Chiral Magnetovortical Instability and Dynamo

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- arXiv:2307.06746
- Talk: Instabilities in chiral plasma Jul.16 Xu-Guang Huang

Outline

1. Introduction
   - Alfvén Wave
   - Chiral Alfvén Wave
2. Chiral Magnetovortical Instability
   - CVE and Dynamical Electromagnetic Field
   - Dispersion Relation and Instability
   - CME-Chiral Plasma Instability
3. Dynamo Effect
   - CVE and Dynamo
4. Summary and Outlook
   - Summary and Outlook

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Alfvén Wave

Ideal magnetohydrodynamics(MHD) equations [1]

$$\begin{aligned}
&\nabla \cdot \boldsymbol{B} = 0, \quad \partial_t \boldsymbol{B} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) \\
&\rho[\partial_t \boldsymbol{v} + (\boldsymbol{v} \cdot \nabla)\boldsymbol{v}] = -\nabla P + \frac{1}{\mu_0}(\nabla \times \boldsymbol{B}) \times \boldsymbol{B} \\
&\partial_t \rho + \nabla \cdot (\rho \boldsymbol{v}) = 0, \quad \partial_t s + \boldsymbol{v} \cdot \nabla s = 0, \quad P = P(\rho, s)
\end{aligned} \tag{1}$$

Small amplitude waves, we linearize (1) by

$$\boldsymbol{B} = \boldsymbol{B}_0 + \boldsymbol{b}_1, \boldsymbol{v} = \boldsymbol{v}_0 + \boldsymbol{v}_1, P = P_0 + p_1, \rho = \rho_0 + \rho_1, s = s_0 + s_1 \tag{2}$$

0(1)-equilibrium (perturbation) quantity. For $\boldsymbol{v}_0 = 0 = \nabla \cdot \boldsymbol{v}_1$,plane wave

$$\boldsymbol{v}_1, \boldsymbol{b}_1, p_1, \rho_1, s_1 \sim exp[i(\boldsymbol{k} \cdot \boldsymbol{x} - \omega t)] \tag{3}$$

[1] (mass density-ρ, fluid velocity-$\boldsymbol{v}$, pressure-P, magnetic field- $\boldsymbol{B}$, entropy per unit mass-s, vacuum magnetic permeability-μ_0.)

Alfvén Wave

eqs.of motion with $\boldsymbol{B}_0 \cdot \boldsymbol{b}_1 = 0$, and dispersion relation of Alfvén wave

$$\partial_t \boldsymbol{b}_1 = (\boldsymbol{B}_0 \cdot \nabla)\boldsymbol{v}_1, \qquad \partial_t \boldsymbol{v}_1 = \frac{1}{\mu_0 \rho_0}(\boldsymbol{B}_0 \cdot \nabla)\boldsymbol{b}_1 \tag{4}$$

$$\omega^2 - \frac{(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{\mu_0 \rho_0} = 0 \Rightarrow \omega = \frac{\boldsymbol{B}_0 \cdot \boldsymbol{k}}{\sqrt{\mu_0 \rho_0}} \tag{5}$$

the **magnetic tension**(restoring force) balances inertia, and disturbances are communicated by Alfvén waves.

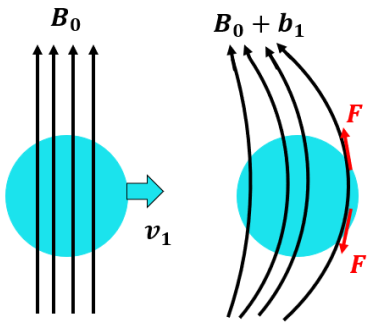

Figure 1: Magnetic field lines are frozen in ideal MHDs

Chiral Alfvén Wave-CAW

The Chiral hydrodynamics eqs. for plasmas of a **single right- handed** chiral fermions in **external electromagnetic field** are [2]

$$\partial_\mu T^{\mu\nu} = F^{\nu\lambda} j_\lambda \tag{6}$$

$$\partial_\mu j^\mu = -CE^\mu B_\mu \tag{7}$$

$E^\mu = F^{\mu\nu} u_\nu, B^\mu = \frac{1}{2}\epsilon^{\mu\nu\alpha\beta} u_\nu F_{\alpha\beta}$ are defined in the fluid rest frame, C is anomaly coefficient($C = \pm\frac{1}{4\pi}$ for R or L). In the Landau-Lifshitz frame [2, 3]

$$T^{\mu\nu} = (\epsilon + P)u^\mu u^\nu - Pg^{\mu\nu} + \tau^{\mu\nu} \tag{8}$$

$$j^\mu = nu^\mu + \xi_\omega \omega^\mu + \xi_B B^\mu + \nu^\mu \tag{9}$$

ξ_B, ξ_ω corresponding to CME,CVE.

[2] D.T.Son and P.Surowka,PRL.103,191601(2009)

[3] N.Yamamoto,PRL.115,141601(2015)

Chiral Alfvén Wave-CAW

In nonrelativistic limit $|\boldsymbol{v}| \ll 1$, and assuming plasmas with homogeneous and static ϵ, P, n, also at high temperature $T \gg \mu$(and so n) [3]

$$(\epsilon + P)\partial_t \boldsymbol{v} = \xi_\omega \boldsymbol{\omega} \times \boldsymbol{B}, \qquad \boldsymbol{\nabla} \cdot \boldsymbol{v} = 0 \tag{10}$$

setting $\boldsymbol{B} \cdot \boldsymbol{v} = 0$, $\boldsymbol{B} = B\hat{z}$. The plane wave solution of Right-CAW

$$\omega = -\frac{\xi B}{\epsilon + P} k_z \qquad (\xi_\omega \approx \frac{DT^2}{2}, D = \frac{1}{12}) \tag{11}$$

the CVE induces a **Lorentz(restoring)** force .

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CVE and Dynamical Electromagnetic Field

A natural extension is CAW with **dynamical EM field** . [4, 5]

$$\begin{aligned} &\partial_\mu T^{\mu\nu} = F^{\nu\lambda} j_\lambda \\ &\partial_\mu j_A^\mu = C_A E^\mu B_\mu, \qquad \partial_\mu j^\mu = 0 \\ &\partial_\mu F^{\mu\nu} = j^\nu, \qquad \partial_\mu \tilde{F}^{\mu\nu} = 0 \end{aligned} \tag{12}$$

where $\tilde{F}^{\mu\nu}$ is the dual of $F^{\mu\nu}$, $j^\mu(= j_R + j_L)$-vector current, $j_A^\mu(= j_R - j_L)$ -axial current. Then

$$\begin{aligned} T^{\mu\nu} &= (\epsilon + P) u^\mu u^\nu - P g^{\mu\nu} + \tau^{\mu\nu} \\ j^\mu &= n u^\mu + \xi_\omega \omega^\mu + \xi_B B^\mu + \nu^\mu \\ j_A^\mu &= n_A u^\mu + \kappa_\omega \omega^\mu + \kappa_B B^\mu \end{aligned} \tag{13}$$

$\xi_\omega(\kappa_\omega)$ -vector(axial) CVE, $\xi_B(\kappa_B)$ -vector(axial) CME.

[4] N.Yamamoto,PRD.93,065017(2016).

[5] S.Pu,J.Gao,Q.Wang, arXiv:1008.2418v2[nucl-th]; M.Isachenkov and A.Sadofyev,PLB 697,404(2011)

CVE and Dynamical Electromagnetic Field

Considering the nonrelativistic limit $|\boldsymbol{v}| \ll 1$. The power counting : $\partial_t \sim \mathcal{O}(\epsilon_t), \boldsymbol{\nabla} \sim \mathcal{O}(\epsilon_s)$, $\boldsymbol{v}, \boldsymbol{b} \sim \mathcal{O}(\delta)$, they are three independent expansion parameters $\epsilon_s, \epsilon_t \ll 1$, $\delta \ll 1$, so the equations of motion

$$u_\nu \partial_\mu T^{\mu\nu} = u_\nu F^{\nu\lambda} j_\lambda, \quad (g^\rho_\nu - u^\rho u_\nu)\partial_\mu T^{\mu\nu} = (g^\rho_\nu - u^\rho u_\nu) F^{\nu\lambda} j_\lambda \tag{14}$$

keeping terms to $\mathcal{O}(\epsilon_t \delta, \epsilon_s \delta^2, \epsilon_s^2 \delta)$

$$(\partial_t + \boldsymbol{v} \cdot \boldsymbol{\nabla})\epsilon + (\epsilon + P)\boldsymbol{\nabla} \cdot \boldsymbol{v} = 0 \tag{15}$$

$$(\boldsymbol{v} \cdot \boldsymbol{\nabla})P = 0 \tag{16}$$

$$(\epsilon + p)(\partial_t + \boldsymbol{v} \cdot \boldsymbol{\nabla})\boldsymbol{v} = -\boldsymbol{\nabla} P - \boldsymbol{v}(\partial_t + \boldsymbol{v} \cdot \boldsymbol{\nabla})P + \boldsymbol{j} \times \boldsymbol{B} + n\boldsymbol{E} + \nu \boldsymbol{\nabla}^2 \boldsymbol{v} \tag{17}$$

also the vector current conservation and axial current equation

$$\partial_t n + \boldsymbol{\nabla} \cdot \boldsymbol{j} = 0, \quad \boldsymbol{j} = n\boldsymbol{v} + \xi_\omega \boldsymbol{\omega} + \xi_B \boldsymbol{B} + \sigma(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) \tag{18}$$

$$\partial_t n_A + \boldsymbol{\nabla} \cdot \boldsymbol{j}_A = C\boldsymbol{E} \cdot \boldsymbol{B}, \quad \boldsymbol{j}_A = n_A \boldsymbol{v} + \kappa_\omega \boldsymbol{\omega} + \kappa_B \boldsymbol{B} \tag{19}$$

CVE and Dynamical Electromagnetic Field

Considering the conductivity σ is large enough, $n\boldsymbol{v} = (\boldsymbol{\nabla}\cdot\boldsymbol{E})\boldsymbol{v} \ll \sigma\boldsymbol{E}$, also $n\boldsymbol{E}$, assuming P, ϵ are constants, $\nu = 0$, then keeping $\mathcal{O}(\delta)$

$$
\begin{aligned}
(\epsilon + P)\partial_t \boldsymbol{v} &\approx \boldsymbol{j}\times\boldsymbol{B} \\
\boldsymbol{j} &\approx \sigma(\boldsymbol{E} + \boldsymbol{v}\times\boldsymbol{B}) + \xi_B\boldsymbol{B} + \xi_\omega\boldsymbol{\omega} \\
\nabla\cdot\boldsymbol{v} &= 0 \\
\nabla\times\boldsymbol{B} &\approx \boldsymbol{j} \\
\nabla\times\boldsymbol{E} &= -\partial_t\boldsymbol{B} \\
\nabla\cdot\boldsymbol{B} &= 0
\end{aligned}
\tag{20}
$$

where $\boldsymbol{\omega} = \boldsymbol{\nabla}\times\boldsymbol{v}$. In order to describe $\partial_t\boldsymbol{B}$, we rewrite $\boldsymbol{E}$ by $\boldsymbol{B}, \boldsymbol{v}$

$$
\begin{aligned}
\boldsymbol{E} &= \eta(\boldsymbol{j} - \xi_B\boldsymbol{B} - \xi_\omega\boldsymbol{\omega}) - \boldsymbol{v}\times\boldsymbol{B} \\
&= \eta(\nabla\times\boldsymbol{B} - \xi_B\boldsymbol{B} - \xi_\omega\boldsymbol{\omega}) - \boldsymbol{v}\times\boldsymbol{B}
\end{aligned}
\tag{21}
$$

here $\eta = 1/\sigma$ is resistivity.

CVE and Dynamical Electromagnetic Field

The evolution eqs of hydro and magnetic field are [6, 7, 8]

$$(\epsilon + P)\partial_t \boldsymbol{v} = (\boldsymbol{\nabla} \times \boldsymbol{B}) \times \boldsymbol{B} = (\boldsymbol{B} \cdot \boldsymbol{\nabla})\boldsymbol{B} - \frac{1}{2}\boldsymbol{\nabla}(\boldsymbol{B}^2) \tag{22}$$

$$\partial_t \boldsymbol{B} = \boldsymbol{\nabla} \times (\boldsymbol{v} \times \boldsymbol{B}) + \eta(\boldsymbol{\nabla}^2 \boldsymbol{B} + \xi_B \boldsymbol{\nabla} \times \boldsymbol{B} + \xi_\omega \boldsymbol{\nabla} \times \boldsymbol{\omega}) \tag{23}$$

Considering small perturbation $\boldsymbol{B} = \boldsymbol{B}_0 + \boldsymbol{b} = B_0 \hat{\boldsymbol{z}} + \boldsymbol{b}$ ($\boldsymbol{b} \sim \mathcal{O}(\delta)$)

$$(\epsilon + P)\partial_t \boldsymbol{v} = (\boldsymbol{B}_0 \cdot \boldsymbol{\nabla})\boldsymbol{b} - \boldsymbol{\nabla}(\boldsymbol{B}_0 \cdot \boldsymbol{b}) \tag{24}$$

$$\partial_t \boldsymbol{b} = (\boldsymbol{B}_0 \cdot \boldsymbol{\nabla})\boldsymbol{v} + \eta \boldsymbol{\nabla}^2 \boldsymbol{b} + \eta \xi_B \boldsymbol{\nabla} \times \boldsymbol{b} - \eta \xi_\omega \boldsymbol{\nabla}^2 \boldsymbol{v} \tag{25}$$

(24) implies $\boldsymbol{\nabla}^2(\boldsymbol{B}_0 \cdot \boldsymbol{b}) = 0$, so we set $\boldsymbol{B}_0 \cdot \boldsymbol{b} = 0$, also $\boldsymbol{B}_0 \cdot \boldsymbol{v} = 0$(explicitly v_z =const), here we take $\boldsymbol{b} = (b_1, b_2, 0)$, $\boldsymbol{v} = (v_1, v_2, 0)$.

[6] N.Yamamoto,PRD.93,065017(2016).

[7] M.Giovannini,PRD.93,103518(2016)

[8] M.Giovannini,PRD.88,063536(2013)

Dispersion Relation and Instability

For plane-wave solution, (24),(25) lead to

$$(\epsilon + P)(-\omega)\boldsymbol{v} = (\boldsymbol{B}_0 \cdot \boldsymbol{k})\boldsymbol{b} \tag{26}$$

$$(\eta \boldsymbol{k}^2 - i\omega)\boldsymbol{b} - i\eta\xi_B \boldsymbol{k} \times \boldsymbol{b} = [i(\boldsymbol{B}_0 \cdot \boldsymbol{k}) + \eta\xi_\omega \boldsymbol{k}^2]\boldsymbol{v} \tag{27}$$

we just focus on the CVE (setting $\xi_B = 0$)

$$\omega^2 + i\eta\boldsymbol{k}^2\omega + i\eta\xi_\omega \boldsymbol{k}^2 \frac{\boldsymbol{B}_0 \cdot \boldsymbol{k}}{\epsilon + P} - \frac{(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{\epsilon + P} = 0 \tag{28}$$

whose solutions are

$$\omega = \omega_\pm \equiv \frac{1}{2}[-i\eta\boldsymbol{k}^2 \pm \sqrt{\frac{4(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{\epsilon + P} - \eta^2\boldsymbol{k}^4 - i \cdot \eta\xi_\omega \boldsymbol{k}^2 \frac{4(\boldsymbol{B}_0 \cdot \boldsymbol{k})}{\epsilon + P}}] \tag{29}$$

from (29), we will find a new instability which is related to the CVE and magentic field.

Dispersion Relation and Instability

We use geometric method to explain (29). First, setting

$$\omega = \omega_1 + i \cdot \omega_2 \tag{30}$$

here $\omega_1, \omega_2 \in \mathbb{R}$, then (28) leads to

$$C_1: \quad \omega_1^2 - (\omega_2 + \eta \boldsymbol{k}^2/2)^2 = \frac{(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{\epsilon + P} - \frac{\eta^2 \boldsymbol{k}^4}{4} \tag{31}$$

$$C_2: \quad \omega_2 = -\frac{\eta \boldsymbol{k}^2}{2} \frac{\xi_\omega}{\sqrt{\epsilon + P}} \frac{(\boldsymbol{B}_0 \cdot \boldsymbol{k})}{\sqrt{\epsilon + P}} \cdot \frac{1}{\omega_1} - \frac{\eta \boldsymbol{k}^2}{2} \tag{32}$$

C_1, C_2 are two hyperbola curves, the cross points of them are solutions.

One can draw the figures of two curves. For example, considering a case: $(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2/(\epsilon + P) > \eta^2 \boldsymbol{k}^4/4$ and $\boldsymbol{B}_0 \cdot \boldsymbol{k} > 0$, we show a schematic diagram

Dispersion Relation and Instability

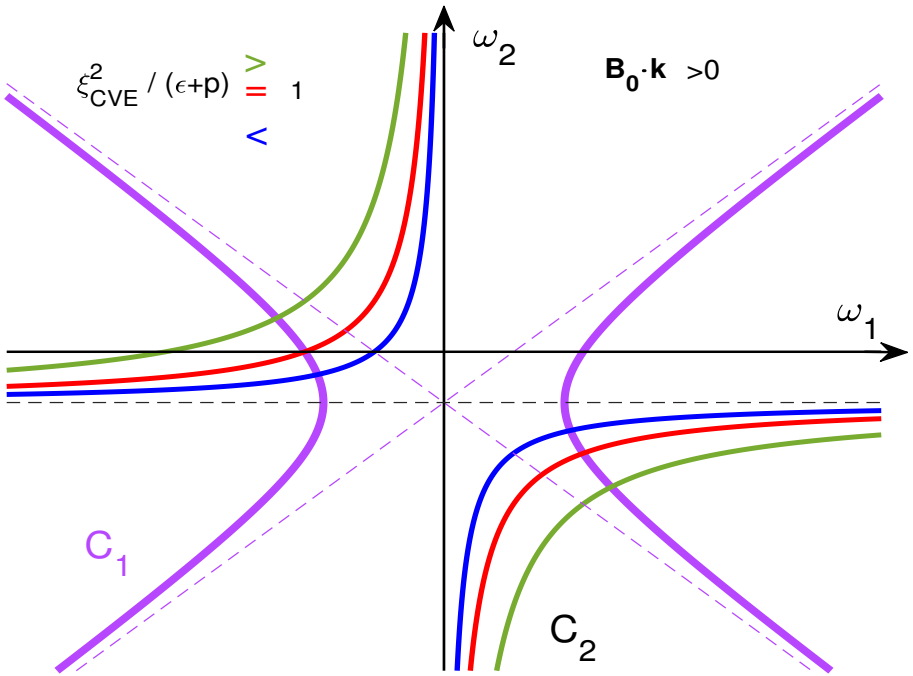

Figure 2: $\omega_2 - \omega_1$ of C_1, C_2

Green-$\xi_\omega > \sqrt{\epsilon + P}$, **Red**-$\xi_\omega = \sqrt{\epsilon + P}$, **Blue**-$\xi_\omega < \sqrt{\epsilon + P}$

Dispersion Relation and Instability

We summarize the real(Re) part and imaginary(Im) part of $\omega_\pm$ in (29).

$\boldsymbol{B}_0 \cdot \boldsymbol{k}$	CVE	$\mathrm{Re}(\omega_+)$	$\mathrm{Im}(\omega_+)$
$+$	$0 < \xi_\omega$	$+$	$-$
$-$	$\sqrt{\epsilon + P} < \xi_\omega$	$+$	$+$
	$\sqrt{\epsilon + P} = \xi_\omega$	$+$	0
	$\sqrt{\epsilon + P} > \xi_\omega$	$+$	$-$

$\boldsymbol{B}_0 \cdot \boldsymbol{k}$	CVE	$\mathrm{Re}(\omega_-)$	$\mathrm{Im}(\omega_-)$
$-$	$0 < \xi_\omega$	$-$	$-$
$+$	$\sqrt{\epsilon + P} < \xi_\omega$	$-$	$+$
	$\sqrt{\epsilon + P} = \xi_\omega$	$-$	0
	$\sqrt{\epsilon + P} > \xi_\omega$	$-$	$-$

$+(-)$ means a positive(negative) value. Because $\boldsymbol{v}, \boldsymbol{b} \sim exp[i(\boldsymbol{k} \cdot \boldsymbol{x} - \omega t)]$, $\mathrm{Im}(\omega_\pm) > 0$ means an instability.

Dispersion Relation and Instability

Let's go back to (29) again

$$\omega = \omega_{\pm} \equiv \frac{1}{2}[-i\eta \boldsymbol{k}^2 \pm \sqrt{\frac{4(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{\epsilon + P} - \eta^2 \boldsymbol{k}^4 - i \cdot \eta \xi_\omega \boldsymbol{k}^2 \frac{4(\boldsymbol{B}_0 \cdot \boldsymbol{k})}{\epsilon + P}}] \tag{29}$$

the instability occurs once $\xi_\omega > \sqrt{\epsilon + P}$ and applicable to any $|\boldsymbol{k}|$. Because the CVE and magnetic field are both included, we call this instability **Chiral Magnetovortical Instability(CMVI)**.
Considering the limit conditions, for small and large $|\boldsymbol{k}|$

$$\omega \approx \pm \frac{(\boldsymbol{B}_0 \cdot \boldsymbol{k})}{\sqrt{\epsilon + P}} - i\frac{\eta}{2}(1 \pm \frac{\xi_\omega}{\sqrt{\epsilon + P}})\boldsymbol{k}^2 \tag{33}$$

$$\omega \approx -i\frac{\eta}{2}\boldsymbol{k}^2 \pm i\frac{\eta}{2}\boldsymbol{k}^2 \pm \frac{-\xi_\omega(\boldsymbol{B}_0 \cdot \boldsymbol{k})}{(\epsilon + P)} \pm i \cdot [\frac{\xi_\omega^2}{(\epsilon + P)} - 1] \cdot \frac{(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{(\epsilon + P)\eta \boldsymbol{k}^2} \tag{34}$$

Dispersion Relation and Instability

An intuitive picture about the CMVI.

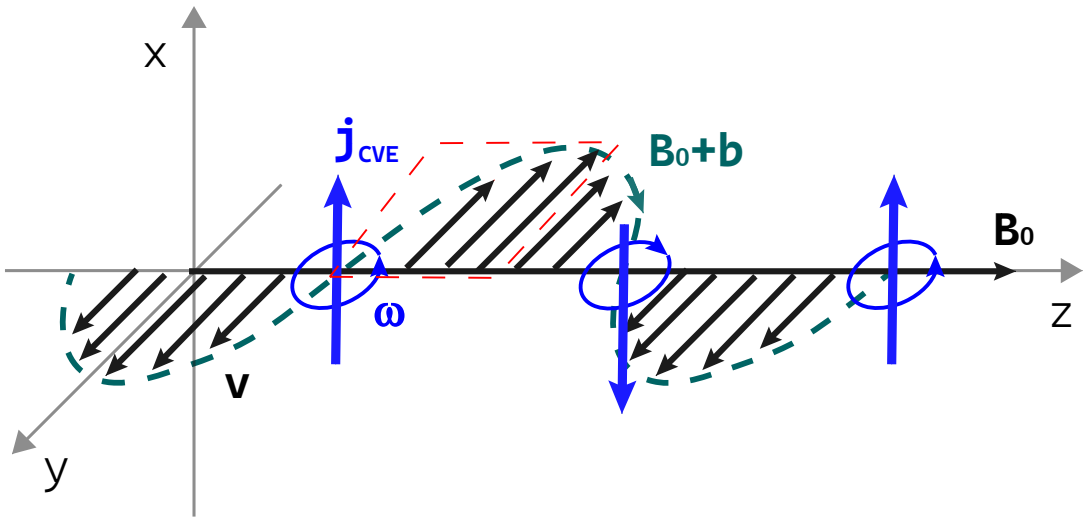

Figure 3: CMVI

The CVE currents induce new magnetic fileds around themselves, the new magnetic fields will add the perturbed magnetic fields $\boldsymbol{b}$. If the CVE is strong enough to overcome the dissipative effects ($\xi_\omega > \sqrt{\epsilon + P}$), then $\boldsymbol{b}$ increases in red region.

CME-Chiral Plasma Instability

Considering CME term ξ_B, thus (24),(25) lead to

$$(\epsilon + P)(-\omega)\boldsymbol{v} = (\boldsymbol{B}_0 \cdot \boldsymbol{k})\boldsymbol{b}, \quad (\eta \boldsymbol{k}^2 - i\omega)\boldsymbol{b} - i\eta\xi_B \boldsymbol{k} \times \boldsymbol{b} = i(\boldsymbol{B}_0 \cdot \boldsymbol{k})\boldsymbol{v} \quad (35)$$

with $\boldsymbol{k} = (0, 0, k_3)$, so the dispersion relation is

$$\omega = \frac{1}{2}[-i\eta k_3(k_3 - \lambda\xi_B) \pm |k_3|\sqrt{-\eta^2(k_3 - \lambda\xi_B)^2 + \frac{4B_0^2}{\epsilon + P}}] \quad (\lambda = \pm 1) \quad (36)$$

there are four modes $\omega_{\pm,\lambda}$. One can prove the instability of (36) will appear in interval

$$|k_3| \in (0, \xi_B) \quad (37)$$

this the **Chiral Plasma Instability** [9].

[9] Y.Akamatsu and N.Yamamoto, Chiral Plasma Instabilities PRL.111,052002(2013)

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CVE and Dynamo

Dynamo effect is used to explain the origin of magnetic fields in galaxies, stars, and planets, which is due to the hydrodynamic motion of an electrically conducting gas, fluid, or plasma. For **kinematic dynamo**, the velocity field $\boldsymbol{V}$ is predetermined and the magnetic field does not affect $\boldsymbol{V}$. The dynamo equation is

$$\partial_t \boldsymbol{B} = \boldsymbol{\nabla} \times (\boldsymbol{V} \times \boldsymbol{B}) + \frac{\eta}{\mu_0} \boldsymbol{\nabla}^2 \boldsymbol{B} \tag{38}$$

the dynamo is possible when induction term $\boldsymbol{\nabla} \times (\boldsymbol{V} \times \boldsymbol{B})$ overwhelm the magnetic diffusion term $\frac{\eta}{\mu_0} \boldsymbol{\nabla}^2 \boldsymbol{B}$, so one can introduce magnetic Reynolds number R_m to judge $\boldsymbol{B} \uparrow$ or $\boldsymbol{B} \downarrow$

$$R_m = \frac{\mu_0 V L}{\eta} \simeq \frac{|\boldsymbol{\nabla} \times (\boldsymbol{V} \times \boldsymbol{B})|}{|\eta / \mu_0 \boldsymbol{\nabla}^2 \boldsymbol{B}|} \tag{39}$$

where $L(V)$ is the characteristic lengthscale (flow speed) of the plasma.

CVE and Dynamo

The Ponomarenko(1973) dynamo [10] : A conducting fluid fills a cylinder and

$$\boldsymbol{V} = \begin{cases} (0, r\Omega, U) & (0 \leq r \leq a) \\ \mathbf{0} & (a < r) \end{cases} \tag{40}$$

r is radius, Ω, U are constants. Note that $\boldsymbol{\nabla} \cdot \boldsymbol{V} = 0$. Plugging the ansatz

$$\boldsymbol{B}(r, \theta, z, t) = \boldsymbol{B}(r) e^{i(n\theta - kz) + \gamma t} \tag{41}$$

From dynamo eq, one can obtain the critical magnetic Reynolds number [10]

$$R_m^c \approx 17.7 \qquad (n = 1) \tag{42}$$

The CME modifies the Ponomarenko dynamo [11, 12]

$$\partial_t \boldsymbol{B} = \boldsymbol{\nabla} \times (\boldsymbol{V} \times \boldsymbol{B}) + \frac{c^2}{4\pi\sigma} \boldsymbol{\nabla}^2 \boldsymbol{B} + \xi_{CME} \boldsymbol{\nabla} \times \boldsymbol{B} \tag{43}$$

[10] R. Fitzpatrick, Plasma Physics: An Introduction (Taylor & Francis, London, 2015)

[11] c -light speed, $\xi_{CME} = ge^2(\mu_L - \mu_R)/4\pi^2\hbar\sigma$-chiral anomaly coefficient.

[12] V.Galitski,M.Kargarian,and S.Syzranov,PRL.121,176603(2018)

CVE and Dynamo

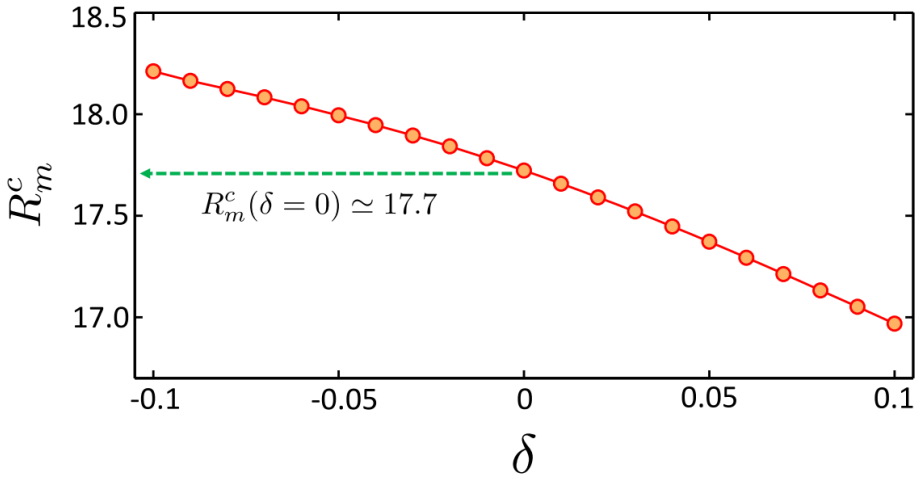

Figure 4: $R_m^c - \delta(= 4\pi\sigma\xi_{CME}/kc^2)$ (n=1) see (43)

For CMVI, the dynamo eq. is governed by (23)

$$\partial_t \boldsymbol{B} = \boldsymbol{\nabla} \times (\boldsymbol{v} \times \boldsymbol{B}) + \eta(\boldsymbol{\nabla}^2 \boldsymbol{B} + \xi_B \boldsymbol{\nabla} \times \boldsymbol{B} + \xi_\omega \boldsymbol{\nabla} \times \boldsymbol{\omega}) \qquad (23)$$

$\boldsymbol{\omega} = \boldsymbol{\nabla} \times \boldsymbol{v} \neq 0$, so in Ponomarenko dynamo the CVE has no contribution. Also, the Lorentz force acts on the velocity field, that is **the CMVI is not a kinematic dynamo**.

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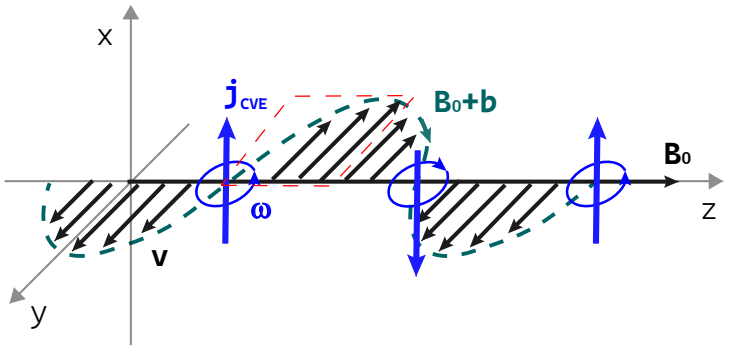
Summary and Outlook

1.A new instability-**Chiral Magnetovortical Instability (CMVI)**.

$$\omega = \omega_{\pm} \equiv \frac{1}{2}[-i\eta \boldsymbol{k}^2 \pm \sqrt{\frac{4(\boldsymbol{B}_0 \cdot \boldsymbol{k})^2}{\epsilon + P} - \eta^2 \boldsymbol{k}^4 - i \cdot \eta \xi_\omega \boldsymbol{k}^2 \frac{4(\boldsymbol{B}_0 \cdot \boldsymbol{k})}{\epsilon + P}}]$$

the CMVI occurs when $\xi_\omega > \sqrt{\epsilon + P}$ and for any value of $|\boldsymbol{k}|$.



2. The CMVI will supply a new dynamo action.
3. Considering the CMVI in an anisotropic chiral MHDs.

Thank you for your attention!