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A revised theory of the diamagnetic cavity of comets

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Abstract

The physics of the diamagnetic cavity of a comet is governed by a set of three coupled partial differential equations. The classical description of the cavity – although surprisingly successful in explaining many aspects of the observations – concentrates only on solving a single equation in the long distance and zero resistivity limit. Recent observations of the Rosetta mission provide comprehensive plasma data about a multitude of cavity crossing events and reveal the cavity as a dynamic object with many new and interesting features. Here we show that exact analytical solutions of the equations exist for a much more general case, which provide new insight into the properties and dynamics of the phenomenon. For the most general case the system of equations can be integrated numerically. The generalized solutions show that the magnetic field does not drop to zero immediately inside the cavity, but rather features a rapid exponential decay. Outside the cavity, for longer distances the field approaches the classical solution. The plasma velocity first drops rapidly as the plasma enters the cavity boundary; for larger distances it decreases as 1/r towards its asymptotic value in the infinity. In general, the velocity does not necessarily approach zero in the infinity, there are inward and outward moving solutions as well, explaining the dynamic nature of the cavity. Interestingly, these moving solutions imply a small, but finite field value inside the cavity. Thus, in contrast with prevailing belief, the magnetic field inside the cavity is in general not zero, but small. The shape of the magnetic field solution also depends on the asymptotic plasma velocity, consequently, the field gradient is different for inward and outward moving boundary crossings. The ion density has a strong peak in the boundary layer of the cavity. Away from the boundary – both inside and far outside – the density shows a 1/r dependence, but with different coefficients. The sharp density increase in the boundary layer affects the size of the cavity: the size scales as the square root of the density ratio at the jump. Thus the cavity size is larger than that predicted by the classical theory.