NSTX-U

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The Potential Contribution of RF Sheaths to Field-Aligned SOL Losses on NSTX

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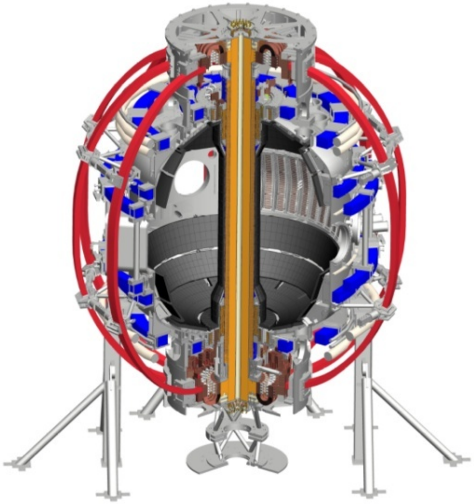

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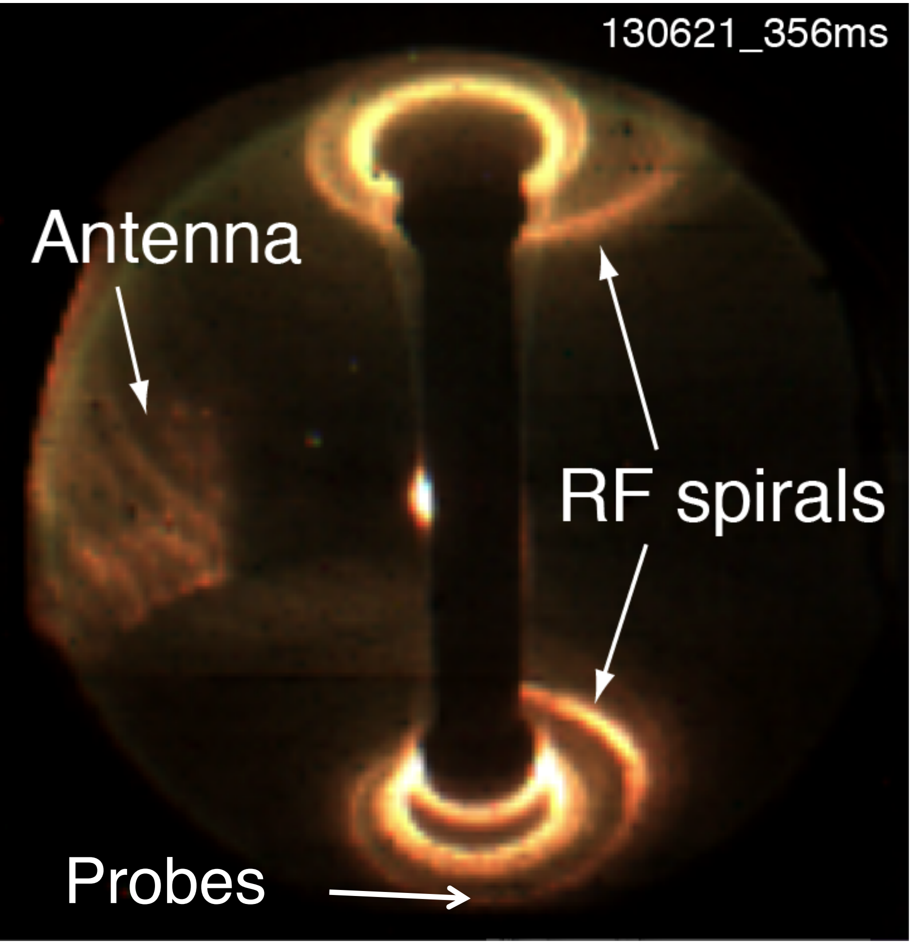
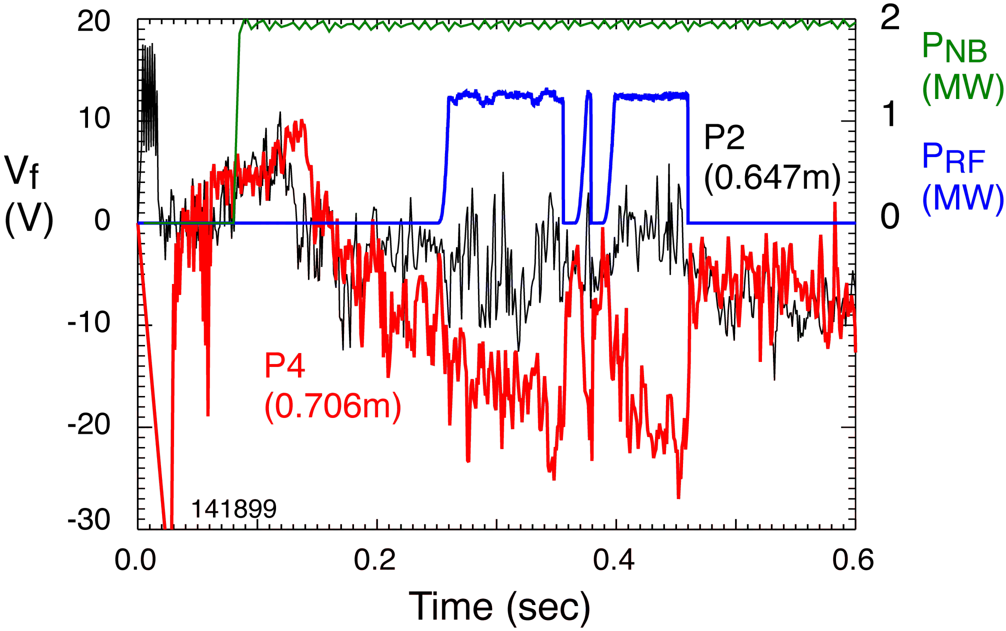
Significant HHFW losses in SOL can perhaps be understood by analyzing Langmuir probes

Midplane camera image



Up to 2 MW/m^2 heat flux measured under spiral

RF affects Langmuir-probe floating potential



Only probes underneath spiral are affected

RF rectification is a candidate mechanism to explain the change in Langmuir probe signals

- RF electric field drives enhanced electron current to wall
  - Due to nonlinear IV characteristic for sheath

- Probe floating potential shifts to more negative value

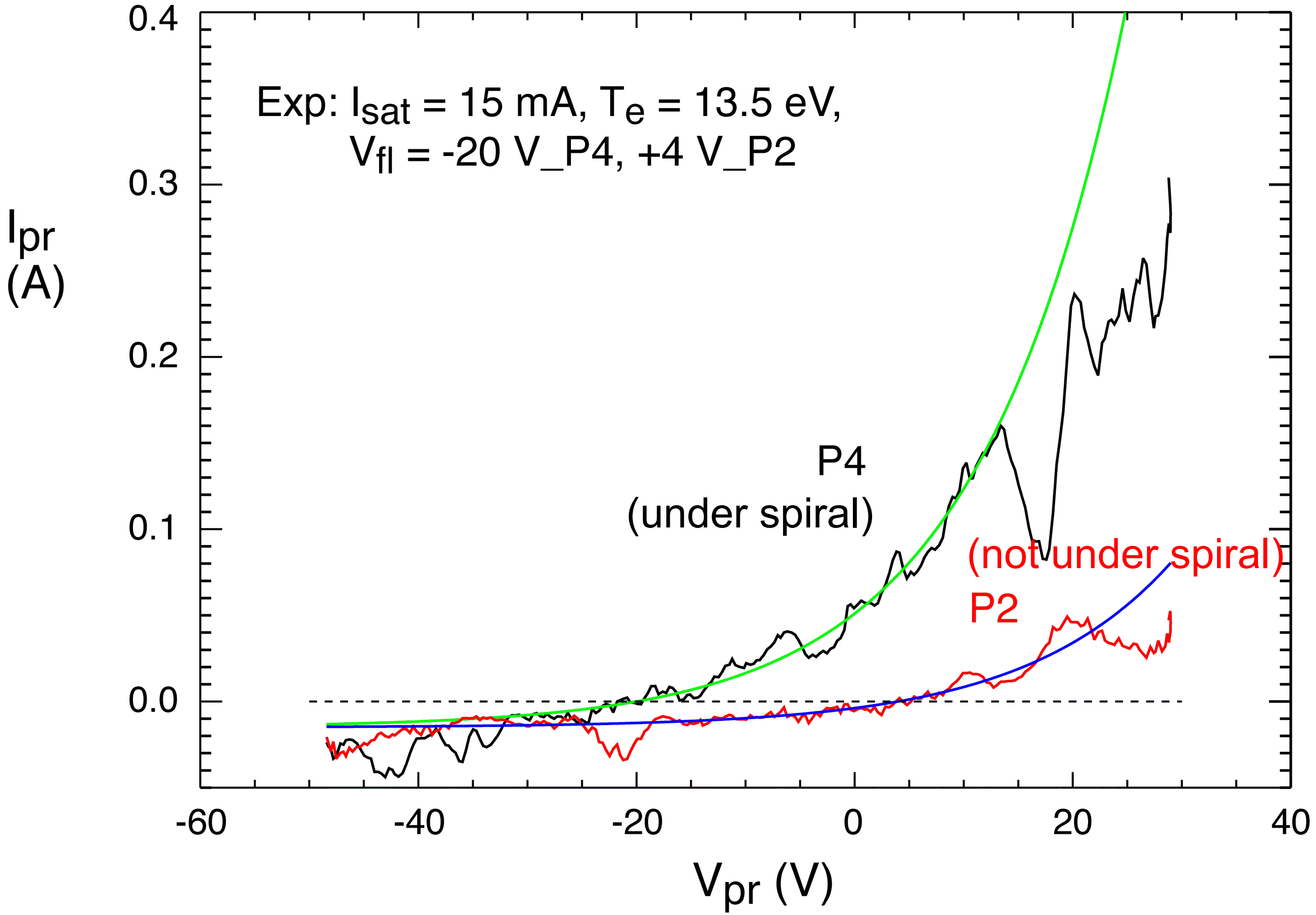
$$\exp\left[\frac{\Delta V_f}{T_e}\right] = I_0\left(\frac{V_{RF}}{T_e}\right)$$

- RF rectification blamed for ICRF-induced impurity contamination: enhanced ion-bombardment and erosion

- This talk focuses on a far-field sheaths
  - Formed away from antenna due to propagating waves

[A. Boschi and F. Magistrelli, *Il Nuovo Cimento* **29** (1963) 487.] [J. C. Hosea, PhD thesis, Stanford Univ., 1966]

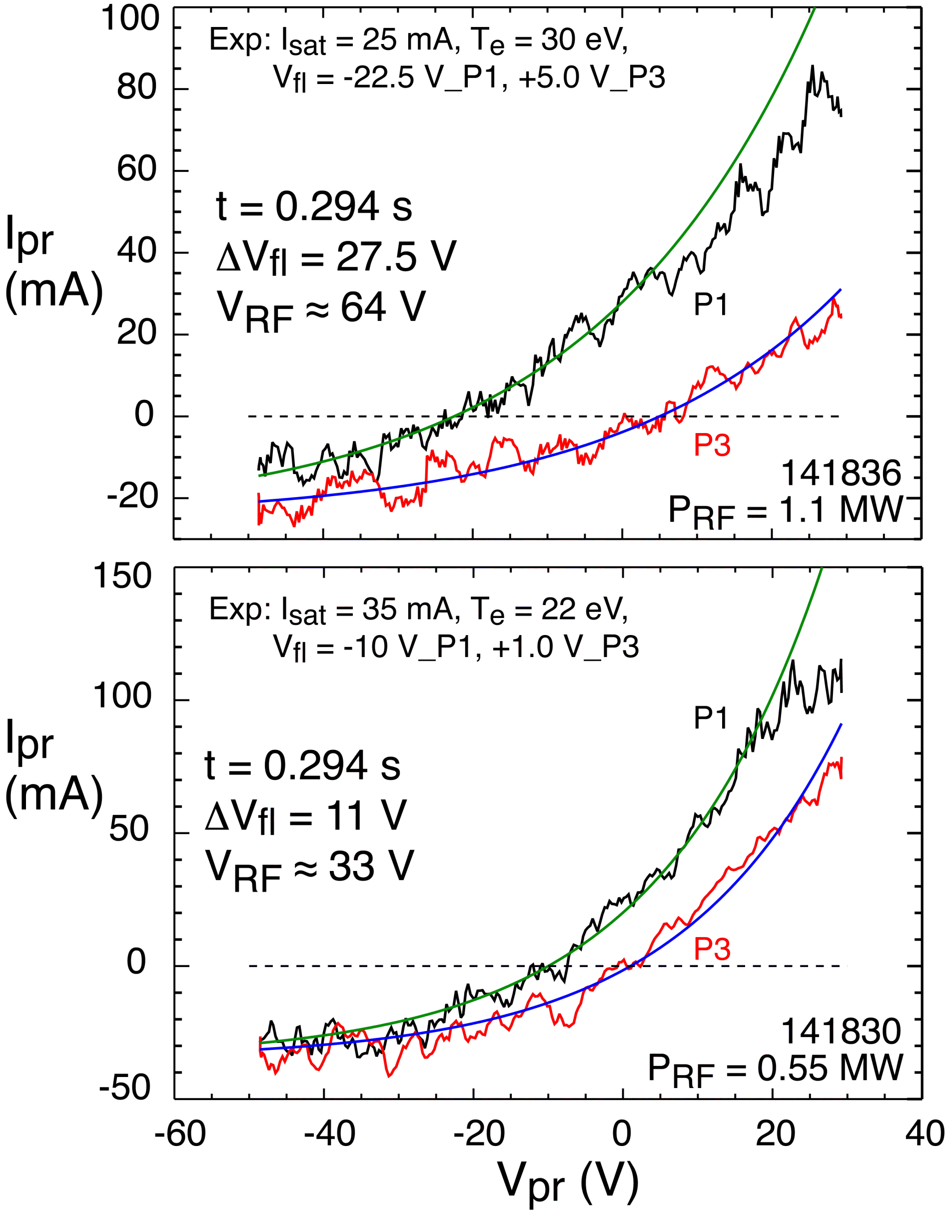
Fitting probe characteristics with RF rectification yields reasonable fits around V_{fl} and yields V_{RF} = 43.7 V



RF + NBI
141899
t = 0.4515 s
6 sweep avg
(1 sweep ~ 1 ms)

- Assume same I_{sat} and T_e values for both probes
  - Only change V_{fl}
- Resulting fits are reasonable for both characteristics especially in vicinity of floating potential

Similar results found for RF-only discharges V_{RF} = 64 V for P_{RF} = 1.1MW and V_{RF} = 33 V for P_{RF} = 0.55 MW



- RF-only shots; no NBI
    - 141836, P_{RF} = 1.1 MW
    - 141830, P_{RF} = 0.55 MW
    - t = 0.294 s
- V_{RF} increases with P_{RF} from 0.55 MW to 1.1 MW
- V_{RF} is not ~ $\sqrt{P_{RF}}$ but SOL plasma conditions are different as well
- Assuming RF rectification gives V_{RF} ~ 30 – 70 V

V_{RF} enhances sheath transmission factor (heat flux to surface) Indicates RF rectification contributes substantially to spiral

- Heat flux to probe biased at V is : $q_{surface} = \gamma(V) * j^{+}_{sat} * T_e$
  - γ(V) is the sheath transmission factor

- $V_{fl\text{-}RF}$ and $V_{fl\text{-}noRF}$ floating potentials relative to ground (tile voltage)

$$\gamma_{noRF} = -\frac{V_f}{T_e} + \frac{V_{fl-noRF}}{T_e} + 2.5\frac{T_i}{T_e} + \frac{2}{1-\sigma_e}\exp\left[-\frac{V_{fl-noRF}}{T_e}\right]$$

[P.C. Stangeby Plasma Physics Series (2000)]

- Add RF potential $V_{RF}\sin(\omega t)$ and average over RF period

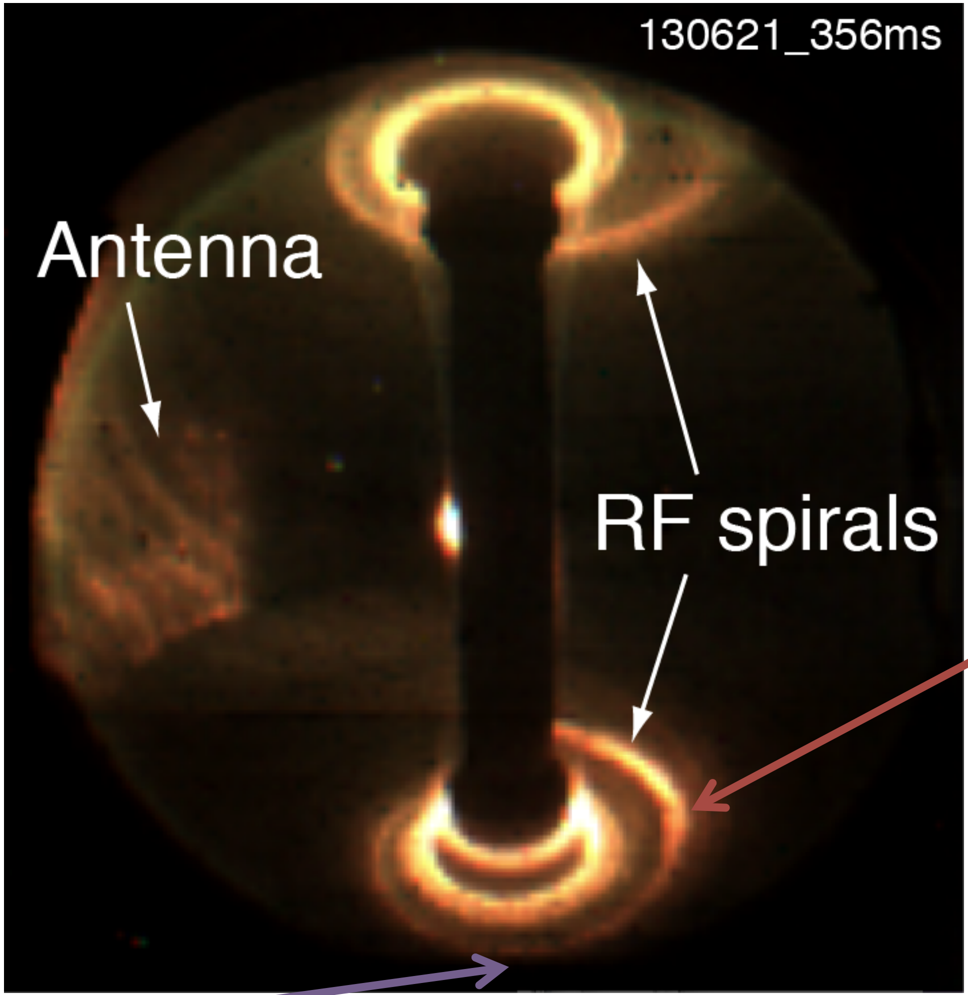
$$\gamma_{RF} = -\frac{V_f}{T_e} + \frac{V_{fl-noRF}}{T_e} + 2.5\frac{T_i}{T_e} + \frac{2}{1-\sigma_e}\exp\left[-\frac{V_{fl-RF}}{T_e}\right]$$

- For the RF + NBI case (141899):

No RF	**$\gamma_{noRF} = 7.12$**	**$q_{noRF} = 0.103$ MW/m^2**
With RF	**$\gamma_{RF} = 14.43$**	**$q_{RF} = 0.209$ MW/m^2**

- In rough agreement with IR measurements in the vicinity of the vessel gap

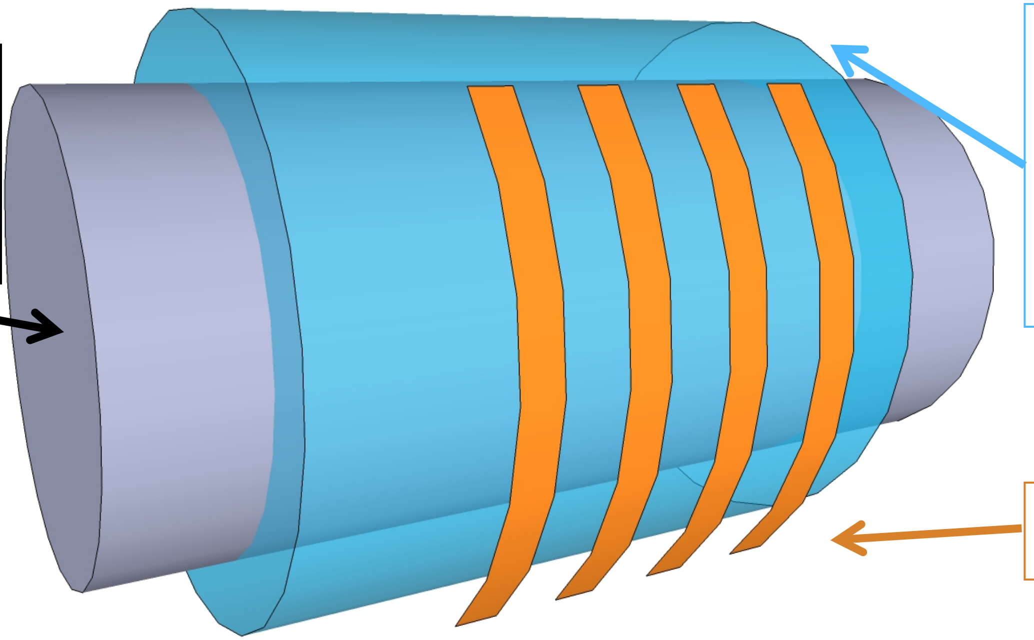
Increase of gamma should be even larger if measured at more intense portion of spiral



Most intense portion & location of new probes in upgrade

Langmuir probe location

Cylindrical cold-plasma model



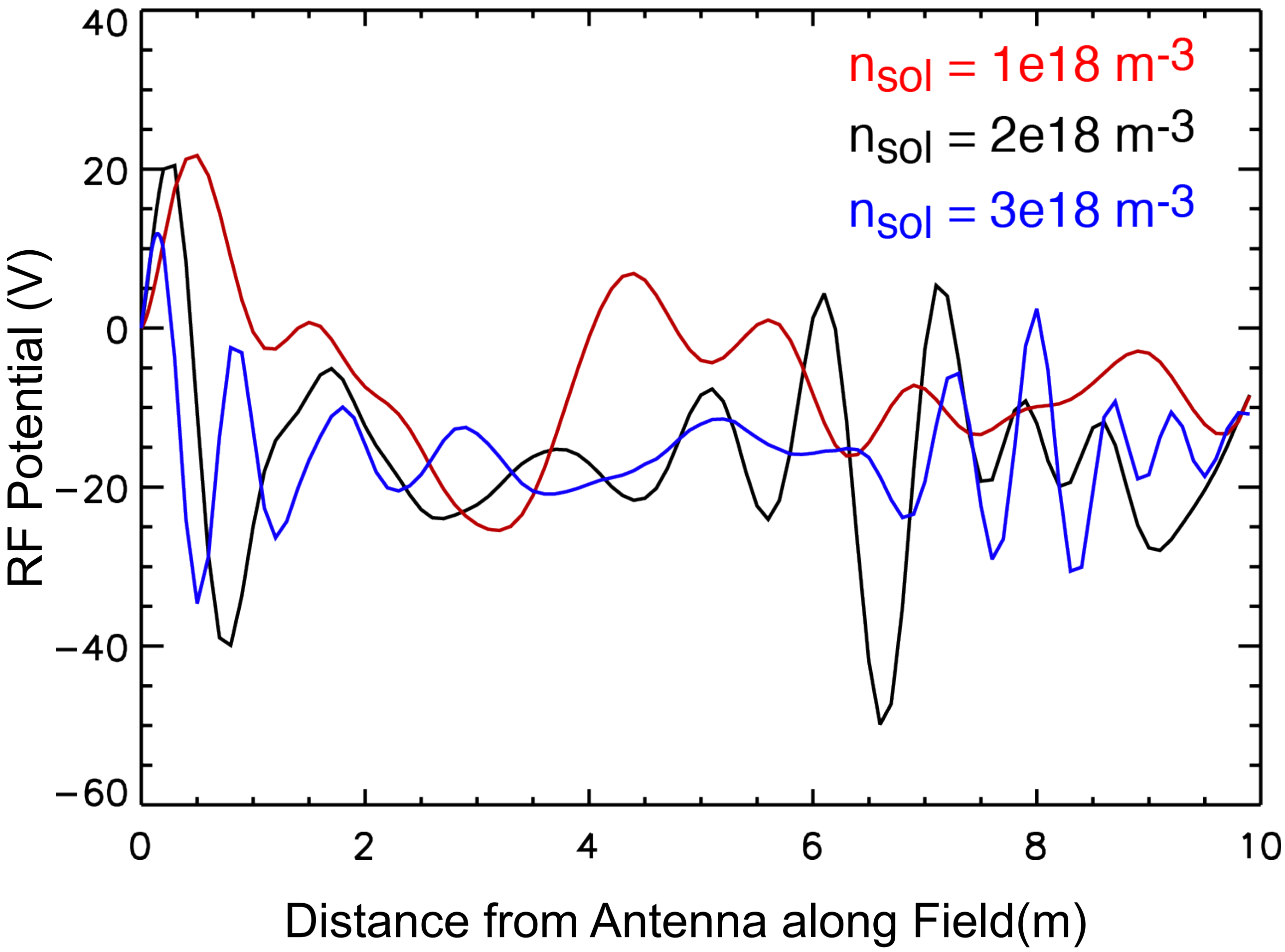
High density core
$n_e \sim 5e19\ m^{-3}$

Low density annulus ('SOL')
$n_e \sim 1\text{-}3e18\ m^{-3}$

Antenna

- Model retains finite electron mass
- Still being validated
  - Poynting flux computation agrees with antenna loading calculation to within 1%

Computed V_{RF} is of same order as probe analysis



- Integrate E_z along a field line
  - Located in middle of SOL
- Includes azimuthal wavenumbers from -10 to +10
- Results for 1 kA of RF current on antenna
- Gives V_{RF} ~ 10–30 V

Conclusion: RF rectification may be contributing substantially to fast-wave losses in the SOL

- If shift in probe characteristic is RF rectification, then V_{RF} ~ 30 – 70 V
  - Better accuracy expected with fast-acquisition probes using coaxial feeds and broadened sweep range

- Cold-plasma model gives V_{RF} on the same order (~ 20 - 30 V)
  - Given simplifications involved in model, this is encouraging
  - Will perform similar calculations with AORSA results

- Sheath transmission factors predicted to be enhanced (x2) with RF
  - Better IR coverage in NSTX-U

- Emerging self-consistent picture that RF rectification could be playing a substantial role in fast-wave losses in the SOL

V_{RF} enhances sheath transmission factor (heat flux to surface) Indicates RF rectification contributes substantially to spiral

- Heat flux to probe biased at voltage V is : $q_{surface} = \gamma(V) * j^{+}_{sat} * T_e$

$$\gamma(V) = -\frac{V_f}{T_e} + \frac{\Delta V}{T_e} + 2.5\frac{T_i}{T_e} + \frac{2}{1-\sigma_e}\exp\left[-\frac{\Delta V}{T_e}\right]$$

$\Delta V = V - V_f$, with V_f relative to V_{pl} [P.C. Stangeby, Plasma Physics Series (2000)]

– $V_{fl\text{-}RF}$ and $V_{fl\text{-}noRF}$ floating potentials relative to ground (tile voltage) with and without RF

– Add RF potential $\Delta V = - V_{fl\text{-}0} + V_{RF}\sin(\omega t)$ and average over the RF period

$$\gamma_{noRF} = -\frac{V_f}{T_e} + \frac{V_{fl-noRF}}{T_e} + 2.5\frac{T_i}{T_e} + \frac{2}{1-\sigma_e}\exp\left[-\frac{V_{fl-noRF}}{T_e}\right]$$

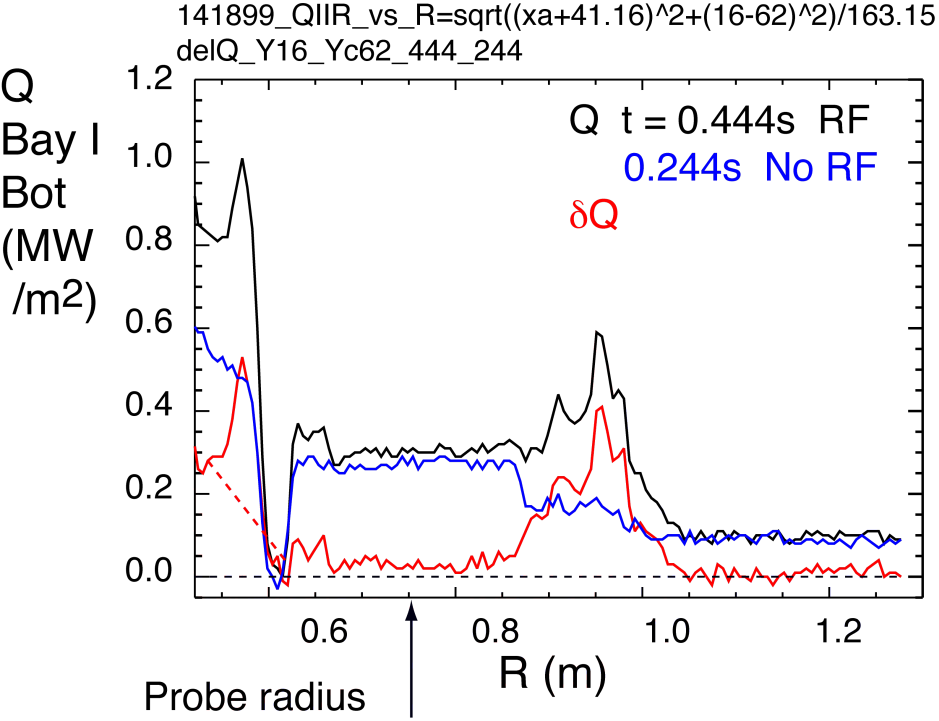
$$\gamma_{RF} = -\frac{V_f}{T_e} + \frac{V_{fl-noRF}}{T_e} + 2.5\frac{T_i}{T_e} + \frac{2}{1-\sigma_e}\exp\left[-\frac{V_{fl-RF}}{T_e}\right]$$

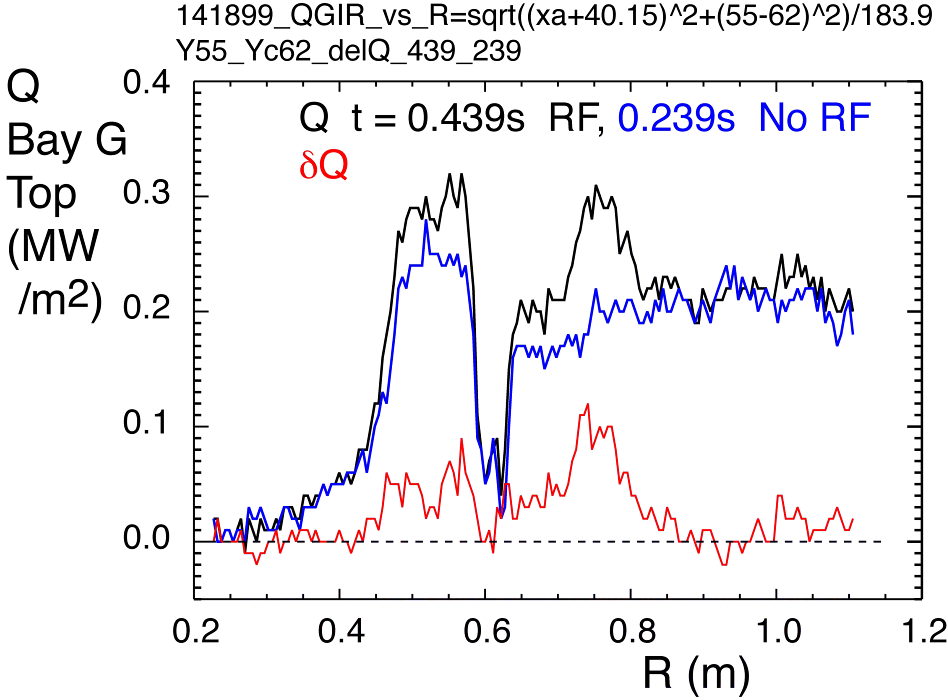
- Energy flux to probe at $V_{pr} = 0$ (tile V) is enhanced for RF relative to no RF

– For the RF + NBI case (141899): $\gamma_{0\text{-}RF=0} = 7.12$ $q_{0\text{-}RF=0} = 0.103\ \mathrm{MW/m^2}$

$\gamma_{0\text{-}RF} = 14.43$ $q_{0\text{-}RF} = 0.209\ \mathrm{MW/m^2}$

Levels of heat flux to the probe compare well with estimates from IR measurements of $q_{surface}$





- Q is not measured at Bay B – rough estimates of $Q_{bay\ B}$ from IR measurements at Bay I are made in vicinity of the probe radial location
  - Background ~ 0.3 MW/m^2; with RF ΔQ ~ 0.3 at peak
- From Bay G measurement (top): background ~ 0.2; with RF ΔQ ~ 0.1
- Thus, heat flux measurements to probe are comparable with these results within the uncertainties associated with the probe and IR measurements