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# Sulphur III lines and the excitation mechanism in NGC 1052

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**Summary.** We have measured the intensities of [S III] $\lambda\lambda$9069, 9532 in the nucleus of the classic Liner elliptical galaxy NGC 1052. Their strength favours photoionization as opposed to shock-heating models, which is in agreement with recent [O III] electron temperature data for NGC 1052 and with [S III] data for some other Liners.

## 1 Introduction

NGC 1052 is a radio elliptical galaxy with one of the strongest [O II] $\lambda$3727 emission lines observed in ellipticals (Mayall 1939; Minkowski & Osterbrock 1959) and with marked signs of nuclear activity, having a compact, variable radio source (Heeschen 1970; Cohen *et al.* 1971; Disney & Wall 1977) and a compact, polarized power-law infrared source (Rieke, Lebowski & Kemp 1982; Becklin, Tokunaga & Wynn-Williams 1982; Carter *et al.* 1983).

Koski & Osterbrock (1976) measured optical emission line intensities including the weak temperature-sensitive line [O III] $\lambda$4363 by subtracting the spectrum of a pure absorption-line elliptical and found an electron temperature $T$([O III]) >25 000 K from which they inferred that the emission lines are excited by shock-wave heating. Fosbury *et al.* (1978) used an off-nuclear spectrum for subtraction and came to similar conclusions, finding $T$([O III]) = 39 000 K and $T$([O II], [S II]) = 20 000 K. These conclusions were supported by a study of the ultraviolet spectrum with *IUE* in which a spatially extended continuum due to warm stars was found (which is not unusual), but there was no evidence for a non-thermal, power-law continuum (Fosbury *et al.* 1981). On the other hand, more recent studies of $\lambda$4363, using elliptical galaxies chosen to give optimum fitting to the underlying stellar background, have led to the conclusion that this line is weak (Keel & Miller 1983) or undetectable (Rose & Trippico 1984), and there is evidence for an ionizing continuum, in a deeper *IUE* exposure taken in 1984 November (M. A. J. Snijders, private communication).

NGC 1052 is a classic example of a 'Low Ionization Emission Line Region' or Liner (Heckman 1980), and shock excitation was generally favoured as the source of emission lines in these objects (Heckman 1980; Baldwin, Phillips & Terlevich 1981) until 1983 when it was pointed out that many, if not all, spectral features of Liners could be as well or better explained by photoionization models with a power-law continuum and a low ionization parameter (Ferland & Netzer 1983; Halpern & Steiner 1983; Keel 1983a; Binette 1985), making them an extension of Seyfert galaxies. An alternative photoionization model based on very hot stars ('Warmers') resulting from extensive mass loss in the Wolf–Rayet phase of stars having over 60 times the Sun's mass has been proposed by Terlevich & Melnick (1985) for Liners and Seyfert 2 galaxies, while Péquignot (1984) has developed detailed models for NGC 1052 involving density stratification and photoionization by a composite spectrum.

Liners are so common, especially among early-type spirals (Keel 1983b), that the issue of their excitation mechanism is of considerable interest, bearing as it does on the question of whether most large galaxies have a central 'engine' or alternatively whether a range of Seyfert phenomena can be explained by normal processes of star formation. However, there are not many criteria that are completely unambiguous, because the predicted spectrum from shock excitation is so sensitive to the shock velocity that quite a wide range of line ratios can be more or less fitted by a suitable combination of models (*cf*. Table 1). In particular, the weakness of [O III] $\lambda$4363 does not rule out shock models with a velocity of 90 km $s^{-1}$ or less. Conversely, the weakness of He II rules out pure power-law models (Fosbury *et al.* 1978), but can be explained by a composite ionizing spectrum (Péquignot 1984) or by imposing a suitable cut-off. The great strength of [N II] in Liners is more compatible with photoionization, if one is unwilling to accept a large overabundance of nitrogen increasing systematically to lower shock velocities (Pagel 1984; Phillips *et al.* 1984), but this is a general argument not necessarily applying to any particular case.

Recently it was shown that measurements of the far-red [S III] lines $\lambda\lambda$9069, 9532, taken in conjunction with the strengths of [S II], [O II] and [O III], provide a good way to distinguish between photoionization and shock heating, because [S III] is very weak in shock models with velocities of the order of 100 km $s^{-1}$ or less which are needed to fit other line data, but considerably stronger in photoionized models (Stasińska 1984; Péquignot 1984; Díaz, Pagel & Wilson 1985). In this paper we extend the [S III] measurements to NGC 1052 and show that the results favour photoionization.

## 2 Observation and reduction

The nucleus of NGC 1052 was observed on 1984 August 18/19 with the cassegrain spectrograph of the Isaac Newton Telescope at the Roque de los Muchachos Observatory, La Palma, Canary Islands, using the 235-mm camera and a 400 l $mm^{-1}$ grating giving a linear dispersion of 104 Å $mm^{-1}$. The detector was a CCD camera with a GEC Type P8600 front-illuminated chip with 576 pixels of 22 $\mu$m along the dispersion direction, and the spectrum from $\lambda$6300 to $\lambda$9800 was covered in three exposures which were later merged before calibration with the standard star HR 7596 (Hayes 1970). The slit width was 1.4 arcsec, giving a resolution of 5 Å and the extracted data cover an effective slit length of 10 arcsec in position angle 270° (the minor axis is in position angle 210°). Reductions were carried out using STARLINK routines at Herstmonceux and are similar to those described by Díaz *et al.* (1985) except that in this case there is no fringing problem.

The resulting spectrum is shown in Fig. 1 in two versions, one being the flux-calibrated spectrum corrected for continuous atmospheric extinction and the other having the major atmospheric absorption bands (including the troublesome water vapour bands near 9400 Å) divided out. Following Fosbury *et al.* (1978) we assume negligible reddening in the optical region.

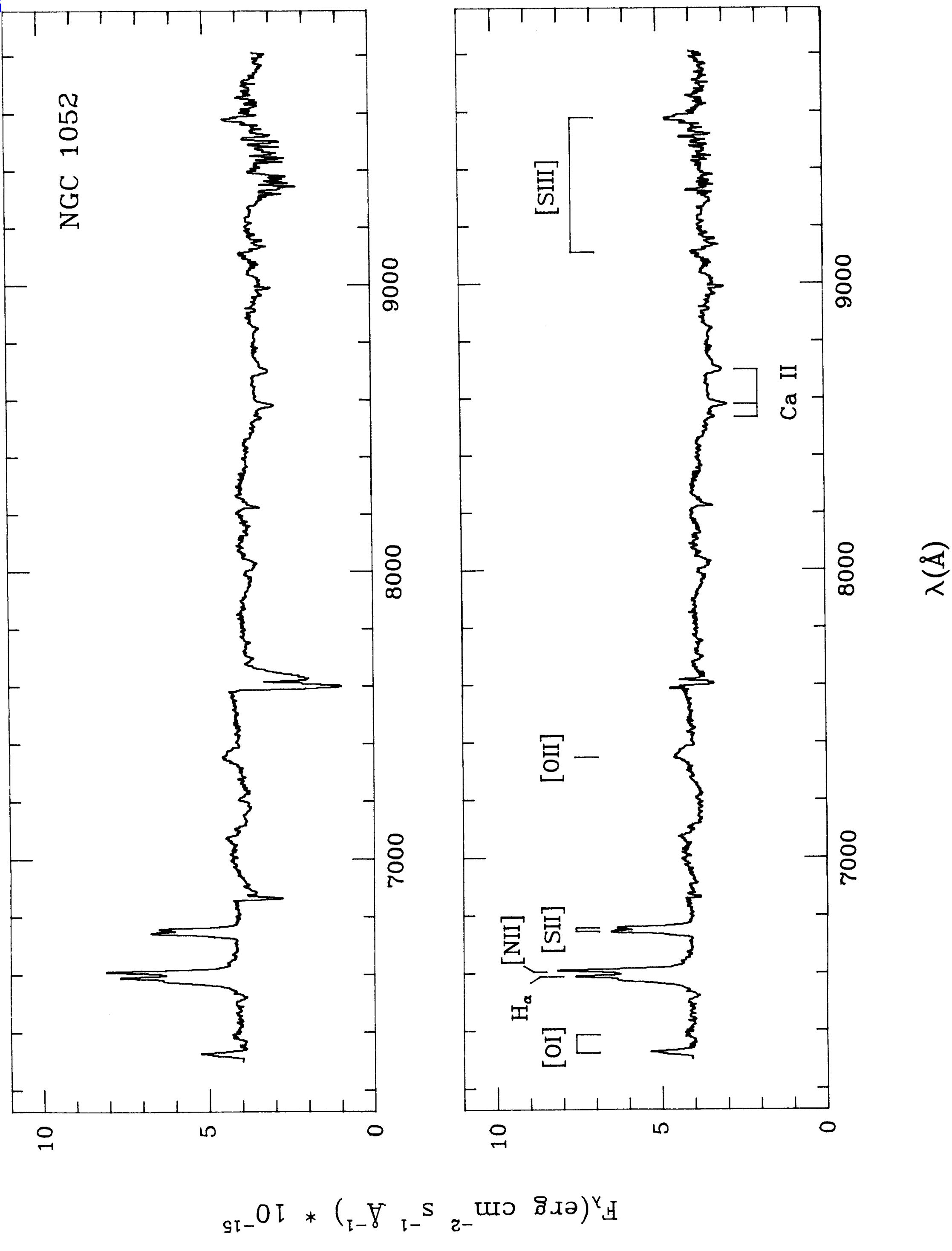


**Figure 1.** Red spectrum of the nuclear region (1.5×10 arcsec$^2$) of NGC 1052, with major telluric absorption bands divided out in the lower version. Wavelengths are in the observer's frame.

## 3 Results and discussion

We present our results in Table 1, together with the ultraviolet and optical measurements of Fosbury *et al.* (apart from $\lambda$4363) and predictions from several models: the three most nearly fitting shock models of Shull & McKee (1979), a power-law photoionization model computed with Ferland's code (*cf.* Terlevich & Melnick 1985) and a composite model derived from the computations of Péquignot (1984) in which 2/3 of the flux comes from component C1 (density 300 $cm^{-3}$) and 1/3 from component C2b (density $10^4$ $cm^{-3}$). Both components are ionized by an 80000 K blackbody (which leads to weaker He II than the pure power law) with excitation parameter $3.5\times10^{-4}$ and a flat X-ray tail, and the dense component enhances the auroral lines of [O II] and [S II]. This choice among his models seems preferable to Péquignot's own, in view of the new results on [O III] $\lambda$4363.

The shock models give a poor fit to the data, because a shock velocity of 90 km $s^{-1}$, which seems to be the best compromise for the visible lines, predicts too little emission in [O I] $\lambda$6300 and too much in the ultraviolet lines, especially C II $\lambda$1335 and C II] $\lambda$2326, whereas the pure power law does fairly well over the whole wavelength range with a minimum of assumptions and the simple composite model that we have taken from Péquignot's calculations fits all lines within a factor of 2 or better. The agreement with shock models might perhaps be improved by assuming more reddening in the ultraviolet or the presence of a component with a lower shock velocity, but our [S III] measurements lead to a still more direct argument for photoionization, because any combination of shock models that comes near to explaining the other lines underpredicts [S III] by a factor of 10 or more.

**Table 1.** Relative line intensities in NGC 1052.

| Line | $\lambda$ (Å) | Observed | | Shock models | | | Photo-ionization models | |
|---|---|---|---|---|---|---|---|---|
| | | Fosbury *et al.* | This work[a] | 80 km $s^{-1}$ | 90 km $s^{-1}$ | 100 km $s^{-1}$ | Péguignot | Power law[b] |
| C II | 1335 | <16 | | 11 | 151 | 164 | 19 | 11 |
| C IV | 1550 | <21 | | 0 | 4 | 290 | | 0 |
| He II | 1640 | <15 | | 0 | 1 | 29 | 34 | 96 |
| [O III] | 1663 | <14 | | 0 | 46 | 143 | | 1 |
| N III] | 1750 | <14 | | 0 | 21 | 45 | | 0.5 |
| C III] | 1909 | 21 | | 1 | 40 | 280 | 41 | 24 |
| C II] | 2326 | 72 | | 69 | 320 | 328 | 112 | 122 |
| [O II] | 3726/9 | 800: | | 296 | 915 | 700 | 798 | 883 |
| [Ne III] | 3869 | 60: | | | | | 61 | 55 |
| [S II] | 4068/76 | 45 | | 10 | 23 | 28 | 24 | 22 |
| [O III] | 4363 | <6[c] | | 0 | 7 | 18 | 1 | 1.6 |
| He II | 4686 | <10 | | 0 | 0 | 3 | 5 | 15 |
| H$\beta$ | 4861 | 100 | | 100 | 100 | 100 | 100 | 100 |
| [O III] | 4959/5007 | 299 | | 7 | 200 | 498 | 354 | 441 |
| [N I] | 5199 | 20 | | 34 | 36 | 80 | 27 | 20 |
| [O I] | 6300/63 | 199 | | 42 | 44 | 108 | 113 | 120 |
| H$\alpha$ | 6563 | 286 | (286) | 346 | 321 | 307 | 291 | 268 |
| [N II] | 6548/84 | 400 | 489 | 123 | 263 | 299 | 495 | 448 |
| [S II] | 6716 | 167 | 168 | 84 | 146 | 222 | 125 | 156 |
| [S II] | 6731 | 134 | 160 | 67 | 120 | 182 | 124 | 163 |
| [O II] | 7320/30 | 40: | 42 | 8 | 48 | 35 | 39 | 23 |
| [S III] | 9069 | | 51 | 2 | 2 | 7 | 111 | 111 |
| [S III] | 9532 | | 128 | 5 | 5 | 17 | 267 | 266 |

[a]From the noise in the continuum, we estimate our error to be ±15 units.
[b]$\nu^{-1.5}$ with no cut-off, density $10^3$ $cm^{-3}$, ionization parameter $10^{-3.5}$, solar composition.
[c]Rose & Trippico (1984).

Part of the discrepancy with shock models can, of course, arise from uncertainties in the atomic data input to the models, which would vitiate our argument if these are sufficiently large to produce an error of this order for [S III]. A direct (if not completely conclusive) test of such uncertainties is provided by the comparison made by Dennefeld (1982) between shock models and his measurement of [S III] in Kepler's supernova remnant. In this case the models underpredict [S III] by a factor of about 2 – a much smaller discrepancy than the one we find here. Conversely, the photoionization models overpredict [S III], again by about a factor of 2, which is similar to the discrepancies shown for Seyfert nuclei and the Crab nebula, as well as some other liners, in fig. 5 of Díaz *et al.* (1985). Thus the [S III] intensities in NGC 1052 are just as expected for photoionization, and add very significantly to the difficulties in accounting for the emission on the basis of shock-heating.

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