ENERGY CONFINEMENT IMPROVED WITH NEON INJECTION IN THE DIII–D TOKAMAK*

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INTRODUCTION

- **L-mode energy confinement has been observed to improve with impurity radiation on several tokamaks both limiters and divertors.**
  - **ISXB Z-mode (1985)**
  - **JFT-2M IL-mode (1988)**
  - **TEXTOR I-mode (1994), RI-mode (1996)**
  - **ASDEX-U (1995)**
  - **DIII-D (1997)**

- **The energy confinement times are as high as ELM free H-mode in the best cases but more typically about 1.5 times ITER-89p-P L-mode scaling.**

- **Favorable conditions include: neon injection, high density, q95=3, no sawteeth, co-NBI.**

- **Some DIII-D discharges with neon injection make a transition from an improved low mode (IL-mode) to and improved high mode (IH-mode). The IH-mode is an ELM free plasma with an edge transport barrier but with energy confinement higher than normal H-modes.**

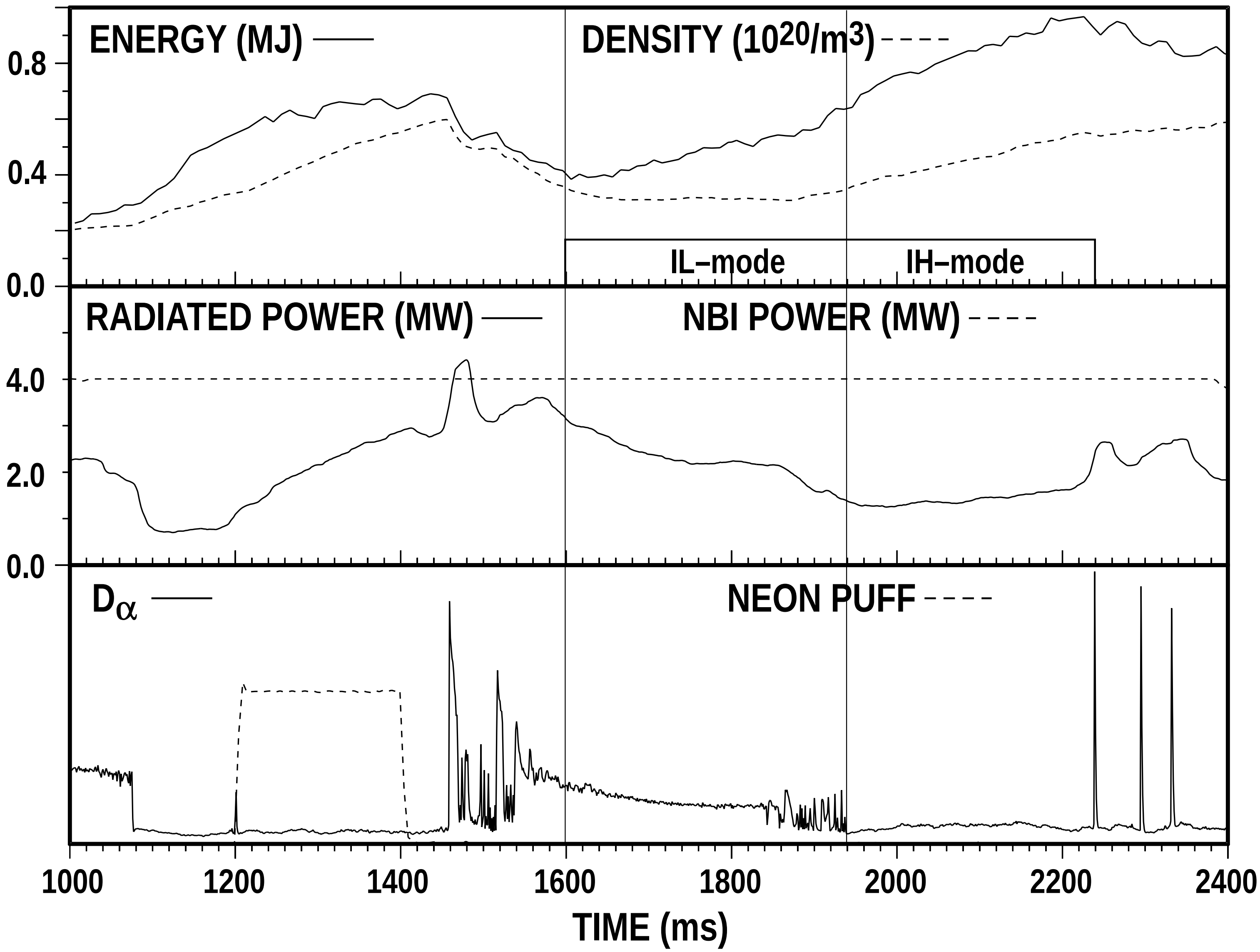
- **Analysis of a single DIII-D discharge (86457) which has both an IL-mode and IH-mode phase will be presented.**

- **The fully stripped neon density profile has been measured with CER for the first time in an enhanced regime due to neon radiation.**

- **The ExB velocity shear will be shown to suppress the drift wave turbulence in the central region in both IL- and IH-mode.**

- **The neon impurity itself is found to directly reduce the transport due to high wavenumber electron temperature gradient (ETG) modes.**

OVERVIEW OF DIII–D SHOT 86457



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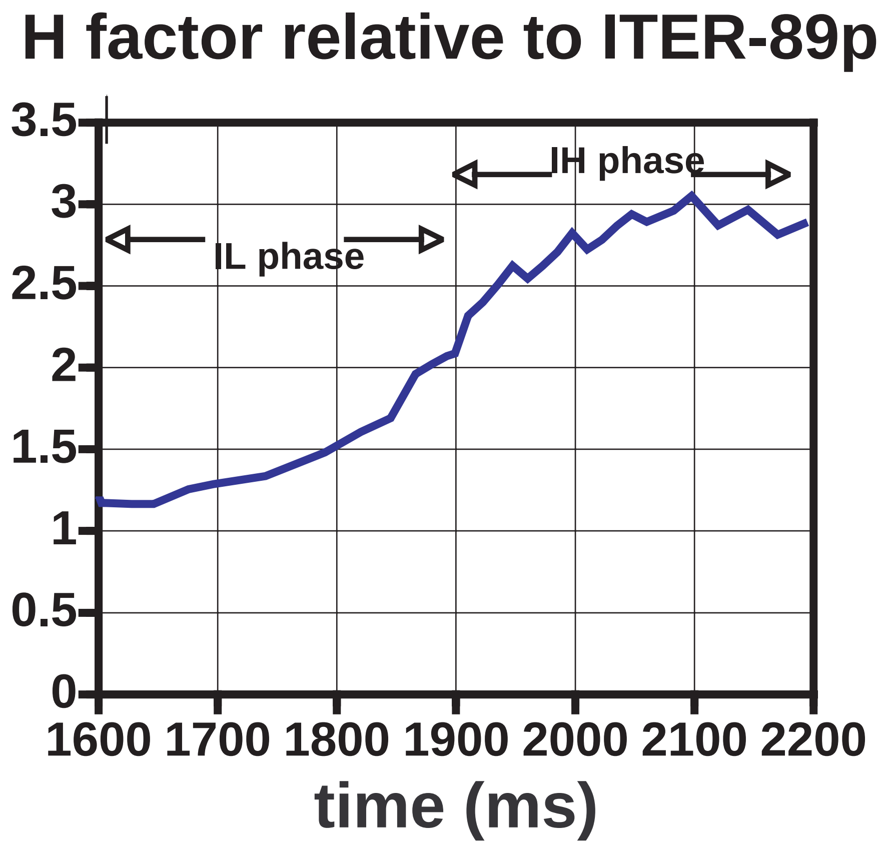
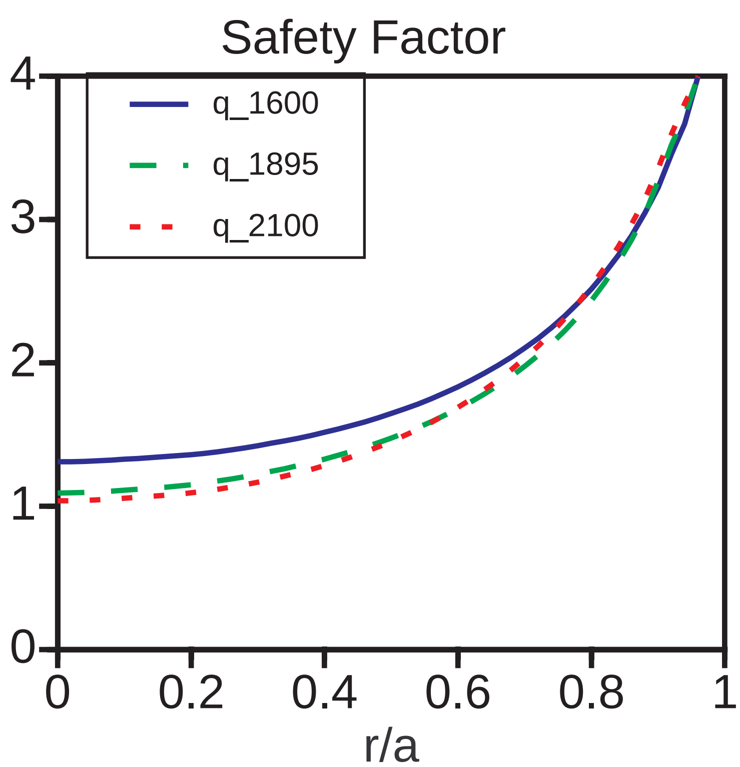
ENERGY CONFINEMENT FOR 86457

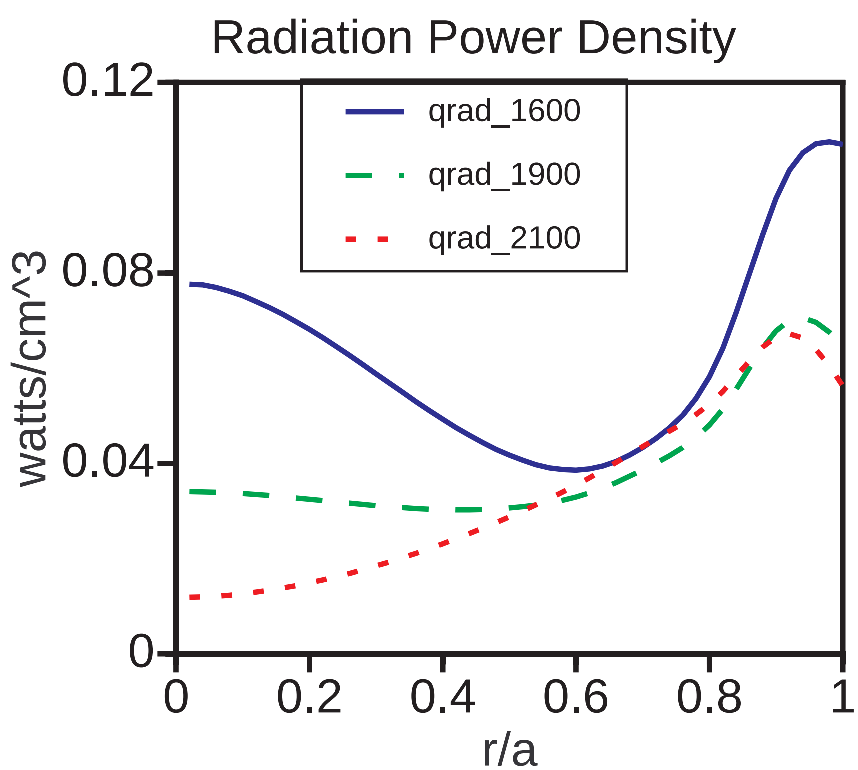
- The energy confinement doubles during the IL-mode phase.
- At the peak performance of the IH-mode the energy confinement is 3 times ITER-89p scaling.



PROFILES FOR DIII-D SHOT 86457

- **Three time slices are shown: 1.6 s start of IL-mode, 1.9 s end of IL-mode, 2.1 s peak performance time of IH-mode.**





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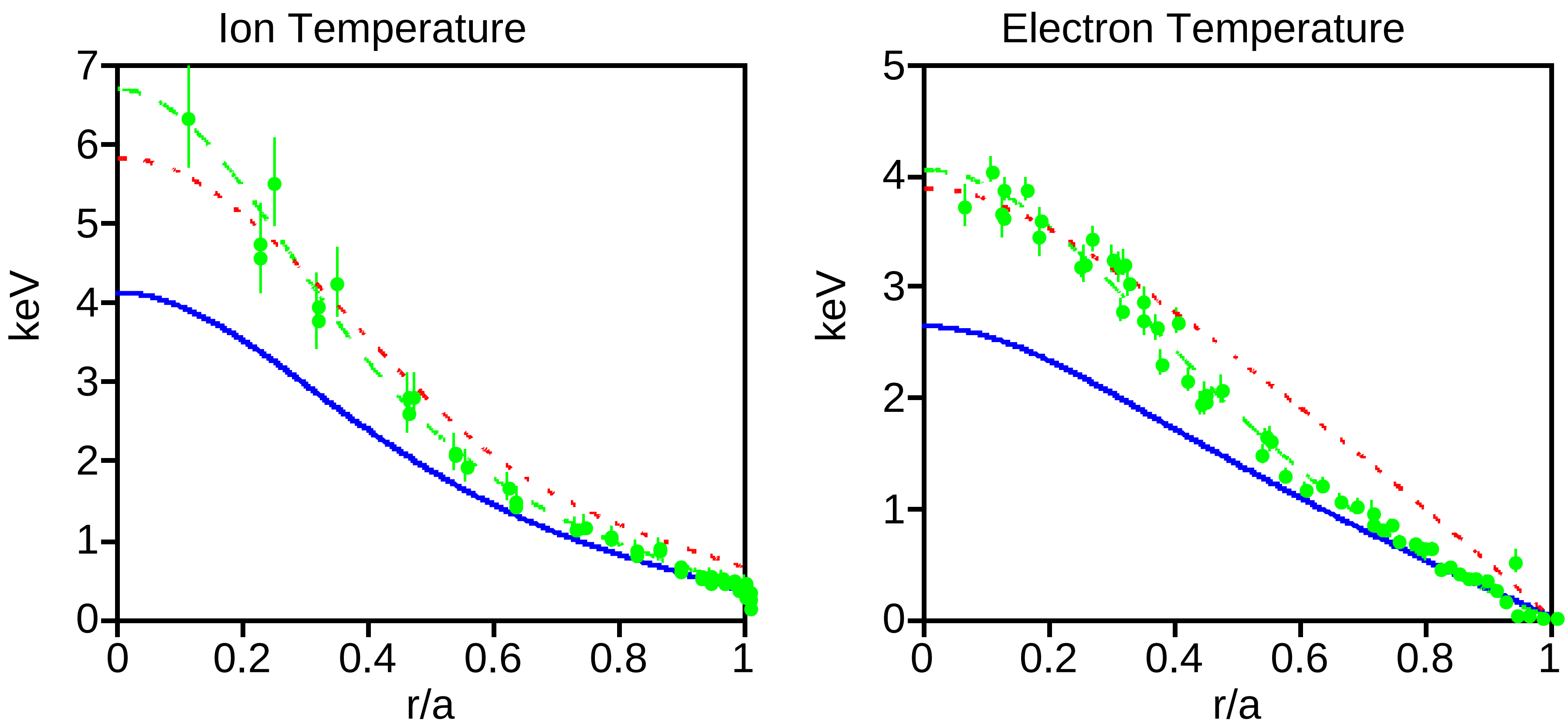
- **The central temperatures rise during the IL-mode phase 1.6-1.9 s.**



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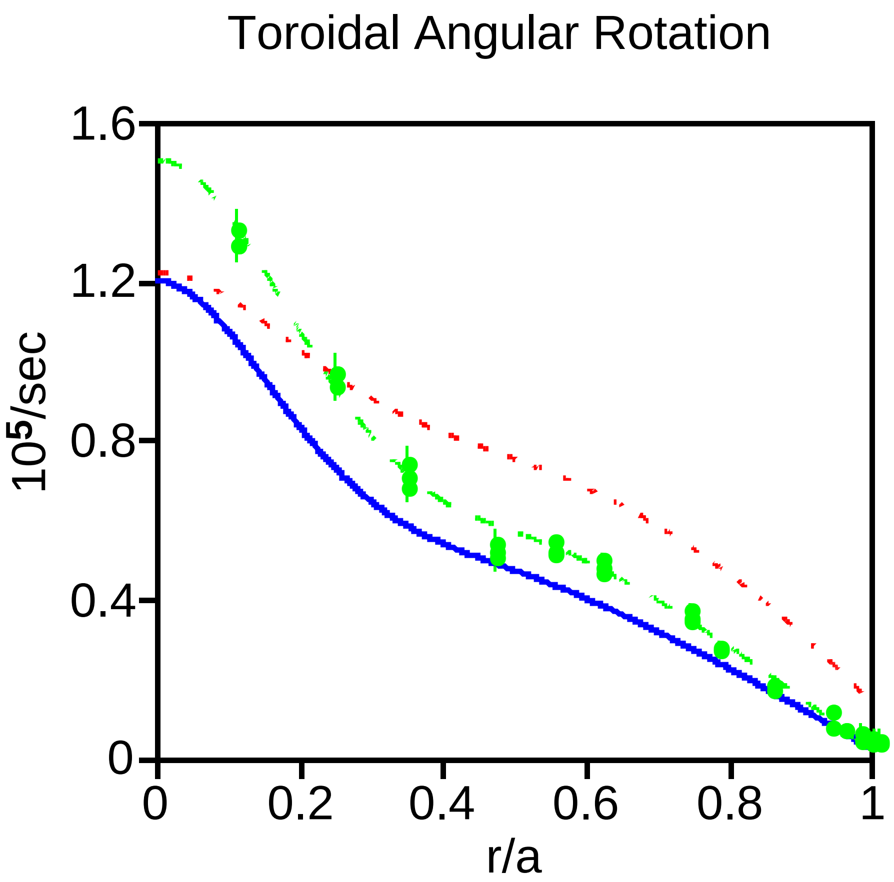
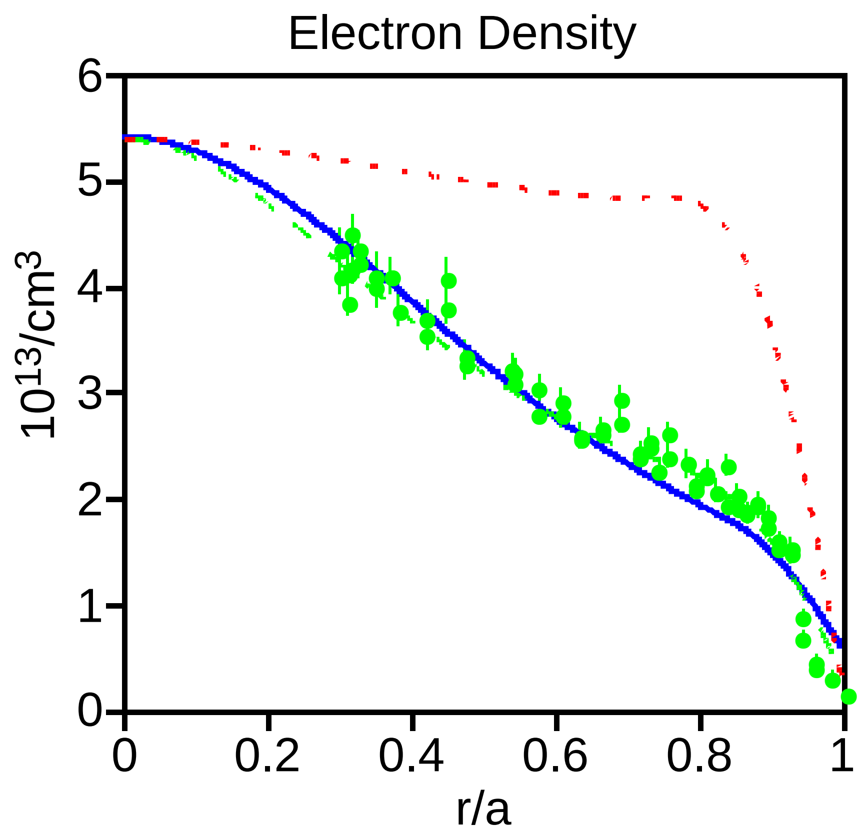
- The toroidal rotation peaks but the electron density is unchanged during the IL-mode phase.

- The electron density profile evolution during the IH-mode 2.1s is typical of ELM free H-modes or VH-modes.





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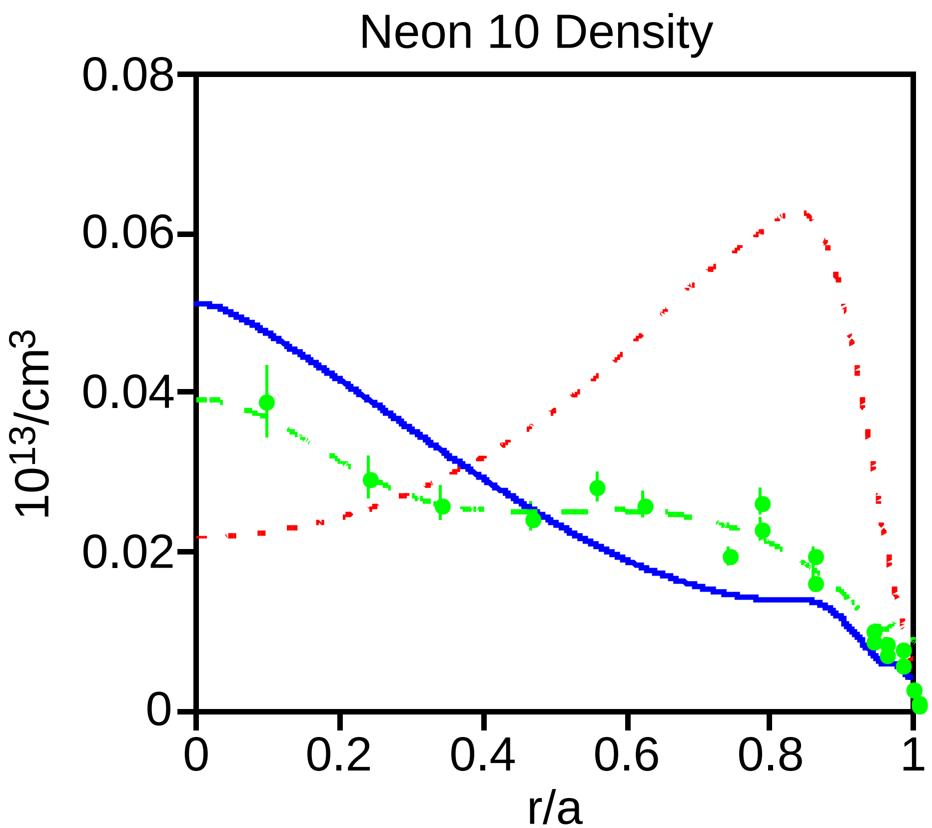
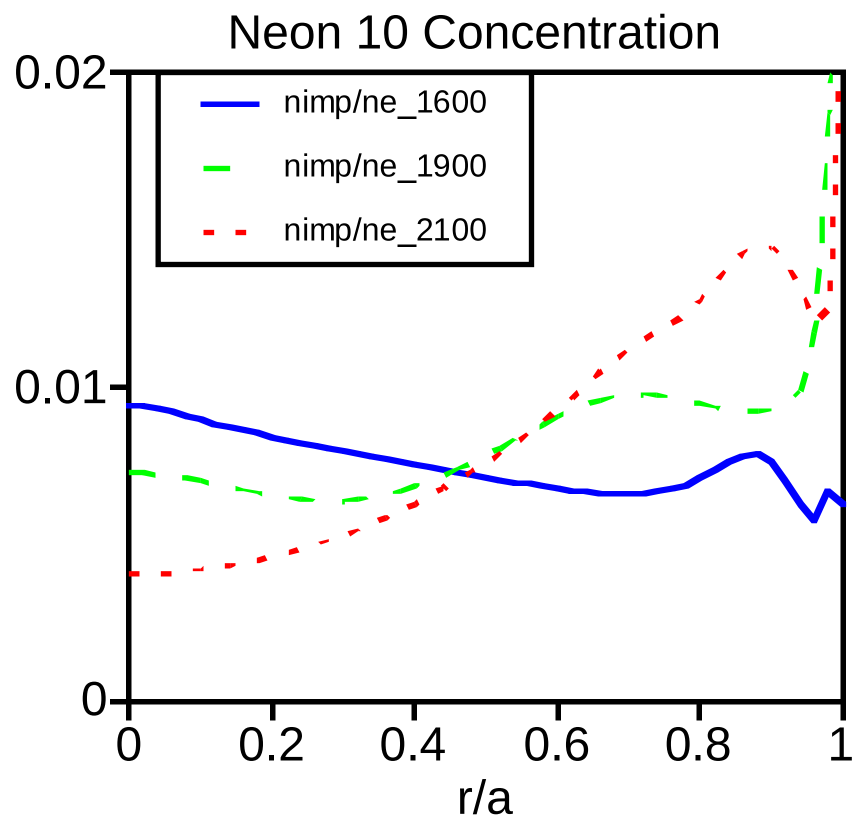
- **The neon 10+ density becomes very hollow after the transition to IH-mode rising at the edge and falling in the center. This behavior is also seen in VH-modes. (M. Wade APS97)**





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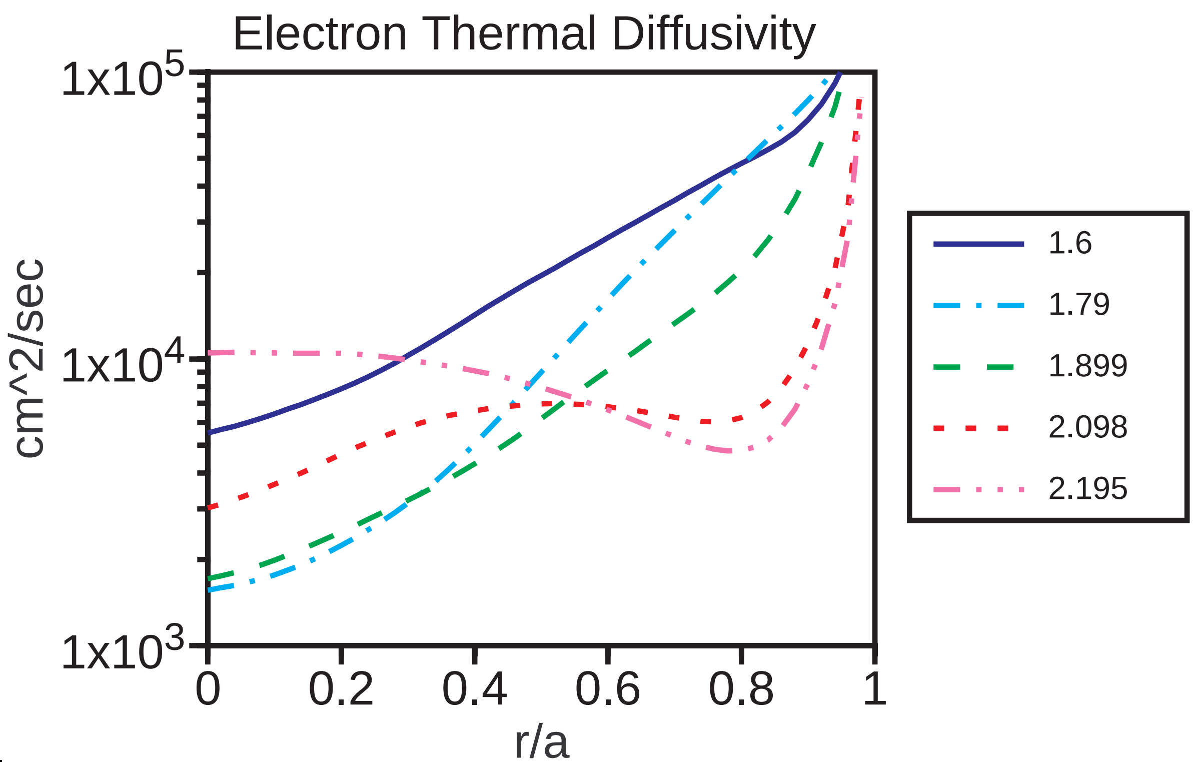
POWER BALANCE THERMAL DIFFUSIVITIES

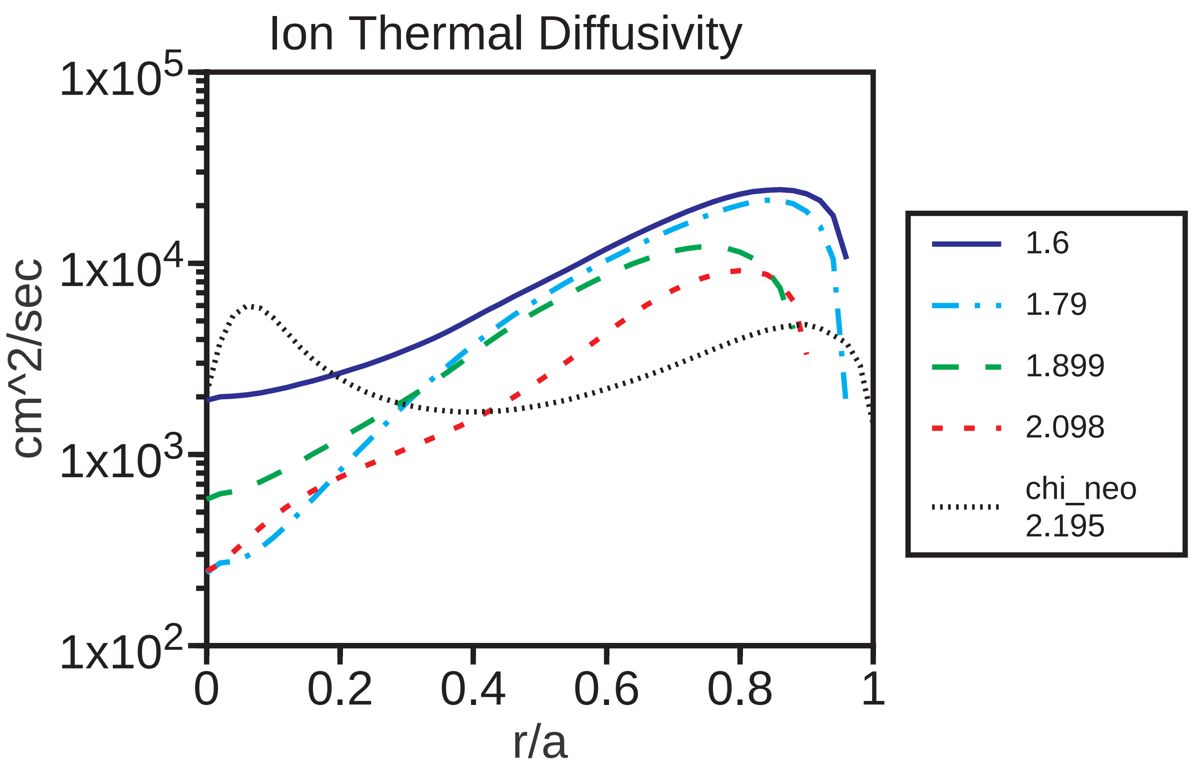
- **The electron thermal diffusivity reduces in the center during the IL-mode phase 1.6,1.8,1.9s but rises in the center during the IH-mode phase 2.1, 2.2 s.**

- **The electron thermal diffusivity shows and inverse relation to the neon density during the IH-mode phase.**



phase.

- **The ion thermal diffusivity reduces first in the center and then expands towards the edge.**



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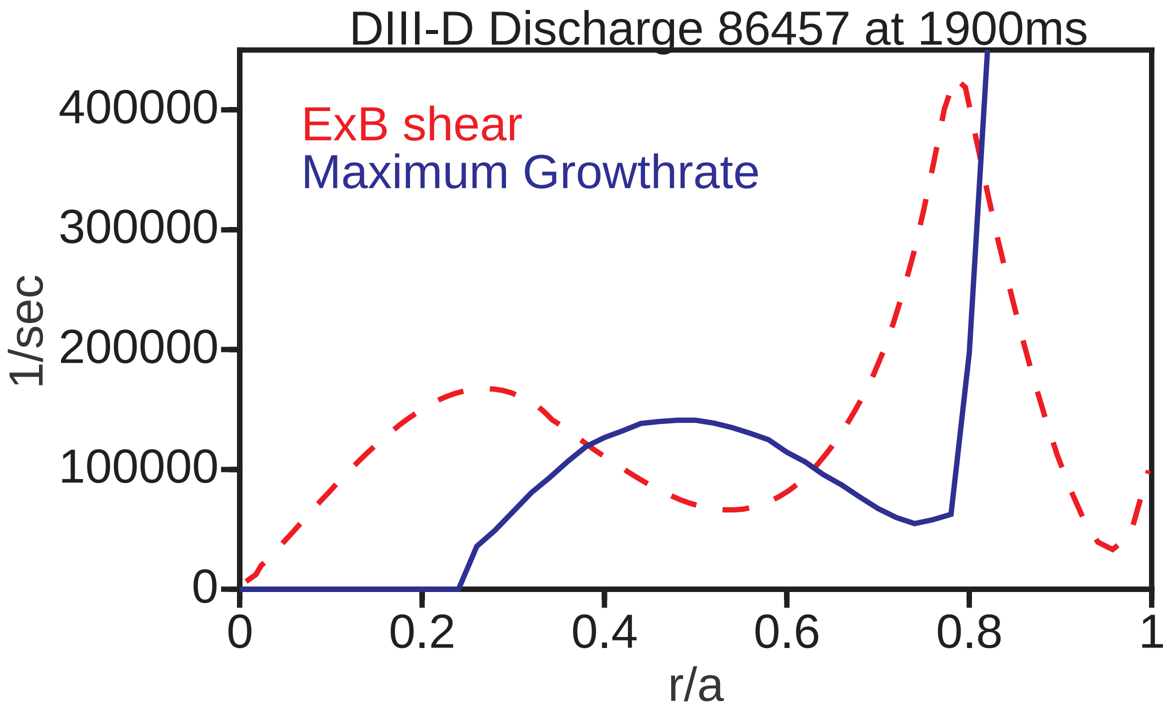
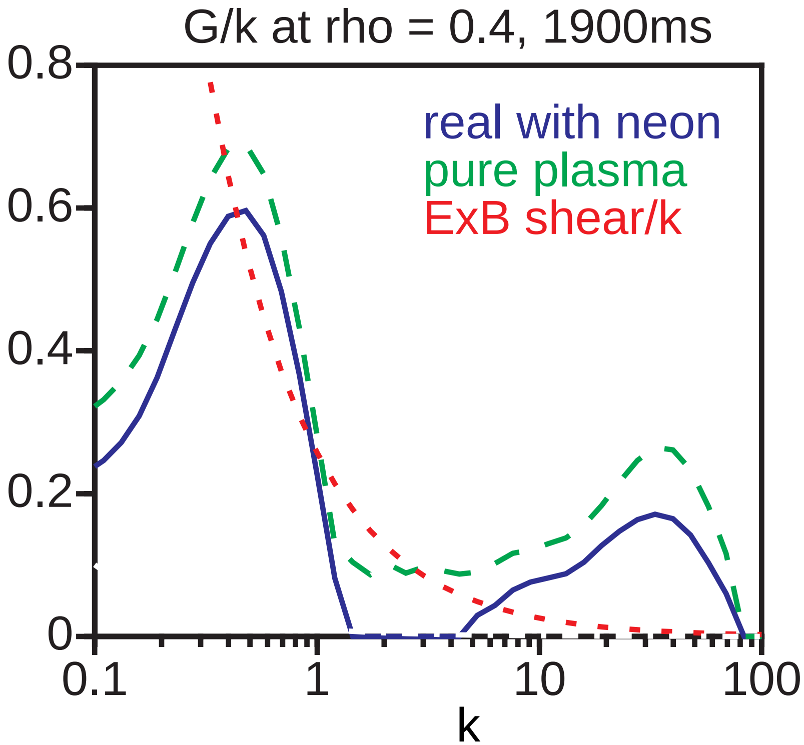
WHAT CAUSES THE IMPROVED ENERGY CONFINEMENT?

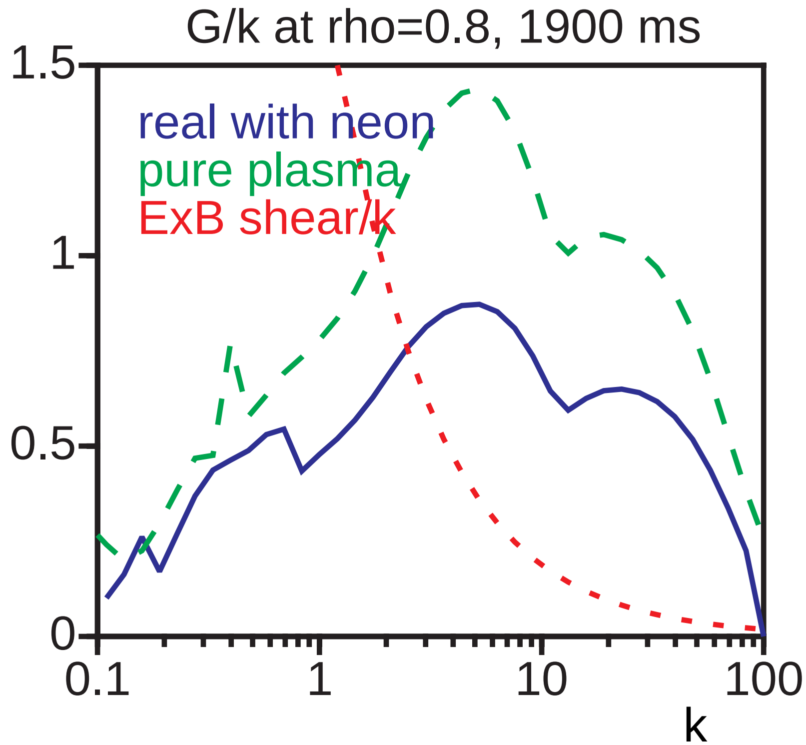
- **The maximum linear growth rate of toroidal ITG modes is computed using M. Kothschenreuther's comprehensive gyrokinetic stability code.**
- **The ITG mode should be quenched in the regions where the ExB shear exceeds the maximum growth rate. (Waltz's rule APS97)**



DRIFT WAVE GROWTH RATE SPECTRA

- The ITG-TEM modes are separated from the ETG mode by a stable gap at r/a=0.4. In this region Waltz's ITG quench rule is expected to work and does.
- At r/a=0.8 there is no stable gap in the drift wave spectrum. The ExB shear is expected to eliminate only the low k part of the spectrum.





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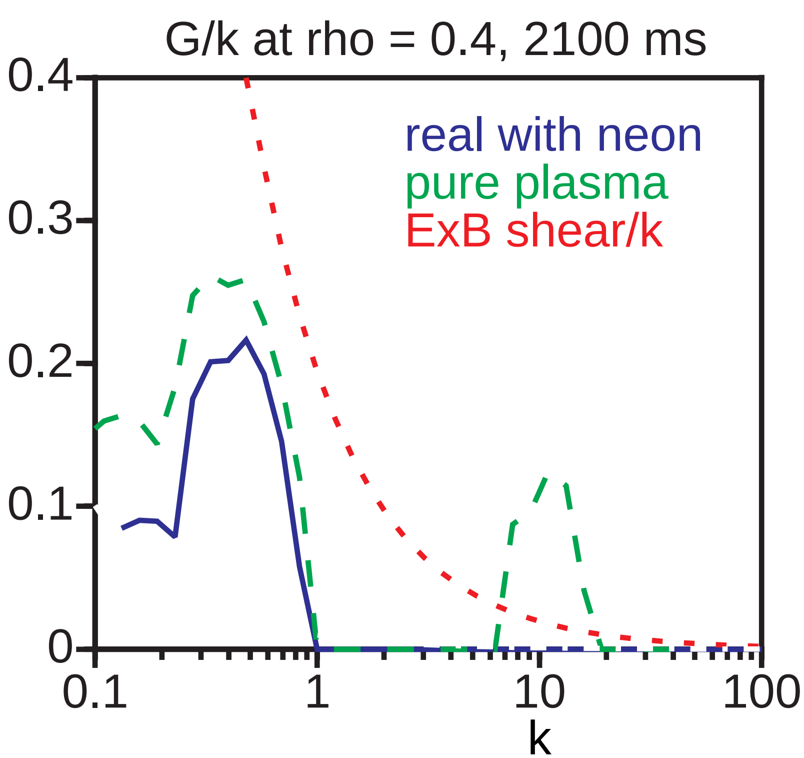
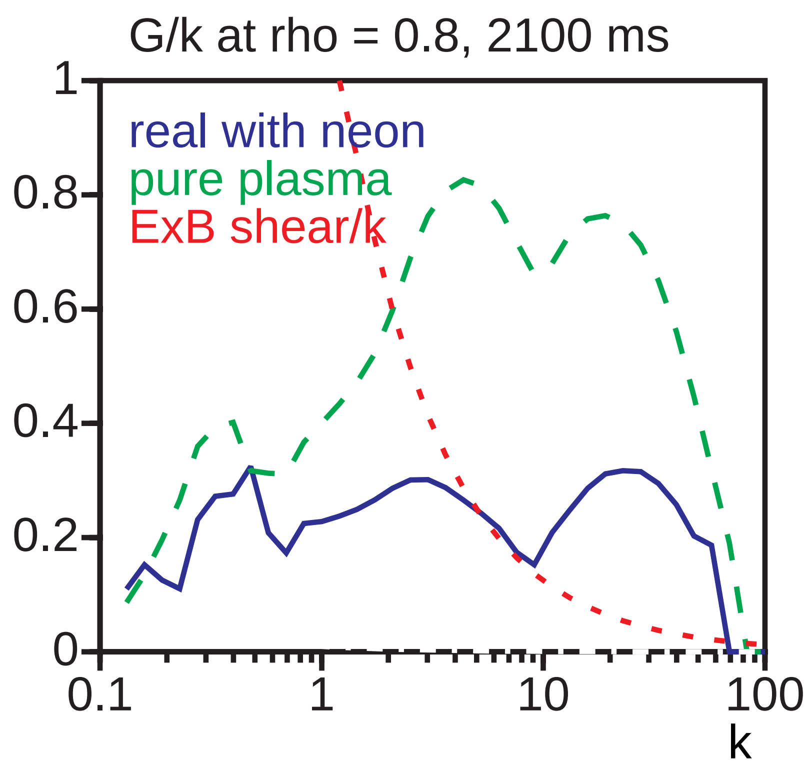
- The neon is directly stabilizing to the high k ETG modes. The transport remaining after ExB shear suppression is about half a large as in a hypothetical pure plasma.
- The neon stabilization of ETG modes agrees with the inverse correlation between the electron thermal diffusivity and the neon concentration in IH-mode.
- The neon stabilization of the ETG modes is a mass dependent effect. It is a candidate to explain the isotope effect. It should primarily effect the electron thermal transport.





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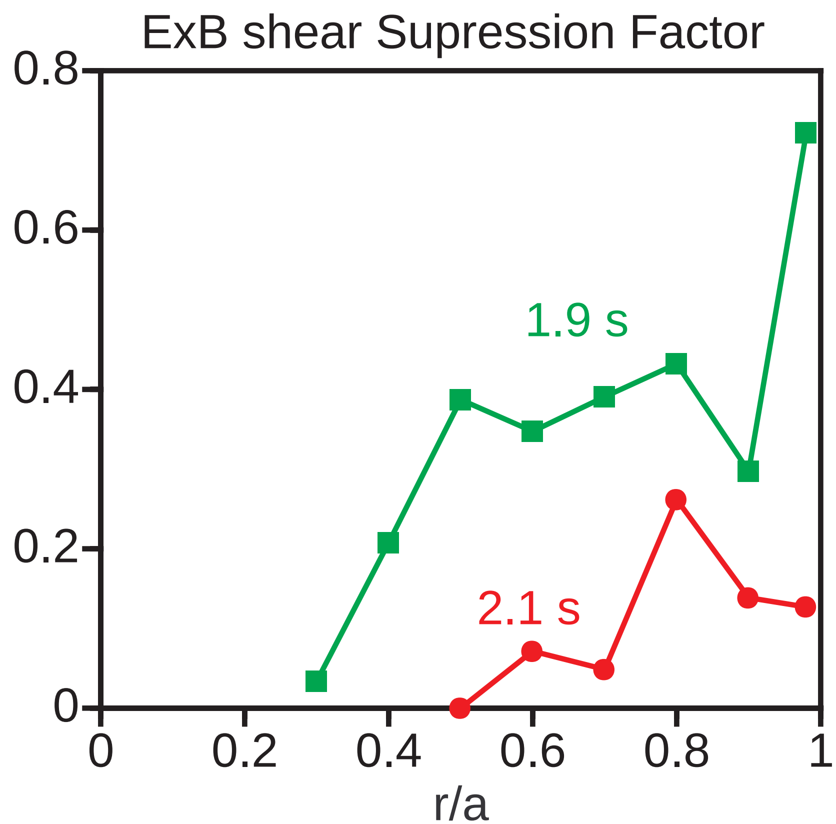
- Integrating (G-W_{ExB})/k dlog(k) gives a measure of the turbulent diffusivity including ExB shear. The ratio of this integral to the integral with W_{ExB}=0 is a measure of the ExB shear suppression factor for the turbulent part of the transport.



- The point of complete suppression agrees well with the point where the ion thermal diffusivity crosses neoclassical. The increased suppression in the outer half of the plasma during the IH-mode (2.1s) qualitatively agrees with the power balance trend.

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SUMMARY

- A new high confinement regime has been observed on DIII-D, the IH-mode.
- This regime has reduced turbulent transport in the center and the edge.
- The low k ITG and TEM modes are suppressed by ExB velocity shear.
- The high k ETG modes are stabilized by the neon directly. This is also a possible cause for the isotope effect.
- The IH-mode suggests a path to a steady state ELM-free regime since the neon radiation at the edge could keep the edge pressure gradient below the ideal ballooning mode limit.
- The low core dilution and hollow neon density profile of IH-mode is an advantage over IL-mode.