Scientific Image Processing System Photometry tool

```
#pragma omp parallel for
for ( i = 0; i < Depth; i
    int j;
    double ix, ix2;
    double iy, iy2;
    double rp;
    unsigned int * PPixel

    iy = (double) (i - Dep
    iy2 = iy * iy;
    PPixel = (unsigned int

    for ( j = 0; j < Width
        ix = (double) (j -
        ix2 = ix * ix;
        rp = ix * ix2 * x3
        rp = rp * Scale;
        rp = rp * 100.0 + 1
        if (rp < 0) {
            (*PPixel) = 0;
        } else if (rp > (do
            (*PPixel) = (uns
        } else {
            (*PPixel) = (uns
        }
        PPixel++;
    }
```

Pavel Cagas

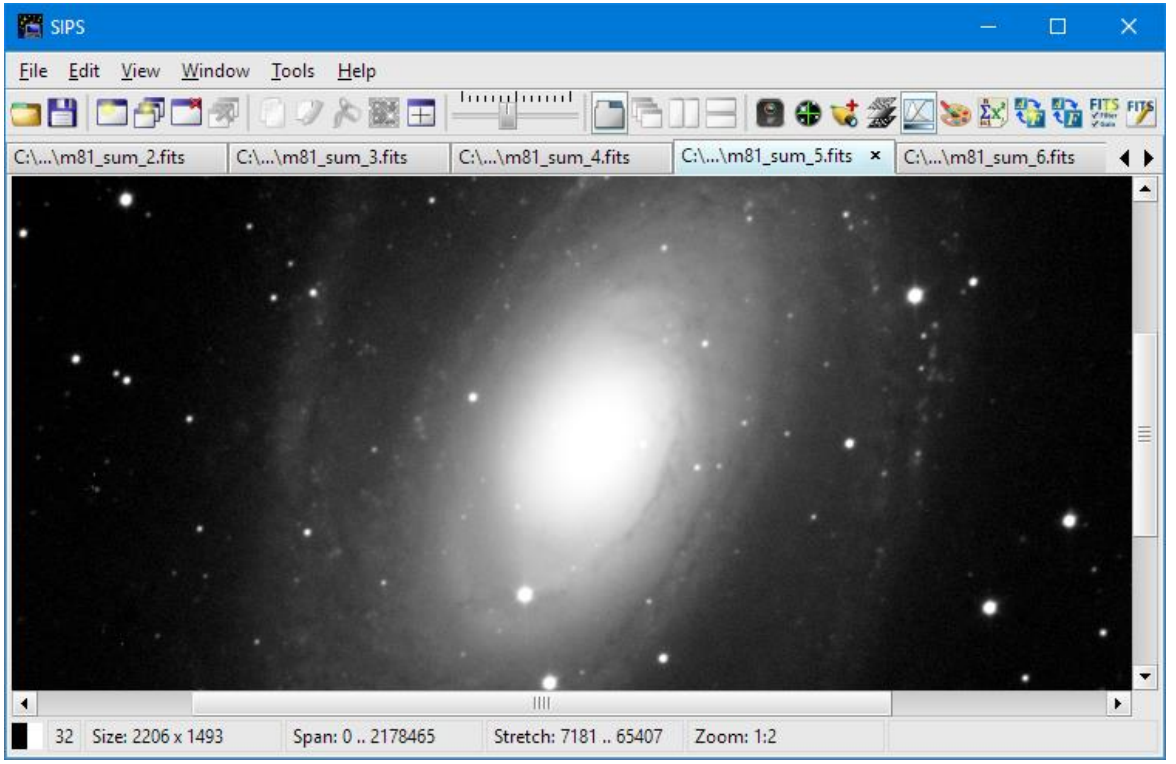
http://www.tcmt.org/

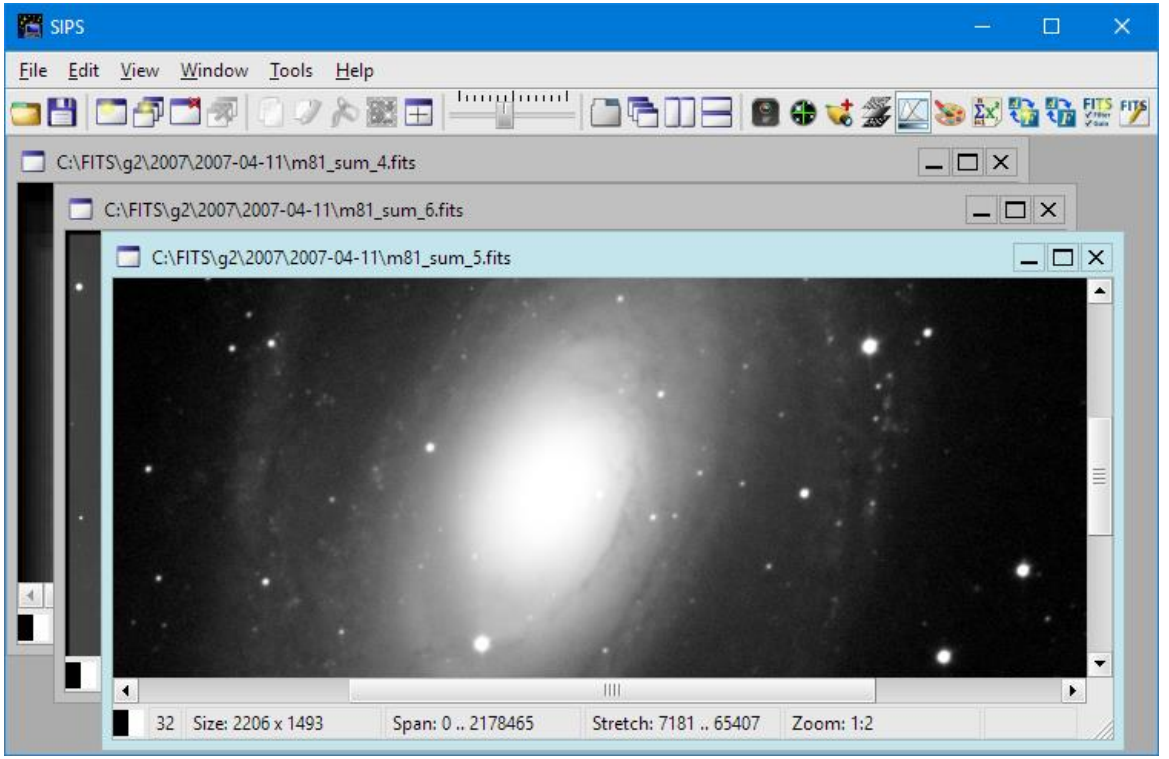
What is SIPS?

- **SIPS** abbreviation means
  Scientific **I**mage **P**rocessing **S**ystem
- The software package evolved from a tool to control cooled cameras and perform exposure series to advanced package containing both observatory control tools and image processing tools
- SIPS is focused to astronomy research, not to aesthetical Astro-photography processing
- SIPS is a free software running on Windows OS

Basic concepts

- Workspace
  - Images in Tabs or individual sub-windows
  - Image Sets in sub-windows
- Tools
  - Individual pop-up windows
  - Tool windows always float over main window



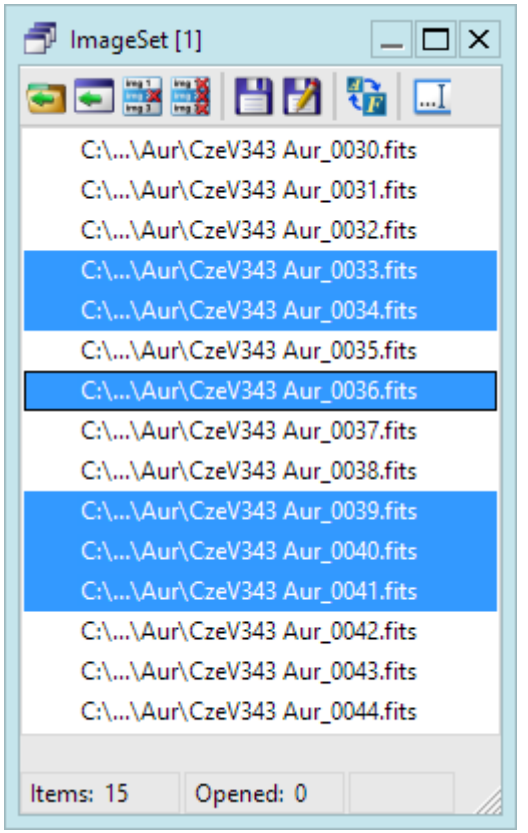


SIPS tools

- Hardware control (imaging, guiding and context cameras, telescope mount, focuser, observatory dome, GPS, …)
- 16/32-bit image display (histogram and stretch, color palettes)
- FITS files handling (+header definitions, edit)
- Image calibration and transformation (mirror, rotate, …)
- Image math operations and filters (median combine, …)
- Image blinking and stacking (monochrome and RGB)
- Astrometry and **Photometry**

Image sets

- Many operations may (sometimes must) be performed on many images at once
- SIPS allows definition of images sets (lists)
  - Processing of multiple images does not work directly with disk files
- Advantages:
  - Significantly higher speed
  - Universality (location on disk or file name not important, images can be in memory only without existing file).
- Disadvantage:
  - Demanding to computer memory

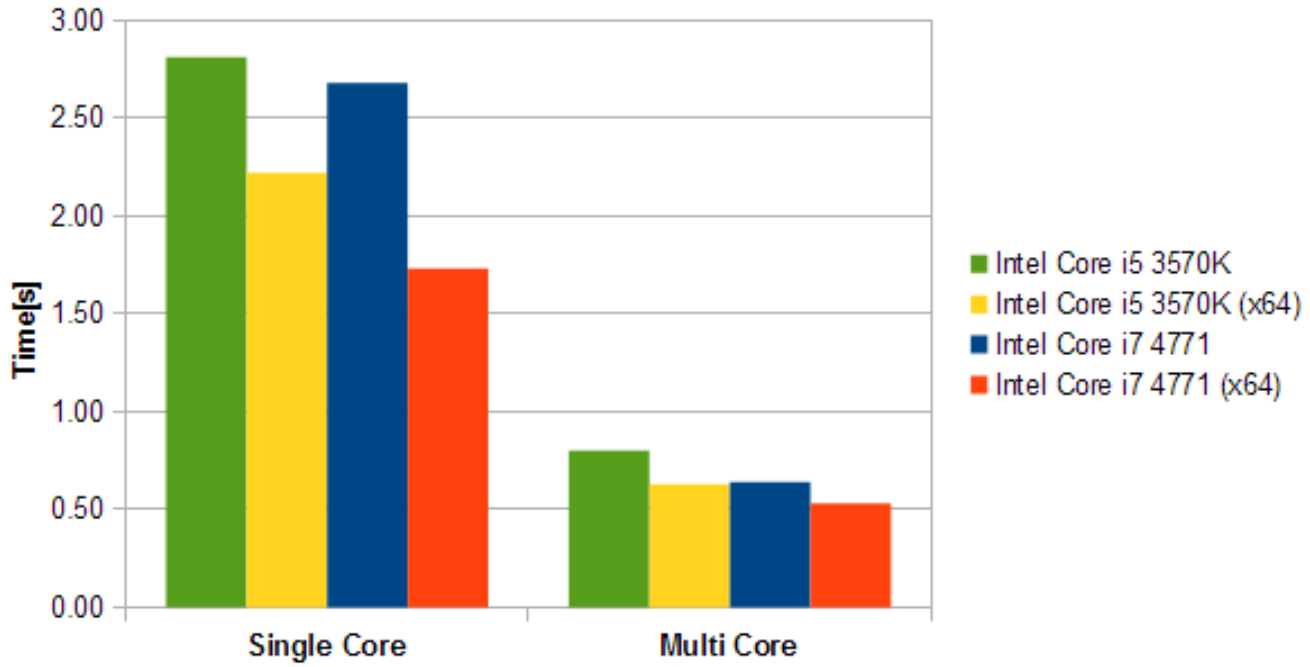


64-bit SIPS

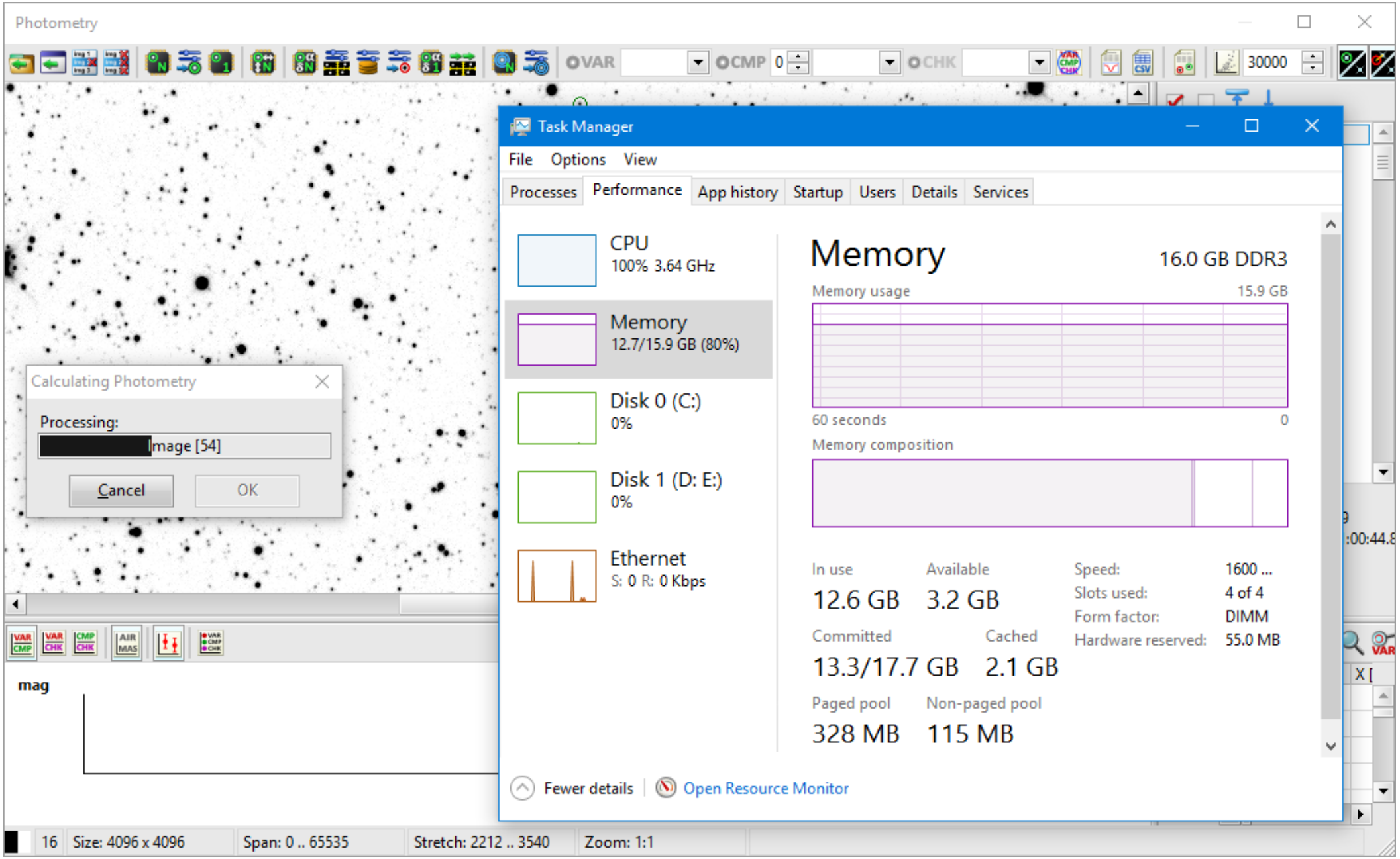
- SIPS is available in both 32 and 64 bit versions
- **32 bit** version seamlessly runs on both 32 bit and 64 bit Windows
- **64 bit** version requires 64 bit Windows
  - Also all drivers used (ASCOM, …) have to be 64 bit
- 32 bit version is limited to:
  - 3GB when working on 32 bit system
  - 4GB when working on 64 bit system
- 64 bit version is virtually unlimited, available memory depends on memory installed on the particular PC

32 vs. 64 bit processing speed comparison: Finding stars on 3k × 3k images

- 64 bit version executes complex algorithms up to ~20% faster than 32 bit version on the same PC
  - But simple algorithms may be slightly slower
- E.g. 64 bit version running on 3,4 GHz 4C/4T Core i5 is faster than 32 bit version running on 3,5 GHz 4C/8T Core i7

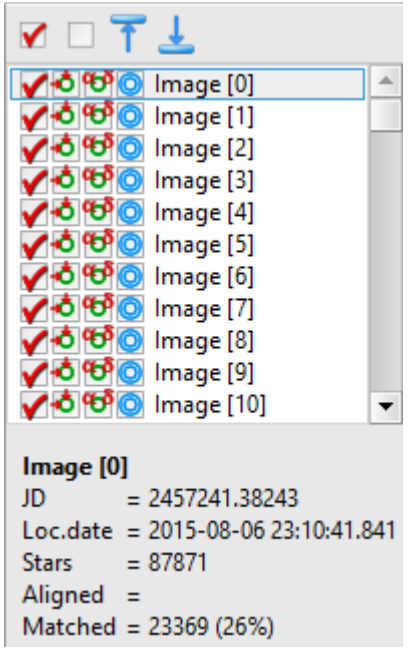


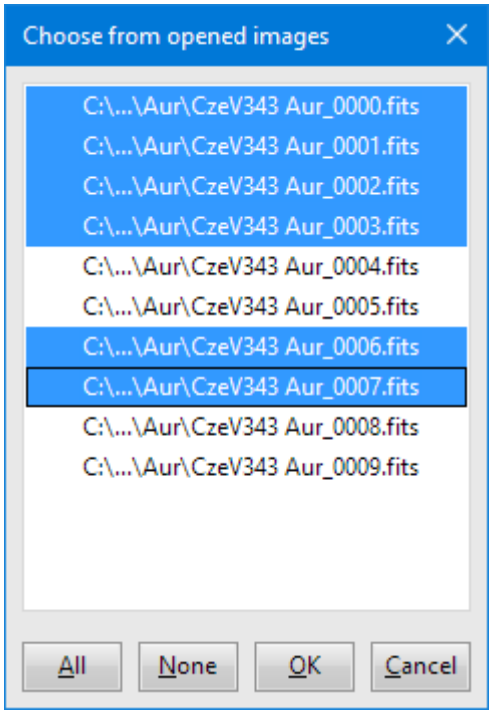
64-bit SIPS overcomes 4 GB memory limit

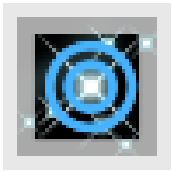


SIPS tool implicit sets

- Numerous tools contain own “implicit” image set:
  - Image Blink, Image Add, Photometry, …
- Images can be opened from files …
- … or included from images already opened in windows or other sets
- Regardless if the image is opened in window or in one or more sets, every image is present in memory only once
  - Multiple occurrence of image within SIPS only increases reference counter



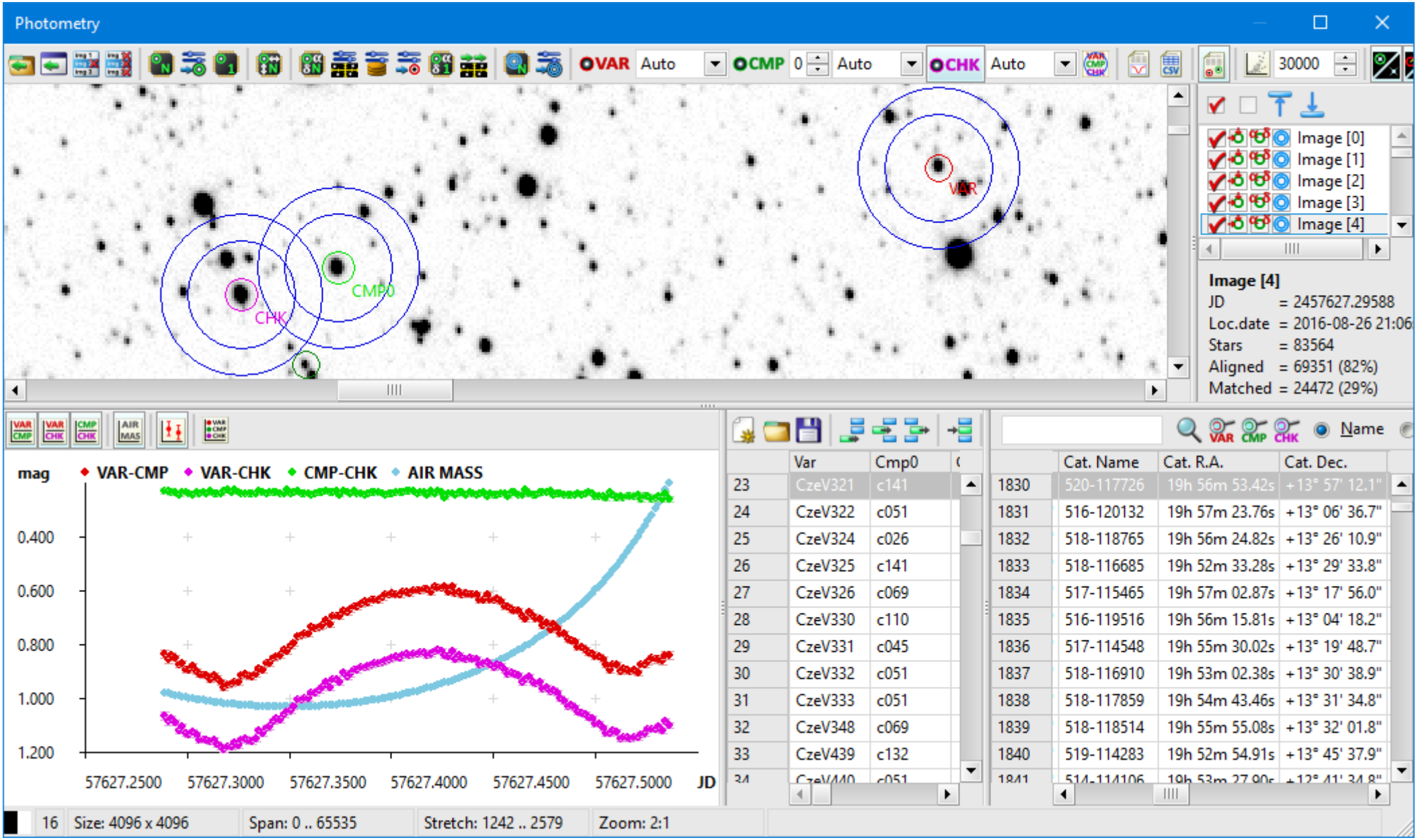




Photometry tool

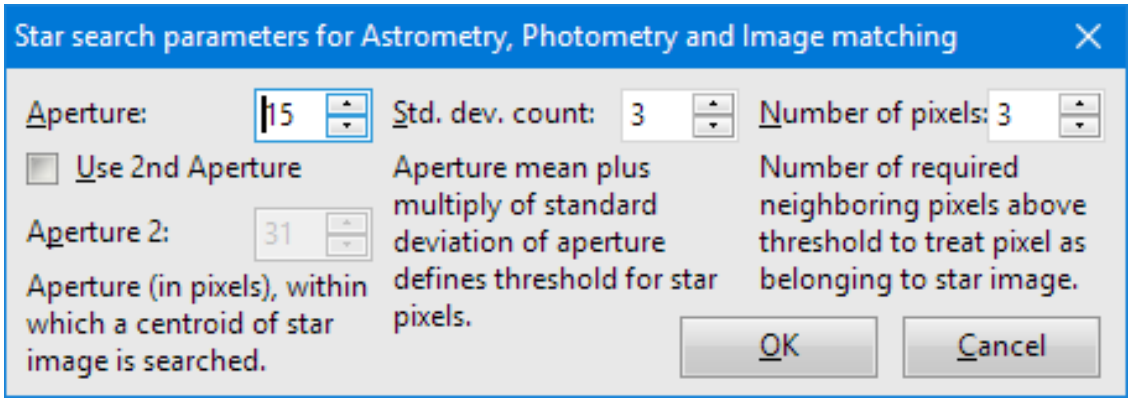
- Photometry tool uses all the functionality already present in SIPS and provided by other tools:
  - FITS file manipulation (open, save, header editor, …)
  - Image set manipulation
  - Image display (stretch, zoom, color palettes, ...)
  - Image math and transformation (median-combine, rotation, mirroring, soft-binning, resampling, ...)
  - Raw image calibration (dark frame, flat field)
  - …

Photometry tool design goals



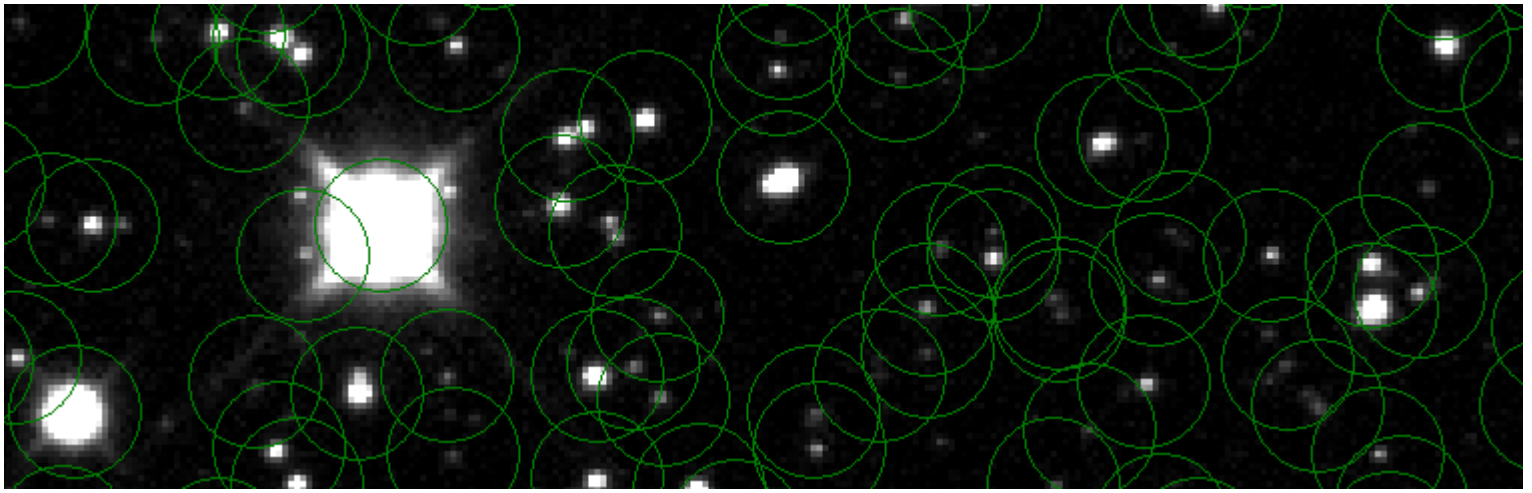
Reliability and robustness

- As robust star search as possible, minimal number of required parameters:



- It is not necessary to limit sharpness or roundness (parameters introduced by DAOPHOT package), these parameters work only “conditionally” in real world either way
- No camera read noise or gain is needed to find stars

- It is not necessary to define FWHM or brightness
  - Especially in wide fields the FWHM (brightness) range is huge and it is not possible to define limitations to fit the brightest as well as weakest stars in the field

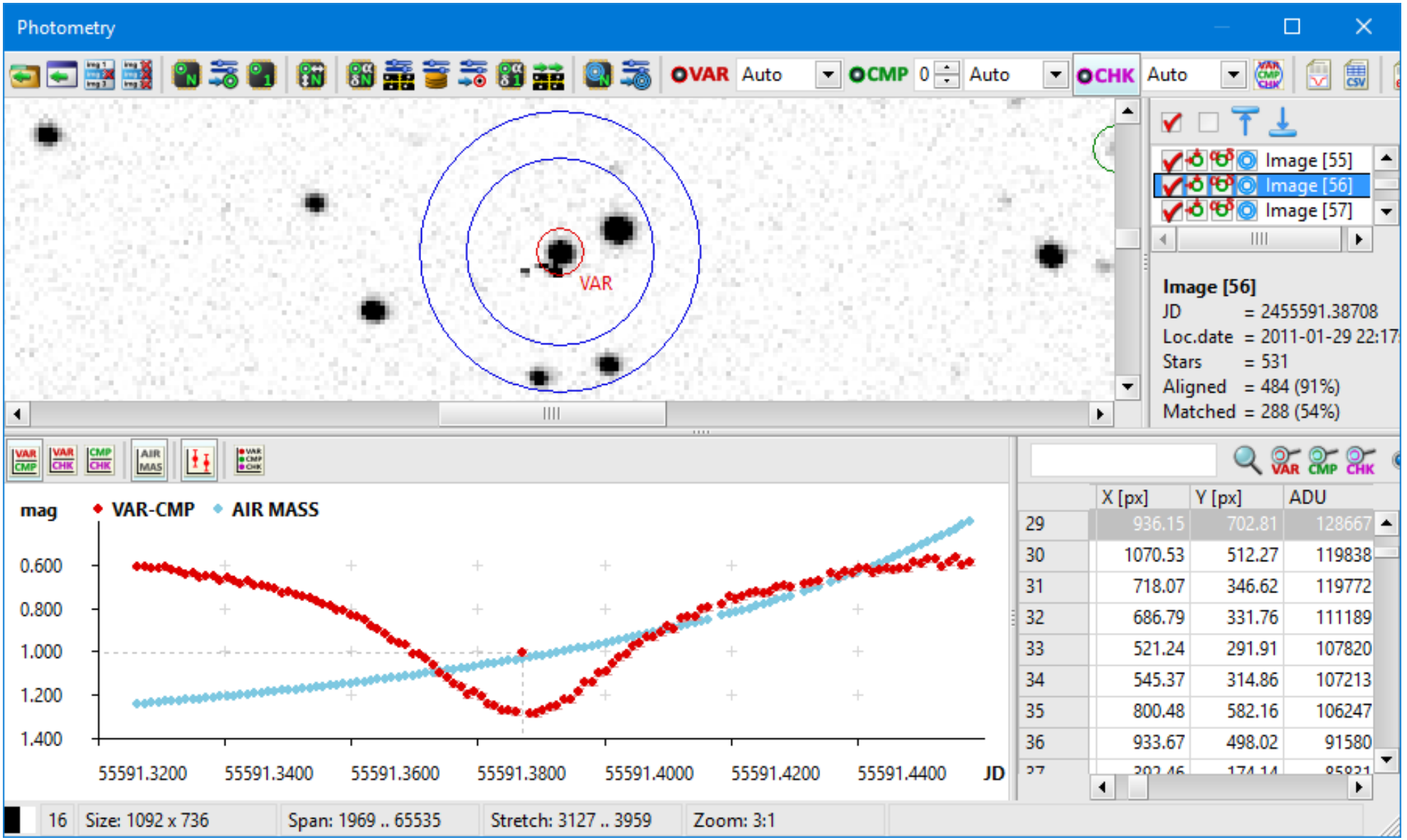


- No reference frame:
  - Any star on any frame can be found on all other frames
  - “Search variable” function works on any image in the set

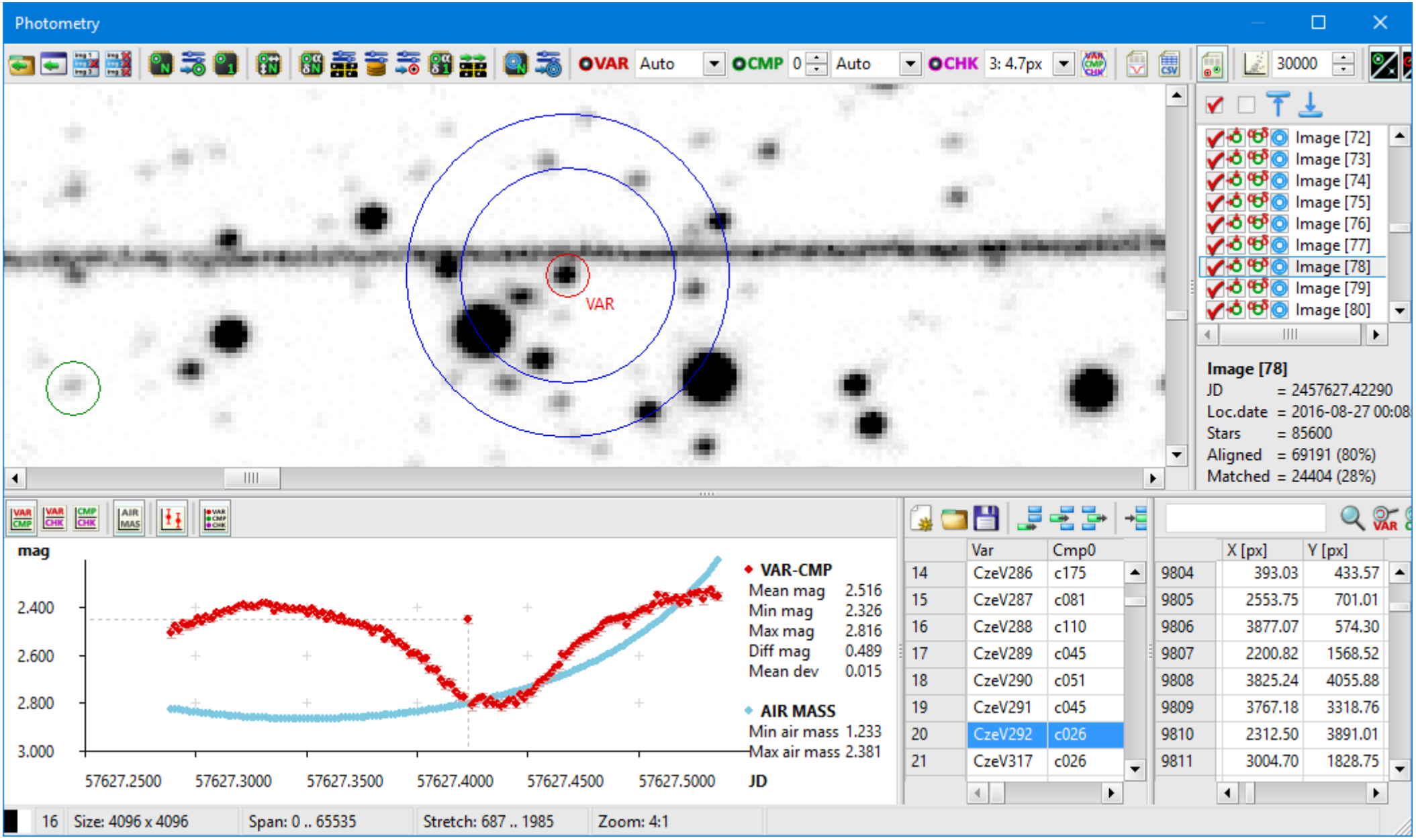
Interactivity and immediate availability of all information

- Instant display of real image with selected star for every light curve point allows judging of outlier cause (hot-pixel, passing satellite, radiation spike, ...).
- Arbitrary (from 1/8 to 8×) and fast image zoom
- Table (sheet) with all parameters of all detected stars (position, coordinates, catalog data, fluxes in various apertures, standard deviations …).
- Mutual connection of GUI elements:
  - Selecting image in set shows it and updates star table
  - Selecting star in table shows it on image
  - Selecting a point in light curve show the image etc.

Example of radiation spike within aperture

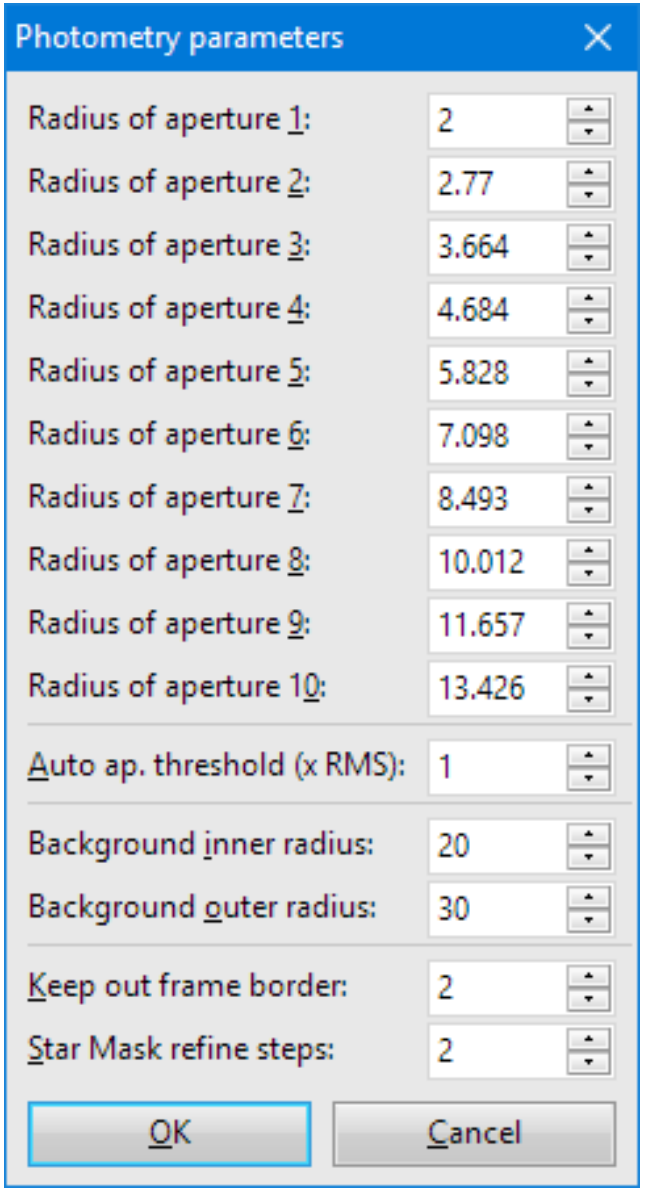


Example of satellite passing through aperture



Apertures

- Predefined set of 10 apertures
- SIPS also calculates automatic aperture from the star image profile and calculates flux (in addition to predefined apertures).
  - Automatic aperture is set for all images in series
  - The second greatest aperture in series is chosen (one aperture extreme is ignored)

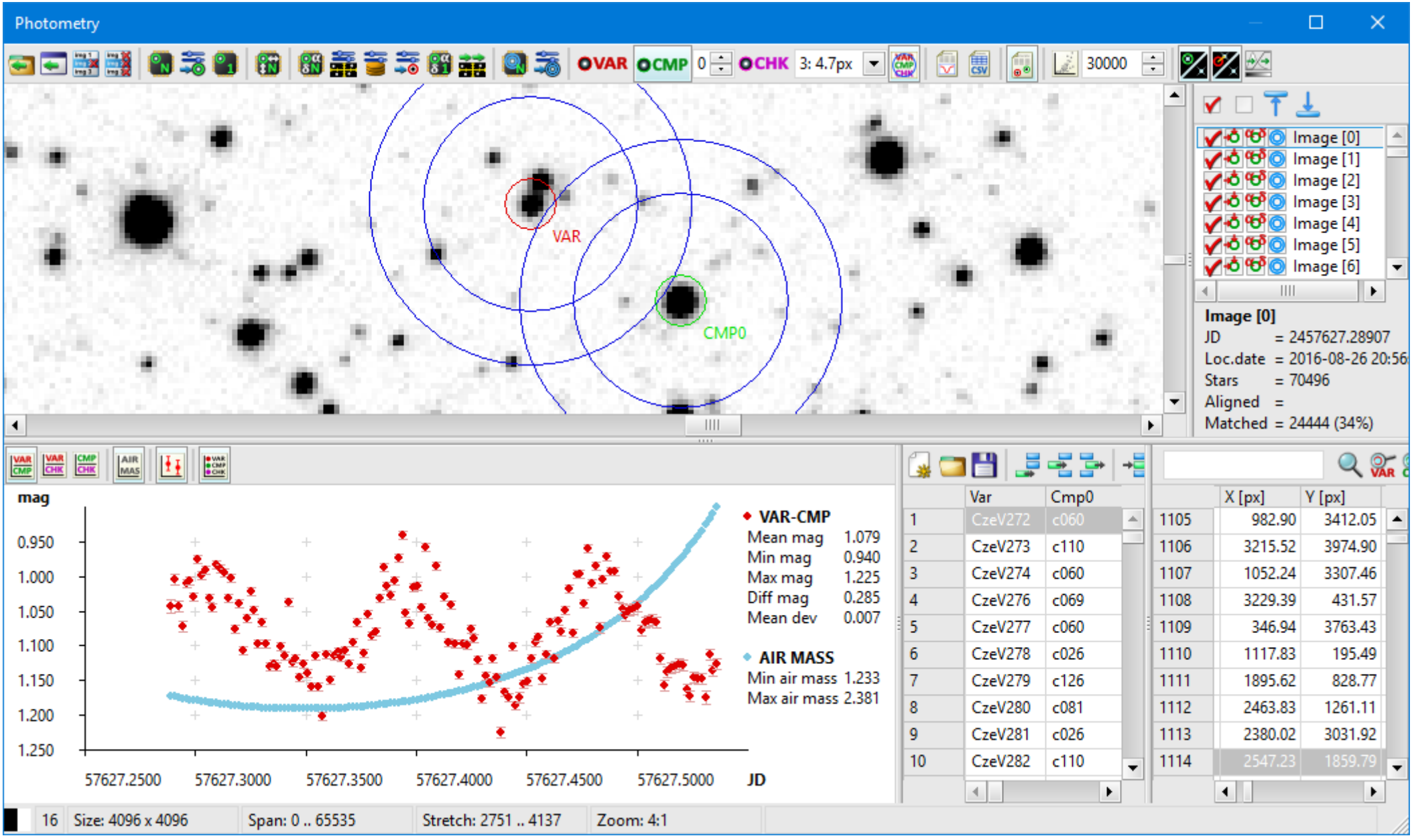


Different apertures for variable, comparison and check stars

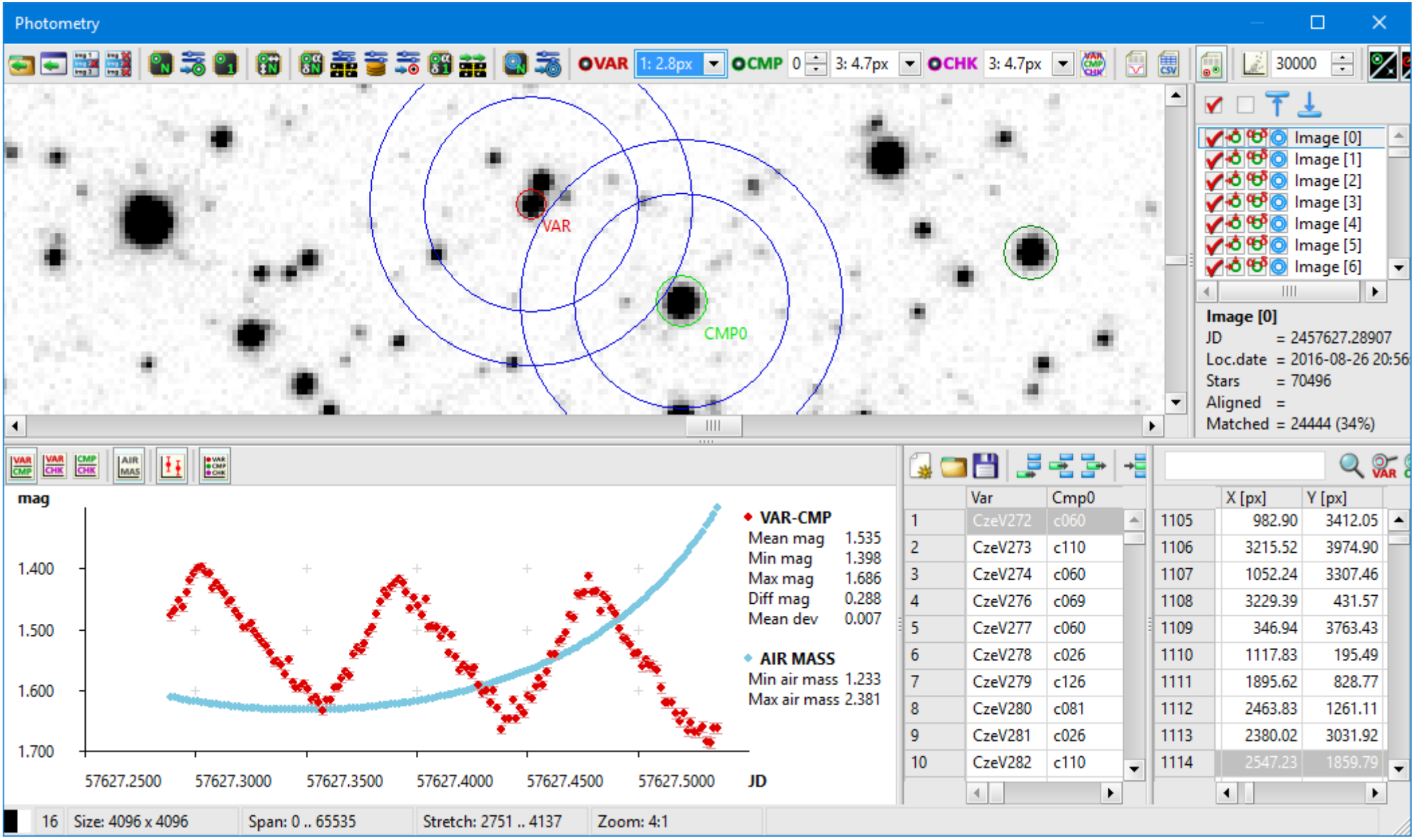
- Ability to define independent apertures for variable, comparison and check stars
- Especially in the case of wide fields, the optimal comparison star (bright enough but not saturating) is much greater than weak variable star

- Possibility to define different apertures allow:
  - Include only light from star and thus increase S/N
  - Eliminate influence of nearby stars

δ Sct star with a close star using the same aperture like comparison star



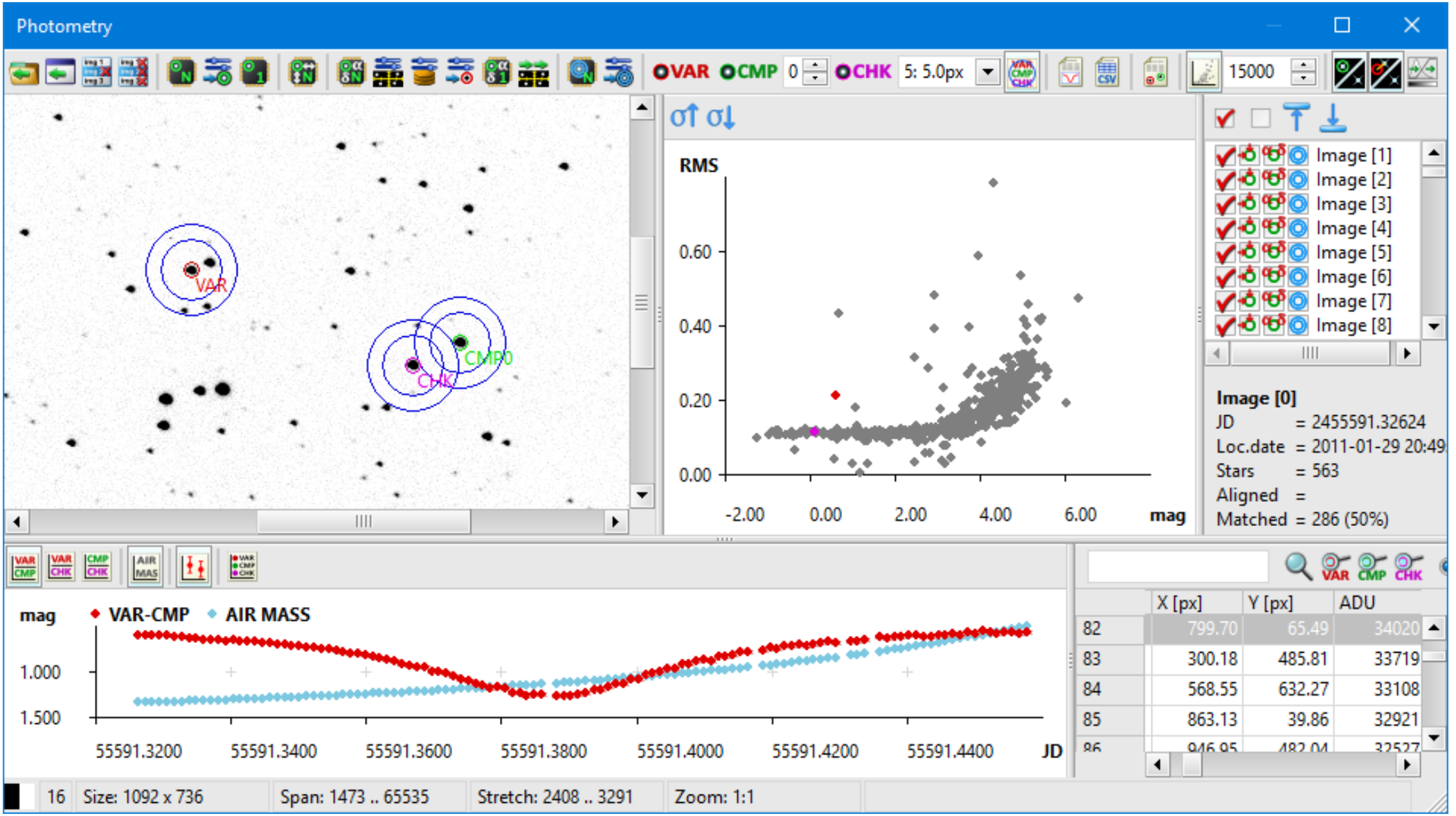
δ Sct star with a close star using different apertures



Finding brightness changes (variable stars)

- Any image from series can be chosen as reference
- Individual stars can be inspected depending on the standard deviation
  - Inspecting of stars based on the brightness is possible due to presence of table of all stars
- Number of stars included into the chart can be limited
- Selection of another image in series closes the chart automatically

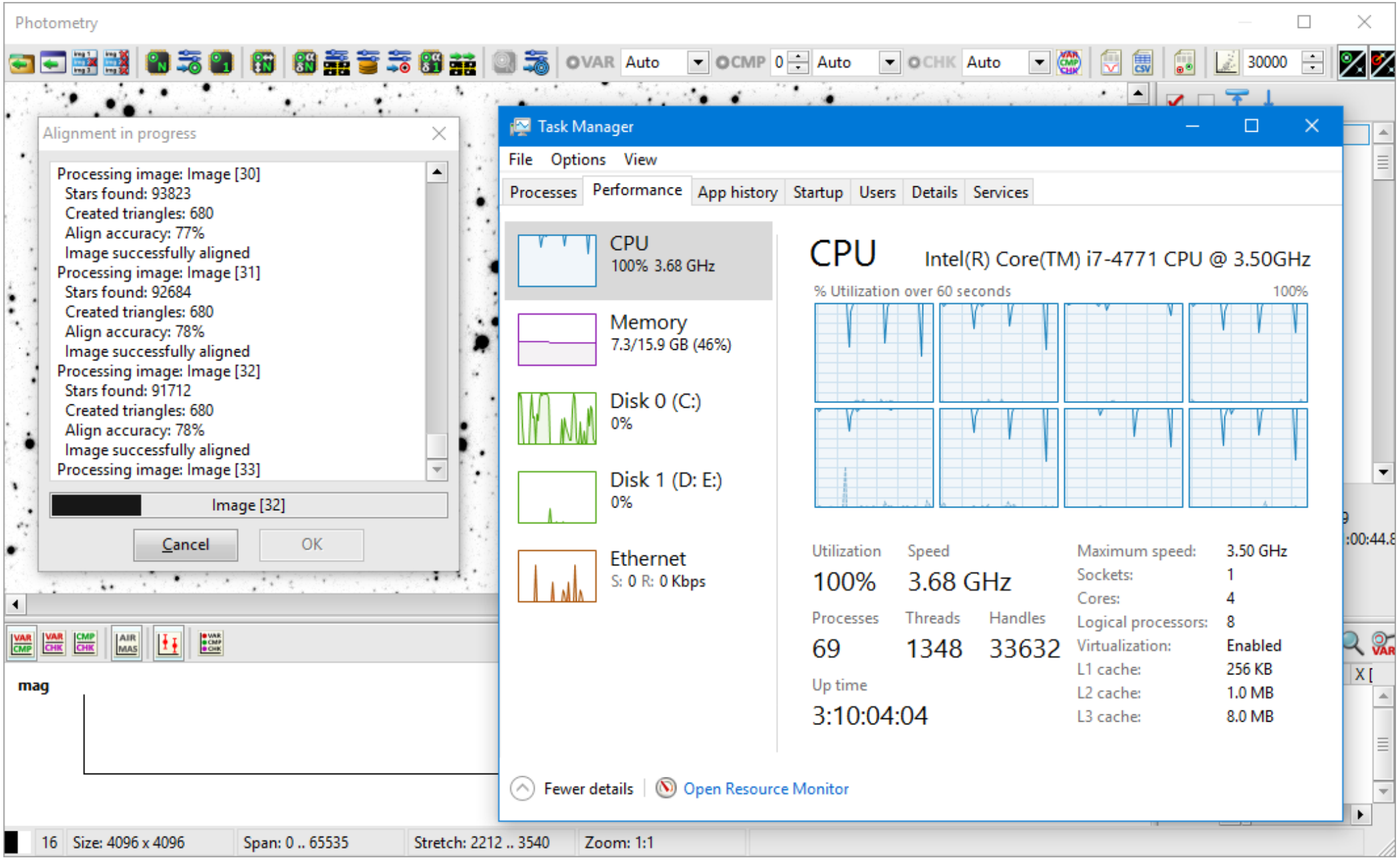
Example of searching for new variables



Processing speed and parallel execution

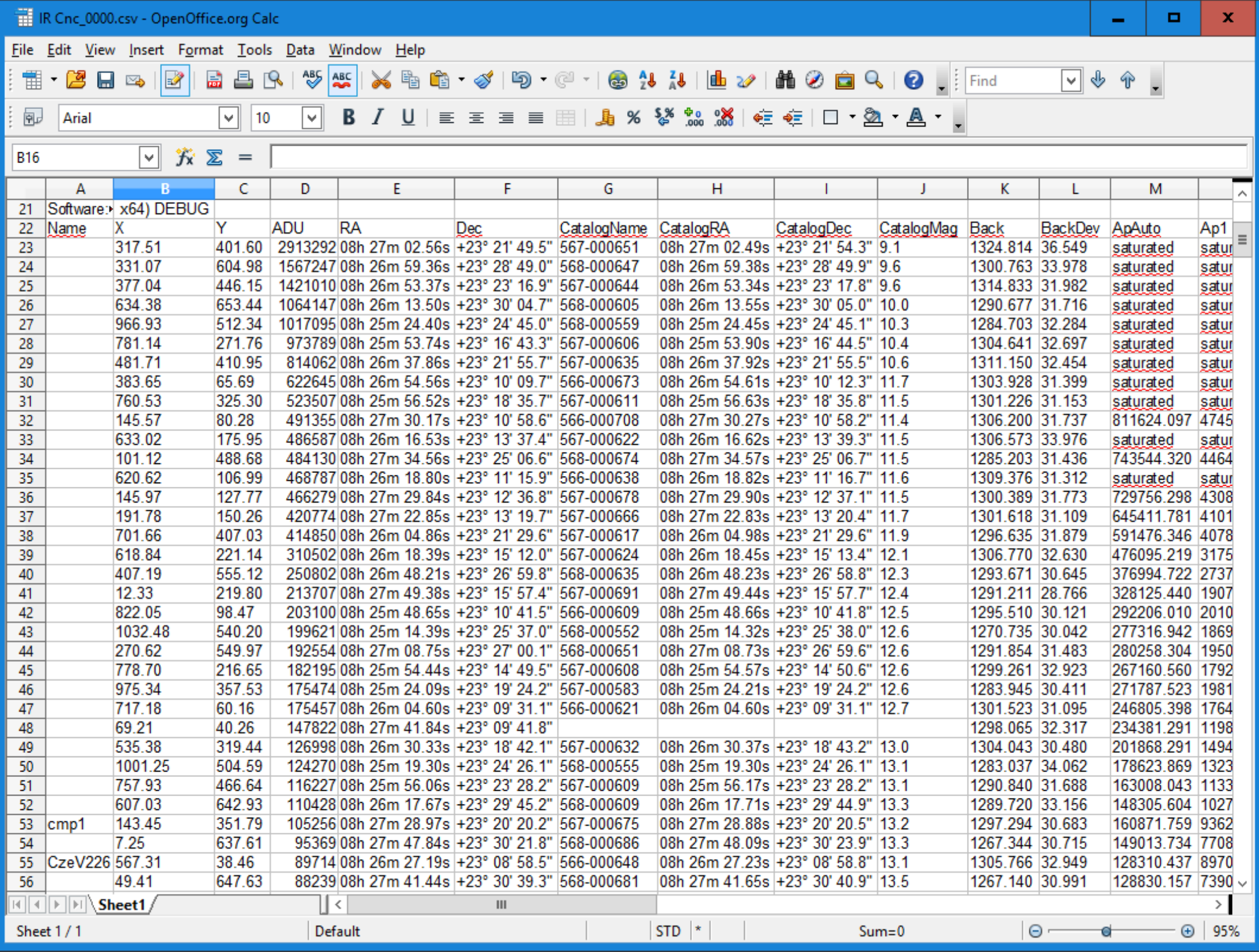
- Processing speed is essential for wide fields with tens of thousands of stars no to wait many hours (or through the night)
- Test run:
  - Open 101 images 4k × 4k from disk and their calibration (dark, flat)
  - Find stars, align images and calculate photometry
- SIPS ~4× faster compared than Muniwin (16^m41^s vs. $1^h07^m49^s$).
  - SIPS processed more stars (33000-45000 vs. 2500-5000)
  - Execution time strongly depends on various parameters

SIPS utilizes all avilable CPU cores



Photometry with astrometric reduction

- Astrometric reduction can be performed for every image in the series
  - EQ coordinates (α, δ) are determined for every star
  - If a star is matched with catalog, catalog data are added to the star description (id, coordinates, magnitude, color, …)
- SIPS can save all data (every star on every image) for later processing (upload to server etc.)
- Data contain:
  - Star's user-assigned id (if any) and calculated coordinates
  - Catalog data (if matched with catalog star)
  - Fluxes for all apertures (including auto) + background flux



	A	B	C	D	E	F	G	H	I	J	K	L	M	
21	Software:	x64) DEBUG												
22	Name	X	Y	ADU	RA	Dec	CatalogName	CatalogRA	CatalogDec	CatalogMag	Back	BackDev	ApAuto	Ap1
23		317.51	401.60	2913292	08h 27m 02.56s	+23° 21' 49.5"	567-000651	08h 27m 02.49s	+23° 21' 54.3"	9.1	1324.814	36.549	saturated	satur
24		331.07	604.98	1567247	08h 26m 59.36s	+23° 28' 49.0"	568-000647	08h 26m 59.38s	+23° 28' 49.9"	9.6	1300.763	33.978	saturated	satur
25		377.04	446.15	1421010	08h 26m 53.37s	+23° 23' 16.9"	567-000644	08h 26m 53.34s	+23° 23' 17.8"	9.6	1314.833	31.982	saturated	satur
26		634.38	653.44	1064147	08h 26m 13.50s	+23° 30' 04.7"	568-000605	08h 26m 13.55s	+23° 30' 05.0"	10.0	1290.677	31.716	saturated	satur
27		966.93	512.34	1017095	08h 25m 24.40s	+23° 24' 45.0"	568-000559	08h 25m 24.45s	+23° 24' 45.1"	10.3	1284.703	32.284	saturated	satur
28		781.14	271.76	973789	08h 25m 53.74s	+23° 16' 43.3"	567-000606	08h 25m 53.90s	+23° 16' 44.5"	10.4	1304.641	32.697	saturated	satur
29		481.71	410.95	814062	08h 26m 37.86s	+23° 21' 55.7"	567-000635	08h 26m 37.92s	+23° 21' 55.5"	10.6	1311.150	32.454	saturated	satur
30		383.65	65.69	622645	08h 26m 54.56s	+23° 10' 09.7"	566-000673	08h 26m 54.61s	+23° 10' 12.3"	11.7	1303.928	31.399	saturated	satur
31		760.53	325.30	523507	08h 25m 56.52s	+23° 18' 35.7"	567-000611	08h 25m 56.63s	+23° 18' 35.8"	11.5	1301.226	31.153	saturated	satur
32		145.57	80.28	491355	08h 27m 30.17s	+23° 10' 58.6"	566-000708	08h 27m 30.27s	+23° 10' 58.2"	11.4	1306.200	31.737	811624.097	4745
33		633.02	175.95	486587	08h 26m 16.53s	+23° 13' 37.4"	567-000622	08h 26m 16.62s	+23° 13' 39.3"	11.5	1306.573	33.976	saturated	satur
34		101.12	488.68	484130	08h 27m 34.56s	+23° 25' 06.6"	568-000674	08h 27m 34.57s	+23° 25' 06.7"	11.5	1285.203	31.436	743544.320	4464
35		620.62	106.99	468787	08h 26m 18.80s	+23° 11' 15.9"	566-000638	08h 26m 18.82s	+23° 11' 16.7"	11.6	1309.376	31.312	saturated	satur
36		145.97	127.77	466279	08h 27m 29.84s	+23° 12' 36.8"	567-000678	08h 27m 29.90s	+23° 12' 37.1"	11.5	1300.389	31.773	729756.298	4308
37		191.78	150.26	420774	08h 27m 22.85s	+23° 13' 19.7"	567-000666	08h 27m 22.83s	+23° 13' 20.4"	11.7	1301.618	31.109	645411.781	4101
38		701.66	407.03	414850	08h 26m 04.86s	+23° 21' 29.6"	567-000617	08h 26m 04.98s	+23° 21' 29.6"	11.9	1296.635	31.879	591476.346	4078
39		618.84	221.14	310502	08h 26m 18.39s	+23° 15' 12.0"	567-000624	08h 26m 18.45s	+23° 15' 13.4"	12.1	1306.770	32.630	476095.219	3175
40		407.19	555.12	250802	08h 26m 48.21s	+23° 26' 59.8"	568-000635	08h 26m 48.23s	+23° 26' 58.8"	12.3	1293.671	30.645	376994.722	2737
41		12.33	219.80	213707	08h 27m 49.38s	+23° 15' 57.4"	567-000691	08h 27m 49.44s	+23° 15' 57.7"	12.4	1291.211	28.766	328125.440	1907
42		822.05	98.47	203100	08h 25m 48.65s	+23° 10' 41.5"	566-000609	08h 25m 48.66s	+23° 10' 41.8"	12.5	1295.510	30.121	292206.010	2010
43		1032.48	540.20	199621	08h 25m 14.39s	+23° 25' 37.0"	568-000552	08h 25m 14.32s	+23° 25' 38.0"	12.6	1270.735	30.042	277316.942	1869
44		270.62	549.97	192554	08h 27m 08.75s	+23° 27' 00.1"	568-000651	08h 27m 08.73s	+23° 26' 59.6"	12.6	1291.854	31.483	280258.304	1950
45		778.70	216.65	182195	08h 25m 54.44s	+23° 14' 49.5"	567-000608	08h 25m 54.57s	+23° 14' 50.6"	12.6	1299.261	32.923	267160.560	1792
46		975.34	357.53	175474	08h 25m 24.09s	+23° 19' 24.2"	567-000583	08h 25m 24.21s	+23° 19' 24.2"	12.6	1283.945	30.411	271787.523	1981
47		717.18	60.16	175457	08h 26m 04.60s	+23° 09' 31.1"	566-000621	08h 26m 04.60s	+23° 09' 31.1"	12.7	1301.523	31.095	246805.398	1764
48		69.21	40.26	147822	08h 27m 41.84s	+23° 09' 41.8"					1298.065	32.317	234381.291	1198
49		535.38	319.44	126998	08h 26m 30.33s	+23° 18' 42.1"	567-000632	08h 26m 30.37s	+23° 18' 43.2"	13.0	1304.043	30.480	201868.291	1494
50		1001.25	504.59	124270	08h 25m 19.30s	+23° 24' 26.1"	568-000555	08h 25m 19.30s	+23° 24' 26.1"	13.1	1283.037	34.062	178623.869	1323
51		757.93	466.64	116227	08h 25m 56.06s	+23° 23' 28.2"	567-000609	08h 25m 56.17s	+23° 23' 28.2"	13.1	1290.840	31.688	163008.043	1133
52		607.03	642.93	110428	08h 26m 17.67s	+23° 29' 45.2"	568-000609	08h 26m 17.71s	+23° 29' 44.9"	13.3	1289.720	33.156	148305.604	1027
53	cmp1	143.45	351.79	105256	08h 27m 28.97s	+23° 20' 20.2"	567-000675	08h 27m 28.88s	+23° 20' 20.5"	13.2	1297.294	30.683	160871.759	9362
54		7.25	637.61	95369	08h 27m 47.84s	+23° 30' 21.8"	568-000686	08h 27m 48.09s	+23° 30' 23.9"	13.3	1267.344	30.715	149013.734	7708
55	CzeV226	567.31	38.46	89714	08h 26m 27.19s	+23° 08' 58.5"	566-000648	08h 26m 27.23s	+23° 08' 58.8"	13.1	1305.766	32.949	128310.437	8970
56		49.41	647.63	88239	08h 27m 41.44s	+23° 30' 39.3"	568-000681	08h 27m 41.65s	+23° 30' 40.9"	13.5	1267.140	30.991	128830.157	7390

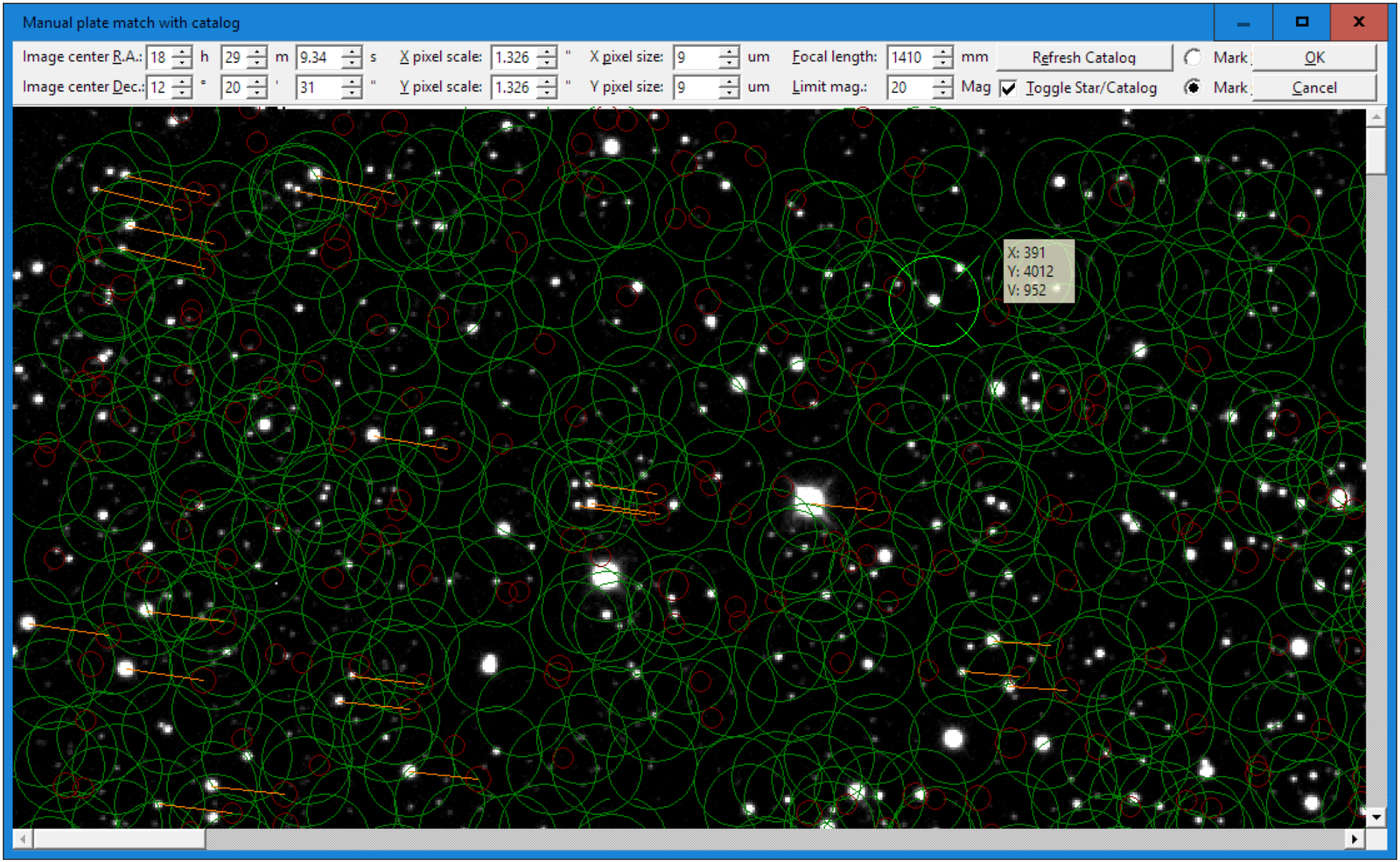
Correction of telescope field deformation

- Field deformation correction is essential for astrometric reduction of images from wide-field (and thus corrected) telescope setups
  - Field deformation is not natural only for corrected Newtonians, but for all corrected reflectors and refractors
  - Example – wrongly retouched portion of mosaic, showing mutual shift of stars on neighboring images taken with FSQ106ed APO refractor

Field deformation

- Field deformation correction is implemented by two 2D 3rd order polynomials, independent for x and y axes
- These polynomials are created by the **Astrometry** tool, the **Photometry** tool only uses these them
  - Deformation is calculated from difference among stars on image and in catalog
  - But pairing of image and catalog stars is not possible in the case of large fields due to field deformation (Head 22)
  - So Astrometry offers the possibility to manually match image and catalog

Manual match of image and catalog



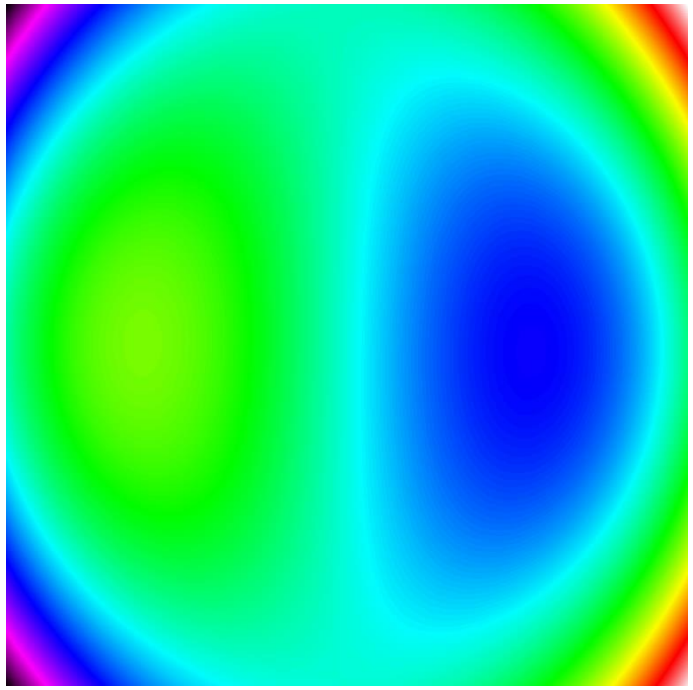
Calculation and storing of polynomials

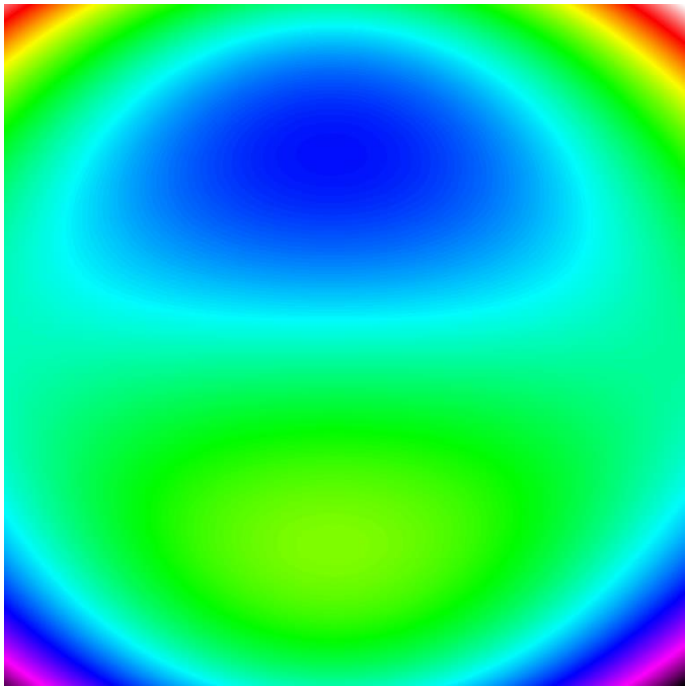
Astrometry

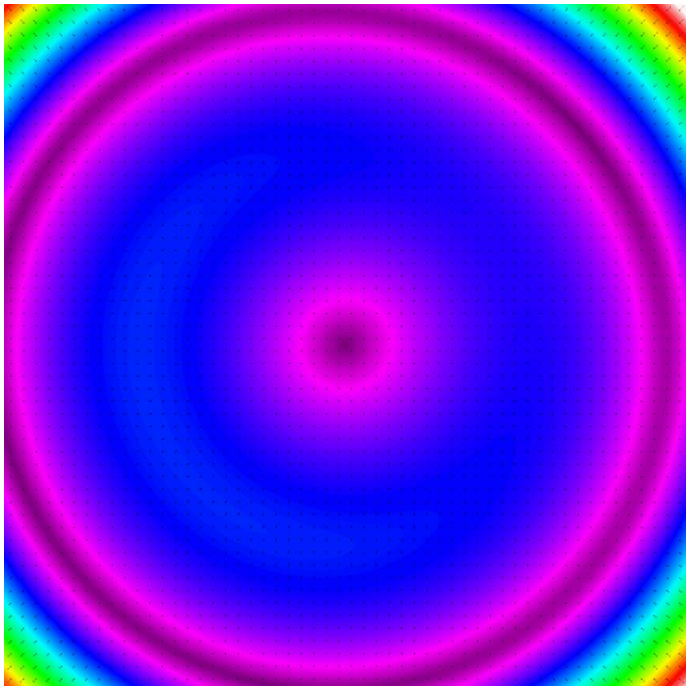
C:\FITS\test\TY Tri.fits

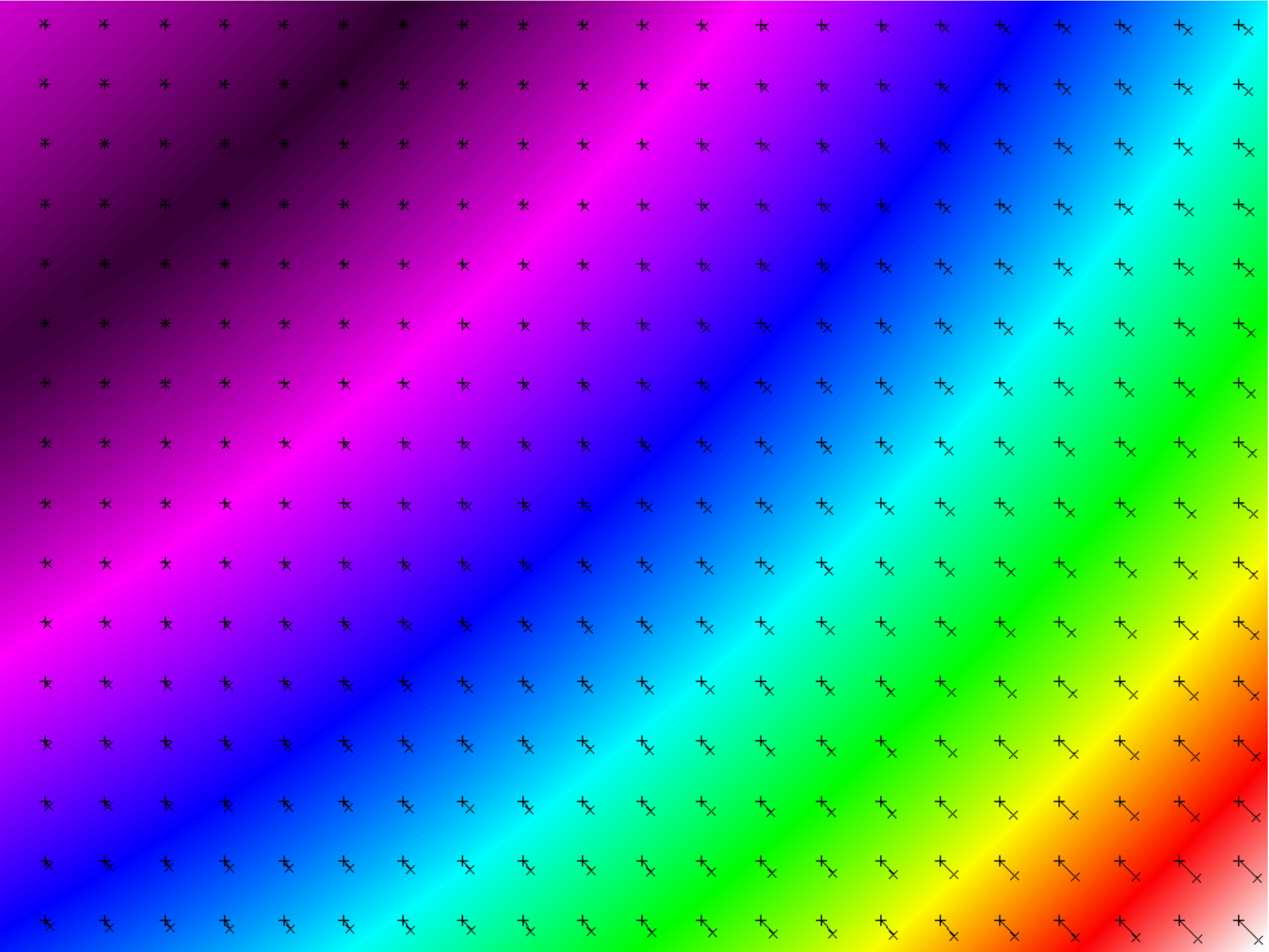
	*	Catalog	X [px]	Y [px]	ADU	R.A.	Dec.	Mag.	S/N
1	*	614-005660	983.84	552.72	888792	02h 02m 18.10s	+32° 44' 30.4"	9.24	9725.777
2	*	615-005795	153.49	700.00	1006737	02h 04m 34.29s	+32° 49' 41.3"	9.16	7954.861
3	*	613-006082	131.41	147.49	660353	02h 04m 37.96s	+32° 30' 37.7"	9.78	8958.169
4	*	614-005647	1051.47	365.09	457422	02h 02m 07.21s	+32° 38' 01.2"	10.17	10317.060
5	*	613-006089	78.01	125.54	543066	02h 04m 46.70s	+32° 29' 52.4"	10.16	11182.924
6	*	613-005961	959.83	268.39	348794	02h 02m 22.31s	+32° 34' 42.2"	10.64	11871.503
7	*	614-005727	488.95	319.41	201639	02h 03m 39.39s	+32° 36' 32.2"	11.42	5145.053
8	*	614-005718	560.01	418.71	172168	02h 03m 27.69s	+32° 39' 57.3"	11.10	7361.860
9	*	614-005744	365.23	617.57	169165	02h 03m 59.55s	+32° 46' 50.0"	11.49	7282.924
10	*	614-005736	426.58	469.28	191914	02h 03m 49.54s	+32° 41' 42.8"	11.35	7305.664

Matched stars: 312 Image center RA: 02h 03m 30.02s Dec: +32° 38' 12.5" Residuals RA: 0.93" Dec: 0.85"



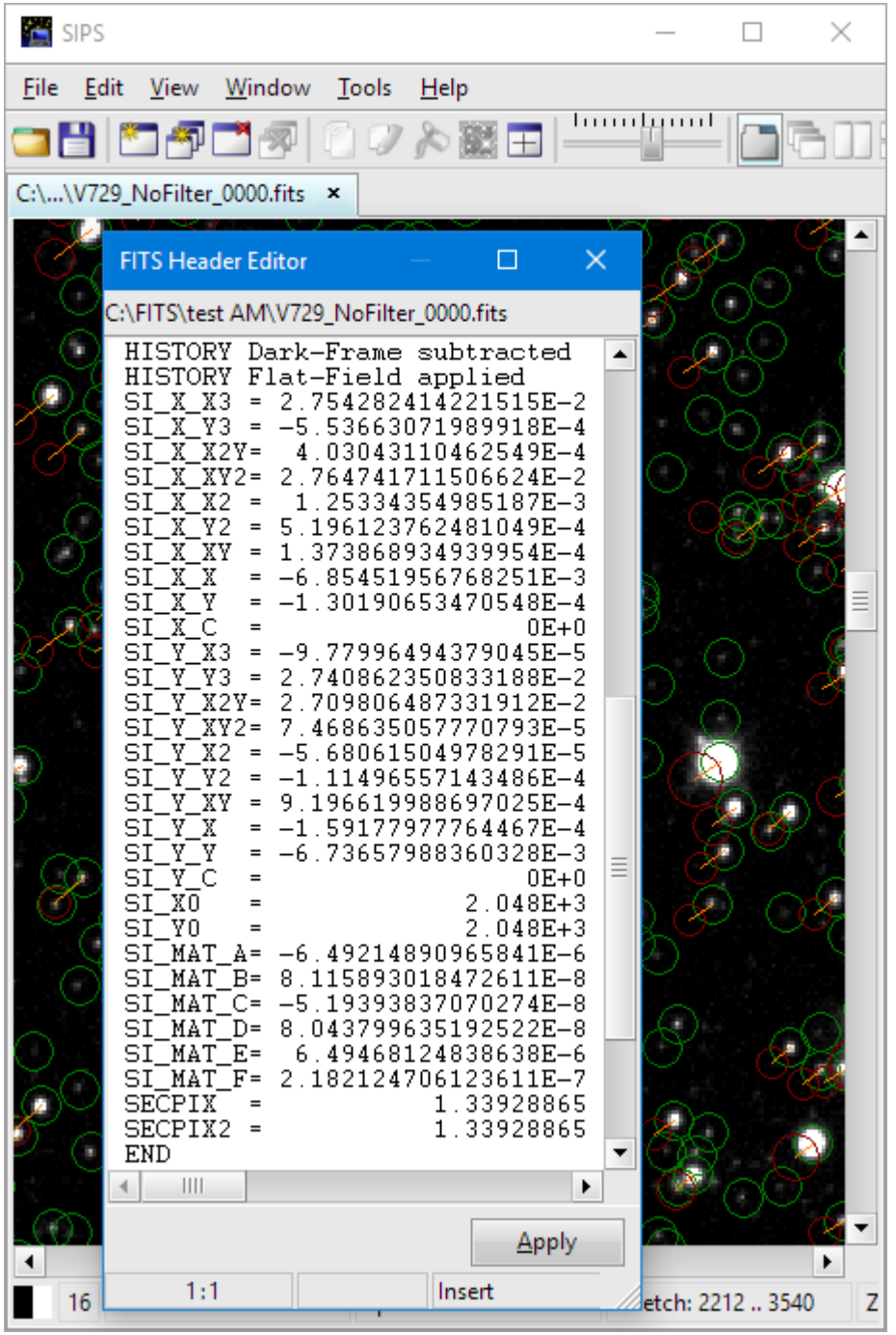




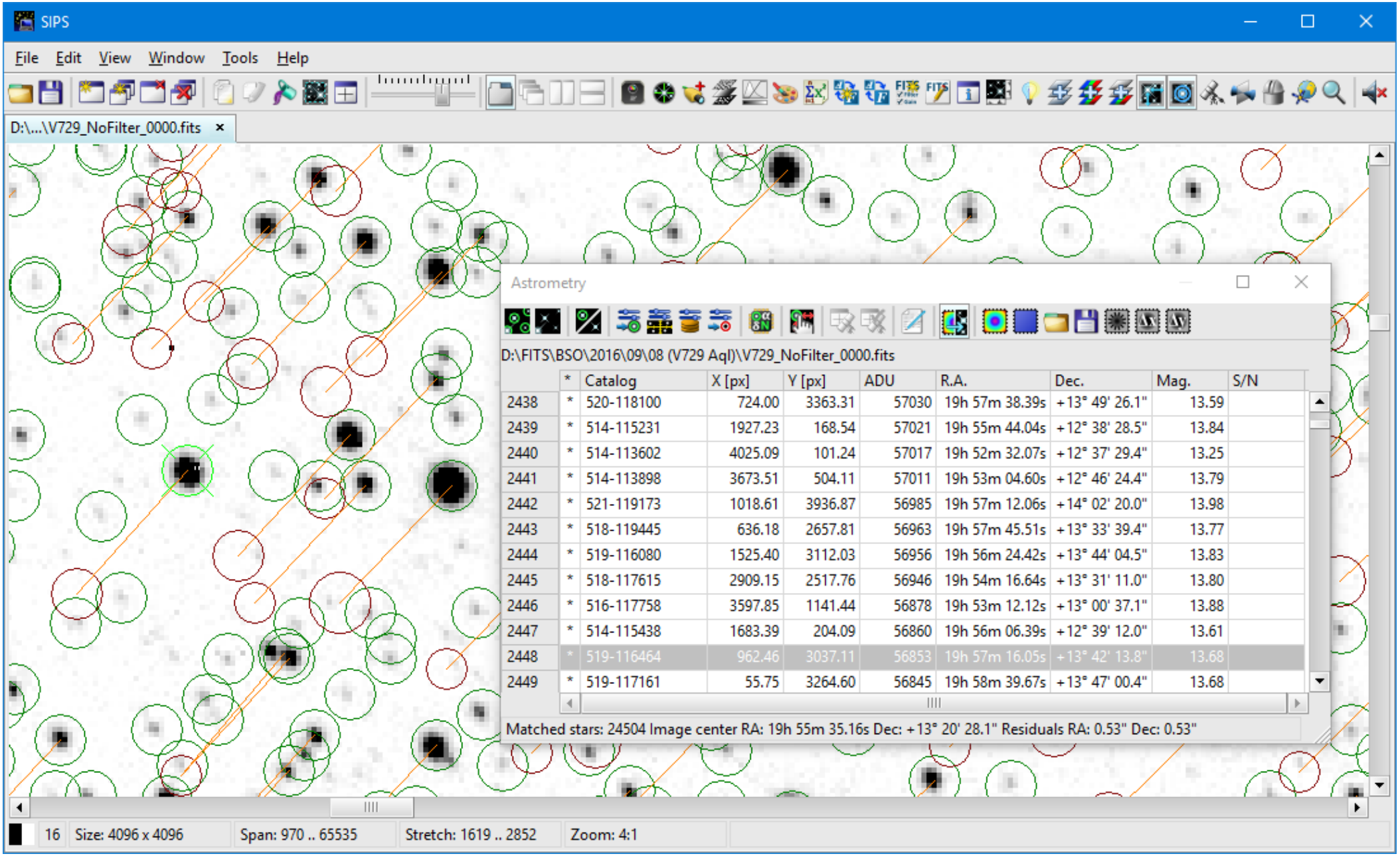


Correction is stored into FITS head

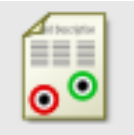
- Coefficients of correction polynomials are stored into FITS headers
- Matching can be repeated anytime later without knowledge of actual optics



Solved image in SIPS



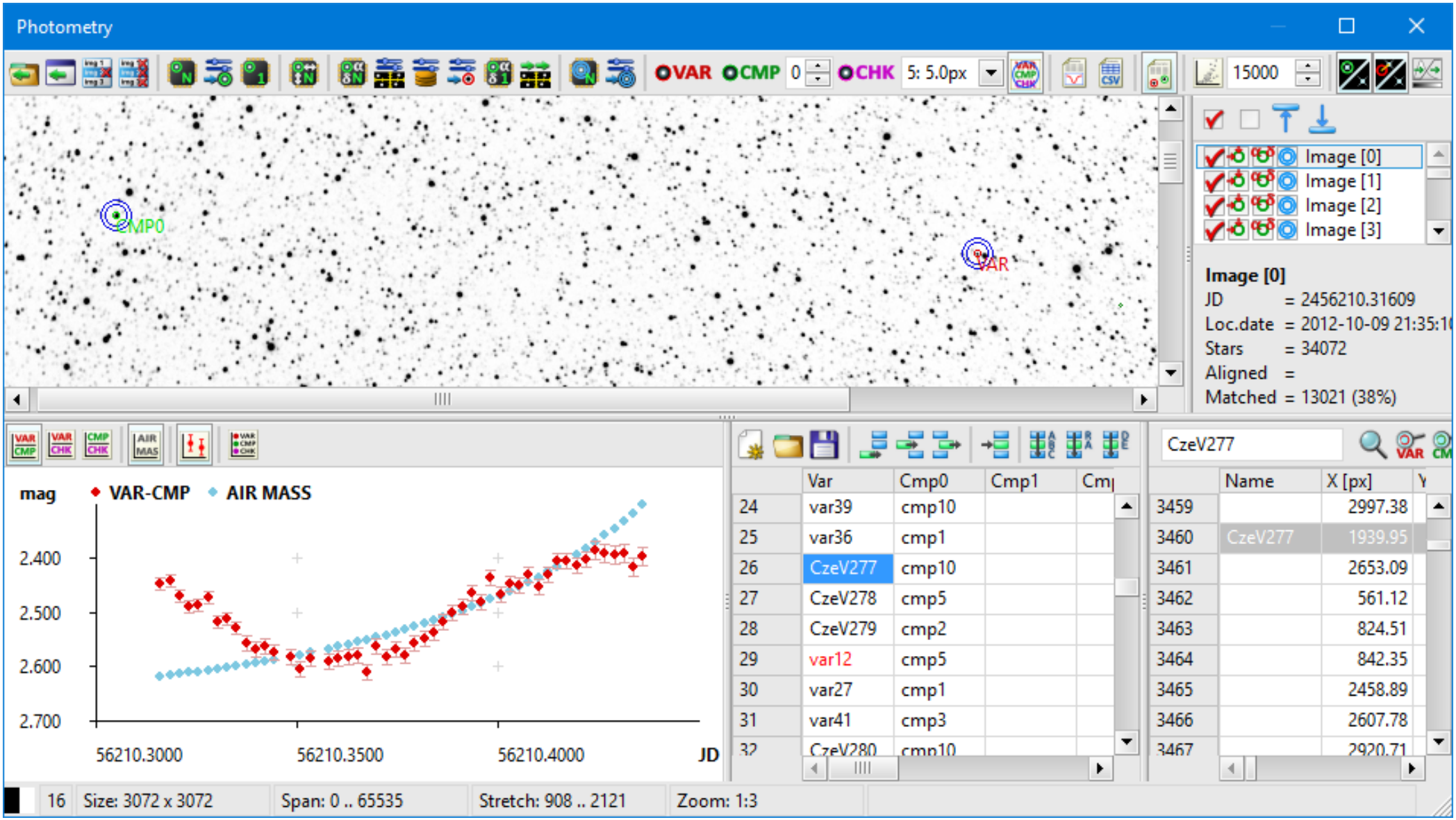
	*	Catalog	X [px]	Y [px]	ADU	R.A.	Dec.	Mag.	S/N
2438	*	520-118100	724.00	3363.31	57030	19h 57m 38.39s	+13° 49' 26.1"	13.59	
2439	*	514-115231	1927.23	168.54	57021	19h 55m 44.04s	+12° 38' 28.5"	13.84	
2440	*	514-113602	4025.09	101.24	57017	19h 52m 32.07s	+12° 37' 29.4"	13.25	
2441	*	514-113898	3673.51	504.11	57011	19h 53m 04.60s	+12° 46' 24.4"	13.79	
2442	*	521-119173	1018.61	3936.87	56985	19h 57m 12.06s	+14° 02' 20.0"	13.98	
2443	*	518-119445	636.18	2657.81	56963	19h 57m 45.51s	+13° 33' 39.4"	13.77	
2444	*	519-116080	1525.40	3112.03	56956	19h 56m 24.42s	+13° 44' 04.5"	13.83	
2445	*	518-117615	2909.15	2517.76	56946	19h 54m 16.64s	+13° 31' 11.0"	13.80	
2446	*	516-117758	3597.85	1141.44	56878	19h 53m 12.12s	+13° 00' 37.1"	13.88	
2447	*	514-115438	1683.39	204.09	56860	19h 56m 06.39s	+12° 39' 12.0"	13.61	
2448	*	519-116464	962.46	3037.11	56853	19h 57m 16.05s	+13° 42' 13.8"	13.68	
2449	*	519-117161	55.75	3264.60	56845	19h 58m 39.67s	+13° 47' 00.4"	13.68	



Working with Field Description

- Field description purpose is to save all marked stars (variables, comparison and check stars) into description file and later just use this file to rapidly generate light curves and reports of all stars of interest in the particular field
- Individual stars are identified with their equatorial coordinates, so the successful astrometric solution of all images in the Photometry image set is necessary
  - If the particular star is not included in the used catalog, it can be still included into field description, it is only identified by coordinates and not by catalog name

Example of field description pane opened



Description file is simple text file

```
[Description]
version = 1
catalog = UCAC4

[Stars]
cmp2 = 5.395547204E-1; 5.691312848E-1; 614-005727; 5.395552059E-1; 5.691316911E-1
cmp3 = 5.38700184E-1; 5.701288131E-1; 614-005718; 5.387024041E-1; 5.701280414E-1
v4 = 5.410245319E-1; 5.721339355E-1; 614-005744; 5.410203177E-1; 5.721310928E-1
cmp1 = 5.402964787E-1; 5.706426903E-1; 614-005736; 5.402940474E-1; 5.706397623E-1
v2 = 5.414696827E-1; 5.72068233E-1; 614-005749; 5.414679461E-1; 5.720669083E-1
v1 = 5.414845401E-1; 5.718940758E-1; 614-005750; 5.41483305E-1; 5.718923996E-1
v3 = 5.412030003E-1; 5.721243677E-1; 614-005747; 5.41198191E-1; 5.721220898E-1

[Variables]
v1 = cmp3; ; ; ; ; ; ; ; ; ;
v2 = cmp1; ; ; ; ; ; ; ; ; ;
v3 = cmp2; ; ; ; ; ; ; ; ; ;
v4 = cmp3; ; ; ; ; ; ; ; ; ;
```

Summary: how to use Photometry tool

- Include images into image set (load, add, …)

- Optional **Find** stars (could be repeated)
  - Cancels **Match**, **Astrometry** and **Photometry**

- **Match** images (**Finds** stars if not found)

- Calculate **Astrometry** (**Finds** stars if not found)

- Calculate **Photometry**
  - Requires **Match** and/or **Astrometry**

- Light curves, search variables, save report, ...
  - Requires **Match** and **Photometry**

- Save table of all stars into CSV
  - Requires **Astrometry** and **Photometry**

- Work with **Field Description**
  - Requires **Match**, **Astrometry** and **Photometry**

What is on the development plan?

- Automatic assignment of comparison star(s) according to color (B-V), brightness etc.
- Photometry of moving targets
- “On-the-fly” processing of images just acquired from the camera during observing session
- Tools for reduced data processing
  - Light curve from data from multiple nights
  - Searching for long time span changes
  - It is hard to estimate all possibilities …

SIPS is a freeware, download links are available at:

http://www.tcmt.org/software.html

or go directly to:

http://www.gxccd.com/cat?id=146&lang=409

Contact to the author:

pc@tcmt.org

Thank you for your attention

Questions?