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CCD positions for eight Jovian irregular satellites⋆,⋆⋆

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ABSTRACT

The astrometric positions of eight irregular Jovian satellites are given for the oppositions of the planet from 1995 to 1999. These positions were measured on 204 CCD frames obtained at the Cassegrain focus of a 1.6 m reflector. They are compared with the theoretically calculated positions from JPL Development Ephemeris. The observed minus-calculated standard deviation for all observations of the eight satellites are $\sigma_\alpha = 0\overset{''}{.}071$ and $\sigma_\delta = 0\overset{''}{.}052$. The USNO-A2.0 catalog was used for the astrometric calibration.

Key words. astrometry – celestial mechanics

1. Introduction

Around Jupiter, 63 satellites are known nowadays, with 8 regular and 55 irregular. Regular satellites are in nearly circular, near equatorial orbits revolving about Jupiter in the same direction as Jupiter's rotation. The irregular satellites orbit far from the planet in eccentric orbits, but with a significant inclination toward Jupiter's equator.

There are some difficulties in determining the positions of Jupiter's irregular satellites: the satellites are faint bodies with visual magnitudes between 15 and 20. In this paper, the images are immerged in a very rich stellar field, therefore identifying the satellites becomes very difficult and even exhausting. Also, the determination of the center of the images with only a number of very small pixels requires specific algorithms to allow the accomplishment of precise measurement.

This work is a systematic program of astrometric observation of Jupiter's satellite system which was started in 1982 at the Laboratório Nacional de Astrofísica (LNA/MCT), Brazil (Veiga et al. 2005). The observations recorded in this paper were made during 19 nights, with in the period of 1995 to 1999, when 204 CCD frames were obtained. In this work precise positions of the satellites are presented for the four irregular Jovian satellites with direct orbits, Himalia (*J VI*), Elara (*J VII*), Lysithea (*J X*), and Leda (*J XIII*), and for the four irregular satellites with retrograde orbits, Pasiphae (*J VIII*), Sinope (*J IX*), Carme (*J XI*), and Ananke (*J XII*) (Aksnes 1978; Jacobson 2000).

2. The observations

The observations were made at the Cassegrain focus of the 1.6 m Ritchey-Chretien reflector (Perkin-Elmer) at the Laboratório Nacional de Astrofísica (LNA/MCT) Itajubá-Brazil, with geographical coordinates of $3^h02^m19^s$ longitude, $-22°32'04''$ latitude, and 1872 m of altitude. The focal distance of the Cassegrain combination is equal to 15.8 m, and the focal plane is $13\overset{''}{.}0$/mm (see Veiga et al. 1995).

Two CCD's type were used to take the 204 images: the first with an array of 770 × 1152 square pixels corresponding to 22.5 μm, $0\overset{''}{.}294$ on the sky. The second had an array of 1024 × 1024 square pixels corresponding to 24 μm, $0\overset{''}{.}312$ on the sky. No filter was used and the exposure time for the observations of the eigth satellites varied from 5 to 300 s depending on the meteorological conditions. More details are shown in Table 1.

3. The measurements and astrometric calibration

The ASTROL routines package (Colas & Serrau 1993) was employed to measure the satellite and stellar image centers. Each center was determined by a two-dimensional Gaussian fitting a circular area around the image, and the background was removed by a second-degree polynomial. This background removal is essential for avoiding systematic errors in the measurements of the satellite centers. The errors of the centering procedure were $0\overset{''}{.}028$ for all satellites and $0\overset{''}{.}015$ for the field stars.

The classical process of astrometric calibration was used to determine the observed coordinates of the satellites in the sky. In this process, the stars' USNO-A2.0 catalog was used as a reference system. The UCAC2 catalog, which has better astrometric precision, was used to correct the local systematic errors of the USNO-A2.0 catalog.

Using the mean coordinate for all the observations on each night, the same stars in the UCAC2 catalog and USNO-A2.0 were identified, in a field of 2 degrees by 2 degrees. A least-square procedure was used with those positions based on a Householder transformation (Lawson & Hanson 1974) to fit the transformation parameters. A second-degree polynomial was used to determine the stars of the USNO-A2.0 catalog corrected coordinates. The characteristic standard deviation of the residuals for the stars from all the stellar fields was at $0\overset{''}{.}18$.

⋆ The list of observation (full Table 2) is only available in electronic form at the CDS via anonymous ftp to
cdsarc.u-strasbg.fr (130.79.128.5) or via
http://cdsweb.u-strasbg.fr/cgi-bin/ qcat?J/A+A/453/349
⋆⋆ Based on observations made at the Laboratório Nacional de Astrofísica/MCT-Itajubá-Brazil.

Table 1. The main information about the observations for each night and each irregular satellite. In the sequence we have: the number of the frames (Fr.), the mean exposure time in seconds (Ex.), and the number of reference stars (St.) used in the astrometric calibration of the frames. The CCD type is given in the last column: type I with an array of the 770 × 1152 square pixels, corresponding to 22.5 μm, and type II with an array of the 1024 × 1024 square pixels, corresponding to 24 μm.

	Himalia (*J VI*)			Elara (*J VII*)			Pasiphae (*J VIII*)			Sinope (*J IX*)			Lysithea (*J X*)			Carme (*J XI*)			Ananke (*J XII*)			Leda (*J XIII*)			CCD type
Nights	Fr.	Ex.	St.	Fr.	Ex.	St.	Fr.	Ex.	St.	Fr.	Ex.	St.	Fr.	Ex.	St.	Fr.	Ex.	St.	Fr.	Ex.	St.	Fr.	Ex.	St.	
95-May-23																			02	90	32				I
95-June-13	02	60	10																						I
96-June-21	05	20	118	04	60	153										03	120	164							II
96-June-22				04	60	170	04	120	178	02	180	205													II
96-June-24							02	180	176	02	240	201	02	240	178	02	300	179	02	300	169				II
96-June-25	04	60	178	04	180	121	04	180	162	03	240	164													II
96-June-26	04	60	183	02	180	105																			II
96-Jul.-25	08	05	08	13	10	122							10	10	123										II
96-Jul.-26	05	05	63	10	10	111	10	10	148																II
96-Jul.-27	10	05	159	10	10	133										02	10	91							II
96-Aug.-22	04	10	104																						I
96-Oct.-02																02	300	91	01	90	122				I
97-Aug.-13				02	180	15																			I
97-Aug.-14													02	240	17	02	300	14				02	300	12	I
97-Aug.-15	02	60	18				04	180	18	04	240	20	04	240	08	02	300	15	04	300	15				I
97-Aug.-16													02	240	10	02	300	09							I
98-June-05				02	180	05																			II
98-Sep.-03				03	180	06				03	240	06	03	240	08	02	240	09	05	240	06	02	240	07	II
99-Sep.-21													02	180	06										II

Table 2. Sample of the list of observations available only in electronic form. Starting from Col. 1 we have: the international code adopted for Jupiter's satellites; the time in year, month, and decimals of the day in Universal Time; and the coordinates' right ascension and declination, given in degree and fraction. These topocentric observed positions of eight satellites refer to a mean equator and equinox J2000 system.

Code	Time	Right Ascension	Declination
506	1995 6 13.1079861	247.1854646	–20.7743250
506	1995 6 13.1101505	247.1852150	–20.7742888
506	1996 6 21.0608356	286.4460509	–22.7136093

Table 3. Observed minus calculated statistics for all observations of each satellite. The units are arcseconds and $\overline{\alpha}$, $\sigma_{\overline{\alpha}}$, $\overline{\delta}$, $\sigma_{\overline{\delta}}$ are the means and the standard deviations for the residuals in right ascension and declination. $N_{\rm obs}$ is the final number of observations for each satellite. σ_{α^*} and σ_{δ^*} is the standard deviation of the stars' reference residuals. Those two columns give the means of the standard deviations, in arcseconds, over all observed nights for the each satellite. In the last column, $\overline{N}_{\rm stars}$, we have the mean number of reference stars used in the astrometric calibration.

Satellites	$\overline{\alpha}$	$\sigma_{\overline{\alpha}}$	$\overline{\delta}$	$\sigma_{\overline{\delta}}$	$N_{\rm obs}$	σ_{α^*}	σ_{δ^*}	$\overline{N}_{\rm stars}$
Himalia (*J VI*)	0.009	0.070	0.039	0.054	44	0.188	0.213	102
Elara (*J VII*)	–0.012	0.064	0.013	0.060	54	0.235	0.230	112
Pasipahe (*J VIII*)	0.010	0.052	0.028	0.039	24	0.213	0.200	134
Sinope (*J IX*)	–0.018	0.049	0.005	0.034	14	0.155	0.118	99
Lysithea (*J X*)	–0.025	0.077	0.008	0.054	25	0.153	0.162	68
Carme (*J XI*)	0.008	0.080	0.008	0.047	25	0.211	0.210	81
Ananke (*J XII*)	–0.015	0.097	0.025	0.038	14	0.146	0.120	44
Leda (*J XIII*)	–0.012	0.046	-0.002	0.016	04	0.183	0.113	10

Finally, using the star positions in the field of each CCD frame observation (measured and from the corrected catalog), a new least-square procedure was used to determine the parameters of the scale and orientation. The first-degree polynomial was then used to determine the equatorial coordinates of the satellites. The standard deviation of the mean residuals and the mean of the star number, used for the astrometric calibration of the observations of each satellite, are shown in the last three columns of Table 3.

In the list, available only in electronic form, the topocentric observed positions of eight satellites are referred to a mean equator and equinox J2000 system. The time is given in year, month, and decimals of the day in Universal Time. The coordinates' right ascension and declination are given in degree and fraction, with seven significant digits.

Based on the international code, adopted for Jupiter's satellites, starting from Col. 1 of the list, we have: the number of satellite, the date of the observation, topocentric observed right ascension and declination. Table 2 gives a sample of the electronic list.

4. Results

In this section the observed positions of the eight irregular Jovian satellites are compared with their theoretical positions. The ephemerides used in this work are available electronically

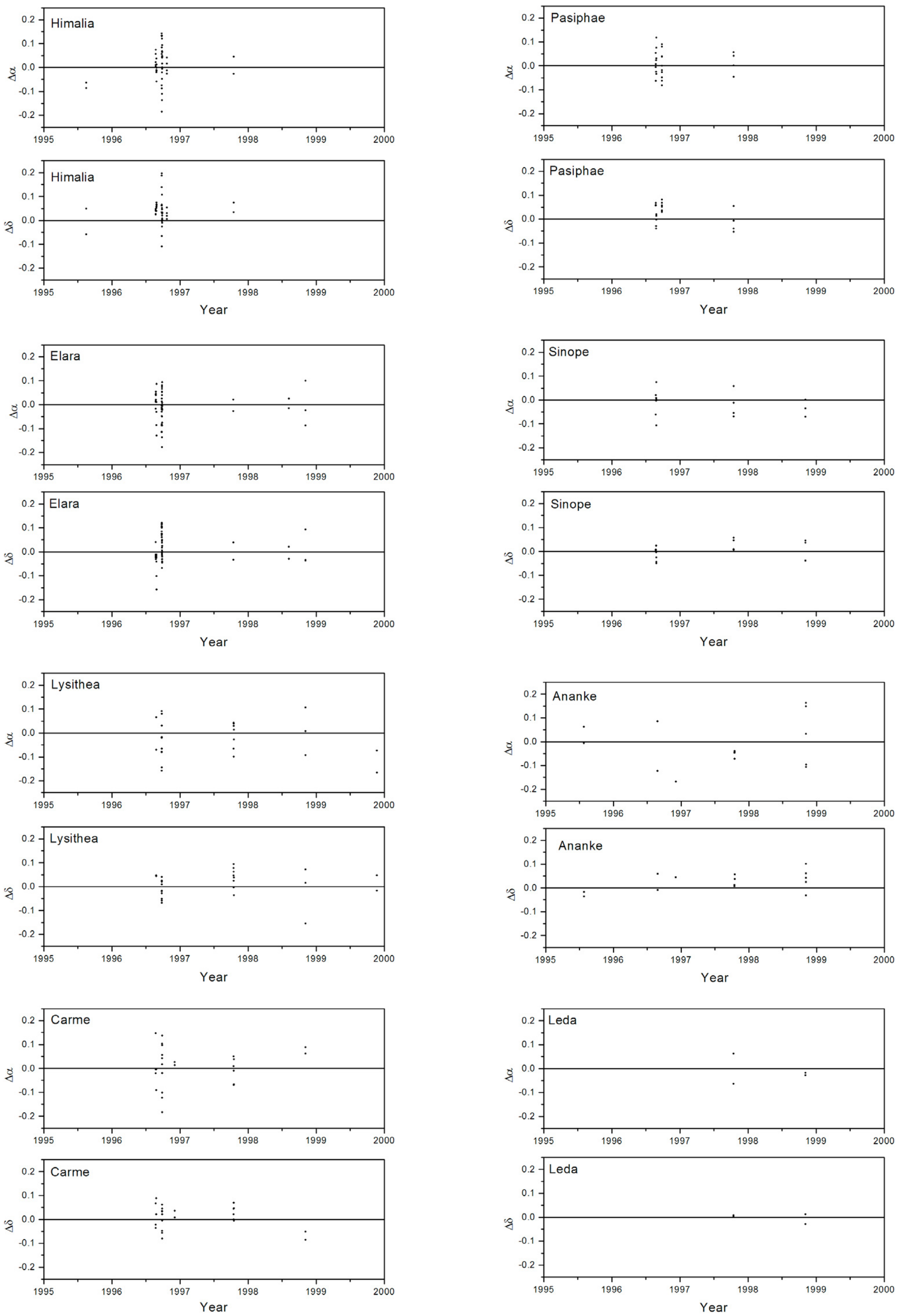

Fig. 1. Residuals, in arcseconds, for each one of the eight satellites as a function of time. $\Delta\alpha$ and $\Delta\delta$, $(\alpha_{\text{observed}} - \alpha_{\text{calculated}})$ and $(\delta_{\text{observed}} - \delta_{\text{calculated}})$, refer to respectively.

from the JPL Horizons on-line solar system data and ephemeris computation service (Giorgini et al. 1996). The model for the orbits of these satellites is a numerical integration of their motion equations (Peters 1981) that includes the effects of an oblate Jupiter, pertubations from the Galilean satellites, and pertubations from the Sun, Saturn, Uranus, and Neptune (Jacobson 1991, 2000).

Table 3 gives the $\Delta\alpha$ and $\Delta\delta$ residual means and the standard deviation of each satellite. From Table 3 we can see the mean of the observed residuals minus the calculated ones for all satellites: $\Delta\overline{\alpha} = -0''.005$ and $\Delta\overline{\delta} = 0''.019$ and the standard deviations, $\sigma_{\overline{\alpha}} = 0''.071$ and $\sigma_{\overline{\delta}} = 0''.052$.

In Fig. 1 we have the distribution of residual $\Delta\alpha$ and $\Delta\delta$ in function of time for the eight satellites.

5. Concluding remarks

In this work were presented 204 CCD observations of the eight irregular satellites of Jupiter, made with the same telescope and distributed over 19 nights between 1995 and 1999. Their error ($\sqrt{(\sigma_{\overline{\alpha}})^2 + (\sigma_{\overline{\delta}})^2}$) is about $0\farcs09$. This result shows that the CCD observations and the measure and astrometric calibration system together allowed us to determine precise positions. We can see that in the distribution of residuals (Fig. 1) no tendency is verified for the 5 years, showing a good agreement with the Jacobson ephemeris. The result of $\sqrt{\sum \overline{\alpha}^2 + \sum \overline{\delta}^2}$ is smaller than $0\farcs02$.

If we compare the residuals with those presented by Jacobson (2000), we conclude that they are very small. Unfortunately, the number of observations is relatively small for each satellite; however, putting these observations together with all the other ones published, the results can contribute to improved accuracy of the ephemerides.

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