High-Power Performance of a 100-kW class Nested Hall Thruster



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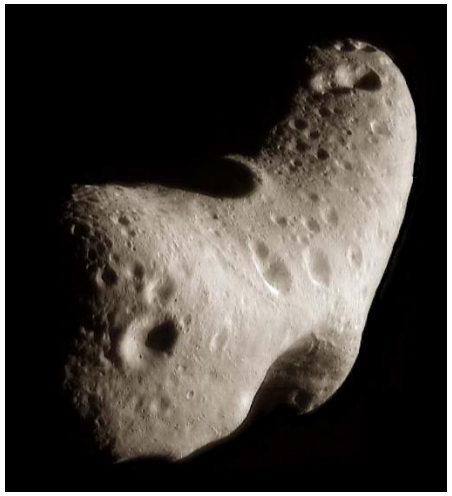
Many missions are enabled by multi-hundred kW EP systems

Earth orbit transfer



200 kW @ 1500 s: LEO to GEO transfer

Near-Earth asteroids



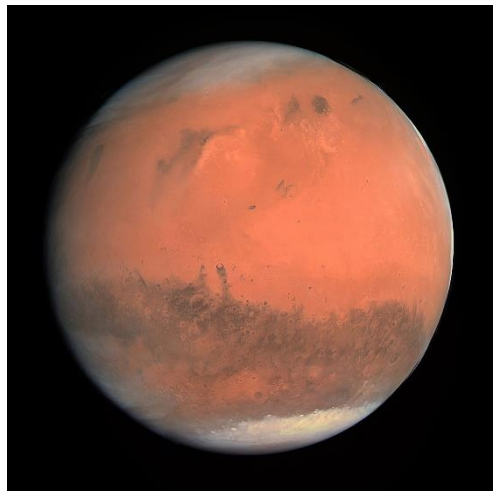
300 kW @ 1800 s: cargo tug

Phobos



300 kW @ 3000 s: cargo
700 kW @ 1800 s: humans

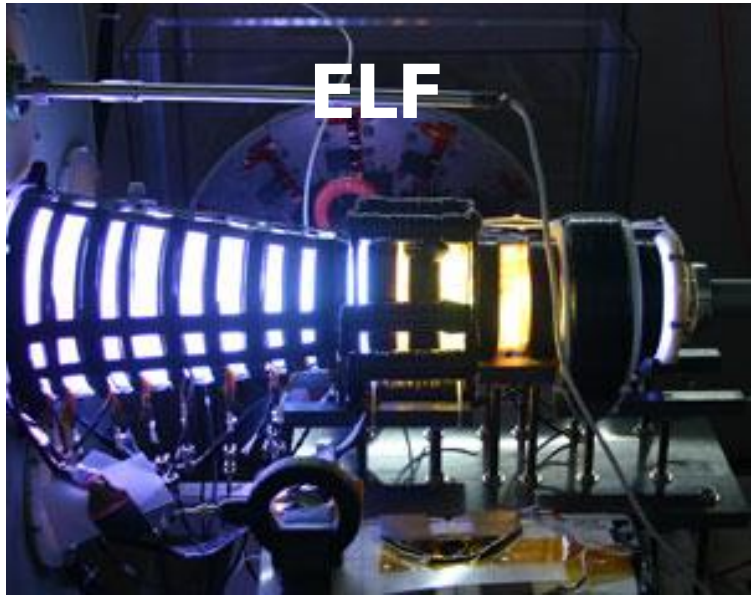
Mars



600 kW @ 3000 s: cargo
800 kW @ 3000 s: humans

NASA is funding three options for 100-kW class electric propulsion

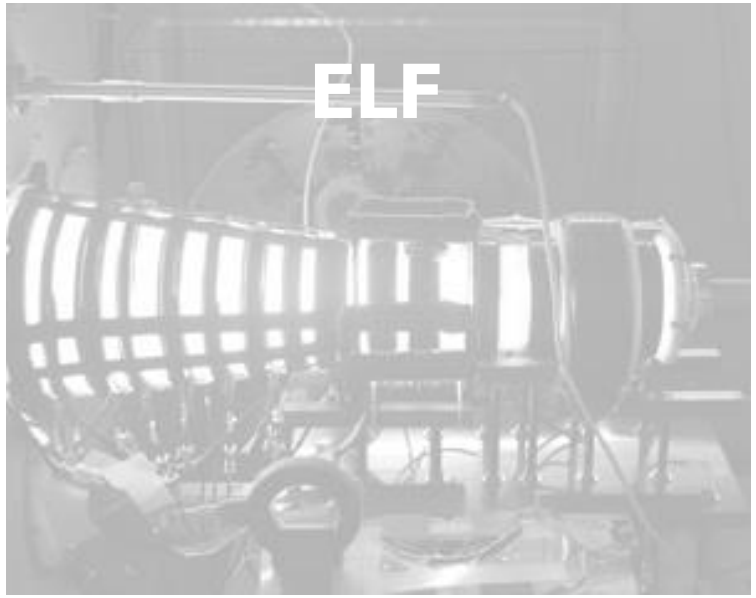






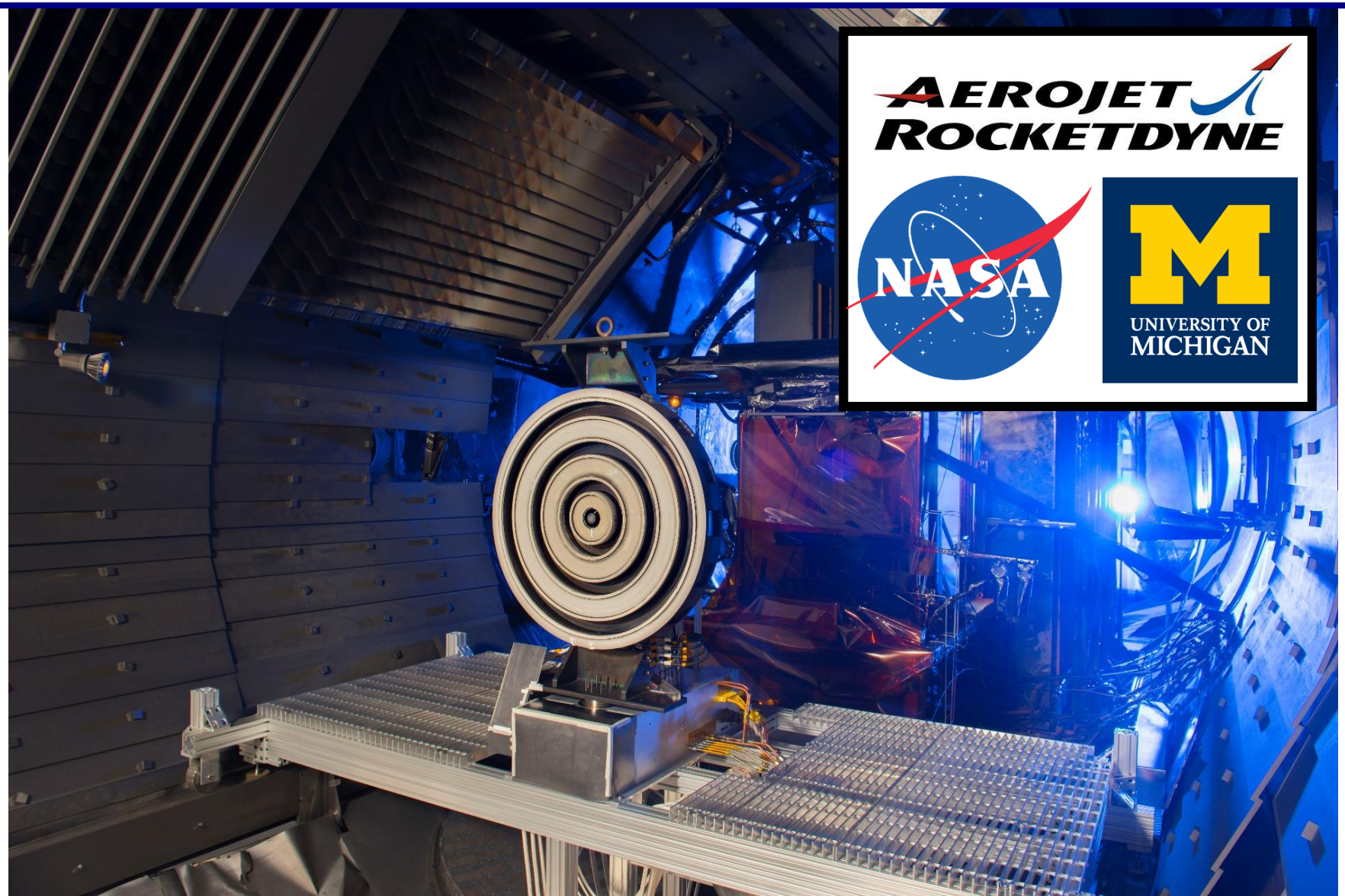
The XR-100 system features the X3, a nested Hall thruster developed at UM



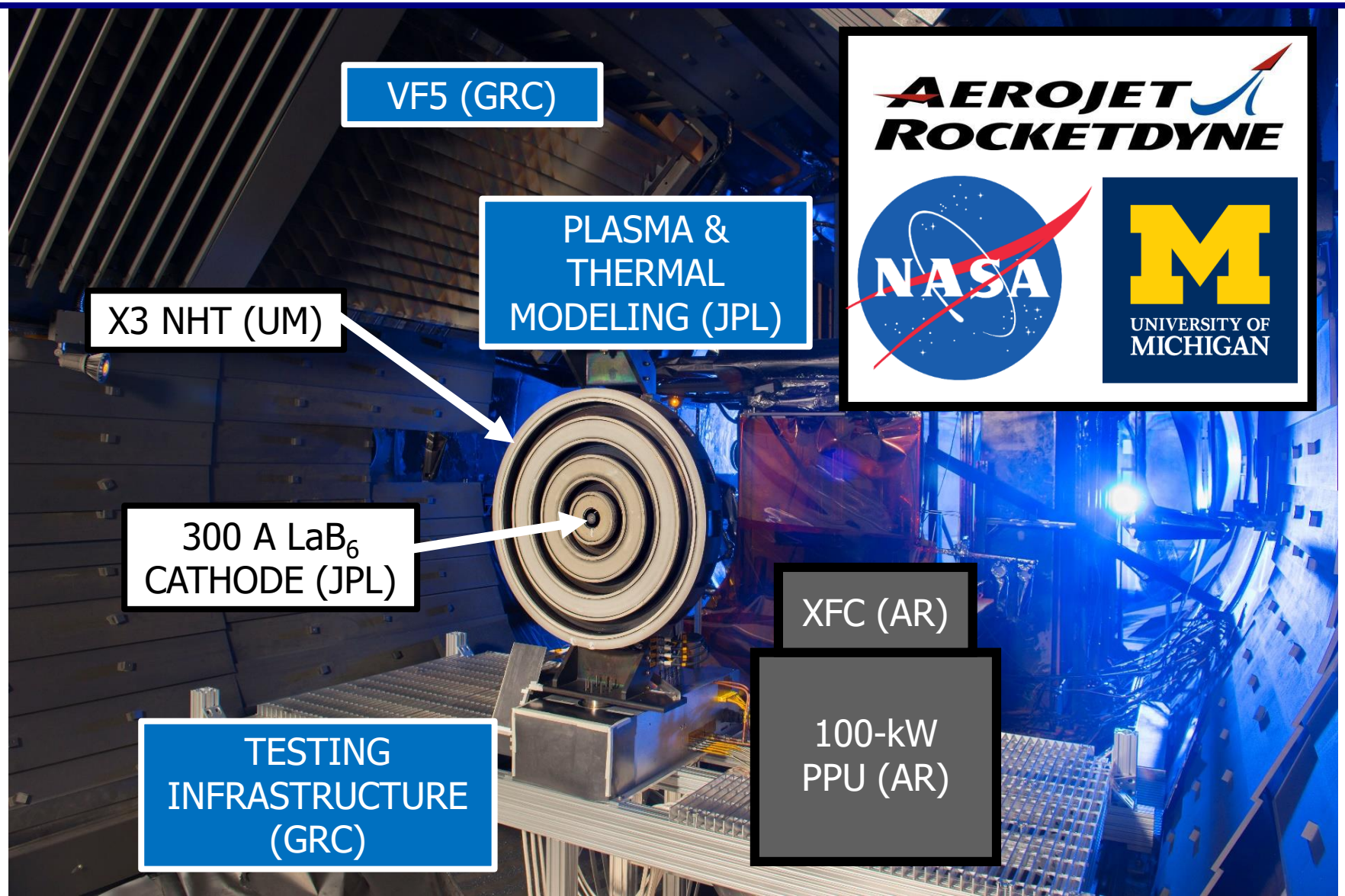




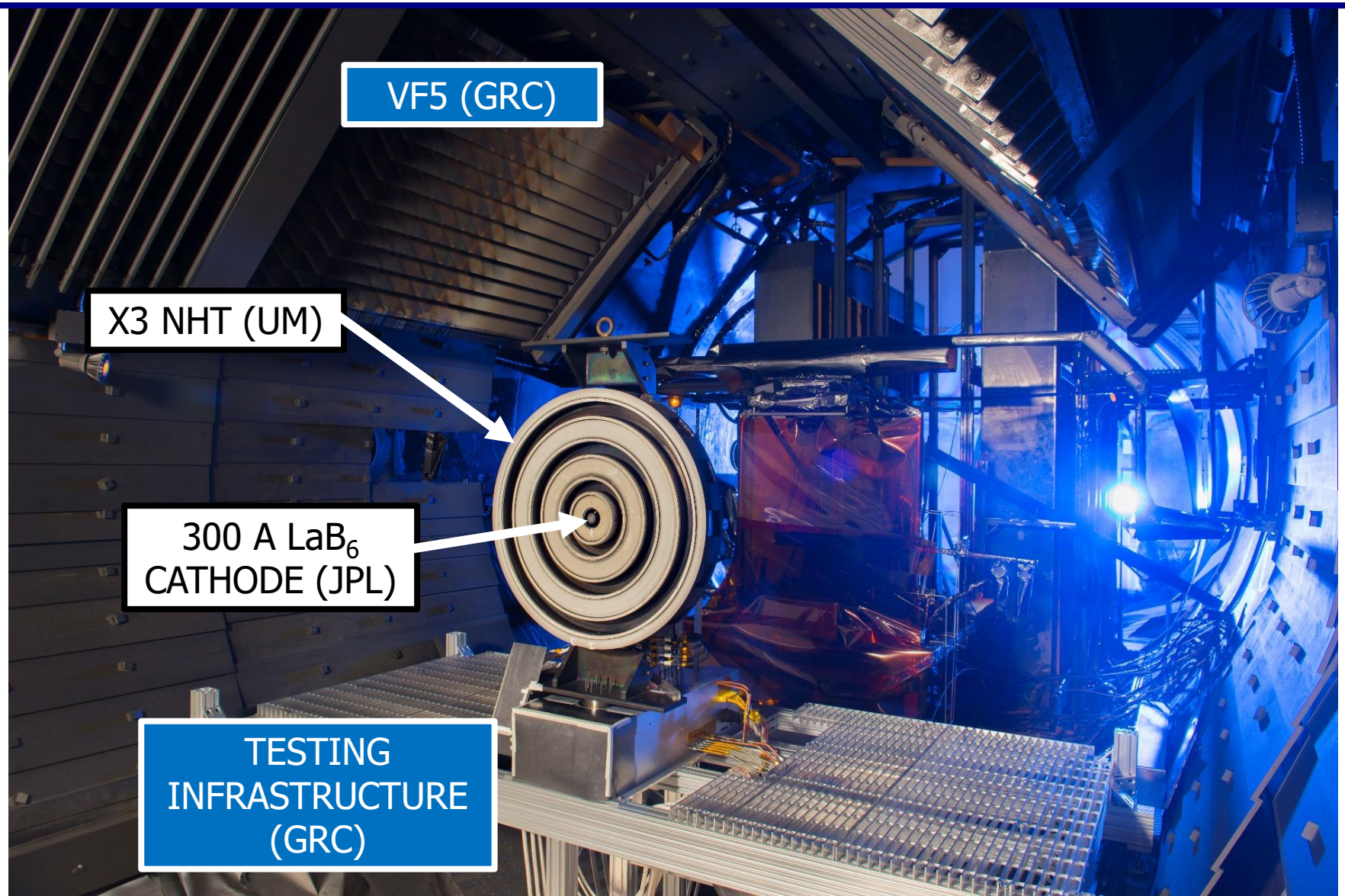
The XR-100 system



The XR-100 system



Testing focused on thruster and facilities



A Brief History of NASA High-Power Hall Thruster Development

Timeline of NASA high-power Hall thruster development

1999



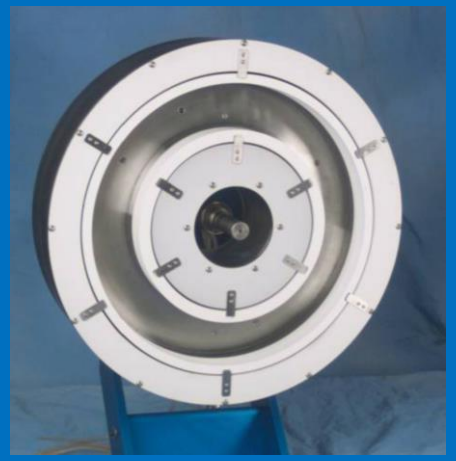
NASA-457M

- 50 kW class
- Operated to 100 kW (850 V and 1000 V)

Timeline of NASA high-power Hall thruster development

1999 **2003**





NASA-457M

- 50 kW class
- Operated to 100 kW (850 V and 1000 V)

NASA-400M

- 50 kW class
- High-I_{sp} operation (via NASA-173M)

Timeline of NASA high-power Hall thruster development

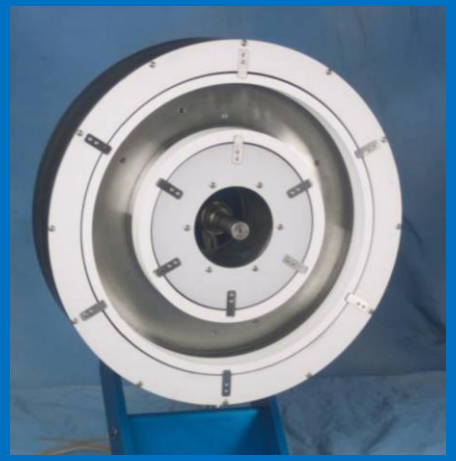
1999



NASA-457M

- 50 kW class
- Operated to 100 kW (850 V and 1000 V)

2003



NASA-400M

- 50 kW class
- High-I_{sp} operation (via NASA-173M)

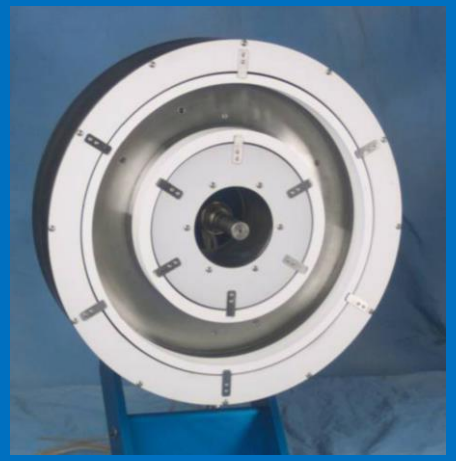
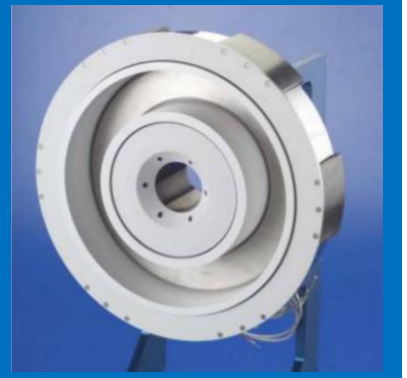
2004/2012



NASA-457Mv2

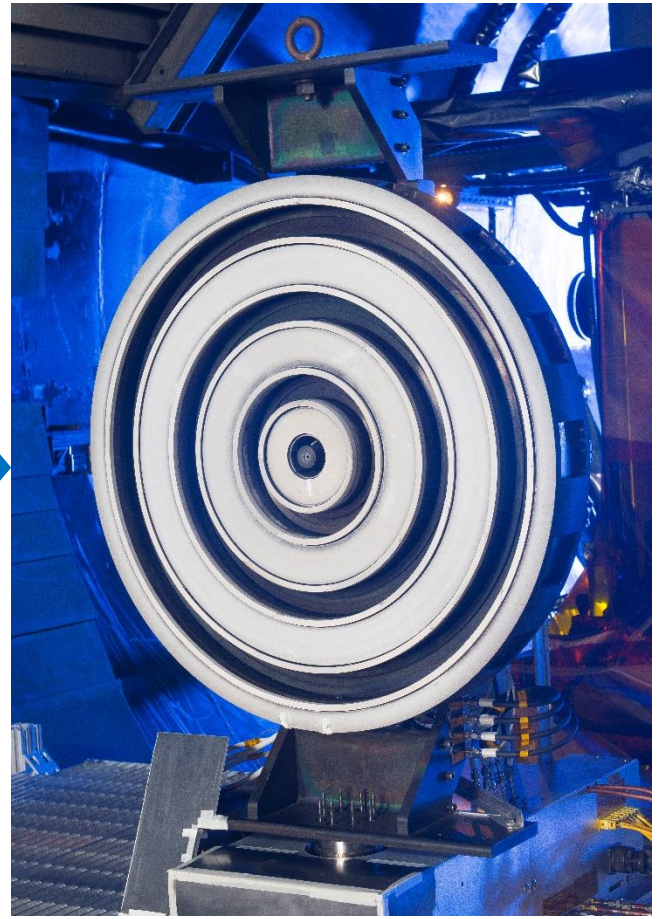
- 50 kW class
- Improved efficiency over v1

Timeline of NASA high-power Hall thruster development

1999	2003	2004/2012	2005/2011
			
NASA-457M • 50 kW class • Operated to 100 kW (850 V and 1000 V)	**NASA-400M** • 50 kW class • High-I_{sp} operation (via NASA-173M)	**NASA-457Mv2** • 50 kW class • Improved efficiency over v1	**NASA-300M** • 20 kW class • Best efficiency yet (65-73% anode)

All this work (and lessons learned) fed directly into X3 design



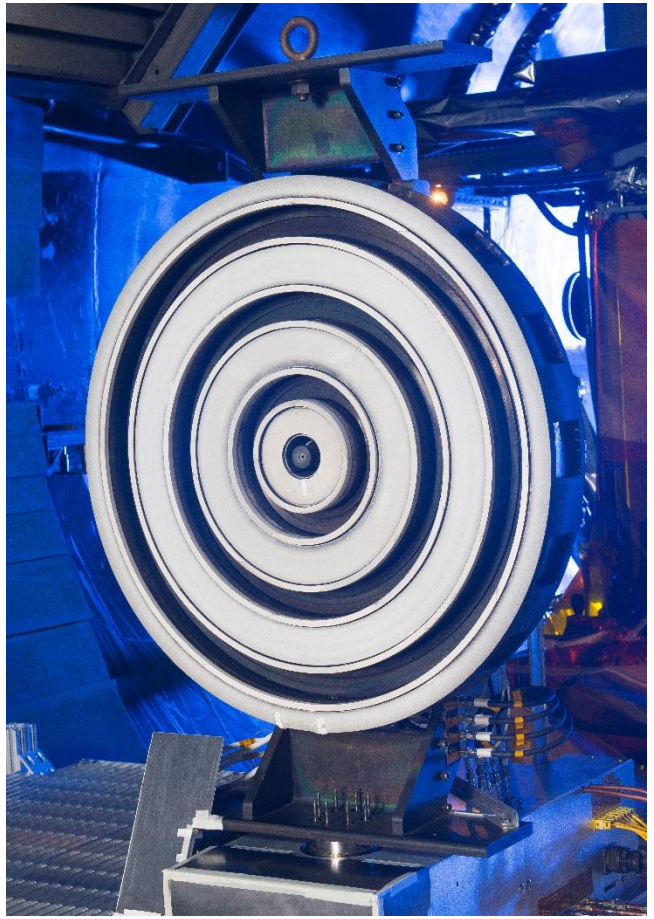


Open questions about the X3 and NHTs

Does the X3 provide expected performance?

Are there cathode coupling issues?

How do the channels interact with each other?

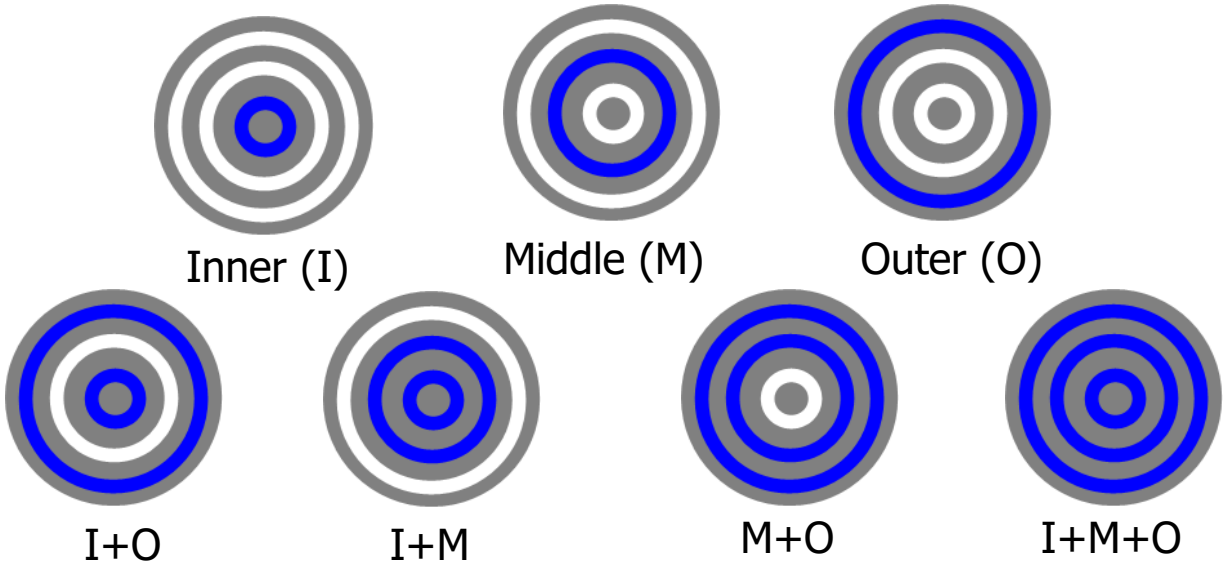


X3 Performance Results

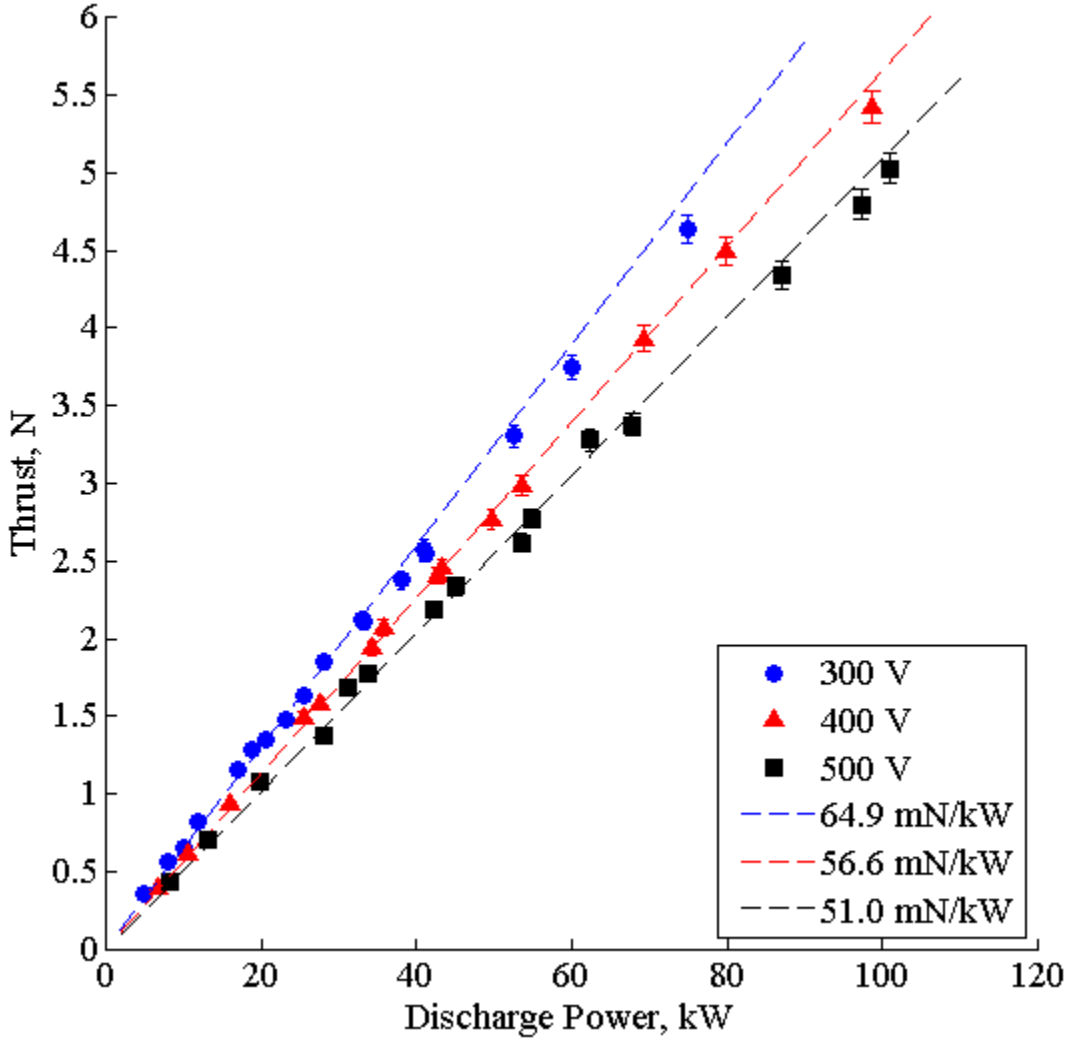
Thruster was throttled through 47 unique conditions

300 V	400 V	500 V
0.6 j_{ref}	0.6 j_{ref}	0.6 j_{ref}
1.0 j_{ref}	1.0 j_{ref}	1.0 j_{ref}
1.3 j_{ref} **	1.3 j_{ref} **	

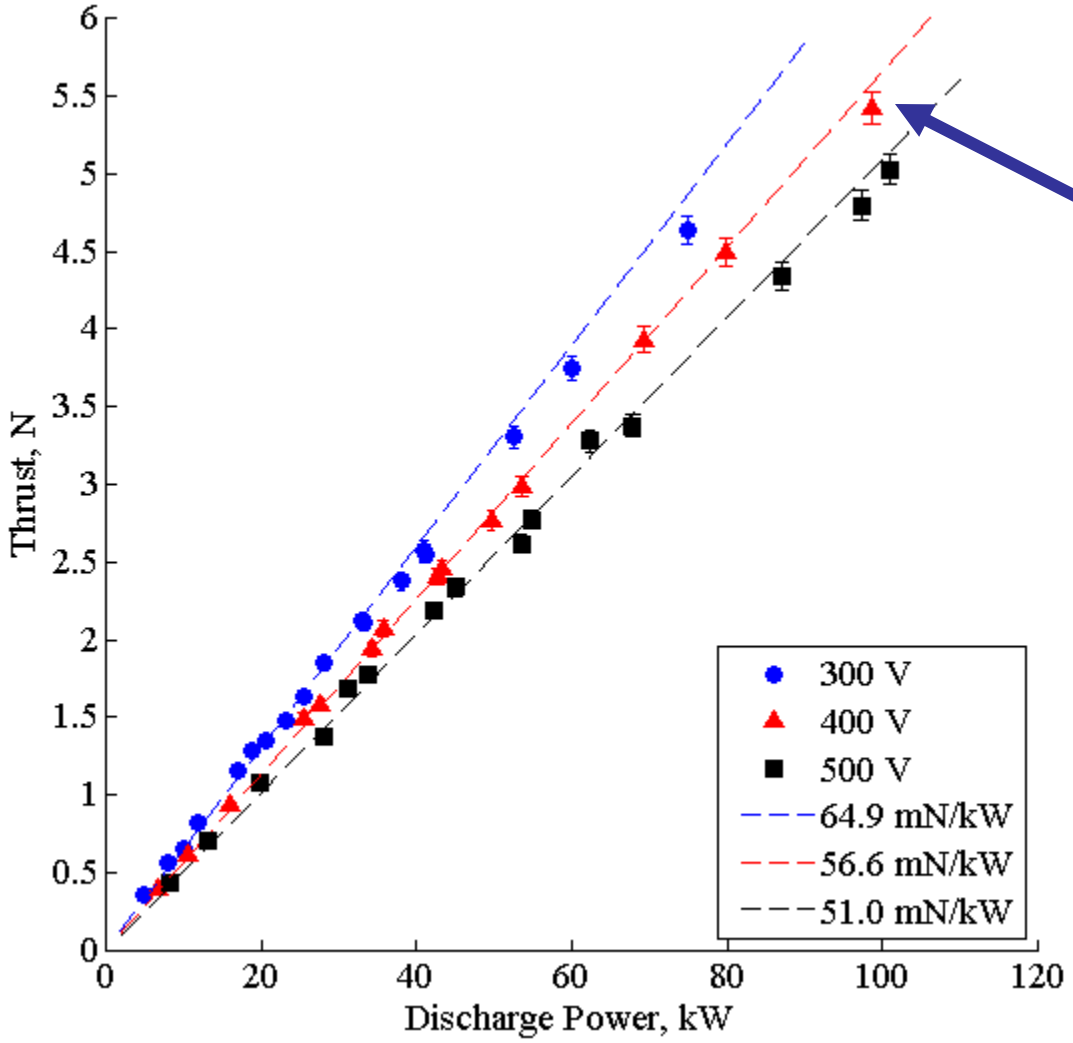
At each (V_d, j) condition:



Thrust versus power is linear for each discharge voltage

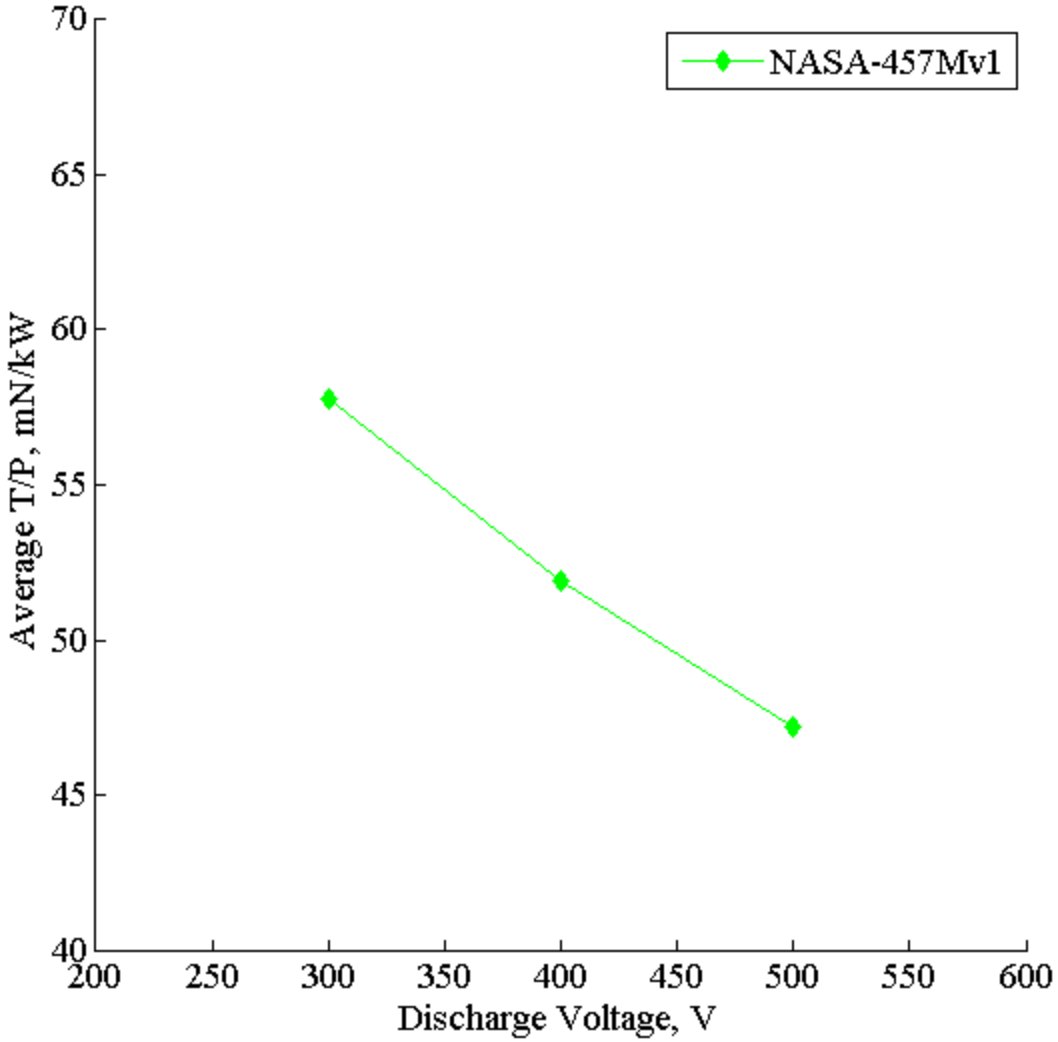


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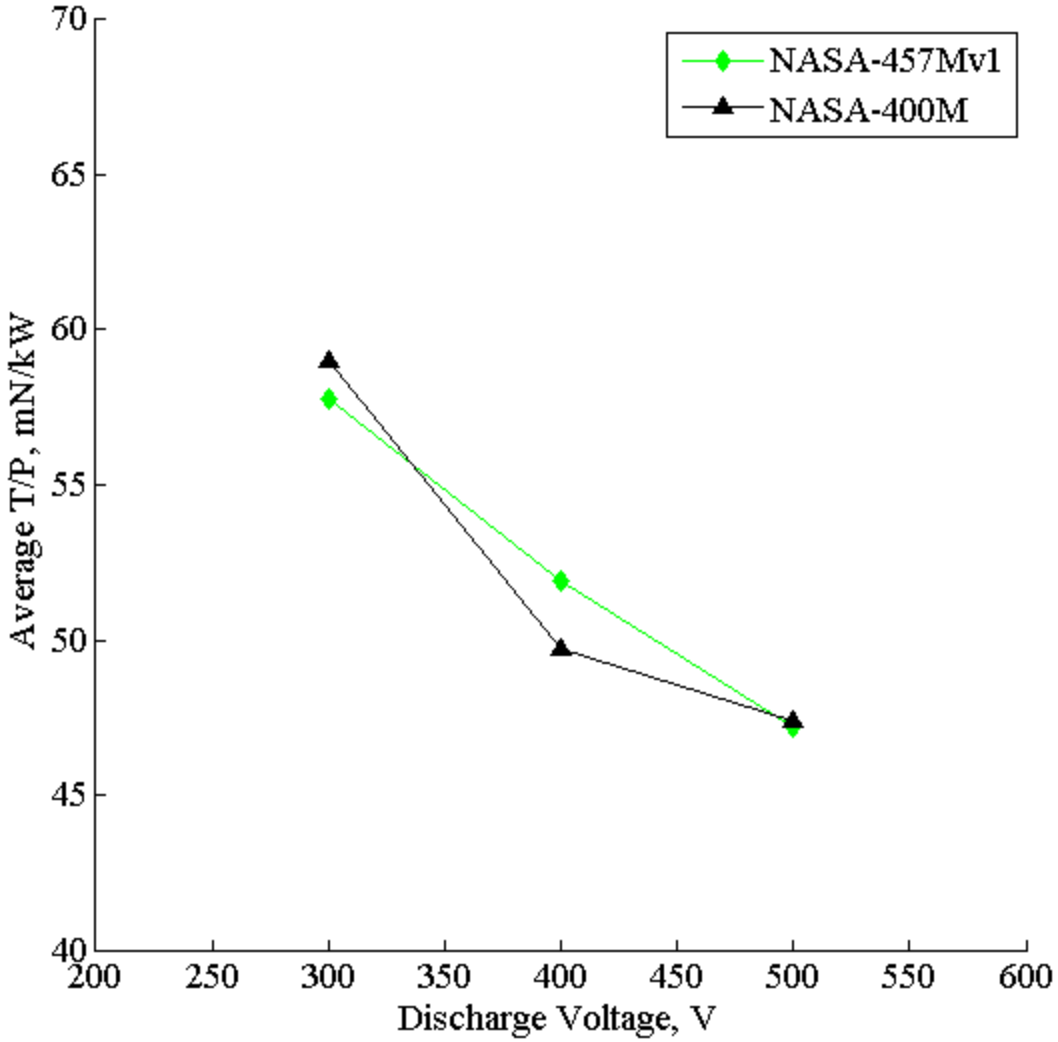


5.4 N at 400 V, 98 kW

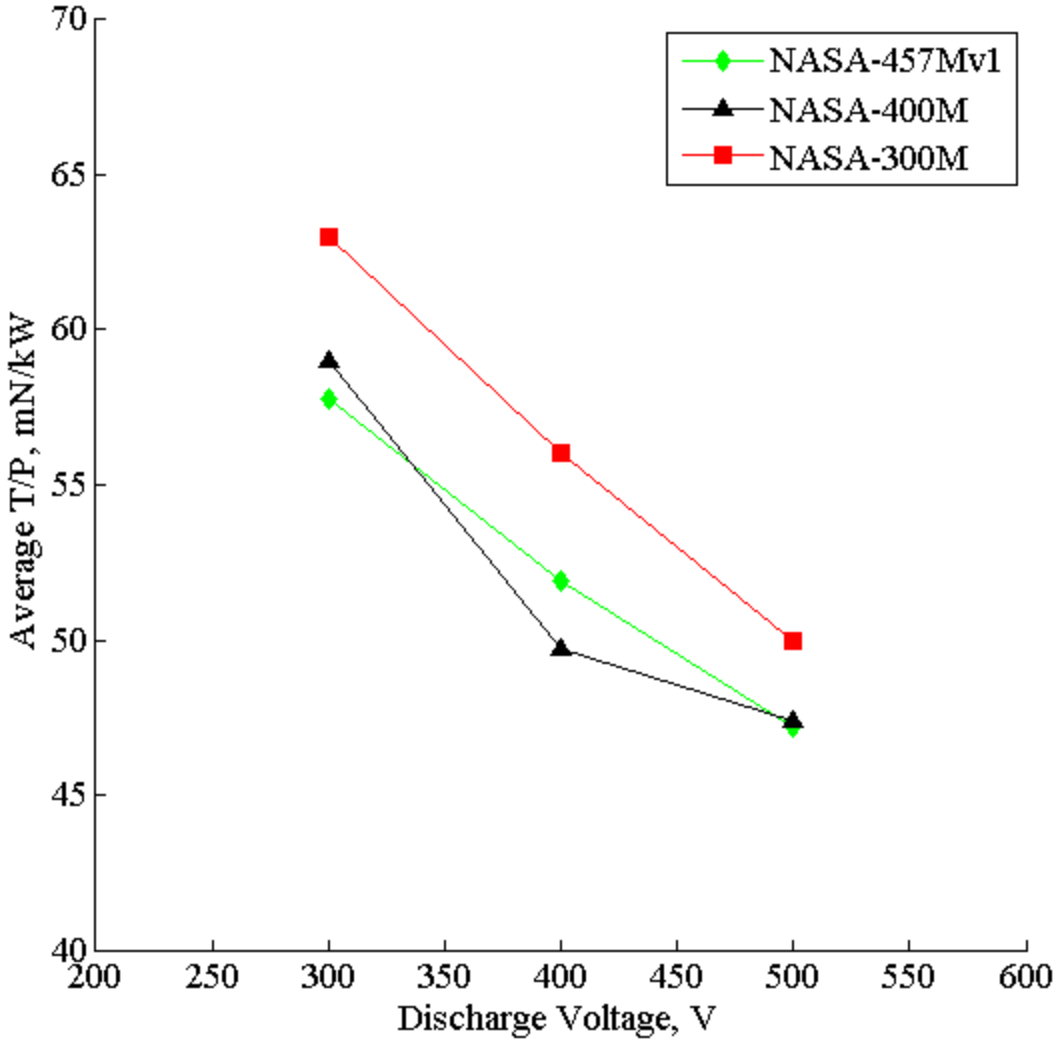
Average T/P ratio compared to other high-power thrusters



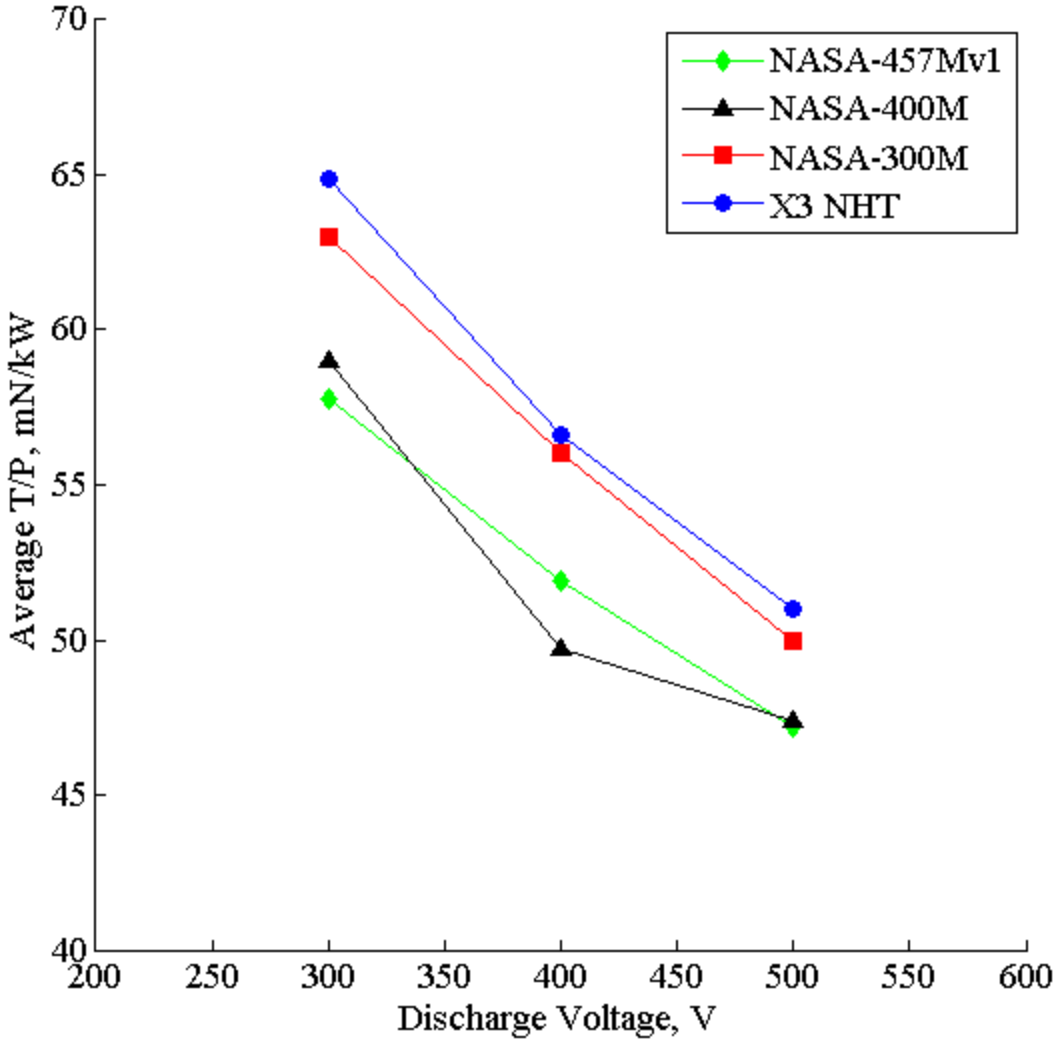
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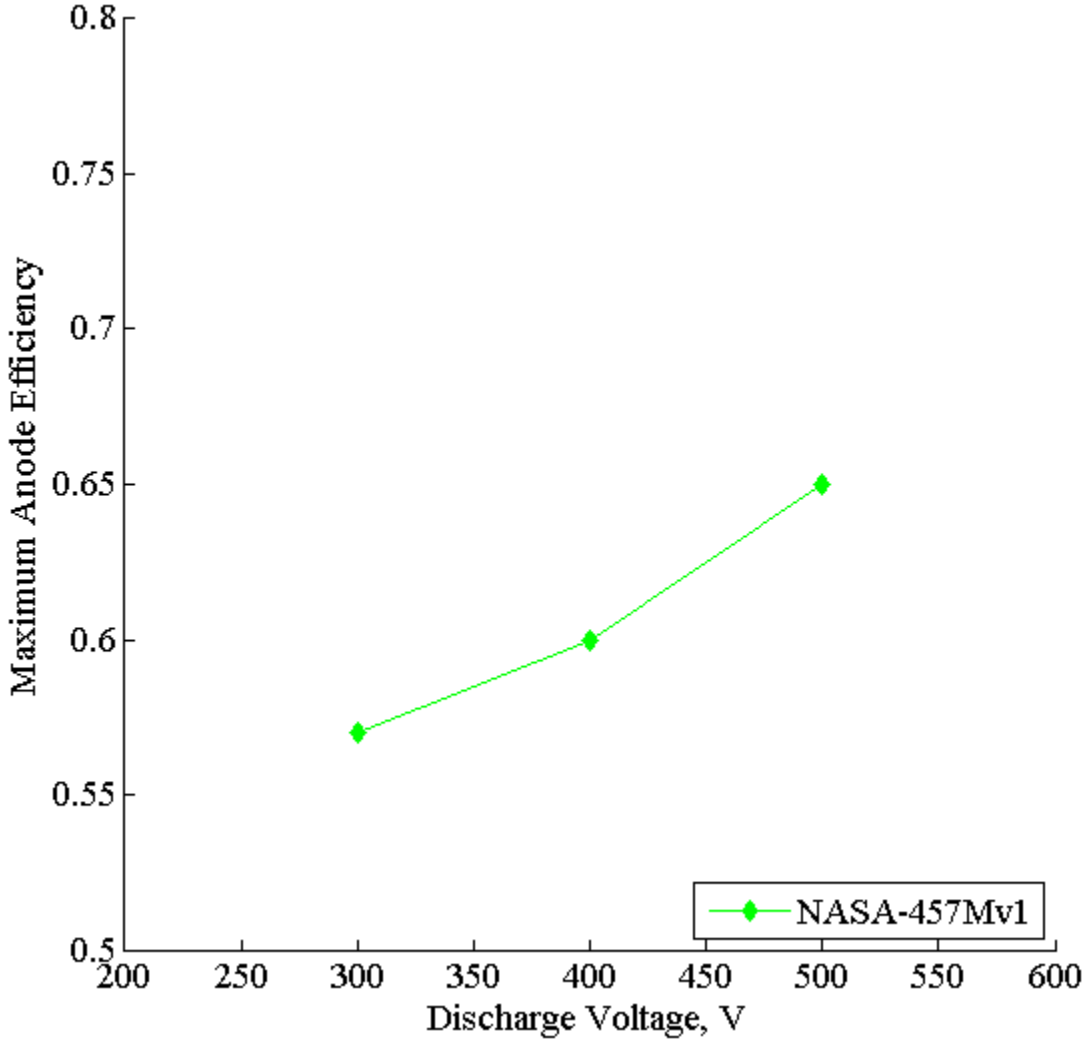
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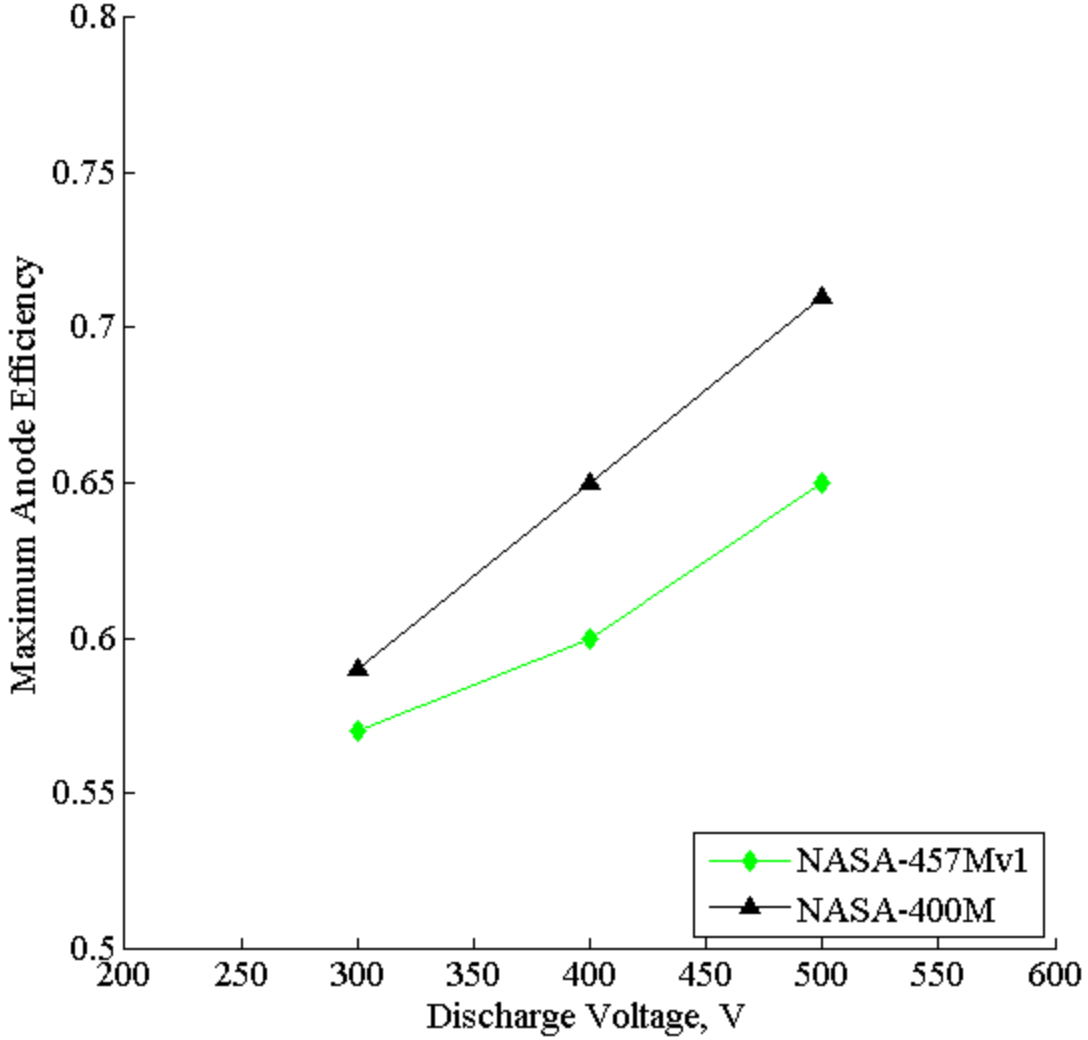
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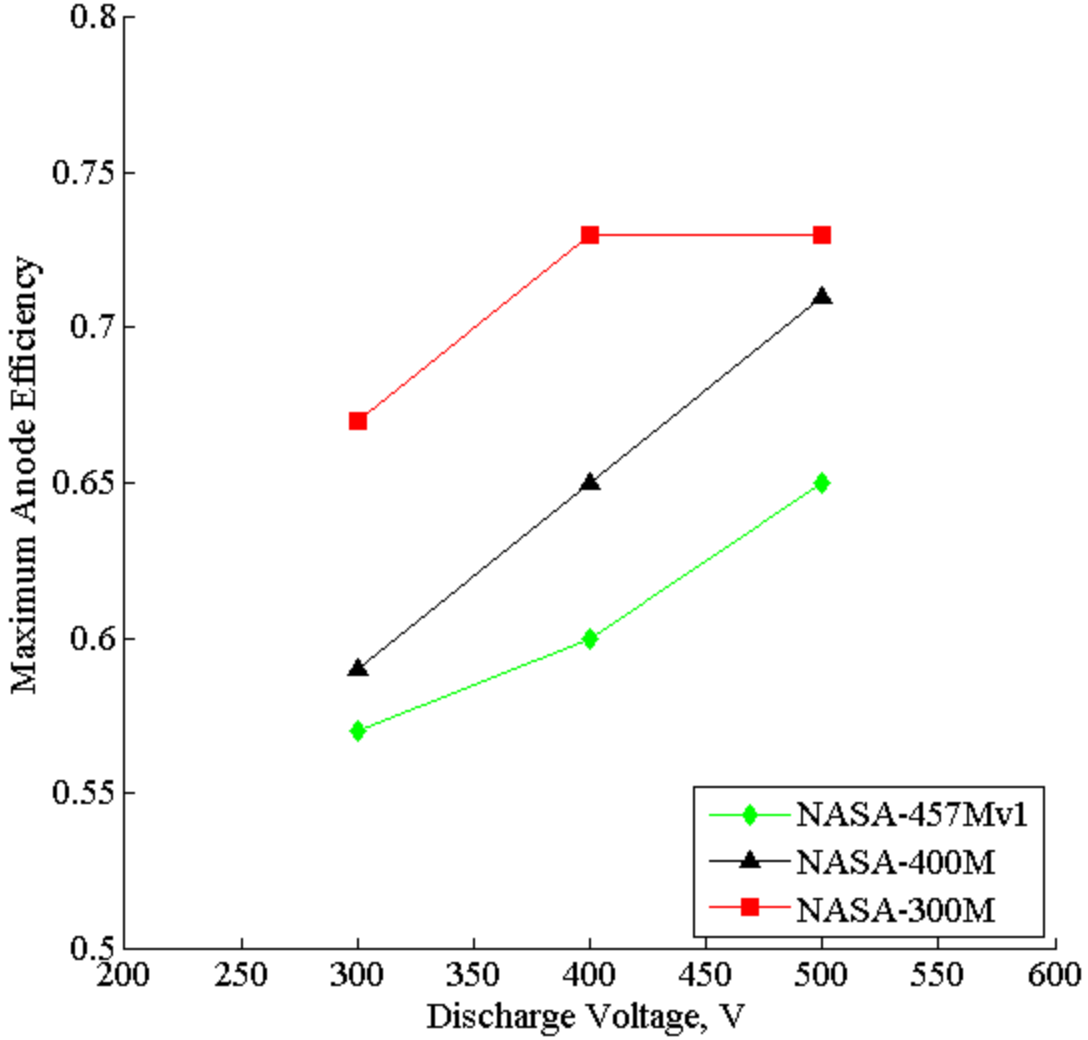
Maximum anode efficiency compared to other thrusters



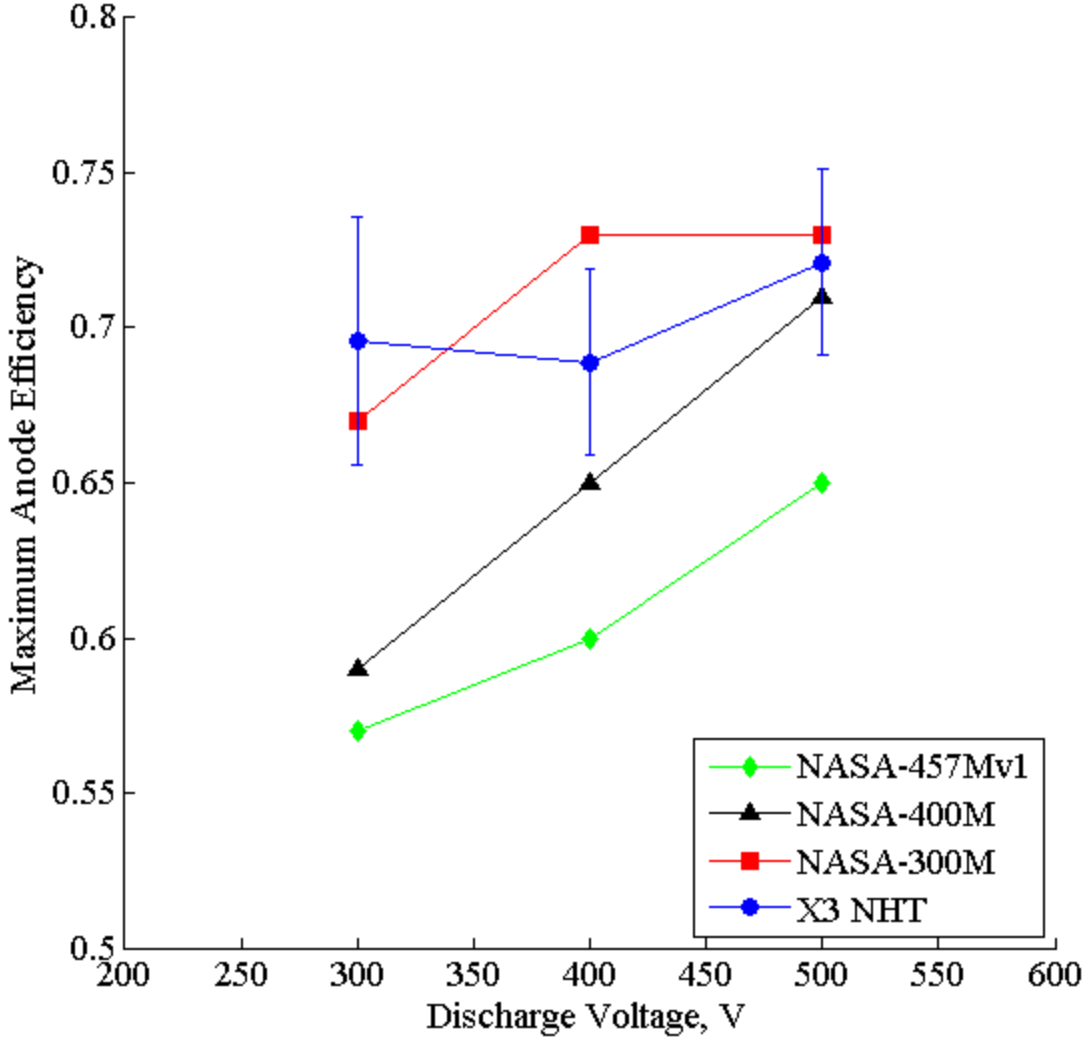
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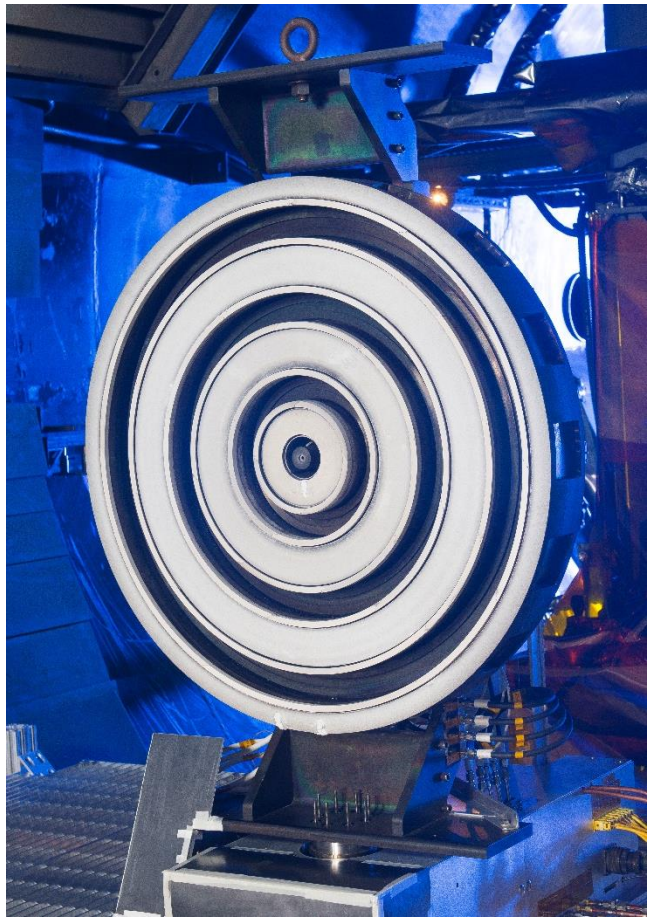


Open questions about the X3 and NHTs

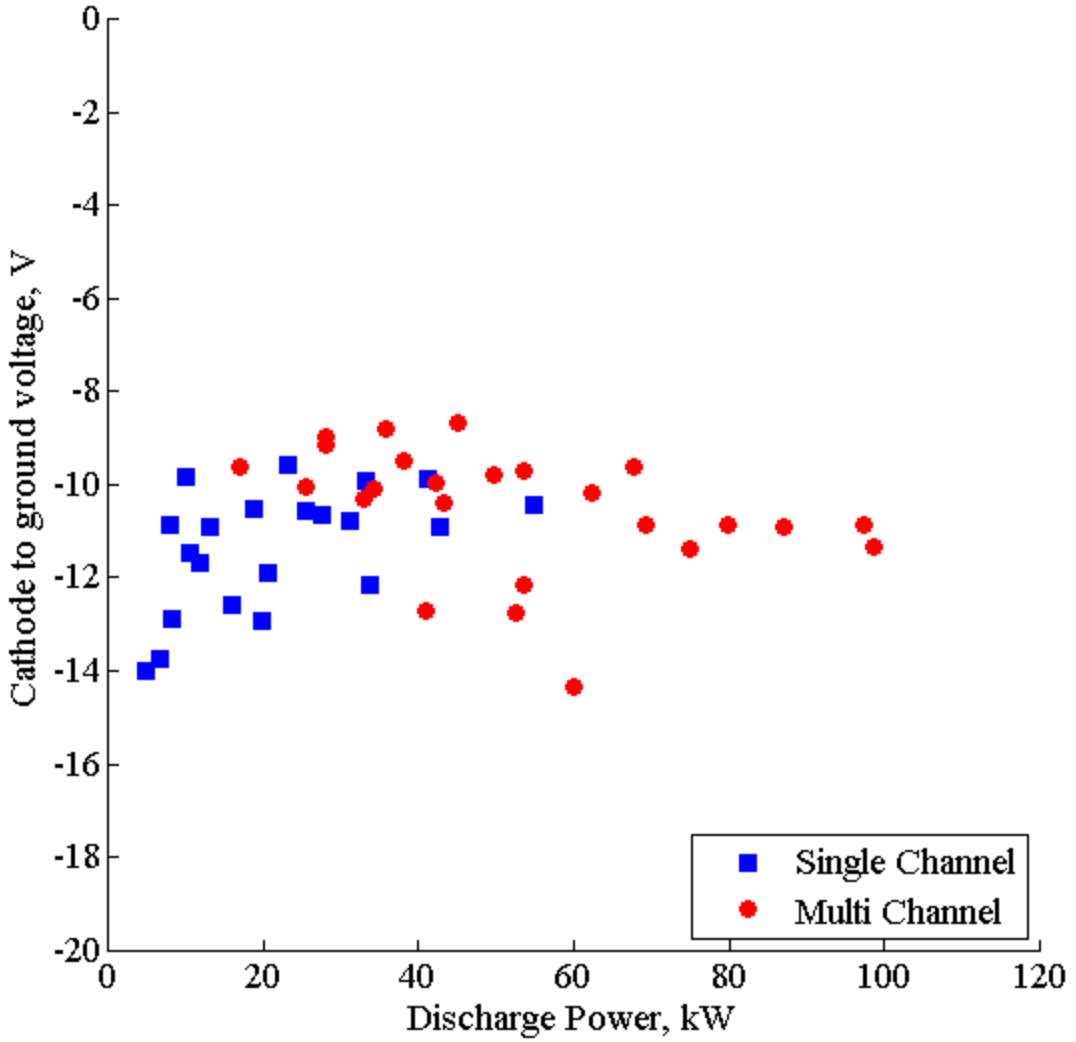
Does the X3 provide expected performance?

Are there cathode coupling issues?

How do the channels interact with each other?



Cathode to ground voltage varied between –9 and –14 V

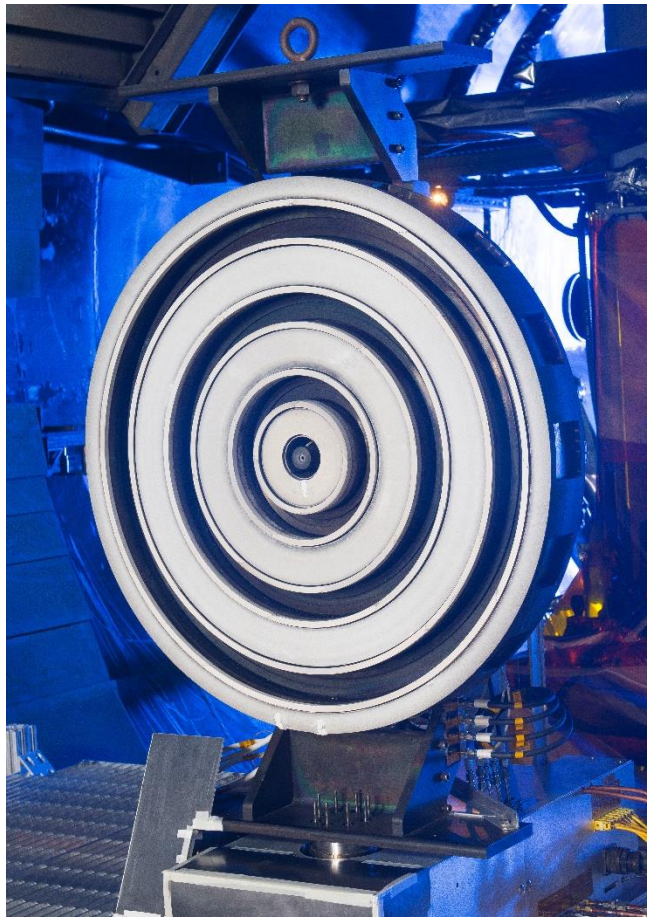


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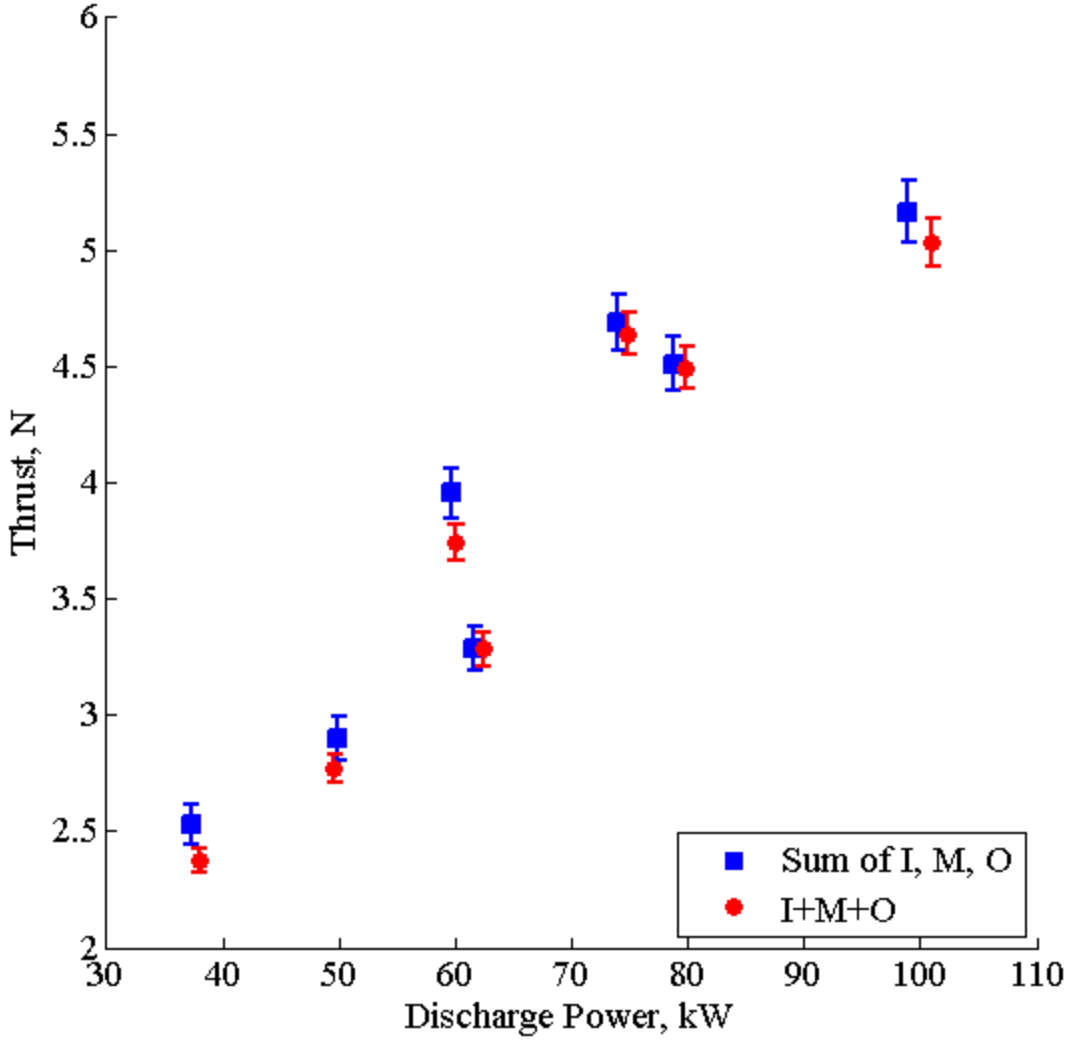
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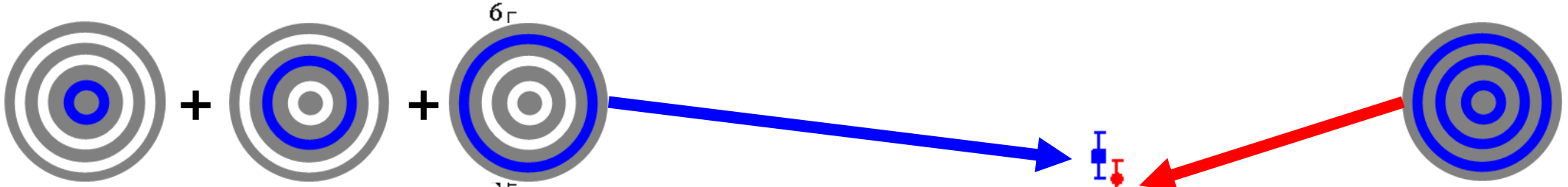
How do the channels interact with each other?

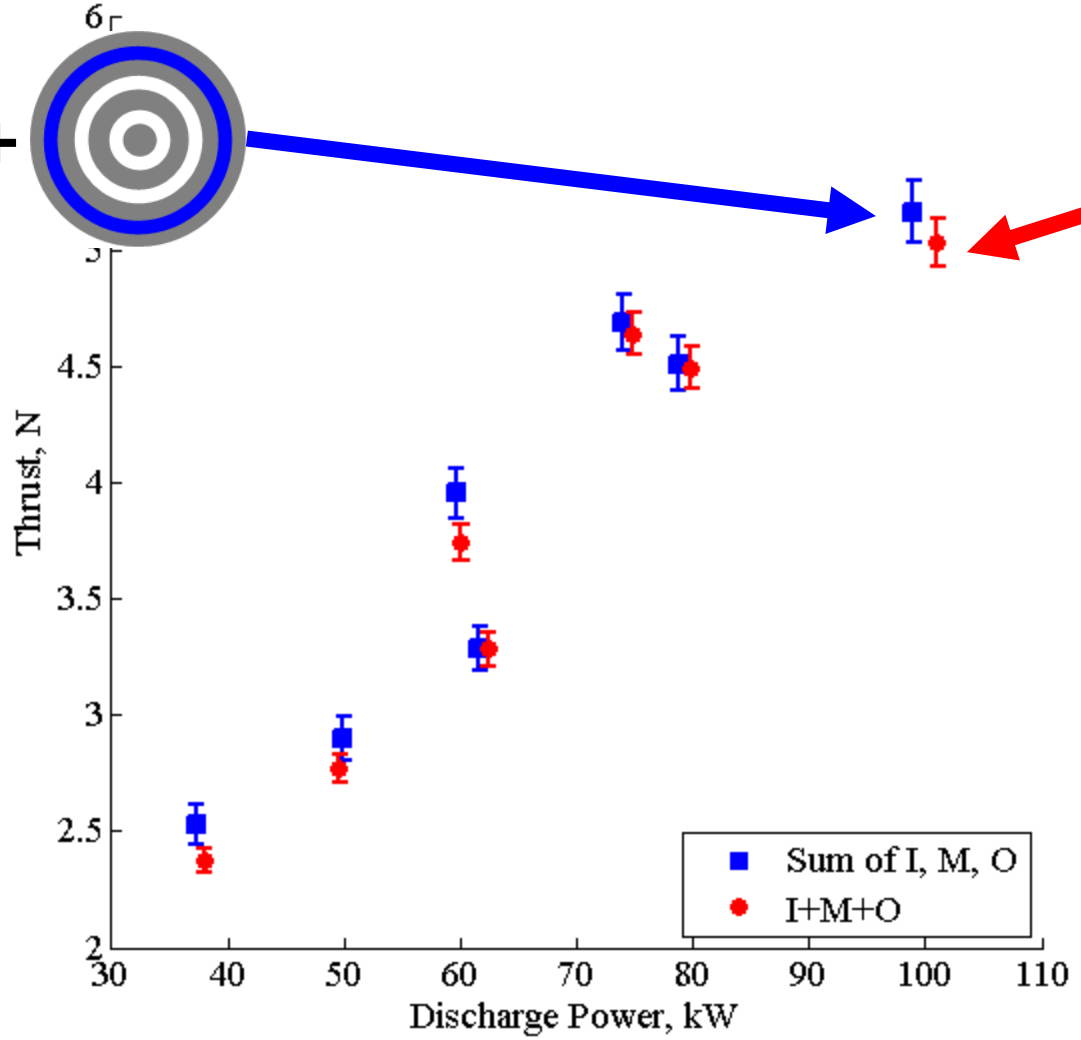


Thrust for I+M+O is not significantly higher than sum of individual channels

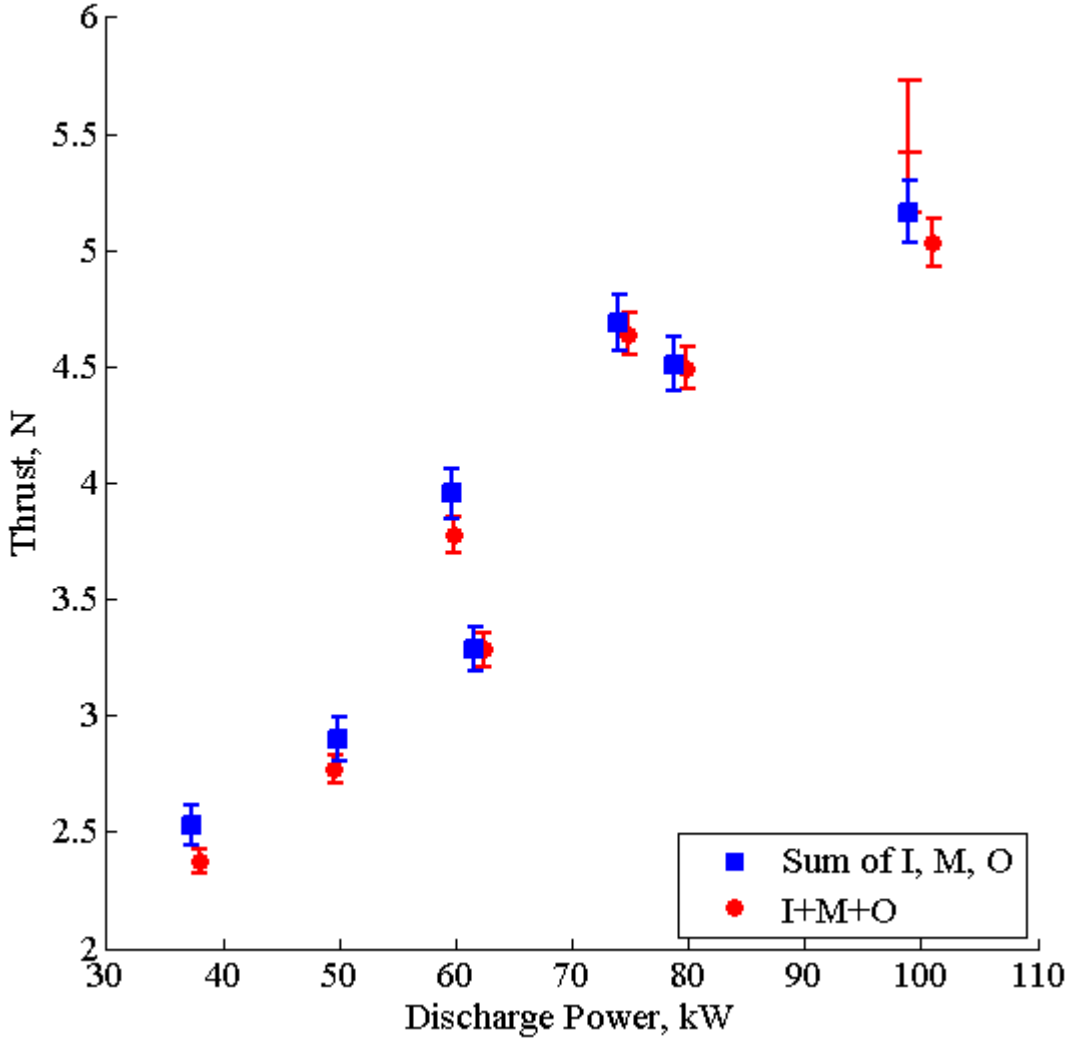


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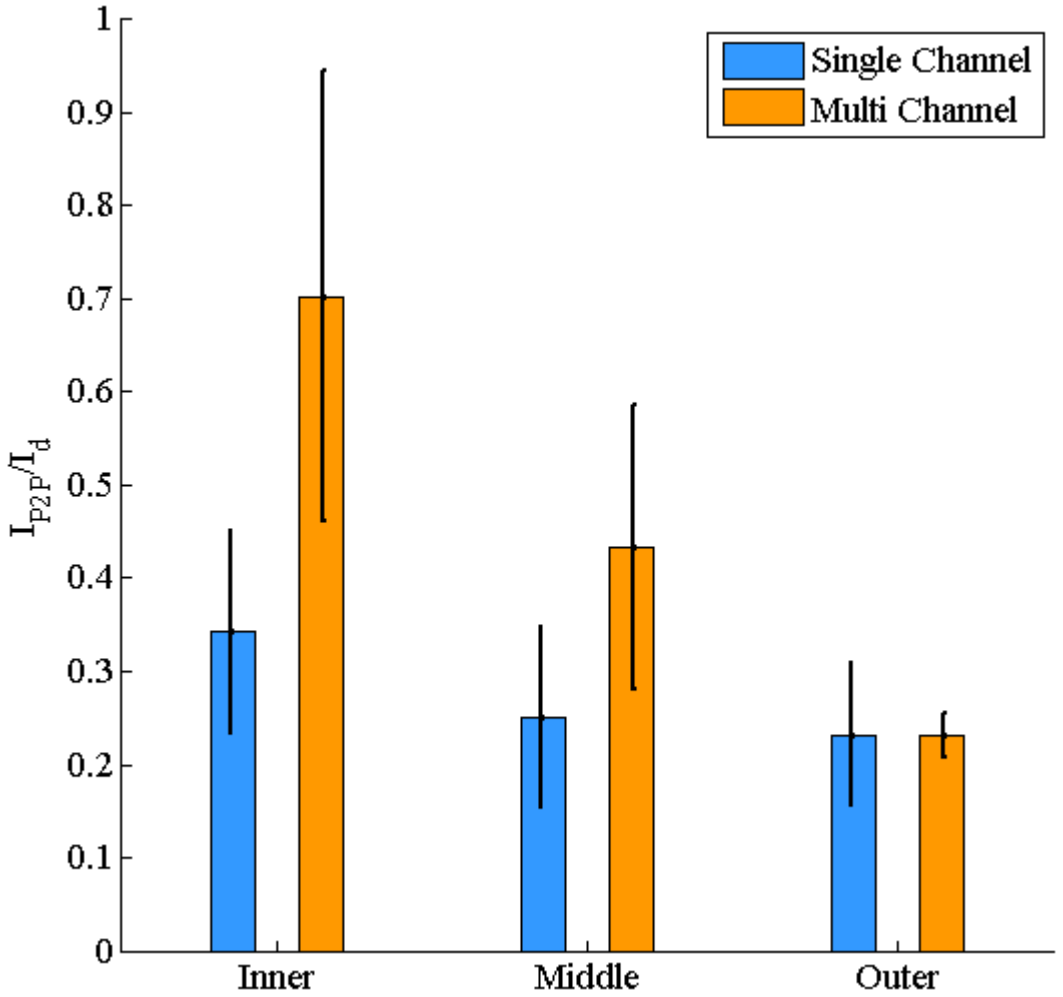




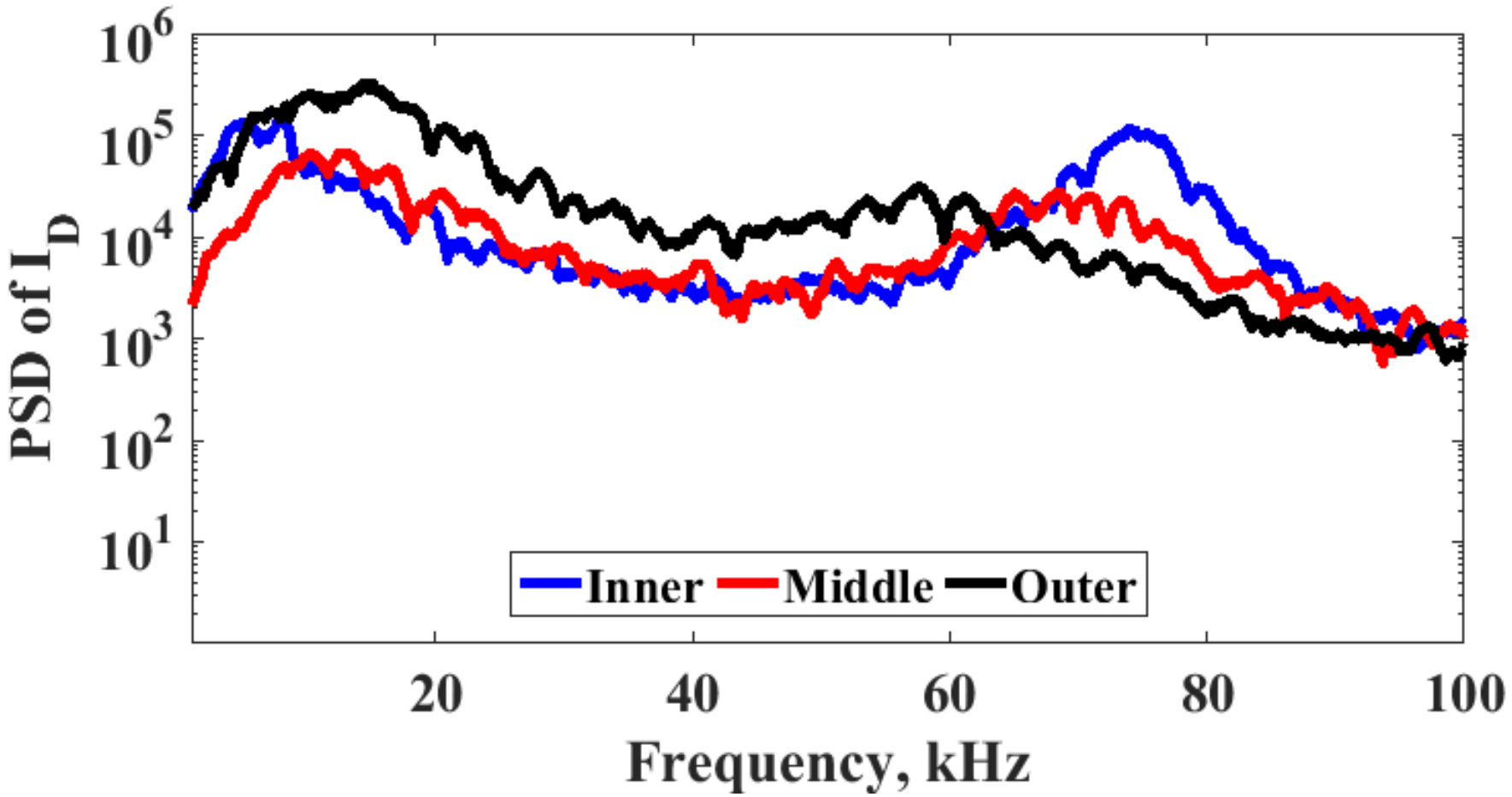
X2 work showed 5—11% increase in multi-channel thrust



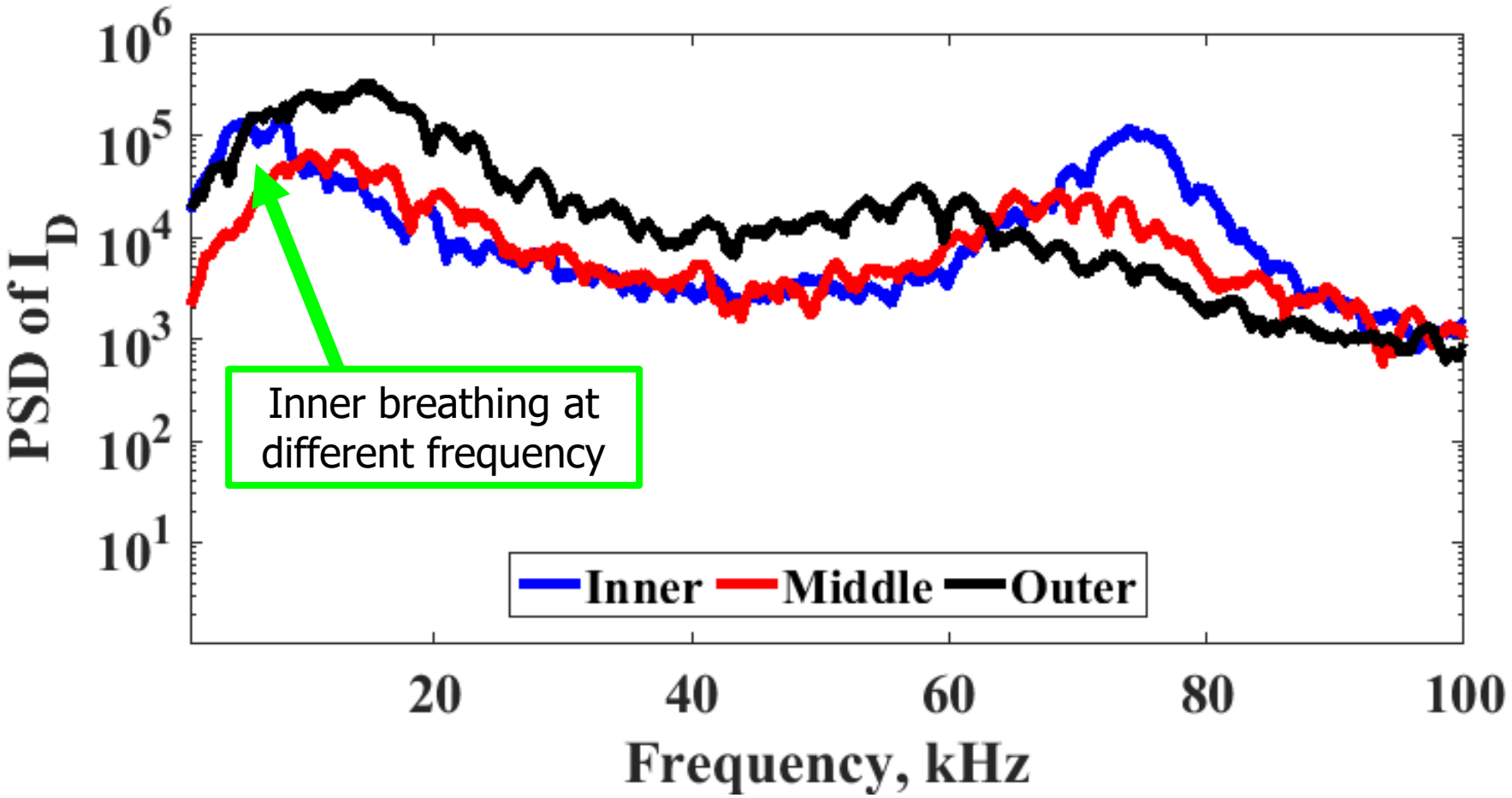
Oscillations changed between single- and multi-channel operation



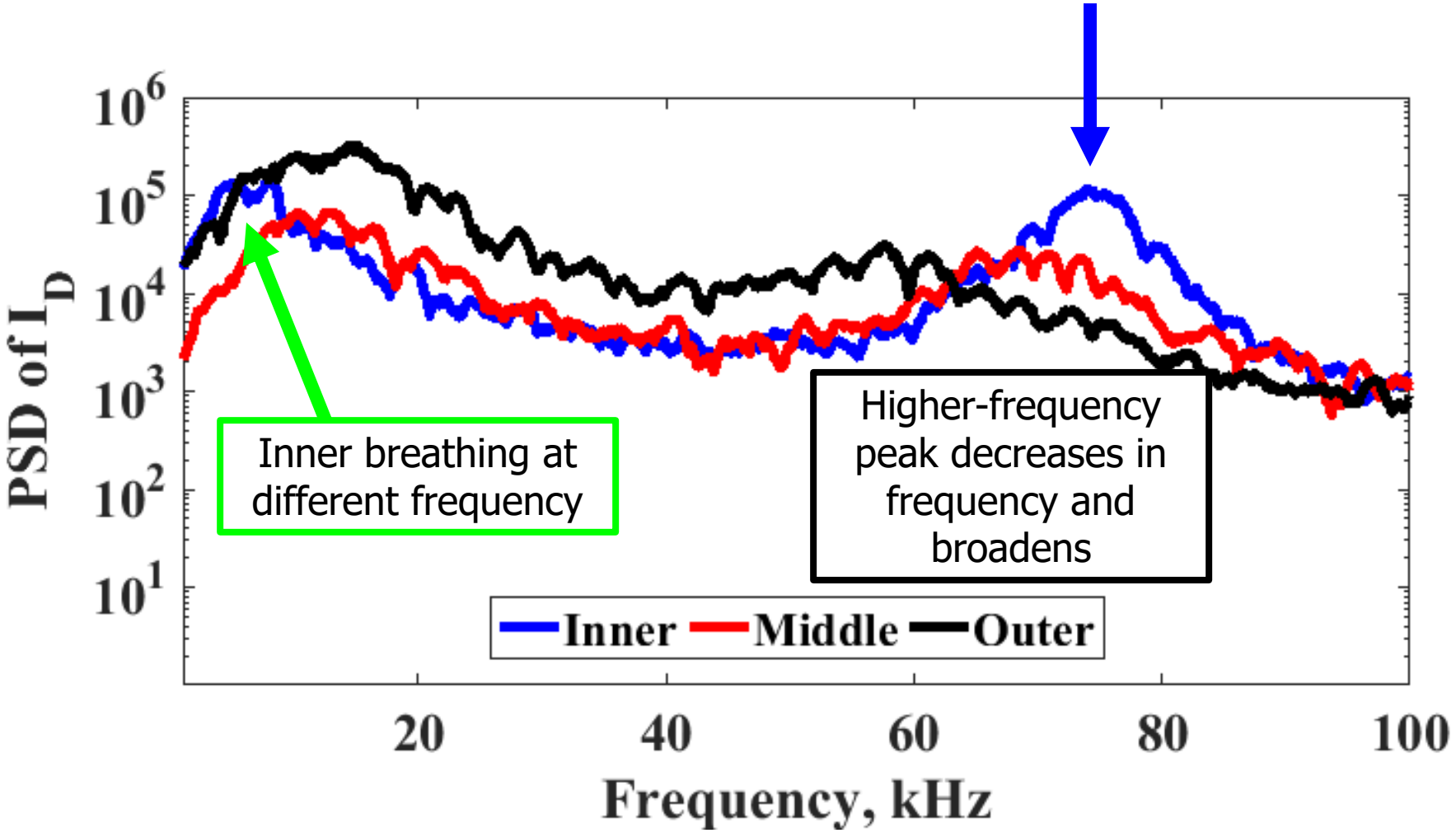
Example PSD from multi-channel operation



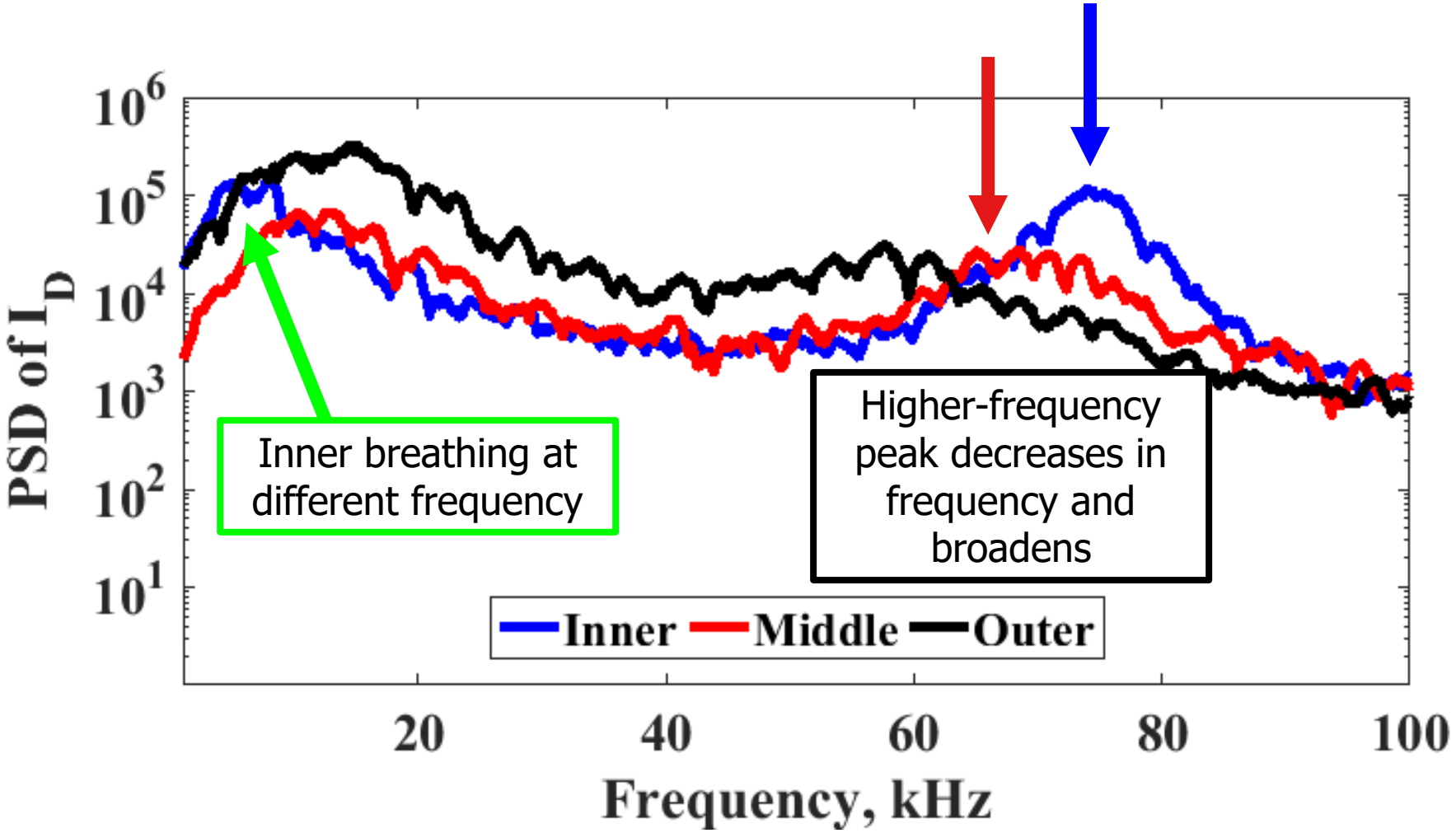
Example PSD from multi-channel operation



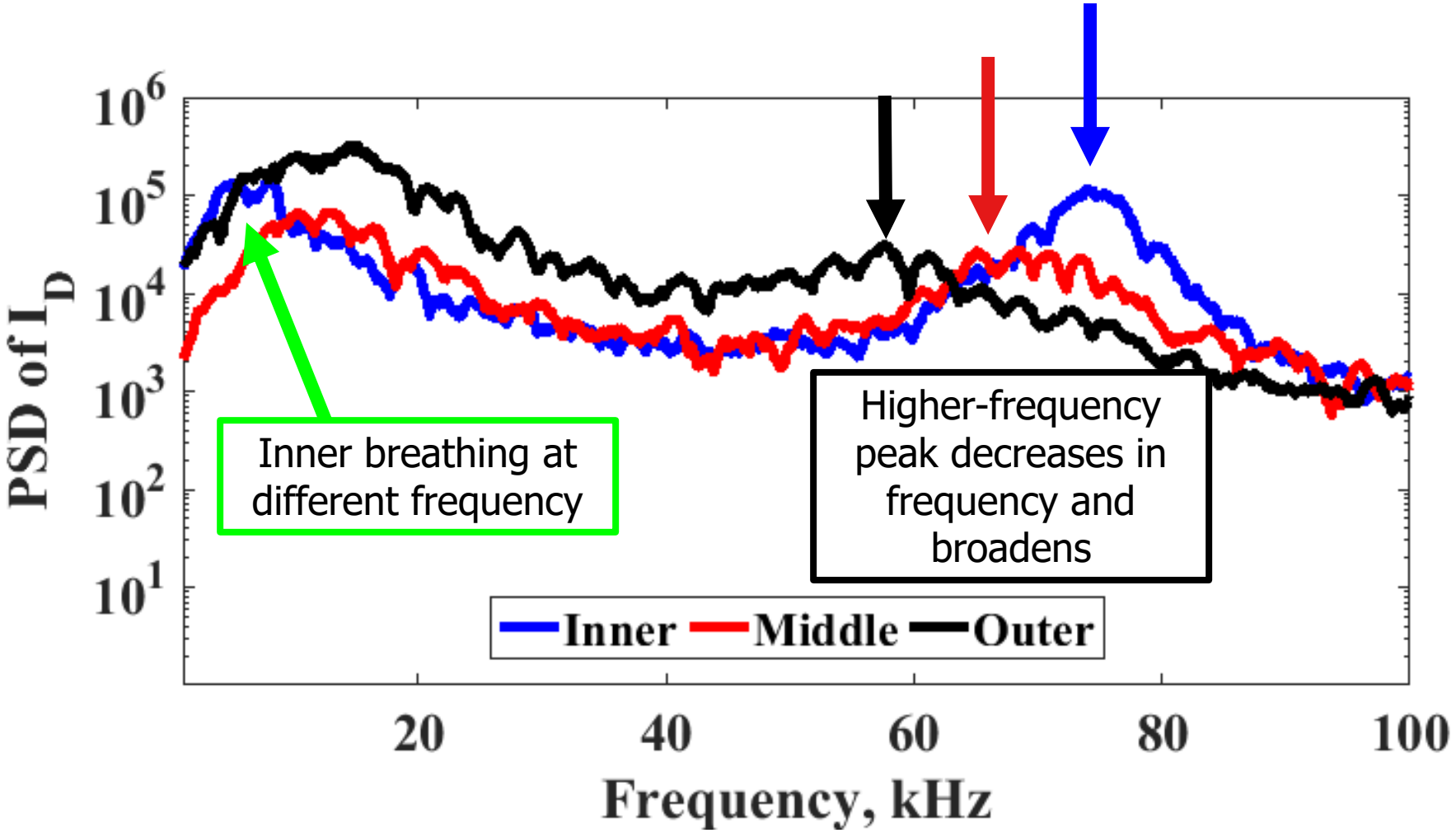
Example PSD from multi-channel operation



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Example PSD from multi-channel operation

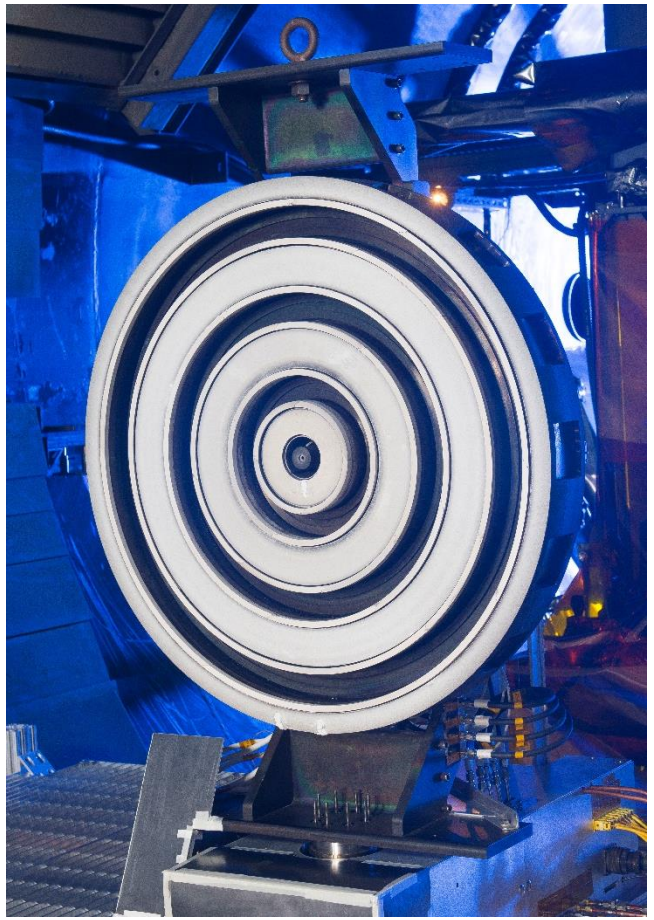


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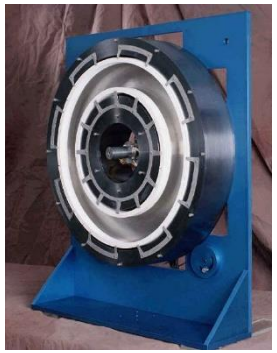
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The X3 is expanding the boundaries of Hall thruster operation

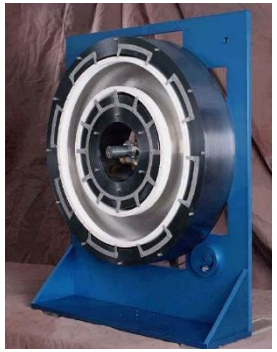


96 kW
@ 3460 s

112 A

3.3 N

The X3 is expanding the boundaries of Hall thruster operation



96 kW @ 3460 s (η_t=0.58)

112 A

3.3 N

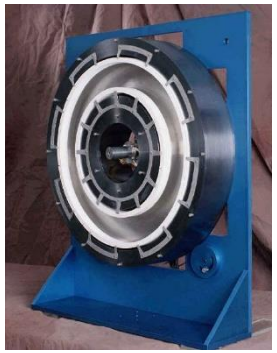


102 kW @ 2400-2600 s (η_t=0.63)

247 A

5.4 N

The X3 is expanding the boundaries of Hall thruster operation



96 kW @ 3460 s (η_t=0.58)

112 A

3.3 N



102 kW @ 2400-2600 s (η_t=0.63)

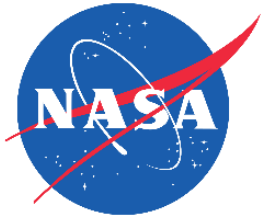
247 A

5.4 N



Acknowledgments

- NASA Space Technology Fellowship (NNX14AL67H)
- NASA Next Space Technologies for Exploration Partnerships (NNH16CP17C)
- At GRC: Eric Pencil, Luis Pinero, Wensheng Huang, Taylor Seablom, Chad Joppeck, Richard Senyitko, Jim Zakany, Nick Lalli, Jim Zologowski, Kevin Blake, Joshua Gibson, David Yendriga, Larry Hambly, George Jacynycz
- Dan M. Goebel at JPL
- Sarah E. Cusson at UM

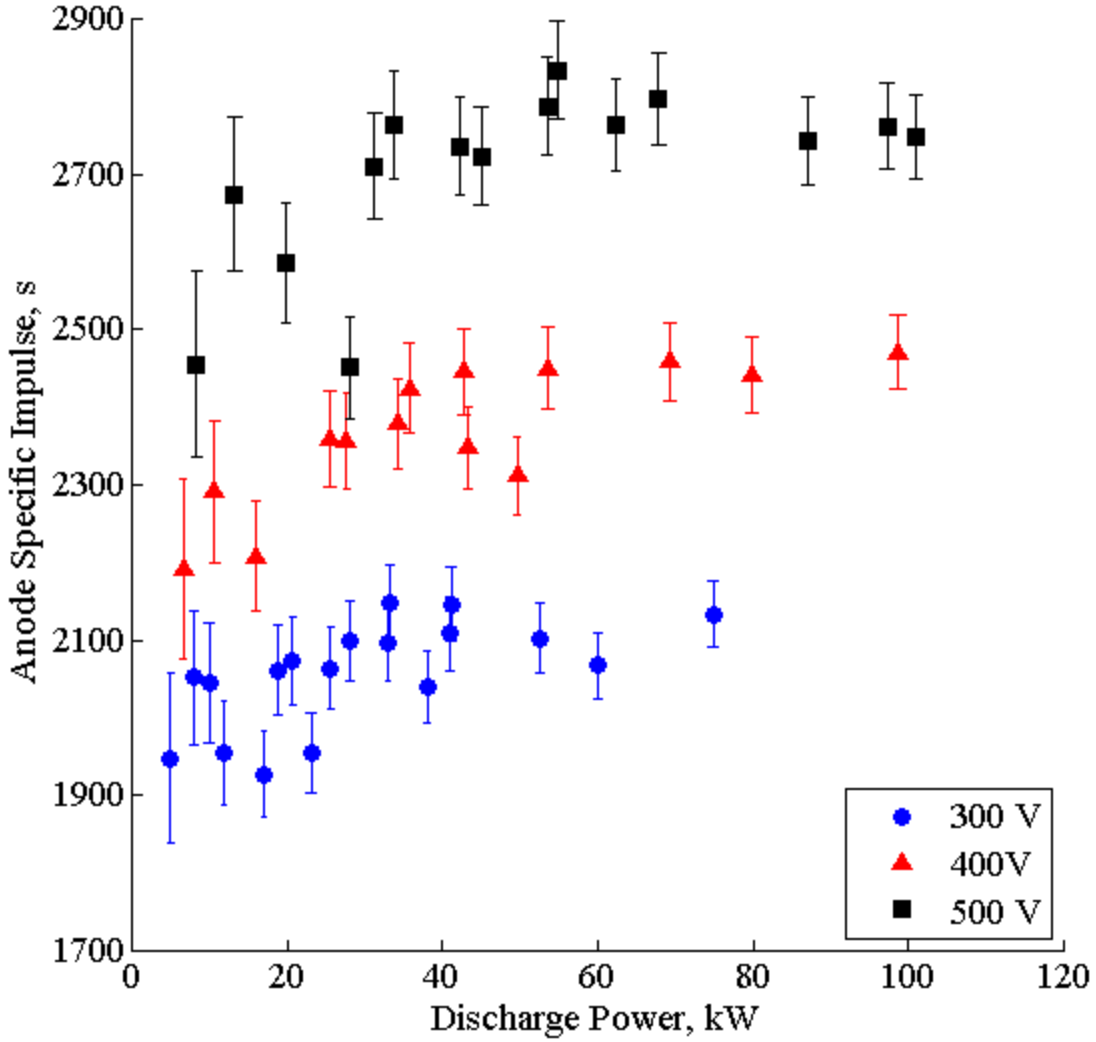




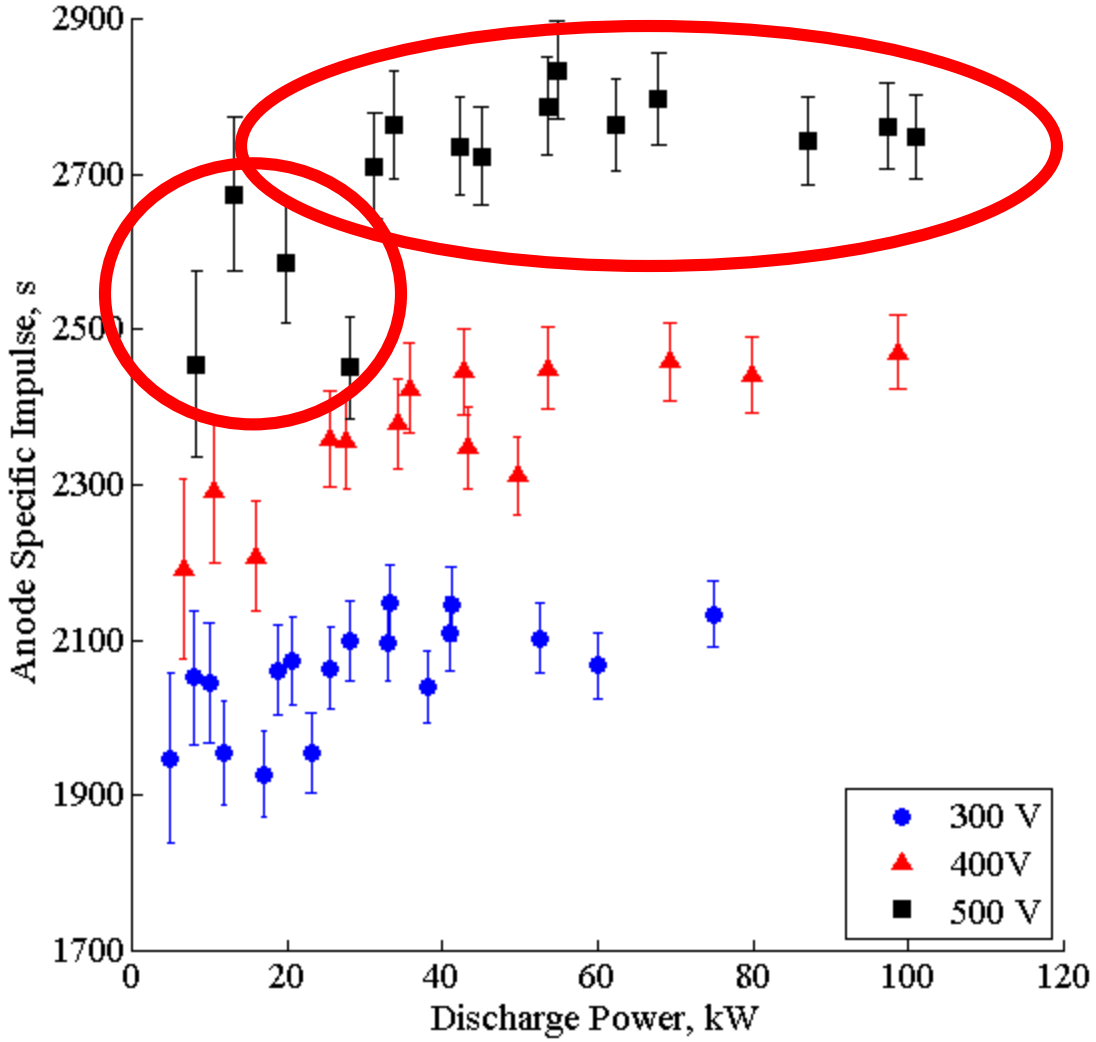
Questions?

Backup Slides

Anode specific impulse versus discharge power



Consistent except for low current density



Maximum anode I_{sp} comparable to other high-power Hall thrusters

