# Plasma Diagnostics Package (PDP) for Studying High-Power Hall Thrusters in Flight

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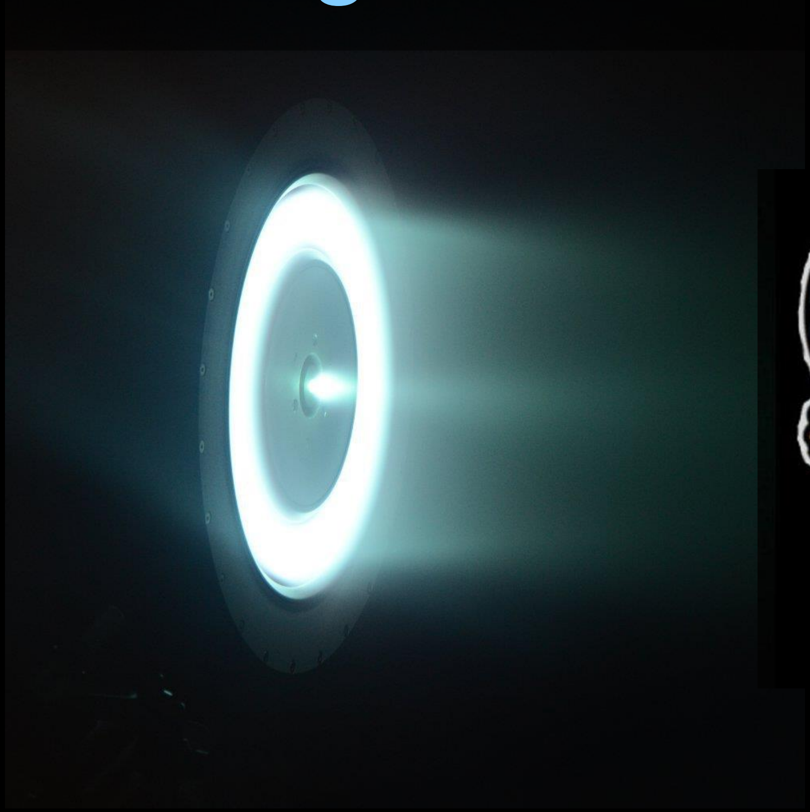
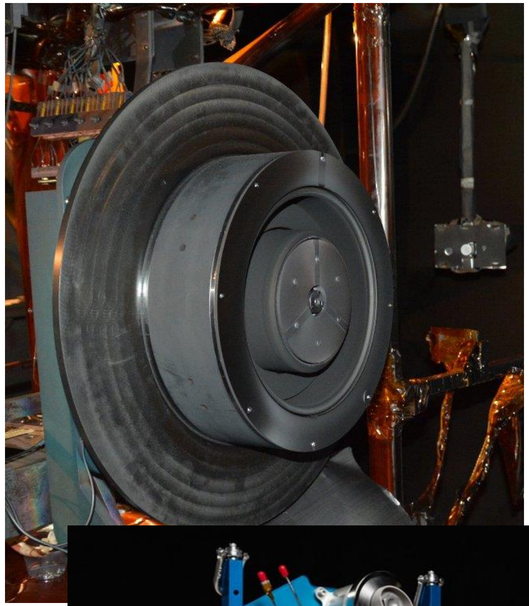
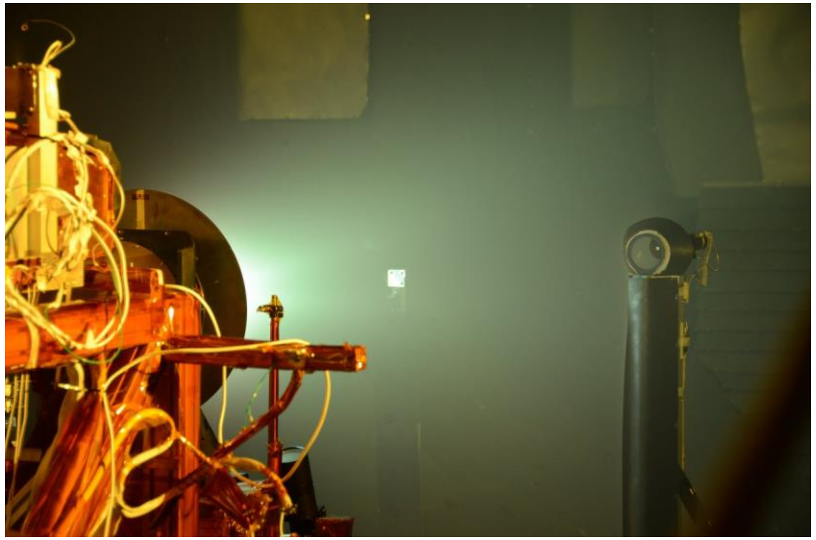
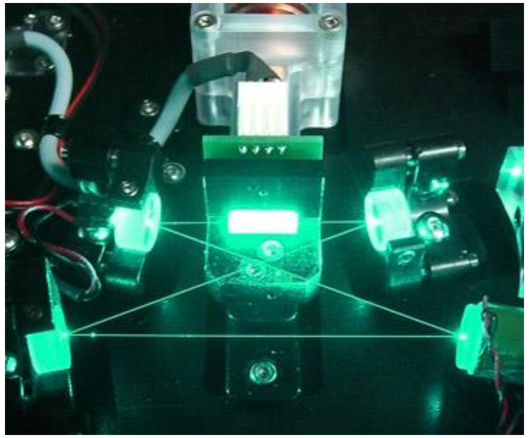


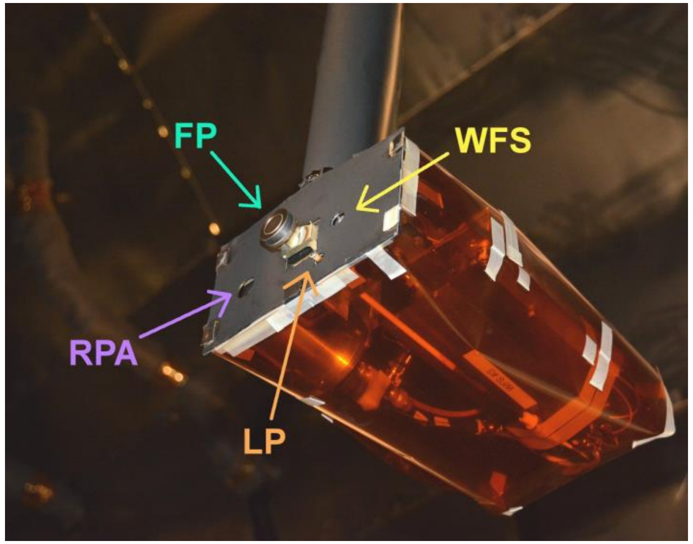
Present at Michigan Institute for Plasma Science and Engineering (MIPSE)
Ann Arbor, Oct 2, 2019

# About Me



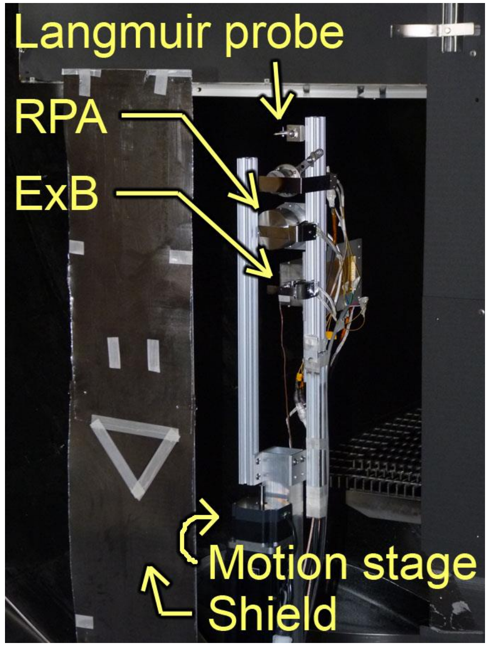




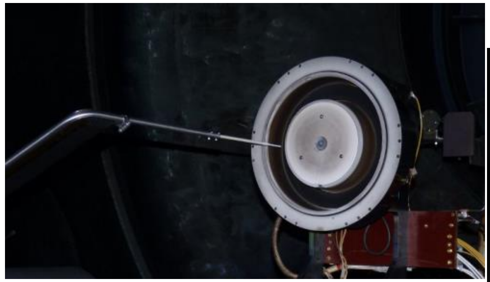


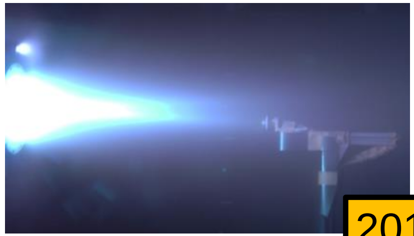
# The path to PI

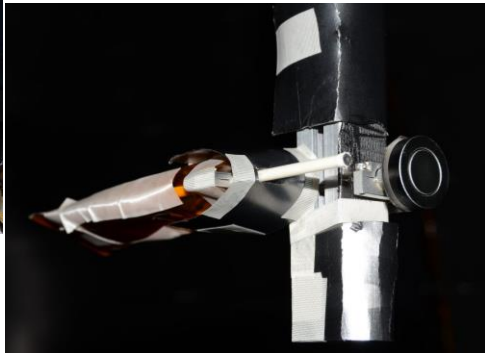
- PI = Principal Investigator, a.k.a. the person with the burning question that needs to be answered

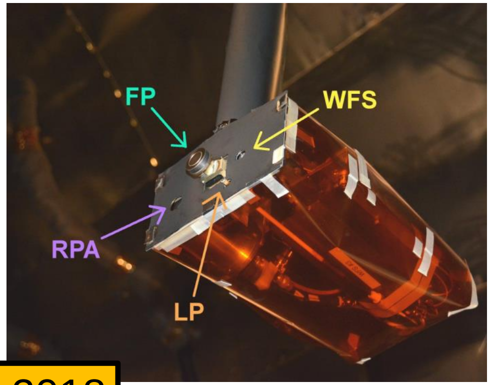



2011

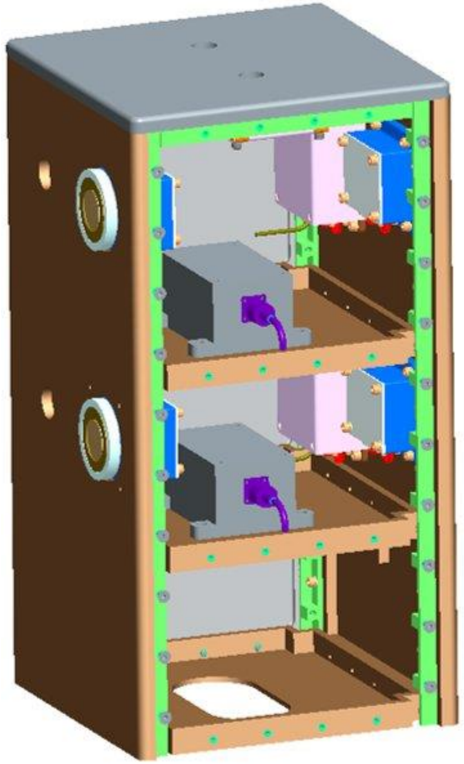









2011-2018



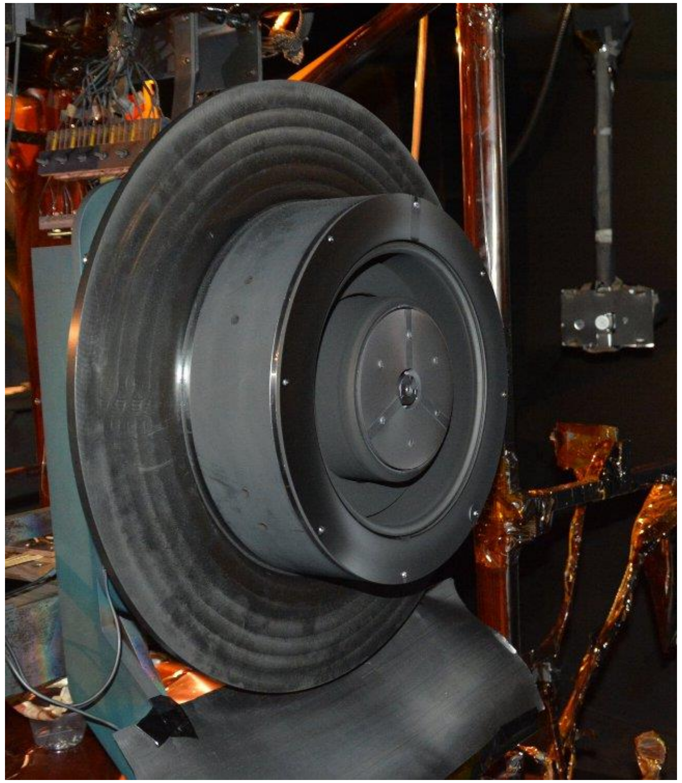
2017+

# Part 1 Outline

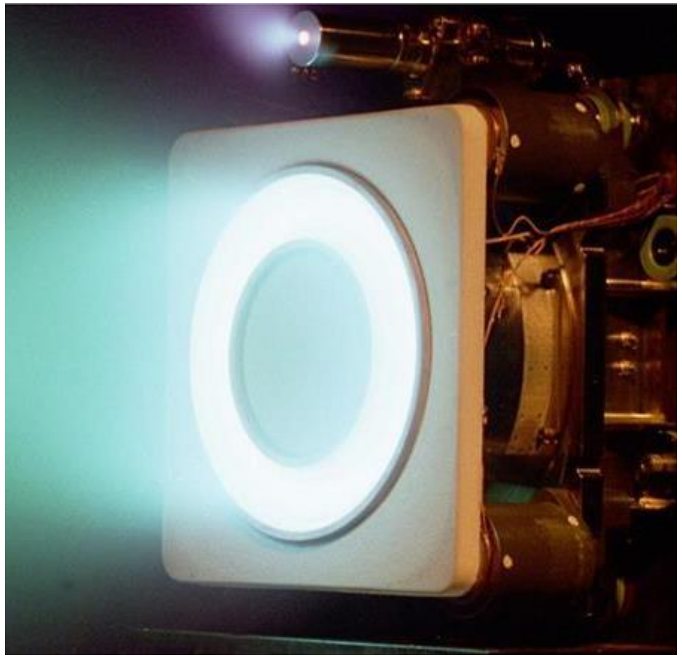
- What is Plasma Diagnostics Package?
  - How did it come about?
  - What question does it answer?
  - What are the measurements and approach?
  - Where are we going to measure?
  - How will we use PDP?

# The story started with HERMeS

- In 2012, NASA Space Technology Mission Directorate initiated the development of high-power long-life Hall thruster: 12.5-kW HERMeS
  - 3x power and 50% higher discharge voltage compared to state-of-the-art thruster (XR-5)
  - Many times longer wear life
- Must be developed with extensibility to higher power thruster (Mars transport)
  - Need on-orbit data to provide feedback for the next design



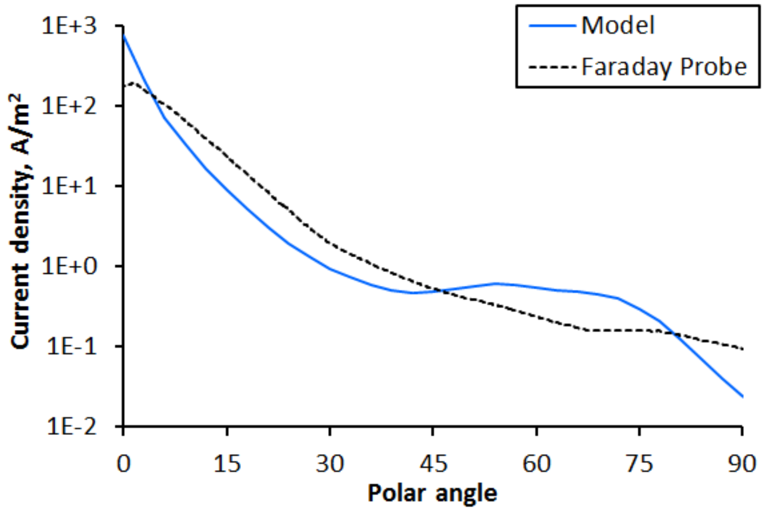
HERMeS

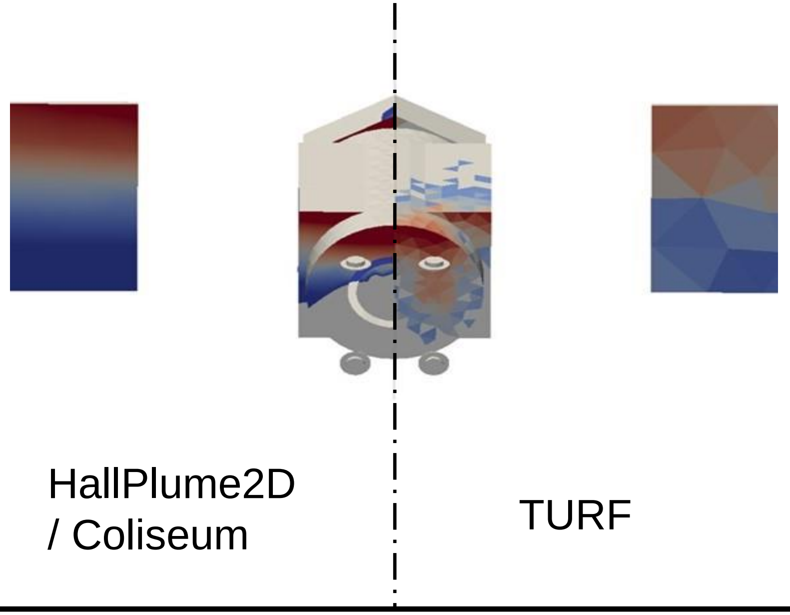


XR-5

# What will the plasma plume of HERMeS do to the spacecraft?

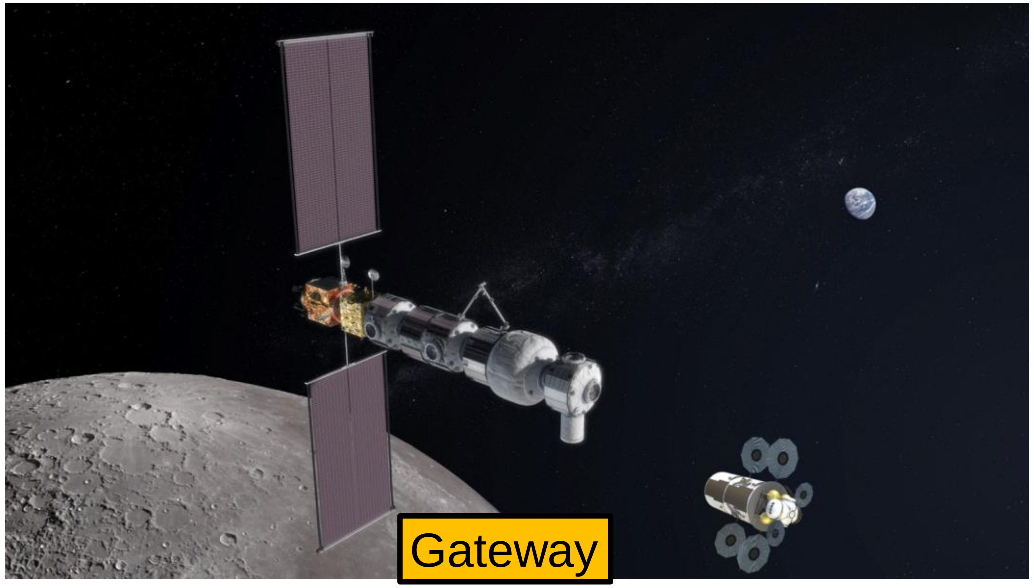
- Flight thruster system has built-in basic telemetry but no plume data
- Large uncertainties in plasma plume predictions
  - Leads to large stay out zones and protective shielding
- Strong evidence from earlier probe packages of differences between ground test and on-orbit behaviors
- Need to fly a probe package: Solar Electric Propulsion (SEP) Plasma Diagnostics Package



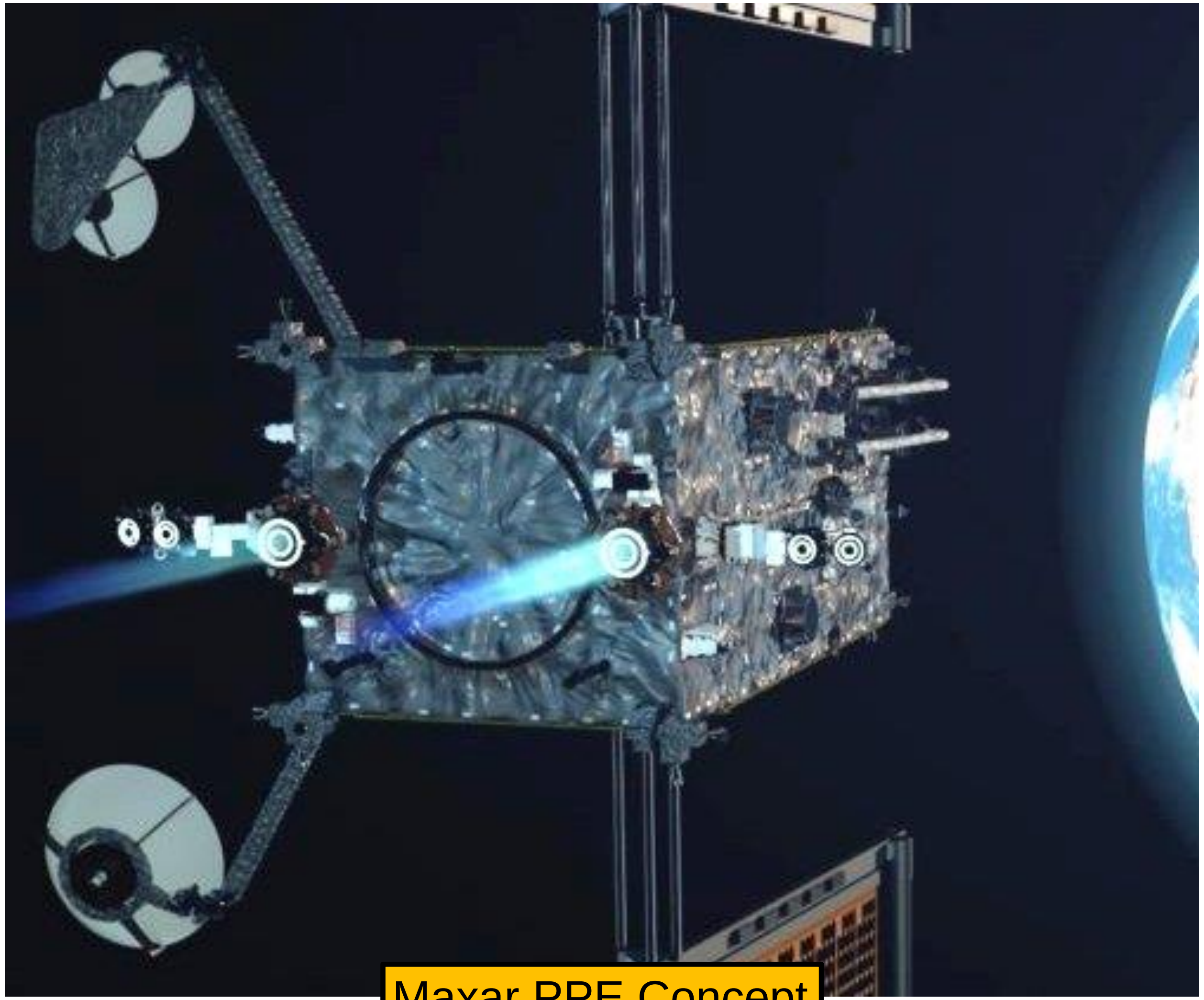



# Then came the Power and Propulsion Element

- PPE, the first element of a Lunar Gateway for return of human presence to the Moon
  - Provides power and propulsion to the rest of Gateway
- Feature two AEPS Hall thrusters (flight version of HERMeS) and four lower power Hall thrusters



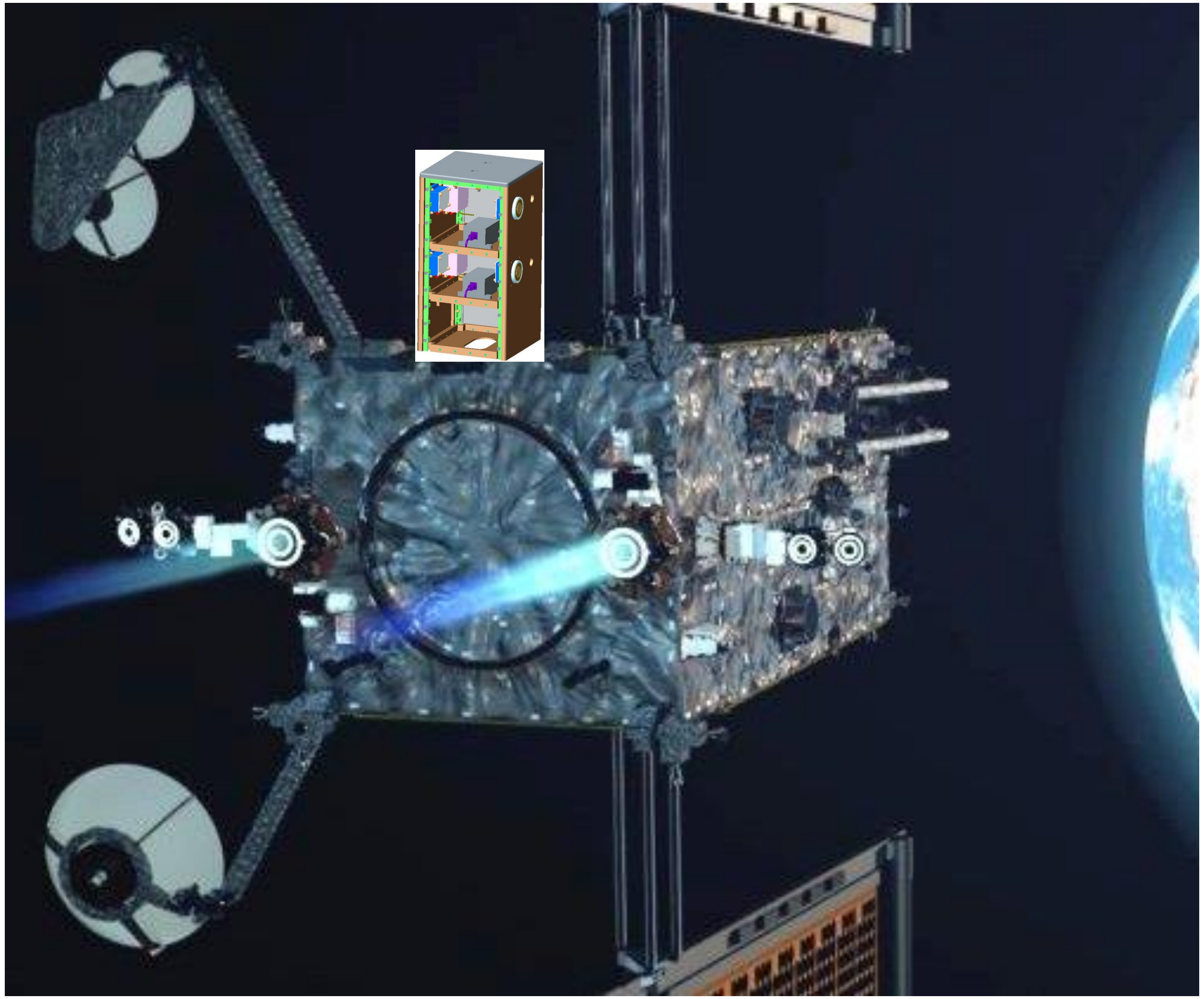
Gateway



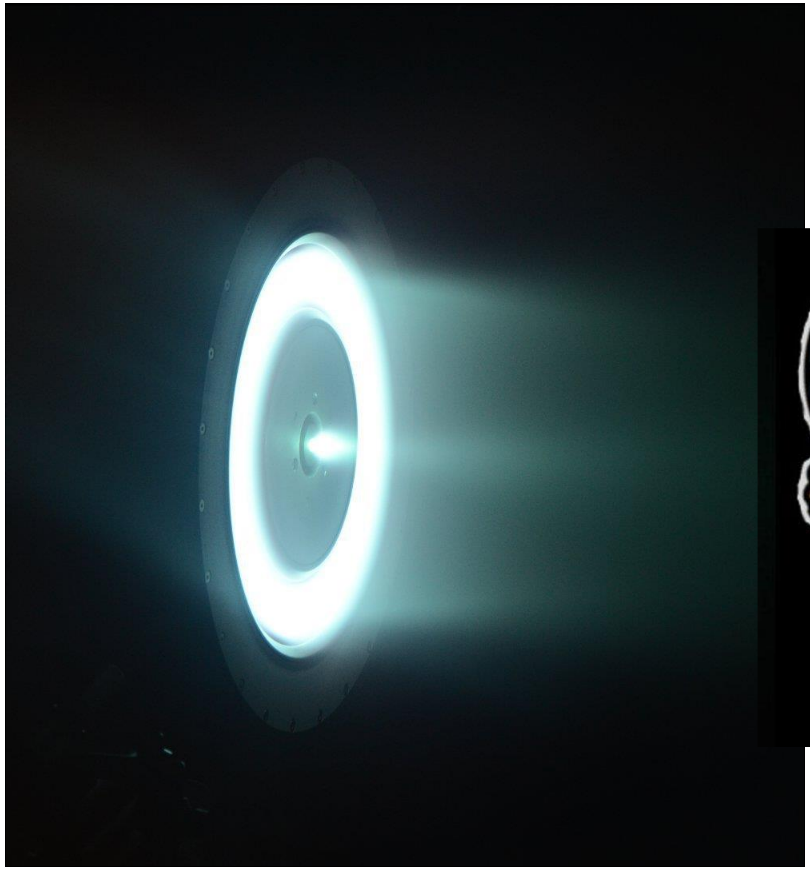
Maxar PPE Concept

# And a partnership was born

- SEP and PPE have common interest: we both want to know what will the plume of the Hall thrusters do to the spacecraft
  - SEP wants to know more about the science for future Hall thruster design
  - PPE wants to know if any changes to spacecraft operation may be needed



# What are we going to measure?
# (Audience exercise)



# Stakeholder Exercises

Initial set:

- 33 pieces of data
- 33 instruments

# What is PDP going to measure?

| # | Name of Data | Location | Notional Sensor |
|---|---|---|---|
| 1 | Discharge current waveforms | IPS PPU | Discharge current sensor |
| 2 | Time-resolved ion flux, electron temperature, plasma potential | TPA | Planar probe (PP) |
| 3 | Ion energy distribution | TPA | RPA and WAPA |
| 4 | Ion charge state | TPA | Charged species spectrometer (ground test only) |
| 5 | Time-resolved/energy-filtered ion characteristics | TPA | HS-RPA |

**IPS:** Ion Propulsion System

**PPU:** Power Processing Unit

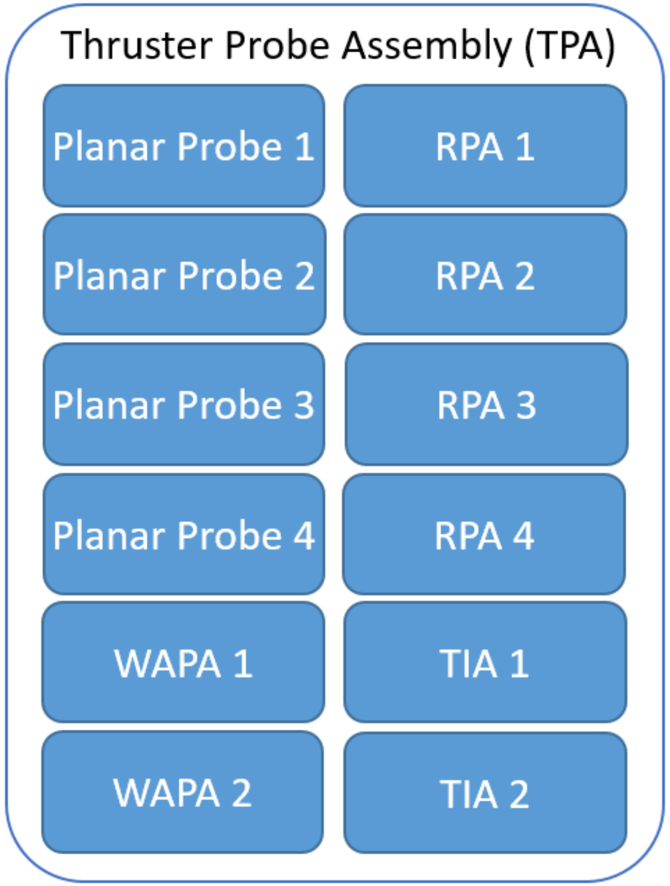
**TPA:** Thruster Probe Assembly

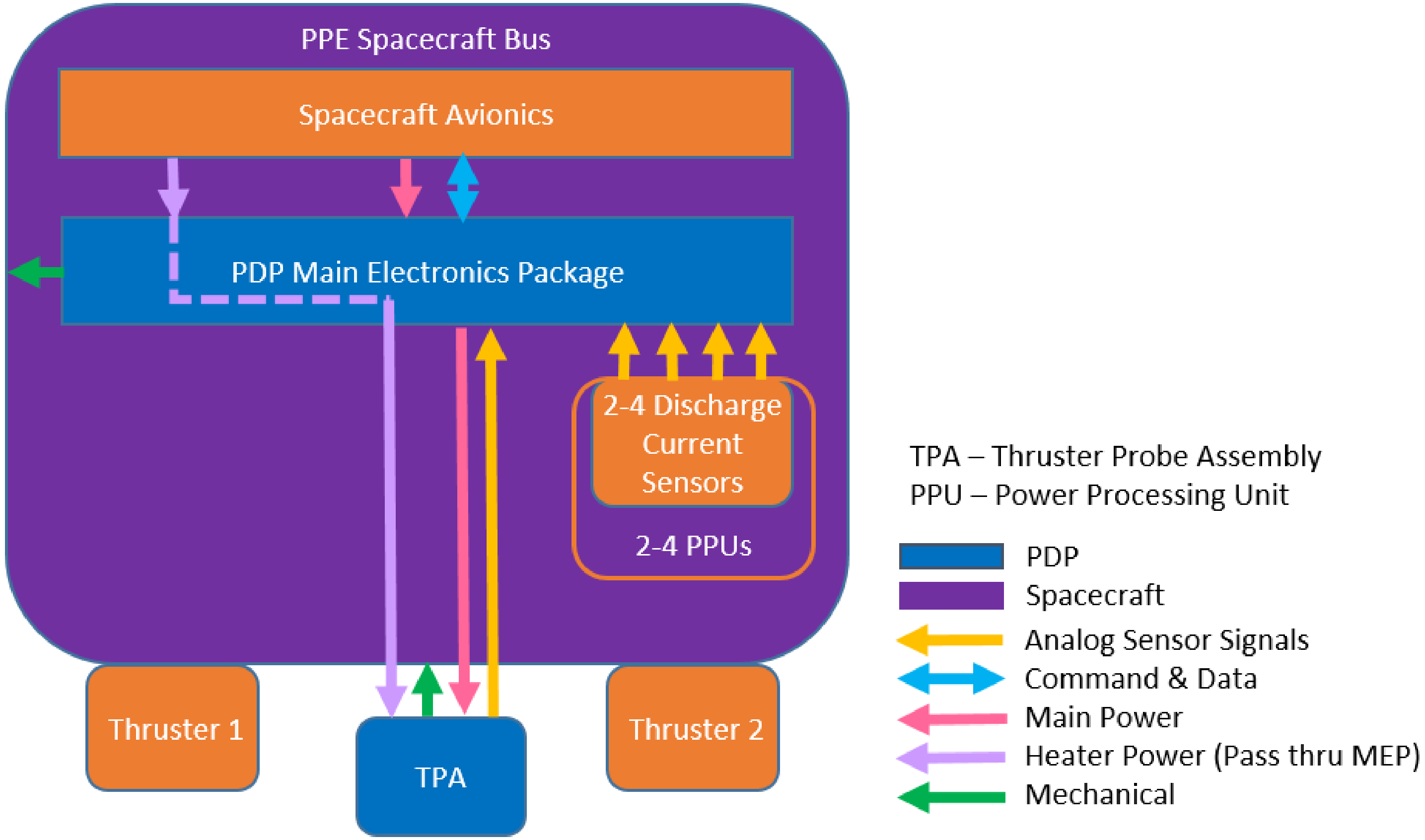
**HS-RPA:** High Speed Retarding Potential Analyzer

**WAPA:** Wide-Angle Potential Analyzer

- Focus on data that improve plasma model so we can make better predictions
- Want data at different time and angular locations with respect to the thruster
- Want data in ground test to serve as baseline

# Architecture: What is PDP's approach to taking the measurements?




**TIA:** Trans-Impedance Amplifier, let's you take high speed RPA measurements

**MEP:** Main Electronics Package, the brain

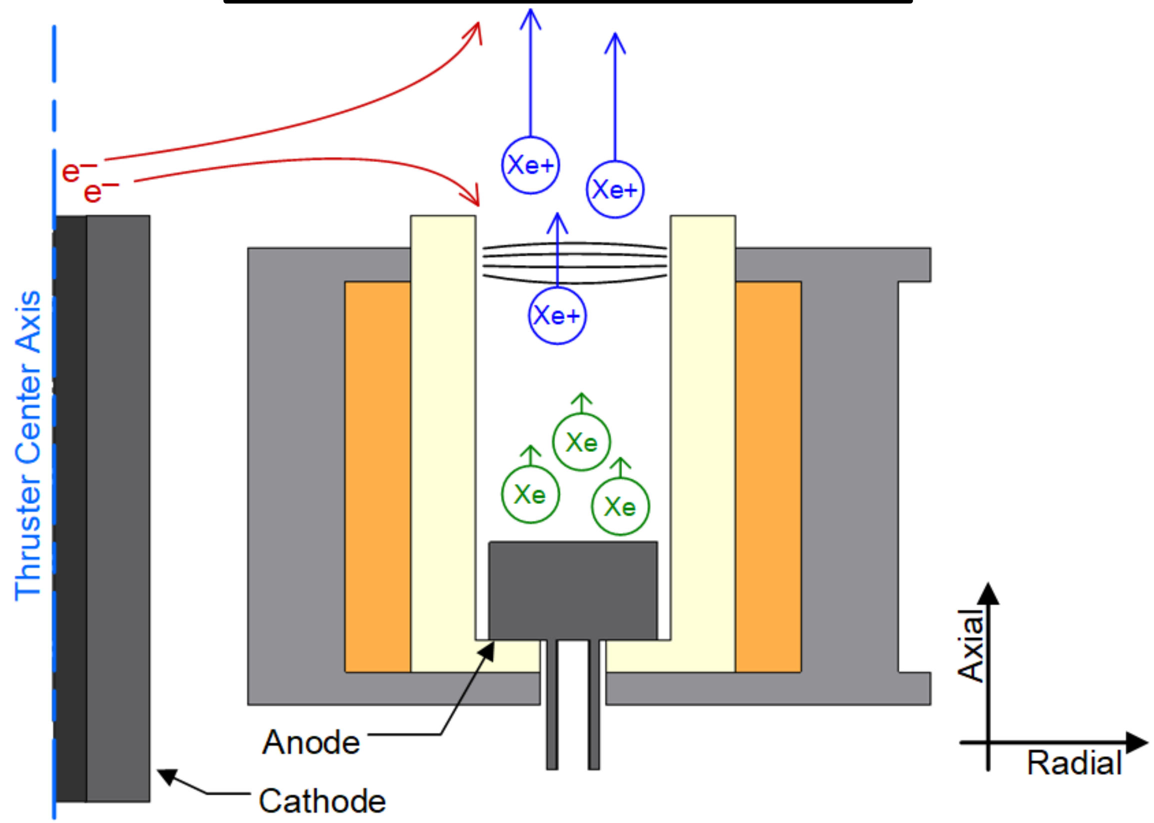
# Where are we going to measure?
# Let's have a closer look at the thruster

- Advanced Electric Propulsion System (AEPS)
  - Built by Aeroject Rocketdyne using HERMeS as a blueprint
  - Four main throttle points from 300 V to 600 V
  - Magnetic shielding topology
  - Centrally mounted cathode, 7% cathode flow fraction
  - Cathode tied to thruster body

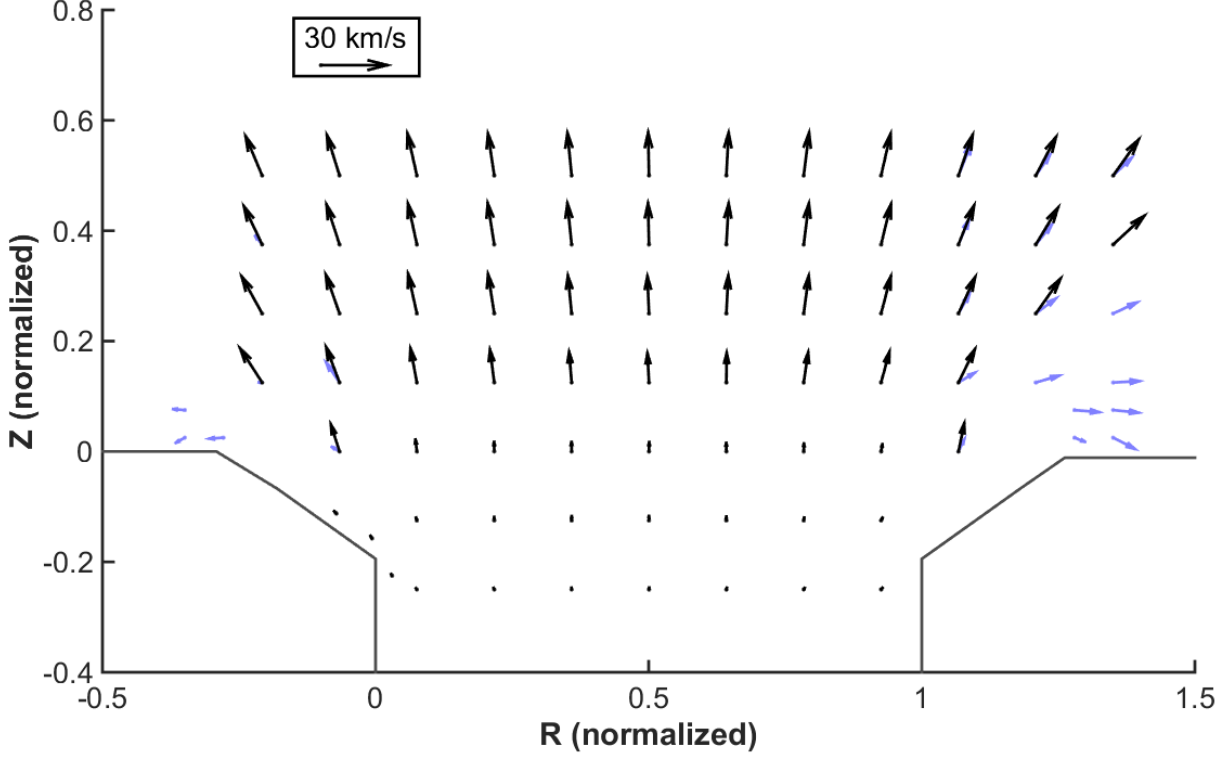
| Discharge voltage, V | Discharge power, kW |
|---|---|
| **300** | 6.25 |
| **400** | 8.33 |
| **500** | 10.42 |
| **600** | 12.50 |

# Hall thrusters can spray plasma side ways

Simple diagram of Hall thruster

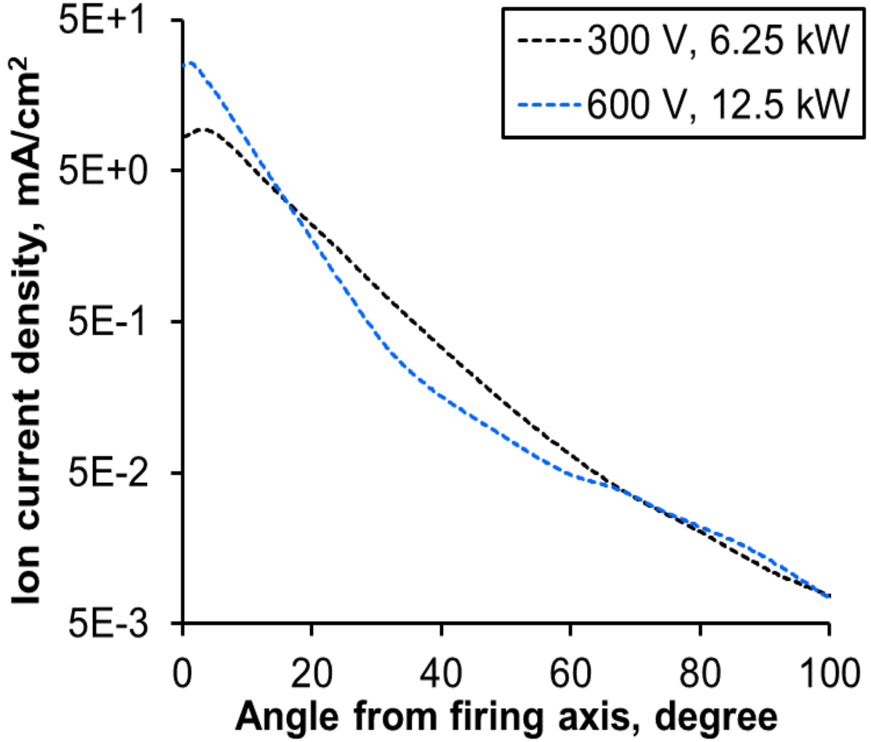


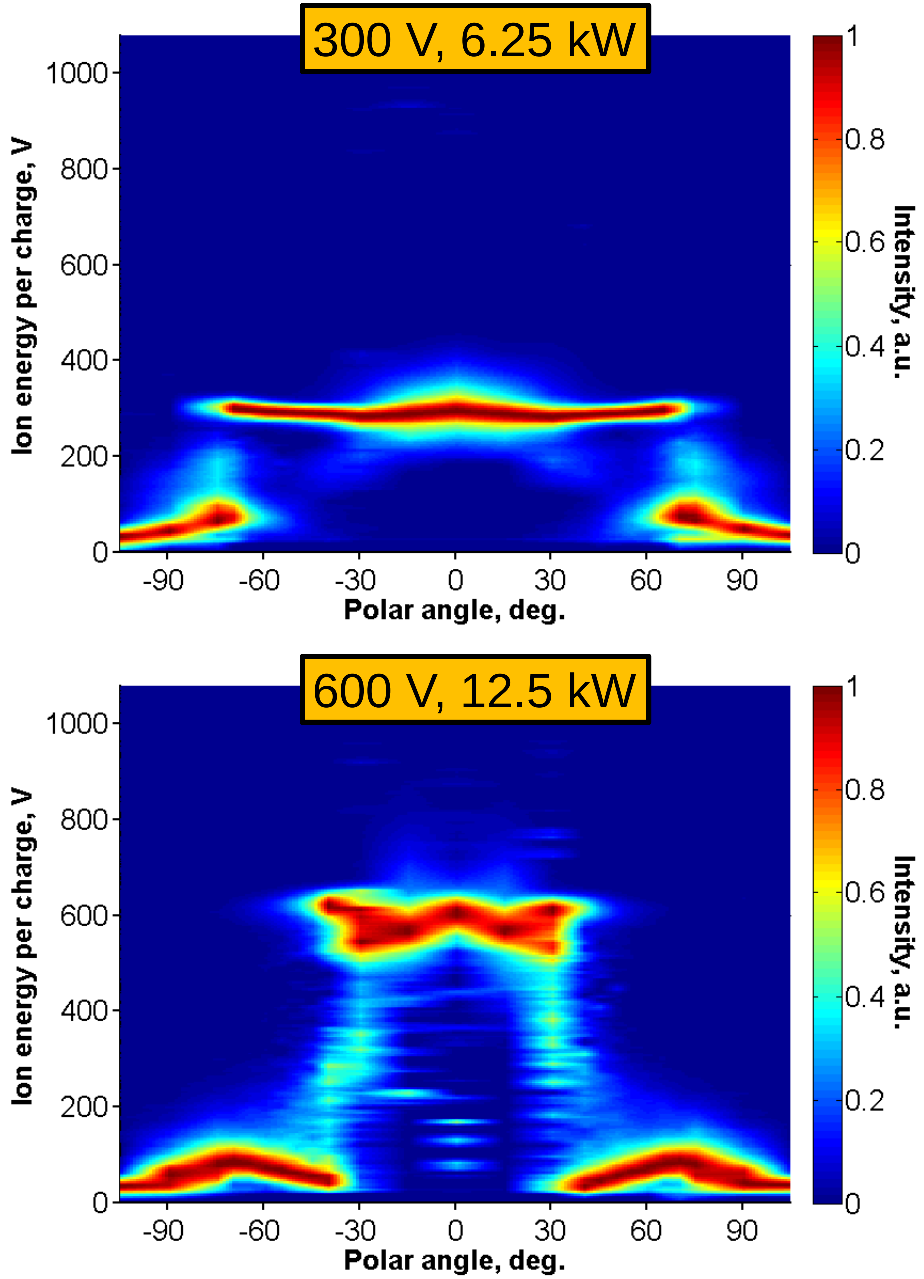

Ion Velocity Vector from HERMeS
300 V, 6.25 kW



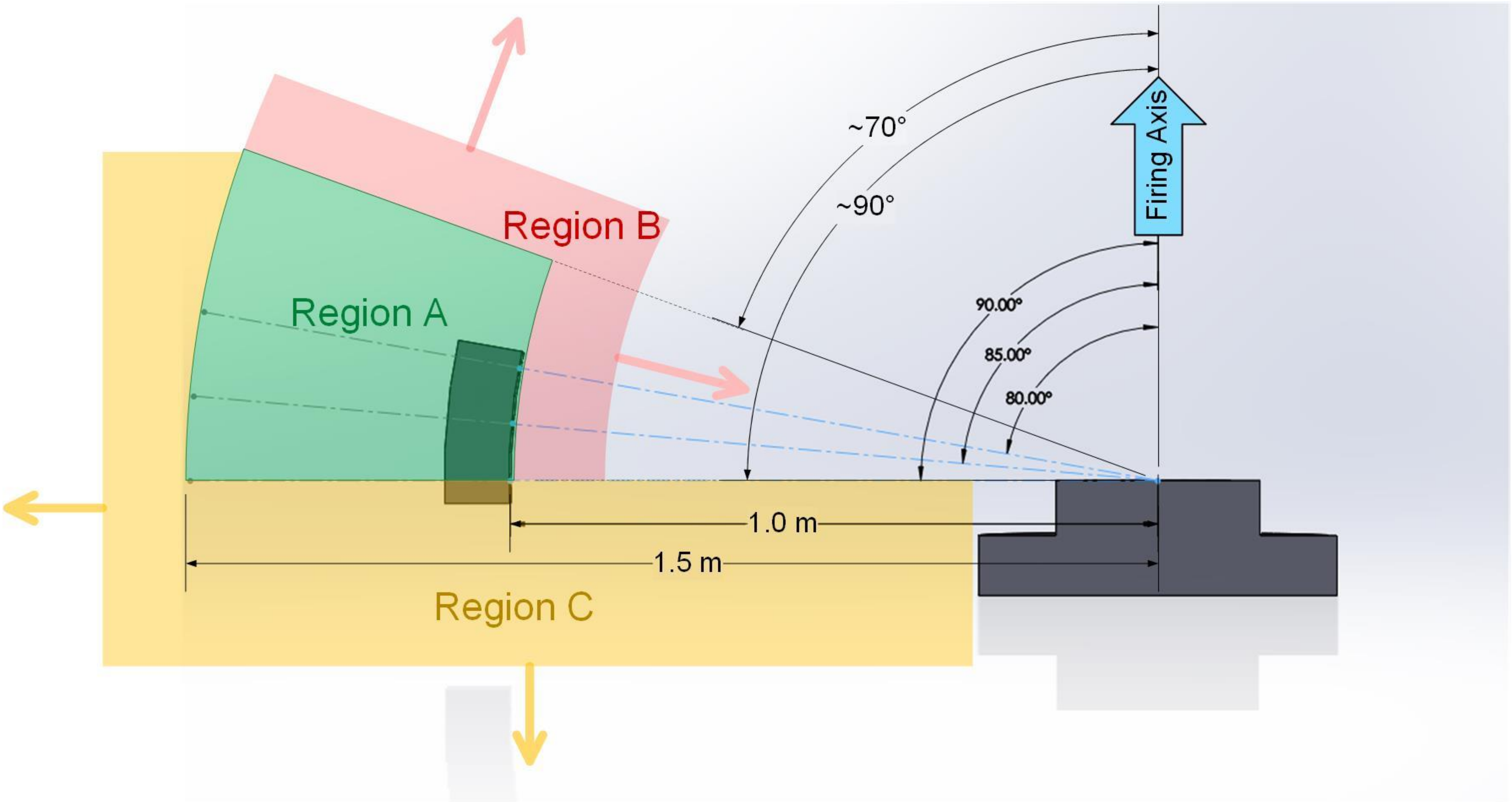

Generally a cold plasma: Ions and electrons are not thermalized with each other

# What does that plasma plume look like?

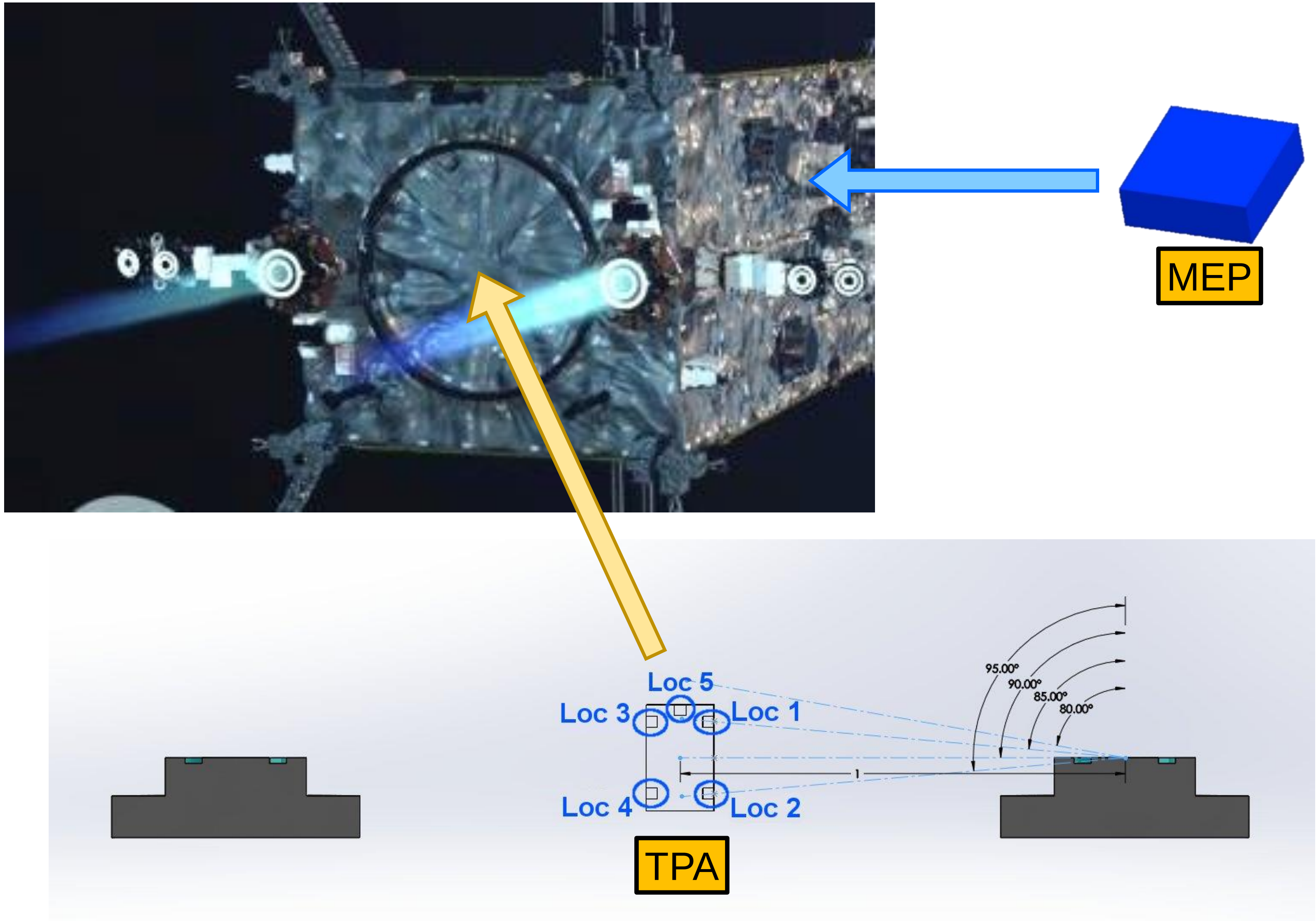


# Where are we going to measure? Ideally..

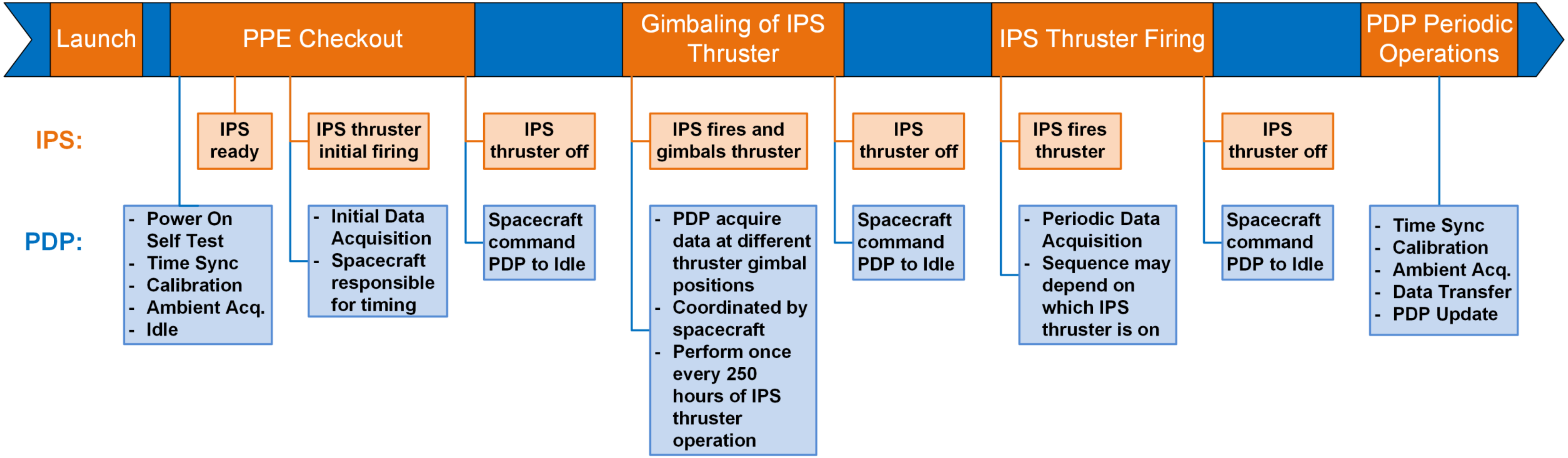


# Where are we really going to measure?




- Loc 1-4: 1 RPA, 1 PP each
- Loc 5: 2 WAPA

# Concept of Operations: How will we measure?



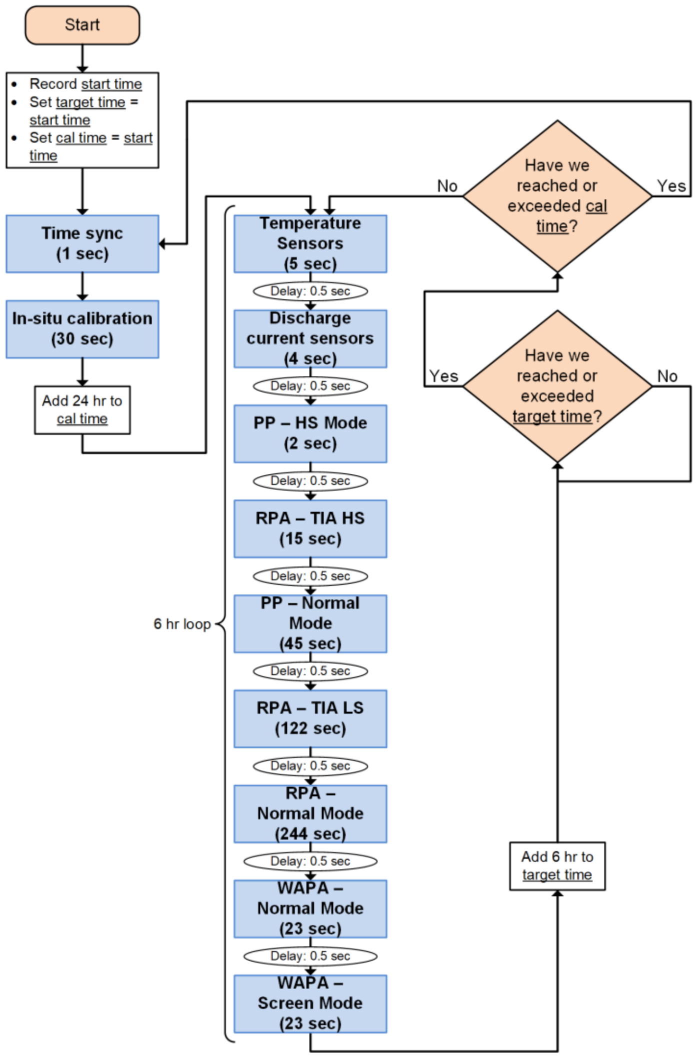

During initial thruster firing:
- Every 10 min for 2 hr
- Every hr for 22 hr

Every once in a while:
- Gimbal thruster towards sensors
- Several angles
- Repeat regularly

After initial firing:
- Take data whenever any thruster is on
- Every 6 hr until forever

# Typical Data Set

- Discharge current sensors (500 kHz)
  - Discharge current waveform
- High speed planar probes (500 kHz, w/DCS)
  - Ion current density fluctuations
- High speed RPAs (500 kHz, w/DCS)
  - 4-5 bias voltages
  - Separate beam ion oscillations from low energy ion oscillations
- Planar probes
  - Plasma potential, electron temperature, plasma density
- RPA and WAPA
  - Ion energy per charge



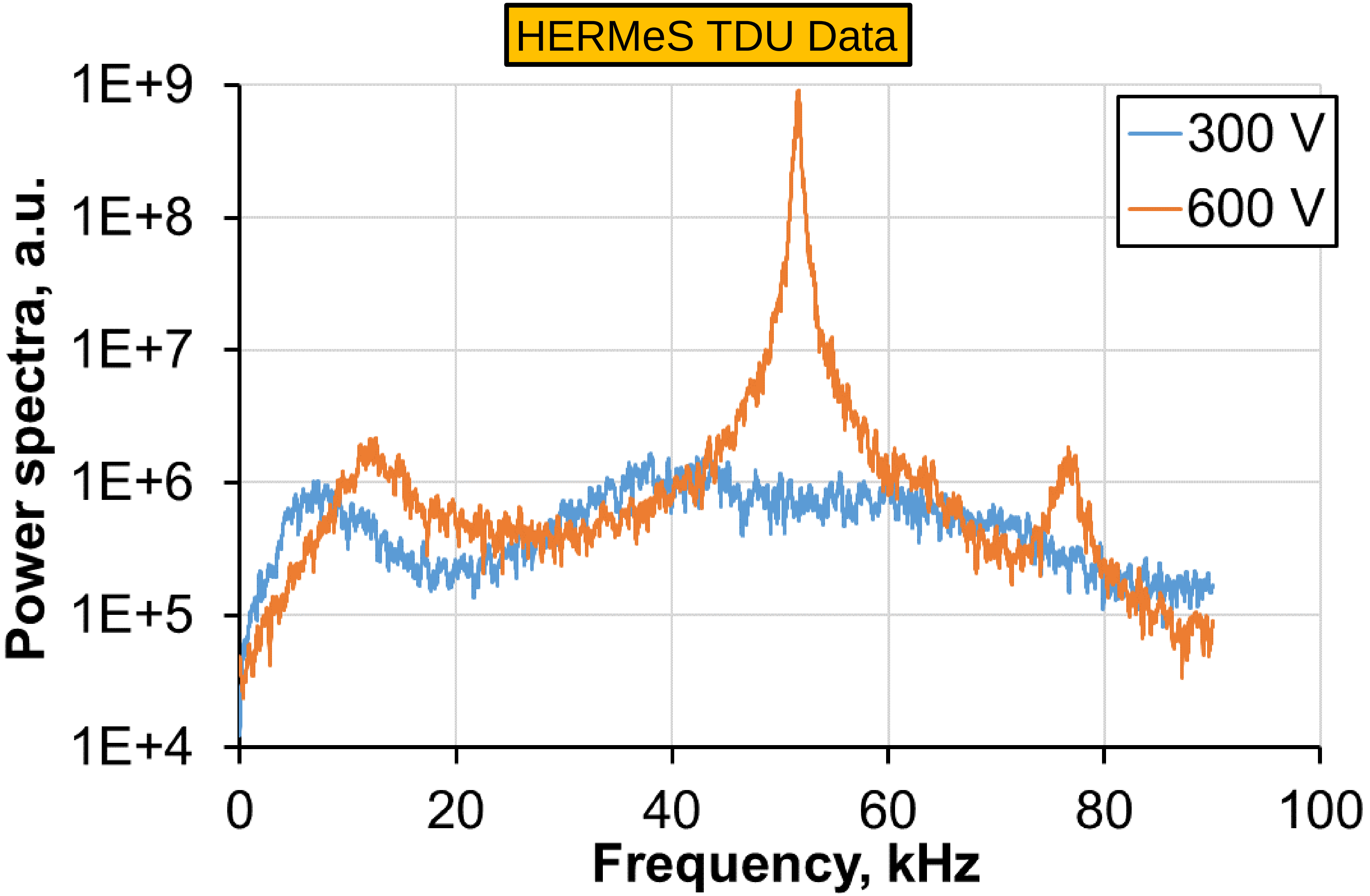
# Part 2 Outline

- How do PDP sensors work?
  - Discharge Current Sensor
  - RPA
  - WAPA
  - Planar Probe

# Discharge Current Sensor

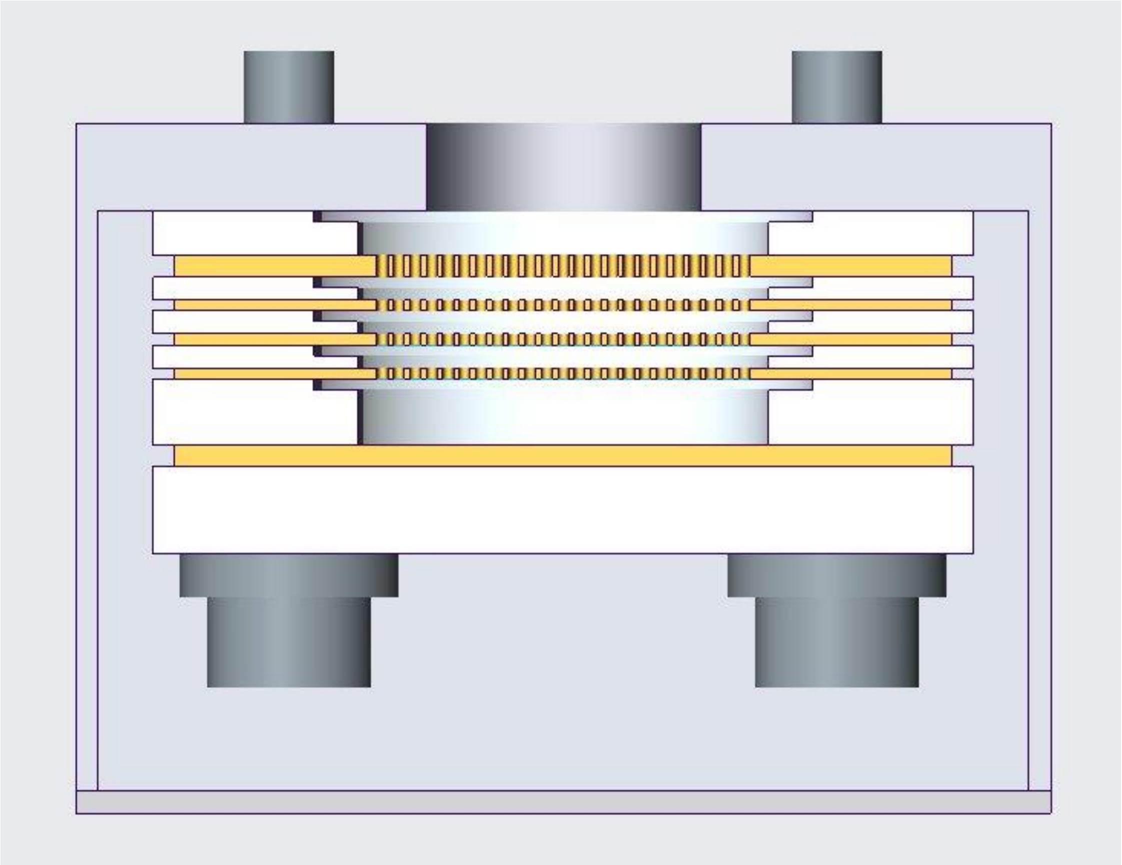
- Precision transformer measuring AC component of thruster discharge current via magnetic induction
  - Strictly speaking not part of PDP but part of IPS PPU
- Cannot instrument thruster directly
- DCS allow us to capture the “state” of the thruster
  - Captures oscillation frequency and magnitude
  - Time-lagged phased portrait

# Discharge Current Sensor Usage

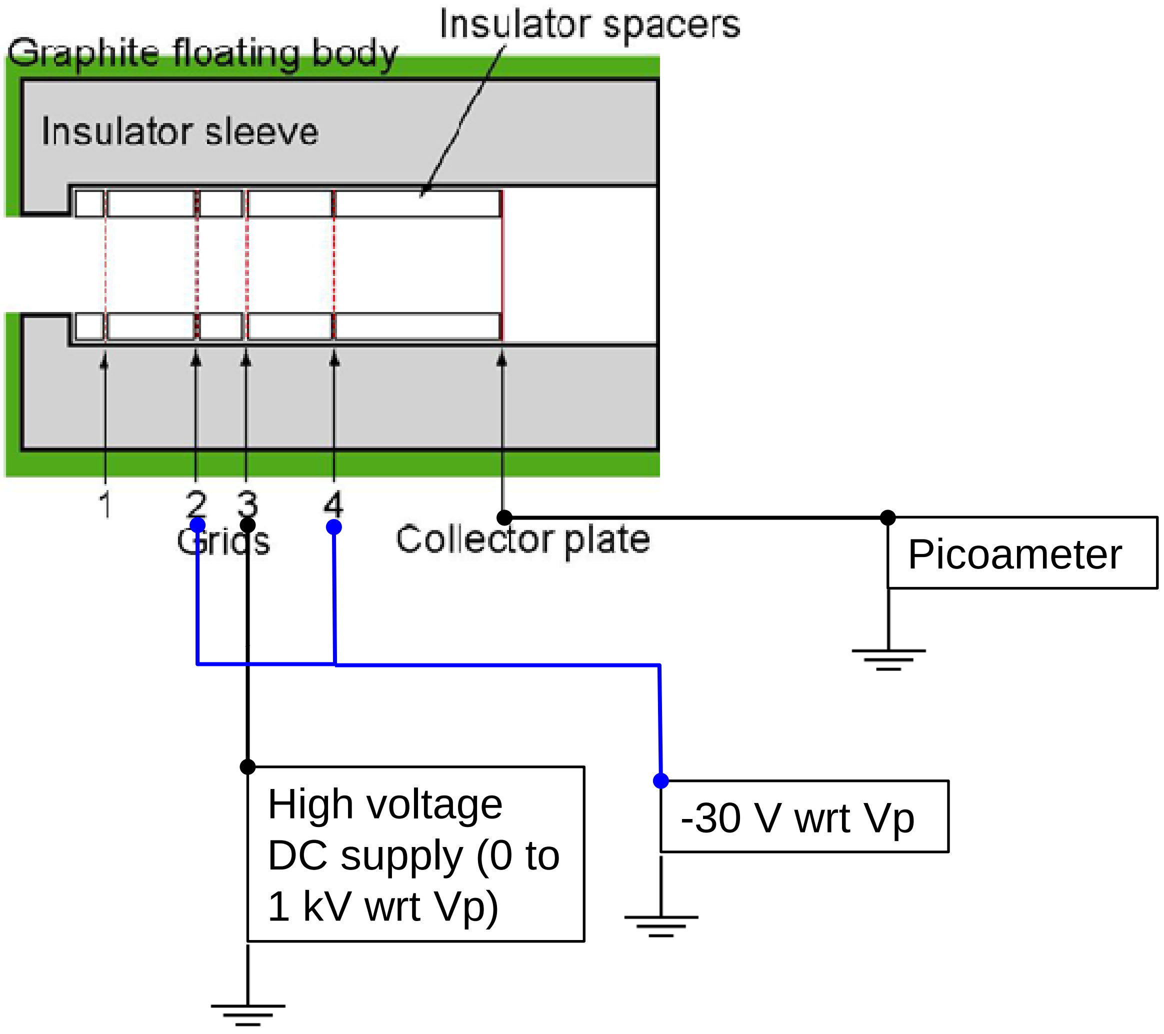


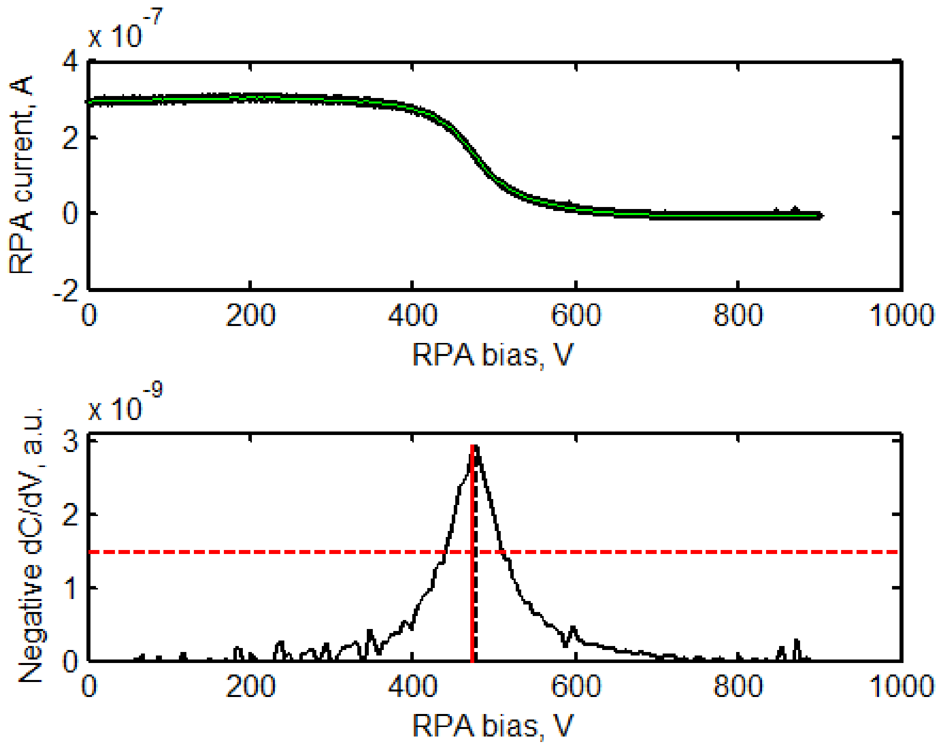
# Retarding Potential Analyzer

- Standard 4-grid design
- Key design parameters:
  - Aperture diameter
    - Electron backstream
  - Grid gap
    - Space charge build up
  - Grid thickness
    - Survive being constantly blasted
  - Acceptance angle
    - Defined by aperture diameter versus stack height
  - Backsputter protection



# RPA Usage

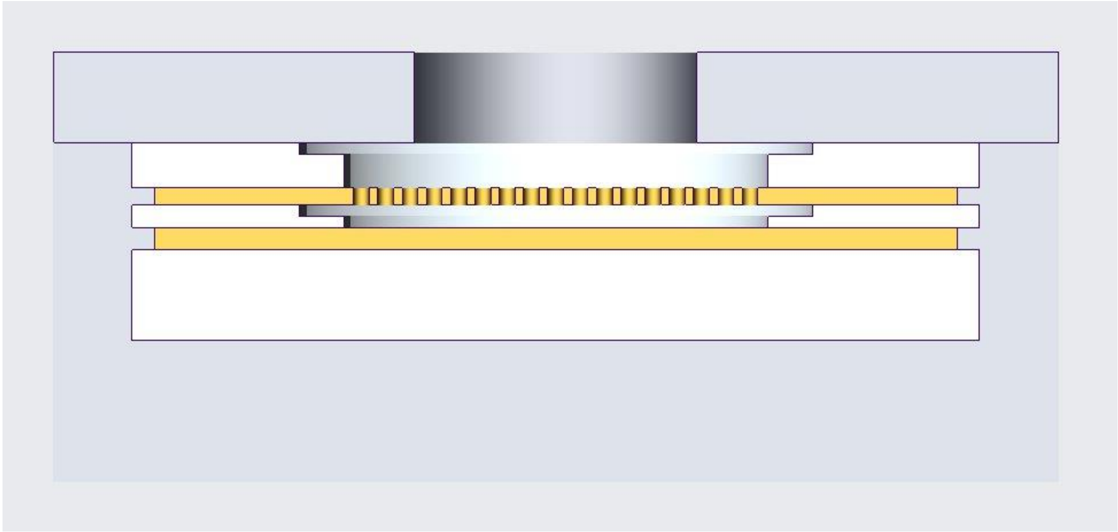


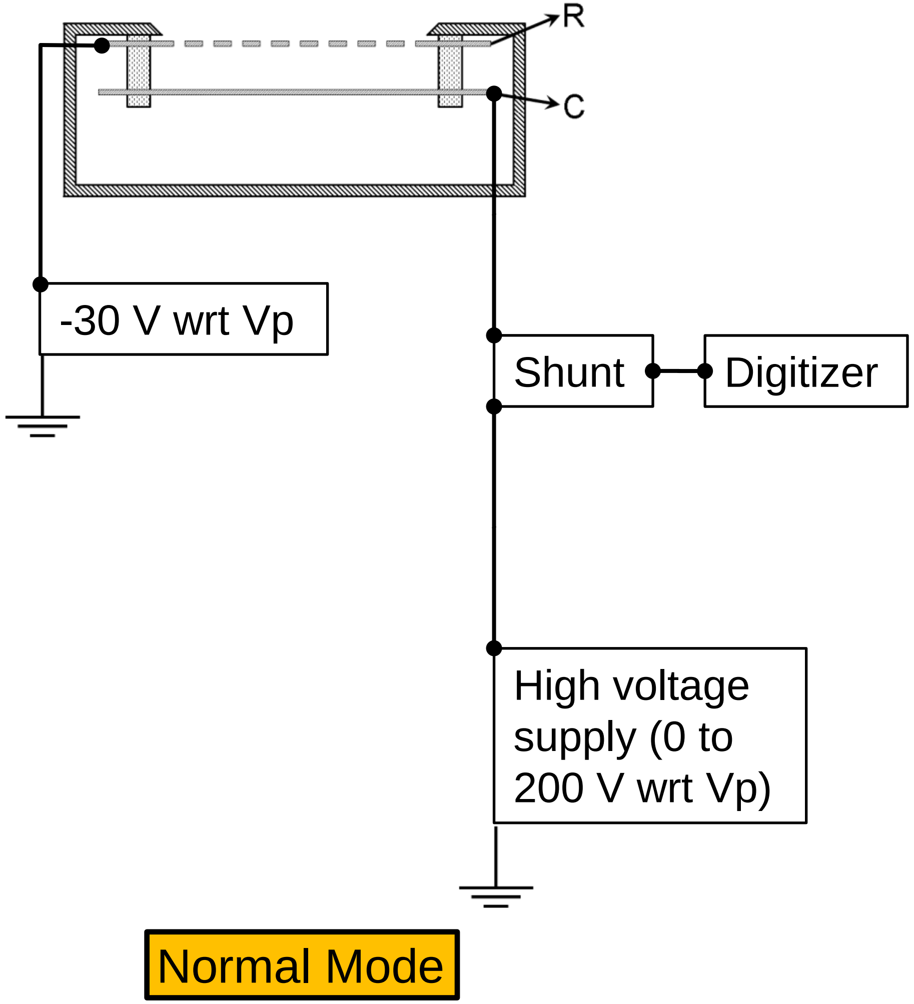

- In high-speed mode, use grid 3 as an ion filter and measure collector at high speed

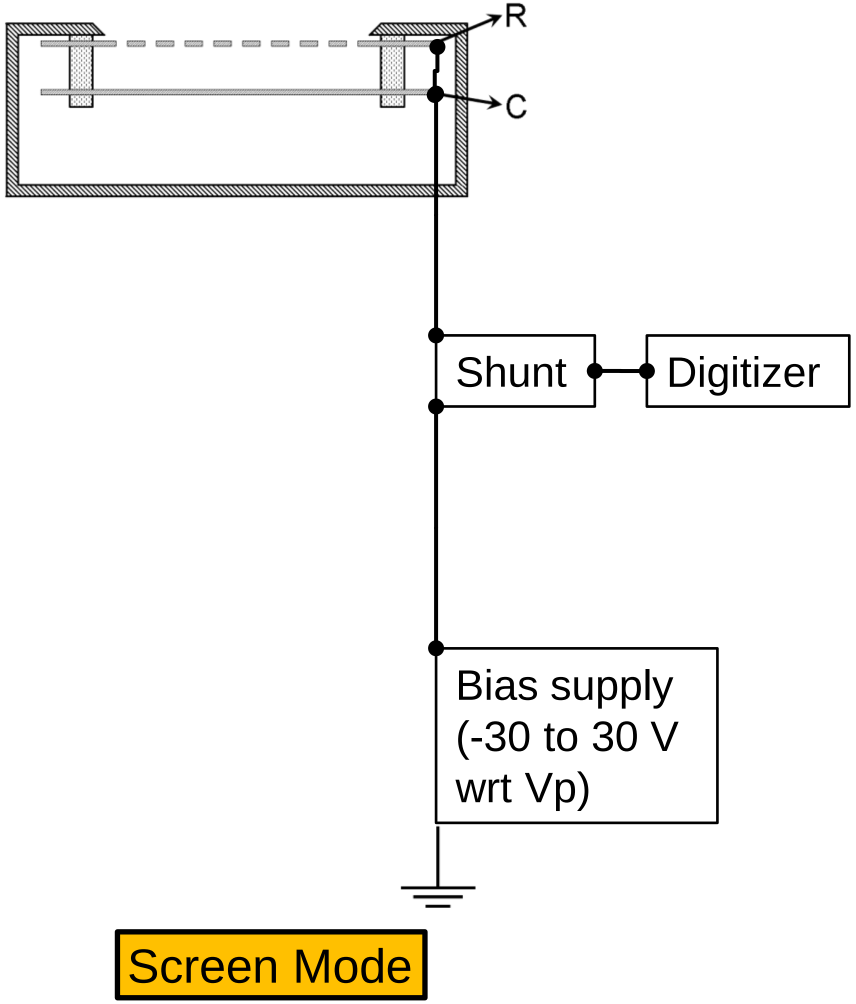
# Wide-Angle Potential Analyzer

- 2-grid design
- Compared to RPA, much wider angle of acceptance but lower energy resolution
- Key design parameters:
  - Aperture diameter
    - Electron backstream
  - Grid gap
    - Space charge build up
  - Grid thickness
    - Survive being constantly blasted
  - Backsputter protection



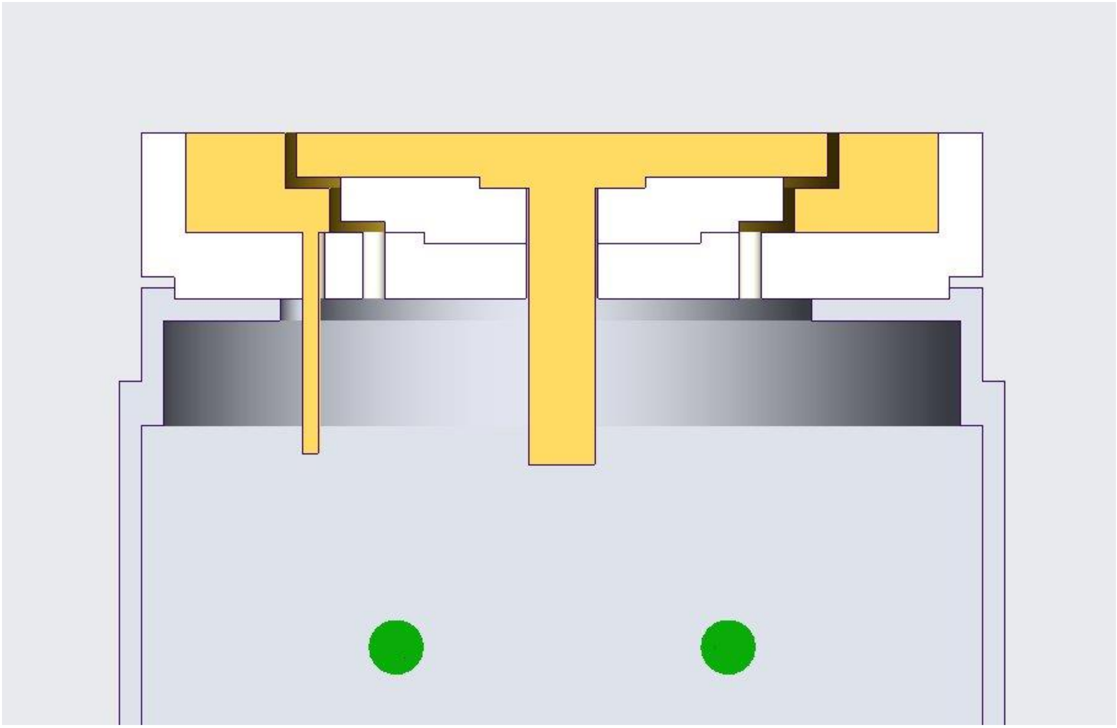
# WAPA Usage


R
C
-30 V wrt Vp
Shunt
Digitizer
High voltage supply (0 to 200 V wrt Vp)
Normal Mode

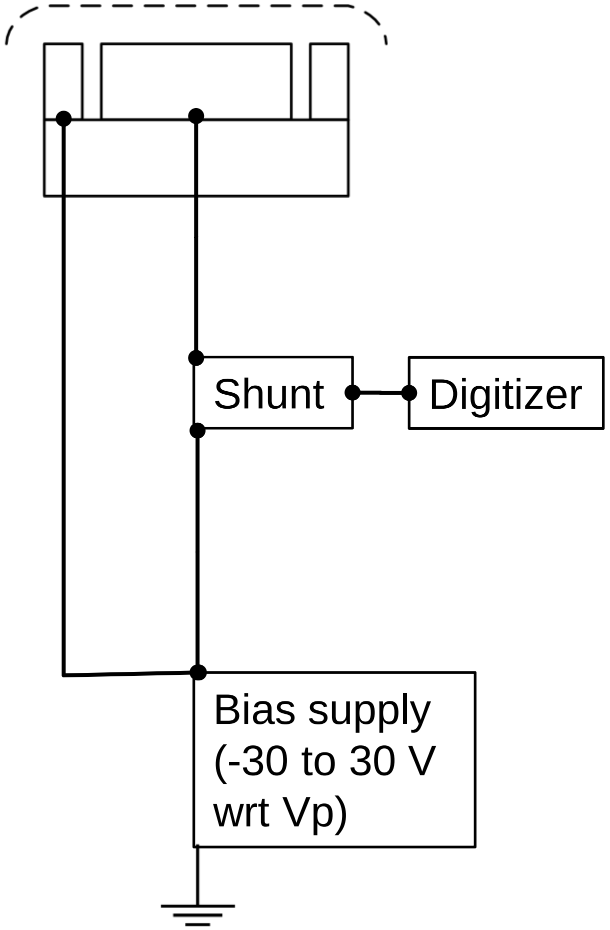

R
C
Shunt
Digitizer
Bias supply (-30 to 30 V wrt Vp)
Screen Mode

# Planar Probe

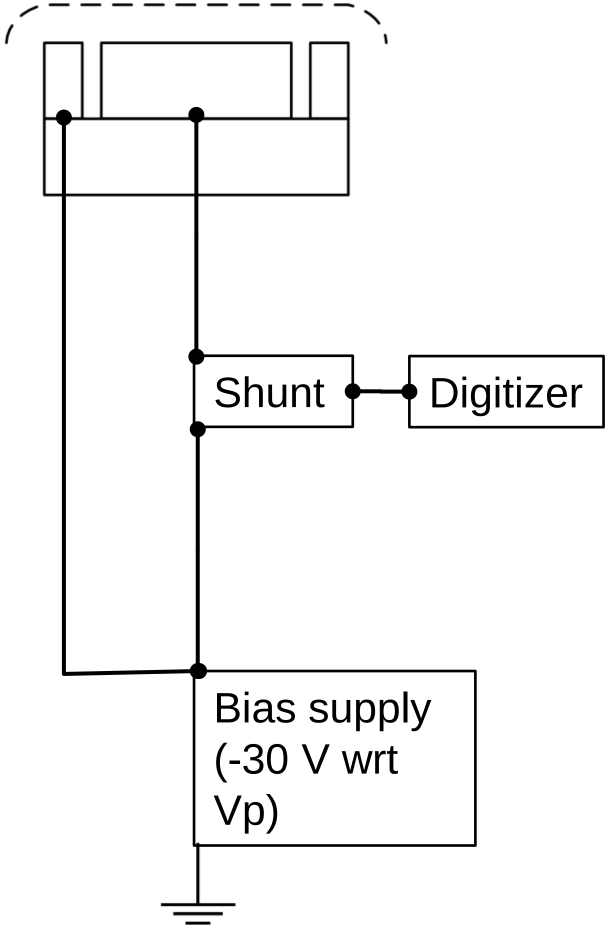
- Planar design with guard
  - Better for directed ions
- Key design parameters:
  - Collection area
    - Need to measure 4.5 orders of magnitude variation in density
  - Collector-guard gap
    - Minimize sheath distortion without shorting
  - Backsputter protection



# PP Usage

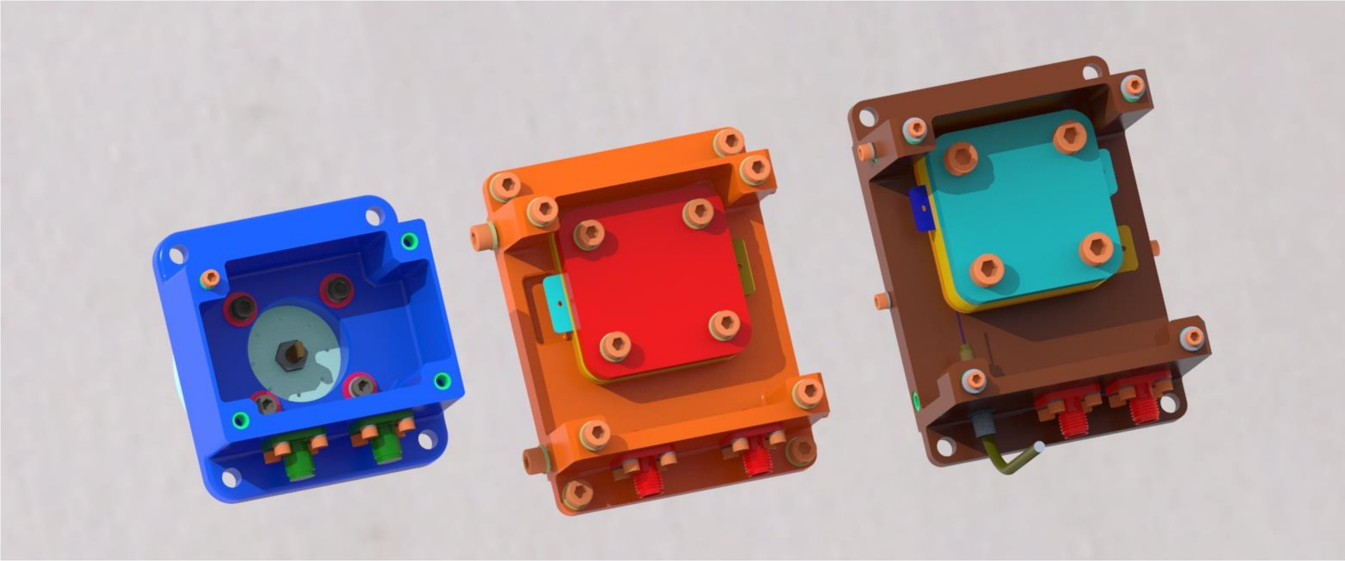


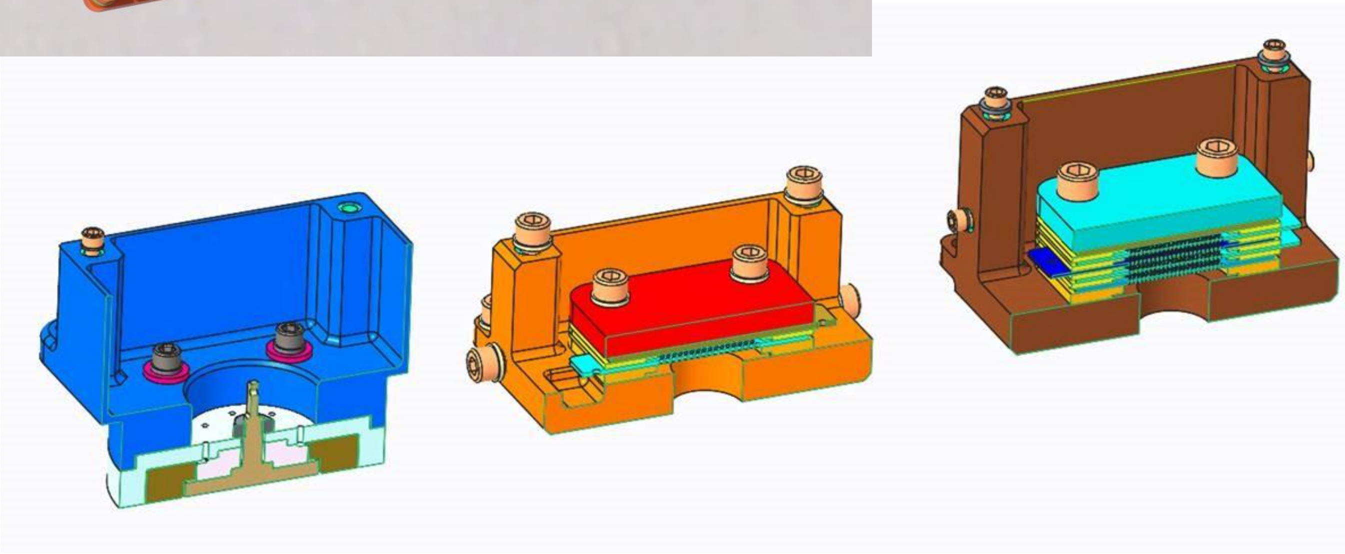

Normal Mode (Langmuir)




High Speed Mode (Faraday)

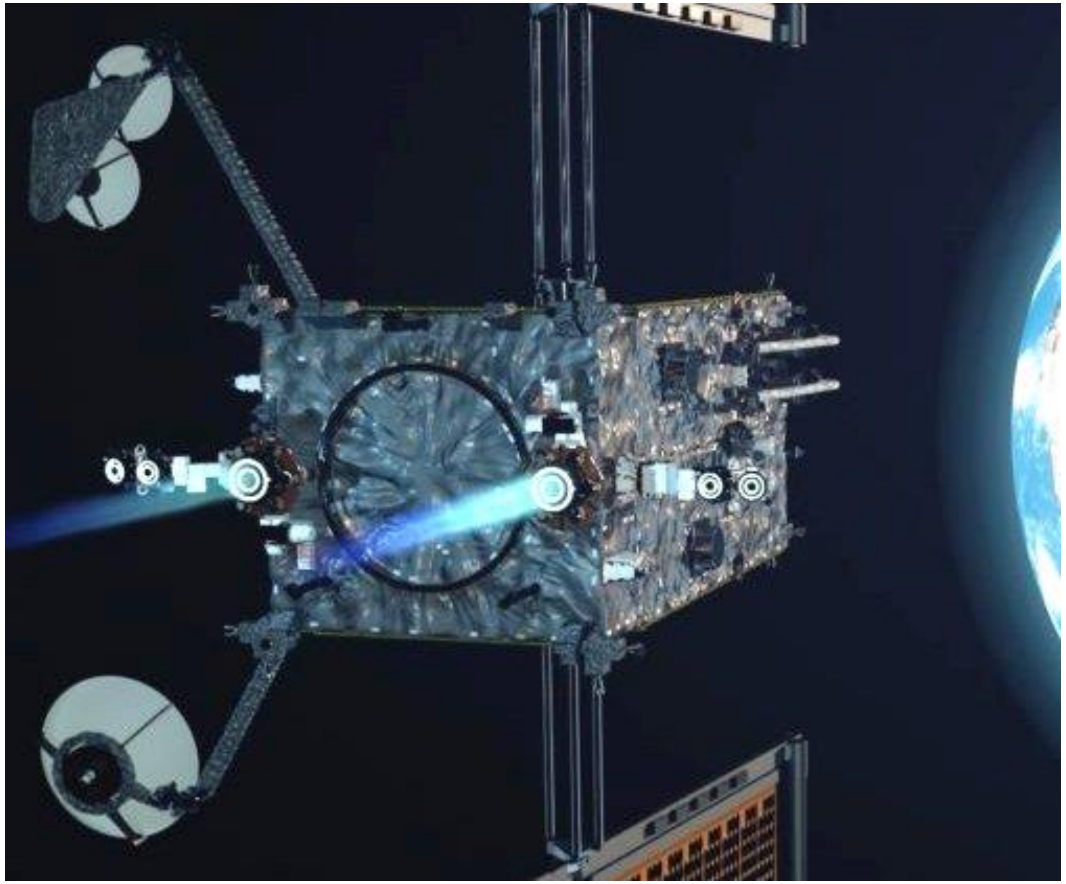
# Design completed, starting fabrication!

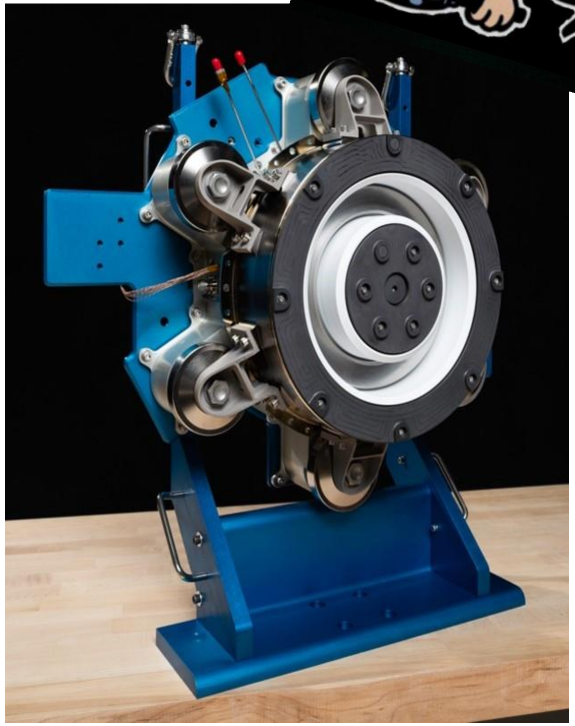


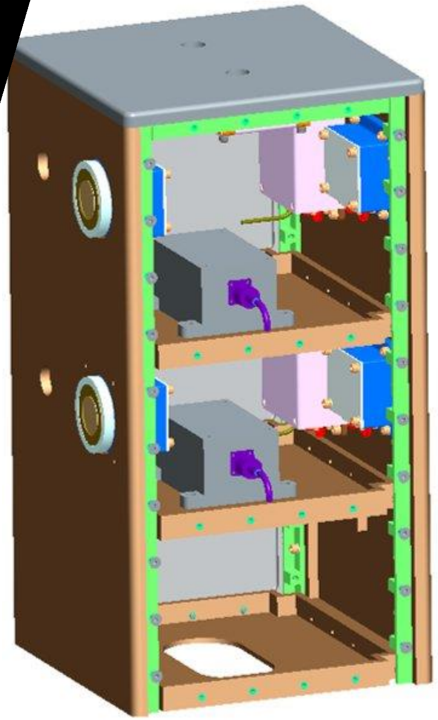


# The PDP Team

# PPE to launch in 2022, look forward to results!







# Questions?