CCD PHOTOMETRY OF SN 1974G FROM PHOTOGRAPHIC PLATES USING A KODAK DCS200 CAMERA

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Abstract

We have investigated the use of a Kodak DCS200 camera, which mounts a 1524 x 1012-pixel uncooled CCD as the detector in a conventional Nikon 8008s camera, to digitize and obtain photographic photometry from typical plates in the Maria Mitchell Observatory (MMO) plate collection. We tested the photographic stability of the camera system on photographic standard sequences in several fields, finding a linear correlation between instrumental aperture magnitudes and standard photographic magnitudes, with an rms deviation of 0.1 magnitude. We then applied the methods to digitize a 1 cm square area surrounding SN 1974G in NGC 4414 on a series of five plates taken within a week of maximum light. The major source of the 0.2-magnitude uncertainty in SN 1974G magnitude measurements was determining the local background surrounding SN 1974G. However, the photographic magnitudes we derived agree within 0.2 magnitude of points interpolated from published light curves. We conclude that the Kodak DCS 200 camera is an excellent and economical device for digitizing small areas of plate collections for special study.

1. Introduction

The advantages of using a CCD include reproducibility of field star magnitudes within 0.05 magnitude and the capability for data reduction within the NOAO-released software IRAF (Image Reduction and Analysis Facility), although digitizing areas of photographic plates cannot improve the original detective quantum efficiency of the photographic emulsion. The Kodak DCS200 camera consists of a Nikkon 8008s body with an uncooled 1524 x 1012 pixel CCD chip and an optional 75MB hard drive, capable of storing up to 50 8-bit images recorded by the camera. For digitizing small plate regions at maximum resolution, we found a Nikkon 60 mm micro lens advantageous. We acquired images through the Macintosh software Adobe Photoshop 3.1.1, through which we exported the files to UNIX systems for data reduction.

2. Selection of star sequence

As a representative standard sequence, we chose the star sequence Selected Area 57 (Stebbins *et al.* 1950), which contains over 20 stars within a 6 mm square area, ranging in photographic magnitude between 9.04 and 17.46. Star sizes on the plates ranged between 0.2 mm and 1 mm. Avoiding saturated stars and stars within one magnitude of the plate limit (magnitude 17.5), we used 14 stars ranging in magnitude from 13.33 to 16.59 on four different plates (Table 1). We based plate selection on background uniformity, star shape (related to the region's position on the plate), and exposure time. We chose two plates, NA 6592 and NA 7477, with SA 57 near the center of the plate, which yielded much rounder stellar images than sequences on plates NA 6822 and NA 7504, where SA 57 was near the edge of the plate. The selection also included two

Table 1. SA 57 on selected MMO plates (103aO photographic emulsion).

Plate	*Date*	*R. A. (1950)*	*Dec.*	*Exposure time*
1. NA 6592	Feb. 1, 1981	13 07	+29.8	46 min.
2. NA 6822	Apr. 16, 1982	12 49	+27.6	45 min.
3. NA 7477	Apr. 13, 1985	13 06	+29.1	60 min.
4. NA 7504	June 14, 1985	12 54	+29.3	60 min.

exposure times: NA 6592 and NA 6822 had exposure times of approximately 45 minutes, while NA 7477 and NA 7504 had 60-minute exposure times.

3. Camera parameters

We aimed for exposures which minimized the contribution from electronic noise and filled the 8-bit dynamic range of the chip. We manipulated three parameters to obtain these optimal exposures: ISO rating (light sensitivity), shutter speed (exposure time), and aperture (amount of light). Using a Bencher Illuma copy stand for uniform back illumination, we found an aperture of f/5.6 worked best with shutter speeds of 1/250 second and 1/125 second, depending on the background density of the plate. For all exposures, we maintained an ISO rating of 100 because ISO ratings over 100 showed increased noise from the chip.

4. Data reduction within IRAF

Measuring magnitudes of stars in uncrowded fields within IRAF involves three primary components: (1) dark frame subtraction, (2) flat field division, (3) aperture photometry using the APPHOT package in IRAF. We divided all images by a normalized flat to correct for the pixel-to-pixel variation in sensitivity across the chip. In taking flat frames, we used an aperture of f/11 at 1/250 second, which showed the lowest standard deviation around the mean. Variations in the flats were only 0.76% across the chip. We obtained star magnitudes by using the PHOT task within the APPHOT package. The resulting magnitude is sensitive to the size of the aperture and sky annulus position and width. Therefore, the three parameters we edited were aperture, the inner radius of the sky annulus, and the annulus width. We used a 12-pixel aperture for the entire field, based on aperture growth curves of stars 11, 8, 58, and 72 within SA 57. It was necessary to choose a sky annulus inner radius large enough to include the local background of the star without interference of values from the star, yet not so large as to be misrepresentative of the local star background. Using star profiles, we found inner radii of 18 pixels worked well for most stars. Changing annulus width from 2 to 10 pixels changed instrumental magnitudes by 0.05 magnitude, a significant amount, but small compared to the 0.1 magnitude uncertainty associated with the least squares fitting routine.

5. Linear correlation

We plotted the instrumental magnitudes calculated within PHOT against standard photographic magnitudes listed in Stebbins *et al.* (1950) (Table 2). Using a least squares fit, we found correlations ranging between 0.97 and 0.99, indicating a strong linear relationship. For individual frames, standard deviations ranged from 0.076 magnitude to 0.158 magnitude, the average rms deviation being 0.1 magnitude (Figures 1a, 1b).

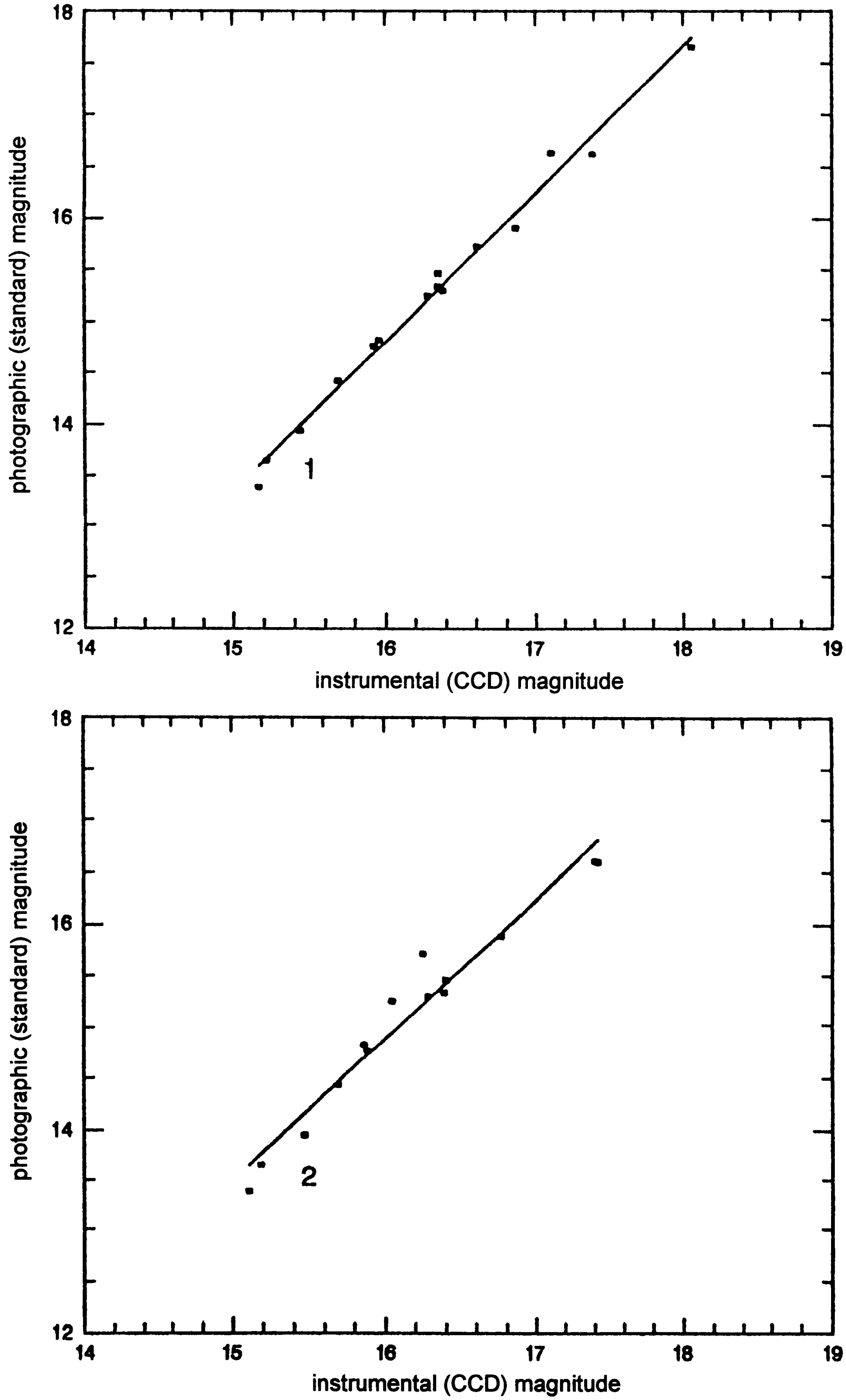
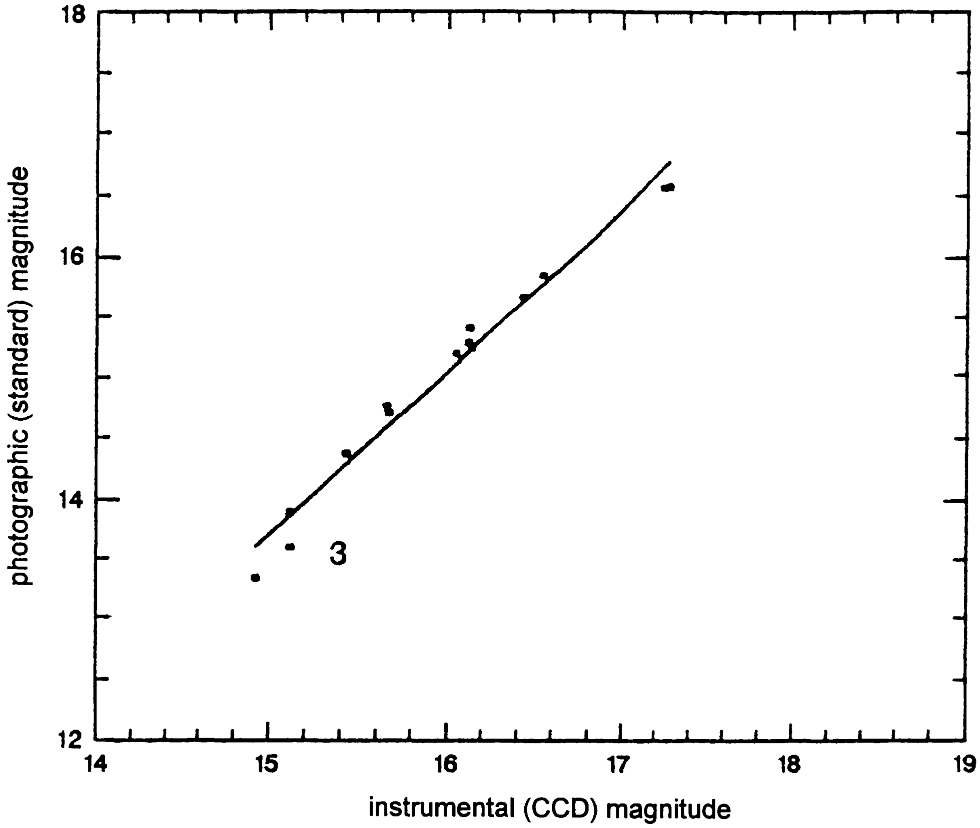


Figure 1a. Linear correlation between instrumental and standard photographic magnitudes for the standards in the field of SA 57. The graphs show the individual points and calculated linear fits for each frame. Top: NA 6592; bottom: NA 6822.



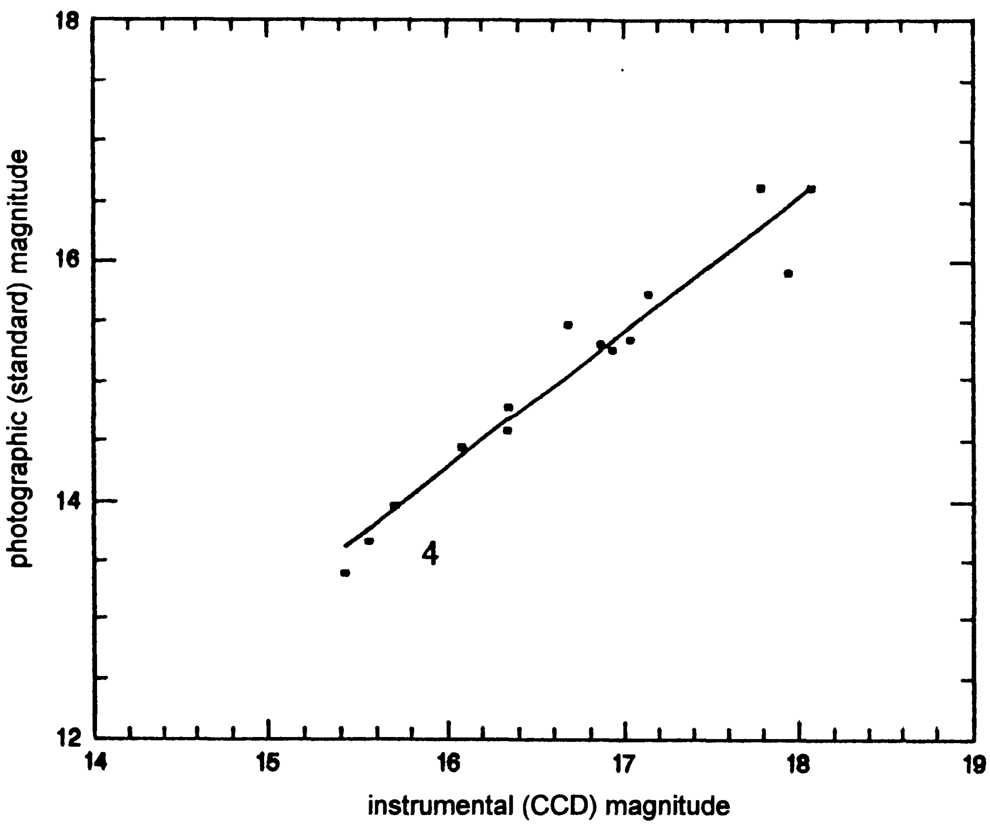


Figure 1b. Linear correlation between instrumental and standard photographic magnitudes for the standards in the field of SA 57. The graphs show the individual points and calculated linear fits for each frame. Top: NA 7477; bottom: NA 7504.

Table 2. SA 57 instrumental and photographic magnitudes.

Star No.	m_{pg}	m_{ins} *NA 6592*	m_{ins} *NA 6822*	m_{ins} *NA 7477*	m_{ins} *NA 7504*
40	15.26	16.401	16.299	16.127	16.880
25	15.69	16.633	16.260	16.417	17.153
58	14.78	15.976	15.878	15.653	16.365
72	15.30	16.367	16.406	16.107	17.053
16	14.38	15.704	15.710	15.430	16.103
7	15.21	16.301	16.054	16.039	16.946
8	13.60	15.233	15.200	15.114	15.578
36	15.87	16.884	16.785	16.530	17.952
11	13.33	15.182	15.118	14.924	15.477
63	16.58	17.396	17.433	17.225	18.080
61	16.59	17.121	17.414	17.257	17.793
59	14.72	15.941	15.902	15.663	16.361
77	13.90	15.459	15.486	15.114	15.725
82	15.42	16.367	16.418	16.112	16.690

6. Light curve of Type Ia SN 1974G in NGC 4414

Knowing that the camera and our measurement techniques could be used to establish a linear relationship between instrumental and photographic magnitudes, we were interested in applying the process to the measurement of a variable star in the field of the plates. We chose the challenging case of the Type Ia supernova 1974G in the late-type spiral galaxy NGC 4414 (Barbon *et al.* 1989). The five plates in the MMO plate collection cover an eleven day period, beginning May 9, 1974 (Table 3). Fortunately, a photographic magnitude sequence has been established in the field of the galaxy NGC 4414 (Patchett and Wood 1976). The five sequence stars range in magnitude from 12.5 to 14.5; these magnitudes bracket the maximum and minimum magnitudes of SN 1974G found on the five plates in the collection. We took three f/5.6-aperture, 1/250-second exposures for each of the five plates listed. Magnitudes varied 0.05 magnitude among the three exposures for individual plates. Data reduction followed the same process as for SA 57. Using a least squares fit based on the five sequence stars surrounding the supernova, we found linear relations for the five frames. The supernova instrumental magnitude was converted to a photographic magnitude by substituting the instrumental magnitude into the linear relation for each frame (Figure 2; Table 4). We plotted these supernova magnitudes with interpolated points from the published light curve of Patchett and Wood (1976). The magnitudes measured on the Observatory plates fit within 0.2 magnitude of the interpolated points (Figure 3).

Table 3. SN 1974G on selected MMO plates (IIaO photographic emulsion).

Plate	*Date (JD)*	*R. A. (1950)*	*Dec.*	*Exposure time*
1. NA 5391	24442177.580	12 25	+28.5	31 min.
2. NA 5392	24442181.582	12 25	+28.5	30 min.
3. NA 5393	24442182.572	12 25	+28.5	30 min.
4. NA 5394	24442187.576	12 25	+28.5	30 min.
5. NA 5397	24442188.609	12 25	+28.5	30 min.

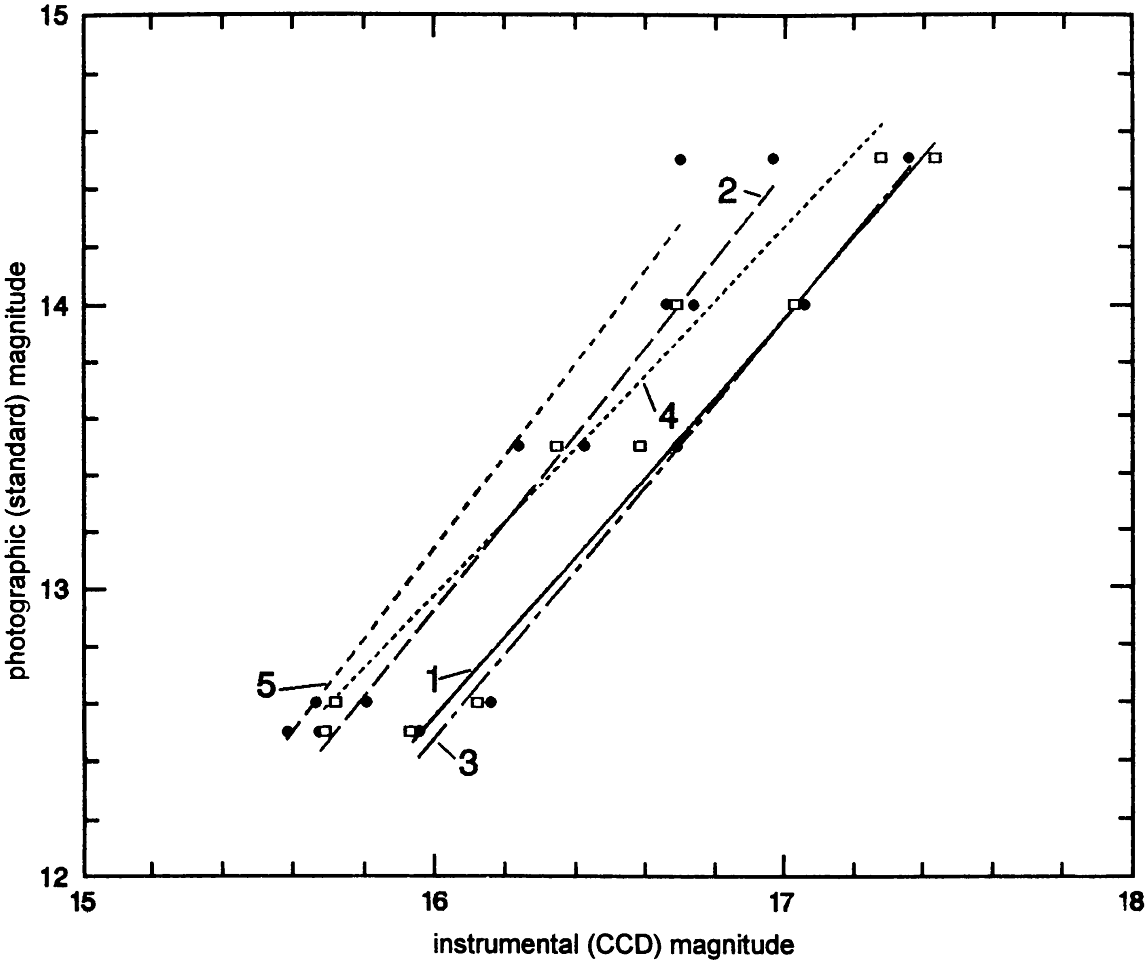


Figure 2. Photographic transformation for the sequence in the field of SN 1974G. Individual points and linear fits for the five frames are plotted to illustrate the relationship between instrumental magnitudes found within IRAF and previously published photographic magnitudes from Patchett and Wood (1976). Numbers correspond to plates listed in Table 3. There is no difference between open squares and closed circles.

Table 4. SN 1974G instrumental and photographic magnitudes.

Star No.	m_{pg}	m_{ins} *NA 5391*	m_{ins} *NA 5392*	m_{ins} *NA 5393*	m_{ins} *NA 5394*	m_{ins} *NA 5397*
4	12.5	15.938	15.685	15.956	15.676	15.583
5	12.6	16.124	15.718	16.158	15.804	15.663
8	13.5	16.584	16.276	16.681	16.421	16.239
6	14.0	17.030	16.691	17.060	16.741	16.663
7	14.5	17.430	17.774	17.358	16.967	16.698
SN		15.891	16.002	16.478	16.432	16.154
SN m_{pg}		12.401	12.982	13.176	13.588	13.396
Std. Dev.		0.096	0.103	0.073	0.076	0.158

Linear equations used to calculate the photographic magnitudes of the supernova:

NA 5391: 1.3952x - 9.7696
NA 5392: 1.1284x - 7.5606
NA 5393: 1.4683x - 11.0191
NA 5394: 1.5280x - 11.5203
NA 5397: 1.6109x - 12.6277

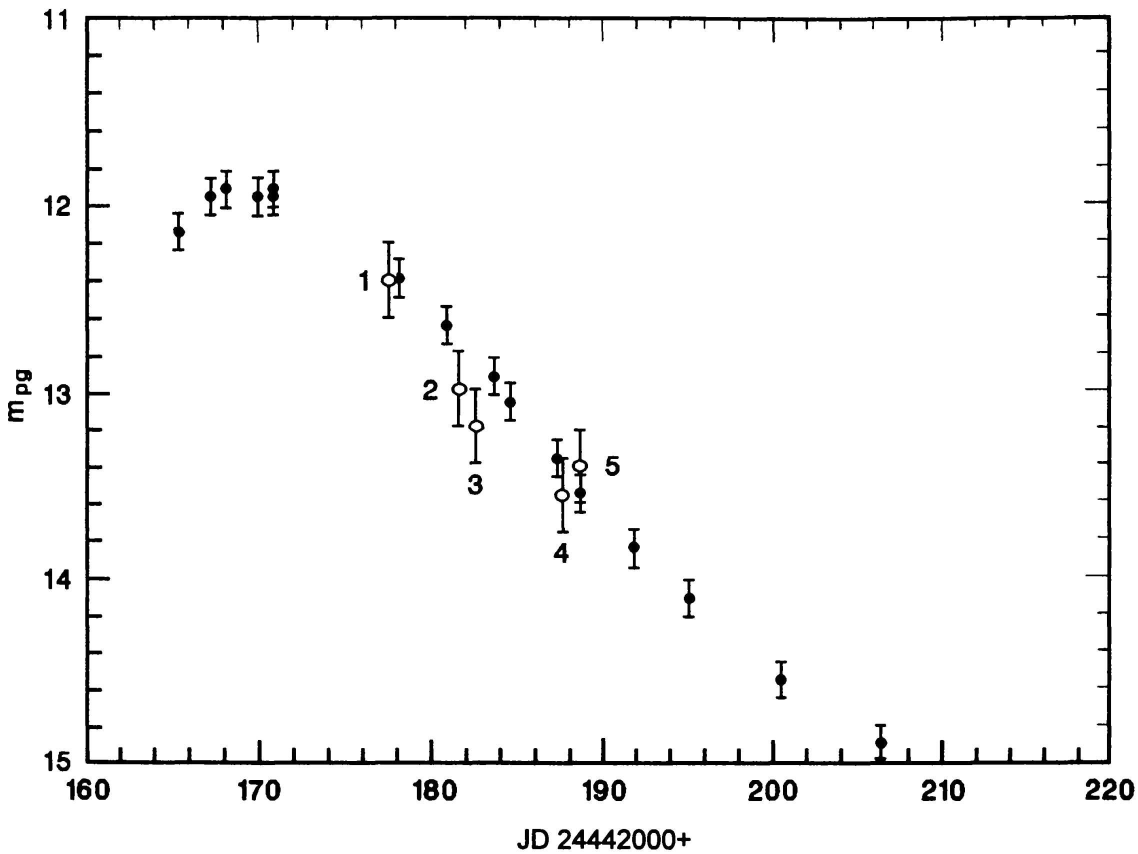


Figure 3. The light curve for SN 1974G from Patchett and Wood (1976). Closed dots are points interpolated from the curve in the article, including error bars of 0.1 magnitude, the error listed in the article. Open circles represent magnitudes measured from the MMO plates with error bars of 0.2 magnitude.

7. Analysis

Plate quality was very important; uneven development created great uncertainty in the local background and poorly trailed stars created difficulty in choosing an aperture. We chose plates with both round and distorted star shape and we found round star images produced more accurate measurements, judging by the rms deviations around the transformation. However, a large aperture compensated for the irregular shape. We found that the other plate selection criterion, plate exposure length, didn't significantly affect measurement precision, except for eliminating certain stars from the selection due to star saturation and stars within a magnitude of plate limits. Within PHOT, variation of the sky annulus value most affected the magnitude—variations by several counts caused higher uncertainties in the instrumental magnitude than the 0.05-magnitude uncertainty caused by variation of the annulus width. It was this four- to-five count variation in supernova local background, caused by the underlying galaxy, that created an uncertainty of 0.2 magnitude. However, even with the difficulty of determining a local background value, the magnitudes differed by less than 2.5% from the magnitudes interpolated from the light curve of Patchett and Wood (1976).

8. Conclusion

Use of the Kodak DCS200 camera is an easy, economical way to obtain magnitudes for stars below saturation and at least one magnitude above plate limits on photographic plates, given access to data reduction facilities such as the NOAO-released software IRAF. Plate quality is an important consideration because the camera cannot improve original image quality and detective quantum efficiency. With uniform illumination and proper exposure, we were able to measure magnitudes of standard stars accurate to 0.1 magnitude and magnitudes of SN 1974G to 0.2 magnitude; this additional uncertainty was caused by variations in the sky annulus value.

9. Acknowledgements

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