# Periodicities of the Solar Wind and its Fast Streams


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# PERIODICITIES IN THE SOLAR WIND

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# Rapid Solar Wind Appearance during 11-yr Solar Cycle

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# On the Relationship between Solar Wind Characteristics and Geomagnetic Activity

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# Outline

- Fast Solar Wind ↔ High Speed Streams (HSSs)
- Solar Winds Types
- Data and Methods
- Parameters used
- HSSs Intensity (Importance) during SCs 20 – 23
- Lomb Scargle Methods – results
- Fast Fourier Transform – results
  - Periodicities
  - Phase shift between 11-yr SCs of W and HSSs

**HSS DEFINITION:** ***„A large increase in the solar wind velocity lasting for several days (at least two days)".***

**MAIN SELECTION CRITERIUM:** **$\Delta V1 \geq 100$ km/s lasting for two days, where: $\Delta V1$ – the difference between the smallest 3-hr velocity value for a given day (V0) and the largest 3-hr value the following day (V1).**

**HSS CATALOGUES: (1964 – 1996: SCs nos. 20 – 22)**

- Lindblad, B.A., Lundstedt, H., 1981, Sol. Phys. 74, 197-206; 1983, Sol. Phys. 88, 377-382;
- Lindblad, B.A., Lundstedt, H., Larsson B., 1989, Sol. Phys. 120, 145-152;
- Mavromichalaki, H., Vassilaki, A., Marmatsouri, E., 1988, Sol. Phys. 115, 345-365;
- Mavromichalaki, H., Vassilaki, A., 1998, Sol. Phys. 183, 181-200;

**1996 – 2007; SC 23**

- Maris, O., Maris G., 2007, **unpublished yet**; at: http://www.spaceweather.eu/, in Cap. "Data Catalogs for SW" or at: http://venus.nipne.ro/new1/HSS_Catalogue.html).

# Solar Wind Types (I)

## *1. Fast wind in high-speed streams*

| | |
|---|---|
| High speed | 400 - 800 $kms^{-1}$ |
| Low density | 3 $cm^{-3}$ |
| Low particle flux | $2 \times 10^8$ $cm^{-2}$ $s^{-1}$ |
| Helium content | 3.6 %, stationary |
| Source | coronal holes |
| Signatures | stationary for long times (weeks!) |

## *2. Low-speed wind near activity minimum*

| | |
|---|---|
| Low speed | 250 – 400 km $s^{-1}$ |
| High density | 10 $cm^{-3}$ |
| High particle flux | $3.7 \times 10^8$ $cm^{-2}$ $s^{-1}$ |
| Helium content | below 2 %, highly variable |
| Source | helmet streamers near current sheet |
| Signatures | sector boundaries embedded |

# Solar Wind Types (II)

### *3. Low speed wind near activity maximum*

Similar characteristics as 2., except for

| | |
|---|---|
| Helium content | 4%, highly variable |
| Source | related to active regions |
| Signatures | shock waves often imbedded |

### *4. Ejecta following interplanetary shocks*

| | |
|---|---|
| High speed | 400 – 2000 $kms^{-1}$ |
| Helium content | up to 30% |
| Other constituents | often $Fe^{l6+}$ ions; in rare cases $He^{+}$ |
| Signatures of magnetic clouds | in about 30% of cases |
| Sources | erupting prominences |

## DATA SOURCES:

- **OMNI 2 data, obtained from the GSFC/SPDF OMNI Web interface at [http://omniweb.gsfc.nasa.gov](http://omniweb.gsfc.nasa.gov)**
  - **the solar wind velocity (1 hour resolution);**
- **HSS CATALOGUES 1964 – 2007: (SCs nos. 20 – 23)**
  - **the fast solar wind intensity (27 days – a Bartels rotation – resolution)**

## METHODS $\rightarrow$ Spectral Analysis:

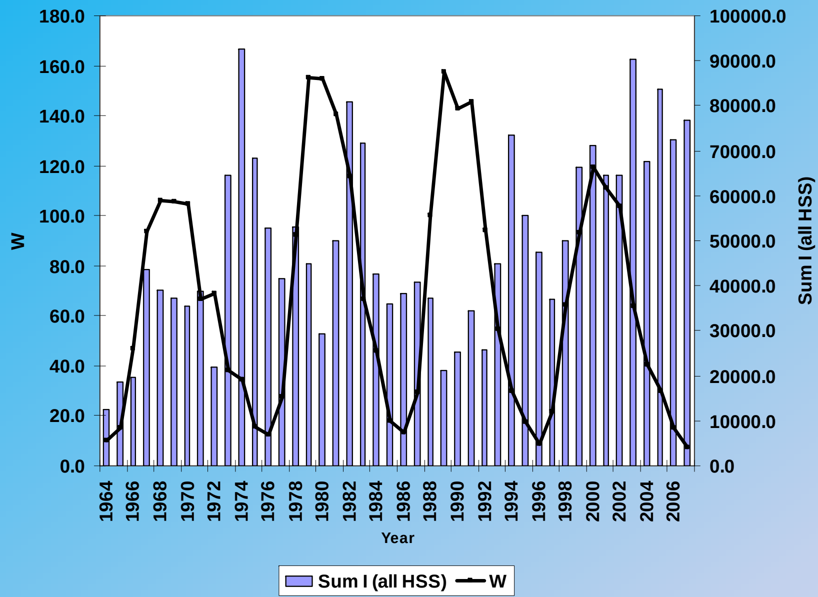
- **Lomb-Scargle method**
  - $\Rightarrow$ **power spectrum** $\Rightarrow$ **spectral components**
- **Fast Fourier Transform (FFT)**
- **FFT of the LabView graphic programming environment**
  - $\Rightarrow$ **phase of spectral components**

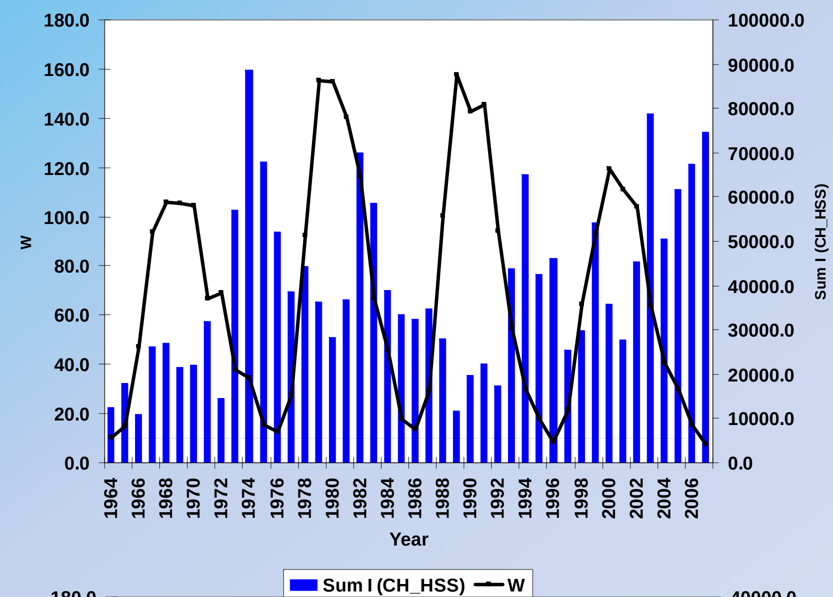
# PARAMETERS used:

- the solar wind velocity, V – 1 day resolution;
- the HSS intensity (importance), I – 27 days resolution (a Bartels Rotation – BR)
  - HSS duration $\rightarrow$ d (days);
  - HSS maximum velocity $\rightarrow$ $V_{max}$ (km / sec);
  - HSS velocity gradient $\rightarrow$ $\Delta V_{max} = V_{max} - V_o$;
  - HSS intensity (importance) $\rightarrow$ $I = \Delta V_{max} \times d$

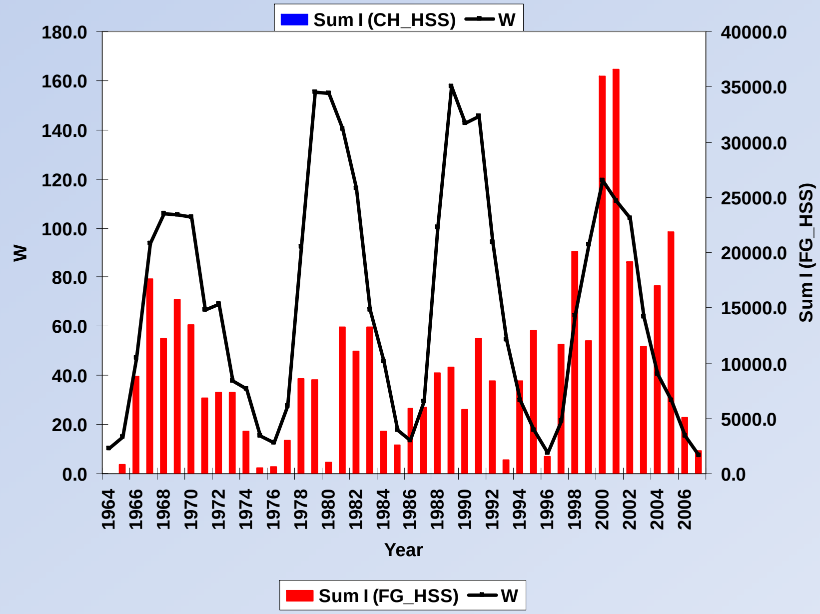
– Finally, the weighted values : $I_p = \sum I / \sum d$, were calculated per BR or per month

# HSS Importance during SCs 20 – 23

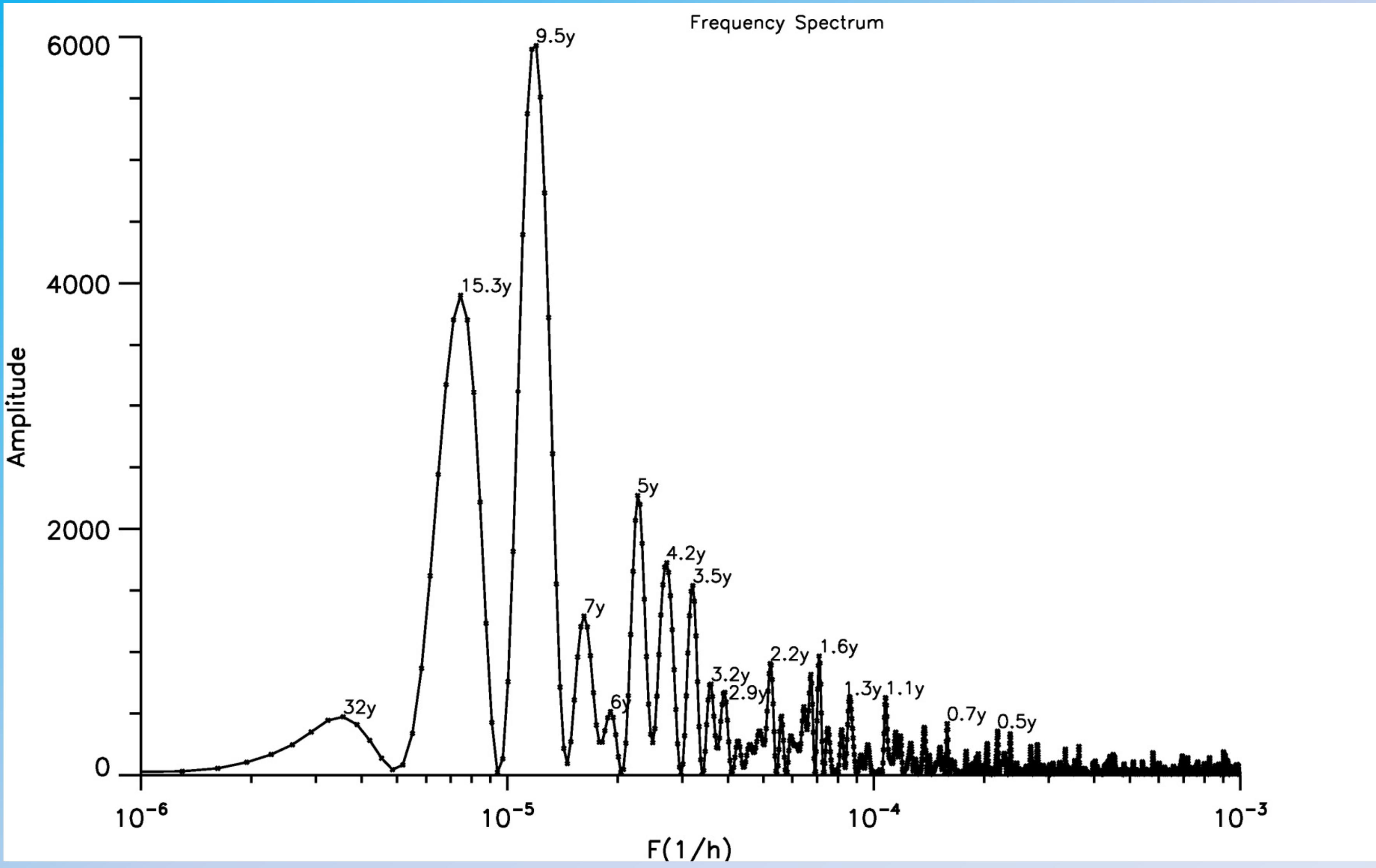



- CH_HSSs and all HSSs;
- FG_HSSs of SC 23 in comparison with ones of SCc 20-22;
- SC 23 peculiarities.

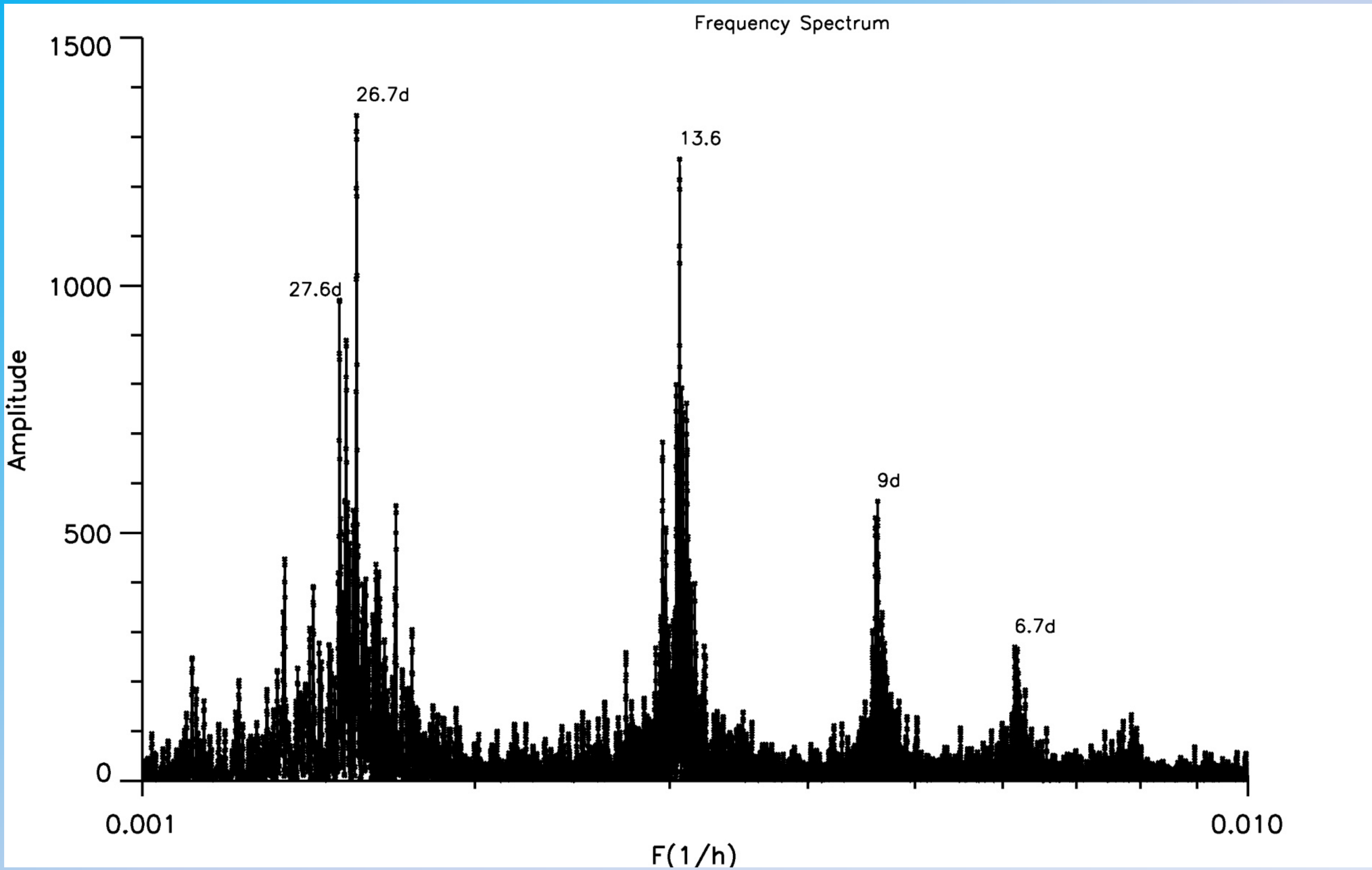


# Lomb-Scargle spectral method (LS) – I



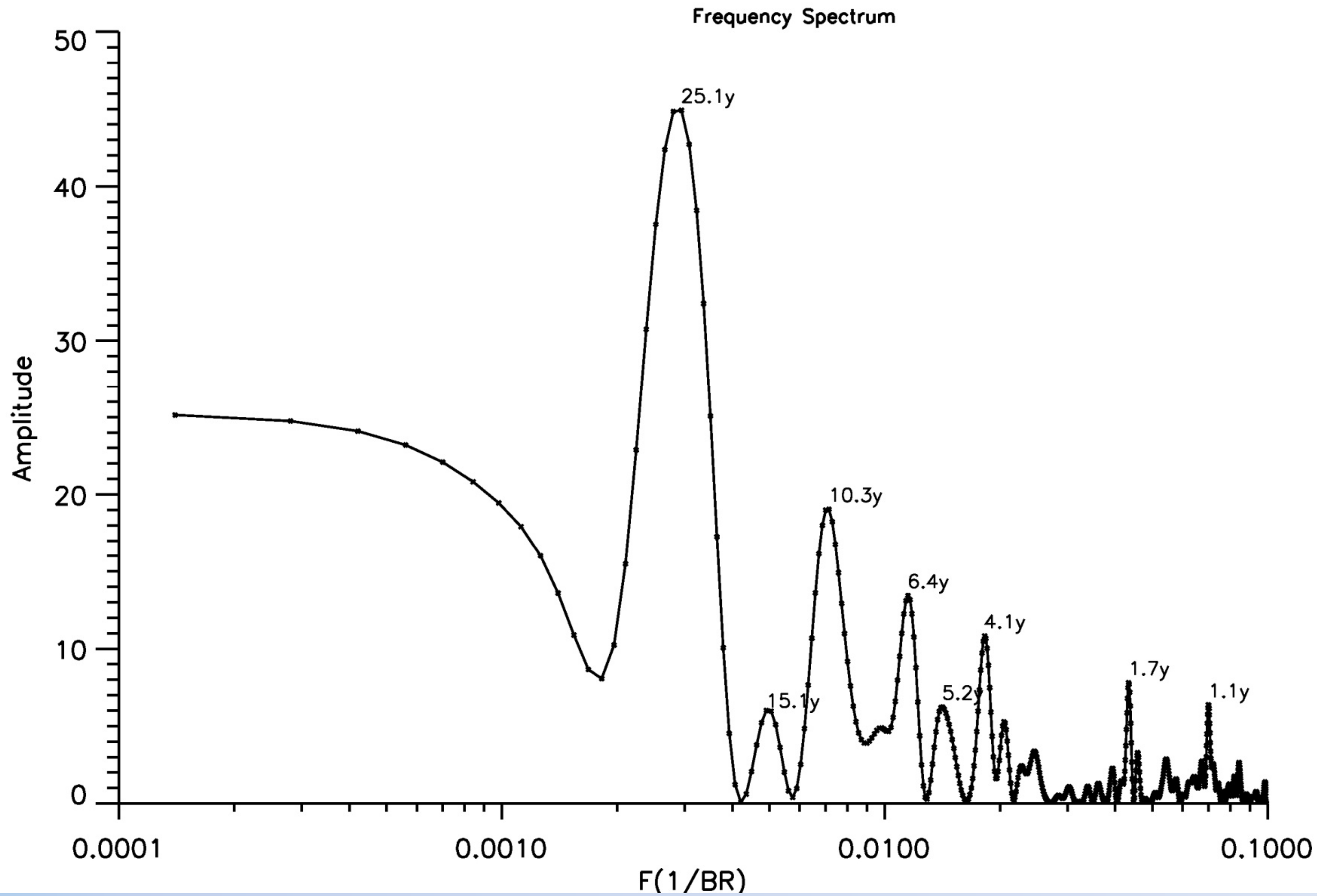

**Lomb spectrum of the Solar Wind for long term periods (Years)**

# LS – II



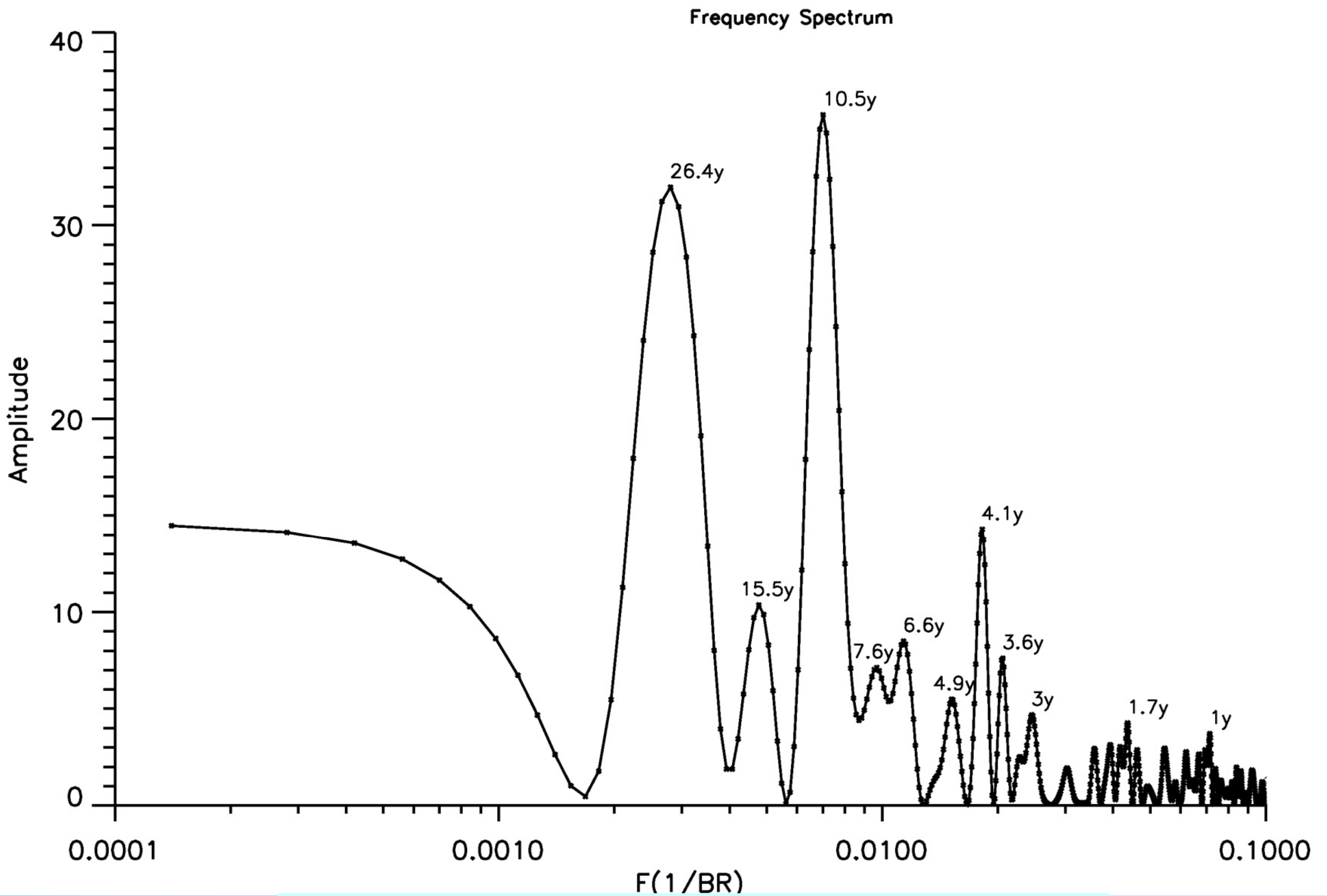

**Lomb spectrum of the Solar Wind for short term periods (days)**

# LS - III



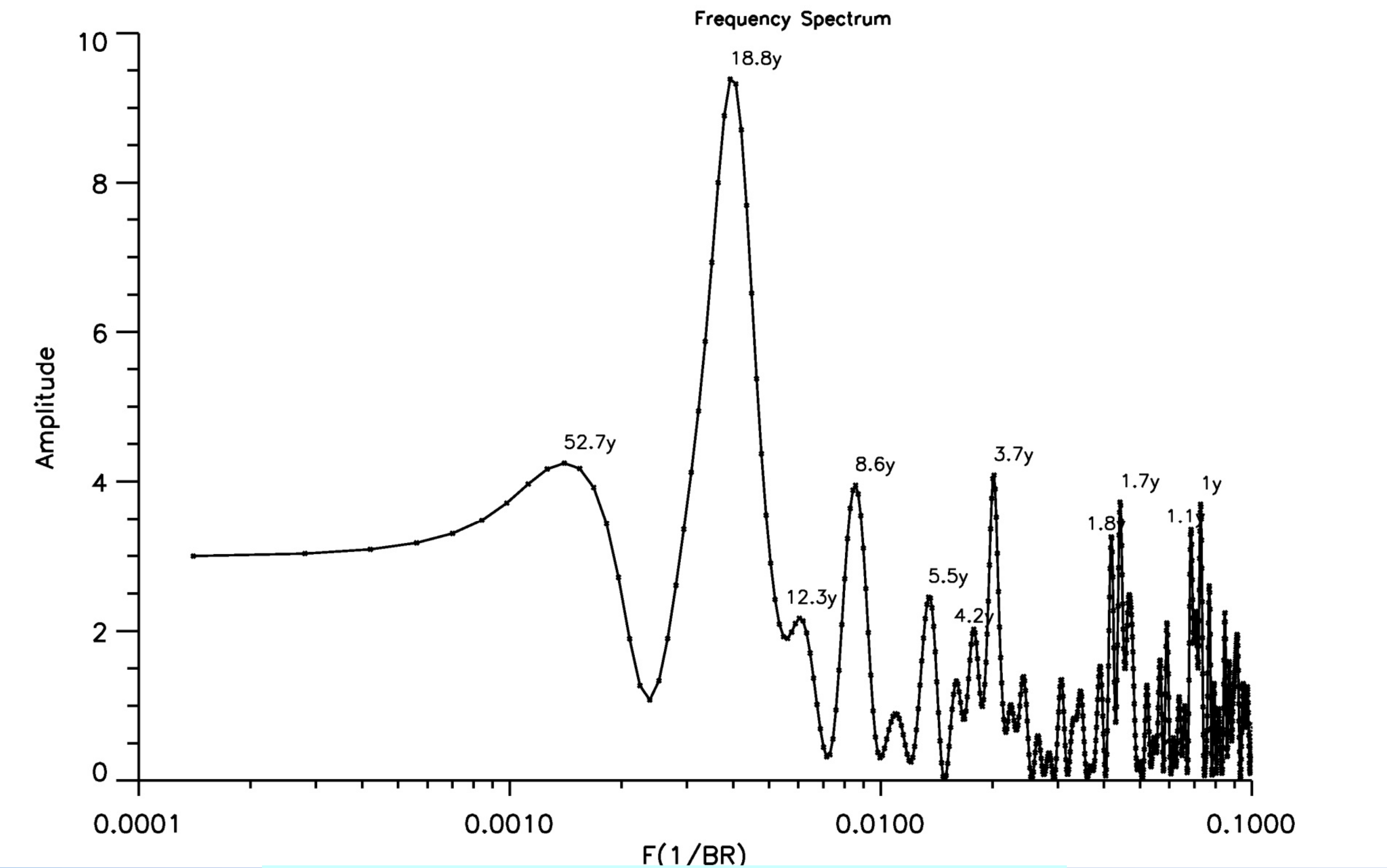

**Lomb spectrum of I for all HSSs**

# LS - IV




**Lomb spectrum of I for the CH_HSSs**

# LS - V




**Lomb spectrum of the I for FG_HSSs**

# Periods:

**The period $T_{I\_HSS}$ and $T_V$ of each spectral component found in the Lomb periodogram can be calculate for HSS intensity and solar wind velocity, respectively, as:**

$$T_{I\_HSS,n} = 1/(F_n \times n_B/n_Y)$$

$$T_{Vn} = 1/(F_n \times n_d/n_Y)$$

**where:**

**$n$ = Order of spectral component;**

**$F_n$ = Frequency of the spectral component of n order;**

**$F_n = n/N$**

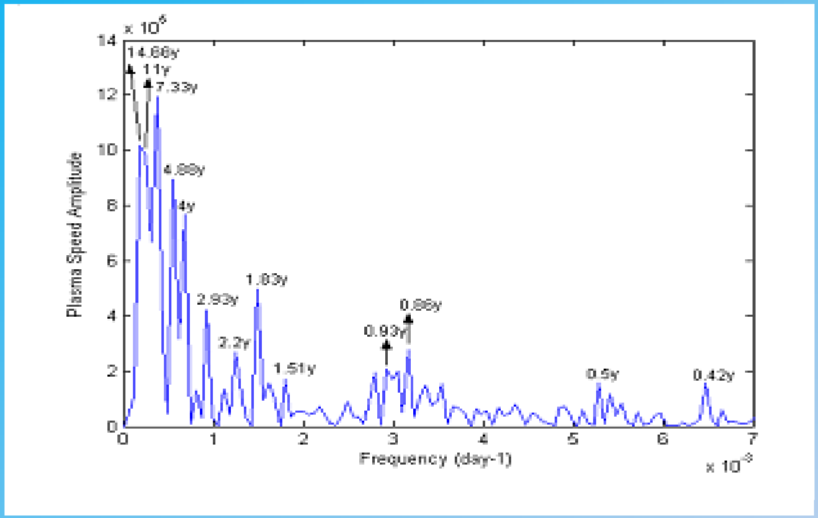
**$N$ = Numbers of spectral series component;**

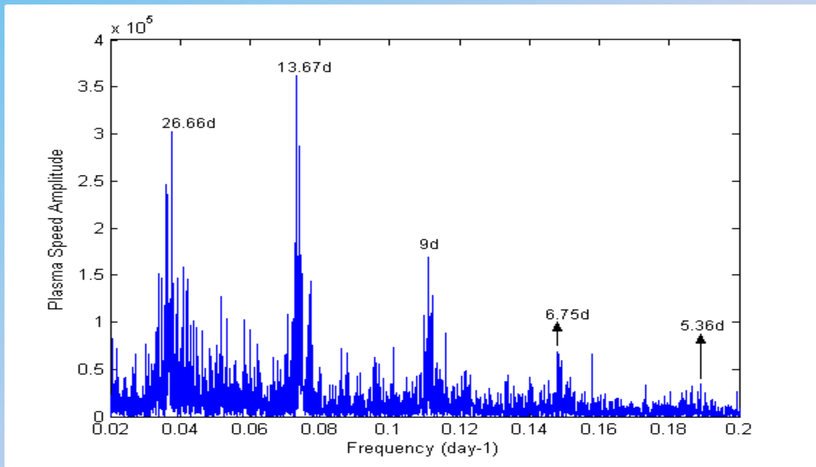
**$n_B$ = Number of days per Bartels Rotation (27);**

**$n_Y$ = Number of days per year (365);**

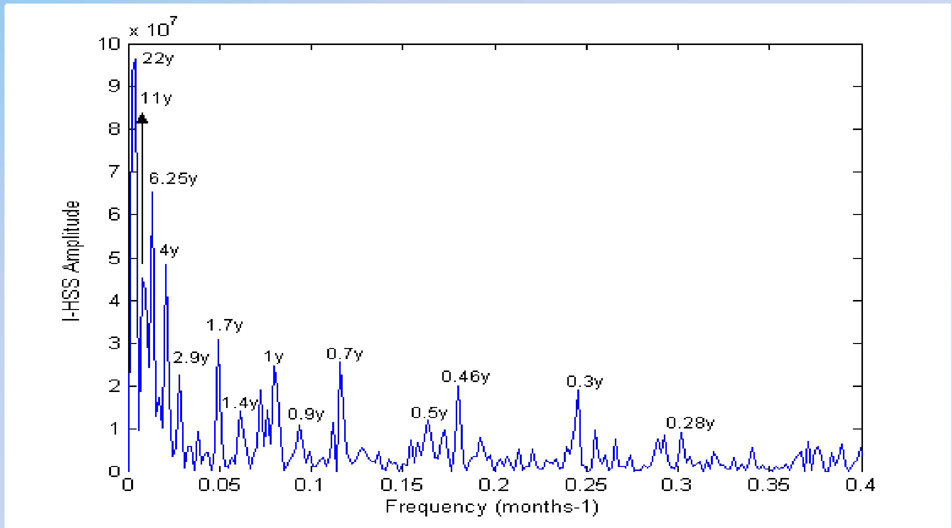
**$n_d$ = Number of hours per days (24).**

# FFT




The frequency spectrum of V daily values in the $(0–6)\times10^{-3}$ day$^{-1}$ interval (the left panel) and the same spectra in the 0.02–0.2 day$^{-1}$ interval (the right panel)




The frequency spectrum of I for all HSS

# Periods found

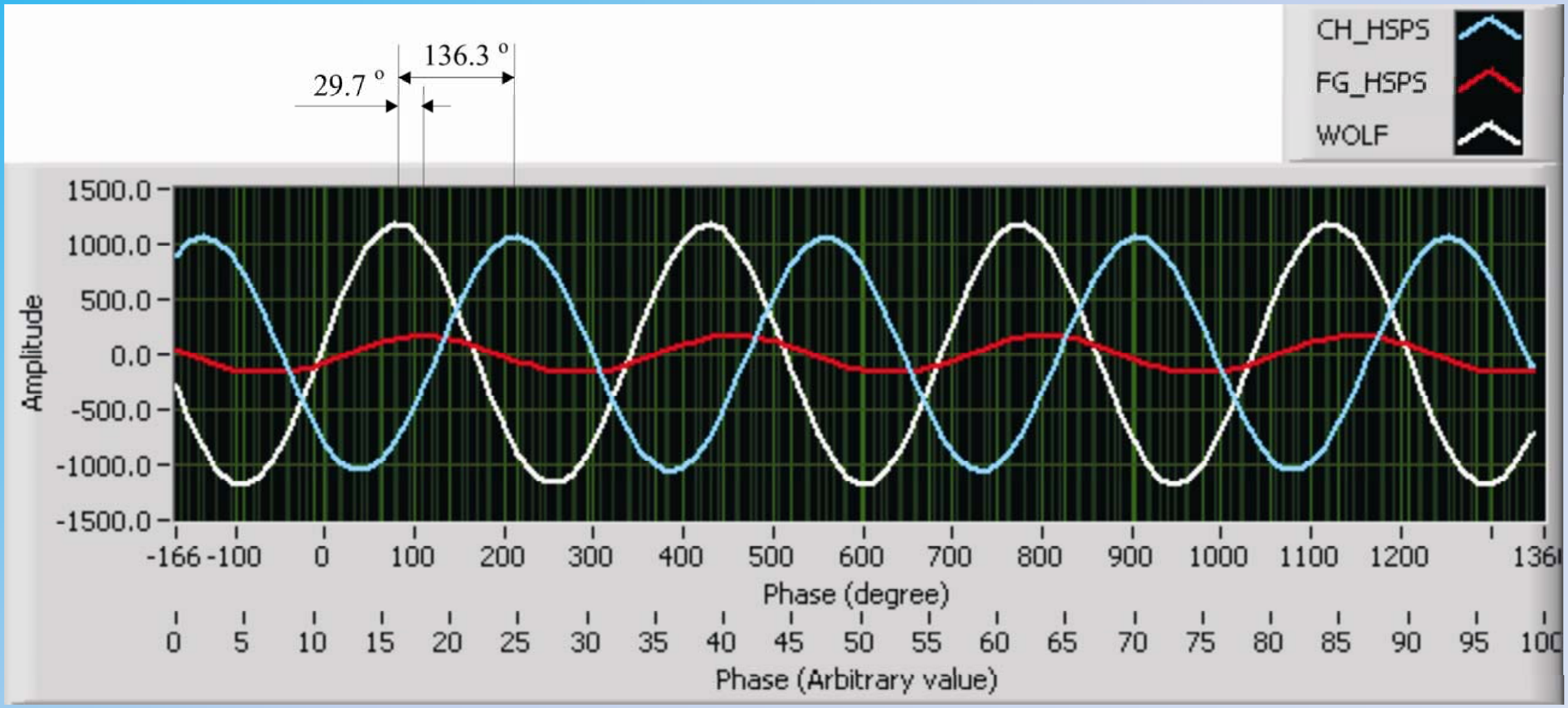
| Index (parameter) | V | | I for all HSS | |
|---|---|---|---|---|
| Method | LS | FFT | LS | FFT |
| Periods (years) | 15.3 y | 14.46 y | 25.1 | 22 |
| | 9.5 y | 11 y | 10.3 | 11y |
| | 7 y, | 7.33 y | 6.4 | 6.25y |
| | 5 y; 4.2 y | 4.88 y | 4.1 | 4 |
| | 3.5 y; 2.2 y | 2.93; 2.2 y | - | 2.9; 1.7 |
| | 1.6 y; 1.1 y | - | 1.7; 1.1 | 0.5; 0.46 |
| | 0.7 y | 0.5 y | | |
| Periods (days) | 26.7 d | 26.66 d | | |
| | 13.6 d | 13.67 d | | |
| | 9.d | 9 d | | |
| | 6.7 d | 6.75 d | | |

**Our results for solar wind are similar to many other authors:**

- **Richardson, J. D., 1994, 1995:** 1.3 y, 155 d (0.42 y)
- **Emery, B. A., 2008:** 27 d, 13.5 d, 9 d, 183 d (0.5 y)
- **Kuznetzova, T. V., 2007:** 10.8 y, 3.73 y, 1.55 y, 1.3 y
- **Verma, V. K., :** 7 y, 2.9 y, 2.4 y, 7 d
- **Rangarajan, G. K., 1999:** 9 y, 42 m (3.5 y), 16 m (1.33 y)
- **Prabhakaran Nayar S.R., 2002:** 10.6 y, 9.6 y, 5.5 y, 1.3 y, 180 d (0.5 y), 27d, 14d

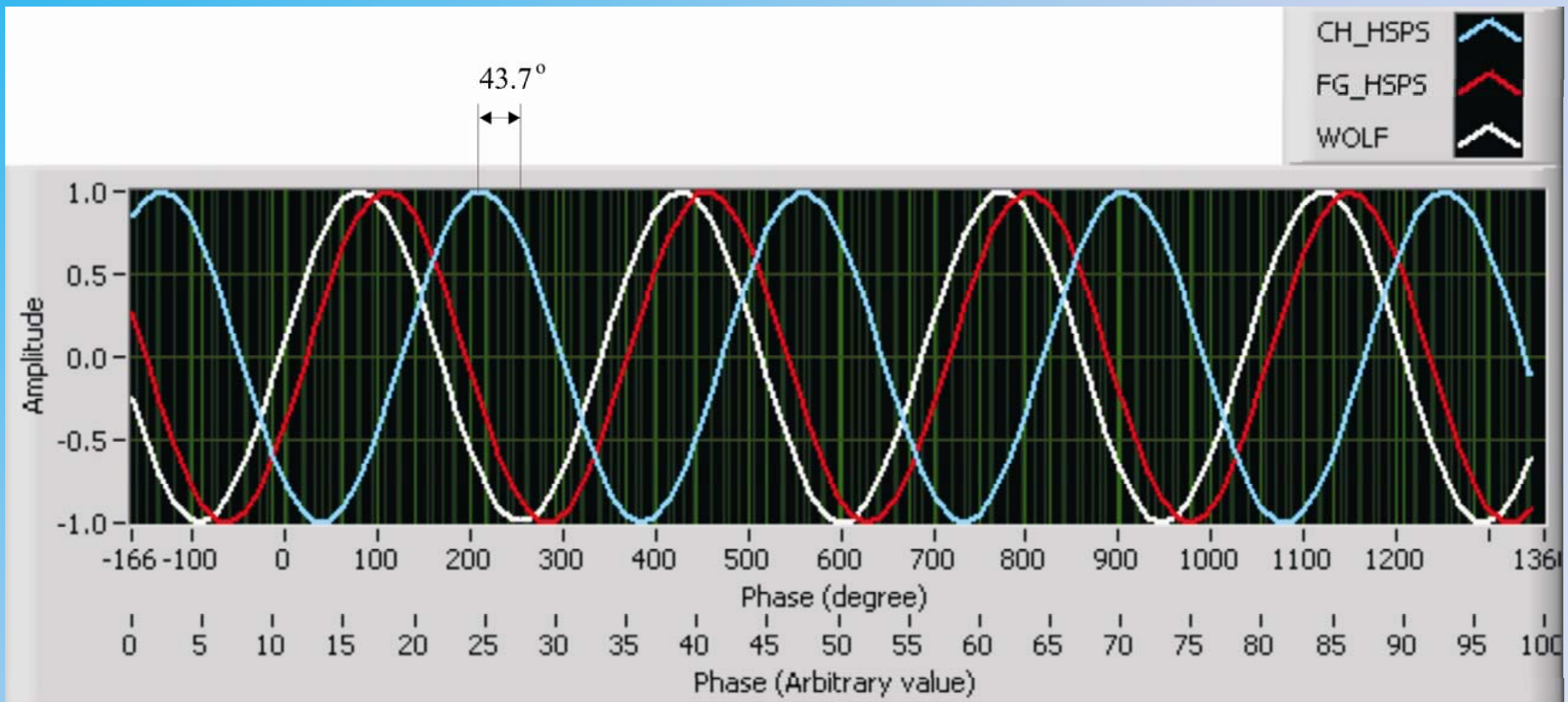
**Relative minor differences between different authors result from different time interval and resolution for data series.**

# FFT – LabView




**The phase and relative amplitude of the 11-year components for W, I of CH_ and FG_HSSs**

# FFT – LabView




**The phase and normalized amplitude of the 11-year components for W, I of CH_ and FG_HSSs**

# Phase Shift:

- **The maximum amplitude of the Wolf series (W) is obtained for the spectral component of fourth order;**
- **With n = 4, N = 595, $n_B$ = 27 and $n_Y$ = 365, result a period $T_4$ = 11 years, the classic solar cycle;**
- **The same period is found in all spectra HSSs (as the maximum one or significant one, at least). It results a cyclic behavior of the HSS with the basic solar cycle (11-yr).**
  - **The phase of the spectral components (n = 4) are:**

**F (W) = -166.1 º**

**F (CH_HSS) = 57.6 º**

**F (FG_HSS) = 164.2 º**

- **It results a phase shift between W and HSSs:**

**ΔF (W, CH_HSS) = -166.1º - 57.6º + 360º = 136,3 º**

**ΔF (W, FG_HSS) = -166.1º – 164.2º + 360º = 29.7 º**

⇒the maximum of the CH_HSS is shifted with 136.3 $^{o}$ after maximum of the Wolf cycle, and the maximum of the FG_HSS is shifted with 29.7 $^{o}$ after maximum of the Wolf cycle;

⇒ the maximum activities of the CH_HSS are shifted with 43.7$^{o}$ before the minimum of the Wolf solar cycle;

These shifts, converted in time, mean:

**⇒the maximum of CH_HSSs take place with ~4.16 years after maximum of the solar cycles, or with ~1.34 years before solar minimum;**

**⇒maximum of the FG_HSS take place after maximum of solar cycle with ~0.9 years.**


THANKS
FOR YOUR
KIND ATTENTION!