DEGAS 2 Analysis of Edge Neutral Density Diagnostic Data

D. P. Stotler, P. W. Ross, et al.

Princeton Plasma Physics Laboratory
Princeton University
Princeton NJ 08543

REVISED: FEBRUARY 22, 2008

PPPL
PRINCETON PLASMA
PHYSICS LABORATORY

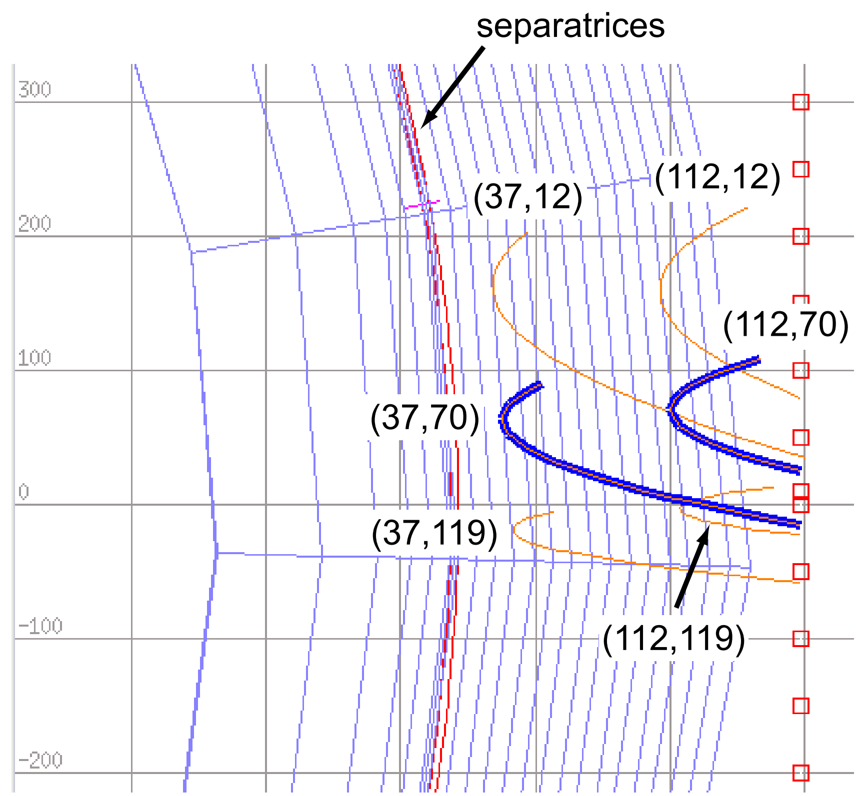
NSTX

Camera View

- Started with Patrick's calibration data: four points in each of two planes,
  - For each point, had (x, y, z) and pixel coordinates (ix, iy).
- For each plane, fit:
  - $Ax + By + Cz + 1 = 0$,
  - $x = E \times ix + F \times iy + G$,
  - $z = H \times ix + I \times iy + J$.
  - Did this with singular value decomposition (SVD),
    - Initial test and application of technique.
    - Used again later.
  - Fit errors are < 1 mm,
    - I.e., comparable to precision of calibration data.

Analysis Approach

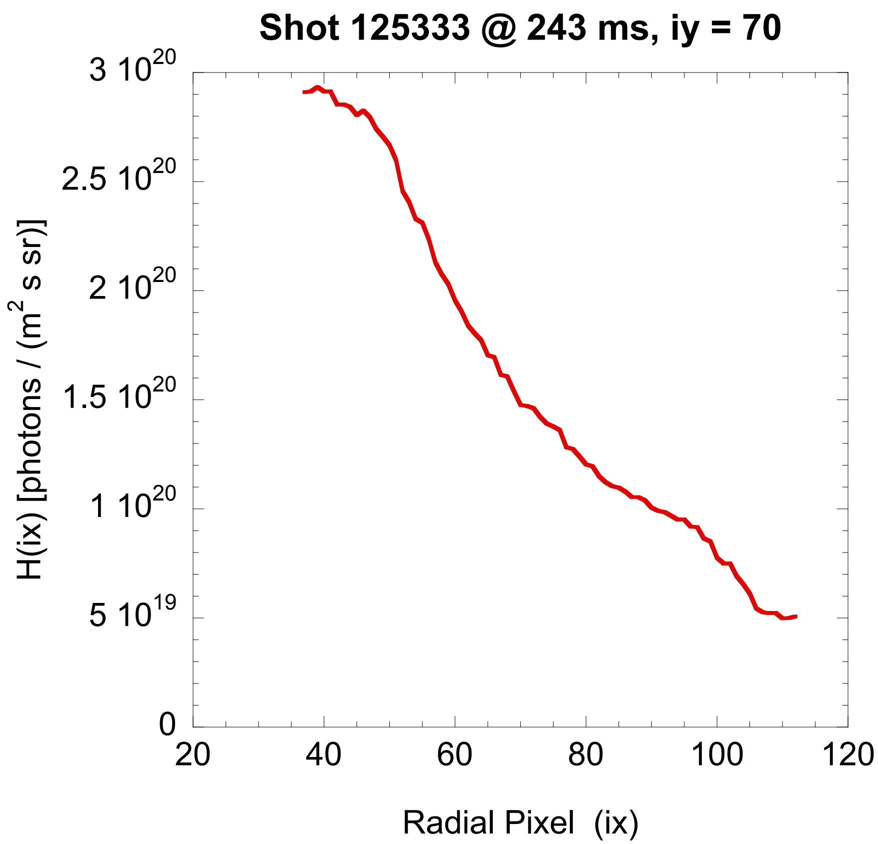
- Contemplated 2-D analysis, but observed poloidal variation probably due to optics, filter, etc. (PWR).
- Instead analyze $iy = 70$ row of pixels.
  - $ix = 37 \rightarrow 112$ is the useful window (PWR).
- Build 2-D SOL mesh based on 125333 at 245 ms (EFIT02),
  - Could probably be used for other shots / times without significant error.
- "Fit" neutral density in zones intersected by camera chords to match camera data: $H_i = \sum_j S_{ij} N_j$.



Camera Image Processing and Scaling

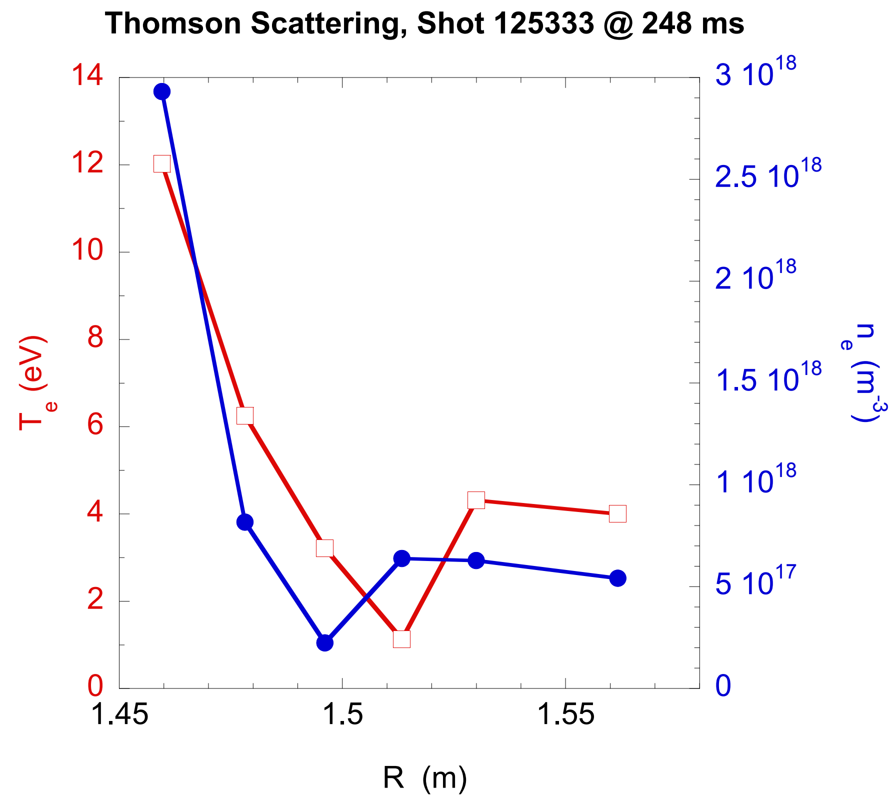
NSTX

- Apply a median filter to eliminate speckles.
- Then: abs_frame = (image - back_image) × rel_image × freq $\times 10^4$, where:
  - image = raw data,
  - back_image = background frame (1204214),
  - rel_image = calibration frame (1204215),
  - freq = framing rate (136 frames/s).
  - Final factor takes units to photons / (m^2 s sr).
- Analyzing shot 125333, frame at 243 ms.



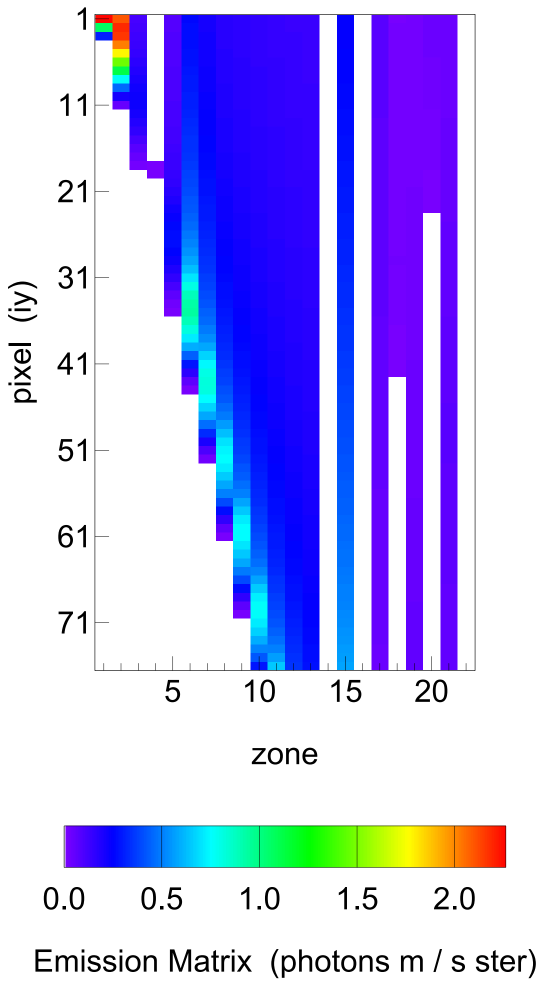
Data From DEGAS 2

- S_{ij} = emission rate at zone $j \times$ "zone_frag(i,j)" [photons m / (s sr)],
- Chords:
  - zone_frag(i,j) = length of chord i through zone j $/4\pi$ (units: m / sr).
  - Computed in 3-D during setup of DEGAS 2 geometry.
- Atomic physics data,
  - Get $n = 4/n = 1$ density ratio from H CR model as function of n_e, T_e,
  - Get n_e and T_e at miplane from Thomson scattering,
    - Using 125333 at 248 ms.
  - Interpolate onto mesh assuming constant on flux surfaces.
  - Then, emission rate per atom = $A_{4\rightarrow2}[N(n = 4)/N(n = 1)]$, with $A_{4\rightarrow2} = 8.419 \times 10^6$ s^{-1}.



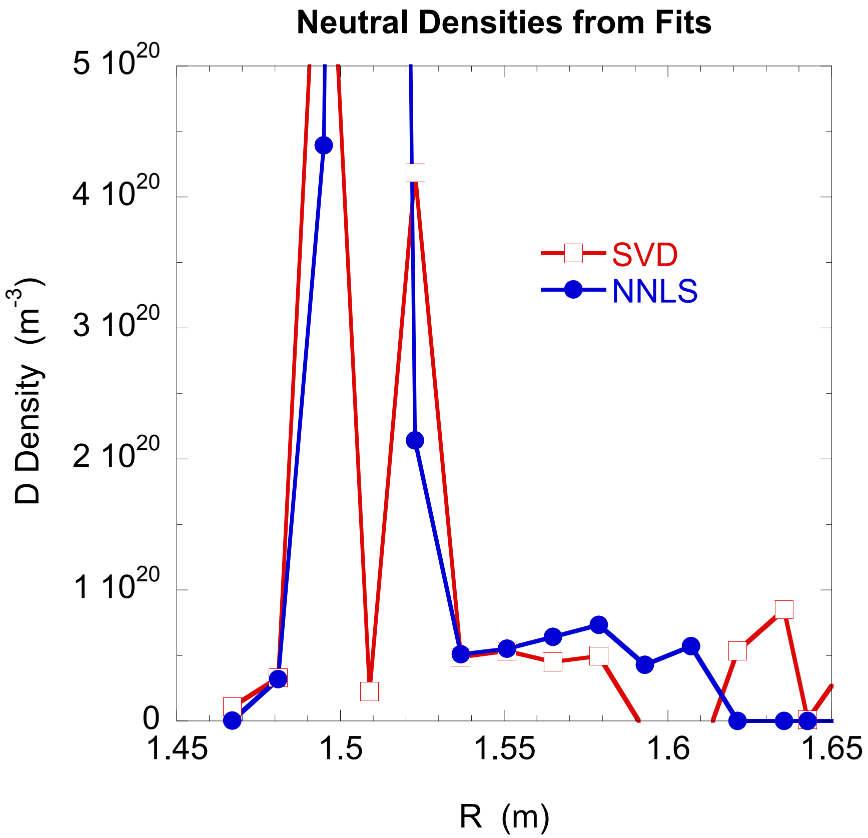
Fitting Procedure

- Isolate zones for which zone_frag $>$ 0 and order by R,
  - $\Rightarrow$ 22 zones (some are small triangles).
- S_{ij} has 76 rows & 22 columns.
- Fit is overdetermined,
  - $\Rightarrow$ can used SVD.
- Unexpectedly difficult,
  - SVD gives some densities < 0.
  - So, also using non-negative least squares fitting (Pomphrey).



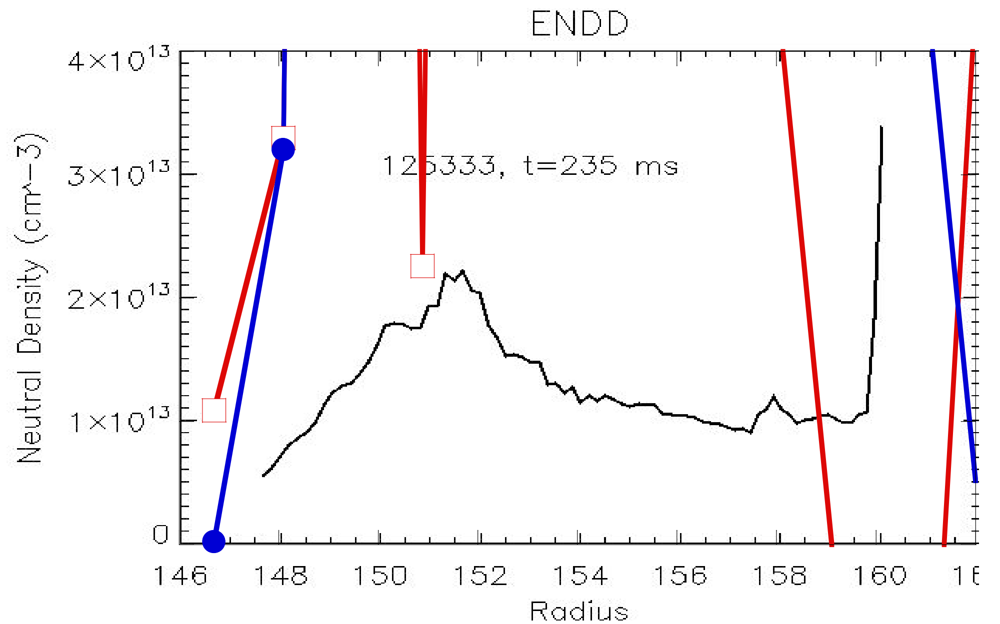
Results

- SVD & NNLS agree at handful of points,
- Correspond to zones where S_{ij} shows structure,
- Consider these densities well determined.
- Elsewhere, two results disagree significantly,
  - Associated with small T_e or zone_frag,
  - $\Rightarrow$ these densities poorly determined.



Results

- SVD & NNLS agree at handful of points,
- Correspond to zones where S_{ij} shows structure,
- Consider these densities well determined.
- Elsewhere, two results disagree significantly,
  - Associated with small T_e or zone_frag,
  - $\Rightarrow$ these densities poorly determined.
- Get neutral densities $\sim 5 \times 10^{19}$ m^{-3}, significantly greater than $0.5 - 2 \times 10^{19}$ m^{-3} Patrick showed at APS.



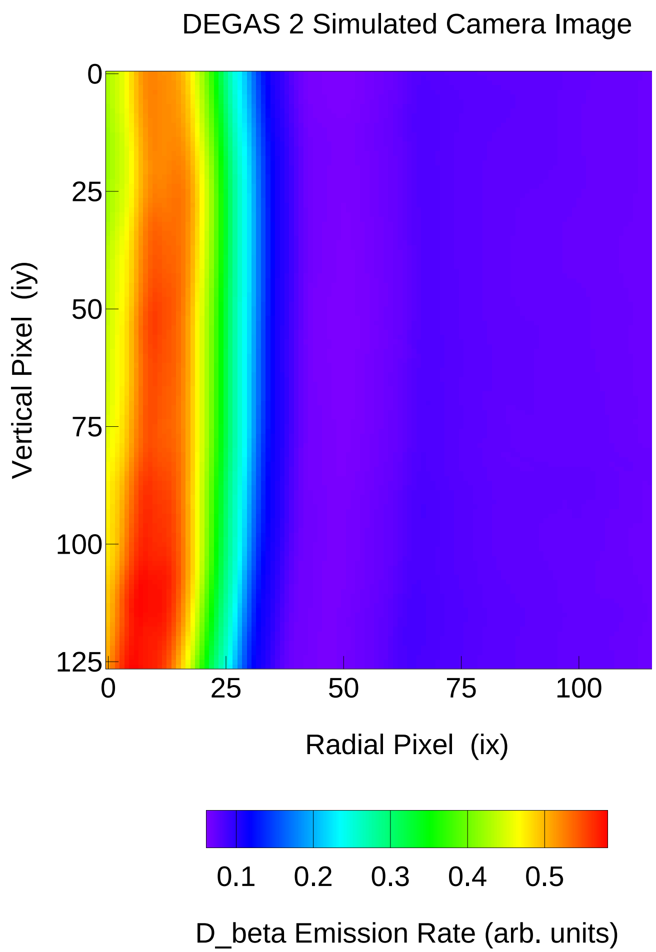
Simple Analysis

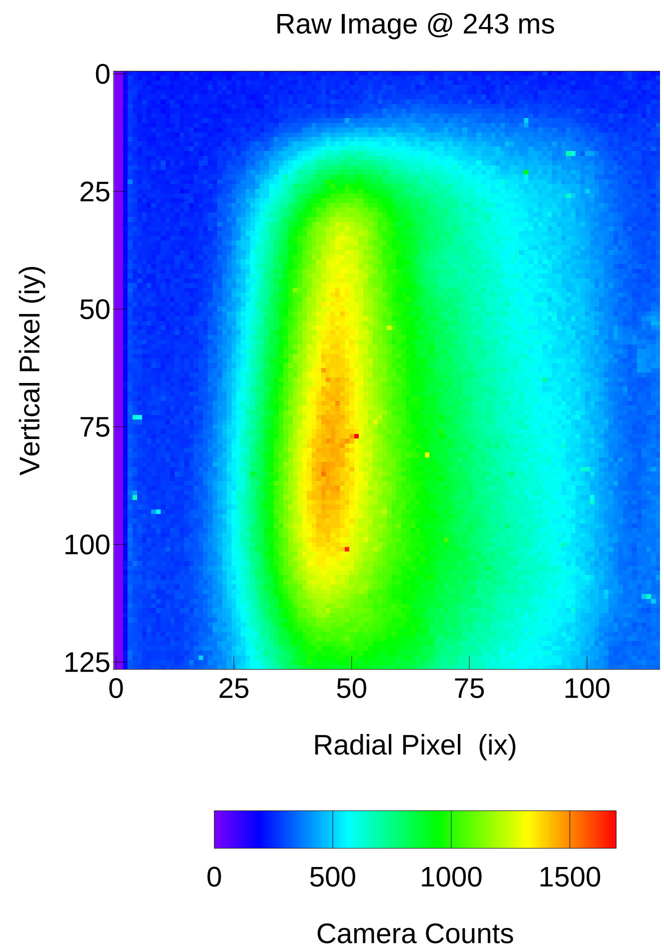
NSTX

- 1st two chords & zones have larger S_{ij} than others
- $\Rightarrow$ can make first cut at their density: $H_i = (S_{i1}N_1 + S_{i2}N_2) + \sum_{j>2} S_{ij}N_j$.
- Define $S_{i1}N_1 + S_{i2}N_2 \equiv (S_{i1} + S_{i2})\bar{N}_{1,2} \Rightarrow \bar{N}_{1,2} < H_i/(S_{i1} + S_{i2})$ is an upper bound.
- From Patrick's data: $H_1 = H_2 = 2.9 \times 10^{20}$ photons / (m^2 s sr).
- From matrix: $S_{11} + S_{12} = 4.4$ photons m / (s sr) $\Rightarrow \bar{N}_{1,2} = 6.6 \times 10^{19}$ m^{-3}.
- And: $S_{21} + S_{22} = 3.2$ photons m / (s sr) $\Rightarrow \bar{N}_{1,2} = 9.1 \times 10^{19}$ m^{-3}.

- Are these matrix elements reasonable?
  - At $T_e = 10$ eV, $n_e = 10^{18}$ m^{-3}, emission rate ~ 100 photons / s,
  - For second chord, path length through second zone ~ 0.4 m,
  - $\Rightarrow$ matrix element $\sim 0.4 \times 100/4\pi \simeq 3$.

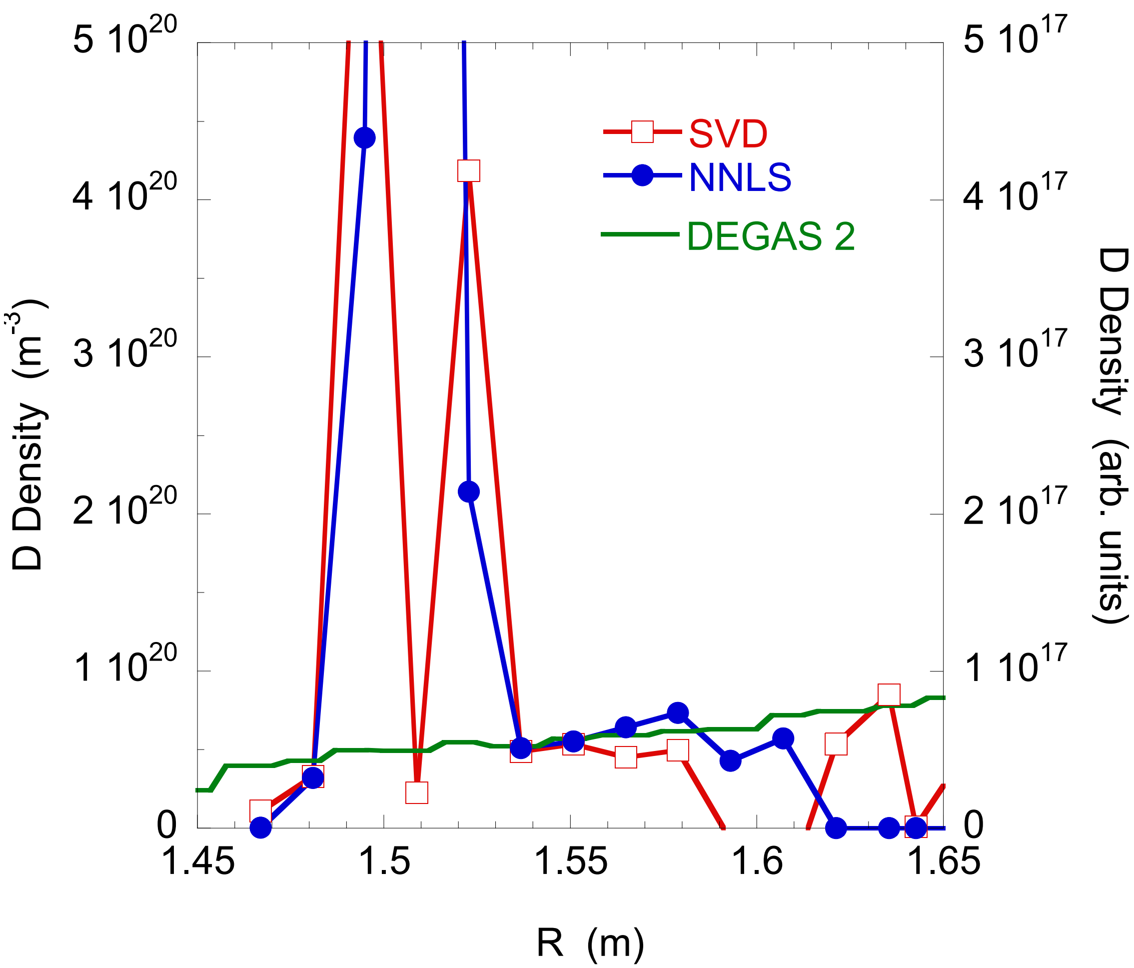
DEGAS 2 Simulation Using Uniform Gas Source





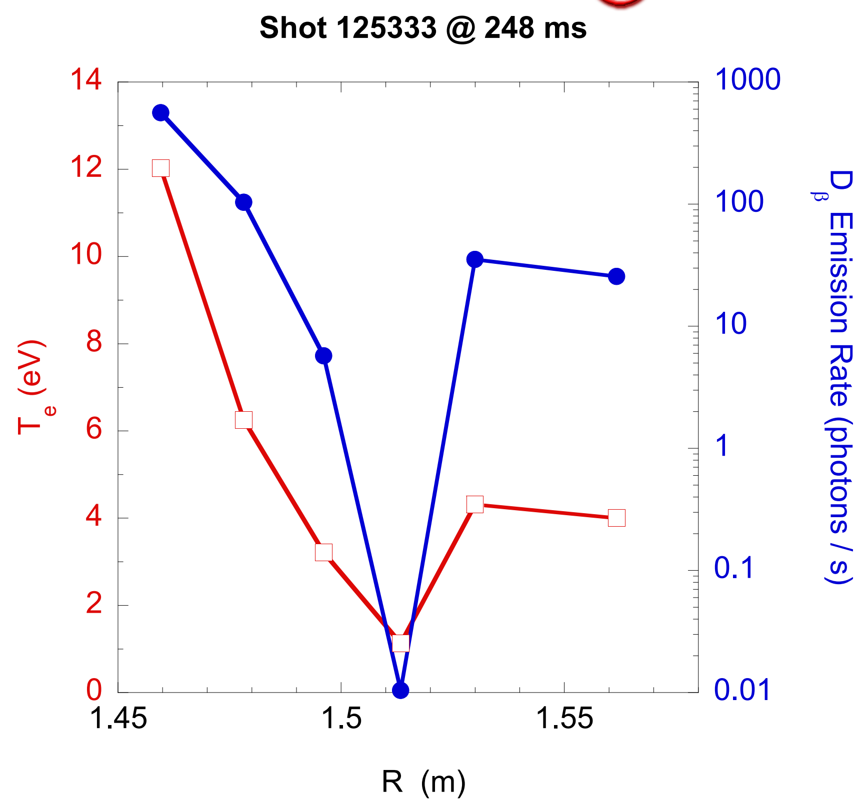
Look very different! Are they really? Filter? Optics?

DEGAS 2 Density Profile May Not Be So Different



Conclusions I

- Key problem is sensitivity of emission rate to T_e & relatively large variation in T_e. Effective exponents:
  - At 1 eV, $\alpha_T = 9$,
  - At 10 eV, $\alpha_T = 1$.
  - α_n varies less $\sim 0.8 - 0.9$.
- $\Rightarrow$ no reasonable way to concoct an "average" T_e profile looking at one or more TS profiles.
- Need to look at smaller R where emission less sensitive.
- Will still want to account for profile variations during frame.



Conclusions II

NSTX

- Difficulties with inversion algorithms probably associated with this sensitivity,
  - These are otherwise very capable algorithms,
  - ⇒ treat any algorithm here with caution.
- Patrick can use above simple estimates to check his numbers,
  - Pin down source of discrepancy.
- Not sure what to make of uniform gas puff result from DEGAS 2.
- All of this ignores molecular contributions,
  - Not sure if they are significant,
  - Not even sure I have data to estimate.