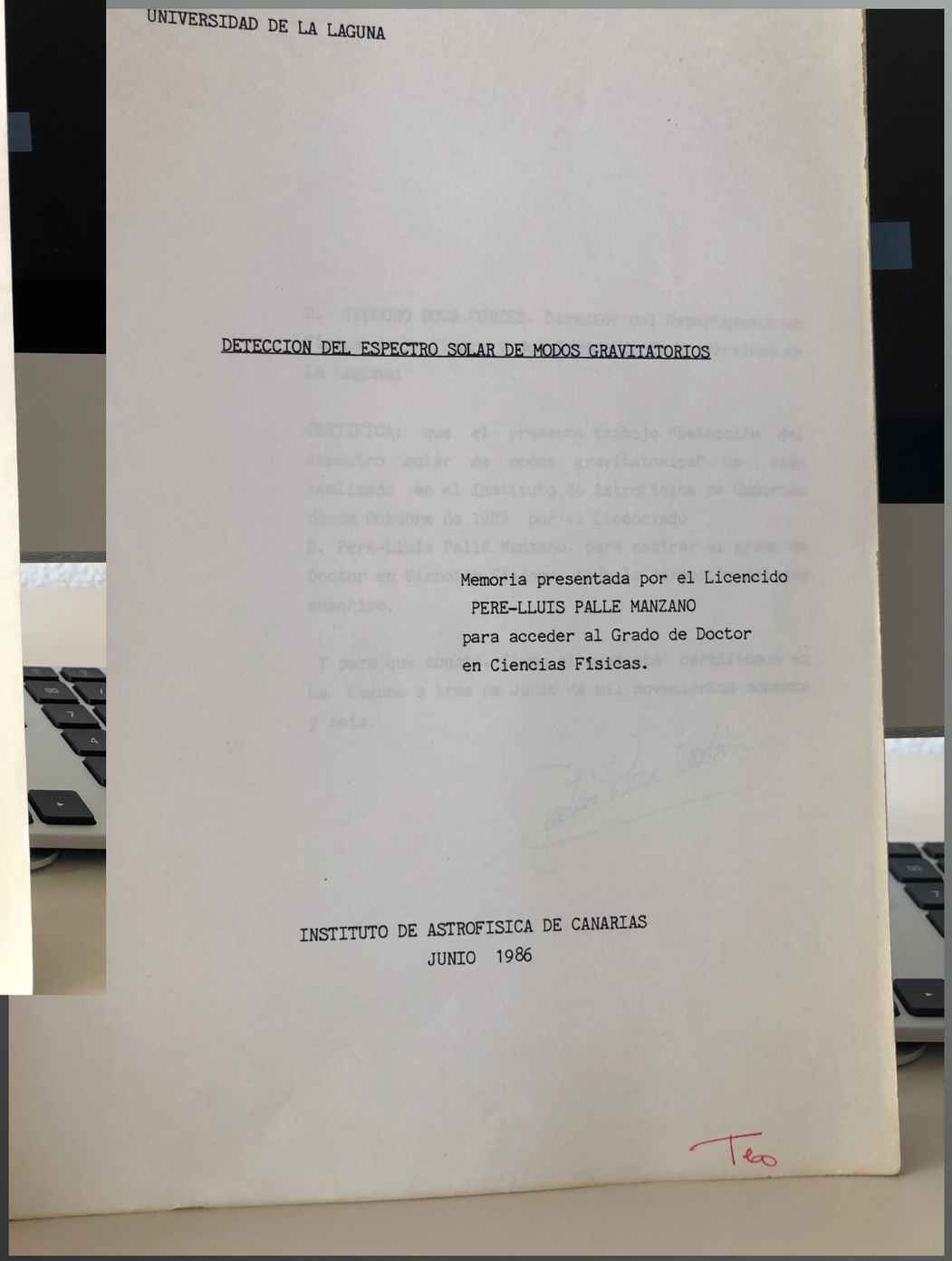
Fragile detection of solar g-modes

Hannah Schunker

Jesper Schou, Patrick Gaulme, Laurent Gizon

Long Controversial History

Using 4 consecutive years of Mark-I observations (the only node of the BiSON network from 1976 till 1992) at Observatorio del Teide



Hannah Schunker

Overview

1. Reproducing Fossat et al. 2017

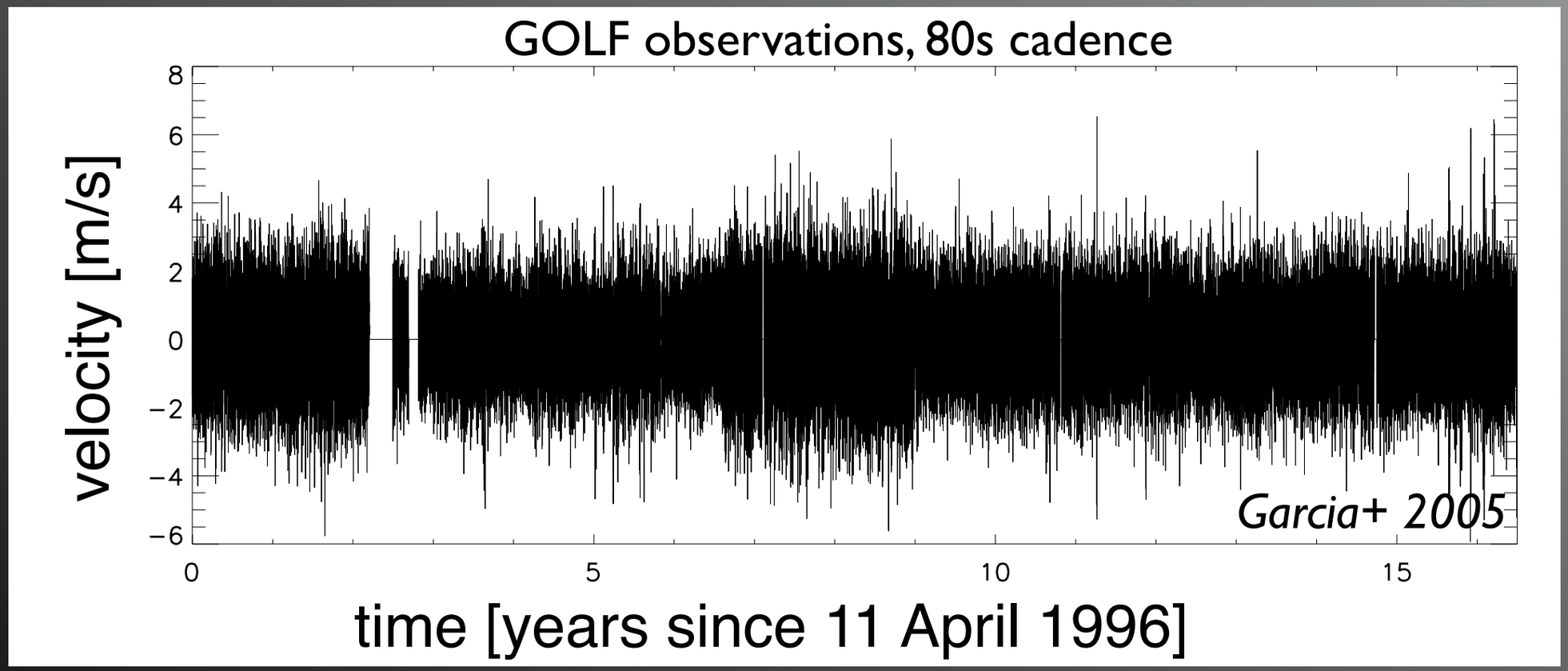
2. Sensitivity to parameters
   i. Fitting function to measure RTTT
   ii. Smoothing of AC
   iii. Start time of data series
   iv. Cadence of RTTT measurements

3. MC parameter study

Observations

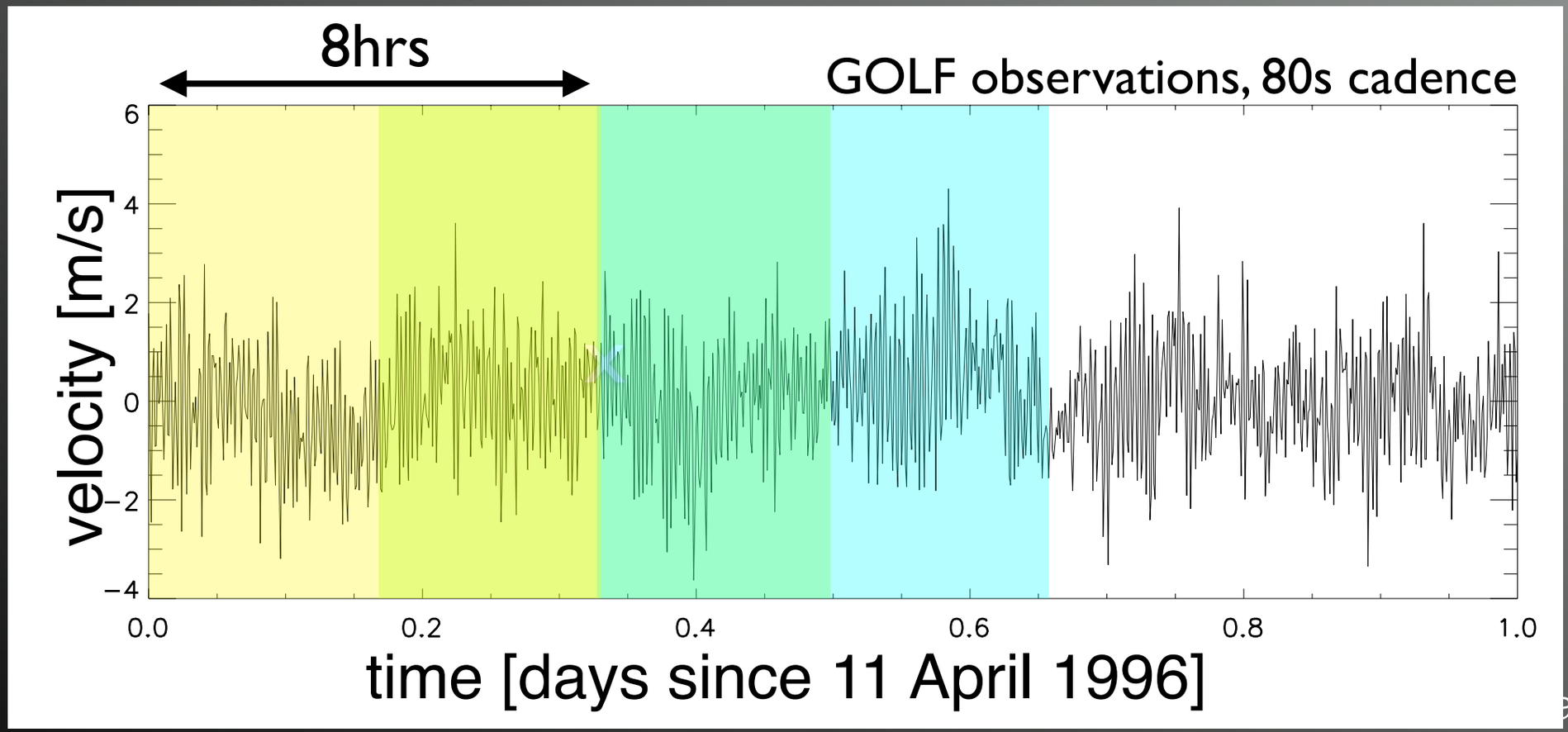
Global Oscillations at Low Frequencies (GOLF) onboard ESA's Solar and Heliospheric Observatory (SOHO)

16.5 years, 80 second cadence *Garcia et al. 2005*



Reproducing Fossat

- Measure changes to the round-trip travel-time (RTTT) of the *p*-modes over this 16 years of observations
- Divide the data series into segments 8 hours long, with a 4 hour cadence (36130)
- Zero-pad up to 10^6 seconds (278 hours)



Reproducing Fossat

Compute the FT of each 8-hour padded segment
Compute the mean 8-hour PS
Fit a Gaussian between 1.5 - 5 mHz

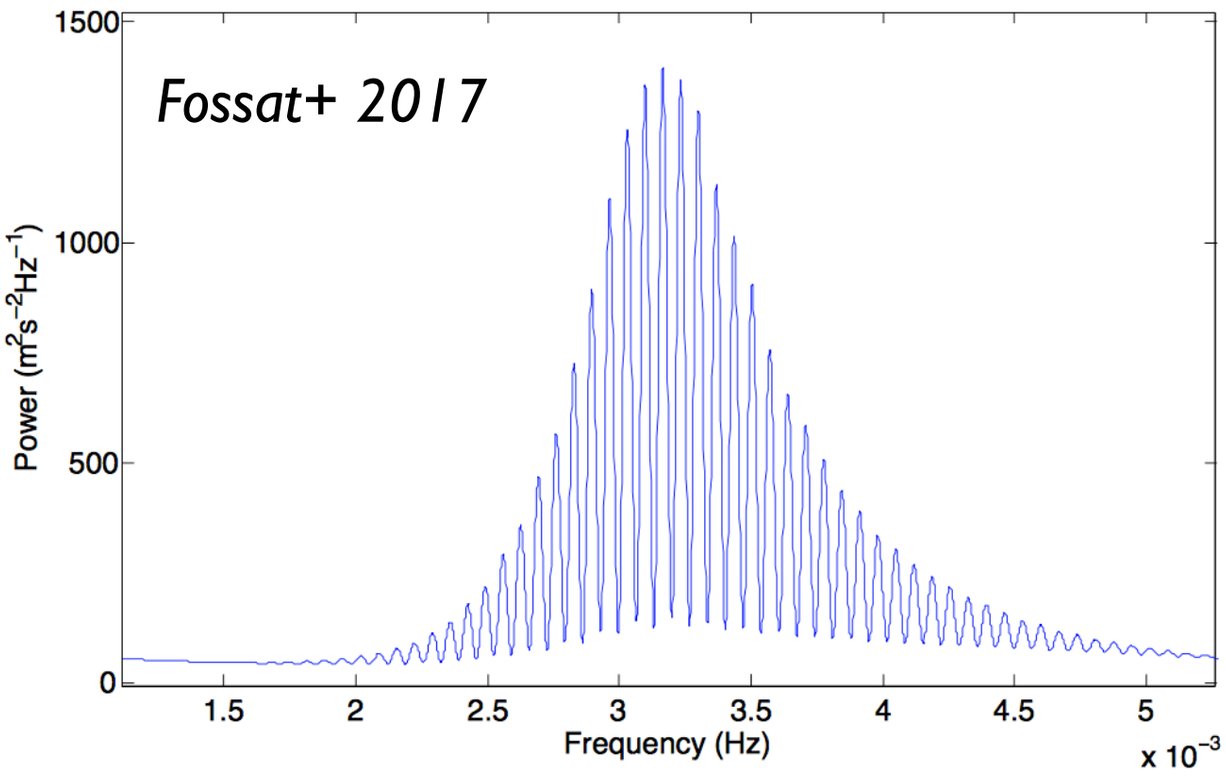
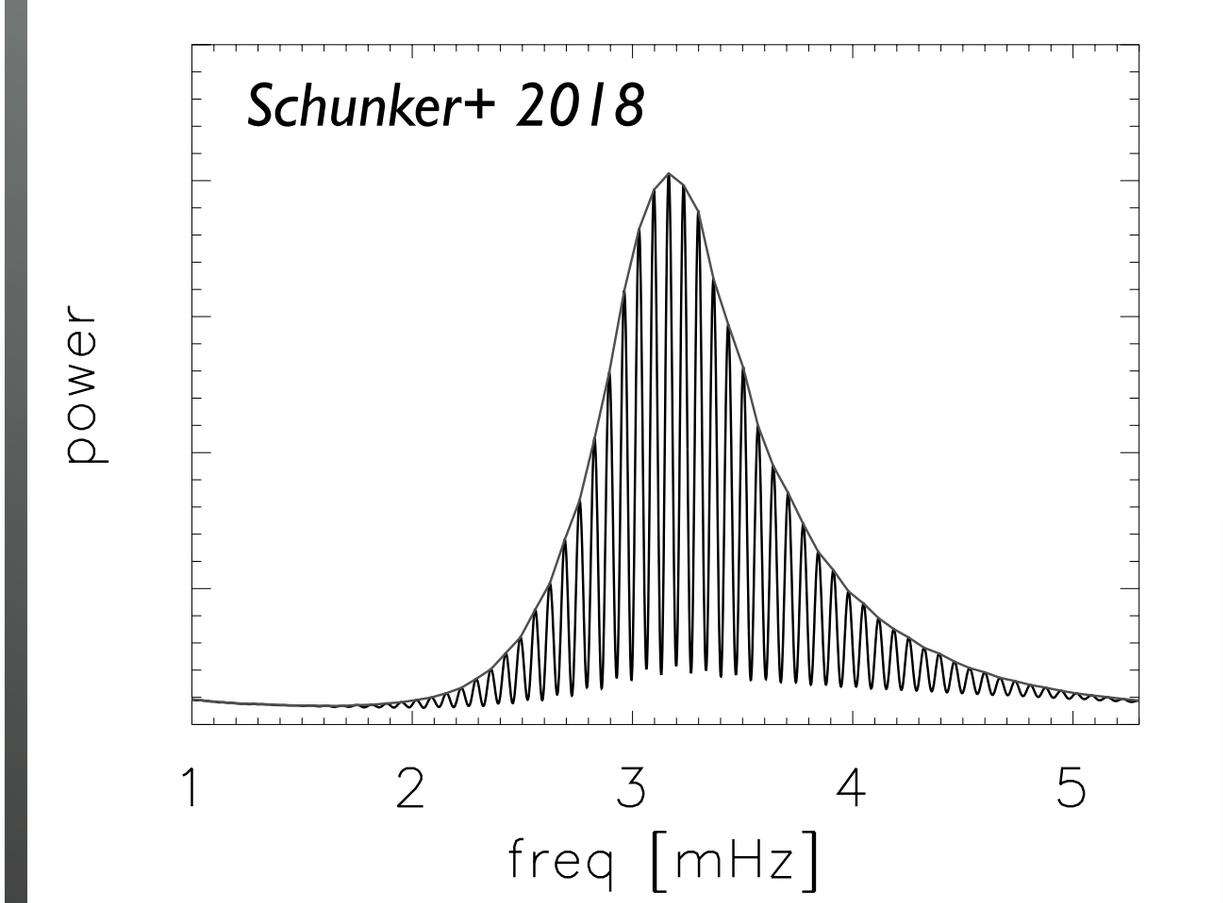


Fig. 2. From the same 16.5-year data set as Fig. 1, this is an average of 34 612 spectra computed from 8-h selections taken at intervals of 4 h.



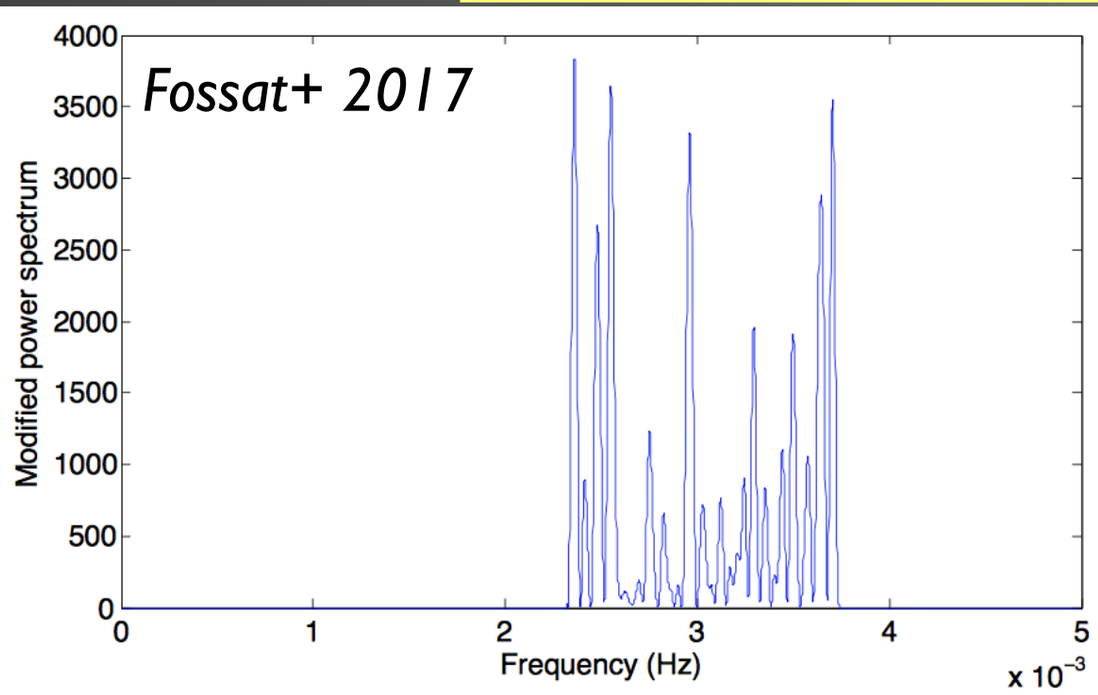
Reproducing Fossat

For each 8 hour segment, FT and filter for low-frequency *p*-modes

Normalise by the Gaussian fit

Shift to zero frequency, zero pad 125 mHz, FT

regular spacing of the *p*-modes with same harmonic degree



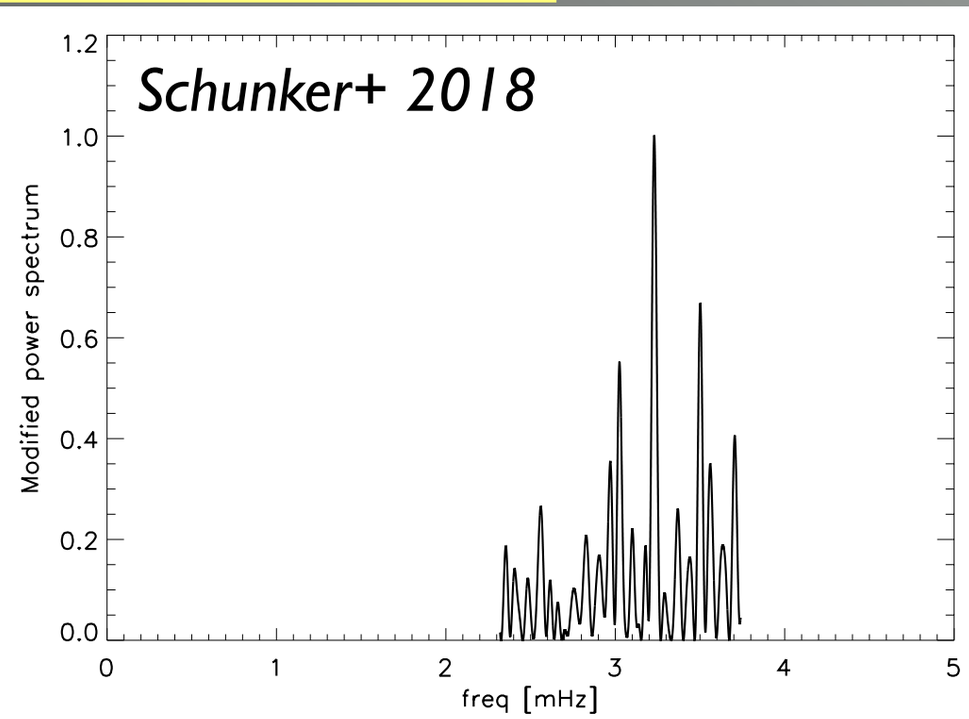
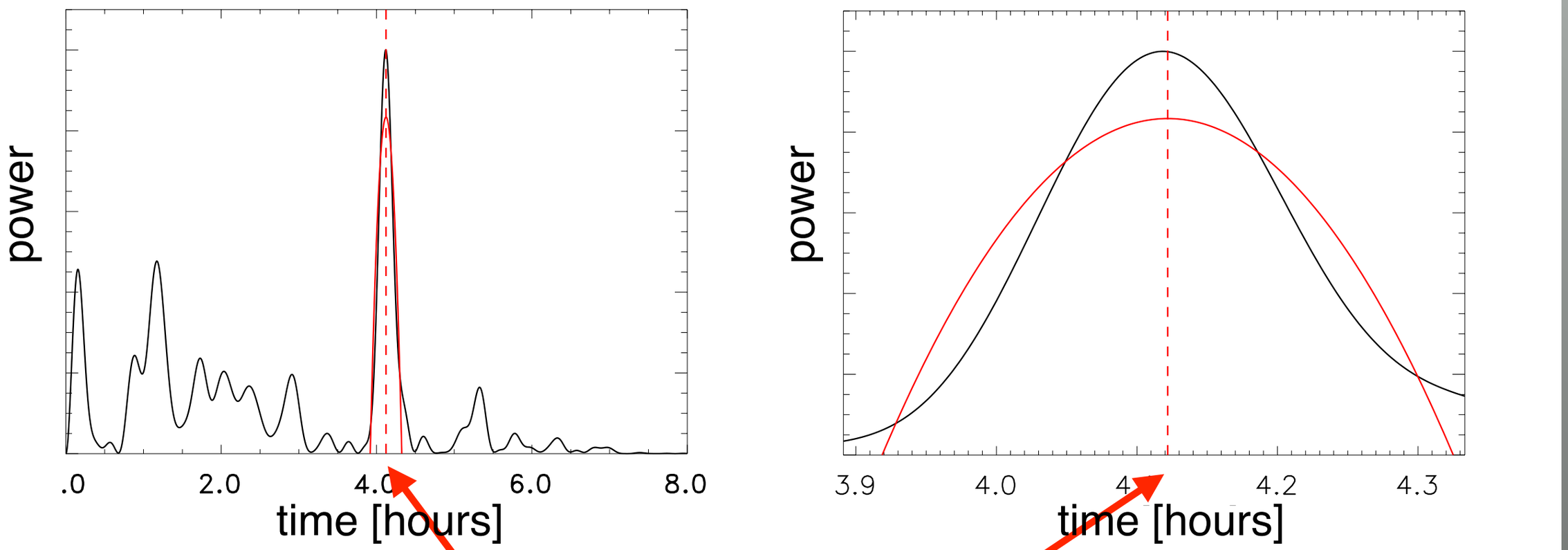


Fig. 3. Example of one of the 34612 GOLF power spectra, limited to the range 2.32–3.74 mHz and divided by the envelope of the mean spectrum of Fig. 2.

Test: Measuring RTTT

- Measure the RTTT by least-squares fitting a quadratic function (4 hours 3 minutes) for each 8 hour segment



Schunker+ 2018

Round Trip Travel Time

Reproducing Fossat

- Compare average temporal power spectrum

Average temporal power spectrum

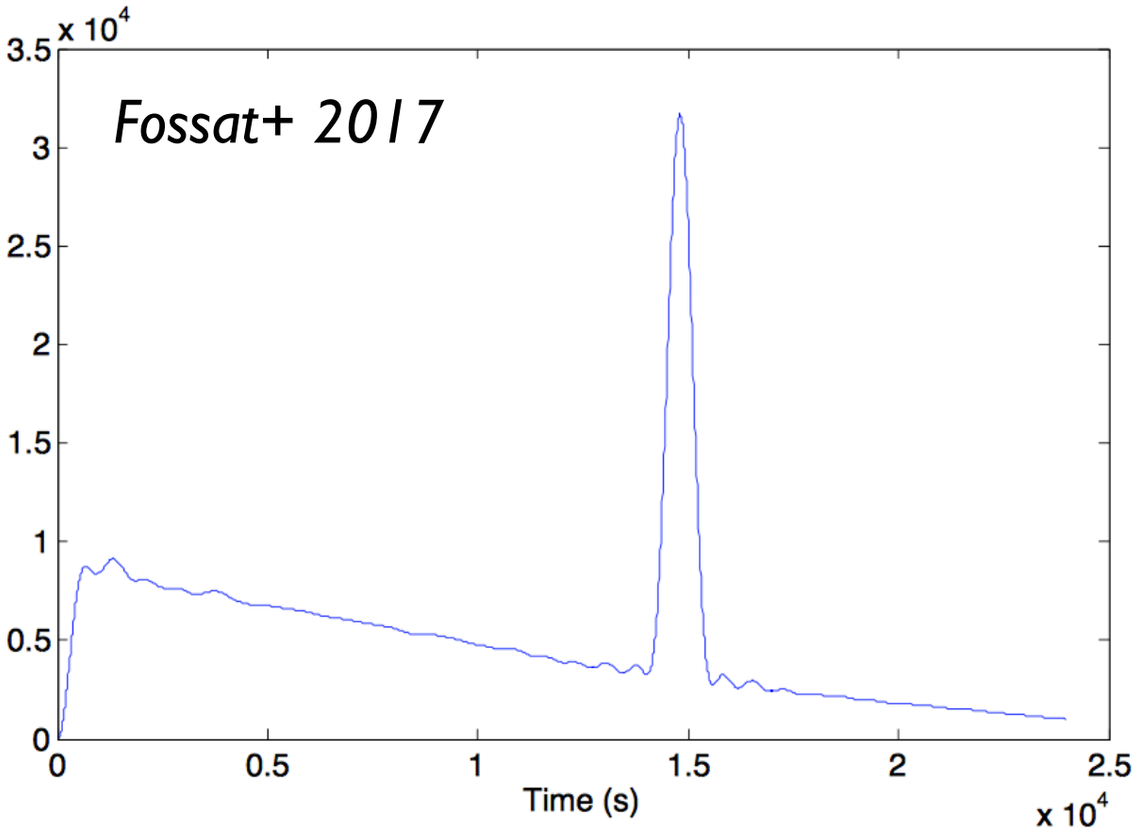
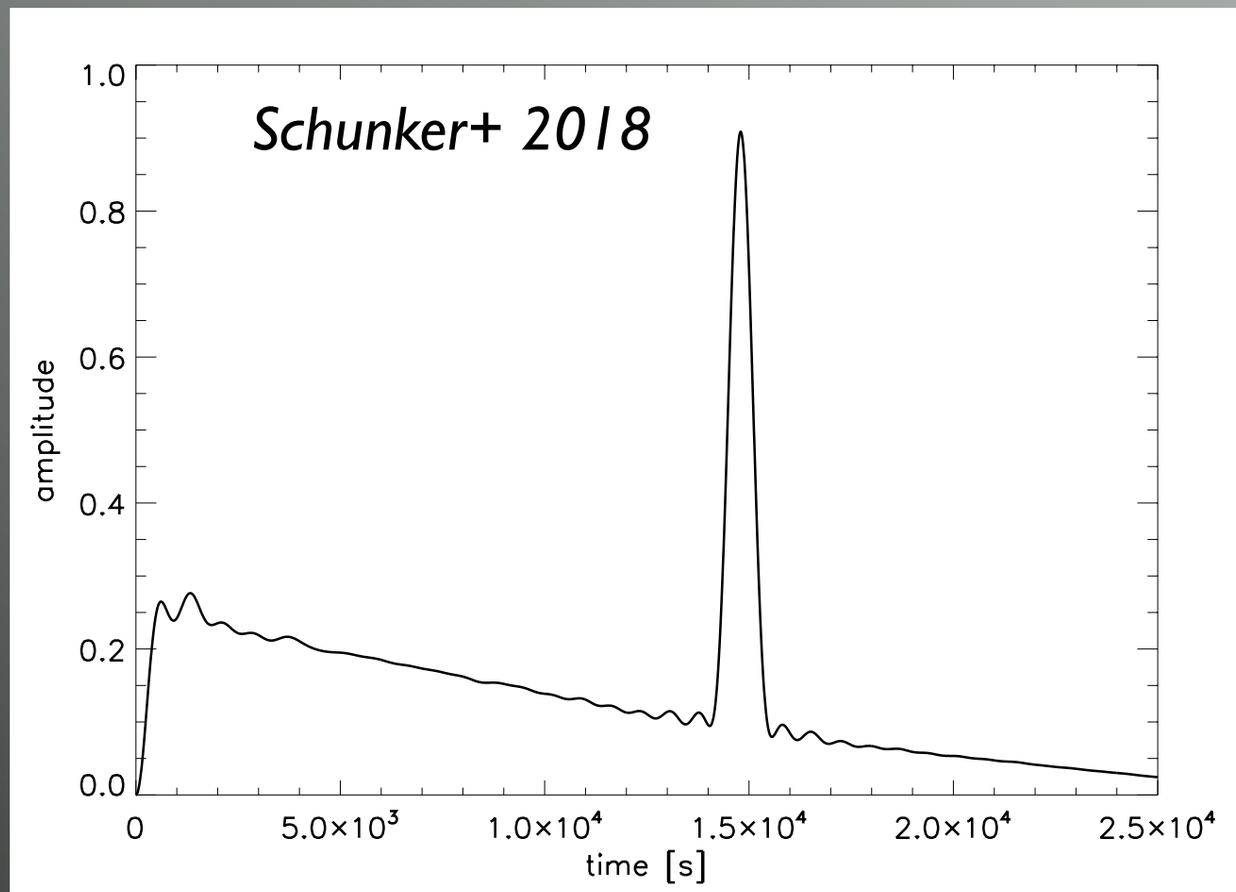


Fig. 5. Sum of 34 612 power spectra similar to the spectrum shown in Fig. 4.



4 hours 3 minutes

Hannah Schunker

Reproducing Fossat

- 16.5 year long series of the RTTT at a 4 hour cadence (clipped at +/- 240s)

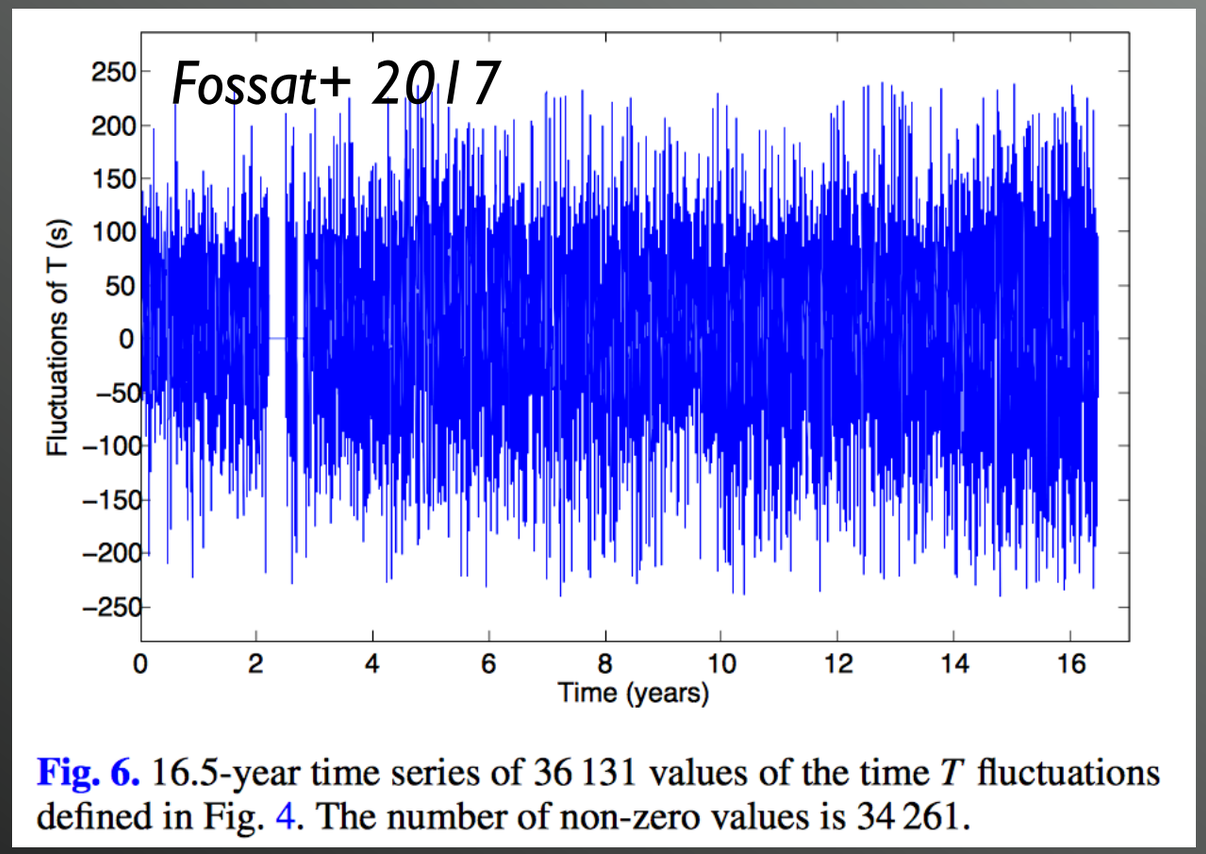
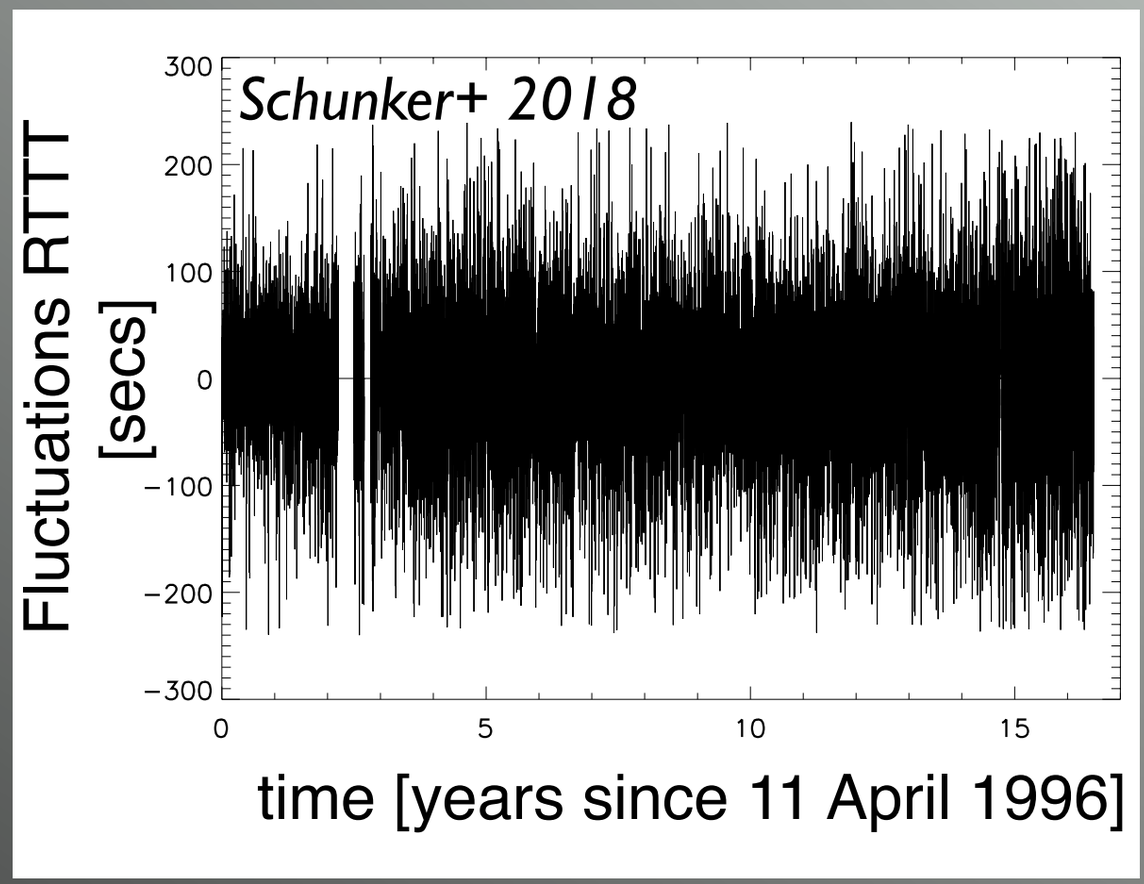


Fig. 6. 16.5-year time series of 36 131 values of the time T fluctuations defined in Fig. 4. The number of non-zero values is 34 261.



- Perturbations should vary at the frequency of the density perturbations to the core caused by the g-modes

Hannah Schunker

Reproducing Fossat

- Power spectrum should show the frequency at which the RTTT changes due to density perturbations of the core caused by g-modes

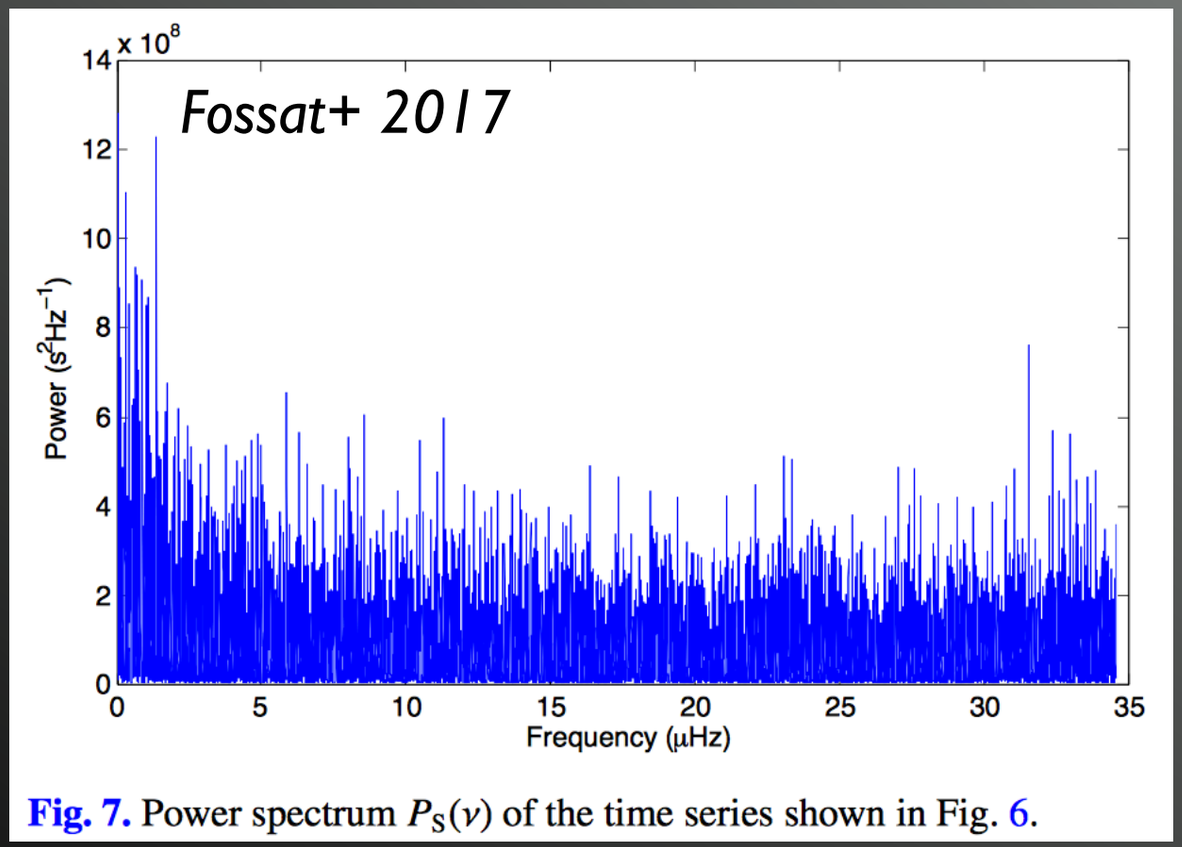
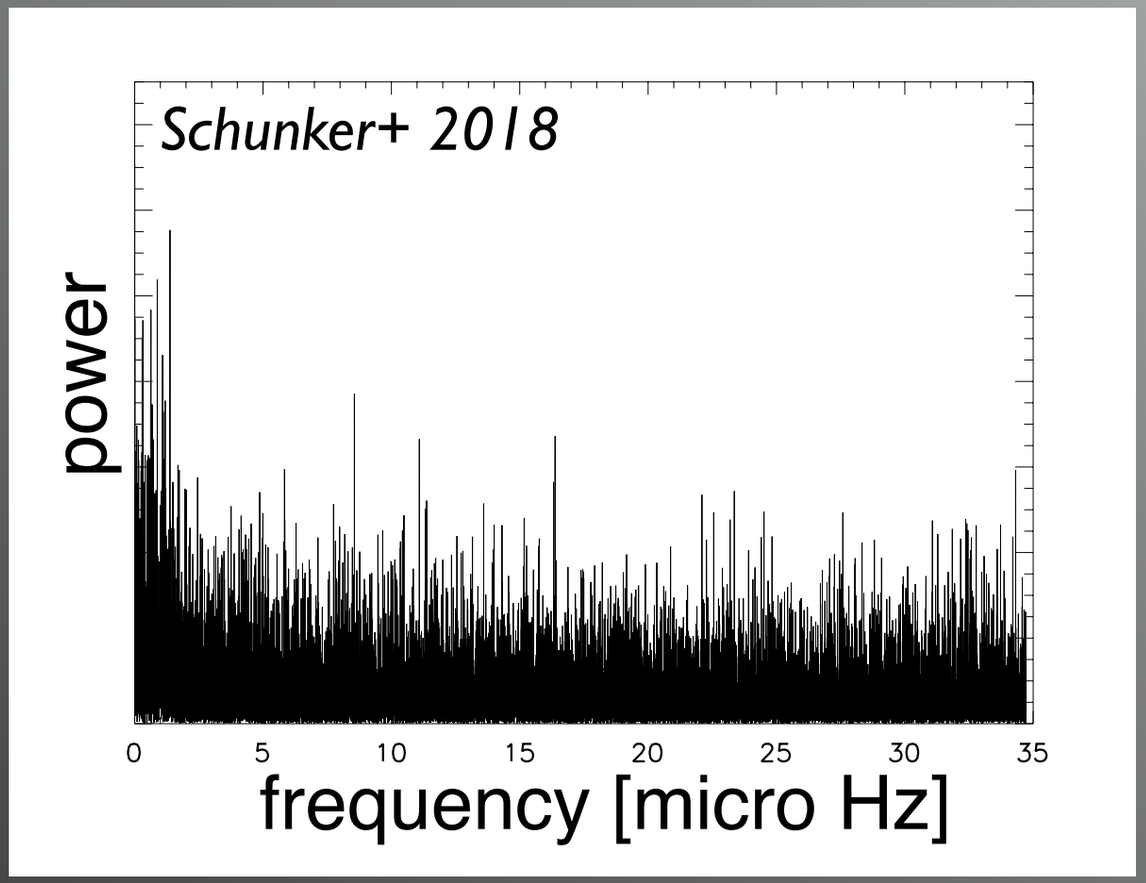


Fig. 7. Power spectrum $P_S(\nu)$ of the time series shown in Fig. 6.



Hannah Schunker

Reproducing Fossat

- Low frequency range looks similar.
No sign of SOHO orbit or solar cycle

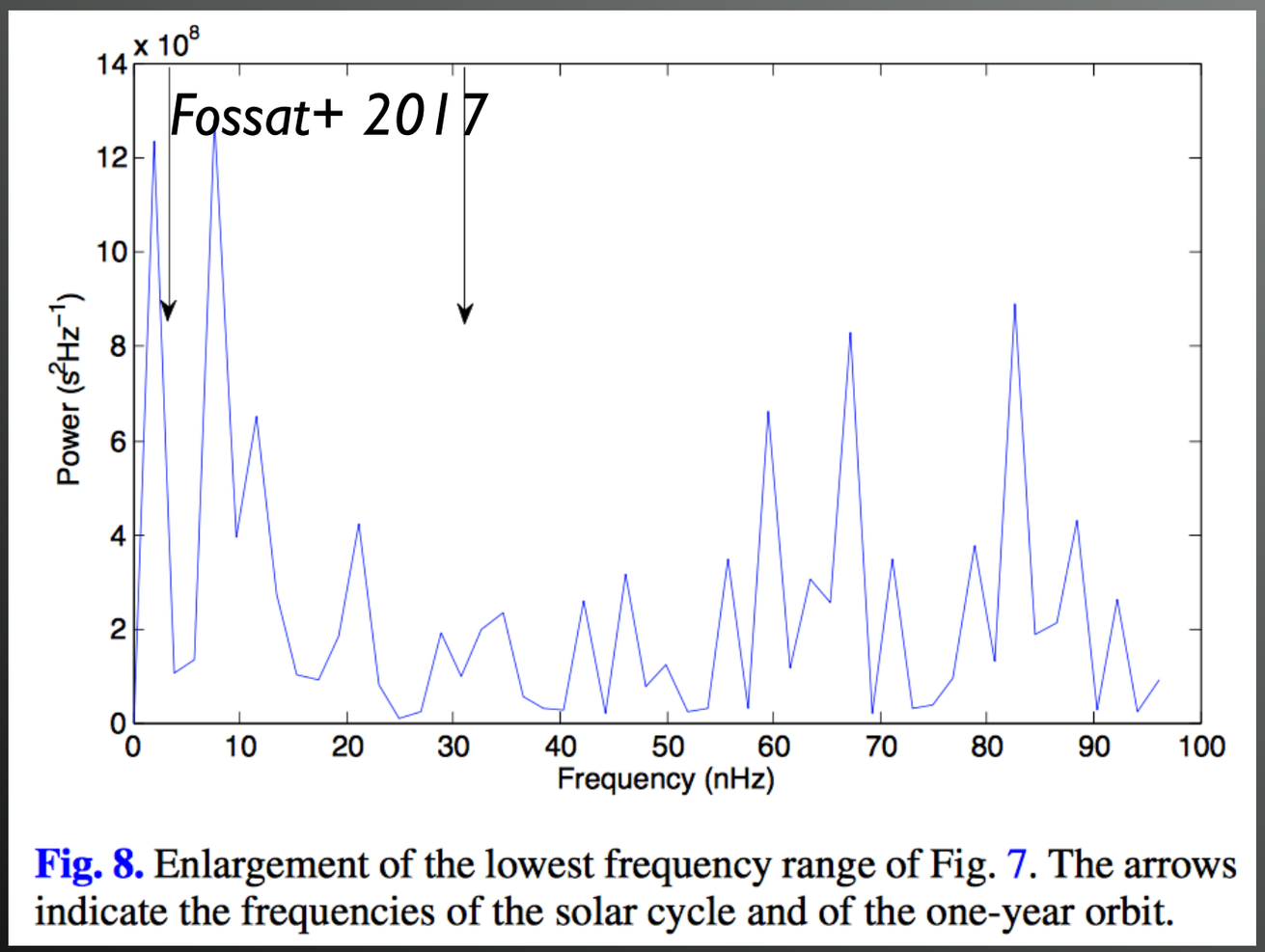
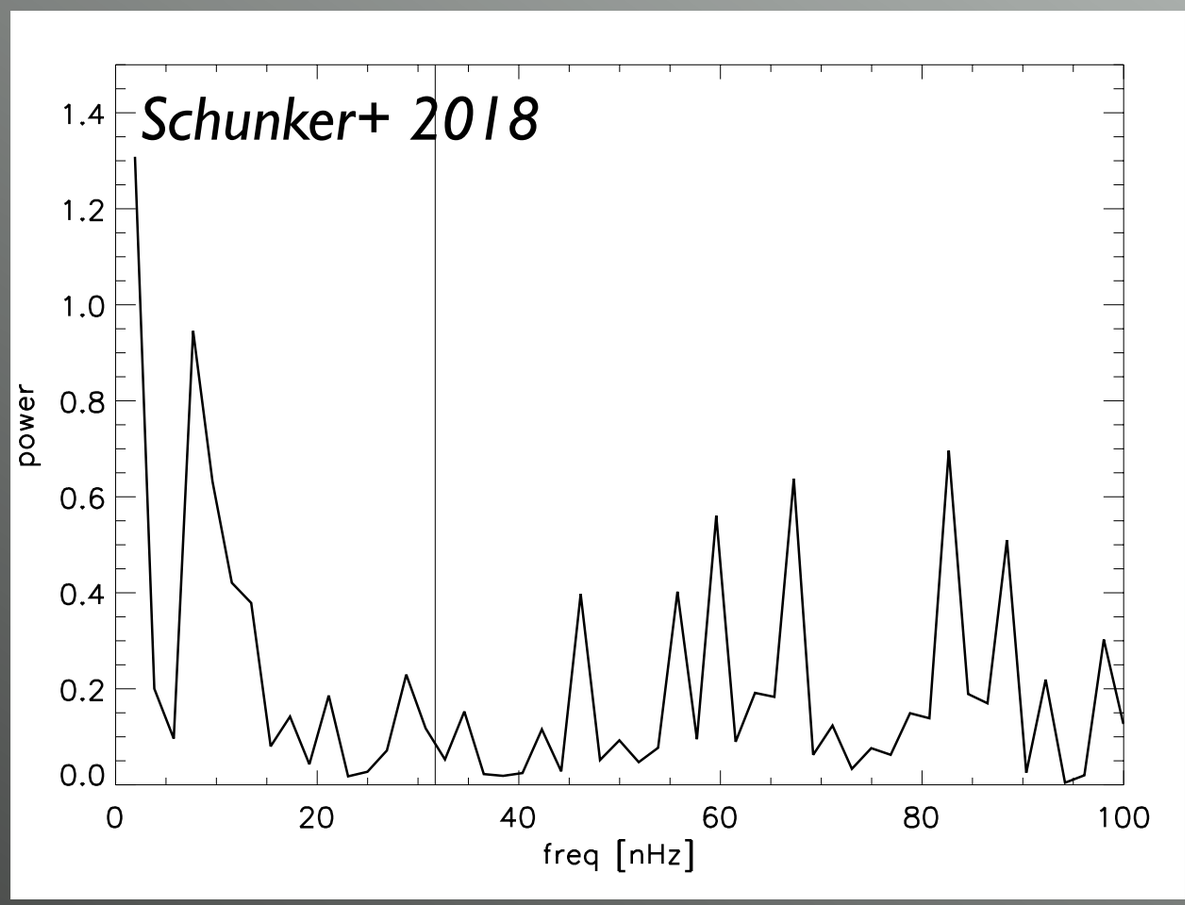


Fig. 8. Enlargement of the lowest frequency range of Fig. 7. The arrows indicate the frequencies of the solar cycle and of the one-year orbit.



Hannah Schunker

Reproducing Fossat

- Autocorrelate the power spectrum
- Peaks should correspond to rotational splittings; $\Omega_g = 1286\ \mathrm{nHz}$, 2.9 x Ω_p

Qualitative reproduction

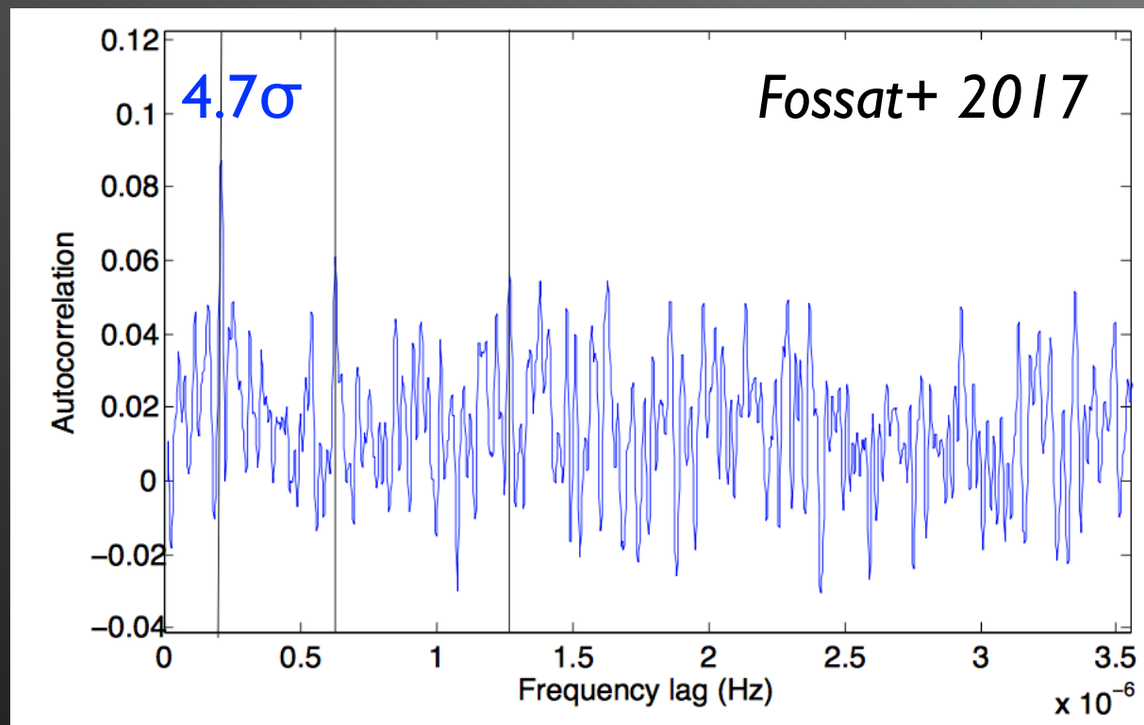
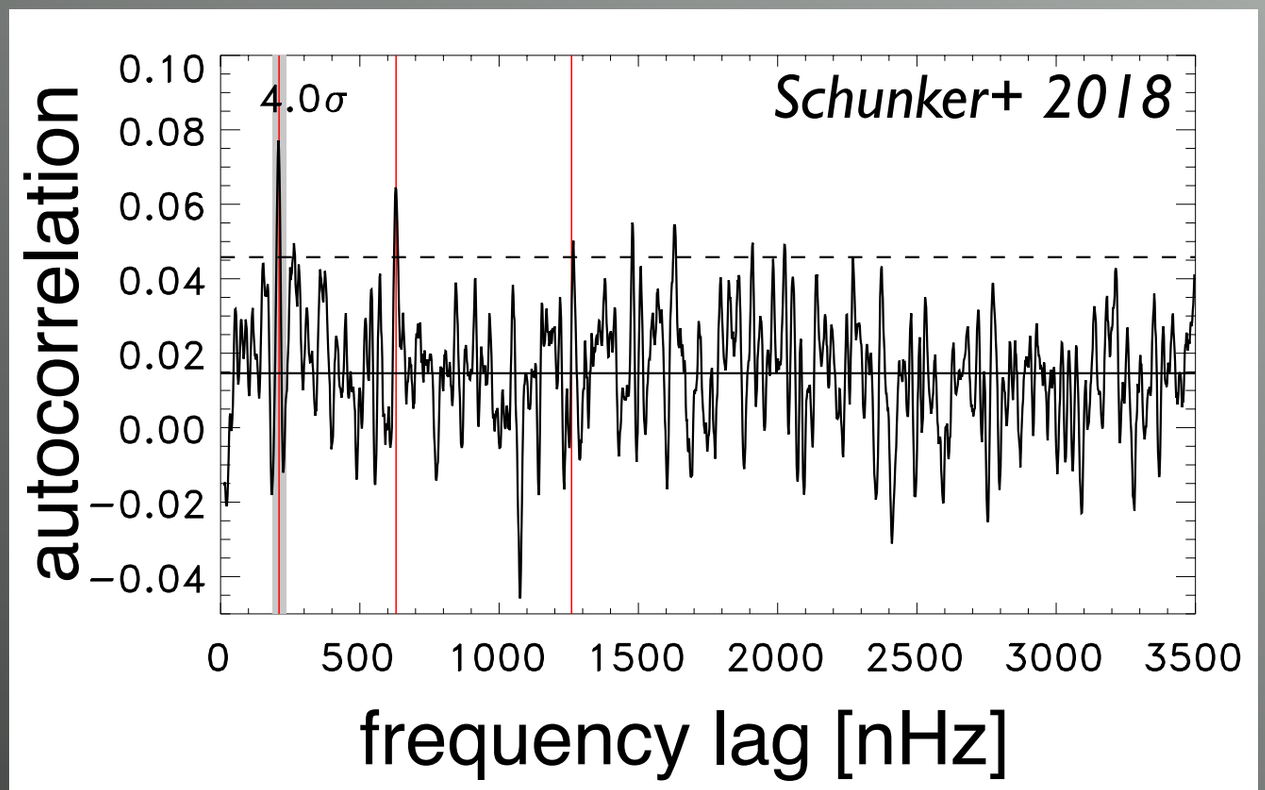


Fig. 10. Autocorrelation function $A(\nu)$ of the frequency range 5.5–34.7 μHz of the power spectrum shown in Fig. 7. The first value displayed is bin number 7, i.e., 0.013 μHz. The vertical lines are at 210, 630, and 1260 nHz.



Testing the Robustness

- Numerous subjectively chosen parameters
  - amount of data used (full 16.5 years)
  - cadence of the RTTT (4 hrs)
  - length of the segments (8 hrs)
  - amount of zero-padding (lots)
  - normalisation (Gaussian)
  - frequency band (2.32-3.74 mHz)
  - width to fit (800 seconds)
  - fitting function to measure RTTT (quadratic)
  - smoothing (6 pixels ~ 11 micro Hz)
  - …

Overview

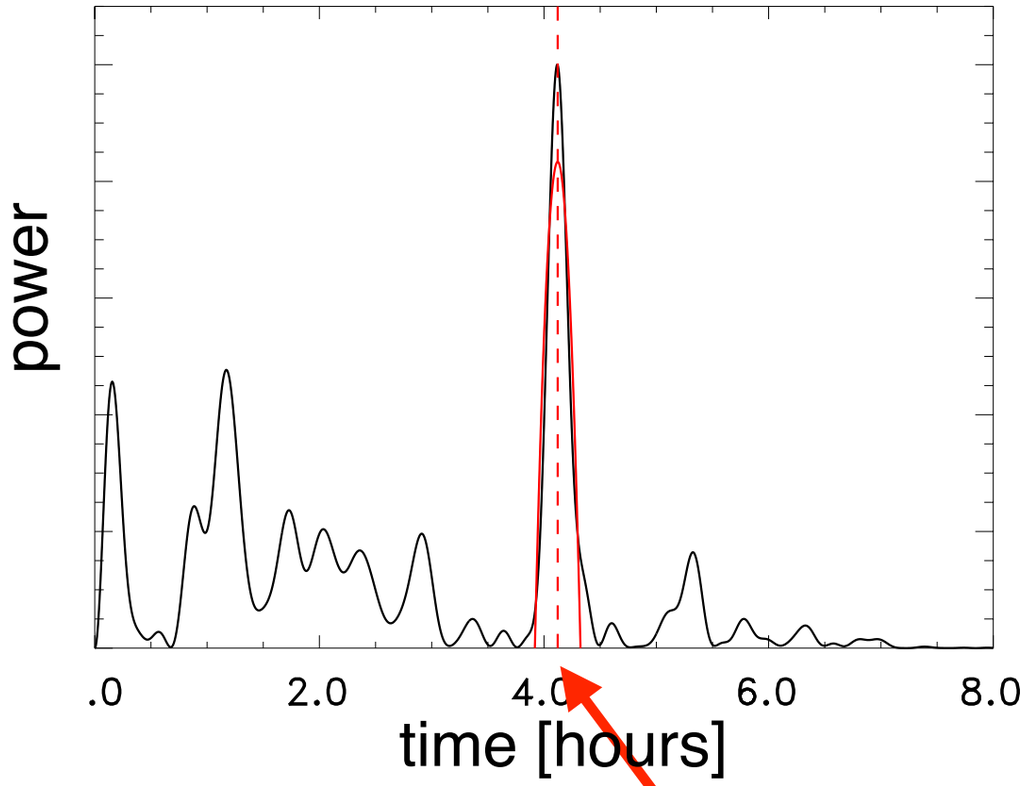
1. Reproducing Fossat et al. 2017

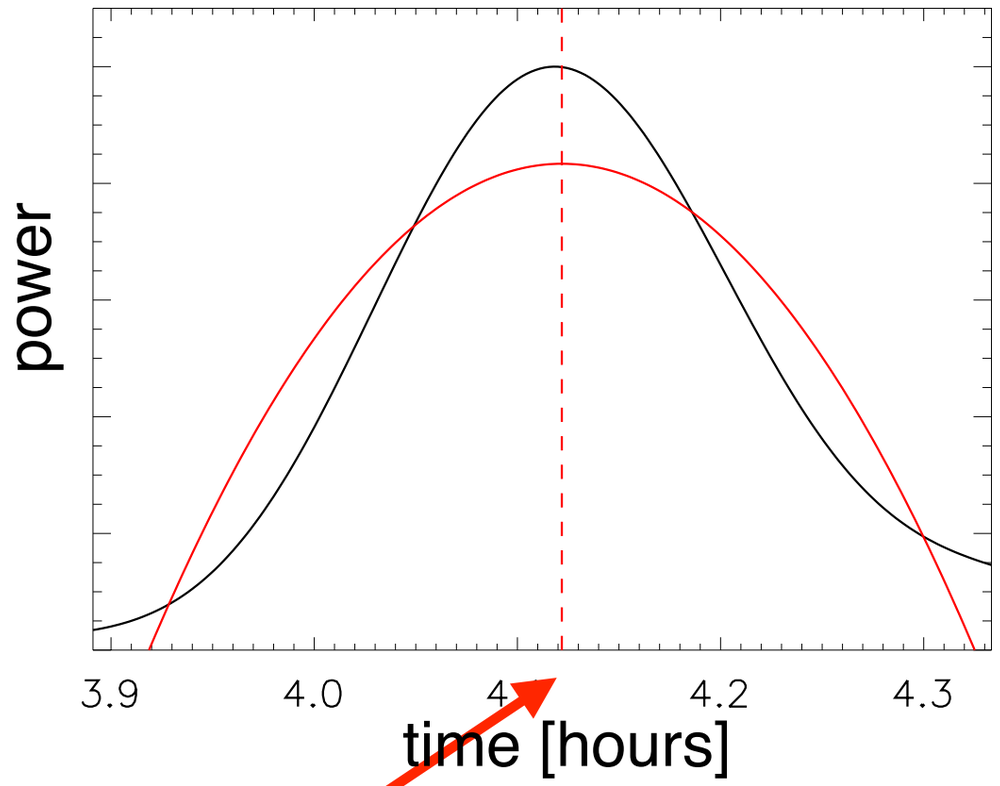
2. Sensitivity to parameters
   i. Fitting function to measure RTTT
   ii. Smoothing of AC
   iii. Start time of data series
   iv. Cadence of RTTT measurements

3. MC parameter study

Test: Measuring RTTT

- Measure the RTTT by fitting a quadratic function (4 hours 3 minutes)

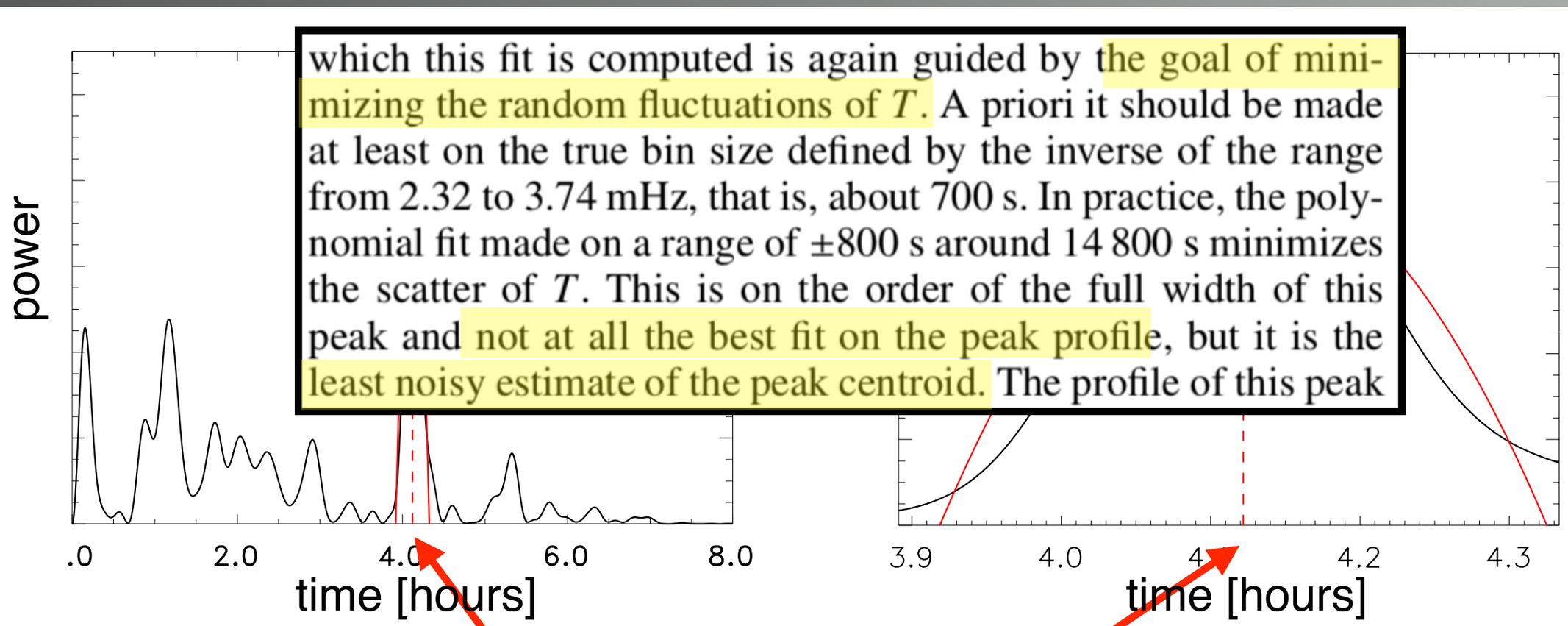




Round Trip Travel Time

Test: Measuring RTTT

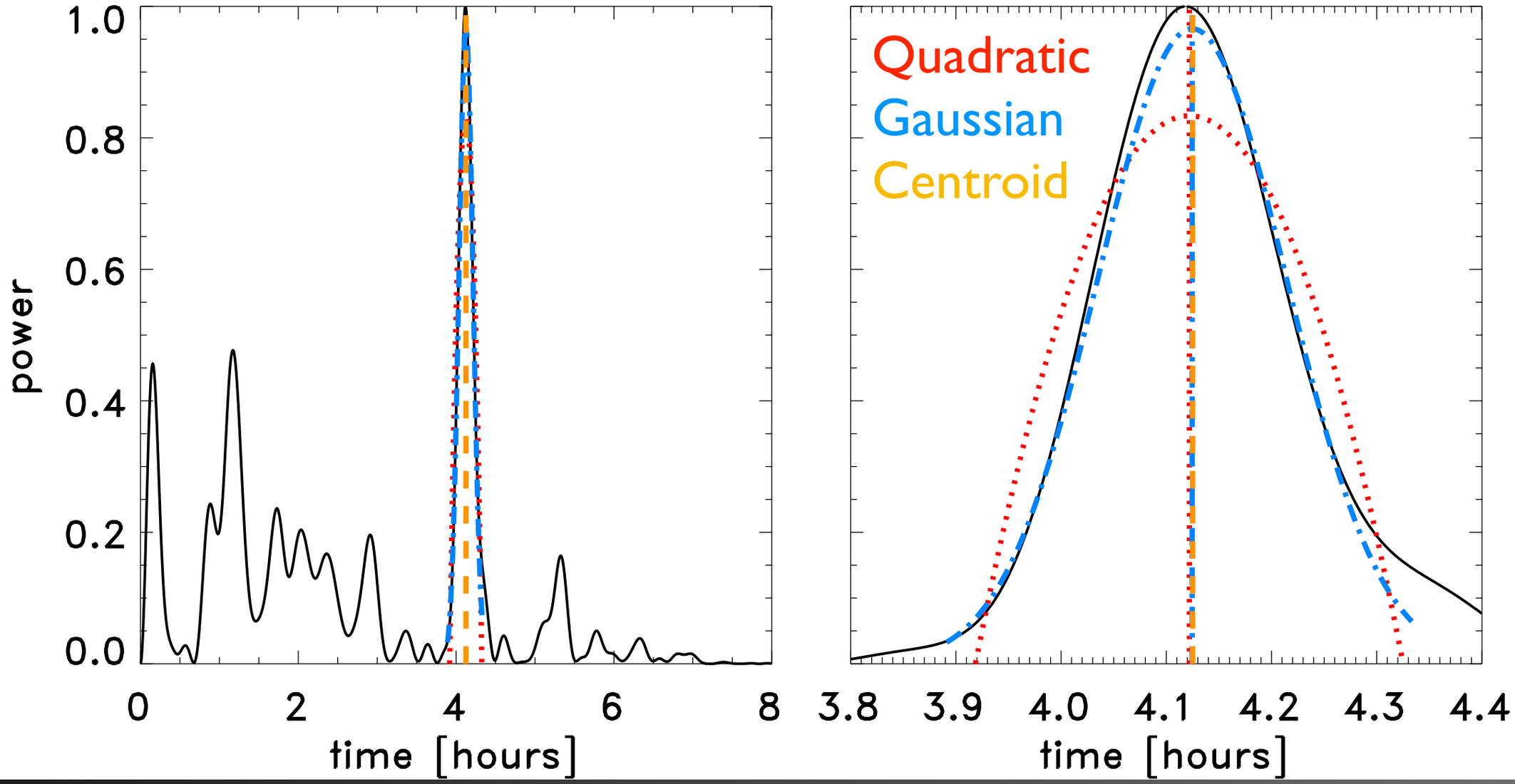
- Measure the RTTT by fitting a quadratic function (4 hours 3 minutes)



Round Trip Travel Time

Test: Measuring RTTT

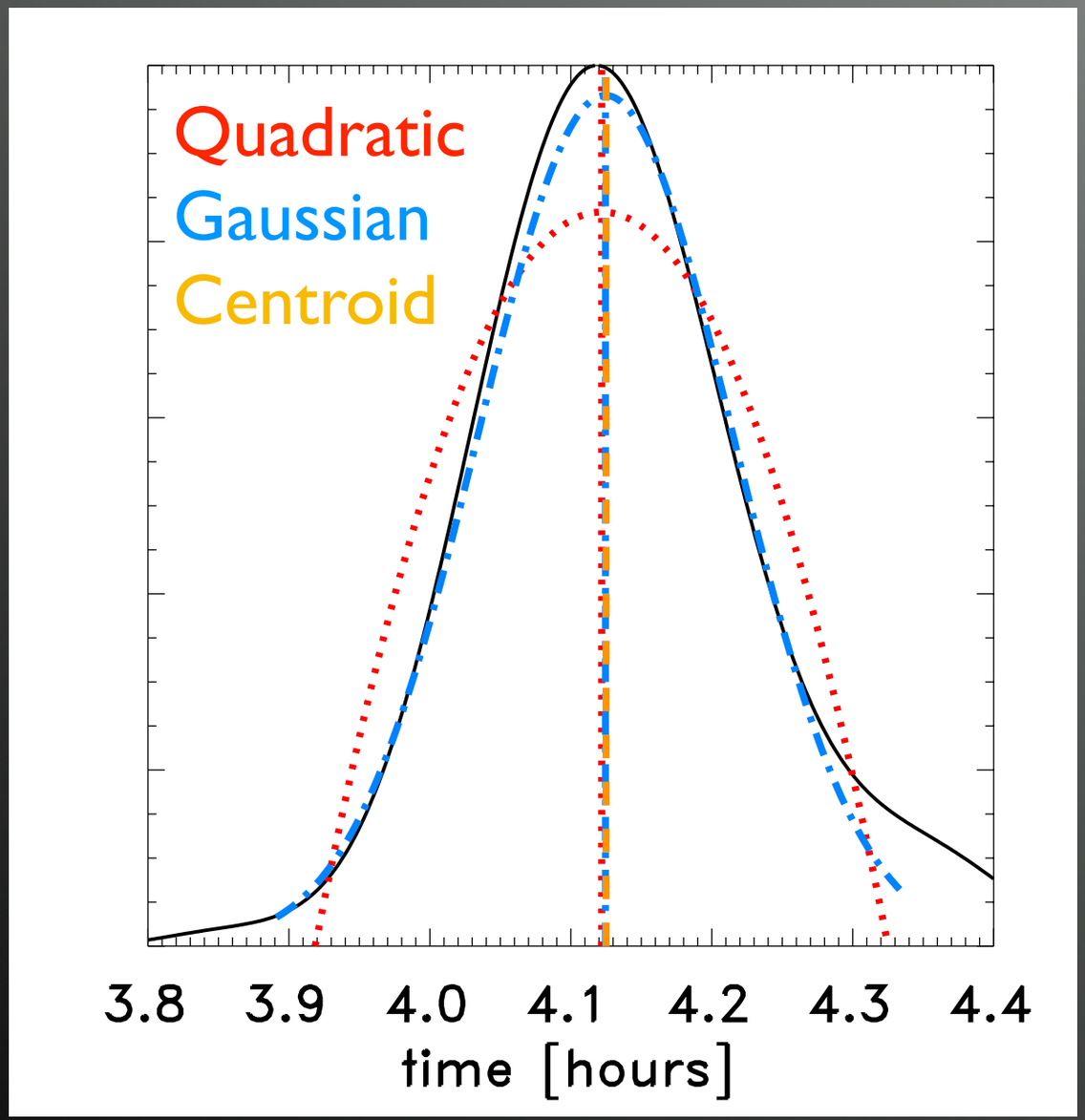
- Try other fitting functions

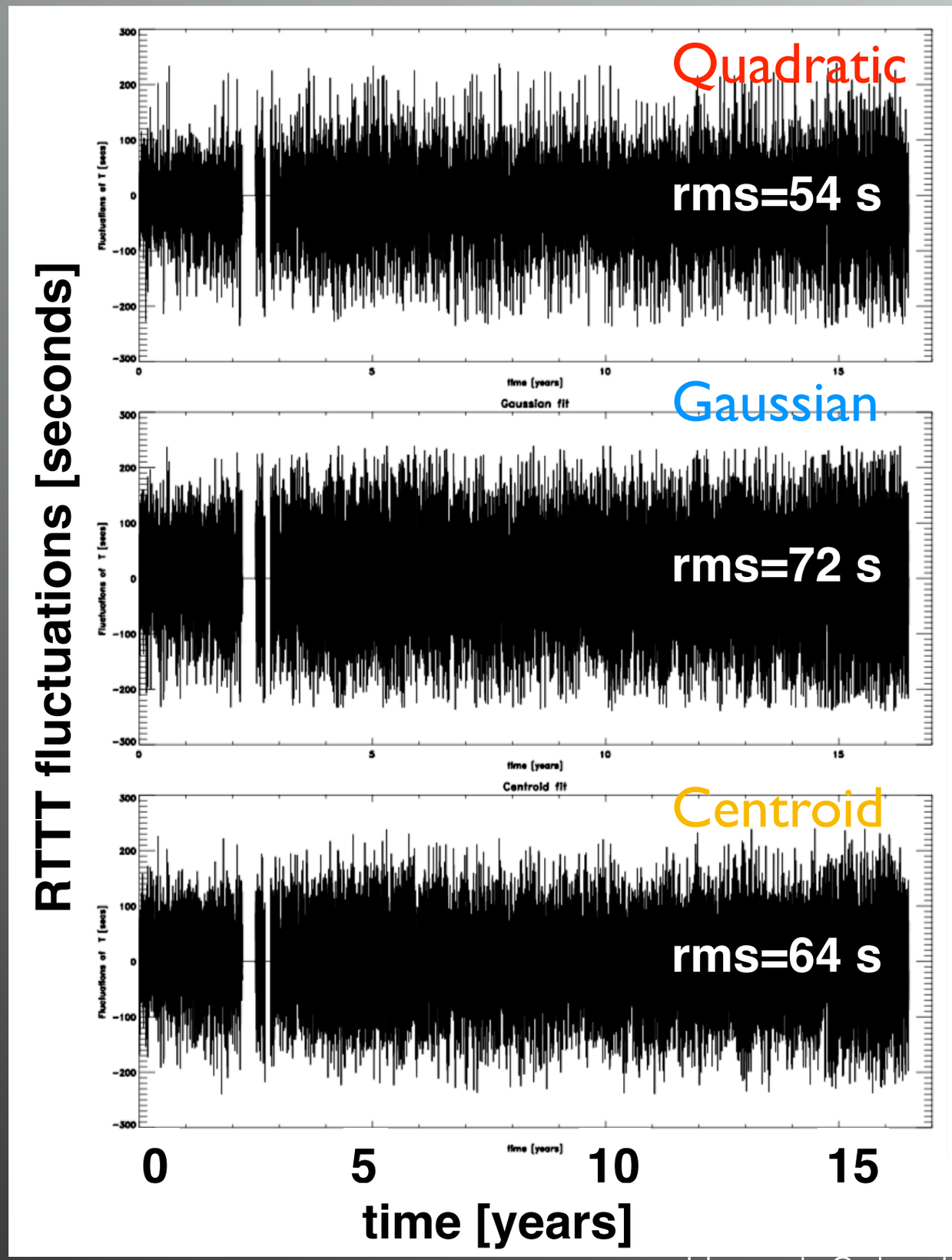


Example of one 8 hour segment

Test: Measuring RTTT

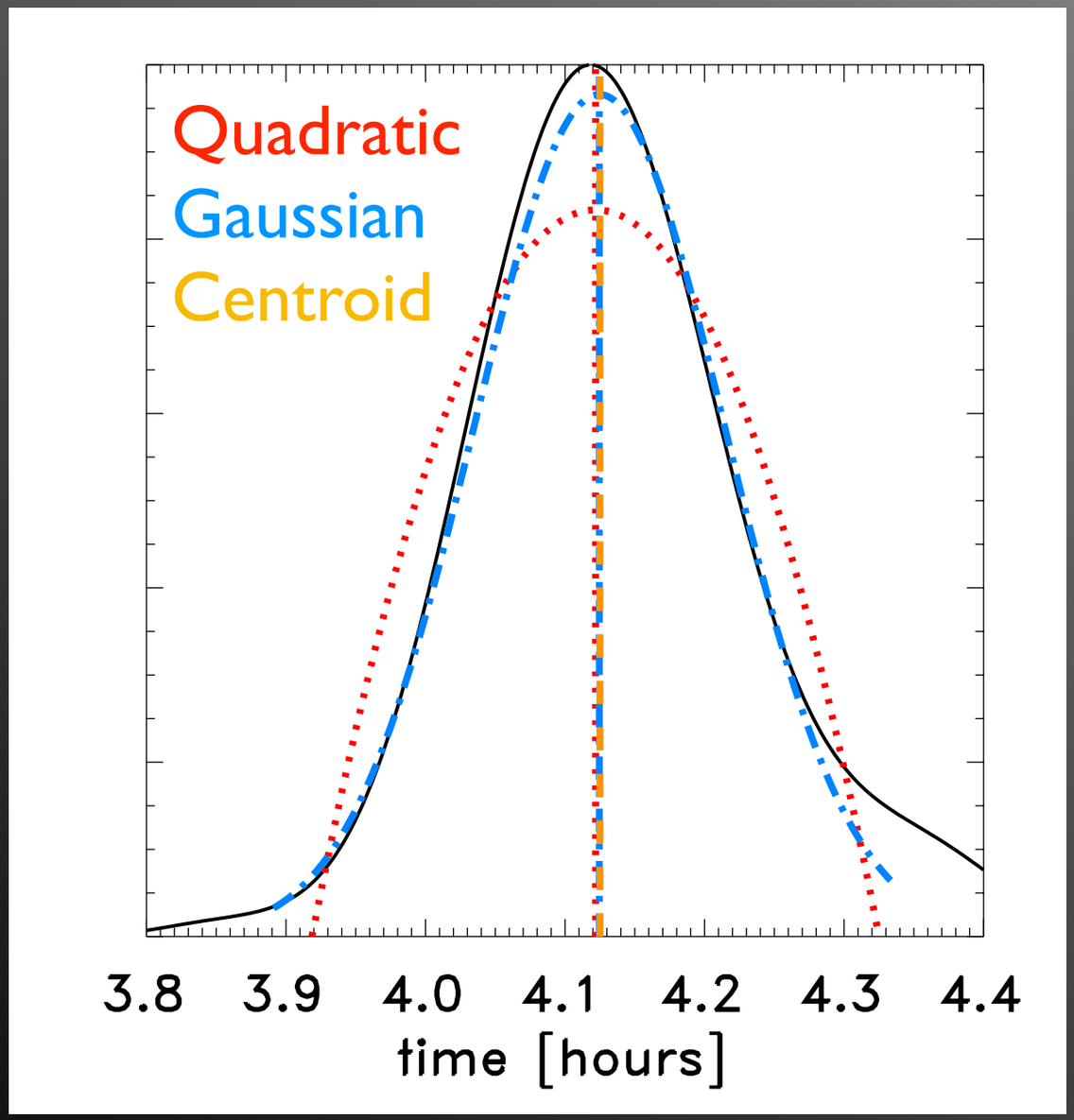
- Try fitting other functions
- Clip at +/- 240s

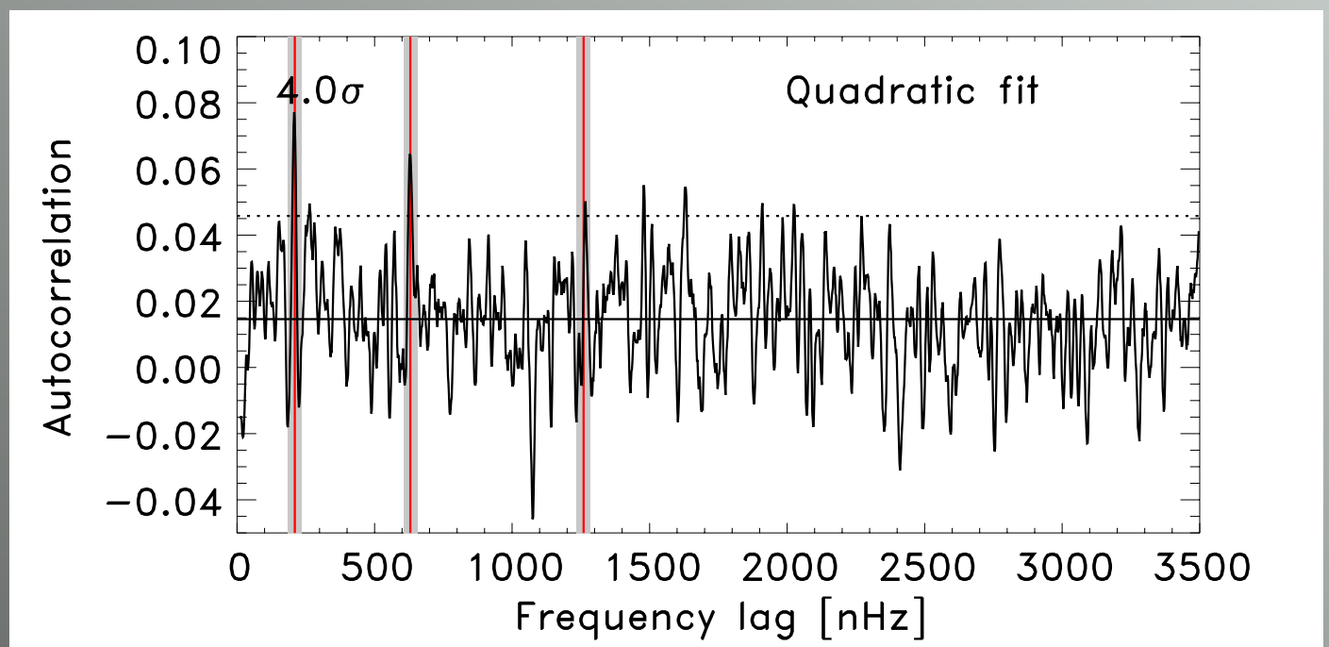




Test: Measuring RTTT

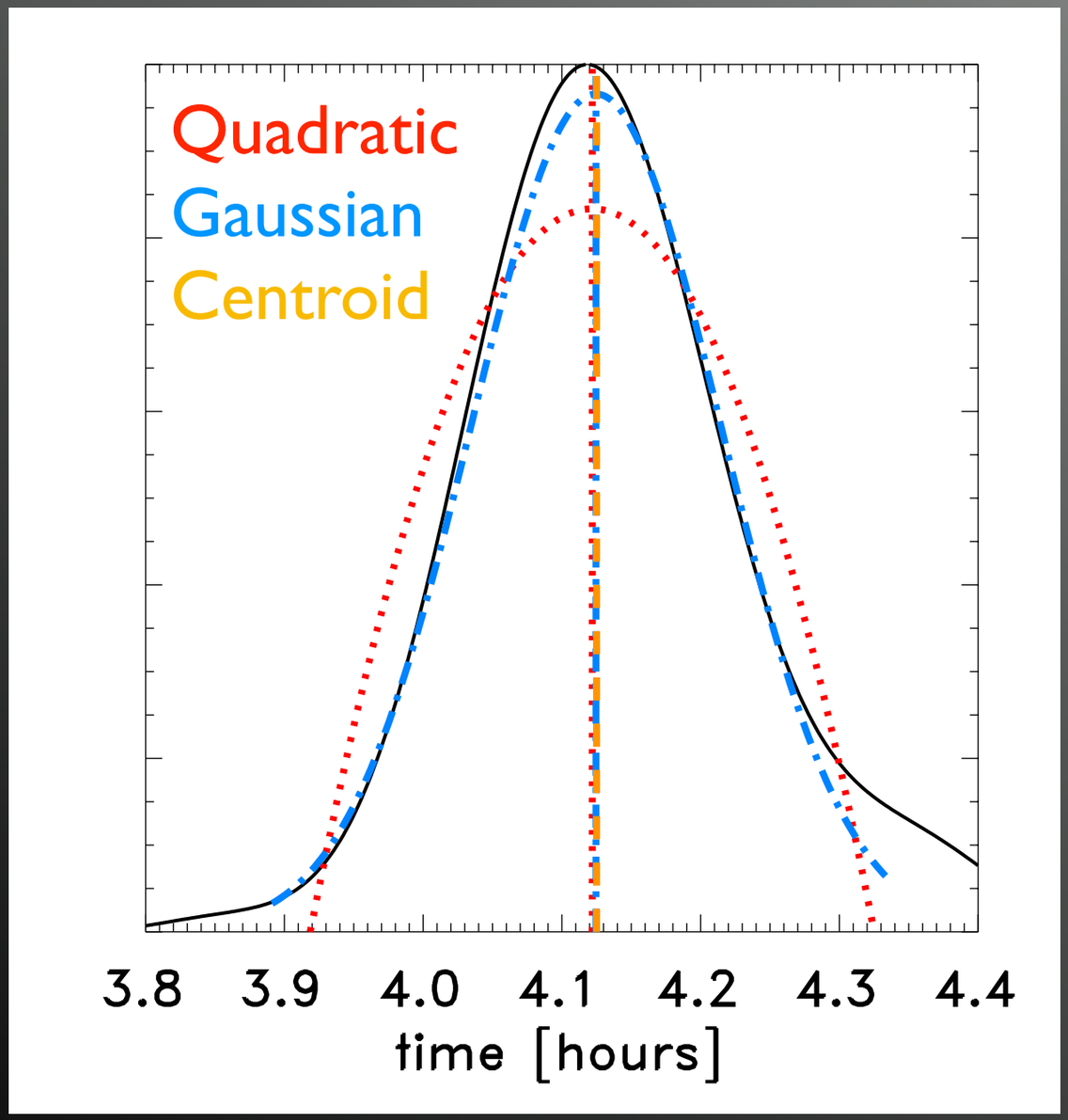
- Try fitting other functions

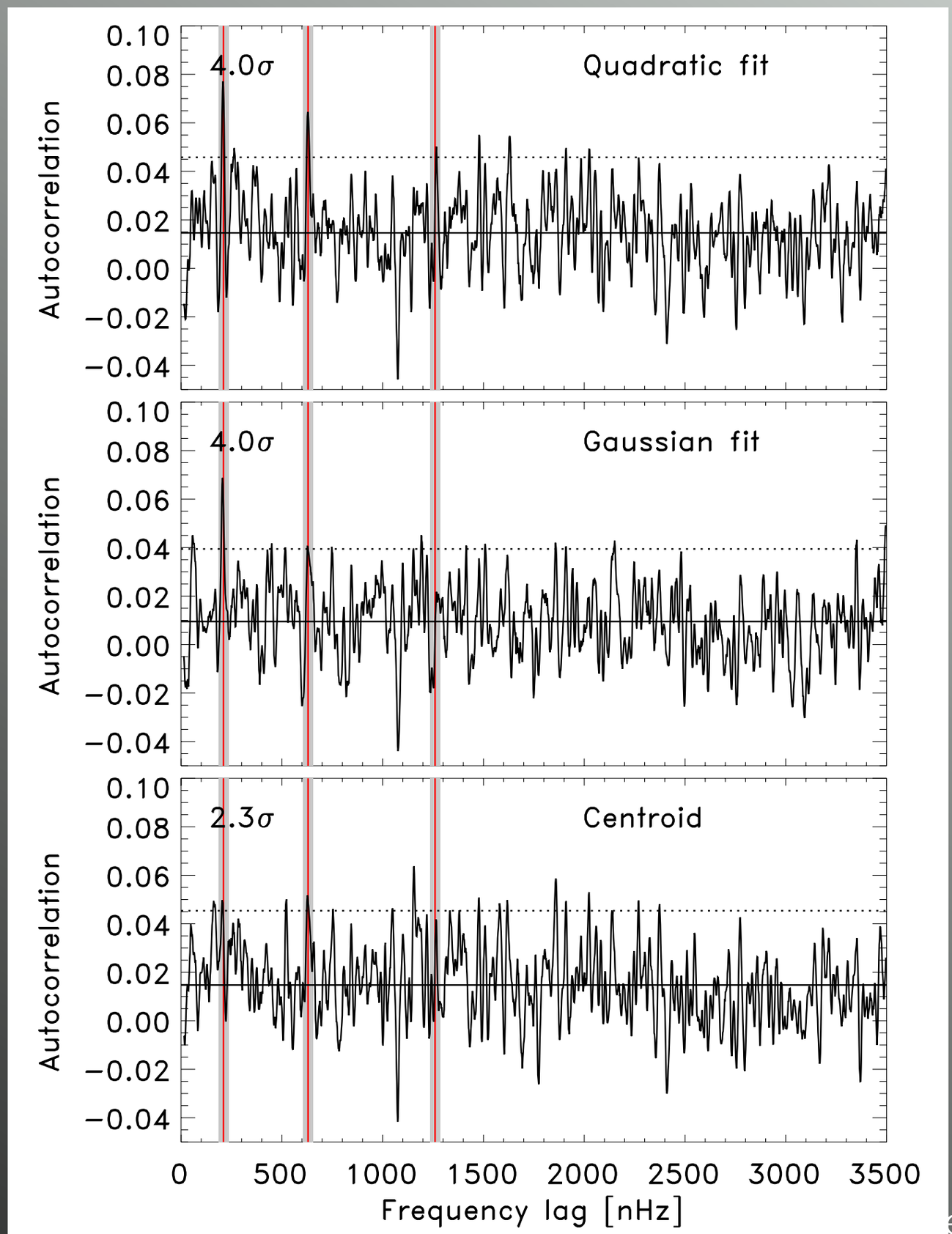




Test: Measuring RTTT

- Try fitting other functions





Overview

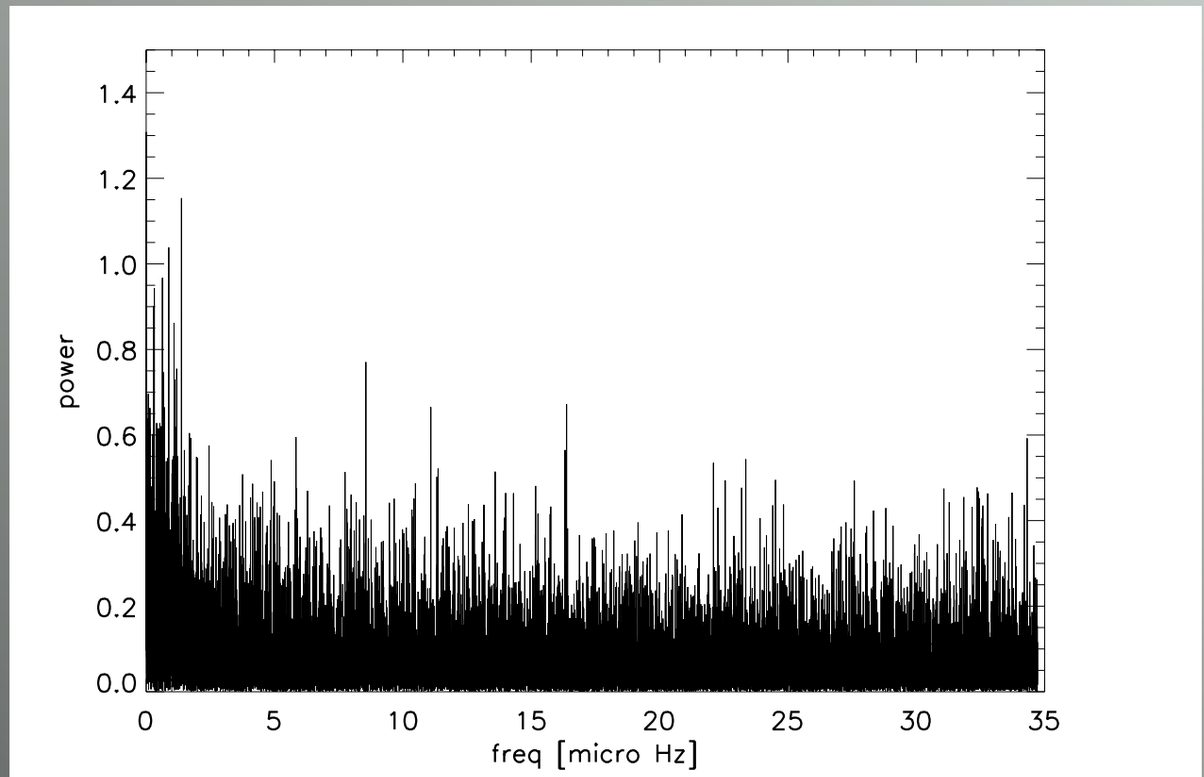
1. Reproducing Fossat et al. 2017

2. Sensitivity to parameters
   i. Fitting function to measure RTTT
   ii. Smoothing of power spectrum
   iii. Start time of data series
   iv. Cadence of RTTT measurements

3. MC parameter study

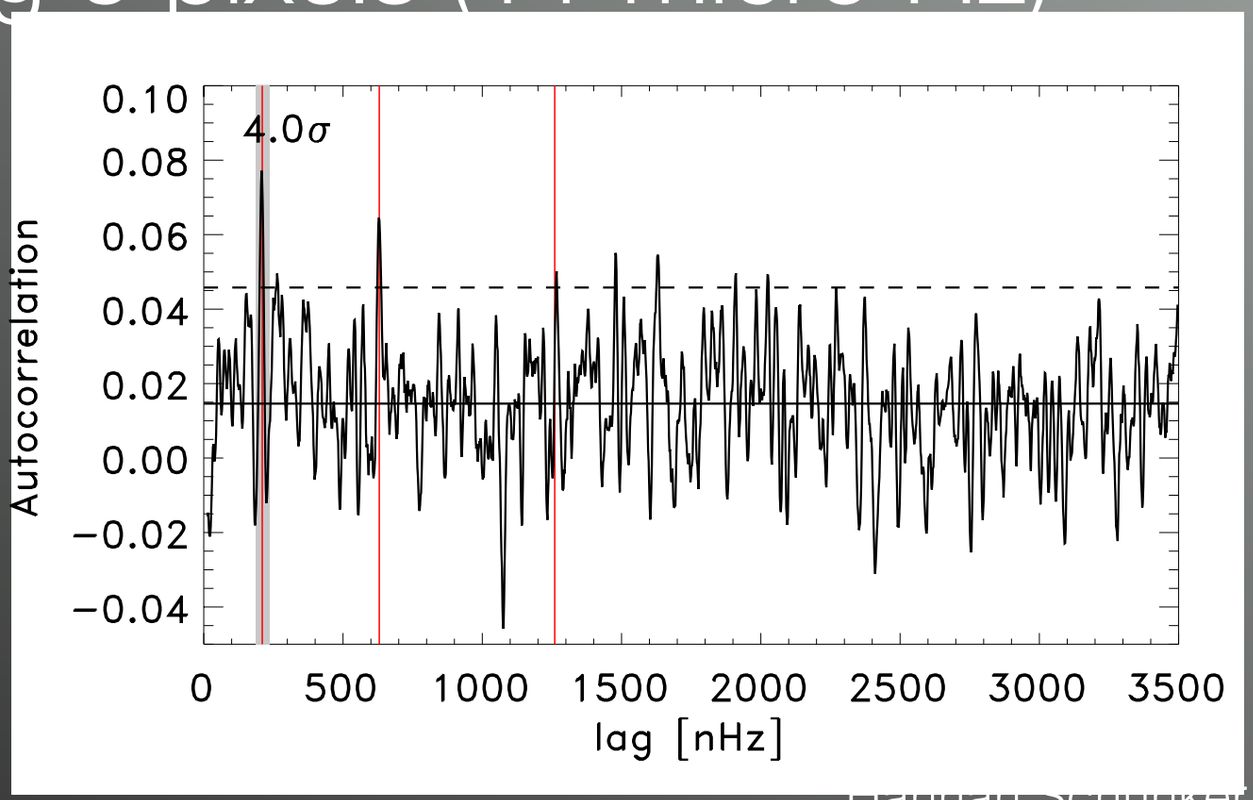
Test: Smoothing

Power spectrum

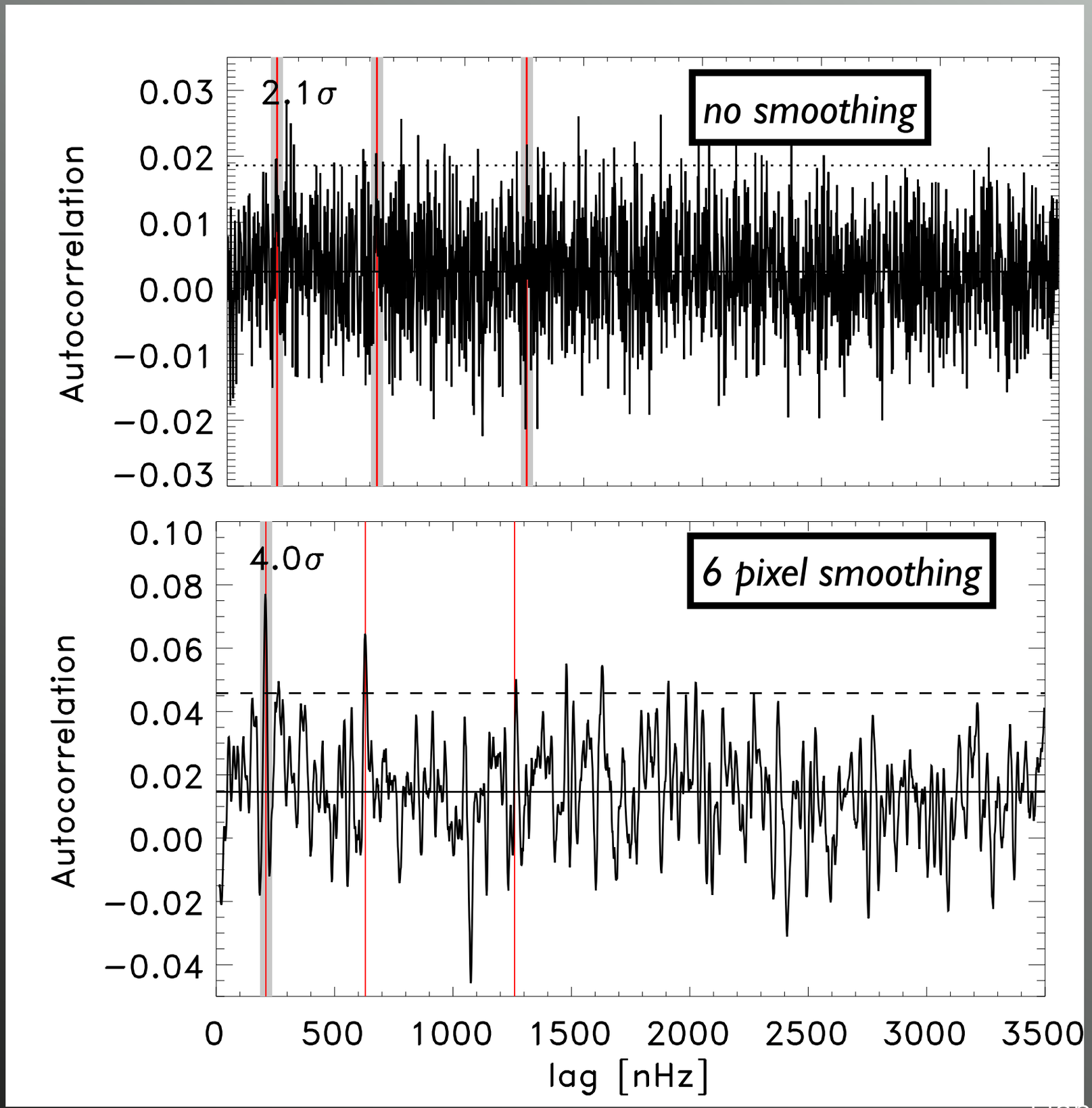


Box-car smoothing 6 pixels (11 micro Hz)

Auto-correlation

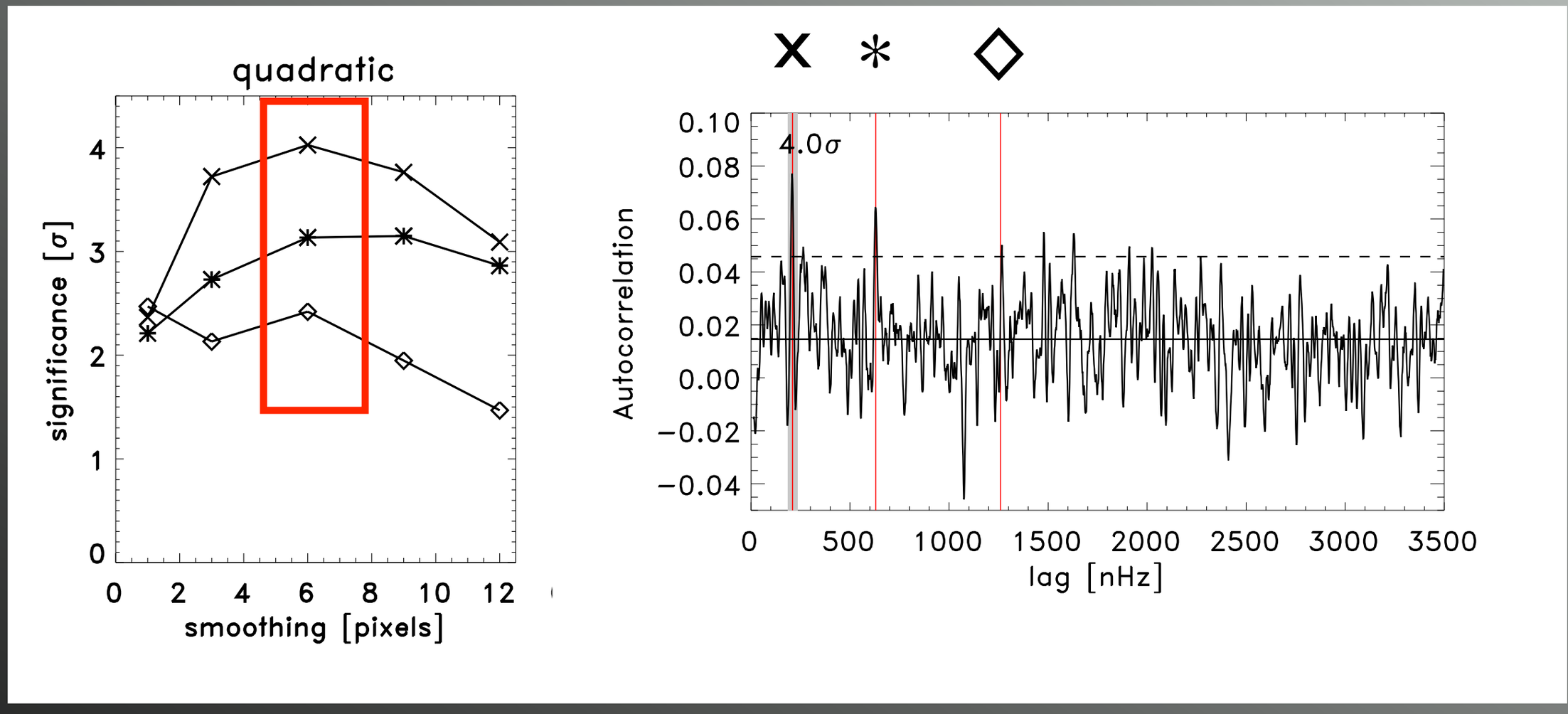


Test: Smoothing



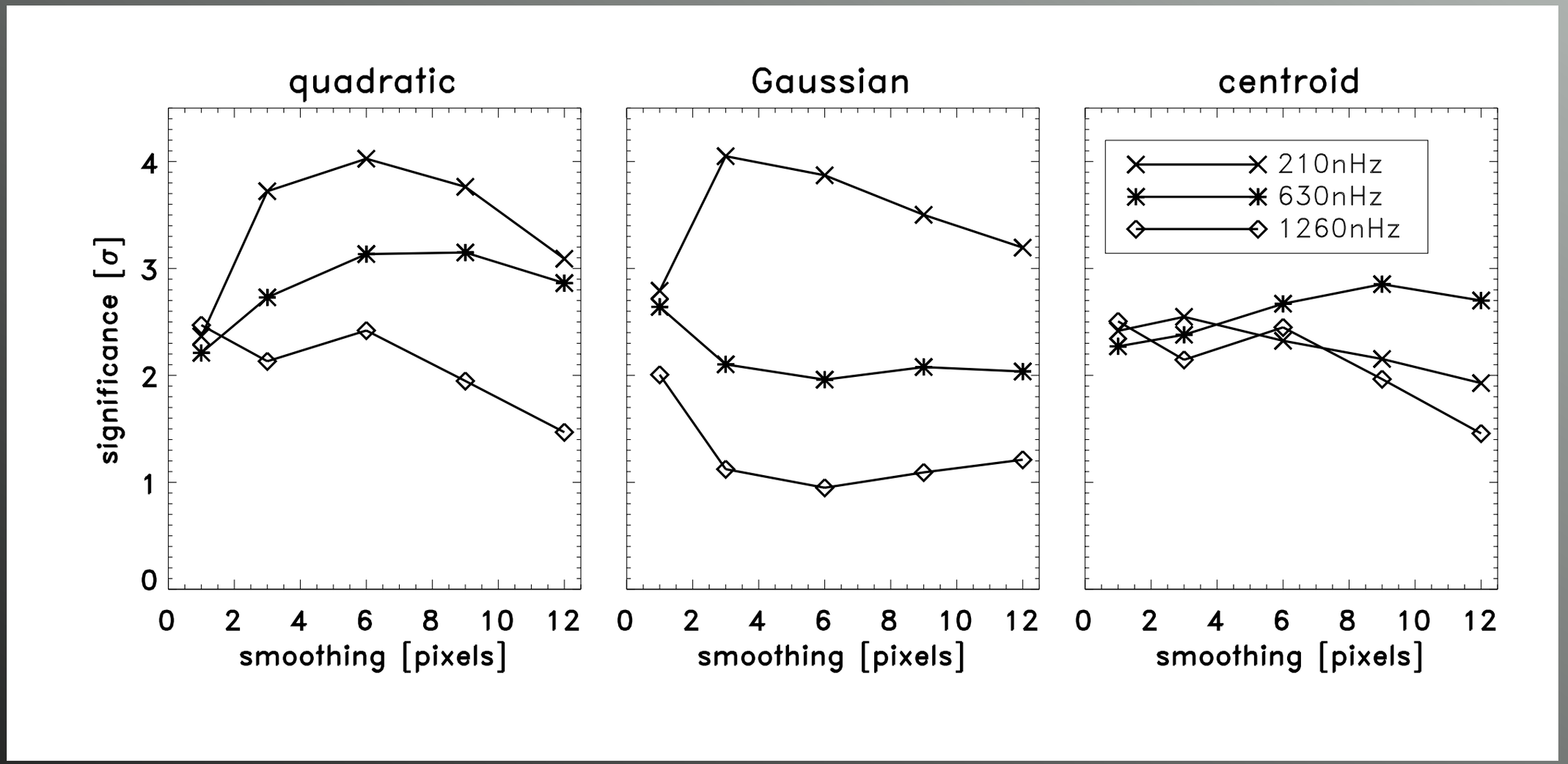
Test: Smoothing

- Smoothing is key to obtaining the significance



- Required because the modes are not strictly equally spaced (asymptotic)

Test: Smoothing



Overview

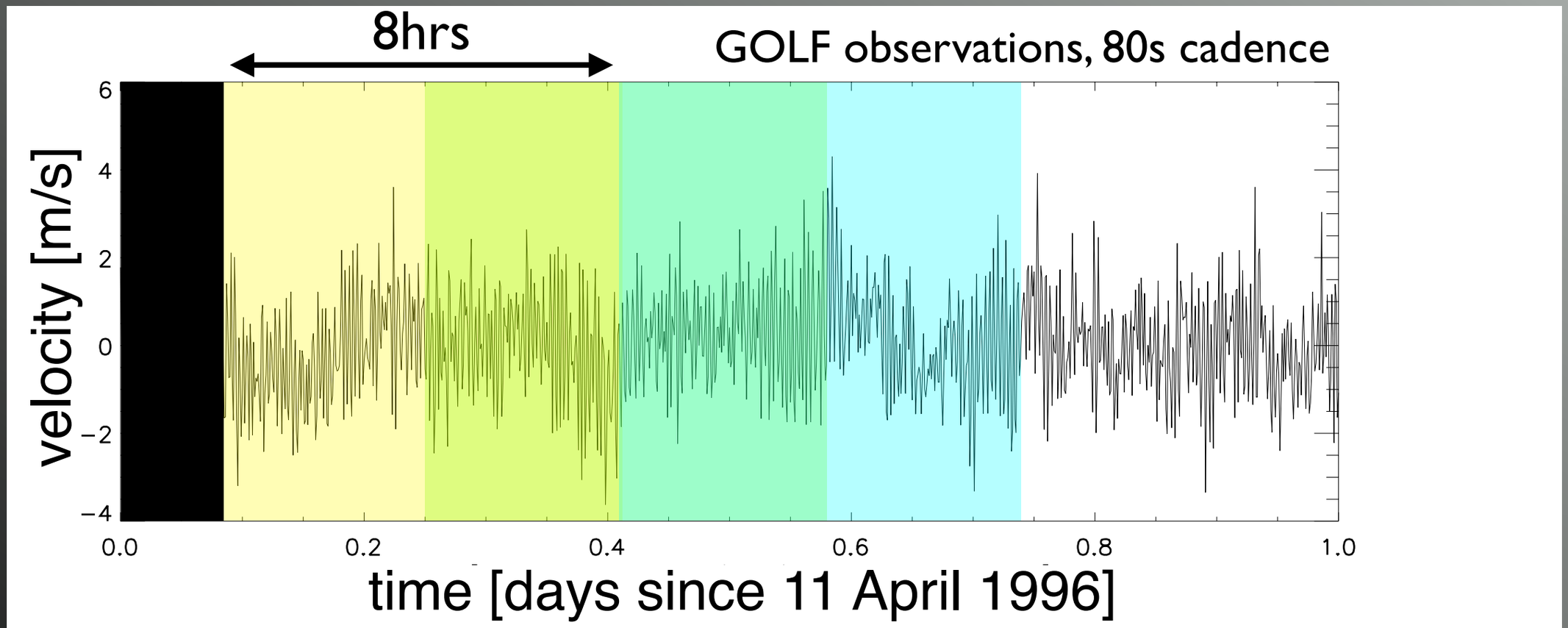
1. Reproducing Fossat et al. 2017

2. Sensitivity to parameters
   i. Fitting function to measure RTTT
   ii. Smoothing of AC
   iii. Start time of data series
   iv. Cadence of RTTT measurements

3. MC parameter study

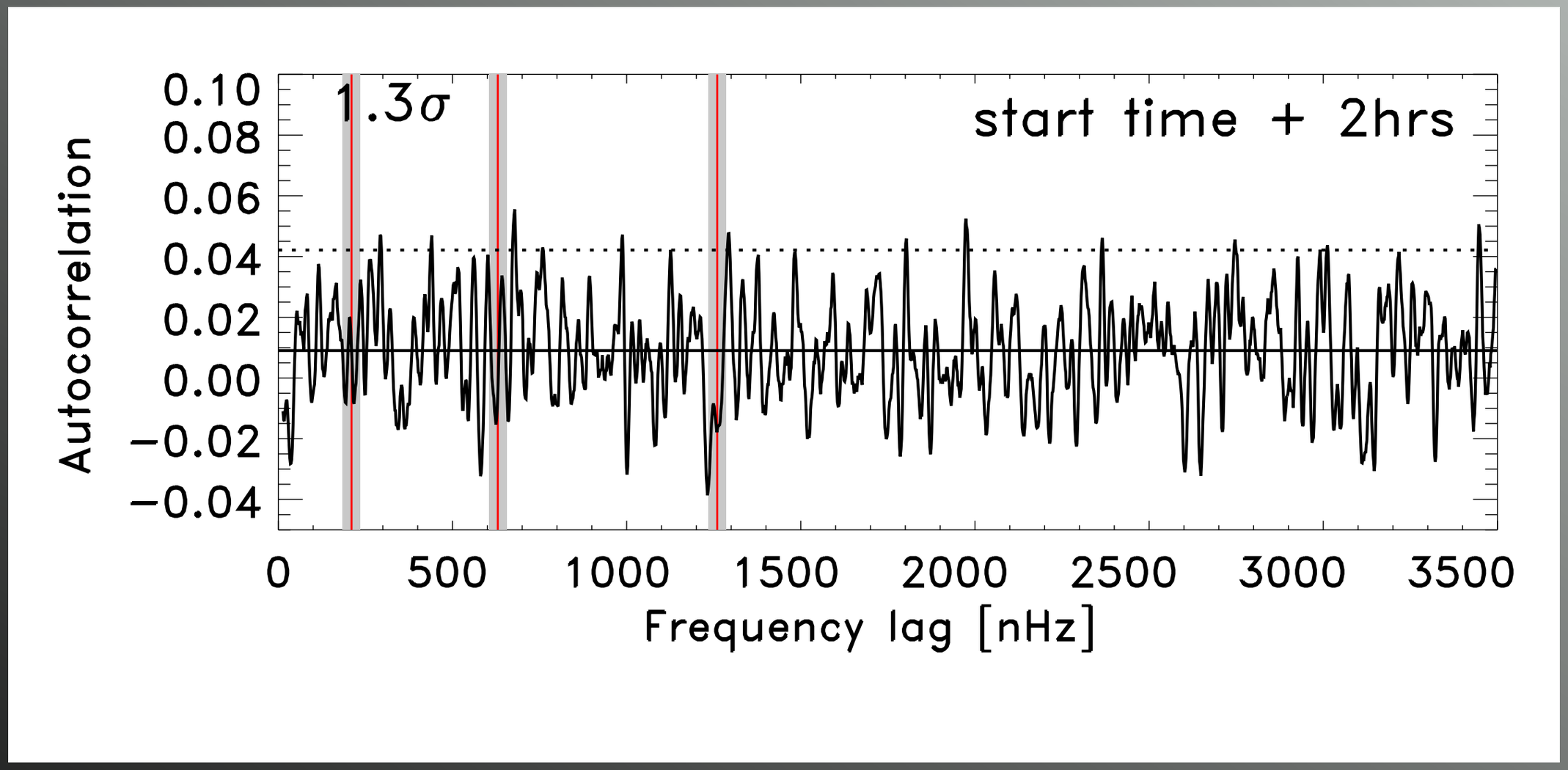
Test: offset data segments

- Removed 2 hours from beginning of 16.5 year data series

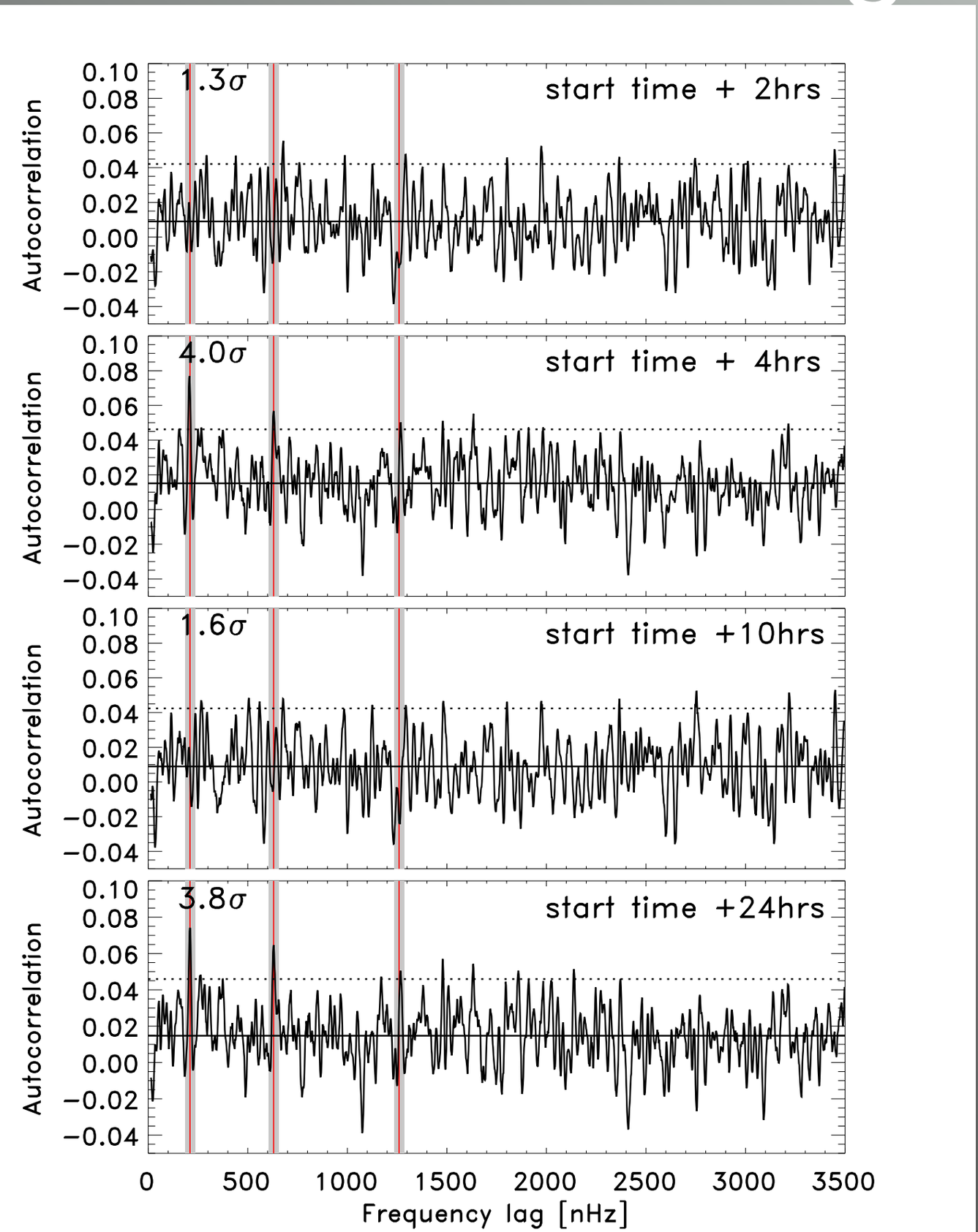


- Repeated exactly the same original analysis

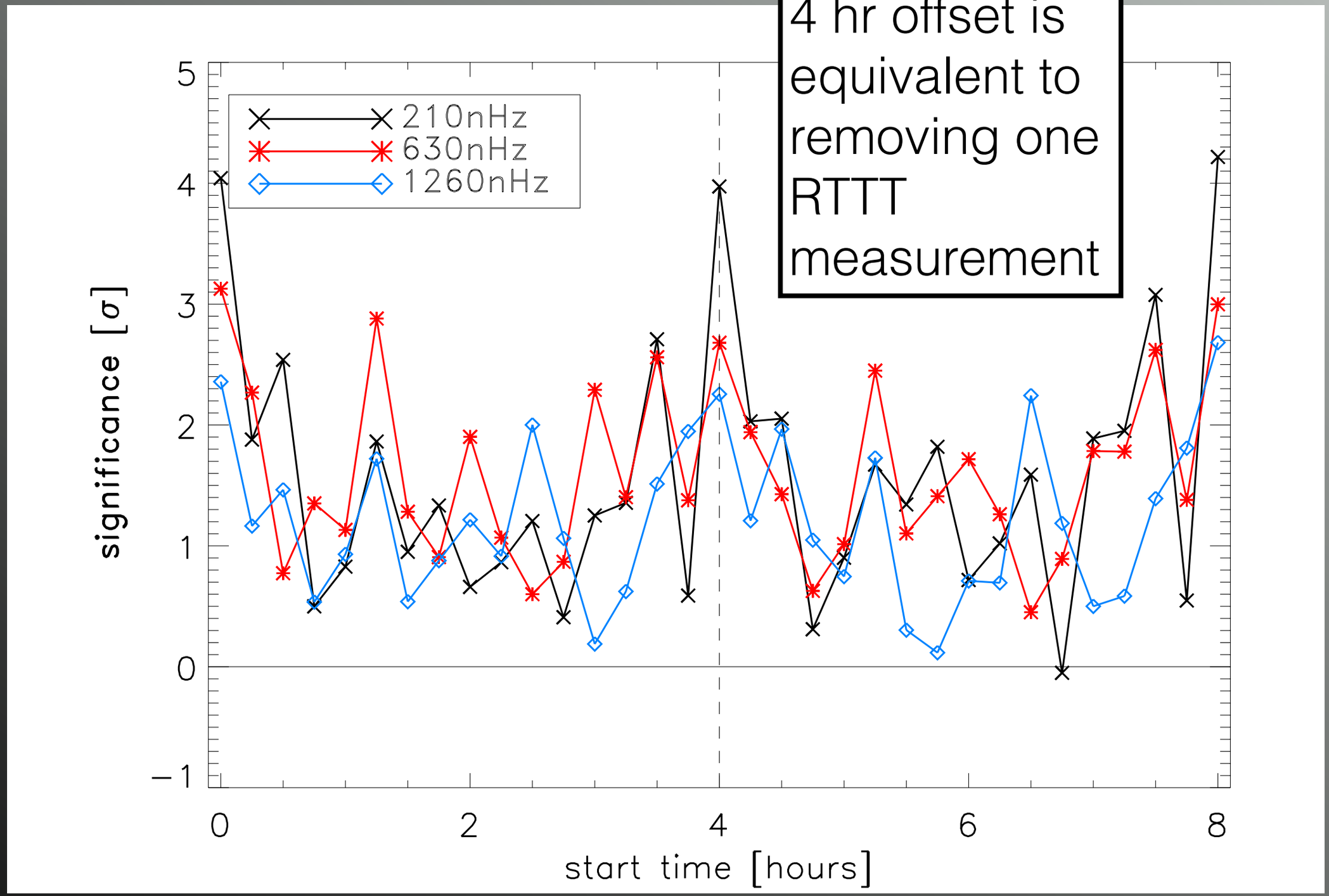
Test: offset data segments



Test: offset data segments



Test: offset data segments



Schunker+ 2018

Overview

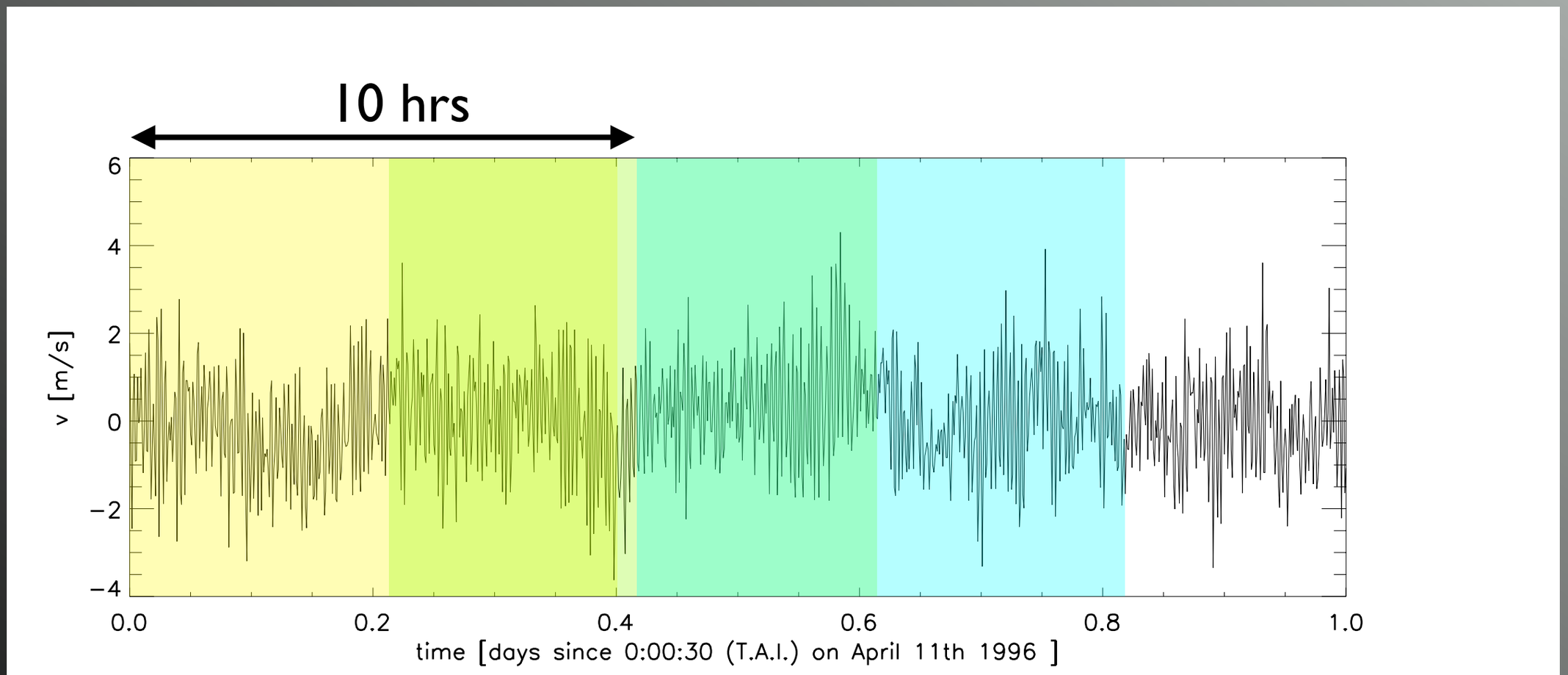
1. Reproducing Fossat et al. 2017

2. Sensitivity to parameters
   i. Fitting function to measure RTTT
   ii. Smoothing of AC
   iii. Start time of data series
   iv. Cadence of RTTT measurements

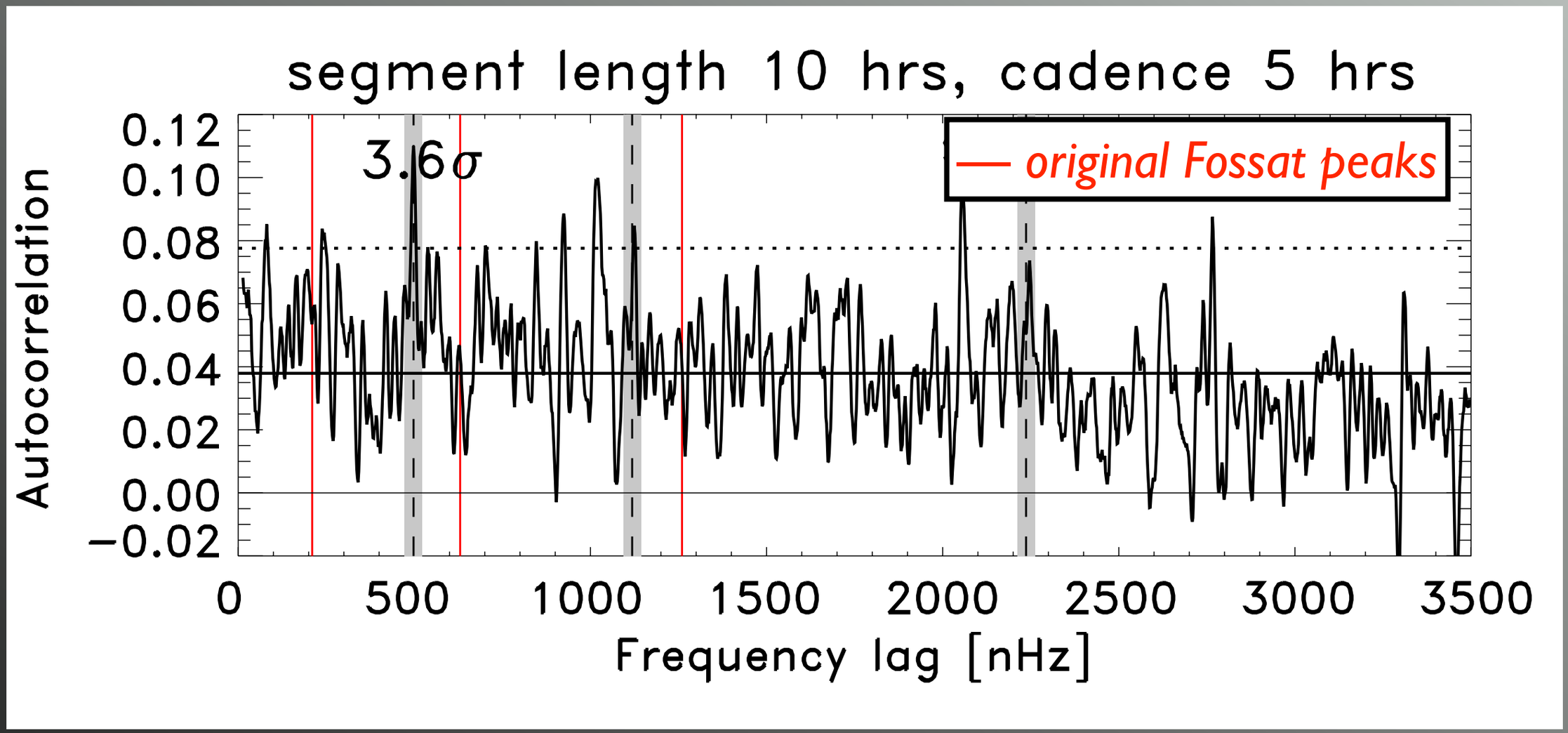
3. MC parameter study

Test: cadence of RTTT measurements

Original segments 8 hrs long with a 4 hr cadence
Now we try 10 hrs long with a 5 hr cadence

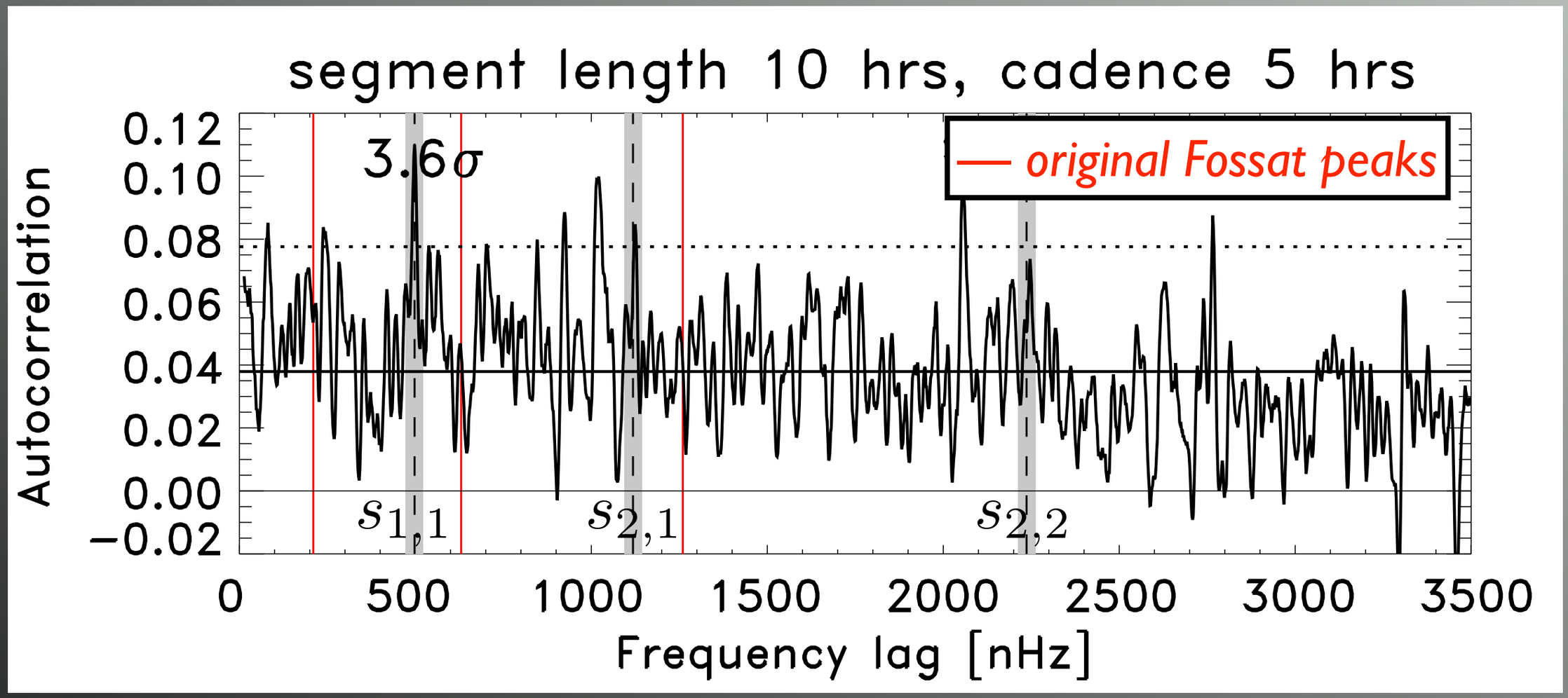


Test: cadence of RTTT measurements



- Scaled the clipping of RTTT fluctuations by the ratio to the rms of the nominal case

Test: cadence of RTTT measurements



$$s_{\ell,m} = m[\beta_\ell \Omega_{\rm g} - \Omega_{\rm p}] \qquad \Omega_{\rm p} = 433 \text{ nHz}$$

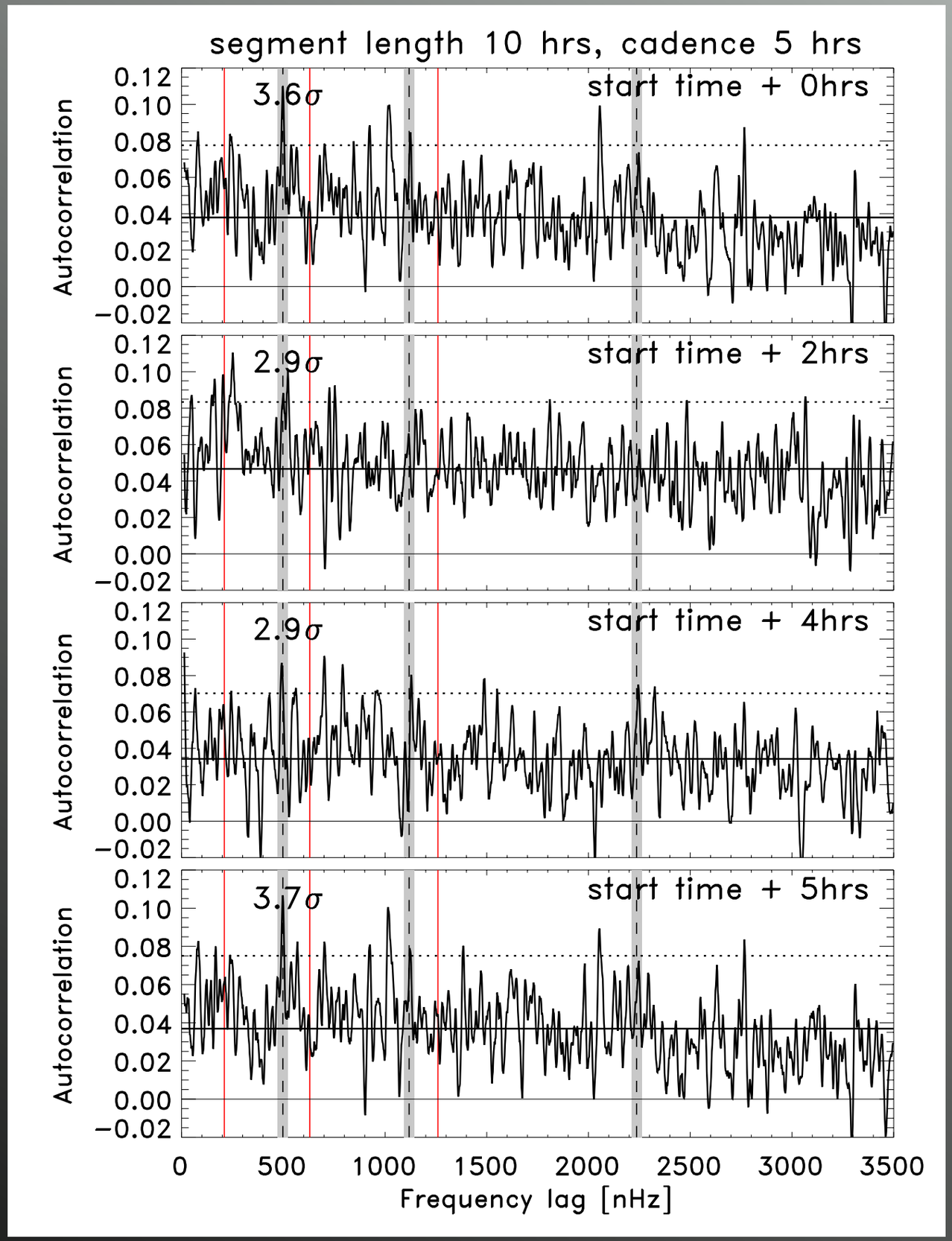
Assume largest peak is $\ell = 1, m = 1$,

$\Omega_g = 1862$ nHz 4.3x Ω_p

(1277 ±10 nHz, 2.9x Ω_p)

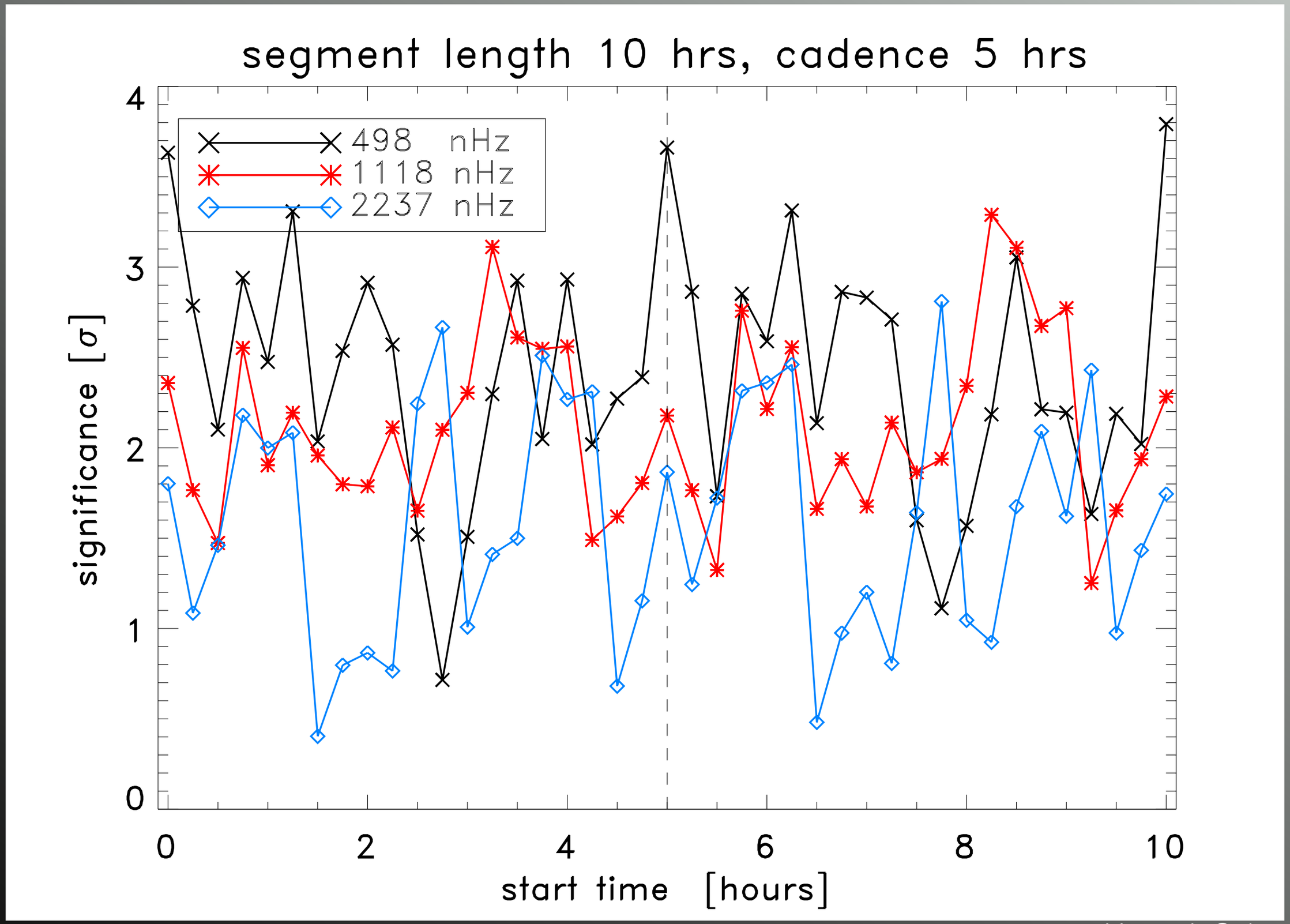
Hannah Schunker

Test: offset and cadence



Hannah Schunker

Test: offset and cadence



Overview

1. Reproducing Fossat et al. 2017

2. Sensitivity to parameters
   i. Fitting function to measure RTTT
   ii. Smoothing of AC
   iii. Start time of data series
   iv. Cadence of RTTT measurements

3. MC parameter study

Monte Carlo parameter study

- Retain 4 hour cadence (8 hour length)
- Length of temporal padding (10^6 s)
- Oversampling filtered *p*-mode PS (125 mHz)

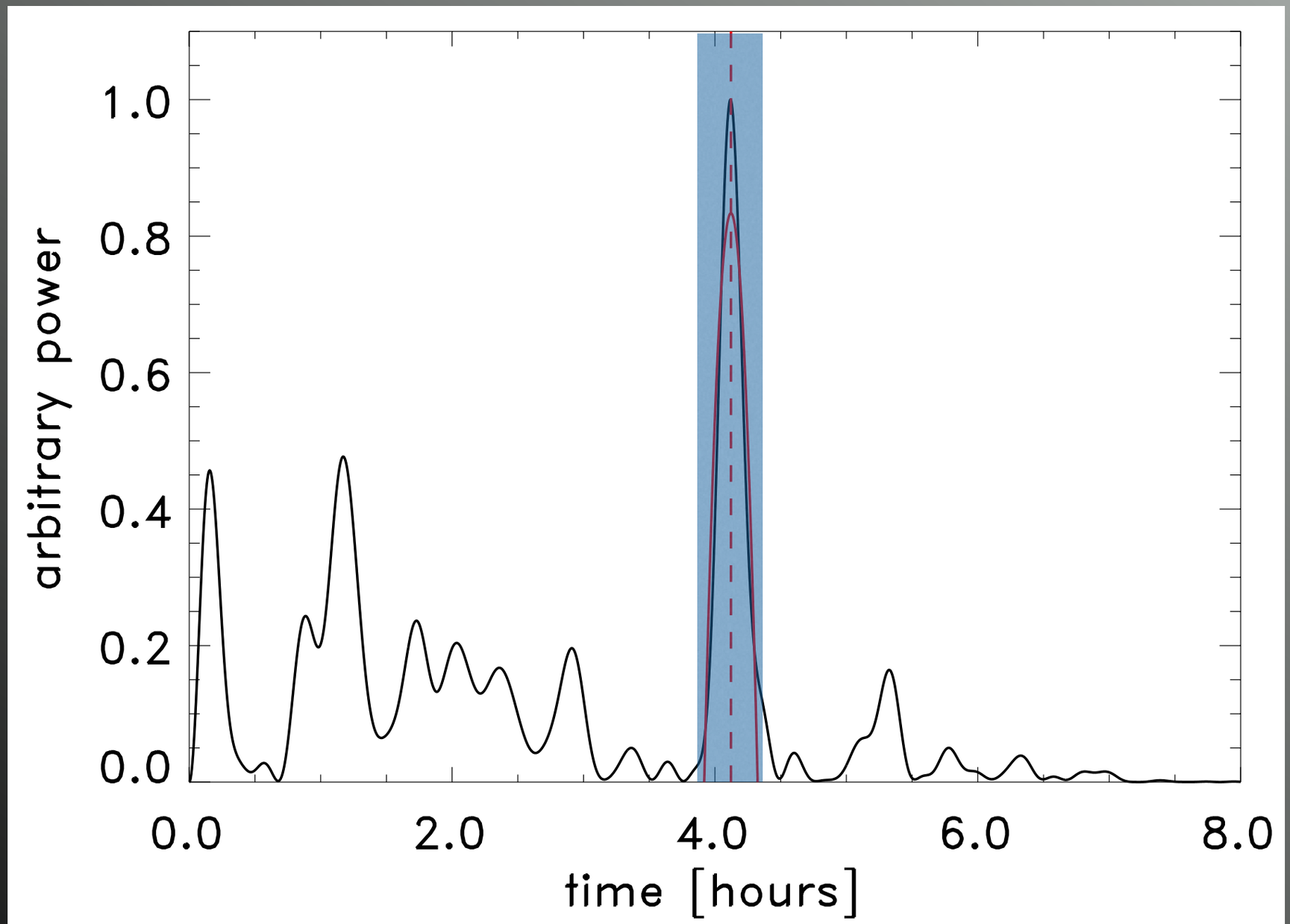
- Offset start time by 2 hours
- Three fitting functions to measure RTTT (quadratic, Gaussian, centroid)
- Smoothing of AC (4-9 pixels)

1000 realisations

1. Width of fitting window to measure RTTT
2. Band-width of filter for p-modes
3. Range to fit Gaussian to normalise PS

Monte Carlo parameter study

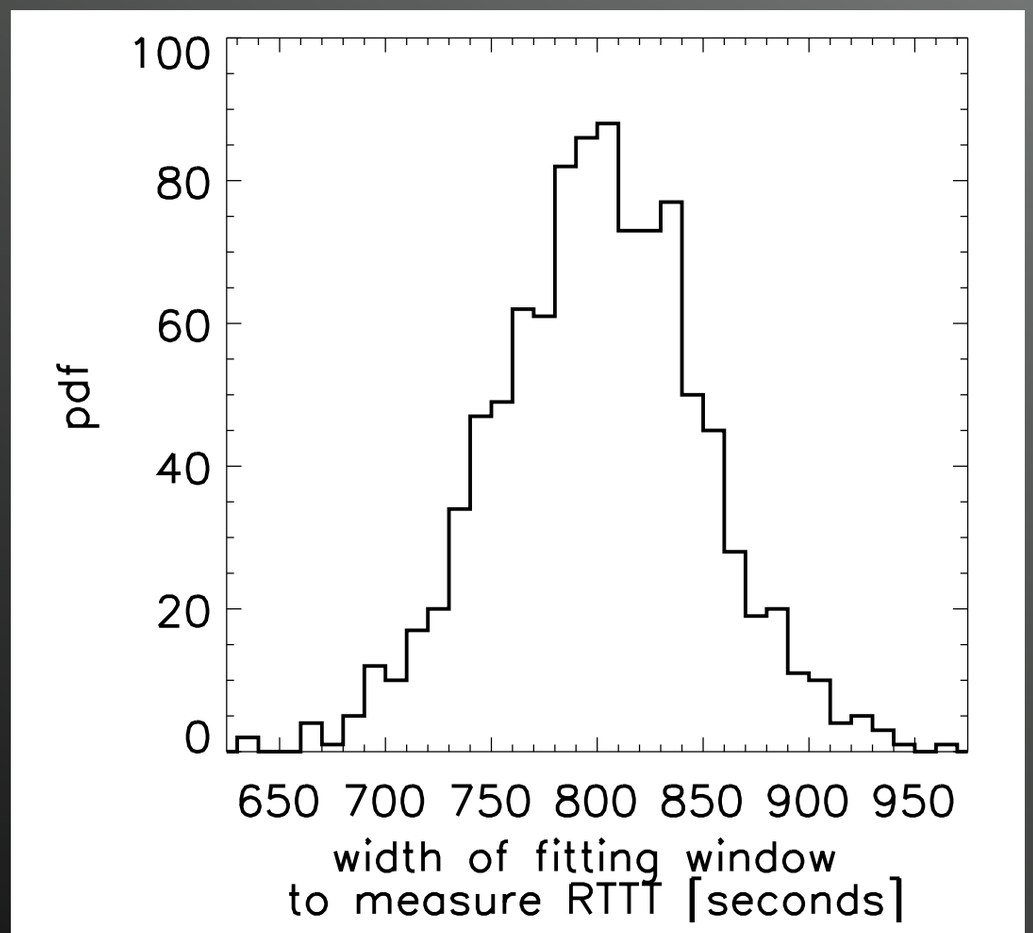
Nominally 800 s centred at 4h 3m

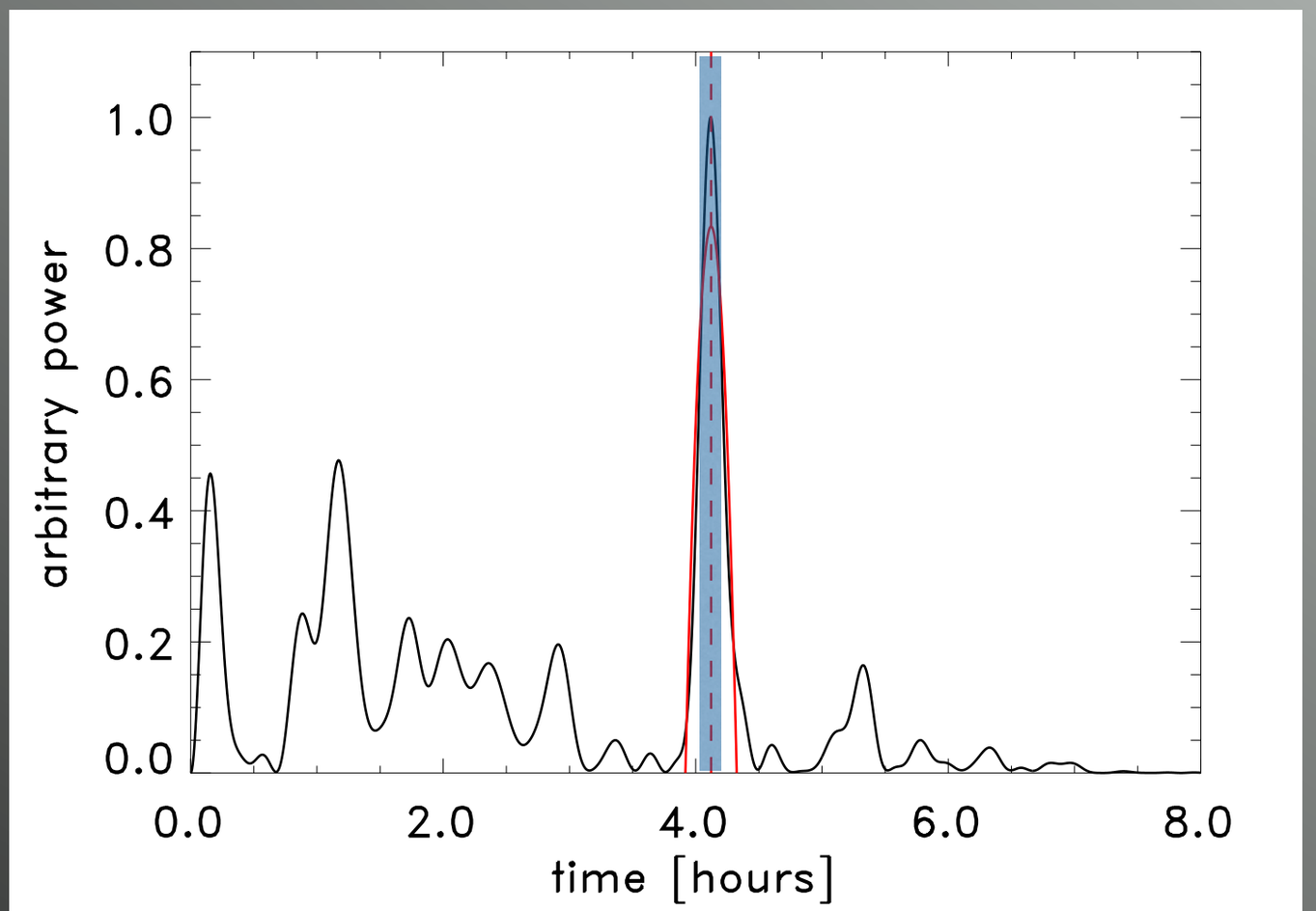


Hannah Schunker

Monte Carlo parameter study

Nominally 800 s centred at 4h 3m
Gaussian distributed standard deviation 50 s

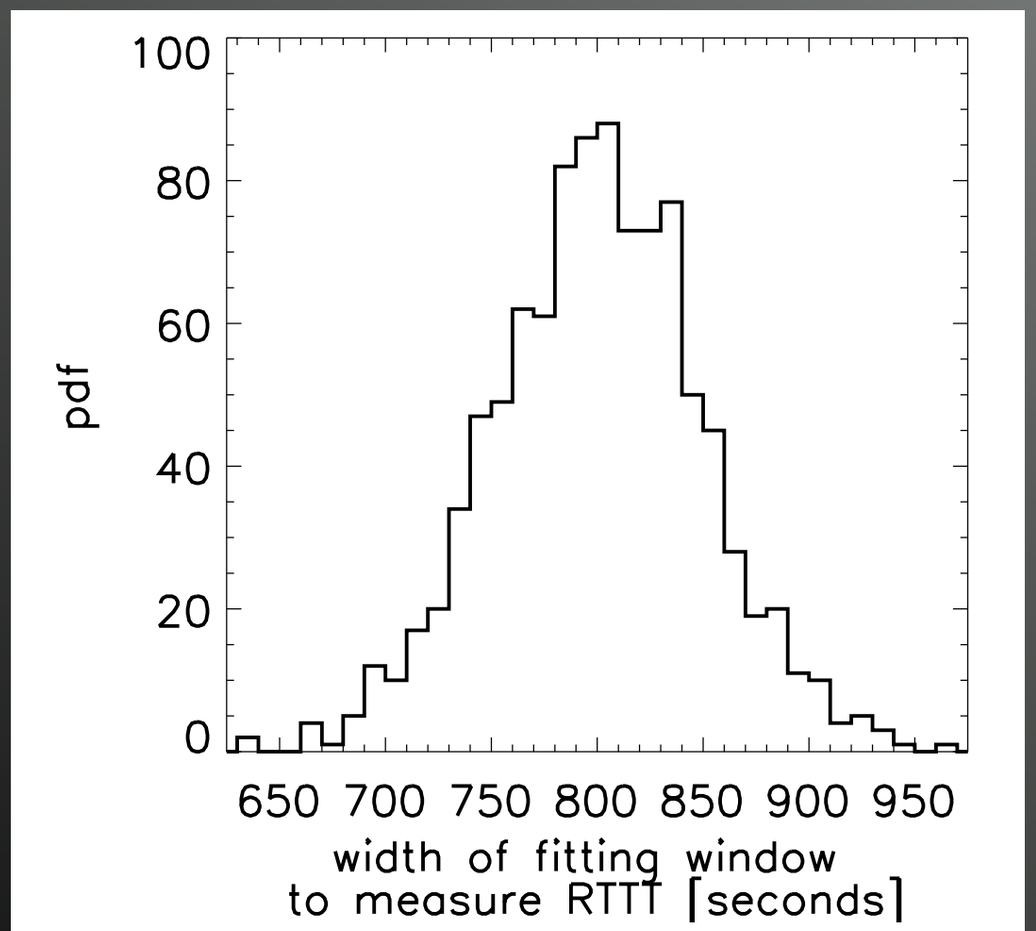


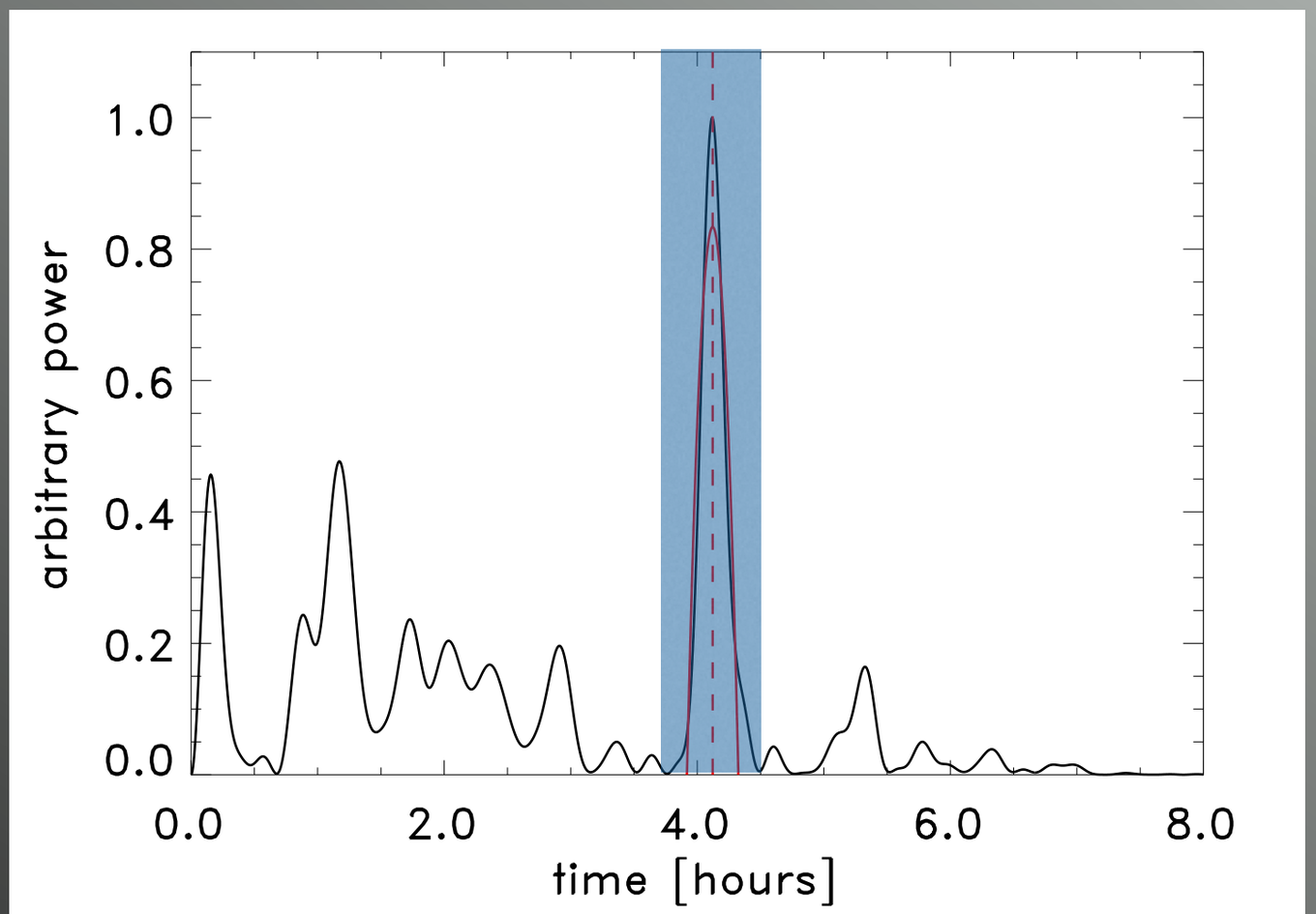


Hannah Schunker

Monte Carlo parameter study

Nominally 800 s centred at 4h 3m
Gaussian distributed standard deviation 50 s

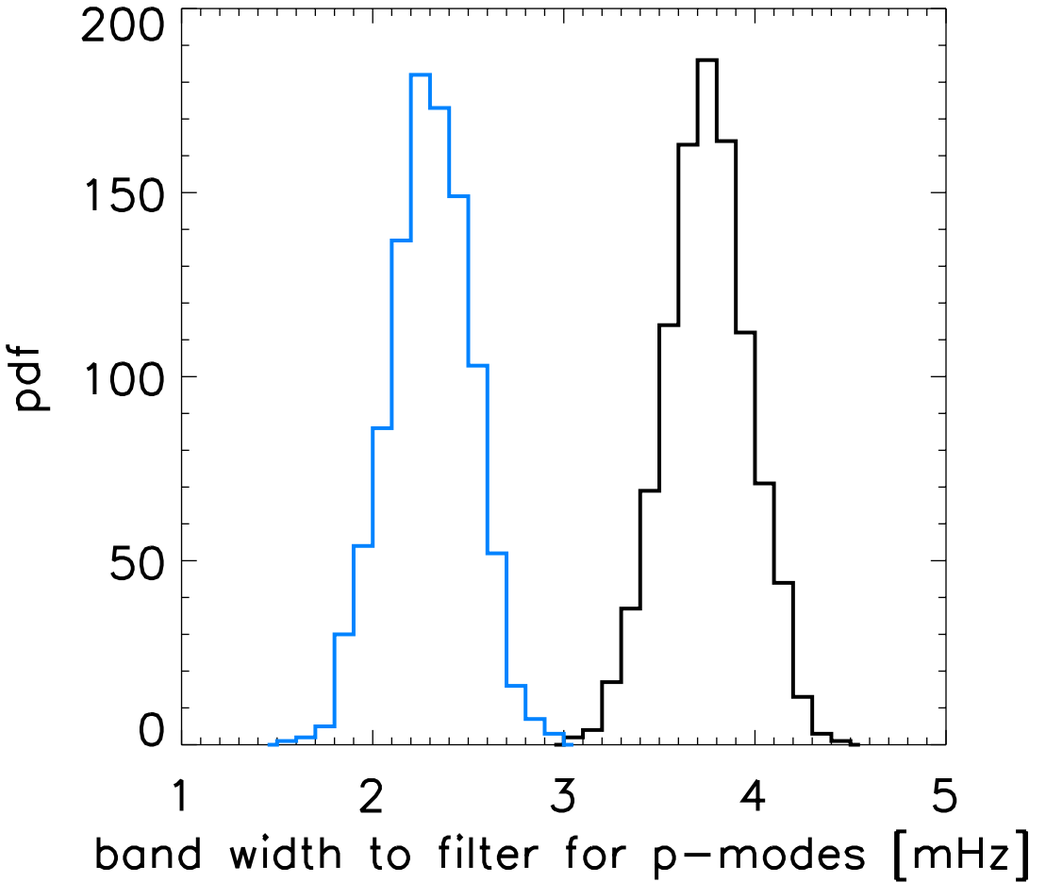


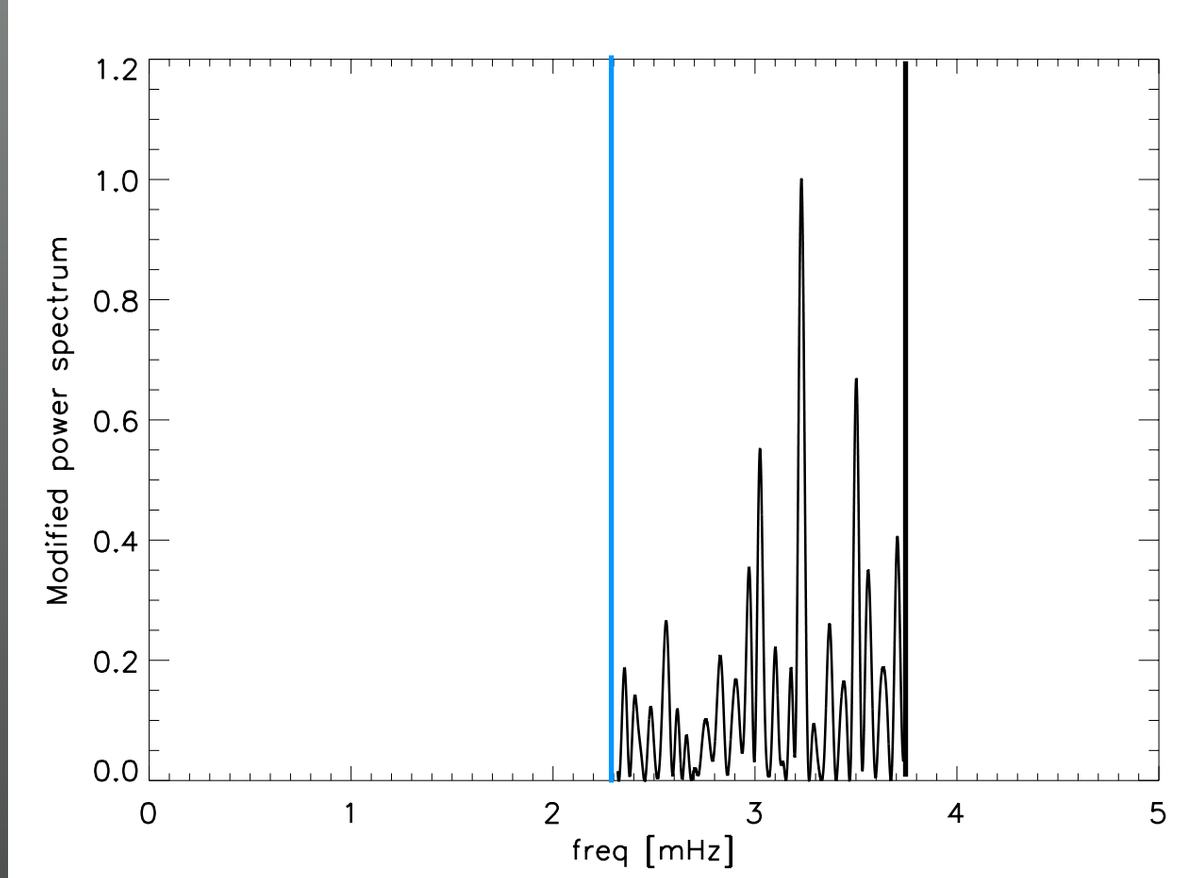


Hannah Schunker

Monte Carlo parameter study

Nominal range 2.32 to 3.74 mHz
Gaussian distributed standard deviation 0.5 mHz

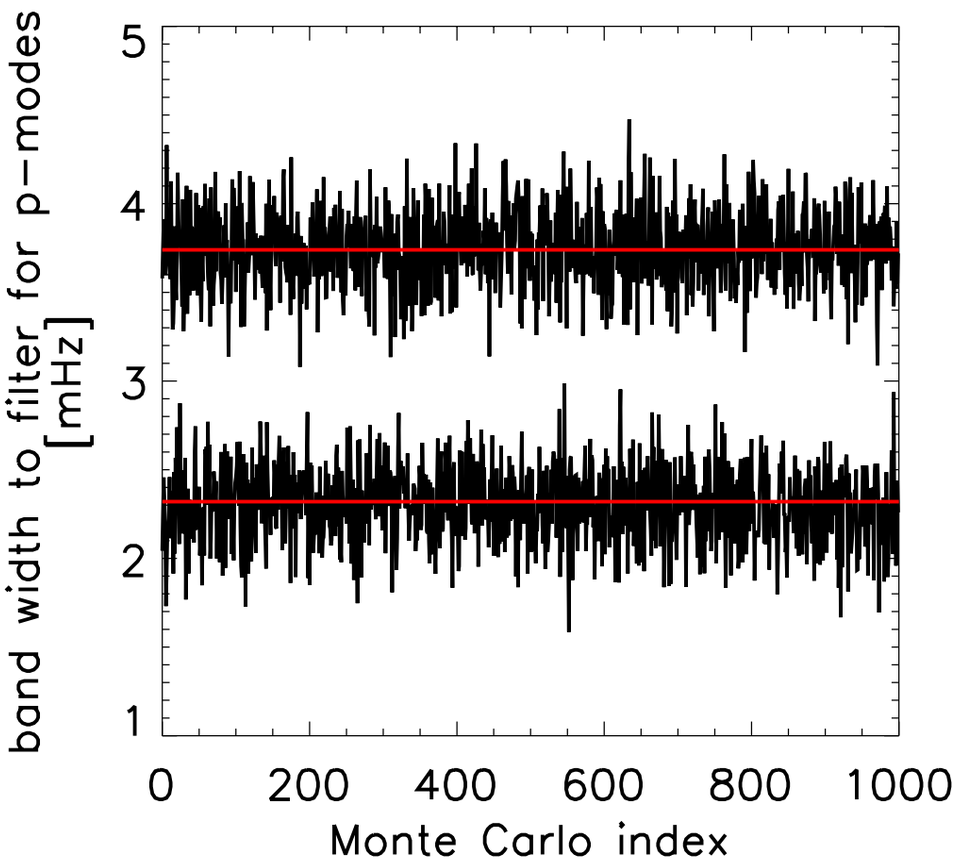


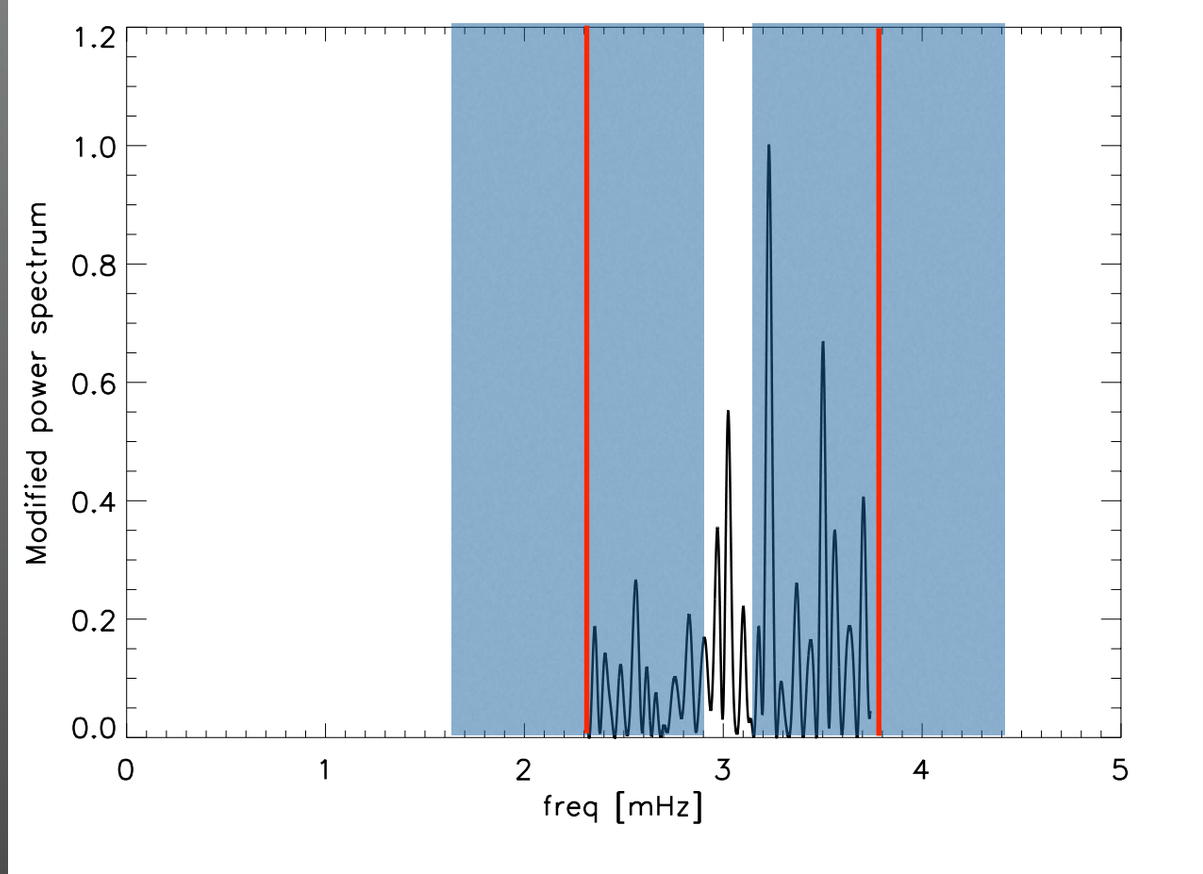


Hannah Schunker

Monte Carlo parameter study

Nominal range 2.32 to 3.74 mHz
Gaussian distributed standard deviation 0.5 mHz
Widths vary by 0.5 mHz to 2.4 mHz



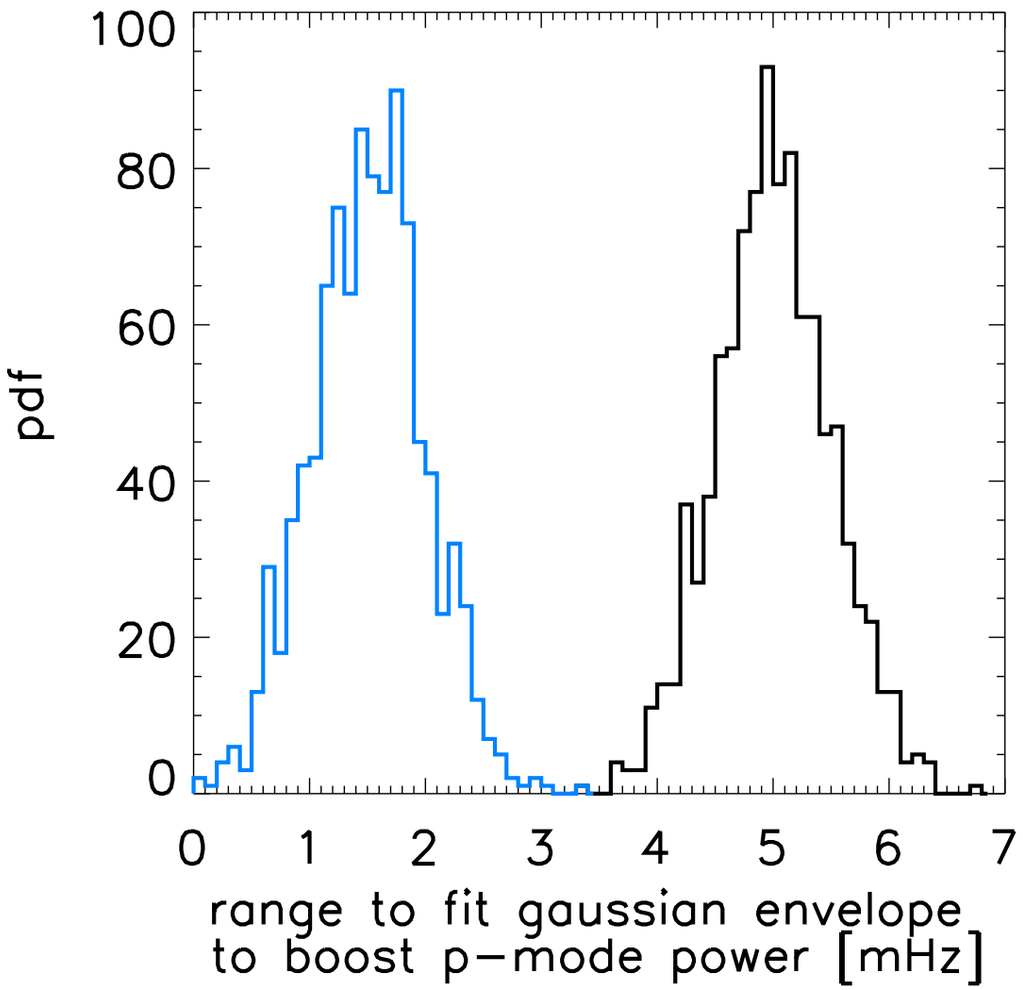


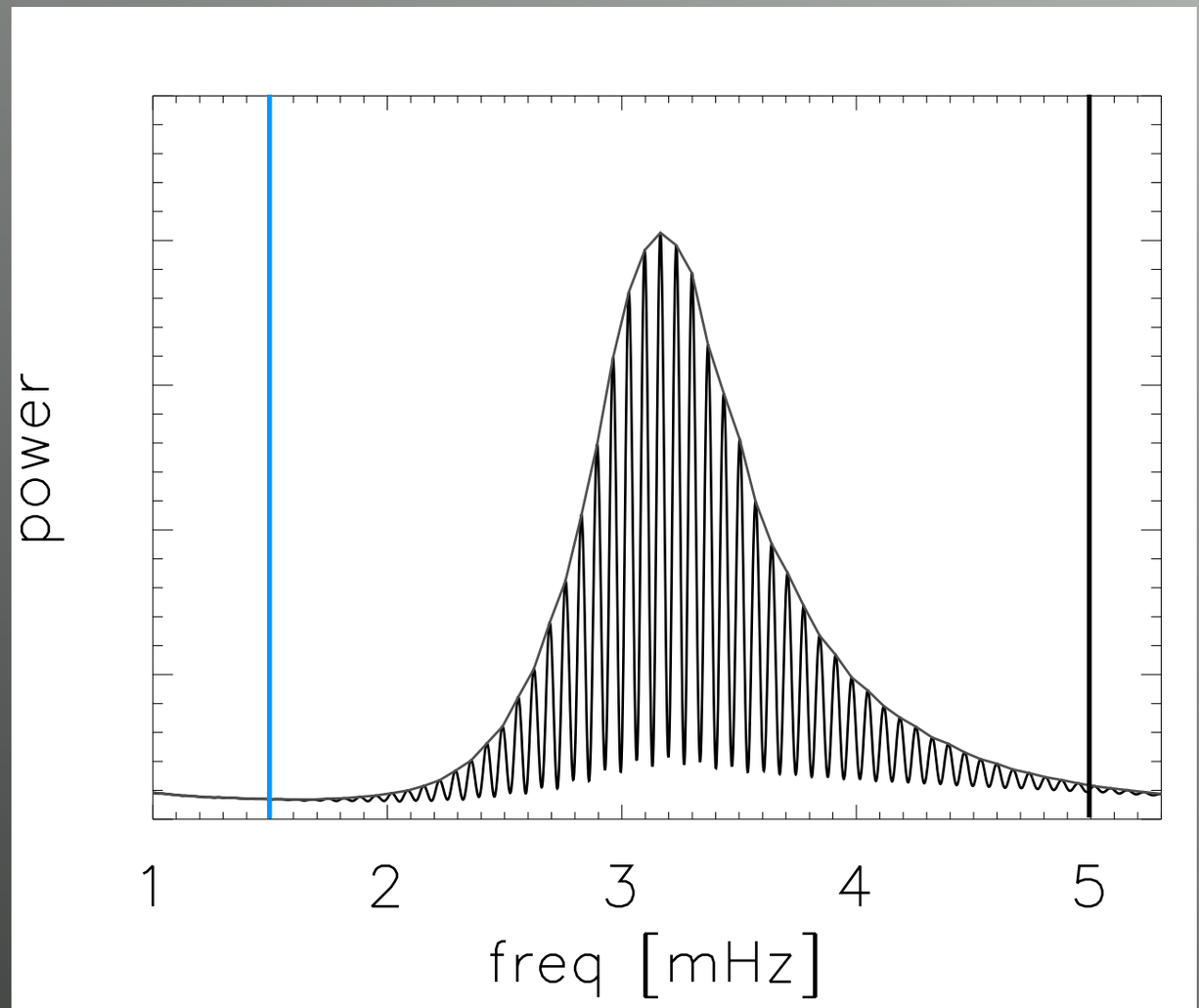
More or less modes, more or less asymptotic, more or less amplitude….

Hannah Schunker

Monte Carlo parameter study

Nominal range 1.5 to 5 mHz
Gaussian distributed standard deviation 0.5 mHz
Minimum width 1.1 mHz, maximum 6 mHz

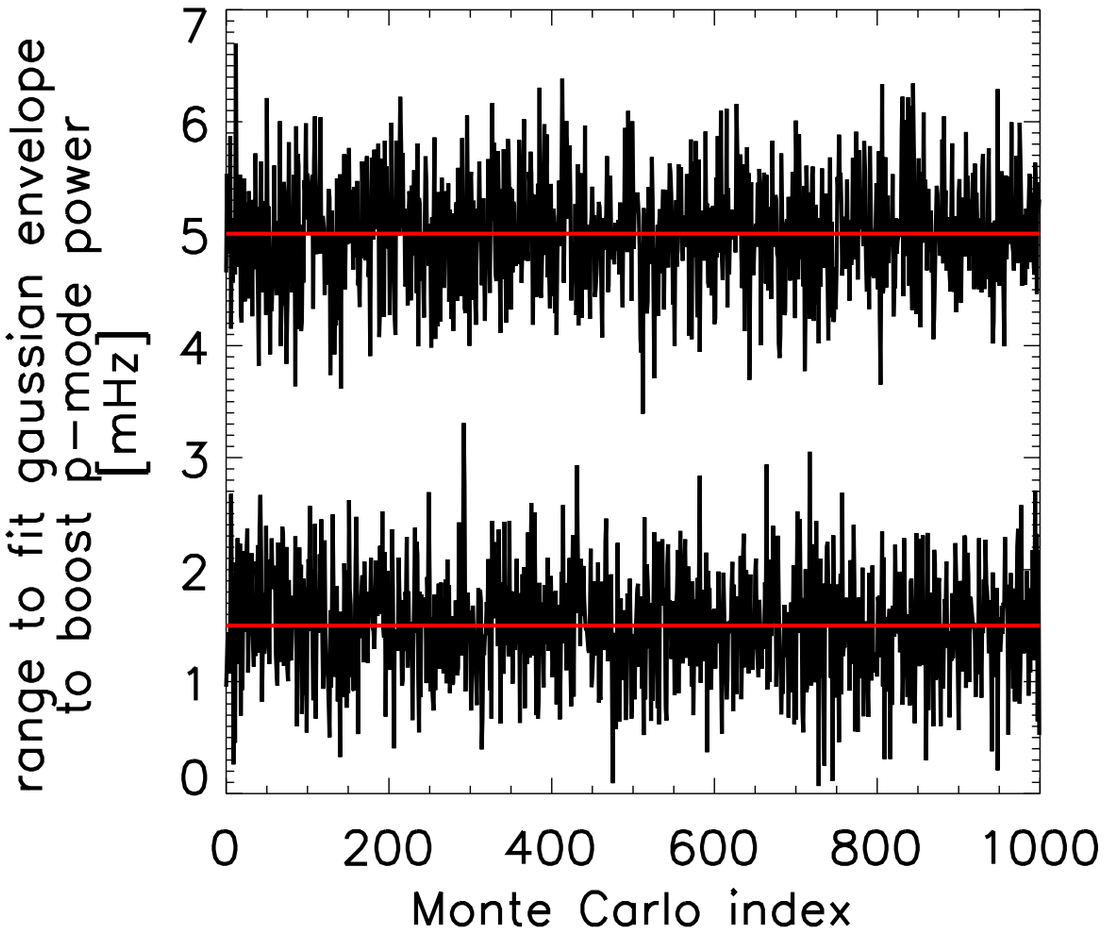


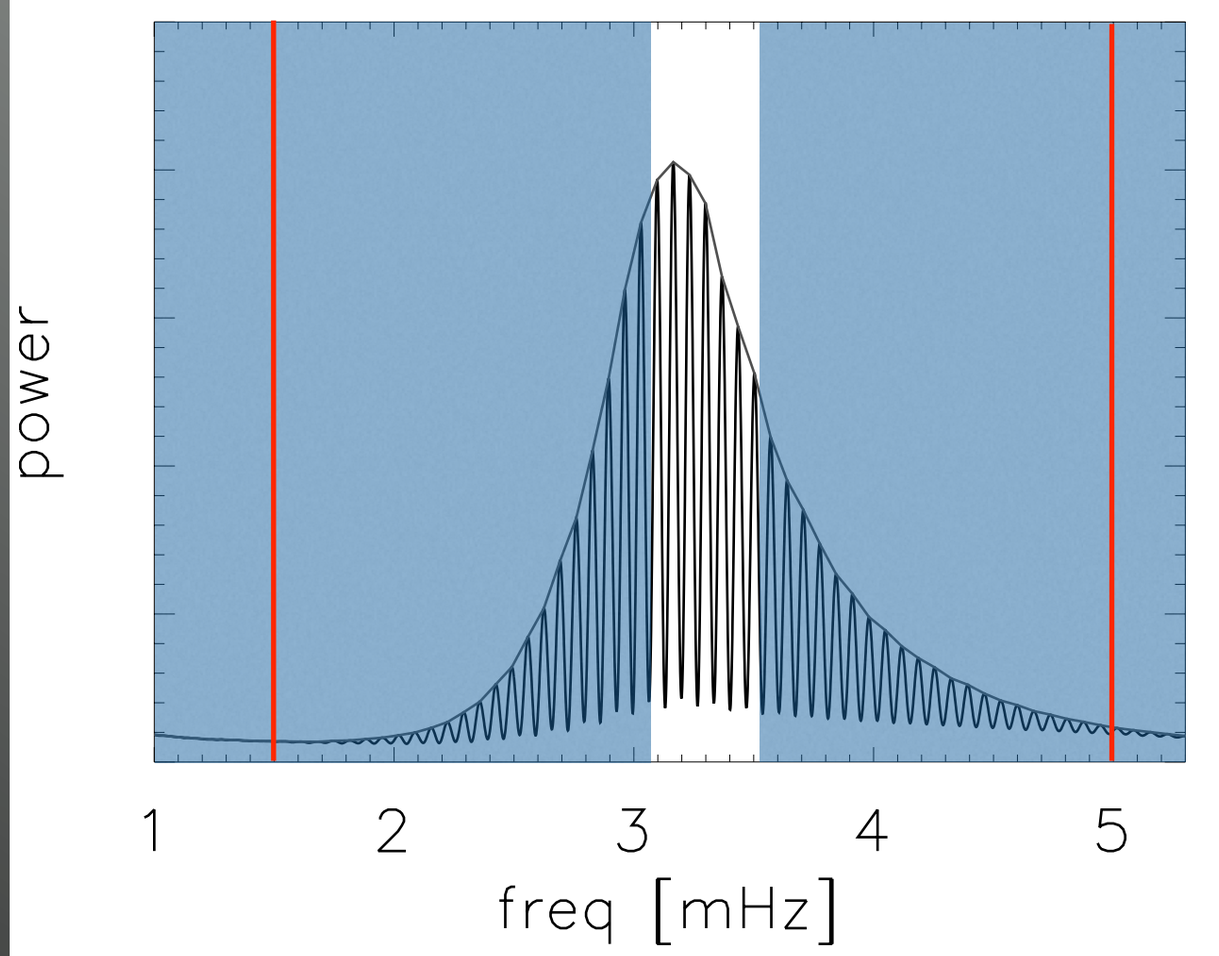


Hannah Schunker

Monte Carlo parameter study

Nominal range 1.5 to 5 mHz
Gaussian distributed standard deviation 0.5 mHz
Minimum width 1.1 mHz, maximum 6 mHz

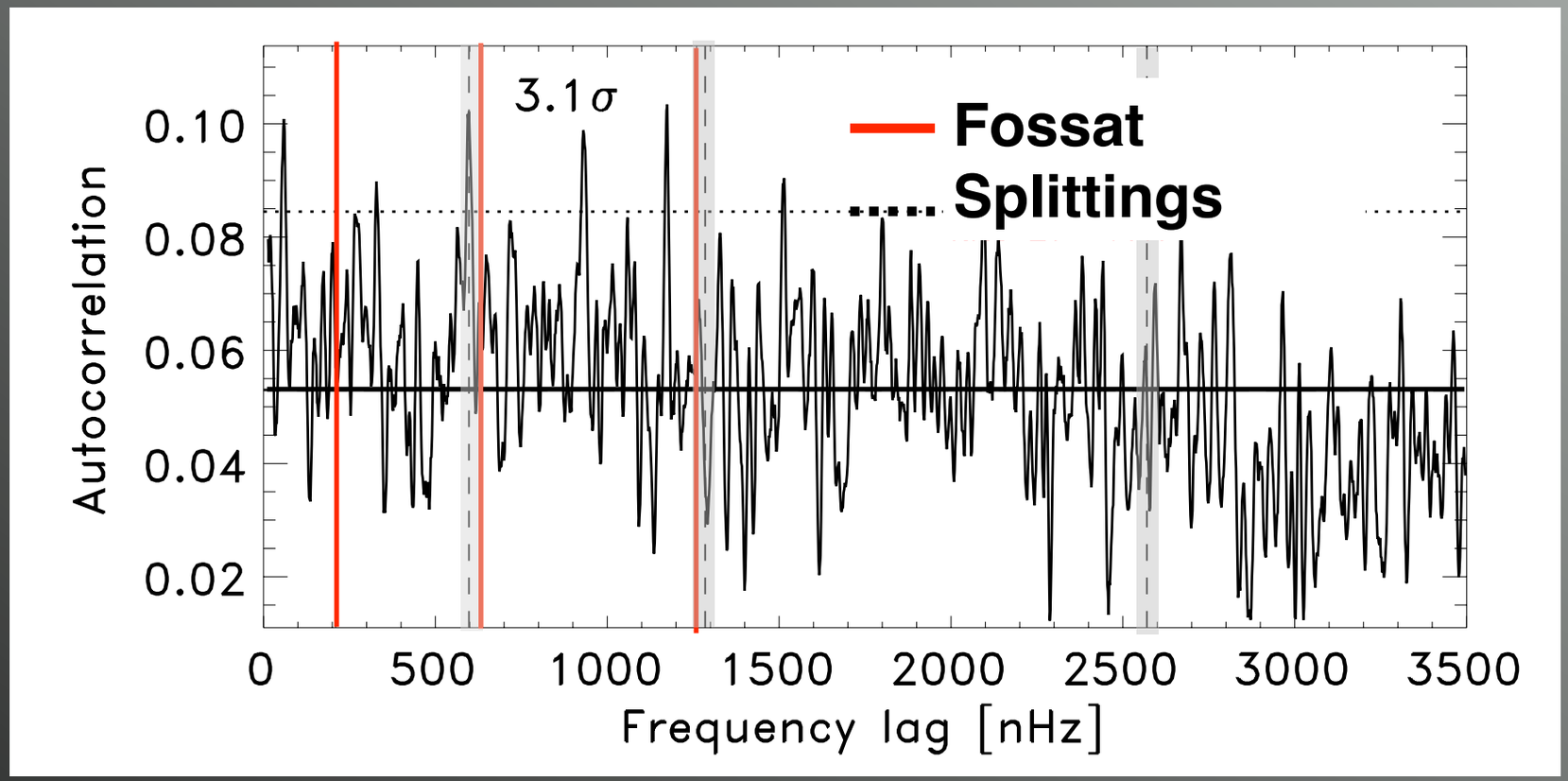




Hannah Schunker

Monte Carlo parameter study

work in progress

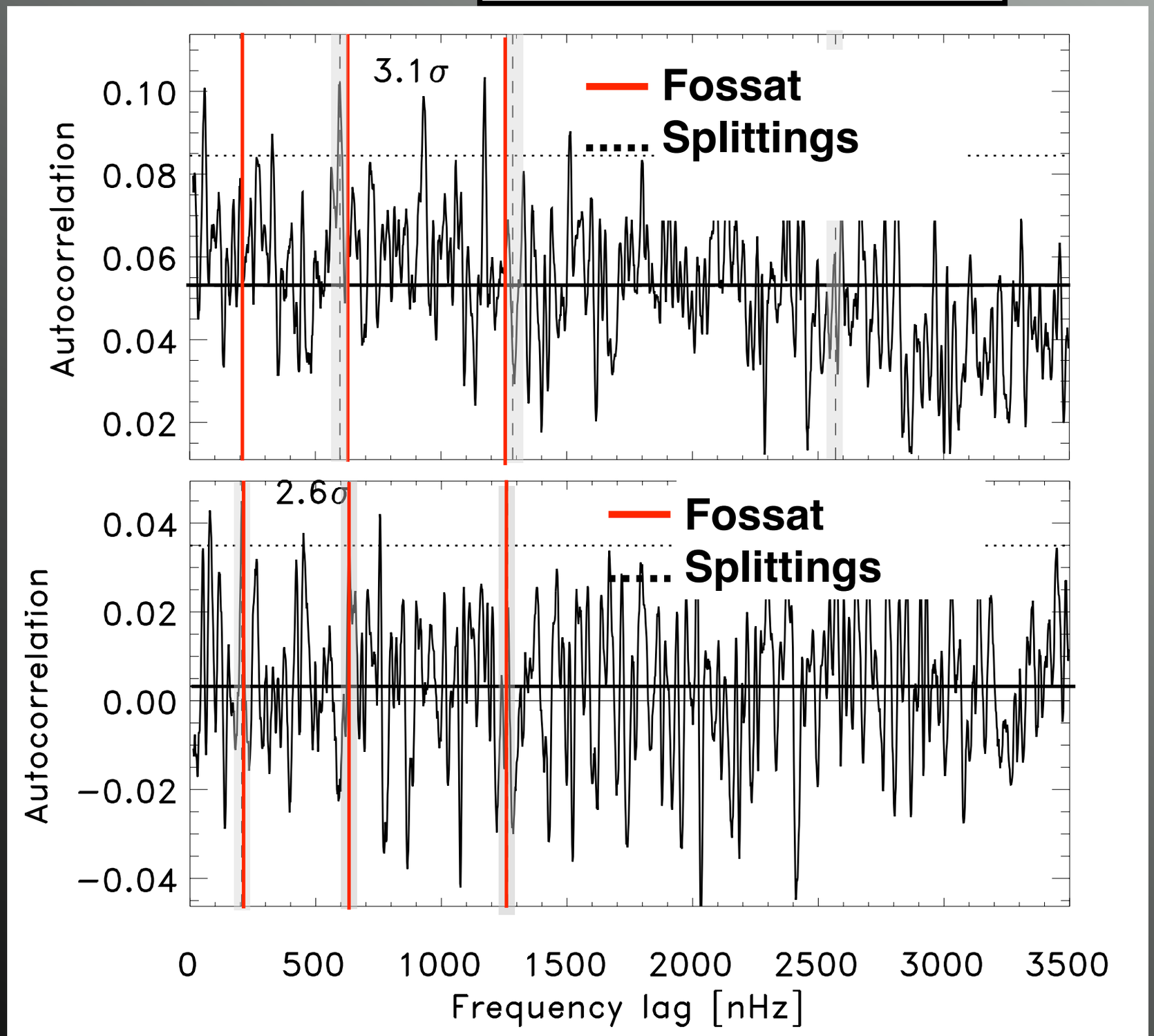


original parameters
2hr offset

Hannah Schunker

Monte Carlo parameter study

work in progress



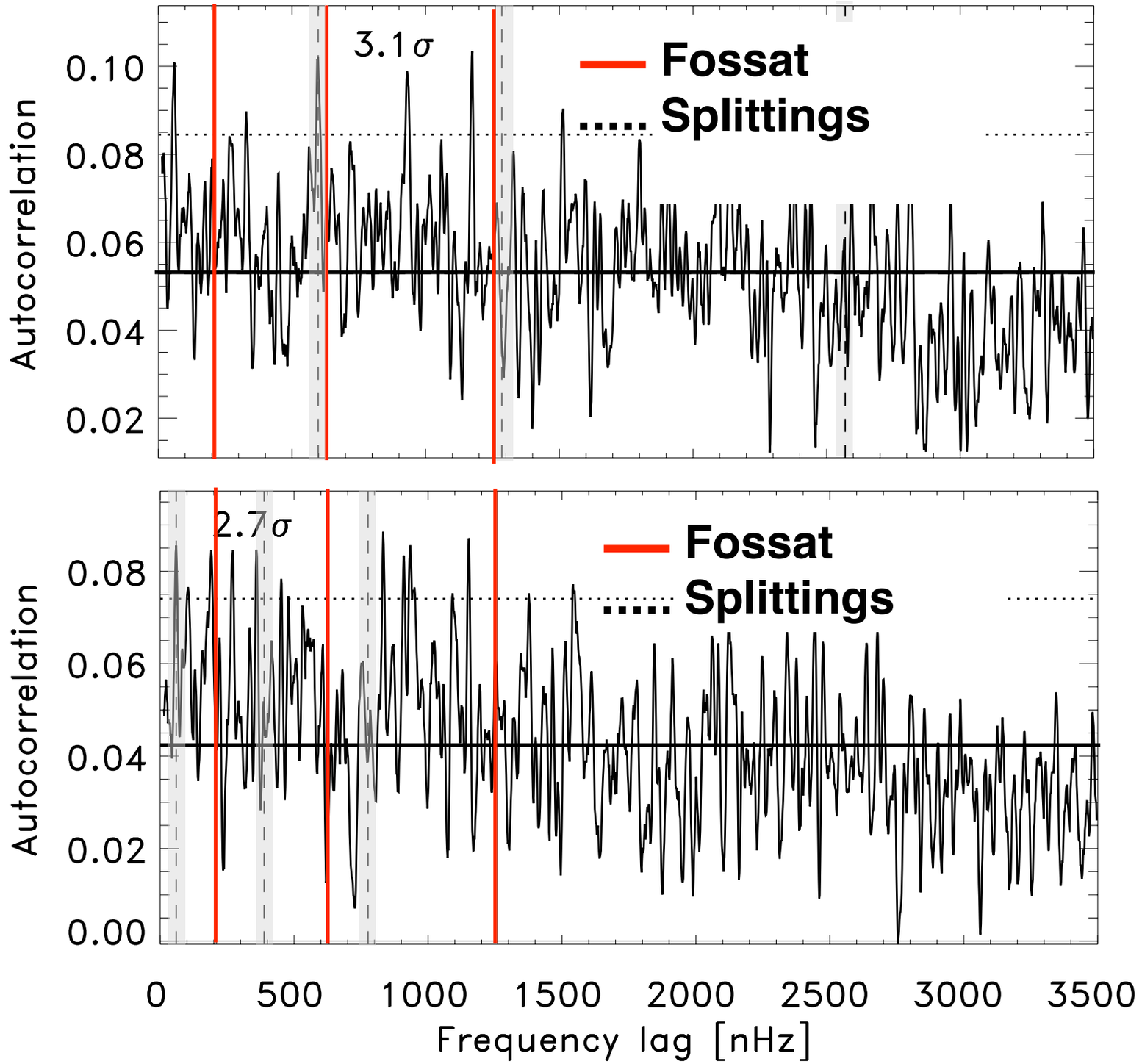
original parameters
2hr offset

MC realisation #294

Hannah Schunker

Monte Carlo parameter study

work in progress



original parameters
2hr offset

MC realisation #666

Monte Carlo parameter study

work in progress

Find maximum of autocorrelation

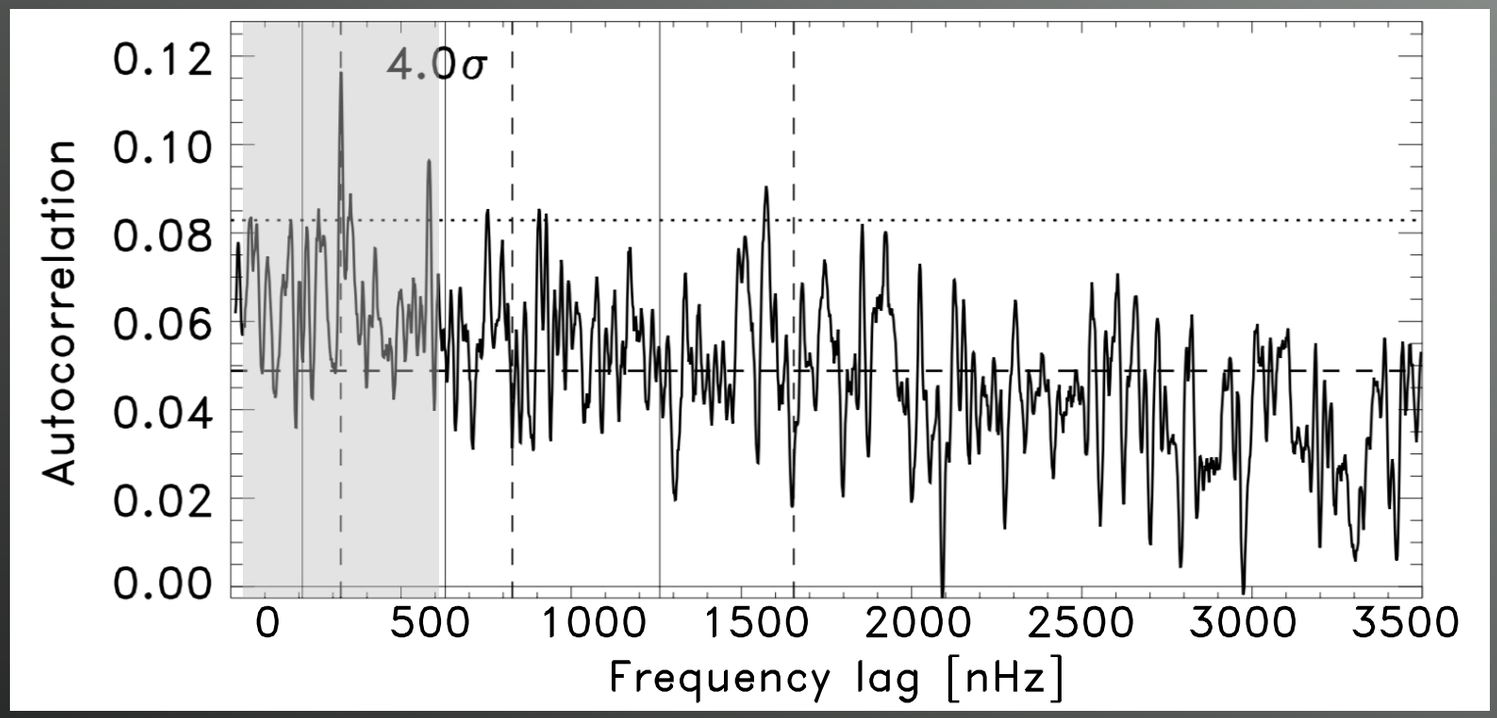
>30 nHz, <500 nHz

Significance of main peak for quadratic fit to RTTT

mean 2.9 σ

min 1.7 σ

max 4.6 σ

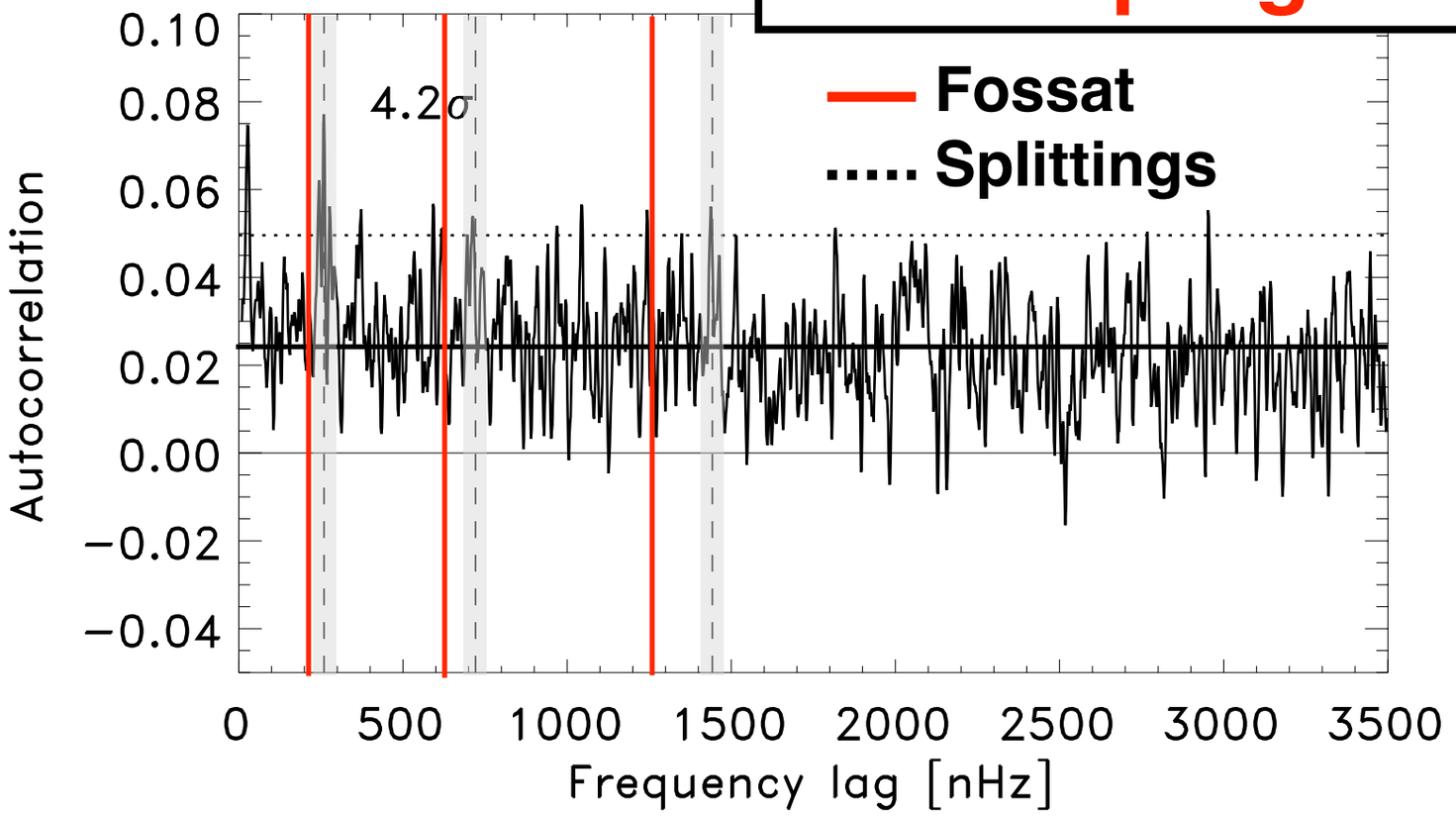


16% of main peaks have a significance > 4 σ

Hannah Schunker

Monte Carlo parameter study #32

work in progress



Identified maximum peaks ≥ 4σ (>30 nHz, <500 nHz)

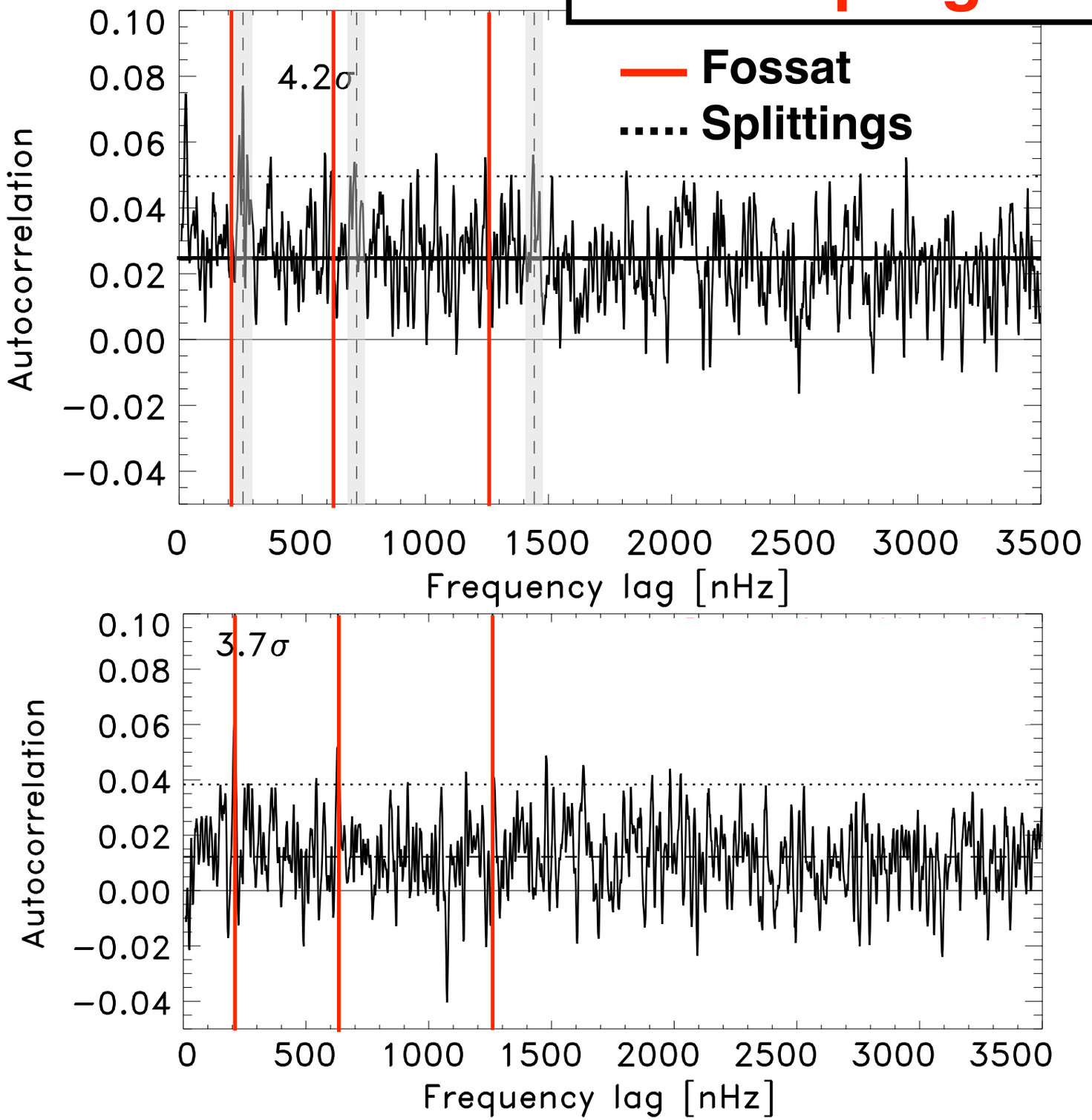
Computed locations of expected splittings

4 pixel smoothing

Hannah Schunker

Monte Carlo parameter study #32

work in progress



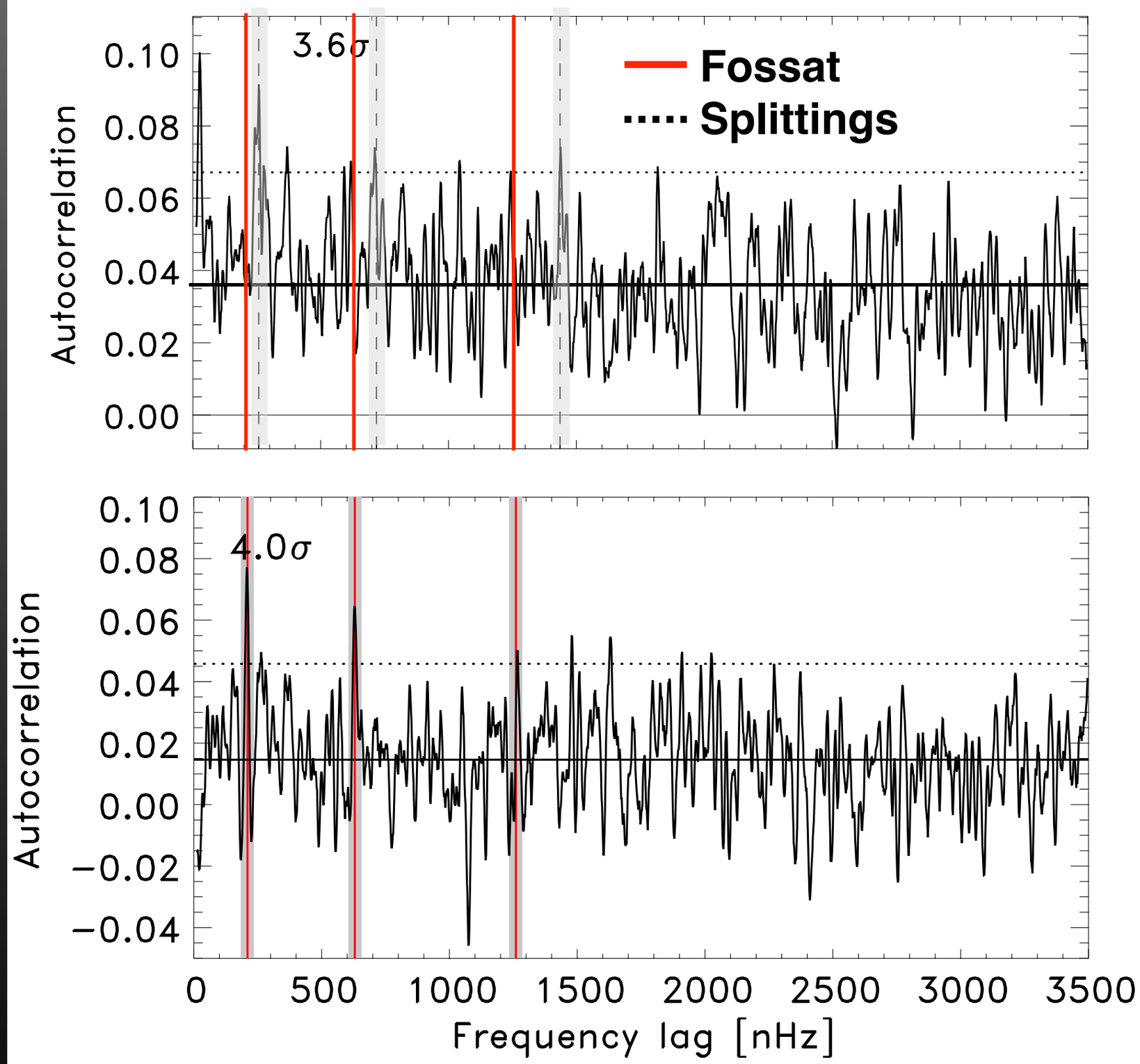
4 pixel smoothing

Original analysis
(no start-time offset)

4 pixel smoothing
(6 pixel smoothing
shows 4σ)

Hannah Schunker

Monte Carlo parameter study #32

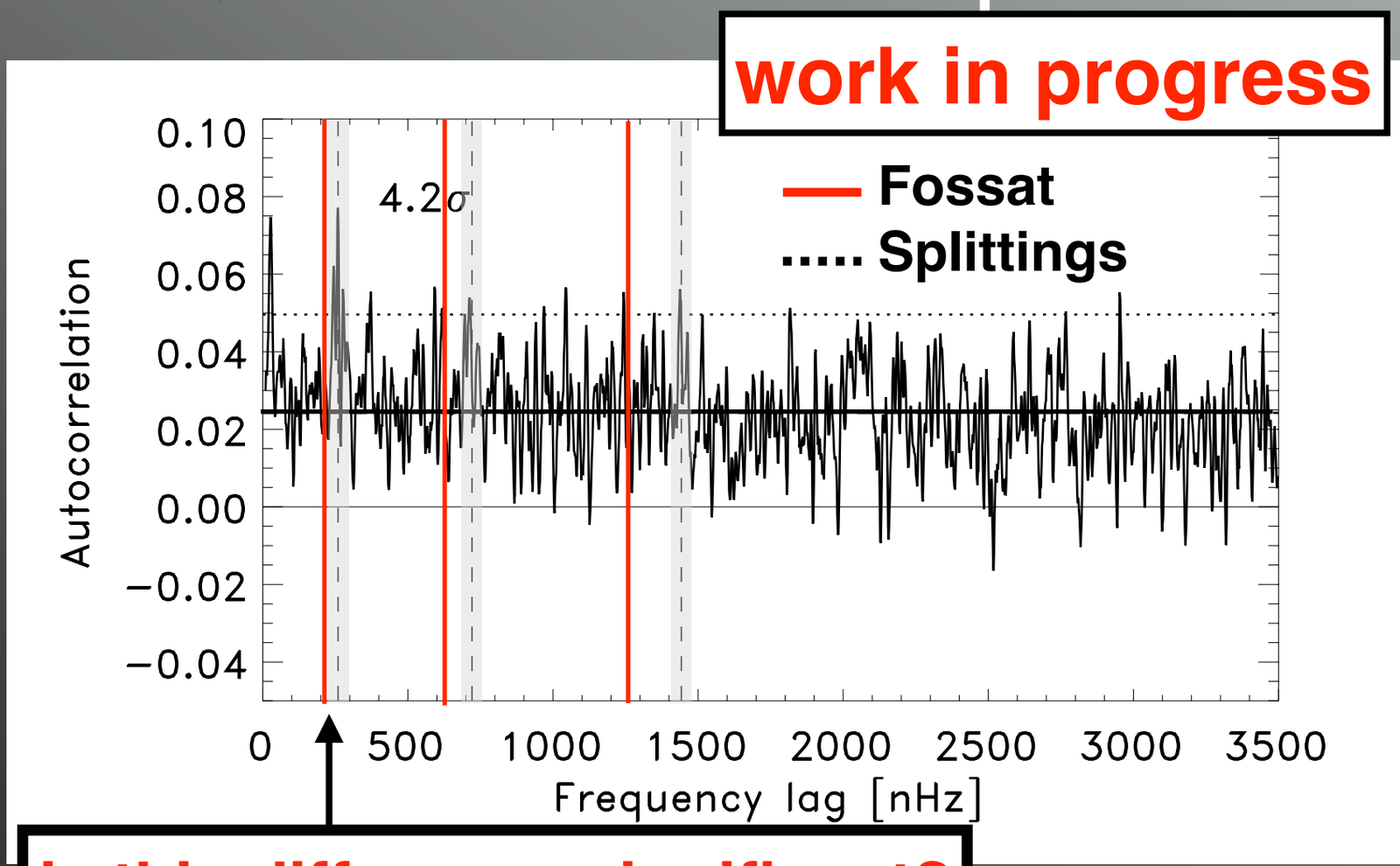


6 pixel smoothing

Original analysis
6 pixel smoothing

Hannah Schunker

Monte Carlo parameter study #32



- Did not find the equivalent signal
- At least a 1 in 5000 chance of finding a similar signal (240 nHz)

Ωg = 1286 nHz

	#32	Fossat
Start-time offset	2 hours	0
p-mode band width	1.77 - 3.9 mHz	2.32 - 3.74 mHz
Width to fit RTTT	741 seconds	800 seconds
Gauss fit window	1.57 - 4.26 mHz	1.5 -5 mHz
Smoothing	4 pixels (7 nHz)	6 pixels (11 nHz)
g-mode rotation	1286 nHz	1277 ± 10 nHz

Summary

1. Qualitatively reproduce Fig. 10 *Fossat et al. 2017*

2. Detection is sensitive to a number of parameters in the analysis method
   i. Fitting function to measure RTTT
   ii. Smoothing of AC
   iii. Start time of data series
   iv. Cadence of RTTT measurements (5 hrs; $4.3\Omega_p$)

3. MC parameter study (2 hour offset)
   - no equivalent signal
   - 1 in 5000 chance of finding a similar signal

Conclusion:
- easily broken ⟶ fragile detection
- start time dependence extremely worrying

Further Tests of Robustness

1. Independent instrument confirmation
   MDI, HMI, BiSON, GONG

2. Explore physical assumptions
   Assume: $\ell = 2 \quad \Omega_{\rm g} = 458\ {\rm nHz}$

3. Other stars with *g*-, *p*-, and mixed modes
   Kepler