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Light variations of massive stars (α Cyg variables)⋆

XIX. The late-type supergiants R 59, HDE 268822, HDE 269355, HDE 269612 and HDE 270025 in the LMC

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Abstract. We present and discuss *VBLUW* photometry (Walraven system) of five supergiants in the LMC. For one well-known variable, the hypergiant R 59 = HDE 268757 (G7 Ia$^+$) also Hipparcos photometry and numerous visual observations are available. The second variable is HDE 269612 (F0 Ia), and a third one is HDE 268822 (F6 Ia). Two F6 Ia supergiants turned out to be constant: HDE 269355 and HDE 270025.

Key words. stars: supergiants – stars: individual: R 59 (HDE 268757) – stars: individual: HDE 268822 – stars: individual: HDE 269355 – stars: individual: HDE 269612 – stars: individual: HDE 270025

1. Introduction

In this nineteenth paper in the series on the photometric monitoring of massive stars we discuss *VBLUW* photometry (Walraven system) of five late-type supergiants in the LMC. For R 59 = HDE 268757 = HIP 22794 also Hipparcos photometry and numerous visual observations are available.

2. Observations and reductions

2.1. VBLUW photometry

The five objects were observed with the 90-cm Dutch telescope equipped with the simultaneous *VBLUW* photometer of Walraven, at the ESO, La Silla, Chile. The programme stars were alternately measured four to six times with respect to the comparison star HD 33486 (B9, V = 7.9). Integration times per measurement were two minutes. Further particulars on the observing technique can be found in the previous papers of this series (e.g. van Genderen & Hadiyanto 1989).

The effective wavelengths and the band widths of the five channels are given by de Ruyter & Lub (1986). The V and $V - B$ of this system can be transformed to the equivalent parameters V and $(B - V)$ (with subscript J) of the *UBV* system by formulae derived by Pel (1987) and given in e.g. van Genderen & Hadiyanto (1989). The L band ($\lambda_{\rm eff}$ = 3837 Å) contains the higher Balmer lines and Balmer limit, the U band ($\lambda_{\rm eff}$ = 3623 Å) measures the Balmer jump, and the W band ($\lambda_{\rm eff}$ = 3235 Å) lies in the Balmer continuum (see, for example, Fig. 2 in Sterken et al. 1999). The photometric data in the *VBLUW* system are always given in log intensity scale.

Table 1 lists the photometric results for the common comparison star and the five programme stars in the *VBLUW* system and the computed V and $B - V$ of the *UBV* system (with subscript J). Also given are the average standard deviation σ per differential data point (nightly averages), all in log intensity scale. Thus, mean errors are smaller by a factor two to three. The differential brightnesses and colours will be published in a forthcoming paper in the Journal of Astronomical Data (JAD).

2.2. Hipparcos photometry

R 59 was observed by the one channel photometer of the Hipparcos satellite from 1989 through 1993 and presented in the Hipparcos and Tycho Catalogues (ESA 1997). The Hp magnitudes are based on a very broad passband that almost covers the three Johnson passbands, but has an effective wavelength very close to V. Hence, a correction is often required to match the Hp magnitude scale with that of the ground-based data, because of dependence on the colours of the star.

The statistical effects of the use of the Hipparcos photometric data in variability research have been described by van Leeuwen et al. (1997) and in Vol. 3 of ESA (1997).

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⋆ Partly based on observations obtained at the European Southern Observatory at La Silla, Chile.

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Table 1. The average magnitudes V and colour indices $V-B$, $B-U$, $U-W$ and $B-L$ of the comparison star HD 33486 and the five programme stars (in log intensity scale, *VBLUW* system). The average standard deviation σ per differential data point (in units of 0.001 log intensity scale) is given in the adjacent column. The computed *UBV* parameters (with subscript J, in magnitudes) are also listed. N is the number of data points; the aperture used is 16.″5.

Star	Sp.	V	σ	$V-B$	σ	$B-U$	σ	$U-W$	σ	$B-L$	σ	V_J	$(B-V)_J$	N
HD 33486	B9 V	–0.390		–0.010		0.330		0.078		0.112		7.86	–0.04	
R 59	G7 Ia$^+$	–1.32	2	0.745	3	0.680	9	0.430	46	0.580	7	10.12	1.55	79
HDE 268822	F6 Ia	–1.54	3	0.245	3	0.530	6	0.439	26	0.253	4	10.72	0.57	88
HDE 269355	F6 Ia	–1.717	5	0.200	3	0.542	10	0.371	38	0.229	5	11.16	0.47	44
HDE 269612	F0 Ia	–1.82	5	0.120	3	0.375	10	0.230	23	0.120	5	11.42	0.28	44
HDE 270025	F6 Ia	–2.003	5	0.242	4	0.547	13	0.352	44	0.264	7	11.87	0.56	40

2.3. Visual estimates

The visual estimates of R 59 were obtained by one of us (AFJ) from 1989 through 2003 from his home observatory in Nelson, New Zealand (latitude −41°).

3. The light and colour curves

All figures with the *VBLUW* light and colour curves are as a rule in log intensity scale (indicated on the left) and the error bars represent twice the average standard deviation. Computed magnitude scales for the V and $B-V$ of the *UBV* system are indicated on the right. The curves for the Hipparcos data and the visual magnitude estimates are in magnitude scale, they have the purpose to help the eye see the variations clearly. The tick marks labeled with the dates mark the beginning of the year.

3.1. R 59

R 59 is the latest-type hypergiant in the LMC. The youngest spectral and luminosity classification is given by Hagen et al. (1981): G7 Ia$^+$. Other classifications and photometry are quoted by van Genderen (1979b, hereafter called Paper I), who also presents a discussion on *VBLUW* photometry made from 1973 through 1978 and a comparison with its galactic counterpart HR 5171A = V766 Cen (G8 Ia$^+$).

A time series of *BVRI* photometry was made by Grieve & Madore (1986a,b) in the time interval JD 2 443 464 to JD 2 444 585 (1977–1980). Hagen et al. (1981) present spectroscopic evidence for circumstellar material around R 59, as well as for HR 5171A.

Figure 1 shows the *VBLUW* light and colour curves of at least six consecutive cycles between 1982 and 1991. Note that the scales for brightness and colours are different. It should be noted that in the case of such a red star like R 59, the transformation from $V-B$ to $(B-V)_J$ can result in a systematic error up to a few ~0.^{m}01.

There is no unique relation between brightness and colour, although the tendency to be blue in the light maxima and red in the minima occurs often. Since we are dealing with very extended atmospheres, peculiar relationships between light and colour variations are not unusual. All kinds of density and pressure waves in different layers could well have different effects on the resultant radiation (van Genderen & Hadiyanto 1989).

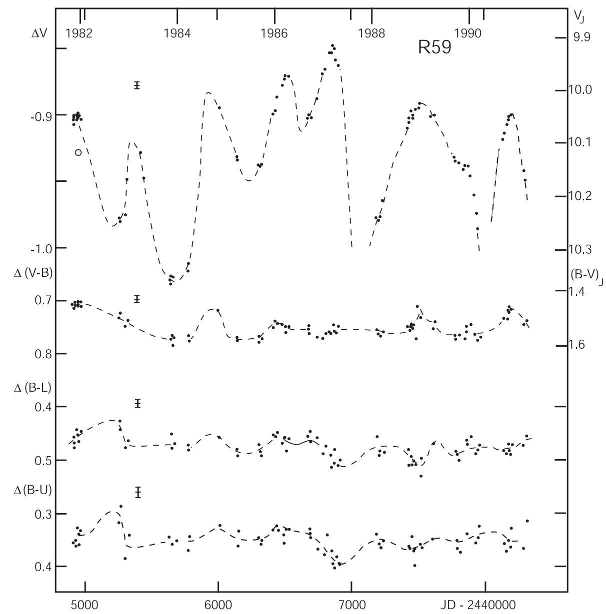

Fig. 1. The light and colour curves of R 59 relative to the comparison star in the *VBLUW* system (to the left, in log intensity scale). To the right: the V and $B-V$ scales of the *UBV* system (in magnitudes). Bright and blue are up.

At some occasions the near-UV (L band: Balmer limit, U band: Balmer jump) varies less than in the B band, with the result that colour indices $B-L$ and $B-U$ are red in the light maxima. The total light amplitude is ~0.^{m}4 and the amplitude for the colours is ~0.^{m}15. In contrast with the conclusion of Paper I, we believe that all variations are due to intrinsic variations of the star.

Figure 2 shows the 60-day binned visual observations for the time interval 1987–1991 as dots. Part of the photoelectric (V_J) light curve of Fig. 1 (three cycles) is represented by the curve. The visual estimates are fainter than the photoelectric (V_J) magnitudes by 0.^{m}45. The error bars of the binned visual estimates represent mean errors. The circles indicate the Hp magnitudes (averaged in twenty-four hours intervals) of the Hipparcos satellite. It appears that the Hp magnitudes are fainter than the V_J magnitudes in accord with the conclusions of Fig. 1.3.4 in ESA Vol. 1 (1997) and of van Leeuwen et al. (1998). In the case of R 59 the difference is 0.^{m}15.

Figure 3 shows the visual estimates for the time interval 1992–2003 with a short run for the Hipparcos data (circles).

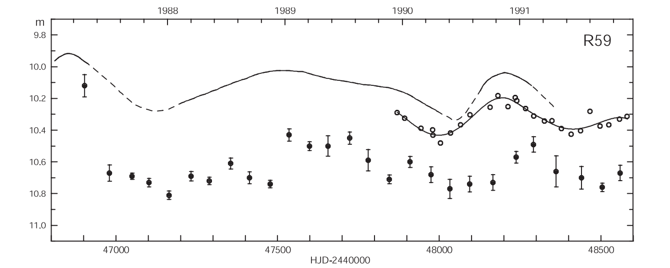

Fig. 2. The 60-day binned visual observations of R 59 between 1987 and 1991 (dots). Part of the photoelectric light curve of Fig. 1 is represented by the upper curve. The Hipparcos observations are represented by circles.

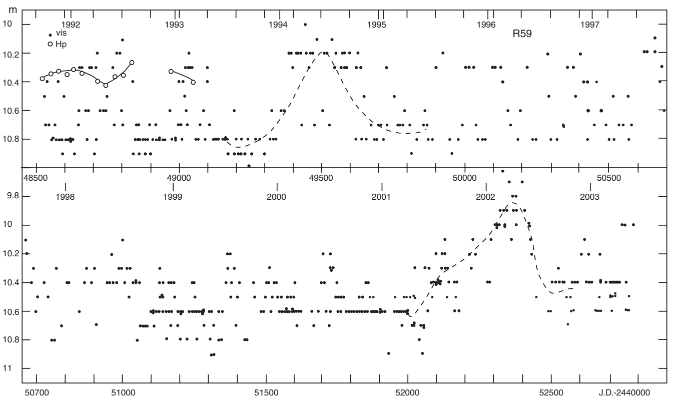

Fig. 3. The visual observations of R 59 between 1992 and 2003. The Hipparcos observations are represented by circles.

Only two prominent cycles can be identified with certainty (dashed curves) thanks to the extreme light amplitudes amounting to $0\overset{\mathrm{m}}{.}6$–$0\overset{\mathrm{m}}{.}8$. The average time scale of the light oscillations derived from the cycles between 1982 and 2003 is ∼1.5 yr, thus, of the same order as for the 1973–1978 interval, viz. ∼1 yr (van Genderen 1979a,b).

3.2. HDE 268822

For HDE 268822 = C 12 = G 505, a variable F6 Ia supergiant, Grieve & Madore (1986a,b) obtained a long run *BVRI* photometry in the time interval JD 2 443 815–JD 2 444 585 (1978−1980) and found a light variation of $0\overset{\mathrm{m}}{.}15$. Small number observations were collected by Ardeberg et al. (1972, *UBV*), Dean et al. (1976, *UBV*) and van Genderen et al. (1982, 1986, *VBLUW*). Individual observations of the last two references will be published together with the longest time series to date (1985–1990, discussed in the present paper), in the Journal of Astronomical Data (JAD).

Figure 4 shows the relative light and colour curves (the $B-U$ and $U-W$ curves are omitted because of the large scatter and the small amplitudes, see below). The total amplitude of the visual brightness is $\sim 0\overset{\mathrm{m}}{.}2$ and the colour $(B-V)_J \sim 0\overset{\mathrm{m}}{.}15$, comparable with those of Grieve & Madore (1986a,b): $\sim 0\overset{\mathrm{m}}{.}15$ and $\sim 0\overset{\mathrm{m}}{.}06$, respectively. These authors also report significant light variations seen over several days, which sounds plausible in view of the steep rising and declining branches. The time scale of the cycles is difficult to determine due to

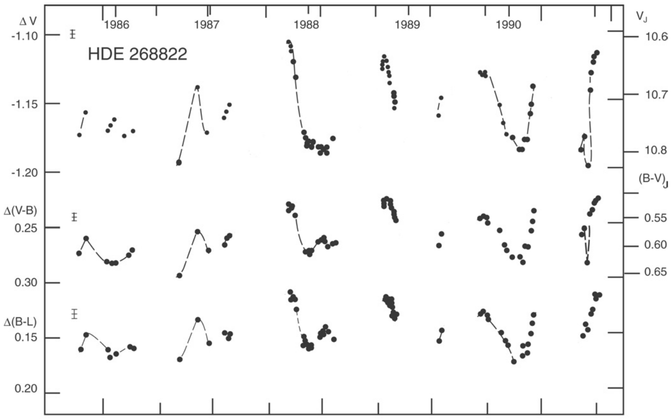

Fig. 4. The light and colour curves of HDE 268822 relative to the comparison star in the *VBLUW* system (to the left, in log intensity scale). To the right: *V* and $B-V$ of the *UBV* system are indicated to the right (in magnitudes). Bright and blue are up. Dotted parts of the light curve: see text.

the gaps in time, but may amount to 180 d, if we speculate that eight cycles are present in the selected time interval JD 2 446 750–JD 2 448 200. The oscillations are variable in duration and amplitude from cycle to cycle. The amplitudes of the colour indices $B-U$ and $U-W$ are very small, which is normal for pulsating stars of that spectral type, like most Population I Cepheids (Pel 1976).

3.3. HDE 269612

HDE 269612 = G 322 is an F0 Ia supergiant which was suspected of variability by van Genderen et al. (1986) and confirmed by van Genderen & Hadiyanto (1989) on the basis of *VBLUW* photometry made in 1986 and 1987. A spectroscopic classification and *UBV* photometry is presented by Ardeberg et al. (1972).

Figure 5 shows the light and colour curves for the time interval 1987–1990. The maximum amplitude of the brightness, including the time series made in 1986–1987, amounts to $0\overset{\mathrm{m}}{.}2$. The behaviour of the colour curves $B-U$ and $U-W$ in Fig. 5 looks similar to those of the 1986–1987 data set: peculiar and with relatively large amplitudes. This can probably be attributed to variations in the Balmer jump (*U* passband) and the Balmer continuum (*W* pass band) by $\sim 0\overset{\mathrm{m}}{.}5$ and $\sim 1\overset{\mathrm{m}}{.}0$, respectively. The time scale of the visual light oscillations is again hard to determine. During the 1986–1987 campaign it was ∼50 d. In Fig. 5 time gaps hamper a proper estimate, but the characteristic time scale could very well be exceed 100 d.

3.4. HDE 269355

HDE 269355 = G 258 is an F6 Ia supergiant which appeared to be constant according to the *BVRI* photometry of Grieve & Madore (1986a,b) who observed the object seven times in the time interval 1978–1980. This is confirmed by our time series made between 1987 and 1990 (present paper). As part of a photometric survey to determine the metal content in the LMC,

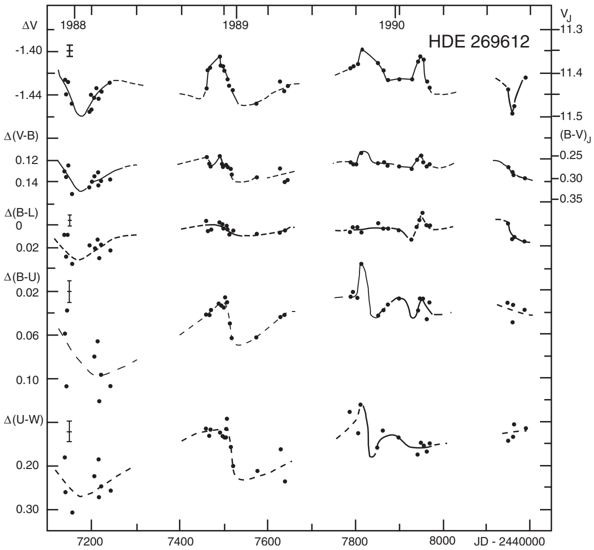

Fig. 5. The light and colour curves of HDE 269612 relative to the comparison star in the *VBLUW* sytem (on the left in log intensity scale). On the right: the V and $B-V$ of the *UBV* system (in magnitudes). Bright and blue are up.

HDE 269355 was observed in the *VBLUW* system a few times in 1982 (van Genderen et al. 1986). All these observations and those made by Ardeberg et al. (1972), made somewhere between 1966 and 1971, suggest a photometric stability over the three decades.

3.5. HDE 270025

HDE 270025 = G 439 is an F6 Ia supergiant which appeared to be constant according to our time series made from 1987 to 1990. Similar to HDE 269355 (Sect. 3.4), this supergiant was observed in 1982 (van Genderen et al. 1986) and somewhere between 1966 and 1971 (Ardeberg et al. 1972). Together with the data set discussed in the present paper, the conclusion is that this object was photometrically stable during three decades.

4. The two-colour diagrams. Discussion

Figure 6 shows the three two-colour diagrams of the *VBLUW* system which are of the same type as the $U-B/B-V$ diagram of the *UBV* system. The thin curved lines represent the main sequence, the arrows represent the reddening line indicated on the left upper corner where the O-type stars reside. For comparison purposes the $(B-V)_J$ scale is also shown. The five objects are plotted uncorrected for foreground reddening as averages (dots), or as a piece of line to indicate the excursion schematically during the instability cycles. The primary identification numbers are indicated in the top panel only.

The total interstellar reddenings are likely small. Based on the charts for the galactic foreground reddenings toward the Magellanic Clouds (Schwering & Israel 1991), the lower limit (see below) of the reddenings $E(B-V)_J$ lies between $0\overset{\rm m}{.}07$ and $0\overset{\rm m}{.}10$, with the exception of R 59, of which it is $0\overset{\rm m}{.}15$. Besides, R 59 is probably also surrounded by circumstellar dust

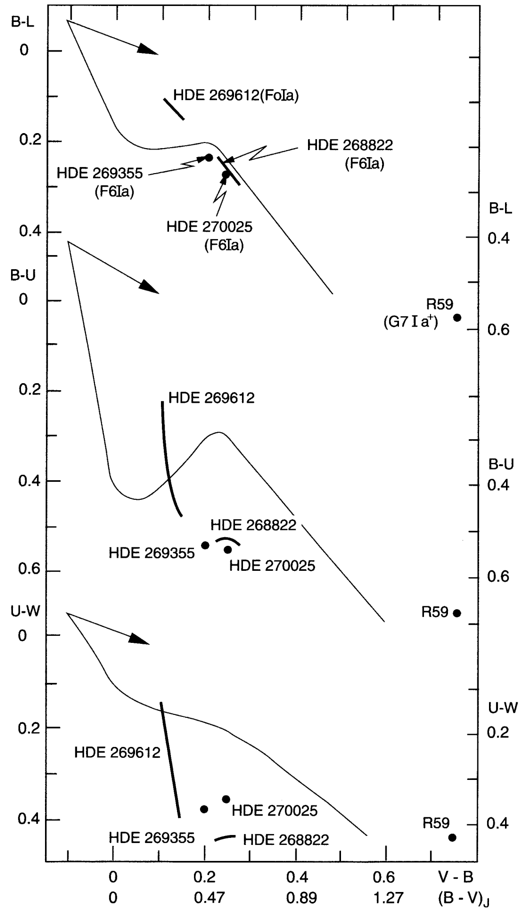

Fig. 6. The mean location, and for two variables the schematic excursions, in the three two-colour diagrams of the *VBLUW* system (in log intensity scale). See below the $V-B$ scale, the corresponding $B-V$ scale of the *UBV* system. The main sequence and the reddening line for O-type stars are represented by the thin curved line and the arrow, respectively.

clouds, considering the IR excess and the 10 μm silicate emission (Hagen et al. 1981), thus, the total foreground reddening is likely $>0\overset{\rm m}{.}15$. It should be emphasized that apart from local fluctuations, smaller than the resolution of 48′, the reddenings obtained with these charts, are only lower limits. The reddenings in the LMC should be added, but are unknown, though likely small as well.

The uncorrected positions of the three F6 Ia supergiants, HDE 269355, HDE 268822and HDE 270025 in the $(V-B/B-L)$ diagram is very close to the intrinsic location for such type of supergiants and Population I Cepheids (Pel 1978), taking metal abundance differences into account. This supports the assertion above about the total foreground reddenings.

The positions of the four F-type supergiants can be plotted in the grid of theoretical colours in the $V-B/B-U$ diagram computed by Lub & Pel (1983) and shown by van Genderen et al. (1986, see Fig. 3 and Table 2). Although, that grid is meant for a solar metallicity, while the metallicity for the LMC is lower, the gravity ($\log g$) can be easily estimated to be ~0.5. The excursion of HDE 268822, outlined by the small curved line, runs parallel to the $\log g$ = constant lines, indicating that during the pulsation the gravity does not change much.

The peculiarity of HDE 269612 in the near-UV is also demonstrated by the abnormal large excursions in $B - U$ and $U - W$, while it is on the average also too blue. It is certainly not a normal pulsating star and it is not excluded that the photometry has been detoriated by a blue field star in the aperture, or alternatively that the star has a blue companion.

R 59, the reddest and most evolved object, is represented by its average colours. Assuming a distance modulus 18.45, a total foreground reddening of $0\overset{m}{.}15$ (a lower limit), a spectral and luminosity type G7 Ia$^+$, $T_{\rm eff}$ ~ 4400 K (de Jager & Nieuwenhuijzen 1987), $M_{\rm bol} < -9.2$ or $\log L/L_\odot > 5.6$.

The average cycle length or quasi-period during the well covered photoelectric time series 1982–1990 (Fig. 1) is ~550 d, while it was ~1 yr for the time series 1973–1978. Whether this really means a significant increase of the pulsation period can only be established in the future. The average colours between these two data sets show a small reddening with time (one decade), but is probably not significant. The galactic counterpart V766 Cen = HR 5171A (G8–K3 Ia$^+$) showed a significant reddening and a drop in brightness within three decades (van Genderen 1992), while the quasi-period remained stable (van Leeuwen et al. 1998).

With respect to the two stable F Ia supergiants, HDE 269355 and HDE 270025, we like to refer to the study of the variability across the HR-diagram as a function of the luminosity (van Genderen 1989). It appeared that the lower the initial mass is ($M/M_\odot < 25$) and the closer the location is to the blue side of the Cepheid strip, the more they are stable. This means that a certain fraction of FG supergiants is stable. The physical parameters $\log L/L_\odot$ and $\log T_{\rm eff}$ of both objects are approximately: 4.94, 3.80 and 4.68, 3.80, respectively. They reside indeed in the area containing other stable FG supergiants. The other two, but variable F-type supergiants, HDE 268822 and HDE 269612 (5.14, 3.80 and 4.82, 3.86, respectively) are situated in the same area.

The cause which makes such an evolved star stable or unstable, likely depends on the evolutionary state e.g. with respect to the number of crossings they have finished.

5. Conclusions

We have investigated the photometric stability of five LMC super- and hypergiants. Three of them were known to be variable: R 59 (G7 Ia$^+$, cycle length about 550 d, HDE 269612 (F0 Ia), cycle length possibly of the order of months and HDE 268822 (F6 Ia), cycle length about 180 d. The two other ones turned out to be stable during the last few decades: HDE 269355 (F6 Ia) and HDE 270025 (F6 Ia).

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References

Ardeberg, A., Brunet, J. P., Maurice, E., & Prevot, L. 1972, A&AS, 6, 249
Dean, J. F., Bywater, R. A., & Warran, P. R. 1976, MNASSA, 35, 123
ESA, The Hipparcos & Tycho Catalogues 1997, ESA SP-1200
van Genderen, A. M. 1979a, A&AS, 38, 249
van Genderen, A. M. 1979b, A&AS, 38, 381
van Genderen, A. M. 1992, A&A, 257, 177
van Genderen, A. M., & Hadiyanto Nitihardjo, G. 1989, A&AS, 79, 401
van Genderen, A. M., van Leeuwen, F., & Brand, J. 1982, A&AS, 47, 591
van Genderen, A. M., van Driel, W., & Greidanus, H. 1986, A&A, 155, 72
Grieve, G. R., & Madore, B. F. 1986a, ApJS, 62, 427
Grieve, G. R., & Madore, B. F. 1986b, ApJS, 62, 451
Hagen, W., Humphreys, R. M., & Stencel, R. E. 1981, PASP, 93, 567
de Jager, C., & Nieuwenhuijzen, H. 1987, A&A, 177, 217
van Leeuwen, F., Evans, D. W., & van Leeuwen-Toczko, M. B. 1997, in Statistical Challenges in Modern Astronomy II, ed. E. Feigelson, & G. J. Babu, 259
van Leeuwen, F., van Genderen, A. M., & Zegelaar, I. 1998, A&AS, 128, 117
Lub, J., & Pel, J. W. 1983, Leiden Observatory, Internal Report
Pel, J. W. 1976, A&AS, 24, 413
Pel, J. W. 1978, A&A, 62, 75
Pel, J. W. 1987, Leiden Observatory, Internal Report
de Ruyter, H. R., & Lub, J. 1986, A&AS, 63, 59
Schwering, P. B. W., & Israel, F. P. 1991, A&A, 246, 231
Sterken, C., Freyhammer, L., Arentoft, T., & van Genderen, A. M. 1999, A&A, 346, L33