Theory and modeling in simplified magnetic configurations

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Z-pincho: why do we care?

• Azimuthal magnetic field generated by current in Z (B~1/R).
• Curvature and grad B present, but no variation in magnitude of B along field.
• No trapped particles, 2D instead of 3D.

Simplified test-bed for theory with key physics included!
Z-pincho stability

- Unstable to ideal interchange mode at large pressure gradient and to entropy mode at moderate pressure gradient
- Kinetic treatment necessary to get stability boundary:

\[
\left| \frac{R/L_n} {v_{th,i}} \right|_{\text{crit}} = \frac{2 (1 + \tau)}{\pi (1 + \tau) - k_{\perp}^2 \rho_i^2 (\pi - 2)}
\]

\[
\omega \left| \frac{L_n}{v_{th,i}} \right| = \left[ \frac{(1 + \tau) \left( \frac{\pi}{2} |R/L_n| - 1 \right) - k_{\perp}^2 \rho_i^2 |R/L_n| (\pi/2 - 1)}{2\pi (1 + \tau^3)^2 |R/L_n|^3} \right]^2 \left( \tau^2 - 1 \pm 2\tau^{3/2} i \right) k_{\perp} \rho_i
\]

Low beta, long wavelength, \( T' = 0 \), collisionless
Z-pinch stability

Red = GK, Black = gyrofluid, Blue = fluid entropy mode,
Green = interchange mode

Ricci et al. (2006)
\[ \frac{L_n}{R} = 0.5 \]

\[ k_\perp \rho = 38 \]

Ricci et al. (2006)
Effect of collisions

- Z-pinch used to test model collision operator for gyrokinetics

\[ \frac{L_n}{R} = 0.5 \]

Barnes et al. (2009)
Zonal flow physics

Ricci et al. (2006)
GSP benchmark

Linear phase - growing $k_y$ modes

Nonlinear phase - steady zonal flow with background turbulence

Surface plots of electrostatic potential, $\Phi(x,y)$

Courtesy K. Gustafson
Particle diffusion in presence of zonal flows

Sanchez et al PRL 2008; Hauff et al PRL 2009

\[
\frac{\sigma^2(t)}{t} = D_{\text{part}} \times 2
\]

Strongest gradient tested

Clearly diffusive after \( t = 600 \frac{R}{v_{\text{th}}} \).

\( L_n / R_c = 0.5 \)

Courtesy K. Gustafson
Conclusions

• Range of interesting physics requires kinetic treatment
• Kinetic treatment made more tractable (analytically and numerically) by using simplified magnetic configuration