THE HR DIAGRAM FOR LUMINOUS STARS IN NEARBY GALAXIES

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HR diagrams for the stellar populations in other galaxies play a fundamental role in our understanding of the progress of stellar evolution and the effects of possible variations in chemical composition. It is important to compare what little information we have about stars in other galaxies with the same types of stars in our own Milky Way. Basically we are asking - are they the same, and how universal are the processes we observe in our Galaxy?

Due to the extreme faintness of stars in other galaxies it is only possible to sample the brightest stars in the nearest galaxies. The observations must then be compared with comparable data for the brightest stars, the supergiants and O-type stars, in the Milky Way.

The data for the luminous stars are most complete for the Milky Way and the Large Magellanic Cloud. The luminosities for the stars in our Galaxy are based on their membership in associations and clusters, and consequently are representative of Population I within $\approx$3kpc of the Sun. The data for the stars in the LMC with spectral types O to G8 come from published observations, and the M supergiants are from my recent observations of red stars in the LMC. This is the first time that the M supergiants have been included in an HR diagram of the Large Cloud. The presence of the red stars is important for any discussion of the evolution of the massive stars.

Comparison of the HR diagrams shows that the supergiants in these two galaxies are remarkably similar. There are several significant features common to both galaxies - 1) a group of very

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luminous O-type stars with M_{bol} between -10^m and -12^m, 2) a lack of supergiants of later spectral type at these very high luminosities, and 3) an obvious upper envelope to the luminosities at $M_{bol} \simeq -9\overset{m}{.}5$ beginning at B5 to A0 which extends across the diagram to the M supergiants. The only obvious difference between the two galaxies is a greater number of the most luminous B and early A-type supergiants in the LMC.

Since the most luminous stars have great potential as extragalactic distance indicators, another useful comparison is the visual luminosities of the supergiants of different spectral types which is summarized in Table I.

TABLE I MAXIMUM VISUAL LUMINOSITIES FOR DIFFERENT SPECTRAL TYPES

Spectral Type Interval	Milky Way M_V	LMC M_V
O	1. $-8\overset{m}{.}5$ 2. -7.8 3. -7.6	1. $-8\overset{m}{.}2$ 2. -8.1 3. -7.5
B,A	1. -9.9: 2. -8.8 3. -8.7	1. -9.8 2. -9.2 3. -9.0
F,G,K	1. -9.5 2. -9.2 (3)	1. -9.2 2. -9.1 (3)
M	1. -7.6 (-8(3)) 2. -7.5 (-7.8(3)) 3. -7.4	1. -7.5 (-8.3(2)) 2. -7.3 (-7.7(3)) 3. -7.1

The magnitudes in parenthesis are their luminosities at maximum light and the number of stars that reach that brightness. The most luminous B to A-type supergiant in the Milky Way may be #12 in Cyg OB2 although there is some doubt about its membership. If it is not a member of Cyg OB2, there will be a significant difference in maximum luminosity between the B and A supergiants in the LMC and the Galaxy. Otherwise, the luminosities of the brightest supergiants confirm the close resemblance of the Population I stars in the galaxies.

The blue/red supergiant ratio (including O stars) is an important indicator for checking evolutionary models and may also be sensitive to abundance variations. The B/R ratio for different luminosity intervals is given in Table II for the Galaxy and the LMC.

TABLE II BLUE TO RED STAR RATIOS

M_{bol} range	Milky Way			LMC		
	B	R	B/R	B	R	B/R
$-5\overset{\mathrm{m}}{.}5$ to $-6\overset{\mathrm{m}}{.}5$	19	10	1.9	26	-	-
- 6.5 to - 7.5	96	27	3.4	81	3	incomplete data
- 7.5 to - 8.5	155	18	8.6	133	14	9.5
- 8.5 to - 9.5	119	7	17.0	76	5	15.2
- 9.5 to -10.5	30	1	30	21	-	>21
-10.5 to -11.5	15	-	-	8	-	-
≤ -11.5	3	-	-	1	-	-

The data for the M supergiants in the LMC are definitely incomplete fainter than $M_{bol} \approx -7\overset{\mathrm{m}}{.}5$, and the other numbers may also change somewhat when additional observations are available. With this in mind, it is clear that the B/R ratios are comparable, confirming that the evolution of the most massive stars in these two galaxies have proceeded in similar ways.

Since the LMC is a companion to the Milky Way it is perhaps not too surprising that the data for the supergiants are so much alike. Therefore it is important to study the luminous stars in more distant members of the Local Group.

In this paper I will just briefly present some preliminary results for the luminous stars in Baade's Field IV in M31 and in NGC 6822. Field IV, one of four along the major axis of M31 is the only one for which a color-magnitude diagram exists from which candidate supergiants can be selected. The outermost spiral arm of M31 passes through Field IV and Baade and Swope have identified four associations in the arm. Spectra for classification have been obtained for fourteen stars in this field and five supergiants have been identified including three B-type supergiants, an F supergiant and an M supergiant. It should be emphasized that Field IV is only one part of one spiral arm and these supergiants are only a small sample of the luminous stars in M31. The HR diagram discussed here is a composite of the four associations and a small cluster in Field IV from which all confirmed foreground stars have been eliminated.

Field IV is ≈ 18.5 kpc from the center of M31 which scaled to the Milky Way corresponds to ≈ 14 kpc from the galactic center, so the most appropriate comparison is with our outer spiral arm - the Perseus arm (R ≈ 12 - 13 kpc). For example, the B/R ratio for Field IV is about 3.0 and the mean ratio for the Perseus arm is 3.2, which is good agreement between the outer parts of two spiral galaxies.

Preliminary results for the supergiants in the irregular galaxy NGC 6822 suggest that there may be some differences for the hot stars. Sixteen stars have been confirmed as members on the basis of spectra and photoelectric photometry of stars selected from Susan Kayser's color-magnitude diagram. In Table I the visual luminosities for the stars in NGC 6822 are compared with results for the Galaxy and the LMC. It is obvious that there may be some difference in maximum luminosity for the O and B to A-type supergiants, however the observations are still incomplete. It is significant that the M supergiants have the same maximum luminosity as in the Milky Way and LMC. Initially stars bluer than (B-V) = $0^m.2$ and redder than (B-V) = $1^m.7$ were selected for observation and the lack of data for the F, G and K-type stars is due to these selection criteria. It is also possible that the visually very luminous late B and early A-type supergiants have not been observed yet. There is some evidence that the reddening determined from some of the early-type members is higher than the foreground reddening, so it is probably necessary to observe somewhat redder stars to identify the A-type supergiants.

The data for the Milky Way and the LMC show that the luminous star populations are remarkably similar. It is not possible to make any definite statement about M31 because only a limited sample of supergiants is available, while for NGC 6822 there is evidence that there are some differences for the early-type supergiants. Further observations are scheduled for the red stars in the LMC and observations are also planned of additional stars in NGC 6822. Other Local Group galaxies included in this study which were not discussed here are M33, IC 1613 and the SMC.

DISCUSSION

McCARTHY: I would like to ask Dr. Philip or Dr. Sanduleak if their recent survey of OB stars in the LMC confirms the lacuna observed in the realm of the supergiants by Dr. Humphreys.

SANDULEAK: The gap in the region of very high luminosity F and G-type stars shown by Dr. Humphreys conforms with our objective-prism survey results for the Magellanic Clouds.

APPENZELLER: At least most (if not all) of the most luminous stars of types A and B in the LMC seem to be variable in light as well as in spectrum. Are such stars included in your HR diagrams or have they been disregarded?

HUMPHREYS: All known variable and peculiar stars have been eliminated in both the LMC and the Milky Way.

CHIOSI: From what was said here one may perhaps get the impression that neutrino energy losses in the advanced phases (core carbon burning, etc.) are the leading factor accounting for the observed lack of very luminous red and perhaps also intermediate spectral type supergiants. This could be the case if the core He-burning phase should entirely or almost entirely occur at high effective temperature. On the contrary the bulk of present evolutionary tracks in the range of massive stars gives quite a different picture, as will be summarized later in my talk. In fact too many red luminous supergiants are forseen by adopting both the Ledoux and Schwarzschild criteria. Moreover the classical results do not account for the observed distribution of the blue supergiants - on the other hand, recent evolutionary computations of stars in the mass range from 20 to 100 $M_{\odot}$, where mass loss in the blue and red phases is taken into account, give a better interpretation of the observations (Chiosi, Nasi and Sreenivasn 1977, Astron. and Astrophys., in press). The results easily account for both the lack of red supergiants and the bulk of the blue ones. Finally I wish to remark that the very close similarity of the HR diagrams for our own galaxy and LMC is a further indication of close similarity of the chemical composition (Y and Z) of supergiant stars in the two galaxies.

LAMB: I would like to mention that recently Iben, Howard and I (Astrophys. J. 1976, 207, 209) have evolved 15 $M_{\odot}$ and 25 $M_{\odot}$ stars, using the Schwarzschild criterion for convection, and including no mass loss. We find good agreement between the evolutionary tracks and time scales and Humphreys' data on the distribution of red and blue supergiants.