EDGE TURBULENCE AND TRANSPORT AS A POSSIBLE CAUSE OF THE TOKAMAK DENSITY LIMIT

MARTIN GREENWALD, BRIAN LABOMBARD
& ALCATOR GROUP
MIT - PLASMA SCIENCE & FUSION CENTER

Presented at
APS-DPP Orlando
November, 2002
Disruptive limit from edge cooling ⇒ current profile shrinks

Hypothesis: Density or collisionality dependent transport ⇒ edge cooling

No widely accepted first principles theory available

Not even agreement on critical physics

How about the role of radiation cooling? \( P_{RAD} \propto n_e^2 f_Z R(T_e) \)

- Power and impurity dependence too strong ⇒ \( n_{LIM} \propto \sqrt{P_{IN}/(Z_{EFF} - 1)} \)

- Threshold mechanisms (MARFEs, detachment, etc) show up well below density limit

- Transport assumptions: ad hoc at best
TURBULENT TRANSPORT IN EDGE INCREASES WITH COLLISIONALITY

- Two regimes observed in scrape-off layer (SOL)
  - Near-SOL: steep gradients, $T_e$ high
  - Far-SOL: flat profiles, $T_e$ low
- Particle flux and transport
  - Near-SOL: cross-field transport low
  - Far-SOL: cross-field transport high
- Fluctuation changes character
  - Near-SOL: low amplitude, short correlation times and lengths
  - Far-SOL: large amplitude, bursty, long correlation times
BURSTY TRANSPORT DOMINATES SOL

Normalized RMS fluctuation level & auto-correlation time of $I_{sat}$ increase as distance into SOL increases.

Probability distribution functions of emission get more skewed toward larger events, as distance into SOL increases.
WE CAN VISUALIZE THE FAR-SOL FLUCTUATIONS - BLOBS

- Fast CCD camera images, 4 µsec framing time
- D$_2$ gas puff $\Rightarrow$ localization
- Large "blobs" dominate far-SOL
- Blobs move poloidally and radially
- Correlation length, correlation time, propagation velocity consistent with probe measurements

(Terry KL2.001)
As the density limit is approached, high transport regime crosses separatrix and moves into main plasma.

- Has the potential to explain range of density limit phenomena.
- Fluctuations can cool edge, eliminate edge shear layer.
- Note: Cooling will precipitate MARFEs, detachment if they have not already occurred.
- Threshold condition? – need to understand interaction of turbulence and profiles – feedback loops.
MAGNITUDES OF TRANSPORT PARAMETERS CORRELATE WITH $n_e/n_G$

- $D_{\text{eff}} = \Gamma/\nabla n$, $V_{\text{eff}} = \Gamma/n$
- $n_e/n_G$ is a proxy for collisionality and other variables critical for the limit
- Turbulence driven convection can compete with parallel transport
- Loss of “stabilizing” influence of parallel transport
- Destruction of shear layer?
• Non-linear 3D gyro-fluid simulations have found regime of extremely high transport

• \( \alpha = -Rq^2 d \beta / dr \) (normalized pressure gradient)

• \( \alpha_D = \rho_s c_s t_0 / L_n L_0 \)

\[
\alpha \left( \frac{T_0^2}{nL_n} \right) \rightarrow \frac{\lambda}{L_n}
\]

(inverse \( \perp \) collisionality)

• Region of ultra-high transport consistent with high density, low temperature

• Similar results from Xu, Hallatschek

• No quantitative predictions yet

(Rogers, Drake PRL 1998)
SUMMARY: We think there is a plausible case for turbulent transport as the critical physical mechanism for the density limit.

Where do we need to go next?

- General question: can we understand the important drives and saturation mechanisms for edge turbulence at high density?
  - What is the role of open field lines and the separatrix? (see Xu UI2.003)
  - Role and dynamics of edge shear layer
  - Does model require that complex transport physics boil down to the "correct" form? Or is it robust with respect to details?
- Where does $I_p$ (or $B_p$) dependence come from?
  - ExB
  - $\alpha_{\text{MHD}}$
- Can we identify a reasonable threshold condition to compute limit?