Modeling Neutral Hydrogen in the HSX Stellarator

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Overview

- The HSX neutral particle population plays an important role in plasma behavior as a result of relatively low operating density
- The DEGAS code [1] is a fully 3D Monte-Carlo neutral particle code that is used to simulate the HSX neutral population
- H-alpha measurements are used to scale DEGAS results to determine quantities including atomic and molecular neutral particle density, neutral particle flux, and ionization rate
- The DEGAS code has been recently upgraded to simulate a supersonic gas injector (SGI) in HSX
- Simulation results indicate:
  - SGI performance will vary by location as a result of distance between SGI and core plasma
  - An SGI in the same location as the current gas puff will increase fueling efficiency from 43 to 47 percent
  - Because DEGAS simulations are steady-state, most likely the predicted fueling efficiency is somewhat overestimated
- The DEGAS code has been compared to the EMC3-EIRENE code [2]
  - Both predict the same general picture of neutral behavior
  - DEGAS predicts a steeper falloff of H and H_2 density in the edge
  - EMC3-EIRENE predicts a region of low H_2 density outside the separatrix
- Several types of wall fueling scenarios were simulated in an attempt to better match H-alpha array data
  - Simulations were able to match measurements relatively well when puffing from C-puffer
  - Simulations were unable to match measurements when puffing from A'-puffer
  - Results suggest that we are not accurately modeling particle fueling and recycling from the HSX wall
  - A n H-alpha camera diagnostic may be used to study HSX wall recycling and developed an improved model

Simulation of Supersonic Gas Injector (SGI)

- Supersonic gas injection is a method of fueling that has been used by many experiments to increase fueling efficiency [3,4]
- A laval nozzle (pictured in Fig. 1) is used to create a narrow cone of supersonic particles
- DEGAS has been upgraded to simulate the installation of an SGI on HSX
  - Gas puff energy was increased from 0.026 eV to 0.06 eV
  - Particle launch angle was changed from a cosine distribution to a narrow zcone with a 4.5 degree half-angle
- The puff and SGI were simulated in the same location with the same particle source rate and background plasma
- Simulations indicate that an SGI can increase fueling efficiency compared to the current gas puff system, but also that it is highly dependent upon position
- This is most likely due to the differences in distance between the SGI locations and the center plasma

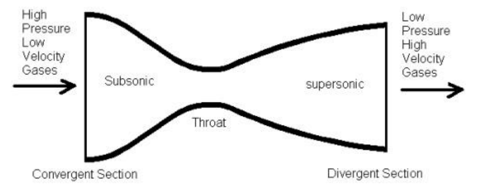


Fig. 1. A typical laval nozzle. HSX will install an SGI system with this type of nozzle with a 4.5 degree half-angle launch cone.

- DEGAS directly calculates the H and H_2 ionization rate at each point in the computational grid
- The particle source rate is directly input by the user
- The H ionization rate within the separatrix and the particle source rate are used to calculate the fueling efficiency [5]
- Fueling efficiency is calculated by

where $$n_f = \frac{dN_i}{dt}\Gamma_{source}^{-1}$$

$\frac{dN_i}{dt}$ is the H ionization rate in the volume

and Γ_{source} is the particle source rate

	H ionization rate	Particle source rate	Fueling efficiency
Puff	2.6e23	6e23	43.44
SGI	2.8e23	6e23	47.15

- Because DEGAS predicts steady state quantities, it is likely that the fueling efficiency is somewhat overestimated as transient behavior is ignored

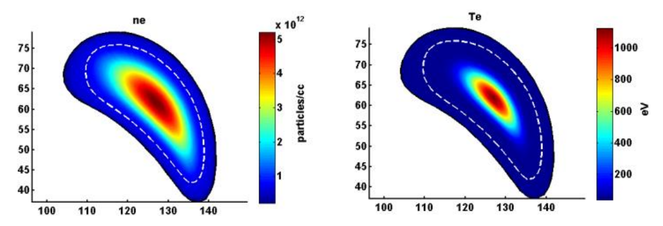


Fig.2. Background plasma in DEGAS simulations. Based on experimental Thomson profiles.

- The SGI was simulated in six poloidal positions at the same toroidal angle
- Overall H profiles were relatively unchanged, but SGI fueling generally decreased the H_2 profile in the edge region as compared to the gas puff
- Fueling efficiency was highly dependent on position– most likely due to differences in distance to the center of the plasma

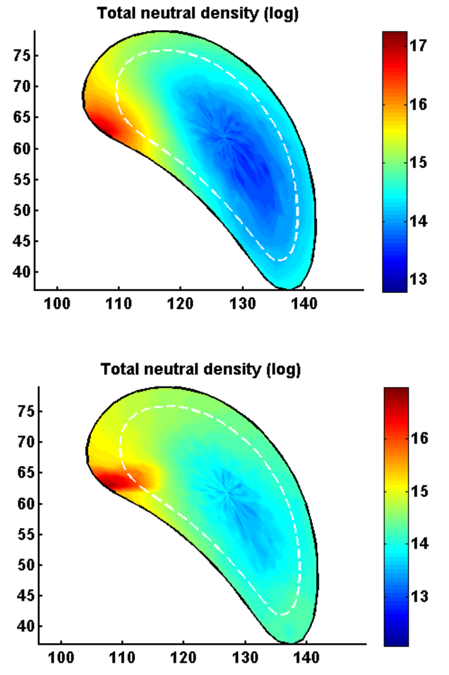


Fig.3. Log plots of total neutral density for puff (top) and SGI (bottom).

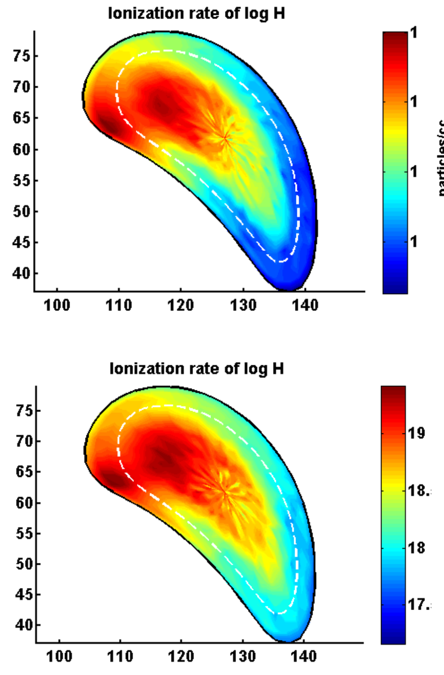
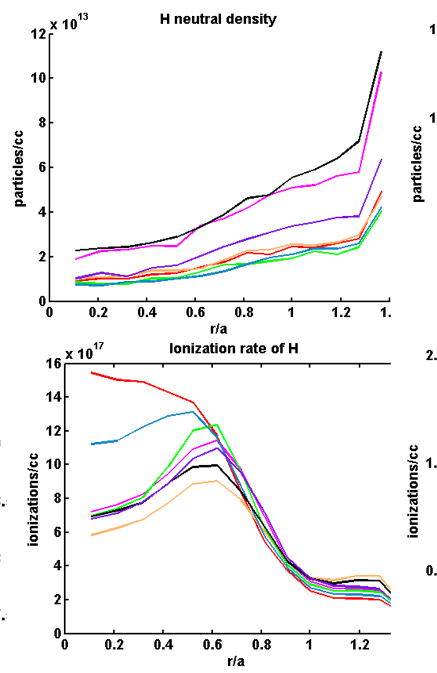
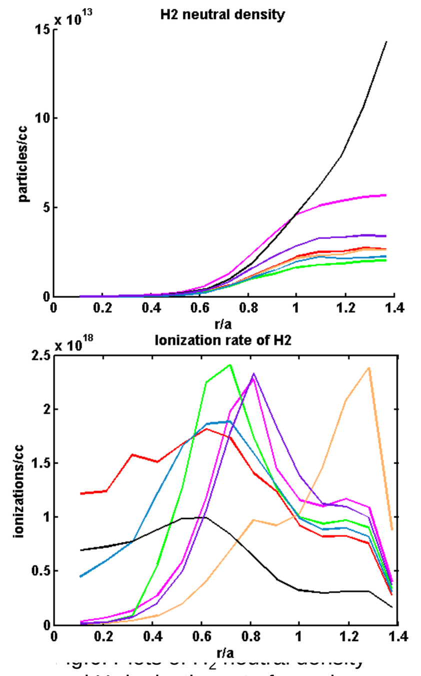


Fig.4. Log plots of H ionization rate for puff (top) and SGI (bottom).



H ionization rate for various SGI positions (colors) and gas puff (black).



and H_2 ionization rate for various SGI positions (colors) and gas puff (black).

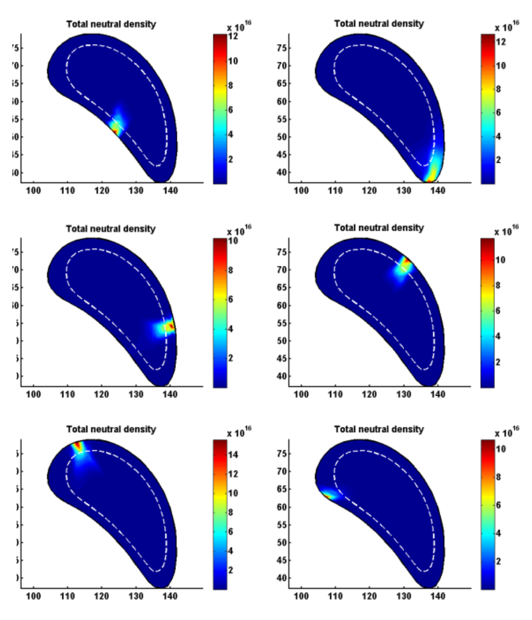


Fig.7. SGI was simulated in these six poloidal positions. Total neutral density is shown for each SGI simulation. Corresponding fueling efficiencies are tabulated in the table to the right.

SGI grid position	Fueling efficiency
9	52.34
18	40.30
27	47.43
36	50.15
45	
54	47.15

Comparison to EMC3-EIRENE

- DEGAS and EMC3-EIRENE simulations for HSX neutral particles were compared
- Efforts were made to make as direct a comparison as possible:
  - Similar values of T_e, T_i, n_e, and n_i throughout the plasma grid
  - The same (HSX) geometry and magnetic configuration (QHS)
  - Same (single) toroidal angle
  - Same wall material (carbon)
- Results:
  - Both agree on the same general picture
  - DEGAS predicts a steeper falloff in neutral density near the edge
  - EMC3-EIRENE predicts a region of low H_2 just outside the separatrix
- There are several factors that may contribute to these differences:
  - DEGAS T_e, T_i, n_e, and n_i profiles are directly input whereas EMC3-EIRENE calculates these profiles
  - DEGAS particle source rate from the wall is directly input whereas it is calculated by EMC3-EIRENE
  - EMC3-EIRENE includes islands, flows, and subsequent poloidal variation in plasma density, temperature, and flow profiles that DEGAS does not
- Future work may include
  - Comparisons at more than one toroidal angle
  - Comparisons of puff fueling behavior

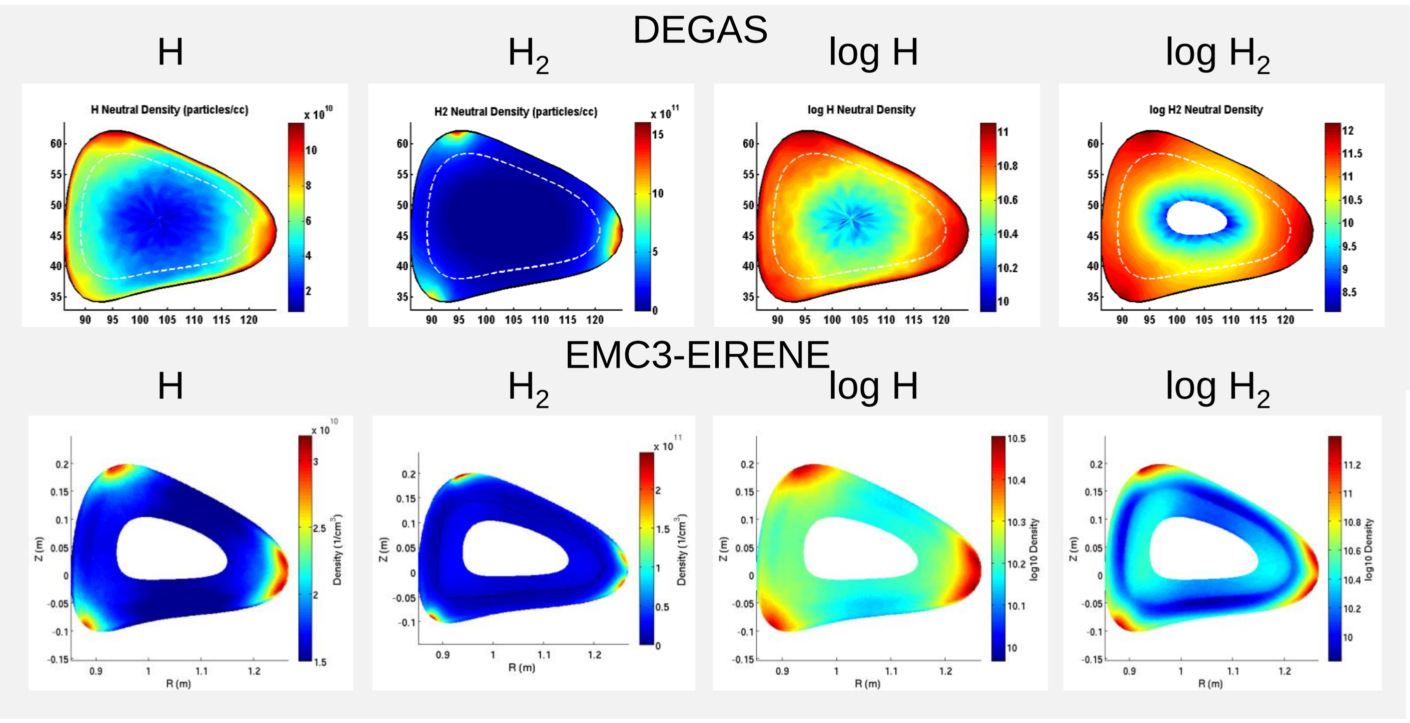


Fig.8. Plots of H, H_2, log H, and log H_2 density as predicted by DEGAS and EMC3-EIRENE at this particular toroidal angle (45 degrees). The center of the DEGAS log H_2 plot has been omitted to remove noise near the plasma center. EMC3-EIRENE plots courtesy of A. Bader.

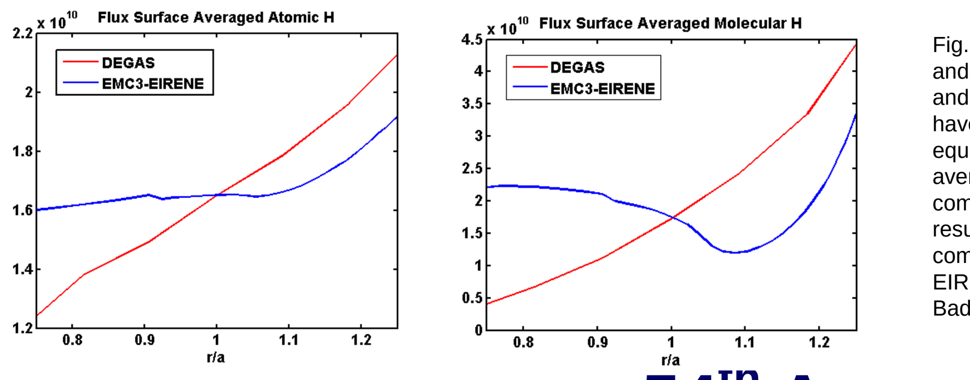


Fig.9. Flux surface averaged H and H_2 as predicted by DEGAS and EMC3-EIRENE. Densities have been normalized to be equal at r/a=1. Flux surface averaged results can only be compared in this region as a result of the EMC3-EIRENE computational grid. EMC3-EIRENE results courtesy of A. Bader.

Efforts to Match H-alpha Measurements

- HSX is currently equipped with 16 H-alpha detectors (and the system will soon be expanded by 20 detectors)
- 9 of these detectors are in a poloidal array in field period C and the rest are in a toroidal array extending around HSX
- DEGAS synthetic H-alpha light is scaled by measured H-alpha in order to obtain calculated neutral quantities
- Several wall fueling configurations were simulated
  - The current HSX strike point model [6]
  - The whole wall as a source
  - Half the wall (every other point) as a source
- DEGAS simulations match reasonably well with poloidal measurements when using C gas puff (very close to poloidal array)
- DEGAS simulations do not replicate all features of toroidal measurements for the C gas puff
- No wall fueling configuration was able to match poloidal or toroidal H-alpha measurements in poloidal array when using A' puffer
- This suggests that we are not correctly modeling fueling from the wall
- Possible future work: develop a better model of wall fueling in HSX
- DEGAS simulations indicate that far from the gas puff, most H-alpha light is produced near the wall (Fig.10)
- This could be studied with an H-alpha filtered camera

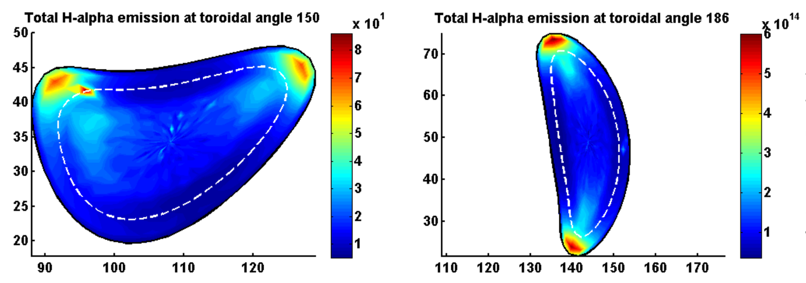


Fig.10. DEGAS predicted total H-alpha emission at two toroidal angles far from the gas puff source. Results suggest that most emission is produced close to the wall and could be investigated with a camera diagnostic.

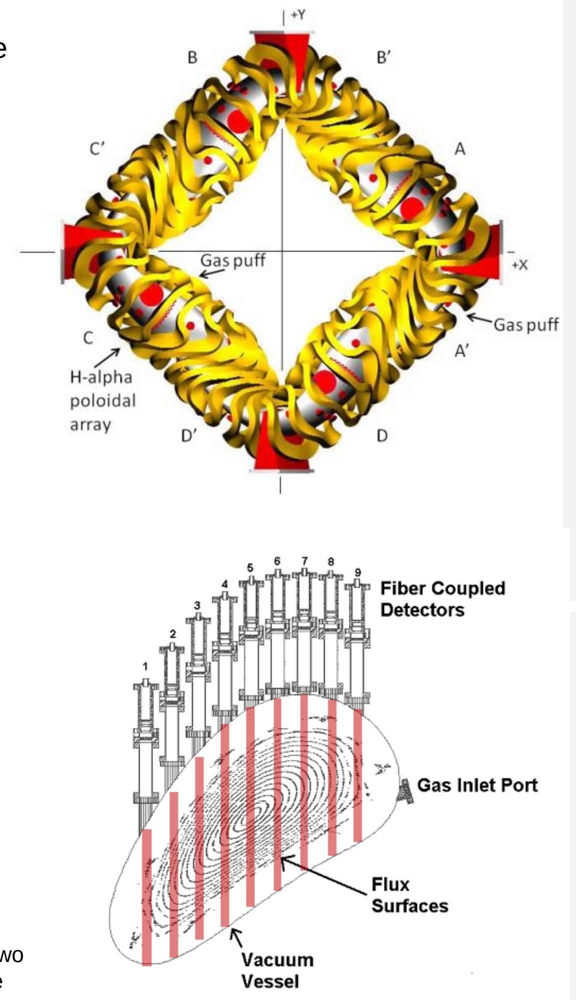
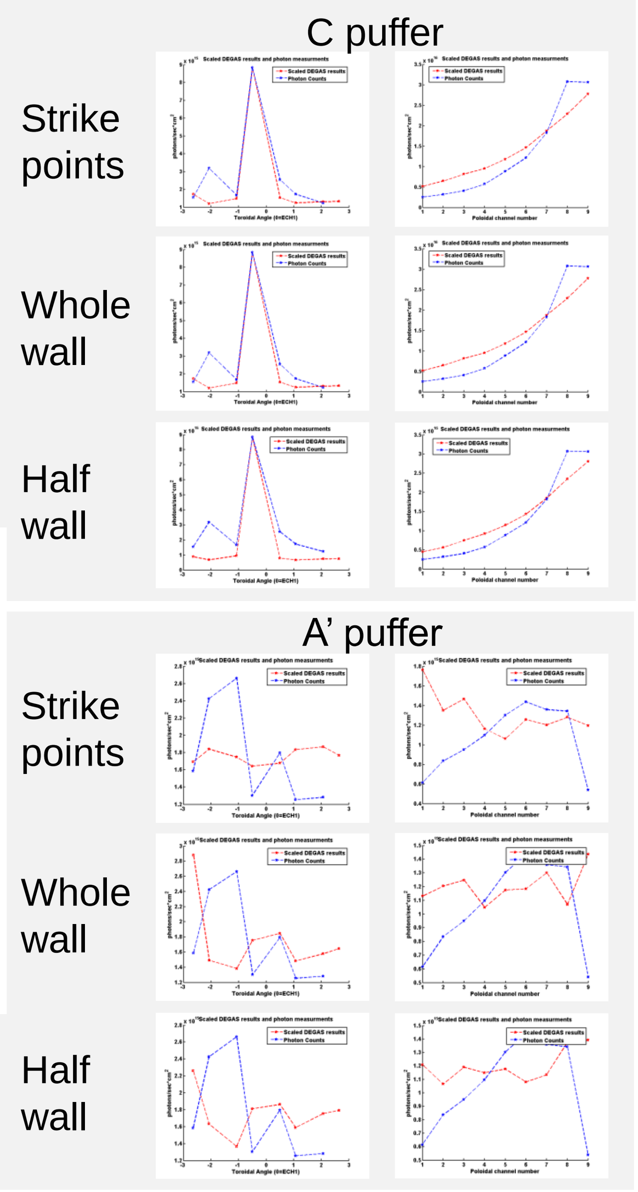


Fig.11. A schematic of HSX that indicates the location of the two gas puffs, the H-alpha poloidal array, and the H-alpha toroidal array.



Summary and Future Work

- Installing an SGI on HSX is predicted to improve fueling efficiency from 43 to up to 52 percent
- SGI performance will vary from 40 to 52 depending on location
- DEGAS has been compared to EMC3-EIRENE for HSX and both generally agree
- Several wall configurations were simulated to in an attempt to match DEGAS predictions to H-alpha data
  - Simulations matched C puff data relatively well
  - Simulations did not match A' puff data
  - This suggests the current HSX wall fueling model is incorrect
- Future work:
- Complete installation of 2 new H-alpha arrays (20 detectors) on HSX
- Install SGI on HSX and compare to simulation
- Consider upgrading to DEGAS 2 [7] if further simulations are needed (faster, newer and currently maintained)
- Use an H-alpha filtered camera system to study plasma wall recycling far from gas source
- Use information from H-alpha camera to develop more accurate model of plasma recycling in HSX and investigate role of neutrals in the SOL

References

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