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Turbulent energy transport and parallel heat flux in the SOL

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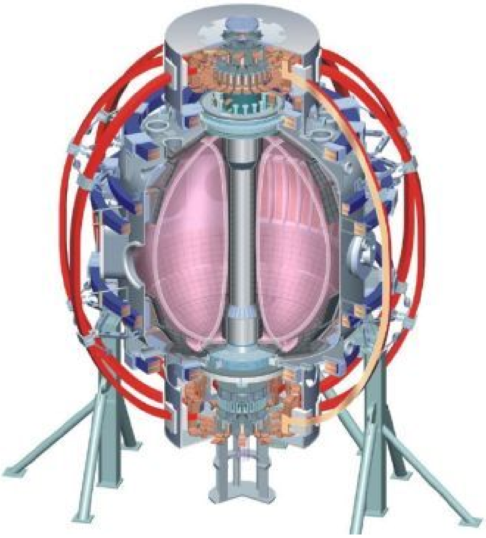

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SOLT code, research goals & FY2010 JRT

- SOLT code
  - 2D fluid turbulence code: model SOL in outer midplane
    - classical parallel + turbulent cross-field transport
  - evolves n_e, T_e, Φ with parallel sheath closure relations
  - strongly nonlinear: $\delta n/n \sim 1 \Rightarrow$ blobs
  - model supports drift waves, curvature-driven modes, sheath instabilities …
  - synthetic GPI diagnostic
- Goals
  - simulation of SOL profiles of $n_e(r)$, $T_e(r)$, $\Gamma(r)$, and $q_{||}(r)$
  - not fully predictive ($\Rightarrow$ use for interpretation); need
    - profile information inside LCS; effective core BCs
    - E_r (model has incomplete physics for plasma rotation) – or fit
    - constrain by data (e.g. dissipation, viscosity)
  - study cross-field energy transport
    - near SOL profiles , SOL width, P scaling
    - far SOL blob transport

FY2010 JRT

Completed blob simulations of a well diagnosed and analyzed shot #112825

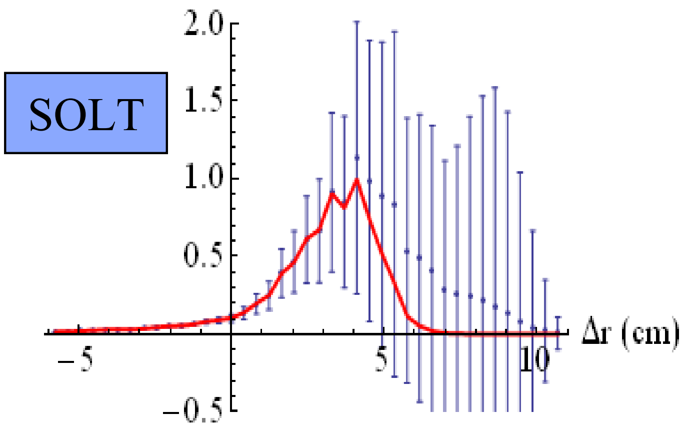
- **He-puff** GPI, low power **L-mode**

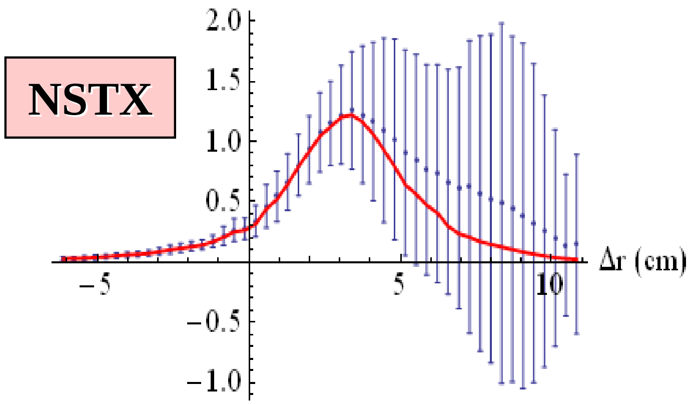
- Conclusions from that study:
  - The simulated turbulence is sensitive to the parameters that control the stability of the system: drives and dissipations, some of which are poorly known, but can be constrained indirectly by data.
  - "Successful" simulation of GPI profiles occurs close to marginality: balance instability drive $\leftrightarrow$ sheared flows, dissipation
  - 2D fluid simulations with the SOLT code yield a reasonable match to GPI data for SOL blob/turbulence.
    - GPI statistics; blob size PDF
    - blob velocity PDF off by factor 2

GPI fluctuations radial dependence

$\langle \bar{I} \rangle$ & Median I (red)

Sheath Entrance @ $\Delta r = 4.52$ cm



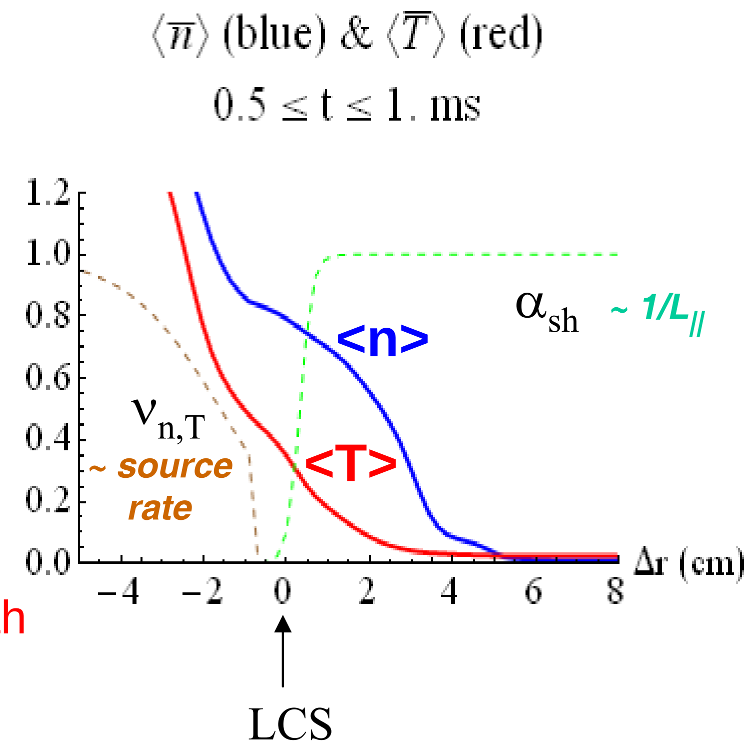


Present work: ELM-free H-mode plasmas (Modelling of XP952)

- Shot selection
  - ELM-free **H-modes** at 0.8 MW and 1.3 MW NBI with **GPI-D puff**
  - shots 135009, 135011 and 135038
- Shot modelling procedure
  - TS profile fit (in core region)
  - GPI data extraction
  - geometry: camera view; magnetic geometry: R_{sep}, connection lengths, B_θ …
  - power across LCS = P_{sep}
  - synthetic GPI for D-puff: $D_0(r)$, atomic physics for D_α emission
- Simulations
  - sensitivity studies to input parameters
- Comparisons (underway)
  - profile comparison with probes: $n_e(r)$, $T_e(r)$
  - mapped divertor heat flux comparison with $q_{||}(r)$ – near SOL
  - blob velocity and size distributions with GPI – far SOL

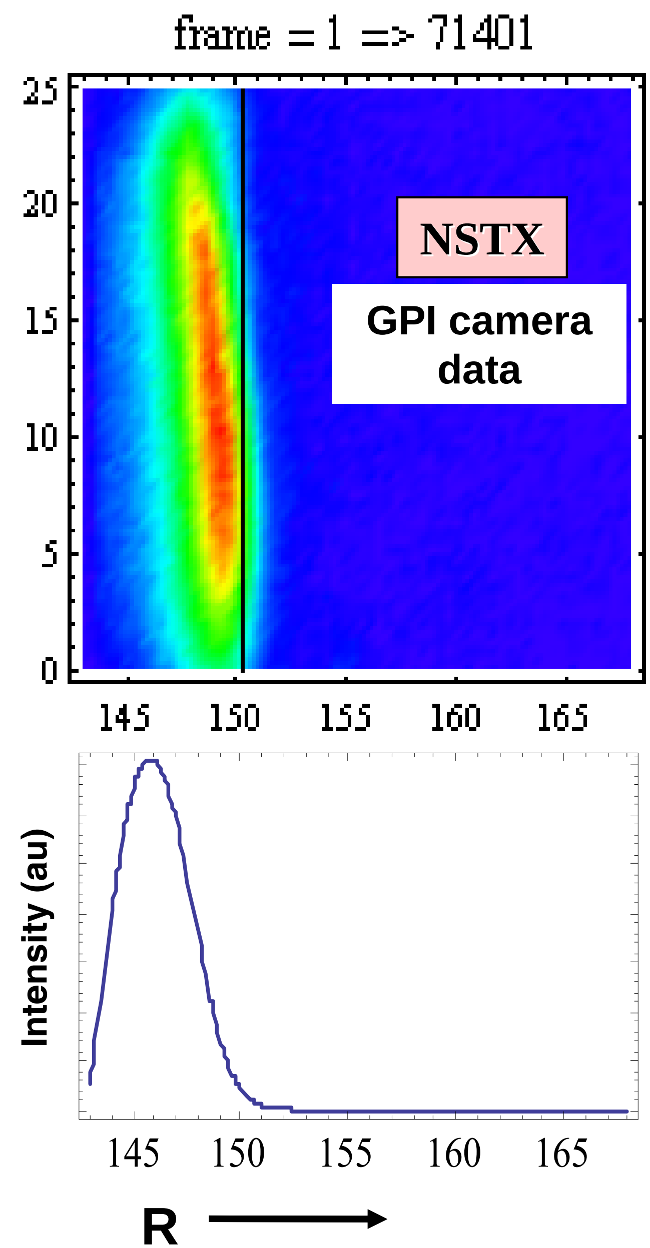
Simulation philosophy

- For these studies, which focus on near SOL profiles, we set up the SOLT code as follows:
  - use ad-hoc sources in closed-surface (“edge”) region to maintain measured profiles of n_e, T_e
  - impose edge zonal flows as a turbulence control parameter
  - the edge region effectively provides a boundary condition for the SOL
- Goal
  - a “first principles” self-consistent simulation *in the SOL*
  - in practice sensitivity of results to some poorly known inputs requires numerical experimentation (“tuning” to achieve realistic results
    - zonal flow strength
    - effective parallel blob length and connection length
    - dissipation parameters (e.g. viscosity)



Synthetic GPI for D-puff has been tested

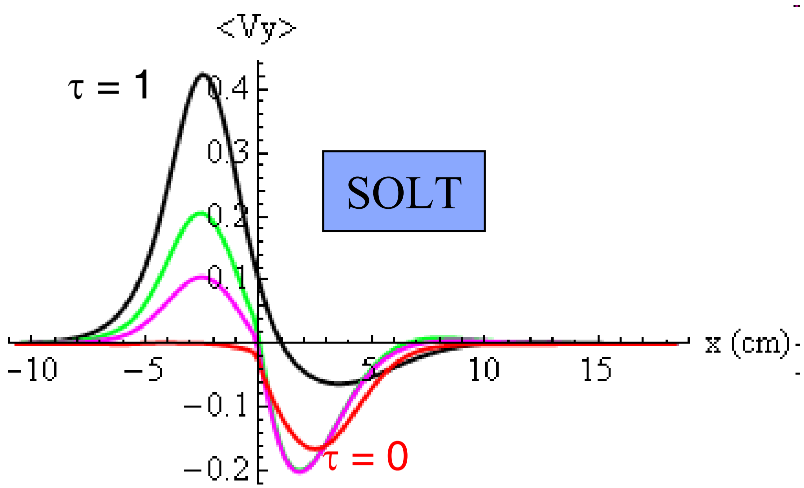
- input ne, Te
    - here from TS data
    - later from SOLT code
- output D-puff emission



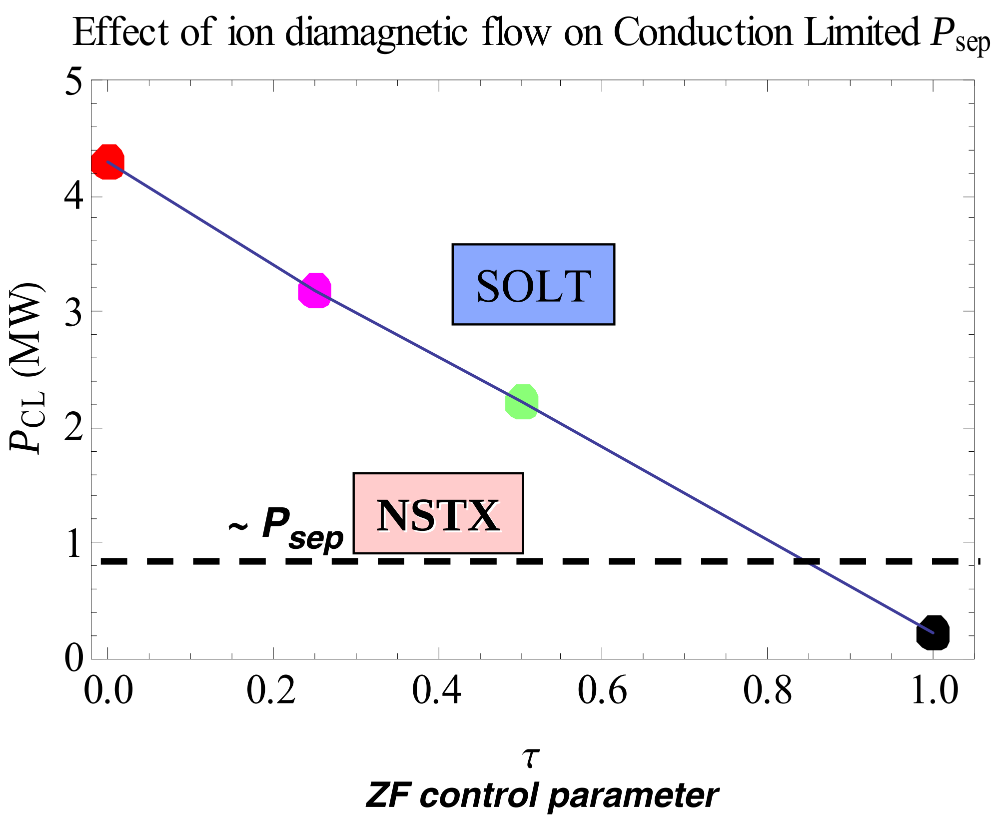
- achieved a good match to data for a quiescent frame
- calculated =>
    - Lundberg & Stotler fits for $D_0(R)$
    - fits to TS profiles for n_e, T_e
    - D_0 emissivity $I(n_e,T_e)$

H-mode simulations require strong zonal flows

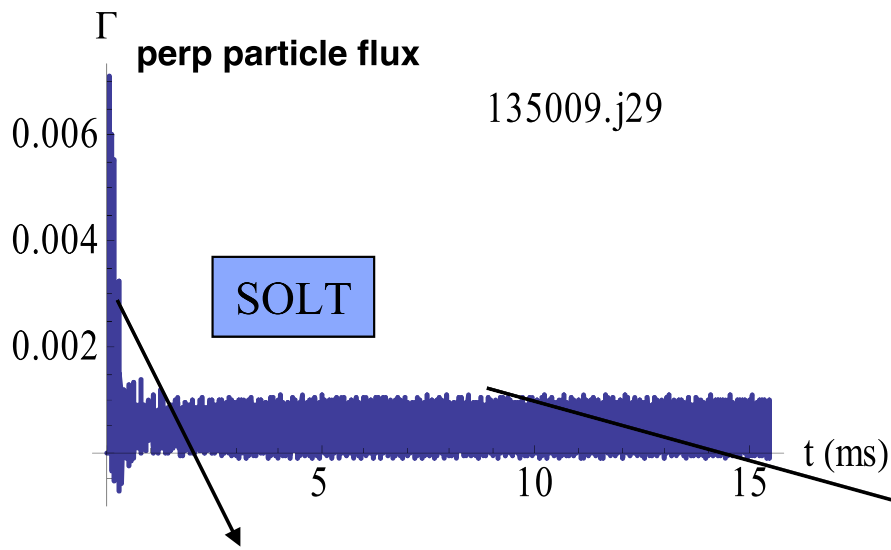
- Results of a sequence of SOLT simulations with varying levels of imposed zonal flow
  - strong zonal flows inhibit heat transport across separatrix
  - ZF required to match P_{sep} of simulation to experiment



Model H-mode ZF by taking E_r from $v_{dia,i}$ in radial force balance. $\tau = T_i/T_e$ is used as a control parameter



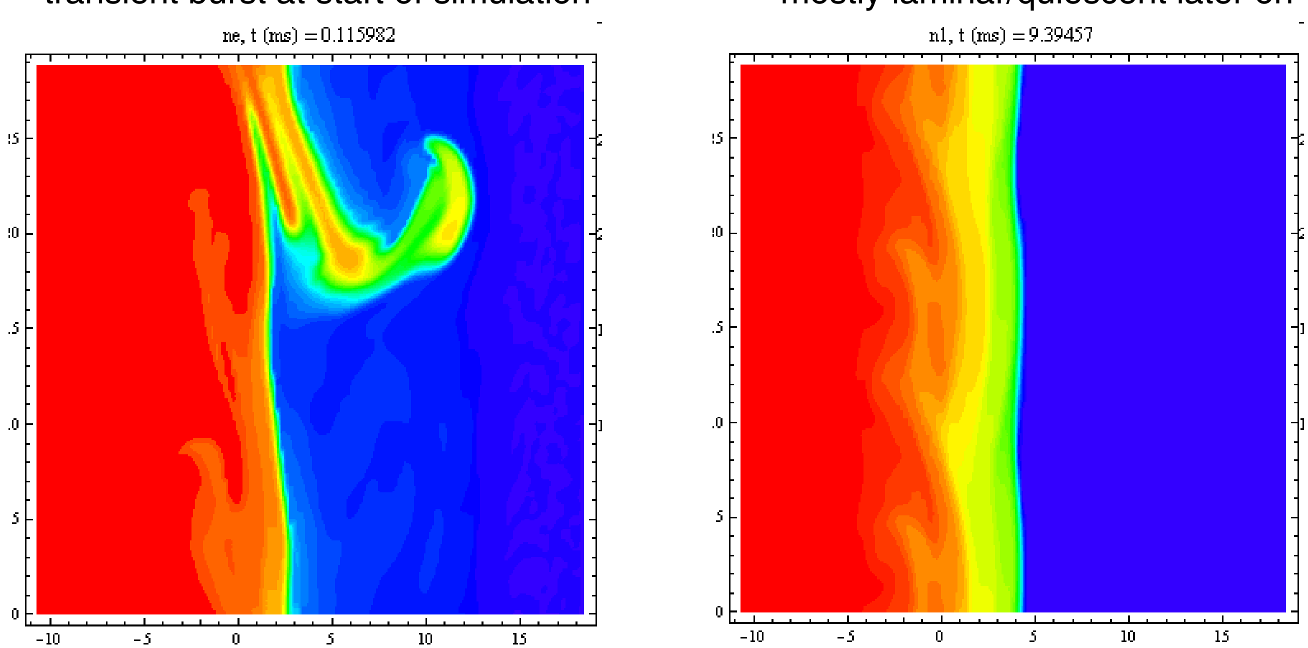
Matched P_{sep} runs show H-mode like, nearly laminar SOL



- rather quiescent over long time-scales
- blob ejection events are (only) triggered by imposed transients (e.g. startup here)

transient burst at start of simulation

mostly laminar/quiescent later on



SOLT

density snapshots

(synthetic GPI comparisons with camera data in progress)

GPI camera data similarly shows sparse intermittent blob ejection

NSTX

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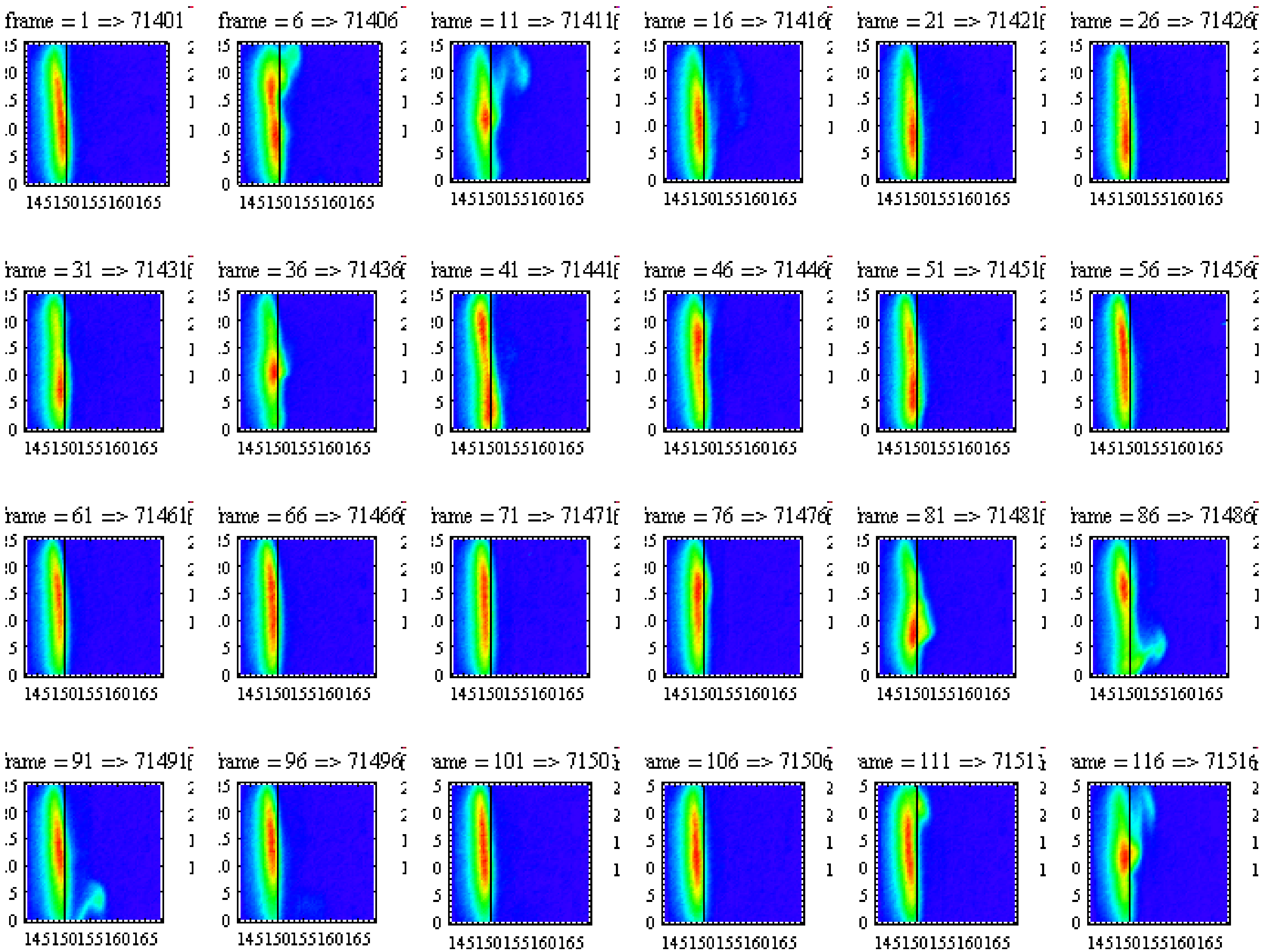
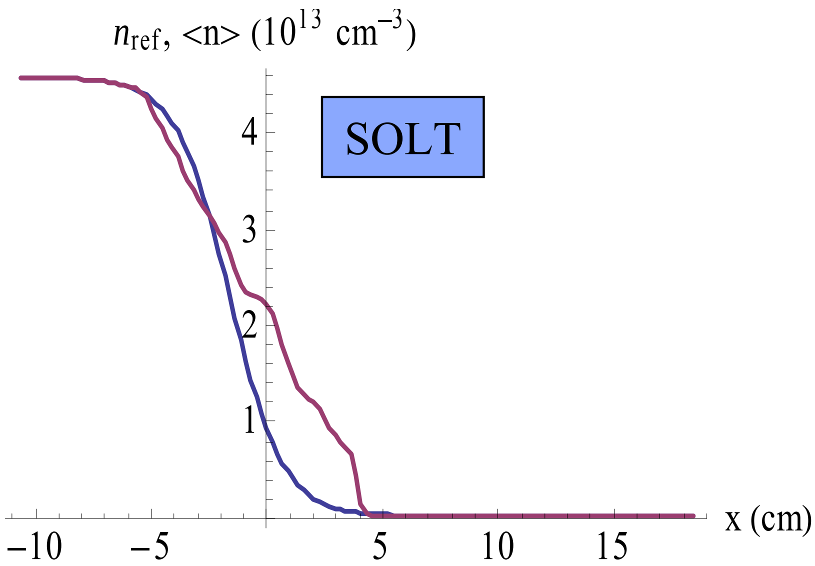
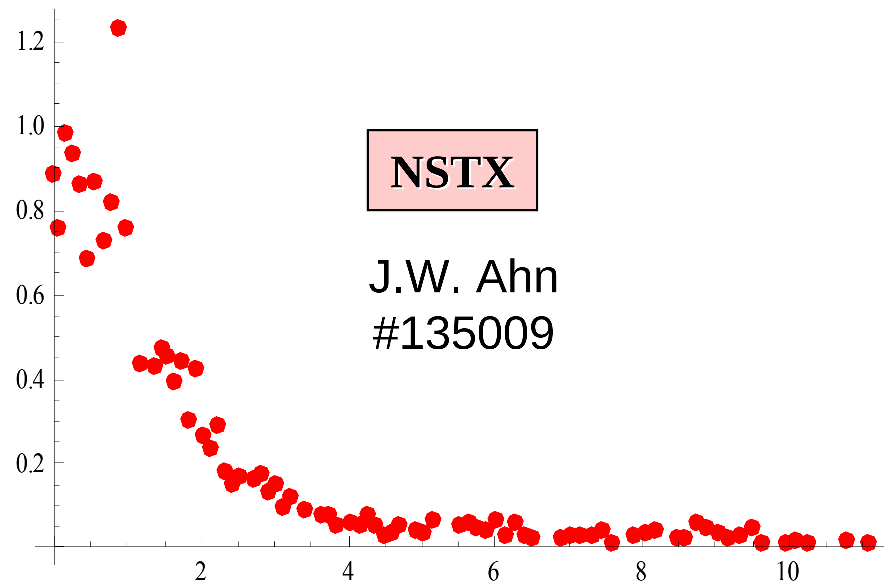


frames shown every 35 μs for a total duration of 0.84 ms (higher time res. available)

Near SOL n_e profile: SOLT vs. NSTX

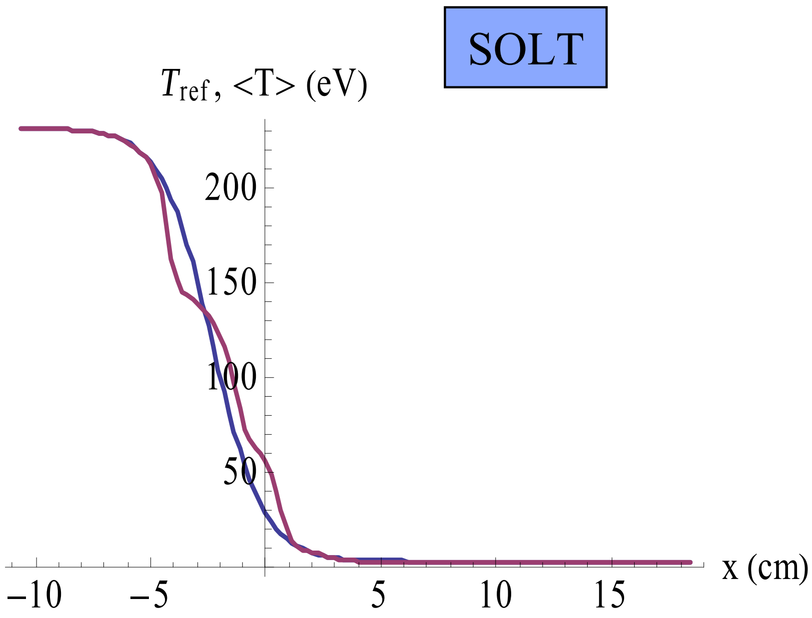
- SOLT profile shows a near-SOL enhancement not seen in probe data
- speculate that this is a 3D effect
  - ejected blobs don’t fill SOL flux tube initially
  - parallel sonic expansion (not in 2D SOLT) dilutes midplane density

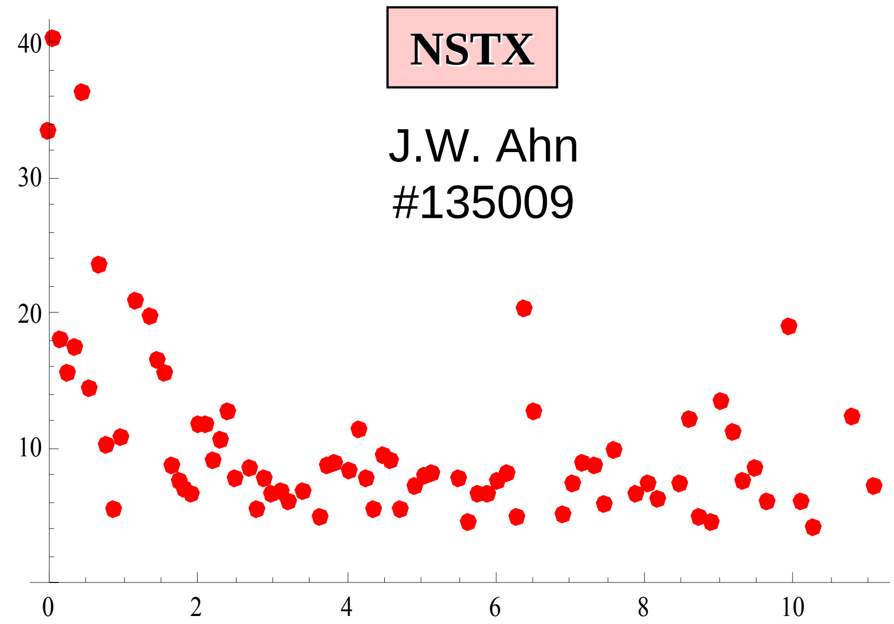




Near SOL T_e profile: SOLT vs. NSTX

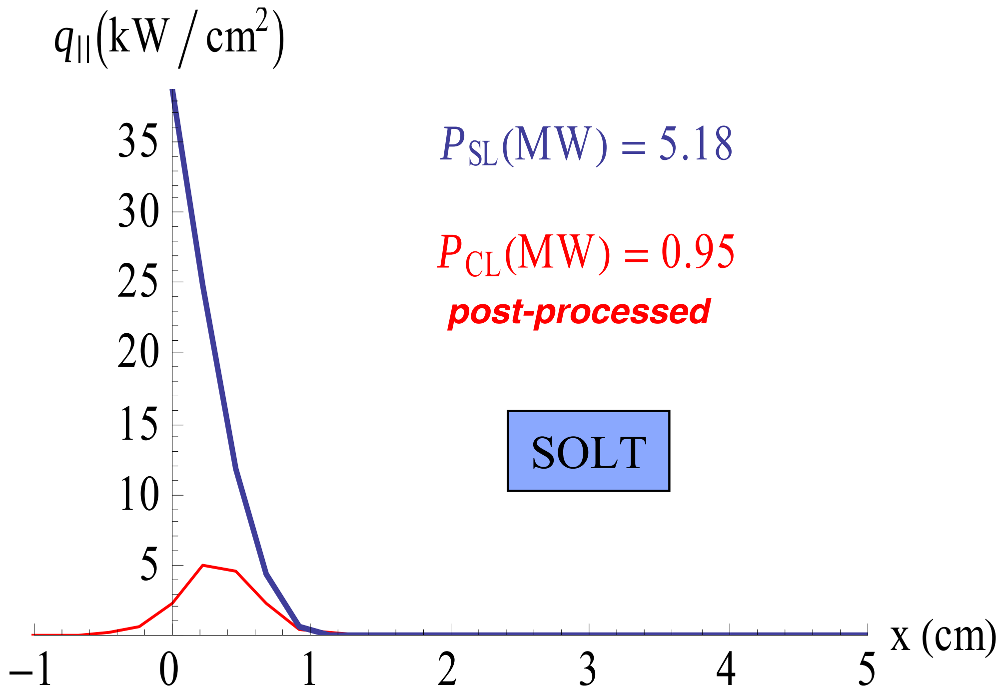
- no near-SOL effect expected from sonic expansion
  - agreement better in this regard
- probe data shows hotter far SOL floor T_e





Parallel heat flux at midplane

- caveat on code dynamics
  - simulations use sheath-limited (SL) heat flux dynamics in the evolution
  - for this shot, need to upgrade to conduction-limited (CL) dynamics
- heat flux magnitude and width similar to experiment
  - detailed comparison in progress



$$P = 2\pi R b_\theta \int dr\, q_{||}(r)$$

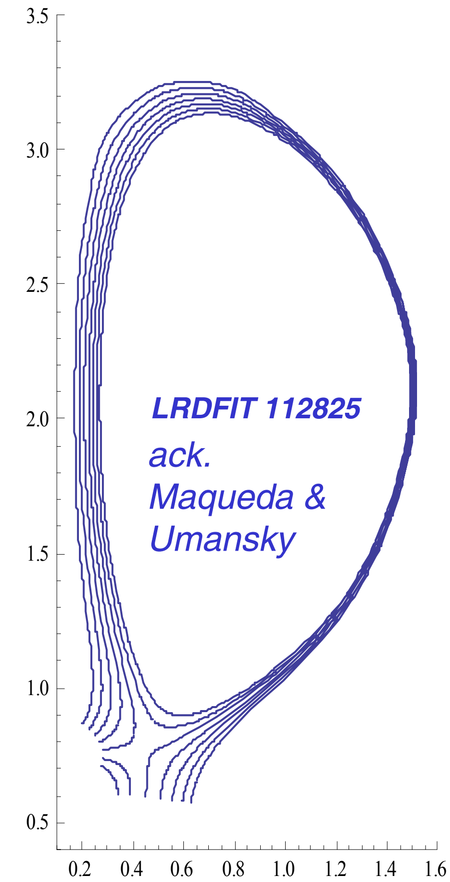
$$q_{||SL} = \left\langle n c_s T s_E e^{e(\Phi_B - \Phi)/T} \right\rangle$$

$$q_{||CL} = \left\langle \frac{3.2 n c_s T}{\Lambda} \right\rangle$$

$$\Lambda = \frac{\nu_{ei} L_{||}}{\Omega_e \rho_s}$$

Caveats and future work

- collisional $q_{||}$ and $\Gamma_{||}$ closures needed in dynamics
- present SOLT results use estimates for magnetic-geometry based inputs
  - compute connection length $L_{||}(x = \Delta r)$ and curvatures from LRDFIT
  - use parallel mode-structure information from the 2DX code to improve fidelity of our 2D SOLT simulations
    - see poster . GP8.00069 Baver et al. for a description of 2DX
- additional code sensitivity studies needed
- fine tune separatrix location in SOLT
  - LRDFIT and power balance separatrix match well
    - LRDFIT R_{sep} = 147.5 cm at Z = 0
    - T_e (30eV)Rmid = 147.2 cm
- Compare SOLT blob velocities in far SOL with GPI data



Summary and conclusions

- Previous work with the SOLT code has modelled some features of edge SOL turbulence and blob transport but questions remain.
  - Can we resolve the factor of 2 discrepancy in the blob velocity?
  - Are the simulations consistent with observed scalings for different shots and regimes (e.g. H-mode)?
- Ongoing work is addressing these questions, plus
  - power (P) scaling studies of SOL width for the three shots (Ahn XP952).
- Results so far show that
  - H-mode simulations require strong edge zonal flows to match P_{sep}.
  - Nearly quiescent/laminar states are found in this case.
  - Blob ejection is (only) triggered by transient forcing in SOLT; and is similarly rare in NSTX camera data.
  - Near-SOL n_e,T_e and $q_{||}$ profiles from SOLT are similar to probe data, but differ in some features with NSTX probe data.
- Results will contribute to the FY2010 Joint Research Target
  - Understand SOL transport of heat, SOL width, and blob transport.