Non-intrusive Characterization of the Wear of the HERMeS Thruster Using Optical Emission Spectroscopy

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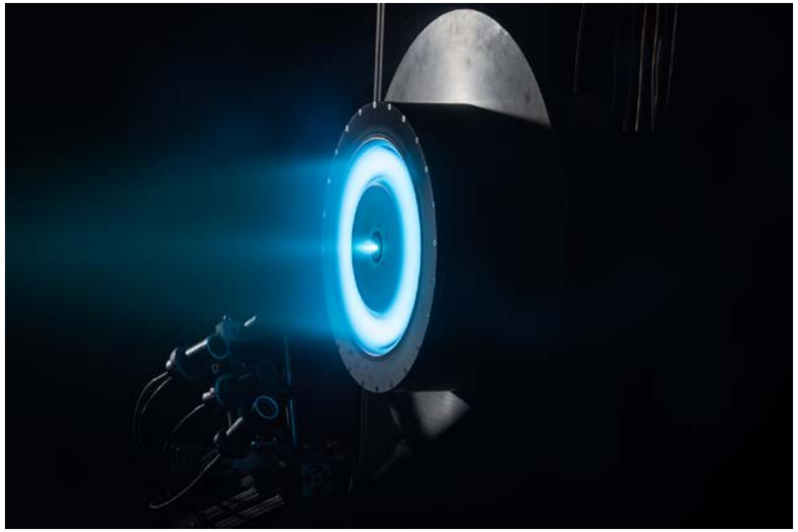
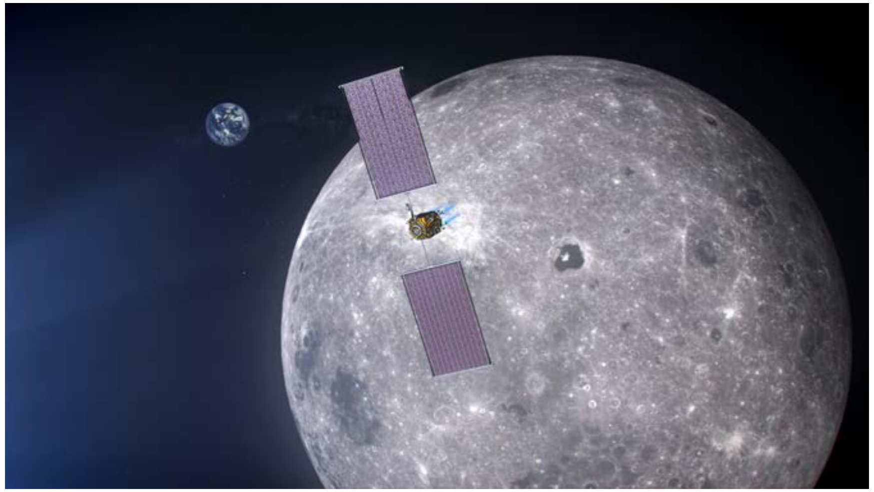
Introduction

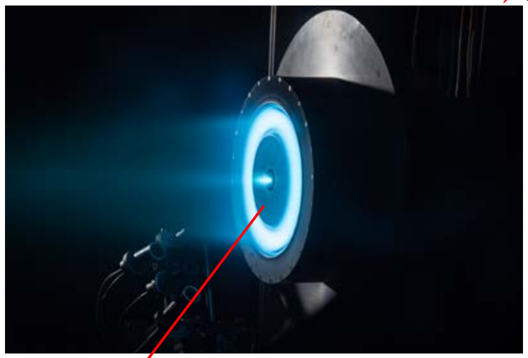
- NASA GRC and JPL team developed a 12.5 kW magnetically-shielded Hall thruster - Hall Effect Rocket with Magnetic Shielding (HERMeS)
- Transitioned to commercial production under Aerojet Rocketdyne's Advanced Electric Propulsion System (AEPS)
- AEPS is baselined as one of the electric propulsions systems on the Power and Propulsion Element (PPE), the first element of NASA's Gateway
- PPE (and Gateway) is one of the first steps in the Artemis lunar exploration program

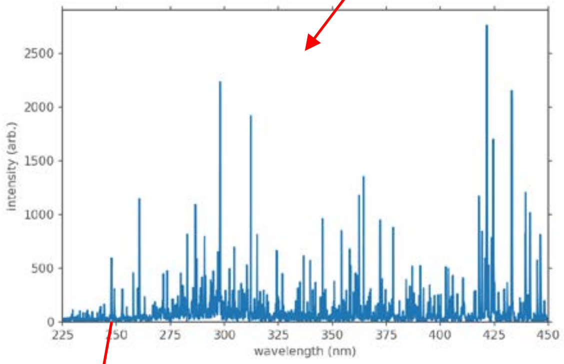


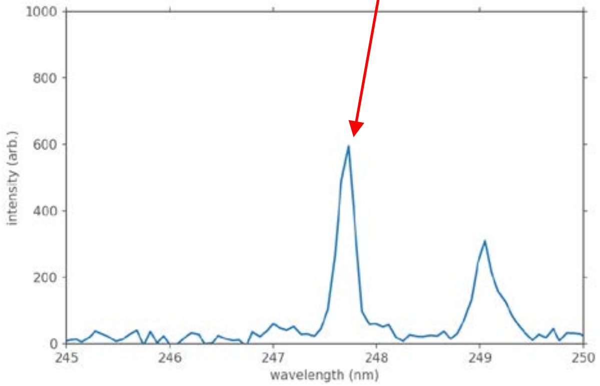


Motivation

- Channel erosion, the life-limiting mechanism in non-shielded thrusters, is virtually eliminated in magnetically shielded configurations
- Front pole cover erosion became the life-limiting mechanism in the HERMeS design
  - Pole covers are carbon
- Pole cover erosion typically measured by removing components after venting facility and scanning with precision profilometer
- Carbon sputtered from pole cover has a spectroscopic signal, which should be correlated to erosion rates
- C I line at 247.9nm is a good candidate

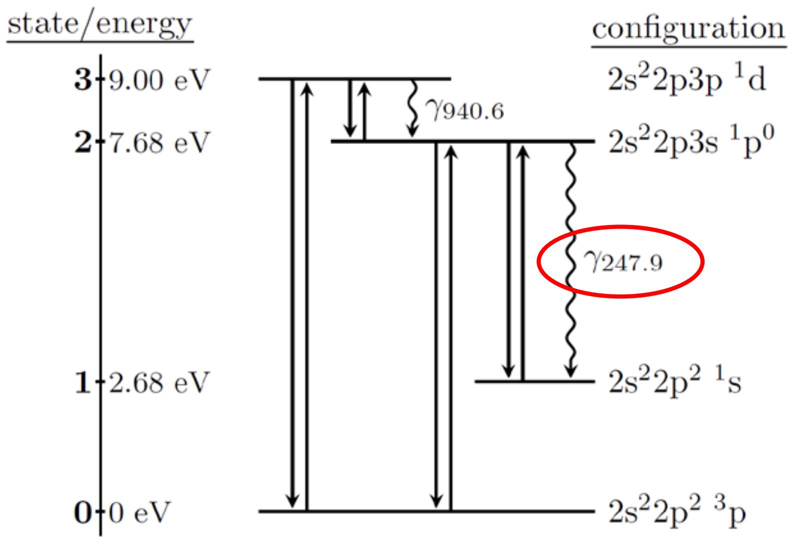






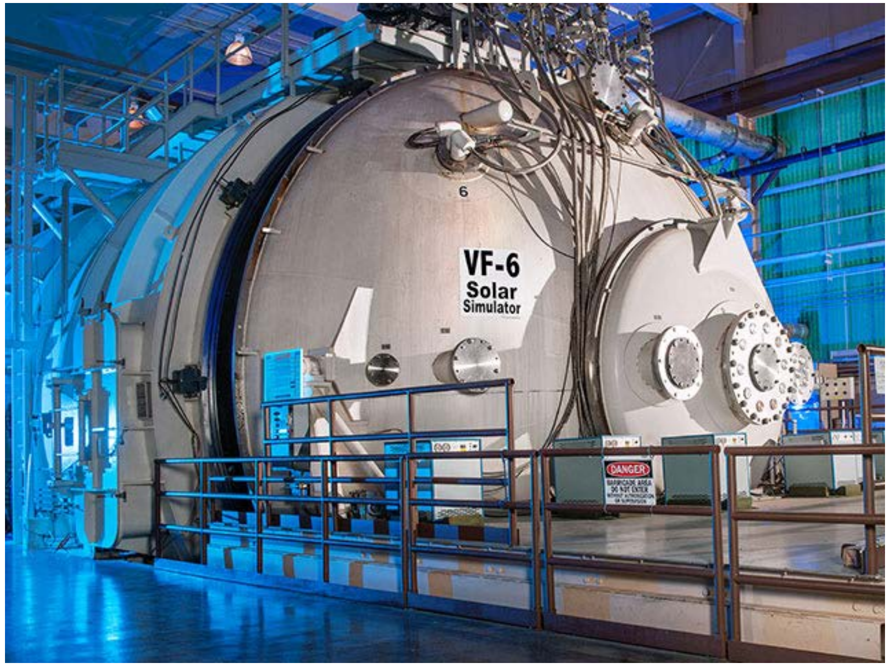
Collisional-radiative model

- In a plasma environment, electrons are excited to higher energy bound states.
- Intensity of a given emission line is proportional to population of the upper state for the transition
- Populations of excited states in plasmas can be determined with corona (low density) or LTE (high density) models based on plasma conditions
- For moderate density plasmas, a collisional-radiative model (CRM) can be used to calculate the dependence of electronic state populations
- Population of upper state is dependent on both total carbon population (due to sputtering) and local electron temperature and density.
- Utilized Hall2De modeling for electron density and temperature profiles in front of the inner front pole cover (IFPC) to inform the CRM



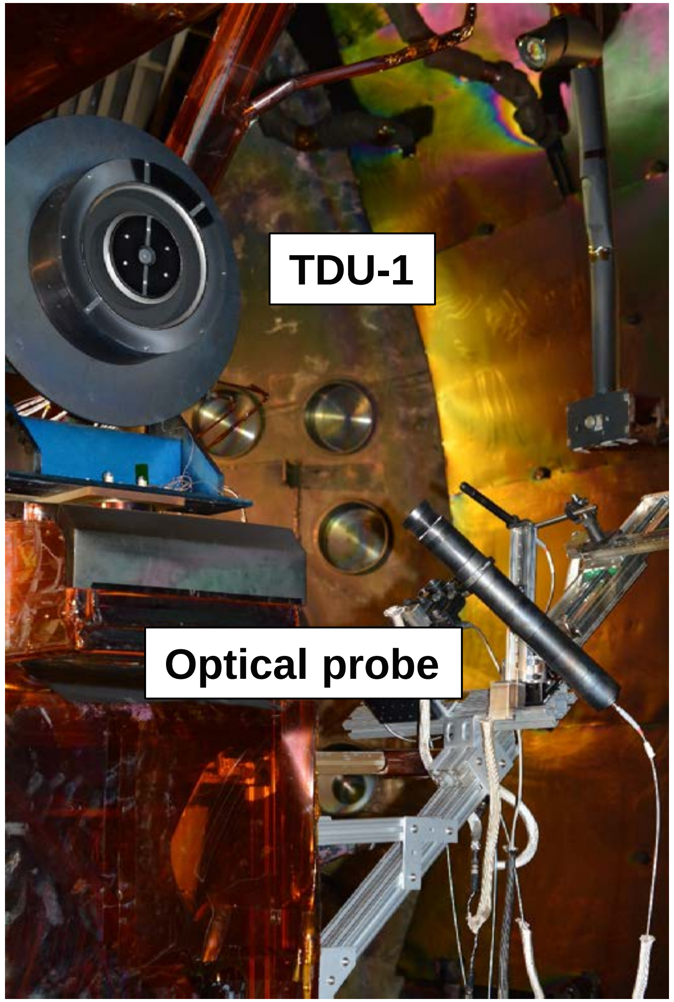
Experimental Setup

- HERMeS TDU-1 thruster
- VF-6 space simulation facility
  - 7.6 m diameter x 21 m long
- Thruster operated at 600 V
- 4 tested magnetic configurations
  - B0, B1, B2, B4
  - B0 is baseline configuration used for TDU-1, TDU-2, and TDU-3 thrusters
  - See *Kamhawi, A902* for more on magnetic configuration testing
- Magnetic field strength scans in multiple magnetic configurations were performed
  - 0.75 – 1.25 B_{nom}



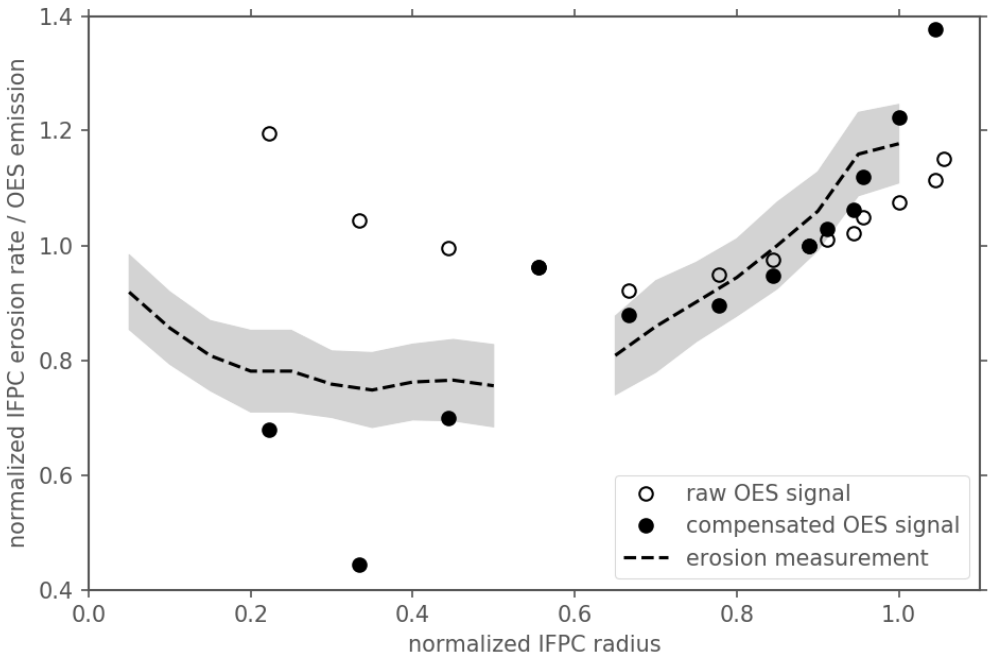
Experimental Setup - diagnostics

- UV-visible spectrometer
  - 225-450 nm range
- UV-VIS fibers
- 200 mm motion stage
- 5 cm diameter optics probe
- Scan parameters:
  - 8 s integration time, 4 scans averaged
  - Dark spectrum subtracted
  - 9 and 13 points sampled across the inner front pole cover (IFPC)



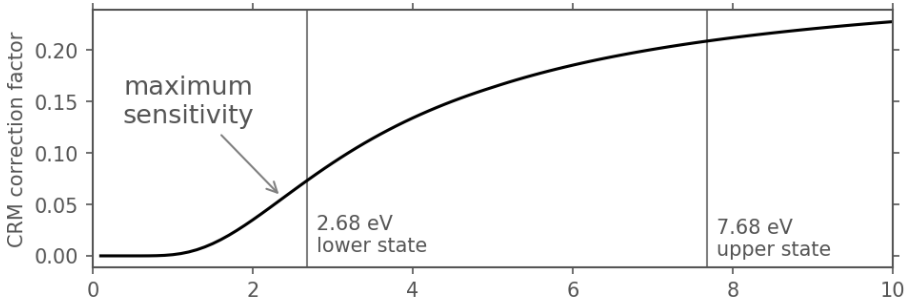
Results - Erosion

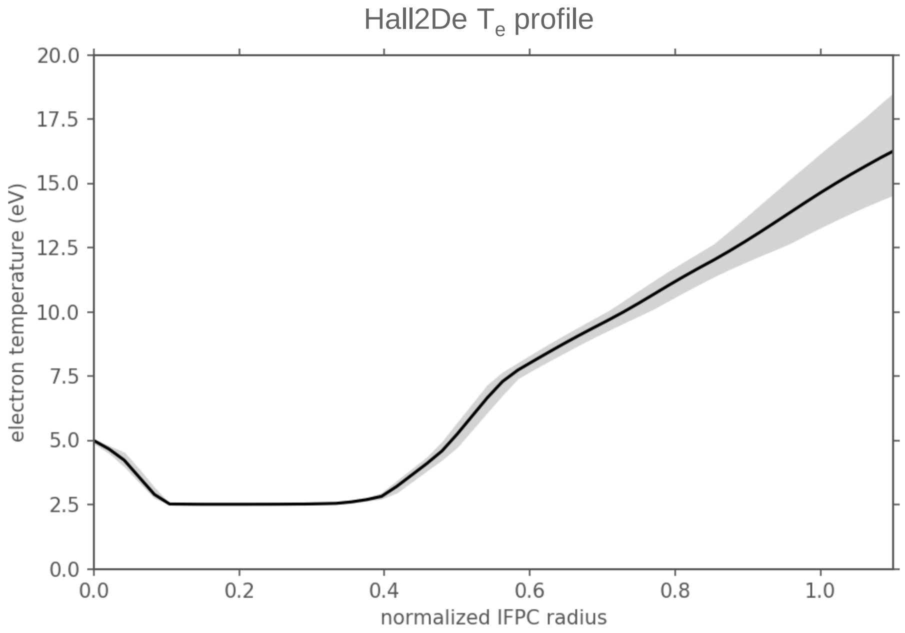
- Representative results in the B2 configuration – B0, B1 configurations similar
  - B4 configuration not wear tested
- Compensated OES signal well correlated to measured erosion rate after 250 h wear test on outer half of IFPC
- Erosion measurements made with non-contact, white light profilometer
- Correlation on inner half of IFPC much lower quality



T_e sensitivity

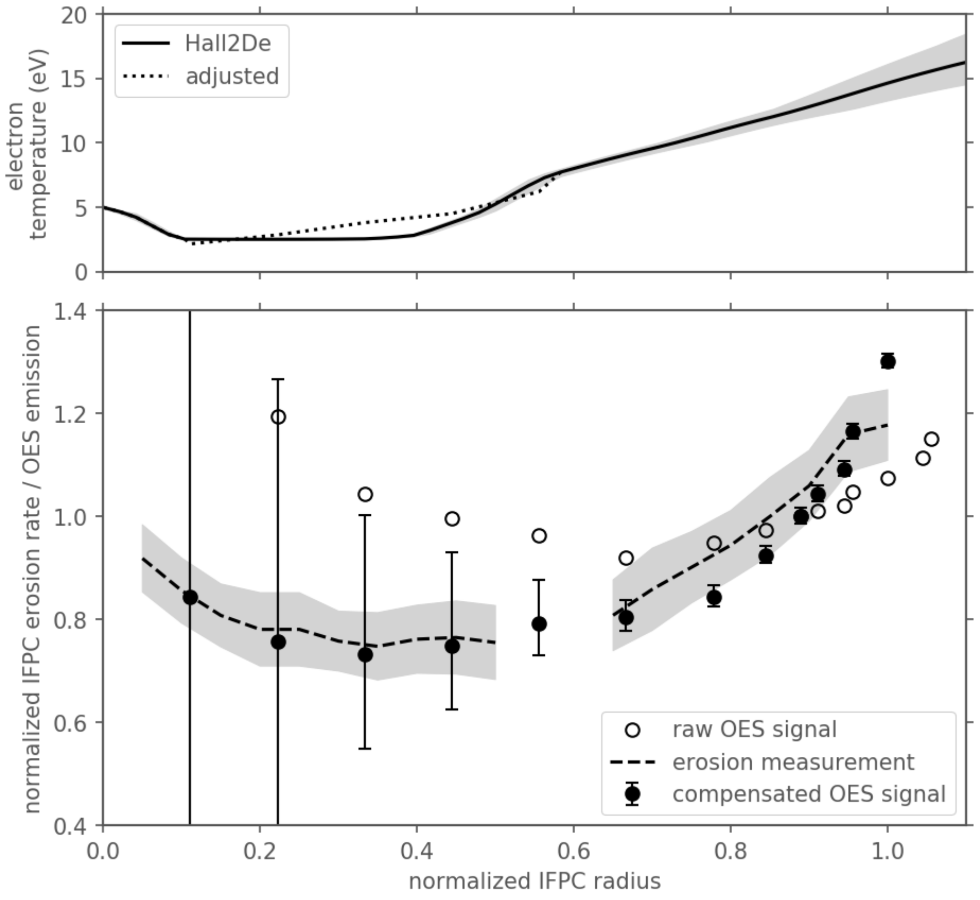
- CRM is very sensitive to T_e below ~ 6 eV
- Above 6 eV, n_e is dominant correction, with T_e secondary
- Below 6 eV, CRM correction factor due to T_e can drop to < 10% of value above T_e
- Maximum sensitivity due to T_e occurs ~ 2.5 eV
- Hall2De T_e profiles in front of inner half of IFPC drop rapidly to 2.5 eV
- Correlation of OES measurement to erosion in the region r ~0 to 0.5 depends on accuracy of input T_e profiles and is very sensitive to small changes in temperature





Adjusted T_e

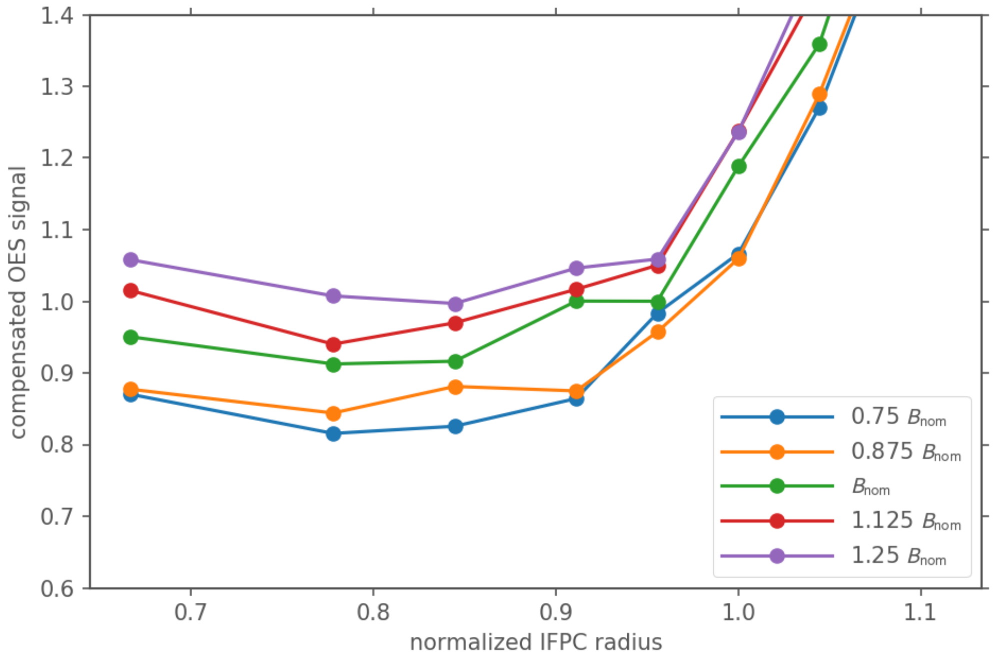
- T_e values on inner half of IFPC adjusted so that compensated OES signal matches with measured erosion rate
- T_e correction required: < 1.25 eV for all points, with an average value of 0.75 eV
- Corrections smooth out T_e profile and are in line with previous optical measurements*
- Error bars represent corrected OES signal with adjusted T_e ±1 eV



*Williams, G., *et al*. Assessment of HERMeS Wear Trends via Optical Emission Spectroscopy. Presented at the 65th Joint Army-Navy-NASA-Air Force Propulsion Meeting, 2018.

B field scan

- Magnetic field was scanned from 0.75 – 1.25 nominal magnetic field for multiple magnetic configurations
- Increase of OES signal observed with increasing magnetic field, ~3% per 10% increase in B
- Increase in signal could be due solely to an increase in n_e, but is likely that it is at least partially due to increased carbon sputtering
- Agrees with trend observed at V_d = 300 V on TDU-3*



*Frieman, J. D., *et al.* Long Duration Wear Test of the NASA HERMeS Hall Thruster. Presented at the 54th AIAA/SAE/ASEE Joint Propulsion Conference, Cincinnati, OH, United States, 2018.

Conclusion

- Optical emission spectroscopy (OES) used on magnetic configuration test campaign for the HERMeS TDU-1 thruster
- CRM model developed to correct raw OES data and correlate it with measured erosion rates
- Technique is sensitive to T_e and n_e profiles in regions of interest
- Diagnostic shows good correlation with measured erosion rates in regions of moderate T_e
- OES shows promise in predicting erosion rates of carbon front pole covers in magnetically shielded thrusters