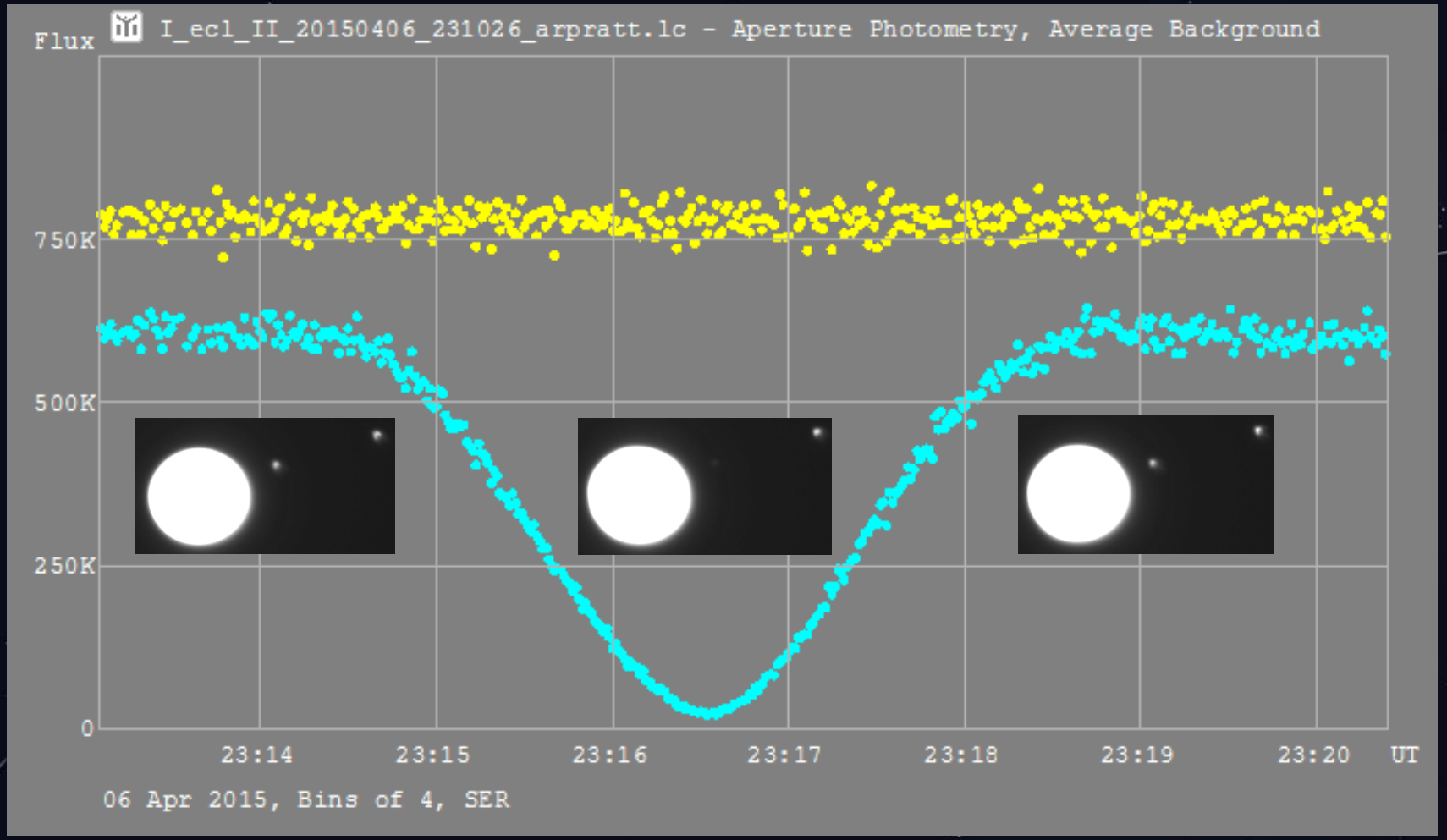
Results from participating in PHEMU15



Alex Pratt (IOTA-ES)

ESOP XXXVII
2018 AUGUST 24th–29th
ROKYCANY – PLZEŇ
CZECH REPUBLIC

ESOP XXXVII
Czech Republic

INTERNATIONAL OCCULTATION TIMING ASSOCIATION
EUROPEAN SECTION

What are PHEMUs?

2014 April

What are PHEMUs?

2015 April

Mutual Phenomena – eclipses and occultations

Why observe PHEMUs? - Astrometric accuracy

Kind of observation	Accuracy in mas	Accuracy in km
Eclipses by Jupiter	150	450
Old photographic plates	100	300
Transit circle	60	180
Plates newly reduced	50	150
CCD observations	40	120
Mutual events	15	45

or 60 km at the distance of Jupiter. Moreover, Robert et al. (2017) have recently demonstrated, for the inner satellites of Jupiter, that the positional accuracy derived from photometric observations still remains more precise than that derived from direct astrometry, even if the use of the most recent *Gaia*-DR1 catalogue (Gaia Collaboration et al. 2016) allowed them to eliminate the systematic errors due to the star references. Thus, our work is crucial for current and future spacecraft navigation (Dirkx et al. 2016), and for dynamical purposes, since the ephemerides are improved by adjusting the new astrometric positions to the theories.

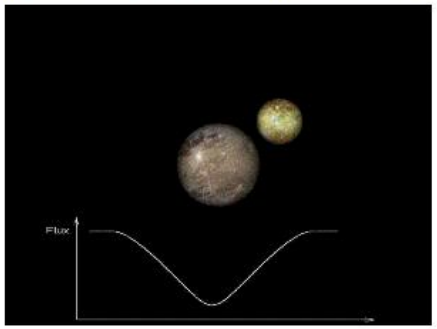
PHEMU15 Pro-Am photometry campaign – Galilean satellites

INSTITUT DE MÉCANIQUE CÉLESTE ET DE CALCUL DES ÉPHÉMÉRIDES

This page has been prepared and the calculations made thanks to the European FP7 program "ESPaCE".

2015: equinoxe on Jupiter

THE CAMPAIGN OF OBSERVATIONS PHEMU15 OF THE MUTUAL PHENOMENA OF THE SATELLITES OF JUPITER (Aug. 2014 - Aug. 2015)



A mutual occultation: the photometric signal

IMCCE and Sternberg Astronomical Institute (Moscow)

PHEMU predictions

Mutual events of the Galilean satellites of Jupiter (2014-2015):
Timescale: UTC

Date	begin: h	m	s	end: h	m	s	Type	Dur minutes	Impact arcsec	mag	flux drop	distance to limb(")	sat(")	
2014 8 17	21	39	8	22	37	14	304	58.1	0.444	5.1	0.161	25.26		:
2014 9 10	17	20	33	17	38	56	4E3	18.4	0.949	5.1	0.014	221.65	31.12	:
2014 9 11	20	23	23	21	41	42	4E3	78.3	0.158	5.1	1.207	63.46	22.58	:
2014 10 5	17	39	13	18	21	2	3E4	41.8	0.625	5.0	0.130	281.74	46.25	:
2014 10 6	20	36	29	20	43	21	204	6.9	0.681	5.4	0.063	125.12		:
2014 10 6	23	30	0	0	45	6	3E4	75.1	0.057	5.0	0.353	98.35	32.36	:
2014 10 15	7	5	15	7	8	48	403	3.5	0.938	4.9	0.013	134.21		:
2014 10 15	13	21	22	13	25	58	402	4.6	0.774	5.4	0.131	91.08		:
2014 10 21	2	1	19	2	4	20	203	3.0	0.943	4.8	0.007	129.32		:
2014 10 24	5	8	30	5	11	37	204	3.1	0.869	5.3	0.017	37.33		:
2014 10 24	8	24	28	8	30	9	104	5.7	0.085	5.2	0.249	13.42		:
2014 10 28	5	31	53	5	40	2	203	8.1	0.535	4.8	0.159	136.22		:
2014 10 29	7	22	40	7	26	17	103	3.6	0.868	4.7	0.026	69.23		:
2014 10 31	2	26	31	4	37	45	4E3	131.2	0.044	4.9	1.393	231.83	48.20	:
2014 10 31	14	36	30	16	56	5	4E3	139.6	0.318	4.9	0.798	160.54	42.31	:
2014 11 1	8	12	1	8	15	25	301	3.4	0.792	4.6	0.074	24.48		:
2014 11 1	11	48	54	11	54	21	401	5.5	0.706	5.1	0.185	69.08		:
2014 11 2	5	53	16	6	12	7	401	18.8	0.268	5.1	0.868	33.92		:
2014 11 2	13	35	52	13	51	34	401	15.7	0.009	5.1	1.113	88.98		:
2014 11 3	12	51	40	13	5	54	403	14.2	0.647	4.8	0.186	250.15		:
2014 11 4	9	4	28	9	14	38	203	10.2	0.164	4.7	0.283	143.21		:

IMCCE and SAI

PHEMU predictions

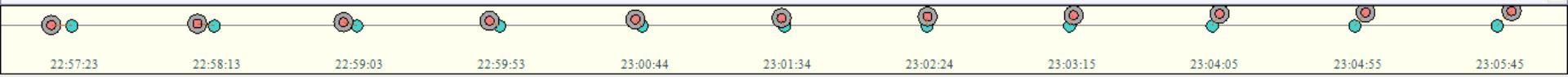
Date 2015		Satel.	Start h m s	End h m s	Magn. %	Dur. s	Flux drop %	Magn. decrease
Jan	3	2e1	09 02 23	09 09 58	12		12	0.14
	6	2e1	22 29 30	22 36 54	17		16	0.19
	7	2e3	15 58 10	16 30 40	A 39	450	31	0.41
	8	2e3	03 23 52	04 08 46	40		28	0.36
	10	2e1	11 53 36	12 00 45	21		20	0.24
	14	2e1	01 13 43	01 20 40	25		24	0.30
	17	3e4	10 02 02	10 08 06	5		24	0.30

British Astronomical Association (Jean Meeus)

PHEMU predictions

Planet Satellites

Europa	Thu 04 Jun, 22:55	5.1	100	-	06 Jan, 10:20	
Io	Tue 16 Jun, 23:01	5.2	100	-	10 Jun, 12:36	*
Io	Sun 21 Jun, 23:25	4.9	100	-	10 Jun, 12:36	*



Io (I) eclipses Europa (II)

Position: Satellites of Jupiter mutual event

Event time: 23:01:34
Error in time: 35 sec
Max duration: 5.9 min

Combined magnitude: N/A
Star magnitude: 6.1 m
Magnitude drop: 0.3 m

Constellation: Leo
Star altitude: 12° @280°
Sun altitude: -8° @330°

Moon: (below horizon)

View details on the web

Io (I) eclipses Europa (II) on 2015 6 16 at 22 1 34

Planet	m	Satelite 1	m1	Satelite 2	m2	Duration	Mag Drop
Jupiter	-1.7	Io (I)	5.8	Europa (II)	6.1	352sec	0.3

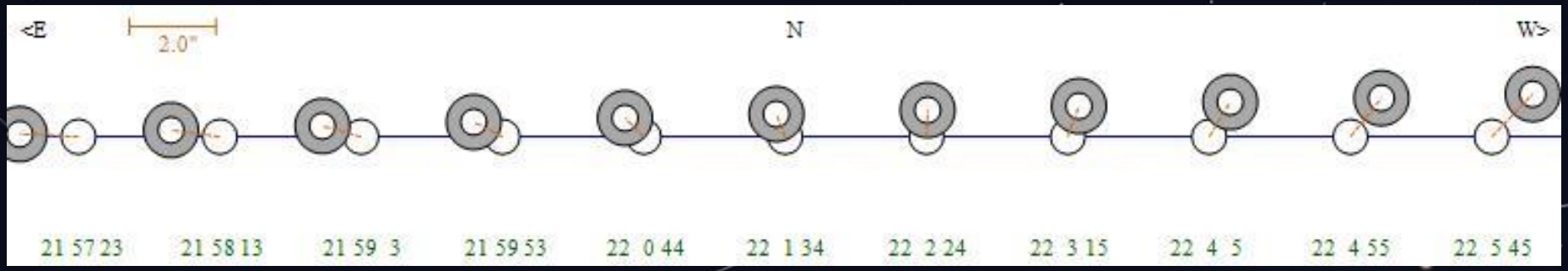
Type	%Ill	Separation from Planet	Planet Diameter	PA	Min Separation
Partial	73.2	68.1"	33.40"	291	0.561"

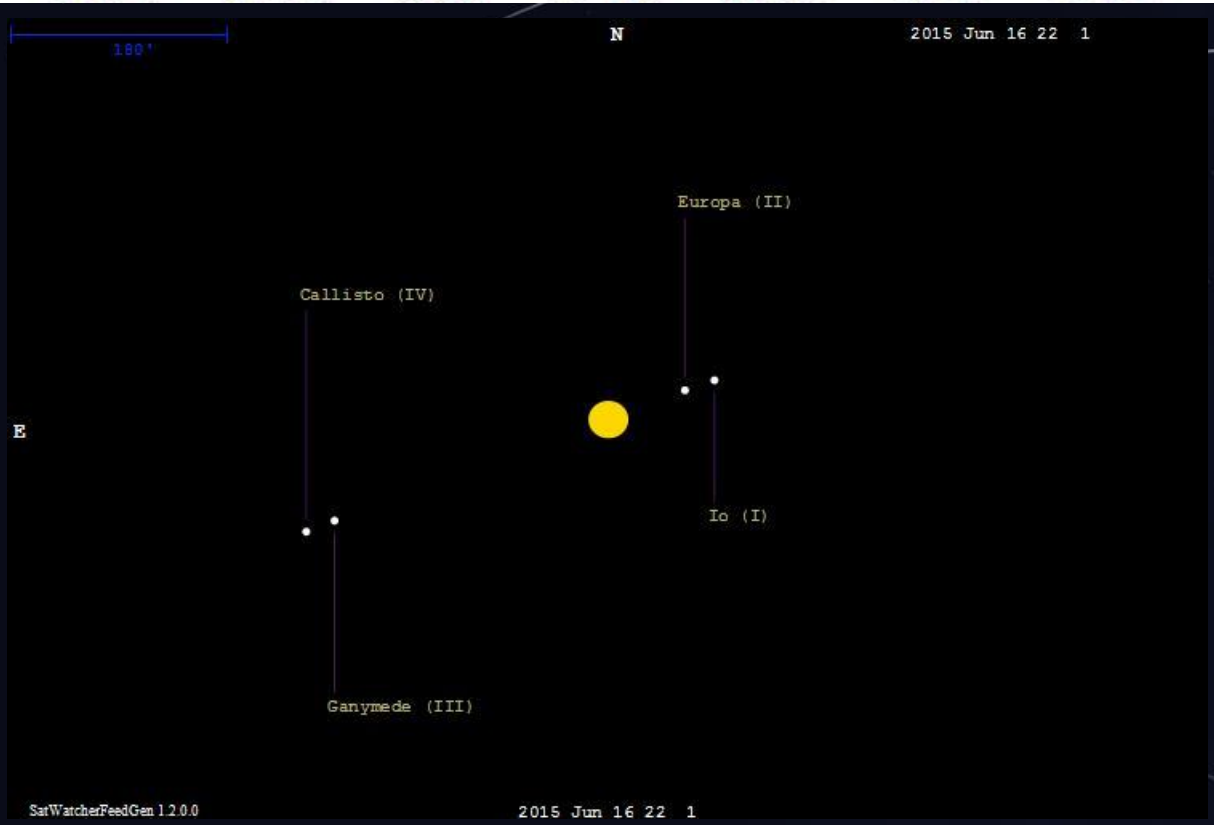
Event Times

Penumbral Start	Partial Start	Total Start	Mid-Time	Total End	Partial End	Penumbral End
21 58 38	22 0 7		22 1 34		22 3 0	22 4 29

OccultWatcher (Occult)

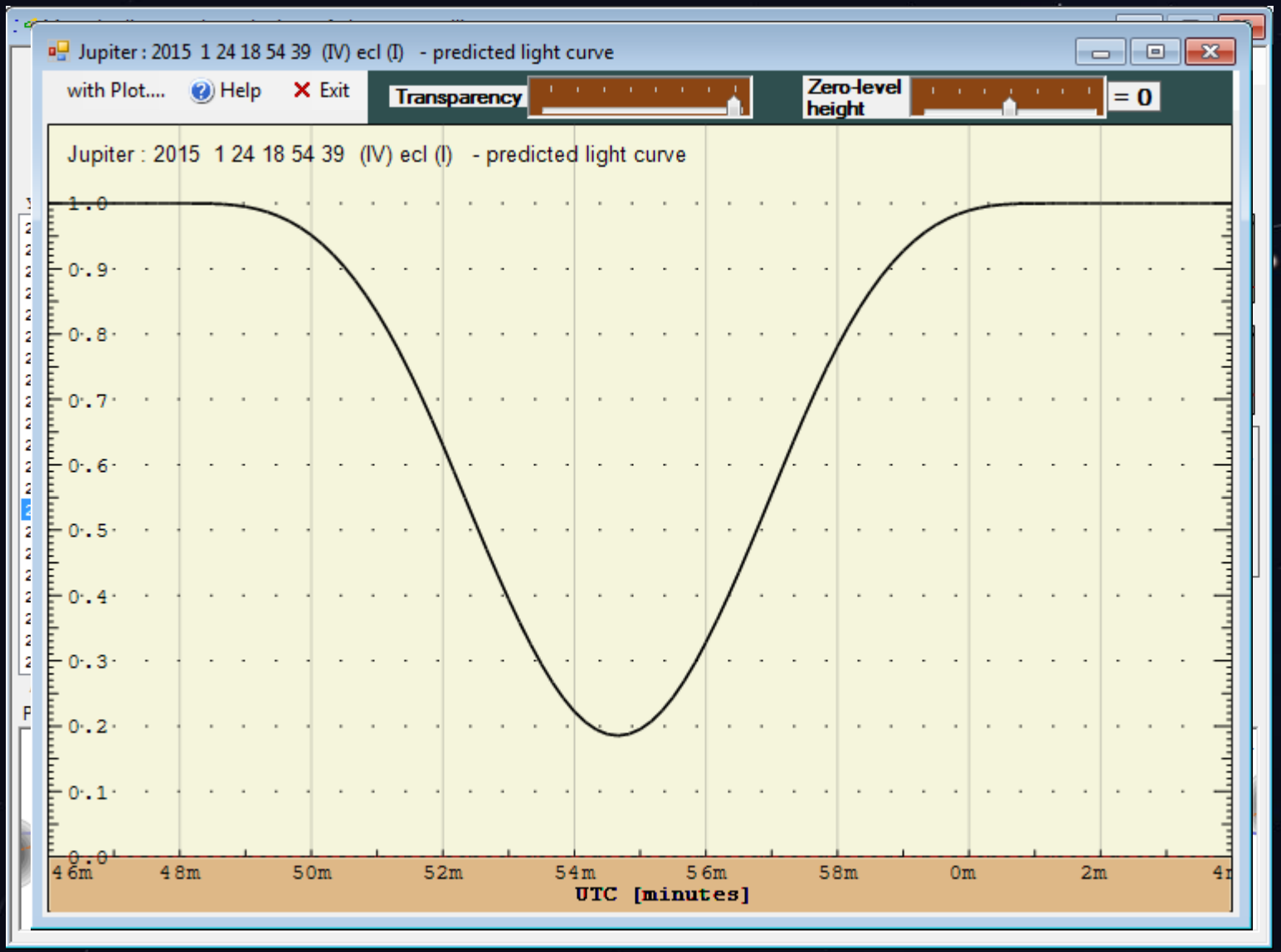
PHEMU predictions





OccultWatcher (Occult)

PHEMU predictions



Occult

Hardware and software

20 cm f/10 SCT (C8)

28cm f/10 SCT (C11)

f/3.3 and f/6.6 focal reducers

Watec 910 HX/RC video camera

IOTA-VTI (GPS)

OccuRec – recording

Tangra – bias, dark frames and flat fields

Tangra - analysis

QHY5L-II mono video camera

CMOS sensor

USB 2.0

1/3-inch format

Up to 200 fps at 320 x 240 pixels

14-bit

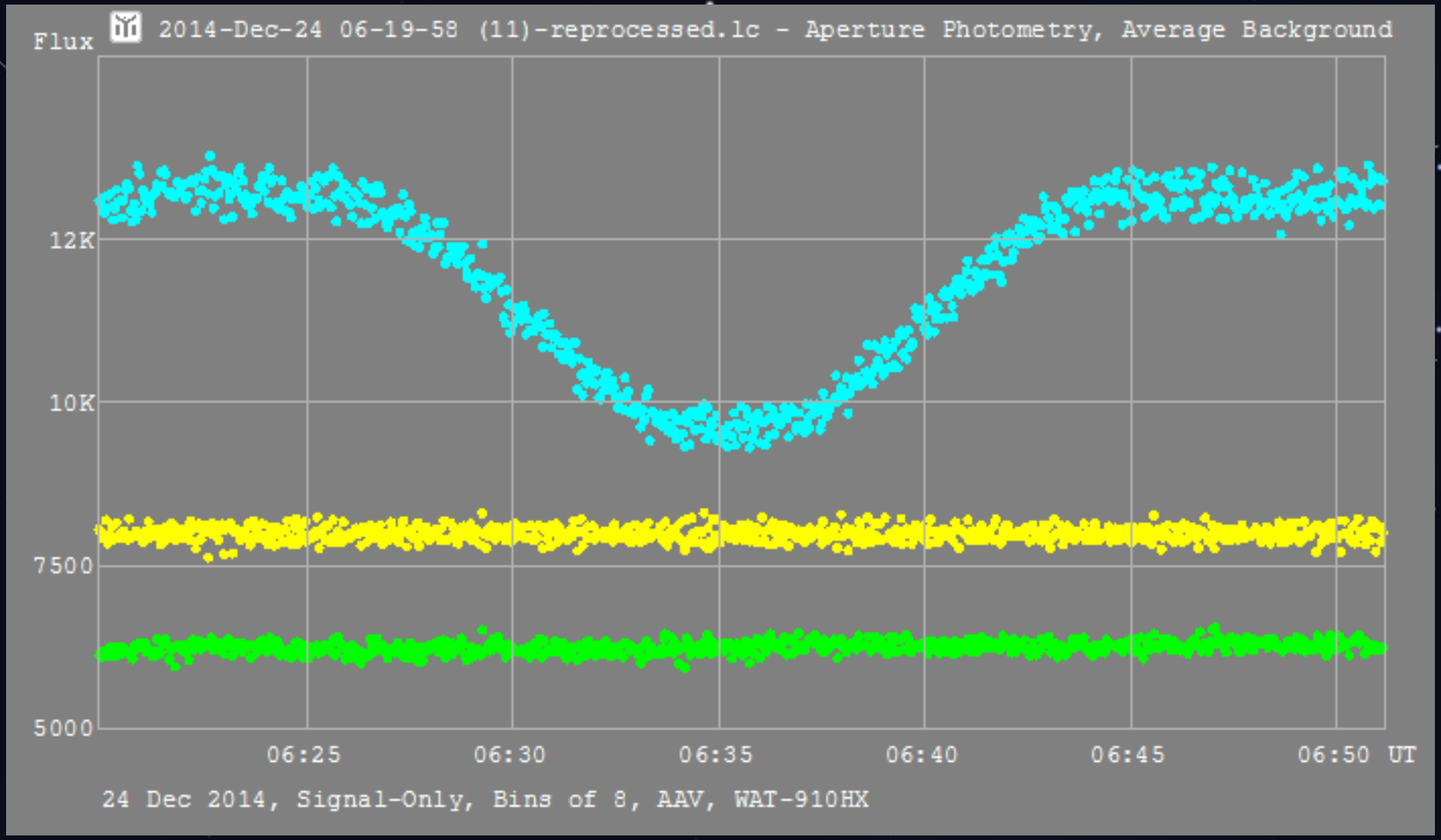
Max QE ~ 74%

FireCapture – recording – SER files – 0.2s exposures – 640 x 480

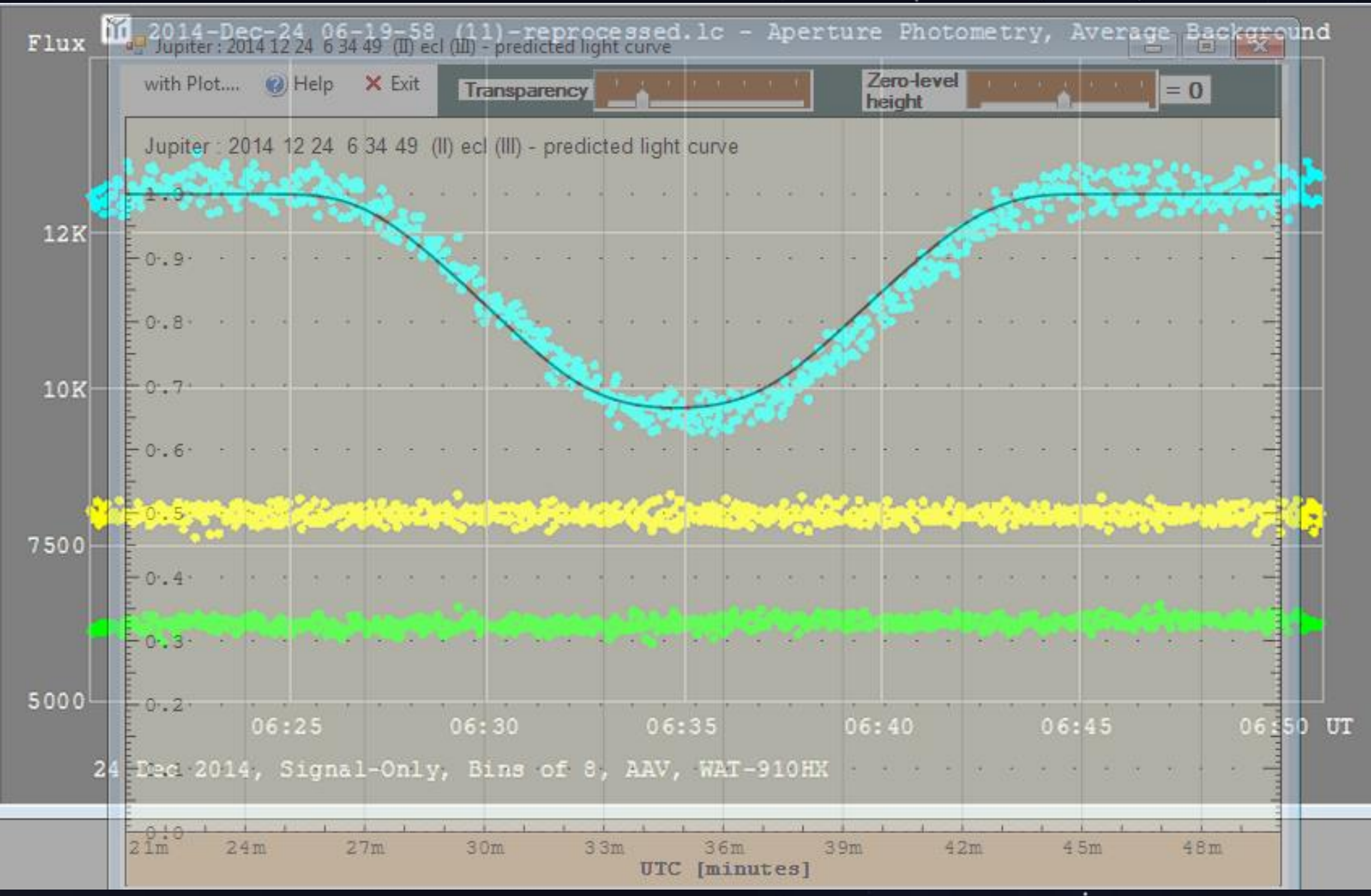
PC clock – Dimension4 - NTP

Tangra - analysis

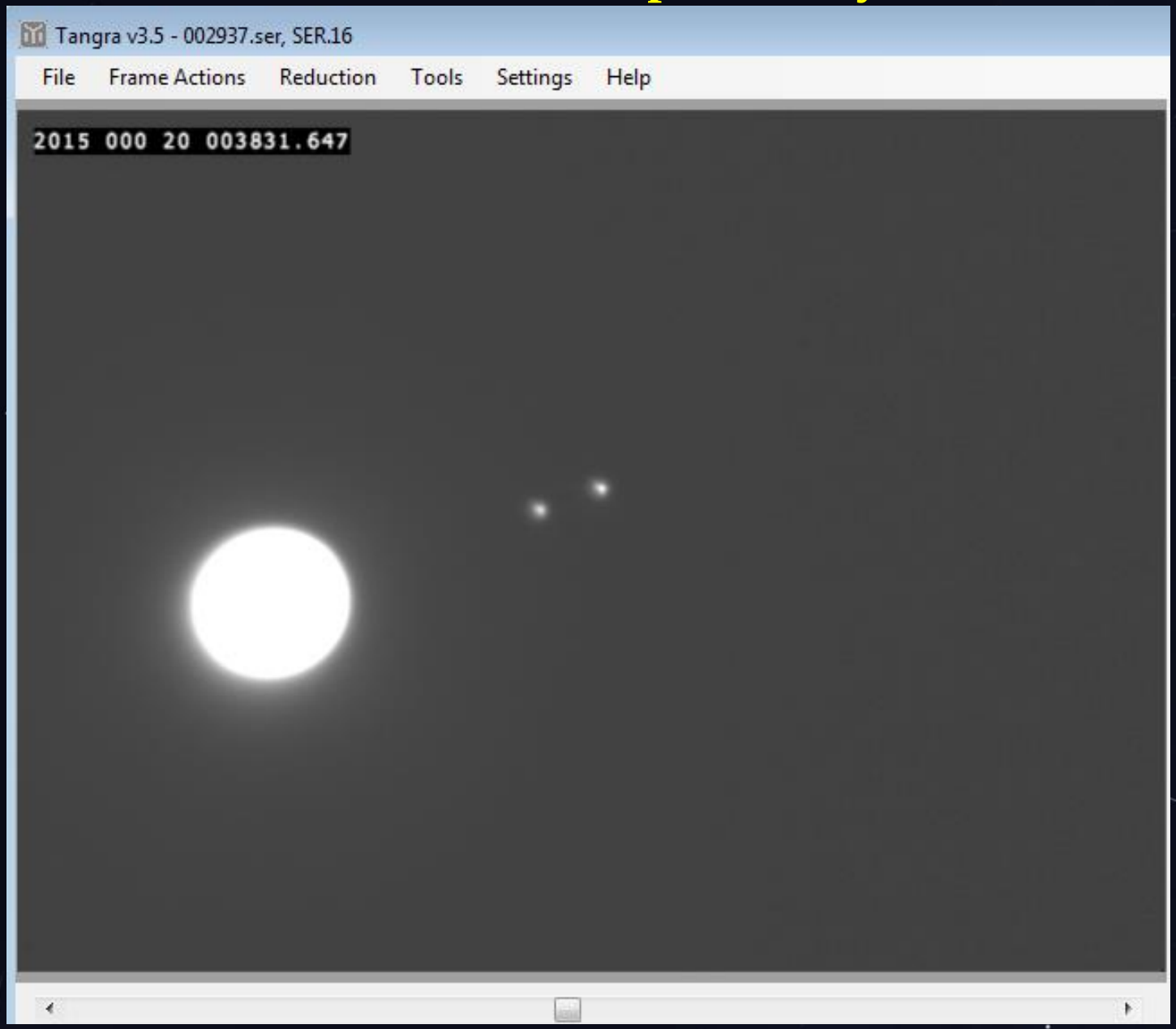
2014 Dec 24 – Europa eclipsed Ganymede



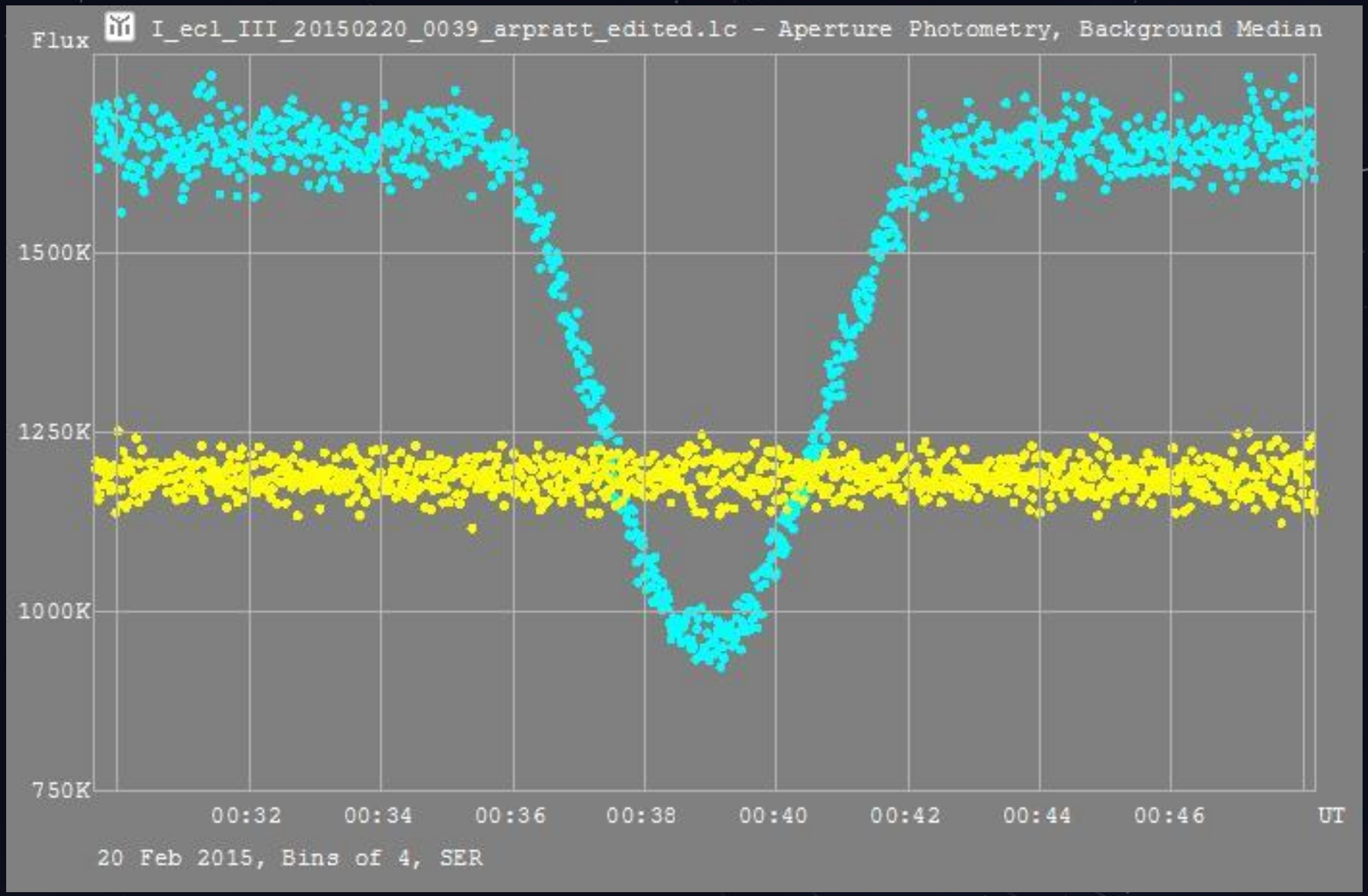
2014 Dec 24 – Europa eclipsed Ganymede



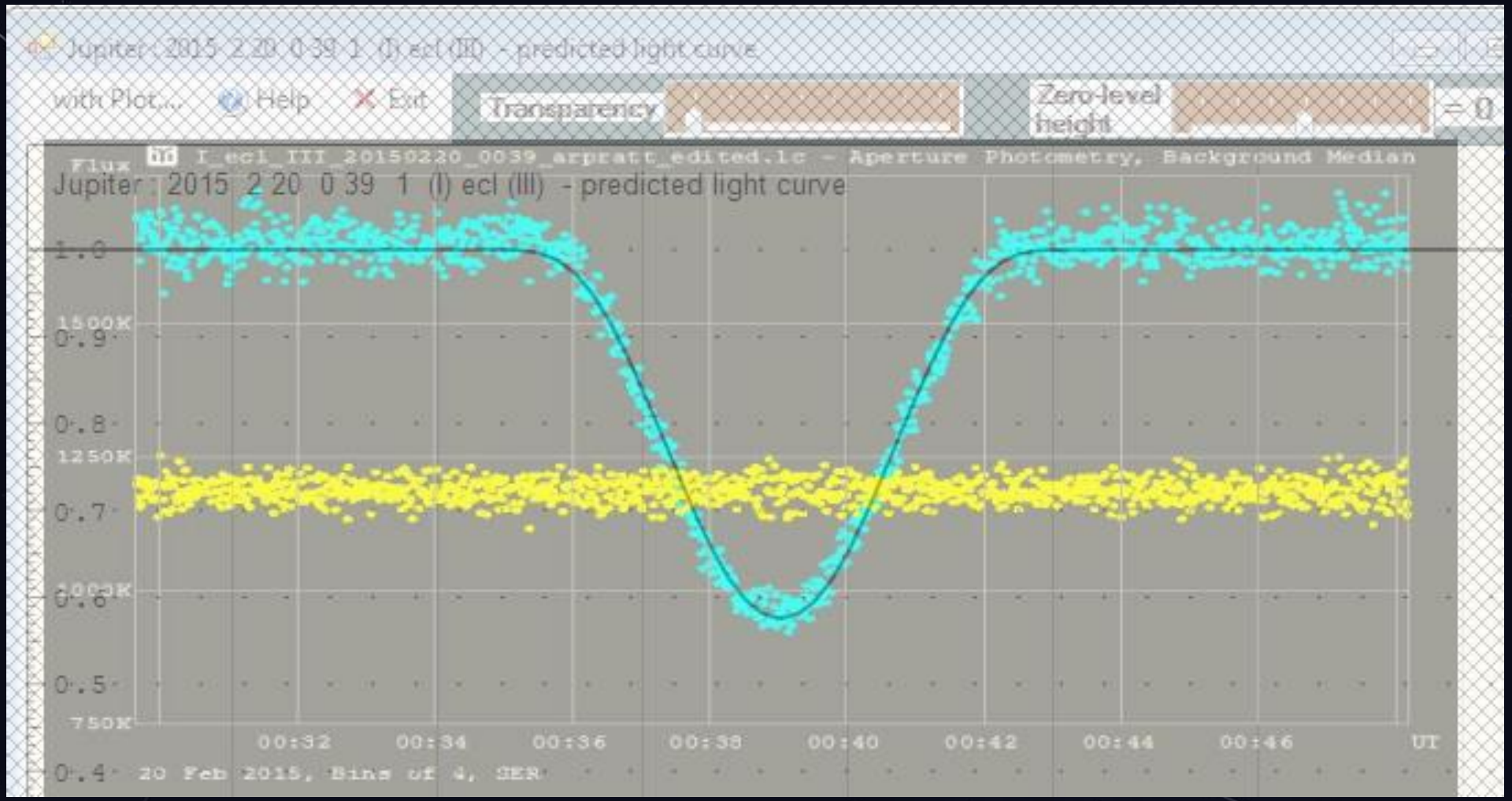
2015 Feb 20 – Io eclipsed Ganymede



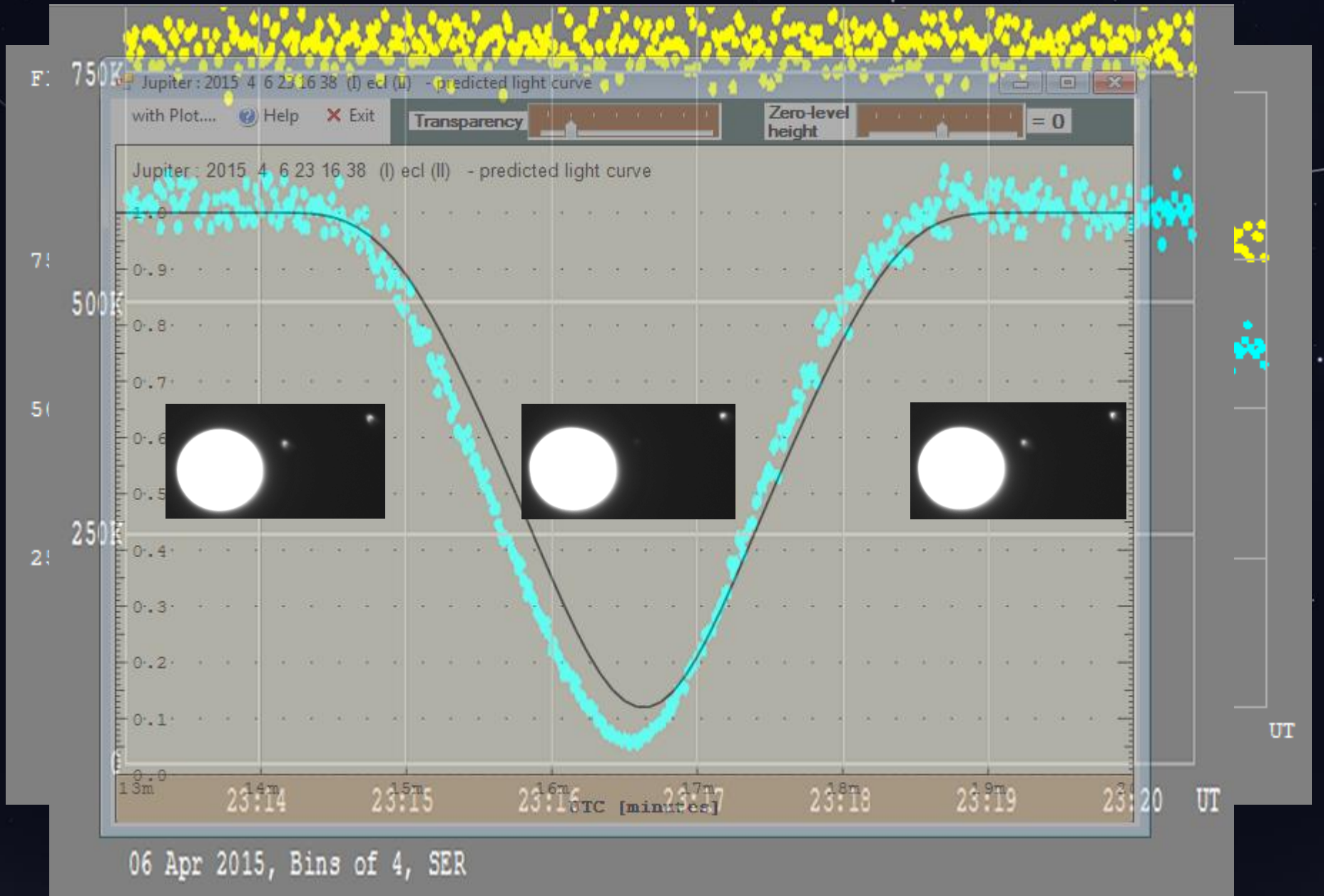
2015 Feb 20 – Io eclipsed Ganymede



2015 Feb 20 – Io eclipsed Ganymede



2015 Apr 6 – Io eclipsed Europa



Observations sent to PHEMU15

18 events submitted

1 event rejected – eclipse and occultation

Bad weather – clouds, strong winds, rain

Received 609 light curves of 442 events from 75 observers

PHEMU15 paper in MNRAS

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS 474, 4730–4739 (2018) doi:10.1093/mnras/stx2957
Advance Access publication 2017 November 21

The PHEMU15 catalogue and astrometric results of the Jupiter's Galilean satellite mutual occultation and eclipse observations made in 2014–2015

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PHEMU15 paper in MNRAS

ABSTRACT

During the 2014–2015 mutual events season, the Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE), Paris, France, and the Sternberg Astronomical Institute (SAI), Moscow, Russia, led an international observation campaign to record ground-based photometric observations of Galilean moon mutual occultations and eclipses. We focused on processing the complete photometric observations data base to compute new accurate astrometric positions. We used our method to derive astrometric positions from the light curves of the events.

We developed an accurate photometric model of mutual occultations and eclipses, while correcting for the satellite albedos, Hapke's light scattering law, the phase effect, and the limb darkening. We processed 609 light curves, and we compared the observed positions of the satellites with the theoretical positions from IMCCE NOE-5-2010-GAL satellite ephemerides and INPOP13c planetary ephemeris. The standard deviation after fitting the light curve in equatorial positions is ±24 mas, or 75 km at Jupiter. The rms (O−C) in equatorial positions is ±50 mas, or 150 km at Jupiter.

IAU Natural Satellites Database

NSDB1-Access to Natural Satellites Astrometric Data Files

Observations of the mutual phenomena of the Galilean Satellites of Jupiter - Raw data

guide for observations of the phenomena of the satellites

Period of observations	Number of observations	Sites of observation	References	Download files content	data1	data2	Available as standard data
1973-1973	94 observ.	27 sites	Arlot et al (1974), Aksnes et al (1984)	Content	Data1	Data2	no
1979-1980	22 observ.	11 sites	Arlot et al (1982), Aksnes et al (1984 & 1984)	Content	Data1	Data2	no
1985-1985	167 observ.	25 sites	Arlot et al (1992)	Content	Data1	Data2	no
1990-1991	375 observ.	55 sites	Arlot et al (1997)	Content	Data1	Data2	no
1996-1997	275 observ.	42 sites	Arlot et al (2006)	Content	Data1	Data2	no
2003-2003	377 observ.	42 sites	Arlot et al (2009)	Content	Data1	Data2	no
2009-2009	457 observ.	74 sites	Arlot et al (2014)	Content	Data1	Data2	yes
2014-2015	607 observ.	74 sites	Saquet et al (2018)	Content	Data1	Data2	no

Note: data1= data on the timing of the mutual events: date of the maximum in UTC and observed magnitude drop (except for the 2009 and 2015 occurrences)
data1= data on the astrometric positions extracted from the mutual events (for the 2009 and 2015 occurrences)
data2= data of the observed photometric lightcurves; date and magnitude drop for each point

back to NSDB home page computations of positions through the ephemerides server

http://nsdb.imcce.fr/obsphe/obsphe-en/fjuphemu.html

Observatories and telescopes

Observatory code with geographic coordinates and telescope parameters.

Code	Longitude degrees to the East	Latitude degrees	Altitude* meters	Telescope type	Diameter cm	Focal length cm	Observatory name, country, IAU code if available
089	31.974700	46.779591	0.0	Refra	12.0	200.0	Nikolaev, Ukraine 089
AAC	283.489222	39.046417	46.0	Refle	36.0	391.0	Arnold, USA
AAT	76.957300	42.996321	0.0	Refle	60.0	750.0	Alma-Ata, Kazakhstan 210
ADS	133.883889	-23.712500	584.0	Refle	35.0	355.6	Desert Springs, Australia
ARM	353.352200	54.170416	0.0	Refle	43.0	294.0	Armagh Obs., Northern Ireland 981
ATH	23.783300	37.968600	0.0	Refle	40.0	320.0	Athens, Greece 066
B10	5.515000	44.215653	0.0	Refle	82.0	470.0	Baronnies Provencales Obs., France B10
BAO	5.896111	43.155556	200.0	Refra	10.0	164.0	Toulon, France
BUC	26.096700	44.221245	0.0	Refle	50.0	750.0	Bucharest, Romania A92
CAB	290.733756	10.030825	486.0	Refle	20.0	100.0	Cabudare, Venezuela
CAL	358.493600	47.701754	0.0	Refle	35.0	355.0	La Couyere Astro. Center, France J23
COG	6.515000	43.251944	50.0	Refra	20.0	200.0	Cogolin, France
COL	5.739167	43.137500	31.0	Refra	12.0	90.0	Marseille, France
COM	9.100000	45.805000	255.0	Refle	25.0	900.0	Como, Italy C13
COO	6.533333	43.250000	10.0	Refra	10.0	780.0	Cogolin, France
DAX	358.969600	43.501243	0.0	Refle	30.0	305.0	Dax Obs., France 958
DFC	172.106778	-43.481361	210.0	Refle	20.0	200.0	Darfield, New Zealand
DFL	172.106778	-43.481361	210.0	Refle	25.0	250.0	Darfield, New Zealand
DIE	4.524444	48.345833	10.0	Refra	10.0	780.0	Dienville, France
DUN	271.883333	41.759000	230.0	Refle	20.3	101.5	Naperville, USA W08
ELG	242.078981	45.572869	835.0	Refle	30.0	152.0	Elgin, USA 440
FCO	283.364594	38.690556	47.0	Refle	25.0	254.0	Chaneyville, USA
FCZ	283.364611	38.690639	50.0	Refle	25.0	254.0	Chaneyville, USA
FLY	149.049306	-35.198694	657.0	Refle	35.0	224.0	Flynn, Australia
FOU	358.908889	45.991111	4.0	Refle	7.0	84.0	Fouras, France
FOZ	305.406200	-25.285830	0.0	Refle	100.0	1000.0	Iguacu, Brazil X57
GAR	240.327700	38.889856	1531.0	Refle	30.0	92.0	Gardnerville, USA
GAS	6.583333	43.216667	10.0	Refra	10.0	780.0	Gassin, France
GIA	8.996400	45.349820	0.0	Refle	28.0	282.0	GiaGa Obs., Italy 203
GLY	23.750000	37.860000	0.0	Refle	28.0	280.0	Athens, Greece 066
GRE	2.744400	48.551901	0.0	Refle	35.0	71.0	Gretz-Armainvilliers, France A07
HOR	15.638222	50.367944	321.0	Refle	150.0	1500.0	Horice, Czech Republic
I73	359.587100	47.791140	0.0	Refle	35.0	391.0	Salvia Obs., France I73
JFR	5.739167	43.137500	31.0	Refle	10.0	1375.0	Marseille, France

Explanation of astrometric results

Astrometric results of observations of mutual occultations and eclipses of the Galilean satellites of Jupiter in 2014-2015.
Explanations.
Version 2017.01.27

Explanations to the Table of astrometric results (first type).

Obs - observatory code (see below).
Type - the type of the phenomenon (eclipse or occultation)
including the satellite numbers in the form "nem" or "nom",
where n is the number of the occulting or eclipsing satellite
and m - is the number of the occulted or eclipsed satellite.
Date - date of observation.
UTC - the time instant in the UTC scale (h, m, s).
X, Y - X=Delta(alpha)*cos(delta), Y=Delta(delta)
(occulting satellite relative to occulted one
or eclipsing satellite relative to eclipsed one)
in arcseconds in ICRF.
sigmaX, sigmaY - rms of X, Y, correspondingly, in arcseconds.
This is because of random errors of the photometry.
O-C_X, O-C_Y - differences of X, Y from the results
of the satellites motion theory (**V. Lainey V2.0**), in arcseconds.
s, pos - apparent distance (arcsec) and positional angle (deg.),
accorsding to X, Y .
Q - index of the result quality, following from processing:
Q=0 - normal result,
Q=1 - doubtful photometric data
Smin - minimum of the normalized modelled flux.

Astrometric results

Astrometric results of observations of mutual occultations and eclipses of the Galilean satellites of Jupiter in 2014-2015.
Version 2017.01.27

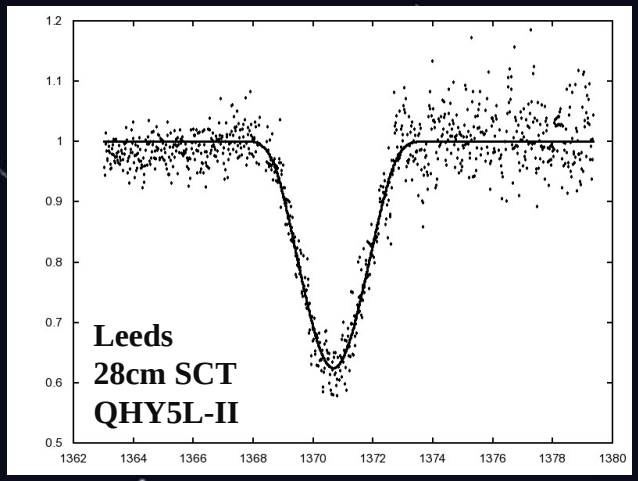
These astromeric results are obtained from the photometric data arrived from the database

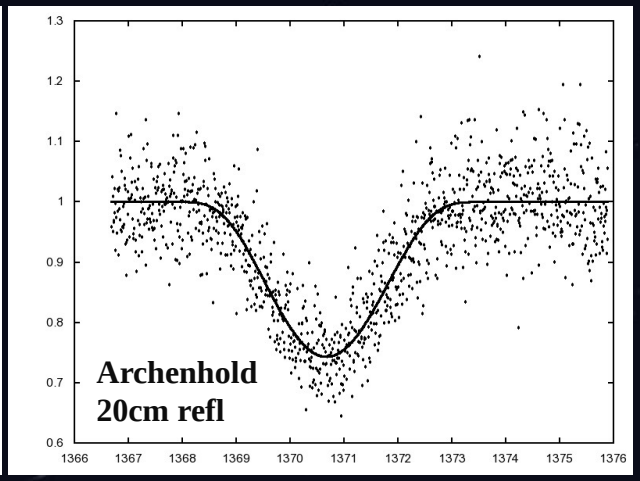
These are results of the first type obtained from the observations where two coordinates could be successfully determined.
(The results of second type see below).

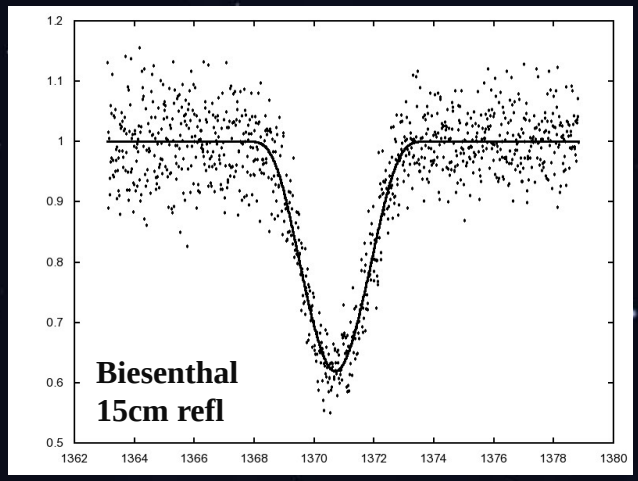
(See Explanations and observatories codes)

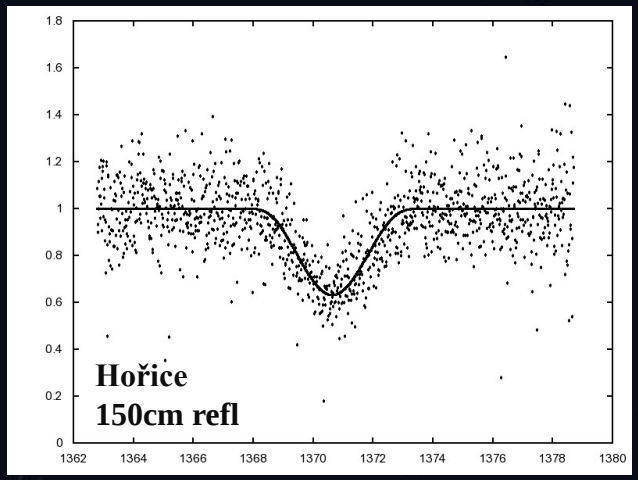
Obs	Type	Date	UTC	X	Y	sigmaX	sigmaY	O-C_X	O-C_Y	s	pos	Q	Smin	Graph
ADS	4e3	2014 9 11	20 57 26.40	-0.2945	-0.1747	0.0120	0.0358	-0.0239	0.0022	0.3424	239.325	0	0.3619	E201409112023_4e3_1_ADS
PKI	3e4	2014 10 7	0 8 47.00	0.0523	0.1717	0.0025	0.0039	-0.0108	0.0913	0.1795	16.950	0	0.1113	E201410062330_3e4_1_PKI
PKI	2o3	2014 10 21	2 3 26.25	-0.2812	-0.7463	0.0274	0.0122	0.1930	0.1211	0.7976	200.642	1	0.9532	E201410210201_2o3_0_PKI
FCO	1o4	2014 10 24	8 27 20.53	-0.2087	-0.5636	0.0158	0.0100	-0.1727	-0.4900	0.6010	200.315	1	0.9157	E201410240827_1o4_0_FCO
LAV	3o1	2014 11 8	11 0 41.94	-0.1898	-0.4997	0.0430	0.0336	0.0544	0.0306	0.5345	200.797	0	0.7448	E201411081000_3o1_0_LAV
FCO	3o1	2014 11 8	11 0 32.76	-0.2610	-0.6871	0.0046	0.0032	-0.0740	-0.1354	0.7350	200.801	0	0.8546	E201411081101_3o1_0_FCO
ADS	1o4	2014 11 10	17 46 19.79	0.2862	0.7532	0.0578	0.0348	-0.0189	0.1265	0.8058	20.803	0	0.9590	E201411101740_1o4_0_ADS
SCO	1o3	2014 11 12	13 11 38.00	-0.1972	-0.5150	0.0095	0.0104	-0.1804	-0.0848	0.5515	200.948	1	0.8295	E201411121309_1o3_0_SCO
P26	4o3	2014 11 19	3 5 52.60	0.2570	0.6728	0.0123	0.0093	0.0198	-0.0976	0.7202	20.906	0	0.7628	E201411190302_4o3_0_P26
PNA	4o3	2014 11 19	3 5 42.60	0.3331	0.8720	0.0469	0.0284	0.0493	0.1195	0.9335	20.907	0	0.8730	E201411190302_4o3_0_PNA
PZA	4o3	2014 11 19	3 5 48.77	0.2913	0.7623	0.0087	0.0059	0.0363	-0.0012	0.8160	20.911	0	0.8147	E201411190302_4o3_0_PZA
ADS	1o2	2014 11 19	18 14 32.65	-0.1432	-0.3692	0.0431	0.0363	0.3751	-0.0387	0.3960	201.197	1	0.7462	E201411191758_1o2_0_ADS
KUR	3o1	2014 11 22	16 34 56.93	-0.0954	-0.2483	0.0089	0.0164	-0.1058	-0.2080	0.2660	201.019	1	0.6050	E201411221631_3o1_0_KUR
ADS	1o3	2014 11 26	18 37 19.13	0.0962	0.2484	0.0188	0.0204	0.0427	0.0757	0.2664	21.168	0	0.7013	E201411261834_1o3_0_ADS
PKI	3o1	2014 12 6	22 15 7.88	0.1542	0.4006	0.0050	0.0049	0.0172	0.1056	0.4292	21.047	0	0.6603	E201412062211_3o1_0_PKI
AAT	2e3	2014 12 9	22 43 4.58	-0.2622	-0.7572	0.0137	0.0079	0.0289	0.0707	0.8013	199.098	0	0.9395	E201412092232_2e3_2_AAT
ARM	2o1	2014 12 12	23 43 8.80	-0.1194	-0.4123	0.0071	0.0088	-0.0022	-0.0071	0.4292	196.145	0	0.6104	E201412122300_2o1_0_ARM
Z92	2o1	2014 12 12	23 42 47.82	-0.1875	-0.6465	0.0074	0.0046	-0.0621	-0.2437	0.6732	196.169	1	0.9109	E201412122308_2o1_0_Z92
GLY	3o1	2014 12 14	1 11 22.83	0.1286	0.3355	0.0048	0.0061	-0.0249	-0.0555	0.3593	20.972	0	0.6235	E201412140100_3o1_0_GLY
TUN	3o1	2014 12 14	1 11 19.64	0.1301	0.3393	0.0071	0.0088	-0.0373	-0.0463	0.3634	20.975	0	0.6251	E201412140100_3o1_0_TUN
CAL	3o1	2014 12 14	1 11 32.09	0.1345	0.3509	0.0151	0.0175	0.0151	-0.0528	0.3758	20.977	0	0.6302	E201412140103_3o1_0_CAL
PKI	3o1	2014 12 14	21 31 41.87	0.0398	0.0967	0.0113	0.0258	0.0458	-0.0352	0.1046	22.375	0	0.5924	E201412142055_3o1_0_PKI
PRA	2e3	2014 12 17	2 32 18.08	-0.2295	-0.6553	0.0109	0.0070	-0.0534	-0.1255	0.6943	199.303	0	0.8559	E201412170224_2e3_1_PRA
PUI	4e1	2014 12 21	3 22 38.23	-0.0796	-0.2327	0.0021	0.0031	-0.0053	-0.0191	0.2460	198.886	0	0.2174	E201412210313_4e1_1_PUI
TUN	4e1	2014 12 21	3 22 43.13	-0.0730	-0.2133	0.0026	0.0059	0.0134	-0.0038	0.2255	198.885	0	0.2015	E201412210318_4e1_1_TUN
PUI	3o1	2014 12 21	4 17 17.11	0.1327	0.3486	0.0063	0.0075	-0.0368	-0.0652	0.3730	20.844	0	0.6241	E201412210412_3o1_0_PUI
TUN	3o1	2014 12 21	4 17 22.43	0.1617	0.4249	0.0057	0.0063	0.0105	0.0043	0.4546	20.832	0	0.6601	E201412210414_3o1_0_TUN
BUC	3o1	2014 12 22	2 13 10.24	0.1464	0.3714	0.0100	0.0113	0.0045	-0.0249	0.3992	21.509	0	0.6436	E201412220154_3o1_0_BUC

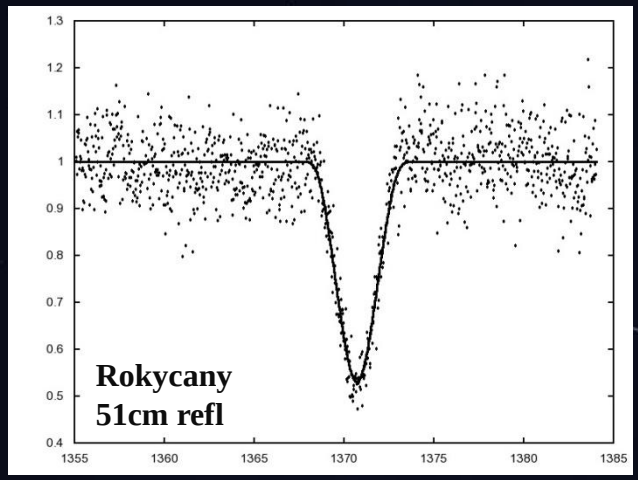
2015 March 18– Europa eclipsed Io (2e1)











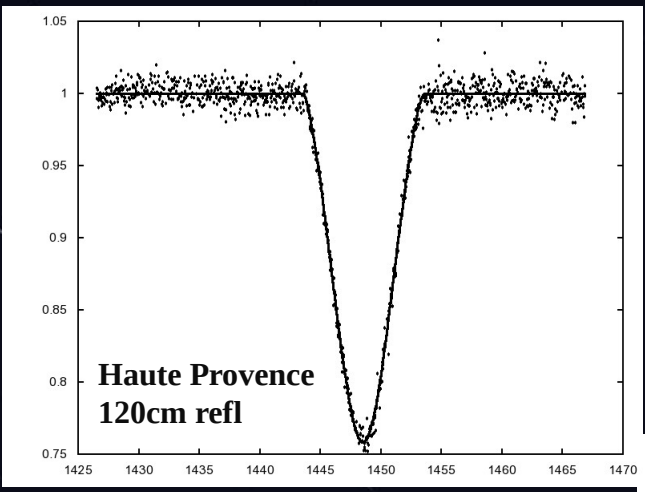
Selected from 17 observations

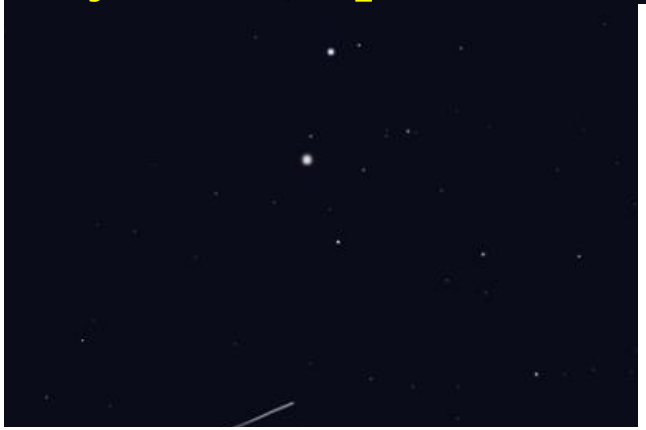
2015 March 18– Europa eclipsed Io (2e1)

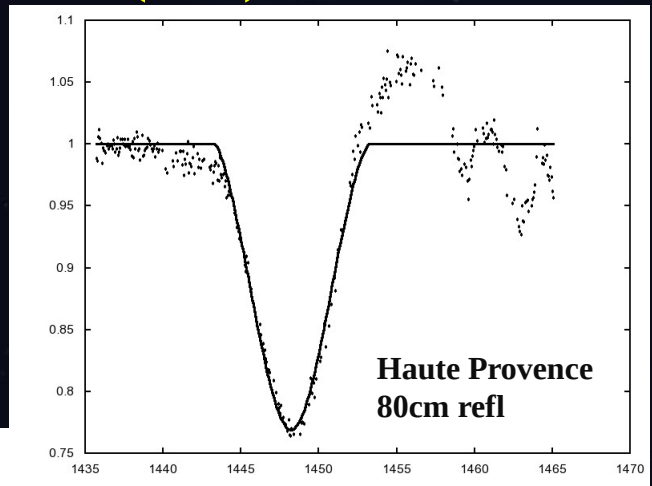
Obs	Type	Date	m	dd	hh	mm	ss	X arcsec	Y arcsec	sigmaX arcsec	sigmaY arcsec	O-C_X arcsec	ABS O-C X	O-C_Y arcsec	ABS O-C Y	Sep arcsec	PA degrees	Q	Flux min
ARM	2e1	2015	3	18	22	50	45.10	0.1406	0.3648	0.0118	0.0097	0.0149	0.0149	-0.0031	0.0031	0.391	21.080	0	0.6157
O12	2e1	2015	3	18	22	50	42.68	0.1415	0.3672	0.0027	0.0022	0.0032	0.0032	0.0042	0.0042	0.3935	21.076	0	0.6186
Z11	2e1	2015	3	18	22	50	44.83	0.1435	0.3723	0.0048	0.0038	0.0163	0.0163	0.0049	0.0049	0.399	21.078	0	0.6248
CAL	2e1	2015	3	18	22	50	25.83	0.1696	0.4398	0.0115	0.0086	-0.057	0.057	0.1108	0.1108	0.4714	21.083	0	0.7051
ROT	2e1	2015	3	18	22	50	44.51	0.1826	0.4735	0.0066	0.0048	0.0538	0.0538	0.1068	0.1068	0.5075	21.085	0	0.7432
OBM	2e1	2015	3	18	22	50	43.61	0.1421	0.3689	0.0065	0.0052	0.0086	0.0086	0.004	0.004	0.3953	21.072	0	0.6207
P26	2e1	2015	3	18	22	50	46.90	0.1406	0.3647	0.0071	0.0058	0.0243	0.0243	-0.0068	0.0068	0.3909	21.078	0	0.6156
PZA	2e1	2015	3	18	22	50	43.33	0.1428	0.3705	0.0058	0.0046	0.0078	0.0078	0.0061	0.0061	0.397	21.078	0	0.6226
SMA	2e1	2015	3	18	22	50	42.28	0.1581	0.4101	0.0213	0.0181	0.0176	0.0176	0.0478	0.0478	0.4395	21.083	0	0.6702
TRE	2e1	2015	3	18	22	50	41.74	0.1438	0.3731	0.0046	0.0036	0.0005	0.0005	0.0119	0.0119	0.3998	21.079	0	0.626
PNA	2e1	2015	3	18	22	50	58.33	0.1214	0.3148	0.0332	0.0296	0.0649	0.0649	-0.0798	0.0798	0.3374	21.085	0	0.7651
HOR	2e1	2015	3	18	22	50	42.70	0.1458	0.3781	0.0146	0.0117	0.0075	0.0075	0.015	0.015	0.4052	21.083	0	0.6319
JVM	2e1	2015	3	18	22	50	43.20	0.1317	0.3416	0.0063	0.0056	-0.0039	0.0039	-0.0225	0.0225	0.3661	21.084	0	0.5871
MAN	2e1	2015	3	18	22	50	41.12	0.1457	0.3781	0.0093	0.0074	-0.0008	0.0008	0.0182	0.0182	0.4052	21.079	0	0.6319
NON	2e1	2015	3	18	22	50	41.67	0.1434	0.372	0.0101	0.0081	-0.0002	0.0002	0.011	0.011	0.3987	21.085	0	0.6244
UNI	2e1	2015	3	18	22	50	42.12	0.144	0.3736	0.0043	0.0035	0.0027	0.0027	0.0117	0.0117	0.4004	21.081	0	0.627
ROK	2e1	2015	3	18	22	50	46.49	0.1144	0.2965	0.0076	0.0069	-0.0041	0.0041	-0.0742	0.0742	0.3178	21.089	0	0.5311
Mean		**2015**	**3**	**18**	**22**	**50**	**45.10**	**0.1442**	**0.3741**	**0.0099**	**0.0082**	**0.0092**	**0.0169**	**0.0098**	**0.0317**	**0.4009**	**21.081**		**0.6389**

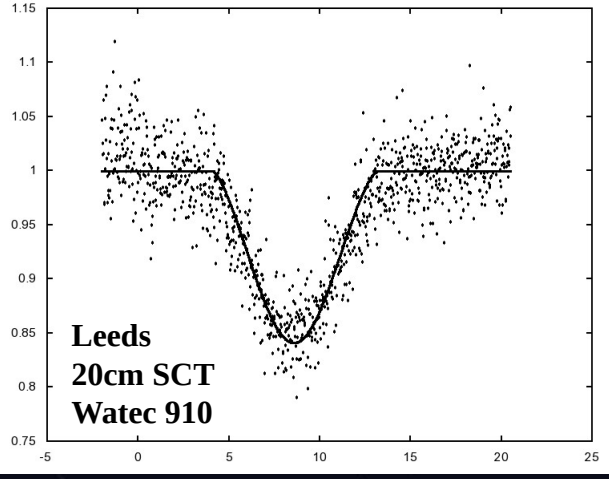
All 17 observations

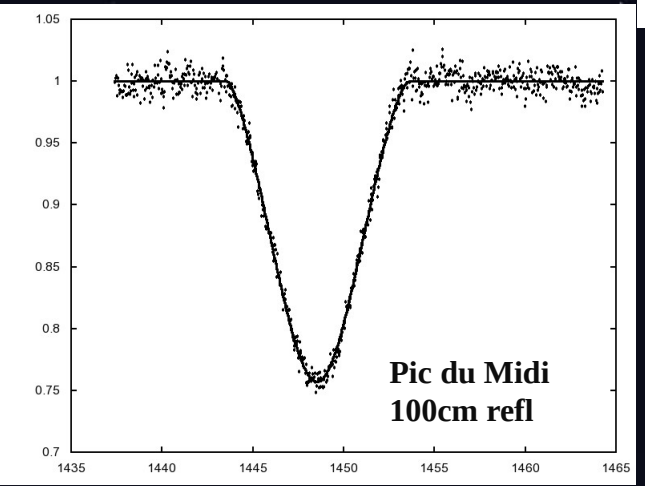
2015 January 7– Europa occulted Io (2o1)

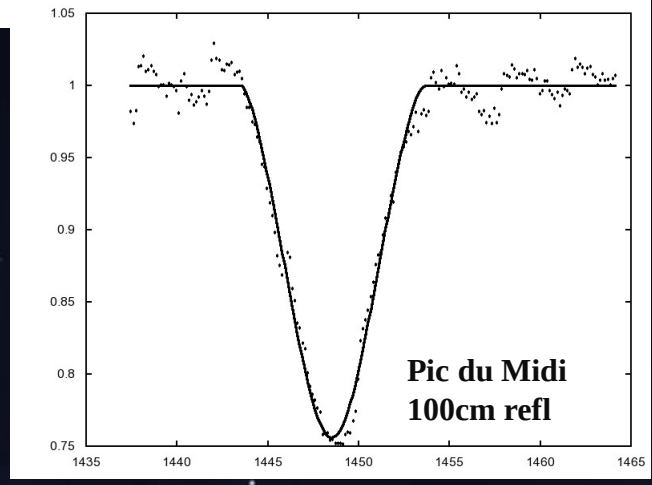




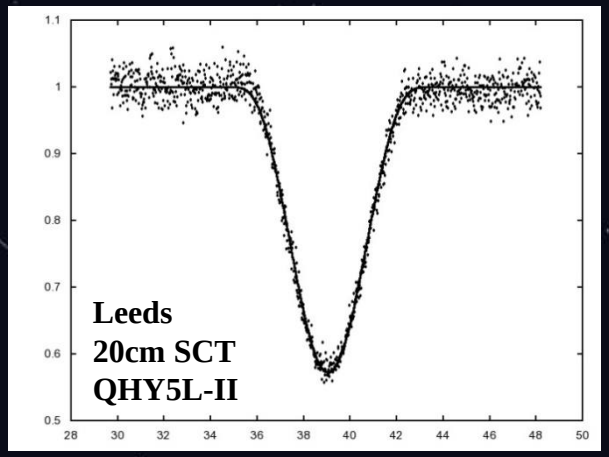


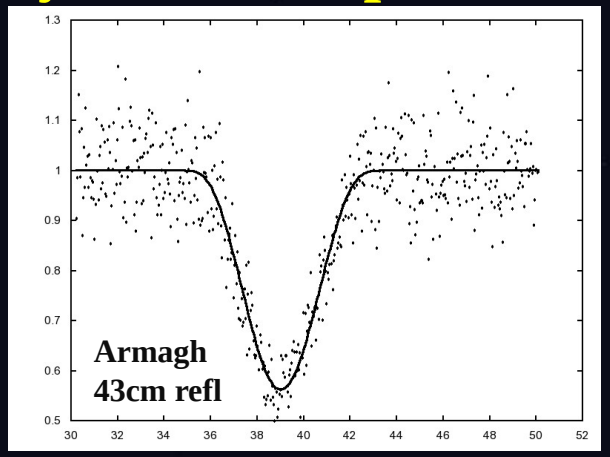


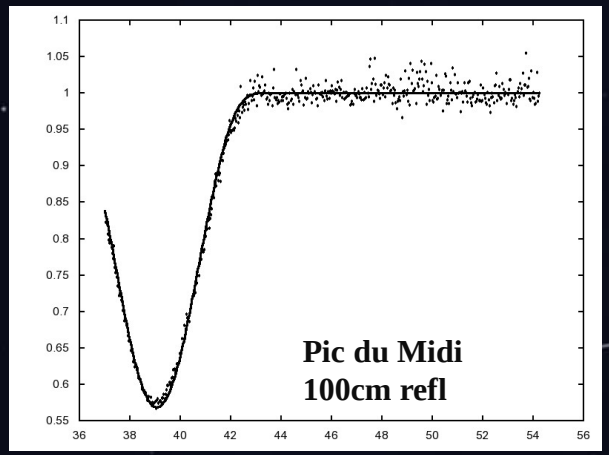


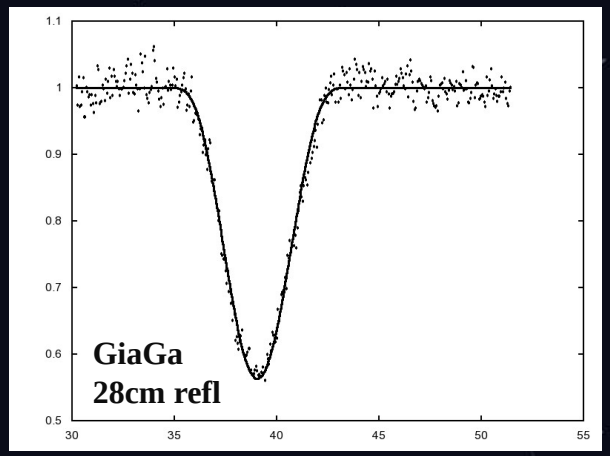


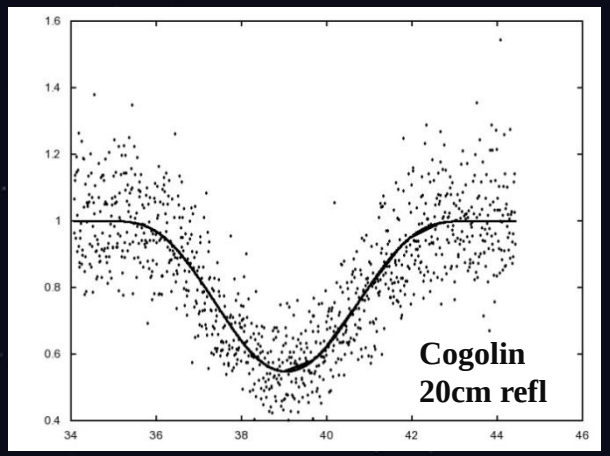
2015 February 20– Io eclipsed Ganymede (1e3)

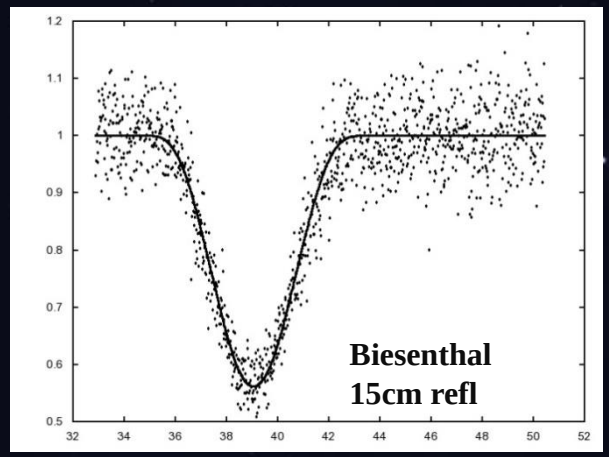


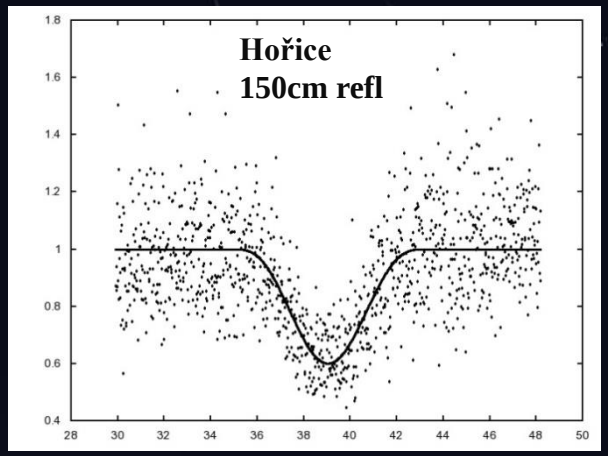


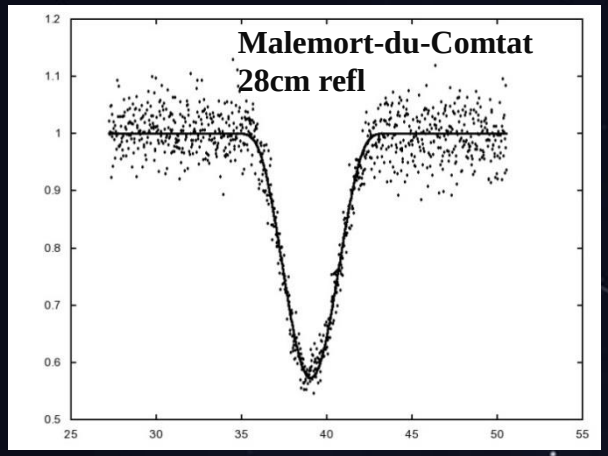




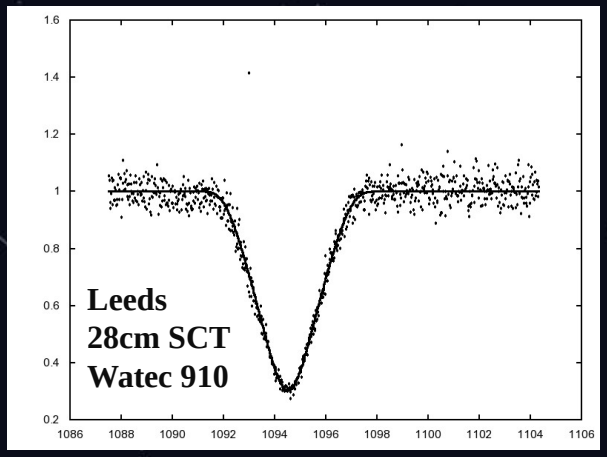


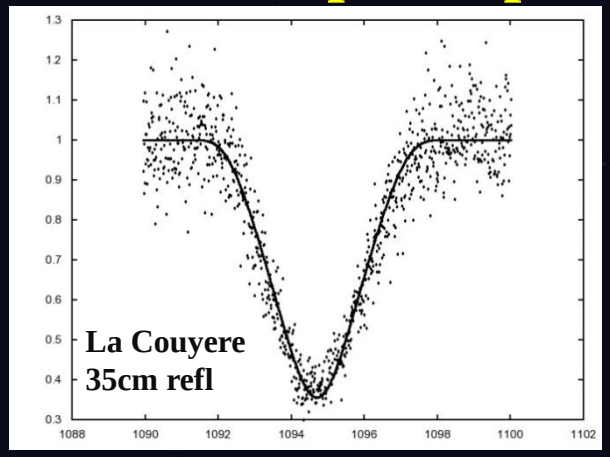


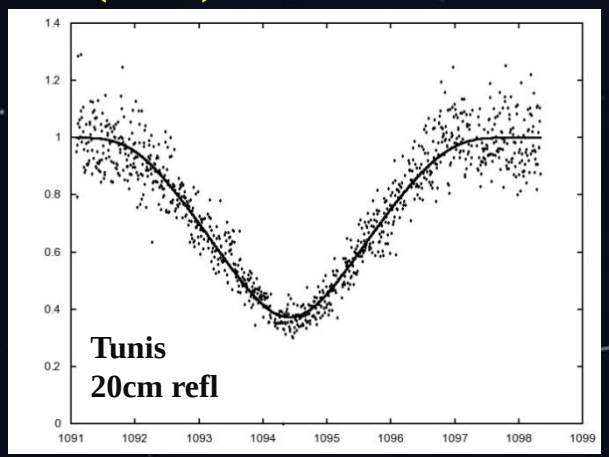


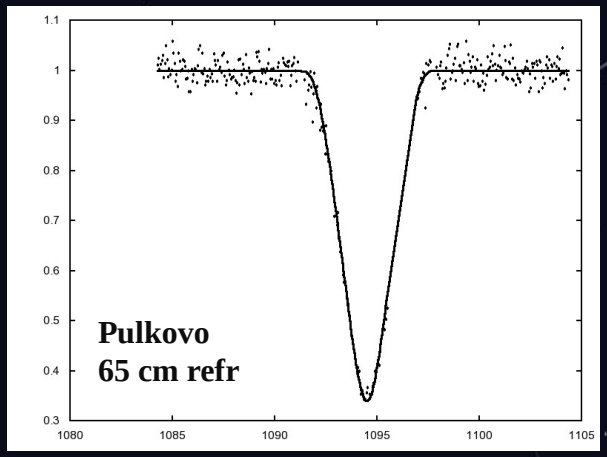


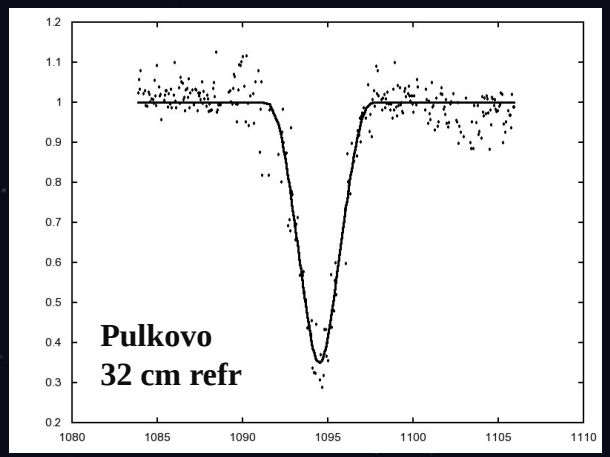
2015 March 4– Europa eclipsed Io (2e1)

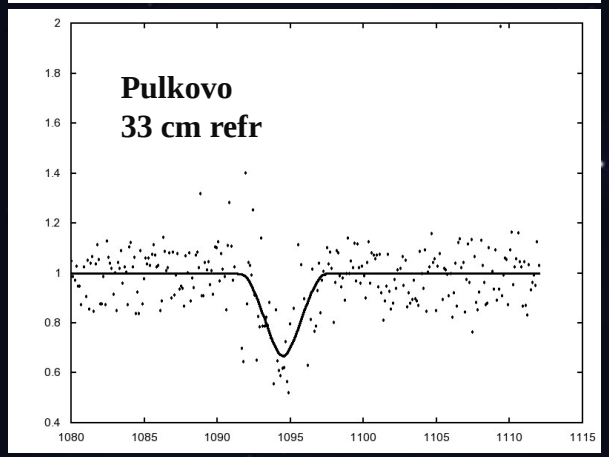


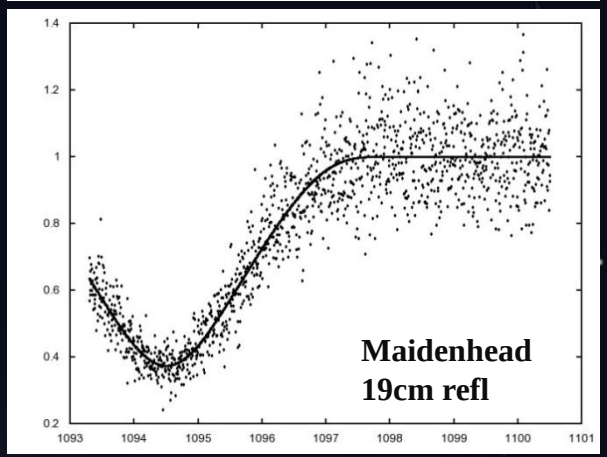


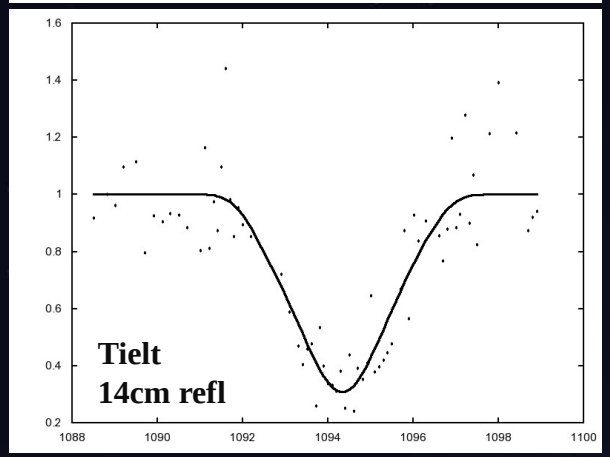


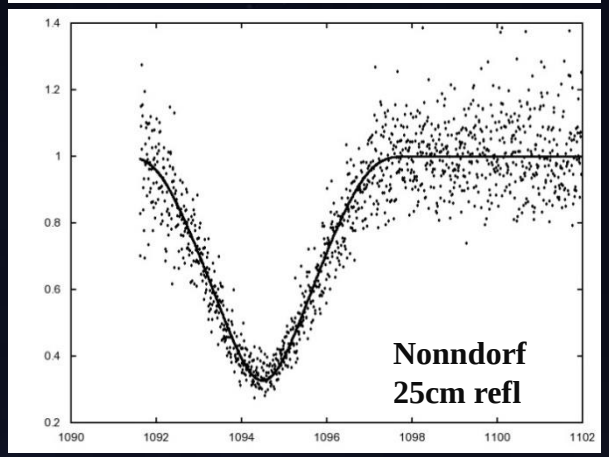




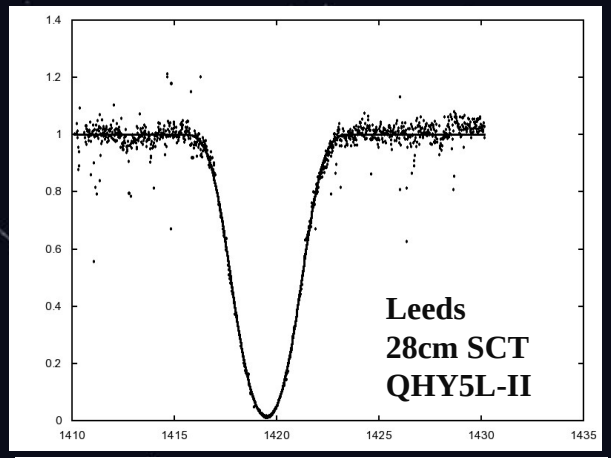


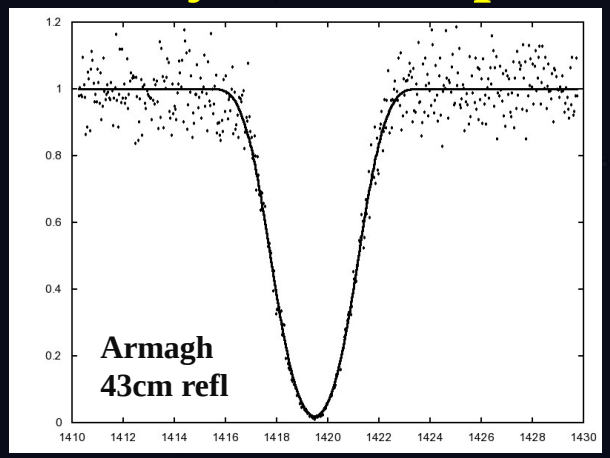


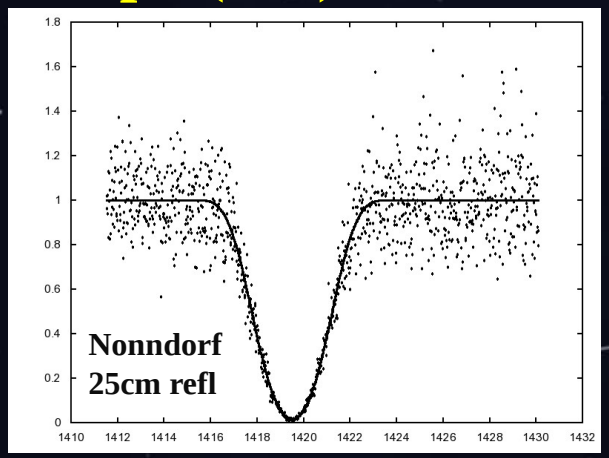


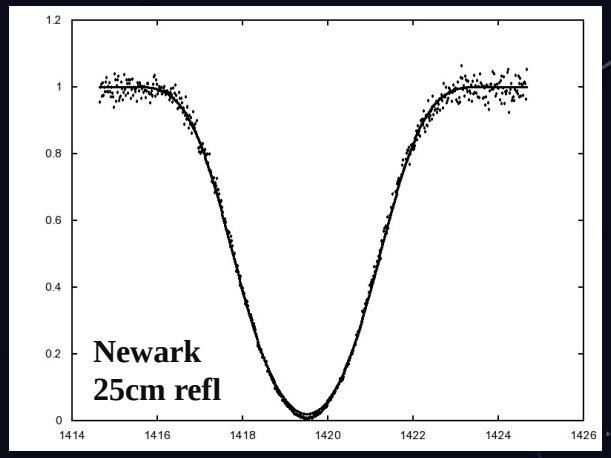


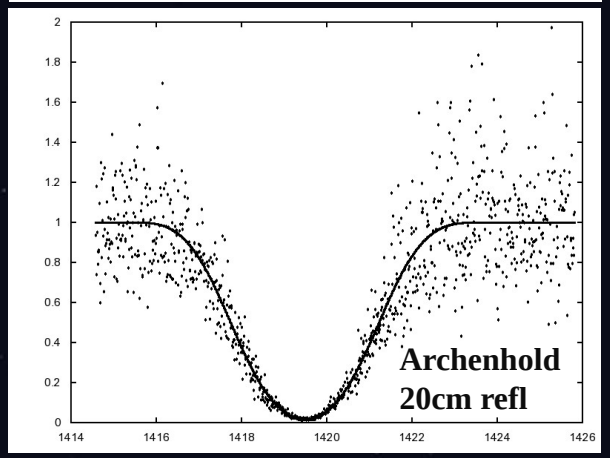
2015 March 9– Ganymede eclipsed Europa (3e2)

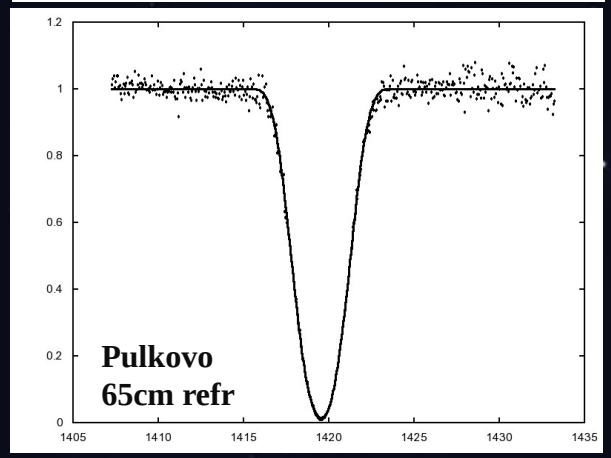


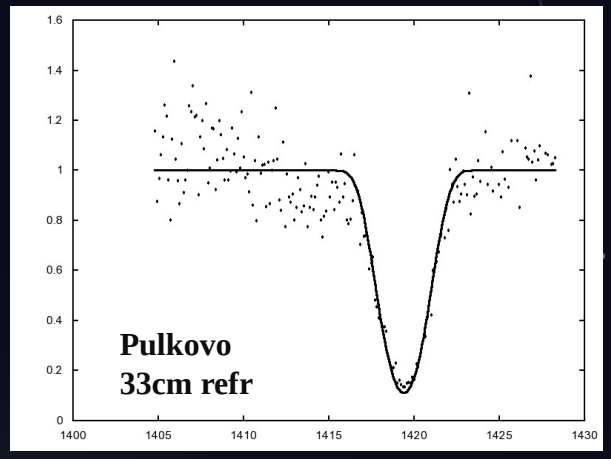


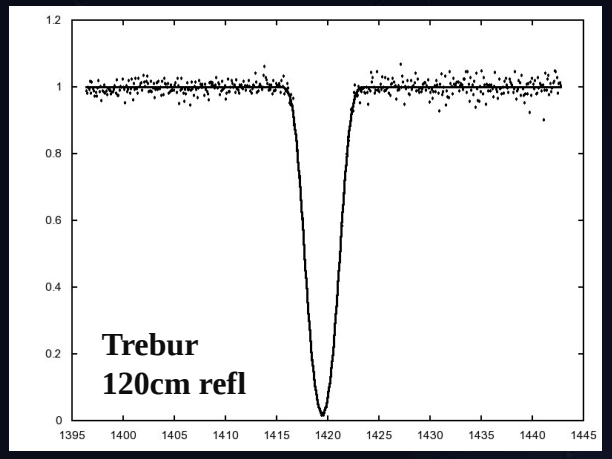


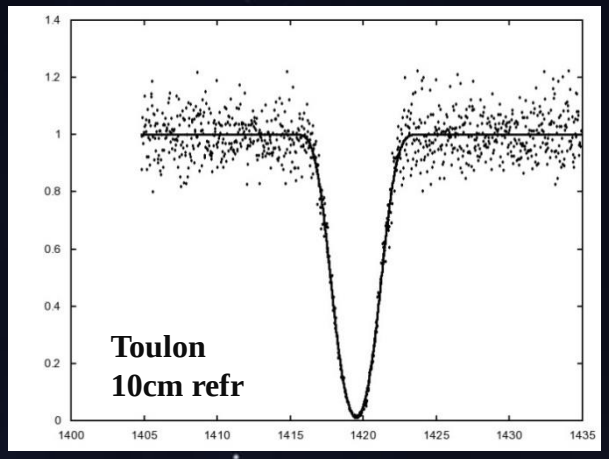












PHEMU15

Observatory	sigmaX mas	sigmaY mas	O-C_X mas	ABS O-C X mas	O-C_Y mas	ABS O-C Y mas
Archenhold	14.2	16.6	32.7	34.6	45.0	53.6
Armagh	33.7	27.6	-19.4	28.2	5.0	34.4
Biesenthal	7.8	8.6	8.1	19.1	-11.6	29.5
Horice	25.0	25.4	15.7	20.5	-0.6	51.0
Leeds	9.2	12.3	9.0	27.0	6.0	50.4
Pic du Midi	6.9	7.2	-11.8	23.2	-10.8	50.7
Prague	12.6	9.6	-11.7	38.6	-17.3	47.8
Rokycany	8.9	33.0	-2.2	6.7	28.6	78.1
Slovice	31.2	15.8	-9.7	9.7	14.2	14.2
Tangra	17.1	13.1	11.0	31.3	-19.3	48.0
Mean	**14.3**	**15.2**	**-2.6**	**22.7**	**0.2**	**48.2**

Data quality – selected stations

PHEMU15 paper in MNRAS

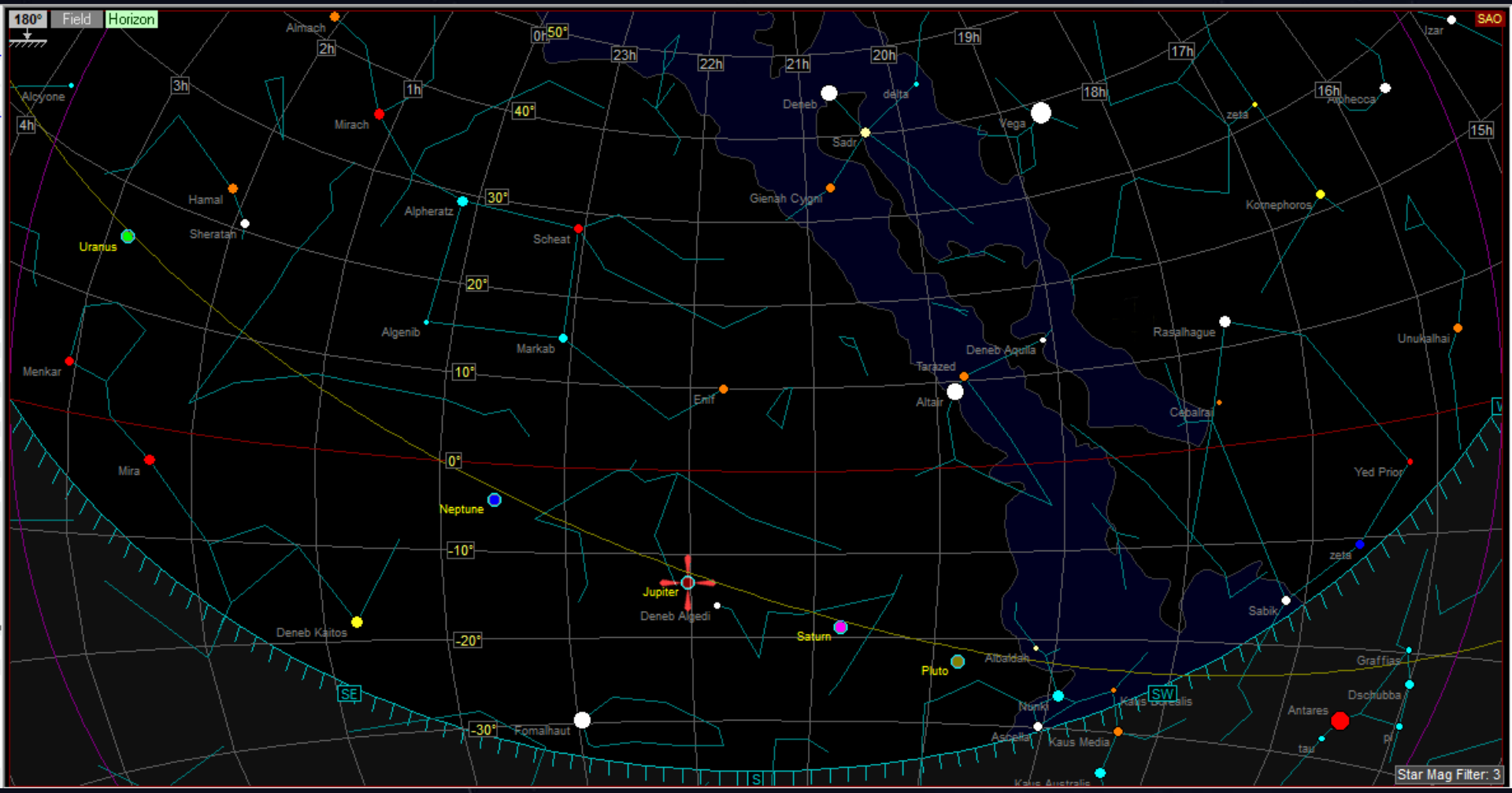
7 CONCLUSIONS

The IMCCE and SAI organized the 2014–2015 PHEMU15 international observation campaign of the mutual events of the Galilean satellites. All the photometric observations of mutual occultations and eclipses were reduced. 609 astrometric results were calculated.

The standard deviations after fitting the light curve in equatorial positions are 23.6 and 24.6 mas in right ascension and declination, respectively. The rms (O−C) in equatorial positions are ±39.2 and ±60.7 mas in right ascension and declination, respectively, according to NOE-5-2010-GAL satellite ephemerides. These results are better than those of the previous PHEMU09 campaign, and confirm the high value in observing mutual events.

The next campaign will begin in 2021 January and end in 2021 November. The occurrence will be less favourable since the maximum of events will occur at the conjunction of Jupiter with the Sun, and 192 events will be observable. The 2021 campaign will be more favourable to the Southern hemisphere, due to Jupiter's declination.

PHEMU21



Jupiter – 2021 August 15

What can we do better in 2021…?

- Predictions
- Hardware and software
- Accurate timestamps – GPS – NTP
- Integration time
- Bias, dark frame and flat field calibrations
- Sensor linearity
- Submit observations

With grateful thanks to…

IAU Natural Satellites Database

http://nsdb.imcce.fr/obsphe/obsphe-en/fjuphemu.html