REST-FRAME OPTICAL SPECTROSCOPIC CLASSIFICATIONS FOR SUBMILLIMETER GALAXIES

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ABSTRACT

We report the results of a systematic near-IR spectroscopic survey using the Subaru, VLT, and Keck Telescopes of a sample of high-redshift ULIRGs mainly composed of submillimeter-selected galaxies. Our observations span the rest-frame optical range containing nebular emission lines such as Hβ, [O iii] λλ4959, 5007, and [O ii] λλ3727, which are essential for making robust diagnostics of the physical properties. Using the Hα/Hβ emission line ratios, we derive internal extinction estimates for these galaxies similar to those of local ULIRGs: A_V ~ 2.9 ± 0.5. Correcting the Hα estimates of the star formation rate for dust extinction results in rates that are consistent with those estimated from the far-IR luminosity. The majority (>60%) of our sample show spectral features characteristic of AGNs (although this partially reflects an observational bias), with ~65% exhibiting broad Balmer emission lines. A proportion of these sources show relatively low [O iii] λ5007/Hβ line ratios, which are similar to those of narrow-line Seyfert 1 galaxies, suggesting low-mass black holes that are rapidly growing. In the subsample of our survey with both [O iii] λ5007 and hard X-ray coverage, at least ~60% show an excess of [O iii] λ5007 emission, by a factor of 5–10, relative to the hard X-ray luminosity compared to the correlation between these two properties seen in Seyfert galaxies and QSOs locally. From our spectral diagnostics, we propose that the strong [O iii] λ5007 emission in these galaxies arises from shocks in dense gaseous regions. Due to sensitivity and resolution limits, our sample is biased to strong-line emitters and hence our results do not yet provide a complete view of the physical properties of the whole high-redshift ULIRG population.

Subject headings: galaxies: active — galaxies: evolution — galaxies: high-redshift — submillimeter

Online material: color figures

1. INTRODUCTION

There is almost irrefutable evidence for an increase in the star formation density with redshift, as demonstrated by emission-line and continuum star formation tracers in wave bands from the ultraviolet to the submillimeter and radio wave bands. This evolution appears to be stronger for tracers that are less sensitive to dust obscuration (e.g., Ivison et al. 2006), suggesting that an increasing proportion of the activity in more distant galaxies may be highly obscured (e.g., Blain et al. 1999, 2002). Indeed, recent results on the mid- to far-infrared emission of luminous but dust-obscured galaxies at high redshift (z ~ 1–3) suggest that the origin of their large infrared luminosities is a mix of dust-obscured vigorous star formation and/or dust-enshrouded active galactic nuclei (AGNs; Yan et al. 2005; Houck et al. 2005; Lutz et al. 2005; Desai et al. 2006). In many sources it is likely that both AGNs and star formation contribute to the emission as a result of the close link required between the growth of supermassive black holes (SMBHs) and bulges in massive galaxies (e.g., Borys et al. 2005).

One of the best studied populations of high-redshift, far-infrared luminous galaxies is that identified in the submillimeter wave band using the SCUBA camera (Holland et al. 1999) on the James Clerk Maxwell Telescope (JCMT). Although they span less than an order of magnitude in submillimeter flux, these galaxies are responsible for much of the energy density in the submillimeter background (Barger et al. 1998; Hughes et al. 1998; Smail et al. 2002; Cowie et al. 2002; Scott et al. 2002). The faintness of these obscured galaxies in the optical wave band has made it difficult to obtain precise redshifts (e.g., Simpson et al. 2004), although some progress has been made using ultraviolet/blue spectrographs (Chapman et al. 2003a, 2005). The median redshift for submillimeter galaxies (SMGs) with 850 μm fluxes of ≥5 mJy is z ~ 2.2 (Chapman et al. 2003a, 2005). The submillimeter and radio fluxes of these systems indicate that their bolometric luminosities are ≥10^{12} L_☉ (Kovacs et al. 2006), confirming that they are examples of high-redshift ultraluminous infrared galaxies (ULIRGs).

This population provides critical constraints on models of galaxy formation and evolution. In particular, if the bolometric emission from SMGs is powered solely by star formation, then these galaxies form about half of the stars seen in the local universe (Lilly et al. 1999). However, it appears likely that both AGNs and star formation activity contribute to the immense far-infrared luminosities of these systems, although it has been difficult to disentangle the precise balance between these two energy sources.
Recent sensitive X-ray analysis suggests that star formation is likely to be the dominant source of the bolometric luminosity in SMGs (Alexander et al. 2005a, 2005b). Further evidence suggests that it is plausible to identify SMGs as the progenitor of massive elliptical galaxies at the present day, based on their large gas, stellar, and dynamical masses (Neri et al. 2003; Greve et al. 2005; Tacconi et al. 2006; Smail et al. 2004; Borys et al. 2005; Swinbank et al. 2004, 2006). Furthermore, combining the X-ray constraints on the AGN within this population with the typical mass estimates suggests that SMGs are the sites of coeval growth of stellar bulges and central black holes (Borys et al. 2005).

Rest-frame optical emission lines provide a powerful tool to investigate many fundamental properties of galaxies, such as star formation rates (SFRs), power sources, internal extinction, and metallicity. Swinbank et al. (2004) conducted a systematic near-infrared spectroscopic survey of 30 SMGs to investigate their SFRs and metallicities and the kinematics of the emission-line gas. However, the wavelength coverage was limited to the region around Hα and so they did not include several emission lines at shorter wavelengths, such as Hβ and [O III] λλ4959, 5007, which are useful for evaluating internal extinction and metallicity or determining the power source.

We present in this paper the results from a near-infrared spectroscopic survey of redshifted [O III] λλ4959, 5007, H/β, and [O II] λ3727 lines for a sample of far-infrared luminous galaxies. The sample is composed of SMGs and optically faint radio galaxies (OFRGs), at z ~ 1–3.5. Chapman et al. (2004) and Blain et al. (2004) claim that high-redshift OFRGs are ULIRGs, with similar bolometric luminosities to SMGs but warmer characteristic dust temperature, resulting in them being undetected in the submillimeter wave band. We use Hα/Hβ emission line ratios to derive the dust extinction in these systems and then employ these estimates to derive extinction-corrected SFRs from the Hα luminosities. In addition, we also use X-ray observations of these objects to compare the strength of the [O III] λλ5007 emission to their X-ray emission and so investigate the power of the AGNs in these galaxies. We adopt cosmological parameters of H0 = 72 km s⁻¹ Mpc⁻¹, ΩM = 0.3, and ΩΛ = 0.7 throughout.

2. OBSERVATION AND DATA REDUCTION

Our sample was selected from the catalogs of SMGs and OFRGs in Chapman et al. (2004, 2005). We chose SMGs/OFRGs in the redshift ranges z = 2.05–2.56 and z = 1.28–1.68, where nebular emission lines such as [O II], H/β, [O III], and/or Hα are redshifted into clear parts of the J, H, and K bands, respectively. In total, 22 targets were observed using the OHS spectrograph on Subaru, ISAAC on the VLT, or NIRSPEC on Keck. The log of the observations is given in Table 1.

2.1. Subaru OHS Observations and Data Reduction

The majority of our spectroscopic observations were taken with the OH Suppression Spectrograph (OHS; Iwamuro et al. 2001) with the Cooled Infrared Spectrograph and Camera for OHS (CISCO; Motohara et al. 2002) attached to the Nasmyth focus of Subaru Telescope (Iye et al. 2004). Observations were obtained on the nights of 2004 April 6 and 7, 2004 June 24–25, and 2005 February 14–16. Sky conditions were photometric on all of these nights with typical seeing 0″.5–0″.7 at 1.6 μm. We used a slit width of 0″.95, which gives a resolution of ∆λ/λ ~ 200 (~1400 km s⁻¹), and used the “SP4” dither pattern, which shifts the object along the slit to four positions in one sequence. After completing each observation, we observed bright A- or F-type stars with the same configuration as the science observation to calibrate the extinction and sensitivity variation with wavelength. During each night we observed at least two photometric standard stars selected from the UKIRT Faint Standards catalog (Hawarden et al. 2001). We used FS 27 and FS 127 for the observations taken in 2004 April, FS 23 and FS 30 in 2004 June, and FS 133 and FS 127 in 2005 February.

The data reduction was performed in the standard manner using custom scripts in IRAF and some C programs provided by the OHS/CISCO instrument teams. First, we subtracted the sky background using the object frames at different dither positions. Next, we fitted the skyline residuals using two-dimensional polynomials and subtracted these from the data. We then shift-added the images from the different dithering positions, using a median combine. As the instrument is stable, wavelength calibration was performed using the nominal conversion of pixel coordinates to wavelength. To confirm the stability of the wavelength solution, we analyzed argon calibration lamp exposures taken during our runs and checked for systematic shifts in wavelength. We found typical systematic shifts of 7–9 Å (~0.05%), which is ignorable in our analysis due to the low resolution of our spectra. Extinction, sensitivity, and photometric calibration were performed by dividing the calibrated spectra with those of the bright A- or F-type standard-star observations after fitting the stellar spectra with models.

2.2. VLT ISAAC Observations and Data Reduction

We conducted observations of four SMGs and one OFRG using the ISAAC spectrograph on the 8 m VLT on 2004 November 22–23 (Table 1). ISAAC was used in medium-resolution mode, which provides spectral resolution of 3000 (~100 km s⁻¹). Seeing was steady at ~0″.8 over the course of the observations, and the observations were taken with a standard 10″ ABBA chop. Preliminary data reduction was performed using the ECLIPSE8 pipeline, using flat fields generated from night calibrations taken after each observation, and wavelength calibration from a solution using the OH skylines. The remaining flux calibration was achieved in IRAF, using corresponding Hipparcos standard stars observed throughout the observing run and near-infrared fluxes derived from the Two Micron All Sky Survey (2MASS) catalog.

2.3. Keck NIRSPEC Observations and Data Reduction

The observations of SMM J0943+4700 (H6/H7) and SMM J1312+4242 (H8/H9) were taken on 2004 April 8 in photometric conditions and 0″.8 seeing using the NIRSPEC spectrograph on Keck. These observations employed the standard ABBA configuration to achieve sky subtraction. Each exposure was 600 s in length and the total integration time was 2400 s. The data were reduced using the WMKONSPEC package in IRAF. We remapped the two-dimensional spectra using linear interpolation to rectify the spatial and spectral dimensions. After subtracting pairs of nod positions (the nod was 20″ along the slit), residual sky features were removed in IDL using sky regions on either side of the object spectrum. For the wavelength calibration we used an argon arc lamp. The output pixel scale is 4.3 ˚A pixel⁻¹, and the instrumental profile has a FWHM of 15 ˚A (measured from the widths of the skylines), which corresponds to ~200 km s⁻¹. We used FS 27 for photometric calibration.

3. RESULTS

3.1. General Spectral Features

We show all of our spectra in Figure 1. We identified emission lines in 20 spectra out of 22 targets that were observed. Most of

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8 Ver. 4.9-0; see http://www.eso.org/projects/aot/eclipse.
the SMGs show weak Hβ emission, but many show strong (and sometimes broad and distorted) profiles in [O iii] λλ4959, 5007. Some of our spectra show additional emission lines of [Ne iii], [Ne v], and [O i] λ6300, which are common in AGNs. Five of the SMGs from our sample [SMM J09431+4700 (H6), SMM J123549.44+621536.8, SMM J123716.01+620323.3, SMM J163639.01+405635.9, and SMM J163650.43+405734.5] display spatially extended structures (≥1′′0) in either the [O iii] λ5007 or Hα emission line (Fig. 2; for evidence of the spatial extension in SMM J163650.43+405734.5 see Smail et al. 2003; Swinbank et al. 2005).

3.2. Comments on Individual Objects

Several of our observations are particularly noteworthy, and we discuss them here. 3.2.1. SMM J02399 – 0134

This galaxy is identified as a submillimeter source associated with a spiral galaxy at z = 1.06, which shows features typical of a Seyfert 1 (Smail et al. 1997, 2002; Soucail et al. 1999). The strong and featureless continuum, together with the spatially compact emission line flux, indicates AGN activity, an interpretation that is further supported by the detection of this source in hard X-rays by Bautz et al. (2000). Our spectrum shows at least two peaks in the Hα emission line with FWHMrest ∼ 200–400 km s−1, consistent with these lines arising from independent components within the system. If we force a single Gaussian profile to the Hα emission, we determine FWHMrest = 1530 ± 500 km s−1, which if it arises from an AGN is narrower than typical Seyfert 1 galaxies, although broader than Seyfert 2 galaxies (∼500 km s−1). This source is also detected in a CO observation by Greve et al. (2005) with a double-peaked profile with an FWHM of 780 ± 60 km s−1 and a separation between the two peaks of ∼400 km s−1, consistent within the errors with our measurements from Hα. We therefore choose to interpret the double-peaked Hα line as evidence for a merger or interaction in this system, with any AGN-produced broad component undetected in our spectrum.
3.2.2. *SMM J09431+4700*

This source was discovered by Cowie et al. (2002) and has been identified with two distinct microjansky radio counterparts: H6 and H7 (Ledlow et al. 2002). These are lensed sources, lying behind a massive cluster Abell 851 at $z = 0.41$ although the amplification is modest: 1.3 times. The redshift for H6 was measured by Ledlow et al. (2002) as $z = 3.349$ from Lyα; H7 was not observed. The rest-frame UV properties of H6 suggest that it hosts an AGN with spectral features similar to a narrow-line Seyfert 1 (Ledlow et al. 2002). We placed the NIRSPEC slit across both radio components and detected [O iii] $\lambda$5007 emission from both...
sources at redshifts of $z = 3.350$ and 3.347 for H6 and H7, respectively. We also detected narrow (FWHM$_{\text{rest}} \sim 350$ km s$^{-1}$) H$\beta$ emission from H6. The [O iii] $\lambda$5007 emission from H6 is spatially extended ($\gtrsim 2''$ or 14.5 kpc; Fig. 2) but has no significant velocity gradient across $\sim 8$ kpc in projection. No hard X-ray emission was detected with the upper limits on $f_{\text{2-10 keV}} < 1 \times 10^{-15}$ ergs s$^{-1}$ cm$^{-2}$ (Ledlow et al. 2002). CO line emission is also detected by Neri et al. (2003) and Tacconi et al. (2006) based on our rest-frame optical redshift, originating from H7 at $z = 3.346$. Millimeter continuum emission has been seen from H6, but assuming that the gas reservoir is at the redshift we find from [O iii] $\lambda$5007, the gas mass of the AGN-dominated component, H6, is a factor of a few lower than that of H7.

3.2.3. SMM J123549.44+621536.8

This source has apparent double-peaked, narrow ($< 1500$ km s$^{-1}$) emission lines in [O ii] $\lambda\lambda$3727 and [O iii] $\lambda\lambda$4959, 5007, with the two components spatially offset by $\sim 0''.2$. The one-dimensional

![Fig. 1.—Continued](image-url)
spectra also show signs of broad H/\text{C}12\emission at $z = 2.195 \pm 0.005$ with an FWHM of 2100 $\pm$ 500 km s$^{-1}$. Both the [O\text{ iii}] $\lambda$5007 and the [O\text{ ii}] $\lambda$3727 emissions are spatially extended with faint wings on scales of approximately 1 arcmin ($\sim 8$ kpc; see Fig. 2). There may also be a very weak, broad multiplet of Fe\text{ ii} $\lambda\lambda5190, 5320$ (Fig. 1), potentially indicating the presence of the narrow-line Seyfert 1 (NLS1) type AGN component (Osterbrock & Pogge 1985; Goodrich 1989). This is consistent with the results of Alexander et al. (2005a), which indicated the presence of a heavily obscured AGN with $N_{\text{H}} \approx 10^{22.5}$ cm$^{-2}$ based on their X-ray spectral analysis. The spatial extension in the bright core of the [O\text{ iii}] $\lambda$5007 likely indicates merging components or rotation along the slit, while the extended wings may reflect “superwind” activity.

3.2.4. SMM J123716.01+620323.3

This source is very bright in the optical ($R_{\text{AB}} = 20.2$) with a redshift of $z = 2.053 \pm 0.005$, and it was classified as a QSO by Chapman et al. (2005) based on the broad rest-frame UV emission lines and comparable luminosities in rest-frame optical and far-infrared wavelength, which exceed $10^{45}$ ergs s$^{-1}$. The source has also been detected in hard X-rays by Alexander et al. (2005a). Our spectrum shows several hydrogen Balmer lines such as H/\beta, H/\alpha, and H/\gamma with broad FWHM$_{\text{rest}}$ ($\sim 2200$–$2700$ km s$^{-1}$) and the [O\text{ ii}] $\lambda\lambda4959, 5007$ doublet with FWHM$_{\text{rest}}$ of $\sim 2200$ km s$^{-1}$. We also detected the [Ne\text{ iii}] and several Fe\text{ ii} lines at $3 \sigma$ significance. The rest-frame optical spectrum is dominated by continuum emission without stellar absorption features, suggesting a large contribution from the AGN component to the total rest-frame optical flux. The [O\text{ iii}] $\lambda$5007 emission lines are wide (FWHM$_{\text{rest}}$ $\sim 2000$ km s$^{-1}$) and spatially extended ($\sim 1''5$, 12 kpc), indicating dynamically active gas motion (Fig. 2). The estimated hydrogen column density from the X-ray spectral analysis is relatively low ($N_{\text{H}} \approx 10^{22.5}$ cm$^{-2}$), which implies that the AGN does not suffer from large extinction. It should be noted that the redshift based on the rest-frame UV emission lines is 2.037 $\pm$ 0.002, which is blueshifted by 1600 $\pm$ 700 km s$^{-1}$ from the redshift indicated by the rest-frame optical nebular emission line. This velocity offset may arise due to broad Ly$\alpha$ emission that may be affected by dust extinction and resonance scattering.

3.2.5. SMM J131222.35+423814.1

This source is another example of an NLS1-type AGN. It lies at $z = 2.560$ and our spectrum displays broad H/\beta emission, with...
Fig. 2.—Position-wavelength maps (left) and slit profiles (right) for sources with spatially extended [O iii] 5007 or Hα lines. From top to bottom, these are SMM J09431+4700 (H6), SMM J123549.44+621536.8, SMM J123716.01+620323.3, and SMM J163639.01+405635.9. In the position-wavelength maps, the contours are spaced from 2σ at 1σ intervals. The dotted lines display the expected wavelengths of the [O iii] 4959, 5007, Hα, or [N ii] lines at the redshifts listed in Table 2. In the slit profiles, the solid and dotted lines show the light profile for the emission lines and neighboring continuum, respectively. The emission-line profiles consist of [O iii] 5007 emission for SMM J09431+4700 (H6), SMM J123549.44+621536.8, and SMM J123716.01+620323.3 and Hα emission for SMM J163639.01+405635.9. The width used for constructing the emission profiles corresponds to 1000 km s⁻¹ in their rest frame. The spatially extended emission in [O iii] 5007 and Hα, relative to the neighboring continuum, is likely to represent outflows of gas from these systems on scales of ~10 kpc. [See the electronic edition of the Journal for a color version of this figure.]
FWHM$_{\text{rest}} \sim 2600 \pm 1000 \text{ km s}^{-1}$ and a low [O III] $\lambda 5007/\text{H}$\beta ratio (0.46$^{+0.32}_{-0.20}$). This source has Ly$\alpha$ [C iv] and He$\alpha$ emission lines in the rest-frame UV spectrum and was classified as a QSO by Chapman et al. (2005). The rest-frame optical emission is dominated by very strong continuum emission without stellar absorption lines, supporting the presence of a luminous AGN component. Unfortunately, there is no coverage of H$\alpha$ emission for this object and so we could not constrain the internal extinction. The [Ne v] line (which is a very clean indicator of AGN activity; Osterbrock 1989) is detected. Furthermore, this source was detected by the X-ray imaging by Mushotzky et al. (2000), confirming the presence of a luminous AGN in the source.

3.2.6. SMM J163639.01+405635.9

This source is a good example of a heavily extincted starburst in an SMG and was recently discussed by Swinbank et al. (2006). This $z = 1.485$ galaxy has a weak H$\beta$ emission line with H$\alpha$/H$\beta = 10.4^{+29.6}_{-0.4}$. The H$\alpha$ and [O III] $\lambda 5007$ emission lines are spatially extended ($\sim 12''$ or 10 kpc; Fig. 2). There is only an upper limit on its X-ray emission, $f_{\text{2--8 keV}} < 2.2 \times 10^{-15} \text{ ergs cm}^{-2}$ from Manners et al. (2003), which does not strongly constrain the presence of a luminous AGN given the possibility of substantial absorption (e.g., Alexander et al. 2005a). The possible detection of the [O III] $\lambda 3030$ emission line may hint at the presence of an AGN, although the line ratios of [O III] $\lambda 6300$/H$\alpha$ $\sim 0.1$ and [O III] $\lambda 5007$/H$\beta \sim 3.5$ can be explained by relatively highly ionized starburst nebulae (Osterbrock 1989).

3.2.7. MM J163655+405910

This heavily obscured AGN at $z = 2.605$ was found in the MAMBO survey of Greve et al. (2004) (and is also called N2 1200.18) and was detected in X-ray imaging with Chandra (Manners et al. 2003). It has broad (FWHM$_{\text{rest}} \sim 2000$–2500 km s$^{-1}$) emission lines of Ly$\alpha$, [C iv], and H$\alpha$ in the rest-frame UV and optical wavelengths, with a high [O III] $\lambda 3030$/H$\alpha$ ratio ($\sim 0.3$; Willott et al. 2003; Swinbank et al. 2006), which is typical of AGNs (Osterbrock 1989). Our data also show asymmetric H$\beta$ and [O III] $\lambda 34959$ emission line profiles, which exhibit “blue wings” in their profiles. Such profiles have been interpreted as evidence for wind activity from the AGN, although contribution from other components is possible (Swinbank et al. 2006).

3.2.8. SMM J221737.39+001025.1

Our ISAAC spectrum shows strong, narrow H$\alpha$, H$\beta$, [O III] $\lambda 3727$, 5007, and [N ii] emission lines at a redshift of $z = 2.610$ (FWHM$_{\text{rest}}$ of H$\beta$ is $290 \pm 50$ km s$^{-1}$). To investigate the rest-frame optical properties, we retrieved an archival $i'$-band image taken with Subaru Telescope’s Prime Focus Camera (Suprime-Cam) using SMOKA. The image shows an elongated structure, $\sim 1''$3, toward the northwest, and the spectrum was taken with the slit aligned along the major axis of this source. We identify two separate H$\alpha$ emission lines with a velocity offset of $\sim 300$ km s$^{-1}$ and a spatial offset $\sim 0''2$–$0''3$ ($\sim 2$ kpc). These suggest that the system is a merger. The H$\alpha$ and H$\beta$ emission lines do not show asymmetric profiles or detectable broad-line components.

3.3. Composite Spectra

Since many of our individual spectra have modest signal-to-noise ratio, we have also constructed several composite spectra to investigate the general properties of subsets of the SMG population.

We create the composite spectra by deredshifting each spectrum based on redshifts measured from the [O III] $\lambda 5007$ lines, subtracting continuum emission using a first-order spline fit, and averaging all of the spectra with $\sim 3$ clipping after normalizing by [O III] $\lambda 5007$ flux. We smoothed the higher resolution spectra taken at Keck and VLT to match the low-resolution Subaru spectra before stacking. Either stacking the spectra with weights based on their individual signal-to-noise ratio or an unweighted stack does not alter any of the conclusions below. We derive a composite spectrum for those sources that show QSO signatures (“QSO,” i.e., classified as QSO) and for those galaxies that individually show signs of an AGN in their optical spectra (“OPT-AGN,” i.e., those classified as AGNs in the “Class” column under the “OPT” category in Table 2). The former is made from only three individual spectra, while the latter comes from nine spectra. The resulting composite spectra are shown in Figure 3. We do not make a composite of starburst (“SB”) sources since there are only two sources in our sample classified as “SB” or intermediate (“Int”) from their rest-frame optical spectrum. The details of the classification are discussed in § 4.1.

The emission lines of H$\beta$ and [O III] $\lambda 3727$, 5007 are clearly seen in both of the composite spectra. In addition, in the “QSO” spectrum, many strong lines are visible, including [Ne III] $\lambda 3869$ and several Fe ii lines at $\lambda = 4570, 5167$, and 5200–5360, although the [O III] $\lambda 3727$ line is only marginally detected. By fitting a Gaussian to the H$\beta$ and [O III] $\lambda 34959$, 5007 emission lines, we measure the FWHM$_{\text{rest}}$ of H$\beta$ as $\sim 2000$ km s$^{-1}$ after correction for the instrumental resolution. This is $\sim 2000$ km s$^{-1}$ lower than the average FWHM of QSOs at $z = 0.1–2.1$ (Jarvis & McLure 2006). The [O III] $\lambda 5007$/H$\beta$ ratio is 0.36$^{+0.33}_{-0.30}$. All of these spectral features are typical of type 1 AGNs studied locally.

On the other hand, in the composite “OPT-AGN” spectrum, a Gaussian profile fit to the H$\beta$ emission line yields FWHM$_{\text{rest}}$ of 1730 $\pm$ 500 km s$^{-1}$ (it should be noted that the H$\beta$ line fit is not improved by including a narrow-line component due to the low spectral resolution of our spectra) and [O III] $\lambda 5007$/H$\beta$ ratio of 3.2$^{+0.8}_{-0.6}$, and the [O III] $\lambda 3727$ line is well detected. The H$\beta$ line, which is broader than typical type 2 AGNs, and relatively low [O III] $\lambda 5007$/H$\beta$ line ratio are similar to those of local NLS1 galaxies (although by definition these should have [O III] $\lambda 5007$/H$\beta < 3.0$). The Fe ii emission lines, which are one of the characteristic features seen in local NLS1 galaxies, are marginally detected with $\sim 2\sigma$ features seen around 5200 Å in the spectrum, and we can see some marginal detections in individual spectra (SMM J123549.44+621536.8, SMM J123635.59+621424.1, SMM J163650.43+405734.5, and SMM J163706.51+405313.8), all of which have broad H$\beta$ emission of FWHM$_{\text{rest}} \sim 2000$ km s$^{-1}$ (Fig. 1). The resultant spectrum is consistent with a scenario where the rest-frame optical spectra classified as “AGN” in the UV in reality comprise two types: one has relatively broad ($\sim 2000$ km s$^{-1}$) FWHM for the H$\beta$ lines, and the other has narrow H$\beta$ lines with a relatively high [O III] $\lambda 5007$/H$\beta$ ratio, typical of type 2 AGNs. There are clearly differences in the extinction of the circumnuclear region of these two types of objects implied by the difference in luminosity and spectroscopic properties of the rest-frame UV emission, although there is no systematic difference in the H$\alpha$/H$\beta$ ratio we measure for them.

4. DISCUSSIONS

4.1. Emission-Line Diagnostics

In Figure 4 we plot the observed [O III] $\lambda 5007$/H$\beta$ versus [N ii]/H$\alpha$ emission line ratios of the 13 galaxies in our sample for which we have secure H$\alpha$ detections and some information about
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<tr>
<td>SMM J136350.43+405734.5</td>
<td>Int AGN</td>
<td>3720±500 Reevaluated after Smail et al. (2003)</td>
</tr>
<tr>
<td>MM J163655+409132.1</td>
<td>AGN AGN</td>
<td>2410±600 Blue wings in Hα and [O iii] 24959</td>
</tr>
<tr>
<td>SMM J163706.31+405313.8</td>
<td>SB</td>
<td>...</td>
</tr>
<tr>
<td>SMM J217337+001402.1</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>SMM J221737.39+001025.1</td>
<td>AGN AGN</td>
<td>290±50</td>
</tr>
<tr>
<td>J04431+0210</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>SMM J1401+0252 (JI)</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>SMM J163658.19+410523.8</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Composite (all)</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Composite (QSO)</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Composite (OPT-AGN)</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

<sup>a</sup> Based on [O ii] 3727 line measurement.
<sup>b</sup> Based on [O iii] 5007 line measurement.
<sup>c</sup> Based on Hα line measurement.
<sup>d</sup> Detected in Tecza et al. (2004).
This diagnostic plot, termed the BPT diagram, can be used to identify the source of gas excitation (Baldwin et al. 1981). Based on this diagram, we classify the spectra into three types: starburst (SB), intermediate (Int), or nonthermal (AGN), as listed in Table 2.

We also classify galaxies as “AGN” that have Hα and/or Hβ FWHM_rest greater than 1500 km s^{-1}, as it is difficult to understand the formation of such large line widths from gas motions in star-forming regions. This limit is also greater than the coarse spectral resolution of OHS (~1400 km s^{-1}). For comparison we also plot the emission-line flux ratios from local ULIRGs (Veilleux et al. 1999) and note that the SMGs in our sample occupy the same region of the diagnostic diagram as local ULIRGs. The lines show...
to investigate the internal reddening of SMGs (at least for those regions that are visible in the rest-frame optical), we plot the Hα/Hβ ratios as a function of their far-infrared luminosities in Figure 5. To calculate $A_V$, we use the reddening curve from Calzetti et al. (2000) and assume an intrinsic Hα/Hβ ratio of 3.0, which is between the values for typical Seyfert 2 galaxies and/or LINERs (3.1; Halpern & Steiner 1983; Gaskell & Ferland 1984) and those for star-forming galaxies (2.85; Veilleux & Osterbrock 1987). The observed Hα/Hβ ratio for the SMGs is typically 5–20, and the derived extinction spans $A_V = 1–4$ with a median value of 2.9 ± 0.5 (where the error comes from bootstrap resampling). This estimate is consistent with the results based on the spectral energy distribution (SED) fitting of optical to near-infrared photometric data (Smail et al. 2004) and slightly

4.2. Extinction and Hidden Star Formation

SMGs are dusty systems with large dust masses, $>10^9 M_\odot$, and high bolometric luminosities ($>10^{12} L_\odot$). The presence of large quantities of dust and its associated reddening may also explain the large discrepancies between the SFRs derived for SMGs from their far-infrared and Hα luminosities (Swinbank et al. 2004), which imply extinction in Hα of factors of ~10–100. There are of course alternative explanations: that the bulk of the far-infrared emission originates from other sources that are too dusty to see even at rest-frame optical wavelengths, such as very highly obscured AGNs, or due to emission that falls outside of the slits used in the Hα measurements. However, the latter explanation is unlikely as these observations are based on radio-identified sources unlikely that a major source of bolometric emission has been missed by the observations.
higher than that derived from optical to mid-infrared SEDs (1.7 ± 0.3; Borys et al. 2005), where the latter did not include any contribution from thermally pulsed AGB stars in the model SEDs, which might lead to an underestimate of the reddening (Maraston et al. 2006).

In Figure 6 we compare the extinction-corrected SFRs derived from the Hα and far-infrared luminosities. The far-infrared luminosities come from Chapman et al. (2003b, 2004) based on SED model fitting to the observed 850 μm and 1.4 GHz fluxes at their known redshifts, assuming that the local far-infrared–radio correlation holds (Condon et al. 1991; Garrett 2002). We also include observations for local Infrared Astronomical Satellite (IRAS) galaxies (Kewley et al. 2002) and Infrared Space Observatory (ISO) galaxies (Flores et al. 2004). The typical A_V in these samples are ∼0.5 and ∼2.4, respectively. The extinction-corrected Hα luminosities for the IRAS and ISO galaxies are all calibrated in the same manner as for our SMG samples based on their Hα/Hβ ratio. The SFRs from the Hα and far-infrared luminosities are derived using the equations given in Kennicutt (1998).

The correlation between the far-infrared and reddening-corrected Hα luminosities (Fig. 6) appears to be relatively good, with a linear relation extending over 5 orders of magnitude in SFR, although with some scatter, with the most luminous SMGs in our sample having SFRs approximately an order of magnitude higher than those of the brightest ISO galaxies. The good agreement between the two SFRs when using the reddening-corrected Hα estimate confirms that the discrepancies between the SFRs seen in Swinbank et al. (2004) are in large part due to dust extinction and moreover that the bulk of the far-infrared luminosity in these galaxies is probably derived from star formation. We note that it is likely that slit losses and placement contribute to the scatter in these measurements as we are combining observations of Hβ and Hα from different telescopes and instruments. For example, our brightest far-infrared source, SMM J163650.43+405734.5 (N2 850.4), has a lower SFR measured from Hα than from the far-infrared. However, this galaxy is spatially extended and has a very complex structure in the rest-frame optical (Smail et al. 2003; Swinbank et al. 2005). It is therefore likely that our slit covered only a part of the Hα-emitting region. Finally, any remaining systematic offset between the two SFR estimates may be caused by the fact that our A_V estimates only reflect the reddening to the optically detectable gas and thus are not necessarily a good indicator of the total column toward the bolometric sources in these objects.

4.3. Growing Black Holes in the SMGs

4.3.1. Spectral Similarity with Narrow-Line Seyfert 1 Galaxies

SMGs are proposed to be the progenitors of present-day massive spheroidal galaxies because of their high SFRs and their large stellar, gas, and dynamical masses (Smail et al. 2004; Neri et al. 2003; Greve et al. 2005; Borys et al. 2005; Tacconi et al. 2006; Swinbank et al. 2006). Most massive galaxies in the local universe contain SMBHs (e.g., Ferrarese & Merritt 2000; Gebhardt et al. 2000; Marconi & Hunt 2003; Heckman et al. 2004). Equally an AGN appears to be almost universally present in SMGs: based on the extremely sensitive X-ray observations of the Chandra Deep Field–North (CDF-N), Alexander et al. (2003, 2005a, 2005b) found more than ∼75% of SMGs to be detected in hard X-rays, indicating that they contain an accreting SMBH. It is therefore interesting to estimate the mass of, and accretion rates onto, the central black holes of SMGs to constrain the coevolution of the SMBHs and the stellar masses of their surrounding bulge (Kawakatu et al. 2003; Granato et al. 2004).

The three sources classified as “QSO” in our sample have characteristics typical of local NLS1 galaxies: low [O iii] λ5007/Hβ ratios (∼0.5–1.8) and detectable Fe ii emission in their individual and also composite spectra (Figs. 1 and 3). NLS1 galaxies are commonly interpreted as hosting rapidly growing SMBHs (Collin & Kawaguchi 2004), and hence the spectral similarities of these SMG QSOs with local NLS1 galaxies could imply comparable physical conditions in the accretion disk around the SMBH in the SMGs. However, the SMGs have FWHM_rest ∼ 2000–2500 km s^{-1} for their Balmer emission lines, and so they are not formally NLS1 galaxies because these line widths are higher than the definition used for NLS1 (FWHM_rest of Hβ of <2000 km s^{-1}). Nevertheless, it is worth noting that their Hβ FWHM_rest are close to the minimum for QSOs at z ∼ 0.1–2.1 (Jarvis & McLure 2006) and narrower than the average of radio-quiet/radio-loud QSOs (∼4800–6500 km s^{-1}). However, we caution that with the limited signal-to-noise ratio in our spectra we may underestimate the line widths, missing weak and broader line components. For instance, in the composite spectrum of SMG QSOs we estimate the FWHM_rest of the H β line as 3200 ± 1000 km s^{-1} using a single Gaussian fit. This is 500–1000 km s^{-1} broader than the mean of the individual spectra, suggesting that there may be an undetected broad component present in them. More secure estimates of the line widths would need either observations of stronger emission lines such as Hα, which are not available for these sources, or much deeper observations.

The FWHM_rest of the Balmer emission lines in those SMGs with AGN-like features (but omitting the three sources classified as “QSO”) are 1000–3000 km s^{-1}. They are at least 1000–2000 km s^{-1} lower than the average FWHM of QSOs at z ∼ 0.1–2.1 measured from Hβ and/or Mg ii lines (Jarvis & McLure 2006), suggesting that the SMGs host lower mass SMBHs. This would support the claims of Alexander et al. (2005a, 2005b; see also Borys et al. 2005) based on Eddington-limited assumptions.
adopt the hard X-ray fluxes from these observations, although
9/22 of them yield only the upper limits. For comparison, we also
plot observations of local ULIRGs (Ptak et al. 2003; Franceschini
et al. 2003), as well as Seyfert 1 and Seyfert 2 galaxies and the
PG QSOs, representative of more luminous type 1 AGNs (Alonso-
Herrero et al. 1997; Mulchaey et al. 1994). All of these com-
parison samples are the observed luminosities: there are no
extension corrections applied to either the X-ray or [O III] λ5007
measurements.

Figure 7 also shows the relation for Seyfert 2 galaxies sug-
gested by Mulchaey et al. (1994). Compared to the QSOs and
Seyfert 1 galaxies, which are selected to represent unabsorbed
hard X-ray sources, the majority of our SMGs are typically an
order of magnitude brighter in [O III] λ5007 for a given hard
X-ray luminosity. We note that a similar excess of [O III] λ5007
emission is also seen in local ULIRGs.

Could this apparent excess be due to absorption/extinction?
The typical hydrogen column densities to the AGNs in SMGs
have been determined by Alexander et al. (2005a), yielding N_H ≈
10^{21}−10^{24} cm^{−2}, with corrections to their hard X-ray luminosities
of 2.5−20 times. Equally, the typical [O III] λ5007 luminosity
correction, adopting the extinction estimated from the Balmer
decrement, A_V ≈ 2.9, is also approximately a factor of 10:
F_{[O~III]~λ5007,abs} = F_{[O~III]~λ5007,corr} \left ( \frac{H\alpha/H\beta}{H\alpha/\beta_0} \right )^{1/2},
where H\alpha/\beta_0 is assumed to be 3.0 (see Bassani et al. 1999).
Unfortunately, we have only one source (SMM J123549.44+621536.8)
with reliable estimates of the H i column density and reddening
correction that has 10 times and 28.5 times corrections to the hard
X-ray and [O III] λ5007 luminosities, respectively, and with
corrected luminosities of 1 \times 10^{44} and 6.2 \times 10^{44} erg s^{−1}, respec-
tively (Fig. 7).

As the extinction corrections for [O III] λ5007 and hard X-ray
luminosities run parallel to the trend in Figure 7, the [O III] λ5007
excess cannot be explained by a simple reddening effect. We also
cautions that the reddening corrections applied to the [O III] λ5007
fluxes are uncertain since [O III] λ5007 may arise in external
shocks that suffer much less extinction than the H\alpha/H\beta ratio sug-
gests. We also note that the apparent [O III] λ5007 excess could
arise simply due to the relatively shallow X-ray coverage in
several of our fields where the sources only have upper limits on
their hard X-ray fluxes. However, the fact that 3/4 sources with
[O III] λ5007 and hard X-ray detections from the CDF-N, which
has by far the best X-ray data, show the excess provides good
evidence for the reality of this feature.

While some of the [O III] λ5007 flux we see arises from the
obscured AGN, we suggest that the excess [O III] λ5007 flux arises,
at least in part, from shock-induced ("superwind") activity.
There are some cases of plausible superwind-driven [O III] λ5007
excesses seen in our SMG sample as seen by the struc-
tured [O III] λ5007 line profiles (asymmetric/broad/multipeaked)
and the spatially extended emission (Figs. 1 and 2; see also Smail
et al. 2003).

In order to examine the possibility that shock-induced gas
causes the excess [O III] λ5007 emission, we first search for the
signature of shock-excited nebular emission using the simple
criterion of [N II] λλ6583/H\alpha ≥ 1 and [S II] λλ6716, 6731/H\alpha ≥
0.5. Using the line ratios from the stacked spectrum of SMGs in
Swinbank et al. (2004), we find that they lie outside of this shock-
induced criterion. However, this criterion is only valid for the
shocks with large outflow velocities and a relatively weak star-
burst radiation field (Veilleux et al. 2005) and therefore may not
be applicable to the SMGs. Another test is to use the line ratios
of [O III] λλ4959, 5007/[O II] λλ3726 and/or [N II] λλ6548, 6883/
[N II] λλ5755, which can be used to estimate the temperature of

The similarities of the rest-frame optical spectral features of
some SMGs to NLS1 galaxies imply rapid growth of the SMBH
in the nuclei of SMGs. A total of 5/9 of the SMGs classified as
"AGN" in our sample have relatively narrow FWHM_{rest} (up to
≈1600−3700 km s^{−1}) for their H\alpha or H\beta emission lines, and 3/5
show marginal Fe emission. Therefore, the Eddington-limited
accretion determined for local NLS1 galaxies may also be ap-
propriate for SMGs. Assuming this, we measured the line widths
are consistent with the estimate of the central BH masses derived
peculiar for SMGs. Assuming this, the measured line widths are
not corrected for extinction or absorption in any of these samples.
The open circle represents the data for SMM J123549.44+621536.8 (the only source with precise measurements for both cor-
rections) with absorption-corrected [O III] λ5007 and hard X-ray luminosities, and the dotted arrow shows the amplitude of these corrections. The bulk of the sources
in our sample show [O III] λ5007 luminosities significantly above those expected from their X-ray emission assuming the local relationship. As we show, applying extinction/absorption corrections to the data will not reduce this excess (as the correction moves objects parallel to the local relation). We suggest that this excess [O III] λ5007 emission arises from shocks within these galaxies. [See the electronic edition of the Journal for a color version of this figure.]

4.3.2. The Origin of [O III] λλ5007 Excesses in SMGs

To further test the claim that SMGs have small SMBH masses,
we compare the [O III] λ5007 and hard X-ray luminosities. There is
a well-studied correlation between the hard X-ray and the opti-
[O III] λ5007 emission line luminosities in local AGNs (e.g., Mulchaey et al. 1994). This correlation can be used to gauge
the black hole masses and the accretion rates of AGNs within our
sample.

In Figure 7 we show the hard X-ray versus [O III] λ5007
luminosities of the SMGs (uncorrected for any extinction/absorption).
All 22 SMGs in our sample have hard X-ray coverage, but of
varying depth (CDF-N, Alexander et al. 2003; CFRS 03hr,
Waskett et al. 2004; SSA 13, Mushotzky et al. 2000; SSA 22,
Basu-Zych & Scharf 2004; ELAIS N2, Manners et al. 2003). We

![Figure 7](image-url)
the nebular gas. These ratios will provide robust estimates of electron temperature of the emission nebulae, yielding high ($\sim 30,000$ K) temperatures if the gas is ionized mainly by shocks (as in the Cygnus Loop) and lower temperature ($\sim 15,000$ K) for photoionization-dominated clouds seen in star-forming regions (Osterbrock 1989). As these methods rely on measurements of relatively weak emission lines [O\textsc{iii}] $\lambda 4363$ and [N\textsc{ii}] $\lambda 5755$, only our composite spectra have sufficient signal-to-noise ratio to be useful. From the composite spectrum in Figure 3 and also from the total SMG composite spectrum in Swinbank et al. (2004), we derive an upper limit on [O\textsc{iii}] $\lambda 4959$, 5007/[O\textsc{iii}] $\lambda 4363 < 37.2$ and [N\textsc{ii}] $\lambda 6548, 683/[N\textsc{ii}] \lambda 7555 < 23.6$. Both ratios imply an upper limit to the electron temperature of less than 20,000 K. This is consistent with the expected temperature in photoionization-dominated clouds (with an electron density of $\sim 10^3-10^4$ cm$^{-3}$). If the electron density is higher than this, collisional de-excitation begins to play a role and the estimated temperature is reduced. These results would appear to rule out the dominance of shock excitation similar to that seen in galactic supernova remnants.

As described in Dopita & Sutherland (1995), the optical line ratios of Seyfert 2 galaxies can also be explained by fast (300–500 km s$^{-1}$) shocks, if the precursor H\textsc{ii} regions in front of the shock absorb most of the UV photons generated by the shocks. The calculated electron temperature is $\sim 17,000$ K for this “shock + precursor” model from Dopita & Sutherland (1995), which is consistent with the limit on the electron temperatures in SMGs estimated from our [N\textsc{ii}] and [O\textsc{iii}] emission line ratios. Thus, there is a plausible origin for the [O\textsc{iii}] $\lambda 5007$ excess we see compared to typical AGNs: shocks associated with supernova explosions in relatively dense gas environments, where the precursor H\textsc{ii} clouds are still present. Thus, we suggest that those sources with high ($\sim 5$–$10$) [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratios and broad ($\sim 2000$ km s$^{-1}$) FWHM of H$\beta$ lines can be explained by a combination of an NLS1-type AGN residing in an environment of shocks associated with supernova explosions in relatively dense gas. This would explain all of their observable properties, including the high [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratios (Dopita & Sutherland 1995).

5. CONCLUSIONS

Using near-infrared spectroscopy, we have observed the redshifted H$\beta$, [O\textsc{iii}] $\lambda\lambda 4959, 5007$, and [O\textsc{iii}] $\lambda 7327$ emission lines in a sample of 22 ULIRGs at high redshifts. Twenty of the sources in our sample are SMGs at $z \sim 1.0$–$3.5$. Combining our observations with previous studies of the H$\alpha$ and [N\textsc{ii}] emission from these galaxies and also with observations of their hard X-ray and far-infrared emission, we have placed constraints on the physical properties of this population. We conclude the following:

1. A majority of our sample (14/22) have spectra that are classified as “AGN” or “QSO” based on several rest-frame optical spectroscopic diagnostics. Specifically, for those sources with detections of the four emission lines necessary to construct a BPT diagram, 8/9 are classified as “AGN.” It should be noted that there is no confirmed pure starburst galaxy in our sample, although several sources show intermediate spectral properties. This is likely to be caused by our sample selection, which is biased toward galaxies with bright near-infrared magnitudes and also to those exhibiting strong line emission. Thus, we caution that our results should not be taken as representative of the whole SMG population.

2. Using the H$\alpha$/H$\beta$ flux ratio, we are able to estimate the internal extinction in our SMGs. We measure a median extinction of $A_V = 2.9 \pm 0.5$, which is similar to the extinction measured in local ULIRGs. This value is also consistent with the estimates from the SED fitting in the rest-frame UV/optical that are derived under the assumption of a dominant dust-reddened young starburst (Smail et al. 2004).

3. We compare the SFRs derived from the dust-extinction-corrected H$\alpha$ luminosities with those derived from the far-infrared luminosities and find reasonable consistency between these for most of the SMGs in our sample. The fact that the corrected H$\alpha$-derived SFRs correspond closely to those estimated from the far-infrared suggests that star formation is the major contributor to the far-infrared luminosities in SMGs.

4. At least 11/19 of the SMGs in our sample show a clear excess in the ratio of their [O\textsc{iii}] $\lambda 5007$ to X-ray luminosities relative to values for local AGNs. The five sources with the highest [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratios ($>10$), which are classified as “AGN” from our spectral diagnostics, show this [O\textsc{iii}] $\lambda 5007$ excess. One possible explanation for the [O\textsc{iii}] $\lambda 5007$ excess is that it is produced by “Compton thick” AGNs. However, this is inconsistent with the column density measurements ($N_{HI}$) from fitting of the X-ray spectra for the sources in CDF-N, and we argue that this is unlikely in most SMGs. Instead, we suggest that the most plausible cause of the [O\textsc{iii}] $\lambda 5007$ excess is shock-induced emission arising from vigorous star formation (supernovae activity). This scenario is supported in several galaxies by spatially extended and/or distorted/multiple [O\textsc{iii}] $\lambda 5007$ emission line profiles. Furthermore, using limits on the electron temperatures from [O\textsc{ii}] and [N\textsc{ii}] emission line ratios, we can explain the excess [O\textsc{iii}] $\lambda 5007$ emission as arising from shocks in dense regions within these systems.

5. The Balmer line widths in 9/22 sample galaxies exhibit broad emission components with relatively small FWHMs ($\sim 1500$–$3700$ km s$^{-1}$). Three of them are classified as “QSO” but have smaller H$\beta$ FWHM (2100–2600 km s$^{-1}$) than are typical for QSOs. They also have lower [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratios and relatively strong Fe$\beta$ emission, both of which are characteristics of local NLS1 galaxies. Among the other six sources, only one shows a low [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratio, and four show high [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratios (larger than seen in NLS1 galaxies). However, the high [O\textsc{iii}] $\lambda 5007$/H$\beta$ ratios may arise from [O\textsc{iii}] $\lambda 5007$ excesses due to shock excitation, and hence removing this contribution would yield lower ratios more consistent with NLS1 classification. Several of these sources also have tentative evidence for Fe$\beta$ emission, again characteristic of NLS1 galaxies. Thus, once account is taken of the potential contribution from shocks to the excess [O\textsc{iii}] $\lambda 5007$ emission, there appear to be close similarities between SMGs and NLS1 galaxies. The spectral classification of SMGs as NLS1 galaxies may then indicate (as has been claimed for local NLS1 galaxies) that SMGs have low-mass black holes that are rapidly growing at high accretion rates (Alexander et al. 2005a, 2005b; Boros et al. 2005). Deeper spectroscopic observations are essential to search for any obscured broad Balmer lines that might indicate larger SMBH masses and confirm the presence of Fe$\beta$ lines that are common in the NLS1 galaxies.

Summarizing our results, we conclude that our sample of SMGs contains a population of vigorously star-forming galaxies with high SFRs and strong extinction. The activity in these systems is driving shocks through the dense gas reservoirs they contain, and some of this material is being expelled from the galaxies. In addition, many of our sources show evidence for low-mass, but rapidly growing, SMBHs. These results confirm the critical role of the submillimeter-bright phase in defining the properties of massive galaxies forming at high redshifts.
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