SAVS.PL

User's Manual

Ver. 1.00

1. Intro

The **Semi-Automatic Variability Search Pipeline** (**SAVS.PL**) is the easy-to-use software which was created for semi-automatic reduction and analysis of a big amount of sky CCD images and detecting new variable stars. It is utilized in the SAVS[1] sky survey operating at the Toruń Centre for Astronomy[2] of the Nicholas Copernicus University[3].

The package

The package consists of two programs – **DAPhot** and **JAMP** – and two catalog files – the Tycho-2 Catalogue and the General Catalogue of Variable Stars.

The DAPhot program's task is reduction of raw CCD frames, detection of stars, measuring stars' brightness with the differential aperture photometry against comparison stars and transforming instrumental coordinates into equatorial ones.

The JAMP application is used for managing and analyzing the collected data. In an automatic way it joins data from single observations into databases which are separately created for every observed field. In this process the cross-identification of objects is done. The program is also used as a viewer for databases' content. Candidates for variable stars are selected by the analysis of variance method.

For astrometric calibration of images the data from the Tycho Catalogue are taken. The included file `tycho2.cat` is written in binary format and bases on the original Tycho-2 Catalogue. The known variable stars are extracted from the `gcvs.cat` file which is the converted version of the original General Catalogue of Variable Stars.

Installation

Just unpack `savs-plxxx.exe` to any directory. Besides of execute files the directory `CATALOGS` will be extracted, in which there are necessary catalog files. During the programs' run some other directories will be automatically created.

About..

The SAVS.PL package is provided as a freeware and "as-is". No warranty of any kind is expressed or implied. In case of bugs and any problems don't hesitate to send e-mail to me:

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For the newest version and updates visit:

http://www.astri.uni.torun.pl/~gm/SAVS/

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[1] For further information on SAVS see `http://www.astri.uni.torun.pl/~gm/SAVS/`

[2] `http://www.astri.uni.torun.pl/`

[3] `http://www.uni.torun.pl/`

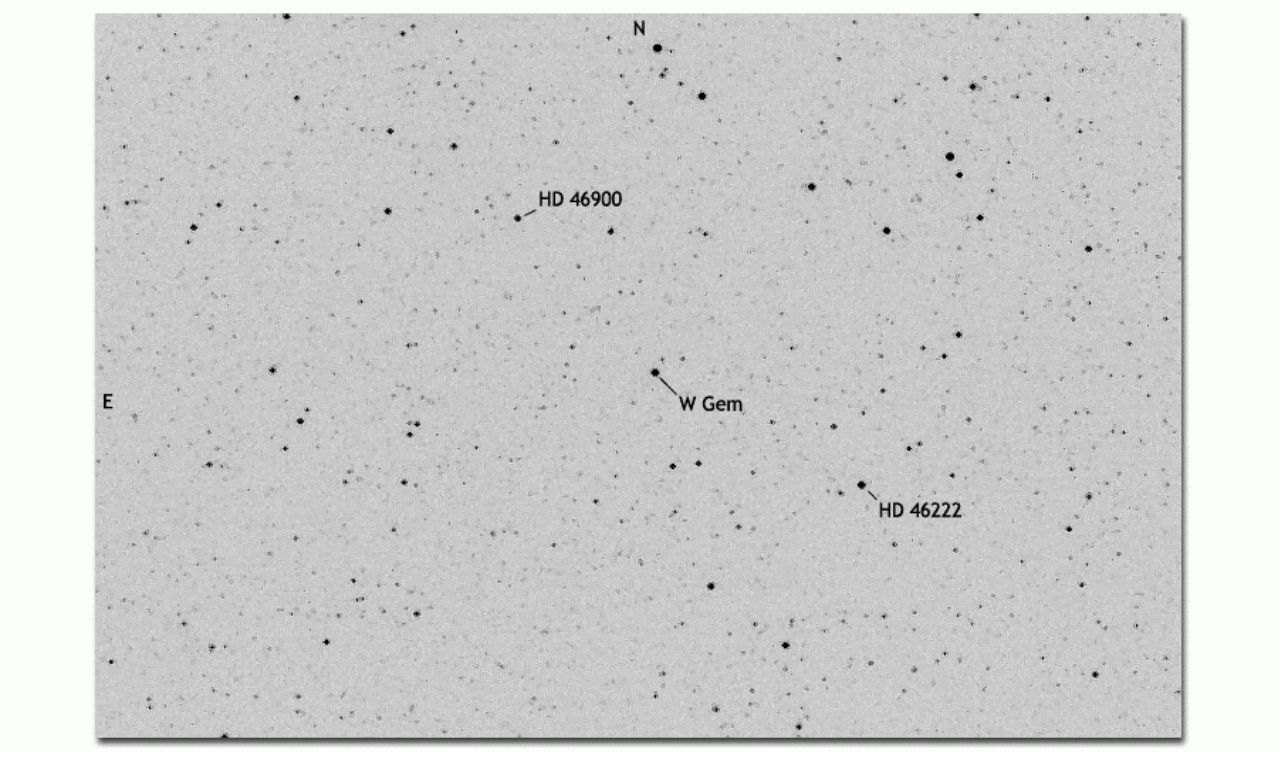
2. Tutorial

In the package 11 exemplary CCD images of the neighborhood of the *W Geminorum* variable and 2 calibration frames are included. They are located in `OBS_DATA` catalog. The observation were made at the Piwnice Observatory of the Nicholas Copernicus University during test run of SAVS sky survey. In this section we will reduce them step-by-step.

Pre-analysis of frames

Open file `OBS_DATA\WGem01.FIT` with any fits viewer (e.g. F-View[4]). At the center of the frame there is a bright star - *W Geminorum*. Now we need some important information about the instrument the observations were made. All included images are flipped in x and y axis so north is down and west at the left. The scale of the image is 13.8 arcsec/pixel. Learning the size of the image we notice that the exposure is 3 x 2 degree wide.

1. Designate coordinates (for epoch J2000.0) of the center of the frame. Any program like SkyMap or Guide would be helpful. We know that all images are centered in the neighborhood of the variable, so we can take its coordinates: RA=$06^h34^m58^s$ and Dec=15°19'50".
2. Find stars which could be used as comparisons. I suggest HD 46900 and HD 46222 (marked in the figure below) - they look pretty good.

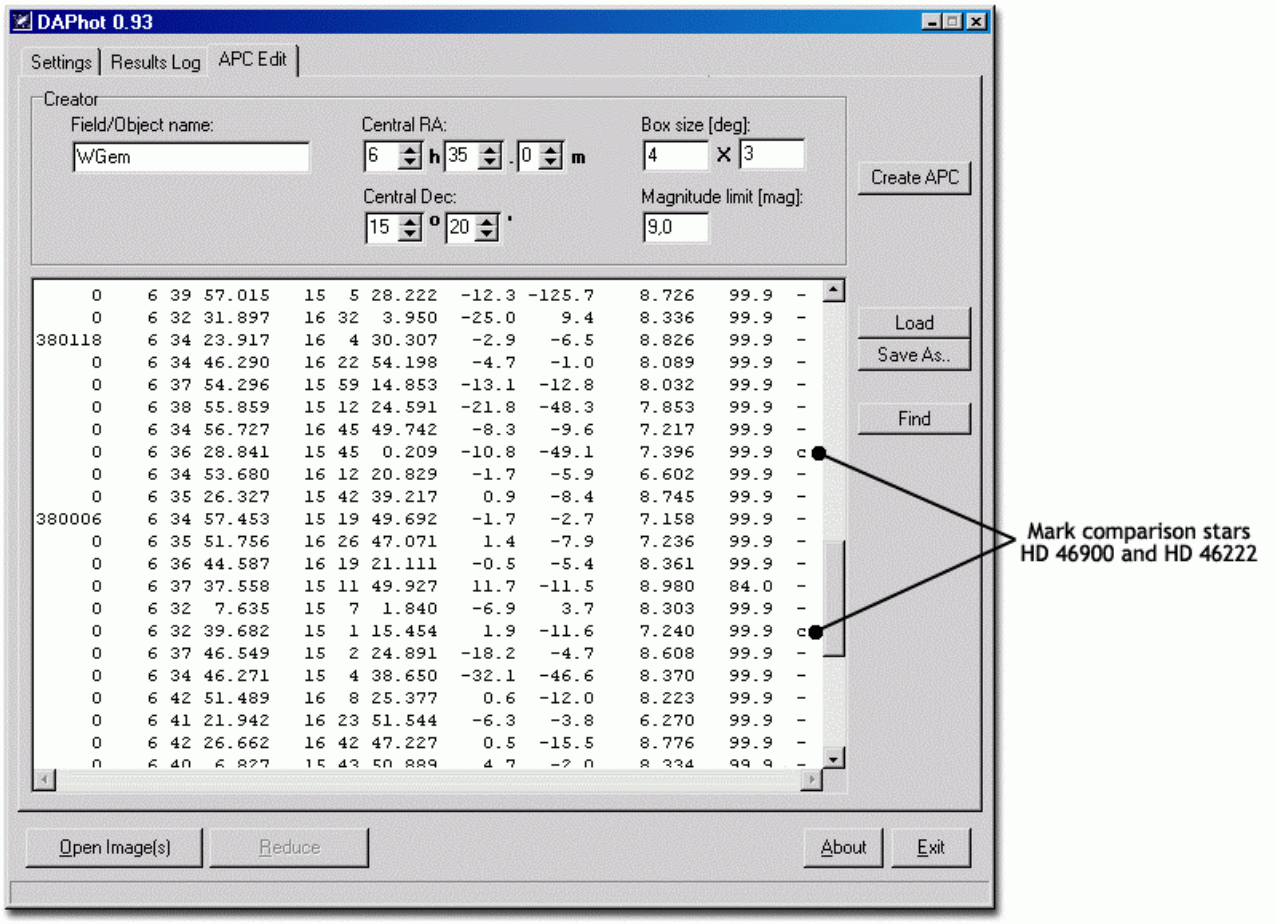


Data Reduction with DAPhot

1. Open DAPhot. The settings are optimized for our data, so we don't need to change them.
2. Prepare catalog file for astrometric and photometric calibration of frames. This activity must be performed only once for a new field. Go to the **APC Edit** tab sheet. In the **Field/Object name** box enter a name of the observed field. For program's automatic run and proper identification it must be the same as a name written under the keyword `OBJECT` in a header of the FITS. In case of our field, as we can check in images' headers, it is `WGem`.
3. Set central coordinates with spin edits.
4. Enter the size of observed field (it should be about 1.5 wider than a real field) - 4 x 3 degrees.
5. Set limiting magnitude for 9.0. Only stars brighter then 9 mag will be extracted from the main catalog.

[4] F-View can be downloaded from `http://www.astri.uni.torun.pl/~gm/index_down.html`

6. Press **Create APC** button. 70 common stars from the Tycho-2 Catalogue and 13 know variables from the GCVS will be extracted. After the operation is ended the window will look like below:

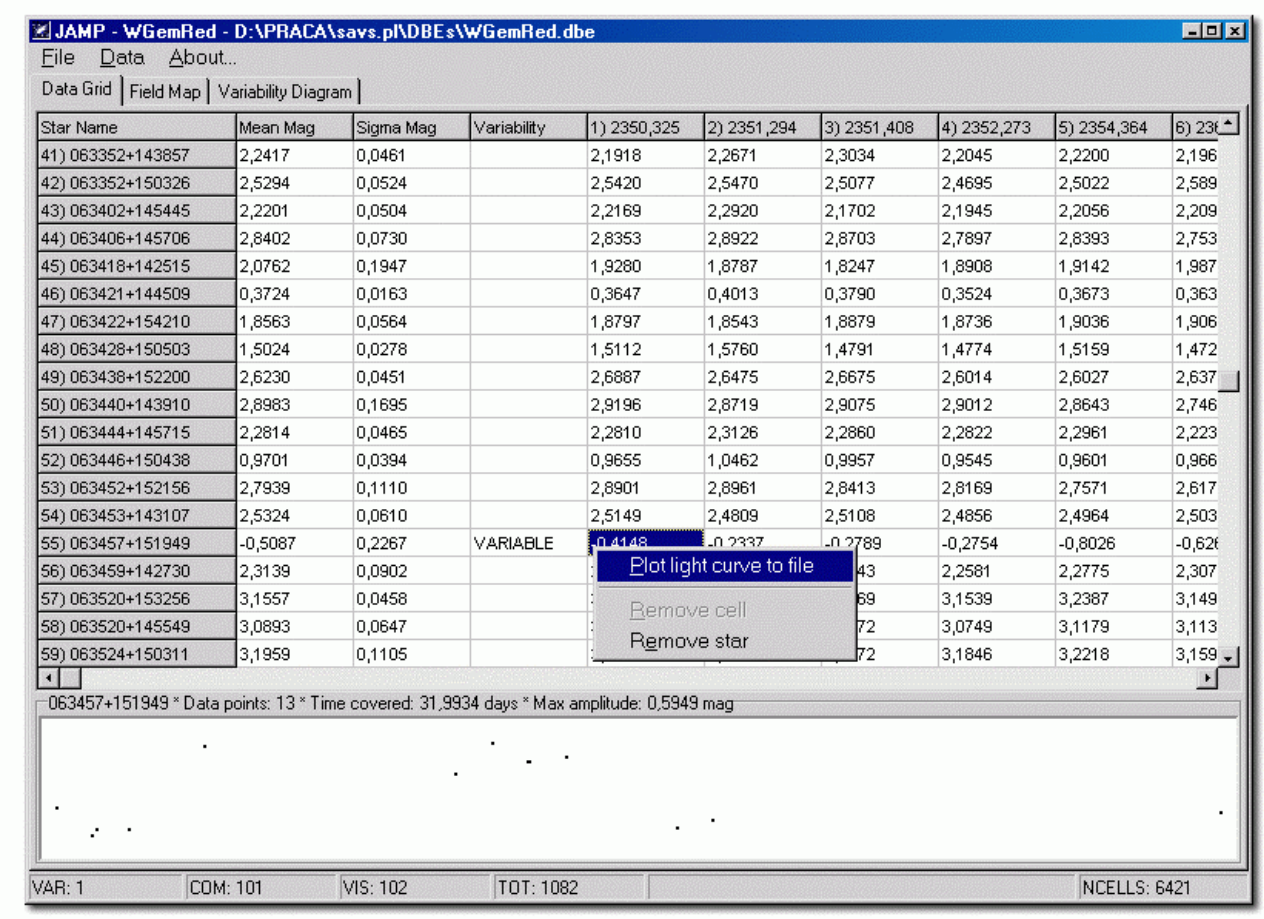


7. Mark comparison stars. Find them by coordinates: HD 46900 (RA=$06^h36^m29^s$ Dec=15°45'01") and HD 46222 (RA=$06^h32^m40^s$ Dec=15°01'15"). Button **Find** can be helpful. For marking replace sigh "-" in the last column with "c". Now these two stars will be recognized by program as comparisons.
8. Save modified APC file as `wgem.apc`. This file already exists because it has been created during the extraction process. Now we are prepared for reduction ☺.
9. Back to **Settings** tab sheet. In the box **Calibration frames** mark **Bias/Dark** and open bias frame BIAS16.FIT from directory `OBS_DATA`. Analogically do with a flat-field frame.
10. Open images which are to be reduced by pressing **Open Image(s)** button. In a dialog window select all 11 files `WGemxx.FIT`. The button **Reduce** will be activated.
11. Press **Reduce** button. In the **Results Log** tab sheet massages will appear. All images should be processed successfully. The output files `*.pht` will be created in the `OBS_DATA` directory. For details about these files see section 2.

Managing data with JAMP

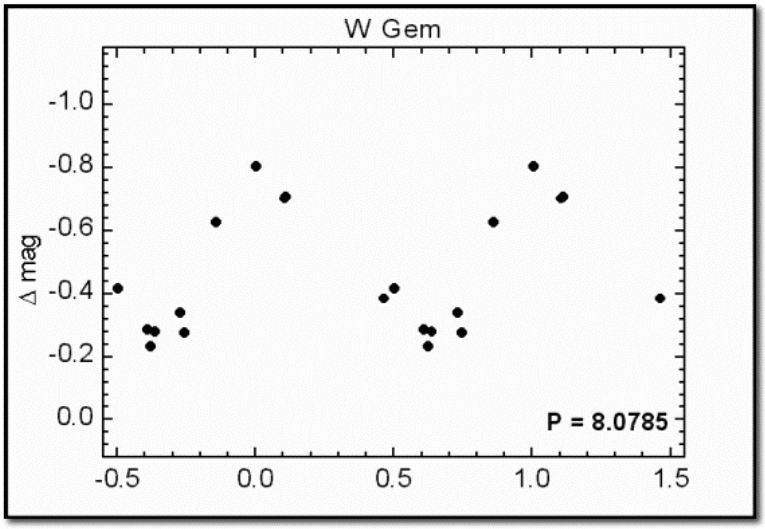
1. Open JAMP program. Now we will join all single output files into a database. From menu **Data** choose **Add Observations** and in a dialog window select output files (they are in the same directory as reduced images).
2. The database `WGemRed.dbe` will be created in directory `DBEs`. Load it by **Load Database** from menu **File**. Its content is visualized in three ways: data grid, field's map and variability diagram.
3. From menu **Data** choose **Options** and in a option window enter 11 in **Display stars having at least .. data points** box. Now only stars being detected in all images are displayed.

4. Search among them variables with analysis of variance method. From menu **Data** choose **AoV (ANOVA)** and in an appeared window set **Min period** on 1 day and **Power threshold** on 0.9. Press **Go!** button. The light curves of potential variables fulfilling defined criteria will be extracted to `VARIABLES\WGemRed` directory. Detected variables are marked in "Variability" column. In our case only one variable star will be found – *W Geminorum*.
5. In the data grid search for *W Geminorum* (star 063457+151949, in line 55) and select it by clicking in any ceil of variable's row. The light curve will appear on the bottom graph.



Star Name	Mean Mag	Sigma Mag	Variability	1) 2350,325	2) 2351,294	3) 2351,408	4) 2352,273	5) 2354,364	6) 23(
41) 063352+143857	2,2417	0,0461		2,1918	2,2671	2,3034	2,2045	2,2200	2,196
42) 063352+150326	2,5294	0,0524		2,5420	2,5470	2,5077	2,4695	2,5022	2,589
43) 063402+145445	2,2201	0,0504		2,2169	2,2920	2,1702	2,1945	2,2056	2,209
44) 063406+145706	2,8402	0,0730		2,8353	2,8922	2,8703	2,7897	2,8393	2,753
45) 063418+142515	2,0762	0,1947		1,9280	1,8787	1,8247	1,8908	1,9142	1,987
46) 063421+144509	0,3724	0,0163		0,3647	0,4013	0,3790	0,3524	0,3673	0,363
47) 063422+154210	1,8563	0,0564		1,8797	1,8543	1,8879	1,8736	1,9036	1,906
48) 063428+150503	1,5024	0,0278		1,5112	1,5760	1,4791	1,4774	1,5159	1,472
49) 063438+152200	2,6230	0,0451		2,6887	2,6475	2,6675	2,6014	2,6027	2,637
50) 063440+143910	2,8983	0,1695		2,9196	2,8719	2,9075	2,9012	2,8643	2,746
51) 063444+145715	2,2814	0,0465		2,2810	2,3126	2,2860	2,2822	2,2961	2,223
52) 063446+150438	0,9701	0,0394		0,9655	1,0462	0,9957	0,9545	0,9601	0,966
53) 063452+152156	2,7939	0,1110		2,8901	2,8961	2,8413	2,8169	2,7571	2,817
54) 063453+143107	2,5324	0,0610		2,5149	2,4809	2,5108	2,4856	2,4964	2,503
55) 063457+151949	-0,5087	0,2267	VARIABLE	-0,4148	-0,2337	-0,2789	-0,2754	-0,8026	-0,626
56) 063459+142730	2,3139	0,0902				43	2,2581	2,2775	2,307
57) 063520+153256	3,1557	0,0458				69	3,1539	3,2387	3,149
58) 063520+145549	3,0893	0,0647				72	3,0749	3,1179	3,113
59) 063524+150311	3,1959	0,1105				72	3,1846	3,2218	3,159

6. The exported light curve of *W Geminorum* can be analyzed with any software, e.g. PerSea[5]. The phased light curve should look like that:



[5] PerSea is available from `http://www.astri.uni.torun.pl/~gm/index_down.html`

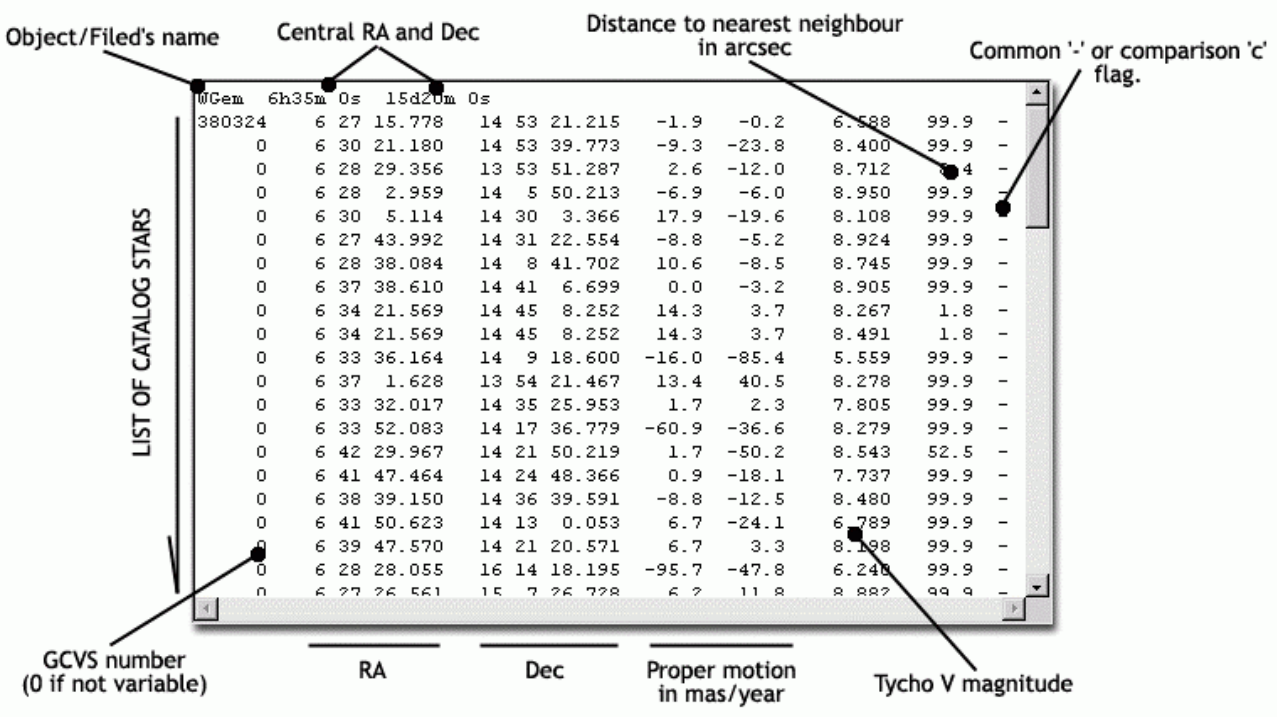
2. DAPhot

DAPhot works only with images written in FITS format. For automatic run it needs some essential information which are usually saved in FITS headers. The variety of conventions used in headers is totally incomprehensible and causes problems in writing automatic software. There is a FITS specification clearly defining acceptable keywords. DAPhot is compatible with Definition of the Flexible Image Transport System (*FITS)* given by the NASA/Science Office of Standards and Technology (NOST) of the National Space Science Data Center (NSSDC) of the National Aeronautics and Space Administration (NASA). The recognizable keywords (besides mandatory ones) are presented in the table:

DATE (UT)	
`DATE-OBS`	Date of observation: yyyy-mm-dd
`OBS-DATE`	Old standard of date of observation: dd/mm/yy. If yy<50 than year=20yy. If yy>50 than year=19yy.
TIME (UT)	
`TIME-OBS`	Time UT of the beginning of the exposure: hh:mm:ss
`UT`	Time UT of the beginning of the exposure: hh:mm:ss
`UT-START`	Time UT of the beginning of the exposure: hh:mm:ss
OTHER	
`FILTER`	Name of filter, acceptable any string of characters. If there is no this keyword the name of filter is set on "NONE".
`EXPTIME`	Time of exposure in seconds, acceptable any integer or floating point number. If there is no this keyword the exposure time is set on 0
`EXPOSURE`	As same as `EXPTIME`
`OBJECT`	Name of observed object or field, acceptable any string of characters. If there is no this keyword the name of object is set on "UNKNOWN".

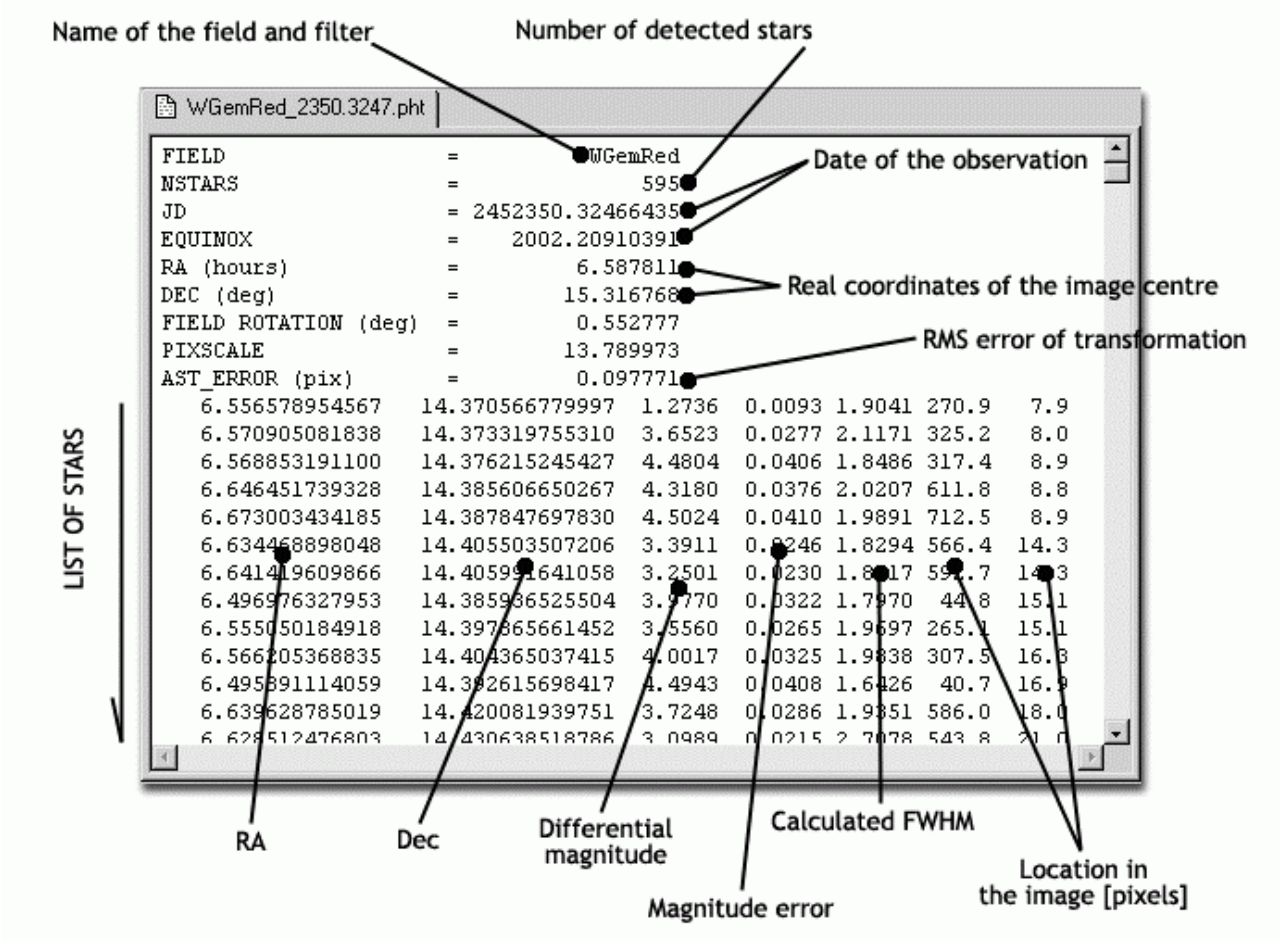
If DAPhot does not work properly with your keywords don't hesitate to contact me for custom version.

For astrometric and photometric calibration of the frame a catalog file (apc file) is necessary. The description, how to create it, is described in the tutorial section. The apc files are stored in directory **`APCs`** (the directory, if doesn't exist, is automatically created). This directory is scanned for these files and their content is saved in program's registry. During reduction process program reads keyword OBJECT in image's header and looks for it in the registry. The successful finding means that the object name is known and program knows which catalog file to utilize. The description of a catalog file is given below:



Optionally DAPhot can subtract bias or dark frame and divide by flat field. These calibration frames must be prepared with other software (e.g. AIP4Win) and must be the same size as reduced images. Flat field does not need to be normalized. The program before division normalize it.

As a result of successful reduction of an image the output file is created in the image's directory. The name of that file is defined by chosen convention, however the file extension is always `pht`. The output file is saved in a text format and can be seen with any ASCII editor. The description of its content is presented in the figure below:

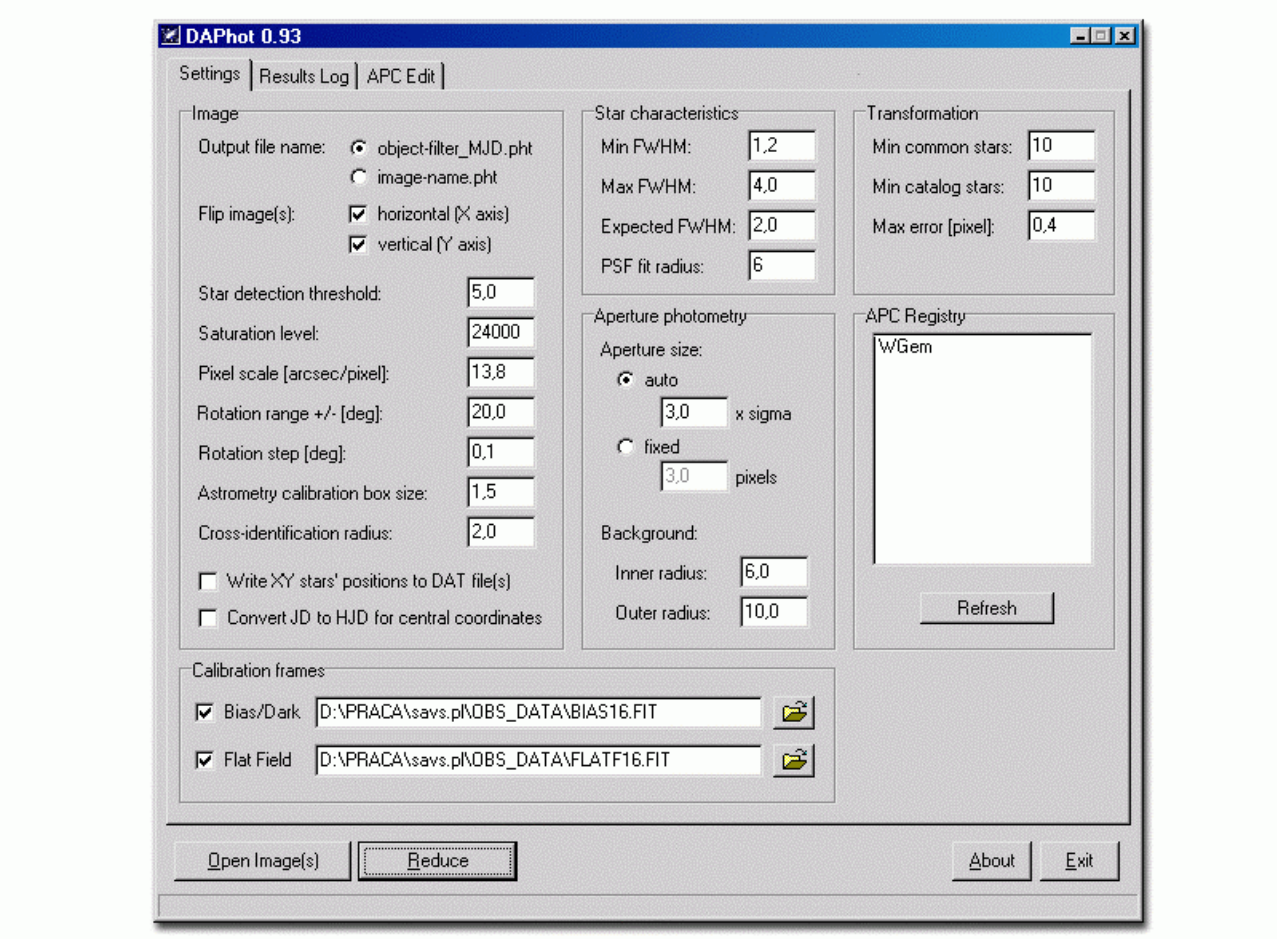


Below there is the description of settings controlling DAPhot's work.

Image

- ***Output file name*** – sets the convention in which the output files will be named.
- ***Flip images*** – decides whether frames should be flipped before analysis and in what axe.
- ***Star detection threshold*** – determines a boundary signal to noise ratio. Only stars with S/N greater than an entered value will be detected.
- ***Saturation level*** – stars with countings greater that entered quantity won't be detected because of saturation. This quantity depends on a detector.
- ***Pixel scale*** – scale of an image, number of arc seconds per one pixel. This value depends on an instrument which the observation were made with.
- ***Rotation range*** – range of a maximal angle by which images will be rotated during finding the transformation of instrumental coordinates (x,y) into equatorial (RA, Dec)
- ***Rotation step*** – step of rotation described above.
- ***Astrometry calibration box size*** – determines the size of a map created from apc file used at the finding of the astrometric transformation. While not all images are centered exactly on the given equatorial coordinates, program will move the image to determine real central coordinates. Therefore a wider template map is needed.

- ***Cross-identification radius*** – maximal acceptable distance between positions of calibration stars from a catalog and an image.
- ***Write XY stars' positions to DAT file(s)*** – checked this option causes that for every image separate file is created in which positions of the detected stars will be written. It can be helpful at examining correct automatic detection.
- ***Convert JD to HJD for central coordinates*** – if this option is checked the time of observation written in an output file will be converted from Julian Days into Heliocentric Julian Day. The heliocentric correction will be calculated for central coordinates of every image.



Star characteristics

- ***Min FWHM*** – determines in pixels the minimal acceptable full width at half maxim of star's profile. Narrower features like spikes won't be detected.
- ***Max FWHM*** – determines in pixels the maximal acceptable full width at half maxim of star's profile. Object with wider FWHM than an entered value won't be detected.
- ***Expected FWHM*** – expected value of stellar profile's width, the initial value for fitting with the least square method.
- ***PSF fit radius*** – number of pixels, counting from central peak, which are used for finding star's full width at half maxim.

Aperture photometry

- ***Aperture size*** – determines the way in which the aperture radius is set. If auto option is selected the aperture radius varies and depends on a width of star's profile which is defined by Gaussian sigma. If fixed option is chosen the aperture radius is fixed for every star in an image.
- ***Inner radius*** – determines inner radius of the background ring.
- ***Outer radius*** – determines outer radius of the background ring.

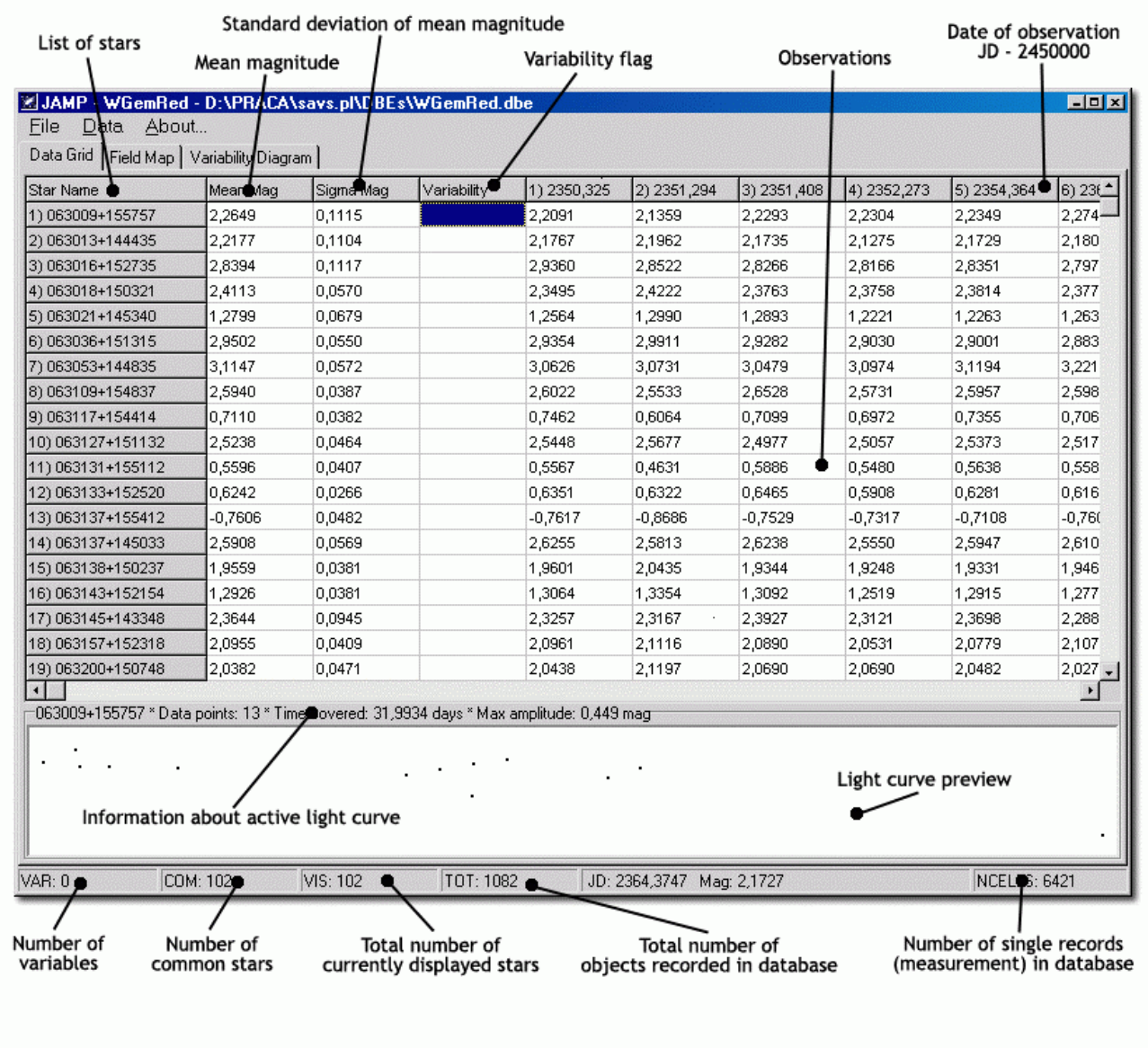
Transformation

- ***Min common stars*** – determines minimal number of common stars successfully identified during the transformation search.
- ***Min catalog stars*** – determines minimal number of stars recorded in a catalog file necessary for beginning of the transformation search.
- ***Max error*** – maximal acceptable rms error of the transformation.

3. JAMP

The JAMP program scans directory `DBEs`, in which there are saved databases, and creates.the registry of already observed fields At the adding of new observations program checks whether for the observed field the adequate database already exists. If the database does exist new observations are just added to it. It there is no database and the field is observed the first time, a new database is created.

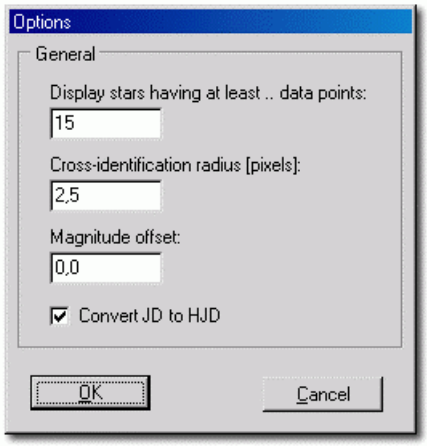
JAMP can also be used as a viewer for databases. The user gets an access for every single photometric measurement. Light curves can be extracted to separate txt files for further analysis. The general description of program's window is presented in the figure below:



Options

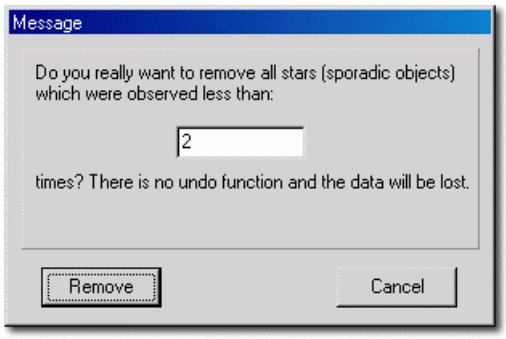
- ***Display stars having at least .. data points*** – stars for which there is less data points than entered value won't be displayed and analyzed. They are treated as if they don't exist.
- ***Cross-identification radius*** – used while adding new data to databases. The star from pht file and star from database will be identified as the same object if the difference between their coordinates does not exceed given value.
- ***Magnitude offset*** – determines the magnitude offset of all measurements recorded in a database. While all magnitudes are differential it is an easy way to get catalog values if only the mean brightness of comparisons is known.

- ***Convert JD to HJD*** – if checked the Julian Days in exported light curves are converted into Heliocentric Julian Days.



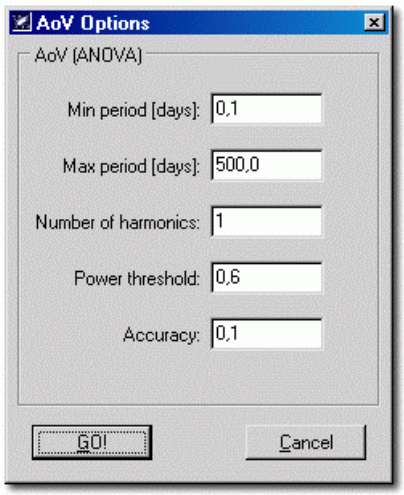
Remove sporadic…

Unfortunately during automatic detection some non-stellar objects can be detected. Because their location on the frames is random they appear in database as stars observed only once. If a database contains dozens of observations it is possible that there is a few record for such sporadic objects. JAMP is equipped with a tool for removing the sporadic events. You are just asked for entering integer value determining sporadic objects, as it is shown in the figure below:



AoV (ANOVA)

JAMP detects periodic variables with the analysis of variance algorithm performed for all stars being displayed from a loaded database. For huge databases with a few hundred thousand records it can take a few hours. However in this way the detection of any weak periodic signal is guaranteed. The light curves of the potential variables are saved in the directory `VARIABLES\<name of field>`.



- ***Min period*** – the beginning of the period range in which period will be searched.

- ***Max period*** – the end of the period range.
- ***Number of harmonics*** – number of harmonics the data will be split into.
- ***Power threshold*** – stars, for which the maximal peak in calculated power spectrum is higher than entered value (periodogram is always normalized to 1), are treated as variables.
- ***Accuracy*** – determines with time coverage the size of frequency bin. The smaller value the more accurate periodogram.

The output files

JAMP can save light curves to separate files. The name of the file is created in the automatic way and consists of coordinates of a star and an extension `dat`. The files are saved in the automatically created directory `VARIABLES` (if they are extracted by the user). The description of the file's content is given below: