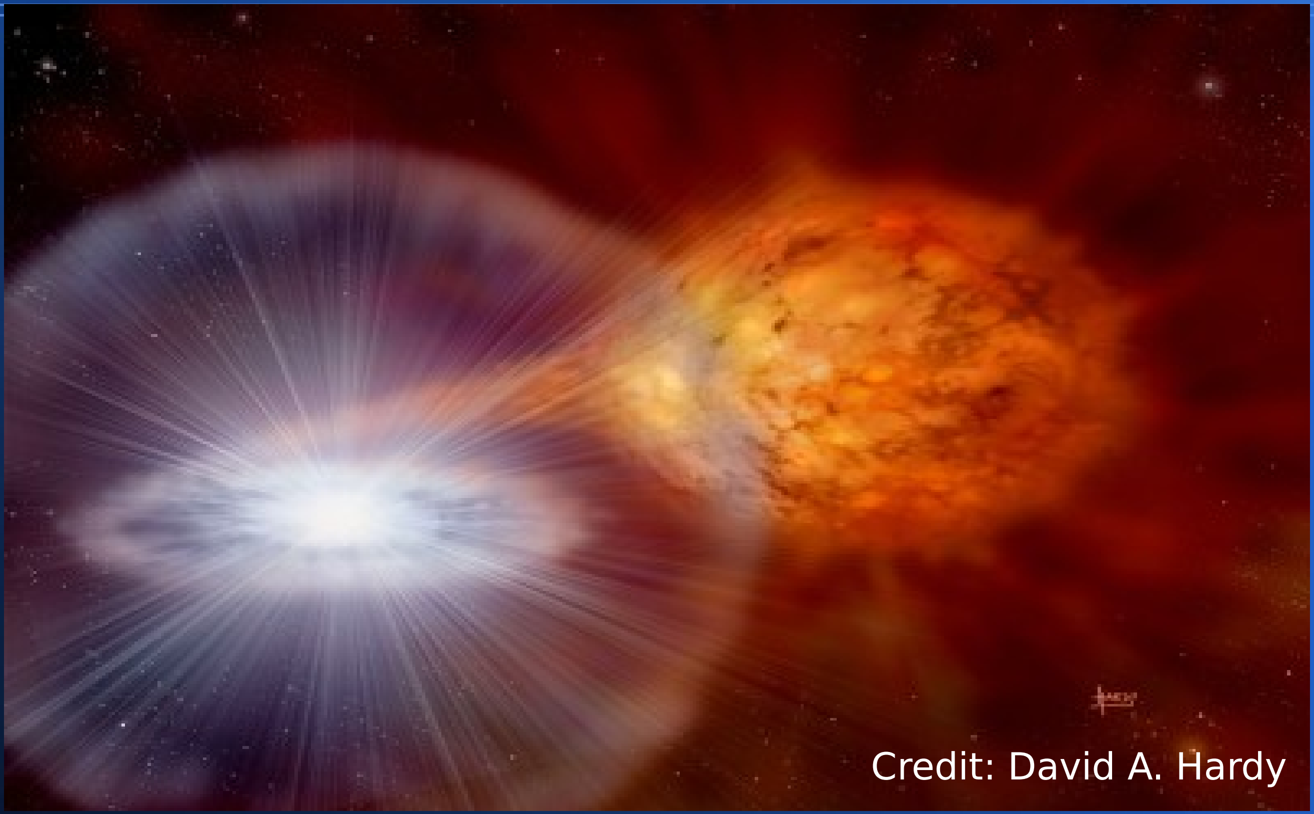
Simulation of compact circumstellar shells around Type Ia supernovae and the resulting high-velocity features



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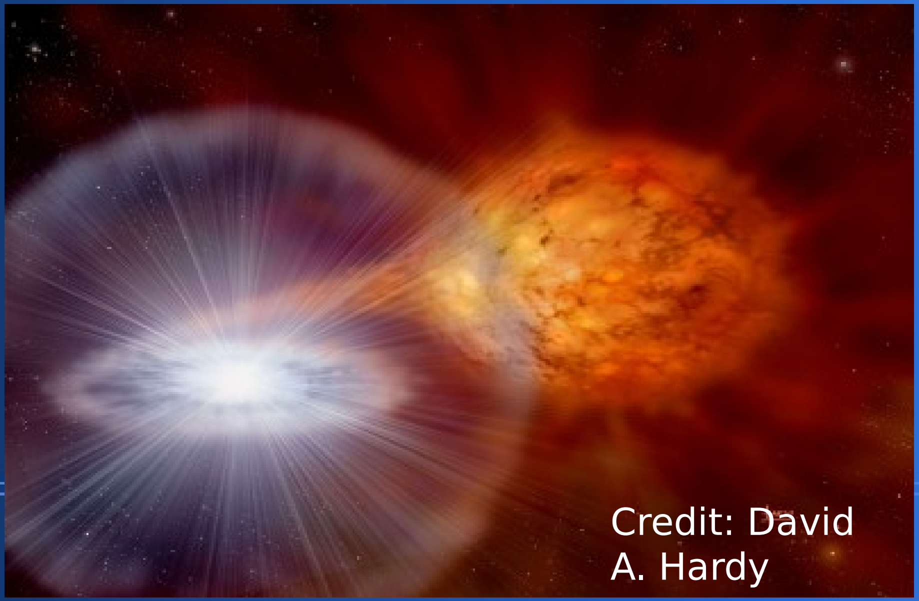
- Friends

Overview

- Type Ia supernovae
- Early observations: high velocity features
- Interaction between supernova and circumstellar medium
- Our 1-D simulations & results to date

Type Ia Supernovae

- Standardizable candles, used for measurements of Hubble flow
- Chemical enrichment (Fe) of galaxies
- C/O white dwarf (SN2011fe)
- Chandrasehkar limit via accretion or merger
- Rapid burning of C,O to Ni

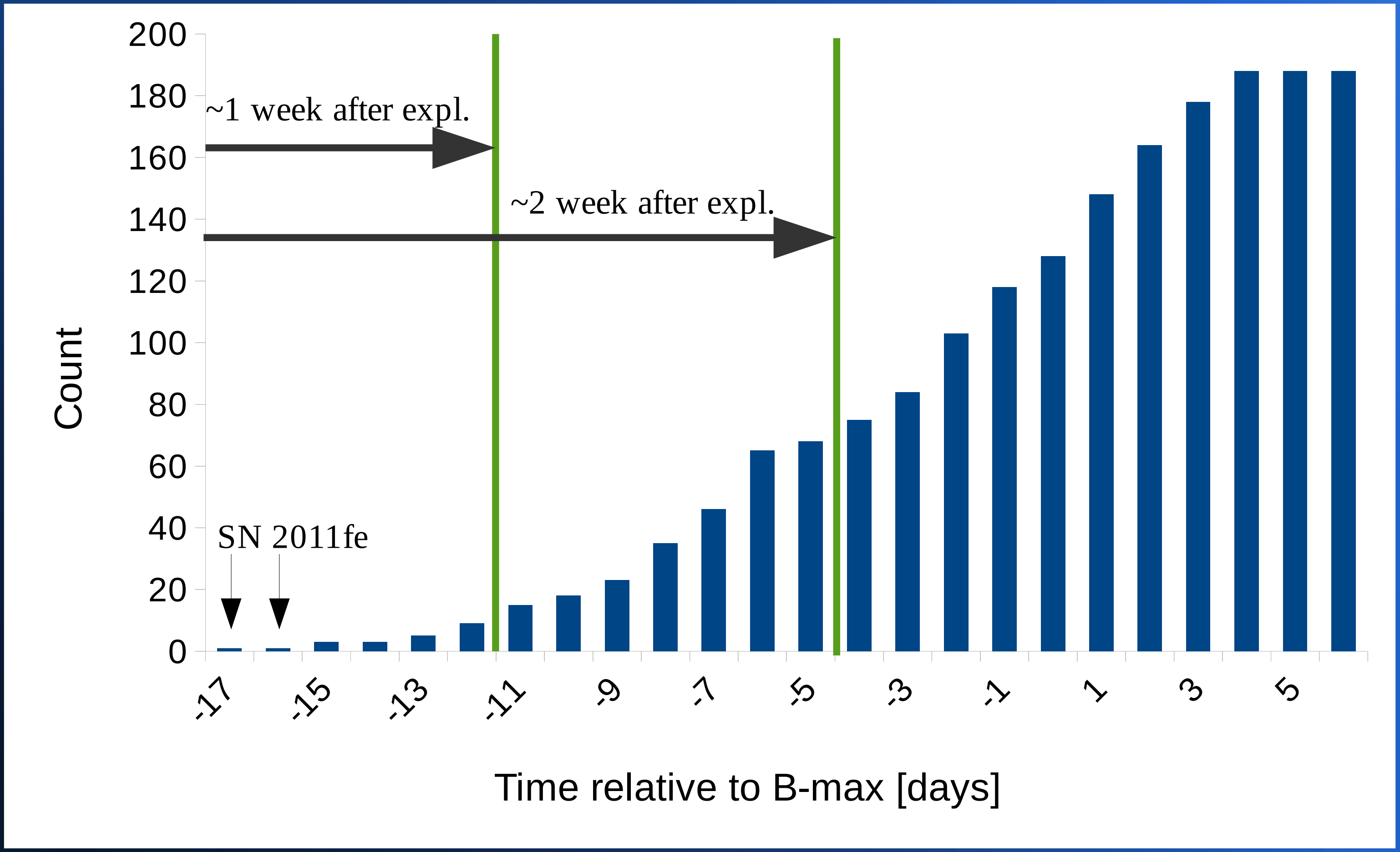


Outstanding Questions

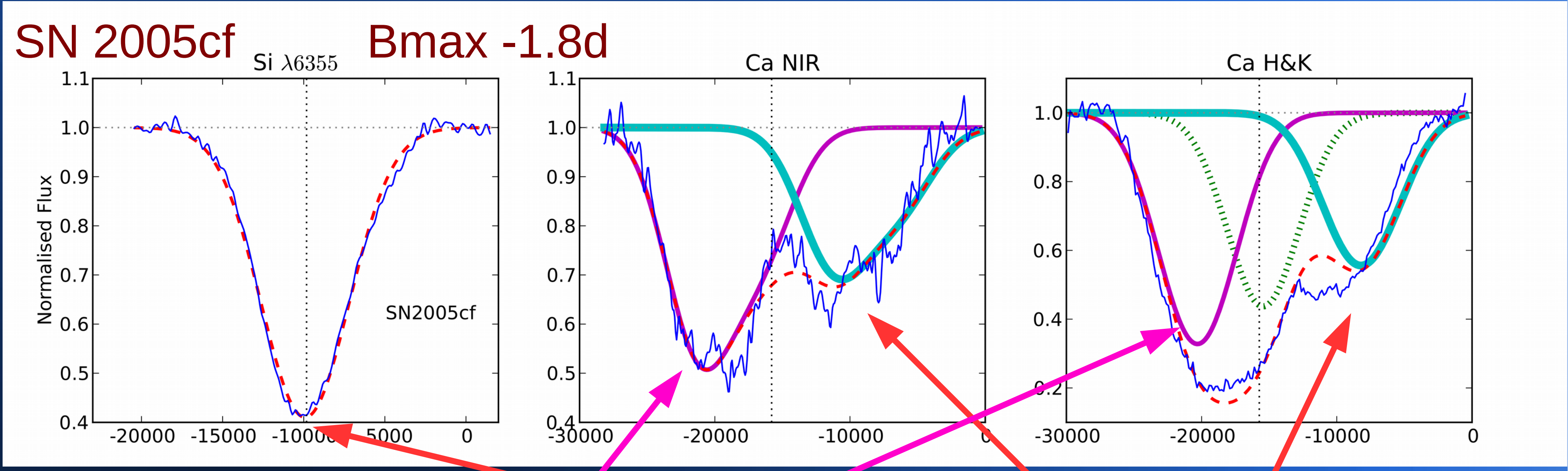
- Configuration of the progenitor system?
  - White dwarf with MS or RG stellar companion
    - “Single Degenerate”
  - Two white dwarfs
    - “Double Degenerate”
- Explosion Mechanism?
  - Central deflagration followed by detonation?
  - Surface shell detonation → cent. def. → Det?
- Several methods to probe
  - Early spectra

Early spectra available

Count of SNe included in Silverman et al. 2015 with spectra available at or after X days



Outermost layers – high velocity features (HVF)

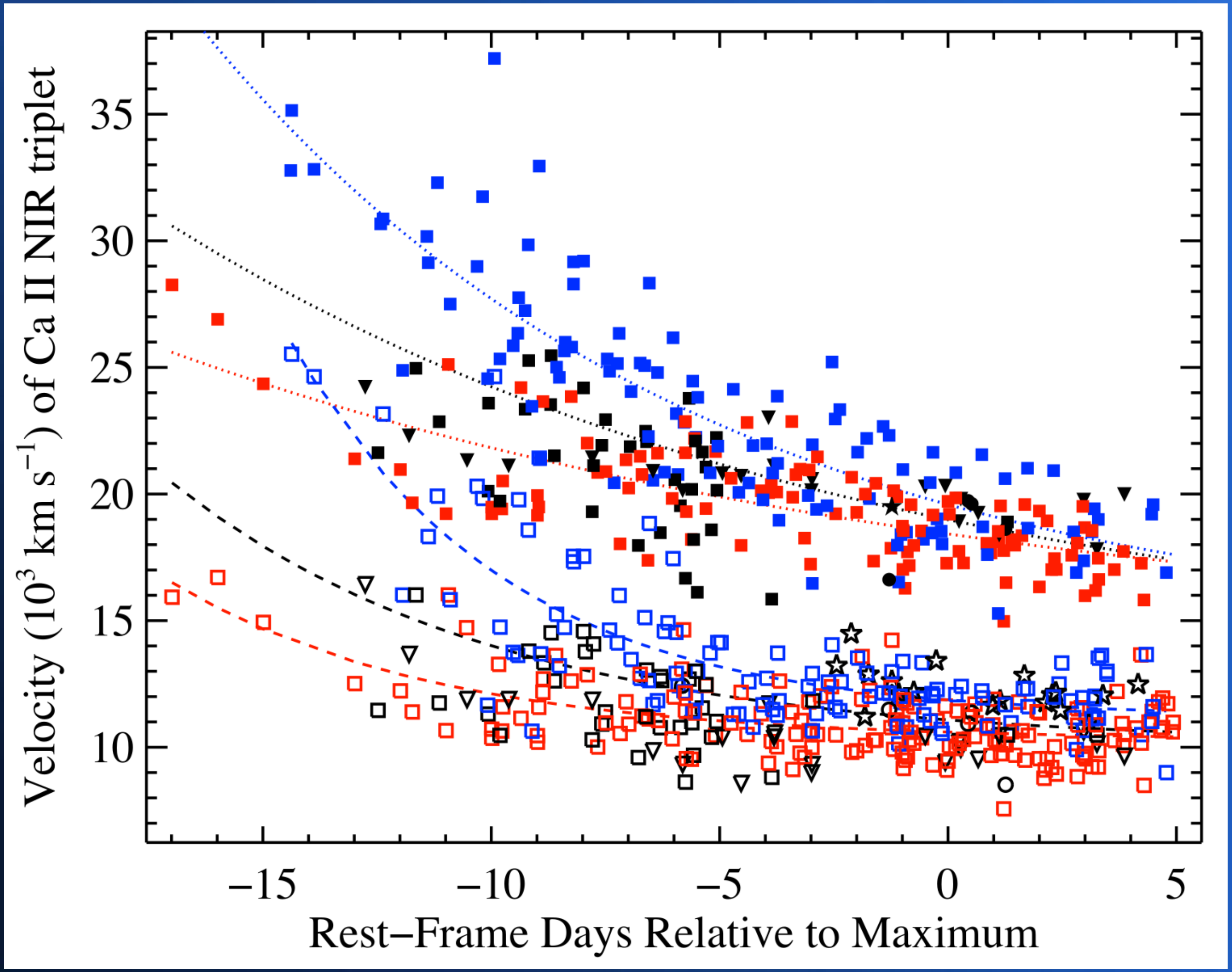


(Childress et al. 2014)

High velocity feature (>~20,000 km/s)

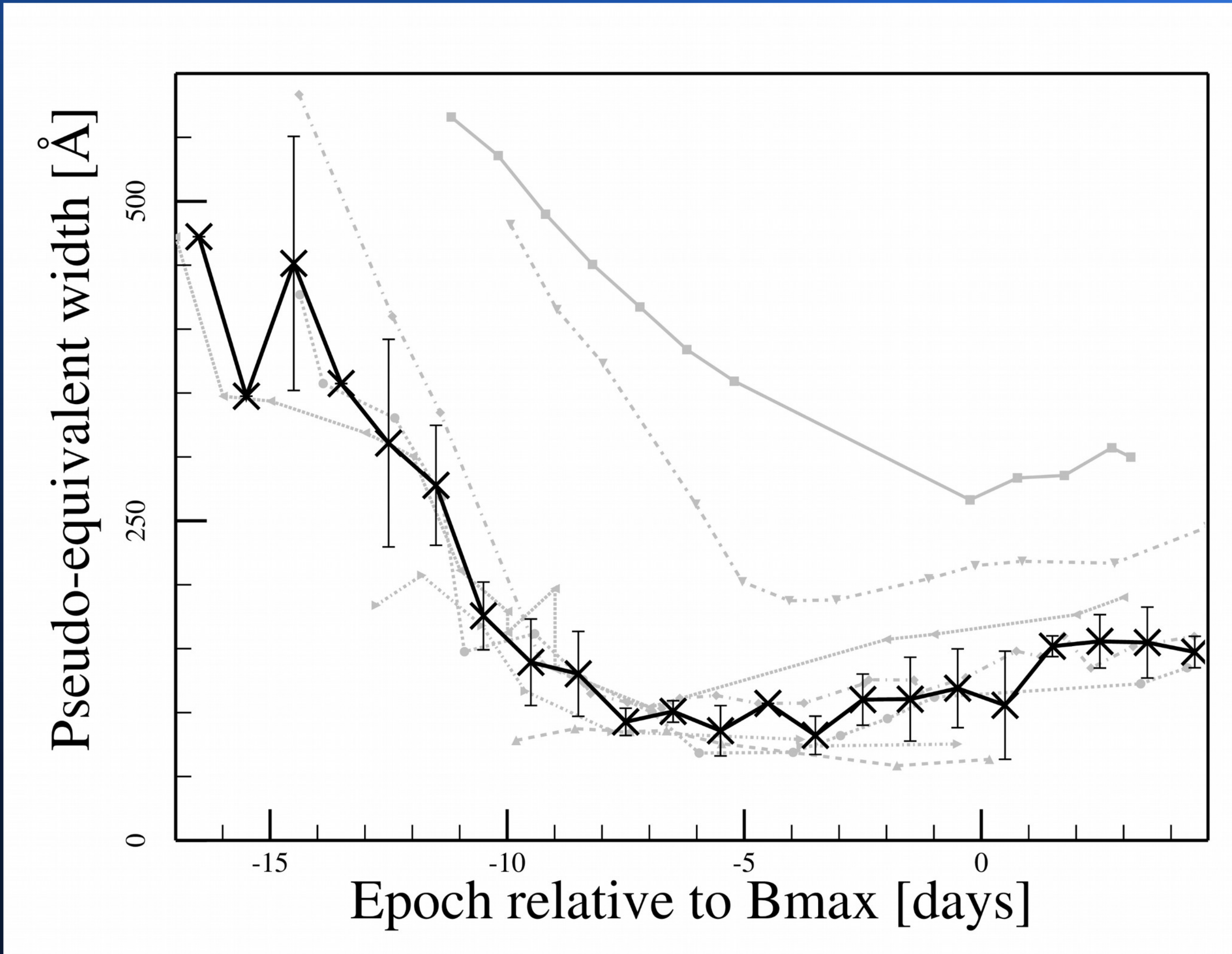
“Typical” Ejecta (~10,000 km/s)

HVF Evolution (Velocity)



(Silverman et al. 2015)

Ca II NIR triplet feature evolution



(Mulligan & Wheeler 2017, data from Silverman et al. 2015)

Observational information about HVF

Velocity >~ 30,000 km/s @ 1-2 days

Consistently >~ 8,000 km/s faster than ejecta

Fade over time (gone by ~1 week after Bmax)

Polarized→clumpy (Wang et al. 2003, Kazen et al. 2003)

Observed in ~90% of SNe.

Calcium (most SNe), Silicon (few SNe, Wang HV)

~ 0.01 Msun of material (Tanaka et al 2008)

Unlikely to be related to pre-explosion wind or extended CSM interation (blue and synchrotron emission)

Questions

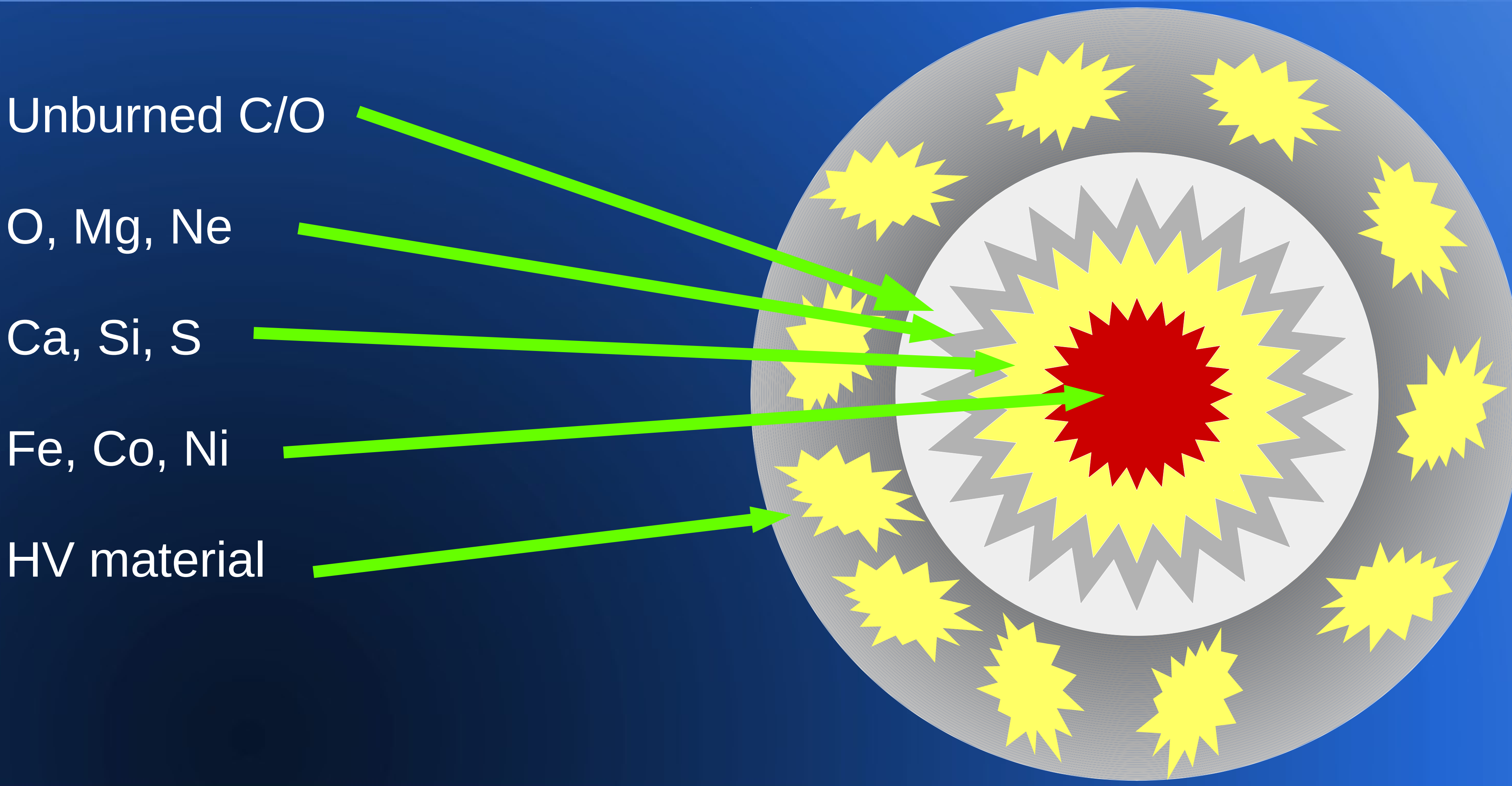
What is required to make high velocity features?

What is the source of the material?

(Accretion? Merger? Surface detonation?)

What is the composition of the material?

SN structure (with HVF)



Sources of HVF

Density enhancement? (Tanaka et al. 2005)

Ionization? (Blondin et al. 2013)

Wind or CSM? (Gerardy et al. 2004)

Energetic clumps from ejecta? (Wang 2003)

Focus on times near max. light

No evidence that velocity and pEW will evolve

Compact Circumstellar Shell

$R < R_{sun}$

Mass: $0.003 – 0.02\ M_{sun}$

Velocity: 0 km/s

Broadly consistent with any compact shell / atmosphere with velocity << eject velocity

Density structure

Simulation & Spectral generation

Hydrodynamics: FLASH 4.1 (1-D spherical)

$$\varrho(\mathrm{v}) \longrightarrow \bar{\tau}_{\mathrm{Sobolev}}(\mathrm{v})$$

Synthetic Spectra: syn++ (modified)

- Ca II NIR triplet (uncontaminated)
- github.com/astrobit/es
- github.com/astrobit/analysis_tools

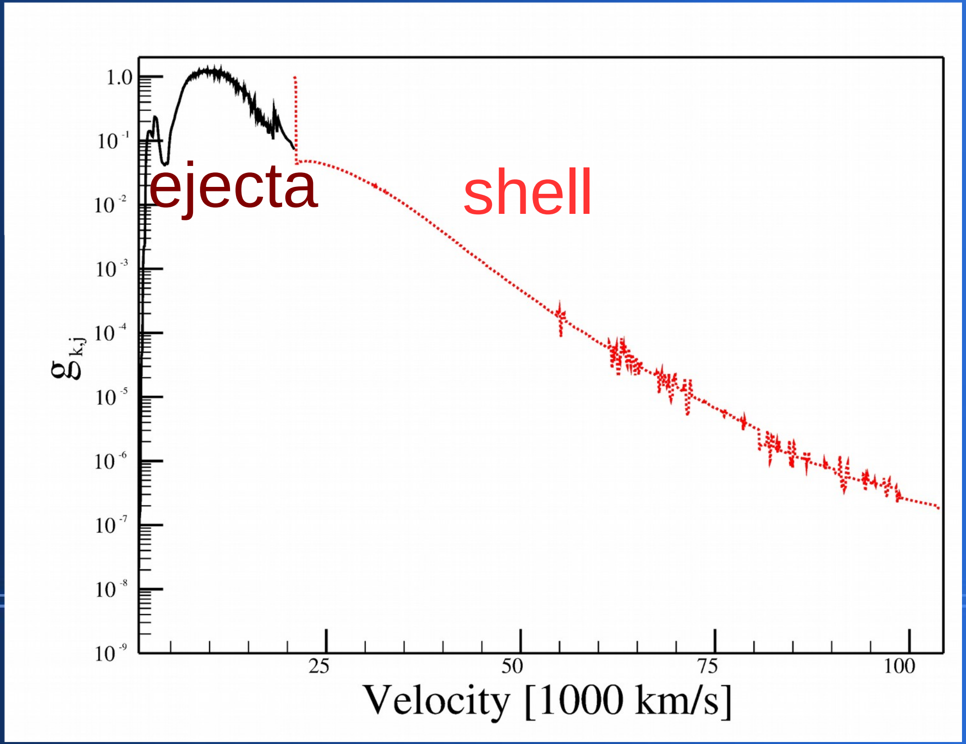
syn++ & the Optical depth profile

$$\tau(v,t) = S t^{-\alpha} g(v)$$

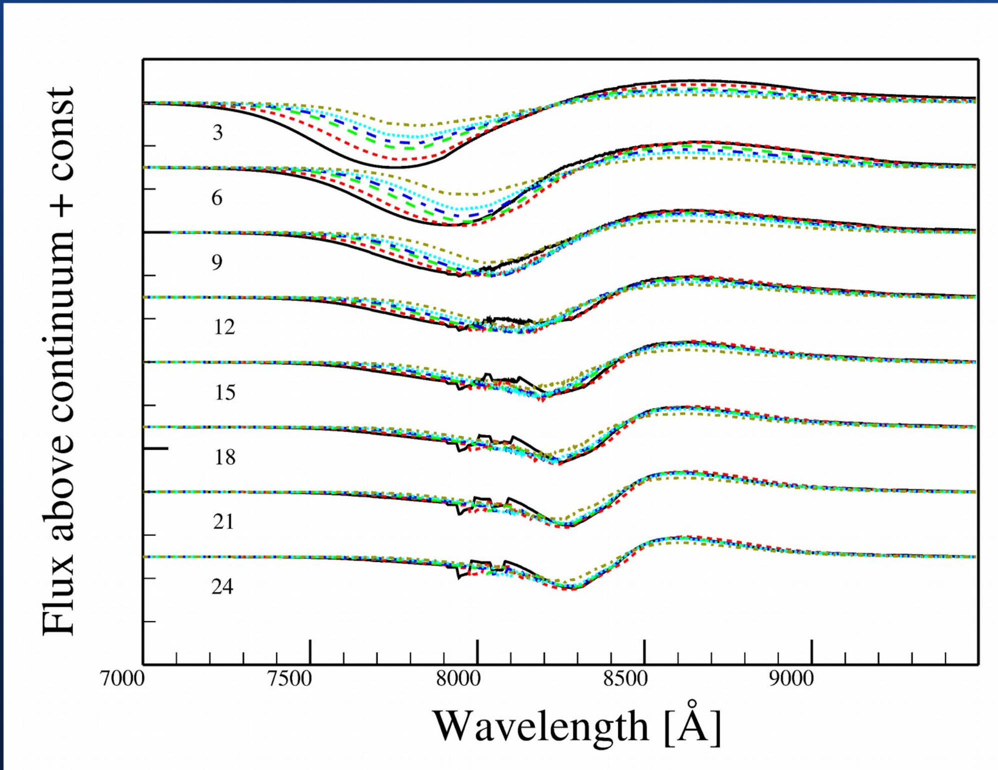
α = time dependance of optical depth; α = 2 (Sobolev, free exp.)
S = scalar factor
g(v) = normalized profile generated from hydrodynamic data

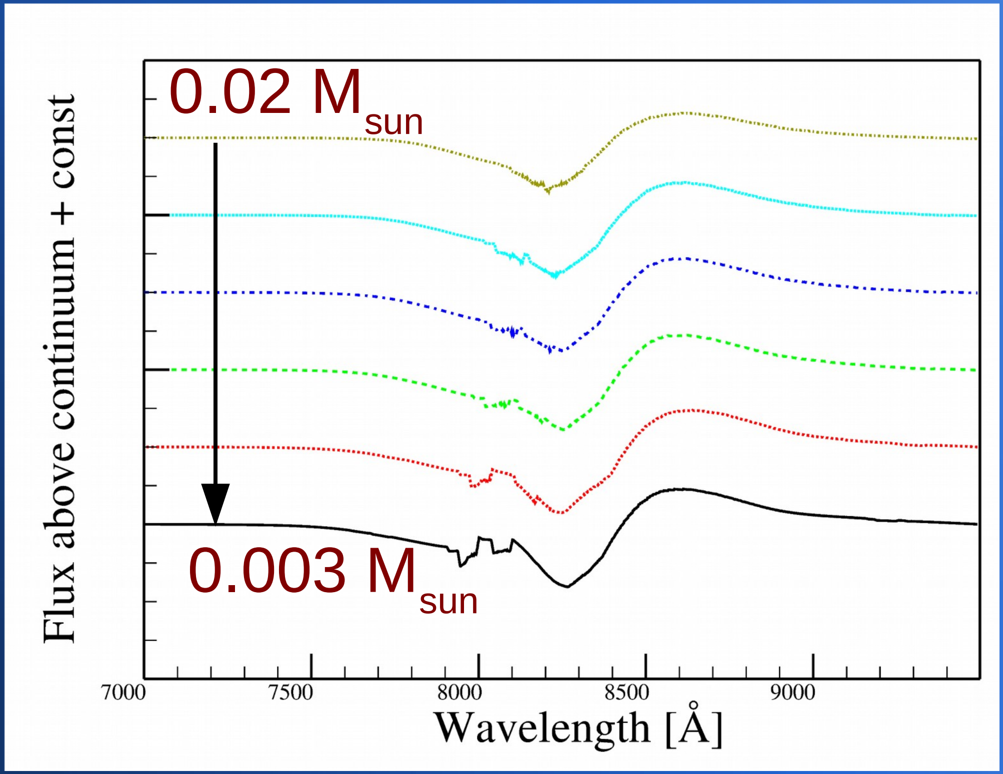
Free parameters:

- Photosphere velocity
- Photosphere temperature
- S(shell)
- S(ejecta)



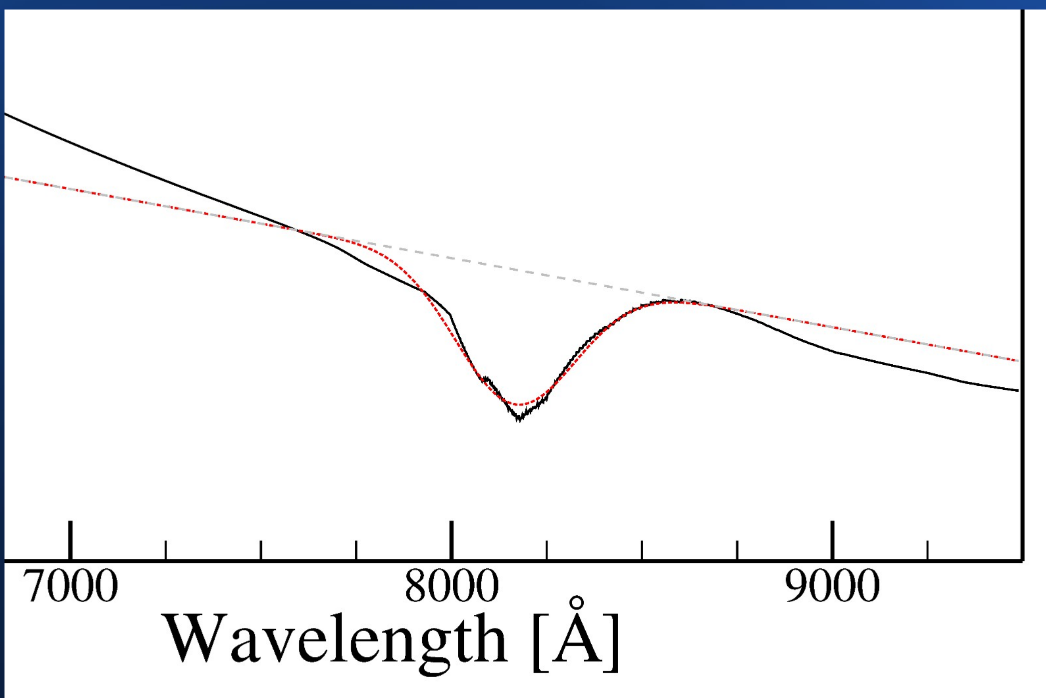
Synthetic Spectra



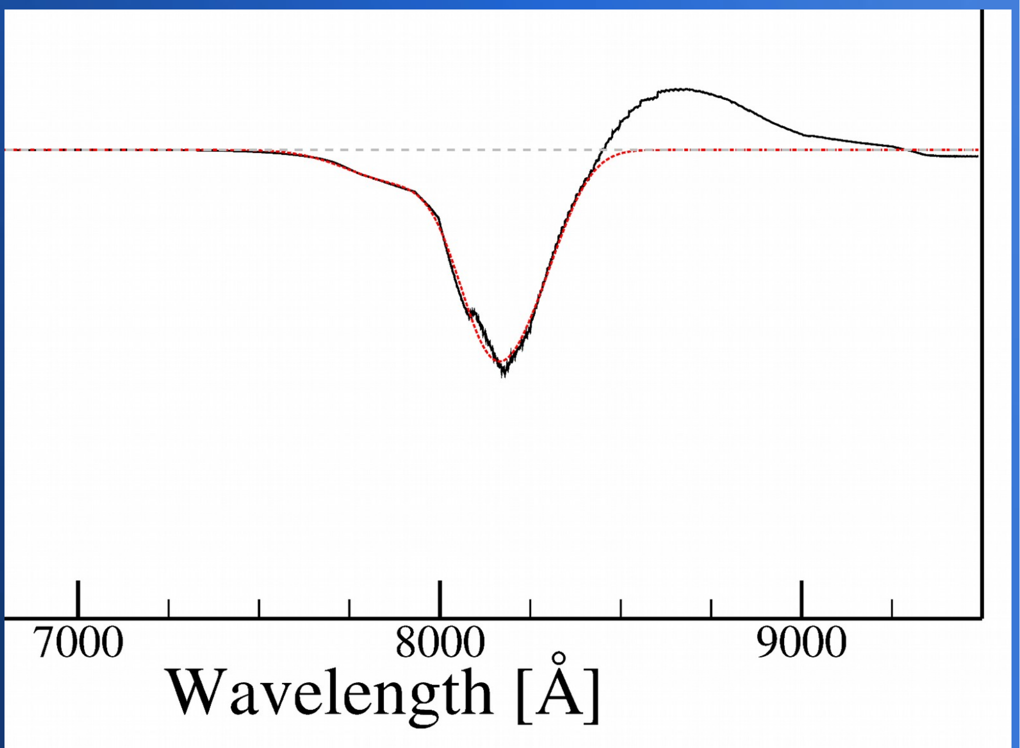


Mulligan & Wheeler 2017

Gaussian fitting for pEW & Velocity

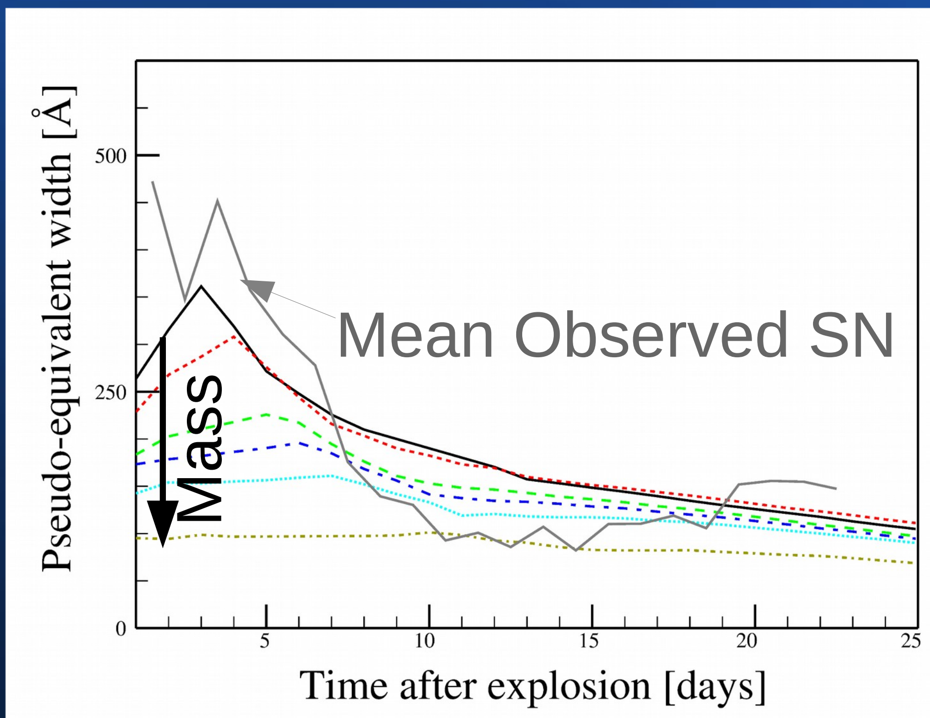


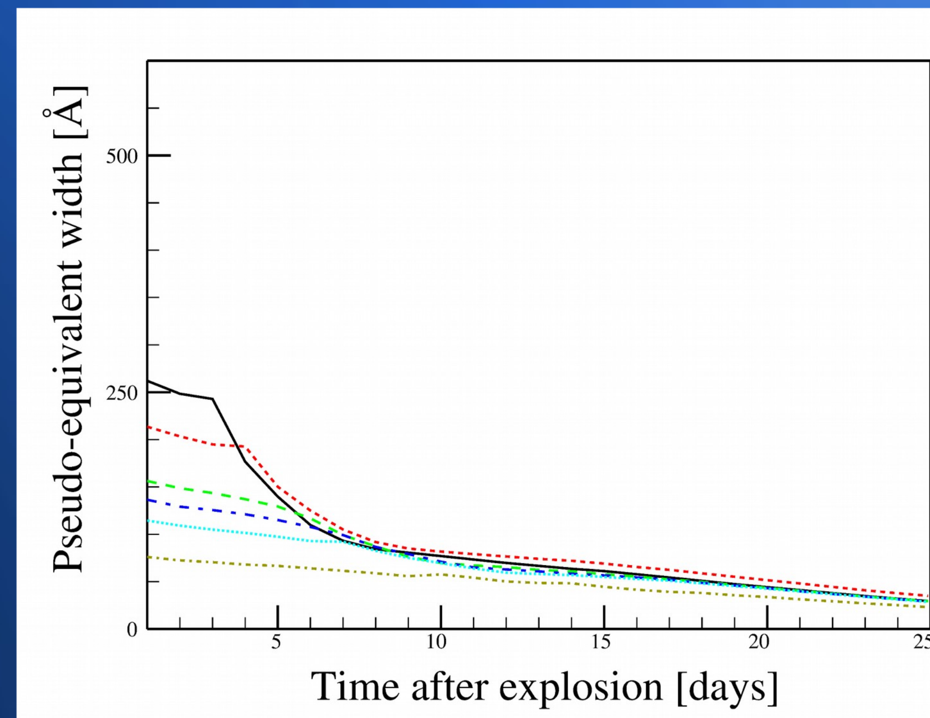
P Cygni method



Absorption method

Evolution of pEW





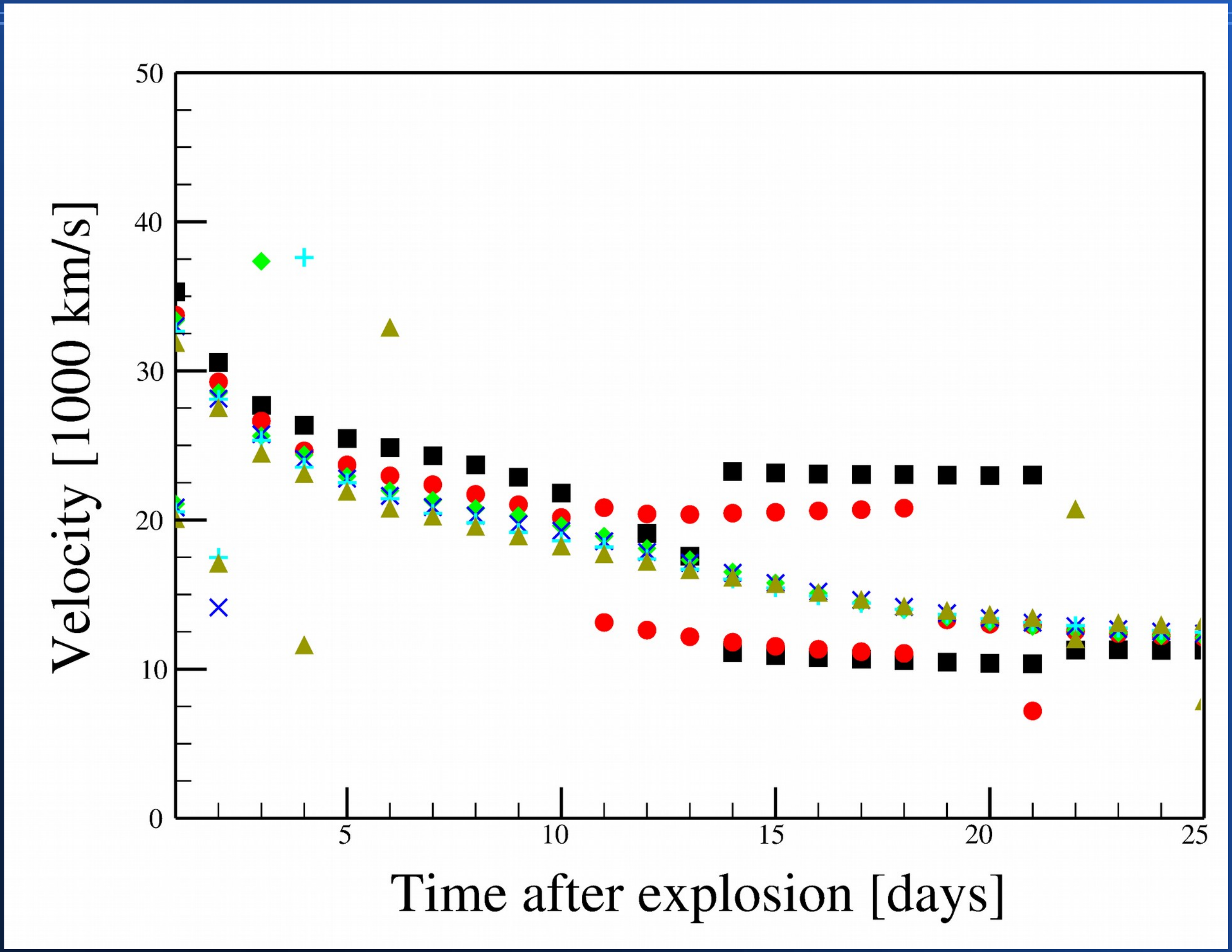
P cygni method

Absorption method

Mulligan & Wheeler 2017, MNRAS

Mass: 0.003 – 0.02 M_{sun}

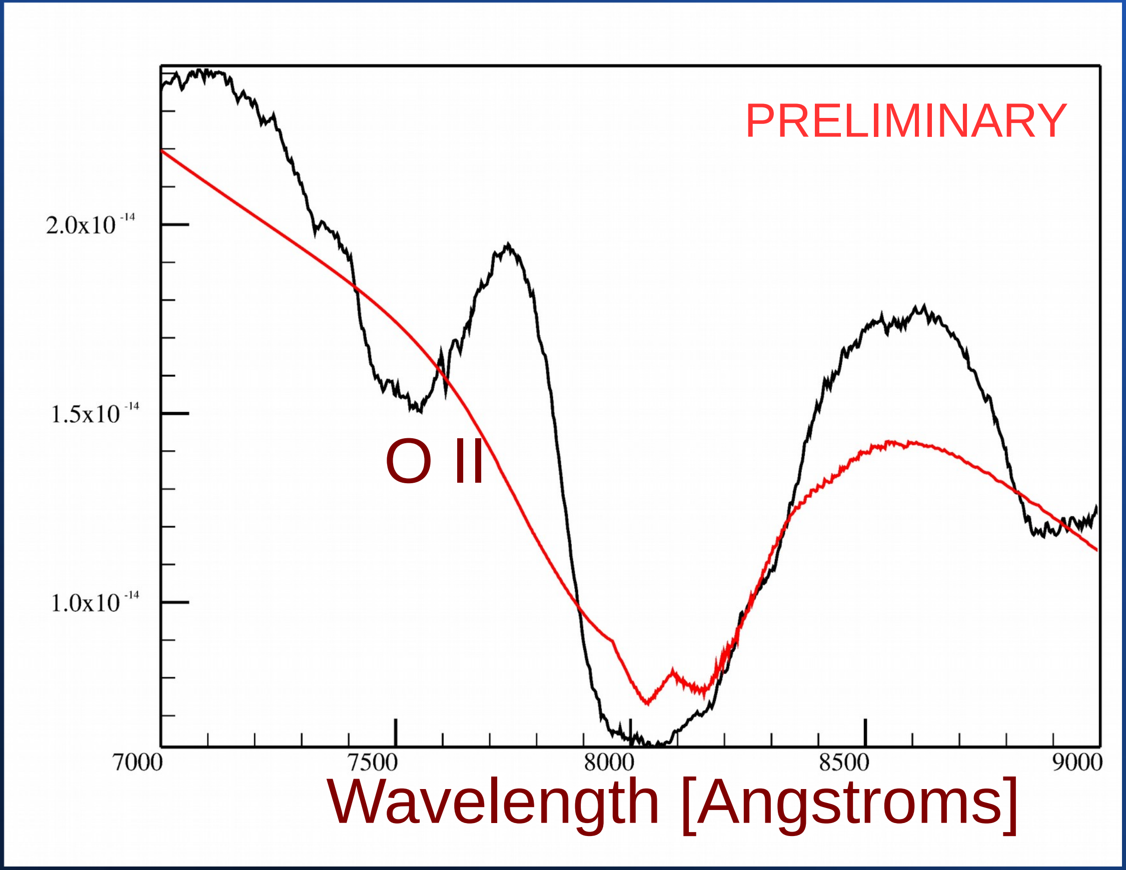
Evolution of Velocity



Black(Square)=0.003 M_{sun}
Red(Circle) = 0,005 M_{sun}
Others=0.008 – 0.02 M_{sun}

(Mulligan & Wheeler 2017)

Fitting to SN 2011fe



Red = model (0.005 Msun)
Black = Pereira et al. (2013)

MJD 55801.2

B-max – 13.3d

t_{exp} + ~6d

Shell composition

$$\tau_{Ca\,II\,NIRT}(v,t)=S_{Shell}\,t^{-\alpha}\,G_{Shell}(v)=\chi\,t\,X_{Ca}\,n(v,t)\left(f_l-f_u\frac{g_l}{g_u}\right)$$

α = time dependance of optical depth; α = 2 (Sobolev, free exp.)
S = scalar factor
G(v) = normalized profile generated from hydrodynamic data

t~ 1d: n(contact discontinuity) ~ 10^{13} cm^{-3}

χ=line specific paramters (oscillator strength, wavelength, etc.)
g = statistical weights
f = fraction of elements in lower and upper states of transition
Computed assuming
X = abundance

X_{Ca} >~ $O(10^{-4})$ for τ ~ 1 PRELIMINARY

Summary

High velocity features in Type Ia SNe

- 90% of SNe
- ~10,000 km/s faster that ejecta
- Ca, occasionally Si

Compact shell as source

- Excess heat radiates away before observation
- Velocity & pEW evolution
- Mass <~ 0.012+/- 0.004 M_{sun}
- May be highly Ca enriched

Ongoing:

- Fitting to SN 2011fe & other interesting SNe