SOL Transport Theory and Modeling

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Motivations for studying edge/SOL turbulence and radial transport

- determines the radial particle and power fluxes across SOL to the wall
  - impacts global confinement, particle inventory, impurities
  - degrades the divertor efficiency
- may provide robust mechanism for the density limit
- may influence L-H transition
- may affect RF coupling and antenna-plasma interactions
- physics (turbulence, shear flows, convection) is generic to all confinement devices where the SOL plasma is subject to external forces (toroidal drifts, centrifugal acceleration)

Our proposed work for FY 2003 involves a comparison of NSTX SOL turbulence data with models of SOL convective transport (e.g. blob model).

Experiments and simulations motivate the blob model

● growing body of experimental & computational evidence that intermittent radial transport in the SOL can be explained by coherent, propagating structures (“blobs”).

- particle fueling in C-MOD is dominated by wall (not divertor) recycling
- observed SOL density profiles are non-diffusive in the far SOL (C-MOD, DIII-D, AUG)

  $\Rightarrow$ importance of convective transport in far SOL
- diagnostic imaging and probe data on NSTX, C-MOD, DIII-D & PISCES + turbulence simulations $\Rightarrow$
  - o intermittent SOL turbulence
  - o coherent structures (radial streamers, blobs)

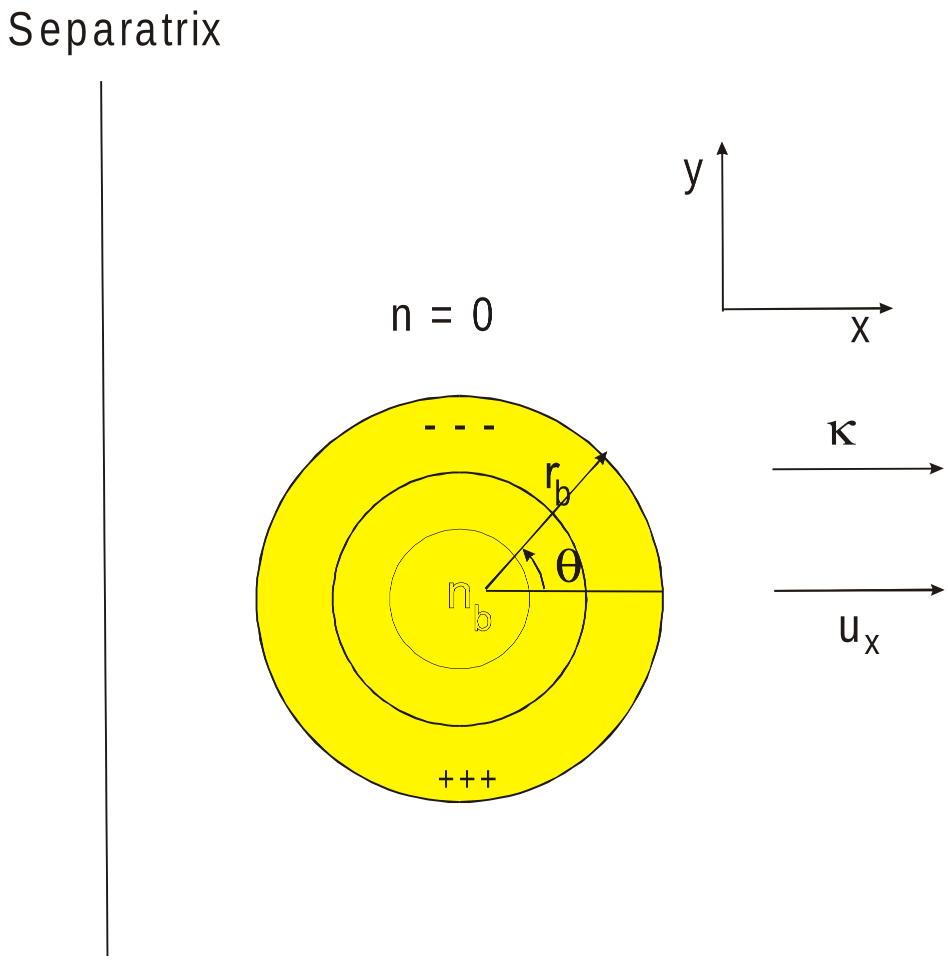
● simple theoretical models of blob propagation and decay exhibit some of the qualitative features seen in the experiments.

Krasheninnikov, Phys. Lett. A**, 283**, 368 (2001)

D’Ippolito, Myra, Krasheninnikov, Phys. Plasmas **9**, 222 (2002)

Physics of blob propagation

- density blobs propagate radially because of curvature drift + sheath resistivity (*small vorticity limit*)



- velocity u_x and penetration Δx depend on blob size r_b

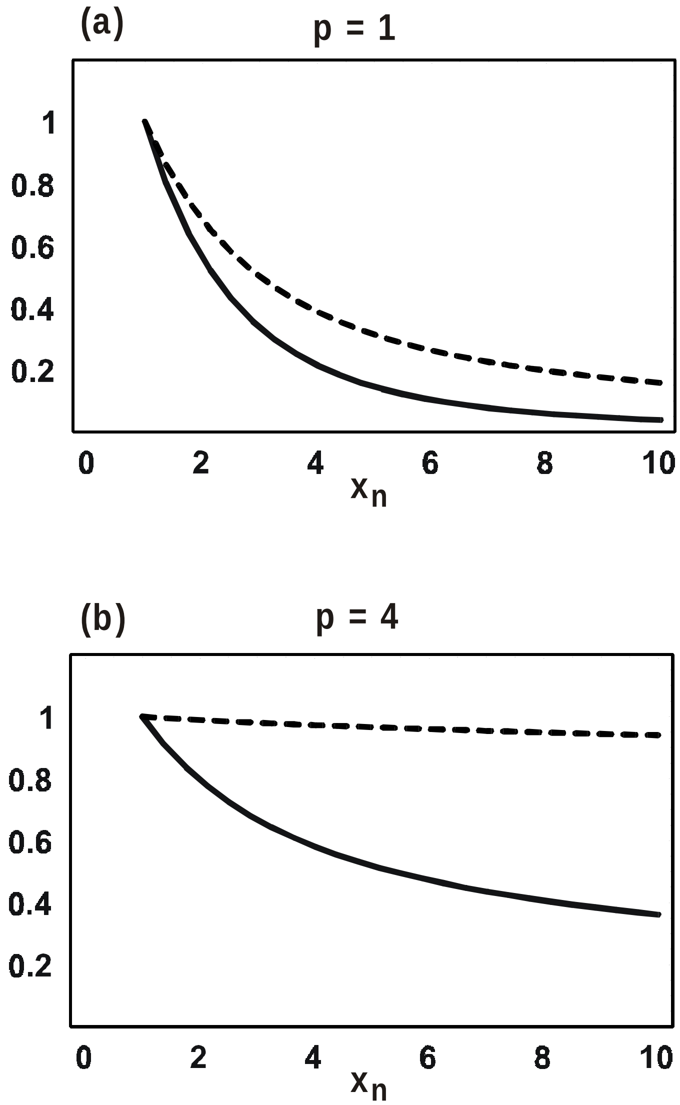
$$n(r) = n_b \exp\left[-\left(r^2/2r_b^2\right)\right] \quad \Rightarrow \quad u_x = \frac{q}{r_b^2} \quad , \quad \Delta x = \frac{u_x L_\parallel}{c_s}$$

Profiles depend on the blob size distribution

Ensemble average over power law distribution $f(r_b) = r_b^{-p}$

$\Rightarrow$ large blobs dominate for p = 1, small blobs for p = 4

dashed curve = radial flux, solid curve = density



D'Ippolito, Myra, Krasheninnikov, Phys. Plasmas **9**, 222 (2002)

Small-scale blobs travel faster and penetrate farther than large blobs

Limitations of the simple model
(density blobs)

- isolated blobs with no background density
- vorticity assumed small
- flute limit along B
- constant T assumed

(more general models of vorticity and temperature blobs have also been considered but do not yield analytic solutions)

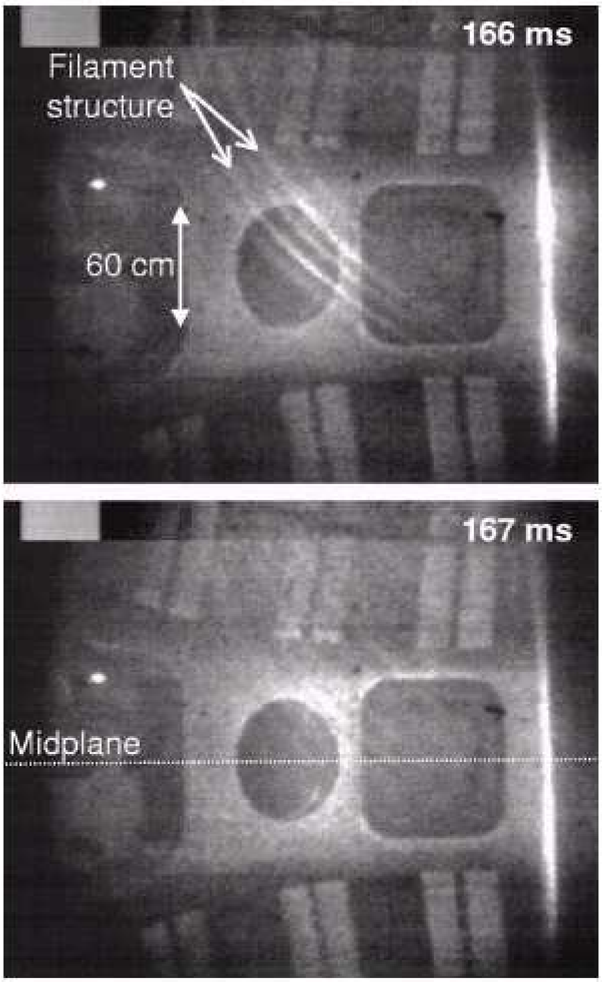
2D simulations (Galkin, Sherwood 2002; Naulin et al., EPS 2002) $\Rightarrow$ vorticity can be important and can slow down propagation. Also, v_x depends on blob amplitude over background.

3D simulations (Xu, TTF 2002) indicate that structure along B can be important in studying density limit.

Temperature gradients will be important in comparing with experimental propagation data.

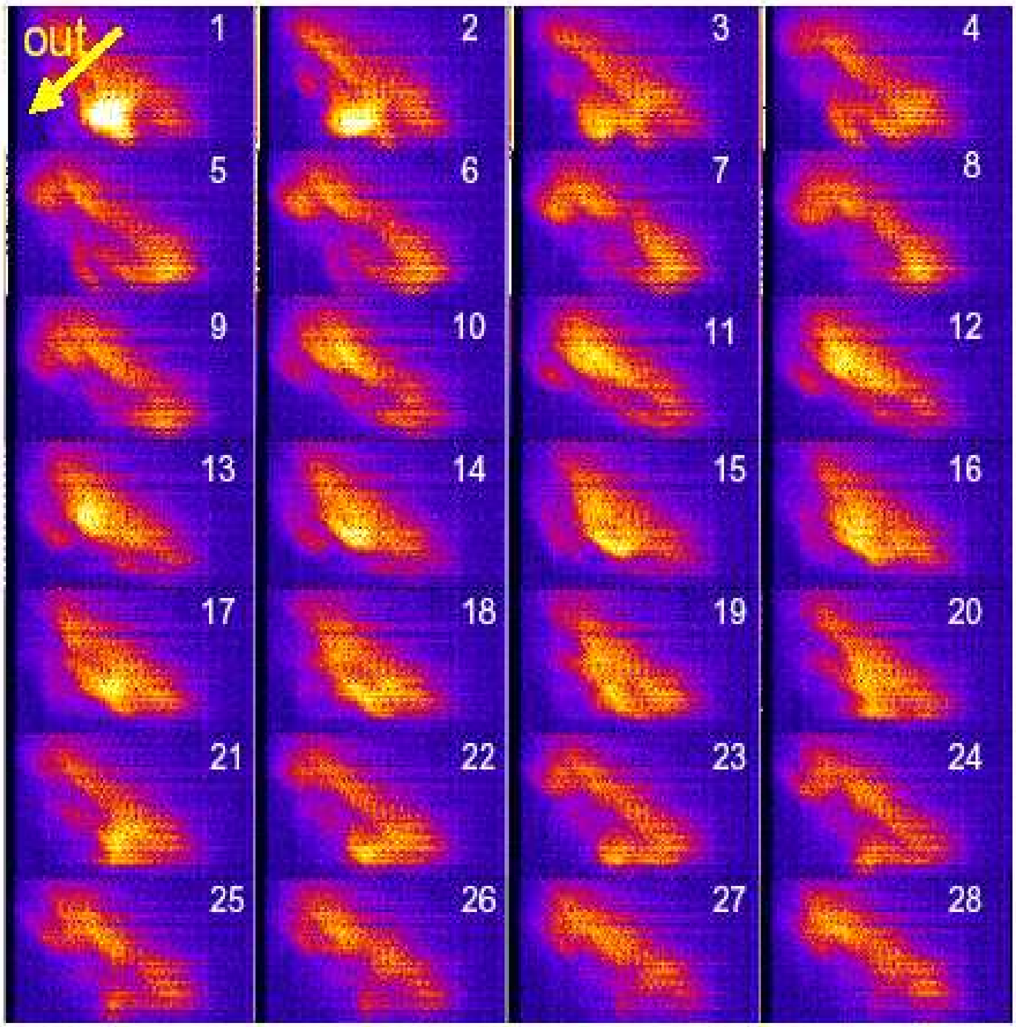
Despite these caveats, the simple model agrees with some qualitative aspects of the computer simulations and experimental data…

Filament-like structures observed in BOUT and GPI



R. Maqueda, S. Zweben X. Xu

GPI with fast camera shows coherent structures moving perpendicular to B (NSTX)

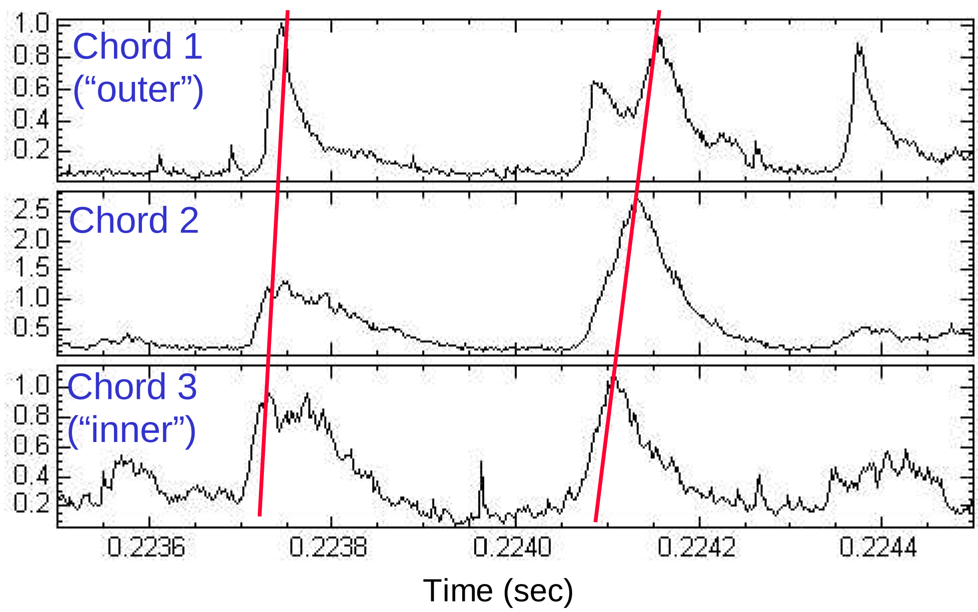


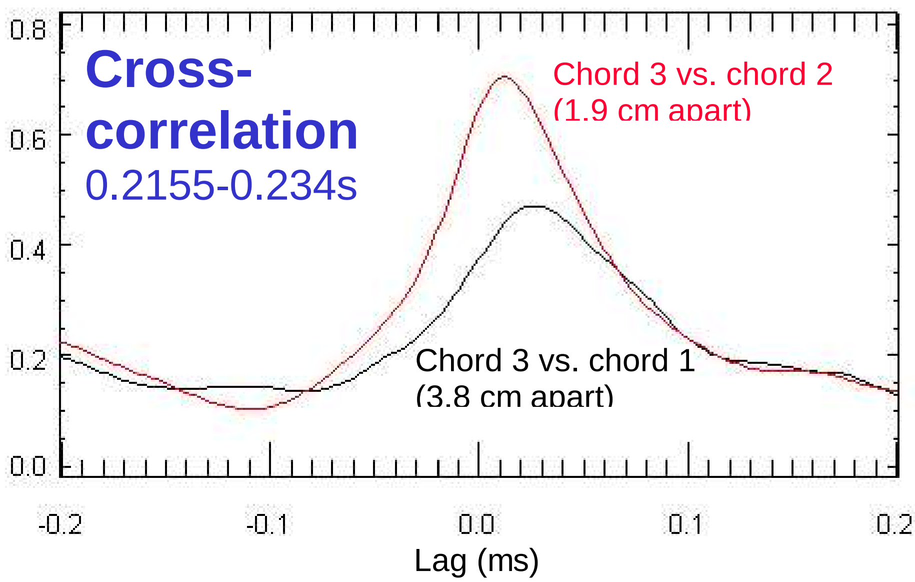
Edge turbulence images from NSTX at 100,000 frames/sec showing a region $\approx$ 30 cm $\times$ 15 cm near the outer midplane with the outer wall toward the lower left corner.

S. Zweben, EPS 2002

Intermittent blobs in L-mode SOL show radial convection towards wall in NSTX

Helium Light Emission (a.u.) vs time (shot 105710)

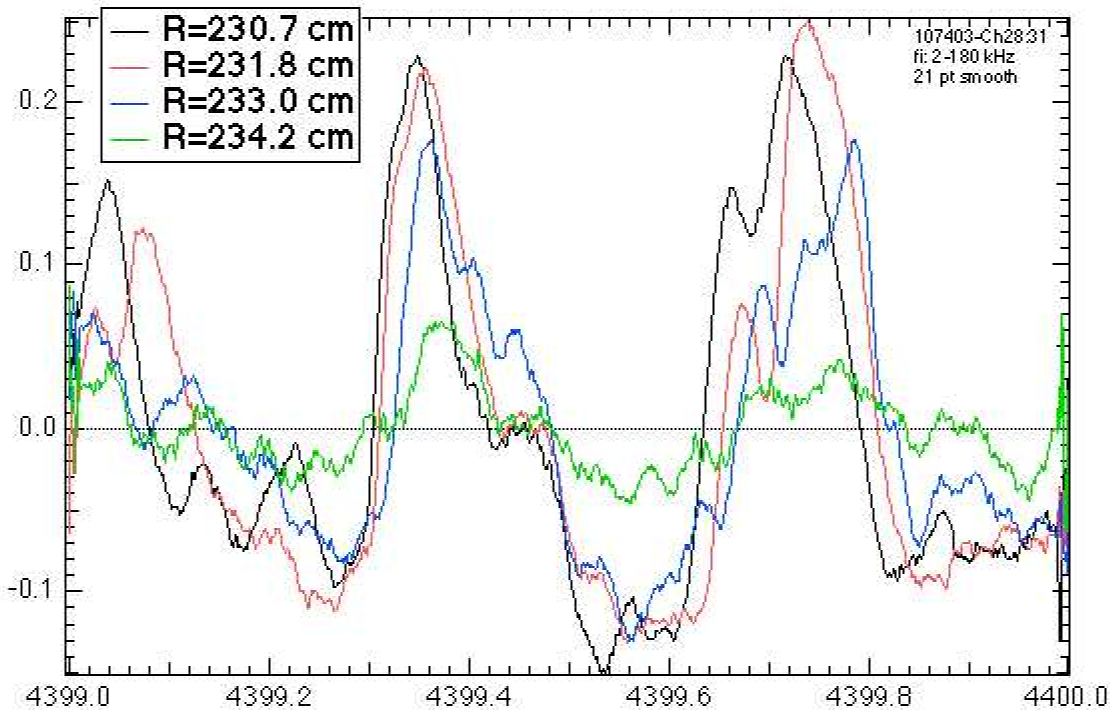




Mean radial velocity ~1700 m/s

(R. Maqueda et al., APS 2001)

DIII-D BES data ⇒ radial correlation & propagation of blobs

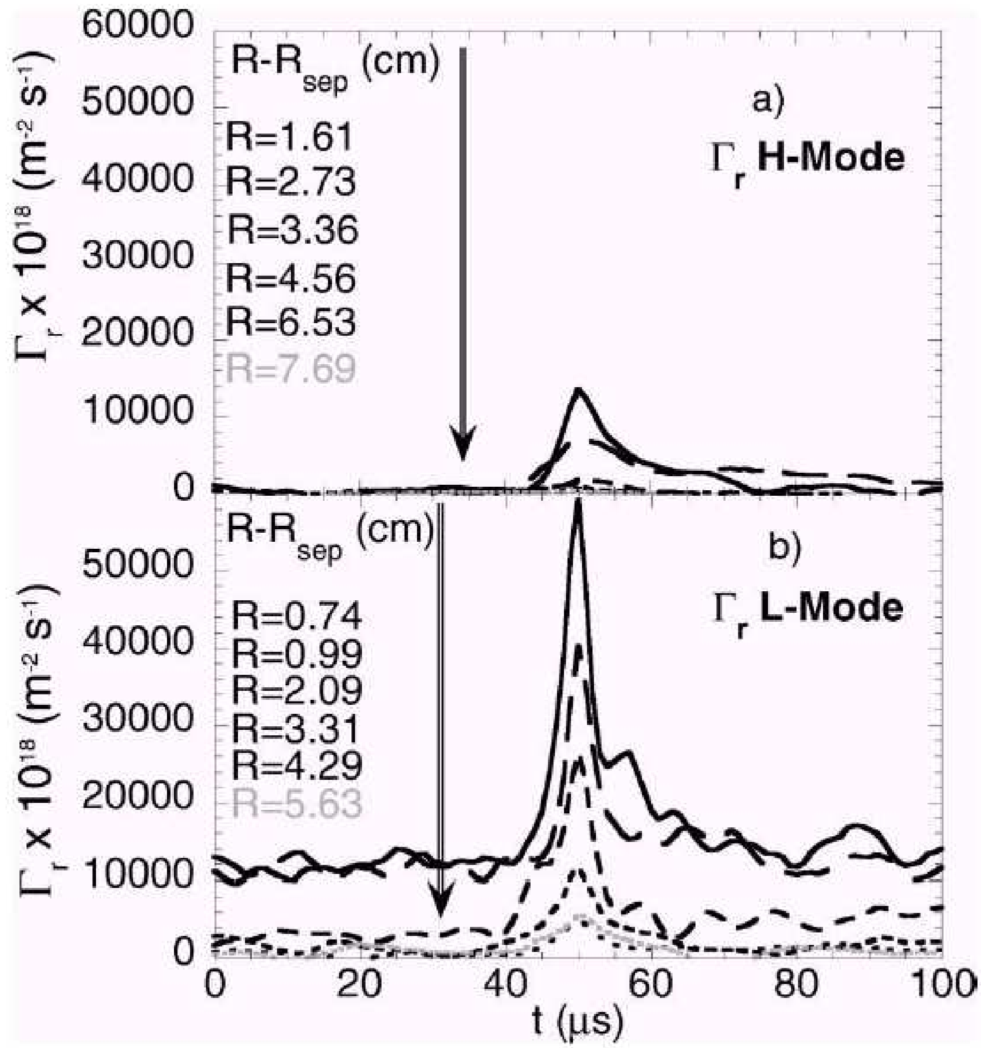


G. McKee

- BES signals show discrete events ("blobs") propagating radially in SOL; equivalent cylindrical blob radius $r_b \approx 1 - 2.5$ cm
- v_x inferred from propagation time shows reasonable agreement with blob model (curvature and **E**×**B** drift physics)
  - data ⇒ $v_x \approx 300–600$ m/s (different blobs, at $\Delta x \equiv x – x_{sep} = 1$ cm)
  - model ⇒ $v_x \approx 500$ m/s (for $r_b = 2$ cm, $L_{||} = 16.7$ m, and measured plasma parameters at $\Delta x = 1$ cm)

(D. D'Ippolito et al., APS 2001)

DIII-D probe data ⇒ intermittent radial particle flux in SOL



J. Boedo et al., Phys. Plasmas **8**, 4826 (2001)

Similar measurements will be carried out on NSTX and will be very useful in testing the theory.

Comparison of blob model to GPI data on NSTX

- initial kinematic analysis of blob motion, sizes and lifetimes (A. Keesee et al.)
  - o blobs propagate radially and poloidally
  - o blob size distribution was obtained
  - o theoretical relation between v_x and blob size not confirmed

- we will extend the above work by carrying out a physics-based analysis of GPI and probe data to see which physical effects are important to understand the data.
  - o infer potential φ from the GPI data, compute $\mathbf{v} = (c/B)\,\mathbf{b}\times\nabla\varphi$, and compare with observed blob motion and with predictions of theory.
  - o is observed motion due to $\mathbf{E}\times\mathbf{B}$ drift?
  - o what is relative importance of vorticity, sheath, and curvature drift physics?

Two limiting cases

In each case the density pattern n(x,y) obtained from the GPI data is input to the theoretical calculation of φ(x,y).

1) Small vorticity limit

$$\varphi = \frac{q}{n} \nabla_y n$$

(simple blob model: sheath resistivity balances curvature drift)

Valid in far SOL. May not be useful for GPI data near separatrix -- *can we get GPI data in far SOL*?

2) Large vorticity limit

$$\nabla_\perp^2 \varphi = \sigma \equiv e(n_i - n_e)$$

where

$$\sigma \equiv n_e e \left[f_1(\varphi) + f_2(\varphi) \right]$$

GPI sheath curvature

(Poisson's eq. + model for charge conservation; equivalently, could solve the vorticity eq.)

Valid in near SOL for GPI data. Numerical code will be developed to solve for φ subject to physical BCs.

Future Directions

- The first task (FY 2003) is to test the extended blob theory (including vorticity) against the GPI data. Comparison with probe data would also be interesting.

  ⇒ distribution of blob sizes
  relation between blob size and transport

- In FY 2004 we will investigate the relation between the observed coherent structures and the BAL/BOUT stability/turbulence simulations

  - Is blob size related to the turbulent cascade scale, to scale of fastest growing mode, or … ?

- Test predictions for

  - scaling of particle flux with parameters (e.g. B, q)

  - L_n of the SOL due to SOL convection

- Investigate relation between SOL density and convection

  - Convection may provide mechanism for a density limit (Myra et al., EPS 2002; Xu, TTF 2002)

  - NSTX provides a different parameter regime than DIII-D or C-MOD for testing this physics.

Summary

- flat (convective) SOL profiles have been observed experimentally and emerge naturally from the blob model; this convection has important implications for fusion experiments.

- radial transport in the blob model depends on the blob scale size distribution, which can be measured.

- a preliminary comparison of the blob model with experimental data from NSTX, C-MOD, and DIII-D shows some points of agreement.

- the simple analytic blob model needs to be generalized for quantitative comparison with experiments and turbulence simulations.

- the GPI data from the fast framing camera is an excellent test bed for quantitative comparison of theory and experiment.