# CCD AND PHOTOGRAPHIC OBSERVATIONS OF THE COMET C/1996 B2 (HYAKUTAKE)

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*Abstract:* About 200 CCD images of the comet C/1996 B2 - HYAKUTAKE were obtained and reduced, using four approaches by PPM stars and one by a GSC star, in March 20, 24, 25 and April 1-st, 1996, in Bucharest. Also, three photographically plates were reduced using PPM stars. The O-C analysis of the astrometric data allowed testing the accuracy of both the observational technique and the reduction method. The variation of the orientation of the comet's tail was also computed.

*Key words:* comet, appulse, astrometry, CCD

## 1. INTRODUCTION

Comets, together with asteroids, play an essential role in the knowledge of the origin and evolution of the Solar System. The spectacular and rare visible naked-eye apparitions of a comet in the inner Solar System become a major event for the astronomical community.

C/1996 B2 (Hyakutake) was announced at the end of January 1996, and became one of the "comets of the century" at the end of this century. The close approach opportunities from the Earth allowed favorable conditions of ground-based observations, even for the modest instruments.

More than 400 comets were observed photographically at Bucharest Observatory (Vass, 1994). The double refractor Prin-Merz of the Astronomical Institute in Bucharest has an $F = 6\text{m/D} = 38\text{cm}$ and works as an astrograph, both photographically and CCD. The plates have a field by 2°×2° and ensure a limiting magnitude 12 (at maximum 30 min exposure time). The CCD has 768×512 pixels, "sees" a 4'×2.5' field and a limiting magnitude 15 (at 15 seconds time of integration). It is used in binning mode 2, 1pixel = 0.62".

## 2. ASTROMETRICAL OBSERVATIONS

In two cloudless nights we obtained three photographically positions of Hyakutake (March 20-th and 24-th), which were measured using an

Rom. Astron. J., Vol. 8, No. 1, p. 43–51, Bucharest, 1998

ASCORECORD machine, and were reduced with a classical least-squares method, using five-PPM stars. The results are given in Table 1.

*Table 1*

**Photographic positions of the comet C/1996 B2**

| Date | Topocentric positions | | Geocentric positions | |
|---|---|---|---|---|
| | $\alpha_{2000}$ | $\delta_{2000}$ | $\alpha_{2000}$ | $\delta_{2000}$ |
| $1996^y 3^m 20^d.930716$ | $14^h\ 52^m\ 21^s.956$ | 4° 40' 13".04 | $14^h\ 52^m\ 20^s.330$ | 4° 40' 47".93 |
| 1996 3 20.950107 | 14 52 20 .179 | 4 47 27 .77 | 14 52 18 .776 | 4 48 02 .66 |
| 1996 3 24.951746 | 14 35 33 .646 | 53 04 50 .37 | 14 35 30 .493 | 53 06 30 .85 |

Since the equipping of the mentioned instrument with the CCD, although various sources have been observed (the Saturnian satellites, asteroid appulses, globular clusters), C/1996 B2 is the first cometary object observed by CCD in Bucharest. His spectacular passing near the Earth in March 1996 offered the opportunity to test this new astrometrical technique on the comet observations.

March 24/25 was the most fruitful night of observation, because of the minimum distance of the comet from the Earth, which produced the greatest proper motion at that time 1'/min (Marsden, 1996), and due to the good meteorological conditions.

The possibility to make astrometrical observations using a CCD was discussed previously (Văduvescu & Vass, 1995). Comparing with the photographical observations, the main problem of the CCD consists in the small field of the receptor $(10.4016'^2)$, and consequently in the small density of the catalogue stars in the field (0.025 PPM stars/CCD field). Nevertheless, there are two important advantages of the CCD: the very short integration time (and accordingly a lot of exposures), and the procedure of the measurement of the source's position (such as the Gauss distribution of the light intensities). This method gives good results mainly to diffuse sources (as the nucleus of the comets), comparing to the visual method at the measuring machine for astrometric positions.

In order to plot the path of the comet through the stars, graphical software, *Celestial Maps v.4.5* was used (Văduvescu & Bîrlan, 1996). Both the program and the ephemeris certified the accuracy of the predictions. Thus, in March 24/25 the comet approached four-PPM stars (PPM34602 at $22^h0^m$, PPM34601 at $22^h34^m$, PPM34595 at $0^h36^m$, and PPM34582 at $1^h39^m$, all in UT). At these moments, 15, 22, 20 and respectively 26 CCD exposures were made using 5-s times of integration (the stars has $V_{ph}$ = 11.1, 10.1, 10.3 and 8.0 respectively).

The method of reduction uses the *one-star* reference systems (Văduvescu & Vass, 1995), and the orientation of the CCD was solved using *two - PPM stars* in the vicinity of the comet. All the 83 positions of the nucleus were reduced and reported to the Central Bureau for Astronomical Telegrams.

The reduced positions of the comet are presented in Figure 1. We can observe the good agreement between the results obtained by the two methods.

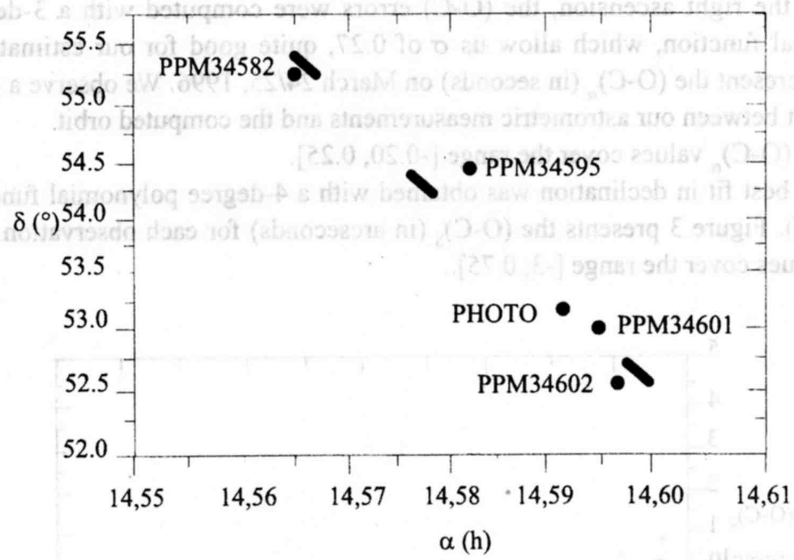


Fig. 1. – Reduced photographic and CCD positions of the comet C/1996 B2

We estimated the possibility to make astrometry using a single reference catalogue star. For this purpose, the (O-C) estimation is a good indicator. We used the comparison of our observations with the computed positions of Smithsonian (B. Marsden, private correspondence). Then, we used a polynomial fit.

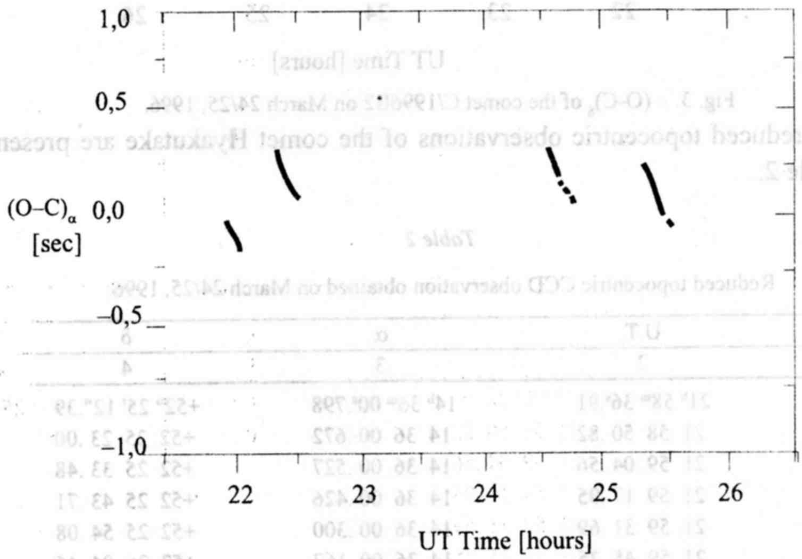


Fig. 2. – $(O\text{-}C)_\alpha$ of the comet C/1996B2 on March, 24/25, 1996.

For the right ascension, the (O-C) errors were computed with a 3-degree polynomial function, which allow us $\sigma$ of 0.27, quite good for our estimations. Figure 2 present the $(O\text{-}C)_\alpha$ (in seconds) on March 24/25, 1996. We observe a good agreement between our astrometric measurements and the computed orbit.

The $(O\text{-}C)_\alpha$ values cover the range [-0.20, 0.25].

The best fit in declination was obtained with a 4-degree polynomial function ($\sigma = 0.05$). Figure 3 presents the $(O\text{-}C)_\delta$ (in arcseconds) for each observation. The (O-C) values cover the range [-3, 0.75].

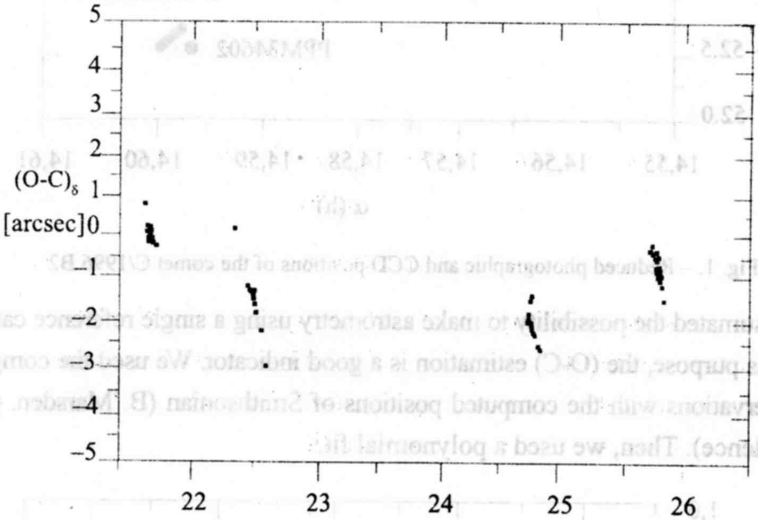


Fig. 3. – $(O\text{-}C)_\delta$ of the comet C/1996B2 on March 24/25, 1996.

The reduced topocentric observations of the comet Hyakutake are presented in the Table 2.

*Table 2*

Reduced topocentric CCD observation obtained on March 24/25, 1996.

| N. | U.T. | α | δ |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 1 | $21^h\ 58^m\ 36^s.91$ | $14^h\ 36^m\ 00^s.798$ | +52° 25' 12".39 |
| 2 | 21 58 50 .82 | 14 36 00 .672 | +52 25 23 .00 |
| 3 | 21 59 04 .56 | 14 36 00 .527 | +52 25 33 .48 |
| 4 | 21 59 17 .95 | 14 36 00 .426 | +52 25 43 .71 |
| 5 | 21 59 31 .69 | 14 36 00 .300 | +52 25 54 .08 |
| 6 | 21 59 45 .25 | 14 36 00 .167 | +52 26 04 .45 |
| 7 | 22 00 12 .38 | 14 35 59 .899 | +52 26 26 .06 |

*Table 2 (continued)*

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 8 | 22 00 25 .95 | 14 35 59 .805 | +52 26 35 .62 |
| 9 | 22 00 39 .69 | 14 35 59 .683 | +52 26 45 .80 |
| 10 | 22 00 53 .16 | 14 35 59 .556 | +52 26 56 .21 |
| 11 | 22 01 06 .82 | 14 35 59 .432 | +52 27 06 .75 |
| 12 | 22 01 20 .38 | 14 35 59 .312 | +52 27 16 .95 |
| 13 | 22 01 33 .95 | 14 35 59 .188 | +52 27 27 .43 |
| 14 | 22 01 47 .60 | 14 35 59 .059 | +52 27 37 .84 |
| 15 | 22 02 01 .16 | 14 35 58 .926 | +52 27 48 .14 |
| 16 | 22 31 15 .08 | 14 35 43 .992 | +52 50 07 .53 |
| 17 | 22 31 29 .16 | 14 35 43 .870 | +52 50 18 .15 |
| 18 | 22 31 42 .82 | 14 35 43 .738 | +52 50 28 .62 |
| 19 | 22 31 56 .38 | 14 35 43 .610 | +52 50 38 .95 |
| 20 | 22 32 09 .95 | 14 35 43 .478 | +52 50 49 .40 |
| 21 | 22 32 23 .60 | 14 35 43 .359 | +52 50 59 .71 |
| 22 | 22 32 37 .25 | 14 35 43 .224 | +52 51 10 .07 |
| 23 | 22 32 50 .81 | 14 35 43 .106 | +52 51 20 .54 |
| 24 | 22 32 50 .81 | 14 35 43 .104 | +52 51 20 .54 |
| 25 | 22 33 04 .38 | 14 35 42 .980 | +52 51 30 .85 |
| 26 | 22 33 18 .12 | 14 35 42 .849 | +52 51 41 .32 |
| 27 | 22 33 31 .68 | 14 35 42 .719 | +52 51 51 .69 |
| 28 | 22 33 45 .24 | 14 35 42 .599 | +52 52 02 .10 |
| 29 | 22 33 58 .81 | 14 35 42 .480 | +52 52 13 .99 |
| 30 | 22 34 12 .46 | 14 35 42 .342 | +52 52 21 .45 |
| 31 | 22 34 39 .59 | 14 35 42 .091 | +52 52 43 .53 |
| 32 | 22 34 53 .33 | 14 35 41 .963 | +52 52 54 .01 |
| 33 | 22 35 06 .81 | 14 35 41 .830 | +52 53 04 .36 |
| 34 | 22 35 20 .46 | 14 35 41 .696 | +52 53 14 .18 |
| 35 | 22 35 34 .11 | 14 35 41 .586 | +52 53 24 .97 |
| 36 | 22 36 14 .03 | 14 35 41 .208 | +52 53 55 .45 |
| 37 | 22 36 41 .07 | 14 35 40 .952 | +52 54 16 .16 |
| 38 | 22 36 54 .63 | 14 35 40 .828 | +52 54 26 .44 |
| 39 | 24 34 34 .20 | 14 34 35 .624 | +54 24 29 .19 |
| 40 | 24 34 48 .03 | 14 34 35 .478 | +54 24 39 .69 |
| 41 | 24 35 01 .68 | 14 34 35 .342 | +54 24 50 .11 |
| 42 | 24 35 15 .33 | 14 34 35 .195 | +54 25 00 .50 |
| 43 | 24 35 28 .81 | 14 34 35 .050 | +54 25 10 .94 |
| 44 | 24 35 42 .55 | 14 34 34 .911 | +54 25 21 .26 |
| 45 | 24 35 56 .11 | 14 34 34 .779 | +54 25 31 .75 |
| 46 | 24 36 09 .68 | 14 34 34 .643 | +54 25 42 .12 |
| 47 | 24 36 23 .33 | 14 34 34 .513 | +54 25 52 .49 |
| 48 | 24 36 36 .89 | 14 34 34 .360 | +54 26 02 .96 |
| 49 | 24 36 50 .54 | 14 34 34 .226 | +54 26 13 .34 |
| 50 | 24 37 04 .11 | 14 34 34 .097 | +54 26 23 .73 |
| 51 | 24 37 17 .76 | 14 34 33 .940 | +54 26 34 .27 |
| 52 | 24 37 31 .32 | 14 34 33 .808 | +54 26 44 .49 |
| 53 | 24 39 06 .45 | 14 34 32 .828 | +54 27 58 .36 |

*Table 2 (continued)*

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 54 | 24 39 20 .10 | 14 34 32 .710 | +54 28 08 .91 |
| 55 | 24 39 33 .75 | 14 34 32 .552 | +54 28 18 .10 |
| 56 | 24 39 47 .23 | 14 34 32 .423 | +54 28 28 .47 |
| 57 | 24 40 00 .97 | 14 34 32 .279 | +54 28 38 .89 |
| 58 | 24 40 14 .45 | 14 34 32 .147 | +54 28 49 .23 |
| 59 | 25 36 22 .23 | 14 33 59 .208 | +55 11 53 .19 |
| 60 | 25 36 35 .97 | 14 33 59 .070 | +55 12 03 .50 |
| 61 | 25 36 49 .45 | 14 33 58 .928 | +55 12 13 .89 |
| 62 | 25 37 03 .10 | 14 33 58 .779 | +55 12 24 .31 |
| 63 | 25 37 16 .67 | 14 33 58 .636 | +55 12 35 .06 |
| 64 | 25 37 30 .32 | 14 33 58 .493 | +55 12 45 .22 |
| 65 | 25 37 43 .88 | 14 33 58 .348 | +55 12 55 .40 |
| 66 | 25 37 57 .53 | 14 33 58 .212 | +55 13 06 .19 |
| 67 | 25 38 11 .18 | 14 33 58 .071 | +55 13 16 .39 |
| 68 | 25 38 24 .66 | 14 33 57 .921 | +55 13 27 .04 |
| 69 | 25 38 38 .40 | 14 33 57 .772 | +55 13 37 .48 |
| 70 | 25 38 51 .88 | 14 33 57 .636 | +55 13 47 .80 |
| 71 | 25 39 05 .53 | 14 33 57 .487 | +55 13 58 .21 |
| 72 | 25 39 19 .18 | 14 33 57 .343 | +55 14 08 .52 |
| 73 | 25 39 32 .75 | 14 33 57 .197 | +55 14 18 .88 |
| 74 | 25 39 46 .40 | 14 33 57 .055 | +55 14 29 .34 |
| 75 | 25 39 59 .96 | 14 33 56 .902 | +55 14 39 .78 |
| 76 | 25 40 13 .53 | 14 33 56 .769 | +55 14 50 .19 |
| 77 | 25 40 40 .66 | 14 33 56 .477 | +55 15 11 .06 |
| 78 | 25 40 54 .31 | 14 33 56 .342 | +55 15 20 .17 |
| 79 | 25 41 07 .87 | 14 33 56 .198 | +55 15 31 .83 |
| 80 | 25 41 21 .52 | 14 33 56 .046 | +55 15 42 .17 |
| 81 | 25 41 35 .09 | 14 33 55 .911 | +55 15 52 .67 |
| 82 | 25 41 48 .74 | 14 33 55 .773 | +55 16 03 .04 |
| 83 | 25 42 02 .30 | 14 33 55 .607 | +55 16 13 .58 |

Those observations are very useful in certain cases, such as the objects weakly observed. Thus, we tested for the first time such a method and we make the evaluation of the measurements with our CCD camera.

## 3. ORIENTATION OF THE TAIL

Figures 4 and 5 present two images of the comet, taken in March 24-th and April 1-st, and viewing in isophotes.

We made measurements of the position angle of the comet's tail using five images for each approach to the PPM stars on March 24/25. First, the position of the nucleus was measured using the centering method described above. After that, using a double representation of the images (in false colors and isophotes), we measured ten position in the tail direction on each image. These absolute coordinates on the images were reduced using linear regression. We obtained in the

Fig. 4. – Comet C/1996B2 (Hyakutake) in 1996, March, 24-th.

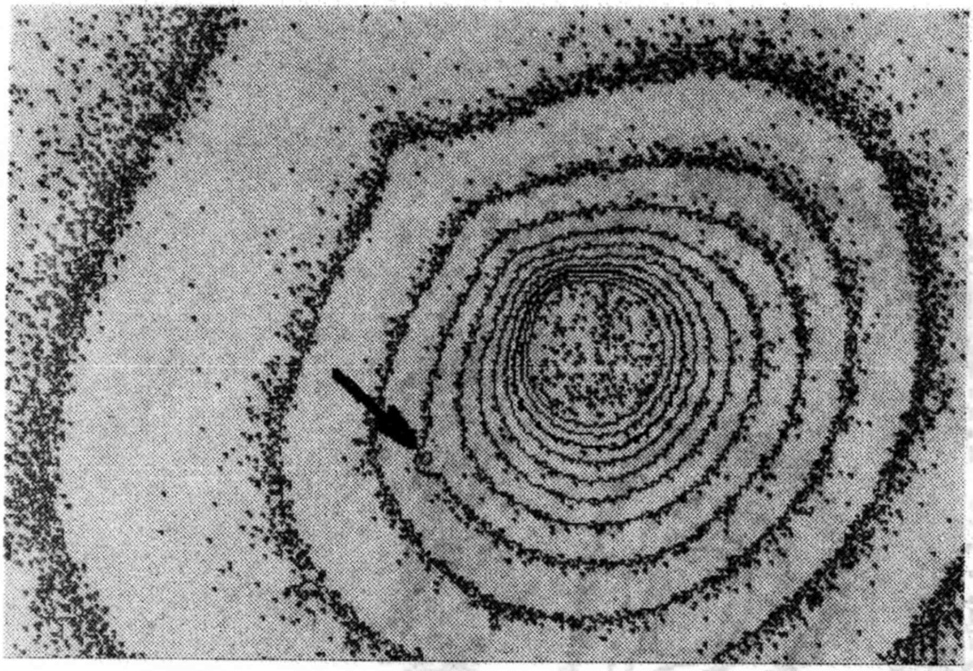

Fig. 5. – Comet 1996/O1 (Hyakutake) on 1996, April, 1-st . The arrow marks the star catalogue.

CCD system the mean values of the position angle of the tail, for each series of the five images. Finally, we added these values to the orientation angle of the CCD camera. The results are presented in Table 3.

*Table 3*

Position angle of the tail, measured clockwise from north

| Date | Angle | RMS |
|---|---|---|
| $1996^y\ 03^m\ 24^d.9167$ | $129^o.9$ | $0^o.4$ |
| 1996 03 24 .9382 | 129 .7 | 0 .2 |
| 1996 03 25 .0243 | 128 .9 | 0 .3 |
| 1996 03 25 .0667 | 128 .5 | 0 .5 |

We fitted the results using a linear function and we found

$$\theta = -0.3886\ t + 138.45\ ,$$

where $\theta$ represents the orientation angle, and $t$ is the time, given in hours.

*Acknowledgements:* We would like to thanks Dr. B. Marsden for promptly taking into consideration our astrometrical requests related to the comet. Special thanks Mrs. A. Alexiu for the "know-how" on the ASCORECORD measuring machine.

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*Received on 14 January 1998*