

An MHD simulation study of the Kelvin-Helmholtz instability at the Martian ionopause with a day-to-night density gradient.

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The effects of a day-to-night density gradient on the linear and nonlinear evolutions of the Kelvin-Helmholtz instability (KHI) at the Martian ionopause have been investigated using 2-D non-local MHD simulations. The KHI is expected to play a major role in transporting mass, momentum and energy across the ionopause from the sheath flow to the Martian ionospheric plasmas, and is thus regarded as one of the candidate processes that have removed a huge amount of ions from Mars through its long history. Recent local MHD simulation studies have pointed out that a density gradient in the vertical direction significantly reduces its linear growth rate and makes KH vortices more inhomogeneous during the nonlinear phase [Amerstorfer *et al.*, 2010]. However, the actual ionopause has a density gradient not only in the vertical direction but also in the horizontal (day-to-night) direction. In order to investigate the effects of a day-to-night density gradient on the evolution of the KHI, we have developed two non-local models by incorporating two elements of a global model, i.e., an aperiodic boundary condition and the day-to-night density gradient, into a local model.

Comparing the results of the aperiodic case (non-local model, without a day-to-night density gradient) with those of the periodic case (local model), we find three notable differences in the evolution of the KHI. Firstly, the peak energy of KH waves in the aperiodic case increases during the nonlinear phase, because of the excitation of longer wavelength modes than the fastest growing mode. Secondly, while the evolution of the main vortices group is mostly the same in both cases, that of the leading vortex is quite different. Thirdly, the ionospheric plasma in the aperiodic case is excavated deeper. We find that these latter two differences are caused by the asymmetry in the structure of both sides of each vortex. When there is a wall-like structure just downstream of a vortex, such as another vortex with a larger amplitude, the sheath flow will be stagnated by the wall-like structure. This stagnated sheath flow induces an enhanced vortex return flow, resulting in a deeper excavation of the ionospheric plasma and elongated filamentary structure. On the other hand, with an insufficient vortex motion on the leading side of a KH vortex, the high pressure fluid cannot wrap the low pressure region along the vortex motion, leading to an imbalance between the pressure gradient force and the centrifugal force associated with the vortex motion. We find that these asymmetries in the vortex structure are responsible for making the latter two differences between the aperiodic and the periodic cases.

We also compare the results of the day-to-night density gradient case with those of the aperiodic case. We find that the KHI is quickly excited in the downstream region even though a perturbation is inserted from the upstream boundary. In previous studies, it has been thought that the KH wave propagates from upstream to downstream, i.e., one-way propagation. However, we find that perturbations associated with the KH wave can propagate also from downstream to upstream. We also find that highly elongated filamentary structures are developed clearly in downstream more than the aperiodic case. But we have to be cautious about this result because we see a leakage of a high density fluid to downstream near the ionopause, which is caused by the effect of the initial condition given with a hyperbolic tangent function following the traditional method.

We also discuss the effect of the day-to-night density gradient case on the loss rate of the ionospheric ions from Mars. We find that the ions loss efficiency in the day-to-night density gradient case is 60-70% of that in the aperiodic case. This result suggests that we should consider the effect of the day-to-night density gradient in the loss rate of planet's atmosphere through KHI.