

A LUMINOUS AND FAST-EXPANDING TYPE Ib SUPERNOVA SN 2012au

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ABSTRACT

We present a set of photometric and spectroscopic observations of a bright Type Ib supernova SN 2012au from -6 days until $\sim +150$ days after maximum. The shape of its early R -band light curve is similar to that of an average Type Ib/c supernova. The peak absolute magnitude is $M_R = -18.7 \pm 0.2$ mag, which suggests that this supernova belongs to a very luminous group among Type Ib supernovae. The line velocity of He I $\lambda 5876$ is about $15,000 \text{ km s}^{-1}$ around maximum, which is much faster than that in a typical Type Ib supernova. From the quasi-bolometric peak luminosity of $(6.7 \pm 1.3) \times 10^{42} \text{ erg s}^{-1}$, we estimate the ^{56}Ni mass produced during the explosion as $\sim 0.30 M_{\odot}$. We also give a rough constraint to the ejecta mass $5\text{--}7 M_{\odot}$ and the kinetic energy $(7\text{--}18) \times 10^{51} \text{ erg}$. We find a weak correlation between the peak absolute magnitude and He I velocity among Type Ib SNe. The similarities to SN 1998bw in the density structure inferred from the light-curve model as well as the large peak bolometric luminosity suggest that SN 2012au had properties similar to energetic Type Ic supernovae.

Key word: supernovae: individual (SN 2012au)

Online-only material: color figures

1. INTRODUCTION

Type Ib supernovae (SNe Ib) are one of subtypes of core-collapse supernovae (CC-SNe), whose early spectra are characterized by strong helium features around maximum (see Filippenko 1997 for a review). SNe Ib belong to a larger group of “stripped-envelope” CC-SNe (Clocchiatti & Wheeler 1997), together with SNe Ic (SNe without hydrogen or helium) and SNe Iib (showing hydrogen only during early phase). It is commonly accepted that a progenitor star of a stripped-envelope CC-SN has lost its hydrogen envelope via either a strong stellar wind in a Wolf-Rayet (WR) phase or an interaction with a binary companion. Deep pre-imaging studies suggest that the former, massive WR path is not always the case (e.g., Maund & Smartt 2005; Crockett et al. 2008). Also, all SNe associated with gamma-ray burst (GRBs) have been found to be SNe Ic, with the most solid cases belonging to broad-line SNe Ic (SNe Ic-BL), attributed to a large kinetic energy of the expansion (sometimes called hypernovae). However, details of the connection are still under debate.

In recent years, many detailed observations have been performed for SNe Ib, and a large diversity has been recognized, e.g., a normal SN Ib SN 1990I (Elmhamdi et al. 2004), a mildly energetic SN 2008D (Mazzali et al. 2008; Tanaka et al. 2009; Modjaz et al. 2009), transitional SNe Ib/Iib SN 2008ax (Taubenberger et al. 2011), 1999dn (Benetti et al. 2011), and 2011ei (Milisavljevic et al. 2013a), a rapidly evolving faint SN 2007Y (Stritzinger et al. 2009), faint Ca-rich SNe 2005E (Perets et al. 2010), and 2005cz (Kawabata et al. 2010), a slowly evolving SN 2009jf (Sahu et al. 2011), an intermediate sample between SNe Ib and Ic SN 1999ex (Hamuy et al. 2002), and a very peculiar SN 2005bf (Anupama et al. 2005;

Tominaga et al. 2005; Maeda et al. 2007). In this Letter, we report on the optical photometry and spectroscopy of SN Ib 2012au in the early phase and discuss the results based on the observations. We show that SN 2012au has observational properties similar to GRB-associated energetic SNe Ic rather than normal SNe Ib/c.

2. OBSERVATION AND DATA REDUCTION

SN 2012au was discovered by Catalina Real-Time Transient Survey SNHunt project on 2012 March 14 UT (Howerton et al. 2012) in NGC 4790 ($d = 23.6 \pm 0.5$ Mpc; Tully 1988; Theureau et al. 2007), and subsequently classified as SN Ib (Silverman et al. 2012; Soderberg et al. 2012; Milisavljevic et al. 2013b). We carried out photometric (54 nights) and spectroscopic (19 nights) observations of SN 2012au from 2012 March 15 through August 19 with HOWPol (Kawabata et al. 2008) attached to the 1.5 m Kanata telescope at the Higashi-Hiroshima Observatory. We used the B , V , R_c , I_c , and z' filters for the photometric observation. We performed point-spread function photometry in each obtained image. Landolt standard fields were used for photometric calibration of several nearby comparison stars. For spectroscopy, we calibrated the flux scale using spectrophotometric standard star HR 4963 obtained in the same nights. We used the sky emission lines simultaneously recorded on the SN spectra for wavelength calibration, and then achieved a wavelength error of $\sim 3.5 \text{ \AA}$ over wavelength range $4500\text{--}9200 \text{ \AA}$ with the resolution of $R \sim 400$. Note that the bright nucleus of the host galaxy exists only $5''$ east from this SN and may contaminate our photometry in the latest phase. However, this effect would be negligible in our discussion. In addition to the spectra of SN 2012au, we present our unpublished spectra of SN 2009jf (two epochs) obtained with GLOWS installed on the 1.5 m telescope at the Gunma Astronomical Observatory.

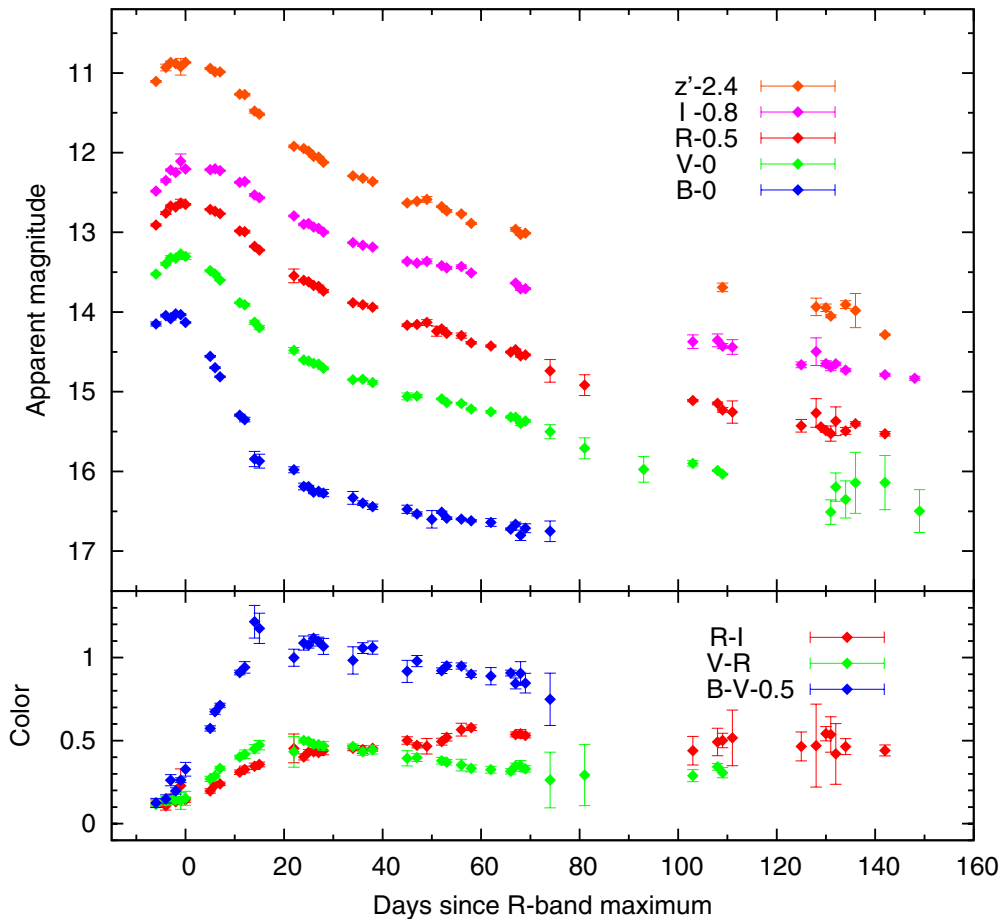


Figure 1. Top panel: $BVRIZ'$ light curves of SN 2012au with magnitude offsets to avoid overlap, as indicated in the panel. The extinction of $E(B - V)_{\text{total}} = 0.048$ mag has been corrected for. Bottom panel: color evolutions in $B - V$, $V - R$, and $R - I$.

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3. RESULTS

3.1. Extinction and Light Curves

We first correct the Galactic extinction of $E(B - V)_{\text{MW}} = 0.048$ mag (Schlegel et al. 1998). For the extinction within the host galaxy, we place a limit as $E(B - V)_{\text{host}} \leq 0.035$ mag from the upper limit of the equivalent width (EW) of the Na I D absorption line (Poznanski et al. 2012) in the averaged spectra. The extinctions in the host galaxy are thus negligibly small ($\lesssim 0.1$ mag in V band).⁸ Therefore, we adopt the total extinction toward SN 2012au as $E(B - V)_{\text{total}} = 0.048$ mag.

The light curves (LCs) and color curves are shown in Figure 1. The SN reached peak brightness $R_{\text{max}} = 13.1 \pm 0.1$ mag on March 21.0 ± 1.0 (which is set to be $t = 0$ day), corresponding to the absolute magnitude $M_{R, \text{max}} = -18.7 \pm 0.2$ mag. A compilation by the Lick Observatory Supernova Search (LOSS) indicates that the mean absolute magnitude of SNe Ib/c is $\langle M_{R, \text{max}} \rangle = -16.1 \pm 1.2$ mag (Li et al. 2011). Another systematic study suggests that $\langle M_{R, \text{max}} \rangle = -17.9 \pm 0.9$ mag for SNe Ib (and -18.3 ± 0.6 mag and -19.0 ± 1.1 mag for SNe Ic and SNe Ic-BL, respectively; Drout et al. 2011). SN 2012au belongs to a very luminous group among SNe Ib. The post-maximum decline within 15 days is estimated to be $\Delta m_{15}(R) = 0.57 \pm 0.06$ mag, which is located near the center

of the cluster of Drout et al.'s samples, which range from ~ 0.4 to ~ 0.8 mag. After $t \sim 30$ days, the SN showed a slow decline with the rate $0.017 \text{ mag day}^{-1}$ (average in 34–111 days) in R band.

In the upper panel of Figure 2, we show a comparison of R -band LC with other CC-SNe, SN 2008ax (Ib/IIf), SN 2009jf (Ib), SN 1998bw (Ic-BL), and SN 1993J (IIf) and also with the LOSS averages. Around maximum, the LC of SN 2012au is very similar to those of SN 1998bw and the LOSS average, showing a slightly slower evolution than LCs of SNe 2008ax and SN 1993J. On the other hand, in the tail of LC ($t \gtrsim 30$ days), SN 2012au shows slower evolution than these SNe except for the slowly evolving SN Ib 2009jf. These facts suggest that the trapping efficiencies of optical and γ -ray photons within the ejecta are larger than the typical.

The color evolution is shown in the lower panel of Figure 1. It becomes progressively redder until ~ 20 days and then its slopes becomes rather flat, which is similar to those seen in other SNe Ib/c. Drout et al. (2011) suggested that the intrinsic $V - R$ colors fall in a relatively narrow range 0.26 ± 0.06 mag around 10 days. In the case of SN 2012au, $V - R = 0.36 \pm 0.02$ mag at 10 days, which is slightly redder than the mean value.

3.2. Spectra

We show the spectral evolution from -6 days to $+138$ days in Figure 3. Around maximum, the absorption line of He I

⁸ This is consistent with $E(B - V)_{\text{host}} = 0.02 \pm 0.01$ mag suggested by Milisavljevic et al. (2013b).

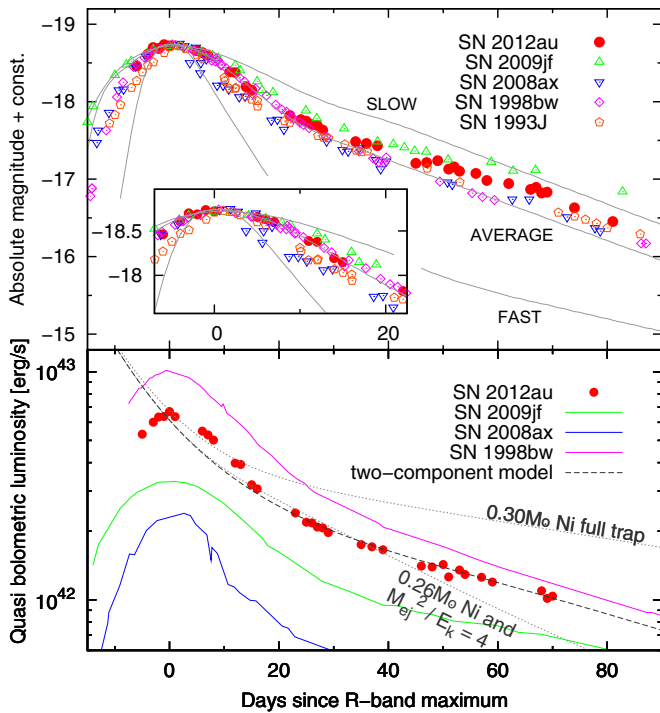


Figure 2. Top panel: *R*-band light curve of SN 2012au compared with those of SN 2009jf (Ib; Sahu et al. 2011), SN 2008ax (Ib/IIf; Taubenberger et al. 2011; Tsvetkov et al. 2009), SN 1998bw (Ic-BL; Patat et al. 2001), and SN 1993J (IIf; Richmond et al. 1996). The lines are for slow, average, and fast LC evolutions of SN Ib/c in the LOSS samples (Li et al. 2011). They are shifted to match to the peak of SN 2012au. Bottom panel: quasi-bolometric LC of SN 2012au compared with those of SN 2009jf, SN 2008ax, and SN 1998bw. We also show some analytic LC models (see Section 4.1).

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$\lambda 5876$ is conspicuous as in other SNe Ib. We can see other He I lines ($\lambda\lambda 6678, 7065$), Fe II $\lambda 5169$, and Ca II IR triplet. After +110 days, nebular emission lines, [O I] $\lambda\lambda 6300, 6364$ and [Ca II] $\lambda\lambda 7291, 7323$, appear. A comparison of the spectra around maximum and +35 days are shown in the bottom panels of Figure 3. It is clear that the blueshift of He I and other lines in SN 2012au is larger than other SNe, which is discussed in Section 4.2.

4. DISCUSSION

4.1. Bolometric Luminosity and ^{56}Ni Mass

From our *BVR* photometry, we calculated quasi-bolometric luminosity, assuming that the *BVR* bands occupy about 60% of the bolometric one around the peak (Tomita et al. 2006). Because of this simple assumption, this bolometric luminosity may well have a large systematic error ($\sim 20\%$). The derived quasi-bolometric LC is shown in the bottom panel of Figure 2. It reaches $(6.7 \pm 1.3) \times 10^{42} \text{ erg s}^{-1}$ at maximum. This is clearly larger than those of SN 2009jf ($3.2 \times 10^{42} \text{ erg s}^{-1}$; Sahu et al. 2011) and SN 2008ax ($2.4 \times 10^{42} \text{ erg s}^{-1}$; Taubenberger et al. 2011; cf. $1.0 \times 10^{43} \text{ erg s}^{-1}$ for luminous SN 1998bw; Nakamura et al. 2001; see below).

A general interpretation of the radiation source of SNe Ib/c around maximum is that the energy generated by the decay of ^{56}Ni and ^{56}Co emerges out of the photosphere as optical radiation (Arnett 1982). Therefore, the ^{56}Ni mass, $M(^{56}\text{Ni})$, can be derived from the peak bolometric luminosity L_{max} and the

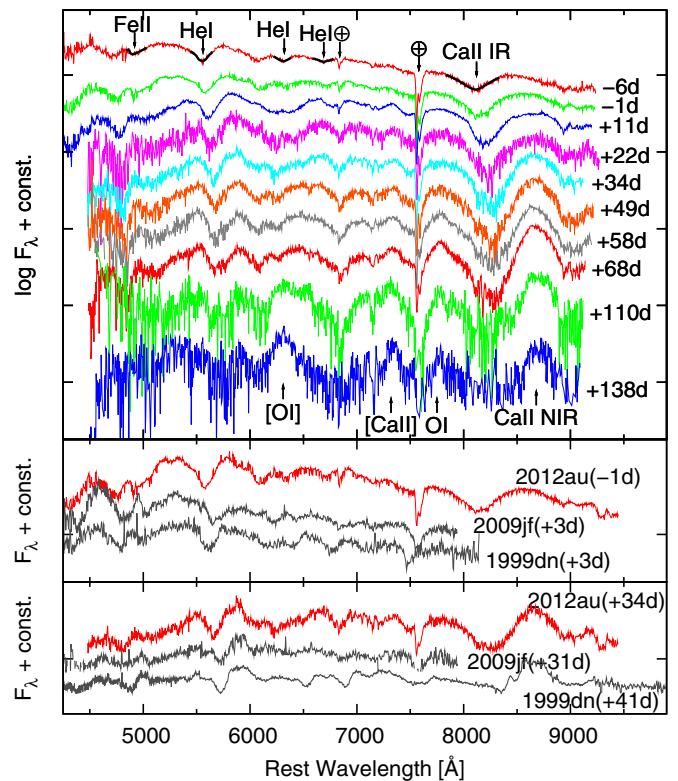


Figure 3. Top panel: spectral evolution of SN 2012au from -6 days to +138 days. Each spectrum is plotted in a logarithmic flux scale and arbitrarily shifted to avoid overlap. The interstellar extinction (Section 3.1) has not been corrected for. Identifications for several features (highlighted by thick short lines on the first spectrum) are shown, Fe II $\lambda 5169$, He I $\lambda 5876$, He I $\lambda 6678$, He I $\lambda 7065$, and Ca II IR triplet. Bottom two panels: comparison of spectra around maximum and +35 days with SN 2009jf (slowly evolving Ib; our unpublished data) and SN 1999dn (typical Ib; Matheson et al. 2001), shown in linear flux scale. The reference spectra of SN 1999dn has been downloaded from SUSPECT (<http://bruford.nhn.ou.edu/~suspect/>).

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rising time t_r (Stritzinger et al. 2006) as

$$L_{\text{max}} = (6.45 \times e^{-\frac{t_r}{8.8}} + 1.45 \times e^{-\frac{t_r}{11.3}}) \times \left(\frac{M(^{56}\text{Ni})}{M_{\odot}} \right) \times 10^{43} \text{ erg s}^{-1}. \quad (1)$$

With $t_r = 16.5 \pm 1.0$ days (Milisavljevic et al. 2013b) and $L_{\text{max}} = 6.7 \times 10^{42} \text{ erg s}^{-1}$, we obtain $M(^{56}\text{Ni}) = 0.30 M_{\odot}$. This ^{56}Ni mass is larger than that in other SNe Ib (e.g., $0.07\text{--}0.15 M_{\odot}$ in SN 2008ax and $0.14\text{--}0.20 M_{\odot}$ in SN 2009jf; see also Drout et al. 2011).

Next, we try to constrain the ^{56}Ni mass from the tail component of the quasi-bolometric LC ($t = 30\text{--}70$ days) using a simple one-zone model (Maeda et al. 2003) as shown in Figure 2. At first, with a simplified assumption that γ -rays are fully trapped and deposit their energy in the ejecta, this model gives ^{56}Ni masses of $0.30 M_{\odot}$ for the peak bolometric luminosity (as is equivalent to Equation (1)). For a more realistic treatment where the γ -rays can only be partly absorbed, we need to provide the optical depth to γ -ray within the ejecta, τ . In this case, the bolometric luminosity in the later phase ($t \gtrsim 30$ days) can be written as⁹

$$L = M(^{56}\text{Ni}) e^{(-t_d/113 \text{ days})} [\epsilon_{\gamma}(1 - e^{-\tau}) + \epsilon_{e^+}] \quad (2)$$

⁹ We show only ^{56}Co decay contribution here for simplicity. The model curves plotted in Figure 2 contain both ^{56}Ni and ^{56}Co decay contributions.

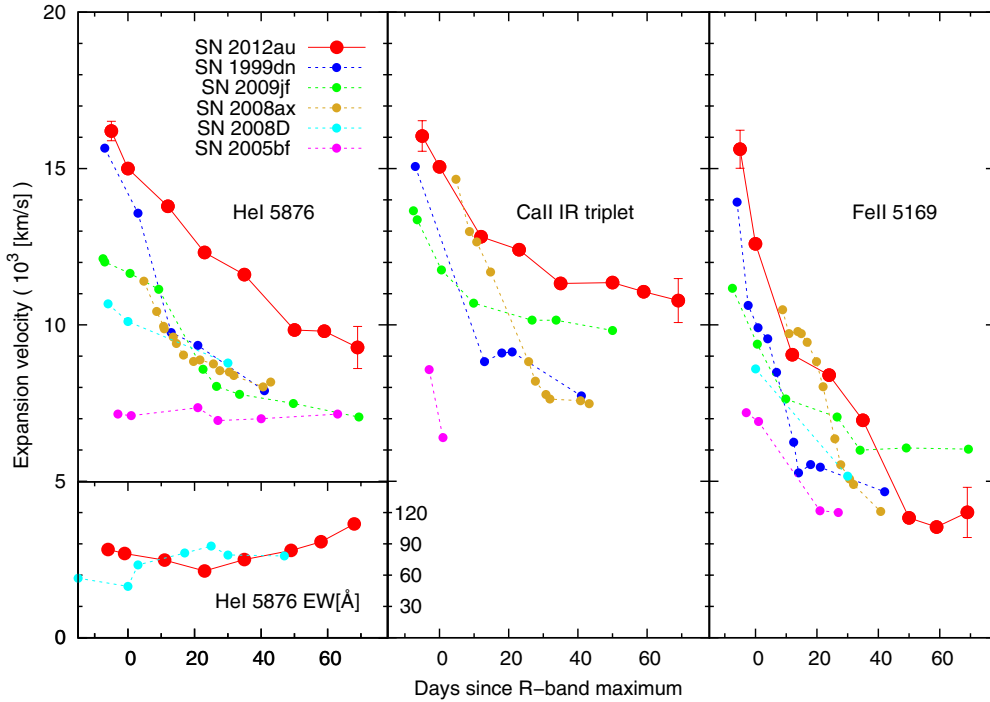


Figure 4. Line velocities of He I $\lambda 5876$, Ca II IR $\lambda 8571$, and Fe II $\lambda 5169$ in SN 2012au compared with those of other SNe Ib. A typical error in each data point is 500–1000 km s^{−1}. The references are common with Figure 5, except for SN 1999dn (Deng et al. 2000), SN 1999ex (Hamuy et al. 2002), and SN 2008D (Modjaz et al. 2009). The error bars in the first and last data points denote typical uncertainties (1 σ) of our velocity estimation.

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and

$$\tau = 1000 \times \frac{(M_{\text{ej}}/M_{\odot})^2}{E_{51}} t_d^{-2}, \quad (3)$$

where t_d is the time after the explosion in days ($\equiv t_r + t$), $\epsilon_{\gamma} = 6.8 \times 10^9$ erg s^{−1} g^{−1} and $\epsilon_{e^+} = 2.4 \times 10^8$ erg s^{−1} g^{−1} are energy deposits by γ -ray and positrons, respectively, and $(M_{\text{ej}}/M_{\odot})$ is the ejecta mass in solar mass unit. By changing these parameters, however, it turns out that we are unable to reproduce the peak and tail simultaneously with a single component (for example, the case of $M(^{56}\text{Ni}) = 0.26 M_{\odot}$ and $[(M_{\text{ej}}/M_{\odot})^2/E_{51}] = 4$ is shown in Figure 2). The tail luminosity requires a small value of τ , while tail slope requires a large value of τ instead.

Therefore, we introduce a two-component model similar to Maeda et al. (2003), consisting of an inner region having large optical thickness τ_{in} and an outer region having small τ_{out} . The luminosity is then expressed as

$$L_{\text{opt}} = M_{\text{in}}(^{56}\text{Ni})e^{(-t_d/113 \text{ days})}[\epsilon_{\gamma}(1 - e^{-\tau_{\text{in}}}) + \epsilon_{e^+}] + M_{\text{out}}(^{56}\text{Ni})e^{(-t_d/113 \text{ days})}[\epsilon_{\gamma}(1 - e^{-\tau_{\text{out}}}) + \epsilon_{e^+}], \quad (4)$$

$$\tau_{\text{in}} = 1000 \times \left[\frac{(M_{\text{ej}}/M_{\odot})^2}{E_{51}} \right]_{\text{in}} t_d^{-2}, \text{ and} \quad (5)$$

$$\tau_{\text{out}} = 1000 \times \left[\frac{(M_{\text{ej}}/M_{\odot})^2}{E_{51}} \right]_{\text{out}} t_d^{-2}. \quad (6)$$

The observation is reproduced reasonably well using this model with $M_{\text{in}}(^{56}\text{Ni}) = 0.14 M_{\odot}$, $[(M_{\text{ej}}/M_{\odot})^2/E_{51}]_{\text{in}} = 20$, $M_{\text{out}}(^{56}\text{Ni}) = 0.12 M_{\odot}$, and $[(M_{\text{ej}}/M_{\odot})^2/E_{51}]_{\text{out}} = 2$ (bottom

panel of Figure 2). This result favors that a dense core exists in their inner region. It is interesting that a similar density contrast has also been derived for the luminous SN Ic-BL 1998bw which possibly produced a jet-like asymmetric ejection (Maeda et al. 2003); $M_{\text{in}}(^{56}\text{Ni}) = 0.11 M_{\odot}$, $[(M_{\text{ej}}/M_{\odot})^2/E_{51}]_{\text{in}} = 26$, $M_{\text{out}}(^{56}\text{Ni}) = 0.44 M_{\odot}$, and $[(M_{\text{ej}}/M_{\odot})^2/E_{51}]_{\text{out}} = 1$. The fraction of ^{56}Ni in the high-velocity component is smaller in SN 2012au, which might suggest either a difference in details of the explosion or a different viewing direction (see also Milisavljevic et al. 2013b).

In this two-component model, the sum of the ^{56}Ni mass is $0.26 M_{\odot}$. The difference from $0.30 M_{\odot}$ derived from the peak luminosity suggests that the ratio of peak bolometric to radioactive luminosities, α , is not unity, but $\alpha \simeq 1.2$ (e.g., Howell et al. 2006). Therefore, the ^{56}Ni mass of $0.26 M_{\odot}$ is likely a better estimation. However, to provide a better comparison to other SNe (where $\alpha \sim 1$ is typically assumed), we adopt $0.30 M_{\odot}$ throughout this Letter.

4.2. Line Velocity and Explosion Parameters

We derived the line velocities of He I $\lambda 5876$, Ca II IR triplet (assumed to the absorption peak at 8571 Å), and Fe II $\lambda 5169$ by fitting a quadratic function to each absorption feature (Figure 4). Around maximum, the He velocity of SN 2012au is $\sim 15,000$ km s^{−1}, which is significantly larger than those of the SNe Ib samples in Branch et al. (2002) that clustered around $\sim 11,000$ km s^{−1}. After 30 days, the He velocities in most SNe Ib decrease and tend to converge at 7000–8000 km s^{−1} (Figure 4; see also Branch et al. 2002). On the other hand, SN 2012au exhibits large He velocity, $\sim 10,000$ km s^{−1} even at +50 days. We also derived the line velocities at He I $\lambda 6678$ and $\lambda 7065$ up to +10 days and confirmed that their velocities are consistent with that of He I $\lambda 5876$ within 1000 km s^{−1}, suggesting that the

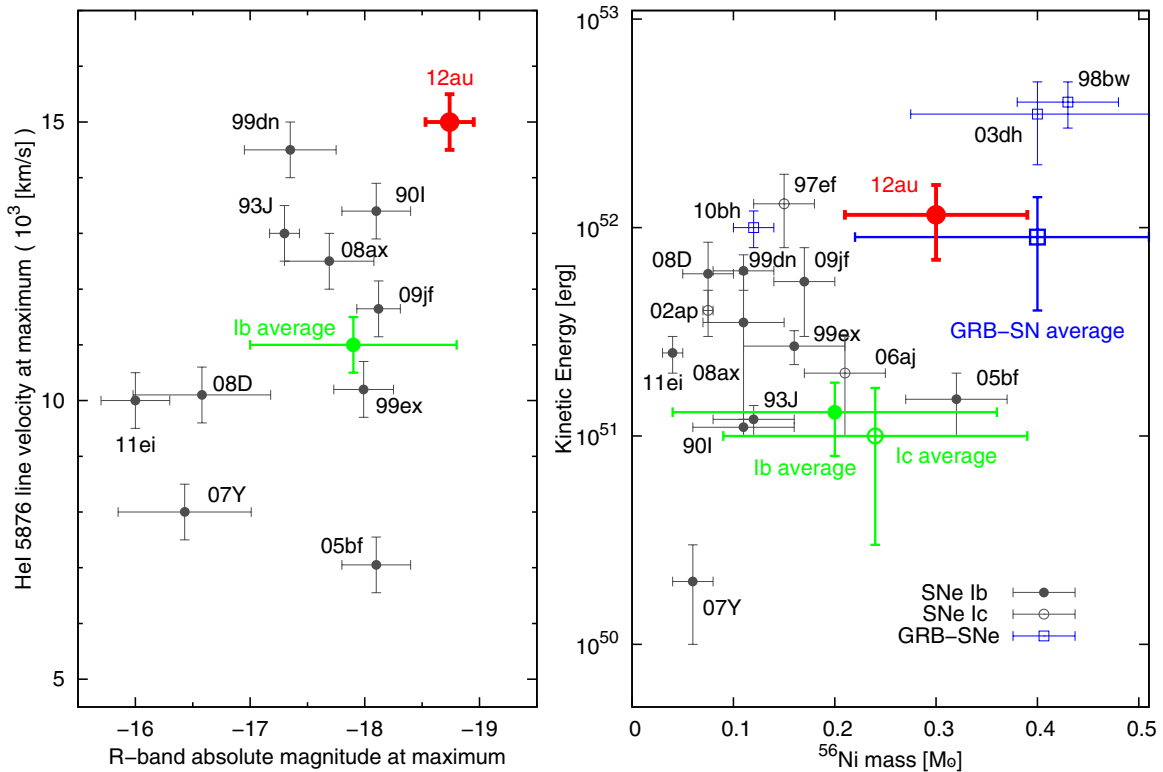


Figure 5. Comparisons of physical parameters of SN 2012au with SN Ib 1990I (Elmhamdi et al. 2004), SN Ib 1993J (Young et al. 1995), SN Ib 1999dn (Benetti et al. 2011), SN Ib 1999ex (Stritzinger et al. 2002), SN Ib 2005bf (Tominaga et al. 2005; Maeda et al. 2007), SN Ib 2007Y (Stritzinger et al. 2009), SN Ib 2008D (Tanaka et al. 2009), SN Ib/Ib 2008ax (Taubenberger et al. 2011), SN Ib 2009jf (Sahu et al. 2011), and SN Ib/Ib 2011ei (Milisavljevic et al. 2013a). The left panel shows the peak R -band absolute magnitude vs. the He I $\lambda 5876$ line velocity around maximum. The right panel shows the ^{56}Ni mass vs. the kinetic energy. We also plot the average values among SNe Ib (Branch et al. 2002; Drout et al. 2011) in both panels, and E_k and $M(^{56}\text{Ni})$ of SN Ic 1997ef (Mazzali et al. 2000), SN Ic 2002ap (Mazzali et al. 2002), SN Ic 2006aj (Mazzali et al. 2006), the luminous SN Ic-BL “hypernova” SN 1998bw (Nakamura et al. 2001), SN 2003dh (Mazzali et al. 2003), SN 2010bh (Bufano et al. 2012), and the average one among SNe Ic and GRB-SNe in right panel. We can see weak positive correlations in both plots; the correlation coefficients are 0.52 and 0.58 for left and right panels, respectively, except for very peculiar SN 2005bf.

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contamination by Na I D to He I $\lambda 5876$ is negligible during the period. The line velocities of Ca II IR triplet and Fe II $\lambda 5169$ are also as large as that of He I at -6 days (Figure 4). The Fe velocity shows a steep decrease from $12,500 \text{ km s}^{-1}$ around maximum to an asymptotic value of $\sim 4000 \text{ km s}^{-1}$ after $+50$ days. This trend is also seen in other SNe Ib, while the velocity in other SNe Ib is lower than 9000 km s^{-1} at maximum (Branch et al. 2002). This may suggest that the distribution of iron is rather widespread, up to the outermost region, in the ejecta.

We show the EW of He I $\lambda 5876$ absorption line in Figure 4. It is about 80 \AA at -6 days, which is larger than that of SN 2008D at similar phase. This might be related with the He envelope mass and/or the distribution of ^{56}Ni .

We estimate the ejecta mass, M_{ej} , and kinetic energy, E_k , using scaling relations. The relevant basic equations are

$$t_r \propto \kappa^{1/2} M_{\text{ej}}^{3/4} E_k^{-1/4} \text{ and} \quad (7)$$

$$v \propto E_k^{1/2} M_{\text{ej}}^{-1/2}, \quad (8)$$

where κ is absorption coefficient for optical photons, and v is a typical expansion velocity (Arnett 1982). We apply this relation to the case of SN 2012au using the parameters derived for well-studied SN 2008D (Tanaka et al. 2009) as the scaling template. We derive the parameters of SN 2012au as $M_{\text{ej}} = 5\text{--}7 M_{\odot}$ and

$E_k = (7\text{--}18) \times 10^{51} \text{ erg}$, where we adopt the He I line velocities around maximum as the expansion velocities.¹⁰

In Figure 5, we plot the peak R -band absolute magnitude $M_{R,\text{max}}$ versus the He I $\lambda 5876$ line velocity v_{He} around maximum (left panel) and the ^{56}Ni mass versus the kinetic energy (right panel) in SN 2012au with those of other SNe Ib (and also SNe Ic in the right panel) for comparison. We see weak positive correlations in both $v_{\text{He}}\text{--}M_{R,\text{max}}$ and $E_k\text{--}M(^{56}\text{Ni})$ except for very peculiar SN 2005bf. To our knowledge, the former correlation has not been pointed out so far; the data point of SN Ib 2012au makes it much clearer. Also in the right panel, the point of SN 2012au is apart from the average of SNe Ib and Ic, and rather near of the average of GRB-associated SNe. These results may indicate that SN 2012au have observational properties similar to hypernova.

5. CONCLUSIONS

We presented early phase optical photometric and spectroscopic observations of SN 2012au and discussed that (1) SN 2012au is a very luminous SN Ib whose peak quasi-bolometric luminosity reached $\sim 6.7 \times 10^{42} \text{ erg s}^{-1}$, and that (2) this SN shows large He I velocity from maximum through

¹⁰ When we use the velocities around $+50$ days, the parameters show only a small fractional changes as $M_{\text{ej}} = 5\text{--}7 M_{\odot}$ and $E_k = (6\text{--}14) \times 10^{51} \text{ erg}$.

+70 days, and (3) there is a possible positive correlation between v_{He} and $M_{R,\text{max}}$ among SNe Ib.

We derived constraints on the explosion parameters for SN 2012au as follows: $M_{\text{ej}} = 5\text{--}7 M_{\odot}$ and $E_k = (7\text{--}18) \times 10^{51}$ erg. While this may contain a large error, the ejecta mass points to the main-sequence mass of $M_{\text{ms}} \sim 20\text{--}30 M_{\odot}$ (see Tanaka et al. 2009). Together with the large explosion energy and the large ^{56}Ni mass, the progenitor of SN 2012au likely had a large main-sequence mass as $M_{\text{ms}} > 20 M_{\odot}$, for which the outer hydrogen envelope had been stripped away but the helium layer still remained.

Although SN 2012au is spectroscopically classified as SN Ib, the bolometric luminosity is large and close to that of SN 1998bw, and the bolometric LC modeling also suggests that although SN 2012au had the helium envelope at the explosion, the structure of the ejecta in SN 2012au is similar to that of SN 1998bw. These, together with the high-velocity absorption features, suggest that SN 2012au has a character close to hypernovae. Finally, we note that independently similar results and discussions were given by Milisavljevic et al. (2013b), mostly based on later phase data than we analyzed in this Letter.¹¹ This may allow us to get an important insight because no GRB-associated SNe Ib has been ever discovered.

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¹¹ At the final stage of preparing this draft, an independent work by Milisavljevic et al. (2013b) appeared on arXiv.