PROCEEDINGS OF SCIENCE

Star formation and dust obscuration at z≈2: galaxies at the dawn of downsizing

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We present first results of a study aimed to constrain the star formation rate and dust content of galaxies at z≈2. We use a sample of BzK-selected star-forming galaxies, drawn from the COSMOS survey, to perform a stacking analysis of their 1.4 GHz radio continuum as a function of different stellar population properties, after removing AGN contaminants from the sample. Dust unbiased star formation rates are derived from radio fluxes assuming the local radio-IR correlation. The main results of this work are: i) specific star formation rates are constant over about 1 dex in stellar mass and up to the highest stellar mass probed; ii) the dust attenuation is a strong function of galaxy stellar mass with more massive galaxies being more obscured than lower mass objects; iii) a single value of the UV extinction applied to all galaxies would lead to grossly underestimate the SFR in massive galaxies; iv) correcting the observed UV luminosities for dust attenuation based on the Calzetti recipe provide results in very good agreement with the radio derived ones.

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How and when galaxies build up their stellar mass content is still a major question for observational cosmology. While a general consensus has been reached in the last years on the evolution of the Galaxy Stellar Mass Function, it still remains unclear and debated the evolution of the star formation rate (SFR) as a function of stellar mass. UV derived SFR suffers from the poorly understood dust attenuation correction. On the other hand, IR SFR estimates suffer from the poor resolution and sensitivities available to present-day IR detectors. Thanks to the observed Radio-IR correlation [1,2] and the optical/NIR-like arcsecond resolution obtainable from interferometric observations, radio continuum turns out to be the ideal dust unbiased SFR tracer.

1. DATA and ANALYSIS

For this work we used the VLA-COSMOS 1.4Ghz mosaic (rms≈10μJy, 1.5" resolution, [3]) in combination with deep B,z, Ks imaging (COSMOS Legacy, [4]). A dust-unbiased sample of about 34000 star forming BzK galaxies (sBzK, [5]) with $K_s < 23$ and $1 < z_{phot} < 3$ was assembled to investigate, in a crucial redshift range for galaxy evolution studies, how star formation rate and dust attenuation depend on galaxy properties. About 2% (4%) of the whole sBzK catalog has a radio (Xray) counterpart. These are mostly "extreme" objects: AGN dominated galaxies or SMG–like starbursts. In order to study star formation and dust content for the *normal* galaxy population, mostly undetected in radio, we removed from the sample all the objects with a radio or a Chandra X-ray (Civano et al., ApJ submitted) counterpart.

For each of the sBzK sources, we produced a cutout in the radio mosaic of 173×173 pixel^2 (60.5 ×60.5 arcsec^2). These cutouts were then stacked to create median images. Median stacking is more robust than mean against the tails of the distribution, while the rms still goes down by $\approx \sqrt{N}$. Total flux is retrieved by fitting a dirty beam convolved Gaussian function to the stacked data. Measured radio fluxes were converted to star formation rates using the median redshift of each stacked sample (1.7 for the whole population), a synchrotron emission spectral index of –0.8, and the conversion factor between radio luminosity and SFR from [2], *i.e.*

$$\mathrm{SFR} = 5.9 \pm 1.8 \times 10^{-22}\ \mathrm{L_{1.4GHz}}\ (\mathrm{M_\odot/yr}), \tag{1.1}$$

where $L_{1.4\mathrm{GHz}}$ is in W Hz^{-1}. Errors on SFRs are the squared sum of the uncertainties coming from the off-source rms in the stacked images, the fitting to recover total fluxes, and the uncertainty in equation (1.1).

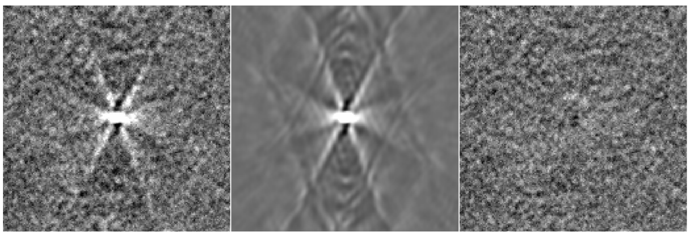

Figure 1: Left: Median stacking result of all the 34000 sBzK galaxies. **Middle:** Best fit dirty beam convolved Gaussian to the stacked data. The total flux recovered is 8.8±0.1μJy. **Right:** Residual image.

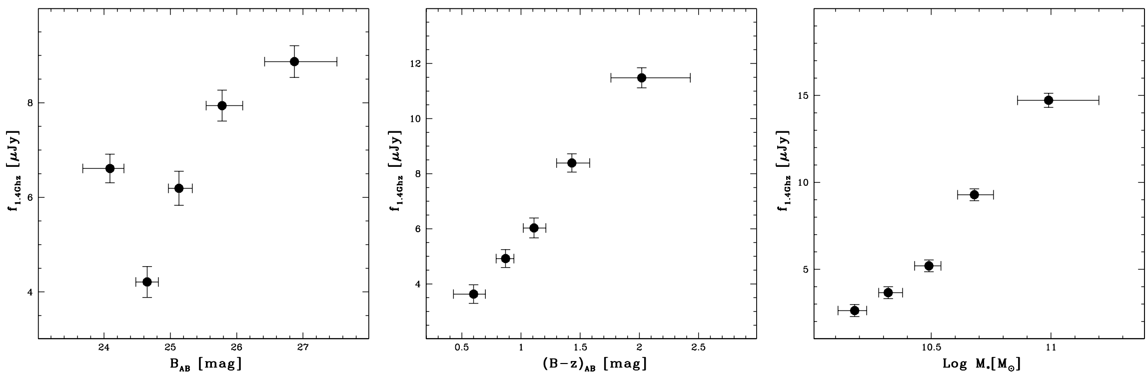

Figure 2: Total radio flux densities versus B band (left), B-z color (middle), and stellar mass (right).

2. FIRST RESULTS

In Figure 2 we show our results for the radio stacking of the AGN–cleaned sBzK sample as a function of: *i)* the observed *B*-band magnitude, which is related to the restframe dust uncorrected UV luminosity; *ii)* the $(B-z)$ color, which for galaxies at $z\sim 2$ is a proxy for the UV slope of the spectral energy distribution and hence it relates to dust extinction; and *iii)* the galaxy stellar mass. We conclude that: 1) overall, the emerging UV light is poorly correlated with the ongoing SFR, and –somewhat counter intuitively– the highest SFRs are found among the UV-faintest galaxies; 2) this happens because galaxies with higher SFRs are more extinguished in the UV; and 3) the SFR increases with stellar mass almost linearly.

In the left panel of Figure 3 we present radio derived specific star formation rates (SSFR=SFR/M_*) for the reduced sBzK sample. From the observed *B*-band magnitudes, and applying a k-correction dependent from the (B-z) color, we also derive UV_{1500} luminosities, uncorrected for dust attenuation, then estimating an uncorrected UV–derived SSFRs, which are also plotted in the same panel with empty symbols.

Some striking features are worth noting in the plot: *i)* the UV-derived SSFR drops dramatically with increasing mass whereas dust free SSFRs show no such effect, the SSFR being constant over almost one dex in mass; *ii)* correcting the UV light with a single value of extinction A_{1500} at all masses (an approximation often adopted in the literature) would result in an artificial decreasing SSFR with increasing mass; and *iii)* the mean dust attenuation is a function of the galaxy stellar mass, with more massive galaxies being more dust-extinguished. By forcing the dust-corrected UV-SFRs to agree with the radio-SFRs, as both a function of galaxy stellar mass and $(B-z)$ color, we obtain how the UV light attenuation A_{1500} at $z\sim 2$ relates to these quantities. The result is shown in the inserts of the middle and left panels of Figure 3. A similar relation was found for a sample of local starburst galaxies by [6]. Our relation naturally extends their results to higher redshifts, and also nicely shows that the sBzK selection is much less biased against highly obscured objects than UV-selected samples. The latter ones are indeed limited to moderate extinctions, such as $A_{1500} <$3.6 mag [6].

In the explored redshift interval the dust attenuation, stellar mass and SFR are all tightly cor-

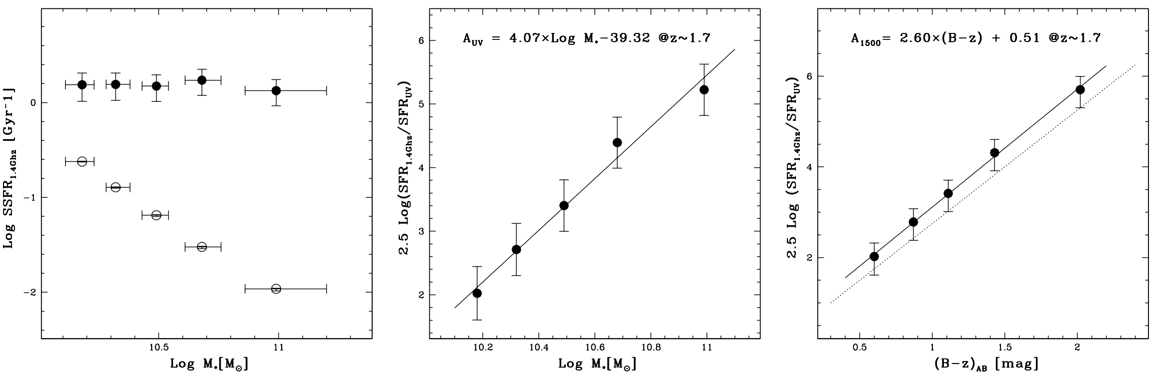

Figure 3: Left: Radio derived SSFR (solid symbols) at z≈ 1.7 are compared to the uncorrected UV derived SSFR (empty symbols) as a function of Log M_*. **Middle:** UV light attenuation (A_{1500} = 2.5×Log($SFR_{1.4GHz}/SFR_{1500}$) as a function of galaxy stellar mass. **Right:** UV light attenuation as a function of B-z color (UV slope). The dotted line shows the attenuation law derived in [4] as described in the text.

related with each other. The middle panel of Figure 5 shows that the dust extinction A_{1500} tightly correlates with galaxy mass. Therefore, assuming a constant value for A_{1500} (independent of galaxy mass) introduces a systematic bias and the resulting SSFR(M_*) relation decreases with increasing stellar mass. We emphasize the excellent agreement of the dust-attenuation correction here derived using the radio data with that derived from the UV continuum slope: the dotted line in the right panel of Figure 3 shows the relation between attenuation and $(B-z)$ color predicted by the Calzetti law [7], as calibrated in [5]. Further results and details can be found in [8].

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