Gyrofluid (GF) / Gyrokinetic (GK) Discrepancy Issues

11/18/97

Greg Hammett
Mike Beer (See Poster P2-14, Wed. Afternoon).
Bill Dorland, et. al.

* Initially thought particle noise/filtering were reasonable candidates for explaining particle/fluid differences.

* A few more, previously agreed upon, tests remain to be done, but evidence is building that noise/filtering not as important as we thought.

* In some cases, appears that GF code not fully converged at high $k_\perp$: Factor of 1.5 in χ in some cases.
  Only 10-20% in others?

* $\chi_{GF} \sim 2-3\ \chi_{GK}$

  Larger near marginal stability,
  GF + GK agree better far from marginal stability.

  ITER predictions at $T_{ped} = 1.5$ keV, $n_e = 1.3 * 10^{14} = 1.5 *$ Greenwald limit

  GF/IFS-PPPL $Q \sim 2$
  Rough GK Fit $Q \sim 6$

Postscript:

A few days after this talk was given, Andris Dimits showed additional new results. It appears that his particle code has successfully met the main remaining noise tests.

Thus, some of the statements I made in this talk are now out of date. But, to maintain a record of the discussion, I've left all of the vugraphs here unchanged.

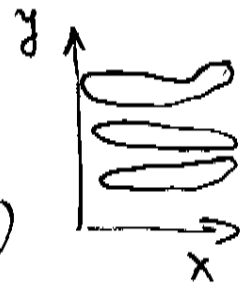
Noise May ↑ or ↓ Simulation χ

$$\chi_{sim} = \chi_{turb} + \chi_{noise}$$

Noise may ↓ turbulence more than it contributes to radial heat flux.

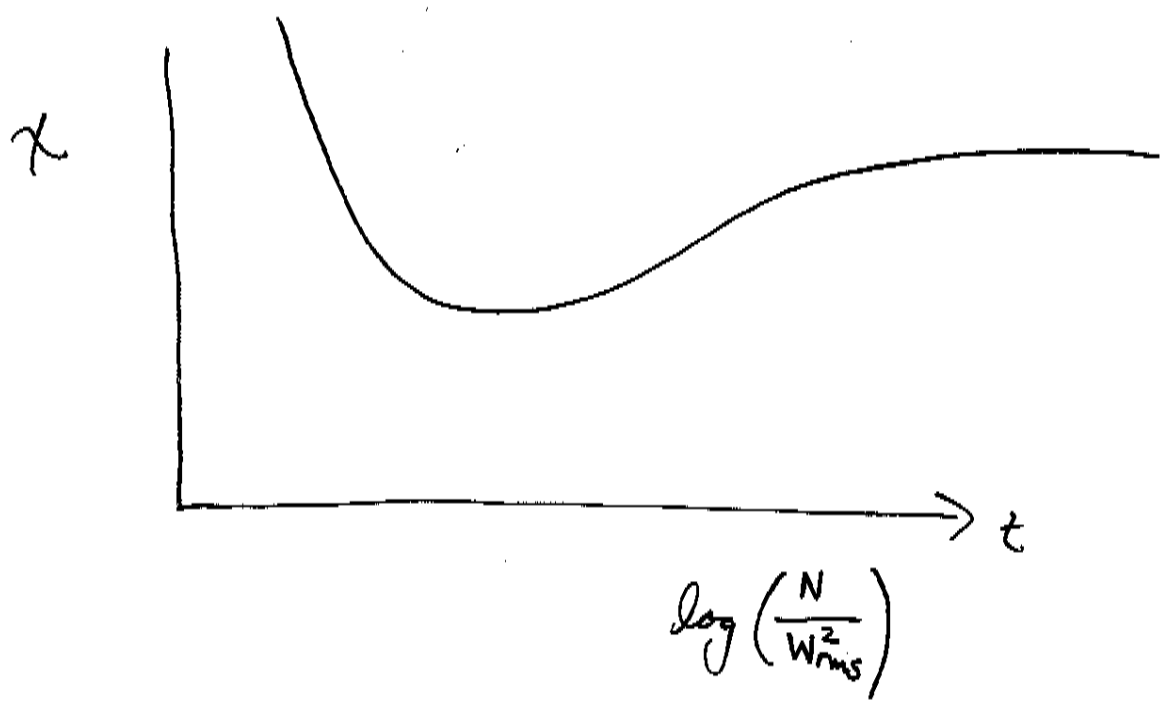
Example: 1. Turbulence elongated radially

Noise is isotropic, can be effective at D_y (break up eddies)



2. Noise in poloidal flow modes ⇒ 0 radial transport but does shear apart eddies.

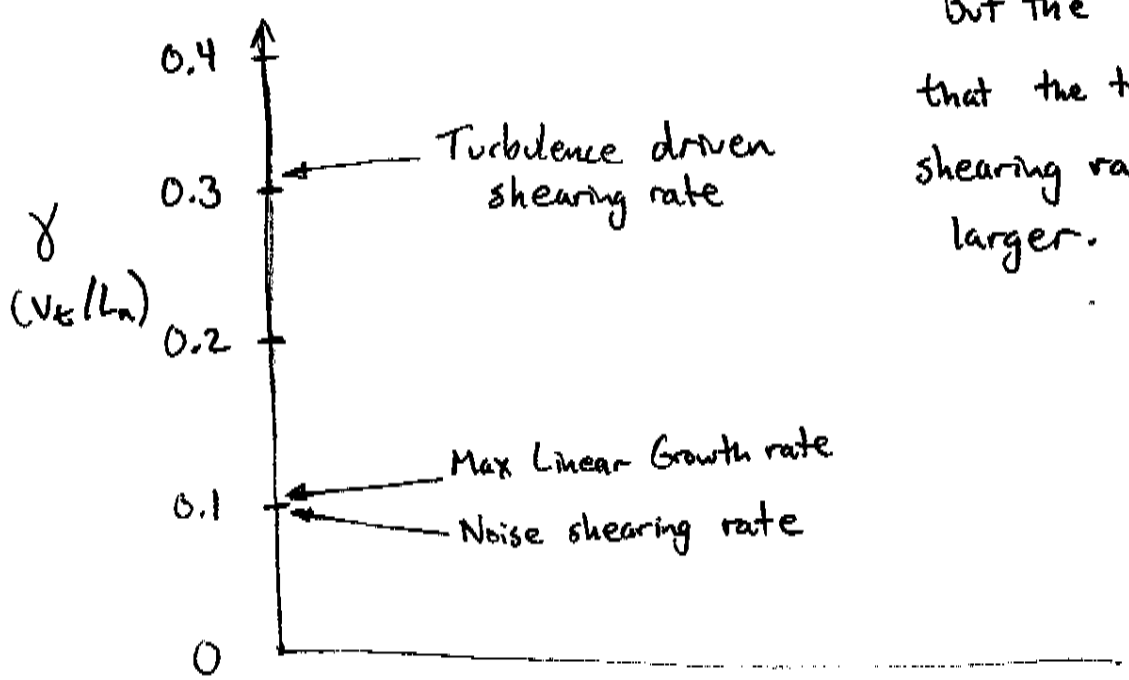
Convergence with N <u>might</u> be non-monotonic?



Puzzle of Noise in Sheared Poloidal Flows Resolved?

Last spring, Kotschenreuther & Dorland estimated that the shearing rate in the poloidal flow noise was comparable to the linear growth rate.
(Thus the worry that particle codes might not be adequately resolved.)

Dimits has now done some of the tests of scrambling particle positions, & found this was indeed true.



But the surprise was that the turbulence-driven shearing rate was even larger.

What no one thought of until after seeing Dimits scrambling tests, is that the dominant contribution to shearing in the noise (& in the turbulence) is at high k_r.

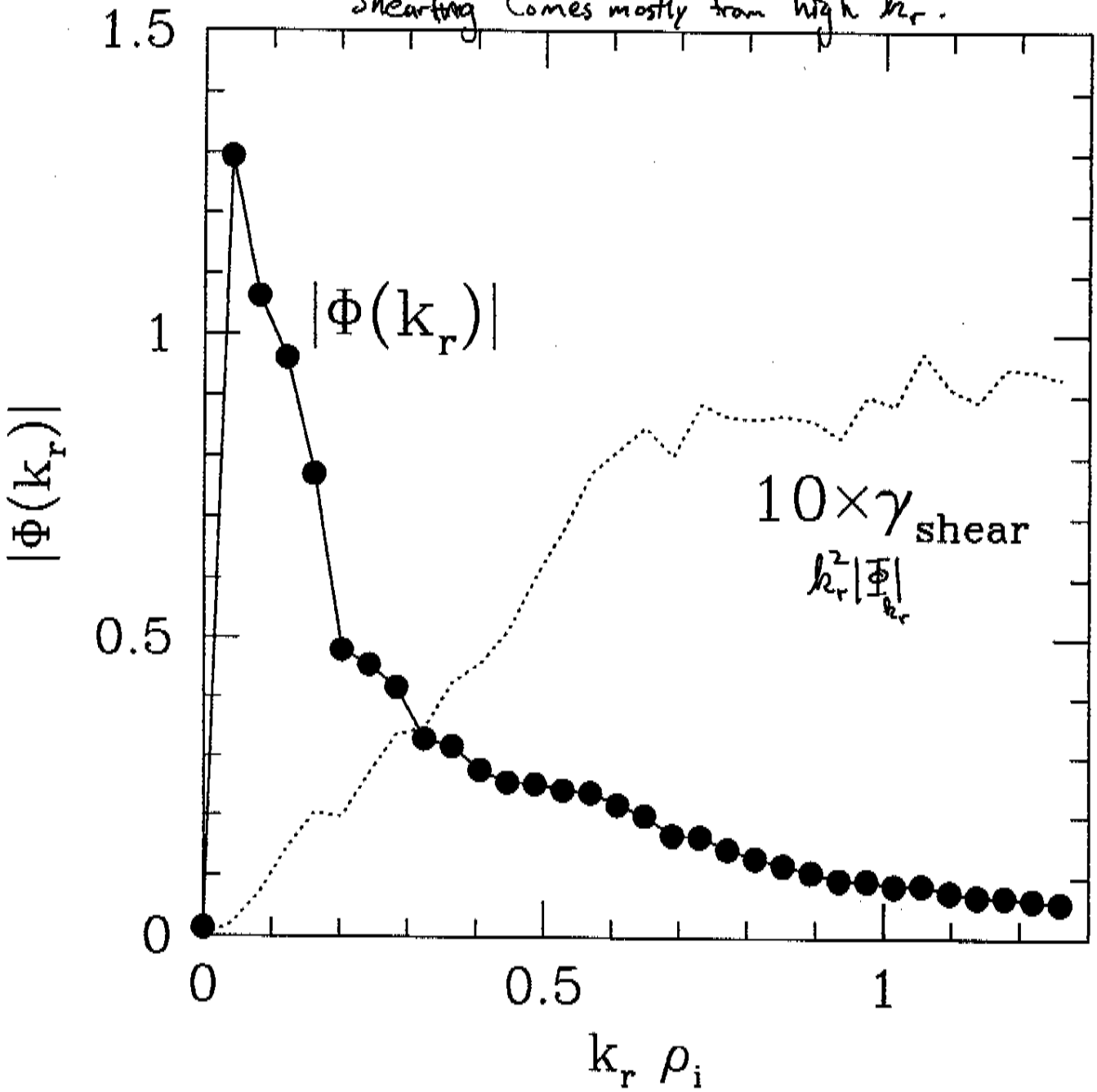
Despite $k_y = k_\parallel = 0$ $(\omega_* = 0)$, high k_r noise will fluctuate in time $\left(\tau_c \sim \frac{1}{|\omega_d|} \sim \frac{1}{V_d |k_r|}\right)$ more quickly than the longer wavelength turbulence.

- Noise starts to shear apart eddies, but then noise reverses sign & <u>unshears</u> the eddies.

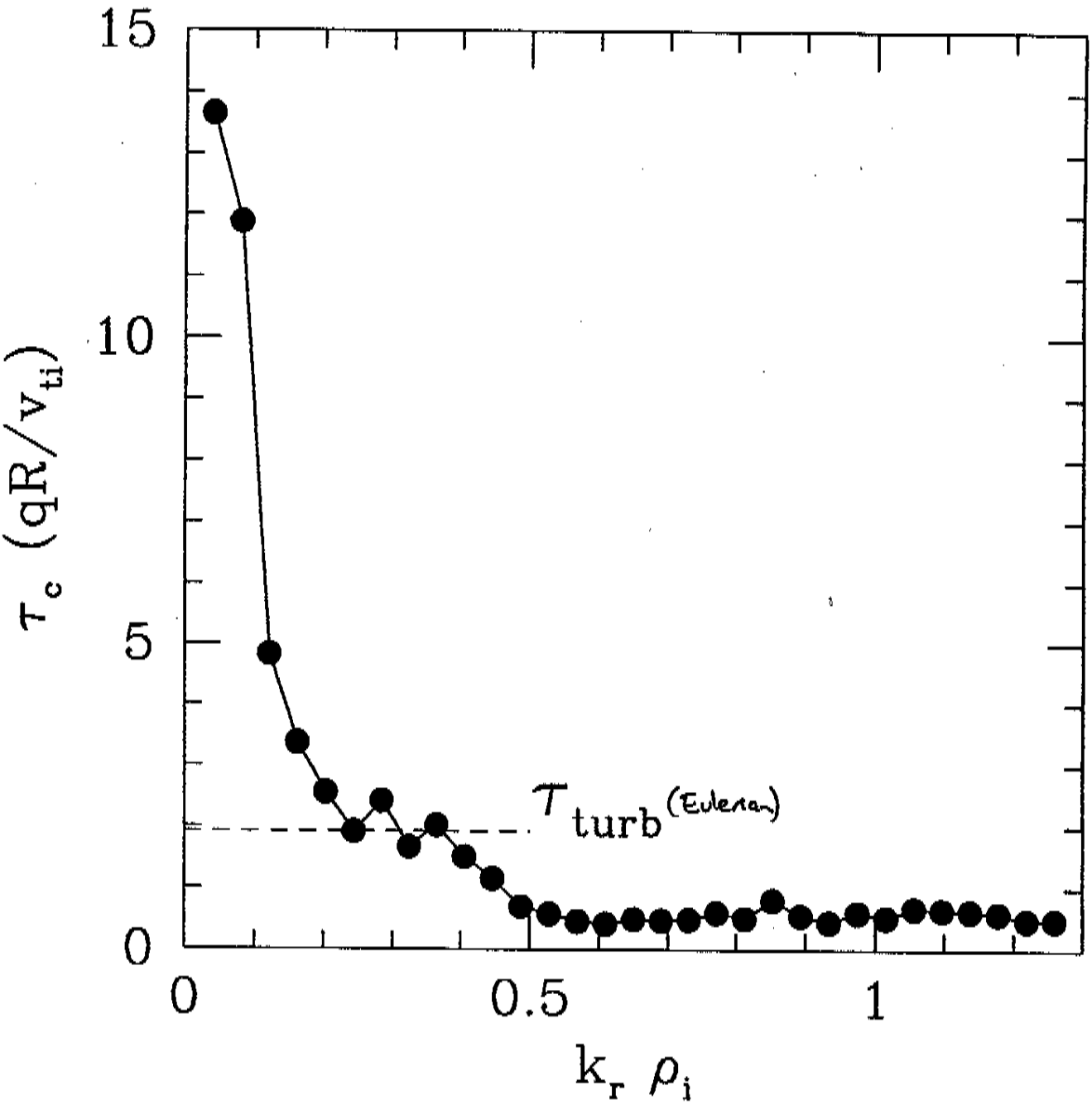
(Shearing rate concept works best for
lower-k slower modes shearing apart
higher-k faster modes.)

Radial Mode Spectrum from Gyrofluid Simulation

"Shearing" Comes mostly from high k_r.



(M. Beer, et.al)



M. Beer et. al.

Evidence building that Particle noise is not a problem, but...

* Dimits has now varied N over a very wide range (0.5-32 M) & if there was a problem would have expected to see it by now. (Sydora N scan shows some similar features.)

* Dimits scrambling test shows poloidal flow noise is small compared to turbulence level.

* But this was at $\frac{r}{R}=0$, $\nabla T_0 = \nabla n_0 = 0$.

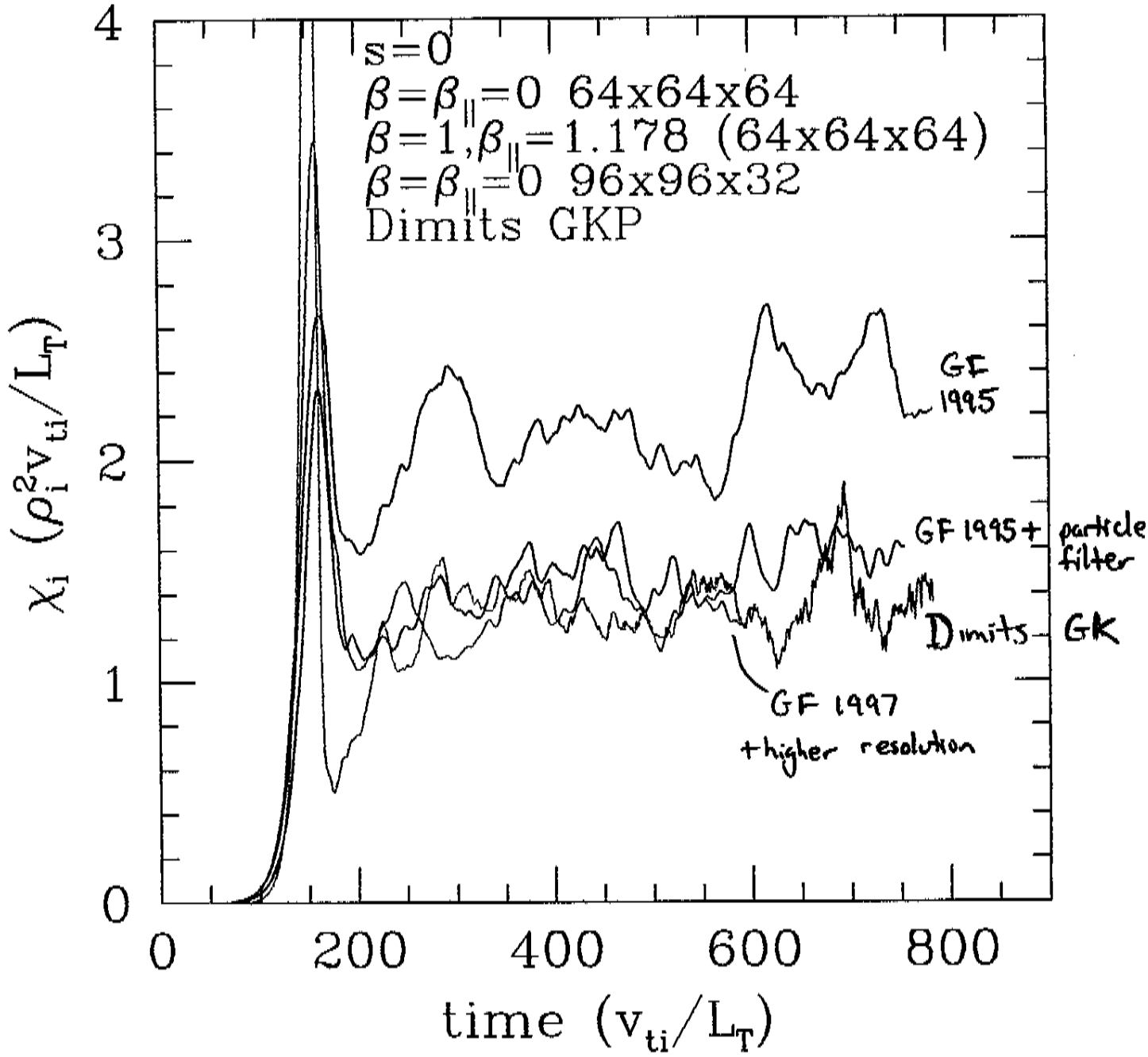
Redo with $\nabla n_0 \neq 0$ $\nabla T_0 \neq 0$ (but $\nabla T_0 \downarrow$ linear instability)

* Look for possible reduction in dielectric shielding of noise by ∇n_0 + ∇T_0 (Nevins + Chen, Phys. Fl. 23, 1973 (1980)).

* Measure χ due to noise in all modes, besides $m=n=0$ modes

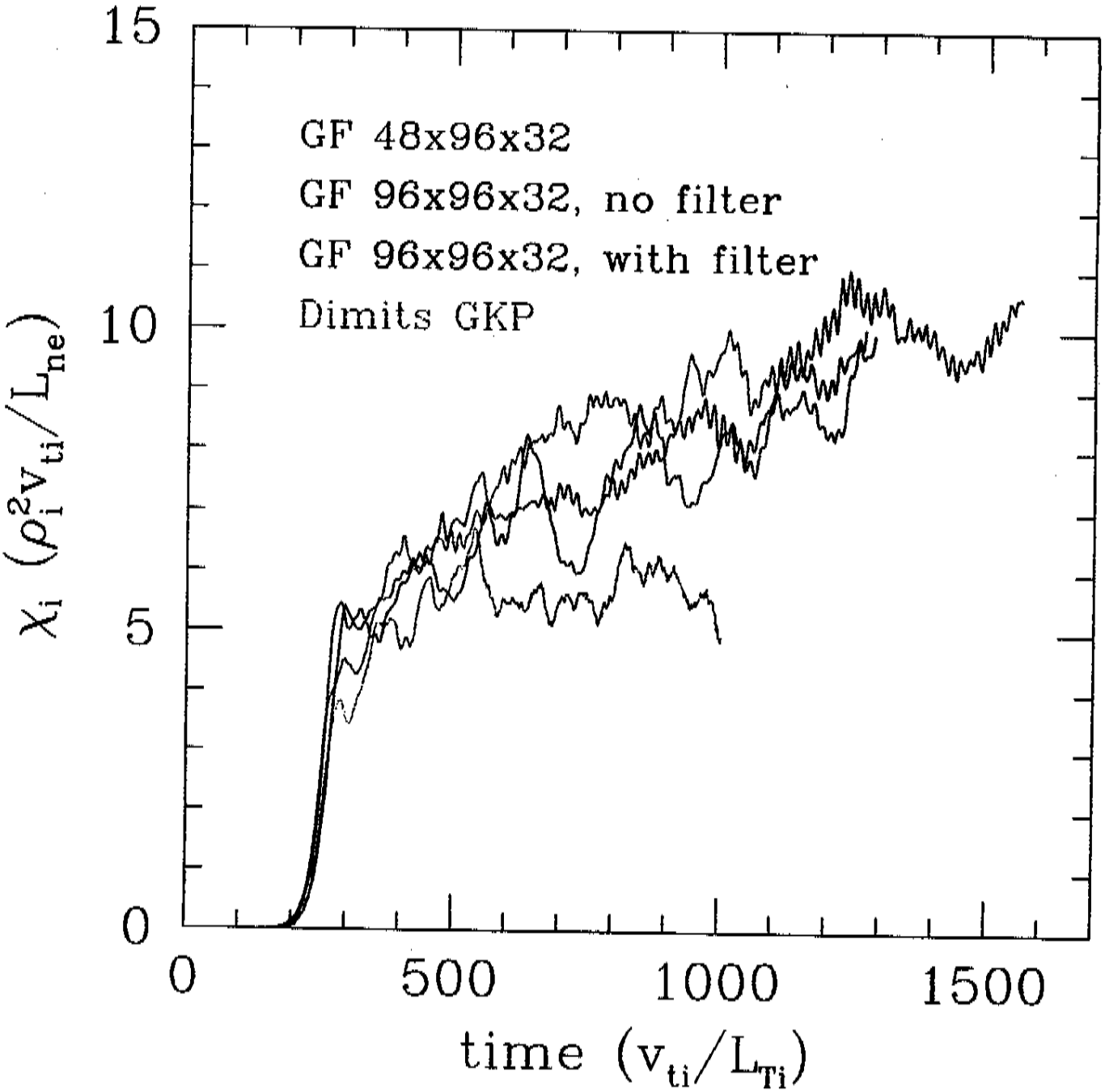
* Will try a method by Hinton (Phys. Fluids 13, 857 (1970)) to inject noise into a nonlinear gyrofluid simulation to look for possible amplification of noise. (reduction in dielectric shielding).

NTP Test case, but $\hat{s} = 0$



In this case, GF resolution at high $k_\perp$ was apparently inadequate, accounts for factor of 65 difference.

NTP test case, $\hat{s} = 1.5$



In other cases, ↑ GF resolution has little effect

(but perhaps even more resolution is needed?)

Particle codes might be right, for the present collisionless regime with adiabatic electrons.

But additional physics may cause GK χ to $\uparrow$ to be closer to the GF/IFS-PPPL χ.

1) Weak collisions (smooths out small scale features in $f(v)$)

2) Trapped electron drive $\rightarrow$ push turbulence deeper into strong-turbulence regime where GF/GK comparisons better?

3) Larger simulation boxes $\rightarrow$ more modes at low $k_\perp$
$\rightarrow$ more turbulent?

4) Some other missing physics? (electromagnetic, ...?)

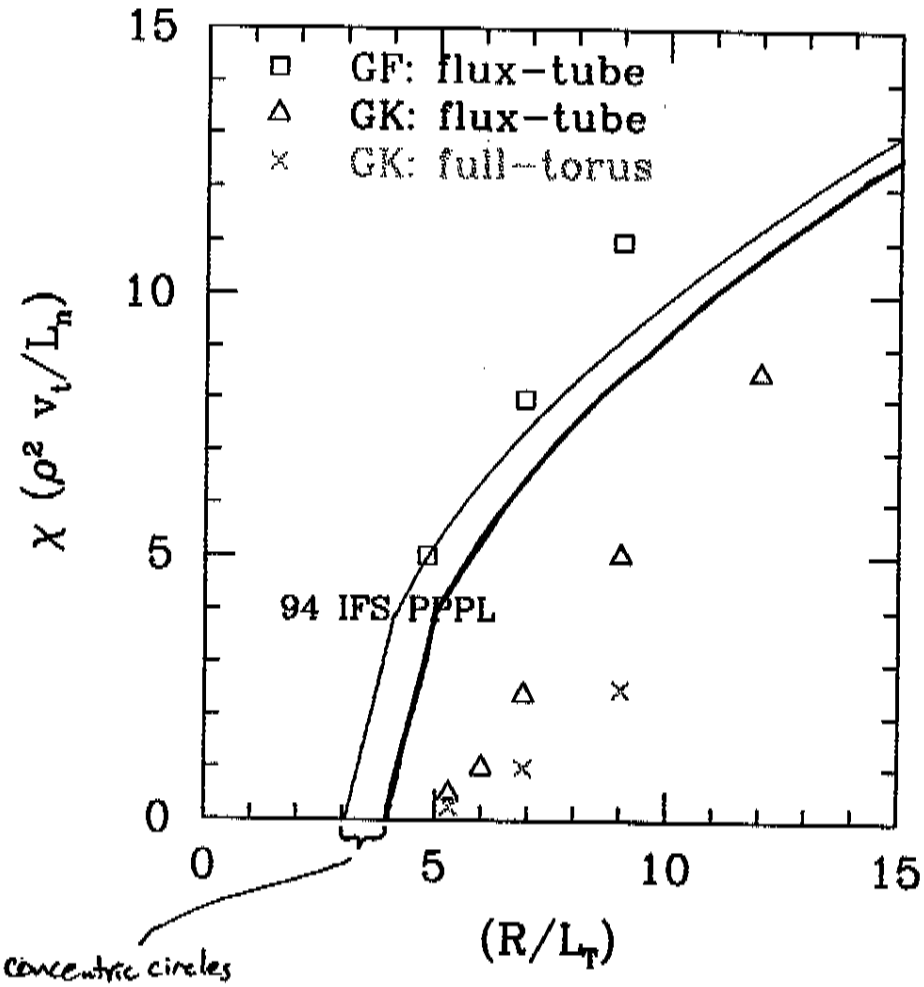
If χ is lowered too much, while it gives more favorable predictions for ITER, it would not match present experiments as well

IFS-PPL χ focused on ITG (+ some trapped electron) drive.
Acknowledged other drives needed for a more complete model.
(Waltz's GLF model is a step in the right direction.)

IFS-PPL χ + ExB shear consistent with many experimental trends: improved performance with T_i/T_e, density peaking, hot edge temperatures, rotation scans, isotope scaling, etc. (see D. Ernst, We p 01 2) profile resiliency, fast perturbations, ...

Several methods of turbulence suppression in tokamaks discovered in past few years.
Unified theoretical picture beginning to emerge.
Can we develop a strong enough quantitative understanding to develop an improved/advanced tokamak design for ITER?

Comparison of Nonlinear Simulations: R/L_T Scan



Simple concentric circles vs. full circular geometry.

- Differences in predictions evident
- IFS/PPPL agrees reasonably well with GF simulations.

Cyclone

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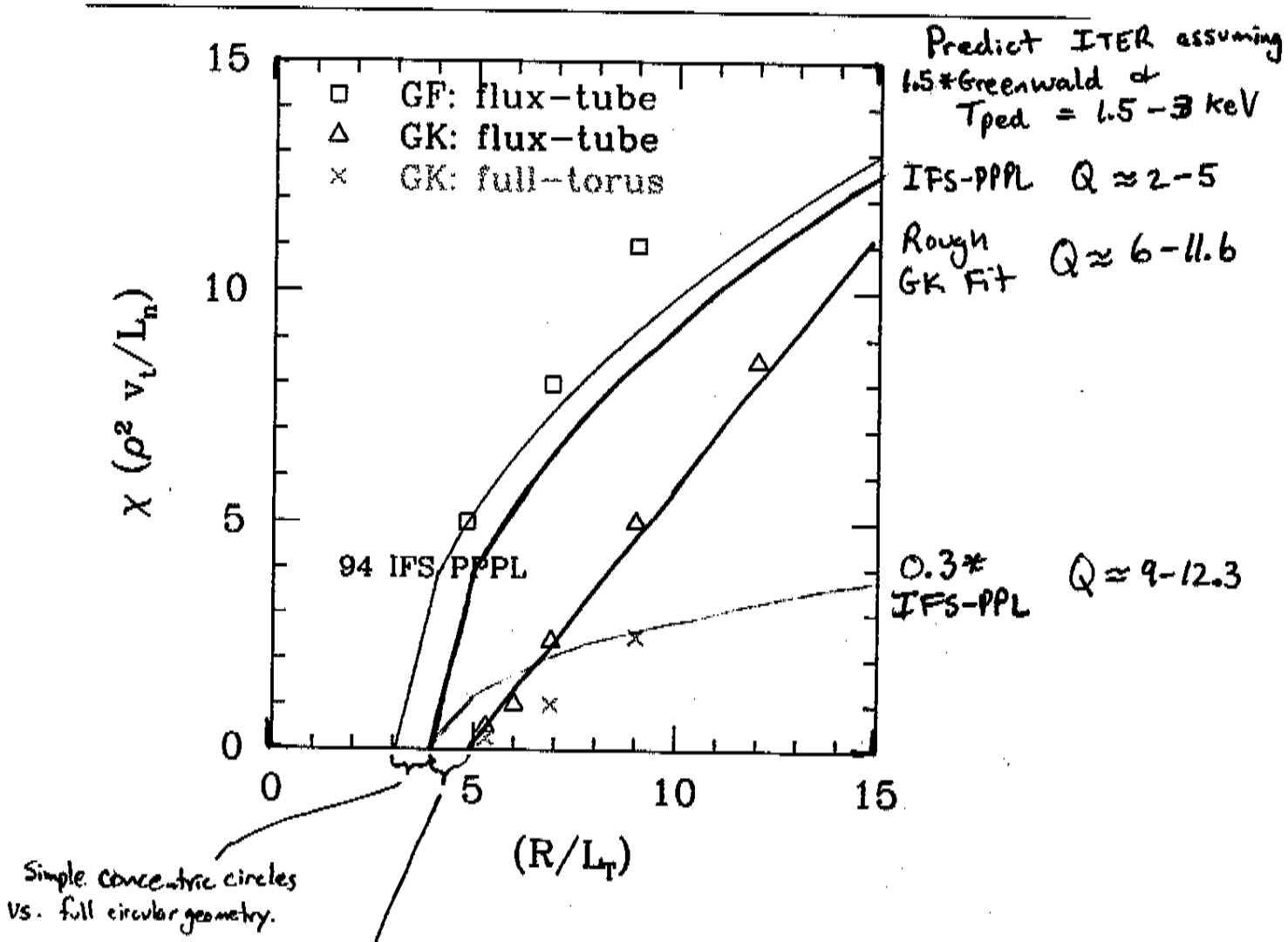

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GK code sees 25% nonlinear upshift in effective critical gradient in some cases.

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ITER Sensitivity Study

$$\chi_{IFS\text{-}PPL} = \frac{cT}{eB}\frac{\rho}{R}\,\mathrm{Min}\left(\frac{R}{L_T} - \frac{R}{L_{Tcrit}}, \sqrt{\frac{R}{L_T} - \frac{R}{L_{Tcrit}}}\right) g\left(q, \hat{s}, \frac{T_i}{T_e}, \ldots\right)$$

Rough GK fit:

$$\chi_{GK} = \frac{cT}{eB}\frac{\rho}{R}\,\mathrm{Min}\left[0.28\left(\frac{R}{L_T} - 1.25 * \frac{R}{L_{Tcrit}}\right), \sqrt{\frac{R}{L_T} - 1.25 * \frac{R}{L_{Tcrit}}}\right] g\left(q, \hat{s}, \frac{T_i}{T_e}, \ldots\right)$$

Linear with reduced slope

Critical gradient upshift

ITER prediction (with various standard assumptions) ← assume:

$T_{ped} = 1.5 - 3$ keV

$Q \approx 2 - 5$

IFS-PPPL
$n_e = 1.3 * 10^{20}/m^3$
$= 1.5 *$ Greenwald

Switch to χ_{GK} for remaining predictions.

$Q \approx 6 - 11.6$ χ_{GK} $n_e = 1.3 * 10^{20}/m^3$

$Q \approx 3.7 - 6.7$ ↓ n_e to $0.97 * 10^{20}/m^3$

$Q \approx 5 - 8.6$

with modest density peaking
$n_{e0} = 1.2 * 10^{20}/m^3$
$n_{eped} = 0.5 * 10^{20}/m^3$
$(\text{parabolic})^{0.5}$

ITER Performance might be improved with:
(or smaller better redesign of ITER might be possible)

(*) Advanced Tokamak techniques, reverse shear, shaping?
(example: high β spherical tokamaks? Dorland invited talk Thurs A.M.)

(*) Pellet injection?

(*) Beam or IBW- driven shear flows?

Low voltage beams (~100 keV) don't penetrate far,
but might give edge shear-flow barrier?
(Torque / Power $\propto 1/\sqrt{V_{beam}}$)

(*) Unknown physics?
T_{ped} high? (Scaling uncertain?)
Alcator C-Mod has strong rotation w/ ICRF + H-mode!

Radiating mantles?