surface composition would be anticipated. Potter and Morgan propose that the high-temperature component results from physical sputtering, which, according to Smyth and Marconi, is the only mechanism definitely capable of generating the necessary velocity distributions, although solar-photon-induced desorption is also a possibility [12].

Sprague et al., who make observations with east-west slits, have reported K enhancement over the Caloris Basin, the largest feature mapped and associated with volcanic terrain, in

*The Mercury Messenger* is published by the Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113 (write to this address if you wish to be added to the mailing list).

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some of their observations [13]. They postulate that the enhancement is primarily due to efficient implanting, to average depths of tens of angstroms, during the mercurian night and subsequent rapid thermal diffusion of atmospheric constituents as the temperature rises at dawn [14]. The onset of rapid diffusion would begin at a lower temperature for Na than for K. Secondly, composition also would play a role if volcanic material on Mercury has enhanced alkali content, as some observations suggest [15]. Killen and Morgan have contested this model, on the basis that the increase in solar activity occurring at the time of this observation may have increased the charged particle population of the magnetic field, thereby stimulating the release of ionic constituents below polar latitudes [16].

**Atmospheric Sources and Sinks:** A variety of origins have been proposed for the discovered gases, which, in most cases, would be released from the surface or interior, resulting in a net loss of the volatilizable materials that form the atmosphere. (Refer to Fig. 3 for a diagrammatic view of atmospheric sources and sinks.) Some combination of micrometeorite impact vaporization and chemical or physical sputtering of surface material, along with degassing (thermal evaporation following diffusion from greater depths), or photon-stimulated desorption could generate  $H_2O$ , Na, and K [5,18,19]. Impact

vaporization or diffusion would tend to produce an atmosphere dominated by volatiles, such as K, Na, and S, whereas physical sputtering or photon-stimulated desorption would result in one composed primarily of major surface constituents. Cheng and co-workers conclude that the observed abundance of Na can be produced by photon-induced processes alone [5]. Sprague prefers diffusion mechanisms [19].

When assumptions are made about the interplanetary meteoroid flux at Mercury's surface and the physical and compositional properties of its regolith (Na must be present in greater than lunar abundance on Mercury), none of which are well constrained at this point, the models of Killen, Morgan, and Potter are consistent with atmospheric Na production resulting from a combination of impact vaporization and physical sputtering [18]. Smyth and Marconi, the only workers to look at the implications of observed brightness profiles of Na and K in terms of velocity distributions, conclude that, of all the proposed mechanisms, physical sputtering is the most adequate for predicting the observations [1,12]. The solar wind, an external source, is probably the source of H and possibly He, which along with Ar could result from degassing. A determination of Ar, and possibly other constituent, isotope ratios would help to resolve the issue of external versus external sources.

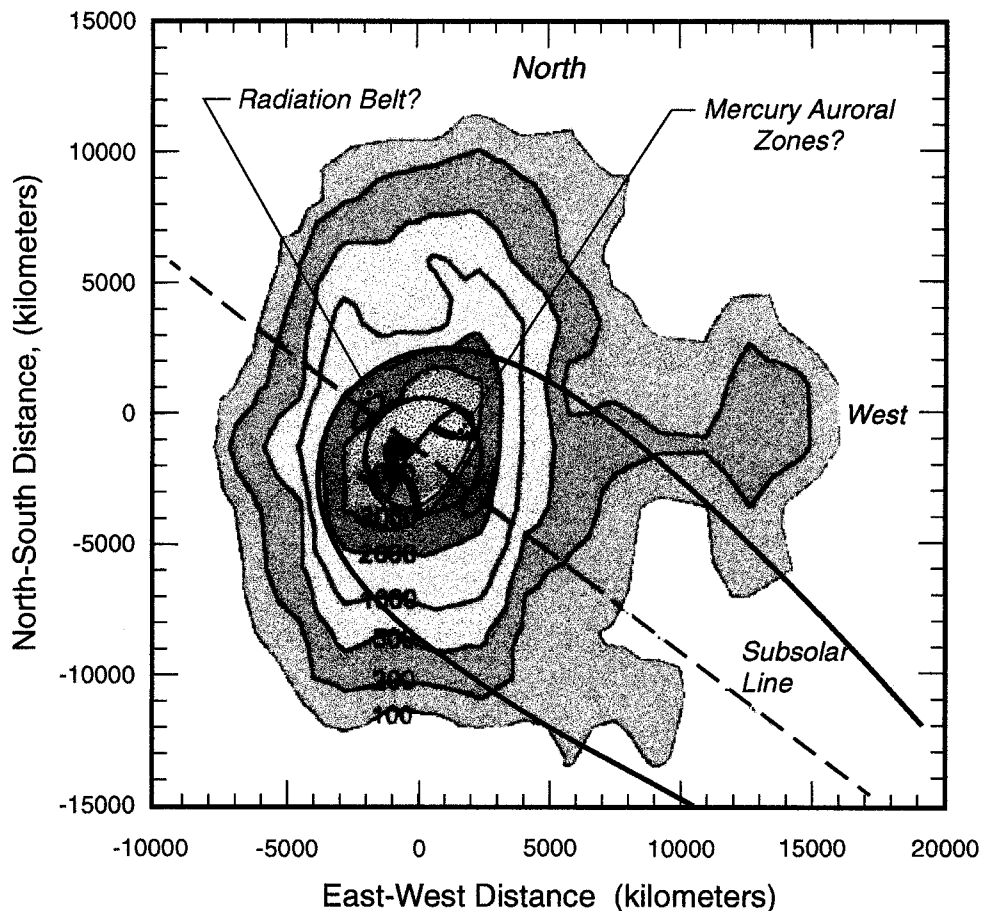


Fig. 2. From Potter and Morgan [10].

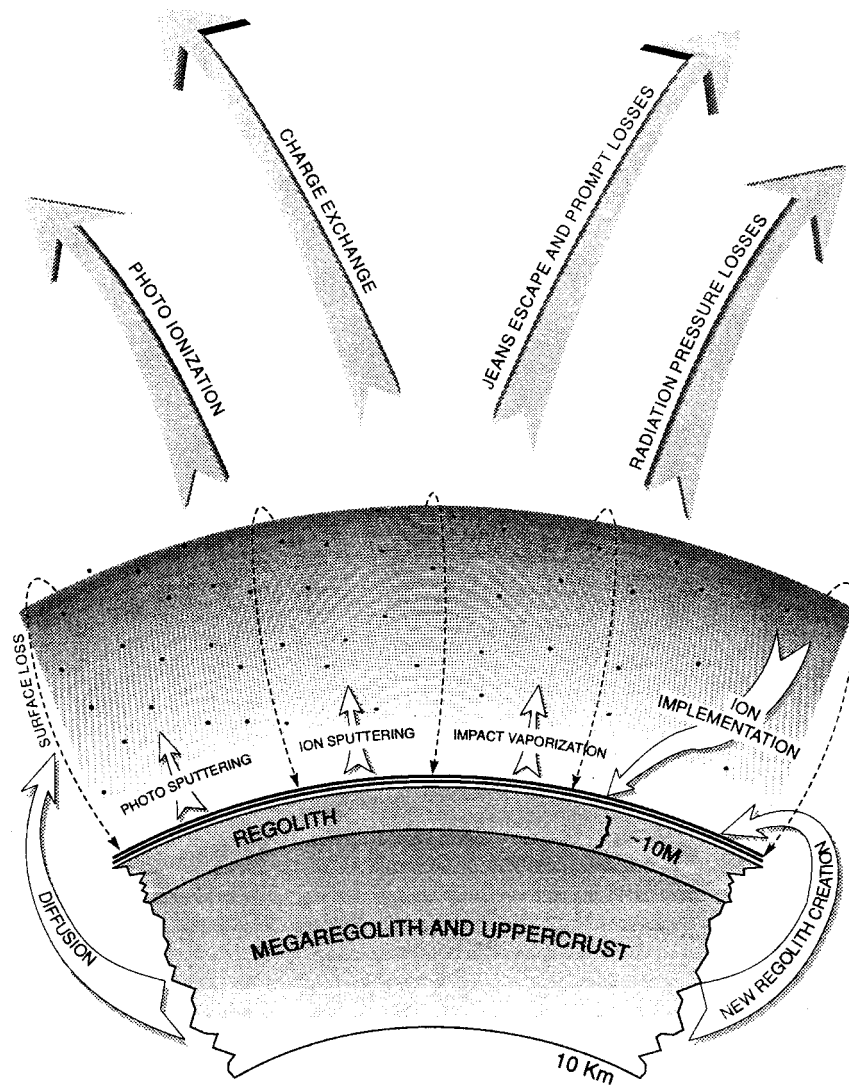


Fig. 3. From Morgan and Killen [18].

Various mechanisms have been proposed for the loss or recycling of volatile surface material. Hydrogen and He have high enough velocities to escape directly, an effect that may be enhanced by suprathermal velocity distributions likely to be present. According to modeling done by Smyth and Marconi and corroborated by observations of Potter and Morgan, average Na and K lifetimes in the atmosphere are short, roughly a couple of hours, indicating that these two constituents will generally stick (accommodate) to the surface after a relatively small number of nonsticking (ballistic) bounces [1,11,12]. Atoms would tend to stick to the surface more readily, and for longer periods of time, during the mercurian night and to become more active, with more atoms returning to ballistic bouncing, as the day returns. The overall effect is that Na and K atoms on the Sun-facing side would be swept away by the radiation pressure, spending more time in ballistic bouncing, and would generate an ambient atmosphere. The proportion in the atmosphere would be greatest at the subsolar point. Toward the terminator, a growing proportion

would be redeposited, sticking to the surface, until the atmosphere became essentially "sucked in" on the nightside.

**Magnetic Field Interactions:** Mercury's permanent magnetic field acts as a vehicle for recycling atmospheric constituents [5,20,21]. Proposed mechanisms, which include greater sputtering of surface minerals in polar regions during magnetic substorms and transport of Na ions along magnetic field lines toward high-latitude regions [20], are supported by the work of Killen, Potter, and Morgan [e.g., 16,22,23]. As a direct result, an increased rate of sputtering would occur in these regions immediately and produce the observed bright spots. Alternatively, Sprague has proposed that enhancements, at least for K, occur by way of auroral precipitation in

#### *Special Announcement*

There will be a special session on Mercury at the fall AGU meeting (December 8–12, 1997). Check the AGU Web site for details.

the magnetotail, later diffusion into the atmosphere, and implantation into the regolith to a variable extent that depends on its physical and compositional properties, shortly after dawn, followed by delayed release during morning degassing of the regolith [24,25]. Weak enhancements have been observed under certain conditions toward evening as well, which is not consistent with Sprague's model [22]. Ip modeled the trajectories of charged particles in the magnetosphere and their likely latitudes of reencounter with the surface as a function of energy [21]. Typically, the bulk of the charged particles, which have less than 1 keV energy, originate from regions near Mercury, and do not actually cross the current sheet and are thus not lost in the magnetopause, reencounter the surface at higher latitudes on the nightside, particularly just before dawn. This pattern is consistent with some observations that show enhancements at higher latitudes, particularly early in the mercurian day. The lack of agreement with all observations may be due to much greater complexity in the actual magnetosphere than in the model, which assumes a uniform electric field [21].

**Implications of Presence and Abundance of Atmospheric Constituents for Formation and History of Mercury:** Measurement of isotope ratios for Ar and other gases, and determination of the distribution of K, Na, S, OH, and Ca, in the context of sputtering and volatilization models, would place important constraints on the surface composition and allow some differentiation among petrologic types as surface constituents, in the absence of direct compositional information, which could best be provided by elemental abundance measurements made from a combined X-ray/ $\gamma$ -ray experiment on a Mercury orbiter. The planet's present atmosphere is potentially diagnostic of Mercury's surface composition and, by implication, its history, the composition of the solar wind and interplanetary dust in the inner solar system, and the morphology of Mercury's magnetic field. The relationship between components of the atmosphere and surface observations, such as IR spectral features [15,26] and the radar-bright poles and structures in the unimaged hemisphere [27], as well as the implications of this relationship for the planet's formation, will be explored in the next issue.

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## Mercury Session at the Lunar and Planetary Science Conference

Eleven papers were presented in the Mercury session at the 28th Lunar and Planetary Science Conference, held in March 1997. Two papers on Mercury's atmosphere included attempts by Morgan and Killen to establish further constraints on  $^{40}\text{Ar}$  production on Mercury, where *Mariner 10* measurements established a very generous upper limit, based on  $^{40}\text{Ar}$  measurements made for the Moon. Their results are difficult to assess because of the lack of knowledge of K distribution in Mercury's crust and complications that arise because of magnetic field interactions that do not occur on the Moon. Emery, Colwell, and Sprague simulated thermal emission from Mercury, using models that incorporate surface roughness effects. Jurgens, Slade, and Rojas presented two papers on the new 3.5-cm radar images and topography from Mercury, with coverage in both imaged and unimaged hemispheres. There is now extensive radar coverage for the entire equatorial region of the planet.

In several papers, *Mariner 10* data were used to produce new products generated with improved processing techniques. Cook, Robinson, and Oberst presented the results of a pilot study to test techniques based on the use of stereo images that will be developed to create a digital elevation model for Mercury. Robinson, Davies, Colvin, and Edwards produced a controlled albedo map of Mercury, treating *Mariner 10* data with improved processing techniques. Robinson, Hawke, Lucey, Taylor, and Spudis recalibrated and mosaicked the *Mariner 10* color data to produce new color unit maps of Mercury, in an attempt to separate opaque mineral abundance from Fe plus maturity. Their work supports the consensus that Mercury is a highly reduced planet with most of its Fe in a metallic core.

Possible ways to model the interior of the planet were presented in three papers. Peale considered the possibility of using an orbiting spacecraft to characterize the core of Mercury. Phillips and Solomon used a new approach to modeling the thermal evolution of Mercury to revisit the question of the compressional strain history suggested by the presence of lobate scarps emplaced over much of the planet's geologically active period. Zuber and Smith simulated the acquisition of Mercury gravity and topography data by an orbiting space-

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craft with modest capabilities and showed that data obtained in this way would be adequate to determine librations from which internal structure could be inferred. ☽

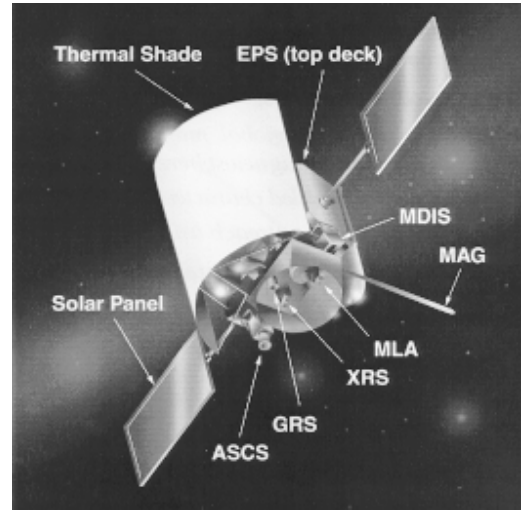
## News Flash: Mercury Candidate for Next Discovery Mission

One of the five finalists for the next Discovery mission is the Mercury MESSENGER (Mercury Surface, Space Environment, Geochemistry, and Ranging) mission, which would be led by Sean Solomon and built by the Applied Physics Laboratory at Johns Hopkins University. This orbital mission would include an imaging spectrometer, X-ray and  $\gamma$ -ray detectors,

### *Note from the Editor*

The editorial board consists of colleagues with a wide range of backgrounds and viewpoints whom I use, at least on occasion, as a sounding board for topics and content of *The Mercury Messenger*. I take full responsibility for the newsletter's final content. In particular, I would like to thank Ann Sprague, Rosemary Killen, and Bill Smyth for their input and feedback on this issue.

and ranging and magnetometer instruments as its payload (see image below). The final selection will be made in September 1997. ☽



An artist's rendering of the MESSENGER spacecraft. The science payload includes the Mercury dual imager system (MDIS),  $\gamma$ -ray spectrometer (GRS) with active shield, magnetometer (MAG), Mercury laser altimeter (MLA), atmospheric and surface composition spectrometer (ASCS), energetic particle spectrometer (EPS), X-ray spectrometer (XRS) balanced filters, and radio science (RS) spacecraft telecommunication system.