THE ASTROPHYSICAL JOURNAL, 605:L109–L112, 2004 April 20

SPIFFI OBSERVATIONS OF THE STARBURST SMM J14011+0252:[1] ALREADY OLD, FAT, AND RICH BY $z = 2.565$

M. TECZA,[2] A. J. BAKER,[2] R. I. DAVIES,[2] R. GENZEL,[2,3] M. D. LEHNERT,[2] F. EISENHAUER,[2] D. LUTZ,[2] N. NESVADBA,[2] S. SEITZ,[4] L. J. TACCONI,[2] N. A. THATTE,[5] R. ABUTER,[2] AND R. BENDER[2,4]
Received 2003 December 20; accepted 2004 March 9; published 2004 March 25

ABSTRACT

Using the SPectrometer for Infrared Faint Field Imaging on the ESO Very Large Telescope, we have obtained *J*-, *H*-, and *K*-band integral field spectroscopy of the $z = 2.565$ luminous submillimeter galaxy SMM J14011+0252. A global spectrum reveals the brighter of this spatially resolved system's two components as an intense starburst that is remarkably old, massive, and metal-rich for the early epoch at which it is observed. We see a strong Balmer break implying a ≥100 Myr timescale for continuous star formation as well as nebular emission-line ratios implying a supersolar oxygen abundance on large spatial scales. Overall, the system is rapidly converting a large baryonic mass into stars over the course of only a few hundred megayears. Our study thus adds new arguments to the growing evidence that submillimeter galaxies are more massive than Lyman break galaxies and more numerous at high redshift than predicted by current semianalytic models of galaxy evolution.

Subject headings: galaxies: abundances — galaxies: evolution — galaxies: formation

1. INTRODUCTION

Deep imaging in the optical and near-IR has made it possible to constrain both the evolution of the cosmic star formation rate (SFR) density (e.g., Madau et al. 1996) and its time integral, the growth of the cosmic stellar mass density (e.g., Dickinson et al. 2003). Short-wavelength studies give an incomplete picture of these trends, however, since an important population of high-redshift galaxies is too obscured to be easily detected. These submillimeter galaxies (SMGs; see Blain et al. 2002 and references therein) have large IR luminosities that are predominantly generated by star formation rather than accretion (Barger et al. 2001; Almaini et al. 2003); as a result, they contribute substantially to cosmic star formation (Barger, Cowie, & Richards 2000). Moreover, as the strikingly different appearances of the Hubble Deep Field at 0.83 μm (Williams et al. 1996) and 850 μm (Hughes et al. 1998) exemplify, SMGs are rarer and forming stars much more intensely than typical optically selected systems.

To understand the evolutionary state of SMGs, we have conducted a detailed rest-frame optical case study using the SPectrometer for Infrared Faint Field Imaging (SPIFFI; Tecza et al. 2000; Eisenhauer et al. 2000, 2003). Our target is SMM J14011+0252 (hereafter J14011), a $z = 2.565$ galaxy lying behind the $z = 0.25$ cluster A1835 and the second SMG to have an optical counterpart identification (Barger et al. 1999) validated by CO interferometry (Frayer et al. 1999). Recent maps of J14011's molecular gas have led to divergent conclusions about its intrinsic size: Ivison et al. (2001) suggest that a large background source undergoes a factor $\mathcal{M} \sim 2.5$ magnification by A1835 as a whole, while Downes & Solomon (2003) argue that a fortuitously located cluster member further boosts magnification of a small background source to $\mathcal{M} \sim 25$. We defer a full discussion of lensing to a future paper; here we focus primarily on the lensing-independent conclusions of high age and metallicity that can be drawn from J14011's global spectrum alone. Throughout this Letter, we assume a flat $\Omega_\Lambda = 0.7$ cosmology with $H_0 = 70$ km s^{-1} Mpc^{-1}.

2. OBSERVATIONS AND DATA REDUCTION

In three SPIFFI "Guest Instrument" runs between 2003 February and April, we observed J14011 in the *J*, *H*, and *K* bands on Kueyen (UT2 of the ESO Very Large Telescope). Weather conditions were extremely stable within and between nights, and the near-IR seeing was better than 0.″6. SPIFFI obtains simultaneous spectra for all pixels in a 32×32 array; our data were obtained with the 0.″25 pixel scale and with spectral resolving power $R \equiv \lambda/\Delta\lambda \sim 1500$ at 1.3 μm, ~2000 at 1.6 μm, and ~2400 at 2.2 μm. Individual exposure times in the three bands were 10, 5, and 10 minutes, respectively; we obtained an "off" frame at a sky position (offset by 20″–25″) for each "on" frame and jittered the telescope by 2 pixel offsets between the on frames themselves. The total on-source integration times were 60 minutes in *J*, 95 minutes in *H*, and 340 minutes in *K*.

We reduced the data within IRAF using modified versions of long-slit spectroscopy tools. After subtracting dark frames and flat-fielding all data (object and sky frames), we masked out bad pixels and interpolated new values using all available three-dimensional information. Object and sky frames were then wavelength calibrated using arc lamp spectra and/or night-sky emission lines. The sky frames were then subtracted, and a linear fit to the background was subtracted across each spectral and spatial row of the data. At this point, the data cubes for each on-off pair were reconstructed, using only integer pixel shifts and assuming that each spatial row of the field covered exactly 32 pixels; although this was not strictly correct, it only slightly reduced the spatial resolution and avoided loss of signal-to-noise due to resampling. A final background subtraction exploited the two-dimensional field of view: objects in the frame were masked out, and the mean of the remaining pixels in a given wavelength plane was subtracted from that plane. Using telescope offsets, we spatially aligned and then combined the data cubes, clipping any deviant pixels in each cell. Telluric correction was applied to the final merged cubes.

[1] Based on observations obtained at the European Southern Observatory, Chile, for program 70.A-0254.

[2] Max-Planck-Institut für extraterrestrische Physik, Postfach 1312, D-85741 Garching, Germany; tecza@mpe.mpg.de, ajb@mpe.mpg.de, davies@mpe.mpg.de, genzel@mpe.mpg.de, mlehnert@mpe.mpg.de, eisenhau@mpe.mpg.de, lutz@mpe.mpg.de, nicole@mpe.mpg.de, linda@mpe.mpg.de, rabuter@mpe.mpg.de, bender@mpe.mpg.de.

[3] Department of Physics, University of California at Berkeley, 366 Le Conte Hall, Berkeley, CA 94720-7300.

[4] Munich University Observatory, Scheinerstrasse 1, D-81679 Munich, Germany; stella@usm.uni-muenchen.de.

[5] Department of Astrophysics, University of Oxford, Keble Road, Oxford OX1 3RH, UK; thatte@astro.ox.ac.uk.

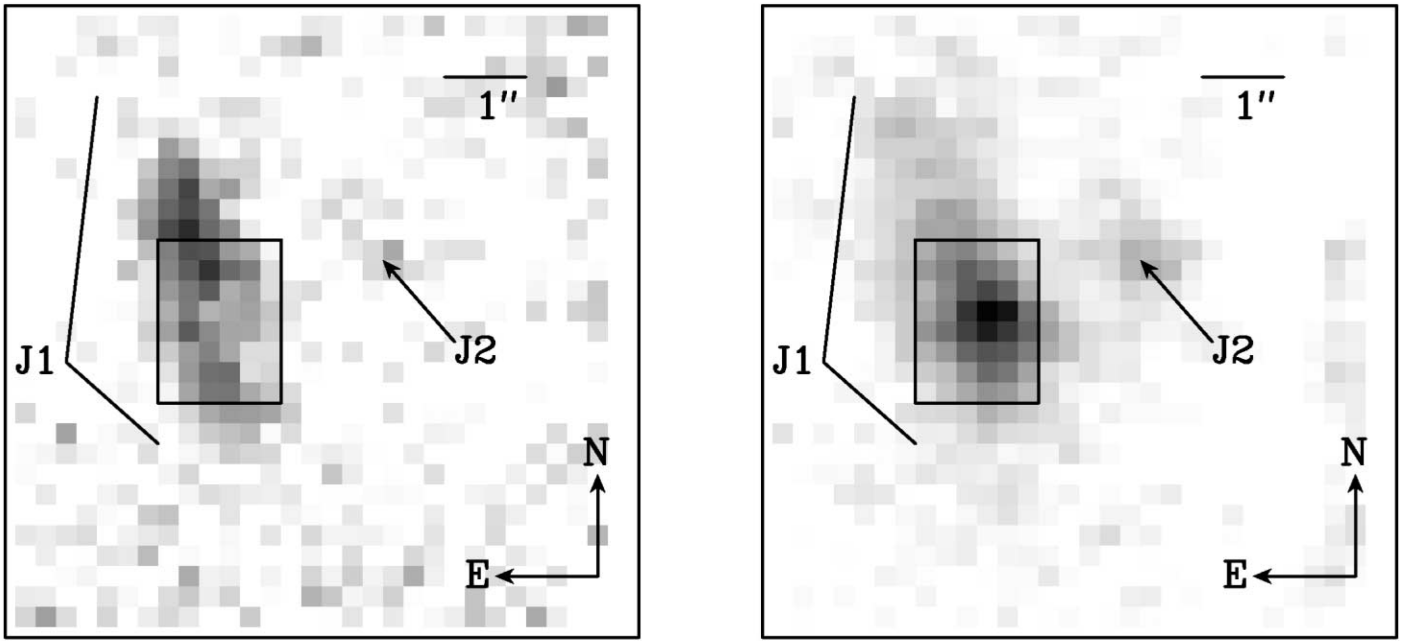

FIG. 1.—*Left*: Continuum-subtracted Hα image of J14011. *Right*: Line-free *K*-band continuum image of J14011. The field of view is $8'' \times 8''$; the aperture used to extract the composite spectrum for J1 in Fig. 2 is overlaid.

Fluxes were calibrated by integrating SPIFFI observations of the UKIRT faint standard FS 135 only over the Mauna Kea Observatory *J*, *H*, and *K* filter bandpasses; the reference photometry of FS 135 itself has a scatter of less than 1% (Hawarden et al. 2001).

3. RESULTS

Figure 1 shows J14011 in continuum-subtracted Hα and line-free *K*-band continuum. Within the bright eastern "J1" component, the SPIFFI data reveal substantial spatial variation in Hα equivalent width: nebular emission is strongest away from the central continuum peak. After using this peak to align all three data cubes, we extracted a spectrum of J1 from the $2'' \times 1\overset{''}{.}5$ region shown in Figure 1. This box encloses about two-thirds of the total continuum associated with J1 in the *K*-band cube and virtually all the emission we detect in *J* and *H*. Figure 2 shows the result and reveals that J14011 has a continuum break between the observed *J* and *H* bands. The lack of a similar break in blank-sky spectra extracted from elsewhere in the SPIFFI field proves that this cannot be an artifact of poor sky subtraction; the $J-H$ color of FS 135, meanwhile, is accurate to 0.3% (Hawarden et al. 2001). The feature's most likely origin is the Balmer break of a ≥100 Myr old stellar population at $z \simeq 2.565$. Quantitatively, the strength of the break can be reproduced by a population synthesis model constructed with the STARS package (Sternberg 1998) for a 200 Myr old episode of continuous star formation with a 1–100 $M_\odot$ Salpeter initial mass function (IMF), solar metallicity, and an extinction $A_V = 0.7$. A crucial implication of this result is that the near-IR continuum emission must be dominated by the high-redshift background source rather than by a foreground cluster galaxy.

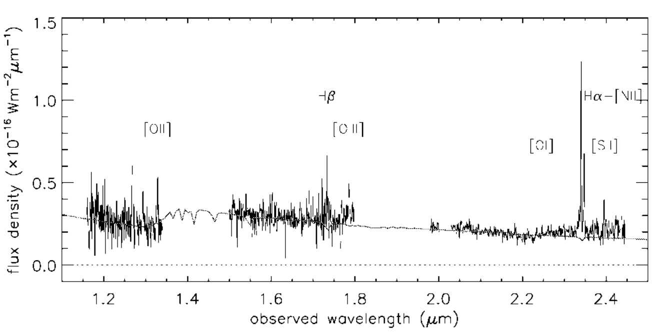

FIG. 2.—*J*, *H*, and *K* spectra of J14011 extracted from a $2'' \times 1\overset{''}{.}5$ aperture. Superposed is the model STARS spectrum for a 200 Myr old continuous star formation episode, assuming solar metallicity, a 1–100 $M_\odot$ Salpeter IMF, and extinction $A_V = 0.7$.

We have also used the spectrum in Figure 2 to measure fluxes and centroids for 11 nebular emission lines; taken together, they imply J1 has a systemic redshift $z_{\rm H\,II} = 2.5652 \pm 0.0006$, in perfect agreement with the $z_{\rm CO}$ derived from millimeter interferometry (Downes & Solomon 2003). Hα emission from the fainter western "J2" component is blueshifted by $\Delta z = 0.0021 \pm 0.0003$ with respect to J1, consistent with the offset measured by Ivison et al. (2000) from rest-UV spectra. The J1 line fluxes allow us to measure the R_{23} estimator for its oxygen abundance (Pagel et al. 1979). After correcting for reddening with a Galactic extinction curve (Howarth 1983) and the color excess $E(B-V) = 0.18^{+0.13}_{-0.12}$ implied by the Balmer decrement, and fixing $I_{4959} \equiv I_{5007}/3$, we derive $\log R_{23} = 0.32 \pm 0.16$. Translation of this index to an oxygen abundance depends on ionization parameter, as quantified by $\log O_{32} = -0.24 \pm 0.22$. Using the fits of Kobulnicky, Kennicutt, & Pizagno (1999) to the calibrations of McGaugh (1991), we infer that $12 + \log\,({\rm O/H}) = 8.96^{+0.06}_{-0.10}$. Relative to the measurement of Allende Prieto, Lambert, & Asplund (2001), this represents an abundance that is supersolar by $0.27^{+0.11}_{-0.15}$ dex. A high [N II]/Hα ratio means J14011 cannot fall on the lower metallicity branch of the [O/H] versus R_{23} relation.

4. THE HIGH MASS OF J14011

Although we reserve a full lensing model of J14011 for a future paper, our SPIFFI data already allow us to evaluate the small-source/high-$\mathcal{M}$ and large-source/low-$\mathcal{M}$ scenarios. As noted above, the strength of the apparent Balmer break in J1 leaves little room for continuum emission from an "extra" lensing galaxy in A1835. The newly confirmed velocity difference between J1 and J2, on top of Lyα and C III] 1909 Å equivalent width differences in their published spectra (Barger et al. 1999; Ivison et al. 2000), indicates that these components are not multiple images of the same background source, contrary to the suggestion of Downes & Solomon (2003). Finally, SPIFFI spatially resolves J1 in an east-west direction; the observed 0''.95 FWHM of Hα emission exceeds the 0''.65 east-west point-spread function dimension. This would not occur if J1 were formed from the merging of a triple-image set.

These direct arguments for a low lensing magnification are nicely complemented by the wealth of self-consistent evidence that J14011 as a whole has a large mass and age. Our estimate of J1's high oxygen abundance is independent of $\mathcal{M}$, provided there is minimal differential lensing from 3726 to 5007 Å rest wavelength. For a closed-box model with solar yield, this metallicity corresponds to a gas/baryonic mass fraction of $\exp(-Z/Z_\odot) \simeq 0.16$. Frayer et al. (1999) measure an $8.2 \times 10^{10}\mathcal{M}^{-1}$ K km s^{-1} pc^2 CO (3–2) line luminosity for J14011. For gas that is dense and warm enough to produce detectable CO (7–6) emission, Downes & Solomon (2003) suggest that molecular gas mass and CO luminosity are related by $M_{\rm gas}/L'_{\rm CO\,(3-2)} = 0.8\ M_\odot$ (K km s^{-1} pc^2)$^{-1}$. Adopting $\mathcal{M} \sim 5$ as a fiducial value for the cluster-only lensing case, we infer a molecular gas mass $M_{\rm gas} \simeq 1.3 \times 10^{10}\ M_\odot$ and therefore a total baryonic mass $M_{\rm bary} \simeq 7.9 \times 10^{10}\ M_\odot$ and stellar mass $M_{\rm stars} = M_{\rm bary} - M_{\rm gas} \simeq 6.6 \times 10^{10}\ M_\odot$. This last value (and with it, our assumption of moderate $\mathcal{M}$) is empirically supported by the mass-metallicity relation, as recently rederived by Tremonti et al. (2004) from a sample of ~51,000 galaxies at $z \sim 0.1$. Their favored translation of R_{23} to metallicity gives $12 + \log({\rm O/H}) \simeq 9.1$ for J1, at which the median stellar mass is $\sim 6.2 \times 10^{10}\ M_\odot$.

For a simple closed-box model, assumption of continuous star formation and a return fraction $R = 0.2$ uniquely sets the length of time for which a galaxy has been forming stars: $t_{\rm SF} = [\exp(Z/Z_\odot) - 1](1 - R)^{-1} M_{\rm gas}\ {\rm SFR}^{-1}$. For J14011, $t_{\rm SF}$ will be independent of lensing because $M_{\rm gas}$ and the SFR depend identically on $\mathcal{M}$. We can estimate the SFR in J14011 from its $S_{850} = 12.3\mathcal{M}^{-1}$ mJy (Smail et al. 2002); for the fiducial spectral energy distribution of Blain et al. (1999) with $T_d = 40$ K, $\beta = 1.5$, and $\alpha = 2.2$, $L_{\rm IR} \simeq 1.9 \times 10^{12}\,(S_{850}/{\rm mJy})\ L_\odot = 2.3 \times 10^{13}\mathcal{M}^{-1}\ L_\odot$. Adjusting the conversion factor of Kennicutt (1998) to match a 1–100 $M_\odot$ Salpeter IMF, we infer SFR $\simeq 1920\mathcal{M}^{-1}\ M_\odot$ yr^{-1} and $t_{\rm SF} \simeq 220$ Myr. This age is consistent with the strength of the Balmer break seen in Figure 2, suggesting that the closed-box assumption made above is not unreasonable. J14011's powerful starburst thus appears to be converting most of its baryons into stars on a fairly rapid (few hundred megayear) timescale.

5. THE HIGH MASSES OF SMGs

Its star formation history and metallicity allow J14011 to join SMM J02399−0136—whose $M_{\rm bary}$ Genzel et al. (2003) infer from its spatially resolved gas kinematics—as an SMG whose large baryonic mass is secure. Thanks to CO confirmation of Keck/Low Resolution Imaging Spectrograph redshifts obtained by Chapman et al. (2003a), this category promises to expand rapidly. Neri et al. (2003) have published CO data confirming the Keck redshifts for three new SMGs; the total set of five has $\langle z \rangle = 2.72$ and a median CO line width of 420 km s^{-1} (FWHM). A fruitful comparison can be made between this SMG sample and the well-studied Lyman break galaxy (LBG) population at $z \sim 3$. In the list of 16 LBGs for which Pettini et al. (2001) report ionized gas kinematics, the median velocity width is 170 km s^{-1} (FWHM) at a slightly larger $\langle z \rangle = 3.12$. Assuming that the (few kiloparsec) size scales of the starbursts are comparable in LBGs and SMGs, the higher velocity widths imply SMGs' dynamical masses should also be larger by a typical factor of 6. If the two populations' dark matter fractions are comparable, we would expect a median SMG baryonic mass exceeding the median $1.1 \times 10^{10}\ M_\odot$ stellar mass estimated for 74 LBGs (Shapley et al. 2001)[6] by the same factor, i.e., $6.6 \times 10^{10}\ M_\odot$. Although the strong clustering of LBGs (e.g., Giavalisco & Dickinson 2001) suggests they share their host halos with much more baryonic mass than is seen in their inner regions, SMGs appear already to have assembled measurably larger masses of baryons or to have been more successful in retaining those baryons in the face of energetic winds. Complementary constraints on the star formation histories and metallicities of more SMGs, like those obtained here for J14011, would further strengthen this case.

In the hierarchical merging scenario for structure formation, massive galaxies are assembled in greater numbers with the passage of time. As several authors have pointed out, the observed number densities of high-redshift galaxies with large stellar masses exceed the predictions of semianalytic models of galaxy evolution within this framework (Cimatti et al. 2002; Daddi et al. 2004; Saracco et al. 2004). As in Genzel et al. (2003), we can also use the number densities of SMGs to apply the same

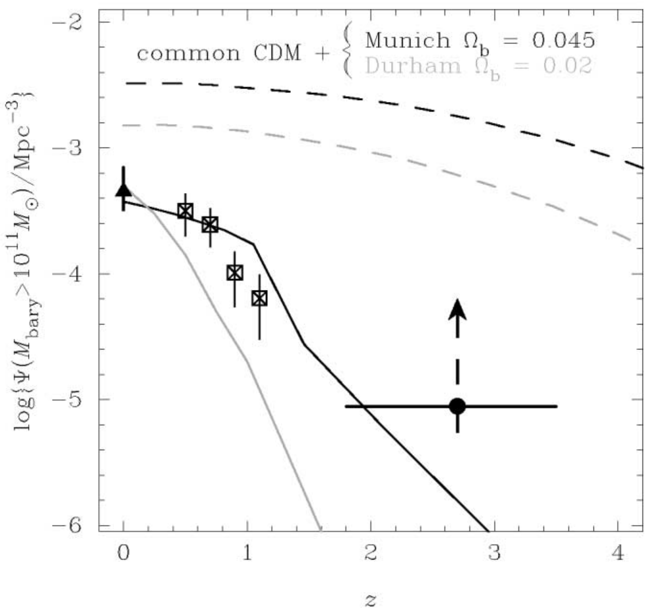

FIG. 3.—Comoving number densities of galaxies with baryonic masses $\geq 10^{11}\ M_\odot$ as a function of redshift. The triangle and open squares show densities of massive stellar systems at $z = 0$ (Cole et al. 2001) and $z \sim 1$ (Drory et al. 2004); the circle shows the density for massive SMGs at $z \sim 2.7$, with a factor of 7 correction for burst lifetime (see § 5). Solid curves show the predictions of semianalytic modeling by the "Munich" group (Kauffmann et al. 1999) and the "Durham" group (an updated version of Baugh et al. 2003); dashed curves show the corresponding number densities of halos with *available* baryonic masses $\geq 10^{11}\ M_\odot$. The two models use the same halo simulations but assume different Ω_b.

[6] This median LBG mass adjusts the Shapley et al. (2001) population synthesis results for a 1–125 $M_\odot$ Salpeter IMF and $H_0 = 70$.

"baryonic mass assembly test" to the models. Smail et al. (2002) report the surface density of SMGs with $S_{850} > 5$ mJy (the threshold above which SMG optical redshifts $1.8 \leq z \leq 3.5$ have been confirmed with CO interferometry) to be 880^{+530}_{-330} deg^{-2}. The Chapman et al. (2003a) sample includes two (of nine) sources above this threshold lying at $z < 1.8$ and excludes the ~35% ± 5% of bright SMGs that lack radio counterparts (Ivison et al. 2002; Chapman et al. 2003b). Two of the five SMGs with CO detections have ≳510 km s^{-1} FWHM line widths that would correspond to $M_{\rm bary} \geq 10^{11}\ M_\odot$ by the above rescaling of LBG stellar masses. This leaves an estimated surface density of 180^{+110}_{-70} deg^{-2} for SMGs with baryonic masses $\gtrsim 10^{11}\ M_\odot$ in the range $1.8 \leq z \leq 3.5$ and a comoving number density of $8.9^{+5.3}_{-3.3} \times 10^{-6}$ Mpc^{-3}.

We must still correct this density upward to account for sources that are comparably massive but no longer luminous enough to have been detected at 850 μm. Adding $t_{\rm SF}$ and the gas exhaustion timescale $M_{\rm gas}$ SFR^{-1} for J14011 implies that the total duration of its current burst will be of order 250 Myr. Relative to the 1.8 Gyr elapsed over the range $1.8 \leq z \leq 3.5$, this would imply a correction factor of 7 for the population as a whole. Figure 3 plots this prediction, together with the comoving number densities of galaxies with stellar masses above the $10^{11}\ M_\odot$ threshold at $z \sim 0$ (Cole et al. 2001) and $z \sim 1$ (Drory et al. 2004). Also plotted are the predictions of semianalytic models, one of which is taken from Kauffmann et al. (1999) and the other an update of Baugh et al. (2003). Since all theoretical and observational values assume the same cosmology and a consistent (either Miller-Scalo or 1–100 $M_\odot$ Salpeter) IMF, we are secure in concluding that the models underpredict the number densities of massive galaxies at $z \sim 2.7$. Couching Figure 3 in terms of *mass* emphasizes that the observed surface densities of SMGs cannot be explained using a very flat IMF alone. We also note that the models contain sufficiently many dark halos of total mass $\gtrsim 10^{11}(\Omega_M/\Omega_b)\ M_\odot$ to account for the observed number densities of massive SMGs, provided their baryons can be rapidly and efficiently assembled into galaxies.

Correcting the observed number density of SMGs to account for their less dust-luminous descendants raises the question of what types of galaxies SMGs can plausibly evolve into. Although LBGs are clearly excluded owing to their smaller masses, an intriguing alternative is the newly identified population whose red $J-K$ colors can stem from a strong Balmer break at $z \sim 2.5$ (Franx et al. 2003). These galaxies appear to be strongly clustered (Daddi et al. 2003) and—assuming a uniform distribution in the redshift range $2 \leq z \leq 3.5$ (van Dokkum et al. 2003)—have a comoving number density $\sim 1.8 \times 10^{-4}$ Mpc^{-3}. Relatively few sources with $J-K > 2.3$ also have 1.2 mm flux densities greater than 3 mJy (Dannerbauer et al. 2004), indicating little direct overlap with the *bright* end of the SMG population (see also Frayer et al. 2004), although fainter (sub)millimeter counterparts may still be present (e.g., Wehner, Barger, & Kneib 2002). With three examples in the Hubble Deep Field–South having (for a Miller-Scalo IMF) stellar masses (0.6–1.4) × $10^{11}\ M_\odot$ (Saracco et al. 2004), it would seem plausible that the more luminous objects with red $J-K$ colors at this epoch could have passed through an SMG phase at higher redshift.

We thank M. Horrobin, C. Iserlohe, A. Schegerer, and J. Schreiber for their hard work on SPIFFI; A. Sternberg for assistance with STARS; C. Baugh, N. Drory, G. Kauffmann, and C. Tremonti for useful discussions; and an anonymous referee for helpful comments.

REFERENCES

Allende Prieto, C., Lambert, D. L., & Asplund, M. 2001, ApJ, 556, L63
Almaini, O., et al. 2003, MNRAS, 338, 303
Barger, A. J., Cowie, L. L., & Richards, E. A. 2000, AJ, 119, 2092
Barger, A. J., Cowie, L. L., Smail, I., Ivison, R. J., Blain, A. W., & Kneib, J.-P. 1999, AJ, 117, 2656
Barger, A. J., Cowie, L. L., Steffen, A. T., Hornschemeier, A. E., Brandt, W. N., & Garmire, G. P. 2001, ApJ, 560, L23
Baugh, C. M., Benson, A. J., Cole, S., Frenk, C. S., & Lacey, C. 2003, in The Masses of Galaxies at Low and High Redshift, ed. R. Bender & A. Renzini (Berlin: Springer), 91
Blain, A. W., Smail, I., Ivison, R. J., & Kneib, J.-P. 1999, MNRAS, 302, 632
Blain, A. W., Smail, I., Ivison, R. J., Kneib, J.-P., & Frayer, D. T. 2002, Phys. Rep., 369, 111
Chapman, S. C., Blain, A. W., Ivison, R. J., & Smail, I. 2003a, Nature, 422, 695
Chapman, S. C., et al. 2003b, ApJ, 585, 57
Cimatti, A., et al. 2002, A&A, 391, L1
Cole, S., et al. 2001, MNRAS, 326, 255
Daddi, E., et al. 2004, ApJ, 600, L127
———. 2003, ApJ, 588, 50
Dannerbauer, H., Lehnert, M. D., Lutz, D., Tacconi, L., Bertoldi, F., Carilli, C., Genzel, R., & Menten, K. M. 2004, ApJ, in press (astro-ph/0402549)
Dickinson, M., Papovich, C., Ferguson, H. C., & Budavári, T. 2003, ApJ, 587, 25
Downes, D., & Solomon, P. M. 2003, ApJ, 582, 37
Drory, N., Bender, R., Feluner, G., Hopp, U., Maraston, C., Snigula, J., & Hill, G. J. 2004, ApJ, in press (astro-ph/0403041)
Eisenhauer, F., Tecza, M., Mengel, S., Thatte, N. A., Röhrle, C., Bickert, K., & Schreiber, J. 2000, Proc. SPIE, 4008, 289
Eisenhauer, F., et al. 2003, Messenger, 113, 17
Franx, M., et al. 2003, ApJ, 587, L79
Frayer, D. T., Reddy, N. A., Armus, L., Blain, A. W., Scoville, N. Z., & Smail, I. 2004, AJ, 127, 728
Frayer, D. T., et al. 1999, ApJ, 514, L13
Genzel, R., Baker, A. J., Tacconi, L. J., Lutz, D., Cox, P., Guilloteau, S., & Omont, A. 2003, ApJ, 584, 633
Giavalisco, M., & Dickinson, M. 2001, ApJ, 550, 177
Hawarden, T., Leggett, S., Letawsky, M., Ballantyne, D., & Casali, M. 2001, MNRAS, 325, 563
Howarth, I. D. 1983, MNRAS, 203, 301
Hughes, D. H., et al. 1998, Nature, 394, 241
Ivison, R. J., Smail, I., Barger, A. J., Kneib, J.-P., Blain, A. W., Owen, F. N., Kerr, T. H., & Cowie, L. L. 2000, MNRAS, 315, 209
Ivison, R. J., Smail, I., Frayer, D. T., Kneib, J.-P., & Blain, A. W. 2001, ApJ, 561, L45
Ivison, R. J., et al. 2002, MNRAS, 337, 1
Kauffmann, G., Colberg, J. M., Diaferio, A., & White, S. D. M. 1999, MNRAS, 303, 188
Kennicutt, R. C., Jr. 1998, ARA&A, 36, 189
Kobulnicky, H. A., Kennicutt, R. C., Jr., & Pizagno, J. L. 1999, ApJ, 514, 544
Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., & Fruchter, A. 1996, MNRAS, 283, 1388
McGaugh, S. S. 1991, ApJ, 380, 140
Neri, R., et al. 2003, ApJ, 597, L113
Pagel, B. E. J., Edmunds, M. G., Blackwell, D. E., Chun, M. S., & Smith, G. 1979, MNRAS, 189, 95
Pettini, M., Shapley, A. E., Steidel, C. C., Cuby, J.-G., Dickinson, M., Moorwood, A. F. M., Adelberger, K. L., & Giavalisco, M. 2001, ApJ, 554, 981
Saracco, P., et al. 2004, A&A, in press (astro-ph/0310131)
Shapley, A. E., Steidel, C. C., Adelberger, K. L., Dickinson, M., Giavalisco, M., & Pettini, M. 2001, ApJ, 562, 95
Smail, I., Ivison, R. J., Blain, A. W., & Kneib, J.-P. 2002, MNRAS, 331, 495
Sternberg, A. 1998, ApJ, 506, 721
Tecza, M., Thatte, N. A., Eisenhauer, F., Mengel, S., Röhrle, C., & Bickert, K. 2000, Proc. SPIE, 4008, 1344
Tremonti, C. A., et al. 2004, ApJ, submitted
van Dokkum, P. G., et al. 2003, ApJ, 587, L83
Wehner, E. H., Barger, A. J., & Kneib, J.-P. 2002, ApJ, 577, L83
Williams, R. E., et al. 1996, AJ, 112, 1335