PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC
102: 888–897, August 1990

# SN 1987A IN THE LARGE MAGELLANIC CLOUD. IV. PHOTOMETRY FROM THE SPECTROPHOTOMETRY

MARIO HAMUY, NICHOLAS B. SUNTZEFF, JORGE BRAVO, AND M. M. PHILLIPS

Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories,* Casilla 603, La Serena, Chile

*Received 1990 April 21, revised 1990 May 14*

## ABSTRACT

Systematic differences in the *UBVRI* photometry of SN 1987A exist between the published photometry from CTIO and SAAO. The largest differences occur in the *I* band where the SAAO photometry is up to 0.4 magnitude brighter than the CTIO photometry. We have measured the filter/phototube response of the CTIO system and have synthesized *VRI* photometry from the CCD spectrophotometry of SN 1987A obtained at CTIO. The differences between the synthesized and photoelectric photometry for both the CTIO and SAAO natural systems are less than 0.05 magnitude. This confirms our previous suggestion that the nonstellar nature of the supernova spectrum can give rise to large systematic errors in photometry obtained at different sites. The comparison of the light curves of any two supernovae can be in error by a similar amount due to the different natural photometric systems.

*Key words:* supernovae–photometry–spectrophotometry

## 1. Introduction

As soon as SN 1987A was discovered by Shelton, Duhalde, and Jones (1987), the major observatories in the Southern Hemisphere initiated long-term programs to obtain optical broad-band photometry of this important object. Broad-band photoelectric photometry has been published by groups at Cerro Tololo Inter-American Observatory (CTIO) (Hamuy *et al.* 1988; Suntzeff *et al.* 1988; Hamuy and Suntzeff 1990, hereafter Papers I, II, and III, respectively), the University of Toronto Southern Observatory (UTSO) in Las Campanas (Shelton 1989), the European Southern Observatory (ESO) in La Silla (Cristiani *et al.* 1987; Burki *et al.* 1989), the South African Astronomical Observatory (SAAO) (Menzies *et al.* 1987; Catchpole *et al.* 1987, 1988, 1989; Whitelock *et al.* 1988, 1989), and the Mount Stromlo and Siding Spring Observatories (MSSSO) (Dopita *et al.* 1988). Due to the brightness of SN 1987A, all these observations were obtained with small telescopes together with standard photometers and photomultipliers. Although each group obtained data spanning at least the first six months of the evolution of SN 1987A, only CTIO and SAAO have continued to monitor and publish data through day 800. Later than day 800 it has been necessary to switch to bigger telescopes and replace the photomultipliers with CCDs due to the faintness of SN 1987A and crowding of nearby stars of similar magnitude (Walker and Suntzeff 1990).

In the previous three papers of this series we have noted large discrepancies among the different *UBVRI* data sets. These differences, which were found to vary in time, were much larger than the internal errors of the photometry. Given the unusual spectrum of SN 1987A, we suggested in Paper I that these discrepancies are likely due to differences in the natural system (filter plus phototube) used at the different observatories. Since none of the actual response curves of the *UBVRI* photometric system have been published, it has not been possible to explicitly quantify the effect of the emission lines on the photometry. Menzies (1989) attempted to reconstruct from the color transformations the *VRI* response curves corresponding to the natural systems at CTIO and SAAO. He showed that the differences in *VRI* photometry of SN 1987A obtained at the two observatories could be explained by the small differences in the natural systems.

The light curve of SN 1987A, and indeed all supernovae, is a very important element in understanding the physics of the explosion and, in particular, the bolometric luminosity. It is therefore essential to understand how the evolution of the spectrum affects the observed colors. To this end we present our measurements of the CTIO *VRI* filter/phototube response curves and the convolution of these curves with spectrophotometry of SN 1987A (Phillips *et al.* 1990). We then use these data to explore the source of the differences in the *VRI* photometry between CTIO and SAAO.

*Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

## 2. Comparison Between the CTIO and SAAO Response Curves

In Papers I–III we have presented updated comparisons between the CTIO and SAAO data sets, which are the only published sets that have spanned the first two years of the evolution of this object. For the purpose of this paper we found it most useful to present a comparison of the individual magnitudes obtained at both sites instead of a comparison of the colors as presented in the previous papers. The magnitudes were compared by linearly interpolating the SAAO photometry to the time of the relevant observation at CTIO. In Figure 1 we present the photometric differences, in the sense of CTIO minus SAAO, plotted as a function of time since core collapse at JD = 2446849.82 (Bionta *et al.* 1987; Svoboda 1987). The systematic trends that can be seen for all five colors are much larger than the internal errors of both data sets, typically 0.02 mag for all filters (Paper III). Except for the *I* band, most of the differences between the CTIO and SAAO data sets are 0.1 mag or smaller. The *I* magnitudes, however, differ by up to 0.4 mag at some epochs.

As suggested in Paper I, the strong emission lines in the spectrum of SN 1987A and the differences between the natural systems used at both observatories probably cause these photometric differences. In order to examine this hypothesis we have determined the response of the CTIO system and compared it with the system used at SAAO, as discussed by Menzies (1989).

### 2.1 *CTIO Bandpasses*

All the CTIO observations were obtained using the standard Tololo set of *UBVRI* filters, as described in the second column of Table 1, and a dry-ice-cooled RCA 31034 GaAs photomultiplier (Graham 1982). The quantum efficiency of the tube was measured in the CTIO CCD laboratory in La Serena. The CCD calibration system was adapted to measure the photomultiplier response. The CCD calibration system works as follows. An Oriel monochromator is illuminated by a light from a

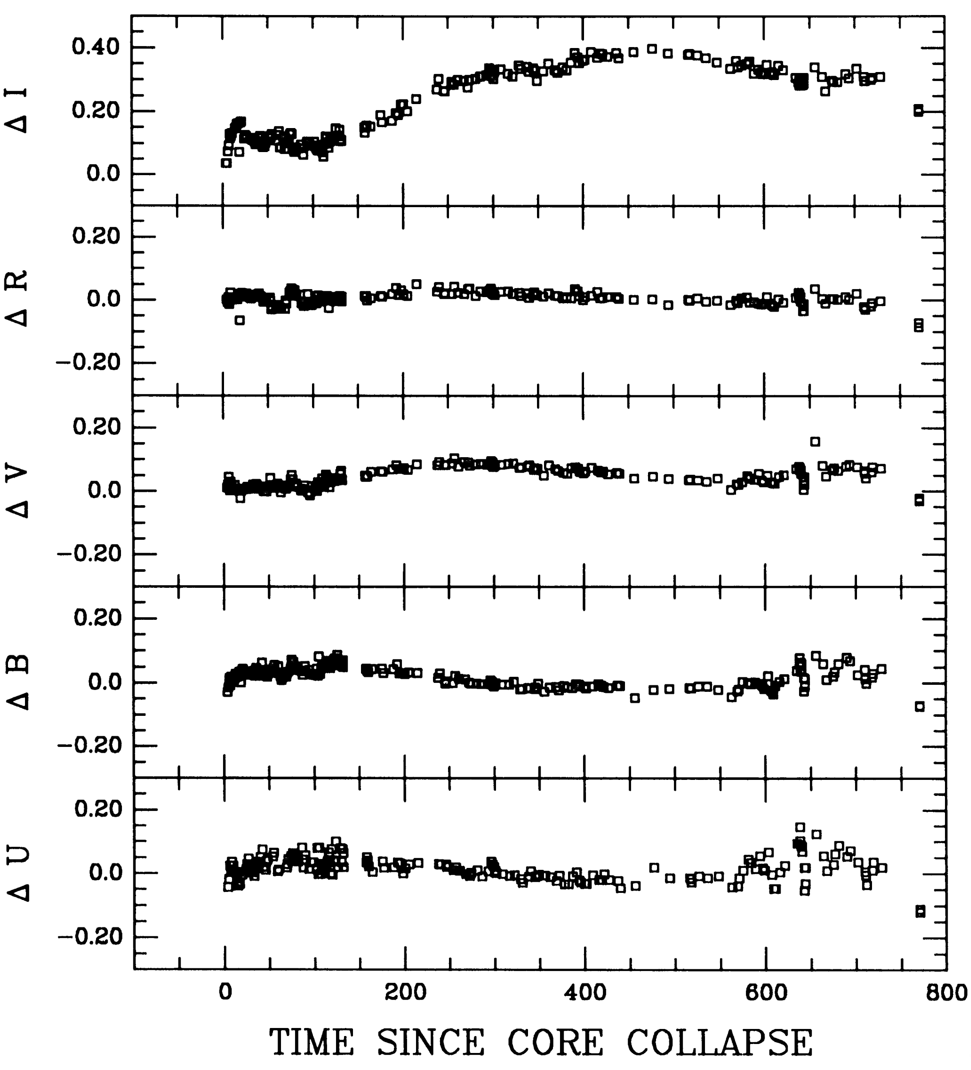


FIG. 1–The differences between the published CTIO and SAAO optical *UBVRI* photometry of SN 1987A, in the sense of CTIO minus SAAO.

TABLE 1

FILTER COMBINATIONS AND PHOTOMULTIPLIERS

| | CTIO | KC | SAAO |
|---|---|---|---|
| Phototube | RCA 31034 | RCA 31034 | Hamamatsu R943-02 |
| Temperature | -78C | -10C | -10/-20C |
| FILTERS: | | | |
| U | C9863 + solid $CuSO_4$(8.8) | - | UG(1) + solid $CuSO_4$(2) |
| B | GG385(2) + BG23(4) + BG12(1.5) | - | BG12(1) + GG385(2) + BG18(1) |
| V | GG495(2) + BG18(2) | Omag302(2) | GG495(2) + BG18(1) |
| R | OG570(2) + KG3(2) | OG570(2) + KG3(2) | OG570(2) + KG3(2) |
| I | RG715(3) + RG780(1) | RGN9(3) | RG9(3) |

Notes:
Numbers in () are thicknesses in mm.
Neutral density filters were added to the SAAO system.

quartz halogen source. The amount of dispersed light produced is limited by an adjustable slit, here set to 2 Å. An optical fiber conducts the monochromatic light to a beamsplitter. Approximately half of the incident light is reflected toward the photomultiplier and the rest is transmitted to a diode with known quantum efficiency. After measuring the response of both detectors at the given wavelength, we switch the positions of the photomultiplier and the diode and the responses are measured again. This technique removes all instrumental effects and, given the known quantum efficiency of the diode, the quantum efficiency of the photomultiplier is determined. The grating was tilted to produce monochromatic light every 100 Å in the blue and 50 Å in the red. The finer sampling in the red was needed to properly measure the red cutoff of the sensitivity of the photomultiplier. Given the poor transmission of the optical fiber in the blue, it was not possible to measure the quantum efficiency shortward of 4500 Å.

There was one small complication in this setup. The optics of the CCD calibration system produce an image of the light source at the position of the detectors which is a circle of light 10 mm wide. While the diode detects only a small fraction of this circular image, all the image is projected onto the sensitive area of the photomultiplier. We did not attempt to measure the ratio of images intercepted by the diode and photomultiplier. Hence, we were not able to measure absolute quantum efficiency. In Table 2 we present the relative quantum efficiency (RQE) of the phototube, arbitrarily normalized to 1 at 4600 Å.

In Table 2 we also present the transmission curves for our *UBVRI* filters. These curves were measured at the Tololo optics laboratory and are the absolute transmission of the filters. The transmission curves were measured every 5 Å, but only the values at the wavelengths where the tube response was measured are given in Table 2. In Figure 2 we present the RQE curve for our photomultiplier along with the filter transmission curves. The convolution of the *VRI* filter transmissions and tube RQE are shown in Figure 3. The response curves in Figure 3 have been normalized to 1 at maximum intensity. Given the extended response of the GaAs cathode, the photomultiplier RQE has almost no effect on the *V* and *R* transmission curves. The red cutoff of the *I* band, however, is entirely due to the RQE of the tube.

## 2.2 *The Kron-Cousins System*

The standard *VRI* Kron-Cousins system (hereafter KC) as created by Cousins (1973, 1980) is defined by the combination of the glass filters, summarized in the third column of Table 1, and a GaAs RCA 31034 photomultiplier operated at a temperature of −10° C. The empirical *v*, *r′*, *i* filter transmission curves were published by Cousins (1980). The response of the specific photomultiplier was not measured by Cousins, but in his 1980 work he convolved an average sensitivity curve of the RCA 31034 tube with the filter curves. Since the sensitivity, $S_\lambda$, and the quantum efficiency, $Q_\lambda$, are related as

$$Q_\lambda \propto S_\lambda/\lambda \ ,$$

the sensitivity curves given by Cousins were divided by λ and normalized to 1 at the peak response for comparison with the CTIO curves. The resulting response curves are shown in Figure 3. It can be seen that, except for small horizontal shifts, the CTIO *V* and *R* bandpasses differ little from the Kron-Cousins bands. The *I* bandpasses, however, are clearly quite different in their shape. The red cutoff is 320 Å bluer for the CTIO *I* filter, while the blue cutoff is 230 Å redward of the KC standard response.

Cole and Ryer (1972) showed that the sharp drop in sensitivity of the RCA 31034 at long wavelengths shifts considerably to the blue when the temperature is low-

TABLE 2

PHOTOMULTIPLIER RESPONSE AND FILTER TRANSMISSIONS
(percentages)

| λ | TUBE RELATIVE | FILTER TRANSMISSIONS | | | | λ | TUBE RELATIVE | | FILTER TRANSMISSIONS | |
|---|---|---|---|---|---|---|---|---|---|---|
| Å | Q.E. | U | B | V | R | Å | Q.E. | V | R | I |
| 2800 | - | 8.2 | | | | 6300 | 81.4 | 6.1 | 75.9 | |
| 2900 | - | 43.8 | | | | 6400 | 80.6 | 2.8 | 72.5 | |
| 3000 | - | 69.3 | | | | 6500 | 79.4 | 1.0 | 70.3 | |
| 3100 | - | 79.7 | | | | 6600 | 78.5 | 65.2 | | |
| 3200 | - | 81.8 | | | | 6700 | 77.8 | 62.1 | | |
| 3300 | - | 81.6 | | | | 6800 | 76.1 | 57.7 | | |
| 3400 | - | 81.5 | | | | 6900 | 74.5 | 54.7 | | |
| 3500 | - | 80.5 | | | | 7000 | 73.3 | 49.4 | | 0.9 |
| 3600 | - | 78.9 | 0.2 | | | 7100 | 71.8 | 45.0 | | 4.1 |
| 3700 | - | 72.0 | 5.6 | | | 7200 | 70.3 | 41.6 | | 10.0 |
| 3800 | - | 65.1 | 18.0 | | | 7300 | 70.0 | 37.2 | | 17.8 |
| 3900 | - | 43.8 | 31.5 | | | 7400 | 68.6 | 33.0 | | 28.5 |
| 4000 | - | 17.1 | 42.1 | | | 7500 | 67.6 | 29.0 | | 42.3 |
| 4100 | - | 4.2 | 48.8 | | | 7600 | 66.7 | 24.4 | | 56.9 |
| 4200 | - | 0.9 | 53.1 | | | 7700 | 65.8 | 21.2 | | 71.0 |
| 4300 | - | 0.2 | 54.9 | | | 7800 | 64.7 | 18.1 | | 81.1 |
| 4400 | - | 0.1 | 54.8 | | | 7900 | 63.5 | 15.7 | | 87.1 |
| 4500 | 99.7 | 0.1 | 52.4 | | | 8000 | 63.5 | 12.9 | | 90.1 |
| 4600 | 99.9 | | 48.2 | | | 8100 | 62.2 | 10.3 | | 89.5 |
| 4700 | 98.4 | | 38.6 | 0.3 | | 8200 | 60.0 | 8.8 | | 92.5 |
| 4800 | 96.7 | | 25.3 | 0.5 | | 8300 | 57.4 | 6.7 | | 92.9 |
| 4900 | 93.9 | | 13.0 | 2.3 | | 8400 | 50.8 | 5.7 | | 93.6 |
| 5000 | 93.6 | | 6.2 | 22.6 | | 8500 | 38.5 | 4.6 | | 93.1 |
| 5100 | 93.7 | | 2.3 | 56.2 | | 8550 | 29.6 | 4.3 | | 93.7 |
| 5200 | 92.3 | | 0.7 | 71.5 | | 8600 | 20.5 | 3.8 | | 92.9 |
| 5300 | 90.3 | | 0.2 | 75.2 | | 8650 | 13.1 | 3.5 | | 93.3 |
| 5400 | 89.9 | | | 74.1 | | 8700 | 6.2 | 3.1 | | 93.5 |
| 5500 | 89.4 | | | 69.8 | 0.0 | 8750 | 3.1 | 2.3 | | 93.7 |
| 5600 | 88.7 | | | 63.2 | 4.7 | 8800 | 1.4 | 1.9 | | 93.8 |
| 5700 | 87.6 | | | 54.0 | 40.0 | 8850 | 0.7 | 1.5 | | 93.9 |
| 5800 | 86.9 | | | 44.2 | 69.6 | 8900 | 0.4 | 1.3 | | 94.1 |
| 5900 | 85.6 | | | 34.3 | 79.1 | 8950 | 0.3 | 1.2 | | 94.1 |
| 6000 | 84.8 | | | 23.6 | 80.0 | 9000 | 0.2 | 1.1 | | 94.1 |
| 6100 | 89.9 | | | 15.4 | 77.0 | 9050 | 0.2 | - | | - |
| 6200 | 82.7 | | | 9.6 | 78.1 | 9100 | 0.1 | - | | - |

ered. They find that this shift amounts to more than 100 Å when the temperature is lowered from −10° C to −78° C. This effect partly accounts for the much bluer red cutoff of the CTIO *I* response curve compared to that of the KC response. Because the response of the GaAs tube operated at the dry-ice temperature cannot be extended farther to the red, in order to make an *I* filter with a minimal color term when used with a GaAs tube, Graham (1982) tried different combinations of glass filters in order to match best the KC *I* effective wavelength. As can be seen in Figure 3, the resulting filter is a good match in effective wavelength to the KC *I* filter, but is much narrower.

2.3 *SAAO Bandpasses*

The filter recipes used at SAAO (Catchpole, private communication; Menzies 1989) are given in the last column of Table 1. The SAAO observations were obtained with a Hamamatsu R943-02 GaAs tube operated at a temperature between −10° C and −20° C. Neither the filter transmissions nor the tube response have been published for the specific instrumentation used at SAAO. Menzies (1989) discusses the probable filter/tube responses for the filter/photometer used to observe SN 1987A.

As discussed by Menzies (1989) the SAAO and KC natural systems are very similar. The major difference between the two systems arises from the use of the Hamamatsu tube at SAAO, whose falloff in response toward red wavelengths is not as steep as the RCA tube employed by Cousins. In addition, the SAAO setup used neutral density filters to decrease the count rate from SN 1987A in order to protect the detector. The small effects on the filter/tube response due to the nongrayness of these neutral-density filters are not known.

### 3. Synthetic Photometry

In Figure 4 we present CCD spectrophotometry of SN 1987A obtained at CTIO on day 198 along with the CTIO and KC *VRI* bandpasses. We have marked the most prominent emission lines that will be shown to affect the synthetic photometry. These are: Na I D λ5893 in the *V* band; [O I] λλ6300,6364 and Hα λ6563 in the *R* band; the [Ca II] λλ7291,7323 lines in the *R* and *I* bands; and the Ca II triplet near 8600 Å near the red edge of the *I* band. All these features have been present in the spectrum of the supernova during most of its evolution.

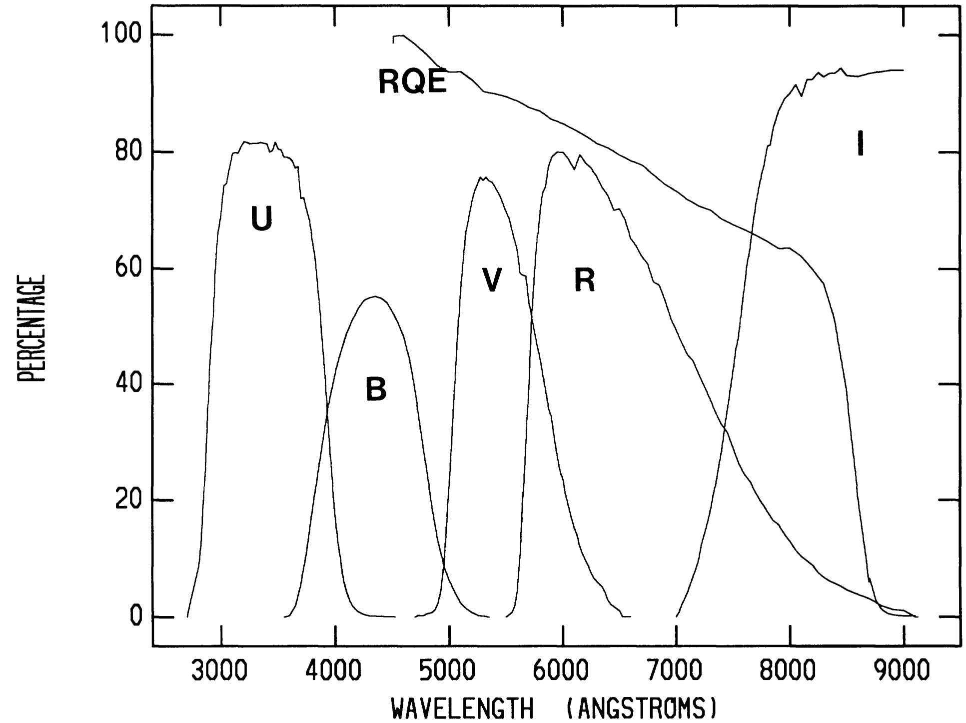


FIG. 2–Transmission curves of the CTIO *UBVRI* filters given in Tables 1 and 2 and relative quantum efficiency (RQE) of the RCA 31034 GaAs photomultiplier used at CTIO for the observations of SN 1987A. The quantum efficiency of the tube was arbitrarily normalized to 1 at 4600 Å.

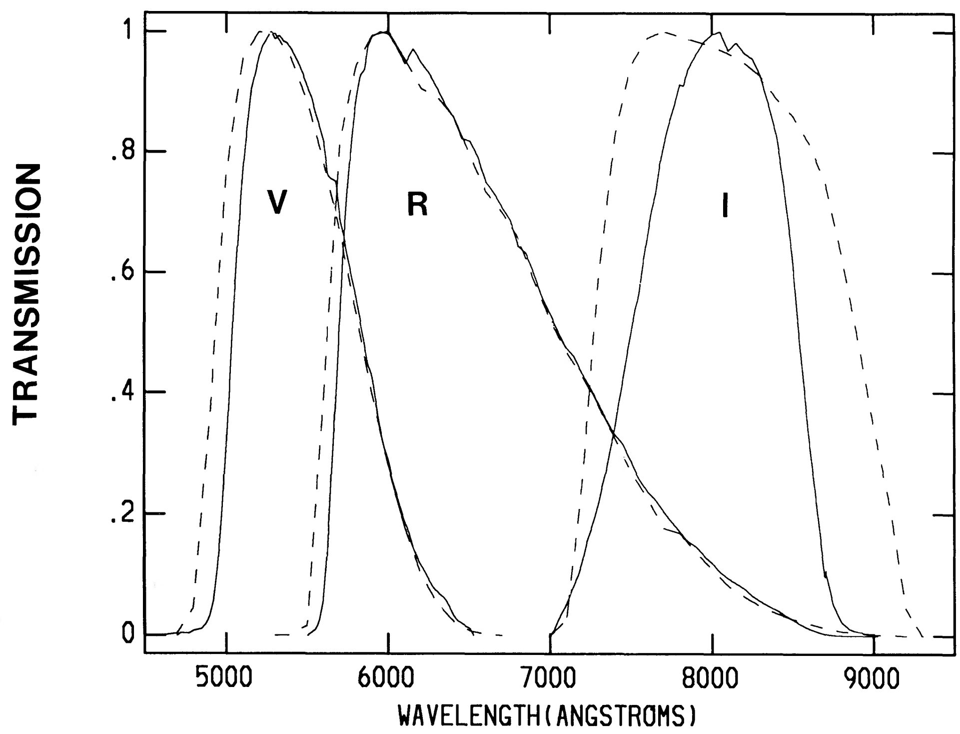


FIG. 3–Combined filter/tube response curves for the CTIO system (solid lines) overplotted with the KC response curves (dashed lines). The response curves have been normalized to 1 at maximum response for comparison.

CTIO observers have produced an atlas of digital spectrophotometry of SN 1987A (Phillips *et al.* 1988, 1990). This atlas contains over 200 spectra covering the time from day 2 after outburst through day 805. Most of the spectra were obtained with the two-dimensional photon counter on the 1.0-m telescope and cover the range

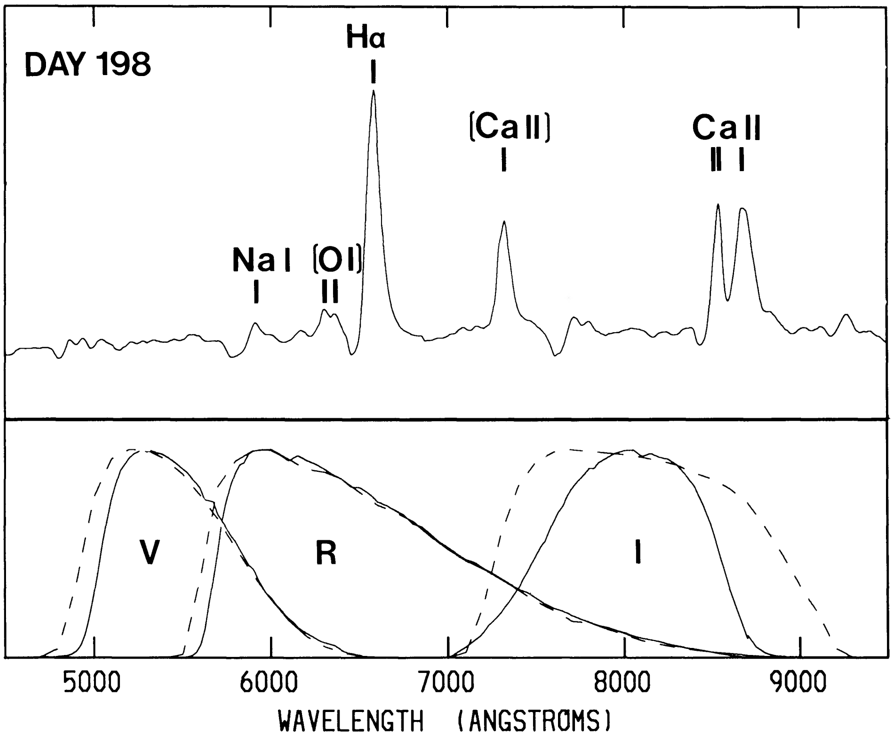


FIG. 4–Upper panel: The spectrophotometry of SN 1987A on day 198 (in units of relative photon flux). Lower panel: *VRI* filter/tube responses of the CTIO (solid lines) and KC systems (dashed lines). The spectrophotometry was obtained at the CTIO 1.5-m Cassegrain spectrograph with a GEC CCD.

3700 Å–7011 Å. A small subset of these data was taken with the 1.5-m and 4-m spectrographs with CCDs and covers the range 3200 Å–11000 Å, with a resolution of 16 Å. We have chosen this higher quality CCD spectrophotometry to simulate the photometry. Spectra obtained after day 589 were not employed due to contamination from stars 2 and 3 (see Phillips *et al.* (1990) for further details). All of the spectrophotometry of SN 1987A was calibrated with respect to the nearby A star δ Doradus. For a given night the flux calibration of SN 1987A was achieved by forcing the spectrum of δ Dor observed right after the supernova to agree with our "master" spectrum of δ Dor. The absolute spectrophotometry of δ Dor has been calibrated with respect to the equatorial grid of secondary spectrophotometric standards (Taylor 1984; Vega is the primary standard). This procedure minimizes many of the typical errors in spectrophotometry such as the assumption of mean monochromatic extinction values, variable extinction, and rapidly varying sky conditions.

The spectrophotometry of SN 1987A and δ Dor was converted from $F_\lambda$ to monochromatic photon flux. Because the photon flux detected by the photometer has been extinguished by the atmosphere, the spectrophotometry was extinguished to the air mass of the observation using the mean atmospheric extinction law given by Stone and Baldwin (1983). We then multiplied the extinguished spectra both by the CTIO and the KC response curves. For example, Figures 5a and 5b show the resulting spectra obtained on day 198 convolved with the CTIO and KC bandpasses. The major difference between CTIO and KC occurs, as expected, in the *I* band.

In Figure 6a we show the contribution of the flux in Na I D to the *V* magnitude. This contribution is nearly 7% for all epochs and the same amount for both photometric systems. In Figure 6b we present the [O I], Hα, and [Ca II] contribution to the *R* band. All these contribute a large and variable percentage to the total flux in *R*. Figure 6c presents the results for the *I* band. It can be seen that the total flux through the KC *I* band is much more affected by [Ca II] and the Ca II triplet than the CTIO system, as previously suggested by Menzies (1989).

We have derived synthetic *VRI* magnitudes of SN 1987A in the CTIO natural system by numerically integrating

$$-2.5 \log_{10} \int N_\lambda Q_\lambda d_\lambda \ ,$$

where $N_\lambda$ is the monochromatic photon flux from the supernova and $Q_\lambda$ is the response of our particular filter/tube combination. We linearly transformed this synthetic instrumental magnitude for the visual bandpass, $v$, and the instrumental colors $(v-r)$ and $(r-i)$ according to the following transformation equations given

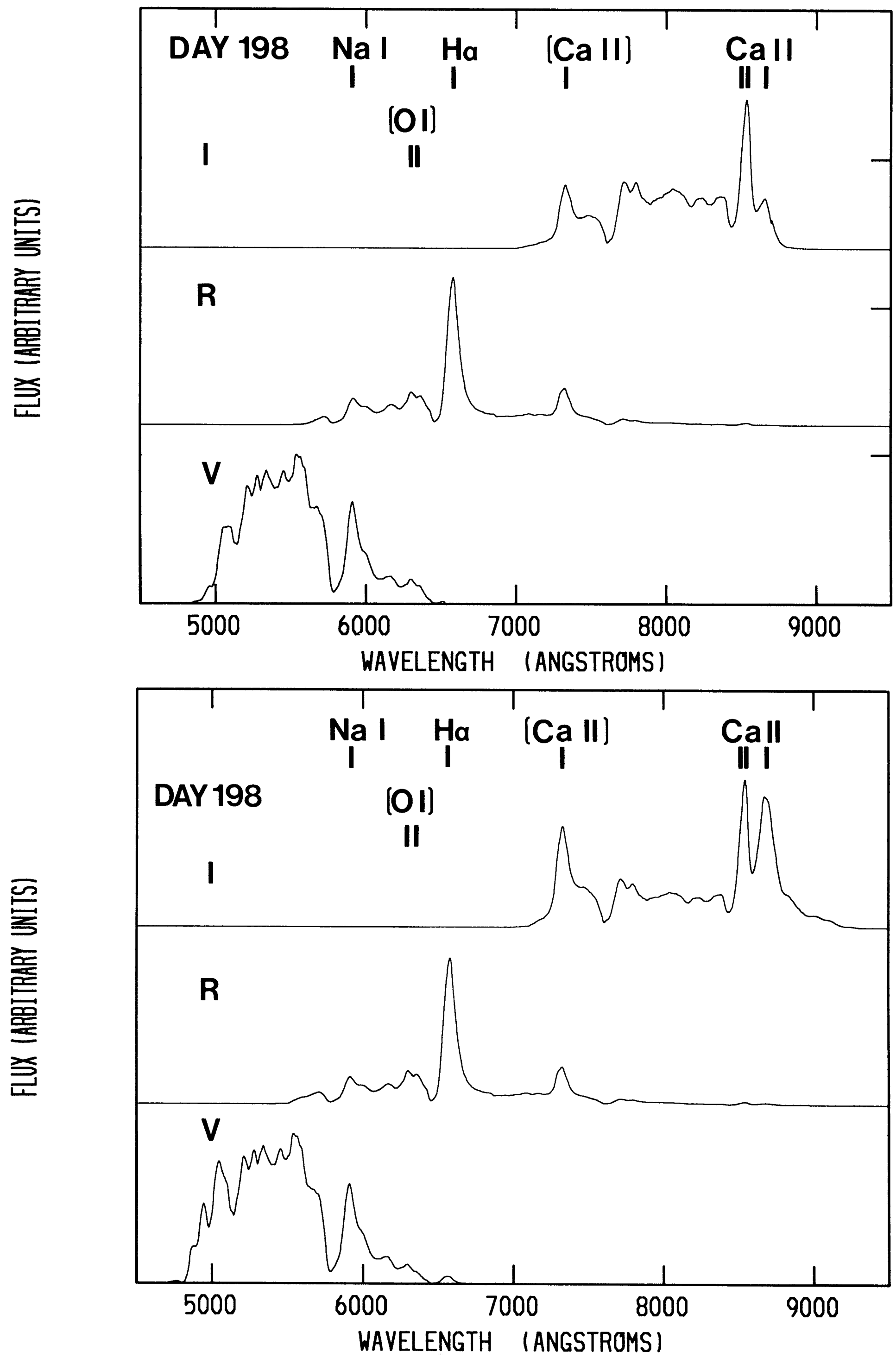


FIG. 5–Convolution of the *VRI* filter/tube responses with the spectrophotometry of SN 1987A on day 198 for CTIO (a) and KC (b). Note the difference in the spectral throughput for the two different *I* bands.

in Paper III, viz.,

$$V = v - 0.013\,(B - V) + \mathrm{ZP}$$

$$(V - R) = 0.971\,(v - r) + \mathrm{ZP}$$

$$(R - I) = 1.011\,(r - i) + \mathrm{ZP}\ .$$

We calculated the zero points (ZP) for each filter by synthesizing magnitudes in the same manner from the spectrum of δ Dor and by using the photometry of δ Dor published in Paper III. In Figure 7a we present the comparison of these synthetic magnitudes with the CTIO

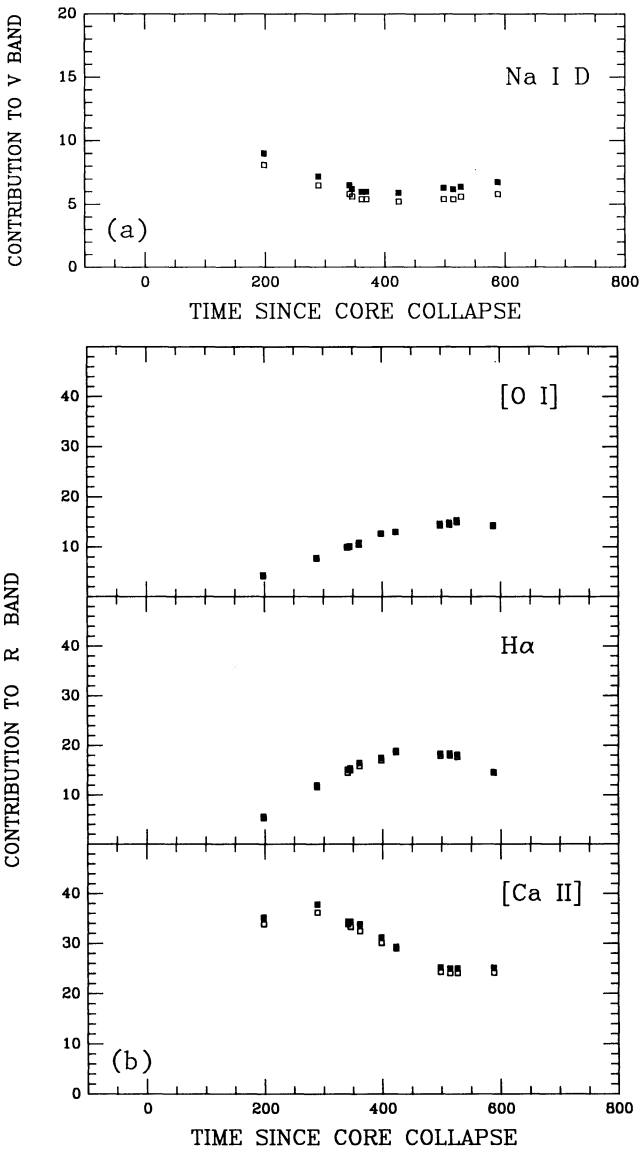


FIG. 6–The ratio of the flux in the most prominent emission lines in the spectrum of SN 1987A to the total flux through the *VRI* bandpasses, plotted as a function of time. The CTIO data are represented by filled squares and the KC data by open squares. Figure 6a presents the contribution of Na I D to the V band. Figure 6b shows the contribution by [O I] (top panel), Hα (central panel), and [Ca II] (lower panel) to the *R* band.

photoelectric photometry, in the sense of photoelectric minus synthetic photometry. The mean differences between the photoelectric and synthetic photometry, together with the standard deviations of the mean, are the following:

$$\Delta V = +0.015 \pm 0.023$$

$$\Delta R = +0.049 \pm 0.024$$

$$\Delta I = -0.016 \pm 0.017 \ .$$

The systematic differences between the synthetic photometry and the observed photometry are 0.05 or less, and the relative photometry is good to 0.02 mag.

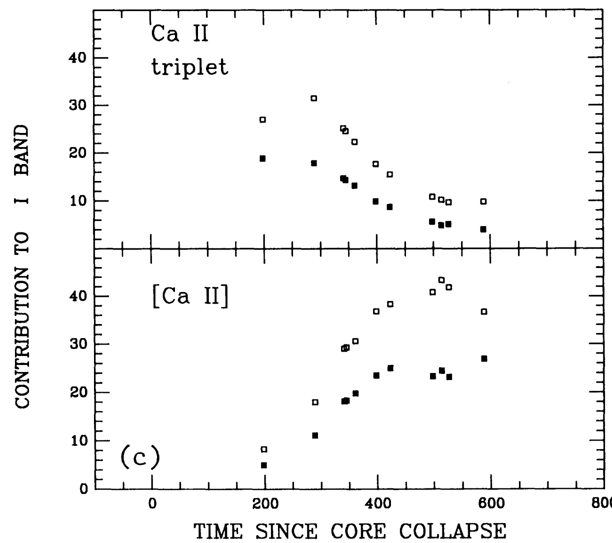


FIG. 6c–shows the contribution by the Ca II triplet (top panel) and by [Ca II] (lower panel) to the *I* band in both systems.

We carried out the same exercise with the KC bandpasses. We transformed the instrumental visual magnitude, $v$, and the $(v-i)$ and $(r-i)$ color indices according to the following equations,

$$V = v - 0.026\,(v-i) + \mathrm{ZP}$$

$$(V-I) = 0.973\,(v-i) + \mathrm{ZP}$$

$$(R-I) = 1.000\,(r-i) + \mathrm{ZP} \ ,$$

given by Cousins (1980). Figure 7b shows the comparison of the KC synthetic magnitudes with the SAAO photometry, in the sense of SAAO minus synthetic. The mean differences between the photoelectric and synthetic photometry along with the standard deviations of the mean are the following:

$$\Delta V = -0.043 \pm 0.021$$

$$\Delta R = +0.011 \pm 0.030$$

$$\Delta I = -0.038 \pm 0.039 \ .$$

The results show that the synthetic photometry agrees with the published SAAO photoelectric photometry to a few hundredths of a magnitude, thereby confirming that the natural system of the SAAO photometry is very similar to that of KC.

Table 3 summarizes the synthetic *VRI* photometry obtained from the CTIO spectrophotometry as a function of time since core collapse, both in the CTIO and KC natural photometric systems.

## 4. Conclusions

We have measured the phototube response and the

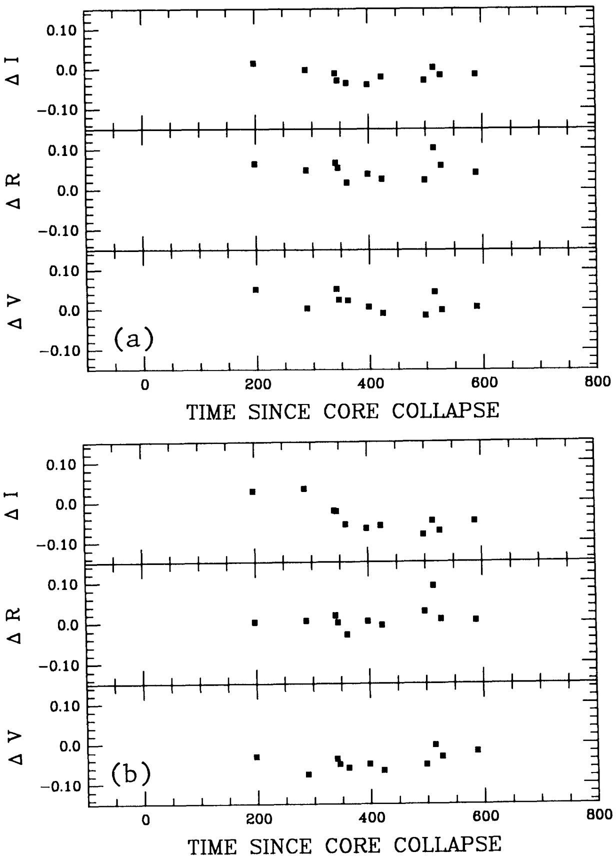


FIG. 7–The differences between the optical photoelectric photometry of SN 1987A and the synthetic photometry in the sense of photoelectric minus synthetic. Figure 7a presents the CTIO photometry compared with the CTIO synthetic magnitudes and Figure 7b the SAAO photometry compared with the KC synthetic magnitudes. Note that in both cases the synthetic photometry is essentially identical to the observed photoelectric photometry.

filter transmission curves for the *UBVRI* filter set used for the photoelectric observations of SN 1987A from CTIO. The photoelectric *VRI* photometry can be reproduced to 0.05 magnitude by the simple convolution of the filter/phototube response with spectrophotometry of SN 1987A obtained with a CCD at the Cassegrain spectrographs of the CTIO 1.5-m and 4-m telescopes. This is much smaller than the systematic trends between the CTIO photoelectric photometry and other published photometry. In particular, there are no systematic differences between the CTIO *I* photometry and the synthetic *I* photometry, whereas there are differences of up to 0.4 magnitude between the photoelectric *I* photometry obtained at other observatories.

We have verified our suggestion, presented in Paper I, that the extremely nonstellar spectrum of SN 1987A, along with small differences in the natural system filter/phototube response among the different observatory photometers, accounts for the differences in the

TABLE 3

SYNTHETIC MAGNITUDES IN THE CTIO AND KC PHOTOMETRIC SYSTEMS

| TIME | V CTIO | R CTIO | I CTIO | V KC | R KC | I KC |
|---|---|---|---|---|---|---|
| 198 | 5.084 | 3.968 | 3.681 | 5.088 | 3.993 | 3.437 |
| 289 | 6.016 | 4.766 | 4.563 | 6.015 | 4.789 | 4.221 |
| 341 | 6.458 | 5.271 | 5.188 | 6.457 | 5.293 | 4.851 |
| 345 | 6.514 | 5.326 | 5.247 | 6.513 | 5.348 | 4.905 |
| 361 | 6.675 | 5.535 | 5.463 | 6.669 | 5.559 | 5.126 |
| 398 | 7.036 | 5.928 | 5.964 | 7.035 | 5.952 | 5.624 |
| 423 | 7.309 | 6.244 | 6.276 | 7.306 | 6.269 | 5.941 |
| 498 | 8.154 | 7.257 | 7.374 | 8.154 | 7.279 | 7.050 |
| 514 | 8.336 | 7.457 | 7.620 | 8.335 | 7.480 | 7.248 |
| 527 | 8.571 | 7.727 | 7.868 | 8.569 | 7.751 | 7.542 |
| 588 | 9.756 | 9.066 | 9.168 | 9.740 | 9.090 | 8.870 |

published photometry for SN 1987A. Such large and systematic differences in photometry are inherent to the nature of the technique, and the comparison of the photometry of supernovae (such as is done in distance scale work), obtained with different natural systems at different observatories, can be in error by many tenths of magnitudes, when the spectra are dominated by emission lines or otherwise are quite nonstellar.

We would like to thank Ricardo González for measuring the *UBVRI* transmission curves. We would also like to thank R. Catchpole for his communication on the specifics of the SAAO photometer setup. M.H. acknowledges partial support from Fondo Nacional de Ciencias y Tecnología (FONDECYT) under grant 727/1990.

REFERENCES

Bionta, R. M., *et al.* 1987, *Phys. Rev. Lett.*, **58**, 1494.
Burki, G., Cramer, N., Burnet, M., Rufener, F., Pernier, B., and Richard, C. 1989, *Astr. Ap.*, **213**, L26.
Catchpole, R. M., *et al.* 1987, *M.N.R.A.S.*, **229**, 15p.
———. 1988, *M.N.R.A.S.*, **231**, 75p.
———. 1989, *M.N.R.A.S.*, **237**, 55p.
Cole, M., and Ryer, D. 1972, *Electro-Optical Systems Design*, June 1972, 16.
Cousins, A. W. J. 1973, *Mem. R.A.S.*, **7**, 223.
———. 1980, *S. Afr. Astron. Obs., Circ.*, **1**, 234.
Cristiani, S., *et al.* 1987, *Astr. Ap.*, **177**, L5.
Dopita, M. A., *et al.* 1988, *A.J.*, **95**, 1717.
Graham, J. A. 1982, *Pub. A.S.P.*, **94**, 244.
Hamuy, M., and Suntzeff, N. B. 1990, *A.J.*, **99**, 1146.
Hamuy, M., Suntzeff, N. B., González, R., and Martin, G. 1988, *A.J.*, **95**, 63.
Menzies, J. W. 1989, *M.N.R.A.S.*, **237**, 21p.
Menzies, J. W., *et al.* 1987, *M.N.R.A.S.*, **227**, 39p.
Phillips, M. M., Hamuy, M., Heathcote, S. R., Suntzeff, N. B., and Kirhakos, S. 1990, *A.J.*, **99**, 1133.
Phillips, M. M., Heathcote, S. R., Hamuy, M., and Navarrete, M. 1988, *A.J.*, **95**, 1087.
Shelton, I., Duhalde, O., and Jones, A. 1987, *IAU Circ.*, No. 4316.
Shelton, I. K. 1989, M.S. thesis, University of Toronto.
Stone, R. P. S., and Baldwin, J. A. 1983, *M.N.R.A.S.*, **204**, 347.
Suntzeff, N. B., Hamuy, M., Martin, G., Gómez, A., and González, R.

1988, *A.J.*, **96**, 1864.
Svoboda, R. 1987, *IAU Circ.*, No. 4340.
Taylor, B. J. 1984, *Ap. J. Suppl.*, **54**, 259.
Walker, A. R., and Suntzeff, N. B. 1990, *Pub. A.S.P.*, **102**, 131.
Whitelock, P. A., *et al.* 1988, *M.N.R.A.S.*, **234**, 5p.
———. 1989, *M.N.R.A.S.*, **240**, 7p.