1989A&A...222...41H

Astron. Astrophys. 222, 41–44 (1989)

ASTRONOMY AND ASTROPHYSICS

Research Note

Two more very massive stars resolved*

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Received February 10, accepted March 31, 1989

Summary. We present new evidence against the existence of very massive stars in the Magellanic Clouds. Using high resolution CCD images and appropriate image restoration methods, we show that Sk 157 and Sk-69°253 (Sanduleak, 1968, 1969), lying in the SMC and LMC respectively, are not single, very massive, but multiple systems. Thus, two of the most massive stars in existence, with the estimated masses of $\sim 85\,M_\odot$ and $>120\,M_\odot$, vanish from astronomy. The results presented here have important implications for star formation models and the extragalactic distance scale.

Key words: Magellanic Clouds – massive stars – multiple systems – initial mass function – distance scale

1. Introduction

In a recent paper (Heydari-Malayeri et al., 1988; hereafter Paper I) we showed that Sk-66°41, one of the brightest blue stars in the Large Magellanic Cloud, previously known as a very massive star (hereafter VMS), is in fact a compact cluster of at least six components. The multiplicity of VMS's has important implications for star formation mechanisms, especially for the upper mass cut-off, and also for cosmological distance determination (Paper I). While the idea of supermassive stars of $\sim 2000\,M_\odot$ seems to be abandoned now, the question of exact upper limit to stellar masses remains open. In this regard, the problem with R136a is not fully resolved, as its main component may be $\sim 250\,M_\odot$ (Walborn, 1984). But can stars of this mass exist? Observational results are of vital importance in answering this fundamental question.

The Magellanic Clouds present unique opportunities for the investigation of these stars, due to their nearness and relatively well-determined distances. We have undertaken a systematic analysis of VMSs in the Clouds. This paper is devoted to Sk 157 and Sk-69°253 (Sanduleak, 1968, 1969), lying in the SMC and LMC respectively, and catalogued among the most luminous stars (Humphreys, 1983). Further results on other candidates will be presented in a forth-coming paper.

2. Observations and data reduction

CCD images of Sk 157 and Sk-69°253 were obtained in August and October 1988 with the 2.2 m telescope at ESO (La Silla). The detector was a double density RCA CCD chip (type SID 503, 1024 × 640 pixels of 15 μm^2), each pixel corresponding to 0.″176 on the sky. The observational data are summarized in Table 1.

The images were corrected for dark current and flat-fielded using the MIDAS package at La Silla. The point spread function (PSF) was defined by fitting a double Gaussian to a bright stellar image on the same frame. This analytic representation was found to be a satisfactory approximation to the PSF. In any case, our results are not very sensitive to small errors on the PSF, at least as far as the brightest components are concerned. This PSF was used to deconvolve the images employing the maximum entropy method described by Skilling and Bryan (1984) with the special constraint of Bryan and Skilling (1980). This constraint requires modelling of the noise in each pixel of the CCD. Both readout noise (with a normal distribution) and photon noise (Poisson distribution) were considered. This method has been found to give reliable results in resolution enhancements (e.g., Bryan and Skilling, 1980).

Table 1. CCD images

Star	Filter	Exposure (s)	Date	Seeing (″)
Sk 157	*B*	30	88 Oct. 28	1.0
	V	20	88 Aug. 31	1.2
	V	30	88 Oct. 28	1.0
	R	30	88 Aug. 31	1.1
	R	20	88 Aug. 28	1.0
Sk-69°253	*B*	40	88 Aug. 31	1.3
	V	25	88 Aug. 31	1.2
	R	15	88 Aug. 31	1.3

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3. Previously known characteristics of the stars

Sk 157 lies towards the diffuse SMC H II region N 85 (Heinze, 1956). Westerlund (1961) in his image of NGC 465 resolved Sk 157 into five components and gave photographic magnitudes and colours of $V=12.59$, $B-V=-0.39$ and $V=12.80$, $B-V=-0.31$ for the two main "stars" respectively. Later on, Ardeberg and Maurice (1977) obtained the following photoelectric photometry for this star: $V=12.17$, $B-V=-0.21$, $U-B=-0.94$, in good agreement with Dachs (1970). The former authros classify Sk 157 as O 9.5: III: and report that Prévot has assigned an even lower luminosity class to this star. Humphreys (1983) derived a bolometric magnitude of -10.3 for Sk 157. This corresponds to a mass of $\sim 85\,M_{\odot}$, using the evolutionary models of Maeder (1983) with high mass loss rates.

Sk-69°253 (HDE 269936) lies south of the famous LMC star formation region 30 Doradus, between the A and B components of the H II region N 158. The visual magnitudes and colours of the star are $V=11.23$, $B-V=-0.02$ and $U-B=-0.81$ (Ardeberg et al., 1972). These authors classified Sk-69°253 as O 9.5: I, while Walborn (1977) derived a spectral type of B 0.7–1 I. The resulting bolometric magnitude of -11.2 (Humphreys, 1983) implies a star with a mass $>120\,M_{\odot}$.

4. Results

Parts of the R and V CCD images showing Sk 157 and Sk-69°253 respectively are presented in Figs. 1a and 2a. The seeing FWHM measurements are reported in Table 1. The processed images (Figs. 1b and 2b) have a FWHM of $\sim 0\farcs4$ after 30 iterations.

Even from the original pictures, obtained in average seeing conditions, it is easily seen that Sk 157 and Sk-69°253 are multiple. The deconvolution shows them to consist of at least 12 and 14 components, respectively. Note that Sk 157 (f) consists of at least two components. The geometry and photometry of the systems are summarized in Table 2. The positions of the various stellar images, with respect to stars labelled (a), are listed in columns 3 and 4. Note that these clusters are less tightly packed than the previously resolved system Sk-66°41 (Paper I). The contribution of each star to the total flux is indicated in column 5. The tentative V magnitude for each component derived from the global magnitude of the cluster (Ardeberg and Maurice, 1977; Ardeberg et al., 1972) is presented in the last column. Westerlund (1961) actually resolved the outer components f, g and h. The remaining eight stars were identified by him as "stars" 113 and 114. His reported magnitudes are in excellent agreement with our estimates, confirming that these are blue stars.

The number and position of the various components are expected to be fairly reliable. Other deconvolution techniques (Magain, 1989) were found to give similar results. On the other hand, the derived magnitudes should be considered as preliminary, especially for the weaker components, as small errors in the wings of PSF may introduce some contamination from the light of neighbouring bright images. Note that the improvement in the final FWHM of the stellar profiles with respect to Paper I may be attributed both to the higher S/N ratio of the original images and to the different method of deconvolution.

The deconvolution was applied to all the images obtained with the different filters. The components show up unambiguously in all processed images, while a slight colour effect appears for some of the components.

Fig. 1a. The CCD R frame of Sk 157. The field, 81 × 99 pixels, corresponds to $\sim 14'' \times 17''$ on the sky. North is at the top, east to the left

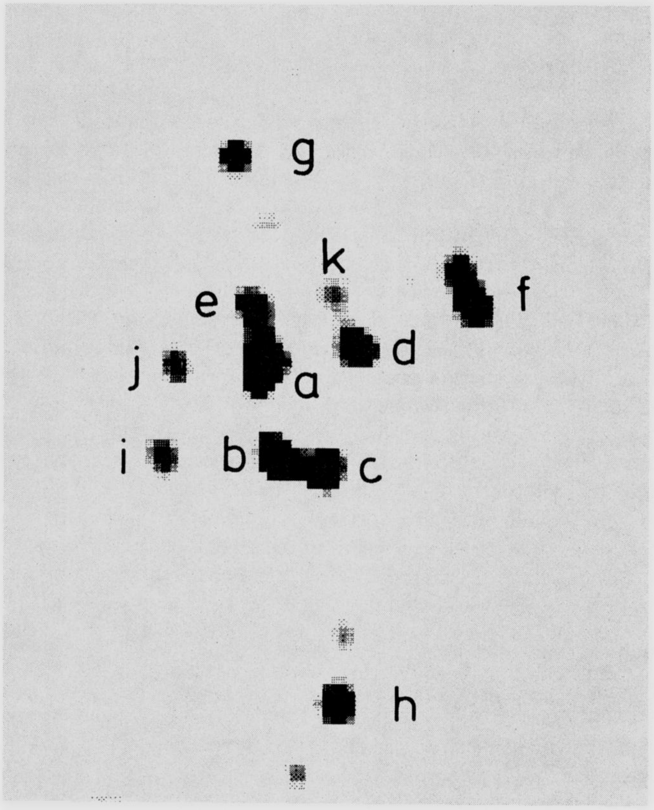

Fig. 1b. Same image after deconvolution

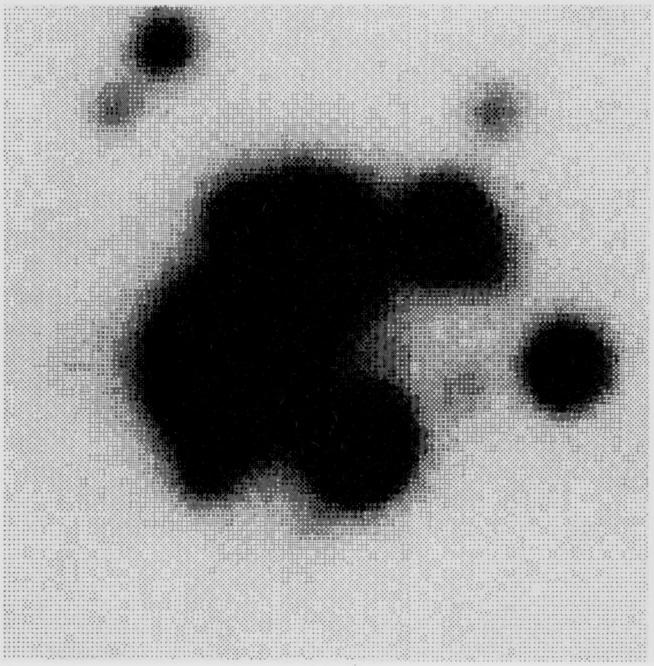

Fig. 2a. The CCD V image of Sk-69°253. The field 81 × 81 pixels, corresponds to 14″ × 14″

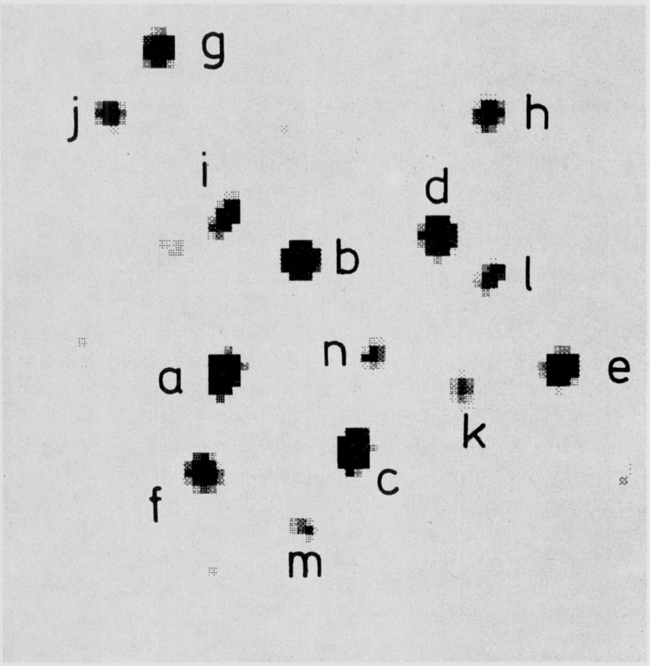

Fig. 2b. Same image after deconvolution

Table 2. Component stars

Star	Component	X (″)	Y (″)	Relative flux (%)	V (mag)
Sk 157	a	0.0	0.0	38.5	13.2
	b	0.4 W	2.1 S	30.1	13.5
	c	1.2 W	2.2 S		
	d	2.1 W	0.4 N	4.4	15.6
	e				
	f	4.5 W	1.4 N	8.8	14.8
	g	0.6 E	4.4 N	2.3	16.3
	h	1.7 W	7.3 S	7.9	14.9
	i	2.2 E	2.1 S	1.4	16.8
	j	2.4 E	0.0	1.1	17.1
	k	1.5 W	1.5 N		
Sk-69°253	a	0.0	0.0	47.6	12.0
	b	1.8 W	2.4 N	31.4	12.5
	c	2.9 W	1.7 S	7.5	14.0
	d	4.7 W	3.0 N	4.2	14.7
	e	7.4 W	0.1 N	2.5	15.2
	f	0.4 E	2.2 S	0.8	16.5
	g	1.4 E	7.0 N	1.1	16.1
	h	5.9 W	5.5 N	0.5	17.0
	i	0.2 W	3.5 N	0.5	17.0
	j	2.4 E	5.6 N	0.4	17.2
	k	5.3 W	0.4 S	0.3	17.5
	l	5.9 W	2.1 N	0.3	17.5
	m	1.7 W	3.3 S	0.2	18.0
	n	3.3 W	0.4 N	0.2	18.0

5. Discussion

Some recent results seem to confirm that O type stars tend to form in groups (Paper I). Assuming that all the resolved components of Sk 157 and Sk-69°253 are O type members, from the magnitudes given in Table 2, we can estimate the corresponding masses. We see that the most massive stars of the clusters have masses of ~ 50 and 70 $M_\odot$, respectively. Therefore, two of the known VMSs with masses of $\sim 85\,M_\odot$ and 120 $M_\odot$, are actually clusters of lower mass stars. The real masses of the main components may be even smaller due to the fact that Sk 157 and Sk-69°253 are not associated with strong H II emission. On the other hand, the discrepancies between the various reported spectral classifications may possibly be due to the observing of different components.

The idea of the existence of VMSs may have origiated from biased observational results as well as uncertain theoretical predictions. We point out that theoretical arguments related to the internal structure of stars are against the existence of VMSs and place a relatively low upper limit of $\sim 60-100\,M_\odot$ (see Paper I; Heydari-Malayeri, 1988, and references therein). As for the observational bias, the idea of VMSs may have been caused by the lack of sufficient spatial resolution.

In deriving the magnitudes of these stars, Dachs (1970), Ardeberg and Maurice (1977), and Ardeberg et al. (1972) used a diaphragm of at least 15″ in diameter. This corresponds to the whole fields shown in Figs. 1 and 2. Therefore, the reported magnitudes are integrated values for the whole clusters. Note that Dachs (1970) made the remark that Sk 157 is a cluster (last column of his table) and recently Lortet and Testor (1988), referring to Westerlund's (1961) image, pointed out the multiplicity of Sk 157. Likewise, Walborn (1977) in his notes described Sk-69°253 as a "compact pentagonal, quintuple visual system, with the brightest component at the apex and separations of the order of 2″–3″. The photometry apparently refers to the whole system". Humphreys (1983), probably due to lack of high resolution images, included these systems in her list of the brightest stars as distance indicators. However, later on she realized that many of the candidate brightest blue supergiants in three nearby spirals, NGC 2403, M 81 and M 101, are not single stars, but compact H II regions, clusters, or composite systems (Humphreys and Aaronson, 1987).

The results presented here and in Paper I cast real doubt about the existence of VMSs in the Magellanic Clouds. The most luminous/most massive stars, if they exist at all, should naturally be confirmed by observations. If spatial resolution is already so criucal for our nearest companion galaxies, the Magellanic Clouds, it will be even more decisive for other members of the Local Group (NGC 6822, M 31, M 33, etc.), not to mention galaxies at greater distances.

Our findings have several implications for star formation models. In the classical method of star counts for deriving the initial mass function (IMF), the sample stars are usually taken from published catalogues (Humphreys and McElroy, 1984), the majority of which have used low resolution techniques. The possible multiplicity of the sample stars, especially for the upper mass limit, which depends on a very small number of stars, can significantly alter the shape of the upper part of the IMF.

If the most massive stars are clusters of lower mass O type stars, the data used for deriving the IMF suffer from incompleteness in the mass interval $\sim 30-60\,M_\odot$.

Is the IMF a universal parameter? This fundamental question cannot properly be answered as long as the problem of the multiplicity of the brightest stars in not solved.

Some workers have reported a relation between the number of the most luminous stars and the metallicity. This result is not confirmed by other investigations (Paper I). The present situation may be due to the possible multiplicity of the observed bright stars.

The multiplicity of the brightest stars also has an important impact on the cosmic distance scale. If a cluster located in an external galaxy is mistaken for a single star, the apparent magnitude is overestimated. This means that in using the brightest stars the distances may have easily been underestimated. This result therefore supports smaller values for the Hubble constant.

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