The Theory of Magnetothermal Instability in Coronal Plasma Flows

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In this summary, the theory of the magnetothermal instability (MTI) is revisited through the lens of the stability of uniform systems, and its implication in the corona dynamics of direct-drive implosions is discussed. The underlying mechanism of this instability corresponds exclusively to the interplay between the Biermann battery generating magnetic (B) fields and the Righi–Leduc term bending the heat flux lines, as shown in Fig. 1. In its most simple configuration, a temperature perturbation δT results in B-field generation $\delta\vec{B}$ via the Biermann battery. This allows the Righi–Leduc heat flux, $\vec{q}_{\mathrm{RL}} \propto \left(T_0^4/n_0\right)\nabla T_0 \times \delta\vec{B}$, to pump heat into the hotter regions of the fluid, thereby driving the MTI by amplifying the δT perturbation.

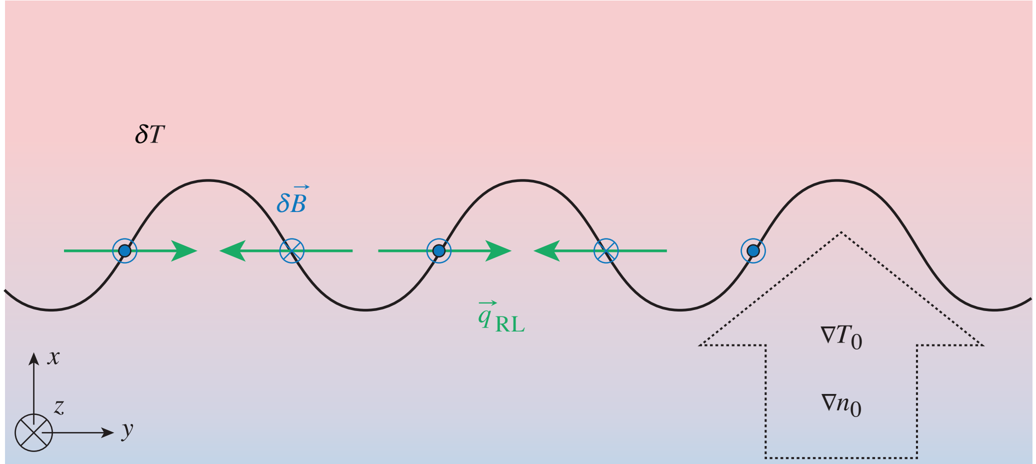

Figure 1
Schematic of the magnetothermal instability as first explained in Ref. 1. It relied on the background ∇T_0 and ∇n_0 being aligned.

The main novelty in the linear stability analysis performed in this summary corresponds to the distinction between the convective and the absolute nature of the perturbation growth. Previous analyses[1–3] identified the MTI as a convective instability and observed significant suppression of its growth rate caused by Nernst convection.[3] In the present linear analysis, we have applied the instability criteria derived by Briggs[4] to prove that, in the region where the Nernst and plasma blowoff velocities cancel, the MTI can be absolute and wave-packet perturbations grow *in situ*. The growth rate thereby derived becomes

$$\gamma\mathrm{MTI}_{\mathrm{ns}^{-1}} = 0.19\, i\bar{\varpi}_{M_2}\,\frac{10}{\log\Lambda}\,\frac{\gamma_0''}{\gamma_0\delta_0 Z}\,\frac{T_{\mathrm{keV}}^{5/2}}{n_{10^{22}\,\mathrm{cm}^{-3}}}\left(\frac{\mathrm{d}\log T}{\mathrm{d}x_{100\,\mu\mathrm{m}}}\right)^2,$$

where γ_0'', γ_0, and δ_0 are coefficients that depend on the atomic number Z given in Braginskii,[5] and the dimensionless frequency $i\bar{\varpi}_{M_2}$ depends on the isothermal Mach number (Ma) of the section in the corona in consideration and the pressure-to-temperature gradient ration (δ), Fig. 2.

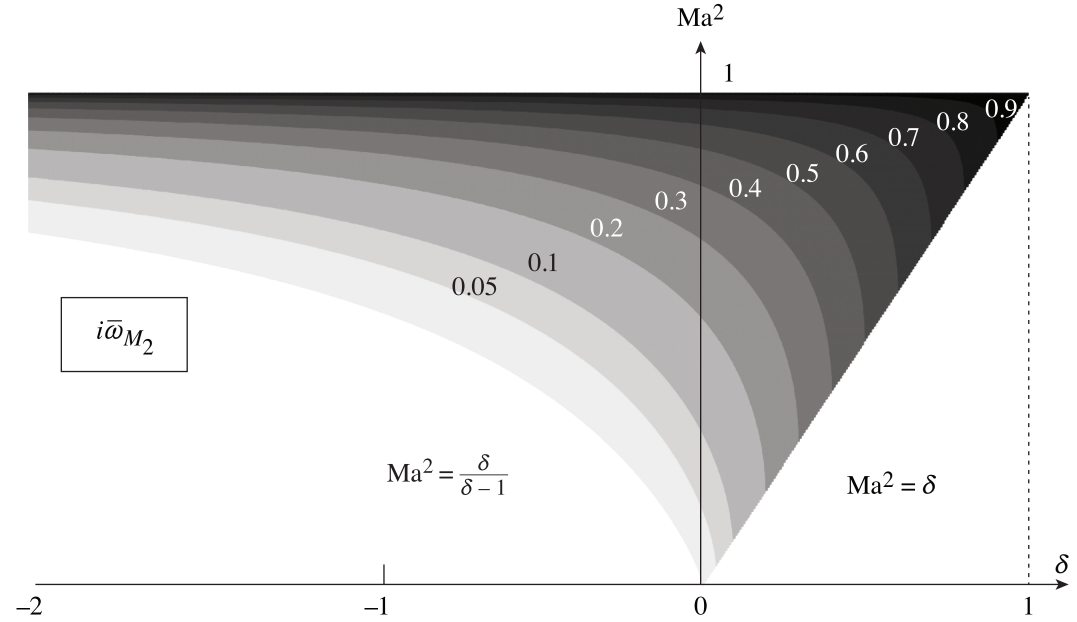

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Figure 2
Isocontours of the temporal growth rate $i\bar{\varpi}_{M_2}$ in the phase space isothermal Mach number Ma and pressure-to-temperature gradient ratio δ.

The analysis has been extended to derive the dispersion relation for short-wavelength perturbations developing in nonuniform profiles with application to coronal plasmas. It is found that the condition for MTI requires the net B-field convection velocity to be small at the isothermal sonic section, and the plasma conditions in this section govern the dynamics of the instability. This theory reveals a picture of the MTI where the conduction layer is the dynamically active region of the corona. Here is found the spatial resonance that causes perturbations to grow *in situ*, hence traveling with the imploding shell and potentially altering its dynamics. The structure of the unstable perturbations tends to elongate filaments in the azimuthal direction, in agreement with the observations made in Ref. 6. They can spread out to regions of outflowing convection velocity, being subsequently stretched radially and filling the outer corona. This picture is in qualitative agreement with the proton radiographs of imploding fast-ignition capsules performed by Rygg *et al.*,[7] who observed striated fields that originate close to the capsule surface, and conjectured that the vast spatial extent of these fields reflects an outward convection of filamentary structures originally produced inside the critical surface.

Applying this theory to direct-drive inertial confinement fusion implosions provides an MTI growth rate in the range of a fraction to few gigahertz (see Fig. 3), which is milder than the ones discussed by Manuel *et al.*[8] and Bissell *et al.*[9] (several to tens of gigahertz). This is mainly due to authors employing growth rate expressions derived from a convective instability analysis, which favors lower-density, higher-temperature regions (outer corona) as more-unstable regions. The outer corona indeed supports unstable waves, but we deem we must impose the requirement for absolute instability to account how the MTI affects the dynamics of the implosion. This holds the plasma state at the conduction layer responsible for the growth rate of the MTI. Finally, analysis of hydro-equivalent implosions suggests that unstable perturbations undergo more *e* foldings of growth in larger-size targets.

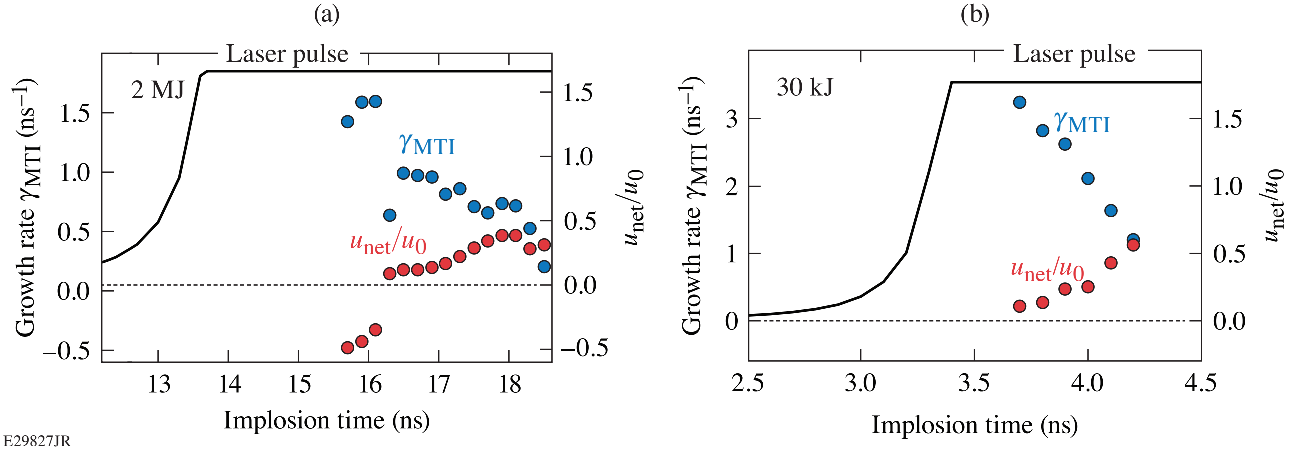

Figure 3
Maximum growth rate γ and velocity ratio u_{net}/u_0 at the isothermal sonic point for(a) 2-MJ and (b) 30-kJ direct-drive implosions. The laser power pulse shape is plotted for reference.

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