

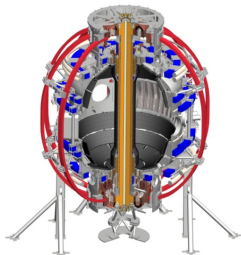
Midplane Neutral Density Profiles in NSTX

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Abstract*

The experimental determination of neutral densities in tokamak plasmas from line radiation is only accurate in the narrow region in which both the excitation rate and neutral density are significant; elsewhere the result is dominated by noise. We propose an alternative, simulation based inversion procedure utilizing tools developed in the validation of the DEGAS 2 Monte Carlo neutral transport code against Gas Puff Imaging camera data [B. Cao, et al., Fusion Sci. Tech. **64**, 29 (2013)]. Here, the Balmer- β emission rate recorded by an absolutely calibrated tangentially viewing camera is used to quantify a simulated, ad hoc neutral gas source at the vacuum vessel wall. This procedure yields absolute radial profiles of deuterium atoms and molecules at midplane. The validity of this characterization of the gas source is confirmed by the similarity of the shapes of the simulated and observed light emission profiles. We also compare the resulting neutral pressures at the vessel walls with data from midplane micro-ion gauges.

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Summary

- Describe simulation based procedure for inverting edge camera data to infer neutral densities,
- Leverages off validation of DEGAS 2 against GPI,
 - And re-uses tools & procedures developed for it.
- Initial application of method appears promising:
 - Profile of light emission approximately replicated,
 - Resulting edge pressure comparable to MIG data.
- Further tests & validation of method remain,
 - E.g., validate D_2 wall source ansatz.
- Missing effects:
 - Newer D_β emission rate are available,
 - Add D_β emission from molecules,
 - Consider effect of turbulence on penetration?
 - See: [Mekkaoui, Phys. Plasmas (2012)].
- Examine other shots.

Multiple Needs for Main Chamber Neutral Density Profiles

- Compute neutral beam charge exchange loss power,
- Estimate effects of neutral atoms on turbulence,
- Evaluate charge exchange fluxes to main chamber & resulting sputtering,
- Interpretation of diagnostic data, e.g., CHERS.

Direct Experimental Determination is Difficult

- See, e.g., [P. W. Ross, Ph. D. Thesis, Princeton University (2010)].
- Balmer- β emission rate:

$$S_{\beta} = n_D(1s) \left[\frac{n_D(n=4)}{n_D(1s)} \right] A_{4 \rightarrow 2} \equiv n_D F(n_e, T_e),$$
$$\Rightarrow n_D = S_{\beta} / F(n_e, T_e).$$

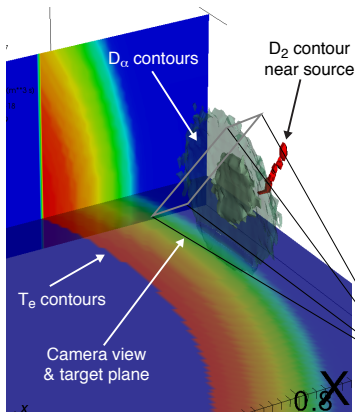
- But, S_{β} & F both significant only in narrow radial region,
 - Farther out, where n_D largest, F is small $\Rightarrow$ poor signal.
 - Farther in, n_D small $\Rightarrow$ poor signal.
- Also requires additional modeling, e.g., Abel inversion, to get n_D profiles.

Direct Modeling Also Problematic

- Largest neutral source typically divertor recycling,
 - Time consuming to construct, comprehensive, consistent characterization of divertor plasma.
 - For practical purposes, essentially non-existent.
- Even if we know divertor source, simulating neutral flow to main chamber challenging:
 - Travels through poorly known SOL plasma,
 - & complex 3-D vessel structures.
- Local wall recycling contributions may be significant,
 - & non-axisymmetric.
 - Little data $\Rightarrow$ also poorly known.

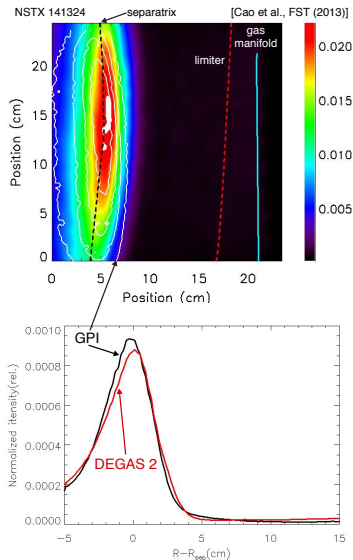
Alternative: Leverage Off Successful Midplane Gas Puff Imaging Simulations

- See: [B. Cao et al., Fusion Sci. Tech. **64**, 29 (2013)].
- See also S. J. Zweben et al. poster NP8.017 (this session).
- Relies on nearby $n_e(R)$ & $T_e(R)$ from Thomson scattering,
 - & assuming $n_e(R)$ & $T_e(R)$ constant on flux surface $\Rightarrow$ know everywhere.
- Flux surface shapes from EFIT,
 - Thomson profiles mapped via $R \Rightarrow$ not sensitive to separatrix location.



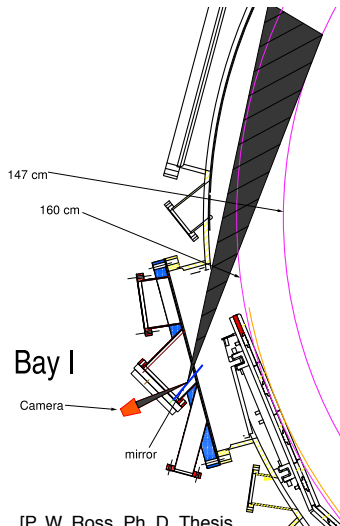
Validated DEGAS 2's Description of D₂ Penetration from Far SOL

- D _{α} radial profiles from D₂ puff matched within estimated uncertainties.
- & matches absolute magnitude,
 - Camera absolutely calibrated,
 - Know total amount of gas injected
⇒ compare photons recorded / D injected.
 - GPI: $1/89 \pm 34\%$,
 - DEGAS 2: $1/75 \pm 18\%$.
- ⇒ DEGAS 2 provides adequate model for D₂ penetration of NSTX midplane.



Key Data: Passive Light Emission from Edge Neutral Density Diagnostic (ENDD)

- Absolutely calibrated tangential camera,
 - $\Rightarrow$ Radial profile, 2 mm resolution.
- 268 frames / second.
 - Slow enough to integrate over ELMs.
- 128×127 pixels, but use only subset.
- Has D_β filter for shots considered here.
- Complete spatial calibration
 $\Rightarrow$ can build DEGAS 2 synthetic diagnostic.



[P. W. Ross, Ph. D. Thesis, Princeton University (2010)]

Set Up DEGAS 2 Simulations Similar to Those Used for GPI

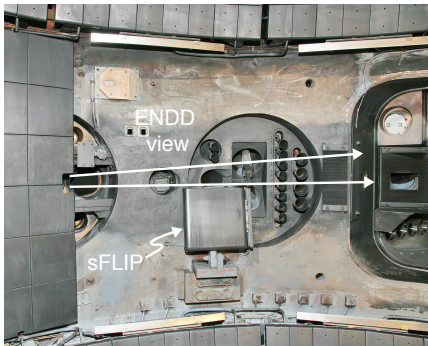
- Geometry & plasma setup procedures derived from those used for GPI,
 - Require minimal human intervention
⇒ might be able to automate & get n_D profiles for many discharges & times.
- Geometry based on EFIT flux surface contours,
 - Rectangular volume around midplane,
 - Top & bottom surfaces are exits.
- Plasma profiles from Thomson & CHERS,
 - Use CHERS to set a fixed n_{D^+}/n_e ,
 - $T_i \simeq T_e$.
- Primary differences from GPI:
 - Synthetic diagnostic for D_β ENDD,
 - And nature of D_2 source ...

Assume Midplane Neutral Density Profiles Insensitive to Neutral Source Details

- Neutral-plasma mean free paths near separatrix $\ll$ poloidal scale lengths,
 - $\Rightarrow$ midplane D atoms & precursor D_2 penetrating from far SOL at nearby poloidal location.
- $\Rightarrow$ Prescribe uniform D_2 source coming from vessel walls,
 - Assign arbitrary magnitude, Γ_{D_2} .
- Sensitivity tests are planned:
 - E.g., compare with $n_D(R)$ from whole device simulations.
- Procedure:
 - Average 10 pixels near middle of simulated ENDD,
 - Overlay with & divide into same from ENDD data
 $\Rightarrow$ overall scale factor for simulation.
 - Apply to all DEGAS 2 output
 $\Rightarrow n_D$ everywhere in problem volume & more.

Simulation Details

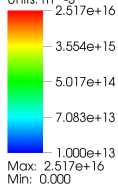
- Scintillator Fast Lost Ion Probe [sFLIP, Darrow, RSI (2008)]: additional recycling surface?
 - If significant, emission up-down asymmetric.



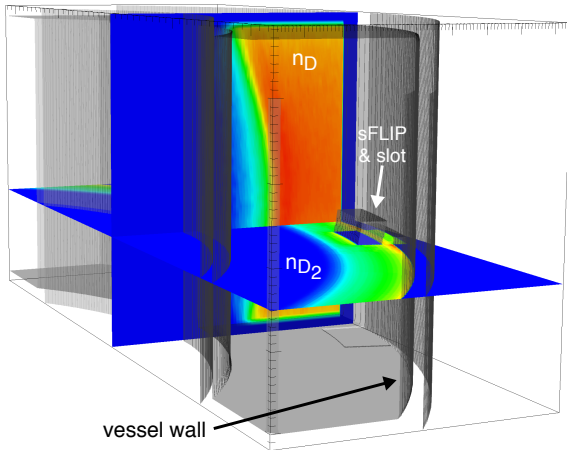
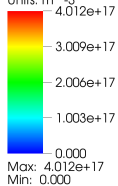
- Compare n_{D_2} with micro-ion gauges (MIG) in midplane ports,
 - See: [Raman, RSI (2003)],
 - Set up vacuum “slot” behind sFLIP to simulate gauge.
- Neutral profiles only for this toroidal location,
 - May not be axisymmetric,
 - MIG data will help.
- Thomson T_e & n_e poor in SOL,
 - Can adjust to improve emission profile match there.

Simulation Geometry

Var: spDden
Units: m^{-3}

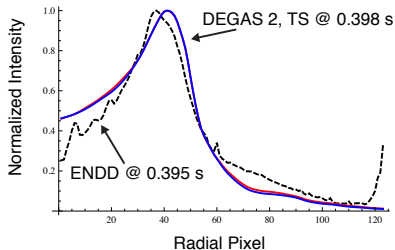
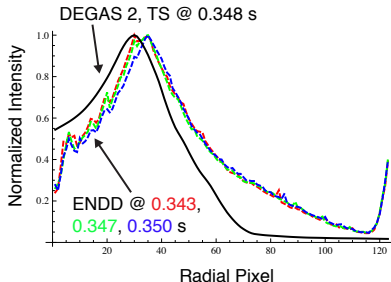
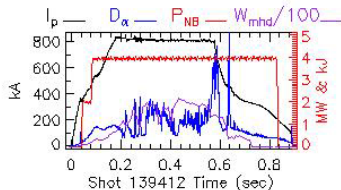


Pseudocolor
Var: spD2den
Units: m^{-3}



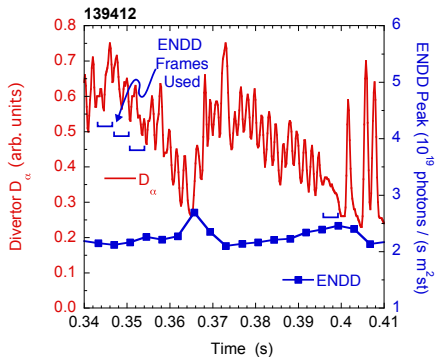
Emission Profiles Agree Reasonably

- Shots available for analysis:
 - Those in which ENDD had D_β filter,
 - & same F-stop used in calibration.
 - $\Rightarrow \sim 90$ shots.
 - 139412 is one analyzed by Scotti.
- Take ratios of profile peaks:
 - 0.348 s: ENDD = $2.27 \times$ DEGAS 2,
 - 0.398 s: ENDD = $2.36 \times$ DEGAS 2.



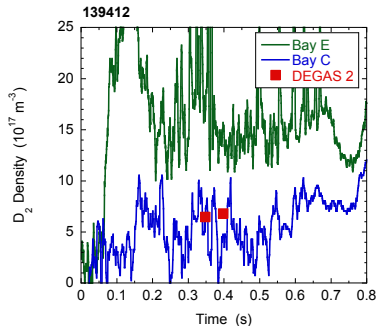
Differences in Agreement Likely Due to ELMs

- ENDD profiles at 0.343, 0.347, & 0.350 broader than that at 0.395,
- **Probably due to ELMs** →
- Thomson $\sim$ instantaneous $\Rightarrow$ less likely to show ELM effects,
 - Thus, not reflected in DEGAS 2 profiles, either.
- ELMs affect neutral penetration,
 - Will increase edge n_e , T_e to account for this.

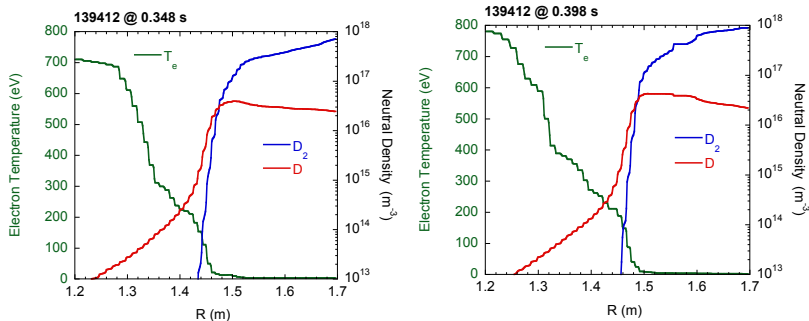


Scaled D_2 Density Matches Micro-Ion Gauges Well

- Bay C midplane:
 - Behind the RF antenna,
 - $\sim 180^\circ$ away from ENDD.
- Bay E midplane:
 - Has line of sight to plasma
 $\Rightarrow$ likely to read higher.
- Calibrated against no-plasma shot 139423.
- Convert P_{D_2} to n_{D_2} at 300 K.



Yields Neutral Density Profiles at Midplane for Two Times



- Scaled to match ENDD emission,
- T_e profile as input to DEGAS 2 for reference.
- Show two times from same shot to assess sensitivity & variation.