# Effects of Surface Coatings on Swarm Langmuir Probe Measurements

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Photo: ESA

# Swarm is a trio of satellites with two Langmuir Probes (LP) each

- Langmuir probes measure current collected on an electrode as a function of applied voltage to obtain plasma density and electron temperature
- Swarm's spherical probes have Titanium nitride and gold (TiN and Au) coatings
- TiN may be affected by neutral particles called contamination


Photo modified from ESA

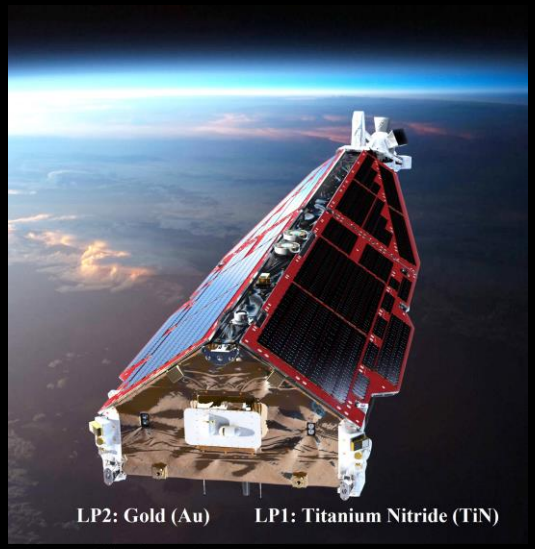
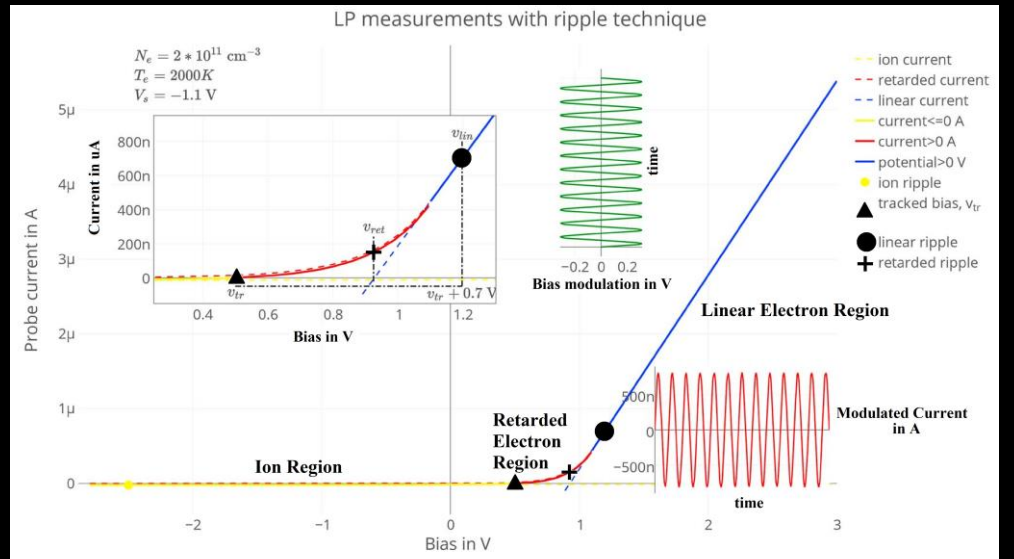



Photo: Modified from ESA

# Swarm has two LP operation modes: Sweep and Harmonic

- Convention: Sweep mode varies the probes voltages from +/- 5V and operates for a fraction of the time
- Innovation: Harmonic mode is the primary operation mode and uses modulation to derive density




$$I = I_{ph}(V_p) + F_e N_e \sqrt{T_e} \exp \frac{V_p}{T_e} + F_i N_i \left(1 - \frac{V_p}{E_i}\right) \approx F_i N_i \left(1 - \frac{V_p}{E_i}\right)$$

$$V_p = V_{bias} + V_s$$

$$d_{ion} = \frac{dI_{ion}}{dV_{bias}} = \frac{|-F_i N_i|}{E_i}$$

$F_i$ = Factor for ion current

$N_i$ = Ion density

$E_i$ = Ion energy

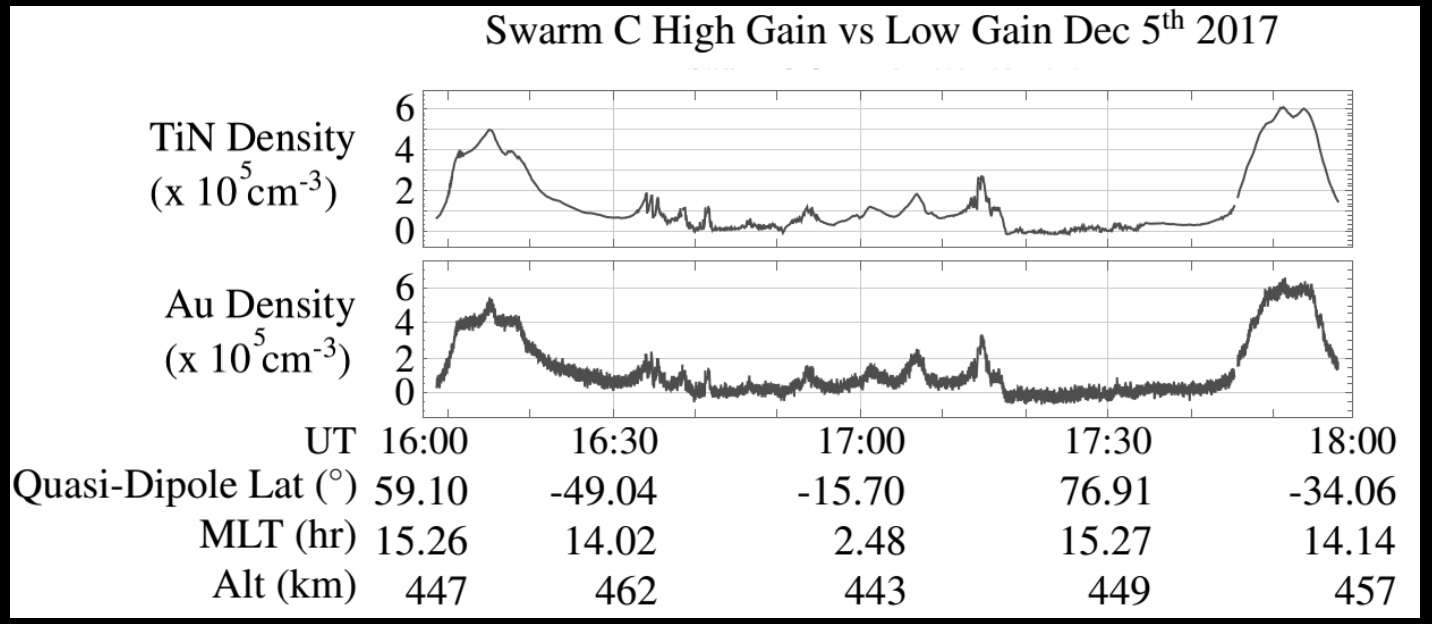
$V_s$ = Spacecraft Potential

$V_p$ = Probe Potential

**Photo modified from Knudsen et al. (2017)**
**Equations from Knudsen et al. (2017)**

# High gain is TiN and Low gain is Au

- The TiN probe is high gain and amplifies current signals
- The Au probe is low gain and is insensitive to ion currents



# Contamination can be thought of as a parallel RC-circuit

- The contaminants can have high resistance and capacitance
- The frequency of the sweep can be increased to minimize the measured effect of the contamination
- Once the on-board probes show indication of contamination, it is hard to remove

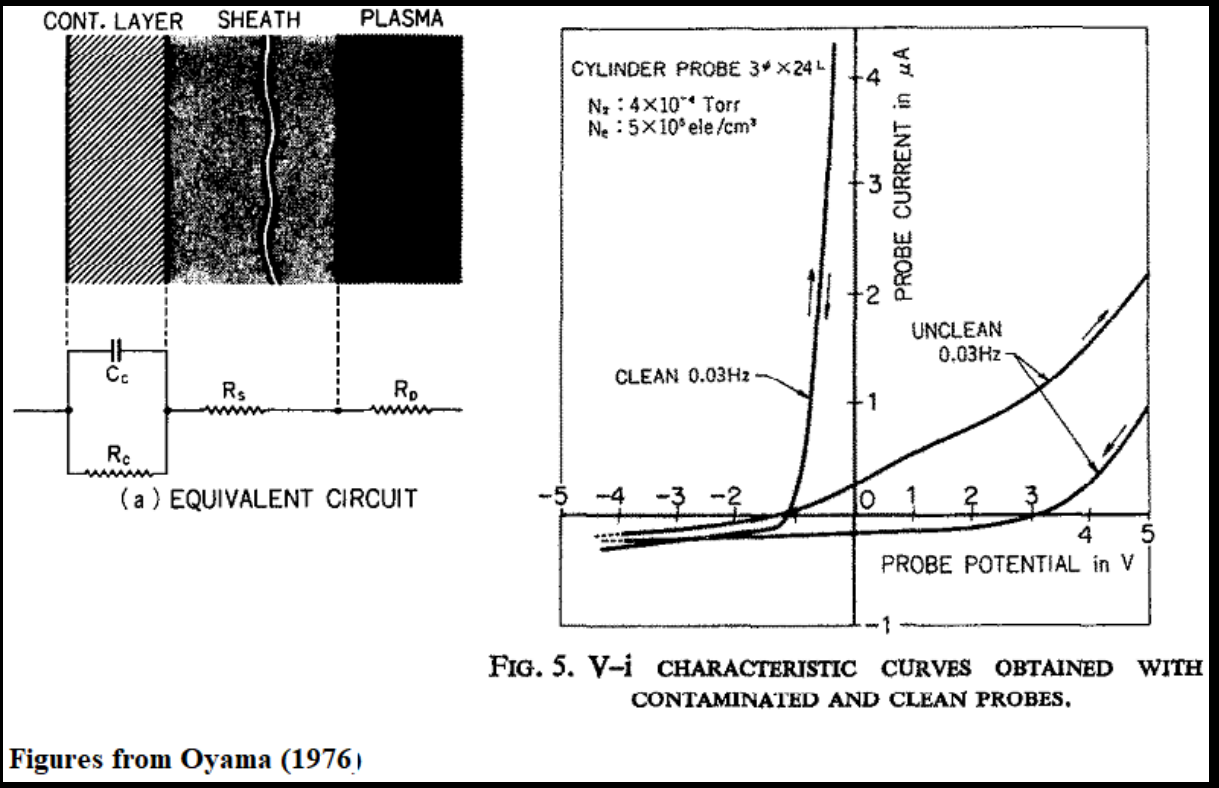
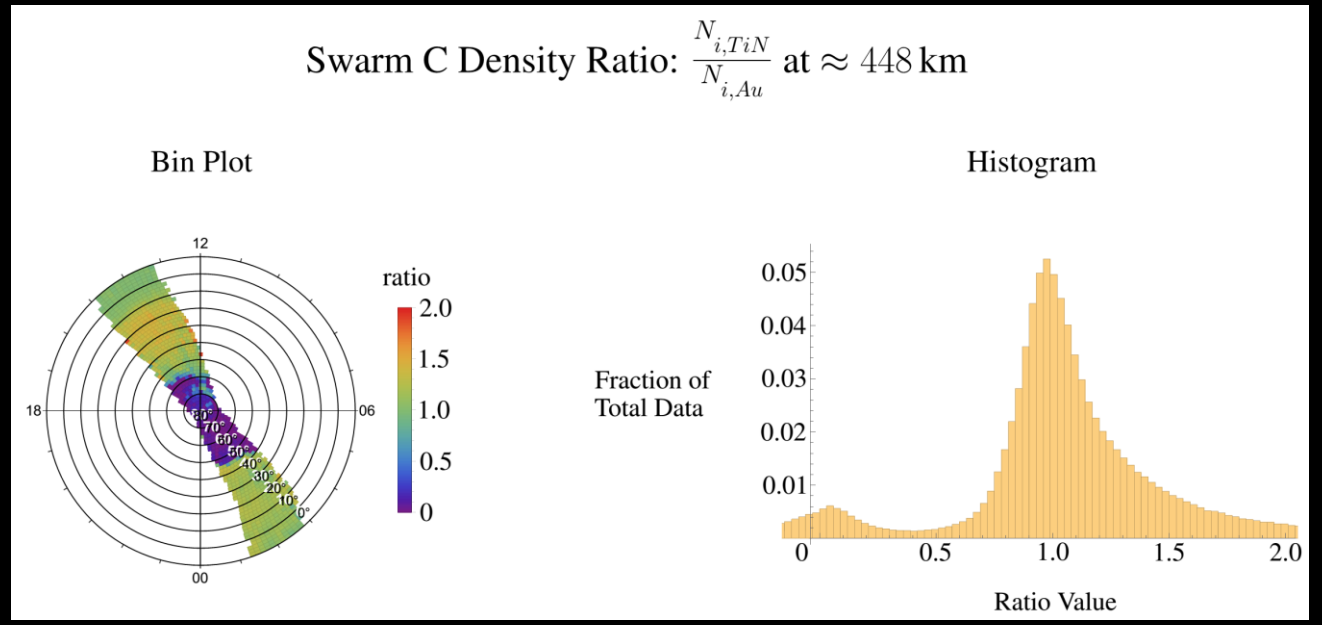



FIG. 5. V–i CHARACTERISTIC CURVES OBTAINED WITH CONTAMINATED AND CLEAN PROBES.

**Figures from Oyama (1976)**

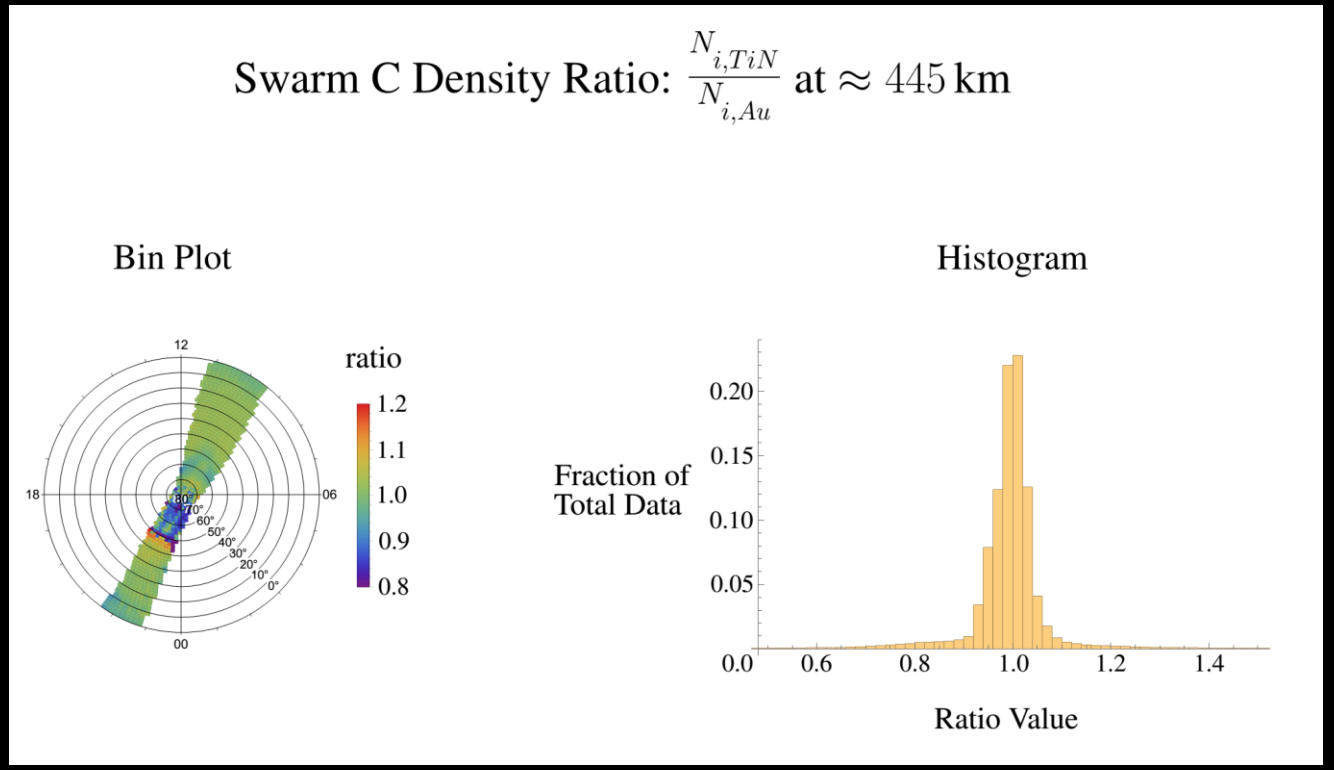
# Charlie had TiN in high gain and Au low gain

- Variables that need to be controlled:
  - Probe angle relative to the Sun
  - Probe mode and gain
  - Plasma density and temperature
  - Magnetic field lines
- Dec 5th 16:00 UTC to Dec 14th 18:00 UTC, 2017



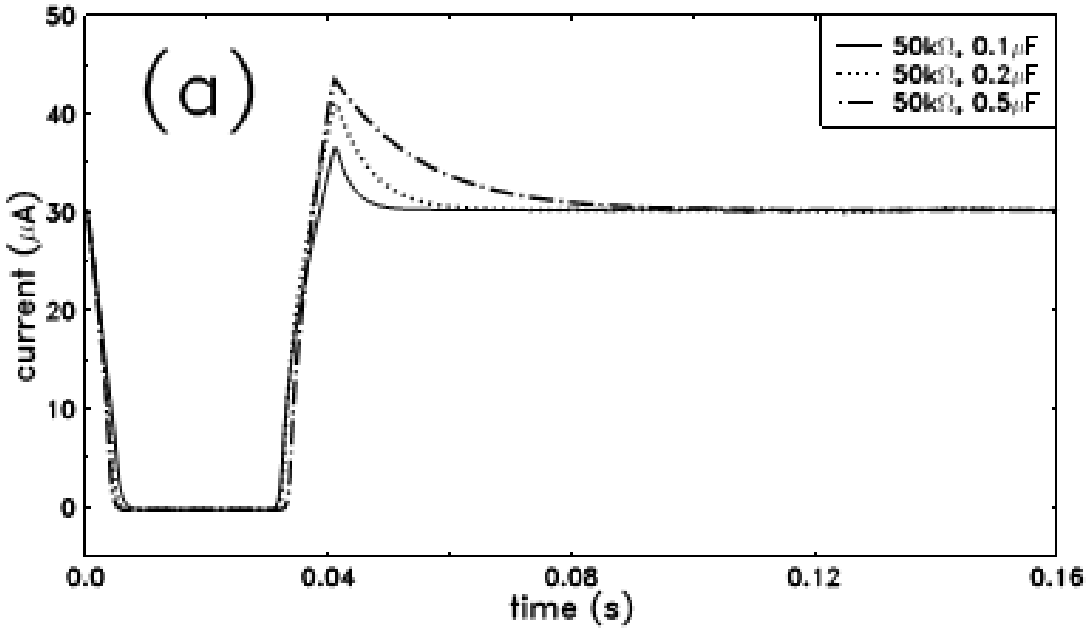
# Charlie had both probes in high gain during harmonic mode

- Jan 14th 19:00 UTC to Jan 22nd 09:30 UTC, 2018



# Summary

- Swarm has three satellites: Alpha, Bravo, and Charlie with two LP
- Au and TiN will be analyzed to determine if any have contamination
- The probes must be in the same environment to isolate the probe coating
- Swarm C shows some differences, but the cause has not been determined
- Future work: Measure temperature, and perform analysis on Alpha and Bravo
- Acknowledgements: Dr. Stephan Buchert and the University of Calgary's Swarm research team for assistance and advice.



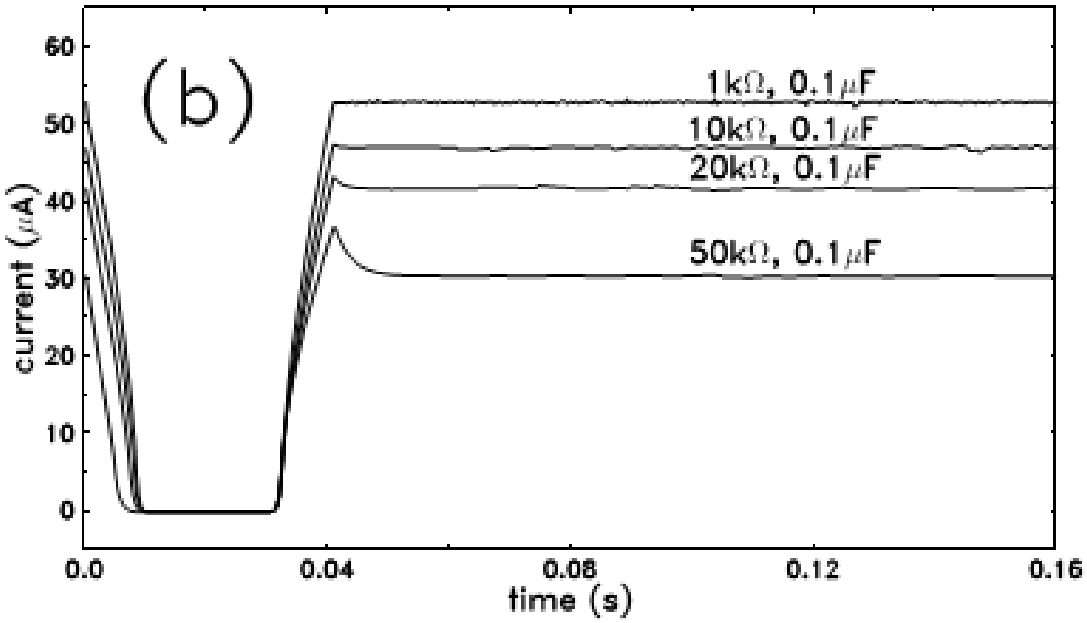




**Figure 5.** (a) The capacitance $C$ mostly influences the height and settling time of the overshoot. (b) The resistance $R$ affects the appearance of an overshoot signal and the value of the plateau current.

**Piel, Hirt and Steigies (2001)**