NITROGEN ABUNDANCES IN THE AMORPHOUS GALAXY NGC 5253

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ABSTRACT

The central complex of ionized gas in the amorphous galaxy NGC 5253 was scanned with the slit of the RGO spectrograph using the imaging spectroscopy system of the Anglo-Australian Telescope. Monochromatic images corresponding to several nebular lines were obtained with a spatial resolution of $2.3 \times 1.3 \operatorname{arcsec}^2$ (1 pixel). The very high signal-to-noise ratio of the spectra allowed the measurements of the electron temperature over 78 pixels using the line ratio [O III] (4959+5007)/4363 and hence abundances of O, N, He, and Ne. A region of high values of log N/O (~ -1.0) was found to correspond with the presence of a cluster of Wolf-Rayet stars. Other areas of the gas complex show the normal deficiency in log N/O (~ -1.4) for this type of object, and no Wolf-Rayet feature is detected. There is an anticorrelation between log N/O versus log O/H, a trend which is not clearly consistent with any existing nucleosynthesis scenario for the origin of nitrogen in low metallicity galaxies.

Subject headings: galaxies: individual (NGC 5253) - nebulae: abundances - nebulae: H II regions

I. INTRODUCTION

The origin of nitrogen, one of the most abundant elements in the universe, is a longstanding puzzle of stellar nucleosynthesis (cf. Edmunds and Pagel 1984). Produced from 12 C and 16 O through the CNO cycle in a hydrogen-burning layer of a stellar interior, nitrogen is a "secondary" element if its synthesis is controlled by the carbon "seed" already present in the star (Tomkin and Lambert 1984). In main-sequence stars, carbon is burned into nitrogen in a warm layer outside the core where little nuclear energy is released. When this star evolves as a red giant, the convective envelope mixes the synthesized nitrogen throughout the outer part of the star (Serrano 1986), and subsequent mass loss via planetary nebulae and novae enriches the interstellar medium with this secondary nitrogen.

Nitrogen is a "primary" element if it is produced from freshly synthesized carbon; this occurs in the helium-burning shell of intermediate mass $(3-9 M_{\odot})$ stars in thermally pulsing giants on the asymptotic giant branch (Becker and Iben 1979, 1980; Renzini and Voli 1981; Matteucci and Tosi 1985), or in very massive stars of pure hydrogen that dredge carbon-rich material from the core into the hydrogen-burning shell (Woosley and Weaver 1982; Woosley, Axelrod, and Weaver 1984). Eventually the outer envelope contains a nitrogen mass fraction of ~ 0.2–0.3 which can be peeled by stellar winds and injected into the interstellar medium (Bessell and Norris 1982; Serrano 1986). The relative consistency of the [N/O] ratio observed in many metal-poor galaxies suggested that nitrogen production has an important primary component in massive stars (Edmunds and Pagel 1978, 1984; Pagel and Edmunds 1981; Vigroux, Stasinska, and Comte 1987).

The large body of extragalactic observations presented by Pagel (1985), Dufour (1986), and Campbell, Terlevich, and Melnick (1986) shows that at low oxygen abundances ($12 + \log O/H < 8.4$), N/O has a mean value of $\log N/O \approx -1.4$ with a great deal of scatter; no systematic variation in N/O with O/H is evident for the groups of irregular galaxies. At higher abundances as found in earlier type galaxies, N/O increases with O/H (Edmunds and Pagel 1984).

This *Letter* presents some results of detailed spectrophotometry of the giant gas complex in the amorphous galaxy NGC 5253. We confirm the presence of an abnormally rich region of nitrogen (solar values of N/O). Moreover the general behavior of N/O in NGC 5253 shows an inverse correlation with O/H. A detailed presentation of the actual data including a discussion on abundances of He, C, and Ne will be published in a forthcoming paper (Walsh and Roy 1988).

NGC 5253 is an amorphous galaxy comparable to M82 showing properties of both elliptical and gas-rich irregular galaxies. Its luminosity profile resembles an elliptical galaxy, but the H II regions in its core extend out to a radius of ~ 20" (Welch 1970), while fainter ionized gas and filaments are detected out to 100" from the nucleus (Graham 1981). Located in the Centaurus group, the galaxy is surrounded by a swarm of star clusters (van den Bergh 1980). We adopt the distance of 2.0 Mpc estimated by de Vaucouleurs (1979); this gives a scale of ~ 10 pc arcsec⁻¹. This makes the central gas complex in NGC 5253 between 100 and 200 times more voluminous than the Tarantula nebula in 30 Doradus. An L58

excellent photograph of the central region of NGC 5253 is presented in Campbell and Terlevich (1984).

II. OBSERVATIONS

The central region of NGC 5253 was mapped spectrophotometrically using the area spectroscopy system (ASPECT) of the Anglo-Australian Telescope with the RGO spectrograph and the IPCS (Clarke et al. 1984). ASPECT coordinates acquisition of spectral data using the IPCS with telescope scanning of a region of sky to produce a cube of spectra of an area. Ten slit positions, separated by 1"6, were studied over the central region of the ionized gas complex of NGC 5253; the 120" long slit was aligned at a position angle of 15°. The observing procedure was identical to that for NGC 2997 (Roy and Walsh 1987; cf. Roy and Walsh 1986), and consisted in taking an integration at each of the 10 slit positions over NGC 5253, followed by a similar integration on a sky position, 86" east and 140" south of the center of the scan. Observations were obtained over two consecutive half-nights giving a total of 72 scans and total integration time per pixel of 2160 s. Seeing on both nights was remarkably constant at 1".2.

A 250 lines mm⁻¹ grating was used in first-order blaze to collimator configuration, resulting in a nominal reciprocal dispersion of 156 Å mm⁻¹, i.e., a resolution of about 7 Å: the wavelength coverage was from 3500 to 7030 Å. The slit width was 1", and the pixel size along the slit was 2".3. The scanned area was $120 \times 16 \operatorname{arcsec}^2 (53 \times 10 \operatorname{pixels})$; at the distance of NGC 5253 the pixels correspond to $10 \times 23 \text{ pc}^2$. Scans were made with neutral density filters to prevent the strong lines (H α , H β , and [O III] $\lambda\lambda$ 4959, 5007) saturating the detector. The reduction procedure followed that described in Roy and Walsh (1986, 1987) and the FIGARO software package was used. The sky-subtracted spectra, flux-calibrated by observation of the spectrophotometric standard L745-46A (Oke 1974), were co-added into data cubes having two spatial dimensions-53 pixels along the slit direction and 10 slit positions. A continuum was fitted to the spectrum excluding the emission lines and subtracted from the line + continuum spectra to produce a pure emission-line spectrum for each pixel. These spectra were assembled into a cube which was sliced at the wavelength bounds of the emission line to produce monochromatic maps of line flux in the main nebular lines. We corrected for underlying stellar continuum absorption by assuming 2 Å of equivalent width of underlying absorption at H β (cf. McCall, Rybski, and Shields 1985; Roy and Walsh 1987). The corrected H α /H β ratio was then used to derive the reddening correction and the Galactic law as tabulated by Seaton (1979) was employed. The resulting extinction map was used to reddening correct the emission-line maps.

The electron temperature and density was determined from the reddening corrected maps of [O III] $\lambda\lambda4959/4363$ and [S II] $\lambda\lambda6717/6731$, respectively. For the electron density maps, a constant electron temperature of 11,700 K was used (the mean value for the whole region), and the collision strengths of Pradhan (1976, 1978) were employed. The density map was then used to produce an electron temperature maps using the collision strengths of Eissner and Seaton (1975). Points with a signal-to-noise ratio of less than 7 on the [O III] λ 4363 line were excluded from these maps, leaving 78 points. Using the density and temperature maps, abundance maps were then generated from the appropriate line ratios (see Walsh and Roy 1988 for details). The total oxygen abundance was formed from the sum of O⁺/H⁺ and O⁺⁺/H⁺ from the 3727 Å and 4959 Å lines, respectively. For nitrogen only the [N II] lines are available so the N⁺/H⁺ ratio was corrected for the presence of N⁺⁺ by using the standard ionization correction factor method (Peimbert and Costero 1967), where

$$\frac{N}{H} = \frac{N^+}{H^+} \frac{(O^+ + O^{++})}{O^+}$$

Errors on the abundances were generated by considering the errors on the T_e estimation from the (photon statistical) errors on the [O III] lines fluxes (largest for the 4363 Å line) and from the line fluxes used in the abundance measurement; extinction correction errors were not, however, propagated. If one uses more recent values for atomic parameters (Mendoza 1983), one finds slightly higher electron temperatures and lower metal abundances; O/H is down by 5% and N/H, by 10%. However, the observed trends and correlations remain the same.

III. RESULTS

A map of nitrogen abundances as N/O ratio is shown in Figure 1. Only pixels 15-40 along the slit are shown on this map. The pixels where nitrogen (N/H) is enhanced are contoured (dotted line) and defined as region A. The region of high N/O (solid line) is unusual by its near solar values; the remaining area shows the ratio N/H (and N/O) to be of much lower values such as generally found in dwarf metal-poor irregulars. The existence of high values of N/O in NGC 5253 is implicit in the observations of Campbell, Terlevich, and Melnick (1986). Figure 2a shows the underlying stellar continuum produced by co-adding the spectra of the pixels displaying high N/H ratios. Figure 2b shows the spectrum of the stellar continuum of the remaining regions having low but normal N/H values. The Wolf-Rayet feature at 4650 Å is clearly visible in the high N/H ratio pixels and is not detected in the low N/H ratio pixels. Therefore, there is a spatial coincidence between the overabundance of nitrogen and the existence of several Wolf-Rayet stars indicating the presence of very massive stars in region A.

The ratio $\log N/O$ for 71 pixels in NGC 5253 has been plotted against $\log O/H$ and is shown in Figure 3. A linear regression fit, with $\log O/H$ as an independent variable, leads to the relation

$$\log N/O = -(4.0 \pm 0.5) - (0.7 \pm 0.1) \log O/H.$$

There is a significant anticorrelation with a correlation coefficient r = -0.55; there is a probability of less than 7×10^{-7} for a chance occurrence in 71 points. Figure 3 shows that at





FIG. 1.—Map of the N/O ratio (×1000) and corresponding error map of the central gas complex in NGC 5253. Area shown is 16" (160 pc) (*horizontal*) by 60" (600 pc) (*vertical*). The solid line defines the region characterized by high N/O values. The dotted line is the region of high N/H values and defines region A. Region B was constructed by co-adding the fluxes of all remaining pixels, i.e., excluding region A. Zeros do not mean zero abundances but too low signal-to-noise ratio. Dot marks center of ASPECT scan at R.A. (1950) = $13^n 37^m 5^{52}$ and at decl. (1950) = $-31^\circ 23' 15''$.

low oxygen abundance, the N/O ratio is high (actually, it is close to the solar value); it then decreases with increasing oxygen abundances. The points with the high N/O values at about $\log O/H = -3.9$ displaying very small error bars correspond to the locally nitrogen-rich region. The usual ionization correction factor (ICF) approach based on the assumption that N/O = N⁺/O⁺ is uncertain when applied to H II regions of high ionization (Dufour 1984); the observed anticorrelation between N/O and O/H could be an excitation effect. To verify this, $\log N/O$ has been plotted against [O III]/H β and no correlation is found; therefore, the behavior of N/O in NGC 5253 is not an excitation effect.

IV. DISCUSSION

The region of strong enhancement of the N/H ratio (reaching solar values) is associated with the presence of a cluster of Wolf-Rayet stars. Study of the evolution of chemical abundances in massive stars shows that winds from Wolf-Rayet stars could contribute to important enrichment of the interstellar medium (Maeder 1983). Large N/H values can result from the evolution of massive stars in the Wolf-Rayet phase (Maeder 1983). Local nitrogen contamination can arise from WN stars (Kwitter 1984; Pagel 1986). Observations of nitrogen-rich filaments in supernova remnants are evidence of efficient enrichment of nitrogen in the atmospheres of evolved stars (e.g., Fesen, Becker, and Blair 1987). However, many uncertainties remain, and it is difficult to link the high N/H ratios in NGC 5253 with the Wolf-Rayet stars in a straightforward manner. It is clear, however, that the local enrichment is very recent, because the turbulent velocity field of the H II complex homogenizes abundances in only a few million years.

We find an inverse correlation between N/O and O/H in NGC 5253 (Fig. 3). It is known that at higher abundances (i.e., values of $12 + \log O/H > 8.5$), the N/O ratio increases as a function of O/H (Pagel and Edmunds 1981; Edmunds and Pagel 1984). It is also interesting to note that the high N/O value (log N/O ≈ -1.1) reported by Dufour (1986) in the very metal poor $(12 + \log O/H \approx 7.2)$ object I Zw 18 is consistent with the trend that we observe in NGC 5253. The anticorrelation between N/O and O/H observed in NGC 5253 suggests that nitrogen has been produced initially in massive and intermediate-mass stars as a primary species. Becker and Iben (1979, 1980) and Renzini and Voli (1981) have proposed that nuclear processing takes place at the base of convective envelope. This so-called envelope burning (EB) process allows large amounts of nitrogen to be produced through the fast conversion of ¹²C into ¹³C and then ¹⁴N just following the third dredge-up during the asymptotic giant branch (AGB) phase of the evolution of intermediate-mass stars. This process had already been suggested by Kaler, Iben,



FIG. 2b

FIG. 2.—Spectra of the central gas complex shown at a scale to show the structure of the underlying continuum. Although this spectrum has not been corrected for reddening, there is a strong rising blue continuum. (a) Spectrum corresponding to region A (Fig. 1) having pixels with overabundant nitrogen. Notice the Wolf-Rayet star signature at 4650 Å; some spectral lines are identified. (b) Spectrum of region B which is the area shown in Fig. 1 but excluding region A; no Wolf-Rayet star feature is detected.

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FIG. 3.—Correlation of $\log N/O$ vs. $\log O/H$. The full line corresponds to the linear regression when $\log O/H$ is used as the independent variable. The coefficient of correlation is -0.55.

and Becker (1978) and Kaler (1983) for the He/H and N/O enhancements observed in planetary nebulae. Renzini (1984) and Renzini and Voli (1981) have shown that the EB process is dependent on metal abundance; the process is more efficient at low metallicity. Therefore at low Z, primary nitrogen production dominates while there is little carbon and oxygen to be processed into nitrogen. At high Z, EB is less efficient while the number of carbon seeds available for being processed (secondarily) into nitrogen increases. However, it is difficult to reconcile the rather long lifetimes $(10^8 \sim 10^9 \text{ yr})$ of intermediate-mass stars with the youth of the star-forming process in NGC 5253 and with the strong fluctuations of abundances in such a small object. Maybe very massive Population III stars of 500 M_{\odot} such as proposed by Woosley and Weaver (1982) and Woosley, Axelrod, and Weaver (1984) could be the source of primary nitrogen in recently evolving galaxies such as NGC 5253. These authors have shown that such massive stars have the ability to produce copious amounts of primary nitrogen (¹⁴ N). Such massive stars, if they exist in starburst galaxies, evolve rapidly and could account for local contamination and the inverse N/O correlation with O/H.

The fluctuations in [O/H] that we observe in NGC 5253 are due to varying stages in star-formation activity within this galaxy. Region A is going through one of its first burst of star formation, while the other H II knots making up region B

have already lived through such bursts, their N/O ratio being now lower but their O/H ratio higher. The wide range of abundance ratios found in NGC 5253 must be strongly emphasized. We find values of N/O and O/H covering as much range as the mean values of the sample of 53 irregular and blue compact galaxies in Vigroux, Stasinska, and Comte (1987) and of 30 objects in Campbell, Terlevich, and Melnick (1986). The fact that chemical abundances have not been homogenized reflects that different regions of NGC 5253 are going through successive stages of short but violent star formation. Velocity fields of such objects are not very strong, and shear from differential rotation cannot assist the turbulent velocity field of the ionized gas in rapidly mixing the new chemicals on a large scale. Local enrichment is proceeding faster than diffusion can take place, leading to significant abundance fluctuations.

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