# Neutral Density Measurement and Modeling in HSX

J. Canik, D.T. Anderson, S.P. Gerhardt,
J.N. Talmadge

*HSX Plasma Lab.*
*Madison, Wisconsin, USA*

# Abstract

The neutral density and particle source rate have been measured experimentally in the Helically Symmetric eXperiment (HSX) using an absolutely calibrated set of 15 $H_\alpha$ detectors. These experiments have been carried out in ECH heated plasma with densities ranging from 0.4 to 1.5 x $10^{12}$ $cm^{-3}$ and injected power up to 65 kW. The $H_\alpha$ brightness from these detectors has been used together with the output from 3-D DEGAS[1] simulations to yield the full neutral density and source rate distributions. The plasma density and source profiles are used to calculate an effective diffusivity of ~$10^4$ $cm^2/s$, which increases towards the plasma edge. The diffusivity shows a dependence on density, but is independent of power. Initial work on accounting for recycling in the DEGAS simulations is also presented.

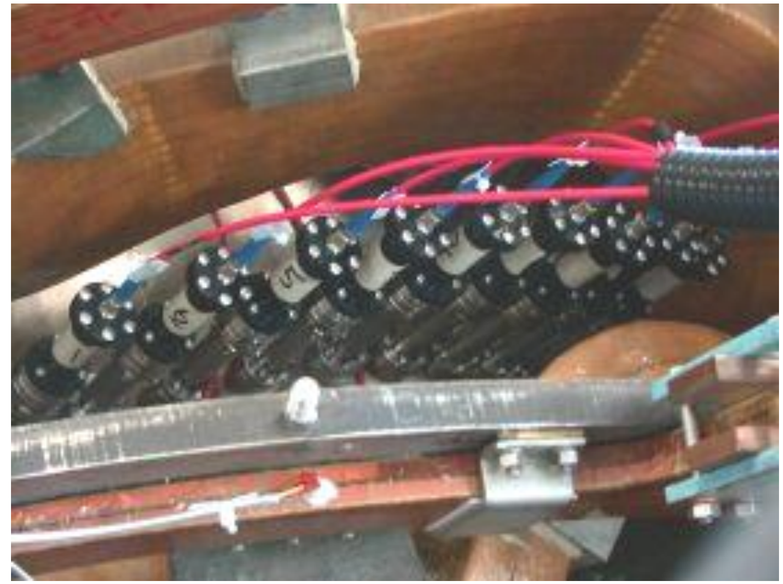
[1] Heifetz, D.B. et. al., J. Comp. Phys. **46,** (1982) 309

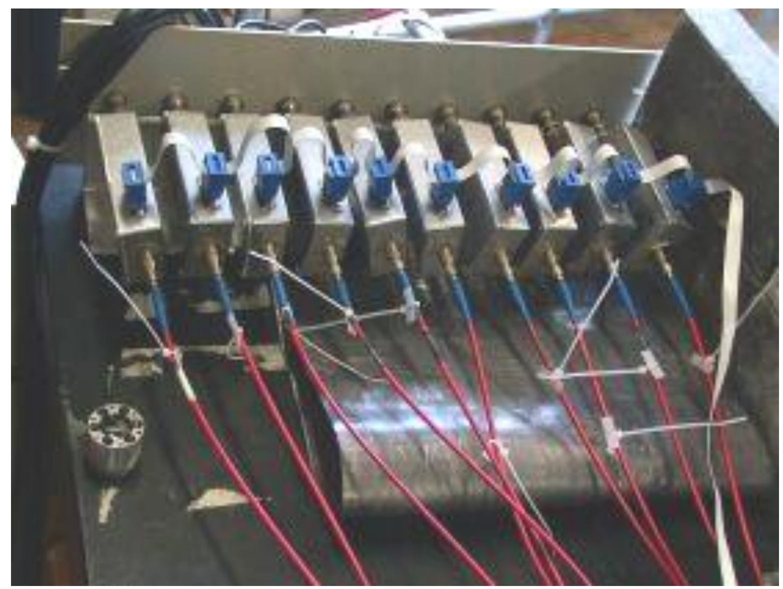
# Outline

- Experimental setup
- Computational setup
- Simulation results and comparison with experiment
- Progress on including recycling
- Conclusion

# The $H_\alpha$ Arrays on HSX

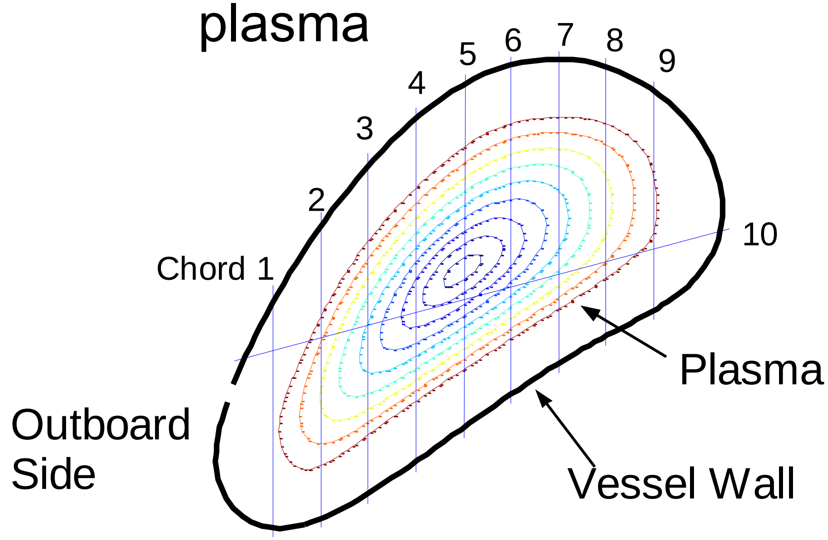
- Light from the plasma is passed through interference filters and imaged onto 1mm core fiber-optic cables.
- The fibers couple the light to photodiodes, which are lead-shielded to prevent contamination by x-rays
- The entire assembly has been absolutely calibrated using an integrating sphere.

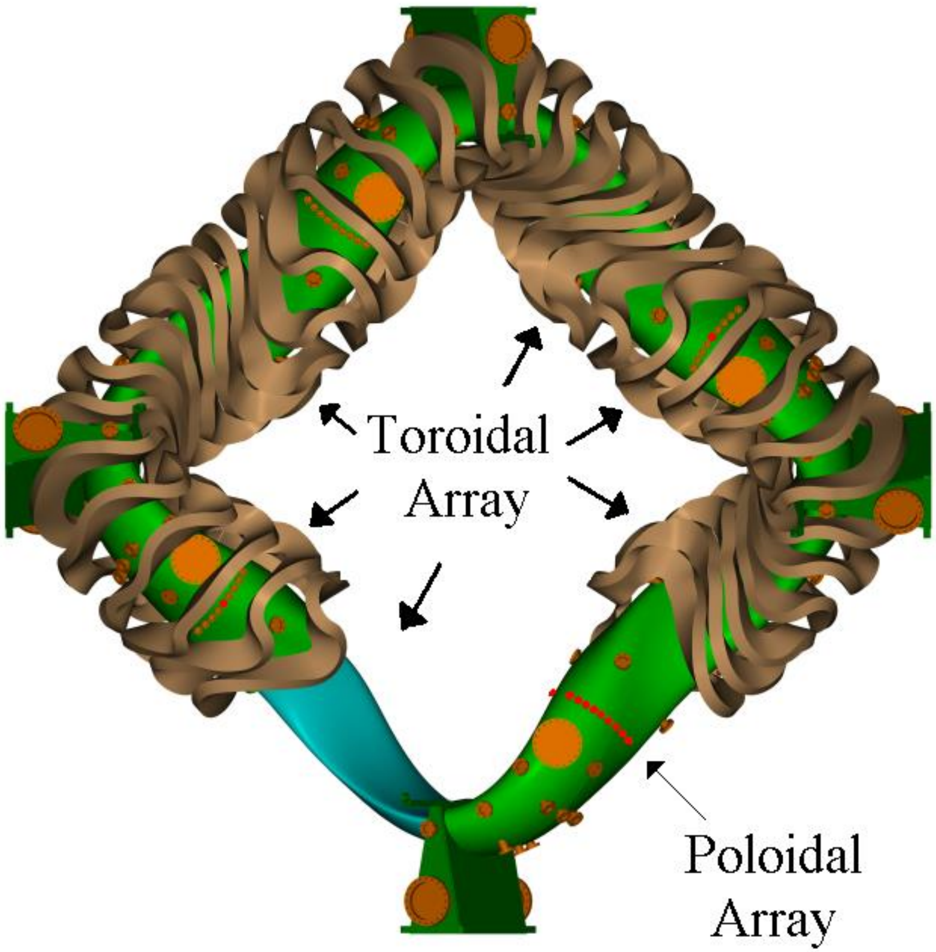




# $H_\alpha$ Array Placement

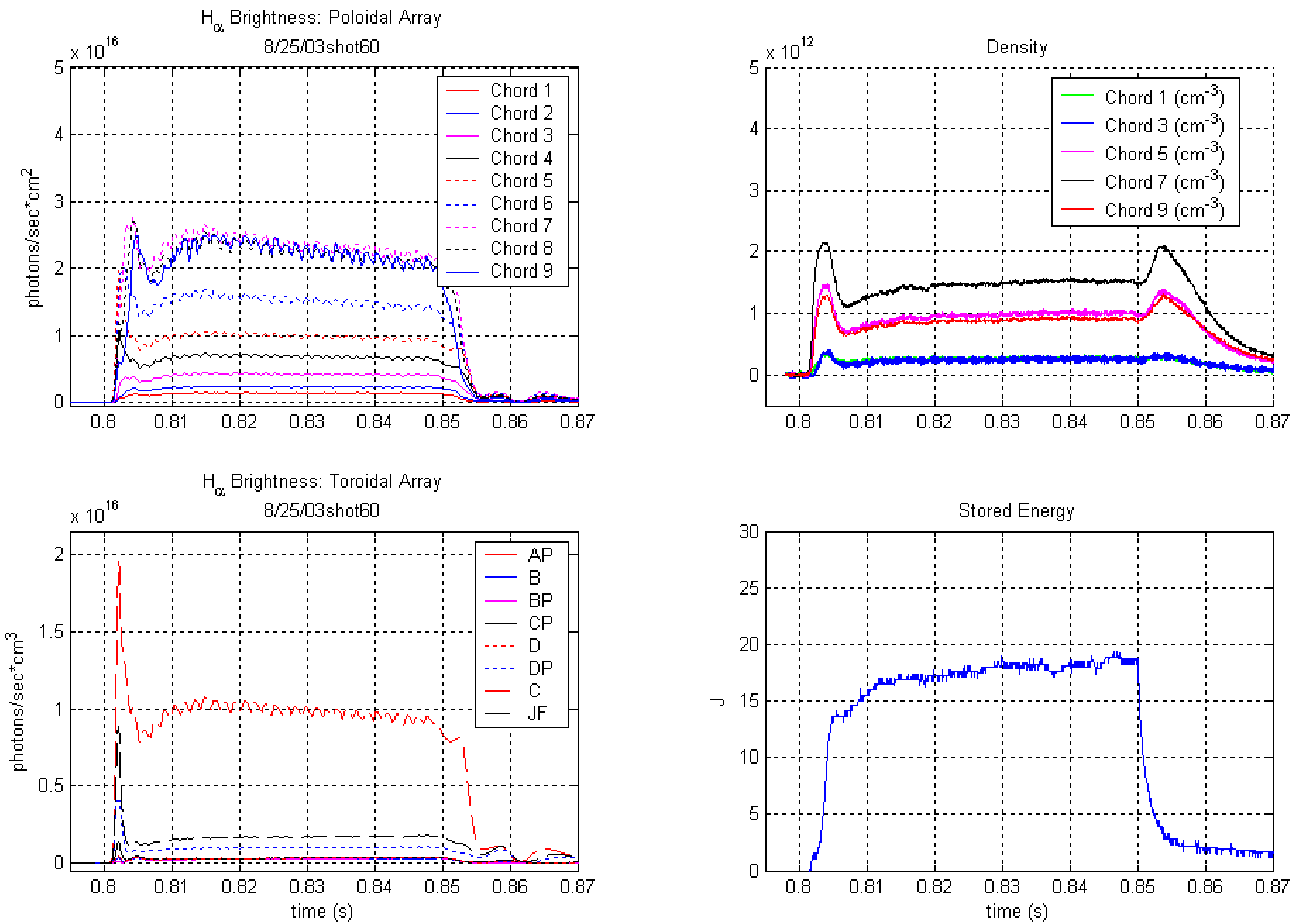
- HSX has 15 $H_\alpha$ detectors forming two arrays
  - Toroidal array: 7 detectors on magnetically equivalent ports
  - Poloidal array: 9 detectors viewing cross section of plasma



# Example Discharge to be Modeled

- 8/25/03 Shot 60: QHS, $n_e$ = 1.5x10$^{12}$ cm$^{-3}$, P = 37 kW

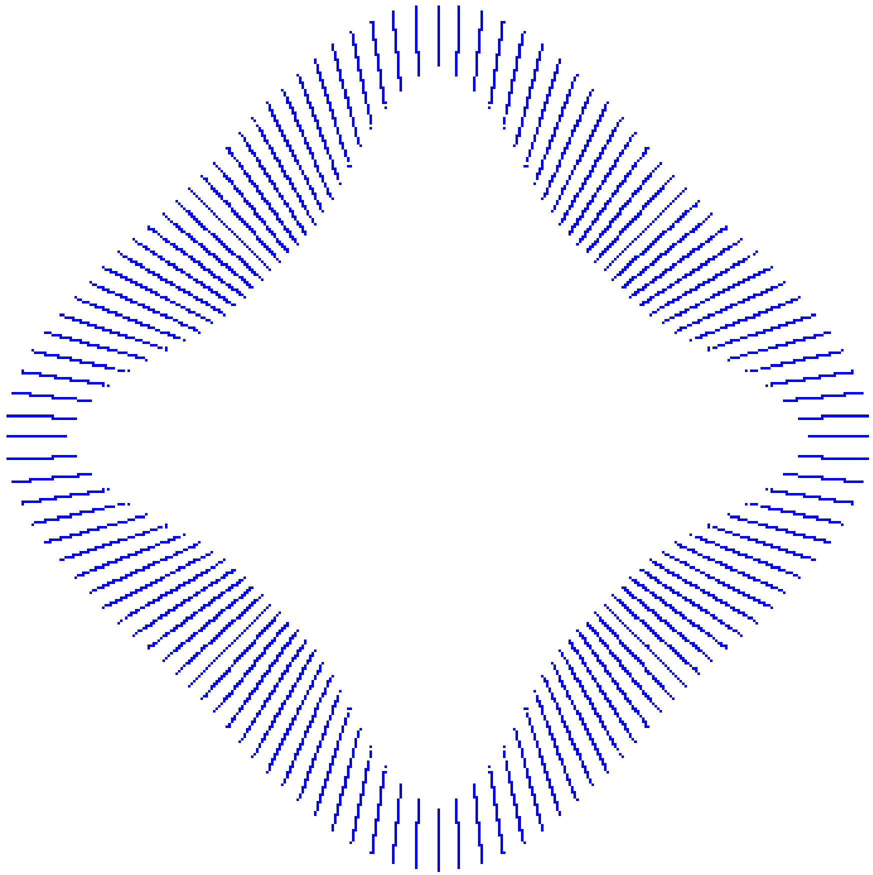


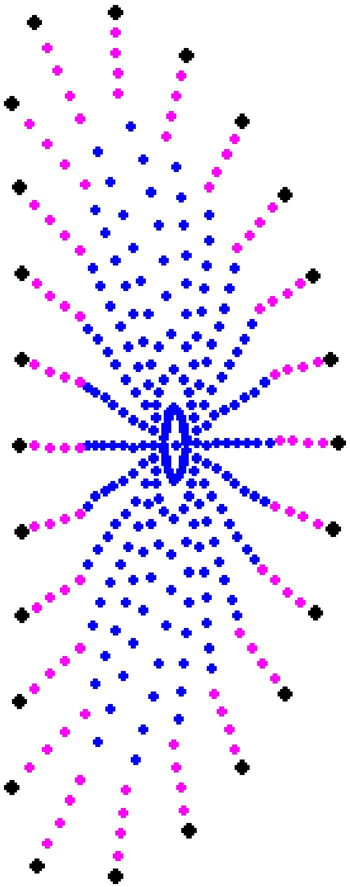
# Neutral Gas Modeling with DEGAS

- DEGAS is a Monte-Carlo neutral gas code (see end of poster)
- Takes as input the plasma position, density and temperature
- Given a location of a gas puff, gives the steady state neutral distribution
- Outputs neutral density, $H_\alpha$ emission, ionization rate, etc.

# HSX Grid

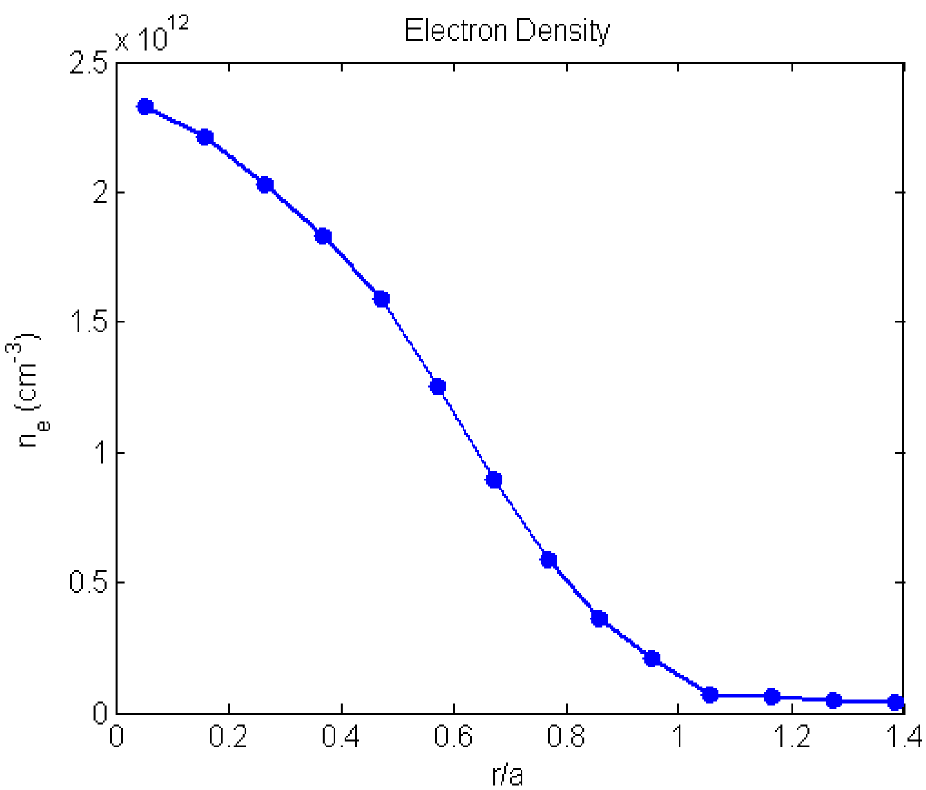
- 15 radial, 25 poloidal, 121 toroidal points
- 3 radial SOL points

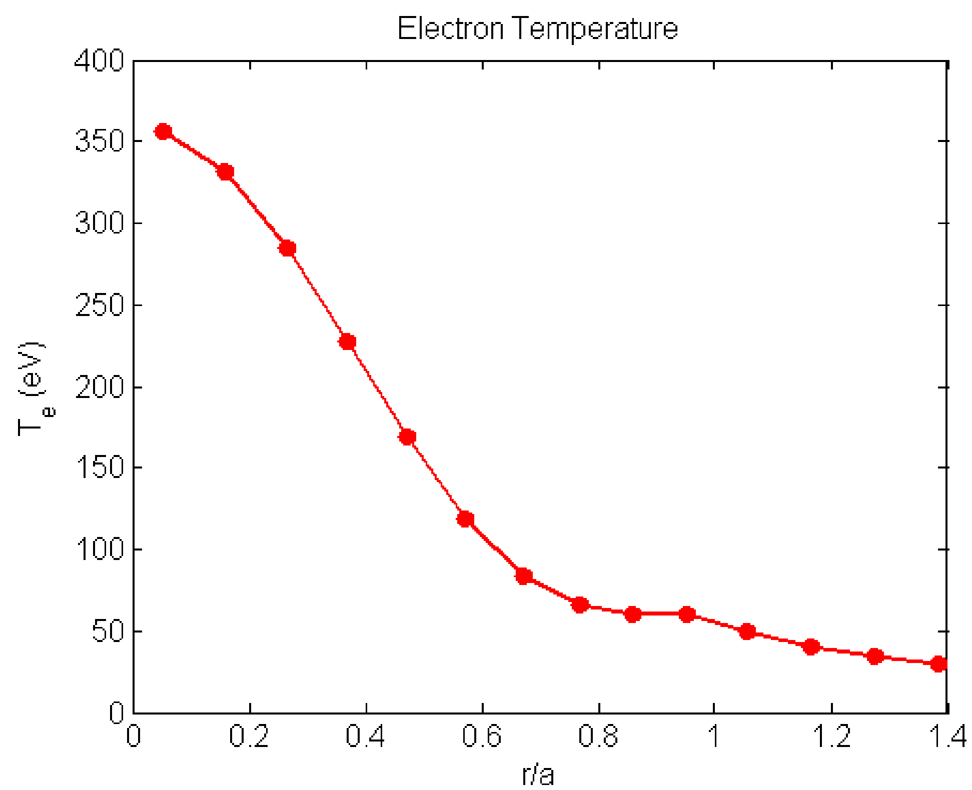




# DEGAS Input

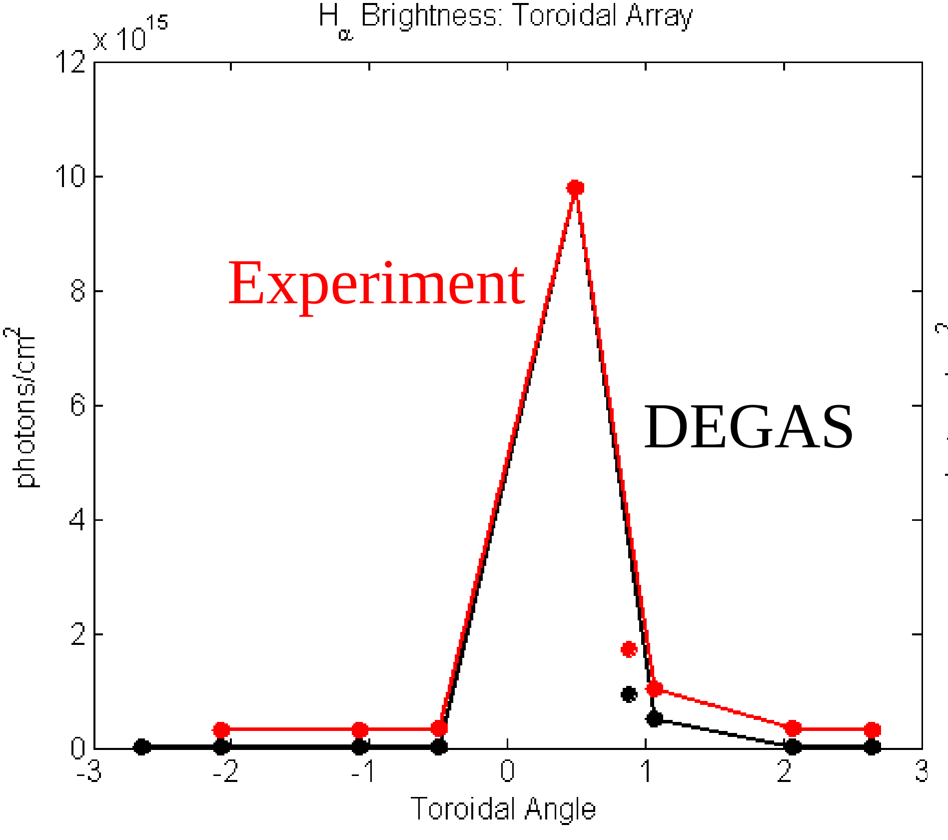
- Density from inverted interferometer data
- $T_e$ profile is parabolic, agrees with central Thomson scattering data
- SOL parameters are estimated

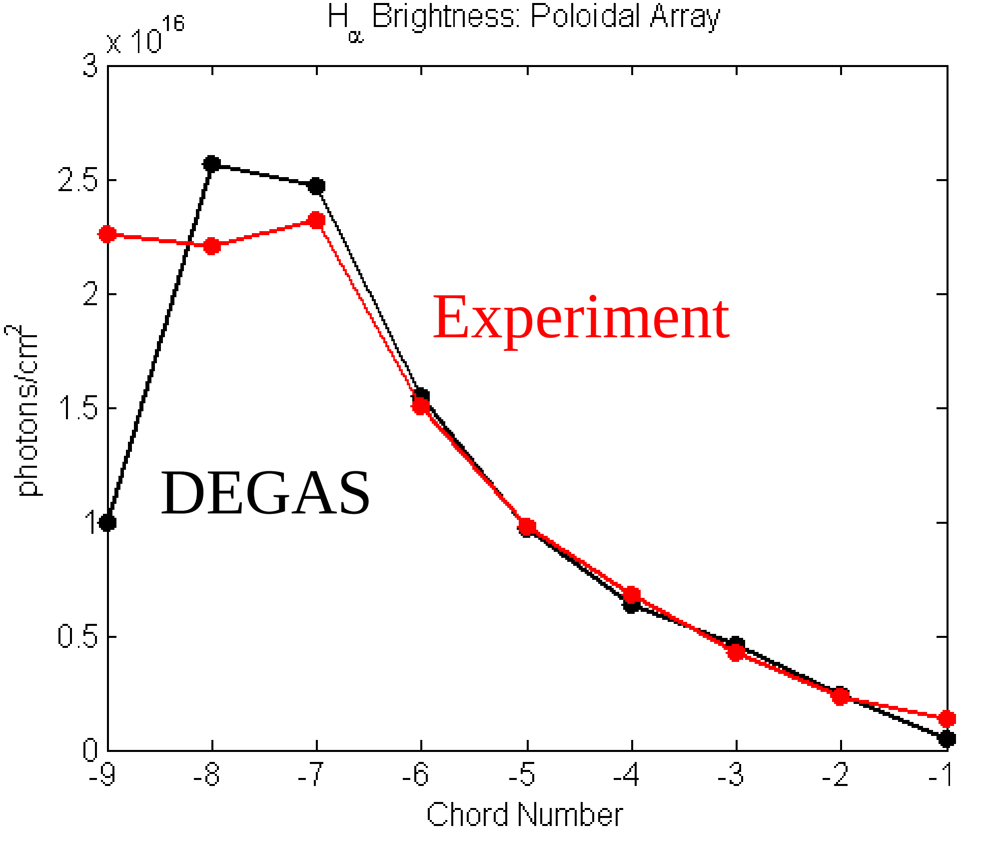


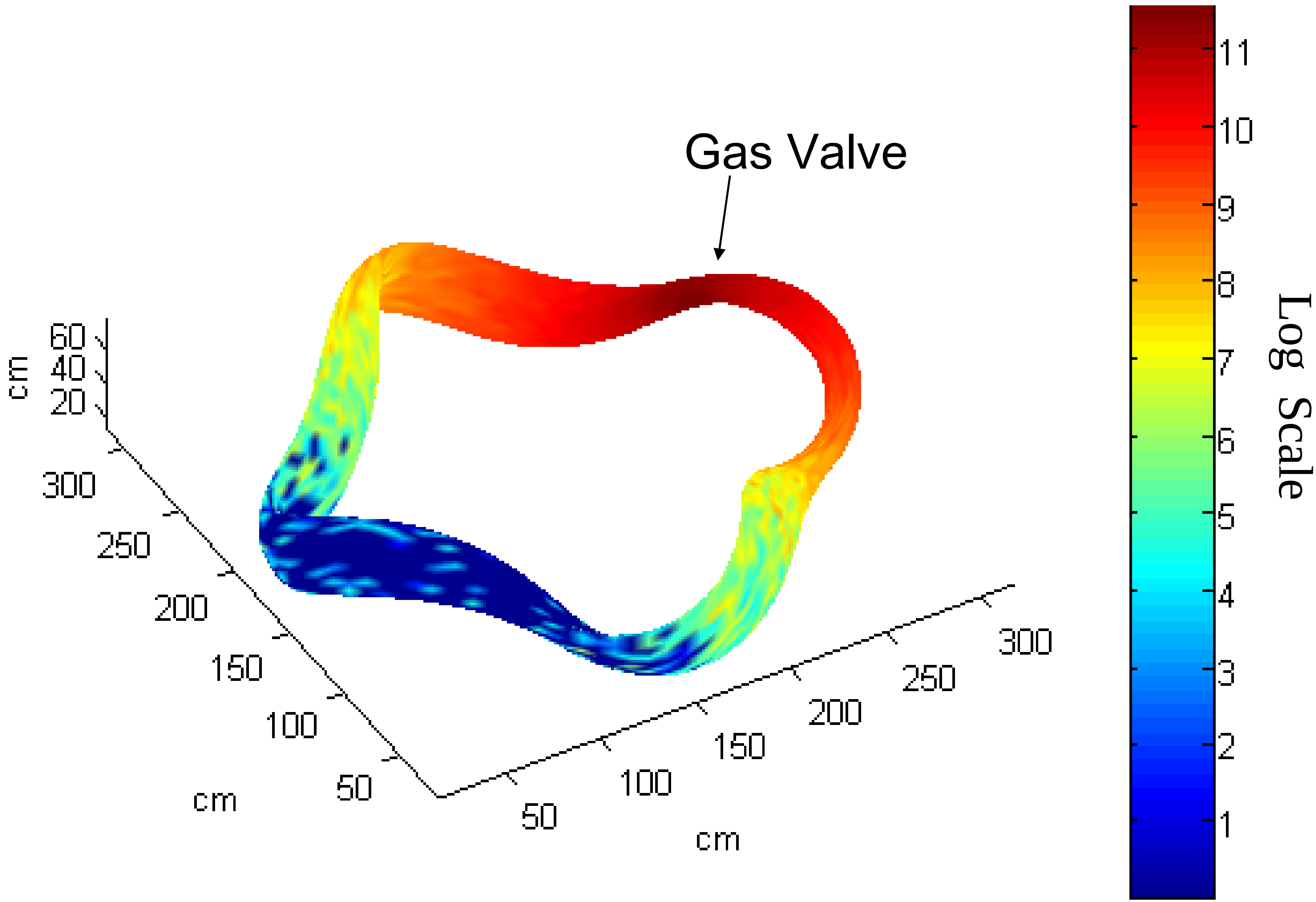
# DEGAS Results are Scaled to Match $H_\alpha$ Brightness

- Results are multiplied to match the central chord of the poloidal array
- Poloidal array shows good match to experiment
- Toroidal array matches at puff, but DEGAS results are low on chords away from puffer -> room for recycling?

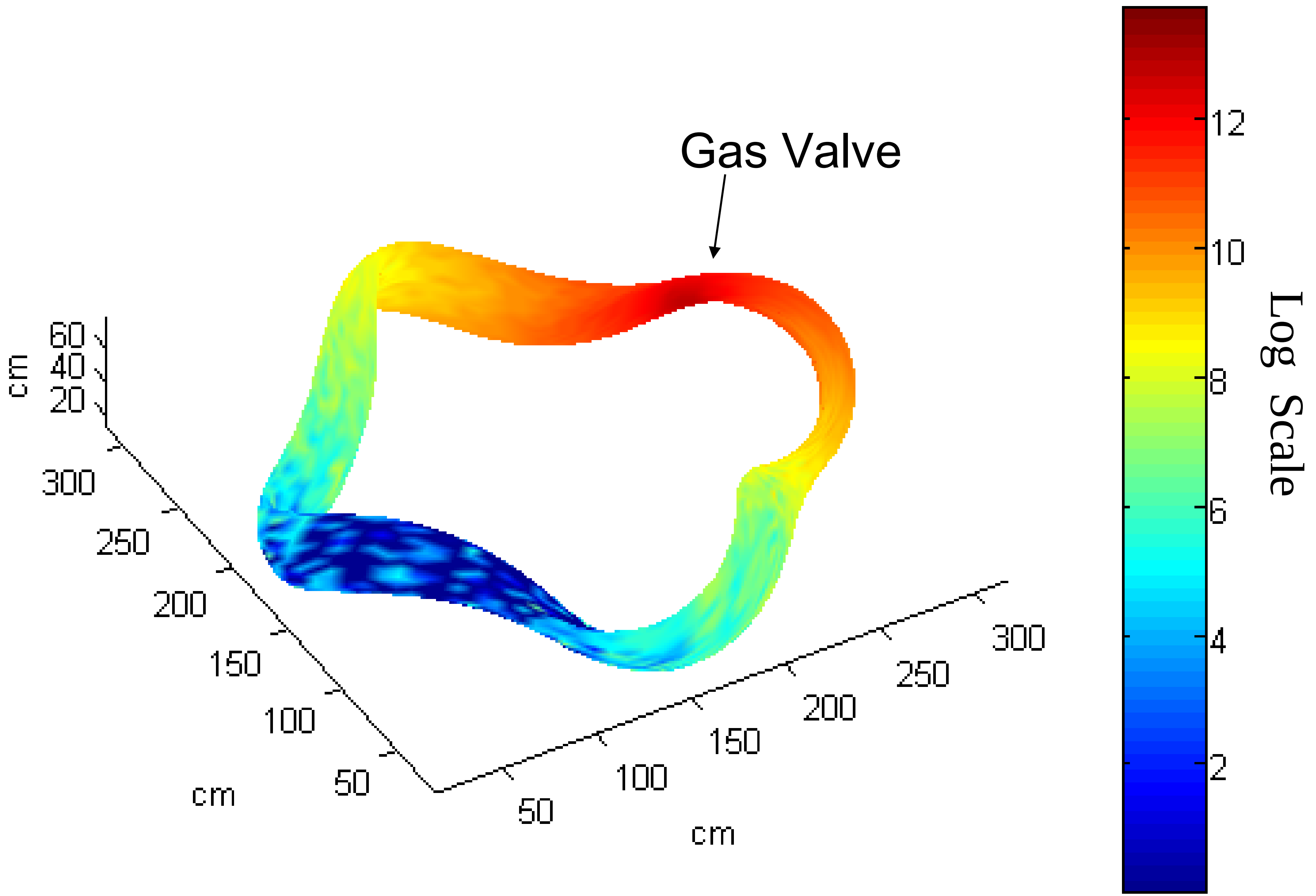


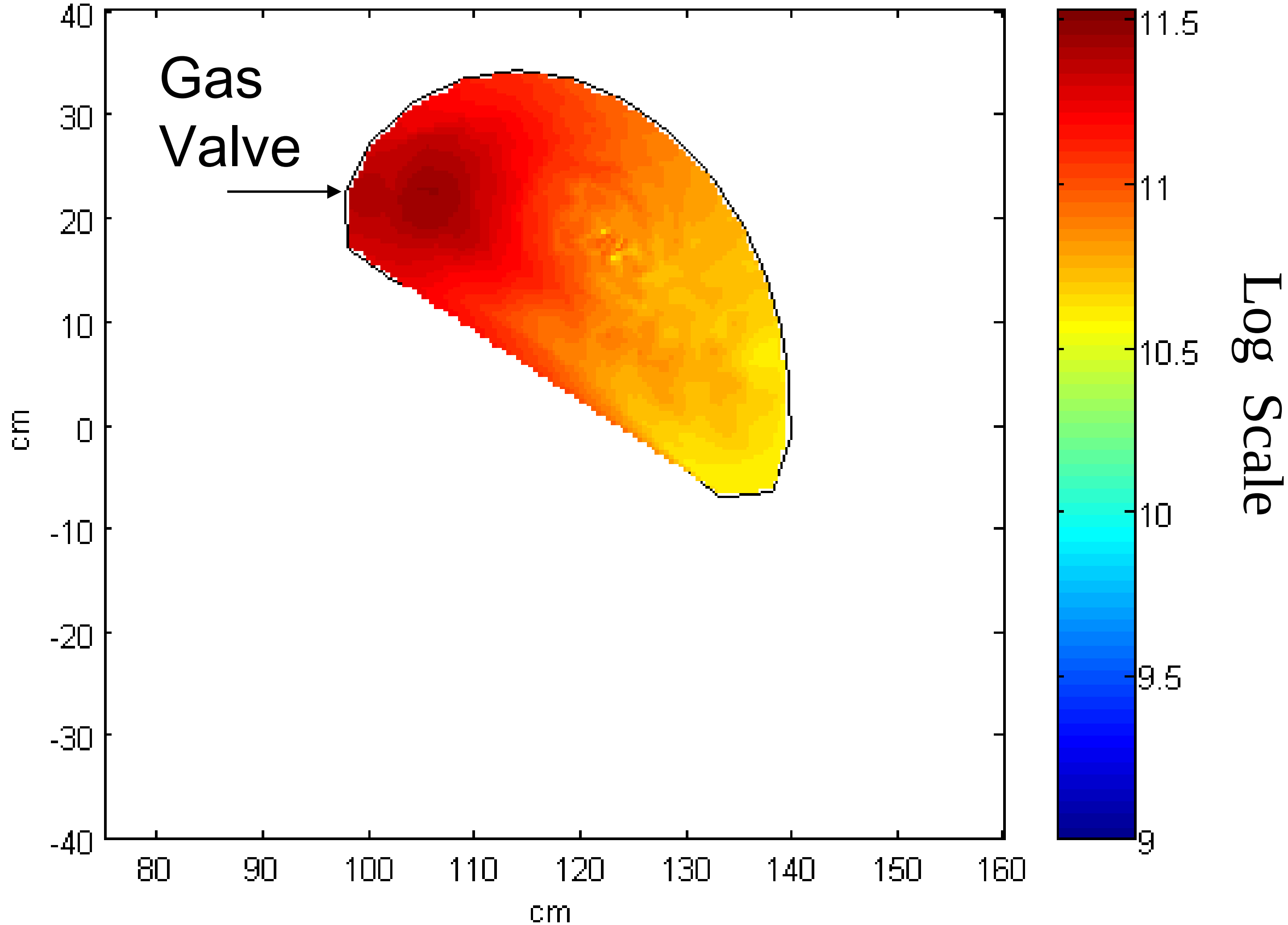
# DEGAS Output: Atomic H



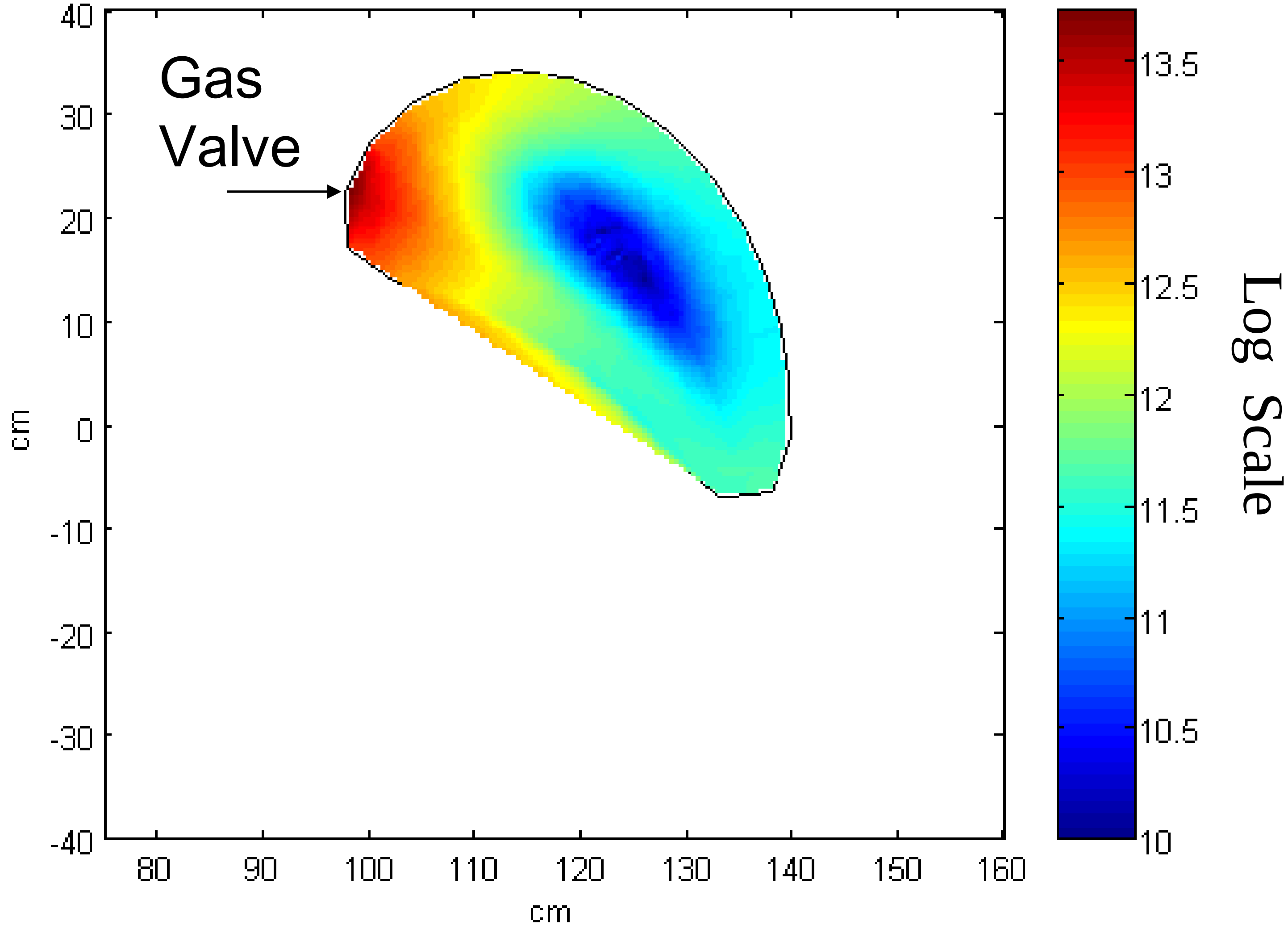
# Molecular Hydrogen



# Atomic H: Cross Sectional View

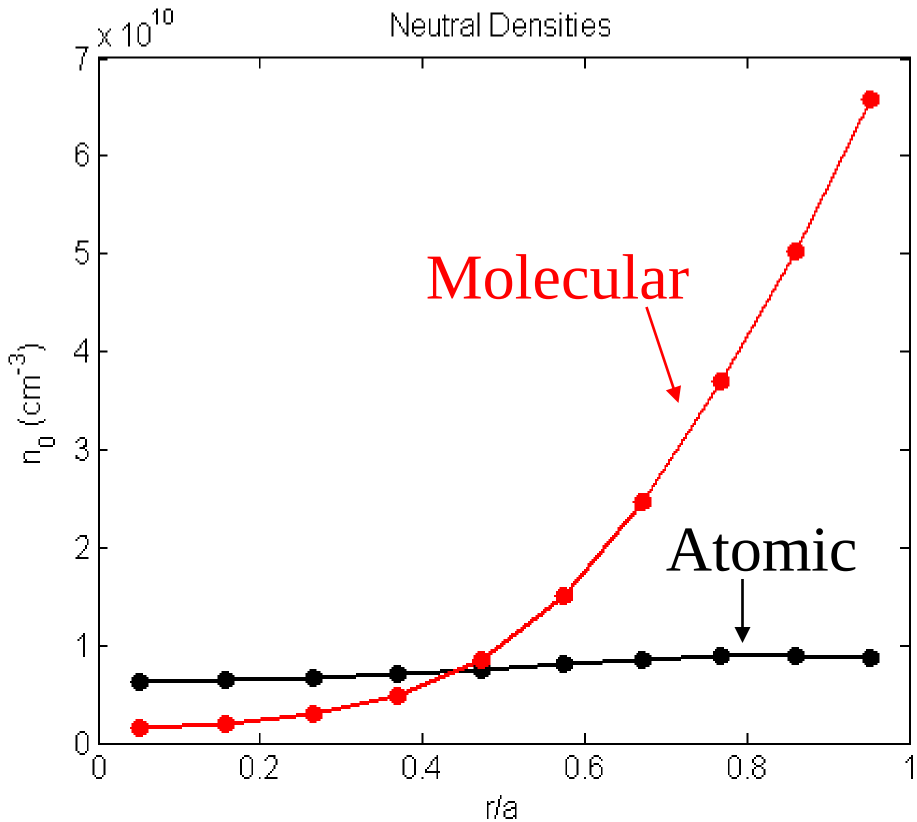


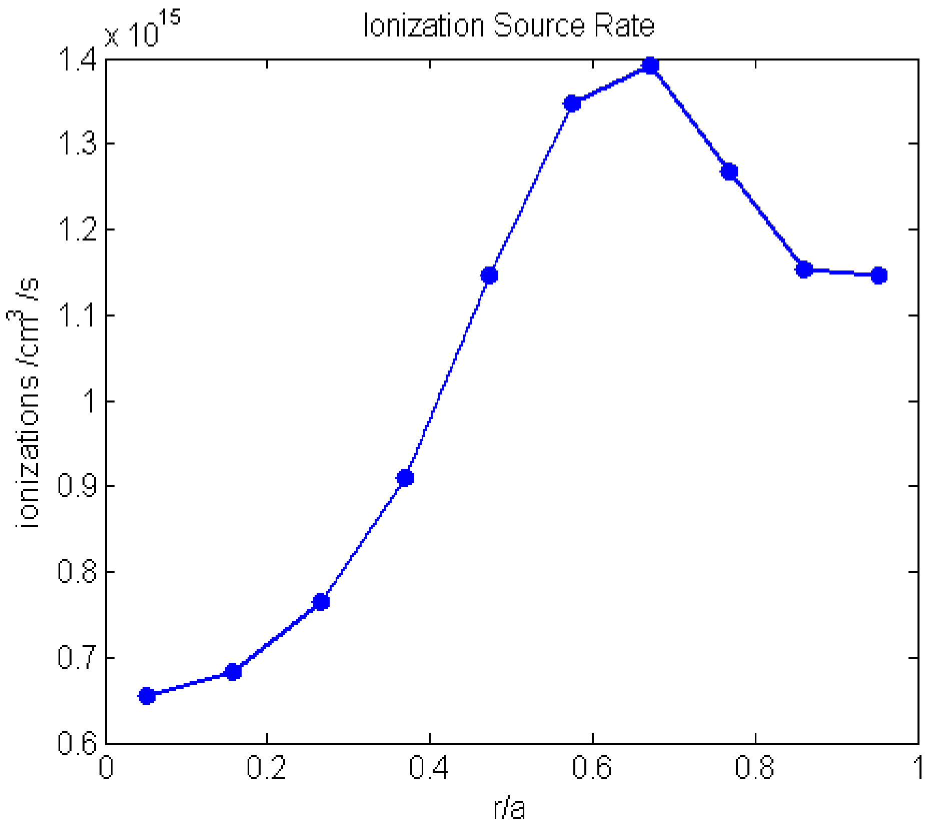
# Molecular H: Cross Section



# Flux Surface Averaged Quantities

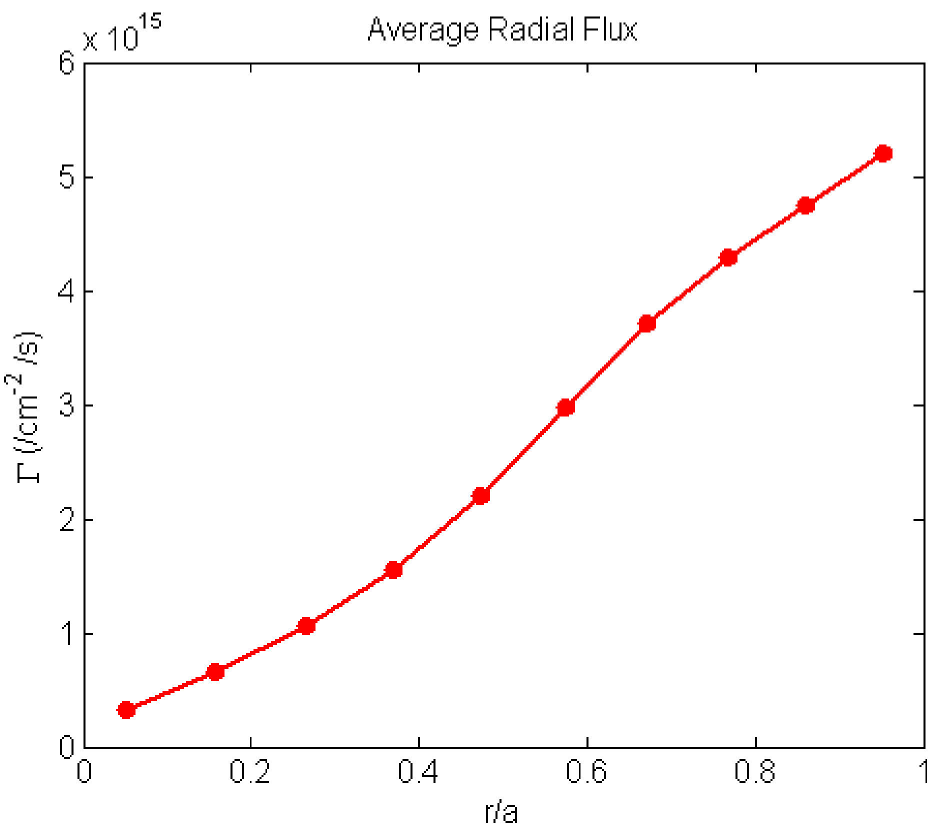
- Source profile is peaked at r/a ~ 0.7, but central fuelling is non-negligible

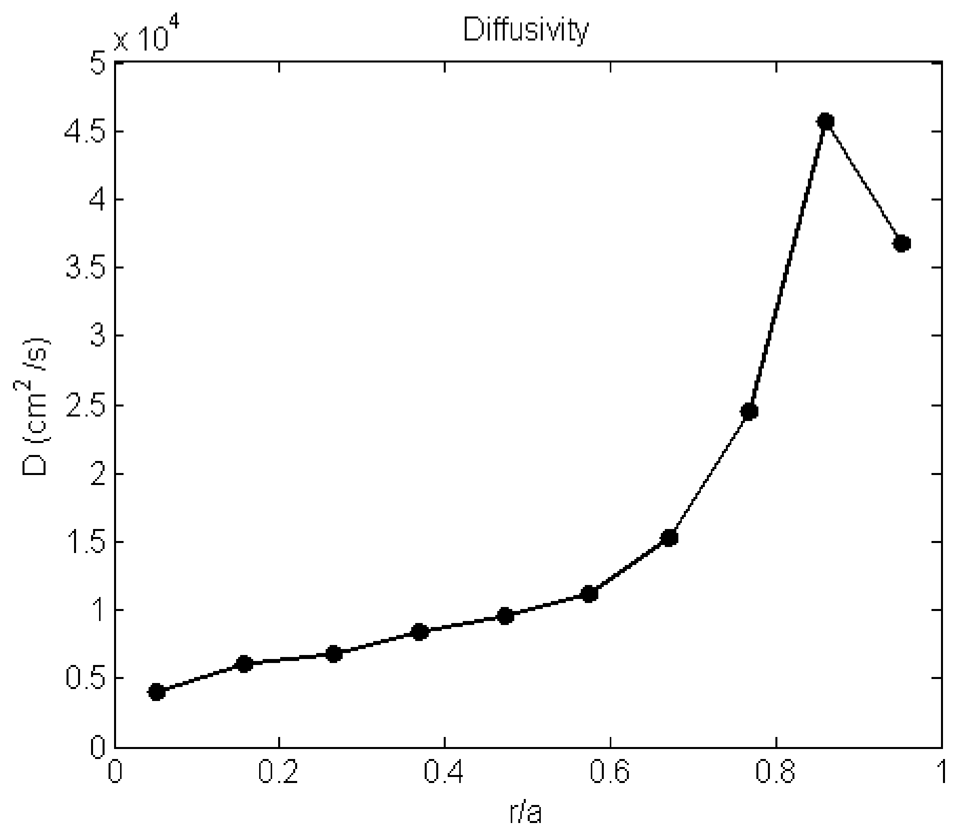


# Transport Quantities

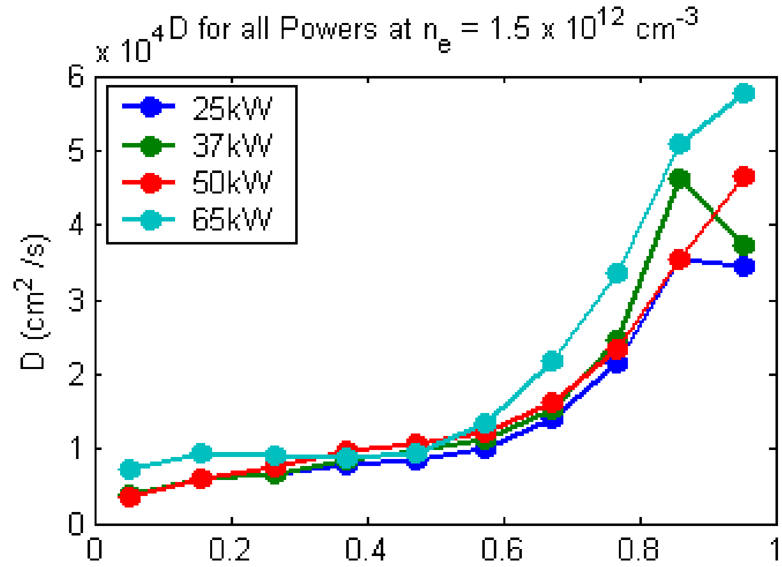
- The total source inside each flux surface and the electron density gradient give an effective diffusion coefficient
- Yields D(r) ~ $10^4$ $cm^2/s$, increasing towards edge
- $n_e$= 1.5 x $10^{12}$ $cm^{-3}$, P = 37 kW

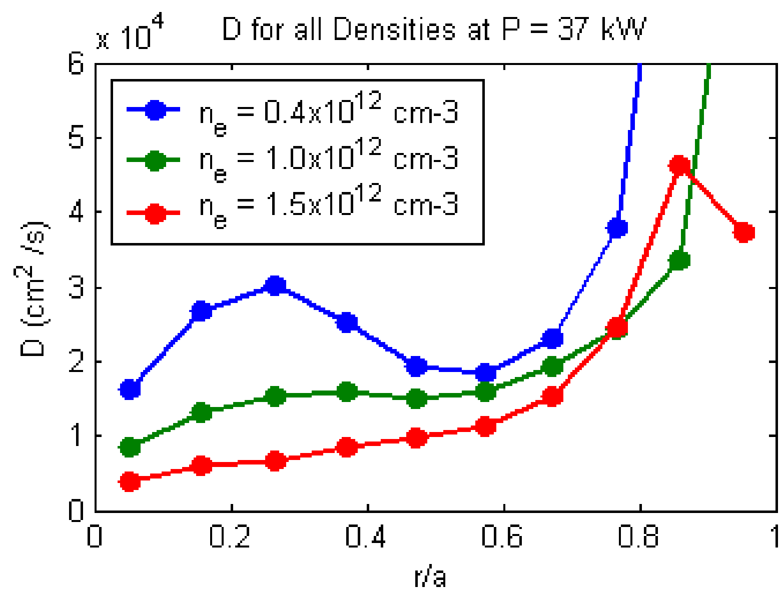


# Power and Density Scan

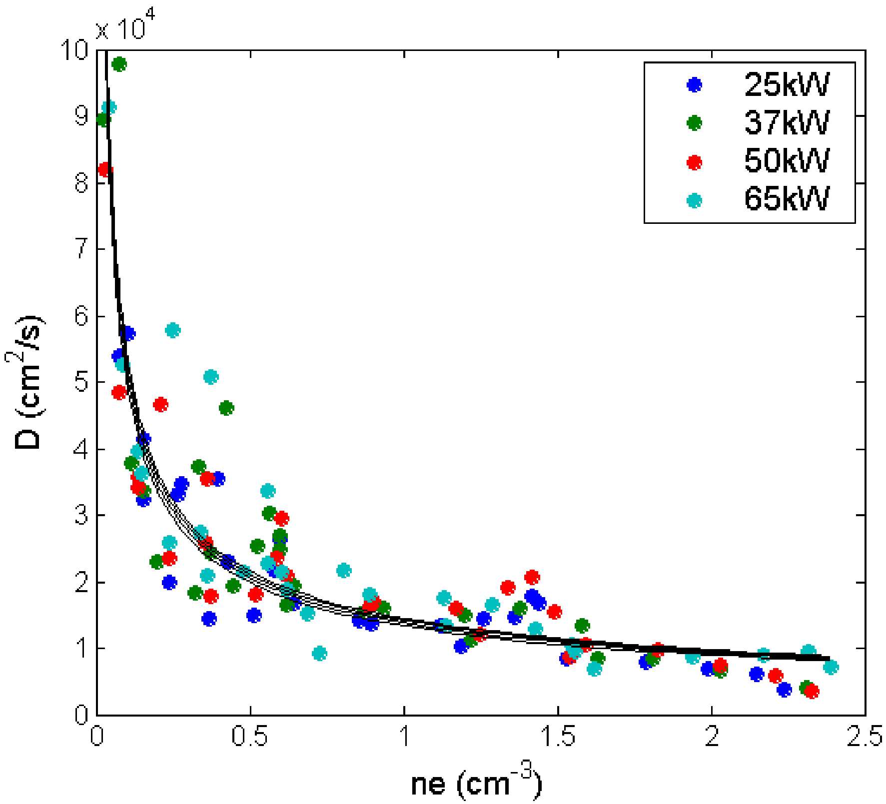
- Discharges were analyzed for powers ranging from 25 to 65 kW, and line averaged densities from $4 \times 10^{11}$ to $1.5 \times 10^{12}$ $cm^{-3}$
- Results shown to right:
  - D for power scan with density held constant at $1.5 \times 10^{12}$ $cm^{-3}$
  - D for density scan with power held constant at 37 kW
- Diffusivity appears to have a much stronger dependence on density than on power



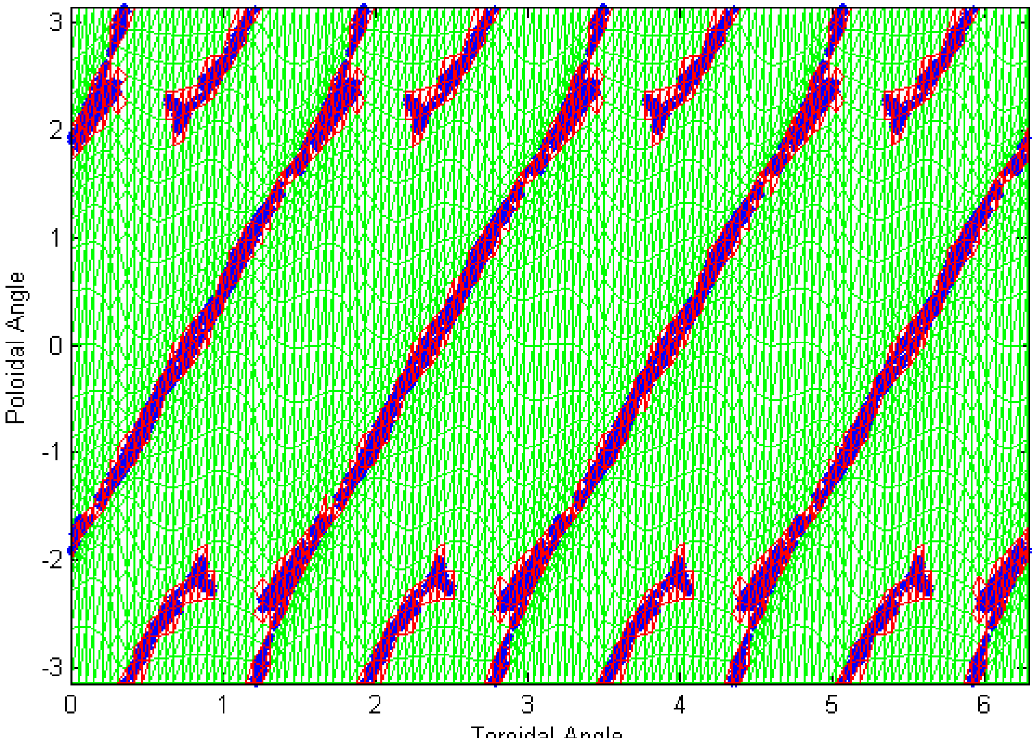
# Power and Density Dependence

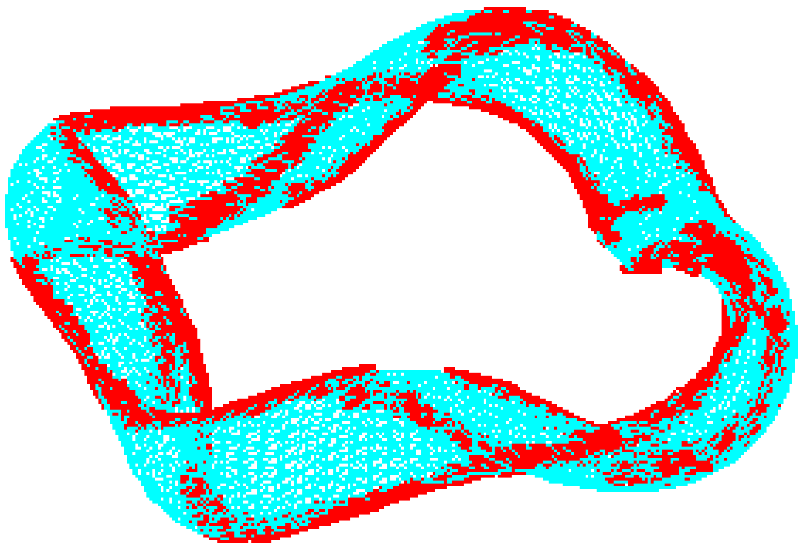
- Local D and $n_e$ plotted for all power levels
- Clear dependence on density, but not power
- Fit gives $D=10^4 n_e^{-.57} P^{.09}$, confirming weak power scaling ($n_e$ in $10^{12}$ $cm^{-3}$, power in kW)



# Recycling

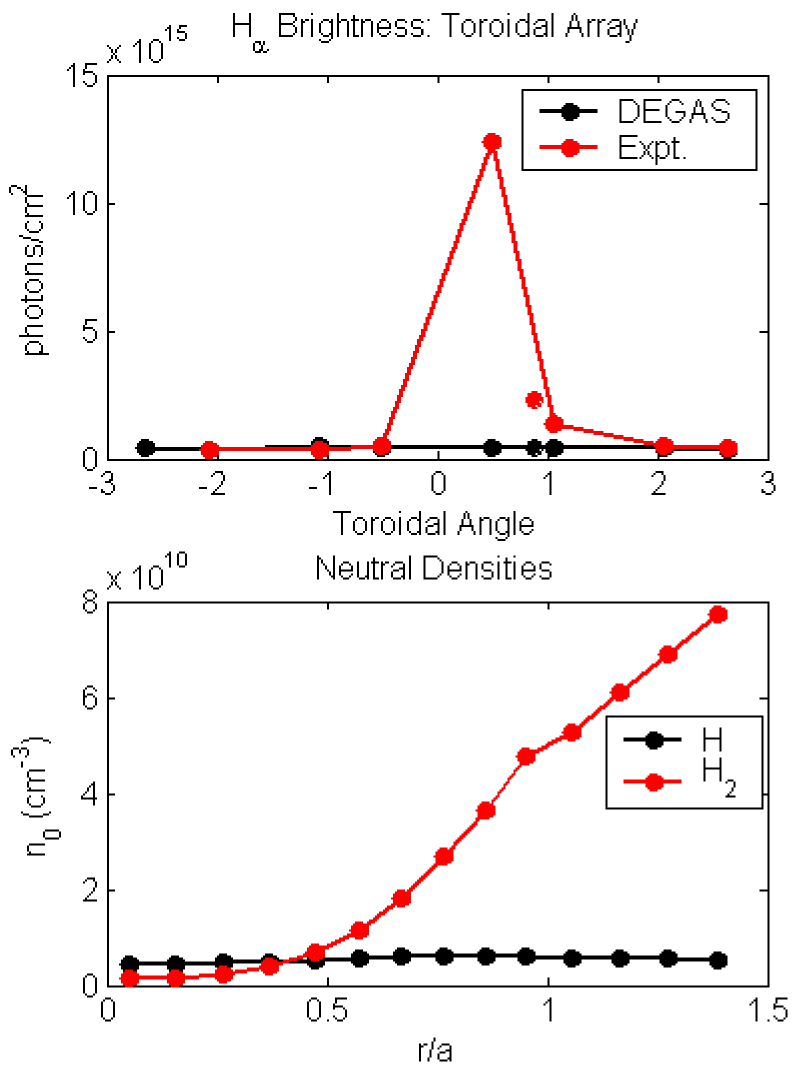
- The complete fuelling model must include recycling
- First estimate is that all recycling occurs where the field lines intersect the vessel (shown below)



# First Recycling Results

- DEGAS results including only recycling shown on right
- Source rate and neutral density appears to be ~0.2-0.5 times that from puff
- Work under way to combine recycling and puff



# Conclusions

- $H_\alpha$ diagnostics have been combined with DEGAS simulations to provide the plasma source rate distribution.
- Transport analysis yields D(r) ~ $10^4$ $cm^2/s$, increasing towards the plasma edge.
- D has a density dependence, but a very weak power dependence.
- Work has begun to include recycling in the DEGAS model for HSX.

# How DEGAS Works

- Input geometry and plasma profiles
- Tell it a source magnitude (#/s) and location
- DEGAS gives each flight a part of that source as its weight
- Calculates mean free paths along trajectory and moves particle to a collision point
- At collision, flight weight reduced by $(1 - \rho_{ion})$, $\rho_{ion}$ is probability of ionization
- Continue until weight too small to care

# Continued…

- Each collision gives (weight * $\rho_{ion}$) ionizations / sec at the location of the collision
- When you're done, you have the ionization source rate (S) everywhere
- Now you get neutral density through the equation $S = n_0(n_e\langle\sigma_e v\rangle + n_i\langle\sigma_i v\rangle)$