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HYDROGEN IN THE SPECTRUM OF SN 1990M: NO MORE?

MASSIMO DELLA VALLE,[1,2] STEFANO BENETTI,[3] AND NINO PANAGIA[2,4]
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ABSTRACT

The detection of hydrogen in the spectra of Type Ia supernovae is matter of recurrent debates, in that it could provide an important constraint on the nature of the progenitors. Currently, the most "robust" evidence for hydrogen in spectra of Type Ia supernovae is given by an Hα absorption line measured by Polcaro & Viotti in an early stage spectrum of SN 1990M. Through the analysis of an unpublished spectrum of this object, obtained with the 1.52 m ESO telescope one day after the SN discovery, we show that the claimed Hα detection is originated by an observational bias. Once the subtraction of the parent galaxy background is properly done, no evidence for an Hα absorption is found in the spectrum of SN 1990M. We set a rough upper limit of to the hydrogen abundance in the supernova atmosphere of H/Si $\leq 2 \times 10^{-6}$.

Subject headings: galaxies: individual (NGC 5493) — supernovae: individual (SN 1990M)

1. INTRODUCTION

Two classes of objects are currently believed to be the most promising candidates for progenitors of Type Ia supernovae: pairs of C—O white dwarfs, making coalescence within a Hubble time, and C—O white dwarfs accreting hydrogen from a subgiant donor via Roche lobe overflow (Branch et al. 1995). However, observational constraints on both classes are very poor. In particular, the suggestion that the progenitors of Type Ia supernovae can be CV-type systems would imply that a small fraction of hydrogen (of the order of $X(\mathrm{H}) \gtrsim 0.01$, Applegate & Terman 1989), stripped off and ablated from the secondary during the explosion, should contaminate the spectrum of the supernova (e.g., Wheeler 1992).

So far, only for three supernovae have there been claims of detection of hydrogen lines, either in absorption or emission, in their early spectra: 1981B (Branch et al. 1983), 1990M (Polcaro & Viotti 1991, hereafter PV), and 1990N (Leibundgut et al. 1991).

In the case of SN 1990N, Leibundgut et al. (1991) present evidence for an unidentified absorption line at 6300 Å that appeared in the spectrum of the SN 2 weeks before maximum. However, assuming this absorption to be Hα, the estimated expansion velocity ($\sim$12,000 km s^{-1}) turns out to be considerably smaller (by a factor of 2) than the values determined for the other lines. While this could indicate the presence in the ejecta of a thin layer of hydrogen that is dragged out by the expanding envelope, the authors themselves suggest that the identification of this feature with Hα is rather unlikely. Furthermore, in a subsequent paper Jeffery et al. (1992) tentatively identified this feature (and a second one at 6900 Å) as blueshifted lines of C II at 6580 and 7243, so that the case for hydrogen lines in the SN 1990N spectrum essentially vanishes.

The possible presence of hydrogen in SN 1981B is based on the detection of a narrow emission line at the rest wavelength of Hα in a spectrum taken about 1 week past maximum (Branch et al. 1983). If this is the case, the line should originate in a slowly moving circumstellar envelope and be powered by the recombination energy following photoionization by the initial UV flash of the supernova. However, also in this case the authors seem to consider this possibility rather unlikely, in view of the fact that no trace of Hα emission was found in the next spectrum obtained only 5 days later, whereas the typical recombination time for ionized circumstellar gas is of the order of months or years. Therefore, there are grounds for reasonable doubt about the line identification, and this case can be dismissed, too.

Apparently, the "most solid" evidence for the presence of hydrogen in the spectrum of a Type Ia SN was provided by Polcaro & Viotti (1991) with an observation of SN 1990M. In a spectrum obtained on June 16.9 these authors revealed a relatively broad absorption line centered at 6619 Å, and with FWHM = 16.7 Å, EW = 1.32 Å. Their interpretation is that the absorption originates in some circumstellar material lost, via intense wind, by the progenitor prior to the explosion.

SN 1990M was also observed a day earlier by Della Valle & Leisy (1991) using the same telescope at lower resolution ($\sim$8 Å), and was reobserved on August 9 with the same equipment. In this Letter, we analyze and discuss our spectra. The main results are (1) once the parent galaxy background is properly subtracted, our early spectrum does not show evidence for Hα; (2) the Hα absorption measured by Polcaro & Viotti can entirely be ascribed to the parent galaxy rather than to the SN; and (3) the abundance of hydrogen relative to silicon in the supernova atmosphere was $\leq 2 \times 10^{-6}$ as compared to the solar abundances.

2. EARLY SPECTROSCOPY OF SN 1990M

Our June spectrum (displayed in Fig. 1) was reduced using standard procedures of the MIDAS package. First, we modeled the background underlying the SN by fitting a second-degree polynomial to the background just adjacent to the SN (over 10″; see Fig. 2, *dashed-dotted line*), then we subtracted this fitted background from the extracted spectrum (i.e., SN + galaxy, *solid line*): the difference is shown by the dashed line. Figure 3 (*top*) shows the result: the absorption line at 6619 found by PV has disappeared. In fact, from the noise level and adopting the same line width as measured for the

[1] Dipartimento di Astronomia, Università di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy; dellavalle@astrpd.pd.astro.it.

[2] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218.

[3] European Southern Observatory, La Silla, Vitacura, Casilla 19001, Santiago, Chile; sbenetti@eso.org.

[4] Affiliated to the Astrophysics Division, Space Science Department of ESA; panagia@stsci.edu.

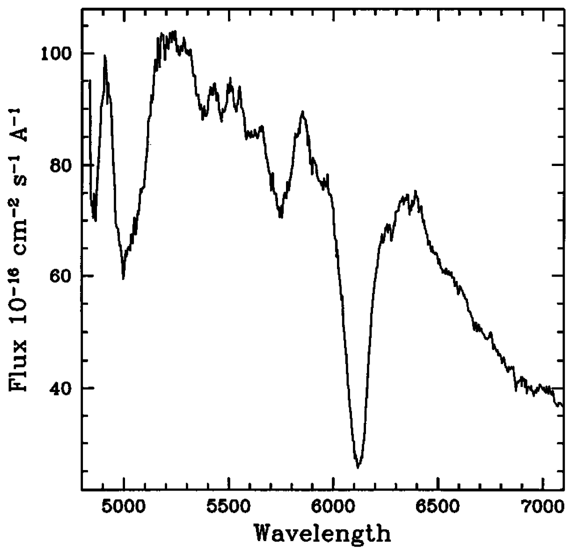

FIG. 1.—Spectrum of SN 1990M obtained on 1990 June 16.1

Si II 6350 Å line, we can set an upper limit (1 σ) to the equivalent width of a possible Hα absorption as

$$EW(\mathrm{H}\alpha) \leq 0.2\ \text{Å}\,.$$

Reading the paper of PV, it appears that the authors may have not given weight to the fact that *the galaxy itself exhibits an* Hα *absorption line* centered at 6621.4 Å with FWHM = 18.4 Å and EW = 2.5 Å (see Fig. 3, *middle*). This profile is rather similar to the feature detected by PV (cf. λ = 6619.2 Å, FWHM = 16.7 Å and EW = 1.32 Å), therefore raising the suspicion that their spectrum of SN 1990M (Fig. 1 of PV) could be heavily contaminated by the galaxy.

As a test of this possibility, we tried to reproduce the profile observed by PV. The best match was obtained by subtracting from the "extracted" spectrum (i.e., SN + galaxy) a background signal as measured at a considerable separation from the supernova (about 35″, where the galaxy background has an intensity comparable to that of the sky). This effect is well illustrated in Figure 3 (*bottom*). Following this procedure, we obtain an Hα absorption line centered at 6619.2 Å with a FWHM of 16.0 Å and EW = 0.9 Å, which are quite similar to the characteristics of the feature reported by PV.

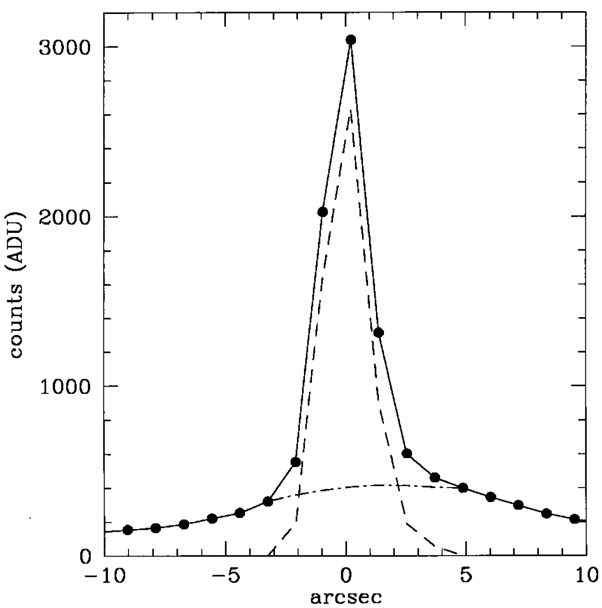

FIG. 2.—Extracted profile of SN 1990M is represented by the dashed line. Dots are the observed profile, and the dash-dotted line is the fit to the continuum adjacent of the SN.

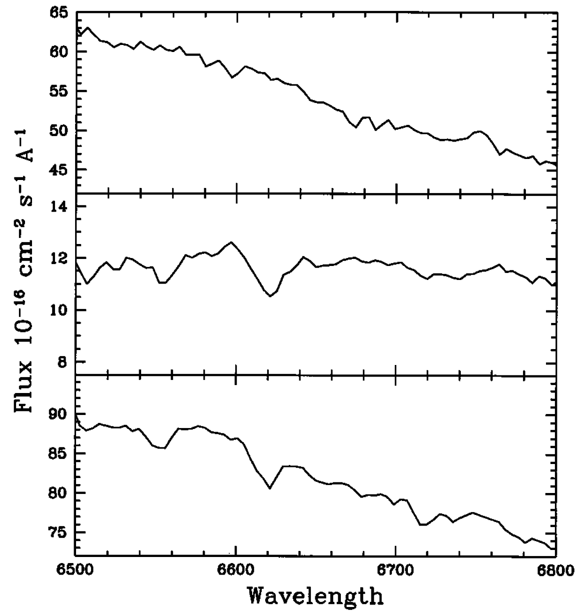

FIG. 3.—(*top*) Enlargment of Fig. 1 around the position (6619 Å) of the Hα detection. The top panel shows clearly that there are no features detectable at 6619 Å above the noise level. (*middle*) Spectrum of the galaxy, displaying Hα in absorption. (*bottom*) Spectrum of the SN once it is strongly contaminated by that of the galaxy (see text).

Further evidence that their spectrum is heavily contaminated by the galaxy emission is provided by the following facts. The continuum slope in our spectrum (see Fig. 1) is definitely steeper (our $\Delta F/\Delta\lambda$ is a full factor of 2 larger than the one that can be measured from the PV profile as estimated from their Fig. 1), thus confirming that their spectrum is contaminated by the flatter spectrum of the galaxy. In fact, PV's spectrum shows also a number of absorption features that are prominent in the spectrum of the galaxy and that are not detectable in our data (e.g., the absorption at ~6550).

From this we conclude that inadequate subtraction of the galaxy background is the cause for the presence of an apparent Hα absorption line in the spectrum of SN 1990M.

3. THE AGE OF 1990M

SN 1990M was discovered by Evans (1990) on June 15 in NGC 5493 at visual magnitude $\lesssim$13.5. On the basis of photometric observations reported in IAU Circulars 5033 and 5043, PV assume that SN 1990M has been caught about one week before maximum. However, the low quality of the photometry does not allow one to set the date of the maximum reliably.

Independent indications about the age of the SN at the epoch of the discovery can be derived from the spectra. A comparison was made with early time spectra of 1981B (Branch et al. 1983), 1984A, and 1989B (Barbon et al. 1989, 1991; Wells et al. 1994) and 1994D (Patat et al. 1996). The spectrogram obtained on June 16 bears similarities with those Type Ia supernovae about 1 week to 10 days past maximum,

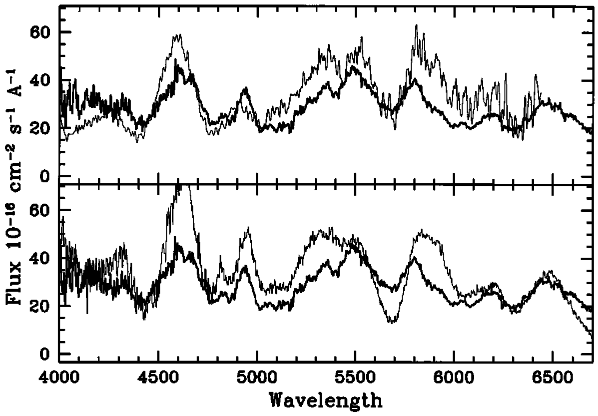

FIG. 4.—Spectrum of SN 1990M obtained on Aug. 9 (*heavy line*) is compared with those of SN 1984A (*top*) and SN 1994D (*bottom*) obtained 69 and 64 days past maximum light, respectively, with the McDonald (1984A) and the ESO 3.6 m (1994D) telescopes.

except for the unusual faintness, at this stage, of the absorptions in the region 5200–5500 Å. The high expansion velocity ($\sim$13,900 km s^{-1}), inferred from the minimum of the Si II 6355 Å absorption, places SN 1990M among the fast expanding Type Ia supernovae (see also Branch & van den Bergh 1993) like SN 1984A. In Figure 4 we display the late stages spectrum of 1990M (*solid line*). The comparison is carried on with late stages spectra of the fast expanding Type Ia supernova 1984A (Fig. 4, *top*) and the "normal" one, 1994D (Fig. 4, *bottom*), obtained at 69 and 64 days past maximum. The match with 1984A is remarkably good, therefore lending support to the idea that SN 1990M was caught a few days after maximum (see Benetti, Capellaro, & Turatto 1990).

From this analysis we conclude that the maximum of 1990M occurred, very likely, between 1990 June 5 and 10. The only reliable $(B-V)$ measurement of the SN $(B-V=0.27\pm0.14)$ obtained by Bond (1990) on June 17 is fully consistent with that of a normal Type Ia SN observed about 10 days after maximum (e.g., Patat et al. 1996). In particular, the $(B-V)$ color and the expansion velocity of SN 1990M at phase +7/+10 are completely different from those of the subluminous SNIa 1991bg at maximum and/or 10 days later (Filippenko et al. 1992; Leibundgut et al. 1993). This rules out that SN 1990M may belong to the class of Type Ia "red and faint," like 1991bg (Turatto et al. 1996) or 1992K (Hamuy et al. 1994).

4. DISCUSSION AND CONCLUSIONS

In § 2 we have shown that there is no evidence of a hydrogen Hα absorption in the spectrum of SN 1990M, and we set an upper limit to its equivalent width of 0.2 Å. Such a stringent limit indicates that the abundance of hydrogen in the SN upper layers must be quite low. In particular, assuming LTE conditions and adopting a temperature around 12,000 K, which is appropriate for an early phase, from the upper limit to the Hα line equivalent width (0.2 Å) and the measurement of the Si II 6350 Å line equivalent width (92 Å) we estimate that the ratio H/Si in the SN atmosphere was $\sim 2\times10^{-6}$ lower than in the Sun, with an uncertainty of a factor of 2–3 because of the uncertainties associated with the LTE and the temperature assumptions (see also Branch et al. 1982).

However, the atmospheric layers of the SN at such an early phase include only a small fraction of the ejecta. For example, adopting an opacity of 0.2 cm^2 g^{-1} (Khokhlov, Müller, & Höflich 1993), an optical depth of unity at about 20 days after explosion corresponds to a mass of only $\sim 4\times10^{-2}\ M_\odot$, which is less than 1/20 of the mass of the ejecta. If we assume that there is perfect mixing in the ejecta, and we use the abundances of the standard W7 model (Nomoto, Thielemann, & Yokoi 1984) as a reference, then a ratio H/Si $\sim 2\times10^{-6}$ would translate into a mass fraction of hydrogen of $X(\mathrm{H})\approx0.007$. On the other hand, if hydrogen exists only in a specific portion of the ejecta, then the fractional abundance could be quite different: if H can be present only in the outermost layers, then $X(\mathrm{H})\ll0.007$ and could be as low as $0.007\times M(\mathrm{atmosphere})/M(\mathrm{total})\approx3\times10^{-4}$. If instead H is buried deep into the ejecta, then values of X(H) higher than 0.007 are possible. One has to consider, however, that considerable amounts of hydrogen cannot be concealed forever, because, as time proceeds the photosphere recedes, thus exposing the inner layers.

This finding, i.e., no evidence for hydrogen in SN 1990M, is not necessarily at variance with the suggestion that CV-type systems can originate Type Ia supernovae (Della Valle & Livio 1994). Indeed, we expect a low realization frequency for such progenitors in old stellar population systems (Branch et al. 1995). However, we note that the high expansion velocity exhibited by SN 1990M, whose parent galaxy NGC 5493 is classified as an S0, is a remarkable exception to the result (see, e.g., Ruiz-Lapuente, Burkert & Canal 1995, and references therein) that the mean velocity of the ejecta is higher for supernovae occurring in parent galaxies of later Hubble types. As suggested by Branch & van den Bergh (1993), this fact could be explained by assuming that the progenitor of SN 1990M belonged to a relatively young stellar population, whose presence may be revealed by the rather blue color of the parent galaxy.

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REFERENCES

Applegate, J. H., & Terman, J. L. 1989, ApJ, 340, 380
Barbon, R., Benetti, S., Cappellaro, E., Rosino, L., & Turatto, M. 1990, A&A, 237, 79
Barbon, R., Iijima, T., & Rosino, L. 1989, A&A, 220, 83
Benetti, S., Cappellaro, E., & Turatto, M. 1990, IAU Circ. 5034
Bond, H. 1990, IAU Circ. 5034
Branch, D., Buta, R., Falk, S. W., McCall, M. L., Sutherland, P. G., Uomoto, A., Wheeler, C., & Wills, B. J. 1982, ApJ, 252, L61
Branch, D., Lacy, C. H., McCall, M. L., Sutherland, P. G., Uomoto, A., Wheeler, C. & Wills, B. J. 1983, ApJ, 270, 123
Branch, D., Livio, M., Yungelson, R. L., Boffi, F., & Baron, E. 1995, PASP, 107, 1019
Branch, D., & van den Bergh, S. 1993, AJ, 105, 2231
Della Valle, M., & Leisy, P. 1991, IAU Circ. 5034
Della Valle, M., & Livio, M. 1994, ApJ, 423, L31
Evans, R. 1991, IAU Circ. 5033
Filippenko, A. V., et al. 1992, AJ, 104, 1543
Hamuy, M. et al. 1994, AJ, 108, 2226
Jeffery, D. J., Leibundgut, B., Kirshner, R. P., Benetti, S., Branch, D., & Sonneborn, G. 1992, ApJ, 397, 304
Khokhlov, A., Müller, E., & Höflich, P. 1993, A&A, 270, 223
Leibundgut, B., Kirshner, R. P., Filippenko, A. V., Shields, J. C., Foltz, C. B., Phillips, M. M., & Sonneborn, G. 1991, ApJ, 371, L33
Leibundgut, B., et al. 1993, AJ, 105, 301
Nomoto, K., Thielemann, F. K., & Yokoi, K. 1984, ApJ, 286, 644
Patat, F., Benetti, S., Cappellaro, E., Danziger, J., Della Valle, M., Mazzali, P. A., & Turatto, M. 1996, MNRAS, in press
Polcaro, V. F., & Viotti, R. 1991, A&A, 242, L9 (PV)
Ruiz-Lapuente, P., Burkert, A., & Canal, R. 1995, ApJ, 447, L72
Turatto, M., Benetti, S., Cappellaro, E., Danziger, J., Della Valle, M., Gouiffes, C., Mazzali, P., & Patat, F. 1996, MNRAS, submitted
Wells, L. A., et al. 1994, AJ, 108, 2234
Wheeler, C. 1992, in IAU Symp. 151, Evolutionary Processes in Interacting Binary Systems, ed. Y. Kondo et al. (Dordrecht: Reidel) 225