The Astrophysical Journal, 407:L1–L4, 1993 April 10

OPTICAL PHOTOMETRY AND POLARIMETRY AND INFRARED PHOTOMETRY OF 3C 345 IN OUTBURST

Mark R. Kidger and José Antonio de Diego
Instituto de Astrofísica de Canarias, 38200 La Laguna, Tenerife, Spain
Leo O. Takalo and Aimo Sillanpää
Tuorla Observatory, Tuorla, SF-21500 Piikkiö, Finland
and
Masami Okyudo
NishiHarima Astronomical Observatory, Sayo-cho, Hyogo 679-53, Japan
Received 1992 November 16; accepted 1993 January 25

ABSTRACT

We present *V*-band CCD photometry, *UBVRI* photopolarimetry, and near simultaneous *JHK* photometry of 3C 345 during a renewed outburst in spring of 1992, which reached maximum at the end of April. The observations also show a large and variable polarization. There are very large variations in the position angle, unlike in previously published photopolarimetry of this object. Both the visible and the infrared magnitudes are amongst the brightest that have ever been measured in this object, whilst the continuum spectral energy distribution shows that excess in *V* which has been observed on some, but not all previous occasions. No convincing evidence is seen of rapid infrared variations on time scales of less than 2 hr.

Subject headings: galaxies: photometry — infrared: galaxies — quasars: individual (3C 345)

1. INTRODUCTION

3C 345 is a blazar with redshift $z = 0.595$, which presents a wide range of phenomena such as large and highly variable polarization, optically violent variable (OVV) activity and variability on all time scales from a few minutes to more than 10 yr. It is also one of the best observed quasars with a very extensive light curve since its discovery in 1965 (Kidger 1990, and references therein). One of the features is the existence of a number of large outbursts that some authorities have suggested may be periodic, although this idea has since fallen out of favor. Outbursts of one and a half magnitudes amplitude or greater have been seen in 1967–1968, 1969, 1971–1972, 1982–1983 and, most recently, in 1991–1992. The most recent outburst has seen the brightness of 3C 345 increase from its historical low of $B = 18.66$ (Kidger & Takalo 1990) in 1990 to maximum in early 1991 (Schramm & Borgeest 1991). The infrared light curve (Takalo et al. 1992a) shows that there was a probable second maximum in 1991 September, just before solar conjunction.

2. OBSERVATIONS AND REDUCTION

The infrared data were taken with the 1.5 m Telescopio Carlos Sánchez (TCS) of El Observatorio del Teide, Tenerife, Spain using the standard CVF photometer. The observing and reduction methods for infrared observations of quasars with the TCS are extensively discussed in Takalo et al. (1992a). The visible photopolarimetry were taken with the 2.56 m Nordic Optical Telescope (NOT) of El Observatorio de Roque de los Muchachos (ORM), La Palma, Spain, using the Turku photopolarimeter. The observing method and data reduction are described in detail in Takalo et al. (1992b). Visible photometry was taken with a standard CCD camera on the 60 cm telescope at NishiHarima Observatory, Hyogo, Japan. This data were reduced using the standard data reduction package within the IRAF suite of computer programs.

3. RESULTS

Tables 1 and 2 present the photometric and polarimetric data, respectively, for 3C 345 during 1992, these data are shown as light curves in Figure 1. Comparison of the infrared magnitudes with monitoring taken between 1991 January and August (Takalo et al. 1992a) shows that the infrared magnitude was about 0.4 mag brighter in all bands than the brightest point measured in 1991. Our infrared light curve is seriously incomplete because the TV acquisition camera on the TCS has a visible limit of 16–16.5, thus not permitting source location at minimum, but indicates that the maximum of this outburst was reached at the end of 1992 April. This is confirmed by the visible light curve for spring/summer of 1992, which shows a well defined maximum of duration approximately 40 days and amplitude 0.8 mag, superposed on a flat plateau, very similar to, although of slightly lower amplitude than the 1969 outburst. By 1992 July, the visible magnitude had declined significantly again but, after a number of unsuccessful attempts, the source was reacquired at the TCS in September, suggesting that there might have been a slight brightening.

The *B*-magnitude observed in late April was the brightest seen in this object since 1984 and has only rarely been exceeded. Only during the 1968, 1972, and 1982/1983 outbursts has this level ever been exceeded for a sustained period of time and then usually only by a few tenths of a magnitude. The total amplitude from minimum to the peak of the outburst is 3.0 mag, the highest ever observed in this object, considerably exceeding the amplitude of the 1972 flare which was of 2.6 mag in total.

Figure 2 shows the flux spectra of 3C 345 for nights when photometry was taken in at least five bands. On two nights simultaneous visible and infrared photometry permits a composite spectrum to be plotted from 0.3–2.2 microns. The data show that the infrared spectrum varies very little between the different observations and is, essentially, a power law. On the

TABLE 1

Details of the Nightly Average Magnitudes for the Photometry of 3C 345 in the Visible and Near-Infrared

UT Date	*U*	*B*	*V*	*R*	*I*	*J*	*H*	*K*
1992-02-05.8	...	...	16.15 ± 0.03	...	...	...	...	...
1992-02-26.8	...	...	16.01 ± 0.04	...	...	...	...	...
1992-03-27.8	...	...	15.89 ± 0.01	...	...	...	...	...
1992-04-25.2	...	...	...	...	...	13.16 ± 0.10	12.30 ± 0.06	11.41 ± 0.06
1992-04-26.2	15.02 ± 0.07	15.78 ± 0.13	15.24 ± 0.08	15.00 ± 0.16	14.43 ± 0.23	13.02 ± 0.04	12.29 ± 0.03	11.35 ± 0.04
1992-04-27.2	...	...	...	...	...	12.97 ± 0.10	12.27 ± 0.04	11.33 ± 0.04
1992-04-28.2	14.86 ± 0.02	15.59 ± 0.03	15.07 ± 0.05	14.78 ± 0.03	14.26 ± 0.04	13.07 ± 0.14	12.18 ± 0.05	11.33 ± 0.04
1992-04-30.2	...	...	...	...	...	12.89 ± 0.09	12.14 ± 0.07	11.29 ± 0.05
1992-05-05.8	...	...	15.16 ± 0.02	...	...	...	...	...
1992-05-11.7	...	...	15.01 ± 0.03	...	...	...	...	...
1992-05-21.7	...	...	15.29 ± 0.08	...	...	...	...	...
1992-05-26.1	...	...	...	...	...	13.10 ± 0.19	12.45 ± 0.13	11.51 ± 0.08
1992-05-26.7	...	...	15.68 ± 0.03	...	...	...	...	...
1992-05-28.1	...	...	...	...	...	13.23 ± 0.13	12.55 ± 0.06	11.86 ± 0.04
1992-06-09.7	...	...	15.79 ± 0.02	...	...	...	...	...
1992-07-03.0	15.71 ± 0.03	16.35 ± 0.04	15.82 ± 0.04	15.51 ± 0.04	14.86 ± 0.07	...	...	...
1992-07-05.1	15.77 ± 0.02	16.35 ± 0.05	15.96 ± 0.09	15.55 ± 0.04	14.94 ± 0.11	...	...	...
1992-07-22.7	...	...	16.43 ± 0.00	...	...	...	...	...
1992-07-24.7	...	...	16.58 ± 0.14	...	...	...	...	...
1992-09-15.0	...	...	...	...	...	...	...	12.23 ± 0.24
1992-09-21.5	...	16.59 ± 0.16	...	...	...	...	...	...
1992-10-26.9	...	...	...	...	...	...	...	12.61 ± 0.29

two nights when we have simultaneous monitoring we see that the visible and infrared spectra do not connect, rather that the infrared fluxes are rather higher than the extrapolation of the visible flux. The spectral index for the data is fairly constant; on both occasions that we have *UBVRIJHK* data the spectral index is −1.3 to −1.4, whilst the infrared spectral index varies from −1.0 to −1.3.

Both the degree of polarization and the position angle show very large changes. This is typical of blazar activity in other objects. In *U* we see a decrease from 9.7% to 1.9% polarization between late April and early July. Other bands showed similar, but smaller changes. There is no clear evidence of either frequency dependent polarization, or of frequency dependent position angle, both of which are frequently seen in other blazars. A 20° position angle rotation is seen in all colors in 1 day near maximum brightness, whilst the total polarization decreased by some 3% at the same time.

On two nights several infrared monitoring points were taken to search for possible rapid variations. The longest sequence of data was a 2 hr monitoring run in *JHK* on the morning of April 28. The evidence for possible variations is unconvincing as a chi-squared test shows that, even in *K*, the probability that the seven observations show variability is just 95%.

4. DISCUSSION

3C 345 has been widely observed by a large number of groups taking both visible photometry (see Kidger 1990 and Webb et al. 1989 for an extensive, but not exhaustive list of references) and visible and or infrared photopolarimetry (see Mead et al. 1988, 1990, and Smith et al. 1986, and references therein). The range of observed polarization is one of the largest known: between 1983 February and June the total polarization in *I* dropped from 36.2% to 1.4% (Smith et al. 1986). However, Mead et al. (1990) observed zero polarization in several visible bands on occasions in 1987, although with rather large 3 σ limits. The near-infrared (*JHK*) polarization is generally, but not always, rather higher than the visible polarization, with the visible usually showing a marked increase in the total polarization from *U* to *I*. On many occasions there is a strong frequency-dependent polarization (FDP), although on others the frequency dependence is complex, with maxima and minima in different filters and, occasionally, the sign of the FDP reverses. Similarly, frequency dependent position angle (FDPA) may or may not be present: the aforementioned data shows all possible scenarios, with FDPA of both signs, complex variation and zero variation all being seen at different epochs. Almost all of the data is in the range of 15°–80° position angle. Kinman (1977) previously noted the existence of a preferred position angle within this range and Cohen & Unwin (1984) reported that the VLBI jet position angle is also close to this value.

Our own data were taken at a time when the peak flux level and the light curve behavior were similar to those registered in 1983. We find though that the total polarization is much lower

TABLE 2

Details of the Polarimetry of 3C 345

UT Date	*U* *P*	*U* P.A.	*B* *P*	*B* P.A.	*V* *P*	*V* P.A.	*R* *P*	*R* P.A.	*I* *P*	*I* P.A.
1992-04-26.2	9.7 ± 0.4%	49°.4 ± 1°.3	10.4 ± 0.6%	48°.8 ± 1°.7	9.2 ± 0.7%	49°.8 ± 2°.0	11.2 ± 0.8%	48°.6 ± 2°.0	11.7 ± 1.1%	48°.4 ± 2°.6
1992-04-28.2	7.2 ± 0.3	71.1 ± 1.2	6.8 ± 0.4	73.0 ± 1.5	7.6 ± 1.5	71.3 ± 2.1	8.4 ± 0.3	69.6 ± 1.2	7.3 ± 0.7	68.3 ± 2.7
1992-07-03.0	1.9 ± 0.5	117.5 ± 7.3	4.1 ± 0.8	103.8 ± 5.6	2.7 ± 0.6	117.5 ± 5.8	4.2 ± 0.6	120.3 ± 4.0	6.6 ± 0.9	96.1 ± 3.9
1992-07-04.0	4.8 ± 1.0	108.0 ± 5.8	5.1 ± 1.8	103.1 ± 9.6	7.7 ± 1.7	93.0 ± 6.3	11.5 ± 2.8	98.5 ± 6.9	4.7 ± 3.4	89.4 ± 17.
1992-07-05.1	5.6 ± 0.5	101.5 ± 2.5	5.3 ± 0.6	89.9 ± 3.0	5.2 ± 1.0	93.5 ± 5.3	6.9 ± 0.9	104.9 ± 3.8	6.4 ± 1.7	86.0 ± 7.6

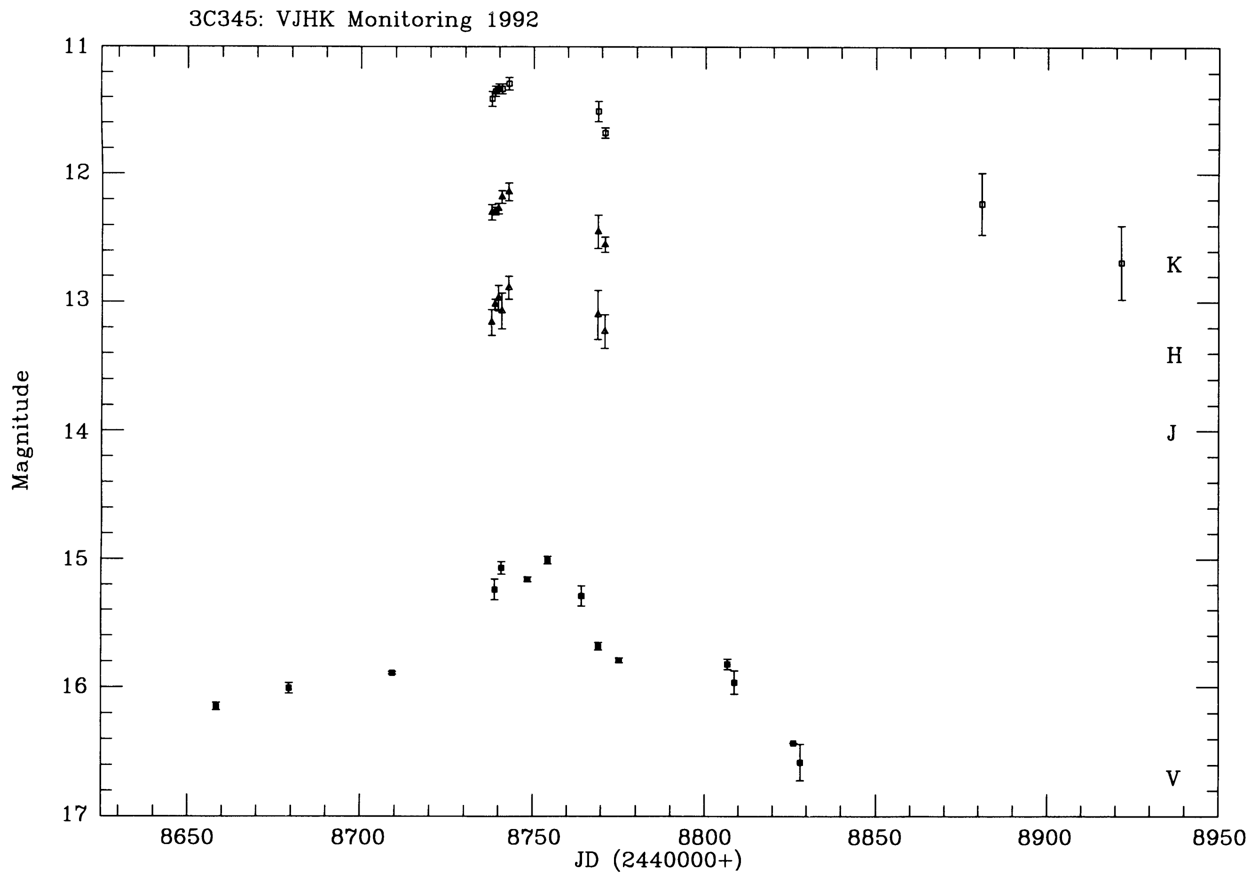

FIG. 1.—Light curve of 3C 345 in the visible and near-infrared for the period 1992 February to October

than that observed in this previous outburst, hence a very large total polarization is not a property of large outbursts. We also see that there is no obvious correlation between the flux, polarization, and position angle during the decline, although Smith et al. (1986) found a very strong correlation. The position angle during the 1992 outburst seems to have been rather larger than that measured in the period 1983–1987, with approximately one-third of the measured values being greater than 100°. The range of variation, from approximately 50°–120° between the end of 1992 April and early July, also seems to be very unusual, or possibly exceptional in this object.

One intriguing detail of our data is possible excess of polarization seen in *B* on 1992 April 26.2 and July 3.0. The *B* band in 3C 345 is very strongly contaminated by the redshifted Mg II (2798 Å) line, which falls near the center of this window. We would expect that, if the spectral lines are unpolarized, as in 3C 273 (de Diego et al. 1992a), there should be some structure in the total polarization caused by the very strong Mg II line. Other "strong" lines such as the Hβ line which enters the *I* window and the much weaker Hγ line which falls in *R* are unlikely to contribute sufficiently to the total flux to affect broad-band polarization significantly. We see though that, in our own rather limited data sample, there seems to be somewhat less variation in the total polarization in *B* than in the other bands and there is some evidence of an excess of polarization in this band compared to the neighboring bands, which could be explained were the Mg II line, in fact strongly polarized, although various scenarios are possible. Curiously though, Mead et al. (1990) actually find a small minimum in the polarization in *B* relative to other bands, This would be consistent with the Mg II line having a low or zero polarization.

Polarized spectra were taken of this object in 1991 June (de Diego et al. 1992a, b) and again in 1992 July, using FOS-2 on the 4.2 m William Herschel Telescope of the ORM. We find that, in 1991 June, when the total polarization was quite low (around 5%), the Mg II line is less polarized than the continuum, but does not have zero polarization, unlike the Hα line of 3C 273. In contrast, Hβ is found to have little influence on the total polarized flux and is thus irrelevant to broad-band photopolarimetry. However, we would caution that not too much significance should be given to a single spectrum and, given the known variability of these objects, a nonsimultaneous spectrum is of little use for interpretation of broad-band photopolarimetry; there is no prima facie reason to reject the possibility that there may also be polarization variability of visible lines. Such putative variations would be superposed on the known constant variability of the continuum polarization and could, in themselves, be a possible explanation for some of the observed complex polarization behavior. There is thus a strong case for monitoring of possible spectropolarimetric line variations as their observation, or even *nonobservation*, would be an extremely important step to understanding the broad-band polarization behavior of these objects or, at very least, aiding to deconvolve some of the different underlying factors that contribute to the observed variability in the broad-band total polarization.

A further interesting detail is the large bump seen in the broad-band energy distribution in *V*. A very large excess in *V* emission was observed at minimum in 1990 and explained as

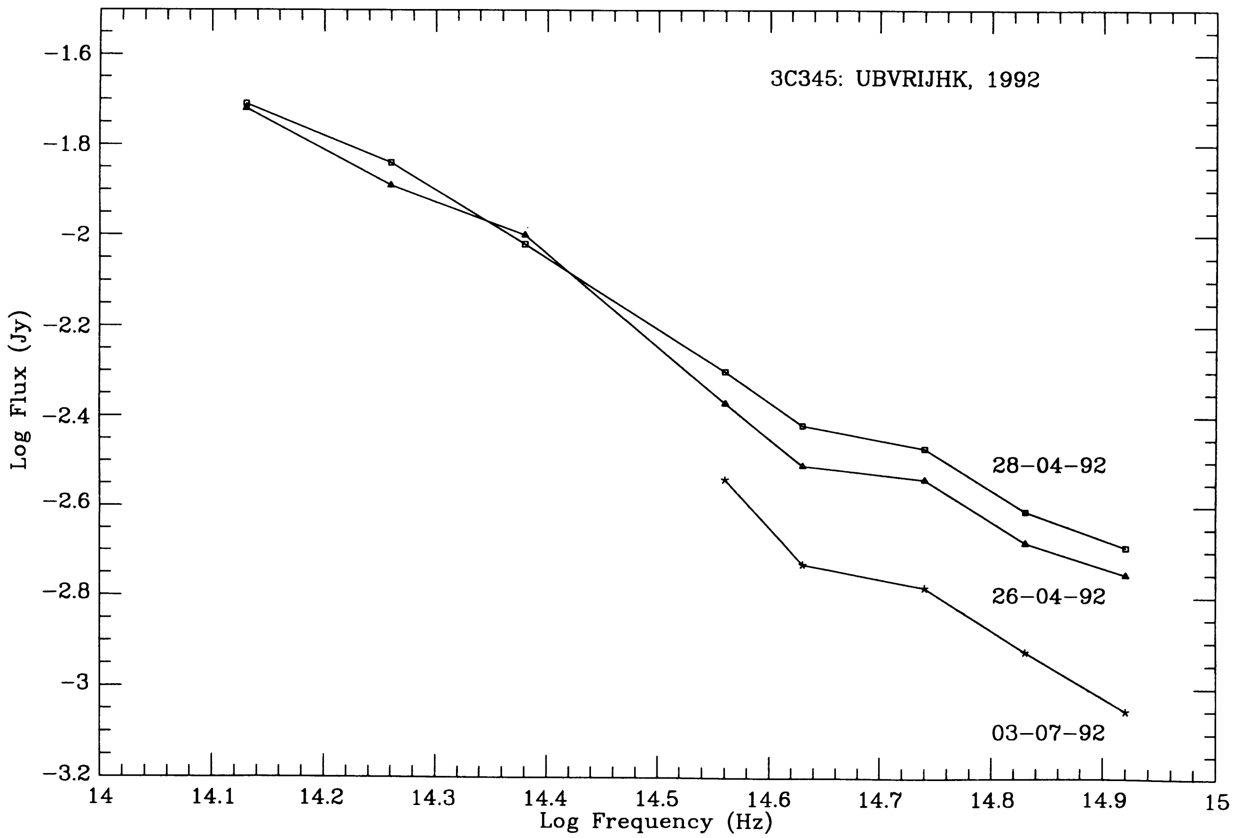

FIG. 2.—Multiband flux spectra for 3C 345 at the maximum of the outburst and in quiescence. The error bars on each point are smaller than the size of the symbols. Significant variations from a simple power-law are seen.

probably being due to the redshifted "blue bump" (Kidger & Takalo 1990). Mead et al. (1988) also observed this bump weakly in 1985, when 3C 345 was declining from outburst and was at a very much lower continuum flux level than in spring of 1992, and interpreted it as being due to a 25,000 K blackbody component. However, Visvanathan (1973), observing the 3C 345 in outburst found that the visible spectrum was a simple power law with no superposed structure. Mead et al. also suggest that their best fit to the amplitude shows evidence of variability, which is consistent with the variable visibility of the excess at different epochs when the continuum flux level is equivalent. We intend to explore this possibility further in a future publication.

5. CONCLUSIONS

Our data show that 3C 345 suffered a renewed outburst in 1992, reaching a maximum brightness of $V = 15.0$ and $B = 15.6$ approximately. The infrared magnitude in all bands was approximately 0.4 mag brighter than in 1991. Large and variable polarization is seen, the highest values being over 10%, although such values are not unusual in this object. We also see considerable variation in the position angle on short time scales; both of these phenomena are typical of blazars, although the second of them appears to be very rare in this object. The total amplitude of the outburst from minimum in 1990 to the brightest point observed in 1992 is 3.0 mag, the largest ever observed in this object, although it is possible that the true maximum was even brighter. The 1990–1992 outburst seems similar to the evolution of the light curve in 1967–1969, when there was a very rapid rise and pronounced double maximum followed a year and a half later by a further, very brief outburst.

The Nordic Optical Telescope in El Observatorio del Roque de los Muchachos is operated by the Nordi Council in collaboration with the Instituto de Astrofísica de Canarias. The William Herschel Telescope in El Observatorio del Roque de los Muchachos is operated by the Royal Greenwich Observatory in collaboration with the Instituto de Astrofísica de Canarias. The Carlos Sánchez Telescope (TCS) in El Observatorio del Teide is operated by the Instituto de Astrofísica de Canarias.

REFERENCES

Cohen, M. H., & Unwin, S. C. 1984, In IAU Symp. 110, VLBI and Compact Radio Sources, ed. R. Fanti, K. Kellerman, & G. Setti (Dordrecht: Reidel), 95
de Diego, J. A., Pérez, E., Kidger, M. R., & Takalo, L. O. 1992a, ApJ, 396, L19
———. 1992b, in Proc. of the 32d Herstmonceux Conf., The Nature of Active Galactic Nuclei (Cambridge: Cambridge Univ. Press), in press
Kidger, M. R. 1990, A&A, 226, 9
Kidger, M. R., & Takalo, L. O. 1990, A&A, 239, L9
Kinman, T. D. 1977, Nature, 267, 798
Mead, A. R. G., Ballard, K. R., Brand, P. W. J. L., Hough, J. H., Brindle, C., & Bailey, J. A. 1990, A&AS, 83, 183
Mead, A. R. G., Brand, P. W. J. L., Hough, J. H., & Bailey, J. A. 1988, MNRAS, 233, 503
Schramm, J., & Borgeest, U. 1991, IAU Circ. No. 5191
Smith, P. S., Balonek, T. J., Heckert, P. A., & Elston, R. 1986, ApJ, 305, 484
Takalo, L. O., Kidger, M. R., de Diego, J. A., Sillanpää, A., & Nilsson, K. 1992a, AJ, 104, 37
Takalo, L. O., Sillanpää, A., Nilsson, K., Kidger, M. R., de Diego, J. A., & Piirola, V. 1992b, A&AS, 94, 37
Visvanathan, N. 1973, ApJ, 179, 1
Webb, J. R., Smith, A. G., Leacock, R. J., Fitzgibbons, G. L., Gombola, P. P., & Shepherd, D. W. 1989, AJ, 95, 374