The Effects of Main Ion Dilution on Transport and Turbulence Ohmic Plasmas in Alcator C-Mod and Comparisons with Gyrokinetic Simulations

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Abstract

Recent gyrokinetic simulation results show that a significant (≥15%) dilution of the main ion species by low-Z impurities can have a significant effect on turbulence and energy transport in low-density ohmic plasmas [1]. Previously this dilution could not be measured easily, because there were no absolute measurements of impurity fractions. To study this effect, new experiments were done where nitrogen was puffed into ohmic plasmas at various densities while a cryopump kept the electron density roughly constant. The turbulence in these plasmas was measured with Phase Contrast Imaging (PCI) [2], and the electron and ion energy transport were computed by the transport analysis code TRANSP. Turbulence simulations based on the plasma profiles were done using the non-linear gyrokinetic simulation code GYRO [3].

Introduction

- Previous gyrokinetic analysis with GYRO indicated that dilution of the main ion species by low-Z impurities can have an effect on the turbulence and transport in ohmic plasmas [1] (see Poster P12 by Porkolab for more information)
- This analysis had only *assumed* an average impurity ion charge and used a derived Z_{eff} to get at the dilution of the main ions
- Experiments were conducted where an impurity ion (in this case nitrogen) was added to change the dilution in a controlled manner

Experimental Setup

- Ohmic target plasmas were done at B_t=5.4T and I_p=0.8 MA from n_e=0.5-1.1 x 10^{20} m^{-3} (line-averaged)
- N2 gas was puffed in until the nitrogen amount reached a steady-state, while a cryopump kept the overall density constant

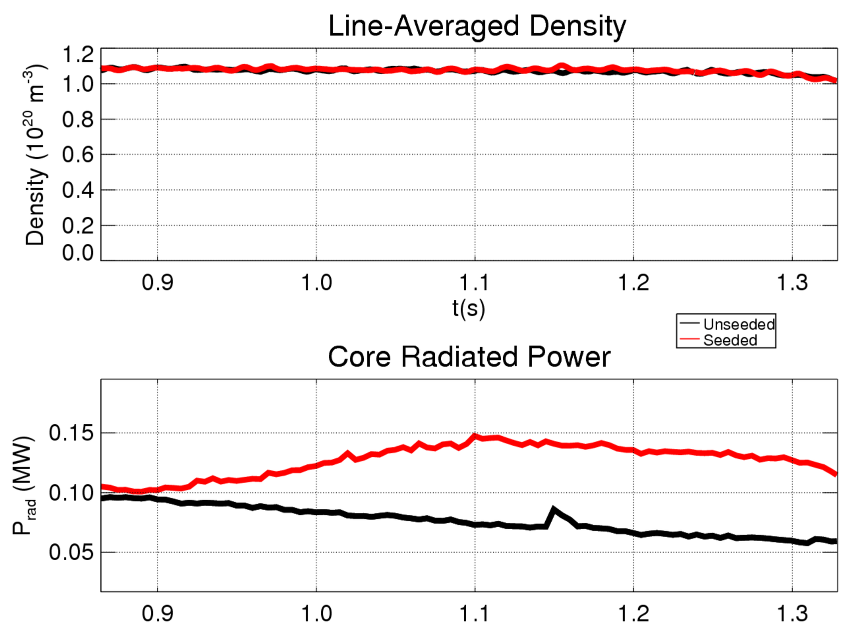
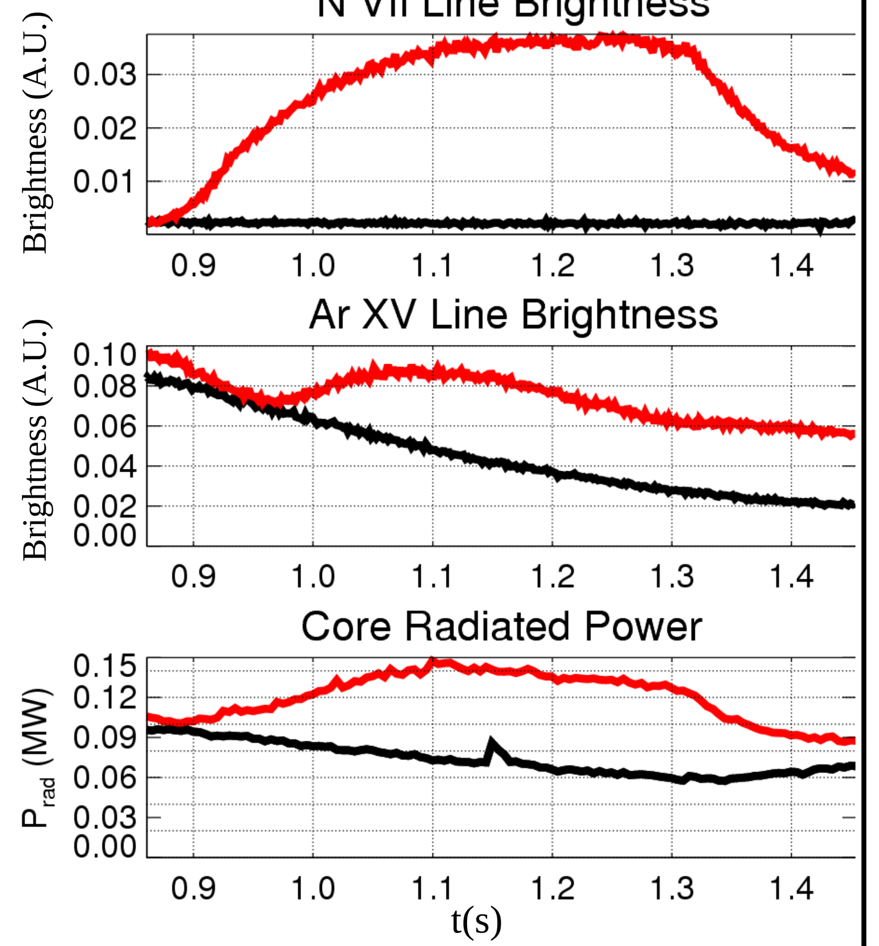


Figure 1: Line-Averaged Density and Core Radiated Power for a Nitrogen Seeded (red) and Unseeded (black) Discharges. Seeding is from 0.9s-1.3s

Experimental Dilution

- Since the line brightness is not an absolute measure of the amount of an impurity species, the impurity density must be inferred from Z_{eff}
- Assuming that n_{imp}/n_e is constant over the profile, the impurity amounts of N and Ar can be found by comparing change in brightness to change in Z_{eff}

Figure 2: Line Brightnesses for a Nitrogen Seeded (red) and Unseeded (black) Discharges. Argon was added to obtain T_i and V_{rot} profiles



$n_e$bar	Z_{eff}	% Ar	% Mo*	% N	% D
1.08	1.35	0.6	0.03	0	98%
1.08	1.65	0.65	<0.01	1.0	93%
0.8	1.7	0.12	0.04	0	97%
0.8	2.5	0.08	0.03	2.3	84%
0.7	2.7	0.23	0.11	0	93%
0.7	3.15	0.06	0.10	2.5	81%
0.5	3.0	0.16	0.17	0	92.5%
0.5	3.65	0.12	0.1	3.3	75%

Table 1: Ion Fractions.
*Molybdenum is Assumed to Account for the Remainder of Z_{eff} (once Argon and Nitrogen are Accounted for)

Experimental Results

- The Nitrogen seeding reduced the ion diffusivity and increase the electron diffusivity
- The seeding does not significantly change turbulent density fluctuations as measured by Phase Contrast Imaging [2]

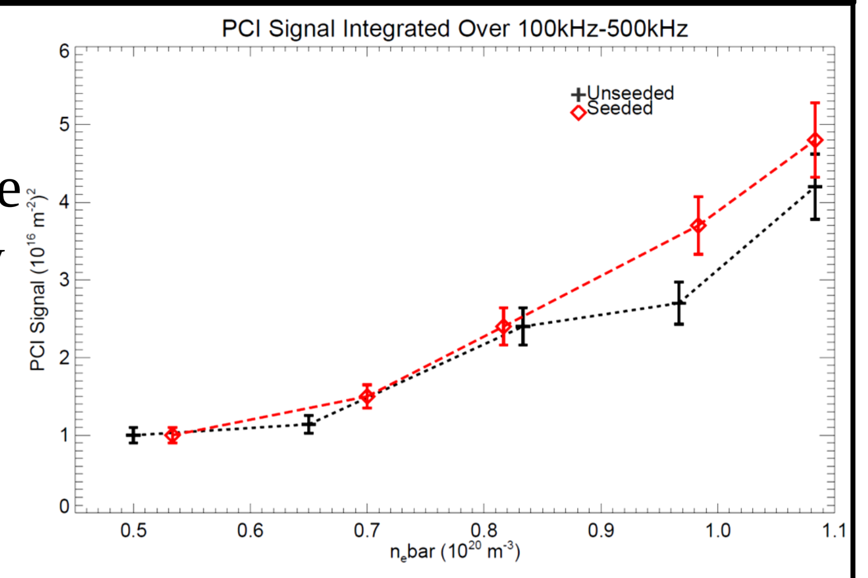


Figure 3: Line-Integrated Density Fluctuations between 100 and 500 kHz

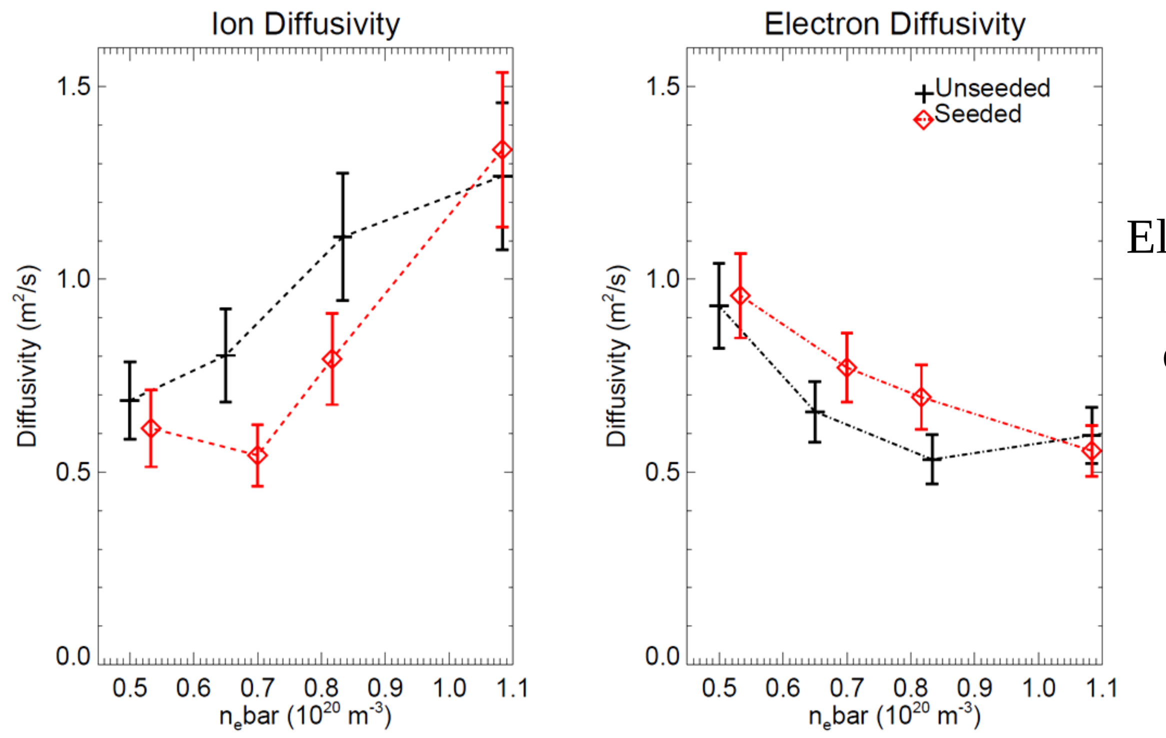


Figure 4: Electron and Ion Heat Flux as computed by TRANSP at r/a = 0.7

Experimental Profiles

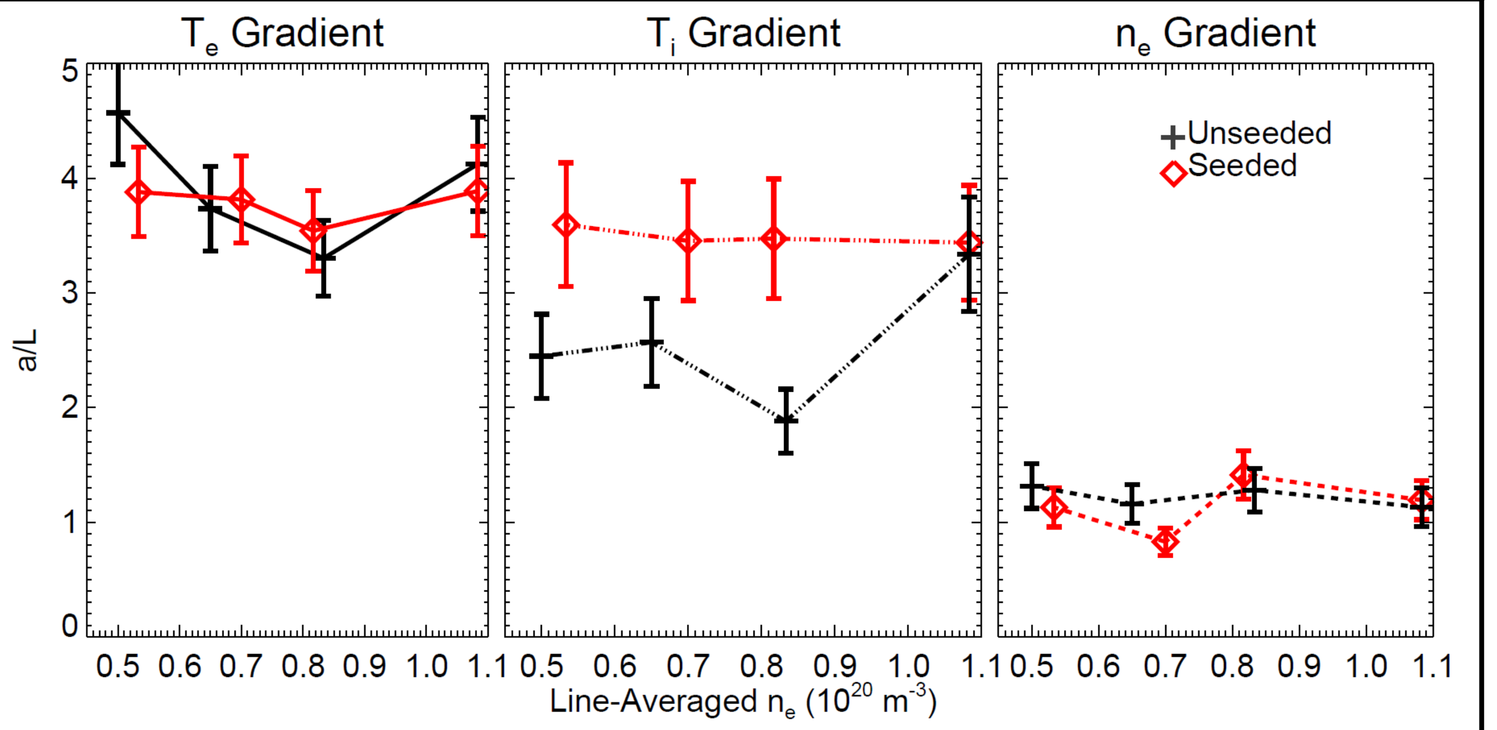
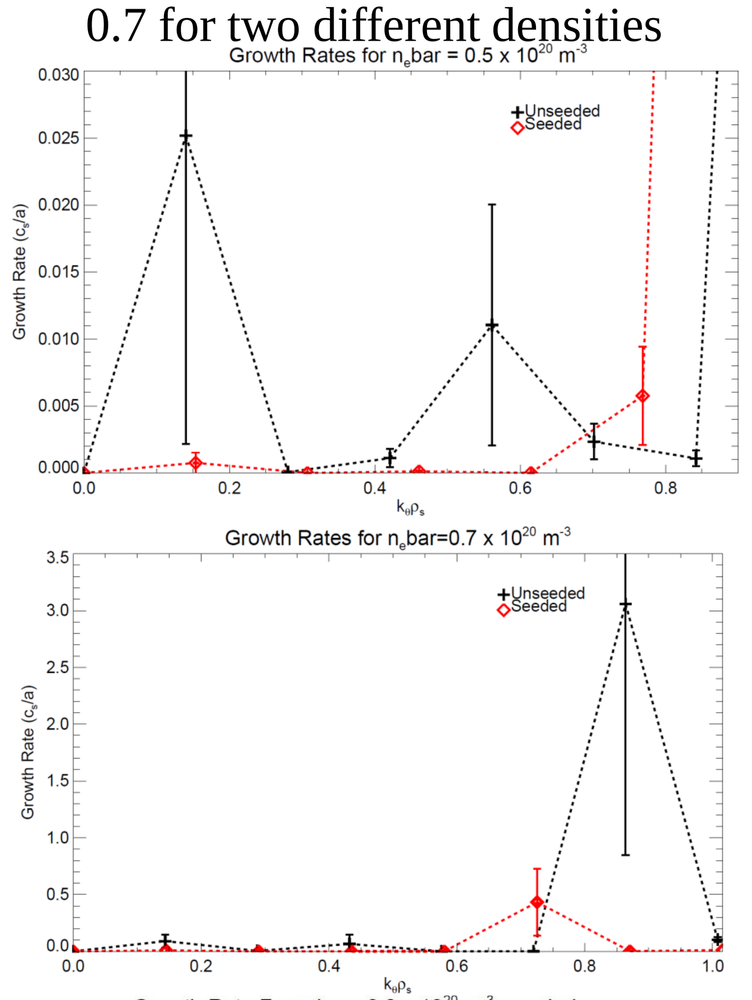


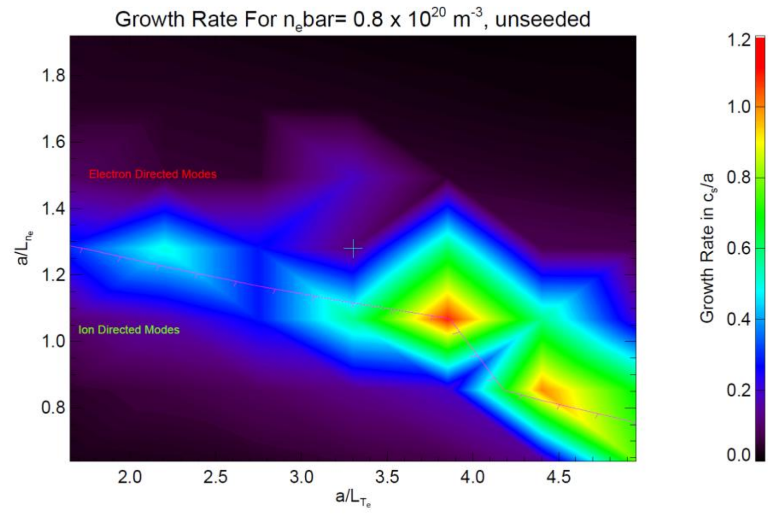
Figure 5: Gradient Scale Length at r/a=0.7 for T_e (left), T_i (middle), and n_e (right). Only L_{Ti} Changes Significantly with Seeding.

Gyrokinetic Results

- Linear GYRO [3] shows that the growth rate goes down with the addition of seeding
- The seeding also brings the turbulence closer to being ion dominated rather than electron dominated

Figure 6: Growth Rate vs. k at r/a = 0.7 for two different densities





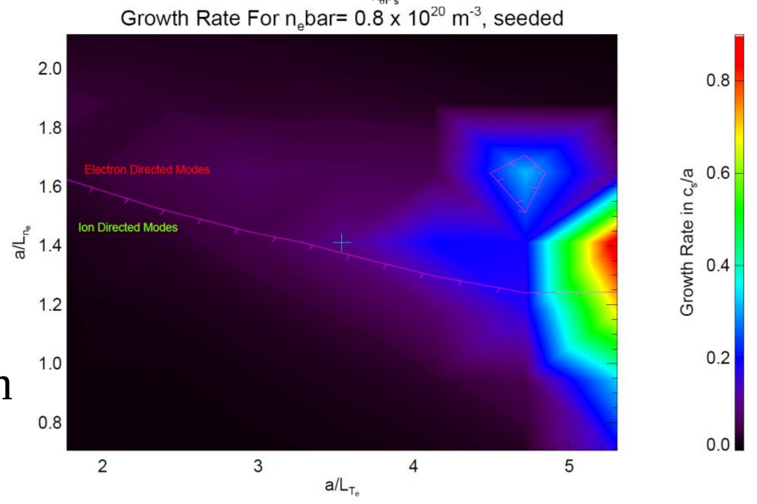


Figure 7: Largest Linear Growth Rate vs. Te and ne Gradients for Unseeded (above) and Seeded (right). The Blue Cross is the Experimental Gradient and the Purple Line is the Boundary between Ion and Electron Directed Modes

Conclusions

- Seeding ohmic plasmas with a low-Z impurity to dilute the main ion species increases electron transport, but generally decreased ion transport
- Linear GYRO simulations showed a significant decrease in over all growth rate when the plasma is seeded

References

1. M. Porkolab et al, Bull. Am. Phys. Soc. 56, no12 139 (2011).
2. M. Porkolab, et al, IEEE Transactions on Plasma Science, 34, 229 (2006).
3. Candy J. and Waltz R. E., J. Comput. Phys. 186 545 (2003).