H19(2007)年度名古屋大学太陽地球環境研究所研究集会「中緯度短波レーダー研究会」
名古屋大学東山キャンパス環境総合館3F講義室2（愛知県名古屋市千種区不老町） 2008.01.28

電離圏人工励起FAIのSuperDARN観測

SuperDARN observation of artificially induced FAIs

and its application to heater induced FAIs

A. Sessai Yukimatu, K. Nishimura, Y.Ogawa,
M. Tsutsumi, N. Sato,
M. Rietveld, D.M. Wright, T.K. Yeoman,
and M. Lester

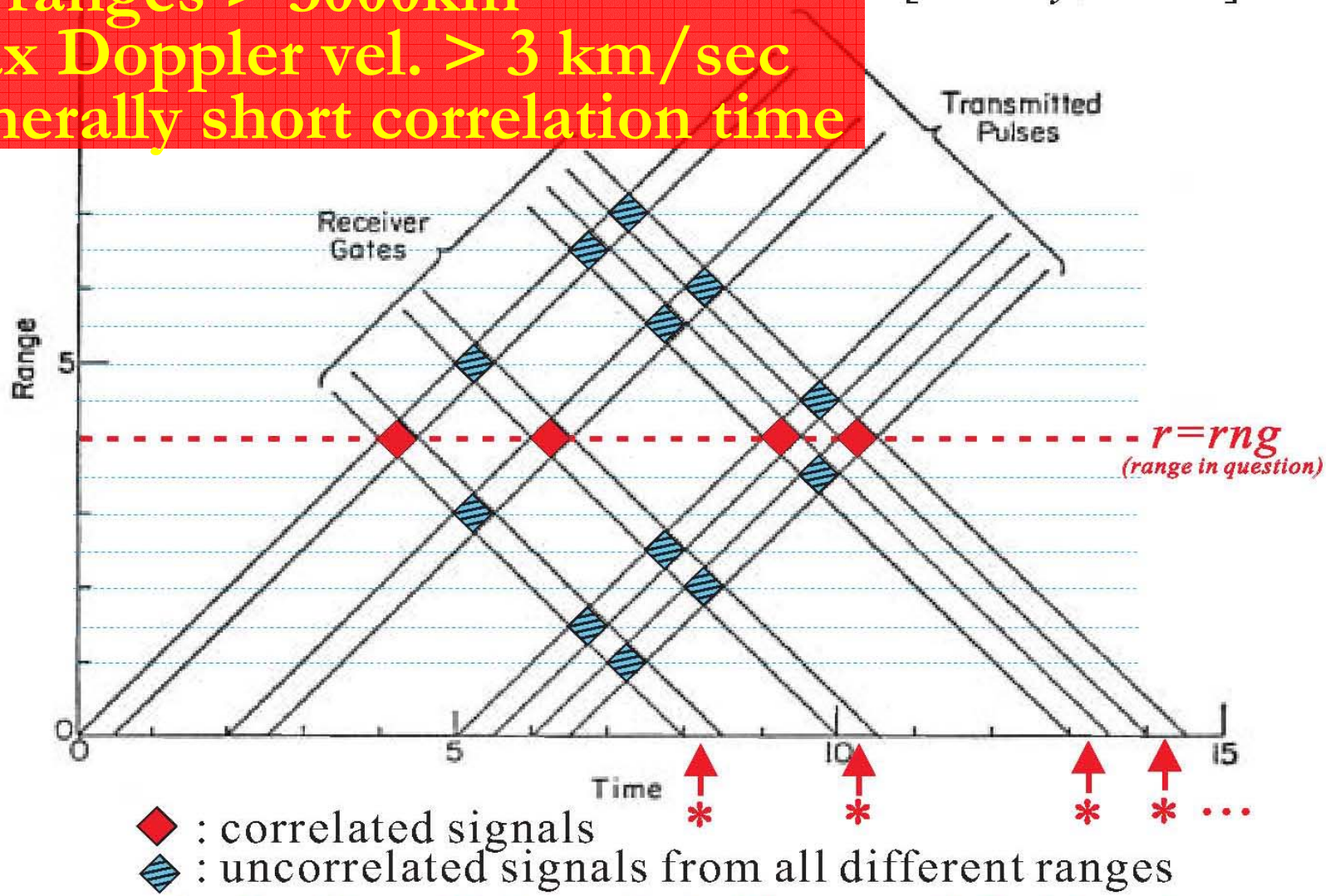
NIPR/ROIS/SOKENDAI, Tokyo,
EISCAT Association and Univ. of Leicester, UK

SuperDARN multi-pulse ACF obs. and raw time series (TMS) analysis

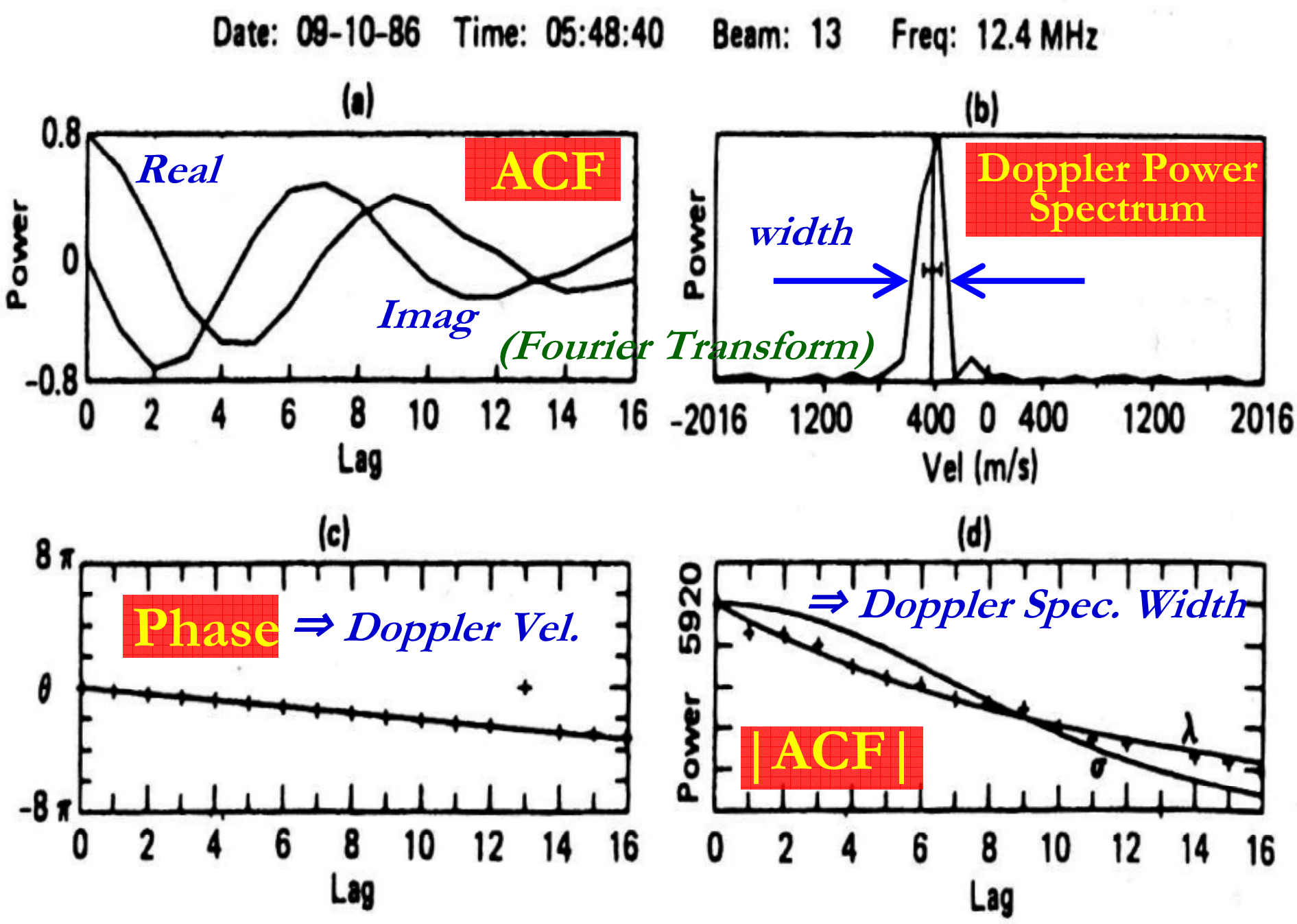
"unequally spaced multi-pulse ACF method"

[*Farley, 1972*]

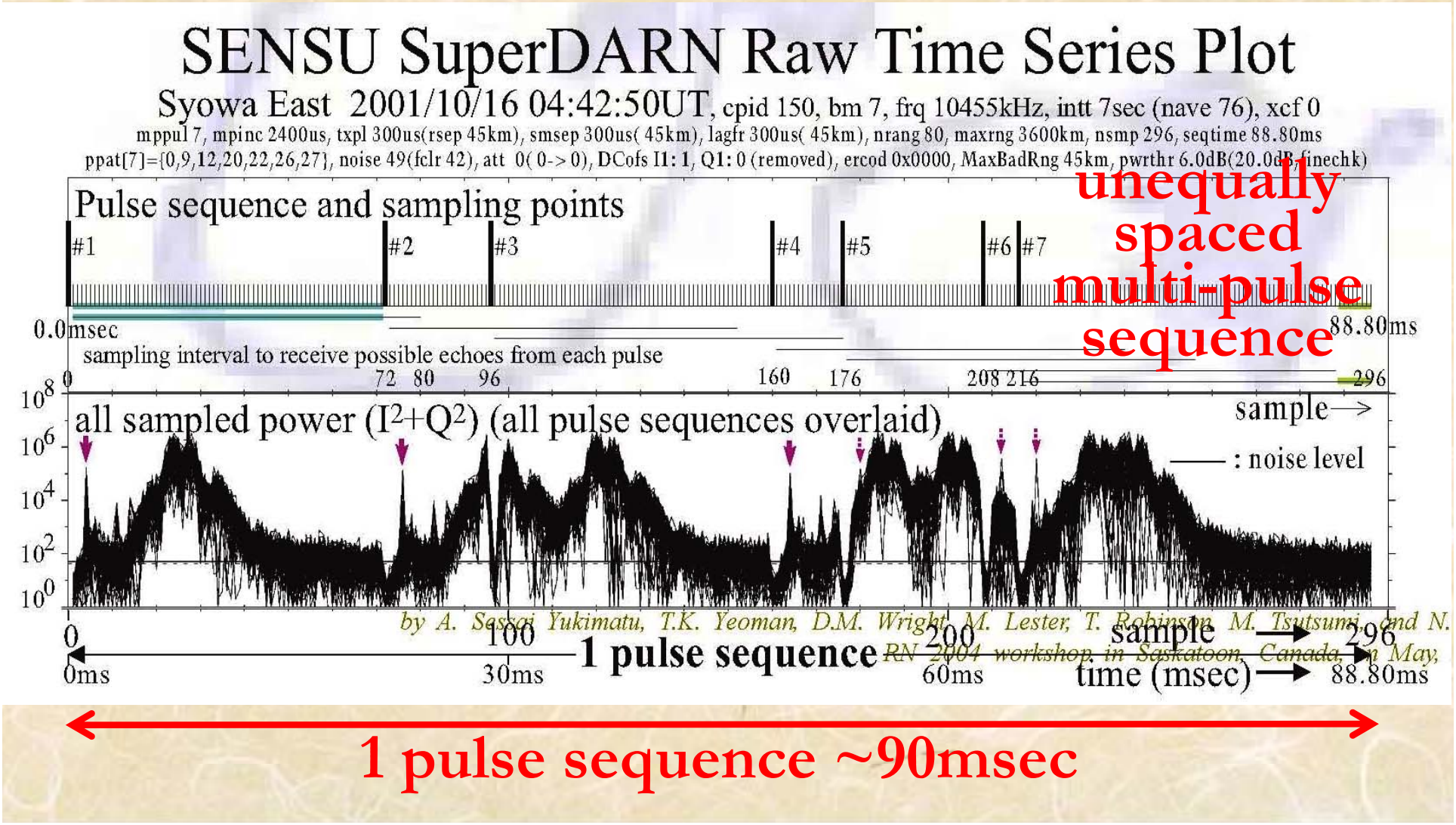
- far ranges > 3000km
- max Doppler vel. > 3 km/sec
- generally short correlation time



=> *Is "raw time series analysis" possible?!?*

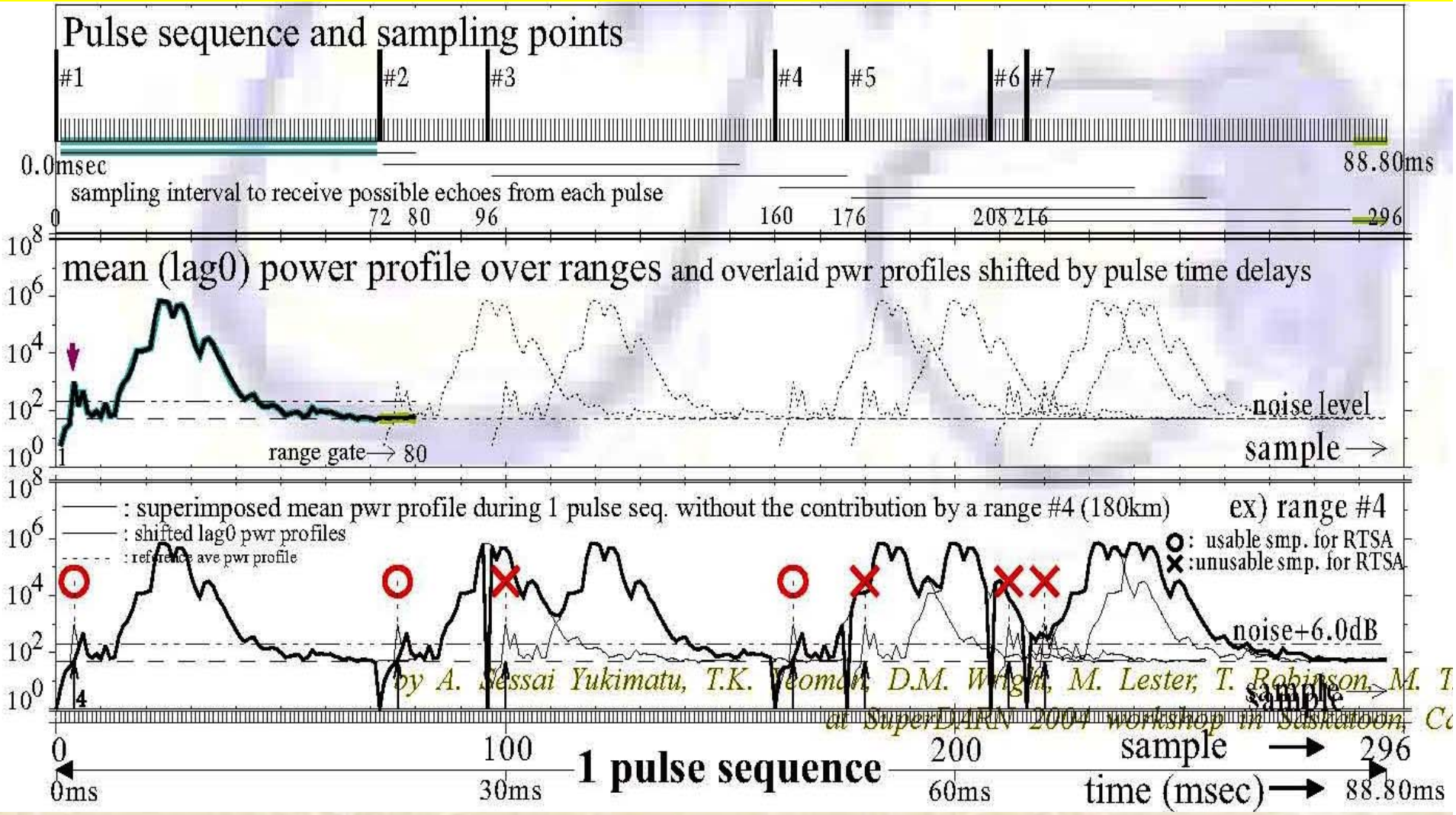

Date: 09-10-86 Time: 05:48:40 Beam: 13 Freq: 12.4 MHz
(a)
0.8
0
-0.8
Power
Real
Imag
ACF
0 2 4 6 8 10 12 14 16
Lag
(Fourier Transform)
(b)
Power
width
Doppler Power Spectrum
-2016 1200 400 0 400 1200 2016
Vel (m/s)
(c)
8 π
θ
-8 π
Phase ⇒ Doppler Vel.
0 2 4 6 8 10 12 14 16
Lag
(d)
5920
Power
⇒ Doppler Spec. Width
| ACF |
λ
σ
0 2 4 6 8 10 12 14 16
Lag

TMS mode does just simply record all the raw IQ samples (with time stamps and all other info)

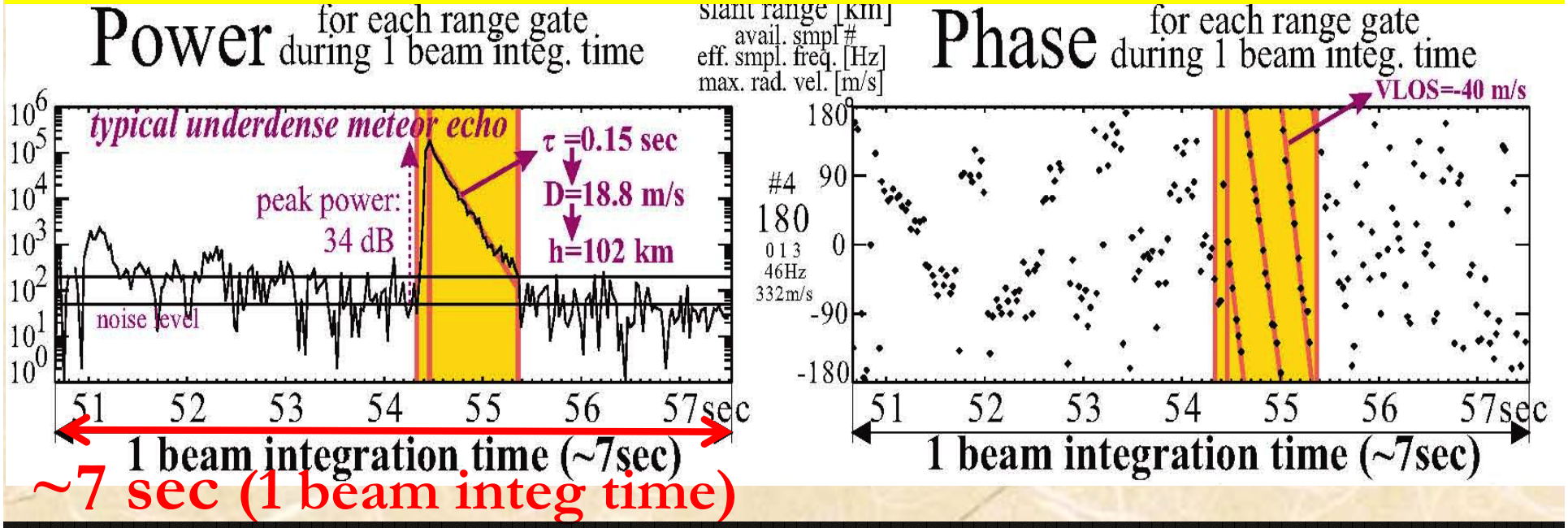


1 pulse sequence ~90msec

Reconstruct (unequally sampled) raw IQ time series for each range gate, not affected much by cross range noises by checking lag0-pwr range profile.
⇒ Very high time resolution (>10Hz, ~400Hz) time series analysis can be performed.

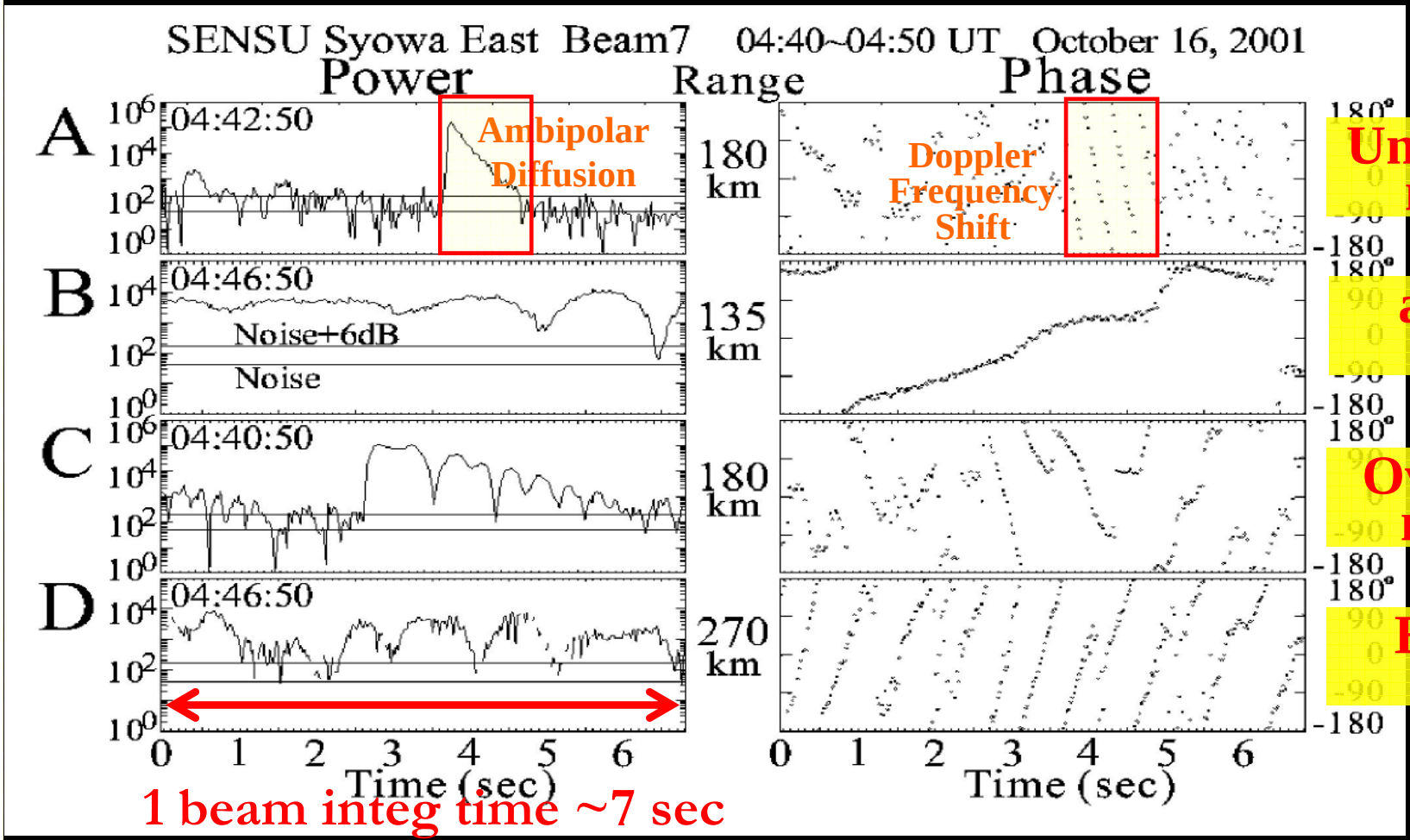


Reconstructed raw time series for a range gate (Power and Phase) during 1 beam integration time of ~7 sec



ACF(frequency domain)観測と平行して、
全IQ samplesを記録し、
cross range effectのないsamplesのみ抽出し、
時系列(time domain)解析も可能とした。
(TMS mode、Yukimatu & Tsutsumi, GRL, 2002)

Time Series



1 beam integ time ~7 sec

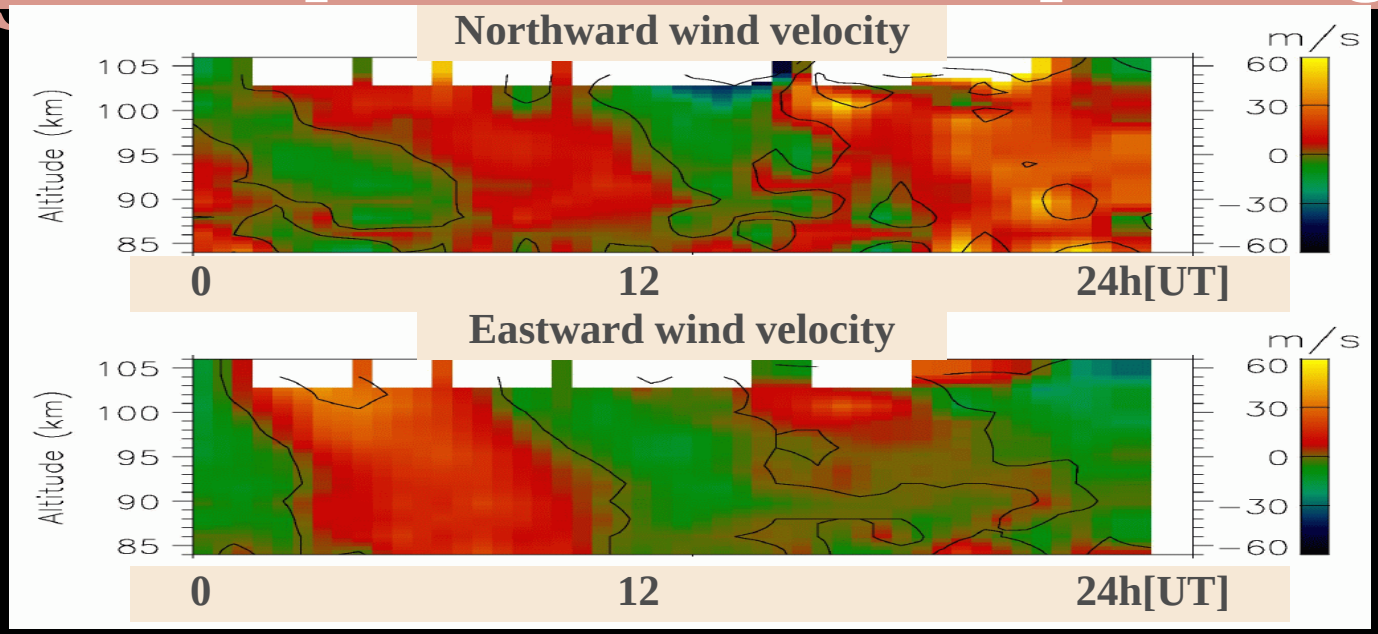
Ambipolar diffusion coefficient calculated from meteor echo power decay ratio can be used to estimate meteor height

Detect under-dense meteor echoes only

2000-6000 echoes a day

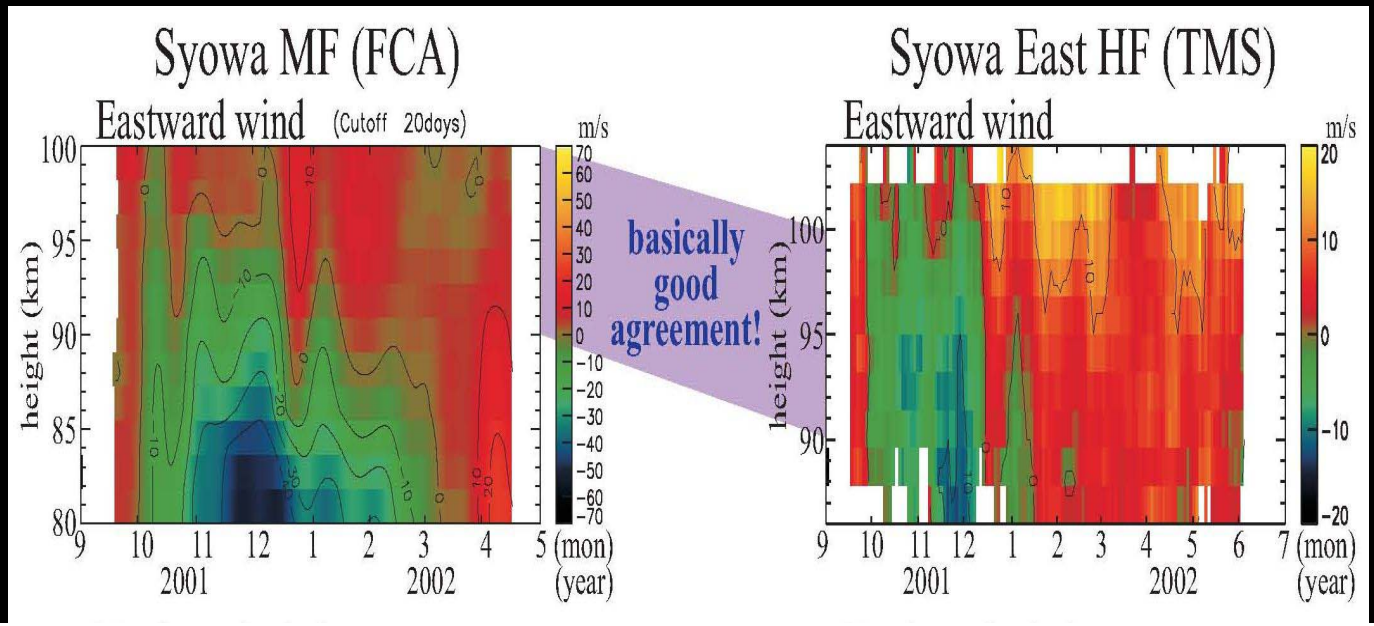
Yukimatu and Tsutsumi, GRL,2002

Daily and seasonal variation of Neutral wind altitude profile around mesopause region @ Syowa



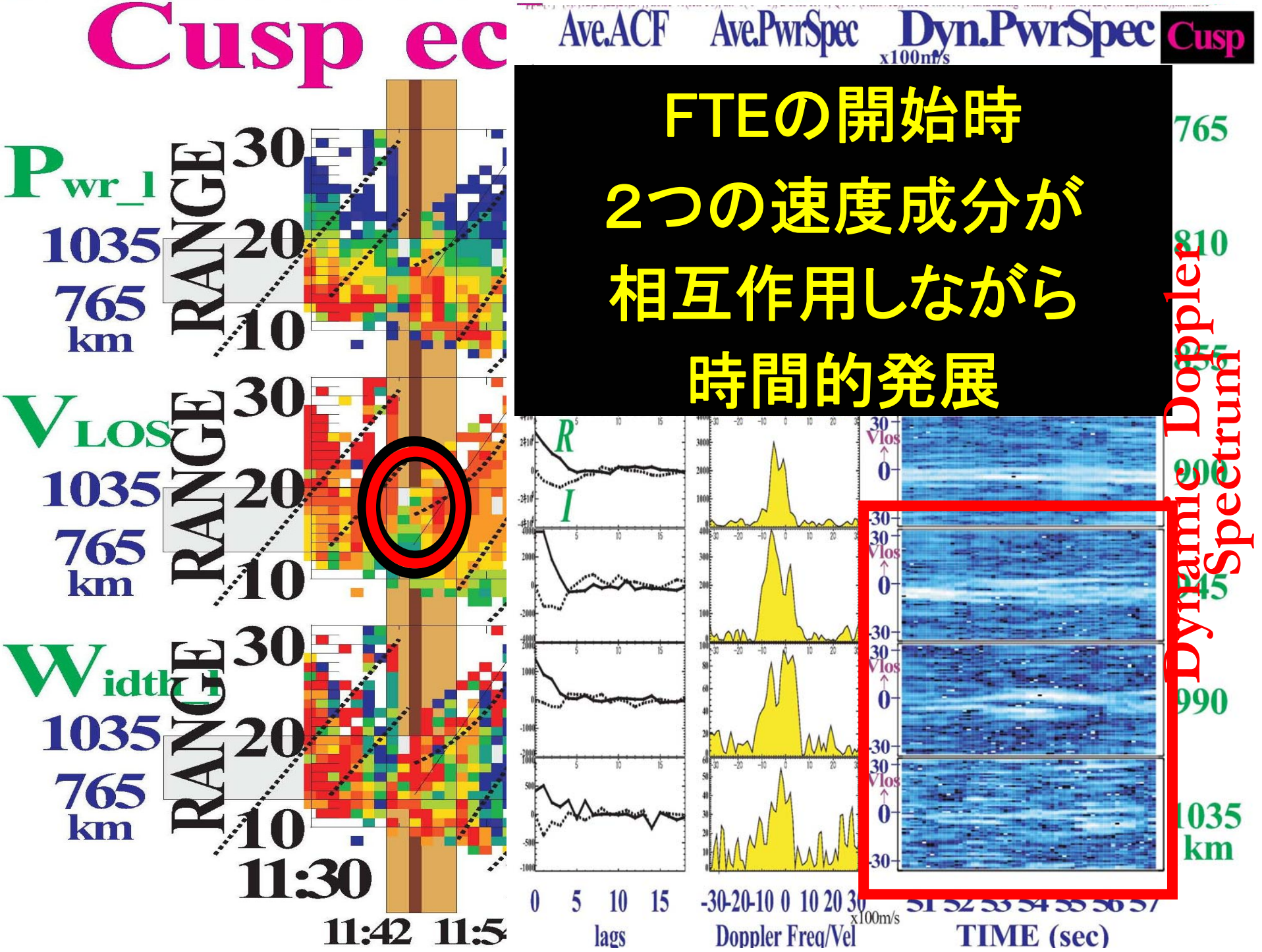
Neutral wind altitude profile firstly obtained with SuperDARN

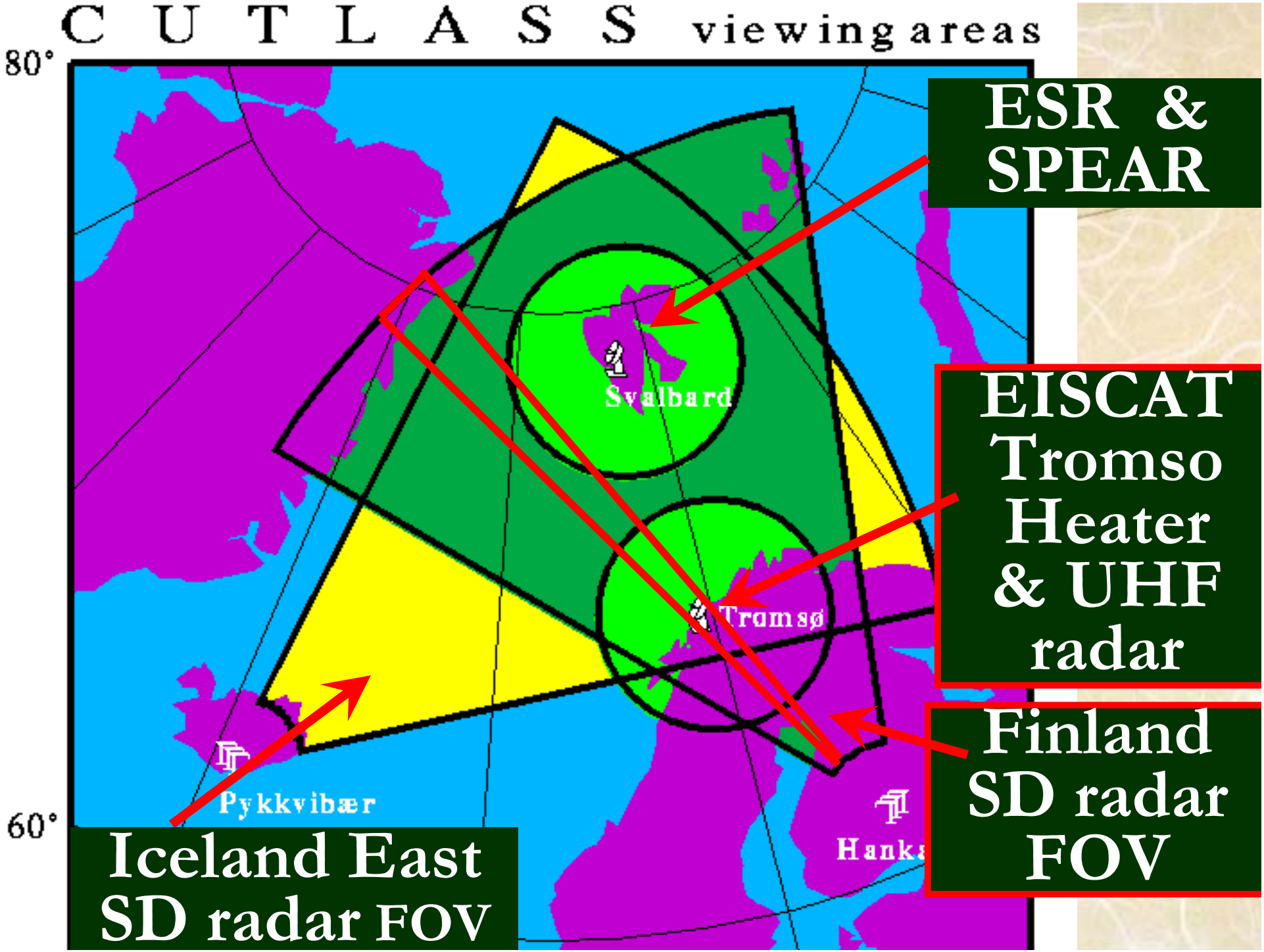
Downward phase propagating semi-diurnal tide



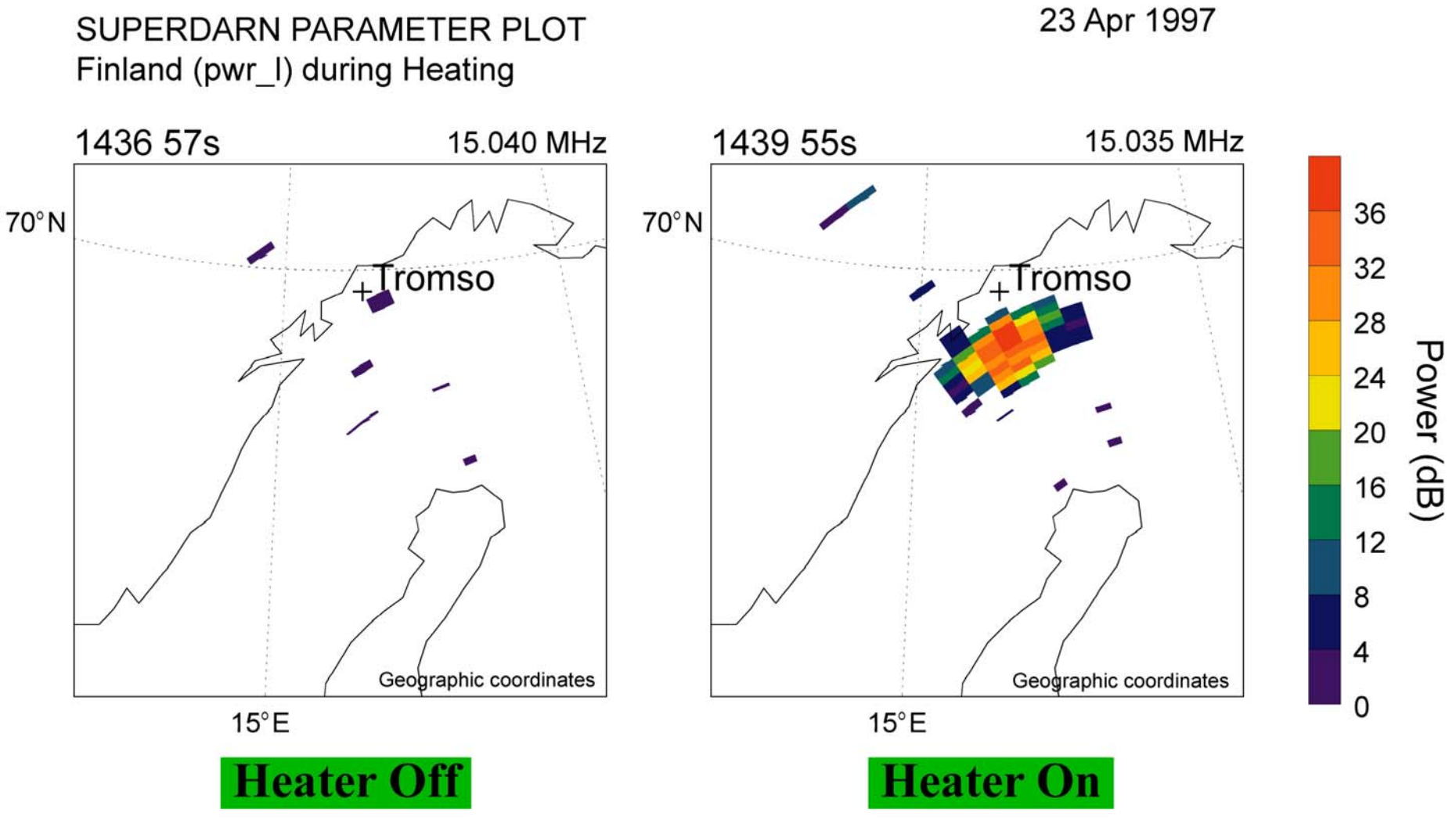
Comparison with MF radar obs.

Good Agreement

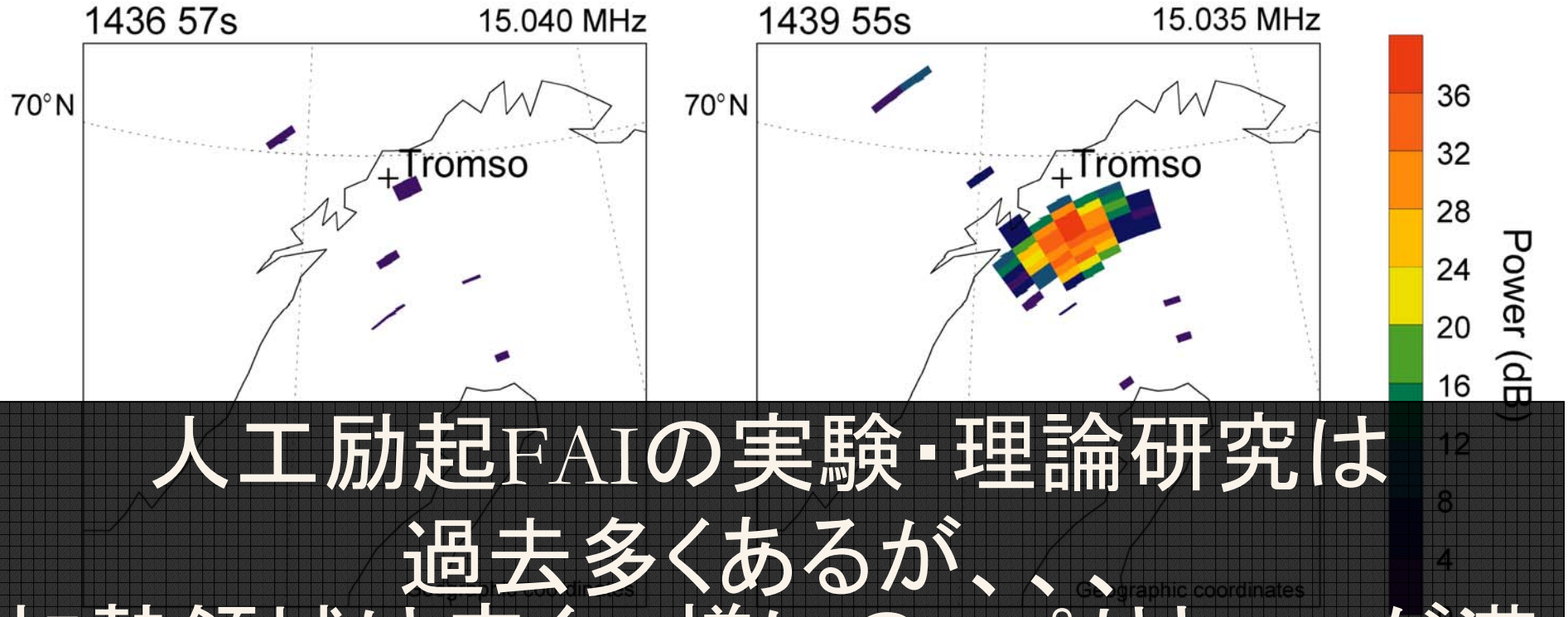

Cusp ec
Ave.ACF
Ave.PwrSpec
Dyn.PwrSpec
x100m/s
Cusp
FTEの開始時
2つの速度成分が
相互作用しながら
時間的発展
Pwr_l
VLOS
Width_l
RANGE
1035
765
km
11:30
11:42
11:5
765
810
855
900
945
990
1035
km
Dynamic Doppler Spectrum
R
I
Vlos
0 5 10 15
lags
-30-20-10 0 10 20 30
x100m/s
Doppler Freq/Vel
51 52 53 54 55 56 57
TIME (sec)


C U T L A S S viewing areas
80°
60°
Svalbard
Tromsø
Pykkvibær
ESR & SPEAR
EISCAT Tromso Heater & UHF radar
Finland SD radar FOV
Iceland East SD radar FOV

Artificially induced FAIs by EISCAT Tromso heating facility observed with CUTLASS Finland & Iceland East SuperDARN radars and EISCAT Tromso UHF radar



EISCAT data:
http://polaris.nipr.ac.jp/~yogawa/sp_ni_fai/



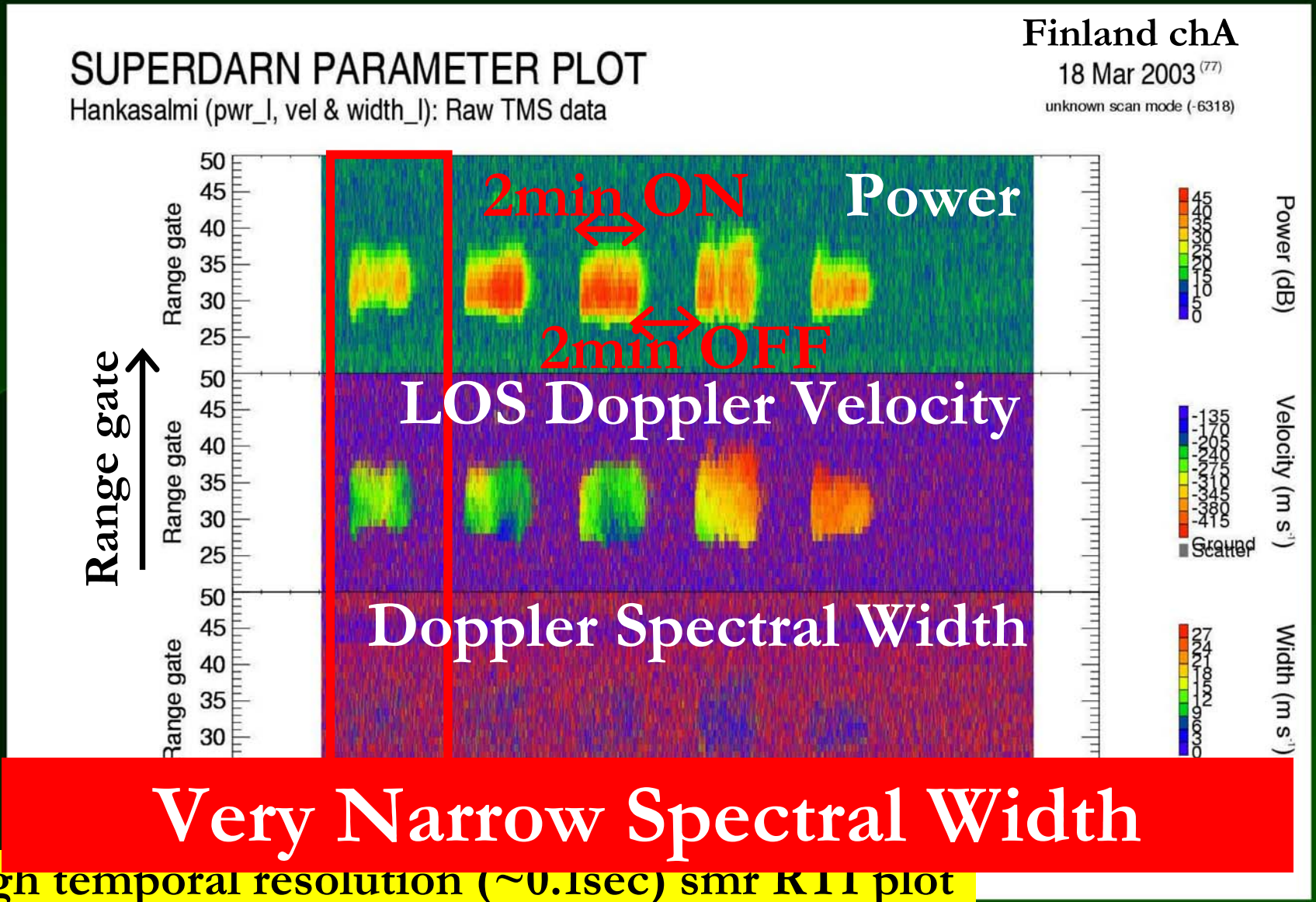
人工励起FAIの実験・理論研究は過去多くあるが、、、

- 加熱領域は広く一様にのっぺりとFAIが満たしているのか？それとも沸騰したヤカンの中のように、Soliton的なFAI(空間・時間scaleは？)が絶えず生成消滅を繰り返しているのか？或いはその混合か？

---- still unknown ⇒ model・理論への貢献

Single frequency TMS heater data analysis

(1 Tx freq during 1 intt)



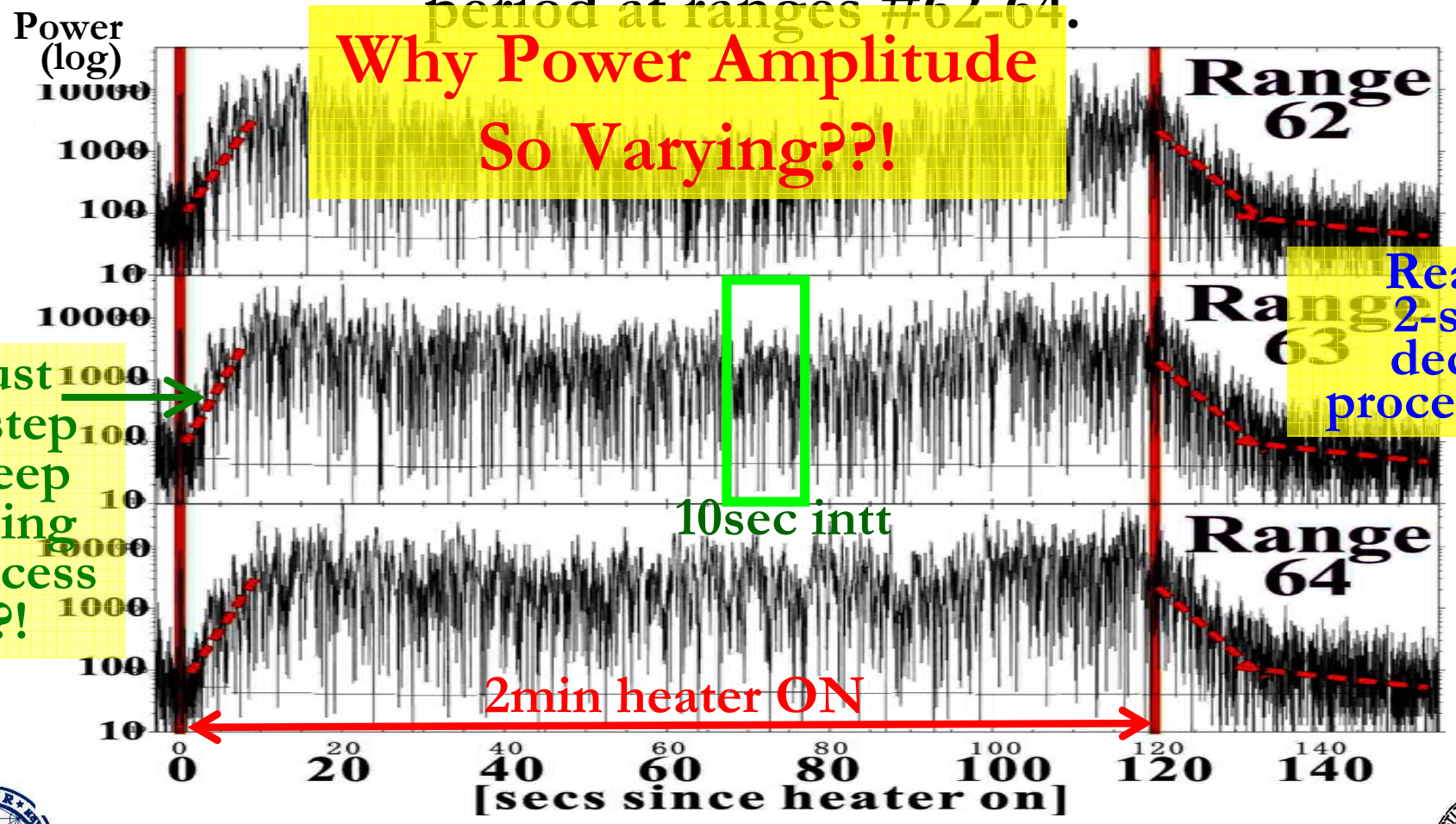
Very Narrow Spectral Width

High temporal resolution (~0.1sec) smr RTI plot by doing fitacf against ACFs constructed from each pulse sequence (~90msec) (not intt)

University of Leicester

Large Power Amplitude Temporal Variation during Heater On period

Temporal variation of high time resol. heater echo power around 2-min heater ON period at ranges #62-64.



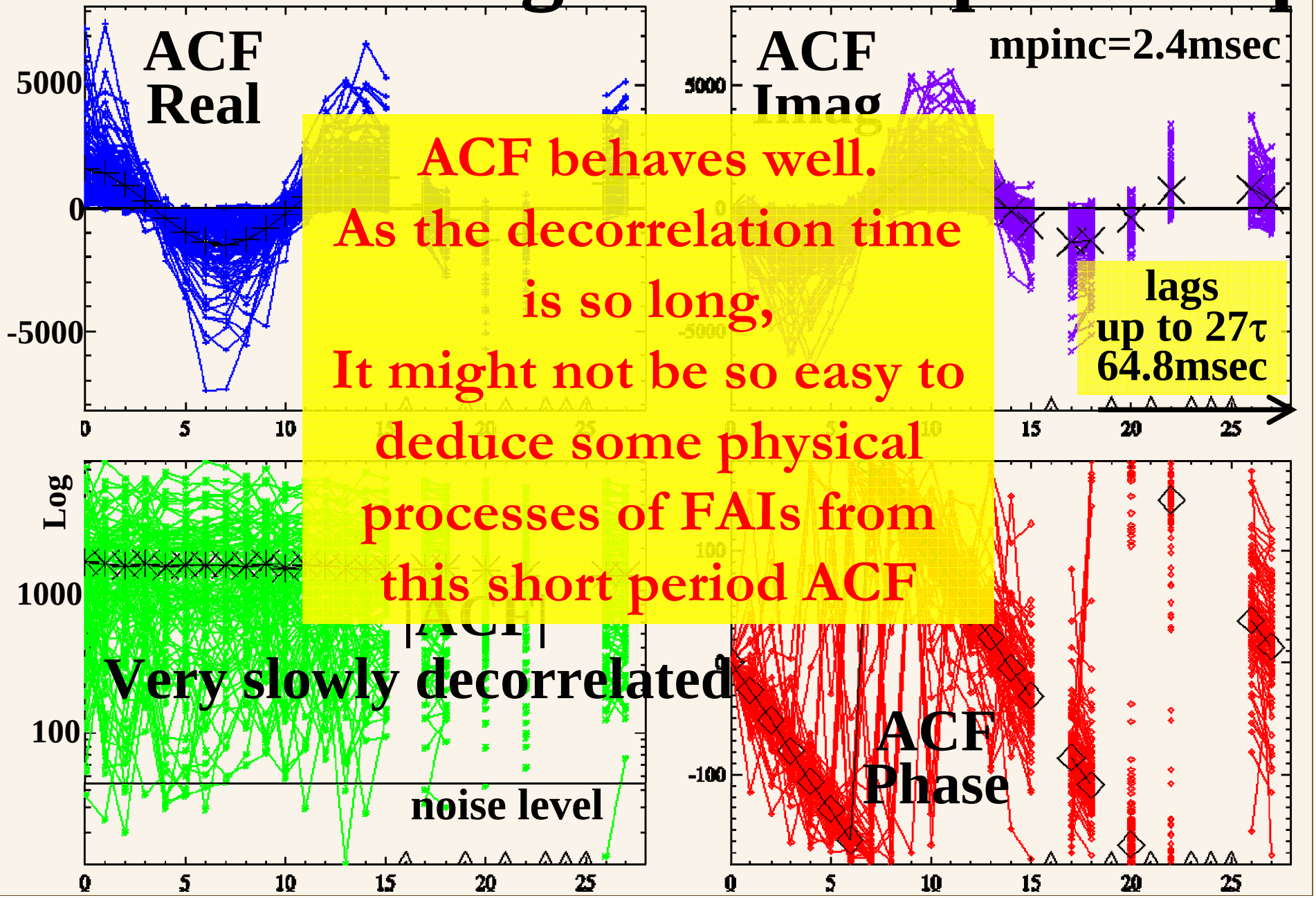
Why Power Amplitude So Varying??!

just 1-step steep rising process ?!

Really 2-step decay processes?

just fading? or reflect FAIs production/decay processes??!

Std ACF w/ lags within a pulse seq.



ACF behaves well.
As the decorrelation time is so long,
It might not be so easy to deduce some physical processes of FAIs from this short period ACF

Long duration ACF, why not?

Calculate ACF of I(t)+iQ(t)

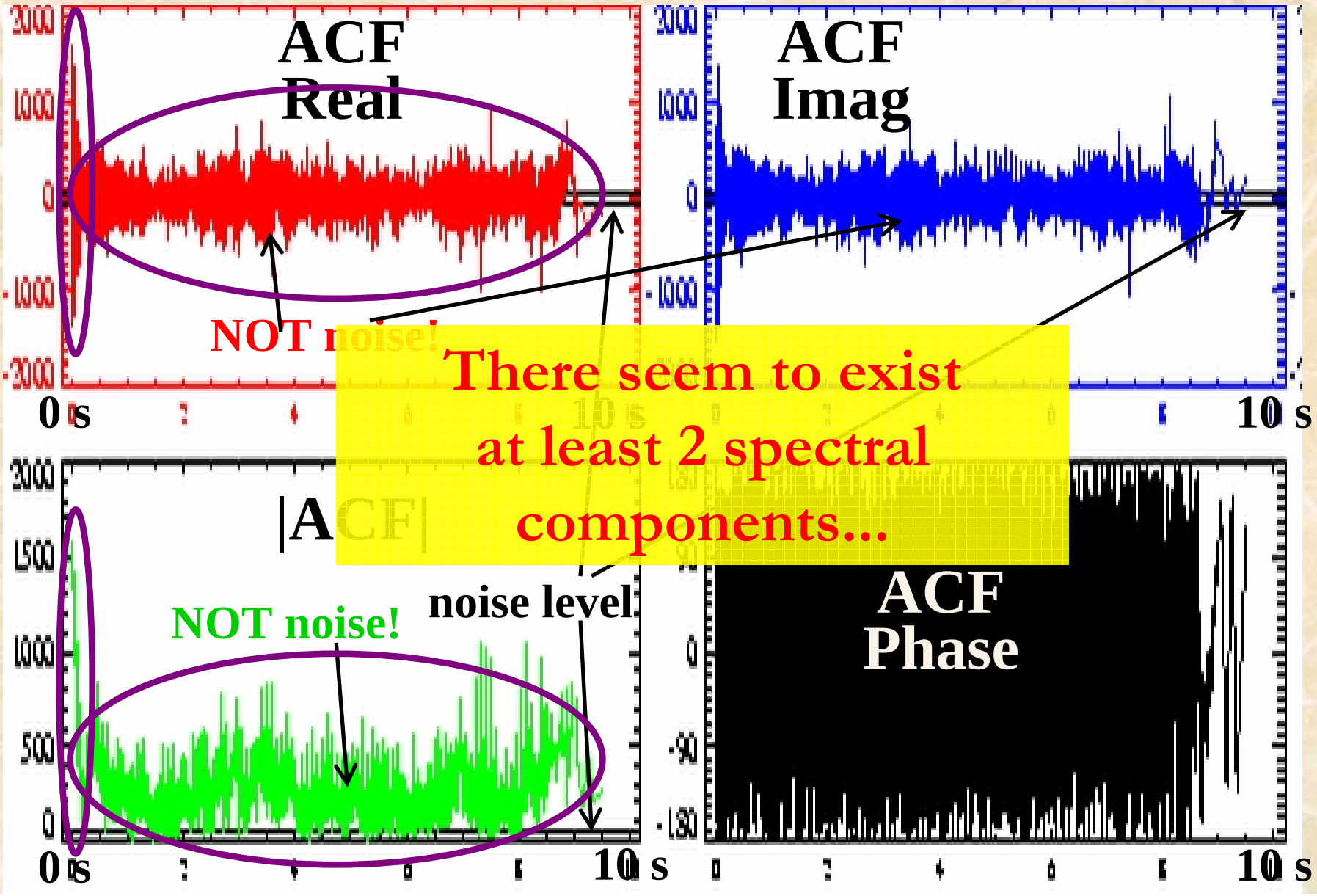
using all the available lags

during one intt period of 10 sec.

(ignore pulse sequence boundaries)

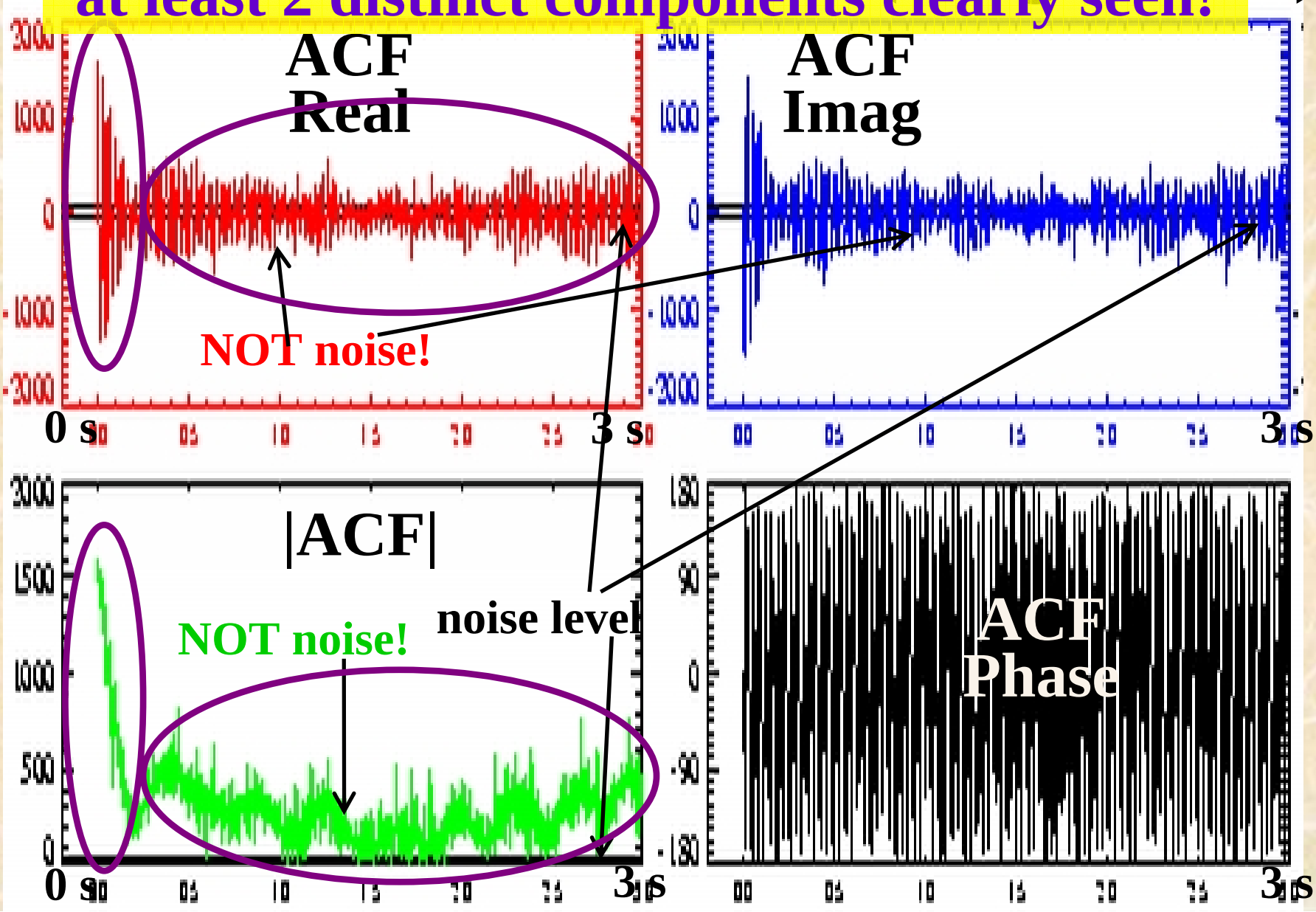
(not equally spaced lags)

LD ACF $\tau \leqq 10$ sec



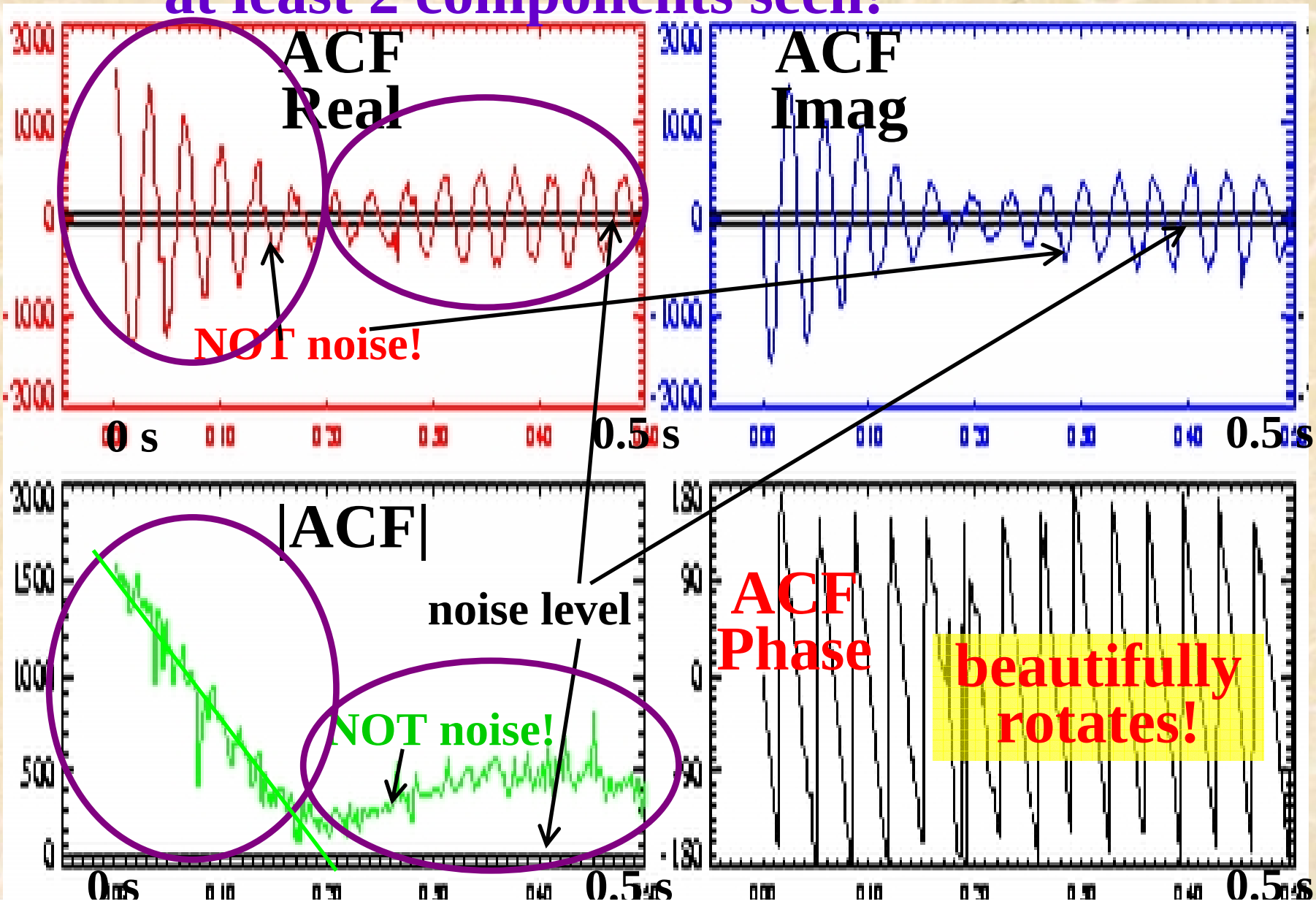
LD ACF $\tau \leq 3$ secs (magnified)

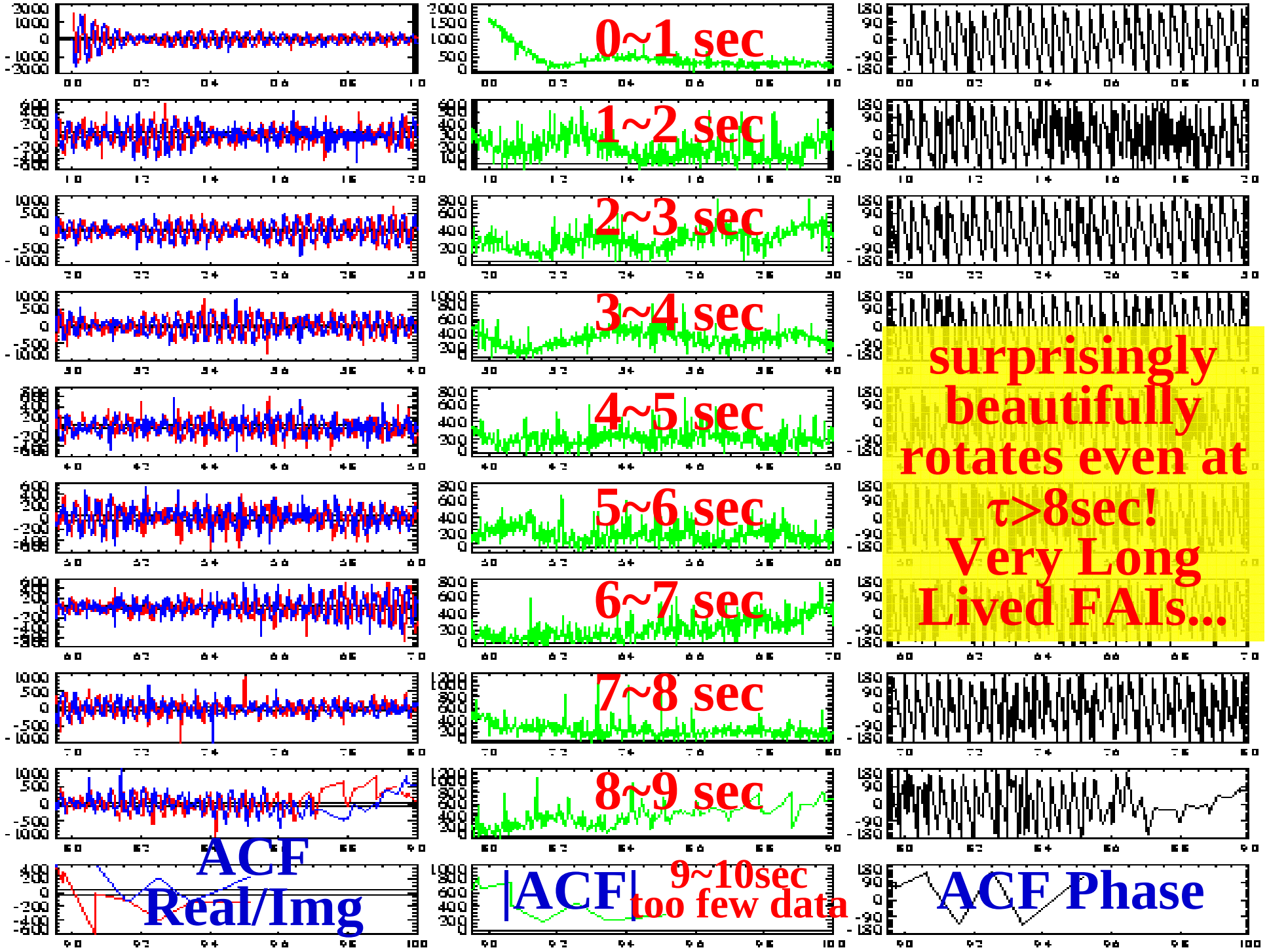
at least 2 distinct components clearly seen!



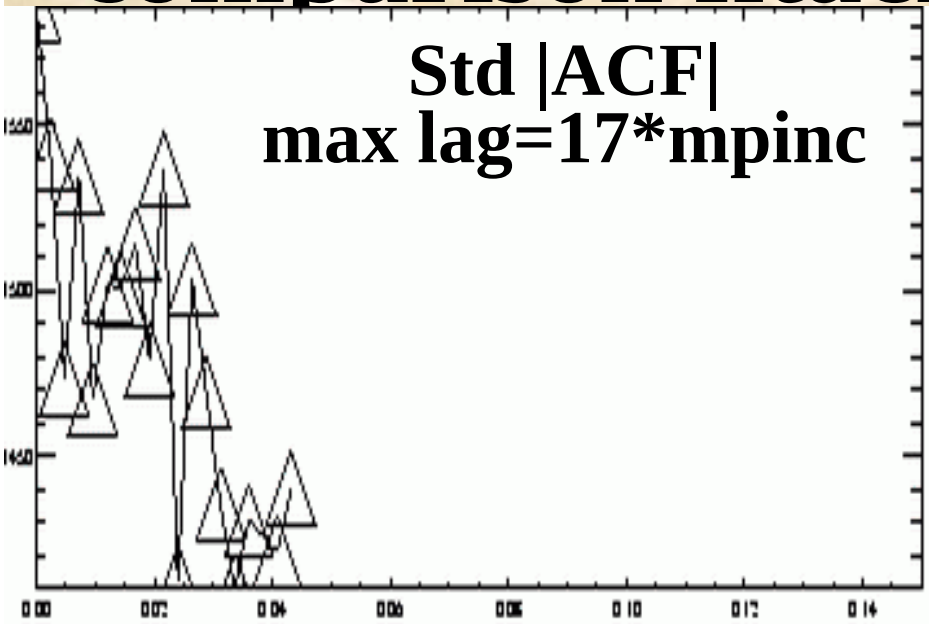
LD ACF $\tau \leqq 0.5$ sec (maginified)

at least 2 components seen!

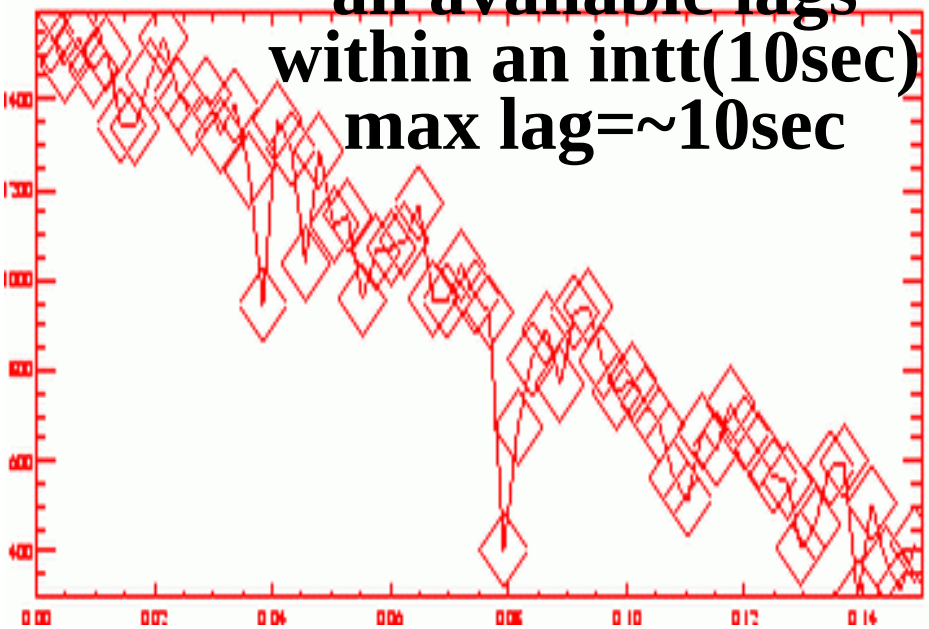


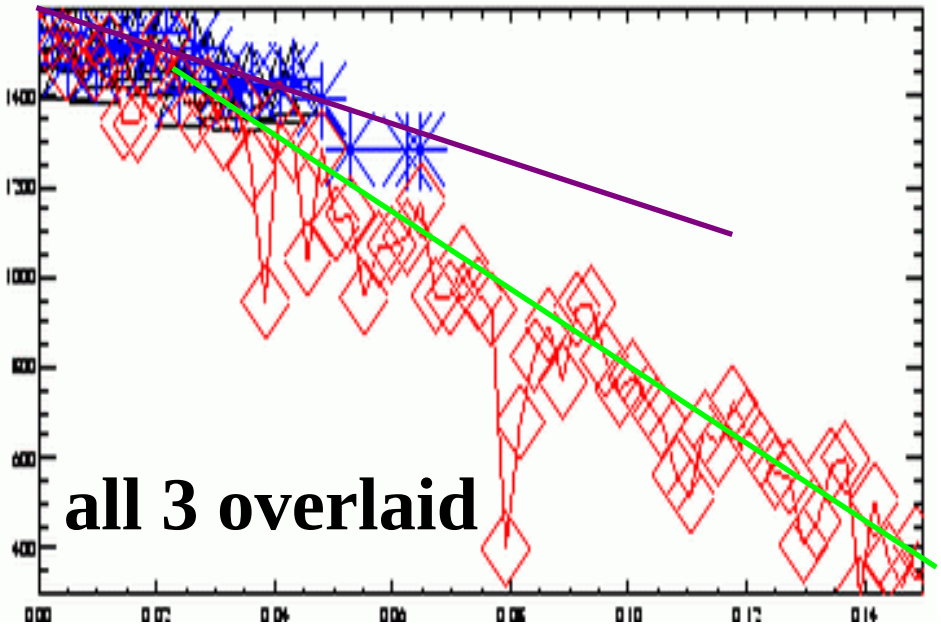

0~1 sec
1~2 sec
2~3 sec
3~4 sec
4~5 sec
5~6 sec
6~7 sec
7~8 sec
8~9 sec
9~10sec
too few data
surprisingly beautifully rotates even at τ>8sec! Very Long Lived FAIs...
ACF Real/Img
|ACF|
ACF Phase

comparison fitacf ACF & new ACF

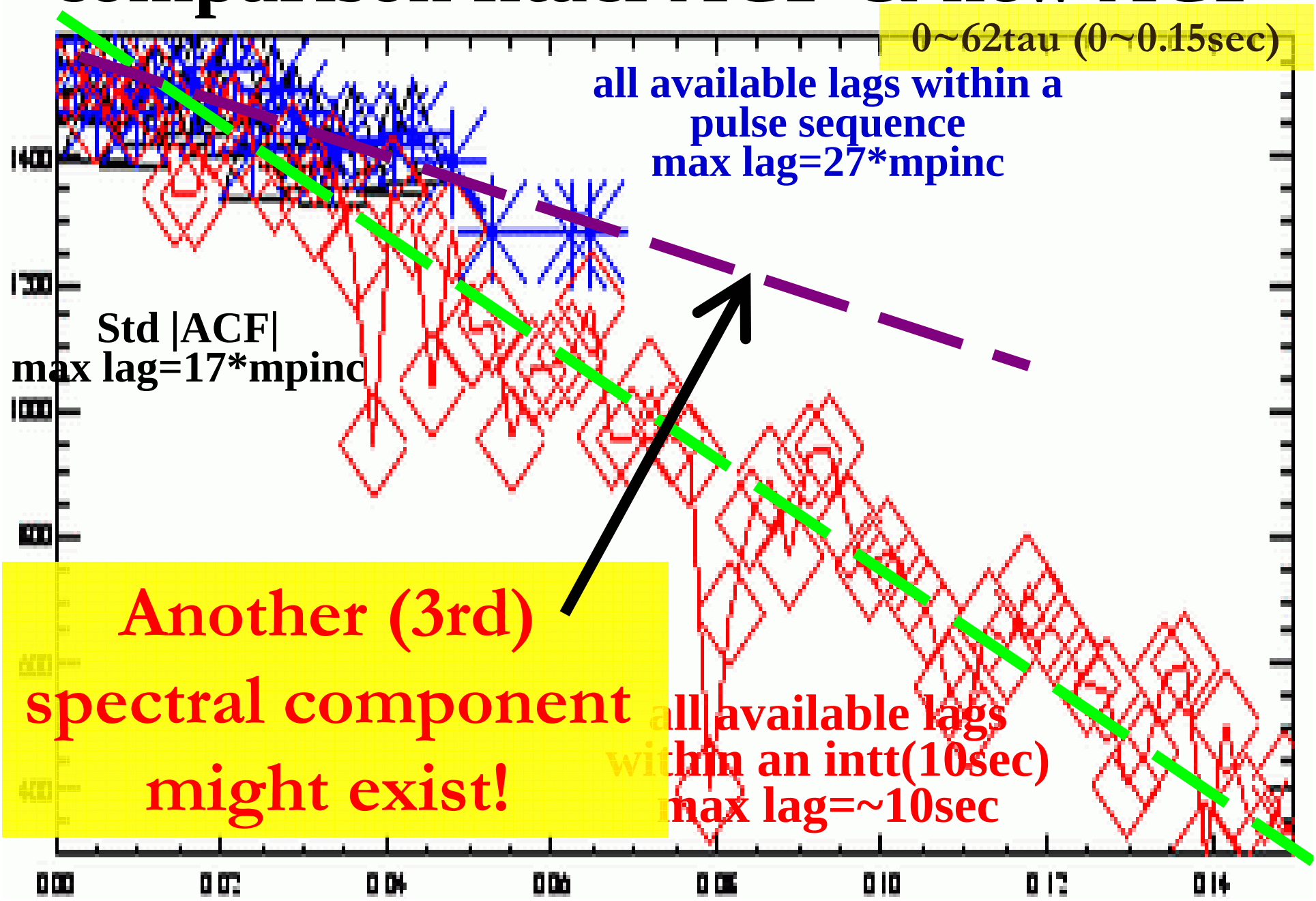


0~62tau (0~0.15sec)

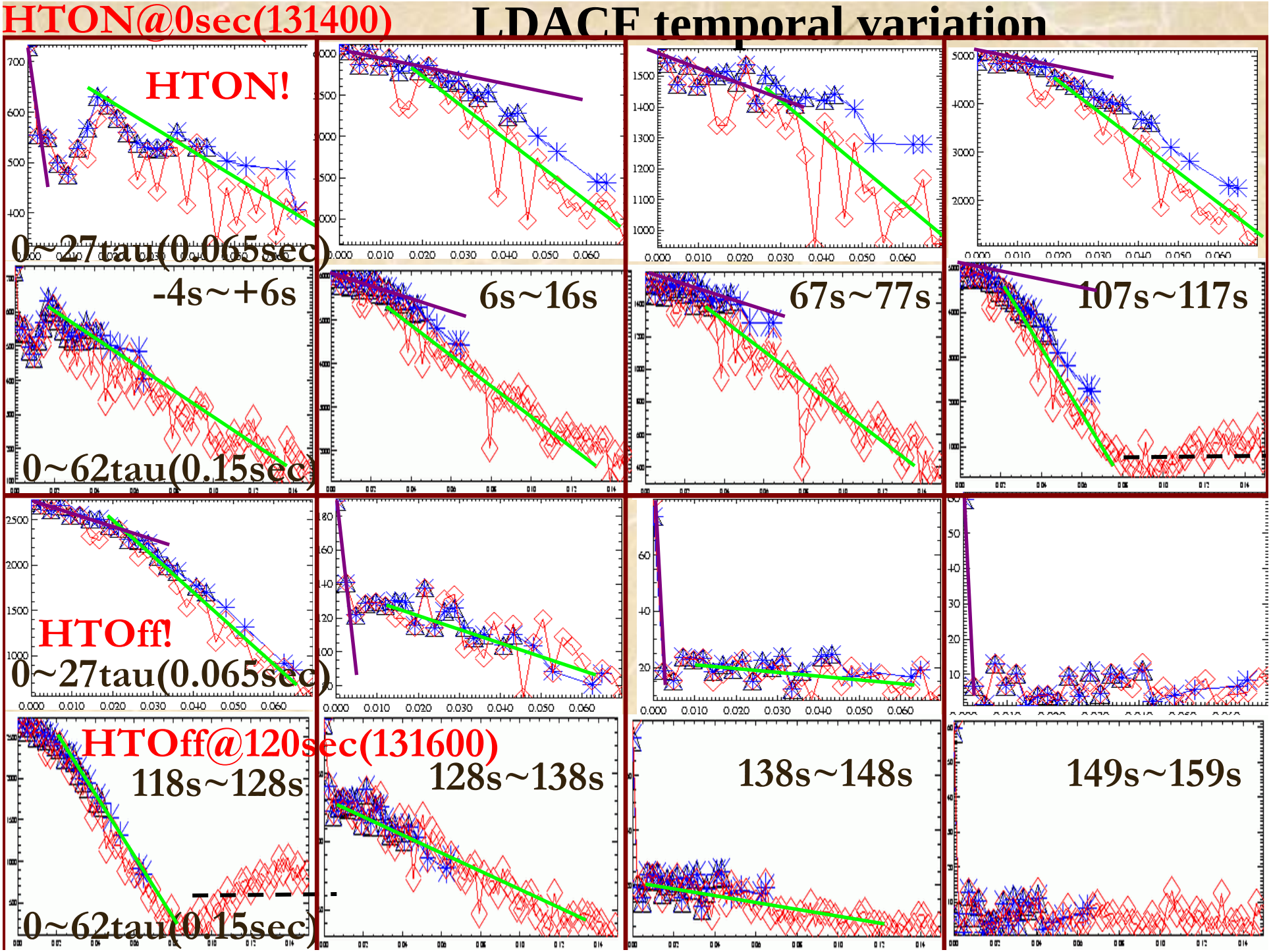




comparison fitacf ACF & new ACF



LDACF temporal variation



Long duration Doppler Power Spectrum (using all the 10 sec data, much finer freq resol), why not?

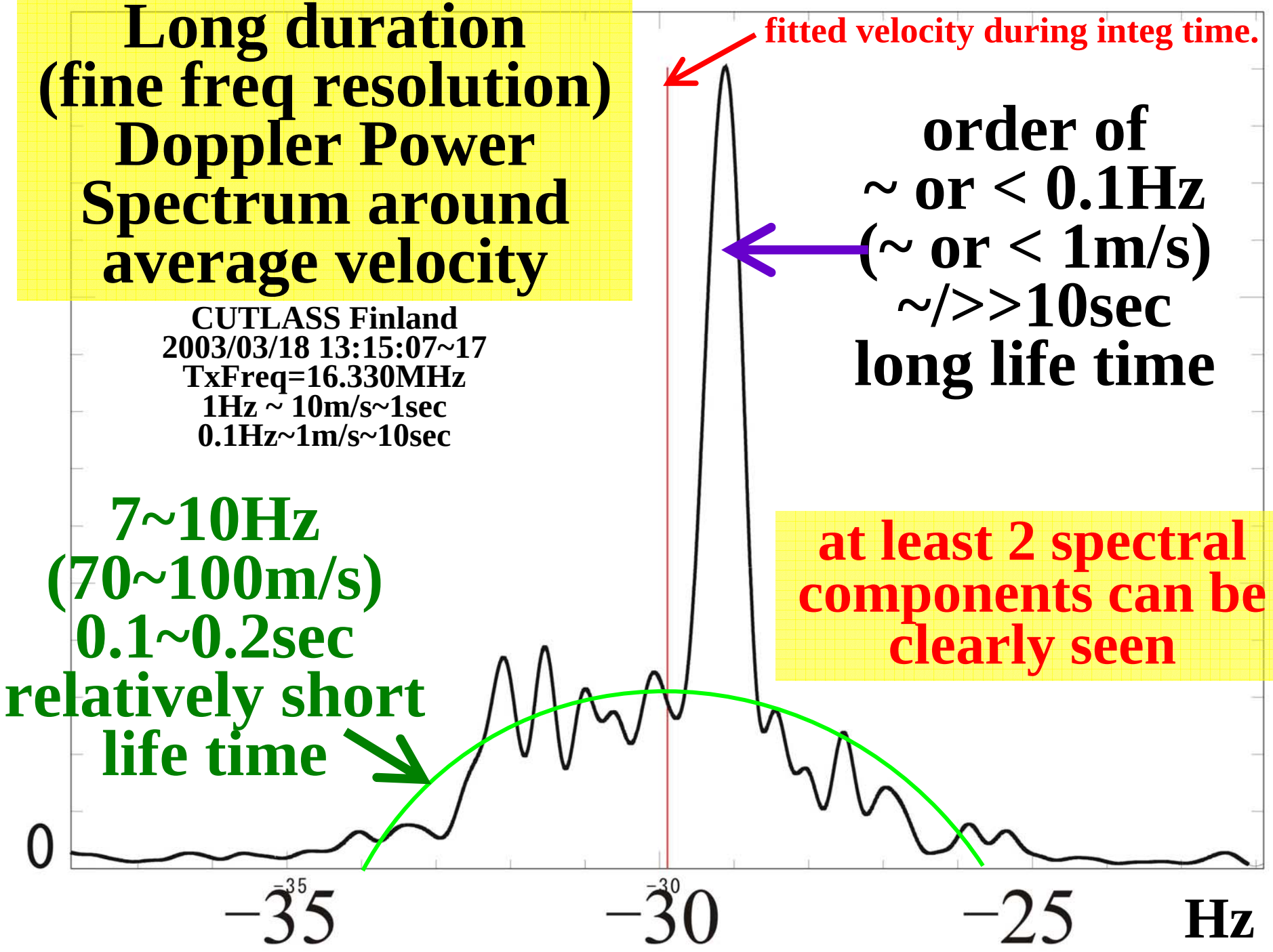
To obtain Power Spectrum with Unequally spaced time series, just do the simple & primitive way..

$$Z(t_k)=I(t_k)+iQ(t_k)$$

$$S(\omega)=\sum_{all\ k} Z(t_k)*\exp(-i\omega t_k)$$

$$PS(\omega)=|S(\omega)|^2$$

Long duration (fine freq resolution) Doppler Power Spectrum around average velocity



Phase leap check

$\phi(t_k) = \mathrm{atan}(Q(t_k) / I(t_k)) + 2n\pi$ (& n=0 for k=0)

where n decided so that $|(\phi(t_{k+1}) - \phi(t_k)) - \omega_d * (t_{k+1} - t_k))| \leqq \pi$

※ambiguity of determining n not happens when ωd is small enough

$\phi'_k = \phi(t_k) - \omega_d * t_k$: subtract trend of average phase velocity

so that phase deviation around average phase rotation can be easily seen

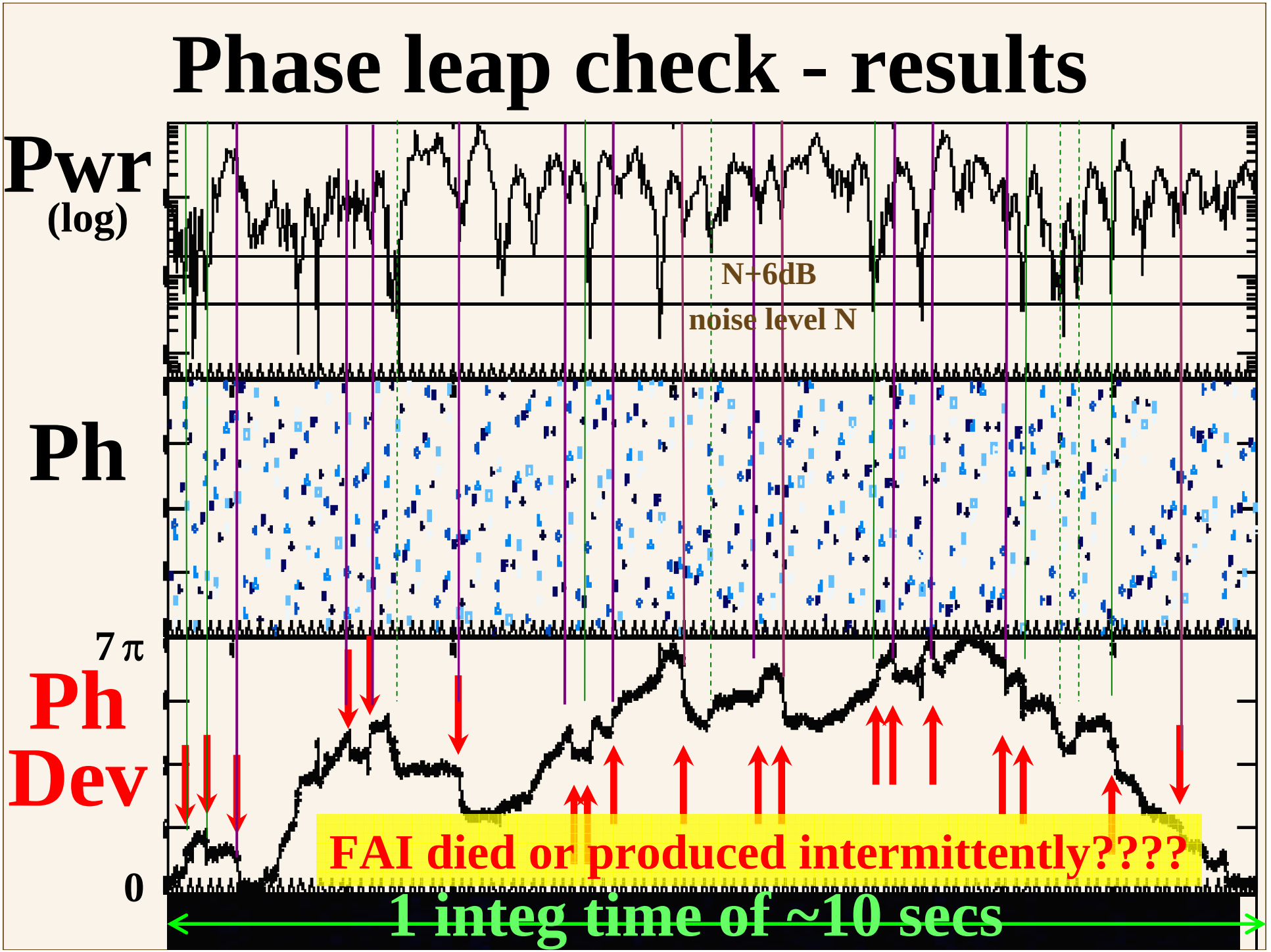
where ω_d : average Doppler angular speed fitted during intt

★Check if ϕ' continuously changes or jumps (leaps) sometimes

If ϕ' changes only continuously, it's just due to change of target LOS velocity or due to fading effect (ray path changing) etc.

If ϕ' sometimes leaps, it might be possibly due to existence of multiple (but not too many) number of FAIs within a range cell & their (intermittent) production and decay processes, whose Doppler shift is very close to the other FAIs but the initial phase is randomly different.

Phase leap check - results



Summary from single freq obs.

1． Heater echoes show large power amplitude temporal variation (~Hz, ~20dB)

2． Both long duration ACF and Doppler Power Spectrum of I,Q show at least 3 distinct spectral components with order of decorrelation time of short 0.1-0.2 sec and long ~/> 10 sec.

3． LD ACF Temporal variation shows different behavior (time scale) of each spectral components.

※ Std fitacf may fit only one of the spectral components due to too short max lag.

4． "Phase leap check" analysis shows phase leaps of FAI ehoces often happen with time order of < 1sec .

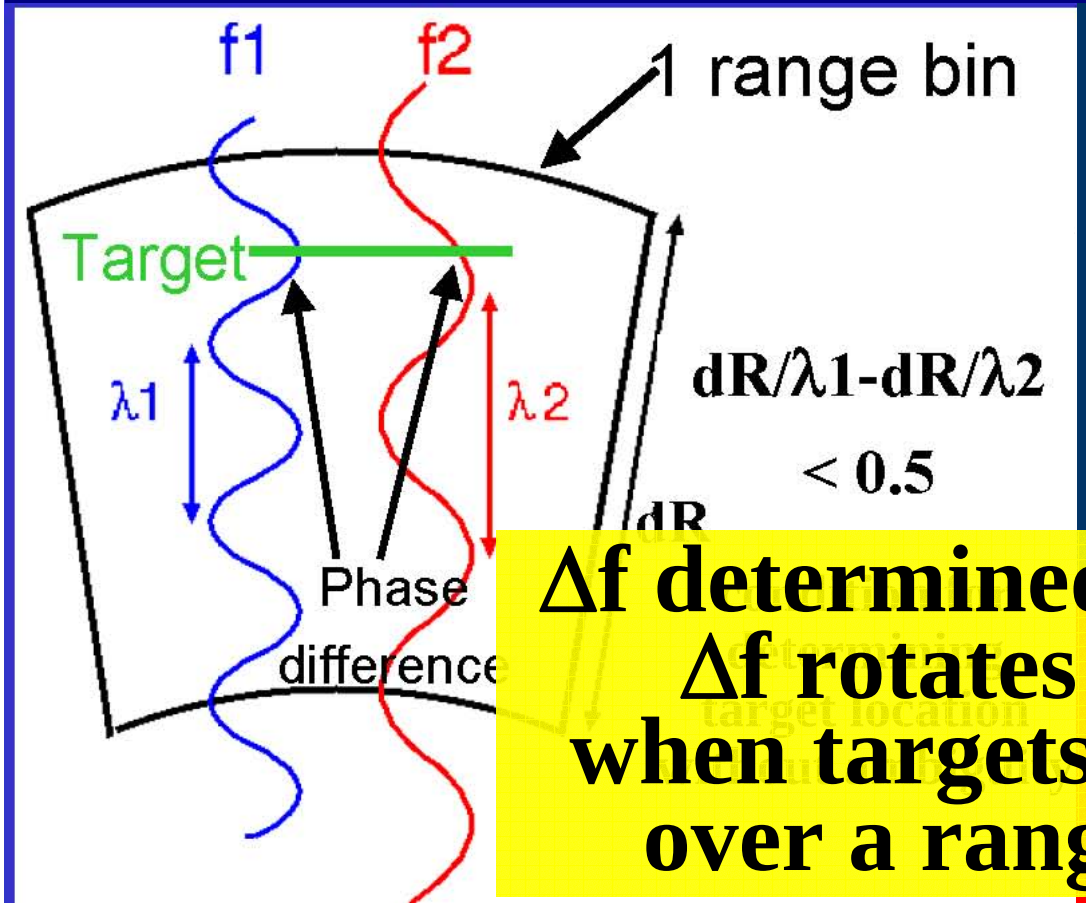
※ Before/after heater on period, such leaps mostly disappeared.

⇒All these above possibly or strongly suggest that repeated production & decay processes of limited number of FAIs within a range cell, possibly partly also with fading effect?

To confirm whether the prev speculation is right, move on to Multi-frequency FDI TMS data analysis

(Dual freq) FDI
(Frequency Domain Interferometer)

Use **2 closely adjacent freqs** (**Δ f~kHz**)
Infer **fine range location within a range cell**
using **phase differences** by **dual freq observation**



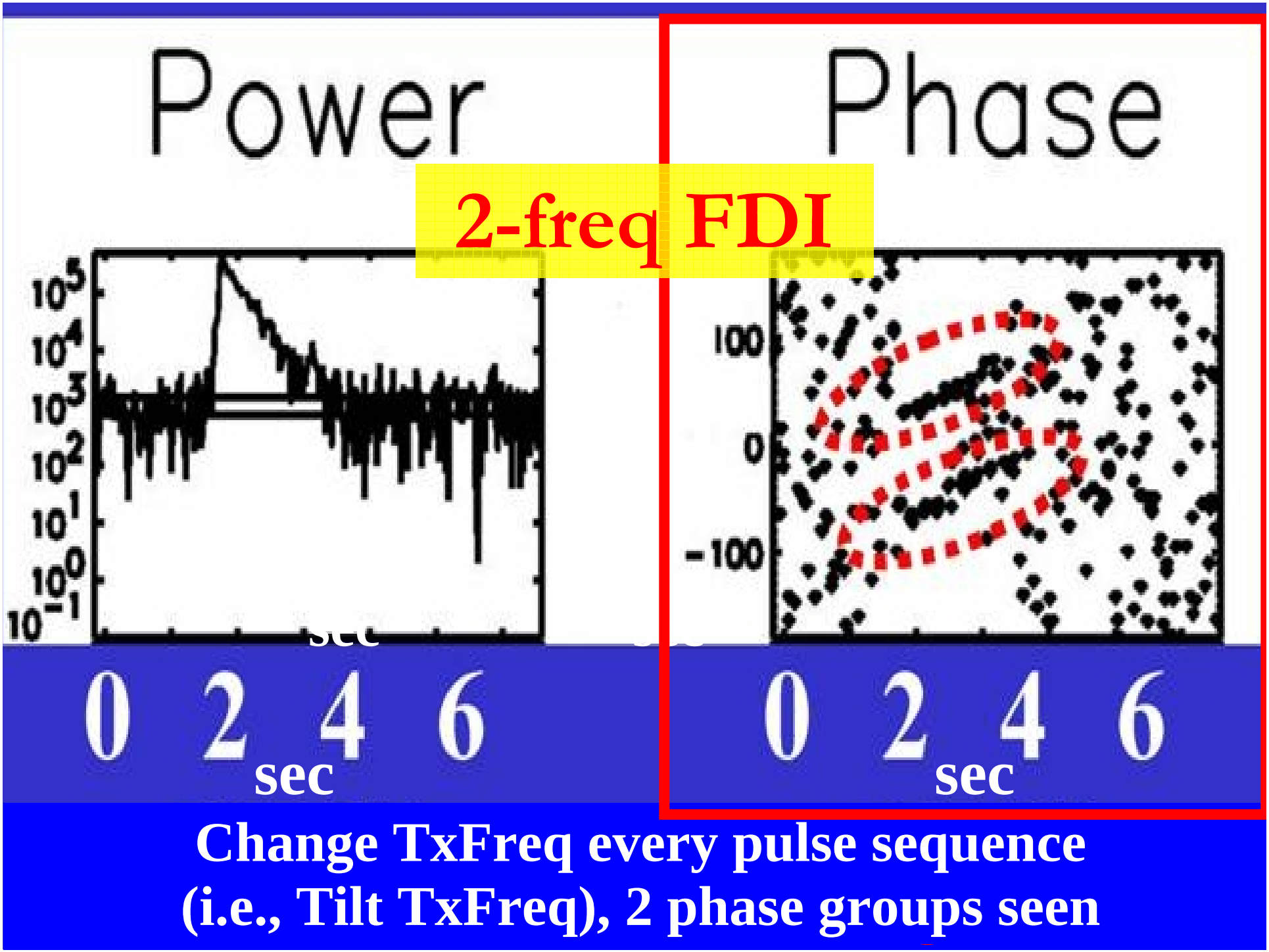
freq difference

|Δ f | < dR/c

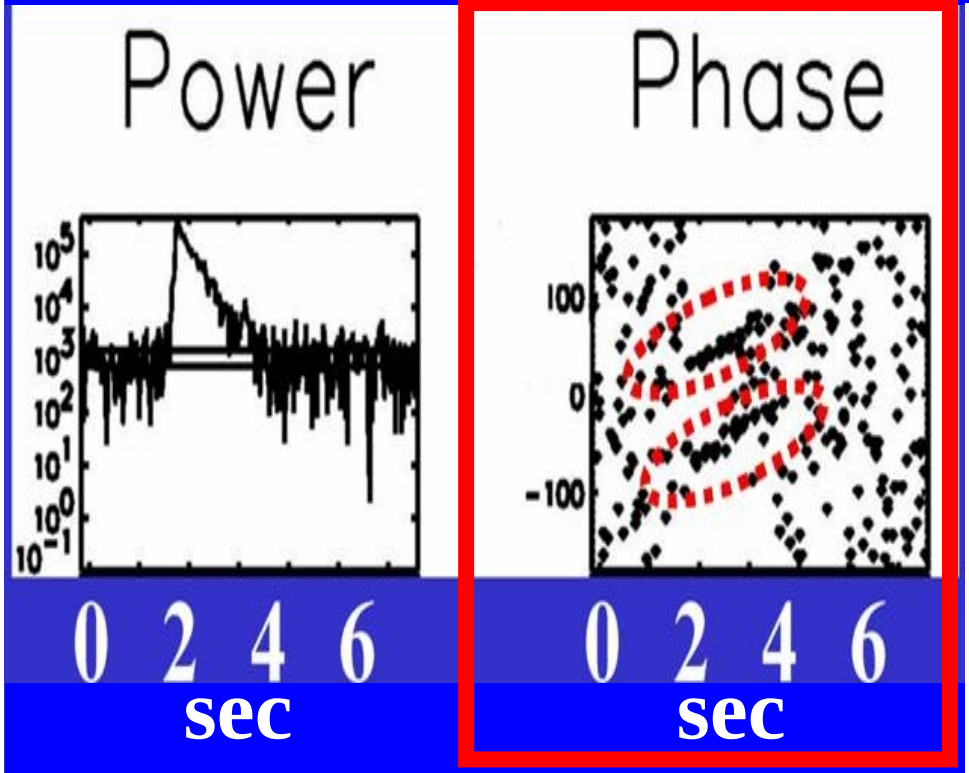
|Δ f | < 3.33 kHz (rsep 45km)
|Δ f | < 5.0 kHz (rsep 30km)
|Δ f | < 10 kHz (rsep 15km)

Δf determined so that
Δf rotates < 2π
when targets moved
over a range cell

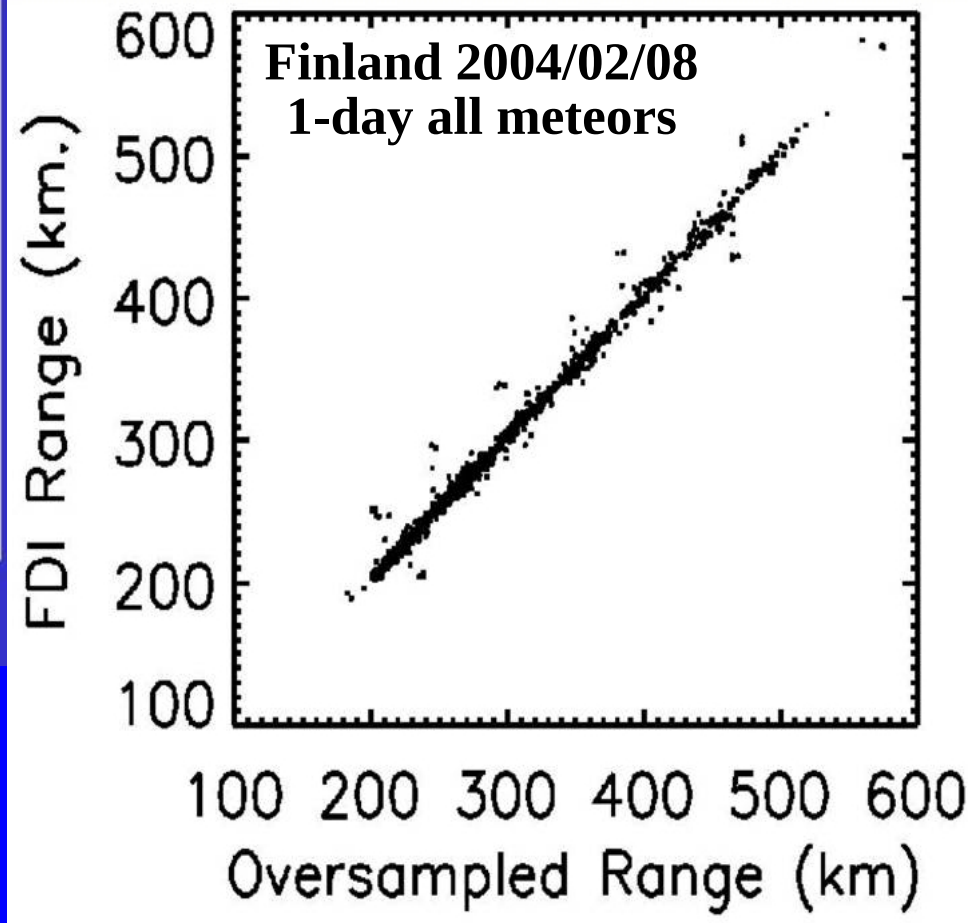
N frequencies
resolve
(N-1) targets


Power
Phase
2-freq FDI
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
100
0
-100
0 2 4 6
sec
0 2 4 6
sec
Change TxFreq every pulse sequence
(i.e., Tilt TxFreq), 2 phase groups seen

High Range Res. Meteor Obs. by Dual Freq FDI (Tutumi et al SD WS 2004)

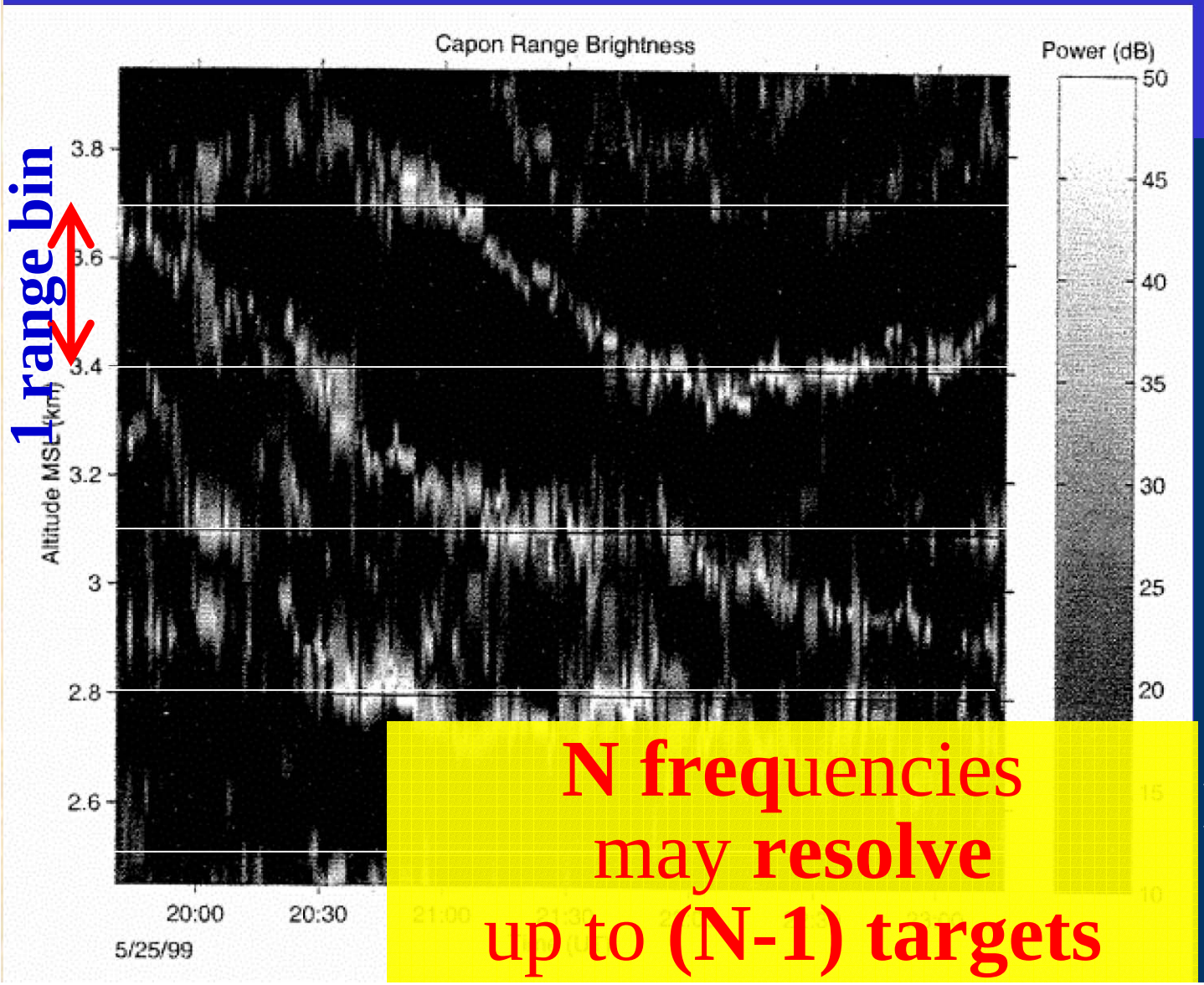


Change TxFreq
every pulse sequence
(i.e., Tilt TxFreq),
2 phase groups seen



FDI vs Over-Sampling
Nice Agreement!

An Example of Multi-freq FDI obs. in case of ST radar stratosphere obs



Palmer et al.,
Radio Sci, 2001.

4-freq FDI echo Power by ST radar.

original rsep=300m

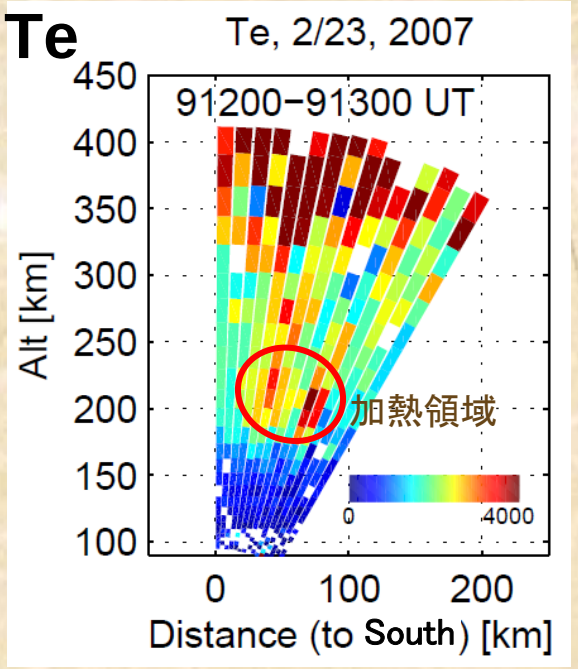
FDI resolved much thinner turbalence layer structures within range cells

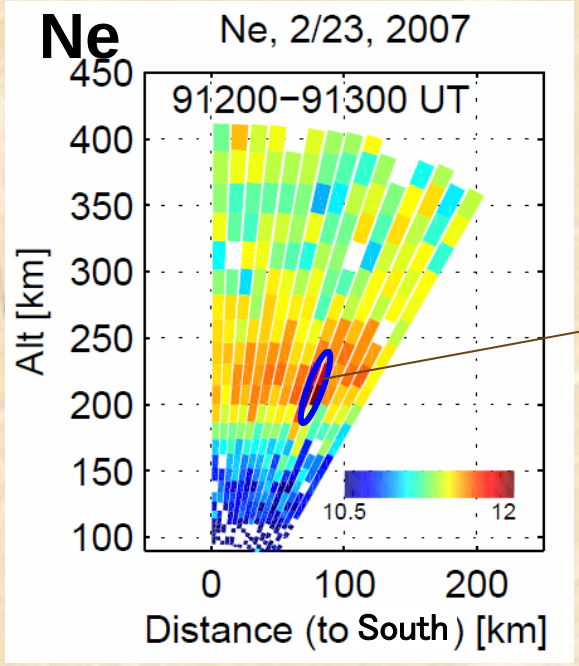
N frequencies may resolve up to (N-1) targets

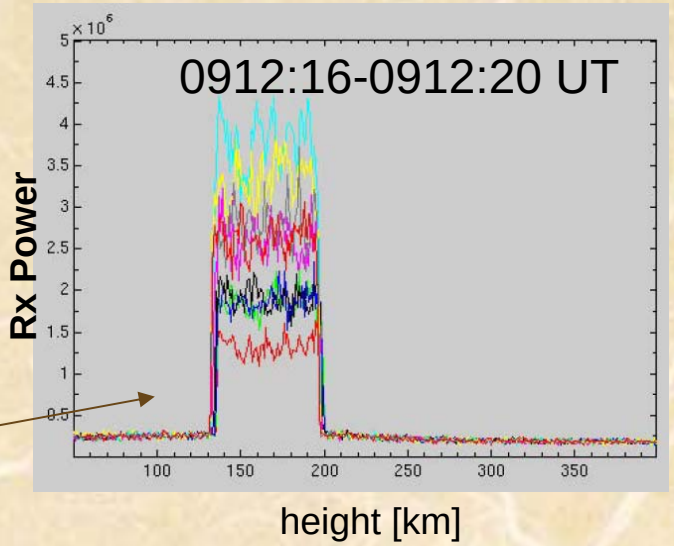
SuperDARN Range imaging by Multi-Freq FDI ~ Initial Results

- Artificially induced FAIs by EISCAT Tromso heater facility observed with CUTLASS Finland SD radar and Tromso EISCAT UHF radar (arc1 + beam swing)
- Multi-freq FDI mode developed to add to TMS code
- Tested around local noon on Feb 16, 23, 26 & 27, 2007
- TMS mode: rsep=15 km, intt=10 sec, & freq change every pulse sequence of ~0.1 sec
- 3～10 freqs with min Δf_{ij}=1kHz (corresponding to 150km) to check whether FDI works properly, though min Δfij=9kHz is the best configuration for the rsep.
- an example of 5 freqs FDI data is shown here.

EISCAT data example



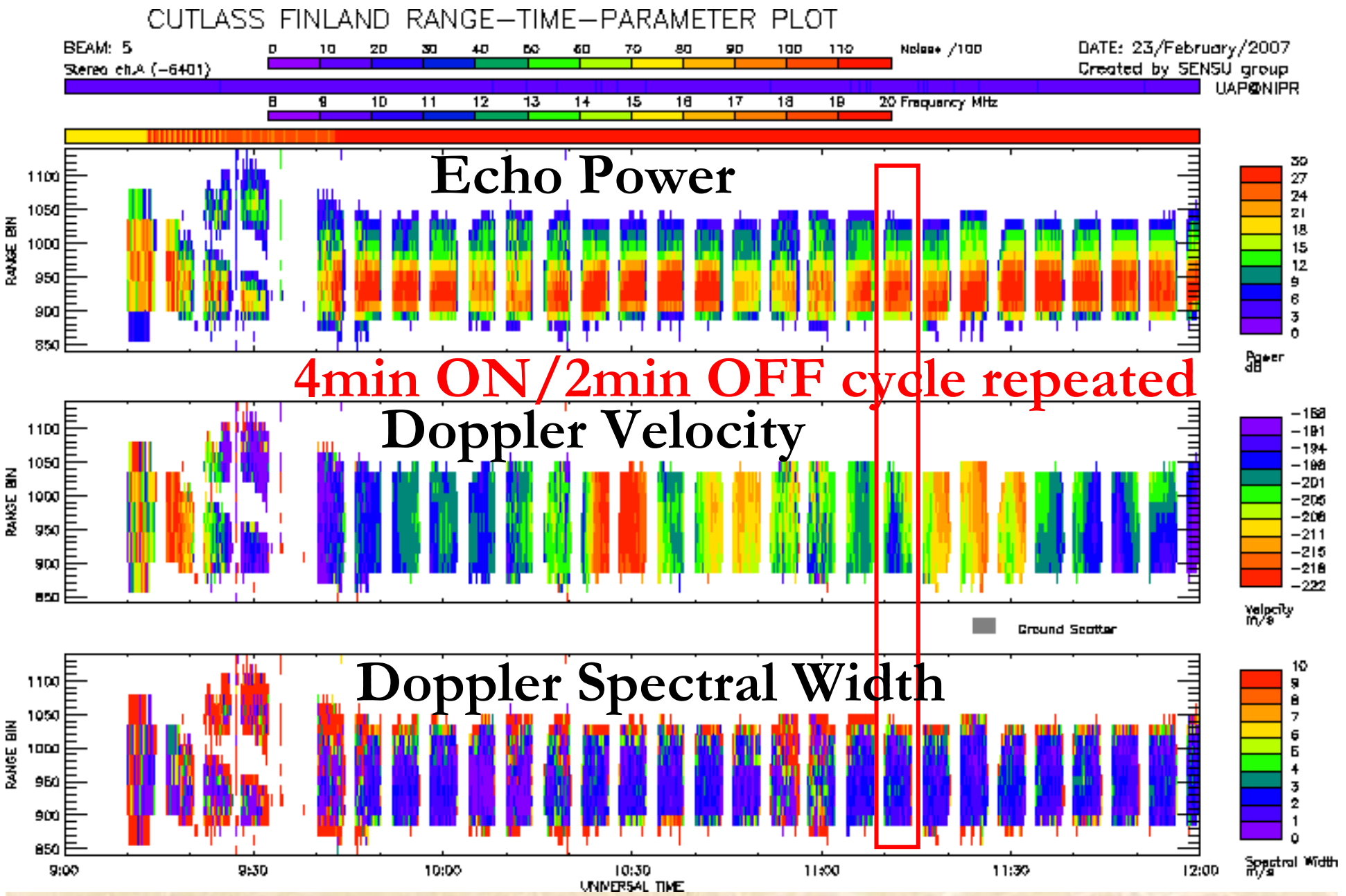




Te 2007/02/23
09:12-09:13 UT
(1 beam scan / min)
Electron heated area clearly seen at 200km divided into 2 parts..

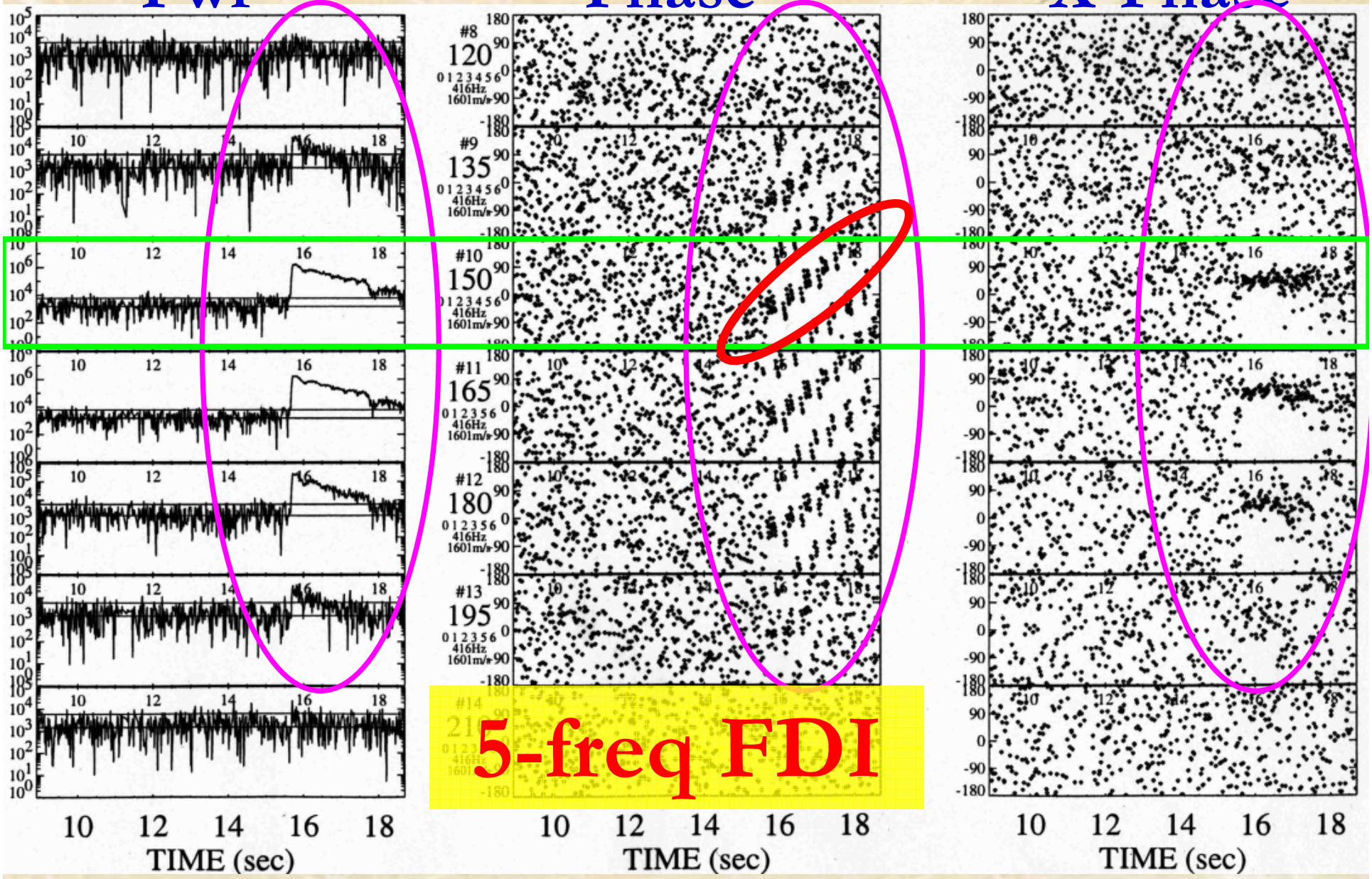
Ne at the same time. Plasma turbelence happens near lower lat heated area

0.4sec resolution temporal variation of Rx power range profile. Ion acoustic wave disturbance around 150km largely varying with time

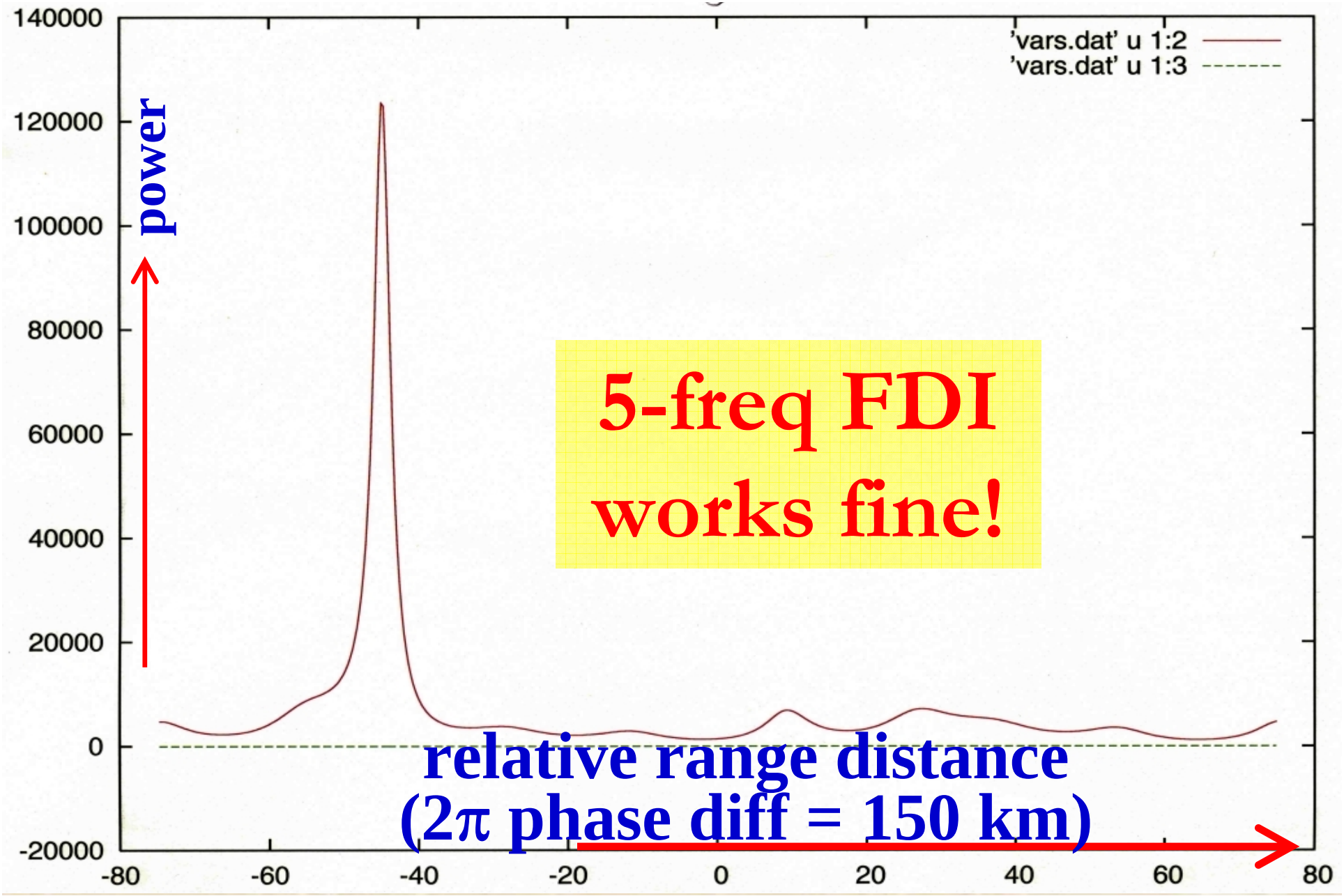


Finland chA 2007/02/23 0900～1200

multi-freq FDI test with meteors



multi-freq FDI test with meteors



Initial phase determination for FDI

1. Determine initial phases for each frequency so that the absolute location of a single meteor echo is determined.

2. Use this initial phases for imaging FAIs at heater echo region (900~1000km)!

3. But This attempt FAILED Unfortunately!!!

4. Due to different ray paths for different Tx freqs (and possibly with fading effect?) for far ranges? (λ order diff. could cause fatal problem!!)
Or Any other possible reasons????

⇒ Meteor cannot be used for initial phase fix!!!

Initial phase determination for FDI

Meteor cannot be used for initial phase fix!!!

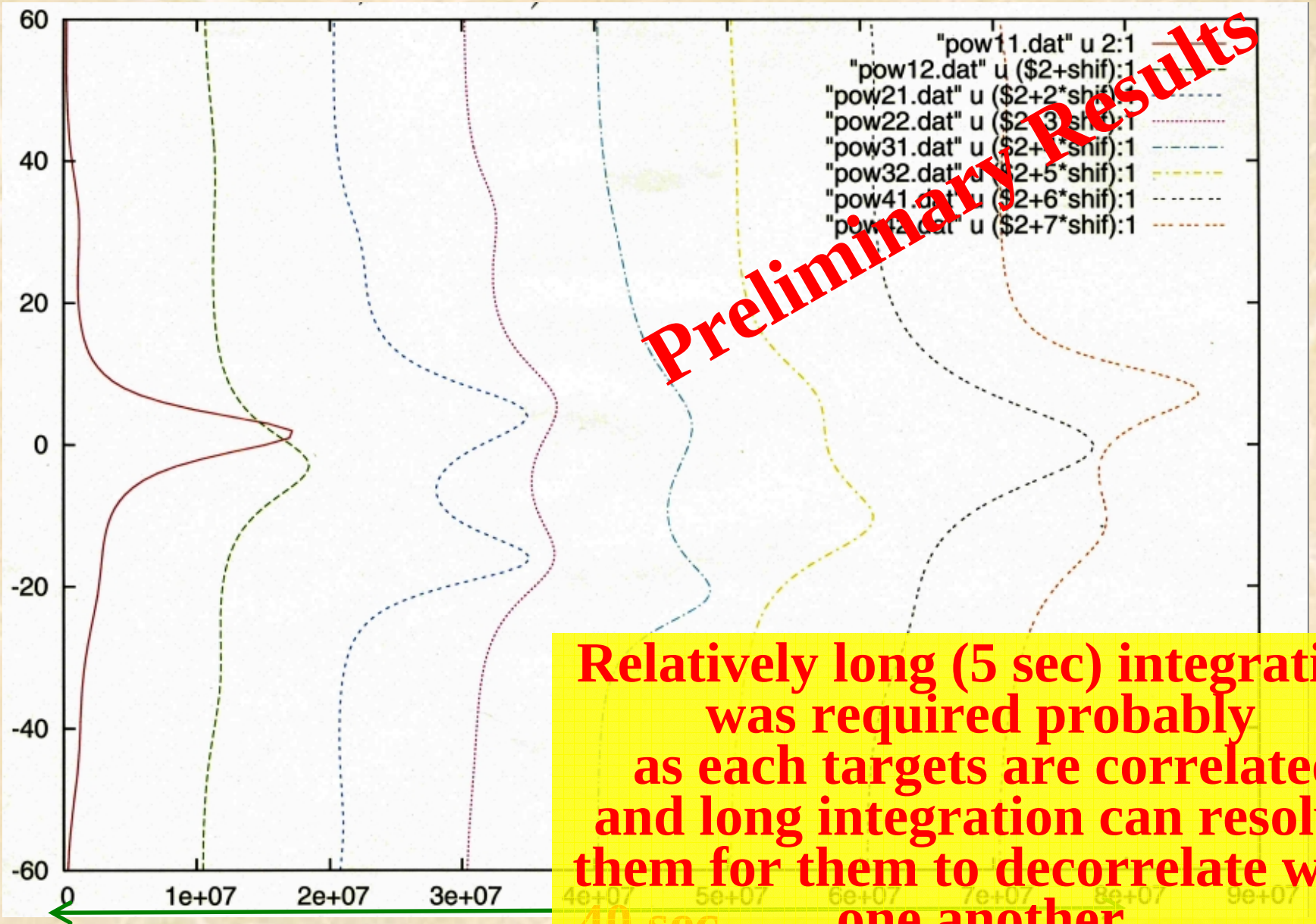
⇒Try to determine it with heater echoes itself

assuming that there is only one spatial peak of echo/target spatial distribution along range direction within a range bin.

(Just an assumption, so could not be the real distribution...)

range#60

Integ every 5 sec. no overlap (all independent) with Capon estimator

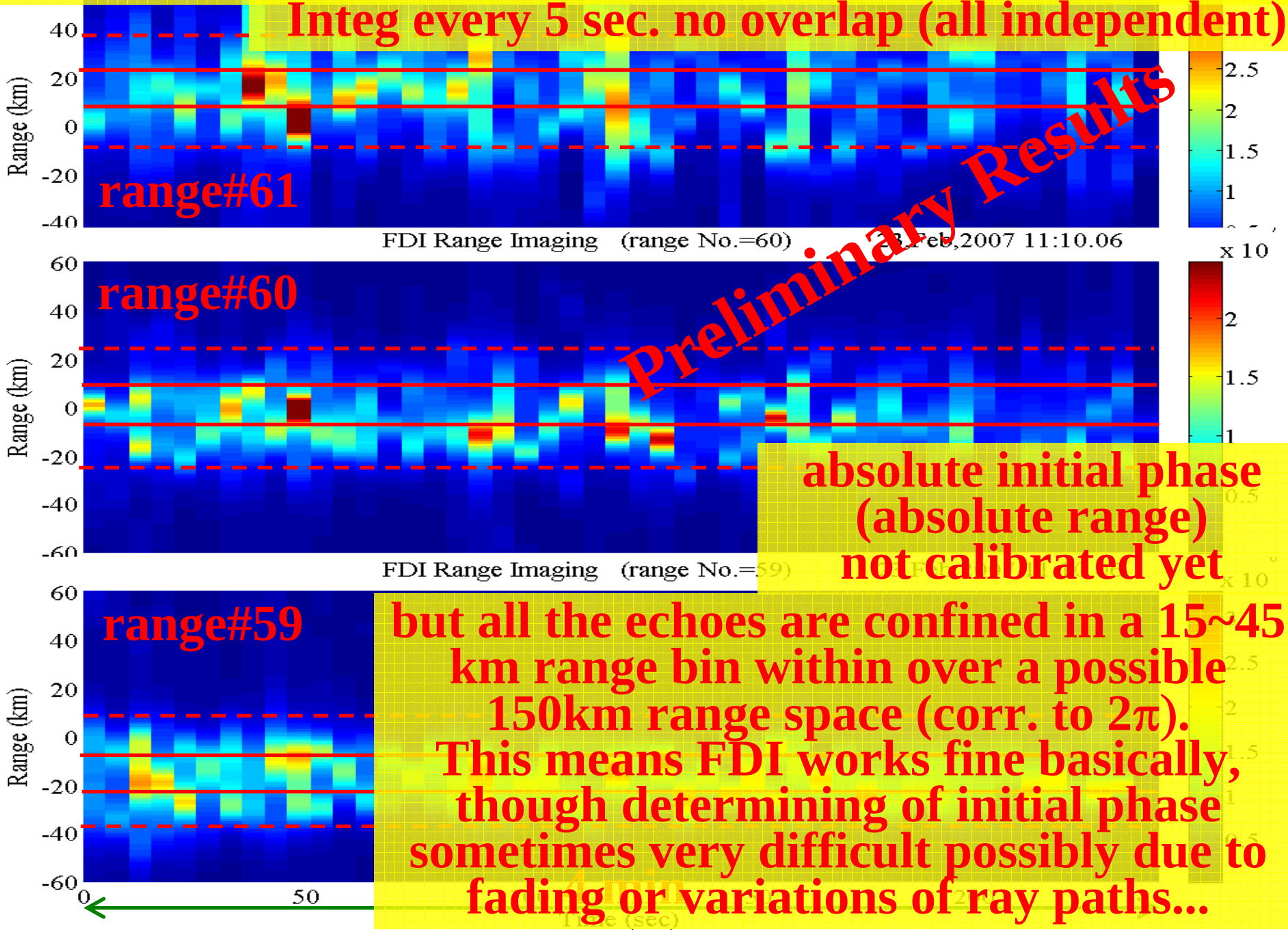


Preliminary Results

Relatively long (5 sec) integration was required probably as each targets are correlated and long integration can resolve them for them to decorrelate with one another

SD Multi-Freq FDI Range Imaging Initial Results (Capon)

Integ every 5 sec. no overlap (all independent)



absolute initial phase (absolute range) not calibrated yet

but all the echoes are confined in a 15~45 km range bin within over a possible 150km range space (corr. to 2π). This means FDI works fine basically, though determining of initial phase sometimes very difficult possibly due to fading or variations of ray paths...

Conclusion

0. Heater FAI TMS data analysed more intensively.

1. Heater echoes show large power amplitude temporal variation (~Hz, ~20dB).

2. Both long duration ACF and Doppler Power Spectrum of I,Q show at least 3 distinct spectral components with order of decorrelation time of short 0.1-0.2 sec and long ~/> 10 sec.
※Std. fitacf may fit only one spectral component or mixture of multiple components.

3. LD ACF temporal variation shows different time scale for each spectral component when heater is turned on or off.

4. "Phase leap check" analysis shows phase leaps of FAI ehoces often happen with time order of < 1sec
※ Before/after heater on period, such leap mostly disappeared.

⇒All these above possibly or strongly suggest that
repeated Creation & decay processes of limited number of FAIs
possibly partly also with fading effect?

Conclusion

5． Multi-freq FDI code developed in TMS mode and applied and tested at the first time to SD radars to resolve multiple targets within a heated range cell.

FAI range imaging within a range cell in range direction firstly & successfully done basically.

6． Results strongly suggest that very long-lived large scale FAI and Small number of short-lived (probably soliton-like?) FAIs coexist within a range cell in the heated area.

7． Analysis of EISCAT data and more optimised FDI configuration with better pulse scheme will be done in near future.

★SDI and FDI are methematically identical and can be combined for new 2-D imaging.

Future

0. Investigate the reason why FDI not always works as expected.

1. Develop more optimised Multi-freq FDI mode/configuration including selection of frequencies, way of scanning frequencies, and change to better pulse scheme, etc. to suit artificially induced FAIs observation.

2. Try to apply FDI method to natural FAI echoes, say cusp backscatters, especially with SENSU Syowa radars.

3. Try to infer the effect of fading more quantitatively to finally estimate the real effect of FAI structure dynamics on the SD power temporal variatioin.

4. Analysis of EISCAT data for comprehensive understanding of creation/decay processes of FAIs

5. Apply SDI as well as FDI to SD radar including hardware update to perform 2-D imaging in some future.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The End