Definitive near-infrared carbon detection in type Ia supernova iPTF13ebh

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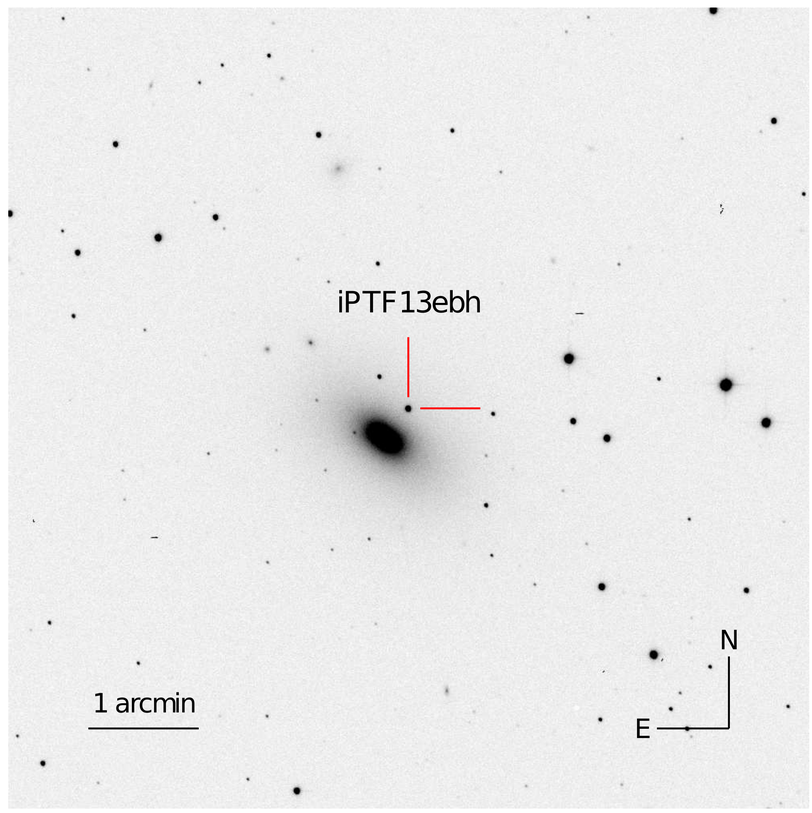
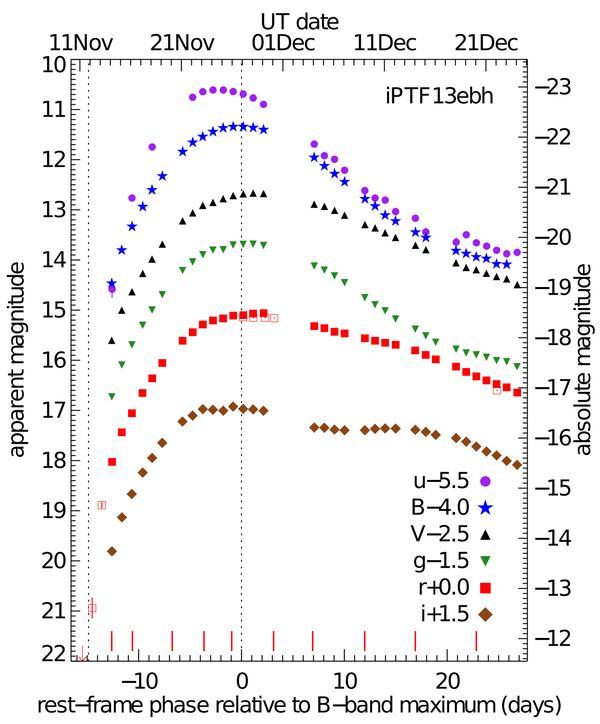
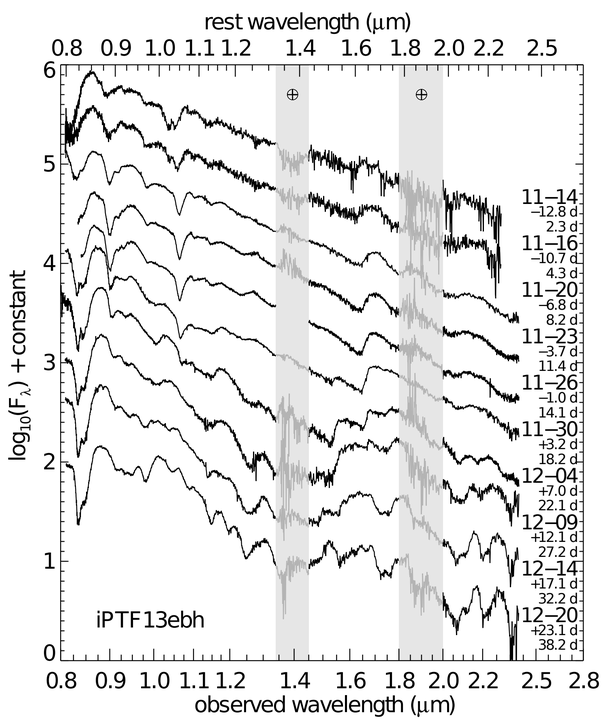
Abstract We present time-series near-infrared (NIR) spectroscopy of the Type Ia supernova (SN Ia) iPTF13ebh with FIRE on the Magellan telescope and GNIRS on the Gemini North telescope. iPTF13ebh was discovered exceptionally young and was intensely followed up in the optical and NIR as part of the Carnegie Supernova Project (CSP), in collaboration with the intermediate Palomar Transient Factory (iPTF) and the CfA Supernova Group. The first NIR spectrum was taken merely 2.3 days after explosion, and is one of the earliest NIR spectra taken of a SN Ia. The most striking feature in the spectrum is the C I λ1.0693 μm line. Not only is it the strongest NIR C I line ever observed in a SN Ia, it is also shown to be much stronger than its strongest optical C II counterpart. The optical light curves show iPTF13ebh to be an exceptionally fast decliner, yet its optical spectra near maximum do not show signs of Ti II features. It is therefore a "transitional" event between normal and 91bg-like objects. iPTF13ebh shows NIR spectroscopic properties that are unique to both the normal and 91bg-like classes, often bridging the properties of the two classes. These NIR observations suggest composition and condition of the inner core very similar to that of 91bg-like events, and a deep reaching carbon burning layer not observed in normal SNe Ia.

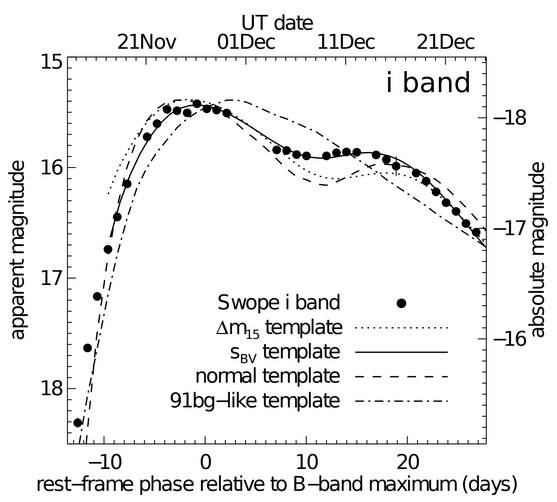




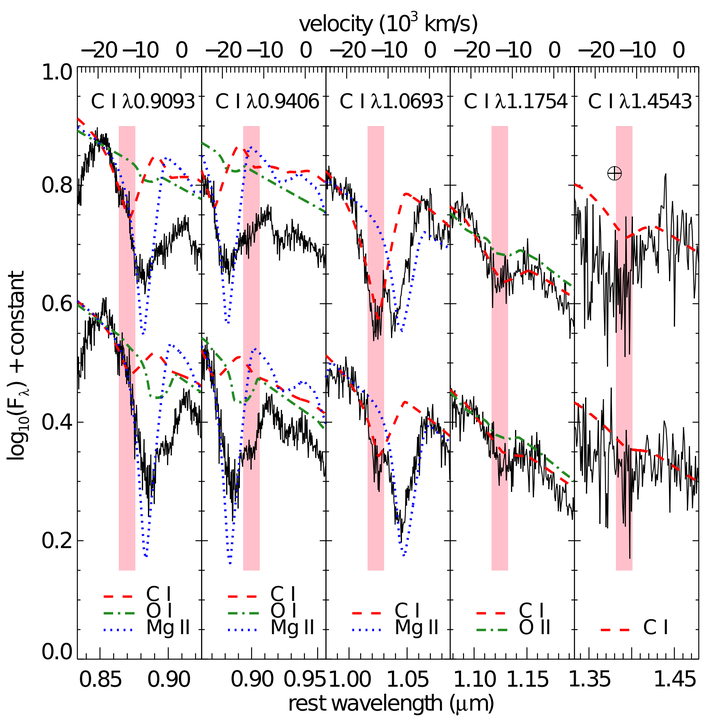
Early discovery The explosion date is well constrained from non-detection and pre-/post-discovery images obtained with one-day cadence from P48 (open symbols). The first NIR spectrum, in fact a classification spectrum, was taken 2.3 days past explosion. Intensive follow up of optical light curves with Swope (solid symbols) and NIR spectra (vertical lines) began on the same night.

Time-series NIR spectroscopy The combination of the classically scheduled time on Magellan and the target-of-opportunity queue observing mode on Gemini North allows spectra to be obtained in regular 2-4 day cadence when the supernova is young.

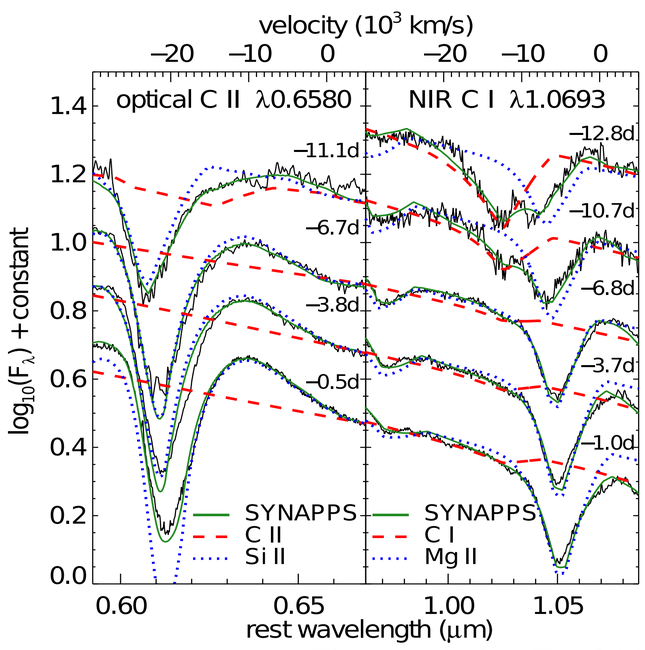




Transitional object iPTF13ebh is a "transitional" object: a fast decliner without showing optical spectroscopic properties of peculiar 91bg-like objects. Many of its properties bridge those of normal and 91bg-like supernovae.

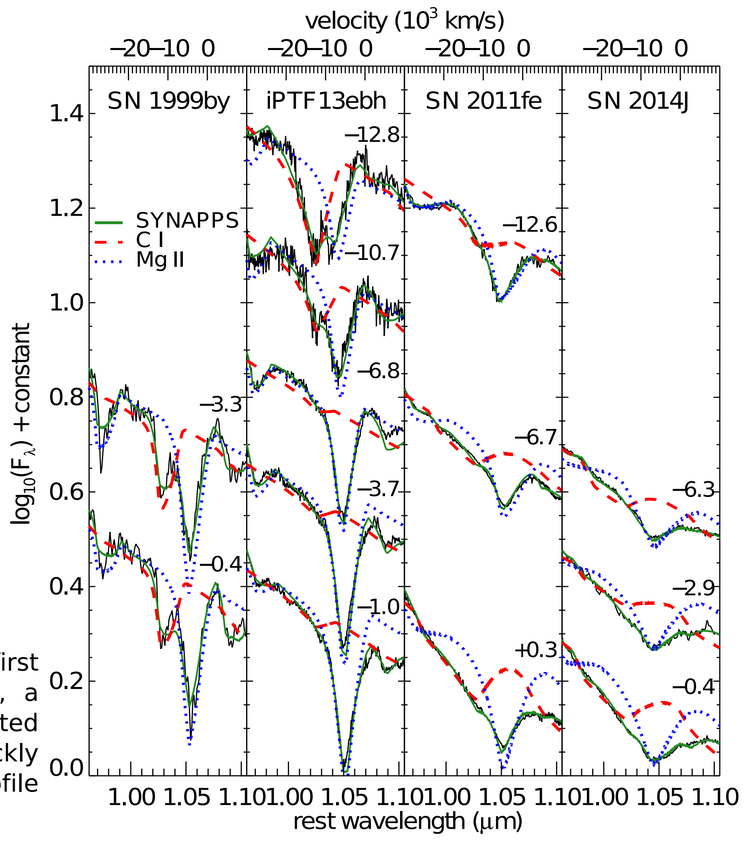


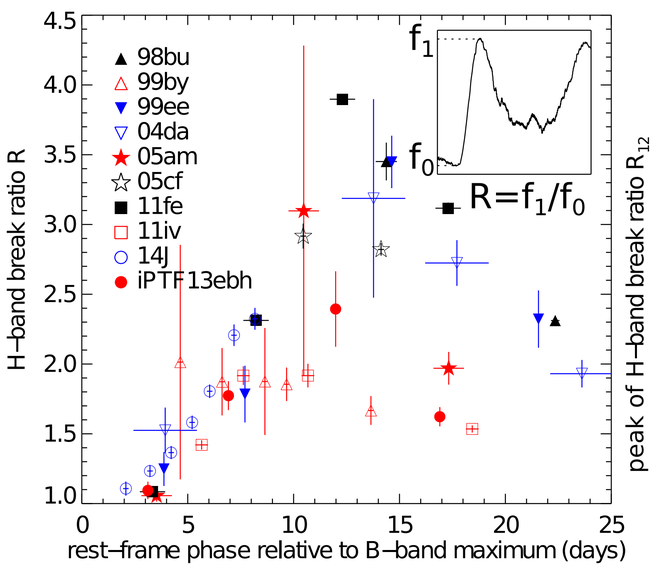
NIR C I lines In the first two NIR spectra, multiple C I lines are identified. C I λ1.0693 μm line is the strongest and also the most isolated of all C I lines.

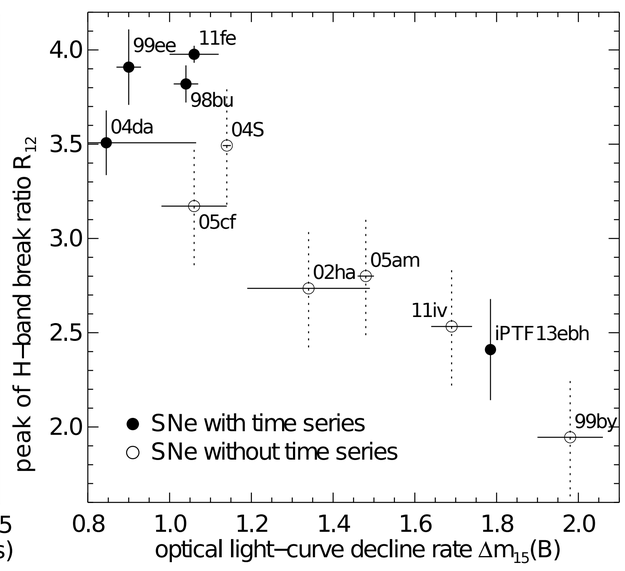


Optical C II vs NIR C I The NIR C I line is much stronger than the optical C II line. This is also true for all four NIR C I detections so far.

Time evolution The C I line first takes on the profile of 99by, a 91bg-like object. While it persisted in 99by, C I in iPTF13ebh quickly weakens and takes on a profile similar to 11fe, a normal SN Ia.







H-band break ratio It is defined as the peak-to-trough flux ratio across the "H-band break" near 1.5 μm. The time evolution of the ratio is similar to normal 11fe. The correlation between the peak of the H-band break ratio and Δm_{15}(B) (Hsiao et al. 2013) is preserved and strengthened with the addition of iPTF13ebh. The strong correlation is consistent with Chandrasekhar-mass models with little mixing. At late phases, the profile becomes more similar to 99by, suggesting composition and condition of the inner core closer to 91bg-like events.