The Outermost Ejecta of Type Ia Supernovae:
As Seen from Optical Pre-maximum Spectra

Tanaka et al. 2006, ApJ, 645, 470
Tanaka et al. 2007, submitted

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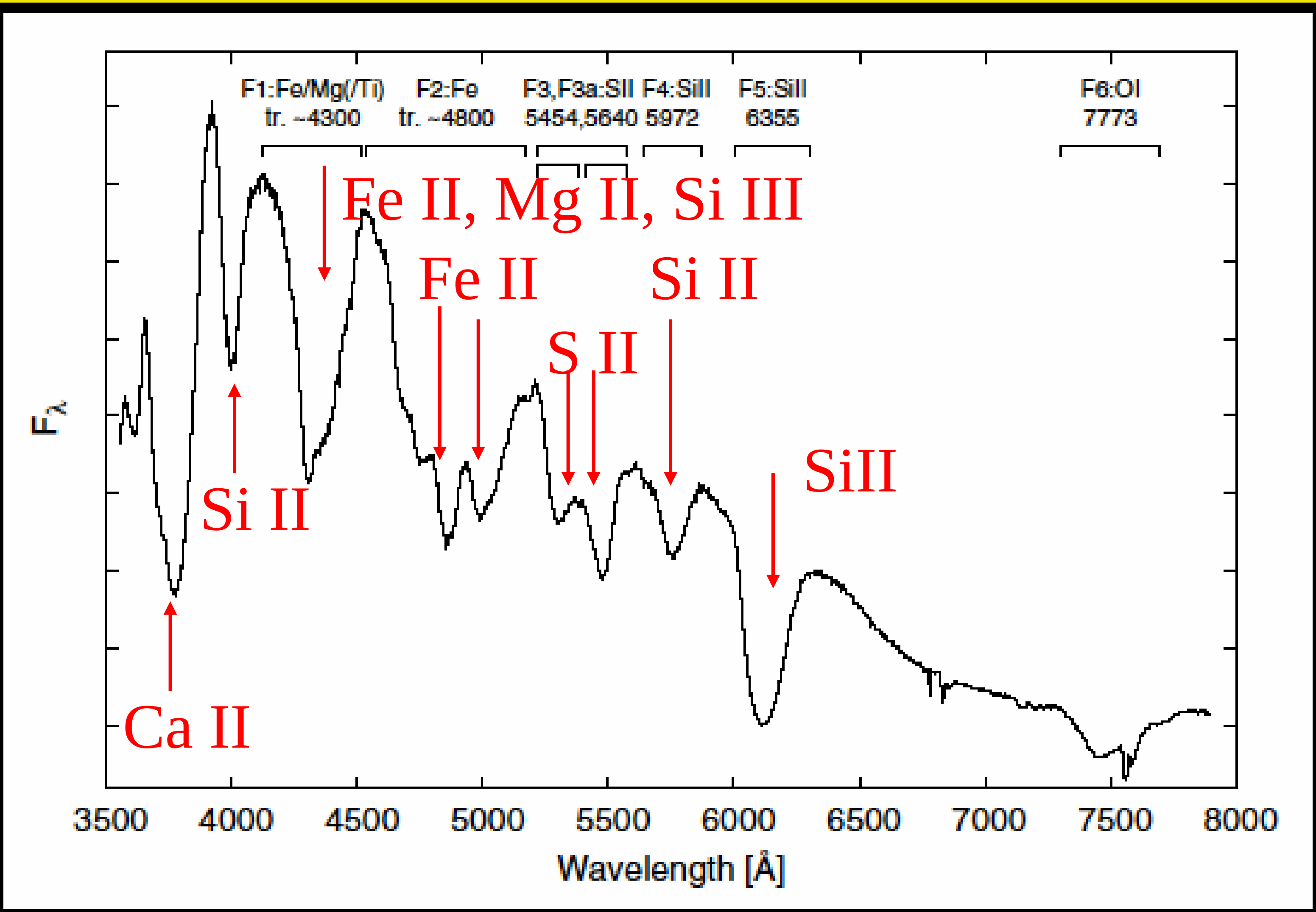
SN 2002bo in NGC 3190

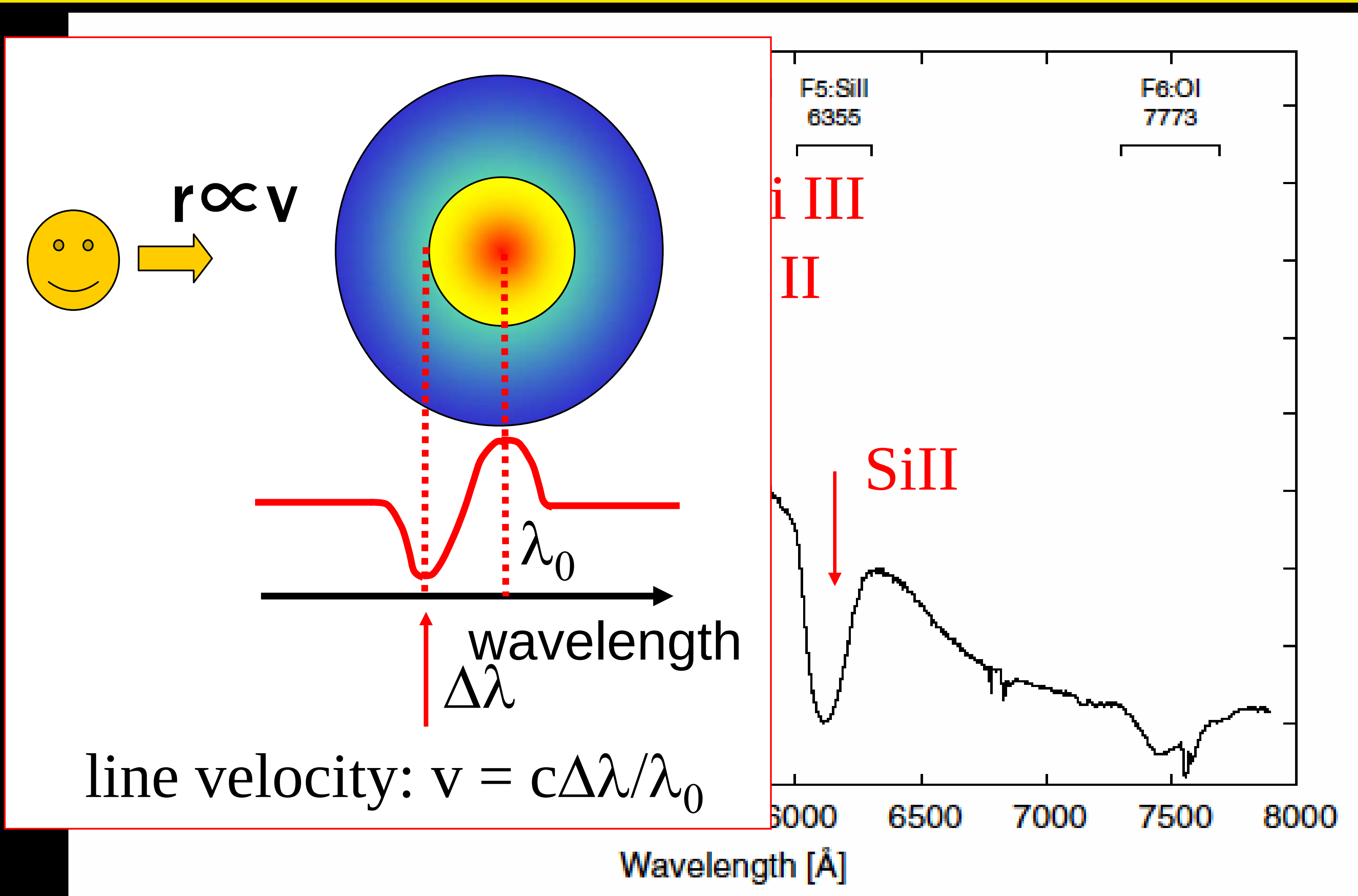
(Picture: Philipp Keller & Christian Fuchs)

SN Ia spectrum @ maximum



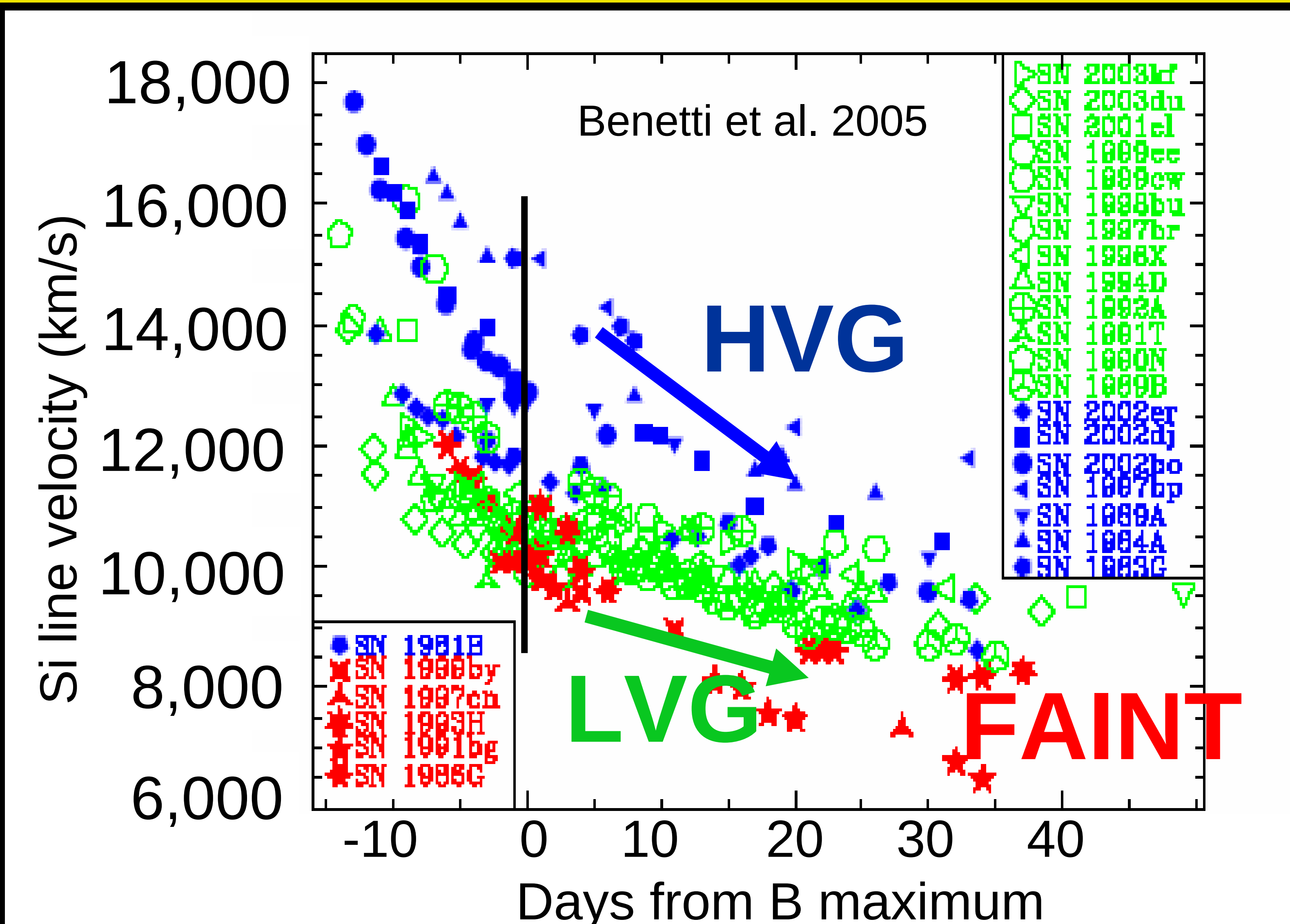
Hachinger et al. 2006

SN Ia spectrum @ maximum

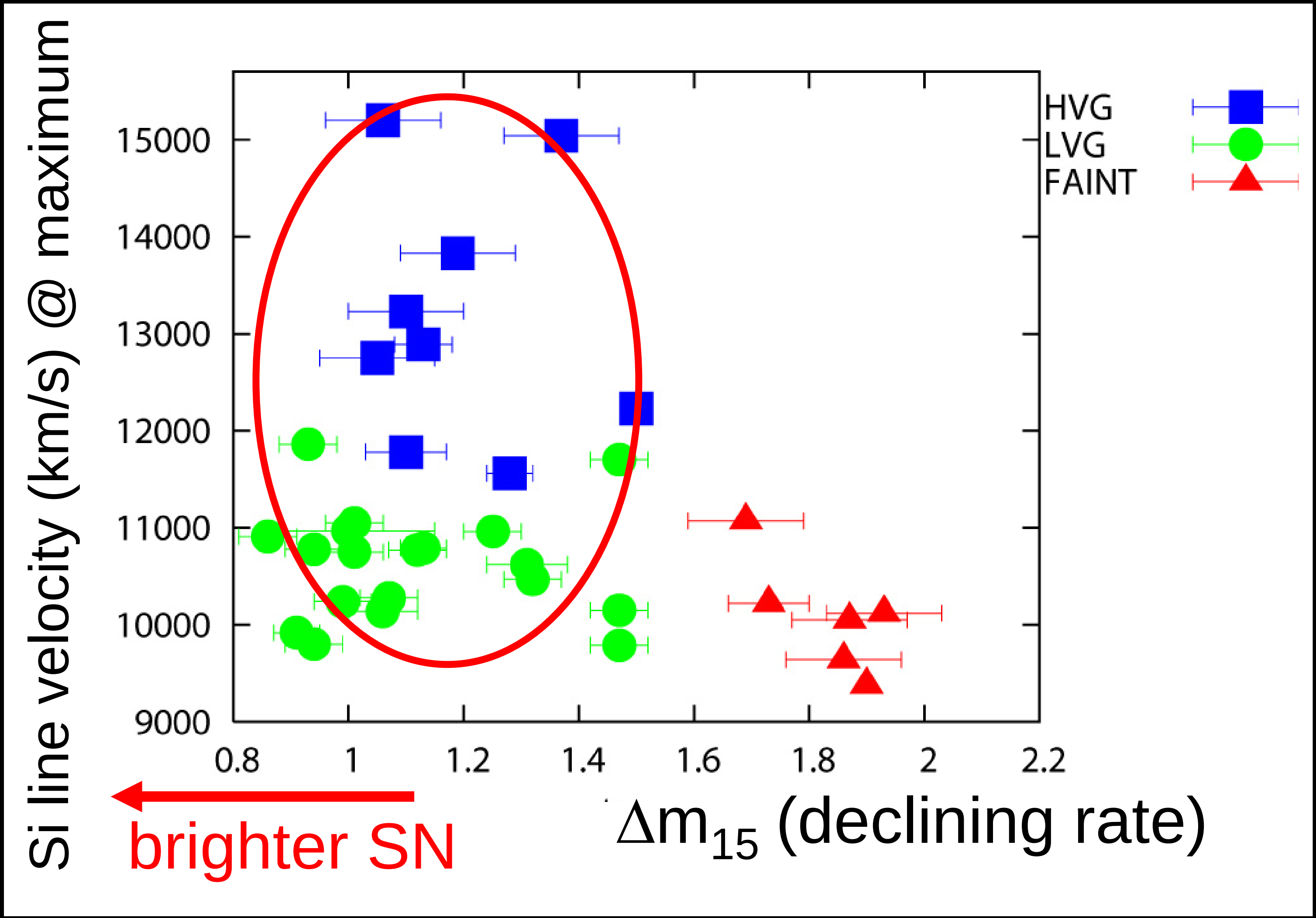


Hachinger et al. 2006

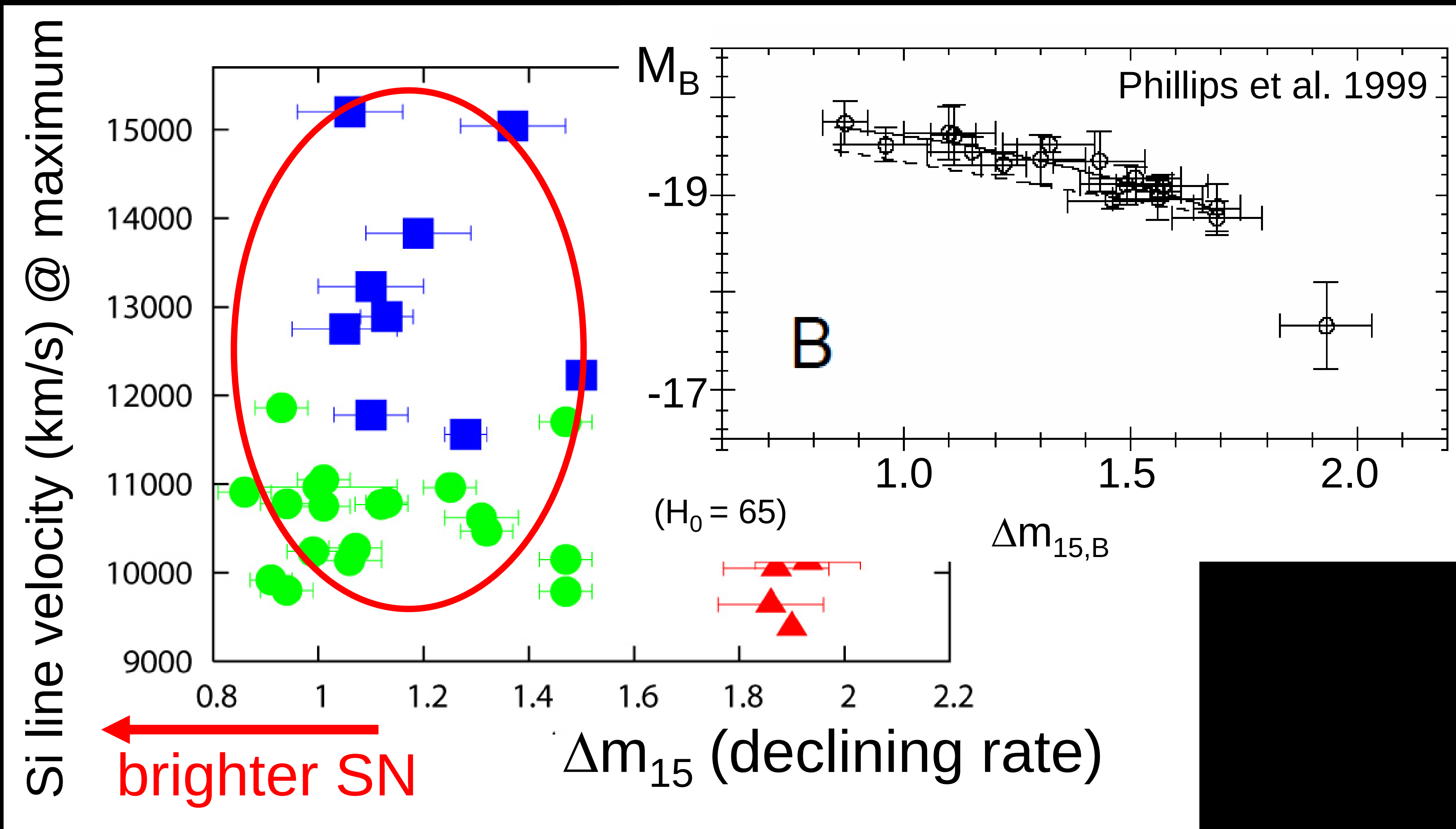
Heterogeneity of early spectra



Diversity in expansion velocity



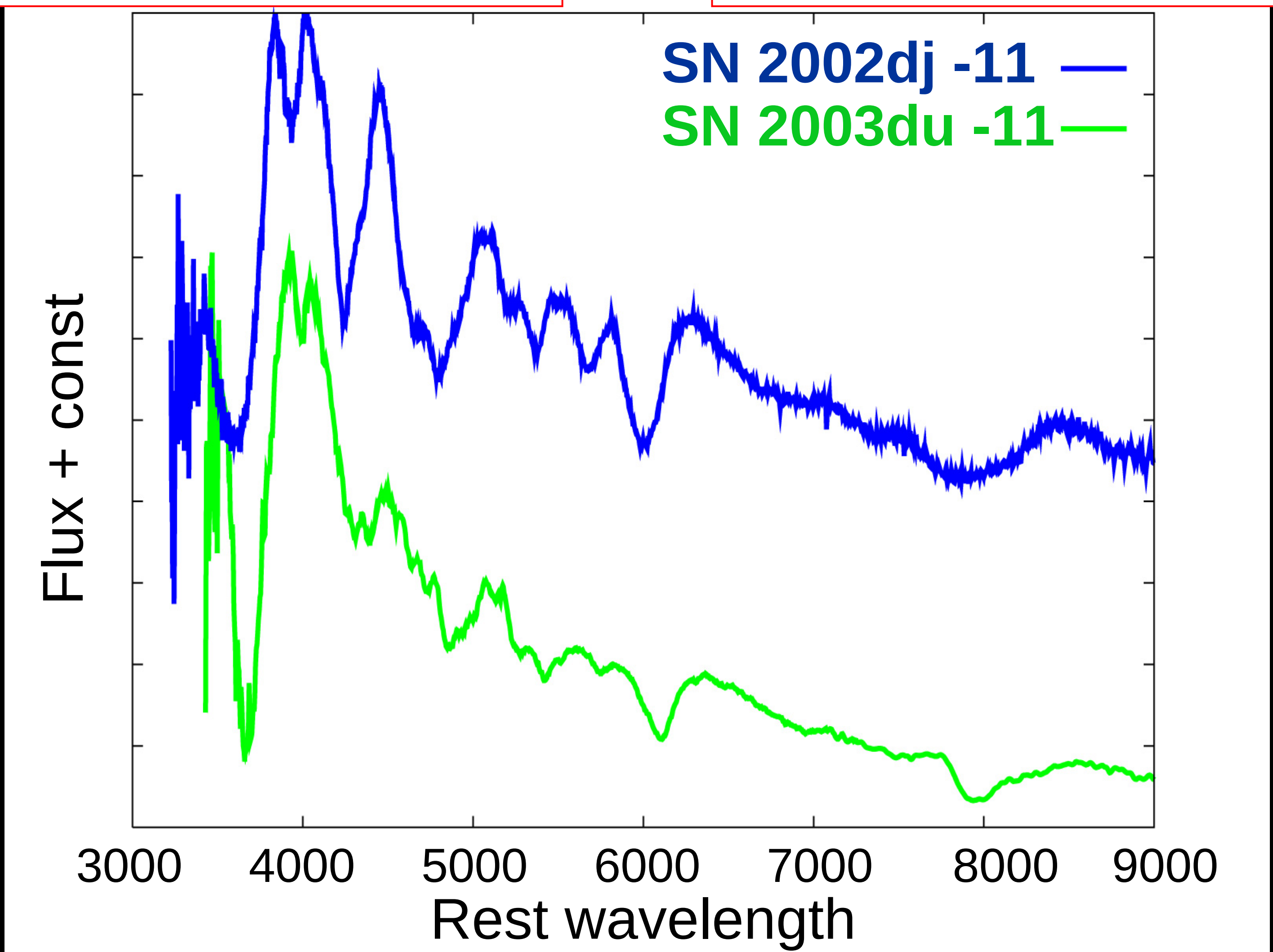
Diversity in expansion velocity



Pre-maximum spectra

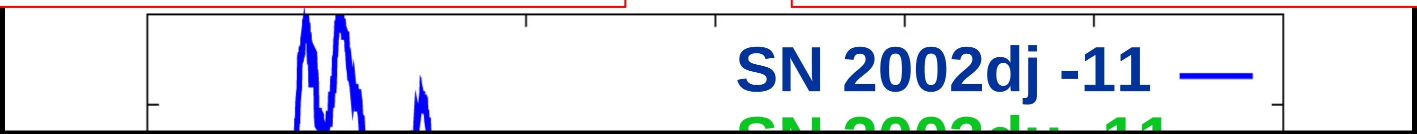
High **V**el. **G**radient

Low **V**el. **G**radient



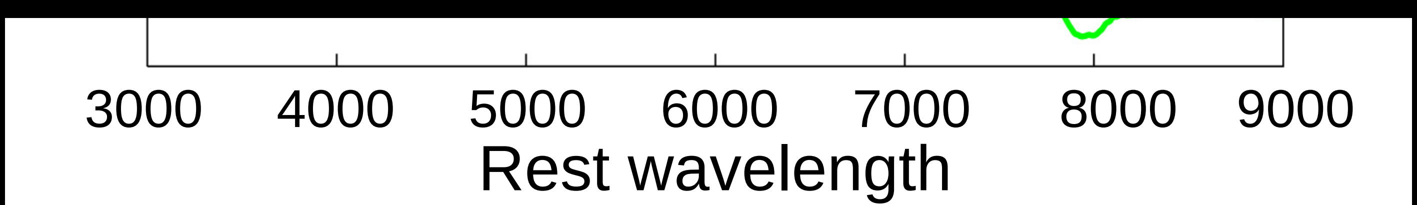
Pre-maximum spectra

High **V**el. **G**radient | **L**ow **V**el. **G**radient

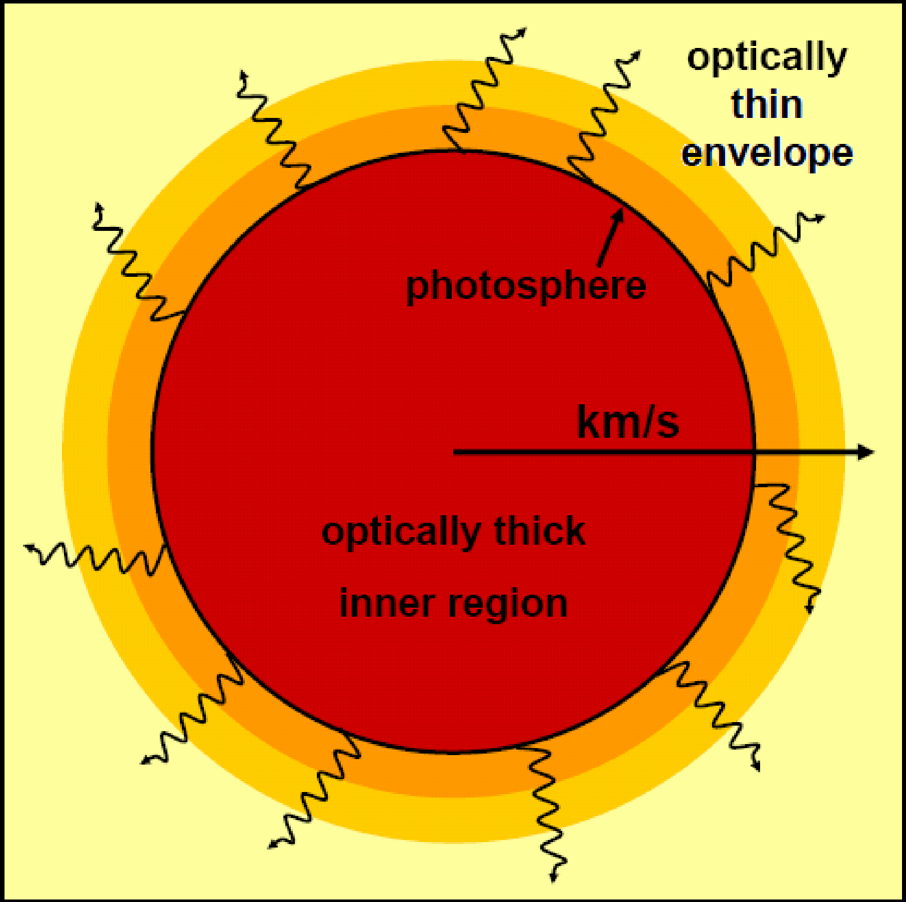


Why pre-maximum?

- Largest diversity
  - Δv ~ 4,000 km/s between HVG & LVG
- Unburned material
  - Fate of burning flame/front
- High velocity CaII lines (v>20,000 km/s !!)
  - Environment of the explosion?



Radiative transfer in SN atmosphere



Stehle 2005

- Monte-Carlo spectrum synthesis code
  - 1D: Mazzali & Lucy 1993
  - 3D: Tanaka et al. 2006
- Input physics
  - Electron scat. & line scat. with line branching (Lucy 1999)
  - Ionizations (photo-ionization = recomibnation)

Supernova Multi-dimensional Radiative transfer code

SAMURAI

^{56}Ni → X-ray - γ-ray (Maeda 06b)

↓

Optical - infrared bolometric light (Maeda et al. 06c)

Time-dependent

thick + thin ↓

Optical - infrared: spectra (Tanaka et al. 06,07)

thin ↓

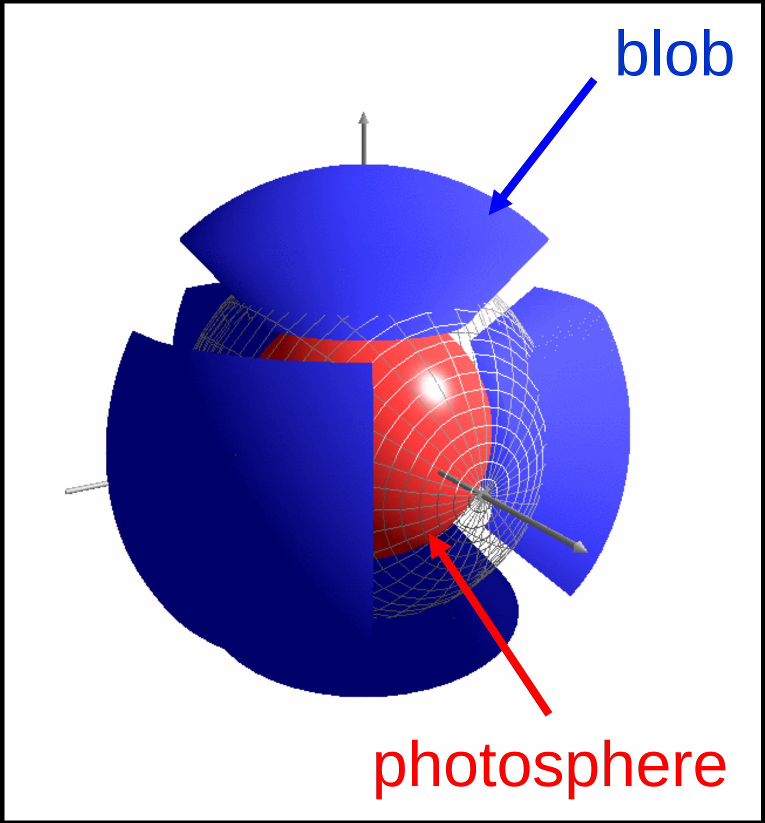
Optical - infrared: spectra (Maeda et al. 06a)

< ~ 30 days

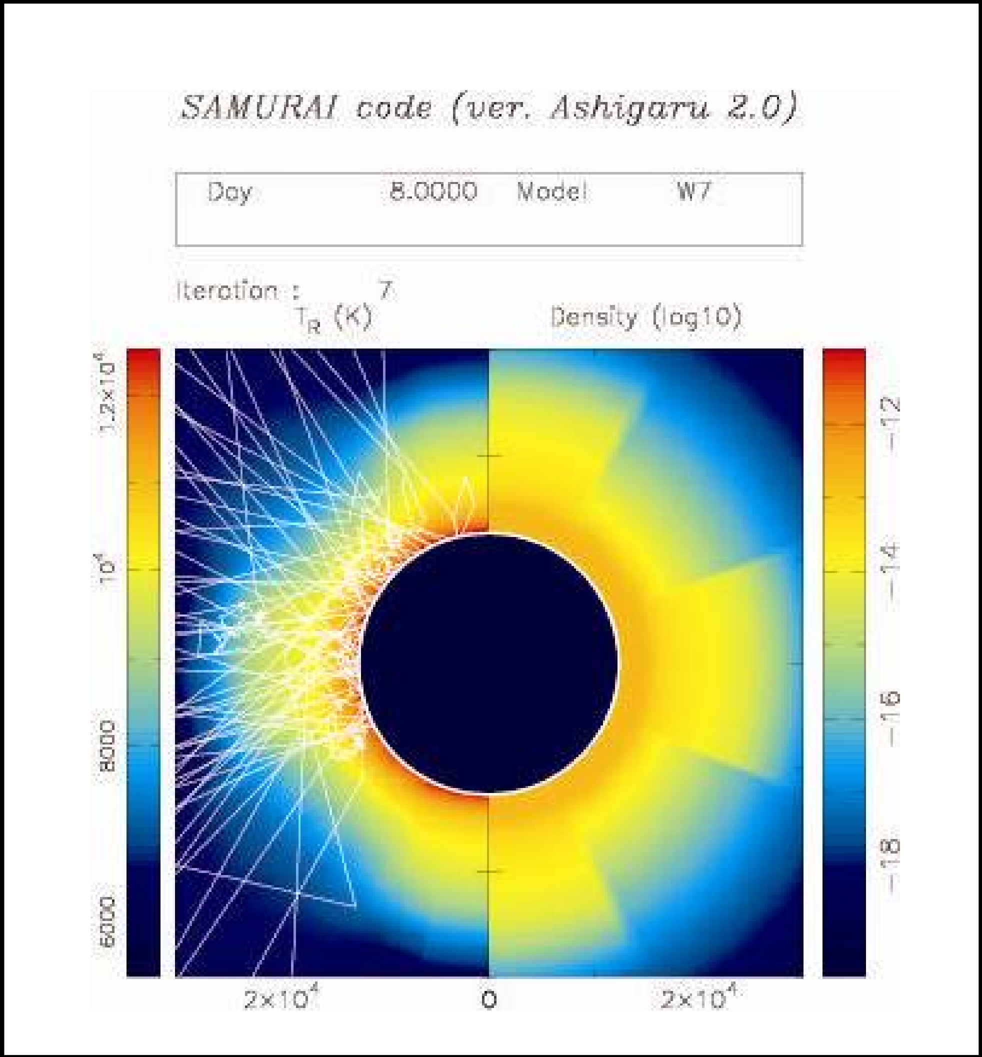
>100 days

epoch (from the explosion)

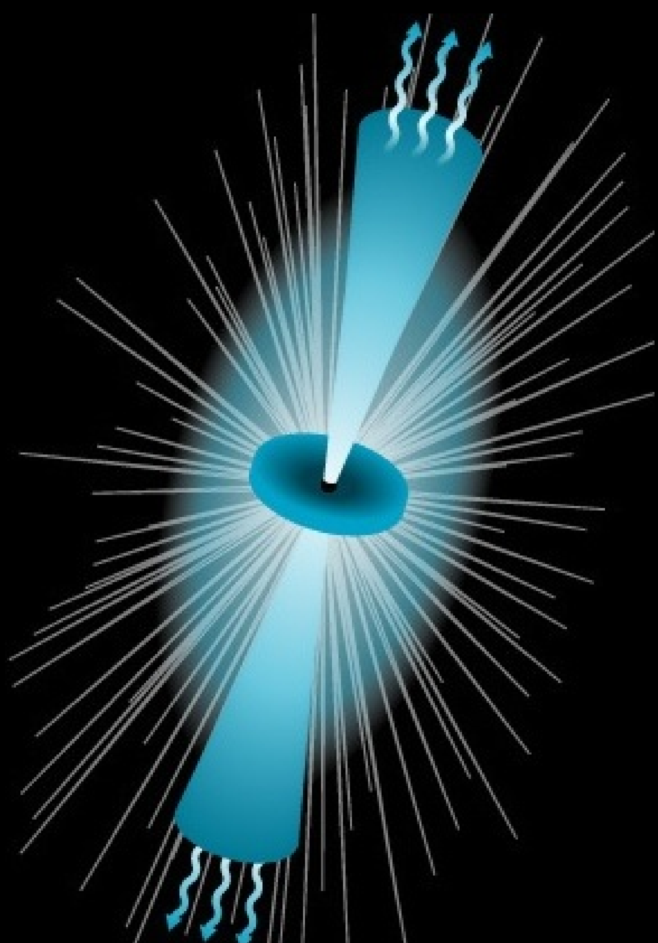
Clumpy SN Ia (toy model)



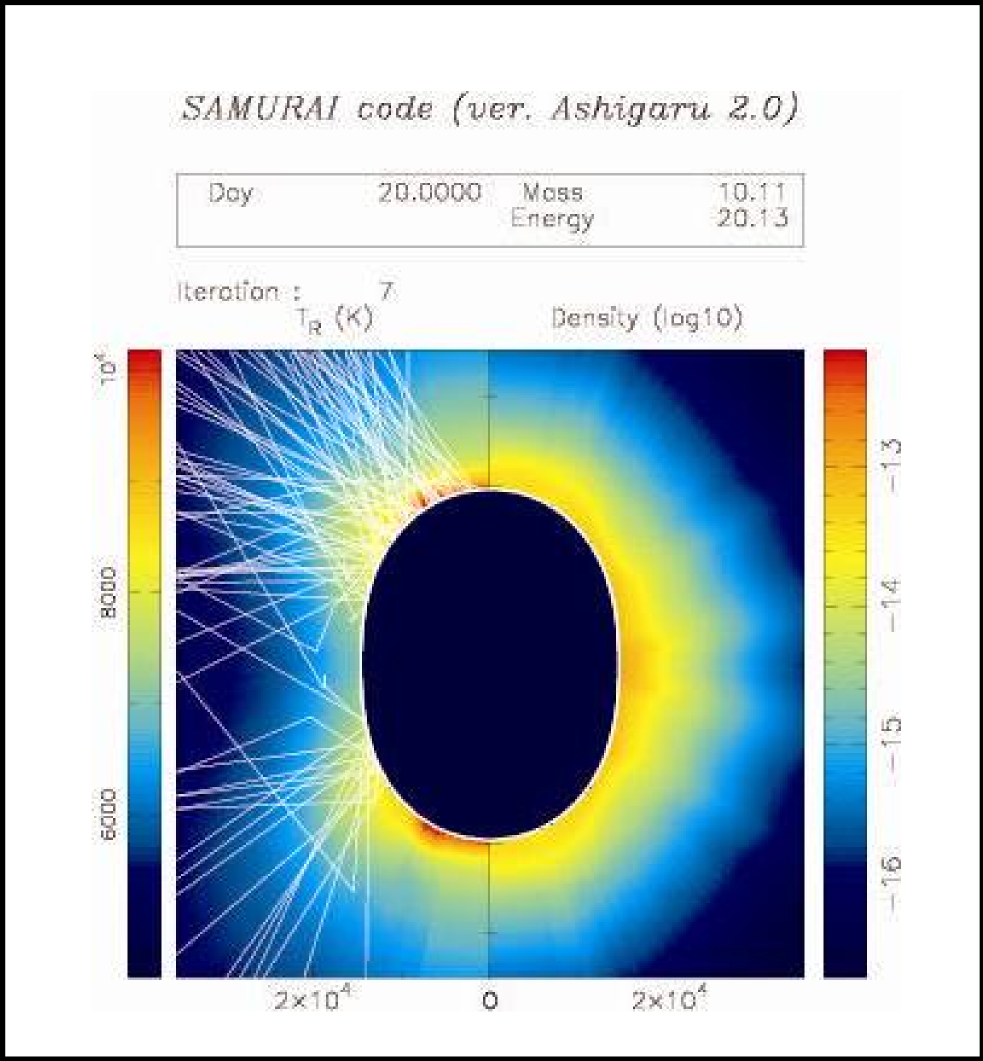
Tanaka et al. 2006



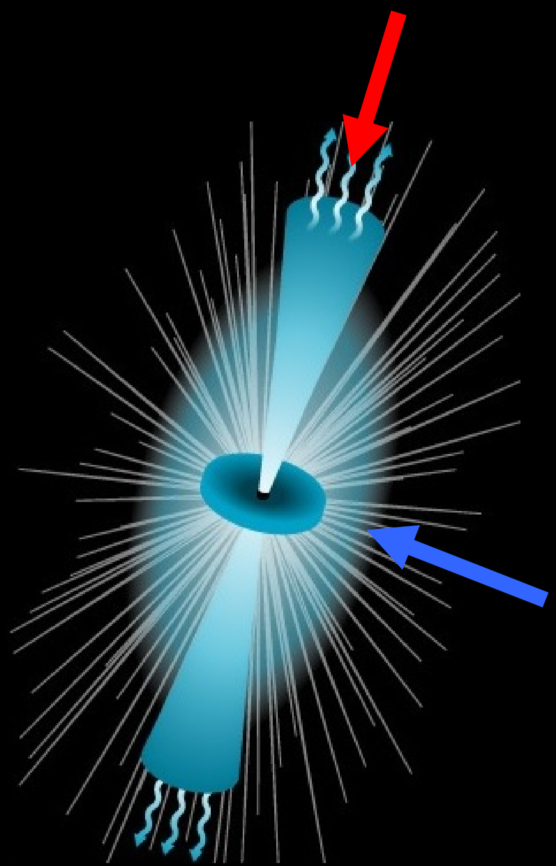
Jet-like core-collapse (from 2D hydro.)



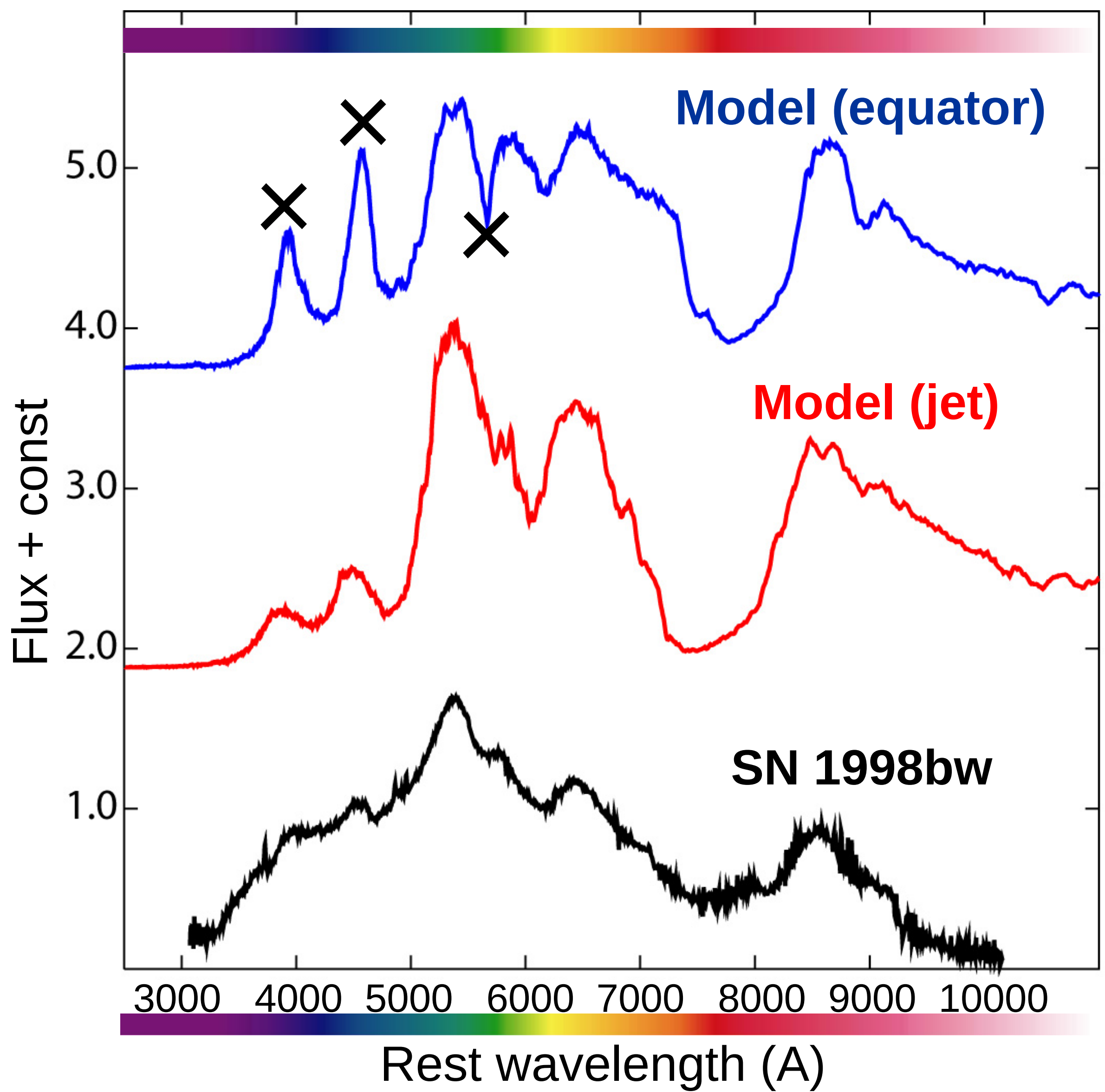
Tanaka et al. in prep



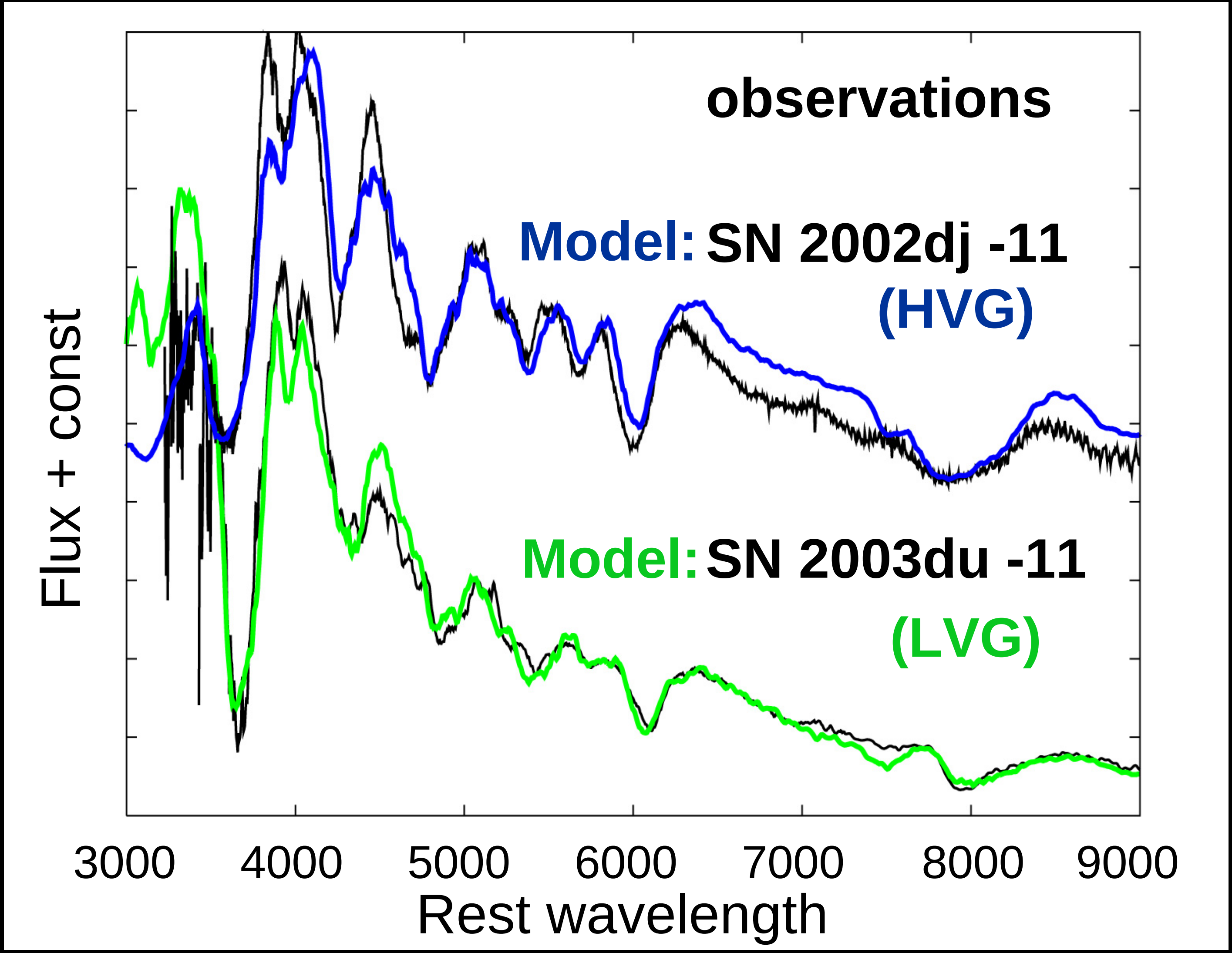
Hypernova spectra (from 2D hydro.)



Tanaka et al. in prep



Spectrum fitting (SNe Ia)



<u>HVG</u>

- SN 2002bo : -8 (Benetti et al. 04)
- SN 2002dj : -11 (Pignata et al. 07)
- SN 2002er : -7.4 (Kotak et al. 04)

<u>LVG</u>

- SN 2001el : -9 (Mattila et al. 05)
- SN 2003cg : -7.6 (Elias-Rosa et al. 06)
- SN 2003du : -11 (Stanishev et al. 07)

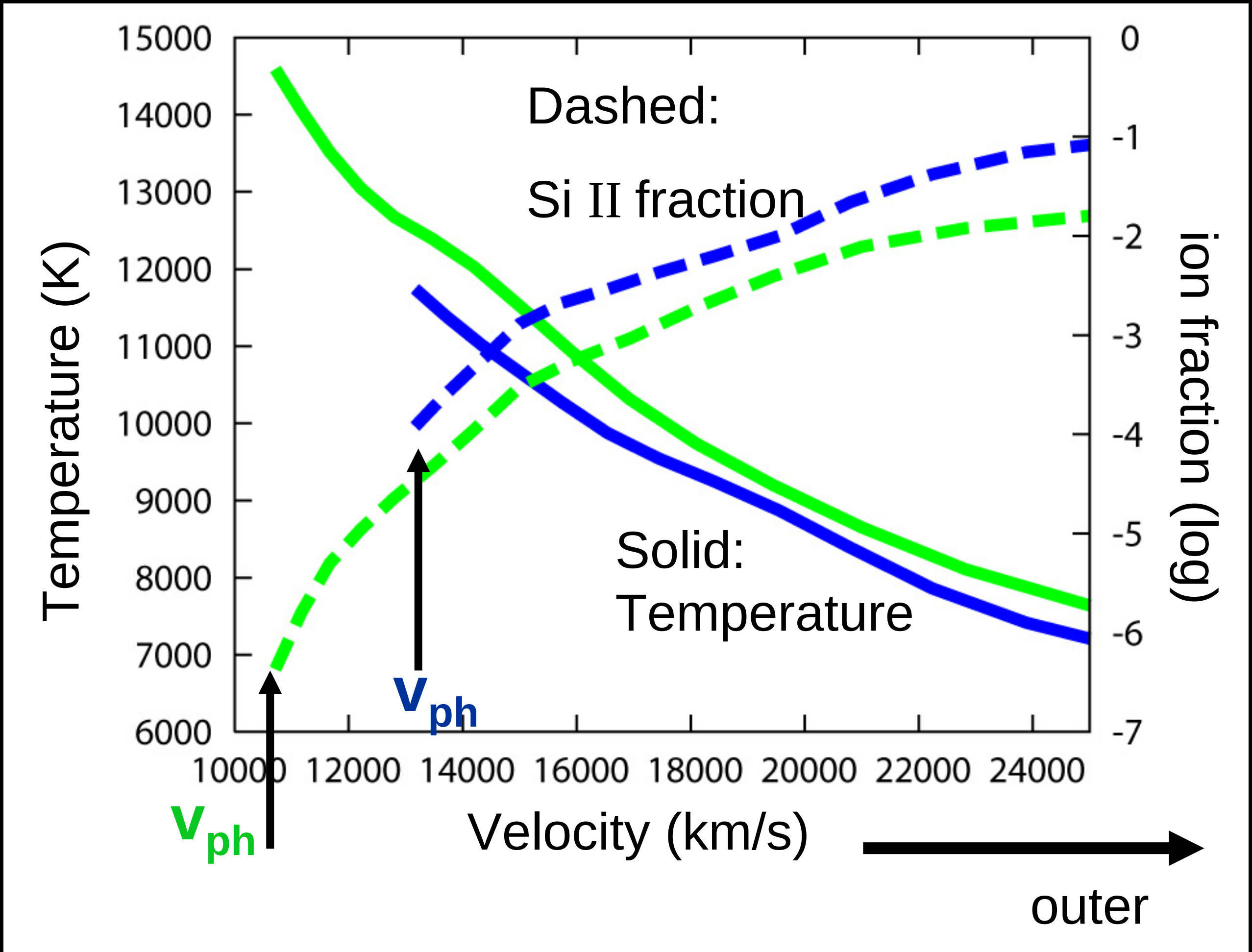
What is learned from pre-maximum spectra?

1. Difference between HVG and LVG

2. Possible presence of unburned carbon

3. High velocity Ca II absorptions

1. HVG and LVG



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High Vel. Gradient

High photospheric velocity

→ Low temperature

→ High Si II fraction

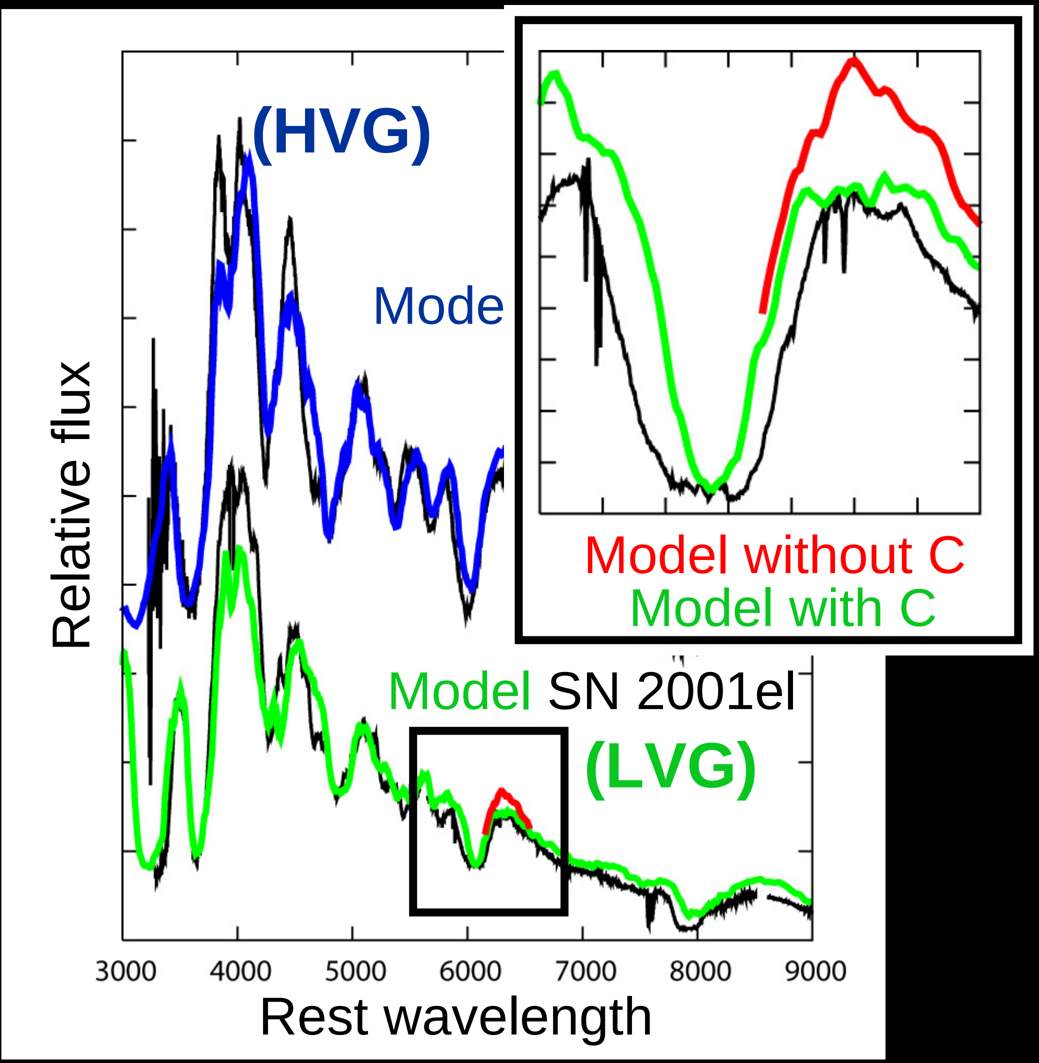
Low Vel. Gradient

Low photospheric velocity

→ High temperature

→ Low Si II fraction

2. Carbon lines



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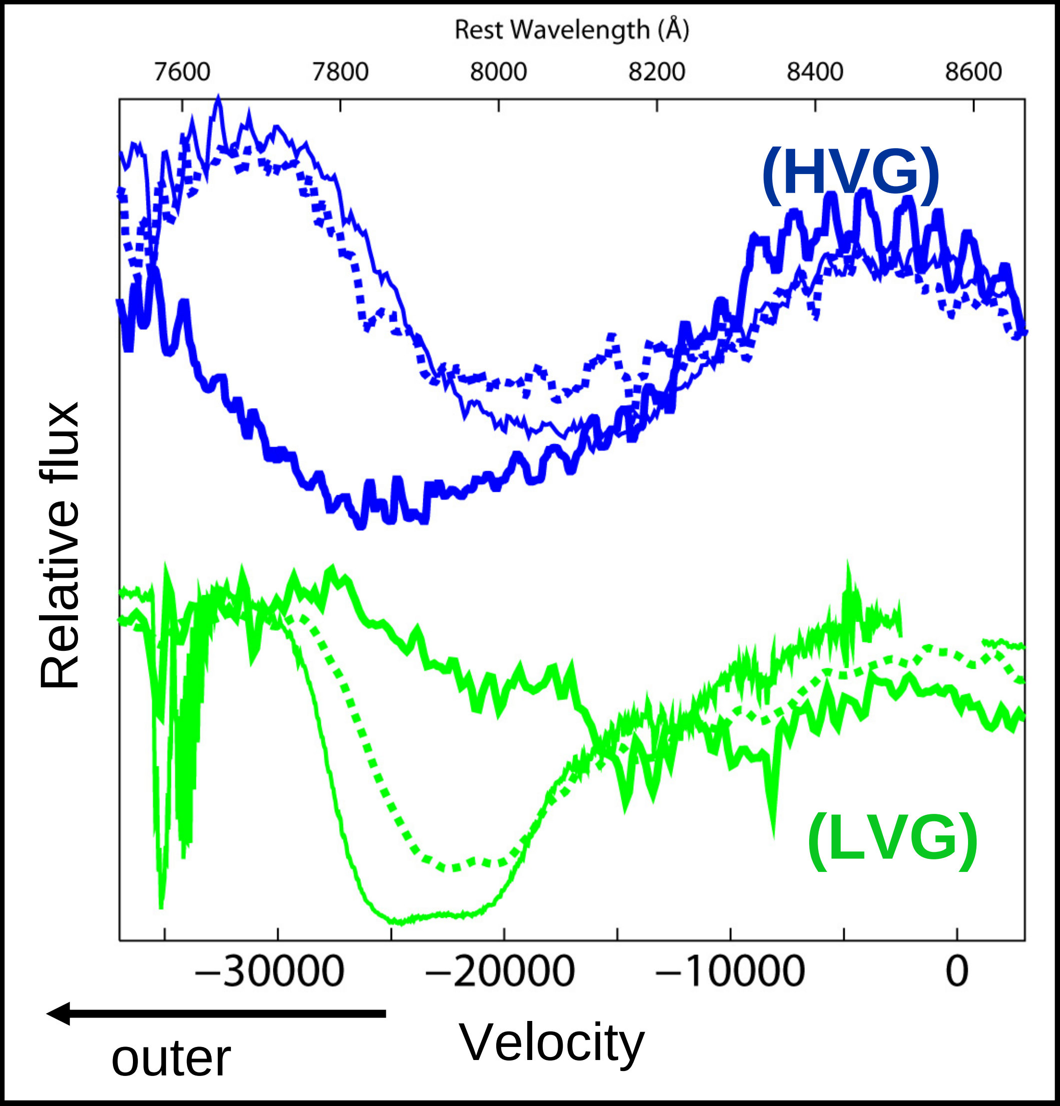
- CII 6578 in LVG
  - X(C) ~ 0.003
  - Other cases
    - SN 2006D (Thomas et al. 06)
    - SN 1999aq (Branch et al. 03)
    - SN 1994D ?
- No C is in HVG
  - X(C) < 1.0 x 10^{-5}
  - Only small amount of C would make a very strong absorption due to low T

3. Ca II high vel lines



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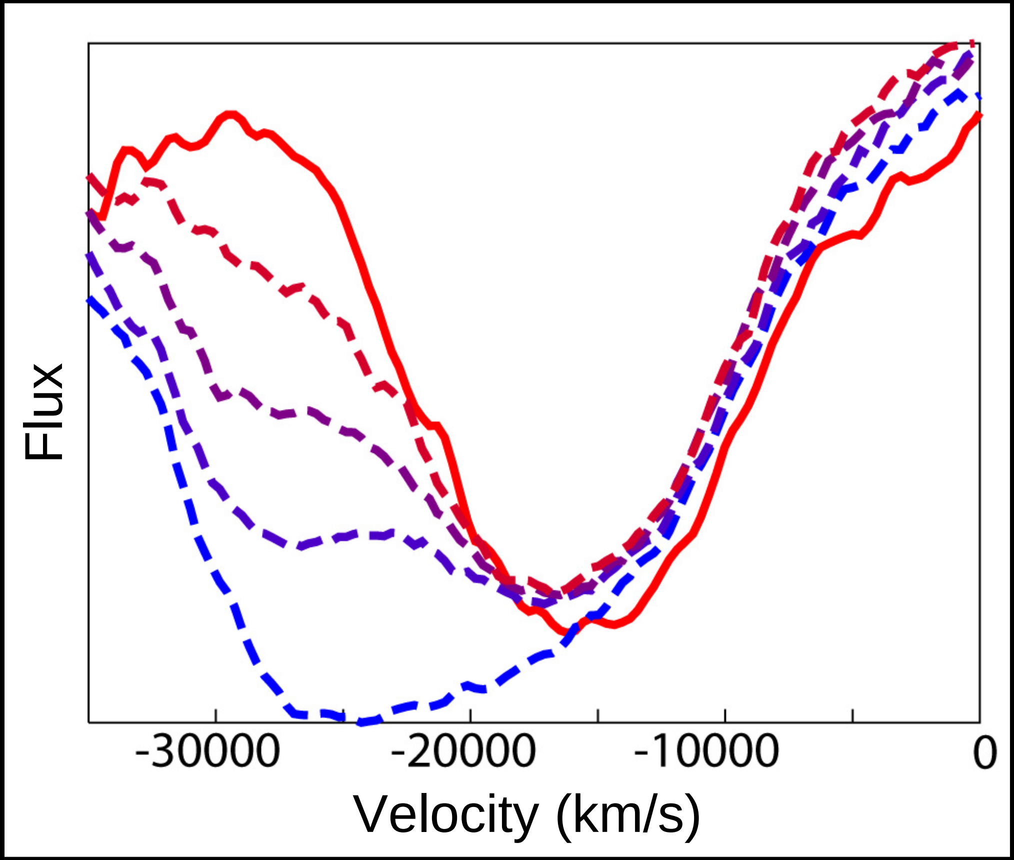
- Ca II profile tends to be detached in LVG

At the photosphere:
suppression of Ca II in LVG due to high T

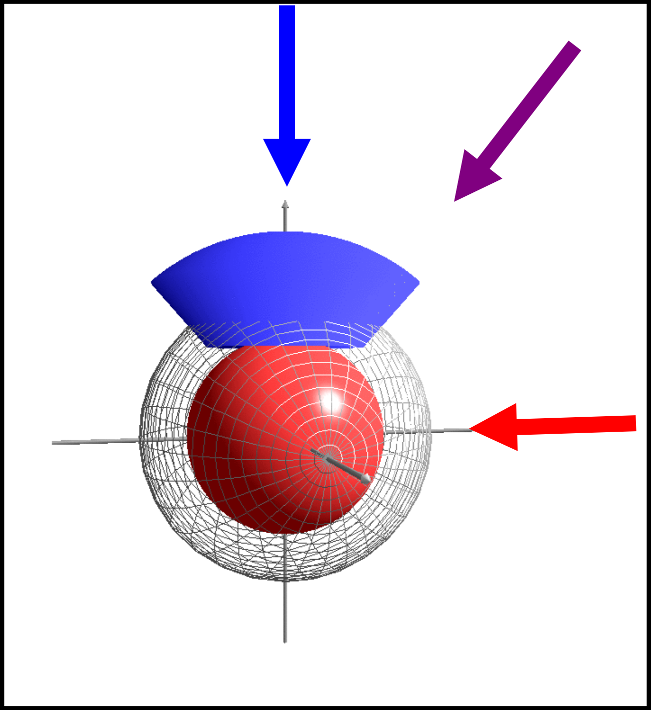
At v > 20,000 km/s:
no relation with inner part

3. Ca II : 3D effect



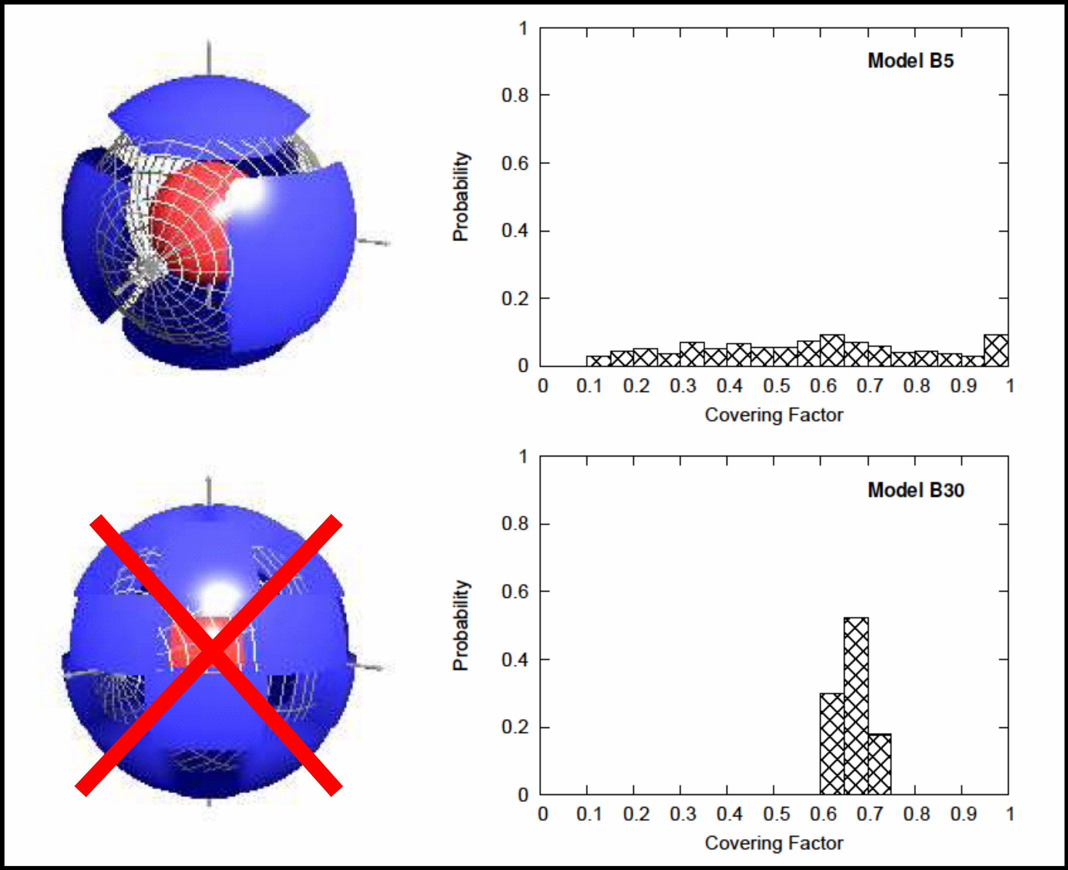
Tanaka et al. 2006
See also Kasen et al. 2003

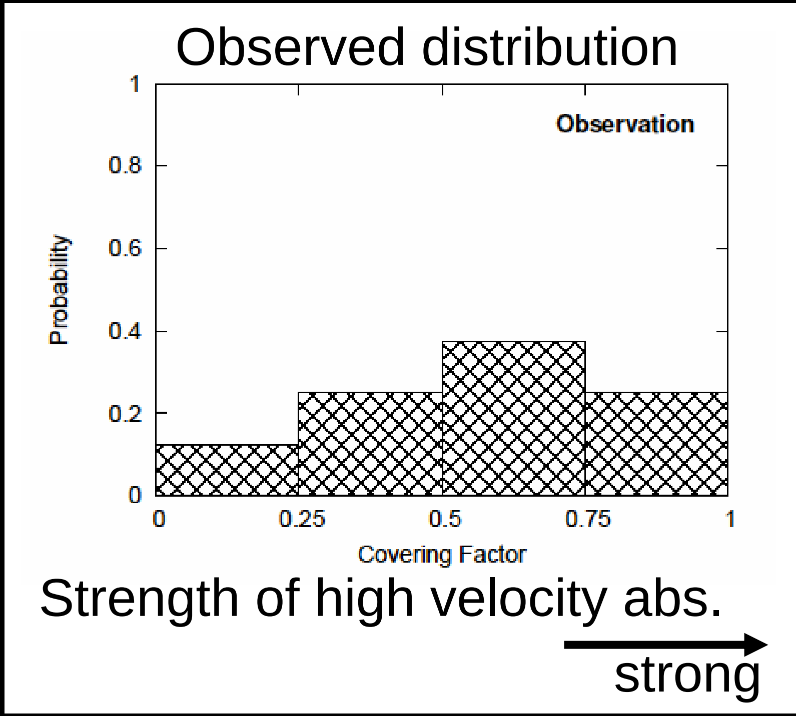
- High polarization level (Wang et al. 2003)



3. Ca II : 3D effect

- High vel. Absorptions are ubiquitous
  (Mazzali et al. 2005)





Tanaka et al. 2006

3. Ca II : 3D effect

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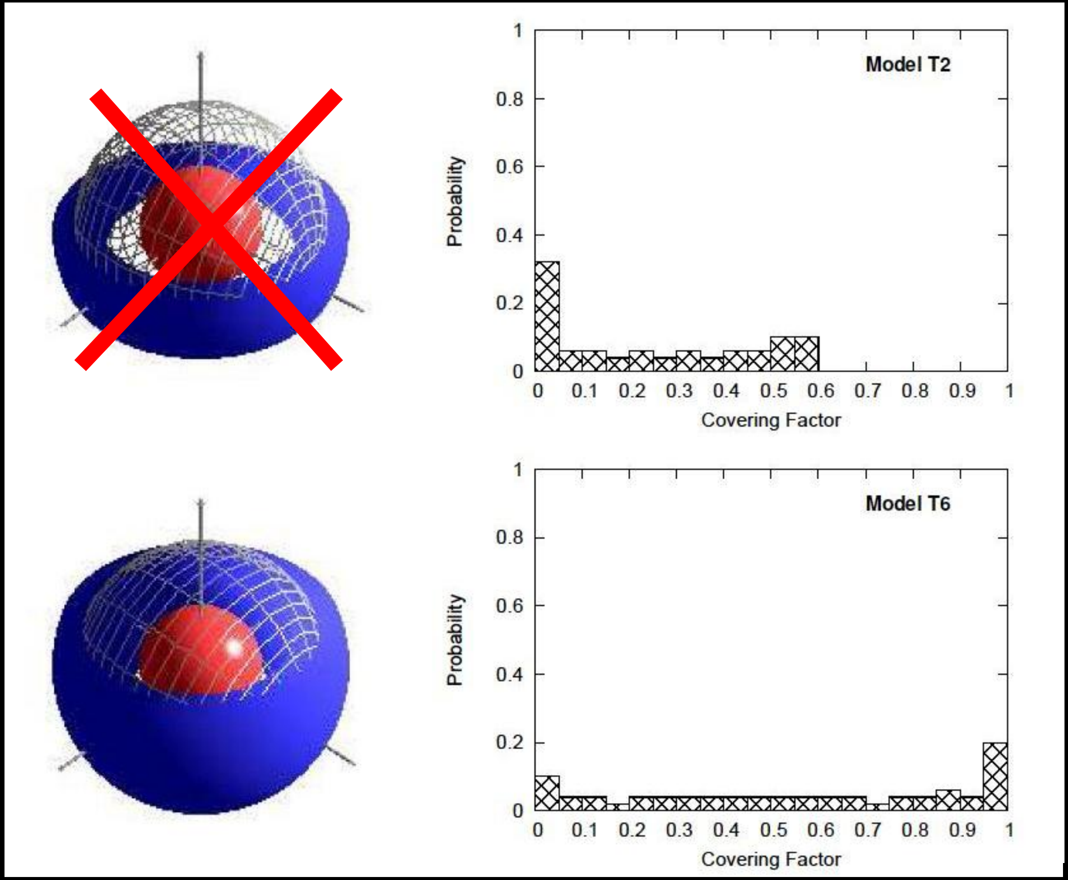

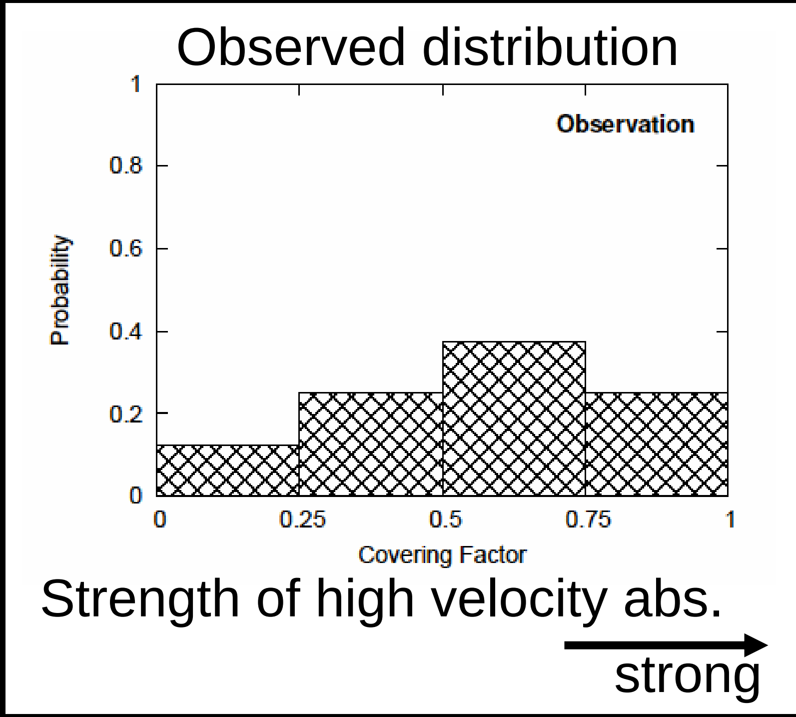

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Summary

- Largest diversity in pre-maximum spectra
  - Different line velocity even in SNe with similar Δm_{15}
- v = 10,000 – 20,000 km/s
  - The control parameter: only photospheric velocity

    → T and ionizations
  - More burning in HVG (Carbon in LVG)
- <u>What causes Δv??</u>

  $\Delta E < 1.0 \times 10^{50}$ erg → $\Delta v < 500$ km/s: not enough

  $\Delta\tau \propto X(^{56}\mathrm{Ni} + \text{stable Fe})$
- v > 20,000 km/s (Ca II and possibly Si II)
  - No relation with the properties at v < 20,000 km/s

Type Ia SN ejecta