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Past and present tidal dissipation in Mercury

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Abstract

Tidal dissipation inside Mercury is expected to have significantly contributed to Mercury's internal thermal state and to its orbital evolution. The total dissipated power depends on the tidal potential and on the interior structure of Mercury. For two different tidal potentials and for a set of plausible interior structure models, we determine the total dissipated power and assess resulting heat flow patterns at the surface and at the inner core surface.

1. Introduction

Past tidal dissipation inside Mercury has significantly contributed to the evolution of Mercury's thermal and dynamical state and it is conceivable that the contribution of the present tidal dissipation is not negligible. Besides contributing to the thermal state of Mercury, viscous friction at the core mantle boundary is responsible for Mercury's secular spin evolution [1]. Moreover tidal dissipation inside the inner core can provide a substantial heat contribution for driving convective motions, and with it a planetary dynamo, inside Mercury's liquid core. Finally, surface heat flow variations resulting from tidal heating can affect local lithosphere thickness variations and may result in distinctive tectonic patterns [2].

Here, we calculate the tidal dissipation inside Mercury for a large set of plausible interior structure models [3] with different mantle and inner core rheologies. We consider two tidal potentials resulting from two different orbital configurations: the present configuration where Mercury is locked in a 3 : 2 spin-orbit resonance and a plausible past configuration where Mercury had a rotation period of 20h. For all models, we calculate the globally dissipated power and study heat flux patterns at the surface and at the inner core surface.

2. Tidal dissipation

Tidal forces from the Sun deform Mercury and because of internal friction generate heat. The amount of generated heat depends on the internal structure of the planet, on its rheology, and on the tidal potential. Since the maximum of the total dissipated power inside a planet is proportional to the tidal frequency, the maximal amount of tidally generated heat inside the early fast rotating Mercury could have been about two orders of magnitude larger than today.

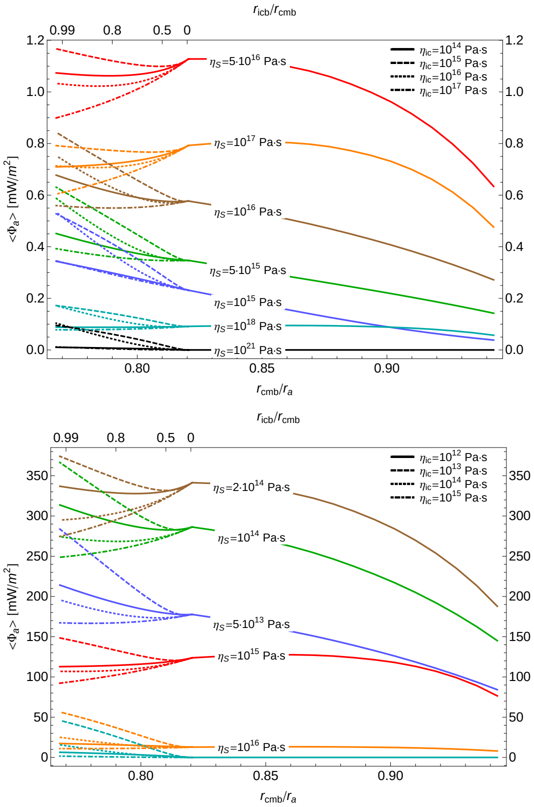

Figure 1: Surface heat flow as a function of core size for the tidal potential of the present 3 : 2 resonance configuration (top) and for an early fast rotating configuration (bottom). $r_{\rm icb}$, $r_{\rm cmb}$, $\eta_{\rm s}$, and $\eta_{\rm ic}$ are the inner core radius, the core radius, the mantle viscosity, and the inner core viscosity.

Depending on the viscosities of both the mantle and the inner core the dissipated power inside an early Mercury could have been as high as $350\mathrm{mW/m^2}$ whereas today it is about $1\mathrm{mW/m^2}$ (see Fig. 1). Besides the tidal frequency, the amount of dissipated power inside a planetary body depends on the volume of the dissipating materials and on the amplitude of the tidally induced deformations. The dissipated power decreases with increasing core size in the absence of an inner core because the volume of the dissipating material decreases, although the deformations increase. Models with a large and strongly dissipating inner core generate the largest amount of frictional heat.

Since the time-dependent tidal potential depends on latitude and longitude, the time-averaged heat flux at the surface and at the inner core surface is not uniform. For both orbital configuration (3 : 2 resonance and fast rotation) tidal dissipation is maximum at the poles and minimum at the equator (see Figs. 2 and 3 for representative patterns of heat flux). Note that the tidal potential associated with the fast rotation configuration results in zonal surface heat flow patterns.

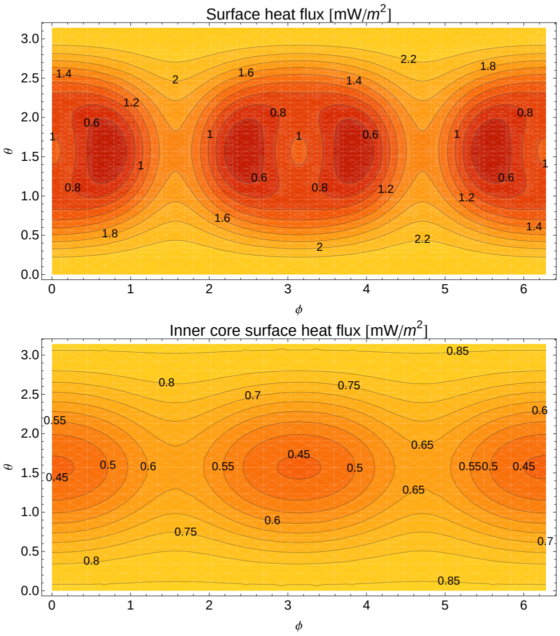

Figure 2: Contribution of the planet mantle to the surface heat flux ($r_{\rm icb}$ = 100km and $r_{\rm cmb}$ = 1988km) and inner core surface heat flux ($r_{\rm icb}$ = 1800km and $r_{\rm cmb}$ = 1860km) for the 3 : 2 resonance tidal potential. ϕ and θ are the longitude and the latitude and where $\eta_{\rm ic} = 10^{14}\,{\rm Pa\,s}$ and $\eta_{\rm s} = 10^{16}\,{\rm Pa\,s}$.

3. Conclusions

Present time tidal dissipation inside Mercury is probably below $1{\rm mW/m^2}$ and it is at least one order of magnitude smaller than heat generated by radioactive elements [4]. It remains to be investigated whether it can have an appreciable effect on Mercury's present thermal state. In any case, tidal heating has a negligible effect on lithospheric thickness variations [2]. However, the tidally dissipated power could have been significantly larger when Mercury was rotating faster, and might have substantially contributed to the thermal state, orbital evolution, and surface tectonic patterns.

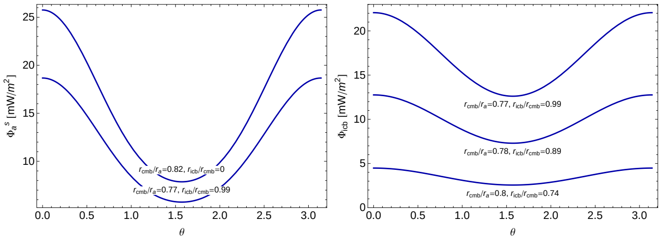

Figure 3: Contribution of the planet mantle to the surface heat flux and inner core surface heat flux for the fast rotating Mercury configuration. θ is the colatitude and $\eta_{\rm ic} = 10^{14}\,{\rm Pa\,s}$ and $\eta_{\rm s} = 10^{16}\,{\rm Pa\,s}$.

References

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