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Magneto-Thermal Instability in Galaxy Clusters

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In the intracluster medium (ICM) of galaxies, exchanges of heat across magnetic field lines are strongly suppressed. This anisotropic heat conduction, in the presence of a large-scale temperature gradient, destabilizes the outskirts of galaxy clusters via the magneto-thermal instability (MTI), and thus supplies a source of observed ICM turbulence. Our aim is to take a fresh look at the problem and construct a general theory that (a) explains the MTI saturation mechanism and (b) provides scalings and estimates for the turbulent levels. We simulate MTI turbulence with a Boussinesq code, SNOOPY, which allows us to carry out an extensive sampling of the parameter space. In two dimensions the saturation mechanism involves an inverse cascade carrying kinetic energy from the short MTI injection scales to larger scales, where it is arrested by the stable entropy stratification; at a characteristic 'buoyancy scale', the energy is dumped into large-scale g-modes, which subsequently dissipate. In three dimensions most of the energy is dissipated at the same scale as its injection, and turbulent eddies are vertically elongated at or below the thermal conduction length, but relatively isotropic on larger scales. Similar to 2D, however, the saturated turbulent energy levels and the integral scale follow clear power-laws that depend on the thermal diffusivity, temperature gradient, and buoyancy frequency. We also show that the MTI amplifies magnetic fields, through a fluctuation dynamo, to equipartition strengths provided that the integral scale of MTI turbulence is larger than the viscous dissipation scale. Finally, we show that our scaling laws are consistent with extant observations of ICM turbulence if the thermal conductivity is reduced by a factor of ~ 10 from its Spitzer value, and that on global cluster scales the stable stratification significantly reduces the vertical elongation of MTI motions.

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