Capon's nonlinear method for recognizing spatial structures in planetary magnetic fields

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Nonlinear and adaptive filter techniques have a wide range of applications in geophysical and space science studies to find the most likely parameter set describing the measurement data or to decompose the data into a set of signals and noise. Above all, the minimum variance distortionless projection (hereafter, Capon's method) has successfully been applied to multipoint data analyses for waves, turbulence fields and current sheets. In view of the upcoming BepiColombo mission, the method is currently being considered as a robust inversion method for the analysis of Mercury's internal magnetic field (Ref. [1,2]).

Due to the plasma interaction of Mercury with the solar wind, the magnetic field within Mercury's magnetosphere is composed of internal and external parts. The internal magnetic field is mainly driven by the dynamo process, whereas the external parts result from currents flowing within the magnetosphere. For the reconstruction of Mercury's internal magnetic field, a robust inversion method, such as Capon's method, for separating the internal parts from the total measured field is required.

Besides the application of a suitable inversion method, the parametrization of the magnetic field contributions to the total measured field is of major importance for the reconstruction of the internal magnetic field. In contrast to the Earth, no completely current-free region is present within Mercury's magnetosphere and therefore, the conventionally used Gauss representation does not yield an entire parametrization for the magnetic field. Extension of the Gauss representation to the Gauss-Mie representation (Ref. [3]) enables the analysis of magnetic field data measured in current carrying regions in the vicinity of Mercury.

In preparation for the obsevations soon to be obtained by the BepiColombo mission, Mercury's plasma interaction with the solar wind is simulated numerically. The resulting magnetic field data are evaluated along the planned trajectories of the Mercury-Planetary-Orbiter and the wanted internal Gauss coefficients are reconstructed from the data. The interplay of Capon's method with the Gauss-Mie representation enables a high-precision determination of Mercury's internal magnetic field at least up to the dotriacontapole.

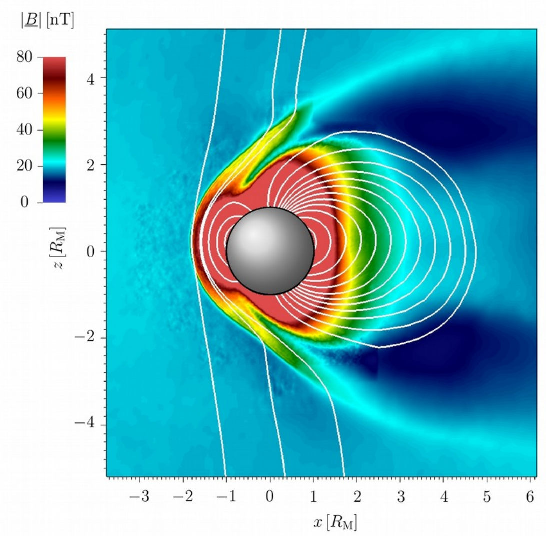

Figure 1. Simulated magnitude of the magnetic field B in the x-z-plane (Ref. [3]). The white lines represent the magnetic field lines and the grey circle of radius 1 R_M symbolizes Mercury.

References
[1] Toepfer et al., Front. Phys., 8:249 (2020a)
[2] Toepfer et al., Geosci. Instrum. Method Data Syst., 9:471–481 (2020b)
[3] Toepfer et al., Earth Planets Space, 73:65 (2021)