Sulfur Abundances in Gaseous Nebulae

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The determination of abundances in planetary nebulae (PN) and H II regions is important for studying the present and past chemical composition of galaxies. Its derivation from the spectral-line intensities involves basically the following steps:

(i) Since gaseous nebulae are optically thin in the observed emission lines the numbers of emitting atoms or ions are proportional to the observed line intensities. Therefore, the relative intensities of the relevant nebular lines must be measured spectrophotometrically. (The spectrum is usually normalized to $I(H_\beta)$ or $I(H_\alpha) = 100$.)

(ii) Atomic data, e.g. transition probabilities and target areas for collisional excitation, are used to deduce the electron temperature, Te, and electron density, Ne, of the nebular plasma from the intensities of the forbidden lines of selected ions.

(iii) Once values of Te and Ne are adopted, the relative line intensities may be used to determine the ionic abundances (relative abundances of the corresponding ions with respect to hydrogen).

(iv) The total abundances of the elements can be obtained after an estimation of what fractions of the atoms of a given element exist in the observed stages of ionization.

The main difficulties with this procedure are that, first, the great range of intensities found in a nebular spectrum requires the use of detectors with a high dynamic range and linear response in the wavelength range of interest and, secondly, that only a small fraction of the atoms are in ionic stages which produce optical lines and, therefore, approximate estimates must be made for all other stages. This is currently done by computing detailed models of individual nebulae for comparison with observed line strengths and by the ionization correction-factor (ICF) procedure, which is based on the assumption that the degree of ionization of an element can be predicted from its ionization potential. In particular, Peimbert and Costero (1969) used the identity between the ionization potential of O^+ (35.1 eV) and S^{++} (34.8 eV) to derive total sulfur abundances under the assumption of $S^{+3}/S^{++} = O^{++}/O^+$. Depending upon the element and the temperature of the ionizing star, the ICF technique is accurate to factors of 2 or 3. In some cases large discrepancies are observed, e.g. abundances derived for different positions in a nebula, and sulfur abundances have been found to be the least accurate among the elements which are usually observed in gaseous nebulae.

Sulfur is multiply ionized in gaseous nebulae. S^+ has its strongest forbidden lines at λλ6716, 6731Å, while S^{++} can be measured from the weak and temperature-sensitive λ6312Å line or from the stronger and less temperature-sensitive lines at λλ9060 and 9532Å. S^{+3} has been measured from the infrared line at 10.5 μm in just a few objects by Dinnerstein in 1980. Therefore, the problem with the sulfur abundances has been the lack of detectors with a good response in the 1 μm region to accurately determine S^{++} by observations of the [S III] λλ9060, 9532Å lines and that S^{+3} and higher ionization states are not optically detectable. This problem is especially important in high excitation PN, e.g. NGC 2440 or NGC 7027, where a significant amount of sulfur can still be in the form of S^{+4} and higher states.

Solid-state image sensors, e.g. Reticons and CCD's, have a very high quantum-efficiency between λλ6000 and 10000 Å, a large dynamic range, and an almost linear response. The present availability at the La Silla Observatory of a Reticon system thus permits us to obtain accurate intensity line ratios in the near infrared region, from which the S^{++} abundances can be derived. On November 1980 and May 1981 a study of galactic PN together with PN and H II Regions in the Magellanic Clouds (MC) was carried out using the 1.5 m telescope equipped with a Boller and Chivens Cassegrain spectrograph and the ESO Reticon system. A dispersion of 173 Åmm^{-1} was used, giving a spectral range from about λλ6300 to 10000 Å, with a resolution of about 5 Å diode^{-1} (see Fig. 1). The Reticon, which was cooled by liquid nitrogen, was maintained at a temperature of −100°C. The continuum spectrum of a tungsten lamp was used to remove instrumental sensitivity variations, the wavelength scale was defined by the spectrum of a HeAr lamp. A correction for the instrumental response function and differential atmospheric extinction was also applied to the data. The data were reduced using the IHAP data reduction system available at La Silla and Garching and also by using the PDP11 Computer system at the Max-Planck Institute for Astronomy in Heidelberg. One manuscript has been completed and already accepted for publication and in this article I would like to share some results and observing experiences at La Silla with the readers of the *Messenger.*

In both of my trips to La Silla the Reticon system functioned without problems. The main source of error in the final, relative intensities was the overall read-out noise. No systematic errors as a function of wavelength or intensity were detected and lines with intensities, I, > 0.8 I (Hα) have an observational error of the order of 8 per cent or less. For lines with 0.8 I (Hα) > I > 0.25 I (Hα), the observational error is in the range 10–25 per cent, while lines with I < 0.2 I (Hα) have observational errors of the order of 30 per cent or greater. The overall efficiency of the system is between 2.5 and 3 per cent at about 8000 Å for a slitwidth of 3 arcsec. This value is in excellent agreement with the 3

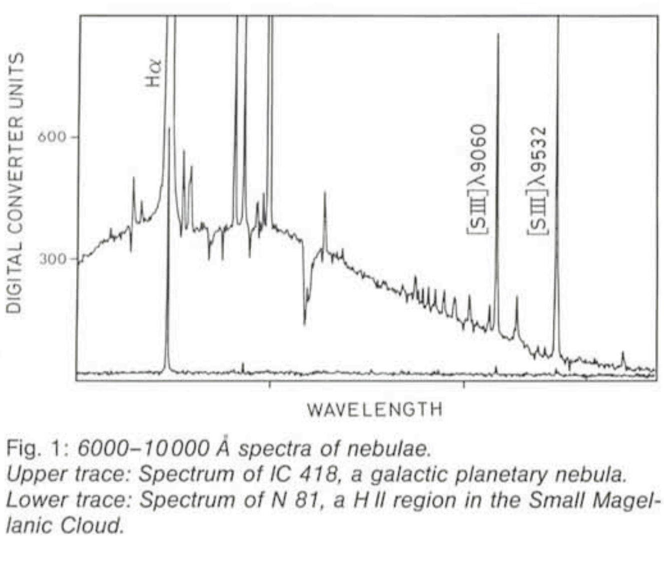

Fig. 1: *6000–10000 Å spectra of nebulae.*
Upper trace: Spectrum of IC 418, a galactic planetary nebula.
Lower trace: Spectrum of N 81, a H II region in the Small Magellanic Cloud.

per cent reported by the ESO staff at 8500 Å using the 3.6 m telescope. Fig. 1 shows the near-infrared spectra of two gaseous nebulae: IC 418, a galactic PN, and N 81, a H II region in the Small Magellanic Cloud. Exposure times are 10 and 30 min. respectively.

The Y-axis represents analog to digital converter units (ADC). The system is set such that 1 ADC corresponds to the rms noise, which is about 1,000 counts. Saturation of an individual diode occurs at about 4×10^6 counts or about 4,000 ADC units. Therefore, a signal of 600 ADC (Hα line of N 81) corresponds to about 15 per cent of the saturation level of the detector.

The [S III] λλ 9060, 9532 Å lines were detected in N 8, N 54, N 81, N 153, P 40 (nebulae in the MC) and in 15 galactic southern PN, while in N 2, P 8 (PN in the MC) and 108–76°1, K 648 (galactic halo PN) the [S III] doublet was detected below a 3σ level or not at all.

TABLE 1: Total Sulfur Abundances

	Log (S/H +12
41 PN	6.80 ± 0.28
22 PN with $O^{++}/O^{+} > 10$	6.82 ± 0.23
11 PN with $2 < O^{++}/O^{+} \leqslant 10$	6.78 ± 0.33
8 PN with $O^{++}/O^{+} \leqslant 2$	6.77 ± 0.39
H II Regions	6.85 ± 0.21
Sun	7.22 ± 0.13
Orion	7.34

Reference: Natta et al. 1980.

Table 1 (after Natta et al. 1980) shows our present knowledge of the total sulfur abundances in nebulae. These figures indicate that the average sulfur abundance for galactic PN is lower than the one in the Sun and the Orion Nebula. Consequently, one of the first concerns has been to compare the Reticon sulfur abundance with the ones reported by Natta et al. (1980). So far, and for galactic PN only, my values for log (S/H)+ 12 range from 6.35 ± 0.20 to 6.75 ± 0.33, depending on the object and ICF method used. In any case, my results seem to confirm a total sulfur abundance in PN lower than the one in the Sun and in the Orion Nebula. A large number of questions remain to be answered. For example, (1) Is the value of log (S/H) + 12 for galactic PN and PN in the MC lower than the equivalent value for H II regions? (2) To what extent do the sulfur abundances in the MC match the ones in the Galaxy?, and (3) Since sulfur is a nucleosynthesis product, to what extent do the answers to the two previous questions influence models of galactic evolution?

As in previous runs, the La Silla staff was very friendly and cooperative, and excepting the search for uninvited vinchucas to my bedroom (I found two), the days were quiet for sleeping.

This work was done while the author was with the Max-Planck Institute for Astronomy in Heidelberg.

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Asteroid Rotation – Hunting for a Record: 1689 Floris-Jan

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Introduction

Last year, in June 1981 – *ESO Messenger* No. 24, p. 22–23 – H. J. Schober published a report on "Spinning Asteroids and Photometry". There he mainly gave a general introduction about what can be done using UBV photometry in order to derive physical properties of asteroids such as geometric forms, diameters, reflectance on the surface, bimodality of asteroids with respect to typology.

A special effort was made to report about the activities to deal with asteroids as "variable objects" like variable stars – showing lightcurves with defined rotation rates to be derived. Among asteroids it was stated that the longest rotation periods found before 1975 were not larger than 20 hours – followed by 654 Zelinda 31ʰ.9 (1975), 393 Lampetia 38ʰ.7, 128 Nemesis 39ʰ.0 (1979), 709 Fringilla 52ʰ.4 (1979) and 182 Elsa 80ʰ.00 (1980), the latter corresponding to 3ᵈ.33.

The Asteroid 1689 Floris-Jan

Combined observations were undertaken in 1980, when measurements were carried out for the asteroid 1689 Floris-Jan between Oct. 7 and Nov. 6, 1980. H. J. Schober observed this object at Cerro Tololo, CTIO, Chile (0.6 and 0.9 m telescopes), J. Surdej at ESO, Chile (0.5 m telescope), and a few points were delivered additionally by A. W. Harris and J. W. Young from JPL, Pasadena, at Table Mountain Observatory (0.6 m telescope). The brightness of the asteroid was only between 13.50 to 14.00 in V. During a few nights even simultaneous measurements were made at ESO and CTIO, using different comparison stars; they do overlap perfectly – proving the high quality of our measurements – the results will be published in detail in *Astronomy and Astrophysics*.

The surprising result is that 1689 Floris-Jan shows a double-wave lightcurve with primary and secondary extrema as many asteroids, with an amplitude of 0.40 magnitude, but with a resulting rotation period of

$$P = 145^h.0 \pm 0^h.5 \ (\hat{=}\ 6^d.042 \pm 0^d.021)!$$

beating the record of 182 Elsa. Due to the colours derived for 1689 Floris-Jan it should not be a S-type asteroid and, depending on the albedo assumption, its diameter is found to be rather small, in the range 9 to 27 km.

The rotation period of six days for 1689 Floris-Jan is the longest one ever published for an asteroid. The histogram in Fig. 1 shows the exceptional position of 1689 Floris-Jan among the more than 300 published asteroid rotation