NSTX-U

Supported by U.S. DEPARTMENT OF ENERGY | Office of Science

PP8.00070

Midplane Neutral Density Profiles in NSTX

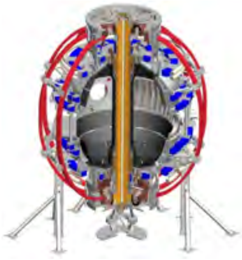
D. P. Stotler

F. Scotti, R.E. Bell, B.P. LeBlanc, R. Raman

and the NSTX Research Team

56th APS-DPP Meeting
New Orleans, Louisiana
October 27 – 31, 2014

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC



Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Abstract*

A procedure for using the DEGAS 2 Monte Carlo neutral transport code to infer neutral density profiles from the Balmer-β emission data recorded by a tangential camera was proposed previously and is examined in more detail here. The simulations track the penetration of an ad hoc neutral gas source at the vacuum vessel wall; the associated light emission seen by the camera is obtained via a synthetic diagnostic. The resulting radial emission profiles compare well with the measured ones, with the ratio of the profile peaks providing scaling factors for the neutral source strength and all output quantities. The procedure yields absolute radial profiles of deuterium atoms and molecules at the NSTX midplane. We will first show that the modeled camera image and density profiles are insensitive to variations in the spatial distribution of the neutral source. The procedure will then be applied to data from a variety of different NSTX operating regimes. A detailed uncertainty and error analysis will also be presented.

*The authors wish to acknowledge P. W. Ross and A. L. Roquemore for the design, construction, and installation of the ENDD diagnostic. This work is supported by U.S. DOE Contracts DE-AC02-09CH11466 (PPPL), DE-AC52-07NA27344 (LLNL), and DE-SC0006757 (University of Washington).

Multiple Needs for Main Chamber Neutral Density Profiles

- For other diagnostics & analyses
  - Neutral beam charge exchange loss power,
  - Interpretation of CHERS data.
- & for study of SOL & pedestal physics, e.g., H-mode pedestal formation.
- Have proposed DEGAS 2 based "forward" method for inferring $n_D(R)$, $n_{D_2}(R)$,
  - See: [D. P. Stotler et al., 21st Plasma Surface Interactions Conference (2014)].
  - Uses Edge Neutral Density Diagnostic data to assess quality & calibrate.
- Method works better for some shots than others,
  - $\Rightarrow$ develop deeper understanding to improve method & reduce uncertainties.

Direct Experimental Determination is Difficult

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

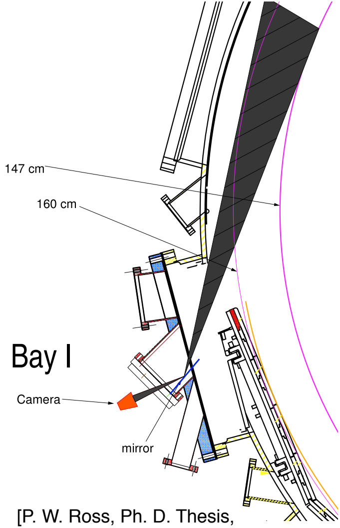
$$S_\beta = n_{\rm D}(1s) \left[\frac{n_{\rm D}(n=4)}{n_{\rm D}(1s)} \right] A_{4\rightarrow 2} \equiv n_{\rm D} F(n_e, T_e),$$

$$\Rightarrow n_{\rm D} = S_\beta / F(n_e, T_e).$$

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

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

- Absolutely calibrated tangential camera,
  - $\Rightarrow$ Radial profile, 1.6 mm resolution.
- 3.7 ms exposure time $=$ 268 frames / second.
  - $\Rightarrow$ integrates over ELMs.
- 128 $\times$ 127 pixels, use only 123 (20 cm) radial $\times$ 66 (9 cm) poloidal.
- 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)]

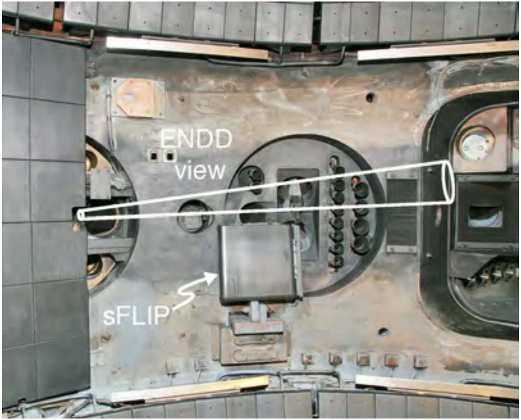
Set Up DEGAS 2 Simulations Similar to Those Used for GPI

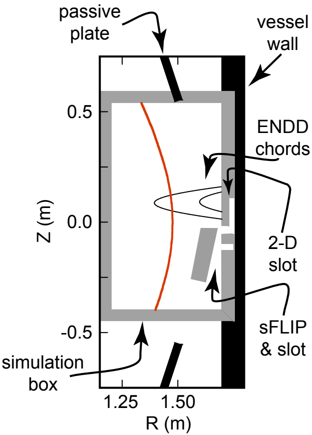
- Geometry & plasma setup procedures derived from those used for GPI [B. Cao et al., Fusion Sci. Tech. **64**, 29 (2013)],
- Geometry based on EFIT flux surface contours,
  - Rectangular volume around midplane,
  - Inner, top & bottom surfaces are exits.
- Plasma profiles from Thomson & CHERS,
  - Use CHERS to estimate n_{D^+}/n_e & T_i/T_e,
  - $T_i = T_e$ for shots used here.
- Primary differences from GPI:
  - Nature of D_2 source,
  - Synthetic diagnostic for D_β ENDD,
  - New CCC $n = 1 \rightarrow 3, 4, 5$ cross sections from [Bray et al., Phys. Reports **520**, 135 (2012)].
  - Presently ignore D_β from molecules.

Source Characterization & Analysis Procedure Specific to ENDD

- Assume midplane neutral density profiles insensitive to neutral source details,
- $\Rightarrow$ Postulate vertically uniform D_2 source coming from vessel walls,
  - Assign arbitrary magnitude: $\Gamma_{D_2} = 10^{20}$ $D_2/(m^2$ s) at wall.
- Compare synthetic ENDD signal with experimental image:
  - Use horizontal row of simulated ENDD pixels at $Z = 9$ cm,
  - Overlay with row from calibrated experimental ENDD smoothed over vertical 10 pixels (1.4 cm) $\Rightarrow$ overall scale factor for simulation.
- Initial runs were 3-D with sFLIP plate,
  - Shielded "slot" behind sFLIP to estimate vessel density.
  - But, contributions from sFLIP were found negligible.
- $\Rightarrow$ most subsequent runs are 2-D / axisymmetric.
  - Different slot configuration for vessel density.

ENDD Geometry

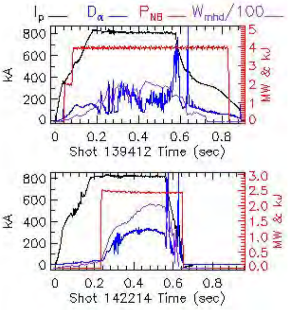


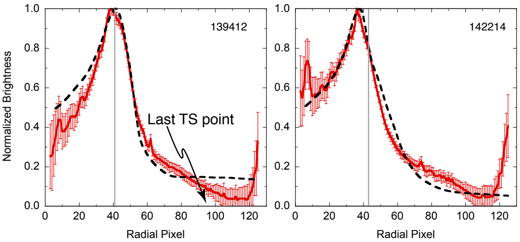


- Scintillator Fast Lost Ion Probe [sFLIP, Darrow, RSI (2008)]: additional recycling surface?

Emission Profiles Agree Reasonably

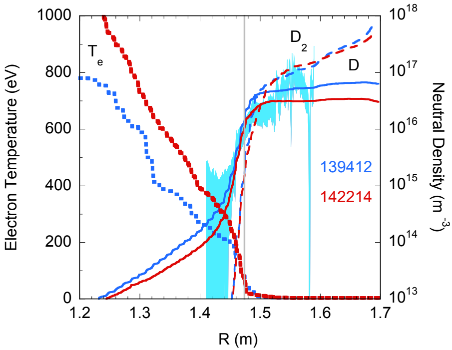
- Apply to two NSTX H-mode plasmas:
  - 139412 $t = 4$ s: $\delta = 0.3$, ELMy,
    - Lull at $t = 0.4$ s.
  - 142214 $t = 4$ s: $\delta = 0.6$, ELM-free.
- High SOL density, $n_e \sim 10^{18}$ m^{-3} $\Rightarrow$ Thomson accurate at all points.
- Take ratios of profile peaks:
  - 139412: ENDD = 2.5 $\times$ DEGAS 2,
  - 142214: ENDD = 1.6 $\times$ DEGAS 2.



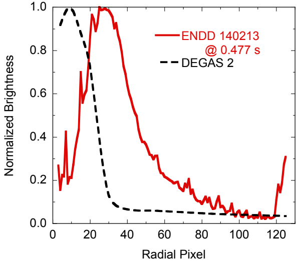


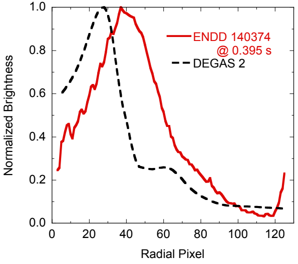
Yields Neutral Density Profiles at Midplane for Two Shots

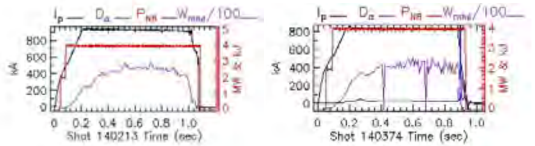
- Scaled to match ENDD emission,
- T_e profile as input to DEGAS 2 & EFIT02 $R_{\rm sep}$ for reference.
- Profiles outside last TS point ($R = 1.56$) constant.
- Include S_β / F density for 142214.



Not All Simulations Work This Well!

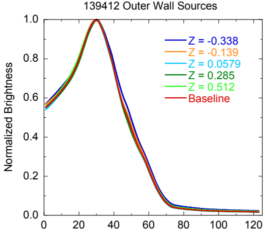


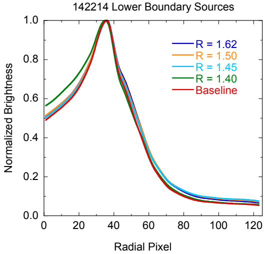


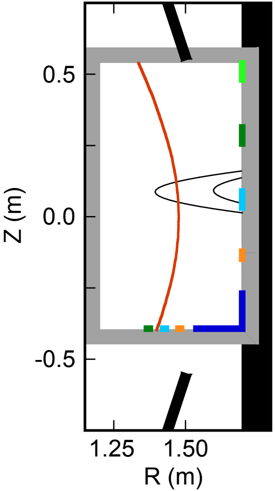


- Both are ELM-free H-modes $\Rightarrow$ TS profiles should be OK.
- Peak in 140213 at left edge of frame $\Rightarrow$ possible vignetting / calibration problem.
- What about 140374?
- There are others . . .

Simulated ENDD Profiles Insensitive to Source Distribution

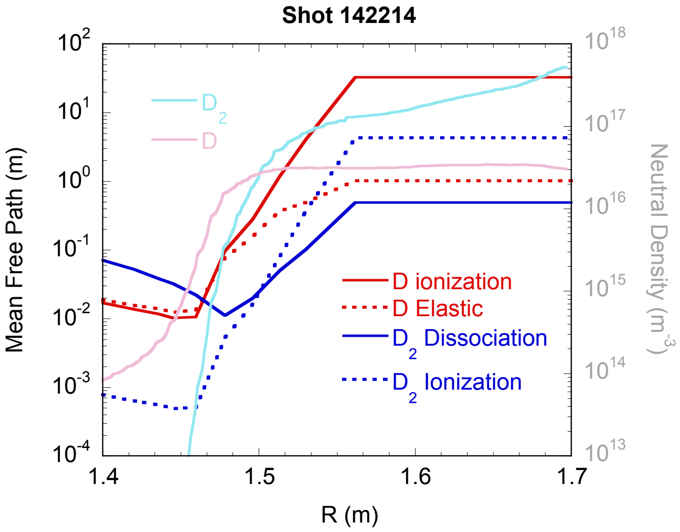






- ⇒ deviations between observed & simulated profiles not due to source characteristics,
- More likely due to inability to accurately reconstruct plasma profiles.
- Origins of subtle trends in simulated profiles unclear.

Far SOL Profiles Dominated by Dissociation & Peaks by Ionization



Suggests Procedure for Inferring Far SOL Plasma Profile Scale Lengths

$$\frac{dS_\beta}{dR} = S_\beta \left(\frac{1}{\lambda_{\mathrm{D}}} - \frac{\alpha_n}{\lambda_n} - \frac{\alpha_T}{\lambda_T} \right),$$

- Where:
  - $d \ln n_e / dR \equiv -1/\lambda_n$, $d \ln T_e / dR \equiv -1/\lambda_T$, $d \ln n_{\mathrm{D}} / dR \equiv 1/\lambda_{\mathrm{D}}$.
  - And $\alpha_n \equiv \partial \ln F / \partial \ln n_e$ & $\alpha_T \equiv \partial \ln F / \partial \ln T_e$.
- Flat D profiles $\Rightarrow \lambda_{\mathrm{D}} \gg \lambda_n, \lambda_T$.
- Procedure:
  - Assume $\lambda_T \ll \lambda_n$ & solve for λ_T, evaluating $d \ln S_\beta / dR$, S_β & α_T at last TS point.
  - Alternative: assume $\lambda_T \gg \lambda_n$ & solve for λ_n.

Peak Location Determined Only by Plasma Profiles & D Ionization

- At peak, D_2 density neglible $\Rightarrow$ no D source.
- Peak location insensitive to CX rate,
  - Only needs to be big enough to thermalize D.
- Neutral continuity equation reduces to:

$$\frac{d(n_{\mathrm{D}} v_{\mathrm{D}})}{dR} = -n_{\mathrm{D}} S_{\mathrm{ion}},$$

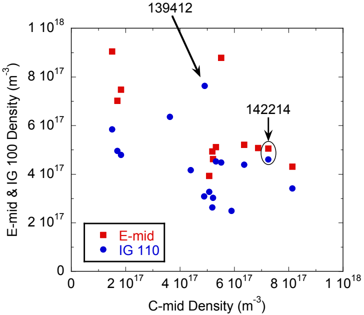
- With D thermalized, $v_{\mathrm{D}} \propto v_{i,th} = \sqrt{2T_i/\pi m_{\mathrm{D}}}$,
- & peak defined by $dS_\beta/dR = 0$:

$$\frac{\alpha_n}{\lambda_n} + \frac{\alpha_T - 1/2}{\lambda_T} = \frac{S_{\mathrm{ion}}}{|v_{\mathrm{D}}|}.$$

- Provides a tool for understanding why some comparisons are better than others,
  - & guide search for improvement.

Can We Compare Vessel Densities with Micro-Ion Gauge Data?

- Survey C-mid, E-mid, IG 110 pressures in 17 shots,
  - Averaged over 0.1 or 0.2 s interval,
  - IG 110 shifted 0.18 s.



- No obvious correlation between them!
- Each is compromised:
  - C-mid very noisy (low end of operating range?),
  - E-mid direct view of plasma $\Rightarrow$ affected by ELMs,
  - IG 110 slow to respond.
- Can only get an upper bound or range of vessel densities.
- Similarly, see no correlations with peak ENDD emissivity.

Summary

- Have found more support for assumption that source details unimportant.
  - And that ENDD brightness / emissivity profiles more sensitive to plasma profiles.
- Will use these insights to get improved matches in other discharges,
  - And then carry out broader survey.
- Can we get more information from ion gauge data?
  - To validate method,
  - & provide comparison values for NSTX-U.
- Envision more routine application in NSTX-U,
  - But, ENDD now looks across beam armor.
  - Would like to relate to densities elsewhere & to 2010 NSTX.