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BGK waves: nonlinear saturated states in space plasmas?

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There has been renewed interest in the theory of Bernstein-Greene-Kruskal (BGK) waves, motivated by recent identifications of electrostatic solitary waves (ESWs) in space plasmas from spacecraft such as Geotail, Fast, Polar, Cassini, and Cluster. These observations make it evident that the observed waves cannot be described by the classical one-dimensional theory. While one-dimensional BGK theory is quite mature, there appear to be no exact three-dimensional solutions in the literature except for the limiting case when the magnetic field is sufficiently strong so that one can apply the guiding-center approximation. We show, in fact, that two- and three-dimensional solutions that depend only on energy do not exist [Phys. Rev. Lett., 95, 245004, 2005]. However, if there exists an ignorable coordinate and solutions depend on both energy and a constant of the motion such as angular momentum, it is possible to construct exact two-dimensional solutions in the presence of a finite magnetic field. The latter are shown to be exact, fully electromagnetic solutions of the steady-state Vlasov-Poisson-Ampère system. Width-amplitude relation of such BGK wave solutions as well as the spatial electric field structures are shown to be consistent with observations. These exact results impose strong constraints on theoretical models that interpret observations of ESWs on the basis of BGK wave theory.