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

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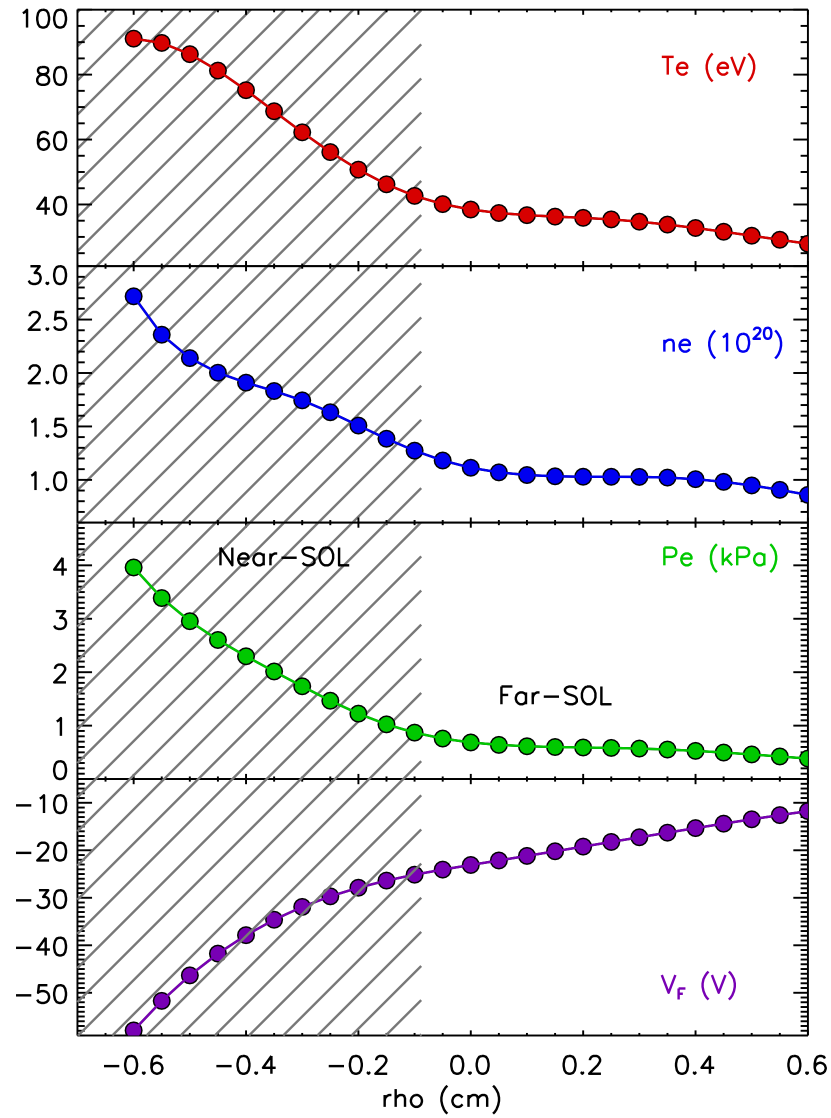
DENSITY LIMITS - THE PHYSICS PROBLEM

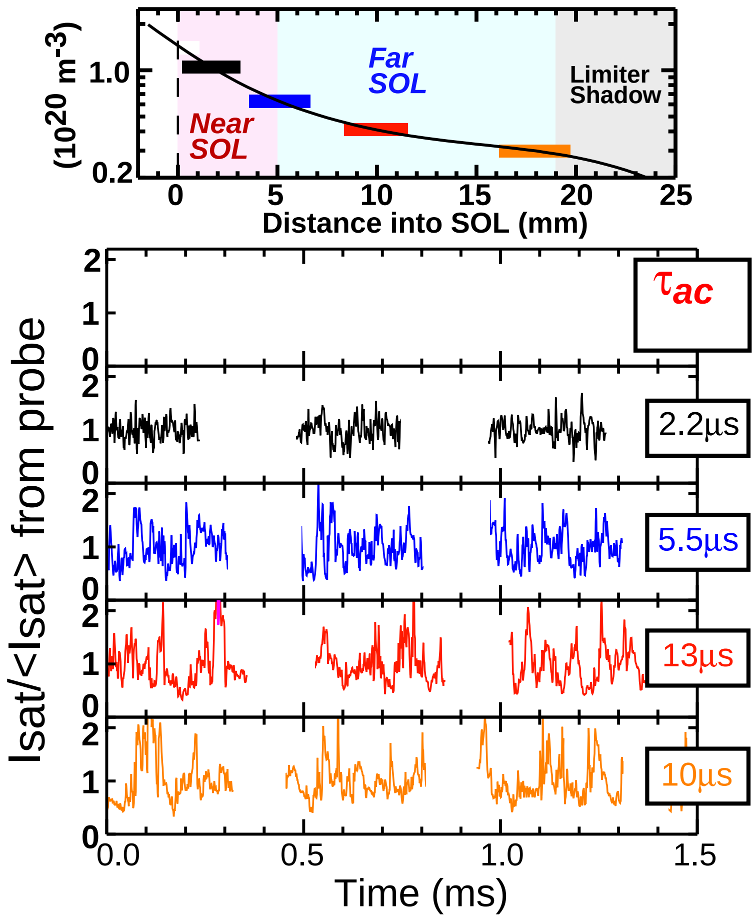
- Disruptive limit from edge cooling $\Rightarrow$ current profile shrinks
- **Hypothesis: Density or collisionality dependent transport $\Rightarrow$ edge cooling**
- **No widely accepted first principles theory available**
- **Not even agreement on critical physics**
- How about the role of radiation cooling? $P_{RAD} \propto n_e^2 f_Z R(T_e)$
  - Power and impurity dependence too strong $\Rightarrow n_{LIM} \propto \sqrt{P_{IN}/(Z_{EFF}-1)}$
  - Threshold mechanisms (MARFEs, detachment, etc) show up well below density limit
  - Transport assumptions: ad hoc at best

TURBULENT TRANSPORT IN EDGE INCREASES WITH COLLISIONALITY

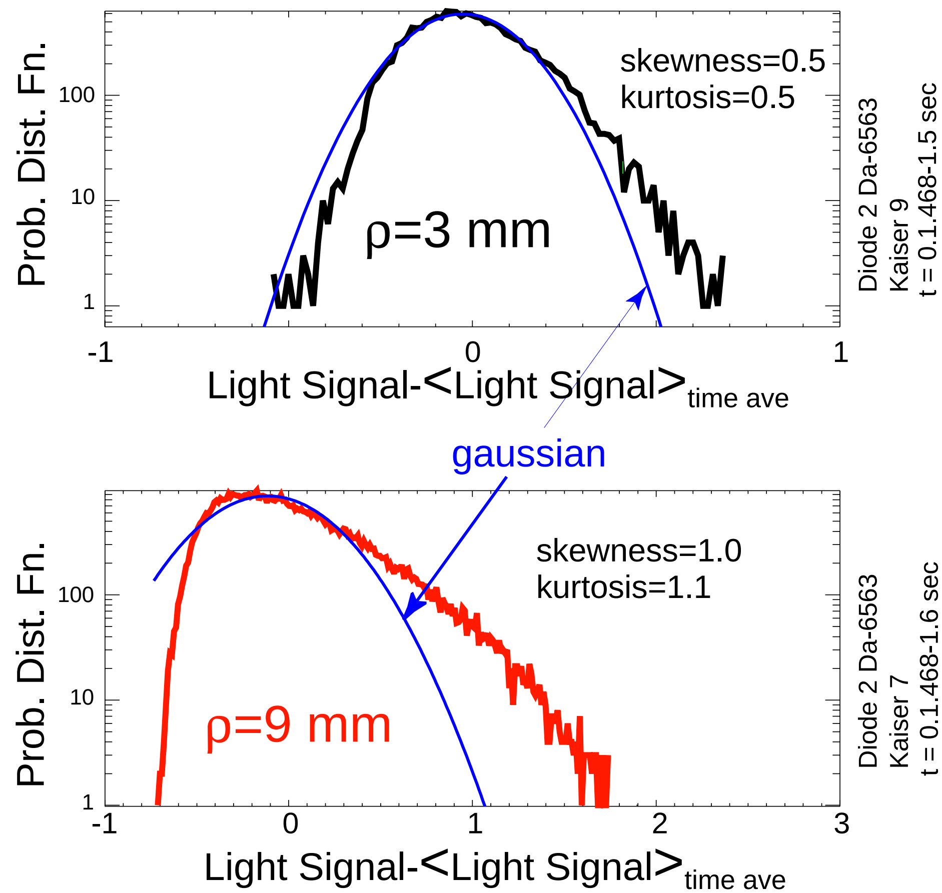
- **Two regimes observed in scrape-off layer (SOL)**
  - Near-SOL: steep gradients, Te high
  - Far-SOL: flat profiles, Te low
- **Particle flux and transport**
  - Near-SOL: cross-field transport low
  - Far-SOL: cross-field transport high
- **Fluctuation changes character**
  - Near-SOL: low amplitude,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



BURSTY TRANSPORT DOMINATES SOL



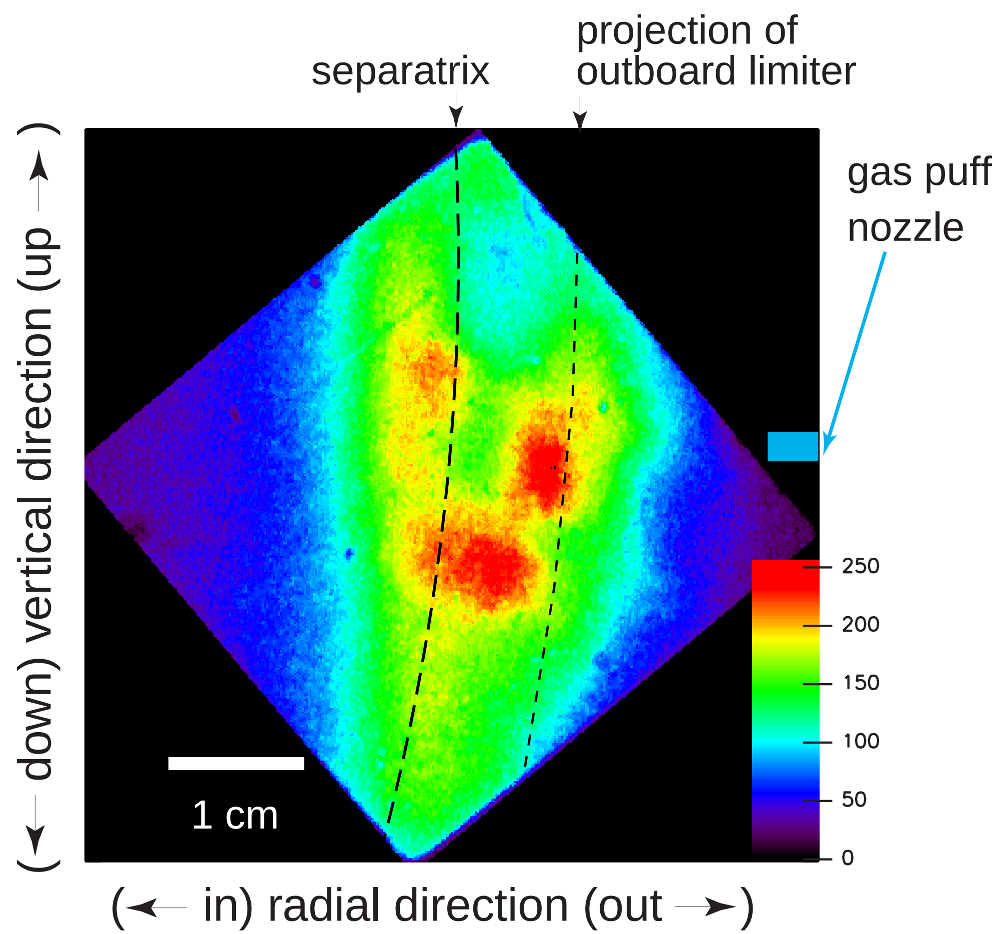
Normalized RMS fluctuation level & auto-correlation time of I_{sat} increase as distance into SOL increases



Probability distribution functions of emission get more skewed toward larger events, as distance into SOL increases

WE CAN VISUALIZE THE FAR-SOL FLUCTUATIONS - BLOBS

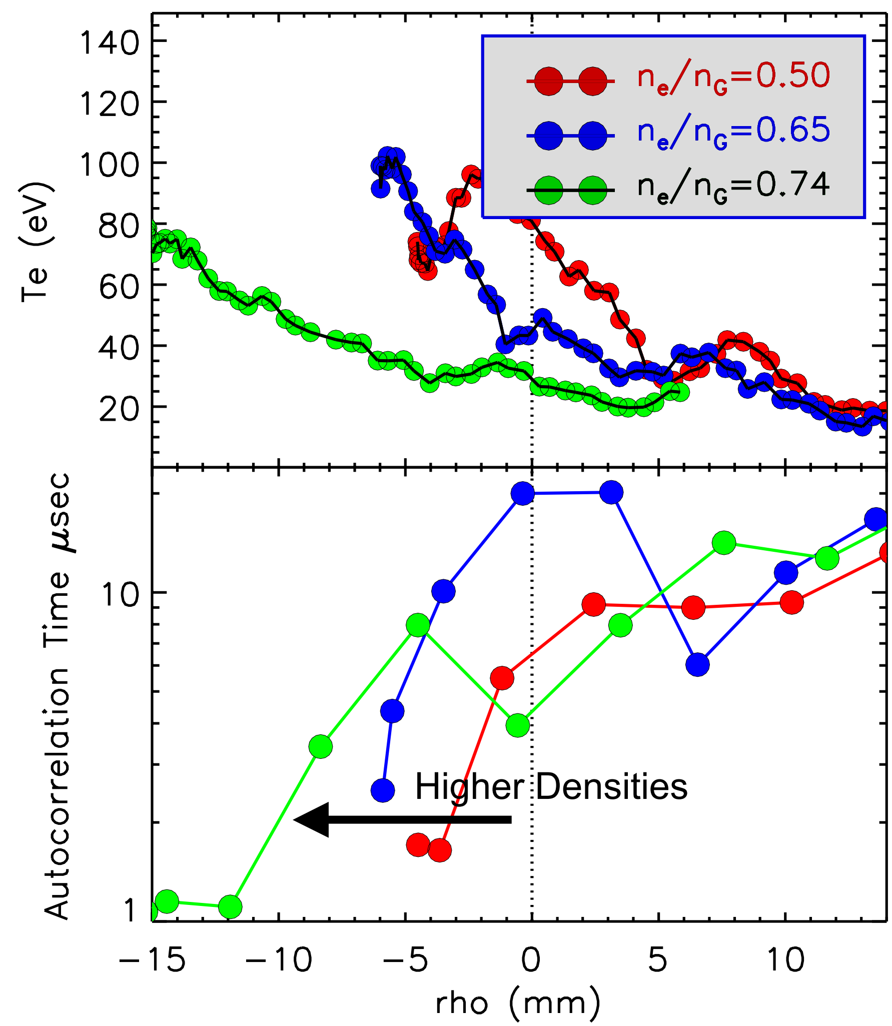
- Fast CCD camera images, 4 μsec framing time
- D_2 gas puff $\Rightarrow$ localization
- Large "blobs" dominate far-SOL
- Blobs move poloidally and radially
- Correlation length, correlation time, propagation velocity consistent with probe measurements



(Terry KI2.001)

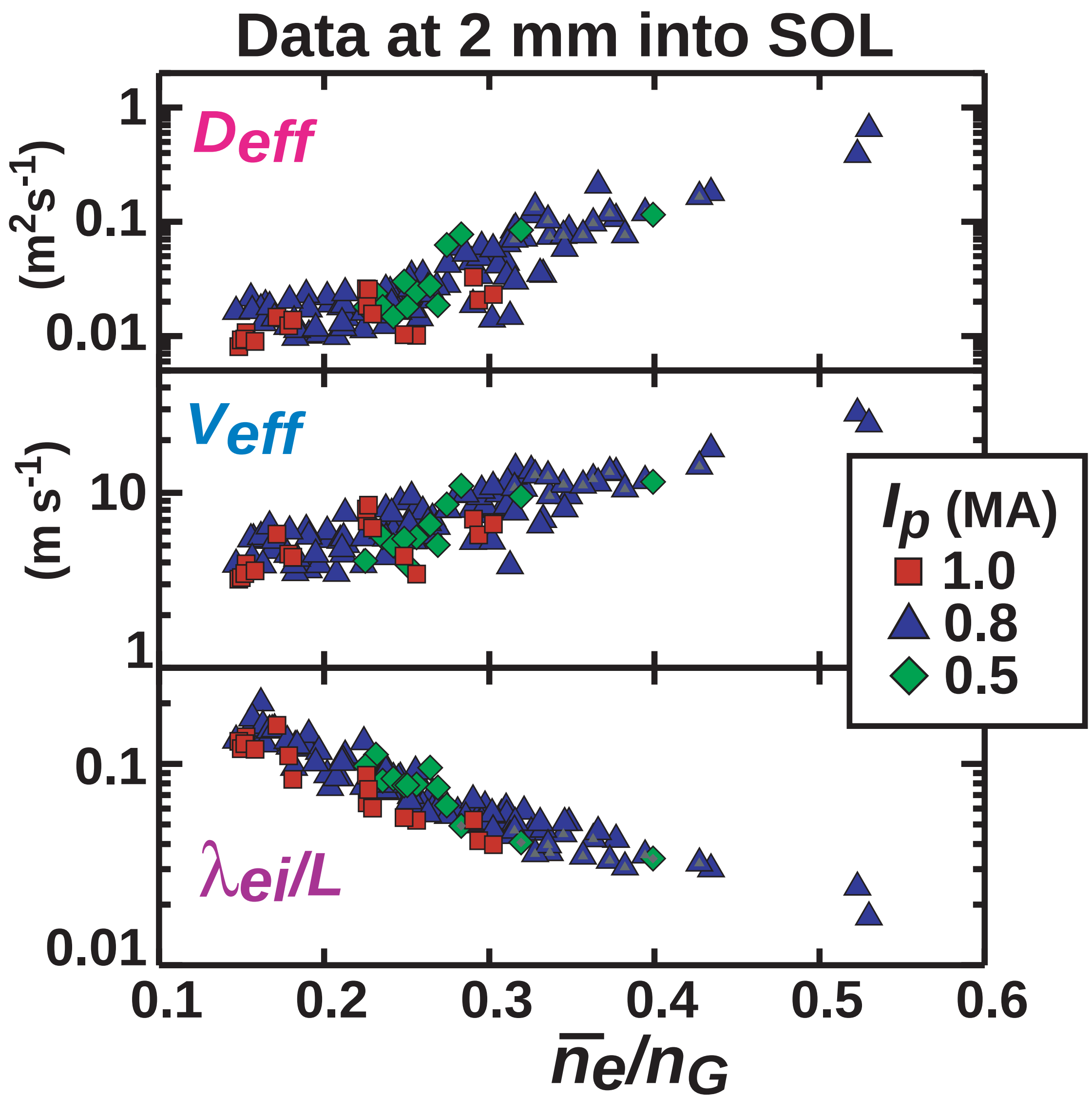
AS THE DENSITY LIMIT IS APPROACHED, HIGH TRANSPORT REGIME CROSSES SEPARATRIX AND MOVES INTO MAIN PLASMA

- 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

- $D_{EFF} = \Gamma/\nabla n$, $V_{EFF} = \Gamma/n$
- 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?

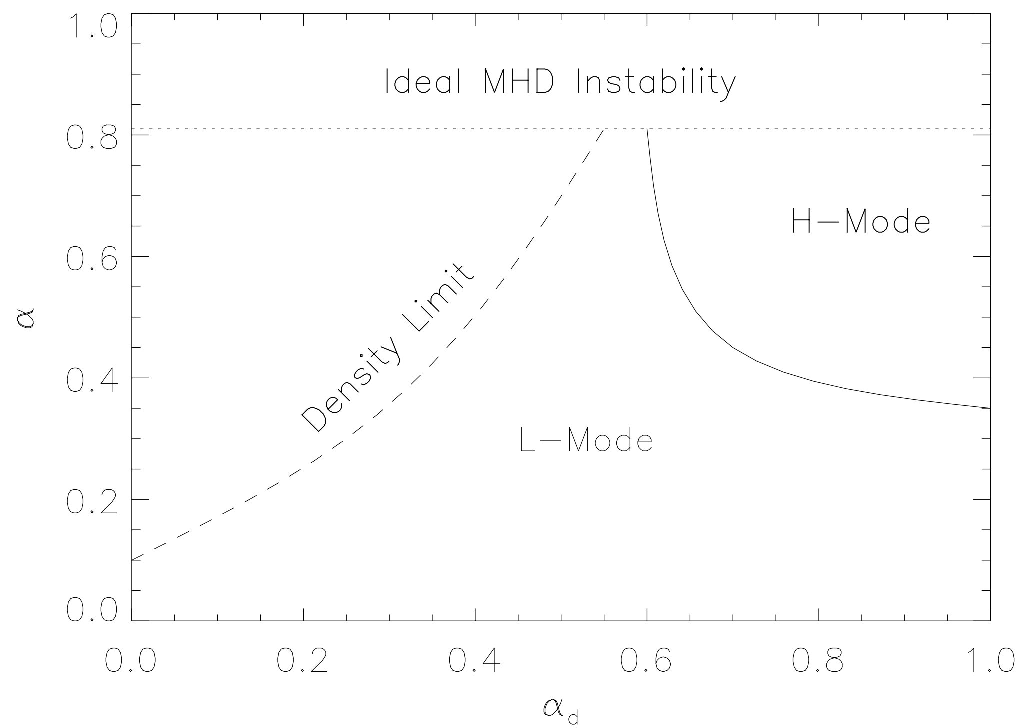


SOME SUPPORT FROM EDGE TURBULENCE SIMULATIONS

- Non-linear 3D gyro-fluid simulations have found regime of extremely high transport
- $\alpha = -Rq^2 d\beta / dr$ (normalized pressure gradient)
- $\alpha_D = \rho_s c_s t_0 / L_n L_0$

$$\propto \left(\frac{T^2}{nL_n} \right) \rightarrow \frac{\lambda}{L_n}$$

(inverse ⊥ collisionality)



(Rogers, Drake PRL 1998)

- Region of ultra-high transport consistent with high density, low temperature
- Similar results from Xu, Hallatschek
- No quantitative predictions yet

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
  - α_{MHD}
- Can we identify a reasonable threshold condition to compute limit?