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CCD astrometric observations of Uranian satellites: 1995-1998⋆,⋆⋆

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Abstract. Astrometric positions of the five largest Uranian satellites from 750 CCD frames taken at the oppositions of 1995 through 1998 are presented. The images were obtained over 35 nights. Observed positions are compared with the calculated positions from GUST86. The standard deviations are better than 0.″05 for the four largest satellites and 0.″08 for Miranda.

Key words: planets and satellites — Uranian system — CCD astrometry

1. Introduction

In 1982 we initiated a systematic program of astrometric observations of natural satellites of the Jovian planets. The results of our Uranian observations, which correspond to 701 images of the system, were presented in three previous papers (Veiga et al. 1987; Veiga & Vieira Martins 1994, 1995). These sets of positions are some of the largest and most accurate in the catalogue of all available published and unpublished Earth-based observations of the satellites of Uranus compiled by Taylor (1998).

In this paper the observations of 750 frames carried out during 35 nights distributed in 12 missions in the 1995-1998 period are presented. Almost all observations were taken near the zenith since the latitude of our telescope (−23°) is close to the declination of the planet in this period.

The paper is organized as follows: in Sect. 2 the observations and reduction procedures are presented; in Sect. 3 the observed and calculated positions are compared. The conclusion is presented in Sect. 4.

⋆ Based on observations made at Laboratório Nacional de Astrofísica/CNPq/MCT-Itajubá-Brazil. Please Send offprint requests to C.H. Veiga.

⋆⋆ Table 1 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/Abstract.html

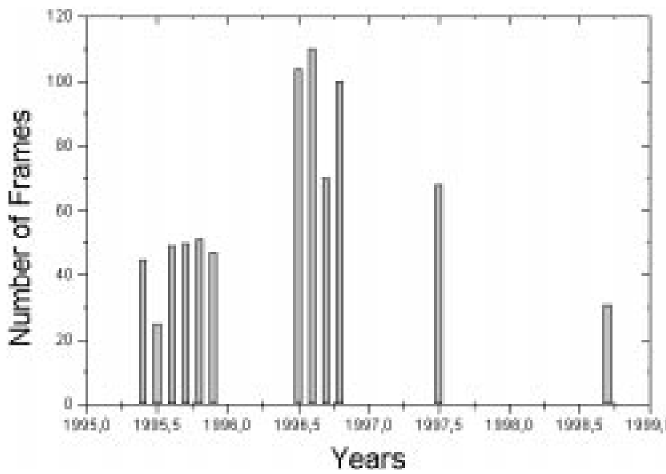

Fig. 1. Distribution of the observations. Every bar corresponds to an observational mission

2. The observations, measures and astrometric calibration

The observations were made at the Cassegrain focus of the 1.6 reflector of the Laboratório Nacional de Astrofísica, Brazil, where the scale at the focal plane is 13″/mm. For more details about the telescope we refer to Veiga et al. (1987). To take the 750 images, a CCD was used. It has an array with 770×1152 square pixels each one measuring 22 μm which corresponds to 0.″294 on the sky. No filter was used and the exposure time varied from 3 to 10 seconds, depending on the meteorological conditions. To avoid the diffraction cross originated from the saturated image of Uranus, a mask with 8 circular apertures was placed between the secondary mirror support vanes.

The distribution of the observations during the four years are presented in Fig. 1. Every bar corresponds to an observational mission.

The ASTROL reduction package (Colas & Serrau 1993) was used to find the center of the satellites and the field stars. For the determination of each center a small area was taken containing the image of a satellite or a star

Table 2. Number of positions, mean and standard deviation, in arcseconds, of the observed minus calculated x and y of the Uranian satellites referred to Oberon. Paper I is for Veiga & Vieira Martins (1994) and Paper II is for Veiga & Vieira Martins (1995)

	Paper I		Paper II		This paper	
Satellite	$\overline{(o-c)}_x$ (σ_x)	$\overline{(o-c)}_y$ (σ_y)	$\overline{(o-c)}_x$ (σ_x)	$\overline{(o-c)}_y$ (σ_y)	$\overline{(o-c)}_x$ (σ_x)	$\overline{(o-c)}_y$ (σ_y)
Miranda	273		368		554	
	0.006	−0.001	0.022	0.001	0.009	−0.009
	(0.128)	(0.106)	(0.065)	(0.070)	(0.083)	(0.070)
Ariel	333		368		745	
	−0.014	0.003	0.007	−0.003	0.007	0.013
	(0.041)	(0.026)	(0.039)	(0.044)	(0.035)	(0.045)
Umbriel	333		368		735	
	−0.001	0.005	0.006	−0.007	0.005	0.009
	(0.040)	(0.040)	(0.043)	(0.049)	(0.034)	(0.047)
Titania	333		368		750	
	−0.006	−0.001	−0.001	−0.012	0.003	0.013
	(0.031)	(0.020)	(0.056)	(0.052)	(0.037)	(0.056)

and a bi-dimensional Gaussian was used to fit the image. When necessary, a second degree polynomial was added. In some cases, the addition of the polynomial is essential since the sky background needs to be removed. This occurs for the images of Miranda which are contaminated by light from the planet. The centering error were $0\farcs030$ for Miranda and $0\farcs015$ for the other satellites and stars.

For the astrometric calibration, we used an adaptation of the secondary catalog method to the special conditions of the small CCD fields. This method, which is presented and tested in Vieira Martins et al. (1996) (see also Assafin et al. 1997a,b), consists in setting an astrometric catalogue for the stars on the CCD, using their images in the Digitized Sky Survey (DSS-I) and the positions of nearby stars from the Guide Star Catalog (GSC1.1) corrected by the PPM Catalog.

The CCD images were corrected with a 6 constants model in the astrometric calibration procedure. Therefore it is not necessary to add any correction for the refraction. Furthemore almost all images were taken at a zenithal distance smaller than 30°.

In Table 1 (accessible in electronic form) we list the observed positions of the four largest Uranian satellites relative to Oberon. The data are presented in the following form: the first line gives the year, month and day and decimal fraction of UTC days, corresponding to the mean instant of the observation. In the next lines we list the name of the satellite followed by $X = \Delta\alpha \cos\delta$ and $Y = \Delta\delta$, in arcseconds referred to Oberon. The reference system is placed on the equator and equinox of J2000.

3. Comparison with theoretical positions

To compare our set of J2000 measured positions with those calculated using the GUST86 theory (Laskar & Jacobson 1987) which refers to the B1950.0 system, the following transformations were done. First, the positions of Uranus in J2000 were obtained from the DE403 ephemeris (Standish et al. 1995). These positions were converted to the B1950.0 reference system using the procedure described by Aoki et al. (1983, Appendix 2). To add on the e-term of the aberration in the transformation, a process of successive approximations (Rapaport 1996) was used. Therefore, the theoretical right ascensions and the declinations of the satellites were calculated in B1950.0 system. Using the Aoki procedure these coordinates were then computed in the J2000 system.

The mean residuals (O–C) and the standard deviations for each satellite are presented in Table 2. In order to compare these observations with those published in our previous papers, the means and standard deviations of our other photographic and CCD observations are added to the table. The residuals were compared with values of Jones et al. (1998). The residuals of their CCD observations are slightly smaller than the residuals presented in this paper. However, the two series of observations had been compared to different ephemeris and it is difficult therefore to analyze the significance of these differences, as stressed also by Jones et al. (1998).

In Fig. 2, the residuals of all our observations for Miranda, Ariel, Umbriel and Titania referred to Oberon are presented as a function of the observational date.

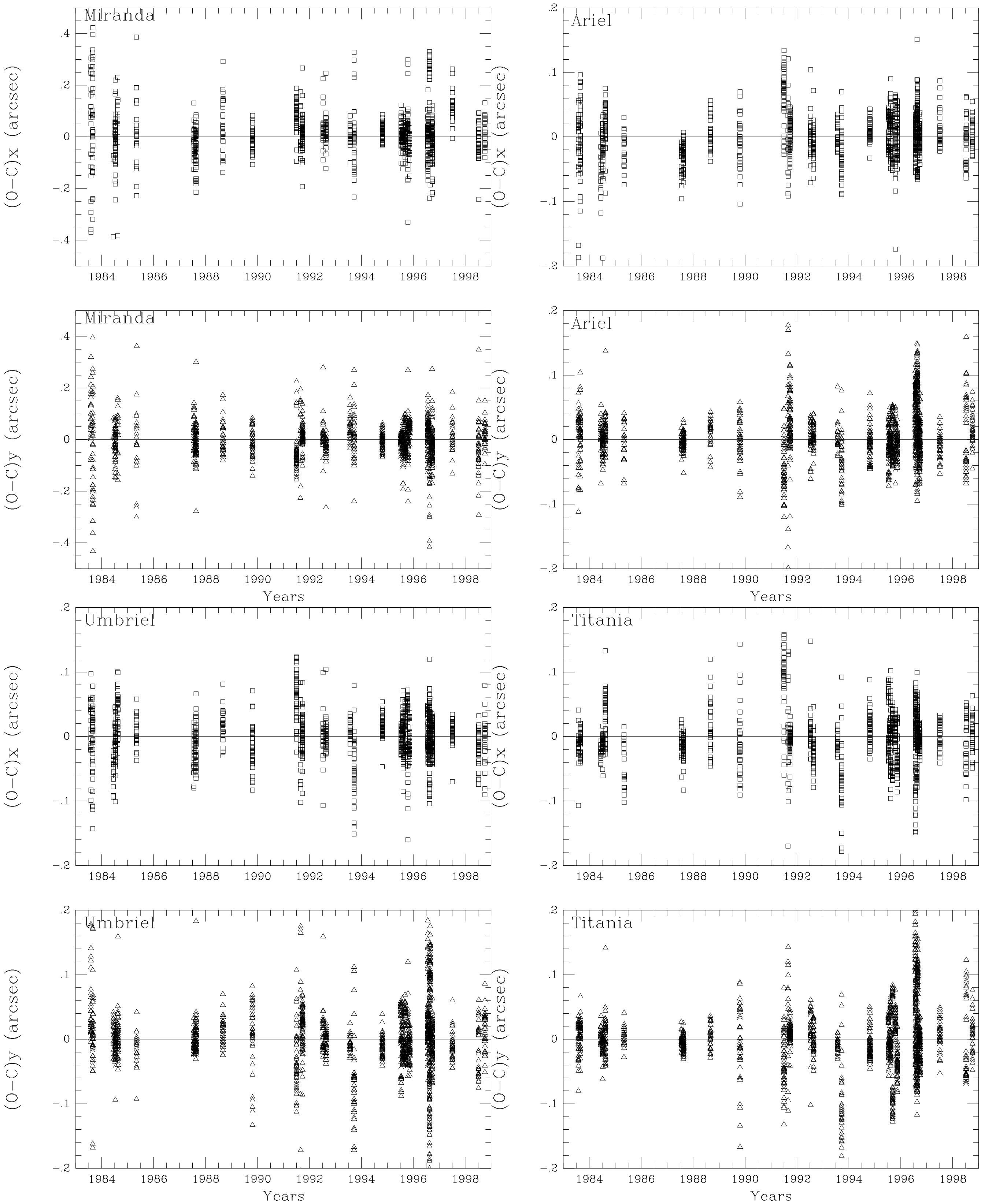

Fig. 2. Residuals for Miranda, Ariel, Umbriel and Titania referred to Oberon versus the date. The observations of this paper correspond to 1995-1998

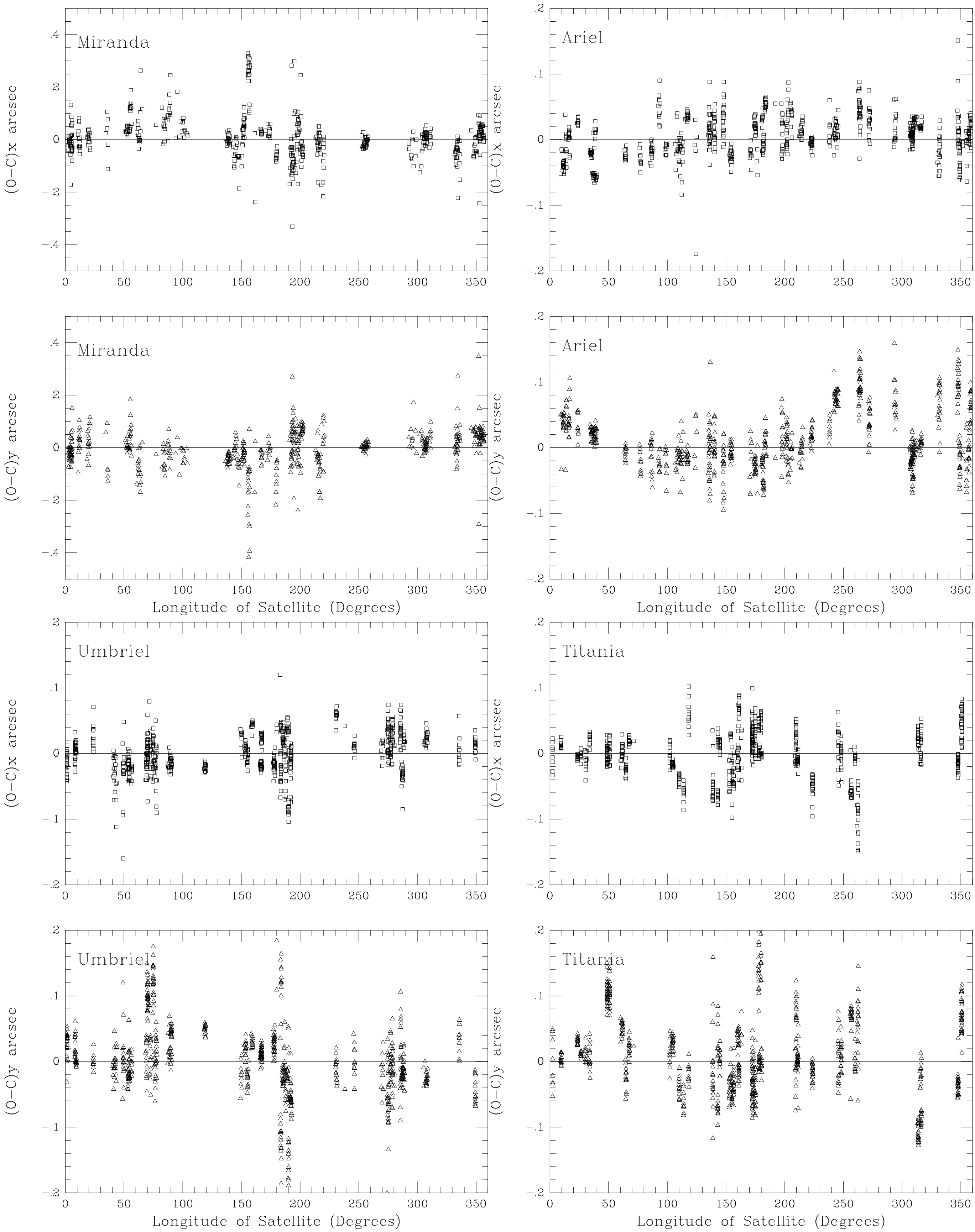

Fig. 3. Residuals for the observations presented in this paper for Miranda, Ariel, Umbriel and Titania referred to Oberon versus longitude

Observe that the vertical scale for Miranda is larger than the scale for the other satellites. It can be seen that the distributions of the residuals are uniform for these 16 years and very similar for the CCD observations (1989-1998).

The CCD residuals as function of the satellite longitude are shown in Fig. 3. It can be seen that there is in general a random distribution for the residuals. However, comparing this figure with Fig. 3 in Veiga & Vieira Martins (1995), a drift of the residual for Miranda can be seen in the X direction for the longitude range between 40° to 100°. Two others drifts can also be seen in direction Y for the longitude intervals (90° to 160°) and (300° to 320°).

4. Conclusion

In this paper 2784 (x, y) positions of the 4 largest Uranian satellites related to Oberon were presented. They are distributed over 35 nights. Putting these observations together with those we published in previous papers, we have 5528 (x, y) observed positions distributed between 97 nights in the period 1983-1998. These positions were observed with the same telescope in very similar conditions. The accuracy of these observations is better than $0\farcs08$ for Miranda and $0\farcs05$ for Ariel, Umbriel and Titania. Therefore this sample is well qualified for use in future improvements in the of the Uranian system dynamics.

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