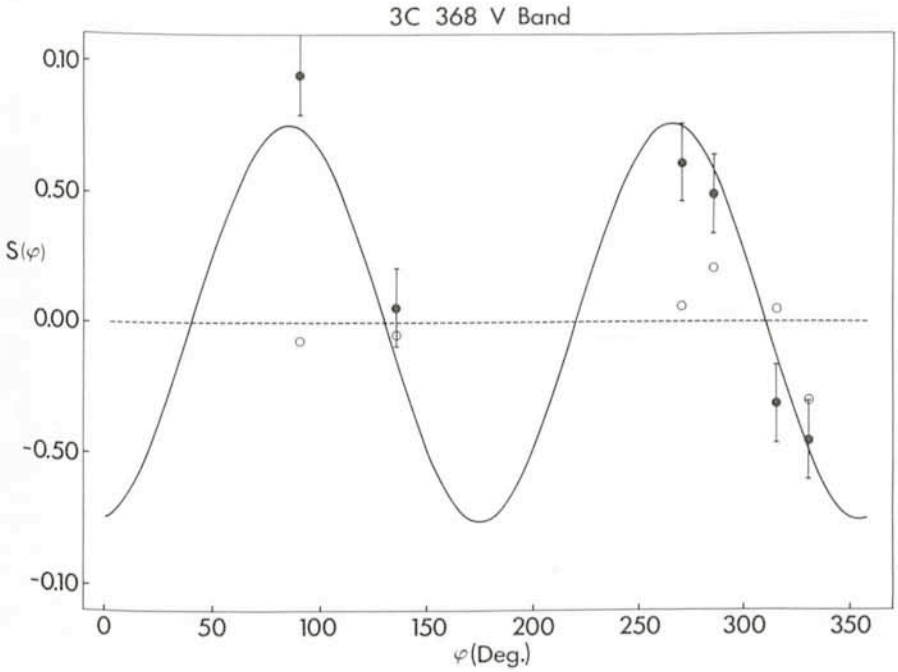

Figure 5: *The measurements (•) of S(φ), the component of the normalized Stoke parameters for linear polarization, for the V images of 3C368 and the fitted cosine curve. Also shown (o) is the average S(φ) for faint stars in the same frames.*

out to be unpolarized as shown in the table.

Finally, there is a statistical bias in the measurement of polarizations close to zero simply because, being the length of a vector, it is a positive definite quantity. This can be corrected using a standard technique (Wardle and Kronberg 1974) and the results are shown as P_{corr} in the table.

The single most important conclusion that can be drawn from these results is that a significant fraction of the light that we see in the optical band cannot be coming directly from stars and this means that the colours cannot be interpreted simply in terms of stellar populations. This has profound and unfortunate consequences for the method of using distant radio galaxies as tracers of normal galaxy evolution. On the positive side, however, it does – if interpreted as light scattering of beams of radiation emanating from active nuclei – lend considerable support to the ideas which are seeking to unify the properties of radio galaxies, quasars and BL Lac objects or Blazars by supposing that their different apparent properties are simply a result of their particular orientation with respect to us, the observer.

In the case of 3C 368, we were able to show that not all of the polarized flux was coming from the nucleus and so the extended structure must also be polarized. 3C277.2 is really too faint to investigate the extension separately using current techniques but clearly a task for the future is to test carefully that the extended structures really are polarized and see if the E-vector is accurately perpendicular to the radius-vector from the nucleus. This is a strong prediction of the scattering model. In addition, the wavelength dependence of the polarized flux can, in principle, distinguish between scattering by electrons and by dust. In 3C368, our two measurements, in V and R, already favour the dust hypothesis in this object although there is no reason why Thomson scattering could not play a role, particularly in massive clusters where there could be a large column density of coronal gas (Syunyaev 1982).

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SN 1987 A: Two Years of Six-colour Photometry with the Danish 0.5-m Telescope

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For several years, a Brazilian-Danish-Spanish group has collaborated on studies of a particular type of variable stars, the so-called eclipsing binaries. Part of the work has consisted of observing the binaries with the Danish 0.5-m telescope in order to obtain accurate light curves in the Strömgren four-colour *uvby* system. In early 1987 we began yet another two-month observing run. Jens Viggo Clausen (Copenhagen) started in late January, one of us

(LPV) took over in mid-February, and BEH arrived on La Silla on February 23, expecting to continue a normal and rather uneventful observing period. On the following day, we added a most abnormal variable, the newborn supernova in the Large Magellanic Cloud, to our observing list!

The observations of SN 1987 A have continued regularly until New Year 1988/89 when the observer, Patricia Lampens from Brussels, together with BEH, who has coordinated the observations, decided that SN 1987A had become so faint that it was time to stop. In the meantime, 20 different observers have, during 27 observing runs, participated in the observations. Coordinating the observations, making everybody use the same comparison stars – and finding out which code names they gave to which comparison star – and maintaining a reasonably constant observing procedure throughout has been a fascinating and sometimes exasperating experience. It has been gratifying, though, to note how willingly every single observer has joined in collecting the data, even though it did mean taking time from their own observing programme.

The immediate task on February 24, 1987, was obvious enough for experienced observers of variable stars, namely to find at least two comparison stars that lie near SN 1987A in the sky, are of approximately the same spectral type, of constant brightness, and of about the same brightness as the supernova. Only, we did not know how bright the supernova would turn out to be and we knew for certain that its spectral type would change drastically during the next weeks and never would appear like that of ordinary stars. We ended up by selecting four comparison stars, two hot ones and two cool ones, and fortunately three of them actually turned out to be of constant brightness.

Deciding which auxiliary equipment to use with the telescope was simple. To the Danish 0.5-m telescope is permanently attached a six-channel photometer designed for observations in the photometric system that the late professor Bengt Strömgren devised: four bands of intermediate width (17–33 nm), situated in the ultraviolet *(u)*, violet *(v)*, blue *(b)*, and yellow *(y)*, plus two bands centred on the blue Balmer line of hydrogen $H\beta$, 3 and 14 nm wide, respectively. We chose to observe through both the *uvby* section and the $H\beta$ section, in the hope that the $H\beta$ observations would give more detailed information on the spectrum near 486 nm than one can get from the intermediate band observations.

A point that worried us while we were waiting to begin the observations on the evening of February 24 was whether the supernova would be too bright to be observed with our telescope without damaging the detectors. As it turned out, SN 1987A obligingly never became too bright for the Danish 0.5-m telescope. Fortunately, three neutral filters are available in the photometer, so when the supernova approached peak magnitude in April 1987, it was sufficient first to attenuate the light through *v* and *b*, and later to insert a filter that reduced the light through all *uvby* bands. The $H\beta$ filters are so narrow that they never presented a problem.

One lesson was hard to learn: the Strömgren system is constructed with the purpose of deriving temperature, surface gravity, absolute magnitude, and chemical composition of stars. In order to obtain useful results, the photometric observations must be very accurate, to better than 0.5%. The light curves for eclipsing binaries, our ordinary observing programme, must be of similar accuracy, and we are usually very concerned about the photometric quality of the night. With the supernova we had to accept that poor observations might be better than no observations at all and with reluctance we took data on nights of abominable photometric quality. March 1987 provided quite a few such nights on La Silla!

Inborn Properties of the *uvby* System

During the data reduction, it became evident that the *uvby* system is devised for precise studies of the physics of ordinary stars and not for obtaining light curves of a supernova. Let us give two examples.

We wanted to present light curves in the six colours. However, normally only the colour difference *b-y* and the double differences m_1 (= $(v-b)-(b-y)$) and c_1 (= $(u-v)-(v-b)$) are used and nowhere in the literature could we find a definition of the zero points for m_1 and c_1. When we asked Professor Strömgren, he confirmed our guess: since there had never been a need for defining the zero points precisely, he had simply added a constant to the original m_1 and c_1 values so that for most stars they would have conveniently small positive values. It was even worse for the $H\beta$ observations. The idea of observing through two bands of different widths, but at the same central wavelength is that the magnitude difference $H\beta$*(narrow)* minus $H\beta$*(wide)* provides the strength of the $H\beta$ line, while the observation is independent of the atmospheric transmission and therefore can become very accurate. Nobody had ever looked separately at the data from each band. We ended up by choosing precise but somewhat arbitrary definitions (Helt et al. 1987).

We also wanted to know how a certain magnitude value could be translated to flux received, expressed in Watts per square metre per Angstrom. In order to do this, one must know how the combined telescope and photometer system transmits and detects light of different wavelengths. Again, such transmission functions were not available because no one had needed them before. Thanks to the cooperation of Ralph Florentin they were calculated in time for the ESO Workshop on SN 1987A in July 1987.

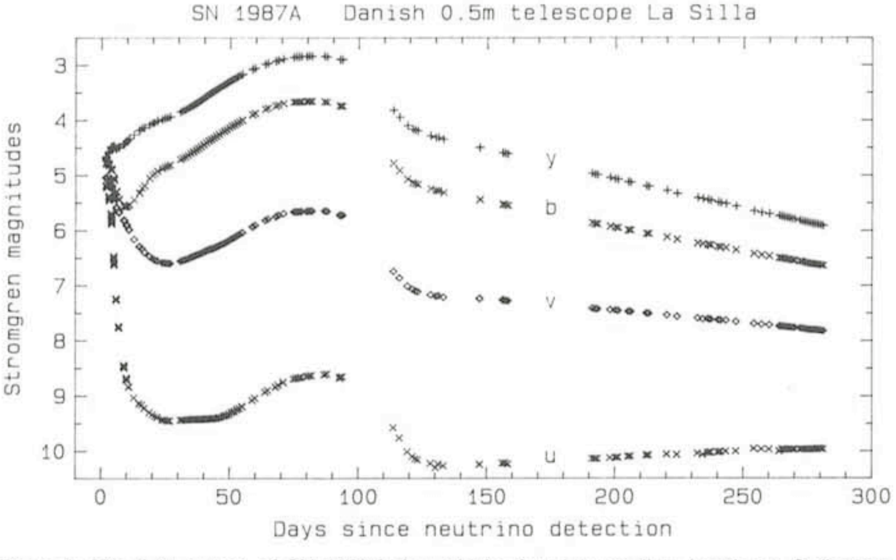

Figure 1: *The light curves of SN 1987A through the four intermediate bandpass Strömgren filters y = yellow, b = blue, v = violet, and u = ultraviolet.*

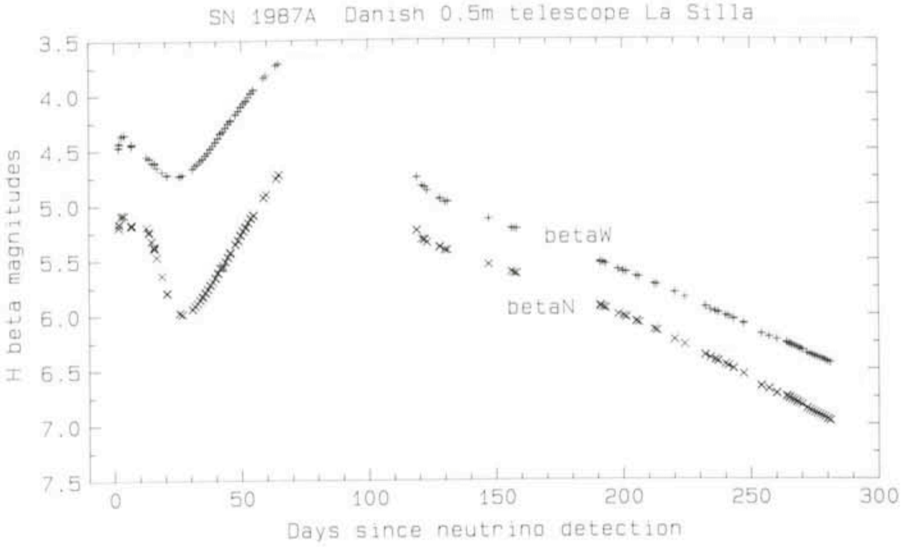

Figure 2: *The light curves of SN 1987A through the two Hβ* filters of bandpass 14 nm (betaW) and 3 nm (betaN).

How to Collect Data from 20 Astronomers Scattered over Europe and South America

Combining observations made by so many astronomers has not always been easy. The Danish 0.5-m telescope is frequently used for long term observing programmes and the observers are normally in no great hurry for reducing their data. The fact that the accompanying figures show light curves only up to December 1987 illustrates this.

Ever since the observations started, it was evident that we should not attempt to transform the observations to the *uvby* standard system. The observations are taken on the instrumental system. Therefore they provide precise information on the light from the supernova through, by now, well known transmission bands. Were we to transform the observations to the standard system, this information would be seriously degraded and we would obtain nothing in return. However, many observers perform transformation to the standard system as a built-in routine in their reduction procedure, and some have found it difficult to calculate values on the instrumental system.

The Light Curves

Figure 1 shows the supernova light curves in *uvby* and Figure 2 the light curves in *Hβ(wide)* and *Hβ(narrow)*. As zero point for time we have taken February 23.316, the time when neutrinos were detected in Japan (Hirata et al. 1987) and in the United States (Bionta et al. 1987) and presumably the time when the supernova collapse took place. All the light curves show the now familiar rise to a broad maximum in May, around day 80–90, followed by the rapid decline and the linear, slow decline corresponding to the phase where the emission of light is powered by radioactive decay of Cobalt 56 to Iron 56.

All transmission bands are so narrow that none of the light curves give a good description of the development of the continuum – with the possible exception of *y* during the first very few days. Instead, they reflect (1) the development of various emission and absorption features with time and (2) the change with time in radial velocity of the atmosphere layers which causes absorption features to move into the bands from the short wavelength side and out of them on the long wavelength side. This was particularly important until around day 20. During that period the radial velocity observed for the absorption features varied from about −17,000 km/s to a level near −5000 km/s. This means that, for instance, the effective wavelength of the *Hβ* bands (486 nm) corresponded to absorption of rest wavelength about 515 nm during the first observations we made and to 495 nm on day 20. So, although we still use the names *Hβ(wide)* and *Hβ(narrow)* and the light curves of course do reflect the changes in *Hβ* emission, they are also strongly influenced by any absorption present with rest wavelengths ranging from 515 nm to 495 nm.

If we compare the six light curves during the first 20–30 days, we see that there is much more structure in the *Hβ (narrow)* light curve than in the other five curves. Clearly, the *uvby* and *Hβ(wide)* transmission bands reflect changes in the continuum as well as the overlying absorption and emission lines, while *Hβ (narrow)* is extremely sensitive to the various features developing and moving through its 3 nm wide transmission band.

For the first three days, both *Hβ (wide)* and *Hβ(narrow)* increase. At this time they measure continuum plus almost pure *Hβ* emission. Then *Hβ (narrow)* decreases at the same time as several absorption features appear in the spectrum on top of the *Hβ* emission peak (see Hanuschik and Dachs 1988, spectra of Feb. 27.0, 28.1). *Hβ(narrow)* increases again near day 11 and finally reaches the broad minimum as late as around day 25. The nearby intermediate transmission band *b* displays the minimum already at day 9.

At the latest time shown by the present light curves we again note the differing behaviour of *Hβ(narrow)* as compared to *Hβ(wide)*. The more rapid decline of *Hβ(narrow)* from day 220 may indicate that at this time *Hβ(narrow)* begins to measure the redward wing of the *Hβ* absorption line (see Catchpole et al. 1988, spectra of October 13, November 3).

We expect the light curves to be useful in several respects: they can serve for comparison with model atmospheres, they can be used for calibration of spectra, and they can, combined with other photometry over a wider wavelength range, help to determine the bolometric magnitudes, i.e., the total flux integrated over all wavelengths.

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