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A broadband spectroscopic search for CO line emission in HDF850.1: the brightest submillimetre object in the *Hubble Deep Field*

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Abstract. We present preliminary results from 70 hours of integration towards the submm selected extragalactic source HDF850.1 with the 100-m Green Bank Telescope in an attempt to measure the spectroscopic-redshift from mm-wavelength emission lines that arise from cool molecular gas fuelling the extremely high rate of star formation activity. In this search for rotational CO emission-lines, the tuning frequencies of the GBT spectrometers in the K-band (18-26 GHz) and the Q-band (40-52 GHz) have been guided by the estimated photometric-redshift ($z \sim 4.1 \pm 0.6$) for HDF850.1 derived from rest-frame radio to FIR data. Given the caveat that receiver resonances and baseline ripples have affected these data, no significant molecular lines, including CO(J=1-0) emission, were detected in this deep search.

1. Introduction

Discovered in a confusion-limited 850μm SCUBA survey of the northern Hubble Deep Field (Hughes et al. 1998), HDF850.1 remains one of the most significant detections (with a flux density of S(850μm)$\sim$ 7.5$\pm$0.5 mJy) of a luminous high-redshift starburst galaxy identified in an un-biased, blank-field submm-wavelength survey. In the last 8 years, despite the wealth and depth of the multi-wavelength data towards the HDF-N, the low spatial resolution of single-dish submm/mm telescopes (with typical beam-sizes of 10–15 arcsecs and positional accuracies of a few arcsecs) has made it difficult to unambiguously identify which (if any) of the nearby faint optical galaxies is the counterpart to this bright submm source. Since HDF850.1 is at the limit of detectibility with the current generation of submm-wavelength interferometers, which could in principle determine the position with sub-arcsec accuracy, a tentative counterpart to HDF850.1 has been identified in ultra-deep IR and radio observations (Dunlop

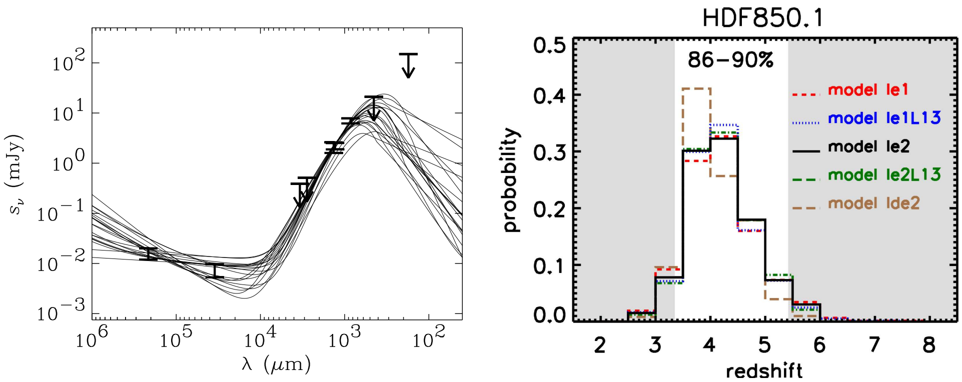

Figure 1. **a)** Photometric data for HDF850.1 over observed far-infrared to radio wavelengths. Also shown are a range of template spectral energy distributions, adopted from nearby starbursts, ultraluminous infrared galaxies, and AGN, all redshifted to fit the data for HDF850.1. **b)** The predicted photometric redshift distribution for HDF850.1, derived from various evolutionary models of the 60 μm luminosity function which is adopted as a prior in these calculations (see Hughes et al. 2002; Aretxaga et al. 2003, 2005). The shaded region defines the redshift boundaries for which the 115.2712 GHz CO(J=1-0) line would emit at frequencies outside the GBT K-band receiver window. The models predict an 86-90% probability that the CO(J=1-0) line is redshifted to K-band frequencies (Aretxaga et al. 2003; Dunlop et al. 2004).

et al. 2004). In order to understand more about the nature of HDF850.1 it is essential that a robust spectroscopic redshift is obtained, enabling a secure estimate of the bolometric luminosity and star formation rate (SFR), as well as leading to measurements of the dynamical mass and age of the dominant stellar populations, identification of any AGN component, galaxy morphology and indications for galaxy-galaxy interactions that may have initiated the violent and massive burst of star formation in this enigmatic object.

2. Observations and Results

We have completed 70 hours of low spectral-resolution observations towards HDF850.1 during dry and stable atmospheric conditions in 2004 & 2005 using the 100-m Green Bank Telescope with both K-band and Q-band receivers. Motivated by the predictions of the photometric redshift distribution (Aretxaga et al. 2003; see also Aretxaga et al. - these proceedings; Fig. 1), based on the radio to FIR, rest-frame spectral energy distribution, we have conducted an ultra-deep wide-band search for redshifted CO(J=1-0) and CO(J=2-1) emission over a significant redshift interval, 3.5< z <5.4. The data were reduced using the NRAO gbtidl package following standard procedures for reducing total-power nodded observations outlined by Vanden Bout, Solomon & Maddalena (2004). The two overlapping 800 MHz observations for each beam are individually fitted with a second or third order polynomial to remove any remaining large-scale spectral baseline structure. This provides a total bandwidth of ~1.5 GHz for each of the

6 tunings that are required to cover the entire 18.0 to 26.5 GHz K-band window. For more details of the observations and reduction see Wagg et al. (2006).

The final K-band spectra for both polarizations are shown in Fig. 2, and includes only the best 50% of the data (with much of the residual data containing either baseline ripples, or receiver resonance features - see papers in these proceedings by Laura Hainline and Dominik Riechers for additional discussion).

Although no obvious CO emission is detected in either the K-band (Fig. 2), or Q-band spectra (not shown here - see Wagg et al. 2006), we calculate upper-limits to the CO line luminosity across the entire K-band receiver following Solomon, Downes & Radford (1992), and a smaller region of the available Q-band window. We adopt the ΛCDM cosmology ($\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 70$ km/s/Mpc). Assuming CO line widths of 1100, 780 and 460 km/s we derive a 3-σ limit to the CO(J=1-0) line luminosity in the range of 3–10×10^{10} K km/s pc^2, which does not include a demagnification factor of ~ 3 to account for gravitational lensing by a foreground elliptical galaxy (Dunlop et al. 2004). For comparison, the CO survey of high-redshift far-infrared luminous galaxies by Greve et al. (2005) has a median line-luminosity of $L'(CO) = 3.8 \times 10^{10}$ K km/s pc^2 and a median linewidth of 780 km/s, which is consistent over much of our redshift range with the limits presented in this paper. Conversion of the CO(J=1-0) line-luminosity in HDF850.1 to a molecular gas mass yields an upper-limit of M(H_2)$\sim$few$\times10^{10}$ $M_\odot$. Further interpretation of the non-detection of CO emission in the context of residual instrumental baseline artefacts and resonances, the accuracy of the photometric redshift technique, and the intrinsic gas content of HDF850.1, is deferred to Wagg et al. (2006).

To conclude, and addressing one of the above possiblities for a non-detection of CO(1–0) in HDF850.1, whilst these GBT observations may have covered an inadequate redshift range, the wide-band ($\Delta\nu \sim 35$ GHz) "redshift receiver" that will operate on the 50-m Large Millimetre Telescope (Erickson et al - these proceedings) will have sufficient instanteous redshift coverage and sensitivity to provide unambiguous spectroscopic redshifts in $\ll 1$ hr per object, for HDF850.1 and other optically-obscured luminous starbursts selected from the population of dust-enshrouded (sub-)mm galaxies (see also Min Yun - these proceedings).

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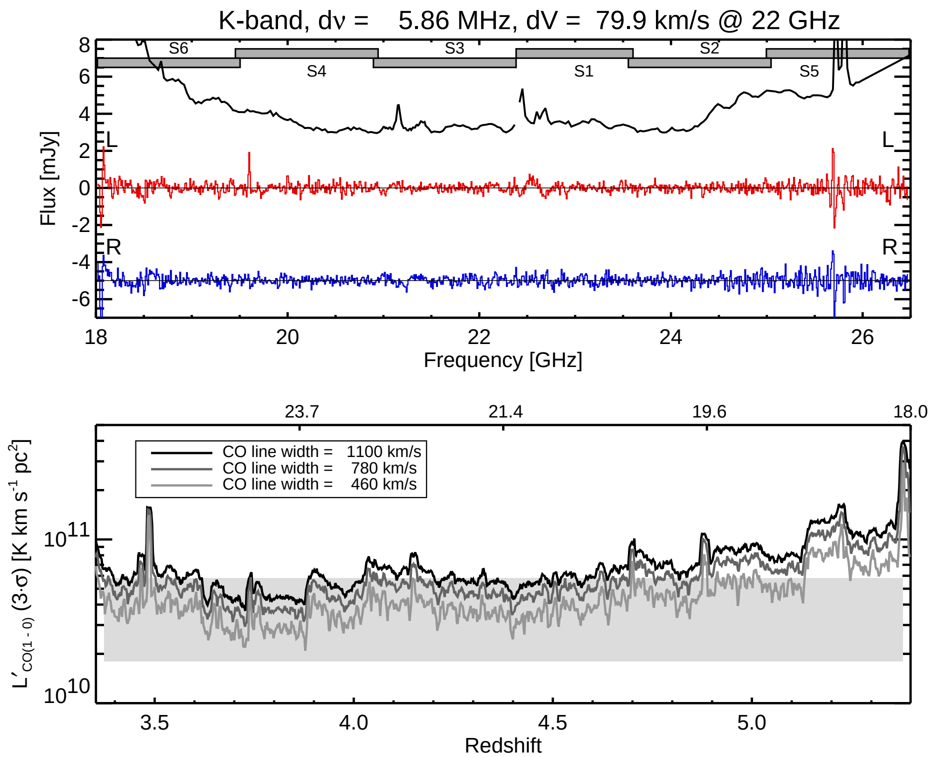

Figure 2. **a)** The K-band spectra of HDF850.1 produced from the best 50% of the data, or 12.3 and 13.9 hours of on-source integration time respectively in the left and right polarization spectra (Wagg et al. 2006). The top solid-line shows the K-band receiver temperature sampled at 30 MHz resolution. Receiver resonance lines appear at various frequencies across the band. Grey boxes show the 6 frequency tunings (each ~1.5 GHz wide) adopted to cover the full K-band window. Receiver resonances, such as the one at 25.7 GHz, also appear in the HDF850.1 spectra. Another noteworthy feature is the emission line at 19.6 GHz seen in the left polarization spectra but not in the receiver temperature curve. This emission feature is also observed in the calibration spectra of 3C295, so we believe it to be another receiver resonance line. **b)** The 3-σ upper-limits to the CO(J=1-0) line luminosity calculated from the co-added left and right polarization spectra, assuming CO line widths of 1100, 780 and 460 km s^{-1}. The shaded region defines the bounds set by the first and third quartile of the CO line luminosities of the 12 SMGs detected in high-J CO line emission (see Greve et al. 2005).