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THE RADIO EVOLUTION OF THE ORDINARY TYPE Ic SUPERNOVA SN 2002ap

E. Berger,[1] S. R. Kulkarni,[1] and R. A. Chevalier[2]

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ABSTRACT

We report the discovery and monitoring of radio emission from the Type Ic supernova SN 2002ap ranging in frequency from 1.43 to 22.5 GHz and in time from 4 to 50 days after the SN explosion. As in most other radio SNe, the radio spectrum of SN 2002ap shows evidence for absorption at low frequencies, usually attributed to synchrotron self-absorption (SSA) or free-free absorption. While it is difficult to discriminate between these two processes based on a goodness of fit, the *unabsorbed* emission in the free-free model requires an unreasonably large ejecta energy. Therefore, on physical grounds we favor the SSA model. In the SSA framework, at about day 2, the shock speed is $\approx 0.3c$, the energy in relativistic electrons and magnetic fields is $\approx 1.5 \times 10^{45}$ ergs, and the inferred progenitor mass-loss rate is $\approx 5 \times 10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$ (assuming a 10^3 km s^{-1} wind). These properties are consistent with a model in which the outer, high-velocity SN ejecta interact with the progenitor wind. The amount of relativistic ejecta in this model is small, so the presence of broad lines in the spectrum of a Type Ib/c SN as observed in SN 2002ap is not a reliable indicator of relativistic ejecta and hence γ-ray emission.

Subject headings: gamma rays: bursts — radiation mechanisms: nonthermal — radio continuum: general — supernovae: individual (SN 2002ap)

1. INTRODUCTION

Type Ib/c supernovae (SNe Ib/c) enjoyed a broadening in interest over the last few years since their compact progenitors (helium or carbon stars) are ideal for detecting the signatures of a central engine. Such an engine is expected in the collapsar model (Woosley 1993; MacFadyen, Woosley, & Heger 2001), the currently popular model for long-duration γ-ray bursts (GRBs). In this model, the engine (a rotating and accreting black hole) provides the dominant source of explosive power. The absence of an extensive hydrogen envelope in the progenitor star may allow the jets from the central engine to propagate to the surface and subsequently power bursts of γ-rays.

Separately, the Type Ic SN 1998bw (Galama et al. 1998) found in the localization region of GRB 980425 (Pian et al. 2000) ignited interest in "hypernovae."[3] SN 1998bw is peculiar for three reasons: It has (1) broad photospheric absorption lines (Iwamoto et al. 1998; Woosley, Eastman, & Schmidt 1999); (2) a large kinetic energy release, $E_{k,51} \sim 30$ ($E_k = 10^{51} E_{k,51}$ ergs is the SN energy), inferred from the optical data; and (3) bright radio emission at early time. Robust equipartition arguments led to an inferred energy of $E_\Gamma \gtrsim 10^{49}$ ergs in ejecta with relativistic velocities, $\Gamma \sim$ a few (Kulkarni et al. 1998, hereafter K98). No other SN has shown hints of such an abundance of relativistic ejecta. Tan, Matzner, & McKee (2001) explained the relativistic ejecta as resulting from an energetic shock as it speeds up the steep density gradient of the progenitor. The γ-ray and radio emission would then arise in the forward shock.

From the perspective of a GRB-SN connection, what matters most is the presence of relativistic ejecta; γ-ray emission traces ultrarelativistic ejecta, but as was dramatically demonstrated by SN 1998bw, the radio serves as an equally good proxy, with the added advantage that the emission is not beamed. Given this, we began a systematic program of investigating at radio wavelengths all SNe Ib/c with features similar to SN 1998bw: a hypernova or broad optical lines.

Y. Hirose discovered SN 2002ap in M74 (distance $d \sim 7.3$ Mpc; Smartt et al. 2002) on 2002 January 29.40 UT (see Nakano 2002). Mazzali et al. (2002) inferred an explosion date of 2002 January 28 ± 0.5 UT. Attracted by the broad spectral features (e.g., Kinugasa et al. 2002; Meikle et al. 2002), we began observing the SN at the Very Large Array.[4]

2. OBSERVATIONS

We observed SN 2002ap starting on 2002 February 1.03 UT and detected a radio source coincident with the optical position at $\alpha(\mathrm{J2000.0}) = 01^{\mathrm{h}}36^{\mathrm{m}}23\overset{\mathrm{s}}{.}92$, $\delta(\mathrm{J2000.0}) = +15°45'12\overset{''}{.}87$, with a 1 σ uncertainty of $0\overset{''}{.}1$ in each coordinate (Berger, Kulkarni, & Frail 2002). A log of the observations and the resulting light curves can be found in Table 1 and Figure 1, respectively.

2.1. *The Radio Spectrum of SN 2002ap*

The peak radio luminosity of SN 2002ap, $L_p(5\ \mathrm{GHz}) \sim 3 \times 10^{25}$ ergs s^{-1} Hz^{-1}, is a factor of 20 lower than the typical SNe Ib/c (Weiler et al. 1998) and $\sim 3 \times 10^3$ times lower than SN 1998bw (K98). The time at which the radio emission peaks at 5 GHz is $t_p \sim 3$ days, which may be compared with 10 days for SN 1998bw (K98) and 10–30 days for the typical SNe Ib/c (Weiler et al. 1998; Chevalier 1998, hereafter C98).

The spectral index between 1.43 and 4.86 GHz, $\beta_{1.43}^{4.86}$ ($F_\nu \propto \nu^\beta$), changes from ~ 0.5 before day 6 to ~ -0.3 at $t \approx 15$ days, while $\beta_{4.86}^{8.46}$ holds steady at a value of ≈ -0.9. This indicates that the spectral peak, ν_p, is initially located between 1.43 and 4.86 GHz and decreases with time. This peak could be due to synchrotron self-absorption (SSA) or (predominantly) free-free absorption (FFA) arising in the circumstellar medium (CSM). Regardless of the dominant source of opacity, the emission for frequencies $\nu > \nu_p$ is from optically thin synchrotron emission.

Massive stars lose matter via strong stellar winds throughout their life, and as a result their CSM is inhomogeneous with

[1] Division of Physics, Mathematics, and Astronomy, California Institute of Technology, MS 105-24, Pasadena, CA 91125; ejb@astro.caltech.edu, srk@astro.caltech.edu.

[2] Department of Astronomy, University of Virginia, P.O. Box 3818, Charlottesville, VA 22903-0818; rac5x@ur.astro.virginia.edu.

[3] There is no accepted definition for a hypernova. Here we use the term to mean an SN with an explosion energy significantly larger than 10^{51} ergs.

[4] The Very Large Array is operated by the National Radio Astronomy Observatory, a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

TABLE 1
RADIO OBSERVATIONS OF SN 2002ap

Epoch (UT)	$F_{1.43\,\mathrm{GHz}} \pm \sigma$ (μJy)	$F_{4.86\,\mathrm{GHz}} \pm \sigma$ (μJy)	$F_{8.46\,\mathrm{GHz}} \pm \sigma$ (μJy)	$F_{22.5\,\mathrm{GHz}} \pm \sigma$ (μJy)
2002 Feb 1.03	…	…	374 ± 29	…
2002 Feb 1.93	211 ± 44	384 ± 50	255 ± 44	348 ± 165
2002 Feb 2.79	250 ± 72	453 ± 50	201 ± 47	…
2002 Feb 3.93	410 ± 41	365 ± 38	282 ± 34	…
2002 Feb 5.96	243 ± 43	262 ± 48	186 ± 42	170 ± 91
2002 Feb 8.00	235 ± 31	282 ± 32	140 ± 27	…
2002 Feb 11.76	337 ± 68	217 ± 45	111 ± 27	…
2002 Feb 13.94	292 ± 38	…	…	…
2002 Feb 18.95	266 ± 42	…	…	…
2002 Mar 4.85 + 11.83	157 ± 34	…	…	…
2002 Mar 18.77 + 19.97	57 ± 33	…	25 ± 25	…

NOTE.—Observations with more than one date have been co-added to increase the signal-to-noise ratio of the detection.

density, $\rho(r) \propto \dot{M}_w v_w^{-1} r^{-2}$. Here r is the distance from the star, $\dot{M}$ is the rate of mass loss, and v_w is the wind speed, which is comparable to the escape velocity from the star. The progenitors of SNe II are giant stars that have low $v_w \sim 10$ km s^{-1}. Consequently, the CSM is dense, and this explains why the FFA model has provided good fits to SNe II (e.g., Weiler et al. 1998).

On the other hand, the progenitors of and SNe Ib and SNe Ic are compact helium and carbon stars that have high escape velocities and therefore fast winds, $\sim 10^3$ km s^{-1}. Thus, a priori, the CSM density is not expected to be high. C98 reviews the modeling of radio emission from SNe Ib/c and concludes that there is little need to invoke free-free absorption. However, synchrotron self-absorption is an inescapable source of opacity and must be included in the modeling of SNe Ib/c (C98; K98).

Low-frequency observations provide the simplest way to discriminate between the two models. In the SSA model, the peak frequency is identified with the synchrotron self-absorption frequency, ν_a, and $F_\nu(\nu \lesssim \nu_a) \propto \nu^{5/2}$. In the FFA model, the free-free optical depth is unity at the peak frequency $\nu_{\rm ff}$, and $F_\nu(\nu \lesssim \nu_{\rm ff})$ decreases exponentially. Lacking the requisite discriminatory low-frequency data, we consider both models.

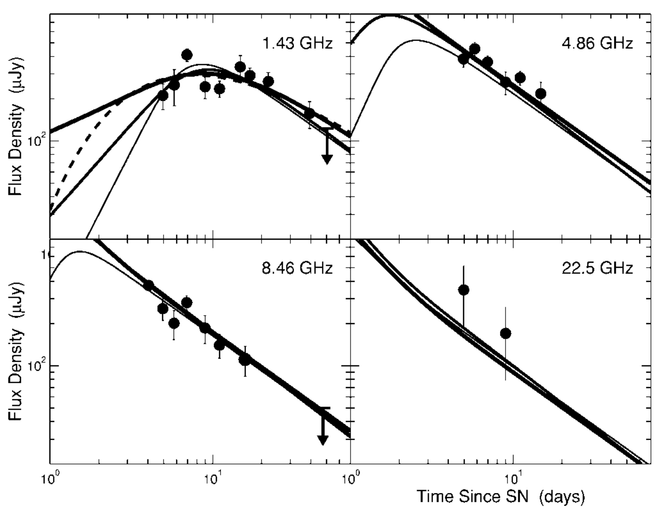

FIG. 1.—Radio light curves of SN 2002ap. Thick solid lines are our three SSA models described in § 3, with $\tau_\nu \propto t^{-1.3}$, $t^{-2.1}$, and t^{-3} in order of decreasing thickness. Dashed line is the model fit based on FFA (§ 4). At 4.86, 8.46, and 22.5 GHz, the SSA and FFA models provide the same fit, since the opacity processes do not influence the optically thin flux. The models diverge in the optically thick regime, which underlines the importance of rapid, multifrequency observations.

2.2. *Robust Constraints*

Before performing a detailed analysis, we derive some general constraints using the well-established equipartition arguments (Readhead 1994; K98). The energy of a synchrotron source with flux density $F_p(\nu_p)$ can be expressed in terms of the equipartition energy density,

$$\frac{U}{U_{\rm eq}} = \frac{1}{2}\epsilon_B \eta^{11}\left(1 + \frac{\epsilon_e}{\epsilon_B}\eta^{-17}\right), \quad (1)$$

where $\eta = \theta_s/\theta_{\rm eq}$, $\theta_{\rm eq} \approx 120 d_{\rm Mpc}^{-1/17} F_{p,\,\rm mJy}^{8/17} \nu_{p,\,\rm GHz}^{(-2\beta-35)/34} \mu$as, $U_{\rm eq} = 1.1 \times 10^{56} d_{\rm Mpc}^2 F_{p,\,\rm mJy}^4 \nu_{p,\,\rm GHz}^{-7} \theta_{{\rm eq},\,\mu{\rm as}}^{-6}$ ergs, and ϵ_e and ϵ_B are the fractions of energy in the electrons and magnetic fields, respectively. In equipartition, $\epsilon_e = \epsilon_B = 1$, and it is clear that a deviation from equipartition would increase the energy significantly.

At about day 7, $F_p(\nu_p = 1.4\ {\rm GHz}) \approx 0.3$ mJy (see Fig. 1). Thus, $\theta_{\rm eq}(t = 7\ {\rm days}) \approx 40\ \mu$as, or $r \approx 4.5 \times 10^{15}$ cm. The resulting equipartition energy is $E_{\rm eq} \approx 10^{45}$ ergs, the magnetic field is $B_{\rm eq} \approx 0.2$ G, and the average velocity of the ejecta is $v_{\rm eq} \approx 0.3c$. We note that any other source of opacity (e.g., FFA) would serve to increase $\theta_{\rm eq}$, $E_{\rm eq}$, and $v_{\rm eq}$.

3. A SYNCHROTRON SELF-ABSORPTION MODEL

The synchrotron spectrum from a source with a power-law electron distribution $N(\gamma) \propto \gamma^{-p}$ for $\gamma > \gamma_{\rm min}$ is

$$F_\nu = F_{\nu,0}\left(\frac{\nu}{\nu_0}\right)^{5/2}(1 - e^{-\tau_\nu})\frac{F_3(\nu, \nu_m, p)}{F_3(\nu_0, \nu_m, p)}\frac{F_2(\nu_0, \nu_m, p)}{F_2(\nu, \nu_m, p)}, \quad (2)$$

where the optical depth at frequency ν is given by

$$\tau_\nu = \tau_0\left(\frac{\nu}{\nu_0}\right)^{-(2+p/2)}\frac{F_2(\nu, \nu_m, p)}{F_2(\nu_0, \nu_m, p)}, \quad (3)$$

$$F_l(\nu, \nu_m, p) = \int_0^{x_m} F(x) x^{(p-l)/2}\, dx; \quad (4)$$

see Li & Chevalier (1999; hereafter LC99). Here $x_m \equiv \nu/\nu_m$ (see Rybicki & Lightman 1979), and ν_m is the characteristic synchrotron frequency of electrons with $\gamma = \gamma_{\rm min}$. The subscript zero indicates quantities at a reference frequency that we set to 1 GHz. Finally, ν_a is defined by the equation $\tau_{\nu_a} = 1$.

The evolution of the synchrotron emission depends on a number of parameters. Following C98, we assume that p, ϵ_e, and ϵ_B in the postshock region remain constant with time; here $\epsilon_e = \epsilon_B = 0.1$. The evolution of the synchrotron spectrum is sensitive to the expansion radius of the forward shock front, $r_s \propto t^m$, which is related to the density structure of the shocked ejecta and that of the CSM. We allow for these hydrodynamic uncertainties by letting $F_{\nu,0} \propto t_d^{\alpha_F}$ and $\tau_0 \propto t_d^{\alpha_\tau}$, where t_d is the time in days since the SN explosion. In the model adopted here, both these indices depend on m and p. It can be shown that the temporal index of the optically thin flux $\alpha = \alpha_F + \alpha_\tau$. The synchrotron characteristic frequency, ν_m, is particularly useful for inferring the CSM density, and we parametrize it as $\nu_m = \nu_{m,0} t_d^{\alpha_{\nu_m}}$ GHz, where $\nu_{m,0} = \nu_m$ GHz. For typical values of m and $\rho(r) \propto r^{-2}$, $\alpha_{\nu_m} \approx -0.9$.

With these scalings and equations (2)–(4), we carry out a least-squares fit to the data. Given the lack of early optically thick data (i.e., 1.43 GHz), it is not surprising that our least-squares analysis allows a broad range of values for α_τ. In Figure 1 we plot fits spanning the minimum χ^2: $\alpha_\tau = -1.3$, -2.1, -3 (corresponding to $\chi^2 = 40, 43, 46$, respectively and 21 degrees of freedom [dof]). We note that for other SNe Ib/c, α_τ ranges from -2 to -3 (C98; LC99).

The fits, in conjunction with equations (13)–(15) of LC99, allow us to trace the evolution of r_s, the total (magnetic+electron) energy (E), and the electron density (n_e) in the shock (Fig. 2). We find that for $\alpha_\tau = -1.3$, $r_s \propto t^{0.25}$; i.e., the blast wave decelerates. However, $\alpha_\tau = -3$ provides the expected $r_s \propto t^{0.9}$. Adopting this physically reasonable model, we obtain $\tau_0(t) = 1.2 \times 10^3 t_d^{-3}$, $F_{\nu,0}(t) = 2.9 t_d^{2.2}$ μJy, and $p = 2$. From Figure 2 we note that the early shock velocity is high ($0.3c$) regardless of the choice of α_τ and is close to that derived from the simple equipartition arguments (§ 2.2).

The mass-loss rate of the progenitor star is estimated from r_s and n_e, $\dot{M}_w = 8\pi\zeta n_e m_p r^2 v_w \approx 9 \times 10^{-9} \nu_{m,0}^{-0.8}\ M_\odot\ \mathrm{yr}^{-1}$, where the compression factor is $\zeta = \frac{1}{4}$, the nucleon-to-electron ratio is taken to be 2, and $v_w = 10^3$ km s^{-1}. Knowing $B_{\rm eq}$ and our assumed ϵ_e, we find $\nu_m \sim 10^7$ Hz, and thus $\dot{M}_w \approx 5 \times 10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$—similar to the value inferred for SN 1998bw (LC99).

There are two consistency checks. First, with this $\dot{M}_w$, FFA is negligible. Second, the kinetic energy of the swept-up material is 2×10^{46} ergs—consistent with our estimate of the equipartition energy and ϵ_e.

3.1. *The Synchrotron Self-Absorption Model in the Context of a Hydrodynamic Model*

The results of § 3 can be tied into a fairly simple hydrodynamic model. Matzner & McKee (1999) show that for the progenitors of SNe Ib/c (compact stars with radiative envelopes), the ejecta postexplosion density profile can be described by power laws at low and high velocities, separated by a break velocity, $v_{{\rm ej},b} = 5150(E_{k,51}/M_1)^{1/2} \approx 2 \times 10^4$ km s^{-1}; here the mass of the ejecta is $M_{\rm ej} = 10 M_1\ M_\odot$. We use $E_{k,51} \approx 4$–10 and $M_1 \approx 0.25$–0.5 for SN 2002ap (Mazzali et al. 2002). At $v_s \approx 0.3c$, the density profile is given by $\rho_s \approx 3 \times 10^{96} E_{k,51}^{3.59} M_1^{-2.59} t^{-3} v^{-10.18}$ g cm^{-3}. This profile extends until radiative losses become important when the shock front breaks out of the star. Using equation (32) of Matzner & McKee (1999), this happens for $v_s \approx 1.5c$ (assuming a typical 1 $R_\odot$ radius for the progenitor star). Thus, the outflow can become relativistic.

Using the self-similar solution of Chevalier (1982), the velocity of the outer shock radius R (assuming $\rho = Ar^{-2}$ CSM) is

$$\frac{R}{t} = 52{,}300 E_{k,51}^{0.44} M_1^{-0.32} A_*^{-0.12} t_d^{-0.12}\ \mathrm{km\ s^{-1}}, \qquad (5)$$

where $A_* = \dot{M}_w / (10^{-5}\ M_\odot\ \mathrm{yr}^{-1})\,[v_w/(10^3\ \mathrm{km\ s^{-1}})]^{-1}$. The shock velocity $\dot{R}$ is insensitive to the circumstellar wind density. Thus, we find that the velocities inferred from the radio observations of SN 2002ap can be naturally accounted for by the outer SN ejecta.

The energy above some velocity V is

$$E(v > V) \approx \int_V^\infty \frac{1}{2} \rho_f v^2 4\pi v^2 t^3\, dv$$
$$= 7.2 \times 10^{44} E_{k,51}^{3.59} M_1^{-2.59} V_5^{-5.18}\ \mathrm{ergs}, \qquad (6)$$

where v_5 is the velocity in units of 10^5 km s^{-1}. For the preferred SN 2002ap parameters, $E(v > V) \approx 3.8 \times 10^{48} V_5^{-5.18}$ ergs. There is therefore plenty of energy in the high-velocity ejecta to account for the observed radio emission, and in fact a kinetic energy $E_{k,51} = 0.5$ would be sufficient.

Given the overabundance of $E(v > V_5)$ relative to the energy inferred from the radio emission, we wonder how secure are the estimates of $E_{k,51}$ and M_1 of Mazzali et al. (2002). In particular, these parameters are derived from early optical observations and are subject to asymmetries in the explosion. For SN 1998bw, the asymmetric model of Höflich, Wheeler, & Wang (1999) yielded $E_{k,51} \sim 2$, an order of magnitude smaller than that obtained from symmetrical models (e.g., Iwamoto et al. 1998).

3.2. *Interstellar Scattering and Scintillation*

Interstellar scattering and scintillation (ISS) is expected for radio SNe (see K98). Indeed, the perceptible random deviations from the model curves (see Fig. 1), which account for the high $\chi^2_{\min}$ could arise from ISS. Using the ISS model of Goodman (1997) and the Galactic free-electron model of Taylor & Cordes

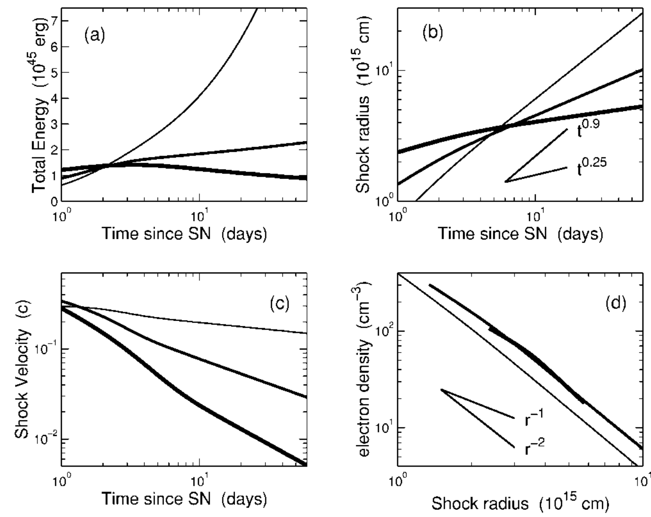

FIG. 2.—Inferred physical parameters based on the SSA models described in § 3. (*a*) Time evolution of the total energy, (*b*) radius of the radio photosphere, (*c*) electron density in the shock as a function of radius, and (*d*) velocity of the shock front as a function of time. Models with $\tau_\nu \propto t^{-1.3}$, $t^{-2.1}$, and t^{-3} are shown in order of decreasing thickness. The most likely fit is the one following $r \propto t^{0.9}$ (i.e., the model with $\tau_\nu \propto t^{-3}$).

(1993), we estimate $m_{8.46} \approx 5\%$, $m_{4.86} \approx 10\%$, and $m_{1.43} \approx 40\%$; m_ν is the modulation index (the ratio of the rms to the mean) for each frequency.

We estimate the actual modulation index empirically by adding $m_\nu F_\nu$ in quadrature to each measurement error so that the reduced $\chi^2_{\min}$ is unity. Here F_ν is the model flux described in § 3. We find $m_{8.46} \approx 10\%$, $m_{4.86} \approx 20\%$, and $m_{1.43} \approx 30\%$, in good agreement with the theoretical estimates. This provides an independent confirmation of the size, and hence expansion velocity, of the ejecta. We note that since the modulation is not severe in any of the bands, the results of § 3 are quite robust.

4. A FREE-FREE ABSORPTION MODEL

In this model the spectrum is parametrized as follows (Chevalier 1984; Weiler et al. 1986):

$$F_\nu = K_1 \nu_5^\beta t_d^\alpha e^{-\tau_\nu},$$
$$\tau_\nu = K_2 \nu_5^{-2.1} t_d^\delta, \tag{7}$$

where $\nu_5 = 5\nu$ GHz. We find an acceptable fit ($\chi^2 = 40$ for 21 dof) yielding $K_1 \approx 2$ mJy, $K_2 \approx 0.4$, $\alpha \approx -0.9$, $\beta \approx -0.9$, and $\delta \approx -0.8$. With these parameters and equation (16) of Weiler et al. (1986), we find $\dot{M}_w \approx 5 \times 10^{-5}\ M_\odot\ \mathrm{yr}^{-1}$ for $v_w = 10^3\ \mathrm{km\ s^{-1}}$ and an optical photospheric velocity of $2 \times 10^5\ \mathrm{km\ s^{-1}}$ at $t = 3.5$ days after the SN (Mazzali et al. 2002).

Using our derived parameters, one day after the explosion $\nu_{\mathrm{ff}} \approx 3.2$ GHz, and $F_\nu(\nu_{\mathrm{ff}}) \approx 1.1$ mJy (Fig. 1). The unabsorbed flux at the peak of the synchrotron spectrum is $F_\nu(\nu_a) \approx 3 \times [\nu_a/(3.2\ \mathrm{GHz})]^{-0.9}$ mJy (note $\nu_a < \nu_{\mathrm{ff}}$ in the FFA model), for which $r_{\mathrm{eq}} \approx 7.5 \times 10^{15} [\nu_a/(3.2\,\mathrm{GHz})]^{-3/2}$ cm. Thus, $v_{\mathrm{eq}} \approx 3c \times [\nu_a/(3.2\ \mathrm{GHz})]^{-3/2}$, which corresponds to $\Gamma = 2[\nu_a/(3.2\,\mathrm{GHz})]^{-1}$ if relativistic effects are taken into account (R. Sari 2002, private communication). Alternatively, if we fix the expansion velocity to the optical value, $v_s \approx 3 \times 10^4\ \mathrm{km\ s^{-1}}$ (Mazzali et al. 2002), we find a brightness temperature, $T_b \approx 4 \times 10^{13}$ K—clearly in excess of the equipartition temperature, again necessitating a high bulk Lorentz factor, $\Gamma \sim 10^2$.

Thus, even if $\nu_a = \nu_{\mathrm{ff}}$ (in which case free-free opacity would not be necessary in the first place), the FFA model requires truly relativistic ejecta or alternatively a large departure from equipartition, resulting in $E \approx 7 \times 10^{50} [\nu_a/(3.2\ \mathrm{GHz})]^{-9}$ ergs (for $v_s \approx 0.5c$ instead of $3c$). Clearly, the energy requirement would increase by many orders of magnitude if $\nu_a \ll \nu_{\mathrm{ff}}$.

5. DISCUSSION AND CONCLUSIONS

SN 1998bw exhibited broad photospheric absorption lines and bright radio emission. These two peculiarities made sense in that the simple theory suggested that broad photospheric features are a reliable indicator of relativistic ejecta, a necessary condition for γ-ray emission.

The Type Ic SN 2002ap elicited much interest because it too displayed similar broad lines. However, from our radio observations we estimate the energy in relativistic electrons and magnetic fields to be quite modest: $E \approx 2 \times 10^{45}$ ergs in ejecta with a velocity ≈0.3c. Both the energy and speed of the ejecta can be accounted for in the standard hydrodynamical model. Thus, our principal conclusion is that broad photospheric lines are not good predictors of relativistic ejecta.

Moreover, the broad photospheric features led modelers to conclude that SN 2002ap was a hypernova with an explosion energy of $E_{51} \sim 4$–10 ergs (Mazzali et al. 2002). However, the radio observations suggest that SN 2002ap is not an energetic event. In the same vein, we note that Kawabata et al. (2002) suggest, based on spectropolarimetric observations, a jet with a speed of $0.23c$ and carrying 2×10^{51} ergs. Such a jet, regardless of geometry, would have produced copious radio emission.

We end with two conclusions. First, at least from the perspective of relativistic ejecta, SN 2002ap was an ordinary SN Ib/c. Second, broad photospheric lines appear not to be a good proxy for either a hypernova origin or γ-ray emission.

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Note added in proof.—Observations of SN 2002ap taken in 2002 August 6.6–13.6 UT at 1.43 GHz reveal that the SN has faded to $F_\nu = 53 \pm 17\ \mu$Jy, as expected from the models in Fig. 1. This rules out the possibility of a jet directed away from the observer at early time, since by the time of these new observations, such a jet would have spread out and become observable.