SNe II the rescue: Determination of H_0 with Type II supernovae in the Hubble Flow

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Abstract: One of the most significant questions in today's cosmology is the cause of the Hubble tension, which is the apparent discrepancy between the early- and late-Universe Hubble constant values. The late-Universe Hubble constant is typically measured through a series of subsequent empirical calibrations, known as the cosmic distance ladder. Here, we demonstrate the use of Type II supernovae (SNe II) as cosmic distance indicators, eliminating the need for external calibrations. This is done by modelling their spectral time series with radiative transfer simulations to estimate physical parameters directly. We utilise a dedicated sample of 24 SNe II observed through a Large Project on ESO VLT UT1 to calculate a new independent value for H_0.

Distance measurements with SNe II were introduced by Kirshner & Kwan (1974), using a method that relates the physical size of the SN, measurable from its spectral features, to its brightness. The method was first used to infer H_0 based on a sample of SNe II by Schmidt et al. (1994). Since then, it was shown that radiative- transfer models are needed to estimate physical parameters and reduce systematic effects (Baron et al. 2004, Dessart & Hillier 2005). Vogl et al. (2024) demonstrated that SNe II indeed provide a viable path for measuring H_0, estimating H_0 = 74.9 +/- 1.9 km s^{-1} Mpc^{-1} through SNe published in the literature, while Csörnyei et al. (2023a, 2023b) tested the internal consistency of the method and compared it to independent distance estimates.

To refine our analysis, we launched the "adH0cc" programme and followed up 24 SNe II in the Hubble flow using VLT UT1 FORS2 (Figs. 1 & 2). We obtained spectral time series and contemporaneous optical photometry, allowing for a distance estimation utilising only FORS2 data. This provides an excellent opportunity to estimate H_0 and to investigate systematic effects in our analysis.

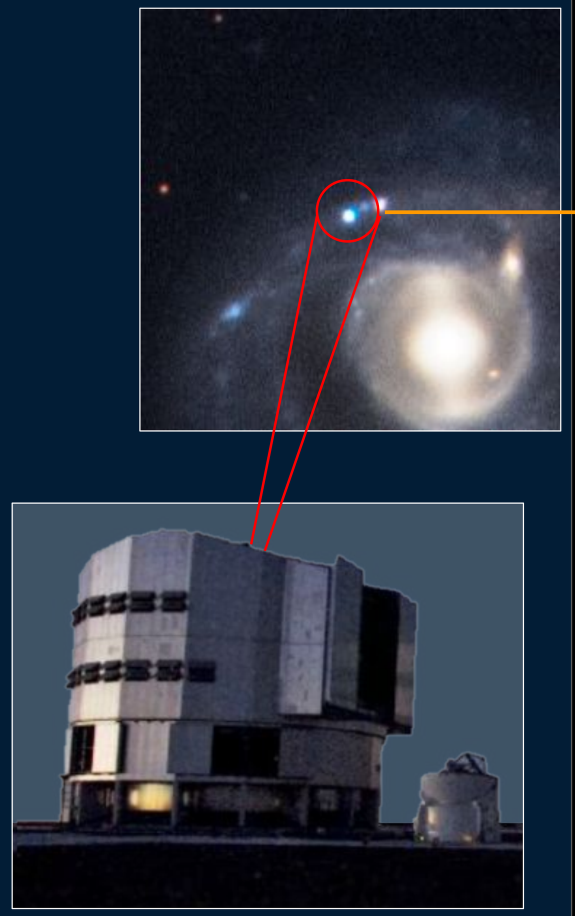


Fig. 1: Illustration of the VLT observations of a sample SN. The top plot shows a cutout of SN 2020yts. We followed 24 SNe II over a period of 3 years, obtaining typically 3-6 spectra for each in the early photospheric phase.

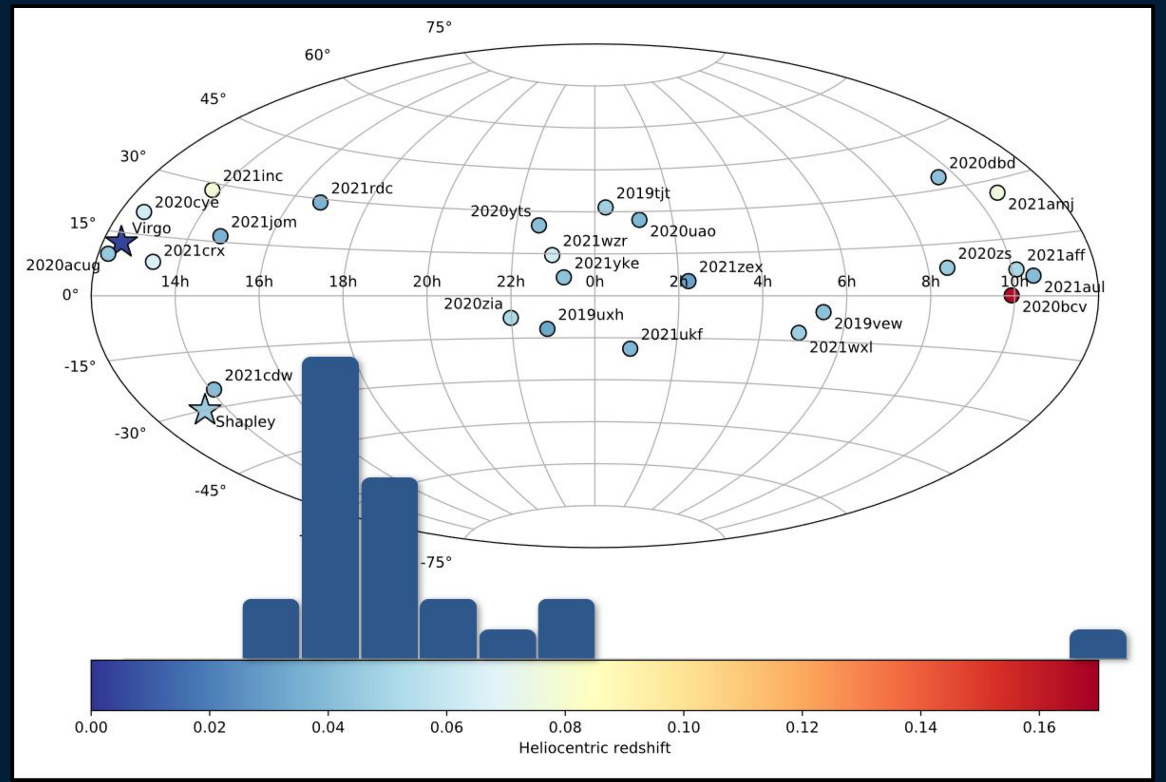


Fig. 2: On-sky and redshift distribution of the adH0cc SN II sample. The heliocentric redshifts of the objects are colour-coded. The histogram at the bottom displays the redshift distribution. Through dedicated observations, we assembled an SN II sample that is well within the Hubble flow; hence, the cosmological redshifts should not be significantly influenced by the peculiar motions of their host galaxies.

To carry out the H_0 measurement, multiple inputs are needed. Beyond the spectra, one needs a simultaneous brightness estimate of the supernova in a well-defined photometric system, which will be compared to the absolute magnitude determined by the radiative-transfer modelling. While it is not a requirement, having a precise estimate of the time of explosion T_0 (as shown in Fig. 3) also helps to decrease modelling uncertainties, allowing for sub-10% distance measurements per SN.

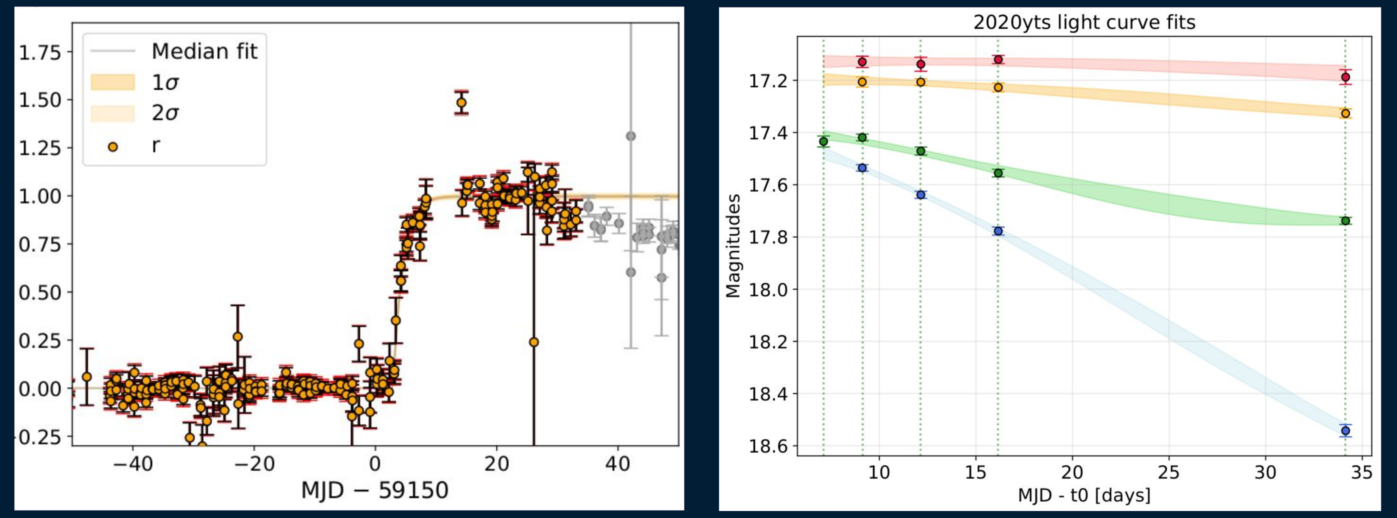
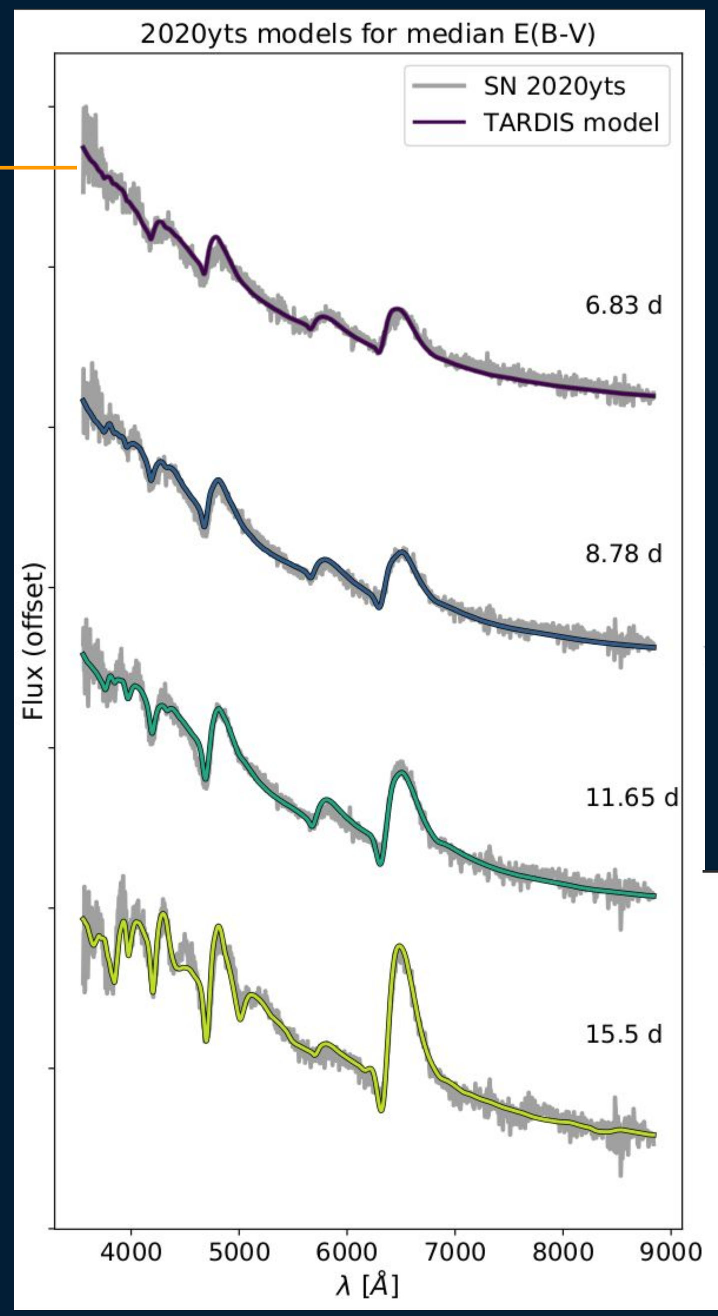


***Fig. 3: (Left)** T_0 estimate for SN 2020yts based on fitting its early light curve from ZTF (Bellm et al. 2019). We assume an inverse exponential model for the rise and achieve a T_0 precision of <1 day. **(Right)** Fitting of the FORS2 light curves of SN 2020yts with Gaussian Processes. These fits are used to estimate the brightness of the SN at the individual spectral epochs (green dashed lines).*

To model the spectral time series of SNe II and obtain their luminosities, we use the radiative- transfer code TARDIS (Kerzendorf et al. 2014), adapted for hydrogen-rich SNe by Vogl et al. (2019). The fits are calculated in an automated fashion, using the spectral emulator designed by Vogl et al. (2020), which efficiently calculates a model spectrum for a given parameter set by interpolating between input model spectra. This enables maximum-likelihood-based fitting.



The outcome of this process is displayed in Fig. 4, which shows the spectra of SN 2020yts along with the calculated radiative-transfer models. The emulator also yields an estimate for the total reddening along the line of sight (see Fig. 5). Given that the reddening towards the supernova remains the same between spectral epochs, we combine the individual reddening estimates with a prior for the Milky-Way reddening (from Schlafly & Finkbeiner 2011) to obtain a precise value for the total reddening, along with the distance.

Fig. 4: Fitted spectral time series of SN 2020yts. We model SN II spectra during the early photospheric phase until ~25 days after the explosion. Until this time, the SN ejecta are almost fully ionised, allowing for simplified treatment using snapshot models instead of full time-dependent radiation transport. Every model here is treated independently, yielding an independent luminosity estimate. These estimates are then combined with the interpolated apparent magnitudes (Fig. 3) to obtain distance estimates.

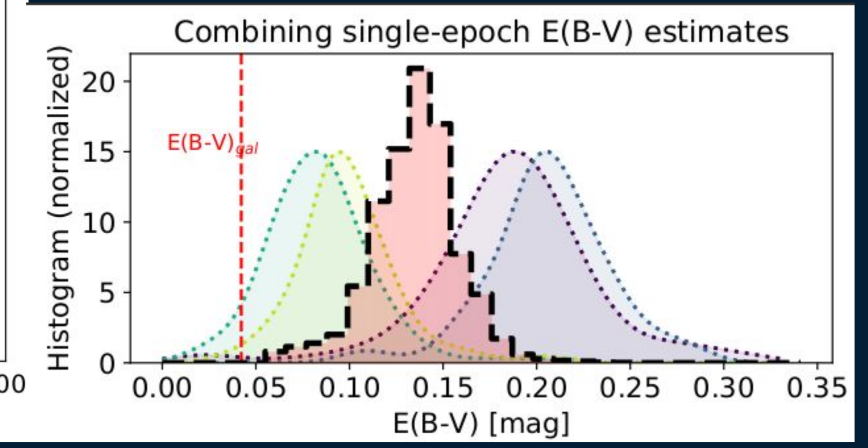


Fig. 5: Combining E(B-V) estimates. Each histogram corresponds to the fit with the same colour in Fig. 4. The red line marks the Galactic reddening. The red histogram is the joint estimate. This step ensures consistency between epochs.

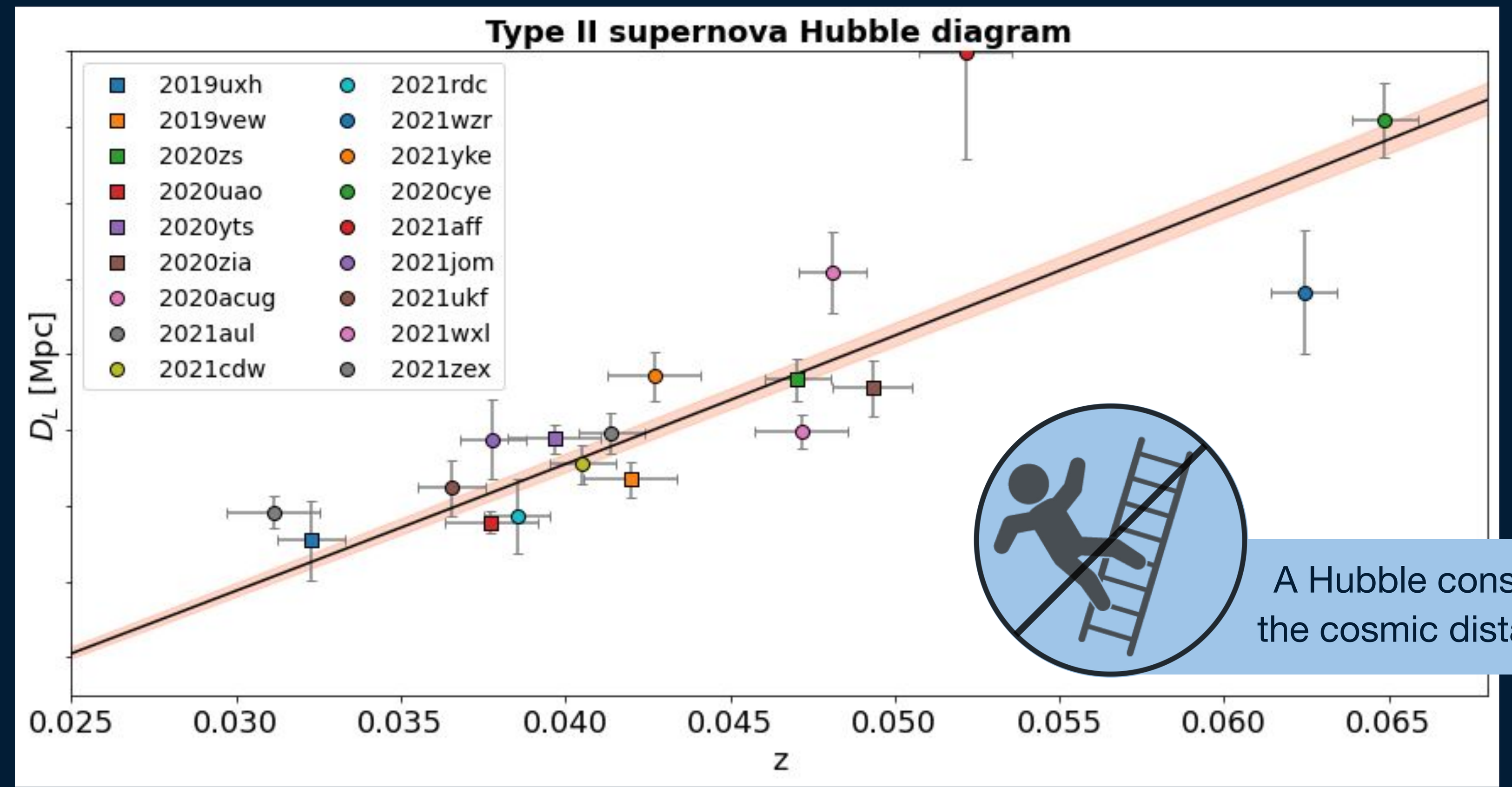


Fig. 6: Blinded Hubble diagram built from the distances estimated to the individual SNe II collected in adH0cc. The curve shows a blinded fit to the Hubble diagram along with the uncertainty bands. Aside from the full sample fit, subgroups of objects will be defined based on data quality and SN properties to investigate systematic effects present in our method, before presenting the H_0 estimates.

Estimated distances to the sample SNe enable the construction of a Hubble diagram that is entirely independent of other techniques. Fig. 6 shows the blinded Hubble diagram obtained from the adH0cc SN sample. In the next few months, the primary focus of the work will be to constrain systematic effects present in our sample, which can arise from modelling imperfections, and to define a final sample for estimating the Hubble constant.

Summary and Conclusion: SNe II are promising distance indicators, which can provide an independent view on the Hubble tension. We have modelled the spectral time series of supernovae observed in our ESO VLT Large Programme, obtaining precise distance estimates, which will be combined into a final Hubble constant estimate. The high quality of the data and in-depth characterisation of the observations will also enable a detailed examination of the systematics affecting the modelling approach, providing critical input for future applications of the method.

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adh0cc.github.io

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