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The radio lightcurve of SN 2008iz in M82 revealed by Urumqi observations

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ABSTRACT

We report on a set of 5 GHz Urumqi observations of the galaxy M82, made between August 2005 and May 2009. From the resulting flux densities, we detect a strong flare, starting in March or April and peaking in June 2008. We identify this flare with supernova SN 2008iz. The time sampling of the radio light curve allows us to obtain information on the precursor mass-loss rate, the strength of the magnetic field in the radiating region, the explosion date, and the deceleration of the expanding shock. We also check the possible contribution of Synchrotron Self Absorption (SSA) to the radio light curve and compare our model with other observations of the supernova at 22 GHz.

Key words. galaxies: individual: M82 – radio continuum: stars – supernovae: general – supernovae: individual: SN 2008iz

1. Introduction

The detection of a radio supernova is an uncommon event. Assuming a typical 5 GHz luminosity peak of $L_{5\,\mathrm{GHz}} \sim 10^{26}\,\mathrm{erg\,s^{-1}\,Hz^{-1}}$, the flux density of a radio supernova at a distance of 10 Mpc can be estimated of the order of 10 mJy, a value which may be hard to detect with a radio antenna of small or average size. This explains why, up to now, only about three dozen objects are detected, while in $\sim$ 150 cases only upper limits are available (see Weiler et al. 2009).

Supernova SN 2008iz was discovered by Brunthaler and collaborators on April 2009 as a bright radio transient in the nearby galaxy M82 (see Brunthaler et al. 2009a, 2009b and 2009c). Brunthaler et al. (2009a) reported on three 22 GHz VLA observation epochs made between March 2008 and April 2009. These authors found that the resulting radio light curve could be modeled using an exponential time decay, but could not be properly modeled using a time power-law decay. This is an intriguing result, since the flux density decay of a supernova is expected to follow a power-law of time (e.g. Weiler et al. 2002).

M82, at a distance of 3.5 Mpc, is a starburst galaxy with an estimated radio supernova rate of 1 supernova every $\sim 10-20$ years (e.g. Muxlow et al. 1994, Fenech et al. 2008). M82 has been repeatedly observed at 5 GHz in the framework of the 'Urumqi IDV monitoring project'. This project was initiated in 2004 in a collaboration of the Max-Planck-Institut für Radioastronomie with the Urumqi Observatory, as part of the National Astronomical Observatories of the Chinese Academy of Sciences. It is still ongoing and aims at the long term monitoring of the flux density variability of Intraday Variable (IDV) sources (see Witzel et al. 1986, Heeschen et al. 1987, Krichbaum et al. 2002 and Kraus et al. 2003) and the systematic search for annual modulation in type II IDV sources (see, e.g., Rickett et al. 2001, Gabányi et al. 2007, Marchili et al. 2008, Marchili 2009). In this program, M82 (also known as 0951+699) was regularly observed as a secondary calibrator.

The investigation of flux density variations of the order of few percent requires that the measurements are precise to within 0.5-1%. For achieving such an accuracy, it is indispensable to spend a considerable amount of the observing time on so-called calibrators – i.e. sources whose luminosity is constant over a time span of at least a few weeks. Due to the stability of its emission, M82 has been included in the source lists of all the 36 observing sessions performed in Urumqi between August 2005 and May 2009.

A visual inspection of the long-term variability curve of M82 revealed the presence of a strong flare in 2008, peaking in June (see Fig. 1). The shape of the flare is consistent with a supernova explosion. The date of the flare coincides with the explosion of SN 2008iz (see Brunthaler et al. 2009c). A deeper analysis of these data demonstrates that the 5 GHz variability curve of M82 provided by the Urumqi telescope traces the evolution of the radio emission from SN 2008iz in all its phases. Thanks to the relatively good sampling, we can estimate the parameters which characterize the supernova explosion.

2. Observations and data calibration

The Nanshan radio telescope is a 25-meter parabolic antenna operated by the Urumqi Observatory. It is located about 70 km south of Urumqi city at an altitude of 2029 m above the sea level with the geographic longitude of 87°E and latitude of +43°. The telescope is equipped with a single beam dual polarization 6 cm receiver (600 MHz bandwidth centered at 4.80 GHz) built by the MPIfR and installed at the secondary focus of the 25 m

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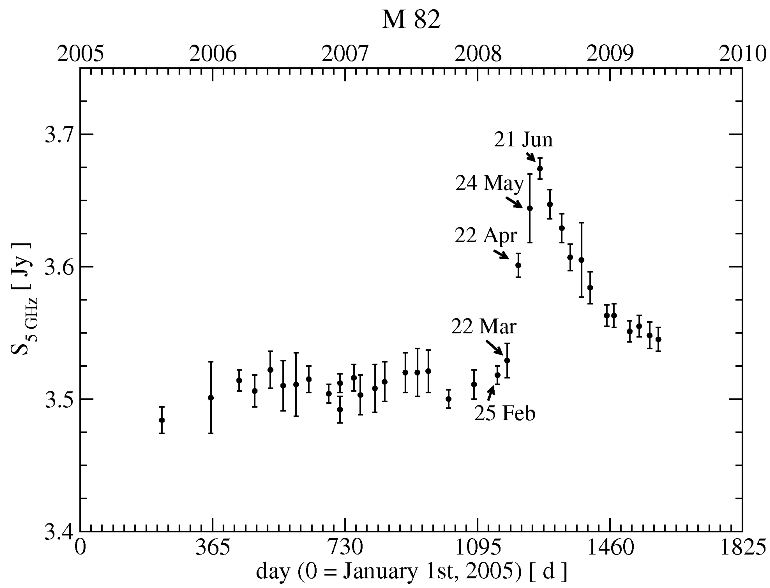

Fig. 1. The 5 GHz variability curve of M82, from Urumqi observations performed between August 2005 and May 2009. Up to February-March 2008, the radio emission from the source is nearly constant. The following increase in the measured flux density, culminating around June 2008, has to be ascribed to the explosion of SN 2008iz.

telescope. A 'Digital Backend' from the MPIfR collects data at a sampling rate of 32 ms. Every 32 ms the frontend setting changes, so that either a calibration signal of 1.7 K T_a is added to the antenna signal and/or the signal phase is switched off by 180° . This fast switching ensures a continuous gain control of the receiving system (for details see Sun et al. 2006 and references therein). The raw data are written to MBFITS format and were analyzed at the MPIfR using a Python based software package written by P. Müller. The analysis includes a sub-scan based combination of the 4 signal-phases, subtraction of baseline drifts and Gaussian profile fits to the cross-scans. This analysis was done independently for the two polarization channels (LCP/RCP) and for the average of the two. Below, we give a short description of this procedure. More details can be found in Kraus (1997), Marchili et al. (2008) and Marchili (2009).

All the flux density measurements have been performed in cross-scan mode. Each scan consists of 8 sub-scans in perpendicular directions over the source position – 4 sub-scans in elevation and 4 in azimuth. This observing mode is particularly suitable for accurate measurements, allowing the evaluation and correction of the pointing offsets. After removing linear baseline drifts of the antenna response caused by the atmosphere – the diffuse background emission on the sky – each subscan was fitted by a Gaussian profile, whose amplitude provides an estimation of the source's flux density, expressed in units of antenna temperature (K). For the Urumqi telescope, at 4.8 GHz, the half-power-beam-width of the Gaussian profile is $\sim$ 600 arcsec. Given such a large beam-width, M82 – whose angular size is of the order of a few tens of arcseconds – appears unresolved. This explains why SN 2008iz could be serendipitously observed during the Urumqi monitoring without compromising the Gaussian profile of the sub-scans.

After a quality-check, aiming to remove those data which do not fit standard quality criteria, an error-weighted average of the sub-scans values provides a single flux density measurement for each scan. The procedure for the data calibration also corrects for gain-elevation and gain-time effects. The former refers to the variations in the gain of the antenna when pointing at different elevations, due to changes in its parabolic shape. The gain-time effect refers to unpredictable variations in the collected flux densities, due to instabilities of the antenna-receiver system or changing weather conditions. Both the effects can be corrected by measuring and parameterizing the variations in the flux density of a sample of calibrators, for the observation of which we spent about 50% of our observing time.

Table 1. Urumqi data for SN 2008iz at 5 GHz frequency. In Col. 1, the observing date (at half-session); in Col. 2, the corresponding day (0=January the 1st, 2008). In Col. 3 and 4, respectively, the flux density and the error estimations.

Observing session (dd.mm.yyyy)	Day (d)	S_{sn} (mJy)	err (mJy)
25.02.2008	55	11	9
22.03.2008	81	19	14
22.04.2008	112	87	11
24.05.2008	144	128	27
21.06.2008	172	157	10
18.07.2008	199	130	13
20.08.2008	232	115	13
12.09.2008	255	95	12
13.10.2008	286	97	29
06.11.2008	310	78	13
22.12.2008	356	60	10
11.01.2009	376	59	11
23.02.2009	419	44	10
21.03.2009	445	45	10
19.04.2009	474	35	12
13.05.2009	498	29	11

The final step of the data calibration is the conversion of the measurements from K to Jy. The conversion factor is obtained through the observation of sources whose flux density values at 5 GHz are fairly constant and well known, such as NGC 7027, 3C 286, and 3C 48.

The 5 GHz variability curve of M82, shown in Fig. 1, consists of 36 data-points, one per observing session. Each point is obtained as the mean of the calibrated flux densities collected during the session (in average, we have $\sim$ 80 scans per session). In order to isolate the flux emission from SN 2008iz (S_{sn}), we need to quantify the contribution of the rest of the galaxy and remove it. The subtraction of the galactic emission is an easy process in the case of M82, because its 5 GHz flux density (S_{tot}) appears to be quite stable on a time scale of years. Between March 2006 and December 2007 we estimated an average S_{tot} value of 3.510 Jy, with a standard deviation of 0.008 Jy.

A deeper investigation of the M82 variability curve revealed the presence of a mild annual cycle in S_{tot} before the supernova explosion. Similar cycles have been found also in the variability curves of other calibrators, therefore their spurious nature is unquestionable. The origin of this systematic flux variation is still unclear, but probably is due to residual calibration errors related to temperature changes at the site, and to changes of the atmospheric and ionospheric conditions. In the case of M82, this variable component can be modeled as a sinusoidal wave with amplitude of 0.007 Jy, peaking in the end of June.

The values of S_{sn} reported in Table 1 have been calculated by subtracting from the total flux density both the average S_{tot} value (3.510 Jy) and the sinusoidal wave contribution described above.

It is worth noting that the flux density contribution from other compact sources in M82 should not affect our results. The one known decaying source, 41.95+575 (see Kronberg et al. 2000), has been shown to have a decay rate of ~8.8% per year (see Muxlow et al. 2005). Considering that the source, as of July 2009, had a flux density at 5 GHz of 10.5 mJy (based on MERLIN observations), its contribution to the global flux variation of M82 can be quantified to a decline of ~0.9 mJy per year.

3. Light curve model

We have fitted the radio emission of supernova SN 2008iz following the model described in Chevalier (1982a, 1982b). This model relates the structure and evolution of the radio emission with the parameters of a hydrodynamical model of interaction between the supernova ejecta and the circumstellar medium (CSM). The synchrotron radio emission is produced by the interaction of relativistic electrons (accelerated at the shock) from the CSM with magnetic fields, which are amplified in the region of expanding shocked circumstellar material. It is assumed that the energy density of the magnetic field and the number density (or energy density) of the electrons scale as the specific kinetic energy of the expanding shocked material. The radial density profile of the CSM is assumed to be $\propto R^{-s}$, with $s = 2$. Weiler et al. (2002) discuss on an analytical model of radio light curves for supernovae, based on the Chevalier model. Radio light curves of several supernovae have been satisfactorily fitted using this model (e.g., Weiler et al. 2002, 2007, and references therein). In our analysis, we used a simplified version of it. If the CSM distribution is homogeneous (i.e., there is no *clumpy* CSM) and we do not consider synchrotron self-absorption (SSA), the flux density of a supernova at a frequency ν can be modeled as

$$S = K_1 \left(\frac{\nu}{5\ \mathrm{GHz}}\right)^{\alpha} \left(\frac{t - t_0}{1\ \mathrm{day}}\right)^{\beta} e^{-\tau} \tag{1}$$

where K_1 is a scaling factor, α is the spectral index of the emission in the optically-thin regime, β is related to the flux density drop at late epochs, t_0 is the explosion date, t is the epoch of observation, and τ is the opacity of the thermal electrons of the CSM to the radio emission. This opacity can be modeled as

$$\tau = K_2 \left(\frac{\nu}{5\ \mathrm{GHz}}\right)^{-2.1} \left(\frac{t - t_0}{1\ \mathrm{day}}\right)^{\delta} \tag{2}$$

where K_2 is a scaling factor, related to the CSM density, and δ is related to the CSM radial density profile. The exponent -2.1 corresponds to the spectral dependence of free-free absorption (FFA) by a thermal ionized gas in the radio regime.

On the one hand, modeling of the emission in the optically-thick regime (i.e., from the shock breakout to, roughly, the flux density peak) strongly depends on the three parameters K_2, t_0, and δ. On the other hand, the emission in the optically-thin regime mainly depends on α and β. Our radio light curve at 5 GHz only has 2 clear flux density measurements in the optically-thick part of the light curve (see Fig. 2). Therefore, it is numerically difficult to reliably fit our data using Eq. 1. Fortunately, β and δ are related with the kinematics of the expansion, since both depend on the CSM radial density profile. Given that the magnetic field energy density scales as the specific kinetic energy of the ejecta, it is straightforward to derive that $\delta = \alpha - \beta - 3$. We used this relationship between δ and β in the modeling of our 5 GHz data in the following way: we fitted these data corresponding to the optically-thin regime by turning off the opacity term (i.e., setting $\tau = 0$). Then, from the fitted value of β and an estimate of α (see next section), we derived δ. Therefore, the only remaining parameter to be fitted, when we included all the data in the modeling, was K_2. With only 1 free parameter, we were able to satisfactorily fit the optically-thick part of the radio light curve.

Following this approach, we arrived at slightly different results depending on the value of the explosion date, t_0, which is practically uncorrelated with the flux densities of the optically-thin regime and, therefore, cannot be well fitted using only this subset of data. However, it is possible to take advantage of the kinematics of the expansion to find out a self-consistent value of t_0. Let us elaborate on this: the size of the expanding spherical shock follows a power law of time (i.e., $R \propto t^m$, where m is the expansion index). The expansion index, m, can be related to β and α as follows, $\beta = \alpha + 3(m - 1)$. From the expansion results based on VLBI observations recently reported in Brunthaler et al. (2009c), we can estimate the explosion date, provided an estimate of m is given. Therefore, we can assume an explosion date, t_0, and fit the corresponding value of β. This value of β will map into a value of m. Then, we can derive an explosion date from the fitted m and the VLBI results reported in Brunthaler et al. (2009c), and look for self-consistency. In the next section, we report on the results obtained from this self-consistent fit of the radio light curve of SN 2008iz.

4. Results

4.1. Explosion Date and Expansion Rate

The relationship between β and m depends on the spectral index α. Therefore, we need an estimate of α for our self-consistent analysis. Brunthaler et al. (2009c) report a spectral index of -0.8 for SN 2008iz, based on VLA observations made on 27 April 2009, ranging from 1.4 to 43 GHz. However, a more careful removal of the diffuse emission in M82 has shown a flattering of the spectrum at 1.4 GHz, while the spectral index between 5 and 43 GHz is -1.08 ± 0.08 (Brunthaler et al. 2009, in prep.). Using this spectral index, together with the fit of flux densities in the optically-thin regime (see previous section), we find a self-consistent expansion index $m = 0.89 \pm 0.03$. Brunthaler et al. (2009c) reported an explosion date on late January 2008, assuming a constant expansion velocity between two VLBI epochs reported. Assuming, however, a decelerated expansion with $m = 0.89$, results in a delay of the explosion date by ~ 20 days, so the

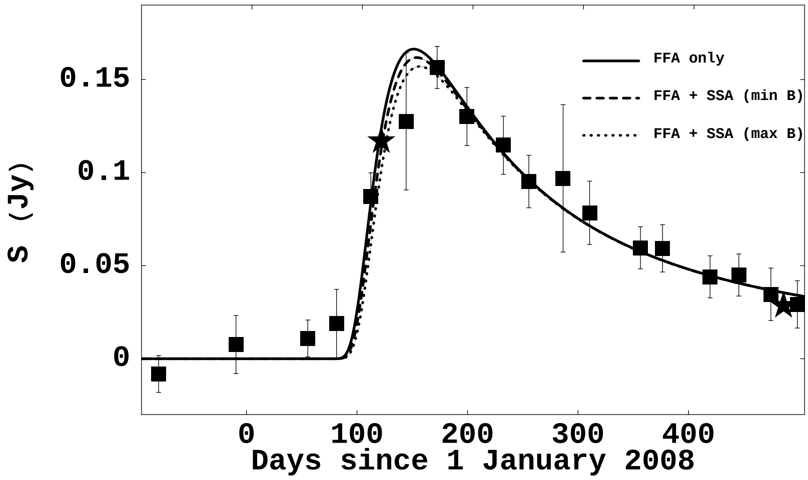

Fig. 2. Light curve of SN 2008iz at 5 GHz. Filled squares, Urumqi data; filled stars, MERLIN data from Beswick et al. (2009). The model with only FFA is shown as a continuous line; the model with FFA and SSA produced by the minimum (maximum) possible equipartition magnetic field is shown as a long-dashed (short-dashed) line.

corrected date of the shock breakout, using a power-law decelerated expansion, shifts to late February 2008. If we use this new explosion date as an input in the fit to the data of the optically-thin part of the light curve, it results in $\beta = -1.43 \pm 0.05$, which maps into $m = 0.89 \pm 0.03$. Therefore, this is a self-consistent result. Delaying the shock breakout to a later (earlier) date would result in higher (lower) values of β. This, in turn, would map into higher (lower) values of m. Since a higher (lower) m corresponds to an earlier (later) explosion date, we can ensure that this self-consistency between β and m is unique. This value of m is also similar to the expansion indices found in other supernovae that could be observed with VLBI (e.g., Marcaide et al. 2009).

Our best-fit parameters of the light curve model, obtained as described in the previous sections, are $K_1 = 214 \pm 4$ mJy, $\beta = -1.43 \pm 0.05$, t_0 = 18 Feb 2008 (±6 days), $K_2 = (11.0 \pm 0.70)\times 10^4$, and $\delta = -2.65 \pm 0.10$. The uncertainties are computed from the diagonal elements of the post-fit covariance matrix.

In Fig. 2 we show the radio light curve of SN 2008iz at 5 GHz, resulting from the Urumqi measurements here reported, together with our best-fit model (continuous line). We also show the two flux density measurements reported in Beswick et al. (2009), based on MERLIN observations. These MERLIN flux densities fit remarkably well to our model. Indeed, Beswick et al. (2009) also reported a flux density increase rate of $\sim$3 mJy day^{-1} over the two day long duration of their first epoch observations starting 1 May 2008. Our best-fit model predicts a flux density increase rate of 3.5 ± 0.6 mJy day^{-1} on the same day, compatible with the rate observed by Beswick et al. (2009). This result confirms the reliability of our light curve model.

4.2. CSM Density and Pre-supernova Mass-loss Rate

The parameter K_2 is related to the square of the CSM density, which is in turn related to the square of the mass-loss rate, $\dot{M}$, of the precursor star, assuming a certain stellar-wind velocity for the precursor (a typical value is 10 km s^{-1} for a Red Super Giant star). Typical values of the mass-loss rates for other supernovae precursor stars are $\sim 10^{-5}$ M$_\odot$ yr^{-1}. According to our fitting results, and using the Eq. 11 of Weiler et al. (2002), the mass-loss rate of the precursor of SN 2008iz would be 3.69×10^{-5} M$_\odot$ yr^{-1}. To obtain this estimate, we have computed the ejecta velocity assuming a decelerated expansion with $m = 0.89$.

4.3. Magnetic Field and Synchrotron Self-Absorption

Since the energy density of the magnetic field and that of the relativistic electrons are both coupled with the specific kinetic energy of the expanding material, a certain equipartition of energy between particles (electrons and protons) and fields applies during the whole expansion. In the case of energy equipartition between particles and fields, it is possible to estimate the magnetic field in the radiating region, provided the size and the total luminosity of the source are known. The expression used for this estimate is taken from Pacholczyk (1970) (see chapter 7, Eq. 15):

$$B_{eq} = (4.5\, c_{12}\, (1 + k)/\phi)^{2/7}\, R^{-6/7}\, L_R^{2/7} \tag{3}$$

where c_{12} depends on the spectral index, α, and the minimum and maximum frequencies considered in the integration of the spectrum. ϕ is the filling factor of the emitting region, R is the source radius, L_R is the integrated radio luminosity, and k is the ratio between the heavy particle energy density to the electron energy density. We do not know the details of the particle acceleration, and the efficiency of acceleration could depend on the particle mass. Hence, k can vary from 1 to $m_p/m_e \sim 2 \times 10^3$. Therefore, we are not able to compute a single value of equipartition magnetic field, but only a range of possibilities. Using the expansion information reported in Brunthaler et al. (2009c) we can derive the source radius for the two VLBI epochs there reported. Then, from the flux densities recovered at those epochs and the source spectral index, we can estimate the range of possible equipartition magnetic fields at both VLBI epochs. In these estimates, we assume that the radio emission has a shell-like structure, with a fractional width of 0.3. This is the model that best describes the radio emission of SN 1993J (e.g. Marcaide et al. 2009).

For the VLBI epoch on 3 May 2008 (63 days after explosion), we obtain a range of possible equipartition magnetic fields between 0.3 and 2.1 Gauss. For the epoch on 8 April 2009 (403 days after explosion), we obtain a range between 0.04 and 0.31 Gauss. In these estimates, we notice that the minimum and maximum magnetic fields at each epoch approximately scale in time in such a way that the corresponding energy density is always proportional to the specific kinetic energy of the shock, as should be the case. All these values are much higher than the typical circumstellar magnetic fields of massive stars ($\sim$ 1 mG), thus suggesting that highly-effective amplification mechanisms (possibly due to Rayleigh-Taylor instabilities close to the contact discontinuity of the shock, see Chevalier 1982b) are taking place in the emitting region of SN 2008iz.

The range of high magnetic fields found for SN 2008iz translates into a relatively large SSA in the emitting region, thus affecting the behavior of the radio light curves, especially at early epochs. SSA effects were not considered in the model proposed by Chevalier (1982b), but were necessary to explain the radio light curves of SN 1993J (e.g. Fransson & Björnsson 1998, Weiler et al. 2007, Martí-Vidal et al. in preparation). Besides the case of SN 1993J, SSA has not been robustly modeled in the radio light curves of any other supernova, however tentative evidence for SSA has also been detected in a few cases. Here, we will compute the effects of SSA on the radio light curve of SN 2008iz, and check whether the inclusion of SSA results in an unsatisfactory fit to these data. If that was the case, our model would not be self-consistent, since it would predict too high magnetic fields for a too low total absorption in the optically-thick regime.

To compute the SSA effects, we use the expression of the absorption coefficient corresponding to a power-law energy distribution of electrons (Pacholczyk 1970):

$$\kappa_\nu = c_6\, n\, B^{1.5-\alpha} \left(\frac{\nu}{2\, c_1}\right)^{\alpha-2.5} \tag{4}$$

where c_6 depends on the spectral index, c_1 is a constant, n is the particle number density, and B is the magnetic field. Assuming a constant magnetic field inside the radiating region, we can integrate the radiative-transfer equation easily. The flux density, corrected by SSA, is then

$$S_{SSA} = S\, \frac{1 - e^{-\tau_{SSA}}}{\tau_{SSA}} \tag{5}$$

where $\tau_{SSA} = \kappa_\nu R_L$, being R_L the line-of-sight depth of the source. Obviously, R_L is not a constant in the case of a spherical shell, but the use of a constant value does not affect the results at the precision level of our estimates. Setting R_L equal to the shell width, in the case of a spherical optically-thick shell, gives us results which only deviate $\sim$ 5% from those obtained if we integrate the radiative transfer equation over the shell.

The only quantity that is not known in Eq. 5 is the electron number density. However, we can estimate κ_ν from the radio luminosity of the source, without knowing n. In the optically-thin regime, the luminosity at a given frequency is equal to the emissivity, ϵ_ν, multiplied by the volume of the source. Therefore, from the luminosity and the size of the source, we can estimate ϵ_ν, and from the source function, ϵ_ν/κ_ν, which is independent of n (see Pacholczyk 1970) we can determine κ_ν. We have estimated the synchrotron absorption coefficient for the second VLBI epoch reported in Brunthaler et al. (2009b), which was taken in the optically-thin regime at 22 GHz.

Once we have estimated κ_ν, we can evolve τ_{SSA} by changing the magnetic field according to the Chevalier model, thus obtaining the opacity time evolution and, therefore, the SSA-corrected radio light curves. We show the resulting curves in Fig. 2, for the cases of minimum and maximum possible equipartition magnetic fields. As it can be seen in the figure, the two extreme values of magnetic fields do not dramatically affect the quality of the fit (the increase of the χ^2 is only 6% for the case of minimum magnetic field, but rises to 50% for the case of maximum magnetic field).

4.3.1. Estimate of magnetic field from the turnover frequency

The crossing point of the light curves at 5 and 22 GHz, which takes place on day $\sim$ 115 (see Fig. 3), is insensitive to slight changes in the fitting parameters, or even to the addition of other absorption mechanisms in the early stages of the supernova evolution, as can be seen in Fig. 3. Therefore, we can use this point to estimate an upper limit of the magnetic field in an alternative way than the one followed in Sect. 4.3. Since the flux densities at 5 GHz and 22 GHz are equal at the crossing point, we can use this condition to estimate the turnover frequency at that epoch (7.81 GHz), together with the corresponding flux density (0.19 mJy), assuming that SSA dominates the absorption. Using these estimates, together with the supernova size interpolated at that epoch, we estimate a magnetic field of 0.5 G.

Since SSA is not the dominant absorption mechanism in the light curve, this estimate of the magnetic field is an upper bound. The magnetic field is inversely proportional to the turnover flux density, and such a flux density would be higher if there were only SSA effects in the light curve.

If we compare this value of the magnetic field with the equipartition values given in Sect. 4.3 (properly interpolated to day 115), we estimate a value of k (see Eq. 3) of only $40 - 50$. This value of k is also an upper bound. It indicates that the acceleration efficiency of the electrons by the shock might be much higher than that of the ions, at least until day 115.

We note, however, that the upper bound of the magnetic field estimated in this section is very sensitive to the estimate of the turnover frequency, which we have obtained by interpolation of only two spectral data points. Any change in the estimate of the turnover frequency would translate into changes in k. For instance, we could obtain equipartition between electrons and ions if the turnover frequency would increase to $\sim$ 15 GHz (assuming the same flux density), which is still between 5 and 22 GHz. Therefore, we cannot strongly argue in favor of a low value of k, based only on the crossing point of the light curves.

5. Comparison with other observations

The model given by Eq. 1 predicts the same power-law decay of flux density at all frequencies in the optically-thin regime. If we compare the flux densities at 22 GHz reported in Brunthaler et al. (2009b) with the predictions of our model at 22 GHz, we see that the two latest data points fit remarkably well to the model. Indeed, according to our model, the first flux density measurement was made very close to the emission peak at 22 GHz, so strong absorption effects may be affecting the flux density of the supernova at that epoch. Indeed, this situation could explain why Brunthaler et al. (2009b) were unable to fit their 22 GHz light curve to a time power law. The first flux density would not follow the expected behaviour in the optically-thin regime.

We notice, however, that our model predicts a too high flux density for the first 22 GHz epoch (a factor of $\sim$2 above the observed value). This could indicate that there are additional absorption mechanisms in the supernova that have not been considered in our modeling. Unfortunately, we have not enough data points in the optically-thick regime to properly model such additional mechanisms. Nevertheless, we can still check whether it is possible to account for this large discrepancy by using additional sources of absorption. Adding, for instance, clumpyness

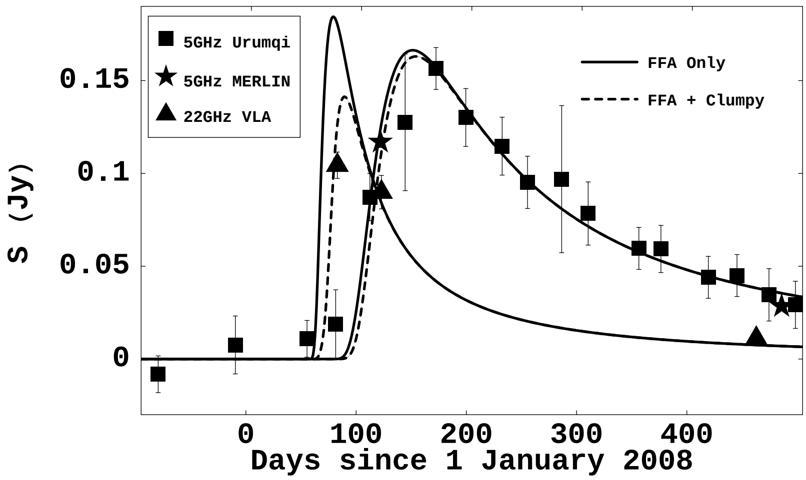

Fig. 3. 22 GHz flux densities taken from Brunthaler et al. (2009b) (filled triangles), plotted along with the 5 GHz data shown in Fig. 2. The model obtained by fitting the 5 GHz data (continuous line) does not describe well the earliest 22 GHz flux density. Assuming a clumpy CSM (dashed line) provides a better fit to this flux density.

to the CSM with $\delta = -5$ (see Weiler et al. 2002) would allow to fit all the 22 GHz flux densities without degrading the quality of our fit at 5 GHz, as we show in Fig. 3. With this value of δ, the clumpy medium will rapidly become homogeneous as the distance to the explosion center increases.

We note that this estimate of δ for a clumpy medium is not the result of a fit. We do not consider any clumpyness of the CSM in our best-fit model. Such a clumpy medium added to the model is just to show that the low quality fit to the earliest flux density at 22 GHz does not necessarily indicate that our model is wrong. It just indicates that something may be missing in our modeling of the very early expansion curve for the highest frequencies.

6. Summary

We report on 5 GHz Urumqi observations of the galaxy M82, in which we detected the radio emission from supernova SN 2008iz as a strong flare in the galaxy light curve. Correcting for the galaxy contribution, we obtain the radio light curve of SN 2008iz. We have used the analytical model described in Weiler et al. (2002) to satisfactorily fit our data. Additionally, the MERLIN flux density measurements reported by Beswick et al. (2009), together with the flux density rate also reported by these authors on 1 May 2008, fit remarkably well to our model.

From the fitted parameters of the light curve, we estimate the mass-loss rate of the precursor star and (using the information given in Brunthaler et al. 2009c, based on VLBI observations) we also give estimates of the explosion date, the deceleration of the expanding shock, and the equipartition magnetic field in the radiating region. We estimate a mass-loss rate of the precursor of $3.69 \times 10^{-5}\,M_\odot\,yr^{-1}$, similar to the typical values for other supernovae, and equipartition magnetic fields of the order of thousands of times larger than the typical magnetic fields around massive stars. This is indicative of strong amplification mechanisms in the radiating region, as predicted by Chevalier (1982b). Adding the contribution of SSA to the light curve does not dramatically affect the quality of our fit.

We compare our model predictions with the flux densities at 22 GHz reported by Brunthaler et al. (2009b). According to our model, the earliest flux density at 22 GHz may be strongly affected by absorption from the CSM. This could have misled these authors to conclude that the flux density decay at 22 GHz cannot be fitted using a time power law. Indeed, the other two flux densities at 22 GHz fit very well to our model, in which we apply the same power-law decay for the 5 GHz data. Our model, however, does not satisfactorily predict the flux density of the earliest 22 GHz epoch. Given that this epoch is very close to the emission peak, we argue that other absorption effects, not considered in our final model, may be affecting the level of emission at 22 GHz in the optically-thick regime. The lack of enough data at such early epochs prevents us from a deep study in that direction.

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References

Beswick, R. J., Muxlow, T. W. B., Pedlar, A., et al. 2009, ATel, 2060
Brunthaler, A., Menten, K.M., Henkel, C., et al. 2009a, ATel, 2020
Brunthaler, A., Menten, K. M., Reid, M. J., et al. 2009b, A&A, 499, L17
Brunthaler, A., Menten, K.M., Henkel, C., et al. 2009c, CBET, 1803
Chevalier, R. A. 1982a, ApJ, 258, 790
Chevalier, R. A. 1982b, ApJ, 259, 302
Fenech, D. M., Muxlow, T. W. B., Beswick, R. J., et al. 2008, MNRAS, 391, 1384
Fransson, C. & Björnsson, C.-I. 1998, ApJ, 509, 861
Gabányi, K. É., Marchili, N., Krichbaum, T. P., et al. 2007, A&A, 470, 83
Heeschen, D. S., Krichbaum, T. P., Schalinski, C. J. & Witzel, A. 1987, AJ, 94, 1493
Krichbaum, T. P., Kraus, A., Fuhrmann, L., et al. 2002, PASA, 19, 14
Kronberg, P. P., Sramek, R. A., Birk, G. T., et al. 2000, ApJ, 535, 706
Kraus, A. 1997, PhD thesis, Bonn University, Germany
Kraus, A., Krichbaum, T. P., Wegner, R., et al. 2003, A&A, 401, 161
Marcaide, J.M., Martí-Vidal I., Alberdi A., et al. 2009, A&A, accepted (arXiv:0903.3833v2)
Marchili, N., Krichbaum, T. P., Liu, X., et al. 2008, arXiv, 0804, 2787
Marchili, N. 2009, PhD thesis, Bonn University, Germany (http://hss.ulb.uni-bonn.de/diss_online/math_nat_fak/2009/marchili_nicola)
Muxlow, T.W.B., Pedlar, A., Willkinson, P.N., et al. 1994, MNRAS, 266, 455
Muxlow, T. W. B., Pedlar, A., Beswick, R. J., et al. 2005, MmSAI, 76, 586
Pacholczyk, A. N. 1970, Radio Astrophysics, (1st Ed.; San Francisco: Freeman & Co)
Rickett, B. J., Witzel, A., Kraus, A., et al. 2001, ApJ, 550L, 11

Sun, X. H., Reich, W., Han, J. L., et al. 2006, A&A, 447, 937
Weiler, K.W., Panagia, N., Montes, M.J. & Sramek, R. A. 2002, ARA&A, 40, 387
Weiler, K. W., Williams, C. L., Panagia, N., et al. 2007, ApJ, 671, 1959
Weiler, K. W., Panagia, N., Sramek, R. A., et al. 2009, AIPC, 1111, 440
Witzel, A., Heeschen, D. S., Schalinski, C. & Krichbaum, T. P. 1986, MitAG, 65, 239