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Magnetically-Dominated Jets inside Collapsing Stars as a Model for Gamma-Ray Bursts and Supernova Explosions

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It has been suggested that magnetic fields play a dynamically-important role in core-collapse explosions of massive stars. In particular, they may be important in the collapsar scenario for gamma-ray bursts (GRB), where the central engine powering the explosion is a hyper-accreting black hole or a millisecond magnetar. We here focus on the magnetar scenario, with an emphasis on the interaction of a newly-born magnetar with the infalling stellar envelope. We first introduce the "Pulsar-in-a-Cavity" problem as a basic-physics paradigm for a magnetar inside a collapsing star. We briefly describe the basic set-up of this fundamental plasma-physics problem, outlining its main features and deriving simple estimates for the evolution of the magnetic field and the magnetic luminosity. We find that, at first, the ram pressure of the infalling plasma acts to confine the neutron-star magnetosphere, enabling a gradual build-up of the magnetic pressure. At some point, the growing magnetic pressure overtakes the (decreasing) ram pressure of the surrounding gas, resulting in a magnetically-driven explosion. The explosion should be highly anisotropic, as the hoop-stress of the toroidal field, confined by the surrounding stellar matter, collimates the magnetically-dominated outflow into two beamed magnetic tower jets. This provides an attractive scenario for the creation of a clean narrow channel for the escape of energy from the central engine through the star, as required by GRB observations. In addition, the delayed onset of the collimated phase of the explosion has interesting consequences for the production of Nickel-56, and hence for the GRB-Supernova connection. Finally, we describe the results of recent numerical MHD simulations related to this scenario.