1989

Sanduleak's Star (LMC Anonymous): Its Similarity in the Far-Ultraviolet with the Luminous Object n Carinae and Sn 1987A

A. G. Michalitsianos
NASA, Goddard Space Flight Center

Menas Kafatos
Chapman University, kafatos@chapman.edu

S. N. Shore
University of Pisa

Recommended Citation

Michalitsianos, A.G., Kafatos, M. Shore, S.N. (1989) Sanduleak's Star (LMC Anonymous): Its Similarity in the Far-Ultraviolet with the Luminous Object n Carinae and Sn 1987A, *Astrophysical Journal*, 341: 367-3. doi: 10.1086/167500

Sanduleak's Star (LMC Anonymous): Its Similarity in the Far-Ultraviolet with the Luminous Object n Carinae and Sn 1987A

Comments
This article was originally published in *Astrophysical Journal*, volume 341, in 1989. DOI: 10.1086/167500

THE ASTROPHYSICAL JOURNAL, 341:367–371, 1989 June 1

SANDULEAK'S STAR (LMC ANONYMOUS): ITS SIMILARITY IN THE FAR-ULTRAVIOLET WITH THE LUMINOUS OBJECT η CARINAE AND SN 1987A

A. G. MICHALITSIANOS[1]
NASA Goddard Space Flight Center, Laboratory for Astronomy and Solar Physics
M. KAFATOS[1]
Department of Physics, George Mason University
AND
S. N. SHORE
Astrophysics Research Center, New Mexico Institute of Mining and Technology
Received 1988 May 9; accepted 1988 November 3

ABSTRACT

Spectra obtained in the far UV wavelength range 1200–2000 Å with the *International Ultraviolet Explorer* (*IUE*) of the peculiar emission object LMC Anonymous, or Sanduleak's Star in the Large Magellanic Cloud, indicate the presence of circumstellar–high-excitation gas, which is rich in CNO processed material. Although LMC Anonymous is a field star whose nebular line–forming region can not be resolved, and whose mass may be considerably smaller than the massive-luminous galactic object η Carinae, the far-UV spectrum of LMC Anonymous closely resembles that of the S Condensation of η Carinae. The similarity between LMC Anonymous and the S Condensation is apparent from the absolute intensity of the N V, N IV], and N III] emission lines compared with the reduced strength of C IV or C III] emission. The narrow–low velocity emission lines observed in SN 1987A indicate strong evidence for circumstellar emission that is rich in CNO-processed material, which was formed when the progenitor was in the high mass-loss phase as a red supergiant. *IUE* spectra of the S-Condensation and SN 1987A may provide important clues concerning the nature of LMC Anonymous, which indicates departures from normal cosmic abundances of nitrogen relative to carbon that are extreme. This could suggest that carbon envelope burning and dredge-up have occurred simultaneously during the helium shell burning stage. These points are discussed in detail.

Subject headings: stars: abundances — stars: emission line — stars: supergiants — stars: supernovae — ultraviolet: spectra

I. INTRODUCTION

The departure from normal solar cosmic abundances associated with the surface composition of evolved stars provides important clues concerning the properties of envelope-core mixing, and the history of nucleosynthesis during advanced stages of stellar evolution in intermediate and massive stars. One object which exhibits significant departures from normal cosmic abundances was discovered in the Large Magellanic Cloud and is known as Sanduleak's Star (LMC Anonymous), at $\alpha(1950.0) = 05^h46^m02\overset{s}{.}6$, $\delta(1950.0) = -71°17'13''$. Until very recently, little was known of this object. LMC Anonymous was incorrectly included among symbiotic stars found in the LMC, because of the presence of an unidentified broad emission feature at 6830 Å, which is generally only seen in high-excitation symbiotic stars that show [Fe VII] emission (Allen 1984). However, in spite of the presence of the λ6830 emission, LMC Anonymous is demonstrably *not* symbiotic, because the optical spectrum provides no evidence whatsoever for a late-type M giant. Furthermore, the far-UV emission-line spectrum is untypical of symbiotic stars in general (see, e.g., Michalitsianos *et al.* 1982).

The first low dispersion (limiting resolution of $\Delta\lambda = 6$ Å) SWP 1200–2000 Å spectra obtained with the *International Ultraviolet Explorer* (*IUE*) of LMC Anonymous in 1982 revealed the presence of the high-excitation emission lines, N V $\lambda\lambda$1239, 1243, N IV] λ1487, and N III] $\lambda\lambda$1749–1754, but the resonance lines C IV $\lambda\lambda$1548, 1550 and intercombination lines C III] $\lambda\lambda$1907, 1909, which are generally strong in objects of normal cosmic abundances, are conspicuously weak, or completely absent. At optical wavelengths, [N II] λ6584 produces the third strongest emission after Hα and [O III] λ5007. The optical and UV spectrum of LMC Anonymous indicates the presence of four ionization stages of nitrogen. The intersystem lines O IV] $\lambda\lambda$1401–1407 and O III] $\lambda\lambda$1660, 1666 may also be present in LMC Anonymous, but are weak. Numerous emission lines that include: [N II], [Ne III], [Ne V], [O I], [O III], [O II], [S II], [S III], He I, Fe VII, and the Balmer lines dominate its optical spectrum (see, e.g., Kafatos *et al.* 1983).

Lack of photometric variability makes LMC Anonymous similar to the luminous blue object S18 in the Small Magellanic Cloud (Shore, Sanduleak, and Allen 1987), but the luminosity of LMC Anonymous, however, is difficult to determine accurately because of uncertainties of extinction. Kafatos *et al.* (1983) adopt the extinction $E(B-V) = 0.3$, which is based on the He II line ratio, which is $I(\lambda1640)/I(\lambda4686) \sim 1.3$; this corresponds to an $E(B-V) \sim 0.3$ ($A_V = 1$ mag). However, from Allen (1980), the Balmer emission lines indicate $A_v = 4$ mag, or $E(B-V) = 1.2$. As discussed by Kafatos *et al.* (1983), the discrepancy between the He II and Balmer line ratio method could be explained if the optical depth in the hydrogen lines is large. UV continuum in the LWR/LWP 2000–3200 Å range of *IUE* was too weak to detect the λ2200 absorption feature to obtain an independent estimate of $E(B-V)$. However, Blair *et al.* (1983) have noted that estimates of extinction based on the

[1] Guest Investigator: International Ultraviolet Explorer

2200 Å feature may be unreliable for peculiar emission stars and symbiotics. The systematic effect may indicate a tendency toward peculiar ultraviolet extinction, in which the Balmer line ratios suggest reddening, while the far-UV is seemingly unaffected. This may have bearing on LMC Anonymous, if it is reddened by circumstellar dust, which makes a straightforward analysis difficult.

Although LMC Anonymous is an isolated field star in the LMC, and is not associated with extended nebular or H II emission, its far-UV spectrum is similar to the S condensation associated with the massive ($\sim 100\ M_\odot$) luminous ($\sim 10^{6.6}\ L_\odot$) galactic object η Carinae (see, e.g., Davidson *et al.* 1982, 1986). The absolute intensity of emission lines of N V, N IV], N III], Si III], and He II, and the absence of C IV and C III] emission which characterizes the *IUE* SWP spectra of the S Condensation, provides strong evidence that ejecta from η Carinae contains material that is rich in CNO-processed material, where a lower limit of $N/C \sim 50$, or a factor of at least 200 greater than normal cosmic abundances. Recently, the UV spectrum of the S Condensation has been compared with the narrow emission-line spectrum of SN 1987A (Kirshner 1988; Fransson *et al.* 1989), where the prominent lines of N V, N IV], and N III] of SN 1987A are believed formed in photoexcited circumstellar material, which was expelled from the 20 $M_\odot$, B3 supergiant progenitor, when SK $-69°202$ was undergoing core-envelope mixing, and a high rate of mass loss as a red supergiant.

Similarly, the strength of nitrogen lines in LMC Anonymous, which includes the intersystem lines of N IV], N III], and the permitted line of N V, compared with relative weak C IV and C III] emission, provides compelling evidence for CNO processing and core-envelope mixing in this object. However, the nitrogen overabundance with respect to carbon of LMC Anonymous exceeds normal cosmic values by a large factor, $\sim$400–600, which is significantly greater than SN 1987A, where $N/C \sim 8.8 \pm 4$ (Fransson *et al.* 1989), or a factor ~ 35 greater than normal values. Other related objects, such as the stationary flocculi in Cas A, show nitrogen overabundance by a factor 3–7 greater than normal cosmic values (Chevalier and Kirshner 1978). As such, the extremely large overabundance of nitrogen in LMC Anonymous, compared with supernova progenitors, and with estimates of N/C in the S Condensation of the massive object η Carinae, distinguishes Sanduleak's Star in the LMC from other systems that indicate CNO processing. These points are discussed in greater detail.

II. OBSERVATIONS

Low-resolution *IUE* spectra in the SWP 1200–2000 Å wavelength range were obtained exclusively in the large 10″ × 20″ entrance aperture on 1982 October 10 (SWP 18315; 295 minutes exposure) and 1985 July 1 (SWP 26327; 425 minutes exposure) of LMC Anonymous. An LWR 2000–3200 Å spectrum (LWR 14428; 120 minutes) revealed only a trace of continuum just above background. The SWP LORES spectra were obtained 986 days apart, and both show the emission lines of N V, N IV], He II, O III], N III], and weak C IV emission, while C III] may be present but just above background. In the longest exposure (SWP 18315) the N V line was $\sim$197 DN, or $\sim$57 DN above background. Absolute line intensities obtained for LMC Anonymous for both epochs are shown in Table 1, with lower limits indicated for C IV. The fluxes shown in Table 1 were obtained using the software data analysis routines available at the Regional Data Analysis Facility at NASA-GSFC.

TABLE 1

SANDULEAK'S STAR (LMC ANONYMOUS): UV LINES OBSERVED WITH *IUE*

Spectral Line	Absolute Flux[a] SWP 18315 (10/17/82)	Absolute Flux[a] SWP 26327 (7/1/85)
N V $\lambda\lambda$1239, 1243	2.3	2.3
N IV] λ1487	1.0	1.1
C IV λ1548, 1550	0.3	0.8[b]
He II λ1640	0.6	0.4
N III] $\lambda\lambda$1750	1.0	0.6
C III] $\lambda\lambda$1907, 1909	$\lesssim$0.1	$\lesssim$0.1

[a] ($\times 10^{-13}$ ergs cm^{-2} s^{-1}); fluxes not corrected for extinction; limiting spectral resolution $\Delta\lambda = 6$ Å.

[b] Indicates strong variability of factors $\sim$2–3 (*see text*).

We estimate that the photometric accuracy for emission lines that are $\sim$40–50 DN above background is $\sim$25%. Accordingly, the flux variation in C IV between 1982 and 1985 (Table 1) appears real, but further observations are required to positively establish variability in this line. Similarly, a suggestion of variability in the He II λ1640 line indicates the object may be quite active. The emission lines of N V, N IV], and N III], however, appear essentially constant. Weak continuum detected in the far-ultraviolet is probably due to free-free and free-bound emission.

In Figure 1, low-resolution far-UV spectrum of LMC Anonymous (*bottom panel*) is compared to spectra of the S Condensation in η Carinae (*middle panel*) (Davidson *et al.* 1986), and with the background subtracted spectrum of SN 1987A (*top panel*) (Fransson *et al.* 1989) obtained in 1987 December. An extinction correction was applied to SN 1987A of $E(B-V) = 0.2$, using the dereddening law for the 30 Dor region in the LMC of Fitzpatrick (1986). The three-point smoothed spectra of the S Condensation and LMC Anonymous are not corrected for extinction. The continuum in the SWP 1200–2000 Å range was quite weak, so an extinction-corrected spectrum is not feasible with the present data. The prominence of the nitrogen intercombination lines of N IV] λ1487 and N III] $\lambda\lambda$1749–1750 are characteristic of all three spectra, and the presence of N V $\lambda\lambda$1238, 1240 indicates high-excitation conditions of $T \sim 10^5$ K.

III. DISCUSSION

We can estimate the properties of the hot star in LMC Anonymous by first considering its apparent visual magnitude, which is $m_V \sim 16$ (Sanduleak 1977), which corresponds to an absolute magnitude of $M_V \sim -3.7$, for an LMC distance = 55 kpc. Limits on interstellar extinction can be derived from the He II λ1640 to He II λ4686 ratio and the Balmer line ratio (Kafatos *et al.* 1983; Allen 1980). From the He II line ratios that are expected to be $I(\lambda1640)/I(\lambda4686) \sim 7$ (Kafatos *et al.* 1983), the object is probably quite heavily reddened. The Balmer decrement is too steep for either of the two cases A or B considered by Pengelly (1964) to be reliable, unless there is substantial reddening. The surrounding nebula could also be optically thick to the Lyman Balmer lines if the emission measure is large. We have used the formulae of Cox and Mathews (1969) and have found that reasonable agreement is achieved if we adopt an intermediate value of $E(B-V) \sim 0.9$. The optical depth in Hα would then be appreciable, i.e., of $\sim$5–10. The optical depth in Lyα is expected to be quite large as well, i.e., $\gtrsim 10^9$. Accordingly, determining an accurate far-UV flux distribution with wavelength is difficult because of the uncertainties in extinction.

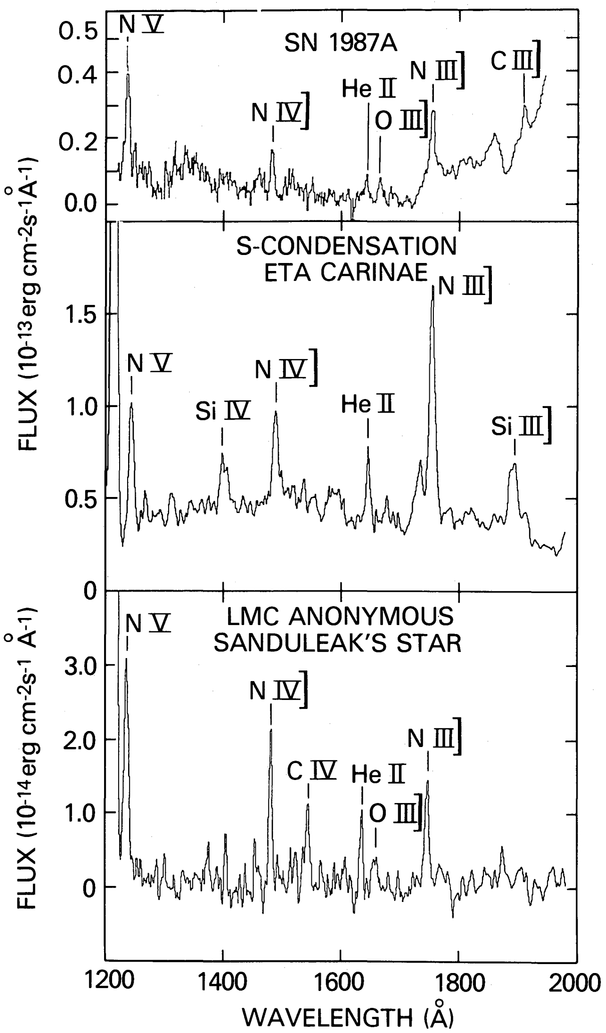

FIG. 1.—*Top: IUE* low-resolution spectrum in the SWP λλ1200–2000 Å camera of SN 1987A obtained by Fransson *et al.* (1988), representative of the narrow–low velocity emission spectrum associated with circumstellar material in 1987 December. The spectrum is an average of exposures in which the contributions from several B stars in the aperture have been removed. Narrow emission lines consisting of N v, N iv], He ii, O iii], N iii], and C iii] are evident. An $E(B-V) = 0.2$ has been applied to the spectrum using the LMC extinction values of Fitzpatrick (1986). *Middle:* The S-Condensation of η Carinae obtained by Davidson *et al.* (1986). The spectrum is not dereddened, but the extinction estimated for the S Condensation is $E(B-V) = 0.6$ (Davidson *et al.* 1986). Prominent emission lines of N v, N iv], N iii] are present, together with He ii, Si iv], and Si iii] are prominent. *Bottom:* Low-resolution spectrum obtained on 1985 July 1 (SWP 26732) of LMC Anonymous (Sanduleak's Star) by Kafatos *et al.* (1983). The relative emission line intensities of N v, N iv], and N iii] are similar to the S-condensation in η-Carinae. Weak C iv λλ1548, 1550 emission is present, which may be variable on time scales of at least 3 yr. The intersystem emission lines of C iii] λλ1970, 1909 are not evident, further indicating a depletion of carbon in circumstellar material. The spectrum has not been corrected for reddening.

Because of these uncertainties, we have determined a range of properties of LMC Anonymous by varying $E(B-V)$ as a parameter. Note that the component of extinction intrinsic to the LMC is small, $E(B-V) \sim 0^{m}.05$, so that substantially large values of absorption in the direction of LMC Anonymous imply the presence of circumstellar dust. However, the *IRAS* Point Source survey failed to detect any measurable infrared emission within a 1″ radius of LMC Anonymous, but the possible presence of dust will be discussed further in the text. We can estimate the Zanstra temperature from the He ii λ4686 to Hβ λ4861 (Kafatos *et al.* 1983; Seaton 1960) ratio, where the effective temperature of the star is not strongly dependent on $E(B-V)$; we find that $T_{\rm eff} \sim 120{,}000$ K. A lower limit of $T_{\rm eff}$ can also be obtained from the He i λ5876 to Hβ λ4861 ratio (Kafatos *et al.* 1983; Seaton 1960), which indicates $T_{\rm eff} \sim 40{,}000$ K. However, this lower limit is sensitive to the value of $E(B-V)$ assumed. Furthermore, radiative transfer effects could explain this large disparant range of effective temperatures. In any case, the unusual strength of N v λλ1238, 1242 requires a rather high effective temperature of the ionizing source, say of $\gtrsim 10^5$ K. A similar problem is seen in S18/SMC (Shore *et al.* 1987). The presence of the unidentified emission feature at 6830 Å in LMC Anonymous, which is found only in high-excitation symbiotic stars when [Fe vii] emission bands are present, could also reflect high values of $T_{\rm eff}$.

The UV emission line intensities can be used to estimate the emission measure $n_e^2 L^3$, which is proportional to the number of photoionizations per second, where L is the pathlength of the emitting region (Kafatos *et al.* 1983). The emission measure, however, is also a strong function of absorption, especially from density sensitive line ratios in the far-UV. The electron density n_e can be estimated from the ratios of the optical forbidden lines. We assume in all cases that the nebular temperature is $T_e \sim 10^4$ K, appropriate for photoionization. From the number of photoionizations per unit time, N_i, we can obtain a lower limit to the photoionizing flux $L_i = I_{\rm H} N_i$, where $I_{\rm H}$ is the ionization potential for hydrogen. A lower value to the bolometric luminosity is obtained, and from M_V and $M_{\rm bol}$ we can estimate a lower limit of $T_{\rm eff}$, and determine the spectral type of the star. The values shown in Table 2 are lower limits and therefore are not in disagreement with the Zanstra temperature.

The range of stellar parameters shown in Table 2 indicates that LMC Anonymous is a hot star whose estimated luminosity is consistent with a giant or even a supergiant if the extinction $E(B-V) \gtrsim 1$. For comparison, the SN 1987A progenitor was a B3 supergiant (Rousseau *et al.* 1978), with $M_V \sim -6.9$, which is appreciably greater than the M_V estimated here for LMC Anonymous of $M_V \lesssim -5.4$, which corresponds to an $E(B-V) \sim 0.9$. Truran and Weiss (1988) have shown evolutionary tracks relevant to SN 1987A for metalicities appropriate to the LMC. For a 20 $M_\odot$ star, the bolometric magnitude is $M_{\rm bol} \sim -6.8$, while the star is on the main sequence, and $M_{\rm bol} \sim -7.8$, when it evolves off the main sequence. For a 15 $M_\odot$ evolutionary track on and off the main sequence, $M_{\rm bol} \sim -6.0$ and -6.8, respectively. The luminosity of LMC Anonymous, when compared to the theoretical tracks, would yield a mass lower than 15 $M_\odot$, unless $E(B-V)$ is greater than unity. However, the presence of strong UV line emission, particularly the great strength N v, argues for much higher temperatures than those appropriate for an early-type B supergiant; it is possible that the LMC Anonymous are more like a Wolf-Rayet star. However, with $E(B-V) \sim 1$, LMC Anonymous has a corrected V magnitude of $m_V \sim 13$, making it as bright as, say, the luminous blue object S 18-SMC, where $m_V \sim 13.5$ (Shore *et al.* 1987). If LMC Anonymous is earlier than an O7 star, its magnitude increases by a BC $\lesssim 3.7$, and the bolometric magnitude increases to $M_{\rm bol} \sim -9.5$. This corresponds to a rather luminous supergiant in the LMC. The high value of $E(B-V)$ would imply then that a considerable amount of dust is likely present in the envelope, similar to η

TABLE 2

Stellar Parameters

$E(B-V)$[a]	$T_{\rm eff}$[b] (K)	T_e[c] (K)	n_e(cm^{-3})[c]	$n_e^2 L^3$(cm^{-3})	L(cm)[d]	$M(M_\odot)$[e]	$T_{\rm eff}$[f] (K)	Spectral Type[g]
0.3..........	120,000	10^4	10^7	5.1×10^{60}	3.7×10^{15} cm	2.1×10^{-4}	$\gtrsim$13,000	B7III-II
0.9..........	120,000	10^4	10^7	4.2×10^{62}	1.6×10^{16}	1.8×10^{-2}	$\gtrsim$35,000	07 V
1.3..........	120,000	10^4	10^7	10^{64}	4.7×10^{16}	4.2×10^{-1}	$\gtrsim$60,000	03 I

[a] Assumed values—best value is 0.9 (*see text*).
[b] Estimated from the He II/Hβ ratio (*see text*).
[c] Nebular temperature assumed, the density then is $n_e \sim 10^7$ cm^{-3} (Kafatos *et al.* 1983).
[d] L is the size of the nebula.
[e] M is the mass of the photoionized region.
[f] Estimated from the emission measure and is a lower limit (*see text*).
[g] Spectral type corresponding to lower limit of $T_{\rm eff}$.

Carinae, and to many of the extreme evolved LMC supergiants. In terms of the relative strengths of the N V, N III], and N IV] lines, a substantial correction of absorption of $E(B-V) \sim 1$ would tend to increase N V and N IV] relative to N III], as evident in the low-resolution SWP extinction corrected spectrum [$E(B-V) = 0.3$] shown by Kafatos *et al.* (1983). On the other hand, if LMC Anonymous is more like η Carinae, which is heavily core reddened, the central object could still be quite luminous, while the extended emission line forming regions are not significantly affected by absorption.

In terms of the nitrogen line strengths relative to carbon and oxygen, IUE SWP 1200–2000 Å spectrum of LMC Anonymous resembles that of the emission-line spectrum of SN 1987A (Fig. 1, *top panel*), as well as the spectrum of the S Condensation in η Carinae (Fig. 1, *middle panel*). A lower limit of the N/C = 8.8 ± 4 and N/O = 1.5 ± 0.8 was found by Fransson *et al.* (1989) in the low-velocity material associated with SN 1987A. The source of photoionized nitrogen-rich material in SN 1987A is explained by the supernova shock impacting the surface of B3 supergiant progenitor. The resulting intense UV radiation photoionizes low-velocity material in a circumstellar region, which was formed when SK $-69°$ 202 was in the high mass-loss phase as a red supergiant. Thus, the composition of circumstellar material from SK $-69°$ 202 should reflect core-envelope mixing prior to core-collapse (Kirshner 1988). A similar process may have also been indicated in the supernova remnant Cas A, where the progenitor probably underwent a phase of high mass loss, until $\sim$40% of the original 25 $M_\odot$ star was lost (Lamb 1978). At the end of the significant mass loss phase, the surface composition of the star was significantly overabundant in ^{14}N relative to ^{12}C (Lamb 1978).

The S Condensation of η Carinae is one of a number of gaseous features which were expelled during repeated outbursts from the massive O3 supergiant, whose luminosity is estimated to be $L = 10^7 L_\odot$ ($M_{\rm bol} \sim -12.5$) (Davidson *et al.* 1982, 1986). The nitrogen to carbon emission-line strengths of the S Condensation indicates strong evidence for CNO-processing, where the N/C is at least $\sim$50. η Carinae is not a pre–main-sequence star, but is probably an evolved massive $\sim$100 $M_\odot$, blue object in advanced stages of evolution (Davidson *et al.* 1986).

In LMC Anonymous, the relative strengths of the intercombination lines of N III], N IV] in the UV, and nebular forbidden lines of [O III] and [N II] in the optical indicate it also has a wind rich in CNO products, which has formed a circumstellar region during a high mass-loss phase, perhaps as a red giant or supergiant. P Cygni line profile structure in the UV and optical emission lines is not evident, although line profile asymmetry which extends the blue wings of the nitrogen lines could indicate mass outflow. If the extinction is based on the He II $I(\lambda1640)/I(\lambda4686)$ ratio which yields an $E(B-V) \sim 0.9$, we find that the observed nebular mass implies a rather high rate of mass loss of $\dot{M} \sim 7 \times 10^{-4} M_\odot$ yr^{-1}, if most of the nebular material was supplied during the hot star evolutionary phase, where $v_{\rm esc} \sim 2000$ km s^{-1}. On the other hand, a more reasonable mass-loss rate of $\dot{M} \sim 10^{-5} M_\odot$ yr^{-1} (Shore *et al.* 1987) if most of the photoionized nebula was created in a slow wind, where $v_{\rm wind} \sim 30$ km s^{-1}, which lasted $\sim 10^6$ yr when LMC Anonymous was a red giant or supergiant, would imply the circumstellar shell is very extended. Evidence for infrared emission at the position of LMC Anonymous is not indicated in the *IRAS Point Source Catalog*. However, the presence of circumstellar dust can not be immediately dismissed because the discrepancy apparent from the He II lines which yield an $E(B-V) \sim 0.3$, and from the Balmer lines which indicate $E(B-V) \sim 1.3$ (Kafatos *et al.* 1983), suggests that circumstellar dust could have anomalous absorption properties. Moreover, a few heavily reddened symbiotic stars with dust (D-types) indicate significant absorption based upon the Balmer line ratios that imply an $E(B-V) \sim 1$. However, they indicate little if any extinction from the 2200 Å absorption feature. In the LMC, luminous blue stars that are IRAS dust sources do not indicate absorption based on the 2200 Å absorption feature (Stahl 1988). Moreover, a dust shell surrounding LMC Anonymous could be rather diffuse, and of order a few parsecs in size, consistent with an average mass-loss rate of $10^{-5} M_\odot$ yr^{-1}. Thus, LMC Anonymous could escape detection in the infrared.

Compared with the SN 1987A and the S Condensation, LMC Anonymous indicates extreme departures from normal cosmic values of nitrogen relative to carbon and oxygen, where N/C $\sim$ 150 and N/O $\sim$ 70 for $E(B-V) = 0.3$. These results are moderately sensitive to the electron temperatures assumed. Davidson *et al.* (1986) assumed that $T_e \sim$ 13,500–16,000 K for the S Condensation, for which they found N/C $\sim$ 50. For SN 1987A, $T_e \sim$ 30,000 K (Fransson *et al.* 1989), while for LMC Anonymous, the range of abundances N/C $\sim$ 100–150, resulting in a nitrogen overabundance relative to carbon of factors 400–600 that corresponds to $T_e \sim$ 20,000 K and $T_e \sim$ 10,000 K, respectively. If T_e of LMC Anonymous is greater, a smaller N/C ratio would be obtained, although this would be difficult to reconcile with photoionization models (see, e.g., Kafatos *et al.* 1983). We emphasize that the N/C $\sim$ 50 ratio obtained by Davidson *et al.* (1986) should be considered a lower limit, and N/C in the S Condensation could be much larger, and comparable to our estimates for LMC Anonymous.

Precise values for abundances are difficult to obtain because N/C depends critically on $E(B-V)$ and T_e. However, for comparison, the high excitation planetary nebula NGC 6302 indicates a nitrogen overabundance of ~ 10 over normal solar values (Aller *et al.* 1981), even though C IV λλ1548, 1550 and C III] λλ1906, 1909 are comparable in emission strength to N III], *N* IV], and N V; C IV in fact is the strongest emission line in the *IUE* SWP λλ1200–2000 range in NGC 6302 (see, e.g., Aller *et al.* 1981). Accordingly, we suspect that in objects where carbon is extremely weak or completely absent, the nitrogen overabundance is correspondingly very large, i.e., by a factor ~ 100, consistent with our estimates for LMC Anonymous.

The strong overabundance of nitrogen relative to carbon and oxygen in the emission line–forming region of LMC Anonymous suggests that CNO cycle is in complete equilibrium. Alternatively, large values of N/C could indicate that core dredge-up and C-N envelope burning has occurred simultaneously (Ulrich and Scalo 1972). Evolutionary tracks for intermediate-mass stars of 2–8 $M_\odot$, with low-metalicity $Z = 0.02$, while in the helium-burning region of the asymptotic giant branch can produce large variations in the C/O and N/O if the dredge up is also occurring. Abundance ratios can vary by factors of ~ 50, and the product of ^{13}CxN can vary by a factor of ~ 500, depending on the initial mass and initial metalicities assumed (see, e.g., Iben and Renzini 1984). These ultraviolet spectra of LMC Anonymous may provide evidence for this process.

IV. SUMMARY AND CONCLUSIONS

Low-resolution *IUE* SWP spectra of the peculiar object LMC Anonymous (Sanduleak's Star) indicates strong evidence for CNO-processed nebular in the vicinity of the star. The luminosity of LMC Anonymous is difficult to determine because of uncertainties in extinction, but the He II $I(\lambda 1640)/I(\lambda 4686)$ line ratios indicate an $E(B-V) = 0.9$, which corresponds to an O7 V star, or for the case $E(B-V) = 1.3$, an O3 I star with $T_{\rm eff} = 120{,}000$ K. Convective mixing in O and B type stars has been suggested to result in a massive star such as η Carinae evolving quasi-homogeneously, so that material drawn to the stellar surface reflects the nuclear processes of the core (Maeder 1987). The extreme departures from normal cosmic abundances of N/C ~ 150 and N/O ~ 70 compared with either the S Condensation of η Carinae, or with the low-velocity circumstellar region of SN 1987A, may indicate that envelope burning during core dredge-up occurred simultaneously, when LMC Anonymous was in the helium-burning region of the asymptotic giant branch, where most of the carbon was being processed into nitrogen.

C IV λλ1548, 1550 fluxes obtained nearly 3 yr apart indicate an increase by at least 60% between 1982 to 1985. The stronger UV lines of N V and N IV] have remained essentially constant over this period (Table 2); N III] and He II λ1640 indicate evidence for variability at the 30% level. If confirmed by future observations, variability of the carbon emission-line strengths could reflect the time scale for convective mixing of core and envelope material, although this will be difficult to establish with the present *IUE* data base. The constant flux observed in the prominent emission lines of N V, N IV], and N III] may indicate that dredge-up occurs over the entire envelope depth, down to the He-shell burning surface, where carbon is produced. Nitrogen would remain fairly constant and more intense relative to carbon, because the CNO products are formed further from the core, whereas carbon is more affected by mixing. If variability in carbon emission is confirmed in future *IUE* observations of LMC Anonymous, it could provide important information concerning the relevant time scales of convective motion deep in the stellar interiors of evolved stars of intermediate mass; C IV line intensity variations can not be primarily the result of ionization changes in the nebula, because we would have expected the intercombination lines of N IV] and N III] to also vary accordingly. More observations will be required to further investigate this point. Future ground-based and spaceborne observations with *IUE* and the Hubble Space Telescope will be required to investigate the temporal nature of emission lines of this extremely interesting object in greater detail.

This work was supported under the *IUE* Guest Investigator Program in the Laboratory for Astronomy and Solar Physics at NASA Goddard Space Flight Center.

REFERENCES

Allen, D. A. 1980, *Ap. Letters*, **20**, 131.
———. 1984, *Pub. Astr. Soc. Australia*, **5**, 369.
Aller, L. H., Ross, J. E., O'Mara, B. J., and Keyes, C. D. 1981, *M.N.R.A.S.*, **197**, 95.
Blair, W. P., Stencel, R. F., Feibelman, W. P., and Michalitsianos, A. G. 1983, *Ap. J. Suppl.*, **53**, 573.
Chevalier, R. A., and Kirshner, R. P. 1978, *Ap. J.*, **219**, 931.
Cox, D. P., and Mathews, W. G. 1969, *Ap. J.*, **155**, 859.
Davidson, K., Dufour, R. J., Walborn, N. R., and Gull, T. R. 1986, *Ap. J.*, **305**, 867.
Davidson, K., Walborn, N. R., and Gull, T. R. 1982, *Ap. J. (Letters)*, **254**, L47.
Fransson, C., Cassatella, A., Gilmozzi, R., Panagia, N., Wansteker, A., Kirshner, R. P., and Sonneborn, G. 1989, *Ap. J.*, **336**, 429.
Fitzpatrick, K. C. 1986, *A.J.*, **92**, 1068.
Iben, E., Jr., and Renzini, A. 1984, *Phys. Repts.*, **105**, 331.
IRAS Point Source Catalog. 1985, Joint *IRAS* Science Working Group (Washington, DC: US GPO).
Kafatos, M., Michalitsianos, A. G., Allen, D. A., and Stencel, R. E. 1983, *Ap. J.*, **275**, 584.
Kirshner, R. P. 1988, in *Proc. 4th Workshop in Astrophysics, SN 1987A in the Large Magellanic Cloud*, ed. M. Kafatos and A. G. Michalitsianos (Cambridge: Cambridge University Press), p. 87.
Lamb, S. A. 1978, *Ap. J.*, **220**, 186.
Maeder, A. 1987, *Astr. Ap.*, **173**, 287.
Michalitsianos, A. G., Kafatos, M., Feibelman, W. A., and Hobbs, R. W. 1982, *Ap. J.*, **253**, 735.
Pengelly, R. M. 1964, *M.N.R.A.S.*, **127**, 145.
Rousseau, J., Martin, N., Prevot, E., Rebeirot, A., Robin, A., and Brunet, J. P. 1978, *Astr. Ap. Suppl.*, **31**, 243.
Sanduleak, N. 1977, *Inf. Bull Var. Stars*, No. 1304.
Seaton, M. J. 1960, *Rept. Progr. Phys.*, **23**, 313.
Shore, S. N., and Allen, D. A. 1987, *Astr. Ap.*, **176**, 59.
Stahl, O. 1988, in *Proc. IAU Colloq. 113, Physics of Luminous Blue Variables*, Val Morin, Quebec, Canada, 1988 August 15–18, in press.
Truran, J. W., and Weiss, A. 1988, in *Supernova 1987A in the Large Magellanic Cloud*, ed. M. Kafatos and A. G. Michalitsianos (Cambridge: Cambridge University Press), p. 313.
Ulrich, R. K., and Scalo, J. M. 1972, *Ap. J. (Letters)*, **176**, L37.

M. KAFATOS: Department of Physics, George Mason University, Fairfax, VA 22030

A. G. MICHALITSIANOS: Laboratory for Astronomy and Solar Physics, Code 684.1, NASA Goddard Space Flight Center, Greenbelt, MD 20771

S. N. SHORE: Department of Physics, Astrophysics Research Center, New Mexico Institute of Mining and Technology, Socorro, NM 87801