Ionospheric Statistics from EOR Data

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LOFAR

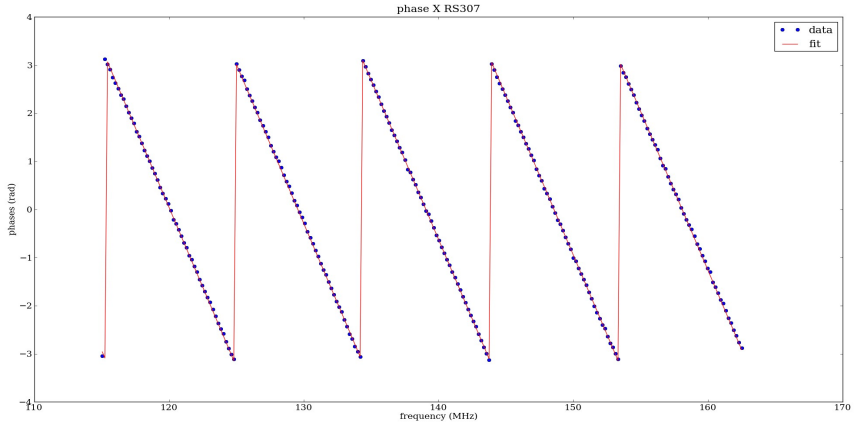
OUTLINE

- Data description
- Extracting dTEC from phase solution
- Time correlation
- Spatial Structure
- Scintillation Winter 2013/2014

Data

- 25 8 hour HBA observations of 3C196
- winter 2012/2013
- BBS solutions:
  - (V. Pandey)
  - full polarization matrix
  - 4 component model of 3C196
  - NO other sources in the skymodel

Getting TEC

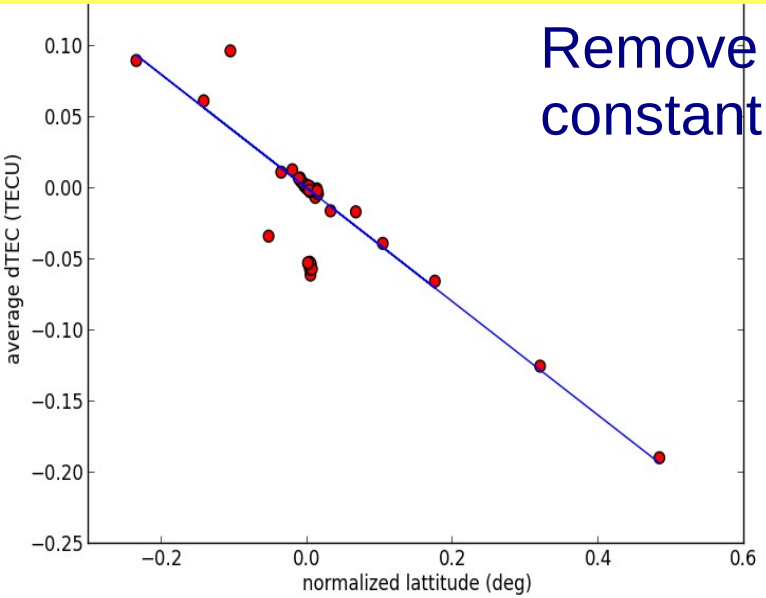


- Start from selfcal phases
- Extract diff Faraday rotation by converting solutions to RL
- Derotate solution matrices, inspect XX, YY phase vs. frequency

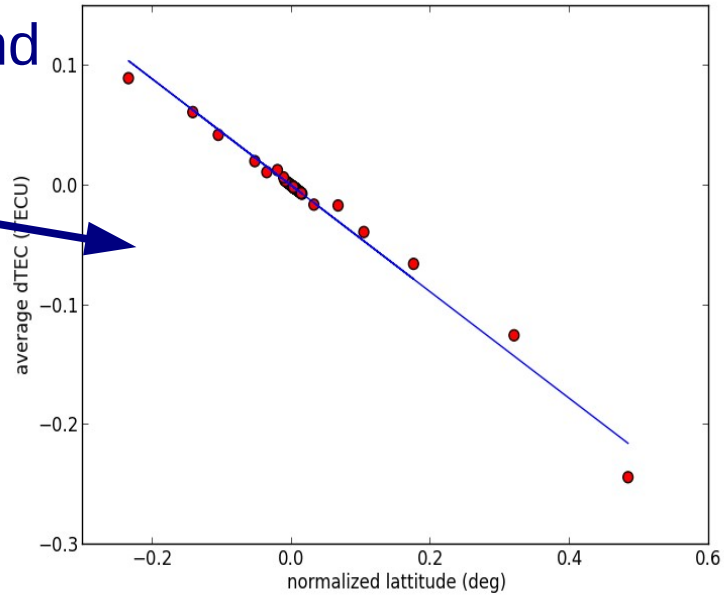
- Unwrap phases, find initial solutions
  $d\varphi = a*\nu + b/\nu$, fit a,b
  a = C1* delay (ns), b= C2 * dTEC(TECU)
- But:
  - $d\varphi \pm 2\pi$ gives different solutions for delay and dTEC
    - ±~3ns and ±~0.05 TECU, depending on the frequency range
    - with almost same χ^2
  - Constant phase: $d\varphi+\varphi_0$ will be absorbed in the solutions with corresponding fraction of offsets
- Remove phase wraps and constant φ_0 by checking spatial correlations (average linear gradient over array)

Code available in experimental area of LOFAR tree and soon in LOSOTO

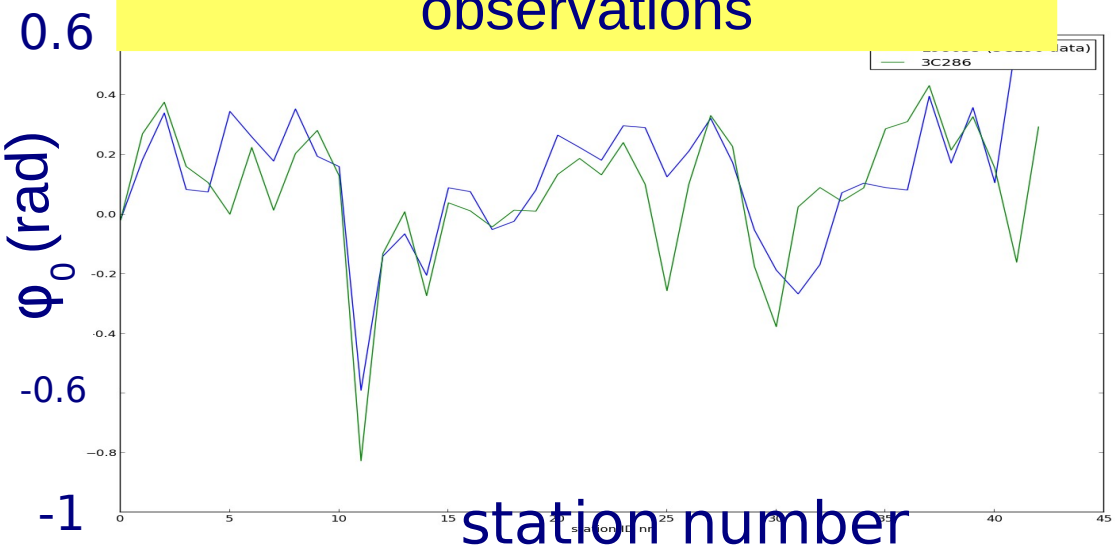
Time average of fitted dTEC vs latitude of station



Remove 2π phasewraps and constant offset (CS only)



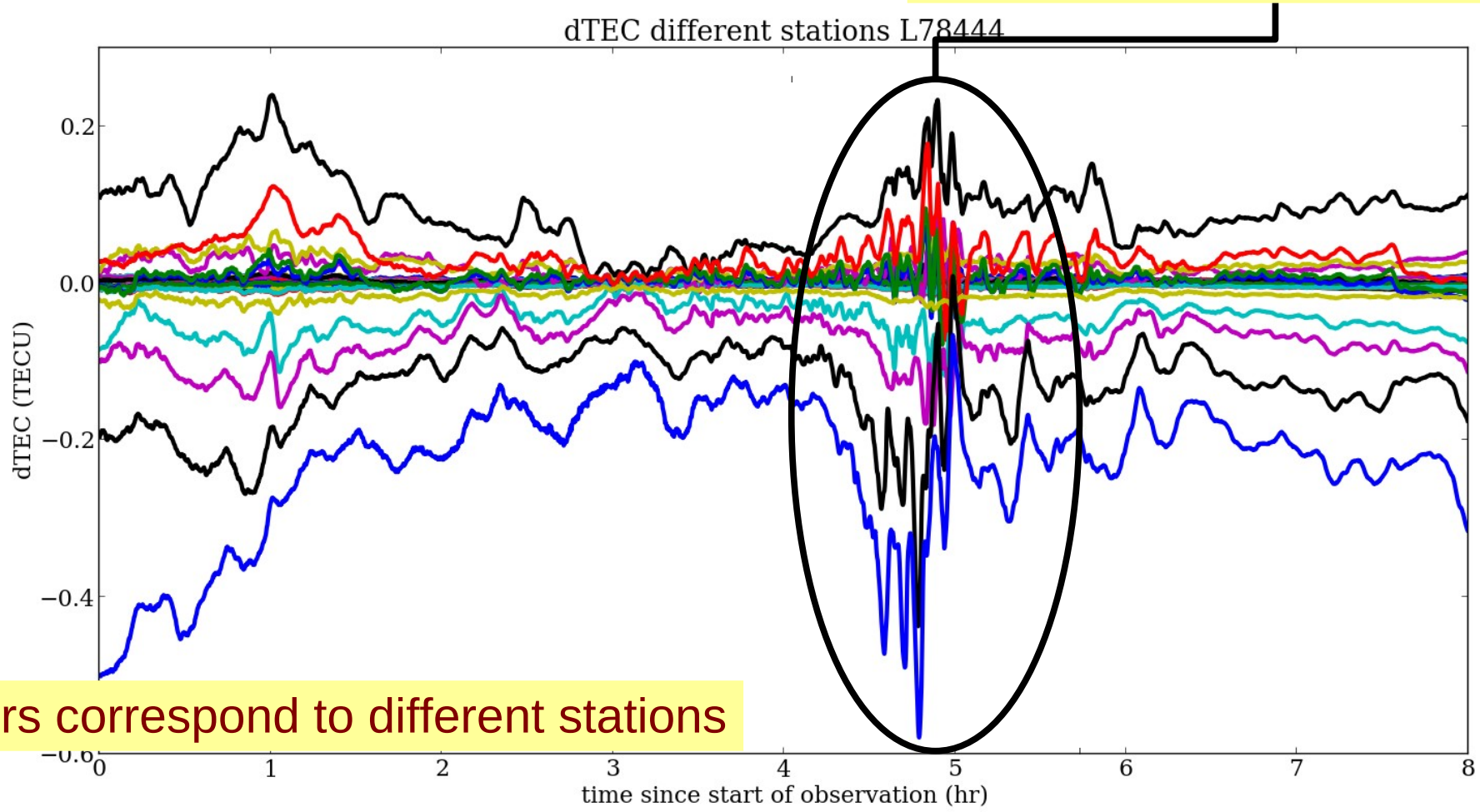
φ_0 per station, two separate observations



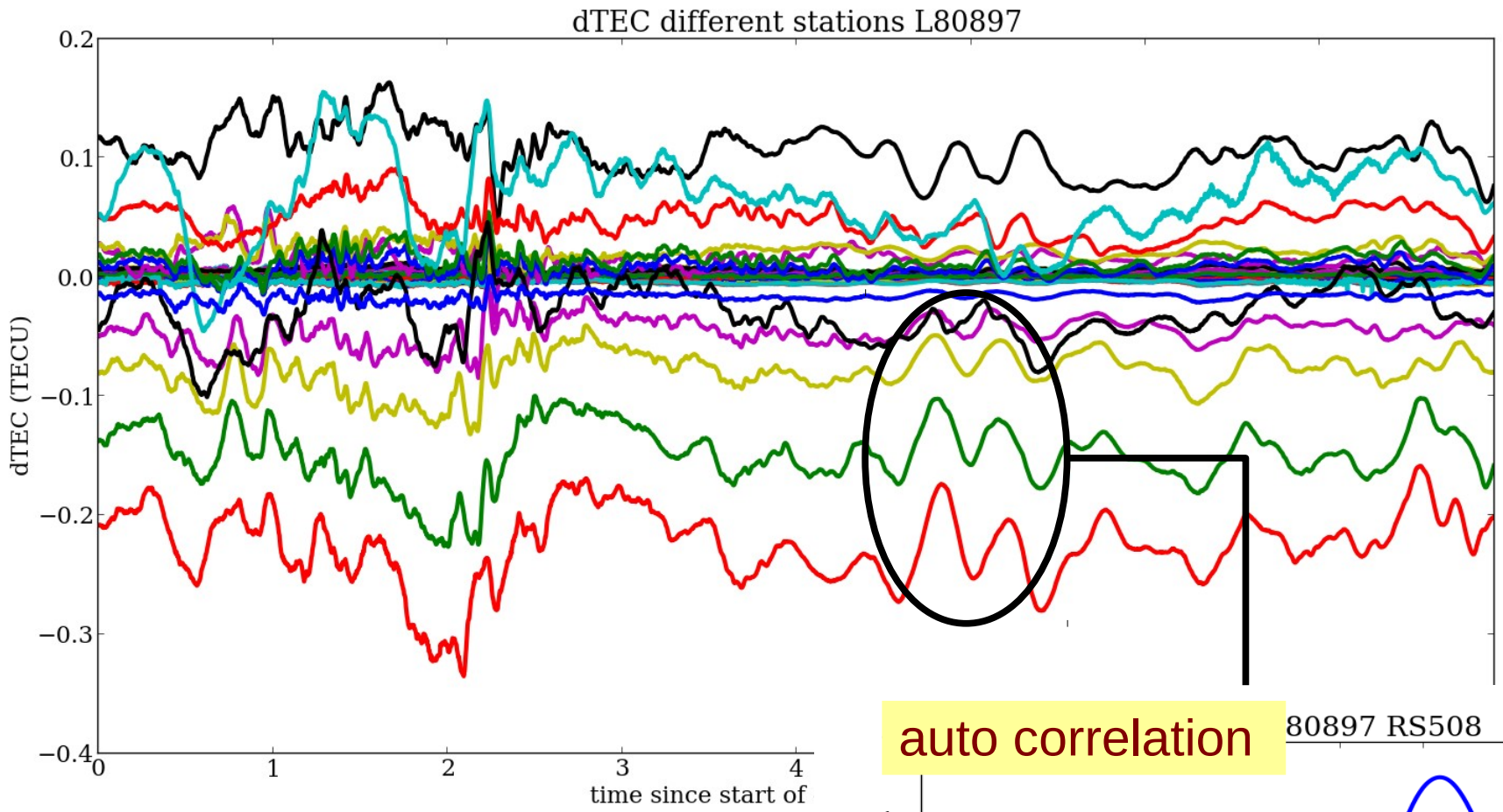
dTEC solutions

- Inspect dTEC solutions versus time for all stations, 25 observations
- Many interesting features, wave like structures...

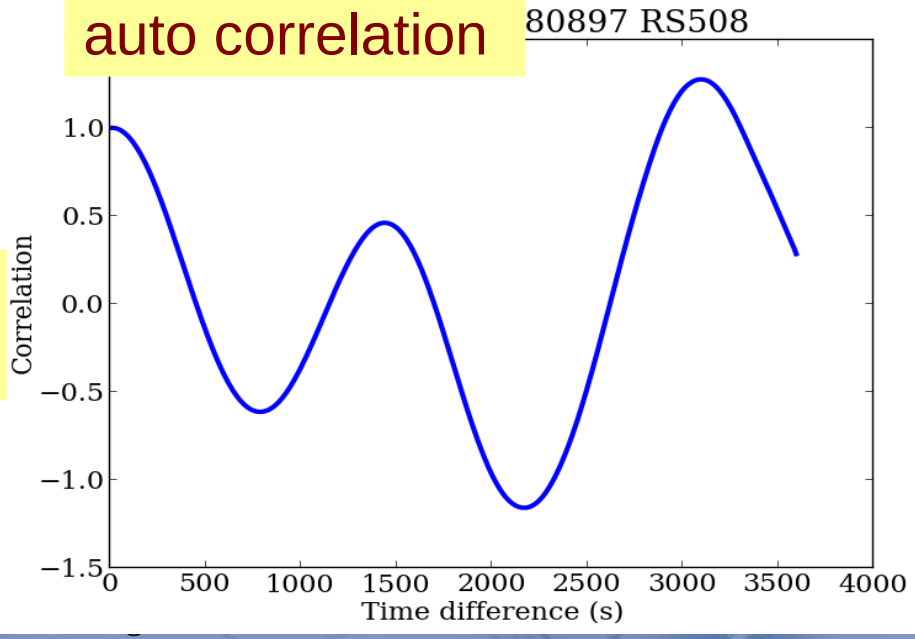
Period with large differential Faraday rotation (observed in raw data)



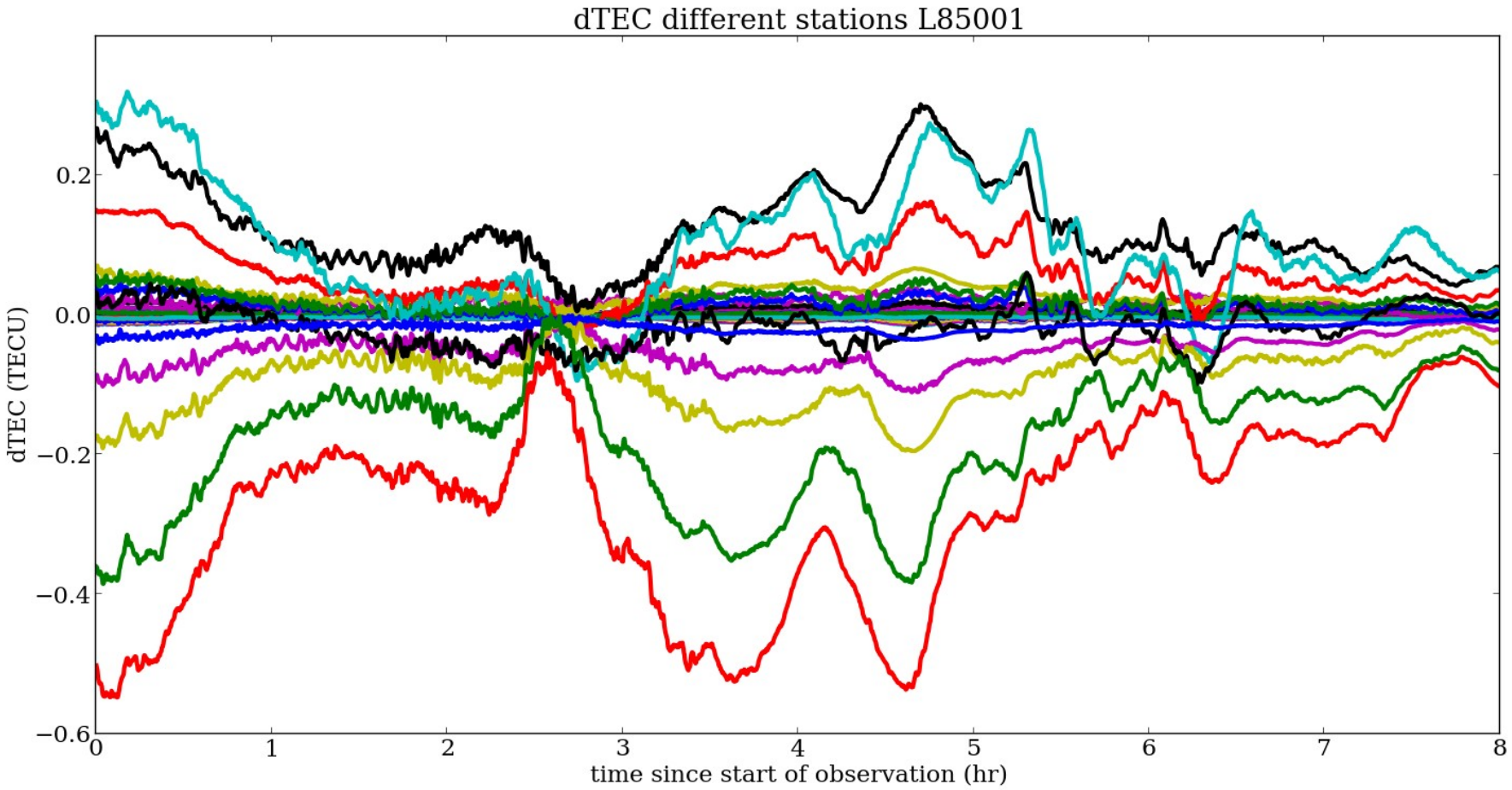
colors correspond to different stations



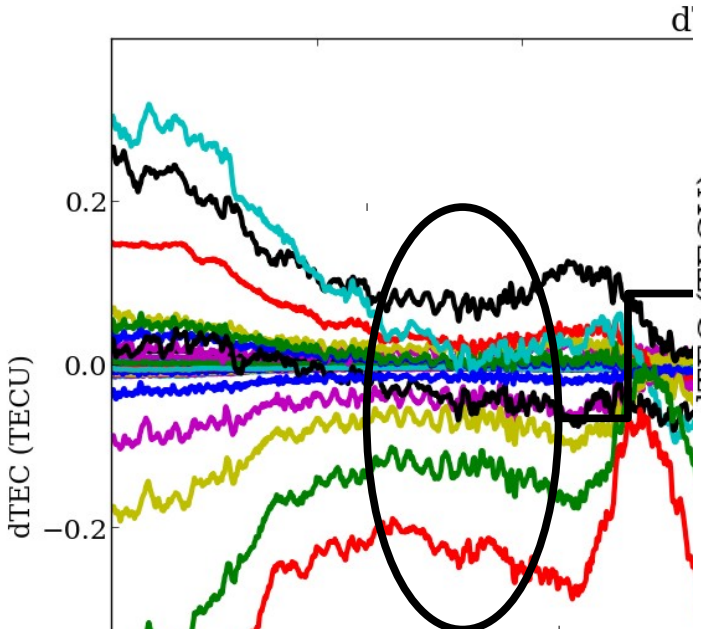
auto correlation

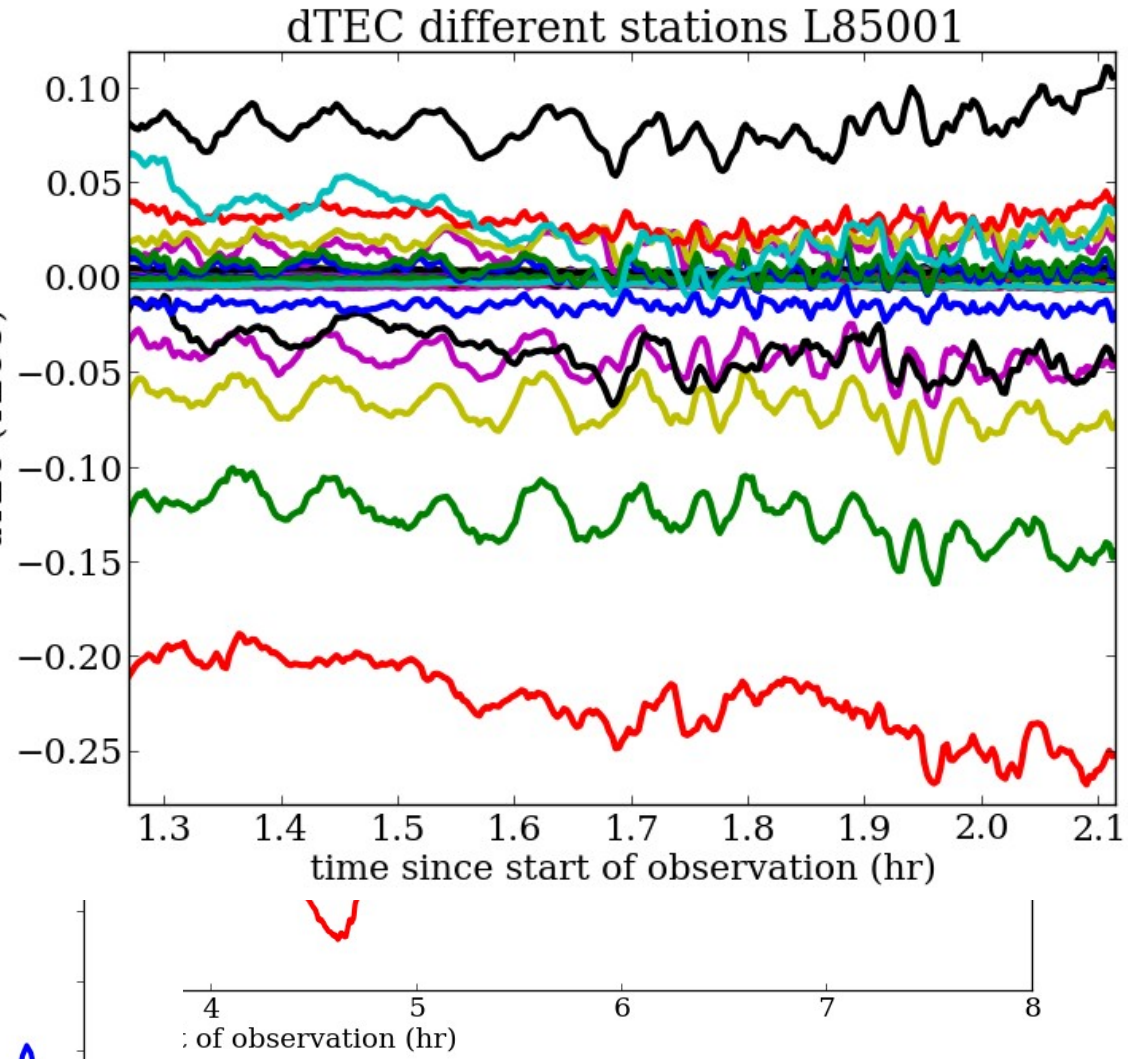


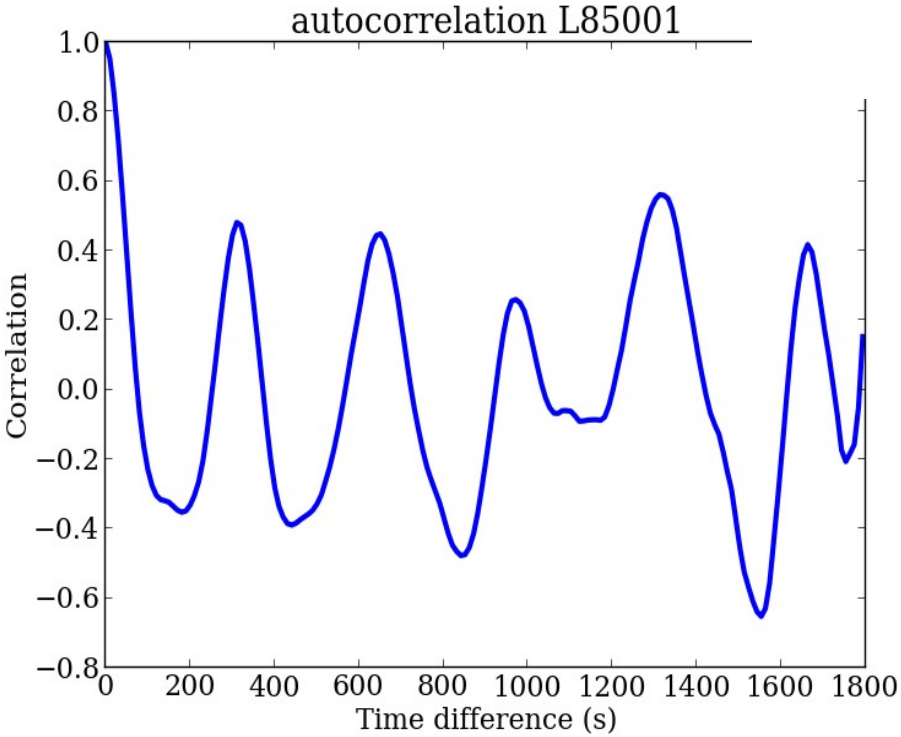
Typical period of waves: ~1500 s corresponding to mTID



Also smaller timescale structures observed


dTEC (TECU)
0.2
0.0
−0.2


dTEC different stations L85001
dTEC (TECU)
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
time since start of observation (hr)
4
5
6
7
8
of observation (hr)


autocorrelation L85001
Correlation
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
0
200
400
600
800
1000
1200
1400
1600
1800
Time difference (s)

Structure function

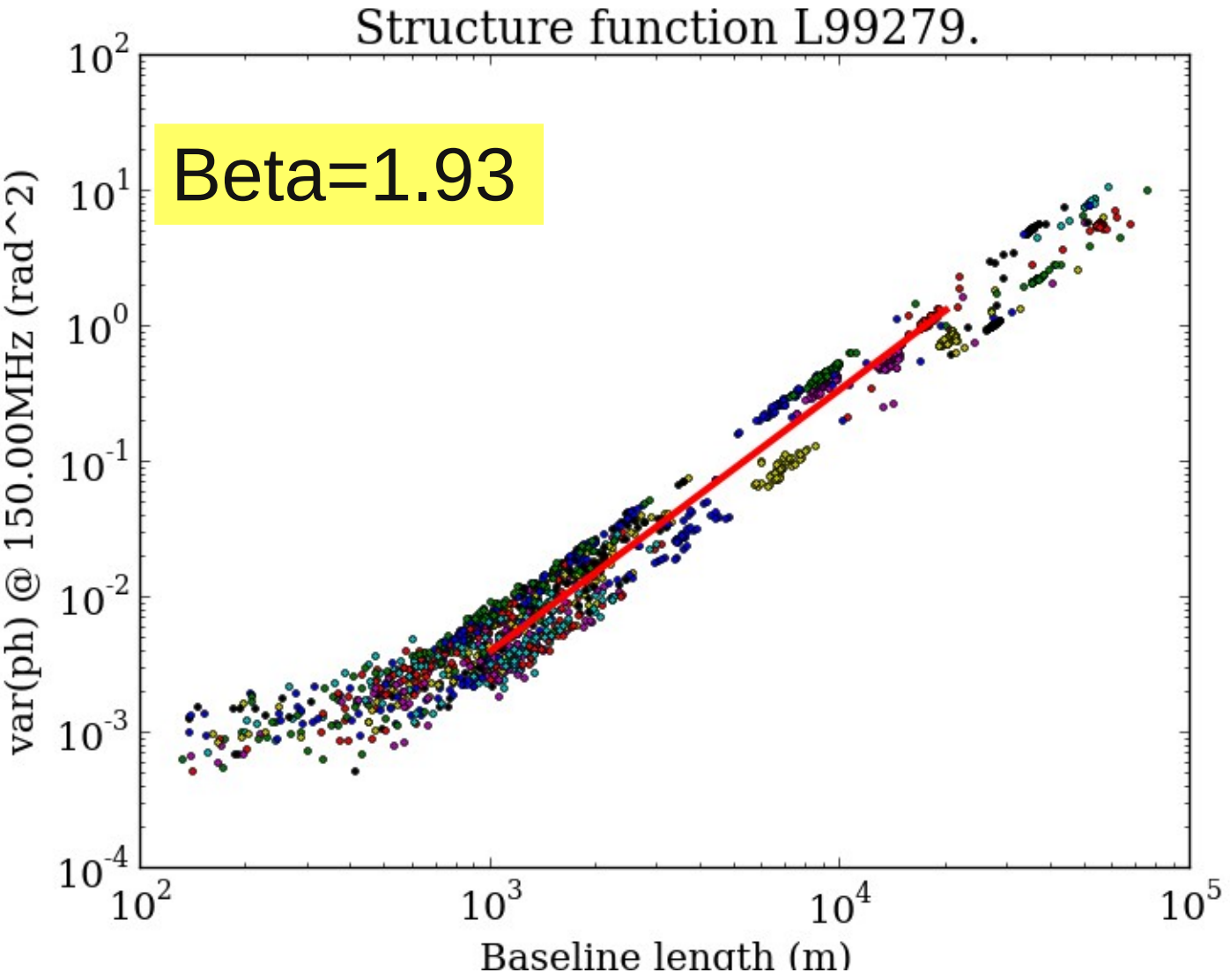
Spatial fluctuations:

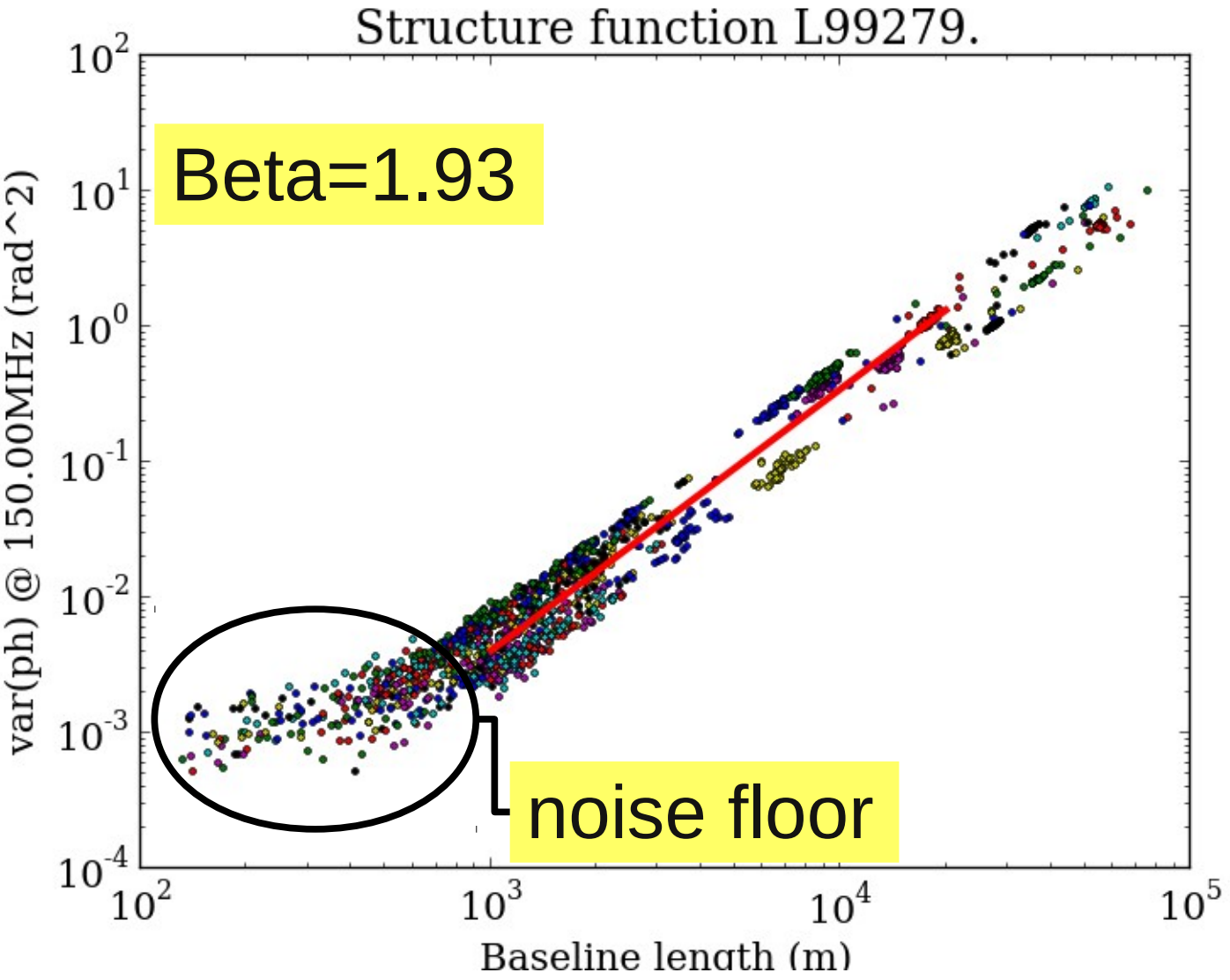
$$D_\varphi(||r_1-r_2||) = \langle(\varphi_1 - \varphi_2)^2\rangle$$

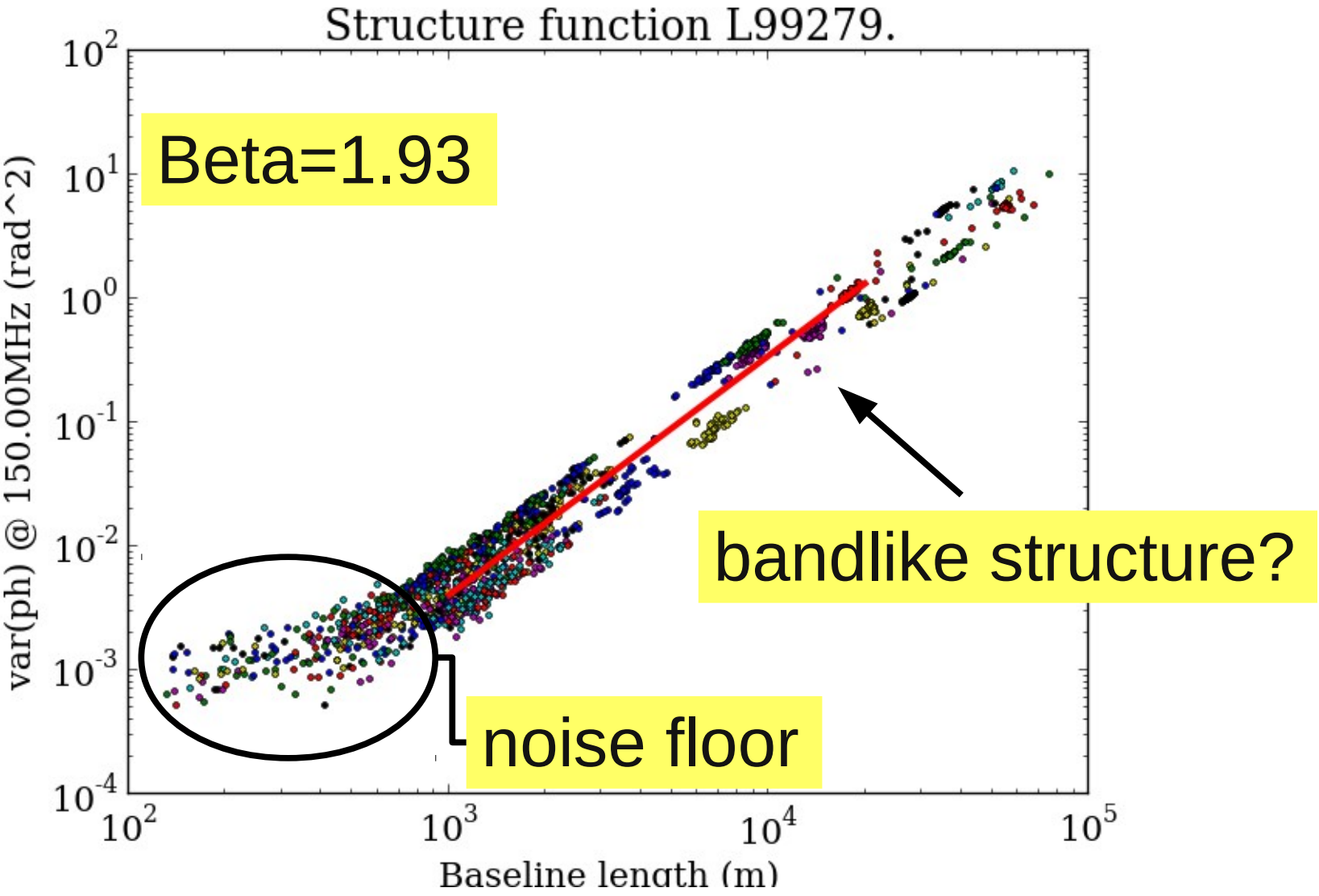
Kolmogorov turbulence, thin layer approximation:

- $D_\varphi(\mathbf{r}) = (\mathbf{r} / s_0)^\beta$
- $\beta = 5/3$,
- s_0: field coherence scale, $D_\varphi(s_0) = 1$ rad^2

Convert dTEC to φ @ 150MHz, plot vs. baselinelength


Structure function L99279.
Beta=1.93
var(ph) @ 150.00MHz (rad^2)
Baseline length (m)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{2}
10^{3}
10^{4}
10^{5}

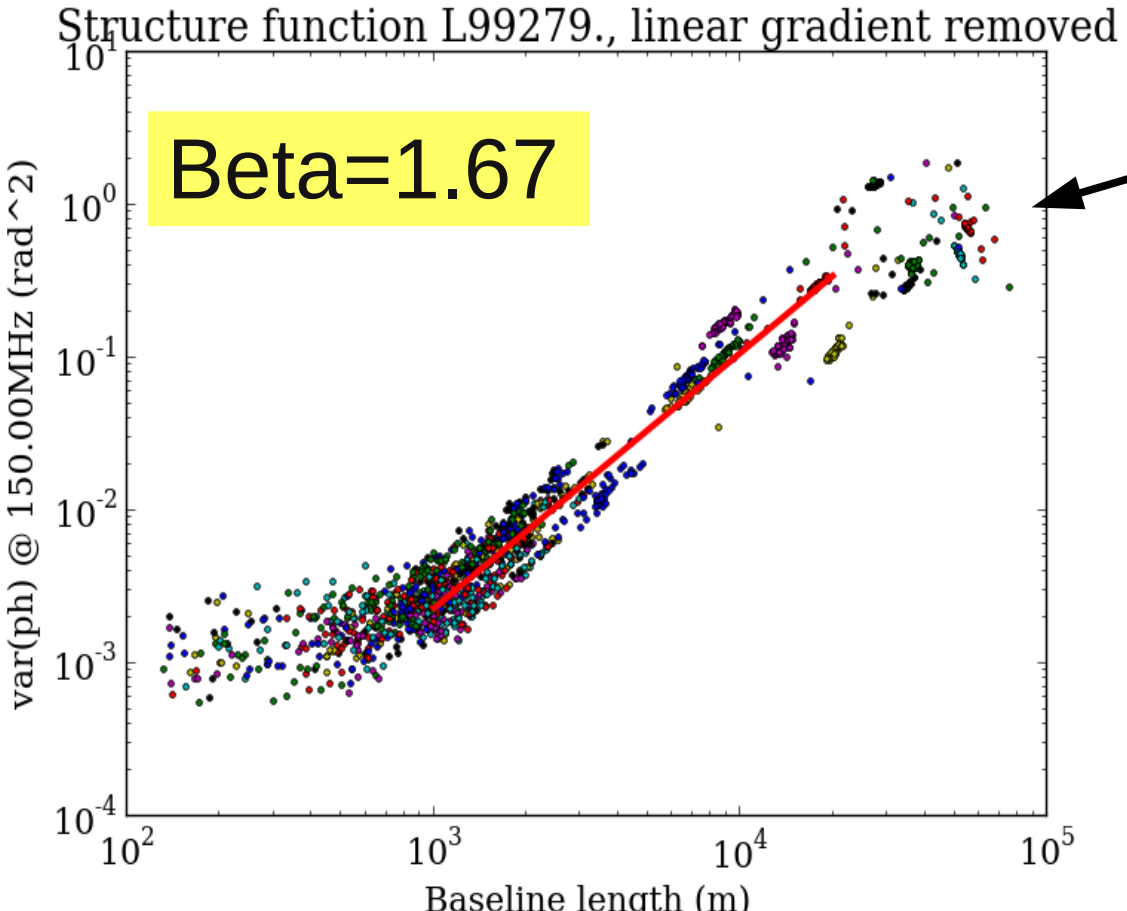

Structure function L99279.
Beta=1.93
noise floor
var(ph) @ 150.00MHz (rad^2)
Baseline length (m)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^2
10^3
10^4
10^5


Structure function L99279.
Beta=1.93
bandlike structure?
noise floor
var(ph) @ 150.00MHz (rad^2)
Baseline length (m)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^2
10^3
10^4
10^5

Linear (mostly NS) gradient over array:

$\beta = 2.$

Remove 2D fitted linear gradient, before calculating var(φ)

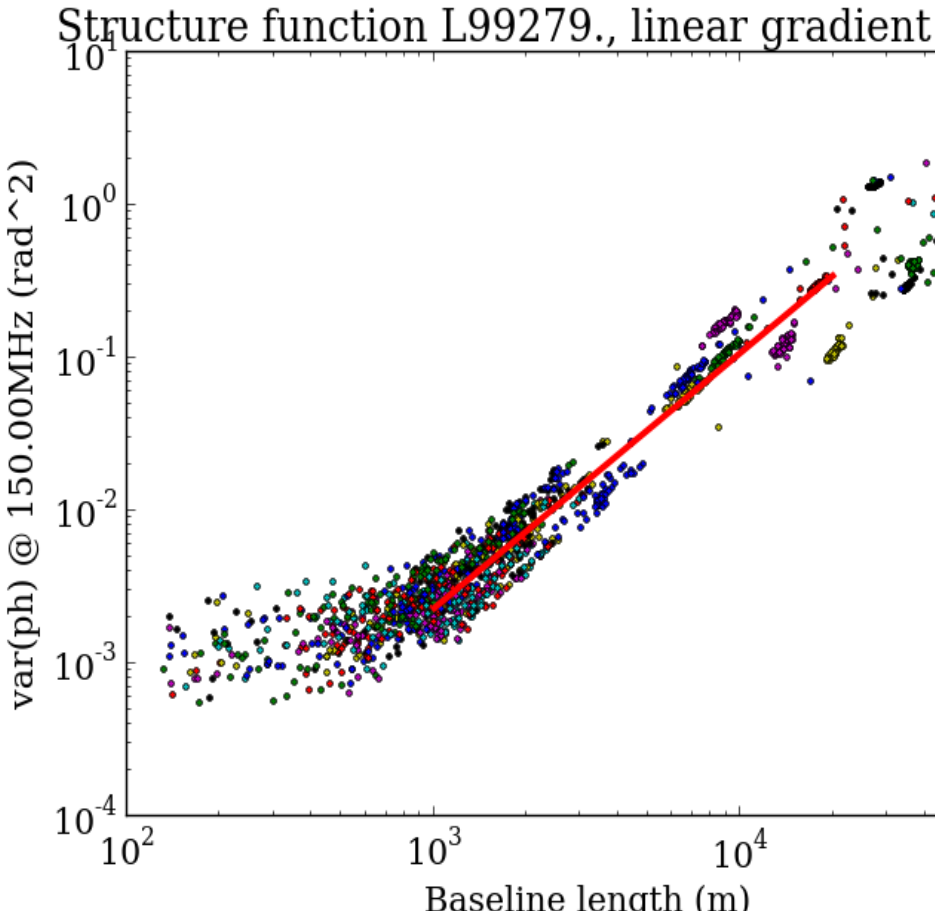


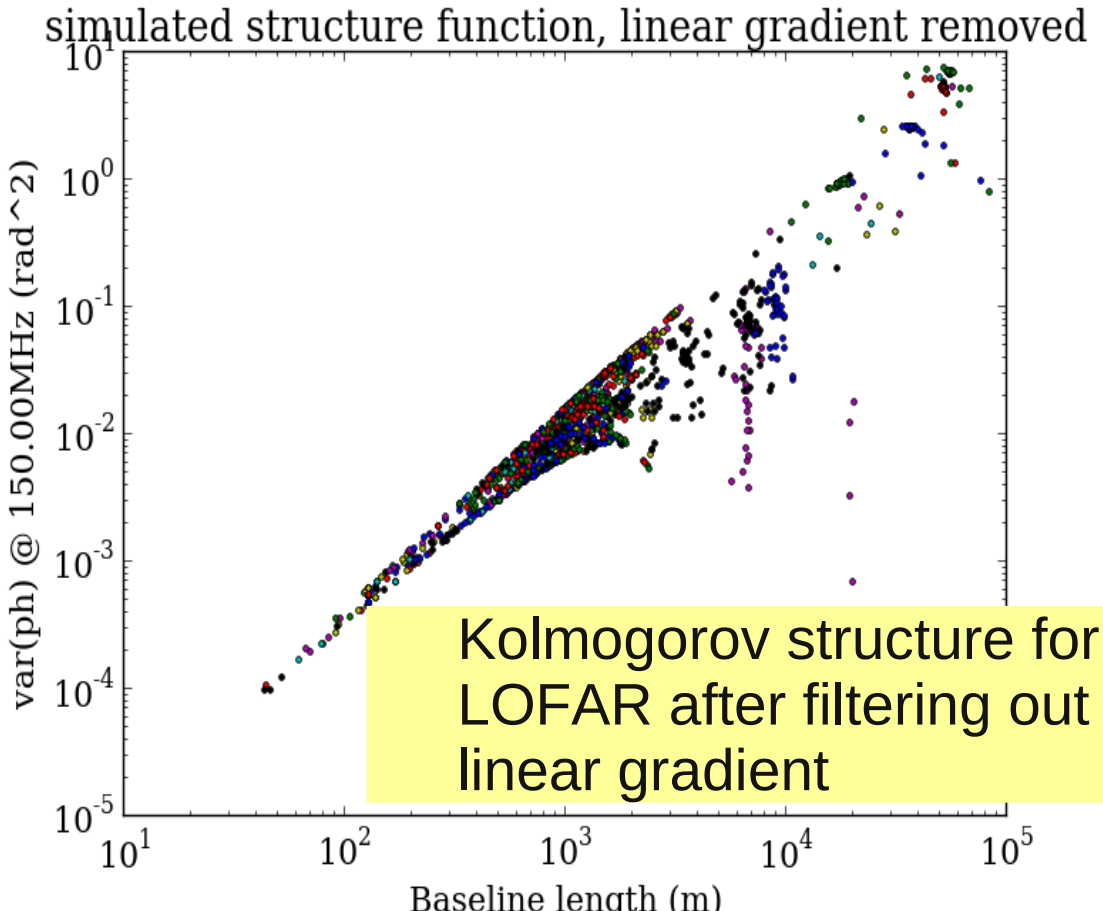
turn over?

Linear (mostly NS) gradient over array:

$\beta = 2.$

Remove 2D fitted linear gradient, before calculating var(φ)



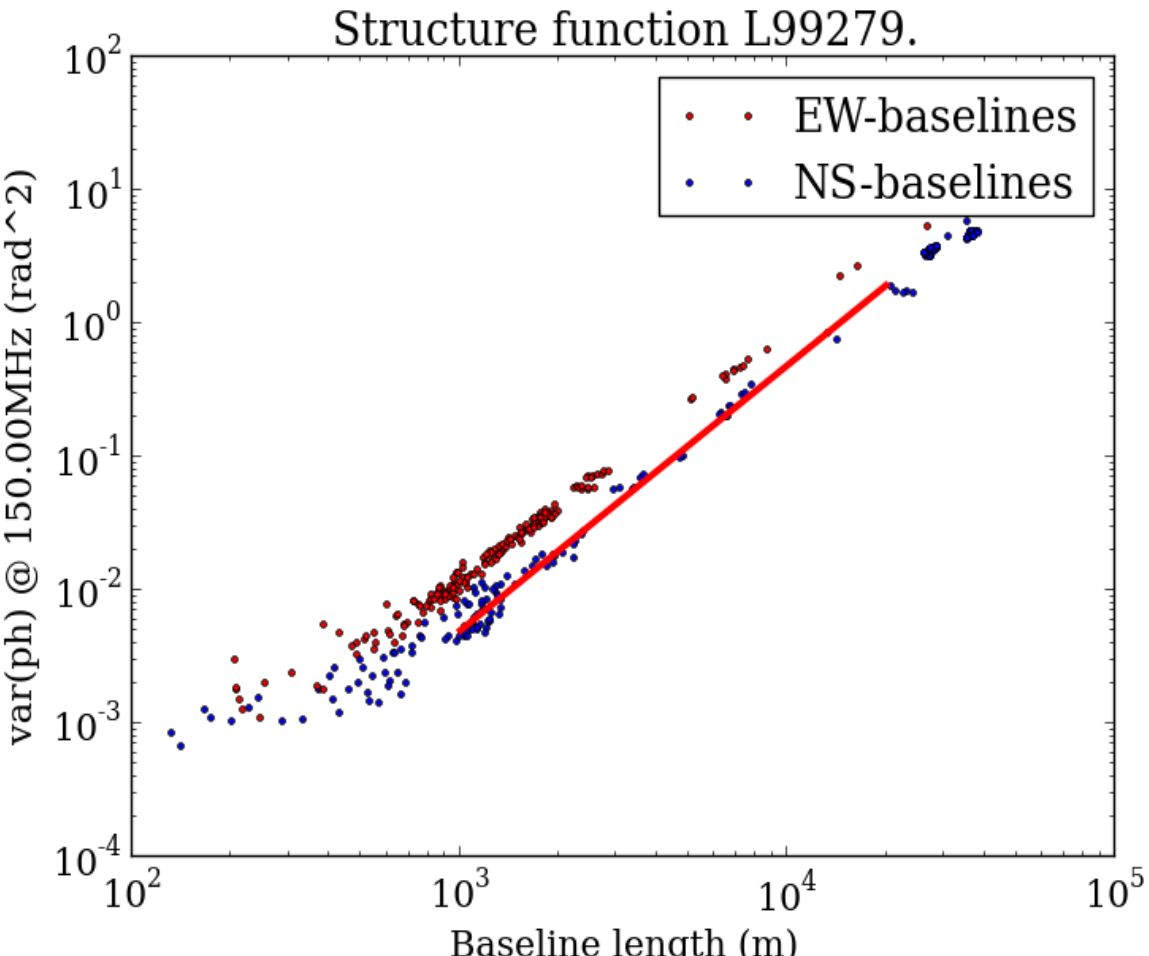


Kolmogorov structure for LOFAR after filtering out linear gradient

band like structure: due to orientation?

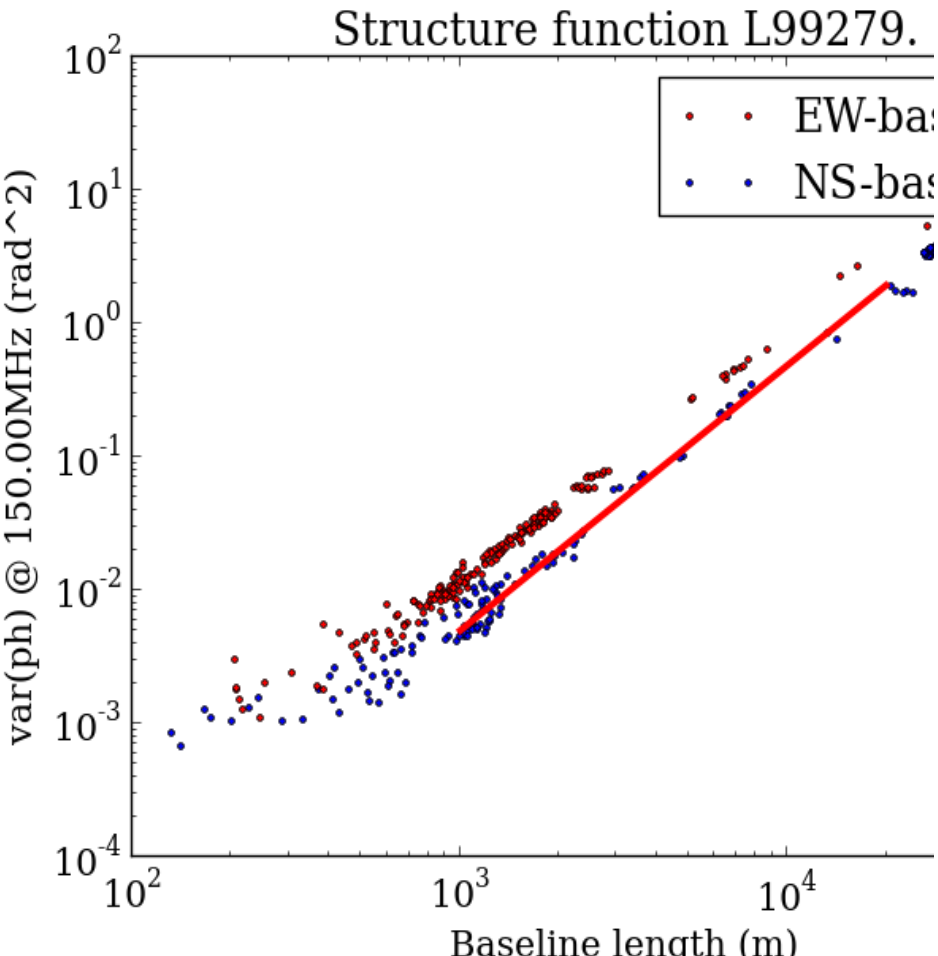
select only NS (EW) oriented baselines (within 10 degrees)

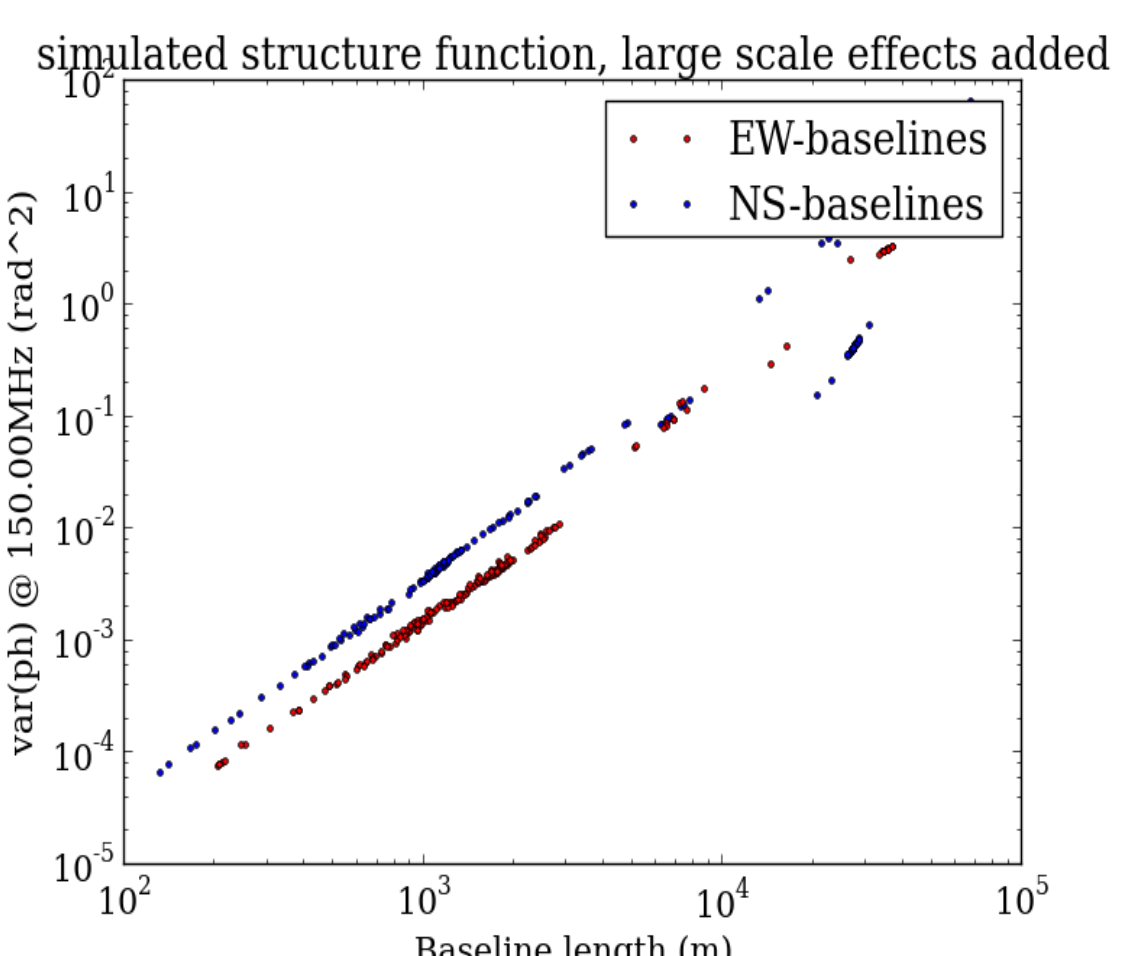
Large scale non-Kolmogorov structures,eg. TID (?)

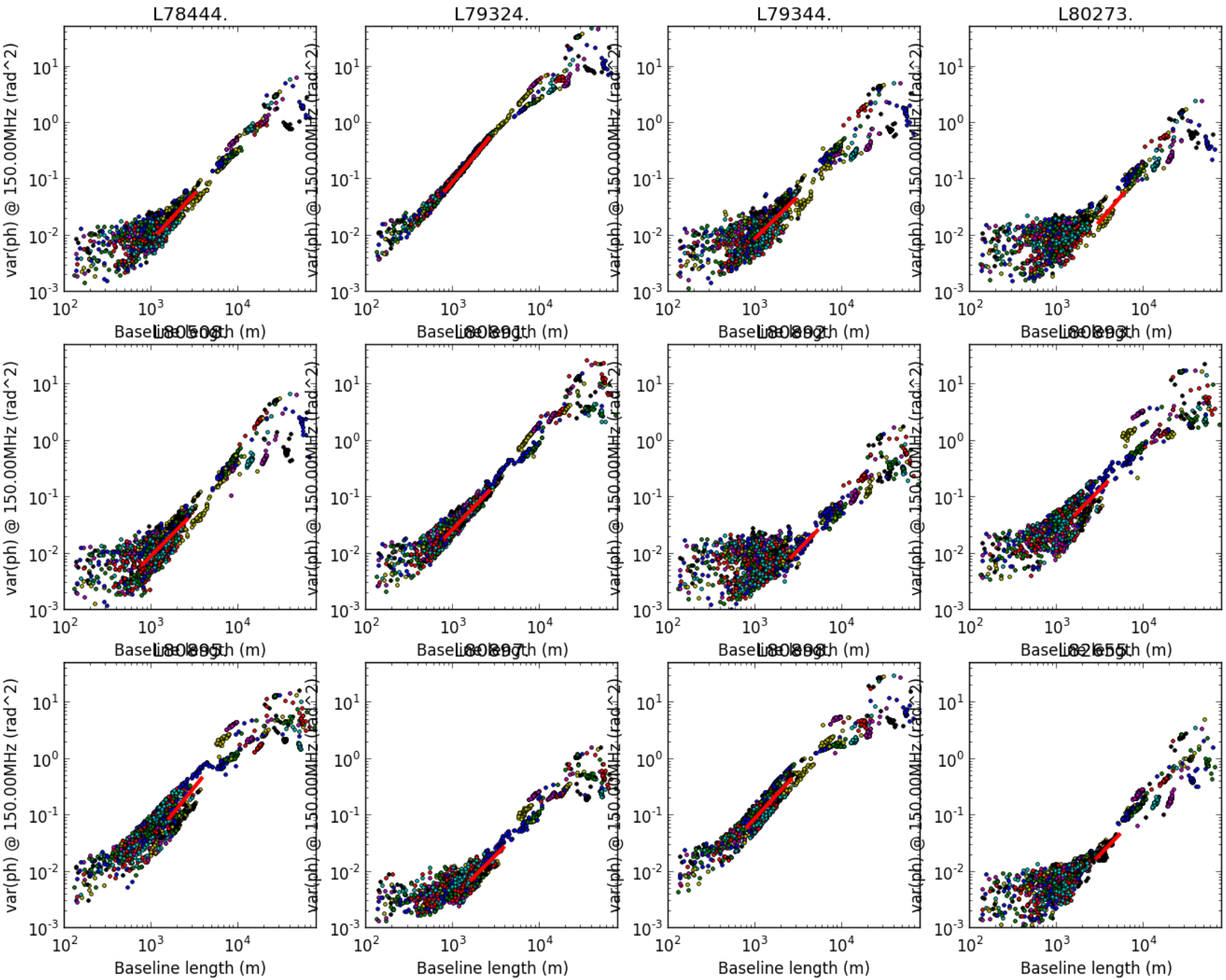


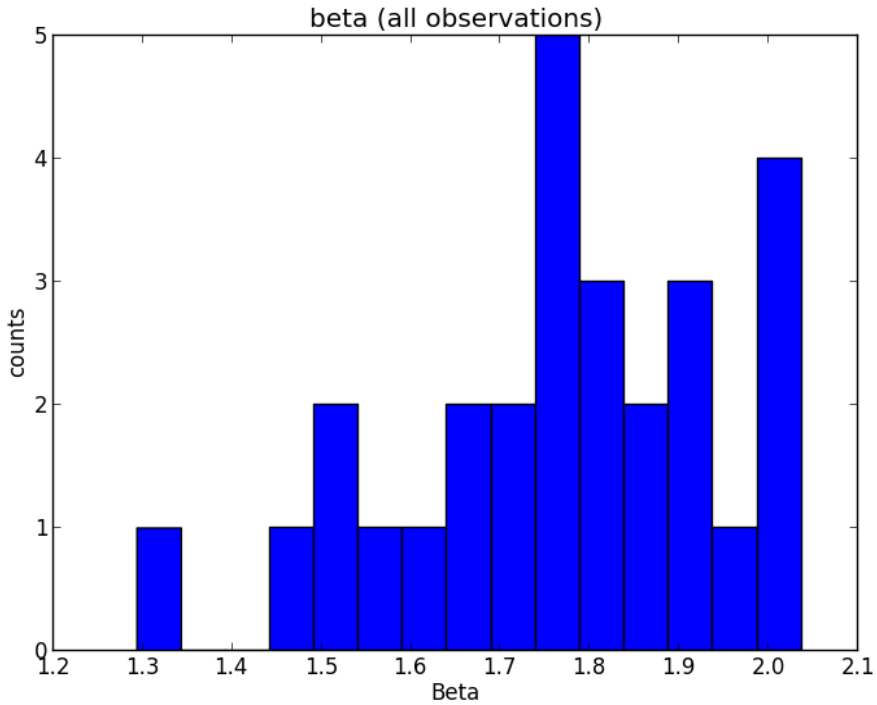
band like structure: due to orientation?

similar structure observed when adding large scale (2^{nd} order 2D fit to data) to pure Kolmogorov spectrum






L78444.
L79324.
L79344.
L80273.
L80503.
L80897.
L80897.
L80897.
L80897.
L80897.
L80897.
L82655.
var(ph) @ 150.00MHz (rad^2)
Baseline length (m)



Distributions for 23 observations

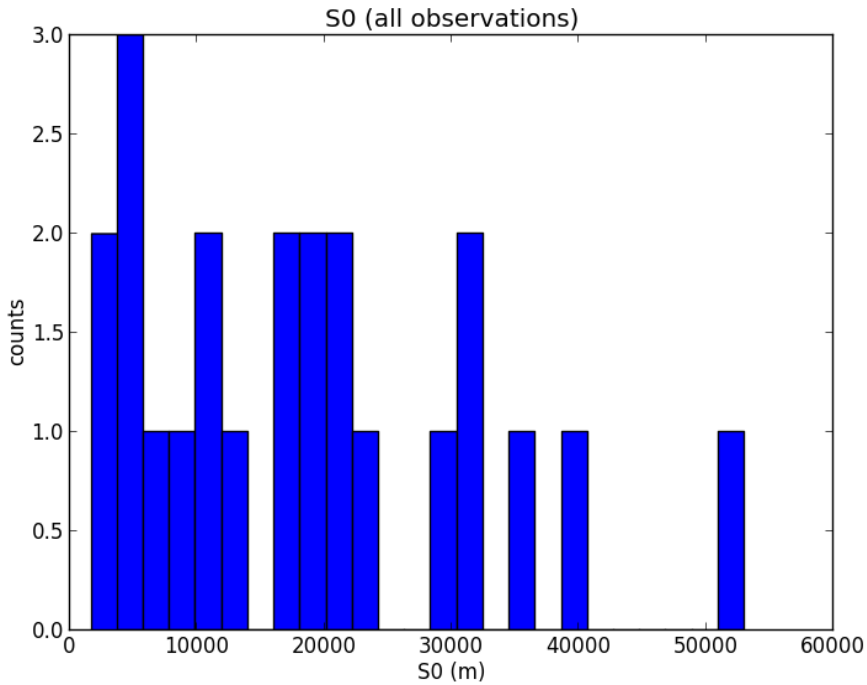
β in general larger than 5/3

large scale effects (TIDs?)

Spatial coherence between 3 and 52 km

Estimate of noise contribution to image of uncorrected ionosphere

rms image inversely proportional to s0

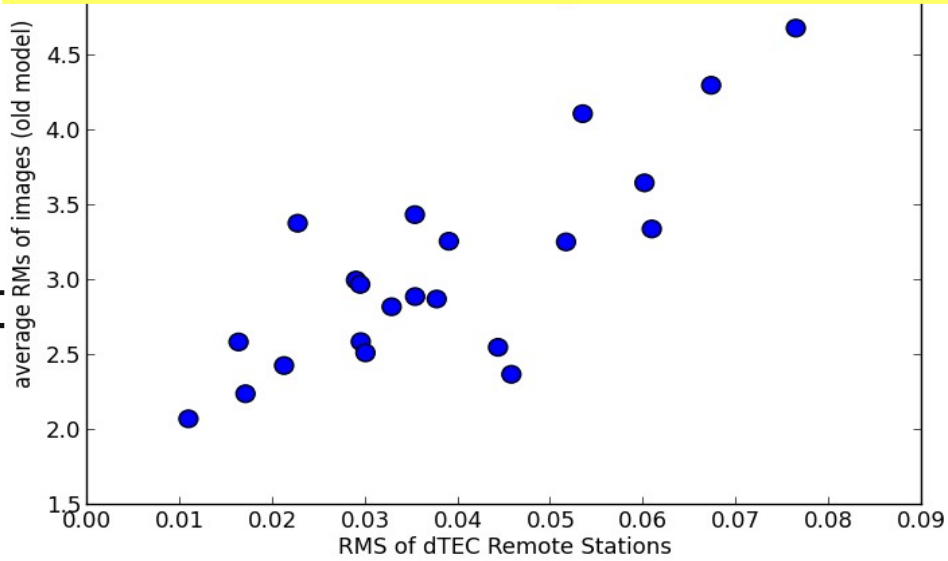


average image noise

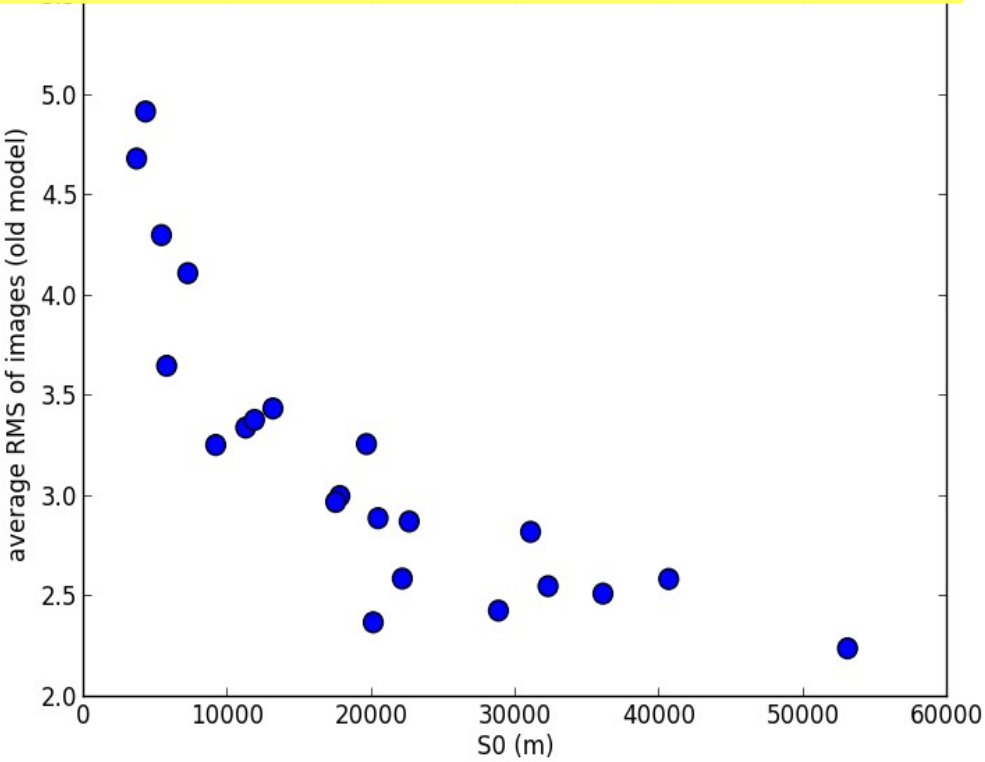
(V. Pandey, old model data)

varies from night to night up to a factor 2

Correlation image noise variance(dTEC) RS



Correlation image noise S_0



S_0 determined on short baselines mostly

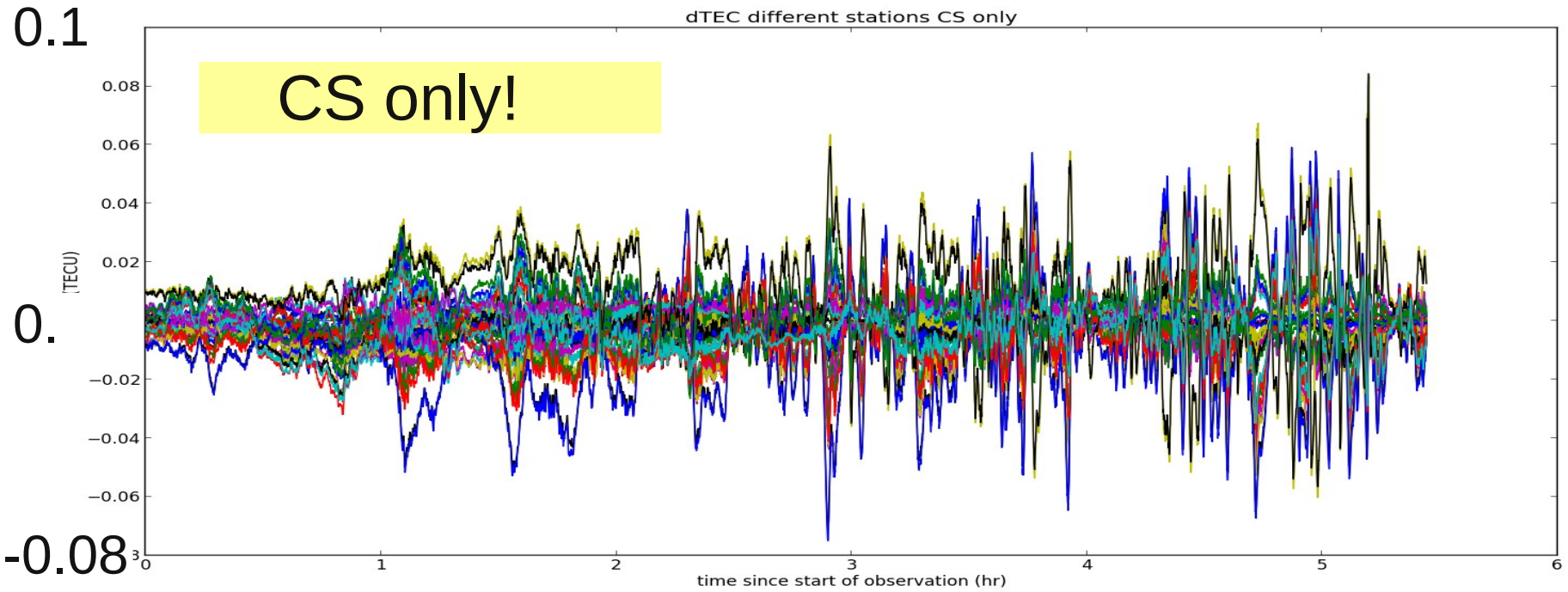
independent measure

Scintillation winter 2013/2014

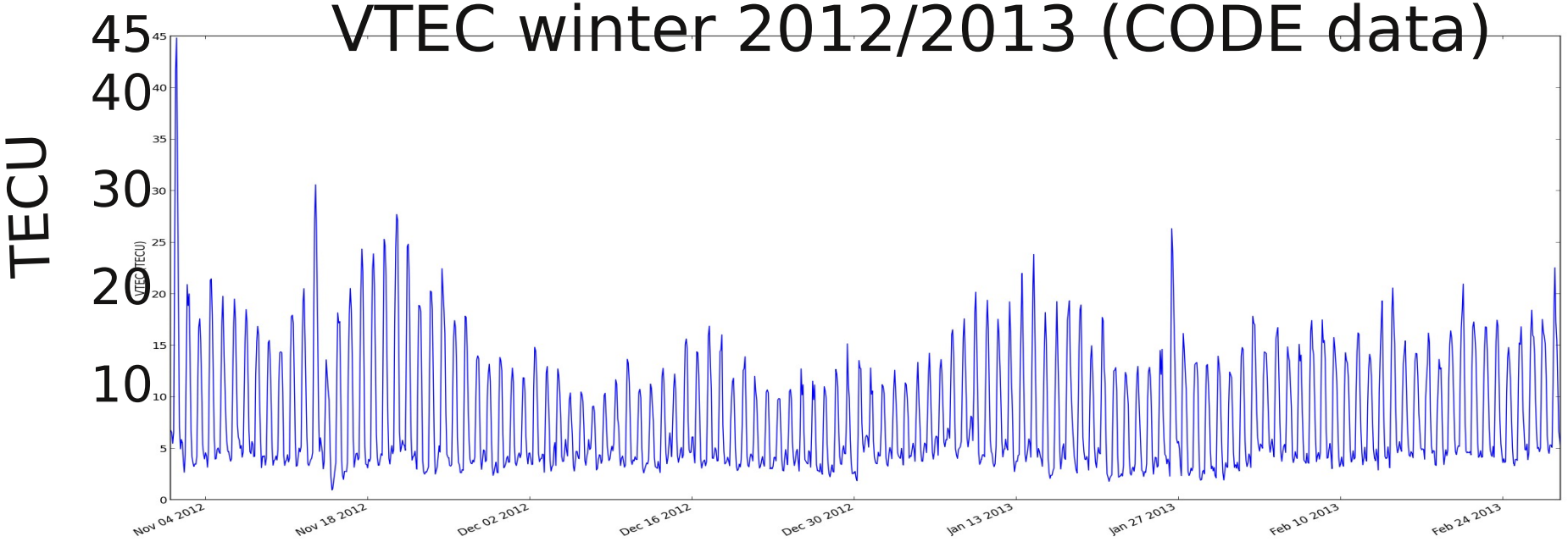
If S_0 < Fresnel scale (~600m @ 2m):

- amplitude decorrelation

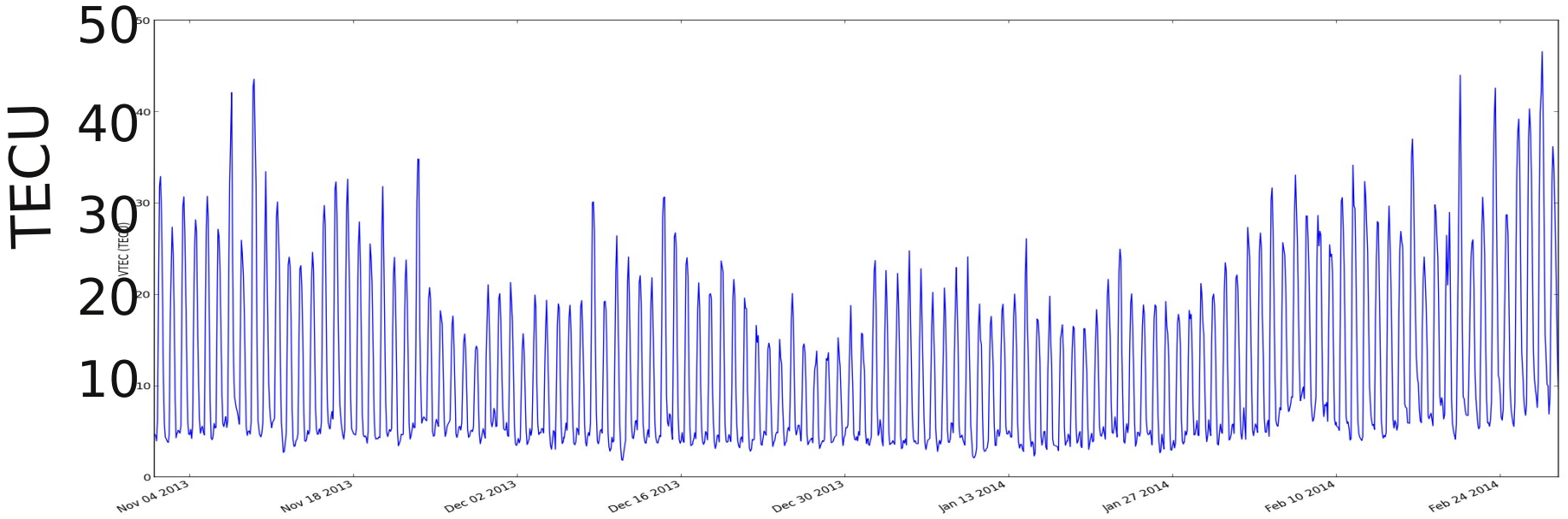
- Not observed in 2012/2013
- Many nights this winter
  - but also very good (=stable ionosphere) nights



VTEC winter 2012/2013 (CODE data)



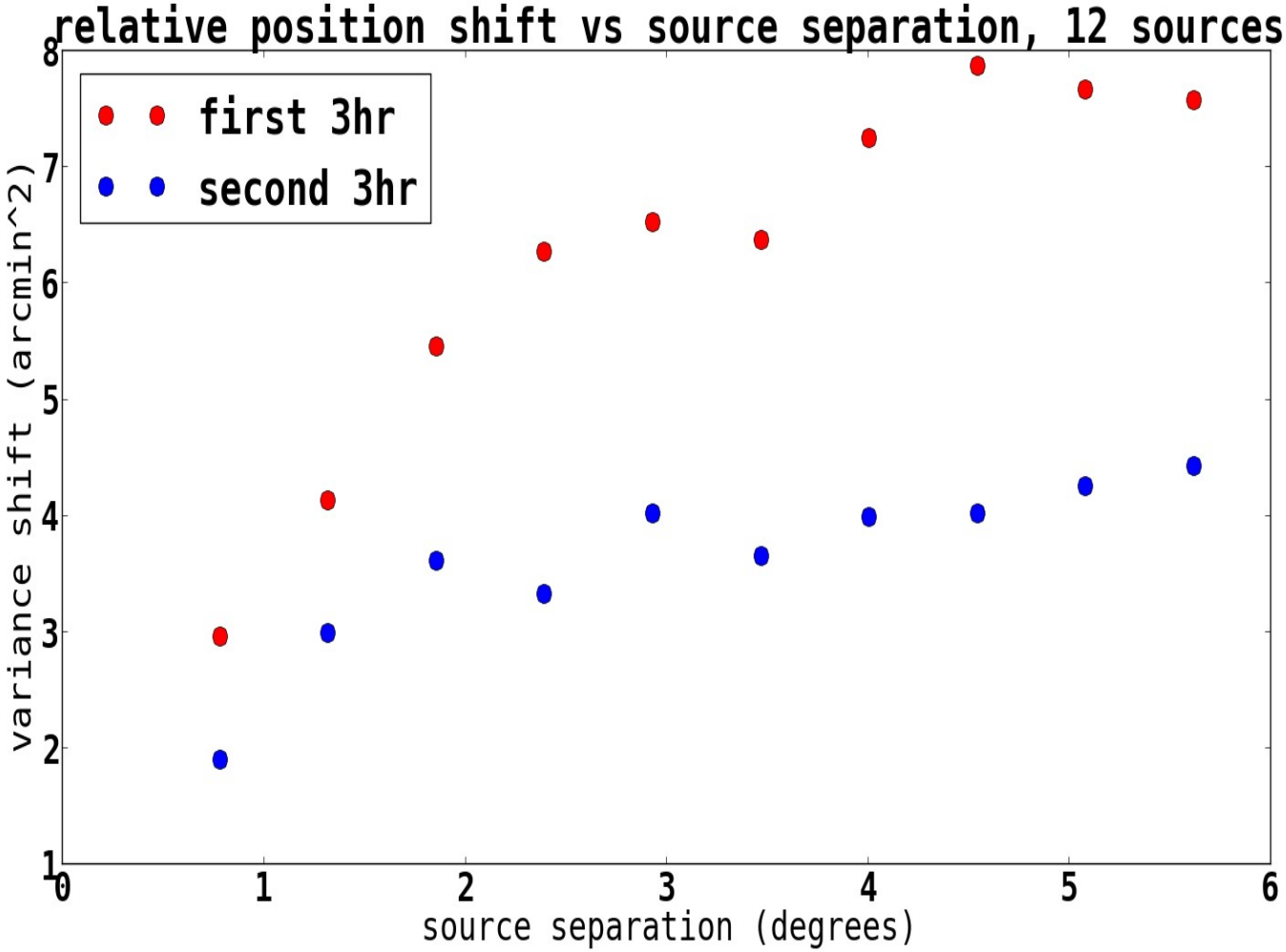
VTEC winter 2013/2014 (CODE data)



movie by G. de Bruyn, using excon (S.Yatawatta)

Fit source positions

correlation between position shift of sources as function of distance between the sources



Conclusion + Acknowledgements

- derive ionospheric structure from selfcal phases
- Night to night image rms correlates with structure of ionosophere
- Position accuracy depends on source separation

Many thanks to

S. vd Tol and V. Pandey!