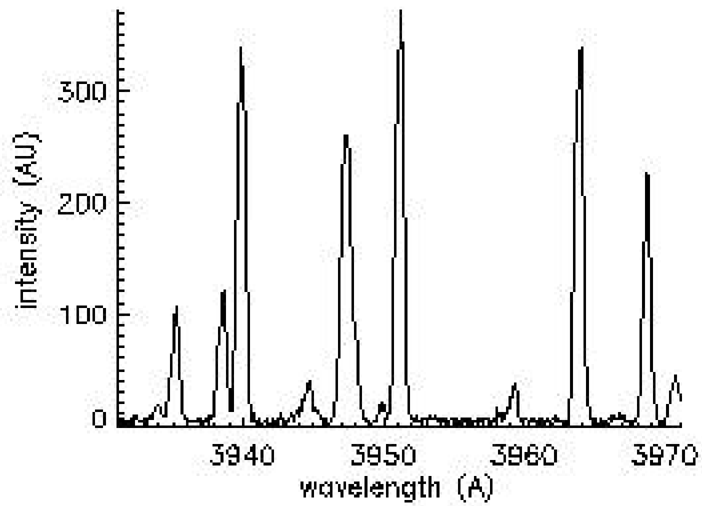
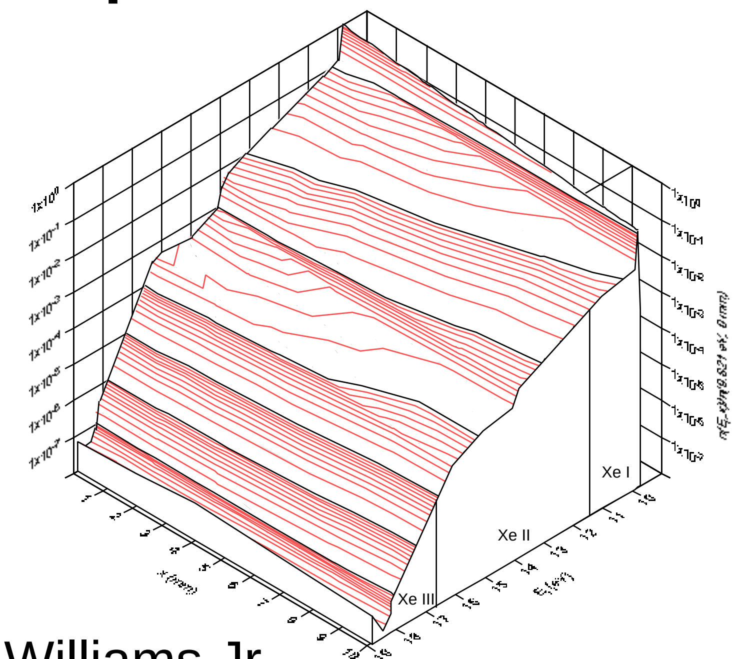
Int’l Conference on Plasma Science 2000

Spectroscopic characterization of FMT-2 discharge ionization processes





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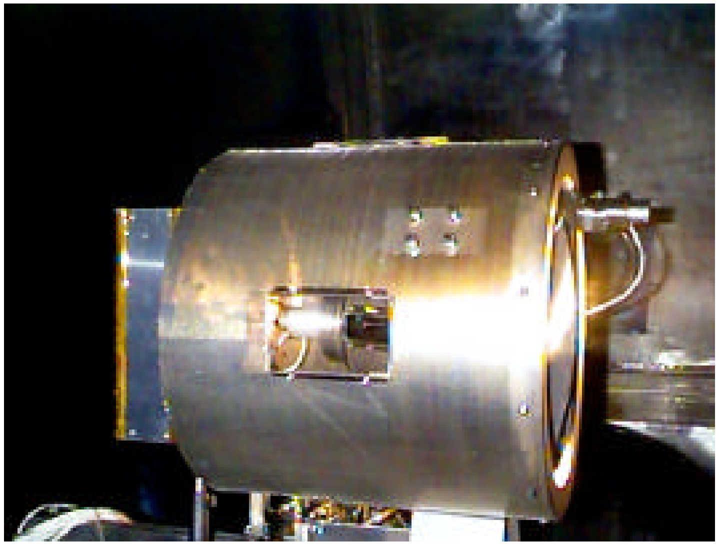
6 June 2000

NSTAR ø30 cm ion engine



NSTAR

- Flight-tested on DS-1
- Standard throttle (TH 15):
    - Discharge current: 13 A
    - Discharge voltage: 25 V
    - Grid voltage drop: 1300 V
    - Power: 2.3 kW

Functional model thruster (FMT)

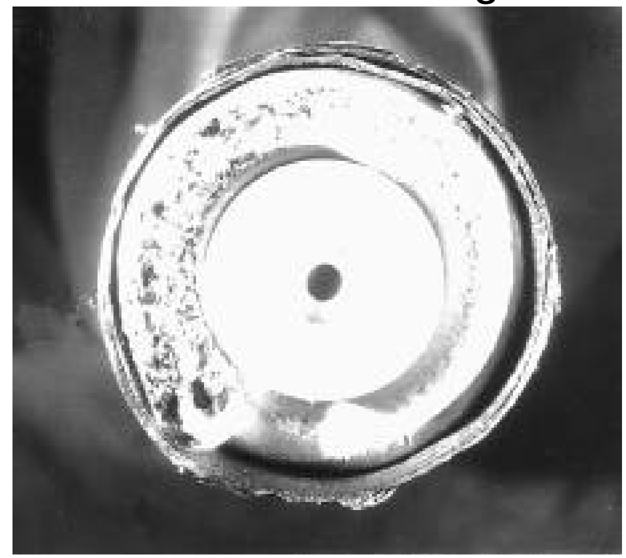
- Precursor to engineering model thruster (EMT)
- Operated at PEPL over entire NSTAR throttling range
- Controlled with modified SkitPac
- Quartz windows give optical access to discharge chamber

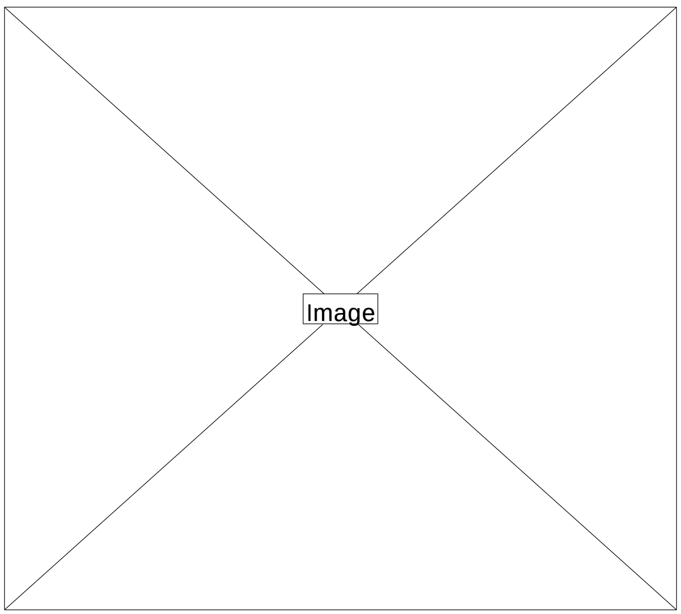
Discharge cathode erosion

NSTAR development wear test

- Severe erosion after 2000 hrs.
    - Outer edge of orifice
    - Heater coil outer sheath
- Limits operational lifetime

Erosion at outer edges





Discharge cathode schematic

Ongoing development effort

- LIF erosion rate diagnostic

Present study

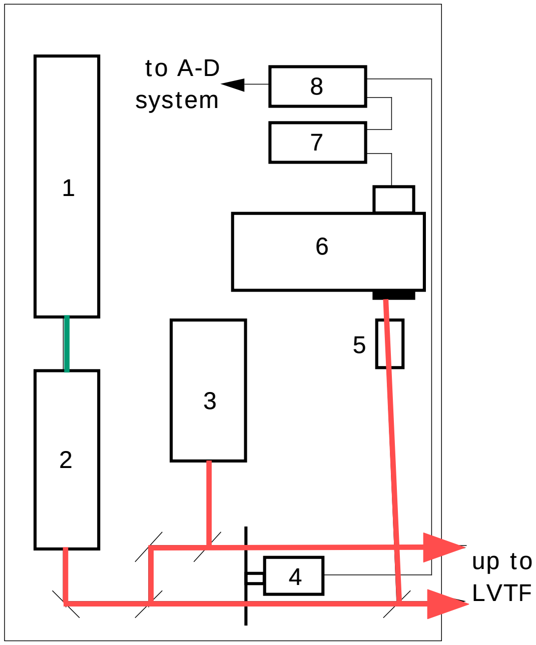
- Xe II LIF at 605 nm
- Emission spectroscopy of Xe I, II & III

Spectroscopic characterization of FMT-2 discharge ionization processes

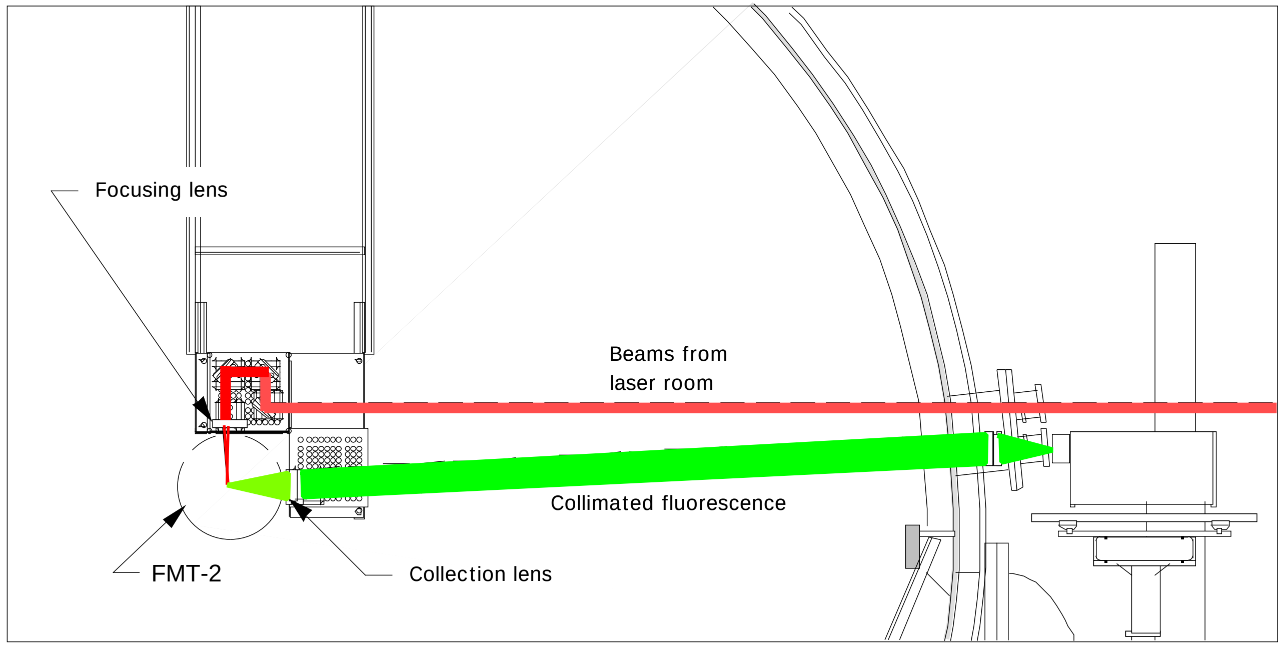
Outline:

- Motivation
- Thruster
- Facility and approach
- Results:
  - Electronic temperature
  - Population densities
  - Xe II temperature and velocity
- Summary and conclusions
- Future work

Four-beam multiplexed LIF technique



Beam conditioning



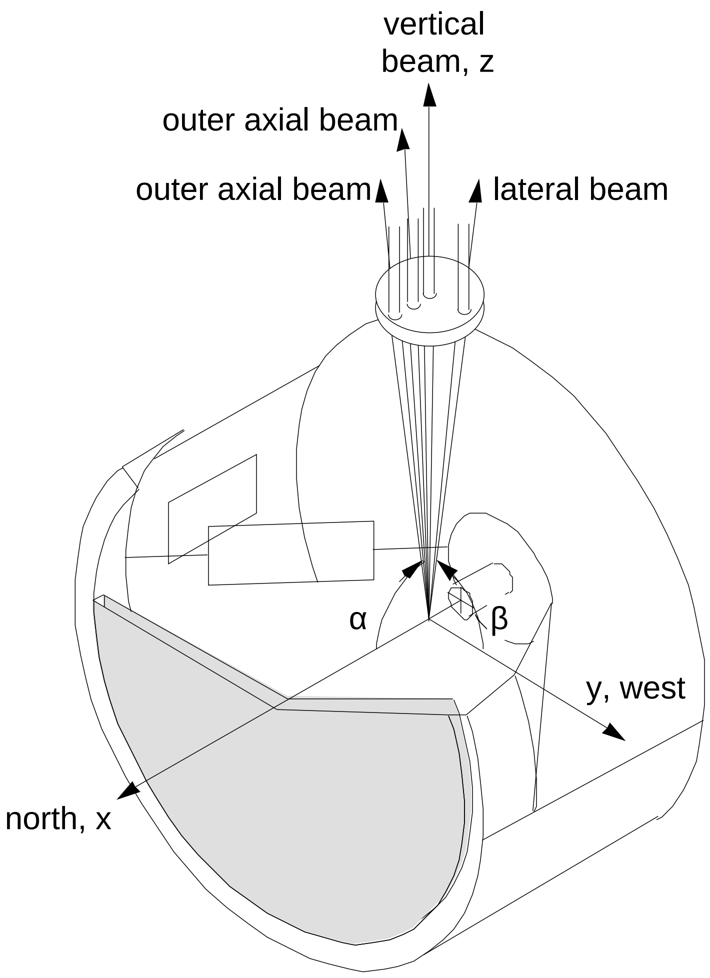
Beam delivery and fluorescence collection

- Multiplex technique:
  - Four parallel beams into LVTF
  - Mirror train directs onto lens
  - Focal point is interrogation spot
- Simultaneous LIF & emission spectroscopy

- Large Vacuum Tank Facility
  - Ø6 x 9 m
  - 0.2 µTorr base pressure
  - Two translation stages

Ion engine and beam angles

- NASA FMT-2 ion engine
  - 2.3 kW class thruster
  - Flight model in use on DS-1
- Primary axes:
  - x, axial, north
  - y, lateral, west
  - z, vertical, up
- Beam axes:
  - ξ_0, angles 10.51° upstream of z-axis
  - ξ_1, angles 7.70° upstream of z-axis
  - ζ, angles 4.48° eastwards of z-axis
  - z, plumb vertical



Emission spectra and state models

- Radiative decay from state i to state j has emission intensity

$$I_{ij} = (hc/4\pi\lambda_{ij})\, A_{ij} \int n_i \, dl$$

- Relating n_i (density at state i) to ground state density requires an appropriate model.

- Local thermodynamic equilibrium (LTE) assumes collisions dominate, so state distribution is Maxwellian:

$$n_i = g_i \exp(-E_i/kT)/Z$$

  - Appropriate for $n_e >> 10^{19} (kT_e/e)^{1/2} (\Delta E/e)^3 \text{ m}^{-3}$

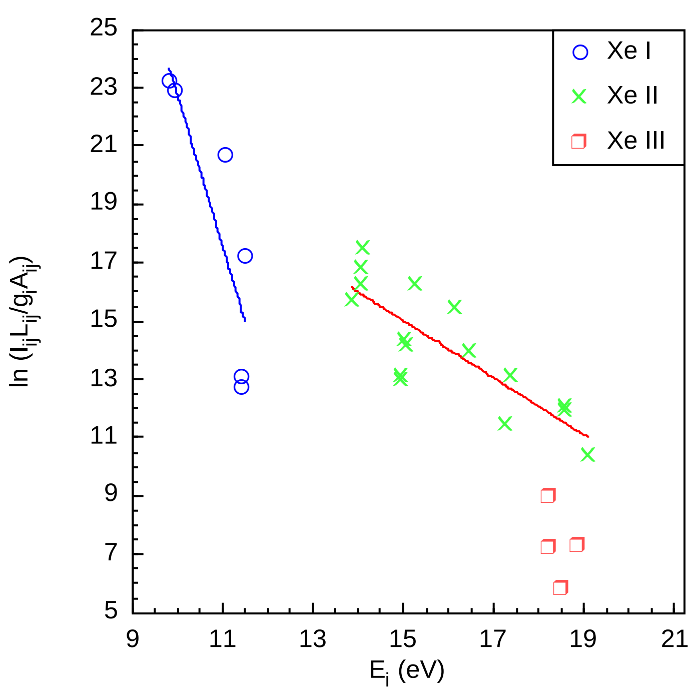
- Corona model assumes collisional excitation balances radiative decay:

$$n_i/n_0 = n_e \langle\sigma v_e\rangle / \Sigma_j A_{ij}$$

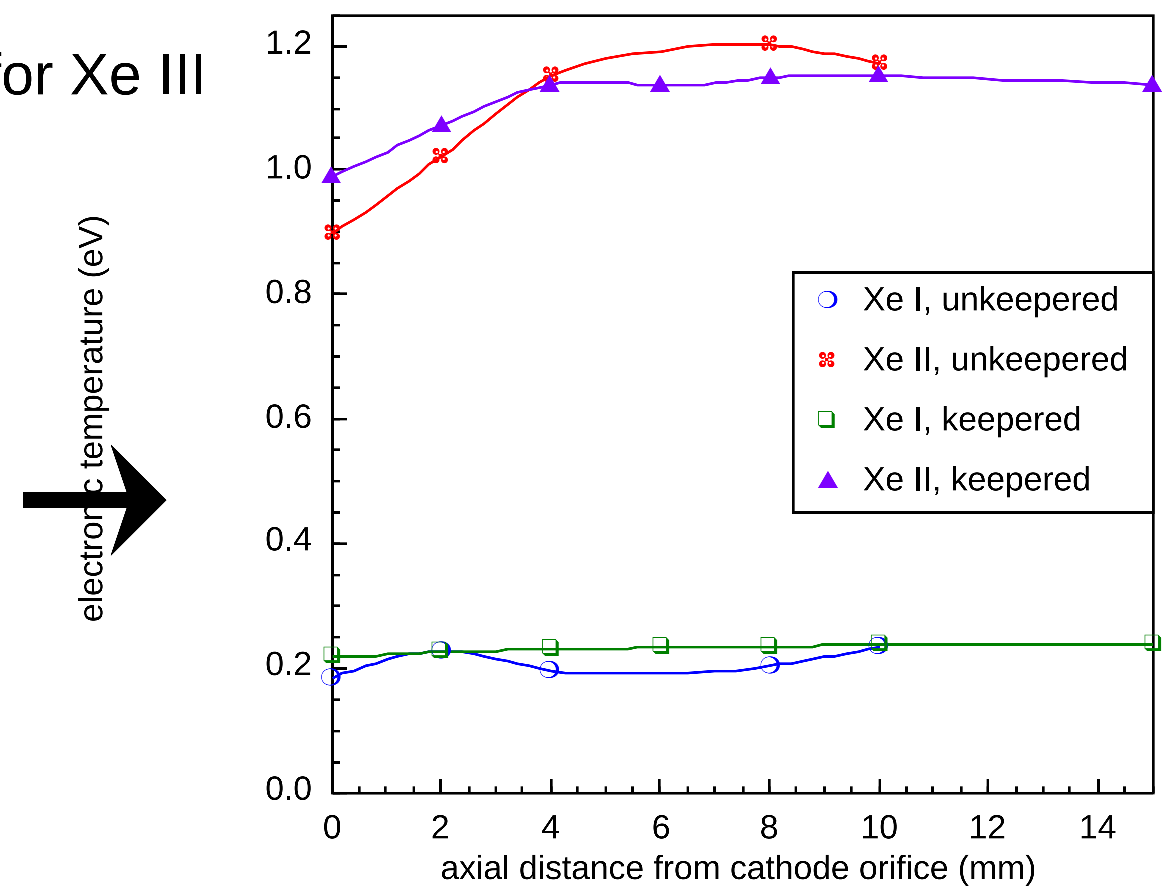
  - Appropriate for optically thin plasma with $A_{ij} >> n_0 n_e \langle\sigma v_e\rangle$
  - Requires knowledge of $n_e \langle\sigma v_e\rangle$; many values not known

Electronic temperatures

- Twenty-seven emission lines per axial location
- T_e by Boltzmann plot
- Insufficient data spread for Xe III



- Electronic temperature at TH 15 (NSTAR operating condition)

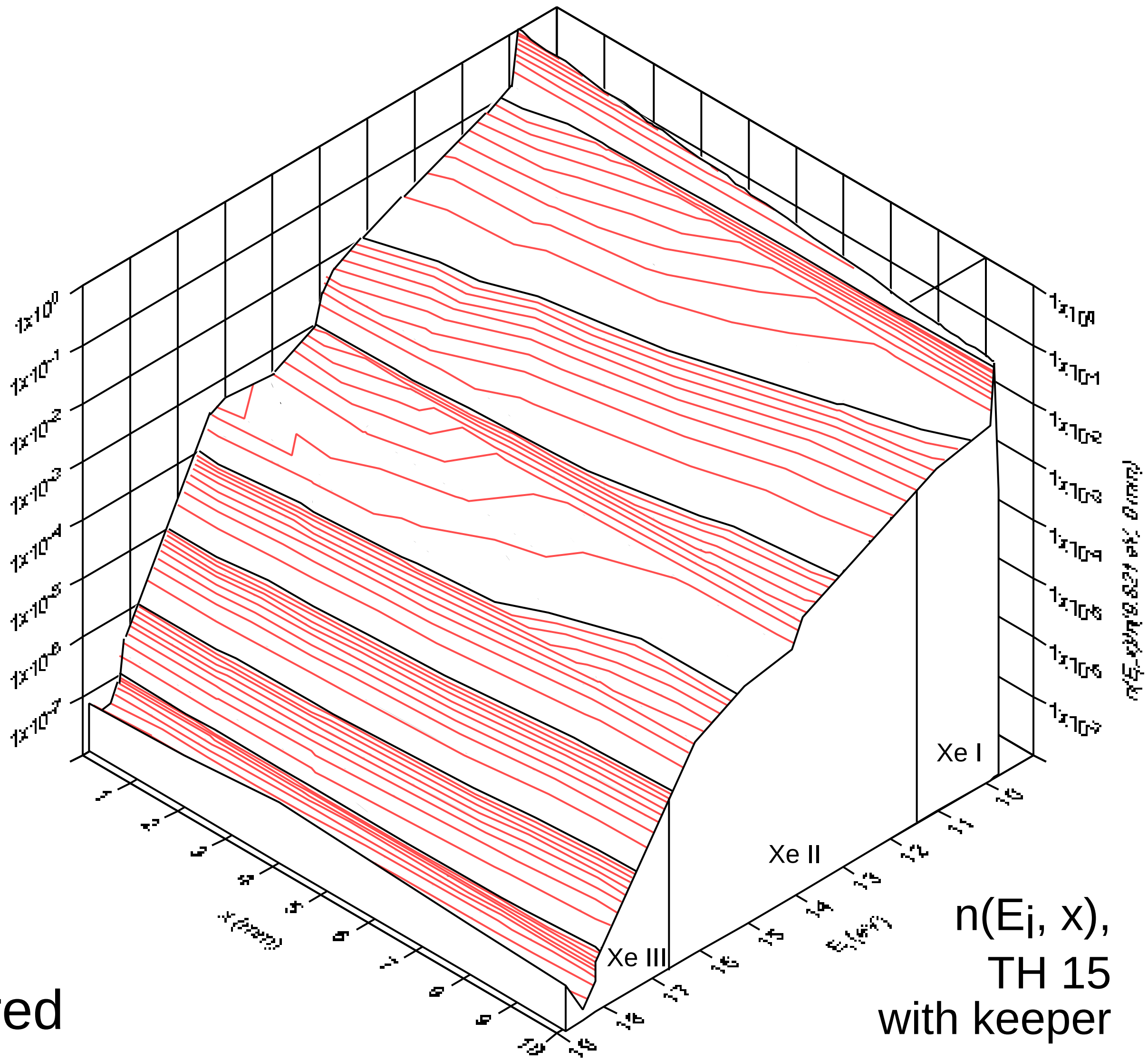


Excited state population density, TH 15

- Population density

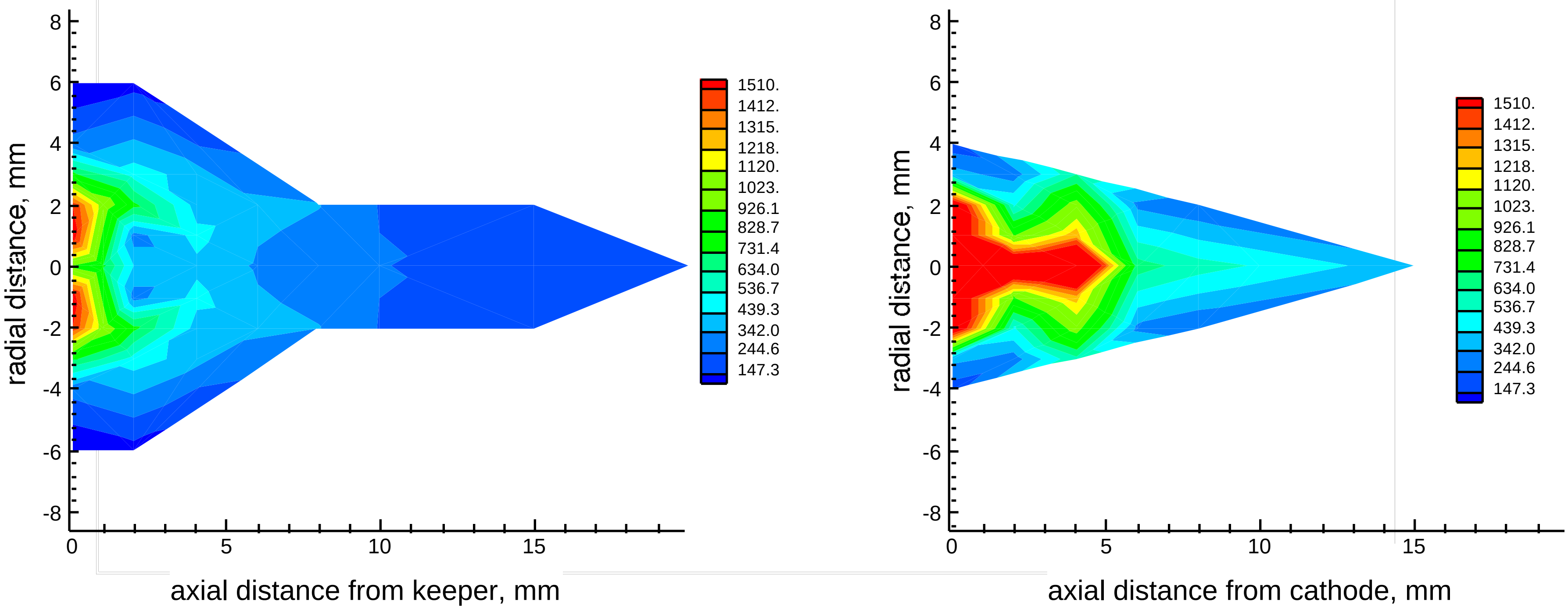
$$n(E_i, x) = K\, I_{ij}\, \lambda_{ij}/A_{ij}$$

- Features:
  - Non-equilibrium
  - Xe I density drops as 1/x (point source)
  - Xe II, III production at $2 \leq x \leq 6$ mm
  - Approaches equilibrium as $x \to \infty$
- Conclusion:
  - LTE not justified
  - Corona model required



$n(E_i, x)$,
TH 15
with keeper

Xe II $^5D_{7/2}$ population density, TH 15



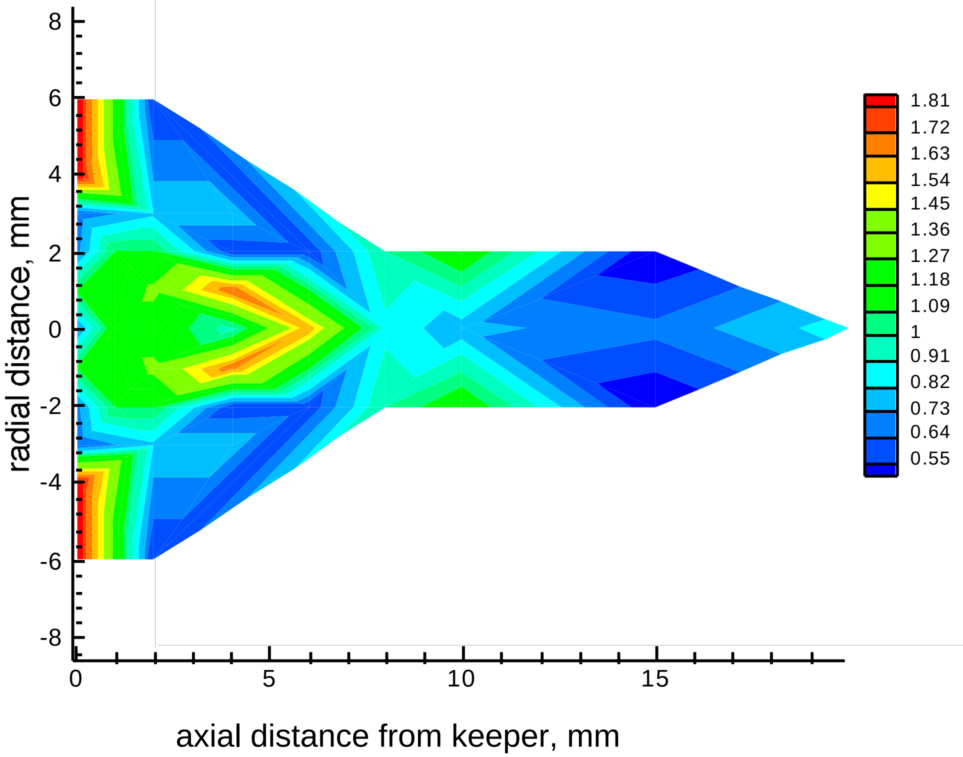
<u>TH 15 with keeper</u>

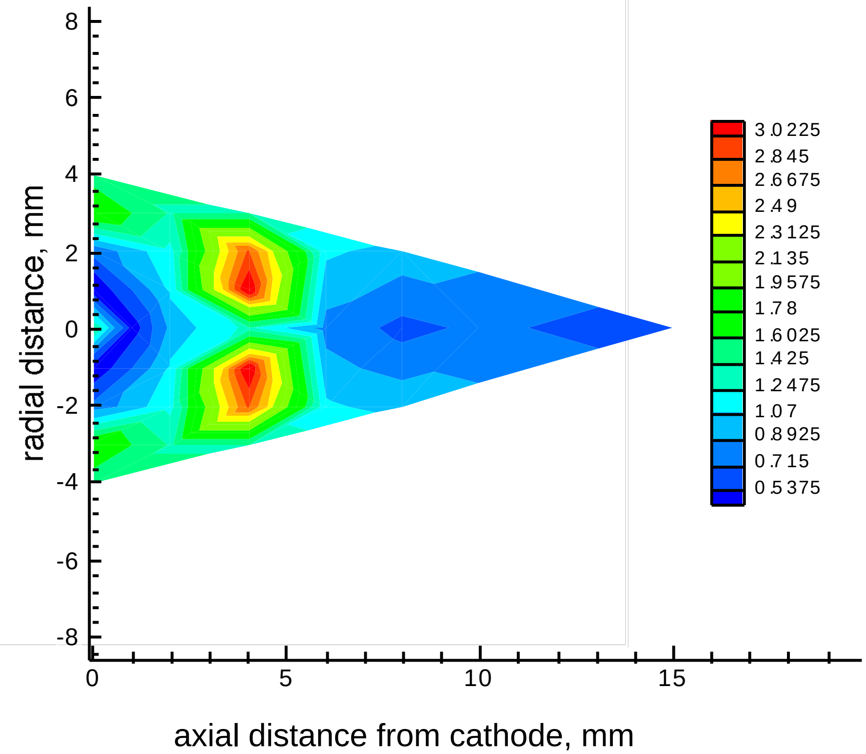
- Highest density at keeper face
- Lower density in core
- Lowest density at keeper edges & far downstream (x ≥ 12 mm)

<u>TH 15 w/o keeper</u>

- Extended high density region
- Highest density in core
- Radially symmetric feature centered at (x,r) = (5,0) mm

Xe II translational temperatures, TH 15

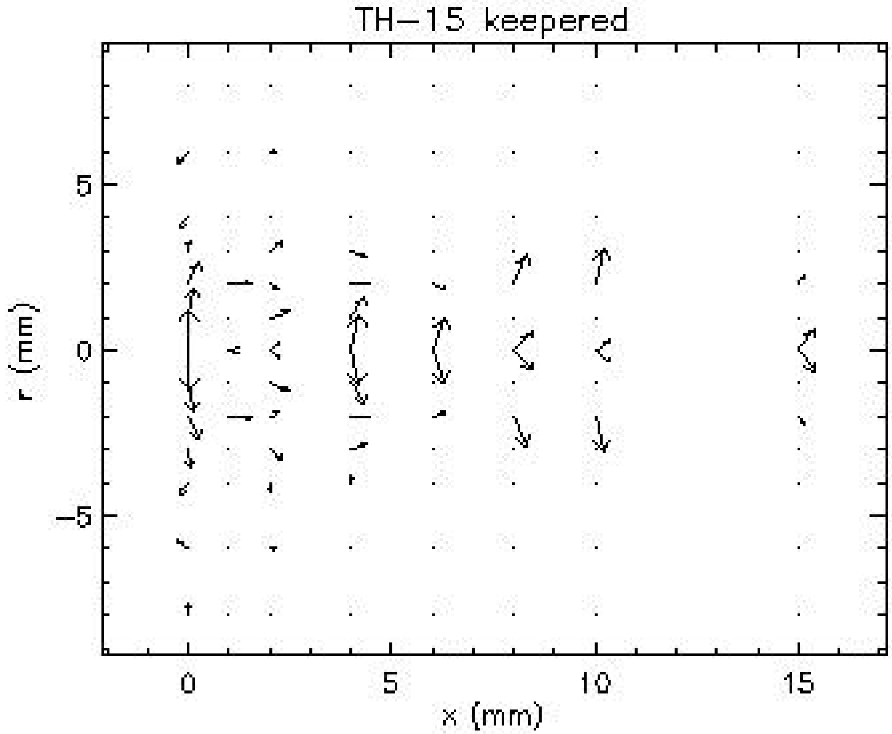


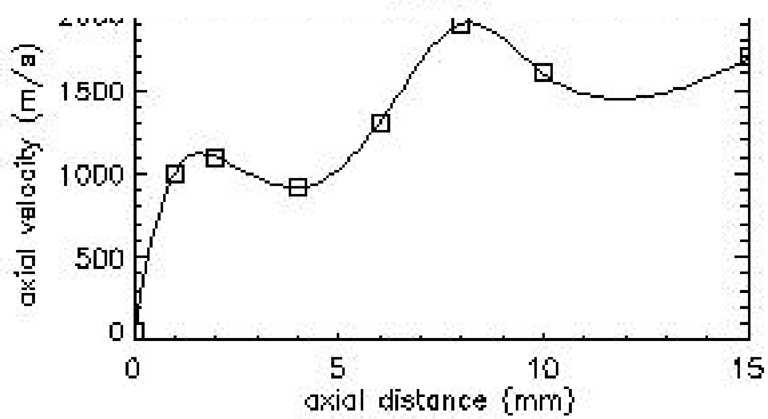


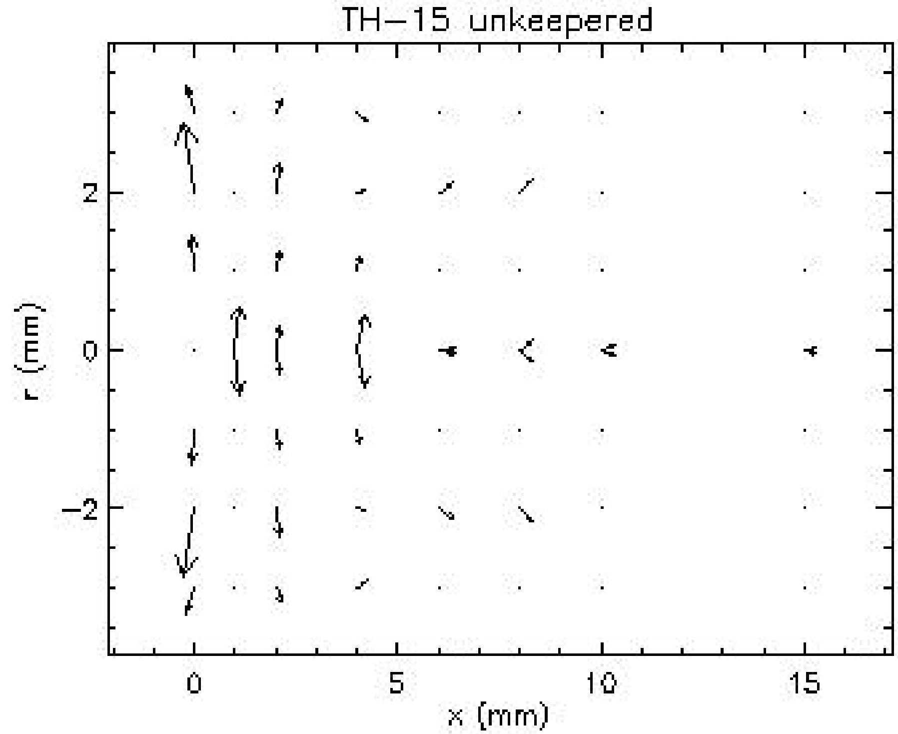
- TH 15 with keeper. Hot spots:
  - Near core, $4 \leq x \leq 6$ mm
  - Past keeper edge, $r > 4$ mm
- Range $0.55 \leq T \leq 1.81$ eV

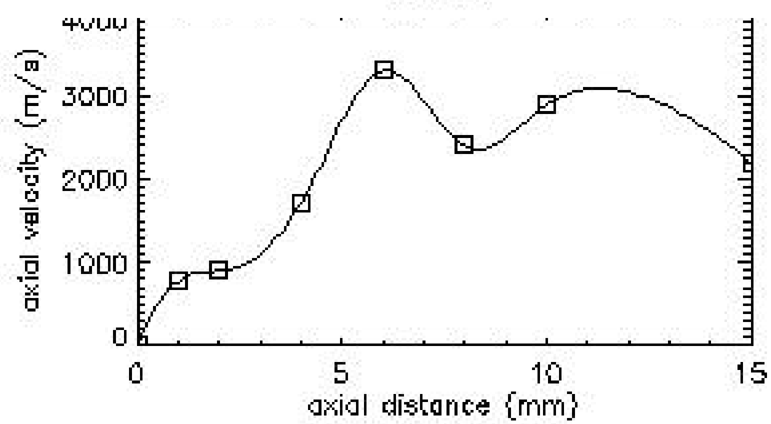
- TH 15 w/o keeper. Hot spots:
  - Outside core, $(x,r) = (4,2)$ mm
- Cold near cathode face
- Range $0.54 \leq T \leq 3.02$ eV

Xe II velocities, TH 15 condition









Summary and conclusions

- LTE assumption invalid for FMT discharge. Corona or radiative-collisional model required.

- High Xe II radial velocity, low translational and electronic temperature at keeper/cathode face.

- Low Xe II density recirculation zone past keeper edge.

- Ion creation zone on $r = 0$ mm, $2 \leq x \leq 6$ mm, partially confirming potential hill theory.

Future directions

- Corona and/or collisional-radiative model development.

- Correlation with sputtered Mo and W concentrations, with and without keeper.

- Simultaneous dual-wavelength LIF: e.g., Xe II @ 823.2 nm and Mo @ 390.3 nm.

Acknowledgements

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