A Rigid-Field Hydrodynamics approach to modeling the magnetospheres of massive stars

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We introduce a new Rigid-Field Hydrodynamics approach to modeling the magnetospheres of massive stars in the limit of very-strong magnetic fields. Treating the field lines as effectively rigid, we develop hydrodynamical equations describing the 1-dimensional flow along each, subject to pressure, radiative, gravitational, and centrifugal forces. We solve these equations numerically for a large ensemble of field lines, to build up a 3-dimensional time-dependent simulation of a model star with parameters similar to the archetypal Bp star sigma Ori E. Since the flow along each field line can be solved for independently of other field lines, the computational cost of this approach is a fraction of an equivalent magnetohydrodynamical treatment.

The simulations confirm many of the predictions of previous analytical and numerical studies. Collisions between wind streams from opposing magnetic hemispheres lead to strong shock heating. The post-shock plasma cools initially via X-ray emission, and eventually accumulates into a warped, rigidly rotating disk defined by the locus of minima of the effective (gravitational plus centrifugal) potential. But a number of novel results also emerge. For field lines extending far from the star, the rapid area divergence enhances the radiative acceleration of the wind, resulting in high shock velocities (up to ~3,000 km/s) and hard X-rays. Moreover, the release of centrifugal
potential energy continues to heat the wind plasma after the shocks, up to temperatures around twice those achieved at the shocks themselves. Finally, in some circumstances the cool plasma in the accumulating disk can oscillate about its equilibrium position, possibly due to radiative cooling instabilities in the adjacent post-shock regions.

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