**The Magnetosphere of Planet Mercury**

The planet

Shape and structure of the magnetosphere

Current systems

Dynamics

Energy sources

Eigen oscillations

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**Planet und Magnetfeld**

Planetenradius: 2439 km

Kernradius: ~1829 km

Mittl. Dichte: 5.42 g/cm³

Rotationsrate: 58.64 Tage

Dipolmoment: 5·10¹⁹ Am²

Ober. Temp.: -173° - 429°

Atmosphäre: Nein

Exosphäre: Ja

Plasmasphäre: Nein

Magnetosphäre: Ja

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**Das Magnetfeld des Planeten Merkur**

Ness et al., 1978

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**Planetary Magnetic Fields**

<table>
<thead>
<tr>
<th>Planet</th>
<th>Radius (km)</th>
<th>Rotationsperiode (Tage)</th>
<th>Äquatoriales Magnetfeld [nT]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merkur</td>
<td>2439</td>
<td>58.6</td>
<td>340</td>
</tr>
<tr>
<td>Venus</td>
<td>6052</td>
<td>243</td>
<td>0.6</td>
</tr>
<tr>
<td>Erde</td>
<td>6371</td>
<td>1</td>
<td>31000</td>
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<tr>
<td>Mars</td>
<td>3397</td>
<td>1</td>
<td>&lt; 0.5</td>
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<tr>
<td>Jupiter</td>
<td>71398</td>
<td>0.4</td>
<td>424000</td>
</tr>
<tr>
<td>Brücke</td>
<td>0.8</td>
<td>3.6</td>
<td>92500</td>
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<tr>
<td>Saturn</td>
<td>60000</td>
<td>9.41</td>
<td>21500</td>
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<tr>
<td>Uranus</td>
<td>25200</td>
<td>0.72</td>
<td>22800</td>
</tr>
<tr>
<td>Neptun</td>
<td>24300</td>
<td>0.70</td>
<td>14400</td>
</tr>
</tbody>
</table>

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**Magnetospheric Plasma Sources**

Mercury: solar wind and sputtering of surface material, e.g. sodium

Earth: solar wind and ionosphere

Jupiter: solar wind and volcanic activity of the moon Io

Saturn: solar wind, atmosphere of moon Titan, sputtering at surfaces of icy moons and rings

Uranus: polar ionosphere, minor solar wind contribution

Neptun: ionosphere, moon Triton

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**The Magnetosphere of Mercury**

No atmosphere

thus no ionosphere but exosphere

No plasmasphere

Weak magnetic field

Multi-ion plasma

Small magnetosphere
Solar Wind: The Embedding Medium

Magnetic field and plasma density

Mercury: 46 - 21 nT 73 - 33 cm⁻¹
Earth: 8 nT 5 cm⁻¹
Jupiter: 1 nT 0.2 cm⁻¹
Saturn: 0.6 nT 0.06 cm⁻¹
Uranus: 0.3 nT 0.01 cm⁻¹
Neptun: 0.005 nT 0.005 cm⁻¹

The velocity is almost constant in the inner part of the heliosphere.

Magnetopause Formation

The magnetopause is a surface where the dynamic pressure of the solar wind and the magnetic pressure of the magnetospheric plasma are in equilibrium:

\[ p_{\text{dyn}} = 2 n_e m_p v_{sw}^2 = \frac{B^2}{2\mu_0} \]

The dynamic pressure of solar wind particles is transferred to the magnetospheric plasma by specular reflection of the particles at the boundary.

Magnetopause Position

The magnetopause stand-off distance along the Sun-Earth line is given by

\[ R_{\text{MP}} = \left( \frac{4B_{\text{Surface}}^2}{2\mu_0 kn_e m_p v_{sw}^2} \right)^{1/6} \]

where \( k = 0.88 \) is a correction factor resulting from gasdynamic approximations to the magnetosheath flow:

At Mercury \( R_{\text{MP}} = 1.5 R_p \)

Electric Currents in the Magnetosphere

Magnetopause currents
No ring current
Neutral sheet current
Tail current
Field-aligned currents
No polar electrojet currents

Magnetopause Current – Chapman-Ferraro Current

At the mp jump in magnetic field by about 24 nT, a value typical also at the terrestrial mp.

From \( \nabla \times \mathbf{B} = \mu_0 j \) a current density of about \( j_{\text{mp}} = 1.5 \times 10^{-4} \text{ A/m}^2 \) results, assuming an mp thickness of 125 km.

Magnetopause Current – Ground Magnetic Effect

Chapman-Ferraro currents produce ground magnetic effects, which at

Earth are of the order of 10 nT added to a 30,000 nT background field
and at

Mercury are of the order of 70 nT added to a 340 nT background field.

The external field matters at the surface !!!!
Field-Aligned Currents

Field-aligned current density: $7 \times 10^{-7} \text{ A/m}^2$

Closure problem as at Earth FACs close in the ionosphere but Mercury has no ionosphere.

Is there a substorm current wedge at Mercury?

Enhanced westward electrojet in the ionosphere or closure via diamagnetic currents in the plasma itself.

Substorms and Flux Transport in the Open Magnetosphere

Dayside reconnection transports plasma and magnetic flux towards the nightside tail where return flux is initiated by reconnection again.

Dungey’s model of the closed and open magnetosphere.

Corotation, Reconnection Induced Convection, and the Plasmapause

Does Mercury have a plasmasphere?

Magnetospheric Convection and Corotation

Corotation implies plasma motion and via the frozen-in theorem

$$\vec{E} + \vec{v} \times \vec{B} = 0$$

electric fields, that is the corotational electric field is given as

$$E_{\text{cor}} = -\frac{\Omega_{\text{Earth}} B_{\text{surf}} R_E^2}{r} \hat{e}_r$$

and corotation driven plasma motion is $E \times B$-drift convection

$$\vec{v}_{\text{cor}} = \frac{E_{\text{cor}} \times \vec{B}}{B^2}$$

Mercury has no plasmasphere.

External Forcing – Internal Reactions?

Mercury Perihelion (3.09 AU)

$E_{\text{cor}}$
**Bulk Modulus and Compressibility**

\[ K = V \cdot \frac{\Delta p}{\Delta V} \]

Modulus

\[ \kappa = \frac{1}{V} \frac{dV}{dp} \]

Compressibility

**The Magnetospheric Bulk Modulus**

\[ R_{MP} = \left( \frac{B_0^2}{\mu_0 \rho} \right)^{1/6} \]

\[ p = n_{sw} m_{p} v_{sw}^2 \]

Magnetopause position

\[ K = R_{MP} \frac{dp}{dR_{MP}} \propto p_{MP} ; \quad p_{MP}(r = R_{MP}) \]

Bulk modulus

\[ \kappa = 1 / K \propto -1 / p_{MP} \]

Compressibility

Mercure has a very stiff, but Jupiter a very fluffy magnetosphere: Mercury rings, Jupiter not !!!!!!

**Ringing the Magnetospheric Bell**

Magnetospheric eigenoscillations are MHD waves in the terrestrial magnetosphere.

Their periods are much longer than proton gyroperiods !!!

**ULF Waves at Mercury**

This is the only published evidence for ULF waves in the Hermean magnetosphere.

Amplitude: 2 nT

Period: 2 s, e.g.

about twice \( T_{proton} \)

this wave is not an MHD wave !!!!

**Global oscillations: The Dungey Problem**

Dipolemagnetosphere

MHD oscillations

Axisymmetric perturbations

Decoupled toroidal and poloidal oscillations

**Global oscillations: Earth**

Decoupled toroidal and poloidal eigenoscillations for axisymmetric ( \( m=0 \) ) perturbations

Voelker, 1963
Global oscillations: Mercury

To treat this question we need Dungey's equations for a non-MHD model of the Hermean magnetosphere as the anticipated eigenfrequencies are less, but comparable to the gyrofrequency.

Mercury: A Two Component Cold Plasma Approach

\[
\epsilon = \begin{pmatrix}
\varepsilon_1 & -i\varepsilon_2 & 0 \\
 i\varepsilon_2 & \varepsilon_1 & 0 \\
 0 & 0 & \varepsilon_3
\end{pmatrix}
\]

Dielectric Tensor; \(0 < \Phi < \Phi_i\)

\[
\varepsilon_1 \equiv \frac{c^2}{v_A^2} + \frac{c^2}{v_A^2} \frac{\omega_i^2}{\Omega_i^2} \\
\varepsilon_2 \equiv -\frac{c^2}{v_A^2} \frac{\omega_i^2}{\Omega_i^2} \\
\varepsilon_3 \equiv -\frac{\omega_i^2}{\Omega_i^2}
\]

Mercury: Global Oscillations

Axisymmetric Perturbations \(m=0\)

\[\vec{E} = -\nabla \Phi + \nabla \times \Psi \vec{\varepsilon}_||\]

Scalar potentials

Toroidal operator using curvi-linear coordinates

\[T(\omega) = \partial_1 \left( \frac{g_2}{g} \partial_3 + \frac{\sqrt{g}}{g_1} \frac{\omega^2}{v_A^2} \right) \]

Toroidal oscillation coupled to poloidal though \(m=0\), due to \(m=2\).

\(\Rightarrow\) Dmitri Klimushkin and Pavel Mager

Kinetic Alfvén Waves in the Hermean Magnetosphere

a) Solar wind buffeting causes ringing of the magnetosphere

b) The scale of the magnetosphere is about 10 x the ion gyroradius

c) Waves generated by buffeting are kinetic Alfvén waves with \(E_\| \approx 0.2\) mV/m (Glassmeier, 2000)

d) Buffeting causes particle heating via kinetic Alfvén waves

Electromagnetic Induction at Mercury

We have a small magnetosphere

Magnetopause currents are close to the planet

Temporal variations of magnetopause currents may cause strong induction effects

As the planet consists mainly out of a highly conducting core

How large are these induced fields?
Summary

Mercury is a new point in the magnetospheric phase space!!!!!