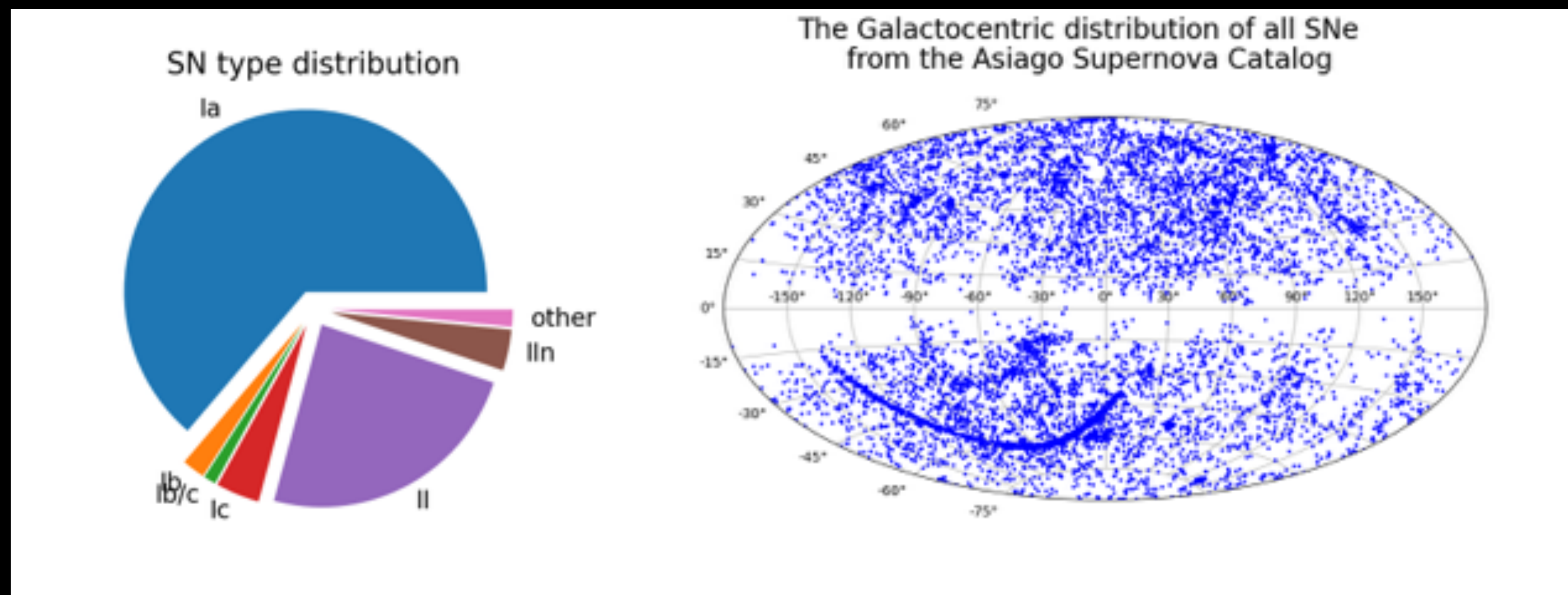
An Extraordinary Journey of the Supernova Astronomers from Padua



Enrico & Massimo at IAU Symposium 296 at Raichak near Calcutta, Jan. 2013

Massimo chairing a session at IAUS 296 Jan 2013

Massimo in conversation with classical dancer Sharmila after the Symposium, Jan 2013

Massimo in Workshop on Supernovae, Tata Inst., Bombay, Jan 2004: Title Slide

Proof that Massimo was there !

A comparative spectroscopic study of SN IIn: SN 2023usc and SN 2017hcc observed with Himalayan Chandra Telescope (HCT)

Alak Ray

on behalf of

V. Sethulakshmi, Riddhiman Sharma & Firoza Sutaria

Tata Institute of Fundamental Research, Mumbai &

Indian Institute of Astrophysics, Bengaluru

Interacting Supernovae and revelations from diagnostics of their line profiles

- Type IIn Supernovae show interaction between fast-moving ejecta of explosion with a slow, high density circumstellar medium (CSM). Their (H) line profiles have multiple componets as they evolve post explosion.

- Narrow emission lines of the Balmer series are seen - hence the eponymous ***type IIn*** (Schlegel 1990, Filippenko 1997), sometimes with a P Cygni profile from pre-shock CSM from the progenitor star at 40-50 km/s [viz the high resolution spectroscopy of SN 2017hcc - Smith & Andrews (2020) showing an axisymmetric outflow in this case] on top of a broader profile.

- These luminous interacting supernovae, sometimes have long risetime (e.g. 57 days for SN 2107hcc) to high peak luminosity (e.g. mag -20.78 in ATLAS o-band for 2017hcc) as well as slow decline afterwards in the optical bands [at late times, +600 days, it declines 0.1 mag/(100days) in V-band — Moran et al (2023) — much slower than expected from radioactive powered SNe from Co^{56} decay typically showing 0.8 mag/(100 days) - Miller et al 2010]. This indicates continuing SN interaction with the CSM that powers the light curve

- The broad and intermediate width components in the deblended line profiles on the other hand show: 1) symmetric Lorentzian profiles from pre-shock CSM broadened by electron scattering at early times (Chugai 2001) and 2) late time transition to multicomponent profiles originating from: 2a) SN ejecta and 2b) post shock shell.

- In the case of SN 2017hcc the profiles show a progressively increasing blueshift with flux deficit in red wings of the broad and intermediate components after about 200 days — the blue shift arises from dust formation in the post shock shell and in the SN ejecta, showing characteristic wavelength dependence of large grains dust according to Smith and Andrews (2020)

SN 2023usc - a type IIn SN

Discovered on 2023 Oct 11 07:56:16.80 UT by Tonry et al, o-band 18.662 mag
Tonry et al (OSU) SCAT Team TNS Astronomical Transients Report 190321

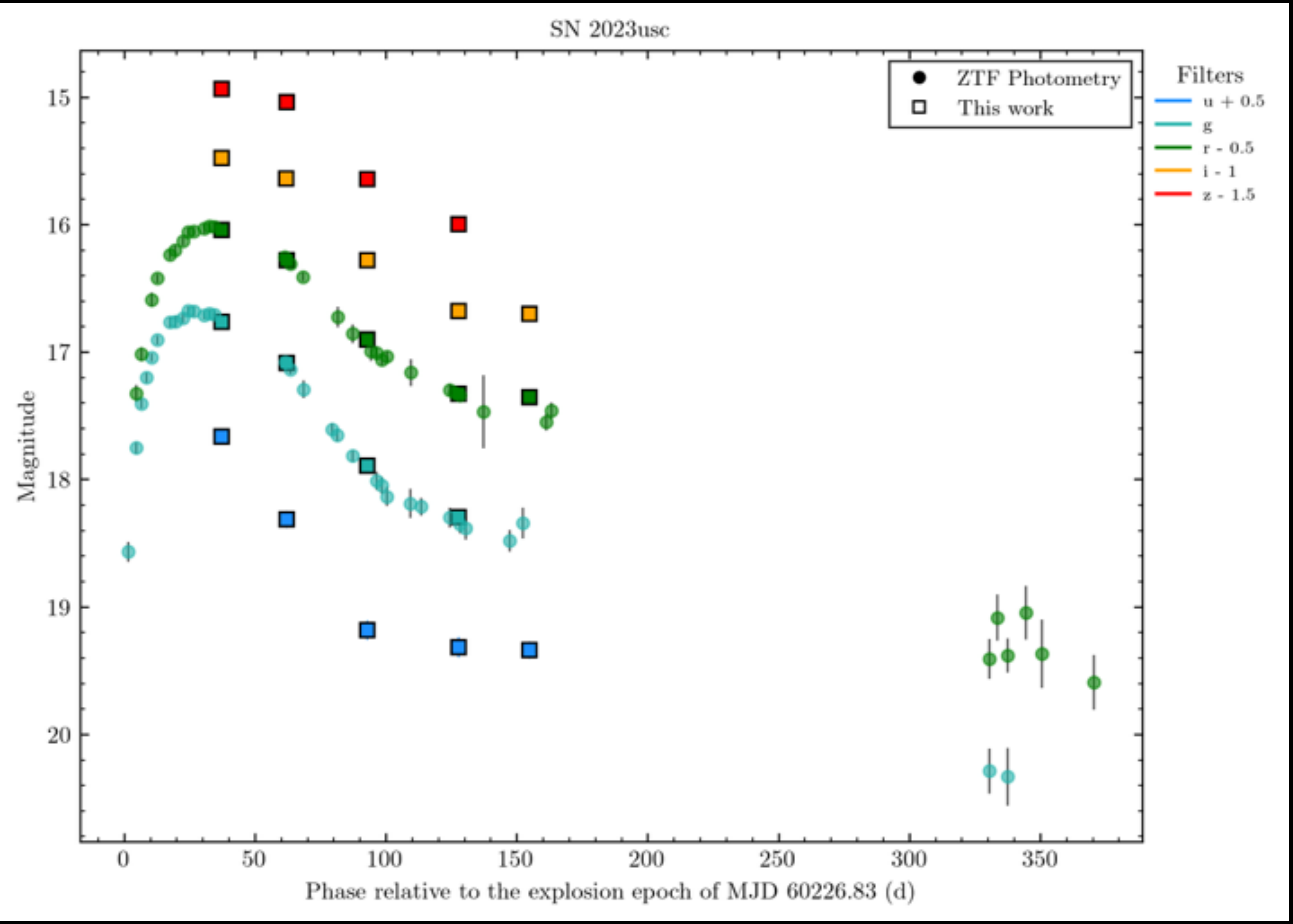
The last non-detection in the field was on 2023-10-08 08:05:48

SN (pink cross) at
05:21:31.670 +00:28:20.96

TYPE IIn Classification by Tucker et al (OSU) at z = 0.06 using SNIFS Instr UH 88 inch Telescope on 2023-10-2212:33:00 TNS Classification Report No. 15833

Light Curves of Type IIn SN 2023usc

HCT obs have been overlaid on photometry from LASAIR-ZTF (2023)



E(B-V) = 0.538 for host +MilkyWay based on Na D1/ D2 redshifted lines and their equivalent widths

A_V = 1.668

g-band peak at 16.68

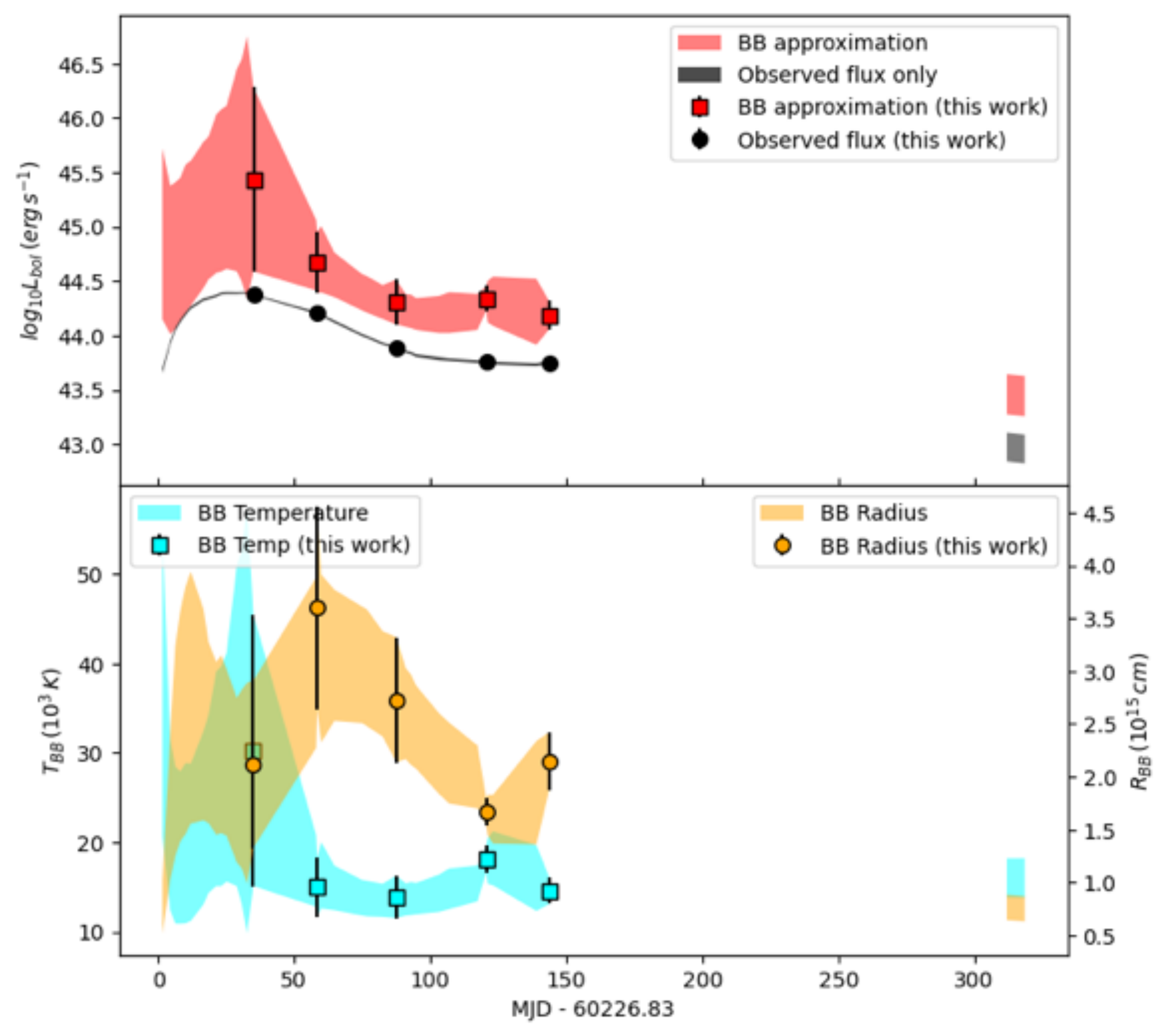
g-band peak occurred on 2023-11-04 MJD= 60252.80594

Adopted expl date: MJD 60226.834 or 2023-10-09 20:00:57.60 UT - midway between discovery and last non-detection

Bolometric Light Curves etc. for SN 2023usc

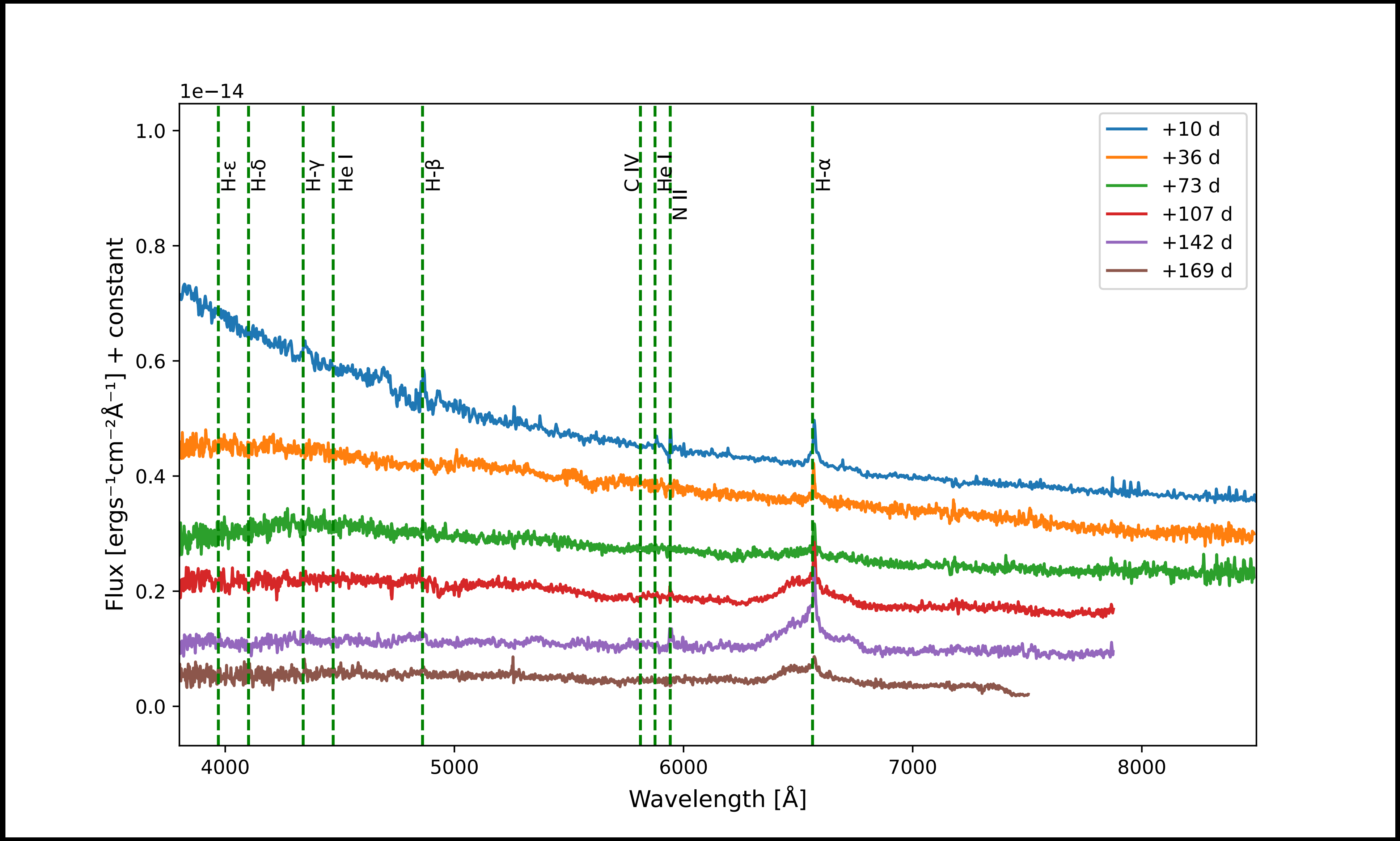
Bolometric light curves calculated by SuperBol code developed by Matt Nichol 2018

In calculating these bolometric light curves and properties, we have not include the r-band magnitudes in the fits, as r-band is strongly contaminated by line emission from the Halpha transitions



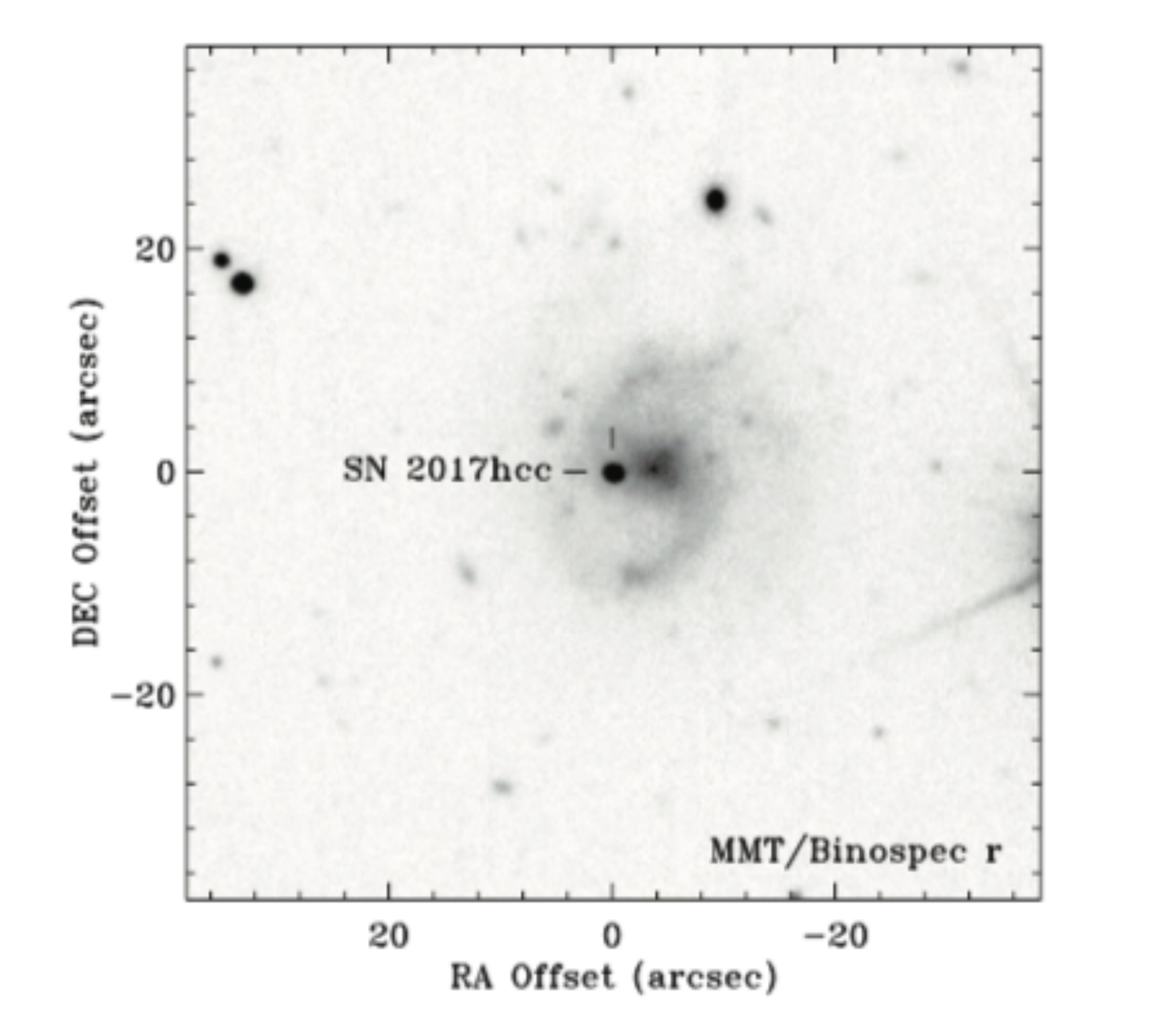
Host + MilkyWay E(B-V) = 0.538 based on Na D1/D2 redshifted lines and their equivalent widths

Spectra of SN 2023usc



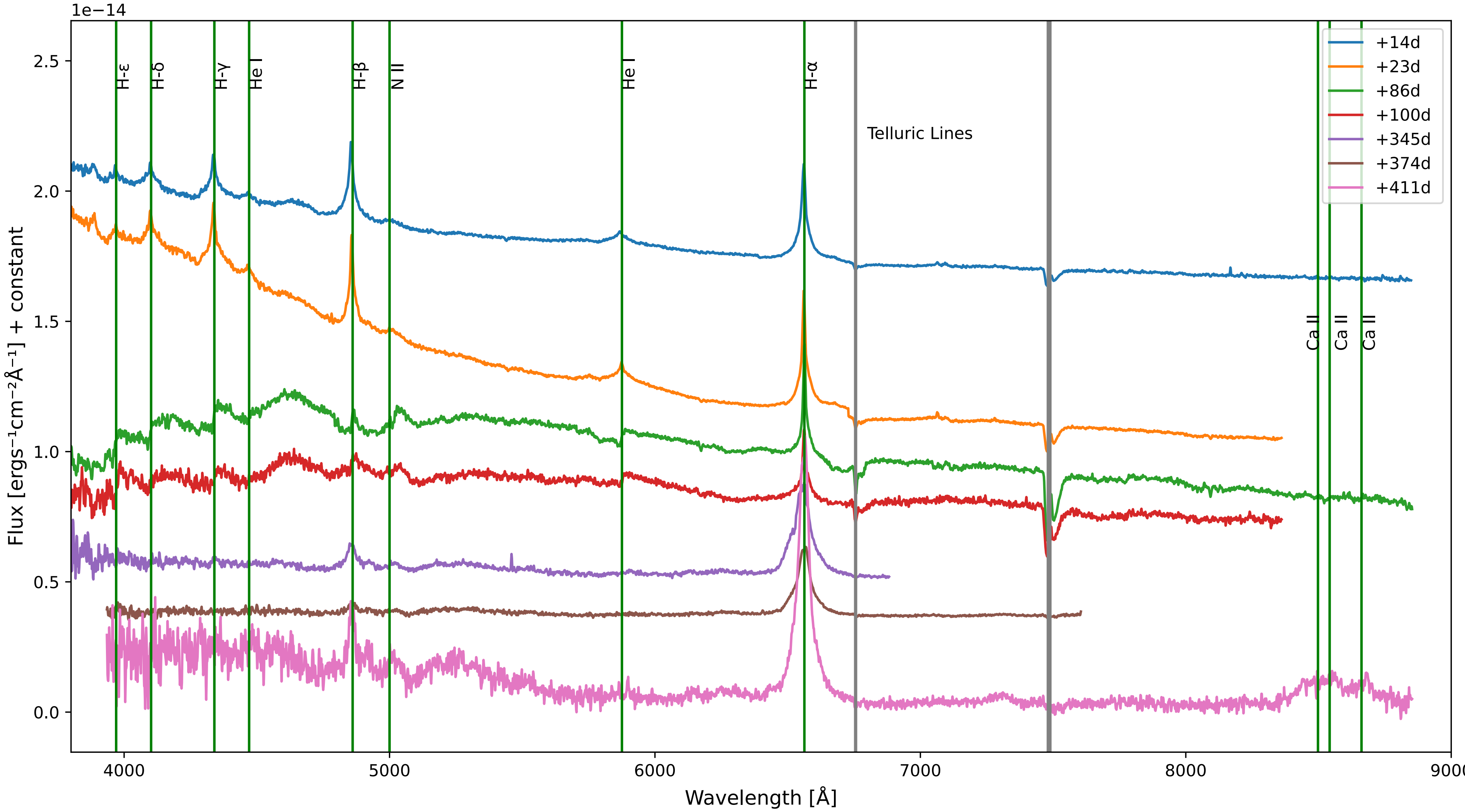
Multi-epoch (+10 d to +169 d post explosion) spectra of SN 2023usc. The 10 d spectrum is from UH88 / SNIFS (SCAT), while the rest of the spectra are from the HCT. The spectra has been shifted to the rest-frame of host galaxy, telluric correction has been applied

SN 2017hcc in Anonymous Galaxy



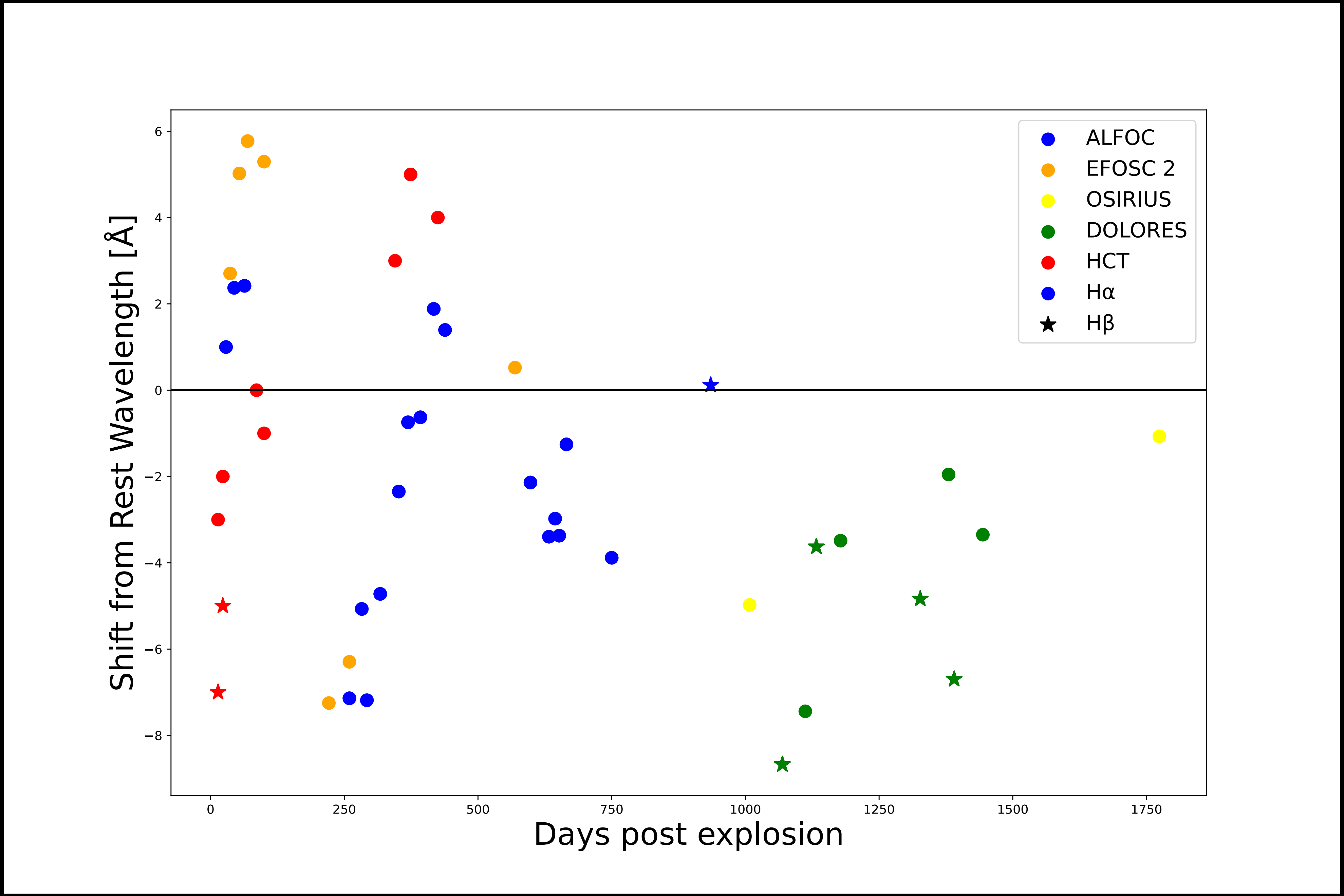
Smith & Andrews 2020
MMT Binospec r-band

2019 July 9



SN 2017hcc Spectra (+14 to +411 d post explosion) at Himalayan Chandra Telescope, Hanle. Spectra shifted to rest-frame of the host galaxy

Shift of H-alpha, H-beta line centroids from rest wavelengths with time

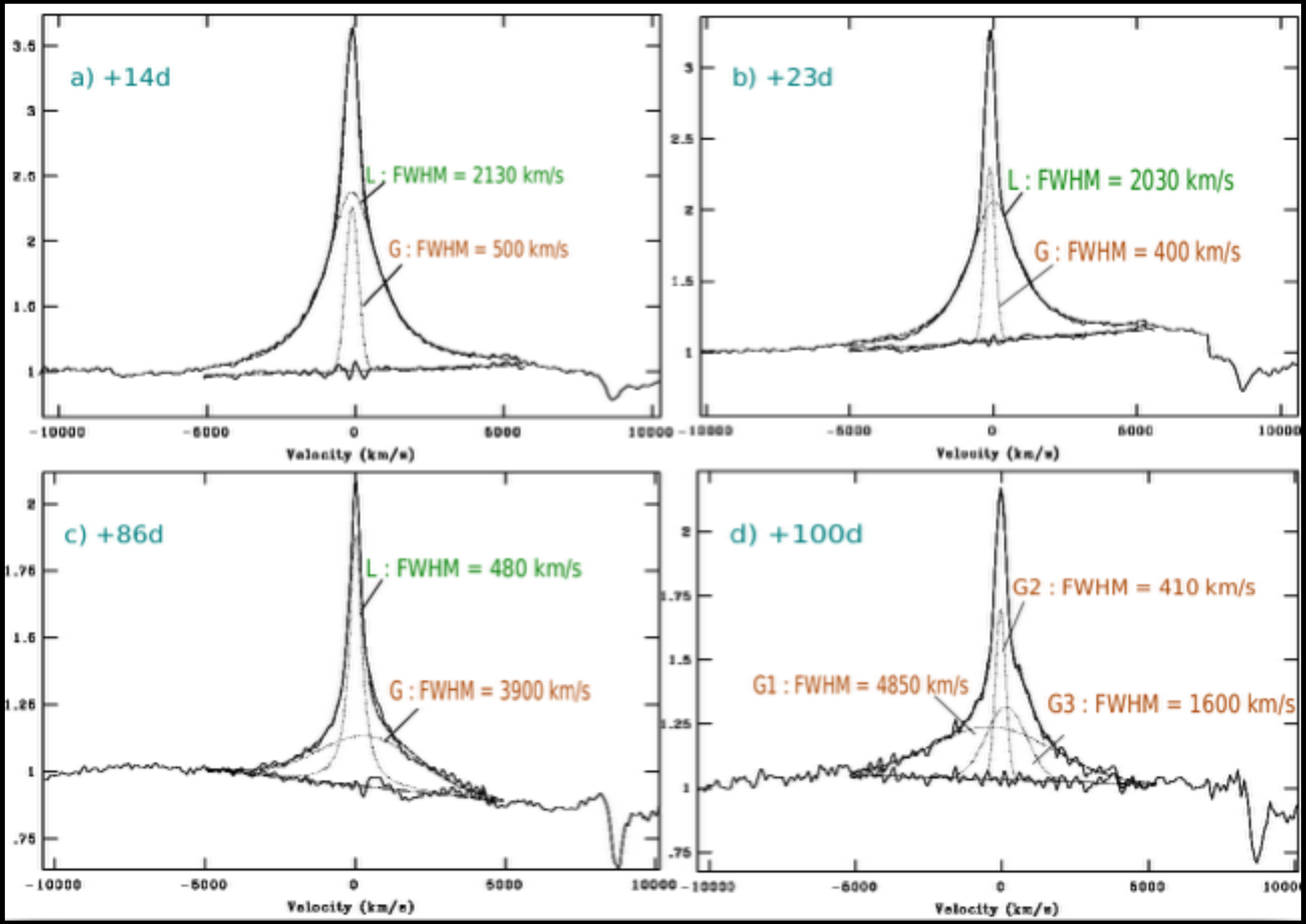


Peak of the Hα line (narrow component) plotted as a function of the epoch of observation. Following Moran et al. (2023), we have shifted the peak of Hα of SN 2017hcc from the rest wavelength 6562.8 Å

Deblending Line Profiles

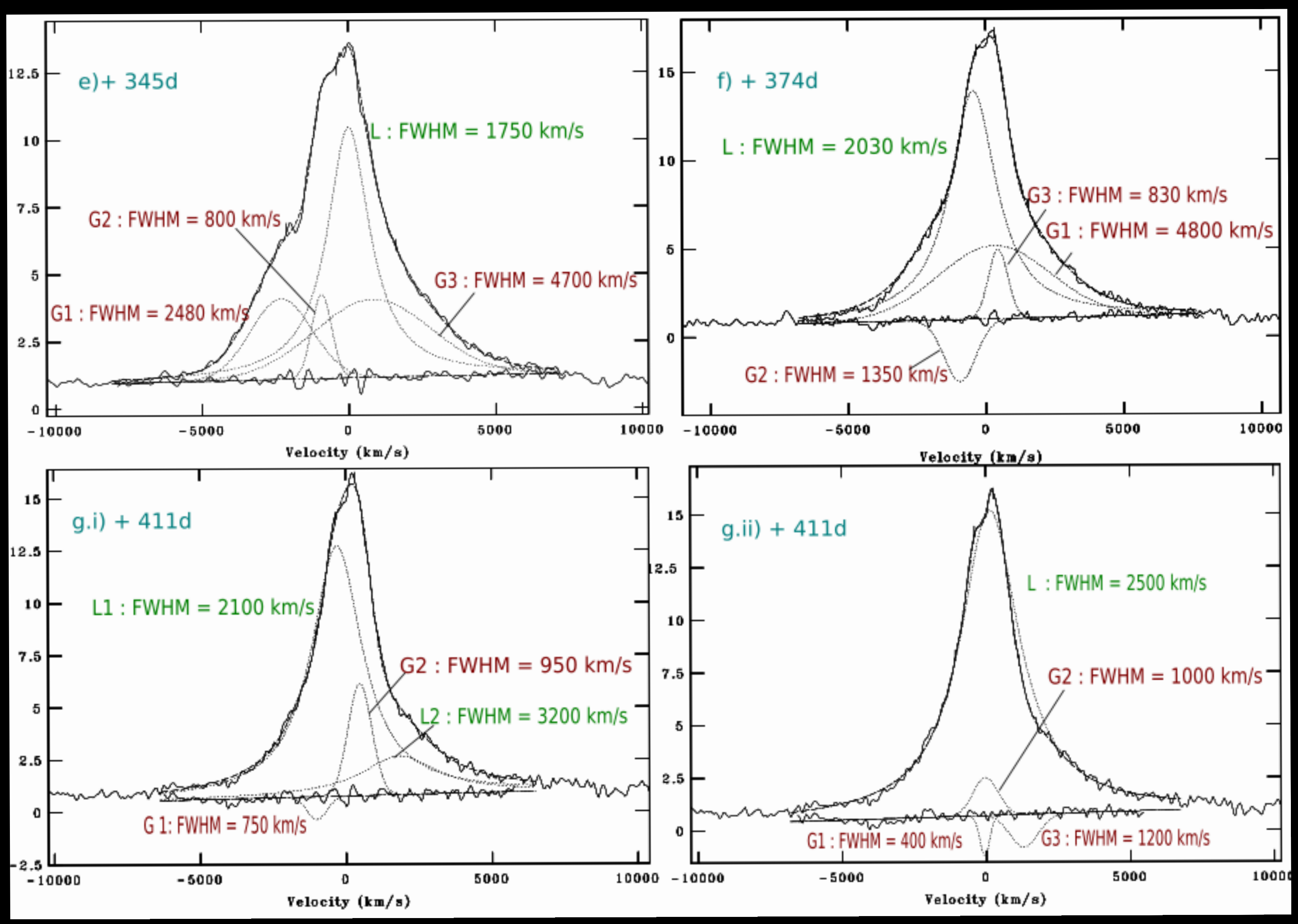
- Deblending emission lines, via IRAF, we obtain several parameters, e.g. line-center, continuum flux, equivalent width, and FWHM of the Gaussian or Lorentzian profiles.
- Line deblending is performed using the IRAF/splot package, and Gaussian or Lorentzian profiles.
- The best fit is selected through multiple trial-and-error attempts, ensuring a minimal RMS and a justified number of Gaussian profiles, which can be categorized as narrow, intermediate, or broad.

SN 2017hcc Deblended H-alpha Line Evolution

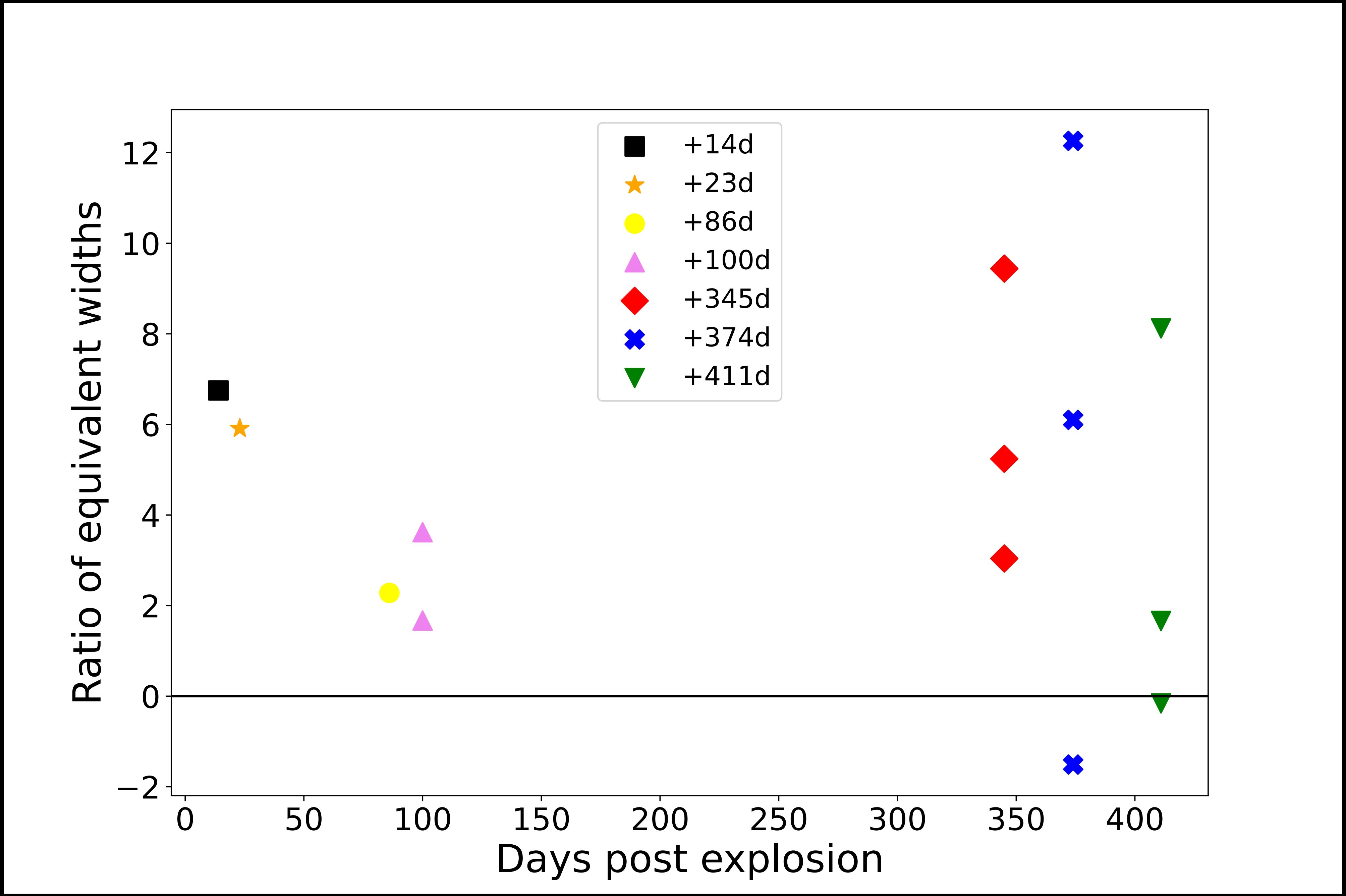


Resolving the Hα line profile of SN2017hcc in to multiple components, from +14 d to +100 d post explosion. All spectra have been boxcar smoothed with a kernel of width 3, and v = 0 km s^{-1} is set 6562.8˚A. The normalized flux is on the y-axis. The best fit profiles are marked as L (Lorentzian) or G (Gaussian), as the case may be.

SN2017hcc Deblended Halpha Line components after 300 days

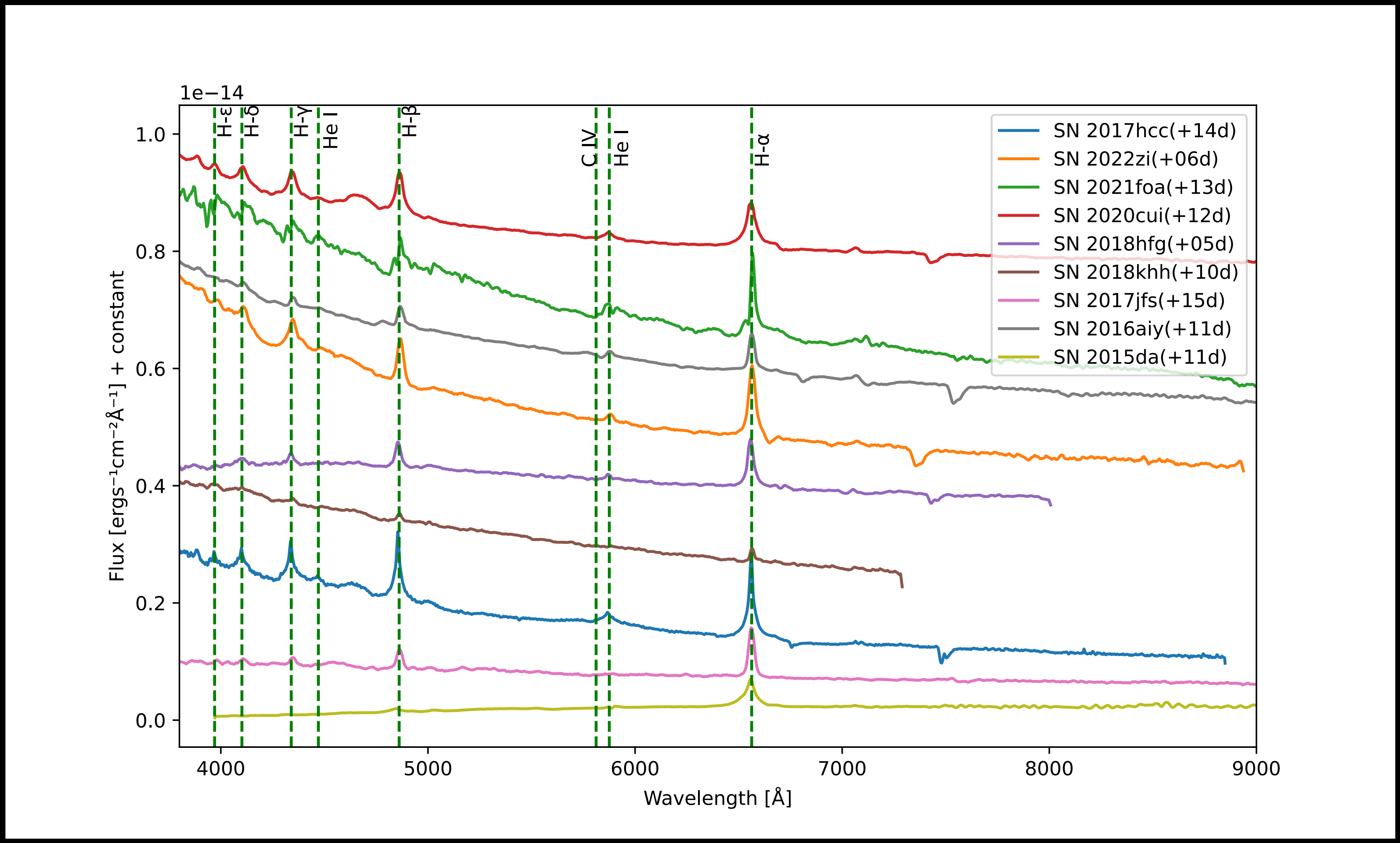


SN 2017hcc: Equivalent widths of deblended components of H-alpha line



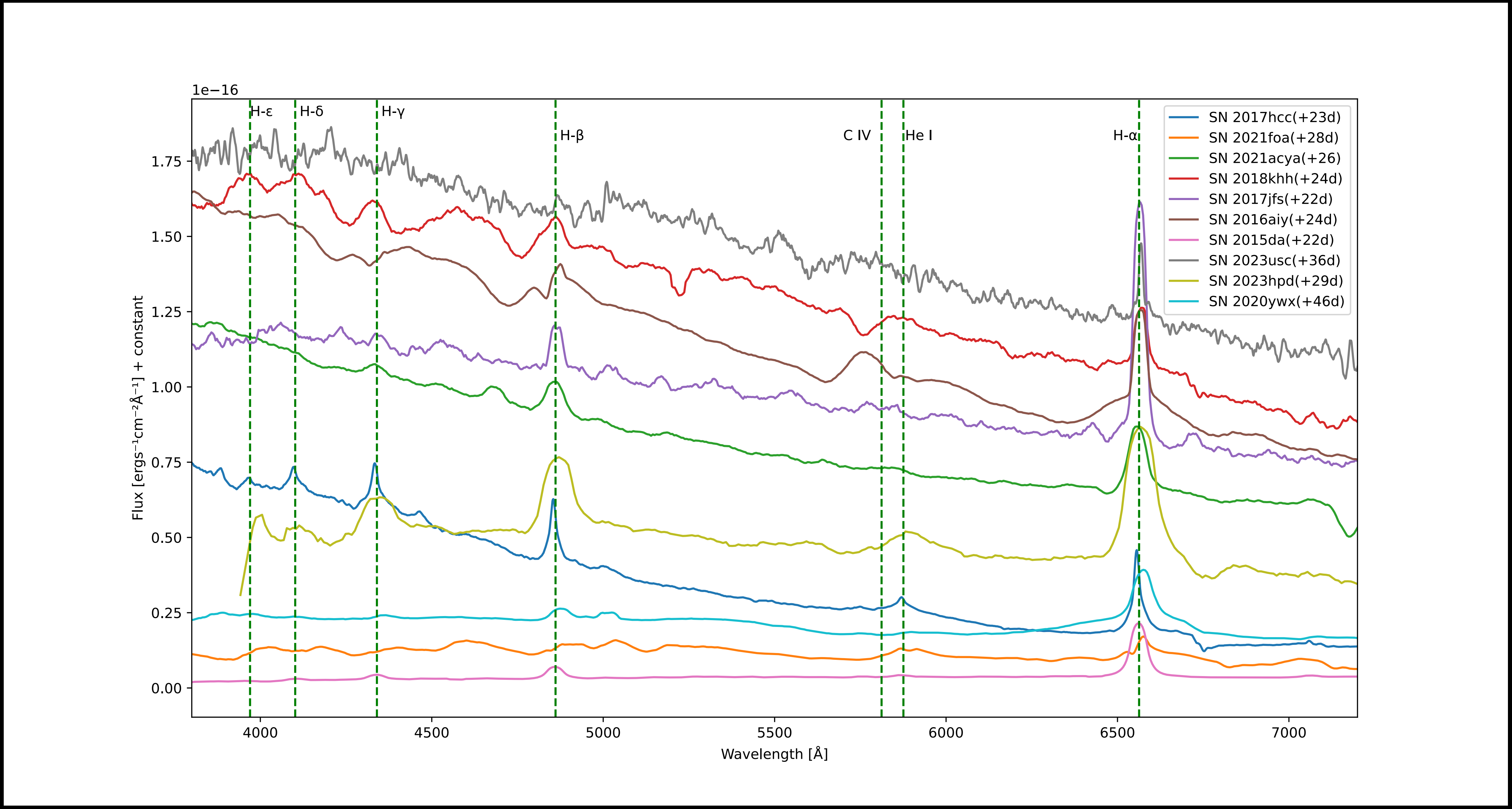
Ratio of equivalent width of the broad component of Hα with respect to narrow and intermediate component (when present)

Early spectra of events classified as type IIn SNe



SN 2021foa: gap transient

Evolution of events classified as type IIn SNe



SN 2021foa: gap transient

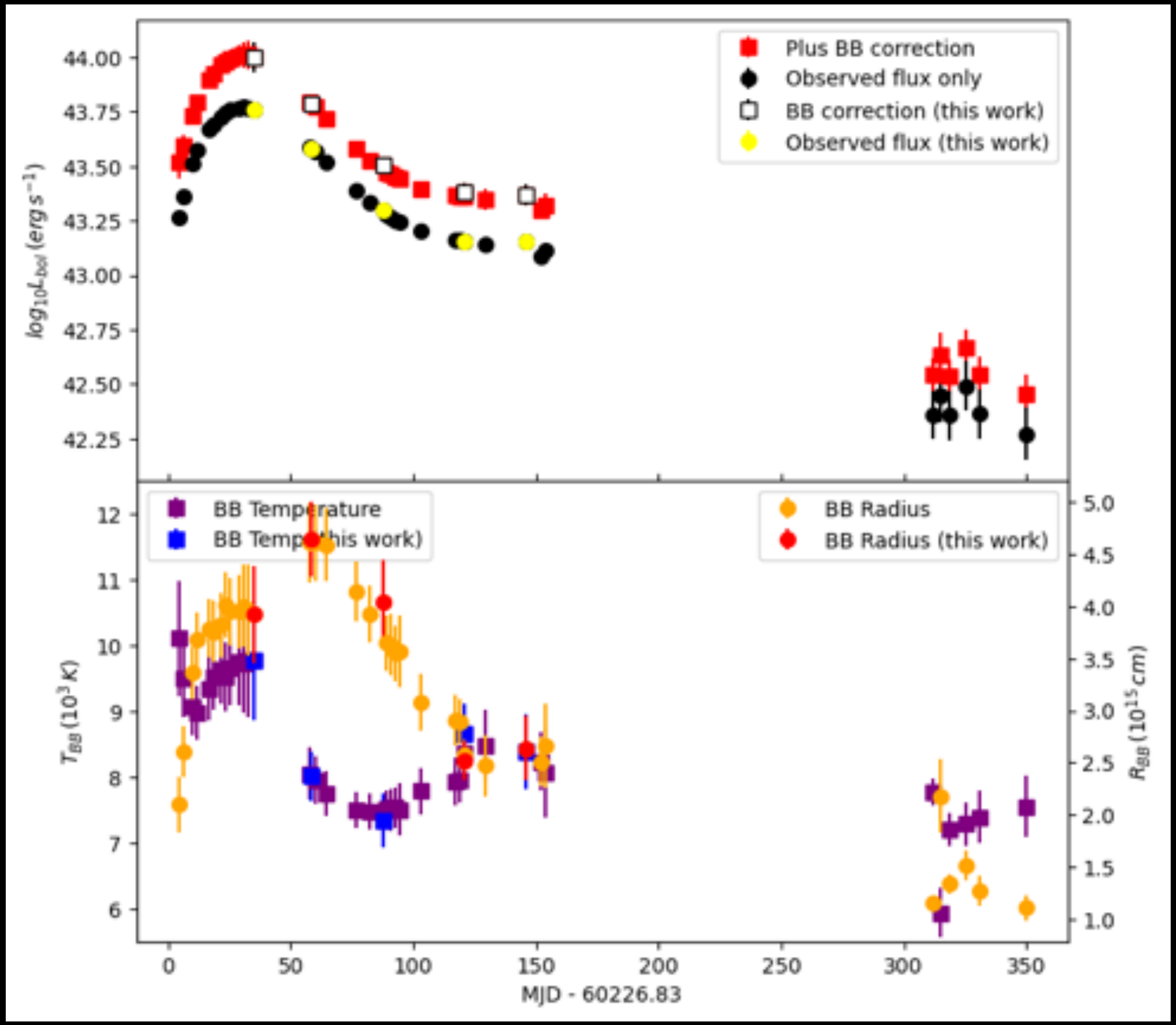
Summary and Conclusions

- We report on photometric and spectroscopic evolution of SN 2023usc and line deblending analysis of this SN and SN 2017hcc. These show how the low, intermediate and high velocity emission components in SN 2017hcc evolve with time
- In SN 2023usc, the narrow line component (~450 km/s) of the H-alpha emission persists for about +107 days after explosion. The intermediate velocity feature (~2000 km/s) seen on +10 days vanishes by +36 days and is replaced by a high velocity feature (> 8000 km/s) by +73 d.
- Since the intermediate velocity feature is likely due to Thomoson scattering of photons deep within the CSM, this chronology suggests that by +36 days the CSM becomes optically thin and emission from the fast ejecta begins to emerge by +73 days. The narrow component actually widens to about 700 km/s which could be the effect of formation of a cool dense shell (CDS) formed after the fast ejecta runs into the CSM. If the shocked ejecta rammed into the CSM by +73 days, then the last epoch of the dense CSM formation would be due to progenitor activity 1257 days (~3.5 years) before the explosion.

Happy and privileged to join the celebration of the careers of the four Astronomers from Padova!
Massimo, Massimo, Enrico and Laura

Thank You

Bolometric Light Curves etc. for SN 2023usc



With only the Milky Way reddening E(B-V) =0.118 in the SN direction from the Na I D1/D2 line EWs

Colour Evolution of SN 2003usc