Y. Chernetenko, L. Gudkova, R. Gumerov,
I. Khamitov, O. Kochetova, N. Maigurova,G. Pinigin

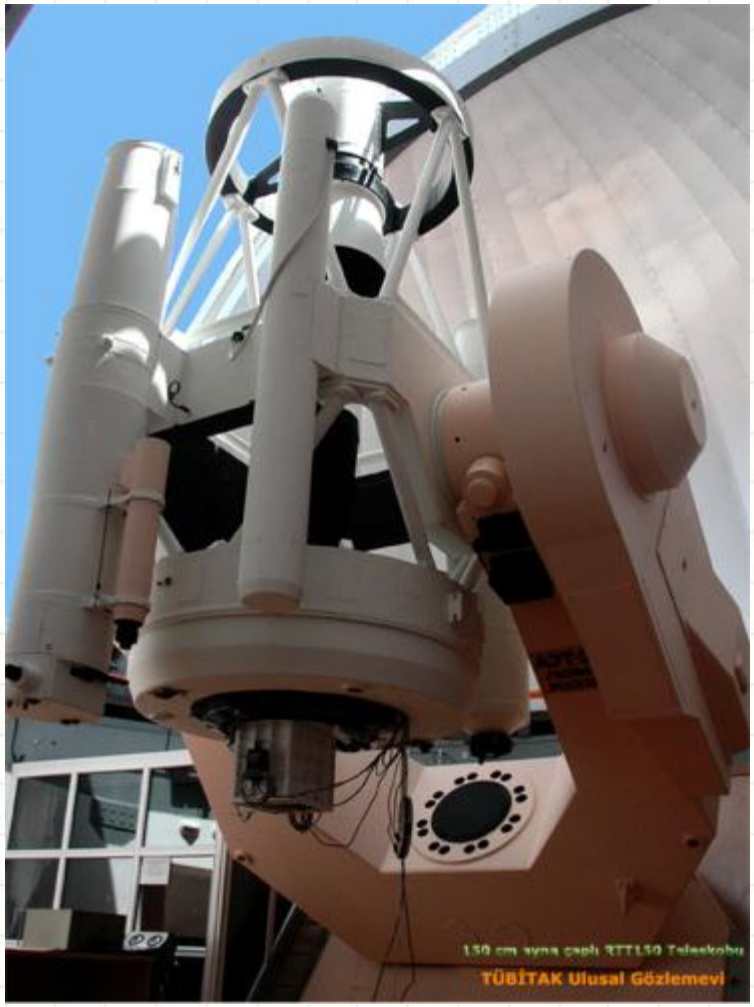
Asteroid observations for mass determination at RTT-150 during 2004-2013

Nadiia Maigurova
Nikolaev Astronomical Observatory,
Ukraine

Plan

- Telescope
- List for observations
- Analysis of astrometrical observations of perturbed asteroids
- Using RTT-150 astrometric observations for mass determination of perturbing asteroids

Russian-Turkish Telescope (D=1.5m)



Taken from
http://www.tug.tubitak.gov.tr/images/rtt150.jpg

Location: Tubitak National Observatory

Observatory Code A84

Coordinates: 36° 49' 27'' N, 30° 20' 08'' E

Elevation: 2500 м

Focal Plane Instruments : CCD-cameras

ANDOR (2Kx2K, 13.5x13.5mkm, 8.2'x8.2 ' FOV, 0.24”/pixel), focus =11.5m

TFOSK (2Kx2K, 15x15mkm, 13' x13' FOV, 0.39”/pixel)

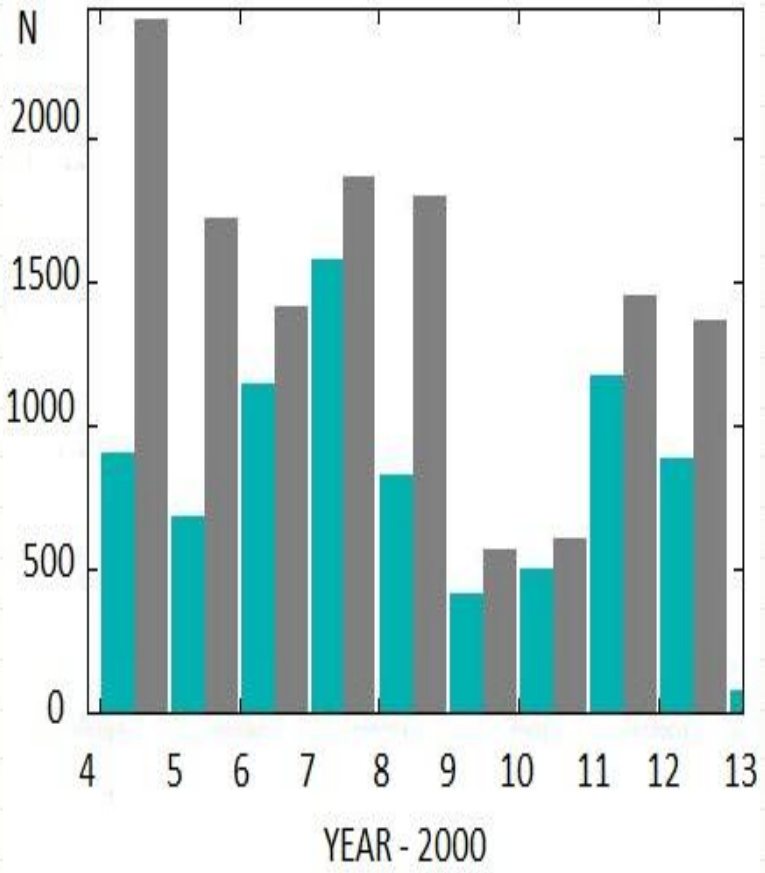
Photometric Systems

Bessel UBVRI

SDSS u'g'r'i'z'

CHARACTERISTICS OF THE RTT-150 ASTEROID OBSERVING PROGRAM

- Time coverage . . . . . **2004 -2013**
- Number of asteroids **231**
  for dynamical mass determination **96**
- Total number of observations . . . **~14.000/8.000**
- Mean number of observations per asteroid **10.4**
  Median **6**
- Mean positional accuracy (RA/DEC), (mas) **.84/68**
- Reference frame **ICRF/UCAC2-4**
- Photometric Systems **V, B, R, g'r'**
- Exposure times (s) **5-300**
- Limiting magnitude (in R). **20.3**
- Declinations observed (deg) . . . . . **.+72 - -30**
  for dynamical mass determination **.+48 - -30**



Number of RTT-150 asteroid observations
Grey column – total, blue column – for mass determination

List for observations

Wide spread of dynamic method of mass determination became available thanks to:

1. Increased accuracy of the modern astrometric catalogues
2. Growing number of astrometric measurements
3. Increased accuracy of ground-based observations

List for observations

- **Program**：lists of single and multiple close encounters by Fienga A. et al., (2003), Galad A., (2001), Galad A. and Gray B. , et al. (2002), Thuillot W., (2004), Mouret S. et al., (2008)

- **Criterion** : deflections of the perturbed asteroids orbits have to change observable quantities (right ascension or declination) and the values of minimum change in right ascension or declination has to be not less 50 mas

List for observations

From table 3 (A. Fienga et al. A&A 406, 2003)

10	75	9/2005	0.0135	5.6478	51.18	218.71	66.17	10/2010
10	410	1/2005	0.7703	1.1202	22.84	-108.29	25.14	6/2010
16	49	10/2016	0.1083	2.8884	16.34	-58.03	-27.5	9/2020
16	1082	2/2003	0.1198	2.4622	20.31	77.59	-14.73	11/2008
19	20	8/2019	0.462	0.2038	295.25	-55.02	16.58	12/2019
19	494	3/2019	0.0103	3.2532	52.2	81.2	34.06	11/2021
48	300	4/2017	0.0084	2.4498	70.55	157.13	-35.2	11/2020
52	627	7/2009	0.0605	3.0013	16.63	-52.97	-15.53	9/2013
87	846	4/2003	0.0609	3.4491	22.28	51.87	-12.15	5/2008
511	856	12/2013	0.1108	3.0394	11.09	64.52	-17.11	5/2019
511	1003	5/2017	0.0819	3.6659	10.31	-97.63	26.52	8/2020
704	253	1/2003	0.02	5.6332	16.33	96.67	-14.7	5/2009
704	977	10/2005	0.0093	9.5192	12.34	60.89	-23.11	8/2009
804	733	2/2015	0.0138	2.3737	45.53	-73.82	-34.89	4/2019

Selection: 105 perturbed asteroids for determination of the masses of 29 perturbing asteroids

List for observations

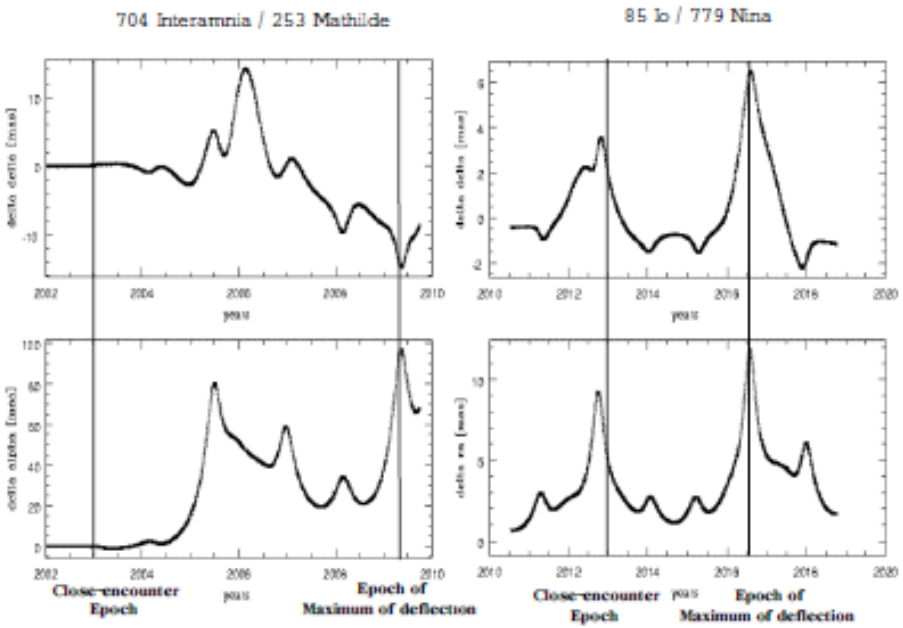


Fig. 1. Perturbations in right ascension and declination induced by the encounter between 704 Interamnia and 253 Mathilde and between 85 Io and 779 Nina. On the first plot, the estimated epoch of encounter is 2003, but the maximum impact would be observed in 2009. The estimated epoch of encounter for the second encounter is 2013, but the perturbations on the observed angles are maximum in 2016.

A. Fienga et al. A&A 406, 2003

PERTURBING –PERTURBED ASTEROIDS

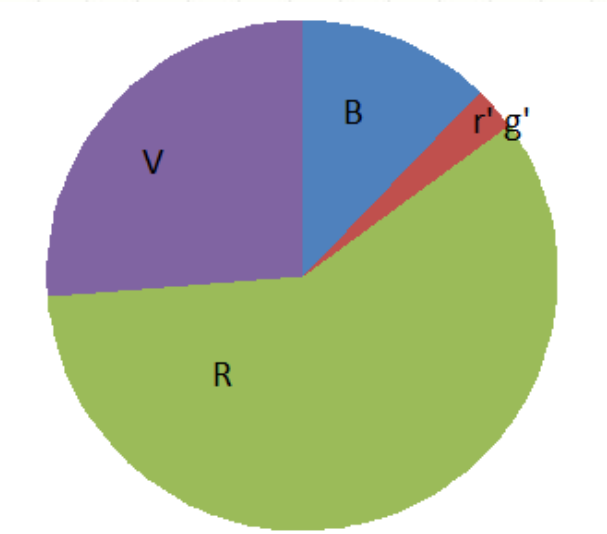
Perturbing Asteroid	Size, km	Number of perturbed asteroids according list:			
		FIENGA (2003)	GALAD (2001, 2002)	THUILOTT (2004)	GAIA
1 CERES	952		5303	119	1847, 4325, 5564, 8038, 8610, 13801, 15518, 43170, 46938, 52708, 57917, 71071, 88041, 97442
4 VESTA	530		17, 113,	535	14949, 15828, 30309, 42965, 71343, 93094
6 HEBE	185				50561
9 METIS	190	175			18163, 42798, 56011
10 HIGIEA	407	75, 410, 209, 983	3946, 6006, 11215, 24433		465, 828, 3630, 6104, 19177, 30051, 49573, 165123, 168793
11 PARTHENOPA	153				28625
13 EGERIA	208		14689		
14 IRENE	152				28701,74483
15 EUNOMIA	255				765, 14401, 19028, 45467
16 PSYCHE	253	60, 316, 468, 1054, 1082		331	12621, 17794, 85665
24 THEMIS	198				4366, 8970, 34519
29 AMPHITRITE	212		987		
31 EUPHROSYNE	256	965			

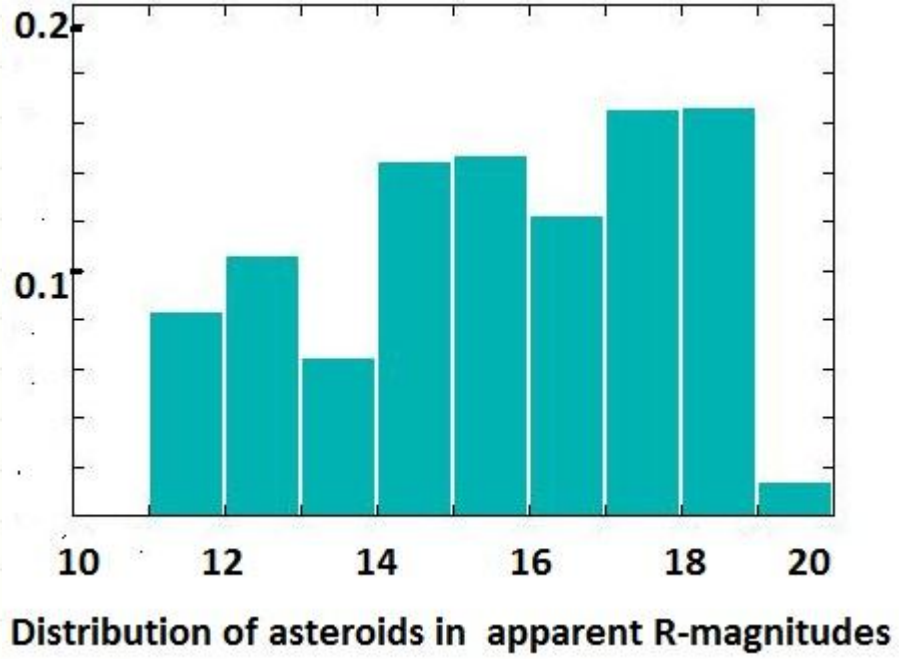
PERTURBING –PERTURBED ASTEROIDS

Perturbing Asteroid	Size, km	Number of perturbed asteroids according list:			
		FIENGA (2003)	GALAD (2001, 2002)	THUILOTT (2004)	GAIA
45 EUGENIA	215		673	834, 4959	47013
52 EUROPE	302		124	110	58, 6210, 8150
64 ANGELINA	?				4000, 9921, 41858
72 FERONIA	86				11349
87 SYLVIA	261	846			8976
88 THISBE	232				33578
94 AURORA	205				99042,161165
128 NEMESIS	188				41756, 89949
268 ADOREA	140				23578
423 DIOTIMA	209				72812, 115432
505 CAVA	115				26953
511 DAVIDA	326		11985	1295	82732
690 WRATISLAVIA	135				257606
704 INTERAMNIA	317	253, 977			
762 PULKOVA	137				14685
790 PRETORIA	170				43488

Size of asteroids are taken from (http://ssd.jpl.nasa.gov/sbdb.cgi#top)

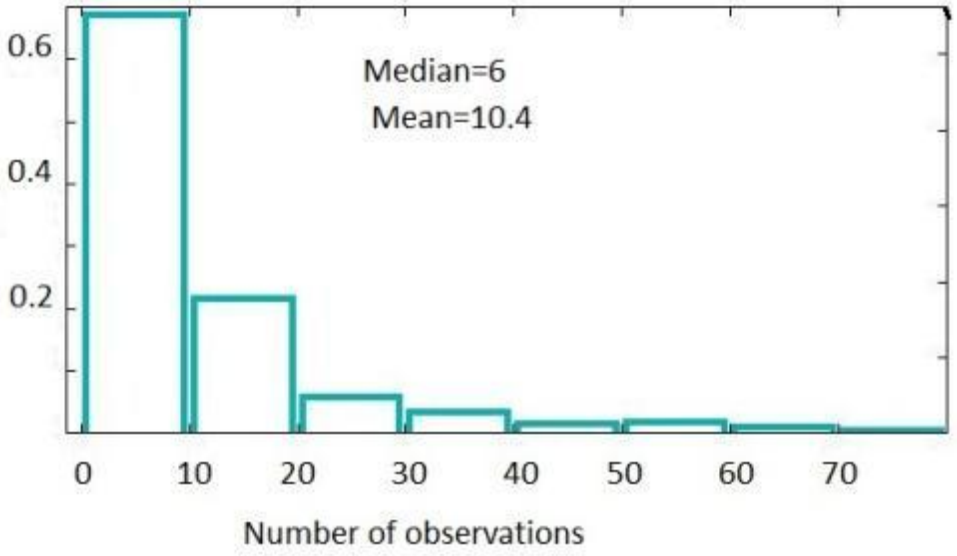
Analysis of astrometric observations of asteroids





Distribution of asteroids in apparent R-magnitudes

Frames with bias, dark and flat field were regularly obtained during asteroid observations at RTT-150.



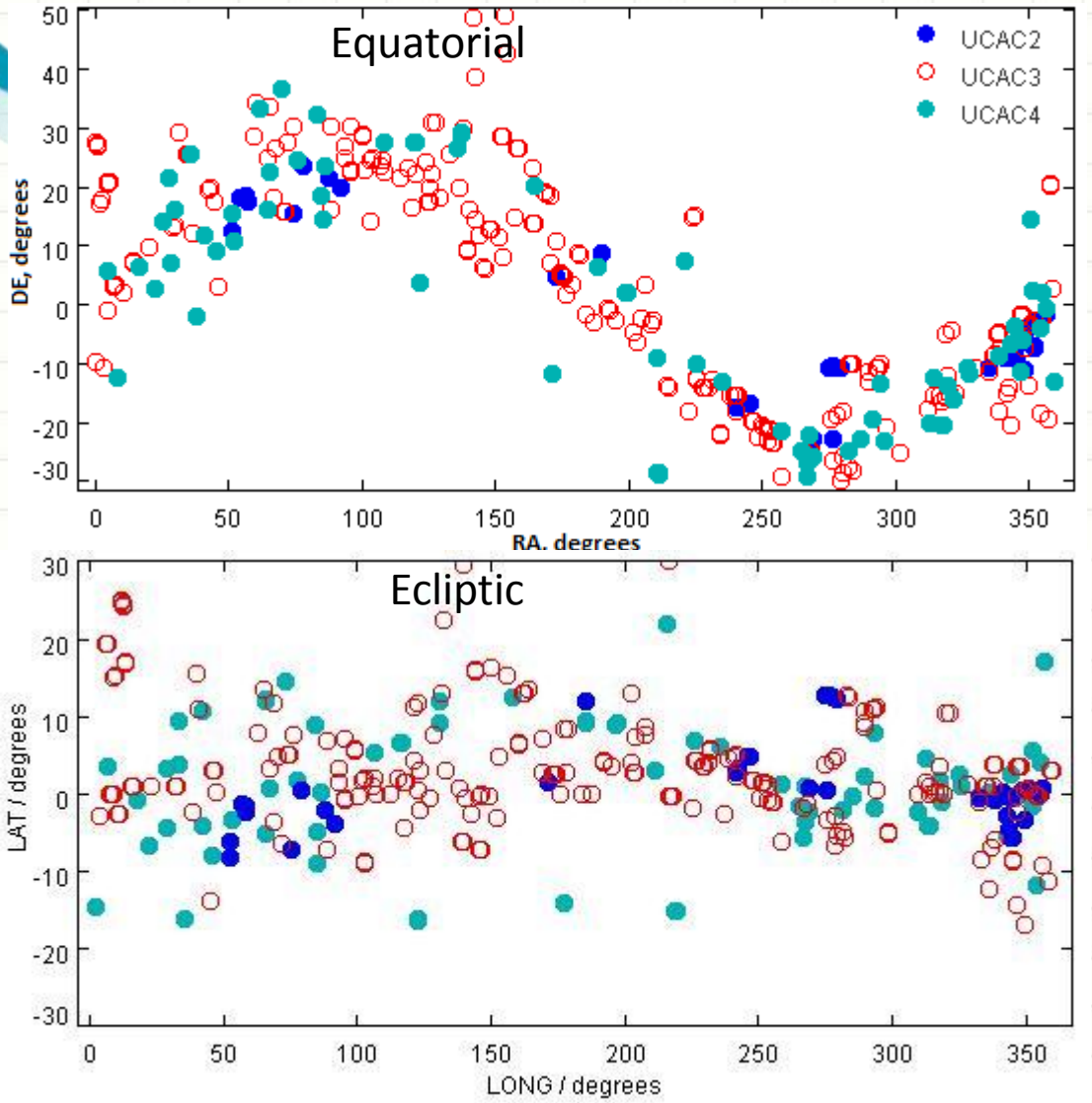
Processing and Astrometric Reductions

- Astrometric reductions were made without bias, dark and flat corrections.

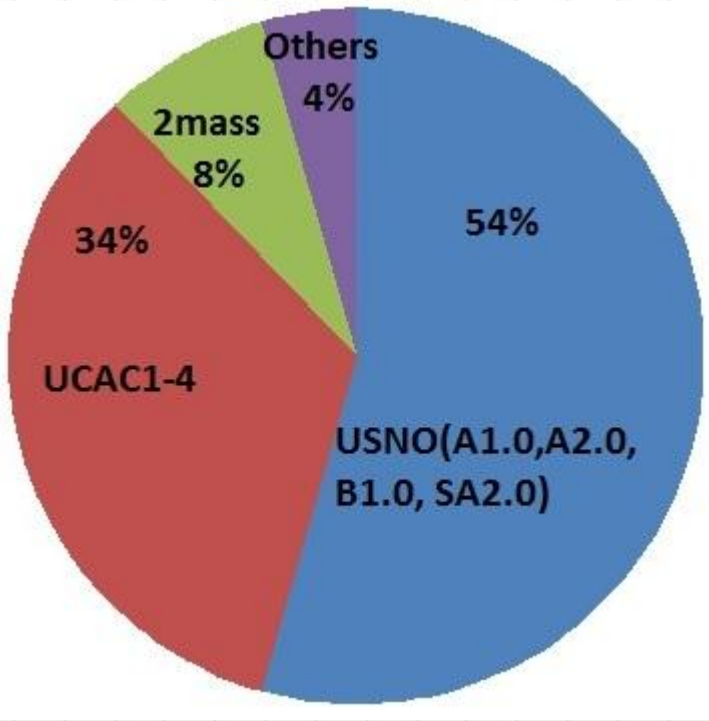
- Getting instrumental coordinates of the objects and reference stars in the system matrix :
  PSF function:
- Radially symmetric Gaussian
  (Astrometrica http://www.astrometrica.at/, Herbert Raab)
  Moffat profile functions (IZM CCD, Igor Izmailov, http://www.izmccd.puldb.ru/)
- Performing astrometrical reductions for equatorial coordinates of objects:
  Reference catalogues UCAC2 -4
  Connection model between the tangential and the measured coordinates:
  Linear, polynomial 2nd order

Analysis of astrometric observations of asteroids

Distribution of the RTT-150 asteroid observations in celestial sphere



Reference Catalogues Used for Asteroid Reductions



D. Farnocchia, S.R. Chesley , A.B. Chamberlin a, D.J. Tholen Star catalog position and proper motion corrections in asteroid astrometry **(2015)**

Processing and Astrometric Reductions UCAC4

The positional accuracy of stars in UCAC4 at mean epoch is about 15 to 100 mas per coordinate, depending on magnitude, while the formal errors in proper motions range from about 1 to 10mas/yr depending on magnitude and observing history. Systematic errors in proper motions are estimated to be about 1 to 4 mas/yr. (Zacharias et al, AJ, 2014)

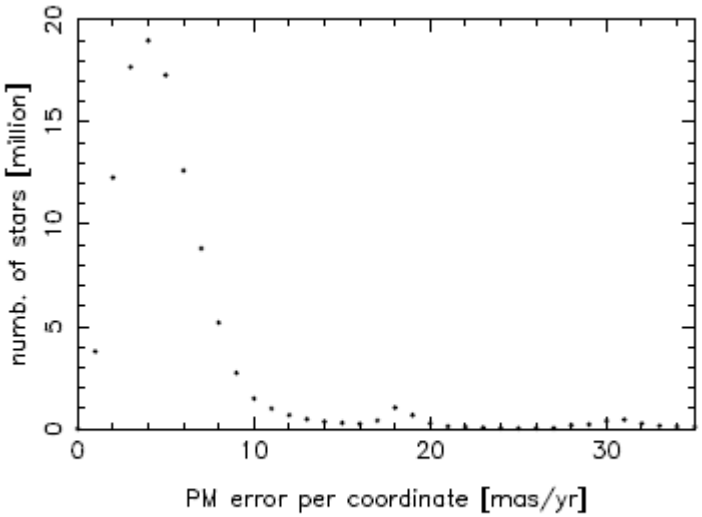


Fig. 24.— Distribution of UCAC4 proper motion errors per coordinate.

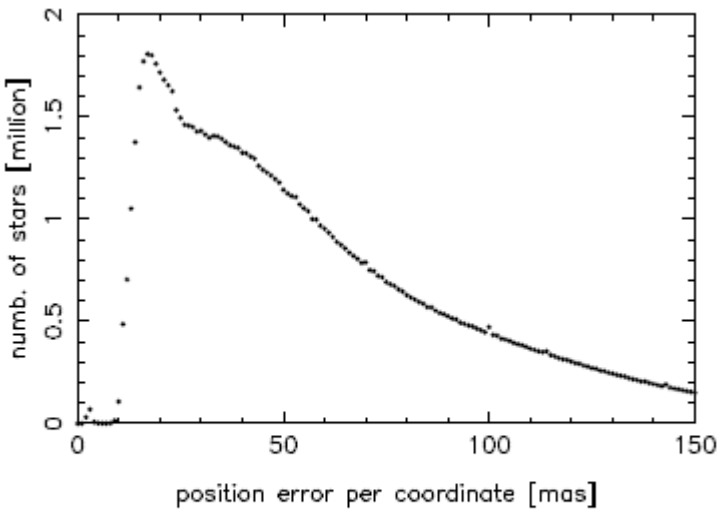
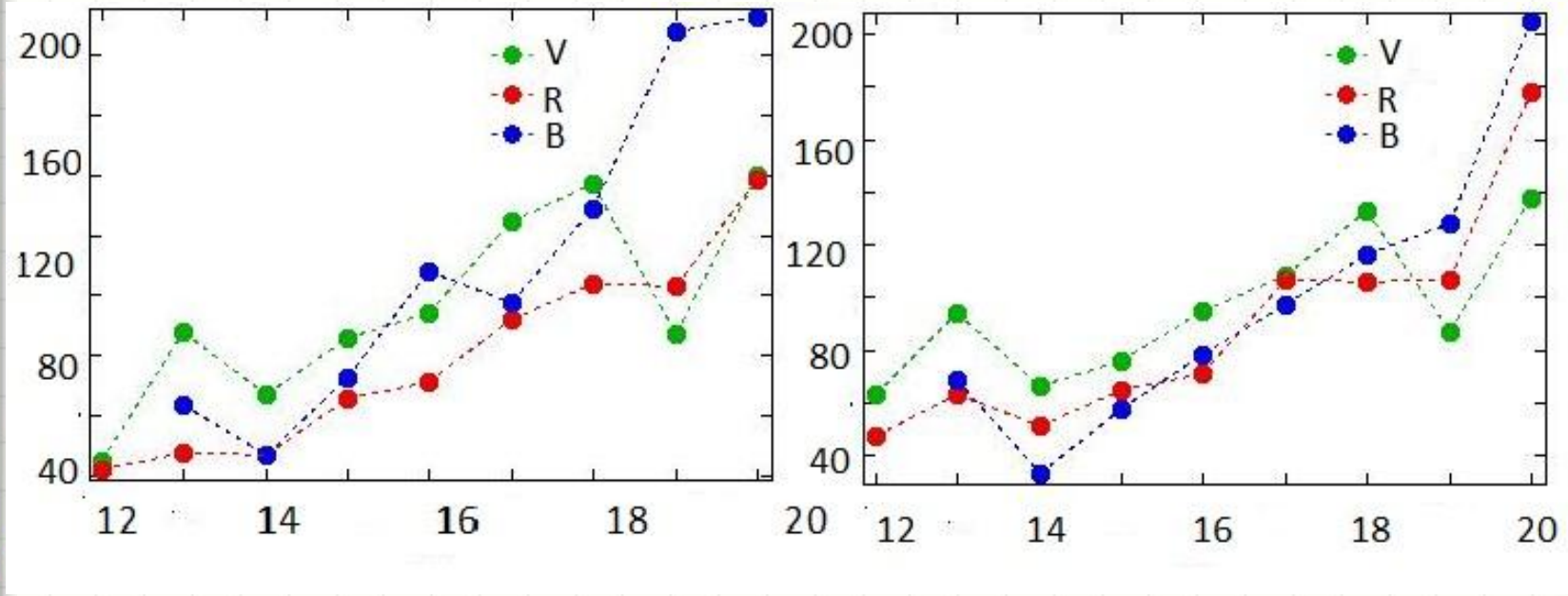


Fig. 23.— Distribution of errors per coordinate for UCAC4 positions at epoch 2000, which is close to the mean epoch.

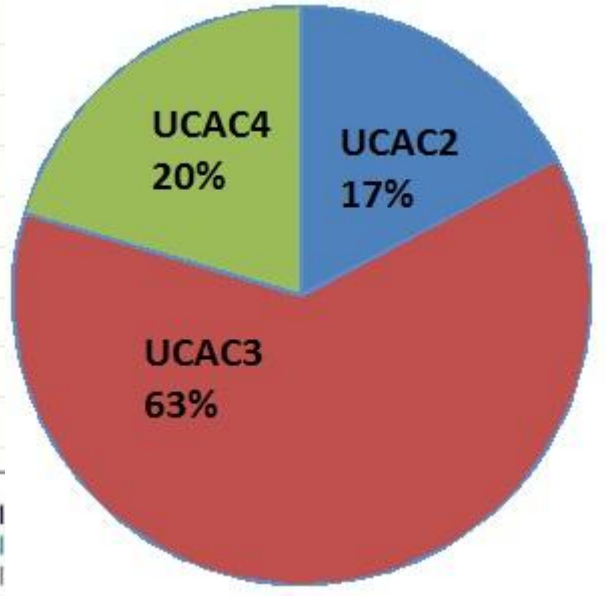
Processing and Astrometric Reductions

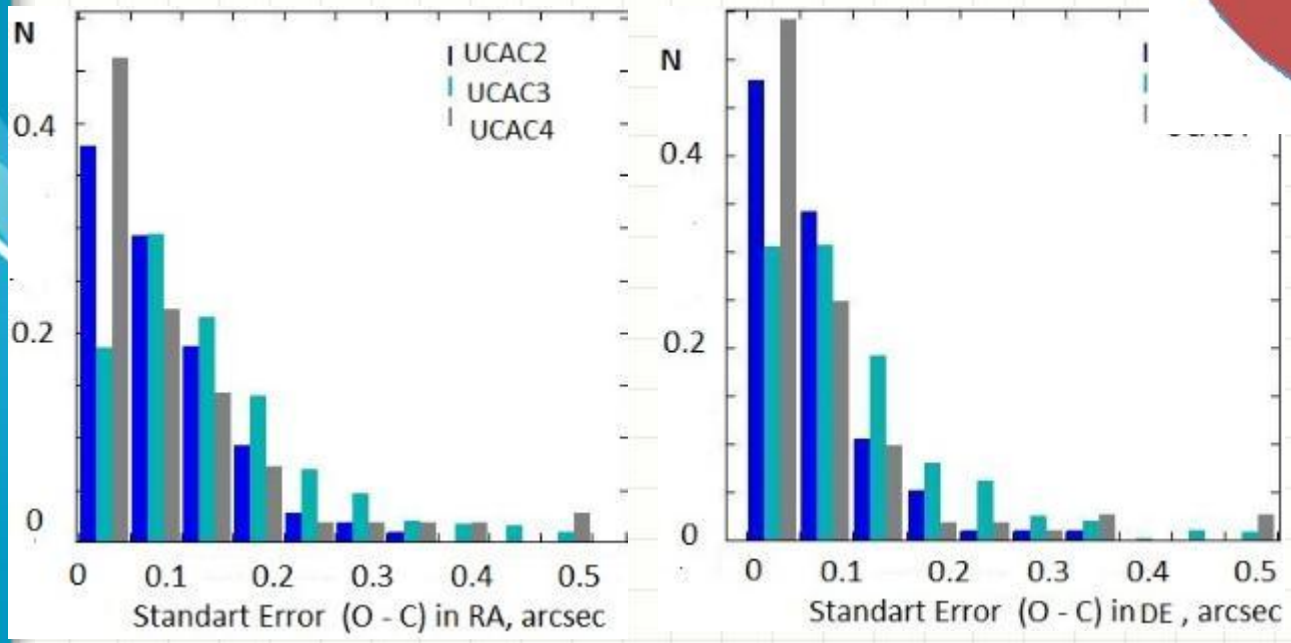


RTT150 positional errors of asteroids are shown as a function of their apparent magnitudes in RA and DE.

Processing and Astrometric Reductions

Catalog	N	$\sigma(O-C)_\alpha$ mas	$\sigma(O-C)_\delta$ mas
UCAC2	3100	58	54
UCAC3	5875	98	74
UCAC4	1876	76	71





Distribution of the standard errors in RA and DEC in different catalogues

Application: Dynamical masses

- The dynamic method of mass determination is based on gravitational influence of perturbing asteroid on perturbed bodies.
- The model of motion includes the gravitational perturbations from all the major planets, as well as Ceres, Pallas, Vesta (the perturbations from the Earth and Moon were considered separately). The major planets' coordinates were calculated using ephemeris DE405.
- Least squares method (LSM) was used to determine the masses of perturbing asteroids for solving systems of conditional equations.

Scheme of weights

YEAR	WEIGHT
< 1901	1/16
1901 – 1950	1/9
1951 - 1996	1/4
> 1996	1

Application: Dynamical masses

I. High precision positions of perturbed asteroids in ICRF/UCAC2-4 system were selected from the catalog of positions asteroids, obtained from observations in 2004-2013. Selected data were used for mass determinations of the 20 perturbing asteroids

Perturbing Asteroid	Mass[1], (Mass_☉)	Uncertainty[1], (Mass_☉)	Mass[2], (Mass_☉)	Uncertainty[2], (Mass_☉)
15	1.38E-011	1.46E-012	1.25E-011	1.34E-012
16	2.19E-013	2.31E-012	3.98E-013	2.17E-012
24	-1.16E-011	4.43E-012	-1.22E-011	4.12E-012
45	-2.71E-011	5.83E-012	-1.70E-011	4.47E-012
52	1.23E-011	1.43E-012	1.25E-011	1.28E-012
423	-1.08E-011	3.72E-012	-1.05E-011	3.34E-012
511	2.57E-011	1.69E-011	2.42E-011	1.60E-011
704	1.17E-011	5.27E-012	1.40E-011	4.85E-012
762	6.46E-012	3.76E-012	5.21E-012	3.04E-012
790	2.14E-012	6.86E-012	4.17E-012	5.36E-012

[1] only MPC data on moment July, 2013;
[2] MPC data+RTT-150 asteroid observations.

Application: Dynamical masses

Perturbing Asteroid	Mass[1], (Mass_☉)	Uncertainty[1], (Mass_☉)	Mass[2], (Mass_☉)	Uncertainty[2], (Mass_☉)
1	4.74E-010	1.03E-012	4.73E-011	0.97E-012
4	1.21E-010	0.42E-012	1.21E-013	0.38E-012
9	0.37E-010	0.65E-011	0.37E-010	0.59E-011
10	0.41E-010	0.84E-012	0.41E-010	0.74E-012
11	0.26E-011	0.41E-013	0.26E-011	0.39E-013
13	0.30E-011	0.18E-011	0.31E-011	0.17E-011
31	-0.37E-010	0.95E-011	-0.21E-010	0.82E-011
64	0.19E-011	0.70E-012	0.16E-012	0.60E-012
72	-0.31E-010	0.94E-011	-0.22E-010	0.82E-011
87	0.59E-012	0.27E-011	0.42E-011	0.22E-011

[1] only MPC data on moment July, 2013;

[2] MPC data+RTT-150 asteroid observations.

The average uncertainty of the mass estimates decreased by 12% percent

64 ANGELINA

60x53x45km	**E-TYPE**	**0.28**	**0.07E-12M☼**	**4000, 9921, 41858**

Perturbed objects for which the mass of the perturbing asteroid 64 had the least errors

Perturbed Asteroid	Uncertainty M_☼
9921	0.05E-11
244	0.14E-11
42420	0.16E-11
4619	0.39E-11

Perturbed Asteroid	Mass _64 M_☼
9921,244,42420,4619 MPC +RTT150 data	(0.31±0.49)E-12
9921 MPC	(0.46±0.55)E-12
9921 MPC+RTT150 data	(-0.02±0.49)E-12

762 PULKOVA

Double	**F-TYPE**		**(0.07-1.3)E-12M☼**	**14685**

Perturbed objects for which the mass of the perturbing asteroid 762 had the least errors

Perturbed Asteroid	Uncertainly M_☼
14685	0.173E-11
269228	0.284E-11
269633	0.342E-11
50	1.232E-11
213834	1.767E-11
143679	1.799E-11

Perturbed Asteroid	Mass _762 M_☼	Tikhonov's regularization
14685, 269228, 269633, 50, 213834,143679 MPC 1900+RTT150 data	(-0.018±1.075)E-12	0.849
14685, 269228, 269633, 50, 213834,143679 MPC 1900	(-0.215±1.147)E-12	0.941
14685 MPC	(2.310±1.727)E-12	
14685 MPC+RTT150 data	(1.763±1.450)E-12	

790 PRETORIA

albedo 0.04	P-TYPE	170km	2.6E-12M☼	43488

Perturbed objects for which the mass of the perturbing asteroid 790 had the least errors

Perturbed Asteroid	Uncertainly M_☼
24362	0.123E-11
22217	0.262E-11
43488	0.412E-11
38631	0.866E-11
64220	0.955E-11
63630	1.004E-11
2051	1.232E-11
221406	1.459E-11
33909	1.528E-11
153063	1.548E-11

Perturbed Asteroid	Mass _790 M_☼
24362, 22217, **43488,** 38631, 64220, 63630, 2051, 221406, 33909, 153063 MPC 1928+RTT150 data	(2.59±0.94)E-12
24362, 22217, **43488,** 38631, 64220, 63630, 2051, 221406, 33909, 153063 MPC 1928	(2.64±0.96)E-12
43488 MPC+RTT150 data	(0.34±3.08)E-12
43488 MPC	(0.88±4.12)E-12

CONCLUSIONS

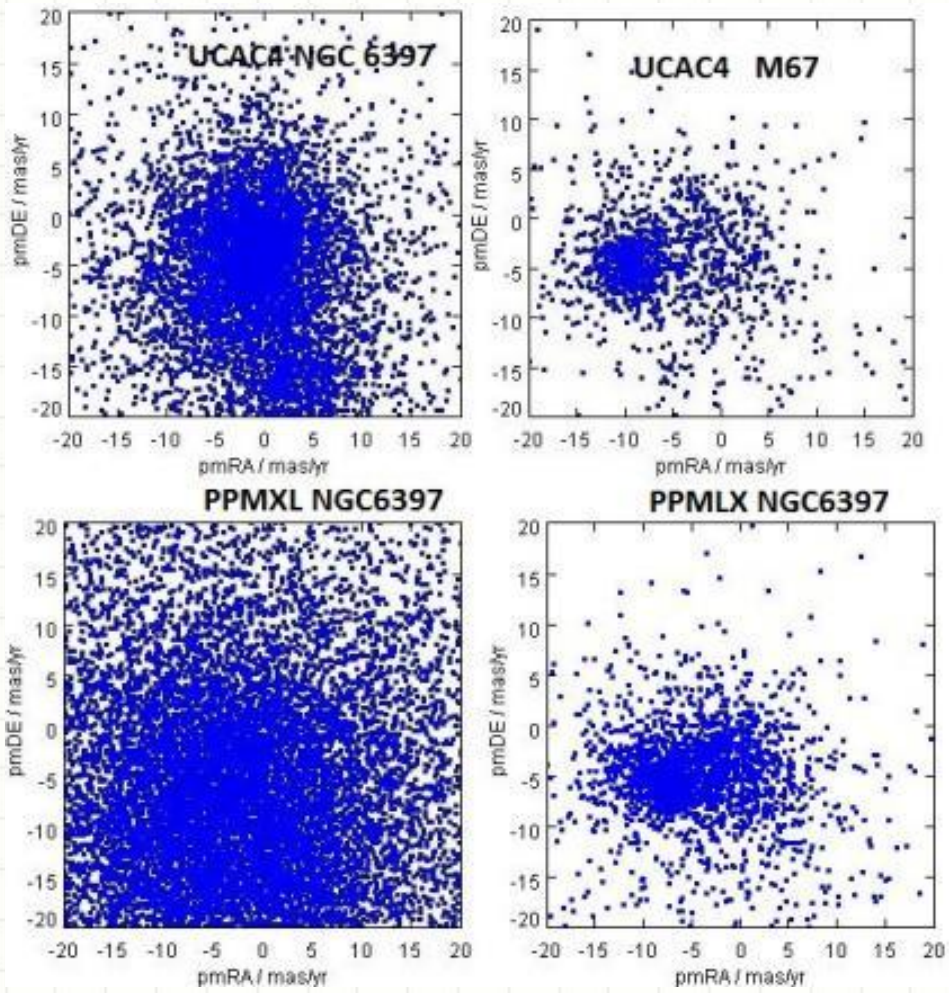
Database of accurate topocentric positions and magnitudes for specially selected 96 perturbed asteroids that have close encounters with other asteroids were obtained. Mean accuracies of 84mas in right ascension and 68mas in declination were achieved for well-exposed images up to R –magnitudes (10-17.5) which degrade to about 200mas for the faintest asteroids R 20.5.

We don't present new masses here, it's only attempt to show important adding modern observations in fitting process.

These data will be useful to combine with very good accuracy but shot-time GAIA data for accurate mass determinations.

THANK YOU!

Processing and Astrometric Reductions



Size of field (30x30) arcsec

Global cluster NGC6397
RA=17h 40m 42.09s
DEC= –53° 40′ 27.6″
(right)

Open cluster M67
RA=08h 51m24s
DEC= +11° 49′
(left)

External test of accuracy of the proper motions of catalogs UCAC4 (top) and PPMXL(bottom)