Type IIb Supernova 2011fu: Spectral and light curve evolution

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ABSTRACT: Type IIb supernovae (SNe) are a subclass of core-collapse supernovae that appear to be a hybrid between SNe characterized by the presence of H in their spectra (Type II) and Type Ib/c SNe (those that do not exhibit H features in their spectra but possibly HeI). We present some preliminary results of the photometric and spectroscopic analysis of type IIb supernova 2011fu. In principle, the characteristics of SN 2001fu are pretty similar to those of canonical type IIb SNe, but its Bessel *UBVRI* and Sloan *uriz* light curves (LCs) present an early peak resembling the unique case of the well studied type IIb SN 1993J (Richmond et al. 1994).

INTRODUCTION:

SN 2011fu (*Figure 1*), of coordinates α=2h08m21.656s and δ=41º28'30.53" (J2000), was discovered in the galaxy **UGC1626** by F. Ciabattari and E. Mazzoni, on September 21.04 UT 2011. The redshift derived distance to UGC1626 (provided by the NASA/IPAC extragalactic database ,NED) is d=77.9 +/- 5.5 Mpc (μ=34.46 +/- 0.15 mag).

SN 2011fu is a target from the *NTT-TNG Large Programme (P.I. S. Benetti)*.

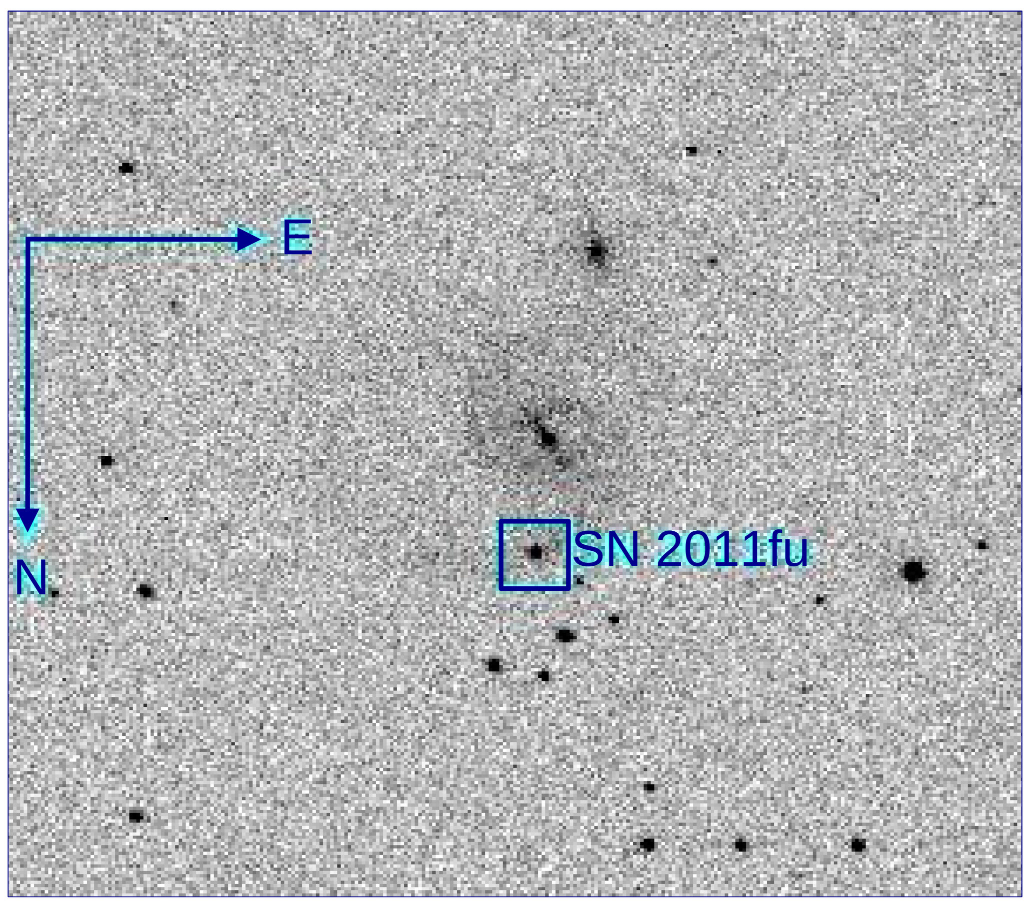

Figure 1: V image of SN2011fu in UGC1626 taken at the Liverpool Telescope (*Observatorio del Roque de los Muchachos*) on September 26th 2011.

Observational follow up and data reduction:

- Thanks to a large collaboration (which includes many European Institutions), photometric and spectroscopic data of SN 2011fu has been obtained at: Liverpool Telescope, Northern Optical Telescope, William Hershel Telescope, Calar Alto Observatory, Asiago Observatory, Faulkes Telescope North (for the optical wavelengths) and Carlos Sánchez Telescope (for the near infrarred - NIR - wavelenghts).
- The observational data ranges from September 23rd 2011 to February 25th 2012 (after this epoch the SN dissapeared behind the sun). The data has been reduced (corrected of overscan, bias, flat field) in the IRAF[1] environment. Instrumental magnitudes were derived with SNooPY (a PSF fitting package developed by E. Cappellaro and F. Patat) and aparent magnitudes were obtained calibrating via standard Landolt fields for the optical wavelenghts. We are still working on the NIR data.

[1]Image Reduction and Analysis Facility (IRAF), a software system distributed by the National Optical Astronomy Observatories (NOAO)

LIGHT CURVES: In *Figures 2* and *3,* Bessel UBVRI and Sloan *uriz* LCs of SN 2011fu are presented in comparison with those of type IIb SNe 2008ax (Pastorello et al. 2008) and 1993J (Richmond et al. 1994). The most **outstanding feature** of SN 2011fu LCs is the appearance of a **peak at early times in all bands** analogous to the first peak in SN 1993J LC. This peak suggests the presence of a low mass H envelope that was heated during shock breakout. For SN 1993J, Woosley et al. (1994) estimated an H mass of 0.2 +/- 0.05 $M_{\odot}$.

Two subcategories of type IIb supernova were proposed by Chevalier & Soderberg (2010) attending to the appearence or non appearence of a first peak in the LC: larger radius progenitors or extended type IIb (*eIIb*) having a first peak in the LC, and smaller radius progenitors or compact type IIb (*cIIb*) not presenting a first peak in the LC. Attending to this subcategorization, **SN 2011fu** would then belong to the **eIIb** type . For a better understanding of the first stages of evolution of SN 2011fu, future modelling of the SN light curve is planned. Our photometric analysis will also be extended to the NIR wavelengths.

SPECTRAL EVOLUTION: In *Figure 4*, we present a sequence of optical spectra of SN 2011fu ranging from 9 to 154.8 days after discovery. The earlier spectra are characterized by **P-Cygni Balmer** features. After maximum, H lines are still present but other features such as the **Call triplet** (849.8, 854.2, 866.2μm) and **HeI** (587.6μm), possibly blended with NaI (589.0 & 589.6μm), become prominent.

In *Figure 5,* spectra of SN 2011fu at phases 9 and 102.8 days after discovery are compared to spectra of SN 1993J and SN 2008ax (both type IIb supernova) at coeval epochs. As it can be seen in the figure, SN 2011fu and SN 1993J are also very similar spectroscopically.

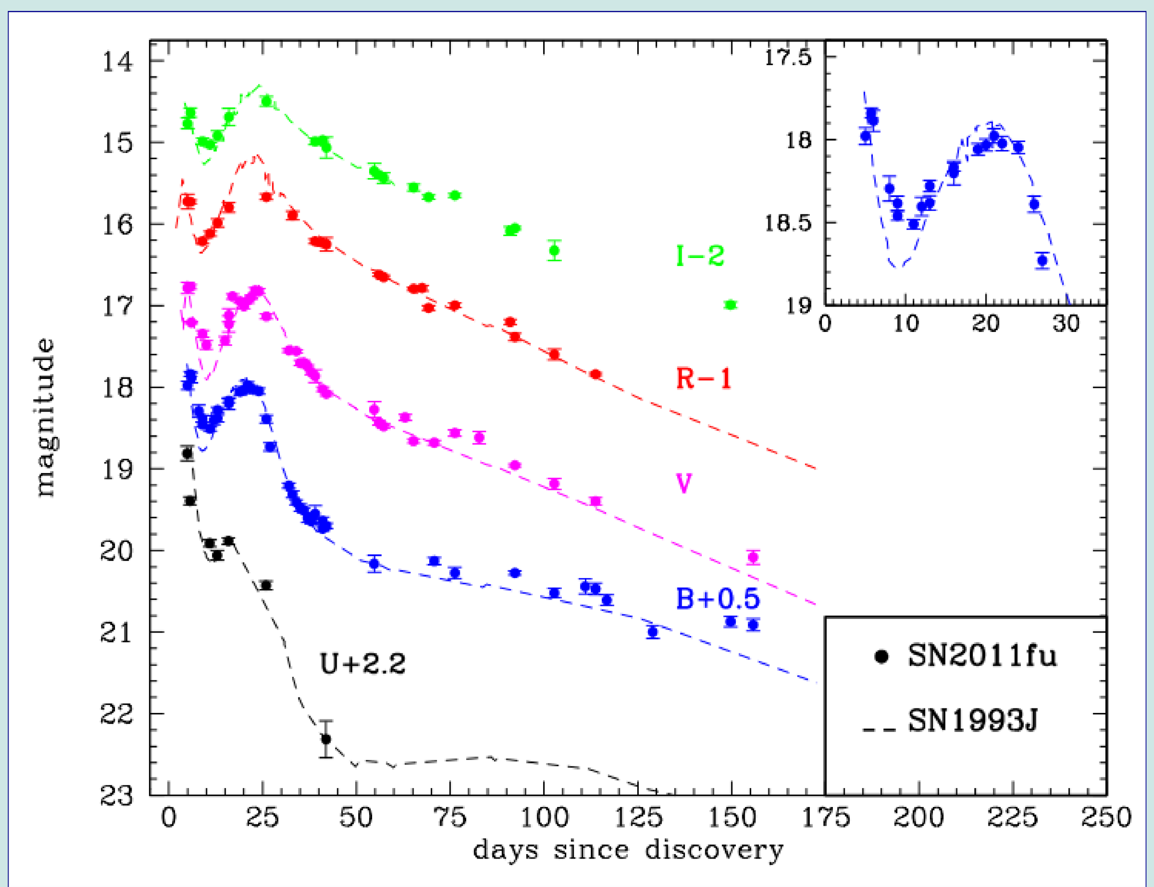

Figure 2: *UBVRI* LCs of SN 2011fu in comparison with those of SN 1993J (Richmond et al 1994). LCs of SN 1993J have been shifted from their original values to facilitate the LC shape comparison.

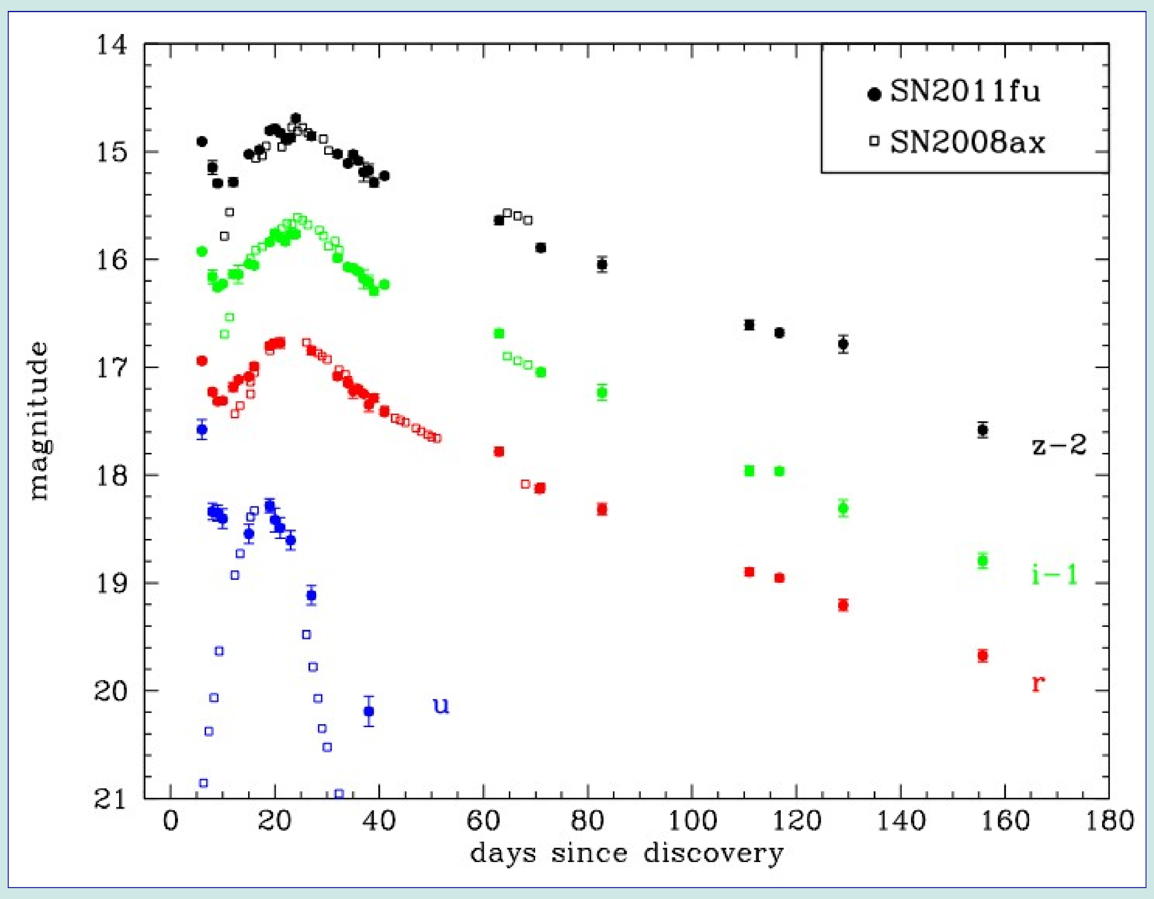

Figure 3: *uriz* LCs of SN2011fu in comparison with those of SN 20008ax (Pastorello et al 2008). LCs of SN 2008ax have been shifted from their original values to facilitate the LC shape comparison.

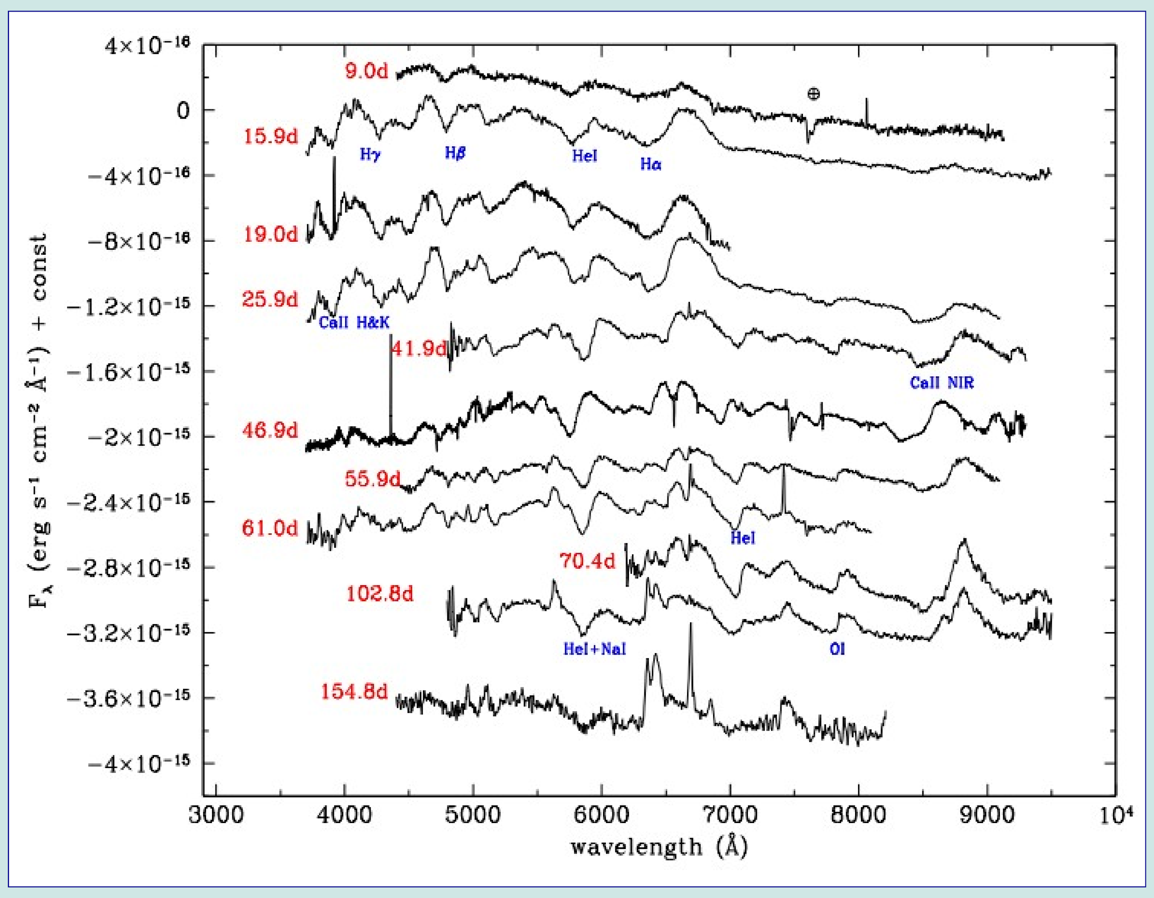

Figure 4: Optical spectral evolution of SN 2011fu from phase 9 up to phase 154.8 days after discovery. The locations of the most prominent spectral features are marked.

An estimate of the absolute B magnitude of SN 2011fu at maximum has been calculated assuming μ=34.46 +/- 0.15 mag and a value of $A_{B,gal}$=0.23 mag (Schlafly and Finkbeiner 2011): **B_{max}=-17.25 +/- 0.15 mag**. This maximum occured on **JD=2455847.50 +/- 0.60** (22 days after discovery). The minimum after the first peak has an estimated value of B_{min}=-16.80 +/- 0.15 mag and occured on JD=2455836.25 +/- 0.58 (10.7 days after discovery).

For SN 1993J, B_{max}=-17.23 mag (Young, Baron & Branch 1995), while for SN 2008ax B_{max}=-17.32 +/- 0.5 mag (Taubenberger et al. 2008).

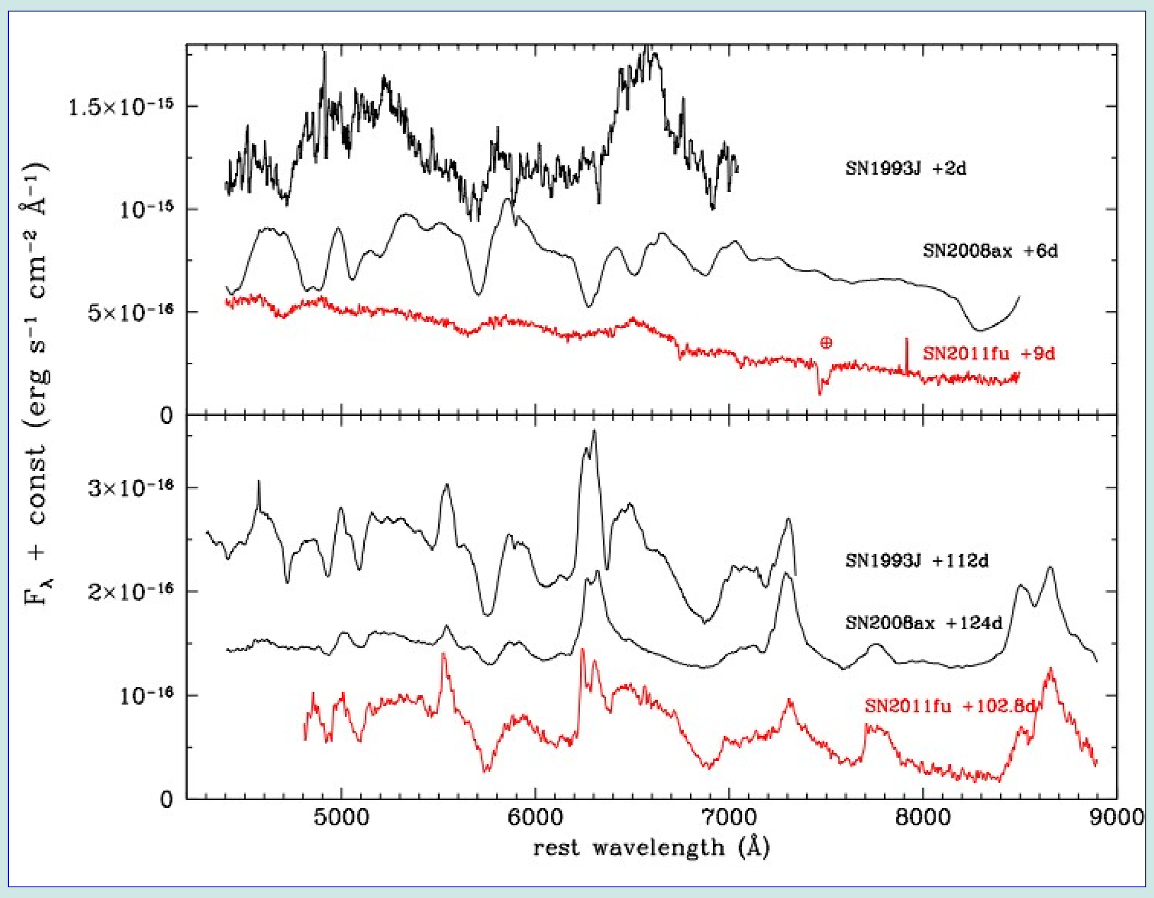

Figure 5: Early and late-time optical spectra of SN 2011fu (the bottom spectrum in each panel, shown in red), along with comparison spectra of the SNe 1993J and 2008ax. All spectra have been corrected for their host-galaxy recession velocities. Ages are relative to the SN discovery.

SUMMARY: We have presented some preliminary results of the analysis of photometric and spectrosopic data of type IIb SN 2011fu. The spectrosopic data does not seem to differ significantly from that of other type IIb SNe although a deeper spectral analysis is yet to be done to interpret possible differences or similarities. From the light curve shape we conclude the supernova arose from an extended progenitor with the presence of a (thin) H envelope. For SN 2008ax, Chevalier and Soderberg (2010) estimated the compact progenitor radius to be of the order of 10^{11} cm, while for SN 1993J (Wooseley et al. 1994) arrived to a progenitor radius of $4x10^{13}$ cm and a H envelope of 0.2 $M_{\odot}$. Although we have not yet modeled the light curve of SN 2011fu, from its shape we expect stellar parameters of the progenitor (radius and H envelope) to be closer to the values estimated for SN 1993J than those for SN 2008ax.

We also note that we must complete the study of the observational properties of SN 2011fu in its late phases of evolution. Observational follow up of SN 2011fu will be resumed in July-August 2012, when it becomes visible again after a period of non visibility due to it being behind the sun.