Measuring Expansion Velocities, Photospheric Temperatures and Dilution Factors of Type II-P Supernovae

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Introduction

Despite being more heterogeneous in their observed properties than Type Ia-s, Type II-P SNe could be surprisingly reliable distance indicators. Either the Expanding Photosphere Method (EPM) ([1,2,3]) or the Standardized Candle Method (SCM) ([4,5,6]) can be applied to derive distances to them, based on simple assumptions on SN physics.

The fundamental equations of EPM are:

$$t = t_0 + D\frac{\theta}{v_{ph}} \qquad \theta = \frac{1}{\zeta(T)}\sqrt{\frac{f_\lambda(1+z)}{\pi B(\lambda(1+z),T)}}$$

where D is the distance, t_0 is the moment of explosion, θ is the angular radius, v_{ph} is the velocity at the photoshere, f_λ is the observed (reddening-free) flux, z is the redshift, $B(T)$ is the Planck function and ζ is the dilution factor that measures the deviation of the emergent spectrum from a pure blackbody radiation. One needs to measure f_λ, T and v_{ph} and do a linear regression of t against (θ/v_{ph}) to get the distance.

The SCM is based on the simple assumption that at +50 days the absolute magnitude is correlated with the velocity.

The application of these methods relies on measuring (or estimating) the photospheric velocity, the temperature and the reddening of Type II-P SNe. The dilution factors are usually calculated from SN model atmospheres ([7,8]).

In this work we present a comparison of several methods for measuring these quantities.

Velocities

Figure 1.: The expansion velocities of SNe are usually derived by measuring the Doppler-shifted absorption minima of the P Cygni line profiles. Using SYNOW we tried to improve the estimates. Creating simple model spectra, where photospheric velocity is an input parameter, we search for those that are the best fit to the whole profile of certain lines of the observed spectra. Here we compare the velocities produced by the model (red) to those from the absorption minima of Hβ (green) and Fe λ5169 (blue) of four well-observed SNe. As expected, the model velocities are close to those from Fe λ5169, and usually much lower than from Hβ. The black lines are the power-law velocities calculated from the velocity at +50 days ([5]). The observed data are from [2], [9], [10], [11], [12].

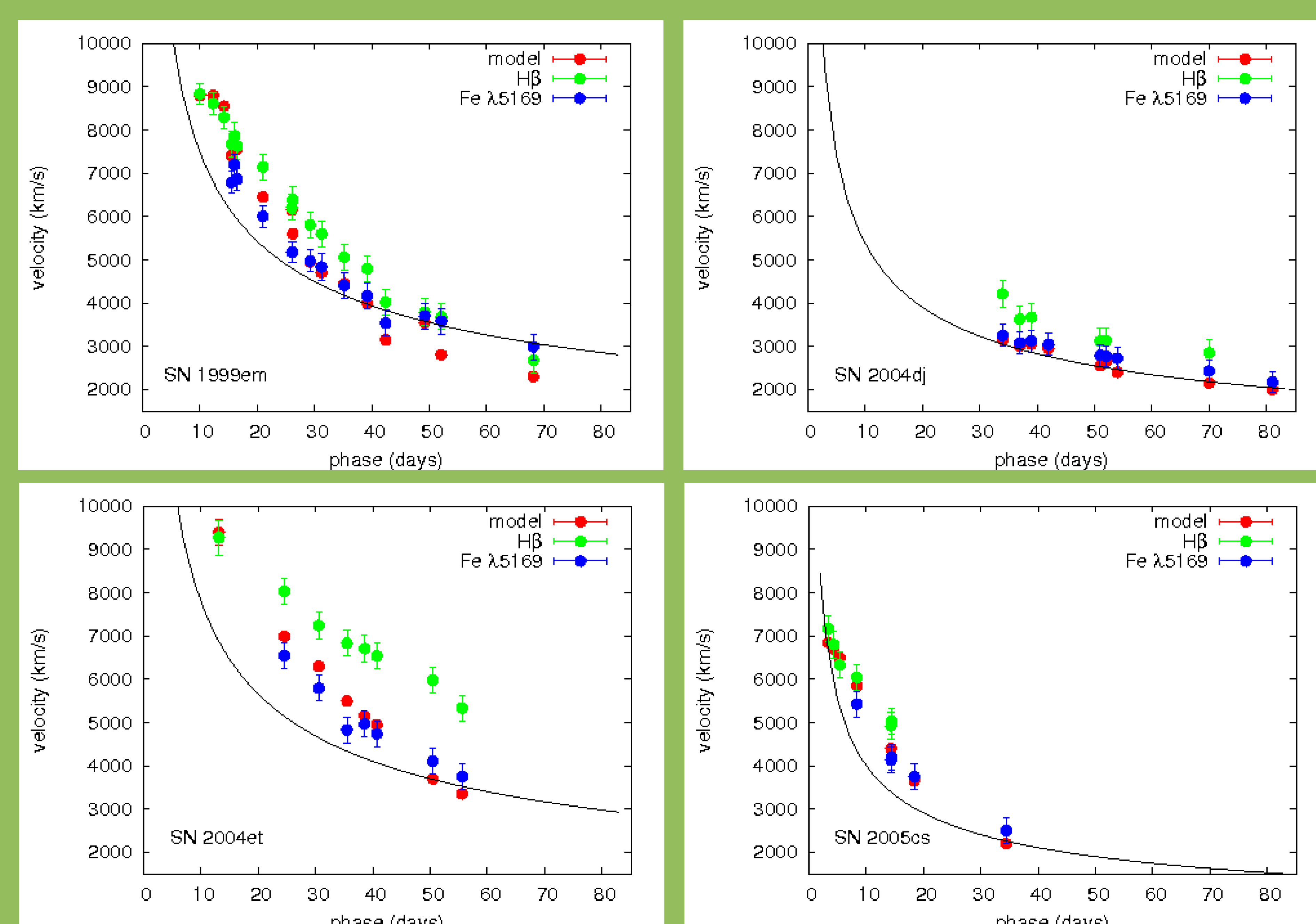
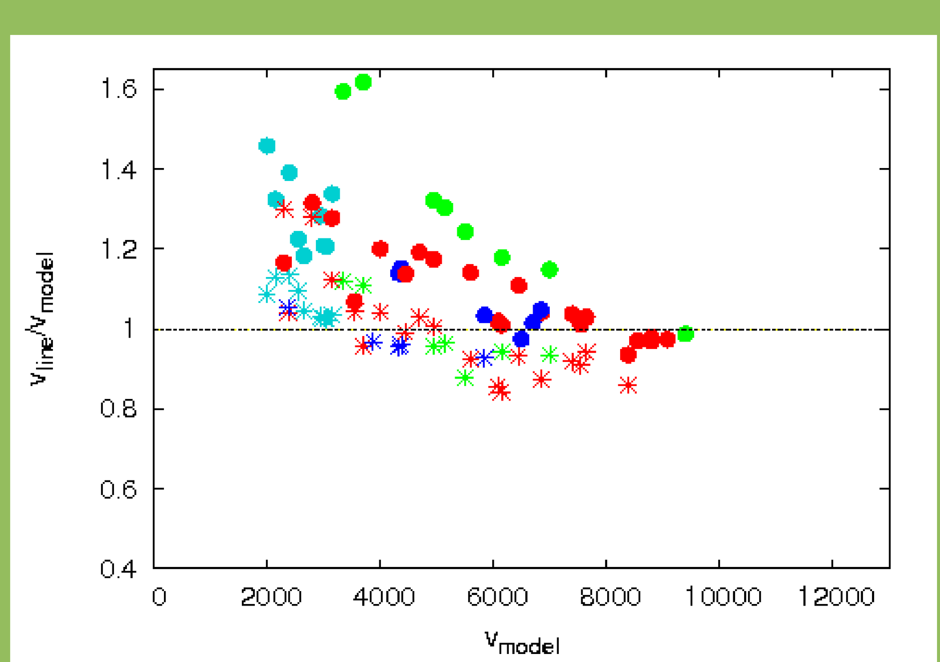


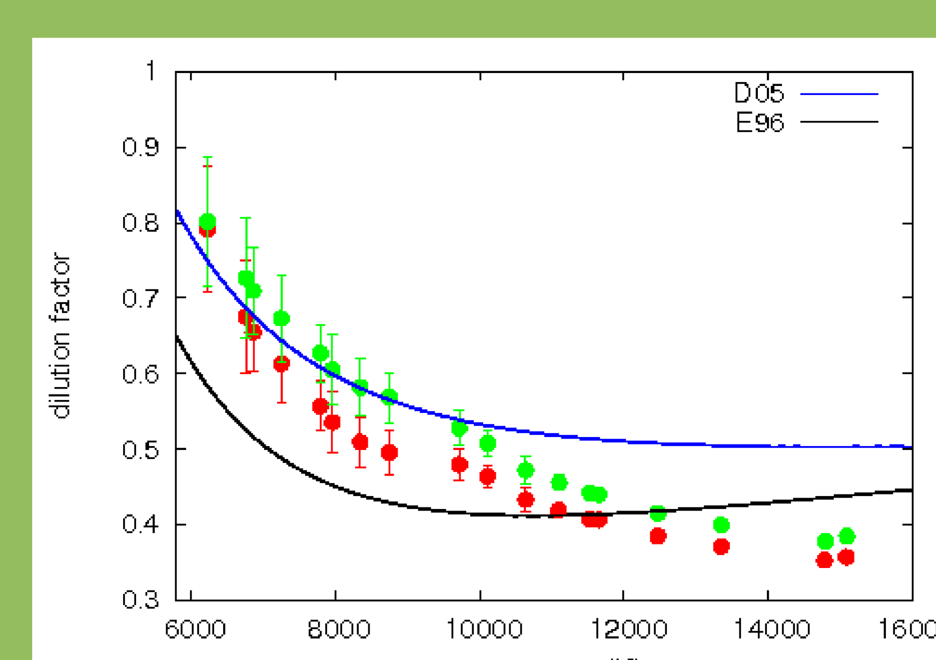
Figure 2.: Comparision of the velocities derived from absorption minima (v_{line}) with the model velocities (v_{model}). Here we plot the v_{line}/v_{model} ratio vs. v_{model}. The features used were Hβ (filled circles) and Fe λ5169 (asterisks). Color codes for different SNe are: red - SN 1999em, green - SN 2004et, turquoise - SN 2004dj, blue - SN 2005cs.



Both features seem to follow the same trend: the models tend to underestimate v_{line} at lower velocities (late phases). Between 4000 and 10000 km/s, i.e. for most the plateau phase, the two methods are consistent with about 20 % precision.

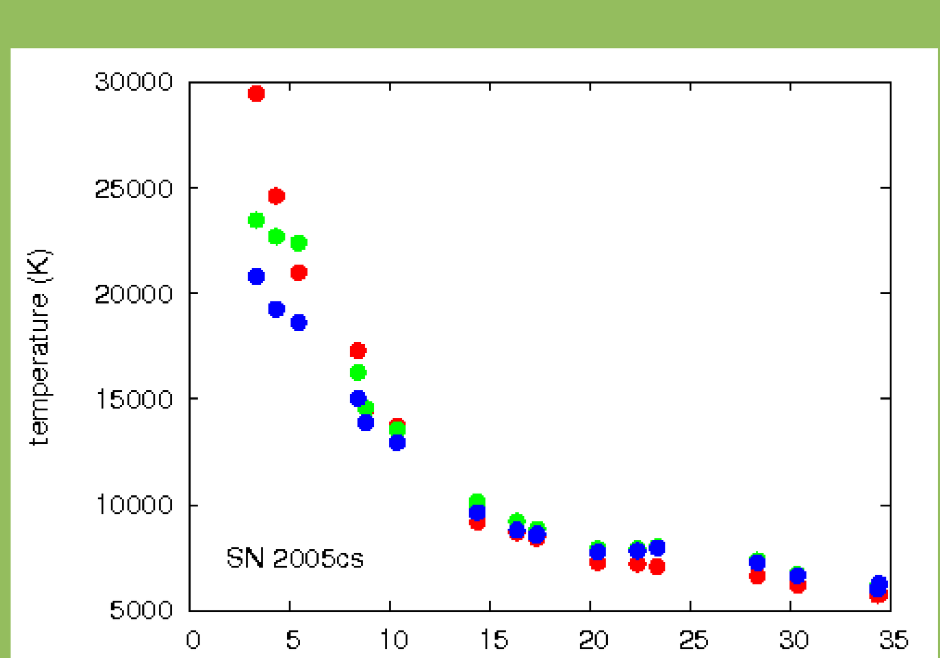
Dilution factor

Figure 3.: The distance of SN 2004et is D = 5.5 ± 0.5 Mpc ([11]). This can be used to estimate the ζs from observations via inverting the equations of EPM (see Intr.). This was done using two methods for velocity measurements: using the minimum of Fe λ5169 line (red) and fitting SYNOW models (green).
The predictions from atmospheric models of [7] (E96, black) and [8] (D05, blue) are also plotted. It seems that the models of D05 overestimate the ζs at high temperatures, but at lower *T*s the agreement with these is slightly better than with E96.



Temperatures

Figure 4.: We derived the photospheric temperatures by fitting blackbodies to observed data (corrected for interstellar reddening) using three slightly different approaches: 1. fitting to broad-band magnitudes (blue), 2. fitting to quasi-monochromatic fluxes converted from the magnitudes (green), 3. fitting to the (reddening-free) spectra (red). This figure shows the results for SN 2005cs. At high *T*s, the three methods produced different values.



This is because in this phase all the data are on the Rayleigh - Jeans tail of the Planck-curve, making the *T* determination very uncertain. The agreement is better below 15000 K.

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