Massive circumstellar envelope around type IIn supernova SN 1995G

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We model the interaction of the supernova SN 1995G with a dense circumstellar (CS) gas in a thin shell approximation. A model fit of the observed bolometric light curve combined with data on the supernova expansion velocity provides an estimate of the density of the CS shell, its mass ($\approx 1 M_\odot$), and age ($\approx 8$ years). It is shown that the derived CS gas density does not depend on the assumed mass of the supernova envelope. This results from the high CS density, which ensures that the forward shock wave is essentially radiative. The derived CS density is consistent with the H$\alpha$ luminosity and with the presence of the apparent effect of Thomson scattering in the red wing of this line. The mass of the CS envelope together with its expansion velocity indicates that the CS envelope was ejected as a result of violent energy release ($\sim 6 \times 10^{48}$ erg) eight years before the supernova outburst.

1 Introduction

Type IIn supernovae (SN IIn) with narrow H$\alpha$ emission, introduced as a separate family by Schlegel (1990), explode in a very dense CS environment. This is demonstrated by the presence of a strong CS H$\alpha$, high bolometric luminosity and strong broad H$\alpha$ emission powered by the CS interaction (Chugai 1990, 1992). An analysis of the optical effects of the CS interaction provides an efficient diagnostic tool for the CS density around SN IIn. The use of this probe led to the detection of the unusually dense CS environment around SN 1987F, (Chugai 1990), SN 1997ab (Salamanca et al. 1998), SN 1997cy (Turatto et al. 2000) and some other SN IIn. For SN 1997ab with the velocity of the CS gas of $\approx 90$ km s$^{-1}$ the derived mass loss is enormous, $\sim 10^{-2} M_\odot$ yr$^{-1}$ (Salamanca et al. 1998). The mechanism for such a tremendous mass loss rate is unclear; it exceeds the mass loss rate of the most extreme cases of a red supergiant superwind by at least a factor of ten.

The problem of the mechanism of a powerful mass loss rate by SN IIn presupernovae is becoming urgent in view of the recent results of the SN 1994W study, which show that the CS shell in this case was created by mass loss with an average rate of $\sim 0.2 M_\odot$ yr$^{-1}$ and the enormous kinetic luminosity, two orders of magnitude greater than the radiative luminosity of a massive
presupernova (Chugai et al. 2003). It was suggested there that such a pow-
erful mass loss by presupernova was related to an explosive event about 1.5
yrs before the SN 1994W outburst. A specific feature of this supernova is
the relatively high velocity of the CS gas \(u \approx 10^3\) km s\(^{-1}\) that eventually
leads to the energy problem for the superwind mechanism.

Originally, the idea of explosive mass loss several years before the super-
nova explosion was proposed by Weaver and Woosley (1979) in connection
with a possible strong Ne flash in the degenerate O/Ne/Mg core. Gras-
berg and Nadyozhin (1986) suggested explosive ejection of the presupernova
envelope roughly 50 days prior to supernova explosion in order to account
for the narrow lines in SN 1983K. However at present the explosive mass
ejection by presupernovae is just a working hypothesis, especially keeping in
mind that Woosley et al (2002) recently expressed doubts about the reality
of their mechanism. In this respect, the study of signatures of the explo-
sive mass ejection by presupernovae (large mass and energy of the CS shell
and small age) can provide us with interesting information about poorly
understood phenomena occurring in presupernovae on the eve of a supernova
explosion.

It was already noted that explosive mass ejection by presupernovae might
occur in those SN IIn which show high CS velocity \(\sim 1000\) km s\(^{-1}\) and
CS subordinate hydrogen and metal lines (Chugai et al. 2003). Apart from
SN 1994W this type of SN IIn includes another well observed supernova
SN 1995G (Pastorello et al. 2002). This supernova has a specific light curve
interpreted as a result of CS interaction (Pastorello et al. 2002).

In the present paper we use the model of the bolometric light curve in
order to extract information about the CS gas density. This will permit us
to derive mass, energy, and age of the CS envelope and thus a conclusion
concerning its origin. In section 2 we give a brief description of the model,
in section 3 we explore model sensitivity to parameters and demonstrate
the uncertainty of the parameters recovered in the case of SN 1997cy. In
section 4 we model the light curve of SN 1995G and derive the mass of the
CS envelope. The discussion of results and their relationship to the H\(\alpha\)
intensity and profile is presented in section 5.

The paper is based upon the photometry and spectra presented by Pas-
torello et al. (2002). We use the Hubble constant of 70 km s\(^{-1}\) Mpc\(^{-1}\).

2 Model

The light curve model applied below was described earlier (Chugai 2001).
Here we only briefly recapitulate its essential features. We consider the
expansion of the supernova in the CS envelope with a given density dis-
Table 1: Model parameters

|   | $M_{\odot}$ | $E_{10^{51}}$ erg | $s$ | $w_0$ $10^{17}$ g cm$^{-1}$ | $\rho_0$ $10^{-15}$ g cm$^{-3}$ | $R_0$ $10^{16}$ cm | $M_{CS}$ $M_{\odot}$ |
|---|----------|-----------------|----|---------------------|------------------------|-----------------|--------------|
| A1 | 5        | 1               | 1  | 0.4                 | 3.2                    | 1               | 1            |
| A2 | 5        | 0.1             | 1  | 0.4                 | 3.2                    | 1               | 1            |
| B  | 1        | 1               | 1  | 0.4                 | 3.2                    | 1               | 1            |
| C  | 5        | 1               | 2  | 2                   | 16                     | 1               | 1            |
| D  | 5        | 1               | 1  | 0.8                 | 6.4                    | 1               | 2            |
| cy1| 5        | 2               | 1.8| 1                   | 8                      | 2.3             | 1.8          |
| cy2| 1.5      | 1               | 1.3| 1.1                 | 9                      | 1.7             | 4.1          |
| G1 | 2        | 0.24            | 2  | 1.2                 | 9.5                    | 2.2             | 1.2          |
| G2 | 10       | 0.6             | 2  | 1.1                 | 8.7                    | 2               | 1.1          |
| G3 | 21       | 1               | 2  | 1.2                 | 9.5                    | 2               | 1.1          |

The interaction of a supernova with its CS environment on a time scale greater than several days weakly depends on the initial epoch of the interaction. We assume the following: the interaction begins at the presupernova radius $R_0$ and the supernova expands freely ($v = r/t$), and its density distribution is an inner plateau with the outer power law density drop ($\rho \propto v^{-9}$). The numerical solution of the equation of motion with the final velocity of the CS gas provides the thin shell radius $R(t)$, and the relative velocities of the supernova and CS gas flows. These permit us to calculate the kinetic luminosity of the forward and reverse shock, which may be transformed into X-ray luminosities of both shocks and eventually into optical bolometric luminosity (Chugai 1992). The contribution of the luminosity supplied by the internal energy stored in the supernova during the explosion is calculated according to an analytical approximation (Arnett 1980, 1982). In our model the full light curve is a linear superposition of this luminosity and the interaction luminosity. This approach permits us to take into account the radiation of the initial internal energy at the early epoch in a straightforward way.

The CS density is described by the density $\rho_0$ at the radius $10^{15}$ cm, or
Figure 1: Bolometric light curves and velocities of the thin shell for models A–D (Table 1). Model A1 (thin line) is a template for other models A2, B, C, D, which are shown in panels a, b, c and d, respectively.

The density parameter \( w = 4\pi r^2 \rho \) at this radius, and by the power index \( (s) \) in the power law \( (\rho \propto r^{-s}) \). The extent of the CS envelope is characterized by the outer radius \( R_b \). With the mass \( (M) \) and energy \( (E) \) of the supernova envelope we have five parameters, which are constrained by the light curve, photospheric radius, supernova expansion velocity and phase of the late rapid light curve decline.

### 3 Parameter sensitivity and SN 1997cy

The sensitivity of the model to parameter variations is demonstrated by the models A1, A2, B, C, D (Fig. 1) with parameters shown in Table 1. The table presents beginning from the second column: supernova mass \( (M) \), energy \( (E) \), power index of the CS density distribution \( (s) \), density parameter \( (\omega_0) \) and density \( (\rho_0) \) at the radius \( 10^{15} \) cm, outer radius of the CS envelope \( (R_b) \), and the mass of the CS envelope \( (M_{cs}) \). The latter is the output value and not a free parameter. We adopt the CS velocity \( 1000 \) km s\(^{-1}\), presupernova radius \( R_0 = 1000 \) \( R_\odot \), and \(^{56}\)Ni mass \( 0.003 \) \( M_\odot \) following the estimate for SN 1994W (Sollerman et al. 1998). The model A1 is
adopted as a standard, with which all the other models are compared. For all the cases Fig. 1 shows the bolometric light curves and the thin shell velocities.

We begin with a brief discussion of the general properties of models. First, they all show a shoulder, which reflects the overtaking of the CS shell boundary by the forward shock. Second, after that time the luminosity is still high. The source of this radiation is the inner shock which is driven by the supersonic velocity jump between the outer supernova material and the thin shell. As the thin shell is accelerated, the inner shock luminosity decreases. Note that the luminosity of the inner shock is lower in the case of a lower mass of the supernova envelope (model B). Finally, for most models, the contribution of the internal energy of the supernova to the luminosity is relatively small, except for the model A2 with a noticeable early bump during the first 50 – 100 days.

Now let us consider the effects of parameter variations. The reduction of the supernova kinetic energy by an order of magnitude reduces the early luminosity by more than an order of magnitude with a less pronounced luminosity decrease at the late epoch (Fig. 1a). The five-fold mass reduction (model B) results in the substantially higher early luminosity due to the higher velocity of the outer shock (Fig. 1b). Still the model B shows a faster decay of the early luminosity because of the fast crossing of the CS
Figure 3: Fe II 5018 Å line in SN 1995G spectra on days 265 and 561 (Pastorello et al. 2002). Both profiles reveal narrow P Cyg component and broad emission component. The latter is related to the dense shell at the supernova boundary. Dotted line shows approximation of the blue part of profile and continuum used for the estimate of the maximal velocity.

envelope. The model C with the steeper density distribution \( s = 2 \) for a similar mass of the CS shell gives, as expected, a higher early luminosity and faster decay (Fig. 1c). The model D with twice as higher mass of the CS envelope results in the higher luminosity and lower velocity of the thin shell (Fig. 1d).

The above analysis implies that a combination of low mass and low energy is able to produce the rather bright SN IIn phenomenon as a result of the efficient deceleration of the bulk of the supernova envelope. As an illustration of this statement let us consider the light curve of SN 1997cy (type IIn), studied by Turatto et al. (2000). In the cited paper the proposed interaction model suggests the large supernova energy \( 3 \times 10^{52} \) erg and mass \( \sim 20 \, M_\odot \). Although this model is plausible, one cannot rule out an alternative model with moderate values of both energy and mass. This is demonstrated by models cy1 and cy2 (Fig. 2 and Table 1). The adopted velocity of the CS envelope is 10 km s\(^{-1}\). Model cy1 with \( M = 5 \, M_\odot \) and \( E = 2 \times 10^{51} \) erg provides a satisfactory agreement with data, while the
model cy2 with $M = 1.5 \, M_\odot$ and $E = 10^{51}$ erg shows an even slightly better fit since it better reproduces the luminosity drop at $t > 600$ days. The velocity of the thin shell is different in these models and such a difference may be crucial in discarding inappropriate models on the basis of the velocity information provided by the line profiles. Unfortunately, there is no straightforward procedure for determining the thin shell velocity in SN 1997cy. So the uncertainty of the choice of the mass and energy remains.

4 SN 1995G light curve and the mass of CS envelope

Let us briefly consider additional observational constraints on the model apart from the bolometric light curve of SN 1995G. The energy distribution in early spectra of SN 1995G provides the estimates of temperature and radius of the photosphere on days 2 and 36 (Pastorello et al. 2002). We believe that the photospheric radius at the early epoch is approximately equal to the radius of the thin shell. The arguments are based upon the result that the thin dense shell is opaque in the optical band in the case of a very dense CS environment ($w \sim 10^{17}$ g cm$^{-1}$) for about one-two months (Chugai 2001). Thus, the first additional observational constraint on the model suggests that the early photospheric radius should approximately coincide with the radius of the thin shell, if the CS density is rather high, i.e. $w \sim 10^{17}$ g cm$^{-1}$.

The next constraint of the model is provided by the expansion velocity of the thin shell. The observational information about this velocity should be extracted from the line profiles, particularly from the maximal velocity of the broad component. Since at the early epoch Thomson scattering can contribute in the broad wings (Chugai et al. 2003), in order to estimate the thin shell velocity we rely on the late nebular spectra of SN 1995G on days 265 and 561. In Fig. 3 the Fe II 5018 Å line is shown for both epochs (Pastorello et al. 2002). This line is free from blending which makes it a reliable indicator of the broad component velocity. The broad component is identified with the dense thin shell, possibly partially fragmented, at the boundary between the supernova and the CS gas as in SN 1994W (Chugai et al. 2003). The maximal velocity in the blue wing of the broad component is estimated using a simple procedure of the linear approximation of the line and continuum flux (Fig. 3). The derived maximal velocities are 3000 km s$^{-1}$ and 2700 km s$^{-1}$ on days 265 and 561, respectively, with a possible uncertainty of 10%. We attribute these velocities to the thin shell. Similar values ($\sim 3000$ km s$^{-1}$) are shown by the maximal velocity in the H$\alpha$ blue wing. However, in this case Fe II emission lines may contribute to the blue
Figure 4: Bolometric light curve of SN 1995G (upper panel) radius of the thin shell (middle) and the velocity of the thin shell (lower panel). Shown are two models (lines) G1 (left) and G2 (right) (see parameters in Table 1). Diamonds are empirical values taken from Pastorello et al. (2002) except for velocities, which are measured in the present paper.

wing flux, which may hamper the reliability of the estimate of the maximal velocity.

The expansion velocity of the CS envelope estimated from narrow absorption lines is \( u = 750 \text{ km s}^{-1} \) according to Pastorello et al. (2002). However, a somewhat larger value \( u \approx 850 \text{ km s}^{-1} \) is demonstrated by the emission lines of the infrared triplet of Ca II (Pastorello et al. 2002, their Fig. 10). We adopt here \( u = 800 \text{ km s}^{-1} \).

Finally, yet another constraint on the model is the observation that after day 700 the light curve shows a more rapid decay which is interpreted as the result of the overtaking of the outer boundary of the CS envelope by the forward shock (Pastorello et al. 2002). This fact will be used to estimate the outer radius of the CS envelope.

Preliminary computations of an extended set of the expansion dynamics and bolometric light curves for SN 1995G reveal the following important feature: it emerges that within empirical constraints the model is not sensitive to either of the two guiding supernova parameters, mass and energy. Selecting mass as a primary parameter, we found that a fit is achievable for a wide range of mass values. Two models with masses \( 2 M_{\odot} \) (model G1) and \( 10 M_{\odot} \) (model G2), with other parameters given in Table 1, show an
acceptable fit of the bolometric light curve, photospheric radius and thin shell velocity (Fig. 4). Note that to reach agreement with the photospheric radius in the first epoch we added 20 days to the age of the supernova given by Pastorello et al. (2002) which means that the explosion of SN 1995G is assumed to occur 20 days earlier than the zero point accepted in the cited paper. However, when some observational phase is mentioned in the text, we retain formally its day according to Pastorello et al. (2002). The models G1 and G2 confirm that the density and mass of the CS envelope do not depend on the adopted supernova mass (Table 1). The density at the radius of $10^{15}$ cm is $\approx 9 \times 10^{-15}$ g cm$^{-3}$, or in terms of the hydrogen concentration for a normal abundance, $n \approx 4 \times 10^9$ cm$^{-3}$.

The independence of the CS gas density on the adopted supernova mass has a simple explanation. For the high CS density required in case of SN 1995G both shock waves (forward and reverse) are essentially radiative during a long period ($\approx 700$ d) which means that for a given total radiated energy the amount of the dissipated kinetic energy in shocks is invariant. Since the forward shock dominates in the luminosity, the latter suggests that the overall radiated energy should be of the order of the average value of $0.5 M_{cs} (v - u)^2$, which thus must be invariant. Given observational constraints on the shell velocity ($v$) and CS velocity ($u$), the total mass of the CS envelope, thus, must also be invariant in different models.

In both models the kinetic energy is lower than the typical energy of core collapse supernovae ($10^{51}$ erg). Although the question of the typical value of the energy for SN IIn is open, it would be instructive to consider a case of a “standard” energy. The model G3 with the energy $E = 10^{51}$ erg shows a sensible fit and again requires the similar CS shell density and mass (Table 1) thus supporting the independence of these values on the adopted supernova mass at least in the range of $2 - 20 M_\odot$. Note, the latter statement can be reformulated in terms of supernova energy as a guiding parameter. In that case the derived CS density around SN 1995G is independent of the supernova energy at least in the range of $(0.24 - 1) \times 10^{51}$ erg.

The fact of the weak dependence of the CS gas density on the adopted supernova mass in the interaction model is of importance for the diagnostics of the CS density around SN IIn. The model of the bolometric light curve in combination with the velocity of the thin shell thus essentially provides us with a confident estimate of the CS density in the limit of the radiative forward shock wave. This tool was already used earlier for SN 1987F in an assumption of the standard supernova energy (Chugai 1992). Now it has become clear that in the limit of high CS density ($w \geq 10^{17}$ g cm$^{-1}$) the derived CS density practically does not depend on the adopted supernova mass, at least in the range of $2 \leq M \leq 20 M_\odot$. 

9
5 Discussion

The CS gas density distribution found above has direct implications for the interpretation of the spectrum of SN 1995G. The similarity of early spectra of SN 1995G and SN 1994W, particularly the presence of the strong effect of Thomson scattering in the H\(\alpha\) profile (Chugai et al. 2003) suggests that a substantial fraction of H\(\alpha\) is emitted by the CS envelope. Is this picture consistent with the above CS density estimate?

The H\(\alpha\) luminosity of the CS envelope in the range of \(r_1 < r < r_2\) in our model (\(\rho \propto r^{-2}\)) is

\[
L(H\alpha) = \frac{1}{4\pi r_1} \alpha_{32} h\nu_{23} (x X w N_A) \left( 1 - \frac{r_1}{r_2} \right),
\]

where \(\alpha_{32}\) is the effective recombination coefficient of H\(\alpha\) emissivity, \(h\nu_{23}\) is the energy of the H\(\alpha\) photon, \(x\) is the ionization degree, \(X\) is the hydrogen abundance, \(N_A\) is the Avogadro number. Substituting in equation (1) the values for day 2, namely, the inner radius \(r_1\) equal to the radius of the photosphere \(1.1 \times 10^{15}\) cm (Pastorello et al. 2002), outer radius \(r_2 = R_b = 2 \times 10^{16}\) cm, \(\alpha_{32} = 1.2 \times 10^{-13}\) cm\(^3\) s\(^{-1}\) (for electron temperature \(10^4\) K), \(w = 1.2 \times 10^{17}\) g cm\(^{-1}\), one obtains \(L(H\alpha) = 6.2 \times 10^{40} x^2\) erg s\(^{-1}\) assuming \(X = 0.7\). On the other hand, the observed H\(\alpha\) luminosity on day 2 is \(L(H\alpha) = 6.3 \times 10^{40}\) erg s\(^{-1}\) (Pastorello et al. 2002). Following the SN 1994W case we assume that the contribution of the CS component in H\(\alpha\) is at least

Figure 5: The same as in Figure 4 but for the model G3.
half of the total line luminosity (Chugai et al. 2003). Comparing the model and observational luminosity of the CS component we thus conclude that both values agree, if the average ionization degree of the model CS envelope is $0.7 < x \leq 1$.

The optical depth of the CS envelope to Thomson scattering for the same epoch is $\tau_T = k_T w x / 4 \pi r_1 \approx 2.6 x$. For the above range of the ionization degree this gives $1.8 < \tau_T < 2.6$. The presence of the strong red wing in Hα on day 2 (Pastorello et al. 2002, their Fig. 10) suggests significant Thomson scattering, so one expects $\tau_T > 1$. Moreover, close similarity of this profile with the Hα in SN 1994W on day 30 (Chugai et al. 2003, their Fig. 10) suggests that the optical depth of the CS envelope in SN 1995G is conceivably as large as $\tau_T \sim 2$, which is consistent with the above range of Thomson optical depth.

To summarize, the density of the CS envelope derived from the interaction model agrees with both the Hα line luminosity and the presence of strong effects of Thomson scattering in this line.

Generally, analysis of CS absorption lines might provide us additional information about the CS density. However this approach would require a rather complicated model of ionization and excitation in the CS envelope. Simple considerations based, for instance, on Fe II absorption, provide a rough lower limit (Sollerman et al. 1998). The requirement that absorption line with the optical depth $\tau$ is present in the spectrum is $\tau > 1$. For an envelope of a size $r$ with the average velocity dispersion on the line of sight of the order of the expansion velocity $v$ (greater than thermal velocity), the latter condition is

$$\tau \approx \sigma(\nu)n_1 r \approx \sigma_0 n_1 r \lambda_{12} / v > 1,$$  \hspace{1cm} (2)

where $\sigma_0 = (\pi \epsilon^2 / m_e c) f_{12}$ is the integrated over frequency cross-section $\sigma(\nu)$, $f_{12}$ is the oscillator strength, $n_1$ is the concentration at the lower level, $\lambda_{12}$ is the wavelength. For the Fe II 5018 Å absorption ($f_{12} = 0.01$) adopting on day 2 the excitation temperature of the lower level equal to the photospheric one, 8800 K (Pastorello et al. 2002), and taking $r$ equal to the photospheric radius ($1.1 \times 10^{15}$ cm) one gets the lower limit of the hydrogen concentration assuming a solar Fe abundance $n > 3 \times 10^7$ cm$^{-3}$ in qualitative agreement with the density found from the light curve analysis.

The outer boundary of the CS envelope ($2 \times 10^{16}$ cm) combined with the CS expansion velocity 800 km s$^{-1}$ implies the age of the CS envelope $t_{cs} \approx 8$ yr which is close to the estimate of the starting time for the strong mass loss, $\approx 12$ yr before the supernova explosion found by Pastorello et al. (2002). The mass of the CS envelope ($1 M_\odot$) combined with the age thus suggests the average mass loss rate $\dot{M} \sim 0.1 M_\odot$ yr$^{-1}$ which is an
enormous value. The estimated total kinetic energy of the CS envelope is \( E_{\text{cs}} \approx 6 \times 10^{48} \) erg and the average kinetic luminosity of the mass loss is then \( E_{\text{cs}}/t_{\text{cs}} \approx 2.4 \times 10^{40} \) erg s\(^{-1}\). This value is almost a factor of two in excess of the typical radiative luminosity of a massive presupernova (\( \approx 10^5 L_\odot \)). Thus the mass loss certainly cannot be attributed to the superwind.

We propose, therefore, that the mass ejection in the SN 1995G presupernova was initiated by some powerful energy release in the hydrodynamic time scale approximately 8 years before the major supernova explosion. In fact we are reproducing here arguments used in the case of SN 1994W to conclude that the CS envelope around SN 1994W was lost as a result of an explosive event \( \sim 1.5 \) yr before the supernova explosion (Chugai et al. 2003). It was proposed there that the explosive mass ejection was initiated by the flash of nuclear burning of Ne in the degenerate O/Ne/Mg core. This assumption follows the original hypothesis of Weaver and Woosley (1979) concerning the behavior of presupernovae with initial masses of \( \approx 11 M_\odot \). A similar possibility might occur also in the case of SN 1995G. Note that the age of the CS envelope around SN 1995G (\( \approx 8 \) yr) lies within the range of the phase for the Ne burning in massive star cores 1 – 10 years before the supernova explosion (Heger 1998).

If the initial mass of the SN 1995G presupernova was actually close to 11 \( M_\odot \) then given a neutron star of 1.4 \( M_\odot \) the supernova ejecta cannot exceed 10 \( M_\odot \). In that case our interaction model predicts that the supernova kinetic energy \( \leq 6 \times 10^{50} \) erg (Table 1). This is lower than the value 1.5 \( \times 10^{51} \) erg adopted for SN 1994W (Chugai et al. 2003). It may well be that the differences of supernova energies and ages of CS shells of SN 1995G and SN 1994W are possibly related to slight differences in their initial masses or in slightly different evolutionary histories.

If the mass ejection of presupernova SN 1995G had an explosive nature then the CS envelope expansion regime must be close to a free expansion (\( u \propto r \)) law, at least in the outer layers. In this respect the increase of velocity derived from CS absorption lines of Fe II between days 330 and 560 (Pastorello et al. 2002) is qualitatively consistent with the possible free expansion CS kinematics.

The envelope ejection with the mass of \( \approx 1 M_\odot \) and kinetic energy of \( \sim 6 \times 10^{48} \) erg should be accompanied by the optical flash eight years before the explosion of SN 1995G. In a simple analytical model of the light curve (Chugai 1991) assuming presupernova radius 100 < \( R_0 < 1000 R_\odot \) we estimate the absolute magnitude of flash maximum as \( -12.5 > M_V > -13.5 \) mag. with the duration of the light curve of 80 – 120 days. For the distance of 63 Mpc the apparent magnitude of maximum for this flash is \( 21.8 > V > 20.8 \) mag. The only available image of the host galaxy NGC1643 close to the suggested time of the presupernova flash is a UK Schmidt plate taken
12 Dec. 1982, 13 years before the SN 1995G explosion. Therefore this image does not constrain the presupernova flash history. Inspection of this plate reveals no object brighter than 20.5 mag. in J band.

6 Conclusion

We performed the modeling of the bolometric light curve and expansion dynamics of SN 1995G in the dense CS environment. As a result we obtained the density and mass of the CS envelope which do not depend on the adopted mass of the supernova envelope. The derived mass of the CS envelope combined with the velocity of the CS gas leads us to conclude that the CS envelope was ejected as a result of energetic hydrodynamical process eight years before the explosion of SN 1995G. We speculate that this mass ejection was initiated by the powerful flash of nuclear burning in the O/Ne/Mg core of presupernova following the earlier conjecture proposed in the case of SN 1994W.

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References

1. Arnett W.D., *Supernovae: A survey of current research*, Ed. M.J. Rees, R.J. Stoneham (Reidel, 1982), p. 221.
2. Arnett W.D., Astrophys. J. 237, 541 (1980).
3. Chevalier R.A., Astrophys. J. 259, 302 (1982a).
4. Chevalier R.A., Astrophys. J. 258, 790 (1982b).
5. Chugai N.N., Sov. Astr. Lett. 16, 457 (1990).
6. Chugai N.N., Sov. Astr. Lett. 17, 210 (1991)
7. Chugai N.N., Sov. Astr. 36, 63 (1992)
8. Chugai N.N., Mon. Not. R. astron. Soc. 326, 1448 (2001).
9. Chugai N.N., Blinnikov S.I., Lundqvist P. *et al.*, Mon. Not. R. astron. Soc. (in preparation) (2003).
10. Falk S.W. and Arnett D.W., Astrophys. J. Suppl. 33, 515 (1977).
11. Grasberg E.K., Nadyozhin D.K., Sov. Astr. Lett. 12, 68 (1986).
12. Heger A., *The presupernova evolution of rotating massive stars*, Ph.D dissertation, MPA 1120 (1998).
13. Nadyozhin D.K., Preprint ITEP No. 1 (1981).
14. Nadyozhin D.K., Astrophys. Space. Sci. 112, 225 (1985).
15. Pastorello A., M. Turatto, S. Benetti *et al.*, Mon. Not. R. astron. Soc.
333, 27 (2002).
16. Salamanca I., Cid-Fernandes R., Tenorio-Tagle G. et al., Mon. Not. R. astron. Soc. 300, L17 (1998).
17. Schlegel E., Mon. Not. R. astron. Soc. 244, 269 (1990).
18. Sollerman J., Cumming R.J. and Lundqvist P., Astrophys. J. 493, 933 (1998).
19. Turatto M., Suzuki T., Mazzali P. et al., Astrophys. J. 534, L57 (2000).
20. Weaver T.A. and Woosley S.E., BAAS 11, 724 (1979).
21. Woosley S.E., Heger A. and Weaver T.A., Rev. Mod. Phys. 74, 1015 (2002).