New results in SOL turbulence modeling of NSTX

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and the NSTX team

- **SOL heat flux width scaling**
- **turbulence and profiles (probe)**
- **blob phenomena and GPI**
- **blob statistics (optical flow)**
- **zonal flow oscillations**

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The SOLT code: physics model

D. A. Russell, et al, Phys. Plasmas 16, 122304 (2009)

Scrape-Off-Layer Turbulence (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 closure relations
  - sheath connected, with flux limits, collisional
- **strongly nonlinear: $\delta n/n \sim 1 \Rightarrow$ blobs**
- model supports drift waves, **curvature-driven interchange** modes, sheath instabilities
- flexible sources for n_e, T_e, v_y (maintain edge/pedestal profiles)
- **synthetic GPI and probes**

L and H-mode simulation methodologies

- L-mode: $\langle v_y \rangle$ from **turbulence generated zonal flows**
- H-mode: $\langle v_y \rangle$ includes E×B from **imposed E_r well in edge region**

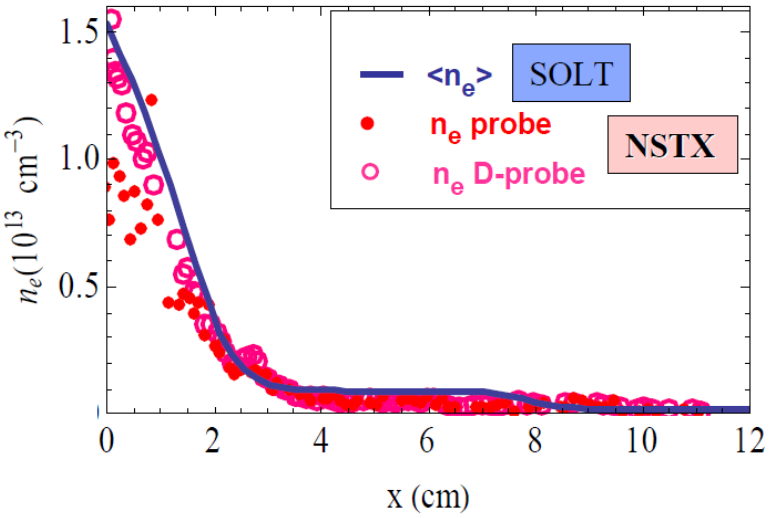
Scaling of SOL heat flux width λ_q

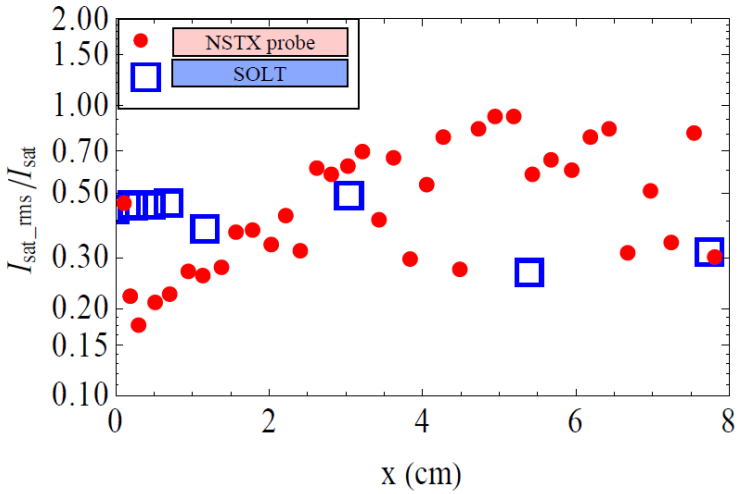
- major modeling effort in support of FY2010 JRT
- power (P) scaling of λ_q [J-W Ahn – low power ELM-free H-mode shots]
- current (I_p) scaling of λ_q [R Maingi – higher power ELMing H-mode shots]
- Absolute agreement is within modeling uncertainties (factor of 2).
- Scaling:
  - weak positive scaling with P
  - inverse scaling with I_p but λ_qSOLT ~ $I_p^{-0.7}$ and λ_qNSTX ~ $I_p^{-2.8}$
- midplane turbulence in SOLT explains some, but not all, of observed scaling

shot	I_p(MA)	P(MW)	λ_q NSTX (cm) midplane	λ_q SOLT (cm) midplane
135009	0.8	0.8	0.36	0.30
135038	0.8	1.3	0.50	0.41
128013	0.8	5.8	1.73	0.76
128797	1.2	6.1	0.56	0.58

J R Myra, et al., PSI (2010) and PoP (in press)

Midplane turbulence levels validated by probes and GPI

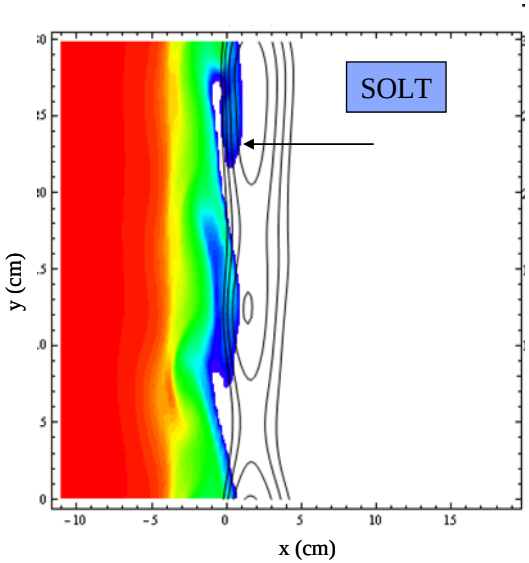




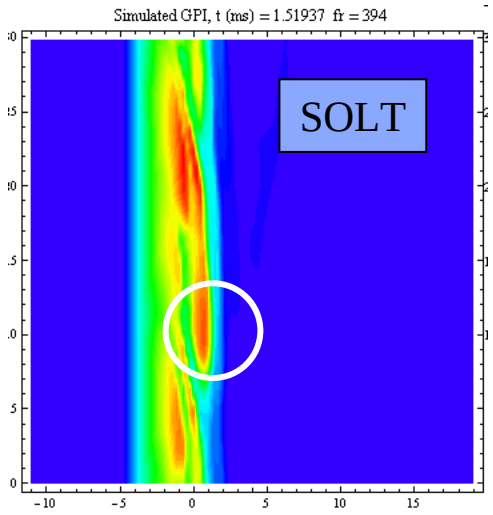
- probe data available for low power cases
- single and double probe average profile data [J-W Ahn and J Boedo] agree well with SOLT simulation
- fluctuation data [J Boedo] is similar to simulation within scatter
- GPI [R Maqueda] available for high power cases (not shown) validates turbulence levels and scaling for I_p scan

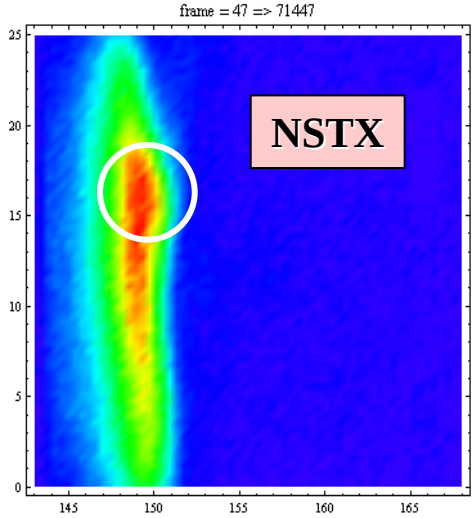
Midplane turbulence in SOLT is the only mechanism for λ_q

Separatrix-spanning convection sets H-mode λ_q



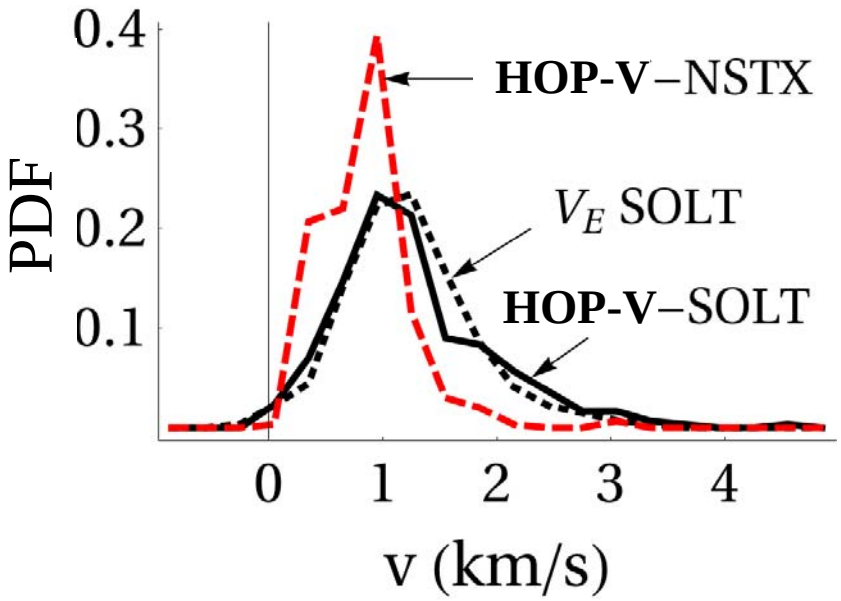
- left: density (color palette) and potential streamlines show convective cells and sheared flows. Emitted blobs are trapped by strong sheared flows
- synthetic GPI [n_{D0} D Lundberg, D Stotler] for trapped blob and GPI data [R Maqueda shot #135009]





Optical flow analysis useful for model validation

- Quantitative comparison of code and experimental data requires processing each through the same analysis stream.
- Here use hybrid optical flow and pattern matching velocimetry (HOP-V) [T Munsat and Y Sechrest]
- NSTX → Maqueda GPI → optical flow → **v**(x,y,t) → blob filter → PDFs
  SOLT → synthetic GPI → optical flow → **v**(x,y,t) → blob filter → PDFs
  → $\mathbf{v}_{E\times B}$(x,y,t) → blob filter → PDFs

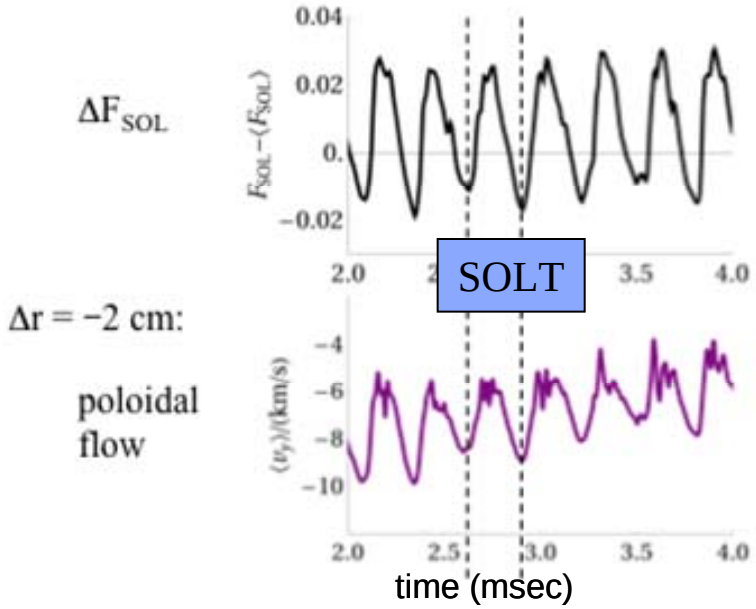


- HOP-V comparisons of NSTX and SOLT are similar
- blob $\mathbf{v}_{E\times B}$ is distributed similarly to HOP-V image velocity

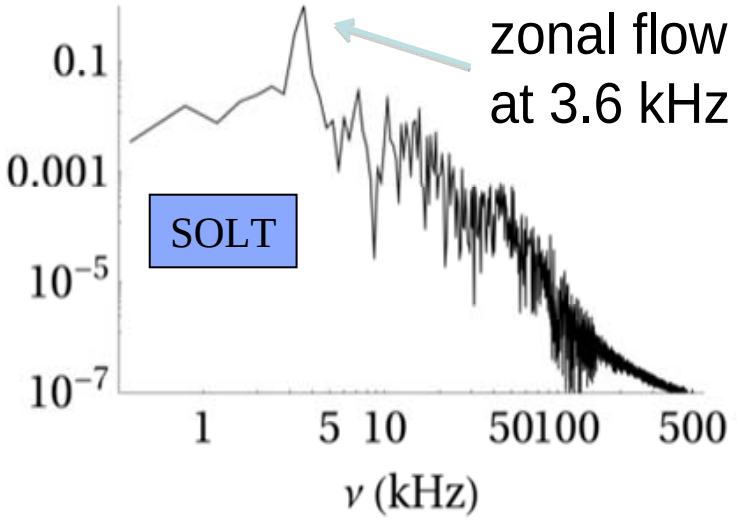
D A Russell, et al
PoP (submitted)

Zonal flow relaxation oscillations

- SOLT simulations show bursty periods synchronized with zonal flow oscillations.
- qualitatively similar to NSTX observations of quiet periods preceding L-H transition and flow oscillations at ~ 3 kHz [S Zweben PoP 2010]



Y Sechrest, et al
PoP (submitted)

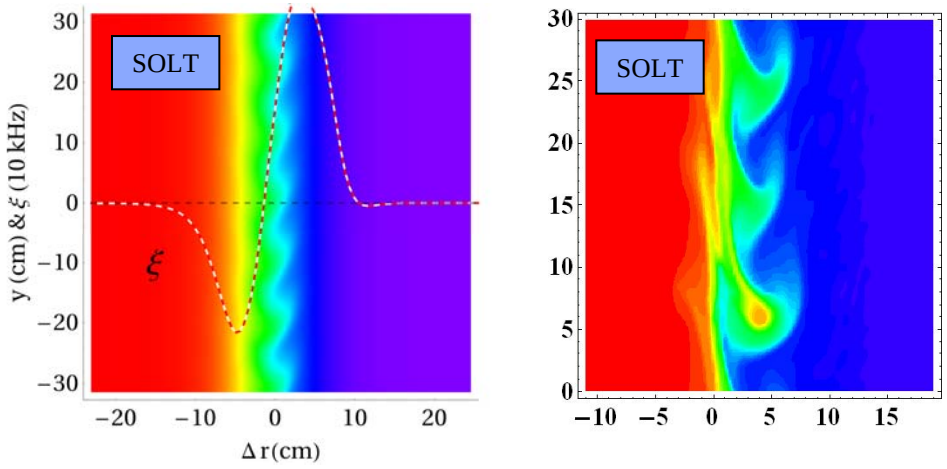


- zonal flow frequency is controlled by relaxation rates
  - pressure profile ~ c_s/R
  - zonal flow viscosity

Qualitative links of SOLT model with experiment

- Turbulence (and blob generation) are greatly reduced in H-modes compared to L-modes
- Strong auxiliary heating power implies increased intense edge activity
- From tens of thousands of GPI images and 100's of code runs: Similar blob phenomena are observed in GPI and SOLT
  - wavy structures and blobs trapped in edge
  - blobs detaching
  - smoke
  - blobs dissipating in near SOL or propagating to wall
  - plasma carried by SOL flow

R Maqueda et al
APS 2010



Quantifying these observations and relationships to L-H mode and SOL width will be part of our future research program

Summary

- There are some encouraging points of agreement (both qualitative and quantitative) between SOLT simulations and a number of experimental diagnostics:
  - SOL heat flux width scaling
  - midplane turbulence levels
  - blob statistics
  - zonal flow oscillations
  - blob phenomena
- Both model and data are in a very strong position for future comparisons to expand our understanding of SOL physics