

Time Domain Astronomy and the VO—user perspective

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□ Outline

- Why bother about Time Domain?
- Why do astronomers need time series?
- How can the VO be useful for the Time Domain community?
- Success of VO with other kind of data.
- Do we have anything similar for Time Series?

□ Why bother about Time Domain?

- Time Domain astronomy encompasses every area of Astronomy:
 - **Periodic phenomena:** binary orbits of stars/extrasolar planets, stellar rotation, stellar pulsation...
 - **Stochastic phenomena:** accretion in CVs, X-ray binaries, Seyfert galaxies, quasars...
 - **Explosive phenomena:** supernovae, gamma-ray bursts, novae, X-ray bursts, transits, gravitational microlensing, flares, tidal disruption events...

□ Why bother about Time Domain?

- Lots of missions specifically designed for Time Domain Astronomy:



- **Transient phenomena** >> follow-up >> Connect events/facilities/people.
 ➡ **VOEvent** developed to facilitate transmission
- **Time Series**

□ Why do astronomers need time series?



- Some astronomers look if an eruptive event on an specific object ever happened and perhaps we missed it (e.g. DASCH project).
- Some astronomers are expecting some stars to go through eruptions at a specific moment and are therefore looking at those stars in a regular basis.

□ Why do astronomers need time series?

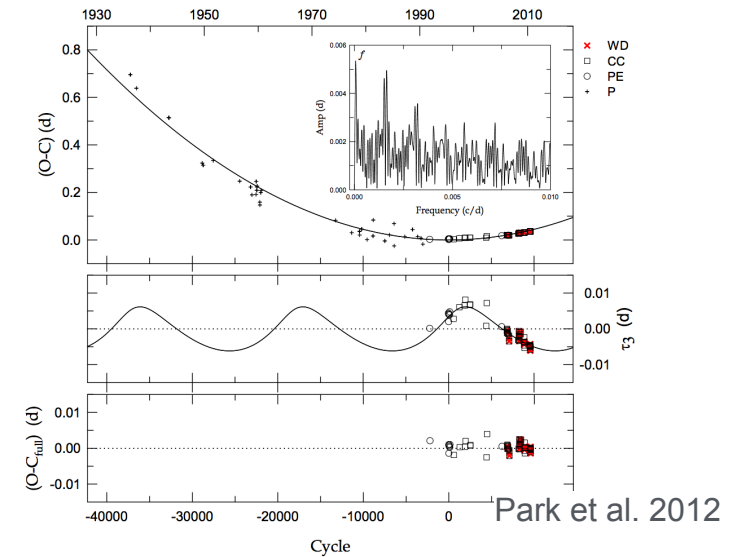
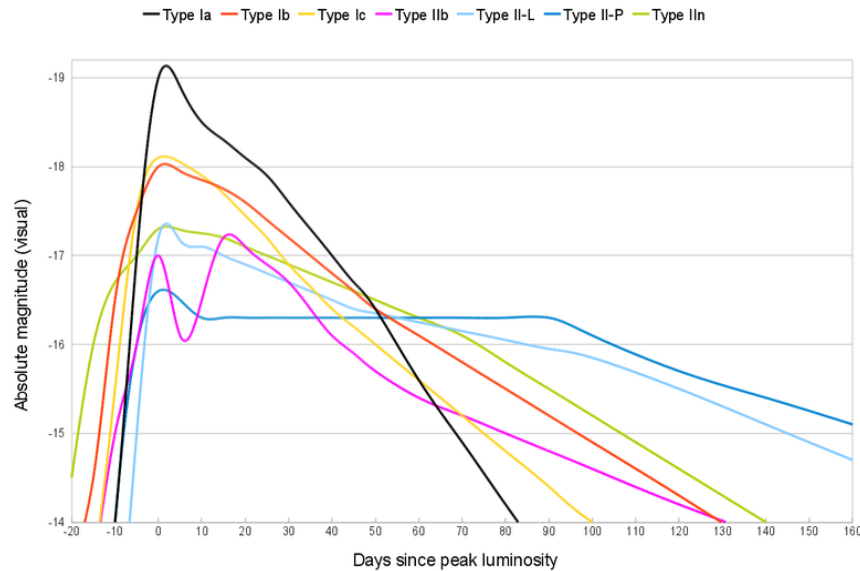
Science cases compiled and documented in the IVOA wiki:

<http://wiki.ivoa.net/twiki/bin/view/IVOA/CSPTIMEseries>

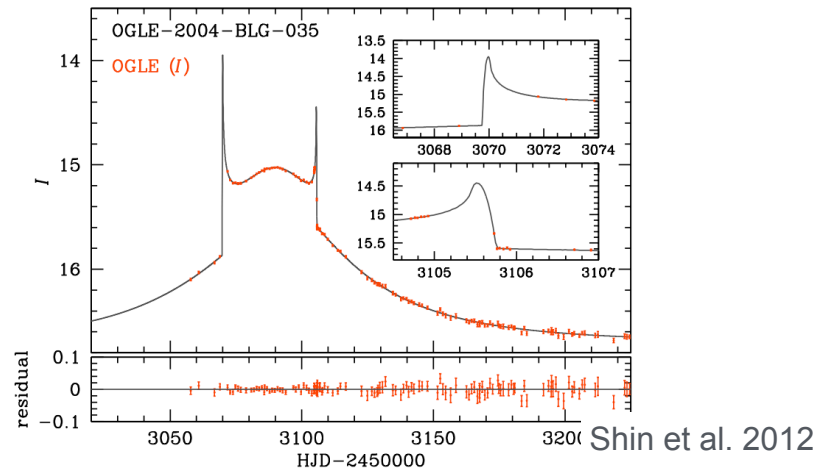
- **3 groups of science cases based on common requirements:**
 - A. Combine photometry and light curves of a given object/list of objects in the same photometric band.

□ Why do astronomers need time series?

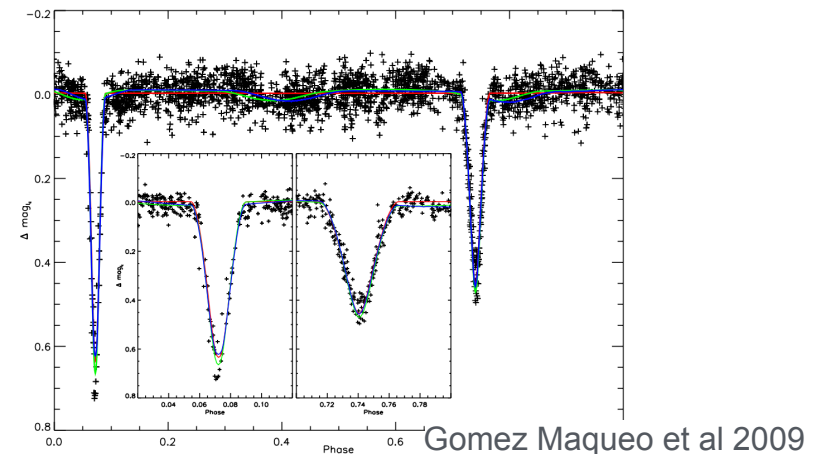
1. SN classification using the light curve.
2. Long-term analysis of eclipsing binaries.



3. Discovering BD by microlensing events.



4. Eclipsing binary systems.



□ Why do astronomers need time series?

Science cases compiled and documented in the IVOA wiki:

<http://wiki.ivoa.net/twiki/bin/view/IVOA/CSPTimeSeries>

- **3 groups of science cases based on common requirements:**
 - A. Combine photometry and light curves of a given object/list of objects in the same photometric band.
 - B. Combine photometry and light curves of a given object/list of objects in different photometric bands.
- 5. Follow-up characterisation of supernovae.

□ Why do astronomers need time series?

Science cases compiled and documented in the IVOA wiki:

<http://wiki.ivoa.net/twiki/bin/view/IVOA/CSPTIMEseries>

- **3 groups of science cases based on common requirements:**
 - A. Combine photometry and light curves of a given object/list of objects in the same photometric band.
 - B. Combine photometry and light curves of a given object/list of objects in different photometric bands.
 5. Follow-up characterisation of supernovae.
 - C. Time series other than light curves.
 6. Exoplanet studies using radial velocities.
 7. Asteroseismic studies of pulsating variables.
 8. Spectral and temporal variability study of X-ray sources.

□ How can VO be useful for the TD community?

- More science cases can be detailed if needed to, but...
 - Do we want to solve every single science case?
 - Should we start with the most complicated case?
 - Or should start from the most simple cases and go on from there?
 - ➡ What is simple? Astronomy isn't, that's for sure.
 - Astronomers like to see a lot of details in their data and will still develop their own tools for that, and that is good.

□ How can VO be useful for the TD community?

- Astronomers:
 - **produce data**: photometric/radial velocity curves, spectra, images, videos...
 - **connect data**: different kinds of observations (e.g. links between photometric & spectral evolution)
 - **share data**: mail, webpages, databases,....
 - ➡ Works at a small scale (people & data) and for some time.
 - **analyse data**
- VO tools and services can help to :
 - curate data (easier, stable and long lasting)
 - share data
 - make the connectivity (interoperability)

□ How can VO be useful for the TD community?

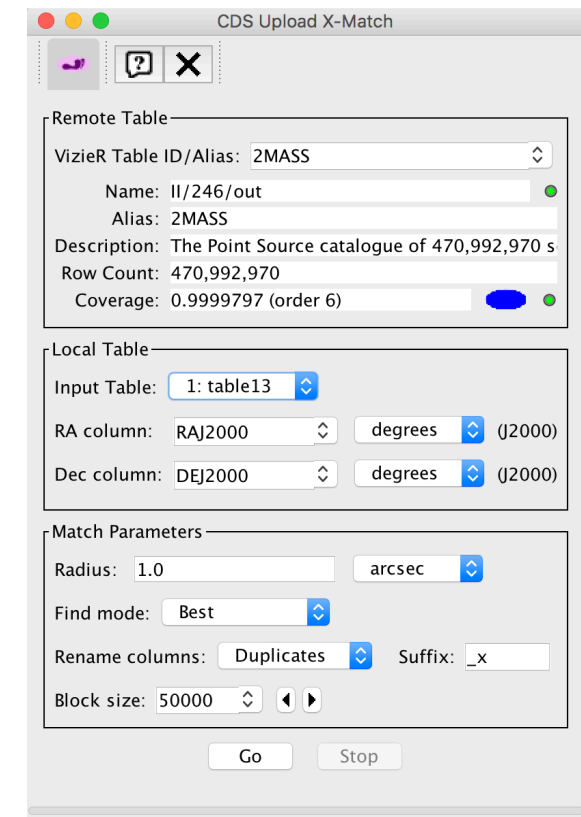
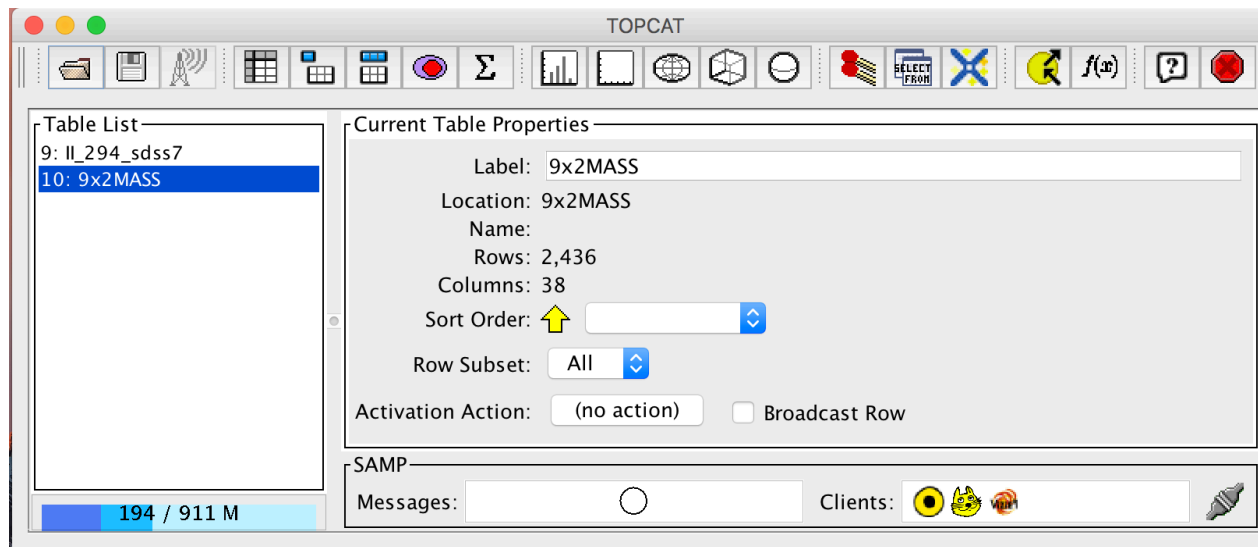
- For TD we want to do the same things we can do with other kind of data:
 - **Find data**: simple/sophisticated queries
 - Quickly **visualise data**: simple/sophisticated plots, videos
 - Make **operations**:
 - periodograms (analysis of variance) find possible periodicity
 - phase-folded curves
 - Interaction between the different services and tools — **interoperability**
 - ➡ gives the user the impression that everything is one unique system.

Discovery & access, visualisation & analysis in a seamless way for the user.

Success of VO with other kind of data

• Tables

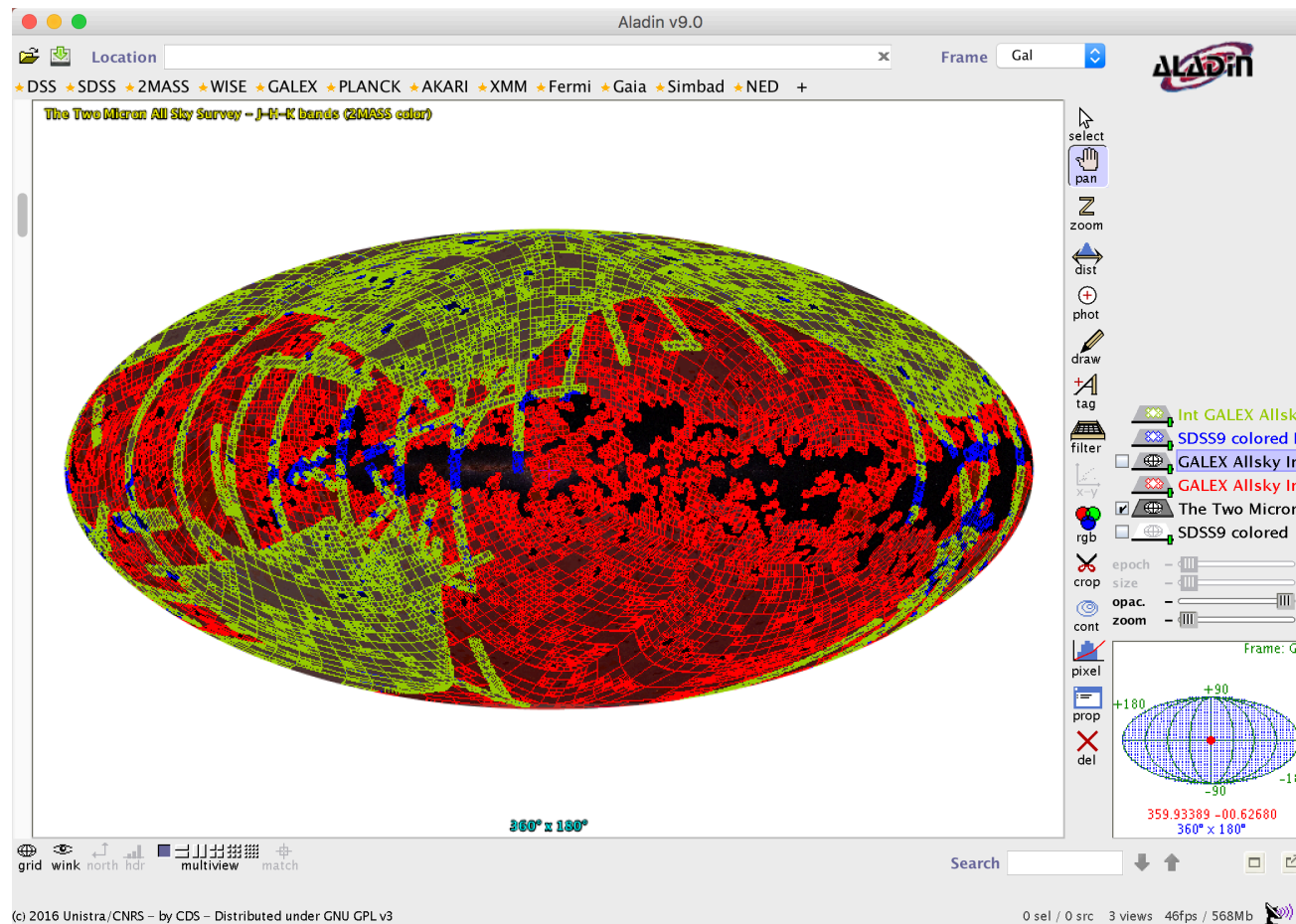
- CDS Xmatch using TOPCAT:
 - a sample of 50000 SDSS sources
 - ~470 million 2MASS sources
 - done in seconds



Success of VO with other kind of data

- Images

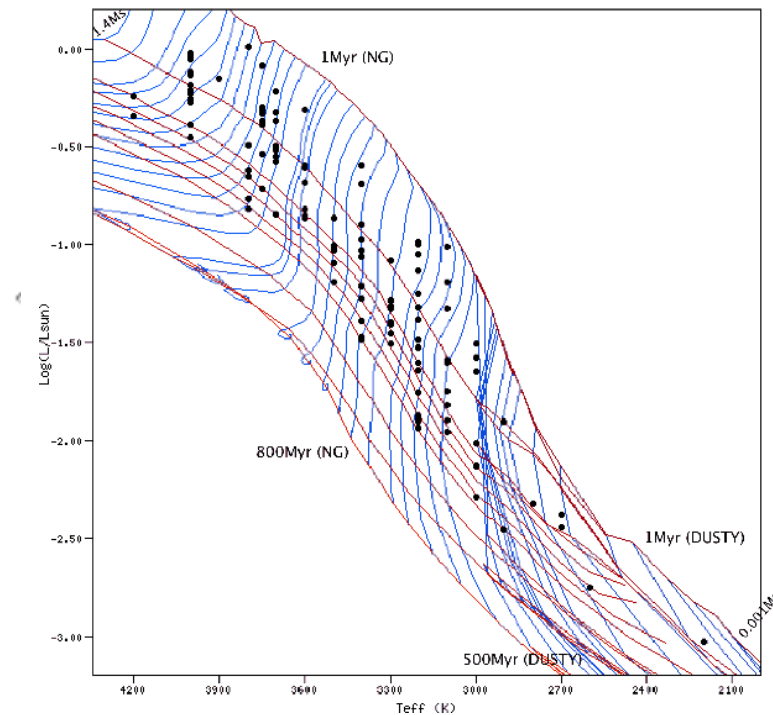
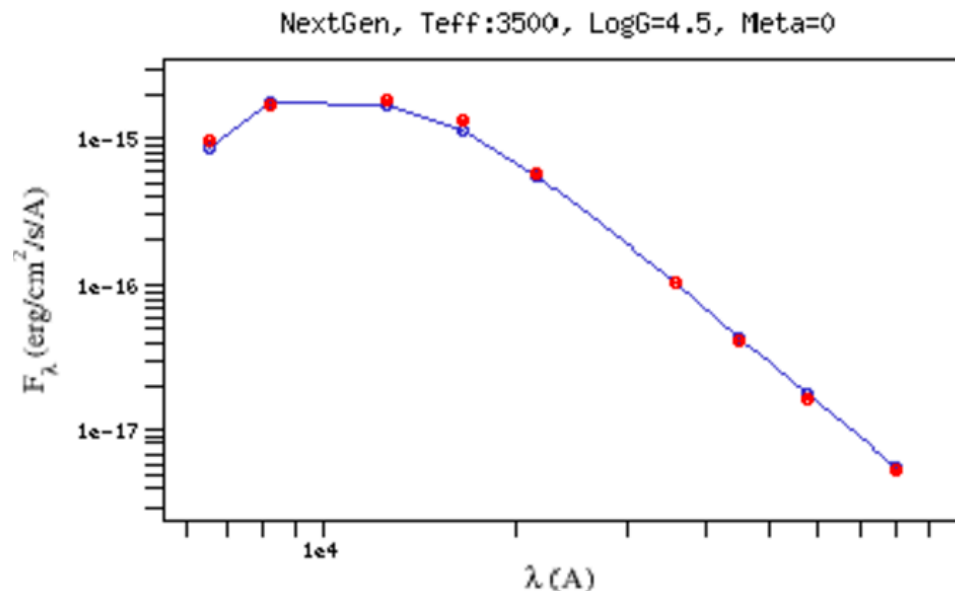
- Aladin intersection of GALEX & SDSS coverage using MOCs.



Success of VO with other kind of data

- **SEDs:**

- VOSA: retrieve photometry and fit stellar models to obtain physical parameters of thousand of objects.



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□ Do we have anything similar for Time Series?

- **Tables:**
 - time is documented in catalogues & literature in heterogeneous ways.
- **Visualisation:**
 - **Images** are static, videos or Cube-HiPS are more appropriate.
 - **2D Plots**
 - for photometry: SEDs viewer, *flux VS wavelength* based on *cone-search* on catalogues with:
 - a) coordinates
 - b) magnitudes / flux
 - for time domain: the equivalent? *flux VS time* based on cone-search on catalogues with:
 - a) coordinates
 - b) magnitudes / flux
 - c) time
- **Operations / analysis**

□ Do we have anything similar for Time Series?

- NASA Exoplanet periodogram service

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Periodogram Inputs Edit Input Table Plot Input Results Documentation

Periodogram Inputs

Input File Options

Upload Data File: Choose file No file chosen Upload

Current Periodogram Data File:
Name: No file loaded.
Source:
Edit Input Table

Select Column Names:
Time Column: Select Column
Data Column: Select Column
Plot Time vs. Data Columns

Input File Information:
Points used:
Time range:
Data range:

Algorithm and Period Settings

Select Algorithm: Lomb-Scargle

Algorithm: Lomb-Scargle

Period Range:
Minimum Period: Enter_Value
Maximum Period: Enter_Value

Period Step Method: Fixed Frequency

Select Method: Fixed Frequency
Fixed Step Size: Enter_Value

Output Options

Output Parameters: Number of Peaks: 50
Peak Sig Threshold: 1.0

User Preferences:
Plot X Axis Default: Period Frequency

Periodogram

Scatter Plot Histogram

EN2_STAR_CHR_0102706252_20070203T130553_20070402T070158.fits

Power

Period [JULIANDAY]

Redraw

X Axis Column: Period [JULIANDAY]
Axis Label: Period [JULIANDAY]
Y Axis Column: Power
Axis Label: Power

Symbols: shape size color

Parameter Summary

File: EN2_STAR_CHR_0102706252_20070203T130553_20070402T070158.fits
Points Used: 9713 of 9713

Parameter	Value
Time Column	DATETT
Data Column	REDFLUX
Algorithm	Lomb-Scargle
Minimum Period	0.011852
Maximum Period	57.747278
Period Step Method	Fixed Frequency
Fixed Step Size	0.0008685
Number of Peaks	50
Peak Sig Threshold	1.0

Table of Peaks Download

Rank	Period	Power	Curve
1	0.07710541	204.470838	View
2	0.06678351	201.219221	View
3	0.49867518	191.862877	View
4	0.03578816	176.424603	View

- Not interoperable (yet?)

□ Do we have anything similar for Time Series?

- Period04 (SAMP)
- Not maintained since 2010?

The screenshot displays three windows from a software application used for time series analysis.

Time string window: Shows the current data file and a table of data points. The table has columns for Date, Observatory, Observer, and Other. The data points are listed in a table with columns for Date, Observatory, Observer, and Other.

Date	Observatory	Observer	Other
2002(v7)	2002	APT	2002-4(v7)
2002(y)	2003	NZ_y	
2003(v7)	2004	Porett2307.7	2002-4(y)
2003(y)		Porett2308.7	
2004(v7)		Porett2309.7	
2004(y)		Porett2400.7	
		Porett2402.7	
		Porett2403.7	
		Porett2404.7	
		Pretorius	
		Rodler20	
		Rodler30	
		SAAO	
		SAAO_1	
		SAAO_2	
		SL	
		BNO_Angel	
		BNO_Rodr	
		S90_2752.0	
		S90_new	
		S90_sid	
		S90_sid_end	
		Snagar	
		Snaga90	
		Susana	
		v7_APT	
		v7_APT_Append	
		v7_Els	
		v7_GH_SAAO	
		v7_SAAO_Botlumelo	
		y_APT	
		y_APT_Append	
		y_Els	
		y_GH_SAAO	
		y_SAAO_Botlumelo	

Period04: offi0204.p04 window: Shows the fit and log settings. The fitting formula is $Z = \sum A_i \sin(2\pi(\Omega_i t + \Phi_i))$. The table below shows the selected frequencies, zero point, and residuals.

Use Freq#	Frequency	Amplitude	Phase
<input checked="" type="checkbox"/> F1	12.7162156	21.922468	0.061043
<input checked="" type="checkbox"/> F2	12.1641219	4.2090985	0.140067
<input checked="" type="checkbox"/> F3	24.2279624	4.20057141	0.700975
<input checked="" type="checkbox"/> F4	23.4033725	4.02745704	0.0285074
<input checked="" type="checkbox"/> F5	9.65627507	3.6926422	0.98513
<input checked="" type="checkbox"/> F6	21.0514985	3.0889328	0.41473
<input checked="" type="checkbox"/> F7	8.1991344	2.77973844	0.852732
<input checked="" type="checkbox"/> F8	19.8678	1.59275062	0.225074
<input type="checkbox"/> F9	19.8680438	1.77980943	0.503188
<input checked="" type="checkbox"/> F10	19.2278261	1.69277161	0.461151
<input checked="" type="checkbox"/> F11	24.1940008	1.5798296	0.602798
<input checked="" type="checkbox"/> F12	20.287774	1.43645746	0.944897
<input checked="" type="checkbox"/> F13	16.0711262	1.06762226	0.275886
<input checked="" type="checkbox"/> F14	34.1151316	0.49214365	0.66969
<input checked="" type="checkbox"/> F15	$c = 2\pi$	0.891692032	0.197183
<input checked="" type="checkbox"/> F16	23.3973632	1.24384502	0.463636
<input checked="" type="checkbox"/> F17	12.161941	0.831112583	0.597265
<input checked="" type="checkbox"/> F18	12.7943772	0.658623411	0.78617
<input checked="" type="checkbox"/> F19	28.1959369	0.550357752	0.386574
<input checked="" type="checkbox"/> F20	34.57371	0.448348635	0.864843
<input checked="" type="checkbox"/> F21	21.232294	0.802703791	0.623724
<input checked="" type="checkbox"/> F22	24.3484879	0.630050675	0.365786
<input checked="" type="checkbox"/> F23	11.1034221	0.649846251	0.469267
<input checked="" type="checkbox"/> F24	32.1895307	0.378753658	0.485526
<input checked="" type="checkbox"/> F25	21.5606508	0.417504441	0.745354
<input checked="" type="checkbox"/> F26	19.1641774	0.589006097	0.259419

Fourier window: Shows the Fourier Calculation Settings and the resulting graph. The graph displays the residuals after 79 frequencies, with a peak at Frequency = 24.3484839 and Amplitude = 0.622712265.

Residuals after 79 frequencies (F=24.3484839, A=0.622712265)
r79 annual f1 #6, sep. colors = (F=0.511127206, A=0.275486231)

Fourier Graph: Residuals after 79 frequencies
Residuals after 79 frequencies (F=24.3484839, A=0.622712265)

□ Why that? What is missing in the VO for Time Series?

We need standards to be defined as soon as possible to develop tools and services that will allow the community to work in Time Domain Astronomy in the VO context.