Metallicity Measurements of Gamma-Ray Burst and Supernova Explosion Sites: Lessons from H II regions in M31

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ABSTRACT

We examine how the small-scale (< kpc) variation of metallicity within a galaxy, which is found in nearby galaxies, affect the observational estimates of metallicities in the explosion sites of transient events such as supernovae (SNe) and gamma-ray bursts (GRBs). Assuming the same luminosity, metallicity, and spatial distributions of H II regions (hereafter HIIR) as observed in M31, we compute the apparent metallicities that we would obtain when the spectrum of a target region is blended with those of surrounding HIIR within the length scale of typical spatial resolution. When the spatial resolution of spectroscopy is ∼< 1 kpc, which is typical for the existing studies of SN sites, we find that the apparent metallicities reflect the metallicities of target regions, but with significant systematic uncertainties in some cases. When the spatial resolution is ∼> a few kpc, regardless of the target regions (which has a wide range of 12+log(O/H) = 8.1–9.3 for the M31 HIIR), we always obtain an apparent metallicity of 12+log(O/H)∼8.8, which is the average metallicity of HIIR in M31. Given that the apparent metallicities measured with ∼> kpc scale resolutions do not necessarily reflect the immediate environment of stellar explosions, current observational estimates of high-metallicity for some long-GRB host galaxies do not rule out the hypothesis that long-GRBs are exclusively born in low-metallicity environment.

Key words: gamma-ray burst: general – supernovae: general – galaxies: abundances – ISM: H II regions.

1 INTRODUCTION

The nature of progenitors of stellar explosions is one of the most important questions in astronomy. It is generally agreed that type II, Ib, and Ic supernovae (SNe) and most long-duration gamma-ray bursts (long-GRBs) originate from core collapse of massive stars with ≥ 8M⊙ at the end of their lives. Despite above theoretical framework, the very physical reasons that define diverse supernova types and possible GRB associations with core collapse events are not clearly identified.

Some theoretical studies on the origin of GRBs using stellar evolution models suggest that a low metallicity may be a necessary condition for a GRB to occur (Z < a few × 0.1Z⊙; e.g., Yoon & Langer 2005; Yoon et al. 2006; Woosley & Heger 2006). Observational studies have also shown that metallicity distribution of GRB host galaxies at redshift z < 1 is significantly biased towards low metallicities than that of general late-type galaxies at similar redshifts (Stanek et al. 2006; Graham & Frucht 2013).

However, the metallicity of a host galaxy is not necessarily identical to that of a progenitor of stellar explosion that occurs in it, and there might be systematic differences between metallicities of host galaxies and progenitors (Niino 2011). Currently it is difficult to quantitatively constrain the relation between progenitor metallicity and GRB occurrence. To address this issue, some observers tried to spatially resolve some GRB host galaxies and measure the metallicity of local environment at GRB sites, and found systematically lower metallicities than the other parts of galaxies (e.g. Levesque et al. 2011).

On the other hand, it is also claimed that the explosion sites of GRB 020819 (Levesque et al. 2010) and GRB 120422A (Schulze et al. 2014, but see also Levesque et al. 2012) have high metallicities. Explosion site metallicities of core collapse SNe are also systematically investigated (e.g.

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Anderson et al. 2010; Kuncarayakti et al. 2013), and the results show that SNe Ibc tend to occur in high-metallicity regions compared to SNe II.

It is not known what spatial resolution is necessary to probe the immediate environment of transient, which would be closely connected to the nature of progenitor star. Especially for GRBs that typically occur at redshifts $z > 1$, a typical spatial resolution of ground-based observations ($\sim 1$ arcsec) corresponds to a few kpc, which is often limited by the seeing of atmosphere (not instrument). Therefore it is likely that there is some metallicity variation below the resolution limit.

Recent observations of local galaxies have begun to unveil the internal metallicity structure of galaxies at a few hundred pc scale. In particular, Sanders et al. (2012, hereafter S12) obtained the spectra of $> 200$ HIIR in M31 (the Andromeda galaxy), and found that $\sim 1/3$ of HIIR pairs with separations less than 500 pc shows significant (i.e., larger than errors) metallicity variation.

In this paper, we examine how the metallicity estimates from spectroscopic observations are affected by a limited resolution. We do this by performing mock blended observations with a limited resolution, assuming the same observed resolutions with a limited resolution, assuming the same observed distribution of emission line luminosities and line ratios of M31 HIIR.

The remaining part of the paper is organized as follows. In §2, we describe the spectroscopic and photometric data sets that we use in this study. In §3, we discuss the variation of metallicities among the M31 HIIR, especially on small scales ($\lesssim$ kpc). In §4, we discuss the line luminosities of HIIR. In §5, we demonstrate the degree of bias in the measured metallicity caused by the small-scale variation in metallicity. In §6, we discuss the implications for current observations of explosion sites of transient events. We summarize our conclusions in §7.

## 2 DATA SETS

We use the observed properties of HIIR in M31 to investigate how the spatial resolution limit affect the metallicity estimates of explosion sites. The M31 is an irreplaceable laboratory to study the small-scale variation of metallicity in interstellar medium (ISM) of a late type galaxy. In M31, the structure of HIIR is resolved down to $< 10$ pc (e.g., Massey et al. 2007; Azimlu et al. 2011), and spectroscopic information is available for more than 200 HIIR (Sanders et al. 2012). The HIIR in the Magellanic clouds have also been studied for decades, however, the number of spectroscopic sample is small for a statistical study ($\sim 20$; e.g., Dufour & Harlow 1977; Pagel et al. 1978; Vermijt et al. 2002). Although some recent studies intensively perform integral field spectroscopic observations of other local late type galaxies (e.g., Rosales-Ortega et al. 2010; Mármol-Queraltó et al. 2011; Fogarty et al. 2012; Blanc et al. 2013), their spatial resolution is $> 100$ pc, which is insufficient to resolve individual HIIR.

Azimlu et al. (2011, hereafter A11) constructed a photometric sample of HIIR based on broadband images taken by the Local Group Galaxies Survey (LGGS, Massey et al. 2006), covering the whole disk of M31. The sample contains 3961 HIIR with Hα luminosities $L_{\text{H}\alpha} \gtrsim 10^{34.5}$ erg s$^{-1}$, excluding known and potential planetary nebulae (PNe). The largest spectroscopic sample of HIIR in M31 was constructed by Sanders et al. (2012), who obtained spectra of 253 HIIR and 407 PNe, selected from the LGGS images and some samples of emission line objects in the literature.

In this study, we use the photometric and spectroscopic sample of M31 HIIR provided by A11 and S12 to examine how spatial resolution affects the observed properties of transient event sites. Following S12, we obtain the HIIR positions in a deprojected coordinate on the disk of M31 assuming following quantities: the inclination angle of $12^\circ.5$ (Simien et al. 1978); the distance to M31 of 770 kpc (Freedman & Madore 1990); the position of M31 center ($\alpha, \delta$) and the angle of disk major axis relative to north celestial pole ($\phi$) as

\begin{align}
\alpha &= 00^h 42^m 44.52^s \ (J2000) \\
\delta &= +41^\circ 16' 08.69'' \ (J2000) \\
\phi &= 37^\circ 42' 54''
\end{align}

(Baade & Arp 1964).

## 3 METALLICITIES OF THE HII REGIONS

### 3.1 Metallicity diagnostics

S12 obtained the fluxes of following emission lines: $[\text{O}\,\text{II}]3727, \ [\text{O}\,\text{III}]4363, 4959, 5007, \ [\text{H}\beta, \ [\text{N}\,\text{II}]6548, 6584, \ [\text{H}\alpha]$, and $[\text{S}\,\text{II}]6717, 6731$. Not all of these lines are detected for all HIIR in the S12 sample. It should be noted that S12 obtained the line fluxes with 1.5 arcsec fibers. The fiber loss corrections are not available in S12, thus the fluxes are different from the total fluxes of the HIIR. Therefore we only use the ratio between different lines in S12 sample, but not the absolute flux values.

Various metallicity calibration methods are proposed to measure the metallicity of ionized gas in HIIR. However, the results of different calibration methods are not always consistent with each other (e.g., Kennicutt et al. 2003; Kewley & Ellison 2008). In this study, we use $[\text{N}\,\text{II}]/\text{H}\alpha$ line ratio (hereafter $[\text{N}\,\text{II}]$) as an indicator of metallicity with the empirical calibration by Nagao et al. (2006) to maximize our sample size with metallicity estimates. Among the 253 HIIR in the S12 sample, Hα and $[\text{N}\,\text{II}]$ lines are detected for 223 HIIR, while $R_{23} = ([\text{O}\,\text{II}]3727+[\text{O}\,\text{III}]4959+[\text{O}\,\text{III}]5007)/\text{H}\beta$, which is also a popular metallicity indicator, is available only for 61 HIIR. Therefore adopting the $[\text{N}\,\text{II}]/\text{H}\alpha$ method increased our sample size with metallicity estimate by a factor of $\sim 3.7$.

S12 confirmed that the HIIR metallicity distribution measured with the $[\text{N}\,\text{II}]/\text{H}\alpha$ method agrees with that measured with other popular calibration methods. The exceptions are the ‘P method’ (Pilyugin & Thuan 2005) and the ‘direct’ method (e.g., Garnett 1992). However, as discussed in S12, metallicity measurement with the ‘direct’ method is available only for 4 HIIR, and the discrepancies between the direct method and other methods may result from selection effects.

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in S12. The large intrinsic scatter of metallicity discussed in S12 is clearly seen in each $R_{\text{deproj}}$ bin.

S12 pointed out that 33 per cent of close HIIR pairs (with deprojected separations < 0.5 kpc) show difference in metallicity by more than 0.3 dex. To further investigate the metallicity variation at small scales, we compare [N II]/Hα ratio of each HIIR and the nearest one for which [N II]/Hα is available (Figure 2). We do not find any significant correlation between the metallicities of the neighboring HIIR pairs including the cases with deprojected separation of a few 100 pc. This suggests that the ISM in M31 is not mixed efficiently, and that the ISM metallicity varies even on small scales of a few 100 pc.

### 3.2 Metallicity variation in M31

In the calibration by Nagao et al. (2006), [N II]/Hα ratio saturates when $12 + \log(O/H) > 8.90$, and we cannot determine metallicity when [N II]/Hα is higher than this value. S12 excluded the HIIR whose metallicity cannot be determined from their sample. Instead, we include all HIIR with Hα and [N II] detections to our sample, assuming that the HIIR with [N II]/Hα > 0.42 have higher metallicity than those with lower [N II]/Hα (i.e. $12 + \log(O/H) \gtrsim 9.3$). We show the metallicity distribution of M31 HIIR in the top panel of Figure 1. The median metallicity is $12 + \log(O/H) = 8.90$. This is not significantly different from the result of S12 ($12 + \log(O/H) = 8.89$), despite the inclusion of HIIR with high [N II]/Hα ratios. The HIIR metallicity distribution is quite wide with $8.1 < 12 + \log(O/H) < 9.3$.

In the bottom 4 panels of Figure 1, we show the metallicity distribution of HIIR divided into 4 subsamples according to the deprojected galactocentric radius ($R_{\text{deproj}}$). The HIIR metallicities at larger $R_{\text{deproj}}$ are systematically lower (so-called metallicity gradient, e.g. Zaritsky et al. 1994, S12). The median metallicity of HIIR at $R_{\text{deproj}} \leq 10$ kpc, $12 + \log(O/H) = 9.18$, is dramatically higher than that in the outer parts of M31. This “jump” of metallicity distribution at $R_{\text{deproj}} \sim 10$ kpc results from the large fraction of HIIR with [N II]/Hα > 0.42 at $R_{\text{deproj}} \leq 10$ kpc, and is not seen in S12.

### 4 LINE LUMINOSITIES OF THE H II REGIONS

Emission line luminosity distribution of HIIR in a galaxy is also an important issue when we discuss the blending of HIIR in spectroscopy with limited spatial resolution. When we spectroscopically observe multiple HIIR blended within a spatial resolution, the one with stronger line emissions affects the resulting spectrum more. To obtain emission line luminosities of HIIR in the S12 sample, we match the S12 sample to the photometric sample of A11, because fiber corrected total luminosity is not available in the S12 sample.

We match each S12 HIIR to A11 HIIR individually when the separation between fiber position of S12 HIIR and the flux peak location of A11 HIIR is smaller than the HIIR radius determined by A11, and the S12 HIIR of concern is the nearest HIIR in the S12 sample to the photometric sample of A11, because fiber corrected total luminosity is not available in the S12 sample. When the separation between fiber position of S12 HIIR and the flux peak location of A11 HIIR is larger than the HIIR radius determined by A11, and the S12 HIIR of concern is the nearest HIIR in the S12 sample to the photometric sample of A11, because fiber corrected total luminosity is not available in the S12 sample.
To find line emitting regions in M31, A11 used Hα narrow-band images with continuum subtraction based on R-band images. The narrow-band contains Hα and [N II] lines, and A11 corrected the [N II] line contamination to obtain Hα flux assuming a global line ratio of [N II]/Hα = 0.35. We undo this [N II] correction and recalculate Hα and [N II] fluxes based on [N II]/Hα ratio of each HIIR obtained by S12.

Figure 3 compares the Hα+[N II] luminosity distribution of S12 HIIR with Hα and [N II] detections (green solid line) to that of all A11 HIIR (blue dashed line). Although spectroscopic observation is performed only for a small fraction of detected HIIR, the sample with Hα and [N II] detections covers a wide range of line luminosity, 35.0 < log_{10} L_{Hα+[N II]}[erg s^{-1}] < 37.5, while [N II] is hardly observed for HIIR with log_{10} L_{Hα+[N II]}[erg s^{-1}] < 35.0. We also plot the [N II] luminosity distribution for the sample with Hα and [N II] detections (red dotted line). The faint end of the [N II] luminosity distribution suggests that the effective limiting luminosity for a line detection in the S12 spectroscopy was log_{10} L[erg s^{-1}] ~ 34.5, which is close to the limiting luminosity of the A11 sample. The [N II] luminosity distribution is ~ 0.5 dex fainter than the Hα+[N II] luminosity distribution of the same sample, reflecting the typical [N II]/Hα ratio ~ 0.3 in M31.

Now let us consider a case that one tries to obtain the emission line ratio of a specific HIIR of interest (such as an explosion site of a GRB/SN) without sufficient spatial resolution to separate the HIIR from surrounding ones. If the HIIR of interest is bright enough to dominate the total flux within spatial resolution, we obtain the metallicity of the HIIR regardless of the metallicity distribution of surrounding HIIR. When we observe the explosion site of a long GRB and/or a SN Ic, we can actually expect the HIIR that hosted the transient is brighter than other HIIR, because progenitors of these explosions are likely very young (Fruchter et al. 2006; Kelly et al. 2008; Leloudas et al. 2010).

Using the photometric sample of 3961 HIIR by A11, we investigate the fractional contribution of each HIIR to the total Hα luminosity within resolution scale radius R_{res} in the deprojected disk coordinate. Here, fractional contribution means the fraction of L_{Hα+[N II]} to the total Hα+[N II] luminosity of all HIIR within R_{res}. Figure 4 shows the fractional contributions of A11 HIIR versus L_{Hα} for different R_{res}. For R_{res} ~ 1.0 kpc, even the most brightest HIIR have typical fractional contribution of ~ 10 per cent, suggesting that the effect of blending on emission line measurements is significant.

Figure 5 plots L_{Hα} versus metallicities of HIIR. It is clear that brighter HIIR tend to have lower metallicity. One possible cause of this trend is non-detection of [N II] lines for faint HIIR. [N II]/Hα ratio positively correlates with metallicity, and hence it would be difficult to detect [N II] line of a faint metal poor HIIR. The dashed line in Figure 5 shows the relation for a fixed [N II] luminosity of 10^{34.5} erg s^{-1}. Although the lowest L_{Hα} of high metal HIIR naively follow this relation, low metal HIIR typically have much larger L_{Hα}. Hence it might be difficult to explain the L_{Hα}-metallicity relation only by a single limiting flux of line detections. We note that the line detection limit may be not uniform all over the M31 disk, as it is affected by the variation of background radiation from diffuse interstellar gas (A11), and there might be PN contaminations in faint, high-metallicity HIIR (S12).

5 METALLICITY MEASUREMENTS WITH LIMITED SPATIAL RESOLUTIONS

The small-scale metallicity variation and the luminosity distribution of HIIR discussed in previous sections suggest that the observed spectroscopic properties of a GRB/SN site will be largely affected by the blending with nearby HIIR. In this section, we discuss what spatial resolution would be neces-

\[ \frac{L_{\text{H}^{\alpha}}}{L_{\text{NII}} + L_{\text{H}^{\alpha}}} \text{ vs. the fractional contribution plane with } R_{\text{res}} = 0.5, 1.0, \text{ and } 3.0 \text{ kpc (dot-dashed, dashed, and solid, respectively).} \]

\[ L_{\text{H}^{\alpha}} \text{ is plotted against metallicity, and the dashed line shows the } L_{\text{H}^{\alpha}} \text{ detection limit at various } R_{\text{res}}. \]

\[ \frac{L_{\text{H}^{\alpha}}}{L_{\text{NII}} + L_{\text{H}^{\alpha}}} \text{ vs. the fractional contribution plane with } R_{\text{res}} = 0.5, 1.0, \text{ and } 3.0 \text{ kpc (dot-dashed, dashed, and solid, respectively).} \]

\[ L_{\text{H}^{\alpha}} \text{ is plotted against metallicity, and the dashed line shows the } L_{\text{H}^{\alpha}} \text{ detection limit at various } R_{\text{res}}. \]

\[ \frac{L_{\text{H}^{\alpha}}}{L_{\text{NII}} + L_{\text{H}^{\alpha}}} \text{ vs. the fractional contribution plane with } R_{\text{res}} = 0.5, 1.0, \text{ and } 3.0 \text{ kpc (dot-dashed, dashed, and solid, respectively).} \]
Figure 5. Hα luminosities and metallicities of the HIIR with known [N II]/Hα ratio. The open circles at the top represent the HIIR with [N II]/Hα > 0.42, for which metallicity is not determined well. The dashed line represents a constant [N II] luminosity of 10^{44.5} erg s^{-1}. The error bars indicate median and 1-σ scatter of the metallicities in five bins of L_Hα with the log-scale width of 0.5 dex in the range of log_{10} L_Hα [erg s^{-1}] = 35.0–37.5.

sary to obtain a reliable metallicity for a GRB/SN site, and how the observed metallicities differ from the intrinsic ones under the observations with insufficient spatial resolution. In the following, we define the “apparent metallicity” of an HIIR for a resolution scale radius of R_{res} as a metallicity inferred from a ratio of total Hα and [N II] line fluxes of all HIIR inside R_{res}.

As mentioned in §2, the sampling rate of spectroscopic sample is low, and [N II]/Hα ratio is not available for most HIIR by A11. For demonstration purposes, we assume that the HIIR with unknown [N II]/Hα follows the same [N II]/Hα distribution as found in the S12 sample. We divide the S12 sample into four different bins of R_{deproj} (0–10, 10–15, 15–20, and > 20 kpc, as shown in Figure 1) and examine the effect of metallicity gradient through [N II]/Hα distribution. To avoid possible effects of metallicity bias among low-luminosity HIIR discussed in §4, we consider [N II]/Hα distribution of only bright HIIR with log_{10} L_Hα [erg s^{-1}] > 36.5 in the S12 sample in each R_{deproj} bin.

Practically, the apparent metallicities are calculated as follows. For each HIIR with Hα and [N II] detections in S12, we collect all HIIR from the A11 sample which reside within a given radius of R_{res} (deprojected), and sum up Hα and [N II] fluxes. For a A11 HIIR which is matched to a S12 HIIR whose [N II]/Hα ratio is known, Hα and [N II] fluxes are calculated assuming the line ratio (see §4 for the sample matching method). When [N II]/Hα ratio is not available for a A11 HIIR, we randomly select an HIIR in the same R_{deproj} bin from the S12 sample, which has Hα and [N II] detections, and log_{10} L_Hα [erg s^{-1}] > 36.5. Then we calculate Hα and [N II] fluxes of the A11 HIIR assuming the same [N II]/Hα ratio to that of the selected S12 HIIR. We repeat this random realization of apparent metallicities 100 times and obtain 100 apparent metallicities for each of 223 HIIR with Hα and [N II] detections.

We show intrinsic versus apparent metallicities of the HIIR in Figure 6 with R_{res} = 0.1, 0.3, 0.5, 1.0, 2.0, and 3.0 kpc. When R_{res} ≥ 1 kpc, the HIIR with lower (higher) intrinsic metallicities than 12+log(O/H)_{int} = 8.8 have systematically higher (lower) apparent metallicities than intrinsic values. This is because most of contaminating HIIR have [N II]/Hα ratios that correspond to 12+log(O/H) = 8.7–9.0 (Figure 1). In this case, it is difficult to distinguish low-metallicity HIIR from those with high metallicities, because all HIIR with 12+log(O/H)_{int} = 8.2–9.2 have similar apparent metallicities within the scatter. It should be noted that [N II]/Hα ratio and many other metallicity indicators are also affected by physical conditions of gas other than metallicity such as ionization state. It is unclear to what extent the observed variation of line ratios in M31 originates from metallicity variation. However, we can at least conclude that there is a difficulty in measuring the intrinsic line ratio of a transient event site with R_{res} ≥ 1 kpc.

When R_{res} < 1 kpc, the apparent metallicity correlates well with the intrinsic value for the HIIR with 12+log(O/H) < 9.0, although some systematic differences and a scatter greater than typical uncertainties of metallicity measurements (∼0.1 dex, e.g., Nagao et al. 2006) exist for R_{res} = 0.3 and 0.5 kpc.

In Figure 7, we quantify the deviation between intrinsic and apparent metallicities in a different way from Figure 6, by presenting the distributions of ∆log_{10}(O/H) for low-, intermediate-, and high-metallicity HIIR [i.e., intrinsic metallicity of 12+log(O/H) < 8.6, 8.6 ≤ 12+log(O/H) < 9.0, and 9.0 ≤ 12+log(O/H), respectively] with R_{res} = 0.1, 0.5, and 2.0 kpc. In the case of R_{res} = 0.1 kpc, the majority of HIIR have ∆log_{10}(O/H) < 0.1 for all ranges of intrinsic metallicity. In the case of R_{res} = 0.5 kpc, the ∆log_{10}(O/H) distribution still peaks around zero for low- and intermediate-metallicity HIIR, although there is a systematic difference between the two samples [i.e., ∆log_{10}(O/H) > 0 for low-metallicity HIIR and < 0 for intermediate- and high-metallicity, which is consistent with what we see in Figure 6]. For R_{res} = 2.0 kpc, there is no peak at ∆log_{10}(O/H) = 0, meaning that the intrinsic and apparent metallicities hardly agree with each other.

We note that metallicity variation in each HIIR is not considered in our analysis. Observations of some giant HIIR in the Milky Way and the Magellanic clouds have shown that metallicity variation within itself compared to that between different HIIR.

6 IMPLICATIONS FOR GRB/SN SITE STUDIES

Many SNe are found in the local Universe (≤ 100 Mpc), where typical angular resolution of a ground-based optical observation (∼ 1 arcsec) corresponds to ≤ 500 pc. Metallicities of SN sites in the local Universe are usually investigated with spatial resolutions of less than a few hundreds pc (e.g. Anderson et al. 2010; Kuncarayakti et al. 2013), and our results suggest that metallicities measured with such a spatial resolution can be used as a proxy to study immediate environment of transient events, if ISM properties of their host galaxies are similar to those in M31. However, there
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Figure 6. Intrinsic versus apparent metallicity of HIIR with known [N II]/Hα ratio for various $R_{\text{res}}$. The grey dots represent each data point (223 HIIR $\times$ 100 random realization of apparent metallicity in each panel). The circle points at the top of each panel represent data points with apparent [N II]/Hα $> 0.42$. Data points with intrinsic [N II]/Hα $> 0.42$ are plotted separately in the right-hand-side of each panel. The circles and error bars indicate median and 1-σ scatter of the data points in intrinsic metallicity bins (bin width of 0.2 dex). The data points with apparent [N II]/Hα $> 0.42$ are included in the median and scatter calculation. The dotted line indicates the case where apparent metallicity equals to intrinsic metallicity.

might be systematic differences between apparent and intrinsic metallicities when the spatial resolution exceeds a few hundred pc.

When we study transient events whose rate density is much lower than that of SNe (e.g., long-GRBs, $\sim$ several $\times 10^{-7}$ yr$^{-1}$ Mpc$^{-3}$), chances of detecting an event in the local Universe is small, and we need to rely on a sample at larger distance. For now, spatially resolved spectra of long-GRB sites are obtained for 5 low-redshift GRBs as summarized in Table 1. The explosion site of GRB 980425 is the only one which is spectroscopically observed with a comparable spatial resolution to $R_{\text{res}} \sim 0.1$ kpc due to its close distance of $z = 0.0085$ [12+$\log(O/H) = 8.4$, Christensen et al. (2008)].

In other cases, the spatial resolutions are $\gtrsim 1$ kpc, and our results suggest that there might be systematic differences between the observed and actual metallicity. The high metallicities obtained for GRB 020819 and 120422A (Levesque et al. 2010; Schulze et al. 2014) are especially interesting in the context of GRB progenitor studies, casting doubts on the low metallicity of GRB progenitors predicted by theoretical studies (e.g. Yoon & Langer 2005; Woosley & Heger 2006). However, these GRBs reside at redshifts $\sim 0.3$, and hence it is difficult to achieve sufficient spatial resolution. In our analysis, their spatial resolutions of $> 3.0$ kpc would correspond to our calculations with $R_{\text{res}} \geq 1.0$ kpc, in which cases we cannot distinguish low to high metallicity. Thus the observed high metallicities could be significantly different from true values in the immediate environment of the GRBs, up to $\sim 0.5$ dex for M31 (Figure 7). We also note that an independent spectroscopy of the GRB 120422A site by Levesque et al. (2012) indicates a lower metallicity with different slit alignment and seeing size.

7 CONCLUSIONS

In this paper we examine how the small-scale metallicity variation in a galaxy affect the observations of GRB/SN site with limited spatial resolution, using the observational data of HIIR in M31 as a template of metallicity variation in
a late-type galaxy. Our results suggest that, when GRB/SN means that the above observations do not rule out the hypothesis that long-GRBs are exclusively born in a low metallicity environment, as suggested by stellar evolution models (e.g. Yoon & Langer 2005; Woosley & Heger 2006).

However, we would like to emphasize that overall properties of host galaxies are still important clues to the nature of transient progenitors. For example, transient events that originate from low-metallicity stars would occur preferentially (but not exclusively) in low-metallicity galaxies.

Some of the host galaxies of long-GRBs and the explosion sites are found to have high metallicities with limited spatial resolutions of $\gtrsim 1$ kpc (e.g. Levesque et al. 2010; Niino et al. 2012; Elliott et al. 2013; Schulze et al. 2014). However, low-metallicity star formation could still take place in a host galaxy with a high averaged metallicity. In fact, Niino (2011) showed that up to $\sim 25$ per cent of cosmic low-metal star formation in the local Universe takes place in high-metallicity galaxies with $12+$log(O/H) $> 8.8$. This means that the above observations do not rule out the hypothesis that long-GRBs are exclusively born in a low metallicity environment, as suggested by stellar evolution models (e.g. Yoon & Langer 2005; Woosley & Heger 2006).

Our results are based on only the observed statistical properties of HIIR in M31, however, HIIR in other galaxies may have different properties to those in M31. Many GRB host galaxies are in fact dwarf irregulars that actively form stars (e.g. Fruchter et al. 2006), and it is likely that they have different ISM properties to that of spiral galaxies like M31. At the same time, some host galaxies of long-GRBs are spiral galaxies, which often have higher mass and metallicity than dwarf irregulars. These spiral galaxies are especially interesting in the context of metallicity dependence of long-GRB occurrence, and they may have similar HIIR properties to M31. Larger spectroscopic samples of HIIR in dwarf irregulars and other types of galaxies are necessary to further discuss the relation between apparent and intrinsic metallicities in more general population of host galaxies.

With a seeing size of $\sim 1$ arcsec, which is typical of ground-based optical observations, we can achieve spatial resolution of $R_{\text{res}} < 1$ kpc only at redshifts $< 0.1$. To investigate the immediate environment of transients at $z \gtrsim 0.1$ with sufficient spatial resolution, we need observations with a space telescope. Observations in different wavelengths other than the optical may also be a solution once good metallicity diagnostics are found, although currently known metallicity diagnostics do not fall in wavelength ranges in which we can achieve high spatial resolution from the ground (e.g., in near-infrared with adaptive optics or in radio with interferometers) unless they are significantly redshifted (e.g., Giveon et al. 2002; Nagao et al. 2012).

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