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Edge Pedestal and Er-Layer Formation by X-Transport in NSTX[†]

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INTRODUCTION

- L-H transition: a turbulence suppression theory is becoming more popular than a neoclassical bifurcation theory.
- Turbulence suppression: Is it coming from a turbulence-generated sheared (zonal) flow, neoclassical sheared flow, or synergy?
- For a whole truth, a solid establishment of the neoclassical baseline phenomena is essential.
- There is a strong non-ambipolar neoclassical transport mechanism (**X-transport**) in a diverted tokamak edge, which yields an edge pedestal, E_r, and sheared flow.

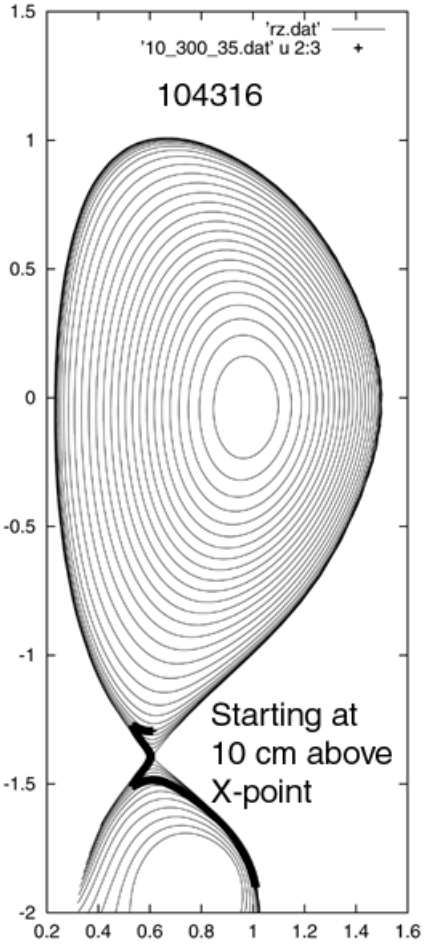
WHAT IS THE X-TRANSPORT?

- Leaky X-region: $B_\theta/B \to 0$.
  Broken toroidal confinement magic.
  Diverted B affects closed surfaces!
- Some banana turning ions get **X-trapped** without single-particle confinement.

$$v_{\mathrm{i}\|}\frac{B_\theta}{B} \lesssim V_{\nabla B} \ll v_{\mathrm{e}\|}\frac{B_\theta}{B}$$

- Built-in $B_x/M^{1/2}$ dependence from $v_{\mathrm{i}\|}/V_{\nabla B}$
- Edge pedestal formation
- Nonambipolar ($n_i < n_e$)

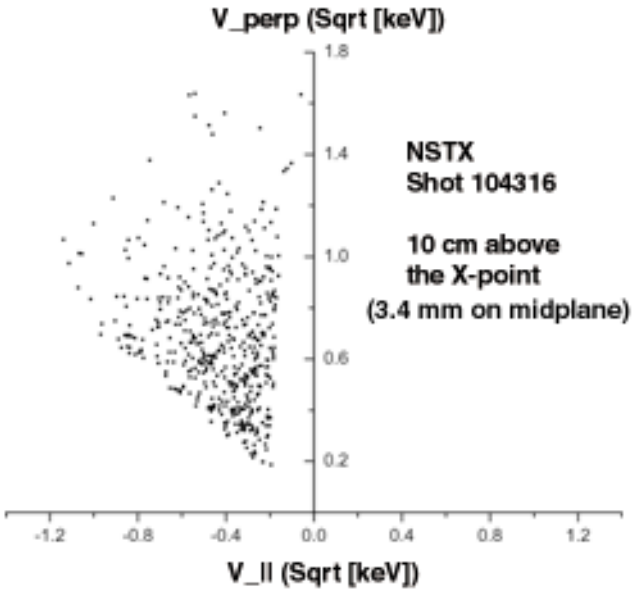
→ Strongly sheared $\mathrm{V_{E\times B}}$



- Convective transport due to **collisional** v-space hole, not a simple orbit loss.
- Localized in X-region at $K \gtrsim T_i$.
- Sensitive to ∇B direction, not to ν_{i*} or limiter.
- Not relying on energetic ion population

X-loss ≫ conventional neoclassical or orbit loss

ION LOSS HOLE WITHOUT Er

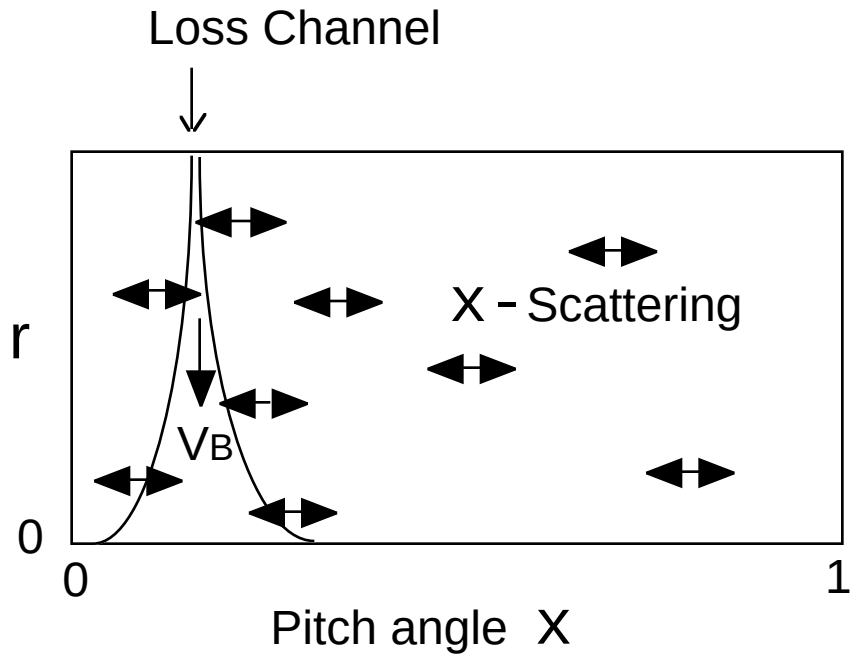


- Loss energy extends down to 100eV ($\sim$ local T_i).

- Radial electric field pushes the loss hole to a much higher energy, where Maxwellian tail ion density is negligible.

X-Transport is a collisional process

- Narrow loss hole in pitch angle space
  $\rightarrow$ high effective pitch angle scattering rate
- Ions in the loss hole scatter in and out of the loss hole as they drift into divertor chamber.
- **A cartoon picture:**



X-Transport is saturated by Er

- X-transport is non-ambipolar (ion loss).
  $\rightarrow$ E_r generation
- E_r reduces X-transport
  (E$\times$B-escape of ions from X-Trapping).
  $\rightarrow$ Saturation of E_r and pedestal

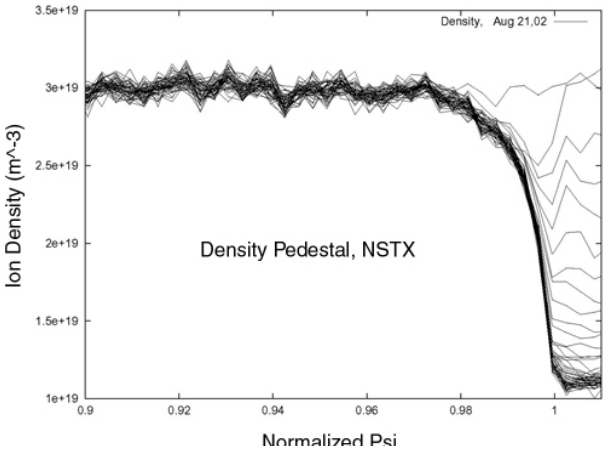
Monte Carlo Edge Simulation by XGC code

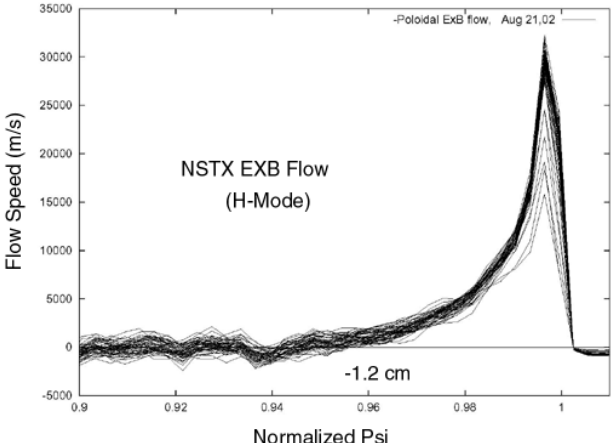
Hamiltonian guiding center code with separatrix and conserving collision operator

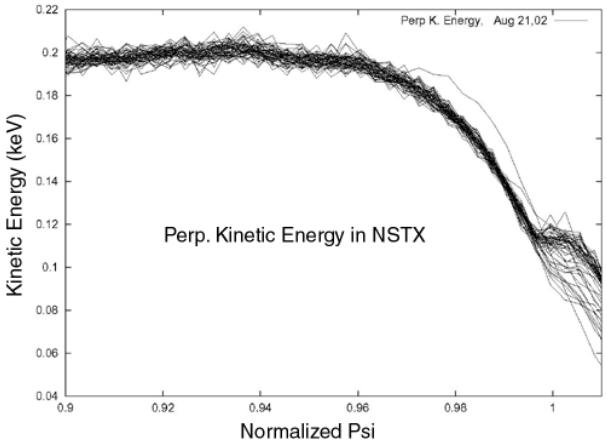
- Assume no turbulence or neutral particles
- X-transport produces strong pedestal and E$\times$B structures at the edge.
- Edge kinetic energy is anisotropic
  $\rightarrow$ Non-Maxwellian edge ions

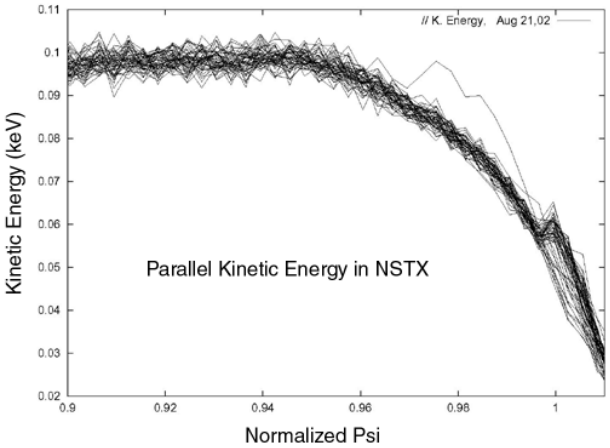
Edge Pedestal formation (poloidal average)

- Simulation without neutrals or limiters:
  $\rightarrow$ a pure X-transport phenomenon
- $\Delta_T > \Delta_n$, $\Delta_{EXB} \simeq 1.2$ cm on midplane



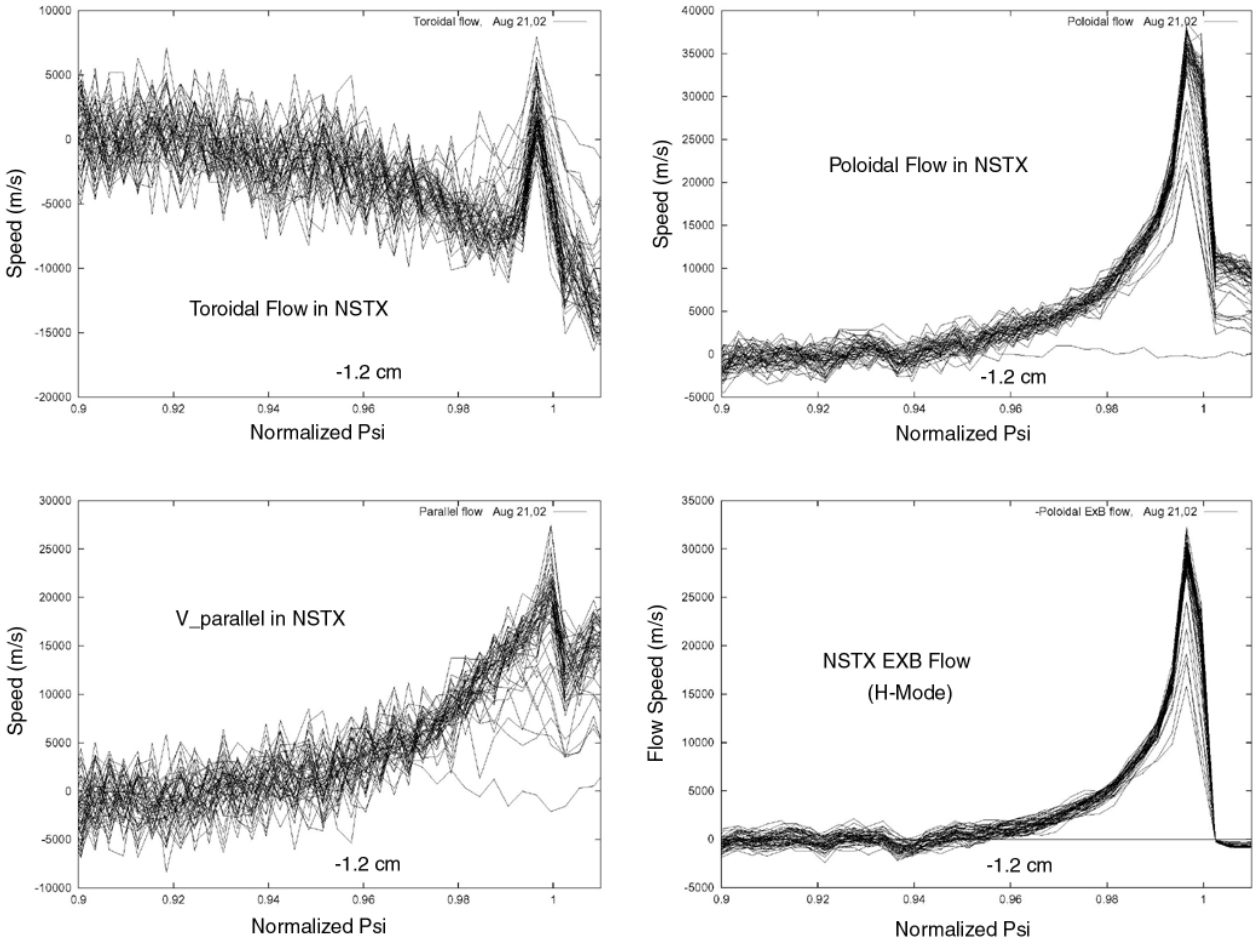






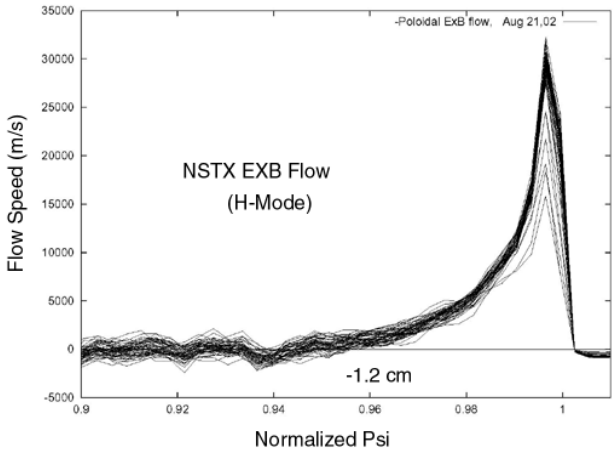
Edge Rotation Development

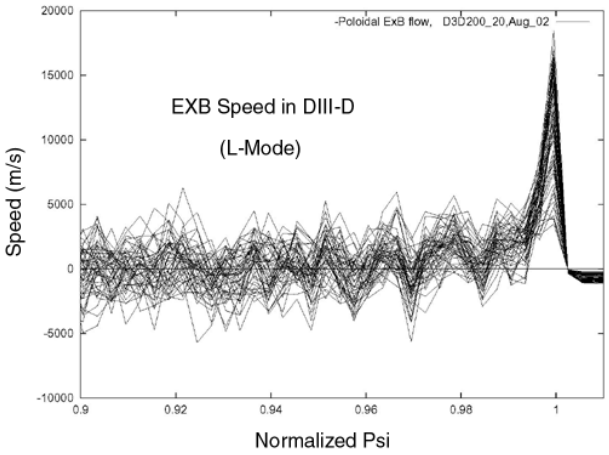
- Plots are in toroidal coordinate system (r, θ, ζ) with $\vec{\zeta} \parallel \vec{B}_T$ and $\vec{j}_p$ opposite to $\vec{B}_T$.
- Notice the difference between V_{tor} and $V_{\parallel}$ due to large $V_{\rm pol}$: $V_{tor} = V_{\parallel}(B_{tor}/B) - V_{\rm pol}(B_{pol}/B)$.



Comparison of EXB between NSTX (ST) and DIII-D (tokamak)

For the same edge condition
($T_{ped} = 200eV$, $n_{ped} = 3 \times 10^{13}\ cm^{-3}$),
NSTX shows greater V_{EXB} magnitude and
much greater width.





Natural consequences of X-transport

CS Chang, et al, Phys. Plasmas, September (2002)

- $V_{\nabla B}$ into divertor is preferred.
- Lower P_{thres} with single than double null
- Consistent with $P_{LH} \propto B\ n\ S\ /\sqrt{M}$
- Can yield pedestal width and height
- Insensitivity to ν_*
- Radial X-point position dependence
- Fast or slow H-transition

CONCLUSION and DISCUSSION

- Convective loss by X-transport provides a baseline mechanism for edge pedestal and E_r' formation.
- X-transport naturally contains most of the scaling trend in P_{LH} ($\propto BnS/M^{1/2}$, ∇B direction, etc).
- Effect of hot ions is interesting: to be studied soon.
- Neutral particles may play a significant role in X-transport: to be studied soon.
- Turbulence theories may become much easier on the X-transport platform.
  - X-Transport can define a difference between limiter and divertor L-H.
    - Limiter: turbulence-generated zonal flow alone
    - Divertor: turbulence on X-generated sheared flow.
  - May suggest a distinction between H and VH
    - H: Turbulence on X-generated sheared flow
    - VH: Turbulence-generated zonal flow alone