



# Workshop Overview

**Thomas Liu (NASA GRC), John Ziemer (NASA JPL), &  
Dan Eckhardt (AFRL Edwards)**

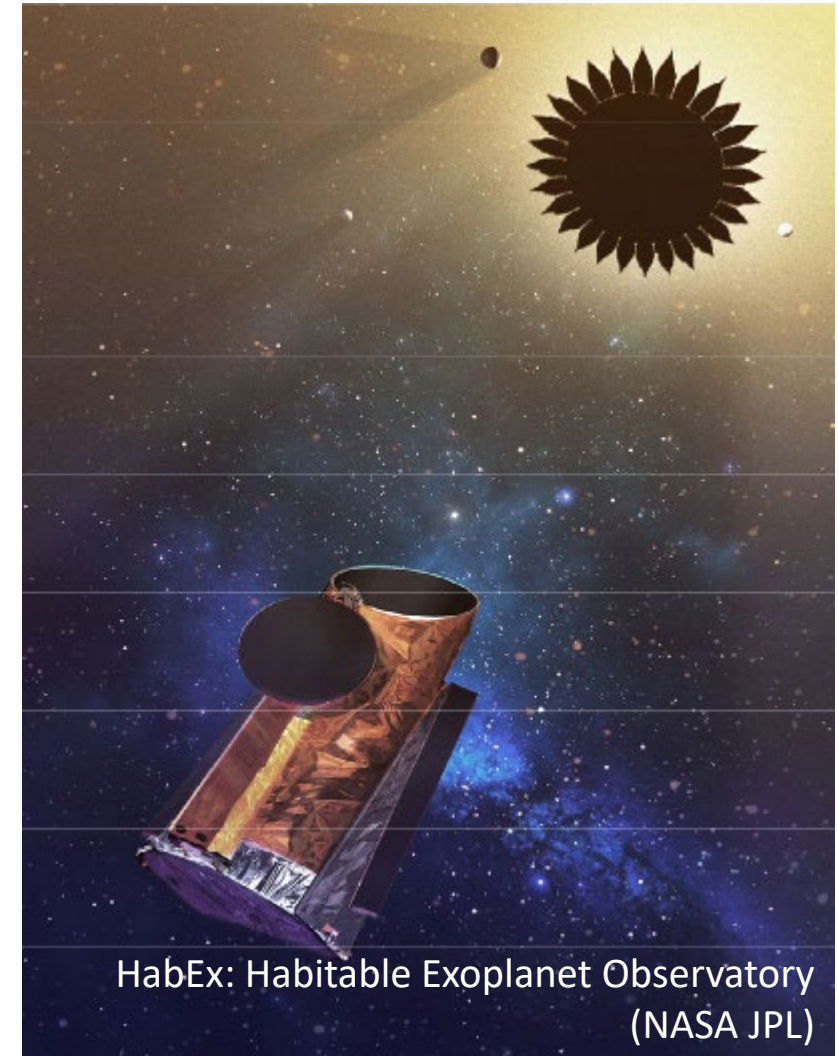
**2022 AIAA SciTech Forum  
January 3-4, 2022**

# Electrospray Propulsion

## 2015 NASA Technology Roadmap: TA 2.2.1.5

*Electrosprays provide thrust using a conductive fluid and electrostatic fields to extract and accelerate charged droplets, clusters of molecules, or individual molecules or ions*

- Mission capability
  - Precision 6-DOF actuation with low vibrations
    - Astrophysical observatories
    - Formation flight of coupled / distributed spacecraft
  - Primary propulsion for small spacecraft
- Technology challenges
  - Extended lifetime operations for large total impulse
  - Low contamination impact on spacecraft





# Workshop Goals

- With the growing interest in electropray propulsion for academic, commercial, and government missions, these workshops are intended to involve participants in the electropray propulsion community in:
  1. Addressing ongoing challenges with electropray operational lifetime and propulsive efficiency
  2. Promoting best practices associated with testing and modeling of electropray propulsion systems in technology development and verification / validation
- These workshops are open to SciTech attendees, so workshop talks and discussions should only include information approved for public distribution.
- If these workshops prove beneficial to the community, they may become a recurring feature at future SciTech forums.



# Lifetime for Electric Propulsion Systems

- Lifetime is quantified by one or more of the following:
  - Hours of Operation
  - Total Impulse
  - Total Throughput
  - Total Energy
- These lifetime quantities are interrelated and depend on operating conditions (i.e., duty cycle, thrust level, flow rate, power, etc.), making a single “life test” difficult for broadly qualifying a new technology.
- Therefore, the ultimate goal is to have **physics-based models of thruster wear-out and failure mechanisms that can be used to predict lifetime**.
  - Models must be verified against known problems and validated on test data
  - Models should also support assessment and quantification of uncertainty



# Workshops: Lifetime & Total Impulse

- **Physics and Challenges for Lifetime and Total Impulse**
  - *Session Chair: John Ziemer (NASA JPL)*
  - Session I (EP-04): Monday, 03 January 11:30 - 12:45 PST
  - Session II (EP-07): Tuesday, 04 January 11:30 - 12:45 PST
- Areas of focus include:
  - electrode wear
  - propellant deposition on thruster head surfaces
  - charge imbalances
  - electrical and thermal load imbalances
  - coupled effects between thrusters in close proximity
  - uncertainties in quantifying mass flow rates in passively-fed systems

# Electrospray Efficiency Discrepancy

How to achieve the theoretical efficiencies of electrosprays?


Recent tests suggest the presence of an anomalous mass loss mechanism during thruster operation:

$$\dot{m}_a = \dot{m} - \dot{m}_i - \dot{m}_v$$

$\dot{m}_a$ : Mass flow due to anomalous process which occurs only during firing  
 $\dot{m}$ : Total mass flow; Obtained from thruster mass change during test campaign  
 $\dot{m}_i$ : Mass flow due to ion emission; Obtained from Time-of-flight data  
 $\dot{m}_v$ : Mass flow due to finite vapor pressure; Obtained from thruster outgassing tests

$$\langle \dot{m} \rangle = \frac{\Delta m}{\Delta t}$$

$$\dot{m}_i \approx \frac{4 V_{em}}{D_f^2} \int_0^\infty I(t) t dt$$

where  $\dot{m}_v + \dot{m}_a > 0$   reduced mass utilization efficiency,  $\eta_m = \frac{\dot{m}_i}{\dot{m}}$



# Workshops: Efficiency

- **Physics and Challenges for Efficiency**

- *Session Chair: Dan Eckhardt (AFRL Edwards)*

- Session I (EP-10): Monday, 03 January 16:00 - 17:15 PST

- Session II (EP-12): Tuesday, 04 January 16:00 - 17:15 PST

- Areas of focus include:

- propellant utilization losses from mixed ion-droplet emission and polydispersivity

- divergence losses from off-axis emission

- power efficiency losses with thruster operating time

- propellant sensitivities to temperature and electrochemistry

- effects from finite vapor pressure and volatiles in the propellant

- geometric deviation from optimal configurations

- test facility effects



# Agenda: Monday, January 3

## **Lifetime / Total Impulse Session I (EP-04): Monday, 03 January 11:30 - 12:45 PST**

*Session Chair: John Ziemer (NASA JPL)*

- Workshop overview (10 min)
- Richard Wirz (UCLA): “Testing and Modeling Considerations for Electro Spray Thruster Life and Total Impulse Determination” (35 min)
- Lifetime & Total Impulse discussion (30 min)

## **Efficiency Session I (EP-10): Monday, 03 January 16:00 - 17:15 PST**

*Session Chair: Dan Eckhardt (AFRL Edwards)*

- Session overview (10 min)
- Manuel Gamero-Castano (UCI): “Estimation of the Main Sources of Inefficiencies in Electro Spray Propulsion” (35 min)
- Efficiency discussion (30 min)



# Agenda: Tuesday, January 4

## **Lifetime / Total Impulse Session II (EP-07): Tuesday, 04 January 11:30 - 12:45 PST**

*Session Chair: John Ziemer (NASA JPL)*

- Session overview (10 min)
- Lifetime & Total Impulse discussion (25 min)
- Thomas Liu (NASA GRC) & John Ziemer (NASA JPL): Electro spray TRL considerations (20 min)
- TRL discussion (20 min)

## **Efficiency Session II (EP-12): Tuesday, 04 January 16:00 - 17:15 PST**

*Session Chair: Dan Eckhardt (AFRL Edwards)*

- Session overview (5 min)
- Deborah Levin & Joshua Rovey (UIUC): “Predicting Electro spray Thruster Emissions Through Fundamental Modeling and Measurements” (35 min)
- Efficiency discussion (30 min)
- Workshop wrap-up (5 min)



# TRL Discussion

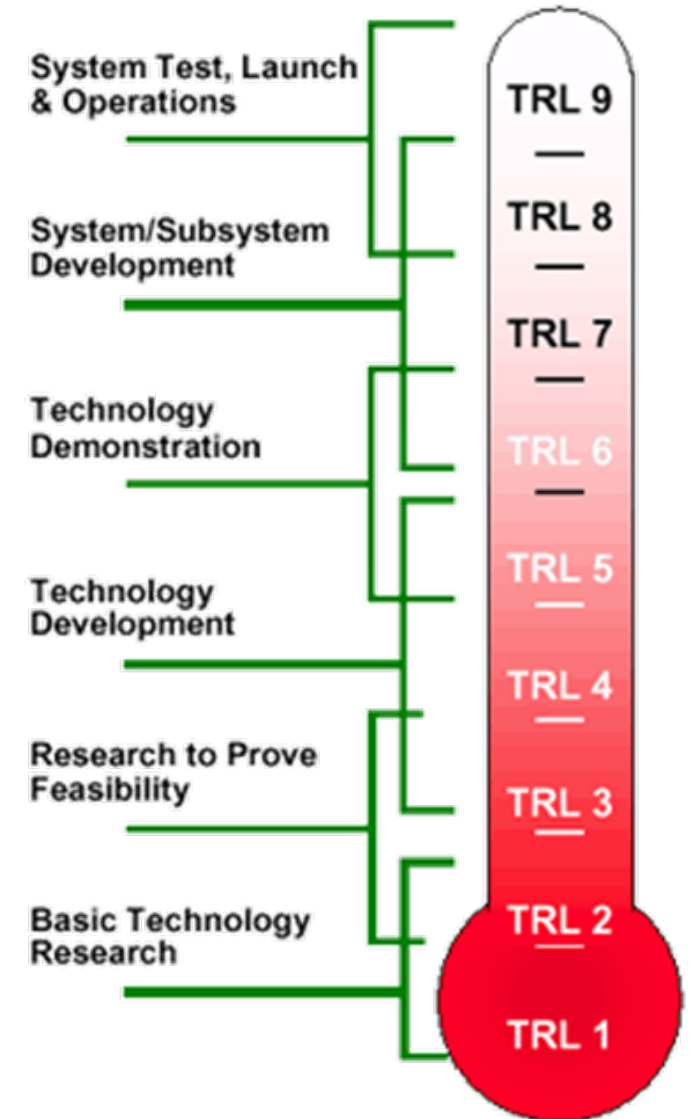
Thomas Liu (NASA GRC)

January 4, 2022

# Micro-Propulsion TRL

**Problem: Application of TRL can be inconsistent, and self-evaluations are frequently overstated**

- 2019 JANNAF paper (Distribution A): *JANNAF Guidelines for the Application of Technology Readiness Levels (TRLs) to Micro-Propulsion Systems*
  - Revised update to AIAA-2016-5113 (Hargus & Singleton)
  - Collaboration between AFRL and NASA (GRC / GSFC / JPL)
  - **Update anticipated for 2022 JANNAF**
- Key features of framework
  - Tailors to micro-propulsion systems for small spacecraft
  - Seeks common ground between DoD / NASA interpretations and terminology
  - Focuses on system rather than component TRL
  - Specifies entrance / exit criteria for TRL

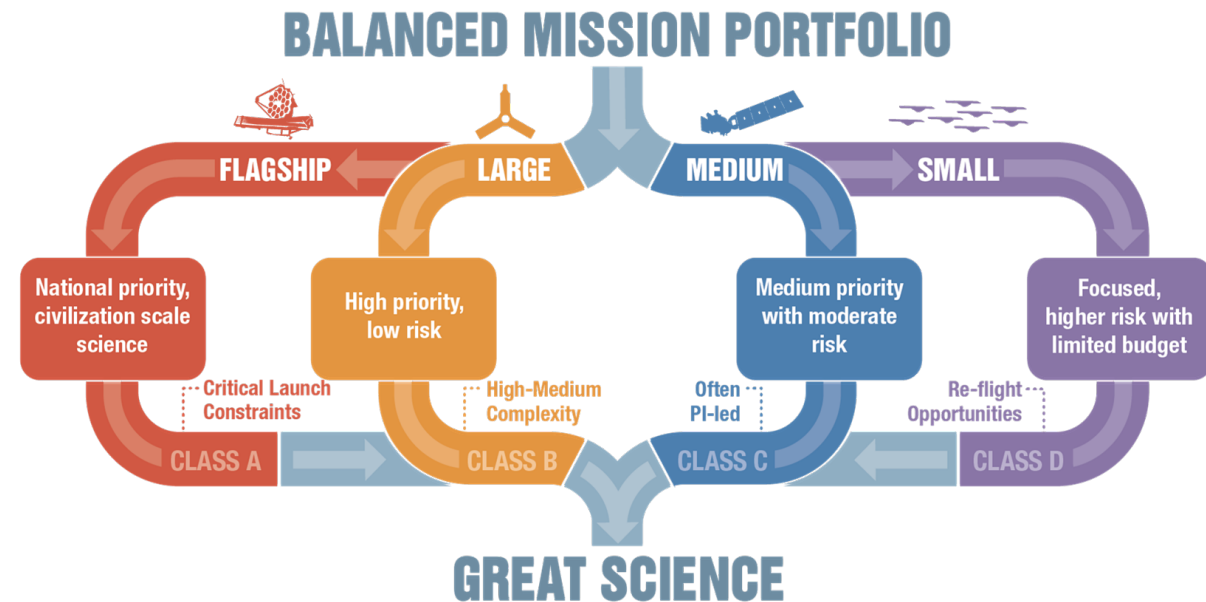


# Micro-Propulsion Design Reference Missions (DRM)



**Problem: Technology development frequently lacks relevant mission application requirements for flight qualification and demonstrations [Colleen Marrese-Reading (NASA JPL)]**

- Reduce risk of micro-propulsion technologies being delivered for flight demonstrations with limited success or failures
- Develop representative DRMs (“eigen-missions”) that capture key mission requirements for guiding technology maturation and validation
- **White paper anticipated for 2022 JANNAF**
- **Workshop anticipated for 2022 / 2023**



TRL 3

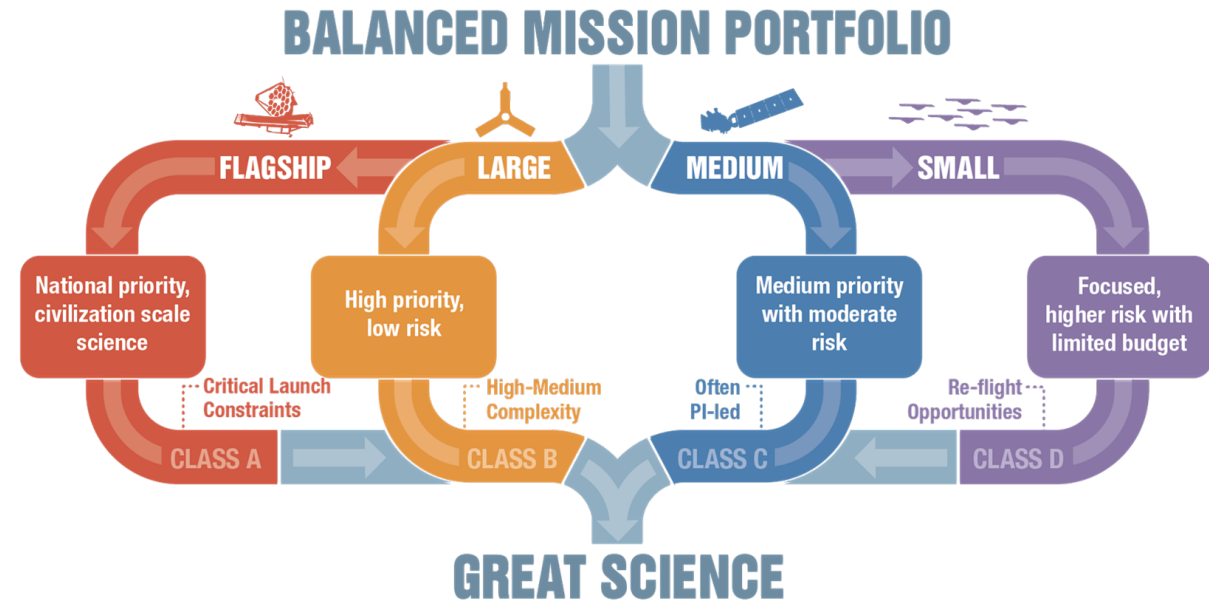


TRL 4+

# EP Qualification for Class-D Missions

**Problem: Need exists to strike better balance between cost effectiveness and engineering rigor**

- Recommended guidelines for a minimum floor of EP flight qualification activities
- Best practices to avoid recurring issues and common pitfalls with EP flight qualification
  - Mission-specific requirements verification
  - Integrated assembly level
  - Test-like-you-fly (TLYF) qualification sequence
- **NASA recommended guidelines anticipated to be released in 2022**



TRL 4/5 → ? → TRL 6/7



# Workshop Wrap-Up



# Thanks!

- AIAA SciTech Forum
- Volunteer speakers
  - Professor Wirz & UCLA
  - Professor Gamero-Castano & UCI
  - Professors Levin & Rovey & UIUC
- Participating audience

## Contacts

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