LONG DURATION WEAR TEST OF THE NASA HERMES HALL THRUSTER

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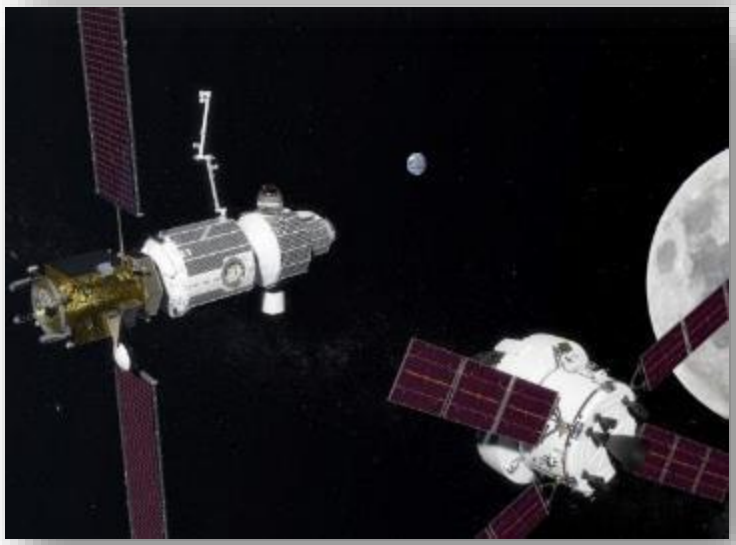
Motivation



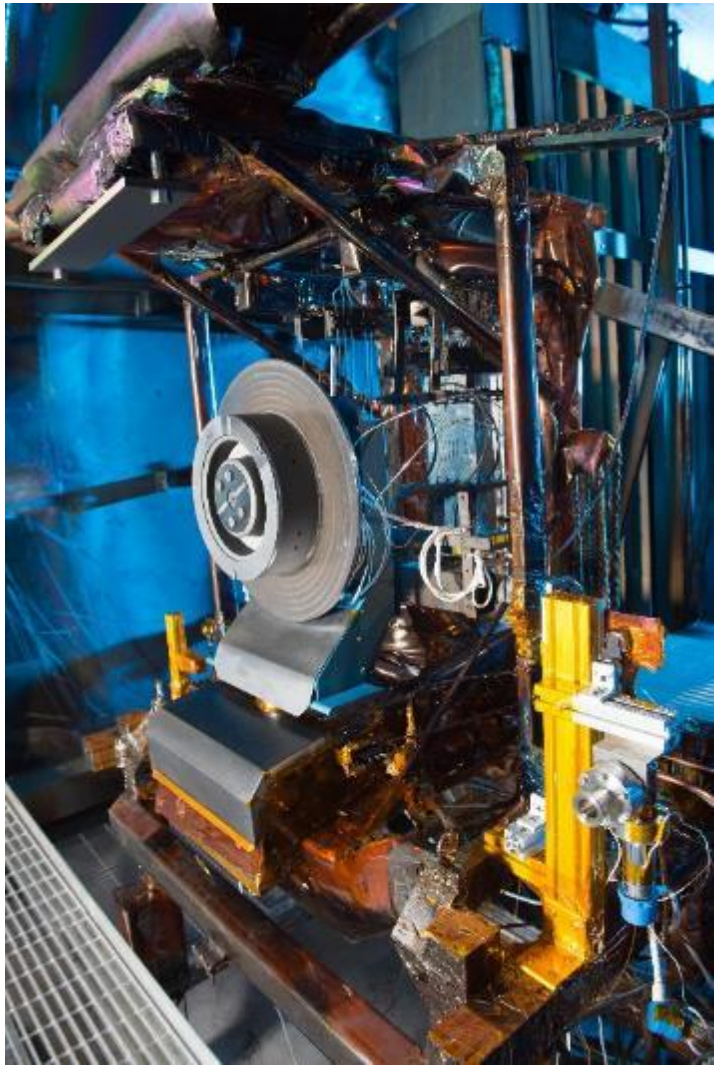
- NASA has been developing Hall Effect Rocket with Magnetic Shielding (HERMeS) to serve as high-power EP capability for future missions
  - ***Power and Propulsion Element of NASA's Gateway***

- HERMeS Long Duration Wear Test (LDWT)
  - Comprised of multiple segments with the aim of addressing potential risk areas for the Advanced Electric Propulsion System (AEPS) development effort
    1) TDU-1 Wear Test (Williams, et al., AIAA-2016-5025, 2016)
    2) TDU-3 SDWT (Williams, et al., IEPC Paper 2017-207, 2017)
    3) TDU-3 LDWT
       a) Demonstrate performance, plume, and wear of the TDU-3 Hall thruster over an extended operation time

Experimental Apparatus

HERMeS TDU-3

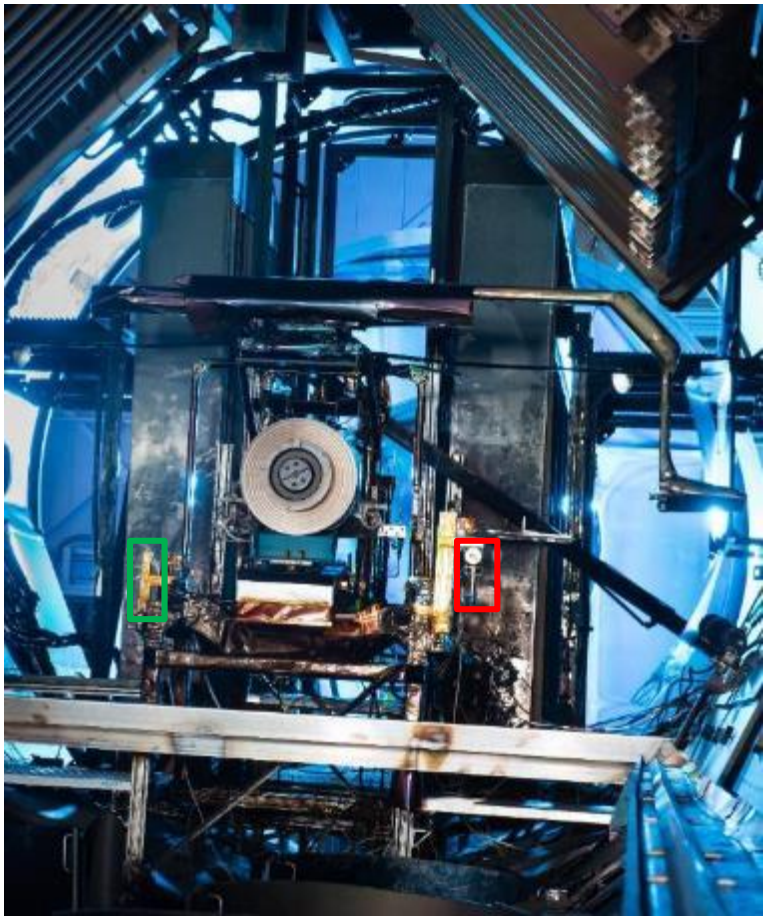
- Same thruster used for SDWT with minor modifications:
  - Thickness and position of cathode keeper
  - New magnet coils (field shape unaltered)
- Changes relative to TDU-1 detailed by Kamhawi et al. (IEPC 2017-392)
  - Resulted in minimal variation in operating characteristics
- Thruster electrically configured per recommendations from Peterson et al.(AIAA Paper 2016-5027)
  - Thruster body electrically tied to cathode
  - Dielectric coating on all surfaces within 1 m of exit plane
- Power and propellant supplied using calibrated commercial laboratory systems
  - Flow rate uncertainty: 1%
  - Voltage uncertainty: ±0.06 V
  - Current uncertainty: ±0.03 A
- Thrust measured with inverted pendulum thrust stand (± 0.8% uncertainty) (Mackey, AIAA-2018-4516)



Experimental Apparatus

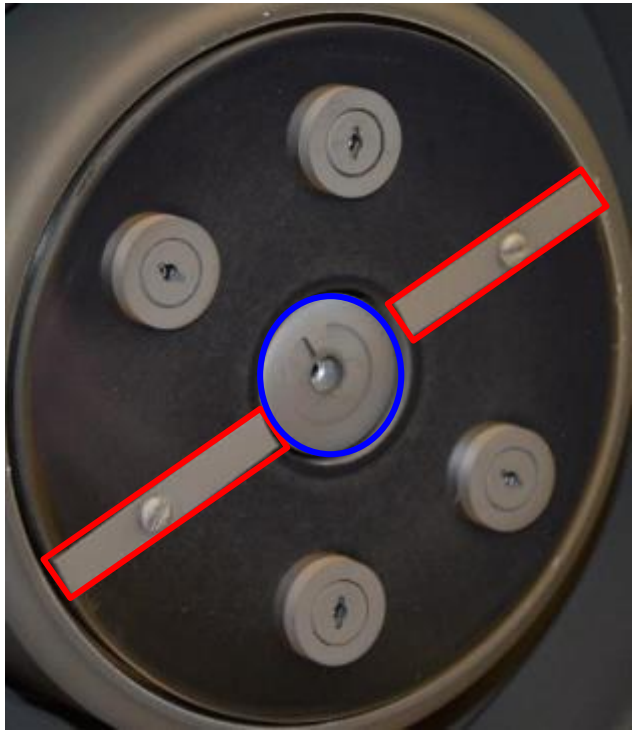
GRC VF-5[17-22]

- Facility dimensions:
  - Diameter: 4.6 m
  - Length: 18.3 m
- Pumping capacity:
  - Nominal pumping speed: ~700 kl/s on xenon
  - Nominal operating pressure: 4.5 µTorr at 12.5 kW throttle point
- Pressure measured with 2 internal BA-style hot-cathode ionization gauges
  - IG #2
    - Faces downstream
    - 0.8 m radially outward from thruster centerline
  - IG #3
    - Faces radially
    - 0.7 m radially outward, centered 0.08 m upstream of thruster exit plane
  - Gauges EP configured:
    - Calibrated on Xe
    - Elbow with additional plasma screen
    - Housing grounded to facility
- Facility configuration consistent with previous HERMeS wear tests



Experimental Apparatus: Wear Measurements

- Graphite IFPC, keeper, and OFPC modified to enable wear measurements
  - Components polished pre-test to maximize surface uniformity
  - Graphite masks installed to provide unexposed reference surfaces:
    - IFPC: two graphite strips covering approximately 95% of radius at 2 and 8 o'clock
    - Keeper: graphite ring with a tab protruding radially inward
    - OFPC: series of graphite strips covering approximately 95% of radius
- Erosion measurements made with a chromatic, white-light, non-contact profilometer
  - Data analyzed per ISO 5436-1 guidance for a type A1 step
  - Typical uncertainties ±2 µm accounting for:
    - Instrument error
    - Surface roughness
    - Non-flat surface geometry



Test Overview

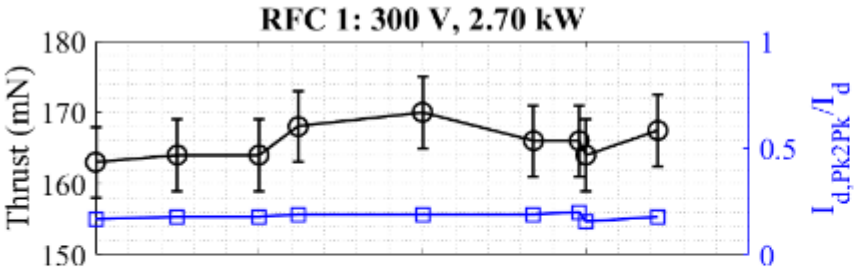
- The LDWT has accumulated approximately 1720 h of total operating time divided into four test segments:

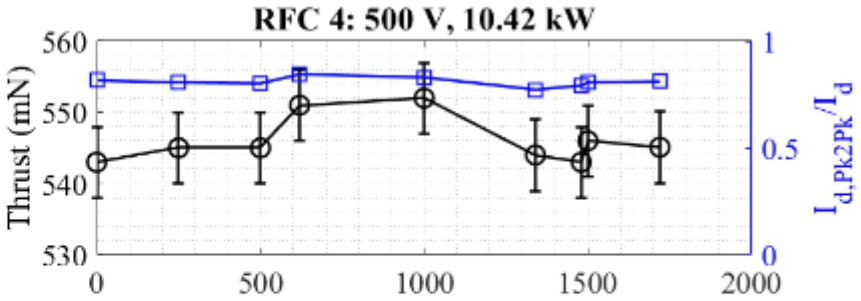
Segment	Operating Condition	Operating Time (h)
I	600 V/1 B	1015
II	300 V/1 B	248
III	300 V/0.75 B	213
IV	300 V/1.25 B	239

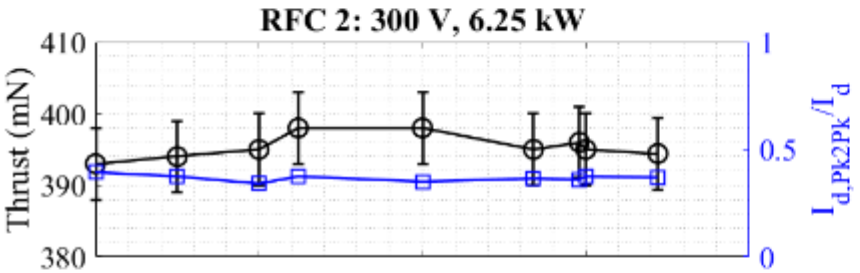
- Wear assessed at the end of each segment as well as at the mid-point of segment I
- Performance periodically characterized at 6 reference firing conditions (RFCs)

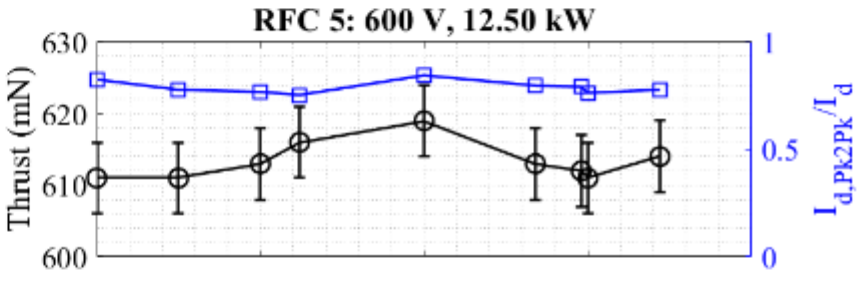
RFC	Discharge Voltage (V)	Discharge Current (A)	Discharge Power (W)
1	300	9.00	2700
2	300	20.83	6250
3	400	20.83	8333
4	500	20.83	10417
5	600	20.83	12500
6	630	20.83	13123

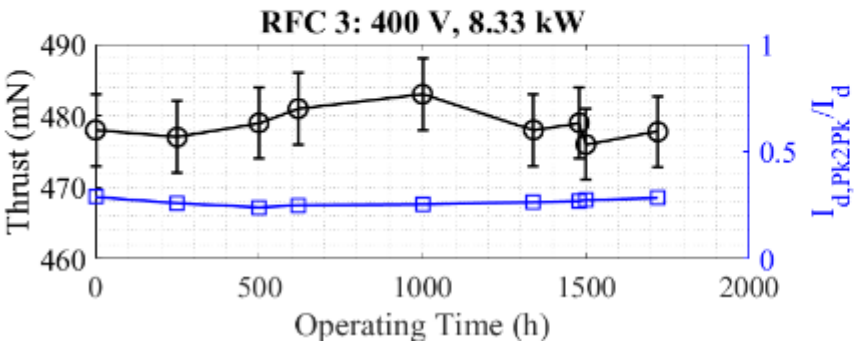
Results: Performance and Stability

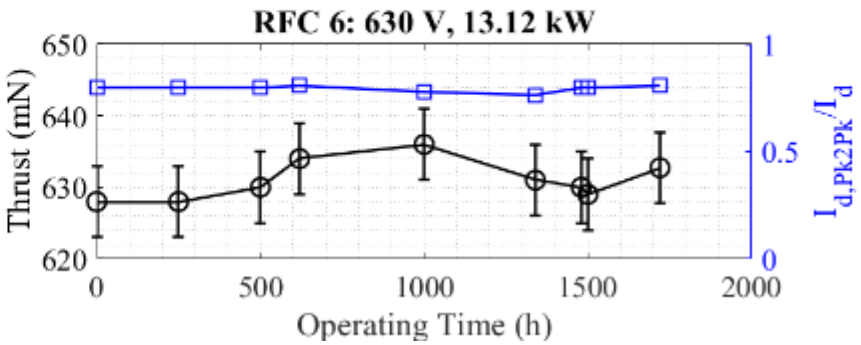






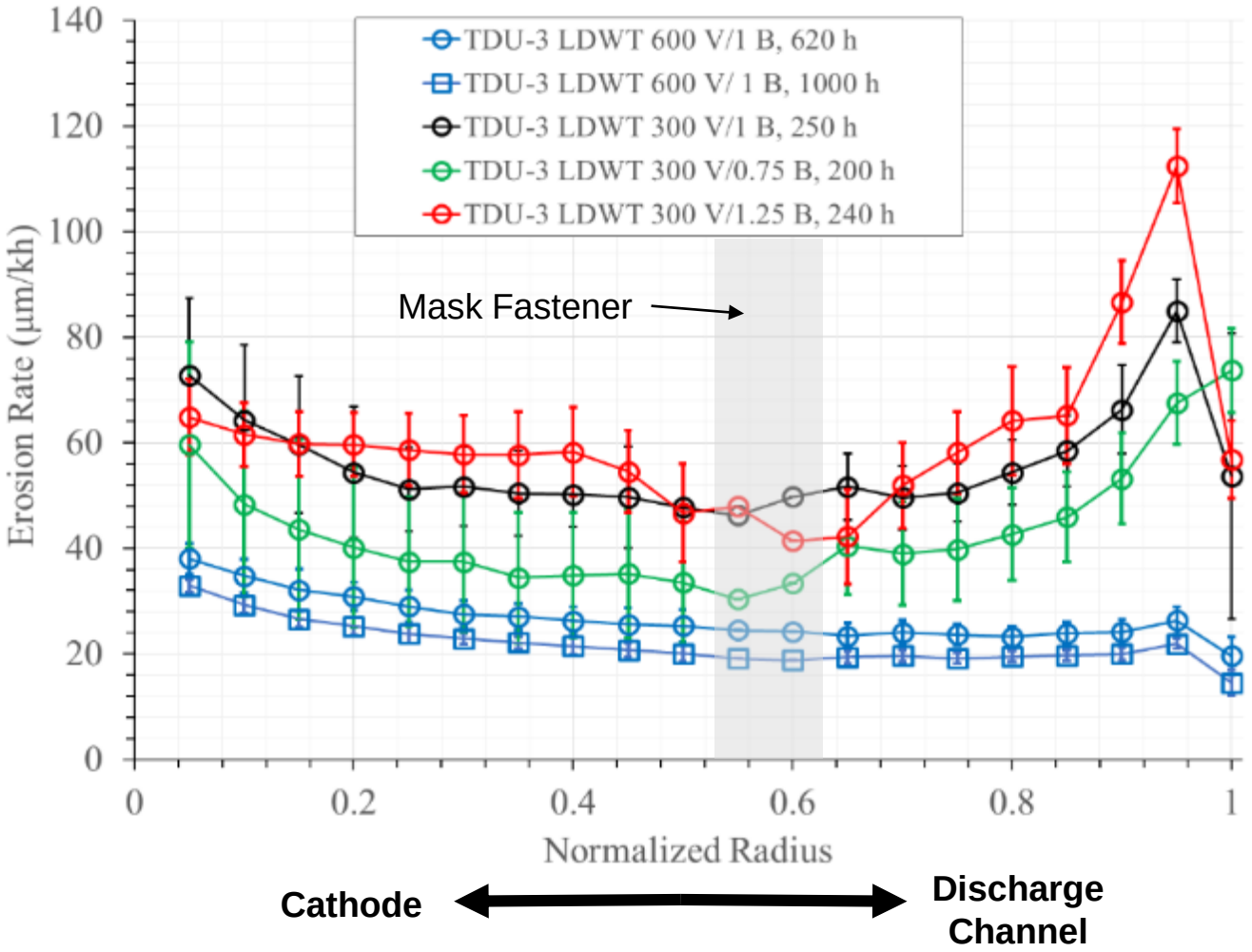






Performance and stability vary by less than the uncertainty during LDWT and when compared against previous TDU wear tests

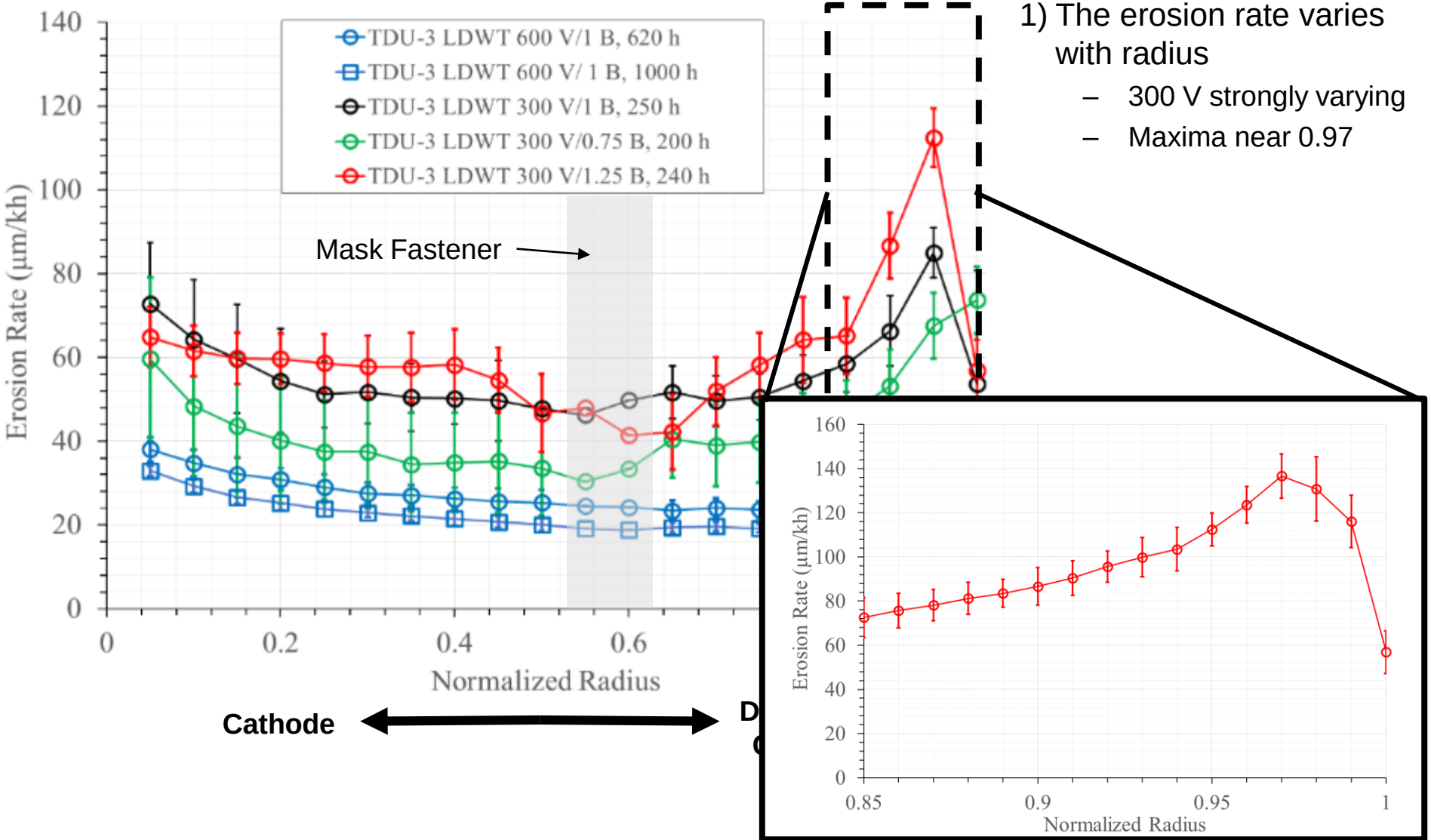
Results: IFPC Wear



Key Observations:

1) The erosion rate varies with radius
   - 300 V strongly varying

Results: IFPC Wear



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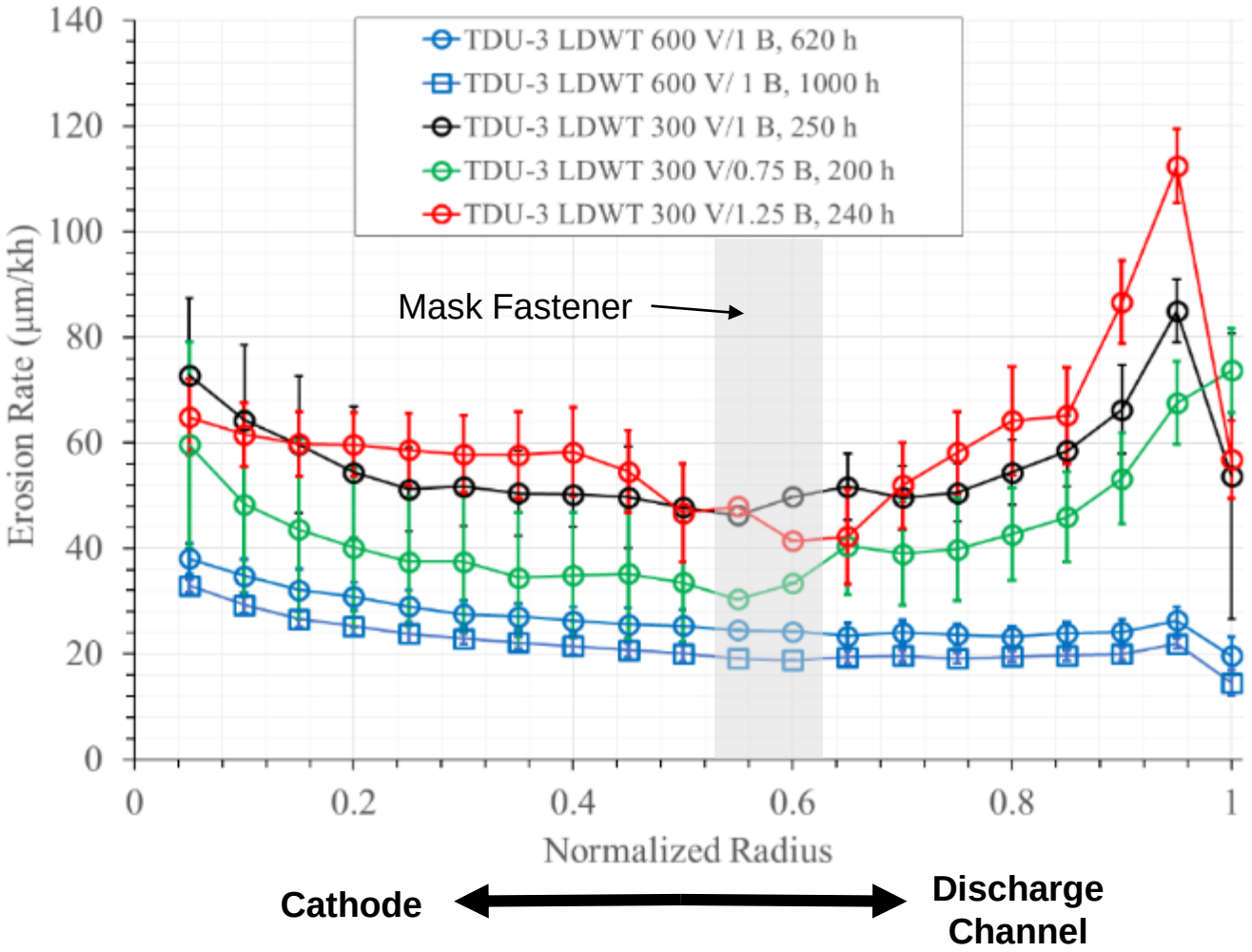
   - Maxima near 0.97

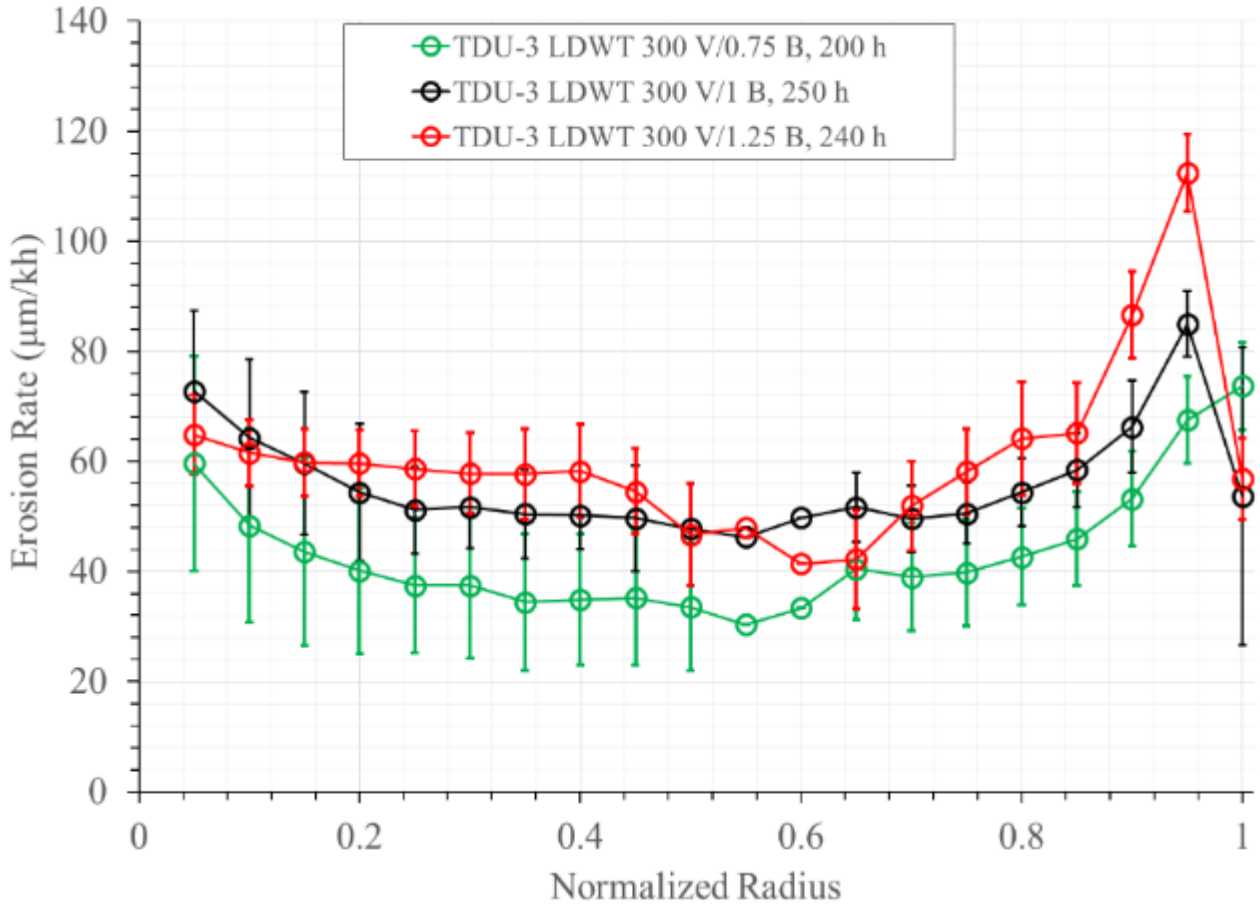
Results: IFPC Wear



Key Observations:

1) The erosion rate varies with radius
   - 300 V strongly varying
   - Maxima near 0.97
2) The erosion rate at 600 V decreases with time
   - Consistent with TDU-1 wear test
3) The erosion rate at 600 V/1 B is 76% less than 300 V/1 B
   - Driven by axial shift in acceleration zone

Results: IFPC Wear



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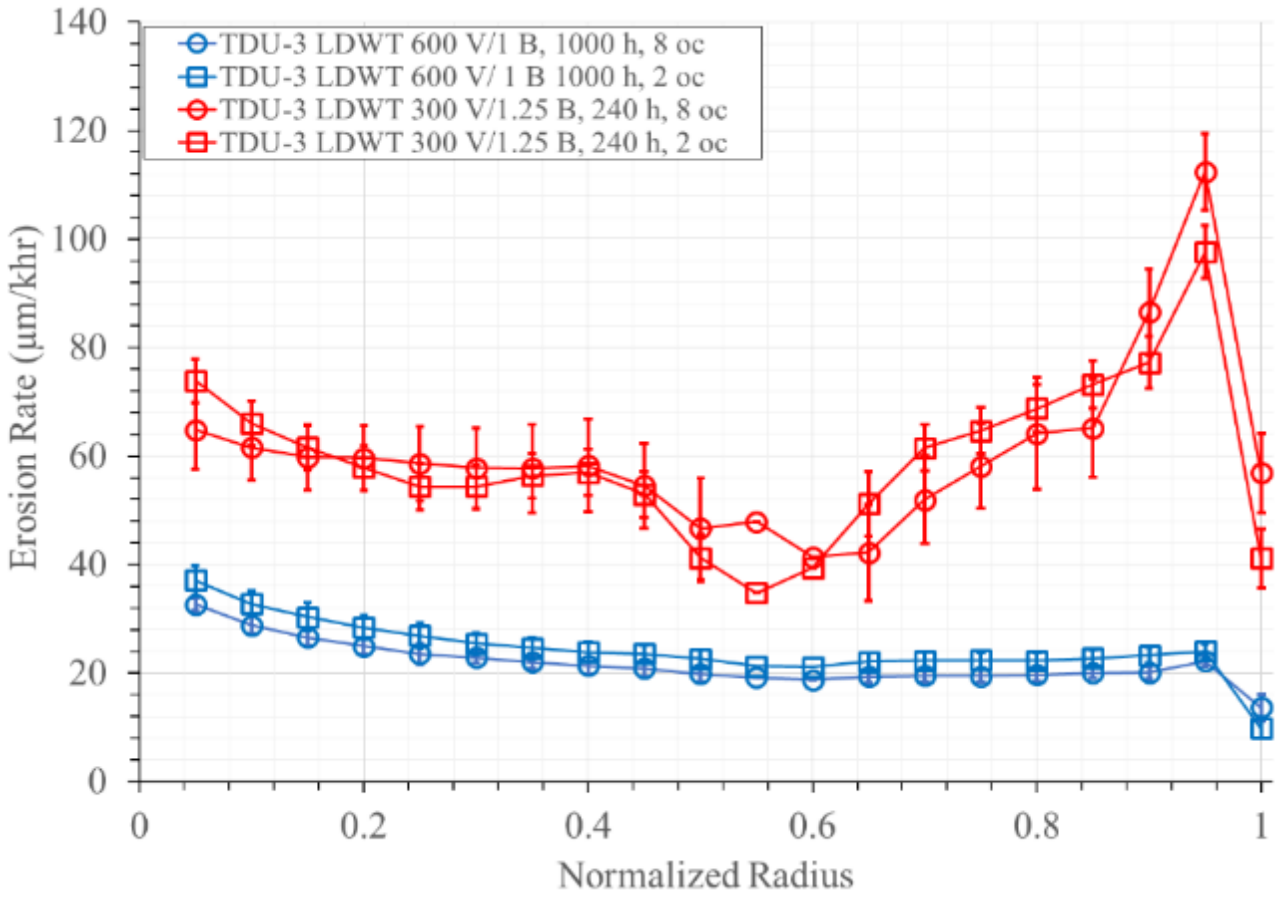

Cathode ⟷ **Discharge Channel**

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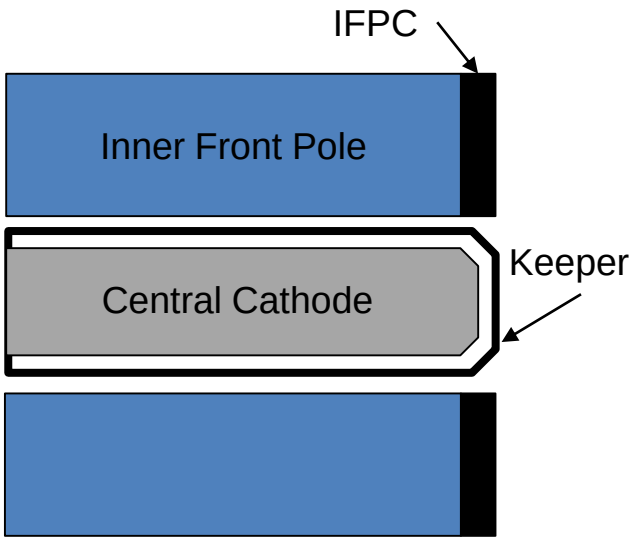
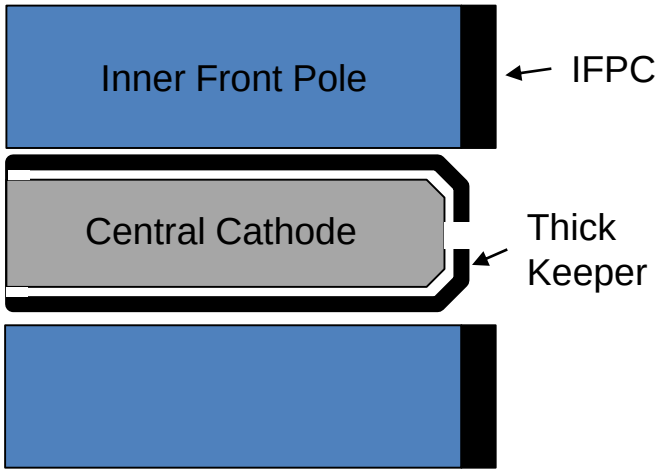
3) The erosion rate at 600 V/1 B is 76% less than 300 V/1 B
   - Driven by axial shift in acceleration zone
4) At 300 V, the erosion rate increases with magnetic field strength
   - Cause not presently known
5) IFPC wear is azimuthally symmetric

Results: Keeper Wear

- Keeper position and thickness changed relative to SDWT to try to mitigate elevated wear rates



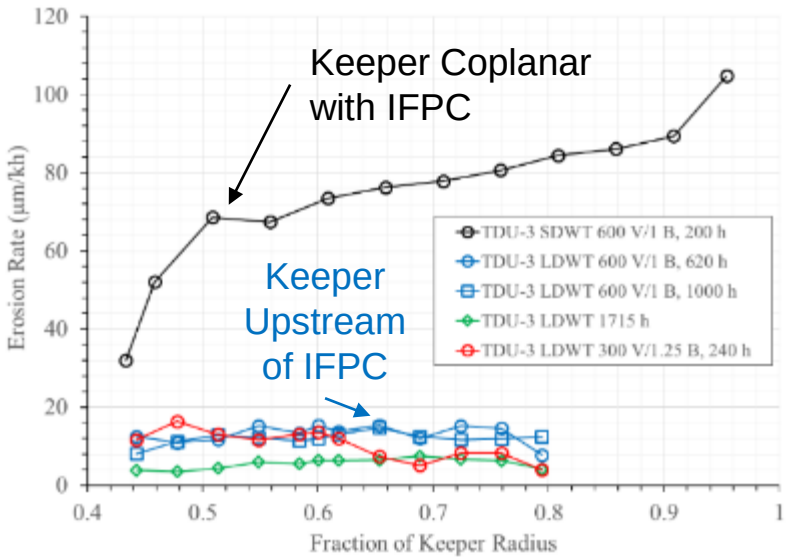
SDWT: Keeper Coplanar with IFPC

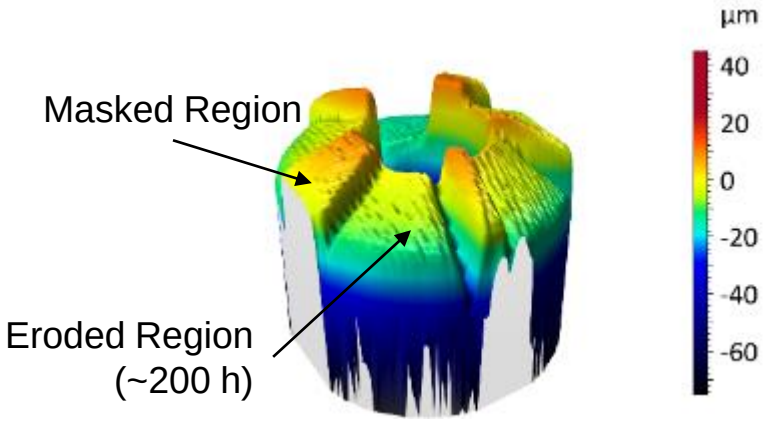


LDWT: Keeper Upstream of IFPC

Results: Keeper Wear

- Keeper position and thickness changed relative to SDWT to try to mitigate elevated wear rates
- Radially-averaged keeper erosion rates for operation at 600 V, 12.5 kW, nominal magnetic field:
  - SDWT: 80 µm/kh (Coplanar Keeper)
    - Rates increase near IFPC and decrease near orifice
  - LDWT: 13 µm/kh (Upstream Keeper)
    - No significant radial variation in erosion rates observed
- Trends qualitatively supported by 3D keeper surface maps





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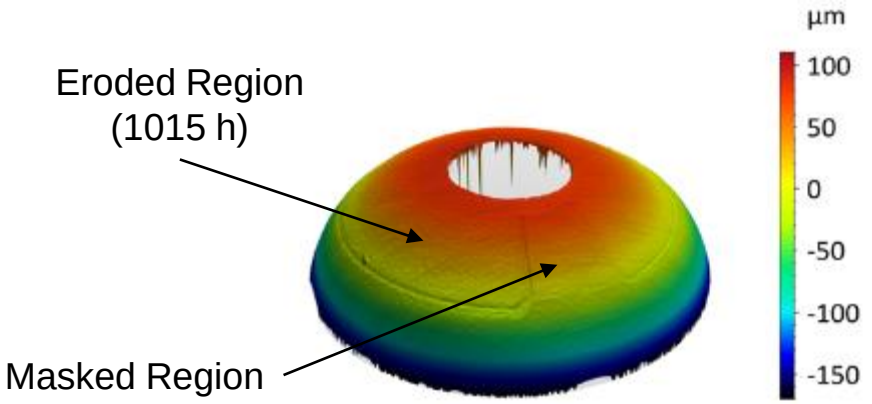
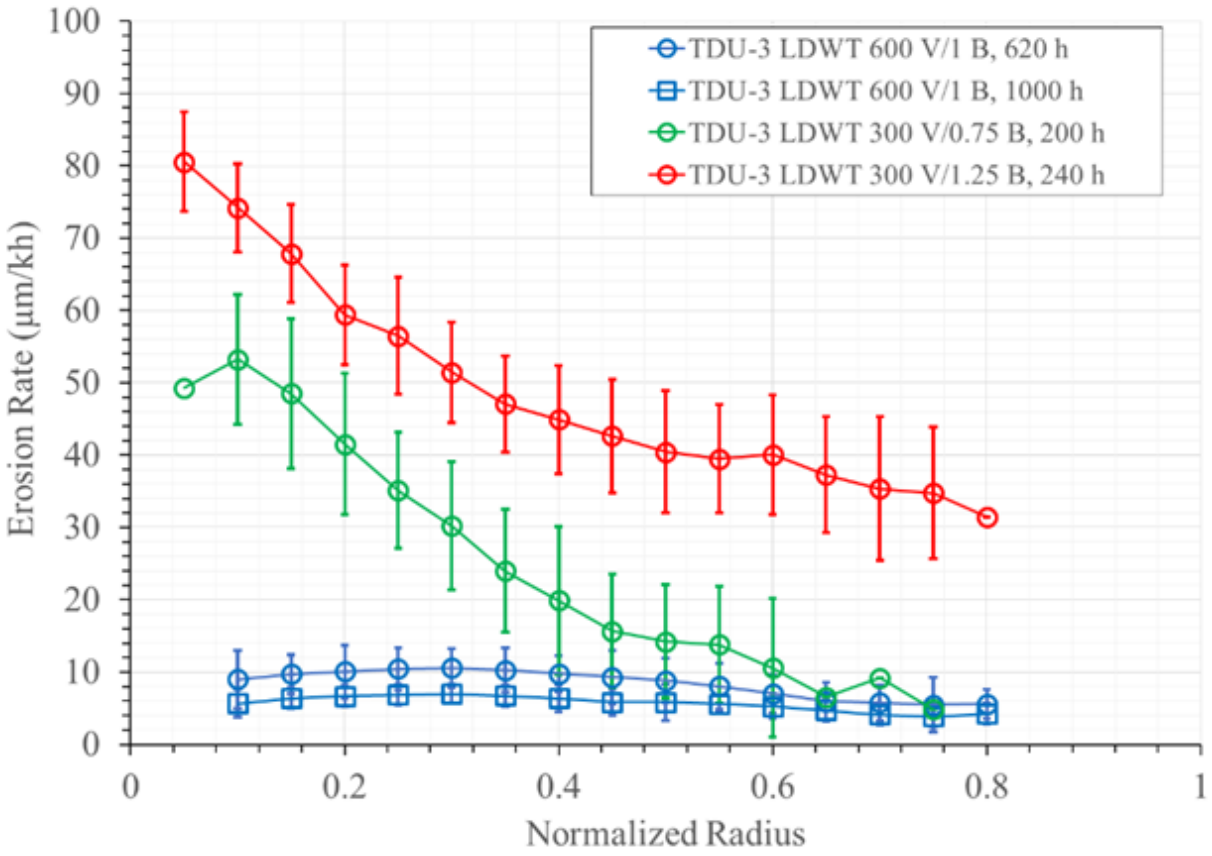


LDWT: Keeper Upstream of IFPC

Results: OFPC Wear

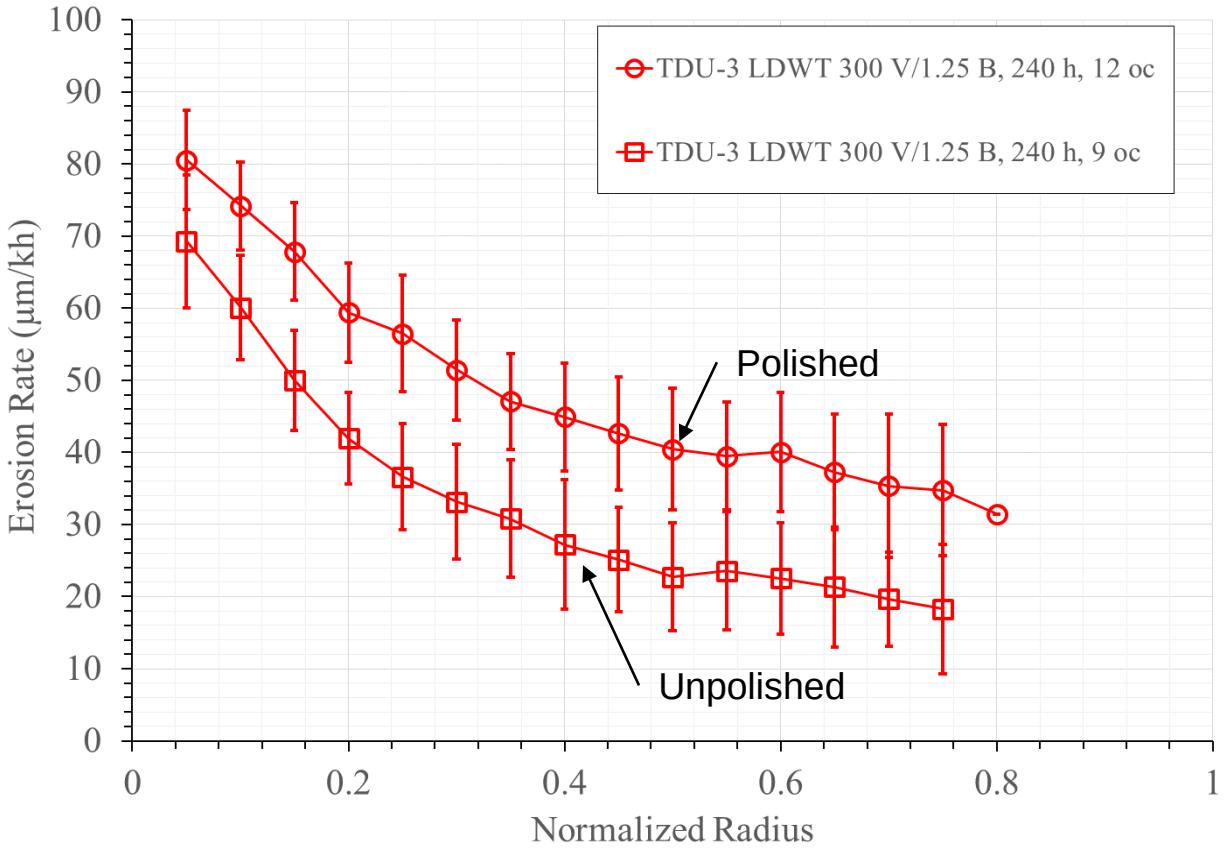


Discharge Channel ⟷ **Outer Thruster Edge**

Key Observations:

1) The erosion rate varies with radius
   - Maxima near channel
2) The erosion rate at 600 V/1 B is 25% of 300 V/0.75 B
3) At 300 V, the erosion rate at 1.25 B is 1.4x higher than at 0.75 B

Results: OFPC Wear



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4) OFPC wear appears azimuthally asymmetric
   - Pre-test surface finish different
   - Suggests possible link between surface finish and erosion rates

Results: OFPC Wear

Beginning of Test: Surface Polished Higher Erosion Rates

End of Test: Surface Roughened Lower Erosion Rates

Key Observations:

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   - Maxima near channel
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3) At 300 V, the erosion rate at 1.25 B is 1.4x higher than at 0.75 B
4) OFPC wear appears azimuthally asymmetric
   - Pre-test surface finish different
   - Suggests possible link between surface finish and erosion rates
   - Link would also explain apparent time dependence of IFPC erosion rate

Conclusion

- The NASA HERMeS TDU-3 Hall thruster was successfully operated over 1,720 hours in four different operating conditions in a long duration wear test
- The TDU-3 demonstrated consistent performance and stability over the course of the LDWT and relative to previous wear tests
- The TDU-3 measured wear rates, at several operating conditions, provided detailed insight into the expected life of the thruster and most importantly provided invaluable data for the HERMeS thruster modeling effort
  - Upstream shift in keeper position mitigated elevated erosion rates observed during SDWT
  - IFPC and OFPC wear were observed to:
    - Increase between operation at 600 V and 300 V
    - Increase with magnetic field strength at the 300 V operating condition
  - A potential link between surface finish and erosion rates was observed, which could explain:
    - Time variation of IFPC erosion at the 600 V operating condition
    - Apparent asymmetry in OFPC wear at the 300 V, 1.25 B operating condition