Simulated Poloidal Rotation Effects on Kink Modes for the Electric Tokamak

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Preface:

Advanced, calibrated theory codes are being used to explore some of the new physics ET may produce. This new physics of global poloidal rotation will be tried on ET as part of a path to a near unity beta tokamak regime.

Outline:

- Quick review of gyrokinetic simulations
- Test kink mode used for rotation studies
- Poloidal rotation and test mode stability
- Discussion of poloidal rotation effects

A Gyrokinetic Code was used to Explore Rotation-Turbulence Effects

- We used a *global* 3-D code developed at UCLA by R. Sydora {Plasma Phys. Control. Fusion 38 (1996) A281}.
- Poloidal rotation is imposed directly in the EXB drift velocity from a specified E_r

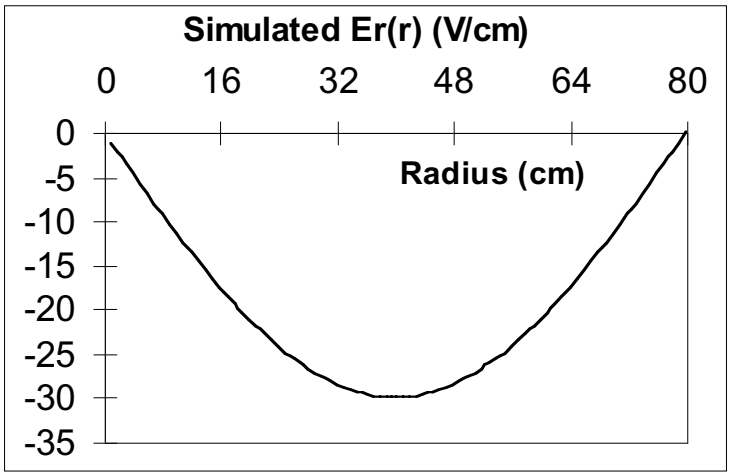
Limitations:

- Adiabatic electrons assumed: $\frac{\delta n_e}{n_e} = \frac{e\phi}{T_e}$
- collisionless (not so correct)
- no Reynold's stress evolution (no fluctuation induced flows)
- mode growth far from marginality: $\nabla n = 0$

We Modeled a Possible Typical ET Start-up Plasma

[see Kissick et al., Phys. Plasmas **6** (1999) 4722]

- A He plasma, rf heated with the following parameters: $n_e(0)=5X10^{12}$ cm^{-3}, $T_i(0)\sim T_e(0)$ = 500 eV, R = 500 cm, a = 80 cm, and B_T = 2500 Gauss



This corresponds to in the code:

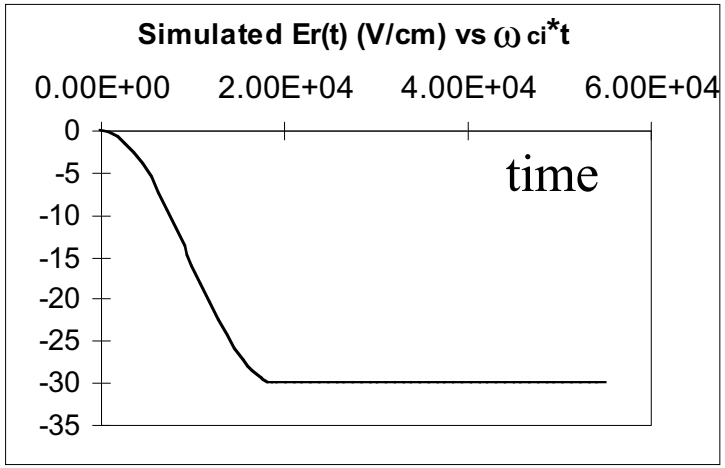
$R/a = 6.25$

$a/\rho_i = 87.7$

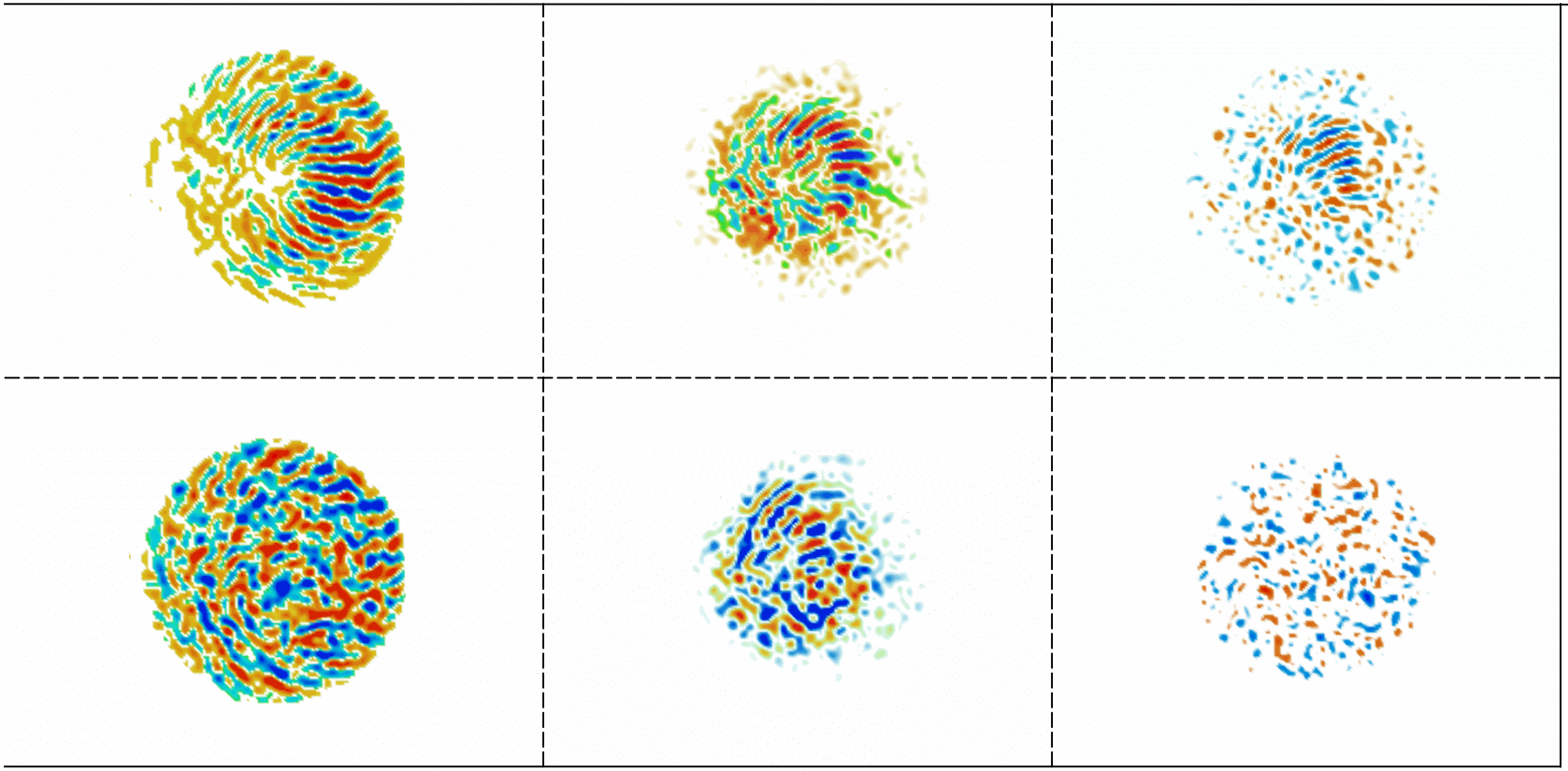
$m_i/m_e = 7370.$

$L_T/R = 0.160$

(But no density gradient)



Fluctuations Are Destroyed With Bulk Poloidal Rotation



Peak of linear phase

Nonlinear saturation

0.0 V/cm	-11. V/cm	-28. V/cm
(no rotation)	$M_\theta \sim 0.4$	$M_\theta \sim 1.0$

Cross-sections, potential fluctuations

Our Goals Are High Beta -- Rotation *Shear* may Get Us Through the Limit

For ET (A ~ 5-7), the hard beta limit may likely be dominated by **global kink instabilities**. Initial work[1] with this is confirmed and expanded here:

==> shear in poloidal rotation *CAN* destroy kinks.

But,

We are also aware that poloidal rotation at or above the poloidal Alfven speed can cause possible ideal MHD problems[2]. See 3 below for more details on this issue. However, high beta itself may cure stability beyond[4].

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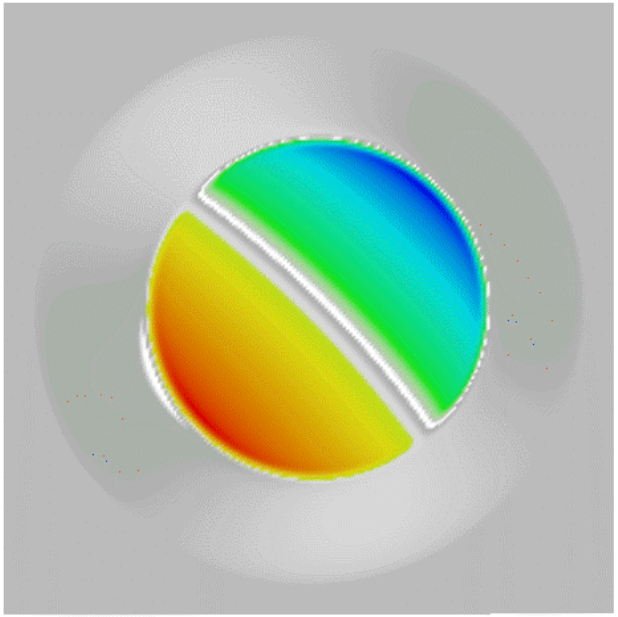
1. **"Effect of Externally Imposed and Self-Generated Flows on Turbulence and Magnetohydrodynamic Activity in Tokamak Plasmas," J.-N. Leboeuf, J.M. Dawson, V.K. Decyk, M.W. Kissick, T.L. Rhodes, and R.D. Sydora, Invited paper at the 41st Annual Meeting of the American Physical Society - Division of Plasma Physics, Seattle, WA, Nov. 15-19, 1999. To be published in May issue Physics of Plasmas.**

2. A.B. Hassam, Nuclear Fusion **36** (1996) 707.
3. "Expected Poloidal Rotation Effects in the Electric Tokamak," M.W. Kissick, J. Dawson, J.-L. Gauvreau, P.-A. Gourdain, S. Kruger, J.-N. Leboeuf, L.W. Schmitz, R. Sydora, A. Tarditi, R.J. Taylor, poster GP1.83 at the 41st Annual Meeting of the American Physical Society - Div. of Plasma Physics, Seattle, WA, Nov. 15-19, 1999.
4. S.C. Cowley, Physics of Fluids B **3** (1991) 3357.

NIMROD and Reduced FAR Produced the Same Mode with the Same Input

We produced the same global 1/1 kink mode with FAR, reduced FAR (J.A. Holmes, et al., Phys. Fluids **25** (1982) 800; E.D. Held, et al., Phys. Plasmas **6** (1999) 837.), and NIMROD (A.H. Glasser, et al., Plasma Phys. Control. Fusion **41** (1999) A747.)

Without any imposed **rotation**

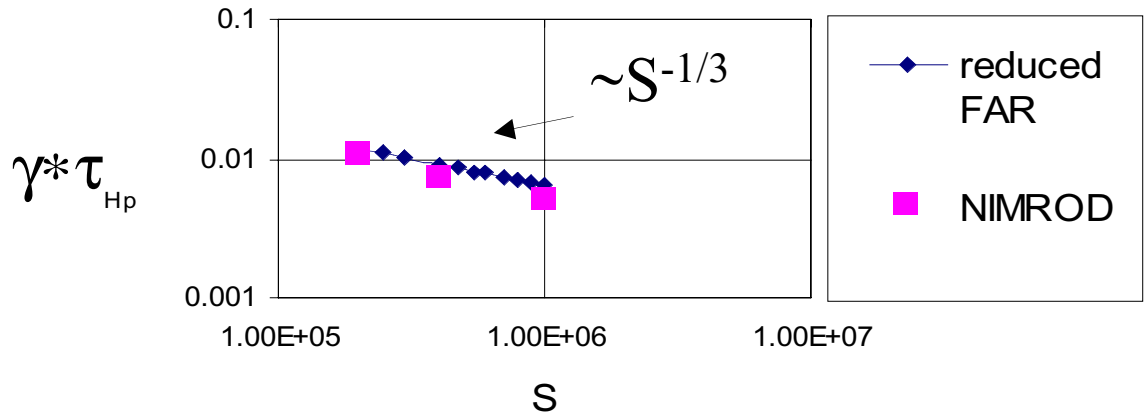


as a test mode for realistic ET parameters and poloidal rotation less than but near the poloidal sound speed.

$A = 7.1$,
$\beta_0 = 0.8\%$,
$\rho_{q=1} = 0.6$
(q_a low on purpose)

The Mode is Robust and Behaves as Expected from Theory

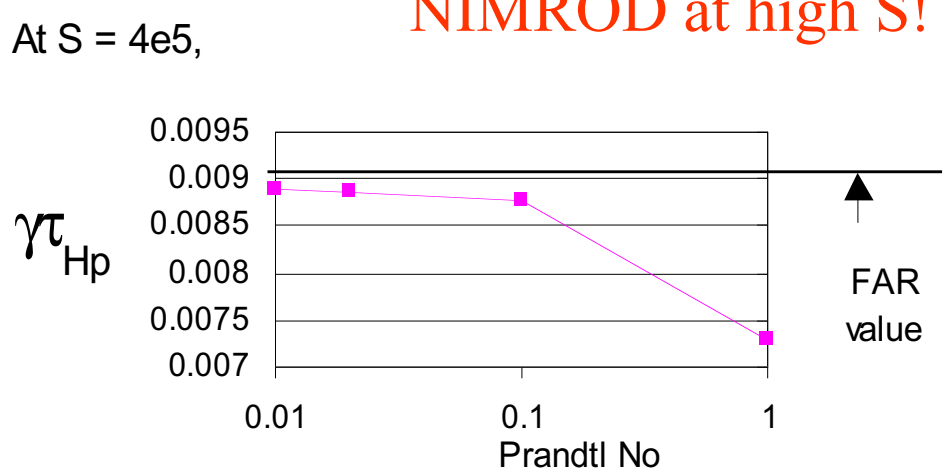
Theory* predicts the growth rate to have an $S^{-1/3}$ scaling which the codes all do see:



First use use of NIMROD at high S!

* Hastie et al., Phys. Fluids **30** (1987) 1756.

There is a viscosity knob in NIMROD which can lowered to give convergent values to Reduced FAR:



We are starting from a real mode

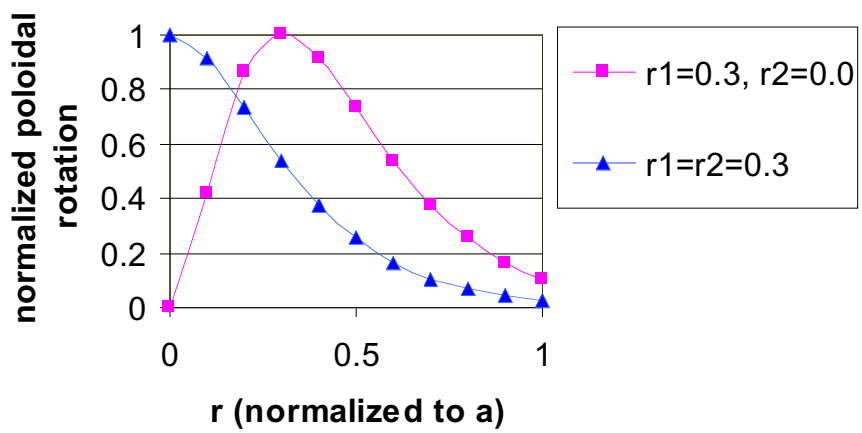
We Used a Variety of Rotation Profiles So Far

A generic poloidal rotation profile was used in reduced FAR:

$$V_\theta = \left(\frac{|r + r_2|}{r_1} \right)^2 \exp\{2 - 2|r + r_2| / r_1\}$$

2 cases correspond to parameter choices for r_1 and r_2 (normalized to a):
NOTE: if peak beyond q=1 at r=0.6, its *close* to rigid rotation - **no effect**

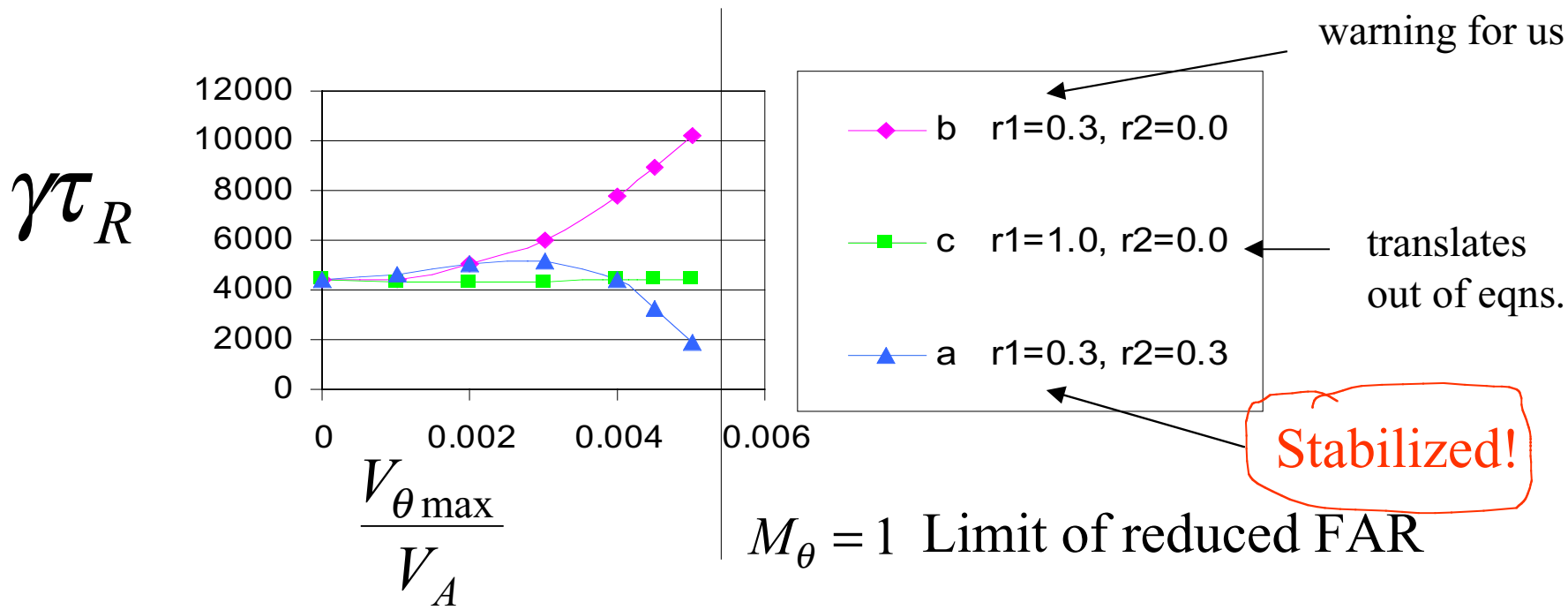
(a) peak at/near axis:
$r_1 = 0.3$; $r_2 = 0.3$
(b) peak inside q=1:
$r_1 = 0.3$; $r_2 = 0.0$
and another case is no rotation at all



The Robust Result is 3 types of Solutions For These Global Profiles

For a variety of values for r1 and r2, the solutions split into 3 types:

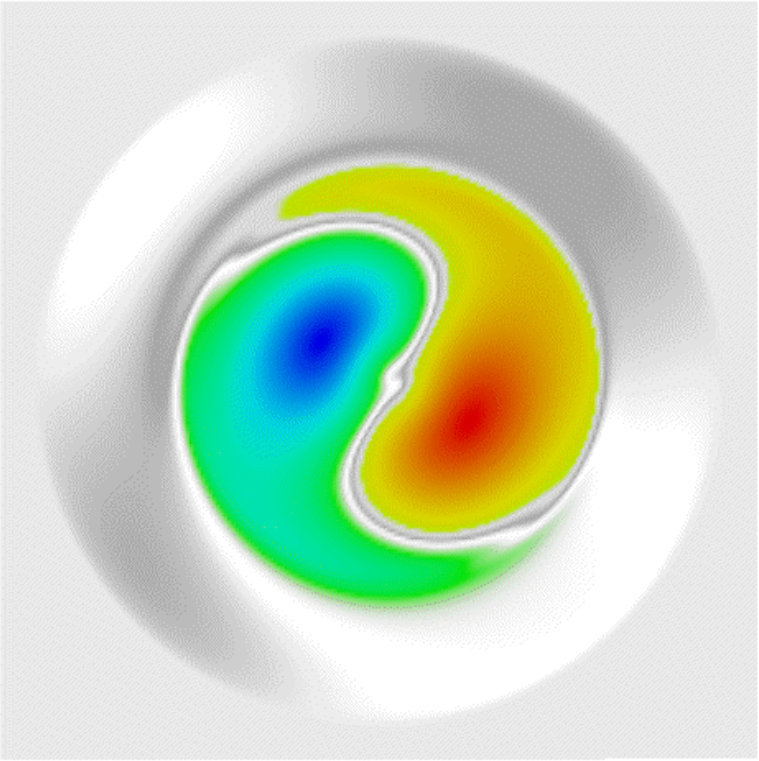
a. stabilizing mode growth for max very near or "at" core
b. enhanced mode growth for max location less than q=1 location
c. no effect for max near edge: "close" to rigid rotation: translates out



Case b: Enhanced Growth From Poloidal Rotation

Case b: rotation max between axis and q=1

Here the mode growth is enhanced by rotation itself.



Shear effects are weak here and the Kelvin-Helmhotz term had little effect.

The mode just lives and grows at the place where shear is lowest and rotation is maximum.

Case b: Enhancement Likely Caused by Centripetal Energy

From Hastie et al., the growth rate of the mode goes like beta to m~2:

$\gamma_{\text{mode}} \sim \beta^m$ But for low beta: $\gamma_{\text{mode}} \sim \beta$

The rotation acts like an effective pressure OR weakened B_{pol}:

Consider the zeroth order reduced MHD momentum equation in r-direction:

$$\frac{V_\theta^2}{r}\rho_0 = \nabla_r\left(p_0 + \frac{B_0^2}{2}\right) + \frac{B_{pol}^2}{r}$$

There is a similar expression for the R-direction which shows that toroidal rotation acts to decrease the confinement of B_{tor}

Case b: We can think of this Centripetal Energy as an Effective Beta for THIS Mode

The mode is then excited by the velocity *relative to the outer plasma* as if it was a pressure, leading conceptually to an effective beta:

$$\beta_{eff} \approx \left[p_0 + \left(B_0 / B_{pol} \right)^2 \rho_0 V_\theta^2 / 2 \right] \frac{2}{B_0^2}$$

For just poloidal: similar for toroidal except $B_{tor} \sim B_0$

It is consistent with when this effect starts, in the range: $\frac{V_\theta}{V_A} = 0.004$

We have $\beta_{eff} \approx 0.008 + 0.0016$ Where the input beta is 0.8%

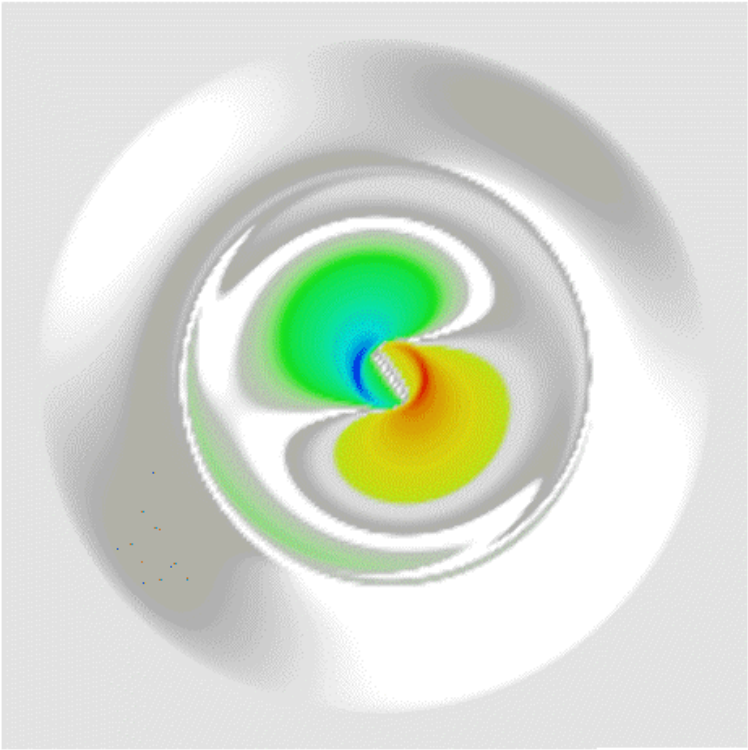
Poloidal Rotation is B_{tor} / B_{pol} more effective than toroidal at doing this!

Case a: Mode Can be Stabilized if Enough Shear, Centripetal Effect Weak

The mode is sheared apart!

Enough rotational shear can decorrelate this mode

Case a: the rotation max right "at" the axis (like a galaxy!)



The Kelvin-Helmhotz term did have a few percent effect on the growth rate.

Case a: The Shearing Rate Becomes Important if Larger Than Growth Rate

For this situation, we expect shearing to become important when:

$$\langle r\omega' \rangle \equiv \frac{2}{a^2} \int_0^{r_{q=1}} \left(r \frac{d\omega}{dr}\right) r dr > \gamma_{\text{mode}} \Big|_{V_\theta = 0}$$

After some algebra for this velocity profile, the above becomes:

$$\frac{V_{\theta\,\max}}{V_A} > 0.004$$

Which is about where the growth reduction is !

Before that point, it suffers from centripetal energy as well as case b

This is Part of a Series of Studies to Help Predict the Effects of Various *Poloidal* Rotation Profiles

Transport (ion heat):

-- rotational shear is good

-- supersonic bulk is good

MHD Stability (kinks):

-- rotational shear is good

-- bulk is,

- good, if conducting wall
- bad, from centripetal energy

Equilibrium:

-- bulk is bad IF rotation at poloidal Alfven speed, otherwise its fine

Other effects to explore:
high beta,
toroidal rotation,
shaping

==> This will help us design rotation profile control

Conclusions

Transport *on ET is likely to only further improve with poloidal rotation: shear AND bulk!*

Stability *to kink modes can be improved with poloidal rotation shear, but this requires care to avoid centripetal energy drive terms.*

Future work*: look at the effects of plasma shaping, and toroidal rotation and its shear, high beta, extrapolate to external modes.*