Future of Space Propulsion for US Space Force

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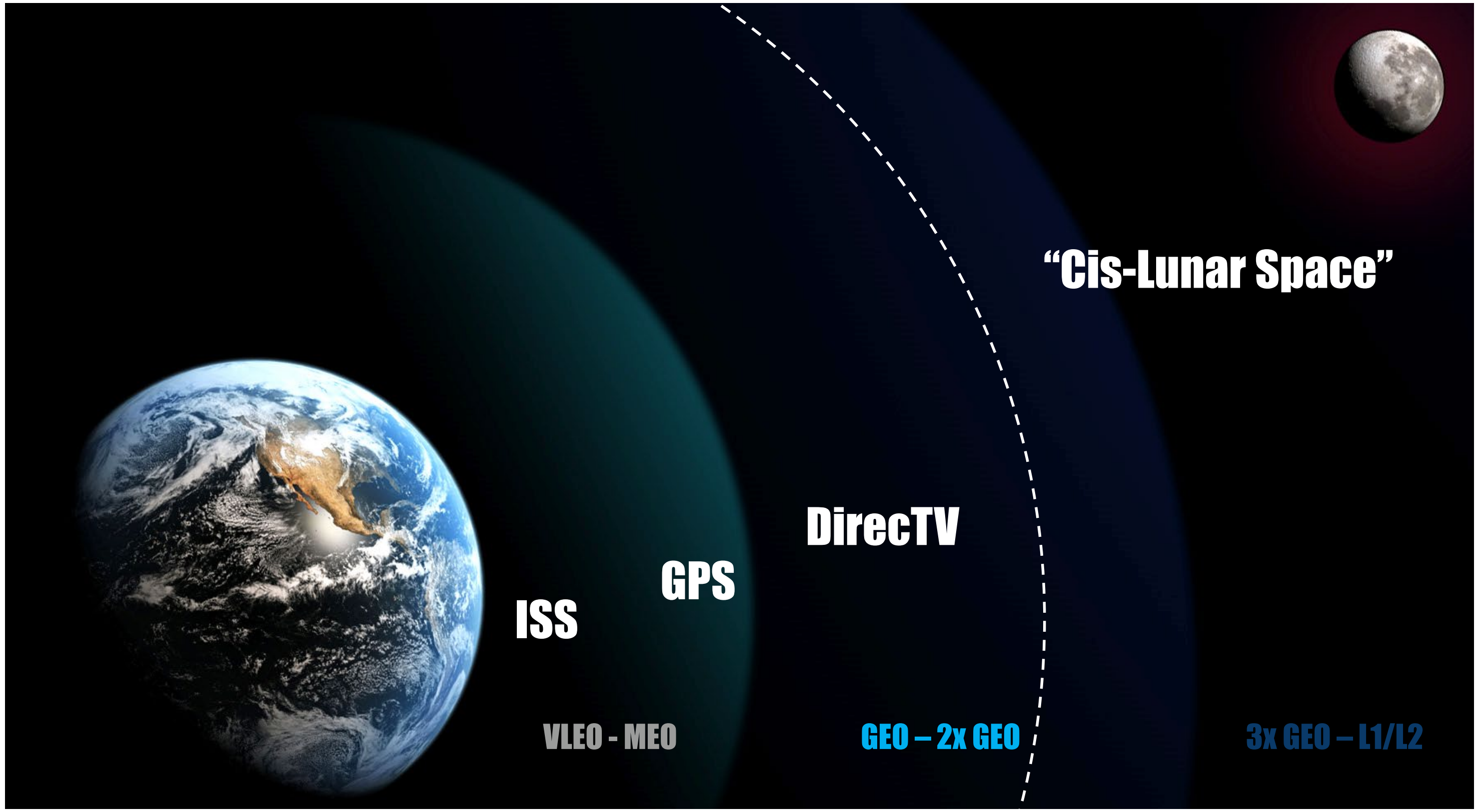
Overview

- Introductory Info
- Landscape of Space today
- What are our adversaries doing
- What we are doing to change
- What is happening at the AFRL Rocket Lab

These are the thoughts and opinions of Joe Dechert and do not represent the views of the DoD or any government agency

Some introductory stuff

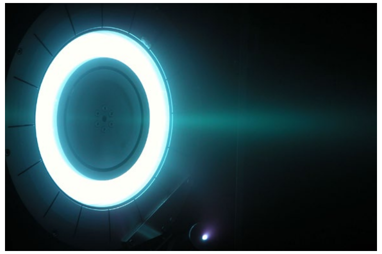


VLEO: Very Low Earth Orbit
LEO: Low Earth Orbit

MEO: Medium Earth Orbit
GEO: Geo-Synchronous Earth Orbit

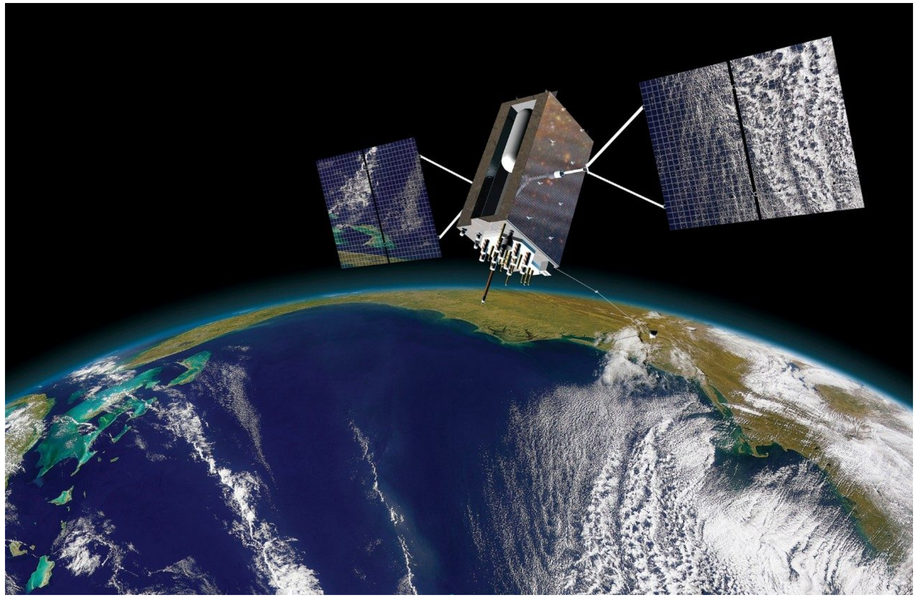
Chemical Propulsion

Electric Propulsion



State of-the-current

- DoD in-space propulsion focused on station keeping and minimal orbital maneuvering
- $100M to $1B+ per DoD satellite with 10-15 year service life
- Incredibly high cost of SV's inhibit acceptance of risk
  - Years of development, testing, and verification
  - Unwillingness to use new technologies
  - Large investment in mission assurance
- Resulted in 50+ years of stagnation in hydrazine based in-space propulsion technology



https://www.lockheedmartin.com/en-us/news/features/history/gps-iii.html

DoD – Historical Perspective

Spacelift — **Assured Access**
EELV (Delta II, Delta IV, Atlas V, Falcon Heavy, Vulcan)

PNT — **8x more powerful military signal**
GPS II (4 klbs – 0.75-2 kW, 7.5-12 yrs)
GPS III (8.5 klbs – 2.2 kW 15 yrs)

Missile Warning — **Shorter revisit time and greater sensitivity**
DSP (2-5 klbs – 0.4-1.2kW – 1.25-5 yrs)
SBIRS (10 klbs – 14 yrs)

Comm — **10x higher throughput**
MILSTAR (10 klbs, 8 kW, 10 yrs)
AEHF (13.5 klbs, 14 yrs)
DSCS (6 klbs, 1.5 kW 10 yrs)
WGS (13 klbs, 10 kW, 14 yrs)

- Longer mission requirements
- More power
- More Mass

Does this CONOP continue for contested space?

Direction of Industry

- Smaller, more numerous
  - Decline of the big GEO satellite
  - Emergence of LEO megaconstellations
  - NewSpace (SmallSat; Cubesats)

Starlink (SpaceX)

- 800 in orbit (starting 2018); FCC approval for 12,000; Expansion to 42,000
- Orbit: LEO (550km)
- 227 kg per S/C
- Kr HET

Oneweb (UK)

- 68 in orbit (staring 2019), 650 for initial constellation
- Polar LEO (~1200 km) – 7 year lifespan
- 150 kg per S/C
- Xenon HET

Kuiper (Amazon)

- 3,236 planned
- 600 km orbit
- Likely EP

TeleSat

- 298 planned
- 800kg, Kr HET

- Underlining ALL commercial ventures is the bottom line → cost of propulsion is strongest driver in developing new capabilities
  - Community is looking (by and large) for cheaper and faster delivery

Opportunity to leverage Cost-Effective space technology

There is an enterprise-wide call for innovative, game-changing technology

- S&T 2030
  - "Continually drive new warfighter capabilities to the USAF & USSF through transformational multidisciplinary systems of systems innovation"
  - "Set an unmatched pace"

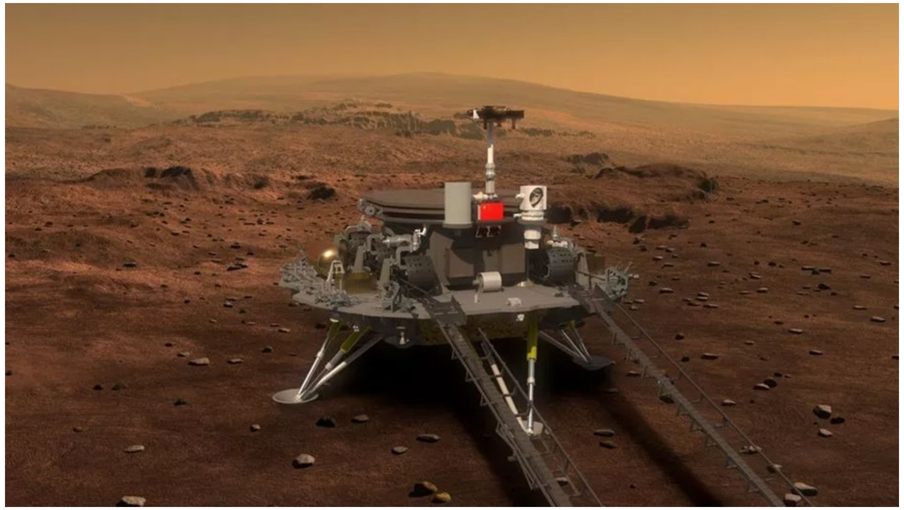
- Chief of Space Operations' Planning Guidance
  - "I expect commanders and program managers to accept moderate risk associated with innovation and experimentation to build an agile force that better ensures our long-term competitive advantage in space."

- CSAF: Accelerate, Change, or Lose
  - We must adapt and accelerate—now—to ensure our continued ability to best serve our Nation
  - Good Enough Today Will Fail Tomorrow

The 21st century space race is about space assets/resources

Our Adversaries are moving fast

- China's space presence is growing rapidly in Earth, Lunar, and Martian theaters
- Electric Propulsion (EP) is an area of concentration from the China National Space Administration
- Inspired by publically-available technologies
  - 1960s: Ion and PPT
  - Since 1990s: Ion, MPD, Hall, PPT, Electrospray
  - Planned for 50 kW Hall by 2020
- Rapidly growing
  - Moon missions
  - Telecommunications (all-EP platform ~2020)
  - Space Station plans
  - Satellite deliveries
  - Mars missions
- Anti-Satellite Program
  - 2007 Test created more than 35,000 pieces of debris[1]
  - Pentagon Report: developing tech to reach satellites in GEO[2]



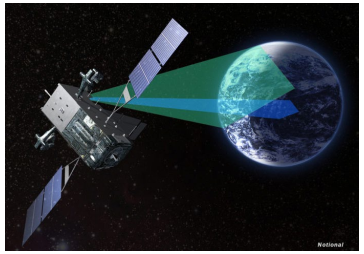
[1] https://www.space.com/3415-china-anti-satellite-test-worrisome-debris-cloud-circles-earth.html
[2] https://spacenews.com/pentagon-report-china-amassing-arsenal-of-anti-satellite-weapons/

China is having success with missions to the moon

Mission	Launch date	Launch vehicle	Notes	Status
Phase 1				
Chang'e 1	24 Oct 2007	Long March 3A	Lunar orbiter; first Chinese lunar mission.	Success
Chang'e 2	1 Oct 2010	Long March 3C	Lunar orbiter; following lunar orbit mission flew extended mission to 4179 Toutatis.	Success
Phase 2				
Chang'e 3	1 Dec 2013	Long March 3B	Lunar lander and rover; first Chinese lunar landing, landed in Mare Imbrium with Yutu 1.	Success
Queqiao 1	20 May 2018	Long March 4C	Relay satellite located at the Earth-Moon L_2 point in order to allow communications with Chang'e 4.	Ongoing
Chang'e 4	7 Dec 2018	Long March 3B	Lunar lander and rover; first ever soft landing on the Far side of the Moon, landed in Von Karman Crater with Yutu 2.	Ongoing
Phase 3				
Chang'e 5-T1	23 Oct 2014	Long March 3C	Experimental test flight testing technologies ahead of first Lunar sample return; tested return capsule and lunar orbit autonomous rendezvous techniques and other maneuvers.	Success
Chang'e 5	Q4 2020	Long March 5	Lunar orbiter, lander, and sample return; scheduled to land near Mons Rümker and return a sample to Earth for the first time since the Soviet Luna 24 mission in 1976.	Planned
Phase 4				
Chang'e 6	2023–2024	Long March 5	Lunar orbiter, lander, and sample return; scheduled to land at a currently undisclosed site near the lunar south pole, which will most likely depend on the outcome of Chang'e 5.	Planned
Chang'e 7	2024	Long March 5	Lunar orbiter, lander, rover, and mini-flying probe; expected to perform in-depth exploration of the lunar south pole to look for resources.[20]	Planned
Chang'e 8	2027	Long March 5	Full mission details are currently unknown; may test new technologies including an ISRU system, ahead of future crewed exploration of the Moon.	Planned

China is building a Cis-Lunar Presence

We are at a historic inflection point for space



"Space is no longer the sanctuary it was 30 years ago; it is becoming increasingly congested, contested and competitive"
-Gen John Hyten

- USSF standup
  - Tasked with defending US interests in space
  - Economic interests in the moon/cis-lunar space
  - Teamed with NASA to build a presence in cis-lunar space

USSF – NASA MOU, 9/21/2020
"USSF now has an even greater surveillance task for space domain awareness (SDA) in that region, but its **current capabilities & architecture are limited by technologies and an architecture designed for a legacy mission**"

Addressing the threat

- Build a comprehensive military advantage in space[1]
- Maneuverability
  - Collision avoidance
  - Threat evasion
- Flexibility to adapt to changing mission needs & perform a wide-swathe of mission requirements
- Space Domain Awareness
- Sustained cis-lunar operations
- Logistics: on-orbit refueling[3]

SPACENEWS

Orbit Fab to launch first fuel tanker in 2021 with Spaceflight

[2]

[1] 2020 Defense Space Strategy
[2] https://cisac.fsi.stanford.edu/news/security-space-0
[3] https://spacenews.com/orbit-fab-to-launch-with-spaceflight/

What's happening at the Rocket Lab

Rocket Lab Overview

- Over 450 personnel on-site
  - Civil service, military, contractors

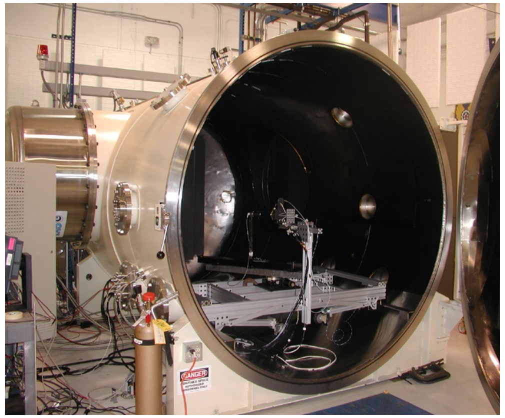
65 square miles

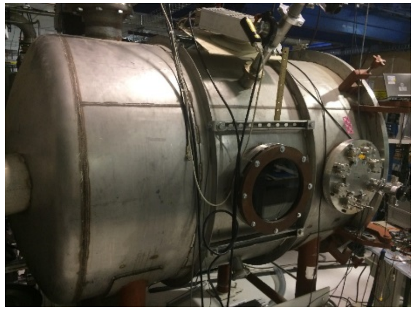
- 135 buildings
- 19 liquid engine stands
- 13 solid rocket motors stands

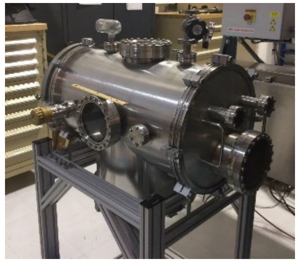
In-Space Propulsion Branch

- Multiple efforts spanning basic research (AFOSR / TRL 1-3) to applied technology development (6.3 / TRL 4-5) and flight demonstration (6.3+ / TRL 7)
  - Combination of contracted and in-house efforts, often coordinated with other government agencies (particularly NASA centers)
  - Customers
    - USSF
    - Space and Missile Center
    - Other GOV agencies

AFRL Vacuum Facilities (Edwards AFB)



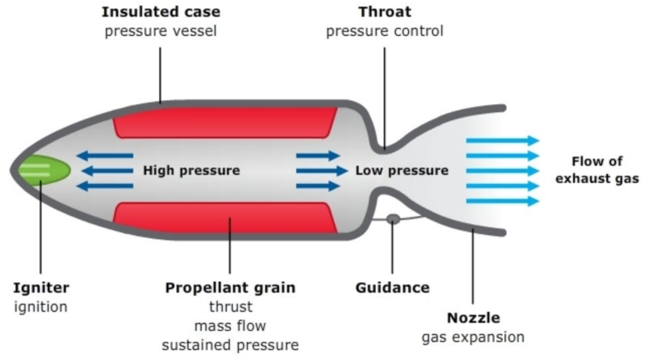




Spacecraft Propulsion Overview: Reaction engines

Chemical Propulsion - Reaction mass and acceleration energy are fundamentally integrated in propellant

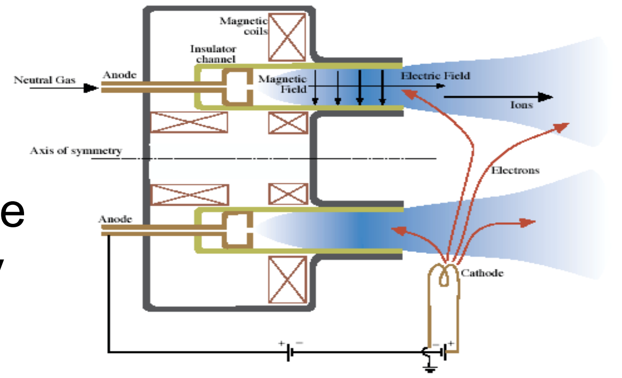
- On-orbit propulsion requires storable propellants, so MMH (monoprop) and MMH/NTO (biprop) have been preferred combinations for the last 50+ years
- Materials properties and chemistry provide ultimate limits on performance



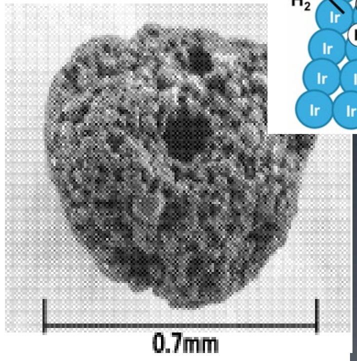
https://www.theflatearthsociety.org/forum/index.php?topic=67626.930

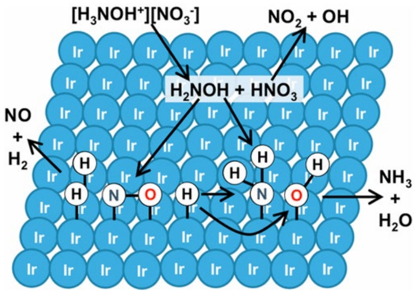
Electric Propulsion (EP) - Separate reaction mass and energy source

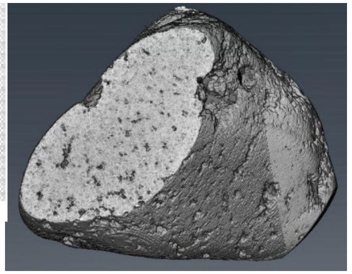
- Wide set of reaction mass candidates selectable for different properties
  - Since acceleration is by electrostatic or electromagnetic forces, no major materials or chemistry constraints → easy to accelerate propellant to very high velocity



Advanced IL Chemical Propulsion

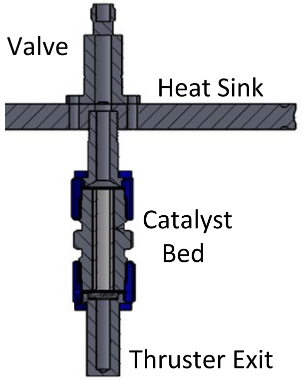


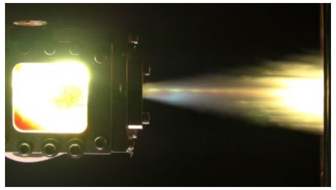


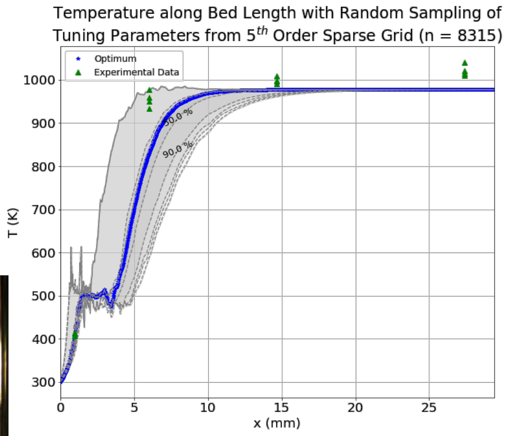


Leading transition of advanced green monopropellants to community

- Based on Ionic Liquid (IL) research pioneered at AFRL/RQR







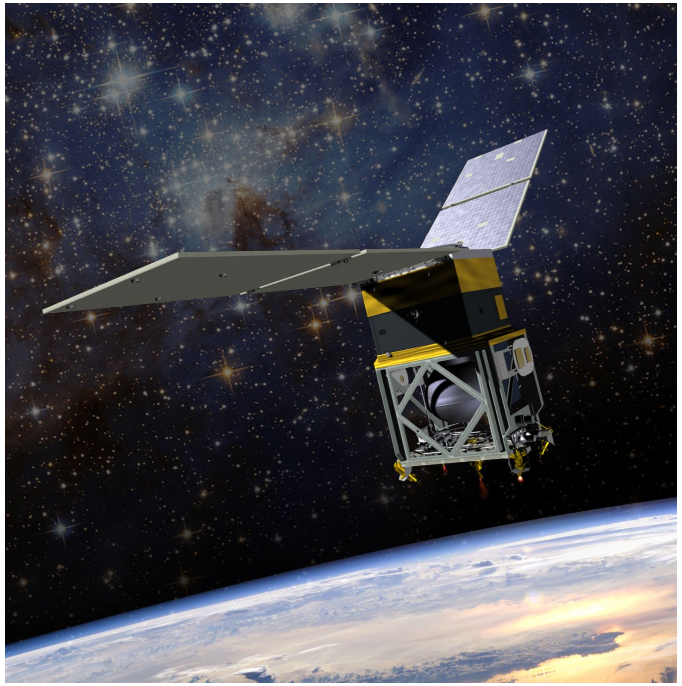
ASCENT

Hydrazine

Properties	AF-M315E	Hydrazine
Isp, lb_f-sec/lb_m	266	242
Density , g/cc	1.465	1.01

Recent Tech Transition - GPIM

- Green Propellant Infusion Mission
- Launched in June 2019
- Collaboration with AFRL, NASA & Ball Aerospace
- 13 month mission
- 154-kilogram satellite
- Completed numerous test to include de-tumble test

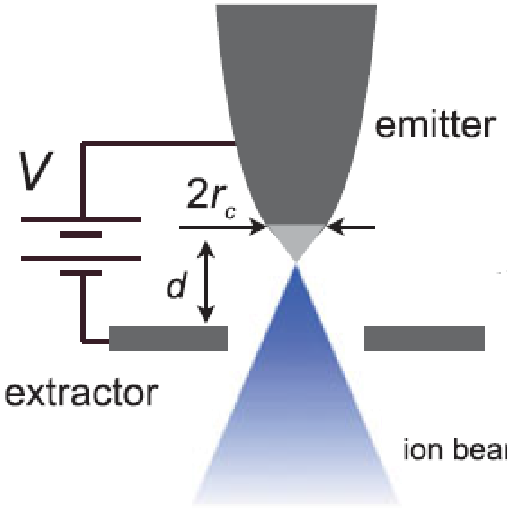


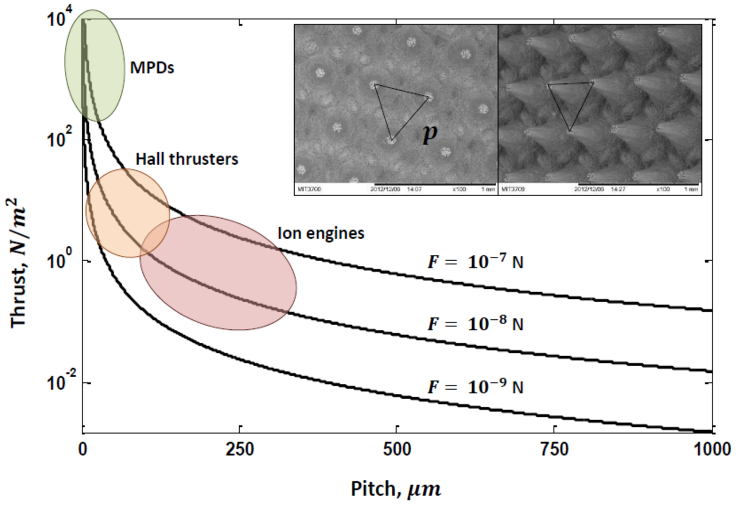
https://www.nasa.gov/mission_pages/tdm/green/overview.html

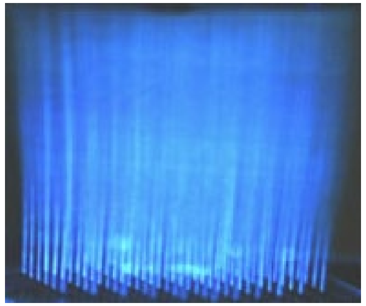
https://spacenews.com/ball-aerospace-wrapping-up-green-propellant-smallsat-demo-mission/

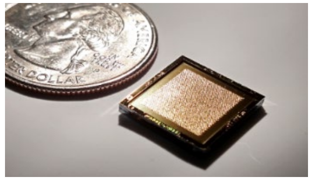
IL Electrosprays

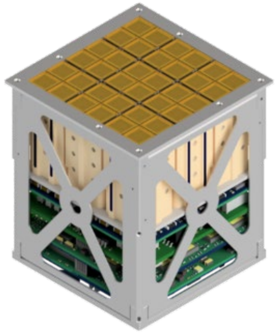
- Very high theoretical electric efficiency (>80%)
  - Excellent candidate for small S/C propulsion
- Potentially scalable to large systems
- Compatibility with a wide range of IL propellants



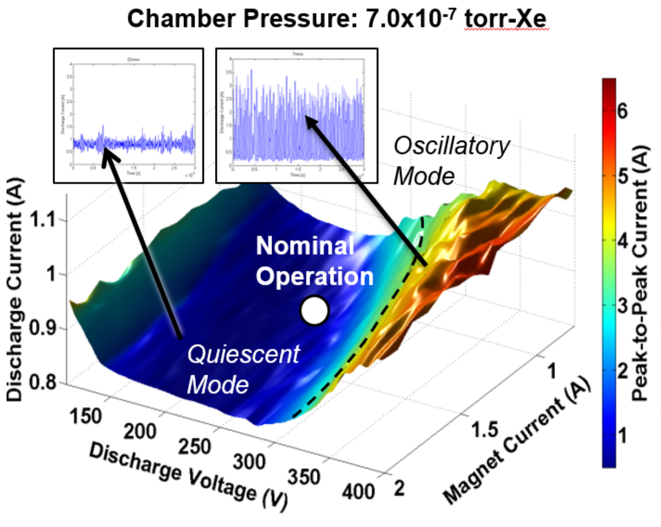


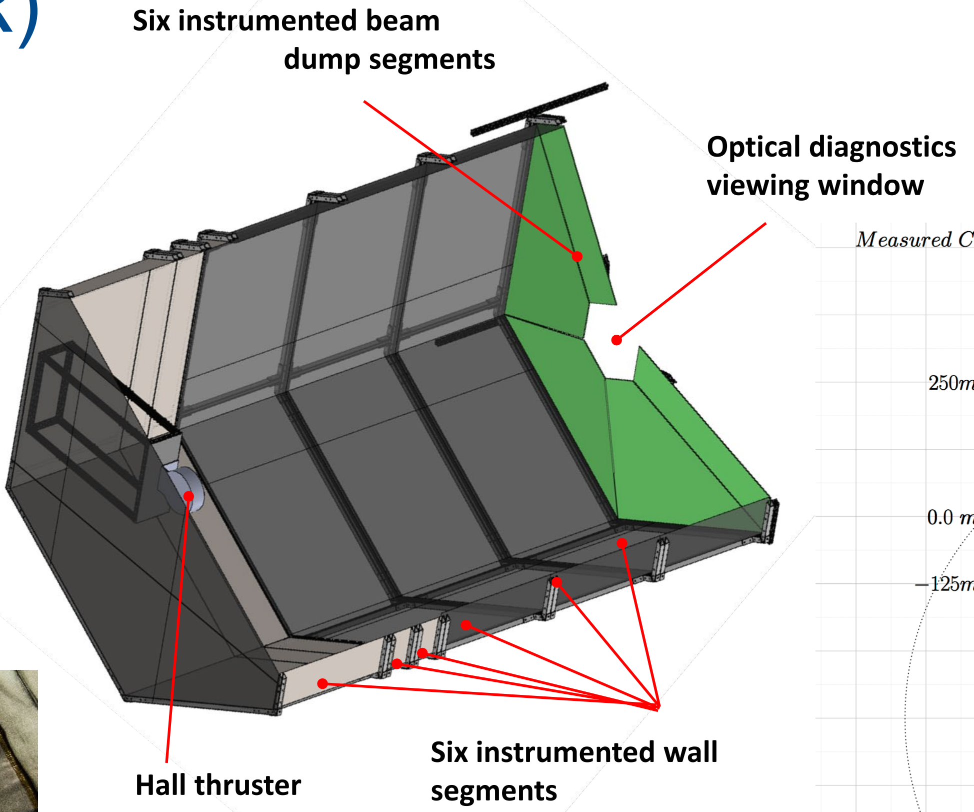


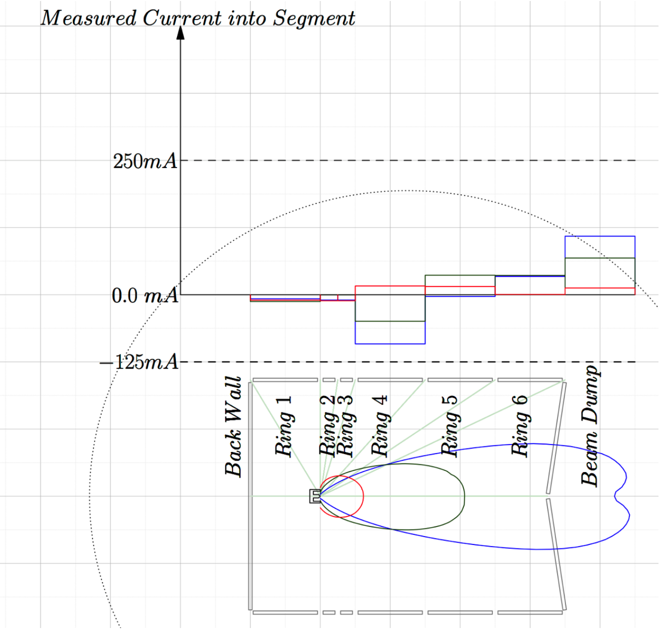


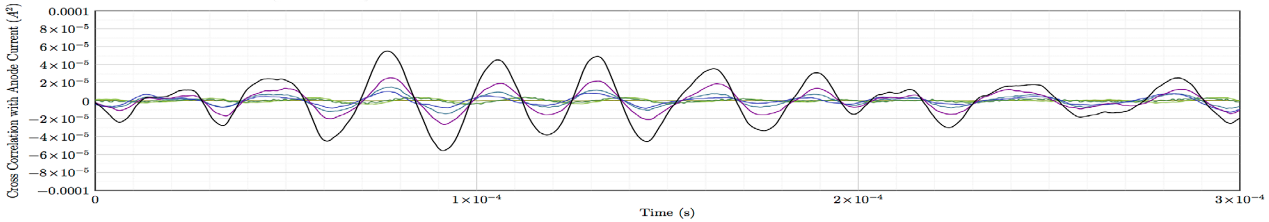


EP TEMPEST (AFOSR)









Conclusion

- Landscape of Space today
- What are our adversaries doing
- What we are doing to change
- What is happening at the AFRL Rocket Lab

Questions?