Thermal Cycle Lifetest of Swaged Cathode Heaters

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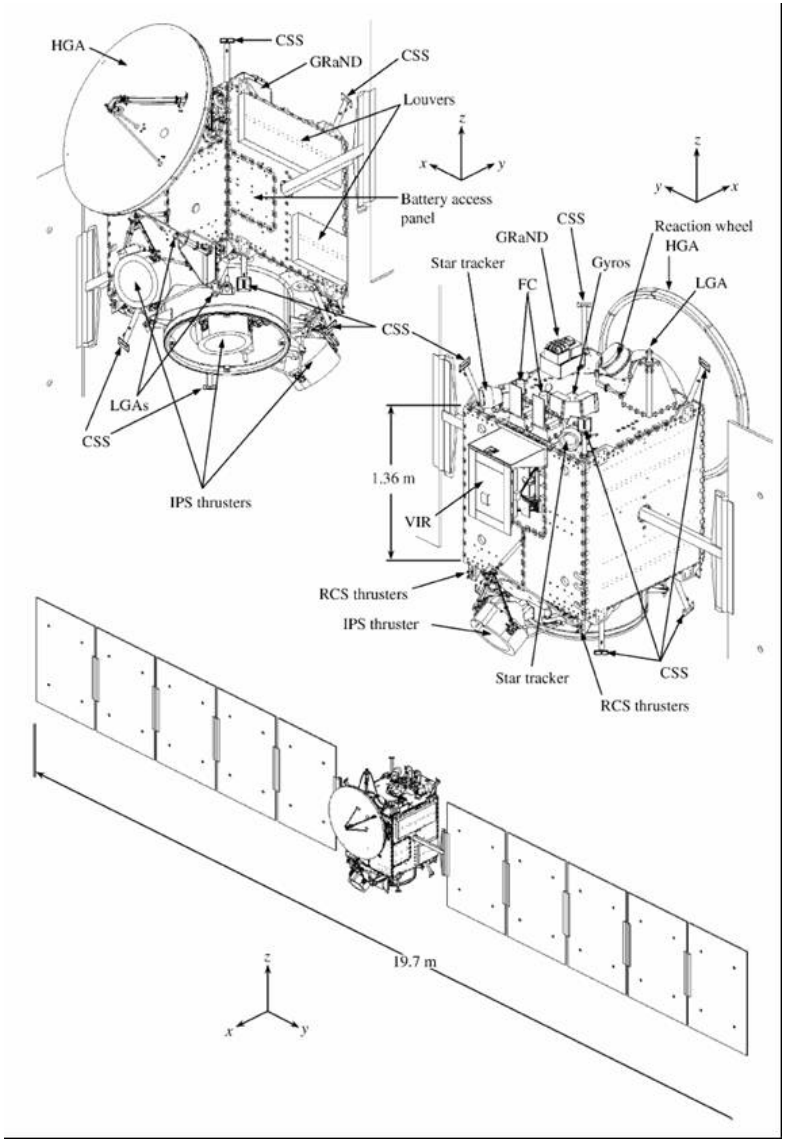
Dawn

Dawn Mission and Flight System

- Dawn will launch in June-July, 2007 and will rendezvous with the two heaviest main-belt asteroids: Vesta and Ceres

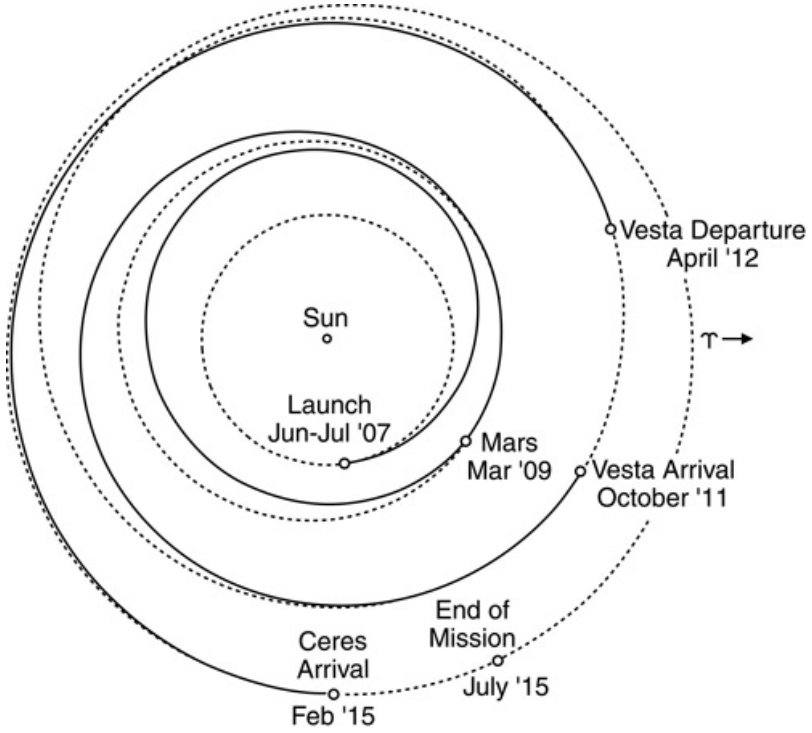
- There are three science instruments on the Dawn spacecraft
  - The Gamma Ray and Neutron Detector (GRAND): provided by Los Alamos National Laboratory
  - The Visible and Infrared (VIR) mapping spectrometer: provided by the Italian Space Agency
  - The Framing Camera (FC): provided by Germany

- The Ion Propulsion System (IPS) includes three 30-cm diameter ion thrusters operated one at a time



Mission Requirements

- The IPS is used to provide all post-launch ΔV including:
  - The heliocentric transfer to Vesta
  - Orbit capture at Vesta
  - Transfer to the Vesta science orbits
  - Departure and escape from Vesta
  - The heliocentric transfer to Ceres
  - Orbit capture at Ceres
  - Transfer to the Ceres science orbits
- The IPS must process ~395 kg of xenon
  - 132 kg per thruster if all three thrusters work
  - 198 kg per thruster if one fails at the beginning of the mission



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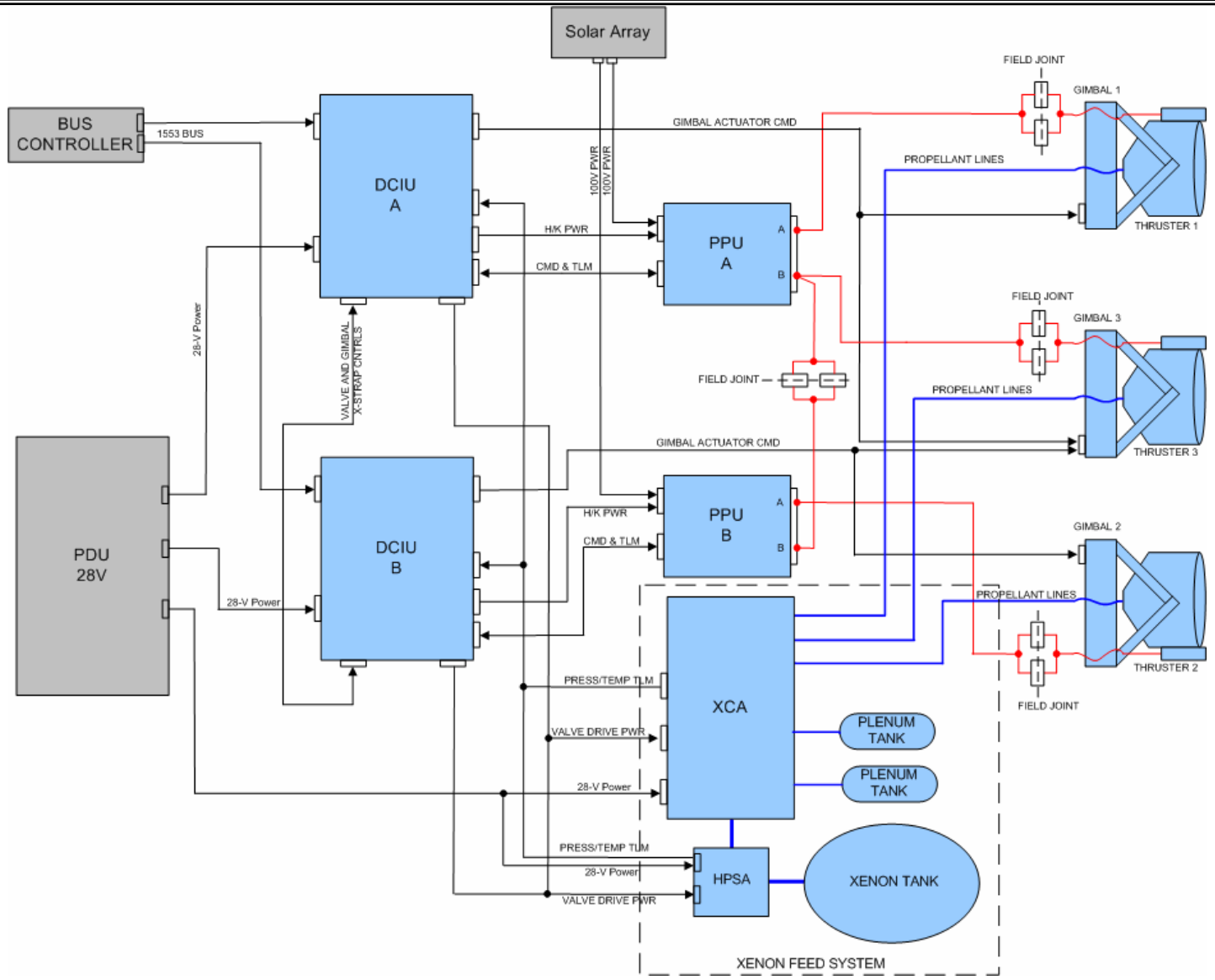
Dawn IPS Block Diagram



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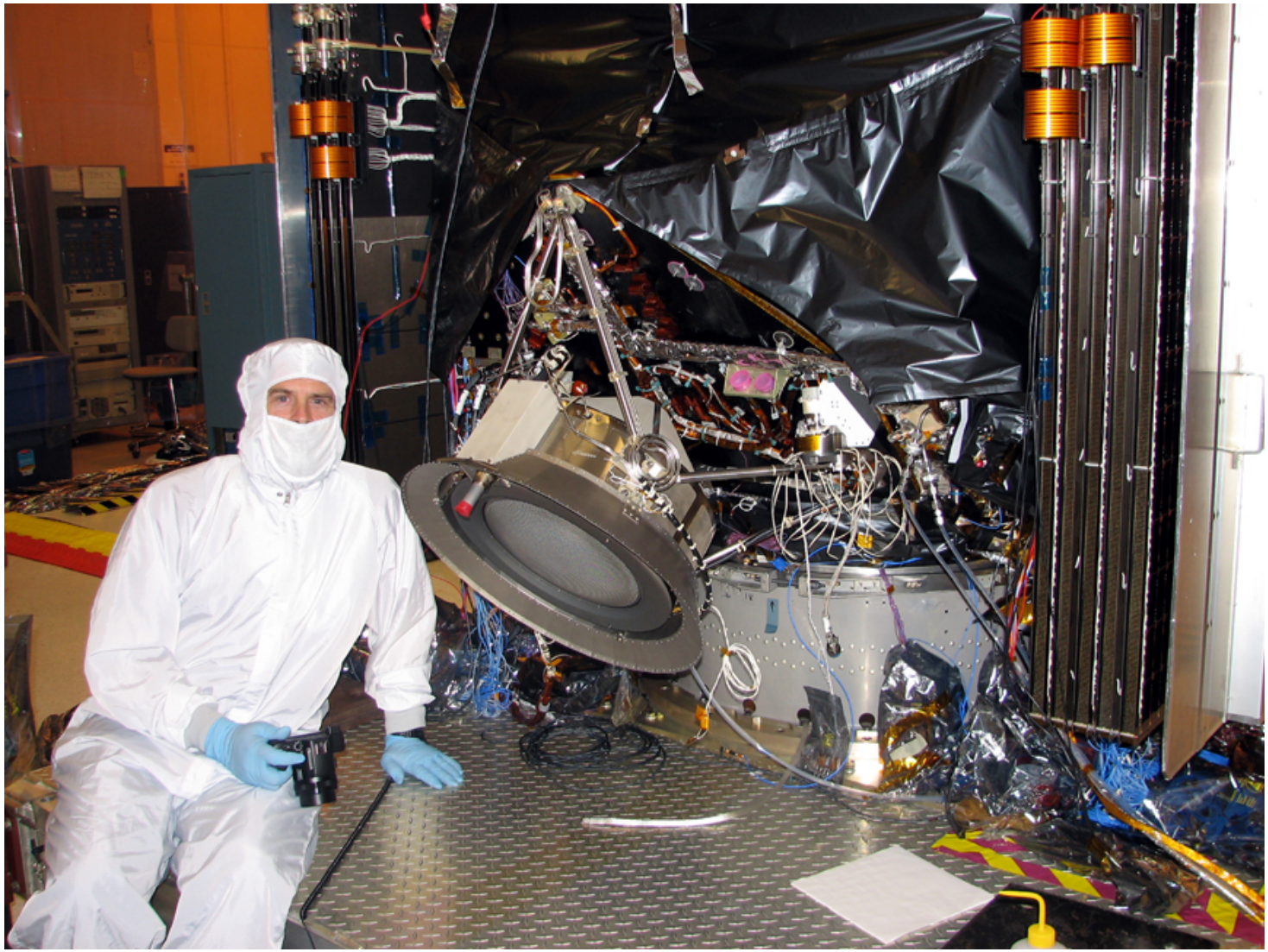
One of Three Ion Thrusters on the Dawn Spacecraft



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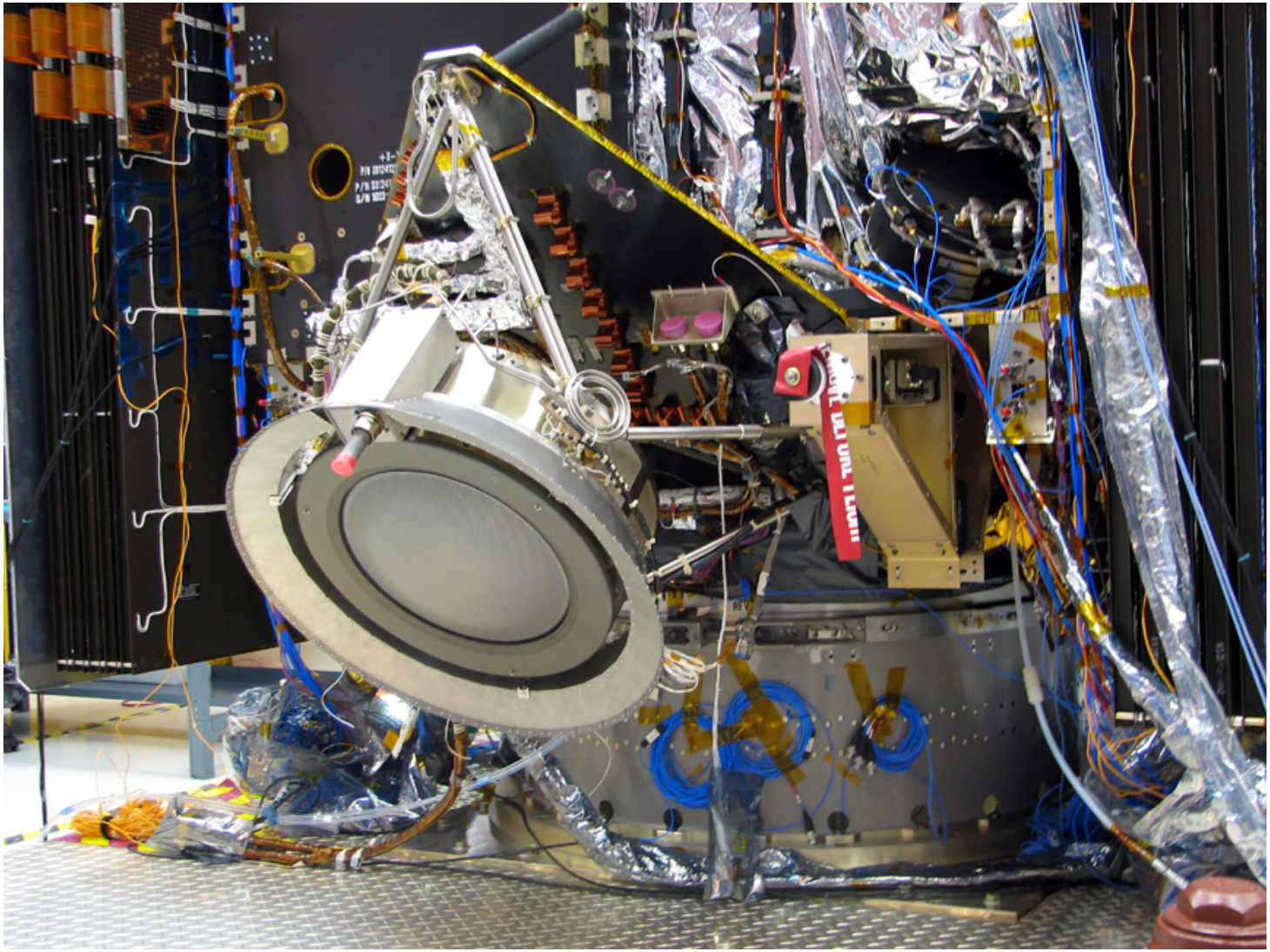
One of Three Ion Thrusters on the Dawn Spacecraft



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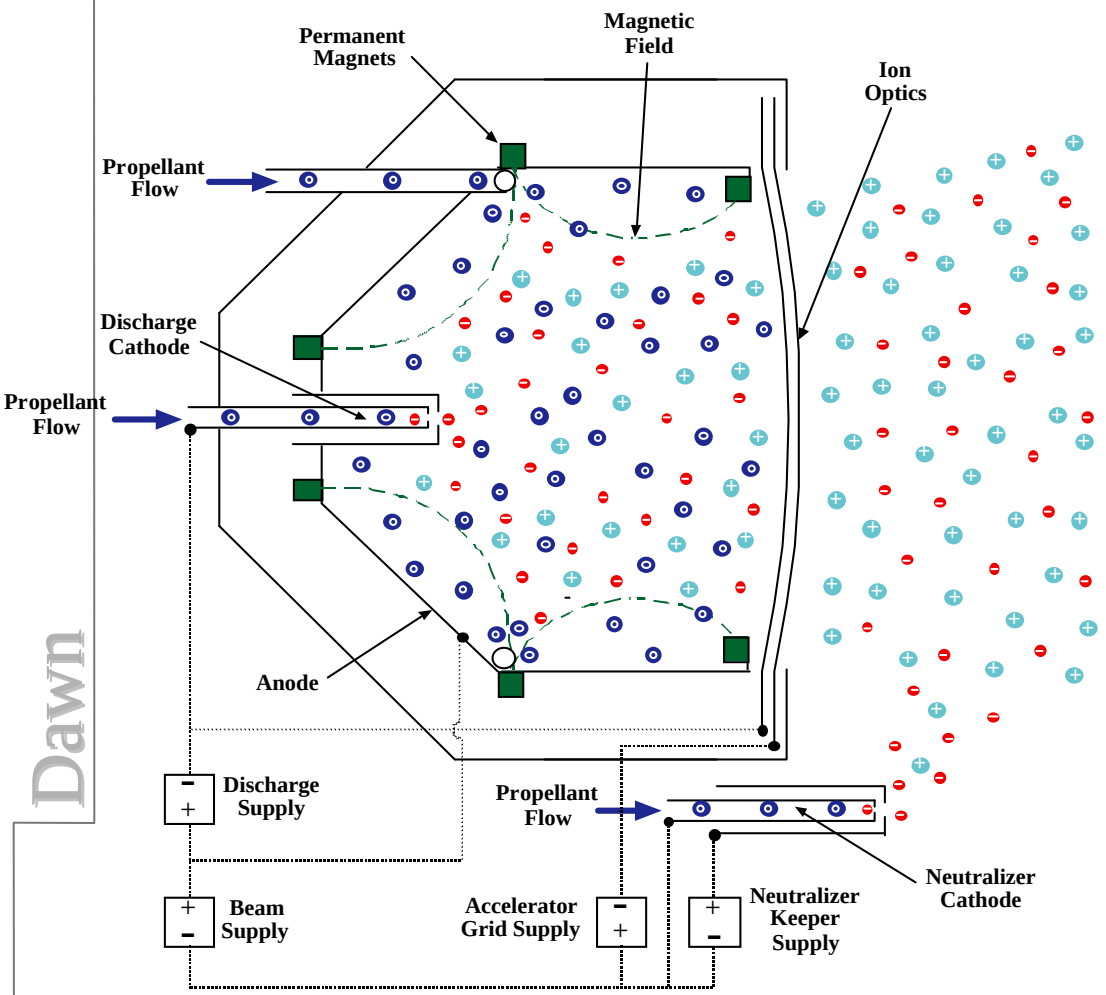
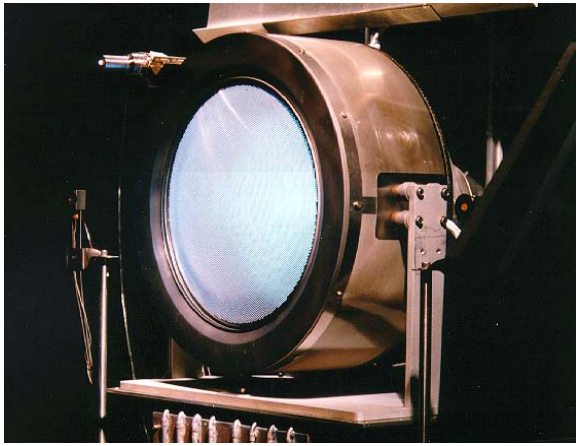
Ion Engines Exploit Plasma Discharges to Produce Thrust



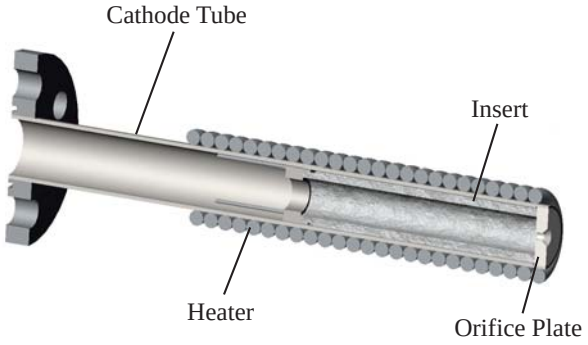
Three Major Engine Components

- Discharge Chamber
  - Creates ions by electron bombardment of xenon propellant
- Ion Optics
  - Two closely spaced grids which create a high electric field that accelerates ions that drift into gap between grids
- Neutralizer Cathode
  - Emits electrons to neutralize charge on spacecraft and positive charge in the ion beam



Engineering Model 30 cm Thruster in 8200 Hour Wear Test at JPL

Hollow Cathodes Serve as the Electron Sources for the Plasma Discharges



- Main and neutralizer discharges are sustained by thermionic emitters
- Both cathodes must be preheated so the emitter reaches 1150-1200°C
- The Dawn mission requires periodic thruster shutdown for data transmission and coast periods
- Conservative estimates of number of cycles and resulting minimum temperatures per thruster:
  - 275 cycles to about 5°C
  - 25 cycles to approximately -95°C

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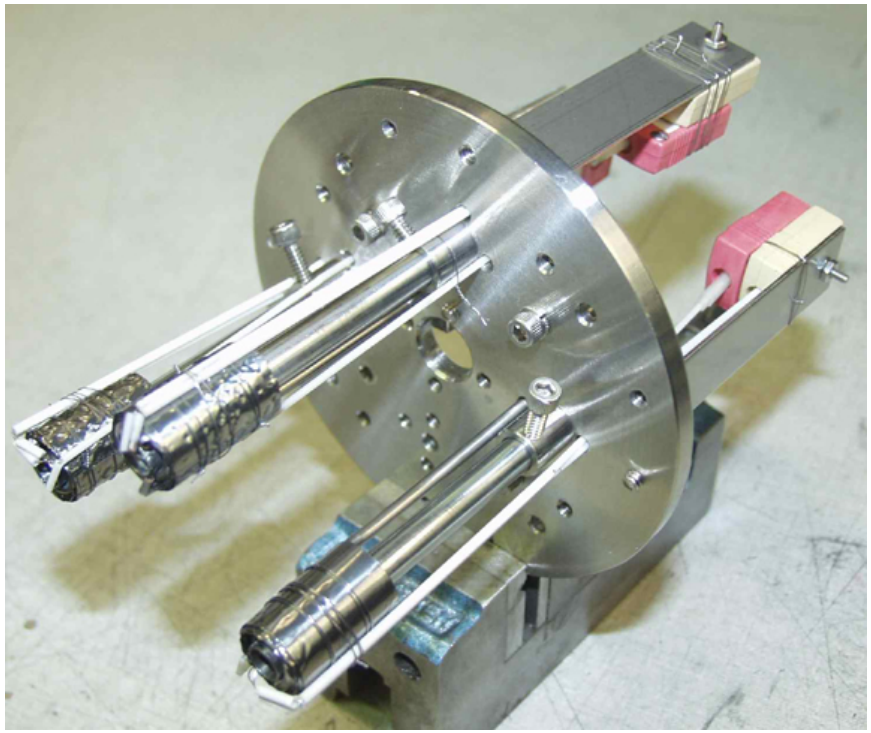
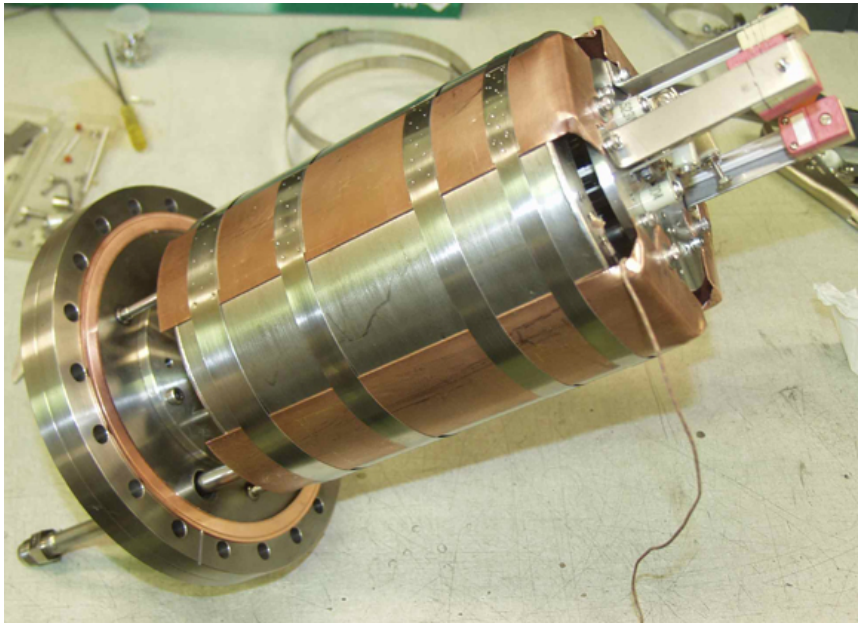
Heater Installation for Thermal Cycling Test



- Heater mount is thermally connected to an LN2-cooled shroud
- Entire assembly fits in a small vacuum chamber



- Three heaters mounted on tubes with radiation shields similar to the flight configuration
- Each assembly has 1 type K and 1 type C thermocouple spot-welded to the tube near the heater

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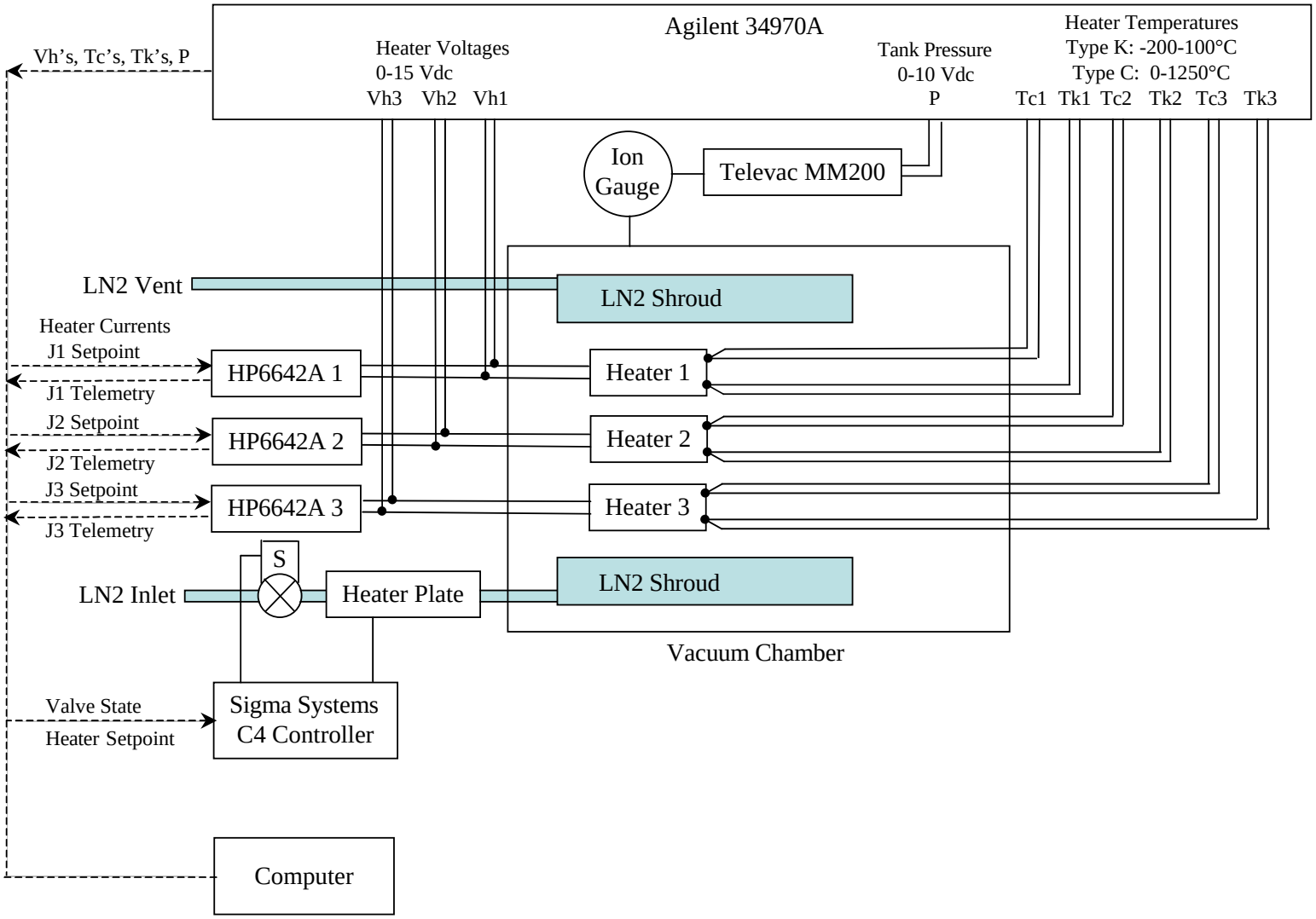
Data Acquisition and Control System



Test Setup

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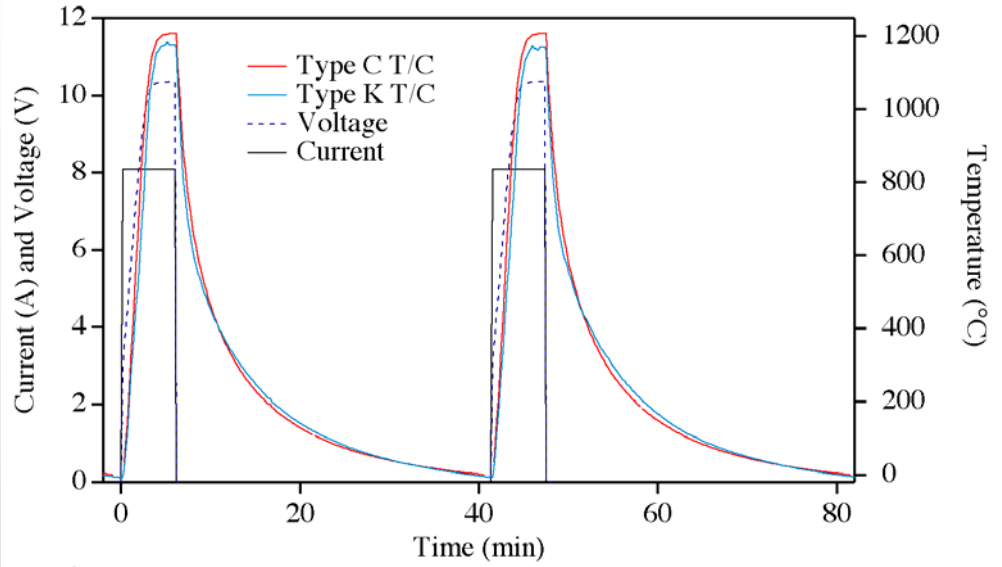
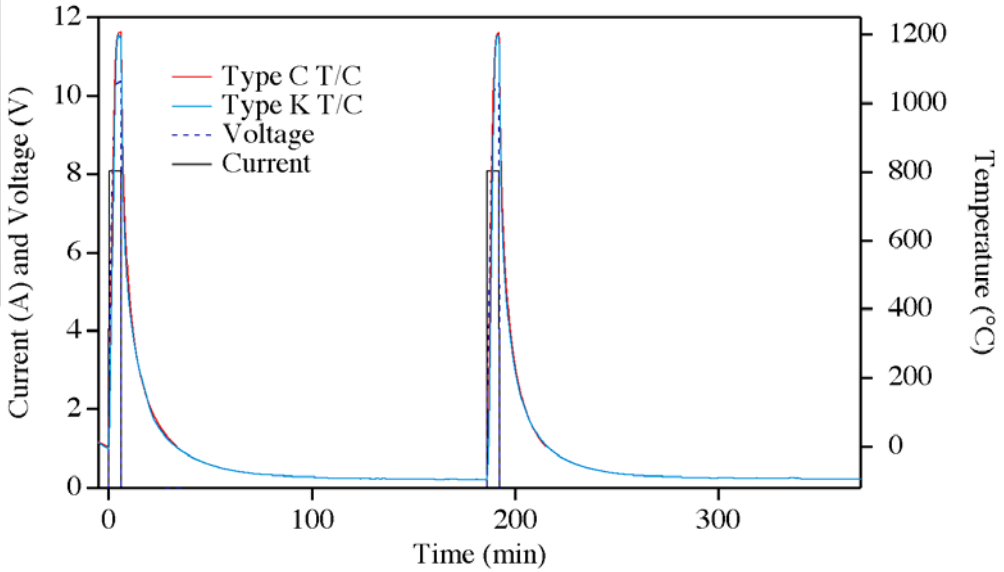
Thermal Cycling Profile





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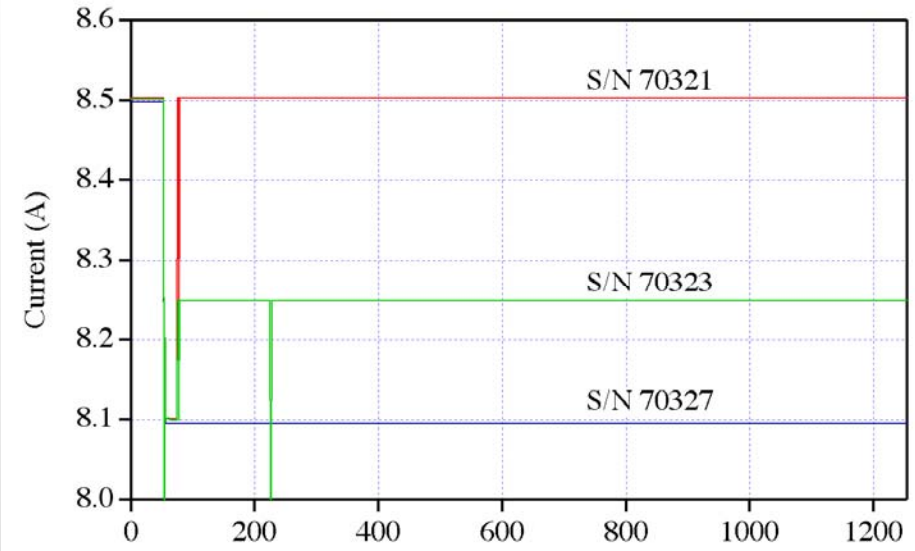
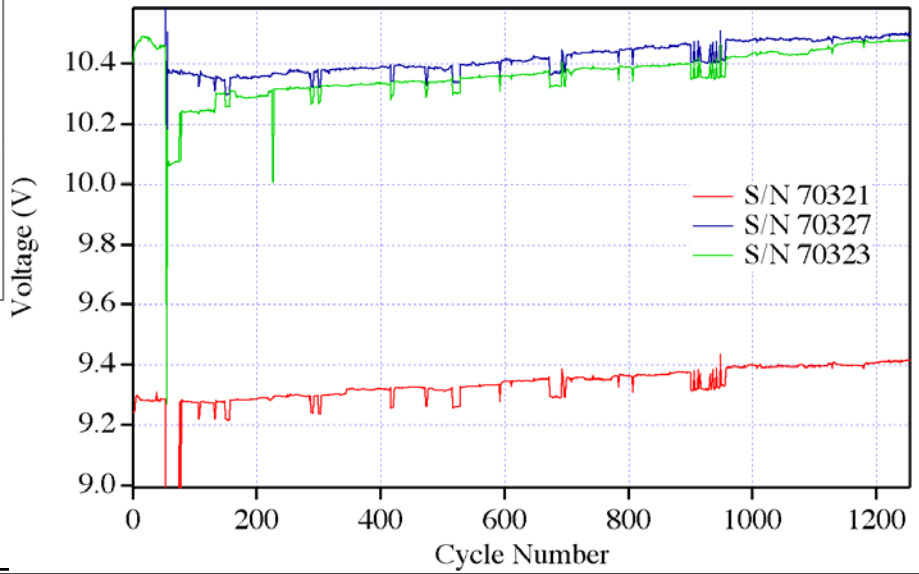
- The thermal cycling test is designed to simulate approximately three complete mission profiles
  - 1200 cycles total
  - 90% at cold soak temperature of -10°C
  - 10% distributed throughout the test at cold soak temperature of -110°C
- The thermal design allows:
  - Steady-state hot temperatures after about 6 minutes of heating
  - Minimum temperature of -10°C in ~45 min cycles
  - Minimum temperature of -110°C in about 3 hour cycles

Current-Voltage Characteristics





- Current setpoints varied in first 80 cycles to determine power dissipation
- Final setpoints for heaters 2 and 3 chosen to yield 84-85 W
- Heater 1 has lower resistance and was operated at 8.5 A (~79 W)

- Voltages increased by 0.06-0.13 V over the course of the test
- Voltages at the end of the 6 min heater cycle are slightly lower when initial temperature is -110°C compared to -10°C; may not have reached steady state.

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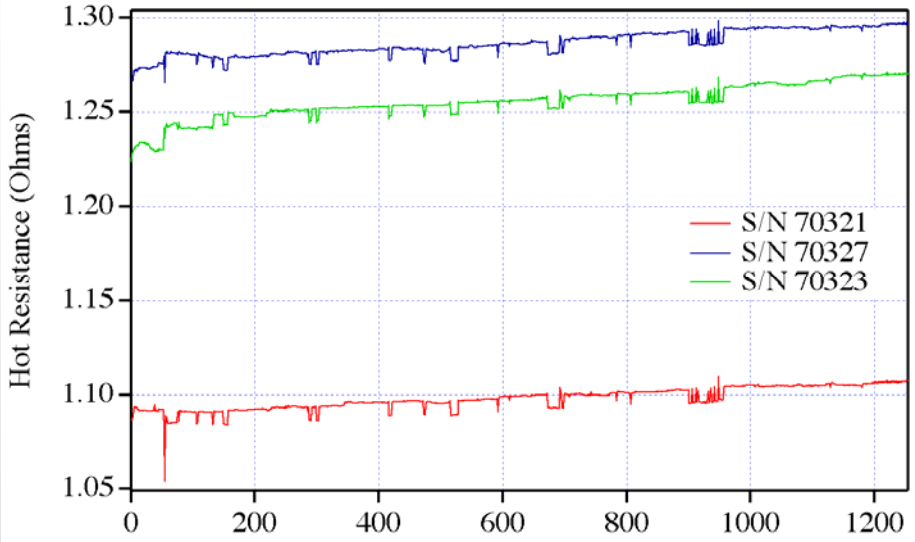
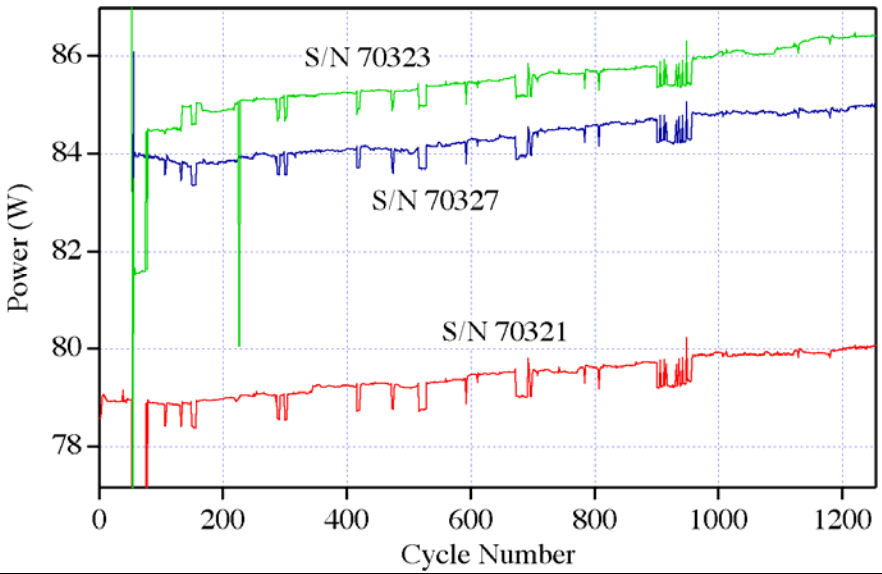
Heater Resistance and Power Dissipation





- Hot resistance increased by 0.006 to 0.014 ohms
- Power levels increased by 0.5-1.0 W due to increased resistance

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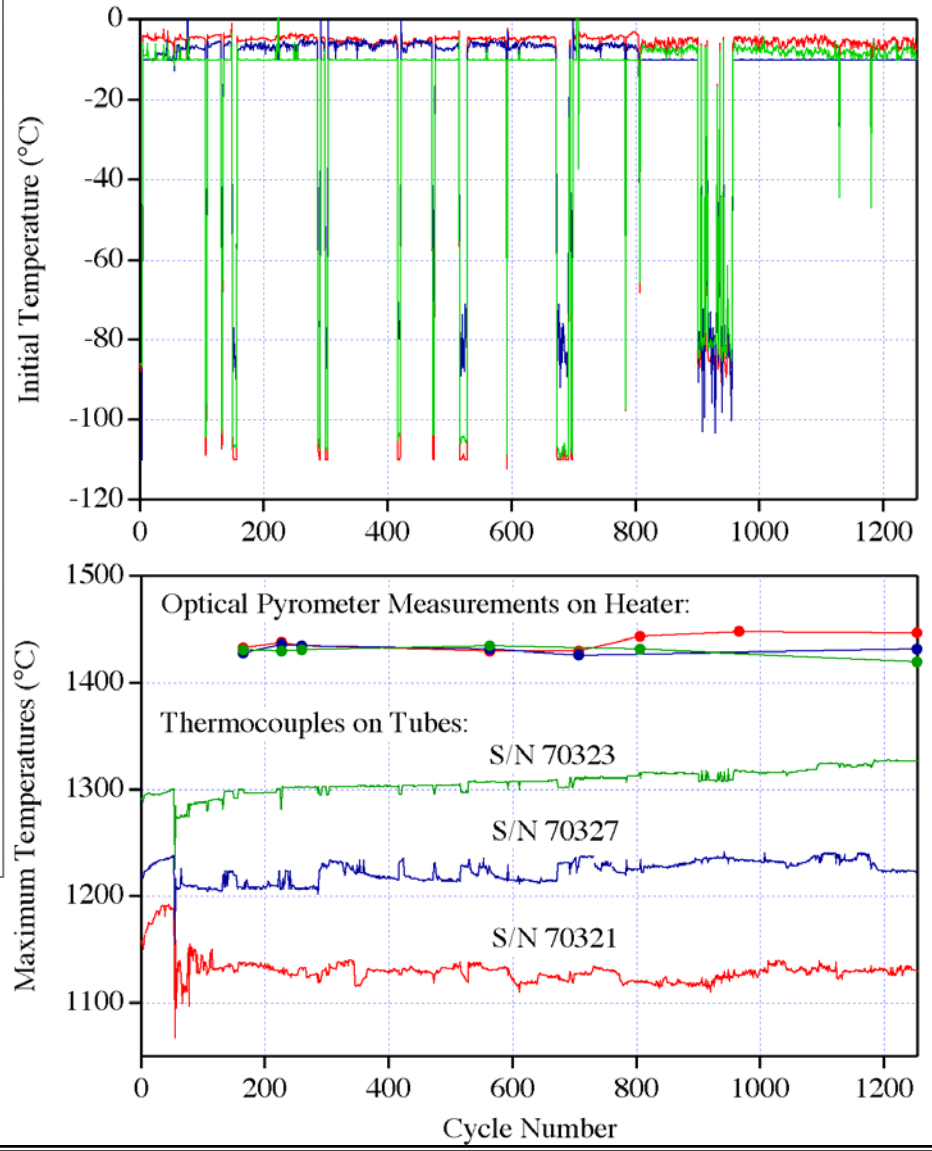
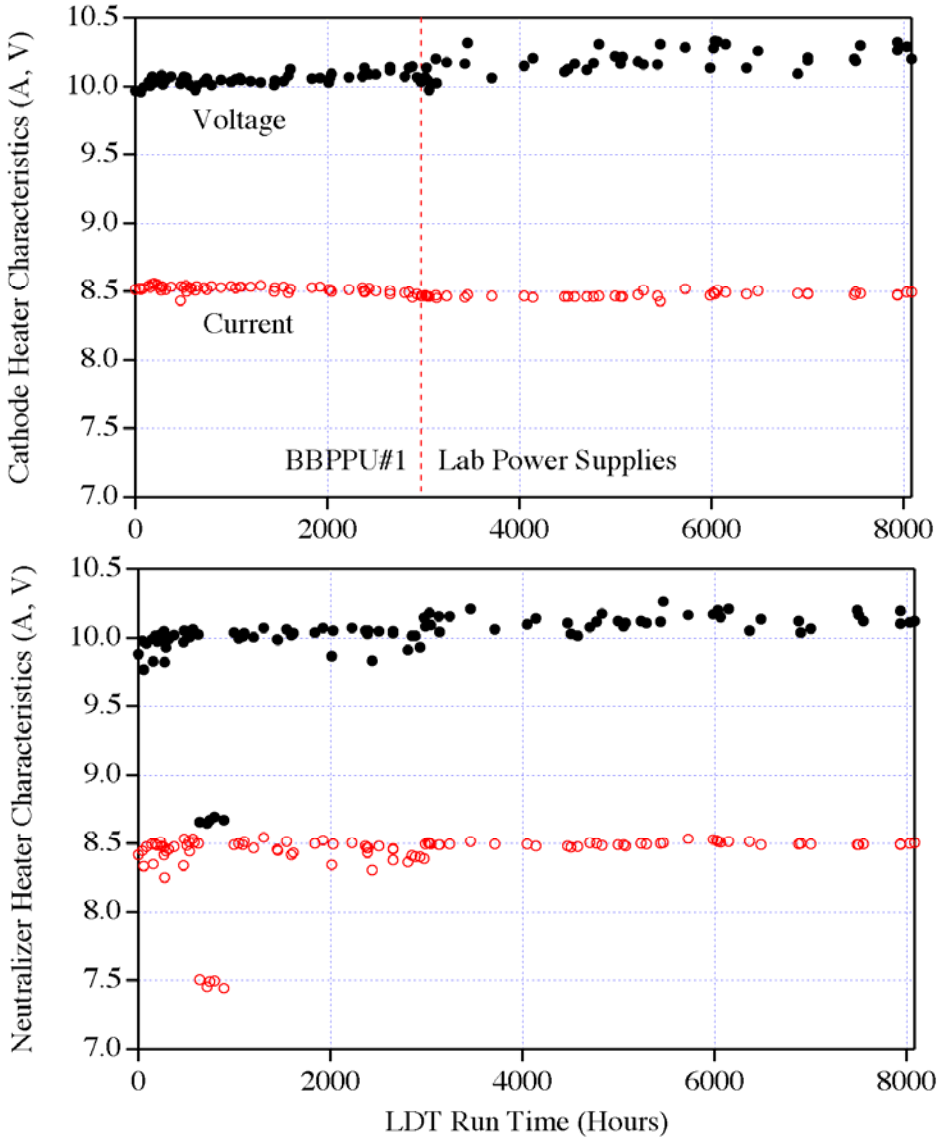
Minimum and Maximum Temperatures



- Cold soak temperatures have been -10°C (1120 cycles) and -110°C (134 cycles)
- Peak temperatures measured on the cathode tube near the heaters have been approximately constant except for that of heater 3, which has increased slightly

Current-Voltage Characteristics from the NSTAR LDT



- The NSTAR Life Demonstration Test (LDT) included
  - 8200 hours of operation
  - 108 cycles from room temperature
- Both heaters experienced slight increases in voltage

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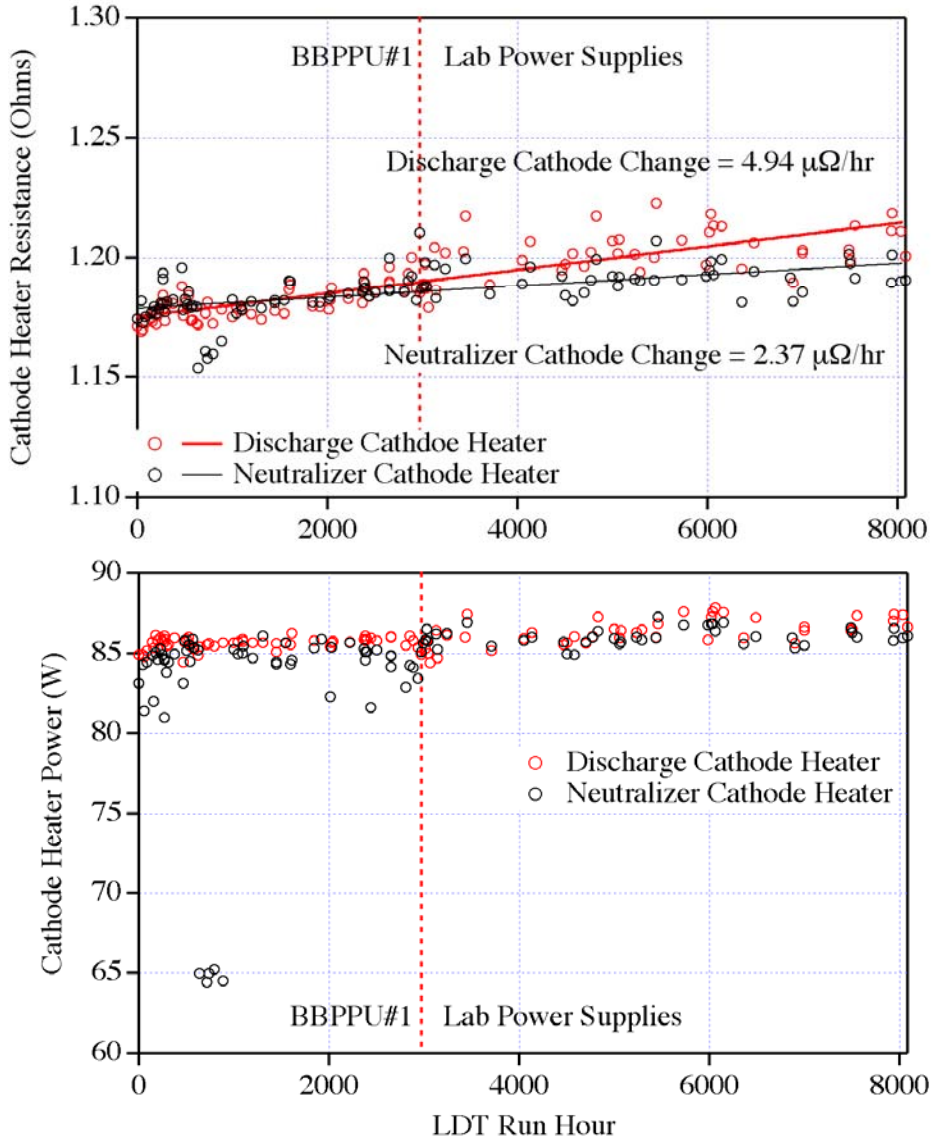
Power and Resistivity Changes During the LDT



- Heater resistivity increased by 0.02-0.04 ohms
- Heater power increased from 85 to 86 or 87 W

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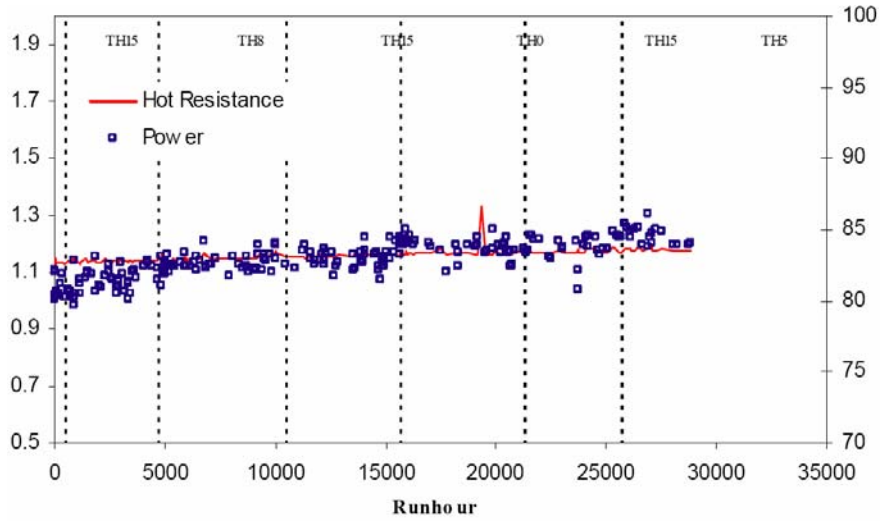
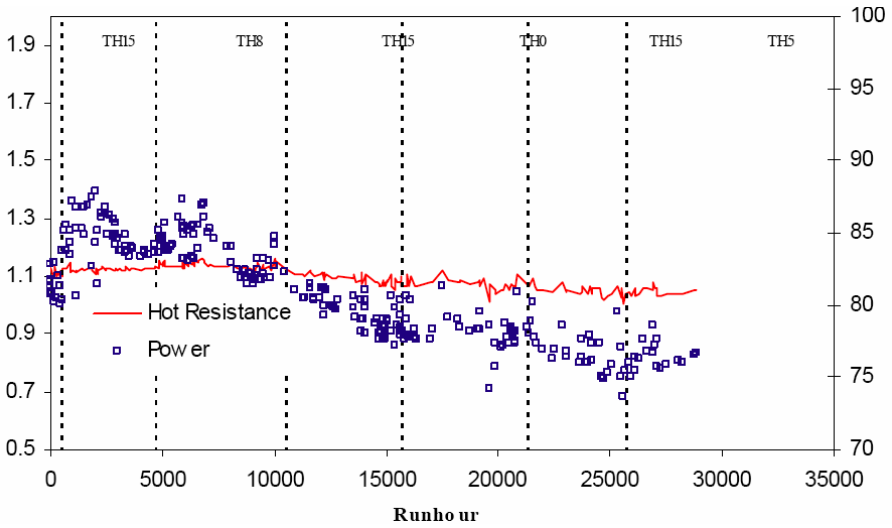
Power and Resistivity Changes During the ELT





- The NSTAR Extended Life Test (ELT) included
  - 30,200 hours of operation
  - XXX cycles from room temperature
- The neutralizer heater resistance and power increased slightly over the test
- The discharge cathode heater resistance and power dropped slightly, probably because of a change in the thermal environment

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Conclusions

- A total of 1254 cycles were accumulated
  - Heater currents chosen to give 85 W of power for two heaters; third heater has lower resistance and is operated at the maximum current of 8.5 A and 79 W
  - 134 cycles (~10%) were at a cold soak temperature of -110°C; the rest at -10°C
- Heater characteristics changed slowly over the test
  - Voltages have increased 0.06 - 0.13 V
  - Hot resistance has increased by 0.006 - 0.014 ohms
  - Power dissipation has increased by 0.5 to 1 W
- Behavior is consistent with changes observed in long duration tests (LDT examples included)
- No evidence of life-limiting phenomena due to thermal cycling; destructive post-test analysis currently underway

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