High-speed Dual Langmuir Probe with Ion Saturation Reference (HDLP-ISR) for Hall Thruster Plume Measurements

Michael J. Sekerak, Professor Alec D. Gallimore (PI) – *University of Michigan*
Dr. James E. Polk (Mentor) – *NASA Jet Propulsion Laboratory*

Problem Statement

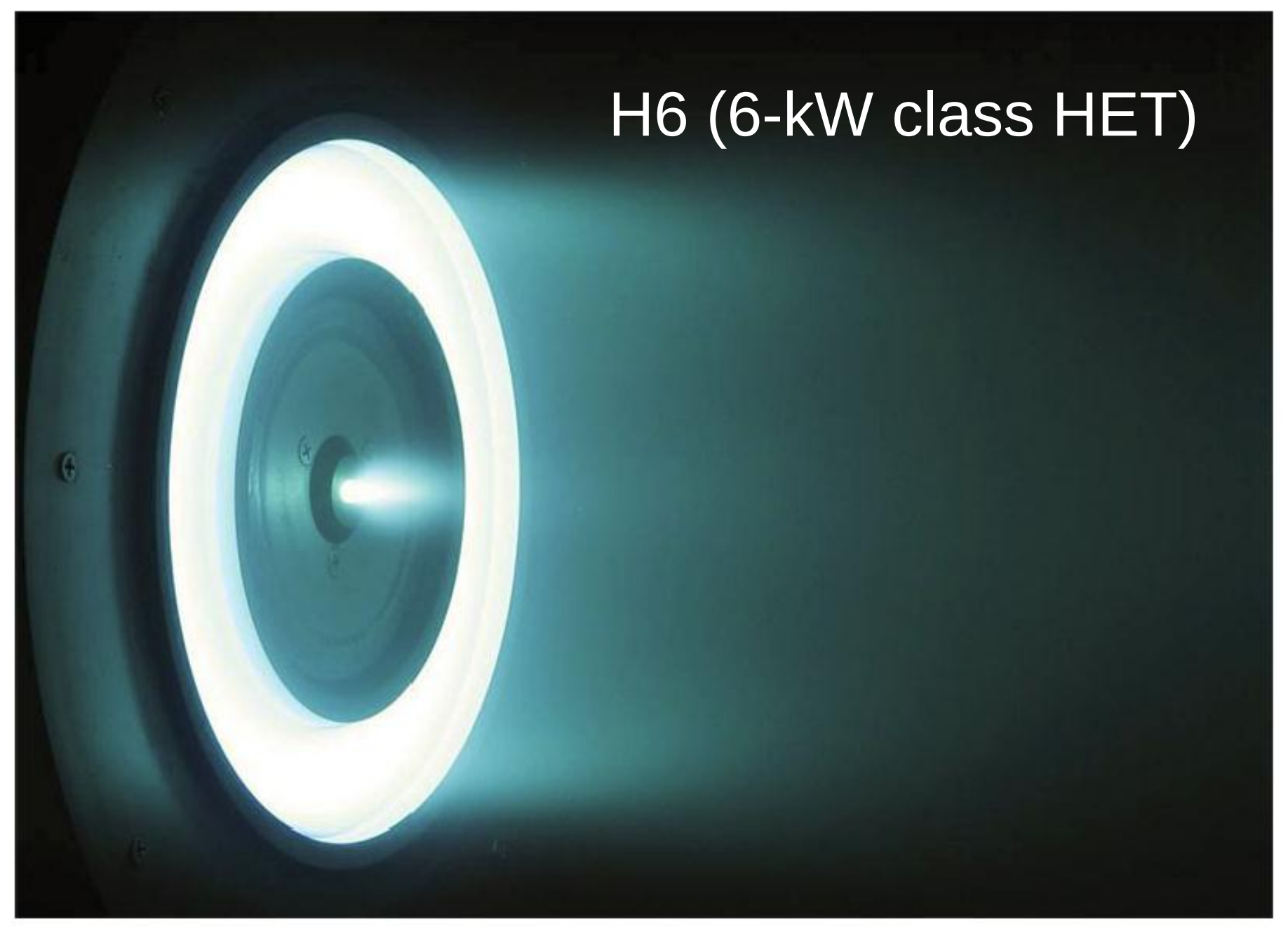
Hall Effect Thrusters (HETs) are being increasingly used for and considered for a variety of space missions, including satellite station-keeping, orbit raising and interplanetary exploration; understanding their underlying physics of operation is critical to improving HET efficiency, operational lifetime and spacecraft interaction. Despite decades of development and on-orbit operation, end-to-end physics models of HETs from first principles do not exist because the question of anomalous electron transport (how so many electrons cross magnetic field lines to reach the anode) is unresolved. HETs are steady-state devices with a multitude of kilohertz and faster plasma oscillations that are not fully understood yet may impact their performance and interfere with spacecraft subsystems.

Objective

Enable time-resolved measurements of plasma properties including: ion density, electron density, electron temperature or energy distribution function and plasma potential at 100's kHz. Correlate these measurements to high-speed imaging to develop a more complete understanding of HET oscillations.

Methodology

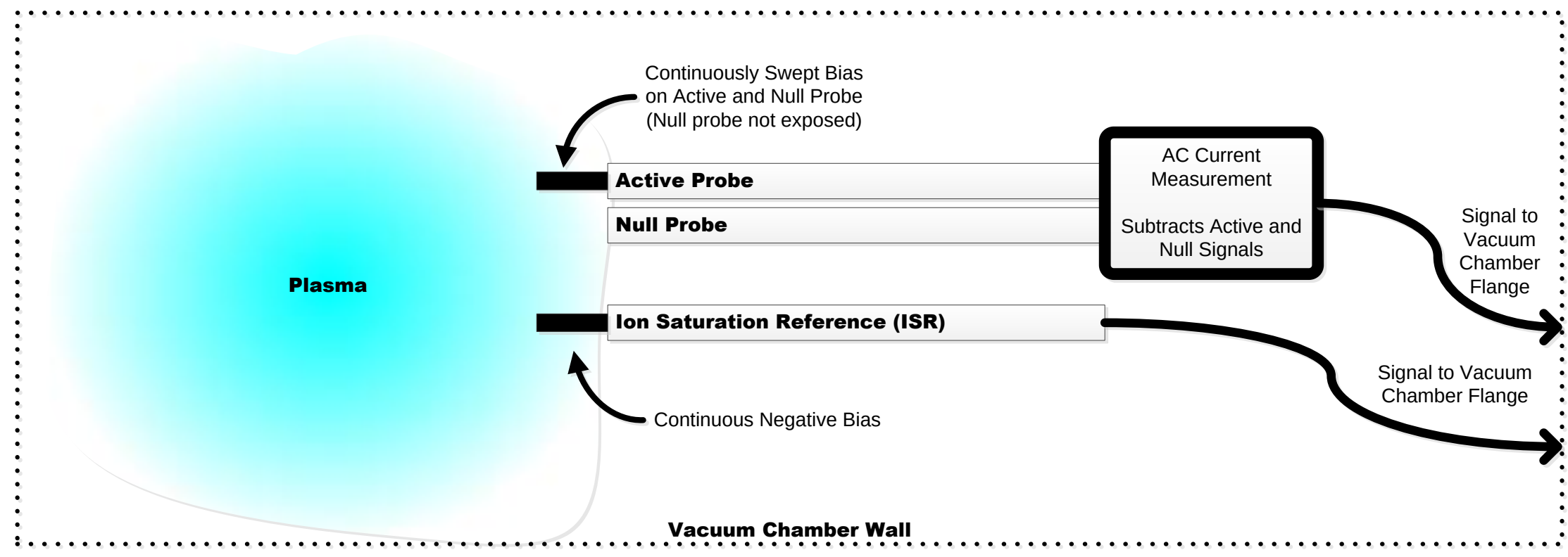
HETs are known to operate in different oscillatory modes with differing efficiencies and plasma characteristics, particularly the axial breathing mode and the azimuthal spoke mode. Both phenomena are believed to be related to ionization processes and it is uncertain how they interact or feed off each other, however, it is strongly suspected these modes greatly affect anomalous electron transport. In order to investigate these phenomena, high-speed diagnostics are needed to observe time resolved plasma properties and correlate them to thruster operating conditions. Recent developments of a High-speed Dual Langmuir Probe (HDLP) developed by Dr. Robert Lobbia and ultra-fast imaging analysis developed by Dr. Michael McDonald have been expanded and combined to measure plasma plume properties at 100's kHz and compared with images acquired at 87,500 frams/sec.



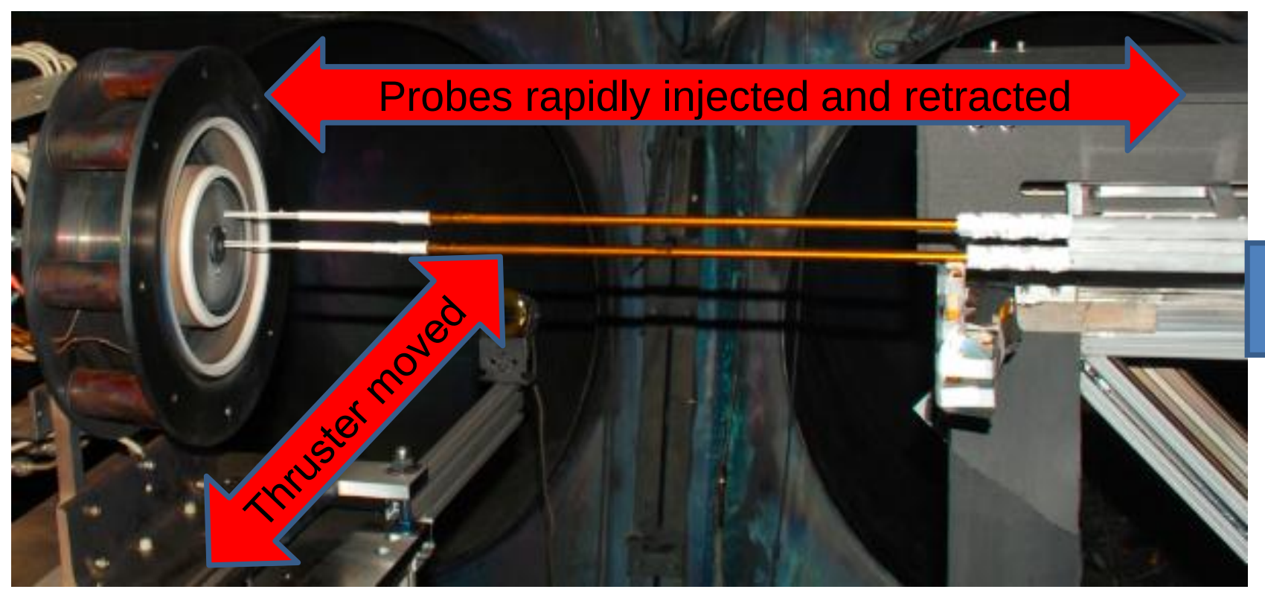
Publications

1) M. Sekerak, M. McDonald, R. Hofer, and A. Gallimore, "Hall Thruster Plume Measurements from High-Speed Dual Langmuir Probes with Ion Saturation Reference," presented at the 34th IEEE Aerospace Conference, Big Sky, MT, 2013.
2) M. Sekerak, M. McDonald, R. Hofer, J. Polk, B. Longmier, and A. Gallimore, "Time Resolved and Time Averaged Hall Thruster Plume Measurements," presented at the 49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, San Jose, CA, 2013.
3) M. McDonald, M. Sekerak, A. Gallimore, and R. Hofer, "Plasma Oscillation Effects on Nested Hall Thruster Operation and Stability," presented at the 34th IEEE Aerospace Conference, Big Sky, MT, 2013.

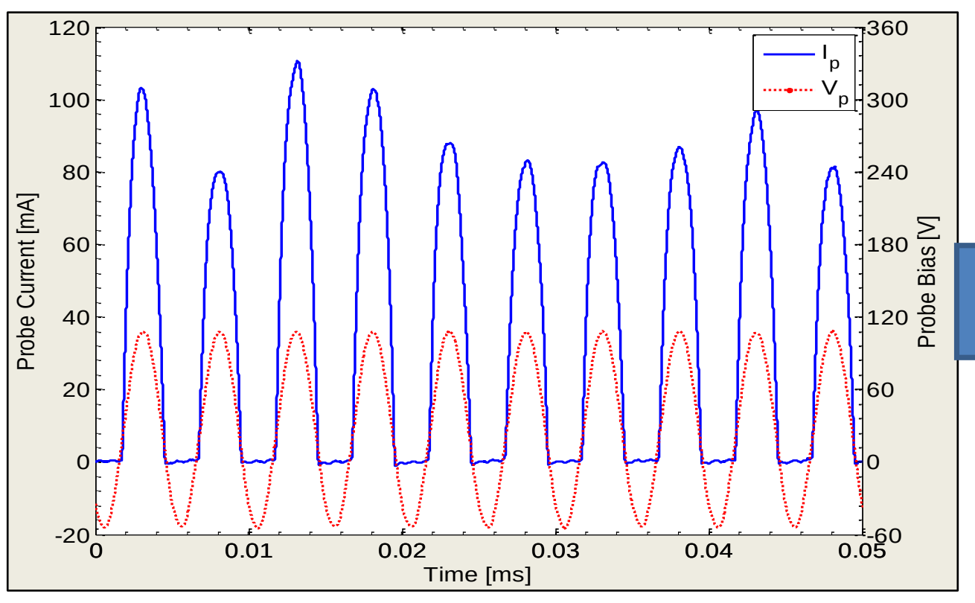
HDLP-ISP Data Acquisition and Processing



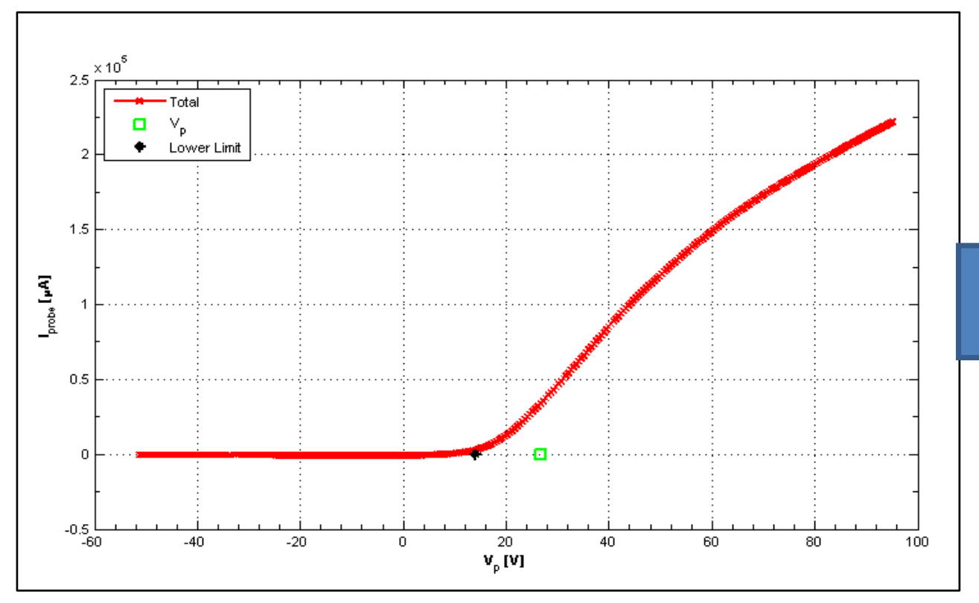
The HDLP-ISR: Active and null probes are swept at 100's kHz and +/- 50 to 100 V. Active probe has small area in contact with plasma. Null probe is completely isolated from the plasma. Null probe cancels capacitive current and noise common to both lines by subtracting signals in the chamber. The ISR probe is maintained at a constant negative bias in ion saturation regime and acts as reference for the swept signal.



Probes are mounted onto the High-speed Axially Reciprocating Probe (HARP) table and injected into the plasma towards the thruster. Thruster is moved laterally to acquire different radial positions.



Time history of current and voltage on the swept probes and ISR current simultaneously sampled at 180 MS/s with a 16-bit Data Acquisition System.



In post processing, the current and voltage signals are "chopped" into individual I-V traces. For time averaged values, all I-V traces within an axial range of 1 mm are averaged together. For time-resolved, every other I-V trace is averaged together.

Collisionless, thin-sheath Langmuir Probe Analysis

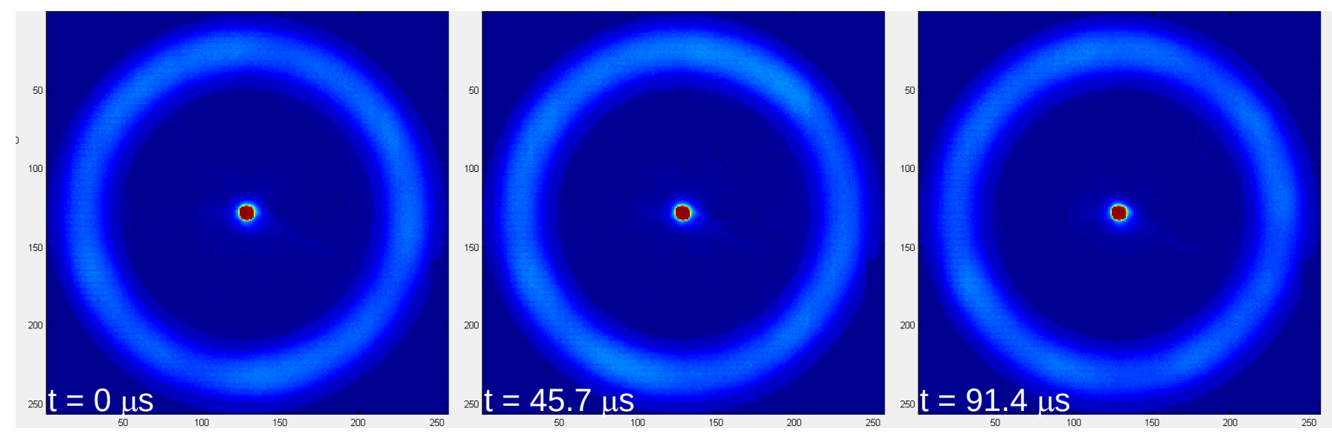
Plasma potential and electron saturation current from: $\left[dI_e/d\phi\right]_{peak}$

Electron temperature from inverse slope of: $dI_e/d\phi$

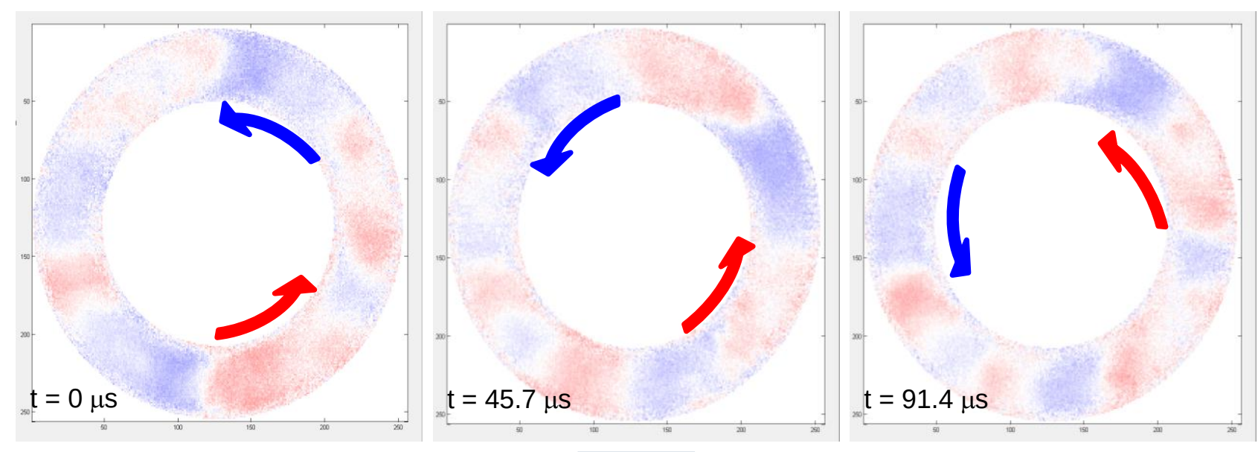
Electron Density from: $n_e = \dfrac{I_{e,sat}}{0.25 A_{probe} V_{th}}$

Traditional collisionless, thin-sheath Langmuir probe analysis used to analyze each I-V trace regardless of whether it is time-averaged or time-resolved.

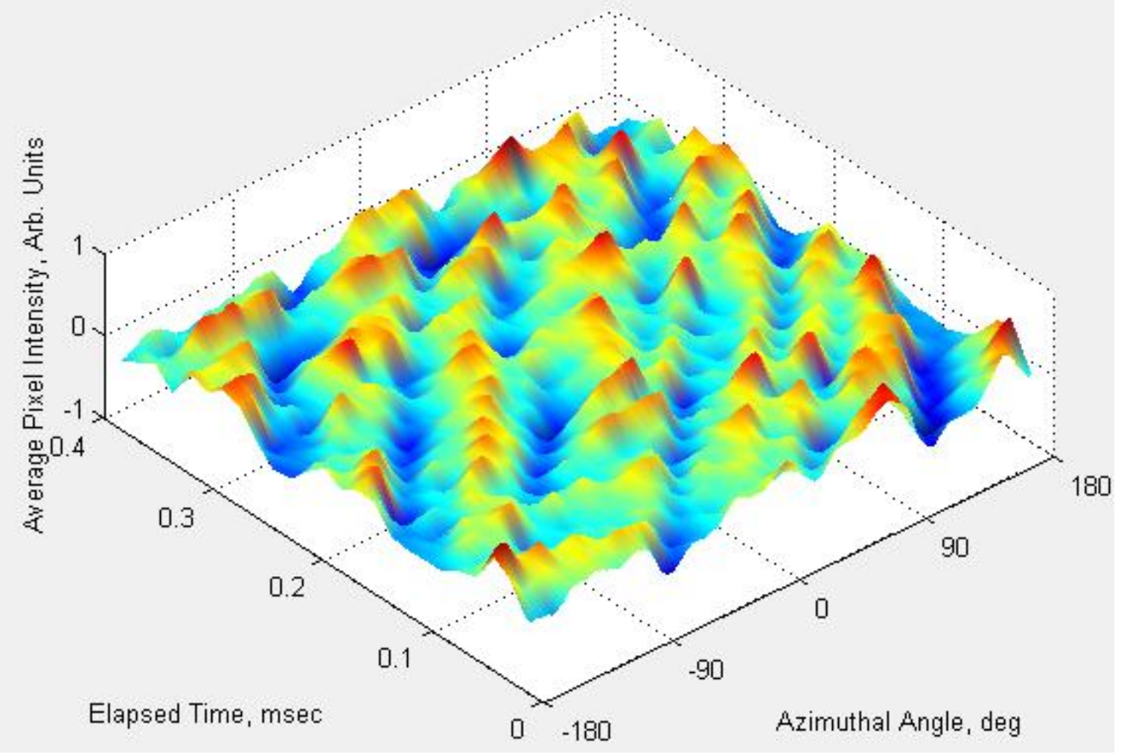
FastCam Image Analysis



Raw images acquired with Photron SA5 FastCam at 87,500 frames/sec and imported into MatLab.

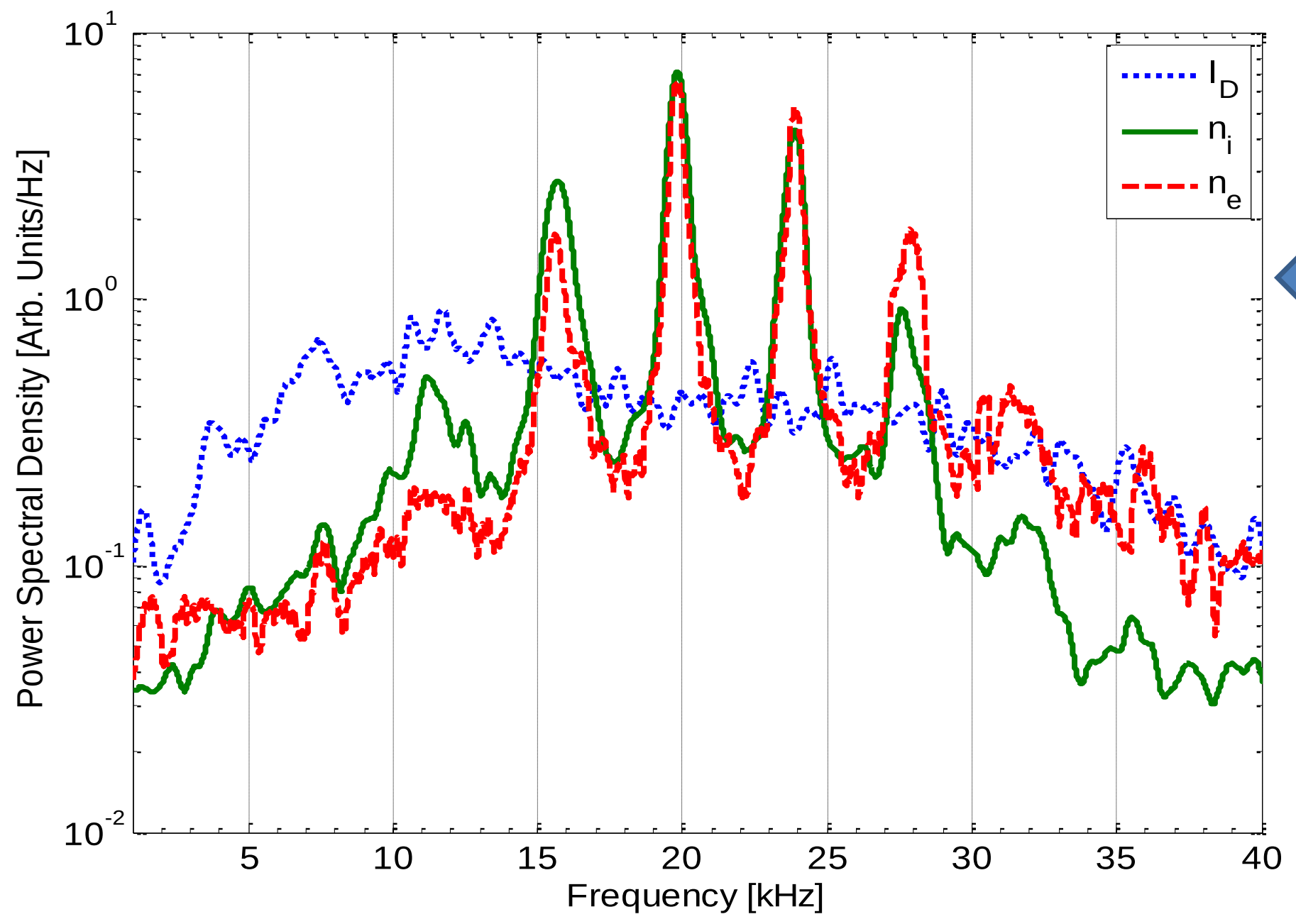


Processing images isolates the channel, removes the cathode and AC-couples each frame. Spokes can be seen moving azimuthally in ExB direction around the discharge channel.

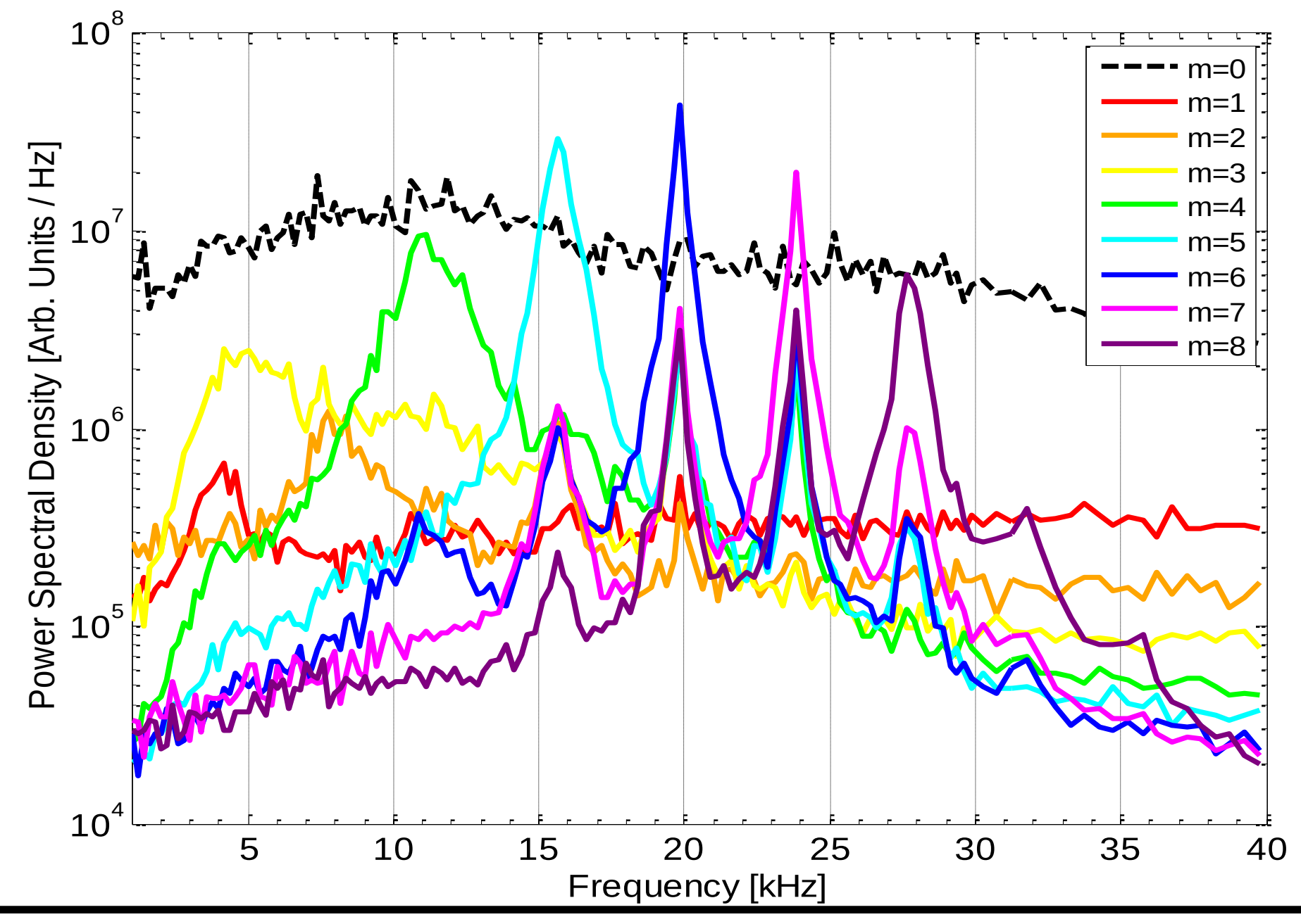


2-D spoke surface is generated showing time evolution of azimuthal light intensity.

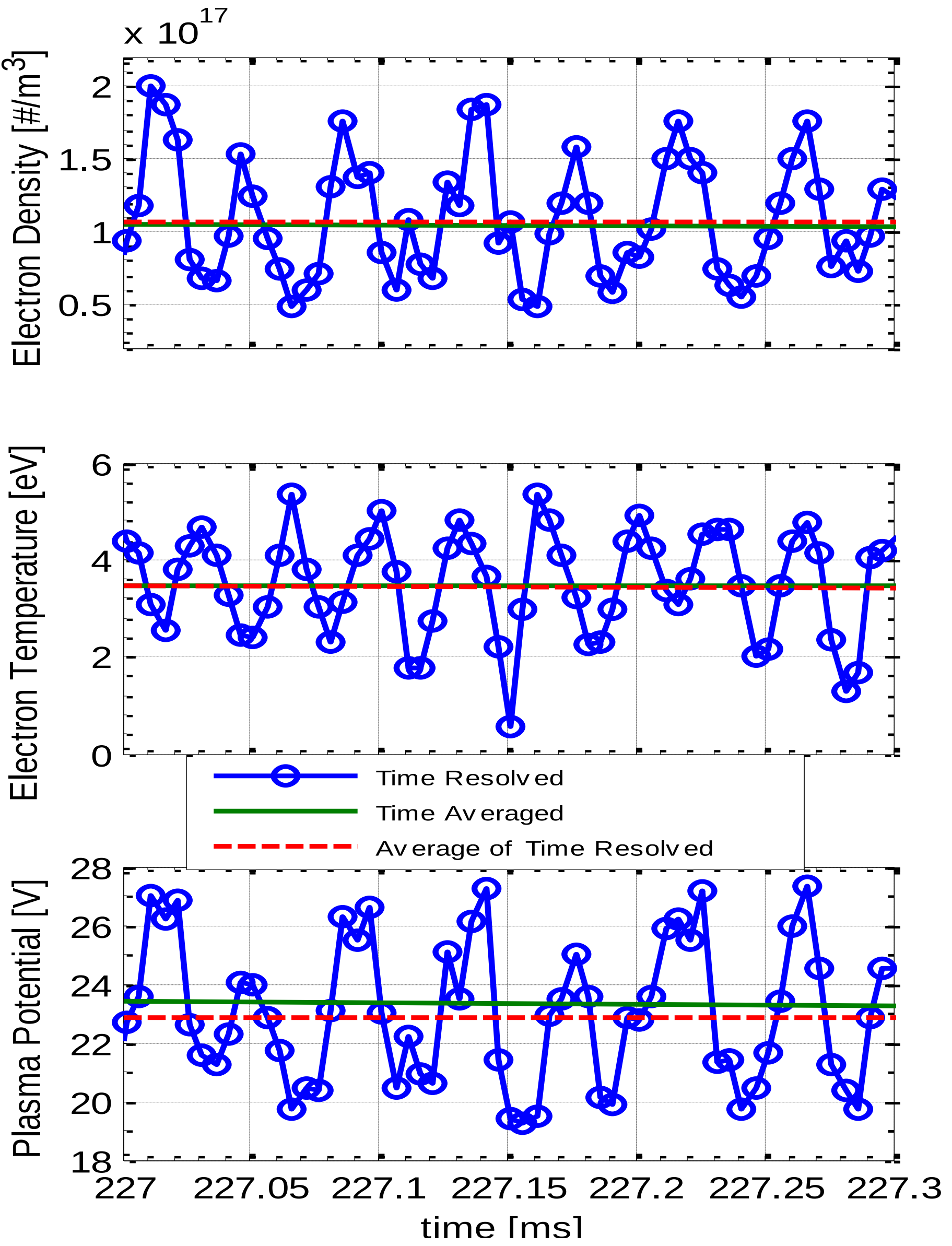
Power Spectral Density (PSD)



PSD of time-resolved plasma density oscillations (above) match PSD of visible rotating spokes in the discharge channel (below).



Example Time-Resolved Plasma Properties (H6 at 300 V)



Time-resolved electron density, electron temperature and plasma potential for $R/R_{channel}$ = 1.25 and time 227.0 to 227.3 ms (axial position of $Z/R_{channel}$ = 2.13 during probe injection). The plasma sampling frequency is 200 kHz.

Example Time-Averaged Plume Maps (H6 at 300 V)