Particle Transport Studies with Perturbations

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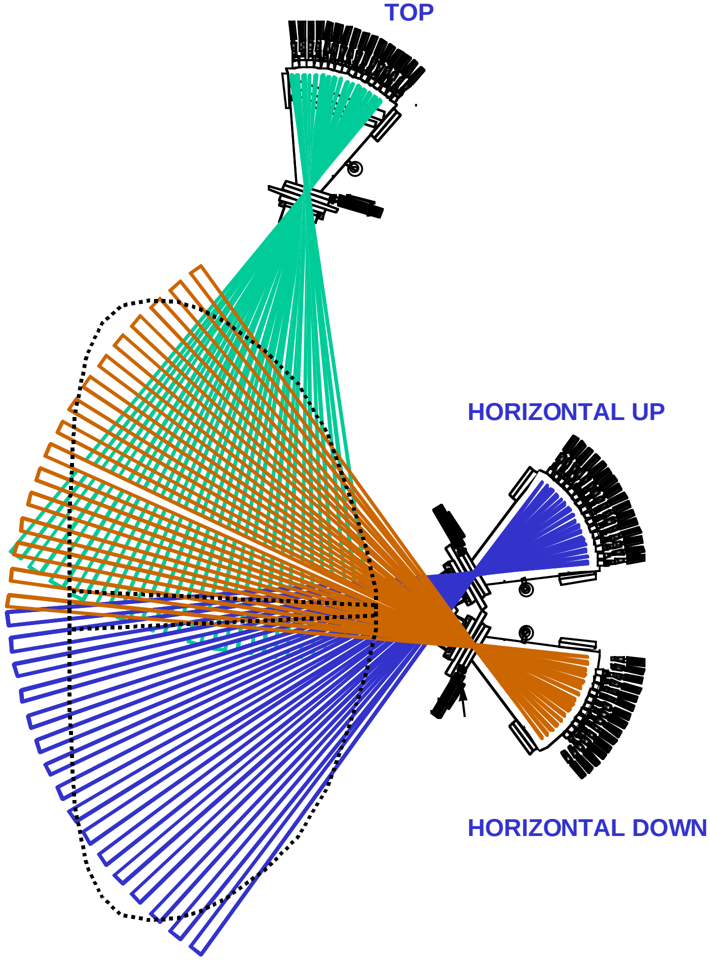
Motivation

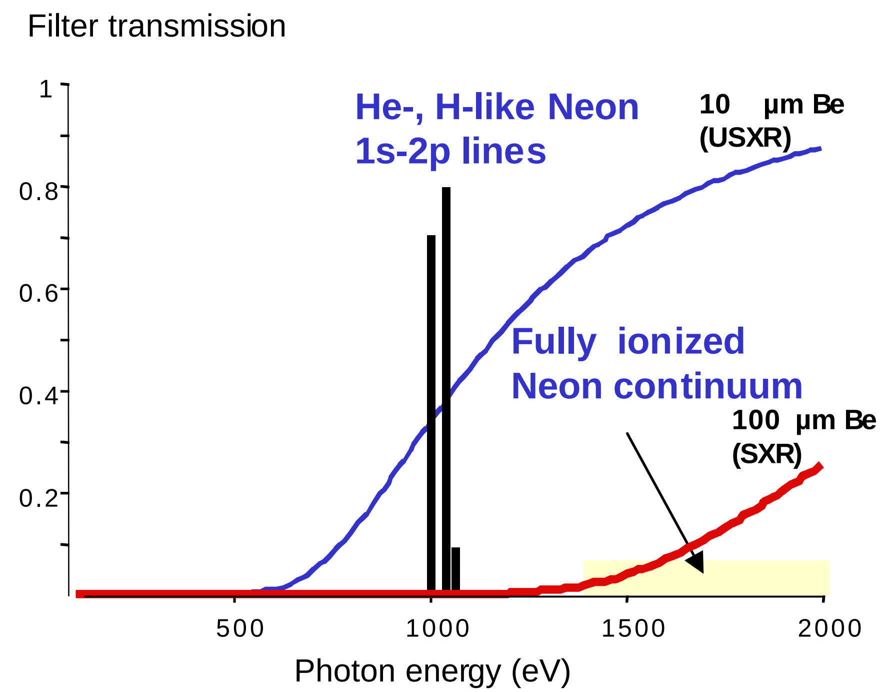
- **First cut at impurity transport:**
  - **order of magnitude estimate of D, V**
  - **probe radial discontinuity suggested by modeling of intrinsic impurities**

Tools

- **Short (5 ms), non-perturbing Ne puff ($N_{Ne} \approx 0.1\% \ N_e$) into NBI discharges**
- **USXR imaging system**
- **High resolution USXR and VUV spectrometry**
- **MPTS and EFIT data**
- **Atomic physics (HULLAC) and time-dependent impurity transport (MIST) modeling (*D. Stutman et al. EPS 2001*)**

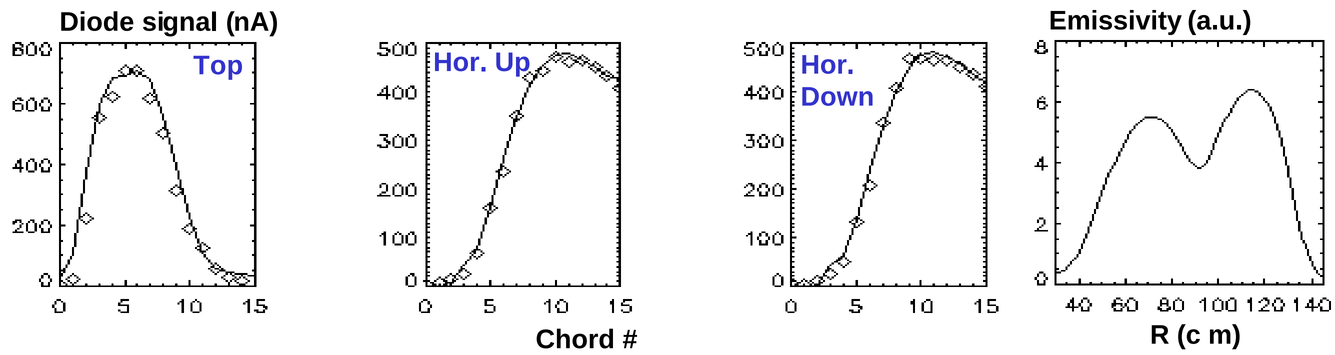
USXR arrays on NSTX

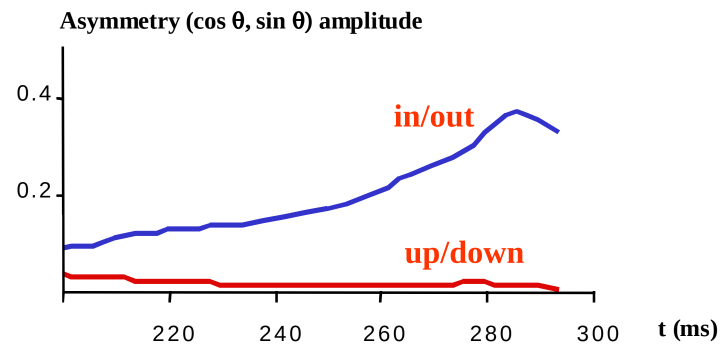




- **USXR/SXR filtering discriminates He-, H-like from fully ionized Neon profiles**
- **Background emissivity subtracted using consecutive reference shots**

Inversion of USXR data



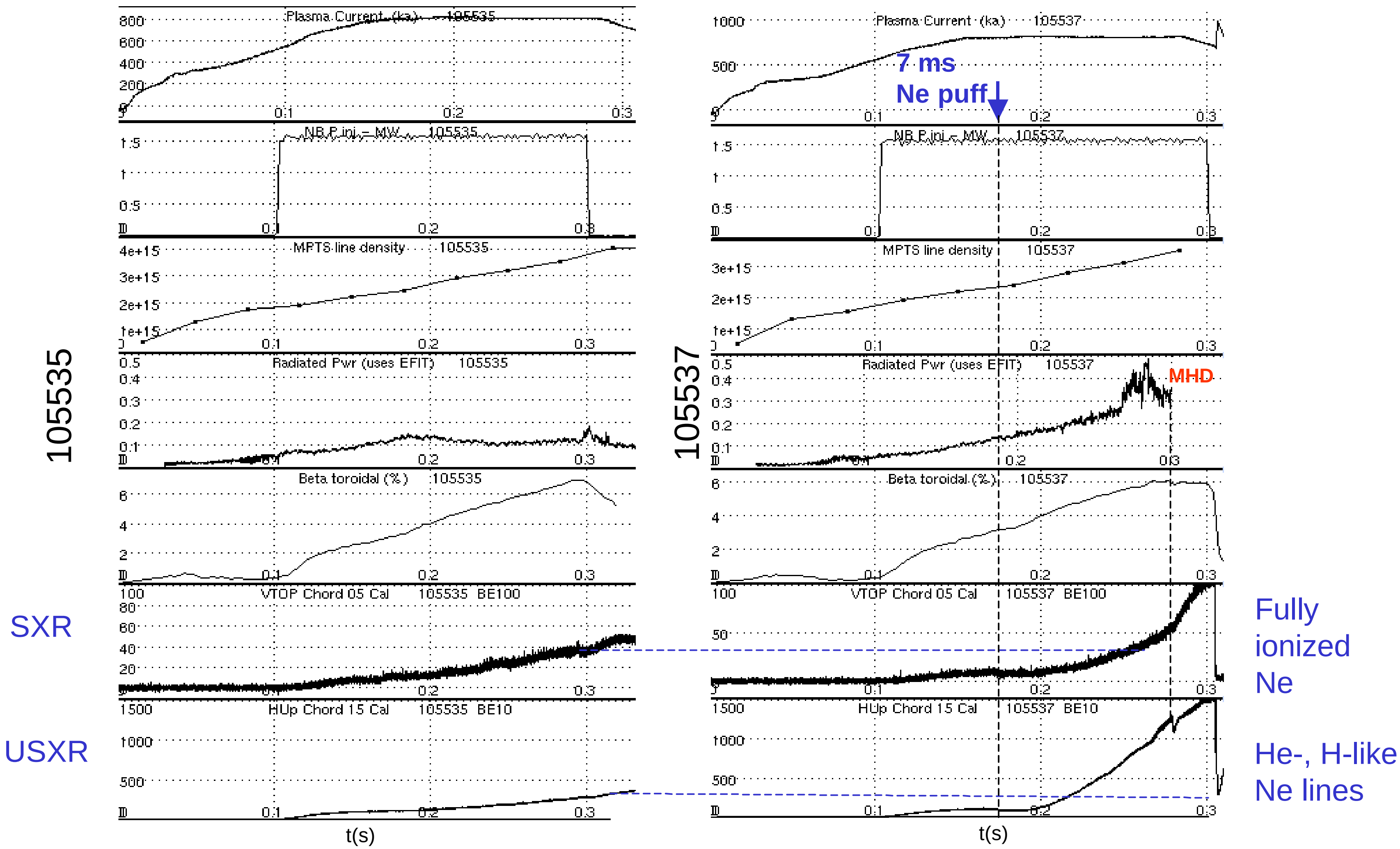


- **Average emissivity profiles obtained using the horizontal arrays:**

  - relative up/down symmetry, despite significant in/out asymmetry

- **Polynomial fit on EFIT flux surfaces**

Experimental results (center stack limiter)



- **Order of magnitude increase in USXR (Ne lines) signal, almost no SXR increase**
- **No significant I_p, Ne, β_T perturbation**
- **Only 100-150 kW increase in P_{rad}**

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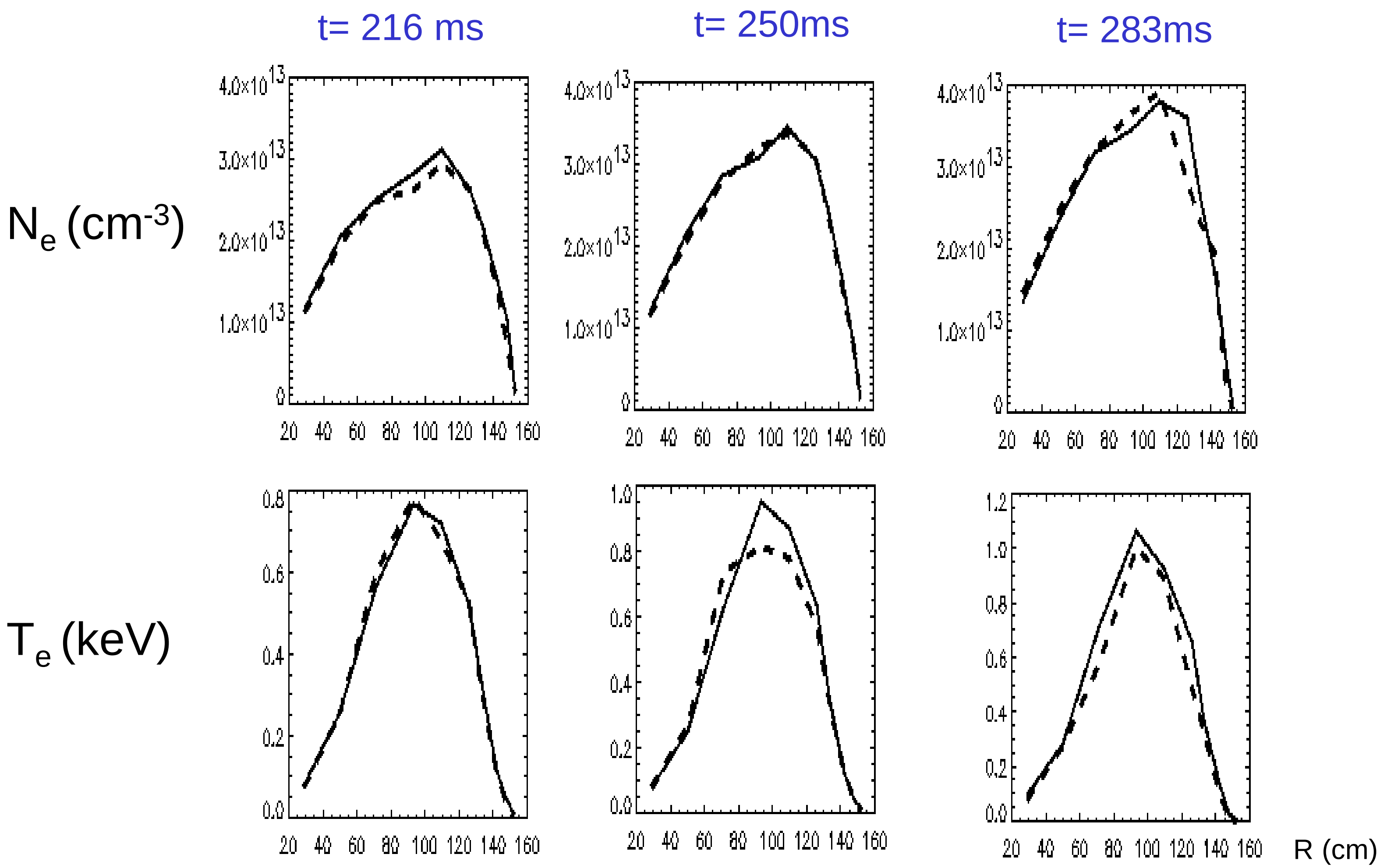
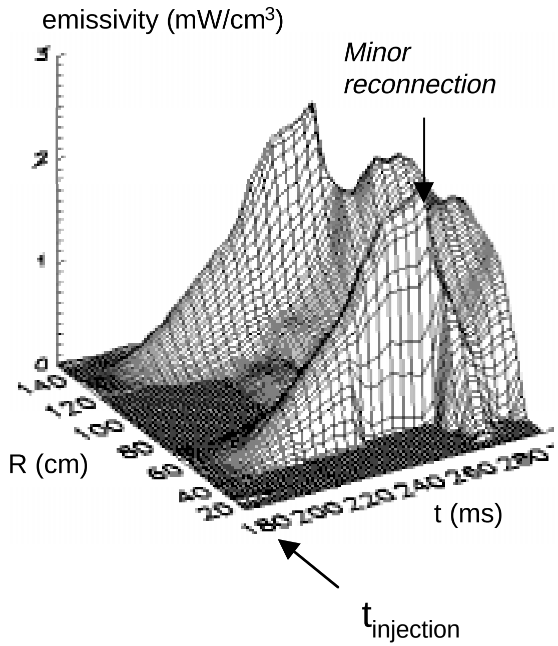
MPTS in 105535 vs. 105537



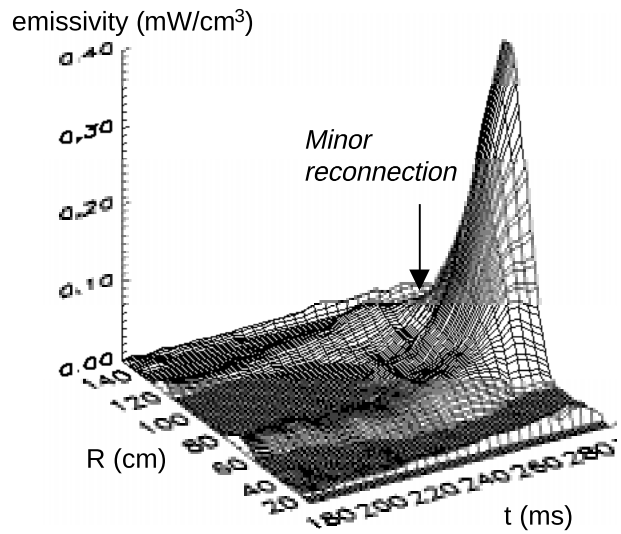
- **Within shot-to-shot reproducibility limits MPTS profiles not affected**

Neon emissivity (background subtracted)

He-, H-like Ne lines
(USXR)



Fully ionized Ne
(SXR)



- **Hollow shell of He-, H-like line emission until MHD event at t ≈ 260 ms**
- **Almost no Ne penetrates the core until collapse of He-, H-like shell at MHD**

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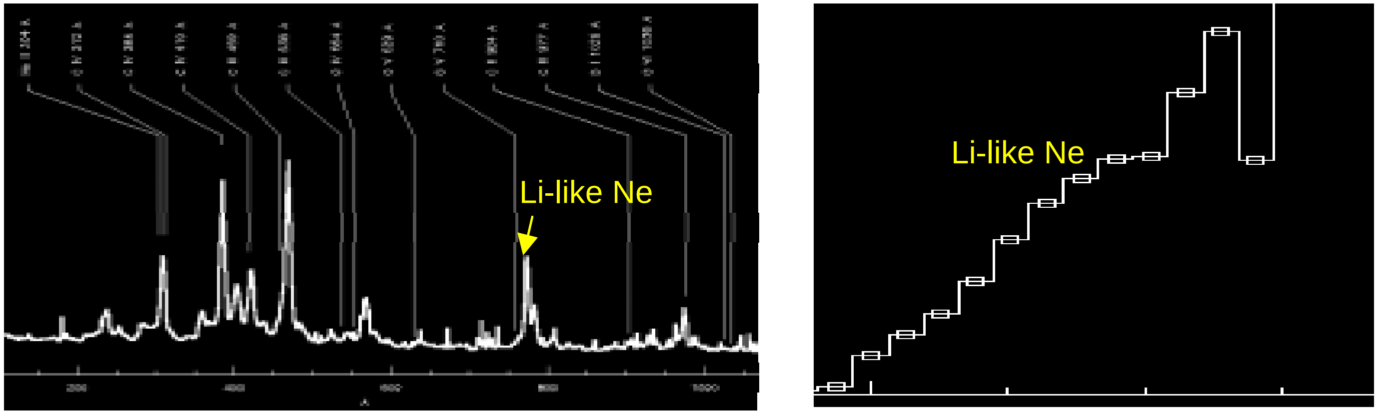
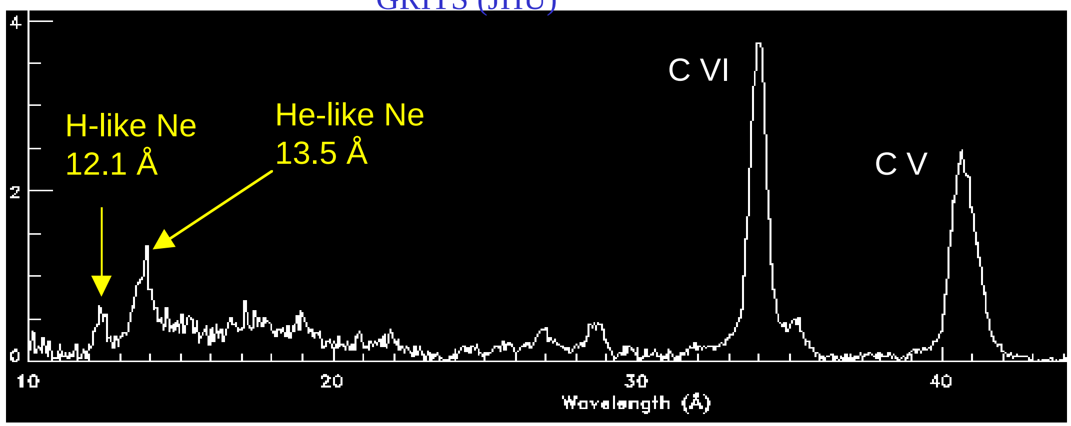
Spectroscopic data (t ≈ 250 ms)

SPRED (V. Soukhanovskii, PPPL)

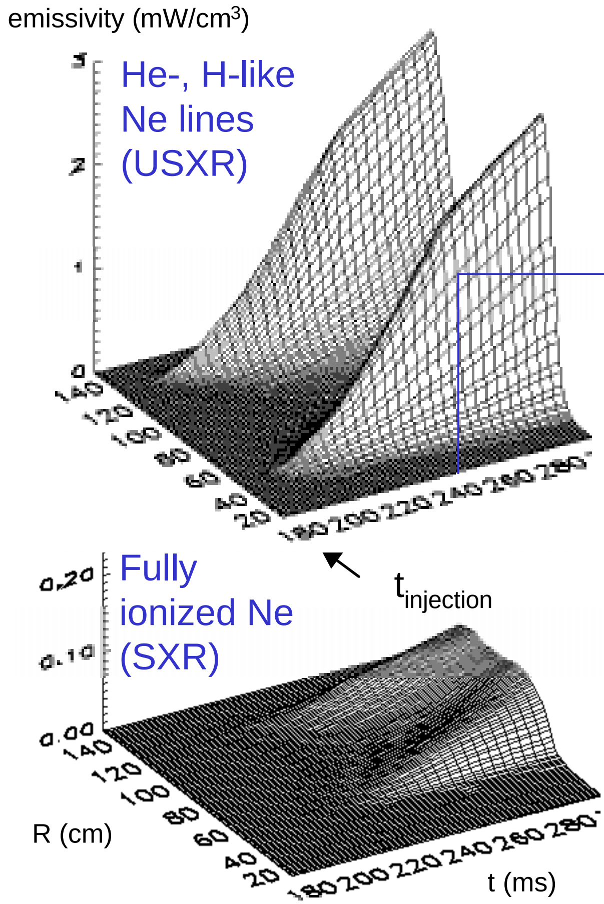


GRITS (JHU)

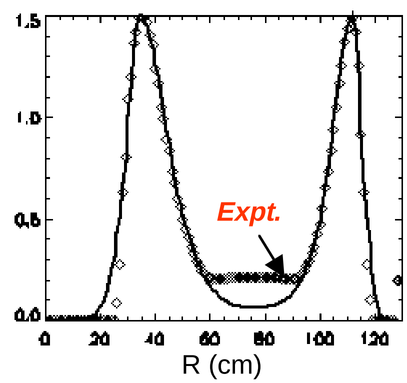


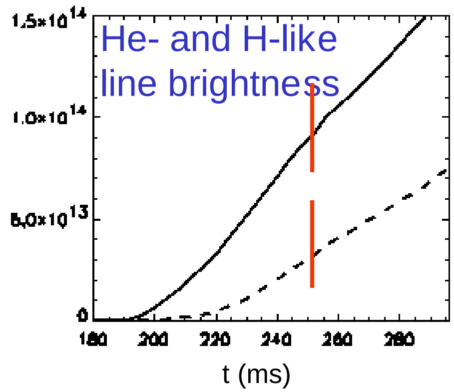
- **Li-like Ne time-history used in the modeling to constrain neutral Ne source**
- **Linear increase indicates Ne source persists after puff (center stack)**
- **Dominance of He-like over H-like emission suggests Ne stagnation in outer plasma**

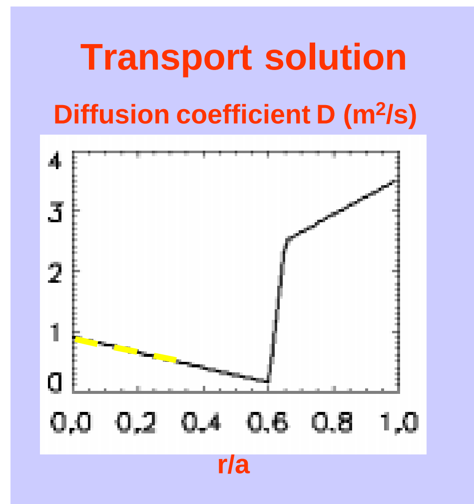
Modeling results



Expt. and computed profiles t=240 ms

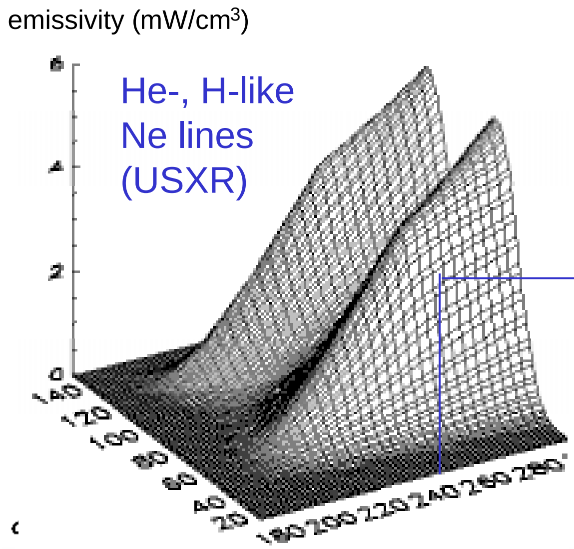


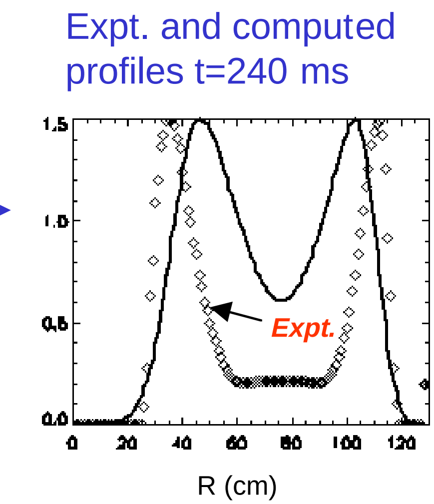


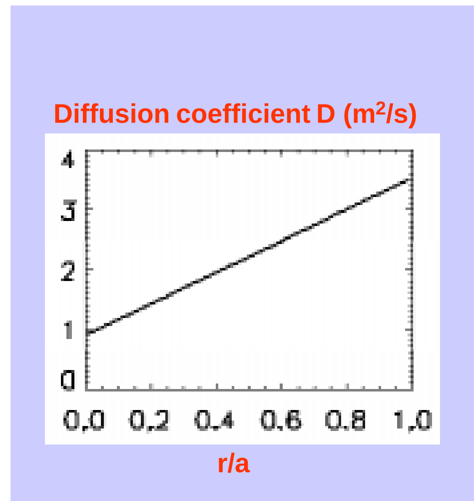


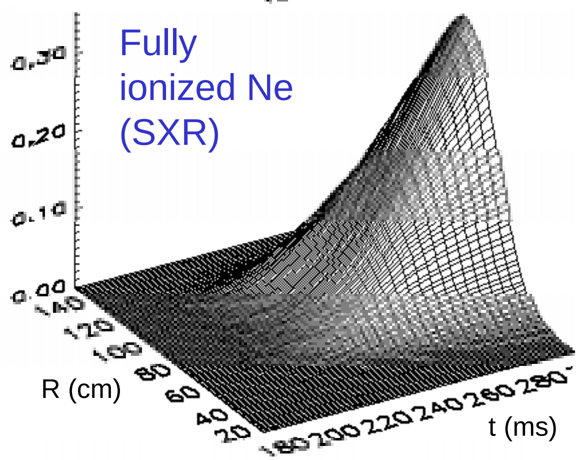
- **Large discontinuity in transport at r/a ≈ 0.65 required to reproduce Neon evolution**
- **D ≈ a fraction of a m^2/s inside 'barrier', a few m^2/s outside**
- **Convective velocity not manifest on present experimental time scales**
- **Similar result in diverted plasmas; background profiles suggest core pinch (preliminary)**

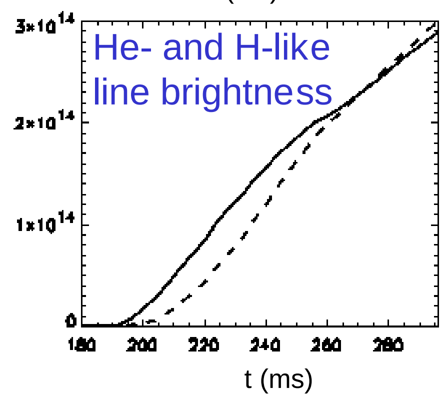
Without barrier







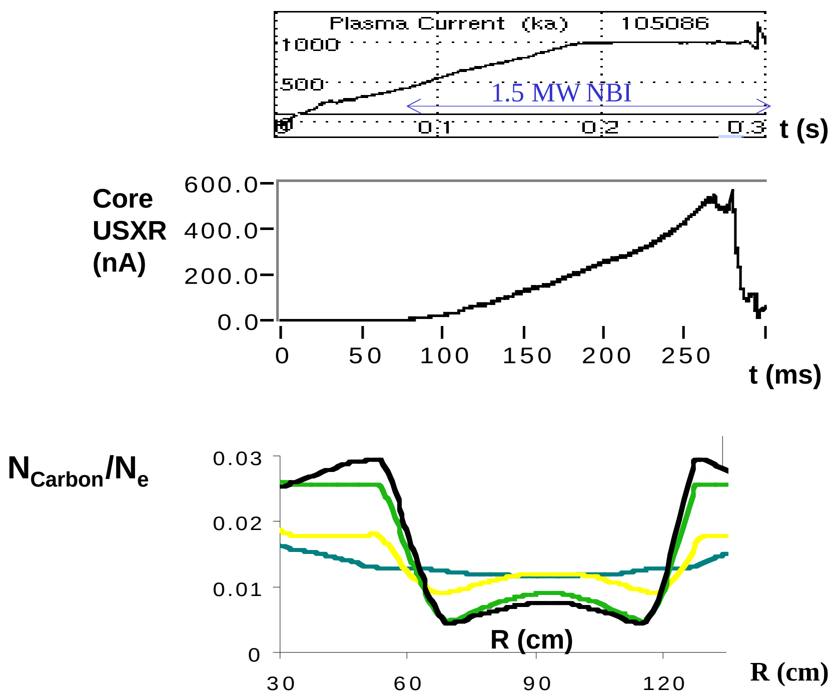




- **Removing the barrier shifts and broadens the He-like shell, produces substantial core emission from fully ionized Neon and increases the H-like fraction**

Steady-state impurity profiles

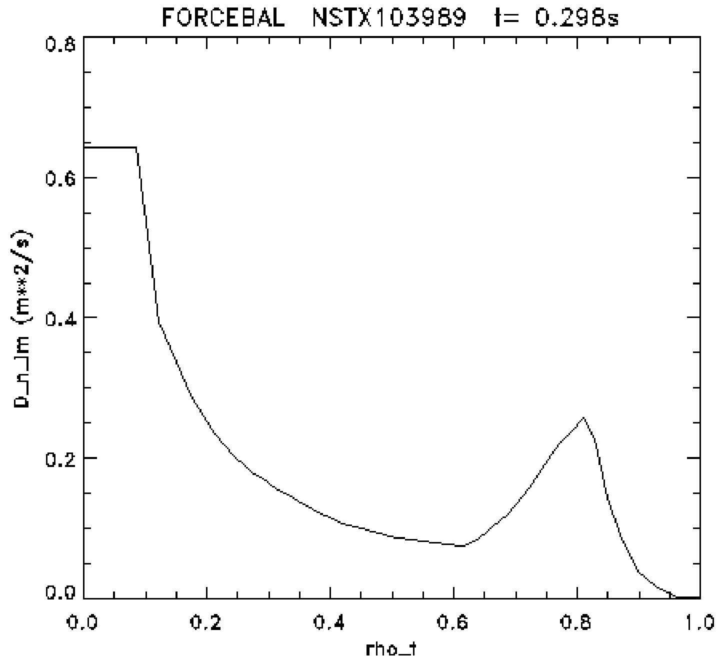
NBI #105086

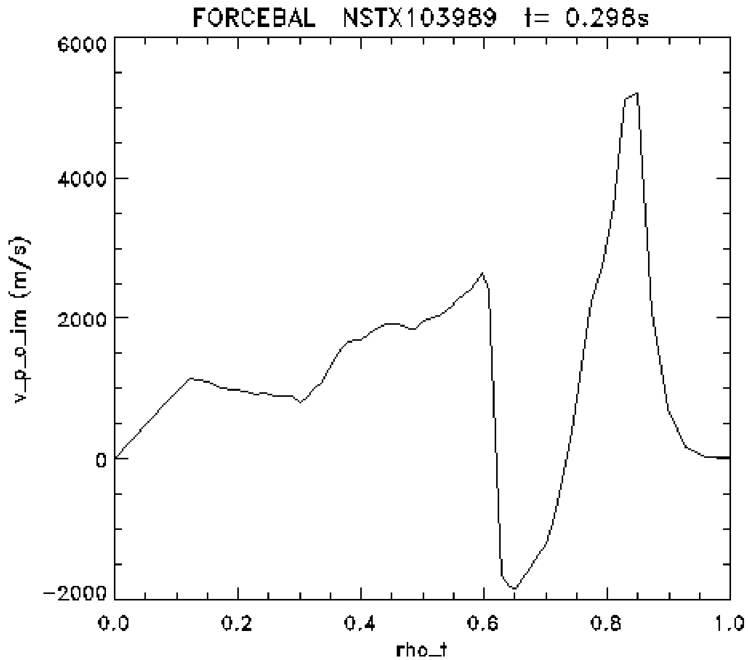


- **Modeling of steady-state USXR profiles indicated 'step' in impurity density at r/a ≈ 0.6-0.7 and first suggested existence of barrier *(D. Stutman et al., EPS 2001)***

Preliminary neo-classical estimates (V. Soukhanovskii)

Shot #103989





- **NCLASS run with experimental profiles including the impurity density 'step'**
- **Experimentally estimated D (r/a < 0.6) in the range of the neoclassical predictions**
- **Impurity 'step' appears to promote sheared poloidal rotation**

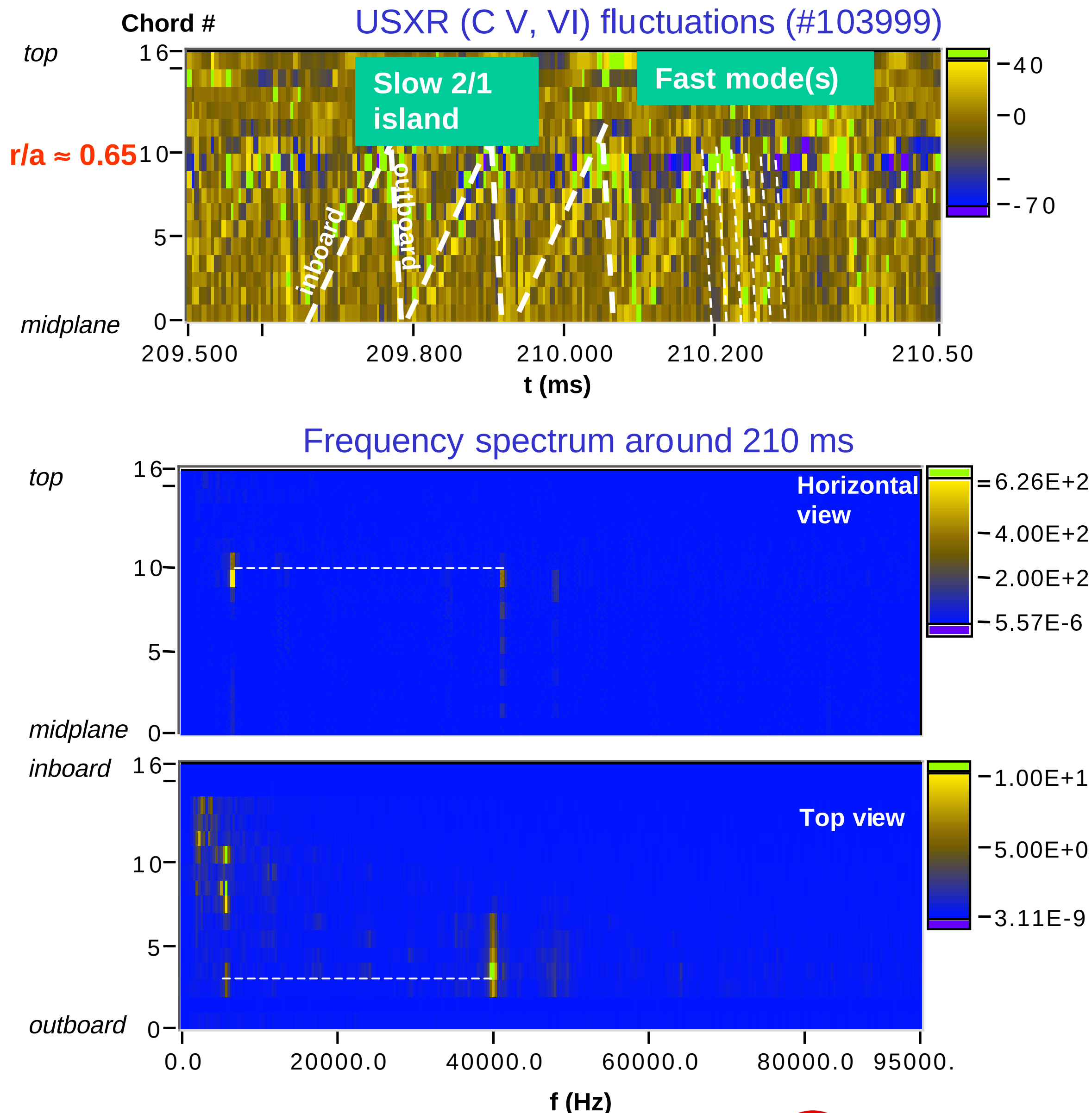
Correlation with MHD

- Low energy imaging shows slow and fast mode(s) rotating near barrier radius r/a ≈ 0.65, with fast mode a bit more inside (sheared layer)

- Slow mode is ‘regular’ 2/1 island in rigid toroidal rotation with the bulk plasma

- Fast mode(s) have only outboard amplitude and ≈ m≥ 4 structure

- Some aliasing possible



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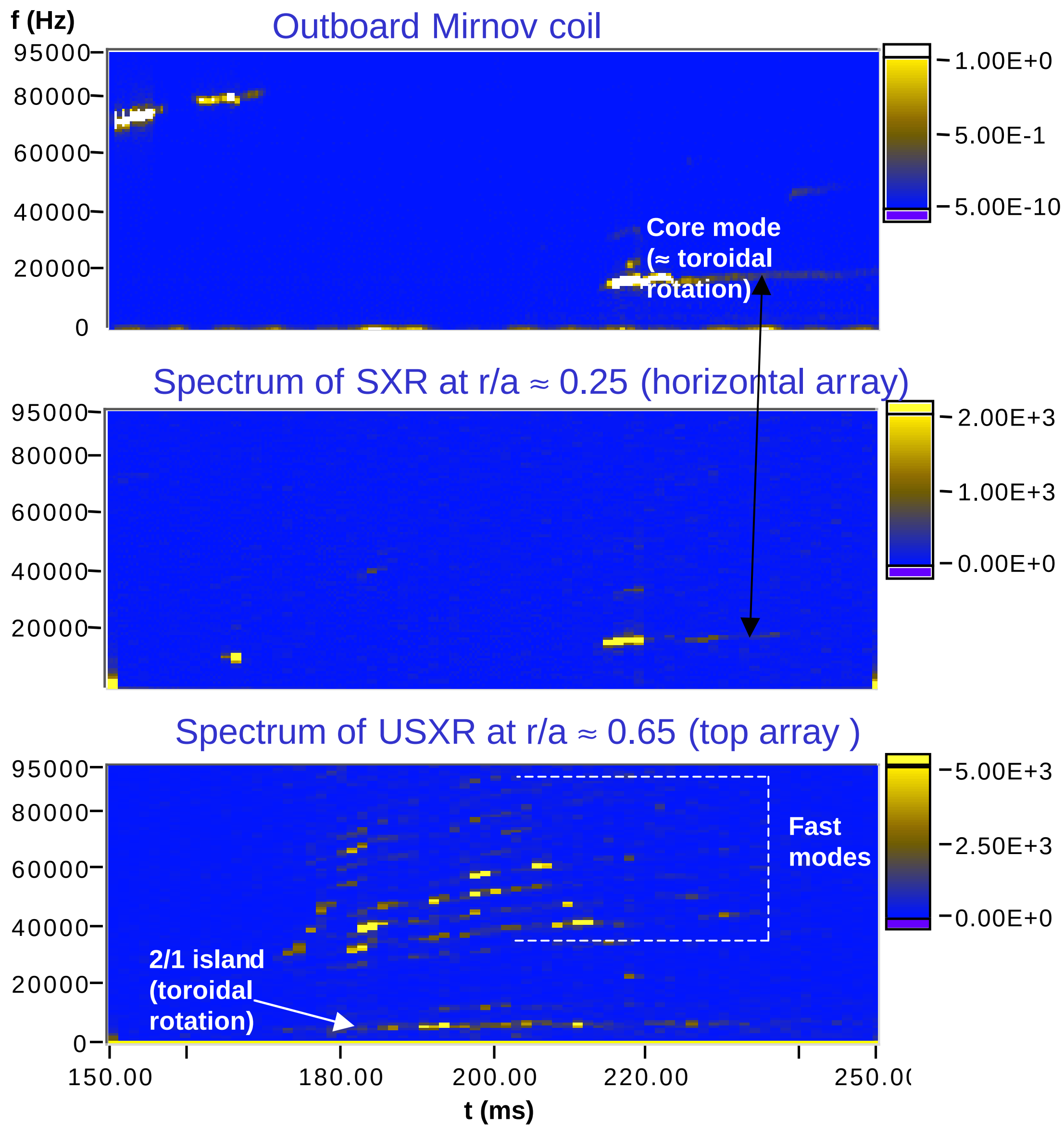
USXR versus magnetics

• **Outboard Mirnov does not see the peripheral USXR modes/filaments**

• **USXR spectrogram again indicates sheared rotation around r/a ≈0.65**

• **Toroidal shear too low for the observed frequency difference**

•**Layer with fast mode(s) in poloidal rotation could explain the USXR fluctuations and sustain transport barrier**



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Summary

• **First experiments seem to indicate particle transport barrier around r/a ≈ 0.6**

• **Barrier consistent with step in intrinsic C profile from USXR modeling**

• **Some fueling data/modeling also seem to suggest slow particle penetration to core**

• **D(r/a < 0.6) ≈ a fraction of a m^2/s close to the neoclassical estimate**

• **Barrier located around q=2 surface**

• **USXR MHD (?) fluctuations indicate sheared rotation around this surface**

• **Possible self-consistent scenario for barrier formation at rational surface:**

island forms -> magnetic drag shears toroidal rotation -> transport decreases -> impurities accumulate -> sheared poloidal rotation -> further transport decrease …