Spectral classification of the supernova SN2009af

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ABSTRACT

The aim of this work is the classification of the supernova SN2009af in UGC1551 observed at the Asiago Astrophysical Observatory with the 122 cm "Galileo" telescope. By analysing the spectra and the well evident P-Cygni profile of the $H\alpha$ line we were able to classify our object as a type II SN. We also calculated other parameters such as ejecta velocity, absolute magnitude and luminosity.

I. INTRODUCTION

A supernova is a star that undergoes a tremendous explosion and a sudden brightening: during this time its luminosity becomes comparable to that of an entire galaxy.
An important feature for the classification of the SNe is the light curve, which is a plot of magnitude as a function of time. In the graph below (Fig. 1) we can see a maximum peak followed by a decline.

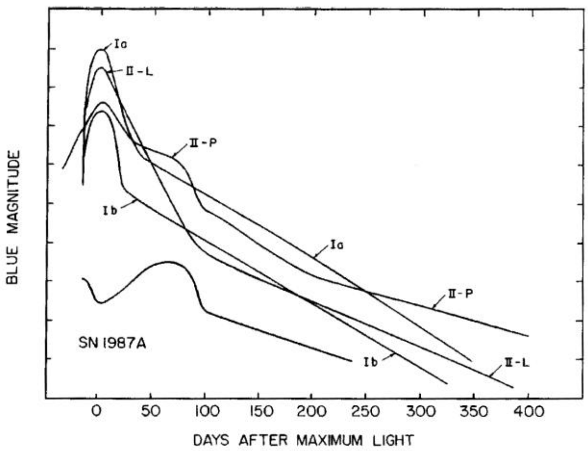

Fig. 1. Light curves of different SN types.

SNe can be divided in two main classes that are classified on the basis of the presence or absence of hydrogen lines in their spectra as type I SNe (SNI) or type II SNe (SNII), respectively.
If a type I SN shows the SiII line it is called SN Ia. The type Ib is characterized by the presence of HeI. If the SN shows neither SiII nor HeI it is called Ic.

The categories of the type II are based on the light curves. The type IIP shows a slower decline (plateau) followed by a normal decay, while the type IIL shows a linear decline of the light curve. Moreover we can find type IIb SNe which look like type II SNe at the beginning but then their spectrum becomes more similar to a SN Ib/c.
Some peculiar type Ib/c and IIn SNe with explosion energies $E > 10^{52}$ erg are often called hypernovae.

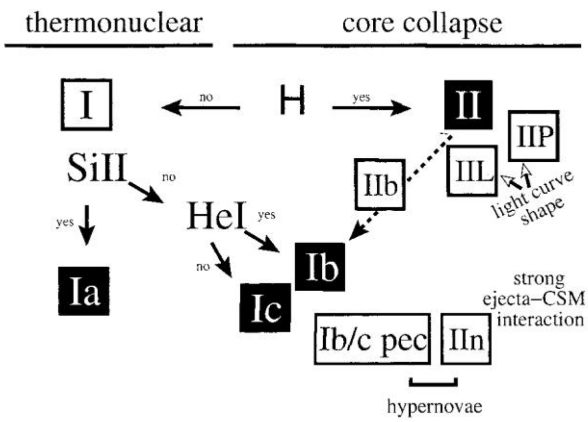

Fig. 2. The current classification scheme of supernovae.

SNIa are discovered in all type of galaxies, elliptical ones as well, and are not associated with the arms of spirals as strongly as other SN types.
The overall homogeneous spectroscopic and photometric behaviour of SNIa has led to a general consensus that they are associated with the thermonuclear explosion of a white dwarf.
The uniformity of their light curves, their high luminosity and relatively small luminosity dispersion at

maximum (<M_B> = -18.6) allow us to use them as standard candles in order to determine distances.
The spectra of SN Ia are characterized by lines of intermediate mass elements such as calcium, oxygen, silicon and sulphur during the peak phase and by the absence of H at any time. Then the contribution of the Fe lines increases and several months after the maximum the SN Ia spectra are dominate by [Fe II] and [Fe III] lines.
Type II are observed in arms of spiral galaxies which are rich in gas and dust and where star formation is ongoing and young stars are abundant. Type II SNe are associated with the death of massive stars due to the collapse of the Fe core at the end of evolution. These stars have large H-rich envelopes evident also in their spectra. Stellar evolutionary calculations suggest that stars with M > 8-10 $M_\odot$ undergo all major burning stages ending with a growing Fe core.
Supernovae are very important because they are the main source of the heavy elements found in the universe.

II. OBSERVATIONAL DATA

The Supernova we studied is SN2009af belonging to the galaxy UGC1551 in the constellation of Aries.

Fig. 3. SN 2009af in UGC1551.

Right Ascension	02h03m37.5s
Declination	+24d04m32s
Classification	SB IV-V
Velocity	1671 km/s
Redshift	0.008909
Magnitude	13.50
Major Diameter	2.8 arcmin
Minor Diameter	2.3 arcmin
Distance	37.09 Mpc

Fig. 4. Astronomical data of UGC1551

We observed the SN using the 122 cm telescope "Galileo" at the Asiago Astrophysical Observatory on February 18th 2009. We took 5 x 20 min exposures in order to collect a stronger signal.

III. WORK DESCRIPTION

The raw spectra give us information about how photons are dispersed by the spectrograph. However, we cannot make any measure of energy, wavelength or any other feature. Therefore, raw data have to be transformed into scientific data. Moreover, any other light source that reaches the spectrograph disturbs our spectrum, and so we must apply some corrections in order to isolate the light from the object we are interested in.
For the spectroscopic analysis of SN 2009af we used the program IRAF through which we were able to correct the errors in the image and to extract the spectrum. The program uses four types of files:
BIAS, which is obtained through an almost null duration exposure (with the shutter closed) and must be subtracted from the data we took;
FLAT-FIELD, i.e. the data based on the continuum spectrum of a lamp, which allow us to correct the errors deriving from the lack of homogeneity in the CCD;
WAVELENGTH CALIBRATION FRAMES, i.e. a Hg-Ar-Ne spectral lamp used to compare the pixel position on the CCD of the emission lines produced by this lamp with their known wavelengths (in angstrom);
FLUX CALIBRATION FRAMES, i.e. one or more standard stars, whose flux as a function of wavelength is known; its observed intensity on the CCD in photon counts units is compared with physical units.
In addition, we have to subtract the spectral lines and the diffuse emission produced by the sky. Finally, we have to add the 5 exposures to increase the quality of the spectrum, that is to increase the signal-to-noise ratio of the spectrum.
As a result the obtained information can be represented into a wavelength-flux graph.

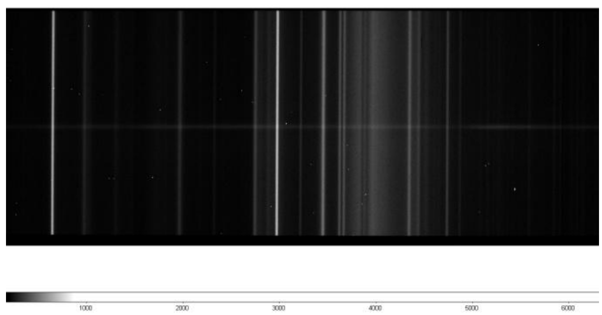

Fig. 5. Spectrum of SN2009af, February 18th.

In the spectrum we can notice the typical P-Cygni profile.

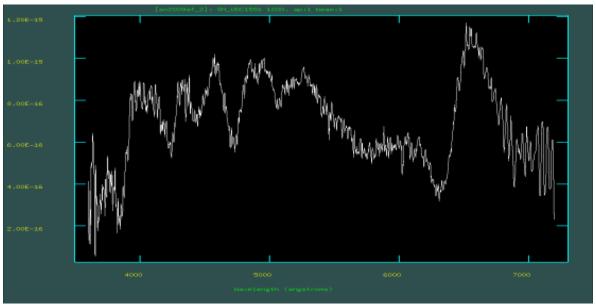

Fig. 6. Spectrum of SN2009af **λ-F**$_{\lambda}$.

The P-Cygni profile is visible in stars with a powerful stellar wind or an expanding shell of gas. In particular, we can observe some blueshifted absorption lines and some redshifted emission lines.

The absorption lines derive from the part of the expanding photosphere that is coming towards the observer. Their radial velocity corresponds mainly to the expansion velocity of the ejected material and the Doppler shift is obviously negative. On the contrary, the emission lines come from the lateral regions of the shell which move on average perpendicularly to the line of sight. This singular profile was first observed in the celestial body called P-Cygni (34 Cygni).

For each element in the ejected atmosphere of our SN, we can see a P-Cygni profile, which can be well evident as in the Hα line, or not very defined, as in the case of the Hβ line. By overlaying a gaussian function on the absorption profile, we are able to calculate the wavelength of the Hα line of the ejecta and therefore their velocity, using the following equation:

$$z = \frac{(\lambda - \lambda_0)}{\lambda_0} = \frac{v}{c}$$

$$z = \frac{(6301 - 6563)}{6563} = -0.0399207$$

$$v = -0.0399207 \cdot c = -11967945.15 \text{ m/s} \approx -12000 km/s$$

This is the expansion velocity of the gas that composes the photosphere of the supernova derived from the blueshift. Although, we must subtract the velocity of the host galaxy UGC 1551, V= 2670 km/s, the real expansion velocity of the ejecta is the following:

$$v = -12000 - 2670 = -14670 \text{ km/s}$$

We calculated the distance of the SN from the redshift of the galaxy UGC 1551 (z = 0.00891) using Hubble's law:

$$v = H_0 D$$

finding a distance of 37 Mpc.

We compared the SN with other 3 stars in the same field in order to estimate the apparent magnitude.

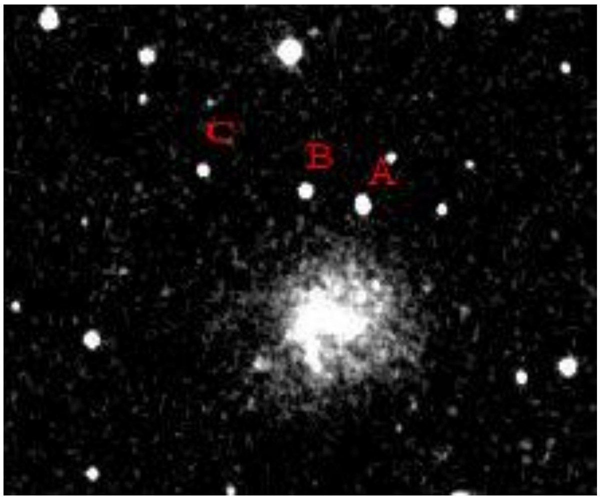

Fig. 7. Image of the stars A, B and C near the galaxy UGC1551.

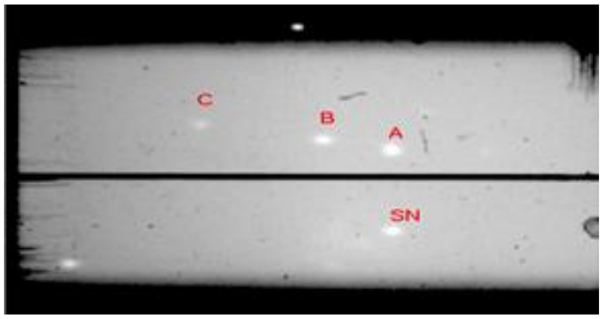

Fig. 8. Image of the SN and the stars A, B and C we took from the spectrograph.

At first, we took the apparent magnitude of the stars A, B and C from the USNO-B1.0 catalogue.

A) mag: 15.25 B2
14.37 R2 Instrum: 12.64
13.59 IMag

B) mag: 16.15 B2
15.21 R2 Instrum: 12.82
14.63 IMag

C) mag: 18.01 B2
16.28 R2 Instrum: 13.47
15.04 IMag

Instrumental magnitude of the SN: 12.79mag.

Then, we calculated the difference between the instrumental magnitudes of the stars we had chosen and that of the SN:

$$x = A - SN = -0.15$$
$$y = B - SN = 0.03$$
$$z = C - SN = 0.68$$

After that, we subtracted the differences we found from the values of the magnitude of the stars in the catalogue in R2 bands.

$$A_{R2} - x = 14.52$$
$$B_{R2} - y = 15.18$$
$$C_{R2} - z = 15.60$$

We calculated the average which is 15.10.
Then we calculated the absolute magnitude from the apparent magnitude:

$$M = m + 5 - 5\log_{10} d$$

Where M = absolute magnitude, m = apparent magnitude and d = distance in pc.
The absolute magnitude is -17.75.
Finally we used Pogson's law to calculate the luminosity of the SN:

$$M - M_{sun} = -2.5 \times \log \frac{L}{L_{sun}}$$

The luminosity is 4.14×10^{35} W = 4.14×10^{42} erg/s (1.08×10^{9} $L_{\odot}$).

IV. RESULTS

To classify a supernova we should have both the spectrum and the light curve. Since we did not have the latter, we tried to make some hypotheses by studying only the spectrum. Certainly, it is not a type I SN for the presence of hydrogen lines. On the contrary, we are able to classify it as a type II Supernova, because of the strong Hα emission. Moreover, by comparing the spectrum of SN 2009af to that of type II SN 1992H, taken 20 days after maximum published by Filippenko (1997), we noticed an evident similarity between the two spectra.
We compared SN 2009af with one of the most studied type IIb SNe, 1993J in M81. We overlaid the spectrum of SN2009af with the one of SN 1993J on April 21st.

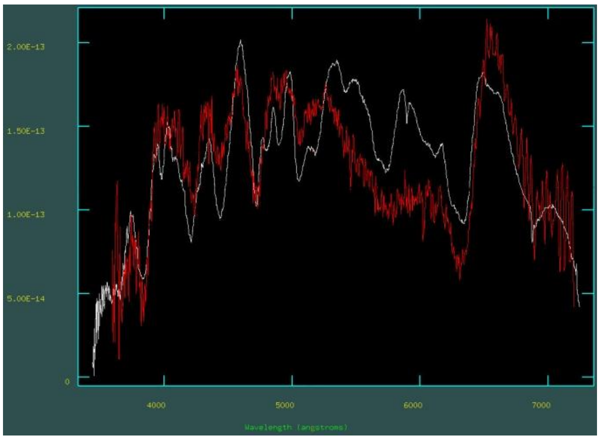

Fig. 9. Comparison between the spectra of the SN2009af (red) and the SN1993J (white) in the 21st day after the explosion.

We noticed an evident similarity in particular in the regions 3700 - 5000 Å and 6200 - 6900 Å. In these ranges we can see that the P-Cygni profiles are almost analogous. However, the spectra are not very similar between 5000 Å and 6200 Å. This means that we cannot exclude the possibility of a type IIb classification for SN 2009af. To do this we should analyse the supernova for a long period, taking some spectra at different dates in order to create a chronological evolution of the star.
At present, we are unable to define if SN 2009af is a SN II-P , SN II-L or another subclass. We should have the light curve and more detailed studies of the supernova.

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