Detection of C III in the Type Ia SN 2010kg

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SN 2010kg – Basic Information

- Discovery: Dec 1, 2010 (Nayak et al. 2010)
- Coordinates: RA= 4:40:08.40, DEC= +7:21:00.0
- Host galaxy: NGC 1633
- Offset: 10".5 W, 3".0 N
- Distance: 60.425 ± 6 Mpc (Theureau et al., 2007)
- Spectral classification: Ia (broad-line subclass)

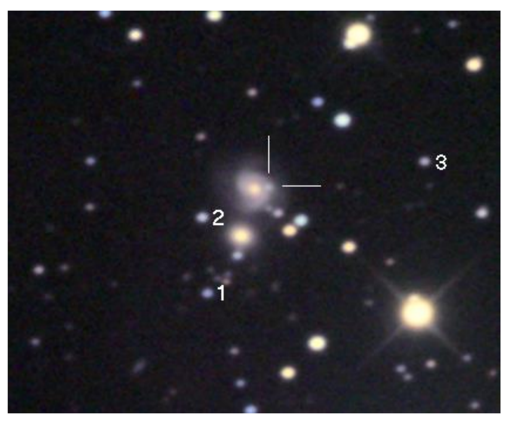

Fig. 1 *SN 2010kg in galaxy NGC 1633. Photo was taken by Joseph Brimacombe*

Broad-line SNe are a subclass of Type Ia, defined by Branch et al. (2006) based on the strength of the Si II 6355 Å feature, which is much broader than in core-normal Ia SNe. The spectra display high mean expansion velocities for all line forming regions, while the decline rate of the velocities show large variation (Blondin et al., 2012). Unburned material (C, O) is not expected in the spectra (Blondin et al., 2015).

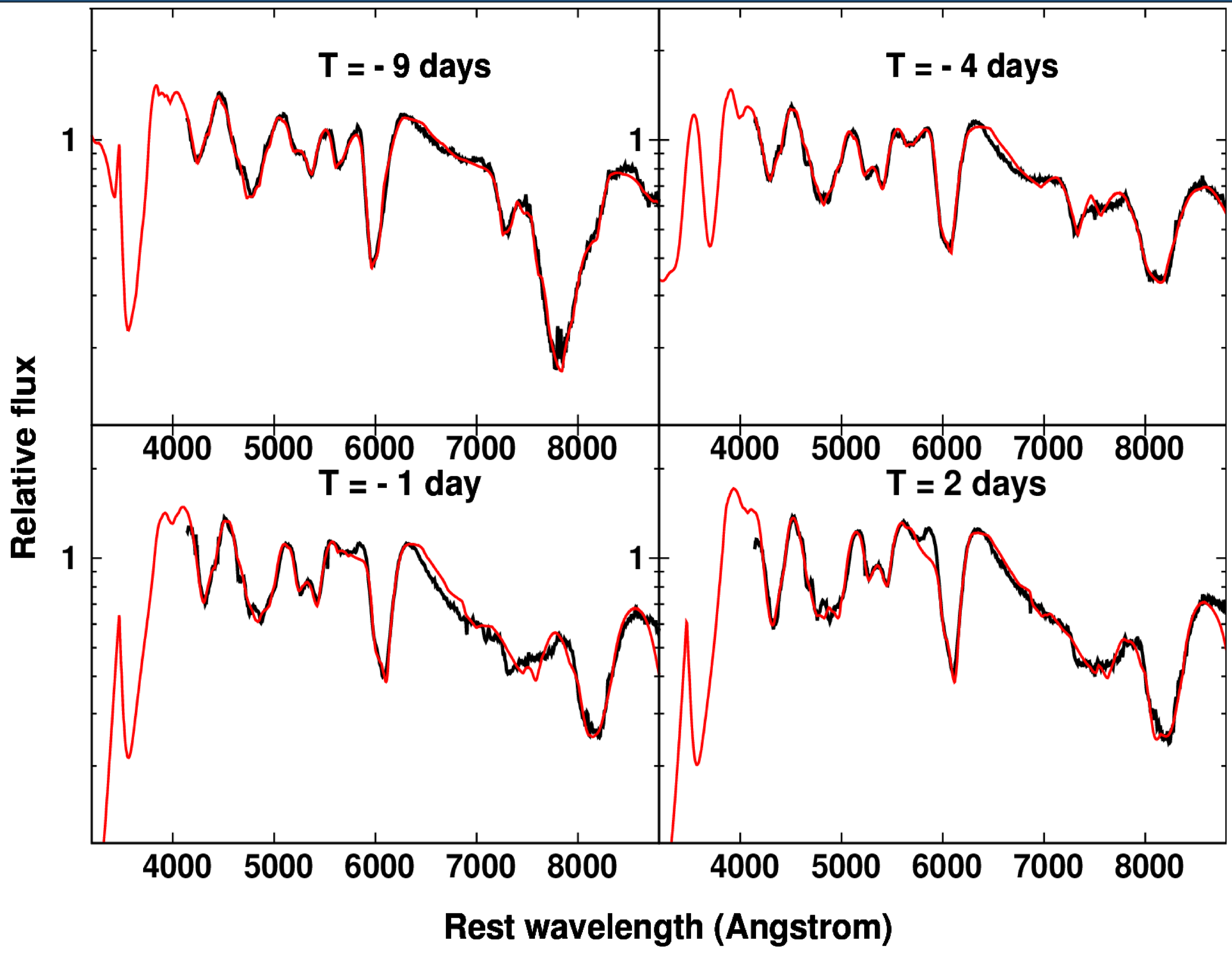

Fig. 2 *Observed spectra (black lines) of SN 2010kg at four different epochs (from the total of 11), with respect to B-band maximum and the best fit synthetic spectra (red lines) made with Syn++. All spectra were obtained with the Marcario Low Resolution Spectrograph (LRS) attached to the Hobby-Eberly Telescope (HET) at McDonald Observatory, Texas.*

Syn++ line identification

We analyzed the spectroscopic data of SN 2010kg obtained with the Hobby-Eberly Telescope between -11 and +4 days with respect to B-band maximum. The analysis was made with Syn++ (Thomas et al., 2011), the input parameters of which are the optical depth, the minimum velocity of the line forming region, the e-folding velocity of the opacity profile and the Boltzmann excitation temperature for each ion, while the whole synthetic spectrum can be modified by the photospheric temperature and velocity. We also allowed detached features (having $v_{min} > v_{phot}$) to be present in the spectra during the fitting.

Because of the strongly overlapping broad lines the line identification is ambiguous and the investigation of the whole spectral range is necessary for every ion. The reliably identified ions are Ca II, Si II, S II, Fe II, Fe III, O I, Na I, Mg II and C III **(Fig. 3)**. Note, that we used Ti II and O II to reach better fitting at some epochs, while Co II was added in order to reproduce the strong flux decrease below 4000 Å. Ca II and Si II high velocity features (HVF) were also identified.

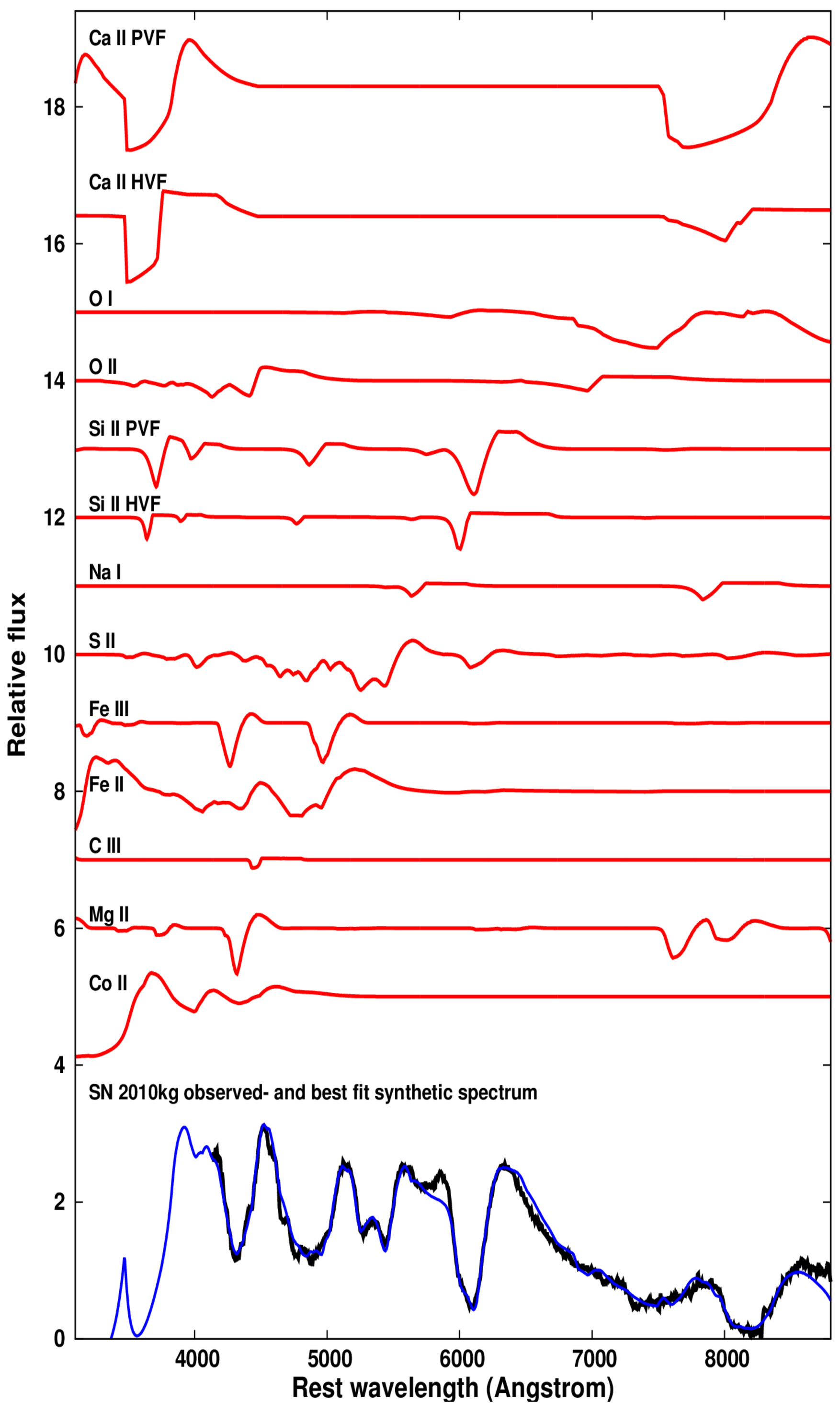

Fig. 3 *The normalized single-ion synthetic spectra at the moment of maximum light*

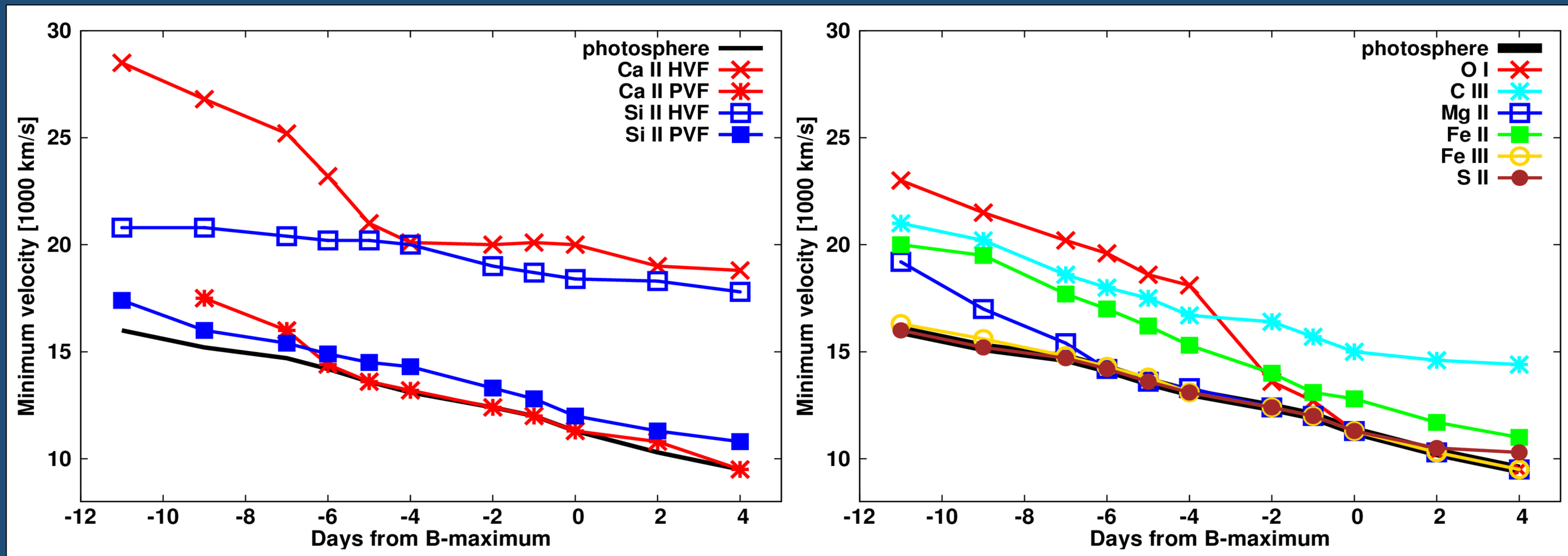

Fig. 4-5 *The minimum velocity of the line forming regions (v_{min} parameter in Syn++) for singly-ionized calcium and silicon (left panel, both photospheric- and high velocity features plotted) and the other identified ions (right panel). The velocity of the photosphere is plotted with black line on both figures.*

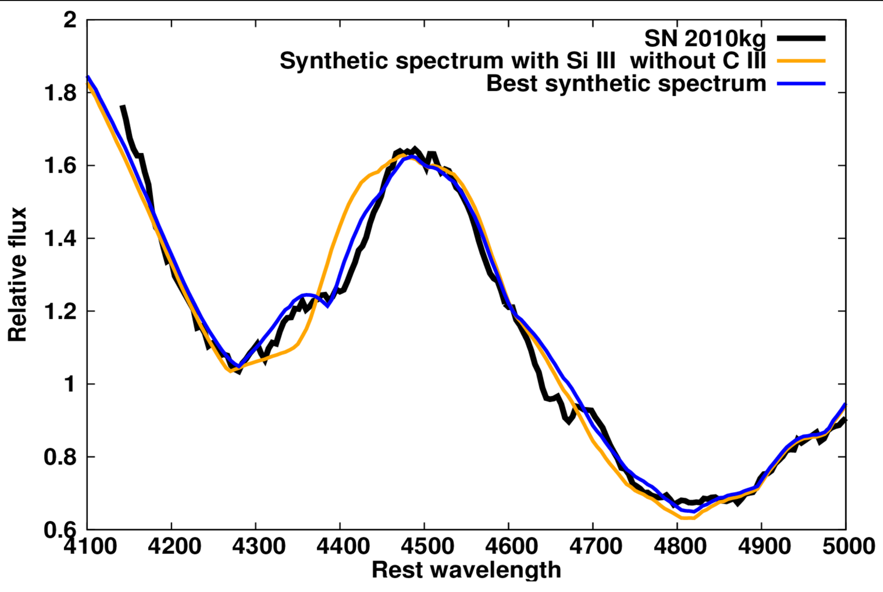

Fig. 6 *Fitting the 4400 Å feature with C III (blue line) and with Si III (orange line) at 6 days before maximum light*

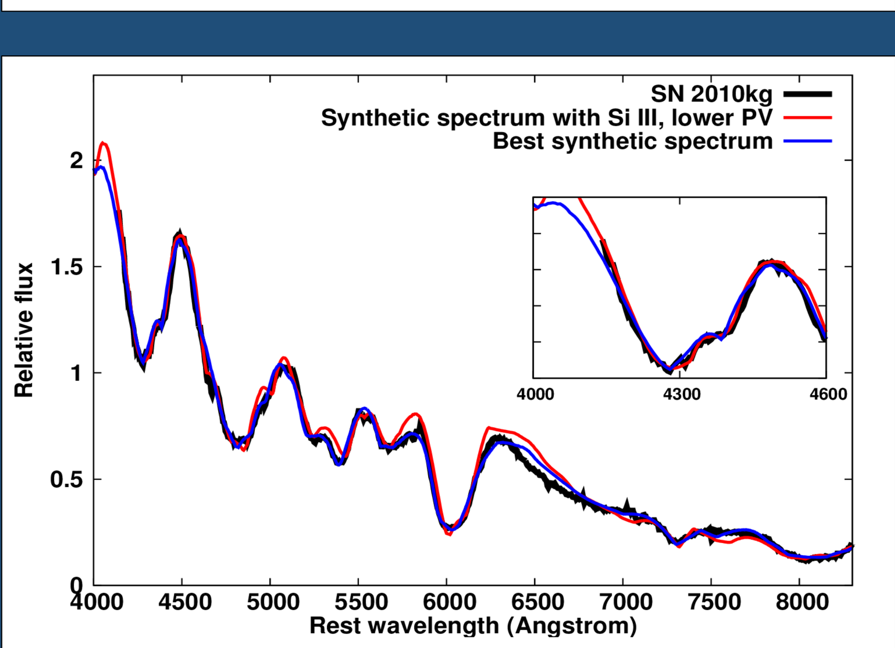

Fig. 7 *The best-fit synthetic spectrum (6 days before maximum light) with PV = 14,200 km/s (blue line) and with PV = 11,000 km/s (red line). The latter is needed for fitting 4400 Å feature with Si III.*

Carbon detections & possible C III contribution

Significant amount of carbon in the supernova ejecta can be a sign for the unburned material from the CO-progenitor or from the companion star. C II can be identified in the spectra of 30% of Type Ia supernovae (Silverman & Filippenko, 2012), thus during the early epochs, the presence of carbon could be a sign of diversity. Note that the commonly accepted delayed-detonation model does not support the presence of unburned material, except in the outermost regions of ejecta (Maeda et al., 2010), but deflagration models leave unburned carbon down to ~15 000 km/s (e.g. W7, Nomoto, Thielemann, & Yokoi 1984). After studying all observed spectra of SN 2010kg, it seems probable that neither C I nor C II is present in them (**Fig. 8**).

Previously, the presence of C III was identified only in the spectra of SN 1999aa (Garavini et al., 2004). The only resonant line of C III is at ~4400 Å; this feature was fitted mainly with Si III in the literature. We investigated the possible presence of both ions. Detached C III (at ~16,000 km/s at B-maximum) shows a good fit to this part of the spectrum, while Si III needs significantly lower photospheric velocity (~11,000 km/s) to fit the red wing of the absorption feature (**Fig. 6**). On the other hand, lower photospheric velocity disturbs the fitting of Fe III 5156, the S II W feature at ~5400 Å and the pseudo-emission of Si II 6355 (**Fig. 7**).

Using LTE-assumptions, the relative optical depths of different carbon ions can be calculated (Hatano et al., 1999). The turn-off point between single- and double ionized carbon is at about 15,500 K, which is much higher than the expected ejecta temperature based on the whole spectrum (~11,000 K). However, if the electron density is only N_e ~ 10^5 cm^{-1} instead of $5.2 \cdot 10^9$ cm^{-1} used by Hatano et al. (1999), then the C III / C II turning point moves to ~ 11,000 K. (**Fig. 9**).

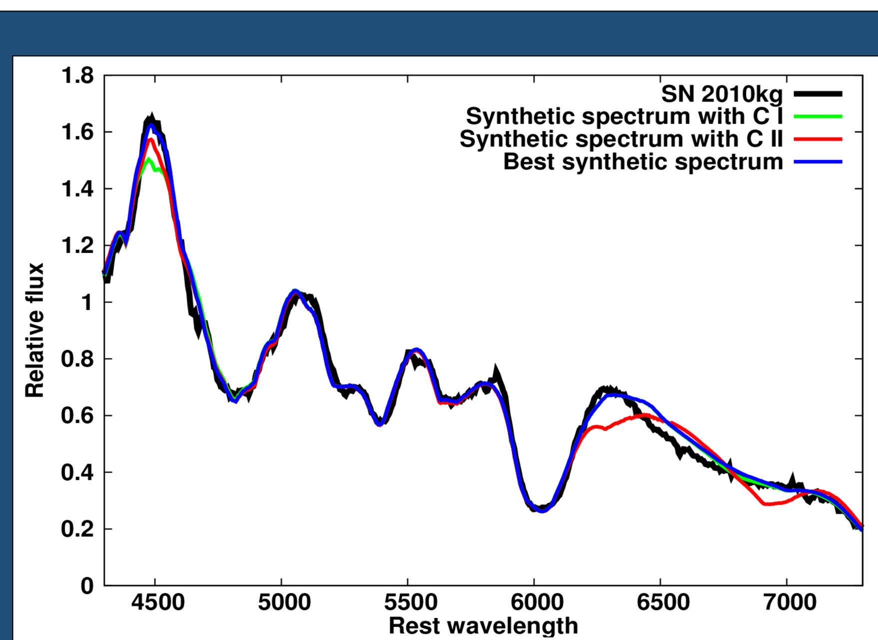

Fig. 8 *The effect of adding C I or C II to the synthetic spectrum 6 days before B-band maximum*

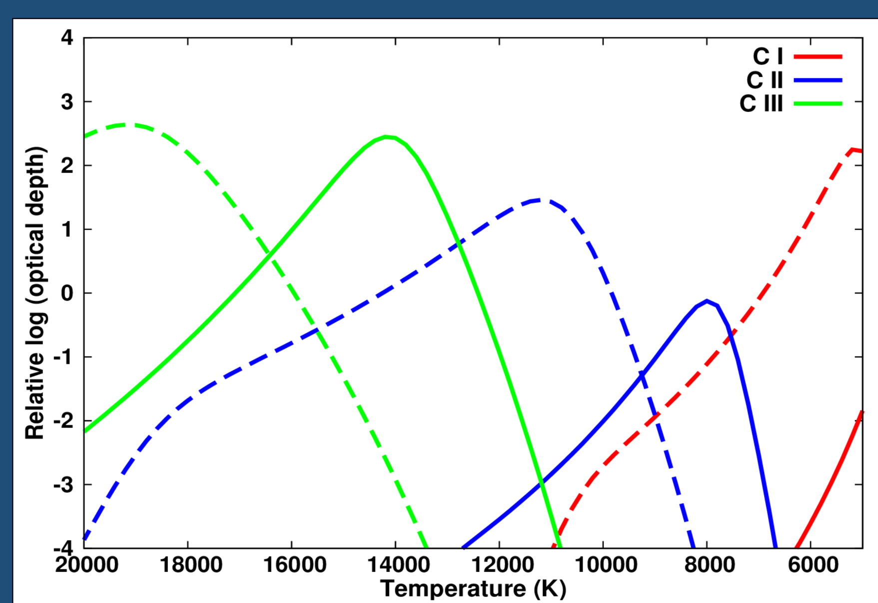

Fig. 9 *The relative optical depth values of carbon ions with electron density $N_e = 5.2 \cdot 10^9$ $1/cm^3$ (dashed lines) and $N_e = 10^5$ $1/cm^3$ (solid lines)*

Results and conclusions

We analysed eleven spectra of Type Ia supernova SN 2010kg obtained between -11 and + 4 days with respect to the B-band maximum via fitting synthetic spectra made with Syn++.
The main results are as follows:

- Most of the ions, expected in a normal Type Ia SN, were identified.
- The minimum velocities of the line forming regions were mapped: photospheric velocity features ($v \sim v_{phot}$), detached features ($v > v_{phot}$) and high-velocity features ($v >> v_{phot}$) were identified.
- The feature at ~4400 Å can be better fit with detached C III than with low-velocity Si III. The existence of C III at T ~11,000 K might be explained by the lower electron density in the outer ejecta.

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