



Processing service of optical frames for the formation of high-precision observations of asteroids and satellites

LEMUR IS:

One of the best software for automatic multithreaded data processing of astrometric and photometric optical observations.

Implemented as a service and independent standalone/local/built-in/corporate software.

High level of data processing automation due to the many years of formalized experience of astronomy professionals and amateurs, customers and developers.

Relieves the observer's stress by removing the operations such as manual frames comparing for objects detection, and much more.

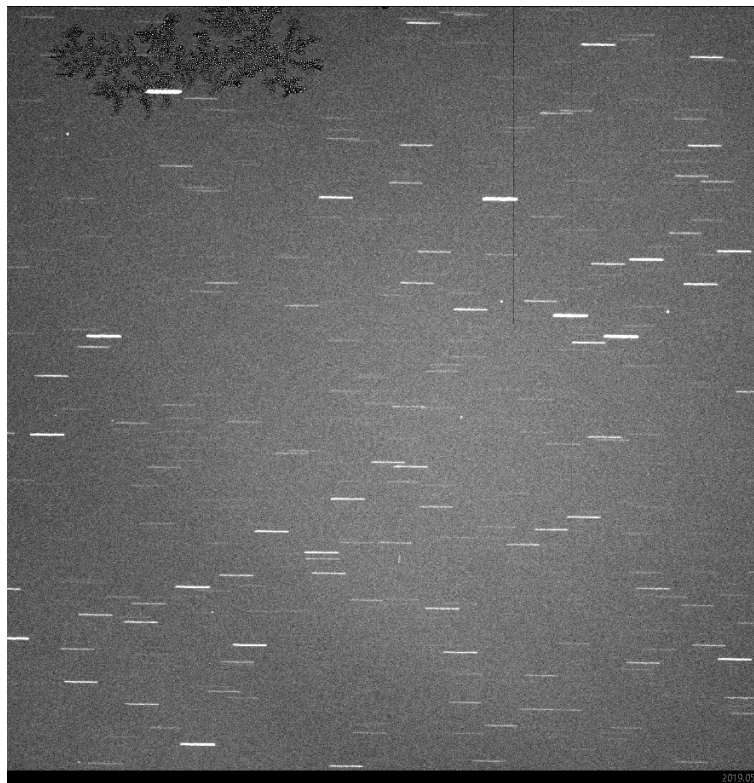
LEMUR CAN:

Organize automatic detection of moving objects and light curves on frames from many telescopes of the observatory!

Help create a moving object detection service for processing frames of amateur astronomers!

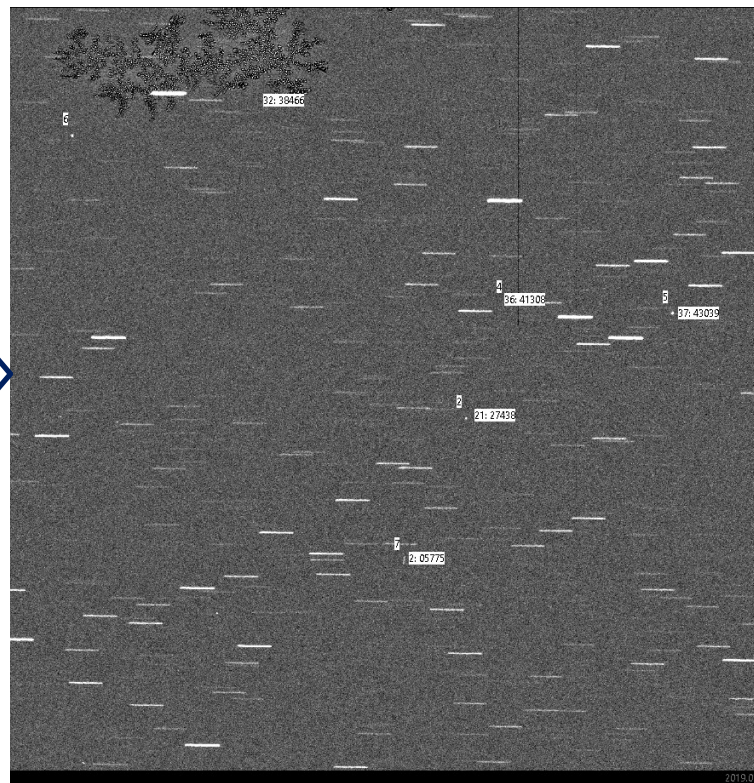
Automate your observational astronomy tasks!

Raw frames

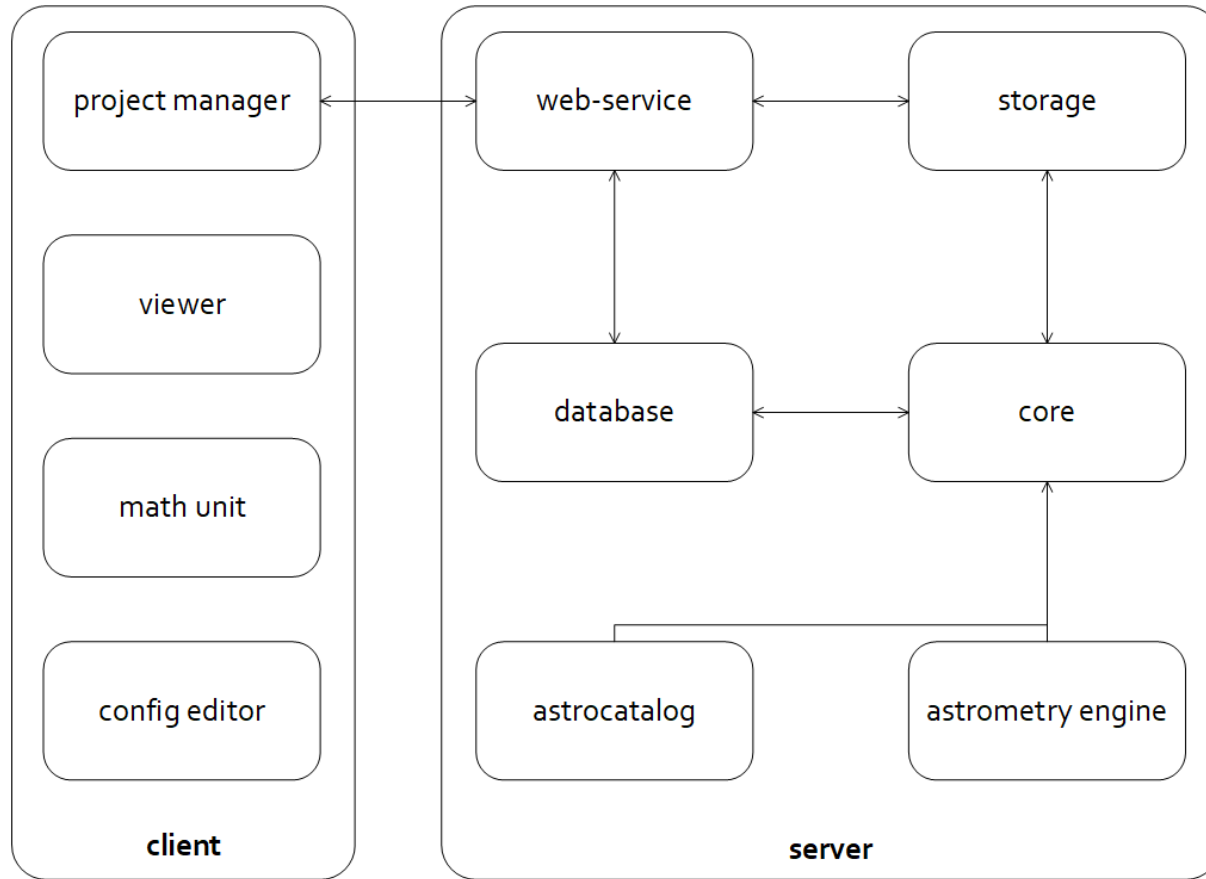


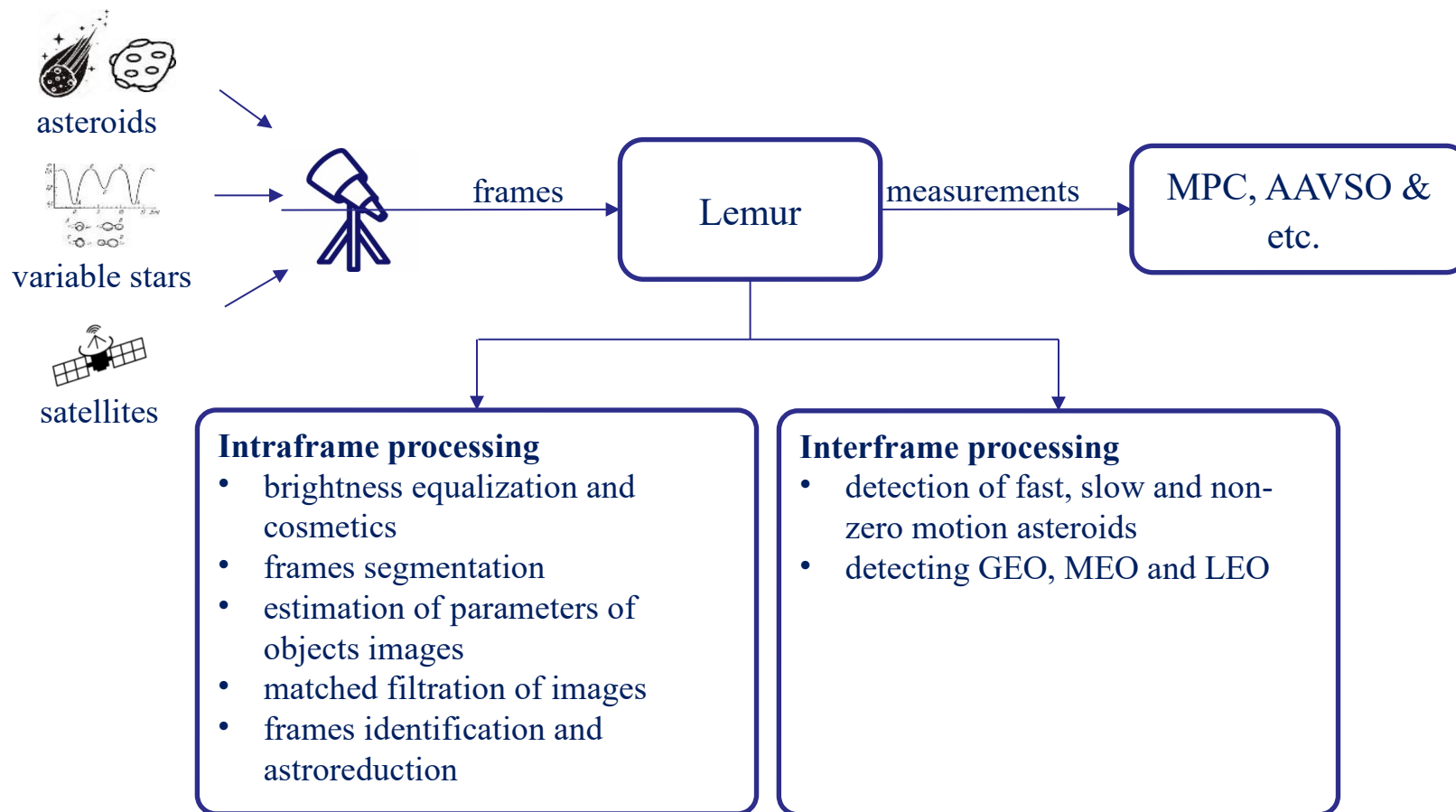
after proc.

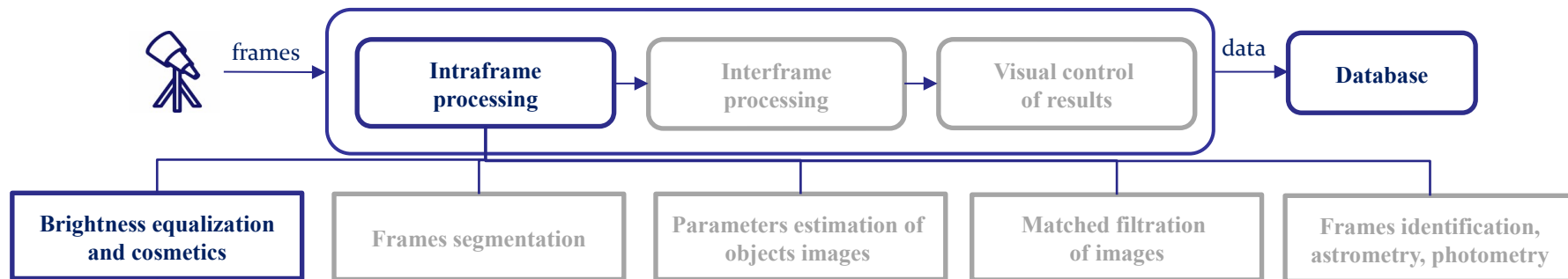
Satellites detected



Lemur architecture







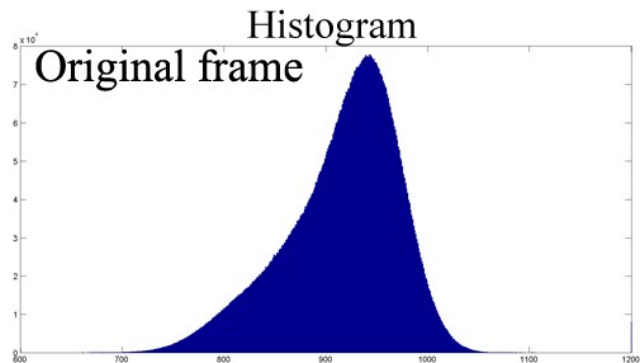
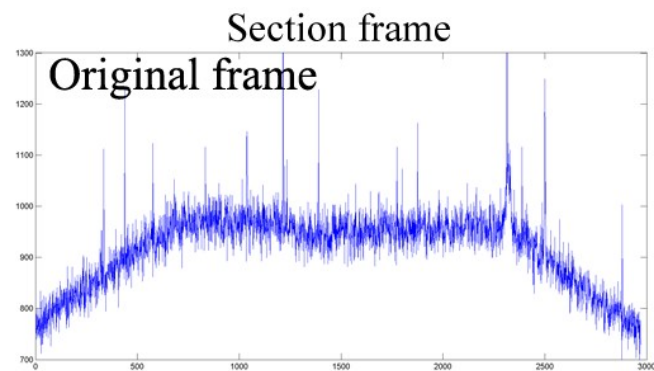
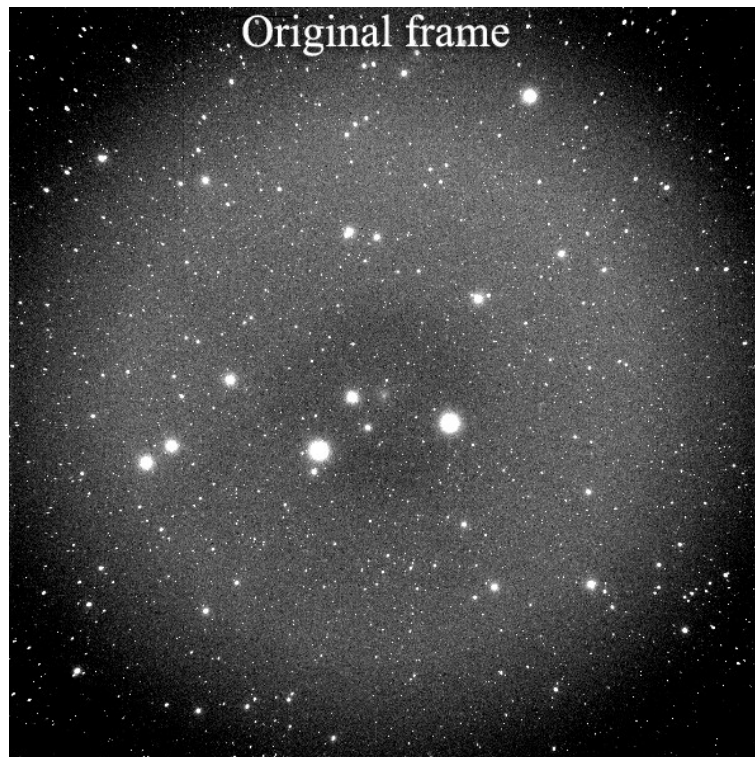
compensates uneven sensitivity and defects of the CCD-camera;

eliminates spurious illumination from extraneous light sources (lights, passing cars), as well as uneven illumination of the frame at “dawn” or near bright stars;

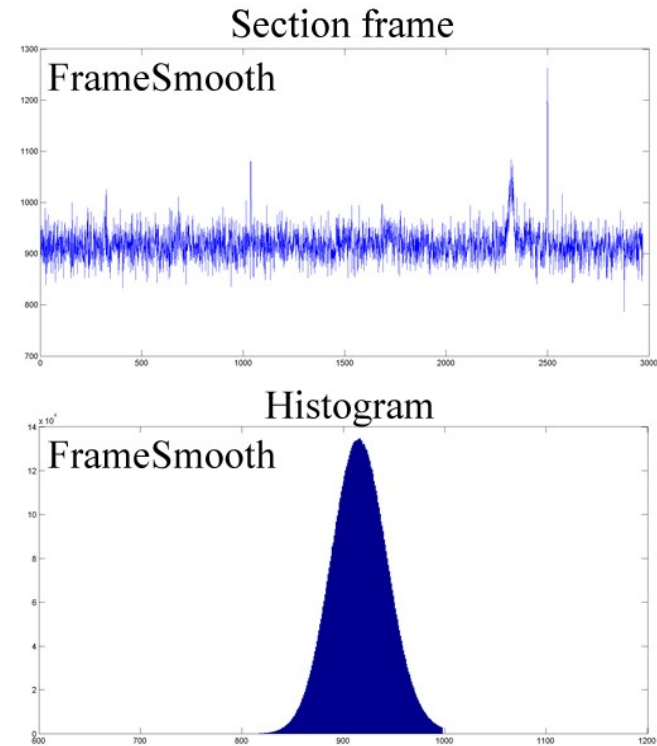
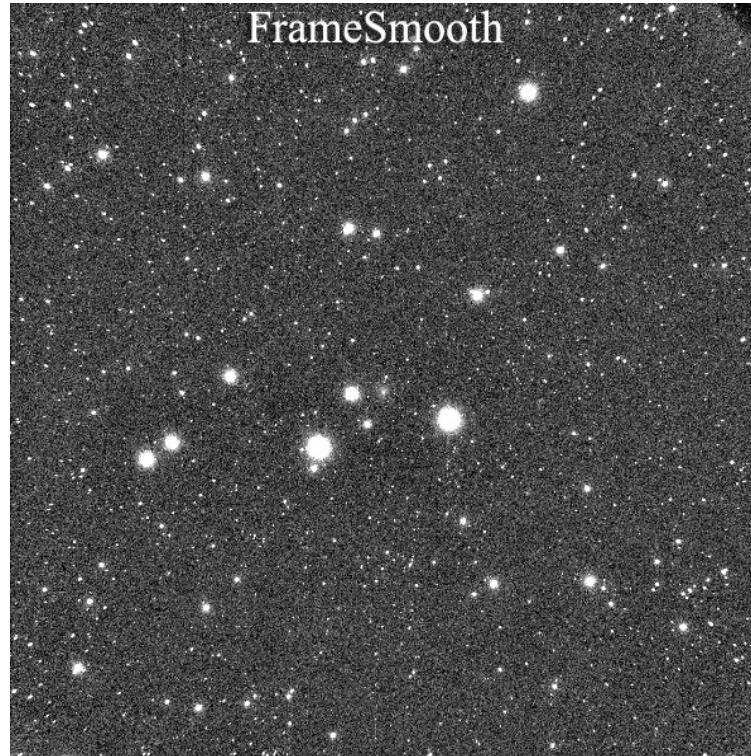
allows to dispense with flat frames;

the use of aligned in brightness frames significantly reduces the errors in detection and parameters estimation of objects images.

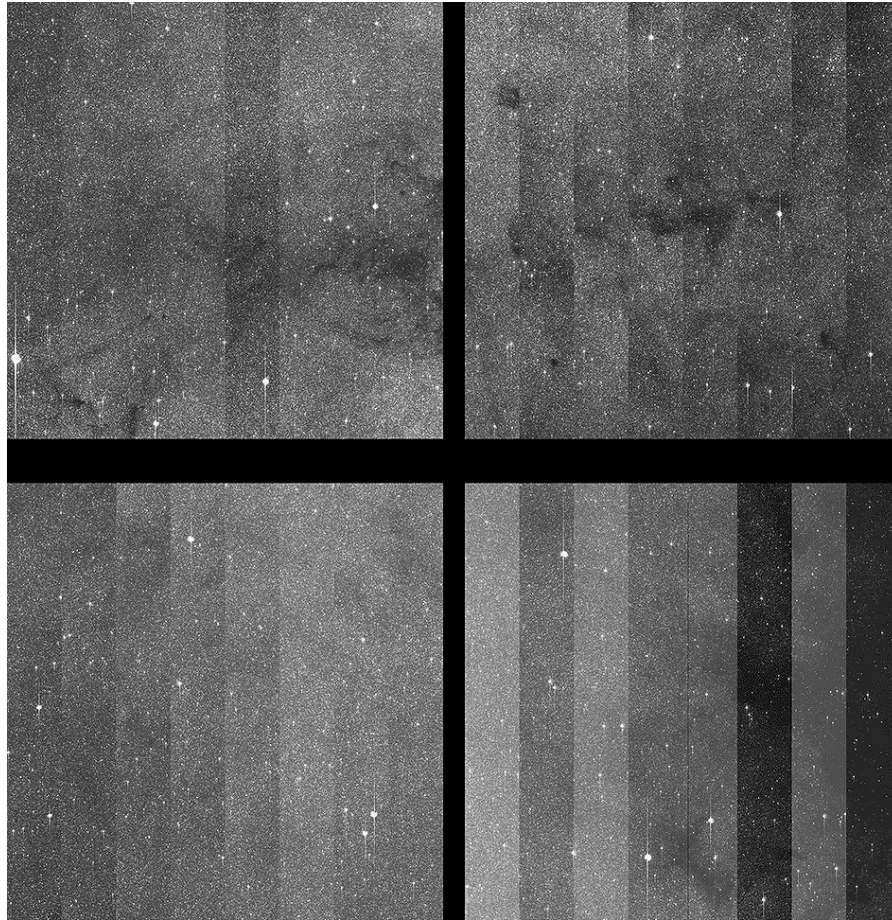
Brightness equalization of digital images



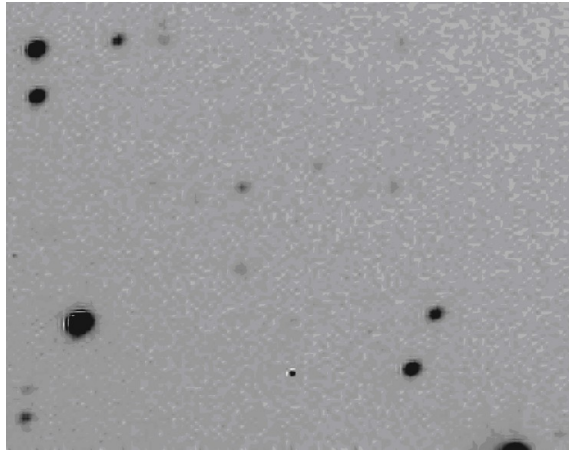
Comparison of alignment results with Lemur (FrameSmooth) and MaxImDL



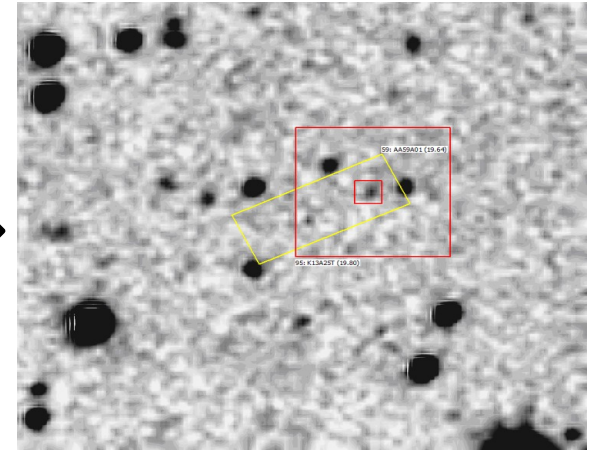
Brightness equalization of multi frames



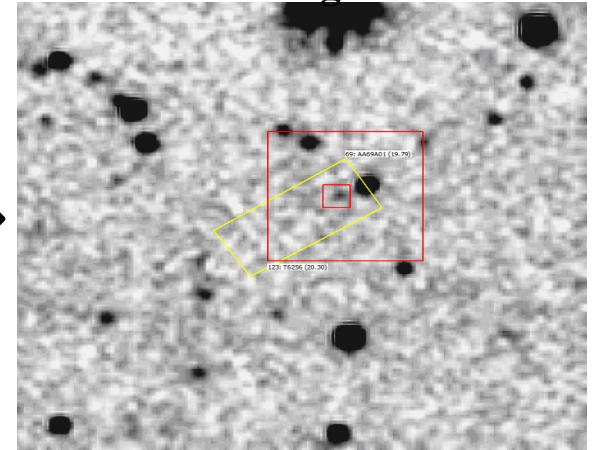
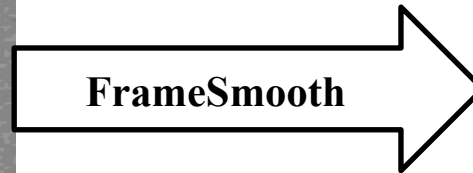
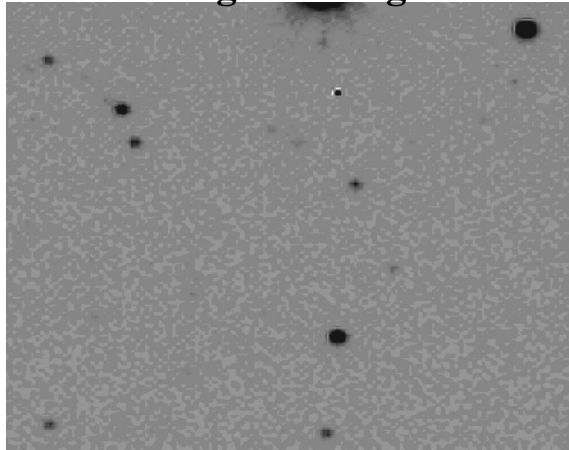
Brightness equalization of multi frames

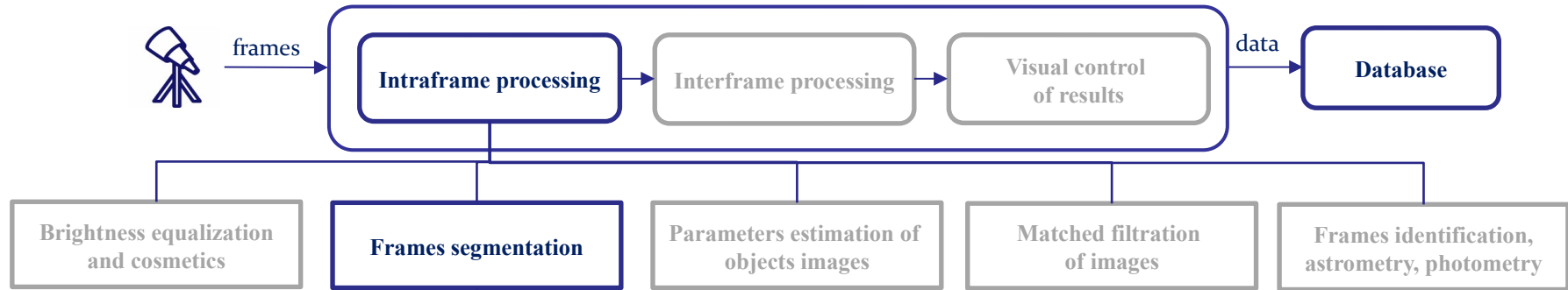


Original image

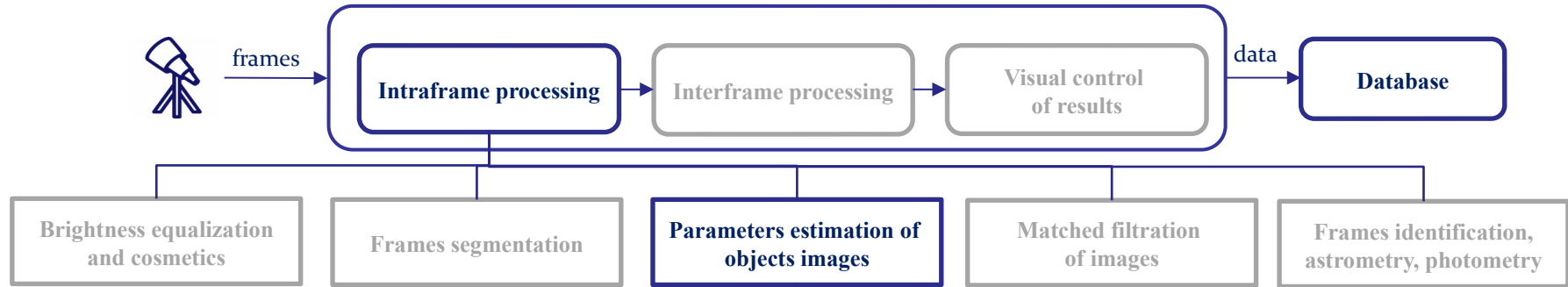


Processing result





- determines the set of CCD-camera pixels which correspond to the objects images in frame;
- uses a complex of classical and original segmentation methods with their adaptive automatic selection for each frame and segment in it;
- classifies objects images into “circular/extended”, and also selects “anomalous pixels”;
- forms segments for objects with small size and for images of large stars with diffraction stretches;
- forms segments for super-extended objects.



— determines the exact rectangular coordinates of objects, instrumental brightness, signal-to-noise ratio, length and other image parameters;

— analytical parameters estimation of point and stroke images of objects before and after the matched filter;

— parameters estimation of the objects images with an analytically undefined profile before and after the matched filter;

— instrumental brightness estimation of circular and extended images, as well as images of objects with an analytically undefined profile.

Parameters estimation of object's image in CCD-frames

Computational method for determining the objects position in CCD-frames

Quality criterion for determining the position of object's image:

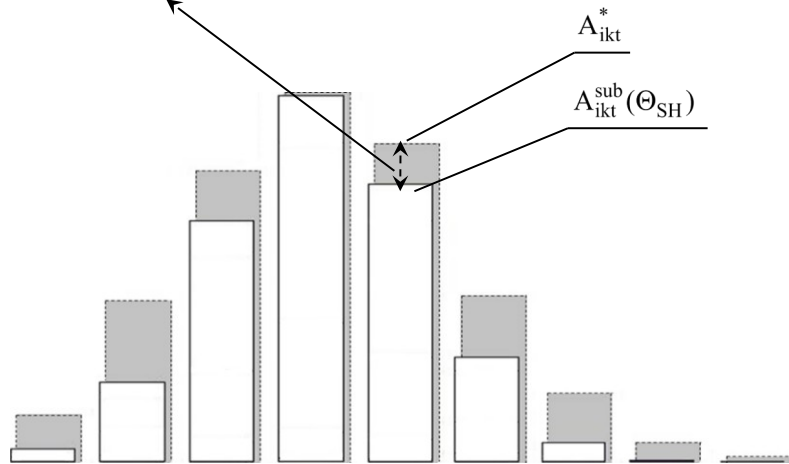
$$F_{\Delta AG1}(\Theta_{SH}) = \sum_{i,k}^{N_{SIFP}} \underbrace{(A_{ikt}^* - A_{ikt}^{sub}(\Theta_{SH}))^2}_{\Delta A_{SH(i,k)}} \xrightarrow{\Theta_{SH}} \min$$

Minimum sum of squares of deviations
between experimental and model brightness of pixels
in the intraframe processing area

$$\Delta A_{SH(i,k)} = A_{ikt}^* - A_{ikt}^{sub}(\Theta_{SH})$$

(4)

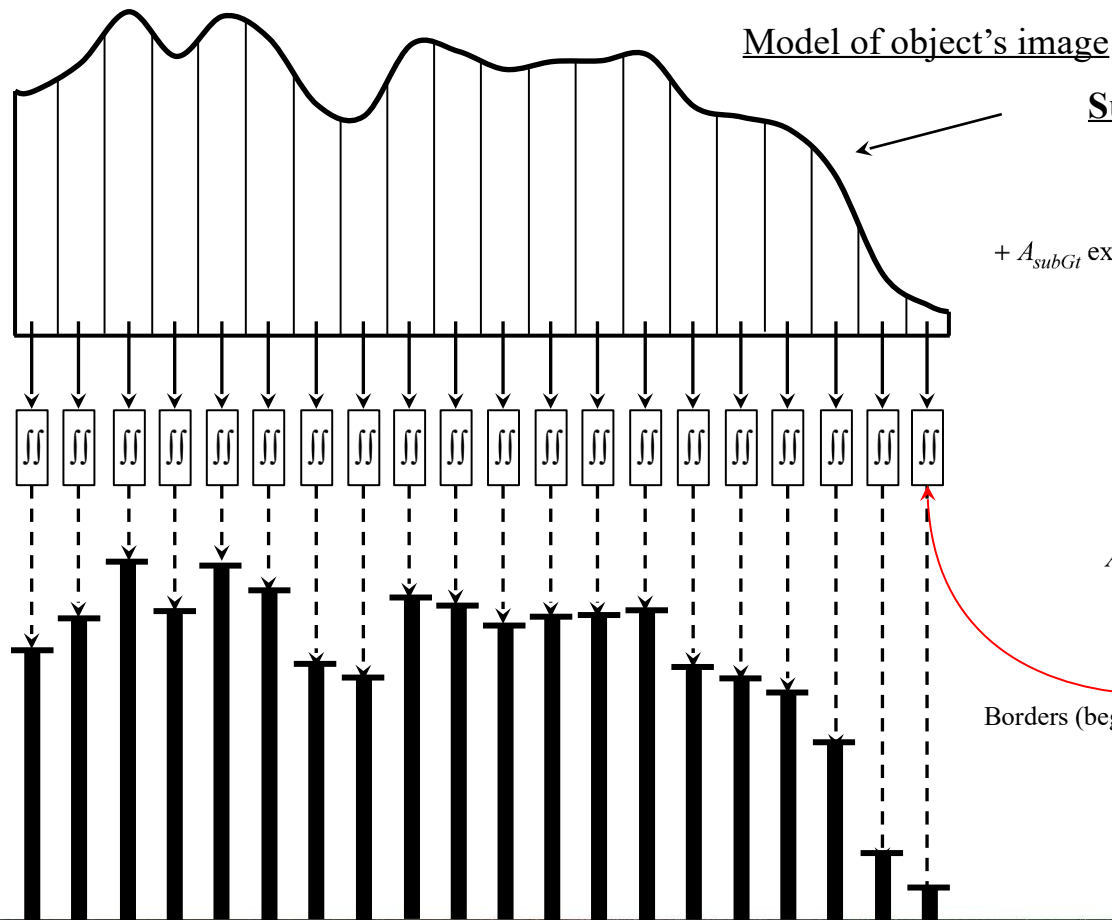
Deviation between experimental and
model brightness of pixel



Real and model object's image

- real object's image
- model of object's image
- Θ_{gent} – vector of estimated parameters
- A_{ikt}^* – experimental brightness of pixels
- $A_{ikt}(\Theta_{gent})$ – model brightness of pixels

Subpixel Gaussian model of extended images of object



Subpixel model of extended image of object:

$$f_{\tau}^{sub}(x_{it}, y_{kt}, \Theta_{\tau}^{sub}) = C_{residual}^{sub} + A_{subGt} \exp \left\{ -\frac{1}{2\sigma_{subGt}^2} \left[(x_{it} - x_{\tau}(\Theta_{\tau}^{sub}))^2 + (y_{kt} - y_{\tau}(\Theta_{\tau}^{sub}))^2 \right] \right\}$$

Model brightness of ik-th pixel in subpixel model of image:

$$A_{ikt}(\Theta_{\tau}^{sub}) = \int_{x_{bi}}^{x_{ei}} \int_{y_{bk}}^{y_{ek}} \int_{\tau_t - \Delta/2}^{\tau_t + \Delta/2} f_{\tau}^{sub}(x_{it}, y_{kt}, \Theta_{\tau}^{sub}) dx_{it} dy_{kt}$$

Borders (beginning and end) of ik-th pixel in CCD-matrix by coordinates x and y:

$$x_{bi} = x_{it} - \frac{\Delta_{CCD}}{2};$$

$$y_{bk} = y_{kt} - \frac{\Delta_{CCD}}{2};$$

$$x_{ei} = x_{it} + \frac{\Delta_{CCD}}{2};$$

$$y_{ek} = y_{kt} + \frac{\Delta_{CCD}}{2}.$$

Subpixel Gaussian model of extended images of object

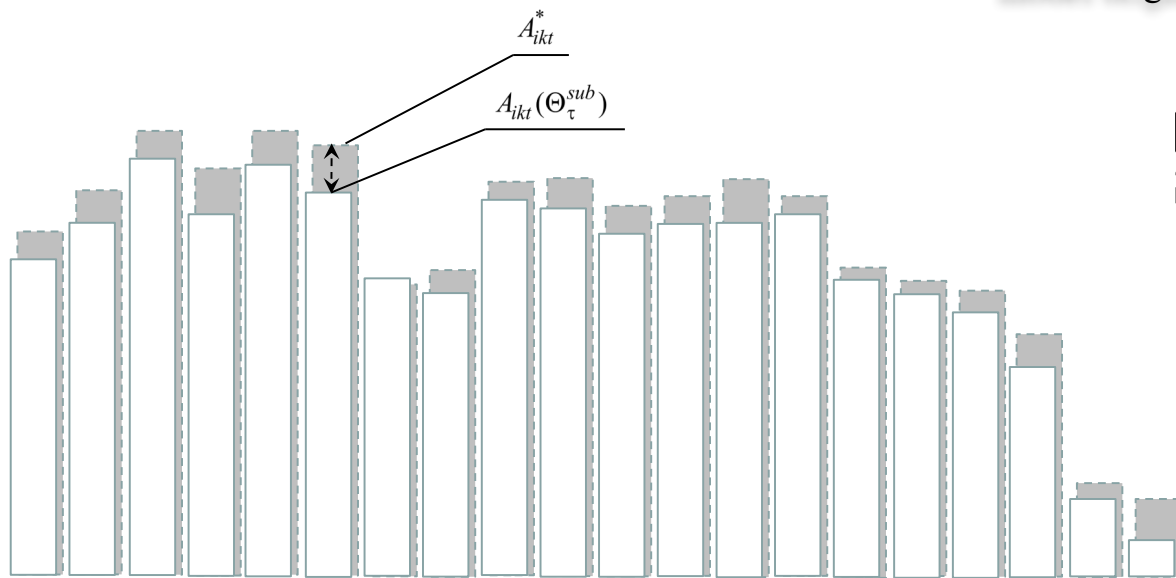
Quality criterion for determining the position of object's image:

$$F_{\Delta A\tau}(\Theta_{\tau}^{sub}) = \sum_{i,k}^{N_{PS}} \left(A_{ikt}^* - A_{ikt}(\Theta_{\tau}^{sub}) \right)^2 \xrightarrow{\Theta_{\tau}^{sub}} \min$$

Minimum sum of squares of deviations
between experimental and model brightness of pixel in
the intraframe processing area

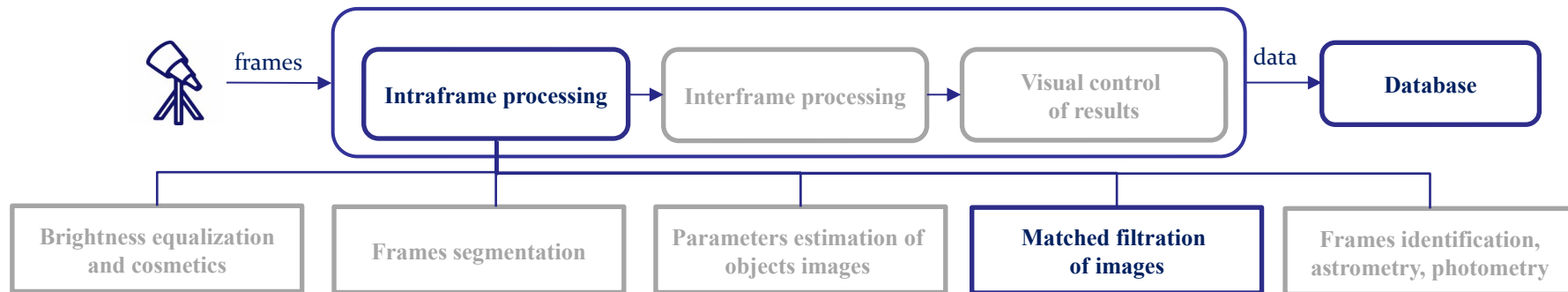
$$\Delta A_{SH(i,k)} = A_{ikt}^* - A_{ikt}(\Theta_{\tau}^{sub})$$

Deviation between experimental and
model brightness of pixel



Real and model object's image

- real object's image
- model of object's image
- Θ_{τ}^{sub} – vector of estimated parameters
- A_{ikt}^* – experimental brightness of pixels
- $A_{ikt}(\Theta_{\tau}^{sub})$ – model brightness of pixels



— selects images of faint stars and objects;

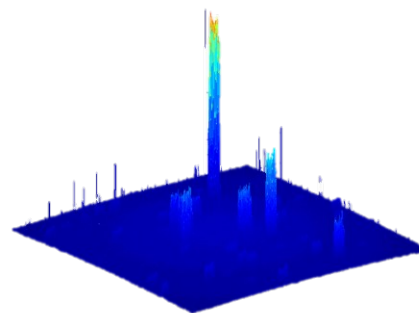
— reduces the number of false objects;

— matched filtration is implemented for images of objects: point (frames with diurnal rotation), stroke and with an analytically undefined profile (frames without diurnal rotation).

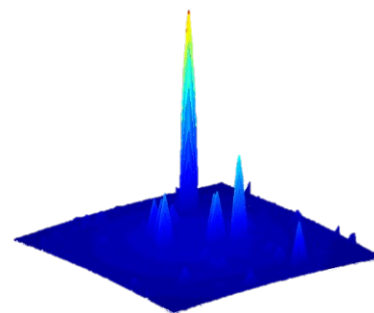
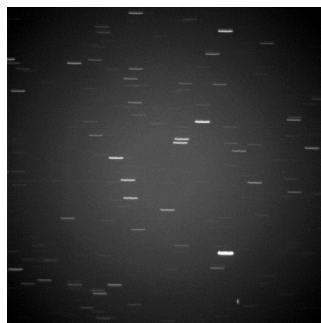
Matched filter for extended images of objects

Matched filter for extended images of objects for CCD-frames
taken without the diurnal tracking

Frame with extended
objects



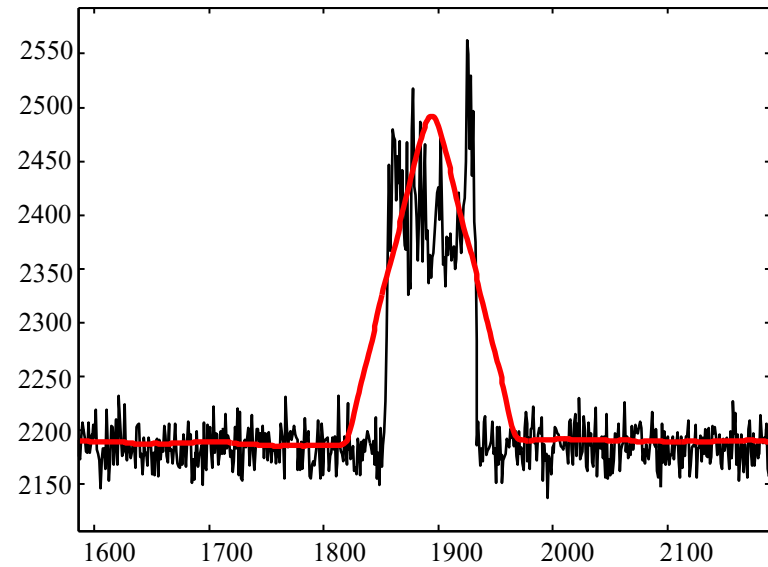
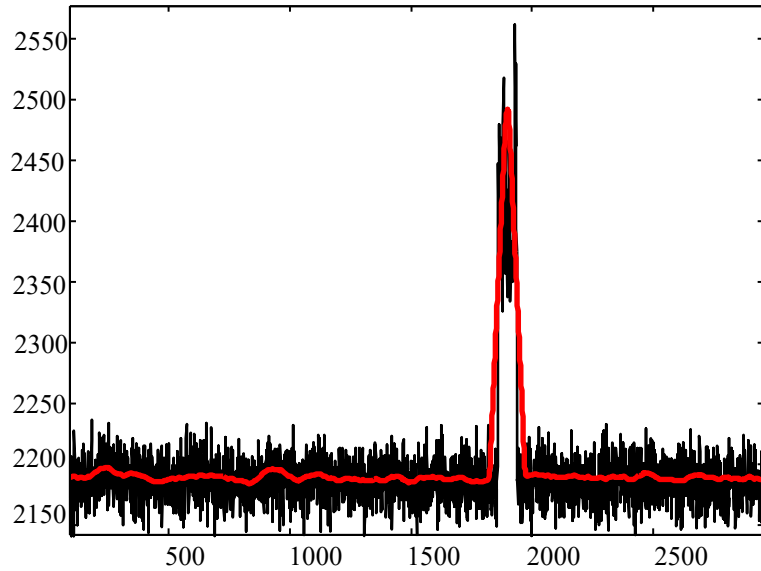
Processing result of
matched filter



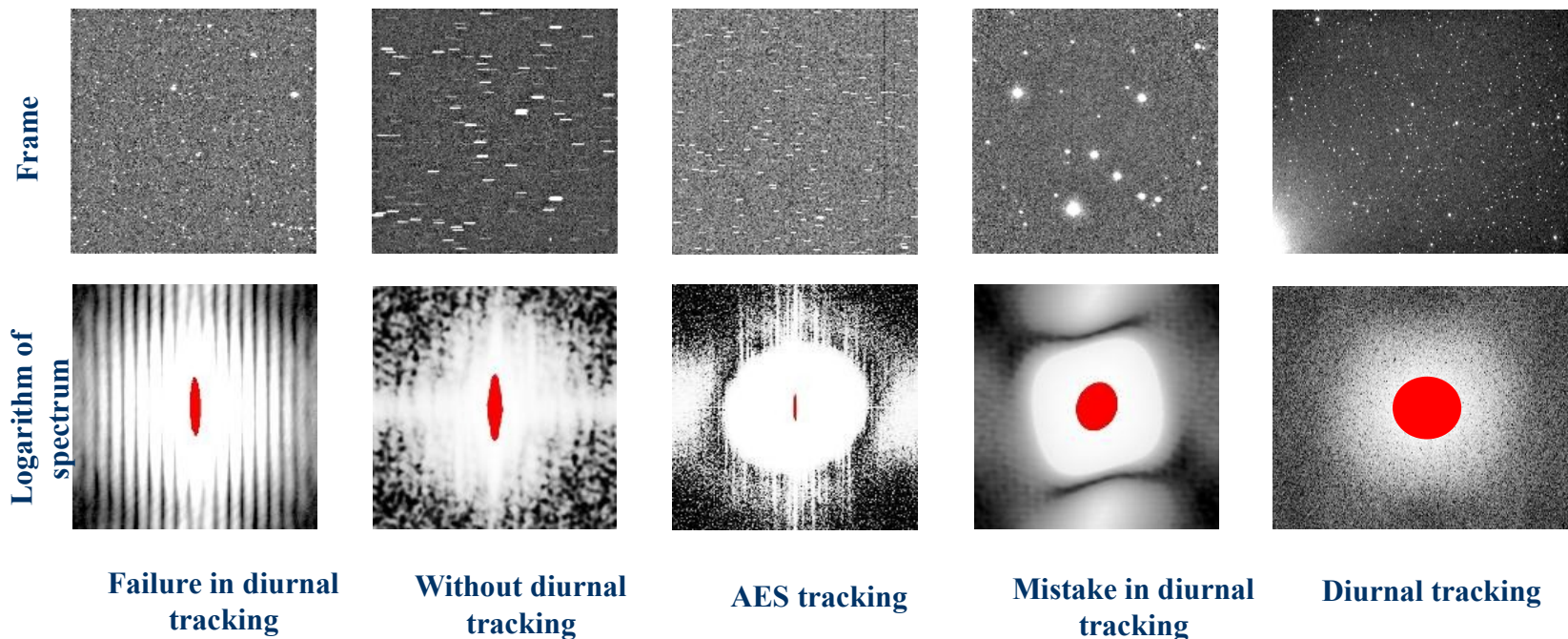
2D

3D

Cross-section image of object before and after applying the matched filter for extended images of object



Examples of CCD-frames and their spectrums with extended images of objects



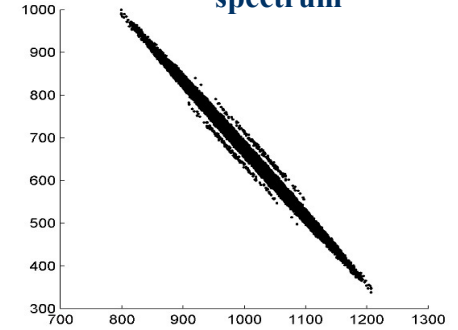
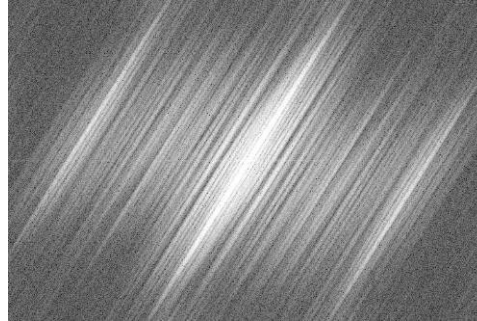
Examples of CCD-frames and their spectrums with extended and point images of objects

Frame

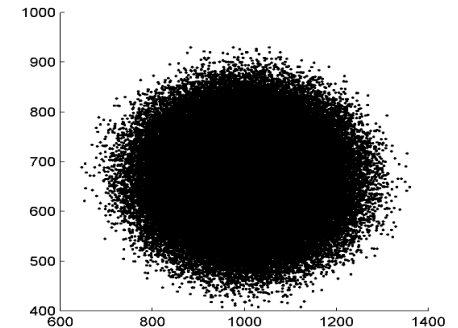
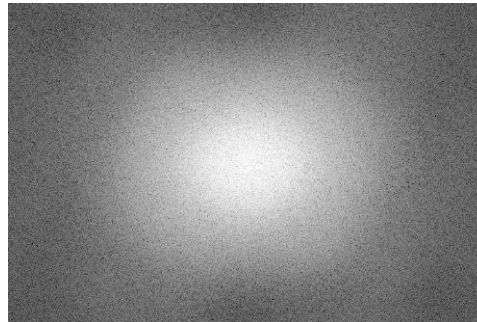
Spectrum

The brightest harmonics of spectrum

Frame with extended images of objects



Frame with point images of objects

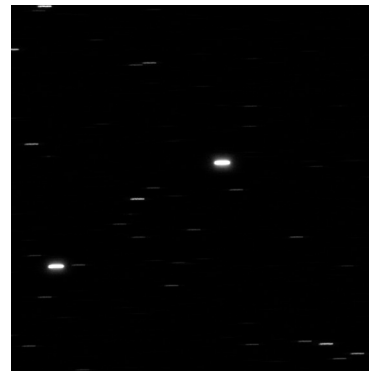


GSO frames addition with stars strokes subtraction

GEO 35815, 38245, 32050



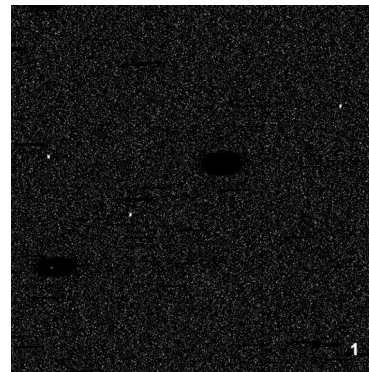
Raw frames



Frames with stars, GSO are invisible



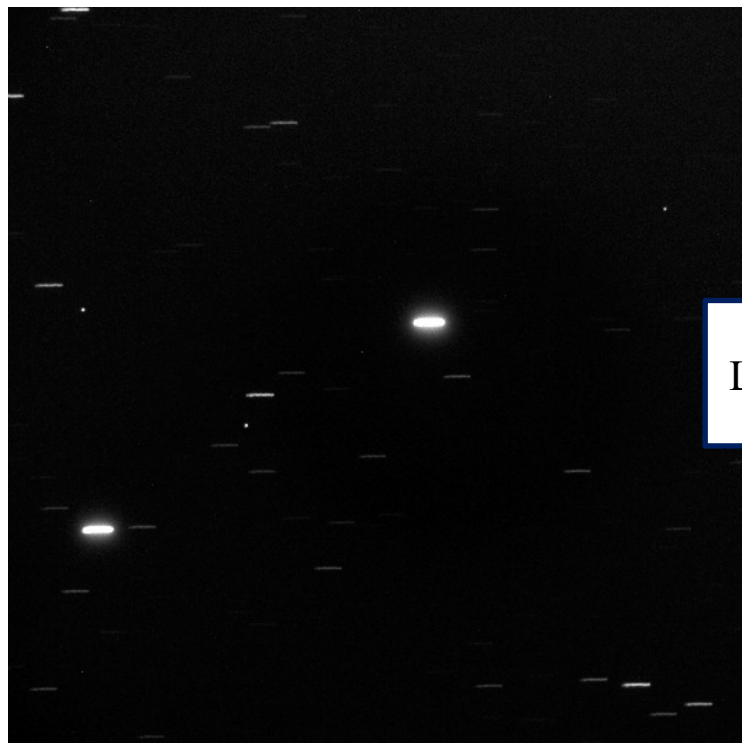
Frames with GSO without stars



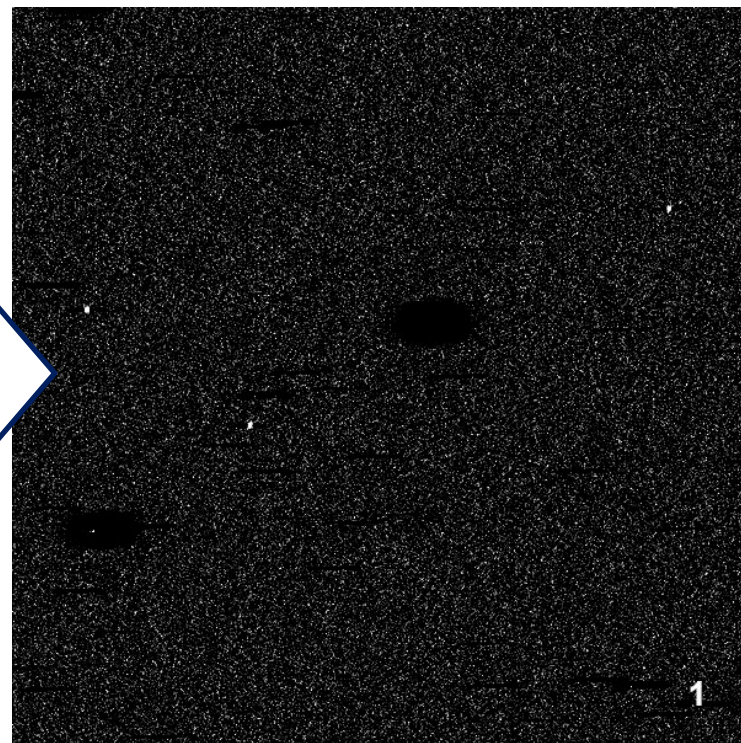
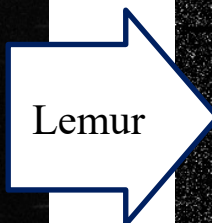
Frames addition

GSO frames addition with stars strokes subtraction

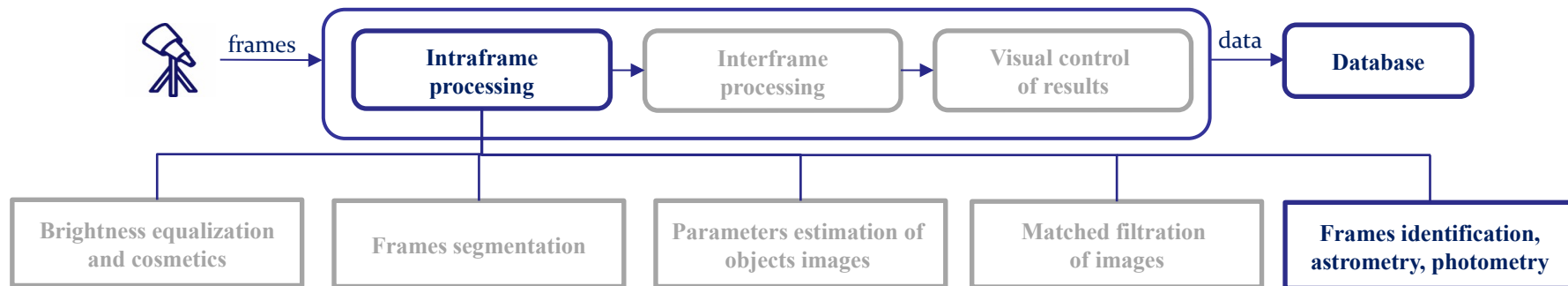
GEO 35815, 38245, 32050



Raw frames



Frames addition



— finds the correspondence between stars images in frame and data of modern star catalogs;

— forms a catalog of objects motionless in a series of frames;

— establishes an analytical relationship between the rectangular frame coordinate system and the ICRS;

— photometry: establishes an analytical connection between instrumental brightness and brightness in the selected star catalog;

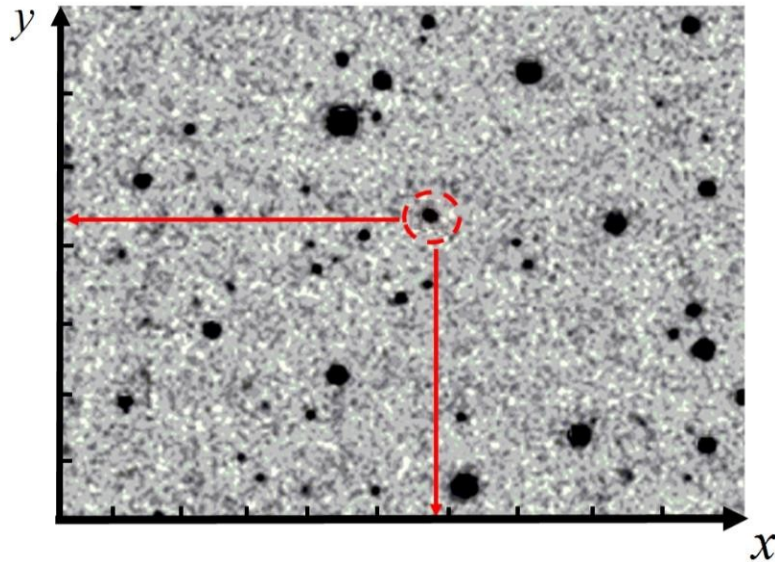
— linear, cubic and fifth degree astrometric reduction models are available;

— automatic selection of astrometric reduction model is implemented;

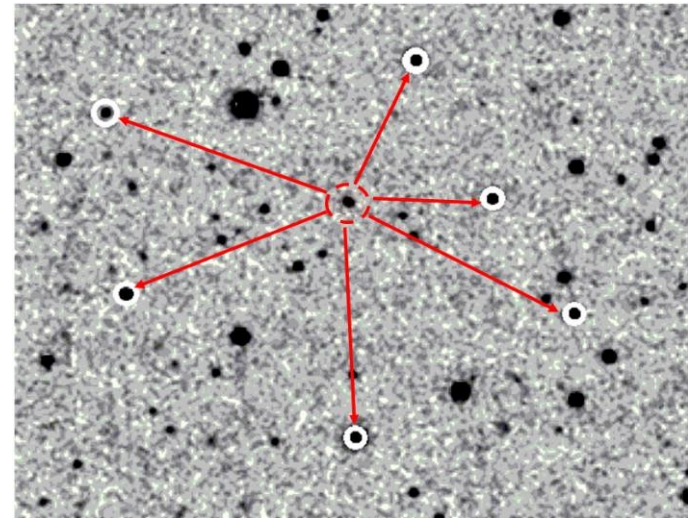
— robust automatic selection of reference stars is implemented.

Selection of reference stars in digital images

Determination of objects angular position in space
according to data from images



a) absolute method



b) relative method

Frames identification with stellar catalogs and astrometry

Identification of measurements in frame with measurements from stellar catalog

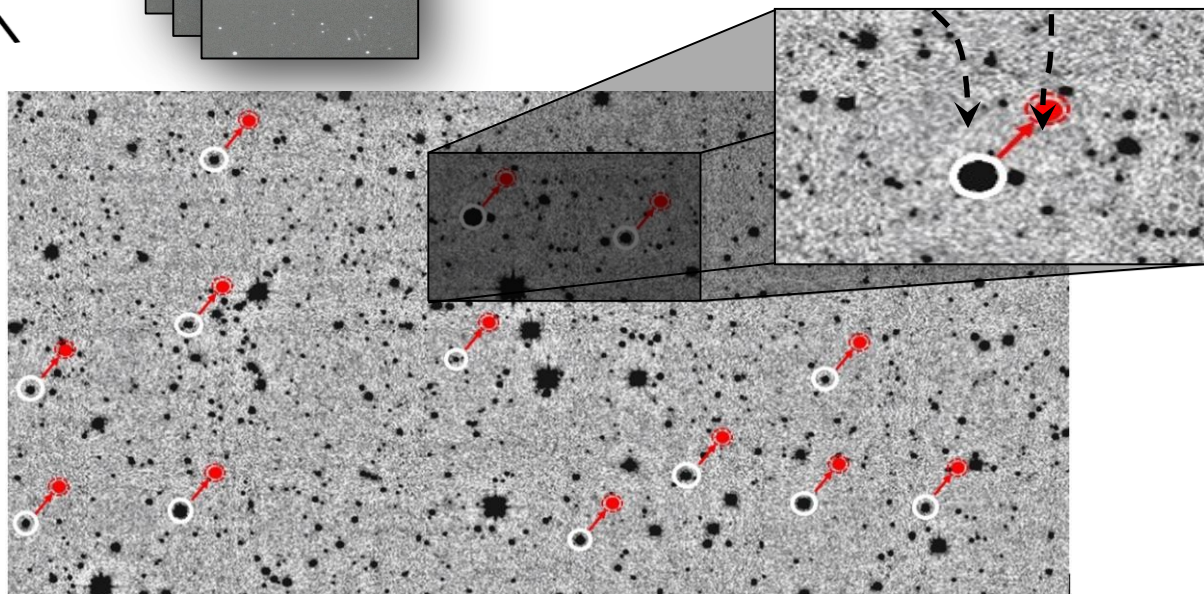
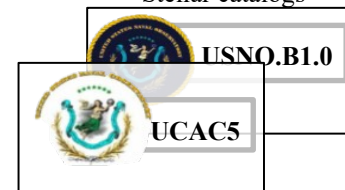
$$\Omega_{nfr} = \{Y_{1nfr}, \dots, Y_{infr}, \dots, Y_{Qnfr}\} \quad (1)$$

$$Y_{infr} = \{A_{infr}; \chi_{infr}\} \quad (2)$$

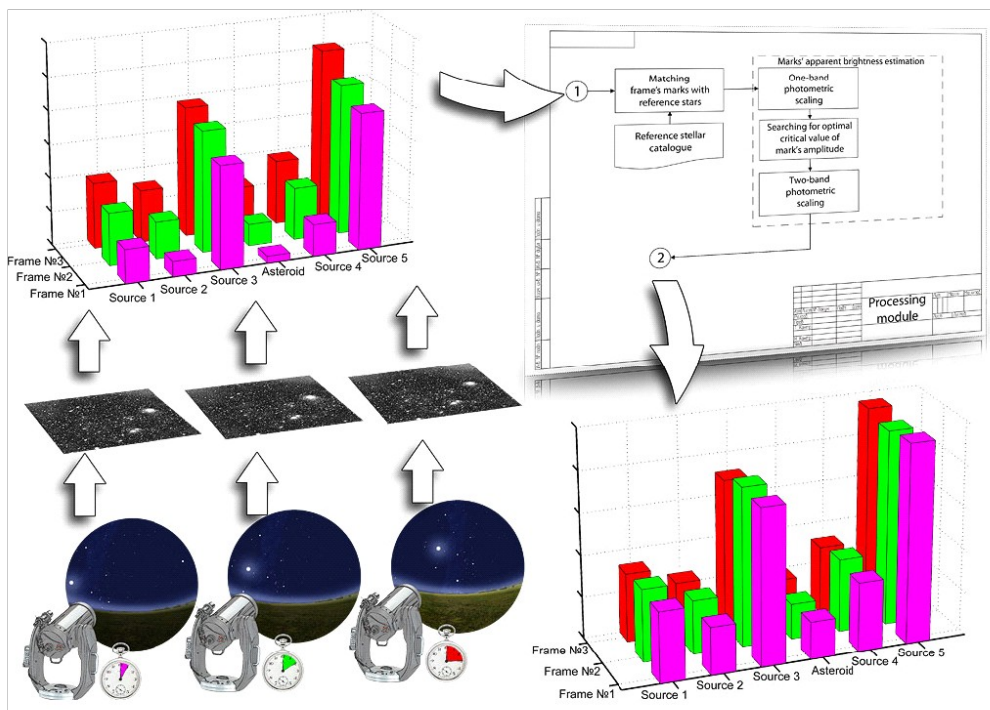
$$\Omega_{cat} = \{\hat{\Theta}_{catj1}, \dots, \hat{\Theta}_{catjn}, \hat{\Theta}_{Qcat}\} \quad (3)$$

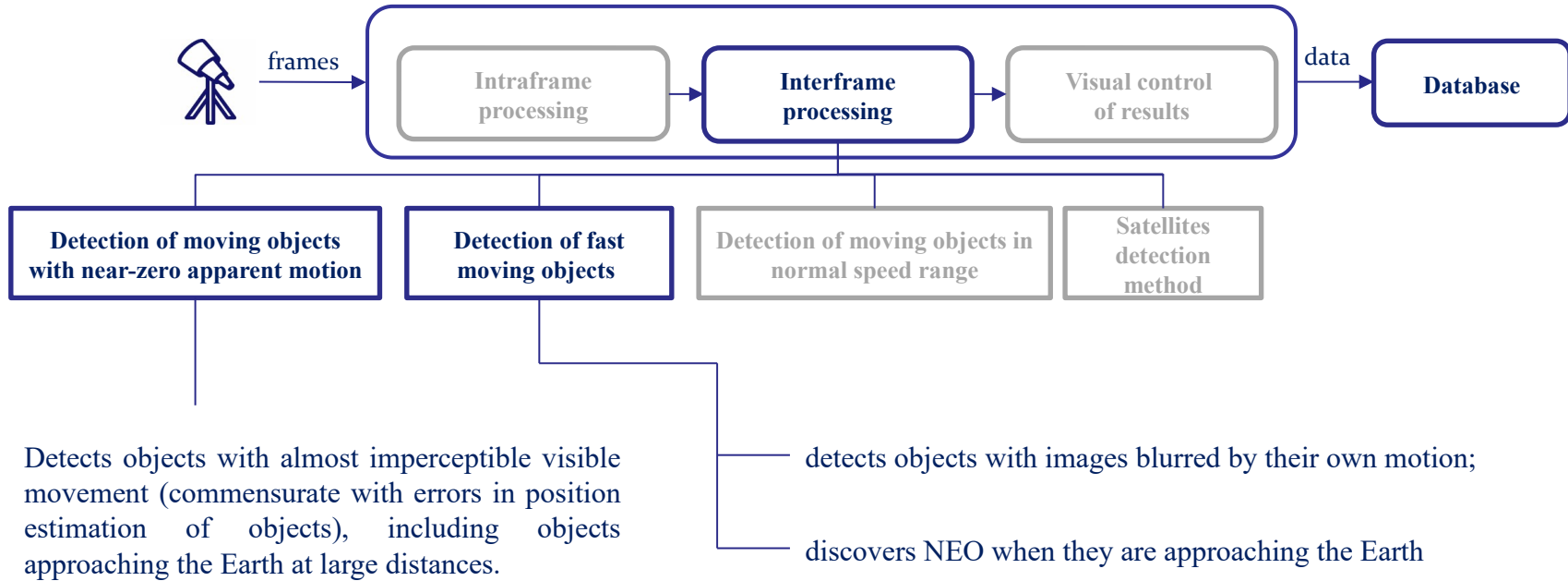
$$\hat{\Theta}_{catjn} = \{\hat{\theta}_{j1}, \hat{\theta}_{j2}, \dots, \hat{\theta}_{jM}\} \quad (4)$$

Stellar catalogs

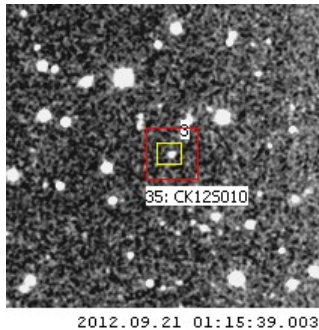
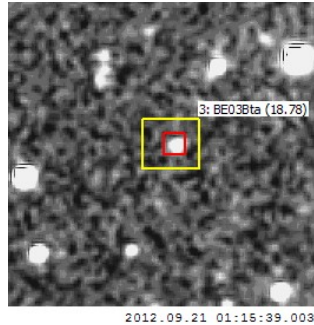


Estimation of asteroids apparent brightness by its signals amplitude

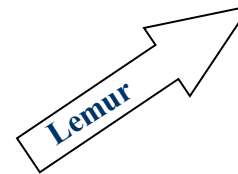
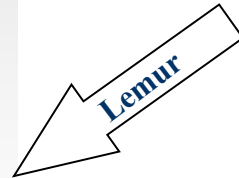




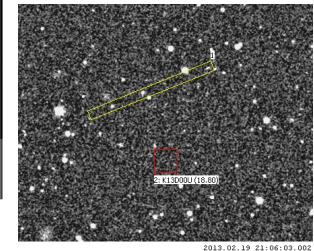
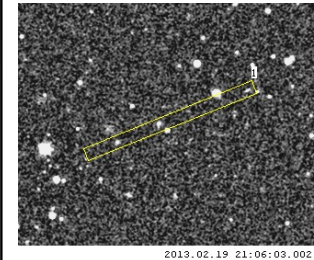
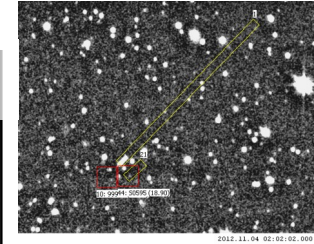
Lemur can detect both very slow and very fast moving object



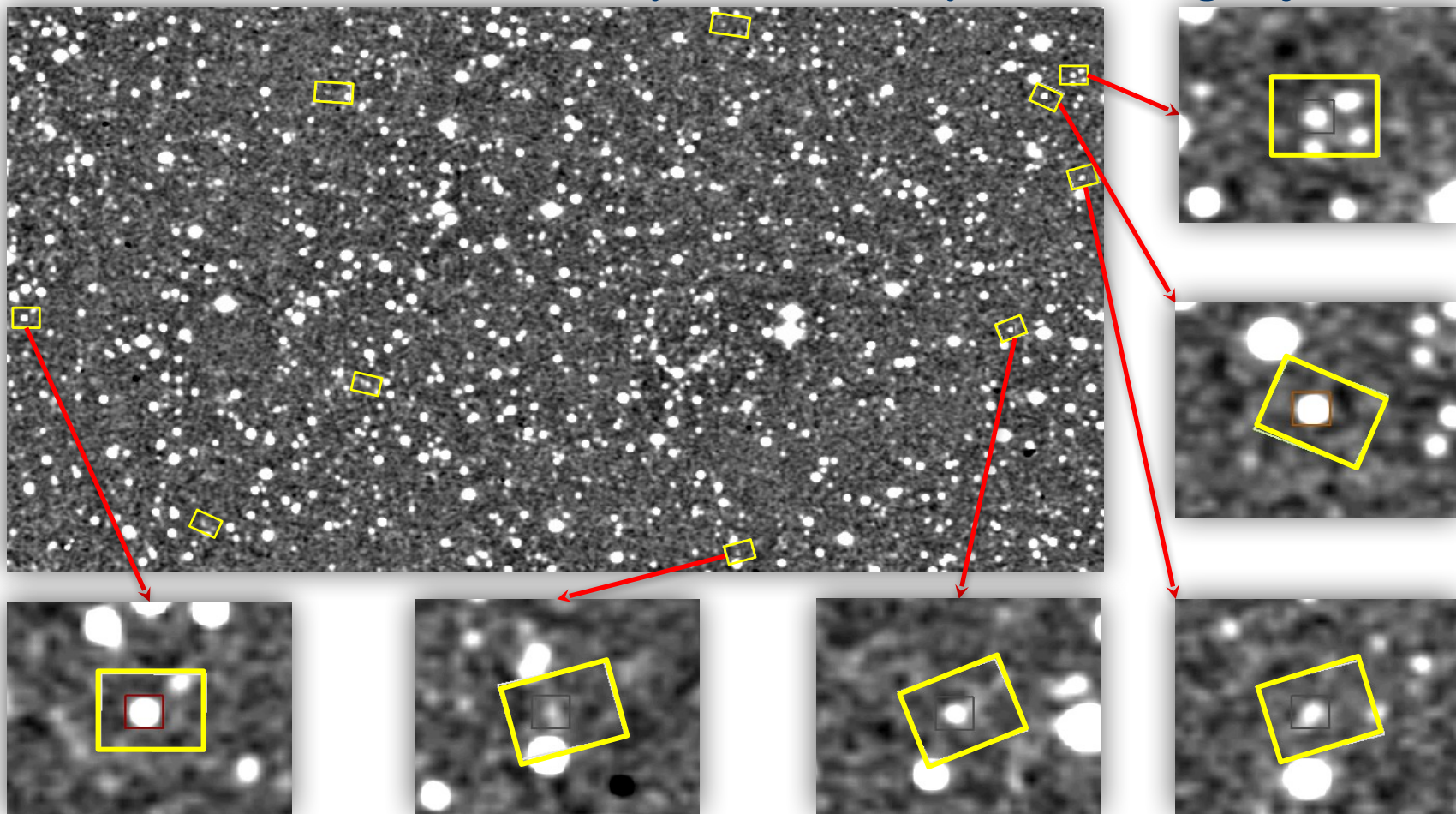
You can see the real images, where Lemur discovered famous comet ISON. On these frames comet is practically not moving between frames. The size of comet about 5 pixels, but it moved only 3 pixels from first to fourth frame.



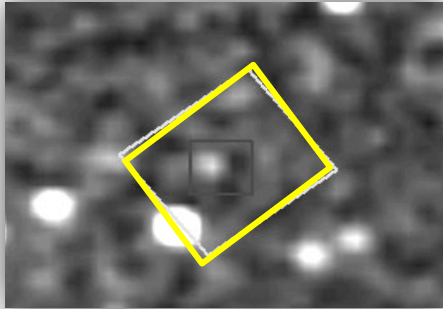
Lemur can detect faint fast moving objects (FMO) by their tracks.



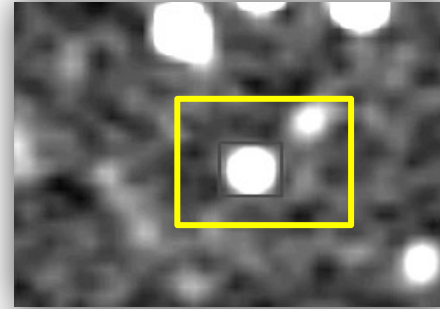
Lemur can detect both very slow and very fast moving object



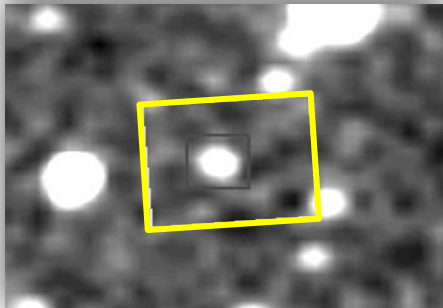
Lemur can detect both very slow and very fast moving object



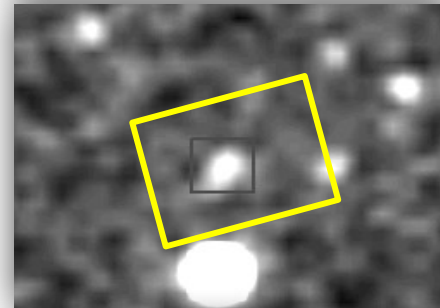
Brightness, mag	19.48
V, arcsec/min	0.282
Vra, arcsec/min	0.212
Vde, arcsec/min	0.186
V, pix/frame	0.921
Vx, pix/frame	0.705
Vy, pix/frame	0.591
S, pix/series	2.763



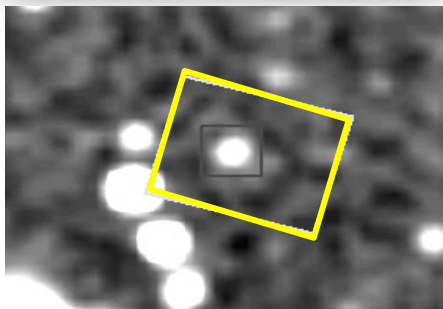
Brightness, mag	17.45
V, arcsec/min	0.451
Vra, arcsec/min	0.441
Vde, arcsec/min	0.094
V, pix/frame	1.467
Vx, pix/frame	1.441
Vy, pix/frame	0.274
S, pix/series	4.401



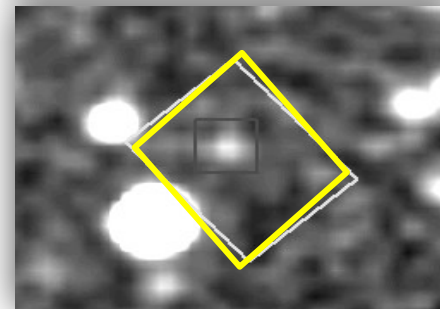
Brightness, mag	17.88
V, arcsec/min	0.360
Vra, arcsec/min	0.358
Vde, arcsec/min	0.036
V, pix/frame	1.175
Vx, pix/frame	1.171
Vy, pix/frame	0.091
S, pix/series	3.525



Brightness, mag	19.11
V, arcsec/min	0.515
Vra, arcsec/min	0.494
Vde, arcsec/min	0.144
V, pix/frame	1.683
Vx, pix/frame	1.626
Vy, pix/frame	0.433
S, pix/series	5.049



Brightness, mag	18.85
V, arcsec/min	0.400
Vra, arcsec/min	0.318
Vde, arcsec/min	0.241
V, pix/frame	1.305
Vx, pix/frame	1.056
Vy, pix/frame	0.766
S, pix/series	3.915

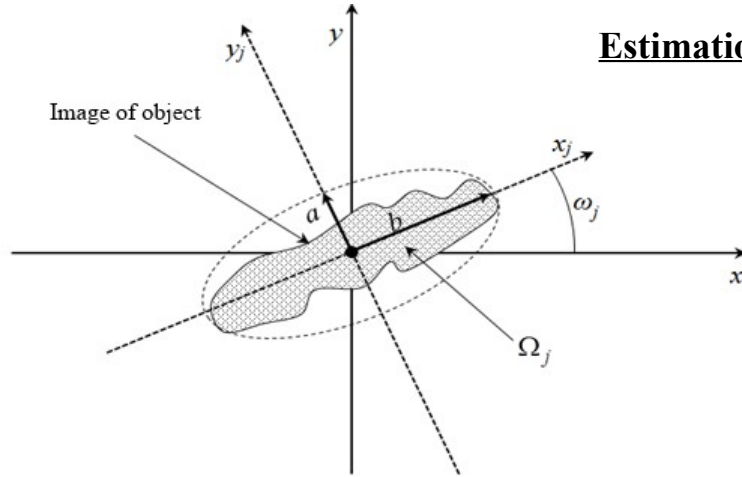


Brightness, mag	19.64
V, arcsec/min	0.638
Vra, arcsec/min	0.434
Vde, arcsec/min	0.468
V, pix/frame	2.084
Vx, pix/frame	1.378
Vy, pix/frame	1.564
S, pix/series	6.252

Method for detection of extended images of objects

Selective signs of extended images of objects during intraframe processing

Estimation of elongation and orientation of object's image

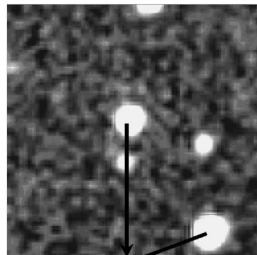


Eccentricity estimation:

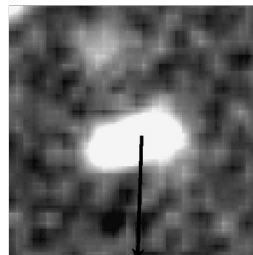
$$\varepsilon_j = \frac{m_{20} + m_{02} - \sqrt{(m_{20} - m_{02} + 4m_{11}^2)}}{m_{20} + m_{02} + \sqrt{(m_{20} - m_{02} + 4m_{11}^2)}}$$

Inclination angle of object:

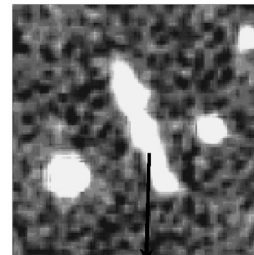
$$\omega_j = \frac{1}{2} \arctan \frac{2m_{11}}{m_{20} - m_{02}}$$



$\varepsilon = 0.0$



$\varepsilon = 0.8$

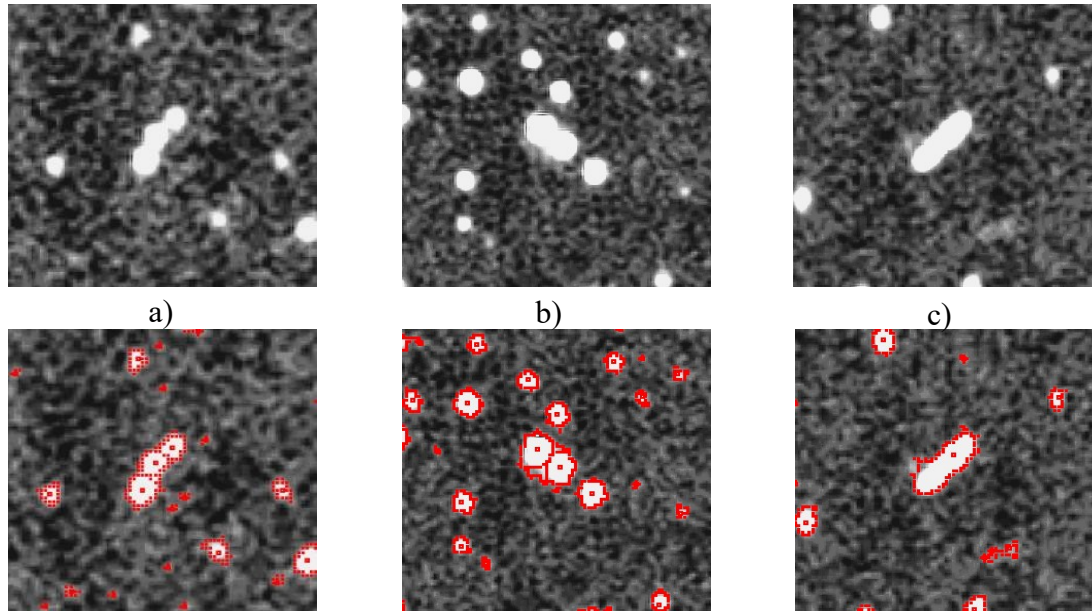


$\varepsilon = 1.0$

Examples of objects images (from point to long)

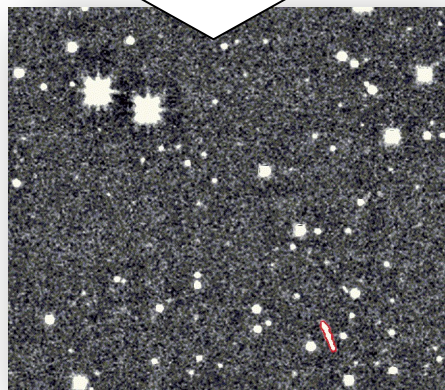
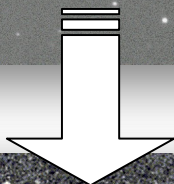
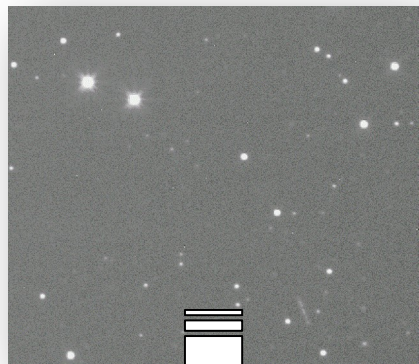
Method for detection of extended images of objects

Checking the belongings of extended images to objects from internal catalog with appropriate rejection (rejection of images of close stars)



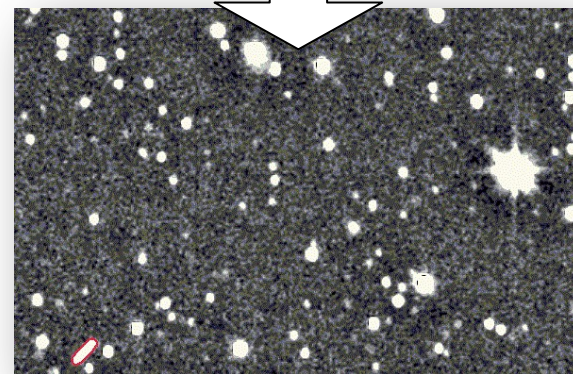
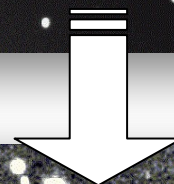
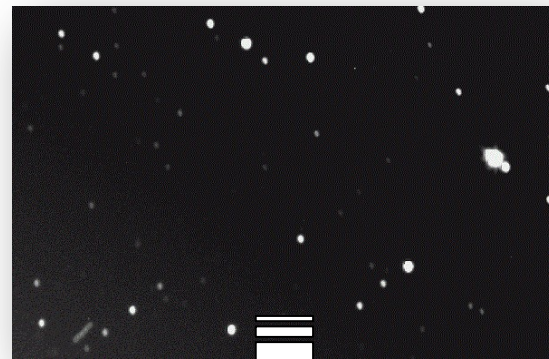
Extended images of objects

Working examples of proposed method for detection of extended images of objects



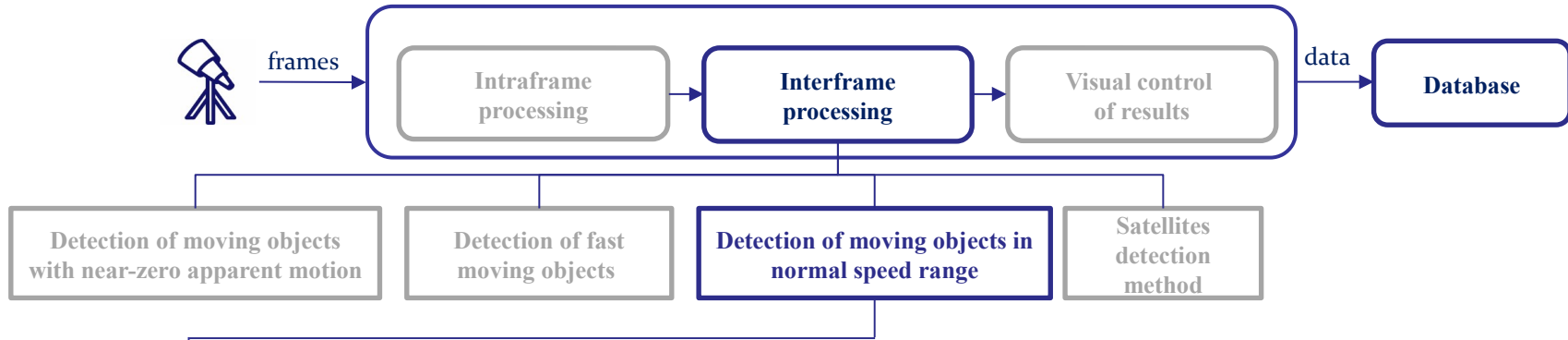
**Characteristics of object
1:**

frame	X_1	Y_1	ε_1	ω_1
1	2557	284	0.9	135.0
2	2637	200	0.9	130.6
3	2707	127	0.9	137.9
4	2779	53	0.9	131.7



**Characteristics of object
2:**

frame	X_2	Y_2	ε_2	ω_2
1	1575	1655	1.0	120.7
2	1539	1559	1.0	111.0
3	1503	1465	1.0	116.6
4	1467	1366	1.0	114.2



— detects and discovers comets, asteroids and satellites in automated mode;

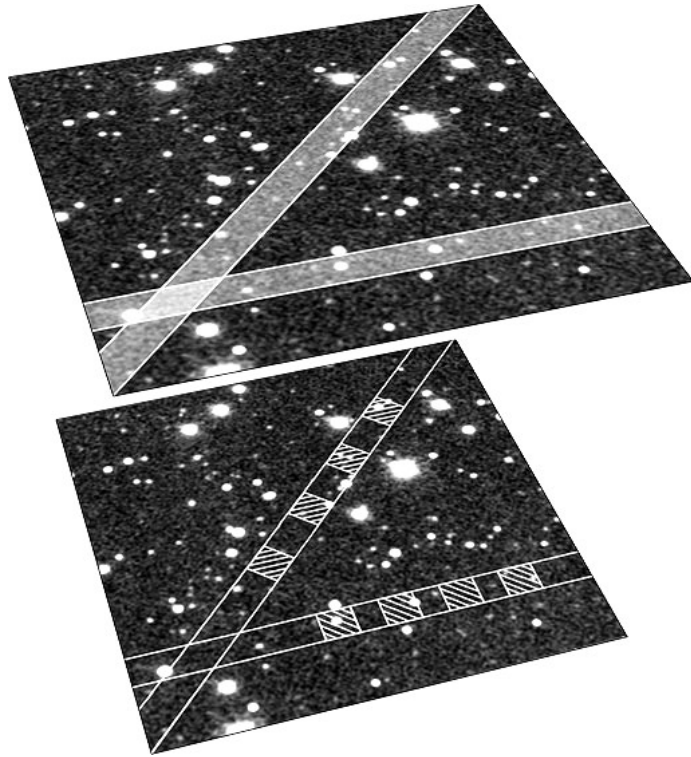
— uses the method of light collecting, which allows energy accumulation of the objects images along trajectories with unknown parameters, which provides high quality detection in telescopes with small aperture;

— works at low thresholds and allows to see very faint and hardly observable objects, for observation of which by traditional methods it is necessary to increase the observing potential in several times;

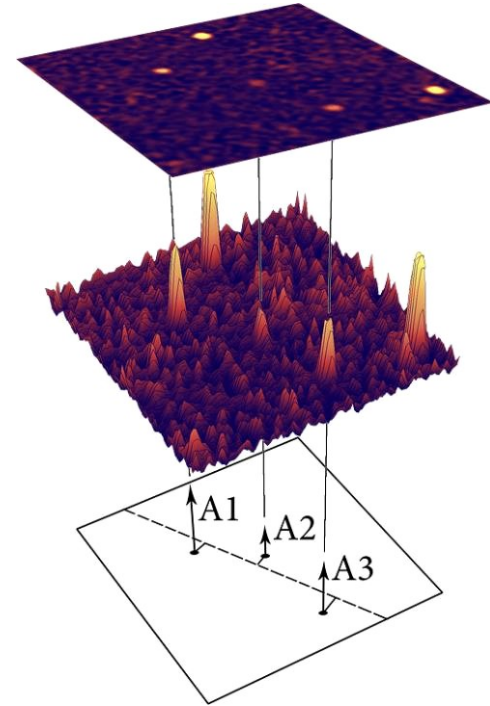
— software has a linear complexity with the measurements number per frame, which allows working at low thresholds and detecting a motion against the background of 5000 false measurements and 20,000 stars.

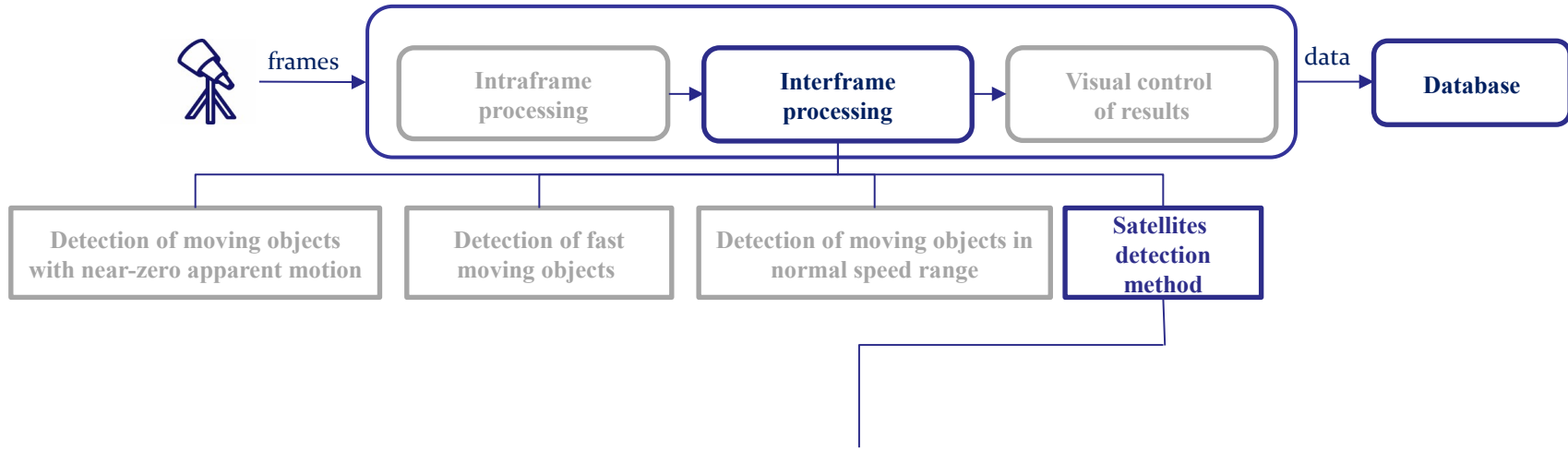
Detection of slow and fast moving objects

Algorithm for moving object detection



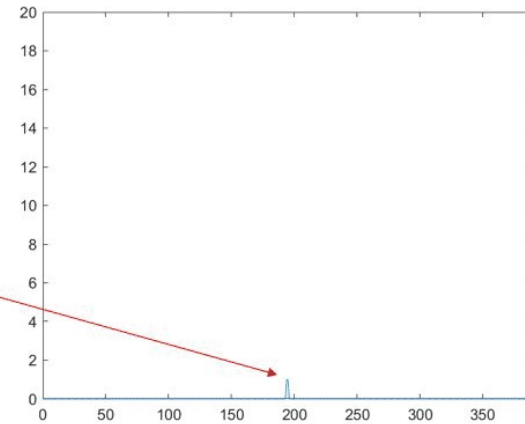
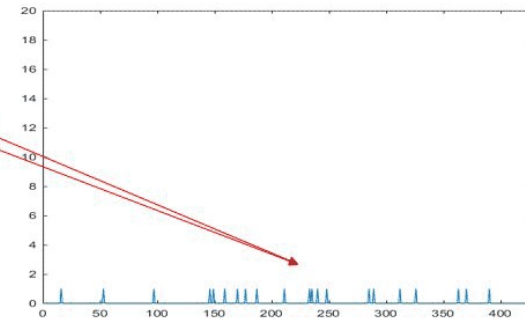
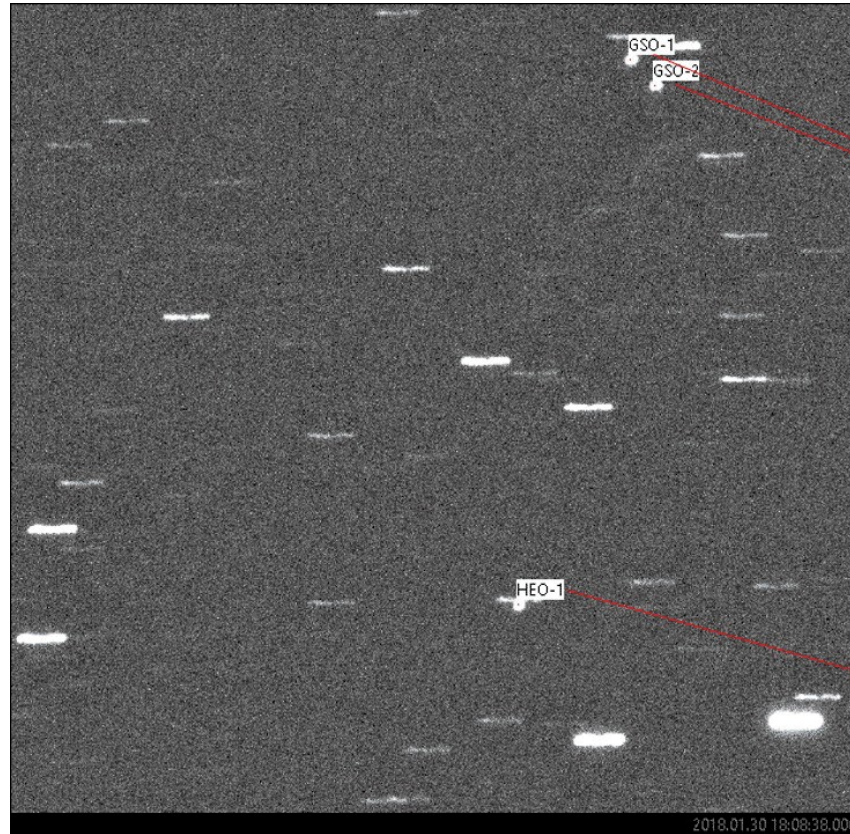
Lemur





Detects satellites with geostationary orbit or high-elliptical orbit on frames with stars background like as strokes made by fixed mounting telescope. Detects satellites with low (LEO) and medium (MEO) Earth orbit.

GSO-Hough detection method





— visualization of a series of frames and detected satellites, comets, asteroids;

— automated satellite measuring in a series of frames: it suffices to mark the satellite in two frames, after which its measurements will be done automatically in the remaining frames with ability to control;

— analysis of satellite measurements in a series of frames: visualization of deviations and measurements censoring;

— reports generation with measurements of asteroids and satellites in the international formats;

— initial determination and clarification of satellite orbit elements;

— on-line loading and identification of detected asteroids and comets from MPC data allows to quickly make a decision about the possible presence of new asteroids and comets in series of frames.



LookSky –visual inspection of asteroids detected

LookSky - Working with Fits files

File Image Tools Window Help

Image view

Manager Objects

Class: Asteroids - Data of ColiTec

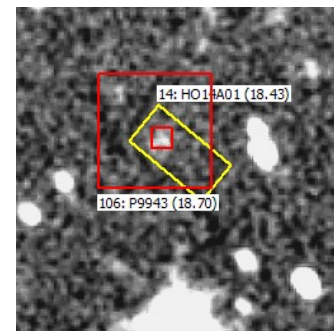
Draw	N	CLTName	V	Vx	Vy	V _{ra}
<input checked="" type="checkbox"/>	1	AA01A12	0.71509	4.769	-1.352	-0.68001
<input checked="" type="checkbox"/>	2	AA02A12	13.89876	-33.658	-90.126	4.98601
<input checked="" type="checkbox"/>	3	AA03A12	0.54567	3.17	-2.047	-0.45869
<input checked="" type="checkbox"/>	4	AA04A12	0.12624	0.474	0.741	-0.06905
<input checked="" type="checkbox"/>	5	AA05A12	0.51162	3.354	-1.177	-0.48157
<input checked="" type="checkbox"/>	6	AA06A12	0.58057	3.999	-0.155	-0.57989
<input checked="" type="checkbox"/>	7	AA07A12	0.70404	4.76	-0.849	-0.69277
<input checked="" type="checkbox"/>	8	AA08A12	0.61177	3.911	-1.583	-0.56684
<input checked="" type="checkbox"/>	9	AA09A12	0.8336	-5.522	-1.862	0.79023
<input checked="" type="checkbox"/>	10	AA10A12	0.57512	3.696	-1.389	-0.53787
<input checked="" type="checkbox"/>	11	AA11A12	0.55796	3.415	-1.831	-0.4896
<input checked="" type="checkbox"/>	12	AA12A12	0.35124	-1.232	-2.142	0.17907
<input checked="" type="checkbox"/>	13	AA13A12	0.60523	3.861	-1.711	-0.55449
<input checked="" type="checkbox"/>	14	AA14A12	0.53211	3.311	-1.773	-0.47011
<input checked="" type="checkbox"/>	15	AA15A12	0.62683	-4.285	-0.664	0.61986
<input checked="" type="checkbox"/>	16	AA16A12	0.58604	3.361	-2.372	-0.4811
<input checked="" type="checkbox"/>	17	AA17A12	0.57948	3.489	-2.125	-0.49255
<input checked="" type="checkbox"/>	18	AA18A12	0.74571	2.708	-4.451	-0.38531
<input checked="" type="checkbox"/>	19	AA19A12	0.64571	4.096	-1.893	-0.58404

Image header

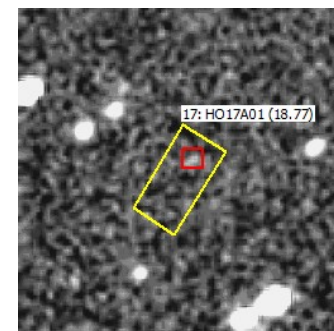
Step_A01-4-001-001.fits

EXPTIME = 2.400000000000E+002 / [sec] Duration of exposure
EXPOSURE = 2.400000000000E+002 / [sec] Duration of exposure
SET-TEMP = -20.000000000000000 / CCD temperature setpoint
CCD-TEMP = -20.000000000000000 / CCD temperature at start of exposure
XPXS2 = 12.000000000000000 / Pixel Width in microns (at YPIX2)
YPIX2 = 12.000000000000000 / Pixel Height in microns (at YPIX2)
XBINNING = 1 / Binning level along the X
YBINNING = 1 / Binning level along the Y
XORGSUBP = 0 / Subframe X position in bits
YORGSUBP = 0 / Subframe Y position in bits
READOUTM = 'Normal' / Readout mode of image
IMAGETYP = 'Light Frame' / Type of image
SITELAT = '32 54 12' / Latitude of the imaging location
SITELONG = '-105 31 42' / Longitude of the imaging location
JD = 2456206.8686342593 / Julian Date at start of observation
TRAKTIME = 0.7200000000000000 / Exposure time used for autotracking
FOCALLEN = 1270.7408988171113 / Focal length of telescope
APTDIA = 455.00000000000000 / Aperture diameter of telescope
APTAREA = 162597.05930203199 / Aperture area of telescope
SWCREAT = 'Maxim DL Version 5.18 130606 18z9w' / Name of the software that created the image

Blink



2013.04.29 03:24:47.000



2013.04.29 03:24:47.000



LookSky –visual inspection of satellites detected

LookSky - viewing and editing colitec-data

File Image Tools Window Help

Manager Survey

#	N	DateTime
01	S	2017.03.23 01:12:20.731
02	S	2017.03.23 01:12:20.784
03	S	2017.03.23 01:12:20.828
04	S	2017.03.23 01:12:20.877
05!	S	2017.03.23 01:12:20.925

Image view

5/5 120

Manager Objects

Class: Satellites - Data of CoLiTec

Draw	N	CLTName	m_m	TrMade	NORAD
<input checked="" type="checkbox"/>	1	HAND001	4.832	MANUA	HAND001

Image pel

☐ X:Y.w
☐ X:Y.b
☒ X:Y.a 495.000 : 310.833
☒ Ra:De 16:03:28.08 -19:26:48.1
☒ I 358.00000

Image area

X:Y.a

Magnifier

x2 x4 x6 x8

Manager of Reports

Format: Mea - Measurement a position and brightness of satellite

SMTP server: smtp.server
Port: 465
Password:

StationCode	2000.0	UTC
HAND001	230317	0112207310 1603253745 -1926353076 0
HAND001	230317	0112207840 1603265471 -1926412404 0
HAND001	230317	0112208280 1603276146 -1926578364 0
HAND001	230317	0112208770 1603287136 -1927056664 0
HAND001	230317	0112209250 1603297427 -1927137412 0

Image header

STEP-16908_011222_230317_33_Exposure=50.0ms_0004.fit

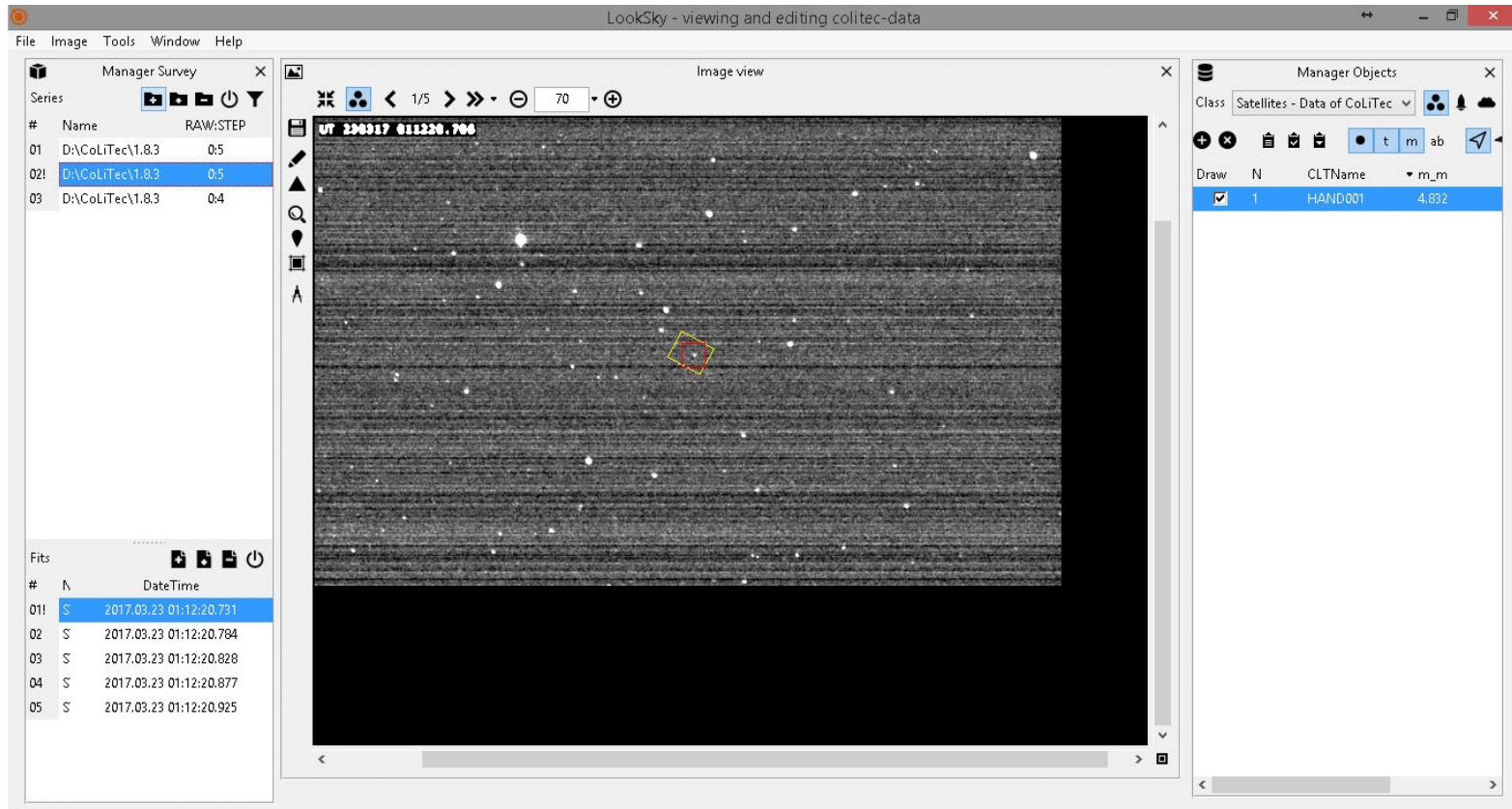
SIMPLE = T / Conforms to FITS standa
BITPIX = 16 / Number of bits per data
NAXIS = 2 / Number of axes
NAXIS1 = 968
NAXIS2 = 608
BSCALE = 1.000000000000 / Data scaling factor
BZERO = 0.000000000000 / Data offset
EXTEND = T / Extension permitted
PCOUNT = 0 / No extra parameters
GCOUNT = 1 / One group
OBSERVER=

Hand Measurer

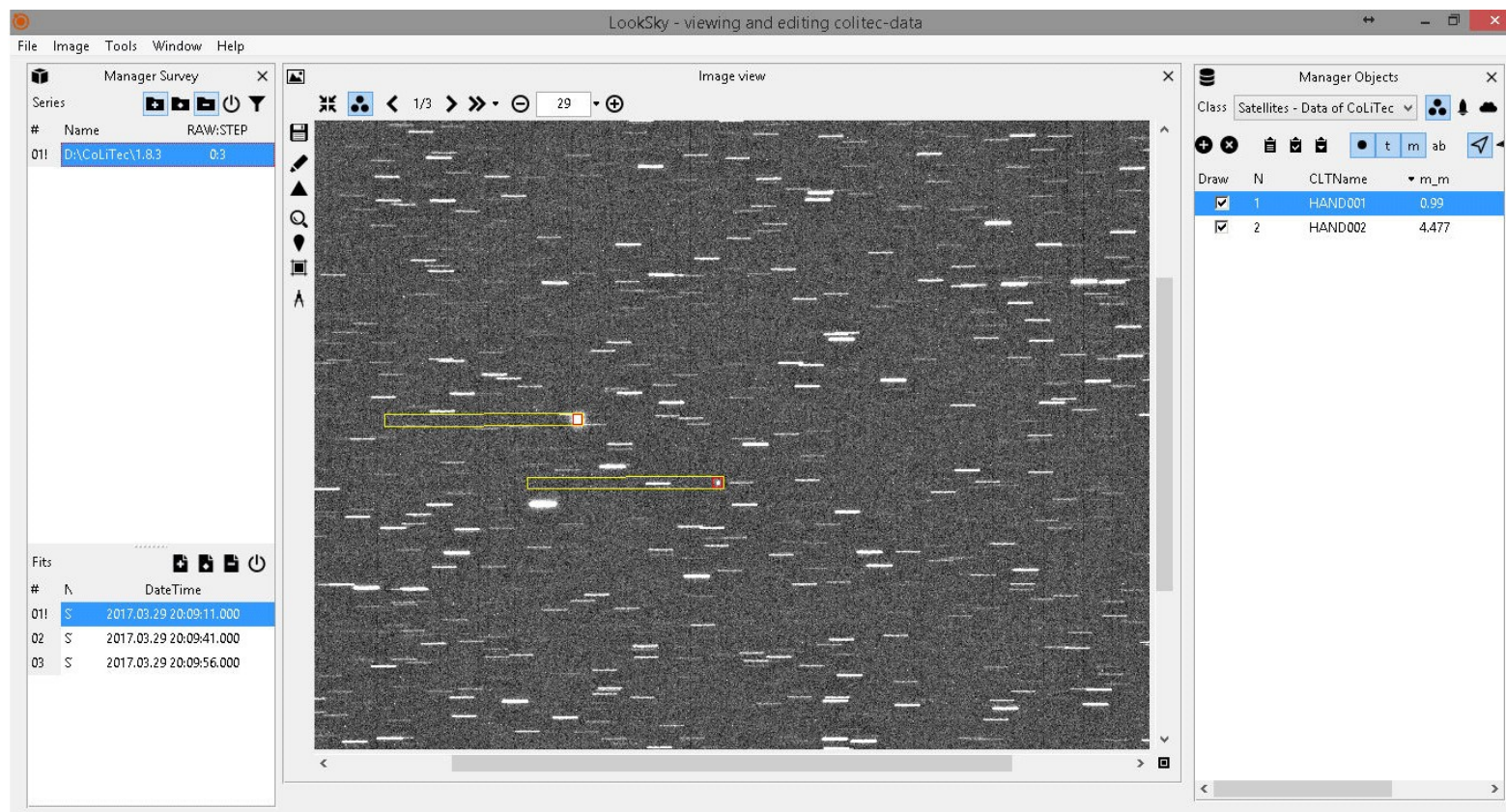
Class: Satellites - Data of CoLiTec

100 4 5.0

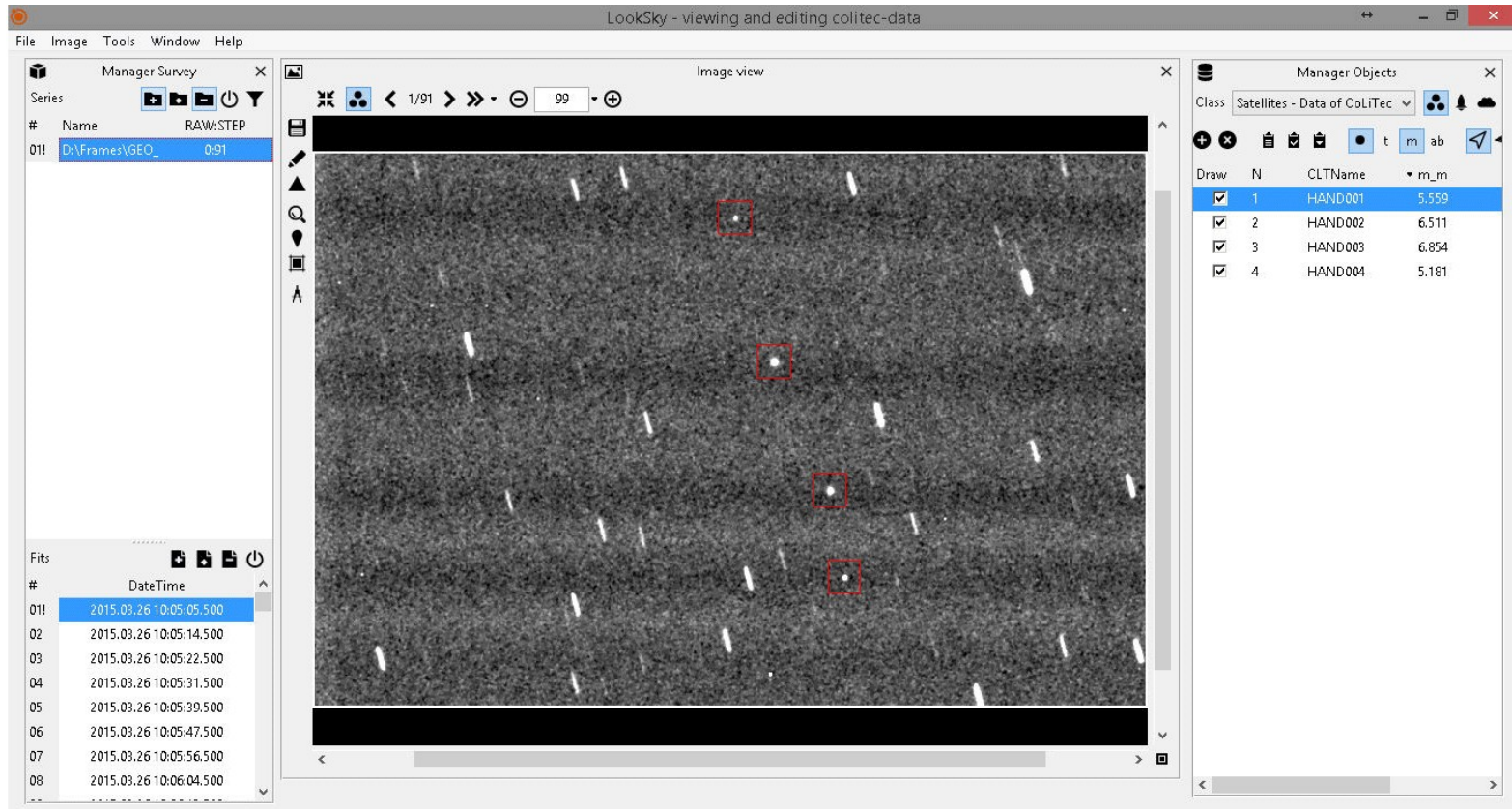
Displaying and navigation of astronomical frames with satellites



Displaying and navigation of astronomical frames with satellites



Displaying and navigation of astronomical frames with satellites



Displaying and navigation of astronomical frames with satellites

LookSky - viewing and editing colitec-data

File Image Tools Window Help

Manager Survey

#	Name	RAW:STEP
01	D:\CoLiTec\1.8.3	0.5
02	D:\CoLiTec\1.8.3	0.5
03	D:\CoLiTec\1.8.3	0.4

Image view

UT 150617 222109.583

Manager Objects

Class: Satellites - Data of CoLiTec

Draw	N	CLTName	m_m
<input checked="" type="checkbox"/>	1	HAND001	5.572
<input checked="" type="checkbox"/>	2	HAND002	4.957
<input checked="" type="checkbox"/>	3	HAND003	5.572

Fits

#	N	DateTime
01	S	2017.06.15 22:21:09.583
02	S	2017.06.15 22:21:10.591
03	S	2017.06.15 22:21:11.587
04	S	2017.06.15 22:21:12.583

A cosmic background image featuring a dark, star-filled space with a prominent, colorful nebula or galaxy structure in shades of purple, pink, and blue, stretching across the top and bottom of the slide.

Our immediate goals:

Online and mass photometry.

Implement the TLE service - it will allow the observer to see the data from the NORAD catalog on the processed frames.

To implement the stacking of the frames in the given range of speeds in order to automatically find the super-weak objects of the solar system.

Improving segmentation, fitting, astrometry, and more...

Thank you!

We are ready for the collaboration!

**Savanevych
Vadym**



[Scopus](#)

[NASA ADS](#)

**Briukhovetskyi
Olexander**



[Scopus](#)

[NASA ADS](#)

**Dikov
Yevhen**



[Scopus](#)

[NASA ADS](#)

**Dmytrenko
Artem**



[Scopus](#)

[NASA ADS](#)

**Khلامov
Sergii**



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