Exploration of control of neutral fueling and exhaust by a pumped limiter at the edge magnetic island chain of the HSX stellarator

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Motivation and goals

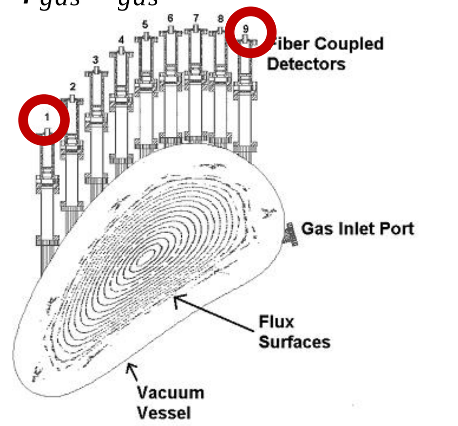
- What is the source/sink inventory for H and He plasmas?
  - What is the role of the wall?
  - How are they impacted by a pumped limiter?
- What are the neutral physics of H and He? What are the dominant processes (C-X, electron ionization, dissociation) ionization profiles, and resulting neutral densities?
  - Is this behavior captured in the DEGAS/EMC3-EIRENE [1,2] models?
  - How is the neutral behavior impacted by the pumped limiter?
- Can the limiter to be used to control the neutral fueling and exhaust?
- Can the pumped limiter improve the plasma operation? (Longer τ_p, increased n_e, larger stored energy, lower radiated power, gradients in the edge pressure profile)?

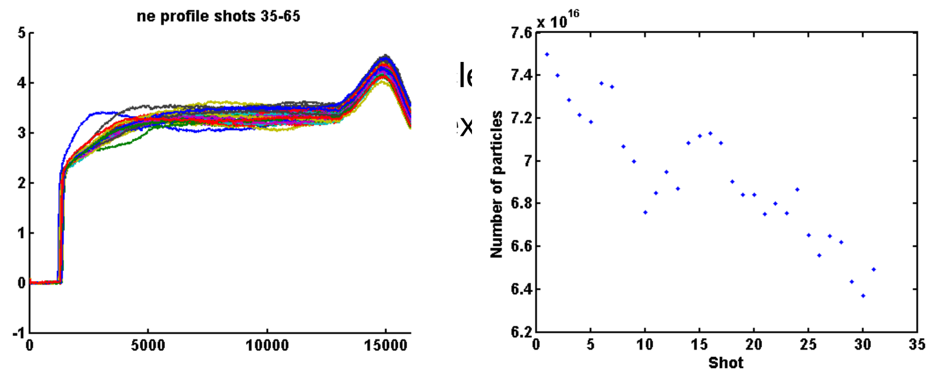
Particle balance helps to analyze sources and sinks, role of wall

- Using the single reservoir model [3], shown on right, to:
  - Determine complete balance of sources and sinks
  - Calculate particle confinement time

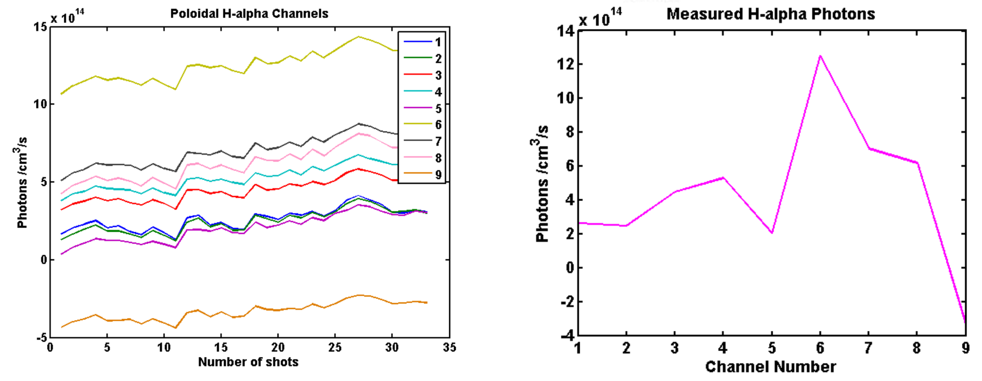
$$\tau_p = \frac{N_{tot}}{-\frac{dN_{tot}}{dt} + f_{rec}\Phi_{rec} + f_{gas}\Phi_{gas}}$$

- f_{gas} , the fueling efficiency for particles that are puffed from a gas valve, is taken from the literature [4], $f_{gas} = 0.1$
- Φ_{gas} , the particle flux from the gas puff source, is measured from gas puff calibration, Φ_{gas}=3.5E18 particles/s
- f_{rec} , the fueling efficiency for particles that are recycled from the wall, is taken from the literature [4], $f_{rec} = 0.7$
- Φ_{rec} , the particle flux from wall recycling, is measured using the two edge channels of H-alpha array (Channels 1 and 9, shown on R), Φ_{rec} = 3.1E20

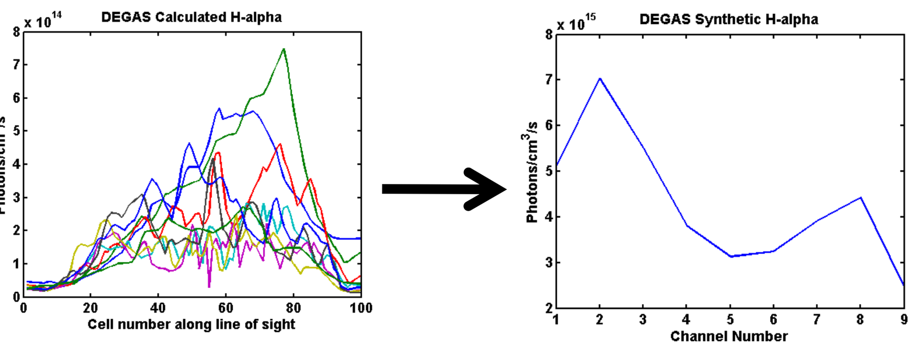




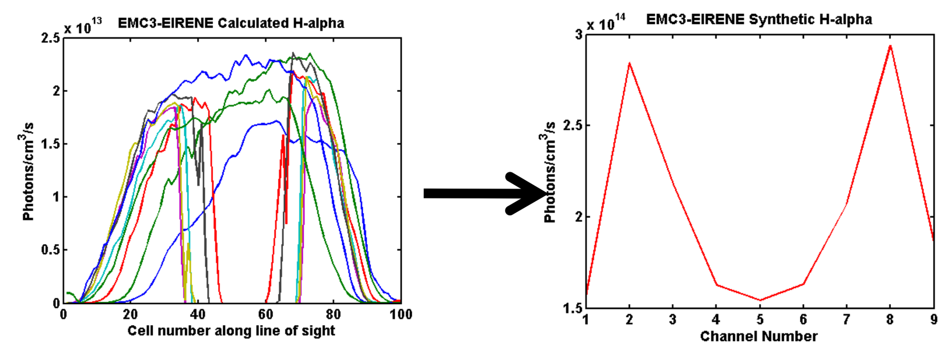
(L) Interferometer time traces of n_e over 30 repeatable discharges. (R) Number of gas particles puffed to maintain the same profile. This indicates that the wall contribution increases throughout the runday.



(L) H-alpha photons for each view over a series of 30 repeatable discharges. The H-alpha levels across edge and core channels increase throughout the runday. (R) Average of H-alpha photons for each view for the same 30 shots.



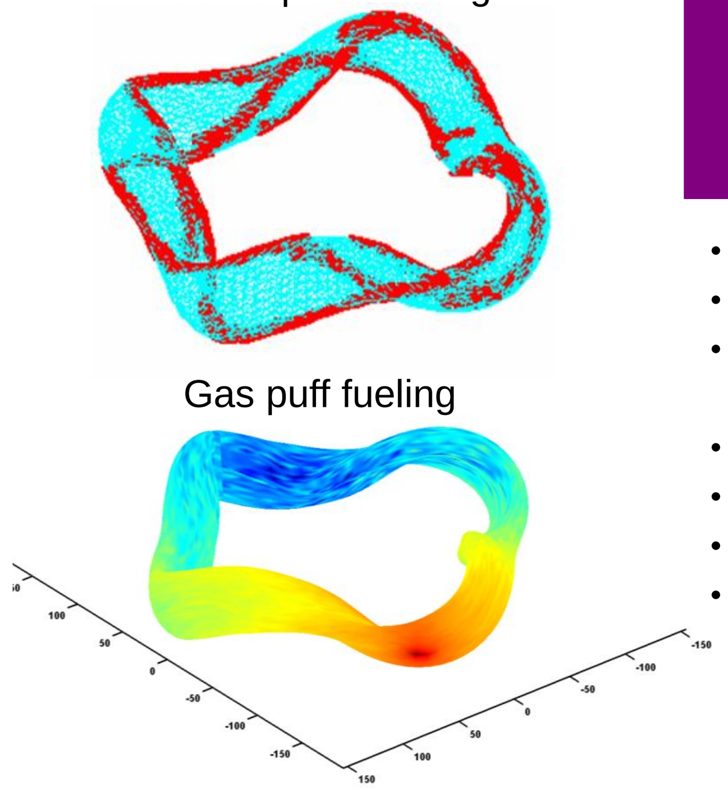
(L) Calculated H-alpha profile for 9 viewing chords from DEGAS. (R) Line integrated synthetic H-alpha for comparison to measurement.

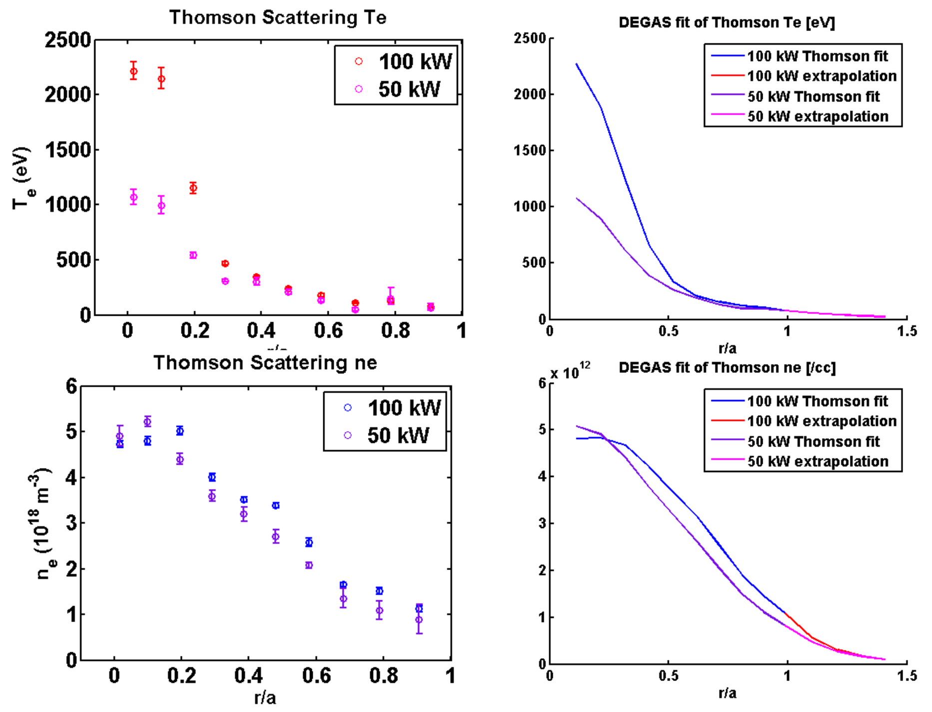


(L) Calculated H-alpha profile for 9 viewing chords from EMC3-EIRENE. (R) Line integrated synthetic H-alpha for comparison to measurement.

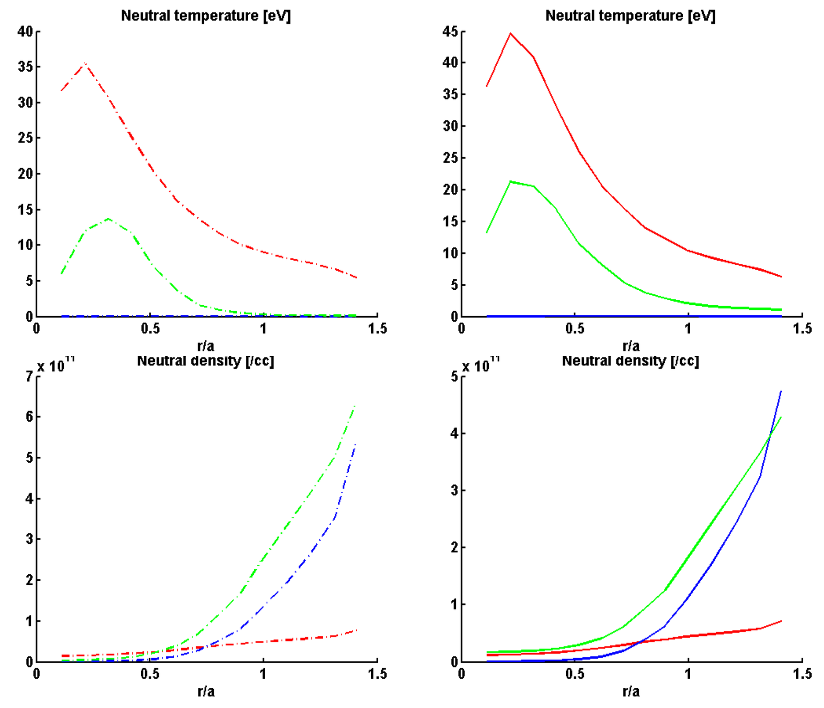
Location of ionization front is robust

- Neutral physics was modeled using the DEGAS [1] Monte-Carlo code
- Fully 3D neutral simulations with static background plasma profiles based on Thomson profiles and CHERS data
- Two separate calculations for gas puff fueling and wall recycling so they can be independently scaled
- In the puff run, we mimic our gas puffer at a toroidally localized wall triangle (on R)
- In the recycling run, we assume the fueling is uniform from a set of strike points calculated from line following (on R)
- The location of the ionization front is robust to change in species and change in heating power
- The importance of using helium is that it is not retained and recycled by the wall
- Numerical tools are ready for comparison and interpretation of measurements





(L) Thomson density and temperature profiles for 50kW and 100kW plasmas. (R) Fits and extrapolations of the Thomson data used in the DEGAS and CRM calculations.

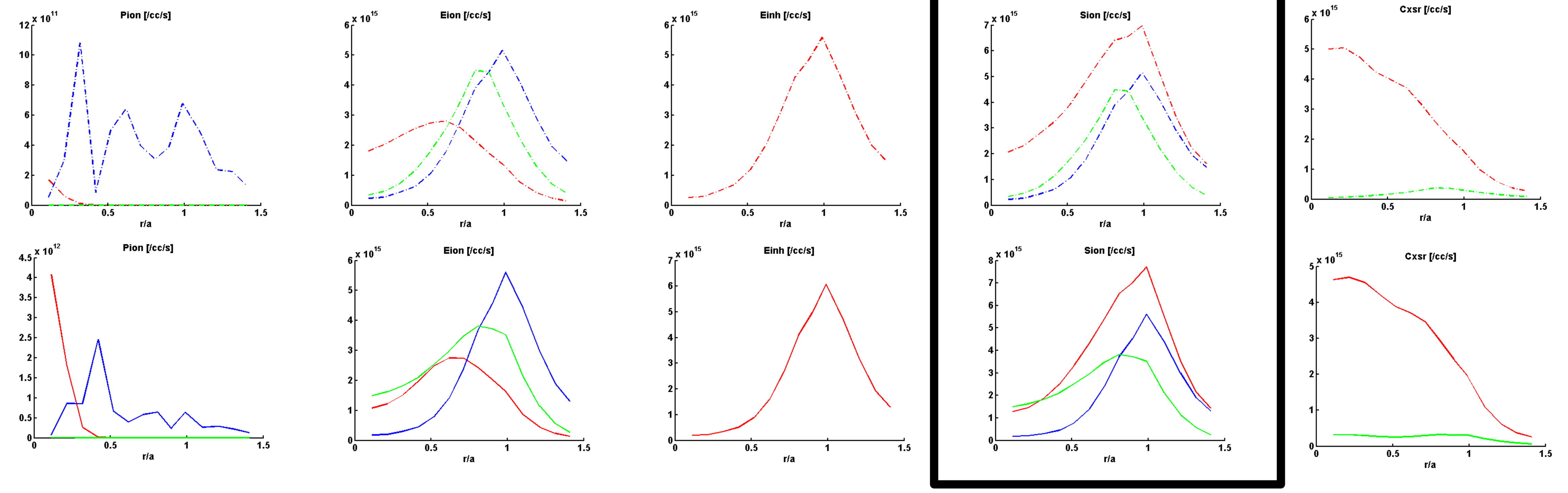


DEGAS calculated neutral density and temperature profiles of H, H_2, and He using 50kW and 100 kW background plasmas.

Atomic H
Molecular H_2
Helium

Dashed line: 50kW
Solid line: 100kW

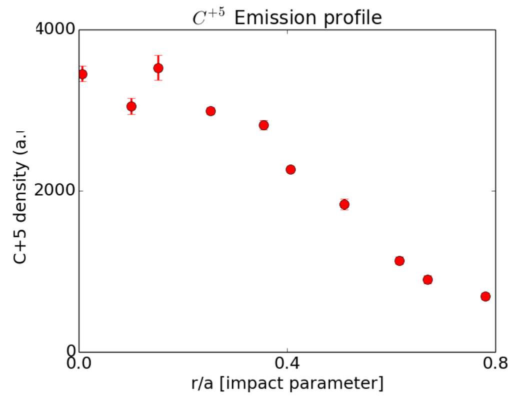
Ion impact ionization	Electron impact ionization	Dissociation	Total Source Rate (S_{ion}) $P_{ion} + E_{ion}$ + Dissoc	Charge exchange
$h^+ + h^0 \longrightarrow 2h^+ + e$	$e + h^0 \longrightarrow h^+ + 2e$	$e + h_2^0 \longrightarrow h^0 + h^+ + e$		$h^0 + h^+ \longrightarrow h^+ + h^0$



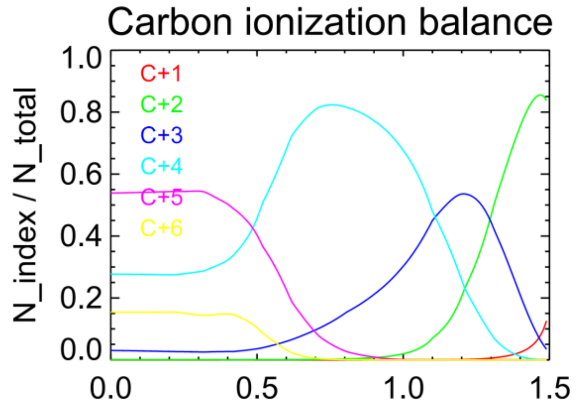
DEGAS calculated source rate profiles of ion impact ionization, electron impact ionization, dissociation, and charge exchange rates (which are shown but do not contribute to the net source rate in these plasmas.) For H, the dominant source mechanism is dissociation. For H_2 and He, the dominant source mechanism is electron impact ionization. The location of the ionization front is robust to changes in species and heating power.

Work in progress to verify the modeled H profile using spectroscopy and CRM

- Chord-averaged C+5 emission profile is measured
- Emission is from both charge-exchange and electron impact excitation (C+6 and C+5, respectively)
- A collisional radiative model (CRM) was used to calculate the carbon ionization balance (shown below) using the same fits of n_e and Te used for DEGAS and the DEGAS calculated neutral H profile
- The resulting CRM C+6 density is lower than the C+5 density in the core, even though T_e is as high as 2.5 keV
- Core densities of C+6 > C+5 were obtained with a "guess" neutral profile with lower core density
- This indicates that the modeled neutral profile may be too large, especially in the core
- Future work may include measuring two charge states of carbon simultaneously, which will allow the H profile to be determined directly



Measured C+5 emission profile at 529 nm.



Ionization balance calculated with CRM. CRM uses DEGAS fits of n_e, T_e, and calculated H profile. C+5 density is greater than C+6 density in the core, even at T_e as high as 2.5 keV.

Future Work

- Use tangential camera view to make wall recycling measurements to determine role of wall
- Expand single reservoir model to include substantial core fueling term
- Make spectroscopic measures of H, H_2, He, He+ density
- Compare spectroscopic measurements to DEGAS and EMC3-EIRENE simulations
- Determine impact of pumped limiter on source/sink balance , neutral physics
- Measurements at limiter target (downstream data) to be compared to upstream probe measurements
- Examine any impacts of the pumped limiter from gross changes in Thomson profiles, stored energy, radiated power, particle confinement time, edge pressure profile

References

1. D. Heifetz et al., *J. Comp. Phys.* Vol. 46, Pg. 309 (1982).
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3. D.S. Gray et al. J. Nucl. Fusion, 38 (1998) 1585.
4. O. Schmitz. J. Nucl. Mat.,390=391 (2009), 330-334.

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