A Barnard's Star Perturbation Search Using McCormick Observatory Photographic Plate Material

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TABLE I. PARALLAX AND PROPER MOTION

Parameter	Value
McCormick Parallax	548.2 ± 1.7 milliarcseconds
Hubble Space Telescope Parallax	545.4 ± 0.3 milliarcseconds
Yale Parallax	545.6 ± 1.3 milliarcseconds
Hipparcos Parallax	549.3 ± 1.6 milliarcseconds
McCormick Proper Motion	10332.4 ± 0.2 milliarcseconds/year
Hubble Space Telescope Proper Motion	10370.0 ± 0.3 milliarcseconds/year
Hipparcos Proper Motion	10368.6 ± 2.1 milliarcseconds/year

ABSTRACT

A time-series analysis of photographic plates taken of Barnard's Star at the Leander McCormick Observatory since 1969 reveals no evidence of periodic perturbations indicative of a planetary companion. Table I lists the proper motion and parallax of Barnard's Star calculated from these observations. Table II lists the resulting annual residuals, which are illustrated in Figure 1. The x- and y-residuals correspond to residuals in right ascension and declination, respectively. The error bars indicate a 95 percent confidence level. Figure 2 shows the periodograms corresponding to these residuals. In neither case does the power at any frequency indicate a signal at a significance level of 50 percent or better. However, this work does not absolutely rule out the possibility that Barnard's Star may have planets.

TABLE II. RESIDUALS FOR ANNUAL NORMAL POINTS

Year	X Residuals (microns)	Y Residuals (microns)	Images
1969	-1.0 ± 0.6	-0.1 ± 1.0	11
1975	-0.6 ± 0.4	-0.3 ± 0.5	50
1976	0.2 ± 0.5	0.8 ± 0.5	41
1977	0.2 ± 0.4	0.3 ± 0.3	81
1978	-0.2 ± 0.3	0.1 ± 0.4	54
1979	0.5 ± 0.4	-0.7 ± 0.5	42
1980	0.4 ± 0.3	-0.1 ± 0.3	93
1981	-0.3 ± 0.4	-0.3 ± 0.4	65
1982	0.2 ± 0.4	-0.3 ± 0.4	50
1983	0.1 ± 0.4	-0.4 ± 0.4	84
1984	0.1 ± 0.9	-0.3 ± 0.7	21
1985	0.4 ± 0.9	-1.8 ± 1.1	8
1986	0.4 ± 0.5	0.4 ± 0.5	53
1988	-1.0 ± 0.5	0.0 ± 0.4	37
1989	0.5 ± 0.4	-0.3 ± 0.4	48
1990	-0.4 ± 0.3	0.6 ± 0.3	102
1992	-1.8 ± 0.9	-0.2 ± 1.2	8
1993	-1.4 ± 0.7	0.0 ± 0.9	17
1998	0.6 ± 0.6	-0.1 ± 0.7	59

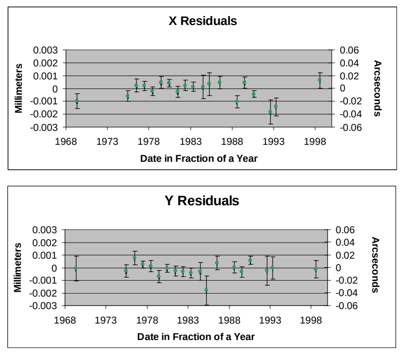


FIGURE 1. RESIDUALS FOR ANNUAL NORMAL POINTS

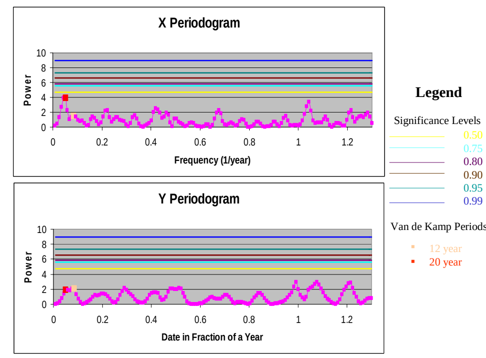


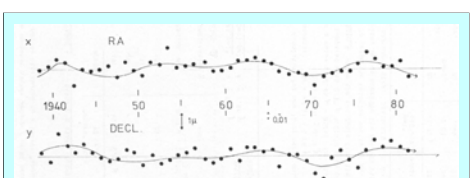
FIGURE 2. RESIDUAL PERIODOGRAMS

HISTORY

Barnard's Star is a particularly interesting object, not only because of its nearness and high proper motion, but also because of the early planet-detection claims. Table III lists several of the physical characteristics of this red dwarf. In 1963, Peter van de Kamp explained perturbations in its proper motion by the presence of a planetary companion. Based upon observations made at the Sproul Observatory between 1916 and 1962, Van de Kamp claimed the star had a planet with about 1.6 times the mass of Jupiter and an orbital period of 24 years. In 1969, he produced another single-planet solution and a two-planet solution to the astrometric wobbles detected. After accounting for instrumentation effects that might have been partially responsible for his initial results, he continued to assert that Barnard's Star had two planets. Figures 3 and 4 illustrate the results of his 1982 analysis, in which he calculated that the detected planets had 0.7 and 0.5 Jupiter masses and 12- and 20-year orbits, respectively. However, the searches listed in Table IV have failed to confirm his results. Although the McCormick Observatory has a substantial collection of photographic material relating to Barnard's Star, these plates have only been partially analyzed in the past. The earlier analyses involving fewer observations also failed to detect any planetary companions.

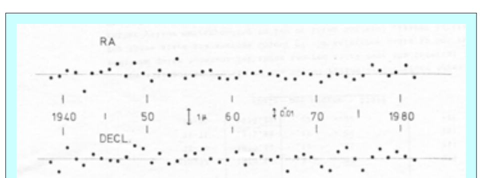
TABLE III. PHYSICAL CHARACTERISTICS

Parameter	Value
Discoverer	E. E. Barnard in 1916
Position (2000)	Ophiuchus α = 17:57: 48.5 δ = +04°41'36"
Magnitude	m_v = 9.55± 0.03 M_v = 13.3± 0.04
Spectral Type	M4V
Mass	$0.16 \pm 0.01 M_{\odot}$



Source: Van de Kamp, 1982

FIGURE 3. SPROUL RESIDUALS FOR ANNUAL NORMAL POINTS



Source: Van de Kamp, 1982

FIGURE 4. SPROUL RESIDUALS AFTER REMOVING ORBITS

TABLE IV. PARTIAL LIST OF BARNARD'S STAR STUDIES

Observers	Year of Publication	Method
Van de Kamp	1963, 1969, 1975, 1982	astrometric (Sproul plates)
Gatewood, Eichhorn	1973	astrometric (Allegheny and Van Vleck plates)
Fredrick, Ianna	1985	astrometric (small set of McCormick plates)
Marcy, Benitz	1989	radial velocity
Skruskie et al	1989	infrared
Henry, McCarthy	1990	speckle interferometric
Gatewood	1995	astrometric (Multichannel Astrometric Photometer)
Ianna	1995	astrometric (small set of McCormick plates)
Benedict et al	1999	Hubble Space Telescope interferometric
Bartlett, Ianna	2001	astrometric (complete set of McCormick plates)

TABLE V. McCORMICK REFRACTOR CHARACTERISTICS

Parameter	Description
Overall System	Fraunhofer refractor manufactured by Alvan Clark and Sons
Objective Size	67 centimeters
Focal Ratio	f/14.857
Focal Length	993 centimeters
Angular Field	0.75 degrees
Plate Scale	20.75 arcseconds per millimeter
Barnard's Star Plates	103aG plates with Wratten #12 filter (500 - 580 nanometer band pass)
Measuring Engine	PDS 1010GM Microdensitometer

TABLE VI. McCORMICK OBSERVATIONS

Parameter	Value
Baseline	April 1969 through August 1998 (~29 years)
Images	924
Plates	294
Nights	105
Reference Stars	12

TABLE VII. POWER SPECTRA PEAKS

	Frequency (1/year)	Power	False Alarm Probability
X Residuals	5.1×10^{-02}	3.9	77%
Y Residuals	1.1	2.9	98%

METHOD AND RESULTS

The observers at McCormick Observatory obtained photographic plate images of Barnard's Star over many years with the 26.25-inch refractor. This analysis relies on those observations made since 1969 because the earlier material is too sparse and of such poor quality so as to be unusable for this study. Table V characterizes the McCormick refractor, which has been in operation since 1885. Table VI describes the observations upon which this analysis is based.

The McCormick flatbed microdensitometer measured the positions of Barnard's Star and 12 reference stars on each of the photographic plates. From these measurements, the McCormick Parallax Reduction Program calculated the proper motion and parallax of Barnard's Star, which are listed in Table I. The proper motion calculation included significant secular acceleration terms. The program output included the residuals associated with each observation. The residuals were combined into the annual normal points listed in Table II and illustrated in Figure 1. The periodograms of the x- and y-residuals were calculated separately using the Lomb method described in *Numerical Recipes in FORTRAN 77*. Frequencies up to four times the Nyquist frequency were searched to produce plots of power versus frequency. Figure 2 shows that the power at no frequency is indicative of a signal at a significance level of 50 percent or better. Table VII summarizes the characteristics of the highest peak in each power spectrum including the probability that the peak could be caused by noise. In both cases, the peaks are most likely false alarms. In addition, no signal is seen at the frequencies corresponding to 12 or 20 years, which are the periods associated the planets reported by Van de Kamp in 1982.

DISCUSSION

This failure to replicate Van de Kamp's results, while not unexpected, does not completely eliminate the possibility that such planetary companions exist. The Sproul Observatory material available to Van de Kamp is unique. In 1982, his analysis used nearly 20,000 exposures on 4,580 plates taken on 1,200 nights between 1938 and 1981 at Sproul Observatory compared with this analysis of fewer exposures at McCormick Observatory. However, the McCormick refractor was not subjected to significant physical changes, such as the modifications made to the Sproul refractor in 1949. In addition, the baseline of the McCormick observations represents only slightly more than twice the period of the more massive, but shorter period, planet described by Van de Kamp. Even with smoothing to annual normal points, the residuals to the proper motion and parallax solutions obtained in this study show the noise typical of photographic plates. Nonetheless, this study further reduces the possibility that planets as massive as Jupiter orbit Barnard's Star.

ACKNOWLEDGEMENTS

We gratefully acknowledge support from NSF grant AST 98-20711 and from Litton Marine Systems, Incorporated.

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