**Session C10 - Advances in Magnetic Confinement Fusion.**
*ORAL session, Saturday afternoon, April 05*
*Washington B, Loews Philadelphia Hotel* **[C10.009]**

# High Speed Imaging of Edge Turbulence in Magnetic Fusion Plasmas

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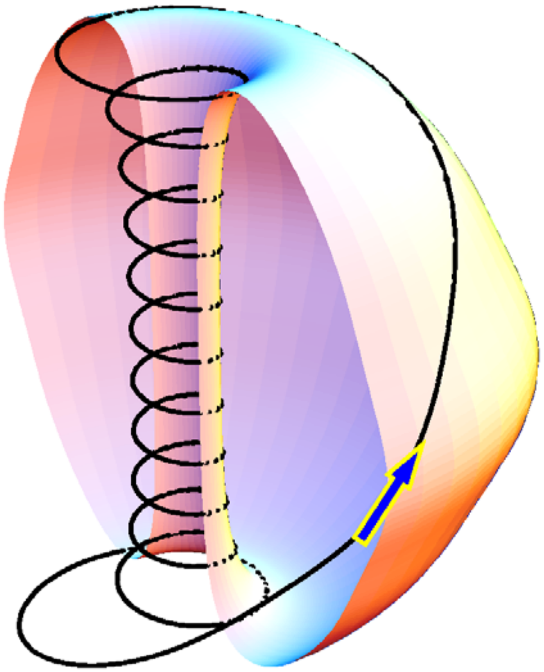
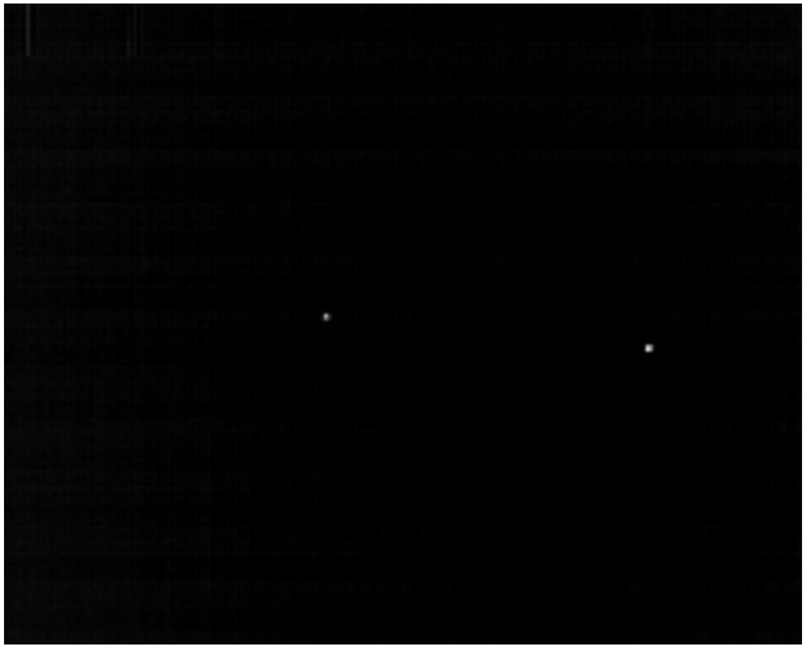
# Images of NSTX Spherical Torus



1000 frames/sec @ 10 μsec exposure / frame



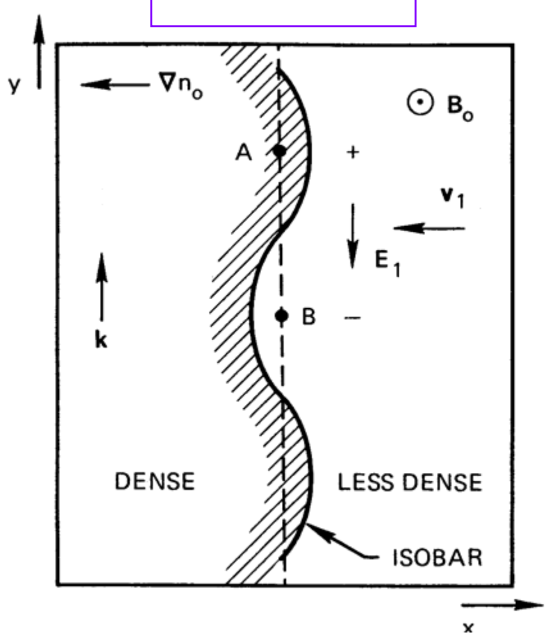
Visible line emission only from “cold” edge at T ≤ 50 eV

Plasma in core emits thermal x-rays at T ≥ 1 keV

# What Causes Plasma Turbulence ?

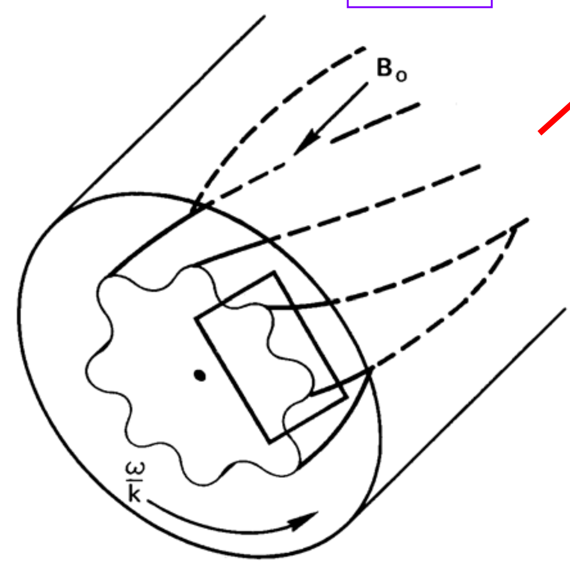
- Large density or temperature gradient across B (≈ $10^5$ $^0$K/cm)
- Linear "drift wave" instability grows with $\lambda \approx 10\rho_i$ at $\gamma \approx 10^6$/sec
- Fast electron motion along B makes spatial structure ≈ 2-D

2-D ⊥ B




3-D

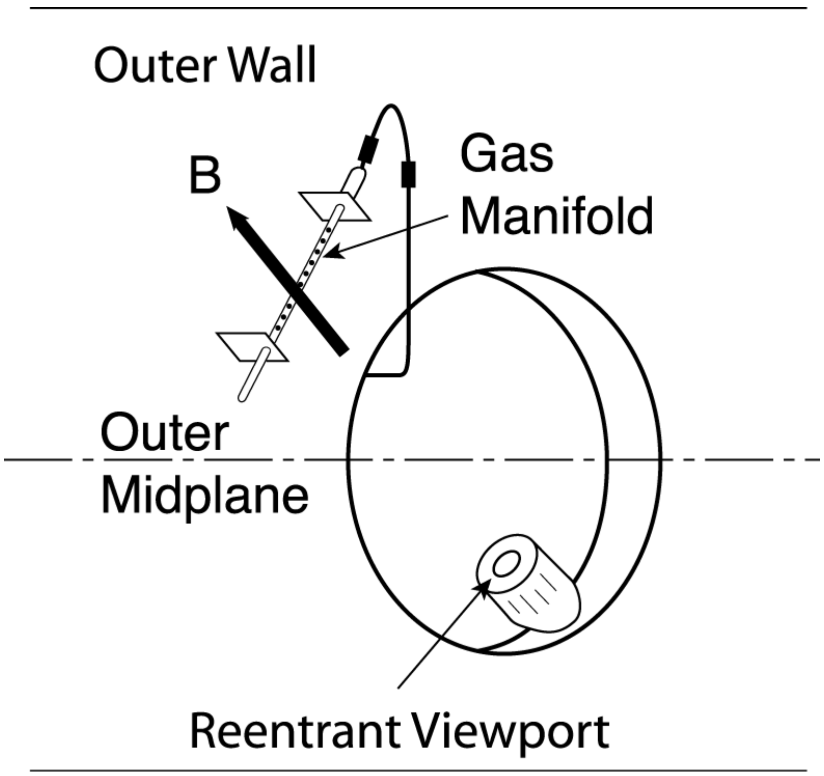
B

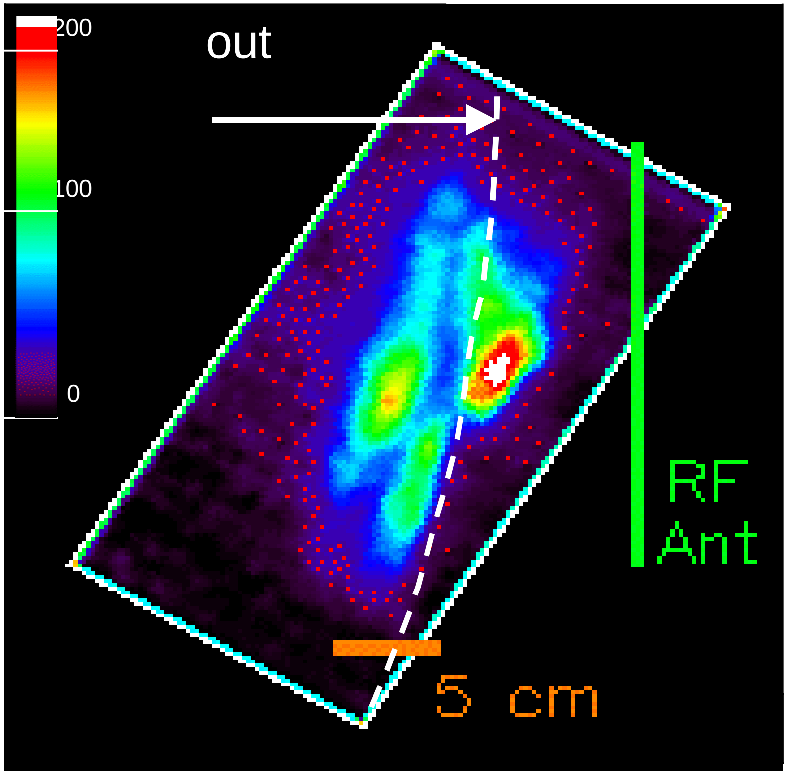



[Chen, Plasma Physics, 1984]

# A Closer Look at NSTX

- Look at He1(587.6 nm) light from neutral gas puff $\propto n_e$
- View along B field line to see 2-D structure $\perp$ B



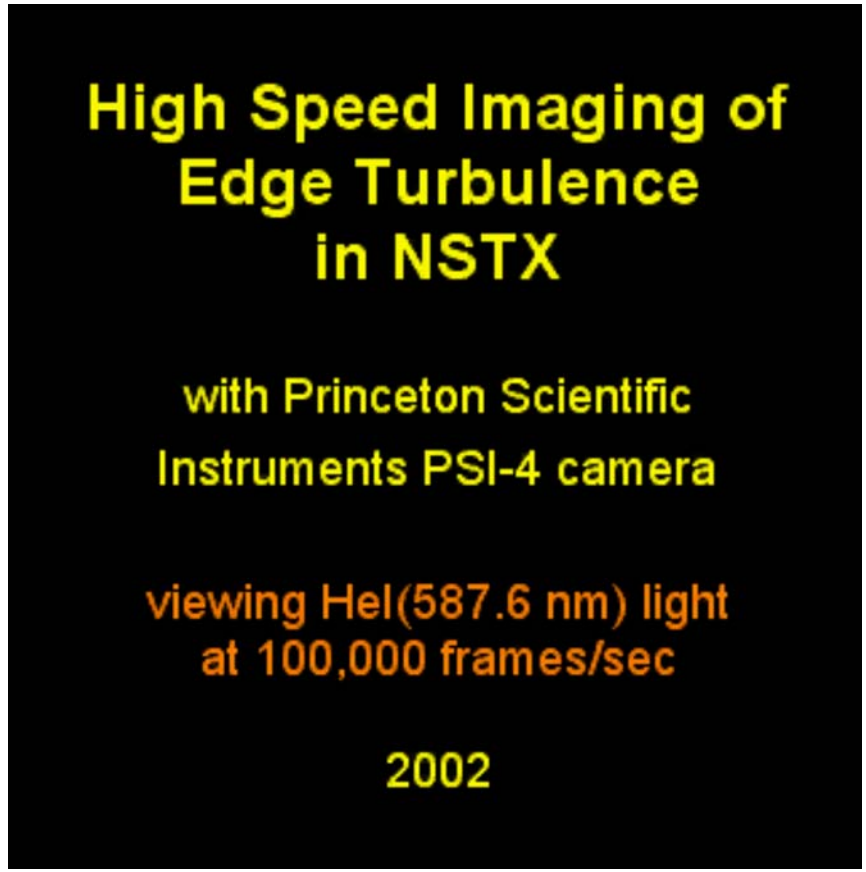



# High Speed Imaging of NSTX Edge

[camera obtained from Princeton Scientific Instruments, NJ]

CCD camera with
100,000 frames/sec
at 10 μsec/frame
for 28 frames/shot

localized structures
move outward
at ≈ $10^5$ cm/sec



# Simulation of Plasma Turbulence

- Use 2-fluid equations in 3-D geometry
- Assume initial conditions and evolve

$$\hat{\alpha}[\partial_t\tilde{\psi} + \alpha_d\partial_y\tilde{\psi}(1 + 1.71\eta_e)] - \nabla_\parallel[\tilde{\phi} - \alpha_d(\tilde{p}_e + 0.71\tilde{T}_e)] = \tilde{J}, \qquad \delta B \quad (1)$$

$$\nabla_\perp \cdot d_t\nabla_\perp(\tilde{\phi} + \tau\alpha_d\tilde{p}_i) + \hat{C}(\tilde{p} + \tilde{G}) - \nabla_\parallel\tilde{J} = 0, \qquad \delta E \quad (2)$$

$$d_t\tilde{n} + \partial_y\tilde{\phi} = \tilde{F}, \qquad \tilde{F} = \epsilon_n\hat{C}(\tilde{\phi} - \alpha_d\tilde{p}_e) - \epsilon_v\nabla_\parallel\tilde{v}_\parallel + \alpha_d\epsilon_n(1 + \tau)\nabla_\parallel\tilde{J}, \qquad \delta n \quad (3)$$

$$d_t\tilde{T}_i + \eta_i\partial_y\tilde{\phi} = \frac{2}{3}[\tilde{F} + \frac{5}{2}\epsilon_n\tau\alpha_d\hat{C}\tilde{T}_i + \kappa_i\nabla_\parallel(\nabla_\parallel\tilde{T}_i + \hat{\alpha}\eta_i\partial_y\tilde{\psi})], \qquad \delta T_i \quad (4)$$

$$d_t\tilde{T}_e + \eta_e\partial_y\tilde{\phi} = \frac{2}{3}[\tilde{F} - \frac{5}{2}\epsilon_n\alpha_d\hat{C}\tilde{T}_e + 0.71\alpha_d\epsilon_n(1 + \tau)\nabla_\parallel J + \kappa_e\nabla_\parallel(\nabla_\parallel\tilde{T}_e + \hat{\alpha}\eta_e\partial_y\tilde{\psi})], \qquad \delta T_e \quad (5)$$

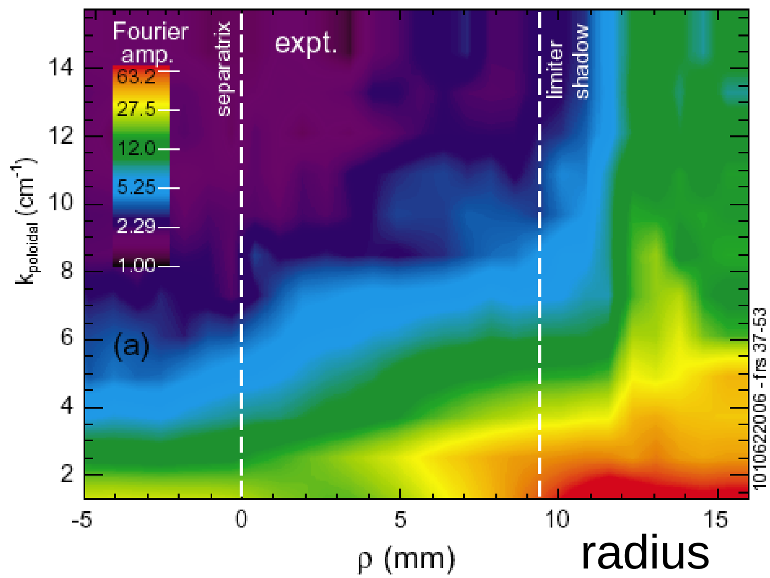
$$d_t\tilde{v}_\parallel = -\epsilon_v[\nabla_\parallel(\tilde{p} + 4\tilde{G}) + (2\pi)^2\alpha\partial_y\tilde{\psi}], \qquad \delta v_{\parallel} \quad (6)$$


[Rogers, Drake, and Zeiler, PRL ‘98]

# Experiment vs. Simulation

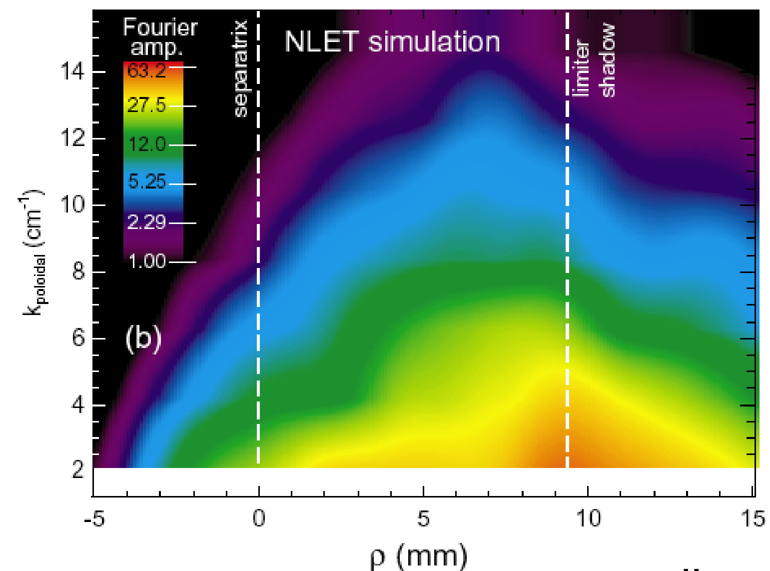
- Compare turbulence size ($k=2\pi/\lambda$) spectrum vs. plasma radius in Alcator C-Mod tokamak at MIT

k ($cm^{-1}$) Experiment




radius

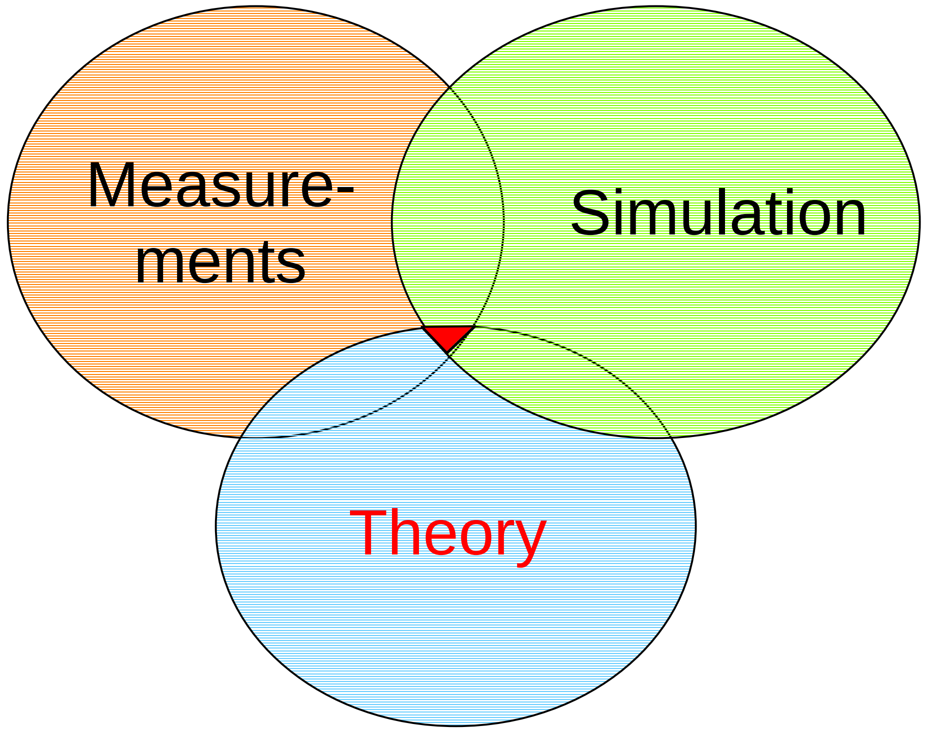
k ($cm^{-1}$) Simulation




radius

***=> simulation reproduces average size scale to within x2***

# Where are We Going ?




⇒ ***Increase red area to explain existing experiments***

⇒ ***Determine optimum magnetic confinement system***