NSTX-U

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Characteristics for a Langmuir probe intercepting the HHFW RF power deposition spiral on NSTX*

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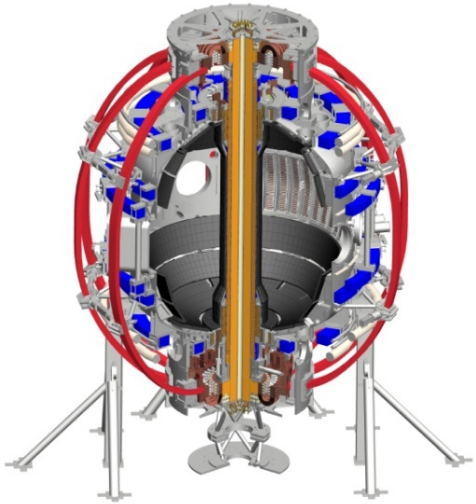

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Outline

Goal ⇒ Investigate Langmuir probe characteristics to determine balance of RF heat flux to divertor between RF rectification and SOL plasma heating

- Hot RF spiral flux enhances the electron current at zero voltage to tiles and Langmuir probes it passes over

•Characteristics for RF + NB case

- Suggest SOL plasma heating is dominant effect
- Not definitive due to limited range of V_{probe} and effect of edge turbulence/ instability

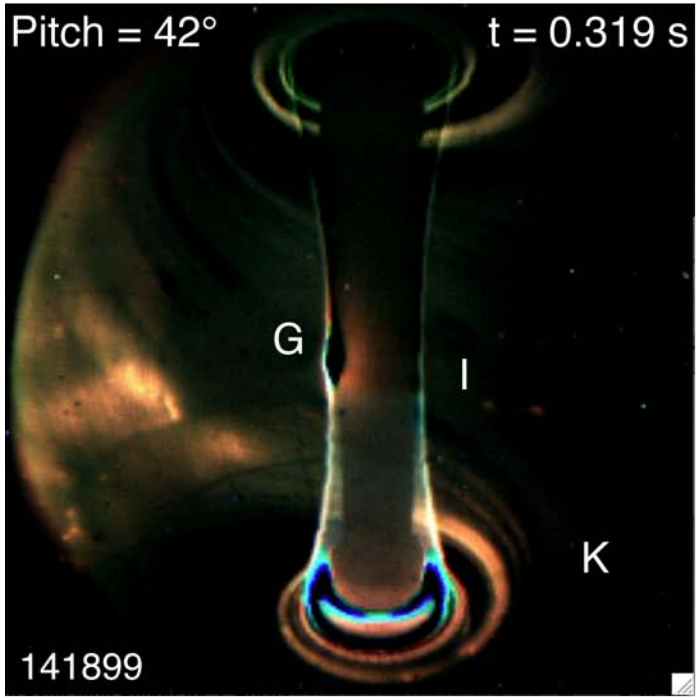
•Characteristics for RF only case

- Some indication of RF rectification
- Effect of edge turbulence less

•Langmuir probe properties that are expected for RF rectification

- Verified at 400 MHZ in two-stream instability study
- If RF currents in the SOL are large enough, the two-stream instability will cause plasma heating

“Hot” RF heat flux spiral on the divertor floor and instrumented tile/Langmuir probe locations



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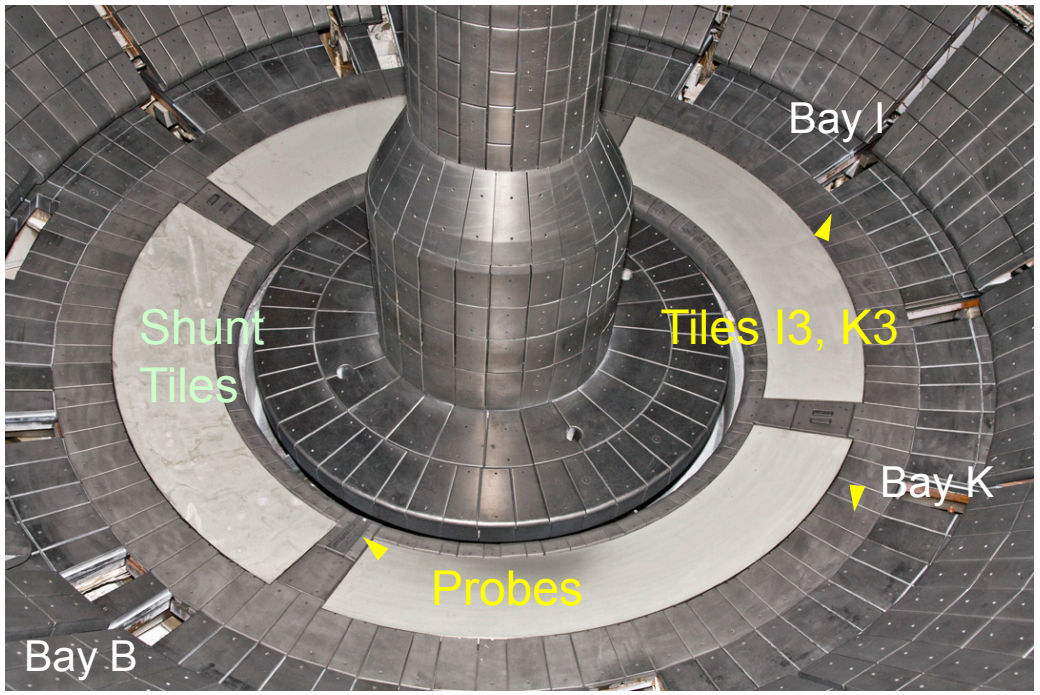
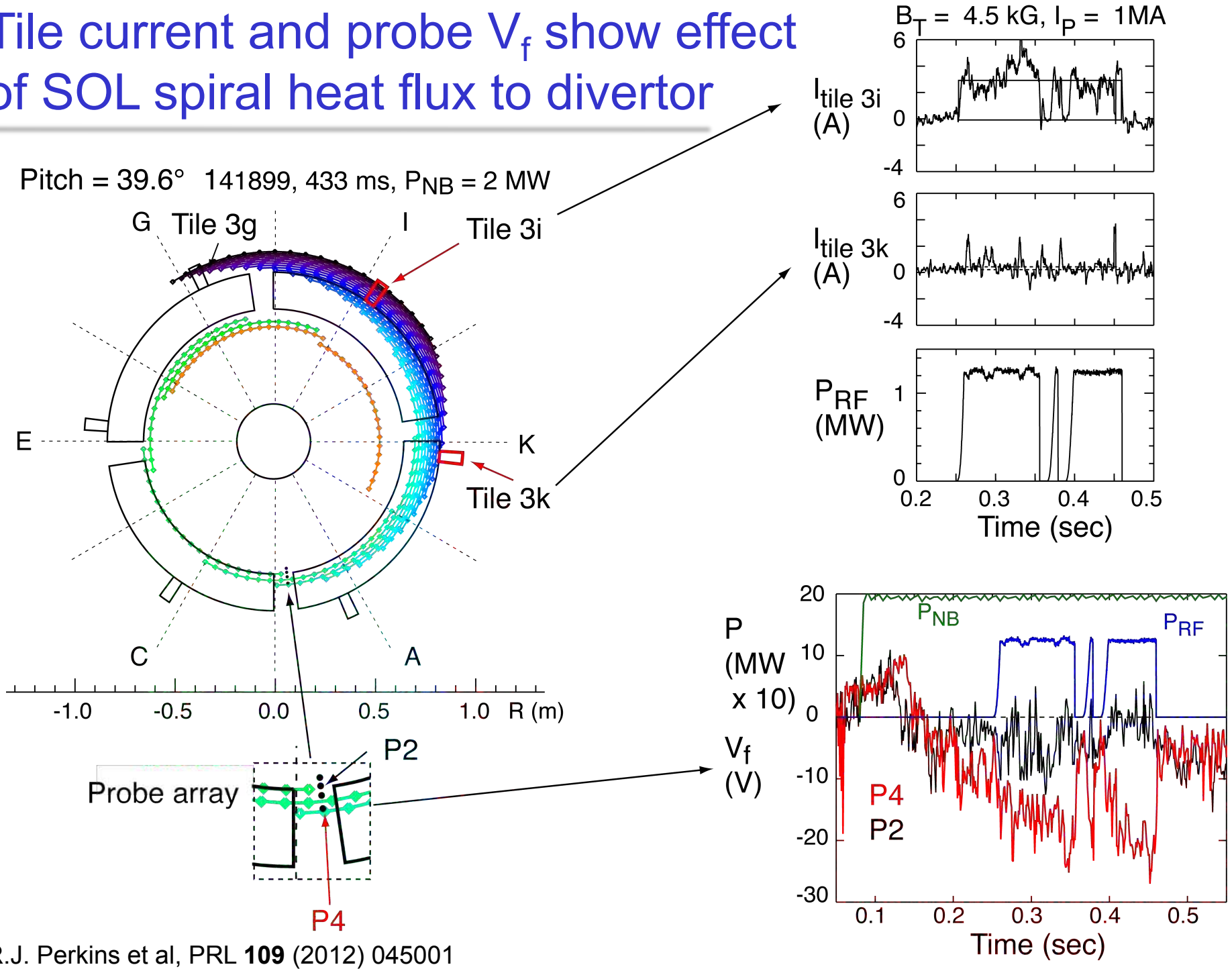


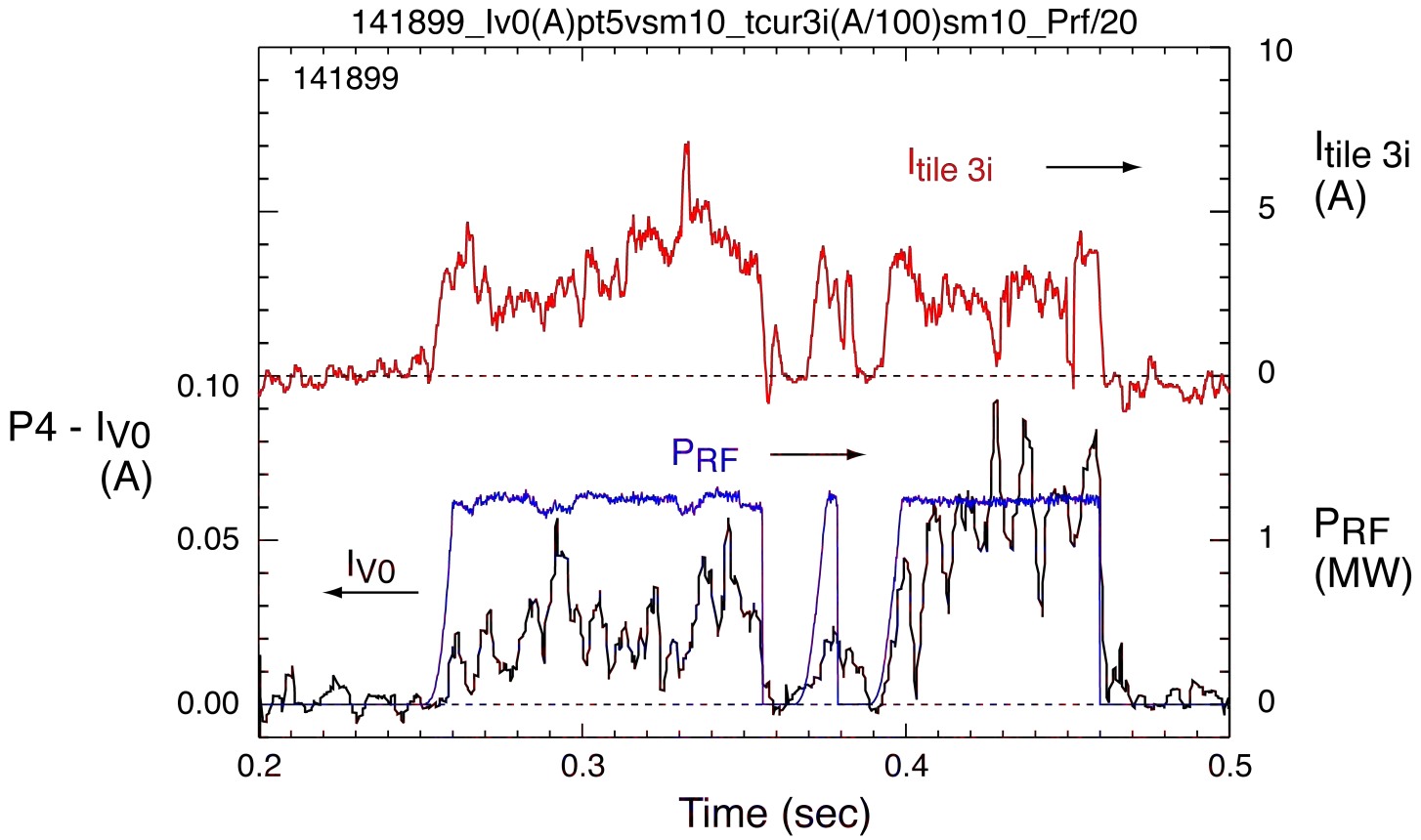
- Toroidal locations are indicated by Bay letters

Tile current and probe V_f show effect of SOL spiral heat flux to divertor



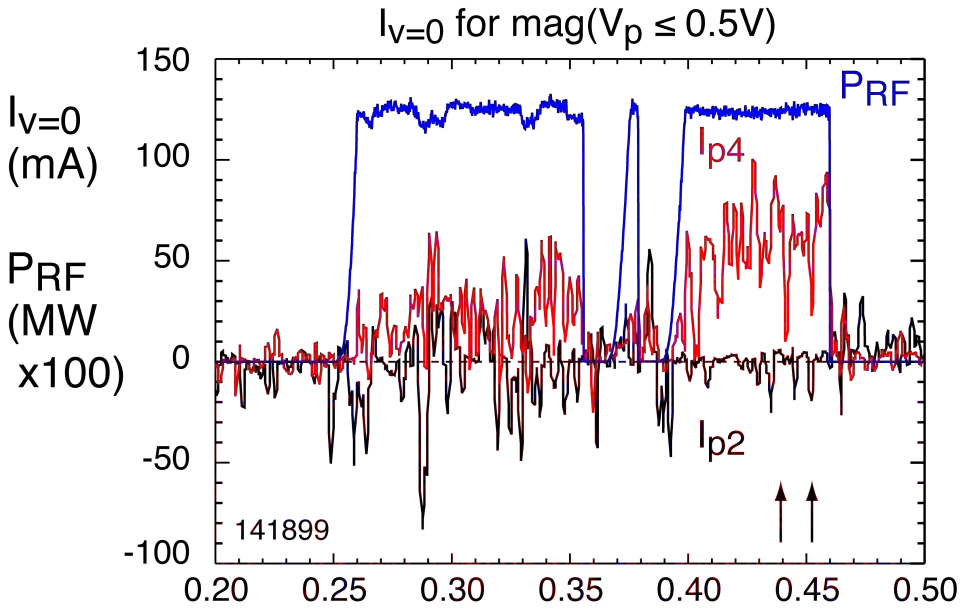
R.J. Perkins et al, PRL **109** (2012) 045001

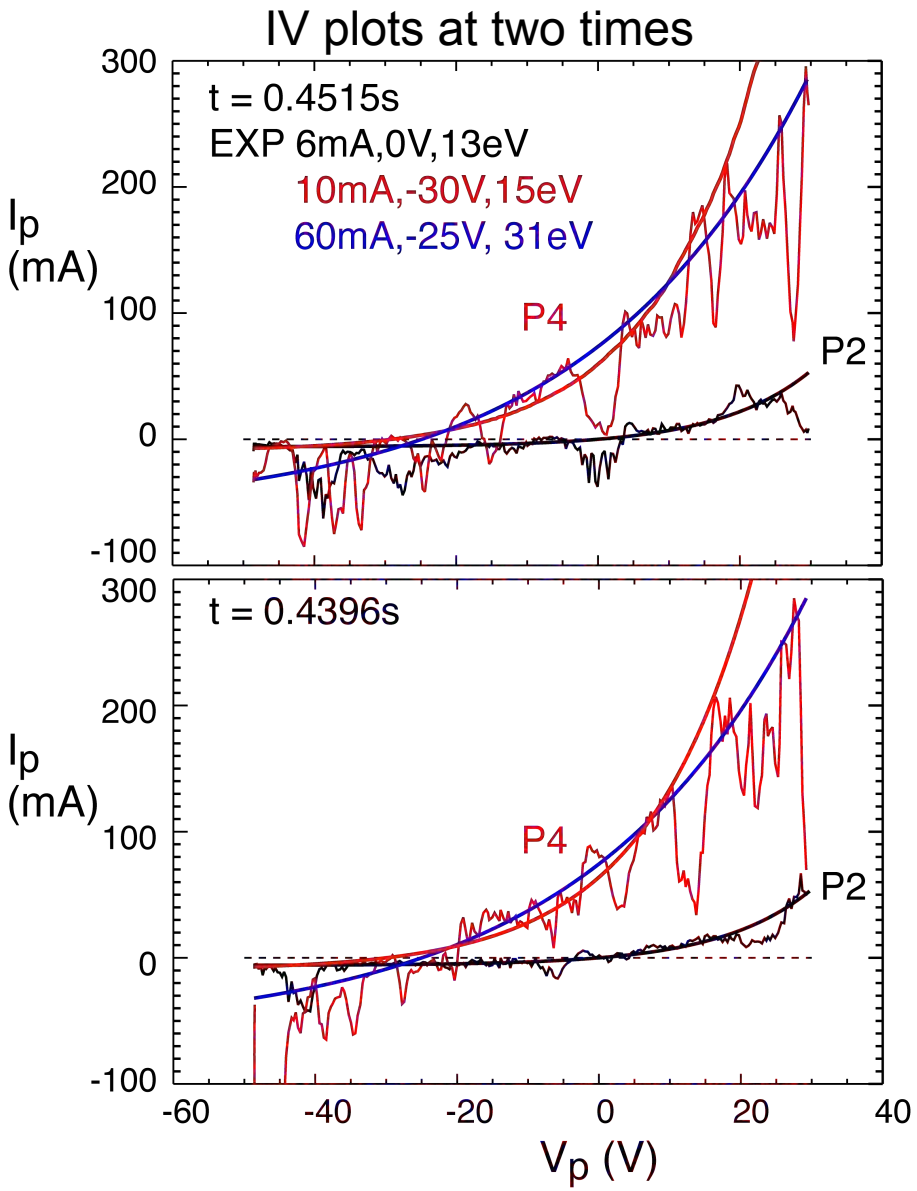
Probe 4 current at zero probe voltage (∝ surrounding tile current) shows electron current to probe as for tile 3i



- Probe current is of order 1/100 of the tile 3i current consistent with its smaller area and a more narrow section of the spiral
- Effect of spiral on RF characteristics depends on RF rectification vs plasma heating

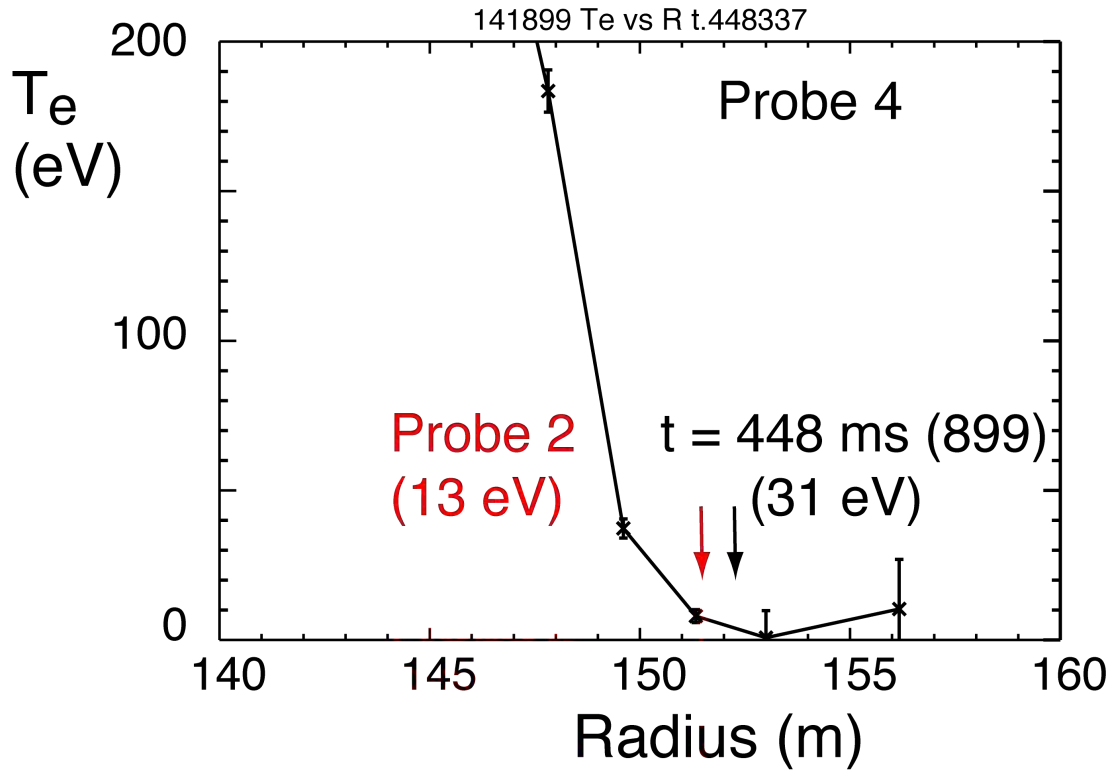
IV characteristics for probe 4 show effect of RF power flux – turbulence at divertor floor evident





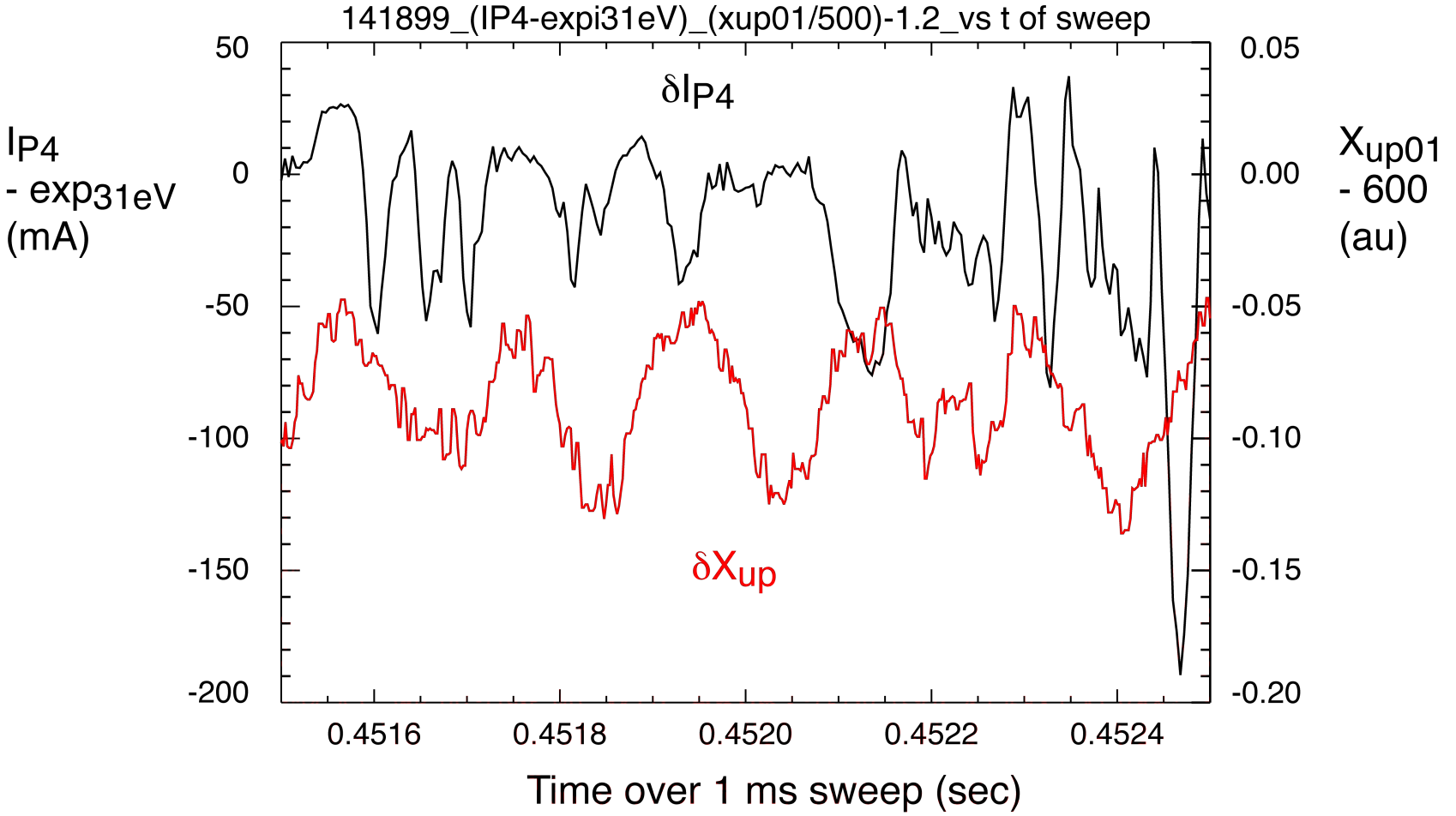
- Probe 4 exponential fits:
  - 15 eV followed by slower rise
  - 31 eV exp only
- Expect:
  (1) rollover for RF rectification,
  (2) pure exp for heating in SOL
- Heating gives best average fit but turbulence prevents definitive selection

Comparison of probe temperatures with Thomson scattering measurements



- The probe 4 "T_e" value is ~ 3 times the Thomson scattering midplane value, whereas the probe 2 " T_e" value is close to the TS value
- This lends support to the "T_e" value of 15 eV with rectification for probe 4

Instability behavior in edge of plasma on soft X-ray signal is consistent with perturbations on the P4 current

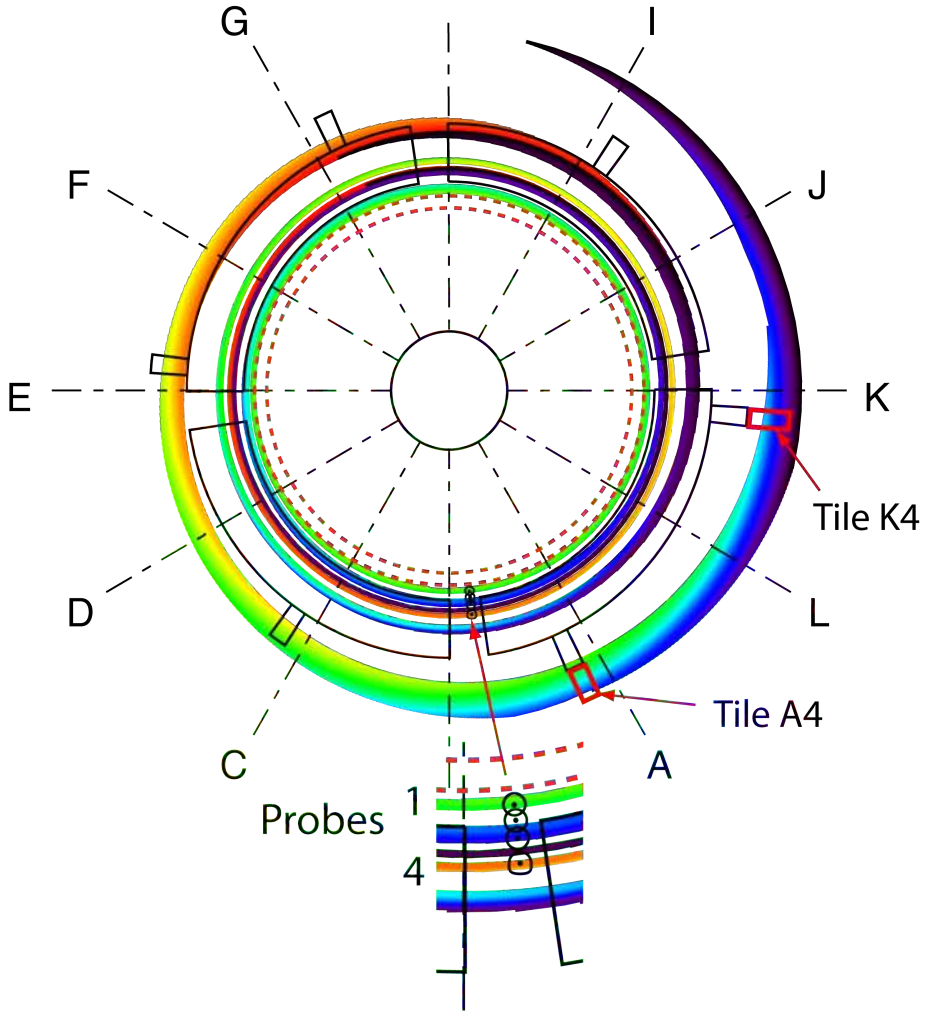


- Will look for correlation with blobs/instability on NSTX-U
- Look for quieter case on NSTX, RF only

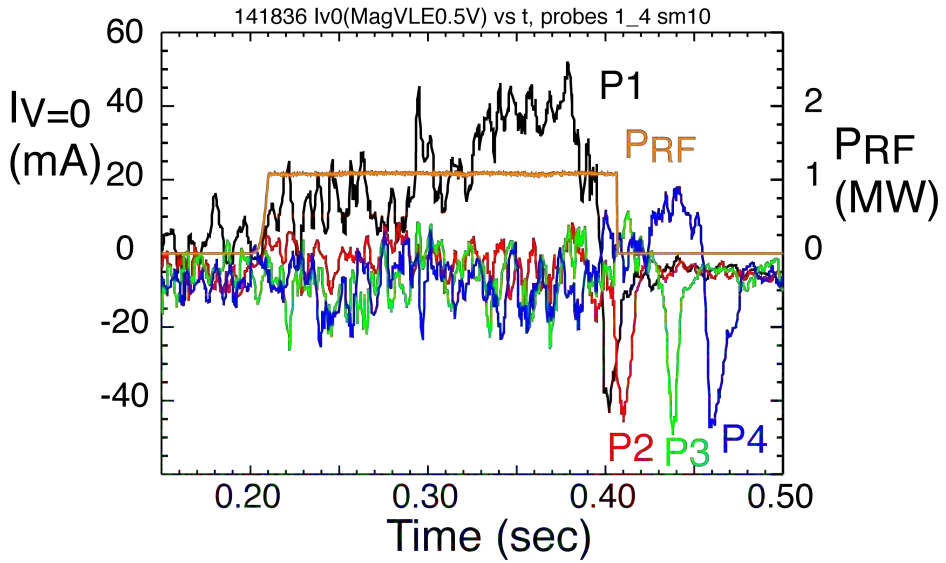
RF only discharge with probe 1 intercepting the RF heat flux spiral near the outer vessel strike radius

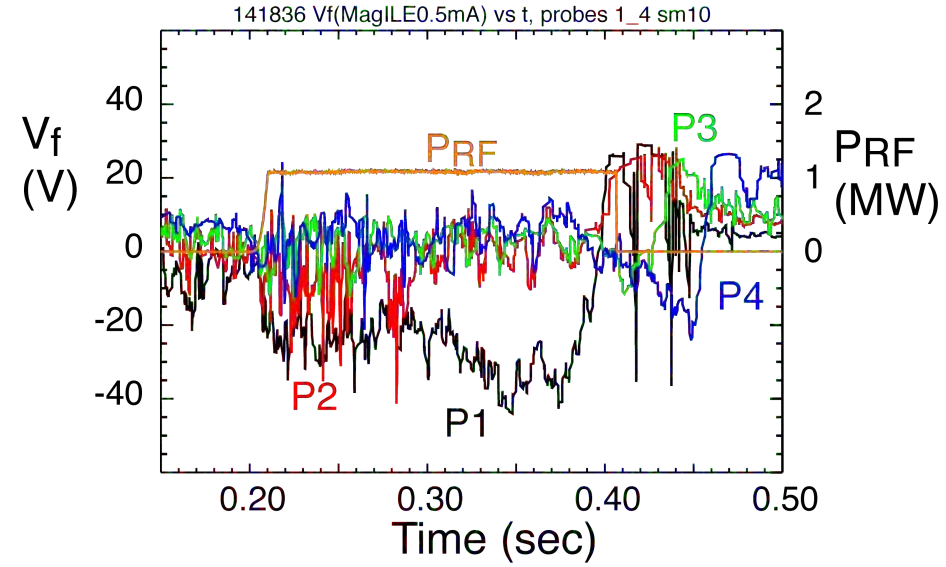
Strike points on the lower divertor

141836, 350 ms, RF only, I_P = 0.65 MA, B_T = 5.5 kG

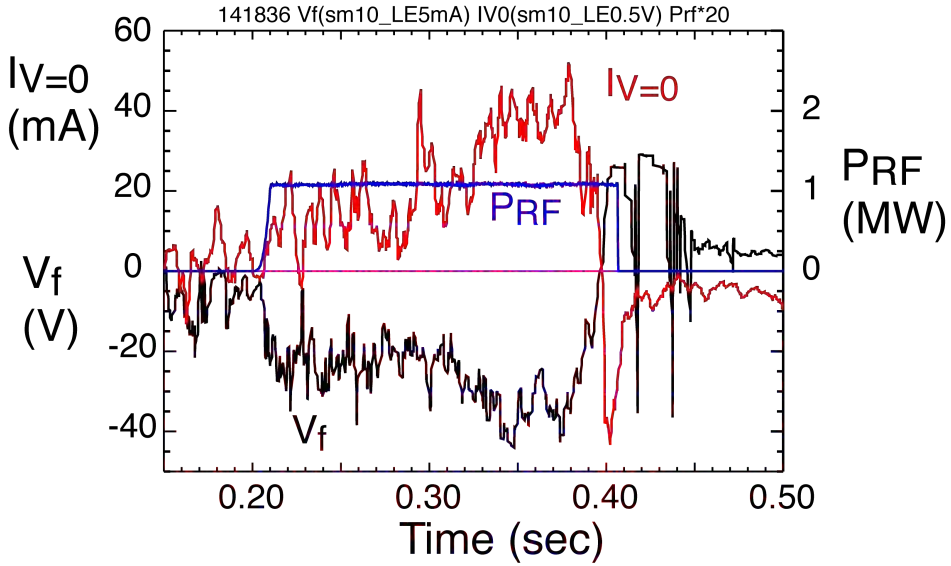


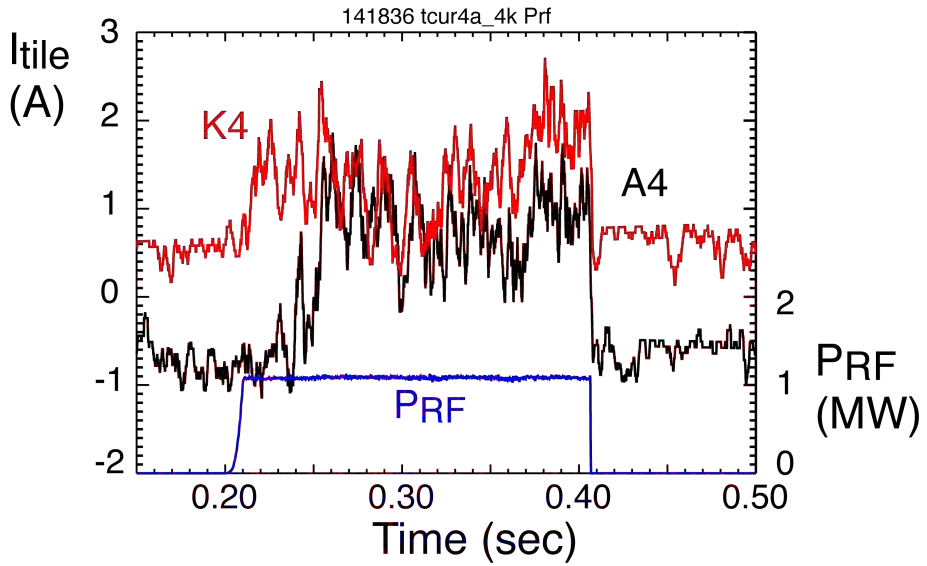
Probe characteristics





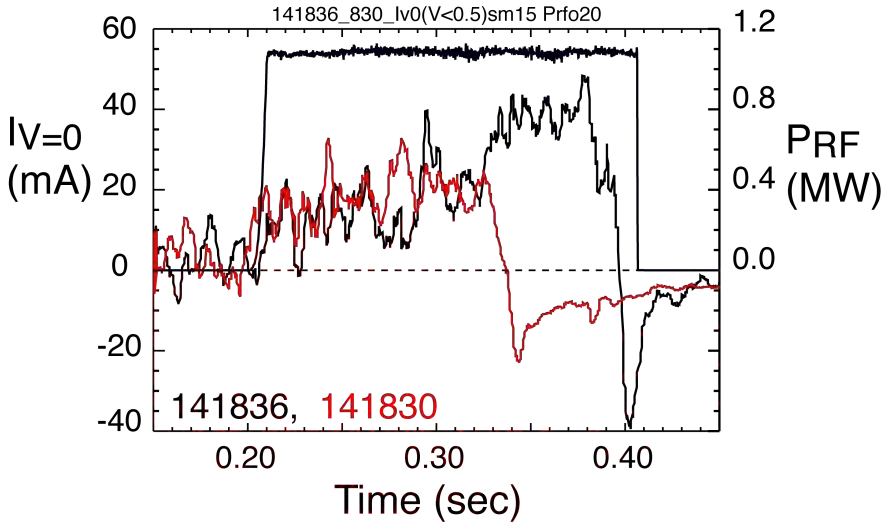
The RF heat flux spiral falls on tiles A4 and K4 for this RF only discharge

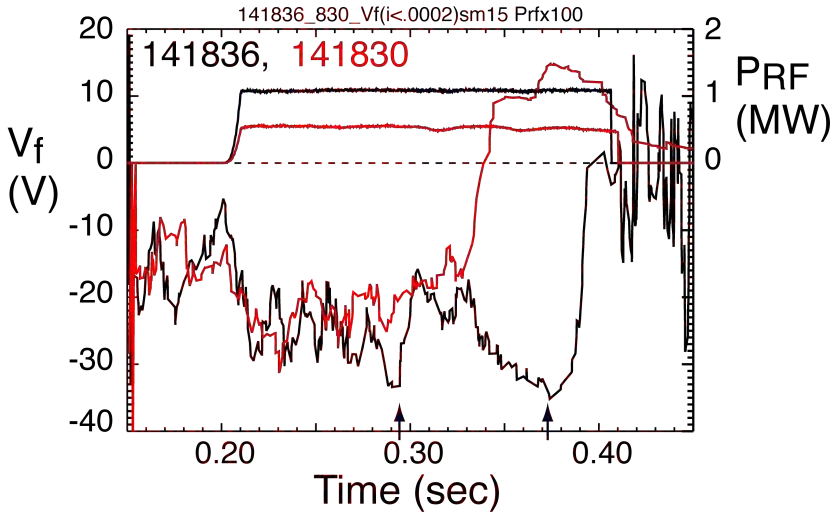




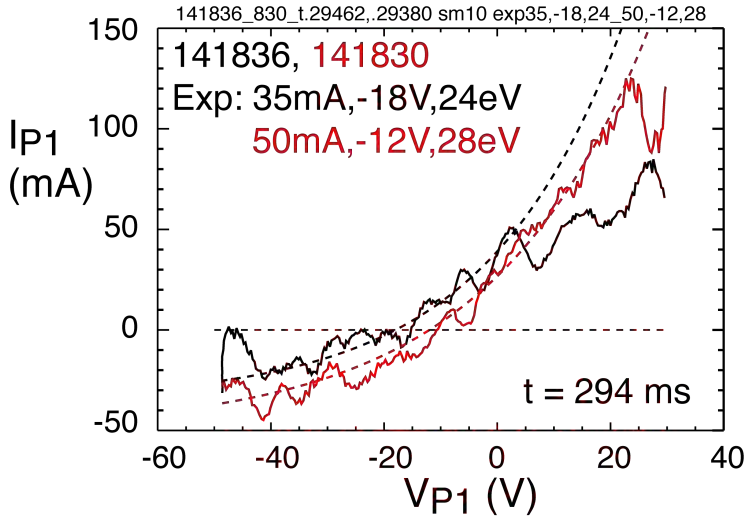
- ΔI_{tile} is up to 2.5 A on tile A4
- Current on tile A4 rises slowly after RF turn-on showing the movement of the plasma
- $I_{V=0}$ and V_f cross through 0 when the outer vessel strike radius passes over the probe

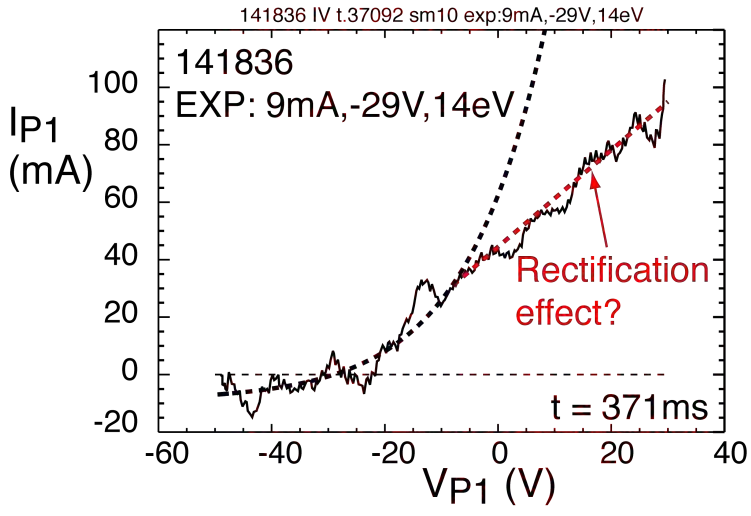
Rectification effect apparent on IV characteristic at P_{RF} = 1.1 MW at two times shown





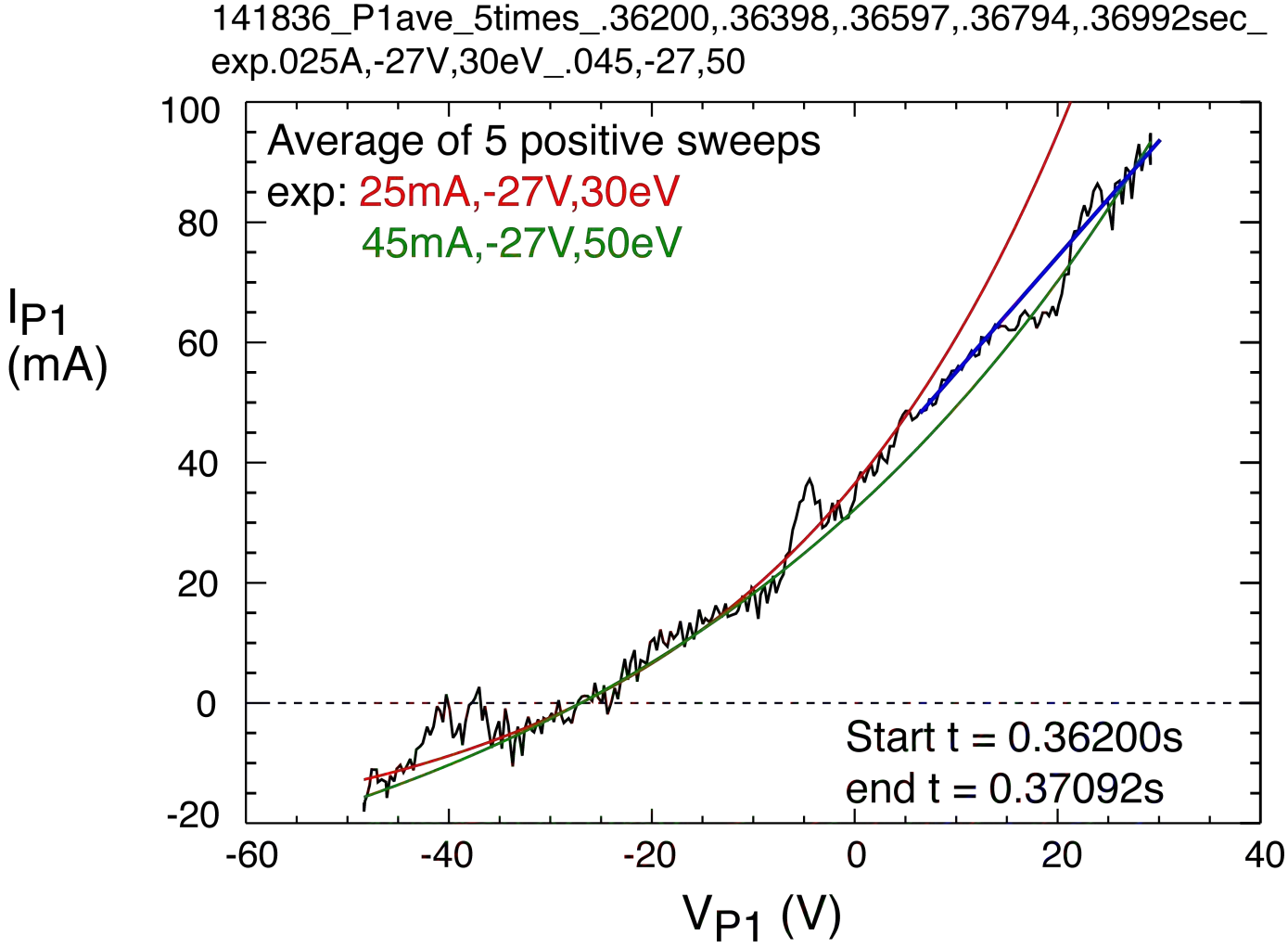
IV characteristics





- Noise is reduced but wider voltage sweep is desirable to be sure of rectification effect

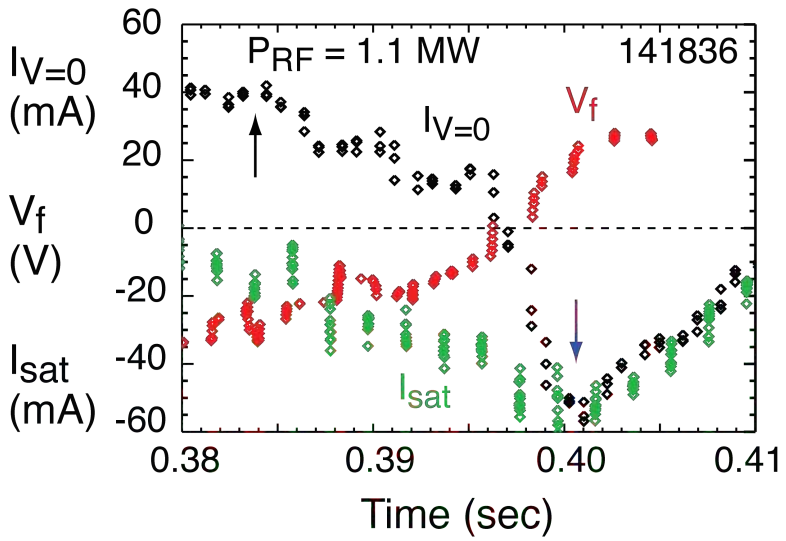
Rectification effect still apparent on IV characteristic averaging over 5 positive sweeps



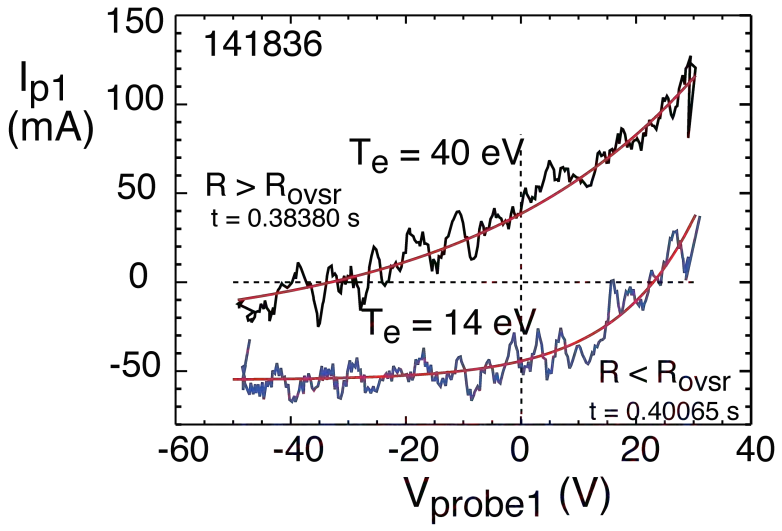
- Wider voltage sweep is still needed to be sure of rectification effect
  - +/- 100V sweep is desirable

Apparent heating is observed at different times without indicating a rectification effect

OVSR crossing P1 at 396 ms (LRDFIT)

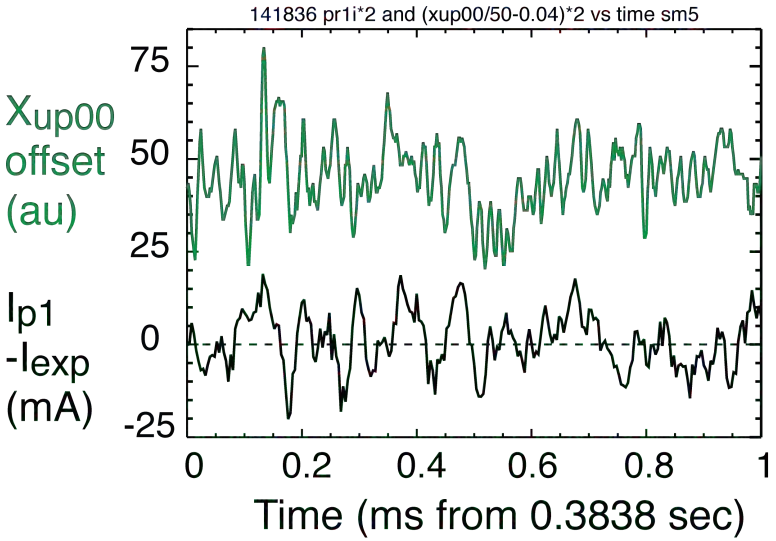


IV characteristics at 384 ms and 401 ms



- At t = 384 ms, prior to the OVSR crossing the probe, T_e ~ 40 eV compared to 14 eV at 371 ms
- In private flux region, T_e ~ 14 eV
- Fluctuations on probe similar to those on edge X-ray signal

Stability at 384 ms



Properties of RF rectification studied on a linear PIG discharge

- TM010 cavity excited a 400 MHz RF current parallel to B ~ 200 G at n_e in the mid $10^{17} m^{-3}$ range
- Langmuir probe and magnetic probe measurements were taken during the discharge afterglow

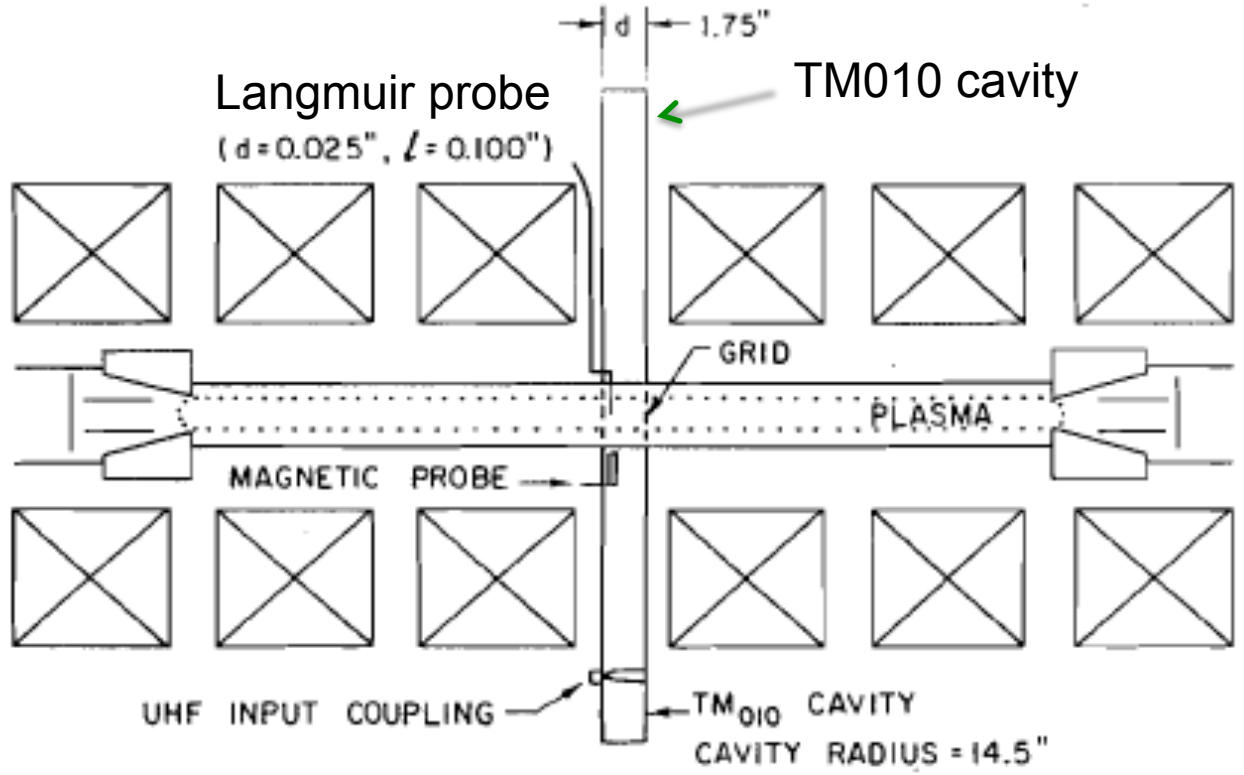


FIG. 3.7. TM_{010} CAVITY-PIPER SYSTEM.

Probe IV characteristics produced at a selected time in the afterglow plasma with Z intensification of scope

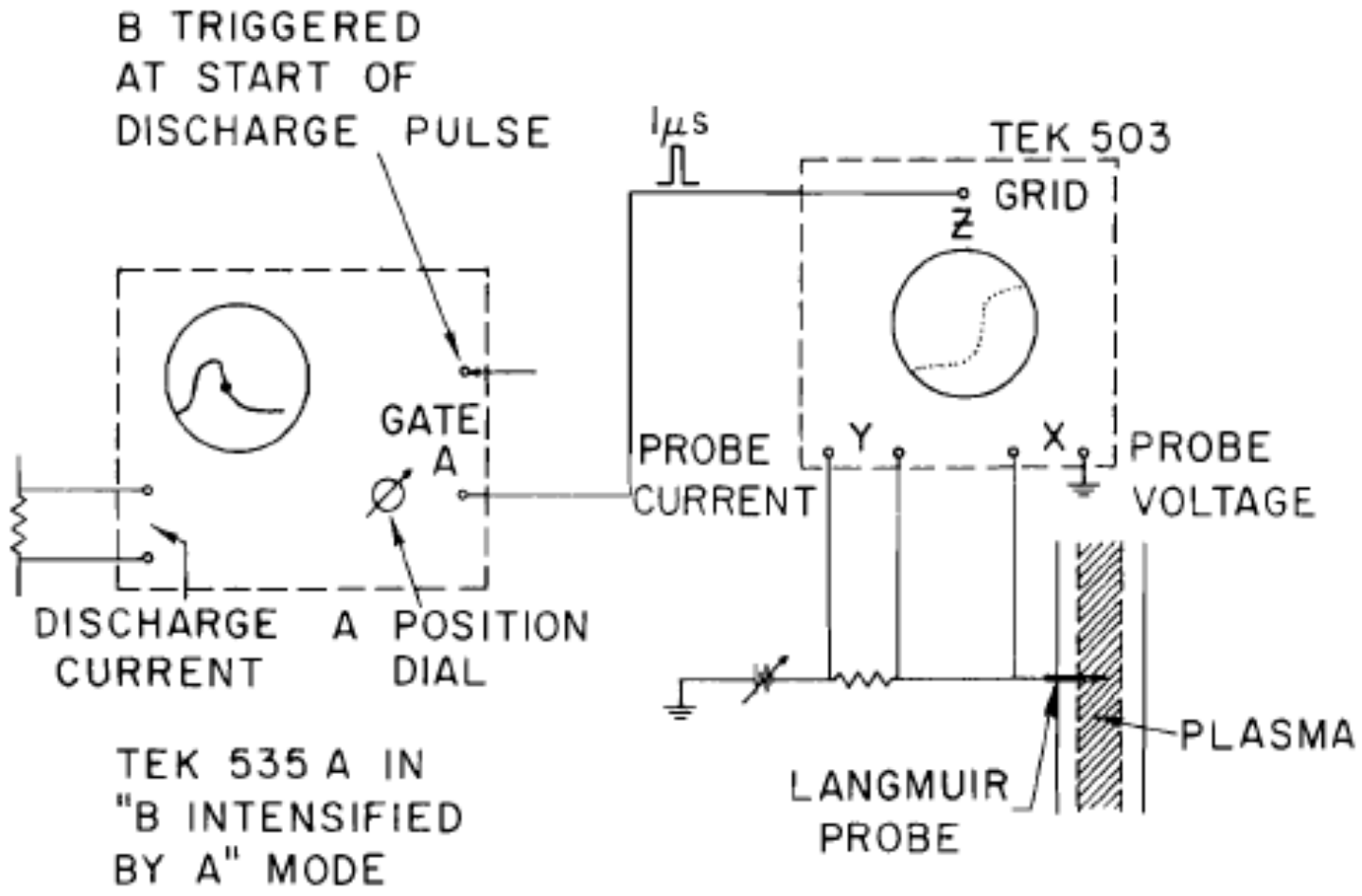


FIG. 5.1. SCHEMATIC OF THE CIRCUIT USED TO PRODUCE TIME-SAMPLED PROBE CURVES.

Expected RF rectification probe characteristics versus RF voltage across the probe sheath for constant saturation currents

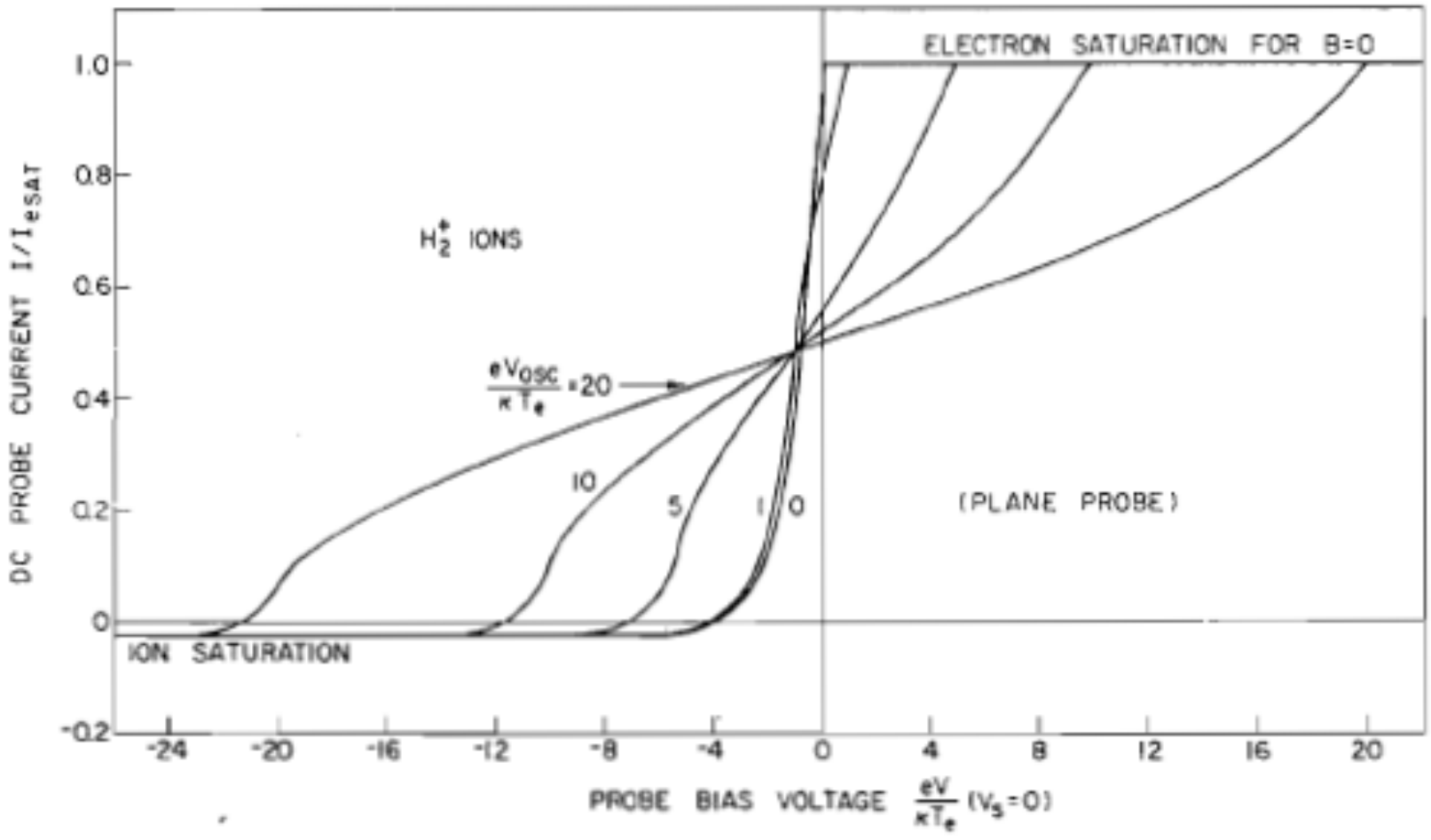
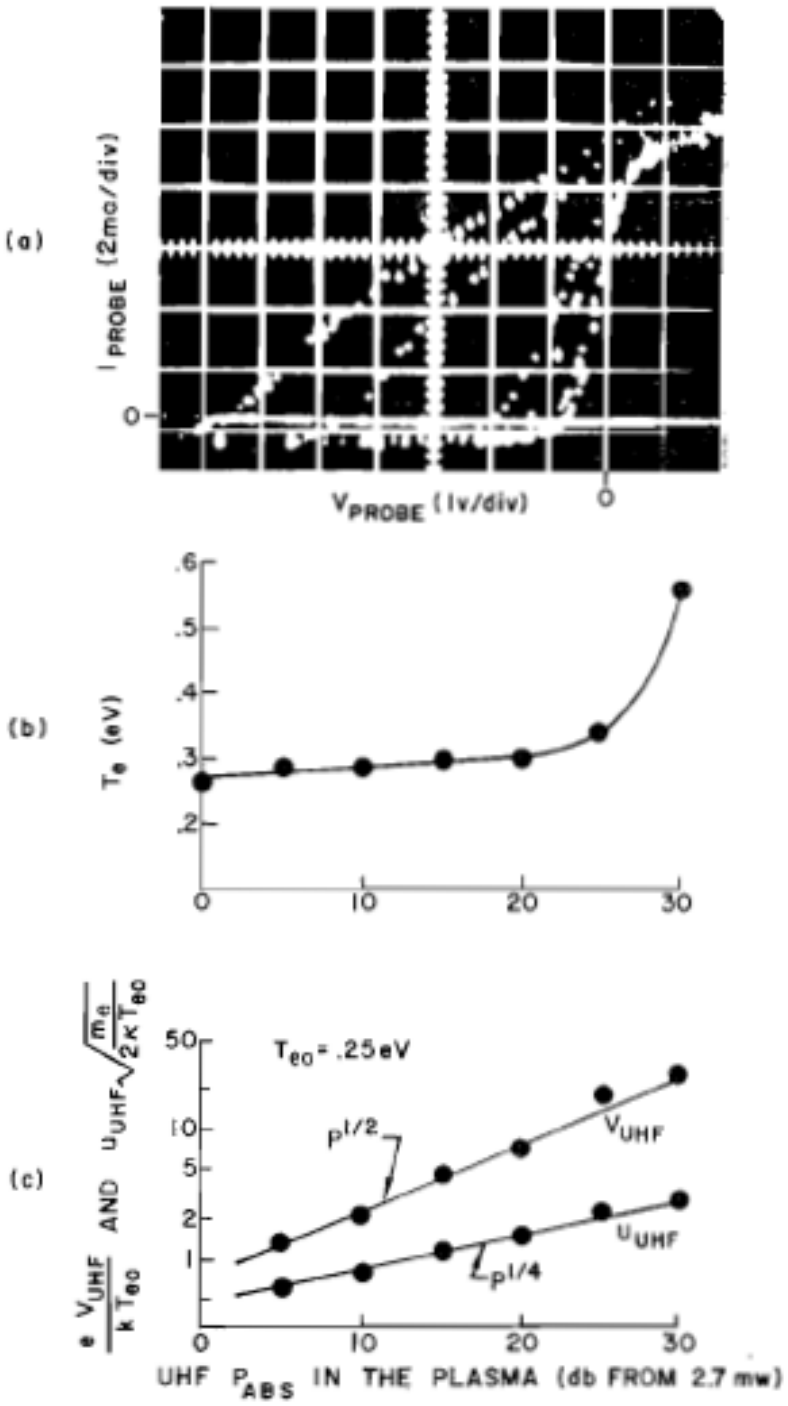


FIG. 5.25. PROBE CURRENT VS PROBE BIAS VOLTAGE FOR SEVERAL AMPLITUDES OF OSCILLATING PROBE VOLTAGE (V_{OSC}).

Probe characteristics vs P_{RF}



a. Probe curves for several values of UHF power absorbed (P_{ABS}) in the plasma. UHF P_{ABS} is increased by 5 db steps for successively higher curves. For the highest curve, P_{ABS} = 30 db above 2.7 mw = 2.7 w.

- V_f moves to more negative V_{probe} as power is increased in 5 db steps from 2.7 mW to 2.7 W

b. Electron temperature vs P_{ABS}. The temperature measurements are not reliable for powers above that designated by the arrow.

- Heating is apparent at highest P_{RF} of 2.7 W, consistent with onset of the two-stream instability

c UHF potential (V_{UHF}) developed across the probe-plasma sheath and UHF electron drift (u_{UHF}) vs P_{ABS}.

Magnetic probe circuit

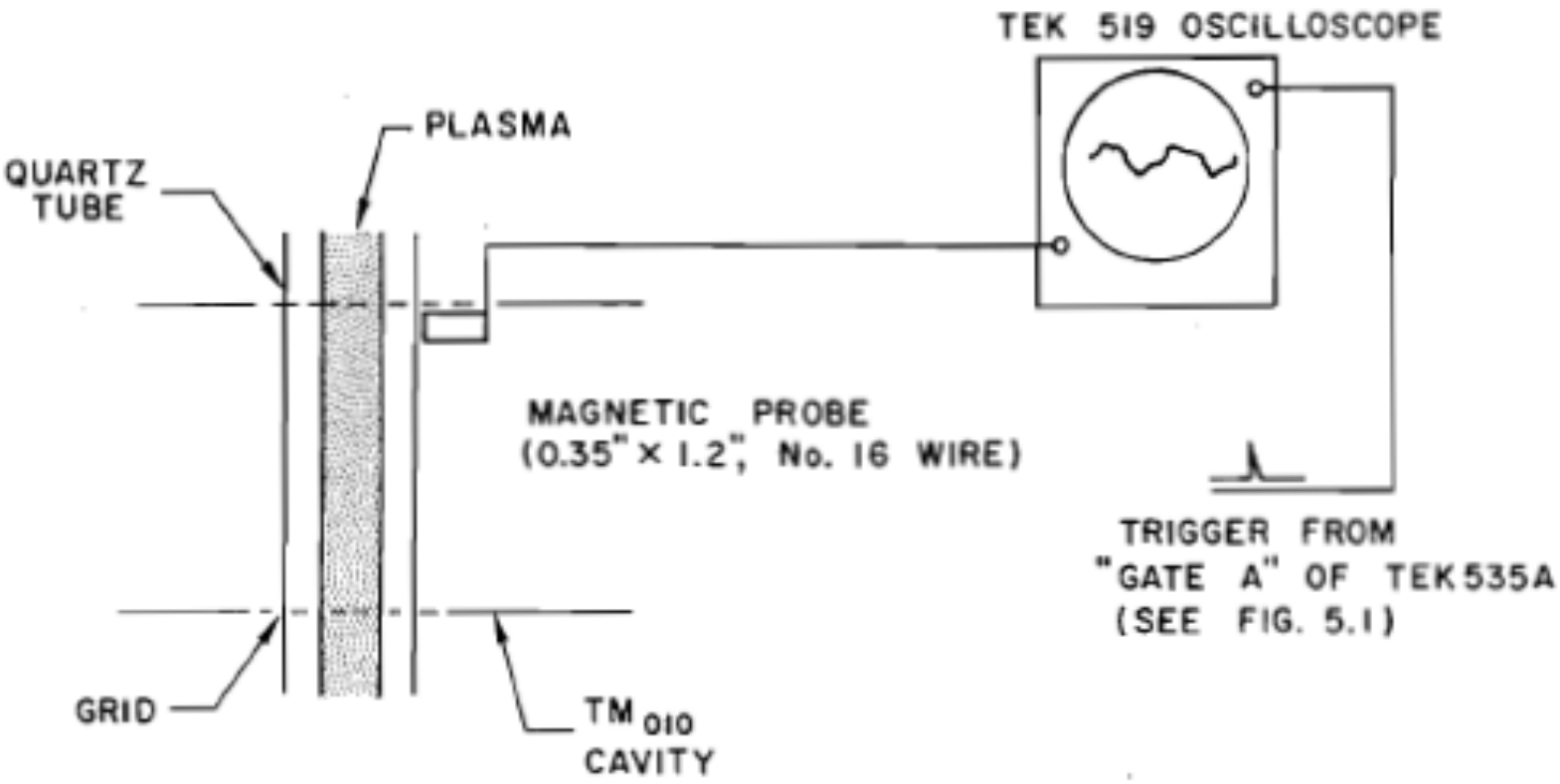


FIG. 6.5. MAGNETIC PROBE CIRCUIT.

- Probe positioned near plasma column inside the cavity to detect field caused by current in plasma
- RF waveform from the probe was measured with a TEK 519 high frequency scope (5 V per division sensitivity)

"Clamping" of current in plasma detected for P_{RF} above ~ 2W - picture here is for P_{INC} = 5 W

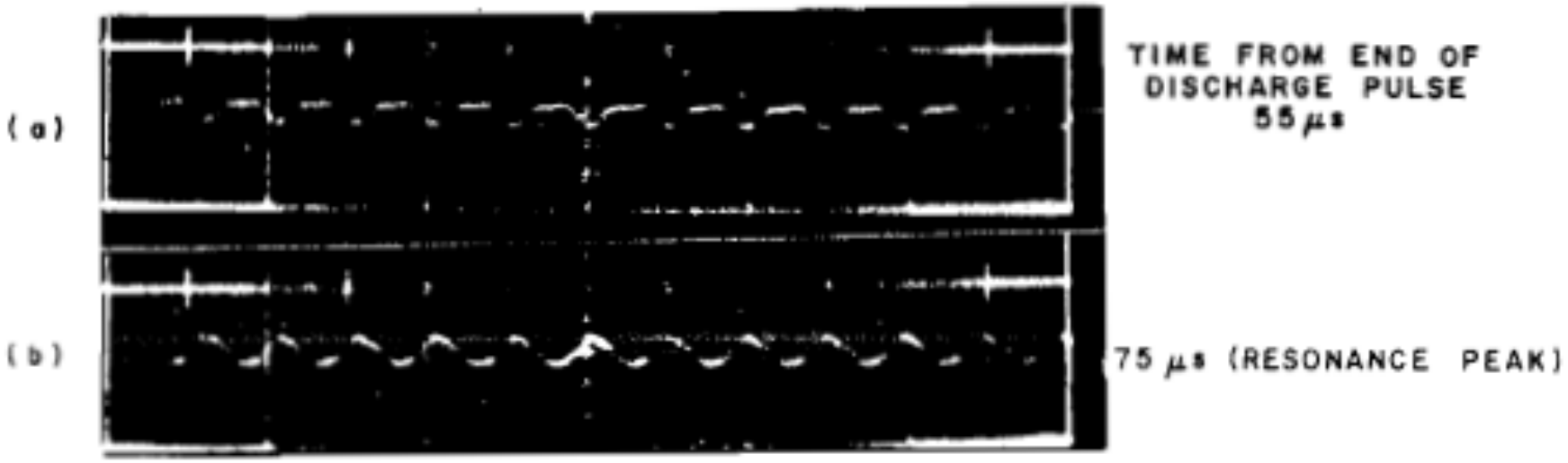


FIG. 6.8. MAGNETIC PROBE CURVES FOR CONDITIONS OF FIG. 6.1 BUT WITH A 3:1 IMBALANCE IN THE PIPER ELECTRON GUN CURRENTS (P_{INC} = 5 w).

- Clamping is consistent with onset of the two-stream instability when the electron drift velocity exceeds the onset velocity
- We plan to look for this effect with RF probes on NSTX-U

Summary and future plans

- Electron current is collected by the tiles (at V_{tile} = 0 volts) and the Langmuir probes (at V_{probe} = 0 V) when intercepting the "hot" RF spiral heat flux
- IV characteristics of probes intercepting the RF spiral indicate SOL plasma heating and RF rectification for NSTX conditions
  - Plasma heating appears to be dominant in RF + NB case and sometimes in the RF only case
  - RF rectification is indicated for some RF only characteristics
- Improved characteristics are planned for NSTX-U
  - Wider V_{probe} range to clearly show electron and ion saturation currents
  - Correlation of I_{probe} fluctuations with edge turbulence/instability/blobs
  - Coaxial probe feeds to permit direct measurements of the RF voltages on the probes
- RF probes will be employed on NSTX-U to investigate probable two-stream instability effects on RF currents in the SOL
  - Comparison with modeling of RF currents to indicate their magnitudes relative to that required for the two-stream instability onset