Large Reynolds number limit of self-sustained MHD dynamo

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MHD dynamo

MHD dynamo: exchange kinetic energy and magnetic energy

Self-sustained, zero net-flux dynamo: No linear instability / No externally imposed magnetic field

Purpose: Apply nonlinear analysis of subcritical shear flows to the dynamo

Self-consistent asymptotic analysis

Assume R is large

$$\epsilon \equiv R^{-1} \ll 1$$

Asymptotic expansion

$$u = \epsilon^{j_0} u_0 + \epsilon^{j_1} u_1 + \cdots$$
$$j_0 > j_1 > \cdots > 0$$

Stretching coordinate and matching

$$Y = y/\epsilon^{k_0}, \qquad k_0 > 0$$

Self-consistent asymptotic analysis

No artificial assumption:

We only neglect really small terms when R is large

No tuning parameter:

All leading order coefficients are determined by the reduced system

No R in the reduced system:

Solution describes parameter dependence of the governing solutions

Self-consistent asymptotic analysis

Theories in shear flows

Linear theory (Lin 1945, and many others)

Nonlinear critical layer

(Smith & Bodonyi 1982, Deguchi & Walton 2013)

Vortex-wave interaction

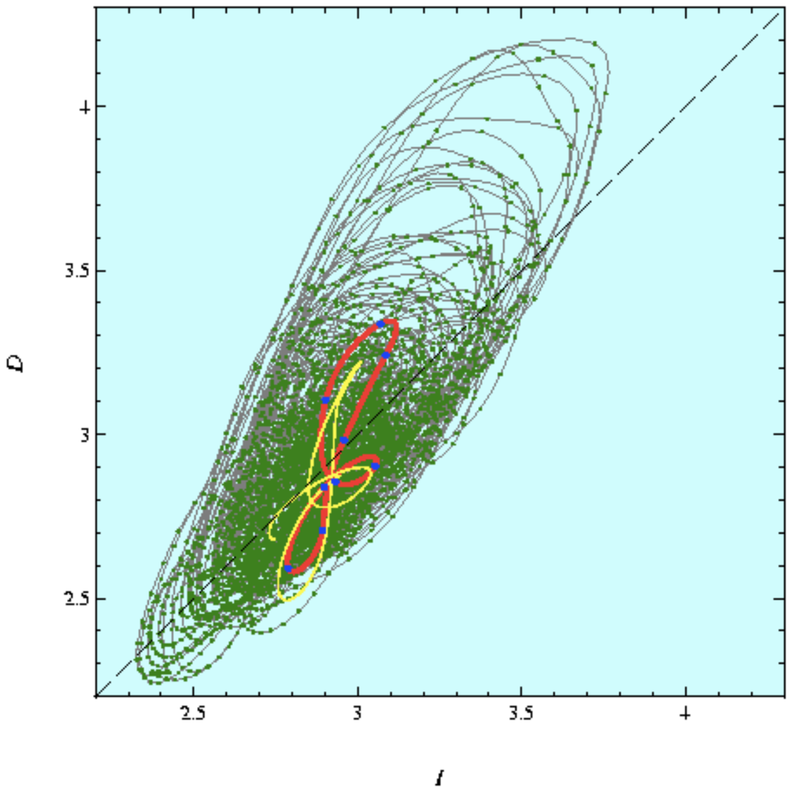
(Hall & Smith 1991, Hall & Sherwin 2010)

Long-wavelength (Deguchi, Hall & Walton 2013)

Short-wavelength (Deguchi 2015)

Dynamical systems approach

Nagata (1990), Clever & Busse (1997), Waleffe (1998), Kawahara & Kida (2001), Faisst & Eckhardt (2003), Wedin & Kerswell (2004), Wang et al. (2007), Gibson et al. (2009), Schneider et al. (2010) …



Kawahara & Kida (2001)

R=400 plane Couette flow

VWI/SSP

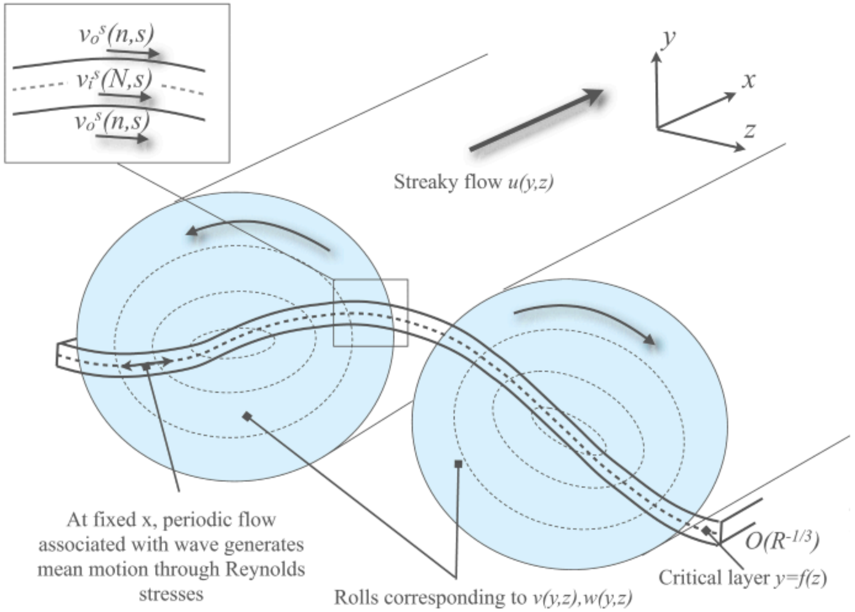
Driving mechanism of streamwise vortices?

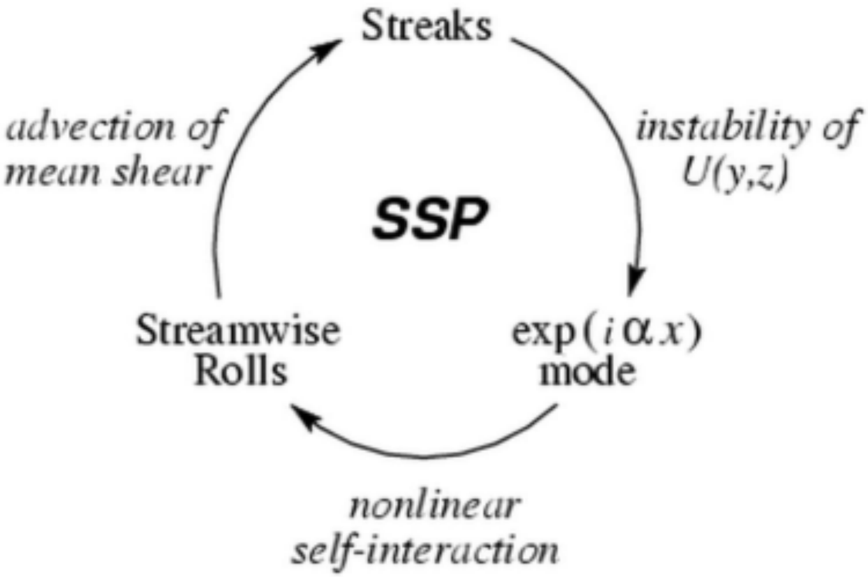
Vortex-wave interaction
  Hall & Smith (1991), Hall & Sherwin (2010)

Self-sustaining process
  Waleffe (1997)

VWI/SSP

Driving mechanism of streamwise vortices?





VWI: Complicated, but
self-consistent asymptotic analysis

SSP: The simplest explanation
for the sustainment mechanism

Magnetic version of SSP

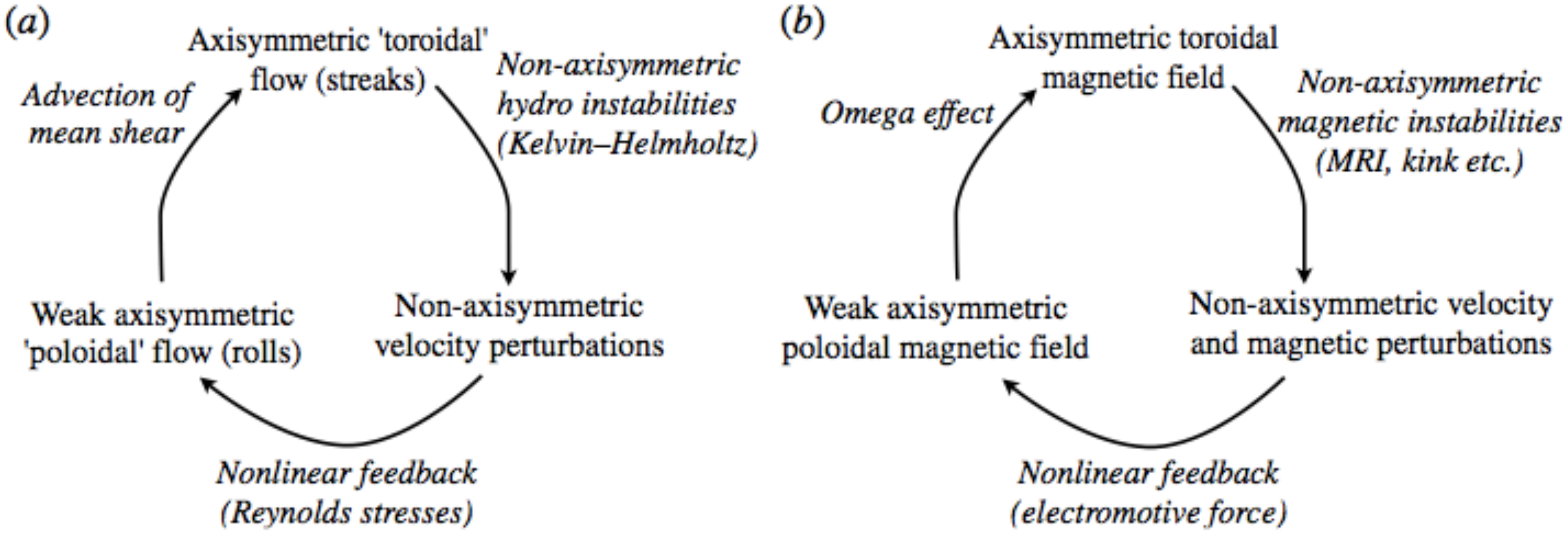


FIGURE 1. (*a*) Hydrodynamic self-sustaining process (Waleffe 1997) and (*b*) self-sustaining dynamo processes in shear flows prone to MHD instabilities (Rincon, Ogilvie & Proctor 2007; Rincon *et al.* 2008).

Figure from Riols et al. (2013)

Rincon et al. (2007)
Rotating plane Couette flow

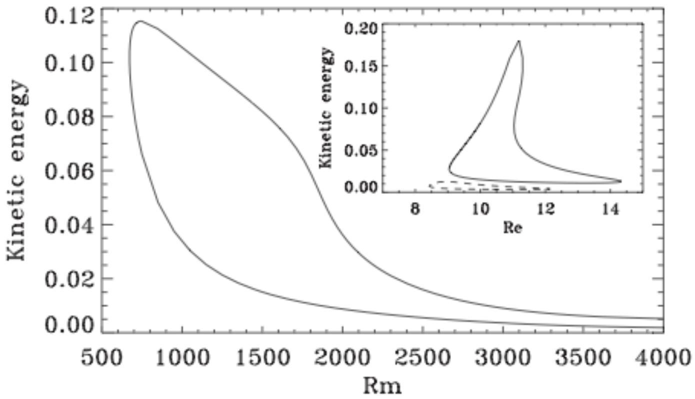


FIG. 7. Continuation with respect to Rm for Re = 10, $(\alpha, \beta) = (0.375, 1)$. Inset: continuation with respect to Re for Rm = 1500 (full line), Rm = 3000 (dashed line). $(N_x, N_y, N_z) = (8, 24, 32)$.

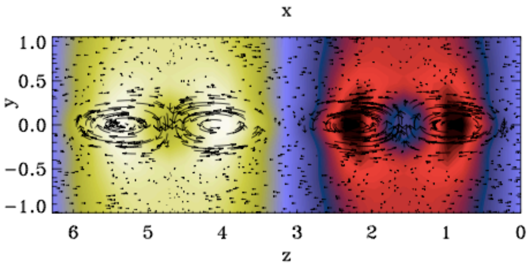
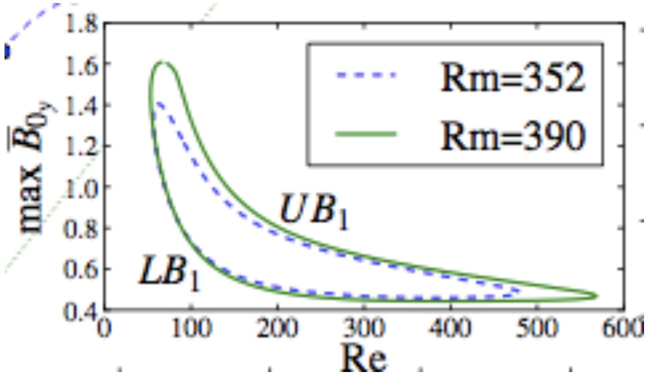
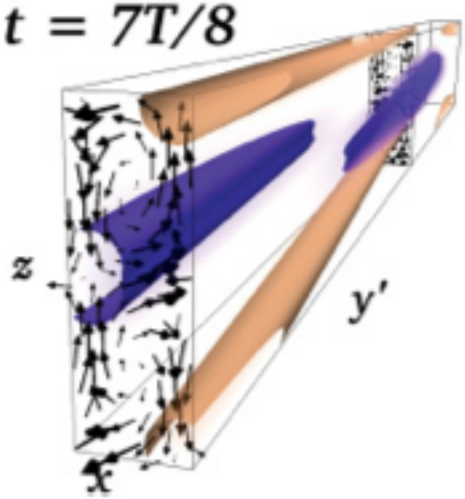


FIG. 6 (color online). Cuts through the unforced ($A = 0$) nonlinear steady solution of Fig. 5 ($\alpha = 0.375$, black dot). Top: b_z at $z = L_z/2$. Bottom: b_x (color scale) and (b_y, b_z) (arrows) at $x = L_x/4$.

Herault et al. (2011)
Rotating shearing box





Formulation of the problem

MHD equations with Hall term

$$
\begin{aligned}
(\partial_t + \mathbf{v}\cdot\nabla)\mathbf{v} - (\mathbf{b}\cdot\nabla)\mathbf{b} &= -\nabla p + \frac{1}{R}\nabla^2\mathbf{v},\\
\partial_t\mathbf{b} = \nabla\times[(\mathbf{v} - H\nabla\times\mathbf{b})\times\mathbf{b}] &+ \frac{1}{RP_m}\nabla^2\mathbf{b},\\
\nabla\cdot\mathbf{v} = 0, \qquad &\nabla\cdot\mathbf{b} = 0.
\end{aligned}
$$

Basic flow: a linear shear

Parameters: Reynolds number, magnetic Prandtl number, Hall coefficient

$$
R = \frac{U_* L_*}{\nu}, \qquad P_m = \frac{\nu}{\eta}, \qquad H = \frac{c_l^{3/2}\rho^{1/2}}{4\pi q_e n_e L_*}
$$

c_l: the speed of light

q_e: the electron charge

n_e is the number densities of electrons

ρ: the fluid density

ν: the kinematic viscosity

η: the magnetic diffusivity

O(1) wavenumbers

Outside of the critical layer, Pm>1

$$\begin{bmatrix} u \\ v \\ w \\ a \\ b \\ c \\ p \end{bmatrix} = \begin{bmatrix} y + P_m^{-1}\overline{u} \\ R_m^{-1}\overline{v} \\ R_m^{-1}\overline{w} \\ P_m^{1/2}\overline{a} \\ P_m^{1/2}R_m^{-1}\overline{b} \\ P_m^{1/2}R_m^{-1}\overline{c} \\ R^{-1}R_m^{-1}\overline{p} \end{bmatrix} + \; P_m^{1/2}R_m^{-1}\left\{ e^{i\alpha x}\begin{bmatrix} \widetilde{u} \\ \widetilde{v} \\ \widetilde{w} \\ \widetilde{a} \\ \widetilde{b} \\ \widetilde{c} \\ P_m^{1/2}\widetilde{p} \end{bmatrix} + \text{c.c.} \right\} + \cdots$$

Magnetic Reynolds number $R_m = P_m R$

O(1) wavenumbers

Outside of the critical layer, Pm>1

$$\begin{bmatrix} u \\ v \\ w \\ a \\ b \\ c \\ p \end{bmatrix} = \begin{bmatrix} \boxed{y + P_m^{-1}\bar{u}} \\ R_m^{-1}\bar{v} \\ R_m^{-1}\bar{w} \\ \boxed{P_m^{1/2}\bar{a}} \\ P_m^{1/2}R_m^{-1}\bar{b} \\ P_m^{1/2}R_m^{-1}\bar{c} \\ R^{-1}R_m^{-1}\bar{p} \end{bmatrix} + P_m^{1/2}R_m^{-1}\left\{ e^{i\alpha x} \begin{bmatrix} \tilde{u} \\ \tilde{v} \\ \tilde{w} \\ \tilde{a} \\ \tilde{b} \\ \tilde{c} \\ P_m^{1/2}\tilde{p} \end{bmatrix} + \text{c.c.} \right\} + \cdots$$

Streak / magnetic streak

Magnetic Reynolds number $R_m = P_m R$

O(1) wavenumbers

Outside of the critical layer, Pm>1

$$\begin{bmatrix} u \\ v \\ w \\ a \\ b \\ c \\ p \end{bmatrix} = \begin{bmatrix} y + P_m^{-1}\overline{u} \\ \boxed{R_m^{-1}\overline{v}} \\ \boxed{R_m^{-1}\overline{w}} \\ P_m^{1/2}\overline{a} \\ \boxed{P_m^{1/2}R_m^{-1}\overline{b}} \\ \boxed{P_m^{1/2}R_m^{-1}\overline{c}} \\ \boxed{R^{-1}R_m^{-1}\overline{p}} \end{bmatrix} + P_m^{1/2}R_m^{-1}\left\{ e^{i\alpha x}\begin{bmatrix} \widetilde{u} \\ \widetilde{v} \\ \widetilde{w} \\ \widetilde{a} \\ \widetilde{b} \\ \widetilde{c} \\ P_m^{1/2}\widetilde{p} \end{bmatrix} + \text{c.c.} \right\} + \cdots$$

Roll / magnetic roll

Magnetic Reynolds number $R_m = P_m R$

O(1) wavenumbers

Outside of the critical layer, Pm>1

$$\begin{bmatrix} u \\ v \\ w \\ a \\ b \\ c \\ p \end{bmatrix} = \begin{bmatrix} y + P_m^{-1}\bar{u} \\ R_m^{-1}\bar{v} \\ R_m^{-1}\bar{w} \\ P_m^{1/2}\bar{a} \\ P_m^{1/2}R_m^{-1}\bar{b} \\ P_m^{1/2}R_m^{-1}\bar{c} \\ R^{-1}R_m^{-1}\bar{p} \end{bmatrix} + P_m^{1/2}R_m^{-1}\left\{ e^{i\alpha x}\begin{bmatrix} \boxed{\begin{matrix} \tilde{u} \\ \tilde{v} \\ \tilde{w} \end{matrix}} \\ \boxed{\begin{matrix} \tilde{a} \\ \tilde{b} \\ \tilde{c} \end{matrix}} \\ \boxed{P_m^{1/2}\tilde{p}} \end{bmatrix} + \text{c.c.} \right\} + \cdots$$

Wave / magnetic wave

Magnetic Reynolds number $R_m = P_m R$

O(1) wavenumbers

Vortex equations

$$[P_m^{-1}(\overline{v}\partial_y + \overline{w}\partial_z) - \triangle_2]\begin{bmatrix}\overline{u}\\ \overline{v}\\ \overline{w}\end{bmatrix} + \begin{bmatrix}0\\ \overline{p}_y\\ \overline{p}_z\end{bmatrix} = \begin{bmatrix}-\overline{v}\\ 0\\ 0\end{bmatrix} + [\overline{b}\partial_y + \overline{c}\partial_z]\begin{bmatrix}\overline{a}\\ \overline{b}\\ \overline{c}\end{bmatrix} + \mathbf{f}_1,$$

$$[(\overline{v}\partial_y + \overline{w}\partial_z) - \triangle_2]\begin{bmatrix}\overline{a}\\ \overline{b}\\ \overline{c}\end{bmatrix} - [\overline{b}\partial_y + \overline{c}\partial_z]\begin{bmatrix}0\\ \overline{v}\\ \overline{w}\end{bmatrix} = \begin{bmatrix}\overline{b} + P_m^{-1}(\overline{b}\partial_y + \overline{c}\partial_z)\overline{u}\\ 0\\ 0\end{bmatrix} + \mathbf{f}_2,$$

$$\overline{v}_y + \overline{w}_z = 0, \qquad \overline{b}_y + \overline{c}_z = 0.$$

$$\mathbf{f}_1 = -\begin{bmatrix}0\\ \{\partial_y\overline{(\Lambda^{-1}|\widetilde{p}_y|^2)} + \partial_z\overline{(\Lambda^{-1}\widetilde{p}_y\widetilde{p}_z^*)}\} + \text{c.c.}\\ \{\partial_z\overline{(\Lambda^{-1}|\widetilde{p}_z|^2)} + \partial_y\overline{(\Lambda^{-1}\widetilde{p}_y\widetilde{p}_z^*)}\} + \text{c.c.}\end{bmatrix}, \qquad \mathbf{f}_2 = H_0\begin{bmatrix}0\\ (\overline{a}_y\overline{b} + \overline{a}_z\overline{c})_z\\ -(\overline{a}_y\overline{b} + \overline{a}_z\overline{c})_y\end{bmatrix} \qquad \triangle_2 = \partial_y^2 + \partial_z^2$$

$$H = P_m^{-1/2}R_m^{-1}H_0$$

Wave equation

$$\partial_y\left(\frac{\widetilde{p}_y}{\Lambda}\right) + \partial_z\left(\frac{\widetilde{p}_z}{\Lambda}\right) - \alpha^2\frac{\widetilde{p}}{\Lambda} = 0, \qquad \Lambda = U^2 - \overline{a}^2$$

$$U = P_m^{-1/2}y + P_m^{-3/2}\overline{u} - s_0$$

Produce an Alfven wave with a scaled speed s_0

O(1) wavenumbers

Vortex equations

Lift up effect

$$[P_m^{-1}(\bar v\partial_y + \bar w\partial_z) - \Delta_2]\begin{bmatrix}\bar u\\ \bar v\\ \bar w\end{bmatrix} + \begin{bmatrix}0\\ \bar p_y\\ \bar p_z\end{bmatrix} = \begin{bmatrix}\boxed{-\bar v}\\ 0\\ 0\end{bmatrix} + [\bar b\partial_y + \bar c\partial_z]\begin{bmatrix}\bar a\\ \bar b\\ \bar c\end{bmatrix} + \mathbf{f}_1,$$

$$[(\bar v\partial_y + \bar w\partial_z) - \Delta_2]\begin{bmatrix}\bar a\\ \bar b\\ \bar c\end{bmatrix} - [\bar b\partial_y + \bar c\partial_z]\begin{bmatrix}0\\ \bar v\\ \bar w\end{bmatrix} = \begin{bmatrix}\boxed{\bar b +} P_m^{-1}(\bar b\partial_y + \bar c\partial_z)\bar u\\ 0\\ 0\end{bmatrix} + \mathbf{f}_2,$$

$$\bar v_y + \bar w_z = 0, \qquad \bar b_y + \bar c_z = 0.$$

$$\mathbf{f}_1 = -\begin{bmatrix}0\\ \{\partial_y\overline{(\Lambda^{-1}|\tilde p_y|^2)} + \partial_z\overline{(\Lambda^{-1}\tilde p_y\tilde p_z^*)}\} + \text{c.c.}\\ \{\partial_z\overline{(\Lambda^{-1}|\tilde p_z|^2)} + \partial_y\overline{(\Lambda^{-1}\tilde p_y\tilde p_z^*)}\} + \text{c.c.}\end{bmatrix}, \qquad \mathbf{f}_2 = H_0\begin{bmatrix}0\\ (\bar a_y\bar b + \bar a_z\bar c)_z\\ -(\bar a_y\bar b + \bar a_z\bar c)_y\end{bmatrix} \qquad \Delta_2 = \partial_y^2 + \partial_z^2$$

$$H = P_m^{-1/2}R_m^{-1}H_0$$

Wave equation

$$\partial_y\left(\frac{\tilde p_y}{\Lambda}\right) + \partial_z\left(\frac{\tilde p_z}{\Lambda}\right) - \alpha^2\frac{\tilde p}{\Lambda} = 0, \qquad \Lambda = U^2 - \bar a^2$$

$$U = P_m^{-1/2}y + P_m^{-3/2}\bar u - s_0$$

Produce an Alfven wave with a scaled speed s_0

O(1) wavenumbers

Vortex equations

Wave Reynolds stress

$$[P_m^{-1}(\overline{v}\partial_y + \overline{w}\partial_z) - \triangle_2]\begin{bmatrix}\overline{u}\\ \overline{v}\\ \overline{w}\end{bmatrix} + \begin{bmatrix}0\\ \overline{p}_y\\ \overline{p}_z\end{bmatrix} = \begin{bmatrix}-\overline{v}\\ 0\\ 0\end{bmatrix} + [\overline{b}\partial_y + \overline{c}\partial_z]\begin{bmatrix}\overline{a}\\ \overline{b}\\ \overline{c}\end{bmatrix} + \boxed{\mathbf{f}_1,}$$

$$[(\overline{v}\partial_y + \overline{w}\partial_z) - \triangle_2]\begin{bmatrix}\overline{a}\\ \overline{b}\\ \overline{c}\end{bmatrix} - [\overline{b}\partial_y + \overline{c}\partial_z]\begin{bmatrix}0\\ \overline{v}\\ \overline{w}\end{bmatrix} = \begin{bmatrix}\overline{b} + P_m^{-1}(\overline{b}\partial_y + \overline{c}\partial_z)\overline{u}\\ 0\\ 0\end{bmatrix} + \mathbf{f}_2,$$

$$\overline{v}_y + \overline{w}_z = 0, \qquad \overline{b}_y + \overline{c}_z = 0.$$

$$\mathbf{f}_1 = -\begin{bmatrix}0\\ \boxed{\begin{matrix}\{\partial_y\overline{(\Lambda^{-1}|\widetilde{p}_y|^2)} + \partial_z\overline{(\Lambda^{-1}\widetilde{p}_y\widetilde{p}_z^{*})}\} + \text{c.c.}\\ \{\partial_z\overline{(\Lambda^{-1}|\widetilde{p}_z|^2)} + \partial_y\overline{(\Lambda^{-1}\widetilde{p}_y\widetilde{p}_z^{*})}\} + \text{c.c.}\end{matrix}}\end{bmatrix}, \qquad \mathbf{f}_2 = H_0\begin{bmatrix}0\\ (\overline{a}_y\overline{b} + \overline{a}_z\overline{c})_z\\ -(\overline{a}_y\overline{b} + \overline{a}_z\overline{c})_y\end{bmatrix} \qquad \triangle_2 = \partial_y^2 + \partial_z^2$$

$$H = P_m^{-1/2}R_m^{-1}H_0$$

Wave equation

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$$U = P_m^{-1/2}y + P_m^{-3/2}\overline{u} - s_0$$

Produce an Alfven wave with a scaled speed s_0

O(1) wavenumbers

Vortex equations

Hall effect

$$[P_m^{-1}(\overline{v}\partial_y + \overline{w}\partial_z) - \triangle_2] \begin{bmatrix} \overline{u} \\ \overline{v} \\ \overline{w} \end{bmatrix} + \begin{bmatrix} 0 \\ \overline{p}_y \\ \overline{p}_z \end{bmatrix} = \begin{bmatrix} -\overline{v} \\ 0 \\ 0 \end{bmatrix} + [\overline{b}\partial_y + \overline{c}\partial_z] \begin{bmatrix} \overline{a} \\ \overline{b} \\ \overline{c} \end{bmatrix} + \mathbf{f}_1,$$

$$[(\overline{v}\partial_y + \overline{w}\partial_z) - \triangle_2] \begin{bmatrix} \overline{a} \\ \overline{b} \\ \overline{c} \end{bmatrix} - [\overline{b}\partial_y + \overline{c}\partial_z] \begin{bmatrix} 0 \\ \overline{v} \\ \overline{w} \end{bmatrix} = \begin{bmatrix} \overline{b} + P_m^{-1}(\overline{b}\partial_y + \overline{c}\partial_z)\overline{u} \\ 0 \\ 0 \end{bmatrix} + \boxed{\mathbf{f}_2,}$$

$$\overline{v}_y + \overline{w}_z = 0, \qquad \overline{b}_y + \overline{c}_z = 0.$$

$$\mathbf{f}_1 = -\begin{bmatrix} 0 \\ \{\partial_y \overline{(\Lambda^{-1}|\widetilde{p}_y|^2)} + \partial_z \overline{(\Lambda^{-1}\widetilde{p}_y\widetilde{p}_z^*)}\} + \text{c.c.} \\ \{\partial_z \overline{(\Lambda^{-1}|\widetilde{p}_z|^2)} + \partial_y \overline{(\Lambda^{-1}\widetilde{p}_y\widetilde{p}_z^*)}\} + \text{c.c.} \end{bmatrix}, \qquad \mathbf{f}_2 = H_0 \begin{bmatrix} 0 \\ \boxed{\begin{matrix} (\overline{a}_y\overline{b} + \overline{a}_z\overline{c})_z \\ -(\overline{a}_y\overline{b} + \overline{a}_z\overline{c})_y \end{matrix}} \end{bmatrix} \qquad \triangle_2 = \partial_y^2 + \partial_z^2$$

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Wave equation

$$\partial_y\left(\frac{\widetilde{p}_y}{\Lambda}\right) + \partial_z\left(\frac{\widetilde{p}_z}{\Lambda}\right) - \alpha^2\frac{\widetilde{p}}{\Lambda} = 0, \qquad \Lambda = U^2 - \overline{a}^2$$

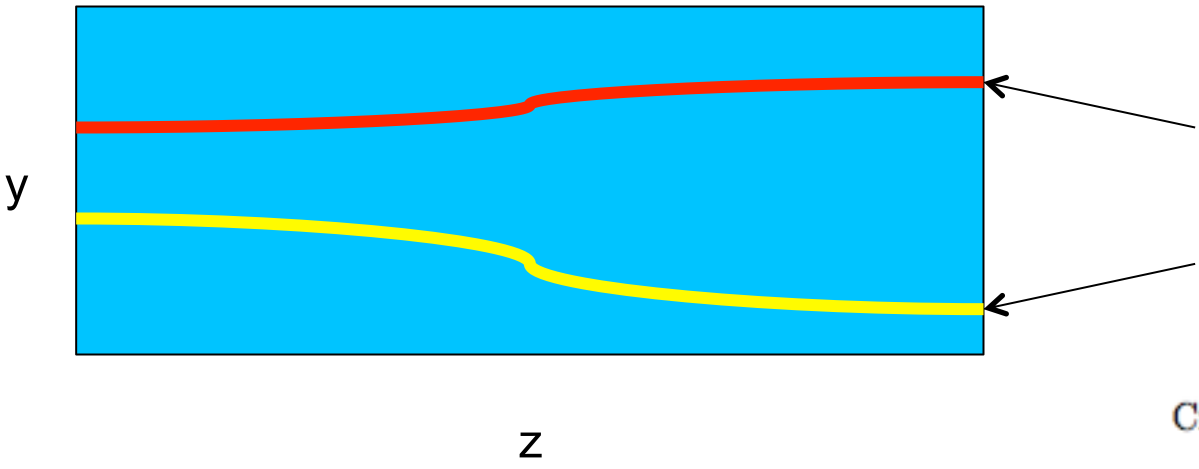
$$U = P_m^{-1/2} y + P_m^{-3/2}\overline{u} - s_0$$

Produce an Alfven wave with a scaled speed s_0

O(1) wavenumbers

There is a stress jump in the roll component.

Resonant absorption theory: Sakurai et al. (1991), Ballai & Erdelyi (1998)



$$y = g_{+}(z) : U + \bar{a} = 0$$

$$y = g_{-}(z) : U - \bar{a} = 0$$

Critical layer thickness $\sim O(R_m^{-1/3})$

$$[\{\mathbf{e}_s \cdot (\overline{v}, \overline{w})\}_n]^{+}_{-} = \left(\frac{\pi}{2U(U_n \pm \bar{a}_n)\alpha^2} \Im\{\widetilde{p}_s^{*}(\alpha^2 \widetilde{p} - \widetilde{p}_{ss})\} \right)\Big|_{y=g_\pm}$$

(n, s) are body-fitted coordinate along the critical layer

O(1) wavenumbers

There is a stress jump in the roll component.

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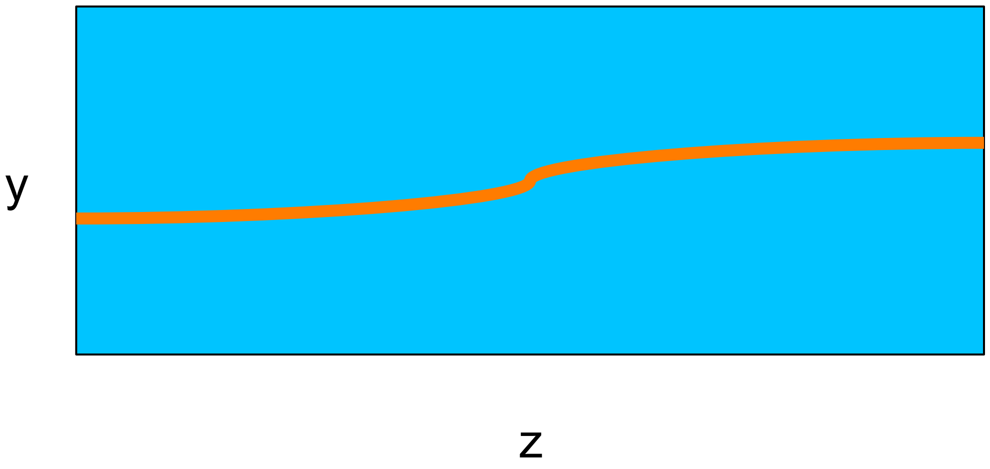


If $g_+ = g_-$

$$\mathbf{f}_1 = \mathbf{0}$$

$$[\overline{p}]_-^+ = \chi(s)F, \qquad [\{\mathbf{e}_s \cdot (\overline{v}, \overline{w})\}_n]_-^+ = \partial_s F$$

$$F = \frac{2\pi(2/3)^{2/3}\Gamma(1/3)|\tilde{p}_s|^2}{\alpha^{5/3}(\gamma_+ - \gamma_-)^2} \left\{ \frac{\gamma_-^2 - P_m^2\overline{a}_n^2}{(U_n - \gamma_+)^{5/3}} + \frac{\gamma_+^2 - P_m^2\overline{a}_n^2}{(U_n - \gamma_-)^{5/3}} \; -2^{4/3}\frac{\gamma_+\gamma_- - P_m^2\overline{a}_n^2}{(U_n - \gamma_+)^{2/3}(U_n - \gamma_-)^{2/3}(U_n(1+P_m))^{1/3}} \right\}\Bigg|_{y=g_\pm}$$

$$\gamma_\pm = \frac{1}{2}\left[U_n(1-P_m) \pm \sqrt{U_n^2(1-P_m)^2 + 4P_m\overline{a}_n}\right]\Bigg|_{y=g_\pm}$$

O(1) wavenumbers

If the Hall term is absent …

(i) The magnetic roll will decay

(ii) The magnetic streak will decay

Therefore the dynamo is a kinematic dynamo on VWI

Long and short waves

Non-kinematic dynamo is possible without Hall term (if Pm is not small)

Long streamwise scale of $R_m = P_m R$ $\partial_x = R_m^{-1}\partial_X$

$$\begin{bmatrix} u \\ v \\ w \\ a \\ b \\ c \\ p \end{bmatrix} = \begin{bmatrix} U \\ R_m^{-1}V \\ R_m^{-1}W \\ P_m^{1/2}A \\ P_m^{1/2}R_m^{-1}B \\ P_m^{1/2}R_m^{-1}C \\ R_m^{-1}R^{-1}P \end{bmatrix} + \cdots$$

Function of (X, y, z)

Long and short waves

Non-kinematic dynamo is possible without Hall term (if Pm is not small)

Similar to hydrodynamic case (Deguchi, Hall & Walton 2013)

$$P_m^{-1}\,[U\partial_X + V\partial_y + W\partial_z]\begin{bmatrix} U \\ V \\ W \end{bmatrix} - [A\partial_X + B\partial_y + C\partial_z]\begin{bmatrix} A \\ B \\ C \end{bmatrix} = -\begin{bmatrix} 0 \\ P_y \\ P_z \end{bmatrix} + \triangle_2\begin{bmatrix} U \\ V \\ W \end{bmatrix}$$

$$[U\partial_X + V\partial_y + W\partial_z]\begin{bmatrix} A \\ B \\ C \end{bmatrix} - [A\partial_X + B\partial_y + C\partial_z]\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \triangle_2\begin{bmatrix} A \\ B \\ C \end{bmatrix}$$

$$U_X + V_y + W_z = 0, \qquad A_X + B_y + C_z = 0. \qquad\qquad \triangle_2 = \partial_y^2 + \partial_z^2$$

Effect of system rotation

Add Coriolis term in the momentum equations

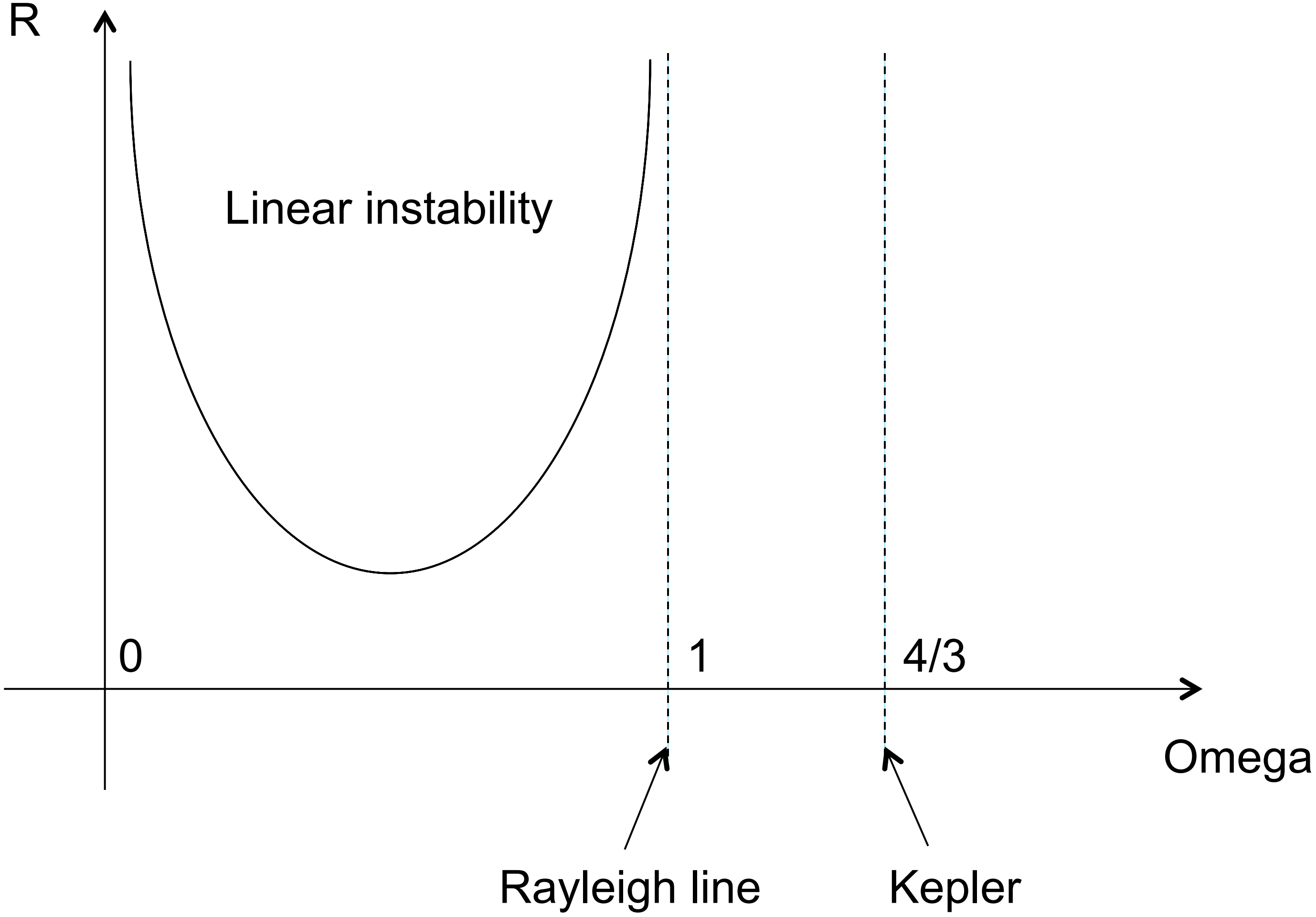
$$[\mathbf{v}\cdot\nabla]\begin{bmatrix}u\\v\\w\end{bmatrix} - [\mathbf{b}\cdot\nabla]\begin{bmatrix}a\\b\\c\end{bmatrix} + \Omega\begin{bmatrix}-v\\u\\0\end{bmatrix} = -\begin{bmatrix}p_x\\p_y\\p_z\end{bmatrix} + R^{-1}\nabla^2\begin{bmatrix}u\\v\\w\end{bmatrix}$$

$$\Omega = \frac{L_*\Omega_*}{U_*}$$

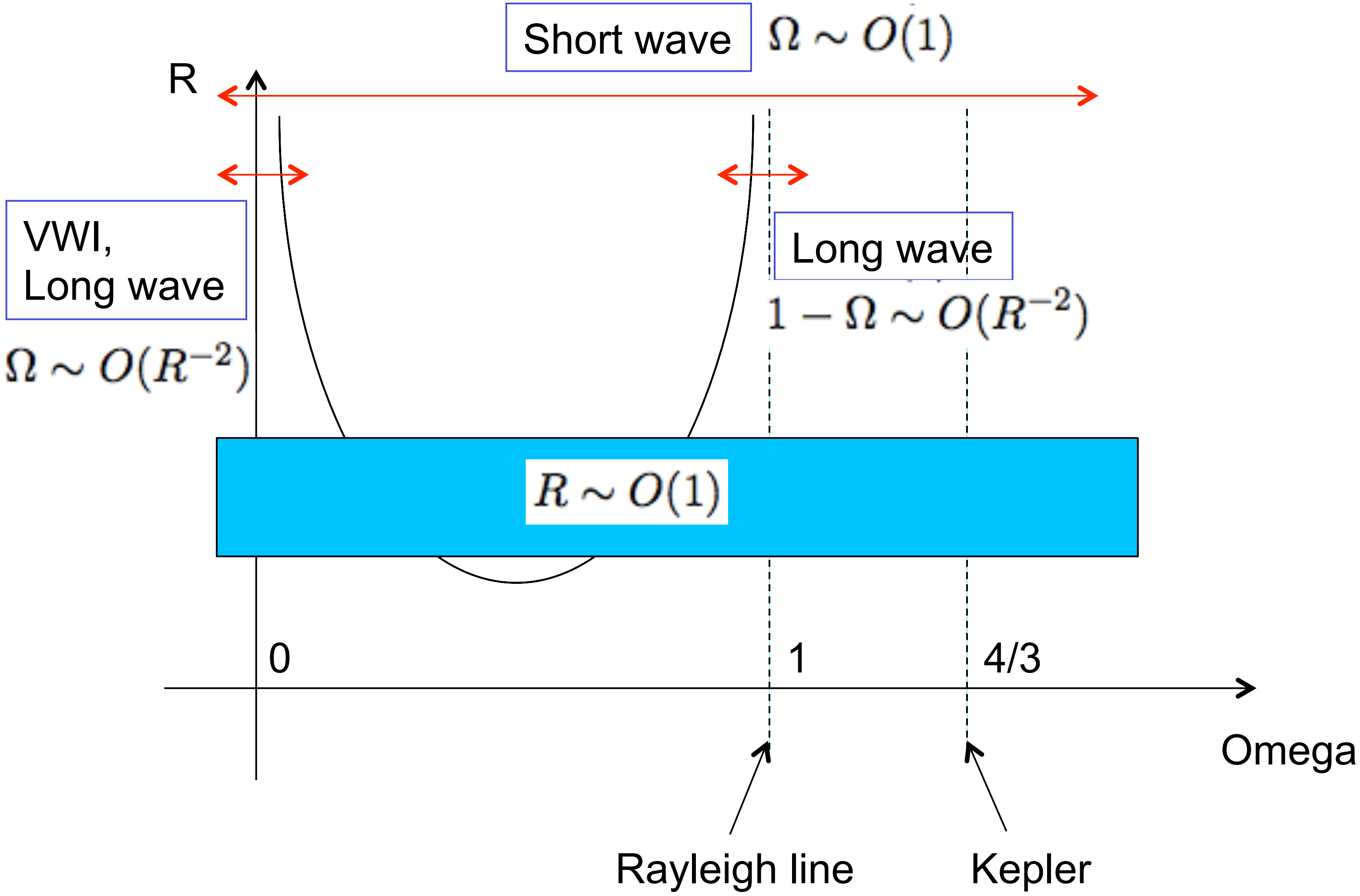
Ω_* is the angular frequency of the system rotation,

In order to balance the Coriolis term, either omega or streak must be small.

Effect of system rotation



Effect of system rotation



Short wave $\Omega \sim O(1)$

VWI,
Long wave

$\Omega \sim O(R^{-2})$

Long wave

$1-\Omega \sim O(R^{-2})$

$R \sim O(1)$

Rincon et al. (2007)
Rotating plane Couette flow

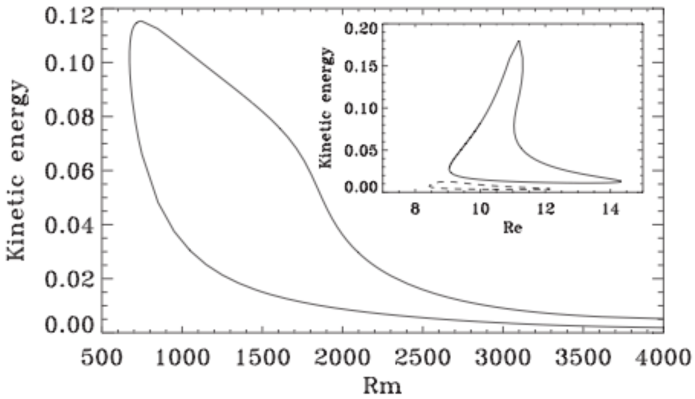


FIG. 7. Continuation with respect to Rm for Re = 10, $(\alpha, \beta) = (0.375, 1)$. Inset: continuation with respect to Re for Rm = 1500 (full line), Rm = 3000 (dashed line). $(N_x, N_y, N_z) = (8, 24, 32)$.

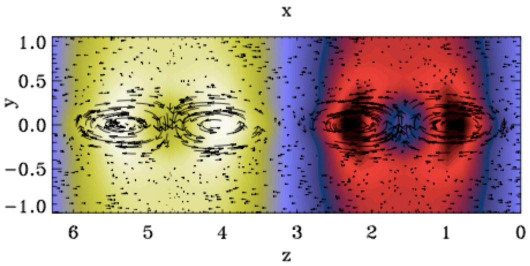
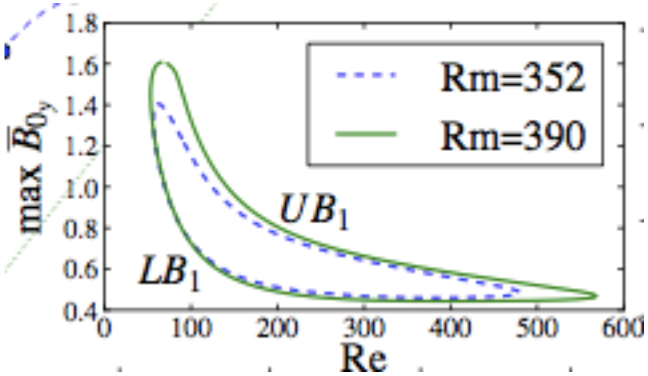
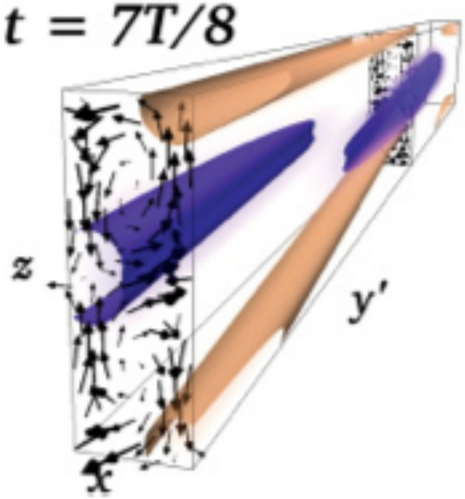


FIG. 6 (color online). Cuts through the unforced ($A = 0$) nonlinear steady solution of Fig. 5 ($\alpha = 0.375$, black dot). Top: b_z at $z = L_z/2$. Bottom: b_x (color scale) and (b_y, b_z) (arrows) at $x = L_x/4$.

Herault et al. (2011)
Rotating shearing box





Conclusion

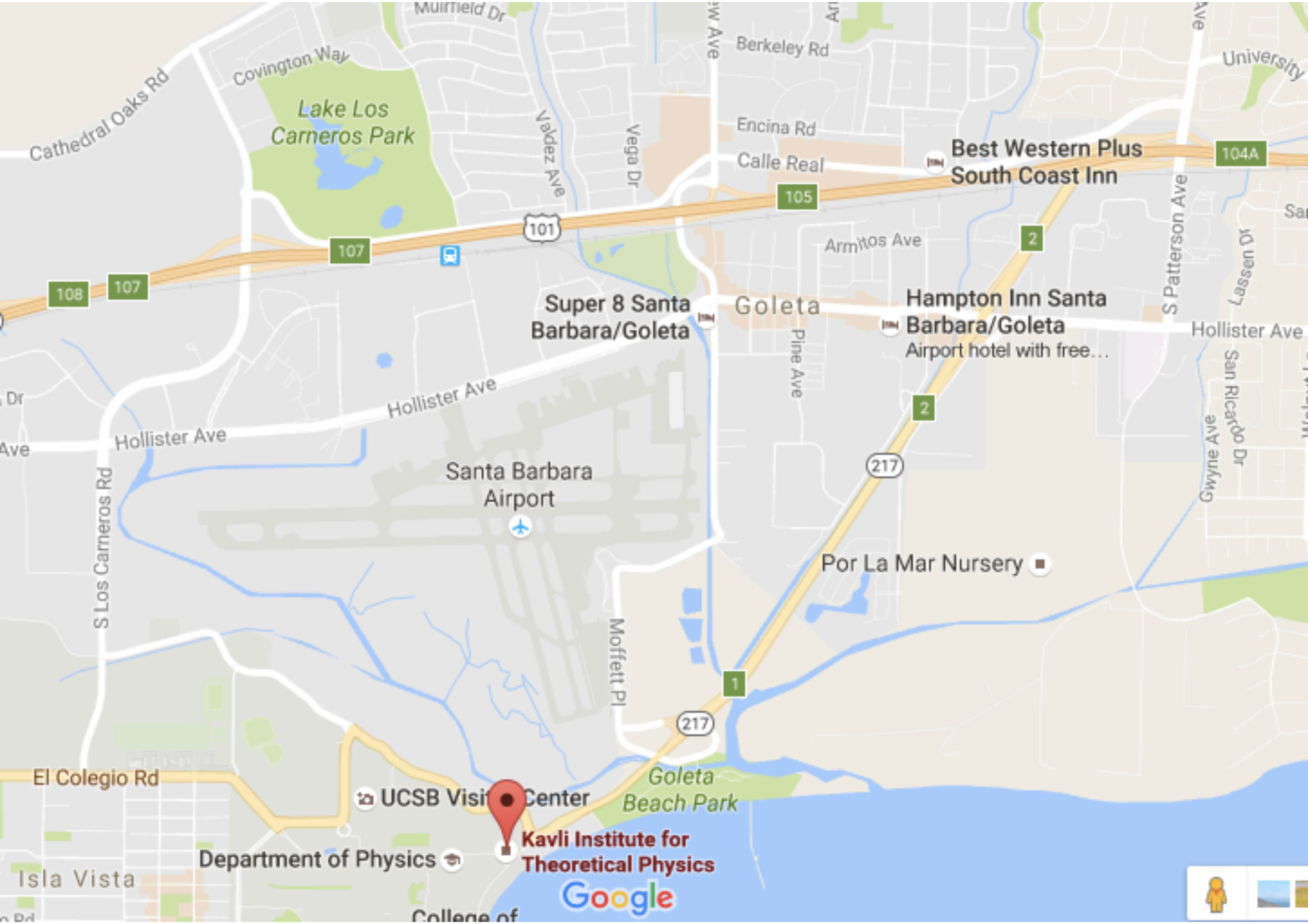
O(1) wavenumbers

- If the Hall term is zero, dynamo is kinematic
- If there is the Hall term Alfven wave drive the streamwise vortex

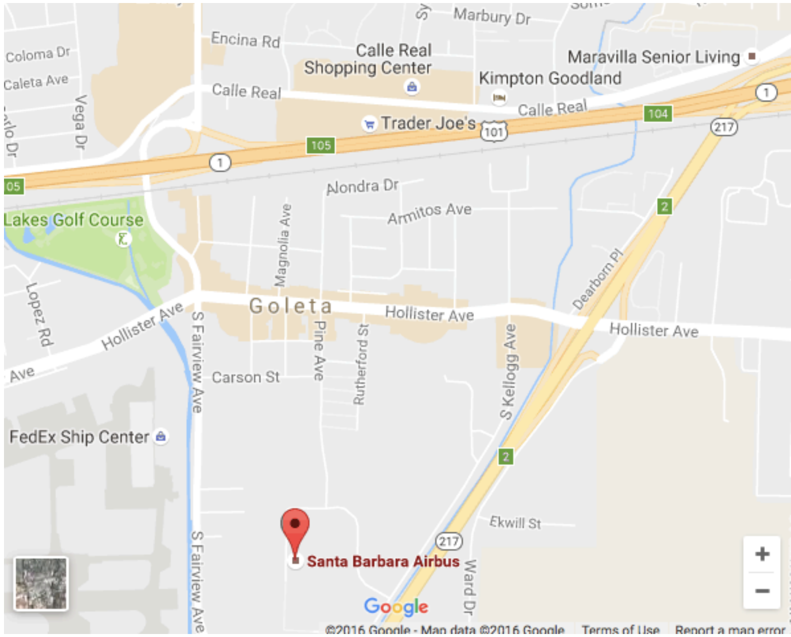
Long wavelength case

- non-kinematic dynamo is possible

Not possible to drive non-kinematic dynamo in astrophysically interesting regime


Muirfield Dr
Covington Way
Cathedral Oaks Rd
Lake Los Carneros Park
Valdez Ave
Vega Dr
Berkeley Rd
Encina Rd
Calle Real
Best Western Plus South Coast Inn
104A
University
105
101
107
108
107
Armitos Ave
2
S Patterson Ave
Lassen Dr
Super 8 Santa Barbara/Goleta
Goleta
Hampton Inn Santa Barbara/Goleta
Airport hotel with free…
Hollister Ave
Pine Ave
San Ricardo Dr
Gwyne Ave
Hollister Ave
Hollister Ave
2
217
Santa Barbara Airport
S Los Carneros Rd
Por La Mar Nursery
Moffett Pl
1
217
Goleta Beach Park
El Colegio Rd
UCSB Visitor Center
Kavli Institute for Theoretical Physics
Department of Physics
Isla Vista
College of
Google

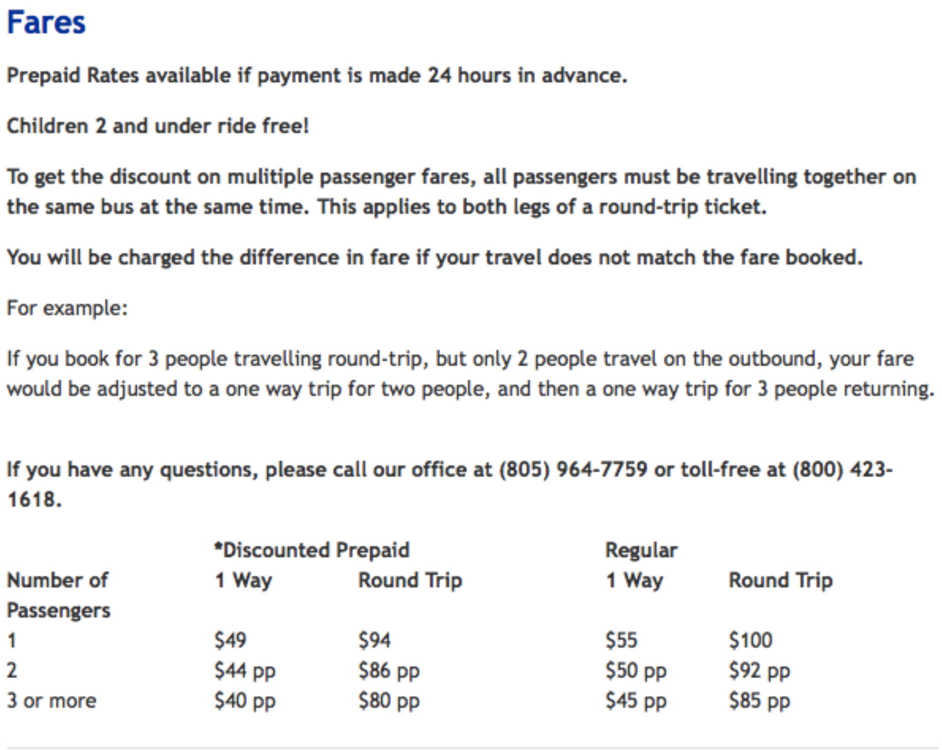
Using the Lower Level at LAX, our drivers stop at each terminal at designated pick-up locations. Passengers should wait for the Airbus at the center island beneath the GREEN markers/signs announcing “Flyaway Buses, Long Distance Vans”. You must be at the proper stop to ensure pick-up. Here is an picture of the location we pick up: *(There are Green signs at each terminal.)*



Click here for larger picture. *(Opens in new window)*

Important info about our pickup times at LAX:

We start at Terminal 1 at the scheduled pick up time. It takes us 15-20 minutes to get around to each of the 8 terminals. This means that if you are at terminals 3-7, the bus will arrive 5-15 minutes after the listed pickup time. If you are waiting and don't see the bus - don't panic! We are making our way around the airport and will be there shortly to pick you up. Below is a link to the map of the airlines at LAX so you can see at which terminal your airline is located.



Fares

Prepaid Rates available if payment is made 24 hours in advance.

Children 2 and under ride free!

To get the discount on mulitiple passenger fares, all passengers must be travelling together on the same bus at the same time. This applies to both legs of a round-trip ticket.

You will be charged the difference in fare if your travel does not match the fare booked.

For example:

If you book for 3 people travelling round-trip, but only 2 people travel on the outbound, your fare would be adjusted to a one way trip for two people, and then a one way trip for 3 people returning.

If you have any questions, please call our office at (805) 964-7759 or toll-free at (800) 423-1618.

	***Discounted Prepaid**		**Regular**	
Number of Passengers	**1 Way**	**Round Trip**	**1 Way**	**Round Trip**
1	$49	$94	$55	$100
2	$44 pp	$86 pp	$50 pp	$92 pp
3 or more	$40 pp	$80 pp	$45 pp	$85 pp

You MUST arrive the Goleta stop **at least 15 minutes prior to departure. For Santa Barbara & Carpinteria Stops **please arrive 10 minutes before departure.****

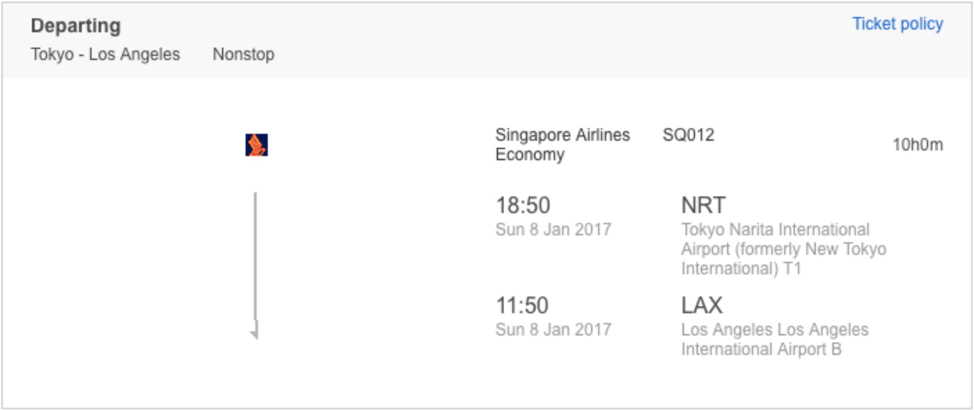
Trip Number	Depart Goleta	Depart Santa Barbara	Depart Carpinteria	ARRIVE LAX
1	03:30am	03:50am	04:10am	06:00am
3	05:30am	05:50am	06:10am	08:15am
5	07:00am	07:20am	07:40am	09:45am
7	08:30am	08:50am	09:10am	11:15am
9	10:00am	10:20am	10:40am	12:45pm
11	12:00pm	12:20pm	12:40pm	02:45pm
13	03:00pm	03:20pm	03:40pm	05:45pm
15	06:00pm	06:20pm	06:40pm	08:45pm

Schedule - From Los Angeles International Airport - LAX

Connections from LAX

Trip Number	BEGIN PICK UP AT LAX	Arrive Carpinteria	Arrive Santa Barbara	Arrive Goleta
2	09:00am	11:00am	11:15am	11:30am
4	11:00am	01:00pm	01:15pm	01:30pm
6	12:30pm	02:30pm	02:45pm	03:00pm
8	02:00pm	04:00pm	04:15pm	04:30pm
10	03:30pm	05:45pm	06:00pm	06:15pm
12	05:30pm	07:45pm	08:00pm	08:15pm
14*	07:30pm	09:45pm	10:00pm	10:15pm
16*	10:00pm	12:15am	12:30am	12:45am

***Trip #14 (7:30pm) and Trip #16 (10:00pm) will take a minimum of 30 minutes to clear the airport.**



Departing

Tokyo - Los Angeles Nonstop

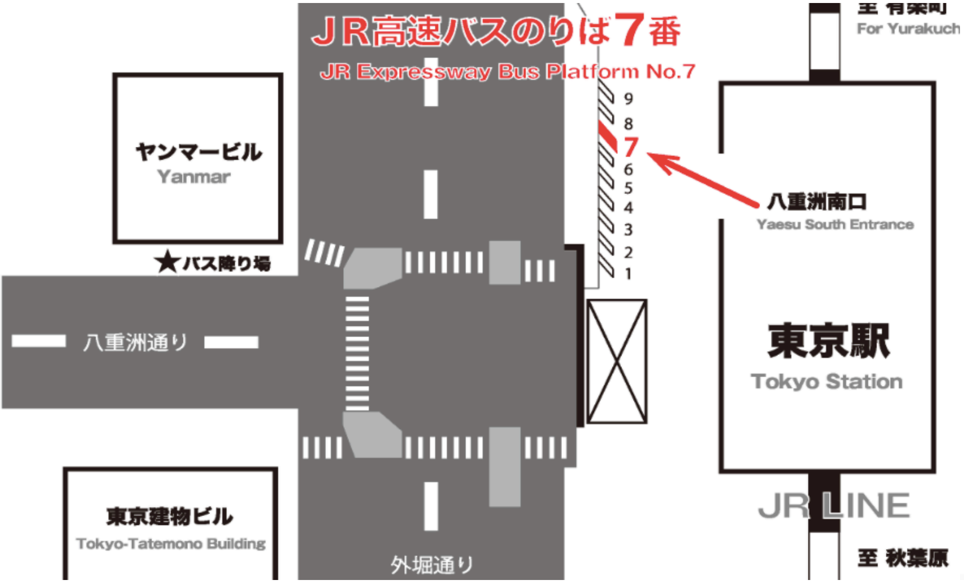
Singapore Airlines SQ012 10h0m
Economy

18:50
Sun 8 Jan 2017
NRT
Tokyo Narita International Airport (formerly New Tokyo International) T1

11:50
Sun 8 Jan 2017
LAX
Los Angeles Los Angeles International Airport B

Your Itinerary

Date	Flight Number	Departing	Arriving	Status	Flight Information
14 Jan 17	QF310 Operated By American Airlines	Los Angeles 2245, 10:45PM Terminal 0	Sydney 0845, 8:45AM 16 Jan 17 Terminal 1	Economy Confirmed	Est journey Time: 15:00 Non-Stop Aircraft Type: Boeing 777
16 Jan 17	QF429	Sydney 1130, 11:30AM Terminal 3	Melbourne 1305, 1:05PM 16 Jan 17 Terminal 1	Economy Confirmed	Est journey Time: 01:35 Non-Stop Aircraft Type: Boeing 737



高速バス発車便専用バスターミナル

連続した案内表示で迷わないバスのりば

東京駅駅舎直結

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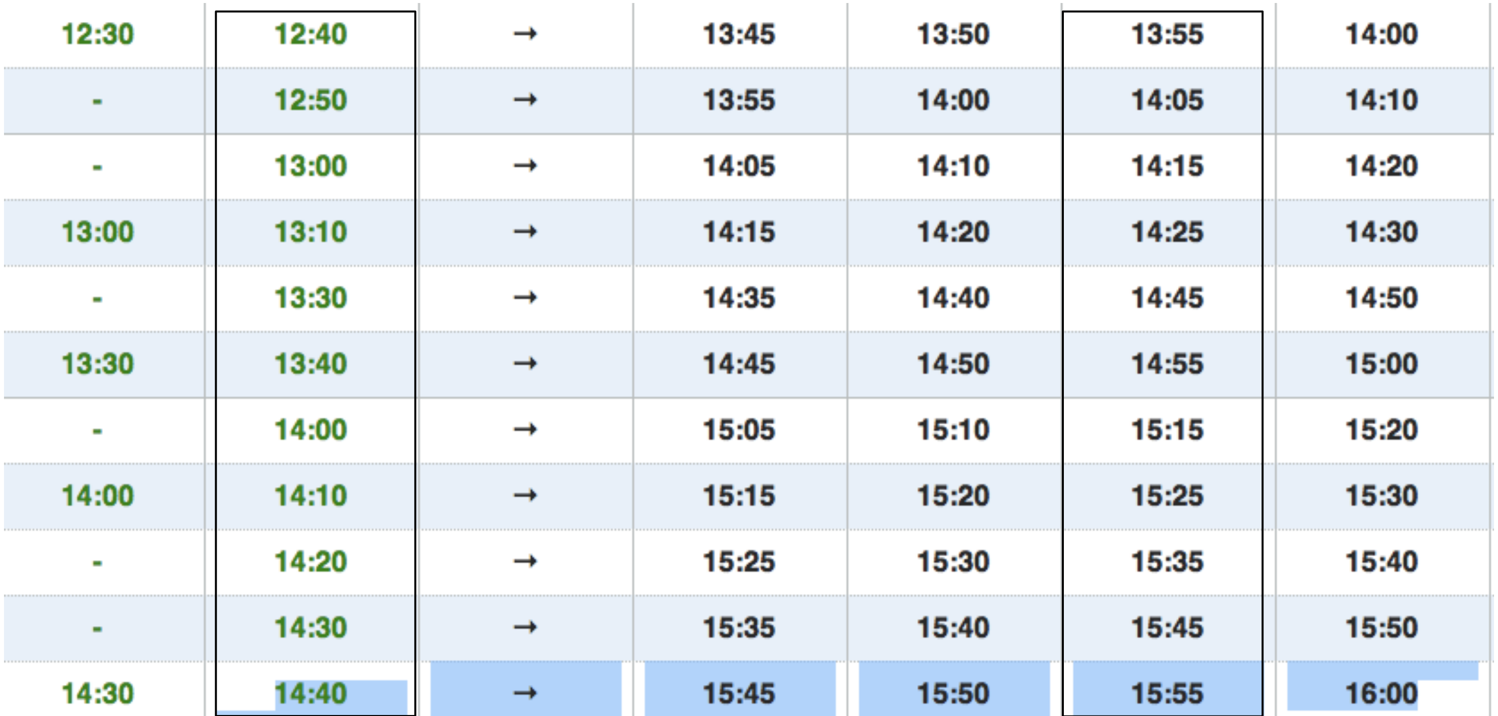

12:30	12:40	→	13:45	13:50	13:55	14:00
-	12:50	→	13:55	14:00	14:05	14:10
-	13:00	→	14:05	14:10	14:15	14:20
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-	14:00	→	15:05	15:10	15:15	15:20
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-	14:30	→	15:35	15:40	15:45	15:50
14:30	14:40	→	15:45	15:50	15:55	16:00

Monday, Jan 09, 2017

08:50AM Invariant Solutions of Navier-Stokes 1 **Chair: Fabian Waleffe (Wisconsin)**

Talks are 30 min + 15 min discussion ***Main Seminar Room***

- 08:50AM - Lars Bildsten (KITP) - *Welcome*
- 09:00AM - Rich Kerswell (Bristol) - *Exact coherent structures in stratified plane Couette flow*
- 09:45AM - Genta Kawahara (Osaka) - *Periodic solutions representing the origin of turbulent bands in channel flow*

10:30AM MORNING BREAK

KITP Courtyard

11:00AM

Main Seminar Room

- 11:00AM - Roman Grigoriev (Georgia Tech) - *Streamwise localization of relative periodic solutions in channel & pipe flows*
- 11:45AM - Carlo Cossu (Toulouse) - *Large-eddy exact coherent structures for wall-bounded turbulent shear flows*

12:30PM LUNCH BREAK

KITP Courtyard

02:00PM Localizaion and Linearity **Chair: Laurette Tuckerman (ESPCI, Paris)**

Talks are 30 min + 15 min discussion ***Main Seminar Room***

- 02:00PM - Marc Avila (Bremen) - *Physics and modeling of laminar-turbulent interfaces in pipe flow*
- 02:45PM - Stefan Zammert (Delft) - *Coherent structures in boundary layers in the quasilinear approximation*

03:30PM AFTERNOON BREAK

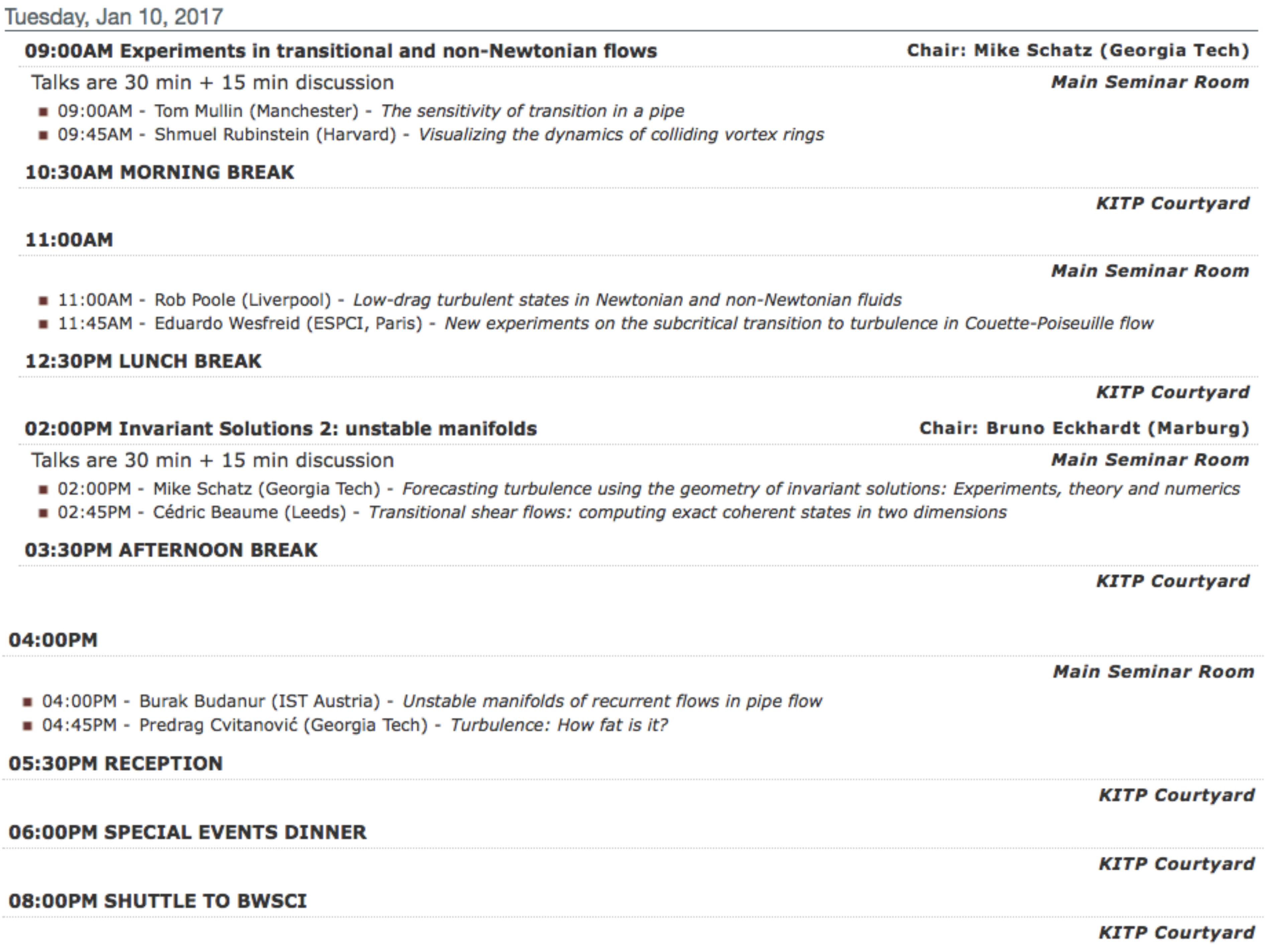
KITP Courtyard

04:00PM

Main Seminar Room

- 04:00PM - Adrian Lozano Duran (Stanford) - *Information flow and causality of streak-roll interactions in time-resolved wall-bounded turbulence*
- 04:45PM - Steven Tobias (Leeds) - *Application of the generalised quasilinear approximation to jets, the helical magnetorotational instability, and rotating Couette Flow*

05:30PM SHUTTLE TO BWSCI



Tuesday, Jan 10, 2017

09:00AM Experiments in transitional and non-Newtonian flows **Chair: Mike Schatz (Georgia Tech)**

Talks are 30 min + 15 min discussion ***Main Seminar Room***

- 09:00AM - Tom Mullin (Manchester) - *The sensitivity of transition in a pipe*
- 09:45AM - Shmuel Rubinstein (Harvard) - *Visualizing the dynamics of colliding vortex rings*

10:30AM MORNING BREAK

KITP Courtyard

11:00AM

Main Seminar Room

- 11:00AM - Rob Poole (Liverpool) - *Low-drag turbulent states in Newtonian and non-Newtonian fluids*
- 11:45AM - Eduardo Wesfreid (ESPCI, Paris) - *New experiments on the subcritical transition to turbulence in Couette-Poiseuille flow*

12:30PM LUNCH BREAK

KITP Courtyard

02:00PM Invariant Solutions 2: unstable manifolds **Chair: Bruno Eckhardt (Marburg)**

Talks are 30 min + 15 min discussion ***Main Seminar Room***

- 02:00PM - Mike Schatz (Georgia Tech) - *Forecasting turbulence using the geometry of invariant solutions: Experiments, theory and numerics*
- 02:45PM - Cédric Beaume (Leeds) - *Transitional shear flows: computing exact coherent states in two dimensions*

03:30PM AFTERNOON BREAK

KITP Courtyard

04:00PM

Main Seminar Room

- 04:00PM - Burak Budanur (IST Austria) - *Unstable manifolds of recurrent flows in pipe flow*
- 04:45PM - Predrag Cvitanović (Georgia Tech) - *Turbulence: How fat is it?*

05:30PM RECEPTION

KITP Courtyard

06:00PM SPECIAL EVENTS DINNER

KITP Courtyard

08:00PM SHUTTLE TO BWSCI

KITP Courtyard

Wednesday, Jan 11, 2017

09:00AM Geophysical and large Reynolds number flows **Chair: Greg Chini (New Hampshire)**

Talks are 30 min + 15 min discussion ***Main Seminar Room***

- 09:00AM - Keith Julien (Colorado) - *Quasigeostrophic investigations of non-hydrostatic, stably-stratified and rapidly rotating flows*
- 09:45AM - Navid Constantinou (UC San Diego) - *Understanding self-organization in turbulent flows by studying the statistical state dynamics*

10:30AM MORNING BREAK

KITP Courtyard

11:00AM

Main Seminar Room

- 11:00AM - Kengo Deguchi (Imperial College) - *The high Reynolds-number limit of self-sustained magnetohydrodynamic dynamos*
- 11:45AM - Joe Klewicki (New Hampshire) - *Invariant representation of mean inertia provides a theoretical basis for the log law in turbulent boundary layers*

12:30PM LUNCH BREAK

KITP Courtyard

02:00PM FREE AFTERNOON Shuttle Available to BWSCI

KITP Courtyard

Friday, Jan 13, 2017

09:00AM Transition to Turbulence **Chair: Beverly McKeon (Caltech)**

Talks are 30 min + 15 min discussion ***Main Seminar Room***

- 09:00AM - Laurette Tuckerman (ESPCI, Paris) - *Transition to turbulence in Waleffe/Kolmogorovian flow*
- 09:45AM - Björn Hof (IST Austria) - *Transition to turbulence in channel flow*

10:30AM MORNING BREAK

KITP Courtyard

11:00AM

Main Seminar Room

- 11:00AM - Masaki Sano (Tokyo) - *Universal transition to turbulence in channel flow*
- 11:45AM - Dan Henningson (KTH, Stockholm) - *Dynamical systems analysis of transition in boundary layer flows*

12:30PM LUNCH BREAK

KITP Courtyard

02:00PM Discussion: Paths Forward **Chair: Mike Graham (Wisconsin)**

Main Seminar Room

- 02:00PM - *All participants-Discussion*

03:00PM CONFERENCE END-SHUTTLE TO BWSCI *Also available to SB Airport and SB Airbus, Goleta location (See Registration Desk before Friday to sign up.)

KITP Courtyard

Thursday, Jan 12, 2017

09:00AM Reduced-order Models **Chair: Dennice Gayme (Johns Hopkins)**

Talks are 30 min + 15 min discussion *Main Seminar Room*

- 09:00AM - Beverly McKeon (Caltech) - *Self-similarity in the resolvent model: Linear response and nonlinear interactions*
- 09:45AM - Mihailo Jovanovic (Minnesota) - *The Color of turbulence*

10:30AM MORNING BREAK

KITP Courtyard

11:00AM

Main Seminar Room

- 11:00AM - Ati Sharma (Southhampton) - *Resolvent modes and invariant solutions*
- 11:45AM - Clancy Rowley (Princeton) - *Data-driven methods for identifying nonlinear models of fluid flows*

12:30PM LUNCH BREAK

KITP Courtyard

02:00PM Pattern Formation and Coherent Structures **Chair: Colm-cille Caulfield (Cambridge)**

Talks are 30 min + 15 min discussion *Main Seminar Room*

- 02:00PM - Melissa Green (Syracuse) - *Tracking coherent structures in massively-separated and turbulent flows*
- 02:45PM - Yongyun Hwang (Imperial College) - *Self-sustaining attached eddies: Skin-friction generation, pressure, and invariant solutions*

03:30PM AFTERNOON BREAK

KITP Courtyard

04:00PM

Main Seminar Room

- 04:00PM - Edgar Knobloch (UC Berkeley) - *A nonlinear model of noise-sustained structures in subcritical systems*

04:45PM POSTER SESSION

KITP Courtyard

05:30PM RECEPTION

KITP Courtyard

06:00PM SPECIAL EVENTS DINNER

KITP Courtyard

08:00PM SHUTTLE TO BWSCI

KITP Courtyard