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# On the reliability of C IV $\lambda$1549 as an abundance indicator for high-redshift star-forming galaxies

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**ABSTRACT**

We reconsider the use of the equivalent width of C IV $\lambda$1549, EW(C IV), as an indicator of the oxygen abundance in star-forming galaxies, as proposed by Heckman et al. for nearby starbursts. We refine the local calibration of EW(C IV) versus log (O/H) by using a restricted wavelength window which minimizes blending with interstellar absorption lines. When applied to the *stellar component only* of the complex C IV $\lambda$1549 features in two high-redshift galaxies with good quality spectra, MS 1512−cB58 ($z = 2.7268$) and Q1307−BM1163 ($z = 1.4105$), the local calibration gives values of the oxygen abundance which are in good agreement with other metallicity determinations based on nebular emission and interstellar absorption lines. Our main conclusion is that for this method to give reliable results at high redshifts, it should only be used on data of sufficiently high spectral resolution ($R \gtrsim 1000$) for stellar and interstellar C IV components to be clearly separated. Oxygen abundances will be systematically overestimated if the local calibration is applied to spectra of high-redshift galaxies obtained with the low resolving powers ($R \simeq 200$–300) of many current wide-field surveys. It will also be necessary to understand better the causes of the scatter in the local relation, before we can be confident of inferences from it at high $z$.

**Key words:** galaxies: abundances – galaxies: starburst – ultraviolet: galaxies.

## 1 INTRODUCTION

Great progress has been made recently towards establishing both the star formation history (e.g. Madau et al. 1996; Hopkins 2004; Bunker et al. 2004, and references therein), and the chemical enrichment history (e.g. Kewley & Kobulnicky 2005; Pettini 2006, and references therein) of the Universe. The latter, whilst observationally more challenging, represents a powerful means of assessing how metallicity responds to star formation from $z \sim 5$ through to the present day.

As discussed by Pettini (2006), various metallicity diagnostics have been applied to the analysis of the spectra of high-redshift galaxies. Those most widely used so far are based on the rest-frame optical emission lines from H II regions (e.g. Pagel et al. 1979; Kewley & Dopita 2002; Pettini & Pagel 2004). In a few exceptionally bright, or gravitationally lensed galaxies, these nebular metallicity measures have been supplemented by the estimates derived from the strengths of photospheric lines from OB stars at rest-frame ultraviolet (UV) wavelengths (e.g. Leitherer et al. 2001; Rix et al. 2004).

These methods have their limitations, however. The accurate measurement of shallow, stellar photospheric features requires spectra of higher signal-to-noise ratio (S/N) than generally attainable at present (see e.g. Erb et al. 2006). The nebular emission lines, on the other hand, are only accessible (from the ground) at redshifts which place them within gaps between the numerous OH emission lines from the night sky which mar the near-infrared (near-IR) spectral windows. The most severe limitation of the nebular abundance diagnostics is that they cease to be applicable at redshifts $z \gtrsim 3.4$, as [O III] $\lambda$5007 is redshifted beyond the $K$-band window. Their application to the increasingly large numbers of galaxies at $3.4 < z < 6.5$ (e.g. Iwata et al. 2005) will have to await the advent of the *James Webb Space Telescope* (*JWST*) in the next decade.

With thousands of UV spectra of galaxies at $z \gtrsim 1.5$ now available (e.g. Steidel et al. 2003, 2004; Le Fèvre et al. 2005), attention naturally turns to searching for useful metallicity measures in the rest-frame UV spectral region. The work by Rix et al. (2004) identified the strong P Cygni lines of C IV $\lambda$1549 and Si IV $\lambda$1397[1] as

[1] For convenience, we use the multiplet wavelengths. The lines are actually blended doublets at wavelengths $\lambda\lambda$1548.20, 1550.78 and $\lambda\lambda$1393.76, 1402.77, respectively.

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the most suitable for this purpose. These features originate in the winds of the most luminous OB stars and their strengths are reduced at subsolar metallicities, reflecting the lower mass-loss rates and wind terminal velocities of these stars at $Z < Z_{\odot}$ (Prinja & Crowther 1998; Leitherer et al. 2001; Vink, de Koter & Lamers 2001). Storchi-Bergmann, Calzetti & Kinney (1994) were the first to confirm observationally a relationship between the equivalent widths of C IV $\lambda$1549 and Si IV $\lambda$1397 in the integrated spectra of local star-forming galaxies recorded with the *International Ultraviolet Explorer* (*IUE*) satellite and their oxygen abundance (determined from nebular emission lines). The correlation was later confirmed and quantified by the analyses of Heckman et al. (1998) and Mehlert et al. (2002).

Heckman et al. (1998) emphasized the fact that the *IUE* spectra, taken through the large entrance aperture, sample comparable physical scales to those encompassed by ground-based spectroscopic observations of high-redshift galaxies and should therefore provide a set of local templates suitable for the interpretation of distant galaxies. Thus, their calibration of the equivalent widths of C IV $\lambda$1549 and Si IV $\lambda$1397 versus O/H has been used to infer the metallicity of galaxies at $z > 1.5$ (e.g. Mehlert et al. 2002, 2005). Given that these wind lines are probably our *only* means of estimating abundances in galaxies at $z \gtrsim 3.5$, as explained above, we thought it important to reassess the local calibrations. Specifically, we examine how well the calibrations perform in the cases of two high-redshift galaxies with exceptionally high S/N UV spectra and for which a number of independent metallicity determinations have been reported. We pay particular attention to the effect which spectral resolution and blending with interstellar absorption lines have on the determination of abundances from UV wind lines.

## 2 LOCAL STARBURSTS

We begin by attempting to reproduce the local calibration by Heckman et al. (1998). To this end, we remeasured the equivalent widths of the C IV $\lambda$1549 and Si IV $\lambda$1397 doublets in the same subsample of 45 star-forming galaxies from the Kinney et al. (1993) low-resolution *IUE* galaxy atlas, performing the equivalent width integrations over the same spectral windows as those used by Heckman et al., 1507–1553 and 1378–1406 Å for C IV and Si IV, respectively. The measurements were made independently by two of us (PAC and RKP) using the Starlink DIPSO software package (Howarth et al. 2003) and averaged to give the quantity EW(C IV + Si IV)/2 which can then be directly compared with the same measurement reported by Heckman et al., as in Fig. 1(a). For the purpose of this comparison, we adopted the same galaxy redshifts and oxygen abundances as Heckman et al., even though there are indications from more recent work (Garnett et al. 2004a; Garnett, Kennicutt & Bresolin 2004b; Bresolin, Garnett & Kennicutt 2004; Bresolin et al. 2005) than the R23 index of Pagel et al. (1979), on which the values of (O/H) in Fig. 1 are based, overestimates the oxygen abundance at high (i.e. apparently super-solar) metallicities.

As can be seen from Fig. 1(a), we do confirm the increase of EW(C IV + Si IV)/2 with log (O/H) + 12 reported by Heckman et al., but also find a 1–2 Å offset between their best fit and ours. This is clearly a concern, further compounded by the relative large dispersion, with standard deviation $\sigma \simeq 1$ Å, between the values of EW(C IV + Si IV)/2 measured independently by two of the authors. The origin of these differences is unclear; they may reflect different placements of the continuum level, but in any case they are certainly a reason for caution in the application of the Heckman et al. relation.

The Si IV $\lambda$1397 wind line is nearly always weaker than C IV $\lambda$1549 and its equivalent width more difficult to reliably measure. We therefore chose to concentrate on C IV $\lambda$1549 alone (as done by Mehlert et al. 2002), and remeasured EW(C IV), this time over a more restricted wavelength interval, 1534–1551 Å, which corresponds to C IV $\lambda$1548.20 wind velocities from $-2750$ to $+550$ km s$^{-1}$ and avoids the nearby interstellar absorption lines Si II $\lambda\lambda$1526.71, 1533.43. Again the values of EW(C IV) were measured independently by two of us and averaged; in this case we found the scatter between the two sets of measure to be considerably smaller than that of the earlier measurements, with $\sigma \simeq 0.2$ Å. Values of EW(C IV) are plotted in Fig. 1(b) versus log (O/H), together with our line of best fit which satisfies the equation:

$$\log(\mathrm{O/H}) + 12 = 7.15 + \frac{\mathrm{EW(C\,IV)}}{3.74}, \qquad (1)$$

where EW(C IV) is in Å.

Also shown with a dashed line in Fig. 1(b) is the relationship between EW(C IV) and log (O/H) + 12 proposed by Mehlert et al. (2002; their equation 3) which is significantly steeper than that found here. Undoubtedly this is due, at least in part, to the wider spectral window adopted by these authors for their equivalent width measurements: 1535–1565 Å, corresponding to velocities of $-2550$ to $+3250$ km s$^{-1}$. Thus, the Mehlert et al. measures refer to the combined (emission plus absorption) equivalent width of the P Cygni feature, as do those by Storchi-Bergmann et al. (1994). The windows chosen by all the analyses of the C IV $\lambda$1549 line mentioned above are compared in Fig. 2(a).

Returning to Fig. 1(b), we see that, apart from the ambiguity due to different wavelength ranges over which EW(C IV) is measured, there appears to be considerable scatter of the data about the line of best fit. This could be due to intrinsic dispersion, reflecting the evolutionary status of the starbursts; to errors in both the measurement of EW(C IV) – the *IUE* spectra are of limited S/N – and the determination of the oxygen abundance; and to varying strength of interstellar C IV absorption which is buried within the stellar P Cygni profile at the low resolution ($R \simeq 250$) of the *IUE* spectra. It is interesting, however, that our line of best fit in Fig. 1(b) is in excellent agreement with the values (open triangles) we measure from the fully synthetic UV spectra produced by Rix et al. (2004) for the standard case of continuous star formation with a Salpeter initial mass function (IMF). These are purely stellar synthetic spectra and so do not include any interstellar absorption.

The degree of contamination by interstellar absorption lines becomes clearer when we compare the low-resolution *IUE* spectra with those obtained with the *Hubble Space Telescope* (*HST*), although the latter normally do not sample the whole galaxy (and thus would generally *under*estimate the interstellar contamination). An example is reproduced in Fig. 2(a) for the Wolf–Rayet galaxy NGC 4214. From the low-resolution *IUE* spectrum, we measure EW(C IV) = 5.2 Å within the spectral range suggested by Heckman et al. (1998), and EW(C IV) = 4.2 Å using our smaller integration window which does not include the interstellar Si II $\lambda\lambda$1527, 1533 absorption lines. The higher resolution *HST* Space Telescope Imaging Spectrograph (STIS) spectrum of a bright knot within the galaxy (NGC 4214-1, Chandar, Leitherer & Tremonti 2004) shows clearly Si II $\lambda$1527 and what, in this instance, appears to be only a weak contribution by interstellar C IV $\lambda$1549 to the P Cygni line.

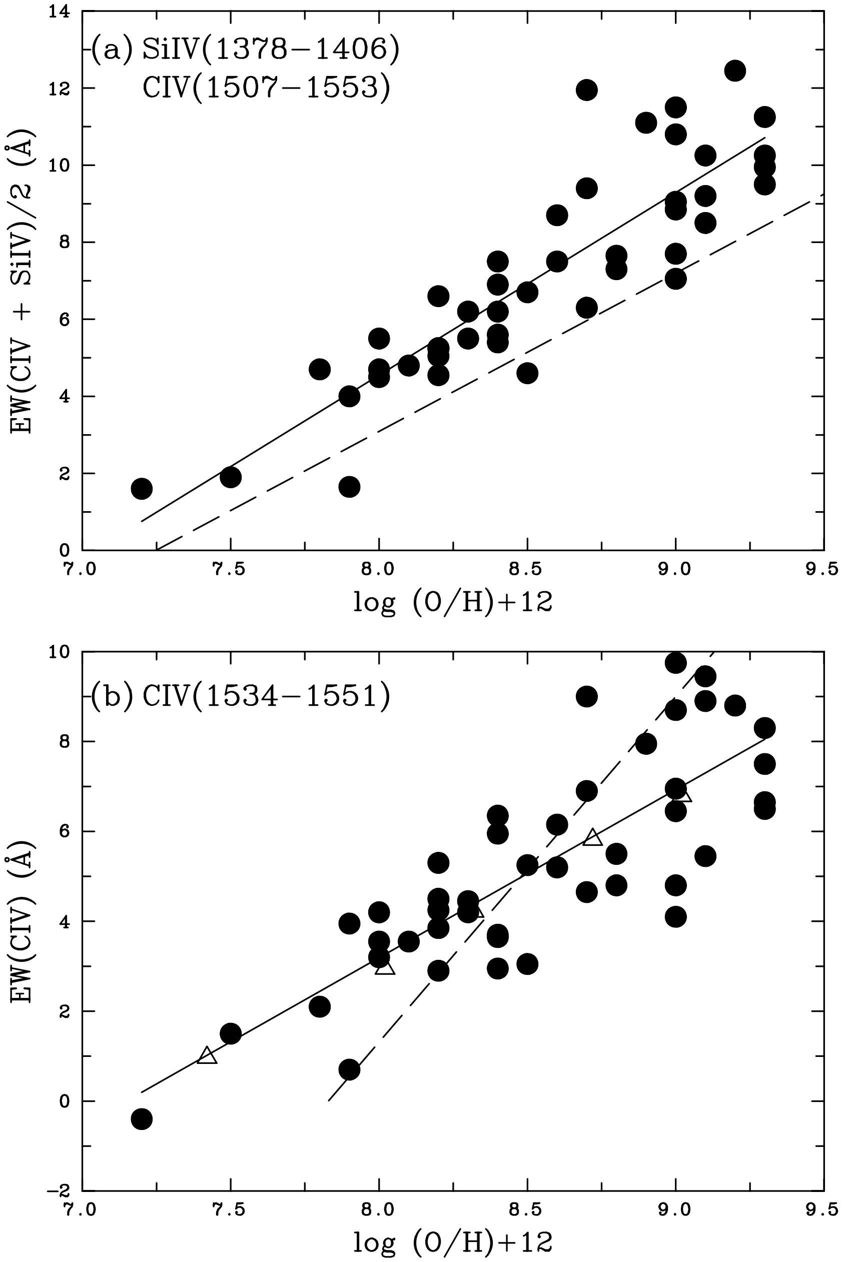


**Figure 1.** (a) Average equivalent widths of the C IV λ1549 and Si IV λ1397 lines, measured from the low-resolution *IUE* spectra of local starburst galaxies, versus the oxygen abundance. Although, we followed the procedure outlined by Heckman et al. (1998) and the measurements refer to the same sample of galaxies, we find a 1–2 Å offset between our best fit (continuous line) and theirs (dashed line); (b) Equivalent width of C IV λ1549 versus oxygen abundance for the same sample of galaxies, but now using a restricted spectral window, 1534–1551 Å, which excludes the Si II λλ1527, 1533 interstellar absorption lines. The continuous line is the best fit to our measurements, given by equation (1), while the dashed line shows the relationship derived by Mehlert et al. (2002) using a wider integration range to measure EW(C IV). The open triangles show the values we measured from the fully synthetic spectra of Rix et al. (2004).

## 3 HIGH-REDSHIFT GALAXIES

### 3.1 Abundances from medium-resolution rest-frame UV spectroscopy

In the case of most star-forming galaxies at high redshifts, however, interstellar absorption *is* a significant contributor to the integrated equivalent width of C IV λ1549, as can be readily appreciated from inspection of the composite spectra of galaxies at $z = 2$–3 published by Shapley et al. (2003) and Erb et al. (2006) .

Provided the stellar and interstellar components can be resolved, it should still be possible to use the equivalent width of the former to deduce the metallicity of the OB stars in which it arises, if the local calibration derived here – and re-enforced by the spectral modelling by Rix et al. (2004) – also applies to high-redshift star-forming galaxies. We test this hypothesis by considering two high-redshift galaxies for which spectra of unusually high S/N are available in the literature, the $z = 2.7268$ gravitationally lensed galaxy MS 1512−cB58 (Pettini et al. 2000, 2002) and the $z = 1.4105$ UV



 

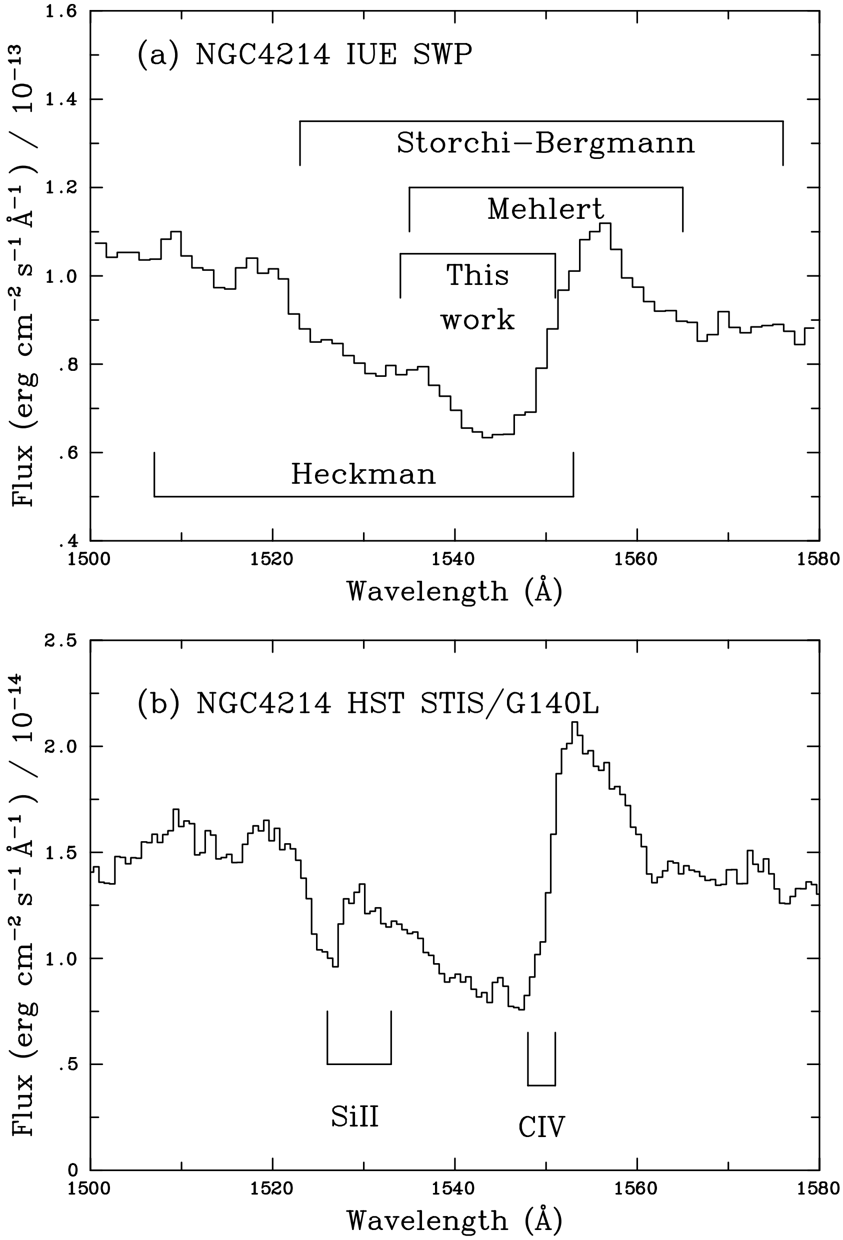


**Figure 2.** (a) Portion of the *IUE*/SWP spectrum of the starburst galaxy NGC 4214 (corrected to the rest frame of the galaxy) from the Kinney et al. (1993) atlas, in the region of the C IV λ1549 line. The resolving power is $R \simeq 250$. Also shown are the windows used by different authors to measure EW(C IV). (b) The same portion of the higher resolution ($R \simeq 600$) archival *HST*/STIS G140L spectrum of a bright UV knot within the galaxy (NGC 4214-1; Chandar et al. 2004). The locations of the narrow interstellar lines of Si II and C IV are indicated.

bright galaxy Q1307−BM1163 from the survey of galaxies in the 'redshift desert' by Steidel et al. (2004) (see Fig. 3).

As can be readily appreciated from Fig. 3, the narrower interstellar lines make a major contribution to the C IV feature in both galaxies. Consequently, we have used the Sobolev with Exact Integral (SEI: Lamers, Cerruti-Sola & Perinotto 1987; Massa et al. 2003) technique to fit solely the wind component, shown by the dotted lines in the figure. The SEI approach has been widely, and successfully, applied to synthesizing the spectral morphology of UV P Cygni stellar wind profiles from OB stars, and as such is ideally suited to our purposes. We measure EW(C IV) = 3.8 Å and 5.5 Å for cB58 and BM1163, respectively. Using the calibration of equation (1), we deduce corresponding oxygen abundances of $\log(\mathrm{O/H}) + 12 = 8.17$ and 8.51, respectively. These values in turn imply metallicities $Z \simeq 0.32$ and 0.71 $\mathrm{Z}_{\odot}$, respectively, relative to the solar abundance $\log(\mathrm{O/H}) + 12 = 8.66$ (Asplund et al. 2004).

We now compare these values with those obtained from other metallicity indicators available for these two galaxies. We consider cB58 first. Nebular emission lines were measured by Teplitz et al. (2000) who deduced $\log(\mathrm{O/H}) + 12 = 8.39$ using the $R23$ index of Pagel et al. (1979). From the emission-line fluxes listed in table 1 of Teplitz et al., it can also be seen that $N2 \equiv \log([\mathrm{N\,II}]\,\lambda\,6583/\mathrm{H}\,\alpha) = -1.04$ which implies $\log(\mathrm{O/H}) + 12 = 8.31$ using the calibration by Pettini & Pagel (2004). Furthermore, from $O3N2 \equiv \log\{([\mathrm{O\,III}]\,\lambda 5007/\mathrm{H}\,\beta)/([\mathrm{N\,II}]\,\lambda\,6583/\mathrm{H}\,\alpha)\} = 1.60$ we find $\log(\mathrm{O/H}) + 12 = 8.22$ from equation (3) of Pettini & Pagel (2004). Each of

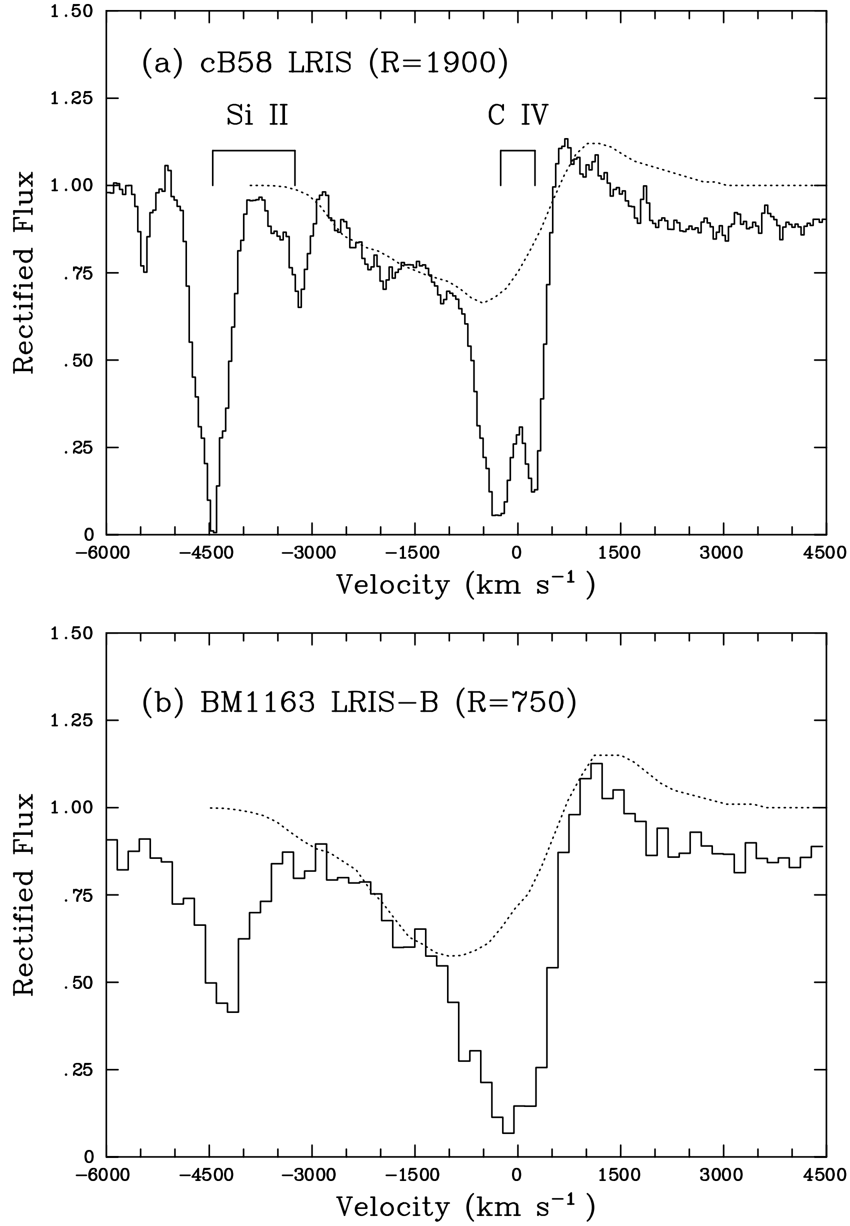


**Figure 3.** Portions of the Keck I/LRIS spectrum ($R$ = 1900) of the $z$ = 2.7268 gravitationally lensed galaxy MS 1512−cB58 (top) and of the Keck/LRIS-B spectrum ($R$ = 750) of the $z$ = 1.4105 UV bright galaxy Q1307−BM1163 (bottom) in the region encompassing the C IV λ1549 spectral feature. Each spectrum has been reduced to the rest frame of the galaxy and normalized using the continuum windows identified by Rix et al. (2004). In each panel, we also show with a dotted line the SEI fit to the stellar wind component of C IV, indicating terminal velocities $v_\infty$ = 3000 and 3200 km s$^{-1}$ in cB58 and BM1163, respectively. Narrower interstellar absorption lines of Si II and C IV are indicated with vertical tick marks. A blend of broad photospheric absorption features depresses the continuum longward of the C IV P Cygni emission peak.

these strong line abundance estimators has an accuracy of about ±0.2 dex.

Using high-resolution spectroscopy, Pettini et al. (2002) were able to measure the abundances of several elements in the neutral interstellar gas of cB58. They found that the alpha-capture elements Mg, Si, P and S have abundances of ∼0.4 solar, while the Fe-peak elements Mn, Fe and Ni are more underabundant, at ∼0.1 solar. In each case, the uncertainty of these determinations is about ±0.1 dex. The difference between the two groups of elements may be real, reflecting the prompt release of the nucleosynthetic products of massive stars, and/or it could be due to dust depletion of the Fe-peak elements – probably both effects contribute.

Comparing all of these estimates with $\log(\mathrm{O/H}) + 12 = 8.17$ ($Z \simeq 0.32\ \mathrm{Z}_\odot$) deduced here from EW(C IV), we conclude that the latter is in reasonable agreement with other abundance indicators. The same conclusion is reached for Q1307−BM1163 for which Steidel et al. (2004) reported $\log(\mathrm{O/H}) + 12 = 8.53 \pm 0.25$ from the $N2$ index, in good agreement with $\log(\mathrm{O/H}) + 12 = 8.51$ we deduced from EW(C IV), although our BM1163 stellar wind fit was in part guided by that of cB58.

Clearly, in both cases discussed here we would have considerably *over*estimated the metallicity had we not been able to resolve the wind component from the interstellar absorption of C IVλ1549. Specifically, the combined equivalent widths, measured within the

**Table 1.** Summary of various metallicity [log (O/H)+12] indicators for cB58 and BM1163 considered here, including strong nebular line methods ($R23$, $N2$ and $O3N2$, see text) and application of equation (1) based on the measured EW(C IV) either excluding (SEI model) or including interstellar contributions.

| Galaxy | $R$ | $R23$ | $N2$ | $O3N2$ | EW(C IV) Wind | EW(C IV) Wind plus ISM |
|---|---|---|---|---|---|---|
| MS1512−cB58 | 1900 | 8.39 | 8.31 | 8.22 | 8.17 | 9.02 |
| | 200 | | | | 8.67 | 8.79 |
| Q1307−BM1163 | 750 | – | 8.53 | – | 8.51 | 9.50 |

narrow window on which equation (1) is based, are 7.0 and 8.8 Å, corresponding to $\log(\mathrm{O/H}) + 12 = 9.02$ and 9.50. These are highly discrepant from all other metallicity measurements, as summarized in Table 1.

Before concluding this section, we point out that our SEI fits to the stellar P Cygni components of the C IV lines in cB58 and BM1163 are further supported by the results of spectral synthesis models. Specifically, Pettini et al. (2003) presented Starburst99 (Leitherer et al. 1999, 2001) fits to the spectral region near 1550 Å in these galaxies obtained using template spectra of OB stars of, respectively, Magellanic Cloud and Milky Way metallicity, and assuming continuous star formation with a Salpeter IMF. The spectral morphology of our SEI fits to the C IV λ1549 profiles in cB58 and BM1163 reproduced in Fig. 3 closely resembles the corresponding Starburst99 models.

### 3.2 Abundances from low-resolution rest-frame UV spectroscopy

The resolution of the Low Resolution and Imaging Spectrograph (LRIS-B) spectrum of Q1307−BM1163 shown in Fig. 3(b) ($R \simeq 750$) is near the minimum required for deconvolving stellar and interstellar components of C IV λ1549. While this resolving power is typical of the surveys for Lyman break, BX, and BM galaxies by Steidel et al. (2003, 2004), many other surveys for high-redshift galaxies have been conducted at lower spectral resolutions. Thus, the FORS Deep Field survey, on which the study of Mehlert et al. (2002) is based, employs $R \simeq 200$; the Gemini Deep Deep Survey (GDDS) of Abraham et al. (2004) has $R \simeq 300$ in the blue (where the C IV λ1549 line falls at the redshifts of most GDDS galaxies); and the VIMOS VLT Deep Survey (VVDS) of Le Fèvre et al. (2005) delivers spectra with $R \sim 230$.

These resolutions are too coarse for the purpose of measuring the equivalent width of the stellar C IV line, as demonstrated in Fig. 4. Once the LRIS spectrum of cB58 shown in Fig. 3 is degraded to $R = 200$, we measure EW(C IV) = 5.8 Å by straightforward integration across our 1534–1551 Å spectral window and EW(C IV) = 5.3 Å from the SEI fit.[2] Even adopting the latter of the these two measurements, we would still overestimate the oxygen abundance at $\log(\mathrm{O/H}) + 12 = 8.57$ from equation (1). Evidently, such low-resolution data are inadequate for measuring abundances via the C IVλ1549 line (see Table 1).

[2] Note that EW(C IV) is not conserved, and is lower than the value we measured from the $R = 1900$ spectrum, due to the restricted integration range of −2750 to +550 km s$^{-1}$ we use.

## 4 SUMMARY AND CONCLUSIONS

The C IV λ1549 line, one of the strongest features in the rest-frame UV spectra of star-forming galaxies, may well be the only tool at our disposal for measuring the degree of chemical evolution of galaxies at $z \gtrsim 3.5$, at least until the advent of ground-based 30-m telescopes and of space-borne near-IR spectrographs on large aperture telescopes such as the *JWST*. This realization has prompted us to reconsider the usefulness and limitations of this transition as an abundance indicator. Our main conclusions are as follows.

(i) C IV λ1549 is a complex spectral feature which in starburst galaxies consists of a blend of stellar P Cygni emission–absorption, narrower interstellar absorption, and potentially nebular emission, although this last component is of minor importance except in galaxies with active galactic nuclei (AGN) (e.g. Leitherer, Calzetti & Martins 2002). The same considerations apply to Si IV λ1397 which is, however, normally weaker, and consequently less accurately measured, than C IV λ1549. Thus, we see little practical advantage in averaging the equivalent widths of the two lines to give a combined measure of the strength of wind absorption, as done by Heckman et al. (1998), and instead consider it advantageous to concentrate on C IV λ1549 alone, as proposed by Mehlert et al. (2002).

(ii) In high-redshift star-forming galaxies, the interstellar component of C IV can be the dominant contributor to the composite spectral feature. It is therefore essential, for abundance determinations, to obtain spectra of sufficiently high resolution for the stellar and interstellar components to be clearly recognized – $R \simeq 1000$ seems to be the minimum resolving power required. A fitting technique such as the SEI method of Lamers et al. (1987) accounts for the stellar wind profile morphology. Without it, the strength of the wind line – and the metal abundance it implies – would be systematically overestimated. Furthermore, we advocate measuring the equivalent width of C IV λ1549, EW(C IV), over a restricted wavelength range, from 1534 to 1551 Å, corresponding to wind velocities in the interval −2750 to +550 km s$^{-1}$, thereby avoiding contamination with Si II λλ1527, 1533 interstellar absorption.

(iii) We have derived a local calibration between EW(C IV), measured between 1534 and 1551 Å, and the oxygen abundance (from the $R23$ method):

$$\log(\mathrm{O/H}) + 12 = 7.15 + \frac{\mathrm{EW(C\,IV)}}{3.74},$$

based on the low-resolution *IUE* spectra of nearby starburst galaxies. While the *IUE* spectra do not resolve stellar and interstellar components, the above relationship is in very good agreement with the fully synthetic starburst spectra computed by Rix et al. (2004). Given that the latter are purely stellar, it would appear that in local star-forming galaxies-unlike their high-redshift counterparts – interstellar C IV absorption makes a relatively minor contribution to the blend.

(iv) We applied the above calibration to the stellar component of the C IV line in two well-observed high-redshift star-forming galaxies – the gravitationally lensed $z = 2.7268$ galaxy MS 1512−cB58 and the $z = 1.4105$ UV bright galaxy Q1307−BM1163. The resulting abundances, 12 + log(O/H) = 8.2 and 8.5, respectively, are in encouraging agreement with those determined by other methods, within the ∼0.2 dex uncertainties of other abundance determinations.

(v) Even so, the local relationship between EW(C IV) and the oxygen abundance shown in Fig. 1(b) exhibits a worryingly large scatter which demands further study.

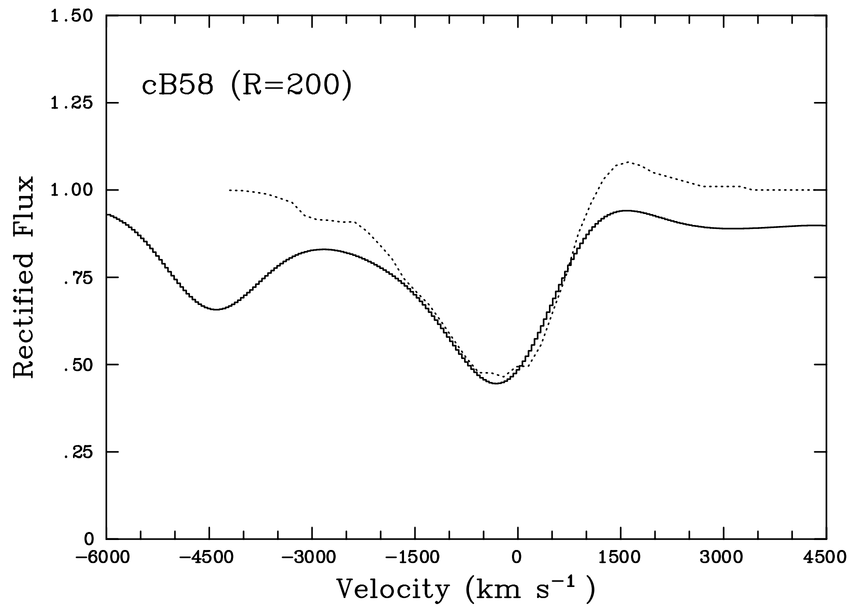


**Figure 4.** Portion of the Keck I/LRIS spectrum of cB58 degraded to a resolving power $R = 200$, typical of many surveys for high-redshift galaxies. At this coarse resolution, even the SEI fitting technique (dotted line) is unable to separate stellar and interstellar components of the C IV line, leading to systematic overestimates of the metallicity.

One problem is the determination of a trustworthy oxygen abundance in the galaxies: values of $12 + \log(\mathrm{O/H}) > 9.0$ ($Z \gtrsim 2\ \mathrm{Z}_{\odot}$) in Fig. 1(b) are called into question by recent work which has failed to confirm supersolar abundances in individual H II regions of nearby spirals (Bresolin et al. 2005, and references therein). If the *R*23 index systematically overestimates (O/H) at high metallicities, the relationship shown in Fig. 1(b) may be altered significantly, rather than requiring a simple systematic downward revision.

A second cause for concern is the fact that EW(C IV) responds not only to metallicity, but also to the age of the starburst, as vividly demonstrated by the difference between 'field' and 'super star cluster' UV light in nearby galaxies (Chandar et al. 2005). However, this difficulty may be alleviated when considering the integrated spectrum of a whole galaxy, for which the idealized case of continuous star formation is more likely to be an adequate approximation to reality.

Thus, in order to improve on the present calibration of EW(C IV) versus (O/H), we require observations of starburst galaxies with sufficiently high *spectral* resolution to separate stellar and interstellar lines, but of sufficiently coarse *spatial* resolution to give an integrated spectrum truly representative of the whole galaxy. Furthermore, such observations should be performed in galaxies where a variety of abundance indicators are available, including at least *N*2 as well as *R*23. Paradoxically, these seemingly mutually exclusive requirements can at present be met most easily in galaxies at $z \simeq 1.5$–$2.5$ observed from the ground with optical and near-IR spectrographs on large telescopes. Certainly, a relationship between EW(C IV) and (O/H) determined for galaxies at $z \simeq 1.5$–$2.5$ would be the appropriate baseline against which to consider galaxies at higher redshifts. Once *HST* is equipped again with a working UV spectrograph, it may become possible to examine such a relationship for much nearer galaxies drawn from large data bases, as produced for example by the Sloan Digital Sky Survey (e.g. Tremonti et al. 2004; Gallazzi et al. 2005) .

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