Increasing the resolution of the FFT for more precise FLR-frequency determination in VLOS

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2022/Mar/09 SD Research meeting presentation by Kawano et al.

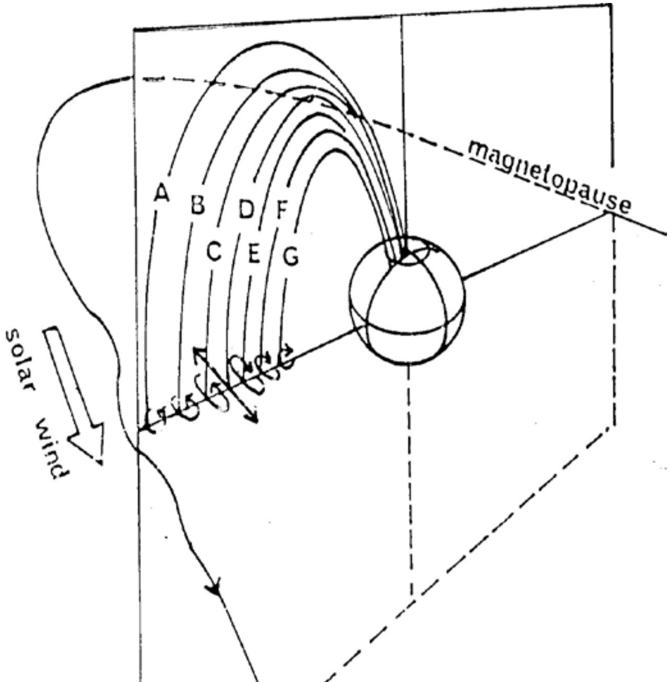
Field-Line Resonance (FLR)
→ Frequency of the field-line eigen-oscillation
→ Magnetospheric Density

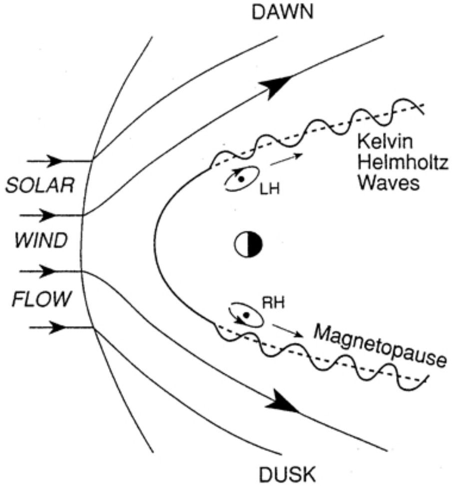
An incoming wave and a magnetospheric field-line eigen-oscillation resonates where the field line's eigen-period matches the incoming-wave period.

Eigen-period ∝ *l* , $\rho^{1/2}$,

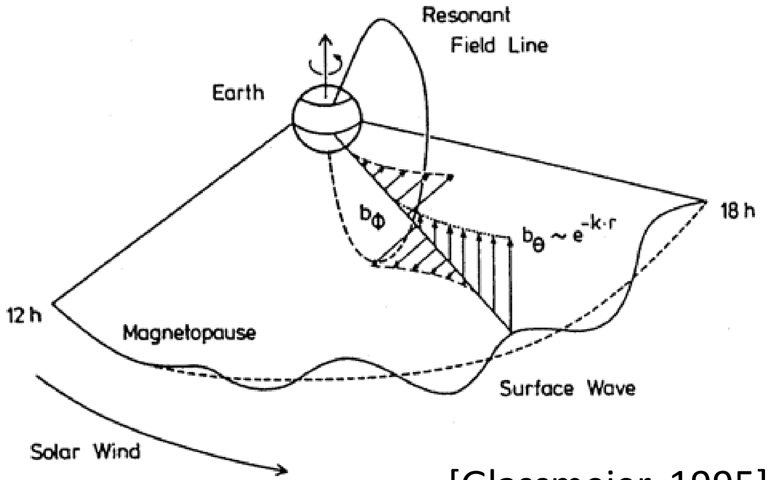
where ***l*** : field-line length,

$\rho^{1/2}$: plasma density



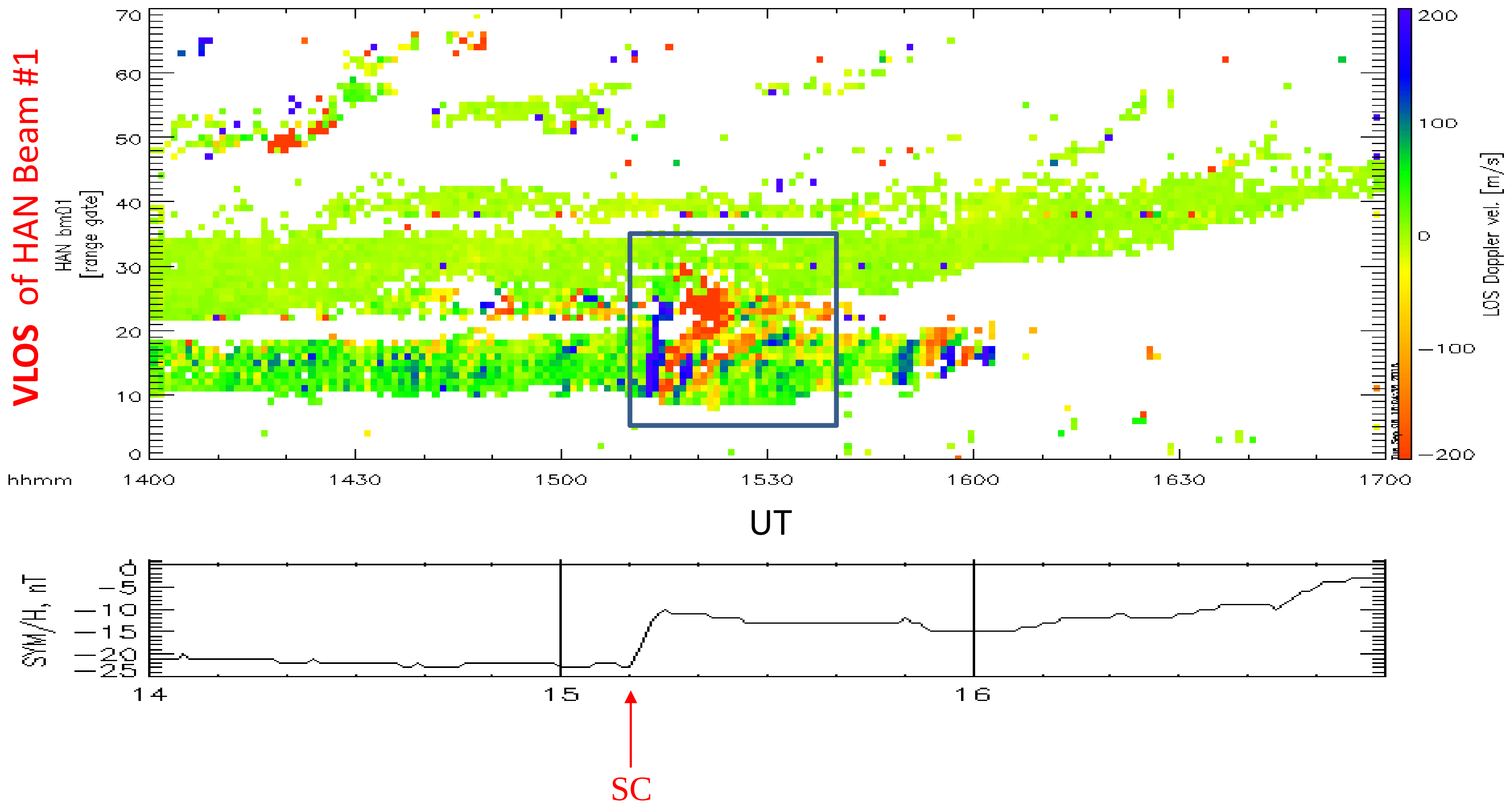


[Hughes, 1994]



[Glassmeier, 1995]

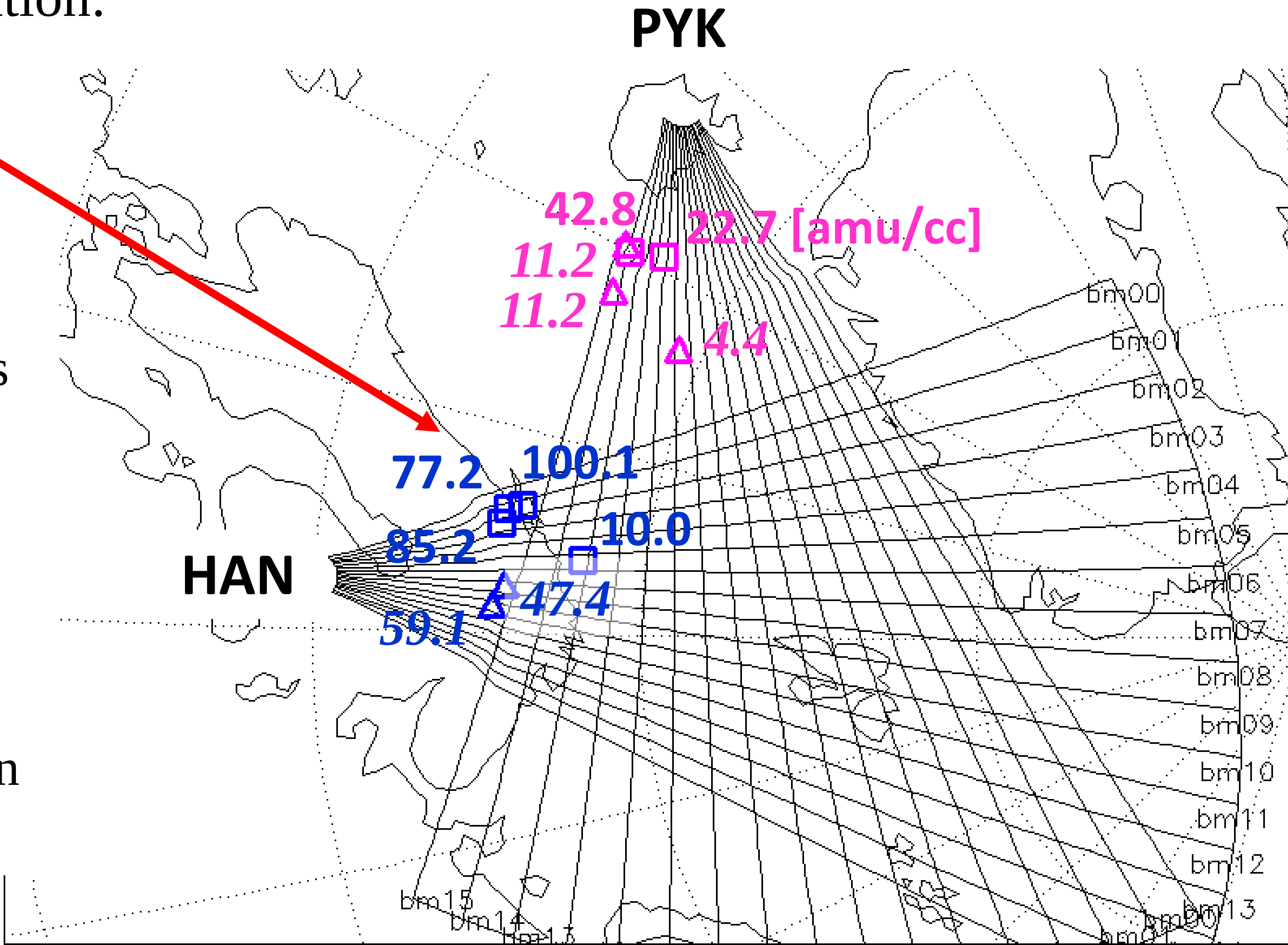
Event of this paper



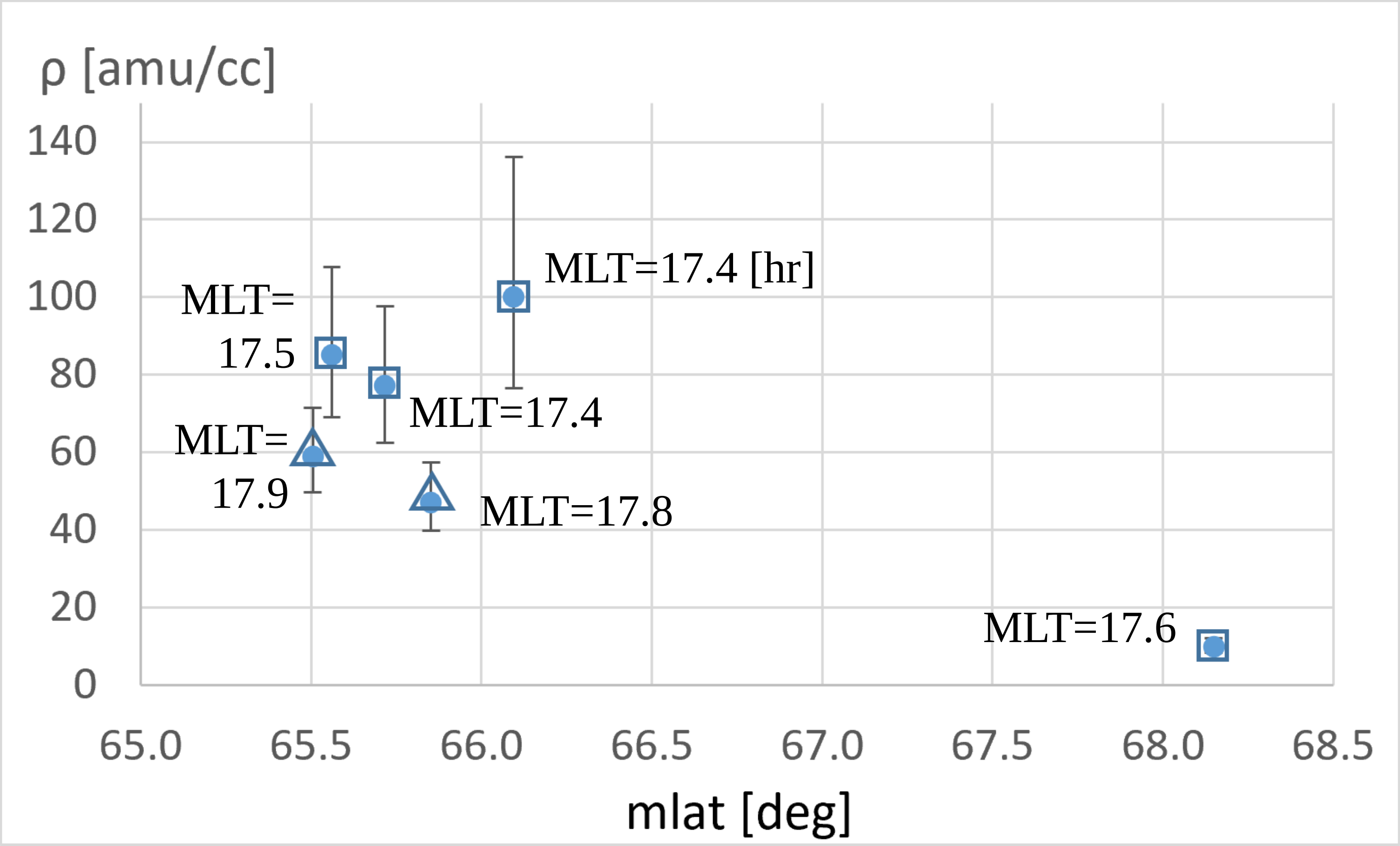
- Density estimates from the auto-ID'ed FLR's

- Features of the density distribution:
  - There are pretty large density fluctuation in the small area.
  - We notice that the densities estimated from the sea-backscattered signals (triangles in the figure) are smaller than those estimated from the ionosphere-backscattered signals.

  → We have estimated the error ranges of the densities shown right (→ next slide):



○ The density estimates of the last slide, shown in a different format, with largest-estimated error bars (assuming that the error in the frequency is 0.5556 / 2.0 mHz)



- The difference in the small area in the last slide (77.2 and 100.1) is within the (largest-estimated) error range.
- The difference between the ionospheric and sea backscatters are also within the error range, but the overlapping of the error bars is not so significant.

○ Density fluctuation in the small area

- The pretty large density fluctuation in the small area, as shown in the last two slides, could be due the quantization of the frequency ($n \times 0.5556$ mHz), coming from the FFT.

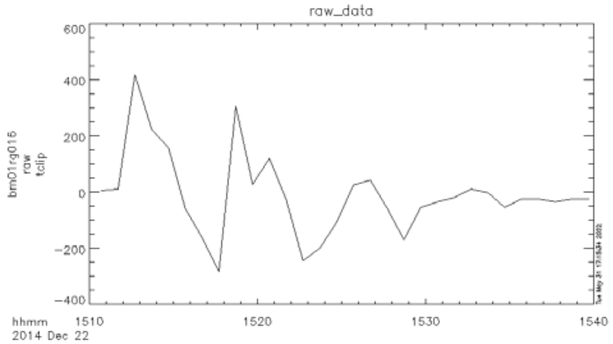
→ Needed: ▪Error estimation (rough estimation was made in the last slide)

▪Increasing the frequency resolution by using

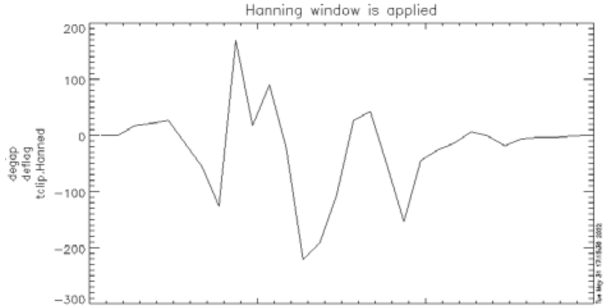
- DFT (direct Fourier Transformation) or
- Zero-padding

→ We have tested the zero-padding (next slide):

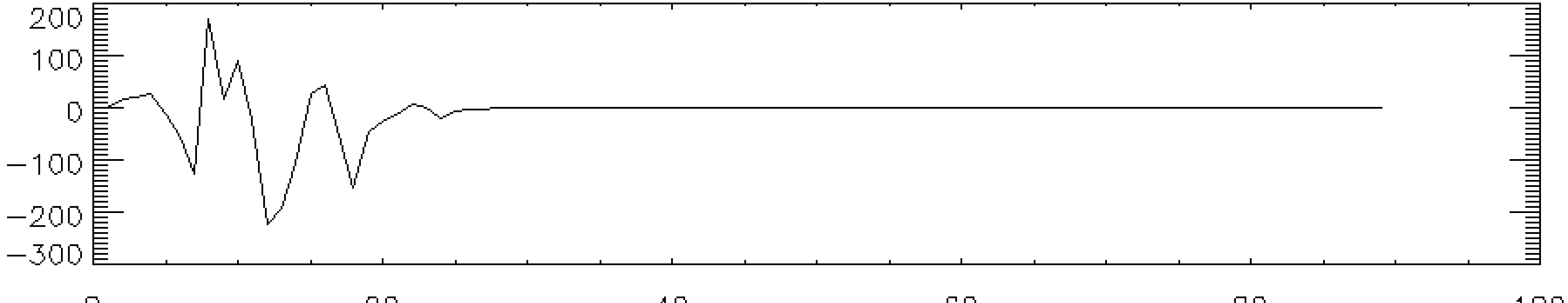
○ Zero-padding



Raw VLOS data
(Beam #01, RG #16,
15:10-15:40 UT



Hanning window
is applied



Zero-padded

○ Zero-padding

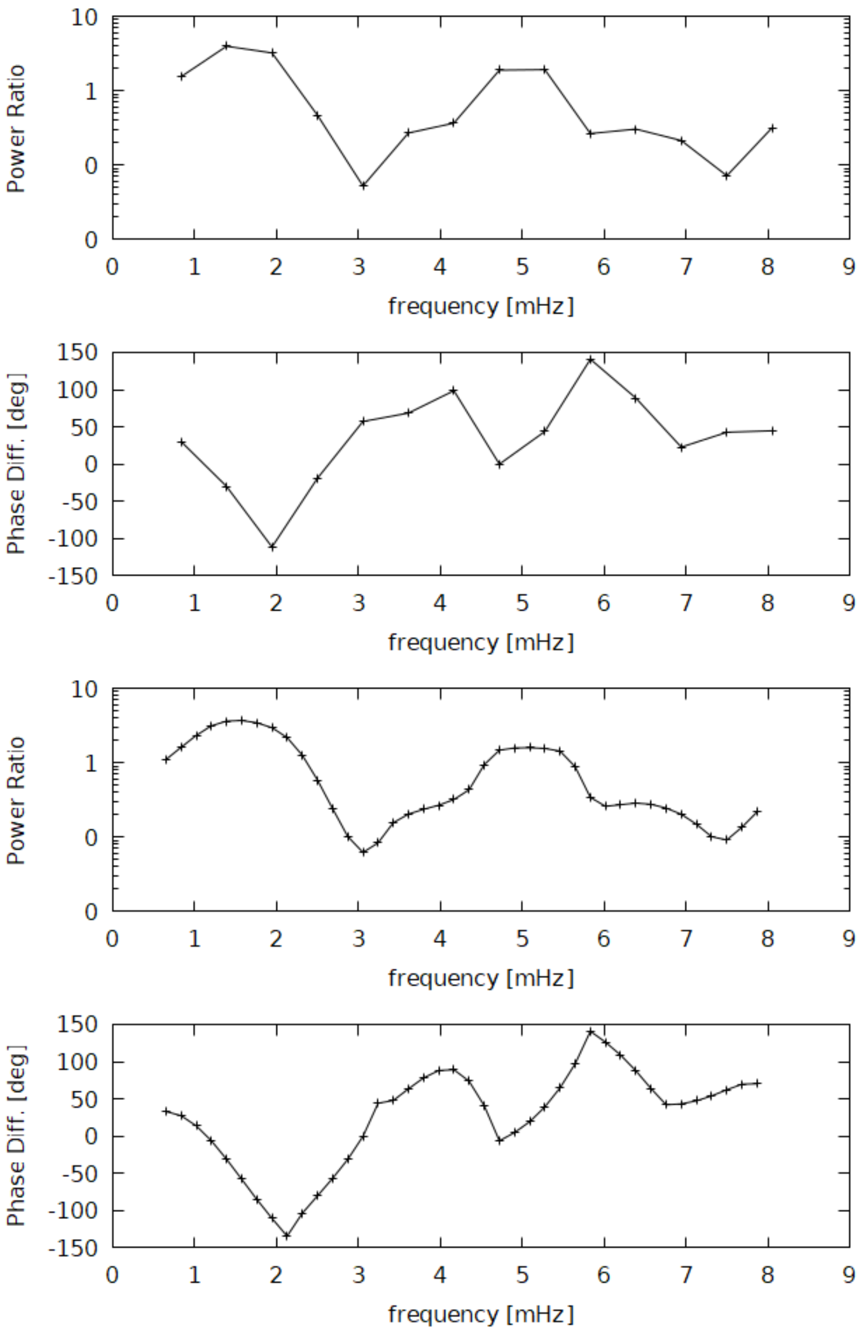
The result of applying the gradient method to

(1) two VOS timeseries-datasets from RGs #18 and #16, after the Hanning window is applied to the each.

(2) two timeseries-datasets of padding zeros to the datasets of (1)

(1)

(2)



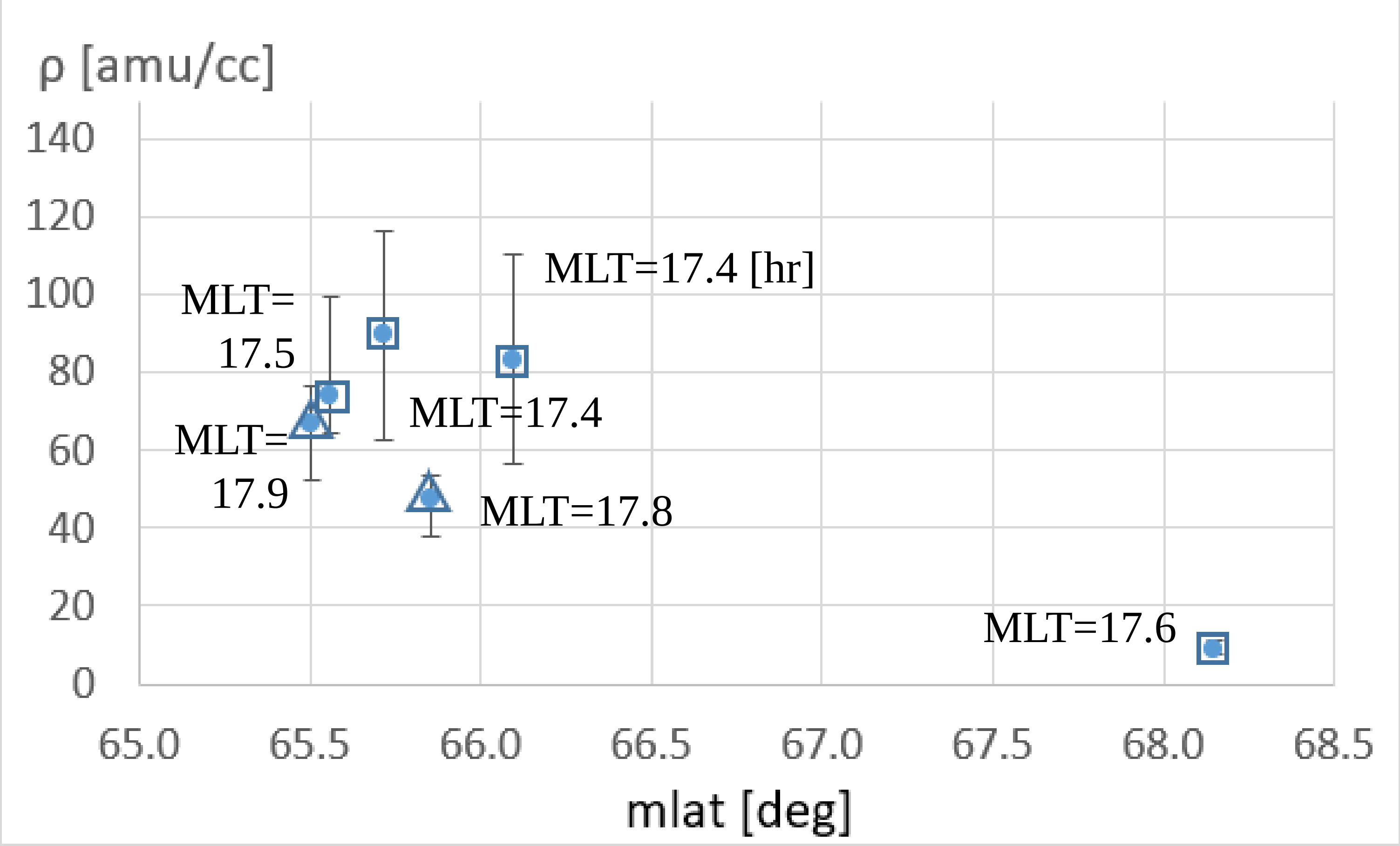
Amplitude ratio

Phase difference

Amplitude ratio

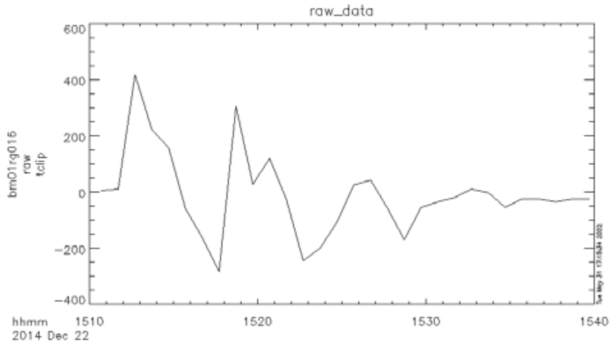
Phase difference

○ The zero-padding-based density estimates, with largest-estimated error bars (assuming that the error range in the frequency is half the frequency distance between the minimum and maximum amplitude-ratio points).

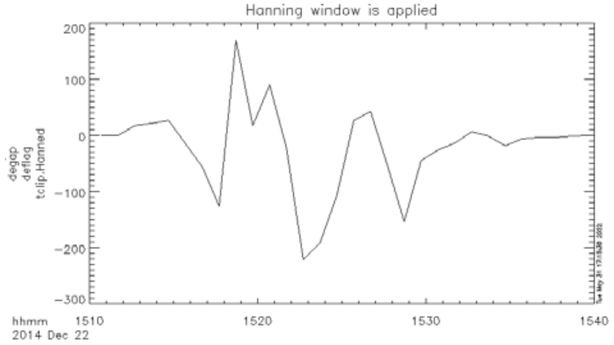


- The difference in the small area has become smaller.
- The difference between the ionospheric and sea backscatters has also become smaller.

○ Effect of applying the Hanning window

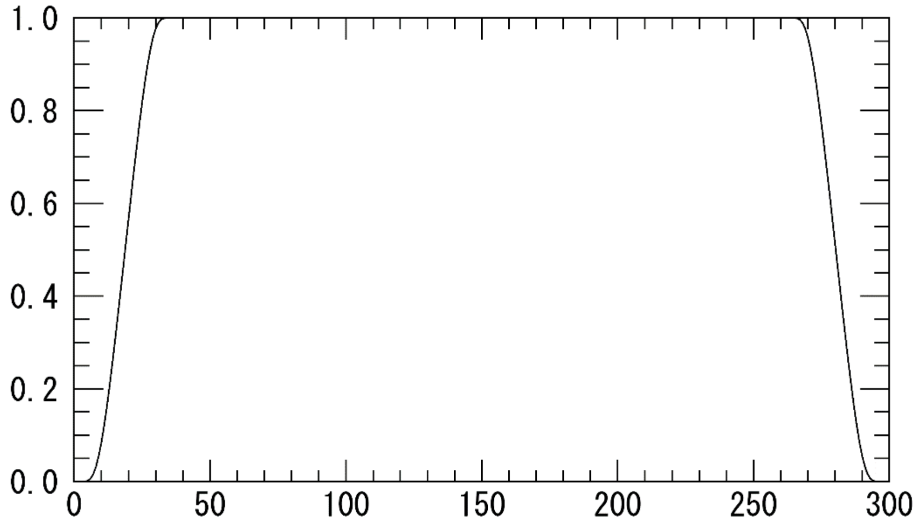


Raw VLOS data
(Beam #01, RG #16,
15:10-15:40 UT

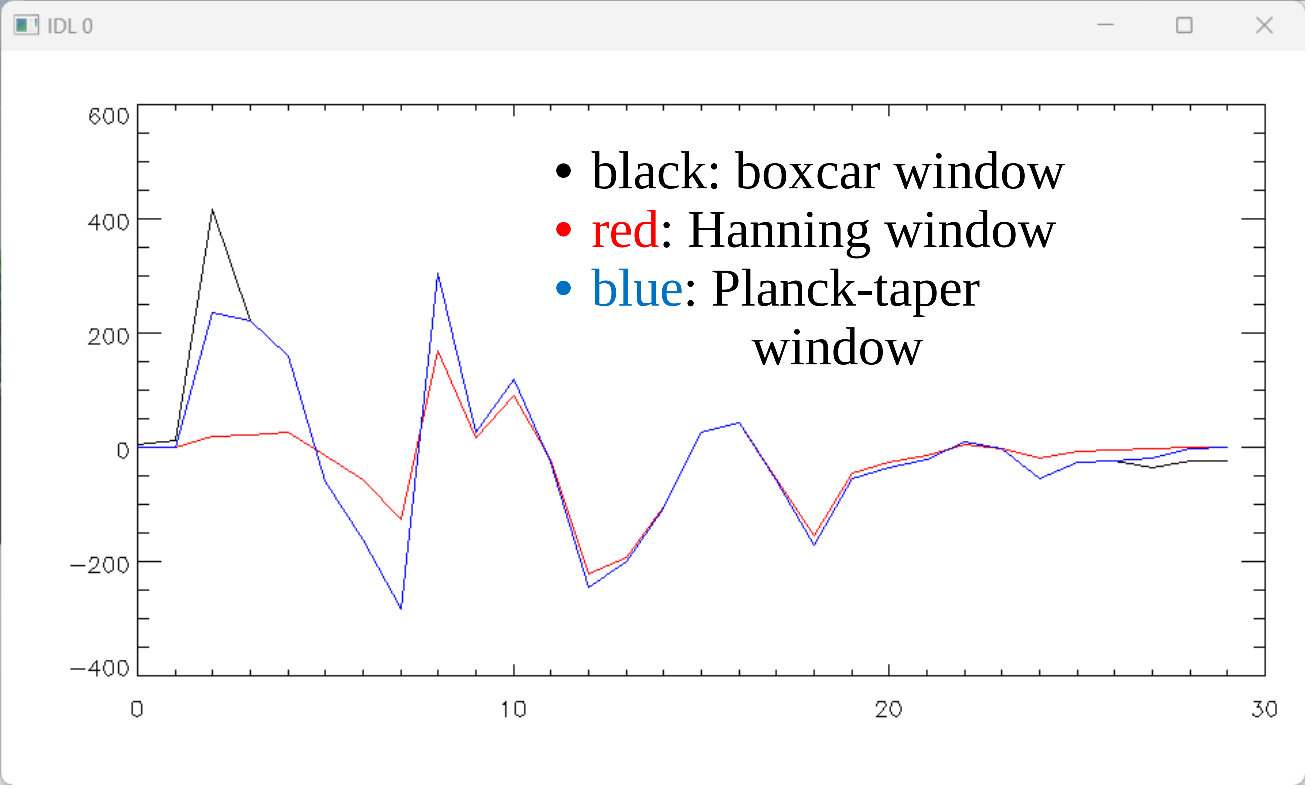


Hanning window
is applied

- The initial pulse just after the SC is almost deleted by the Hanning Window.
  Does not this affect the FFT result?

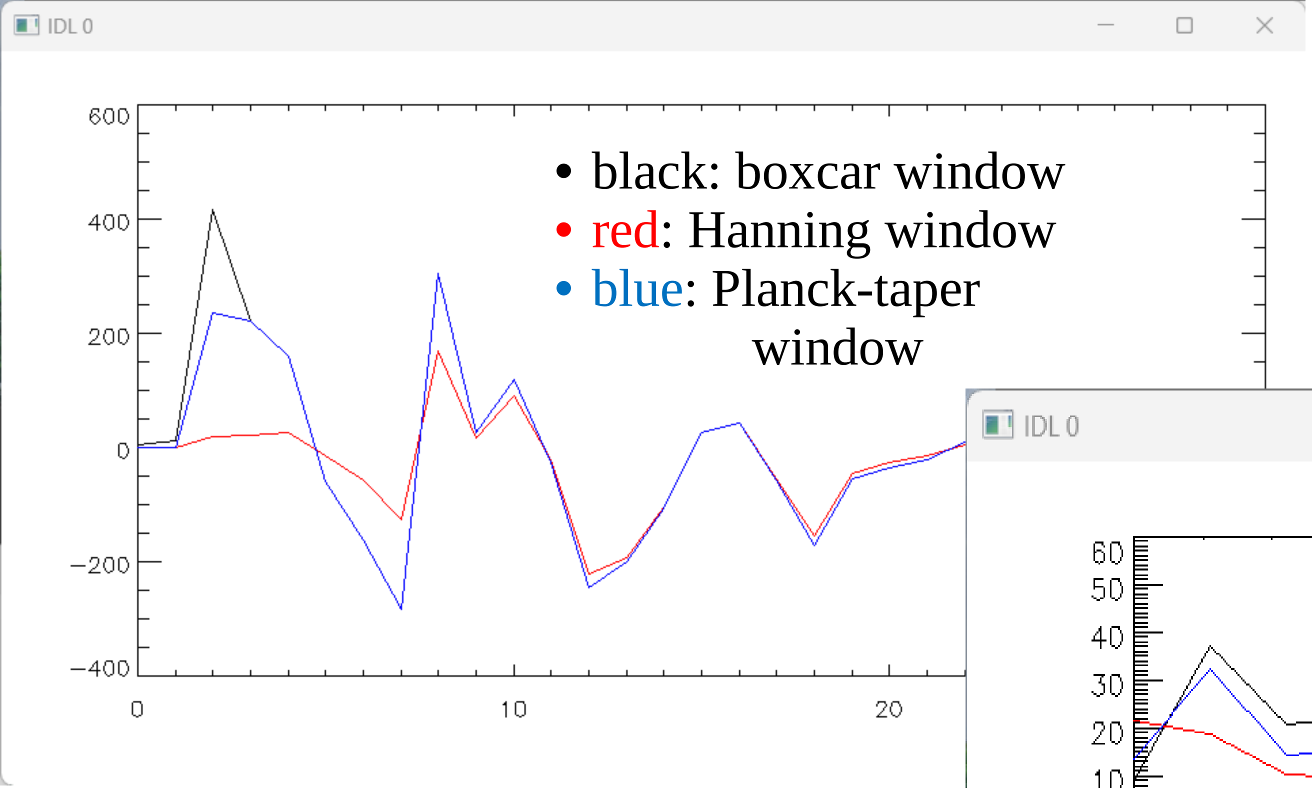


- We have applied the Planck-taper window, and looked at the difference between the two windows

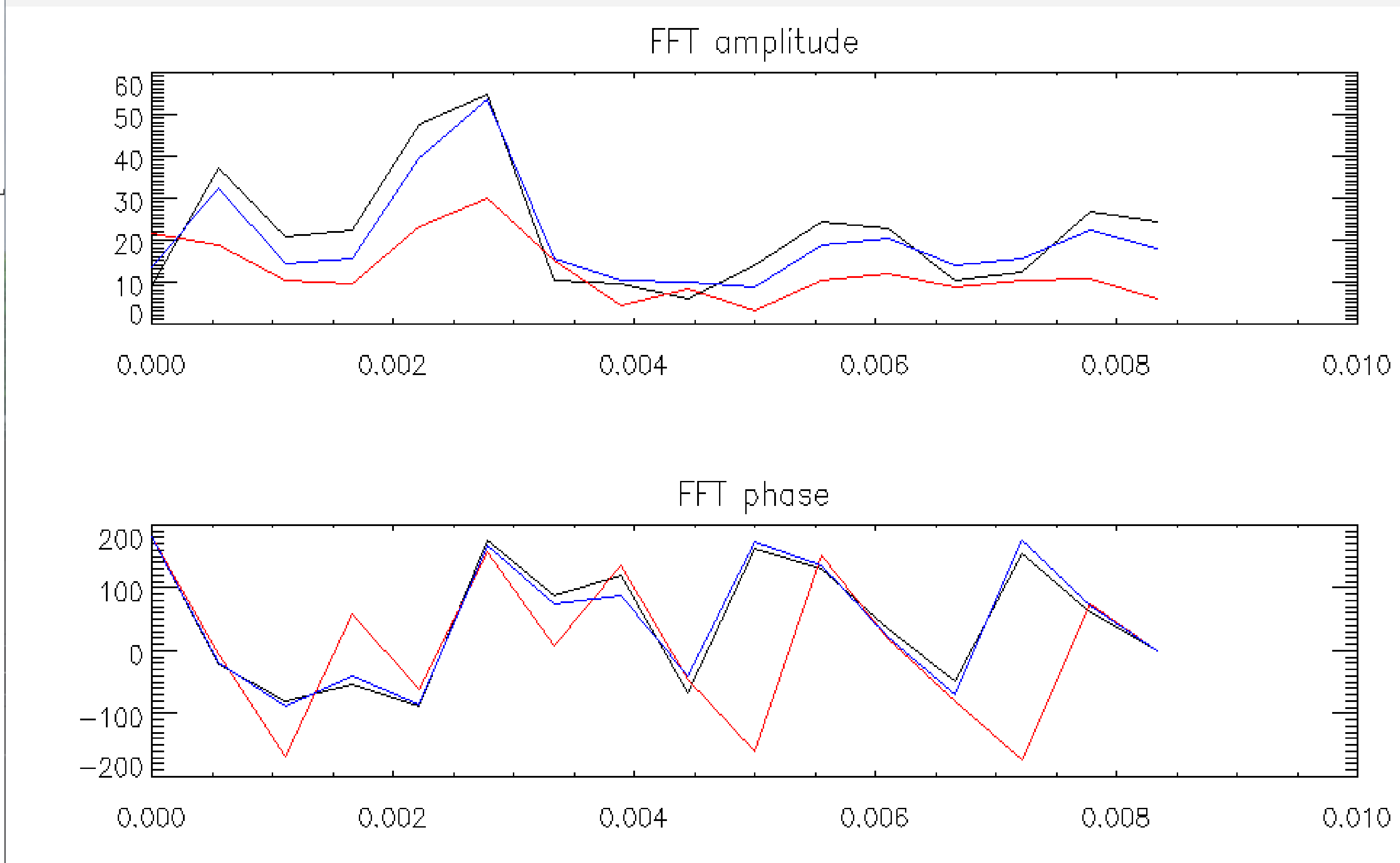


- The initial pulse is pretty well kept with the Planck-taper window, while

- it is almost deleted by the Hanning window.

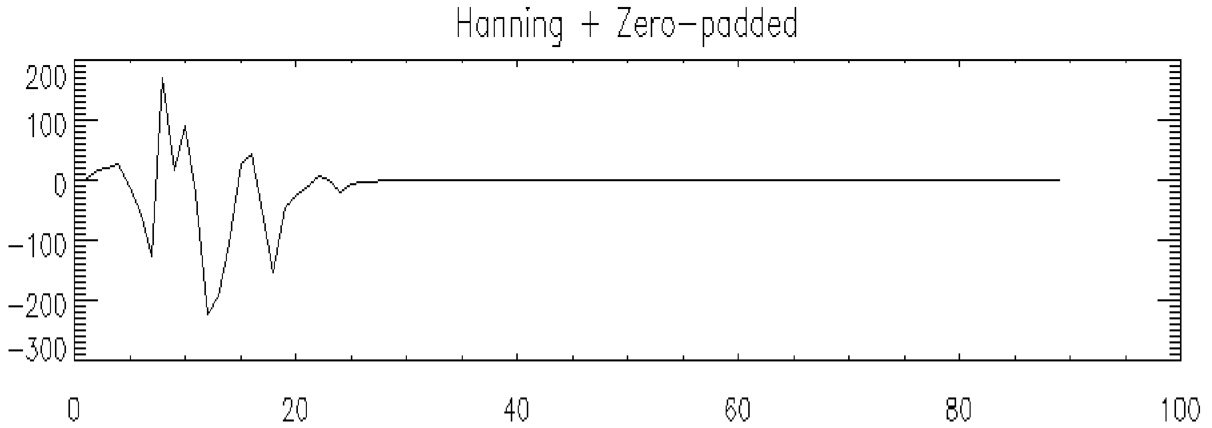


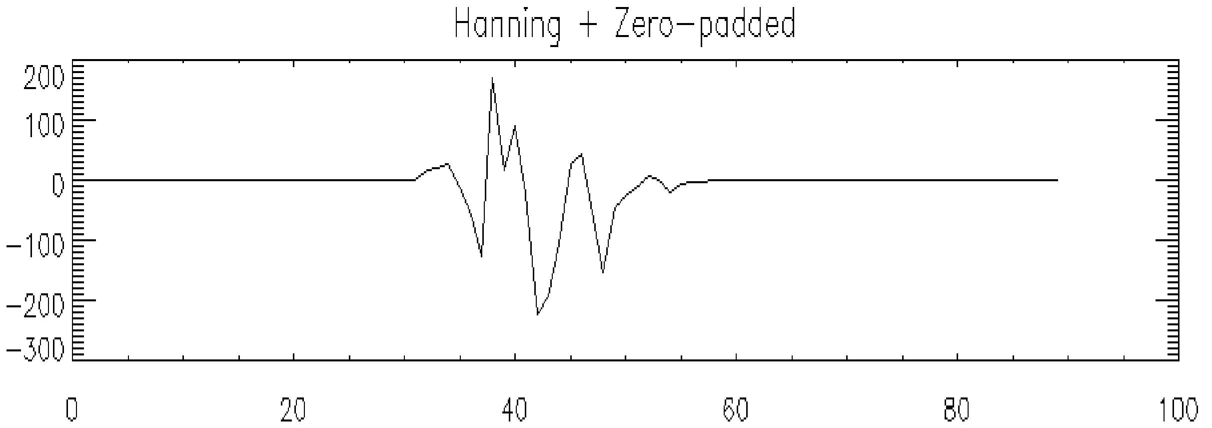
- The amplitude of the highest peak is much smaller with the Hanning than the Plank-taper.
- The phase is the most different near the highest power peak.



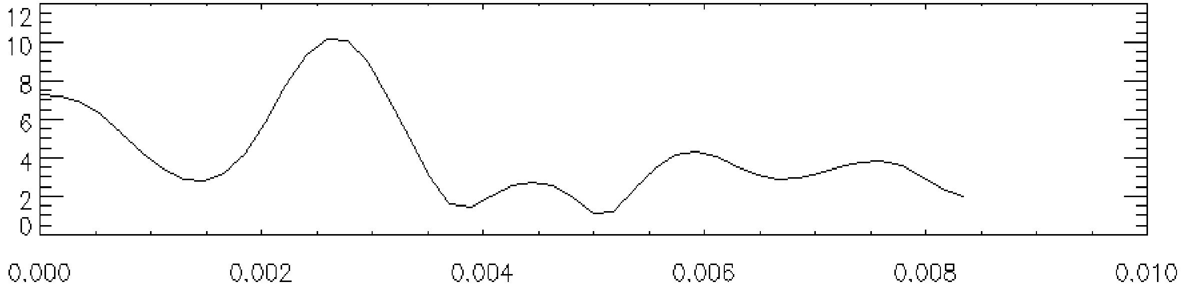
- The initial pulse is pretty well kept with the Planck-taper window, while
- it is almost deleted by the Hanning window.

- Zero-padding before and after the true data

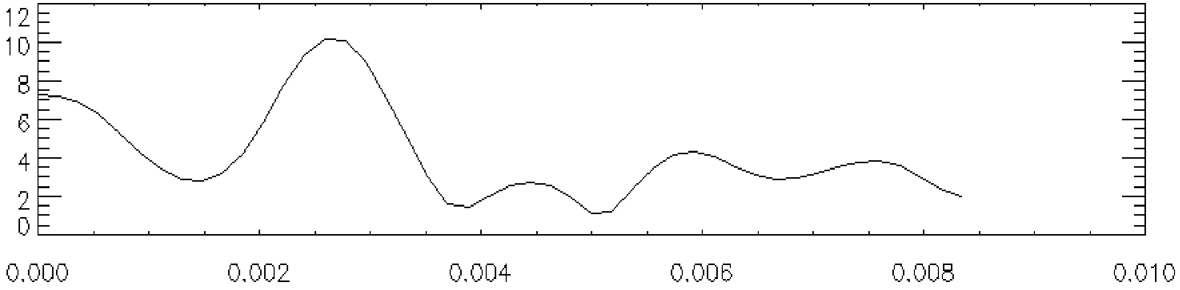




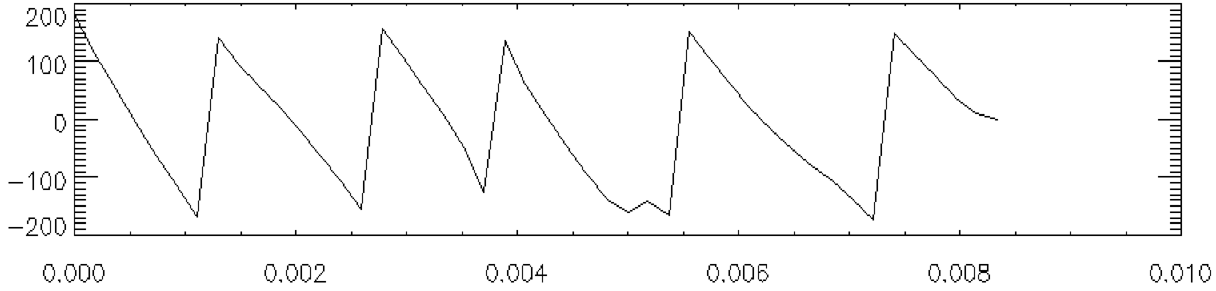
FFT of the above timeseries data, amplitude



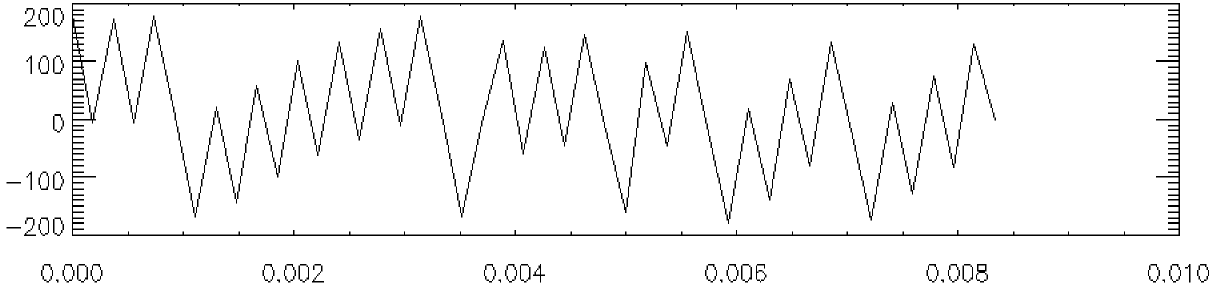
FFT of the above timeseries data, amplitude



FFT of the above timeseries data, phase



FFT of the above timeseries data, phase



○ Summary

- The fluctuations of the estimated plasma density in the small area observed by HAN have become smaller by increasing the frequency resolution.
- For SC-driven perturbations, the Hanning window could be inadequate.

○ Ongoing project

- We have been developing an all-in-one IDL code to automatically identify FLR events for all the beams of a SuperDARN radar at any given time.
- The current codes could be further improved, and we are working on that, too.

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