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# Full-Field Sensitivity of STIS CCD Imaging and its Temporal Dependence

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**ABSTRACT**

*Using calibration data obtained during 1997-2002, a study of the full-field sensitivity of the STIS CCD in clear (50CCD) imaging mode is carried out. Throughputs measured for several stars in deep exposures of a sparse field in the globular cluster ω Cen (= NGC 5139) show a negligible temporal variation of the order of 1% in sensitivity over the past five years. This does not depend on the brightness of the stars considered here, nor on their color (within the range covered, $0.5 < B - V < 0.9$). Also, no significant changes in the CCD throughput were found after the switch to Side-2 electronics in July 2001. We do find a dependence of the count rate on exposure time at recent epochs which increases for fainter stars. The magnitude of this effect is consistent with being caused by Charge Transfer Inefficiency (CTI) of the STIS CCD. Finally, the variation of throughput across the field of view of the CCD is studied and found to be a $< 3\sigma$ effect.*

## Introduction

This report presents a study of the sensitivity of the STIS CCD in imaging mode, across its full field of view. Calibration data accumulated during Cycles 7-10 were used for this report. Given the time covered by the calibration data, a study of the temporal variation of the full-field sensitivity can be performed. Changes in the throughput as a function of position on the detector are also investigated. Allowing for temporal variation of the sensitivity, the dependence of the full-field sensitivity on the brightness and color of stars will be explored. Furthermore, behavior of the full-field sensitivity after the switch of STIS to the side-2 electronics in May 2001 will be studied.

## Observations

The calibration programs 7639, 8416, 8847 and 8912 (cycles 7-10) were executed by observing a sparse photometric standard star field in the outskirts of the globular cluster Omega Cen (NGC 5139) located at RA=13h25m37.04s, DEC=-47d35'38.3" (see Figure 1). The exposures used the clear aperture (`50CCD` mode) to monitor the CCD sensitivity over the whole field of view. This is a star field known from WFPC2 photometric observations. The STIS observations were repeated roughly every six months, so that the spacecraft orientation changed by approximately 180 degrees between different epochs. Details of the observations are presented in Table 1. A CCD gain setting of 4 $e^-$/DN was used for all observations.

The data were reduced using the STIS pipeline (CALSTIS). A total of 12 stars were selected at different locations on the detector as labelled in Figure 1, covering a wide range in magnitudes ($16.5 < m_{ST} < 20.5$; where $m_{ST}$ is magnitude in the STMAG system). The color range covered is $0.5 < B - V < 0.9$ (in the Johnson system). The X,Y positions of the stars at different epochs are presented in Table 2. Aperture photometry was then carried out on these stars using the PHOT task in the APPHOT package within IRAF. To explore the effect of aperture size (and background noise) on the results, different aperture diameters corresponding to 3, 5, 10 and 15 pixels were used. The photometry results are listed in Table 3.

***Temporal variation of the sensitivity***

For each star, the mean of the magnitudes $<m>$ from all the exposures were calculated. The difference between the mean and observed magnitude at any given epoch ($m$ - $<m>$) was then plotted as a function of the time of observation (solid circles in Figure 2). Larger $m$ - $<m>$ values correspond to fainter magnitudes. Different panels in Figure 2 show the temporal dependence of $m$ - $<m>$ for stars of different luminosities. Since year 2001, observations were also carried out with shorter exposure times and different read-out amplifiers to study the effect of imperfect Charge Transfer Efficiency (CTE). As CTE is lower for lower signal levels (e.g., Goudfrooij & Kimble 2002), a comparison of long and short exposures of the same field yields a measure of CTE. (The data with short exposure times are not used in the analysis of temporal behavior of the CCD detailed upon below.)

Least-square fits are performed to the long-exposure data depicted in Figure 2 (filled circles). The results are listed in Table 4. No significant trend with time is observed, i.e., the deviation in the luminosities of individual stars from the mean luminosity over time is relatively constant with time (< 1% over 5 years). Furthermore, for stars with $m_{ST} < 20$, the relation is flat and does not depend on luminosity or color of the star (in the color range covered by these stars). However, lower-luminosity stars (e.g., star ‘g’ with $m_{ST}$ = 20.51) do show a hint of becoming fainter by 2% in latter years.

The sensitivity of this result to the aperture size and the background correction is depicted in Figure 3 which presents the relation between the mean magnitude of the stars measured inside different apertures, as mentioned above, and their rms scatter around the mean. For stars with $m_{ST} < 20$, no increase in rms scatter is found towards fainter magnitudes. Within the errors, this is also independent on the aperture size used. However, for stars with $m_{ST} > 20$, the rms scatter corresponding to larger apertures increases to 0.03. This is consistent with a prediction based on Poisson statistics (see solid line in Fig. 3), indicating the increase in rms at fainter magnitudes to be mostly due to statistical noise. This also confirms that there is no significant dependence of the photometric repeatability for the stars considered here.

The vertical dotted line in Figure 2 indicates the time at which STIS had to switch to its side-2 electronics after the side-1 electronics failed (July 2001). Comparing the STIS/CCD data from before and after this event, we find no significant change in the sensitivity of the detector.

***Charge Transfer Efficiency***

Since calendar year 2001, observations were taken with both long and short exposure times to evaluate the effect of imperfect CTE. The photometry of the short-exposure data is overplotted in Figure 2; they are the solid circles with the highest $m$-$\langle m \rangle$ value at a given epoch. It can be seen that at any given epoch, the difference between magnitudes measured from long vs. short exposures increases for fainter stars. At year 2001.2, the change is from 0.01 (at m=16.93) to 0.07 (at m=20.56). To test whether this difference is due to the effect of imperfect CTE, we corrected the counts in Figure 2 for this effect, using the algorithm published by Goudfrooij & Kimble (2002), which was derived from more extensive monitoring of stellar photometry.

The open symbols in Figure 2 depict our photometry after corrected for imperfect CTE. This correction renders the short-exposure photometry to be consistent with that of the long-exposure one, and further reduces any temporal variation that was apparent from the non-corrected photometry discussed before.

***Full-Field sensitivity of 50CCD***

Since we have shown that there is negligible temporal dependence of the measured brightness of stars in the magnitude and color ranges studied, we combined the data for a given star, taken at different times (separated by four years), without correcting the magnitudes for time dependence. The dependence of sensitivity on the location on the detector is then measured by calculating the mean magnitude of individual stars over the last four years, located at different locations on the detector. Deviations of the magnitudes of each star from the mean are then measured. These deviations, corresponding to 1, 2 and 3 sigma from the mean, are shown in Fig. 4 using different sizes at the star's position on the detector. These correspond to small (1 sigma), medium (2 sigma) and large (3 sigma) circles.

Each of the panels in Figure 4 shows the full-field sensitivity corresponding to a given star. As is clear from Figure 4, there is no evidence for any significant dependence of sensitivity on position on the detector and no deterioration of sensitivity at a given position (i.e. no accumulation of large circles in a given area of the diagrams).

## Summary

The full-field sensitivity calibration of the STIS CCD imaging mode was carried out in the period 1997-2000. We find a negligible temporal variation once the photometry is corrected for imperfect CTE. This is found to be independent of the luminosity and color of the stars involved. The throughput at different locations on the detector is measured and found to be a $< 3\ \sigma$ effect.

## Recommendation

Given the negligible variation of clear (50CCD) imaging throughput with time and and position on the CCD (at least for stars with $B - V$ redder than about 0.5), we can safely reduce the frequency of the full-field sensitivity calibration program for CCD imaging. However, the effect of imperfect CTE is found to be non-negligible and should remain closely monitored in the future.

## References

Goudfrooij, P., & Kimble, R. A., 2002, "Correcting STIS CCD Photometry for CTE loss", in *2002 HST Calibration Workshop*, eds. S. Arribas, A. Koekemoer, & B. Whitmore, p. 105.

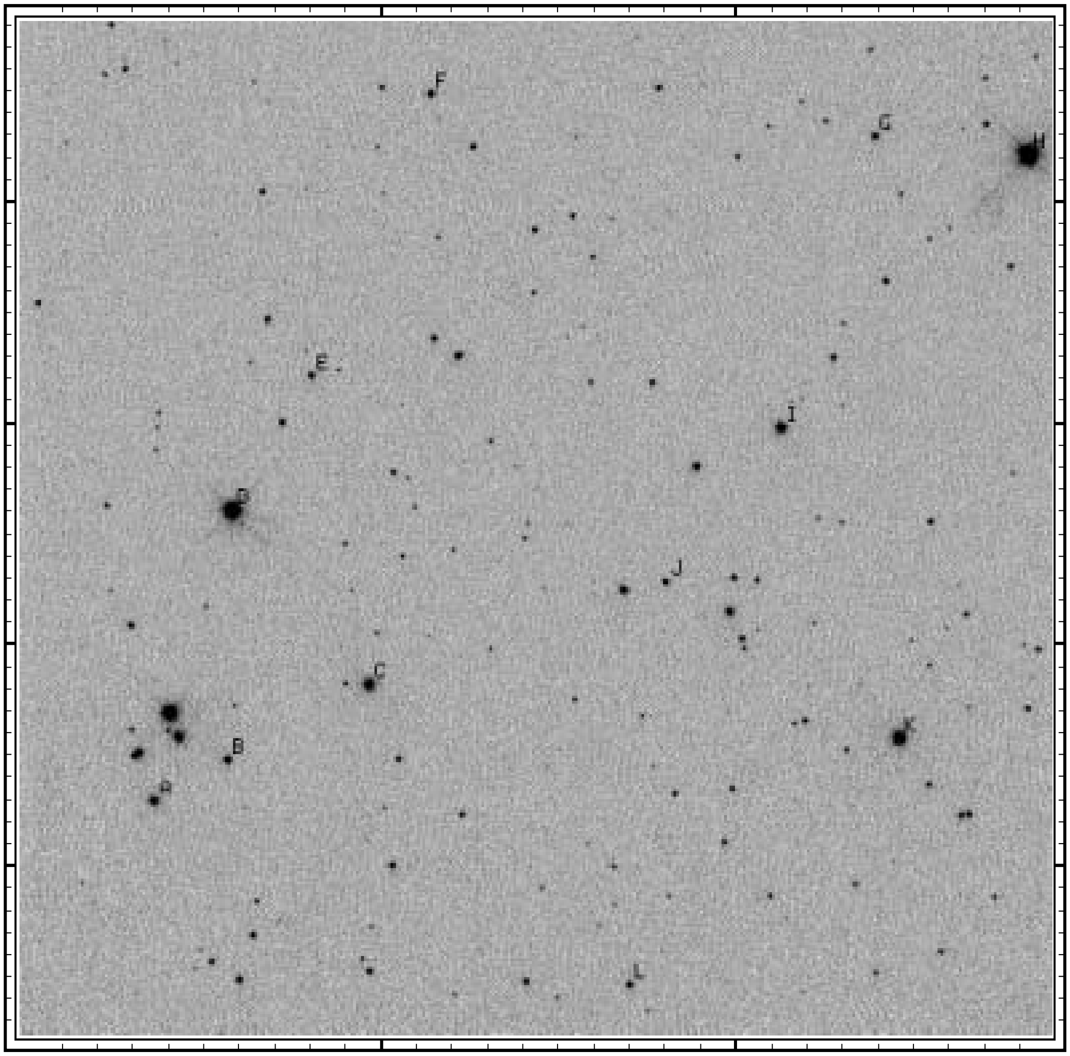

**Figure 1:** STIS/CCD image of cluster NGC5139 with selected stars (of different luminosities and colors) marked.

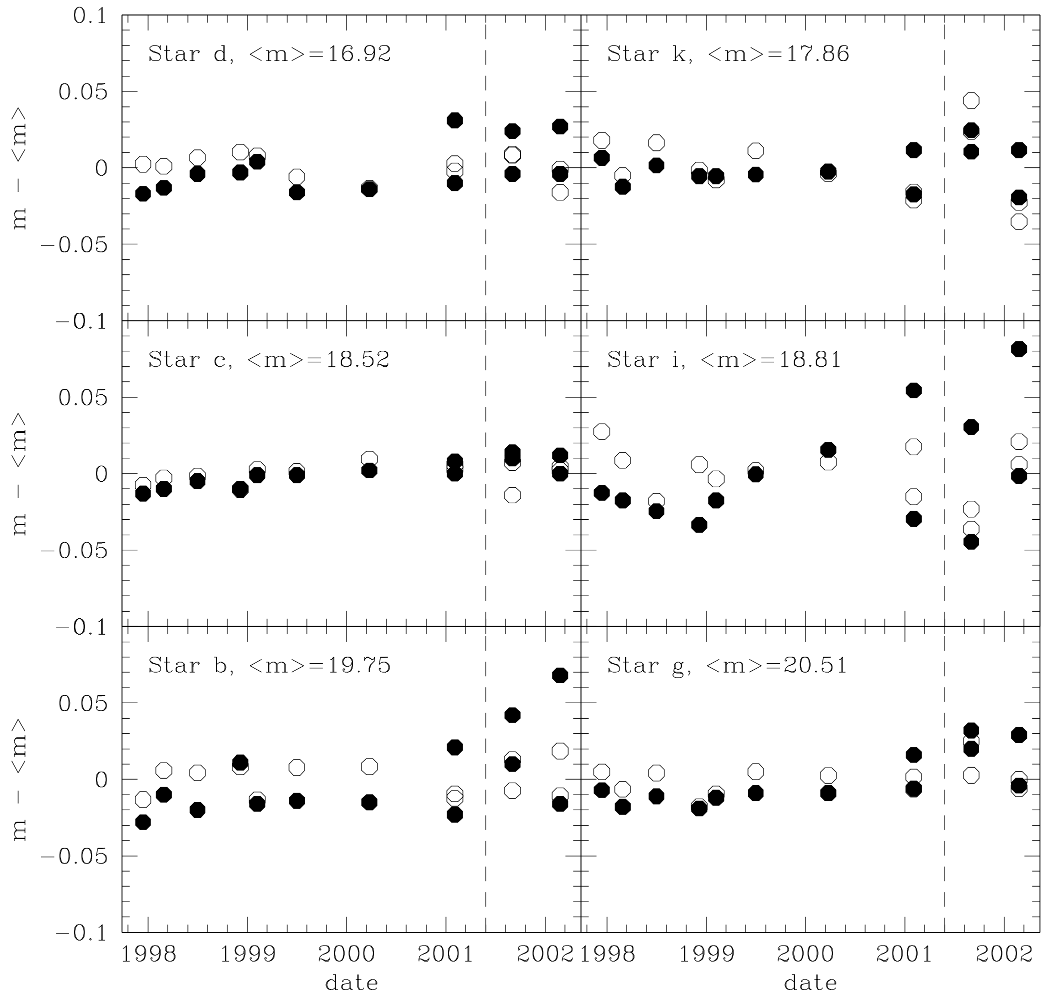


**Figure 2:** Temporal variation of STIS/CCD. Each panel corresponds to a given star of a given magnitude and color (filled symbols). Stars observed using two different exposure times are also included. The first five data points are from 15 sec exposures, next two are 50 sec and final three epochs are taken using both 10 and 60 sec exposures. The data, corrected for CTI effect, are also shown (open symbols). The vertical dotted line corresponds to the time of safing of STIS in May 2001.

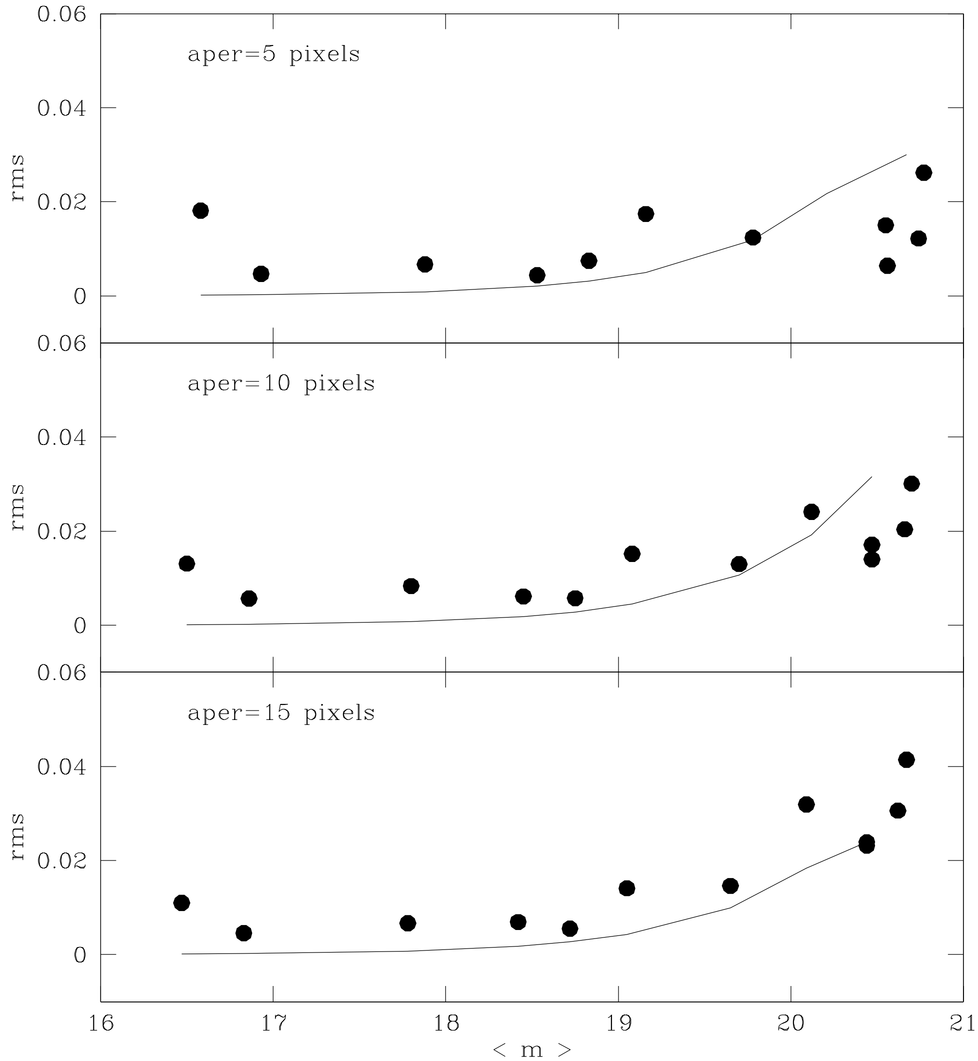


**Figure 3:** Changes in the mean magnitude of individual stars with the rms around the mean. The panels show the relation using different apertures (5, 10, 15 pixels). The lines show the relation due to Poisson noise.

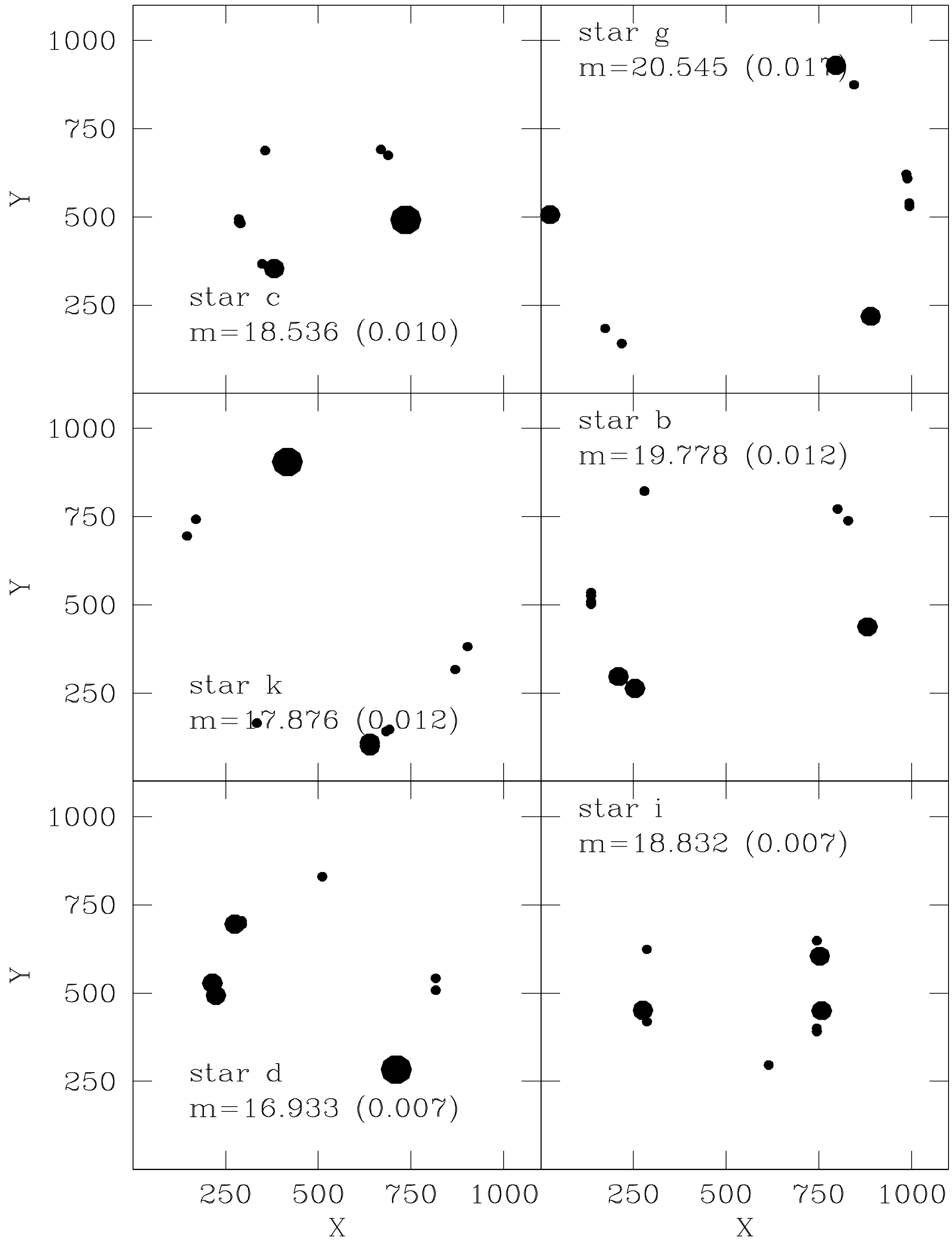


**Figure 4:** Full-field sensitivity of detector. Each panel corresponds to a given star. Symbol sizes indicate 1 sigma (small), 2 sigma (medium) and 3 sigma (large) deviations from the mean. The mean magnitude and 1 sigma deviation for each star are also shown on each panel.

**Table 1.** List of the observations of star cluster at different epochs.

| prog<br>dataset | date | amp | gain | cr-split | exptime (s) |
|---|---|---|---|---|---|
| 7639 | | | | | |
| o4go02010 | 16 Dec 1997 | D | 4 | 5 | 15.0 |
| o4go03010 | 26 Feb 1998 | D | 4 | 5 | 15.0 |
| o4go04010 | 1 Jun 1998 | D | 4 | 5 | 15.0 |
| o4go05010 | 10 Dec 1998 | D | 4 | 5 | 15.0 |
| o4go01010 | 7 Feb 1999 | D | 4 | 5 | 15.0 |
| 8416 | | | | | |
| o5ir01010 | 2 Jul 1999 | D | 4 | 5 | 50.0 |
| o5ir02010 | 26 Mar 2000 | D | 4 | 5 | 50.0 |
| 8847 | | | | | |
| o69902010 | 3 Feb 2001 | D | 4 | 5 | 10.0 |
| o69902020 | 3 Feb 2001 | D | 4 | 2 | 60.0 |
| o69902030 | 3 Feb 2001 | B | 4 | 5 | 10.0 |
| o69902040 | 3 Feb 2001 | B | 4 | 2 | 60.0 |
| 8912 | | | | | |
| o6ib01010 | 1 Sep 2001 | D | 4 | 5 | 10.0 |
| o6ib01020 | 1 Sep 2001 | D | 4 | 2 | 60.0 |
| o6ib02010 | 15 Feb 2002 | D | 4 | 5 | 10.0 |
| o6ib02020 | 15 Feb 2002 | D | 4 | 2 | 60.0 |
| o6ib02030 | 15 Feb 2002 | B | 4 | 5 | 10.0 |
| o6ib02040 | 15 Feb 2002 | B | 4 | 2 | 60.0 |

**Table 2.** Selected stars for the present study with their corresponding X,Y positions at each epoch.

| star | epoch | dataset | x | y |
|---|---|---|---|---|
| a | 1997.95 | o4go02010 | 138.000 | 259.230 |
| b | 1997.95 | o4go02010 | 210.210 | 297.260 |
| c | 1997.95 | o4go02010 | 348.670 | 366.720 |
| d | 1997.95 | o4go02010 | 214.400 | 528.070 |
| e | 1997.95 | o4go02010 | 292.310 | 652.420 |
| f | 1997.95 | o4go02010 | 409.490 | 913.170 |
| g | 1997.95 | o4go02010 | 845.450 | 874.220 |

| star | epoch | dataset | x | y |
|---|---|---|---|---|
| h | 1997.95 | o4go02010 | 995.580 | 857.140 |
| i | 1997.95 | o4go02010 | 752.870 | 604.340 |
| j | 1997.95 | o4go02010 | 639.540 | 461.570 |
| k | 1997.95 | o4go02010 | 869.040 | 317.150 |
| l | 1997.95 | o4go02010 | 604.140 | 88.7200 |
| a | 1998.16 | o4go03010 | 55.3200 | 521.310 |
| b | 1998.16 | o4go03010 | 136.170 | 510.050 |
| c | 1998.16 | o4go03010 | 289.250 | 485.700 |
| d | 1998.16 | o4go03010 | 274.440 | 694.990 |
| e | 1998.16 | o4go03010 | 410.200 | 750.550 |
| f | 1998.16 | o4go03010 | 657.350 | 893.910 |
| g | 1998.16 | o4go03010 | 988.850 | 608.450 |
| i | 1998.16 | o4go03010 | 756.190 | 442.940 |
| j | 1998.16 | o4go03010 | 580.940 | 393.060 |
| k | 1998.16 | o4go03010 | 683.020 | 142.050 |
| l | 1998.16 | o4go03010 | 334.920 | 110.740 |
| a | 1998.50 | o4go04010 | 869.910 | 815.760 |
| b | 1998.50 | o4go04010 | 801.220 | 771.680 |
| c | 1998.50 | o4go04010 | 669.150 | 690.560 |
| d | 1998.50 | o4go04010 | 816.660 | 541.670 |
| e | 1998.50 | o4go04010 | 749.840 | 411.110 |
| f | 1998.50 | o4go04010 | 656.470 | 141.490 |
| g | 1998.50 | o4go04010 | 219.140 | 141.550 |
| h | 1998.50 | o4go04010 | 67.9500 | 145.350 |
| i | 1998.50 | o4go04010 | 286.950 | 418.780 |
| j | 1998.50 | o4go04010 | 387.450 | 570.950 |
| k | 1998.50 | o4go04010 | 146.360 | 695.150 |
| l | 1998.50 | o4go04010 | 390.950 | 945.780 |
| a | 1998.93 | o4go05010 | 188.900 | 215.580 |
| b | 1998.93 | o4go05010 | 254.570 | 263.910 |
| c | 1998.93 | o4go05010 | 380.980 | 353.300 |
| d | 1998.93 | o4go05010 | 224.170 | 492.720 |
| e | 1998.93 | o4go05010 | 282.560 | 627.190 |
| f | 1998.93 | o4go05010 | 359.510 | 902.410 |
| g | 1998.93 | o4go05010 | 796.370 | 928.900 |
| h | 1998.93 | o4go05010 | 947.030 | 934.430 |
| i | 1998.93 | o4go05010 | 744.970 | 648.330 |
| j | 1998.93 | o4go05010 | 654.330 | 490.370 |
| k | 1998.93 | o4go05010 | 902.650 | 381.910 |
| l | 1998.93 | o4go05010 | 674.960 | 116.650 |
| a | 1999.10 | o4go01010 | 55.5100 | 511.290 |
| b | 1999.10 | o4go01010 | 136.590 | 502.000 |

| star | epoch | dataset | x | y |
|---|---|---|---|---|
| c | 1999.10 | o4go01010 | 290.210 | 481.450 |
| d | 1999.10 | o4go01010 | 270.310 | 690.210 |
| e | 1999.10 | o4go01010 | 404.640 | 749.080 |
| f | 1999.10 | o4go01010 | 648.180 | 898.350 |
| g | 1999.10 | o4go01010 | 986.460 | 621.110 |
| i | 1999.10 | o4go01010 | 757.790 | 450.040 |
| j | 1999.10 | o4go01010 | 584.000 | 395.900 |
| k | 1999.10 | o4go01010 | 692.150 | 147.560 |
| l | 1999.10 | o4go01010 | 345.010 | 107.760 |
| a | 1999.50 | o5ir01010 | 903.090 | 773.780 |
| b | 1999.50 | o5ir01010 | 829.590 | 738.460 |
| c | 1999.50 | o5ir01010 | 688.540 | 673.980 |
| d | 1999.50 | o5ir01010 | 816.870 | 508.210 |
| e | 1999.50 | o5ir01010 | 734.600 | 386.640 |
| f | 1999.50 | o5ir01010 | 608.990 | 130.430 |
| g | 1999.50 | o5ir01010 | 174.730 | 183.880 |
| h | 1999.50 | o5ir01010 | 25.2700 | 206.090 |
| i | 1999.50 | o5ir01010 | 276.090 | 450.830 |
| j | 1999.50 | o5ir01010 | 394.390 | 589.550 |
| k | 1999.50 | o5ir01010 | 170.230 | 742.310 |
| l | 1999.50 | o5ir01010 | 443.600 | 961.280 |
| a | 2000.23 | o5ir02010 | 238.690 | 892.420 |
| c | 2000.23 | o5ir02010 | 356.740 | 687.440 |
| e | 2000.23 | o5ir02010 | 639.160 | 758.350 |
| g | 2000.23 | o5ir02010 | 890.070 | 218.280 |
| i | 2000.23 | o5ir02010 | 615.070 | 296.320 |
| k | 2000.23 | o5ir02010 | 334.560 | 165.230 |
| l | 2000.23 | o5ir02010 | 92.03 | 418.02 |
| a | 2001.09 | o69902010 | 57.33 | 555.48 |
| b | 2001.09 | o69902010 | 136.43 | 535.36 |
| c | 2001.09 | o69902010 | 285.78 | 494.33 |
| d | 2001.09 | o69902010 | 294.24 | 703.83 |
| e | 2001.09 | o69902010 | 435.23 | 744.16 |
| f | 2001.09 | o69902010 | 696.53 | 859.16 |
| g | 2001.09 | o69902010 | 994.45 | 539.14 |
| i | 2001.09 | o69902010 | 744.72 | 400.34 |
| j | 2001.09 | o69902010 | 565.47 | 370.09 |
| k | 2001.09 | o69902010 | 639.14 | 109.42 |
| a | 2001.09 | o69902020 | 57.26 | 555.50 |
| b | 2001.09 | o69902020 | 136.36 | 535.40 |
| c | 2001.09 | o69902020 | 285.70 | 494.35 |
| d | 2001.09 | o69902020 | 294.16 | 703.82 |

| star | epoch | dataset | x | y |
|---|---|---|---|---|
| e | 2001.09 | o69902020 | 435.17 | 744.16 |
| f | 2001.09 | o69902020 | 696.48 | 859.19 |
| g | 2001.09 | o69902020 | 994.44 | 539.20 |
| i | 2001.09 | o69902020 | 744.64 | 400.37 |
| j | 2001.09 | o69902020 | 565.41 | 370.12 |
| k | 2001.09 | o69902020 | 639.07 | 109.42 |
| a | 2001.67 | o6ib01010 | 958.58 | 411.43 |
| b | 2001.67 | o6ib01010 | 881.48 | 438.04 |
| c | 2001.67 | o6ib01010 | 735.89 | 491.42 |
| d | 2001.67 | o6ib01010 | 710.08 | 283.54 |
| e | 2001.67 | o6ib01010 | 566.36 | 255.14 |
| f | 2001.67 | o6ib01010 | 296.64 | 161.91 |
| g | 2001.67 | o6ib01010 | 25.96 | 506.13 |
| i | 2001.67 | o6ib01010 | 286.47 | 623.71 |
| j | 2001.67 | o6ib01010 | 467.80 | 638.77 |
| k | 2001.67 | o6ib01010 | 416.81 | 905.00 |
| a | 2001.67 | o6ib01020 | 958.65 | 411.45 |
| b | 2001.67 | o6ib01020 | 881.51 | 438.07 |
| c | 2001.67 | o6ib01020 | 735.94 | 491.44 |
| d | 2001.67 | o6ib01020 | 710.13 | 283.52 |
| e | 2001.67 | o6ib01020 | 566.41 | 255.16 |
| f | 2001.67 | o6ib01020 | 296.66 | 161.94 |
| g | 2001.67 | o6ib01020 | 26.01 | 506.18 |
| i | 2001.67 | o6ib01020 | 286.49 | 623.71 |
| j | 2001.67 | o6ib01020 | 467.84 | 638.77 |
| k | 2001.67 | o6ib01020 | 416.88 | 905.00 |
| a | 2002.15 | o6ib02010 | 57.48 | 546.29 |
| b | 2002.15 | o6ib02010 | 136.51 | 526.16 |
| c | 2002.15 | o6ib02010 | 285.94 | 485.14 |
| d | 2002.15 | o6ib02010 | 294.37 | 694.63 |
| e | 2002.15 | o6ib02010 | 435.36 | 734.91 |
| f | 2002.15 | o6ib02010 | 696.65 | 849.90 |
| g | 2002.15 | o6ib02010 | 994.56 | 529.85 |
| i | 2002.15 | o6ib02010 | 744.74 | 391.15 |
| j | 2002.15 | o6ib02010 | 565.55 | 360.79 |
| k | 2002.15 | o6ib02010 | 639.23 | 100.13 |
| a | 2002.15 | o6ib02020 | 57.45 | 546.33 |
| b | 2002.15 | o6ib02020 | 136.48 | 526.23 |
| c | 2002.15 | o6ib02020 | 285.90 | 485.16 |
| d | 2002.15 | o6ib02020 | 294.34 | 694.65 |
| e | 2002.15 | o6ib02020 | 435.37 | 734.96 |
| f | 2002.15 | o6ib02020 | 696.61 | 849.95 |

| star | epoch | dataset | x | y |
|---|---|---|---|---|
| g | 2002.15 | o6ib02020 | 994.54 | 529.94 |
| i | 2002.15 | o6ib02020 | 744.71 | 391.18 |
| j | 2002.15 | o6ib02020 | 565.52 | 360.89 |
| k | 2002.15 | o6ib02020 | 639.23 | 100.16 |

**Table 3.** Photometry of stars at different epochs. Magnitudes corresponding to different apertures (3,5,10 and 15 pixels) are presented.

| star | epoch | $m_{ST}$ (r=3) | $m_{ST}$(r=5) | $m_{ST}$(r=10) | $m_{ST}$(r=15) |
|---|---|---|---|---|---|
| a | 1997.95 | 19.1540 | 19.0810 | 19.0390 | 19.0250 |
| b | 1997.95 | 19.7620 | 19.6880 | 19.6430 | 19.6290 |
| c | 1997.95 | 18.5360 | 18.4560 | 18.4250 | 18.4050 |
| d | 1997.95 | 16.9230 | 16.8510 | 16.8250 | 16.8080 |
| e | 1997.95 | 20.5480 | 20.4540 | 20.3950 | 20.3830 |
| f | 1997.95 | 20.1710 | 20.0920 | 20.0840 | 20.0970 |
| g | 1997.95 | 20.5490 | 20.4380 | 20.4160 | 20.3870 |
| h | 1997.95 | 16.6030 | 16.5160 | 16.4840 | 16.4650 |
| i | 1997.95 | 18.8230 | 18.7450 | 18.7180 | 18.7050 |
| j | 1997.95 | 20.7610 | 20.6860 | 20.6670 | 20.6100 |
| k | 1997.95 | 17.8860 | 17.8070 | 17.7780 | 17.7600 |
| l | 1997.95 | 20.7720 | 20.6690 | 20.6000 | 20.6350 |
| a | 1998.16 | 19.1270 | 19.0560 | 19.0290 | 19.0050 |
| b | 1998.16 | 19.7800 | 19.7090 | 19.6740 | 19.6300 |
| c | 1998.16 | 18.5250 | 18.4500 | 18.4180 | 18.3930 |
| d | 1998.16 | 16.9260 | 16.8560 | 16.8290 | 16.8100 |
| e | 1998.16 | 20.5610 | 20.4760 | 20.4440 | 20.4350 |
| f | 1998.16 | 20.2120 | 20.1260 | 20.1030 | 20.1270 |
| g | 1998.16 | 20.5440 | 20.4730 | 20.4440 | 20.4440 |
| i | 1998.16 | 18.8270 | 18.7480 | 18.7230 | 18.7130 |
| j | 1998.16 | 20.7380 | 20.6780 | 20.6190 | 20.5760 |
| k | 1998.16 | 17.8670 | 17.7890 | 17.7670 | 17.7560 |
| l | 1998.16 | 20.7730 | 20.7280 | 20.7130 | 20.7390 |
| a | 1998.50 | 19.1820 | 19.1070 | 19.0690 | 19.0440 |
| b | 1998.50 | 19.7700 | 19.6810 | 19.6300 | 19.6180 |
| c | 1998.50 | 18.5320 | 18.4520 | 18.4200 | 18.4040 |
| d | 1998.50 | 16.9310 | 16.8540 | 16.8260 | 16.8080 |
| e | 1998.50 | 20.5700 | 20.4650 | 20.4360 | 20.3830 |
| f | 1998.50 | 20.1980 | 20.0800 | 20.0320 | 19.9960 |
| g | 1998.50 | 20.5370 | 20.4610 | 20.3960 | 20.3530 |
| h | 1998.50 | 16.5720 | 16.4950 | 16.4640 | 16.4440 |
| i | 1998.50 | 18.8360 | 18.7540 | 18.7140 | 18.6930 |

| star | epoch | $m_{ST}$ (r=3) | $m_{ST}$(r=5) | $m_{ST}$(r=10) | $m_{ST}$(r=15) |
|---|---|---|---|---|---|
| j | 1998.50 | 20.7390 | 20.6670 | 20.6380 | 20.5890 |
| k | 1998.50 | 17.8810 | 17.8130 | 17.7870 | 17.7710 |
| l | 1998.50 | 20.7230 | 20.7000 | 20.6950 | 20.7580 |
| a | 1998.93 | 19.1740 | 19.0860 | 19.0420 | 18.9990 |
| b | 1998.93 | 19.8010 | 19.7150 | 19.6630 | 19.6330 |
| c | 1998.93 | 18.5240 | 18.4450 | 18.4200 | 18.4000 |
| d | 1998.93 | 16.9260 | 16.8590 | 16.8330 | 16.8140 |
| e | 1998.93 | 20.5550 | 20.4690 | 20.4480 | 20.4000 |
| f | 1998.93 | 20.2090 | 20.1420 | 20.1070 | 20.1230 |
| g | 1998.93 | 20.5280 | 20.4660 | 20.4530 | 20.4550 |
| h | 1998.93 | 16.5990 | 16.5180 | 16.4850 | 16.4680 |
| i | 1998.93 | 18.8370 | 18.7600 | 18.7280 | 18.7150 |
| j | 1998.93 | 20.7430 | 20.6600 | 20.6370 | 20.6270 |
| k | 1998.93 | 17.8740 | 17.8040 | 17.7750 | 17.7590 |
| l | 1998.93 | 20.8010 | 20.6710 | 20.6560 | 20.6090 |
| a | 1999.10 | 19.1480 | 19.0720 | 19.0350 | 19.0080 |
| b | 1999.10 | 19.7740 | 19.6910 | 19.6420 | 19.6150 |
| c | 1999.10 | 18.5310 | 18.4570 | 18.4250 | 18.4040 |
| d | 1999.10 | 16.9350 | 16.8660 | 16.8380 | 16.8200 |
| e | 1999.10 | 20.5630 | 20.4970 | 20.4680 | 20.4840 |
| f | 1999.10 | 20.2230 | 20.1440 | 20.1370 | 20.1410 |
| g | 1999.10 | 20.5440 | 20.4830 | 20.4540 | 20.4580 |
| i | 1999.10 | 18.8440 | 18.7590 | 18.7290 | 18.7120 |
| j | 1999.10 | 20.7400 | 20.6290 | 20.5740 | 20.5370 |
| k | 1999.10 | 17.8740 | 17.8010 | 17.7720 | 17.7530 |
| l | 1999.10 | 20.8000 | 20.7500 | 20.7190 | 20.7070 |
| a | 1999.50 | 19.1720 | 19.0880 | 19.0550 | 19.0360 |
| b | 1999.50 | 19.7760 | 19.6890 | 19.6540 | 19.6180 |
| c | 1999.50 | 18.5340 | 18.4520 | 18.4250 | 18.4020 |
| d | 1999.50 | 16.9350 | 16.8550 | 16.8270 | 16.8070 |
| e | 1999.50 | 20.5600 | 20.4690 | 20.4340 | 20.4070 |
| f | 1999.50 | 20.2160 | 20.1170 | 20.0950 | 20.0720 |
| g | 1999.50 | 20.5610 | 20.4780 | 20.4400 | 20.4160 |
| h | 1999.50 | 16.5610 | 16.4910 | 16.4650 | 16.4490 |
| i | 1999.50 | 18.8240 | 18.7480 | 18.7170 | 18.6990 |
| j | 1999.50 | 20.7190 | 20.6380 | 20.5940 | 20.5530 |
| k | 1999.50 | 17.8750 | 17.8070 | 17.7800 | 17.7610 |
| l | 1999.50 | 20.7770 | 20.6810 | 20.6530 | 20.6270 |
| a | 2000.23 | 19.1640 | 19.0920 | 19.0640 | 19.0440 |
| c | 2000.23 | 18.5340 | 18.4620 | 18.4360 | 18.4190 |
| e | 2000.23 | 20.5630 | 20.4880 | 20.4690 | 20.4630 |
| g | 2000.23 | 20.5770 | 20.4960 | 20.4730 | 20.4520 |

| star | epoch | $m_{ST}$ (r=3) | $m_{ST}$(r=5) | $m_{ST}$(r=10) | $m_{ST}$(r=15) |
|---|---|---|---|---|---|
| i | 2000.23 | 18.8260 | 18.7500 | 18.7170 | 18.7010 |
| k | 2000.23 | 17.8770 | 17.8090 | 17.7800 | 17.7620 |
| l | 2000.23 | 20.909 | 20.790 | 20.731 | 20.711 |
| a | 2001.09 | 19.341 | 19.183 | 19.094 | 19.065 |
| b | 2001.09 | 19.959 | 19.811 | 19.741 | 19.682 |
| c | 2001.09 | 18.693 | 18.559 | 18.485 | 18.452 |
| d | 2001.09 | 17.065 | 16.944 | 16.877 | 16.850 |
| e | 2001.09 | 20.699 | 20.566 | 20.469 | 20.458 |
| f | 2001.09 | 20.352 | 20.239 | 20.192 | 20.122 |
| g | 2001.09 | 20.765 | 20.616 | 20.540 | 20.473 |
| i | 2001.09 | 18.990 | 18.871 | 18.789 | 18.763 |
| j | 2001.09 | 20.904 | 20.820 | 20.765 | 20.694 |
| k | 2001.09 | 17.998 | 17.891 | 17.816 | 17.787 |
| a | 2001.09 | 19.286 | 19.134 | 19.060 | 19.027 |
| b | 2001.09 | 19.916 | 19.767 | 19.690 | 19.648 |
| c | 2001.09 | 18.671 | 18.537 | 18.466 | 18.438 |
| d | 2001.09 | 17.055 | 16.936 | 16.869 | 16.843 |
| e | 2001.09 | 20.685 | 20.563 | 20.493 | 20.468 |
| f | 2001.09 | 20.315 | 20.208 | 20.140 | 20.114 |
| g | 2001.09 | 20.643 | 20.532 | 20.461 | 20.431 |
| i | 2001.09 | 18.947 | 18.830 | 18.757 | 18.728 |
| j | 2001.09 | 20.856 | 20.745 | 20.666 | 20.624 |
| k | 2001.09 | 17.967 | 17.862 | 17.791 | 17.764 |
| a | 2001.67 | 19.336 | 19.216 | 19.119 | 19.070 |
| b | 2001.67 | 19.948 | 19.832 | 19.743 | 19.702 |
| c | 2001.67 | 18.687 | 18.575 | 18.492 | 18.472 |
| d | 2001.67 | 17.062 | 16.950 | 16.873 | 16.844 |
| e | 2001.67 | 20.719 | 20.588 | 20.487 | 20.367 |
| f | 2001.67 | 20.404 | 20.280 | 20.153 | 20.121 |
| g | 2001.67 | 20.723 | 20.592 | 20.568 | 20.555 |
| i | 2001.67 | 18.977 | 18.864 | 18.783 | 18.743 |
| j | 2001.67 | 20.877 | 20.761 | 20.704 | 20.616 |
| k | 2001.67 | 17.995 | 17.890 | 17.822 | 17.798 |
| a | 2001.67 | 19.302 | 19.177 | 19.093 | 19.061 |
| b | 2001.67 | 19.913 | 19.800 | 19.712 | 19.673 |
| c | 2001.67 | 18.677 | 18.563 | 18.481 | 18.452 |
| d | 2001.67 | 17.059 | 16.946 | 16.869 | 16.840 |
| e | 2001.67 | 20.675 | 20.567 | 20.483 | 20.422 |
| f | 2001.67 | 20.335 | 20.218 | 20.136 | 20.103 |
| g | 2001.67 | 20.639 | 20.517 | 20.458 | 20.441 |
| i | 2001.67 | 18.948 | 18.836 | 18.763 | 18.732 |
| j | 2001.67 | 20.847 | 20.736 | 20.647 | 20.597 |

| star | epoch | $m_{ST}$ (r=3) | $m_{ST}$(r=5) | $m_{ST}$(r=10) | $m_{ST}$(r=15) |
|---|---|---|---|---|---|
| k | 2001.67 | 18.008 | 17.904 | 17.833 | 17.806 |
| a | 2002.15 | 19.348 | 19.196 | 19.129 | 19.117 |
| b | 2002.15 | 20.005 | 19.858 | 19.811 | 19.775 |
| c | 2002.15 | 18.713 | 18.572 | 18.508 | 18.494 |
| d | 2002.15 | 17.069 | 16.948 | 16.883 | 16.857 |
| e | 2002.15 | 20.716 | 20.609 | 20.544 | 20.543 |
| f | 2002.15 | 20.312 | 20.208 | 20.150 | 20.143 |
| g | 2002.15 | 20.748 | 20.643 | 20.544 | 20.554 |
| i | 2002.15 | 18.990 | 18.867 | 18.793 | 18.766 |
| j | 2002.15 | 20.931 | 20.807 | 20.771 | 20.823 |
| k | 2002.15 | 18.004 | 17.891 | 17.816 | 17.789 |
| a | 2002.15 | 19.295 | 19.146 | 19.081 | 19.066 |
| b | 2002.15 | 19.916 | 19.774 | 19.720 | 19.699 |
| c | 2002.15 | 18.674 | 18.539 | 18.472 | 18.455 |
| d | 2002.15 | 17.053 | 16.936 | 16.870 | 16.846 |
| e | 2002.15 | 20.671 | 20.560 | 20.530 | 20.574 |
| f | 2002.15 | 20.323 | 20.222 | 20.182 | 20.213 |
| g | 2002.15 | 20.658 | 20.560 | 20.520 | 20.558 |
| i | 2002.15 | 18.952 | 18.836 | 18.768 | 18.750 |
| j | 2002.15 | 20.858 | 20.753 | 20.714 | 20.747 |
| k | 2002.15 | 17.967 | 17.860 | 17.792 | 17.768 |