Missing Data in Asteroseismology

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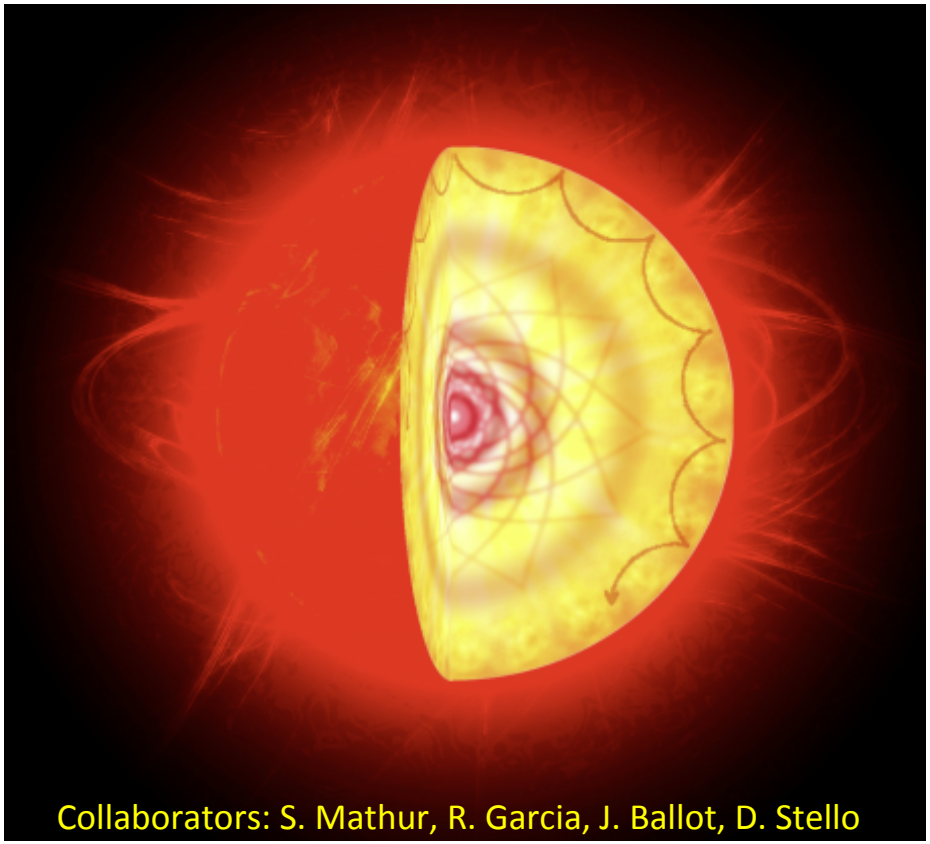
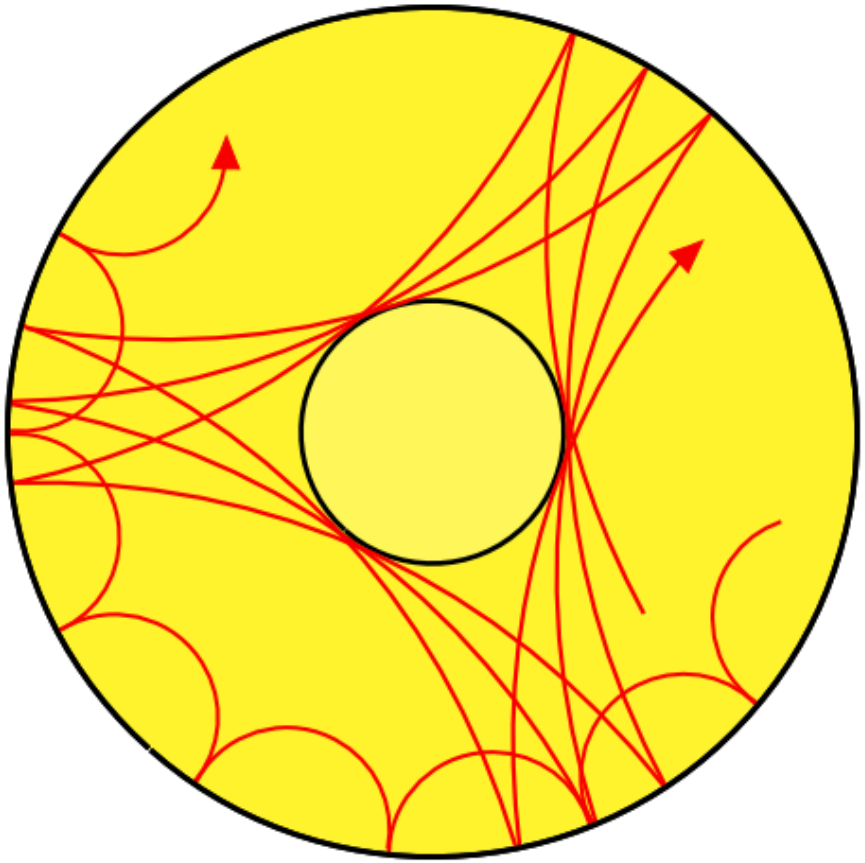
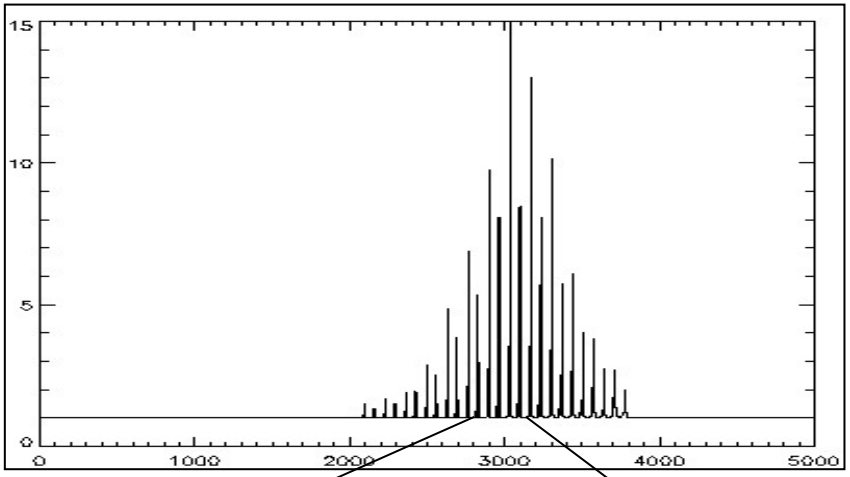


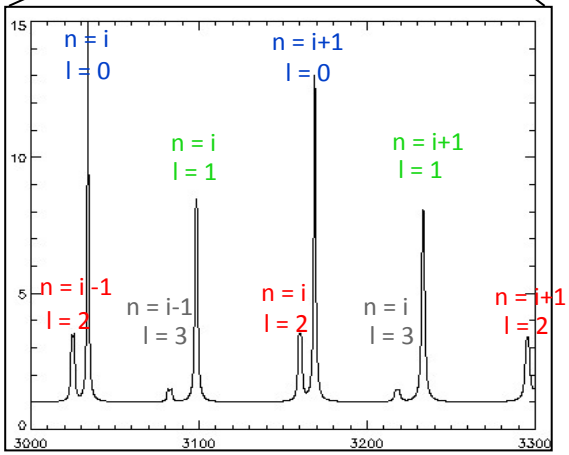
Collaborators: S. Mathur, R. Garcia, J. Ballot, D. Stello

Asteroseismology



Asteroseismology





Origin of Missing Data: Ground Missions

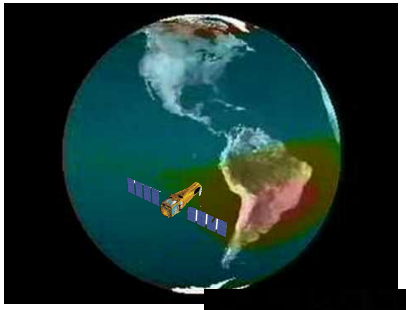
Ground-based observations:

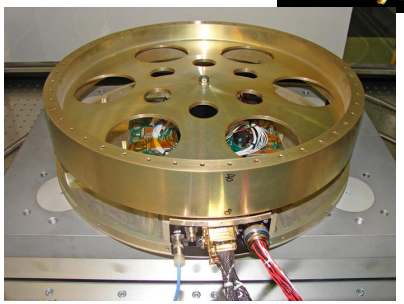
- Weather
- Day/Night Cycle
- Other Factors

Origin of Missing Data: Space Missions

Space-based observations:

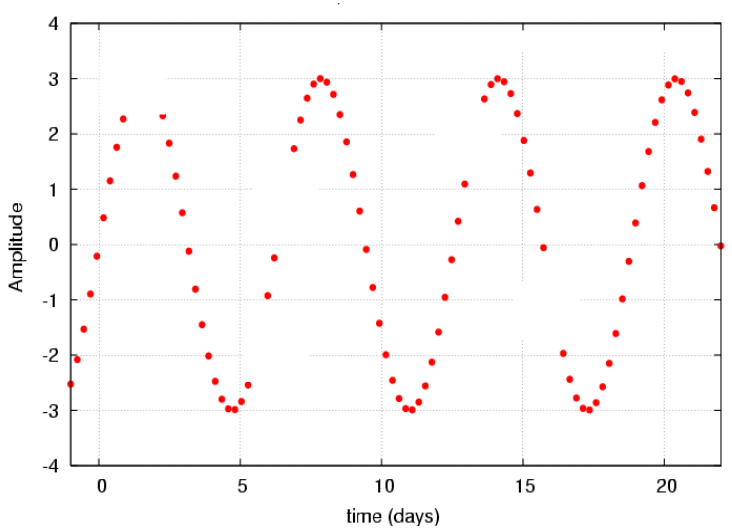
- CoRoT satellite
  - South Atlantic Anomaly (SAA)
- Kepler satellite
  - Downlink Earth pointing
  - Angular Momentum Dump





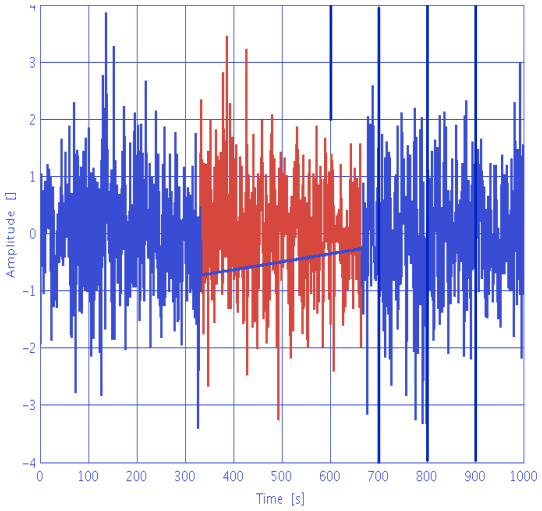
Standard Methods

- Direct Power spectrum estimation
  - Sine Wave Fitting $y = a\cos wt + b\sin wt$
  - CLEAN



Standard Methods

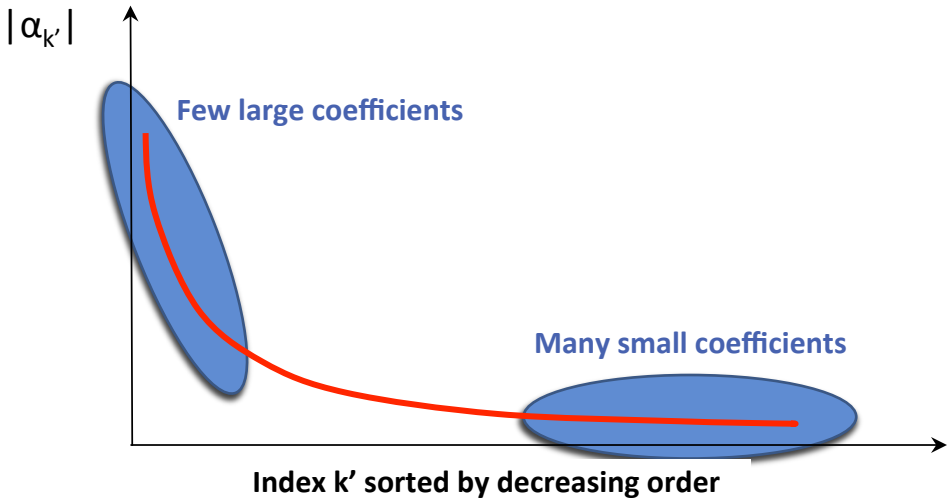
- Direct Power spectrum estimation
  - Sine Wave Fitting
  - CLEAN
- Power spectrum estimation based on gap filling
  - Linear interpolation
  - ARMA
  - Sparse Inpainting



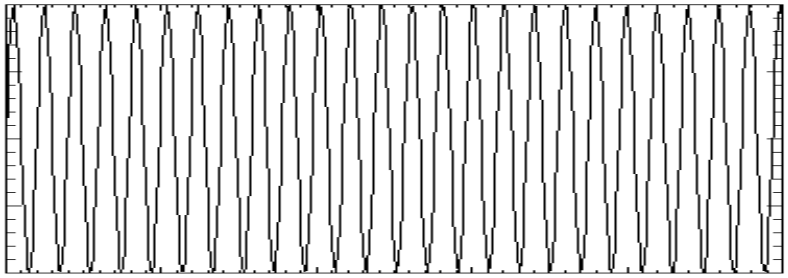
Recent Method

$$W(a,b) = K \int_{-\infty}^{+\infty} \psi^*\left(\frac{x-b}{a}\right) f(x)\,dx$$

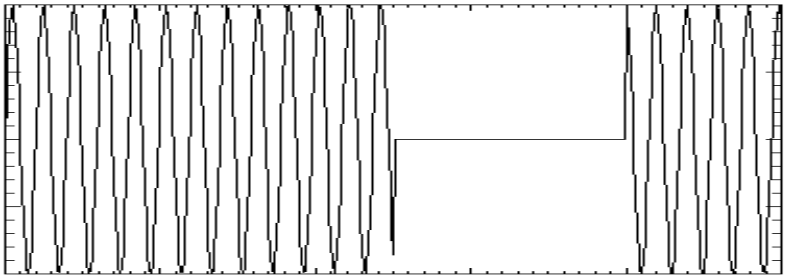
α ψ X



Recent Method: Sparse Inpainting

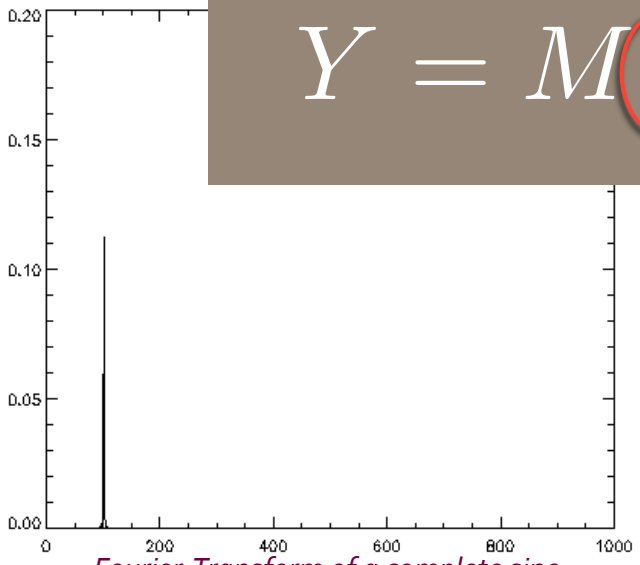


Complete Sine

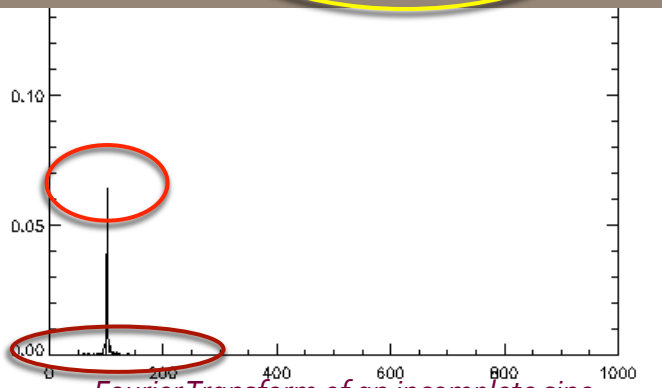


Incomplete Sine

$$Y = M\Phi\alpha \text{ with } \min_{\alpha} ||\alpha||_1$$

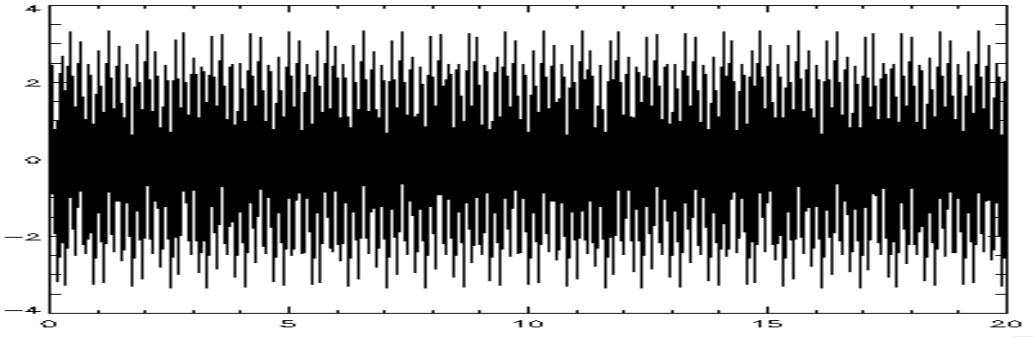


Fourier Transform of a complete sine

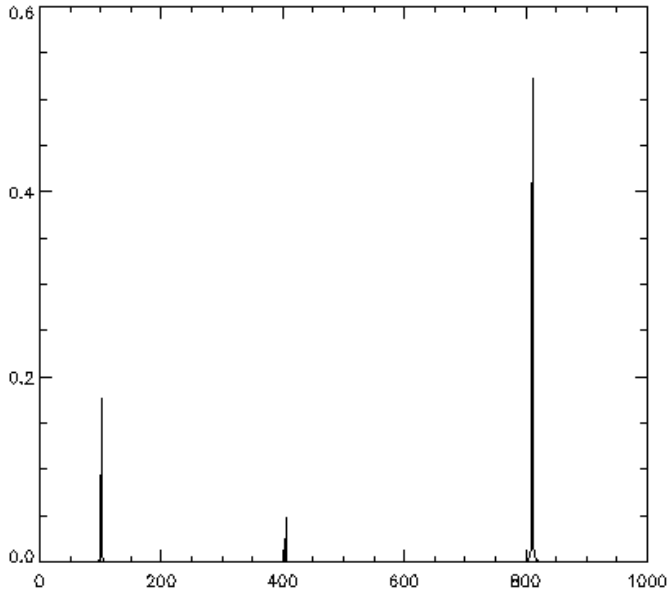


Fourier Transform of an incomplete sine

Sparse Inpainting Algorithm

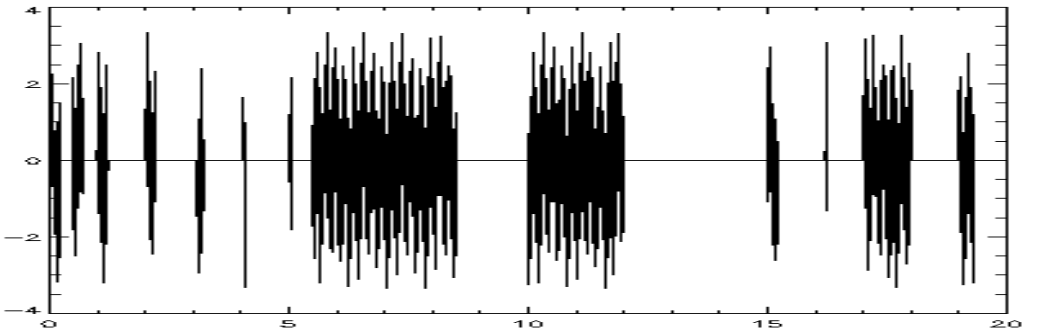


Complete Signal

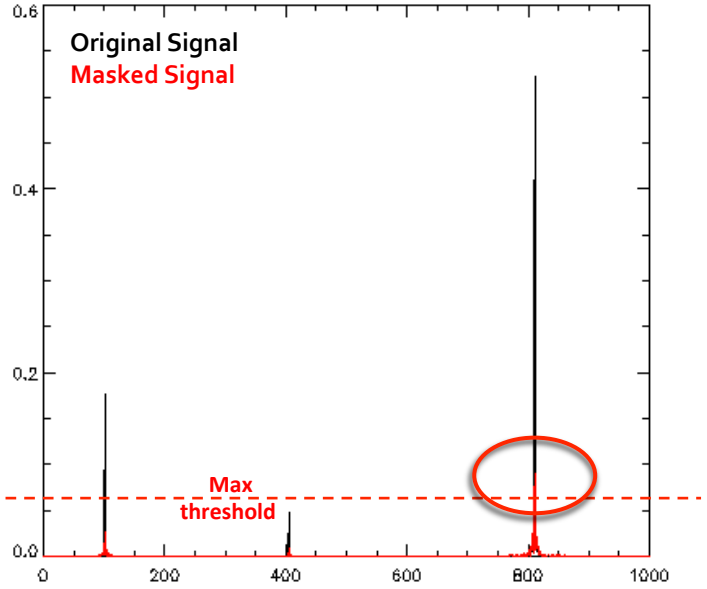


Fourier Transform

Sparse Inpainting Algorithm

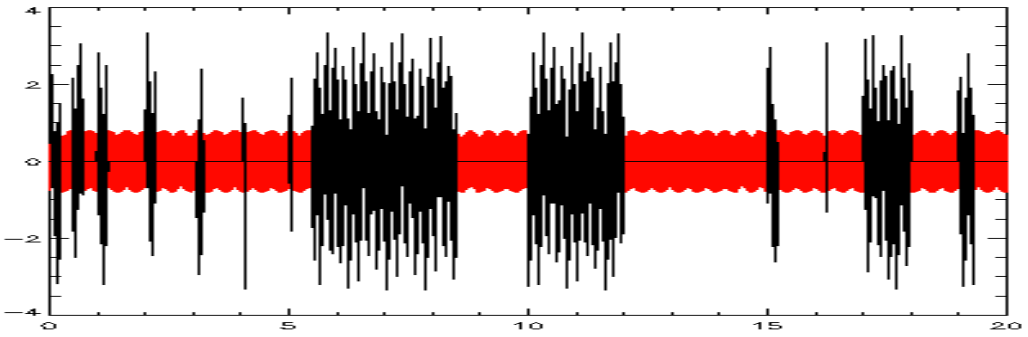


Incomplete Signal

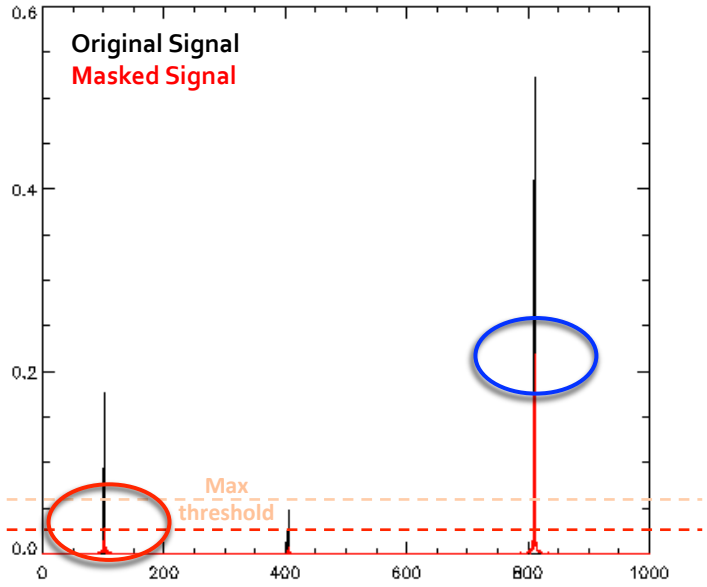


Fourier Transform

Sparse Inpainting Algorithm

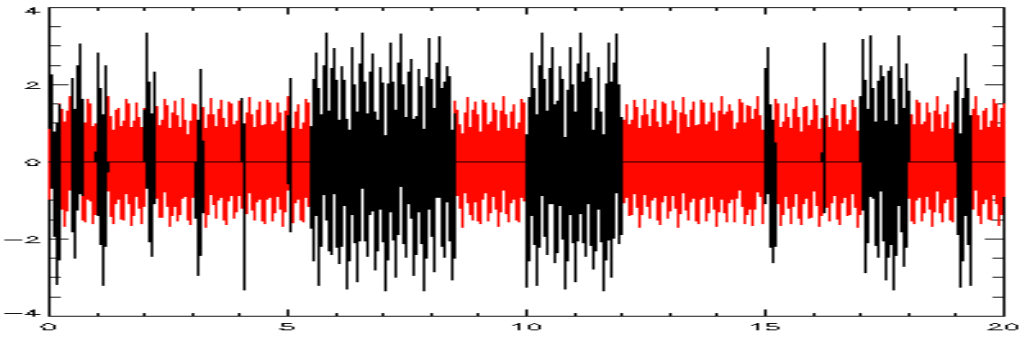


Reconstructed signa at iteration 1

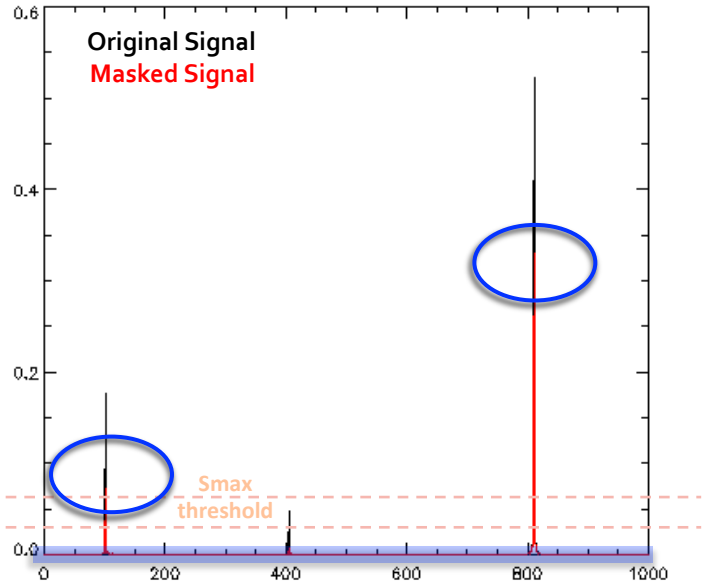


Fourier Transform

Sparse Inpainting Algorithm

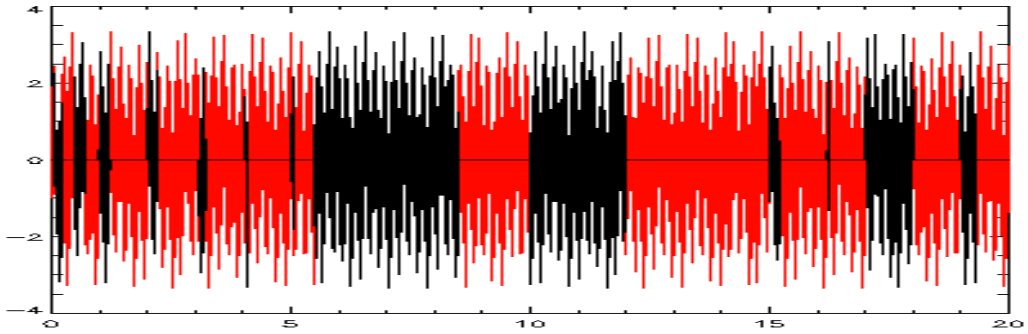


Reconstructed signal at iteration 2

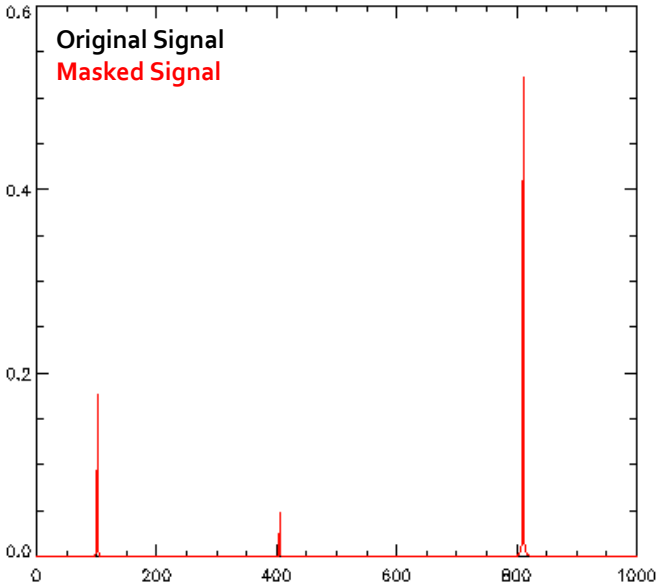


Fourier Transform

Sparse Inpainting Algorithm



Reconstructed signal at iteration N

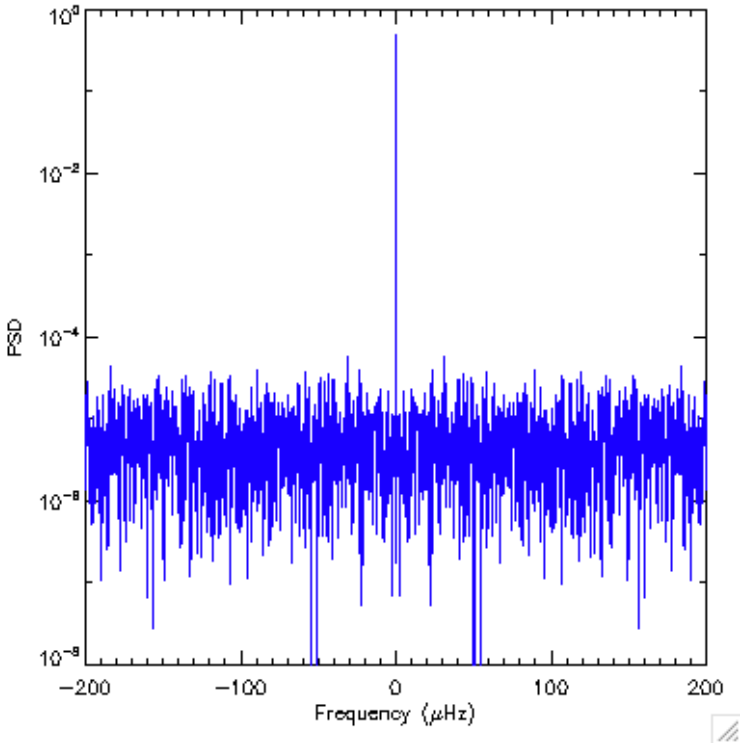


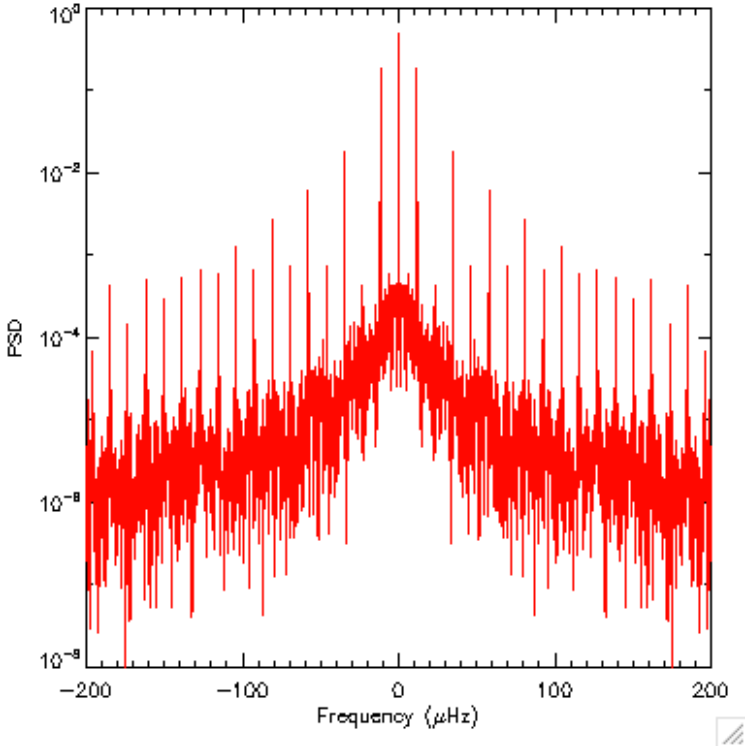
Fourier Transform

Regular vs Random Missing data

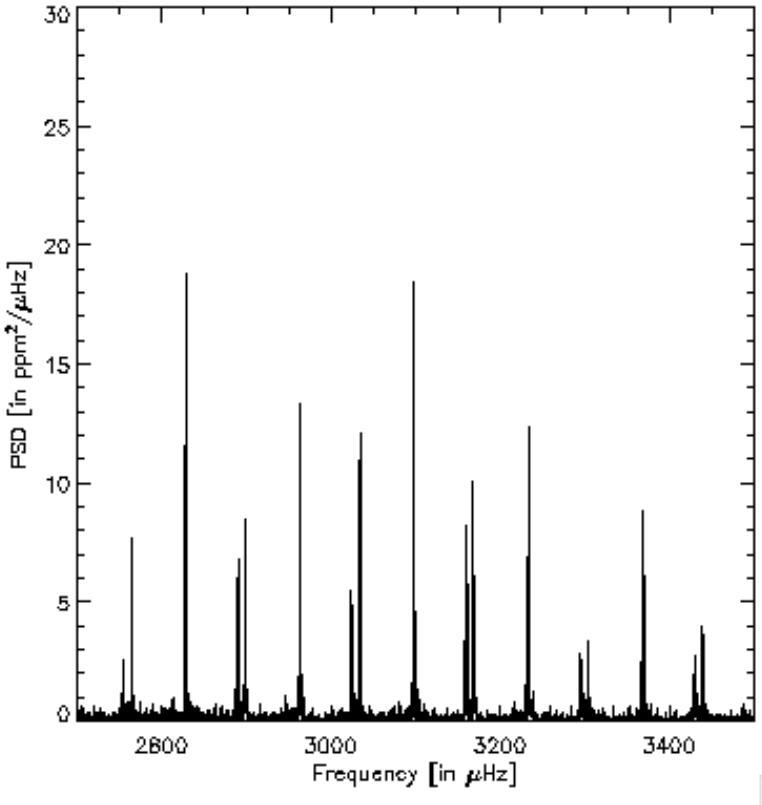
$$Y(t) = M(t)X(t)$$

$$\hat{Y}(f) = \hat{M}(f) * \hat{X}(f)$$



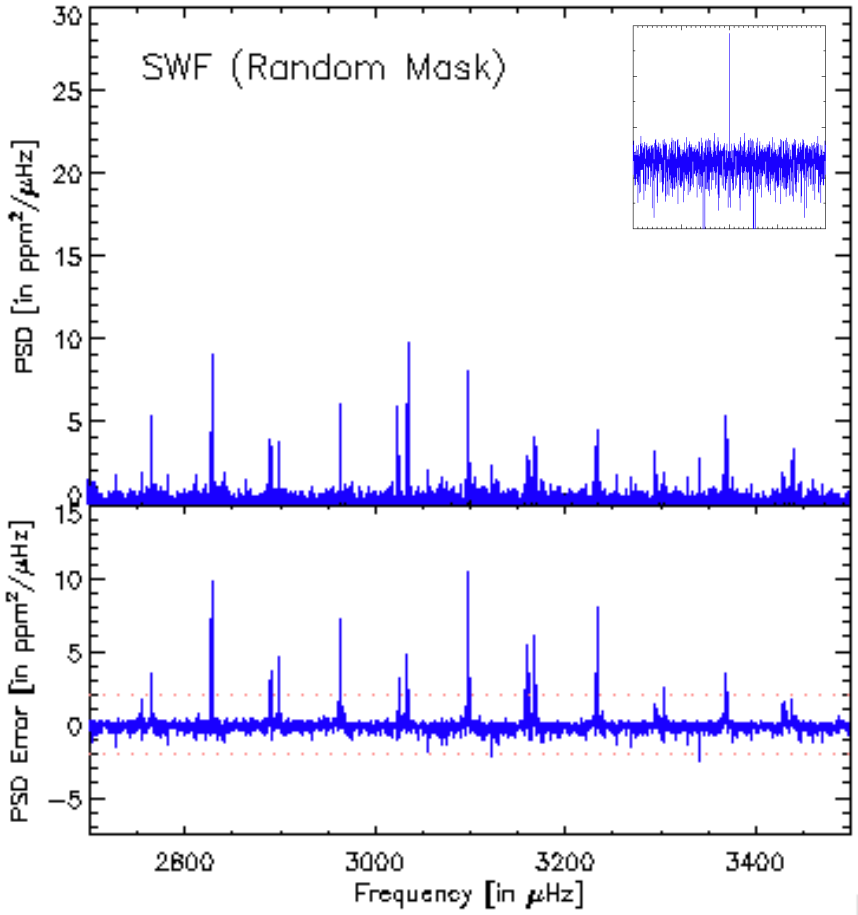


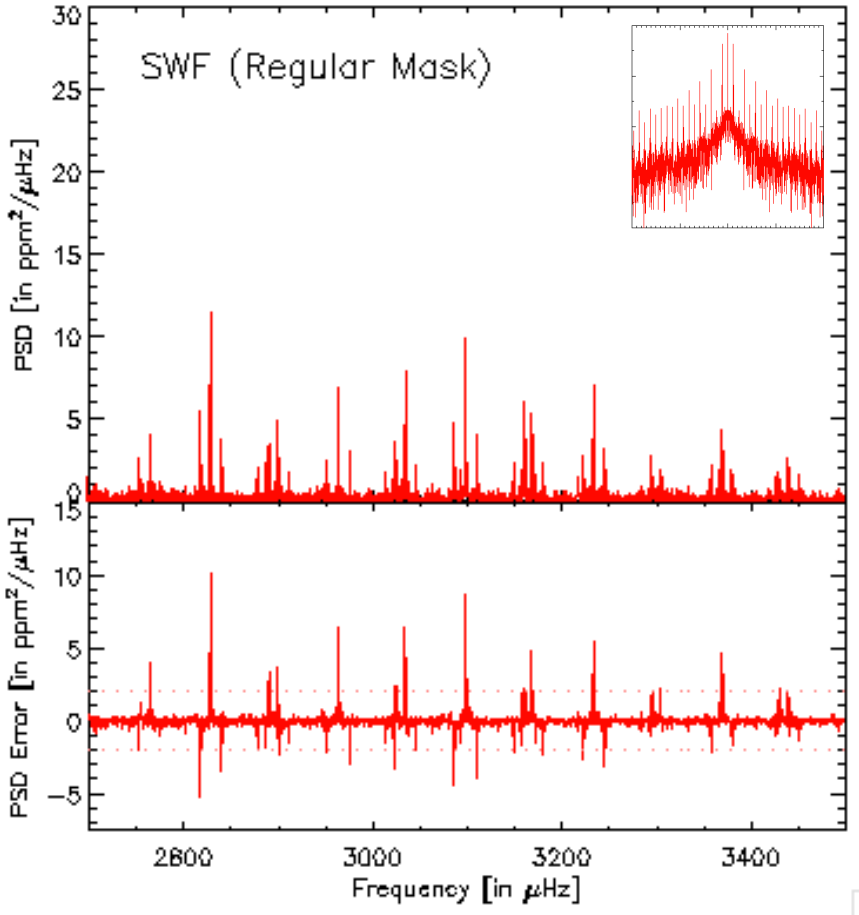
Regular vs Random Missing data



Power Spectrum of the complete time series

Regular vs Random : SWF

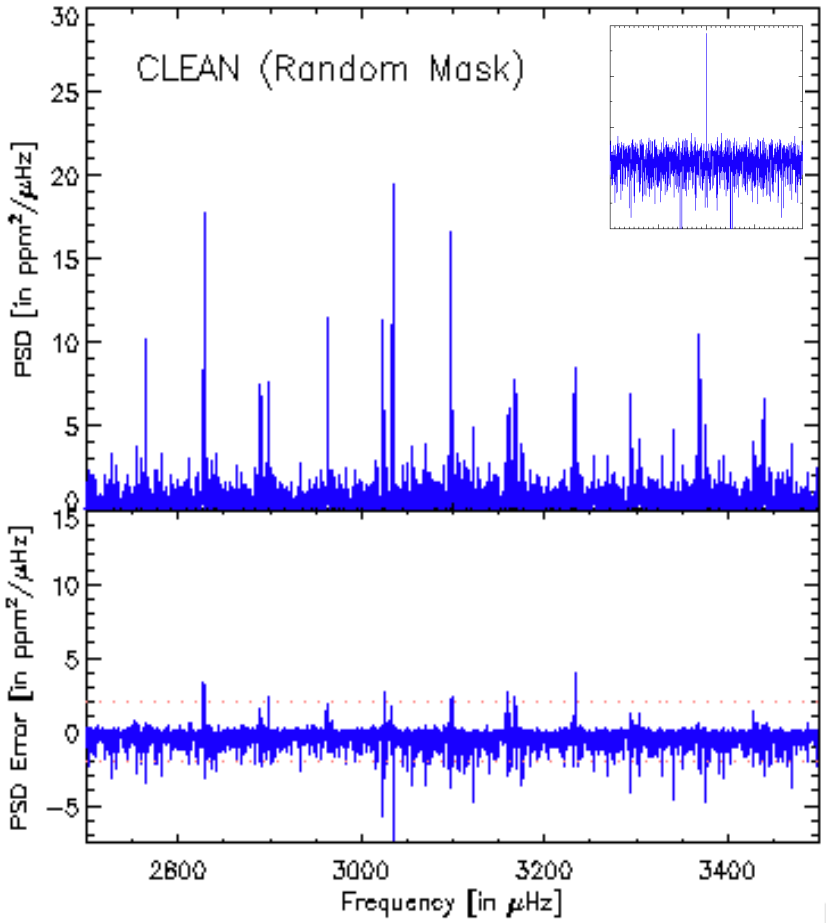


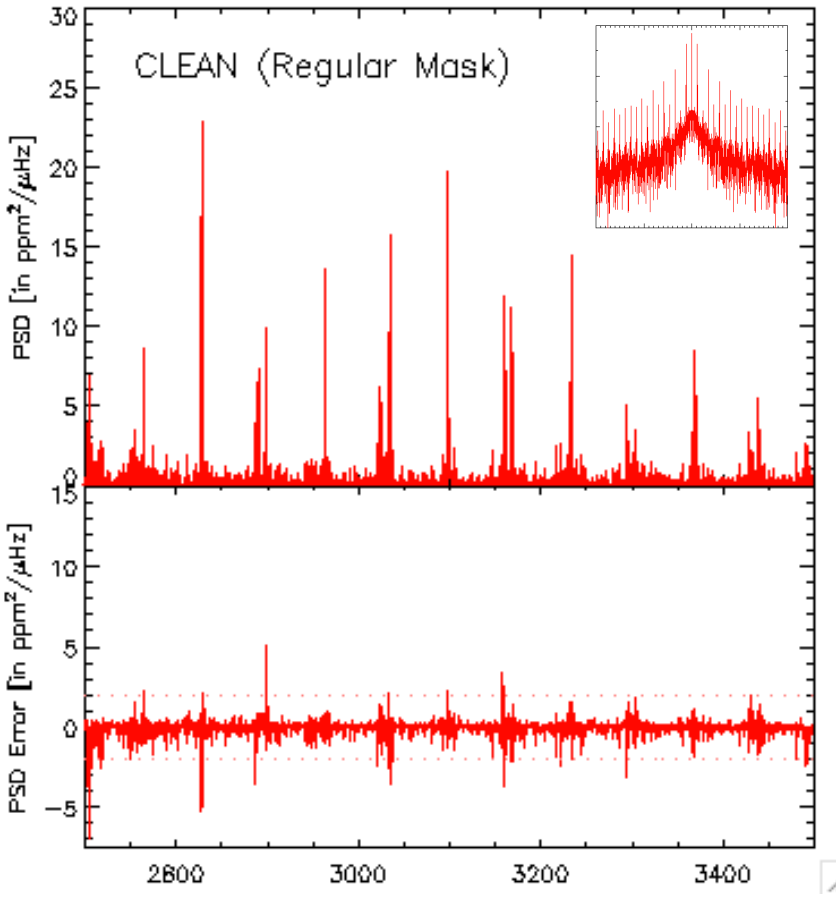


Pires et al., 2015

Duty cycle = 50%

Regular vs Random : CLEAN

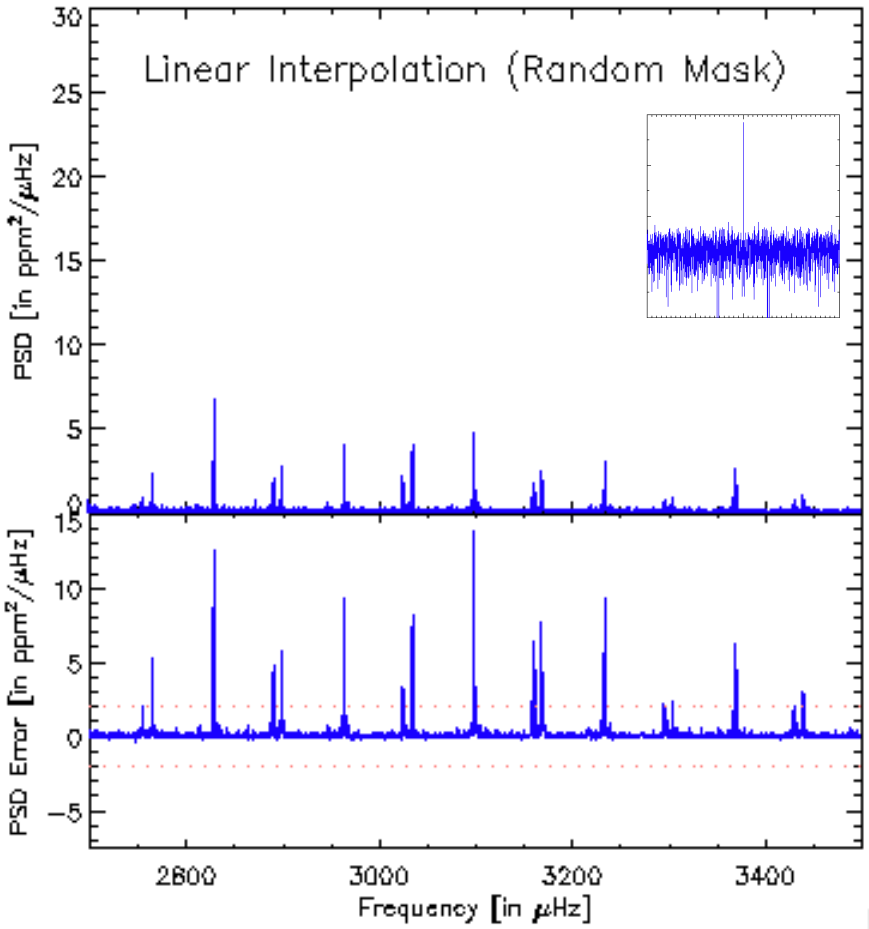


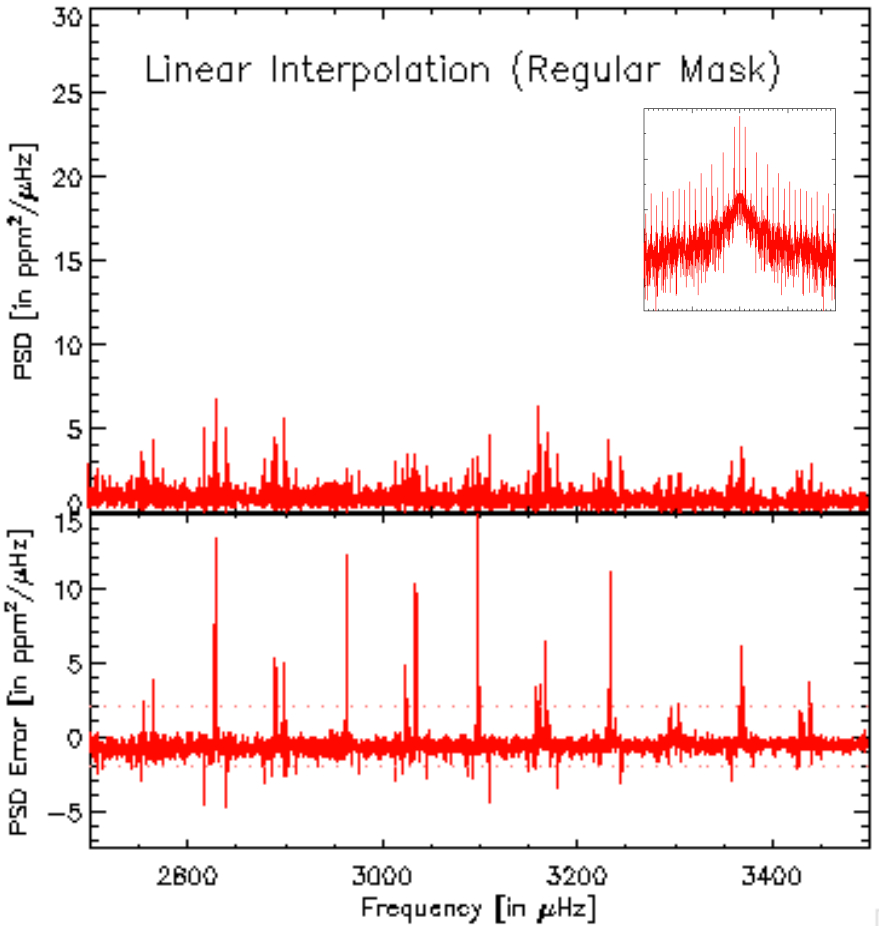


Pires et al., 2015

Duty cycle = 50%

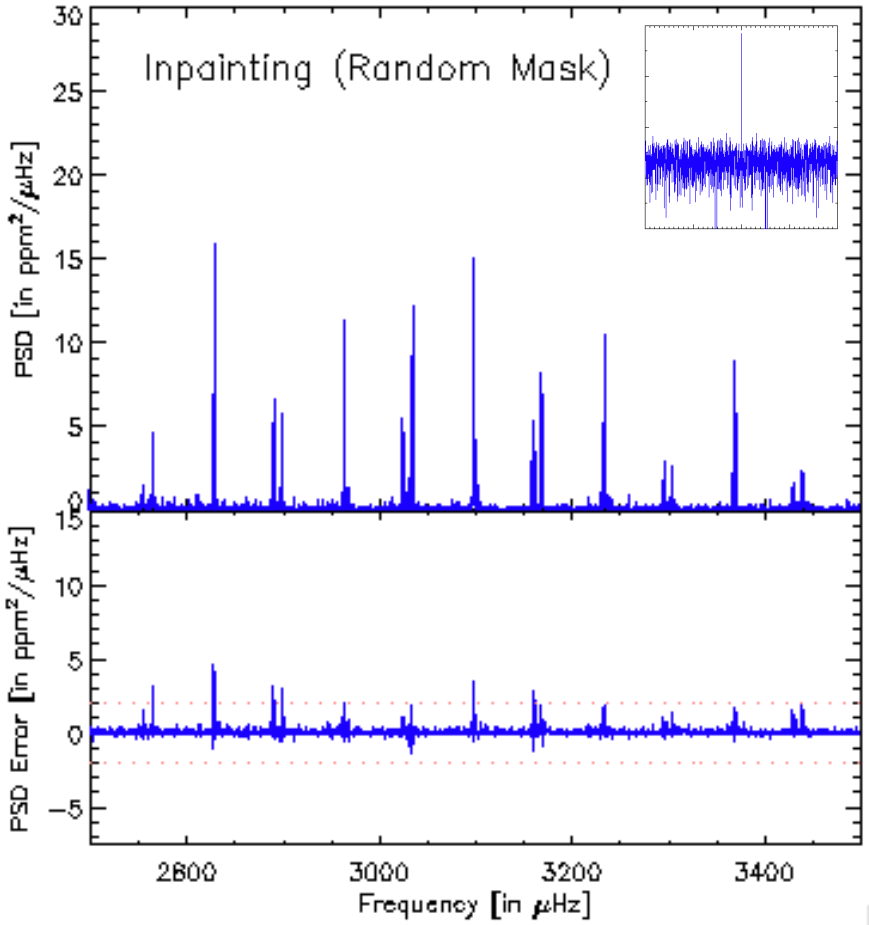
Regular vs Random : Liner interpolation

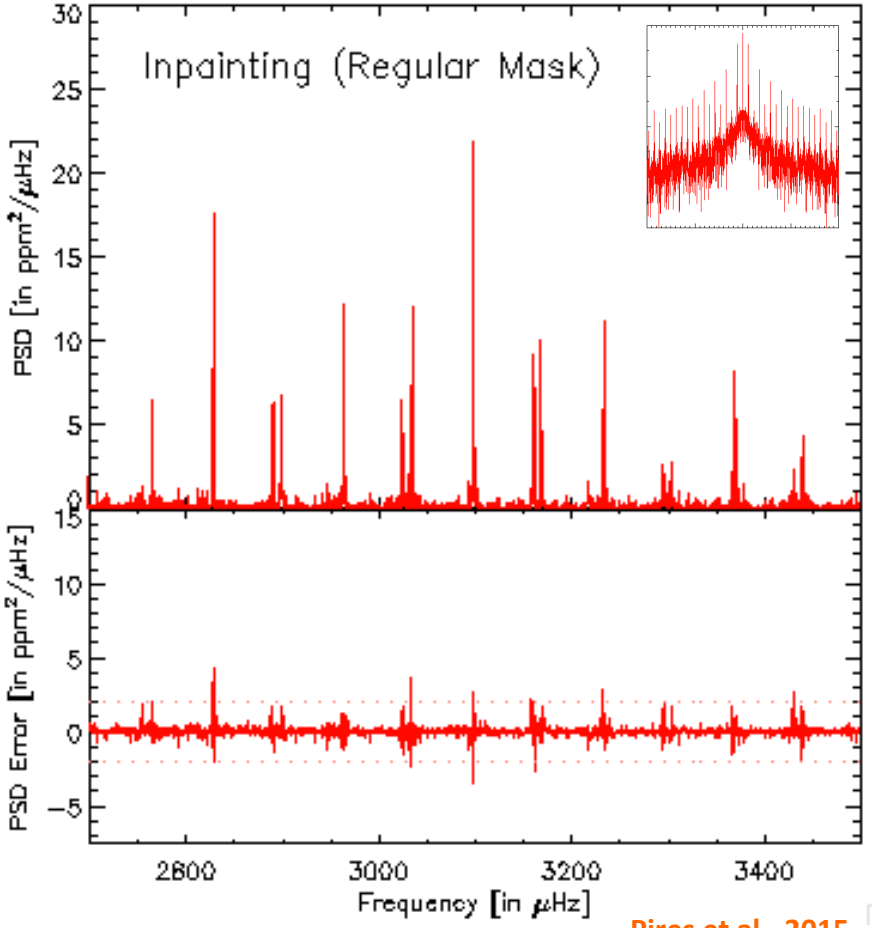




Duty cycle = 50%

Regular vs Random : Inpainting

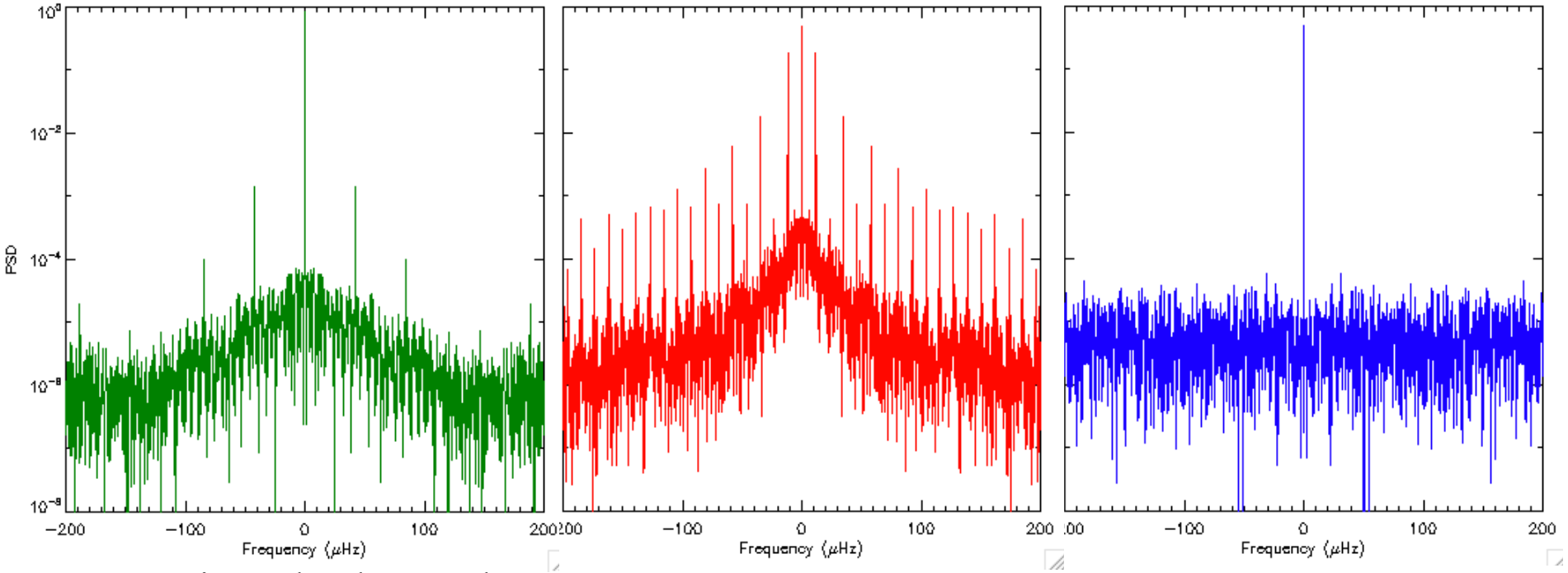




Pires et al., 2015

Duty cycle = 50%

CoRoT-like data : Spectral Window

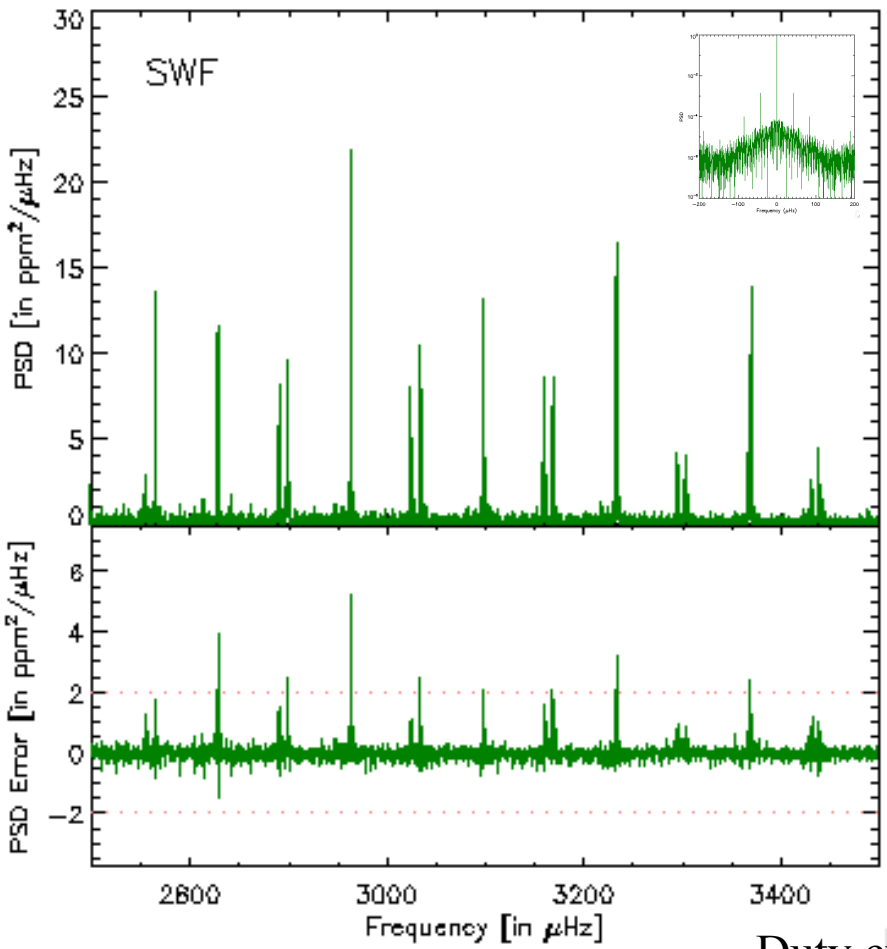


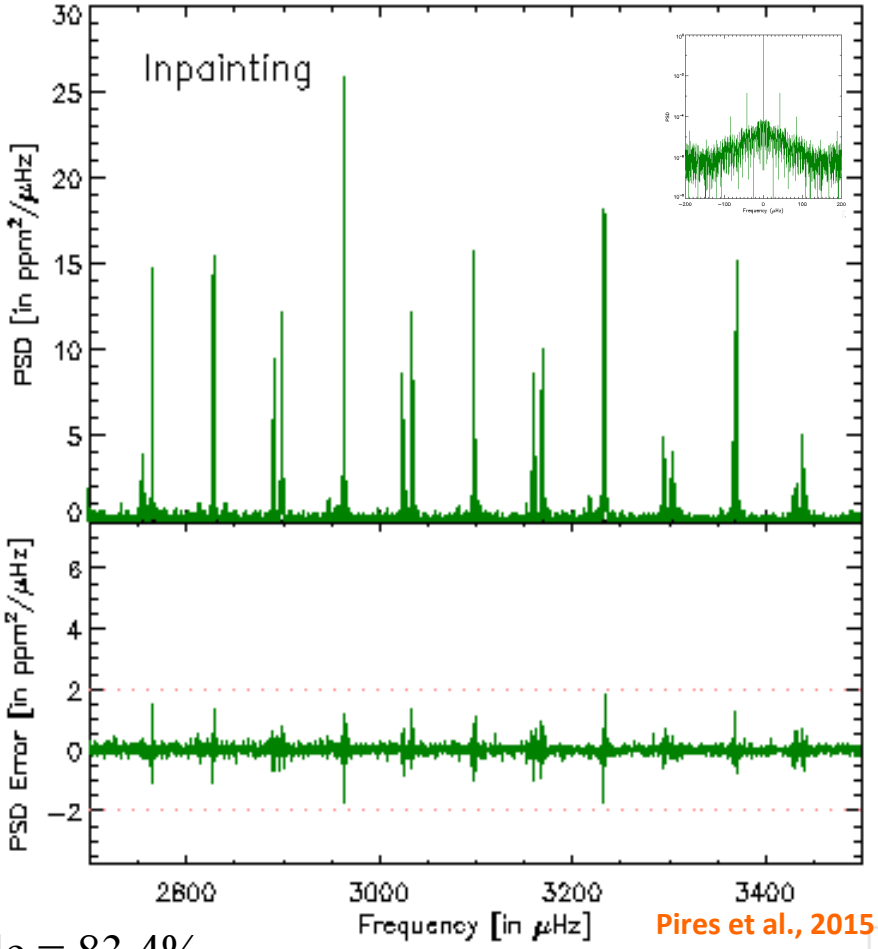
Quasi-regular duty cycle = 83.4 %

Regular duty cycle = 50%

Random duty cycle = 50%

CoRoT-like data : SWF vs Inpainting

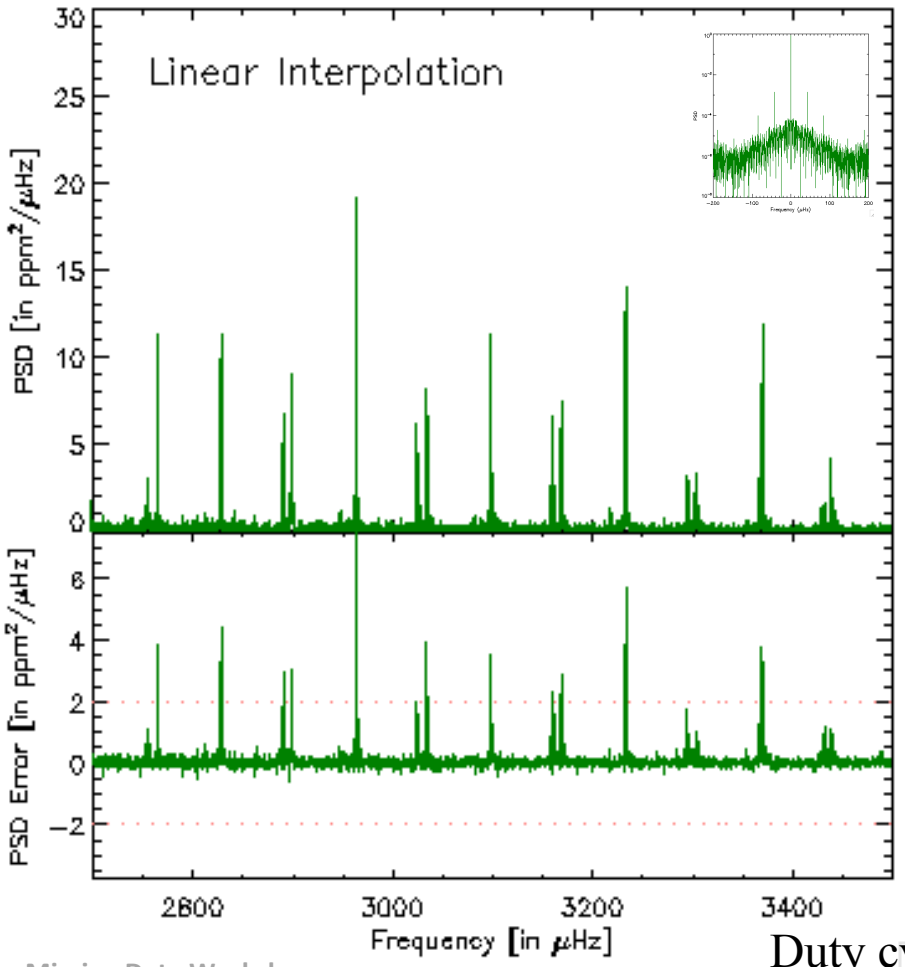


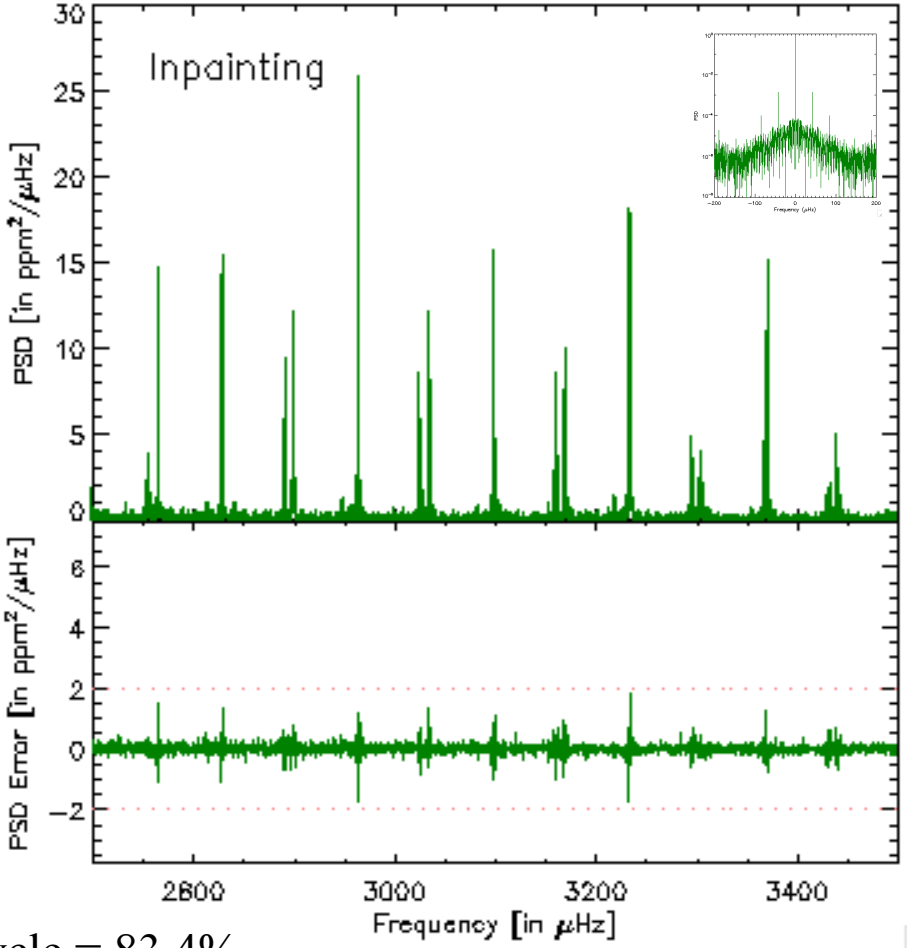


Duty cycle = 83.4%

Pires et al., 2015

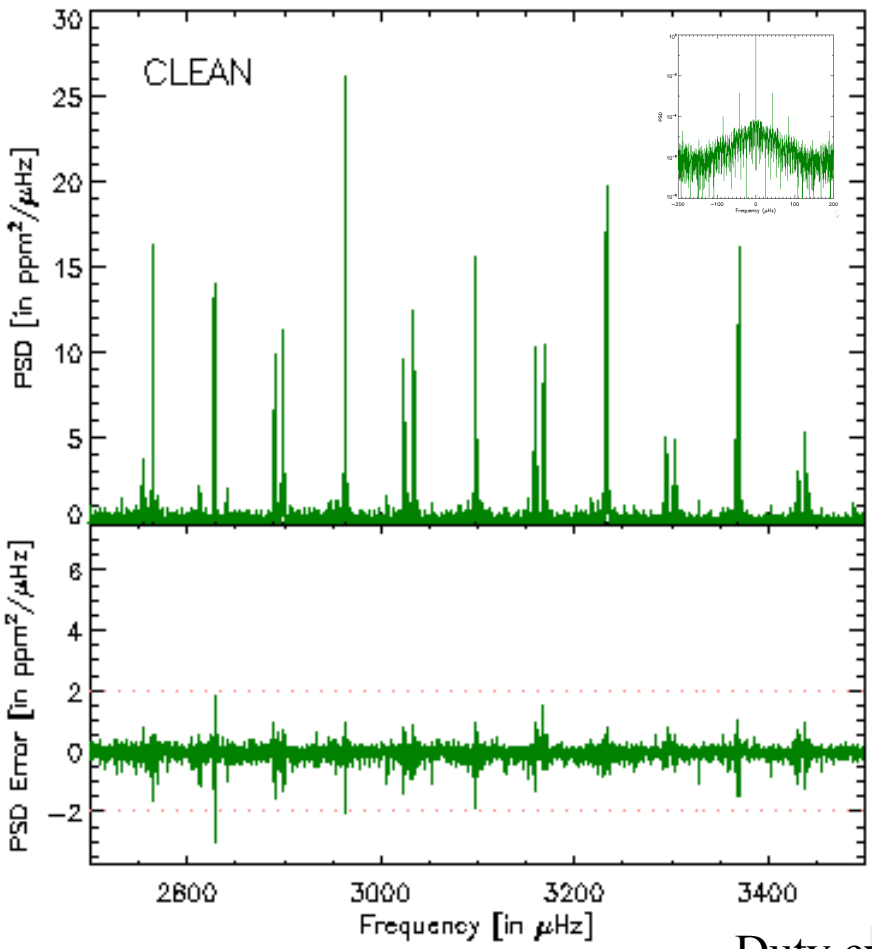
CoRoT-like data : LI vs Inpainting

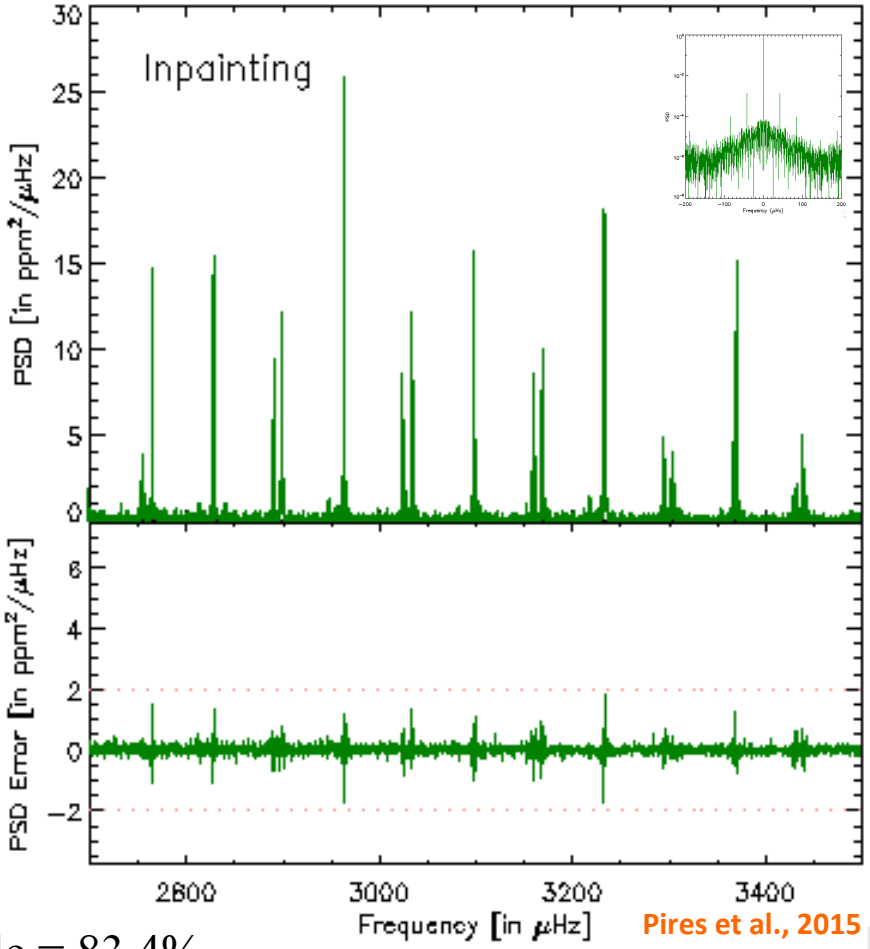




Duty cycle = 83.4%

CoRoT-like data : CLEAN vs Inpainting

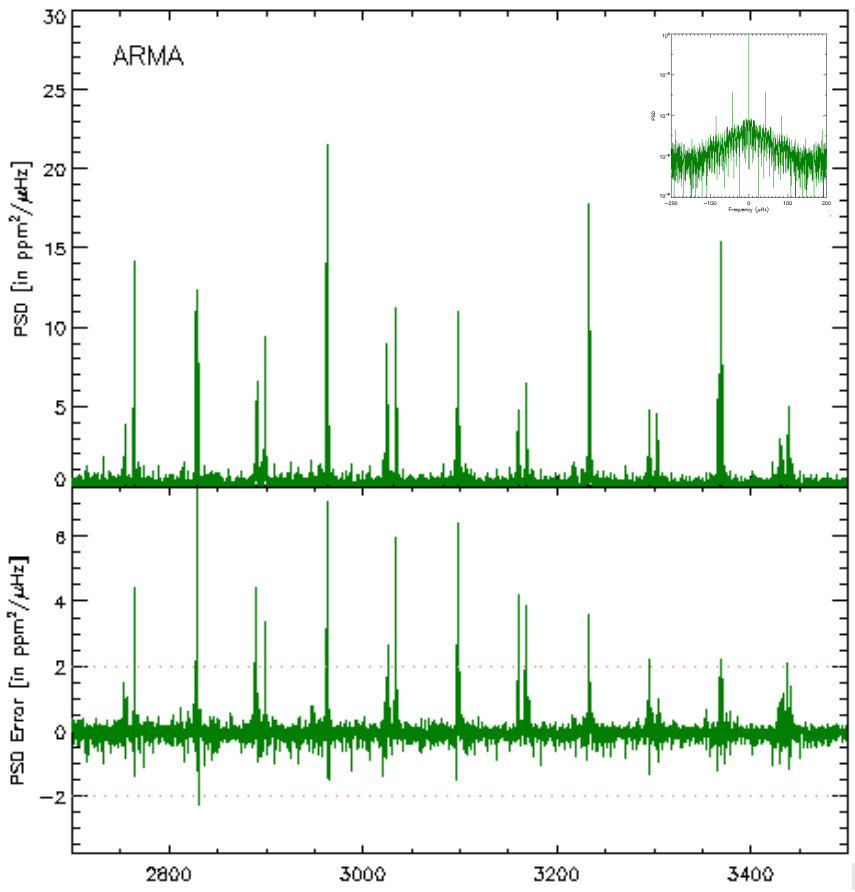


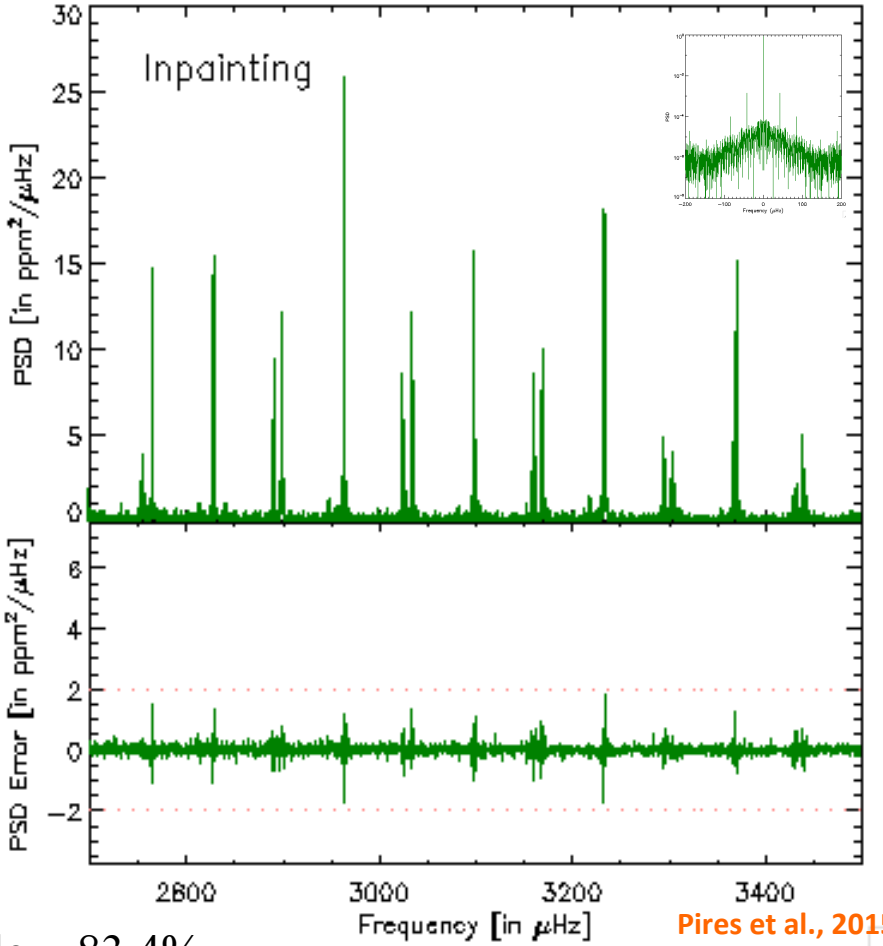


Pires et al., 2015

Duty cycle = 83.4%

CoRoT-like data : ARMA vs Inpainting





Pires et al., 2015

Duty cycle = 83.4%

Processing time

For a time series of 50 days with a sampling of 32s (duty cycle = 50 %):

- SWF
  - 4 hours to compute one tenth of the full power spectrum
- CLEAN
  - about 4 days to compute one tenth of the full power spectrum
- Linear Interpolation
  - Few seconds to compute the full power spectrum
- Sparse Inpainting
  - 4 min to compute the full power spectrum
- MIARMA
  - Few hours to compute the full power spectrum

Applications

- The **Kepler Asteroseismic pipeline** developed by the Kepler AsteroScientic Consortium (KASC) uses the software K-Inpainting to correct the light curves from missing data.

- The **official CoRoT pipeline** will use K-Inpainting software to correct the missing data in both asteroseismic and exoplanet channel.
  - Deadline production code delivery: end of May 2015

K-Inpainting software

CosmoStat
An AIM laboratory @CEA Saclay

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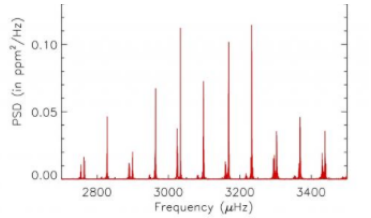
K-Inpainting

Kepler

Welcome to the K-Inpainting web page.
This page introduces the K-Inpainting software (Version 1.0)

In asteroseismology, the observed time series often suffers from incomplete time coverage due to repeated gaps. The presence of periodic gaps may generate spurious peaks in the power spectrum that limit the analysis of the data. Various methods have been developed to deal with gaps in time series data. We propose a new approach to handle the problem, the so-called inpainting method. This technique, based on a sparsity prior, enables to judiciously fill-in the gaps in the data, preserving the asteroseismic signal, as far as possible. This method can be applied both on ground and space-based data. It appears that the inpainting technique improves the oscillation modes detection and estimation. The impact of the observational window function is reduced and the interpretation of the power spectrum is simplified. Additionally, it can be used to study very long time series of many stars because its computation is very fast.

http://www.cosmostat.org/software/k-inpainting/



Power Density Spectrum for a duty cycle of 83% computed using an FFT on the inpainted time series.

Description

K-Inpainting (Inpainting for Kepler) is a software written in C++ with an IDL interface.

Download

Download the K-Inpainting software

END