MMT EXTREMELY METAL-POOR GALAXY SURVEY. I. AN EFFICIENT TECHNIQUE FOR IDENTIFYING METAL-POOR GALAXIES

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Received 2006 October 24; accepted 2007 September 21; published 2007 November 29

ABSTRACT

We demonstrate a successful strategy for identifying extremely metal-poor galaxies. Our preliminary survey of 24 candidates contains 10 metal-poor galaxies of which 4 have log(O/H)+12 < 7.65, some of the lowest-metallicity blue compact galaxies known to date. Interestingly, our sample of metal-poor galaxies have systematically lower metallicity for their luminosity than comparable samples of blue compact galaxies, dwarf irregulars, and normal star-forming galaxies. Our metal-poor galaxies share very similar properties, however, with the host galaxies of nearby long-duration gamma-ray bursts (GRBs), including similar metallicity, stellar ages, and star formation rates. We use Hβ to measure the number of OB stars present in our galaxies and estimate a core-collapse supernova rate of \( \sim 10^{-3} \) yr\(^{-1} \). A larger sample of metal-poor galaxies may provide new clues about the environment where GRBs form and may provide a list of potential GRB hosts.

Key words: galaxies: abundances – galaxies: starburst – gamma rays: bursts

1. INTRODUCTION

Metal-poor galaxies are the key to understanding star formation and gas enrichment in a nearly pristine interstellar medium, and may provide a template for understanding the formation of the first stars. Extremely metal-poor galaxies (XMPGs) are extremely rare: fewer than 1% of dwarf galaxies are XMPGs, with a gas-phase oxygen abundance log(O/H)+12 \( \leq 7.65 \) (Kunth & Östlin 2000; Kniazev et al. 2003). Known XMPGs are mostly gas-rich, blue compact galaxies with spectra dominated by emission lines. The first surveys to search for XMPGs were objective prism surveys (MacAlpine et al. 1977; Kunth et al. 1981; Terlevich et al. 1991). Abundance studies of these surveys revealed up to a dozen XMPGs (Kunth & Sargent 1983; Campbell et al. 1986; Masegosa et al. 1994), but none so extreme as I Zw 18 (Searle & Sargent 1972). I Zw 18, now along with SBS 0335-052W and DDO 68, are the most metal-poor local galaxies known, with log(O/H)+12 ranging from 7.12 to 7.17 (Izotov et al. 2005; Izotov & Thuan 2007). Papaderos et al. (2006) found two new XMPGs in the 2dF survey. Among the 1,000,000 spectra released by the Sloan Digital Sky Survey (SDSS), there are 19 identified XMPGs (Kniazev et al. 2003; Izotov et al. 2004; 2006a; Izotov & Thuan 2007), emphasizing the rarity of such objects.

Kewley et al. (2007) recently announced the serendipitous discovery of a new XMPG, SDSS J080840.85+172856.48 (hereafter SDSS J0809+1729). The object is a stellar point source in the SDSS catalog. It was observed as part of the Brown et al. (2006a) hypervelocity star survey on the basis of its stellar B-type photometric colors. Spectroscopy reveals that the object is not a star but rather a compact blue galaxy at \( c z = 13232 \) km s\(^{-1} \). Our re-analysis shows that the galaxy has log(O/H)+12 = 7.48±0.1. Interestingly, the observed electron density, star formation rate, and total luminosity of this XMPG are remarkably similar to nearby GRB host galaxies (Kewley et al. 2007).

Nearby \( z < 0.2 \) long duration GRBs are observed in metal-poor galaxies (Prochaska et al. 2004; Sollerman et al. 2005; Fruchter et al. 2006; Stanek et al. 2006; Wolf & Podsiałdowski 2007; Wiersema et al. 2007; Margutti et al. 2007). Fruchter et al. (2006) argue that the link between metal-poor galaxies and GRBs originates in the atmospheres of massive stars. Massive metal-poor stars lack the opacity to support significant stellar winds, and thus can produce the anomalous type Ic supernovae associated with nearby GRBs. Berger et al. (2007) argue that GRBs are linked to young starburst populations, which at low redshift happen to be found predominantly in low-mass, metal-poor galaxies. At large redshift \( z > 0.2 \), the metallicity of GRB hosts is much harder to determine (Prochaska 2006). At least one GRB host galaxy is an extremely red and probably metal-rich object (Berger et al. 2007), and other GRB hosts \( 0.2 < z < 1 \) appear consistent with normal metallicity–luminosity relations (Wolf & Podsiałdowski 2007; Margutti et al. 2007). GRBs clearly occur in different types of host galaxies; they are not tied exclusively to the most metal-poor galaxies. Yet finding and studying metal-poor galaxies with properties similar to nearby GRB host galaxies may yield critical clues about the environment where nearby GRBs form.

Inspired by the discovery of SDSS J0809+1729, we designed a survey to find metal-poor galaxies. We use a technique similar to photometric redshifts to identify metal-poor galaxies in the SDSS galaxy catalog. We test this technique and target \( g' \sim 20 \) galaxies with very blue colors, a region of parameter space not well probed by previous surveys. Our strategy uncovers 10 metal-poor galaxies from a sample of 24 candidates, 4 of which are new XMPGs.

In Section 2 we present our technique to find new metal-poor galaxies and discuss the efficacy of our survey. In Section 3 we describe the properties of the entire set of metal-poor galaxies, and compare the galaxies with samples of blue compact galaxies and nearby GRB hosts. In Section 4 we estimate the expected core-collapse supernova rate in our galaxies. We conclude in Section 5.
2. DATA

2.1. Technique to Find Extremely Metal-Poor Galaxies

Known XMPGs outside the Local Group are starburst galaxies characterized by very low internal extinction, high ionization parameter, and large gas-phase electron density (e.g. Kniazev et al. 2003; Izotov et al. 2005; 2006a; Papaderos et al. 2006; Kewley et al. 2007; Izotov & Thuan 2007). As a result, XMPGs have steep blue continua, large [O III]/[O II] ratios, and strong hydrogen Balmer emission lines. These characteristics significantly affect the broadband colors of XMPGs. For example, Figure 1 shows the observed spectrum of SDSS J0809+1729 plotted against the total system throughput of the SDSS u'g'r'i' filter bandpasses\(^4\). The contribution of emission lines to the broadband magnitudes of SDSS J0809+1729 is approximately 3%, 32%, 6%, and 12% at u', g', r', and i', respectively.

The strong emission line contribution to XMPGs’ broadband magnitudes results in unusual colors that change with redshift. For example, at lower redshift, SDSS J0809+1729 does not satisfy the B-star criteria in Brown et al. (2006b) because Hα drops into the r' band and produces a much redder (g' − r') color. Conversely, at higher redshift, Hβ and O III move from g' into r' and also produce a much redder (g' − r') color (see Figure 1). We quantify these effects using the RVSAO package (Kurtz & Mink 1998) to shift the XMPG spectra to different redshifts. We predict the galaxy’s colors at different redshifts by adding the relative change in color to the observed photometry. In effect, we are calculating k-corrections for the XMPG.

Figure 2 plots the resulting color-redshift tracks for SDSS J0809+1729 (solid lines). Over the range 0.0 < z < 0.10, the XMPG’s (u' − g')\(_0\) and (g' − r')\(_0\) colors vary by ~0.3 mag and the (r' − i')\(_0\) color varies by ~1.0 mag. The subscript 0 indicates colors corrected for Galactic extinction following Schlegel et al. (1998). We note that the Johnson/Cousins passbands are much less sensitive than their SDSS equivalents because the strong Hβ/O III and Hα emission lines remain in their respective V and R passbands for 0.0 < z < 0.10.

Knowing how the broadband colors of an XMPG change with redshift, we can search for new XMPGs at other redshifts in the SDSS photometric catalog. Unfortunately, searching for new XMPGs like SDSS J0809+1729 in the stellar catalog is not feasible because of immense contamination from white dwarfs with similar colors. Instead, we search the SDSS galaxy catalog.

We use the color-redshift track of our newly discovered XMPG, SDSS J0809+1729, as the basis for the sample of XMPGs published here. We begin by selecting all galaxies in SDSS DR4 (Adelman-McCarthy et al. 2006) with g' < 20.5. Figure 2(a) plots these galaxies with similar (u' − g')\(_0\) and (g' − r')\(_0\) to SDSS J0809+1729. Only by combining two or more colors can we meaningfully select XMPG candidates. We find ~10\(^3\) galaxies simultaneously within 0.1 mag of any pair of color-redshift tracks and a mere 10\(^2\) galaxies (small squares, Figures 2(b)–(d)) simultaneously within 0.1 mag of all three color-redshift tracks. We visually inspect the objects and find that many are near saturated stars or that they are H II regions in nearby galaxies. After eliminating the unwanted objects, we are left with a sample of 38 photometrically selected XMPG candidates (marked by × symbols, Figures 2(b)–(d)). Our survey is based on this sample of 38 XMPG candidates.

We use a restrictive color selection as the first demonstration of our technique. If our XMPG selection strategy is successful, we can easily broaden the search parameters to identify many more faint XMPG candidates.

2.2. Observations

We obtained spectroscopy of the 24 candidates available on the nights of 2006 May 25–27 and 2006 June 19–20. Table 1 lists the 24 candidates. Observations were obtained with the 6.5 m MMT telescope and the Blue Channel spectrograph. We operated the spectrograph with the 300 line mm\(^{-1}\) grating and a 1″ slit. These settings provide a wavelength coverage of 3400–8600 Å and a spectral resolution of 6.2 Å. Exposure times were typically 30 min. We obtained comparison lamp exposures after every exposure.
We reduce the spectra using standard IRAF spectrual tasks and measure recession velocities from emission lines using the package RVSAO (Kurtz & Mink 1998). We flux calibrate using spectrophotometric standards (Massey et al. 1988) and the standard Kitt Peak atmospheric extinction correction.

For objects obtained in non-photometric conditions, we scale the spectra by the flux ratio of the observed spectroscopic and SDSS broadband magnitudes. We estimate that absolute flux calibration is accurate to ~25%.

We measure emission line fluxes using IRAF splot and fitprof tasks, and find no significant offset between the two methods. Table 2 presents the observed line strengths with their uncertainty range.

Table 2

| Table 2 Observed Line Intensities |
|-----------------------------------|
| F(λ0) Ion | J120955.67 | J123944.58 | J124638.82 | J133424.53 | J142250.72 | J144158.32 | J150316.52 | J151221.08 | J172955.61 | J225900.86 |
|---------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Hα      | +142155.9  | +145612.8  | +350115.1  | +592057.0  | +514516.5  | +291434.2  | +110569.7  | +954911.2  | +5433438.8 | +141343.5  |
| Hβ      | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        |
| Hγ      | 1.23        | 1.23        | 1.23        | 1.23        | 1.23        | 1.23        | 1.23        | 1.23        | 1.23        | 1.23        |
| Hδ      | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        |
| Hε      | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        |
| Nα      | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        |
| Nβ      | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        |
| Nδ      | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        | 1.12        |

Note. * Flux in units of 10^{-16} erg s^{-1} cm^{-2}. Uncertainties are statistical errors only, and do not include the errors due to reddening, stellar absorption, and absolute flux calibration.
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Figure 3. MMT spectra of our four new XMPGs. [O III] λ4363 is well detected in all four objects (see insets). The extremely weak [N II] and [S II] lines visibly indicate the extremely low abundance of these objects. The thumbnail images, courtesy of SDSS, are 48′′ on a side, and show that all four XMPGs appear to be compact dwarfs.

of Aller (1984) and the atomic data compiled by Stasińska (2005).

The gas-phase oxygen abundance depends on line ratios and thus is independent of the uncertainties in our absolute flux calibration. We propagate the errors from the line ratio measurement, the extinction correction, and the stellar absorption correction, and find that the relative errors in metallicities derived using the same method are formally \( \leq 0.07 \) dex. However, the absolute error is at least \( \sim 0.1 \) dex. Thus systematics dominate the errors; our metallicities are accurate at the \( \pm 0.1 \) dex level.

2.3. Survey Efficiency

Our initial survey of 24 candidates contains 10 metal-poor galaxies with \( \log(O/H) + 12 < 8 \), of which 4 are new XMPGs. Thus our strategy is \( \sim 20\% \) efficient for selecting XMPGs. Spectra and thumbnail images of the four new XMPGs are displayed in Figure 3 (see also Table 3). Three of the new XMPGs (SDSS J142250.72+514516.5, SDSS J144158.32+291434.2, and SDSS J225900.86+141343.5) have lower abundance than SDSS J0809+1729. The remaining objects in our survey are either A stars in the Milky Way, galaxies with modest emission lines, and a few odd objects (one E+A, one possible BL Lac, one possible quasar) listed in Table 1.

3. GALAXY PROPERTIES

We now open our discussion to include all the metal-poor galaxies in our survey. Including SDSS J0809+1729, our survey contains five XMPGs and six metal-poor galaxies. Table 3 summarizes the spectroscopic measurements for the 11 galaxies. Because the galaxies are compact objects, our spectra provide reasonable global estimates of their properties. We compare the properties of our galaxies with similar samples of blue compact galaxies (BCGs) and with nearby GRB hosts. Throughout this paper we adopt a flat, \( \Lambda \)-dominated cosmology with \( H_0 = 70 \) and \( \Omega_m = 0.3 \).

3.1. Color and Redshift Distribution

Our 11 metal-poor galaxies are systematically bluer and more luminous than other known BCGs. Figure 4 plots the Gil de Paz et al. (2003) sample of nearby BCGs, for which \( (B - R)_0 \) and \( M_B \) are all available. We estimate \( (B - R) \) for our galaxies from SDSS photometry (Fukugita et al. 1996), and shift the observed magnitudes to the rest-frame using \( k \)-corrections we calculate for \( B \) and \( R \) passbands as described in Section 2. It is clear that our metal-poor galaxies are more than 0.5 mag bluer in \( (B - R)_0 \) than most nearby BCGs. I Zw 18 and UCM 1612+1308 (Rego et al. 1998) are the two BCGs with colors comparable to our metal-poor galaxies. However, our metal-poor galaxies are systematically more luminous than the BCGs with similar colors.

Our 11 metal-poor galaxies are also at greater redshift than most known BCGs. Figure 5 plots the redshift distribution of BCGs (Kong & Cheng 2002; Gil de Paz et al. 2003), metal-poor galaxies from 2dF (Papaderos et al. 2006) and SDSS (Kniazev et al. 2003), our 11 metal-poor galaxies, and the 3 nearest GRB host galaxies (Stanek et al. 2006).
Table 3
Our Metal-Poor Galaxies

| ID                      | $cz$ (km s$^{-1}$) | $MB$ (mag) | $Te$ (K) | log(O/H)+12 | Age (Myr) | Hα/Hβ | L(Hβ) (erg s$^{-1}$) | SFR ($Te$) (M$_{\odot}$ yr$^{-1}$) | N(OB) | SN rate
|-------------------------|--------------------|------------|----------|-------------|-----------|-------|---------------------|----------------|--------|----------|
| SDSS J225900.86+141343.51 | 8918               | −16.4     | 18600    | 7.37        | 4.0       | 2.75  | 1.80 x 10$^{40}$    | 0.21           | 13900  | 4        |
| SDSS J142250.72+514516.49 | 11654              | −15.9     | 19100    | 7.41        | 4.0       | 2.52  | 8.46 x 10$^{39}$    | 0.09           | 6500   | 2        |
| SDSS J144158.32+291434.22 | 13741              | −16.3     | 19400    | 7.47        | 4.5       | 2.80  | 1.08 x 10$^{40}$    | 0.13           | 10400  | 3        |
| SDSS J080840.85+172856.48 | 13233              | −17.1     | 19000    | 7.48        | 4.5       | 2.64  | 1.94 x 10$^{40}$    | 0.18           | 18700  | 6        |
| SDSS J123944.58+145612.80 | 21534              | −17.7     | 17000    | 7.65        | 4.5       | 2.95  | 3.69 x 10$^{40}$    | 0.54           | 37400  | 12       |
| SDSS J151221.08+054911.21 | 24025              | −16.3     | 17500    | 7.68        | 5.5       | 5.46  | 2.63 x 10$^{40}$    | 0.32           | 40600  | 14       |
| SDSS J134242.53+592057.04 | 21800              | −16.8     | 14500    | 7.86        | 5.0       | 2.86  | 1.73 x 10$^{40}$    | 0.23           | 27800  | 9        |
| SDSS J120955.67+142155.91 | 23340              | −17.4     | 15400    | 7.71        | 5.5       | 2.72  | 2.26 x 10$^{40}$    | 0.09           | 6500   | 2        |
| SDSS J140316.52+111056.93 | 23405              | −18.3     | 14800    | 7.85        | 4.5       | 2.69  | 6.31 x 10$^{40}$    | 0.80           | 65800  | 22       |
| SDSS J150316.52+111056.93 | 24308              | −18.3     | 13900    | 8.00        | 4.0       | 3.23  | 9.46 x 10$^{40}$    | 1.98           | 60800  | 20       |

Kewley et al. (2007).

Figure 5. Redshift and luminosity distribution of BCGs (Kong & Cheng 2002; Gil de Paz et al. 2003), metal-poor galaxies from 2dF (Papaderos et al. 2006) and SDSS (Kniazev et al. 2003), our 11 metal-poor galaxies, and the 3 nearest GRB host galaxies (Stanek et al. 2006). MB is calculated for the 2dF galaxies assuming $(B - V) = 0.5$ (Papaderos et al. 2006). MB is estimated for the SDSS galaxies from SDSS photometry (Kniazev et al. 2003). Note that we calculate MB for the 2dF galaxies assuming the average $(B - V) = 0.5$ for that sample (Papaderos et al. 2006). We estimate MB for the SDSS galaxies from $g'$ and $r'$ photometry in Kniazev et al. (2003). Figure 5 shows that the vast majority of known BCGs have redshifts $z < 0.02$. The 2dF and SDSS surveys access fainter magnitudes than earlier BCG samples and thus contain a number of very low luminosity galaxies, plus a few higher-luminosity metal-poor galaxies at $z \sim 0.04$. Our sample of metal-poor galaxies, by construction, spans the range $0.02 < z < 0.08$. Searching a large volume of space enables the discovery of rare objects such as XMPGs.

3.2. Luminosity–Metallicity Relations

Luminosity–metallicity relations are well determined for galaxies ranging from large star-forming galaxies (e.g. Tremonti et al. 2004) to dwarf irregulars (e.g. Richer & McCall 1995). The physical basis for the luminosity–metallicity relation is a mass–metallicity relation: low-mass galaxies are thought to sustain less star formation and retain fewer metals than high-mass galaxies. We now compare the luminosity and metallicity of our galaxies with samples of comparable metal-poor dwarf galaxies. Because there is some disagreement about the calibration of different metallicity-estimate methods, we only consider galaxy samples with metallicities derived with the $T_e$ method.

Figure 6 plots samples of BCGs (Kong & Cheng 2002; Shi et al. 2005), metal-poor galaxies from 2dF (Papaderos et al. 2006) and SDSS (Kniazev et al. 2003), our metal-poor galaxies, and four nearby GRB host galaxies (Stanek et al. 2006). We use metallicities for the GRB hosts calculated using the $T_e$ method as described in Kewley et al. (2007). Figure 6 shows that our sample of galaxies has either lower metallicity by $\sim 0.5$ dex than the Richer & McCall (1995) luminosity–metallicity relation for normal dwarf irregulars, or higher luminosity by 3–5 mag in $M_B$. 

Figure 6. Luminosity–metallicity plot for BCGs (Kong & Cheng 2002; Shi et al. 2005), metal-poor galaxies from 2dF (Papaderos et al. 2006) and SDSS (Kniazev et al. 2003), our metal-poor galaxies, and four nearby GRB host galaxies (Stanek et al. 2006). Our sample of metal-poor galaxies fills in the region defined by the GRB hosts; all these galaxies have lower metallicity by $\sim 0.5$ dex than the Richer & McCall (1995) luminosity–metallicity relation (dashed line) for normal dwarf irregulars.
for case B recombination at \( T \) which average 2
same: our sample of metal-poor galaxies and the GRB hosts are systematically
line), which we shift by +0
Figure 7. 
The nearby BCG II Zw 70 also appears to fall in the region of the luminosity–metallicity diagram outlined by nearby GRB host galaxies. The only other galaxies with similar properties are the five metal-poor 2dF and SDSS galaxies at \( z \sim 0.04 \): 2dF 169299, 2dF 115901, SDSSJ051902.64+000730.0, SDSSJ104457.84+035313.2, and SDSSJ084030.00+470710.2. The nearby BCG II Zw 70 also appears to fall in the region defined by the GRB hosts.

The relative distribution of galaxies in the luminosity–metallicity plot does not change with different metallicity estimators. To illustrate this point, we calculate strong line metallicities using \( R_{23} \) (McGaugh 1991). The strong line metallicities are systematically +0.2 dex larger than the \( T_e \) metallicities, but the overall distribution remains the same: our sample of metal-poor galaxies and the GRB hosts are systematically offset from the Richer & McCall (1995) luminosity–metallicity relation (dashed line), which we shift by +0.2 dex for consistency.

Other samples of nearby, metal-poor galaxies exhibit a large scatter around the luminosity–metallicity relation (Kunth & Östlin 2000). Yet our galaxies appear unusual because of their large systematic offset from the luminosity–metallicity relation. We will use population synthesis models to address the evolutionary paths of our metal-poor galaxies in a future paper.

Remarkably, our sample of metal-poor galaxies fills the region of the luminosity–metallicity diagram outlined by nearby GRB host galaxies. The only other galaxies with similar properties are the five metal-poor 2dF and SDSS galaxies at \( z \sim 0.04 \): 2dF 169299, 2dF 115901, SDSSJ051902.64+000730.0, SDSSJ104457.84+035313.2, and SDSSJ084030.00+470710.2. The nearby BCG II Zw 70 also appears to fall in the region defined by the GRB hosts.

3.3. Extinction
Our sample of 11 metal-poor galaxies suffer from very little internal extinction. Table 3 lists the Balmer \( H_\alpha/H_\beta \) ratios, which average 2.8 ± 0.2. The intrinsic \( H_\alpha/H_\beta \) ratio is 2.86 for case B recombination at \( T = 10^4 \) K and \( n_e \sim 10^2–10^4 \) cm\(^{-3}\) (Osterbrock 1989). Low extinction is expected in low-metallicity galaxies, and is also observed in nearby GRB hosts (e.g. Kewley et al. 2007).

4. SUPERNOVA RATES AND THE GRB CONNECTION
We next ask how frequently GRBs might occur in our sample of metal-poor galaxies, if GRBs are indeed associated with core-collapse supernova in metal-poor galaxies. We start by estimating the number of massive O and B stars in our sample of 11 galaxies, and then estimate the rate of core-collapse supernovae.

Under the assumption of an ionization-bounded nebula, the \( H_\beta \) line luminosity provides an estimate of the ionizing flux present in the galaxies. The metal-poor galaxies suffer from very little extinction, as measured by their \( H_\alpha/H_\beta \) ratios; thus we make no correction for internal extinction. We follow Schaerer & Vacca (1998) and convert the observed \( H_\beta \) ionizing flux to an equivalent number of O stars. We select the “equivalent O7V to O star” ratio \( n_\odot \), based on the stellar age and metallicity of the galaxy; \( n_\odot \), values range from 0.25–0.5. The minimum O star mass is \( \sim 13.3 \) \( M_\odot \) at our metallicities (Vacca 1994). However, core-collapse supernovae will result from B stars with masses as low as \( \sim 8 \) \( M_\odot \). A Salpeter initial mass function has the same \( \eta_\odot \) values as B stars with \( 8–13 \) \( M_\odot \). Thus, the total number of core-collapse supernova progenitors is roughly twice the Schaerer & Vacca (1998) number of equivalent O stars. We list our estimate of the total number of core-collapse supernova progenitors in the column N(OB) (Table 3). On average, there are \( \sim 25,000 \) potential core-collapse supernova progenitors per galaxy in our sample. This number may appear relatively small, but the metal-poor galaxies are dwarfs, not massive galaxies.

We estimate core-collapse supernova rates in our metal-poor galaxies by assuming supernovae occur uniformly over the lifetime of the longest-lived progenitor. The Schaller et al. (1992) stellar evolution track for a 9 \( M_\odot \) star with \( Z = 0.001 \) has a lifetime of 30 Myr. Thus the average rate of core-
collapse supernovae in our metal-poor galaxies is $\sim 10^{-3}$ yr$^{-1}$, with an uncertainty of a factor of a few. In other words, a couple thousand such metal-poor galaxies must be monitored to witness one core-collapse supernova per year. A typical spiral galaxy, in comparison, has a typical SFR of $\sim 10$ $M_\odot$ yr$^{-1}$ (e.g., Brinchmann et al. 2004) and a core-collapse supernova rate $\sim 100$ times larger than the metal-poor galaxies, assuming a constant SFR and Salarpet initial mass function.

The ratio of GRBs to core-collapse supernovae events depends on how narrowly beamed GRBs are. If 1 out of 100 core-collapse supernovae appear as GRBs, then a sample of $\sim 10^4$ metal-poor galaxies must be monitored to witness 1 GRB per year. There is currently little constraint on the space density of metal-poor galaxies, in part because they are such low-luminosity systems. Surveys reaching faint magnitude limits may uncover large numbers of new metal-poor galaxies. How- ever, it may be difficult to detect a supernova coincident on the high surface-brightness core of these galaxies. Figure 3 shows that the four XMPGs, for example, are compact systems. Although metal-poor galaxies are potential GRB hosts, a survey to find GRBs by monitoring a sample metal-poor galaxies appears impractical currently. Future deep imaging surveys, such as Pan-STARRS and the Large Synoptic Survey Telescope (LSST), may be able to detect supernovae in these low-luminosity galaxies.

5. CONCLUSIONS

We have designed a successful strategy to find new metal-poor galaxies. We calculate the expected colors of metal-poor galaxies at different redshifts based on the spectrum of the newly discovered XMPG, SDSS J0809+1729 (Kewley et al. 2007). We observed an initial sample of 24 candidates with the MMT telescope and find 4 new XMPGs with log(O/H) + 12 $\leq$ 7.65, a $\sim 20\%$ selection efficiency.

Our full set of 11 metal-poor galaxies are systematically bluer and more luminous than comparable samples of BCGs. Our galaxies are also systematically more metal poor by 0.5 dex (or more luminous by 3–5 mag) than samples of BCGs, dwarf irregulars, and other metal-poor dwarf galaxies. Remarkably, our galaxies share the same region of the luminosity–metallicity diagram with nearby GRB hosts. The similarity in extinction, stellar age, and star formation rates suggests that our metal-poor galaxies are potential hosts for GRBs.

We estimate an average core-collapse supernova rate $\sim 10^{-3}$ yr$^{-1}$ in our metal-poor galaxies. This estimate comes from an estimate of the number of O and B stars in the galaxies. If GRBs are indeed linked to core-collapse supernova in metal-poor galaxies, future surveys such as Pan-STARRS or LSST may be able to find GRBs by monitoring a large sample of metal-poor galaxies.

The success of our XMPG selection strategy allows us to expand our survey. For example, using the new XMPGs (Figure 3) as additional templates, we identify a total of 335 XMPG candidates in SDSS Data Release 5. Spectroscopic observations of these XMPG candidates are underway.