Analysis of Coronal Oscillations with PWF and PeriodMap techniques in remote accessing

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Outline

- The pre-analysis - *Coronal Periodmapping method*
- The comprehensive analysis - *Pixelised Wavelet Filtration method*
- Test of the methods use coronal and chromospheric dynamics
- The interactive PWF and Periodmap analysis system:

  a) Ideas, Software and main parts;

  b) Multiply and Harmonic PWF analysis;

  c) Control bar description;

  d) Examples
- Automated detection system for SDO/AIA datasets
- First results

The Coronal Periodmapping method

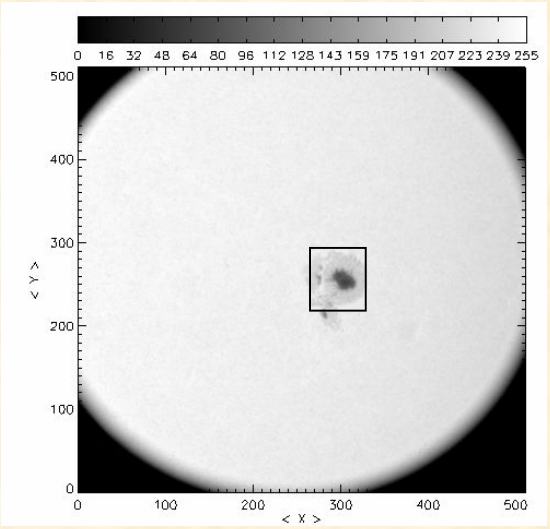
Nakariakov, V. M.; King, D. B., Solar Physics, Volume 241, Issue 2, pp.397-409, 2007

- The main aims of this method is the *fast pre-analysis of coronal imaging data cubes* and the determination of regions and time intervals interesting for detailed study. The method reduces imaging full-disk full-resolution data cubes into a sequence of *static coronal maps*, which are easy to store and to analyze.
- The method is bases upon the following assumptions: the phenomena of interest cause *quasi-harmonic* variations of the emission intensity (seen as spectral peaks in periodograms), the projected wavelength is (much) larger than the pixel size; (the majority of) neighboring pixels oscillate at the *same frequency*.
- Time signals of every pixel are transformed into a *periodogram* with the use of FFT. The FFT algorithm can be parallelized, and is much faster then the data acquisition rate. In each periodogram, the amplitude of the *highest spectral peak* is determined; if it is greater than the average spectral power multiplied by a certain factor (e.g. 4 or 5), this peak is *considered as an oscillation*, and this pixel is assigned with a color corresponding to the frequency of the peak, according to a predefined color scheme

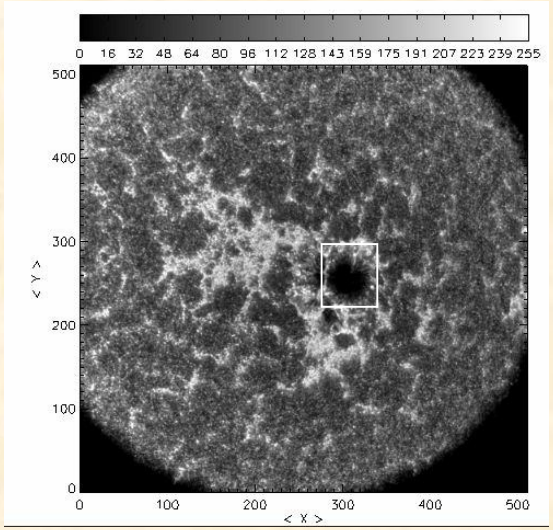
The Coronal Periodmapping method

Nakariakov, V. M.; King, D. B., Solar Physics, Volume 241, Issue 2, pp.397-409, 2007

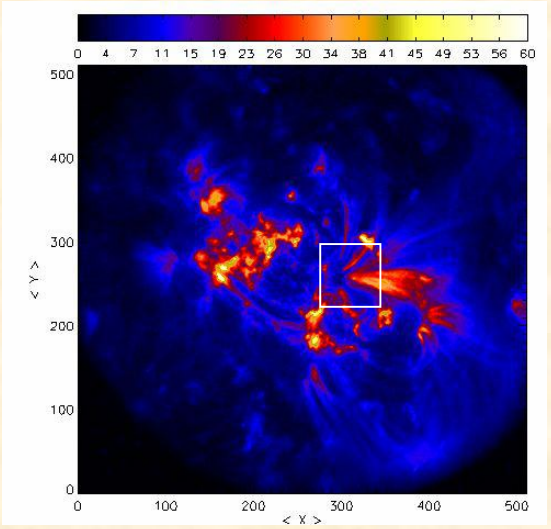
May 04, 2005 TRACE_WL



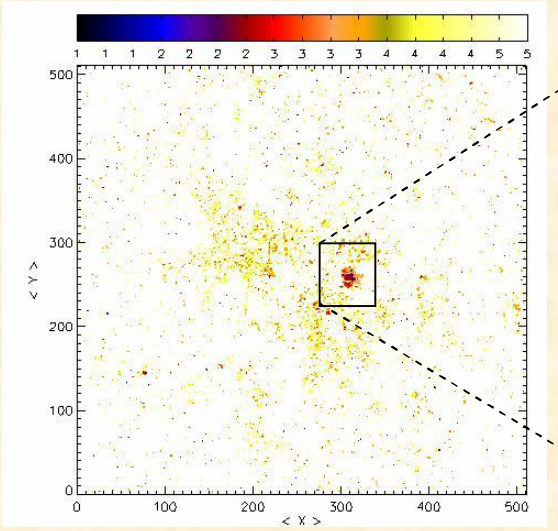
TRACE_1600A



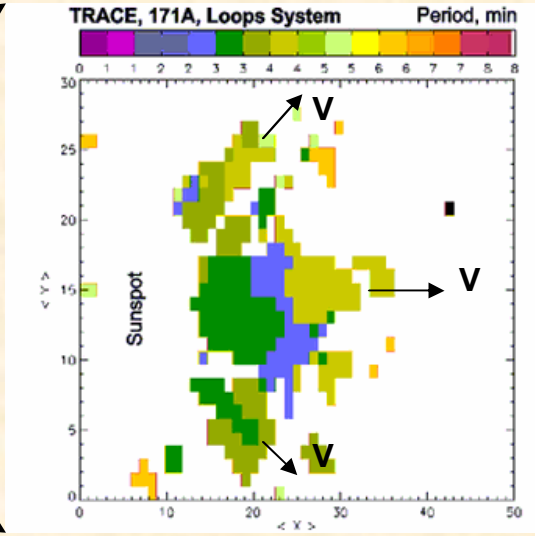
TRACE_171A



Periodmap, TRACE_171A



Sunspot Loop System



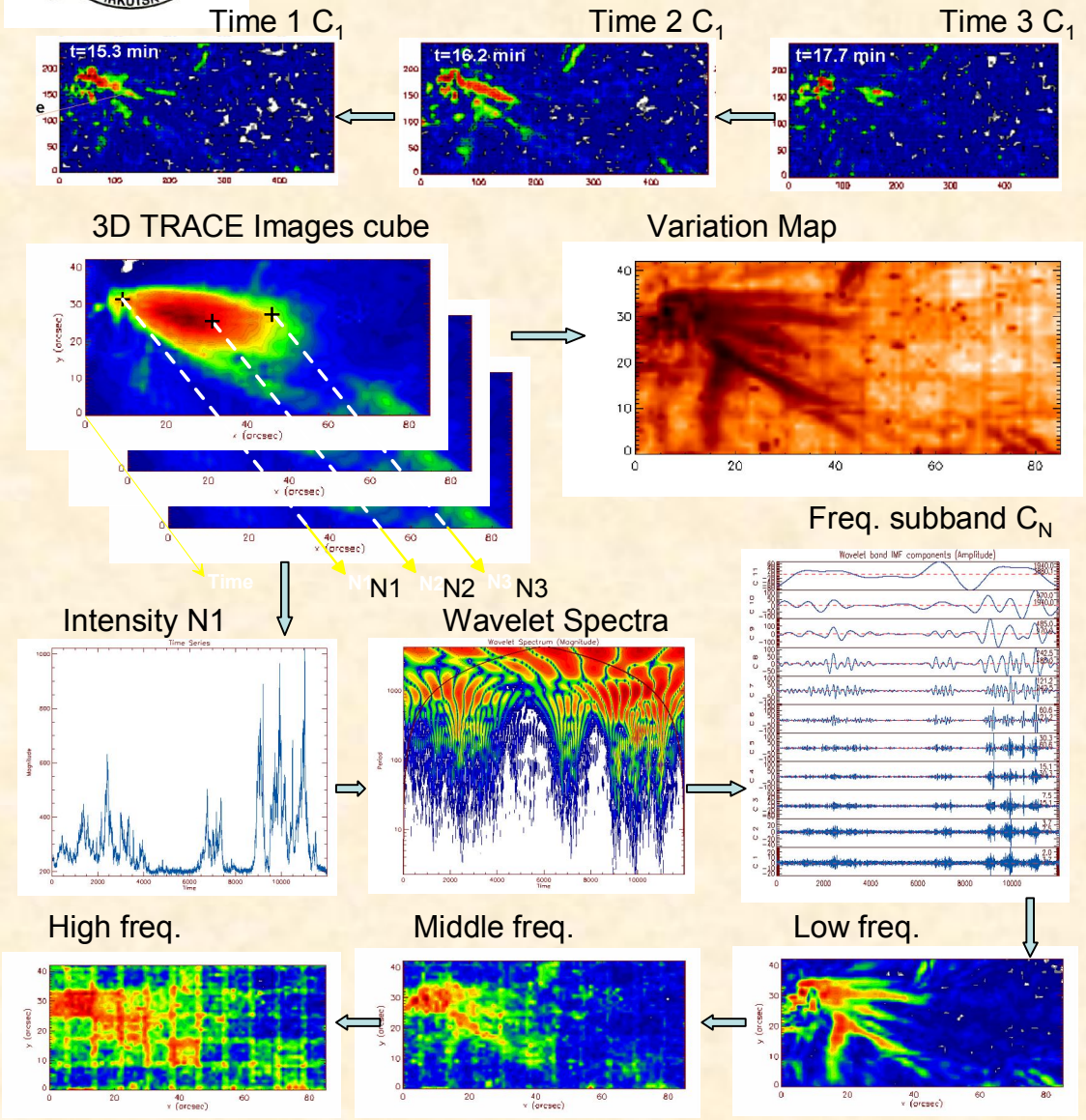
The Pixelised Wavelet Filtration (PWF) method

Sych, R. A.; Nakariakov, V.M., Solar Physics, Volume 248, Issue 2,pp. 395-408, 2008

- The PWF-method is used for determination of the *spatial, temporal and phase structure* of oscillation sources in temporal sequenses of 2D images, based upon the *continuous wavelet transform*. The PWF method allows to obtain information about *the presence of propagating and non-propagating waves* in the data and localize them precisely in time and in space. In addition, the PWF method provides us with the unique information about the *temporal variability* of the power, amplitude and phase spatial narrowband maps of the observed oscillation and waves.
- The PWF method is based upon the wavelet transform described by detail in Torrence and Compo (1998). As the mother wavelet function, we propose to use the *complex Morlet wavelet* which is well localized in both the spectral and physical domains. We will apply wavelet filtration to the time signal of *each pixel*, and decompose the signal in the time domain (time frequencies), creating a four-dimensional (two spatial coordinates, time and frequency) data cube. Averaging over or specifying one or two of those coordinates, we determine the *time spatial distribution* of the power, amplitude and phase of different spectral components in a way to study the time evolution of the spatial-frequency information.

The Pixelised Wavelet Filtration (PWF) method

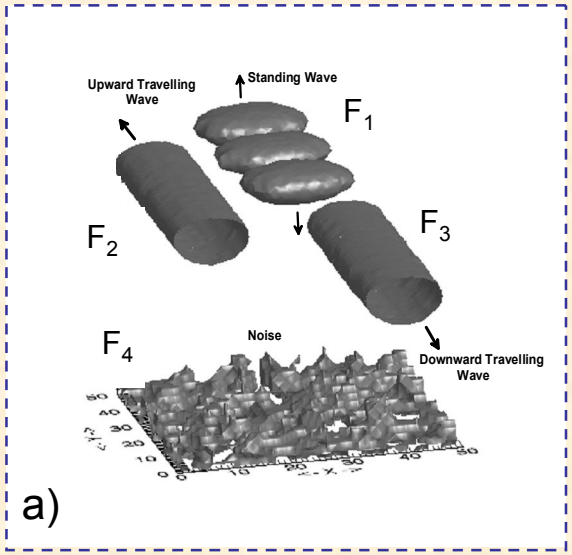
Sych, R. A.; Nakariakov, V.M., Solar Physics, Volume 248, Issue 2,pp. 395-408, 2008

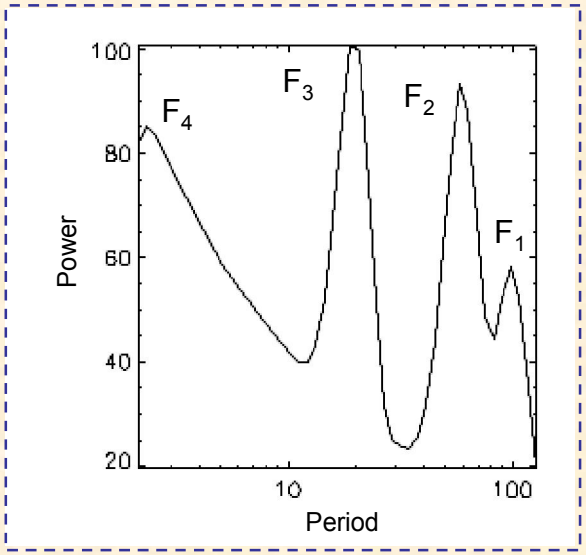


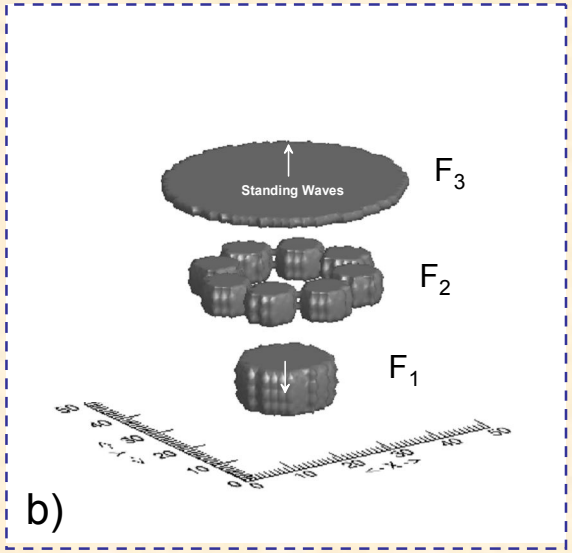
Step by step processing

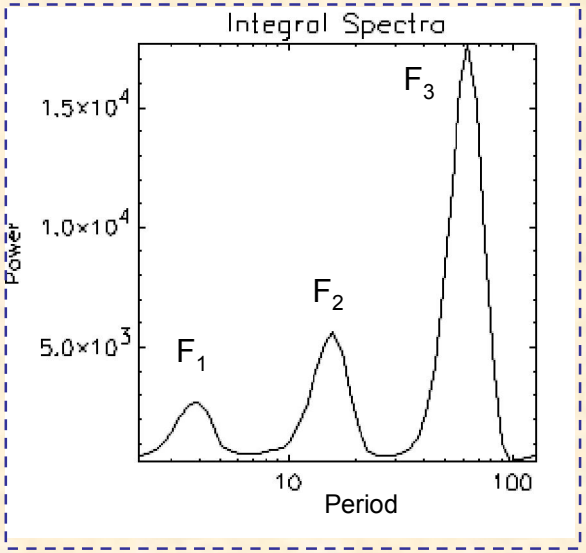
- ✓ The images in the sequence are co-aligned, removing the spatial mismatch between subsequent images.
- ✓ Selection of the object of investigation and the field-of-view.
- ✓ The variance map of the field-of-view preparation for determining the spatial distribution of the integrated power of the time signal.
- ✓ Direct wavelet transform in the time domain, filtering out the spectral components of interest, and inverse wavelet transform. The resultant data cube contains the time variation of the signal in the prescribed spectral band.
- ✓ Calculation of the global wavelet power spectra.

Synthetic 3D oscillations: standing, radial and travelling waves. Modeling coronal loop and sunspot dynamics.





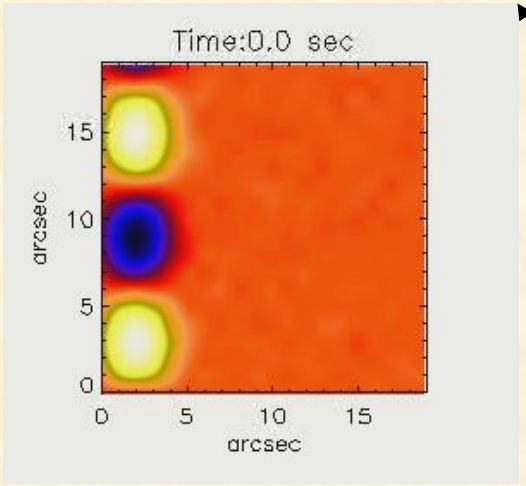




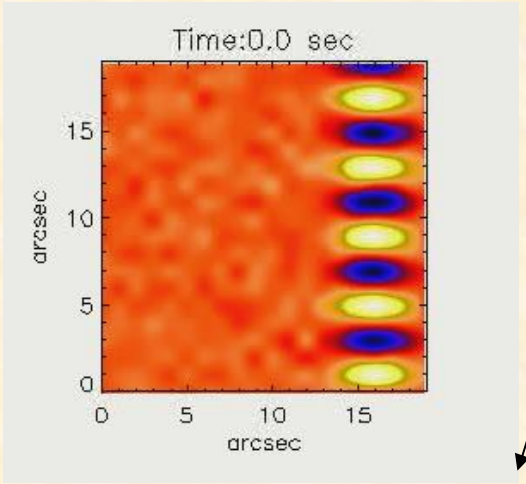
Left panel: The spatial distribution of the signal power of different built-in waves (the broadband power cube). The vertical axis (not shown) corresponds to the periods and shows the detected periodicity: 20, 60, and 100 second mono-chromatic signals and the noise for test of coronal loop dynamics (a) and 4, 16 and 64 s radial test oscillating in sunspot (b).

Right panel: the global spatially-integrated wavelet power spectrum (as an analogue of the Fourier power spectrum) of the analyzed data set

The test narrowband coronal sources. Longitudinal and standing waves.



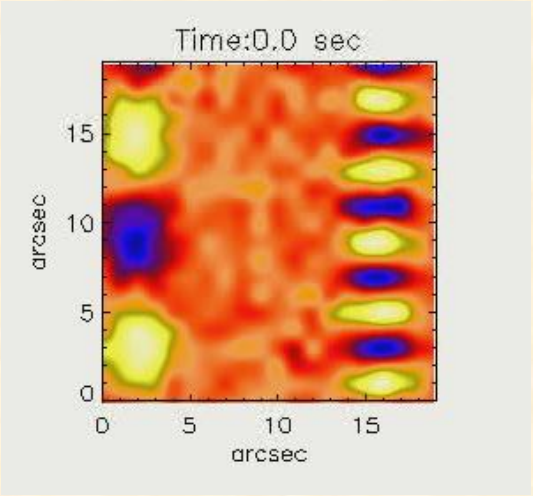
Upward Travelling Waves



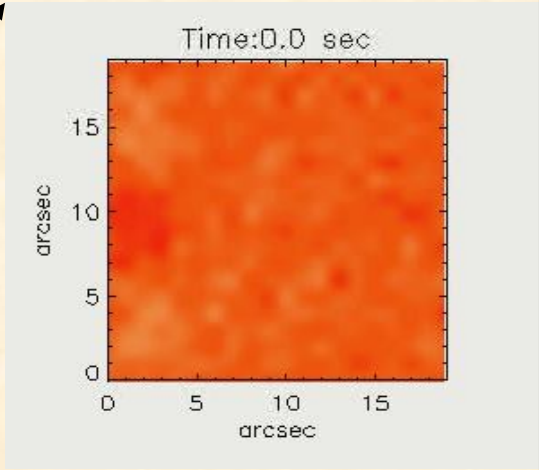
Downward Travelling Waves

Multi-mode Wavelet Filter

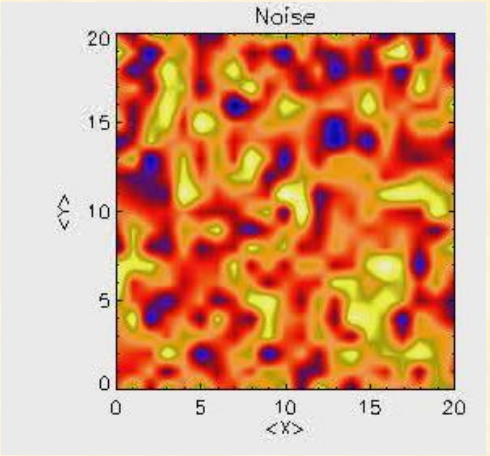
Original 3D temporal images cube



Multi-mode Wavelet Filter



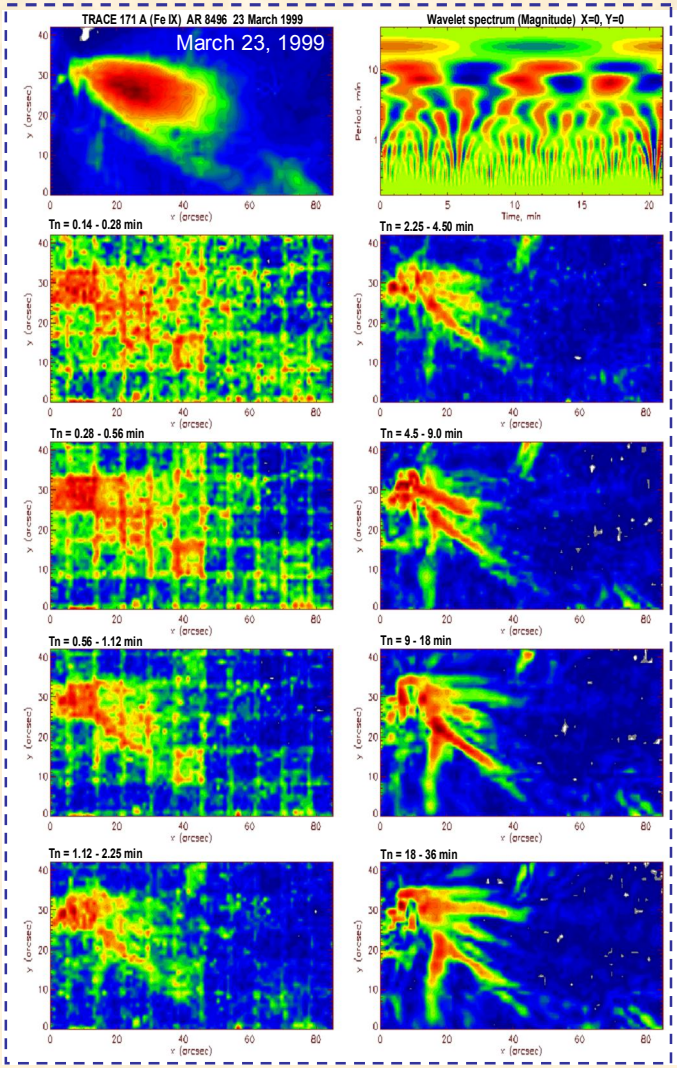
Standing Waves



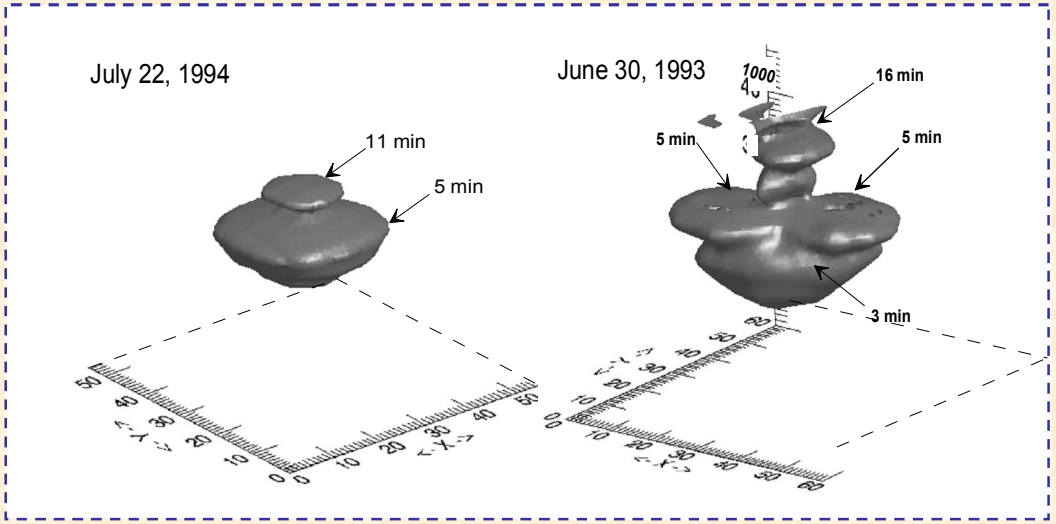
Noise Signal

The examples of the practical application of Pixelised Wavelet Filtration (PWF) method

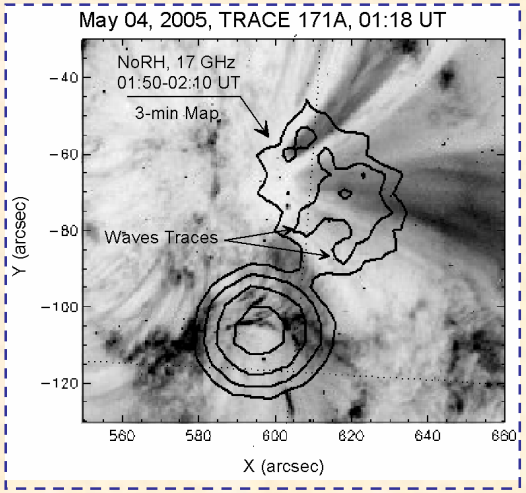
Multiresolution 2D Wavelet Decomposition



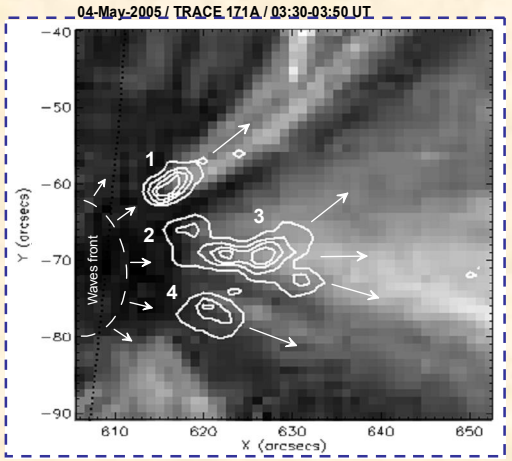
3D distribution of oscillation power in sunspots (NoRH 17 GHz)



Perturbed burst stage



Quiet stage



Analogue: The Interactive 1D Wavelets

http://ion.researchsystems.com/IONScript/wavelet/

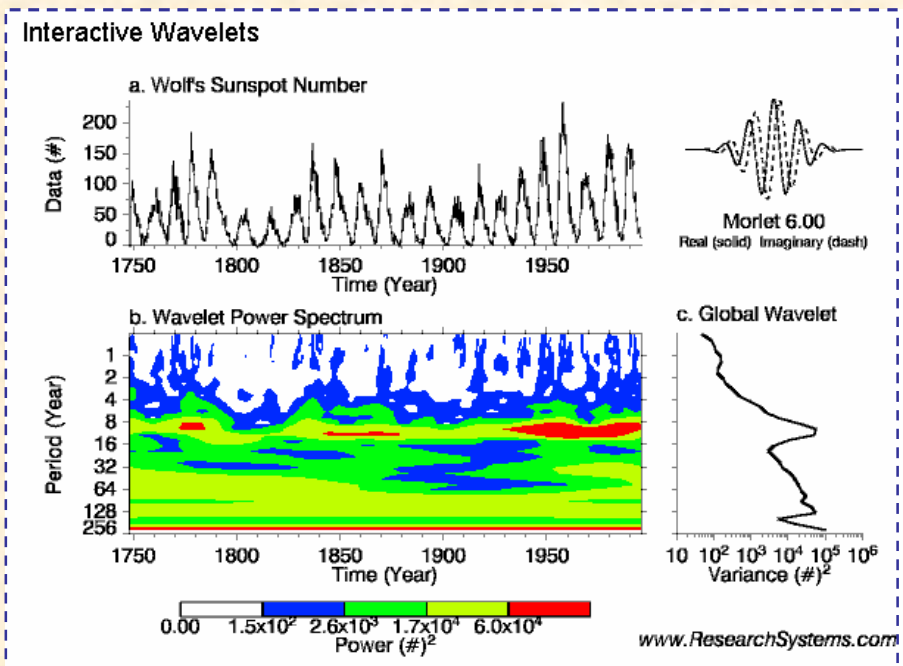


Fig. 1: (a) Data. (b) The wavelet power spectrum. The contour levels are chosen so that 75%, 50%, 25%, and 5% of the wavelet power is above each level, respectively. (c) The global wavelet power spectrum. Reference: Torrence, C. and G. P. Compo, 1998: A Practical Guide to Wavelet Analysis. *Bull. Amer. Meteor. Soc.*, 79, 61-78.

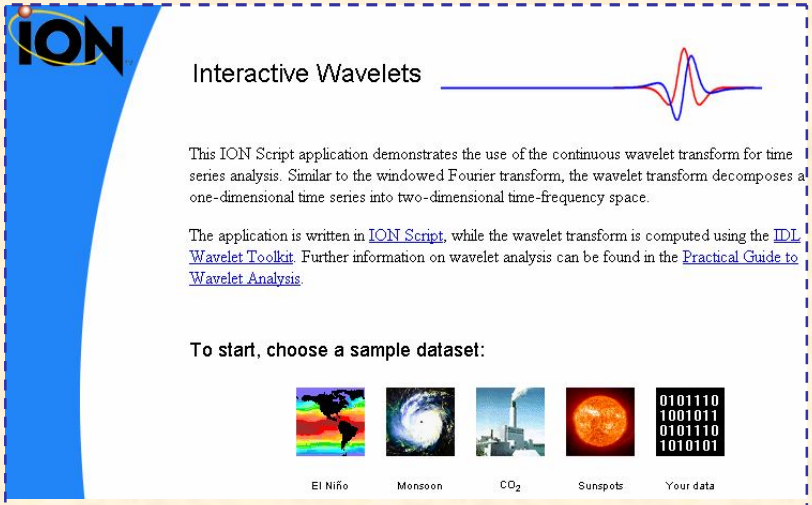
Visualization Options

Submit

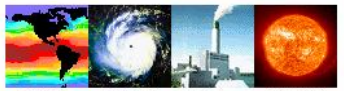
Wavelet
Morlet
Param: 6
Start scale = 2
Scale width = 0.25

Significance
Background spectrum:
None
Level: 10 %

Plotting
Start at X= 0
End at X= 0
Cone of influence
Grayscale



Change datasets



Or enter your own data:

Dataset name: Data
Short name: Data
Data Units: units
X title: Time
X units: Year
Start X = 0
X interval = 1

Data values:

Submit

Treat pairs of numbers as complex

Ideas, Software and main parts of system

Sych, R. A.; Nakariakov, V.M., Solar Physics, Volume 248, Issue 2,pp. 395-408, 2008

Main ideas:

- Remote computer data preparation;
- User computer is used only for data entry;
- The user interacts with the system through the network; (local or global) with a browser, without additional software;
- The data processing software use IDL language;
- 2d-images preprocessing.

Software:

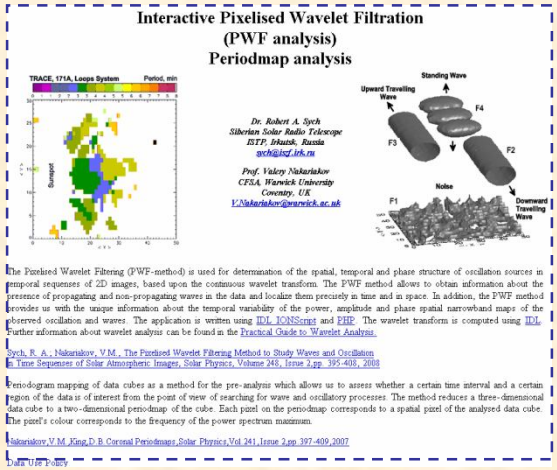
- WEB server Apache – the main web service;
- PHP language – use for realize interactive web interface;
- ION Scripts – start of IDL programs;
- IDL Language – data preparation.

Main parts of the system:

- PHP soft displayed of user interface;
- ION Scripts soft included tags for image preparation and calling IDL programs;
- IDL procedures perform data analysis (wavelet analysis), image preparation and disk recording.

The Interractive PWF and Periodmap analysis server

http://pwf.iszf.irk.ru/

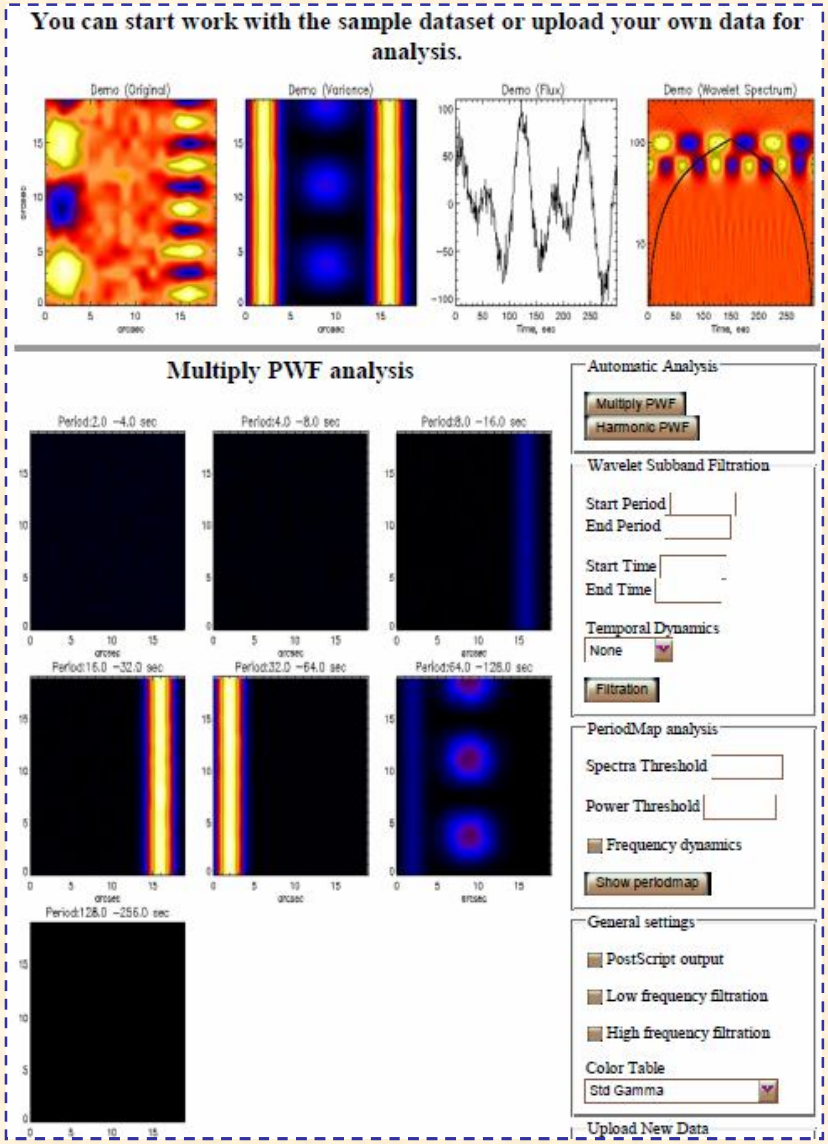


General features:

- Original Image
- Variation Map
- Total Flux
- Wavelet Spectrum

Short explanation of the PWF and Periodmaps methods

Image output area



Control container

Powered by APACHE

Designed by Sergey Anfinogentov ISTP, Irkutsk, Russia
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Description of the control containers

http://pwf.iszf.irk.ru/

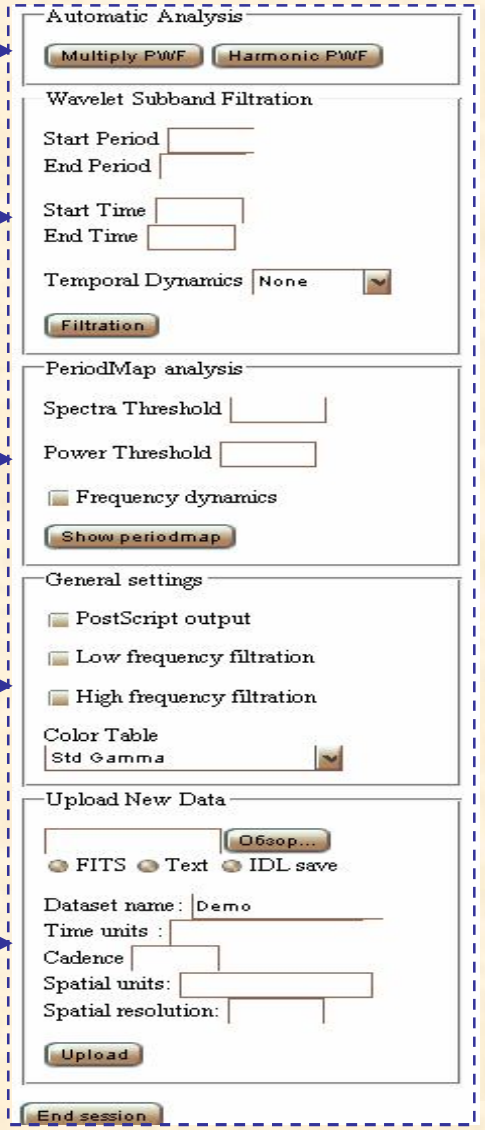
"**Multiply and Harmonic PWF**" analysis in automatic mode

Frequency subband filtration defined by parameters "**Start/End Period**"; "**Start/End Time**" fields define the time interval of filtration process;
The option "**Temporal Dynamics**" allows to obtain temporal dynamics of filtered narrowband amplitude, power or phase maps as a MPEG video file.

Periodmaps of the oscillation sources where color shows significant frequency harmonics. "**Spectra Threshold**"- a threshold of low frequencies harmonics; "**Power Threshold**"-a threshold of power oscillations for pixels displayed on a PeriodMap; "**Frequency dynamics**" as a MPEG video file.

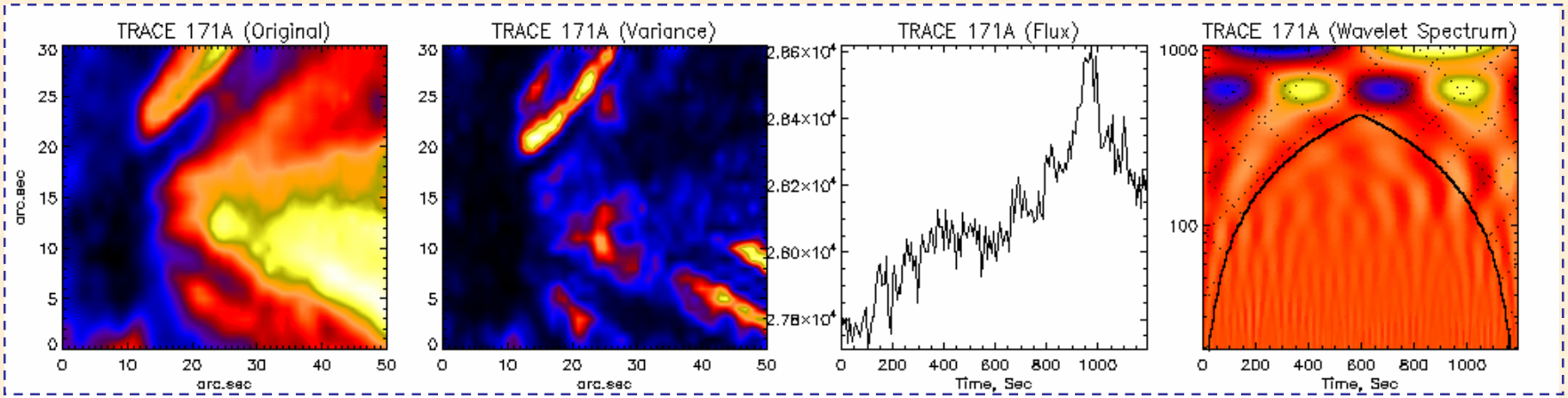
"**PostScript output**" graphic output of the results in the PS file; "**Low frequency filtration**"-polynomial low frequency filtration of the original temporal data cube; "**High Frequency filtration**"-removal of high-frequency noise.

Download a new data for analysis. You can download a data cube images as a **3D FITS file, IDL SAVE file** or an **ASCII file**. The name of sequence images is IMAGE(x, y, t), where x and y are spatial coordinate and t is time. In ASCII file the first 3 rows have x, y and t dimension.



General information about oscillate process in sunspot loops system

May 04, 2005, TRACE 171A, NOAA 10756, STD.fast171



Original frame from 3D (x, y, t) TRACE data

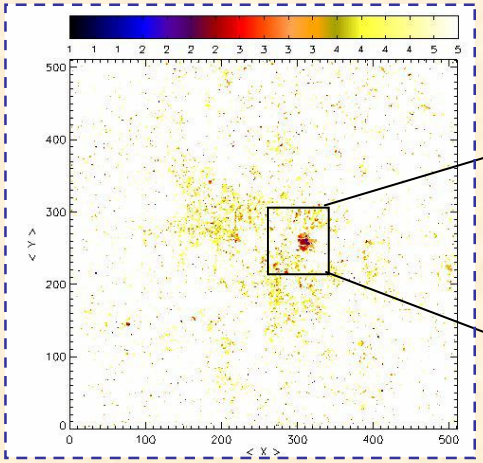
Variation Map

Total Flux

Wavelet spectrum of the flux

Pre-analysis of TRACE coronal imaging data cubes
Periodmap analysis

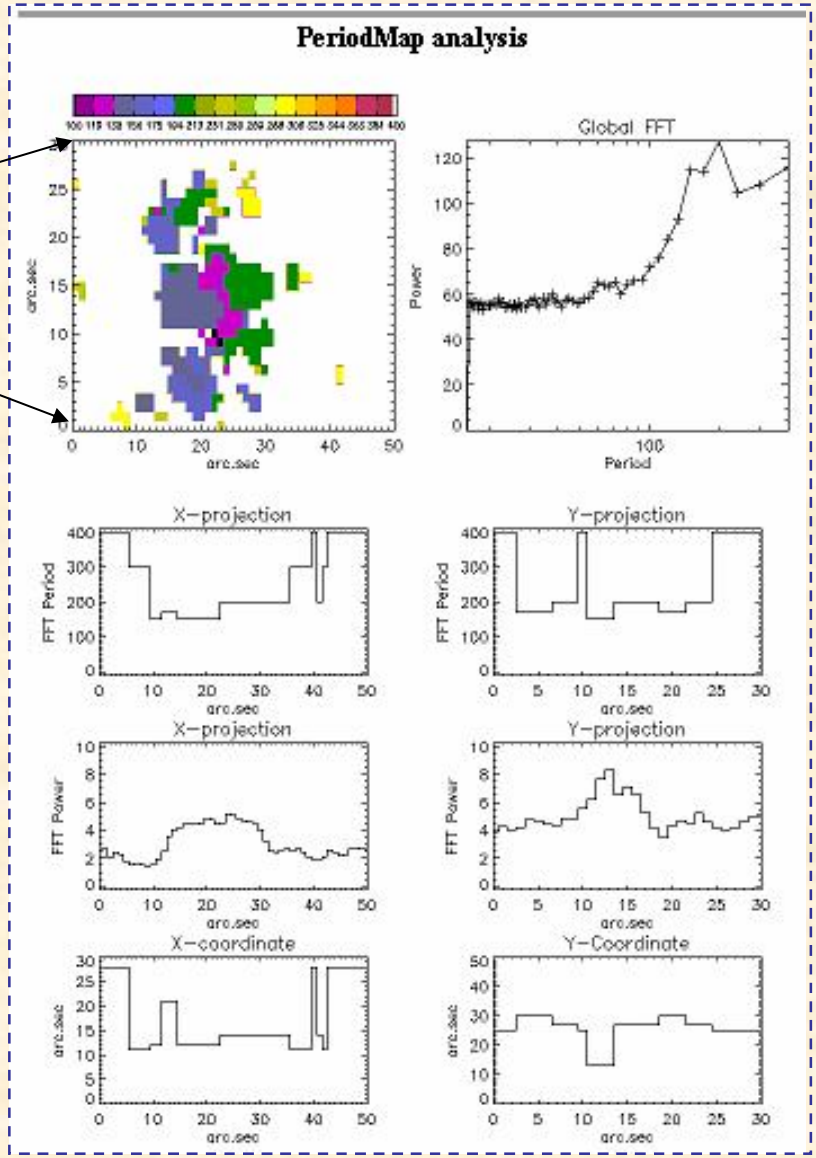
Periodmap



Spatial distribution of a significant period peaks for different projection

Spatial distribution of a power for significant periods peaks

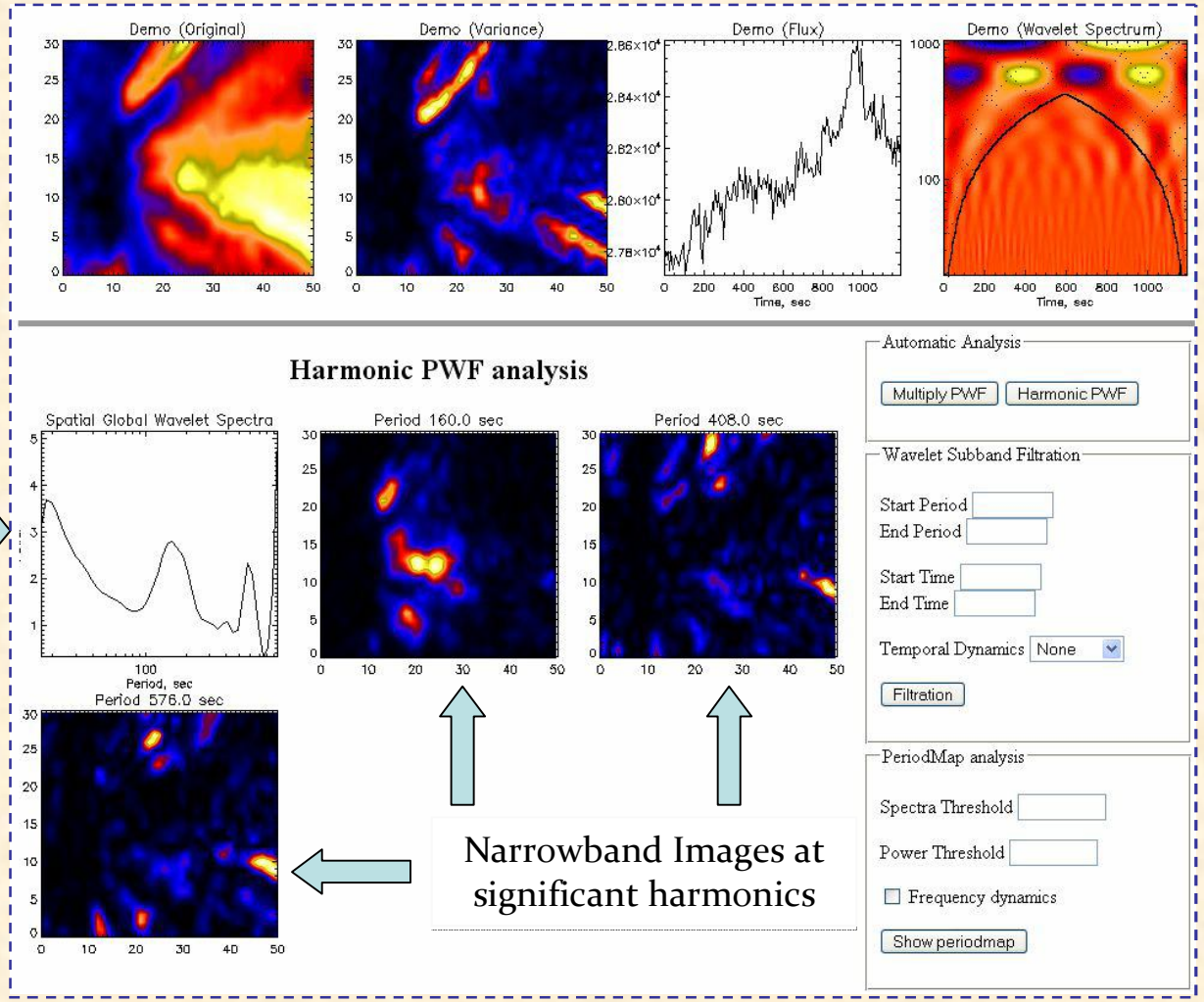
Coordinate of power peaks



Harmonic automatic PWF-analysis

http://pwf.iszf.irk.ru/

TRACE 171A, NOAA 10756, STD.fast171



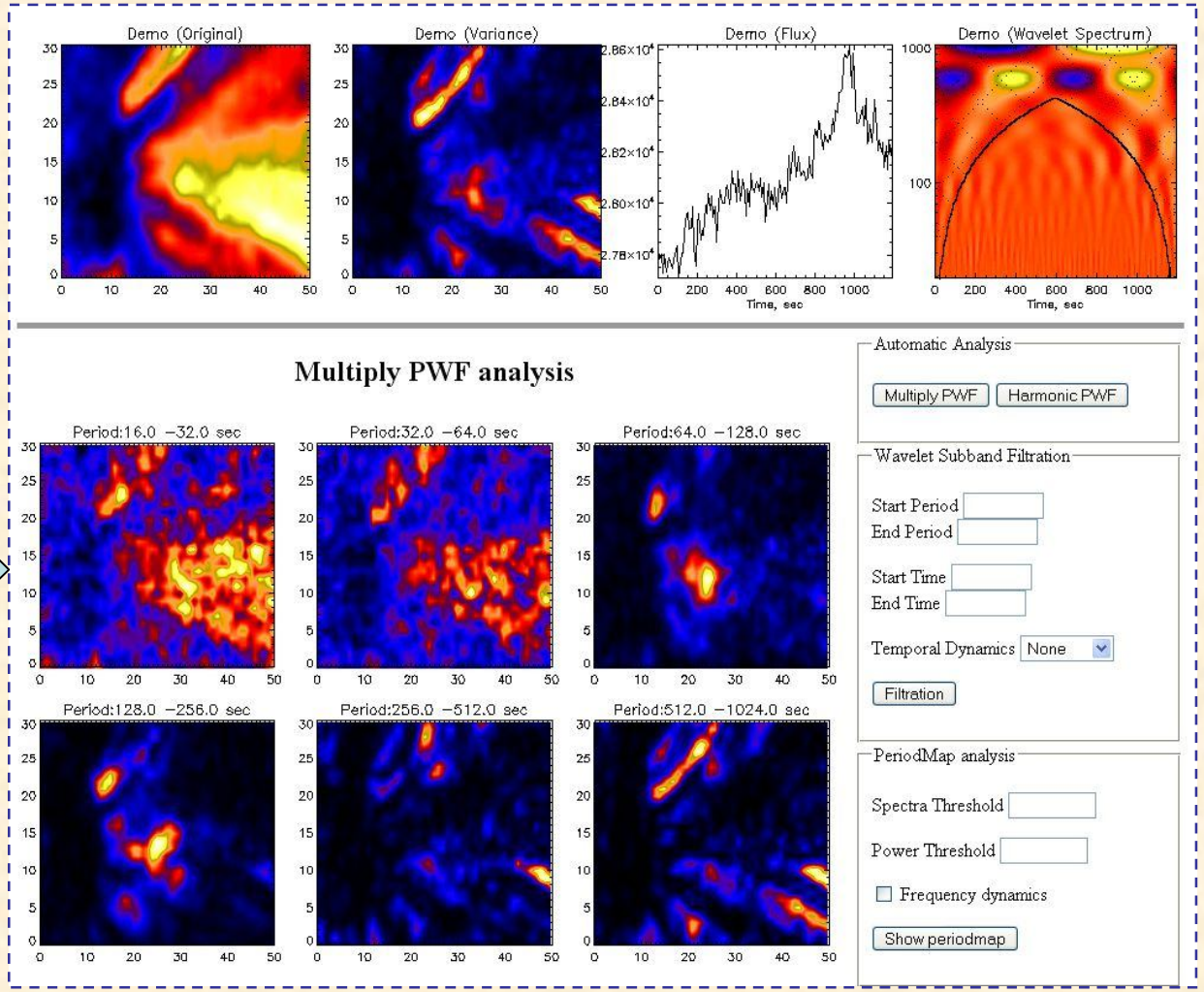
Spatial Global Wavelet Spectrum

Narrowband Images at significant harmonics

Multiply automatic PWF-analysis

http://pwf.iszf.irk.ru/

TRACE 171A, NOAA 10756, STD.fast171



Wavelet subbband filtered images at frequencies multiply two

Proposed Automated detection of coronal waves and oscillations in SDO/AIA datasets

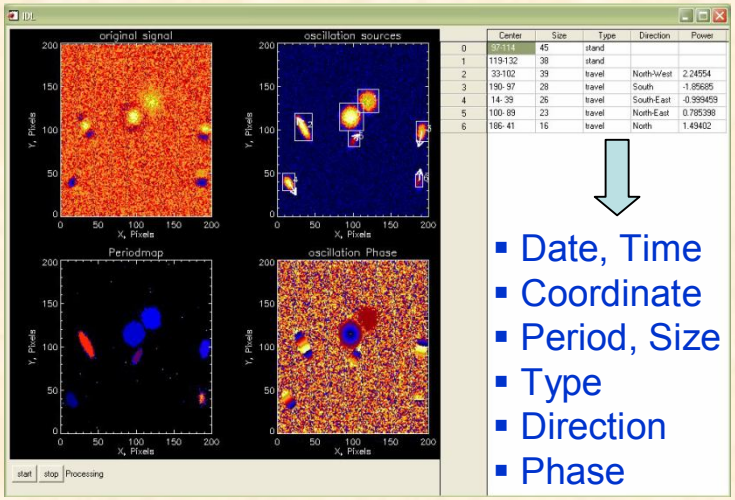
- Full disks data cubes of the 30 and 60 min duration, overlapping in the middle of the sampling time interval, will be processed with the *Coronal Periodmapping technique*. The periodmaps are then stored for the further analysis.

- The selection of the regions of interest *(ROI)* on the map will be performed with the implementation of the *automated pattern recognition method*. This method based on definition of the wave process use spatial distribution of a *Fourier phase signal.* This is allow in automatic mode to obtain information about *type of the waves* – spherical, standing or running, theirs *two dimension coordinates* of the power maximum and *angular distribution* of the waves (wave vector) on the plane coordinates.

- The comprehensive analysis of selected ROI is carried out with the use of the *Pixelized Wavelet Filtering (PWF) method*, which allows to identify the observed *modes* of oscillation, distinguish between *standing and propagating modes*, determine the *spatial structure of the mode* and hence the longitudinal mode number; study the *amplitude and period modulation*, and provided information about the *mode coupling and transformation*.

Automated detection system for SDO/AIA datasets
First results

On-line processing

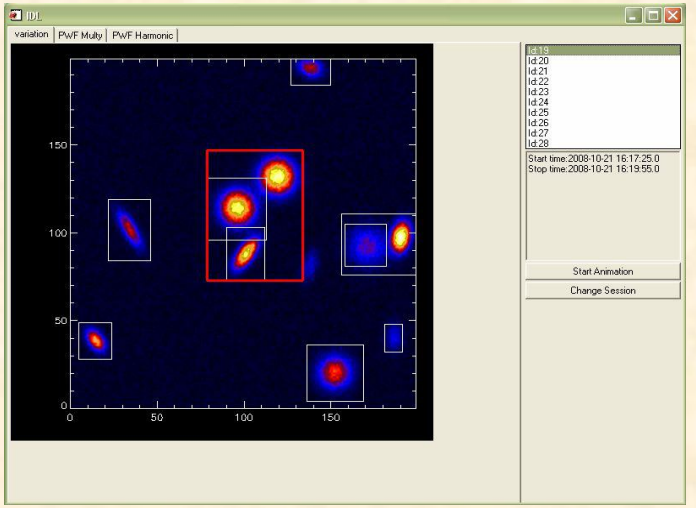


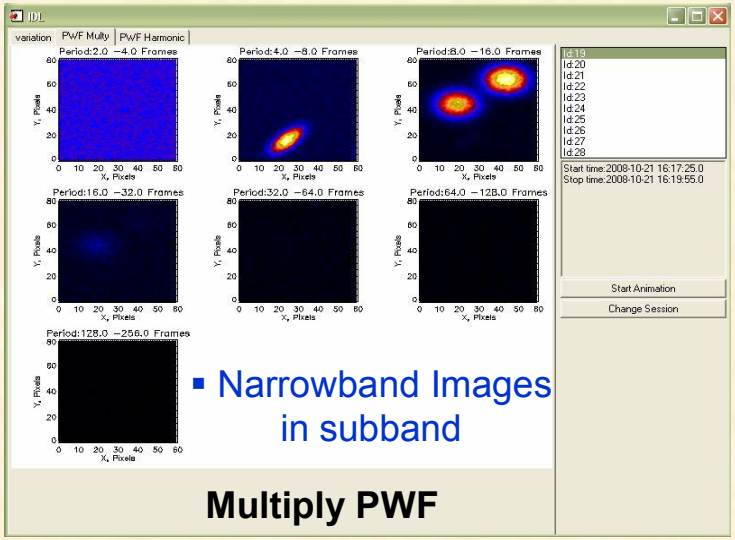
- Date, Time
- Coordinate
- Period, Size
- Type
- Direction
- Phase

Off-line processing

Type of Maps
- Original Map
- Variation Map
- Periodmap
- Phase

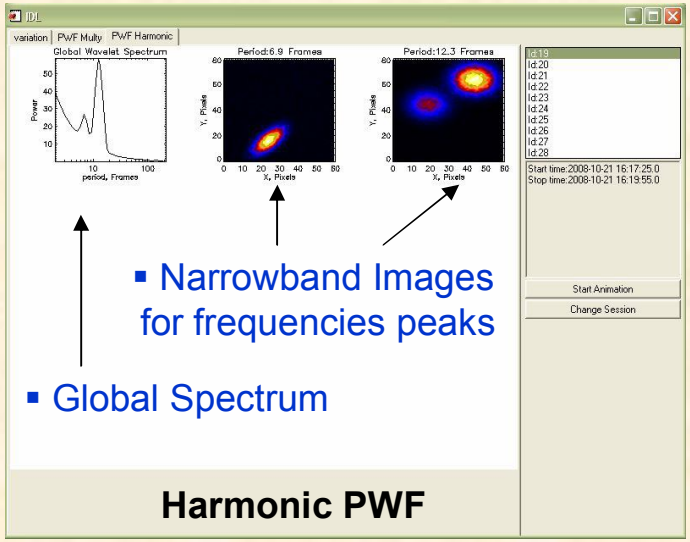
Waves Mode
- Standing
- Traveling
- Spherical





- Narrowband Images in subband

Multiply PWF



- Narrowband Images for frequencies peaks
- Global Spectrum

Harmonic PWF

Conclusion

Access to Interactive Pixelised Wavelet Filtration and PeriodMap analysis server:

www.pwf.iszf.irk.ru

Thank you !