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Stellar magnetic equilibria, their stability and evolution

In many stars, like in the solar convection zone, magnetic fields are very dynamic and constantly regenerated by dynamos. In other cases, particularly in the envelopes of massive main sequence stars, in white dwarfs, and in neutron stars, they appear to be long-lived “fossils” in a stable magnetic equilibrium state.

In this talk, I will show analytical arguments and numerical simulation results to discuss the physical ingredients likely required for such magnetic equilibria and their stability. First, to hold a stable magnetic field, the matter inside a star needs to be stably stratified, which can be achieved by an entropy gradient (in massive main-sequence stars and white dwarfs) or by a composition gradient (in neutron stars). Furthermore, even if this condition is satisfied, the simplest possible magnetic field configurations (purely toroidal or purely poloidal) appear to be unstable, so a combination of mutually stabilizing toroidal and poloidal fields appears to be the simplest stable field configuration, but more complex geometries are possible and may well arise in real stars.

In upper main-sequence stars and white dwarfs, the magnetic equilibria should remain essentially constant in time. In neutron stars, they can dissipate by ambipolar diffusion (relative motions of neutrons and charged particles), possibly accounting for the strong energy release in magnetars and the much weaker fields of very old neutron stars such as millisecond pulsars.