Neutral Transport Simulations of Gas Puff Imaging Experiments on NSTX

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Gas Puff Imaging (GPI) Experiments Designed to Measure 2-D Structure of Edge Turbulence

- Puff neutral gas near outer wall,

- View with fast camera fluctuating visible emission resulting from electron impact excitation of that gas,
  - Compare with 3-D nonlinear plasma simulation codes,
  - Reduced theoretical turbulence models,
  - And with turbulence measured by probes.

- NSTX GPI geometry optimizes data quality,
  - But, 3-D arrangement complicates interpretation,
  - \(\Rightarrow\) extend DEGAS 2 Monte Carlo neutral transport simulations to 3-D.
1. Describe GPI experiments,

2. Construction of 3-D DEGAS 2 Simulations,

3. Benchmark code against experiment,

4. Estimate diagnostic resolution,

5. Use neutral density to infer 2-D plasma profiles from GPI images.
1. Description of GPI Experiments

See also poster LP1.006,
“2-D Imaging of Edge Turbulence in NSTX and Alcator C-Mod”, Lowrance et al.
Gas Puff Imaging Hardware Configuration in NSTX

- Gas Puff Imaging (GPI)
- Area: 16x32 cm
- He gas manifold
- Viewport

Diagram showing the GPI area and its configuration in NSTX.
Camera Records Fluctuating 587.6 nm He I Emission for 28 Frames @10μs/frame
"Target Plane" Defined by Manifold & Center Stack; Location Determined by Measuring Arm
Quantify Cloud Orientation By Fitting Ellipses; Compare to Flux Surfaces Mapped to Target Plane
2. Construction of 3-D DEGAS 2 Simulations
Begin with outline of hardware,

2-D plasma mesh defined using EFIT equilibrium,

Fill remaining volume with triangles, spatial resolution $\sim$ few mm.

Divide into 3-D by $\phi = \text{constant}$ planes,

- Gas source simulated in 3-D.

Single-time $n_e(R_{\text{mid}}), T_e(R_{\text{mid}})$ from Thomson scattering,

- Assume $n_i = n_e(\psi), T_i = T_e(\psi)$ only.

Simulations are time-independent.
Realistic, High Resolution Geometry
NSTX Shot 108321, 187 ms

- flux surface mesh
- He 587.6 nm emission
- gas manifold
- "vacuum" triangles
Spatial Relationships of Physical Objects Clarified by Visualization of 3-D DEGAS 2 Data

- 587.6 nm emission cloud
- neutral He density isosurface
- He density contour outlines simulated manifold
- field-line-following $n_e$ perturbation
- $n_e$ contours on $Z = \text{const.}$ & $Y = \text{const.}$ planes
- corners of camera view

AVS/Express Visualization by S. Klasky & D. Stotler
GPI Camera Emulation

- Directly compute $81 \times 161$ pixel view of camera,

- Each pixel corresponds to chord integral through problem,

- Chords start at viewport,

- Second point is measured 3-D location of intersection with “target plane”.

- Replicate 0.4 cm camera resolution with chords having halfwidth $0.16^\circ$ at target plane.

- Full resolution images computed during post-processing with MPI.
3. Benchmark Code Against Experiment
Compare 3-D DEGAS 2 Camera Images With Experiment

- 3-D plasma used in DEGAS 2 does not correspond to a particular GPI frame ⇒ compare with “averaged” frame,
  - Use median in time to reduce effect of blobs.

- Experimental & simulated contours angled 15°,
  - Simulated emission follows flux / plasma contours,
  - Deviation between cloud & separatrix angles noted before.

- Look for systematic variations in experimental emission cloud orientation,
  - Get flux surface angles from EFIT $\nabla \psi_p$, mapped to camera coordinates.
  - Fit ellipses to 50%, 75%, and 90% emission regions.
Observed & Simulated Cloud Orientations Differ

Shot 108311  
H-mode

Shot 108322  
L-mode

Emission Rate (photons / m² s st)
Flux Surface Angles Steady During '02 Campaign, But Emission Angles Vary
Variation of Emission Cloud Orientation Not Understood

- Systematic changes in angles after run breaks,
  - Optics were removed & replaced each time,
  - ⇒ Discrepancy with DEGAS 2 could be due to misalignment of optical fixture or bumping of mirror.

- Calibration was done after last campaign
  ⇒ probably why last group lines up best with flux surfaces.

- There may be yet other explanations!

- Should do DEGAS 2 simulation of shot from last group.
4. Estimate Diagnostic Resolution
Background Information

- Previous radial resolution estimate $2 \pm 1$ cm based on toroidal cloud width & degree of camera / field alignment,
  - Effect of latter on poloidal resolution: $0.5 - 2$ cm.

- For shots used here $I_p$ & $B_T$ match values used in design of GPI
  \Rightarrow can’t examine misalignment,

- Check toroidal width with slices along camera view,
  1. FWHM = 25 cm for 108322,
  2. 20 cm for 108311,
  3. Observed: 24 cm.
Estimate Resolution with Tracer Perturbation

- Double $n_e$ everywhere along field line passing through a chosen cell.
  - Estimate effect of cloud width & field line curvature.

- Relatively long emission perturbation path in camera-aligned slice
  ⇒ field line-camera alignment is indeed good,

- $\Delta$ (emission) image shows shape of field line as seen by camera, as well as shadowing effect,
  - Radial & poloidal half-widths are same as size of initial cell!
  - ⇒ Toroidal extent of cloud does not significantly degrade radial resolution (at least here).
Camera-Aligned Slice Through 3-D Data Shows Emission Due to Perturbation

Camera-aligned slice through 3-D data shows emission due to perturbation. The graph displays emission rate (photons/m³ s) along the horizontal and longitudinal directions. The emission rates range from 3.4x10²⁰ to 6.7x10²¹ photons/m³ s. The diagram highlights the camera-aligned slice, target plane, manifold, and corners of the camera view.
Perturbed - Unperturbed Camera Image
Highlights Effect of $n_e$ Perturbation
5. Use Neutral Density to Infer 2-D Plasma Profiles from GPI Images

See also poster LP1.070, “Theory and Experimental Analysis of Blobs in the NSTX Boundary Plasma”, Myra et al.
GPI Data + DEGAS 2 Neutral Density
⇒ 2-D $n_e, T_e$

- Use to test theories of blob motion.
  - $n_e, T_e \rightarrow$ potential, $\Phi$,
  - $\Rightarrow \vec{E} \times \vec{B}$ & motion of blobs.

- GPI gives $I = n_0 F(n_e, T_e)$,
  - DEGAS 2 $\Rightarrow n_0$,
  - $F(n_e, T_e)$ known,
  - $\Rightarrow$ can invert if we know $n_e(T_e)$. 
Need to Map 3-D DEGAS 2 Neutral Density to 2-D Camera Coordinates

- Camera signal for pixel $i$:

$$I(i) = \int \frac{dl}{4\pi} F(\vec{x}) n_0(\vec{x}).$$

- $\vec{x}$ and image coordinates $i$ connected by target plane, $\vec{x}_i$,

  - Inversion will yield $n_e(\vec{x}_i)$ and $T_e(\vec{x}_i)$.

- Camera aligned with $\vec{B}$ & blobs constant on $\vec{B} \Rightarrow F(\vec{x}) \sim F(\vec{x}_i) = \text{constant},$

$$I(i) \sim F(\vec{x}_i) \int \frac{dl}{4\pi} n_0(\vec{x}).$$

- Suggests using

$$n_{0,\text{eff}} \equiv \int \frac{dl}{4\pi} n_0(\vec{x}) \simeq I(i)/F(\vec{x}_i).$$
Effective Neutral Density in Camera Coordinates

Effective Neutral Density in Camera Coordinates

- n$_{0,\text{eff}}$ (m$^{-2}$ s$^{-1}$)
- Vertical Pixel
- Horizontal Pixel

- 0.0
- 1.2x10$^{17}$
- 2.4x10$^{17}$

- 0
- 40
- 80

- 0
- 80
- 160
Practical Applications of Effective Neutral Density

- Above approach is approximate, off by factor of a few,
  - Have slightly different, more accurate approach.

- But, existing simulations differ too much from observations,
  - DEGAS 2 $n_{0,\text{eff}}$ must be shifted & rotated to line up emission clouds,
  - In this case, the two approaches work equally well.
  - See poster by Myra et al., LP1.070 for example applications.
SUMMARY

• 3-D DEGAS 2 simulations of GPI reproduce experimental geometry in detail,

• Orientations differ by 15°,
  – Appears to be due to GPI optical alignment problem with shots early in 2002 campaign.

• Radial resolution not significantly degraded by toroidal extent of cloud.

• DEGAS 2 results provide basis for inferring time-dependent 2-D $n_e, T_e$ from GPI data.

Note: This poster is available on the Web at:
http://w3.pppl.gov/degas2/
REFERENCES

  - NSTX GPI description.

  - Detailed analysis of NSTX GPI results.

  - Basic DEGAS 2 description.

  - DEGAS 2 simulations of C-Mod GPI.

- S. I. Krasheninnikov, Phys. Lett. A 283, 368 (2001)
  - Basic theory of blobs.
  - Theory of blob motion.

  - Ditto.

  - He collisional-radiative model.

  - Neutral-ion elastic scattering data.

  - Discussion of C-Mod GPI, including DEGAS 2 results.