Can the submillimeter counts and background be produced by applying a locally derived extinction correction to the population of Lyman break galaxies? We investigate the submillimeter 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 submillimeter 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 submillimeter background at the 25 to 50% level. The brighter submillimeter galaxies making up the rest of the background are either not detected in optical surveys, or if they are detected, their submillimeter emission cannot be reliably estimated from their rest-frame ultraviolet properties.

1 Submillimeter emission from Lyman break galaxies

Measurements of the cosmic star formation rate density (SFRD) 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 SFRD. 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 submillimeter background.

The expected submillimeter 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. Applying this relation to the LBG population, Adelberger & Steidel found that the submillimeter counts and integrated background can be accounted for. As noted by these authors, these estimates are uncertain, since the validity of the $\beta$-FIR/UV correlation at high redshift has not been established, and 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 submillimeter observations of LBGs.
Table 1. Predicted (from UV color and magnitude) and observed submillimeter 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 3σ.

|                         | 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)   | $3.0 \pm 0.2$   | $1.2 \pm 0.2$ |
| $S_{\text{FIR}}/S_{1600}$ (predicted) | $18$ | $2.4$ |
| $L_{\text{FIR}}$ (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     |
| $L_{\text{FIR}}$ (derived) | $2.8 \cdot 10^{12}$ L$_\odot$ | $< 2.6 \cdot 10^{12}$ L$_\odot$ |
| $S_{\text{FIR}}/S_{1600}$ (derived) | $1.3$ | $< 1.9$ |
| $A_{1600}$ (derived)     | $0.8$            | $< 1.0$       |

2 Lessons from strongly lensed Lyman break galaxies

The predicted 850 μm fluxes for most LBGs based on their UV properties are 1 mJy or less, which is too faint for current instrumentation. Submillimeter observations of individual 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 and the object G1 at $z = 4.92$ lensed by the cluster MS 1358+62. Rest-frame UV colors indicate significant reddening in both of these objects.

For both galaxies, the method of predicting the FIR emission based on the UV properties $\beta$ implies strong 850 μm emission (Table 1). The results of our SCUBA measurements are given in Table 1. The object cB58 is detected at the 4.7σ level; the object G1 was not detected. In both cases the procedure of predicting the submillimeter flux from the observed color and magnitude in the rest-frame UV overpredicts the submillimeter emission. The magnitude of the discrepancies is illustrated in Fig. 1. For G1 the discrepancy is not significant, given the scatter in the $\beta$-FIR/UV relation, but the factor 14 discrepancy for cB58 is highly significant.

Since this discrepancy is so large, it cannot be attributed to observational uncertainties. However, an element of uncertainty in the analysis is introduced by differential lensing, if the effective amplification factor of cB58 in the UV is a factor 10 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. However, an extinction correction based on UV properties of one region of a galaxy will not be able to predict the submillimeter 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 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 much less, since UV and FIR emission should have a similar morphology for the $\beta$-FIR/UV correlation to work.

Figure 1. The relation between $S_{\text{FIR}}/S_{1500}$ and $\beta$ for local UV-selected galaxies (filled circles) with the best-fitting parametrization, and the positions of cB58 and G1 with respect to this relation.
3 Discussion and conclusions

These results demonstrate that attempts to produce the submillimeter counts and background based on an extinction correction applied to the LBG population 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 submillimeter 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 $\sim50\%$ of the submillimeter background, it is not possible for the LBGs to produce a dominant fraction (let alone all) of the submillimeter background. A more likely situation is that the LBGs account for 25 to $50\%$ of the submillimeter background as indicated by the faint structure in the HDF at $850\ \mu m$, but that the dominant part of the submillimeter 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 submillimeter background, form a population which cannot be reliably reproduced by extinction corrections applied to the LBG population.

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