Real Time Detection of Supernova Shock Physics with TESS

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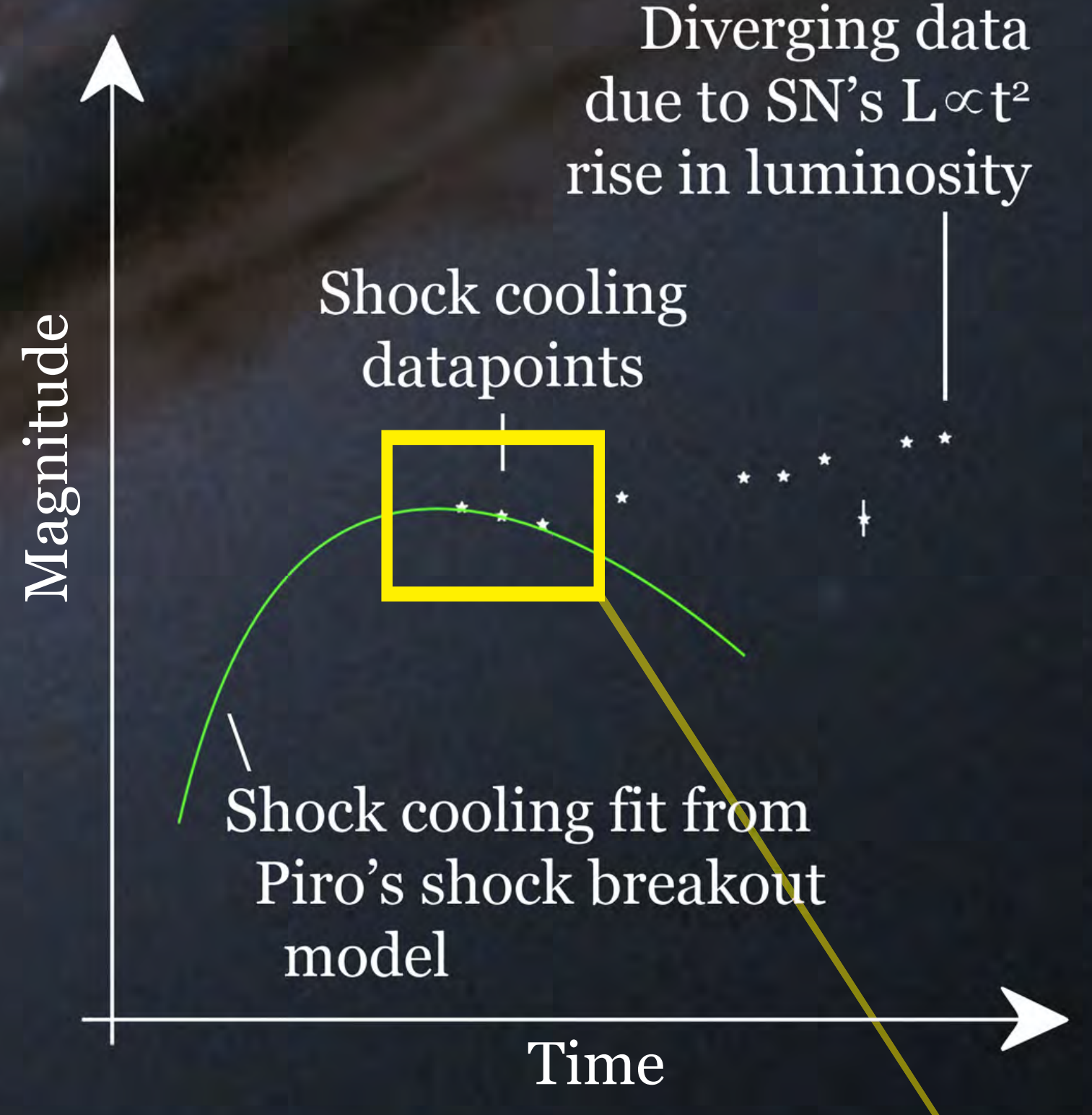
Supernovae are incredibly bright events that can be seen at extragalactic distances away. By studying their early light curves, we will be able to see early shock events such as shock breakout occur, which can reveal a lot about their progenitor systems. WiFeS is an integral field spectrograph mounted to the ANU 2.3m telescope at Siding Springs Observatory. We have utilised WiFeS to follow up on several young, nearby supernovae that occured within the TESS fields during its southern cycle. Through this program, we have tracked the spectral evolution of shock events unfold. One such case, SN2019com, is shown below. TESS's high cadence readouts, and large field of view, provide us with an opportunity to study supernovae using a previously underutilised tool; shock physics.

Supernova imposters are a rare occurance.
Thought to be the result of a Luminous Blue Variable star undergoing huge outbursts, these objects are often flagged as SN multiple times prior to final detonation. These outbursts pump large amounts of matter into the surrounding circumstellar material (CSM), leading to a SN IIn spectrum. The first case of a supernova imposter, SN2009ip, is detailed below. Through our program, we have managed to obtain spectra of shock cooling in a 2009ip-like SN.

Shock breakout is the first visible cue of a supernova detonation.
When supermassive stars run low on fusable material, they start to implode due to gravity. The fusion reaction occuring within produces a shock front, which is trapped by the imploding outer layers. As more material gets absorbed by the core, the outer layers become optically thin, and finally allow the shock front to propagate outwards. This releases a quick, bright burst of high energy light called 'Shock Breakout'. By studying the shock breakout, and resultant shock cooling phase of SN, we can obtain a lot of information about the progenitor system. Variables such as the progenitor radius, ejecta mass, and ejecta velocity can all be determined by applying Piro's or Waxman's model of shock breakout.



Diverging data due to SN's $L \propto t^2$ rise in luminosity

Shock cooling datapoints

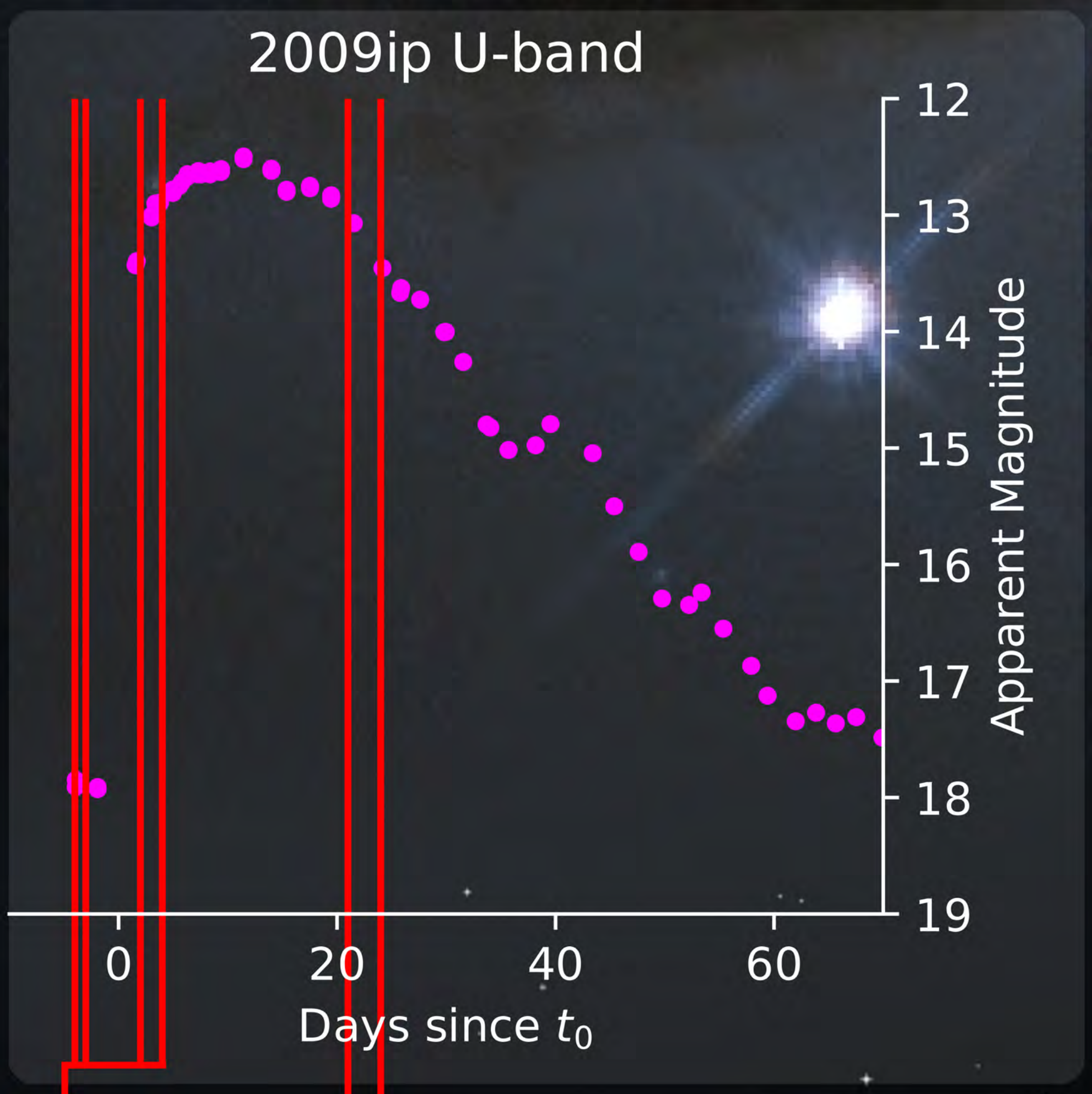
Shock cooling fit from Piro's shock breakout model

Applying Piro's model of Shock Breakout to the shock cooling data points of 2019com reveals:

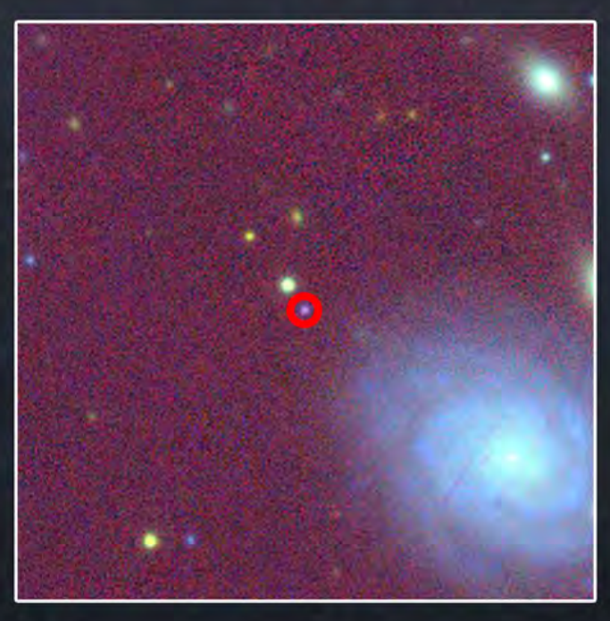
$r \sim 110\ M_{solar}$
$m_{ejecta} \sim 3\ M_{solar}$
$v_{ejecta} \sim 10400$ km/s
$t_{breakout} \sim 5$ days prior to first datum point

These values are in agreeance with an LBV progenitor system, just like 2009ip.

We have obtained spectra from $t_{breakout}$ giving us a glimpse into how the early shock physics unfolds.

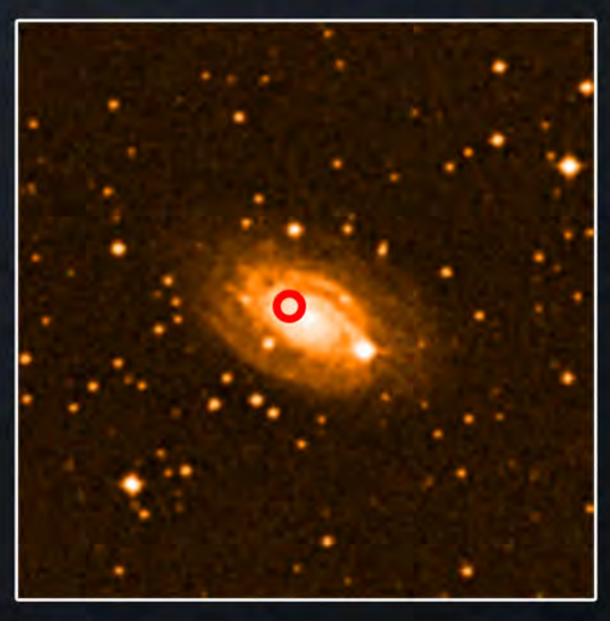


2009ip U-band



NGC 7259

2009ip	**2019com**
The Supernova Imposter -	- 2009ip-like
z = 0.005944 -	- z = 0.012799
Unknown environment -	- Known Environment
LBV progenitor -	- Compatible with LBV
Multiple detonations -	- Unknown if prior detonations
	- Shock cooling present



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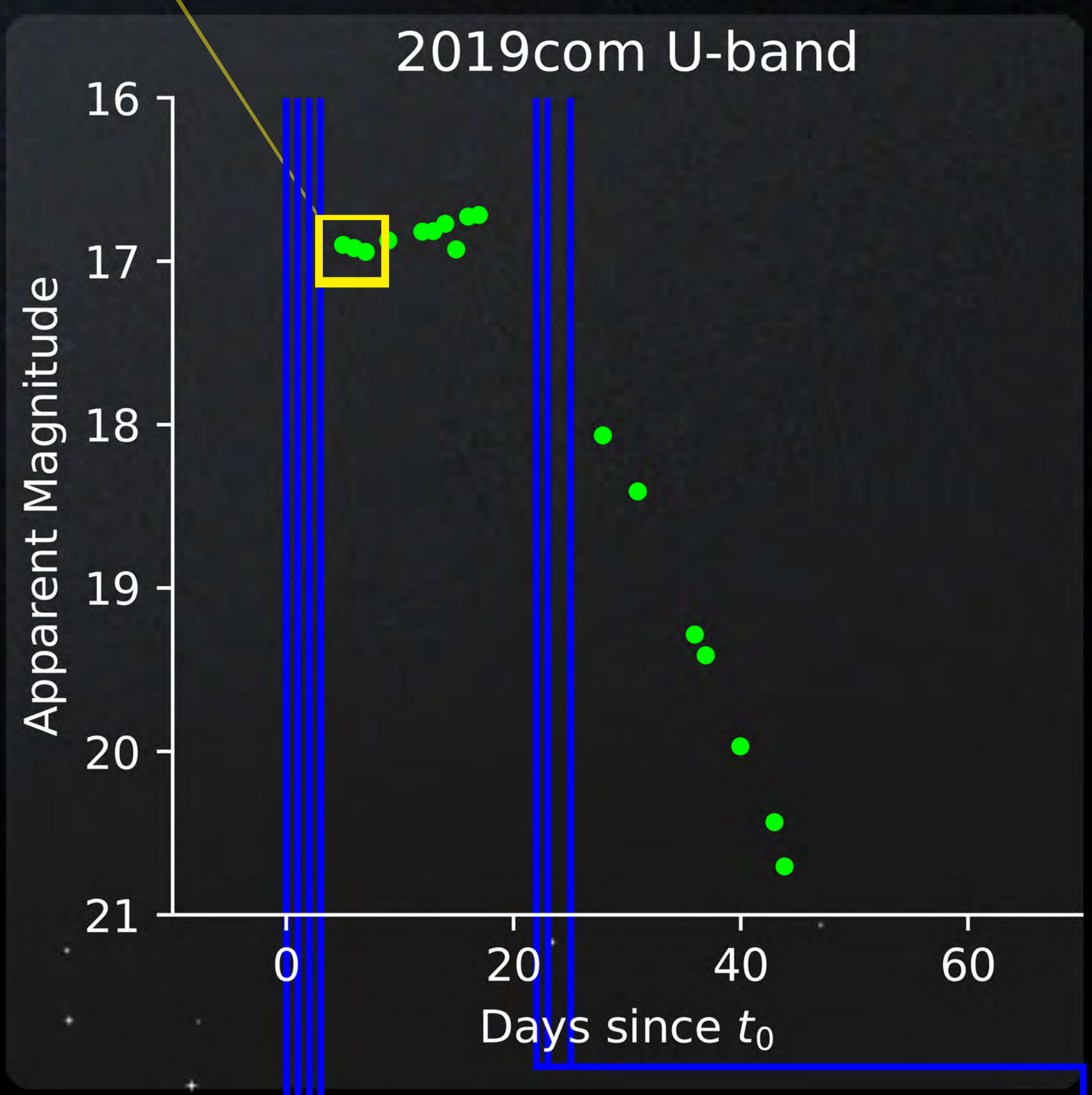
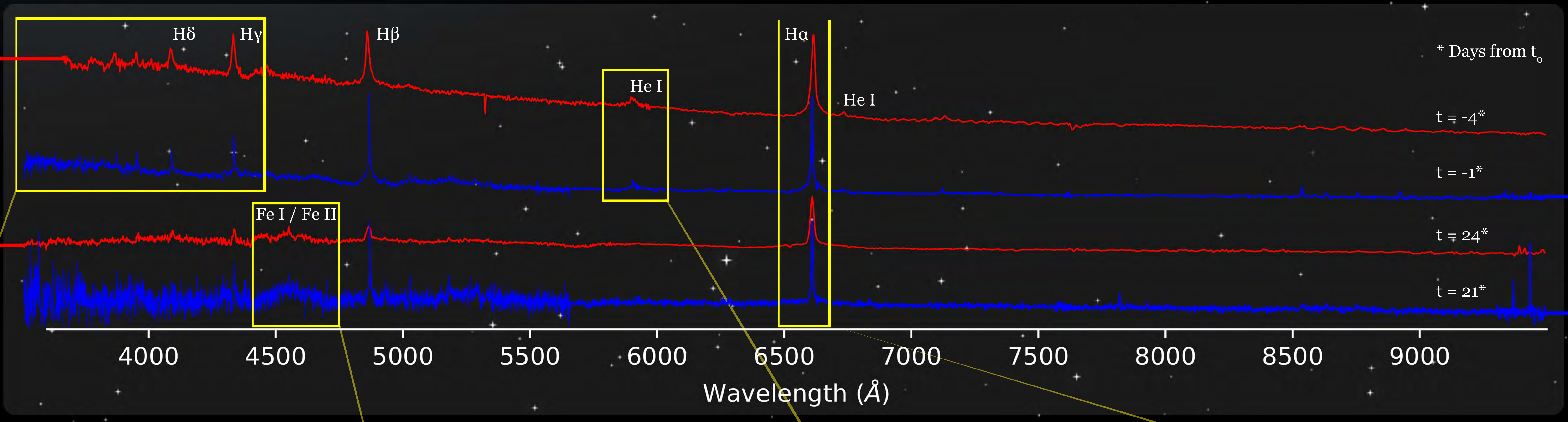
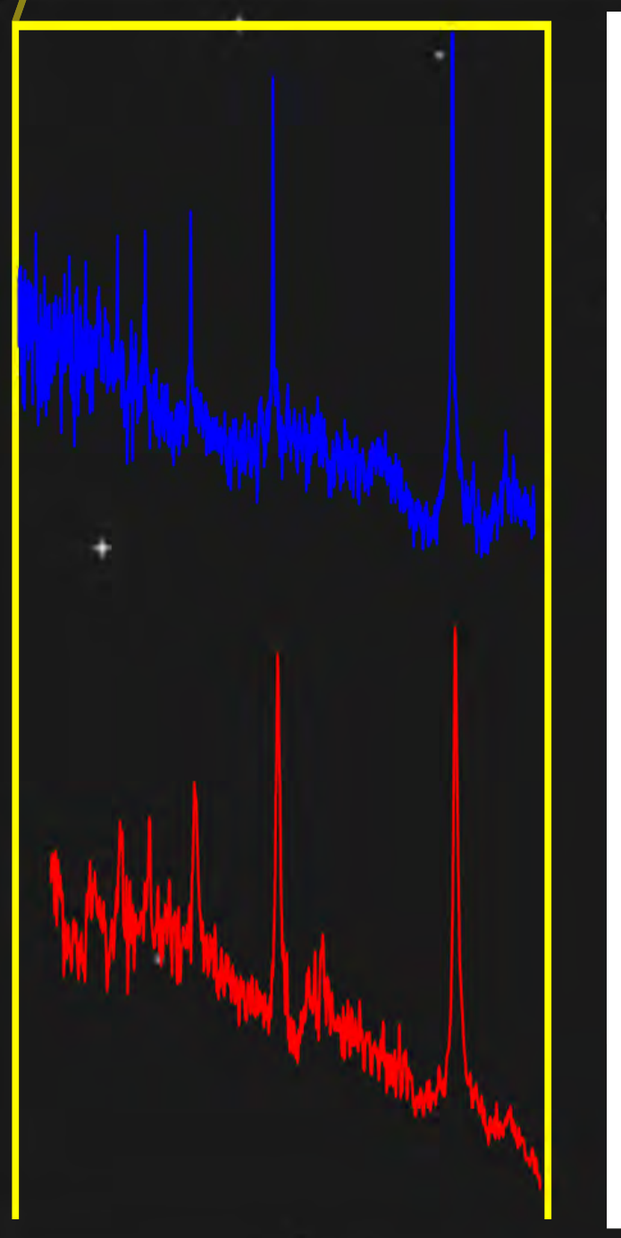
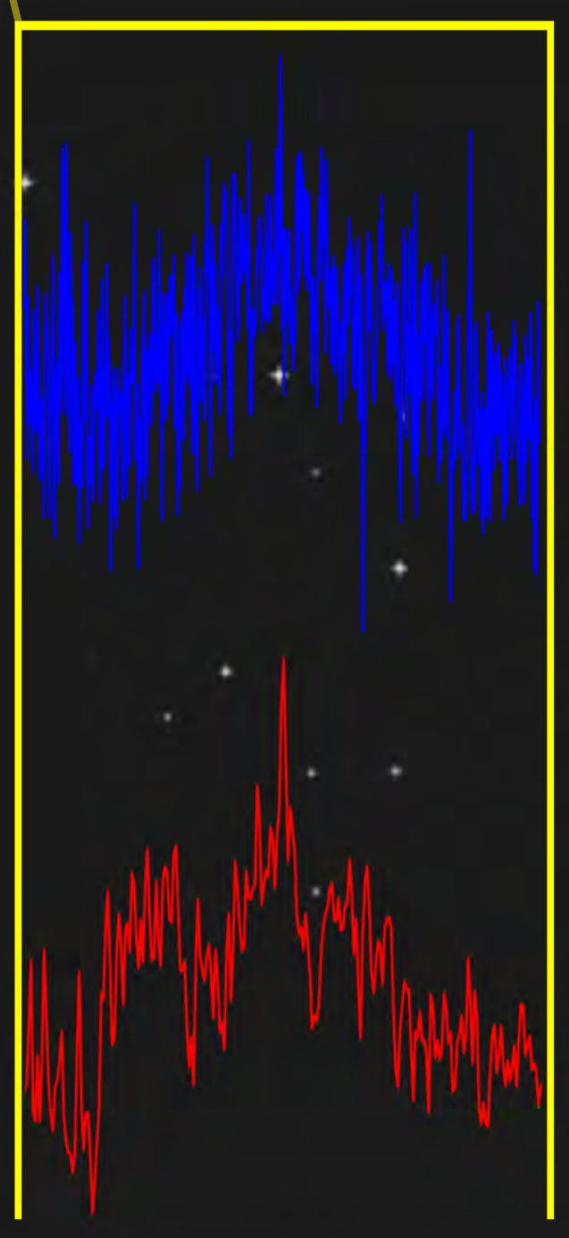


2019com U-band

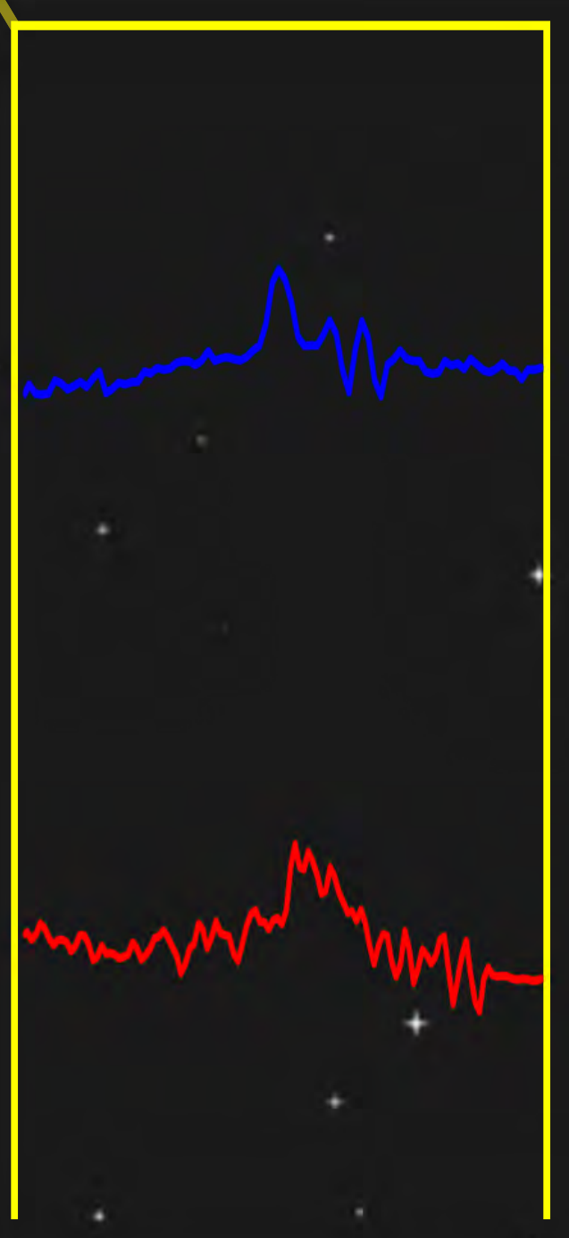




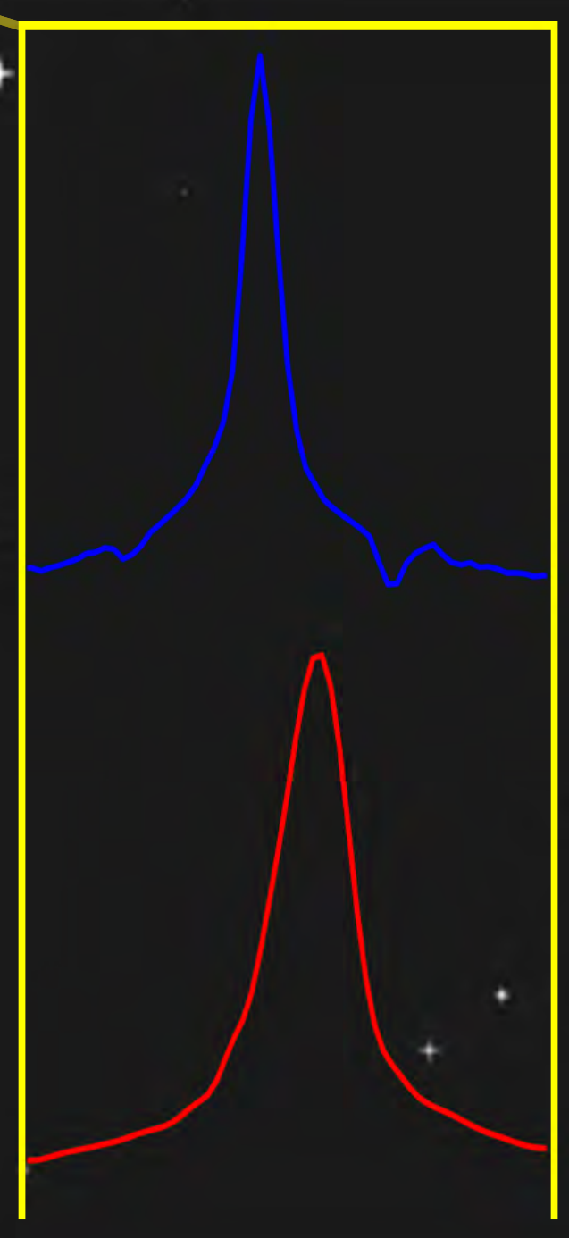
Blue Excess
A blue excess is fairly typical of SN and acts as an indicator that the supernova is indeed young. By analysing the gradient of the early time spectra, we can ascertain the temperature of the shock front by comparing with the black body emission curve.



Broad Fe
Both SN show a broad iron emission lines approximately 20 days after shock breakout. This is an atypical feature for a SN IIn to display



Vanishing He
Helium lines which are apparent at early epochs vanish at later dates. Helium is unexpected from SN IIn, and indicates a dense CSM.



Prominent Hα
Typical of Type II SN. FWHM measurement reveals two Gaussians overlayed.

For 2019com
$v_{CSM} \sim 211$ km/s
$v_{ejecta} \sim 10{,}400$ km/s