CONNECTION BETWEEN THE ICRF AND THE DYNAMICAL REFERENCE FRAME FOR THE OUTER PLANETS

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ABSTRACT

This work brings an approach intending to improve the connection between the Dynamical Reference Frame and the Extragalactic Reference Frame. For that, close encounters of outer Solar System objects and quasars are used. With this goal, Uranus, Neptune and two quasars were observed at Laboratório Nacional de Astrofísica (LNA), Brazil. The optical reference frame is the HCRF, as given by the UCAC2 catalogue. The first results show an accuracy of 45 mas – 50 mas in the optical positions. The optical minus radio offsets give the local orientation between the catalogue and radio frame. From this, it is possible to place the optical planet coordinates on the extragalactic frame. A comparison between the new corrected optical coordinates and the respective DE ephemeris to these planets can give the instant orientations of the Dynamical Reference Frame with regard to the ICRS, for this zone of outer Solar System.

Key words: Extragalatic Reference System; Quasars; Dinamical Reference Frame.

1. INTRODUCTION

The materialization of the ICRS (Arias et al. 1995) is provided by VLBI positions of radio compact quasars, to accuracy better than 1 mas. With the adoption of the ICRS as the Fundamental Reference System by IAU on 1 January 1998, the importance of the orientation between the different frames used in astronomy and the Extragalactic Reference System was increased. For the inner planets, the orientation of the Dynamical Reference Frame with respect to the ICRF (Ma et al. 1998) was obtained at the 2 mas level (Standish 2000). It was done using accurate methods, such as by radar and laser ranging measurements and specially by VLBI measurements to the Magellan spacecraft near Venus and the Phobos spacecraft near Mars. However, the same was not done to the outer Solar System region.

Now, we propose to calculate the orientation of outer Solar System objects relative to precise coordinates of the extragalactic objects by using simultaneous optical observations of these outer objects and radio sources related to the ICRF, which is the primary realization of the ICRS. Here, we present the first results of quasi-simultaneous close encounter observations (about 2 degrees) between Neptune and QSO 2047-1669, and Uranus and QSO 2211-1328. The quasars are compact VLBA calibrator sources with positional precision at 0.5 mas. In this way, possible stability (Feissel 2000) and structure effects (da Silva Neto et al. 2002) are unlikely. The VLBA position for these quasars is associated to the ICRF at the miliarcsecond level. The CCD fields were observed on $10' \times 10'$ frames, taken at the 0.60 m Cassegrain telescope from Laboratório Nacional de Astrofísica (LNA), Brazil. In each session a large number of both QSO and planet images were taken to lessen local atmospheric effects. The reduction was done on the Hipparcos Catalogue Reference System (HCRS, Perryman et al. 1997), through the UCAC2 catalogue, whose positional precision ranges from 20 mas to 70 mas (Zacharias et al. 2004). Beside this precision, the UCAC2 gives a high stability to astrometric work on the fields of this size (Assafin et al. 2004).

The local orientation between the UCAC2 and the ICRF is obtained from the QSO observed (relatively to UCAC2 stars) minus formal ICRF position. Next, the local orientation correction is applied to the planets observed positions, also reduced relative to UCAC2 stars. At this point, the planets instantaneous positions relatively to ICRF are obtained. Finally, the ICRF planets positions can be compared to the DE Ephemeris. The differences represent the instant orientations of the Dynamical Reference Frame regarding to the Extragalactic radio frame, at the Neptune and Uranus zone.

2. THE IMAGE REDUCTIONS

All CCD images were photometrically corrected using standard IRAF routines, bias and flat-field corrections. Target images affected by cosmic rays, bad pixels and other spurious, nearby objects were manually reduced, eliminating the respectively affected pixels. The (x,y) positions of images came from spherical symmetrical Gaussian model fits, with accuracy at the 25 mas level, through a modified version of Software for Analyzing Astrometric CCD (SAAC) data package (Winter 1999).

Investigation of possible (x,y) position dependencies with regard to the CCD center distance was done, and the results plotted in Figure 1. The figure shows that there is no evident dependency.

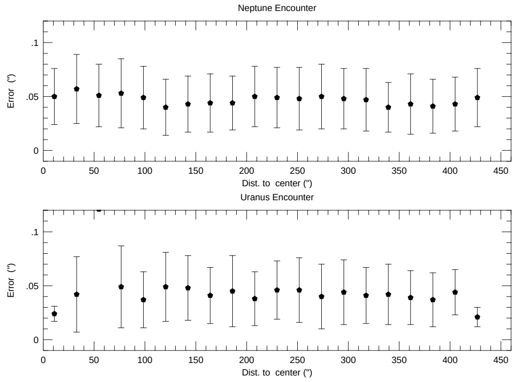

Figure 1. The (x,y) Gaussian position errors for all measured objects against their distance to the CCD centre. Each point is an average of at least 12 (x,y) Gaussian position errors.

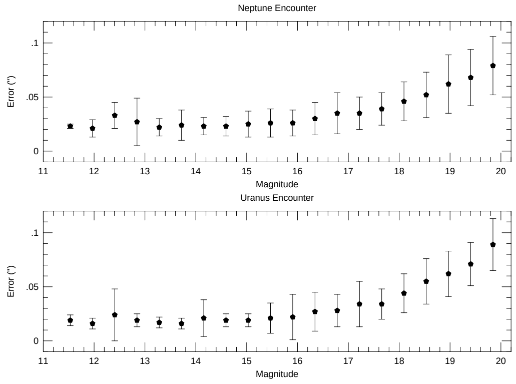

Figure 2. The (x,y) Gaussian position errors for all measured objects versus their magnitudes. Each point is an average of at least 15 (x,y) Gaussian position errors.

We also investigated possible (x,y) position dependencies regarding magnitude. Figure 2 displays an evident growth of (x,y) position errors from 16 magnitude on toward its faint end. This effect was expected, and indicates the astrometric behaviour toward the telescopes' magnitude limit, as well as the optimum magnitude range of observations (Assafin et al. 2004). It is important remember that 16 magnitude is also the brightness faint end of UCAC2 stars. The (x,y) position errors for both QSOs are at 25 mas level.

3. THE OPTICAL REDUCTION

Here, we present the preliminary results related to the optical mean catalogue. Appropriate corrections are still being developed and will not be shown here. The optical positions were obtained on the HCRS through the UCAC2 catalogue by least squares adjustment using a three constants plate model for each coordinate. On average, 30 catalogue stars were found in each observed field, and 20% of these stars were discarded in the reductions for the Neptune encounter. In the Uranus case, 10 catalogue stars were found on average for each field, and of these only 1 star was discarded per field.

The comparison between optical measured and catalogue positions give an indication of the optical coordinate precision computed to the observed objects. Table 1 brings the standard deviations of the optical measured minus catalogue coordinate differences (O - C) for the reference catalogue stars.

Table 1. Standard deviations of (O - C) differences between the optical measured and UCAC2 coordinates. $< N >$ is the mean number of observed catalogue stars in the CCD fields and $< N_u >$ is the mean number of used catalogue stars. All values are in mas.

Fields	σ_α	σ_δ	$< N >$	$< N_u >$
Neptune	43	49	30	24
2047-163	42	46	30	24
Uranus	43	49	12	11
2211-132	50	34	09	08

Table 1 points to a typical precision (standard deviation) of 45 mas to 50 mas for the computed optical coordinates. This number can be understood as the typical precision of the optical coordinates obtained here.

A practical way to verify these (O – C) distributions is shown in Figure 3. On this, each point is the average of all (O – C) differences obtained for each catalogue star, and the ellipses axes are the standard deviations of the respective coordinate differences. The distributions are compatible with a 2-dimension normal distribution.

Position dependencies regarding magnitude and star distance to CCD centre were conducted. In Figure 4, the (O – C) differences are plotted against UCAC2 magnitudes. There are signs of (O – C) growth toward higher magnitudes in both figures. The UCAC2 itself foresees a position error increasing from 20 mas up to 70 mas toward the faint magnitude end. However, when taking into account the involved precision, no conclusions can be asserted in that favor.

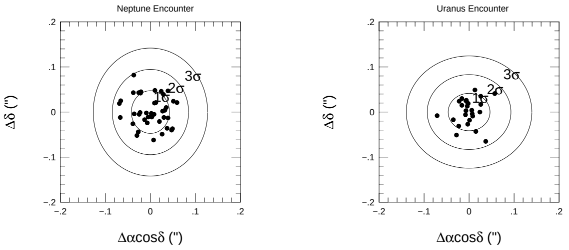

Figure 3. Each point represent the (O – C) mean difference for one star catalogue. Ellipses have the standard deviations as axes for the respective coordinate differences. Neptune and Uranus close encounters have respectively 53% and 70% of points inside the 1σ boundary for each distribution. 99% and 100% inside 2σ and 100% inside 3σ boundary for both distributions.

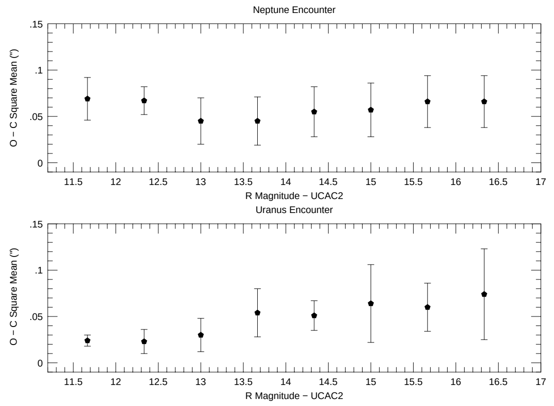

Figure 4. (O – C) positional differences versus UCAC2 magnitude. Each point is an average of at least 15 star catalogue differences. The error bars are the standard deviations of each mean point.

Figure 5 shows no evident dependencies on the (O – C) positional differences with regard to CCD centre star distance.

4. QSO AND PLANET OPTICAL POSITIONS

The astrometric reduction with UCAC2 stars provides optical coordinates for Uranus, Neptune and the two quasars in the catalogue frame. The comparison between the optical and the radio positions of the two extragalactic sources gives the respective local orientations between the UCAC2 frame and the radio frame. Table 2 presents the mean offsets between the radio and optical positions, in the sense optical minus radio (O – R).

The (O – R) standard deviations in Table 2 indicate the obtained coherency to both quasars optical positions, which is not much larger than the typical optical position errors estimated before (Table 1). This coherence value is an estimate of astrometric reduction inaccuracy, that we can essentially attribute to the UCAC2 coordinates inaccuracy, since the obtained precision of the (x,y) positions is at 25 mas level.

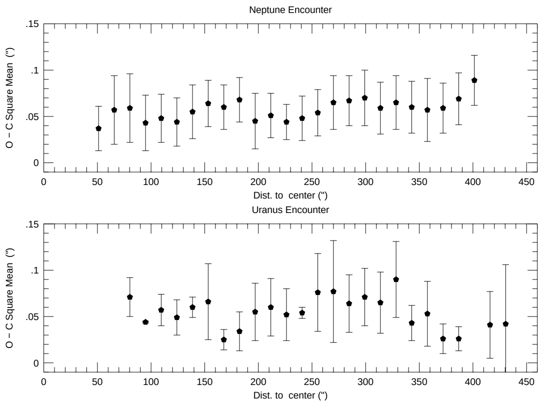

Figure 5. (O – C) positional differences versus star distances to CCD centre. Each point is an average over 10 star catalogue differences at least.

Table 2. Offsets averages between optical measured and radio positions (O – R) from the two quasars of the close encounters. E is the standard error of each (O – R) offsets' average. All values are in mas.

	$\overline{\Delta\alpha\ cos\ \delta}$	E $\overline{\Delta\alpha}$	$\sigma_{\Delta\alpha}$	$\overline{\Delta\delta}$	E $\overline{\Delta\delta}$	$\sigma_{\Delta\delta}$
2047-163	+70	09	51	−03	11	61
2211-123	−62	09	31	−61	10	34

From this point, one can use the (O – R) offsets' averages on Table 2 as corrections to place the accurate planet's optical positions directly onto the extragalactic reference frame, that nowadays is onto the ICRF.

Now, the ICRF planet's positions can be compared to the DE ephemeris. The differences represent the instant orientations of the Dynamical Reference Frame with regard to the ICRF, at the Neptune and Uranus zone in the outer Solar System. As the first results are preliminary and appropriate corrections are still being developed we will not present the instant orientations here.

5. CONCLUSION

An investigation on the orientation between the Dynamical Reference Frame and the ICRF on the outer Solar System region was performed. For that, Uranus, Neptune and two fixed, radio compact quasars were observed with a 0.6m Cassegrain telescope at LNA, Brazil. The first results show an accuracy of 45 mas to 50 mas for the quasars and the two planets optical positions derived on the UCAC2 frame. The optical minus radio position offsets, that were found at similar star position's accuracy, give the local orientation between the catalogue and radio frame. This can provide the accurate planet's optical coordinates directly on the ICRF. The errors here obtained are an improvement over the present level of precision for the orientation between the ICRF and the Dynamical Reference Frame outside the inner regions of the Solar System. This indicates that the connection on these distant zones can be done with higher precision using close encounters of outer Solar System objects with quasars. This distinct approach, applied on the framework of Gaia, may render an even better connection with Dynamical Reference Frame, at the 10 μas level.

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