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INFRARED LUMINOSITIES OF M SUPERGIANTS AND THEIR USE AS DISTANCE INDICATORS

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ABSTRACT

Infrared photometry of the brightest red supergiants in five Local Group galaxies shows that their K (2.2 μm) luminosities range from about -12 mag in the Milky Way and the LMC to approximately -11.4 mag in the SMC, NGC 6822, and IC 1613. This dispersion contrasts with the situation for the visual luminosities of the brightest M supergiants in the same galaxies which are nearly constant at $M_V = -8$ mag. This spread in the brightest K luminosity is due to variations in the spectral type distribution of the M supergiant population which may depend on the metallicity of the parent galaxy. Thus without further information on the spectral type of the star, the large range in M_K limits the usefulness of the M supergiants as distance indicators in the infrared.

Subject headings: galaxies: general — infrared: general — stars: late-type — stars: supergiants

I. INTRODUCTION

Increasing empirical evidence suggests that the brightest M supergiants are excellent extragalactic distance indicators for spiral and Magellanic-type irregular galaxies. Following the original suggestion by Sandage and Tammann (1974), Humphreys has obtained spectra and visual photometry of the brightest red stars in six Local Group galaxies: M33, NGC 6822, IC 1613, the LMC and SMC (Humphreys 1979*a*, *b*; 1980*a*, *b*), and the Milky Way galaxy (Humphreys 1978). She finds that the brightest M supergiants in each of these galaxies have visual luminosities of $M_V = -8.0 \pm 0.2$ mag.

Because the maximum visual luminosity of the M supergiants is apparently constant among the galaxies studied, we thought it would be worthwhile to determine their luminosities in the infrared to evaluate their usefulness as distance indicators in a spectral region where the M supergiants are very bright. In addition, accurate correction for visual extinction due to dust is a problem for these stars, but in the infrared extinction is much less; typically about 0.1 mag at K (2.2 μm) for stars in distant galaxies. Observations of these stars in the infrared also provide the best means for determining their bolometric luminosities.

In this *Letter* we summarize the results for the visual, infrared, and bolometric luminosities of the brightest M supergiants in the LMC, SMC, NGC 6822, IC 1613, and our own Galaxy.

II. OBSERVATIONS

Most of the optical data used in this *Letter* are already published, as are the infrared observations for the galactic supergiants. All of the infrared data for the M supergiants in the LMC, SMC, NGC 6822, IC 1613, and additional optical observations for the SMC supergiants and some of those in the LMC will appear in a more comprehensive paper to follow (Elias, Frogel, and Humphreys 1981). The *JHK* photometry was obtained on the 4 m and 1.5 m telescopes at Cerro Tololo Inter-American Observatory (CTIO) and the 2.5 m du Pont telescope at Las Campanas and are on the system of Frogel *et al.* (1978) and Elias and Frogel (in preparation).

For each galaxy, except the LMC, the brightest M stars have essentially been selected by their visual luminosity; that is, the stars observed in the infrared were chosen from the papers by Humphreys on the brightest supergiants. For the LMC, infrared observa-

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tions are available for additional stars from the catalog by Sanduleak and Philip (1977) and an unpublished infrared survey by Elias. Three of the LMC stars selected on the basis of their infrared luminosities are absent from the visually selected sample because of composite spectra or crowding. They do not represent a distinct group of stars. The notes to Table 2 indicate the origin of the data set for the infrared observations.

III. RESULTS AND DISCUSSION

The visual and infrared data for the brightest M supergiants in the five galaxies are summarized in Tables 1 and 2. In each table, the star designation, its spectral type, its apparent V and K magnitudes are given with the extinction at V[4] (we have adopted $A_K = 0.1\ A_V$), and the resulting corrected apparent V and K magnitudes and $(V-K)_0$ color. The absolute V and K magnitudes are then derived from the distance modulus for each galaxy which is given at the top of each subsection of Table 2. For the galactic supergiants, the distance modulus of the stellar association to which each belongs is used. Bolometric magnitudes have also been calculated either by integrating under the energy distribution curve for those stars with near simultaneous optical and infrared data (Frogel, Persson, and Cohen 1981) or by use of a mean relationship between BC_K and $J-K$ for supergiants (Elias, Frogel, and Humphreys 1981).

Most of these stars are known variables at visual wavelengths (B and V), but we have found no evidence for large variations in the infrared; variations are typically 0.1 mag at K with a maximum of 0.3 mag. In this *Letter* we are using the brightest photoelectrically observed V magnitude and are not including the visual luminosity at maximum light which must be somewhat uncertain for the supergiants in other galaxies. However, for information, the maximum visual luminosity (Humphreys 1978) of the galactic supergiants is given in the remarks column of Table 1.

The LMC is the only galaxy for which it was possible to select the brightest supergiants by their apparent K magnitudes, and we find little difference between the stars selected to be the brightest at K and those that are visually brightest. In the SMC and NGC 6822, we have observed enough stars in addition to those in Table 2 to be confident that there are no stars which are unusually bright at K among the visually fainter stars.

In Table 3 the three brightest visual, infrared (K), and bolometric luminosities for the M supergiants are listed for each galaxy, and the number in parenthesis indicates the number of stars with each luminosity. It is important to realize that the most luminous star at the different wavelengths (M_V, M_K, or $M_{\rm bol}$) in a given galaxy is not necessarily the same star because of the strong dependence of $V-K$ color and the bolometric correction on spectral type. The uncertainties in the luminosities arising from the estimated errors in the distances for each galaxy are given under the galaxy name. The error estimate assigned to the adopted distance modulus of NGC 6822 by Humphreys (1980*a*) suggests that its distance may be slightly underestimated.

The constancy of the brightest visual luminosity near -8 mag, emphasized in the series of papers by Humphreys, is obvious from Table 3. It is equally apparent that the brightest K luminosities are not nearly as constant. This is because the $V-K$ color and, consequently, the absolute K luminosity depend strongly on spectral type (e.g., Lee 1970). In the SMC none of the M supergiants are classified later than M2 and most are K5–MO (Humphreys 1979*b*). Although a much smaller data set is available, the same is apparently true for the M supergiants in NGC 6822 and IC 1613. On the contrary, there are many stars in the solar neighborhood and the LMC with spectral types M2–M4 and therefore much larger $V-K$ colors. The small galaxy-to-galaxy scatter in M_V means that the variations in M_K should be as large as the $V-K$ variations.

On the basis of the K luminosities of these M supergiants, these five galaxies appear to divide into two groups: the Galaxy and the LMC with $M_K = -12$ mag for their brightest M supergiants, and the SMC, NGC 6822, and IC 1613 for which $M_K = -11.4$ mag (when the possible underestimate of the NGC 6822 distance is considered). This variation in the maximum K luminosity is due to the differences in the spectral type distribution of the M supergiants in the three smaller irregulars, most likely resulting from their lower metal abundance (Humphreys 1979*b*), which may be correlated with the mass and hence luminosity of the galaxy.

There may also be a similar separation in the maximum bolometric luminosities for the M supergiants between these same two groups of galaxies. For the Galaxy and the LMC, the maximum $M_{\rm bol}$ is $= -9.3$ mag while it is -9.0 mag for the SMC, NGC 6822, and IC 1613; however, the errors in the luminosities, typically ± 0.2 mag, make this difference less significant than for the infrared luminosities.

With the above results, we conclude that although the brightest visual luminosities of the M supergiants are very constant over a range of galaxy types, the maximum luminosities at K are dependent on the spectral types of the M supergiant population. The resulting spread in M_K prevents these stars from being good

[4]The visual extinction estimates for the M supergiants in the Milky Way, LMC, NGC 6822, and IC 1613 are from the papers by Humphreys and in the SMC from Elias, Frogel, and Humphreys (1981). Parentheses indicate that A_V is estimated from nearby blue or red supergiants.

TABLE 1

VISUAL AND INFRARED DATA FOR THE BRIGHTEST M SUPERGIANTS IN THE SOLAR NEIGHBORHOOD

Star	Sp. Type	m_V	m_K	Ref	A_V	m_{V_0}	m_{K_0}	$(V-K)_0$	Assoc. $(m-M)_0$	M_V	M_K	Remark
μ Cep	M2 Ia	3.8	-1.65	2	2.4	1.4	-1.9	3.3	9.6 Cep OB1	-8.2	-11.5	
BD +24°3902	M1 Ia	9.0	1.7 1.6	1 2	5.0	4.0	1.1	2.9	11.5 Vul OB1	-7.5	-10.4	
KY Cyg	M3 Ia	10.6	0.3 0.2	1 2	6.9	3.7	-.5	4.2	11.3 Cyg OB1	-7.6	-11.8	$M_{Vmax} = -7.9$
HD 143183	M3 Ia	7.6	0.7	3	2.4	5.2	.5	4.7	12.7 Nor OB1	-7.5	-12.2	
PZ Cas	M4 Ia	8.5	1.0 1.0	1 2	3.0	5.5	.7	4.8	12.0 Cas OB5	-6.5	-11.3	$M_{Vmax} = -7.6$
KW Sgr	M3 Ia	9.3	1.3 1.5	1 2	3.8	5.5	.9	4.6	12.4 Sgr OB5	-6.9	-11.5	$M_{Vmax} = -7.8$
BC Cyg	M3.5 Ia	10.0	0.2 0.2	1 2	5.4	4.6	-.3	4.9	11.3 Cyg OB1	-6.7	-11.6	$M_{Vmax} = -7.7$
BI Cyg	M3 Ia-Iab	9.3	0.6 0.6	1 2	4.6	4.7	0.1	4.6	11.3 Cyg OB1	-6.6	-11.2	$M_{Vmax} = -7.5$

References
1. Neugebauer and Leighton (1969), "Two Micron Sky Survey," NASA SP-3047.
2. Lee (1970)
3. Humphreys and Ney (1974)

TABLE 2

VISUAL AND INFRARED DATA FOR THE BRIGHTEST M SUPERGIANTS IN THE LMC, SMC, NGC 6822, AND IC 1613

Star	Sp. Type	m_V	m_K	A_V	m_{V_o}	m_{K_o}	$(V-K)_o$	M_V	M_K	Remark
a. LMC* $(m-M)_o = 18^m.6 \pm 0.2$										
Case 46-44	M1 Ia	11.4	6.8	.9	10.5	6.7	3.8	-8.1	-11.9	W b-67
Case 46-32	M0 Ia	11.8	7.1	1.2:	10.6	7.0	3.6	-8.0	-11.6	B32, HV 2561
Case 45-38	M1 Ia	11.7	7.4	1.0:	10.7	7.3	3.4	-7.9	-11.3	W CI-6, HV 2595
Case 46-39	M1 Ia	11.9	7.3	.9	11.0	7.2	3.8	-7.6	-11.4	W b-73
Case 46-2	M2 Ia	11.9	7.3	.9	11.0	7.2	3.8	-7.6	-11.4	B28, HV 2450
Case 29-33	M4 Ia	11.7	6.8	.5	11.2	6.7	4.5	-7.4	-11.9	B18, HV 888, *
Case 46-21	Composite	-	7.0	(.5)	-	6.9	-	-	-11.7	HDE 269551, *
Case 46-19	M2 I+B	-	7.2	(.5)	-	7.2	-	-	-11.4	NGC 1962 #29, *
NGC 2044 #46	-	-	6.8	(.9)	-	6.7	-	-	-11.9	*
b. SMC* $(m-M)_o = 19^m.0 \pm 0.2$										
Case 107-1	K5-M0 Ia	11.3	7.6	0.6	10.7	7.5	3.2	-8.3	-11.5	
Case 106-1A	M0 Ia	12.2	7.9	1.2	11.0	7.8	3.2	-8.0	-11.2	
HV 11423	M0 Ia	11.8	7.8	0.6	11.2	7.8	3.4	-7.8	-11.2	
Case 104-5	M0 Ia	12.2	8.0	1.0	11.2	7.8	3.4	-7.8	-11.2	
Case 120-14	K5-M0 I	11.9	8.2	0.7	11.2	8.1	3.1	-7.8	-10.9	
Case 101-6	M1 I	12.7	-	1.45	11.2	-	-	-7.8	-	
Case 118-15	M0 I	12.1	7.9	0.85	11.2	7.8	3.4	-7.8	-11.2	
c. NGC 6822* $(m-M)_o = 23^m.2 +0.2, -0.0$										
B110	M0 I	16.5	12.8	1.2	15.3	12.7	2.6	-7.9	-10.5	
V18	M1-M2 I	16.7	12.2	1.3	15.4	12.0	3.4	-7.8	-11.2	
V19	M1 I	17.6	12.5	1.7	15.9	12.3	3.6	-7.3	-10.9	
C79	M0-M1 I	17.0	12.5	1.0	16.0	12.4	3.6	-7.2	-10.8	
V12	M1 I	17.4	12.7	1.3	16.1	12.6	3.5	-7.1	-10.6	
C26	M0-M1 I	17.6:	13.0	1.0	16.6	12.9	3.7	-6.6	-10.3	
V14	cM	17.5	12.6	0.7	16.7	12.5	4.2	-6.4	-10.7	
d. IC 1613* $(m-M)_o = 24^m.3 \pm 0.1$										
V38	M0 Ia	16.9	13.1	.7	16.2	13.0	3.2	-8.1	-11.3	
V32	M1 Ia	17.1	13.1	.4	16.7	13.1	3.6	-7.6	-11.2	
V58	-	17.6	14.1	(.3)	17.3	14.1	3.2	-7.0	-10.2	
V43	M1 I	17.5	14.4	(.3)	17.2	14.4	2.8	-7.1	-9.9	

NOTES.—LMC: The first five stars in this table rank 1 through 4 in M_V. The four additional stars have m_K brighter than the faintest of the five stars chosen visually. Thus these are the nine stars with the brightest m_K magnitudes and include the five selected by M_V. Of the four which were selected by their apparent K magnitude alone: Case 29-33 (= B18) is probably one of the visually brightest M supergiants in the LMC. Its visual luminosity at maximum light is $M_V = -8.1$ (Humphreys 1979*a*). Case 46-21 and Case 46-19 both have composite spectra (Sanduleak and Philip 1977; Humphreys 1979*a*); consequently, the visual luminosity of the M supergiant cannot be determined independent of its companion. NGC 2044 #46 (Mendoza and Gomez 1973) is in a very crowded field and there is no available visual photometry for it. On the basis of its infrared colors, it is a probable M supergiant.

SMC: The stars chosen for infrared photometry were selected from the list of confirmed M supergiants by Humphreys (1979*b*). The stars listed here rank 1 through 4 in M_V, and the brightest in m_K are included in this group.

NGC 6822: The seven brightest stars (m_V) from Humphreys (1980*a*) were chosen for the infrared observations.

IC 1613: The four brightest stars (m_V) from Humphreys (1980*a*) are the only ones observed in the infrared.

distance indicators in the infrared unless additional information is available to determine spectral type or color or perhaps the metallicity of the galaxy. Evidently, the *K* magnitude (or *JHK* data) alone is not sufficient for use as a distance indicator.

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TABLE 3

LUMINOSITIES OF THE BRIGHTEST M SUPERGIANTS

Luminosity	Milky Way (±0.25)	LMC (±0.2)	SMC (±0.2)	NGC 6822 (−0.2, +0)	IC 1613 (±0.1)
M_V..........	−8.2	−8.1	−8.3	−7.9	−8.1
	−7.6	−8.0	−8.0	−7.8	−7.6
	−7.5 (2)	−7.9	−7.8 (5)	−7.3	−7.1
M_K..........	−12.2	−11.9 (3)	−11.5	−11.2	−11.3
	−11.8	−11.7	−11.2 (4)	−10.9	−11.2
	−11.6	−11.6	−10.9	−10.8	−10.2
M_{bol}	−9.4	−9.3	−9.1	−8.8	−9.0
	−9.2	−9.2	−8.9	−8.5	−8.8
	−9.1	−9.0	−8.8 (3)	−8.4	−7.9
$M_{V_{\mathrm{galaxy}}}$......	−20.5:	−18.5	−16.8	−15.7	−14.8

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