Emission-Line Properties of the LMC Bubble N70

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ABSTRACT

We present a spectrophotometric imaging study of the emission bubble N70 (DEM 301) in the Large Magellanic Cloud. N70 is approximately 100 pc in size with a nearly circular shell-like morphology. The nebular emission is powered by an uncertain combination of EUV photons, intense winds, and supernova shock waves from the central population of high-mass stars (the OB association LH 114). We have obtained narrow-band images (FWHM ∼6Å) of N70 in the light of Hαλ6563, [N II]λ6584, [S II]λλ6717,6731, and [O III]λ5007, along with the corresponding red and green continua. The resulting line fluxes and flux ratios are used to derive ionization rates, nebular densities, volume filling fractions, and excitation indices. The photoionizing luminosity inferred from the embedded stellar population is more than adequate to account for the observed hydrogen ionization rate.

We compare the emission-line photometry with that derived from similar imaging of the Orion nebula and with data collected from the literature on other emission-line regions in the LMC. Compared to the Orion nebula, N70 shows much higher [S II]/Hα intensity ratios which increase smoothly with radius — from < 0.3 near the center to > 1.0 towards the outer filamentary shell. The measured intensity ratios in N70 more closely match the range of excitation spanned by giant and supergiant H II shells and by some of the supernova remnants observed in the LMC. The contending ionization and excitation processes in the interior and outer shell of N70 are evaluated in terms of the available data. EUV photons probably contribute most of the inner nebula’s ionization, whereas a combination of photoionization plus collisional ionization and excitation of sulfur atoms by low-velocity shocks seems to best fit the emission-line luminosities and intensity ratios observed in the outer shell.
Considerations of the radiative and mechanical energetics that are involved may indicate the need for one or two supernova explosions having occurred during the last $\sim$ Myr.
1. Introduction

N70 (DEM 301; $5^h43^m16^s −67°50'53''$ (J2000)) in the Large Magellanic Cloud is an especially prominent bubble of line-emitting gas which appears to be powered by a population of hot massive stars in its interior. Its nearly circular symmetry has prompted several studies aimed at determining which mechanisms govern the dynamical and radiative evolution of this seemingly isolated and “simple” starburst. An early spectrophotometric study by Dopita et al. (1981) led to the conclusion that N70 represents a giant cavity that has been blown into a massive H I cloud by the embedded cluster of hot, windy stars. Ultraviolet radiation from the O stars was regarded as the dominant source of ionization in the shell.

Lasker (1977) suggested that additional excitation by stellar winds is necessary to explain the high $[S \text{II}]/\text{H}\alpha$ line ratios that he observed. The detection of lopsided X-ray emission from the southwestern quadrant of N70 indicated to Chu and Mac Low (1990) that a supernova explosion occurred inside a wind-blown bubble. The energy from such a supernova would have provided additional heating of the gas inside the bubble, accounting for the higher-than-expected X-ray emission, and could have shocked the pre-existing shell of warm gas in the visible shell, raising its $[S \text{II}]/\text{H}\alpha$ line ratio.

More recently, Oey (1996a, 1996b) has attempted to explain the dynamics of N70 with standard pressure-driven bubble models; in doing so, she has examined the stellar population of the central OB association, LH 114 (Lucke and Hodge 1970). The current population of stars in LH 114 has an initial mass function (IMF) slope consistent with a Salpeter IMF slope. If only the stars interior to the edge of the nebula are considered, a slightly flatter slope of $\Gamma \sim −1.0$ is determined ($\Gamma_{\text{Sal}} = −1.35$). The mean age of these stars is approximately 5 million years; three stars are approximately 40 $M_{\odot}$ and none are more massive (Oey 1996a).
Based on this inferred age, Oey found that N70 is a “high-velocity” superbubble which is dynamically inconsistent with the standard model—the expansion velocities observed in N70 being too high for the observed radius and age (Oey 1996b). This, of course, assumes that the motions observed in N70 are in fact due to expansion, which Dopita et al. (1981) contests. Kinematics of N70 have been observed by Dopita et al. (1981), Rosado et al. (1981), Blades et al. (1980), Georgelin et al. (1983), and Lasker (1977), yielding velocity dispersions of order 40 km s\(^{-1}\) but differing conclusions regarding the overall velocity field.

In this paper, we present narrow-band images of the ionized bubble in the light of \(\text{H}\alpha\), [S II], [N II], and [O III]. These images were taken at the CTIO 1.5-m telescope with the Rutgers Fabry Perot imaging system and Goddard Fabry Perot etalons whose tunable narrow-band capability enables the clean separation of the \(\text{H}\alpha\lambda6563\) and [N II]\(\lambda6584\) lines as well as the doublet lines of [S II]\(\lambda6717\) and [S II]\(\lambda6731\). The resulting line flux and flux ratio measurements are used to derive nebular ionization rates, densities, volume filling fractions, and indices of excitation. Analysis of these spectrophotometric indices and comparison with similar data on the Orion nebula and other line-emitting sources in the LMC indicates that a mix of radiative and collisional (shock) processes is responsible for ionizing and exciting the gas in this shell. Empirically, the N70 flux ratios span a range of values similar to that of other LMC giant and supergiant shells except for a few regions with unusually high [S II] that are more characteristic of supernova remnants. A comparison with shock models (e.g. Shull and McKee 1979, Hartigan et al. 1994) indicates that the high [S II]/\(\text{H}\alpha\) line ratios and the low, Orion-like [N II]/\(\text{H}\alpha\) line ratios in N70 are difficult to reconcile with a hybrid mode of nebular photoionization and shock-excitation without invoking special circumstances.

The Fabry-Perot observations of N70 and the data reduction are described in Section 3. Images of the \(\text{H}\alpha\), [N II], [S II], and [O III] line emission and of their intensity ratios
are presented and discussed in Section 3. Comparisons with the Orion Nebula, other line emitting regions in the LMC, and nebular models are made in Section 4, where constraints on the total radiative and mechanical energetics are considered. A summary of our results is presented in Section 5.

2. Fabry-Perot Observations and Reductions

Compared to the previous spectrophotometric studies of N70 (Dopita et al. 1981, Lasker 1981), the observations presented herein represent an improvement in sensitivity and multi-spectral coverage at H\(\alpha\), [N II], [S II], and [O III], including resolution of the [S II] doublet, thereby enabling a more detailed and comprehensive analysis of the nebular ionization and excitation. While previous studies have presented images of N70 in the light of H\(\alpha\), none have imaged the entire nebula in [N II], [S II], or [O III] using CCD technology or the very narrow bandwidths allowed by Fabry-Perot cameras. While the spectroscopy employed by these studies allows one to obtain kinematic information, the present observations are the first to afford a comprehensive look at how the emission line fluxes and ratios change on small scales (< 1 pc). Imaging of the Orion nebula (M42, NGC 1976) was obtained to provide a check on the spectrophotometric reductions and subsequent interpretations.

2.1. Observations

N70 and the Orion nebula were imaged with the CTIO 1.5-m telescope and Rutgers Fabry-Perot camera between 28 October and 1 November 1993. The imaging system consisted of a piezoelectrically controlled scanning etalon and a servocontroller, both made by Queensgate Instruments, Ltd. (Atherton et al. 1981), an interference filter with \(\approx 100\AA\)
bandwidth to block out multiple interference orders, re-imaging optics, and a CCD detector. Instead of the high-spectral resolution etalons (FWHM $\approx 1\text{–}2\text{Å}$) that are standard with the Rutgers Fabry-Perot camera, we installed lower-resolution etalons (FWHM $\approx 5\text{–}30\text{Å}$) normally resident in the Goddard Astronomical Fabry-Perot Imaging Camera (GAFPIC, Brown et al. 1994). These etalons, also made by Queensgate, are optimized for imaging nebular emission in a variety of lines rather than mapping the nebular kinematics in just one line. The calibration of etalon spacing as a function of wavelength was obtained by scanning the line emission from spectral lamps. This was done several times each night, thereby attaining tuning accuracies of less than $\pm 1\text{Å}$.

Initial observations were made with the Goddard “blue” etalon and CTIO’s Tek#4 512×512 CCD chip, where the image scale was 1\text{″}1 pixel$^{-1}$ and the total field of view was circular with a diameter of 7\text{′}2. The “blue” etalon was tuned to a bandwidth of 7$\pm 1\text{Å}$ (FWHM) for imaging the \[\text{O III}\] emission and green continuum. During the second half of the run, observations were made with the Goddard “red” etalon and the Tek 1024 #1 chip; the image scale was 0\text{″}96 pixel$^{-1}$ and the resulting field of view was circular with a diameter just over 7\text{′}. The Goddard “red” etalon was tuned to a bandwidth of 6$\pm 1\text{Å}$ (FWHM) for the H\text{α}, \[\text{N II}\], and \[\text{S II}\] observations. The average radial velocity of N70 with respect to the local standard of rest is $\sim 290$ km s$^{-1}$ (Dopita et al. 1981), resulting in a redshift of the \[\text{O III}\]\(\lambda 5006.8\) line to 5011.6Å, H\text{α}\(\lambda 6562.8\) to 6569.1Å, \[\text{N II}\]\(\lambda 6583.6\) to 6590.0Å, \[\text{S II}\]\(\lambda 6717.0\) to 6723.5Å, and \[\text{S II}\]\(\lambda 6731.3\) to 6737.8Å. Atmospheric seeing averaged 2\text{″}2 (FWHM), enabling spatial resolution on the order of 0.6 pc, assuming a distance of 55 kpc to the LMC ($m – M = 18.7$; Feast and Catchpole 1997). Sky transparency varied from clear to heavy cirrus. A summary of the imaging is presented in Table 1.
2.2. Reductions

Overscan fitting and subtraction, residual bias averaging and subtraction, domeflat averaging and division, and skyflat smoothing and division were carried out using the CCDRED routines within IRAF\footnote{IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.}. The standard and target frames were air-mass corrected using the mean extinction coefficients at Cerro Tololo (Stone and Baldwin 1983). Cosmic rays were removed with the \texttt{cosmicrays} task, which can be used to identify cosmic rays in fields where only one image has been obtained.

The H\textsubscript{\alpha}, [S II], [N II], and red continuum images were calibrated with spectrophotometric standards taken close in time to the N70 observations (LTT 9239 and LTT 2415; Hamuy et al. 1992, Stone and Baldwin 1983). The standards were chosen because they have weak Balmer absorption lines, so their flux ($F_{\lambda}$) is almost constant in the wavelength region of interest. We interpolated between the published fluxes (in 50Å bins) to arrive at the predicted flux through our 6Å bandpasses. The standard star calibration error is estimated at $\lesssim 15\%$.

The images of the Orion nebula were taken during cirrus and intermittent clouds, so calibration with standard stars was not possible. Therefore, we bootstrapped our Orion calibrations to the wide-field images at H\textsubscript{\alpha}, [N II], and [S II] (FWHM = 15Å, 15Å, 36Å, respectively) that were obtained by Walter et al. (1992) under photometric skies; this procedure should yield photometric accuracies of approximately 10%.

Because the [O III] and green continuum images of N70 were taken in cirrus, they could not be calibrated with observations of standard stars. Instead, an approximate
calibration was constructed based on the observed spectral types of the ionizing stars in N70. The spectral energy distributions of six stars classified between O5 and B0 (Oey 1996a) were estimated based on the Silva and Cornell (1992) library of stellar optical spectra. The closest spectral type in the catalog was chosen for each star, and the flux at the green continuum (5031 Å) was predicted based on the calibrated flux at 6751 Å. The green continuum image was calibrated to yield the correct stellar fluxes in the presence of foreground reddening ($E(B - V) = 0.06$), and the [O III]-band image was matched to it. The scatter in measured 6751 Å to 5031 Å flux is about 20%, so we can determine the green continuum calibration only to this accuracy at best. Regardless of the uncertainty in the absolute calibration, this [O III] image of N70 is the first to be published, revealing unique morphological characteristics that have been previously unrecognized.

Once the individual images were calibrated and sky background subtracted, the closest continuum image was subtracted from the on-line image to form an emission image. These emission maps are presented in the next section. One of the difficulties with Fabry-Perot imaging is that the central wavelength of the bandpass changes with radial distance from the center of the field of view. The stellar spectra are essentially flat over the wavelength range of the individual observations, so the continuum images are unaffected. However, the emission-line images are subject to an increasing blueshift with field angle, amounting to $\sim 4$ Å at the edge of the field (Atherton et al. 1981; Caulet et al. 1992). The net effect of this shifting of peak transmissivity is to decrease the monochromatic sensitivity at the edge of the field.

To correct for this effect, post-observation “spectral flat fields” were made using images of the Orion nebula that were taken with fixed-wavelength interference filters (Walter et al. 1992). The spectral flats were created by dividing Walter et al.’s Orion images by the corresponding Fabry-Perot images and smoothing the results. This was done with the
continuum-subtracted images in Hα, [N II], and [S II](λ6717 + λ6731). Because Walter et al.’s [S II] image includes both [S II] doublet lines, the individual [S II] images could not be corrected separately; however, the individual corrections should be very similar, so the line ratio λ6717/λ6731 is basically unaffected. After correction by these spectral flats, the total net line fluxes of N70 increased by factors of 1.25 in Hα, 1.05 in [N II], and 2.32 in [S II].

The large increase in [S II] flux is due to the concentration of [S II] emission at the edges of N70, near the edge of the field. Line ratios were not as affected, changing by less than 10% at the edge of the field for [N II]/Hα and up to 50% for [S II]/Hα. No corrections were made to the [O III] images.

Reddening corrections were determined based on Oey’s spectroscopy and photometry of stars in LH 114 (the association inside N70); her median $E(B-V)=0.06$ (Oey 1996a) was used with reddening coefficients from Mathis (1990) ($R_V = 3.1$) to determine the interstellar reddening and extinction (0.2 magnitudes in $V$). When comparing line ratios, it is worth noting that Dopita et al. (1981) used $A_V = 0.6$ magnitudes, which over-corrects in the blue.

Intensity ratio maps, presented in the next section, were created by dividing the dereddened emission images. The line ratios that are tabulated and discussed are given for specific regions in the nebulae, where the aperture photometry was done on the emission line images and then the summed fluxes were ratioed. Both observed and dereddened Hα fluxes are presented; the low level of reddening derived for N70 means that dereddened [N II]/Hα and [S II]/Hα ratios remain essentially unchanged from the observed values.
3. Emission-Line Maps and Spectrophotometry

Observations of N70 over the past twenty years have revealed an ionized shell with remarkable spectrophotometric properties. The current Fabry-Perot data provide observations of the main circular structure of N70 at Hα, [N II], [S II], [O III], and their respective line ratios. The FWHM of stellar images is 2.3 pixels, or 2″2. At an LMC distance of 55 kpc, this allows spatial resolution on the order of 0.6 pc.

3.1. Maps

Figure 1a is the final dereddened Hα image of N70. The locations of the two O stars D301-1005 and D301NW-8 (notation of Oey (1996a)) are marked in it and all subsequent emission images and ratio maps. These stars are marked with the larger crosses in Figure 1b, the 6536Å continuum. The labeled stars in this figure are those which Oey (1996a) classified; their spectral types are noted. Oey chose stars with a reddening-free index $Q = (U - B) - (B - V) \leq -0.70$ and $V \leq 16.0$; her sample should be reasonably complete in O to early B stars. The stellar content will be discussed more fully below. Note the lack of nebular emission in the continuum image, indicating that N70 is truly an emission-line nebula with negligible scattered continuum light.

The other three N70 emission-line images [N II]λ6584, [S II]λ6717 + λ6731, and [O III]λ5007 are presented in Figures 2a, 2b, and 2c, respectively. The [S II] and [O III] images are at the original resolution, but [N II] was smoothed with a 2 pixel (1″92) Gaussian to increase the signal-to-noise in the displayed image.
The H\(\alpha\), [S II], and [O III] images were combined to form the color-coded image shown in Figure 3. Blue is [O III], green is H\(\alpha\), and red is [S II]. The colors were scaled so that features of all three emission lines could be seen. This picture, along with Figures 1 and 2, shows that despite the overall circular symmetry of N70, significant and unique substructure exists at each emission line.

EDITOR: PLACE FIGURE 3 HERE.

Most notably, strong H\(\alpha\) and [O III] emission is evident interior to the outer shell, whereas the [S II] image shows no such central concentration of emission. The interior emission is closely associated with the hottest O-type stars (labeled in Figure 1b), thus indicating a stellar power source for the nebula sufficient to ionize oxygen twice \((E > 35.1\ eV)\). For reasons more fully explored in Section 4.3, the interior H\(\alpha\) and [O III] emission is most likely due to photoionization from the hot stars and subsequent excitation of the [O III] by nebular electrons.

Away from the centrally concentrated hot stars, the nebular emission shows filamentary substructure in what appears to be a weblike morphology. Lozinskaya (1992) notes that this sort of emission structure indicates shock processes at work in the presence of irregularities in the ambient medium. Many of the well-observed “mature” supernova remnants—such as the Veil Nebula in Cygnus, S147 in Taurus, and the Vela and Gum nebulae (Lozinskaya 1992)—are characterized by similar filamentary structure in the same emission lines.

Figure 4 shows the central portion of the Orion Nebula in H\(\alpha\), [N II], and [S II] emission. The Trapezium stars (\(\theta^1\) Ori) as well as \(\theta^2\) Ori A and B were saturated in the long [S II] exposure and so were not effectively subtracted out of the resulting emission-line images (Figure 4c). Only \(\theta^1\) Ori C and \(\theta^2\) Ori A were saturated in the [N II] image, and none were saturated in the short H\(\alpha\) exposure (Figure 4a), probably because of thicker cirrus during
that exposure. To bootstrap calibrations, all comparisons between our images and those of Walter et al. (1992) were done in regions away from these bright stars. Ghost images of the Trapezium stars are barely discernible in the southwest part of the emission images, and of \( \theta^2 \) A in the northwest. These are especially apparent on the \([\text{S II}]\) image. (Only one of the stars in N70, near the edge in the north-northwest, was bright enough to cause a noticeable ghost image.) The Orion images provide important checks on our reduction methods as well as spectrophotometric benchmarks for diagnosing the line emission in N70 (discussed more fully in Section 4.1). Pogge et al. (1992) have presented spectrophotometric Fabry-Perot observations of the Orion Nebula including ratio maps very similar to those that were constructed from our data; our data agree well with these published maps and ratios and hence are not presented herein.

Unlike the situation with Orion, intensity ratio maps of N70 have not been previously available. Figure 5 presents three intensity ratio maps useful for our analysis. Figure 5a is \([\text{N II}]/\text{H} \alpha\), Figure 5b is \([\text{S II}] (\lambda 6717 + \lambda 6731)/\text{H} \alpha\), and Figure 5c is \([\text{O III}]/\text{H} \alpha\). The \([\text{S II}]/\text{H} \alpha\) map is not smoothed in order to make the change in \([\text{S II}]/\text{H} \alpha\) across the individual filaments clearer. \([\text{N II}]/\text{H} \alpha\) and \([\text{O III}]/\text{H} \alpha\) do not show this fine structure, so to increase signal-to-noise, the maps have been Gaussian smoothed (\(\sigma = 2\) pixels).

3.2. Spectrophotometric Results

In addition to the intensity ratio maps, emission-line flux ratios were determined for sections of the nebulae using polygonal aperture photometry. This method averages over
large areas of emission, but allows larger signal-to-noise measurements and comparisons. Figures 6a and b label the polygons used in N70 and Orion, respectively. The flux in each of these regions was summed in the individual emission-line images and then ratioed; the Hα fluxes and line ratios with respect to [N II], [S II], and [O III] are presented in Table 2 for N70, and Hα fluxes and line ratios with respect to [N II] and [S II] are presented in Table 3 for Orion.

The uncertainties in the ratios due to the determination of the background is estimated to be less than 30% for [N II]/Hα, less than 15% for [S II]/Hα near the bright rim of N70, and less than 30% for [S II]/Hα in the central region where the [S II] flux is the lowest. The “spectral flat” correction changed the measured [N II]/Hα ratios by less than 10% regardless of their location in the field of view. The [S II]/Hα ratios were decreased by ∼5% at the center of the field by the correction; the correction to the [S II]/Hα ratio then increases radially up to 100% at the N70 rim. The effects are most severe for the northern rim. For example, the [S II]/Hα ratio of regions 3, 4, and 5 are increased by 40% by the “spectral flat” correction and region 3 by almost 100% while region 6 is increase by only 25%. However, the uncertainties in the measured ratios are by no means this large; the errors are dominated by uncertainty in the value of the background.

The emission measure for each of the N70 apertures was calculated from the Hα surface brightness, $I_{H\alpha}$. The emission measure is defined as $EM = \int n_e^2 \, dl$, where $l$ is the column
depth of the emitting material and \( n_e \) is its electron density. For gas with singly ionized hydrogen and helium, \( n_e \approx 1.1n_H \). The number of protons \( n_H \) can be calculated from the \( \text{H}\alpha \) flux. Assuming \( T_e = 10^4 \, \text{K}, EM \, (\text{pc cm}^{-6}) = 4.4 \times 10^{17} \times I_{H\alpha} \, (\text{erg cm}^{-2} \, \text{sec}^{-1} \, \text{arcsec}^{-2}) \). With the definition of the emission measure and a simple spherical shell model, analytic relationships between emission measure and root mean square (rms) electron density can be derived. The simplest are for a line of sight through the center of the shell and for a line of sight through the edge of the shell. The first of these relationships, using emission measures from the center of the optical shell, is

\[
n_{\text{rms}}^2 = \frac{EM_{\text{center}}}{2\Delta R_s}
\]

where \( \Delta R_s \) is the shell thickness. The second relationship, using emission measures from the bright rim of the shell, is

\[
n_{\text{rms}}^2 = \frac{EM_{\text{rim}}}{2R_s} \left[ \frac{\Delta R_s}{R_s} \left( \frac{\Delta R_s}{R_s} \right)^2 \right]^{-1/2}
\]

where \( \Delta R_s \) is the shell thickness and \( R_s \) is the radius of the shell, measured out to the edge of the optical emission.

From our N70 observations, we determine a shell radius of approximately \( 3'2 \), or 51 pc, and a shell thickness of \( 7''5 \), or 2 pc. The shell thicknesses were determined from visual examination of radial plots of the \( \text{H}\alpha \) emission, where the thickness was set to the full-width quarter-max of the radial profile of emission across the filaments. Using (dereddened) emission measures near the center of N70, but away from the central two knots, yields \( n_{\text{rms}} \sim 7.5 \, \text{cm}^{-3} \); emission measures near the rim results in \( n_{\text{rms}} \sim 4-6 \, \text{cm}^{-3} \). The volume filling factor \( f = n_{\text{rms}}^2/n_e^2 \), where \( n_e \) is the density in the “clumps” of gas in the shell and can be determined from measurements of [S II] lines as discussed later in this section.
The Hα flux measurements can also be used to deduce the Lyman continuum necessary to ionize the gas in N70. Assuming the Case B hydrogen recombination coefficient, 

\[ N_{\text{Lyc}} = \frac{L_{\text{H}^\alpha}}{h\nu_{\text{H}^\alpha} \alpha_{\text{H}^\alpha}} = 7.3 \times 10^{11} \times L_{\text{H}^\alpha} \]

for \( T = 10^4 \) K. The dereddened Hα luminosity of N70 is \( 4.3 \times 10^{37} \) ergs sec\(^{-1}\), so the number of ionizing photons needed is \( 3.1 \times 10^{49} \) s\(^{-1}\).

The luminosity of Lyman continuum photons produced by the stars in the central cluster can be estimated based on Oey’s (1996a) spectral classifications. The spectroscopically identified stars marked on Figure 1b include one each of O3If, O5III, O7V, O8III, O9V, and two O9.5V stars as well as several B stars. Using \( \log T_{\text{eff}} \) and \( M_{\text{bol}} \) from Oey’s Table 4, radii of the stars can be calculated. (Because we choose to use a distance modulus of 18.7 instead of 18.4 as Oey did, we subtracted 0.3 from the \( M_{\text{bol}} \) in the table.) Masses of these stars are estimated from her H-R diagram in order to approximately determine \( \log g \).

Using \( T_{\text{eff}} \), \( \log g \), and assuming \( \log Z/Z_\odot = -0.3 \), the Kurucz (1992) model atmospheres can be used to estimate the flux of ionizing photons \( (\text{cm}^{-2} \text{ s}^{-1}) \) from the stars. The Lyman continuum luminosity for each star is then calculated using the radius determined above. The total ionizing luminosity from the cluster is \( 7.0 \times 10^{49} \) photons s\(^{-1}\), twice as much as is necessary to ionize the interstellar hydrogen in N70. The ultimate fates of any EUV photons beyond what is necessary to ionize the emission nebula can include absorption by dust, absorption by other atomic species, and escape from the nebula. As expected, the late O and early B stars contribute very little to the ionizing radiation; the O3If and O5III stars alone contribute over 60% of the total Lyman continuum. Varying the choice of stellar metallicity between \( \log Z/Z_\odot = -1.0 \) and 0.0 changes the ionizing flux by less than 5%.

Another way to estimate the Lyman continuum luminosity from the cluster is with the compilations of Vacca et al. (1996). Stellar parameters such as radius, mass, absolute
magnitude, radius, and Lyman continuum flux (both photons cm$^{-2}$ s$^{-1}$ and total s$^{-1}$) are tabulated by spectral type and luminosity class. Based on the spectral classification of the N70 stars, the ionizing luminosity determined from Vacca et al. (1996) is $2.2 \times 10^{50}$ photons s$^{-1}$, seven times higher than the hydrogen ionization rate in N70. These luminosities are for solar-metallicity stars, but as determined above, the metallicity only slightly affects the amount of Lyman continuum radiated by the stars.

The factor of three difference from the previous determination is because Vacca et al. calculate radii almost twice as large as we found. The root of this difference is in the bolometric magnitudes assumed for each spectral type. Oey (1996b) determined bolometric corrections in the manner described by Massey et al. (1995) using broadband colors. Vacca et al. (1996) discuss their calibration of $M_V$ with spectral type; in general they determine brighter absolute magnitudes. For the two hottest stars, the differences are 0.9 and 1.9 magnitudes, which translates into more luminous and thus larger stars for the same effective temperature. The discrepancy between the two determinations of bolometric magnitude and thus ionizing luminosity shows that this can be a tricky business, and should illustrate the large uncertainties in the calculated ionizing luminosity. However, our predictions of ionizing luminosity are quite consistent with that recently tabulated by Oey and Kennicutt (1997).

As discussed at length in Section 4, the line ratios in Table 2 and Figure 5 are discordant with a straightforward photoionization model. The [N II]/H$\alpha$ ratios in Table 2 are similar to those in the central regions of Orion, but the [S II]/H$\alpha$ ratios are much higher than expected for a photoionized nebula.

In addition, there is a definite increasing trend in the [S II]/H$\alpha$ intensity ratio across the individual filaments on the face of N70 in addition to the overall increasing [S II]/H$\alpha$ intensity ratio with increasing radius from the center of the nebula. This can be seen in
Figures 2b and 3b. Figure 7 displays cuts across three filaments in N70; the \([\text{S} \text{ II}]/\text{H}\alpha\) ratio rises with distance from the center of N70. A fourth plot shows a cut across the Orion Bar; the \([\text{S} \text{ II}]/\text{H}\alpha\) ratio is multiplied by a factor of ten in order to see it on this scale. As discussed below, the Bar is an ionization front in the Orion nebula seen edge on. The cut across the bar has similar shape as cuts across N70 filaments, but the \([\text{S} \text{ II}]/\text{H}\alpha\) ratios are much smaller. Also the physical scale is much smaller in Orion; 16 pixels total only 0.03 pc while 16 pixels totals 4.1 pc linear distance in N70.

**EDITOR: PLACE FIGURE 7 HERE.**

The discussion of the reduction of the N70 \([\text{S} \text{ II}]\) images focussed on the sum of the individual \([\text{S} \text{ II}]\lambda 6717\) and \([\text{S} \text{ II}]\lambda 6731\) images. Although the “spectral flat fields” could not be individually derived for these two line images, we can assume that the radially decreasing “gain” in each of these images is similar and thus measure the density-dependent \([\text{S} \text{ II}]\lambda 6717/\lambda 6731\) line ratio (Osterbrock 1989). As Table 2 shows, these ratios range from 1.4 to 1.9; for \(T = 10^4\) K, the maximum \(\lambda 6717/\lambda 6731\) line ratio in models is about 1.4 at the low density limit. Therefore, the density of gas in N70 is low, probably \(< 100\ \text{cm}^{-3}\), in all parts of the optical nebula. Because we can not constrain \(n_e\) any further, we constrain the filling factor in the shell only to be \(> 0.002–0.006\) using the rms densities determined from the emission measure of the gas. If \(n_e\) were only 10 cm\(^{-3}\), the filling factor in the shell would be \(\sim 0.2–0.6\).

4. **Comparison with Orion, LMC Emission-Line Regions, and Nebular Models**
4.1. Orion

When comparing N70 to the Orion Nebula, it is important to remember how much more detail we can see in nearby objects—Orion is \(\sim 450\) pc away (Goudis 1982), 120 times closer than N70. At the distance of the LMC, the part of the Orion Nebula seen in our images would be contained in 3.5 pixels! In addition, our coarse resolution (pixel scale 0\(\prime\).96/pixel and seeing \(\sim 2\prime\).2) limits the amount of fine structure we would be able to see in our N70 images, especially when compared with Orion and LMC emission regions which have been observed with WFPC2.

As previously mentioned, Pogge et al. (1992) present two-dimensional images of the central region of Orion. The complexity of these images is apparent; the central bright regions are certainly ionized by the Trapezium stars, but there are also Herbig-Haro objects, the “Dark Bay” (very high absorption), and the “Bar”. Wen and O’Dell (1995) have constructed a three-dimensional model of this region of the Orion Nebula. In their model, Orion is a “blister” on the edge of the giant molecular cloud OMC-1 rather than a classical Strömgren sphere. Wen and O’Dell (1995) find that most of the radiation from the Orion Nebula arises from a relatively thin surface layer of ionized material, and have used that information to model the geometry near the Trapezium (\(\theta^1\) Ori). They show that the emission enhancement seen just to the west of the Trapezium is due to the “hilly” structure of the ionized layer; the bright emission comes from an area which is closer to the ionizing stars than average. The Dark Bay is an area where the “lid”, or the ionization front between an Earth observer and the Trapezium, is thicker than average and has increased absorption by neutral gas and dust. The Bar, on the other hand, is the ionization front seen edge on. This is consistent with the thinness of the Bar in [N II] and [S II] compared to H\(\alpha\) (see Figure 4) and with the enhancements in the [N II]/H\(\alpha\) and [S II]/H\(\alpha\) that would arise in such a transitional layer where sulfur and nitrogen have yet to reach their highest
ionization stages (c.f. Petuchowski and Bennett 1995). The [O III] image of Pogge et al. (1992) shows that the higher-ionization material is mainly on the northwest side of the Bar, closer to the ionizing stars. The [N II]- and [S II]-bright objects which are to the southeast of the Bar near $\theta^2$ Ori A are the shock-excited Herbig-Haro objects M42-HH3 (closer to the Bar) and M42-HH4 (a little further to the southeast).

Figure 8 is a plot of the emission line ratios for Orion and N70 from Tables 2 and 3. The differences between the two emission regions are obvious: the Orion Nebula, even in the shock-excited Herbig-Haro objects, has a moderate range of [N II]/H\textalpha and very low [S II]/H\textalpha throughout, while N70 has consistently lower [N II]/H\textalpha by $\sim 50\%$ but a wide range of [S II]/H\textalpha ratios. As seen in Table 3 and Figure 8b, the [N II]/H\textalpha ratios across the face of Orion are lower than those in the Bar or in the Herbig-Haro objects. The regions of N70 with low [S II]/H\textalpha have [N II]/H\textalpha most similar to that seen in Orion; Table 2 and Figure 8a show that these regions are close to the ionizing stars and hence are most likely photoionized like the central regions of Orion. This is corroborated by Figure 2c, which shows that [O III], a higher-ionization state, is quite elevated near the central stars that power N70. There is disagreement over whether or not Orion has lower metallicity than solar (Walter et al. 1992), but in either case the average LMC nitrogen abundance of 0.4 solar (Russell and Dopita 1992) is significantly less than that of Orion, which can explain the lower [N II]/H\textalpha ratios seen in N70.

The enhanced [S II]/H\textalpha emission-line ratios across Orion’s Bar and the outer filaments in N70 lead one to wonder whether the filaments in N70 are actually just ionization fronts like the Orion Bar. However, as mentioned above, the physical scale and relative amount of [S II] emission is very different in N70 than in Orion. An ionization front in N70 would occur
over physical lengths too small to be distinguished due to the effects of seeing. Another difference is apparent when comparing Figures 1a and 2b with Figures 4a and 4c: while the width of the filaments in N70 is approximately the same whether measured in Hα or [S II], the same is not true for the Orion Bar. The Bar’s Hα emission extends over a much larger area than its [S II] emission, consistent with the [S II] tracing the transitional ionization front. The similar Hα and [S II] widths in the filaments of N70 indicate that the elevated [S II]/Hα ratios are not due to multiple ionization fronts within the nebula. Instead, the displacement in Hα and [S II]/Hα peaks observed in N70 is consistent with an outward propagating shock front that is “back illuminated” by the embedded cluster of OB stars (see Figures 5b and 6). The back illumination would be responsible for the inward-facing Hα peak, while the shock front would explain the enhanced [S II] emission.

The special ionization and excitation mechanisms required for the elevation of the [S II]/Hα intensity ratios can be constrained by comparison with other emission nebulae and with theoretical models.

4.2. LMC Emission-Line Regions

When comparing N70 with objects in the Large Magellanic Cloud, differences in metallicities can be assumed to be small. Observed emission-line ratios of various objects in the LMC were collected from the literature and plotted in Figure 9. The supernova remnants are from Danziger and Leibowitz (1985) with the exception of two from Westerlund and Mathewson (1966). The H II region line ratios are those observed by Wilcots (1992). Hunter (1994) conducted a survey of ionized shells and supershells in the LMC; her “giant shells” have radii 50 to 300 pc, and her “supergiant shells” have radii greater than 300 pc. The data plotted are for a variety of positions within three giant shells and three supergiant shells rather than the average line ratio across these shells. The N70 ratios in Table 2 are
also plotted. As shown in Figure 9, the [N II]/H$\alpha$ and [S II]/H$\alpha$ flux ratios found in N70 span a range of values similar to that of giant and supergiant shells. However, a significant population of regions show even higher [S II]/H$\alpha$ flux ratios that are more characteristic of supernova remnants (SNRs).

Unlike the comparison with the Orion Nebula, the line ratios in the central regions of N70 are very similar to those of H II regions in the LMC. The H II regions in Wilcots’ (1992) sample are “classical” H II regions with “interesting” morphologies. Their H$\alpha$ luminosities are in the range of $10^{36}$ to $10^{37}$ erg s$^{-1}$, a bit lower than N70. However, the H$\alpha$ luminosity of the two central knots (1 and 2 in Figure 6a) is $5.3 \times 10^{36}$ erg s$^{-1}$, similar to Wilcots’ H II regions. The line ratios of these regions of N70 are also similar to some of Hunter’s (1994) giant shells; she identifies these as H II regions within the shells. We believe the same is true for the region of N70 directly encircling the ionizing stars; these are volumes where photoionization is the main influence on the gas. Of course the massive stars are blowing winds into the gas, but there is nothing to distinguish these regions from other nebulae interacting with massive main-sequence stars.

The line ratios of N70 share some properties with the sample of SNRs; however, many of the SNRs have higher [N II]/H$\alpha$ but similar [S II]/H$\alpha$. As discussed below, these regions perhaps have higher shock velocities than those important in N70. This comparison shows that the very high [S II]/H$\alpha$ ratios measured in N70 are not unknown in LMC emission regions. The exception is the point at [S II]/H$\alpha$=2.06, which is the north rim of the nebula, and an area where the shape of the rim is not circular. It is possible that this is a volume expanding into lower density material, or that there is some off-center effect of winds or a supernova.
The more intriguing comparison is with the giant and supergiant shells (Hunter 1994). Like N70, these shells show a range of both $\text{[N II]}$/H$\alpha$ and $\text{[S II]}$/H$\alpha$ ratios. The trends in these line ratios are very similar for all of the shells; some regions of the shells are more like H II regions, and others are more like SNRs. In her paper, Hunter presents many plots of diagnostic line ratios. Although the data presented here does not include many of the line ratios that Hunter examined, this spectrophotometric information can be collected from the literature on N70 (Lasker 1977, Lasker 1981, Dopita et al. 1981) and compared with the giant and supergiant shells. For example, N70 line ratios such as $\text{[O III]}$/H$\beta$ and $\text{[O II]}$/[O III] are also consistent with the values measured for Hunter’s sample.

4.3. Nebular Models

A complete modeling of the photoionization and shock conditions in N70 is beyond the scope of this paper. However, comparison with existing models can yield significant insights on the respective roles played by stellar photons and shock waves.

Shull and McKee (1979) constructed theoretical models of interstellar shocks moving through a low-density medium. Their models pre-ionize the gas in front of the shock with UV flux created by the shocked gas itself. In slow shocks, such as those to be considered below, the gas flowing toward the shock is only partially pre-ionized. The strength of the Balmer lines are sensitive to the pre-ionization, but metal-line strengths depend more strongly on collisional excitation by electrons behind the shock. With solar abundances, pre-shock density $n_0 = 10$ cm$^{-3}$, and shock velocity of 40 km s$^{-1}$, the Shull and McKee (1979) models predict $\text{[N II]}$/H$\alpha = 0.02$ and $\text{[S II]}$/H$\alpha = 1.24$. One of the models also explores the effect of depleted abundances on line ratios, predicting that [O I], [N I], and [S II] are strengthened while [O II], [O III], and [N II] are weakened relative to H$\alpha$ due to diminished cooling and a larger hydrogen recombination zone.
Hartigan et al. (1994) examine slower shocks, down to 15 km s$^{-1}$, but with higher pre-shock densities ($n_0 = 10^2$, $10^3$, and $10^4$ cm$^{-3}$). These models show the [S II]/H$\alpha$ flux ratio increasing with decreasing shock velocity, reaching a peak value of $\sim$2 at a shock velocity of 25 km s$^{-1}$ in the $10^2$ cm$^{-3}$ model. In addition, [N II]/H$\alpha$ decreases and [N I]/H$\alpha$ increases with decreasing shock velocity, as would be expected if the shock no longer has the energy to ionize the nitrogen. ($S^0 \rightarrow S^+$ requires only 10.4 eV while $N^0 \rightarrow N^+$ requires 14.5 eV). Extending these results to the lower pre-shock densities estimated for N70 (0.1 – 0.7 cm$^{-2}$; Rosado et al. 1981; Meaburn 1978) would suggest further enhancement of [S II] as collisional de-excitation can be ignored.

The high [S II]/H$\alpha$ ratios seen in N70 can be explained with the aforementioned models with shock velocities of 25 to 40 km s$^{-1}$, consistent with the reported expansion velocities of 20 – 40 km s$^{-1}$ (Lasker 1977, Blades et al. 1980) but less than the expansion velocity of 70 km s$^{-1}$ found by Rosado et al. (1981). The low [N II]/H$\alpha$ ratios in the outer parts of N70 are also consistent with this interpretation. However, the [O III]$\lambda$5007/H$\beta$ and [O II] $\lambda\lambda$3726,3729/H$\beta$ measured by Lasker (1981) and Dopita (1981) as well as the [O III]/H$\alpha$ presented here are higher than the flux ratios predicted by the low-velocity shock models. We therefore propose that N70 has distinct regions of photoionization augmented to varying degree by shock ionization and excitation. This composite powering is qualitatively apparent by comparing the morphology of the [S II] emission with the H$\alpha$, [N II], and [O III] emission morphologies, which are more similar to each other than to the shock-excited [S II].

The unusually bright [O III] emission seen in the southern edge of N70 cannot be

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Dopita et al. (1981) argues that the velocity field in N70 cannot be interpreted as simple expansion. Even without coherent expansion, the observed velocity dispersion is sufficient to provide collisional (shock) excitation consistent with the models.
explained by the proposed photoionization plus slow-shock model. Perhaps a stronger shock has excited the gas on the southern rim. X-ray data from the Einstein satellite (Chu and Mac Low 1990) are suggestive of an off-center supernova within the bubble, as their model explains. The detection is marginal, but the enhanced [O III] emission could come from a higher velocity shock than that exciting the [S II] on the western and northern rims of N70.

4.4. Radiative and Mechanical Energetics

In her study of ionized bubbles in the LMC, Oey (1996b) found that those with high X-ray luminosities and large expansion velocities have discrepantly small radii relative to their expansion ages and stellar wind powering. She concluded that the dynamical discrepancy is probably caused by recent supernova events accelerating the shells to higher expansion velocities than would be obtained by stellar winds alone. She also suggested that additional energy sink mechanisms might explain the anomalously smaller radii. Because her sample of “superbubbles” included N70, further constraints on the relevant energetics can be obtained by considering both the mechanical and radiative luminosities that are involved.

4.4.1. Sources

As shown in Figure 1b, N70 contains 17 massive stars with spectral types ranging from B2.5V to O3If (Oey 1996a). The total wind luminosity from this population was modeled by Oey (1996b) to be no more than $10^{37}$ erg s$^{-1}$ (see her Figure 1). A total mechanical luminosity of $1.5 \times 10^{37}$ erg s$^{-1}$ is obtained using the spectral classifications in Oey (1996a), the corresponding luminosities (for Galactic stars) listed in Leitherer (1997), and adjustments for the LMC’s lower metallicity. Here, we used the theoretical prediction
that $\dot{M} \propto Z^{0.8}$ and $v_\infty \propto Z^{0.13}$, where $L_w = \dot{M} v_\infty^2 / 2$ (Leitherer 1997). Given this source of power, is it sufficient to explain the currently observed X-ray luminosity, enhanced [S II] emission, and expanding motions?

### 4.4.2. Sinks

N70 is noted for having a high X-ray luminosity relative to predictions based on its size and expansion velocity (Oey 1996b, Chu and Mac Low 1990). Observations by the Einstein observatory yield $L_x(Einstein) = 1.8 \times 10^{35}$ erg s$^{-1}$ (Chu and Mac Low 1990), which when scaled up by 3 to the 0.1–2.4 keV ROSAT bandpass becomes $L_x(ROSAT) = 5.4 \times 10^{35}$ erg s$^{-1}$, or about 7 times higher than is predicted from the nebular dynamics (Chu et al. 1995).

For our purposes, it is worth noting that the total X-ray luminosity comprises a negligible fraction of the total mechanical power that is available from the stellar winds.

Another, more important, radiative sink of input mechanical power is the excess [S II] emission that we measure. From Table 2, the ratio of summed [S II] and H$\alpha$ fluxes is 0.77, with a total [S II] flux of $9.24 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$, yielding a total [S II] luminosity of $3.37 \times 10^{37}$ erg s$^{-1}$. If photoionization typically produces flux ratios of $f([S\ II]) / f(H\alpha) \leq 0.4$ (see Figure 9), then $\geq50\%$ of the [S II] emission must result from other, more mechanical, ionization/excitation processes. The required powering of $L([S\ II]) \geq 1.7 \times 10^{37}$ erg s$^{-1}$ would be multiplied by about 1.5, if the excess cooling by [O I] is included (Dopita et al. 1981). These power requirements are marginally higher than those provided by the stellar winds, leaving little “wiggle room” for any other energy sinks such as nebular expansion.

A variety of techniques can be used to estimate the kinetic energies and mechanical luminosities associated with expanding shells of gas (cf. Tenorio-Tagle and Bodenheimer 1988, Lozinskaya 1992). All of these techniques are critically sensitive to the density and
structure of the surrounding medium as well as the powering timeline, and hence are fraught with uncertainties. The disparities in size, age, and expansion velocity found by Oey (1996b) underscore these difficulties. Nevertheless, the expansion energetics can be significant and hence are worth estimating.

In their kinematic study Rosado et al. (1981) obtain a swept up mass of $2.3 \times 10^3 M_\odot$ and an expansion velocity of 70 km s$^{-1}$, thus deriving a kinetic energy of $1.1 \times 10^{50}$ erg. A more representative expansion velocity is about 35 km s$^{-1}$ (Chu and Kennicutt 1988), resulting in kinetic energy of $2.8 \times 10^{49}$ erg. Averaging this energy over the 5 My lifetime of the cluster would then yield a mechanical luminosity of $2 \times 10^{35}$ erg s$^{-1}$—comfortably less than the $10^{37}$ erg s$^{-1}$ available from the winds.

Slightly higher estimates of mechanical energy ($E_m = [1 - 7.5] \times 10^{50}$ erg) are obtained with a momentum-conserving model for the expansion (Tenorio-Tagle and Bodenheimer 1988), where

$$E_m = 5.3 \times 10^{43} n_0^{1.12} R^{3.12} v^{1.4},$$

the expansion velocity is $v \approx 35$ km s$^{-1}$ and the ambient density is assumed to be $n_0 \approx 0.1-0.5$ cm$^{-3}$.

We conclude that the radiative and mechanical sinks of energy collectively exceed the input wind power by factors of $\sim 2$, the observed radiative sink of [S II] alone being dominant. Allowing for other radiative sinks such as [O I], [O II], and [O III] in the optical (Dopita et al. 1981) and by C II, C II, C III, and C III] in the UV (cf. Dopita et al. 1984) would further exacerbate the observed disparity in energetics. One or two recent supernovae with individual energies of $10^{51}$ ergs would be sufficient to make up the difference. Recent supernova activity would also help to explain the anomalously high expansion velocity and X-ray luminosity.
5. Summary

N70 is a fascinating emission-line region in the Large Magellanic Cloud whose spherical symmetry belies its complex powering. The data presented here cannot solve the mystery of N70’s dynamic history, but can provide new insights on the nebular energetics based on diagnostic emission line ratios such as \([\text{N II}] / \text{H}\alpha\) and \([\text{S II}] / \text{H}\alpha\). Our conclusions are as follows:

• Although N70’s dynamics cannot be well explained by a standard pressure-driven bubble model (Oey 1996b; note that the high luminosity half of her sample of bubbles are inconsistent with the model), its emission-line ratios—\([\text{N II}] / \text{H}\alpha\) and \([\text{S II}] / \text{H}\alpha\) from our data and \([\text{O III}] / \text{H}\beta\) and \([\text{O II}] / [\text{O III}]\) from the literature—match well with the ratios of other LMC giant and supergiant shells in the LMC (Hunter 1994).

• N70’s central regions emit emission lines with flux ratios similar to those of photoionized H II regions, while the rim of the N70 shows elevated \([\text{S II}]\) emission. The ionization of all of the hydrogen can be attributed to stellar EUV photons, but additional processes such as slow shocks are necessary to explain the combination of high \([\text{S II}]\) emission and low \([\text{N II}]\) emission, especially in the northeast and southern parts of the nebula.

• The energetics associated with the stellar winds, expanding shell, and radiating \([\text{S II}]\) are best reconciled if one or two supernova explosions have occurred within N70 in the past \(\approx 10^6\) years. The enhanced \([\text{O III}]\) emission and marginal X-ray detection to the south also indicate higher velocity shocks from recent supernovae.

\textsuperscript{6}The samples of Oey (1996b) and Hunter (1994) do not overlap; a useful endeavor would be to collect emission-line diagnostics for Oey’s sample for comparison with Hunter’s data, as well as to investigate the dynamics of Hunter’s sample using Oey’s model.
A wealth of information about the small-scale details of ionization and shock fronts has been gained about other emission regions with HST and WFPC2 (e.g. Hester et al. 1995, 1996); some of the remaining questions about N70 could be answered with higher resolution images, especially a finer-scale mapping of line ratios across its filaments.

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Fig. 1.— (a) Dereddened Hα emission-line image of N70 taken with a Fabry-Perot imaging system with FWHM~6Å. (b) 6536Å continuum; stars are labeled with spectral types from Oey (1996a). The field of view has a diameter of about 7′, or 110 pc at the distance of the LMC.

Fig. 2.— Dereddened emission-line images of N70: (a) [N II] (smoothed with a 2 pixel Gaussian), (b) [S II], and (c) [O III]. The FWHM is ~6Å for [N II] and [S II], and ~7Å for [O III]. The field of view has a diameter of about 7′.

Fig. 3.— Color-coded image of N70 constructed from emission-line images. Blue is [O III], green is Hα, and red is [S II]. Note that yellow = green + red.

Fig. 4.— Emission-line images of the central region of Orion, approximately centered on the Trapezium: (a) Hα, (b) [N II], (c) [S II]. The field of view has a diameter of about 7′, or less than 1 pc.

Fig. 5.— Emission-line ratio maps of N70: (a) [N II]/Hα, (b) [S II]/Hα, and (c) [O III]/Hα. The [N II], [O III], and Hα maps were smoothed before constructing the [N II]/Hα and [O III]/Hα ratios. The [O III]/Hα map does not account for the radially decreasing sensitivity at [O III] (see text).

Fig. 6.— Hα images of N70 and Orion showing the polygonal apertures used for aperture photometry of various regions of emission. Fluxes and ratios are listed in Tables 2 and 3.

Fig. 7.— [S II]/Hα intensity ratios across three filaments in N70, one in the southeast, one in the south, and another in the west. These filaments are characteristic of many of the filaments in N70. The [S II]/Hα ratio across the Orion Bar is also plotted (multiplied by a factor of ten so that it could be seen more easily). Each of the four cuts begins on the side of the filament closer to the ionizing stars (LH 114 for N70 and the Trapezium for Orion).
and extends 16 pixels (15.4'') radially away from the center. 15.4'' corresponds to 4.1 pc at the distance of the LMC and 0.034 pc at the distance of Orion.

Fig. 8.— [N II]/Hα vs. [S II]/Hα for regions in N70 and the Orion Nebula. The ratios plotted are those in Tables 2 and 3 from the polygonal apertures shown in Figure 6.

Fig. 9.— [N II]/Hα vs. [S II]/Hα for a variety of line-emission regions in the Large Magellanic Cloud. The line ratios of N70 span the excitation domain populated by giant shells, supergiant shells, and even SNRs.
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