Space Flight

Plasma Data Analysis

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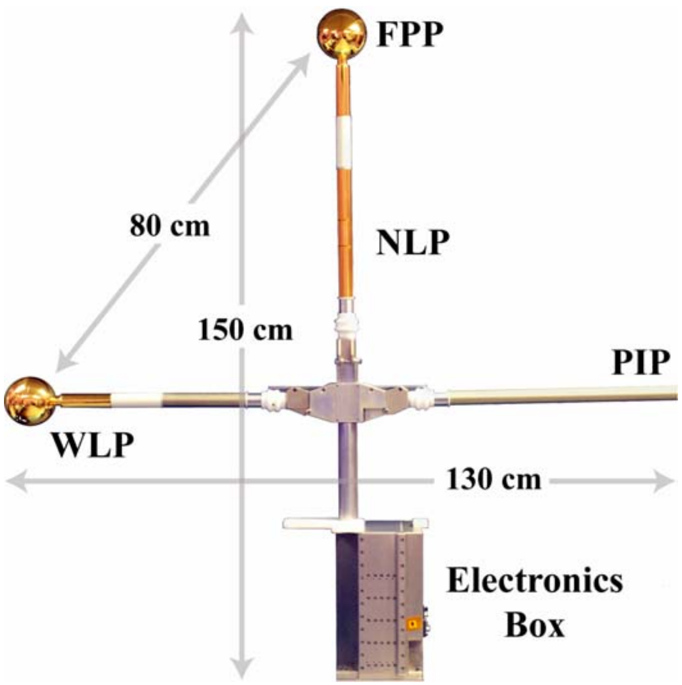
Outline of Presentation

- *FPMU Description and its implementation on ISS*
- *FPP analysis*
- *PIP analysis*
- *LP analysis*
- *ISS charging features*
- *Equatorial Ionospheric Features*
- *Extra: LP analysis of Laboratory Plasma Source*

Floating Potential Measurement Unit (FPMU)



FPP: Floating Potential Probe

WLP: Wide-sweep Langmuir Probe

NLP: Narrow-sweep Langmuir Probe

PIP: Plasma Impedance Probe

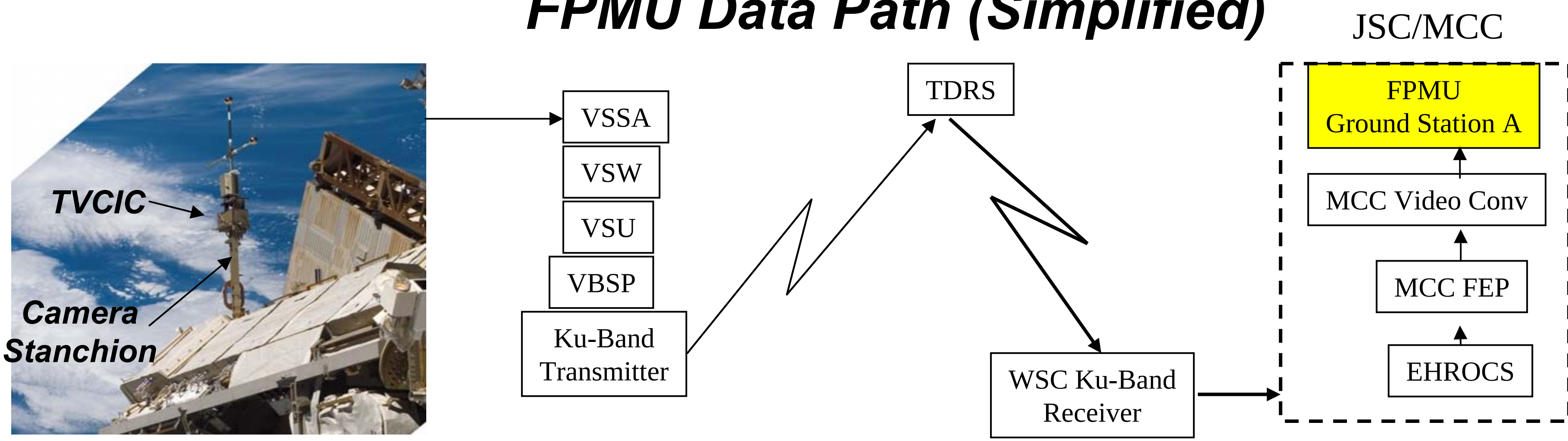
Role:

- Obtain floating potential and ionosphere plasma measurements for validation of the ISS charging model
- Assess Photo-Voltaic array variability
- Interpreting IRI predictions

Sensor	Measured Parameter	Rate (Hz)	Effective Range
FPP	V_F	128	-180 V to +180 V
WLP	N T_e V_F	1	10^9 m^{-3} to $5x10^{12}$ m^{-3} 500 K to 10,000 K -20 V to 80 V
NLP	N T_e V_F	1	10^9 m^{-3} to $5x10^{12}$ m^{-3} 500 K to 10,000 K -180 V to +180 V
PIP	N_e	512	$1.1 \cdot 10^{10}$ m^{-3} to $4 \cdot 10^{12}$ m^{-3}

Redundant measurements of each parameter!

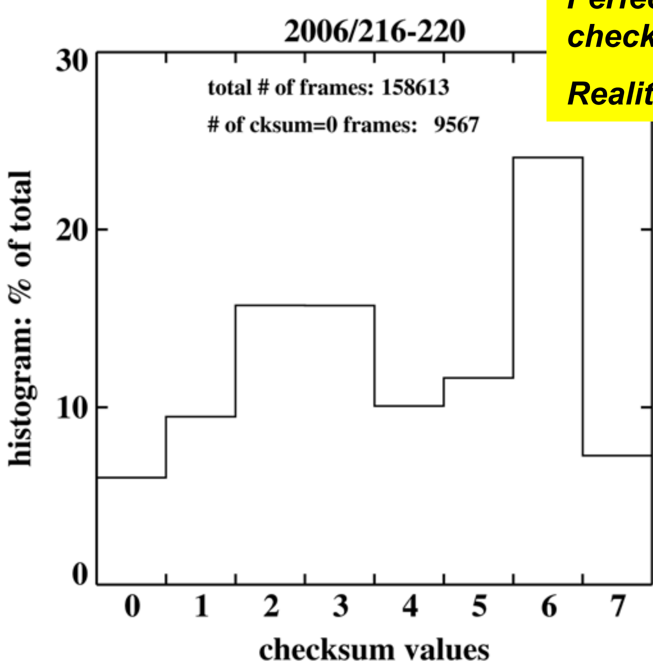
FPMU Data Path (Simplified)



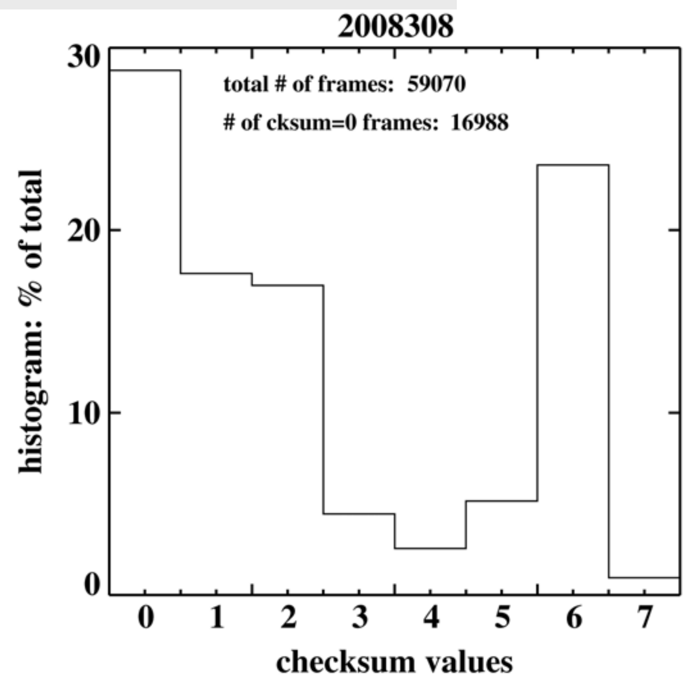
FPMU data passes through many “boxes” before capture by the ground station!

Perfect transmission: 100% checksum=0

Reality: telemetry noise

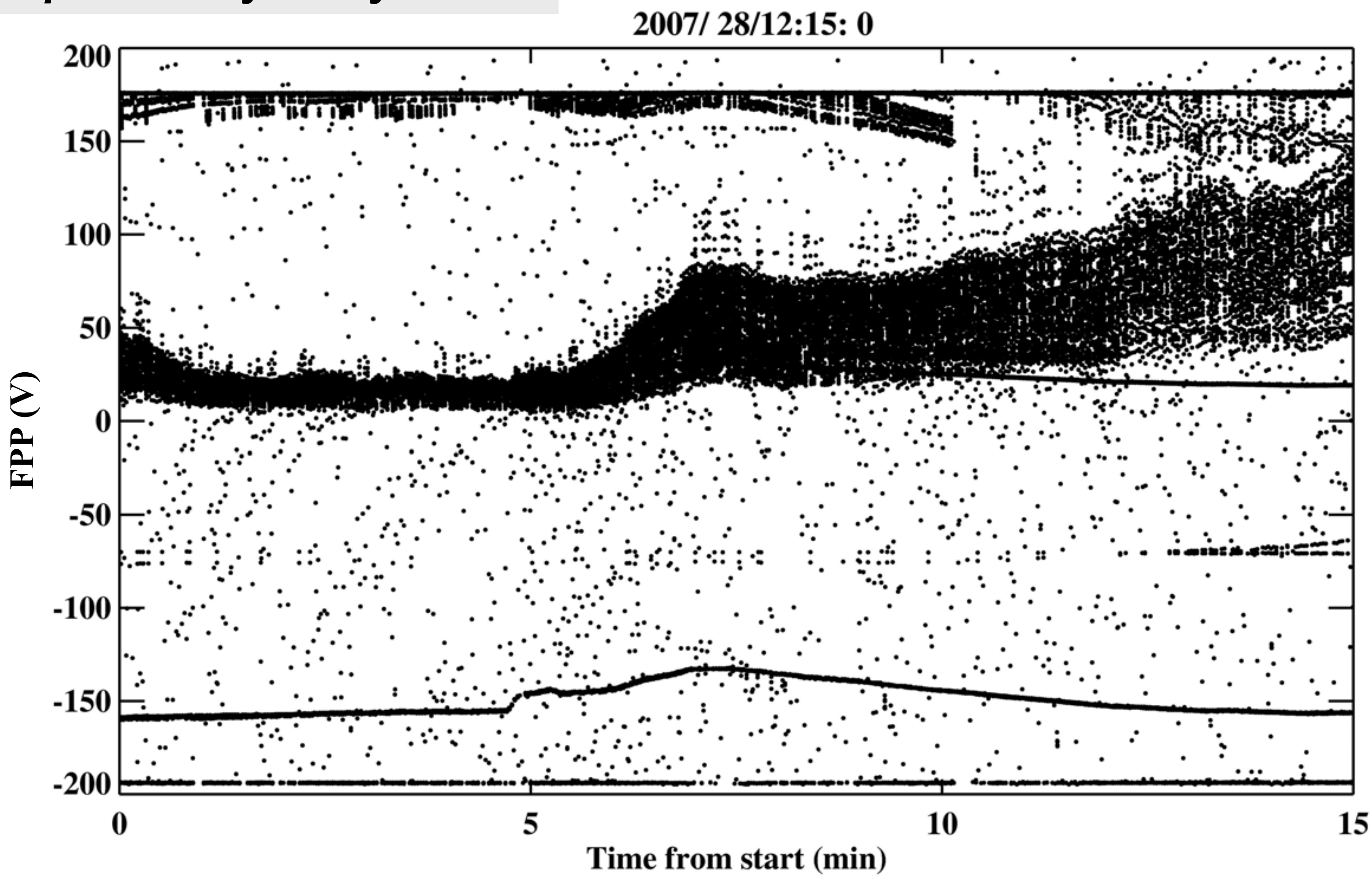


Some improvement in 2008:



FPP is effectively a high-impedance volt meter acquiring data at 128Hz.

Example of very noisy data:



What is the true signal ?

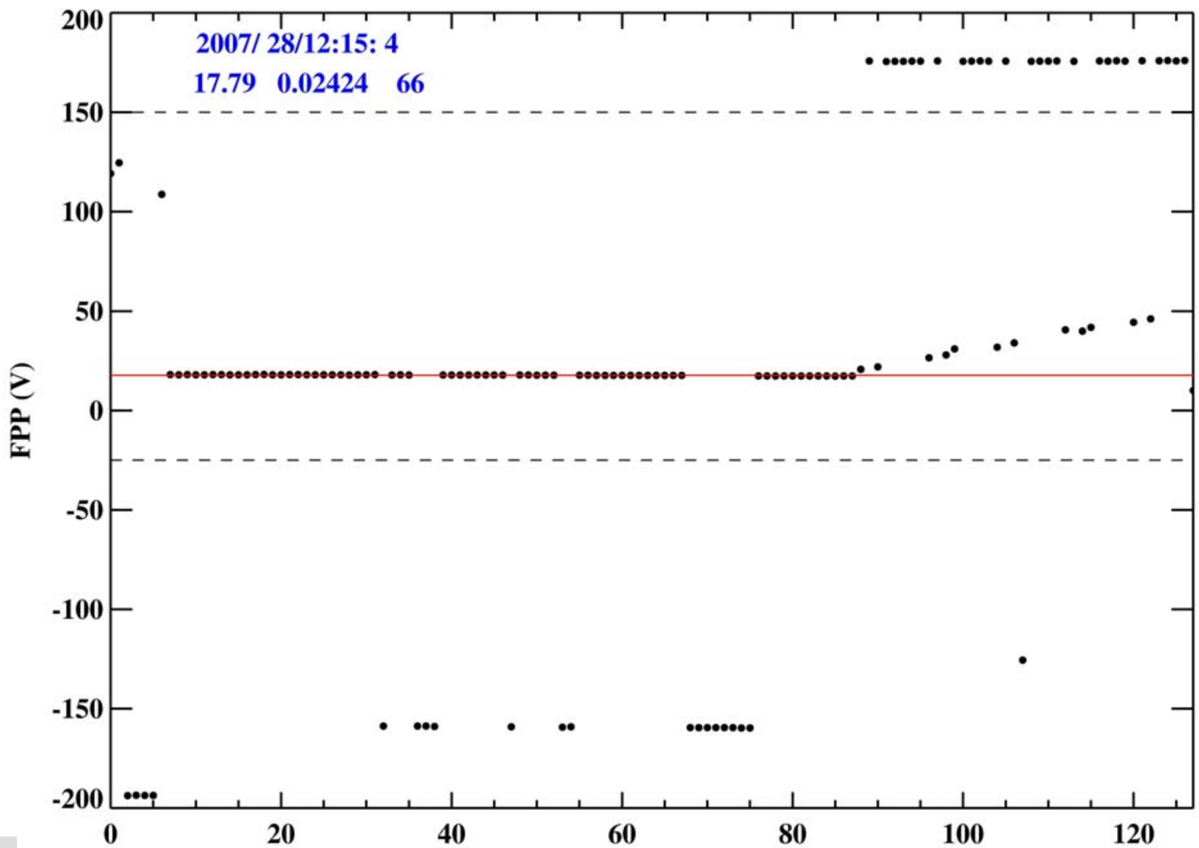
FPP analysis method

Logic

- ***Band-pass filter: -25 ≤ fpv ≤ 150***
- ***Apply median filters***
- ***Iterative process to exclude values > 2σ***

Acceptance Criteria

- ***|fp_sdev/fpv| ≤ 0.2***
- ***no. of surviving points ≥ 51***

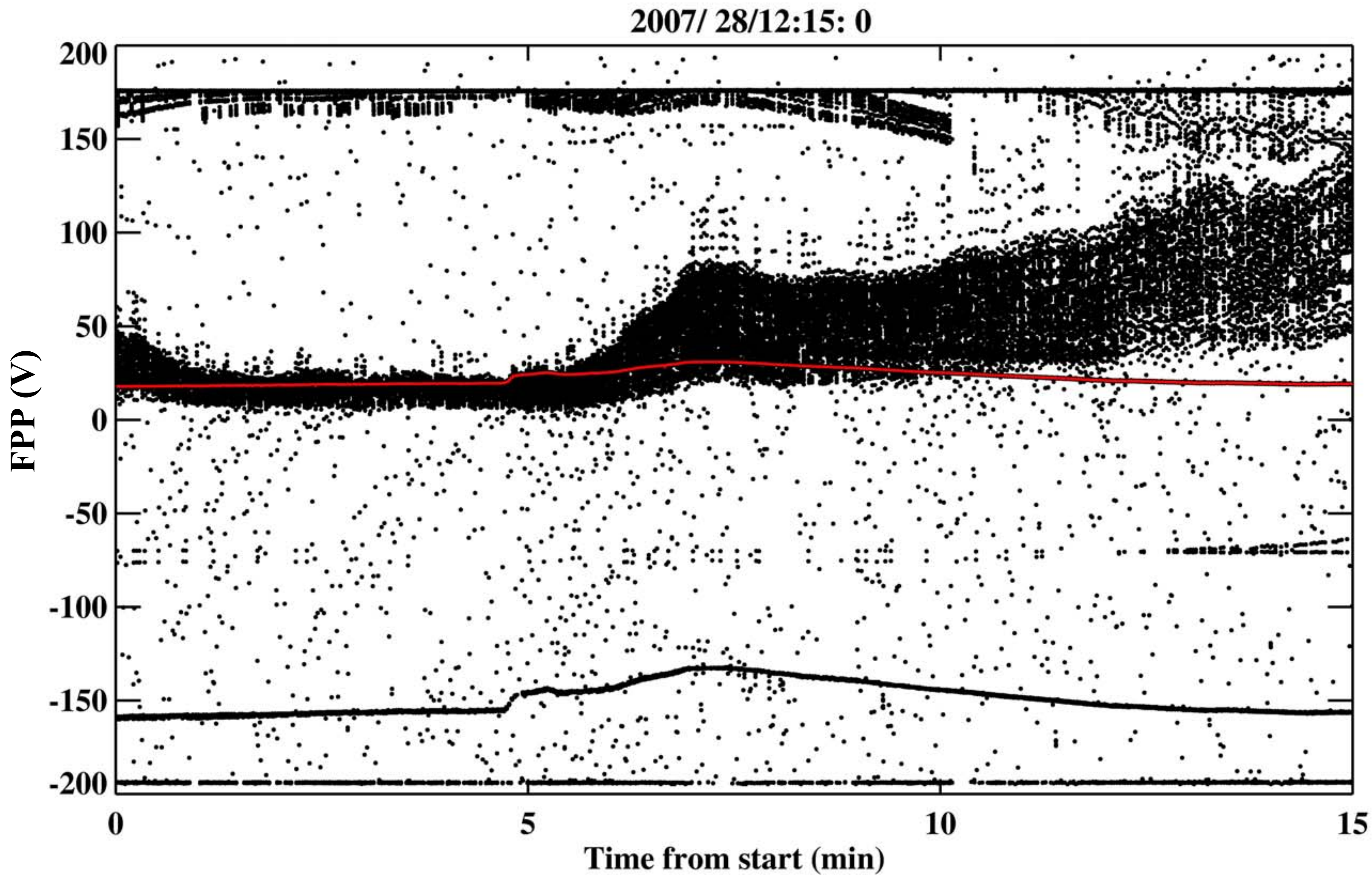


Recovery rates

> 98% (in general)

> 90% (for the noisiest data)

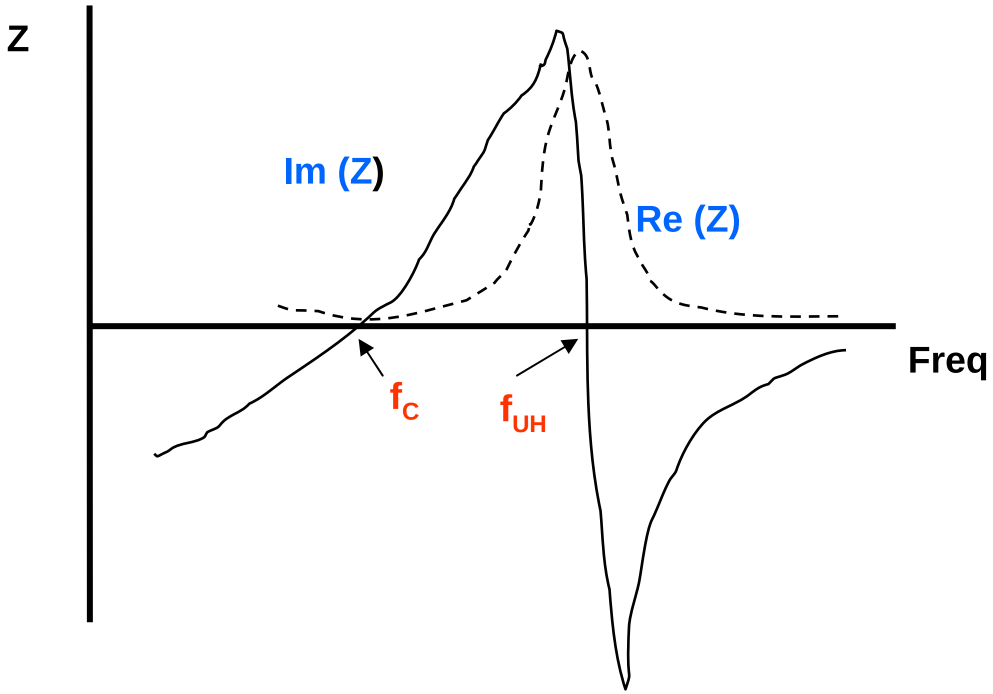
FPP example with analysis result:



PIP Analysis

PIP measures the self impedance of a short, cylindrical antenna.

Antenna impedance Z as function of applied voltage frequency: The real part is the resistance while the imaginary part is the reactance (or phase). Zero phase occurs at the electron cyclotron frequency (f_c) and the upper hybrid frequency (f_{uh}).



PIP frequency sweep: 0.1 to 20 MHz in 256 steps

PIP Analysis

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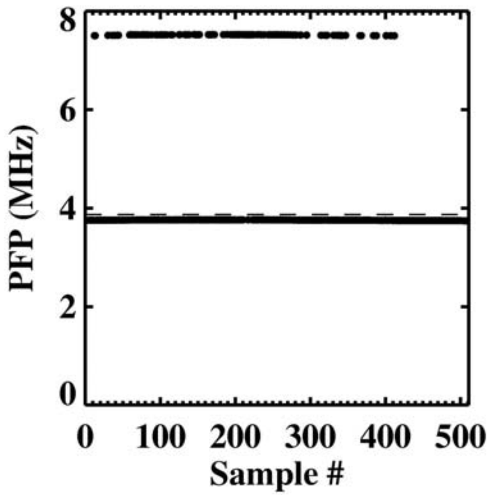
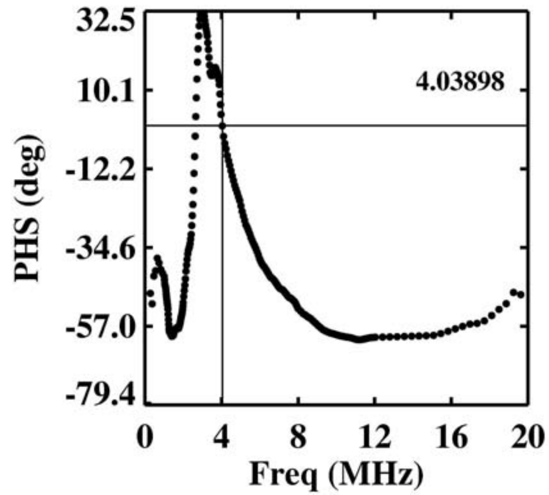
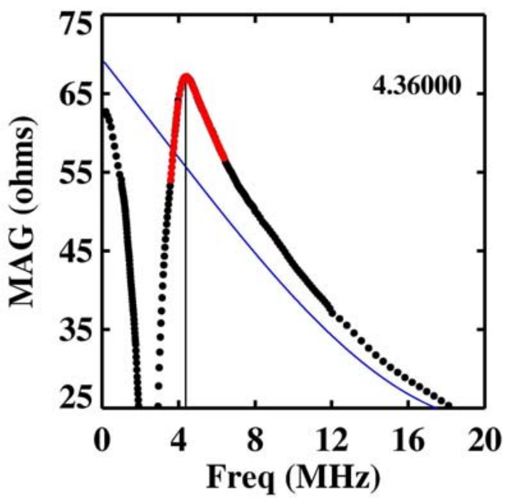




Phase behavior not consistent due to tracking problem !

512-point freq sweep



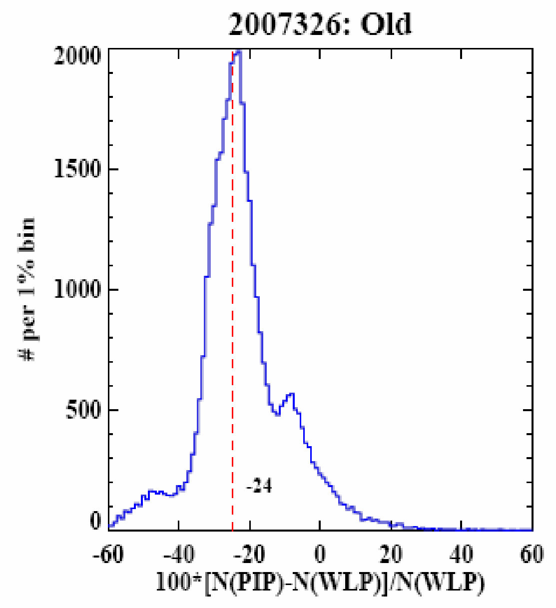
Peak in MAG always exists!

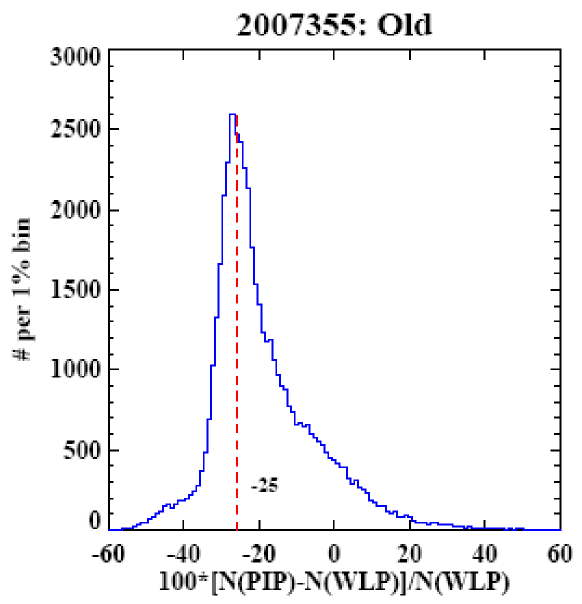
Upper hybrid resonance:

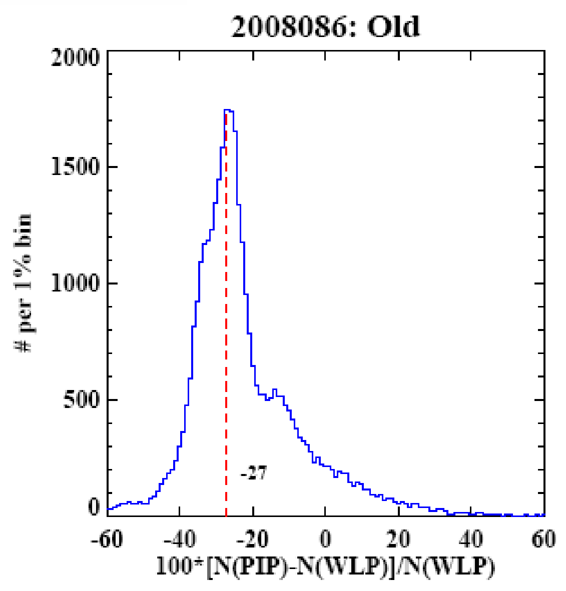
$$f_{uh}^2 = f_p^2 + f_c^2$$

$$N_e(m^{-3}) = 1.24x10^{-2}[f_{uh}^2 - f_c^2]$$

Comparison of PIP and WLP derived density







PIP Analysis

- ***The PIP-derived density is generally lower than the WLP-derived density from the ion ram current.***

- ***A modification to the PIP analysis has been introduced:***

  - ***During passage through the equatorial region at ~ 2007/355/02:45, a deep ionospheric hole was encountered. The density is < $1x10^9$ m^{-3} . The Magnitude -vs- frequency response in the middle of the hole has been extracted. The response has been curve-fit to the IDL GAUSSFIT function with nterms = 4.***

PIP Analysis

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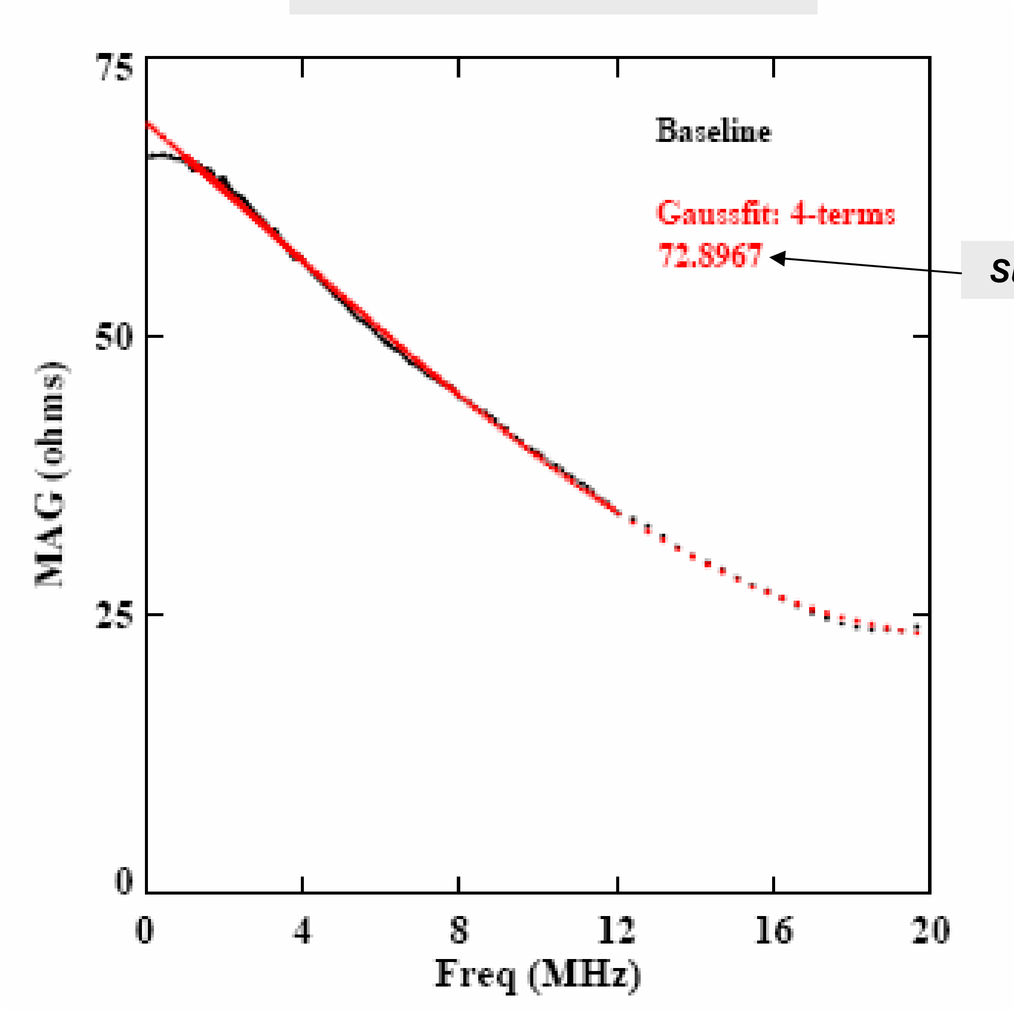

Sum of square of differences

PIP fit w/residuals

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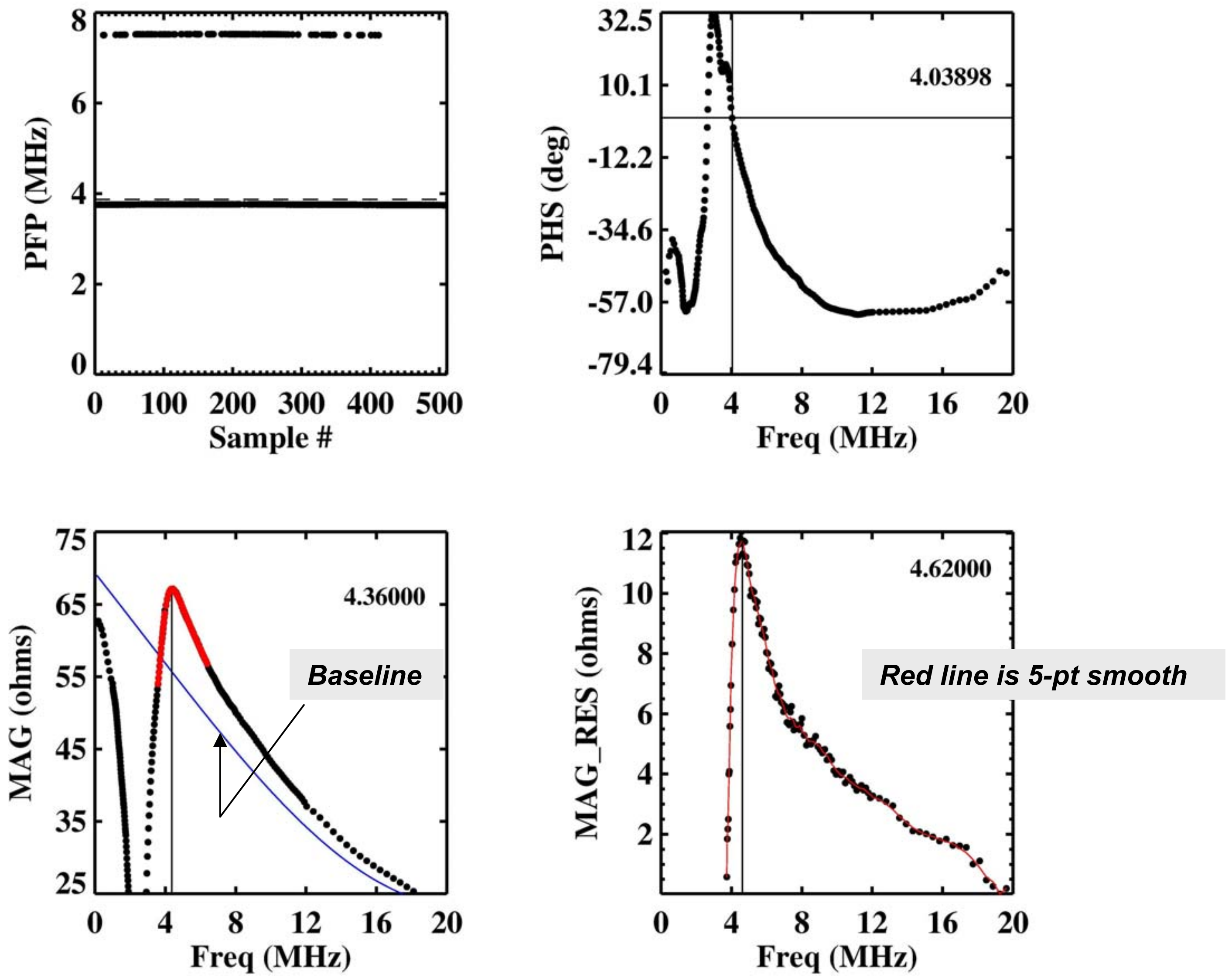
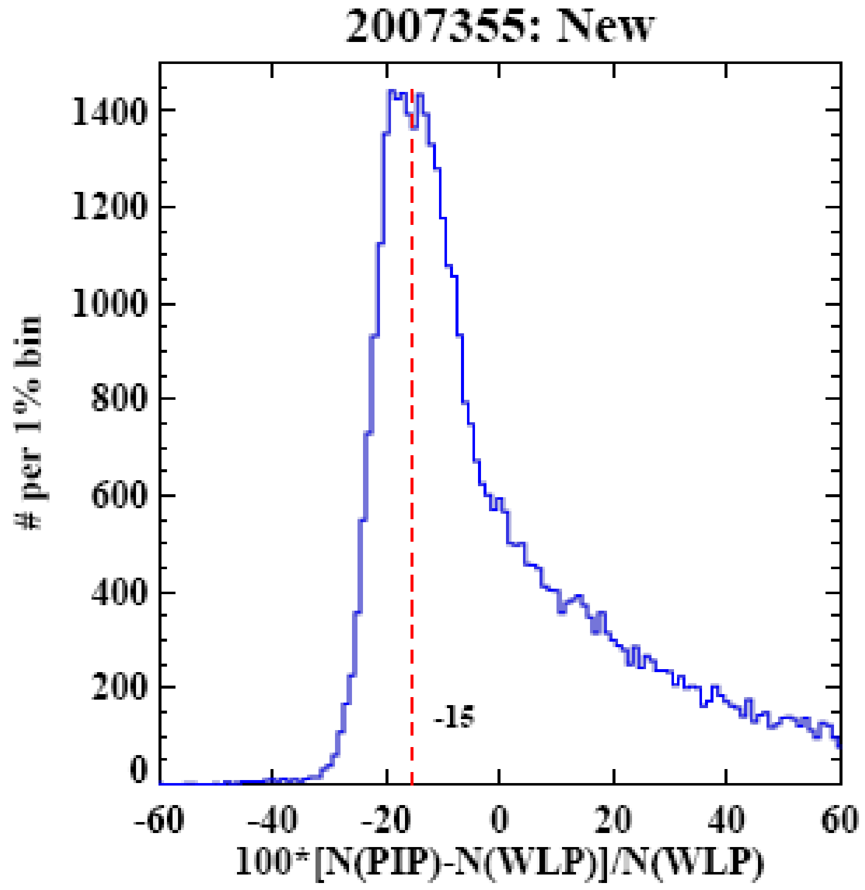
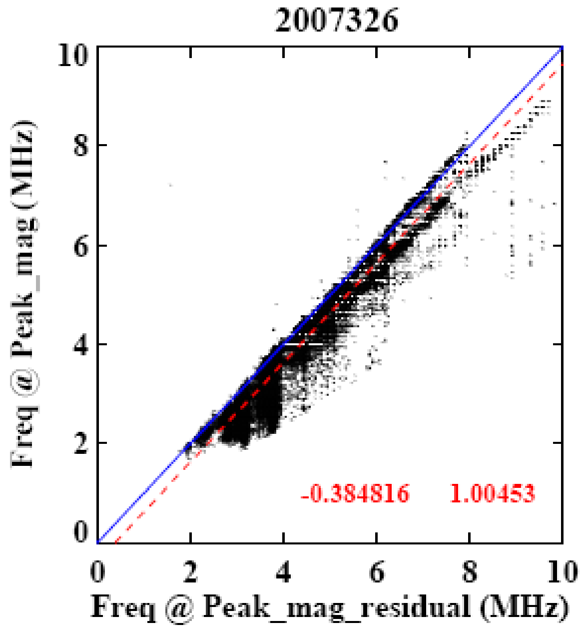
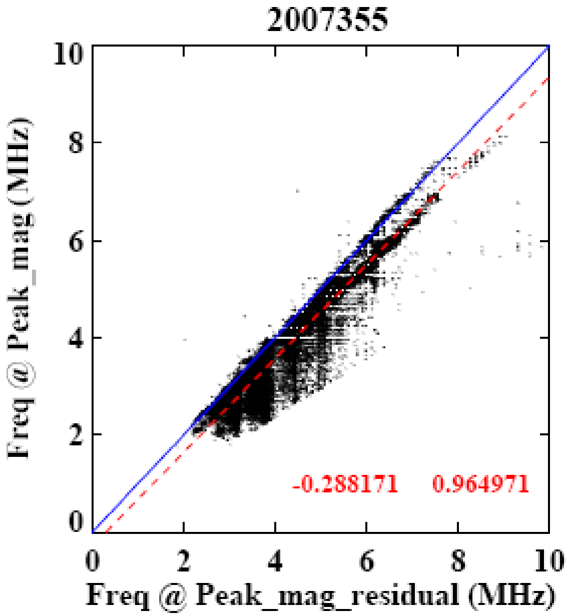


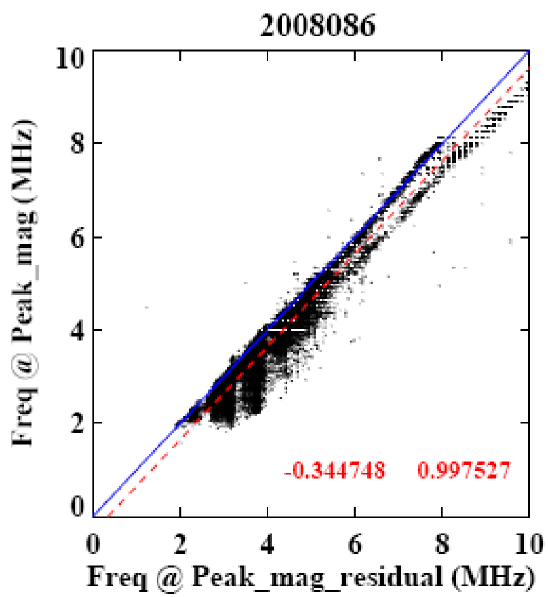
PIP Analysis



PIP analysis: additional refinement







If a peak could not be determined from the residual curve, then the peak from the Magnitude -vs- frequency curve is used with a constant of 0.3 added. This 0.3 factor may change as more days are examined…. <u>Not implemented yet!</u>

LP analysis: Probe design

***WLP voltage sweep*:**

1-sec for -20 to +80 V

1-sec +80 V to -20 V

***Voltage step size*:**

250 mV from –20 V to 0

25 mV from 0 to 50 V

250 mV from 50 V to 80 V

Implication for Te measurement:

ΔV_{step} (V)	T_e (K)	No. of points/ decade current change	No. of points/ 1 e-fold current change
0.025	800	6	3
0.025	500	4	2

***NLP voltage sweep*:**

1-sec for -4.85 to +4.85 V

1-sec +4.85 V to -4.85 V

***Voltage step size*:**

constant 12 mV

***Implication for Te measurement*:**

ΔV_{step} (V)	T_e (K)	No. of points/ decade current change	No. of points/ 1 e-fold current change
0.012	800	13	6
0.012	500	8	4

Probe radius/Debye length (≡ Debye ratio) ~ 2 – 22

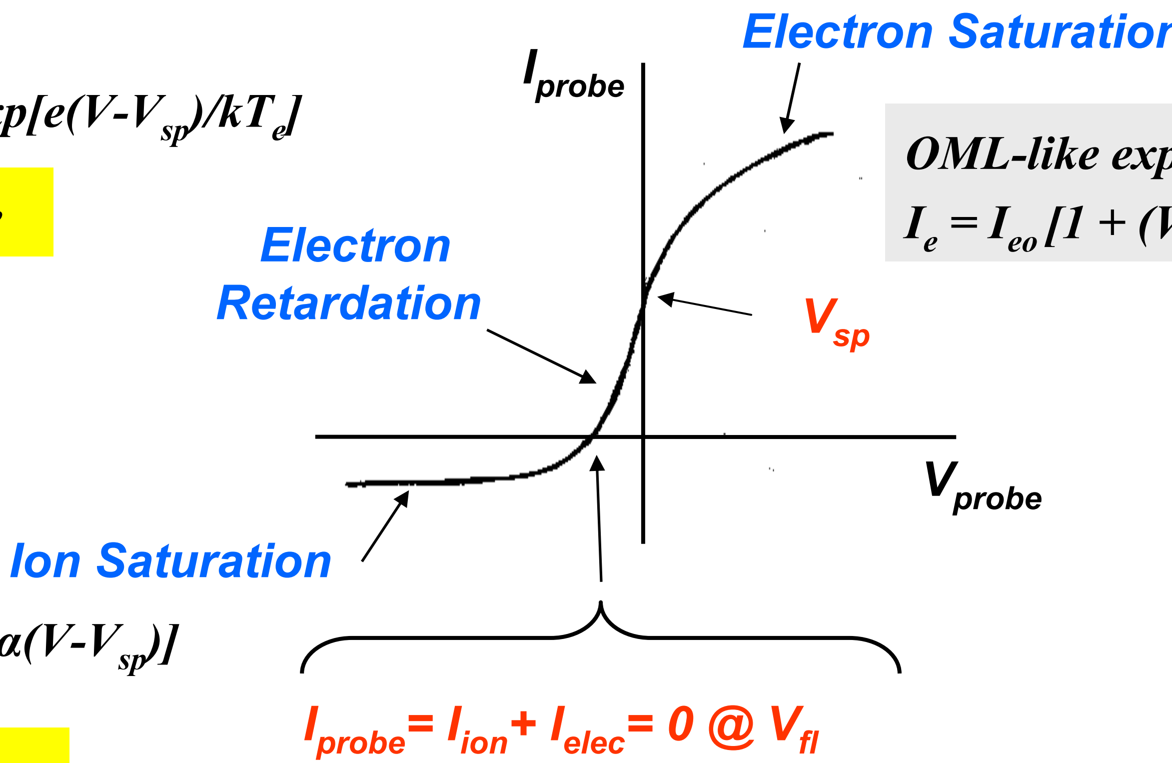
Probe radius/electron gyroradius ~ 2.

Not OML!

Typical Langmuir Probe I-V Curve

$I_e = I_{eo} \cdot exp[e(V\text{-}V_{sp})/kT_e]$

$T_e \sim 1/slope$



OML-like expression:

$I_e = I_{eo}[1 + (V\text{-}V_{ref})/kT_e]^{\gamma}$

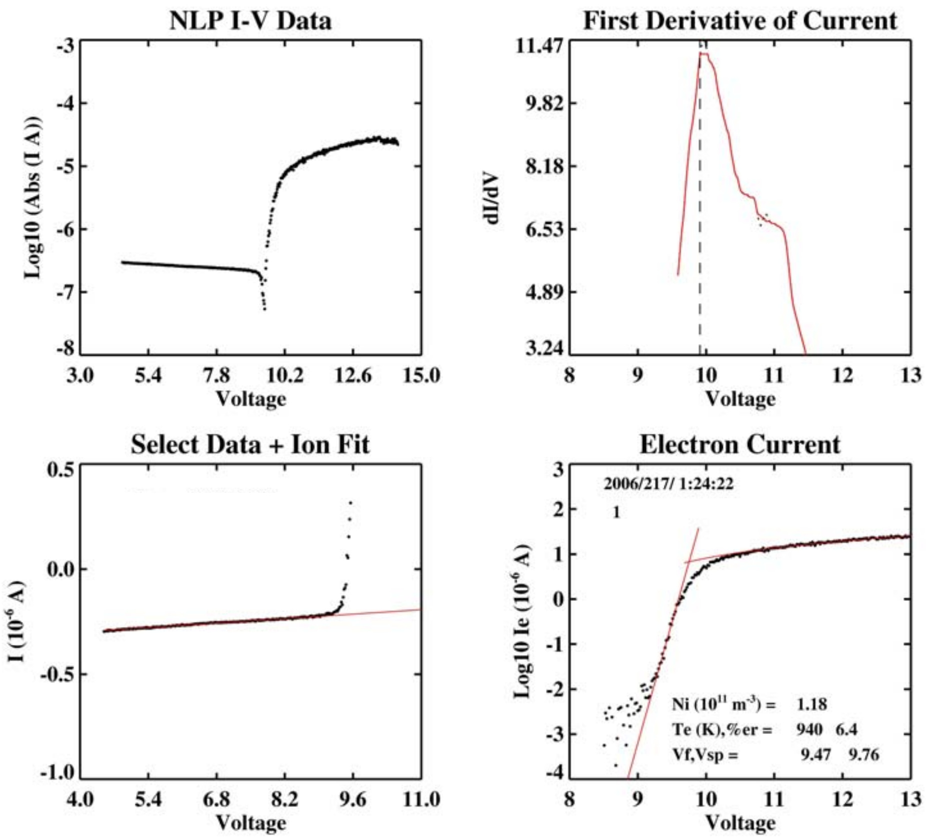
$I_i = qN_i V_{ISS} A[1+\alpha(V\text{-}V_{sp})]$

$N_i \sim I_i / A_{cross\text{-}section}$

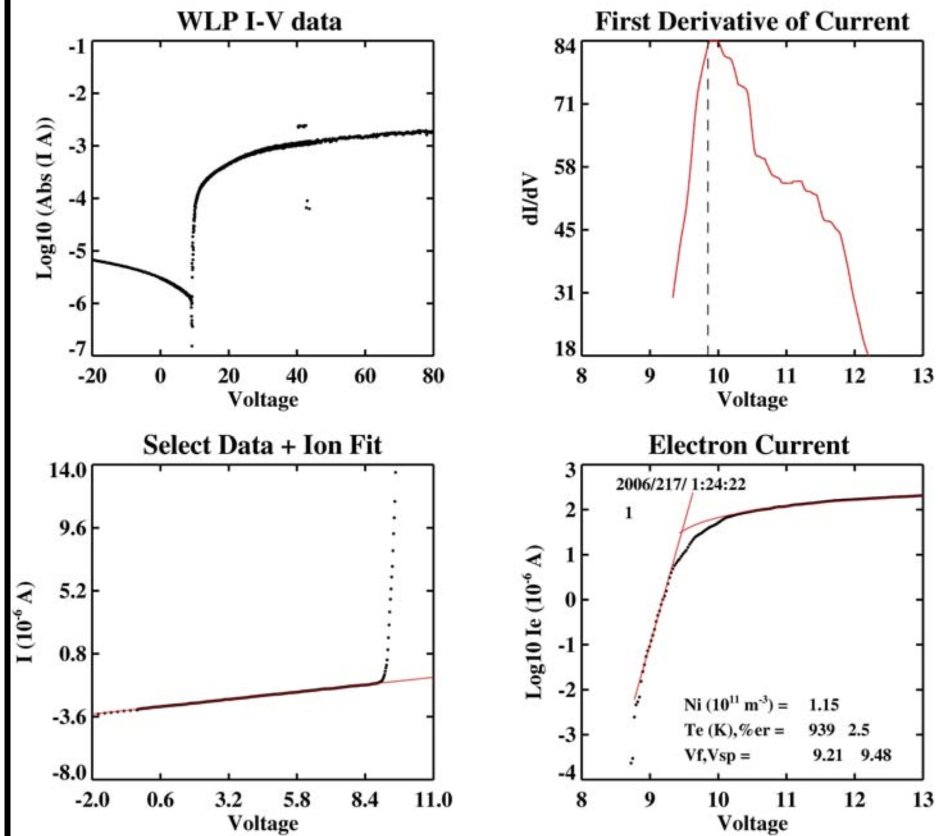
LP analysis

- The "graphical method" has been employed – each section fit separately
- Much filtering and logic used to overcome noise in telemetry
- Fitting sequence:
  - Locate floating potential V_{flt} [from $I_{total} = 0$]
  - If day, adjust for photoelectron current (not used at present)
  - Ion saturation region [fit to linear equation]
  - Determine electron current [$I_e = I_{total} - I_{ion}$]
  - Estimate space potential V_{sp} [voltage at maximum of dI_e / dV]
  - Electron retarding region [linear fit for $\log_{10}(I_e)$] - Acceptance criteria: (Δslope/slope) ≤ 10.0
  - Electron saturation region [fit to OML-like equation over a few volts ≥ initial guess for V_{sp}]
  - Determine V_{sp} via intersection of curves from electron retarding and saturation regions
  - If V_{sp} different from its initial guess by > 0.5 V, then iterate once on the electron retarding and saturation regions
  - Derive ionospheric properties using standard equations

LP analysis: "good" data

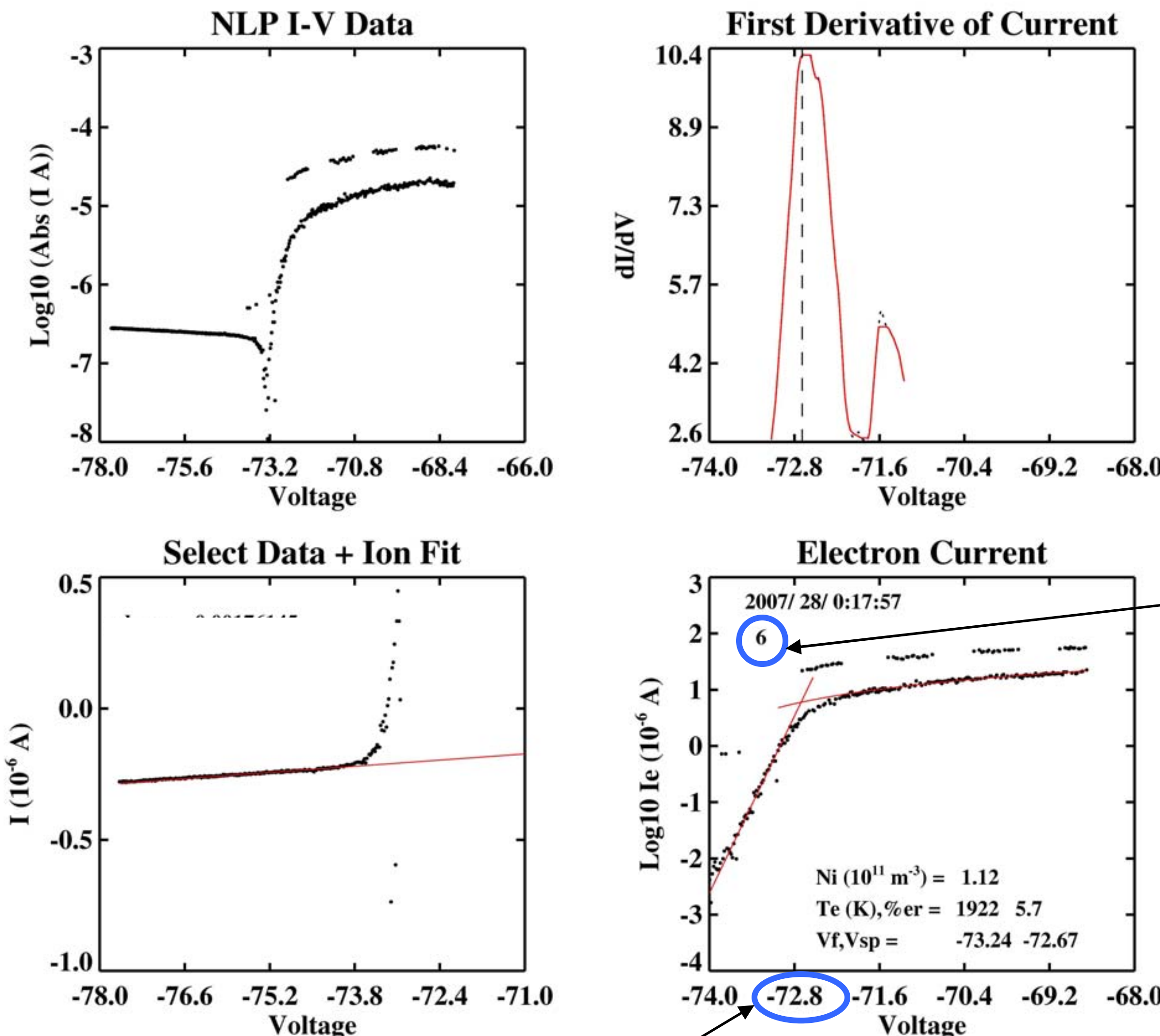


$Ne = 1.33x10^{11}\ m^{-3}$
for A= πrL



$Ne = 0.82x10^{11}\ m^{-3}$
for A= $2\pi r^2$

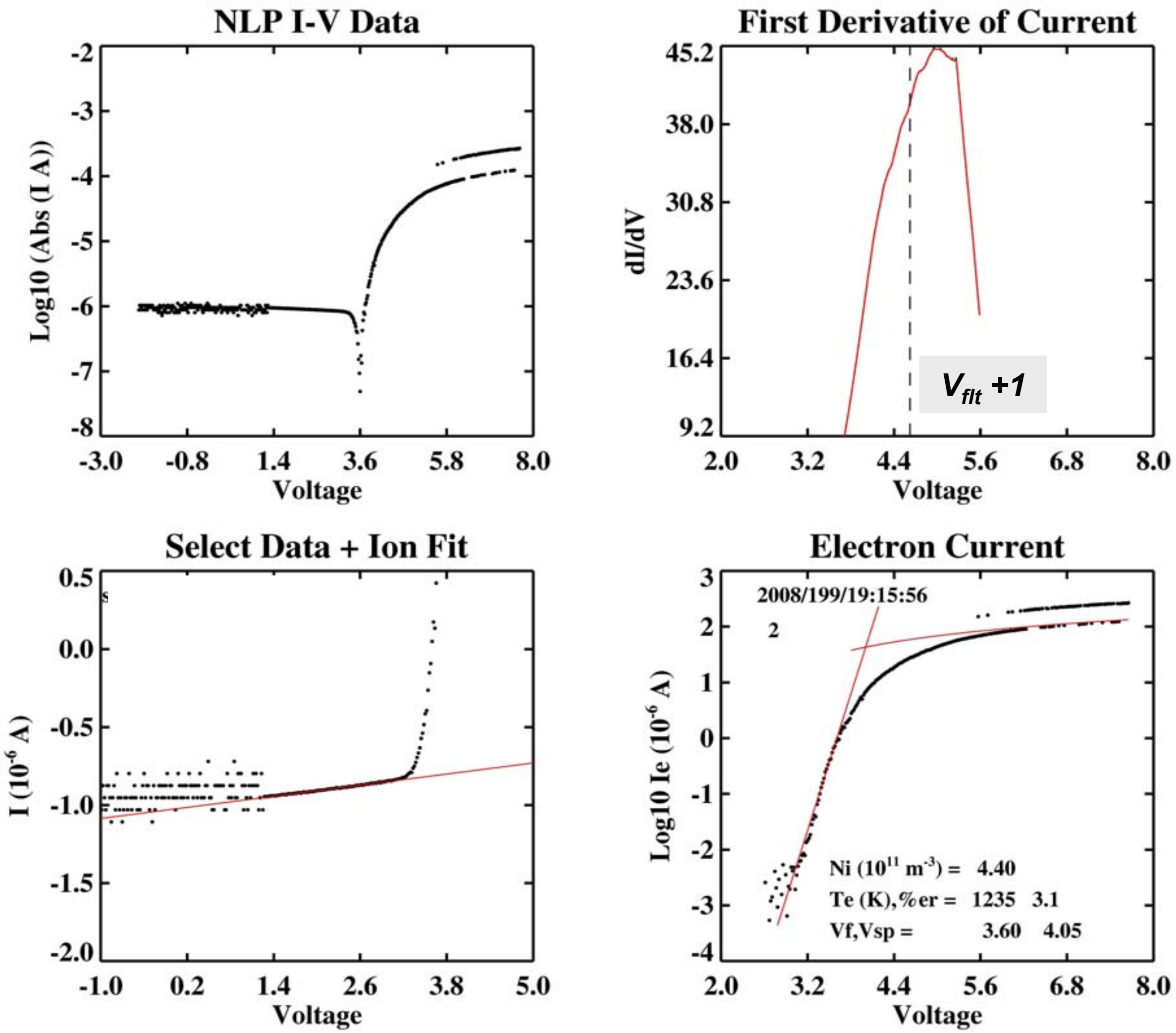
LP analysis: noisy data



High checksum value!

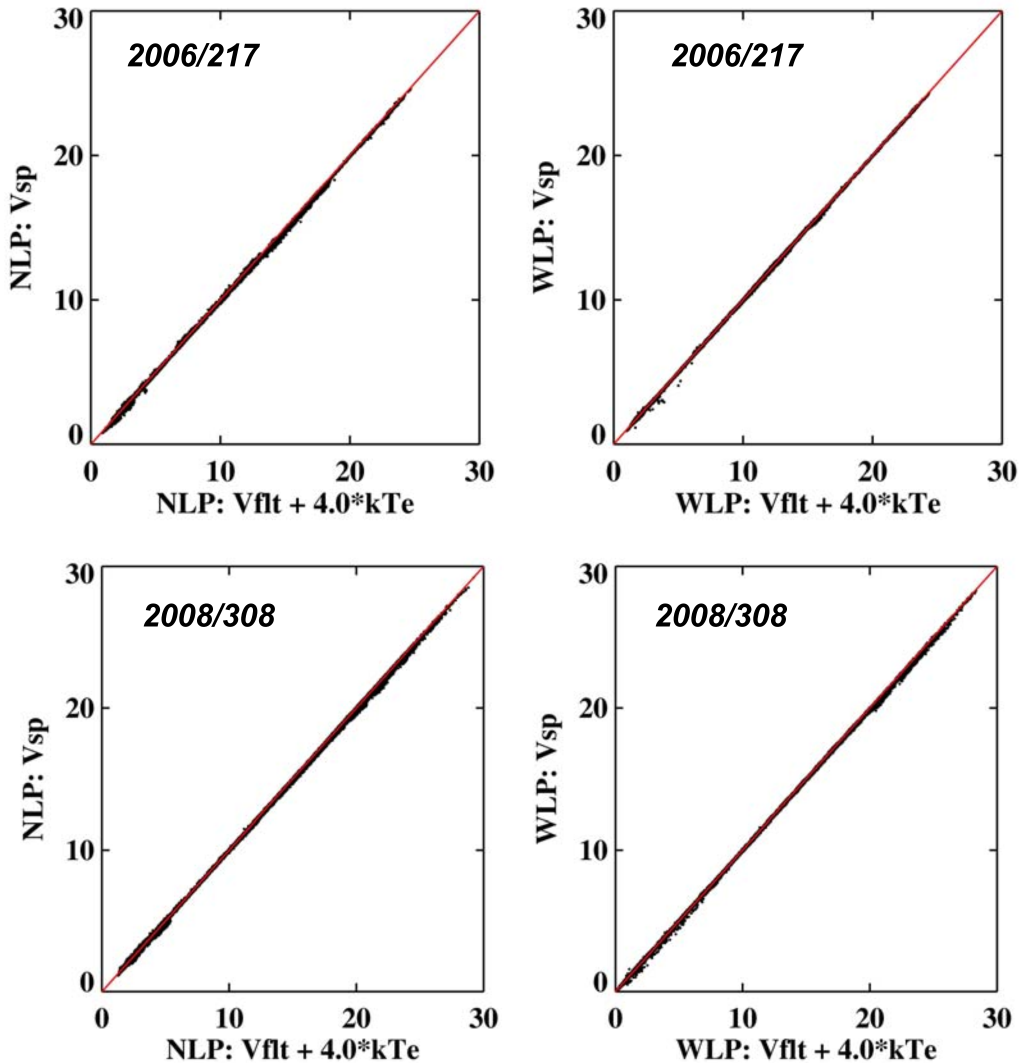
Ground processing generates NLP sweep at +/- 5 V centered on FPP value. If FPP data word is corrupted, then sweep values are corrupted. However, Ni and Te values are OK because measured currents are passed in telemetry and Te depends only on slope (dI/dV where dV is known).

LP analysis: noisy data

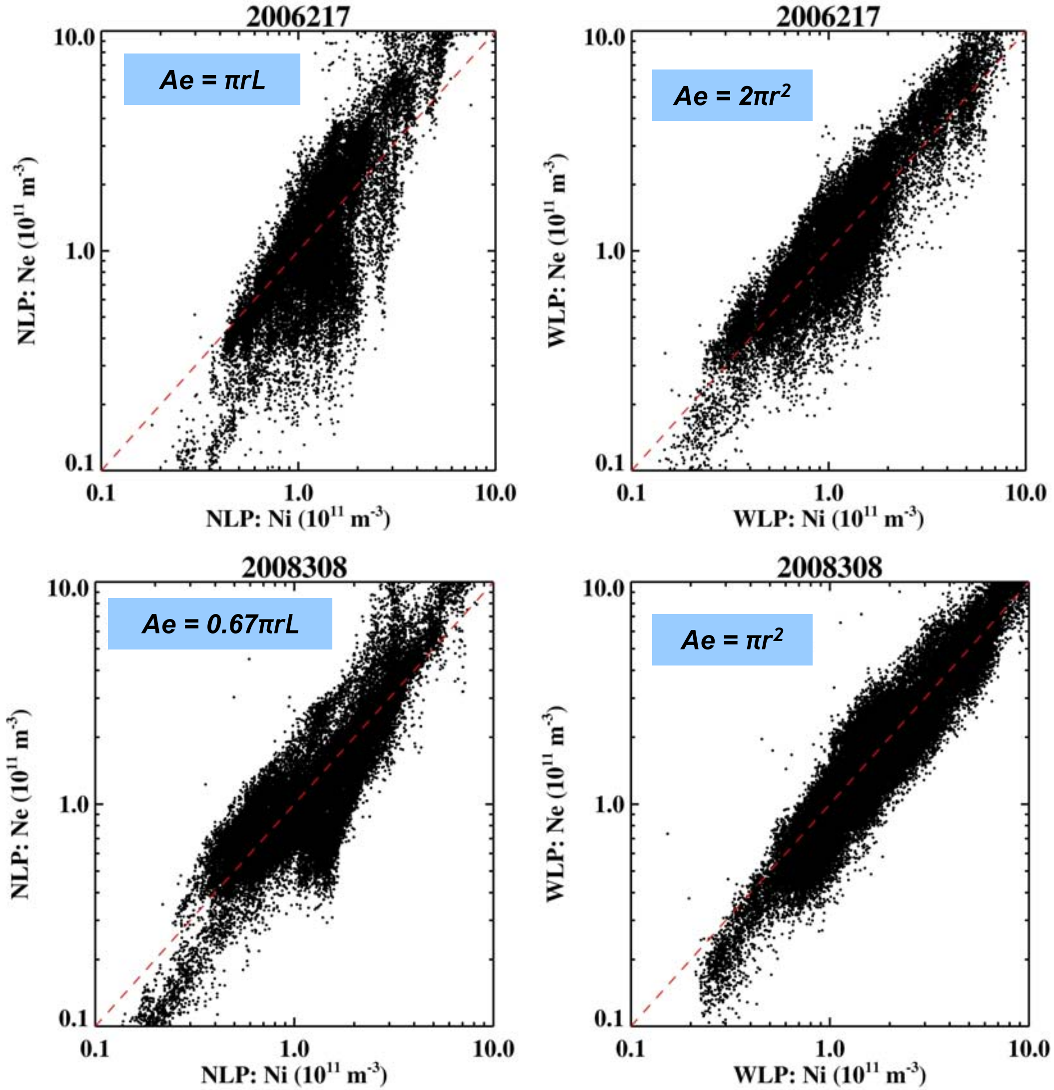


LP analysis: relationship between Vsp and Vflt

Theory says that Vsp – Vflt ~ few*kTe

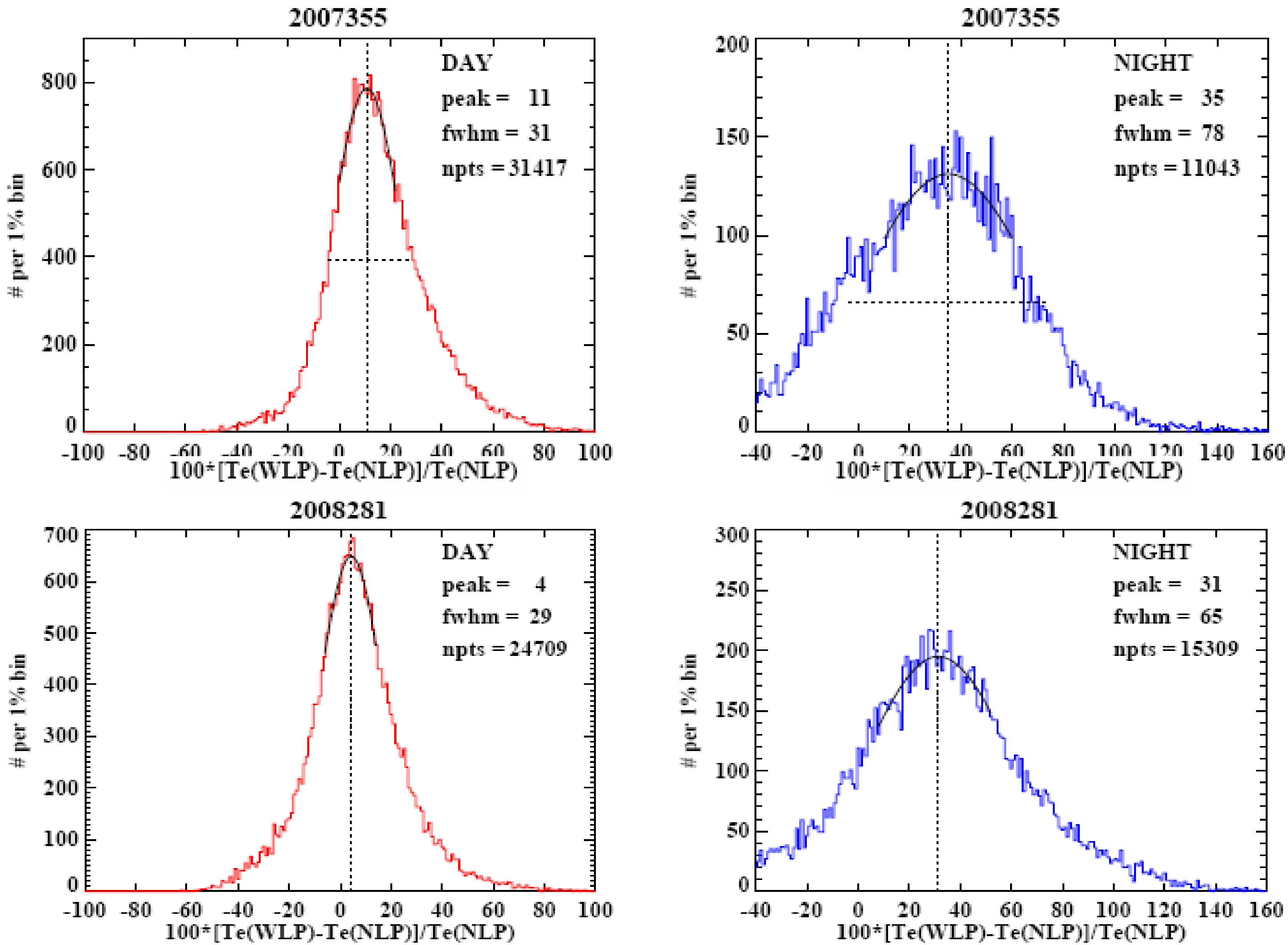


LP analysis: what to use for collecting area to derive Ne ?

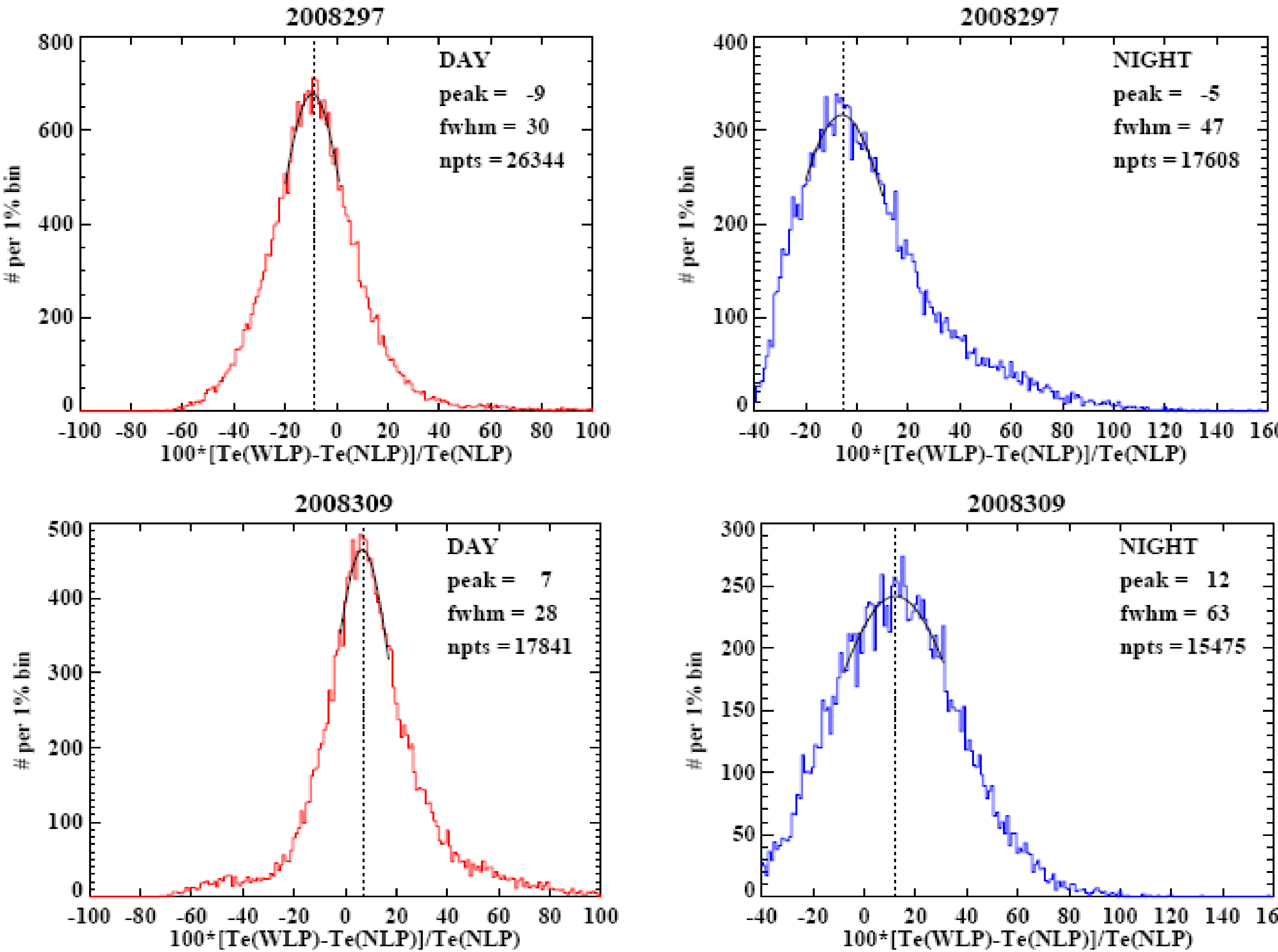


Answer is not straightforward.

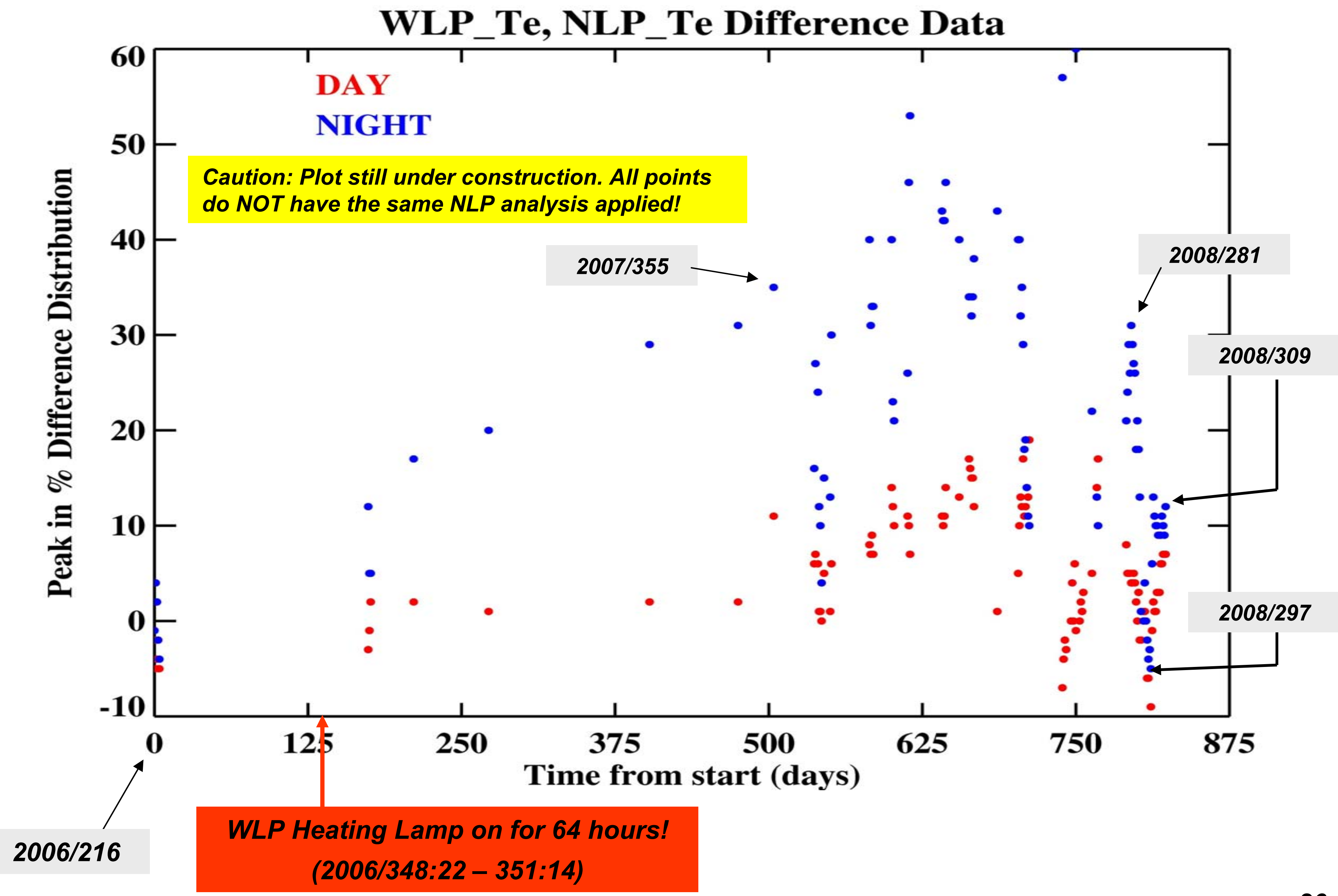
LP analysis: Disagreement between NLP-Te and WLP-Te



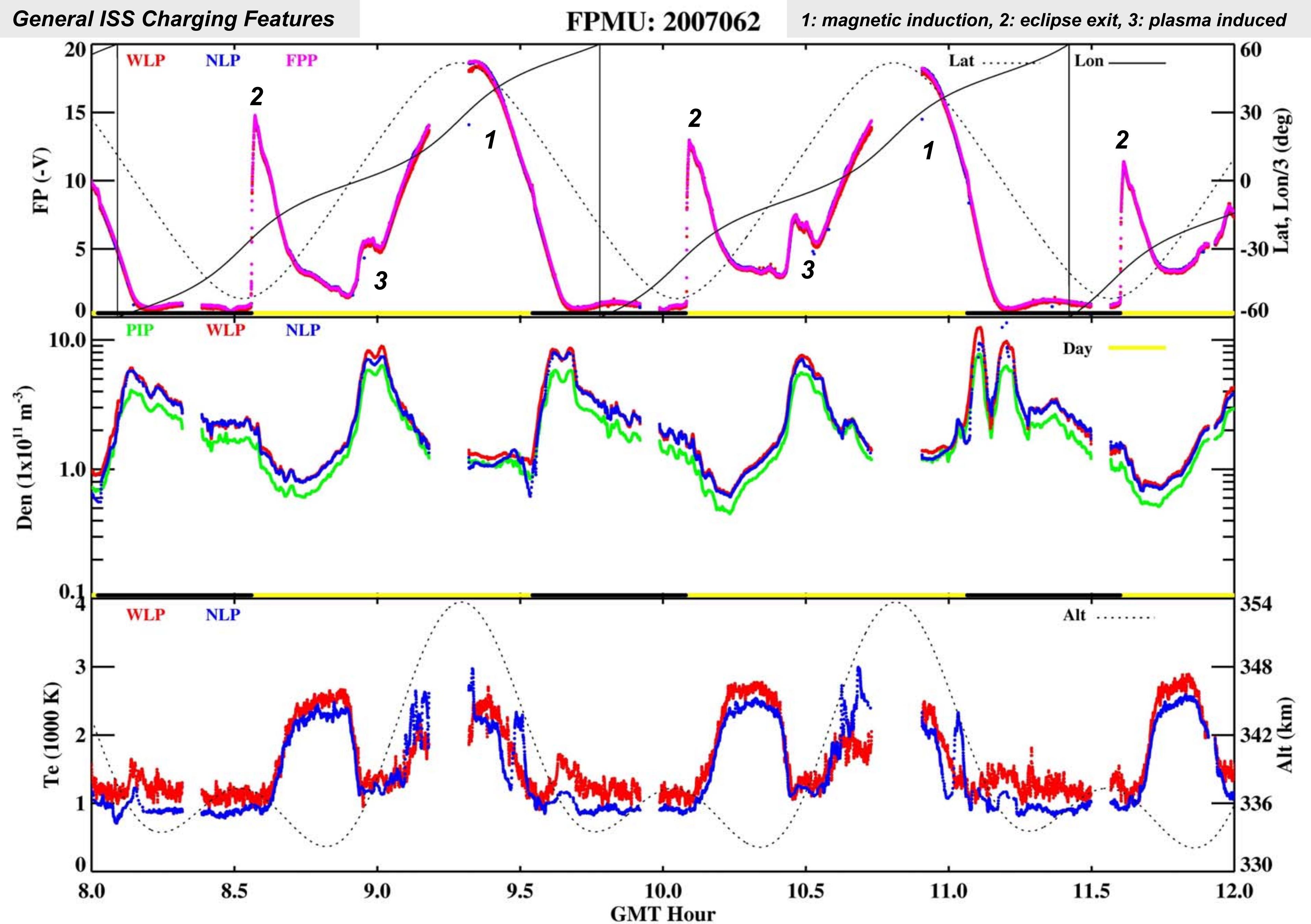
LP analysis: Disagreement between NLP-Te and WLP-Te



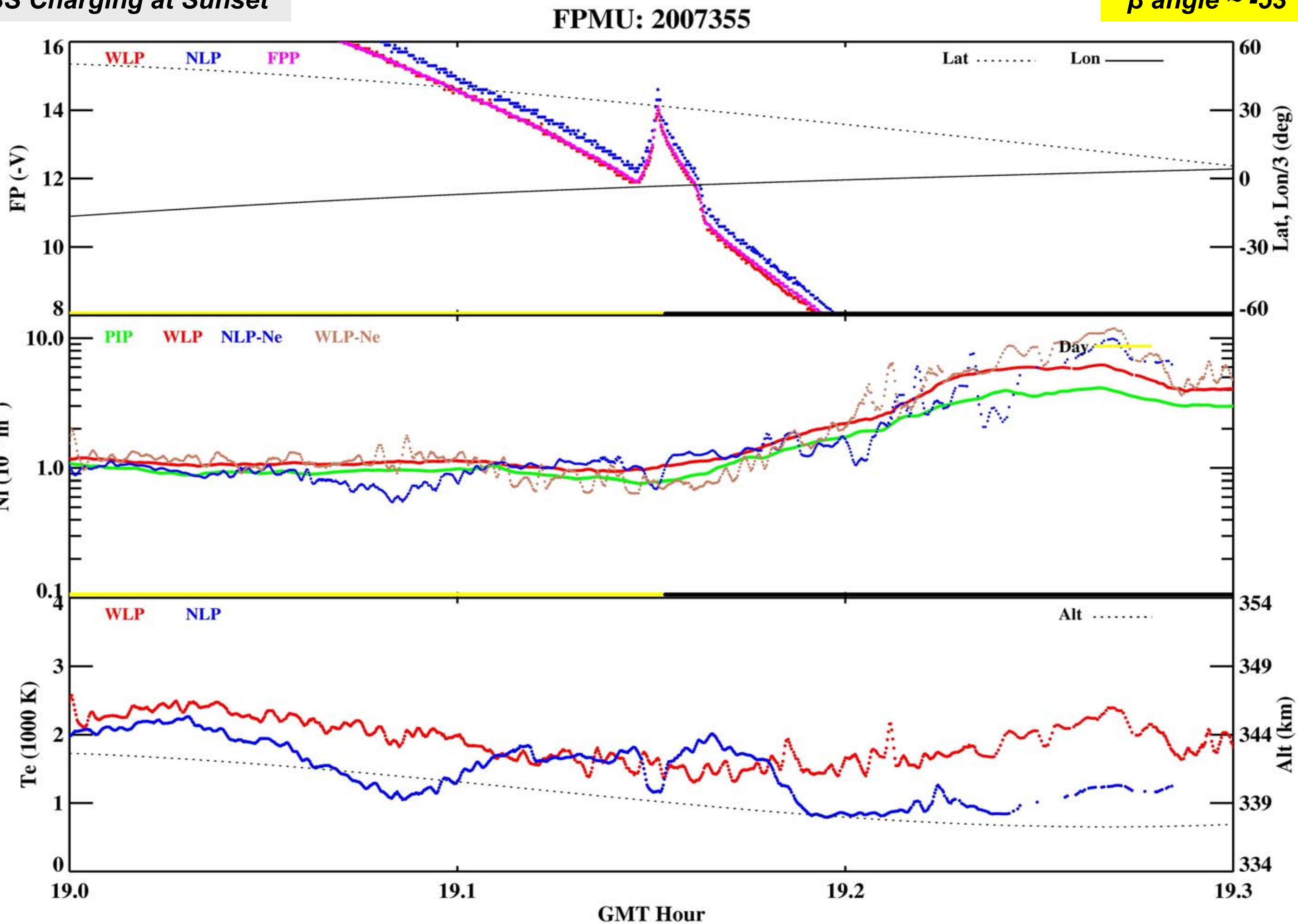
LP analysis: Time history of differences of WLP-Te with NLP-Te



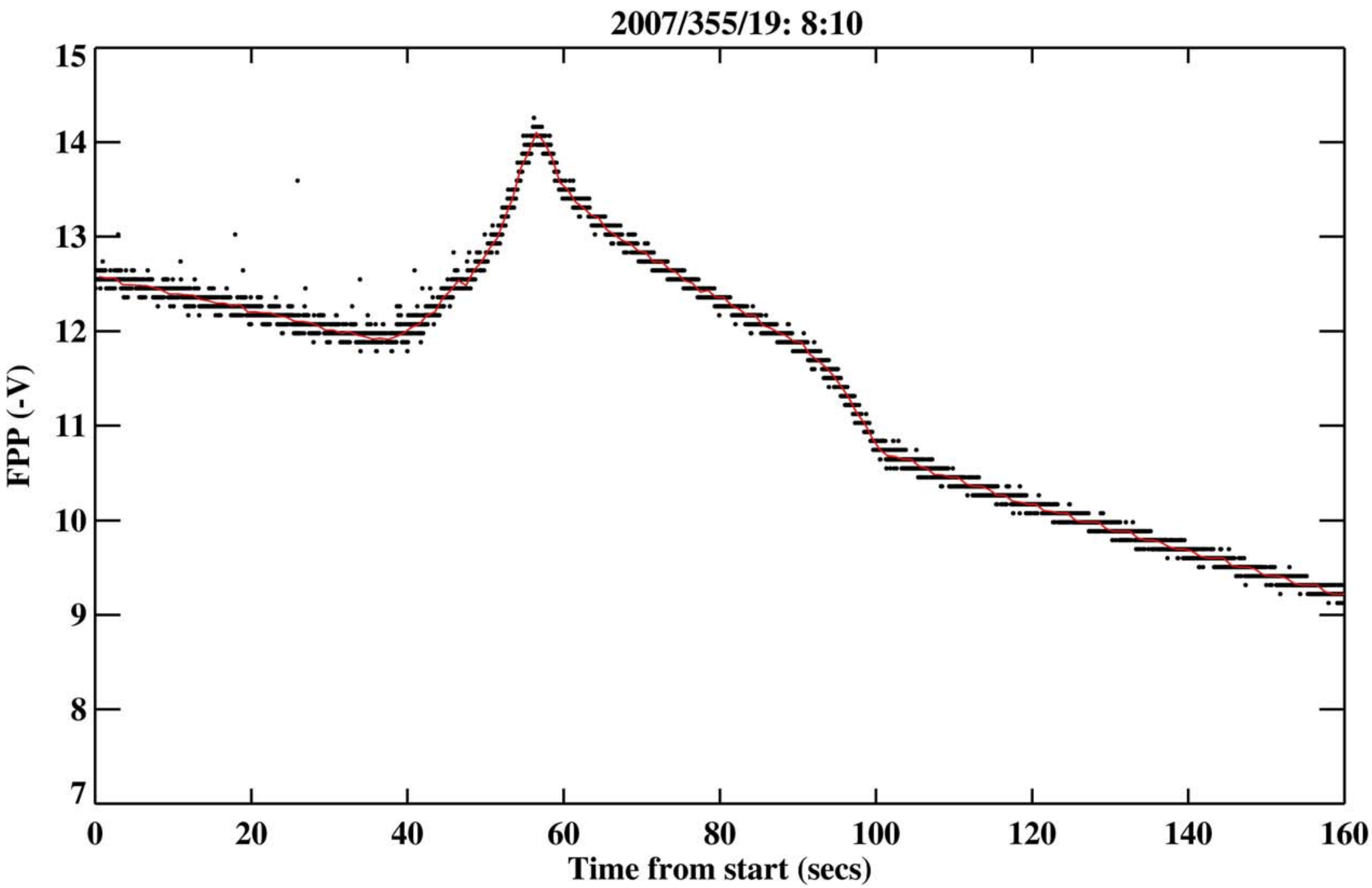
1: magnetic induction, 2: eclipse exit, 3: plasma induced



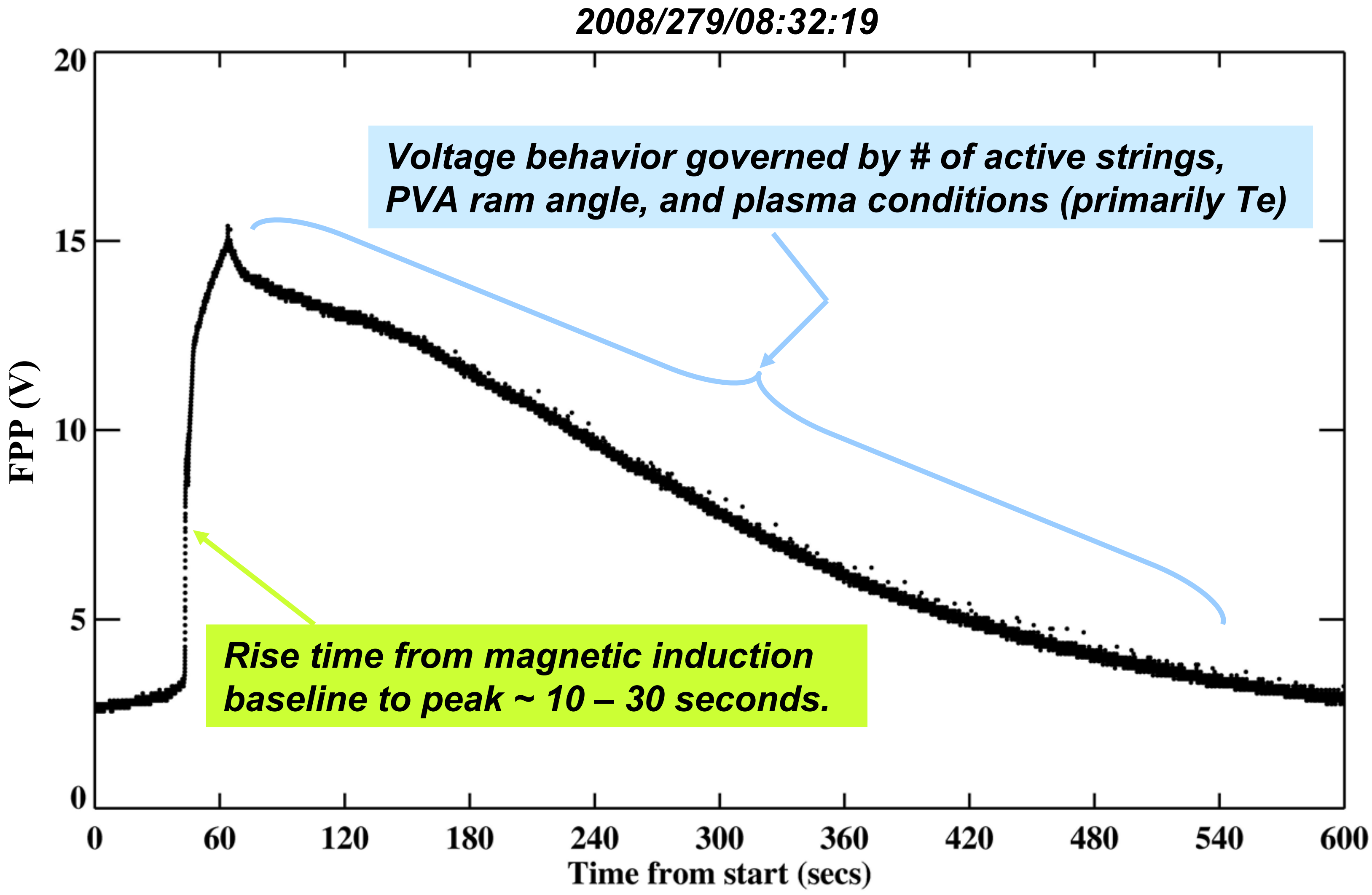
β angle ~ -53°


FPMU: 2007355
WLP
NLP
FPP
Lat
Lon
FP (-V)
Lat, Lon/3 (deg)
16
14
12
10
8
60
30
0
-30
-60
PIP
WLP
NLP-Ne
WLP-Ne
Day
Ni (10^{11} m^{-3})
10.0
1.0
0.1
WLP
NLP
Alt
Te (1000 K)
Alt (km)
4
3
2
1
0
354
349
344
339
334
19.0
19.1
19.2
19.3
GMT Hour

β angle ~ -53˚

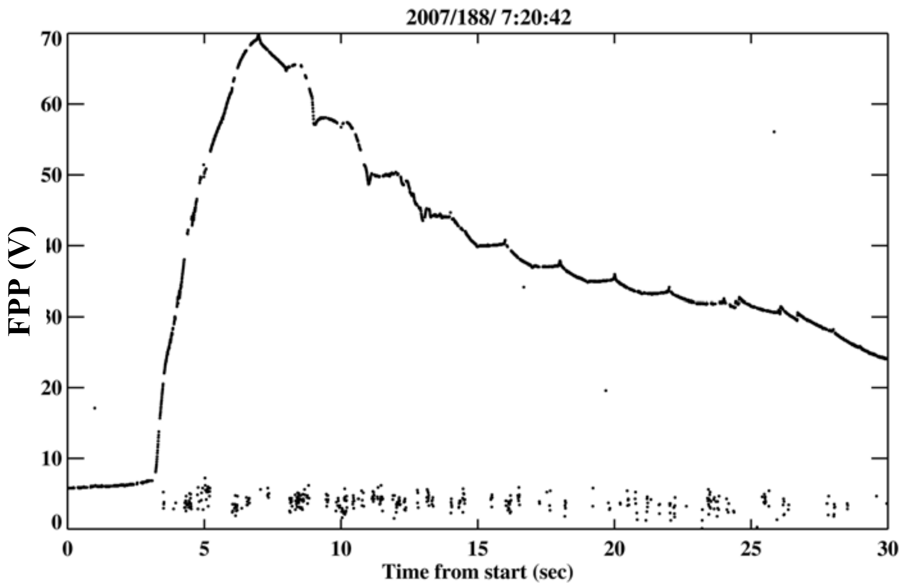


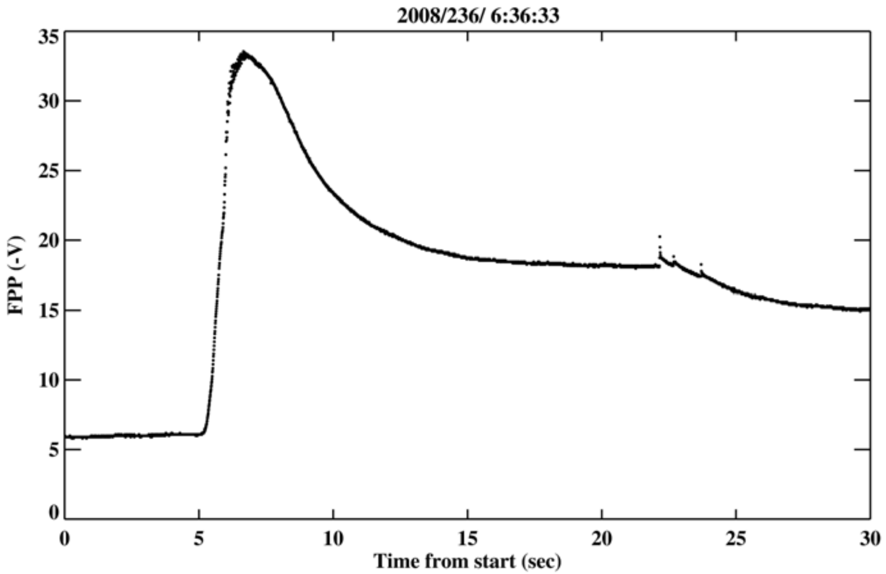
2007/355/19: 8:10
15
14
13
12
11
10
9
8
7
FPP (-V)
0
20
40
60
80
100
120
140
160
Time from start (secs)



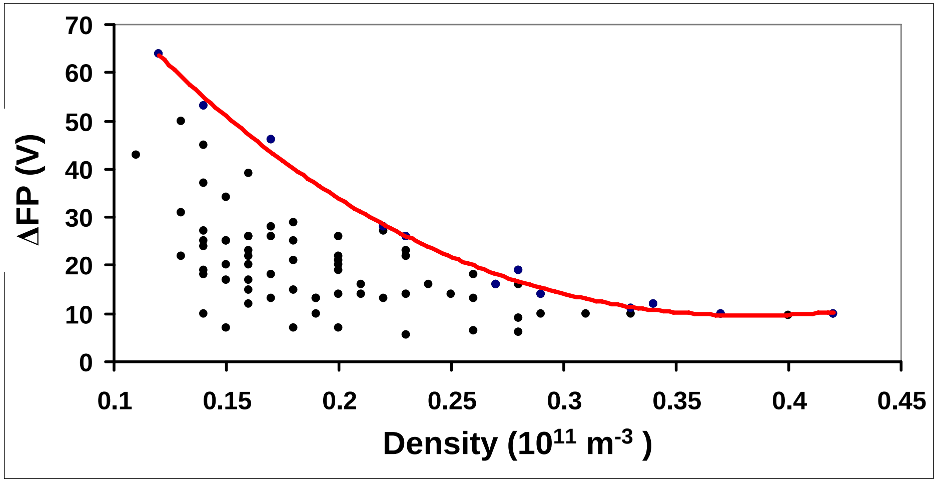
For NCEs in general: at a given density, the lower the Te the greater the charging amplitude

Rapid because leading and trailing edge occurs much faster: rise times generally ≤ 5 secs and decay time ~ 10 – 30 secs.

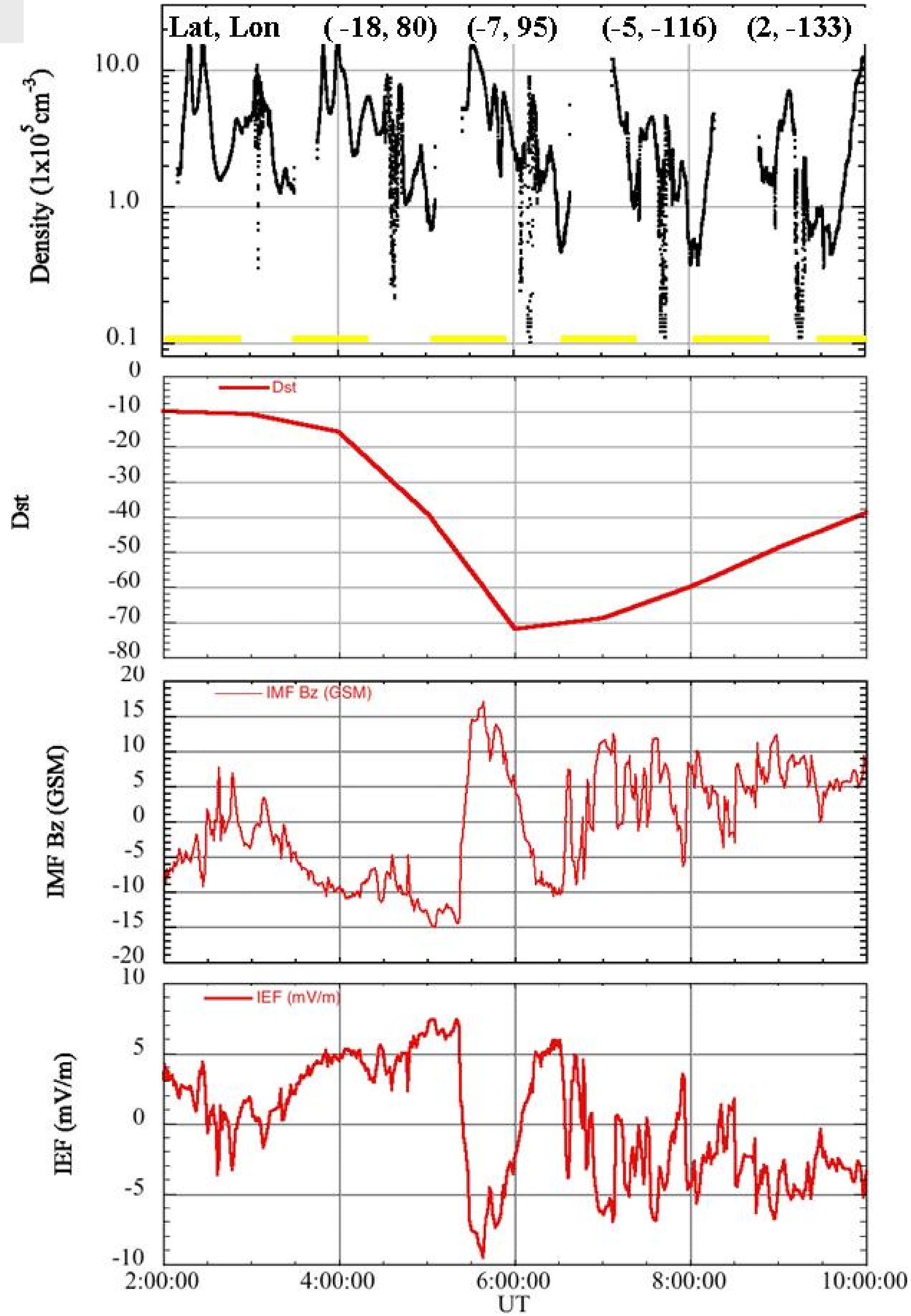


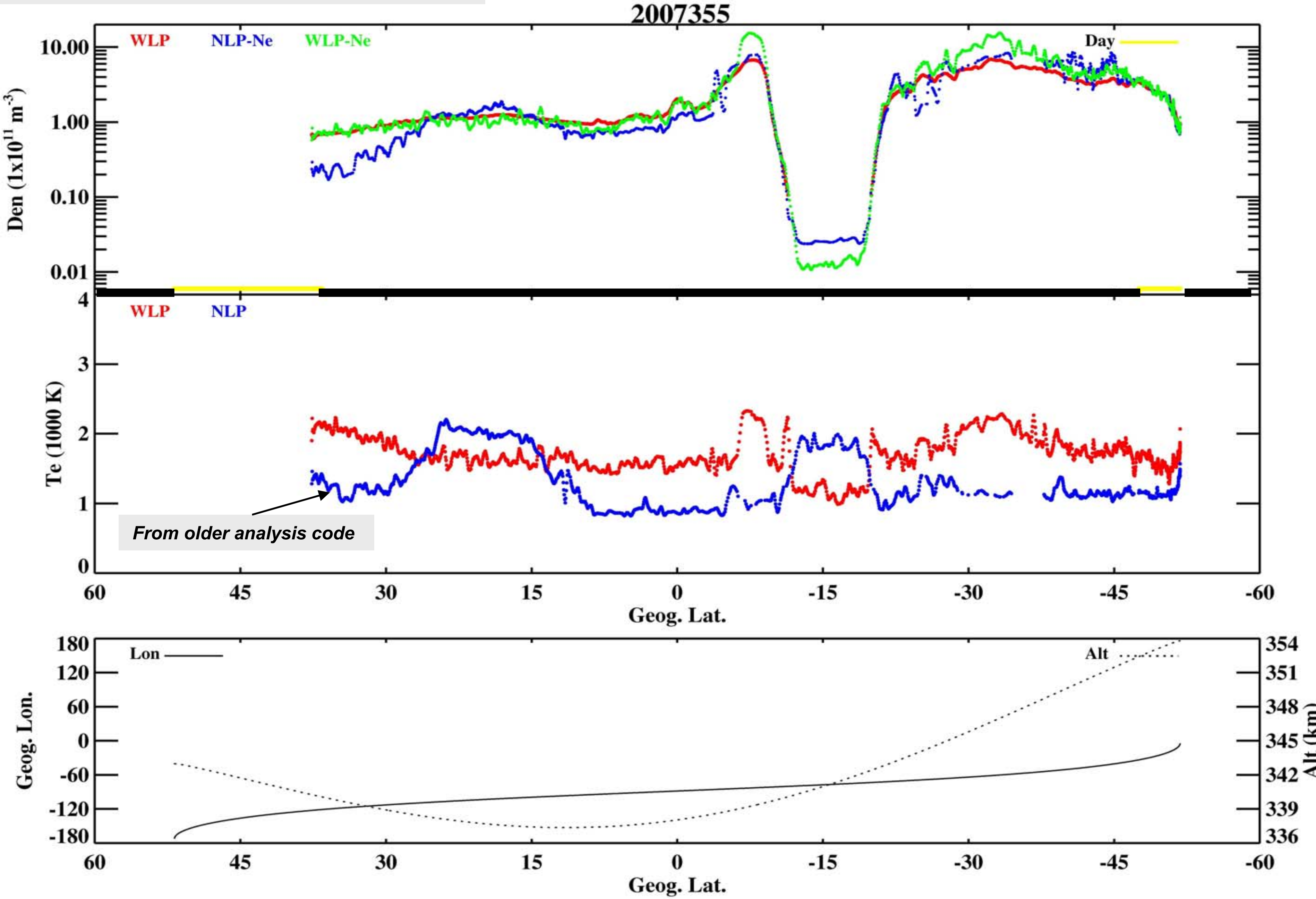


RCE amplitude to first order is inversely related to density



Equatorial Ionosphere Observations from March 9, 2008



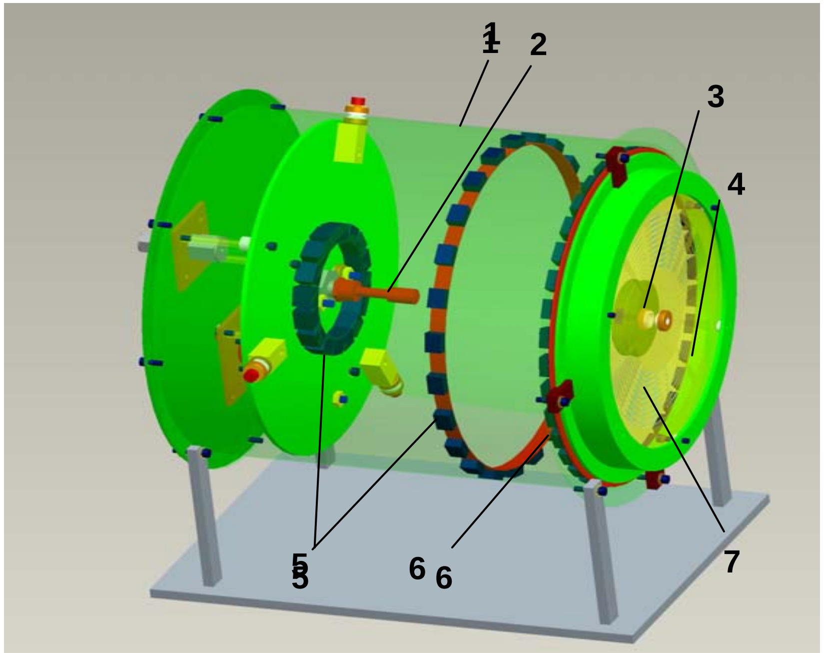

2007355
WLP
NLP-Ne
WLP-Ne
Day
Den ($1x10^{11}$ m^{-3})
10.00
1.00
0.10
0.01
WLP
NLP
Te (1000 K)
4
3
2
1
0
From older analysis code
60
45
30
15
0
-15
-30
-45
-60
Geog. Lat.
Lon
Alt
Geog. Lon.
180
120
60
0
-60
-120
-180
354
351
348
345
342
339
336
Alt (km)
Geog. Lat.

Extra:
LP analysis
of
LEO plasma simulation source

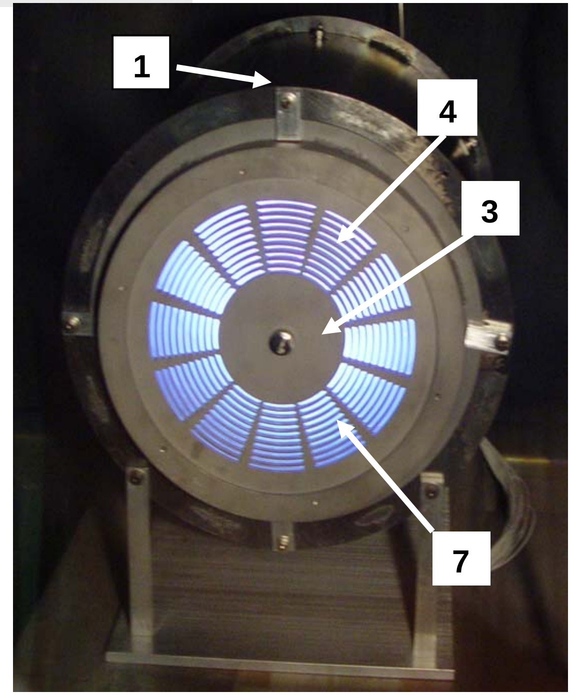
Colorado State University LEO plasma simulation source

Courtesy of John Williams

(a)

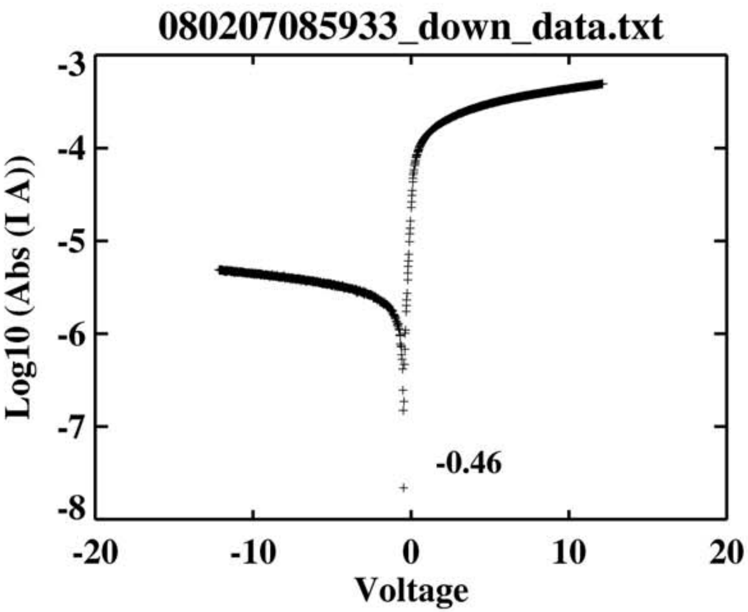


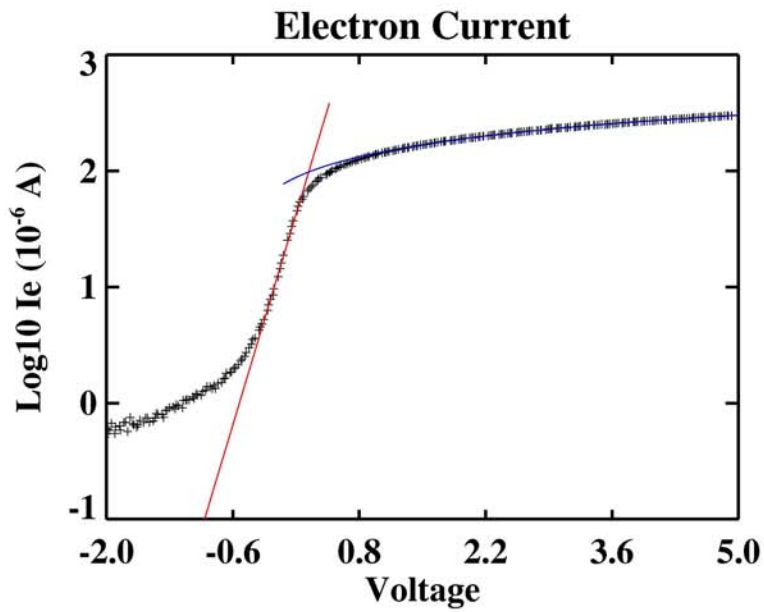
(b)

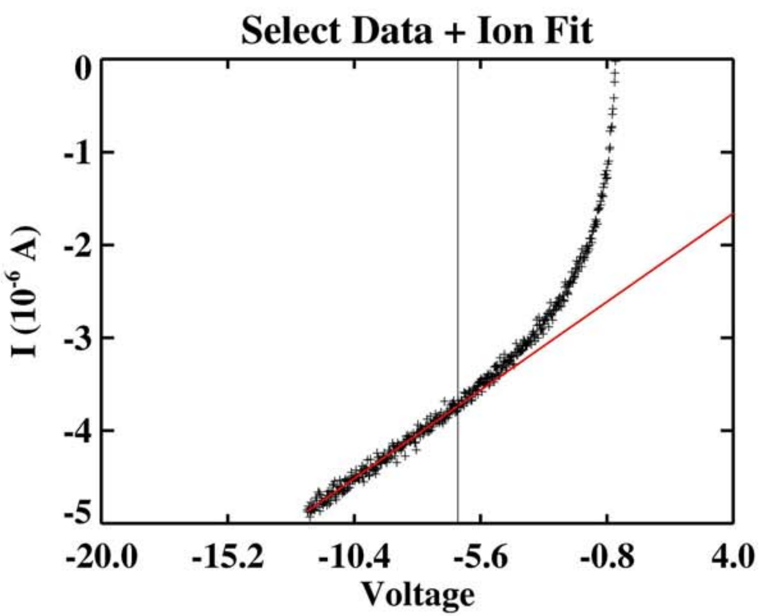


(a) Plasma Source CAD model: 1– Discharge chamber outer wall (anode), 2– hollow cathode, 3–inner part of the magnetic filter, 4- neutral density grids, 5– Sm-Co magnets, 6– outer part of the magnetic filter, 7- coaxial plasma expansion region. (b) Photograph of Plasma source during operation

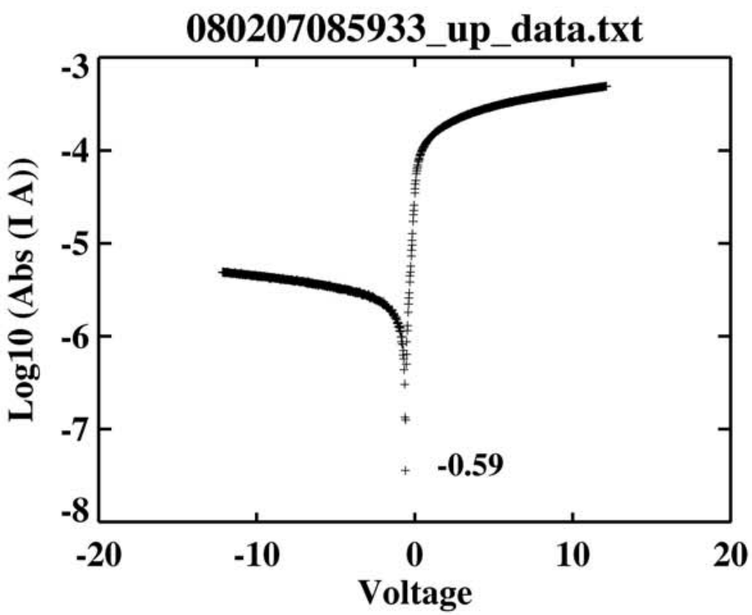
Submitted to Plasma Sources, Science, and Technology

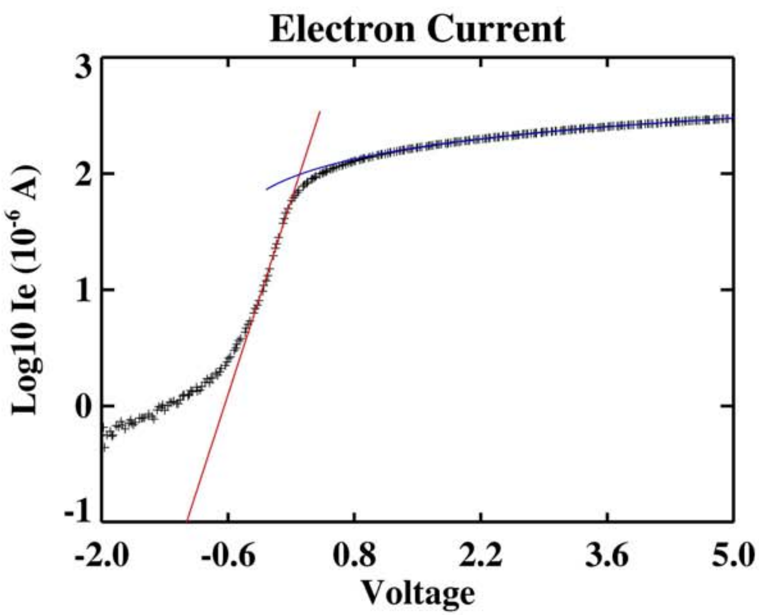


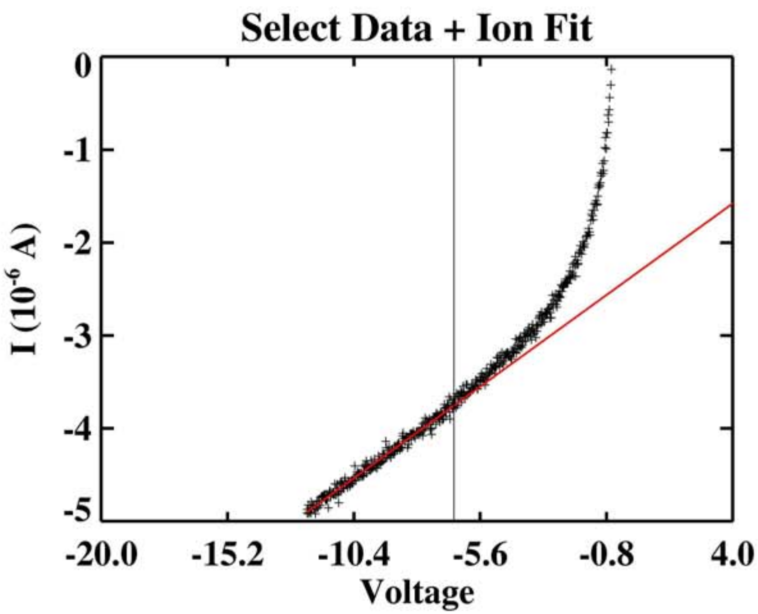




Ni (10^{11} m^{-3}) =	15.7	
Te (eV),%err =	0.167	1.6
Vf,Vsp =	-0.46	0.32







Ni (10^{11} m^{-3}) =	15.3	
Te (eV),%err =	0.181	1.9
Vf,Vsp =	-0.59	0.28

Concluding remarks:

- ***The thrust of this presentation was to highlight real world data and its complications.***
- ***Noise is usually present.***
- ***Theoretical probe response guides analysis logic, acceptance criteria, etc.***
- ***Refinements to logic, acceptance criteria, etc. based on previous experience.***
- ***Hopefully hardware operation and choice of downlinked data is robust in order to give options for analysis.***
- ***Be wary of your software logic:***
  - ***continually review it to make sure that all quirks in data are handled reasonably.***
  - ***the computer logic is only as smart as you make it*** $\Rightarrow$ ***continually "eyeball" data with curve-fits.***
- ***Reach out to colleagues***

We at MSFC are very much in debt to C. Swenson, C. Fish, A. Barjatya, and D. Thompson for many discussions concerning the FPMU!