Nonlocal transport in the scrape-off layer

P. Manz\textsuperscript{1,2}, F. Fischer\textsuperscript{1}, G. Birkenmeier\textsuperscript{1,2}, D. Carralero\textsuperscript{2}, G. Fuchert\textsuperscript{2}, S. Marsen\textsuperscript{3}, B. Nold\textsuperscript{4}, M. Ramisch\textsuperscript{4}, T.T. Ribeiro\textsuperscript{2}, B.D. Scott\textsuperscript{2}, U. Stroth\textsuperscript{2,1}, R.S. Wilcox\textsuperscript{5}

\textsuperscript{1}Technische Universität München, Germany
\textsuperscript{2}Max-Planck-Institut für Plasmaphysik, Garching, Germany
\textsuperscript{3}Max-Planck-Institut für Plasmaphysik, Greifswald, Germany
\textsuperscript{4}Institut für Grenzflächenverfahrenstechnik und Plasmatechnologie, Universität Stuttgart, Germany
\textsuperscript{5}Oak Ridge National Laboratory, OakRidge TN, USA

EFTSOMP Workshop, Lisbon, 30.6.2015
Why turbulence in the far SOL?

• Conditional averaged picture at the shear layer
• Statistics of blob trajectories
• Relation between turbulence spreading and blob generation
• Results from HSX, TJ-K, WEGA
Blob generation

theory:

- Interchange instability generates radial extended structures (streamer)

- Shear flow breaks streamer up into blobs
• delta-f gyrofluid code
• electron and ion density (-> potential)
• perpendicular and parallel ion and electron temperature (finite Larmor radius effects)
• parallel ion dynamics (ion sound waves)
• electromagnetic (magnetic fluctuations)
• solves equilibrium (global)
• 3D
• transtion from closed to open field lines (sheath connected boundary conditions) at separatrix
Deterministic cartoon

Blob generation
- blobs merge
- exchange particles and energy
- break up

(turbulence spreading)

O. Gürcan et al. Phys. Plasmas 2005
Blob definition:

Identify possible blobs at every time step:

(i) positive density perturbations exceeding the standard deviation by a factor of 2.5

(ii) has to fulfill (i) over a connected spatial extent
   (11 points in the simulation grid ~ 5mm)

(iii) track possible blobs for a least 50 time steps (~25 µs)
Statistics of blob trajectories

- Blob trajectory density (a.u.)
- Skewness

Spreading model

mean free energy

\[
\frac{1}{2} \frac{\partial \langle n \rangle^2}{\partial t} = - \frac{\partial}{\partial r} \left( \langle n \langle \tilde{v}_r \tilde{n} \rangle \rangle \right) + \langle \frac{\partial n}{\partial r} \rangle \langle \tilde{v}_r \tilde{n} \rangle.
\]

turbulent energy

\[
\frac{1}{2} \frac{\partial \langle \tilde{n}^2 \rangle}{\partial t} = - \langle \frac{\partial n}{\partial r} \rangle \langle \tilde{v}_r \tilde{n} \rangle - \frac{1}{2} \frac{\partial}{\partial r} \langle \tilde{v}_r \tilde{n}^2 \rangle.
\]
Spreading model

mean free energy

\[
\frac{1}{2} \frac{\partial \langle n \rangle^2}{\partial t} = - \frac{\partial}{\partial r} \left( \langle n \rangle \langle \tilde{v}_r \tilde{n} \rangle \right) + \left\langle \frac{\partial n}{\partial r} \right\rangle \langle \tilde{v}_r \tilde{n} \rangle.
\]

turbulent energy

\[
\frac{1}{2} \frac{\partial \langle \tilde{n}^2 \rangle}{\partial t} = - \left\langle \frac{\partial n}{\partial r} \right\rangle \langle \tilde{v}_r \tilde{n} \rangle - \frac{1}{2} \frac{\partial}{\partial r} \langle \tilde{v}_r \tilde{n}^2 \rangle.
\]

energy exchange
Spreading model

Mean free energy

\[
\frac{1}{2} \frac{\partial \langle n \rangle^2}{\partial t} = - \frac{\partial}{\partial r} \left( \langle n \rangle \langle \tilde{v}_r \tilde{n} \rangle \right) + \langle \frac{\partial n}{\partial r} \rangle \langle \tilde{v}_r \tilde{n} \rangle.
\]

Turbulent energy

\[
\frac{1}{2} \frac{\partial \langle \tilde{n}^2 \rangle}{\partial t} = - \langle \frac{\partial n}{\partial r} \rangle \langle \tilde{v}_r \tilde{n} \rangle - \frac{1}{2} \frac{\partial}{\partial r} \langle \tilde{v}_r \tilde{n}^2 \rangle.
\]

Local drive

\[
\omega_D = - \frac{\langle \frac{\partial n}{\partial r} \rangle \langle \tilde{v}_r \tilde{n} \rangle}{\frac{1}{2} \langle \tilde{n}^2 \rangle}
\]

Turbulent spreading

\[
\omega_S = - \frac{1}{2} \frac{\partial}{\partial r} \langle \tilde{v}_r \tilde{n}^2 \rangle \Bigg/ \frac{1}{2} \langle \tilde{n}^2 \rangle.
\]
Local drive vs. spreading

\[ \omega_D = -\frac{\langle \partial n / \partial r \rangle \langle \tilde{v}_r \tilde{n} \rangle}{\frac{1}{2} \langle \tilde{n}^2 \rangle} \]

\[ \omega_S = -\frac{\frac{1}{2} \partial}{\partial r} \langle \tilde{v}_r \tilde{n}^2 \rangle}{\frac{1}{2} \langle \tilde{n}^2 \rangle} \]


Nonlocal transport in SOL
Conducting wall instability

$\nabla T$

$\tilde{\phi} = \Lambda \tilde{T}_e < 0$

$\tilde{\phi} = \Lambda \tilde{T}_e > 0$

$\nu_{\text{ExB}}$

$E$

$r$

$B \bigotimes$

see talk by Valentina Nikolaeva today

Results from HSX

ETDB (www.ipp.mpg.de/ISS/)

Local drive (kHz)

Spreading drive (kHz)
Results from TJ-K and WEGA

ETDB (www.ipp.mpg.de/ISS/)

TJ-K

WEGA

Nonlocal transport in SOL

F.Fischer Batchelor thesisTUM
• Blobs are not generated at one particular position

• At ASDEX Upgrade L-mode sheath connected conditions most blobs are generated outside the separatrix (CWI)

• Turbulence spreading a more suitable diagnostics for blob generation than the skewness alone

• Turbulence spreading should play the key role for turbulence in the far-SOL (once the background gradient is small)

local drive
\[ \omega_D = -\frac{\langle \frac{\partial n}{\partial r} \rangle \langle \tilde{v}_r \tilde{n} \rangle}{\frac{1}{2} \langle \tilde{n}^2 \rangle} \]

turbulent spreading
\[ \omega_S = -\frac{1}{2} \frac{\partial}{\partial r} \frac{\langle \tilde{v}_r \tilde{n}^2 \rangle}{\frac{1}{2} \langle \tilde{n}^2 \rangle} \]
Skewness as the basic parameter

\[ \text{Skewness} \]

\[ \text{blob generation position (skewness = 0)} \]

\[ \text{Isat (}\sigma\text{)} \]

\[ \log \text{PDF} \]

\[ \text{skewness} = 0.87 \]

ASDEX Upgrade: B. Nold et al. PPCF 2010

P. Manz

Nonlocal transport in SOL
Additional material
GEMR (AUG) finite Larmor radius effects

P. Manz
GEMR (TJ-K)
Blobs propagate radially outward

- **charge separation by curvature/gradB drift**
  \[
  \mathbf{V}_D \nabla B = - \frac{W}{q} \frac{\mathbf{B} \times \mathbf{B}}{B^3}
  \]

- **ExB drift accelerates blobs radially**
  \[
  \mathbf{V}_D \mathbf{E} \times \mathbf{B} = \frac{\mathbf{E} \times \mathbf{B}}{B^2}
  \]

Plasma filaments or blobs

Blobs are intermittently expelled density filaments in the scrape-off layer (SOL)

- Elongated along the magnetic field line
- Low magnetic field component (in contrast to ELMs)

[Origin and turbulence spreading of plasma blobs]

[B. Nold, PhD thesis]