Mobile Device to Digitize the photographic plates:

first results

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Camera, lens and scheme

«Jupiter 21 M»
(vintage Soviet lens)

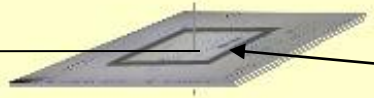
focal length **200 мм**
aperture **1:4.0 ÷ 1:22**
field of view **12°**
resolution (center/edge)
40/30 lines/mm
lens mount **M42x1**

Digital camera Canon EOS 5D Mark II

extension tube

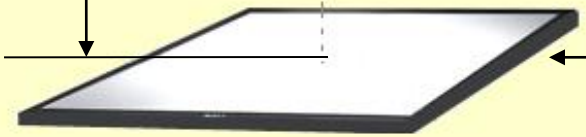
21.1-megapixel
sensor type - **CMOS**
size - **36 x 24 мм**
maximum resolution – **5616 x 3744**
bpp - **42**
ISO **50 - 3200**

~1200 mm



Photographic plate,
photographed area is **80x120 mm**

~1200 mm



LCD as a backlight
(out of focus depth)

NB: Camera, lens and carrier of plate are mounted on a rigid vertical stand which fixed to the main wall to reduce vibrations during process.

Calibration

- 2008, Brussels. Measurement of the template by means of DAMIAN (Digital Access to Metric Images Archives Network)

Template is a photographic plate (16 x 13 cm) with about of 200 round marks which are made by photographic method. Size of mark is **250 - 300** microns

- Correction of distortion, set DAMIAN's measured coordinates X, Y [mm] as standart

- Reduction model

n=3

$$\begin{cases} X = \sum_{i}^{n}\sum_{j}^{i} a_{ij} x^{j} y^{n-j} \\ Y = \sum_{i}^{n}\sum_{j}^{i} b_{ij} y^{j} x^{n-j} \end{cases}$$

x, y — measured coordinates of template marks, **px**.

X, Y — standart coordinates of template marks, **mm**.

- Comparison our measurements with DAMIAN's one

- Calculating of reduction's parameters $\mathbf{a_{ij}}$, $\mathbf{b_{ij}}$

Distortion of DAMIAN's lens

Partly overlapping imagets are taken from template with DAMIAN.
Size of imagets is 7x7 mm (field of lens's view).
About of 100 marks of template were placed on 2 or 4 imagets.

Calculation of differences for camera's coordinates for two imagets:

$$\Delta X\ [mm] = Xpos1 - Xpos2$$
$$\Delta Y\ [mm] = Ypos1 - Ypos2$$

Generation of equations system:

$$\Delta X\ [mm] = f\,(tp_i, X_1[px], Y_1[px]) - f\,(tp_i, X_2[px], Y_2[px])$$
$$\Delta Y\ [mm] = f\,(tp_i, X_1[px], Y_1[px]) - f\,(tp_i, X_2[px], Y_2[px])$$

tp_i – parameters of the transformation of coordinates, obtained taking into account the distortion

X_1, Y_1 – coordinates of mark on 1-st imaget, px.

X_2, Y_2 – coordinates of the same mark on 2-nd imaget, px.

Solution of system by the method of least squares and determination the parameters tp_i . σ_{1X} = **0.15** μ, σ_{1Y} = **0.17** μ.

Correction of distortion

Code of function for coordinate transformation from pixels to mm:

```
void vdam(double x,     // pix
        double y,     // pix
        double* xmm,   // mm
        double* ymm,   // mm
        double XPOSITION,// from fits head
        double YPOSITION,// from fits head
        double ti1, //    ! pixel coordinate of x distortion center.
        double ti2, //    ! pixel coordinate of y distortion center.
        double ti3, //    ! initial scale [mm/pixel] x-axis
        double ti4, //    ! initial scale [mm/pixel] y-ax
        double tp1,// 1. scale  X
        double tp2,// 2. rot.   X
        double tp3,// 3. offset X  not used
        double tp4,// 4. scale  Y
        double tp5,// 5. rot.   Y
        double tp6,// 6. offset Y  not used
        double tp7,// 7. dist.Off.X
        double tp8,// 8. dist.Off.Y
        double tp9 // 9. distor.
        )
{
   x = x+1;
   y = y+1;
   y = 1025-y;
   x = (x - ti1) * ti3;
   y = (y - ti2) * ti4;
  double r2 = x*x + y*y;

  double dx = tp1*x + (tp2*y-tp7*(3.0*x*x+y*y)
                - tp8*x*y*y  + tp9*x*r2);

   double dy = tp4*y+tp5*x-tp7*x*y*y
                - tp8*(x*x+3.0*y*y) + tp9*y*r2;

   *xmm = 1281*ti3-dx +XPOSITION;

   *ymm =         +dy +YPOSITION;

 }
```

Calibration

- Digitization of template by Canon camera and measurements

- Reduction model

n=3

$$\begin{cases} X = \sum_{i}^{n}\sum_{j}^{i} a_{ij} x^{j} y^{n-j} \\ Y = \sum_{i}^{n}\sum_{j}^{i} b_{ij} y^{j} x^{n-j} \end{cases}$$

x, y — measured coordinates of template marks, **px**.

X, Y — standart coordinates of template marks, **mm**.

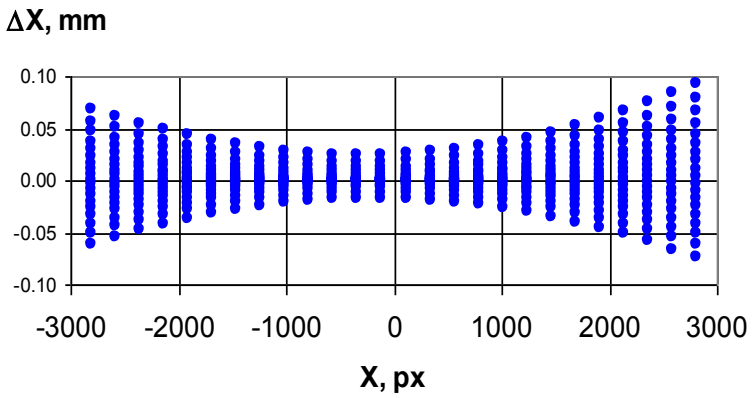
- Comparison our measurements with DAMIAN's one

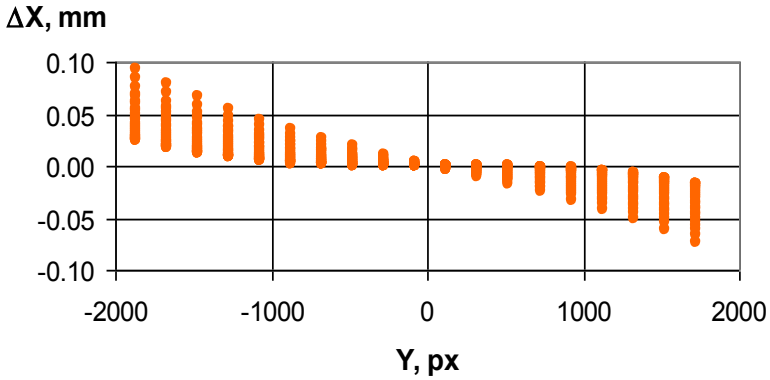
- Calculating of reduction's parameters $\mathbf{a_{ij}}$, $\mathbf{b_{ij}}$

Systematic errors before correction

The dependence of the systematic errors in **X**

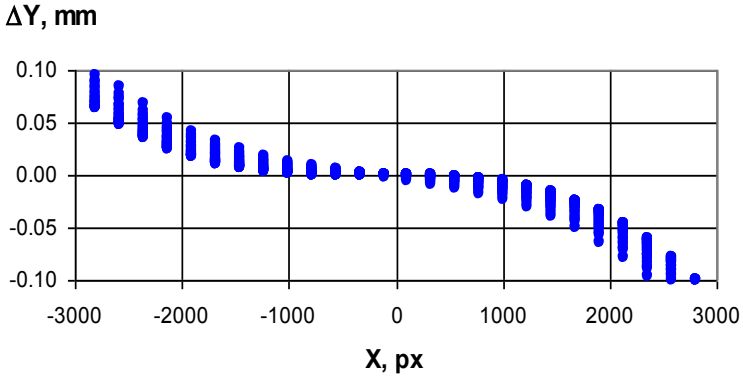
from X-coordinate and from Y-coordinate

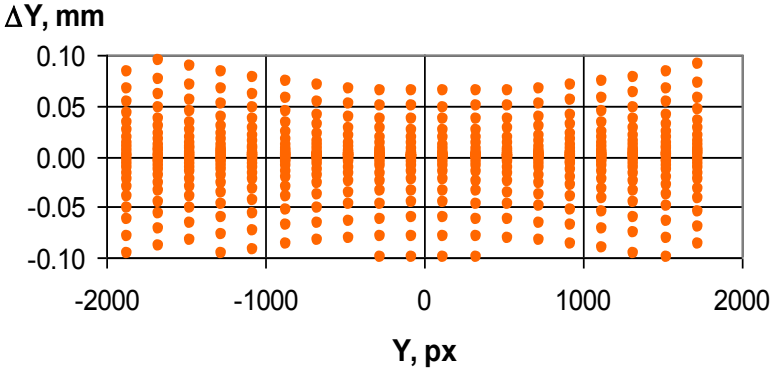


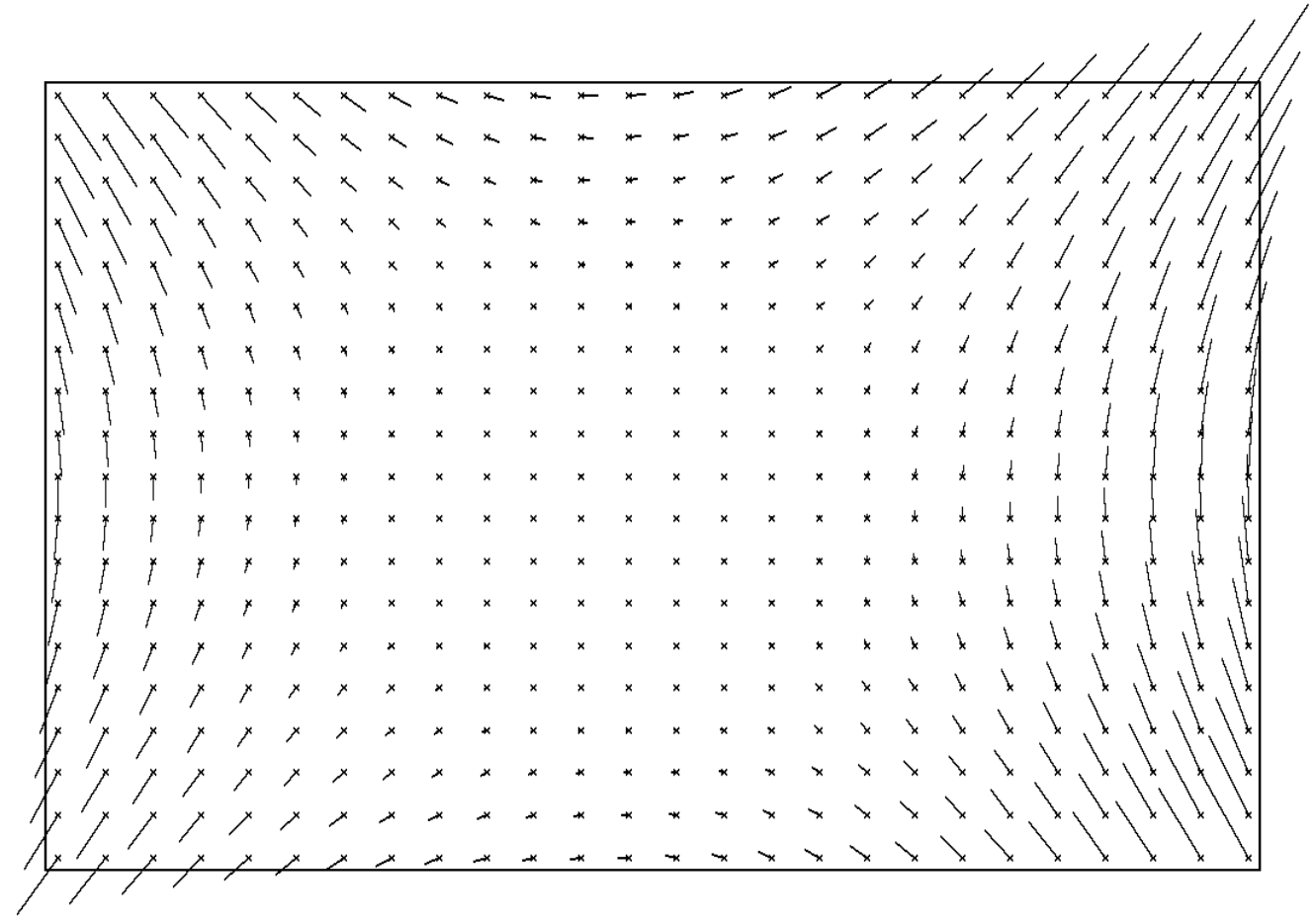


The dependence of the systematic errors in **Y**

from X-coordinate and from Y-coordinate

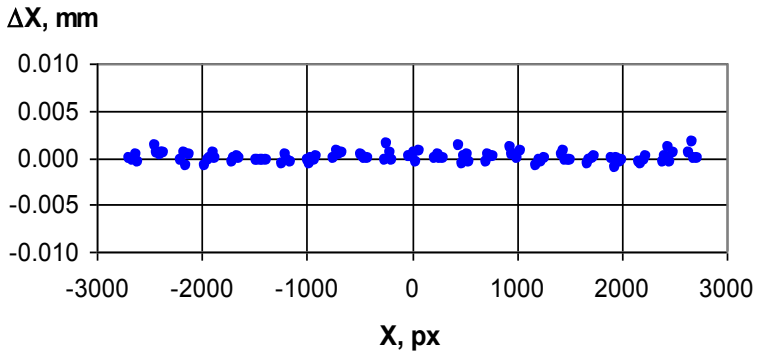


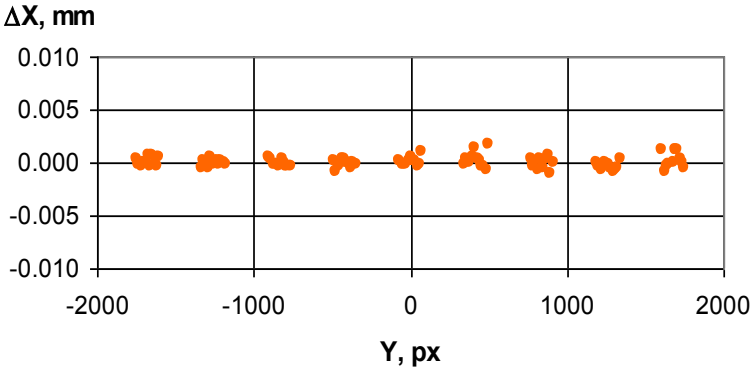




The vector field of systematic errors of the digitized image (3744x5616 px).
Maximal errors are **0.0900 mm** for **X** and 0.1000 mm for **Y**.

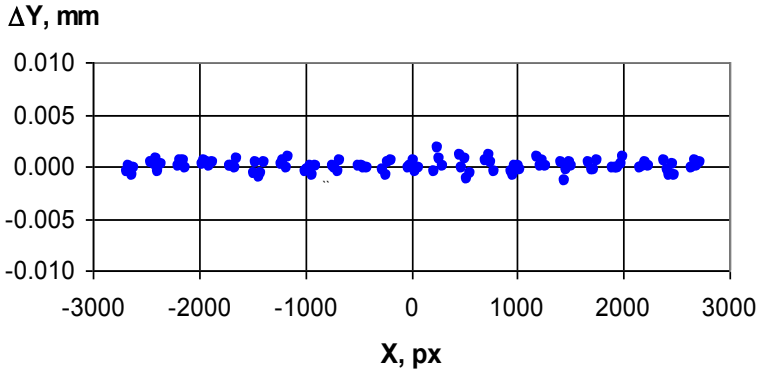
Residuals

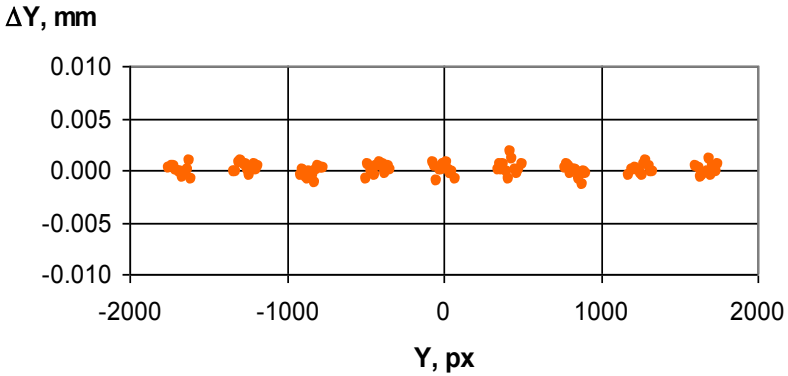




The dependence of the residuals in **X**

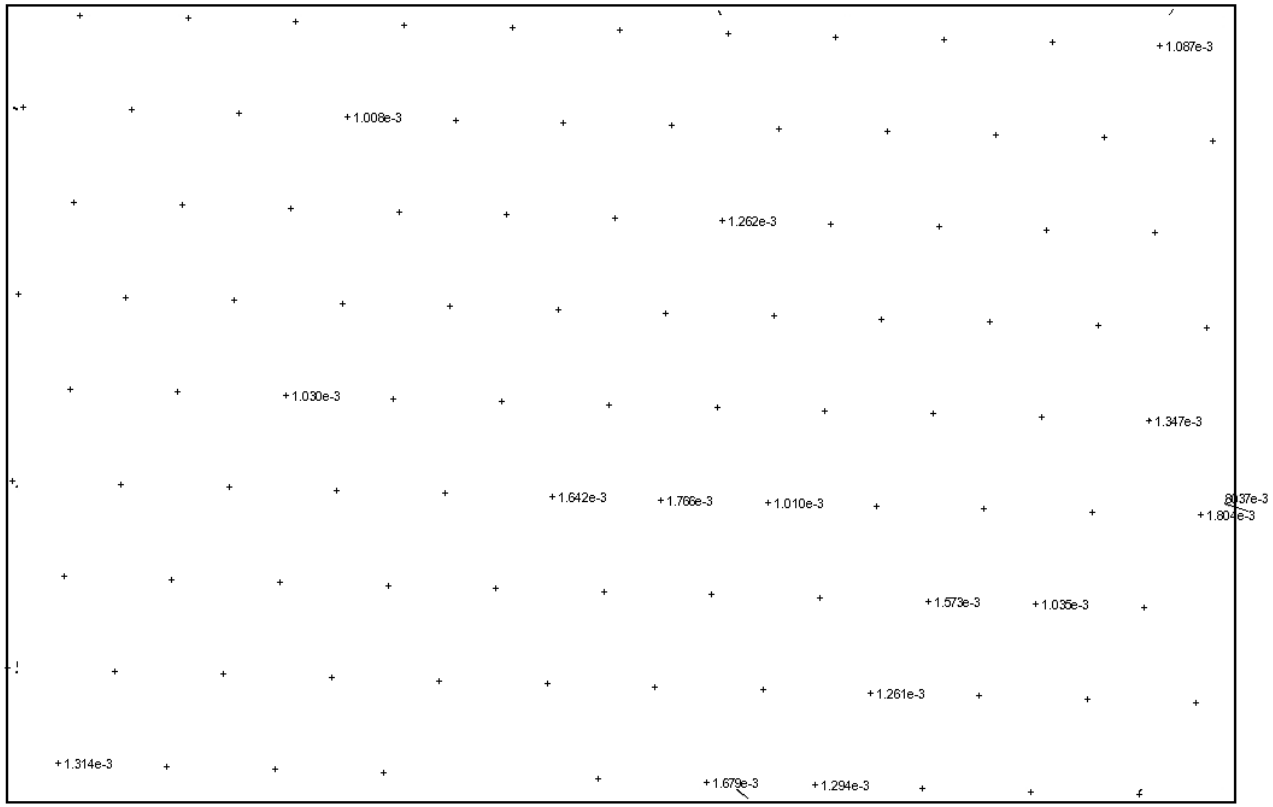
from X-coordinate and from Y-coordinate





The dependence of the residuals in **Y**

from X-coordinate and from Y-coordinate



$\sigma_{1X} = 0.56\ \mu$, $\sigma_{1Y} = 0.63\ \mu$, number of measurements - 30

Residuals after correction of aberrations.
Maximal errors are **0.0017 mm** for **X** and **0.0017 mm** for **Y**
at the egde of image

Stability of measurements

Template was digitized at different positions and was measured for several times. The comparison was made using the Turner's method.

rms, μ	σ_X	σ_Y	**N**
multiple digitization **without plate offset**	**0.37**	**0.39**	**10**
multiple digitization **with plate offset**	**0.49**	**0.50**	**10**
comparison of digitized template with one, **turned on 180°**	**0.73**	**0.88**	**10**
comparison of digitized template with one, **turned on 90°**	**0.63**	**0.63**	**10**

Table 1. Stability of measurements. N – number of digitizations and measurements used for deriving an average error.

Test: measurements of ADS 8002

Photographic plates

- **55 plates** by 26-inch refractor (D 65cm, F10413mm, Scale 19.80"/mm).
- 5 reference stars into area of 75x90 mm.
- number of exposures - 5 ÷ 20.
- **1 px** of digitized image corresponds to **21 μ** of plate.

Previous measurements

- by semi-automatic measuring mashine "Askorecord"
- by automatic measuring machine "Fantasy"
- scanner Microtek Scan Maker i900 by two methods

The optimal shooting mode for the best image:

- Spectral range – white background
- Aperture - 8
- Exposure - $\frac{1}{4}$, ISO 400
- Lens - 300 mm «TAIR-3» vs 200mm «Jupiter 21 M»

- "Live-view" mode with raised the mirror
- Pause before shooting
- Multiple shooting of plate

Comparison of accuracies

	N	mean σ	ADS 8002 A		ADS 8002 B	
			σ_X [μ]	σ_Y [μ]	σ_X [μ]	σ_Y [μ]
Fantasy	**25**	**0.81**	**0.77**	**0.83**	**0.97**	**0.66**
Askorecord	**25**	**1.57**	**1.34**	**1.72**	**1.29**	**1.95**
Fantasy	**36**	**0.84**	**0.81**	**0.82**	**1.06**	**0.68**
Scaner by method 1	**36**	**2.95**	**1.88**	**3.72**	**2.57**	**3.65**
Fantasy	**30**	**0.77**	**0.67**	**0.75**	**1.00**	**0.64**
Scaner by method 2	**30**	**1.80**	**1.51**	**1.56**	**2.61**	**1.49**
Fantasy	**40**	**1.03**	**1.00**	**1.11**	**1.19**	**0.83**
digitized by Canon	**40**	**1.02**	**1.03**	**0.95**	**1.07**	**1.01**

Table 2. Standard deviations (in microns) for one plate in X and Y for components A and B of double star ADS 8002. N- number of plates used for comparison.

Average accuracy of measuring methods

«Askorecord»	1.94
Scanner (method by I. Izmailov)	3.51
Scanner (method by S. Kalinin)	2.33
«Fantasy»	1.00
Digitization by Canon	0.99

Accuracy of Fantasy's measurements is adopted as 1

Results – trigonometric parallaxes of ADS 8002 components

By automatic measuring machine "Fantasy" -

$\pi_A = 43.25 \pm 6.3$ mas

$\pi_B = 31.9 \pm 7.5$ mas

By measurements of plates digitized with camera **Canon**

$\pi_A = 51.22 \pm 6.6$ mas

$\pi_B = 30.9 \pm 6.6$ mas

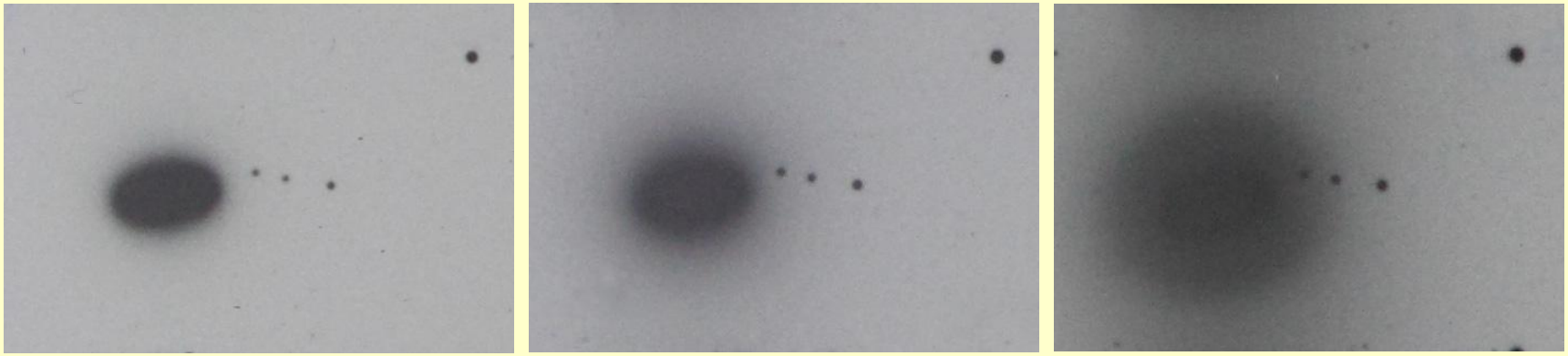
Example of photographic observations of Saturn's satellites

Observational material: 1975 jan, feb, mar, 10 nights, 24 plates

Objects: **S2 - S8**

Emulsions and exposures:

ORWO NP 27 1^m | ORWO NP 27 3^m | KODAK 103ad 3^m



Digitization, measurements and reduction:

- Digitization template and plates by camera Canon (2 plates per minute)
- Measurements with software package IZMCCD (by I. Izmailov) – **x,y [px]**. Centers of images are defined by Moffat profile
- Calibration and transformation **x,y [px]** to **X, Y [mm]**
- Astrometric reduction by Turner's method (9-12 reference stars for plate) using TYCHO2 as reference catalog

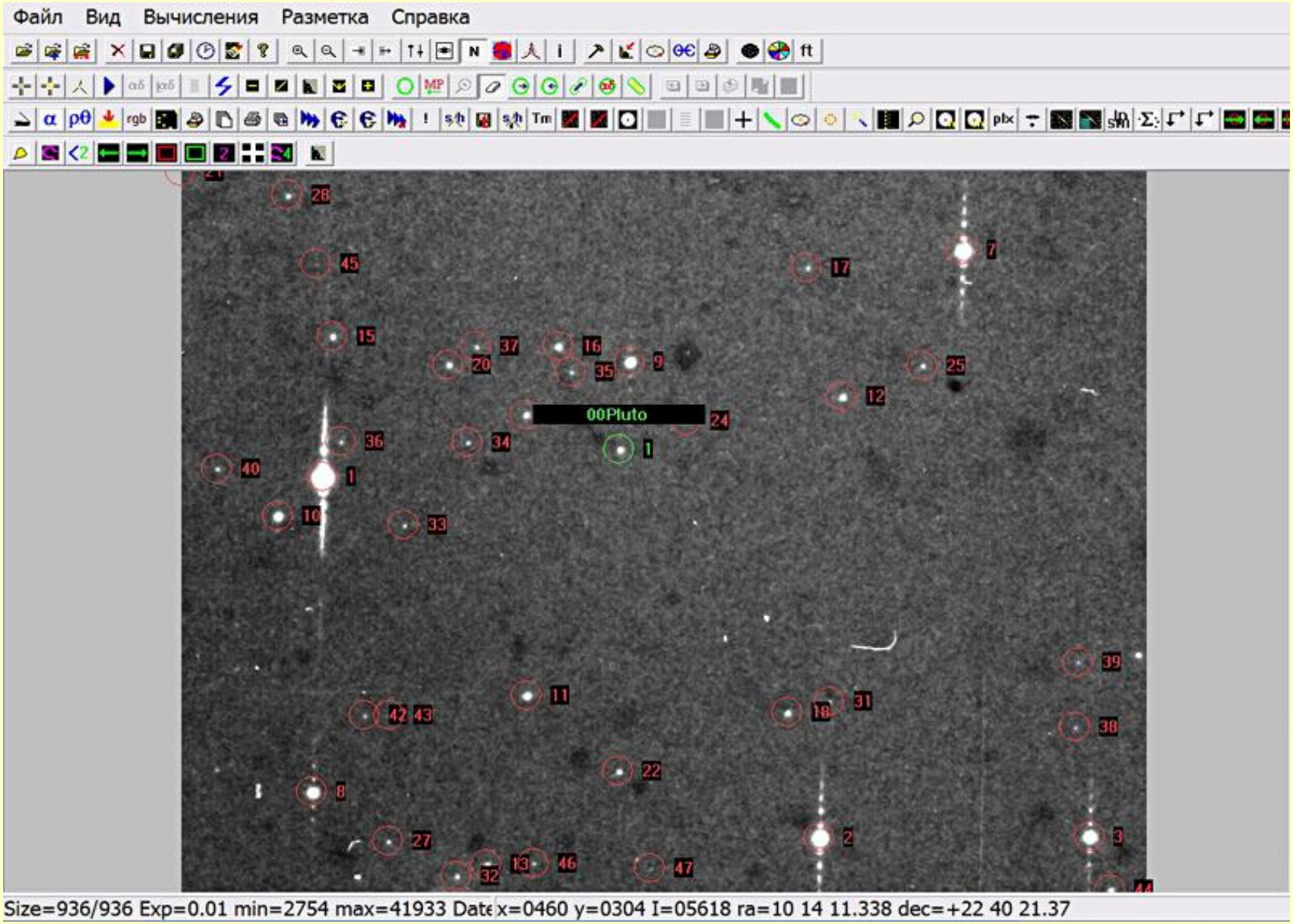
Comparison with a theory

All theoretical positions of Saturnian satellites were taken with Natural Satellites Ephemeride Server **MULTI-SAT** (N.Emelyanov). Ephemeris were calculated according to theory NOE-6-2011-MAIN (V.Lainey, 2011).

Satellite	**mean** $(O-C)_\alpha \cdot \cos\delta$	**mean** $(O-C)_\delta$	$\sigma_{(o-c)\alpha}$	$\sigma_{(o-c)\delta}$	ε_α	ε_δ
Enceladus S2 8 position	**-0.16**	**0.09**	**0.24**	**0.27**	**± 0.15**	**± 0.12**
Tethys (S3) 23 positions	**-0.04**	**-0.01**	**0.16**	**0.06**	**± 0.06**	**± 0.03**
Dione (S4) 52 positions	**-0.03**	**0.04**	**0.13**	**0.10**	**± 0.04**	**± 0.04**
Rhea(S5) 67 positions	**-0.07**	**0.01**	**0.12**	**0.09**	**± 0.04**	**± 0.03**
Titan (S6) 82 positions	**-0.12**	**0.02**	**0.16**	**0.08**	**± 0.05**	**± 0.03**
Hyperion (S7) 8 positions	**0.00**	**-0.07**	**0.24**	**0.22**	**± 0.30**	**± 0.16**
Iapetus (S8) 71 positions	**-0.07**	**-0.01**	**0.16**	**0.09**	**± 0.07**	**± 0.04**

Mean values of (O-C) residuals, standard deviation σ, arcsec, and average errors of mean positions ε, arcsec.

Plates with Pluto images



Pluto positions

64 plates with Pluto were obtained with Normal Astrograph and digitized with Canon camera (now in process of data treatment).

(O-C) for Pluto from some plates

	By our method		by DAMIAN	
UTC	$(O-C)\alpha*\cos\delta$	$(O-C)\delta$	$(O-C)\alpha*\cos\delta$	$(O-C)\delta$
1956 03 16.883330	0.11	-0.13	-0.21	-0.26
1956 03 31.809130	-0.05	-0.11	-0.23	-0.25
1956 04 30.885810	0.43	0.01	-0.22	-0.13

Advantage and shortcoming

Some advantages of this method of digitization:

- Digitization speed – 2 plates per minute;
- Absence of distortions caused by the irregularity of the movement scanner line;
- Absence of distortions associated with the mosaic of the image;
- Distortion of digitized image are caused by lens aberrations and easy to correct;
- Camera is easily replaced in the case of failure or upgrade to next model;
- Stand with the carrier of the plate and camera is mobile and may be delivered to remote storage of glass plates;
- Low cost: camera < 2000 euro, lens - priceless, others components - some more 300 euro.

Disadvantage:

Low resolution. **1 px** of digitized image corresponds to **21 μ** of plate.

Conclusion

Digitization of photoplates with Canon EOS 5D Mark II camera,

equipped with «Jupiter 21M» lens,

are suitable for measurements for astrometric goals.

Thank you for attention!

Camera and lens

Canon EOS 5D Mark II

21.1-megapixel full-frame **CMOS** digital camera
sensor size **36 x 24 мм**
maximum resolution **5616 x 3744**
bpp - **42**
ISO **50 - 3200**

«Jupiter 21 M»
(vintage Soviet lens)

- focal lenght **200 мм**
- aperture **1:4.0 до 1:22**
- field of view **12°**
- resolution (center/edge) **40/30 lines/mm**
- lens mount **M42x1**