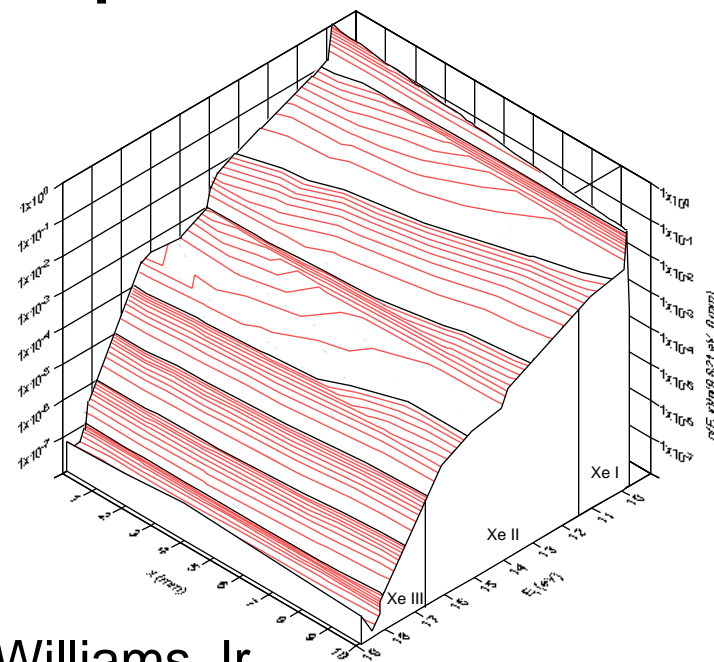
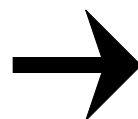
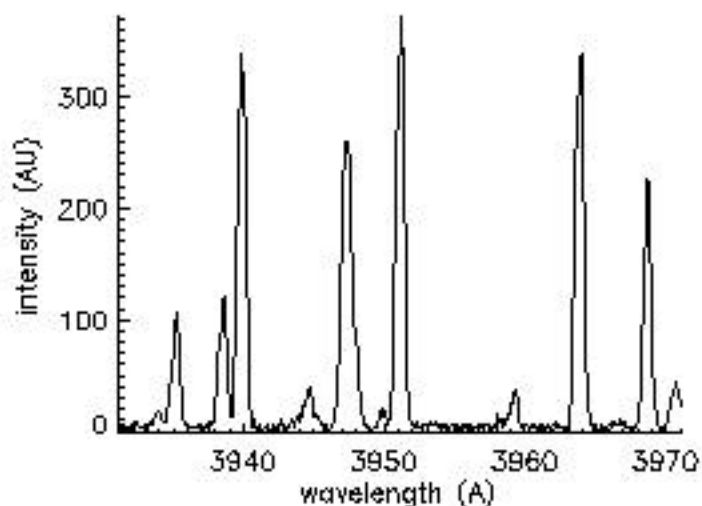


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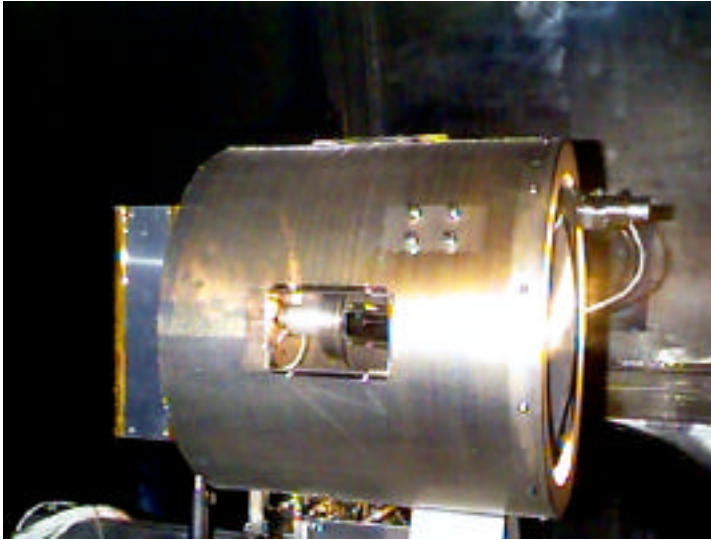
Spectroscopic characterization of FMT-2 discharge ionization processes



Timothy B. Smith, George J. Williams Jr.,
Yoshiteru Hidaka, Kathryn Glick and Alec D. Gallimore
Plasmadynamics and Electric Propulsion Laboratory
Department of Aerospace Engineering
The University of Michigan
Ann Arbor, MI

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

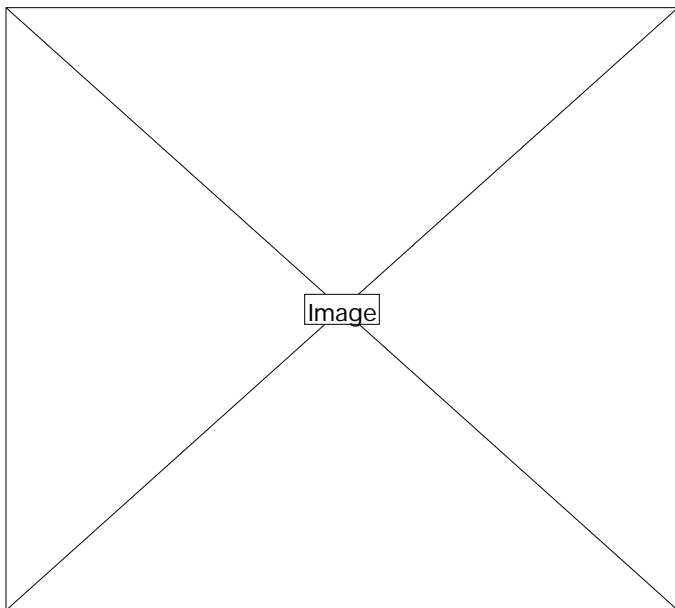
Functional model thruster (FMT)

- 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



Discharge cathode schematic

Erosion at outer edges



Ongoing development effort

- LIF erosion rate diagnostic

Present study

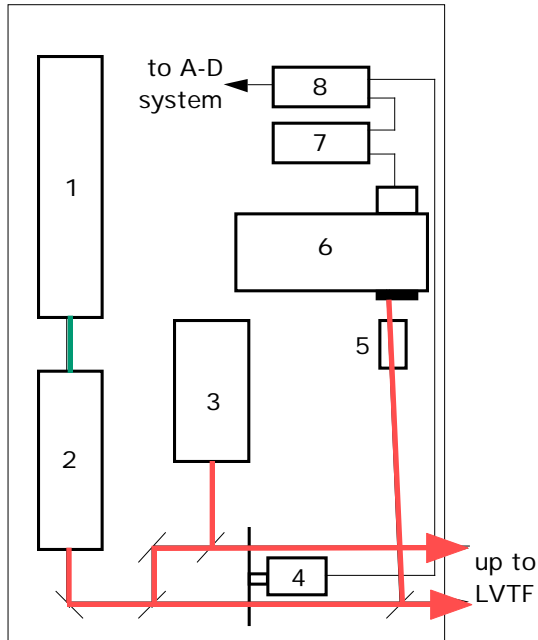
- Xe II LIF at 605 nm
- Emission spectroscopy of Xe I, II & III

Spectroscopic characterization of FMT-2 discharge ionization processes

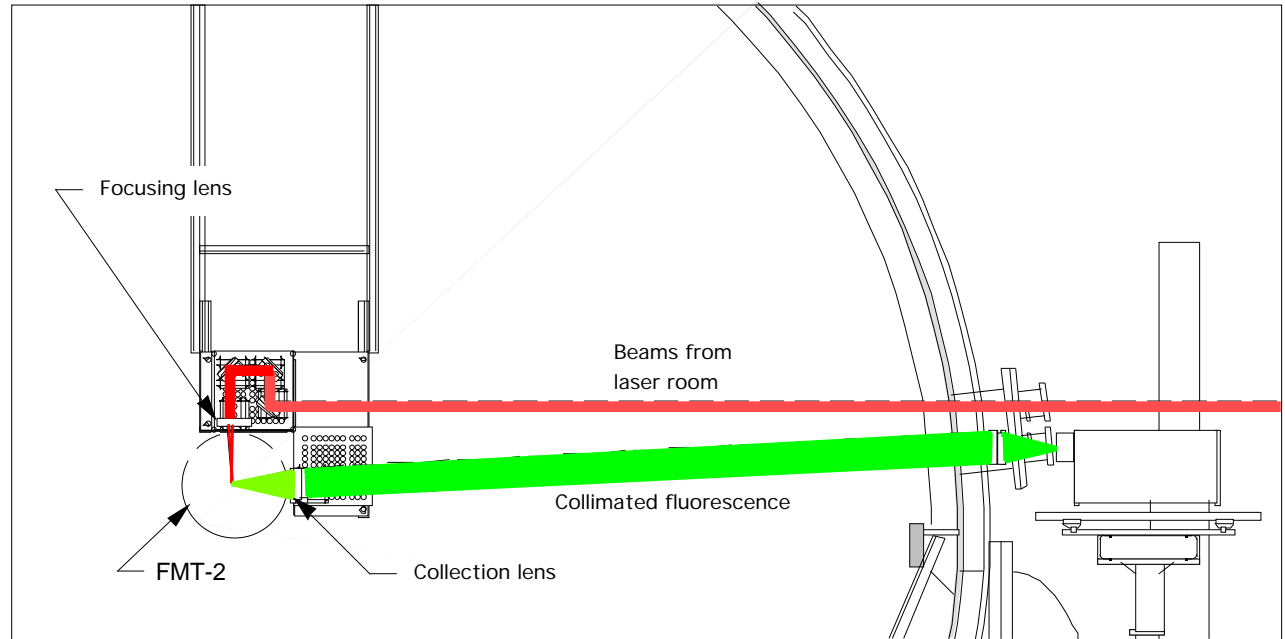
Outline:

- 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

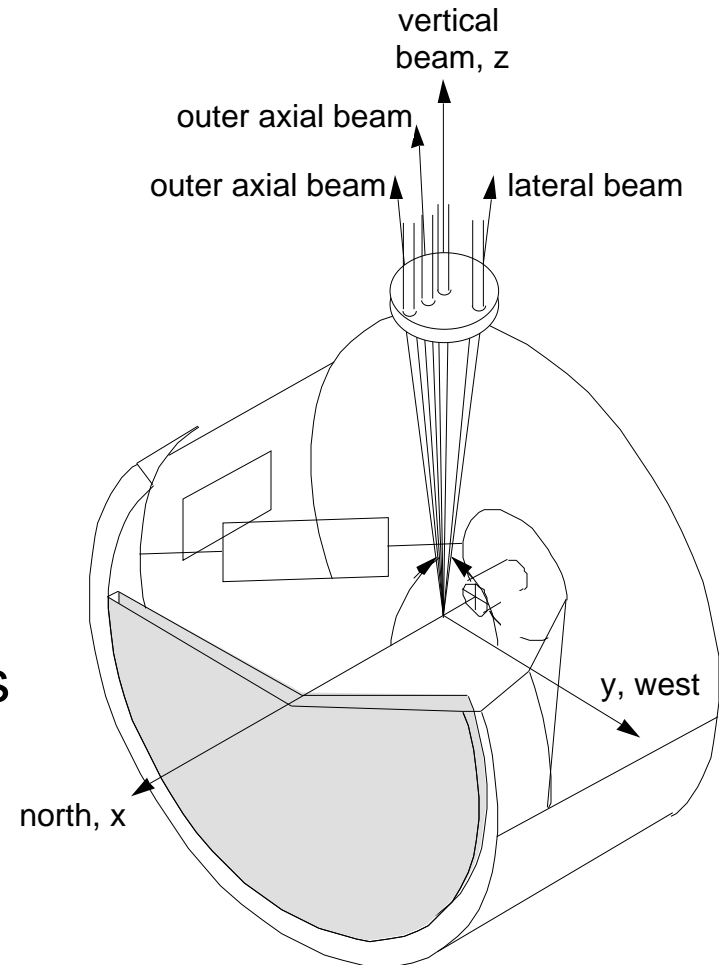
- Simultaneous LIF & emission spectroscopy

- Large Vacuum Tank Facility

- Ø6 x 9 m
- 0.2 μ Torr 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:
 - θ_0 angles 10.51° upstream of z-axis
 - θ_1 angles 7.70° upstream of z-axis
 - ϕ 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

$$I_{ij} = (hc/4\pi) A_{ij} n_i d\Omega$$

- 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 $n_e \gg 10^{19} (kT_e/e)^{1/2} (\lambda/E/e)^3 \text{ m}^{-3}$

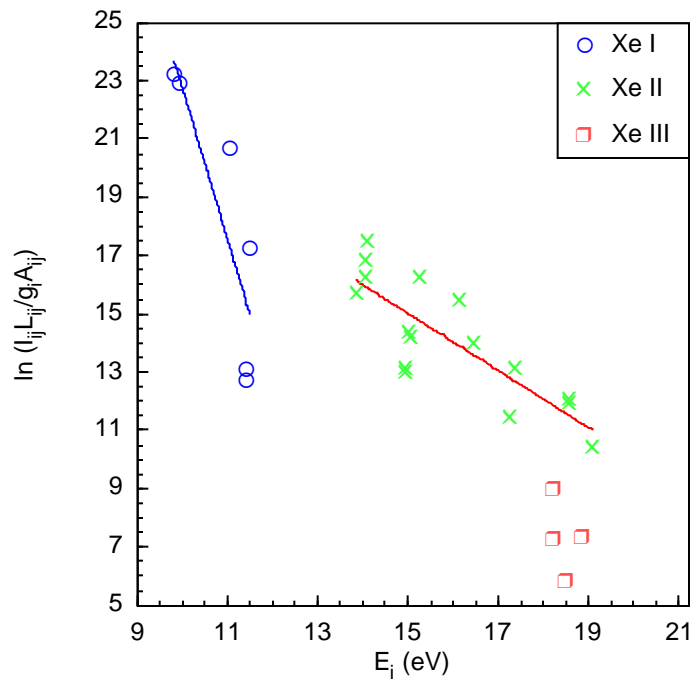
- Corona model assumes collisional excitation balances radiative decay:

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

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

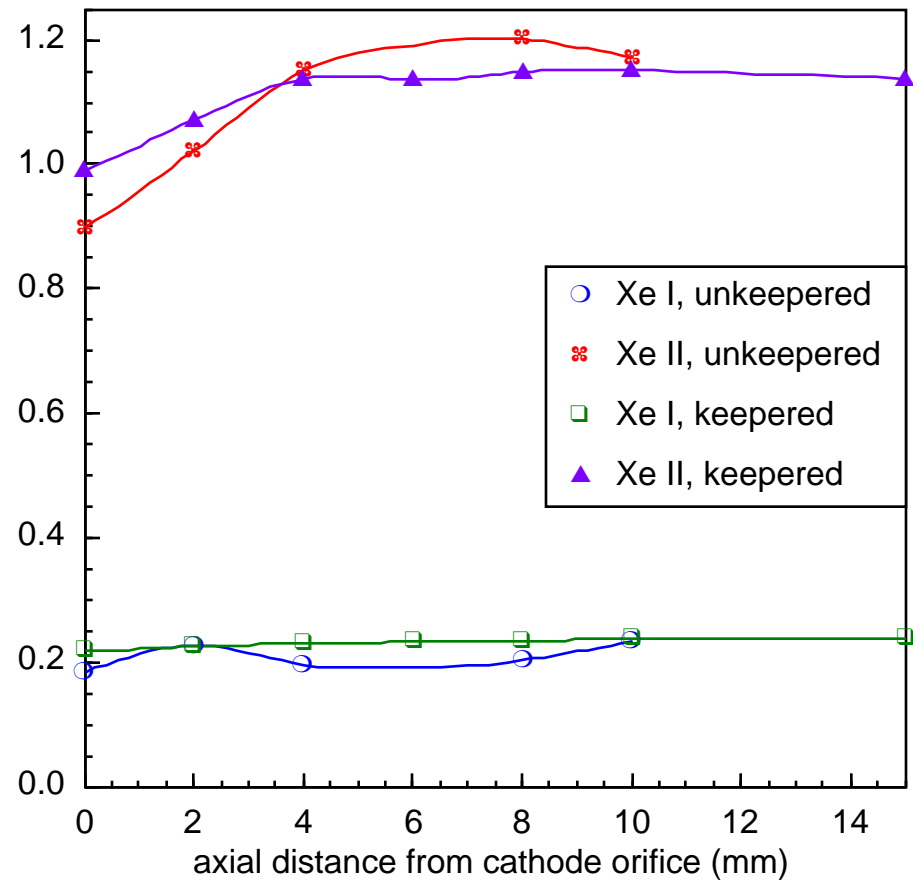
Electronic temperatures

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



electronic temperature (eV)

- Electronic temperature at TH 15 (NSTAR operating condition)



Excited state population density, TH 15

- Population density

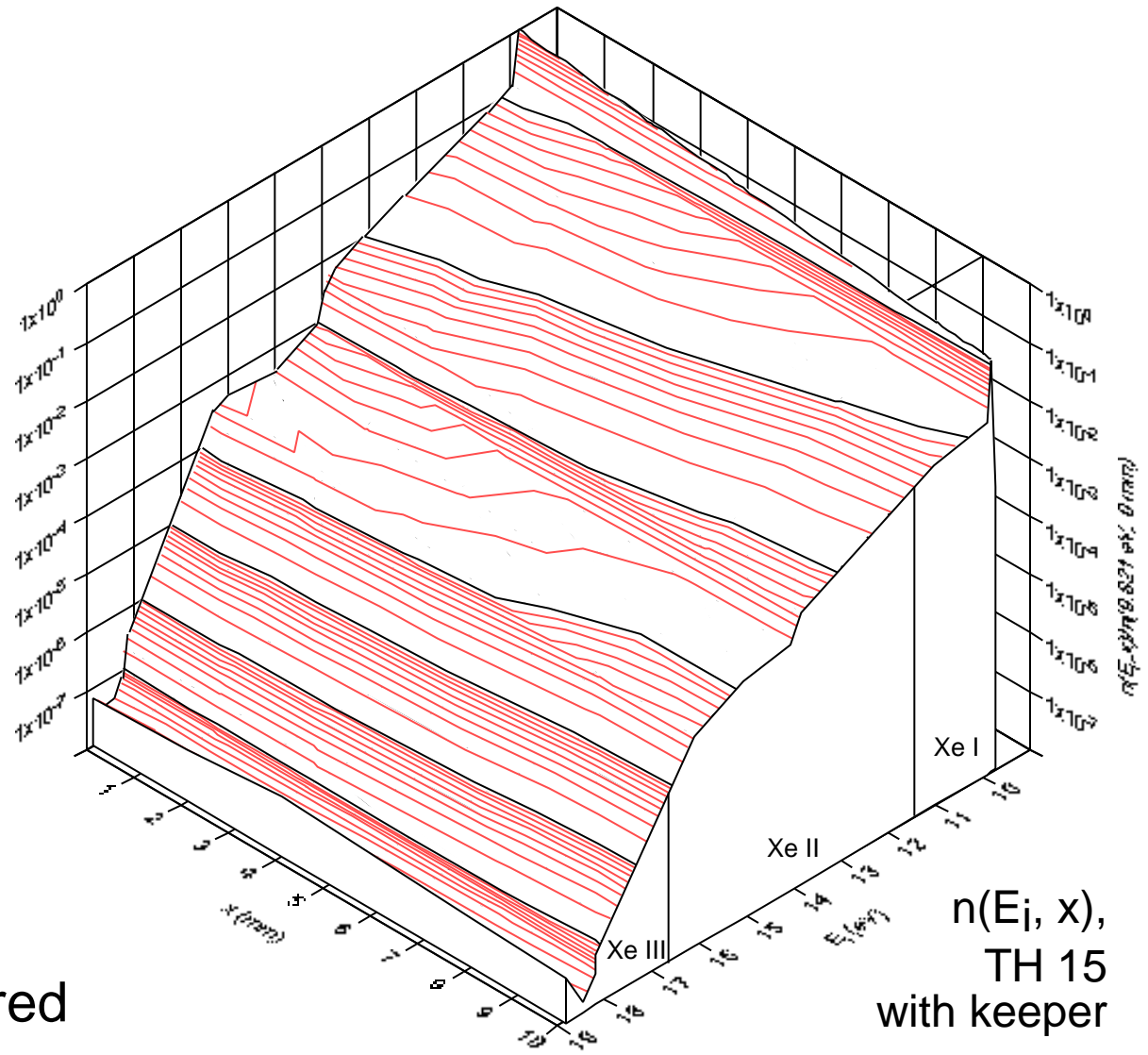
$$n(E_i, x) = K I_{ij} \quad ij/A_{ij}$$

- Features:

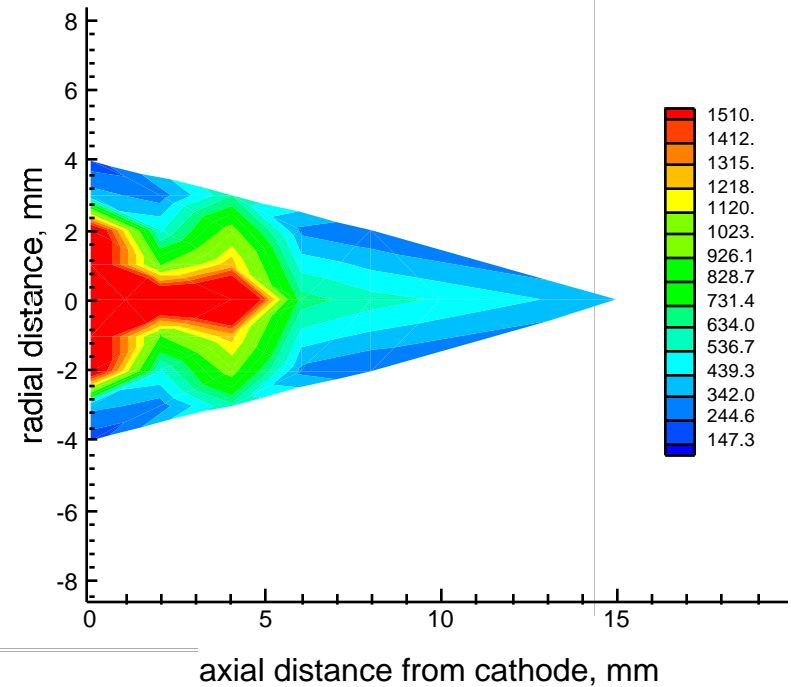
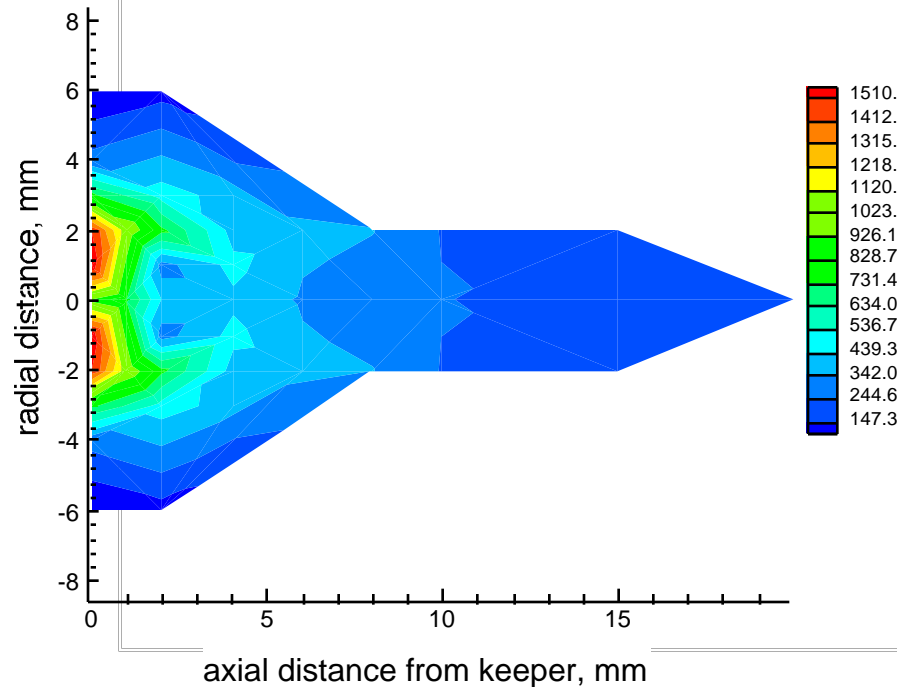
- Non-equilibrium
- Xe I density drops as $1/x$ (point source)
- Xe II, III production at 2×6 mm
- Approaches equilibrium as $x \rightarrow$

- Conclusion:

- LTE not justified
- Corona model required



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



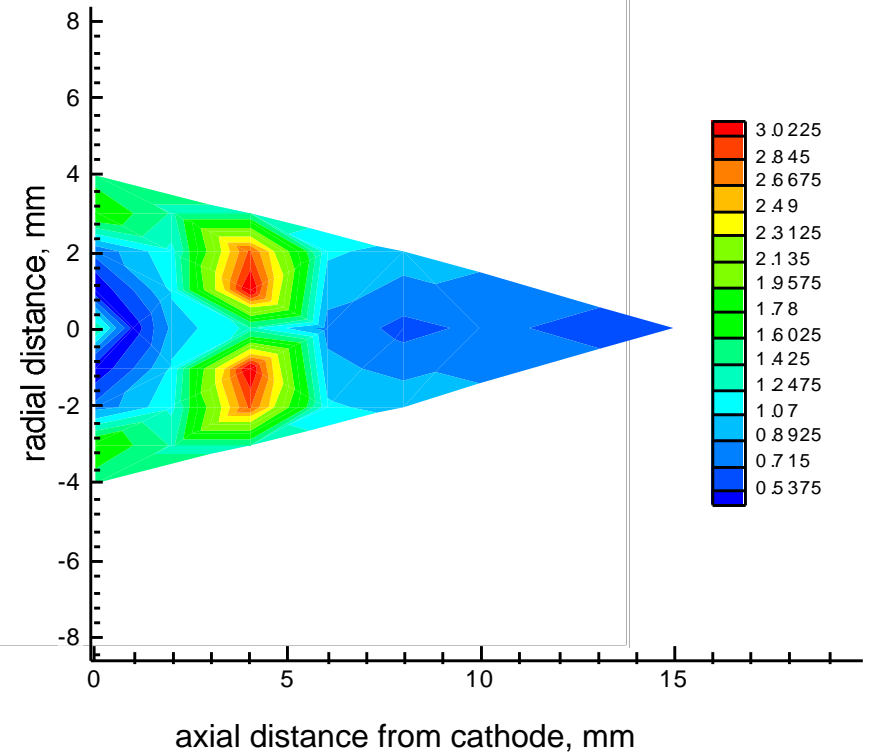
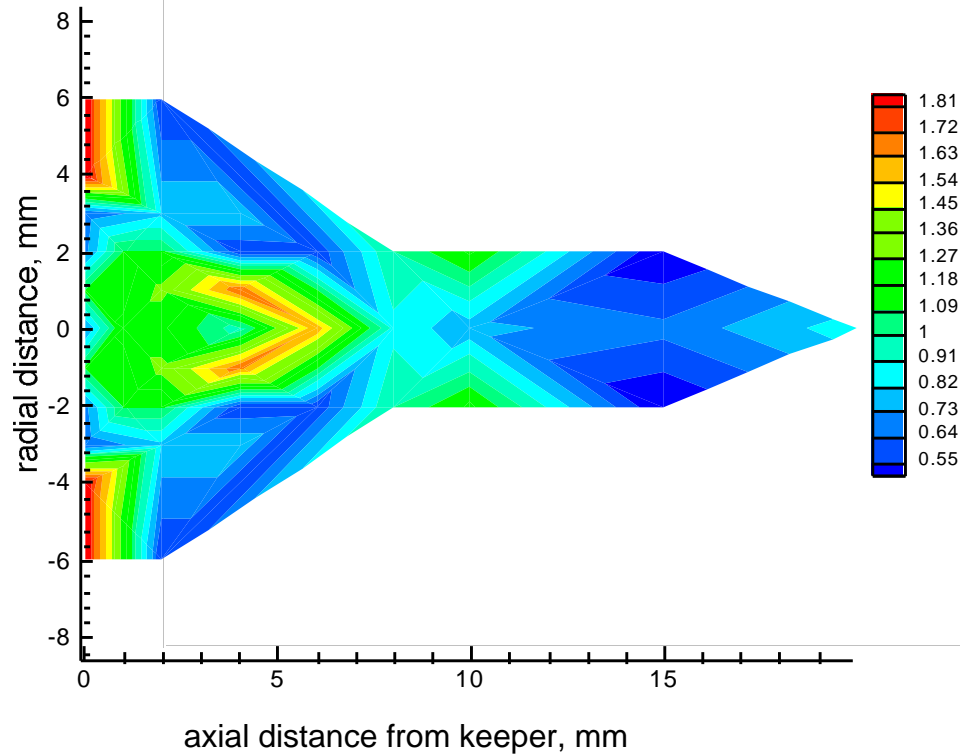
TH 15 with keeper

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

TH 15 w/o keeper

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

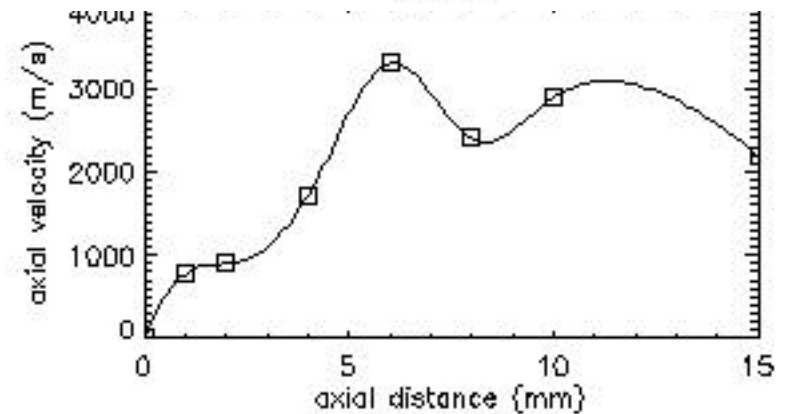
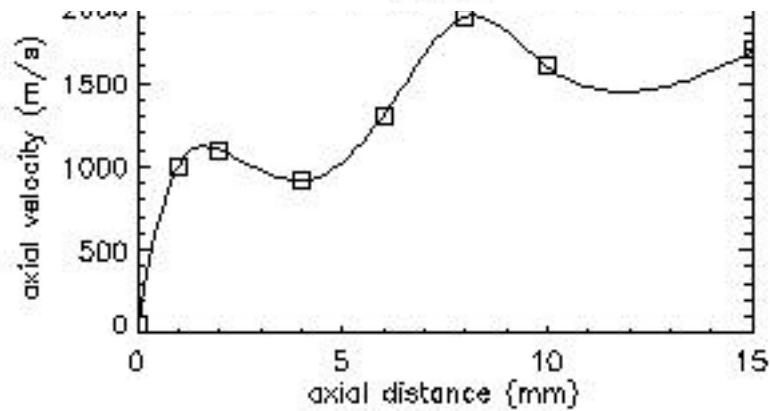
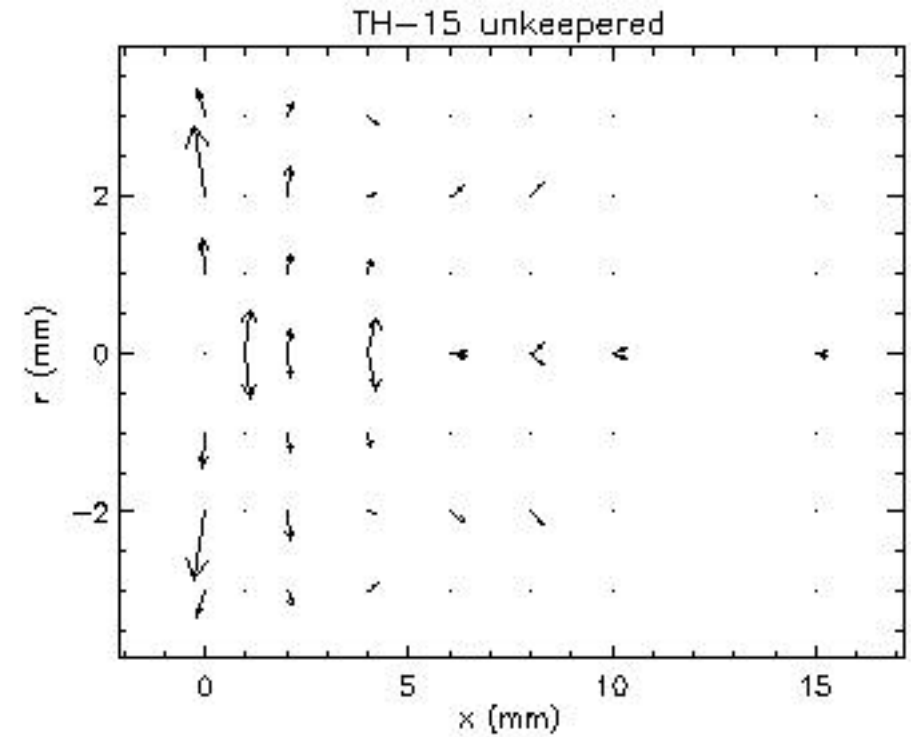
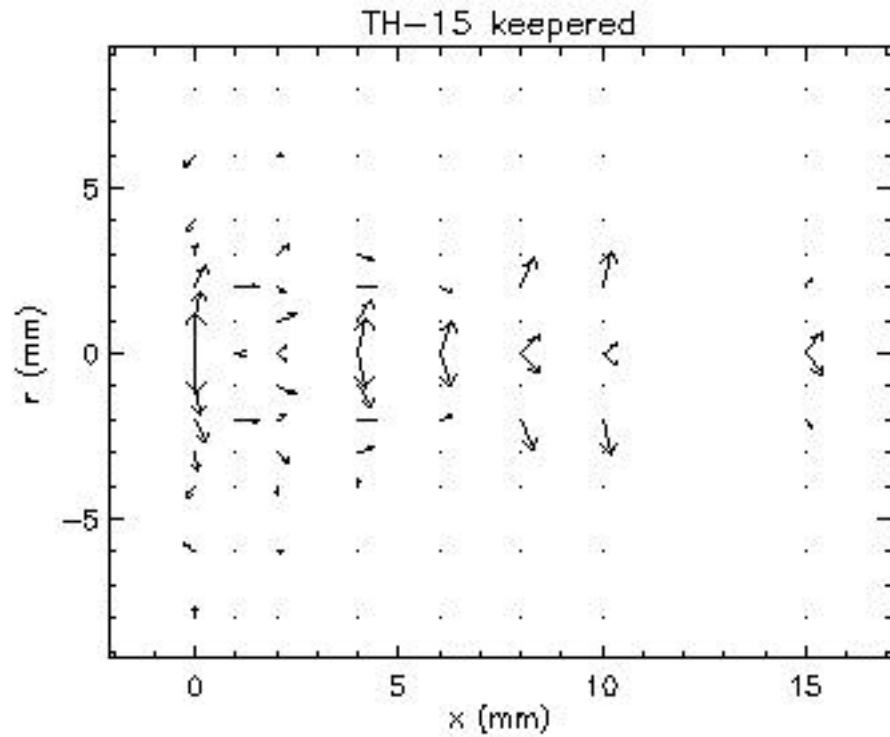
Xe II translational temperatures, TH 15



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

- TH 15 w/o keeper. Hot spots:
 - Outside core, $(x,r) = (4,2)$ mm
- Cold near cathode face
- Range 0.54 T 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, 2×6 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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