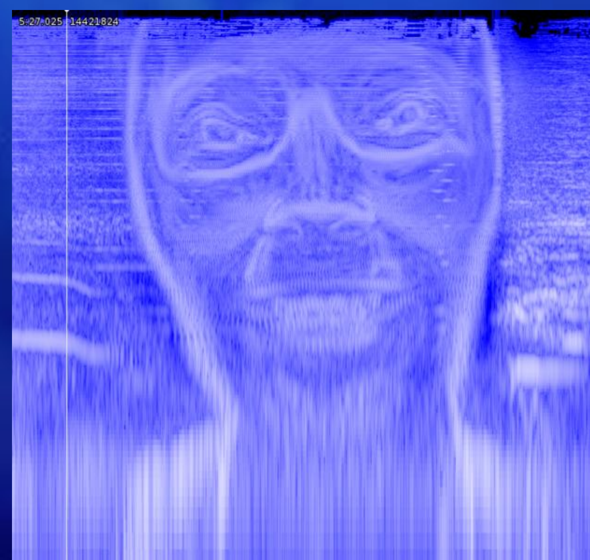
PERTURBATIONS OF OBSERVATIONS. NOISE REDUCTION APPLIED TO ASTEROSEISMOLOGY.



Javier Pascual Granado
CCD 21/10/2009

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Noise characterization and Time Series Analysis

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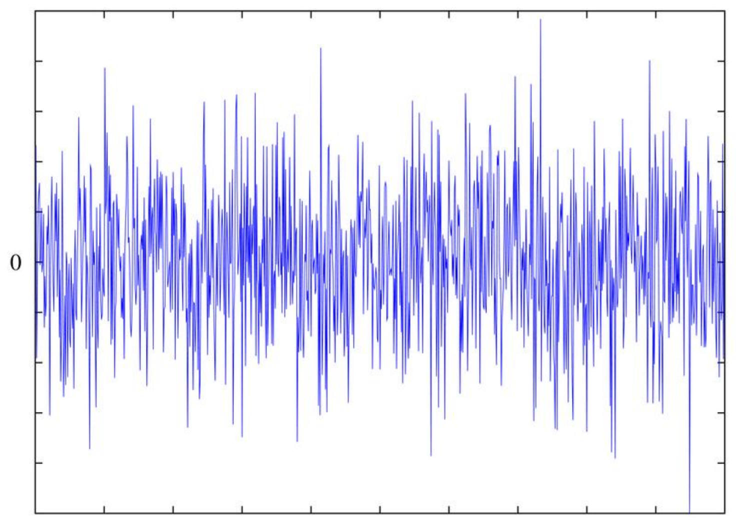
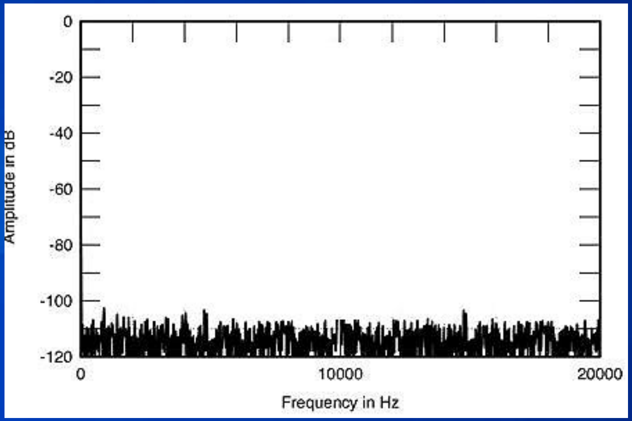
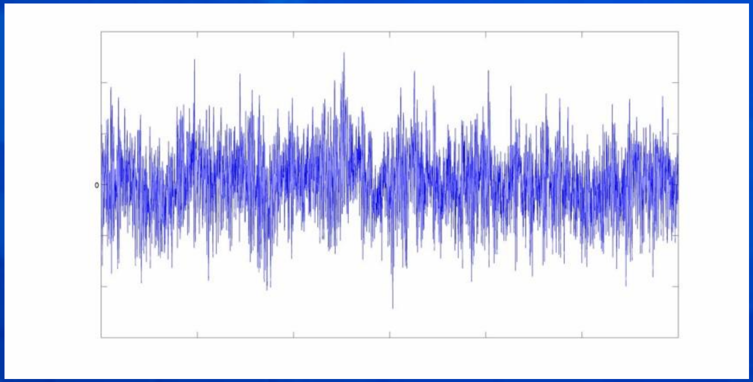
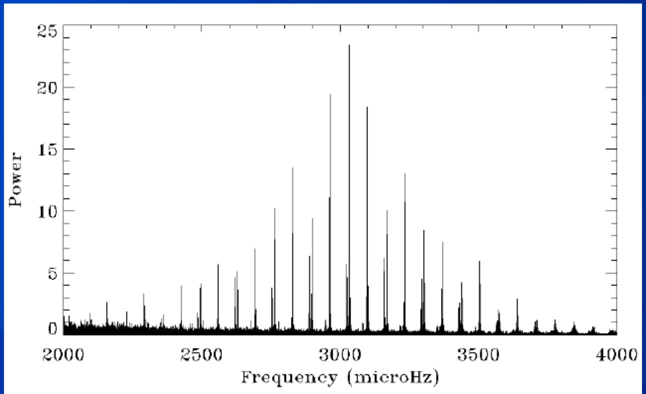


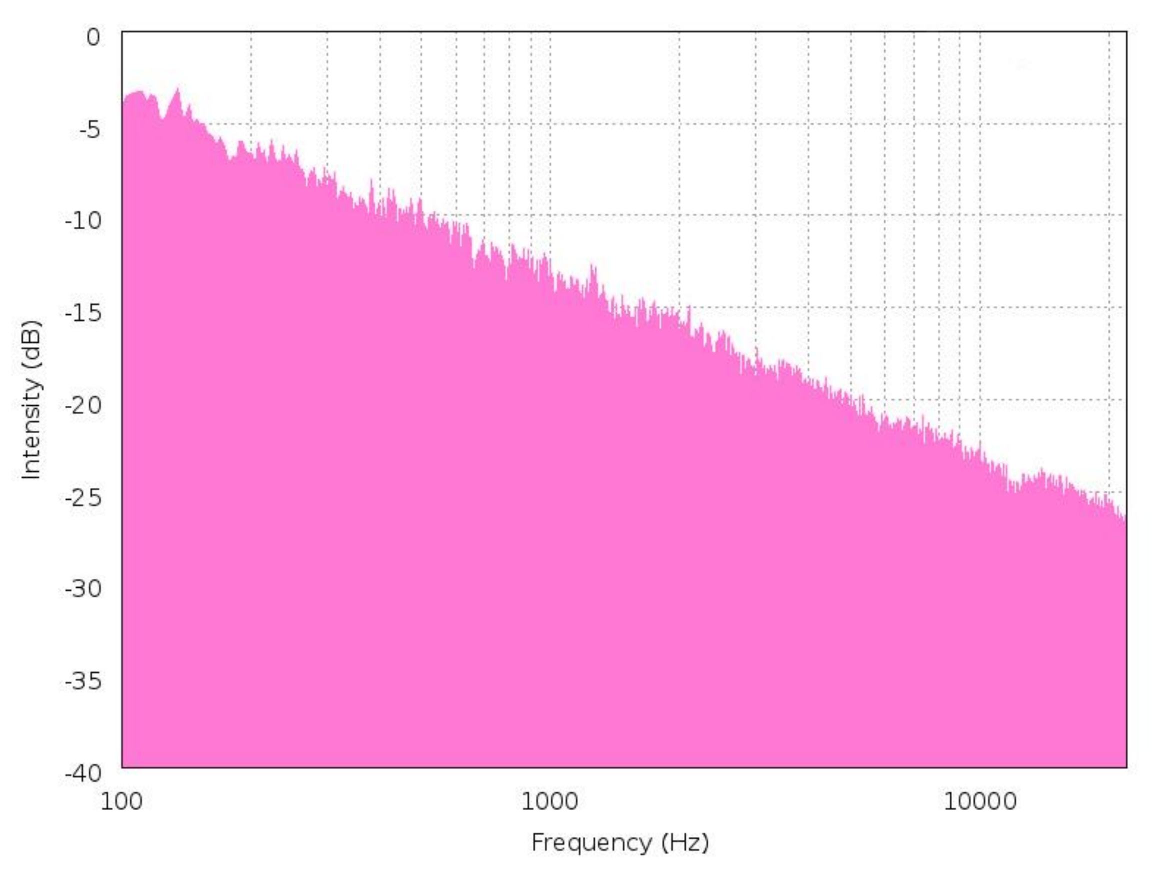






Noise characterization and Time Series Analysis

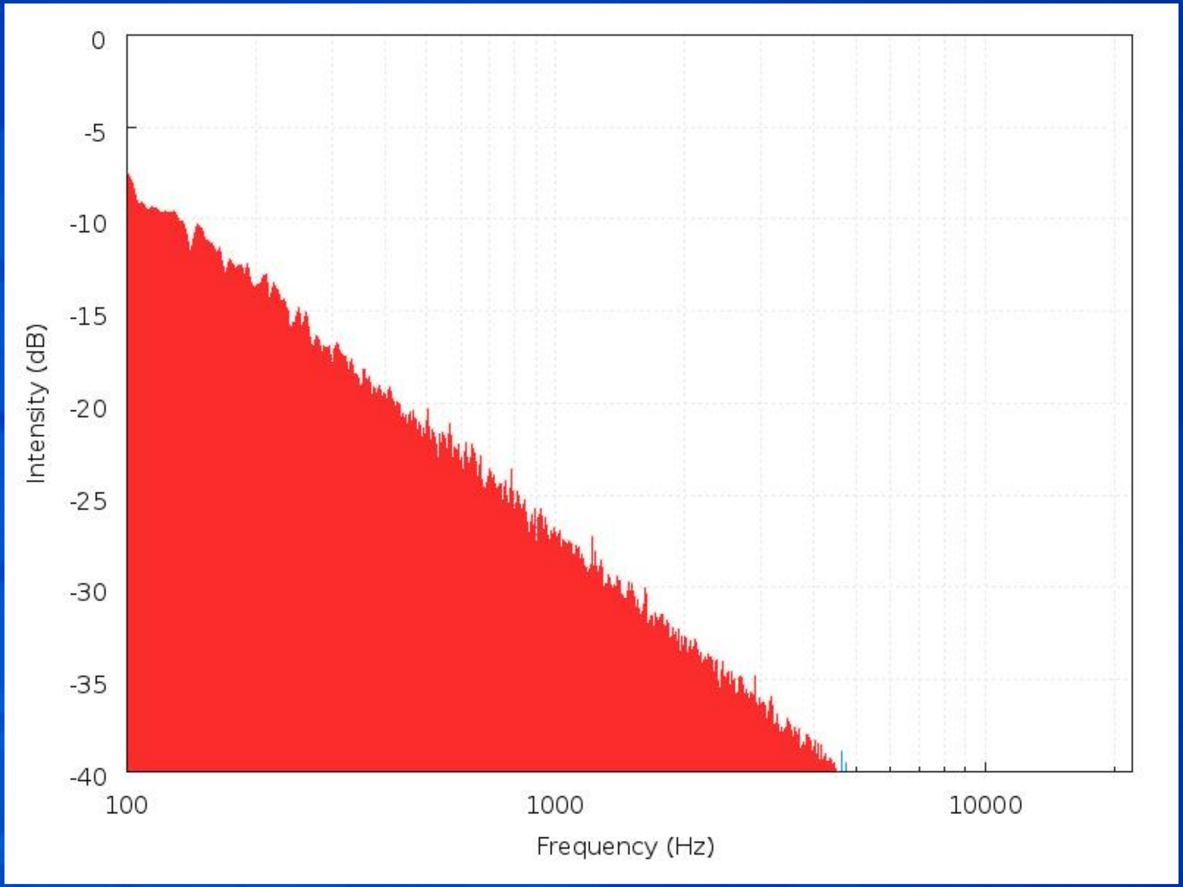
The Colors Of Noise



Pink noise

Noise characterization and Time Series Analysis

The Colors Of Noise



Red noise

Noise characterization and Time Series Analysis

Some Examples In Astrophysics

•Thermal noise due to a nonzero temperature is approximately white gaussian noise.

• Photon-shot noise due to statistical fluctuations in the measurements has a Poisson distribution and a power increasing with frequency. It is a problem with weak signals.

• Also seismic noise affect to sensible ground instruments like LIGO (gravitational wave detector). Nevertheless, for LISA the noise characterization adopted is a gaussian noise.

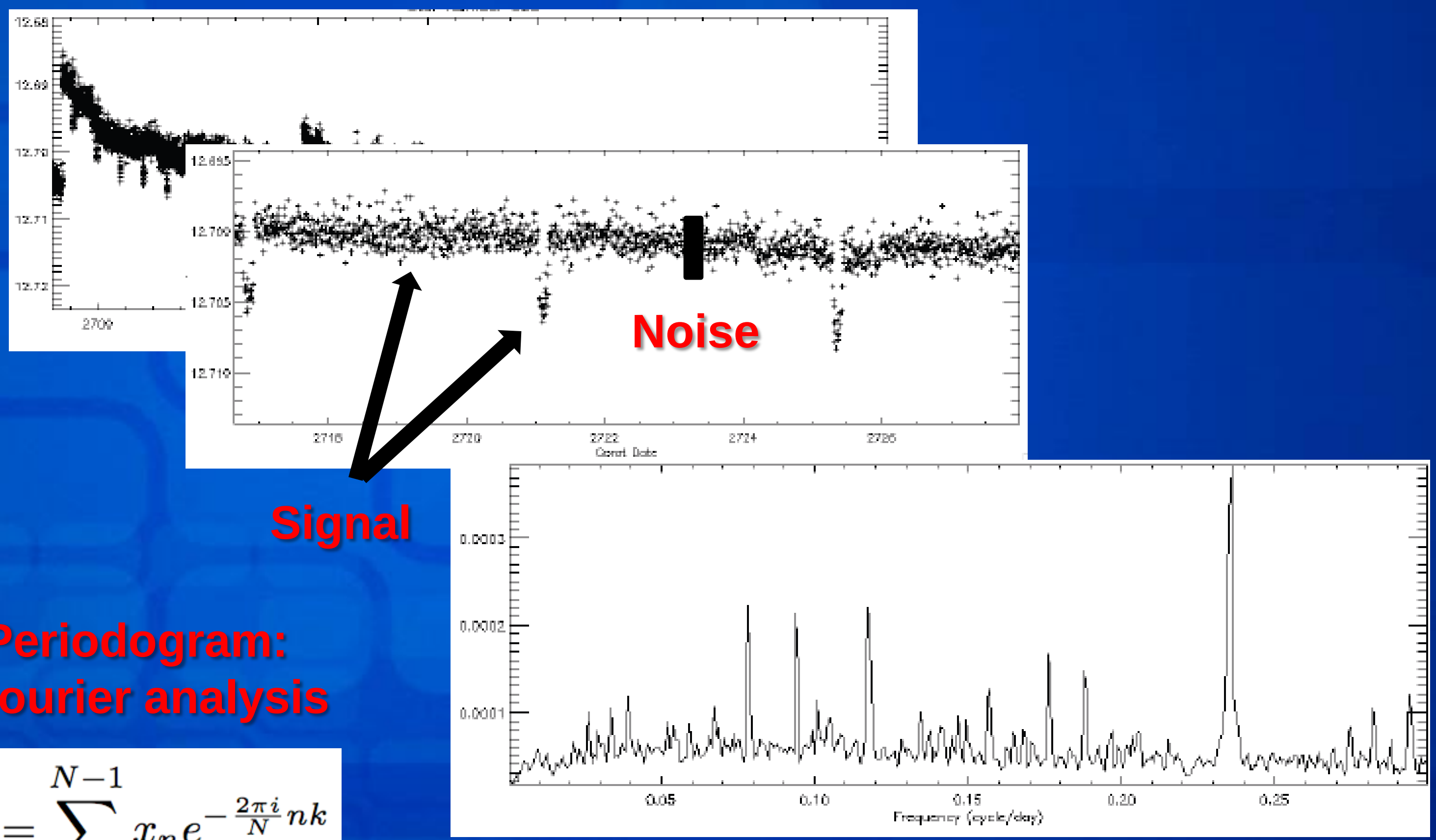
•Observations of the black hole candidate X-ray binary Cyg X-1 by EXOSAT, show a continuum power spectrum with a pink noise.

• In asteroseismology the noise is assumed to be of white gaussian type.

Noise characterization and Time Series Analysis

Time Series: Spectral Estimation

A light curve (or a photometric time series) is a set of data points ordered In time. $t_{i-1}-t_i$ might not be constant.

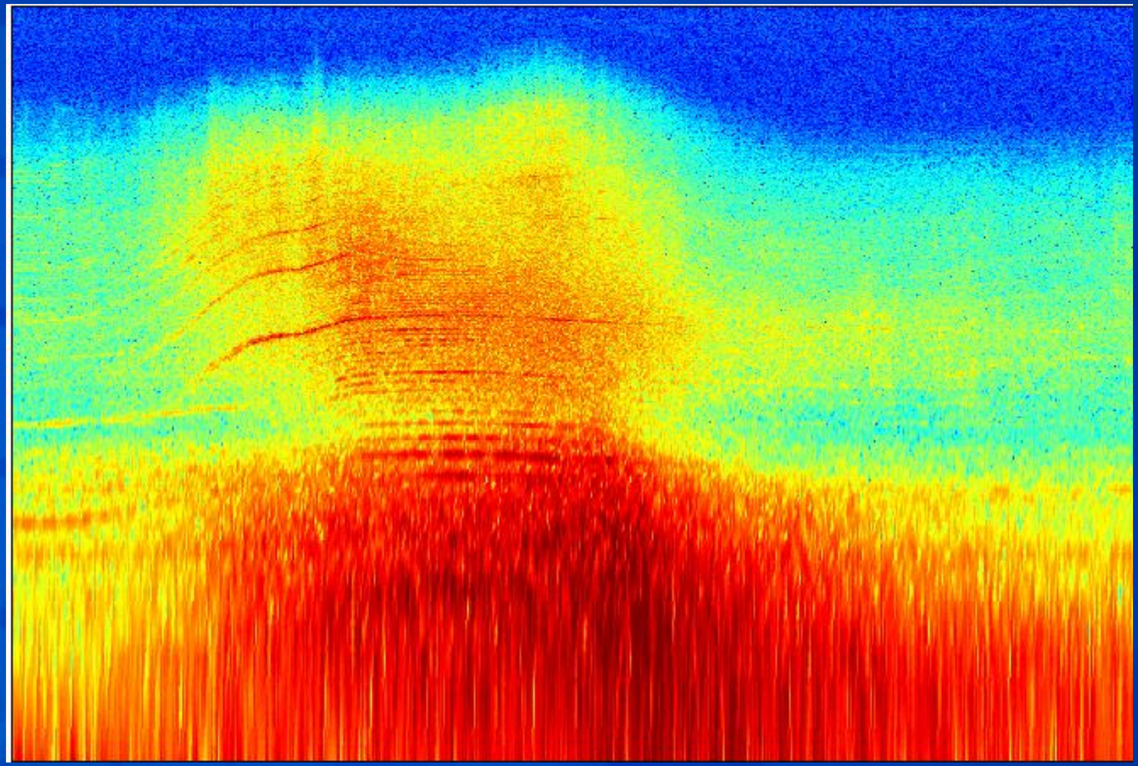


Periodogram: Fourier analysis

$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N} nk}$$

Noise Characterization and Time Series Analysis

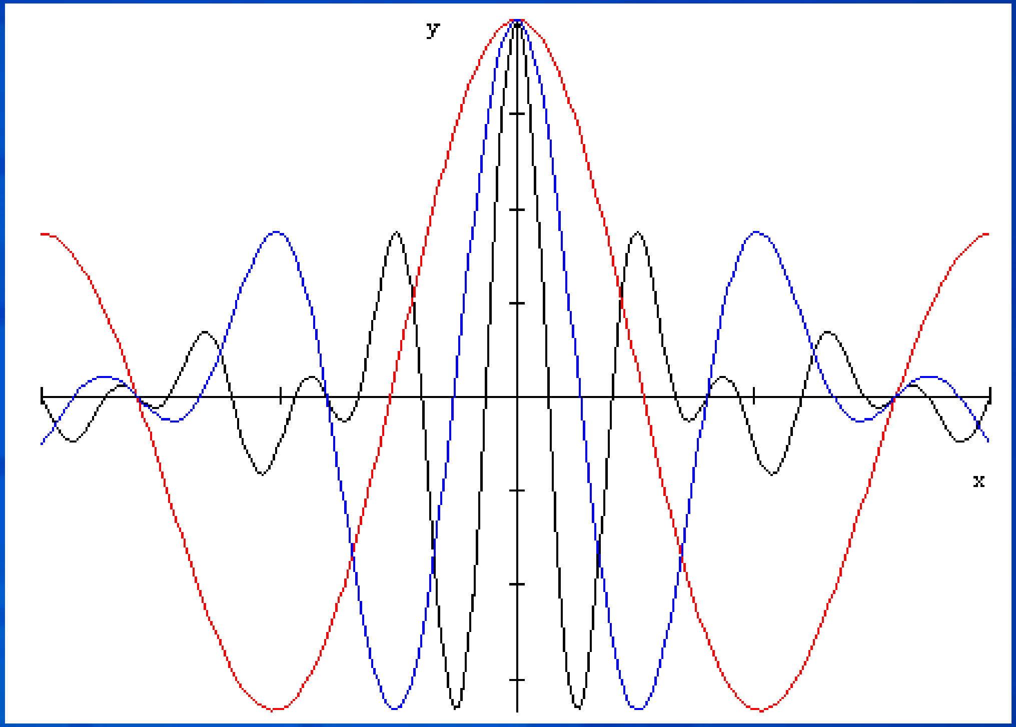
Time Series: Spectral Estimation



Spectrogram: Boeing 777 acoustic noise

Noise Characterization and Time Series Analysis

Time Series: Spectral Estimation



Wavelets

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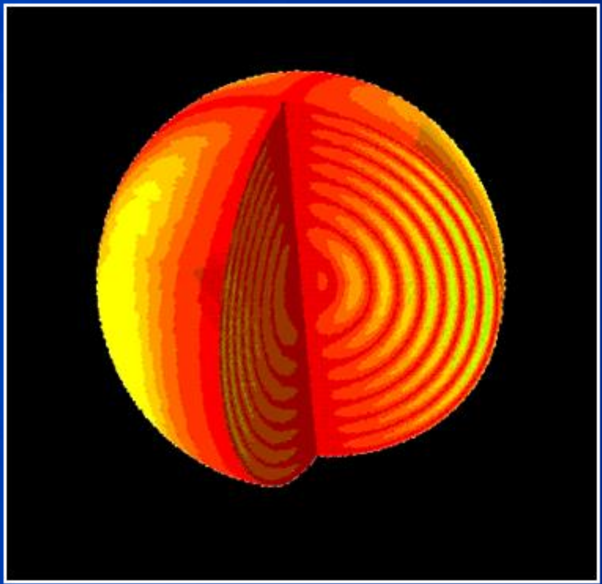
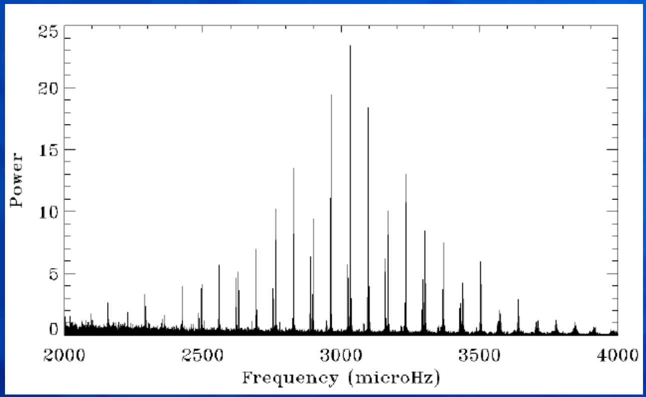
Noise reduction applied to asteroseismology

Origin and objectives

- The fortuit discovery of 5 min periodic movements on the Sun by Lloyd Evans & Raymond Michard, is confirmed months later by Leighton stating the base of Helioseismology. (1962)
- Some years later Deubner propose (1967) that these movements are the signs of global oscillation modes.

Waves propagating inside the sun in radial direction.

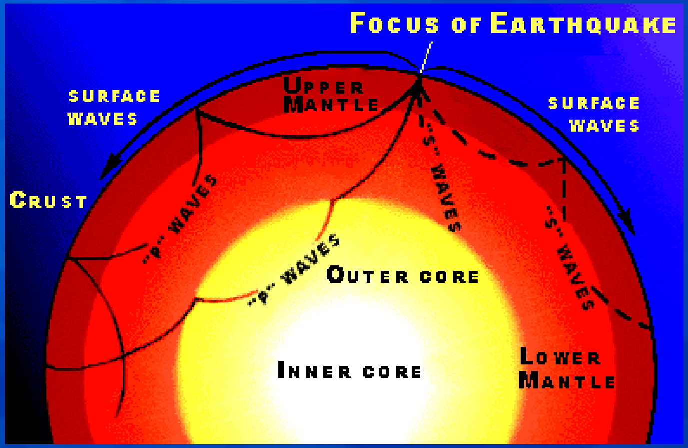




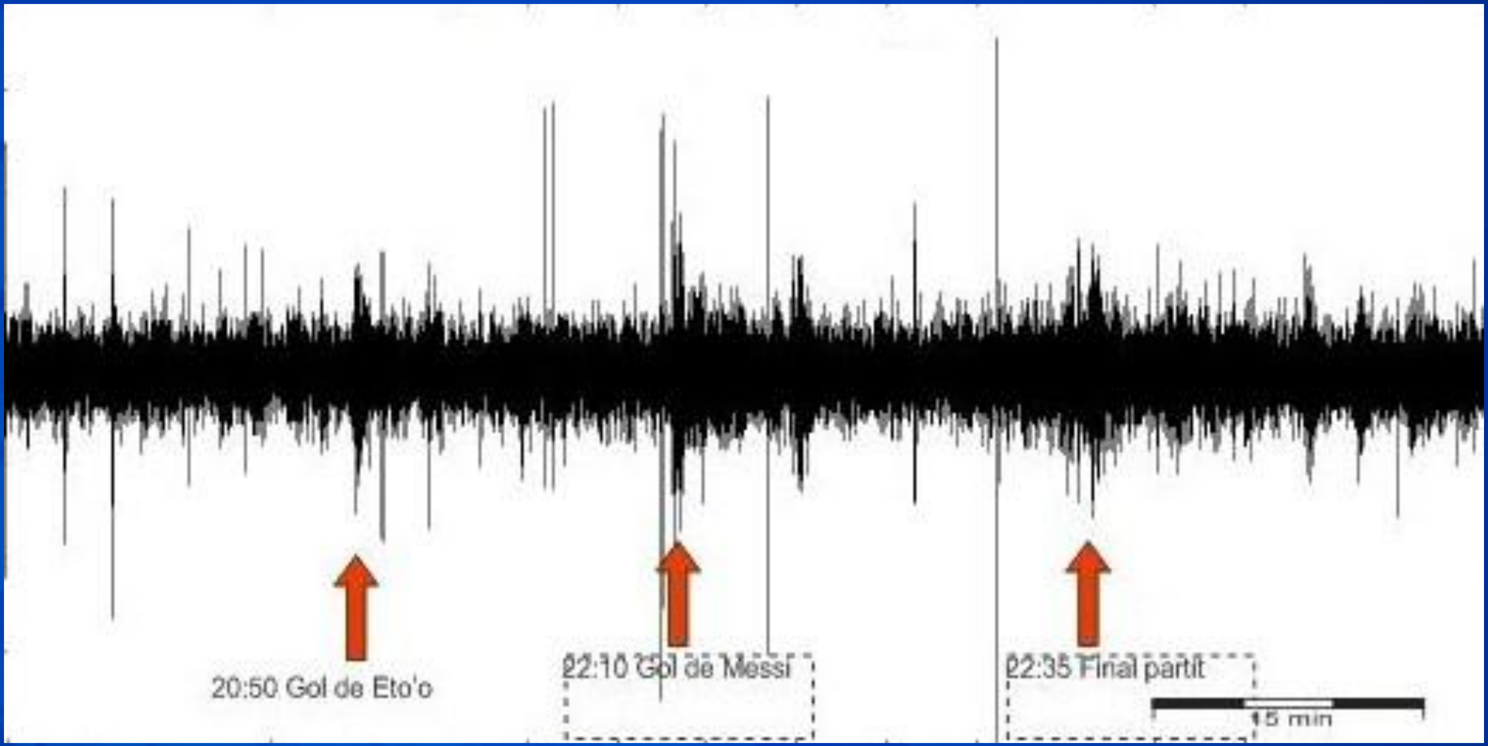
Nowadays, a lot of oscillations have been detected in the sun as also in other stars due to space missions like Soho, CoRoT, and Kepler.

Noise reduction applied to asteroseismology
Origin and objectives

- The Sun and all variable stars experiment perturbations of p and ρ
- Because of this, oscillations are excited which propagate inside the stars
- The frequencies of oscillations depend on the cavity in which they propagates. Detecting those frequencies it is possible to sound the stellar interior and determine the structure of the star. Similarly as in Terrestrial Seismology.



Noise reduction applied to asteroseismology
Origin and objectives

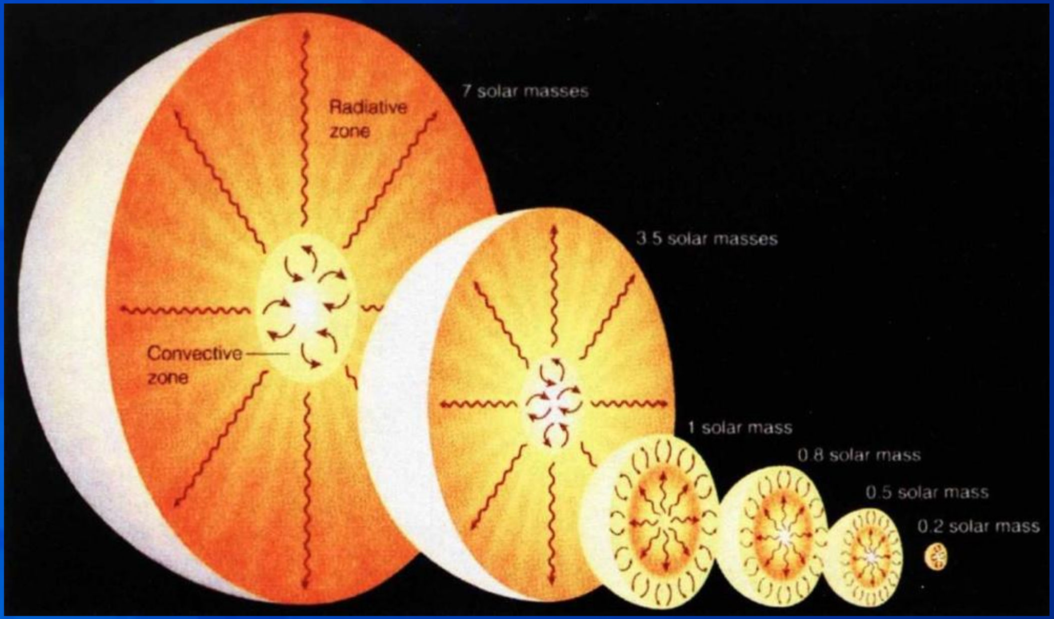


Noise reduction applied to asteroseismology
Origin and objectives

- The aim of asteroseismology is a better understanding of stellar structure and evolution.

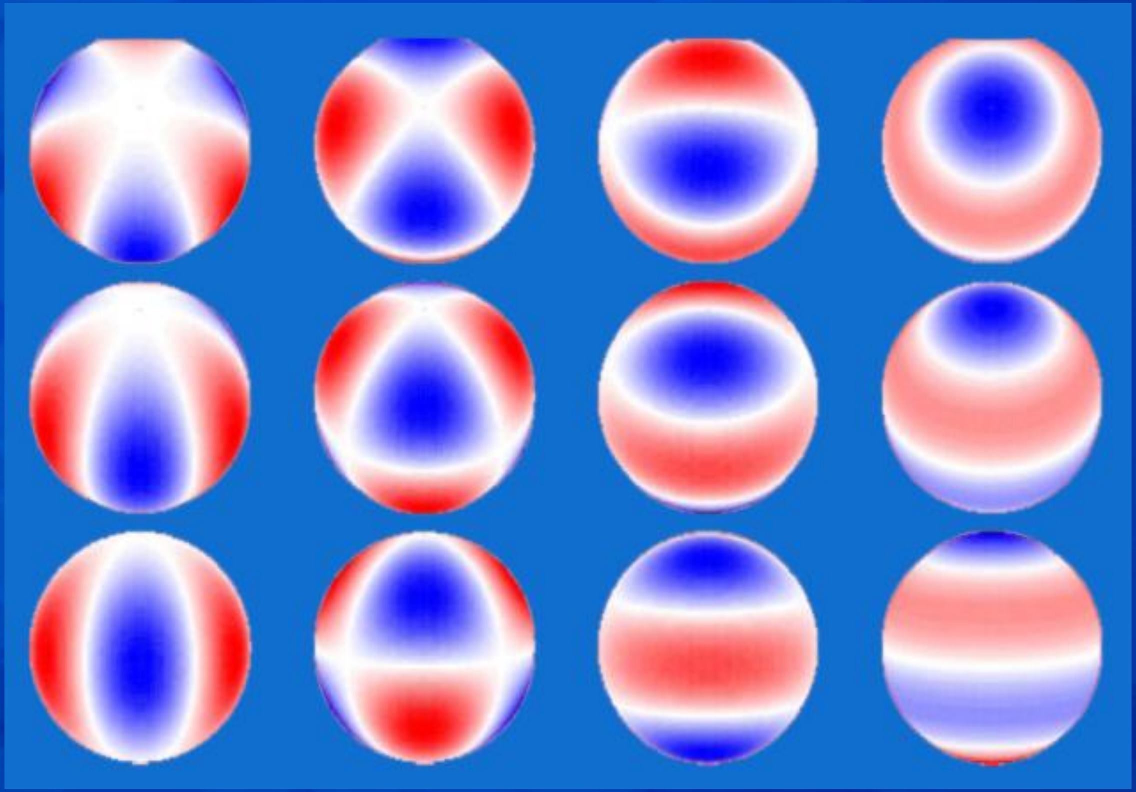
- Stellar interior regions:
  - Convective region
  - Radiative region

- Stellar physics problems
  - Convection
  - Rotation effects
  - Magnetic fields



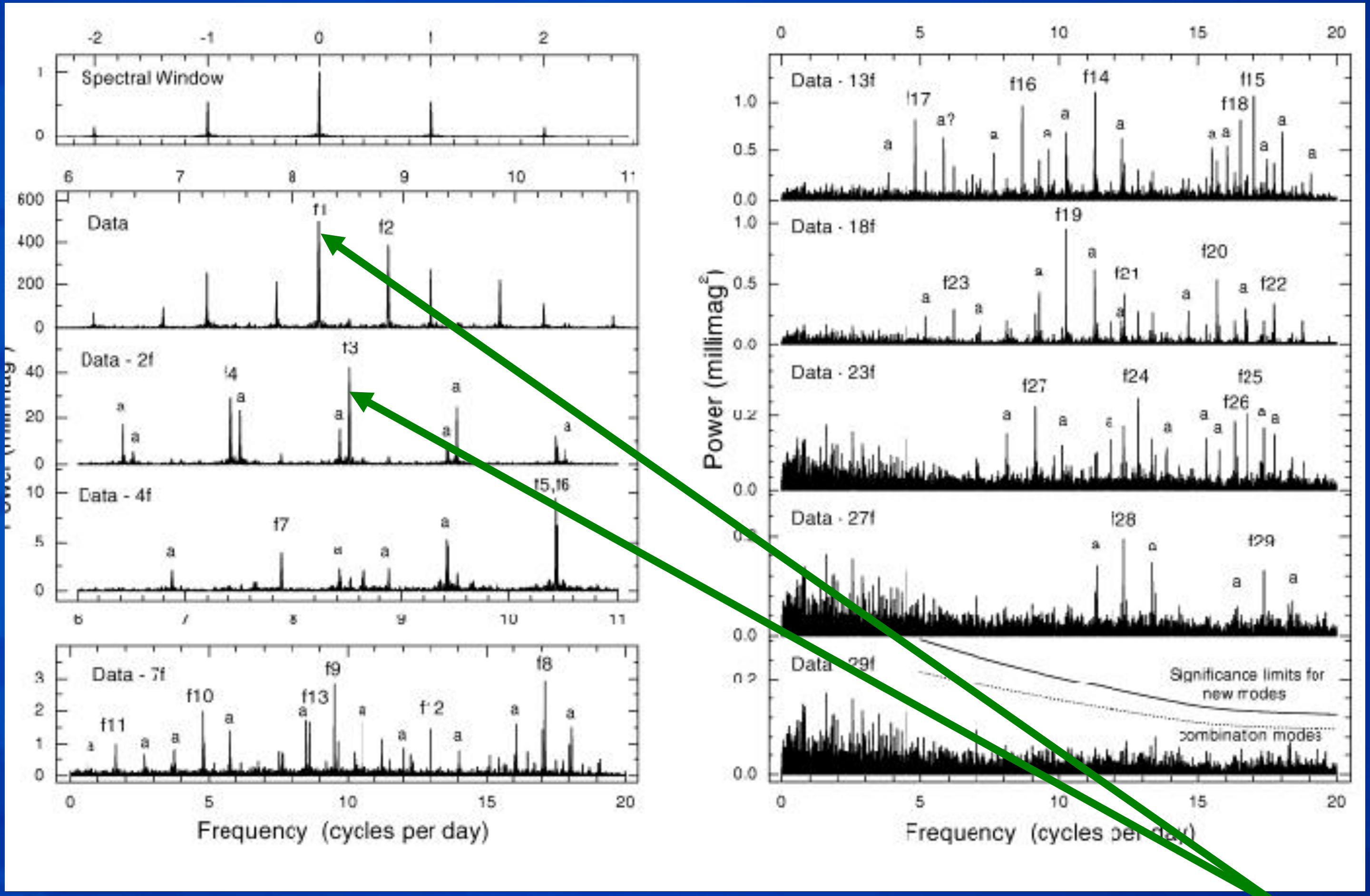
Noise reduction applied to asteroseismology
How does it works?

In the spherical symmetry approximation, each mode can be associated to a spherical harmonic $Y^l_m(\theta,\phi)$



¿(n,ℓ,m)?

Noise reduction applied to asteroseismology
How does it works?



(n,ℓ,m)

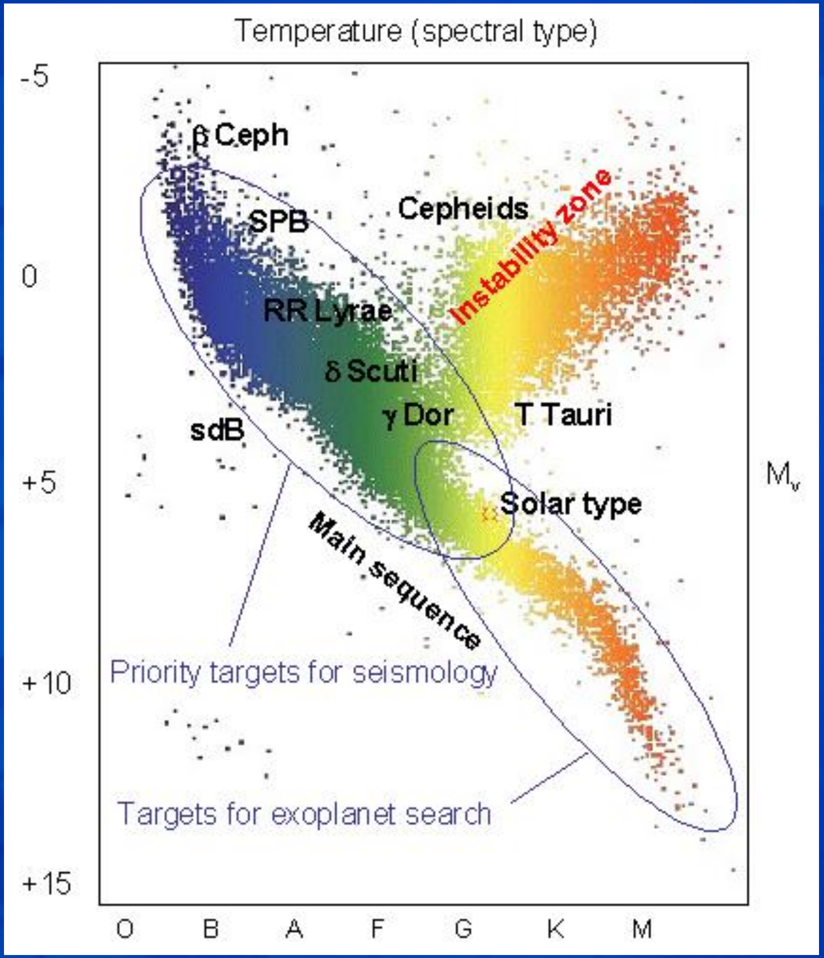
CoRoT Mission

France Austria Belgium Germany

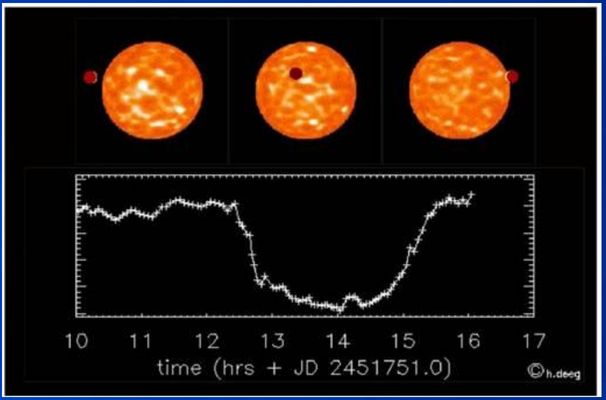
esa Spain Brazil

- **High precision in S/N: 2ppm detection, as 8 telescopes of 8 m from the ground.**
- **Largely uninterrupted sequences: 1/T -> 0.1 μHz**
- **Sampling < 1 min . Frequency domain (0.1, 10 mHz).**

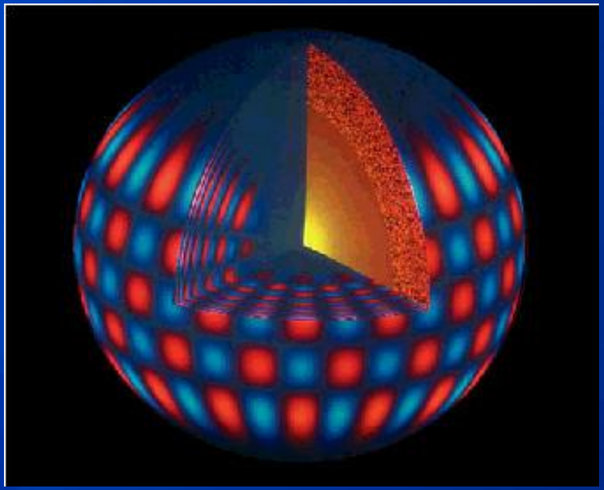
Noise reduction applied to asteroseismology
CoRoT



Búsqueda de exoplanetas



Sismología estelar



Noise reduction applied to asteroseismology

A new method for noise reduction: PAM

$$Y_{i1} = X_{i1} + Z_{i1}$$

Fourier Transform of a set Y_1 where X_1 is signal,

and Z_1 is white noise

$$\frac{1}{n}\left(|\bar{X}_1 + \epsilon_1| + |\bar{X}_2 + \epsilon_2| + \ldots + |\bar{X}_n + \epsilon_n|\right)$$

Averaging periodograms

Noise reduction but also resolution is reduced

Traslation property of the Fourier Transform

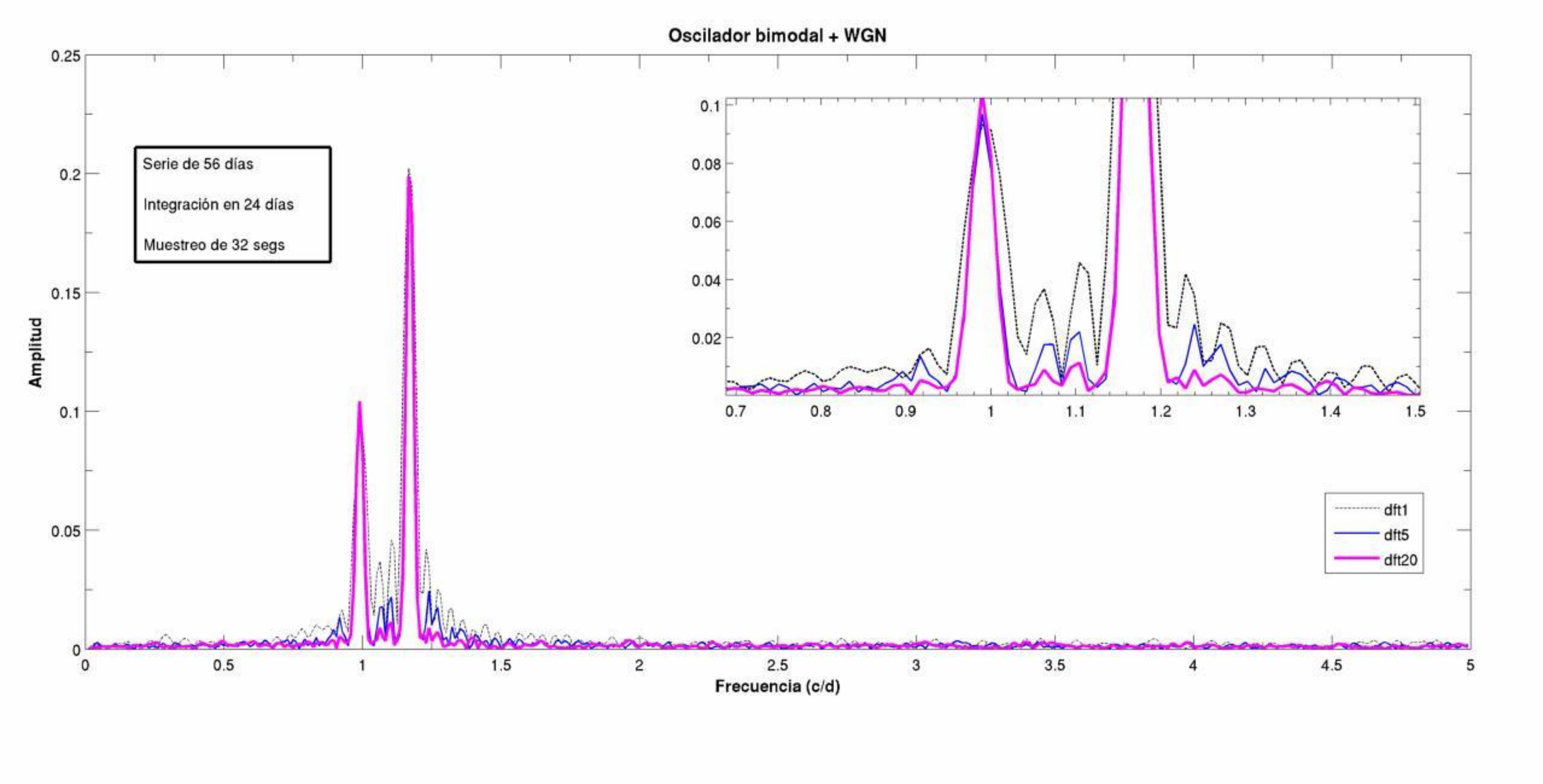
$$\bar{X}_{i2} = \bar{X}_{i1} e^{-i\omega\tau}$$

New average

$$\frac{1}{n}\left(\left|\sum_i^n \bar{X}_i + \sum_i^n \epsilon_i\right|\right)$$

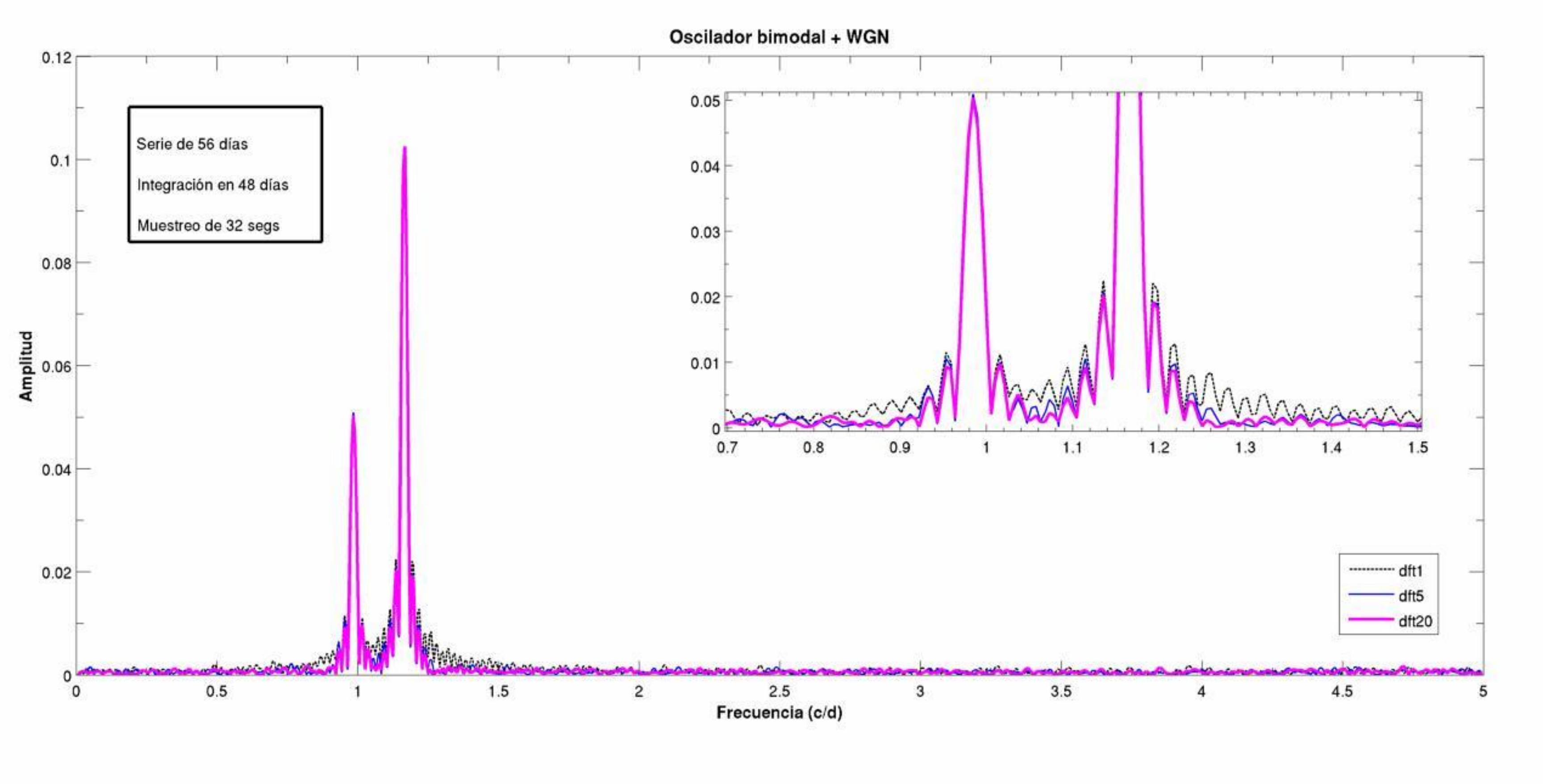
Noise reduction with a better resolution

Noise reduction applied to asteroseismology
Application: numerical experiment



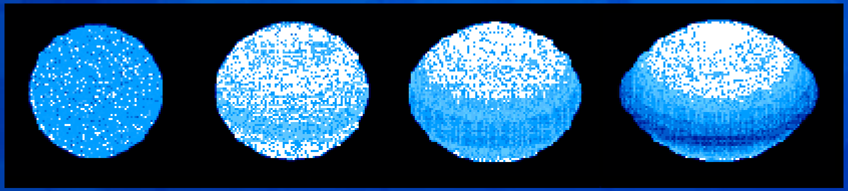
Noise reduction applied to asteroseismology

Application: numerical experiment



Noise reduction applied to asteroseismology

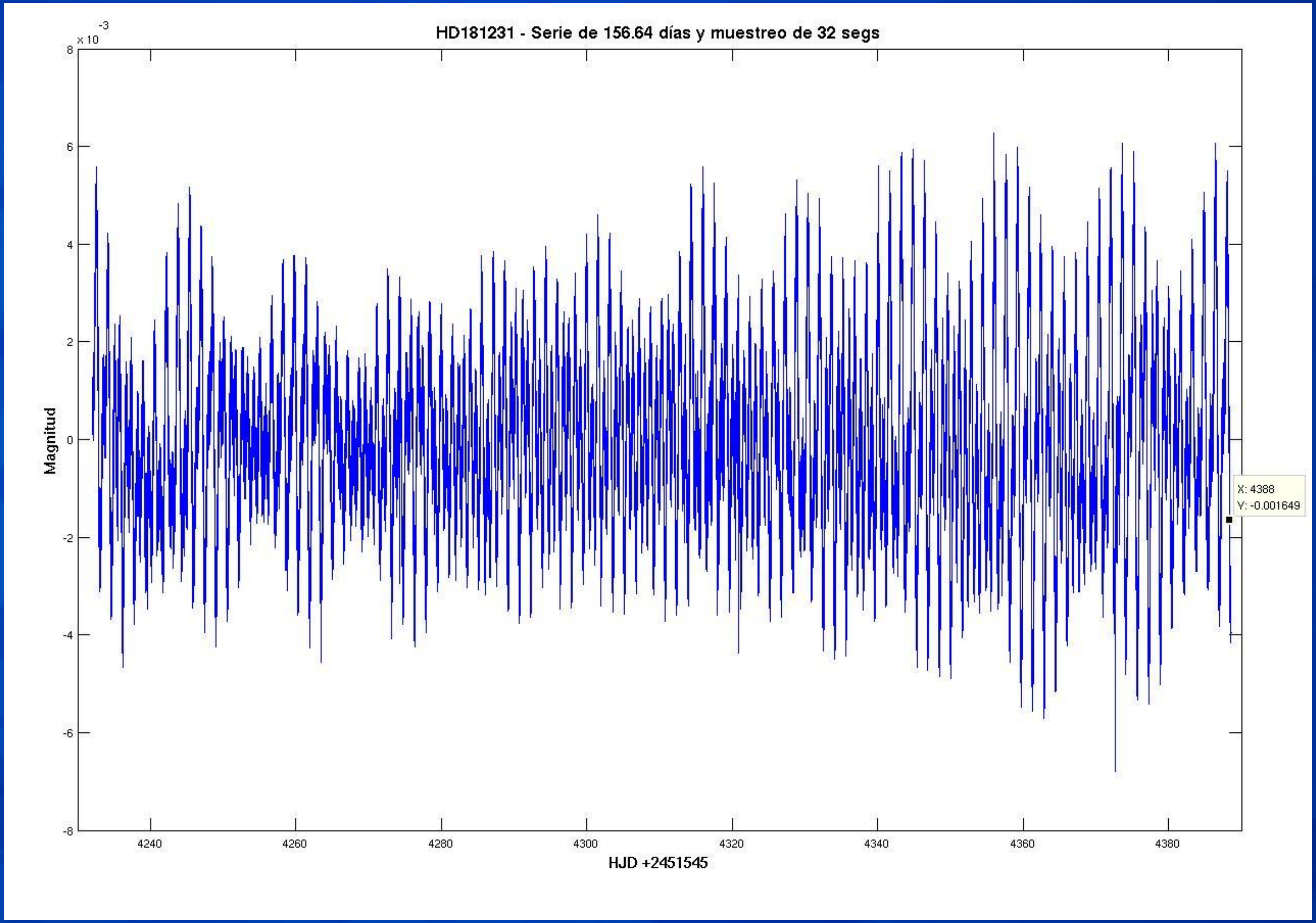
Application: Be Stars



- Be stars are spectral type B stars with a circumstelar disc which is responsible of Balmer lines emission.
- They possess a very rapid rotation, reaching almost critical velocities.
- Different ranges of variability has been detected: from short time variability to long time (years).
- Short time variability in these stars is associated to oscillation modes.

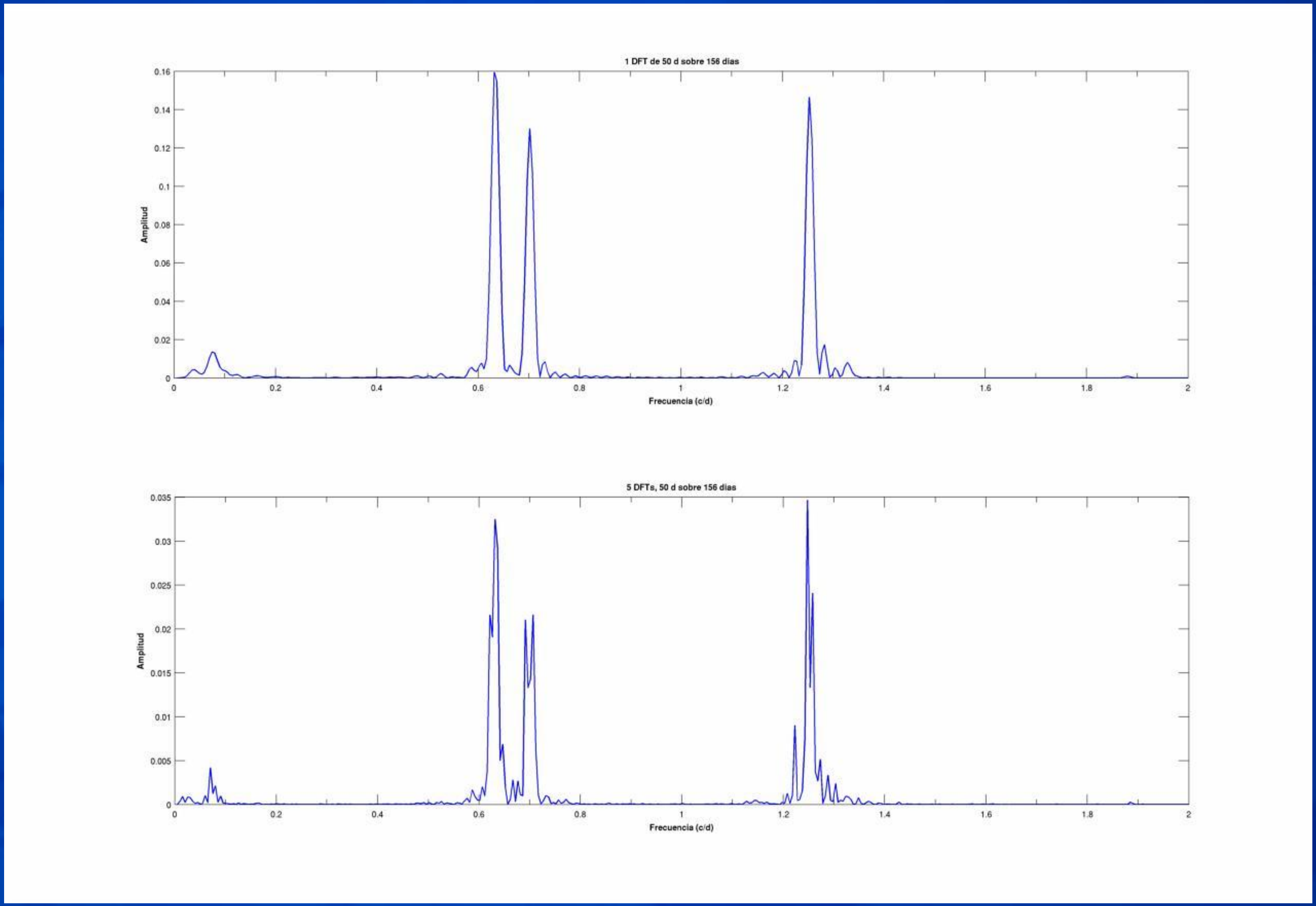
Noise reduction applied to asteroseismology

Application: HD181231 star

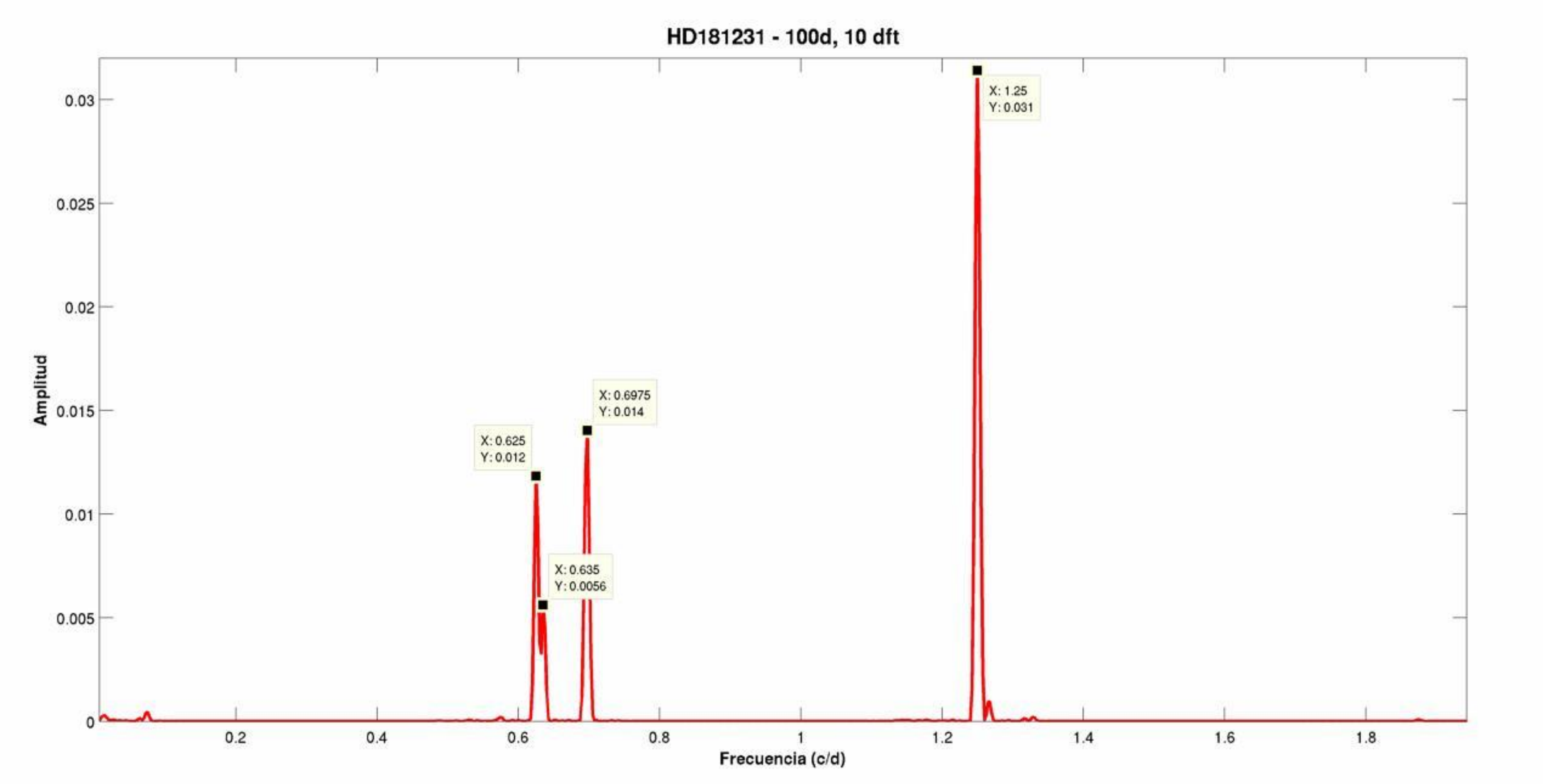


Noise reduction applied to asteroseismology

Application: HD181231 star



Noise reduction applied to asteroseismology
Application: HD181231 star



Noise reduction applied to asteroseismology

Application: HD181231 star

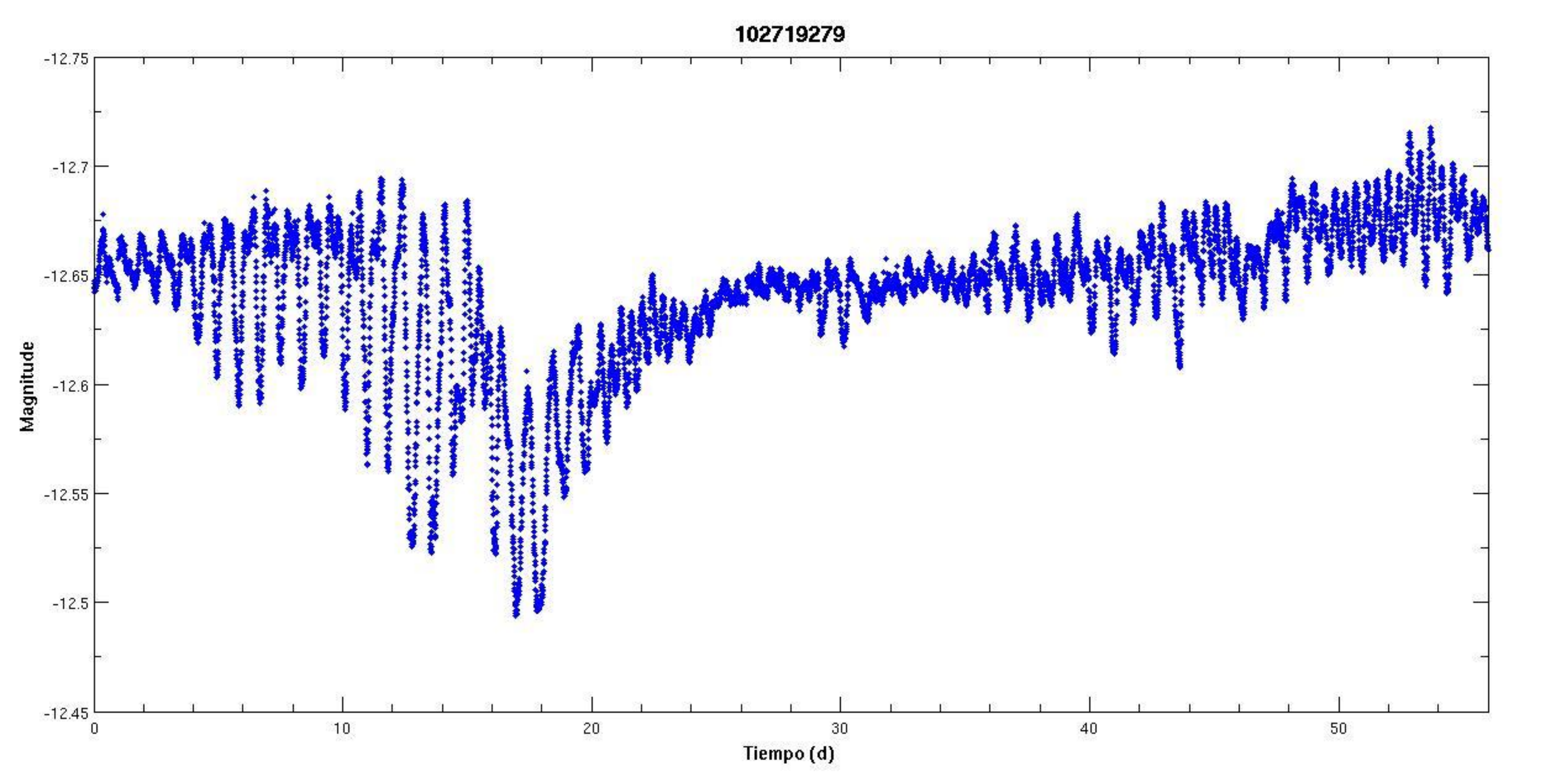
Frecuencia (c/d)	Var.3 sums.	Var.10 sums
0.575	8.4 %	8.5 %
0.624	25.5 %	28.5 %
0.695	25.1 %	28.5 %
1.247	25.2 %	28.3 %
1.840	27.9 %	36.1 %

$$\hat{\sigma}^2 = \sum_i |\hat{F}_{\omega_i}|^2$$

$$\frac{SNR}{N} \sim \frac{A_0^2}{2\sigma_0^2}$$

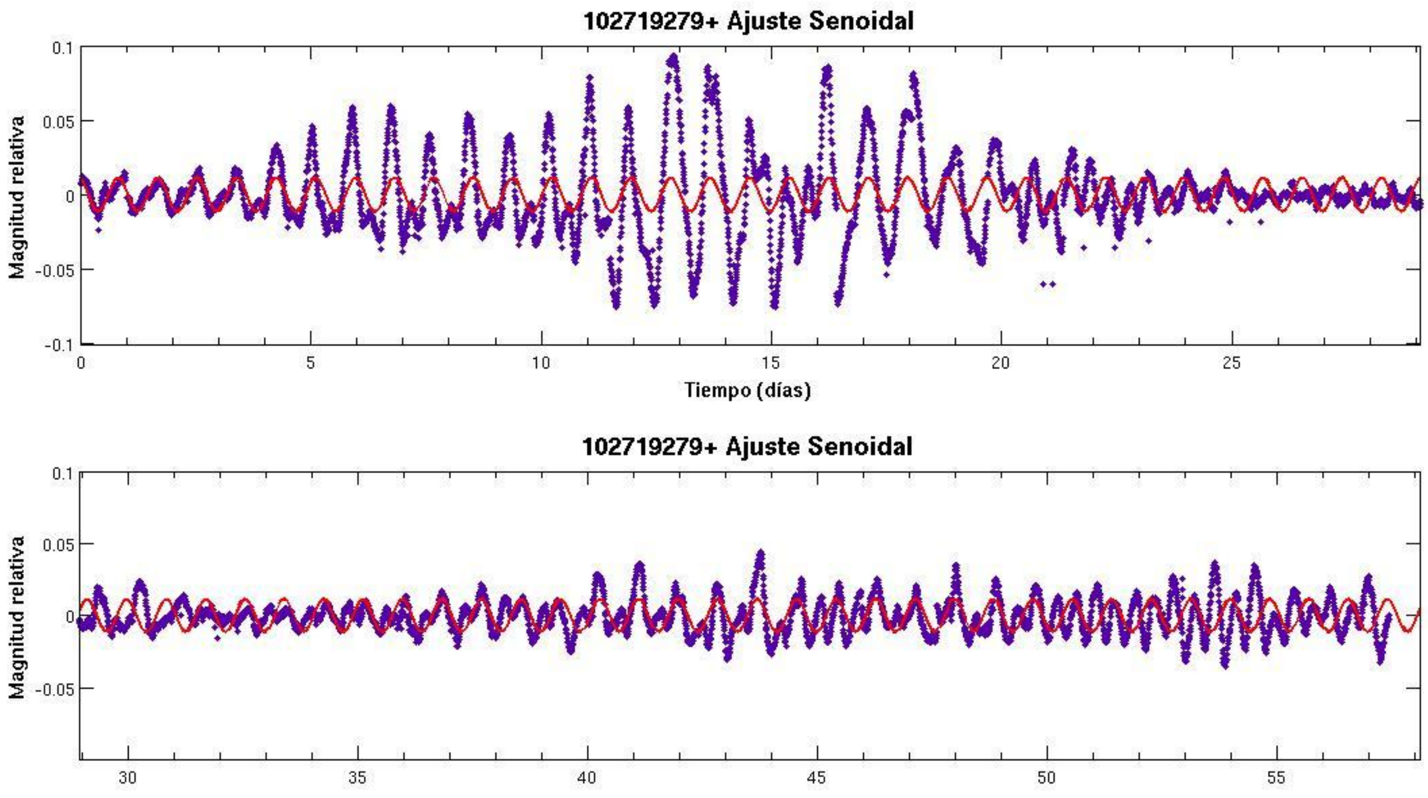
Frecuencia (c/d)	Var.10 sums
0.575	62.3 %
0.624	2.7 %
0.695	23.8 %
1.247	10.7 %
1.840	-27.4 %

Noise reduction applied to asteroseismology
Application: 102719279 star



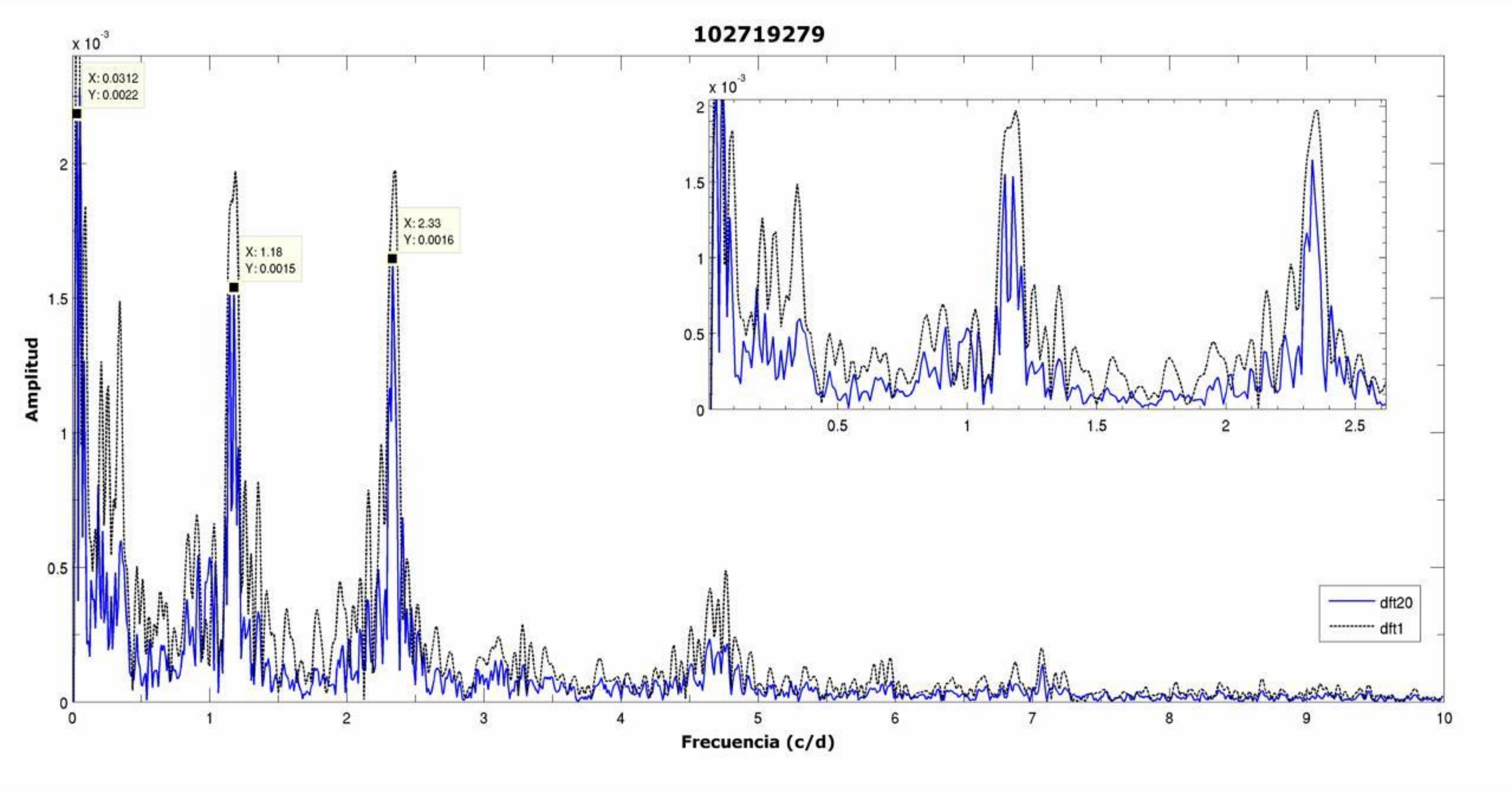
Noise reduction applied to asteroseismology

Application: 102719279 star



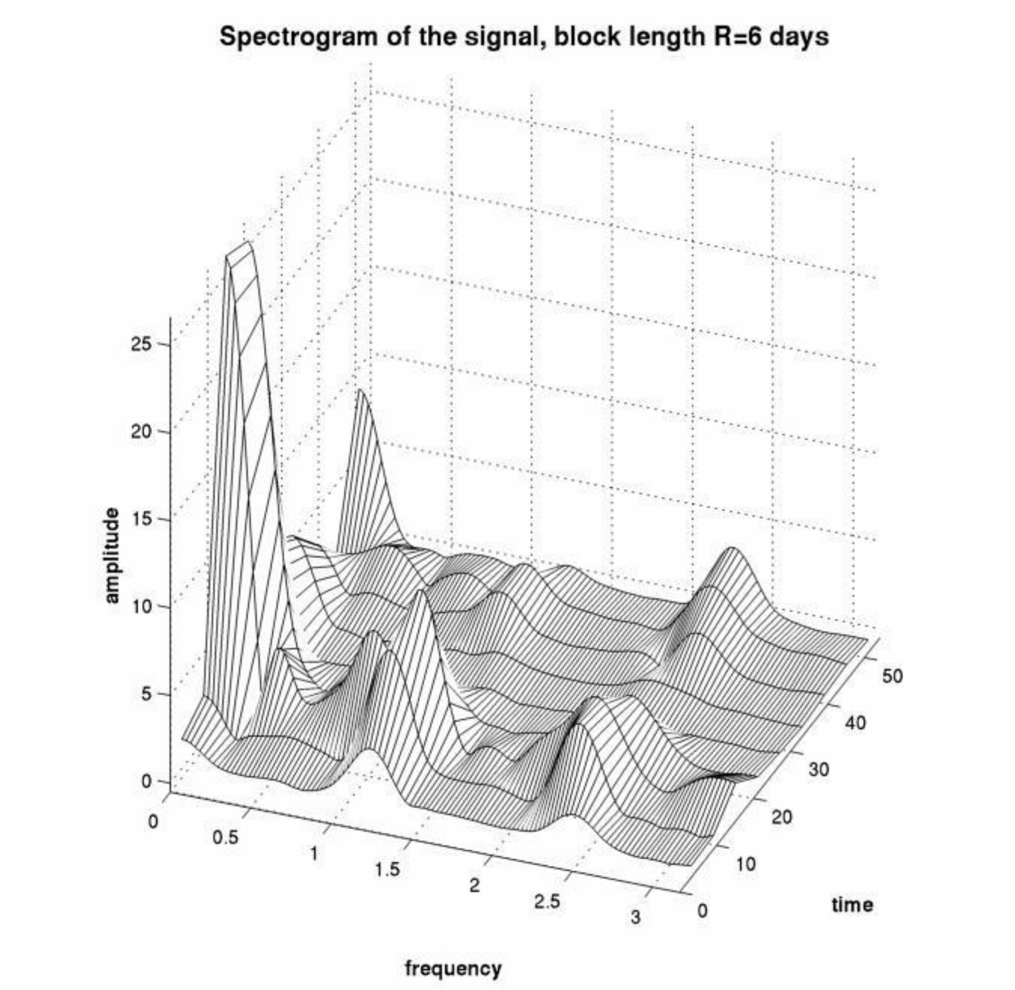
Noise reduction applied to asteroseismology

Application: 102719279 star



Noise reduction applied to asteroseismology

Application: 102719279 star



Conclusions

- For HD181231 the SNR has been enhanced in 25-28% using our method.
- For 102719279 three freqs. has been detected and identified with an l=2 oscillation mode.
- The Phase Adding Method has proved to be an effective tool for noise reduction and signal detection.
- Theres no limitation to extend this method to 2D.
- It has to be remarked that the requirement of white noise is not always fullfilled.
- An extension of the method for non-uniform sampling is in progress.

…porque todos los finales
son el mismo repetido
y con tanto ruido
no escucharon el final.
(Joaquín Sabina)

END