# Starbursts and the High-Redshift Universe

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**Abstract**

Starbursts are episodes of intense star-formation that occur in the central regions of galaxies, and dominate the integrated emission from the galaxy. They serve as local analogs of the processes that were important in the origin and early evolution of galaxies and in the heating and chemical enrichment of the inter-galactic medium. They may also play an important role in the AGN phenomenon. In this contribution I review starbursts from this broad perspective, with a specific focus on the use of UV spectroscopic diagnostics that can be 'calibrated' at low-redshift and then applied at high redshift. From the analysis of the UV properties of local starbursts we have learned: 1) dust dramatically affects our view of high-mass star-formation 2) more metal-rich starbursts are redder and more heavily extincted in the UV, more luminous, have stronger vacuum-UV absorption-lines, and occur in more massive and optically-brighter host galaxies 3) the strong interstellar absorption-lines directly reflect the hydrodynamical consequences of the starburst. These results suggest that the high-redshift 'Lyman Drop-Out' galaxies are typically highly reddened and extincted by dust (average factor of 5 to 10 in the UV), may have moderately high metallicities (0.1 to 1 times solar?), are probably building galaxies with stellar surface-mass-densities similar to present-day ellipticals, and may be suffering substantial losses of metal-enriched gas that can 'pollute' the inter-galactic medium. I also discuss UV observations of the nuclei of type 2 Seyfert galaxies. These show that compact (100 pc-scale) heavily-reddened starbursts are the source of most of the 'featureless continuum' in UV-bright Seyfert 2 nuclei, and are an energetically significant component in these objects.

# 1 Introduction

Starbursts are sites of intense star-formation that occur in the 'circum-nuclear' (kpc-scale) regions of galaxies, and dominate the integrated emission from the 'host' galaxy (cf. Leitherer et al 1991). The implied star-formation rates are so high that the existing gas supply may sustain the starburst for only a small fraction of a Hubble time (in agreement with detailed models of the observed properties of starbursts, which imply typical burst ages of order $10^8$ years). Both optical objective prism searches and the IRAS survey have shown that starbursts are major components of the local universe (cf. Huchra 1977; Gallego et al 1995; Soifer et al 1987). Indeed, integrated over the local universe, the total rate of (high-mass) star-formation in circumnuclear starbursts is comparable to the rate in the disks of spiral galaxies (Heckman 1997). Thus, starbursts deserve to be understood in their own right.

Starbursts are even more important when placed in the broader context of contemporary stellar and extragalactic astrophysics. The cosmological relevance of starbursts has been dramatically underscored by one of the most spectacular discoveries in years: the existence of a population of high-redshift ($z > 2$) star-forming field galaxies (cf. Steidel et al 1996; Lowenthal et al 1997). The sheer number density of these galaxies implies that they almost certainly represent precursors of typical present-day galaxies in an early actively-star-forming phase. This discovery therefore moves the study of the star-forming history of the universe into the arena of direct observations (Madau et al 1996), and gives added impetus to the quest to understand local starbursts.

Starbursts may also play a vital role in the AGN phenomenon. Indeed, perhaps the most important unanswered question concerning the AGN phenomenon is the fundamental nature of the energy source. There are sound theoretical arguments in favor of accretion onto supermassive black holes (e.g. Rees 1984), and the observational evidence that such 'beasts' exist is growing (Kormendy & Richstone 1995; Miyoshi et al 1995; Tanaka et al 1995). On the other hand, circumnuclear starbursts can have bolometric luminosities that rival even powerful QSO's (cf. Sanders & Mirabel 1996 and references therein), and there have been recurring suggestions that such starbursts may play an important role in the Seyfert galaxy phenomenon (e.g. Weedman 1983; Perry & Dyson 1985; Terlevich & Melnick 1985; Norman & Scoville 1988; Cid Fernandez & Terlevich 1995).

Observations in the vacuum-UV spectral regime are crucial for understanding local starbursts, for relating them to galaxies at high-redshift, and for probing the 'starburst-AGN connection'. Only in this spectral regime can we clearly observe the direct spectroscopic signatures of the hot stars that provide most of the bolometric luminosity of starbursts (e.g. Sekiguchi & Anderson 1987; Fanelli, O'Connell, & Thuan 1988; Leitherer, Robert, & Heckman 1995). Moreover, the vacuum-UV contains a wealth of spectral features, including the resonance transitions of most cosmically-abundant ionic species (cf. Kinney et al 1993). These give UV spectroscopy a unique capability for diagnosing the (hot) stellar population and the physical and dynamical state of gas in starbursts and AGN.

Since ground-based optical observations of galaxies at high-redshifts sample the vacuum-UV portion of their rest-frame spectrum, we can not understand how galaxies evolved without documenting the vacuum-UV properties of galaxies in the present epoch. In particular, a thorough understanding of how to exploit the diagnostic power of the rest-frame UV spectral properties of local starbursts will give astronomers powerful tools with which to study star-formation and galaxy-evolution in the early universe.

In the present paper I will first briefly review the observed UV properties of starbursts in the local universe. I will then describe the implications these results have for our understanding of star-forming galaxies at high-redshift. Lastly, I will describe results from our on-going program of UV imaging and spectroscopy of type 2 Seyfert nuclei and discuss their implications for the 'starburst-AGN connection'.

# 2 UV Spectroscopy of Local Starbursts

## 2.1 Observational Overview

### 2.1.1 The UV Continuum: Probe of Dust

The effect of dust on the UV properties of starbursts is profound. Previous papers have established that various independent indicators of dust extinction in starbursts correlate strongly with one another. Calzetti et al (1994;1996) show that the spectral slope in the vacuum-UV continuum (as parameterized by $\beta$, where $F_\lambda \propto \lambda^\beta$) correlates strongly with the nebular extinction measured in the optical using the Balmer decrement. Meurer et al (1997;1998) show that $\beta$ also correlates well with the ratio of far-IR to vacuum-UV flux: the greater the fraction of the UV that is absorbed by dust and re-radiated in the far-IR, the redder the vacuum-UV continuum. The interpretation of these correlations with $\beta$ in terms of the effects of dust are particularly plausible because the *intrinsic* value for $\beta$ in a starburst is a robust quantity. Figures 31 and 32 in Leitherer &

Heckman (1995) show that $\beta$ should have a value between about -2.0 and -2.6 for the range of ages, initial mass functions, and metallicities appropriate for starbursts.

### 2.1.2 The UV Lines: Probes of Gas & Stars

The vacuum-UV spectra of starburst are characterized by strong absorption features. These absorption features can have three different origins: stellar winds, stellar photospheres, and interstellar gas.

Detailed analyses of HST and HUT spectra of starbursts show that the resonance lines due to species with low-ionization potentials (OI, CII, SiII, FeII, AlII, etc.) are primarily interstellar in origin. In contrast, the resonance lines due to high-ionization species (OVI, NV, SiIV, CIV) can contain significant contributions from both stellar winds and interstellar gas, with the relative importance of each varying from starburst to starburst (Conti et al 1996; Leitherer et al 1996; Heckman & Leitherer 1997; Gonzalez-Delgado et al 1998a,b; Robert et al 1998). While the oft-used 'fiducial' UV spectrum of the starburst NGC 1741 clearly shows the characteristic broad, blueshifted stellar wind profiles in these high-ionization lines, NGC 1705 is a counter-example in which the interstellar medium actually dominates the CIV and SiIV absorption (York et al 1990; Heckman & Leitherer 1997; Sahu & Blades 1997). A comparison of the two starburst spectra is shown in Figure 1. The most unambiguous detection of stellar photospheric lines in starbursts is provided by excited transitions, which are usually rather weak (cf. Heckman & Leitherer 1997).

As a guide to the discussion to follow, in Figure 2, I present two high signal-to-noise vacuum-UV spectra formed by averaging together the International Ultraviolet Explorer (IUE) spectra of many starburst galaxies. The first template ('low-metallicity starburst') was formed from starbursts with metallicity less than 0.4 solar (mean of 0.16 solar). The second ('high-metallicity starburst') was formed from starbursts with metallicity greater than 0.5 solar (mean of 1.2 times solar). It is interesting to note that the vacuum-UV spectra of starbursts are dominated by strong *absorption*-lines, but the nebular *emission*-lines are very weak (the reverse of the situation in the visible – cf. Leitherer 1997).

## 2.2 Lessons Learned

We (Heckman et al 1998 – hereafter H98) have just completed an analysis of the vacuum-UV spectroscopic properties of a large sample of starburst galaxies in the local universe using the data archives of the IUE satellite. Taken together

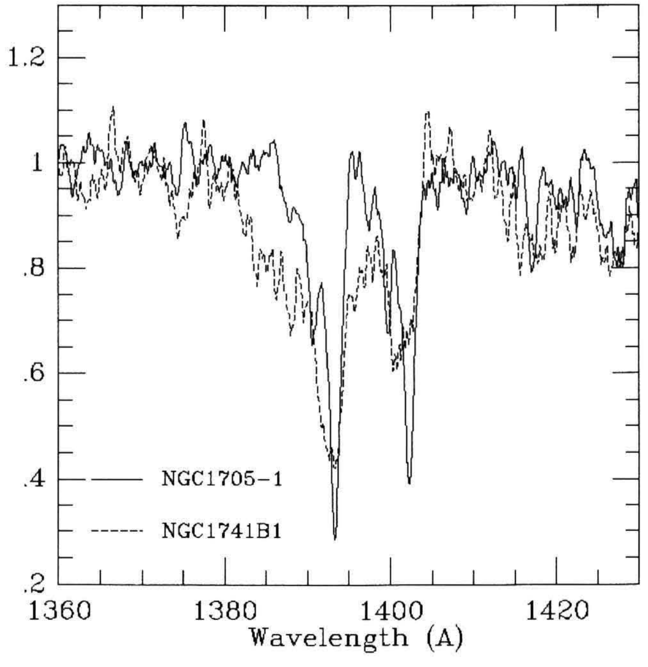


**Figure 1.** Spectral region around the SiIV$\lambda\lambda$1394,1403 doublet. The starbursts NGC 1705 and NGC 1741 are compared. The spectra were normalized and the wavelength scales are in the restframe of each galaxy. Note the strong blue-shifted wing on the SiIV profile in the NGC 1741 spectrum, indicating hot star winds. The narrow doublet in NGC 1705 is instead largely due to interstellar gas. Thus, even though the SiIV equivalent width is roughly the same in both starbursts, spectra with adequate spectral resolution and signal-to-noise are required to establish its physical origin. The implications for the interpretation of spectra of galaxies at high-redshift are obvious.

with the results of previous spectroscopic studies of starbursts in the vacuum-UV, the principal lessons we have learned are as follows:

**First, UV spectra of adequate spectral resolution and signal-to-noise are required to ascertain the origin of the observed absorption-lines.**

The data on NGC 1705 (Heckman & Leitherer 1997) highlight the difficulty in using the UV spectra of galaxies to deduce their stellar content: data of

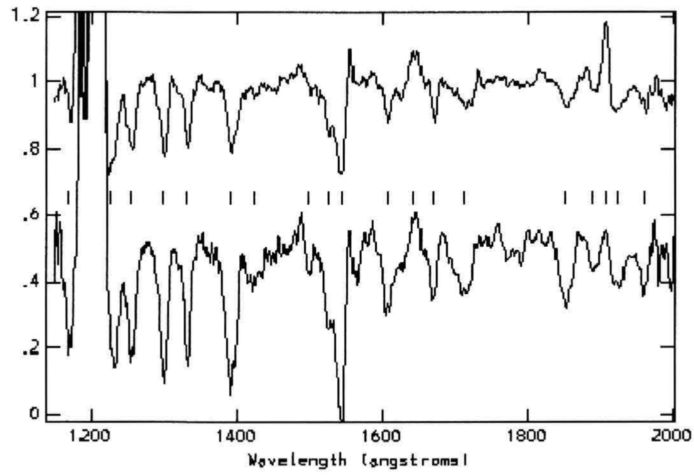


**Figure 2.** IUE spectra of local starbursts with low-metallicity (top) and high-metallicity (bottom). Each spectrum is a weighted average of the spectra of about 20 starbursts. The mean metallicities are 0.16 solar (top) and 1.2 solar (bottom). A number of features are indicated by tick marks and have the following identifications (from left to right): CIII$\lambda$1175 (P), NV$\lambda$1240 (W), SiII$\lambda$1260 (I), OI$\lambda$1302 plus SiII$\lambda$1304 (I), CII$\lambda$1335 (I), SiIV$\lambda$1400 (W;I), SiIII$\lambda$1417 plus CIII$\lambda$1427 (P), SV$\lambda$1502 (P), SiII$\lambda$1526 (I), CIV$\lambda$1550 (W;I), FeII$\lambda$1608(I), HeII$\lambda$1640 emission (W), AlII$\lambda$1671 (I), NIV$\lambda$1720 (W), AlIII$\lambda$1859 (I;W), SiIII$\lambda$1892 (P), CIII]$\lambda$1909 (nebular emission-line), FeIII$\lambda$1925 (P), FeIII$\lambda$1960 (P). Here, I, P, and W denote, respectively, lines that are primarily of interstellar, stellar photospheric, or stellar wind origin. The strong emission feature near 1200 Å is geocoronal Ly$\alpha$.

relatively high spectral resolution and signal-to-noise are needed to reliably isolate the stellar and interstellar components. Simply measuring the equivalent widths of the lines is not enough: it is the *profile shapes* that contain the key information (see Figure 1).

**Second, dust has a profound effect on the emergent UV spectrum.**

This point has been discussed in §2.1.1 above, and further details may be found in Meurer et al (1997;1998). Here, I just want to mention some of the systematic ways in which the extinction correlates with other fundamental properties of the starburst.

The amount of dust-extinction and reddening is well-correlated with metal-

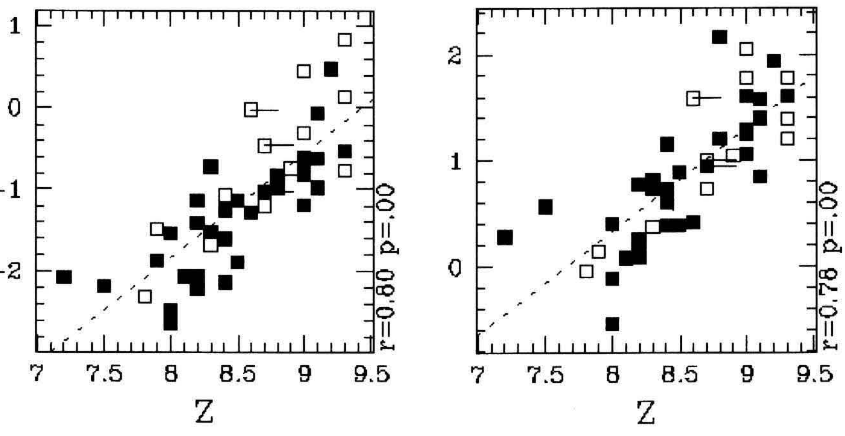


**Figure 3.** Plots of the log of the starburst Oxygen abundance (on a scale where the solar value is 8.9) *versus* two dust-indicators. In the left plot, the spectral slope of the vacuum-UV continuum (as parameterized by $\beta$, where $F_\lambda \propto \lambda^\beta$. In the right plot, the log of the ratio of far-IR to vacuum-UV flux. Heavily-reddened and -extincted metal-rich starbursts lie to the upper right of each plot.

licity, as shown in Figure 3. At low metallicity (<10% solar) a significant fraction of the intrinsic vacuum-UV actually escapes the starburst ($L_{IR}/L_{UV} \sim$ unity), and the vacuum-UV colors are consistent with the intrinsic (unreddened) colors expected for a starburst population ($\beta \sim$ -2.3). In contrast, at high metallicities (> solar) 90% to 99% of the energy emerges in the far-IR ($L_{IR}/L_{UV}$ = 10 to 100) and the vacuum-UV colors are very red ($\beta \sim 0$). Storchi-Bergmann, Calzetti, & Kinney (1994) had previously noted the correlation between metallicity and UV color.

These correlations have a straightforward interpretation: the vacuum-UV radiation escaping from starbursts suffers an increasing amount of reddening and extinction as the dust-to-gas ratio in the starburst ISM increases with metallicity. This will be true provided that neither the gas column density towards the starburst, nor the fraction of interstellar metals locked into dust grains are strong inverse functions of metallicity.

Interestingly, H98 also find that the amount of vacuum-UV extinction in starbursts correlates strongly with the bolometric luminosity of the starburst: only starbursts with $L_{bol}$ < few $\times 10^9$ $L_\odot$ have colors expected for a lightly reddened starburst and have vacuum-UV luminosities that rival their far-IR luminosities. Starbursts that lie at or above the 'knee' in the local starburst luminosity function ($L_{bol}$ > few $\times 10^{10}$ $L_\odot$ – cf. Soifer et al 1987) have red UV continua ($\beta \sim$ -1 to +0.4) and are dominated by far-IR emission ($L_{IR} \sim 10$ to 100 $L_{UV}$). We also find that the amount of vacuum-UV extinction in starbursts correlates well with the absolute blue magnitude and the rotation speed of the galaxy 'hosting' the starburst: starbursts in more massive galaxies are more dust-shrouded.

**Third, the metallicity of the starburst also strongly affects the UV spectrum.**

Apart from the effects of dust, a starburst's metallicity is the single most important parameter in determining its vacuum-UV properties. The properties of the vacuum-UV absorption-lines are strongly dependent on metallicity. Figure 2 shows that both the high-ionization (e.g. CIV$\lambda$1550 and SiIV$\lambda$1400) and low-ionization (e.g. CII$\lambda$1335, OI$\lambda$1302, and SiII$\lambda\lambda$1260,1304) resonance absorption-lines are significantly stronger in starbursts with high metallicity.

The metallicity-dependence of the high-ionization lines (noted previously by Storchi-Bergmann, Calzetti, & Kinney 1994) is not surprising, given the likely strong contribution to these lines from stellar winds. Theoretically, we expect that since stellar winds are radiatively driven, the strengths of the vacuum-UV stellar wind lines will be metallicity-dependent. This is confirmed by available HST and HUT spectra of LMC and especially SMC stars (Walborn et al 1995; Puls et al 1996).

Figure 2 also shows a metallicity-dependence for the strengths of the UV absorption-lines that are of stellar-photospheric rather than interstellar origin (we know they are not interstellar lines because they correspond to transitions out of highly excited states). Such lines are generally rather weak in starburst spectra and/or blended with strong interstellar features. They include CIII$\lambda$1175, SiIII$\lambda$1417, CIII$\lambda\lambda$1426,1428, SV$\lambda$1502, SiIII$\lambda$1892, and FeIII$\lambda\lambda$1925, 1960.

The weak but statistically-significant correlation between metallicity and the strength of the low-ionization resonance lines (which are primarily formed in the interstellar medium of the starburst) is also unsurprising. Analyses of HST spectra (cf. Pettini & Lipman 1995; Heckman & Leitherer 1997; Sahu & Blades 1997; Gonzalez-Delgado et al 1998a) show that the strong interstellar lines are saturated (highly optically-thick). In this case, the equivalent width of the absorption-line (W) is only weakly dependent on the ionic column density ($N_{ion}$): $W \propto b[\ln(N_{ion}/b)]^{0.5}$, where b is the normal Doppler line-broadening parameter. Over the range that H98 sample well, the starburst metallicity increases by a factor of almost 40 (from 0.08 to 3 solar), while the equivalent widths of the strong interstellar lines only increase by an average factor of about 2 to 3. This is consistent with the strong interstellar lines being quite optically-thick.

**Fourth, the properties of the strong interstellar absorption lines reflect the hydrodynamical consequences of the starburst, and do not straightforwardly probe the gravitational potential of the galaxy.**

As noted above, analyses of HST and HUT UV spectra of starbursts imply that the interstellar absorption-lines lines are optically thick. Their strength is therefore determined to first-order by the velocity dispersion in the starburst (see above). Thus, these lines offer a unique probe of the kinematics of the gas in starbursts. The enormous strengths of the starburst interstellar lines (equivalent widths of 3 to 6 Å in metal-rich starbursts) require very large velocity dispersions in the absorbing gas (few hundred km $s^{-1}$). Are these gas motions primarily due to gravity or to the hydrodynamical 'stirring' produced by supernovae and stellar winds?

Both processes probably contribute to the observed line-broadening. H98 find only a very weak (but still statistically significant) correlation between the strengths (widths) of the interstellar absorption-lines and the rotation- speed of the host galaxy. The weakness of the correlation suggests that gravity alone is not the whole story. The most direct evidence for a non-gravitational origin of the gas motions comes from analyses of HST and HUT spectra, which show that the interstellar lines are often blueshifted by one-to-several-hundred km $s^{-1}$ with respect to the systemic velocity of the galaxy (Heckman & Leitherer 1997; Gonzalez-Delgado et al 1998a,b; Sahu & Blades 1997; Lequeux et al 1995 ; Kunth et al 1998). This demonstrates directly that the absorbing gas is flowing outward from the starburst, probably helping to 'feed' the superwinds whose emission is readily observed in the optical, X-ray, and radio regime (cf. Heckman, Lehnert, & Armus 1993; Lehnert & Heckman 1996a).

# 3 Implications at High-Redshift

The results summarized in §2.2 have a variety of interesting implications for the interpretation of the rest-frame-UV properties of galaxies at high-redshift.

Powerful starbursts in the present universe emit almost all their light in the far-infrared, not in the ultraviolet. Thus, an ultraviolet census of the local universe would significantly underestimate the true star-formation-rate and would systematically under—represent the most powerful, most metal-rich starbursts occuring in the most massive galaxies. This *may* also be true at high-redshift, where the current estimates of star-formation rely almost exclusively on data pertaining to the rest-frame vacuum-UV. For example, current samples might under-represent young/forming massive elliptical galaxies.

Using the strong correlation between the vacuum-UV color of local starbursts ($\beta$) and the ratio of far-IR to vacuum-UV light emitted by local starbursts, Meurer et al (1997) estimate that an average vacuum-UV-selected galaxy at high-redshift (e.g. Steidel et al 1996; Lowenthal et al 1997) suffers 2 to 3 magnitudes of extinction.

As shown recently by Burigana et al (1997), the existing limits on the far-IR/sub-mm cosmic background are consistent with the global star-formation rates inferred by Meurer et al at z>2 due to dusty starbursts unless the dust in these galaxies is quite cool ($T_{dust}$ < 20 K) compared to the dust in local starbursts ($T_{dust} \sim$ 30 to 60 K). This seems very unlikely, since the bolometric surface-brightnesses of the high-redshift galaxies are similar to local starbursts (Meurer et al 1997), implying that the energy density of the radiation field that heats the grains is similar in the two types of objects (cf. Lehnert & Heckman 1996b).

In any case, it seems fair to conclude that the history of star-formation in the universe at early times (z > 1) will remain uncertain until the effects of dust extinction are better understood.

The strong correlation shown in Figure 3 between vacuum-UV color ($\beta$) and metallicity in local starbursts – if applied naively to high-z galaxies – would suggest a broad range in metallicity from substantially subsolar to solar or higher and a median value of perhaps 0.3 solar. This is somewhat higher than the mean metallicity in the damped Ly$\alpha$ systems (the major repository of HI gas at these redshifts), but this may be due to selection effects: the UV-selected galaxies are the most actively star-forming regions of galaxies, while the damped Ly$\alpha$ systems tend to sample the outer, less-chemically-enriched parts of galaxies or perhaps proto-galactic fragments (e.g. Pettini et al 1997).

It would also be interesting to use the correlations between absorption line strengths and metallicity in local starbursts to 'guesstimate' the metallicity of the high-z galaxies. One prediction based on the local starbursts (H98) is that the high-z galaxies should show a strong correlation between the strength of the UV absorption-lines (stellar and interstellar) and $\beta$ (the more metal-rich local starbursts are both redder and stronger-lined).

As noted above, Meurer et al (1997; 1998) argue that the UV-selected galaxies at high-redshift suffer substantial amounts of extinction. If their proposed extinction-corrections are applied, the high-z galaxies have very large bolometric luminosities ($\sim 10^{11}$ to $10^{13}$ $L_\odot$ for $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.1$). Interestingly, the bolometric surface-brightnesses of the extinction-corrected high-z galaxies are very similar to the values seen in local starbursts: $\sim 10^{10}$ to $10^{11}$ $L_\odot$ kpc$^{-2}$. The high-redshift galaxies appear to be 'scaled-up' (larger and more luminous) versions of the local starbursts. The physics behind this 'characteristic' surface-brightness is unclear (cf. Meurer et al 1997; Lehnert & Heckman 1996b). However, it is intruiging that the implied average surface-mass-density of the stars within the half-light radius ($\sim 10^2$ to $10^3$ $M_\odot$ pc$^{-2}$) is quite similar to the values in present-day elliptical galaxies. Are we witnessing the formation of ellipticals and/or bulges?

Finally, based on local starbursts, it seems likely that the gas kinematics that are measured in the high-z galaxies using the interstellar absorption-lines are telling us a great deal about the hydrodynamical consequences of high-mass star-formation on the interstellar medium, but rather little (at least directly) about the gravitational potential or mass of the galaxy. Even the widths of the nebular emission-lines in local starbursts are not always reliable tracers of the galaxy potential well (cf. Lehnert & Heckman 1996b). This means that it will be tricky to determine masses for the high-z galaxies without measuring real rotation curves via spatially-resolved spectroscopy.

On the brighter side, if the kinematics of the interstellar absorption-lines can be generically shown to arise in outflowing metal-enriched gas, we can then directly study high-redshift star-forming galaxies caught in the act of 'polluting' the intra-cluster medium and inter-galactic medium with metals in the early universe.

In fact, there is now rather direct observational evidence that this is the case. I will need to digress briefly to explain this evidence. As emphasized above, the interstellar absorption-lines are significantly blue-shifted with respect to the systemic velocity of the galaxy ($v_{sys}$) in many local starbursts. In the high-redshift galaxies there is rarely a good estimator of $v_{sys}$ (although the weak stellar photospheric lines shown in Figure 2 above are a promising possibility in spectra with adequate signal-to-noise). It is also the case in local starbursts that the true galaxy systemic velocity lies between the velocity of the UV interstellar absorption-lines and the Ly$\alpha$ *emission* line (Lequeux et al 1995; Gonzalez-Delgado et al 1998a,b; Kunth et al 1998). This is due to outflowing gas that both produces the blue-shifted absorption-lines and absorbs-away the blue side of the Ly$\alpha$ emission-line. Thus, a purely-UV signature of outflowing gas is a blueshift of the interstellar absorption-lines with respect to the Ly$\alpha$ emission-line (even though neither is at $v_{sys}$).

Recently, Franx et al (1997) have seen just this effect in a spectrum of one of the most distant known objects in the universe: a gravitationally-lensed galaxy at z = 4.92. They find that the Ly$\alpha$ emission line is redshifted by about 400 km $s^{-1}$ relative to the SiII$\lambda$1260 interstellar absorption-line across the entire face of the galaxy. More generally, Lowenthal et al (1997) have constructed a composite UV spectrum of 12 high-z galaxies. This also shows a strong redshifted Ly$\alpha$ emission- line and weak blue-shifted absorption in Ly$\alpha$ and the resonance lines of metal ions in absorption. This composite spectrum strongly suggests that the outflow of metal enriched gas at velocities of a few hundred km $s^{-1}$ is a generic feature of the high-z galaxies. *If* the outflowing gas escapes into the IGM, such flows could bring an IGM with $\Omega_{IGM} \sim 0.01\ h^{-2}$ up to a mean metallicity of $> 10^{-2}$ solar by a redshift of 2.5 (cf. Madau & Shull 1996).

# 4 UV Probes of the Starburst-AGN Connection in Seyfert Nuclei

As noted in the introduction, understanding the role of starbursts in the AGN phenomenon is one of the crucial issues in extragalactic astronomy. I have also documented in this review the utility of UV spectroscopy as a probe of the hot stars that power a starburst.

In order to test the 'starburst-AGN connection' via UV spectroscopy, it is clearly preferable to focus on those objects in which the obscuring torus has providentially blocked out the blinding glare from the central engine (thereby allowing us to study the fainter surrounding 'circumnuclear' region without squinting). Thus, we have focused our attention on the nuclei of type 2 Seyfert galaxies.

Type 2 Seyfert nuclei have long been known to exhibit a 'featureless continuum' ('FC') that produces the UV light and typically 10% to 50% of the visible/NIR light (the rest appears to be light from an ordinary old population of bulge stars). Until recently, it was thought that the optical/UV FC was light from the hidden type 1 Seyfert nucleus that had been reflected into our line-of-sight by warm electrons and/or dust. However, recent optical spectropolarimetry (Tran 1995) shows that this is not the case: most of the optical FC must have some other origin, since it is significantly less polarized than the reflected broad emission-lines. Similarly, we (Heckman et al 1995 – hereafter H95) examined the vacuum-UV (1200 to 2000 Å) spectral properties of a large sample of type 2 Seyferts using IUE data and showed that the lack of any detectable reflected emission from the BLR meant that at least 80% of the UV continuum must have some other origin.

Two possibilities for the optical/UV FC have been advanced. The first (Tran) is that the unpolarized (unreflected) component of the FC (the 'FC2') is produced by thermal emission from hot ($10^5$ to $10^6$ K) gas heated in some way by the central energy source. The second (Cid Fernandes & Terlevich 1995) ascribes the FC2 to a dust-shrouded starburst possibly associated with the obscuring torus. The weakness of the observed UV line emission led H95 to rule out a primarily nebular origin for the UV continuum, and to argue instead that the 'dusty starburst' interpretation is the more plausible one (at least for the UV-bright members of the H95 sample). Moreover, we also showed that the starburst hypothesis can be correct only if the bulk of the observed far-IR continuum from these type 2 Seyferts is re-radiated starburst light. The large far-IR luminosities would then imply that starbursts are an energetically significant component of the Seyfert phenomenon.

However, the IUE data do not have adequate signal-to-noise to unambiguously detect stellar absorption-lines in the Seyferts. Thus, they provide only indirect and inconclusive evidence for a starburst component in the FC of type 2 Seyferts. To directly test this requires the spectroscopic detection of an unusually luminous population of young stars, and this is best accomplished in the vacuum-UV using strong stellar wind lines and weaker stellar photospheric lines (cf. Leitherer, Robert, & Heckman 1995; Heckman & Leitherer 1997). With data of suitable quality, a young stellar component may also be detected in the near UV via high-order Balmer absorption-lines and the Balmer edge from hot stars (e.g. Gonzalez-Delgado, Leitherer, & Heckman 1997).

We have therefore undertaken a program to obtain high-resolution vacuum-UV images and spectra (with HST) and near UV spectra (with ground-based telescopes) of a representative sample of the brightest type 2 Seyfert nuclei. These results have been presented in detail in Heckman et al (1997) and Gonzalez-Delgado et al (1998b). HST imaging shows that the UV continuum source in every case is spatially-resolved (scale size few hundred pc or greater). In some cases the morphology is strikingly reminiscent of UV images of starbursts (compare Figure 4 to images in Meurer et al 1995). In other cases (cf. Capetti et al 1996), a component of the UV continuum is roughly aligned with the inferred polar axis of the obscuring torus (as expected for reflected and/or reprocessed light from the central engine).

Of the sample of 13 type 2 Seyfert with HST vacuum-UV images, only four are bright enough for us to obtain spectra of adequate quality in the crucial UV spectral window from about 1200 to 1600 Å. However, these spectra are decisive: all four show the clear spectroscopic signature of a starburst population

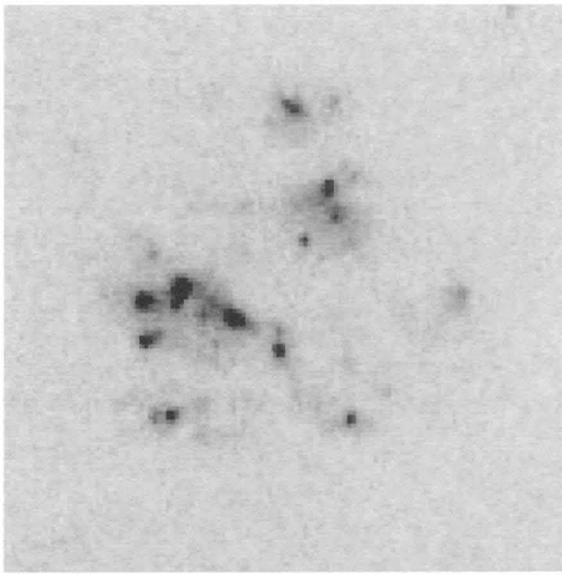

**Figure 4.** HST FOC image of the vacuum-UV (2200 Å) continuum emission in the nucleus of the type 2 Seyfert galaxy NGC 5135. The region displayed is about 1 kpc across. This image is morphologically-similar to those of typical starbursts, including the presence of bright UV knots corresponding to super star clusters. (Meurer et al 1995).

that dominates the UV continuum (Figure 5). In addition to classic strong stellar wind features (NV$\lambda$1240, SiIV$\lambda$1400, and CIV$\lambda$1550), we can also detect weaker and much narrower absorption features from excited transitions (which are therefore indisputably of stellar origin – cf. Heckman & Leitherer 1997; Heckman et al 1997; Gonzalez-Delgado et al 1998b).

In each of the four cases, if we use the empirical 'starburst attenuation law' (Calzetti et al 1994) to correct the observed UV continuum for dust extinction, we find that the bolometric luminosity of the nuclear ($10^2$ pc-scale) starburst is comparable to the estimated bolometric luminosity of the 'hidden' type 1 Seyfert nucleus (of-order $10^{10}$ $L_\odot$). The large-aperture IUE spectra imply the existence of a surrounding larger-scale (few kpc) and more powerful (few $\times$ $10^{10}$ to $10^{11}$ $L_\odot$) dusty starburst that is energetically capable of powering the bulk of the observed far-IR emission from the galaxy. Thus, starbursts are an energetically

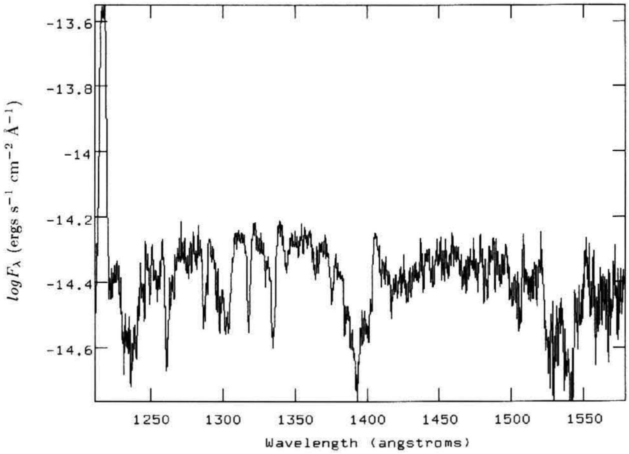


**Figure 5.** HST GHRS vacuum-UV spectrum of the the nucleus of the type 2 Seyfert galaxy NGC 5135 (log$F_\lambda$ vs. $\lambda$). This spectrum was obtained of the region shown in Figure 4. Note the broad, blueshifted stellar wind lines due to CIV$\lambda$1550, SiIV$\lambda$1400, and NV$\lambda$1240 and the unshifted stellar photospheric line due to the excited SiIII$\lambda$1299 and SV$\lambda$1502 multiplets. The other strong narrow lines are interstellar in origin (see Figure 2). Comparing this spectrum to starburst spectra, the only noticeable difference is the strong Ly$\alpha$ emission-line in NGC 5135, which is most likely excited by the ionizing radiation from the hidden 'central engine'.

significant (or even dominant) component of at least *some* Seyfert galaxies.

However, we have HST spectra of only four type 2 Seyferts, and these are strongly biased in favor of cases with high UV surface-brightness. Can we say anything more general? To address this, we have embarked on a program to obtain spectra from about 3500 to 9000 Å of a complete sample of the 25 brightest type 2 Seyfert nuclei in the local universe. These objects are selected from extensive lists of known Seyfert galaxies on the basis of the flux of either the nebular line-emission from the Narrow Line Region (the [OIII]$\lambda$5007 line) or of the nuclear radio source (Whittle 1992).

We are still analysing these spectra, but even a cursory inspection of the near UV region (below 4000 Å) shows that at least one-third have pronounced Balmer absorption-lines whose strength is consistent with a population of late O or early B stars. This group includes three of the four objects with HST vacuum UV spectra. In most of the remainder of the sample, the 'FC' is so weak relative to the light from a normal old-bulge stellar population that its origin is still not clear. There are also several cases in which the Balmer emission-lines from the NLR are so strong in the near-UV that they overwhelm any putative stellar absorption features. Fortunately, the HST vacuum-UV spectrum of one of these (Mrk 477) leaves no doubt that it contains a starburst (Heckman et al 1997).

Thus, when we complete our analysis of these data we will be in a position to judge the general importance of circumnuclear starbursts in the Seyfert phenomenon.

# 5 Conclusions

In a nutshell:

- **Starbursts can teach us valuable lessons about the high-redshift universe.**
- **Starbursts may play a key role in the AGN phenomenon.**
- **Good UV spectroscopic data are essential for understanding starbursts and for probing the starburst-AGN connection. This is true in the universe of the 'here and now' and the 'there and then'!**

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