Control of Fluctuations in the GAMMA-10 by Sheared Flow

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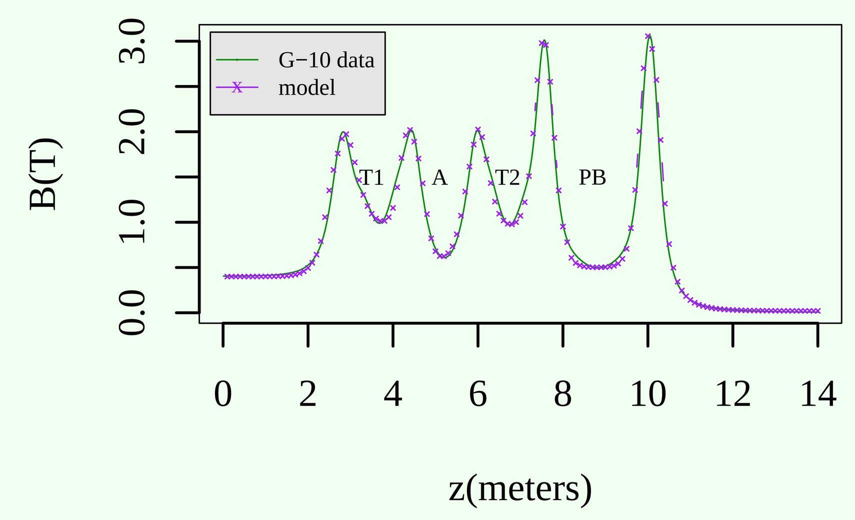

FIGURE 1: Profiles of the axial B in the right-hand side of the GAMMA-10. Grey initials mark regions set up by the mirror coil configurations: transition region 1, anchor, transition region 2, and the plug-barrier region.

- GAMMA-10 experiments show that sheared radial electric field E_r reduces low frequency drift wave fluctuations [T. Cho *et al.* (2006)].
- modeling the GAMMA-10 shows qualitative change in fluctuation spectrum with sheared E_r
- actual magnetic field profiles from data are used to create the equilibrium geometry
- matrix and shooting code methods are used to find the flute-like interchange instability and the drift waves
- simple nonlinear drift wave code with and without E_r shear shows the qualitative change of the turbulence in agreement with the fluctuation data
- drift wave transport formulas predict an order of magnitude increase in energy confinement time over the corresponding size toroidal system

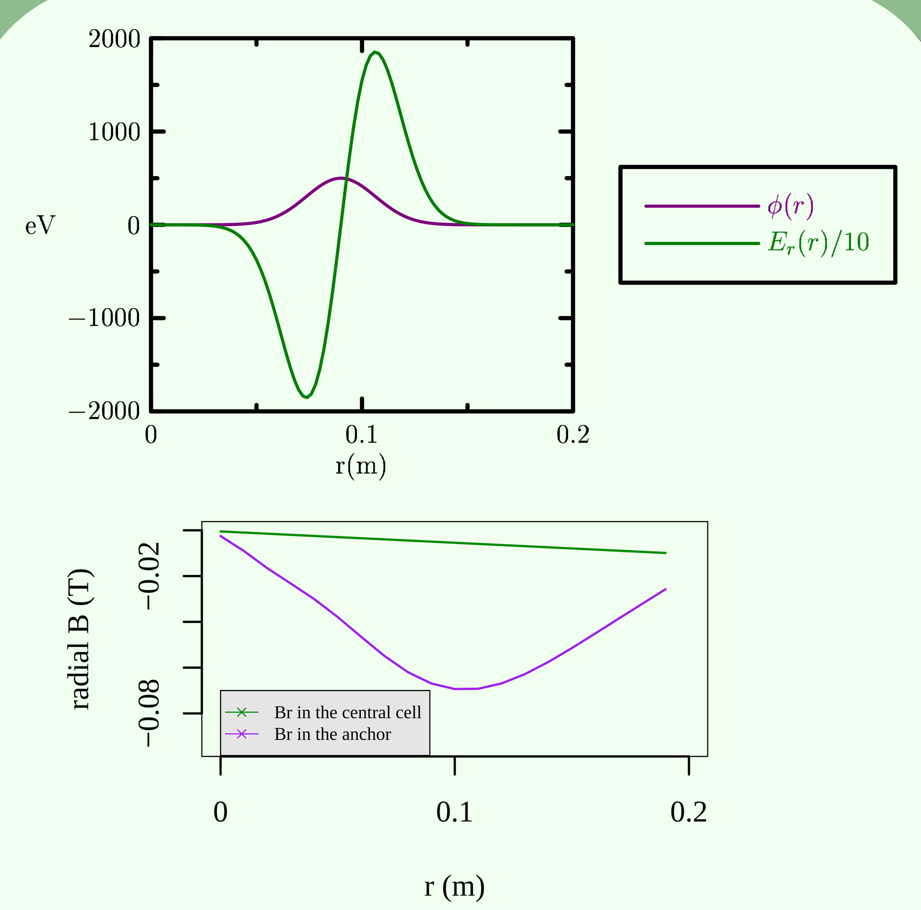

FIGURE 2: Model of sheared electric field and radial magnetic field.

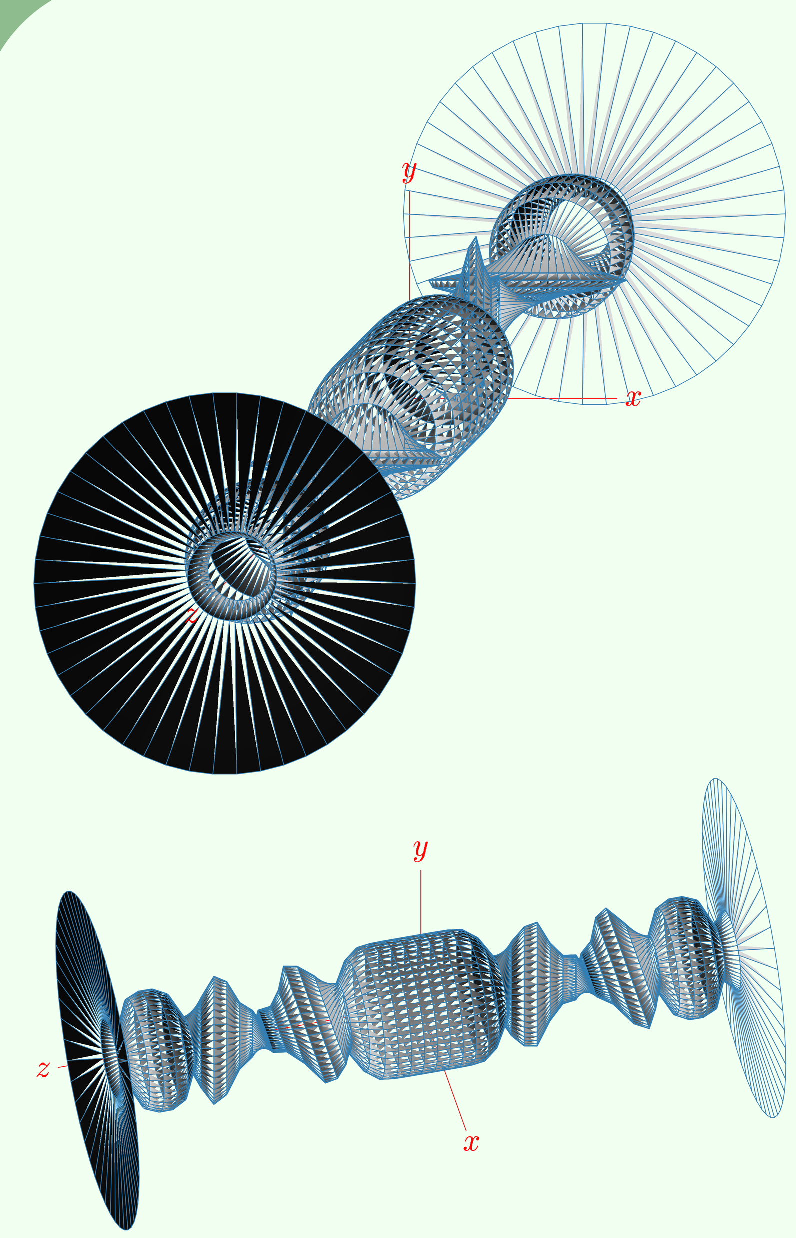

FIGURE 3: A model of the GAMMA-10 with quadrupole anchor cells calculated using formulas from [Furth and Rosenbluth(1964)]. The quadrupole magnetic fields stabilize the anchor regions; they also make the GAMMA-10 not axisymmetric.

Parameter	G10 Dec. 2006	KSTM-FR
a	.18 m	1.5 m
L	6 m	30 m
n_c	10^{19} m^{-3}	10^{20} m^{-3}
n_p/n_c	.1	7
T_e	750 eV	60 keV
T_i	6.5 keV (perp) 2.5 keV (par)	15 keV
B_{cc}	.405 T	3 T
B_{plug}	.49 T	18 T
R_m	5.2	9

The scaling laws we derived in [J. Pratt and W. Horton(2006)] are summarized in the table:

$\tau_{L97} =$	.010	$B^{.99}$	$L^{.93}$	$a^{1.86}$	$n^{.4}$	$P^{-.73}$
$\tau_{H98} =$	.067	$B^{1.08}$	$L^{.46}$	$a^{2.44}$	$n^{.41}$	$P^{-.69}$
$\tau_{ISS95} =$	.080	$B^{.83}$	$L^{0.65}$	$a^{2.21}$	$n^{.51}$	$P^{-.59}$
$\tau_{ISS04} =$	.103	$B^{.89}$	$L^{.6}$	$a^{2.33}$	$n^{.59}$	$P^{-.64}$
$\tau_E^B =$	0.042	$B^{1/2}$	$L^{1/2}$	a^2	$n^{1/2}$	$P^{-1/2}$
$\tau_E^{gB} =$	0.016	$B^{.8}$	$L^{.6}$	$a^{2.4}$	$n^{.6}$	$P^{-.6}$
$\tau_E^{ETG} =$	.025	–	$L^{.33}$	$a^{2.66}$	n^1	$P^{-.33}$

Sheared Electric Fields

We examine the Rayleigh-Taylor equations with a background shear flow in the slab geometry. Here x is the radial coordinate and y is the poloidal coordinate.

$$\left[\frac{\partial}{\partial t} + U_0(x)\frac{\partial}{\partial y}\right]\Delta\phi + J(\phi,\Delta\phi) = \beta_1\frac{\partial p}{\partial\theta} + \nu_1\Delta^2\phi \quad (1)$$

$$\left[\frac{\partial}{\partial t} + U_0(x)\frac{\partial}{\partial y}\right]p + J(\phi,p) = \beta_2\frac{\partial\phi}{\partial y} + \nu_2\Delta p \quad (2)$$

$$\mathbf{U_0}(x) = (0, A\,x) \quad (3)$$

The background velocity is given by U_0. The β_i parameters are associated with the interchange mode, ν_1 is viscosity, ν_2 is diffusivity, and A is the shear parameter (1/s). p is pressure.

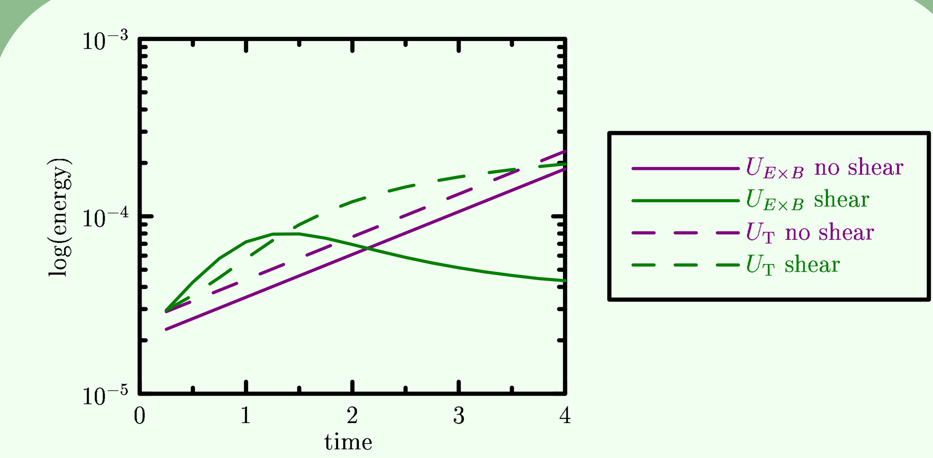

FIGURE 4: Solid lines indicate kinetic energy of the $E\times B$ flow. Dashed lines indicate thermal energy. All energies initially have a linear growth rate. Green lines indicate how the energy grows when a constant shear electric field is applied.

Drift Wave Eigenmodes

The eigenmode equation for $E_{||} = 0$ modes describes the $k_{||}$ spectrum of modes from

$$B\frac{\partial}{\partial z}\frac{k_\perp^2(z)}{B(z)}\frac{\partial\phi}{\partial z} = -\left[\frac{\rho\omega^2k^2}{B^2} + \frac{2k_\theta^2\kappa_r}{B^2}\frac{\partial p}{\partial r}\right]\phi \quad (4)$$

where $\kappa = (\hat{b}\cdot\nabla)\hat{b} = d^2a(z)/dz^2 = -1/R_c$. The lowest eigenmode may have negative $\omega^2 \simeq -p/(\rho R_c L_p)$ when the plasma β is high enough. The condition on β for instability follows from a shooting code that calculates the slight localization in unfavorable curvature regions from eq. 4. This critical β limit is high – approaching unity for tandem mirrors – indicating superior MHD stability. We assume that the plasma pressure remains below this limit. Ryutov and Post give methods of enhancing the pressure limit by providing kinetic plasma flows and injection from the end regions into the last cell [D. D. Ryutov(1987)]. This is called the kinetically stabilized tandem mirror (KSTM) [R. F. Post, TK Fowler, R. Bulmer, *et al.* (2005)]. The simple eigenmode equation is we solve is

$$\frac{\partial^2\phi}{\partial z^2} = -\left[\omega(\omega-\omega_{*i})\frac{a^4}{v_A^2} - \frac{\gamma_{MHD}^2}{v_A^2}a^3\frac{d^2a}{dz^2}\right]\phi \quad (5)$$

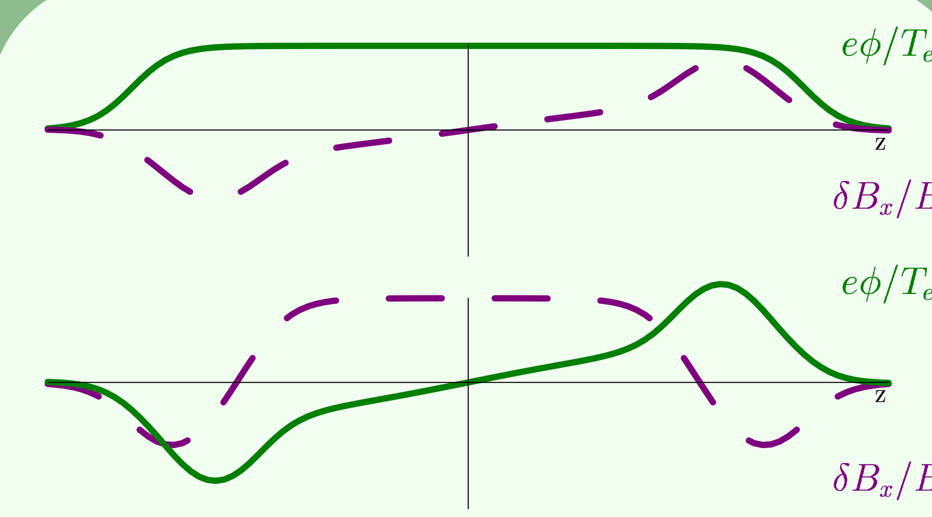

FIGURE 5: A sketch of ion and electron drift wave modes in the central cell of the GAMMA-10. Purple lines indicate magnetic fluctuations; green lines indicate fluctuations in electric potential.

Conclusions and Further Work

- For high temperature tandem mirror operation, the energy confinement time from radial transport, τ_E, dominates over the end loss transport.
- Experimental results from Dec 2006 measure a radial confinement time τ_E = 72 ms. For the same experiments the axial loss time, τ_p is approximately 100 ms.
- Sheared E_r suppresses intermittent turbulence.

We plan to

- calculate and analyze eigenvalues of the GAMMA-10 system exhaustively.
- increase the complexity of our drift wave model in the case that $E_{||} \neq 0$. This more comprehensive system for drift wave eigenmodes will involve solving the coupled pdes for the electrostatic potential and the magnetic perturbation.
- integrate test particle orbits using the eigenmode fields.

References

[T. Cho *et al.* (2006)] T. Cho *et al.* , Phys. Rev. Lett. **97** (2006).

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[R. F. Post, TK Fowler, R. Bulmer, *et al.* (2005)] R. F. Post, TK Fowler, R. Bulmer, *et al.* , Fusion Science and Technology **47**, 49 (2005).