Evidence of merging in the Seyfert galaxy NGC 3393, revealed by modelling the spectra

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ABSTRACT

The discovery (Fabbiano et al. 2001) of two active black holes in the Seyfert galaxy NGC 3393, which are separated by about 490 light years, has revealed a merging event. This has led us to look for other evidence of galaxy collision and merging, using an analysis of the observed spectra in different frequency ranges. In the narrow-line region (NLR) of NGC 3393, we have found pre-shock densities that are higher by a factor of about 10 than in other active galactic nuclei, and we have found patches of ionized matter beyond the observed NLR bulk. These can be explained by the compression and heating of the gas downstream of the shock waves created by the collision. Metallicity, in terms of the O/H relative abundance, is about 0.78 solar. The Mg/H depletion by a factor of about 3, compared with solar, cannot be explained by Mg trapping into dust grains, as a result of high shock velocities. The low O/H and Mg/H abundances indicate mixing with external matter during the collision. Twice solar N/H is predicted by modelling the spectra of high-shock-velocity clouds reached by a $T_e \leq 10^5$ K blackbody flux. This suggests that Wolf–Rayet stars could be created by galaxy collision in the central region.

Key words: radiation mechanisms: general – shock waves – ISM: abundances – galaxies: individual: NGC 3393 – galaxies: Seyfert.

1 INTRODUCTION

A new galaxy that results from the collision of galaxies or from the collision of a galaxy with the interstellar medium (ISM) retains a few records of the parent objects. The most obvious evidence is the multiple (generally double) active galactic nuclei (AGNs) when at least two objects are involved. Yet, the morphological and physical pictures across the product galaxy also show collisional processes involving gas and dust clouds, from supersonic flows throughout the galactic medium, up to star birth and powerful starbursts, depending on the characteristics of the colliding parents. Theoretical simulation and modelling (e.g. Cox et al. 2008a, and references therein; Hammer et al. 2010) have been confirmed by the observations of some mergers, such as Arp 220, NGC 6240, NGC 7212, etc.

In Seyfert galaxies, the ranges of pre- and post-shock densities and of shock velocities might show some traces of collision in some regions inside and outside the narrow-line region (NLR) cone (e.g. for NGC 7212; Contini et al. 2012). There is an important issue concerning the metallicity, which depends on the mixing with external matter enclosed by merging, the new relative abundances of elements ejected by starbursts, the gas trapping into dust grains and matter from regions close to the AGN accompanying the outward wind (Torrey et al. 2012). Subsolar and oversolar relative abundances are both predicted.

Recently, Fabbiano et al. (2011) have reported the presence of two active massive black holes, separated by about 490 light years, in the Seyfert galaxy NGC 3393. They claim that the observation of two black holes very close together, and located deep into the bulge of a regular spiral galaxy, is important for our understanding of AGNs, in general, and of merging galaxies, in particular.

NGC 3393 was observed by Fabbiano et al. (2011) with the Chandra X-ray Observatory camera ACIS-S on 2004 February 28 (ObsID 4868 for 29.7 ks) and on 2011 March 12 (ObsID 12290 for 70 ks). Two obscured AGNs appear in the central regions of NGC 3393, which are most probably powered by mass accretion. The lower limits of the black hole mass are $\sim 8 \times 10^5 M_\odot$ and $\sim 10^6 M_\odot$ for the north-east and south-west sources, respectively (Fabbiano et al. 2011). Two obscured AGNS appear in the central regions of NGC 3393, which are most probably powered by mass accretion. The lower limits of the black hole mass are $\sim 8 \times 10^5 M_\odot$ and $\sim 10^6 M_\odot$ for the north-east and south-west sources, respectively (Fabbiano et al. 2011). Simulation results show that the massive black hole separation and the appearance of the spiral arms created by the merger could resemble those of NGC 3393 about five billion years after collision (Mayer et al. 2007).

This new discovery has turned NGC 3393 into an interesting target to test merging phenomena.

NGC 3393 is a close ($z = 0.0125$), bright ($m_B = 13.1$; de Vaucouleurs et al. 1991) Seyfert 2, classified as an early-type barred galaxy, appearing face-on. It is located in the outskirts of the Hydra cluster (de Vaucouleurs et al. 1991), covering more than 1 arcmin on the sky. Cooke et al. (2000) derived from the redshift a scale of
The strong emission lines in the International Ultraviolet Explorer (IUE) spectrum have suggested that modelling could lead to interesting results. Therefore, Diaz, Prieto & Wamsteker (1988) have presented integrated fluxes of the optical and ultraviolet (UV) spectra, providing a first clue to the physical conditions in the nuclear region. Cooke et al. (2000) have explored the NLR of NGC 3393, on the basis of the characteristic Hubble Space Telescope (HST) image.

IRAS fluxes from NGC 3393 (Moshir et al. 1990) have yielded a total infrared (IR) luminosity of $10^{10} L_\odot$ and a dust mass of $\sim 5 \times 10^8 M_\odot$. If the IR flux is a result of only star formation, a star formation rate of $\sim 4 M_\odot$ yr$^{-1}$ on kpc scale is predicted (Veilleux et al. 1994), corresponding to a low star formation efficiency. Because of the lack of young stars in the central region of the galaxy, Fabbiano et al. (2011) have claimed that the double black hole located deep in the bulge of the NGC 3393 AGN results from a minor merger event.

NGC 3393 is the source of a water maser, which is the only resolvable tracer of warm dense molecular gas in the inner parsec (Kondratko et al. 2008). The radio emission at 13 cm, taken by the Australia Telescope Compact Array, shows an outflow from the nucleus, not coincident with spiral arms or a bar (Bransford et al. 1998). The expanding radio lobes sweep up, shock and accelerate gas into shells (Pedlar, Unger & Dyson 1985), which are fragmented by Richtmyer–Meshkov instability, because of the underlying turbulence near the shock front. By aligning the Very Large Array (VLA) radio and HST optical central sources, Cooke et al. (2000) have found that the [O III] and radio images superpose. The coincidence of radio and optical emission features indicates that shocks are at work.

Long-slit spectroscopy (Whittle et al. 1988) has confirmed a morphological and kinematic association between the radio lobes and the emission-line gas in Seyfert galaxies. Therefore, the high excitation gas extending beyond the radio source, observed by Cooke et al. (2000) in NGC 3393, will be interpreted as a record of the galaxy collision. Whatever the case, the spectra emitted by the clouds will account for both the photoionizing flux (from the AGN and from the stars) and shocks.

In this paper, we investigate the role of the AGN and of prominent stars and their locations in NGC 3393, and we determine the range and distribution throughout the galaxy of shock velocities and pre-shock densities. We pay particular attention to the calculation of the relative abundances to hydrogen of the heavy elements throughout the galaxy, focusing on those identified with metallicity (e.g. oxygen in the present case). This is because metallicity is affected by star formation and by outflows of matter (i.e. by the interactions between the forming galaxy and the intergalactic medium; Sommariva et al. 2012).

We investigate NGC 3393 by modelling the emitted spectra. The formation of shock waves is predicted in colliding systems, so we adopt for the calculations the code SUMA,$^1$ which simulates the physical conditions of an emitting gaseous nebula under the coupled effect of photoionization from an external source and shocks.

In Section 2, we describe the observations of the line spectrum of NGC 3393 by Diaz et al. (1988) and the modelling results. In Section 3, we report and interpret the HST imaging and spectra, the ground-based optical images and the long-slit spectra presented by Cooke et al. (2000). In Section 4, we compare the continuum spectral energy distribution (SED), calculated consistently with the line spectra, with observations. We provide a discussion and concluding remarks in Section 5.

2 COMBINED UV–OPTICAL–IR LINE SPECTRUM

Diaz et al. (1988) have presented a rich spectrum of emission lines from NGC 3393, covering the 1200 and 7000 Å range. The line ratios are characteristic of a type 2 Seyfert galaxy. The UV spectrum shows relatively strong lines, which are useful to constrain the models. At the time, Diaz et al. (1988) believed that NGC 3393 was an early spiral (Sa), which most probably did not have a quasi-stellar nucleus.

Using the low-resolution mode of the IUE and its large aperture $(20 \times 10$ arcsec$^2$), Diaz et al. (1988) detected a strong, flat UV continuum source $(F_\nu = 1.7 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$) spectrum. Comparing the IUE flux of He II 1640 with a ground-based measure of He II 4686 taken through a $4 \times 4$ arcsec$^2$ aperture, they deduced a very low reddening of the emission-line spectrum: $E(B-V) \leq 0.07$, compared to $E(B-V) = 0.06-0.09$ in the Galaxy. Yet, NGC 3393 is an IRAS source, indicating the presence of warm dust (Boisson & Durret 1986).

The optical spectrum was obtained in 1981 with the Image Dissector Scanner (IDS) attached to the Boller and Chivens spectrograph at the Cassegrain focus of the European Southern Observatory (ESO), La Silla, 1.5-m telescope. The UV observations come from the IUE in low dispersion mode through a large spectrograph aperture (SWP20148, 400 min; LWP 2844, 110 min; LWP 7602, 361 min).

The combined UV–optical spectrum presented by Diaz et al. shows many lines that can be used to find the physical and chemical characteristics of NGC 3393 by modelling the line ratios.

2.1 Modelling the line spectra

We have run a grid of models that account for the coupled effect of shocks and photoionization (the primary flux) for both radiation from an active centre and radiation from the stars, on the basis of the arguments previously mentioned: (i) the collision of matter originated at the galaxy encounter and the collision of the NLR matter with the radio outflow from the nucleus; (ii) NGC 3393 contains two black holes in its active centre; (iii) stars and starbursts are generally observed in mergers. A brief summary of the calculation code is given in the following (see also Contini 2009).

The input parameters – the shock velocity $V_s$, the atomic pre-shock density $n_0$ and the pre-shock magnetic field $B_0$ – define the hydrodynamical field. These are used in the resolution of the Rankine–Hugoniot equations at the shock front and downstream. These equations are combined into the compression equation, which leads to the calculations of the density profile downstream. For all the models, we adopt $B_0 = 10^{-4}$ G.

The input parameter that represents the radiation field is the power-law (pl) flux from the active centre $F$ in number of photons cm$^{-2}$ s$^{-1}$ eV$^{-1}$ at the Lyman limit, if the photoionization source is an active nucleus. The spectral indices are $\alpha_{UV} = 0$ and $\alpha_{pl} = -0.7$. Here, $F$ is combined with the ionization parameter $U$ by $U = \alpha_{pl} F(\alpha - 1)/[(E_\text{H})^{-\alpha + 1} - (E_\text{C})^{-\alpha + 1}]$ (Contini & Aldrovandi 1983), where $E_\text{H}$ is the H ionization potential, $E_C$ is the high-energy cut-off, $\alpha$ is the density, $\alpha$ is the spectral index and $c$ is the speed of light.

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$^1$ http://wise-obs.tau.ac.il/~marcel/suma/index.htm
If the radiation flux is blackbody radiation from the stars (bb), the input parameters are the colour temperature of the star $T_\text{c}$ and the ionization parameter $U$ (in number of photons per number of electrons at the nebula).

In models accounting for the shock, another important radiation source is the secondary diffuse radiation emitted from the slabs of gas heated by the shocks at relatively high temperatures.

The geometrical thickness of the emitting nebula $D$, the dust-to-gas ratio $d/g$ and the abundances of He, C, N, O, Ne, Mg, Si, S, Cl, A and Fe relative to H are also taken into account. The distribution of the grain radius downstream is determined by sputtering, beginning with an initial radius of 1 $\mu$m.

The sets of model input parameters that best reproduce the data are regarded as the results. The data contain both random and systematic errors and the calculation results depend on the uncertainties of the atomic coefficients for 12 elements in all the ionization levels. Therefore, it is generally accepted that the models would reproduce the data within a factor of 2.

The calculations start at the edge of an emitting cloud, which corresponds to the shock front (see Contini et al. 2012, for a detailed description of the calculation). Our models adopt a plane-parallel geometry. The gas is compressed and thermalized adiabatically at the shock front, reaching the maximum temperature in the immediate post-shock region downstream, $T \sim 1.5 \times 10^5 (V_c/100 \text{ km s}^{-1})^2$. The downstream region is cut into a maximum of 300 plane-parallel slabs with different geometrical widths, which are calculated automatically, in order to follow the temperature gradient smoothly.

Each line intensity calculated in each slab downstream depends on the electron density, the electron temperature and the fractional abundance of the corresponding ion. The density of the gas is calculated by the compression equation. The fractional abundances of the ions are calculated by resolving the ionization equations, taking into account the primary flux (the photoionization), the secondary flux and collisional ionization. The flux both from the active centre and from the stars, as well as the secondary radiation, is calculated by radiation transfer throughout the slabs downstream.

The ionization equations are coupled with the energy equation for the calculation of the temperature in each slab. The value of $T$ decreases downstream following the cooling rate by free–free, free–bound and line emission, which are calculated in each slab. The line fluxes and dust-reprocessed radiation are integrated throughout the geometrical thickness of the cloud downstream.

We have calculated a large grid of models, changing the input parameters in a consistent way (i.e. by considering the effect of each of them on the different line ratios), until a fine tuning of all the line ratios to the data has been obtained. The calculated spectrum is finally selected by comparing the calculated and observed line ratios in the optical range and by constraining the precision of the fit by discrepancies that are set at $\leq 20$ per cent for the strongest lines (e.g. Ly$\alpha$, [O III]5007+) and $< 50$ per cent for the weakest lines.

### 2.2 Comparison of models with the observations

We start by modelling the observations of Diaz et al. (1988) because many lines are given in a large frequency range. The observed spectra are presented in Table 1. At the top of the table, the UV–optical line ratios to H$\beta$ are shown. In the middle, we report the [Ne V] 14.3 and [Ne III] 15.6 IR line absolute fluxes observed at Earth by Wu, Zhao & Meng (2011). However, note that in Table 1 the calculated line ratios are referred to as H$\beta = 1$, while the observed IR spectral lines are absolute fluxes. Thus, we constrain the models by the [Ne V]/[Ne III] line ratios, to avoid problems of distance, obscuration, etc. At the bottom of Table 1, the models are described by the set of input parameters.

Before discussing the results, we would like to recall that, in our models, the shocks are also present in radiation-dominated clouds. Moreover, we account for the flux from the stars, even if Diaz et al. claim that the UV emission comes from the nuclear region only. Moreover, we account for the flux from the stars, even if Diaz et al. claim that the UV emission comes from the nuclear region only and that the spectral type of NGC 3393 is late enough to yield a negligible stellar contribution in the UV.

Three grids of models were computed by adopting power-law photoionization + shock ($m_{\text{sh}}$), blackbody photoionization + shock ($m_{\text{bb}}$) and shock-dominated ($m_{\text{sh}}$) clouds. The models that best fit the data are presented in Table 1.

The method adopted for the modelling proceeds in two main steps.

#### Table 1. Comparison of calculated and observed line ratios to H$\beta$ = 1.

| Line  | Obs | $m_{\text{ad}}$ | $m_{\text{sh}}$ | $m_{\text{bb}}$ | $m_{\text{sh}}$ | $m_{\text{bb}}$ | FOS |
|-------|-----|----------------|----------------|----------------|----------------|----------------|-----|
| Ly$\alpha$ | 25.7 | 127. | 36. | 30.6 | 35.4 | – | – |
| N v 1252 | 1.58 | 28.9 | 1.29 | 0.04 | 1.43 | 2012 RAS \mbox{©} |
| Si v+ 1403 | 0.63 | 40. | 0.87 | 0.00 | 1.7 | 2012 RAS \mbox{©} |
| N v 1486 | 0.26 | 8. | 0.98 | 0.02 | 0.5 | – | – |
| C iv 1550 | 4.8 | 76.8 | 3.39 | 0.13 | 4. | – | – |
| He ii 1640 | 2.7 | 1. | 4.5 | 1.88 | 2.3 | – | – |
| C iii 1909 | 1.23 | 33.8 | 1.84 | 0.43 | 2. | – | – |
| Ne v 2424 | 1.05 | 5.2 | 0.35 | 0.035 | 0.3 | – | – |
| Mg ii 2789 | 0.78 | 23.8 | 0.5 | 2.27 | 0.2 | – | – |
| [O i] 3727 | 1.9 | 3.3 | 1.5 | 1.2 | 1.65 | 2.15 |
| [Ne iii] 3869 | 0.7 | 2.5 | 1.7 | 1.3 | 1.42 | 1.13 | 1.2 |
| [O iii] 4363 | 0.13 | 1.53 | 0.17 | 0.06 | 0.14 | 0.10 | 0.09 |
| He ii 4686 | 0.3 | 0.074 | 0.67 | 0.28 | 0.34 | 0.29 | 0.25 |
| [Ne v] 4726 | 0.05 | 0.53 | 0.014 | 5.e-4 | 0.024 | – | – |
| [A iv] 4740 | 0.06 | 0.34 | 0.1 | 0.003 | 0.033 | – | – |
| H$\beta$ | 1. | 1. | 1. | 1. | 1. | 1. | 1. |
| [O i] 5007+ | 16.88 | 16.3 | 14.24 | 13.5 | 14. | 13.6 | 13.56 |
| [Fe v] 6087 | 0.19 | 1. | 0.15 | 0.011 | 0.1 | – | – |
| [O i] 6300+ | 0.33 | 0.5 | 0.137 | 0.33 | 0.3 | 0.41 | 0.5 |
| [Ne ii] 6844 | 6.15 | 2.75 | 6.3 | 3.4 | 4. | 4.63 | 4.87 |
| H$\alpha$ | 3.8 | 5. | 2.9 | 2.9 | 3. | 3.38 | 3. |
| [S ii] 6717 | 0.9 | 0.11 | 0.033 | 0.37 | 0.3 | 1.89 | – |
| [S ii] 6731 | 1.25 | 0.25 | 0.073 | 0.8 | 0.65 | – | 1. |
| [Ar iii] 7135 | 0.4 | 0.42 | 0.7 | 0.42 | 0.47 | – | – |
| [Ne ii] 12.8 | – | 0.9 | 0.076 | 0.04 | – | – | – |
| [Ne v] 14.3 | 42.4 | 0.3 | 0.22 | 0.014 | – | – | – |
| [Ne iii] 15.5 | 95. | 0.33 | 1.2 | 1.67 | – | – | – |
| H$\beta$ absolute flux $b$ | – | 3.8e-3 | 4.5 | 0.59 | 1.24 | – | – |
| $V_c$ (km s$^{-1}$) | – | 300. | 100. | 600. | – | – | – |
| $n_0$ (cm$^{-3}$) | – | 1500. | 3000. | 300. | – | – | – |
| $F^c$ | – | 2.3e12 | – | – | – | – | – |
| $T_\alpha$ (K) | – | – | – | 8.64 | – | – | – |
| $U$ | – | – | – | 1. | – | – | – |
| $D$ (cm) | – | 1.e16 | 4.9e16 | 1.e17 | – | – | – |
| $\text{str}$ | – | – | 0. | 1. | – | – | – |
| RW | – | 0.886 | 0.003 | 0.111 | – | – | – |
| $P(\beta_{\text{us}})$ | – | 4.8 | 77.4 | 17.8 | – | – | – |

$^a$Units are 10$^{-21}$ W cm$^{-2}$, from Wu et al. (2011) for the non-hidden BLR Sy2 sample.

$^b$Units are erg cm$^{-2}$ s$^{-1}$.

$^c$Units are number of photons cm$^{-2}$ s$^{-1}$ eV$^{-1}$ at the Lyman limit.

$^d$Here, str indicates infalling (0) or outflow (1).
2.2.1 Physical parameters

First, we determine the physical conditions of the gas, adopting the most plausible relative abundances.

We start by calculating the line ratios of oxygen from different ionization levels, $[\text{O} \, \text{II}] 5007+\beta$, $[\text{O} \, \text{II}] 3727+\beta$ and $[\text{O} \, \text{I}] 6300+\beta$ (the ‘$+$’ indicates that the doublet is summed up), which depend on the fractional abundance of the ions and on $T_e$ and $n_e$, and the $[\text{O} \, \text{III}] 5007+\beta/[\text{O} \, \text{II}] 4363$ line ratio, which depends strongly on $n_e$ and $T_e$. In fact, various oxygen lines are generally observed in the optical range, and the $[\text{O} \, \text{III}] 5007+\beta$ lines are the strongest in Seyfert 2 galaxy spectra.

We try to reproduce the data by changing the input parameters, in particular, $F$, $V$, and $n_0$, considering that $n/n_0$ ranges between a minimum of 4 (the adiabatic jump) and $>100$, depending on $V$ and $B_0$. The temperature of the gas depends on the shock velocity, and the photoionization flux heats the gas to $\sim 2-3 \times 10^4$ K and ionizes the gas.

However, the model cannot be definitive until a satisfactory fit is also found for $[\text{He} \, \text{II}] \beta$ and for $[\text{C} \, \text{IV}]/[\text{C} \, \text{III}]$ in the UV. Both the $\text{He}$ and $\beta$ lines depend directly on the radiation flux from the active centre (primary radiation) in radiation-dominated models, while they depend on secondary diffuse radiation in collisionally dominated regimes.

The consistent fit of the $\text{O}$, $\text{He}$, and C line ratios is complicated by the fact that changing one of the input parameters affects the cooling rate downstream. Consequently, the stratification of the ions changes and the lines must be recalculated using a different set of input parameters.

The nitrogen lines $\text{N} \, \text{V}$ 1252 and $\text{N} \, \text{IV}$ 1486 in the UV and the doublet $[\text{N} \, \text{II}] 6548+6584$ in the optical range are also important when constraining the models. However, we do not know which of the lines of the $\text{N} \, \text{IV}$ multiplet is observed, so we refer to the sum of all the terms as an upper limit. $\text{N} \, \text{V}/[\text{N} \, \text{II}]$ depends on the reddening correction. For a relatively large FWHM of the line profiles, the $[\text{N} \, \text{II}]$ lines are blended with $\text{H} \alpha$, increasing their uncertainty. The models that gave an acceptable approximation to the data were run with $\text{N}/\text{H}$ twice solar.

2.2.2 Relative abundances

The second step of our modelling method is to complete the fit of all the line ratios by changing the relative abundances of elements that appear in the spectrum by a single line. Generally, these elements are not strong coolants (i.e. the corresponding lines are not strong enough to affect the cooling rate downstream).

Lines such as $\text{Mg} \, \text{II}$ and $[\text{Fe} \, \text{II}]$ are unique representatives of the respective elements. Therefore, they are modelled on the basis of their relative abundances, after the physical conditions of the emitting gas have been determined by the line ratios previously mentioned (Section 2.2.1).

The $[\text{S} \, \text{II}] 6717/\text{S} \, \text{II}] 6731$ line ratio depends particularly on the density of the emitting gas. The $[\text{S} \, \text{II}] /\beta$ line ratios depend on the geometrical thickness of the emitting cloud, which is mainly determined by $[\text{O} \, \text{I}] /\beta$. So, the calculated $[\text{S} \, \text{II}] /\beta$ can be adjusted to the observed $[\text{S} \, \text{II}] /\beta$ by changing the S/H relative abundance.

2.3 Results

### 2.3.1 AGN-, star- and shock-dominated clouds

The model $m_{\text{AGN}}$ was calculated by considering that the power-law radiation from the AGN reaches the shock front. In contrast, the radiation flux from the active centre reaches the cloud edge opposite to the shock front. This case has been checked, and it has been dropped because many lines did not fit, in particular $[\text{O} \, \text{I}] /\beta > 1.5$. This result suggests that, in NGC 3393, the NLR gas falls towards the black hole(s).

The absolute fluxes of $[\text{Ne} \, \text{III}]$ and $[\text{Ne} \, \text{V}]$ observed by Wu et al. (2011) (see Table 1) can be used to calculate the distance of the emitting gas from the galaxy centre $r$. Combining the observed flux at Earth with the flux calculated at the nebula for $[\text{Ne} \, \text{III}]$, which is a relatively strong line, we have $F_{\text{calc}} = F_{\text{obs}}[f]$ where $f$ is the filling factor, $d$ is the distance of NGC 3393 from Earth ($d = 54$ Mpc, adopting $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$) and $F_{\text{calc}} = [\text{Ne} \, \text{III}] /\beta \times H_0$ (absolute flux). Here, $r \sim 23/(f/2)^2$ pc for clouds reached by the AGN radiation.

Table 1 shows that the most acceptable approximation to the observed spectrum is obtained by the model $m_{\text{AGN}}$. However, the $[\text{S} \, \text{II}] /\beta$ line ratios are very low compared to observations, and the $[\text{He} \, \text{II}] /\beta$ line ratio is too high. This indicates that the flux from the active centre, required to fit the $[\text{O} \, \text{III}] /\alpha$ line ratio, is too high. However, if we reduce the flux intensity, this would spoil the fit of the oxygen lines from three ionization levels. We check whether the contributions of a shock-dominated model $m_{\text{sh}}$ (representing clouds screened from radiation or too far to be reached) and of a $m_{\text{AGN}}$ model (accounting for radiation from the stars) could help.

The $m_{\text{sh}}$ and $m_{\text{AGN}}$ models were selected from grids with the same criteria as those used to select $m_{\text{AGN}}$.

The best-fitting $m_{\text{sh}}$ model refers to the case representing matter propagating outwards from the stars. The opposite case was dropped because of unacceptable $[\text{O} \, \text{I}] /\beta = 0.02$ relative to the other oxygen line ratios, and very low $[\text{S} \, \text{II}] /\beta$. Stars can drive large-scale winds, ejecting circumstellar gas. The winds and radiation fluxes from the stars enrich and heat the neighbourhood medium, respectively.

The effective temperature of the stars is high $T_e \sim 10^8$ K, but it does lead to an acceptable fit of the calculated to the observed optical spectrum of NGC 3393 (Table 1). We recall that Wolf–Rayet (WR) stars can reach much hotter temperatures than main-sequence stars. A $T_e \leq 140\,000$ K WC star can yield $[\text{Ne} \, \text{III}] 15.6/[\text{Ne} \, \text{II}] 12.8 \sim 10$. Similarly, a $120\,000$ K WN star can reach $[\text{Ne} \, \text{II}] /[\text{Ne} \, \text{III}] = 100$ (Rigby & Rieke 2004). Unfortunately, we do not have the datum of the $[\text{Ne} \, \text{II}] 12.8$ line (Table 1) to constrain the models. In the next section (Sect. 3.1), we see that these WR stars, which ionize and heat the surrounding gas that is characterized by relatively high $V_e$, explain well both the $[\text{O} \, \text{III}] /\beta$ line ratio ($>10$) and the high FWHM observed in the centre of NGC 3393 (Fig. 2).

Cid Fernandes et al. (2004) refer to star formation in Seyfert 2 galaxies. They present model synthesis results that show the percentage in flux at 4020 Å of the featureless continuum, young, intermediate and old stellar populations. They find for NGC 3393 a percentage of 83 per cent for old stars and of 4 per cent for young stars, although Gu et al. (2006) have claimed that, in general, the Seyfert 2 nuclear emission luminosity is mainly a result of young stars and that central starbursts are found in merger Seyfert galaxies (e.g. NGC 6240).

### 2.3.2 Densities and velocities of the emitting gas

The pre-shock densities relative to the $m_{\text{sh}}$ model are similar to those found throughout other starburst galaxies (100–800 cm$^{-3}$; Viegas, Contini & Contini 1999). However, the models that represent the AGN and the shock-dominated clouds show pre-shock
densities higher by a factor of $\leq 10$ than in the NLRs of AGNs (300–1000 cm$^{-3}$; Contini, Viegas & Prieto 2004, and references therein) and in LINERs (100–600 cm$^{-3}$; Contini 1997, see their table 3). This yields downstream densities of $\geq 10^3$ cm$^{-3}$ after compression, depending on $V_c$ and $B_0$. We suggest that the high densities adopted in the $m_{sh}$ and $m_{bb}$ models could be a record of merging.

The velocities throughout the NLR of NGC 3393 (Cooke et al. 2000, see their fig. 8) are relatively low ($\sim 100$ km s$^{-1}$) similar to those found in the clouds in the ‘region of quiescent regime’ (Tadhunter et al. 2000) in the NLR cone of the Seyfert galaxy NGC 7212, most likely a merger and, similar to the shock velocities found close to the Galactic Centre (Contini & Goldman 2011), most likely a low-luminosity AGN (Contini 2011). Higher velocities are found close to the NLR centre of NGC 3393 between $-20$ and 20 arcsec (Cooke et al. 2000; see their fig. 8).

2.3.3 Metallicities

In agreement with previous works on NGC 3393 (Diaz et al. 1988; Cooke et al. 2000), we find that the Mg/H relative abundance should be about one-third of the solar value in the shock-dominated and starburst gas, while in clouds close to the AGN Mg/H is about solar. The solar relative abundances from Allen (1976) are C/H = 3.3 $\times$ 10$^{-4}$, N/H = 9.1 $\times$ 10$^{-5}$, O/H = 6.6 $\times$ 10$^{-4}$, Ne/H = 10$^{-4}$, Mg/H = 2.6 $\times$ 10$^{-4}$, Si/H = 3.3 $\times$ 10$^{-4}$, S/H = 1.6 $\times$ 10$^{-4}$, C/H = 4 $\times$ 10$^{-4}$ and Fe/H = 3.2 $\times$ 10$^{-4}$. Generally, Mg is included in silicate grains, but at shock velocities higher than $\sim 200$ km s$^{-1}$ the grains are destroyed by sputtering. Table 1 shows that the models that overpredict the Mg/H$\beta$ line ratio are $m_{sh}$ and $m_{bb}$, both calculated by $V_c > 200$ km s$^{-1}$. Therefore, the Mg depletion could be a result of mixing with external matter during the merger process. The same is valid for Si.

The models were calculated by adopting N/H twice solar and C/H = 0.7 solar, while the other relative abundances were solar. However, the [S II]/H$\beta$ line ratios depend on the models that are matter bound. We generally choose the geometrically thickness of the clouds on the basis of [O I]/H$\beta$. The larger the cloud, the higher both the [S II]/H$\beta$ and [O I]/H$\beta$ line ratios, because the first ionization potential of sulphur (10.36 eV) is much lower than that of oxygen (13.61 eV).

In Table 2, we compare the UV lines calculated by the $m_{AV}$ average model (Section 2.3.4) with the Faint Object Spectrograph (FOS) blue observations presented by Cooke et al. (2000, see their table 9). The observed line ratios to C IV = 100 are all overpredicted by the model by factors $\geq 2$. The carbon lines in Table 1 were well reproduced by adopting C/H = 0.7 solar. Table 2 shows that a solar abundance should be adopted for C/H and that, most probably, the reddening correction adopted by Diaz et al. (1988) was slightly misleading.

2.3.4 Average spectrum

Table 1 shows that the shock-dominated model, although it fits the [O III] : [O II] : [O I] ratios and their ratios to H$\beta$, as well as the C IV : C III] requirement, overpredicts most of the UV lines by a large factor. However, the $m_{bb}$ model, selected in particular by the agreement of He/H$\beta$ line ratios, underpredicts the UV lines (except the Ly$\alpha$/H$\beta$ line ratio), which compensates for the results of the $m_{sh}$ model. Therefore, the spectra that account for the different radiation sources are summed up with relative weights (RWs), which appear in the penultimate row in Table 1. The average model $m_{AV}$ is shown in Table 1 (column 6) and it is compared with the observational data of Diaz et al. (1988) (column 2) and the ground-based observations (column 7) and the FOS red detector observations (column 8) reported by Cooke et al. (2000, see their tables 7 and 8, respectively). In the last column of Table 1, for comparison, we give a fit to the ground-based low-resolution spectra, co-added over a 8 $\times$ 8 arcsec$^2$ region centred on the nucleus (Cooke et al. 2000). The FOS spectra are also included in the table.

The high RW of the shock-dominated model compensates for the very small absolute flux of the calculated lines, which can be calculated by the H$\beta$ absolute flux. The RWs were selected by the best fit of $m_{AV}$ to the data. The criteria are the same as those adopted to select the $m_{sh}$, $m_{bb}$ and $m_{sh}$ models (discrepancies $\leq 20$ per cent for strong lines and $<50$ per cent for weaker lines), but considering the total combined UV–optical spectrum.

In the last row of Table 1, the resulting percentage of the absolute [O III] 5007$^+$ line for the three models is given: 4.8 per cent for shock-dominated clouds, 77.4 per cent for the AGN photoionized clouds and 17.8 per cent for clouds illuminated by the stars. The AGN contribution dominates, but the shock- and star-dominated models are not negligible because they improve the fit to the data.

3 PHYSICAL CONDITIONS THROUGHOUT THE GALAXY

To obtain some information about the distribution of the physical conditions throughout the NLR, in Fig. 1 we present the modelling of the spectra reported in the different regions of NGC 3393 by Cooke et al. (2000, see their fig. 5). The lines are the most significant ([O III], H$\beta$, H$\alpha$ and [N II]), but they are too few to constrain the models. Nevertheless, we have tried to build up a grid on the basis of the models that were used to fit the spectrum observed by Diaz et al. (1988) (see Table 1). The input parameters of the models are described in Table 3. Fig. 1 shows the results selected from the grid, which reproduce the observed [O III]/H$\beta$ and [N II]/H$\alpha$ line ratios, corresponding to different physical situations. However, the models are not constrained by the other line ratios (see Table 1). If these lines were observed in the different regions of the NLR of NGC 3393, some models would disappear from Fig. 1. However, Table 3 shows that the input parameters included in the grid change smoothly throughout ranges that are consistent with
Figure 1. Modelling the data from Cooke et al. (2000, see their fig. 5). The blackbody radiation (+shock) models are represented by magenta lines, the power-law photoionization (+shock) models are represented by blue/cyan/green lines and the shock-dominated models \((F = 0)\) are denoted by red lines. The black solid line shows the division between the H II regions and the AGN, as given by Cooke et al. (2000, fig. 5). The black asterisks represent the models used in Table 1, and the encircled asterisk represents the average \(m_{AV}\) model. Triangles and encircled triangles reproduce the data of Cooke et al. for the AGN and H II regions, respectively. Details of the model are given in Table 3.

Table 3. Models adopted to explain the data in Fig. 1.

| \(V_s\) (km s\(^{-1}\)) | \(n_0\) (cm\(^{-3}\)) | \(\log F\) | \(T_s\) (10\(^4\) K) | \(D\) (cm) | Type | Symbol |
|---|---|---|---|---|---|---|
| 100 | 3000 | 12.36 | – | 2.9e16–3.9e16–4.9e16–5.9e16–7.9e16–1.e17 | pl | dashed blue |
| 100 | 3000 | 11.3 | – | 1.e15–2.6e15–3.e15–4.2e15–1.26e16–2.26e16 | pl | dot-dashed blue |
| 100 | 2000 | 9.7 | – | 2.4e13–3.4e14–2.4e14–2.9e15 | pl | solid cyan |
| 300 | 2000 | 11. | – | 4.3e14–4.5e14–5.e14–1.1e15–2.5e15 | pl | solid blue |
| 400 | 2000 | 11. | – | 5.8e14–5.5e14–5.6e14–6.9e14 | pl | solid green |
| 400 | 2000 | 11.77 | – | 5.8e14–7.e14–1.8e15–4.28e15–1.17e16 | pl | dashed green |
| 600 | 300 | \(U = 1\) | 2.6–3.6–4.6–5.6–8.6 | 1.e16 | sb | solid magenta |
| 100 | 1000 | \(U = 0.4\) | 3.0–4.0–5.0 | 1.e16 | sb | solid magenta |
| 100 | 1000 | \(U = 0.5\) | 2.6–3.0–4.0–5.0 | 1.e16 | sb | solid magenta |
| 100–200–300–400–500 | 1000 | – | – | \(\leq10^{16}\) | sd | dash-dotted red |
| 100–200–300–400–500 | 100 | – | – | \(\leq10^{16}\) | sd | dash-dotted red |
| 100–200–300–400–500 | 1500 | – | – | \(\leq10^{16}\) | sd | solid red |

the Seyfert 2 NLR physical conditions, avoiding unsuitable large jumps.

3.1 Calculation results

Note that for certain strong line ratios (e.g. [O III]/H\(\beta\)) a high flux from the active centre and a high shock velocity can give similar results, while other spectral lines change. Thus, the results are shifted in different positions in Fig. 1. The same can occur for star-dominated and AGN-dominated models, calculated with different geometrical thicknesses.

We have adopted N/H twice solar, on the basis of the modelling of the average spectrum. Fig. 1 shows that, by calculating the models by N/H between 1 and 2 solar, we can reproduce all the data of Cooke et al. (2000, see their fig. 5).

The observations cover the NLR throughout the galaxy. In this region, the FWHMs of the line profiles show different velocities from \(<100\) to \(\geq400\) km s\(^{-1}\) (Fig. 2). Shocks are created by the underlying turbulence, which might originate from the collision and merging of galaxies, leading to fragmentation of matter. Therefore, the models are calculated using different geometrical thicknesses.

The power-law-dominated models are matter bound. We have calculated the line ratios at different distances from the shock front in each cloud (Table 3), mimicking fragmentation. The results are indicated in Fig. 1 by the '+' over the curves at the distances \(D\) reported in Table 3. A lower \(D\) corresponds to a higher [O III]/H\(\beta\).

High-velocity models (\(\sim300–400\) km s\(^{-1}\)), with a flux log \((F) \leq 12\) and different geometrical thicknesses, reproduce most of the cloud spectra (solid blue and green lines). Low-velocity (\(\sim100\) km s\(^{-1}\)) power-law flux-dominated models (blue dashed and
spectra from the HII regions (magenta dot-dashed and dashed lines, open circles) are well fitted by the star-dominated model, calculated using a blackbody flux corresponding to $U^* \sim 8.6 \times 10^4$ K; magenta solid line) contributes to reproduce the spectrum observed by Diaz et al. (1988) (Table 1). At relatively low $T_s$ ($\leq 5 \times 10^4$ K), the model results follow the line separating the AGN from the HII regions. The line ratios from the HII regions (Cooke et al. 2000, see their fig. 5, open circles) are well fitted by the star-dominated model, calculated using a blackbody flux corresponding to $T_s \leq 5 \times 10^4$ K. The ionization parameter that better fits the spectrum observed by Diaz et al. (1988) is $U = 1$, but a lower $U$ (0.4–0.5) characterizes the spectra from the HII regions (magenta dot-dashed and dashed lines, respectively).

### 3.2 Interpretation of the data

We refer to Fig. 2. The modelling is constrained only by the FWHM of the line profiles and the [O II]/H$\beta$ line ratios. We consider that the FWHM indicates roughly the shock velocity $V_s$ in the observed position.

Schematically, we distinguish four types of clouds: (i) high [O II]/H$\beta$, high $V_s$; (ii) high [O II]/H$\beta$, intermediate $V_s$; (iii) high [O II]/H$\beta$, low $V_s$; (iv) low [O II]/H$\beta$, low $V_s$. High values of [O II]/H$\beta$ are close to 10 and low values are close to 1. High values of $V_s$ are $\sim 400$ km s$^{-1}$, intermediate values are $100 < V_s < 400$ km s$^{-1}$ and low values are $\sim 100$ km s$^{-1}$.

In particular, the velocities – as well as the [O II]/H$\beta$ flux – peak at the centre of the NLR, between -0.5 and 0.5 arcsec. Our models (Fig. 1) show that the emitting gas is ionized by the power-law flux from the AGN ($\log (F) \sim 11 - 12$). Relatively strong shocks are at work, characterizing the velocity field ($V_s = 400$ km s$^{-1}$) and yielding fragmentation of the clouds, as revealed by their low geometrical thickness $D$. The emission-line fluxes from the clouds illuminated by stars with $T_s \sim 8.6 \times 10^4$ K are blended with those photoionized by the AGN power-law flux. Eventually, shock-dominated clouds also contribute.

The top panel of Fig. 2 shows that high and low velocities coexist at slightly larger radii from the centre, while log ([O II]/H$\beta$) are constant at two values: $\geq 1$ and $\sim 0.5$ (bottom panel). The lowest ratios are better explained by the blackbody photoionization in HII regions, while the highest ratios are reproduced by both power-law radiation-dominated and shock-dominated clouds, corresponding to different $V_s$. Note that the AGN-dominated model explains the $V_s = 100$ km s$^{-1}$ clouds with high ionization throughout most of the NLR from east to west.

The FWHM picture is hardly symmetric, even close to the centre, because the clouds correspond to higher values of $V_s$ in the east. At about $-10$ arcsec, the ionization jumps to high values (Fig. 2, bottom panel), which can be explained by shock-dominated clouds with low velocities ($\sim 100$ km s$^{-1}$), and the stars correspond to the low ionization gas (small asterisks). In particular, at $-30$ arcsec,
some highly ionized clouds with $V_s > 100 \text{ km s}^{-1}$ indicate shocks outside the NLR bulk. We interpret these as a collision record. In the west (Fig. 2), the shock-dominated clouds are less evident but they cannot be excluded.

4 CONTINUUM SPECTRAL ENERGY DISTRIBUTION

Fig. 3 shows the SED of the NGC 3393 continuum. The data come from the NASA/IPAC Extragalactic Data base (NED; Lauberts & Valentijn 1989; Moshir et al. 1990; de Vaucouleurs et al. 1991; Kinney et al. 1993; Griffith et al. 1994; Condon et al. 1998; Doyle, Drinkwater & Rohde 2005; Levenson et al. 2006; Peng et al. 2006; Muñoz Marín et al. 2001; Gandhi et al. 2009).

We try to reproduce the data using the same models as those that led to the fitting of the combined optical–UV spectrum presented by Diaz et al. (1988). Two lines correspond to each model, one representing the bremsstrahlung emitted from the gas and the other showing the dust reprocessed radiation flux. We recall that the dust reradiation peak shifts at higher frequencies, the higher the shock velocity, because dust grains are heated collisionally by the gas and radiatively by the power-law or blackbody flux. Collisional heating prevails at relatively high shock velocities. Also, the maximum frequency of the bremsstrahlung increases with the shock velocity (Contini et al. 2004).

Therefore, in Fig. 3, we present the bremsstrahlung calculated by the $m_{\text{bb}}$ model, which is calculated by $V_s = 600 \text{ km s}^{-1}$. The calculation results give a good fit to the observed soft X-ray data. The $m_{\text{pl}}$ model calculated by photoionization from the AGN and a relatively low velocity, $V_s = 100 \text{ km s}^{-1}$, reproduces the data in the near-UV.

The data in the radio frequency range are few but they are enough to show that the flux is a bremsstrahlung with some self-absorption of free–free radiation. The bremsstrahlung are emitted by the same power-law and star blackbody dominated models, which fit the flux in the near-IR and in the soft X-ray ranges, respectively. The radio emission is optically thick to free–free absorption in luminous infrared galaxies (Condon et al. 1991), in agreement with model calculations. Actually, radio synchrotron radiation by the Fermi mechanism at the shock front is not observed in NGC 3393.

Fig. 3 shows that the IR data are well reproduced by the sum of the reprocessed radiation fluxes calculated by the $m_{\text{bb}}$ and $m_{\text{pl}}$ models that appear in Table 1. The IR peak corresponds to a relatively low dust-to-gas ratio ($\sim 10^{-4}$ by mass).

The peak in the optical–UV range is a result of the old background star population. The data are nested inside the blackbody curves, corresponding to star temperatures between 3 and $4 \times 10^3 \text{ K}$. The young hot stars predicted by model calculations have a temperature of $8.6 \times 10^3 \text{ K}$. The corresponding blackbody flux peaks in the UV frequency range. However, below the Lyman limit, up to 0.2 keV, we have very little observational information; observations are difficult because of the heavy absorption by our Galaxy (Fig. 3).

Our results agree with those of Levenson et al. (2006), who have fitted the NGC 3393 nuclear and central spectra using models that account for gas heated at a temperature of $\sim 3.9 \times 10^7 \text{ K}$. Such a temperature can be found downstream of a shock with $V_s \geq 160 \text{ km s}^{-1}$. Moreover, Levenson et al. have reported that most of the soft X-ray emission (at least 60 per cent) is spread (as well as the optical) throughout an area of $1700 \times 770 \text{ pc}$. Actually, the consistent modelling of the line and continuum spectra, presented in the previous sections, indicates that shocks are present throughout the whole NLR, with velocities between 100 and 600 km s$^{-1}$.

Levenson et al. (2006) have claimed that most of the hard X-rays are emitted as reflection continuum emission from the obscured AGN. Although broad FWHM line profiles have not been seen in the optical–near-IR spectra observed up to now, nevertheless Fig. 3 shows that bremsstrahlung emitted downstream of shocks corresponding to at least $V_s = 1000 \text{ km s}^{-1}$ might contribute to

![Figure 3](https://academic.oup.com/mnras/article-abstract/425/2/1205/1190869/1211782)

**Figure 3.** Comparison of the model results with the continuum SED. Data from the NED are denoted by black circles; blue solid line, model $m_{\text{pl}}$; magenta solid line, $m_{\text{bb}}$; red solid line, $m_{\text{sd}}$; red dashed line, shock-dominated model calculated by $V_s = 1000 \text{ km s}^{-1}$ and $n_0 = 1500$; solid and dashed black lines, blackbody flux calculated by $T = 3000$ and 4000 K, respectively (the latter represents the old background star population); dot-dashed line, the blackbody flux corresponding to $8.6 \times 10^3 \text{ K}$. The cyan dashed lines limit the ‘obscured window’.
the hard X-ray emission. Moreover, the near-IR reradiation by dust calculated by such a high \( V_s \) would complete the fit of the IR data in NGC 3393.

5 DISCUSSION AND CONCLUDING REMARKS

When modelling the spectra in this paper, we have obtained the physical and chemical conditions throughout the NLR of the NGC 3393 Seyfert galaxy. We have searched for some evidence of merging within this galaxy, following the results of the X-ray observations presented by Fabbiano et al. (2011). They have found that two black holes coexist in the centre of the galaxy.

The collision of two galaxies suggests immediately that shock waves will result, leading, in general, to star formation in the centre (Cox et al. 2008) and throughout the galaxy.

Therefore, our models account for gas+dust clouds ionized and heated by the power-law flux from the active centre(s), by stars and by the shock.

We have found that the power-law radiation flux from the AGN largely dominates the spectral emission from the gas clouds throughout the galaxy. The flux ranges between \( \sim 10^{44} \) and \( \sim 3 \times 10^{42} \) in number of photons cm\(^{-2}\) s\(^{-1}\) eV\(^{-1}\) at the Lyman limit, which is characteristic of the NLR of AGNs. Because of their small distance, we treat the two black holes as the unique source of power-law radiation flux.

The pre-shock densities are unusually high, a factor of \( \sim 10 \) higher than in the NLR of Seyfert galaxies. Higher densities can reveal that a shock front has crossed the colliding region, compressing the gas throughout the galaxy. The shock wave was most probably the result of different densities on large scales in the colliding galaxy gas.

We have searched for the distribution of the shock fronts and their strength throughout the galaxy and in the surrounding medium. By modelling the spectra in the optical–UV range, we have found that shock velocities range between 100 and 600 km s\(^{-1}\). The velocities peak in the central region of NGC 3393 (Fig. 2). The merging of the disc matter could occur through fragmentation of dust and gas clouds, a typical result of turbulence at the shock front. Indeed, fragmentation is predicted by modelling the emitting cloud spectra, which shows various and small geometrical thicknesses.

Downstream of the shock fronts, the gas is compressed and heated to temperatures that depend on the shock velocity. The spread of shock fronts throughout the NLR agrees with Levenson et al. (2006), who claim that NGC 3393 is characterized by extranuclear soft X-ray emission.

Evidence of a galaxy collision in NGC 7212 has been provided by the observations (Cracco et al. 2011) of high [O iii]/\( H\beta \) line ratios and relatively large [O iii] FWHM profiles outside the NLR cone edges. A similar case is found in NGC 3393. Cooke et al. (2000, see their fig. 8) show a region to the north-east, separated from the core, which they have identified with the bright patch of the [O iii] emission line at \( \sim 20 \) arcsec east, 20, 20 arcsec north of the nucleus. They have claimed that it could be ‘some kind of bow shock’. We suggest that these patches could be the record of a collisional event.

Our results show that stars are present in NGC 3393 with a series of temperatures, from \( 3 \times 10^4 \) to \( 8.6 \times 10^4 \) K. Those corresponding to the highest temperature (\( T_s = 8.6 \times 10^4 \) K) are explained by WR stars. The clouds in the neighbourhood of the high \( T_s \) stars have pre-shock densities of 300 cm\(^{-3}\), shock velocities \( V_s \approx 600 \) km s\(^{-1}\) and the ionized matter is highly fragmented. Fig. 2 shows that they are most probably located close to the galaxy centre, whereas the oldest stars accompanied by relatively low velocities (100 km s\(^{-1}\)) are located throughout the NLR.

Cox et al. (2008) have analysed the starbursts that result from tidal forces in mergers, and their results indicate that galaxies with similar mass produce the most intense bursts of star formation, while mergers of galaxies with different masses are not expected to give birth to new stars. A starburst generally appears in the centre of a merging Seyfert galaxy, between the black holes (e.g. in NGC 6240). Starbursts are not predicted in NGC 3393 by the population model analysis of Cid Fernandes et al. (2004), who evaluated a 4 per cent fraction of young stars and 83 per cent of old stars. However, we have found that high-velocity clouds illuminated by young hot stars contribute 17.8 per cent to the [O iii] 5007+ line flux, compared to low-velocity clouds ionized by the AGN, which contribute \( \leq \) 80 per cent in the NLR. The high-velocity gas surrounding the hot stars provides a relatively large fraction of the central X-ray flux. The relative fraction of young hot stars cannot be easily evaluated because the continuum SED of NGC 3393 shows that the blackbody flux corresponding to \( T = 8.6 \times 10^4 \) K peaks in the UV frequency range, where absorption by our Galaxy is very strong (Fig. 3).

WR stars of type N are characteristic of strong winds spreading nitrogen-rich gas in the NLR. In fact, Table 1 indicates that the emitting nitrogen-rich gas exhibits the highest velocities. Our modelling shows that, besides matter ejected from the stars, the shock-dominated clouds with \( V_s = 300 \) km s\(^{-1}\) would also better fit the [N ii]/\( H\beta \) data, when adopting the N/H relative abundance at least twice solar. These clouds are most probably screened from the star radiation flux by dusty clumps and/or they are too far to be reached by the photoionizing flux.

The metallicity of the wind is the same as the metallicity of gas in the star-forming region from which the wind emerges (Torrey et al. 2012). The nitrogen-rich NGC 3393 results from the competition between included low-metallicity gas and enrichment from star formation. Yet, metallicity is generally related to oxygen abundance.

We have found the solar O/H relative abundances by adopting the Allen (1976) values (O/H = \( 6.6 \times 10^{-4} \)) in the calculation of the spectra. The solar abundances presented by Anders & Grevesse (1989) and Feldman (1992) give O/H = \( 8.51 \times 10^{-4} \), reducing the metallicity in NGC 3393 to 0.78 solar. We have also found a depletion of Mg by a factor of \( \sim 3 \), compared to solar. Mg cannot be trapped into dust grains, which are sputtered throughout the strong shocks.

We suggest that the low O/H and Mg/H relative abundances show mixing with external matter as a result of merging. The high N/H is ‘indirect’ evidence of merging, because it is a product of the central stars, which, in turn, are created by the collision of galaxies of near-equal mass.

In conclusion, by modelling the spectra of NGC 3393, we have found some evidence of galaxy collision and merging. Our results, obtained by consistent calculations, are valid, but they are not definitive because of the scarcity of data.

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