# Lessons from lensed Lyman break galaxies: can dusty Lyman break galaxies produce the submillimetre counts and background?

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**Abstract**

Can the submillimetre counts and background be produced by applying a locally derived extinction correction to the population of Lyman break galaxies? We investigate the submillimetre emission of two strongly lensed Lyman break galaxies (MS 1512+36-cB58 and MS 1358+62-G1) and find that the procedure that is used to predict the submillimetre emission of the Lyman break galaxy population overpredicts the observed 850 $\mu$m fluxes by up to a factor of 14. This result calls for caution in applying local correlations to distant galaxies. It also shows that large extinction corrections on Lyman break galaxies should be viewed with skepticism. It is concluded that the Lyman break galaxies may contribute to the submillimetre background at the 25 to 50% level. The brighter submillimetre galaxies making up the rest of the background are either not detected in optical surveys, or if they are detected, their submillimetre emission cannot be reliably estimated from their rest-frame ultraviolet properties.

*Key words:* Lyman break galaxies, galaxy evolution, submillimetre emission
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## 1 Submillimetre emission of Lyman break galaxies

Measurements of the cosmic star formation density (SFD) based on surveys for Lyman break galaxies (LBGs) are affected by extinction, and attempts to correct for this effect lead to a substantial upwards revision of the SFD (Meurer

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et al., 1999). Since the light absorbed in the ultraviolet (UV) is reradiated in the far-infrared (FIR), LBGs affected by extinction must emit FIR radiation, which will contribute to the submillimetre background.

However, the lack of plausible counterpart LBGs in deep submillimetre surveys with SCUBA at 850 $\mu$m (Hughes et al., 1998) has given rise to the view that the submillimetre galaxies form a separate population which is not represented in LBG samples in the first place, a point of view which has been the subject of considerable debate. We here discuss the relation between the LBGs and the submillimetre galaxies in the light of existing data on submillimetre source counts and background radiation, and recent measurements of submillimetre emission from LBGs, including lensed LBGs.

The expected submillimetre emission from the population of LBGs has recently been estimated based on the observed (if not entirely understood) correlation between the spectral index $\beta$ in the UV (defined by the relation $f_\lambda \propto \lambda^\beta$) and the ratio of FIR to UV flux in a sample of local galaxies observed with the IUE satellite (Meurer et al., 1999). Applying this relation to the LBG population, Adelberger and Steidel (2000) found that the submillimetre counts and integrated background can be accounted for. As noted by these authors, these estimates are still uncertain, since the validity of the $\beta$-FIR/UV correlation at high redshift has not been established, and important ingredients in the analysis such as the distribution of $\beta$ values and its dependence on magnitude, and the luminosity function at faint magnitudes are poorly constrained. It is therefore necessary to verify this analysis by direct submillimetre observations of LBGs.

The predicted 850 $\mu$m fluxes for most LBGs based on their UV properties (Adelberger and Steidel, 2000) are 1 mJy or less, which is too faint for current instrumentation. However, some of the reddest LBGs are predicted to produce detectable 850 $\mu$m emission and a sample of such LBGs can be selected based on their observed rest-frame UV color and magnitude. However, a deep search for 850 $\mu$m emission from a sample of 8 LBGs predicted to have $S_{850} > 1$ mJy produced only one detection; it was concluded that the $\beta$-FIR/UV correlation overpredicted the FIR emission by at least a factor of two (Chapman et al., 2000). Recently, it has been argued, based on an analysis of structure in the faint 850 $\mu$m emission of the Hubble Deep Field (HDF), that the LBGs contribute at least 25% but at most 50% of the submillimetre background (Peacock et al., 2000). These results indicate that the LBGs do contribute to the submillimetre background in a significant way, but that they do not produce a dominant contribution.

Table 1
Predicted (from UV color and magnitude) and observed submillimetre emission of lensed LBGs. Luminosities (not corrected for gravitational amplification) have been derived for $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ and $q_0 = 0.5$. The other results do not depend on cosmology. Upper limits represent $3\sigma$.

| | MS 1512+36-cB58 | MS 1358+62-G1 |
|---|---|---|
| amplification factor | $\sim 50$ | $\sim 10$ |
| $\beta$ (observed) | $-0.74 \pm 0.1$ | $-1.63 \pm 0.1$ |
| $A_{1600}$ (predicted) | $3.0 \pm 0.2$ | $1.2 \pm 0.2$ |
| $S_{\rm FIR}/S_{1600}$ (predicted) | 18 | 2.4 |
| $L_{\rm FIR}$ (predicted) | $3.9 \cdot 10^{13}$ L$_\odot$ | $3.3 \cdot 10^{12}$ L$_\odot$ |
| $S_{850}$ (predicted) | 58 mJy | 5 mJy |
| $S_{850}$ (observed) | $4.2 \pm 0.9$ mJy | $< 4$ mJy |
| $L_{\rm FIR}$ (derived) | $2.8 \cdot 10^{12}$ L$_\odot$ | $< 2.6 \cdot 10^{12}$ L$_\odot$ |
| $S_{\rm FIR}/S_{1600}$ (derived) | 1.3 | $< 1.9$ |
| $A_{1600}$ (derived) | 0.8 | $< 1.0$ |

## 2 Lessons from strongly lensed Lyman break galaxies

Submillimetre observations of LBGs are significantly easier if strongly lensed LBGs are targeted. We have used SCUBA on the JCMT to observe two strongly lensed LBGs: the object cB58 at $z = 2.72$ lensed by the cluster MS 1512+36 (Yee et al., 1996) and the object G1 at $z = 4.92$ lensed by the cluster MS 1358+62 (Franx et al., 1997). Rest-frame UV colors indicate significant reddening in both of these objects (Ellingson et al., 1996; Soifer et al., 1998). In cB58, the Balmer decrement also indicates the presence of extinction (Teplitz et al., 2000) and in fact cB58 is among the reddest quartile of LBGs (Steidel et al., 1999). For both galaxies, the method of predicting the FIR emission based on the UV spectral slopes $\beta$ (Bechtold et al., 1997; Pettini et al., 2000; Soifer et al., 1998) combined with the flux densities at 1600 Å in the rest frame implies strong 850 $\mu$m emission (Table 1). The results of our SCUBA measurements are given in Table 1. The object cB58 is detected at the $4.7\sigma$ level; this detection is confirmed by independent measurements at 250 GHz with the MAMBO instrument at the IRAM 30 m telescope (Baker, 2001). The object G1 was not detected; the quoted upper limit comes from a combination of SCUBA photometry at the position of the brightest knot and SCUBA mapping of the lensing cluster. In both cases the procedure of predicting the submillimetre flux from the observed color and magnitude in the rest-frame UV (Adelberger and Steidel, 2000) overpredicts the submillimetre emission. The magnitude of the discrepancies is illustrated in Fig. 1. While for G1 the discrepancy is not significant, given the scatter in the $\beta$-FIR/UV relation, the discrepancy of a factor 14 for cB58 is highly significant. These estimates should be independent of gravitational lensing if the UV and

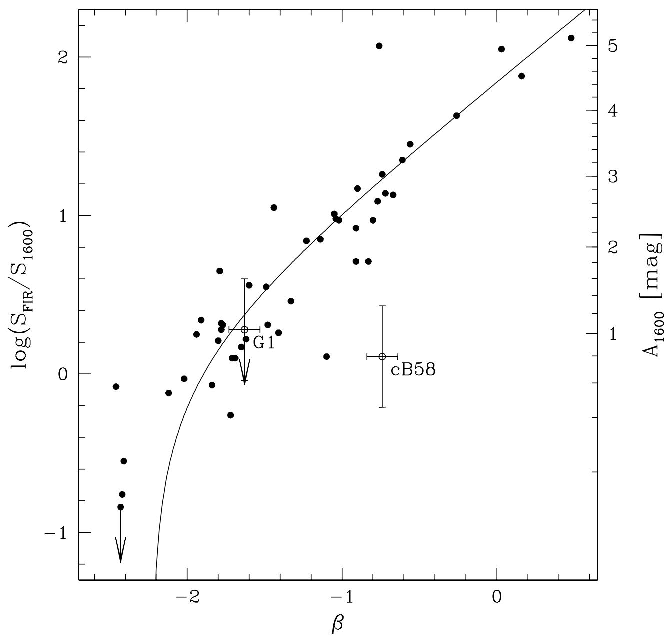


Fig. 1. The relation between $S_{\rm FIR}/S_{1600}$ and $\beta$ for local UV-selected galaxies (filled circles) with the best-fitting parametrization (Meurer et al., 1999), and the positions of cB58 and G1 with respect to this relation.

FIR radiation originate from the same region, which is a requirement for a meaningful prediction of FIR radiation fom UV properties.

Since for cB58 the discrepancy is so large, it cannot be attributed to uncertainties, whether in the observations or in the analysis. For instance, photometric errors (which would affect the determination of $\beta$) are of minor importance, since this galaxy is lensed and therefore relatively bright. The largest uncertainty in the predicted 850 $\mu$m flux comes from converting the derived FIR luminosity into a monochromatic flux density at the observing wavelength, which involves the adoption of a FIR spectral energy distribution (SED). For instance, exceptionally hot dust emission would produce a relatively small 850 $\mu$m flux. However, the range of plausible SEDs based on data of local galaxies introduces at most a factor 2 uncertainty in the predicted 850 $\mu$m flux density (Adelberger and Steidel, 2000).

A final cause of uncertainty in the analysis is introduced by differential lensing, if the effective amplification factor of cB58 in the UV is a factor 14 higher than that in the FIR. A large discrepancy can only be introduced if most of the UV emission comes from the most strongly amplified portions of the source near the caustic, while most of the FIR emission comes from more weakly lensed regions. This situation would require a very different distribution of FIR and UV emission, which is not impossible, as shown by the example of the nearby starburst merger NGC 4048−4039 where the dominant region of obscured star formation as revealed by SCUBA mapping at 850 $\mu$m (Van der Werf et al., 2001) is spatially separated from the light dominating the blue and ultraviolet fluxes. However, an extinction correction based on UV properties of one region of a galaxy will not be able to predict the submillimetre emission in a completely different region of the system. Therefore, if differential lensing plays a major role, the physical basis of using the $\beta$-FIR/UV correlation disappears. For cB58, a lensing model based on new HST data shows that the amplification factor is at least a factor of 5 at every position, and that the intensity-weighted amplification factor in the UV is about a factor of 25 (on both sides of the fold in the arc, so that the total amplification is approximately a factor 50). Thus differential lensing can account for a discrepancy of at most a factor of 5, but probably a lot less, since UV and FIR emission should have a similar morphology for the $\beta$-FIR/UV correlation to work.

## 3 Discussion and conclusions

These results demonstrate that attempts to produce the submillimetre counts and background based on an extinction correction applied to the LBG population (Adelberger and Steidel, 2000) are fraught with considerable uncertainty, and fail in the case of the two lensed LBGs discussed here. While our sample is small, the results argue against the validity of the low redshift $\beta$-FIR/UV correlation in the case of LBGs. Even if the local correlation were valid for high redshift galaxies as well, it still would not be able to produce the brighter submillimetre galaxies. These objects have luminosities putting them in the class of the ultraluminous infrared galaxies (ULIGs), which do not follow the $\beta$-FIR/UV correlation, as shown by recent HST-STIS data of a sample of nearby ULIGs. Since these galaxies already account for $\sim 50\%$ of the submillimetre background, it is not possible for the LBGs to produce a dominant fraction (let alone all) of the submillimetre background. A more likely situation is that the LBGs account for 25 to 50% of the submillimetre background as indicated by the faint structure in the HDF at 850 $\mu$m (Peacock et al., 2000), but that the dominant part of the submillimetre background is made by a small number of ULIGs, which are either not detected in LBG surveys, or if they are detected, cannot be reliably corrected for extinction, in the same way that local ULIGs cannot be extinction corrected based on UV data.

In summary therefore, these results support the view that the brighter 850 $\mu$m galaxies making at least 50% of the submillimetre background, form a population which cannot be reliably reproduced by extinction corrections applied to the LBG population.

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