A Spectroscopic Survey of the Submillimeter Galaxy Population: 85 Redshifts Using Keck/LRIS-B

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Abstract. We present spectroscopic identifications for a sample of 85 millimeter and submillimeter galaxies detected with the SCUBA/JCMT and MAMBO/IRAM30m facilities, all identified with deep 1.4GHz VLA radio observations. The galaxies lie at redshifts $z = 0.5$ to 3.5, We describe their properties, especially the presence of active galactic nuclei (AGN) in the sample, and discuss the connection of the mm/submm galaxies and the formation of spheroidal components of galaxies, which requires knowledge of the timescales of their very luminous activity. For a subset of the galaxies, we show their disturbed and diverse *Hubble Space Telescope (HST)* optical morphologies.

1 Introduction

Millimeter/Submillimeter galaxies – hereafter SMGs (Smail, Ivison & Blain 1997; Barger et al. 1998; Hughes et al. 1998; Eales et al. 1999; Bertoldi et al. 2000) are an important population (Blain et al. 1999, 2002). They are both numerous, with a surface density about 10% that of optically-selected Lyman-break galaxies (LBGs; Steidel et al., 2003), and luminous (possibly because of very high SFRs), with typical luminosities about 10 times greater than LBGs, assuming plausible spectral energy distributions (SEDs). The existing SMGs produce most of the extragalactic mm/submm background radiation intensity, and a significant fraction of the background at far-infrared (FIR) wavelengths (Blain et al. 2002; Smail et al. 2002). They represent a population which is generally difficult to detect at optical wavelengths, with at least the fainter half clearly being missed in current optical cosmological surveys. Unfortunately, the SMG population is notoriously difficult to study! Until now, we have been able to gather almost nothing about their redshifts and morphologies as fundamental observable properties. As a consequence, deriving properties such as total mass and dust temperature, and finding both the fraction of power contributed by AGN and starbursts, and their connection to optically-selected star-forming LBGs, have been the topic of largely idle speculation over the five years since their discovery.

The principal hurdle has always been identification at other wavelengths. SCUBA/MAMBO surveys have large beam sizes (10"–15"), a situation that will remain true for upcoming single-antenna, wide-field instruments: Bolocam, SHARC-II, a bolometer camera on the APEX telescope and SCUBA2. Candidate

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counterparts to SMGs cannot therefore be identified unambiguously without interferometry to pinpoint their positions. However, mm/submm interferometry is currently an arduous process, with tens of hours of integration required to detect a single object at the OVRO MMA or IRAM PdB interferometers.

As a consequence, the 20-cm radio emission from SMGs has become an important, but *second best* surrogate with which to probe both the energy generation processes and morphology of submm galaxies (Ivison et al. 1998; Smail et al. 2000; Barger, Cowie & Richards 2000; Chapman et al. 2001, 2002a, 2003a; Ivison et al. 2002) The problem remains that in order to use a radio wavelength as a surrogate for submm/FIR emission, we would like a clear physical principle connecting the emission at the different wavelengths. We don't yet, but we do have a strong empirical connection: the far-IR–radio correlation (e.g., Helou et al. 1985), which has an RMS dispersion of only 0.2 dex over a large range in luminosity at low redshifts. Radio identification of SMGs has allowed their optical properties to be explored in detail (Chapman et al. 2003a; Ivison et al. 2002). A large range of optical properties is observed for the radio-selected SCUBA galaxies, with 65% fainter than $I > 23.5$. They have red optical-IR colors with $I - K = 3$ to 6 and $< I - K >= 4.3$, but they are not all extremely red objects (EROs). Deep radio observations allow SMGs to be pre-selected with an efficiency of about 40%.

2 Redshifts for SMGs

We have been able to secure redshifts for 85 radio-identified SMGs through deep Keck/LRIS observations (Chapman et al. 2003b, 2004; Ivison et al. in preparation), and the sample is growing rapidly.[1] The spectrum of the brightest example is shown in Fig. 1a. The redshifts allow, for the first time, accurate calculation of luminosities and dust temperatures for the SCUBA galaxy population. We emphasize that obtaining redshifts is not easy, relying heavily on the superb blue sensitivity of the new LRIS-B multiobject spectrograph (Steidel et al. 2004), and often have no detectable continuum emission with which to extract the spectrum. In addition the galaxies are hard to identify, being faint, messy, composite objects in optical images. Because of their small radio/optical offsets (~ 0.5") it is often difficult to assess the best position at which to align the slit. Often we designated several slit positions on different masks for each target. Our spectroscopic completeness is 74% over the magnitude range of the sample from $I = 22$ to 27.

While the issue of correctly identifying the submm galaxy is concerning, 8 out of 12 CO detections with IRAM-PdB have already been made, realizing an unequivocal confirmation of the redshifts (Neri et al. 2003, Greve et al. in preparation). We also note that beyond the radio positional identification, we

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