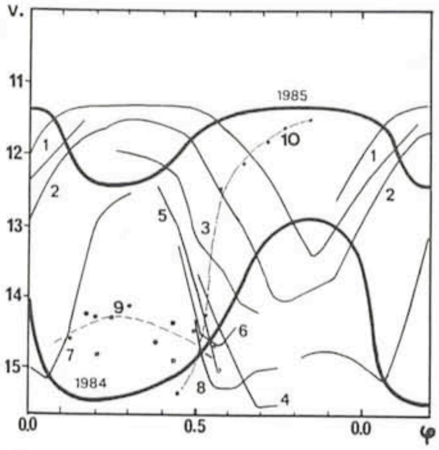

Figure 1: *Evolution of the light curve of NGC 2346 (central star). 1 to 8 are taken from Mendez et al. (1984). 1 = Kohoutek, 1982 Jan. – Feb.; 2 = Gathier, 1982 Mar. – Apr.; 3 = Claria, 1982 Nov.; 4, 5 = Van Driel, 1982 Dec.; 6 = Mendez, 1983 Jan.; 7, 8 = Kohoutek, 1983 Jan.; 9 = Kohoutek and Celnik, 1984 Feb.; 10 = Schaeffer, 1985 Feb. The two thicker lines correspond to our observations: 1984 Sept. – Oct.; 1985 Sept. (taken from* Astron. Astrophys. **160,** *L1–L3 (1986).*

Results

Since 1978 we have observed in particular four cold nuclei of planetary nebulae: FG Sagittae (spectral type K), LoTr5 (G5 star), NGC 2346 (A5 star) and Abell 35 (GB star). Here we report briefly on the two southern objects, NGC 2346 and Abell 35.

NGC 2346

According to Mendez et al. (1982), the central star is an SB1 and its photometric variations (detected in 1981) are due to the passage of a dust cloud in front of the binary system. Infrared observations of Roth et al. (1984) and IUE observations of Feibelman and Aller (1983) have allowed to confirm the dust cloud interpretation.

The optical observations of NGC 2346 during the eclipses, taken all together, were especially informative. The comparison (see Fig. 1) of our photometric observations Sept.–Oct. 1984, Sept. 1985) with the previous one have shown a phase difference, and new properties of the clumpy shell have been suggested (Acker and Jasniewicz, 1985: Jasniewicz and Acker, 1986). In particular the end of the eclipses has been suspected and confirmed in 1986.

Abell 35

Simultaneous spectroscopic and photometric observations of BD 22°3467, the GBIII central star of Abell 35, have been performed at La Silla, in order to elucidate the origin of the light variations and of the Hα emission stellar line shown by Jasniewicz and Acker (1988). Binarity is probably responsible for these variations: this assumption is confirmed by recent IUE observations reported by Grewing and Bianchi (1987).

We have conducted the following observations:

– 43 measurements have been done from February to April 1988 using the P7 differential photometer mounted on the Swiss telescope (mean probable error on the V magnitude 0.008):

– 48 spectra, taken with an exposure time of 25 minutes each, have been collected from 20 to 24 April 1988, using the spectrograph B & C + CCD, mounted on the ESO 1.52-m telescope. The dispersion was 58 Å/mm; all the spectra were centred around the Hα line; the final resolution was 1 pixel = 1.7 Å.

The spectra were reduced using the IHAP procedure. Preliminary results should be given (see Fig. 2).

The faint Hα emission line is double peaked and variable. The spectroscopic variations seem to occur within a range of 20 hours, and thus are in agreement with the photometric period P = 0.765 d. found by us in 1986 and 1987.

The hypothesis related to an accretion disk in a binary system will be tested and discussed after full processing of the data (to appear in *Astron. Astrophys.*).

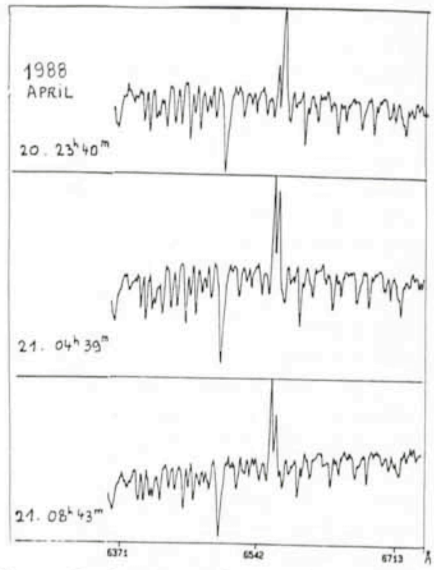

Figure 2: *Spectroscopic variations on the Hα line for the central star of Abell 35 (ESO 1.52-m telescope, B & C + CCD).*

For other cold nuclei, data were collected using the CORAVEL system; but the central stars of planetary nebulae are very faint objects, and the radial velocity variatons we detected in three cases must be confirmed by new series of observations.

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Brey 73: a Multiple Wolf-Rayet Star

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1. Introduction

Detailed observations of several of the most luminous stars in the LMC show that these stars often are multiple systems (Walborn, 1977; Feitzinger et al., 1980; Prevot-Burnichon et al., 1981; Lortet et al., 1986). Most of these stars really are tight clusters where different types of stars are mixed. Moreover, very accurate observations of R 136 by speckle interferometry (Weigelt and Baier, 1985) and of Sk –6641 under very good seeing (Heydari-Malayeri et al., 1988) have revealed eight and six components respectively in a field of about 4 × 4 arcsec^2. The existence of supermassive stars in the LMC is now ruled out, and we must interpret extragalactic young stellar associations very cautiously.

Therefore, being interested in the

population of massive stars in the LMC we are currently carrying out a new spatial high resolution observing programme of all bright Wolf-Rayet stars whose image seems slighty larger than a stellar profile in hitherto published photographs.

Apparently composite objects discovered by spectroscopy as the Wolf-Rayet Brey 18 = HD 269227 = R 84 (Allen and Glass, 1976; Cowley and Hutchings, 1979) will be studied later, when spatial resolution has been improved (less than 1 arcsec) or by speckle interferometry.

A good example of such a large and bright Wolf-Rayet is Brey 73. This star, of integrated magnitude V = 12.2 (Breysacher, 1981) and of type WN 4.5 + OB, is located in the OB association LH 99 (Lucke, 1972) of N 157 B (Henize, 1956) a supernova remnant 7 arcminutes South-West of 30 Doradus. In 1979 Azzopardi and Breysacher reported that this star had a diffuse image and in 1980 Walborn's observations at the RC focus of the CTIO 4-m telescope showed that Brey 73 consisted of two components separated by only 1.5 arcsec. He noticed that the eastern component was slightly brighter, but he did not identify the Wolf-Rayet star. The visual examination of our CCD frames also reveals that Brey 73 is indeed a multiple star.

Even though the seeing was only 1.6 arcsec, thanks to the highly sampled CCD images and using the CAPELLA package for photometry in crowded regions (Debray et al., 1988), developed at the LAS in Marseille, we have been able to resolve and measure no less than eleven components.

2. Observations

The observations were obtained using the UV coated GEC CCD camera attached to the 2.2-m telescope at La Silla in October 1987. The chip has 385 × 576 pixels, each pixel 22 $\mu \times 22\ \mu$, corresponding to 0.26×0.26 arcsec^2 on the sky. The field of Brey 73 (Fig. 1), containing two other Wolf-Rayet (W-R) stars, Brey 71 and Brey 70 a = MGWR 4 (Morgan and Good, 1987), was imaged with a 60 Å continuum filter centred at λ 4794 Å and a narrower one of 50 Å centred on the 4686 Å He II emission line, in order to enhance the He II brightness excess of the W-R. The exposure times were 3 minutes and 2 minutes for the He II and continuum frames respectively. The CCD images were reduced (flat fielding, cleaning, etc. . .) using the MIDAS/VAX image processing system.

3. Reduction

Before applying the CAPELLA programme, we used two reduction programmes in the context of MIDAS:

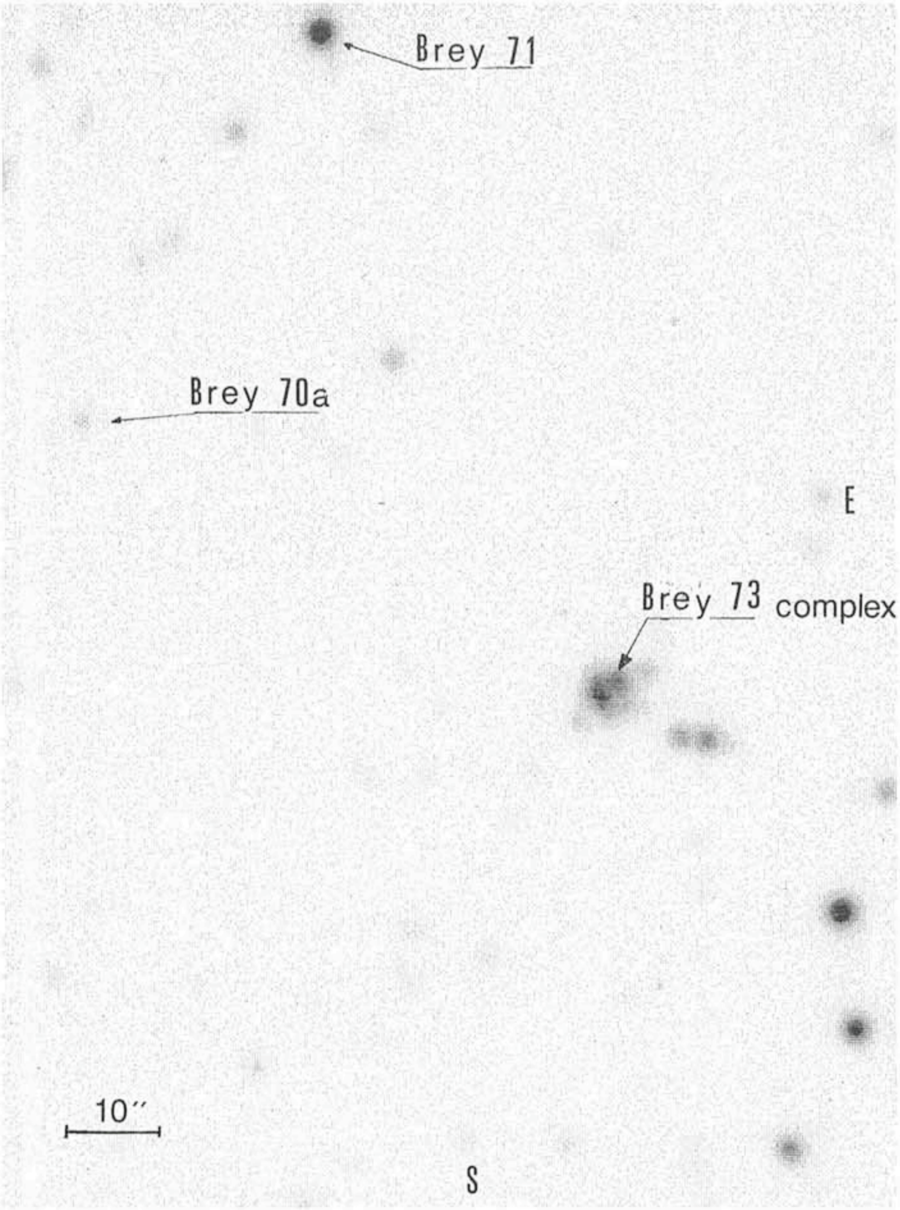

Figure 1: *CCD frame towards Brey 73 through the λ 4686 Å filter.*

– DAOPHOT, a very well adapted programme for crowded fields but non-interactive (Stetson, 1987).

– BIDIM which includes the following steps: Measurement of the slippage between the two frames to a tenth of a pixel, alignment of one image on the other one, determination of standard coefficients, difference after normalization.

In both cases, the W-R was detected in the association (Fig. 2) but could not be accurately located and its photometry could not be carried out either.

The CAPELLA package

The He II and continuum frames have been treated individually and independently following the same operating sequence.

The standard reduction procedure for CCDs (correction of the dark current, of the cold columns, response uniformity, and so on) having been applied for both frames, the image taken in the He II line has then been corrected for local defects (hot pixels, cosmic rays, etc.) with a special "erosion-healing" procedure made by Llebaria (bidimensional package in MIDAS) which restores defective pixel intensities by means of local interpolation from the surrounding area in an extension proportional to the dimensions of the defects.

Stars are then measured using a profile fitting photometry software called CAPELLA (Debray et al., 1988). An experimental point spread function (PSF) is determined from isolated stars which are interactively chosen in the same field. Stars are recentred to a common grid and are averaged together. Pixels intensities which are too far away from the mean value of relevant pixels intensities in the other stellar images are rejected from the computation of the mean. No modeling being used, it is

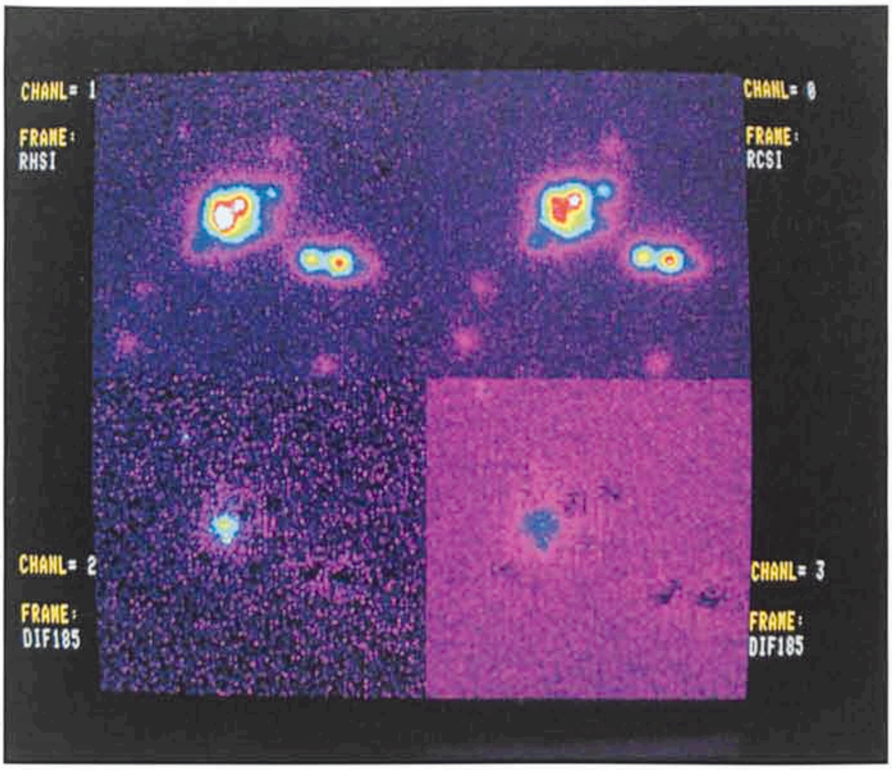

Figure 2 *(Upper left): He II frame of Brey 73 association. (Upper right): Continuum He II frame. (Lower left): Difference after scaling and rebinning using the BIDIM package. The Wolf-Rayet star appears in the middle. (Lower right): Enhancement of residuals due to differences between the two PSF.*

possible to work as in our case with slightly oval, or irregular PSF. Finally, relative fluxes of all stars are measured using linear regression fit with the PSF.

Stars are detected using convolution of the frame with a Laplacian adapted to the PSF FWHM. Detected stars are removed by subtraction of the recentred and scaled PSF. A new detection is performed over the field of residuals and detected objects are added to the previous list.

For each detection, a contamination coefficient quantifies local blending due to nearby stars. This quantity is proportional to cross-correlation of the star with surrounding stars and inversely proportional to the auto-correlation value. As the fitting procedure runs, it is adapted with respect to the coefficient value.

Fairly contaminated stars (typically field stars which are out of the Brey 73 association) are measured using unblended parts of the stellar images for the linear regression fit with the PSF. Two possibilities may occur for very crowded stellar images. If the star is fainter than its immediate neighbours, star measurement is postponed to a next iteration until brighter neighbouring stars have been measured and subtracted. If the star is brighter than its immediate neighbours, they are first evaluated after rough subtraction of the star to be measured, in order to remove them from the wings of the star to be measured using an "up-and-down" procedure. In the case of very blended stars of the Brey 73 association, This "up-and-down" procedure must be iterated at its turn for the correct evaluation of the neighbouring stars.

In the present case, it has been necessary to perform nine successive iterations because of the large overlap of the stellar images in Brey 73 (Fig. 3 and 4). The photometric reduction step required one day of interactively assisted work for each image on a VAX 780, with a Deanza IP 8400 station and CAPELLA in MIDAS.

4. Results and Discussion

Our work reveals that Brey 73 is in fact an aggregate of 11 components (Fig. 5) including the Wolf-Rayet star at a resolution of at least 1.3 arcsec with an effective seeing of 1.6 arcsec.

Apparent magnitude

Figure 6 shows all the stars of the field. Triangles refer to the stars of the Brey 73 association.

It immediately appears that the W-R star Brey 73 is of similar magnitude (at λ 4794 Å) as Brey 71, though the magnitudes quoted for these two stars in the literature are very different.

The calibration of the W-R component in the Brey 73 association was made on the one hand thanks to the single stars Brey 71 (WN 7) and Brey 70a (WN 3–4) of magnitude v = 13.76 (Breysacher, 1986) and 17.64 (Morgan and Good, 1987) respectively, in the u'ubvv' photo-

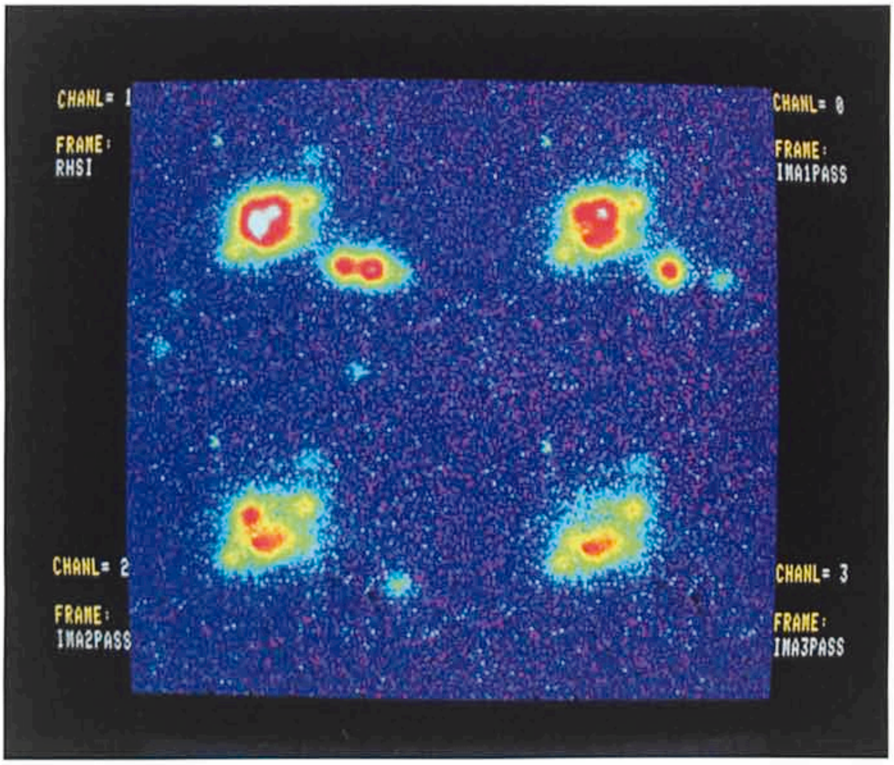

Figure 3: *Successive steps in the processing of the He II frame of the Brey 73 association (Upper left): Original frame. (Upper right): Residuals after first iteration. (Lower left): Id. for second iteration. (Lower right): Id. for third iteration.*

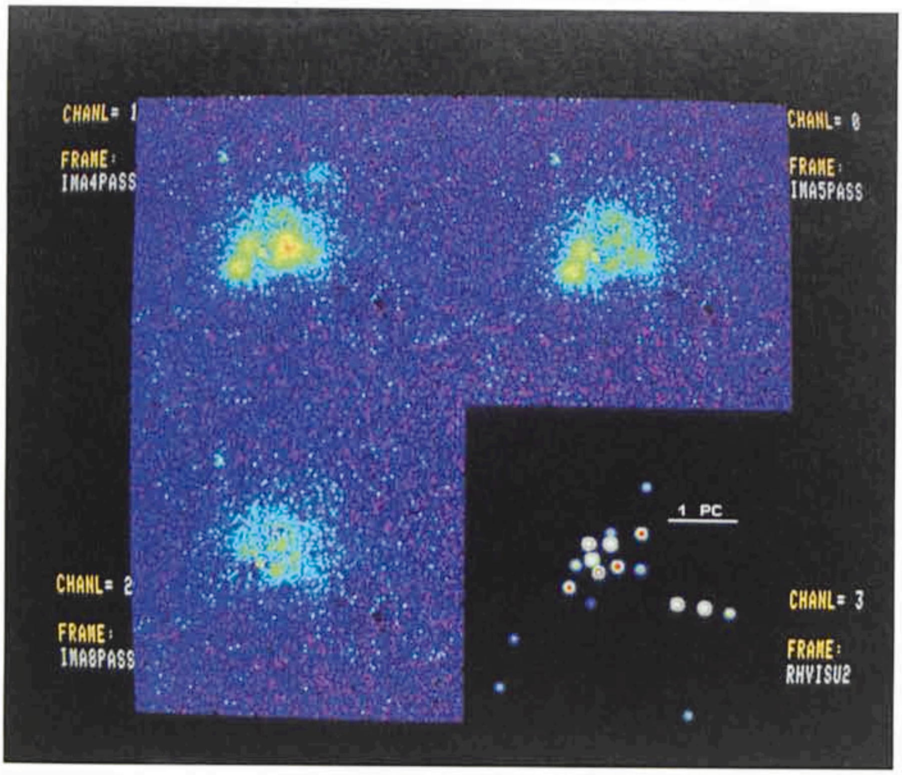

Figure 4: *Successive steps in the processing of the HeII frame of the Brey 73 association (continuation). (Upper left): Residuals after fourth iteration. (Upper right): Residuals after fifth iteration. (Lower left): Id. for eighth (the last one) iteration. (Lower right): 0.25 arcsec reconstitution of Brey 73.*

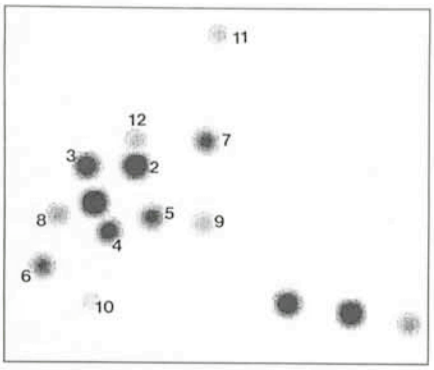

Figure 5: *0.25 arcsec reconstitution of Brey 73 showing stars detected in the association.*

metric system avoiding the W-R emission lines described by Smith (1968), and on the other hand thanks to the integrated magnitudes V = 12.11 of the Brey 73 association and V = 13.96 of Brey 71 in the UBV current photometric system, obtained by Feitzinger and Isserstedt (1983) through an 18 arcsec diaphragm. The difference in magnitude v between the UBV and narrow band u'ubvv' system is determined by the relation v-V = 0.20 for WN 4.5 and v-V = 0.08 for WN 7 stars (Breysacher, 1986). We have checked elsewhere that v (λ 4794 Å) and V are well correlated with the slope 0.97, for stars not redder than 0.4. The correlation v (λ 4794 Å), v (Smith) is expected to be even better with a slope closer to 1.

Table 1 gives different magnitudes v of the W-R in the Brey 73 association. Its calibration from the magnitude v and V of Brey 71 gives two different magnitudes v = 13.74 (column 3) and v = 14.04 (column 4) respectively. The latter value is in good agreement with the magnitude v = 13.99 (column 5) extracted from the integrated magnitude V of the Brey 73 association. From the faint Brey 70a we derived a magnitude v = 13.43 (column 2), the excess in brightness could be due to the nebula. Finally we adopted v = 14.01 as the mean magnitude deduced from the V magnitudes of Brey 71 and Brey 73. The brightest star in the aggregate besides the W-R has a mean magnitude v of about 13.76.

Absolute magnitude

Adopting a LMC distance modulus of 18.5 (Westerlund, 1974) the visual absolute magnitude of a star is given by the relation $M_v = v - A_v - 18.5$ where v is the apparent magnitude, $A_v = R_1 E_{b-v}$ the total absorption in the v band (Lundström and Stenholm, 1984). Adopting $E_{b-v} = 0.12$ and $R_1 = 4.2$ (Breysacher, 1986), we found a magnitude $M_v = -4.99$ instead of -6.7.

This value draws Brey 73 towards the right of the WN 4.5 absolute magnitude histogram (Breysacher, 1986 – Fig. 1) strengthening Breysacher's hypothesis that the mean magnitude of this subclass is not very different from that of WN 3 and WN 4, about −4.2.

As a conclusion, CAPELLA is an excellent help, well adapted for the study of stellar aggregates, even if a great number of intermediate frames must be used in its present status. In the case of Wolf-Rayet stars, the detection and treatment of multiple systems is of special interest as it is a necessary step for an accurate determination of the absolute magnitude of each star, which has far reaching consequences for our understanding of the evolution of massive stars. The comparison with results obtained in our Galaxy, of different chemical composition (Van der Hucht et al., 1988) will also be of great interest.

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TABLE 1. *Magnitudes of the Brey 73 aggregate stars computed from the known measurements of Brey 70a, Brey 71, Brey 73.*

Stars of the Brey 73 aggregate	Magnitude (v) from Brey 70a (v = 17.64)	Magnitude (v) from Brey 71 (v = 13.76)	Magnitude (v) from Brey 71 (V = 13.96)	Magnitude (v) from Brey 73 (V = 12.11)
W-R	13.43	13.74	14.04	13.99
2	13.12	13.43	13.73	13.69
3	13.59	13.90	14.20	14.16
4	14.24	14.46	14.76	14.81
5	14.45	14.76	15.06	15.02
6	14.57	14.88	15.18	15.14
7	14.31	14.62	14.92	14.88
8	15.59	15.90	16.20	16.16
9	15.70	16.01	16.31	16.27
10	16.46	16.78	17.08	17.03
11	16.07	16.39	16.69	16.63
12	15.05	15.36	15.66	15.62

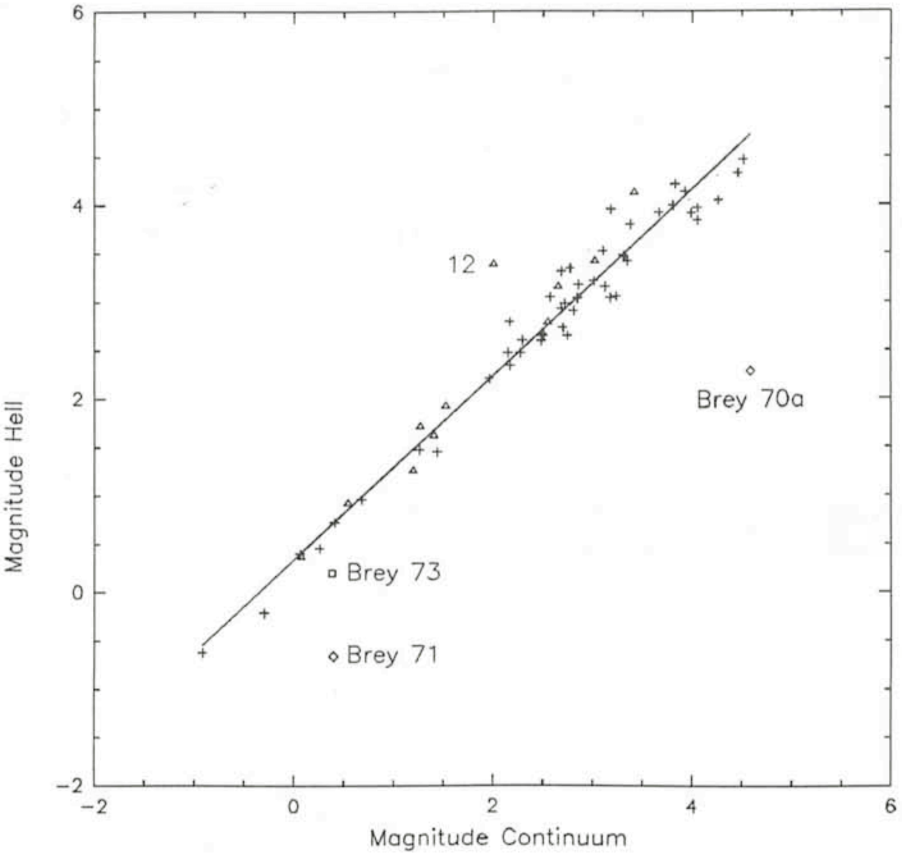

Figure 6: *Plot of the He II relative magnitudes versus the continuum magnitudes of all stars of the frame (90 arcsec × 140 arcsec). The known W-R stars Brey 70a, Brey 71 and the Brey 73 association show a conspicuous He II brightness excess. The stars belonging to the aggregate are represented by triangles. Most of the stars follow a close relationship v (λ 4686 Å) = 0.96 v* (λ 4794 Å) + 0.34 and with a σ rms of 0.22 magnitude after elimination of Brey 70a, Brey 71 and Brey 73. Star 12 is a faint star of the cluster, probably a red one which would need deep, good seeing B and V photometry.

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Spectroscopic Identification of White Dwarfs in Galactic Clusters

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The End Products of Stellar Evolution

The end products of the evolution of single stars are well known: low mass stars leave white dwarf remnants, massive stars undergo a supernova explosion with either a neutron star or a black hole as a remnant.

In a first approximation, it appears to be only the initial mass which determines whether a star ends its life peacefully as a white dwarf or undergoes a core collapse with a quasi instantaneous energy release of $\sim 10^{53}$ erg, visible as a supernova explosion.

Estimates of the maximum initial mass limit M_{WD} for formation of white dwarfs have been made by various techniques.

One possibility is to compare the supernova type II rate with the birth rate of massive stars in our galaxy. Since the former rate is extremely uncertain and can be observed only in external galaxies whereas the initial mass function can be measured only in the solar neighbourhood, the constraints on SN II parents are not stringent. An estimate of the local SN II rate (e.g. Tammann, 1974) tells us that all stars more massive than 5 to 10 $M_\odot$ must become supernovae, and Kennicutt (1984) found that SN II's in Sc galaxies come from stars with masses greater than $8 \pm 1\ M_\odot$.

Since the fate of intermediate mass stars is mainly determined by mass loss in the red giant stage, the combination of stellar evolution tracks through the red giant stages with empirical red giant mass-loss rates also provides an estimate of M_{WD}. The difficulty of this approach is that while mass-loss rates in the normal red giant region are fairly well known and can be parametrized by semi-empirical interpolation formulae

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