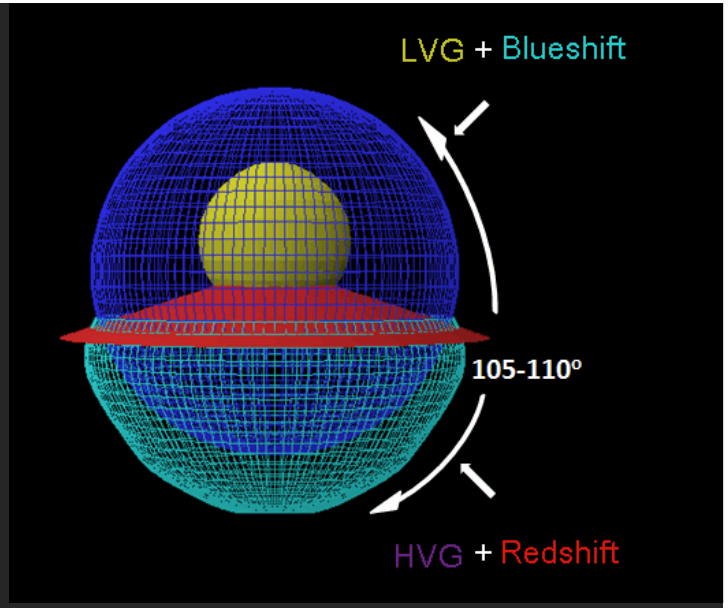
Observational Diagnostics of Asymmetry in SNe Ia



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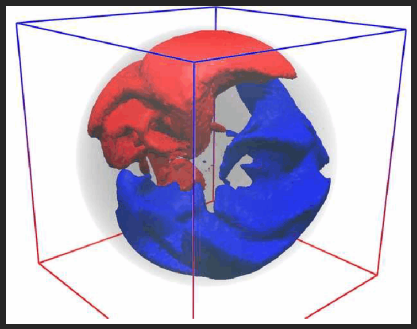
Theory, Observation, then Unification

Asymmetry

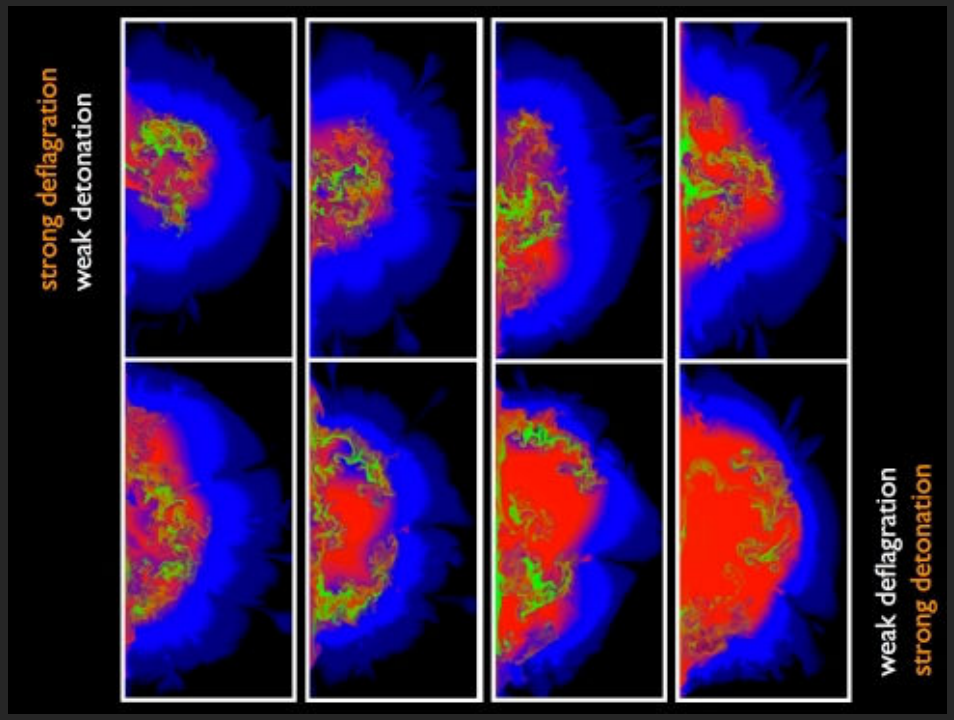
- **A Model** for **off-center** SN Ia explosions.
  - 2010, ApJ, 712, 624.
  - **K. Maeda, F.K. Roepke, M. Fink, W. Hillebrandt, C. Travaglio, F.-K. Thieleman**
- First **observational evidence** in late-phases.
  - 2010, ApJ, 708, 1703.
  - **K. Maeda, S. Taubenberger, J. Sollerman, P.A. Mazzali, G. Leloudas, K. Nomoto, K. Motohara**
- **Unification**: the spectral evolution **diversity**.
  - 2010, Nature, 1 July 2010 issue… **today!**
  - **K. Maeda, S. Benetti, M. Stritzinger, F.K. Roepke, G. Folatelli, J. Sollerman, S. Taubenberger, K. Nomoto, G. Leloudas, M. Hamuy, M. Tanaka, P.A. Mazzali, N. Elias-Rosa**

Asymmetric explosions?

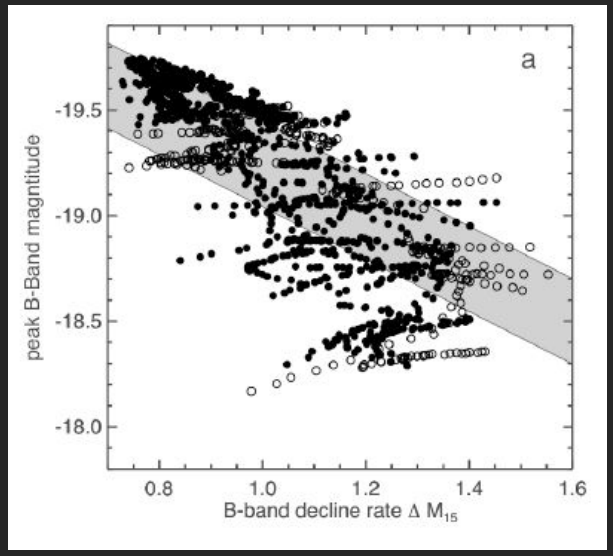
- "spherical" explosion is standard, but it does **not have to be** in theories.



Dipole Convection in progenitor WD (Kuhlen+ 06)



Kasen, Roepke, Woosley, 2009



Peak B

Δm_{15} (Light curve width)

But NO observational evidence

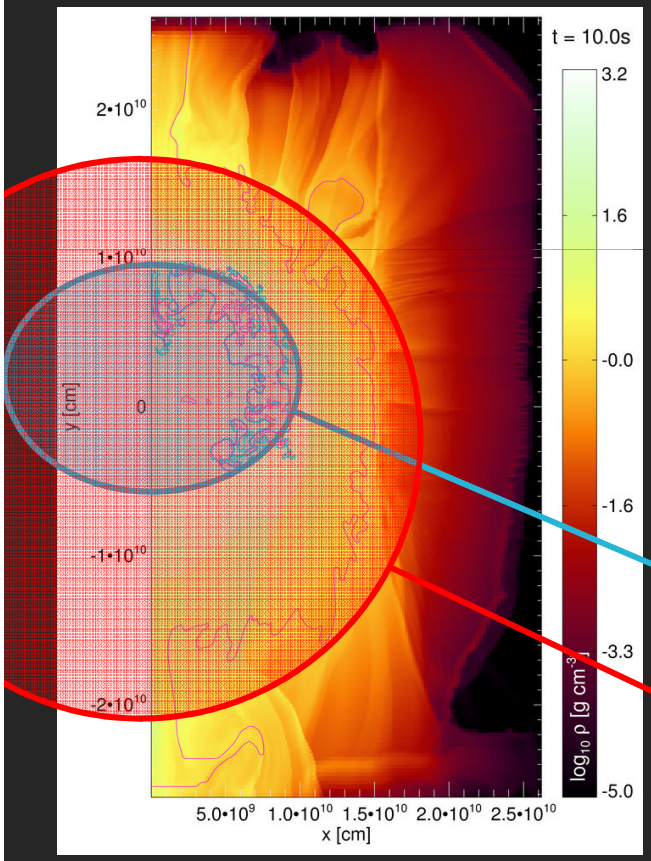
- Theorists have started thinking about the "asymmetric" explosion in these days.
  - Roepke+07, Jordan+08, Kasen+09.

- **Big** problem here.
  - (Some) models may explain some observations, which **can however be explained by SPHERICAL** models as well.

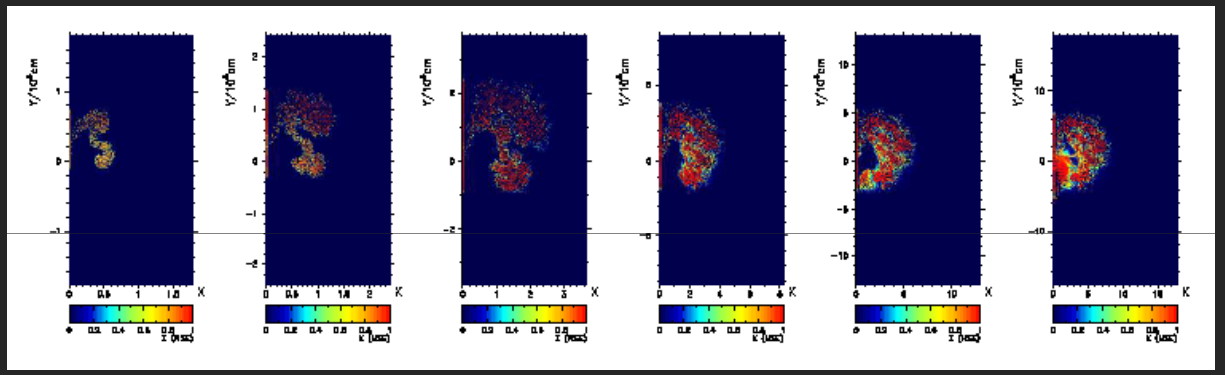
- We need **direct** evidence, which **contradicts any** spherical models.

Where to look into? High-density Ash!

- Example: Ignition at an **offset** (near the center).



Deflagration → Detonation → Fe-peak elements



time

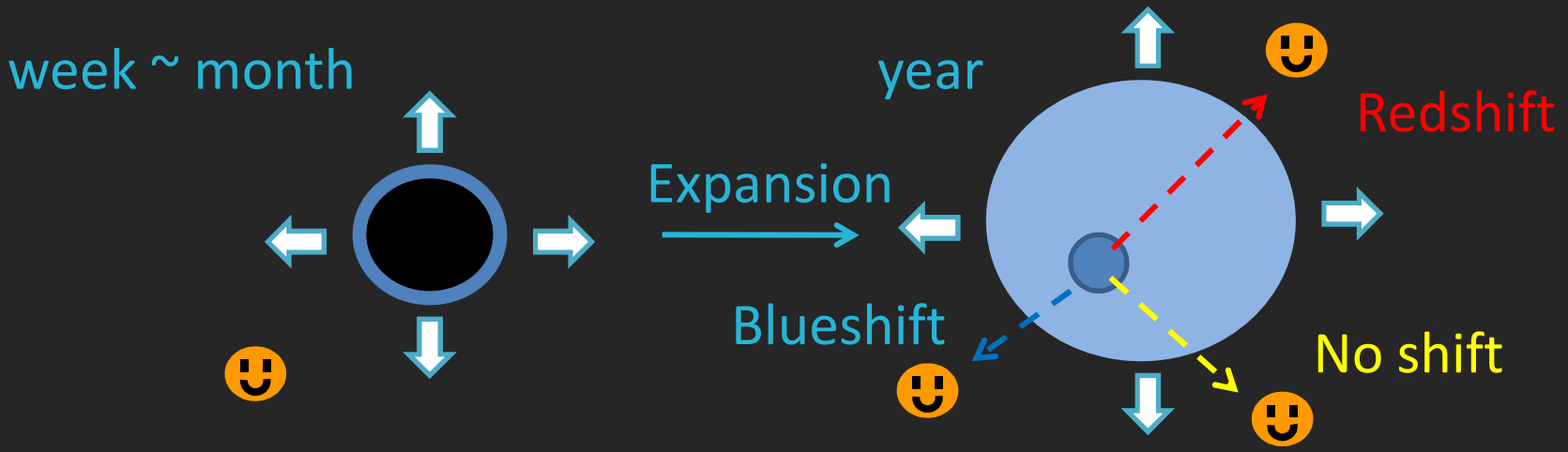
Def. Ash = STABLE Fe+Ni, High Density

Det. Ash = ^{56}Ni (SN power!), Low Density

KM, Roepke, Fink, Hillebrandt, Travaglio, Thielemann, 2010, ApJ, 712, 624

How? Late-time spectra

- Just simple… **Doppler shift** diagnostic of homologously expanding & transparent ejecta.



- (In my opinion) successful for CC-SNe to show the asymmetric and (likely) bipolar nature.
  - KM, Kawabata, Mazzali+, 2008, Science, 319, 1220.
  - Modjaz+08, Taubenberger+09.

KM, Taubenberger, Sollerman+, 2010, ApJ, 708, 1703

Doppler shift diagnostics for SNe Ia

Ionization / particle

$$\frac{4\pi J_\gamma \sigma_\gamma}{\chi_{eff}} = \alpha n_e \frac{n_{i+1}}{n_i} \Rightarrow \frac{n_{i+1}}{n_i} \propto n_e^{-1} J_\gamma$$

^{56}Ni/Co/Fe: radioactive input

Thermal Balance

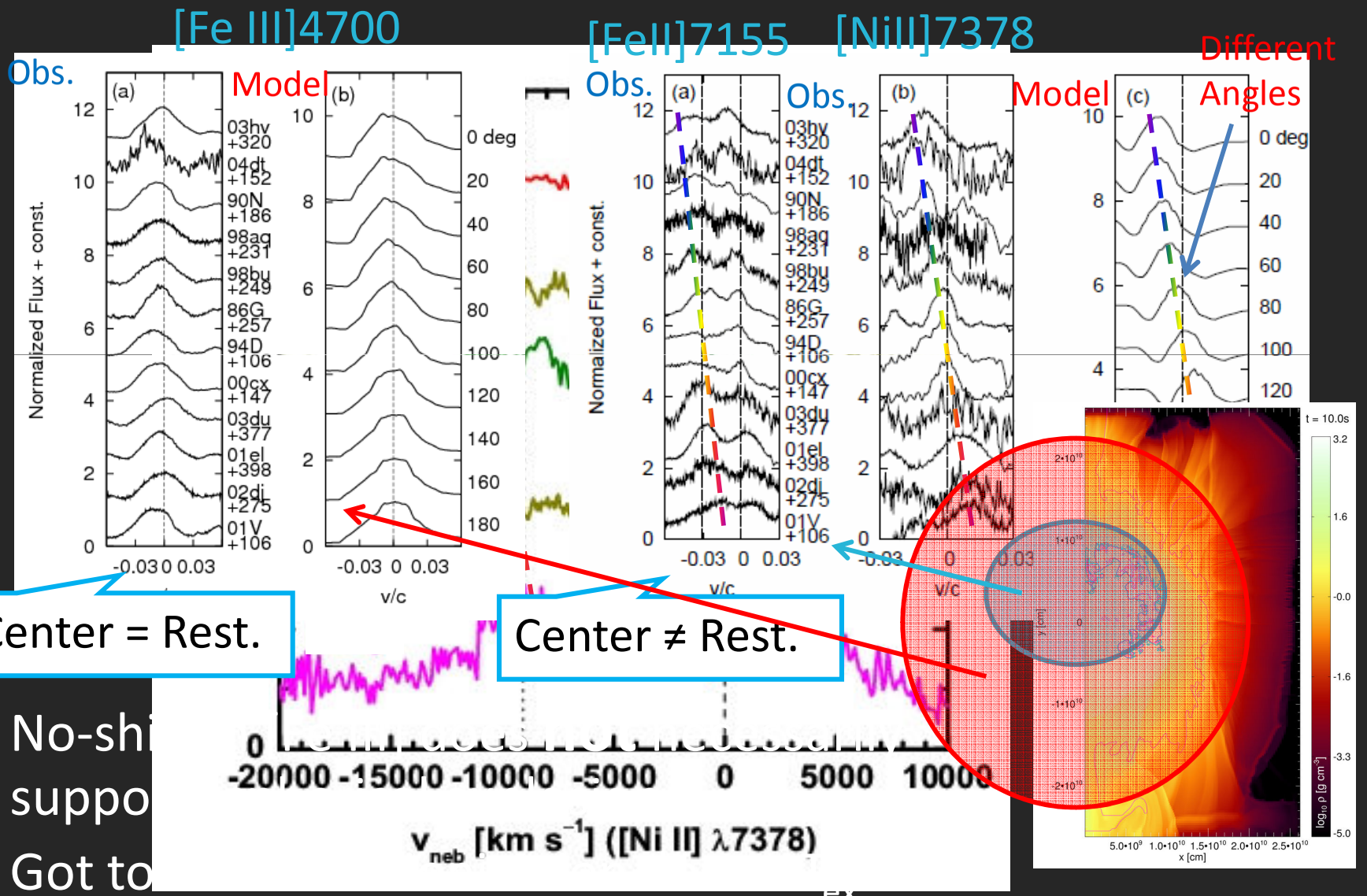
$$L_{line} \propto n_e n_0 \exp\left(-\frac{T_{ex}}{T_e}\right)$$

Excitation T of a line

- STABLE Fe+Ni, high density… **"Def. Ash"**
  - Low ionization(+1), low temperature (~ 5000K).
    - Representative = **[Fe II]7155, [Ni II]7378**.
- ^{56}Ni, low density… **"Det. Ash"**
  - High ionization(+2), high temperature (~ 10000K).
    - Representative = **[Fe III]4701**.

KM, Taubenberger, Sollerman+, 2010, ApJ, 708, 1703

It is there! The first evidence of asymmetry

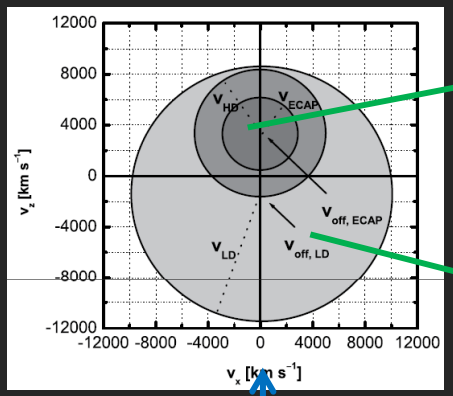


- No-shi
  suppo
- Got to

ex

Obs. from Motohara+06, Gerardy+07, Leloudas+ 09

A strong case: 2003hv

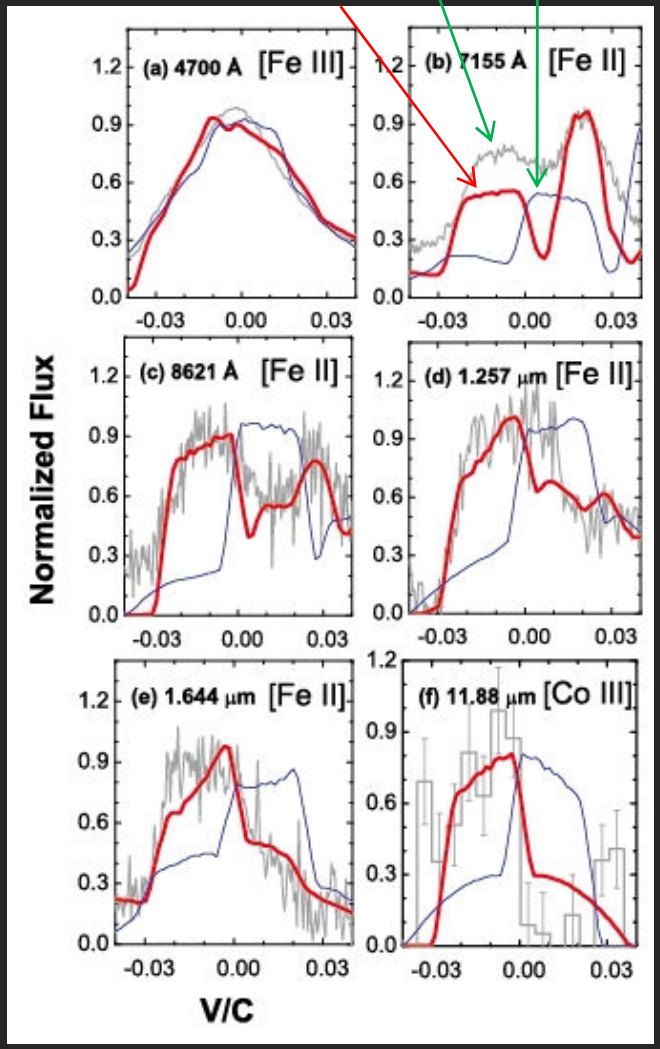


Steble Fe+Ni, high ρ

^{56}Ni, low ρ

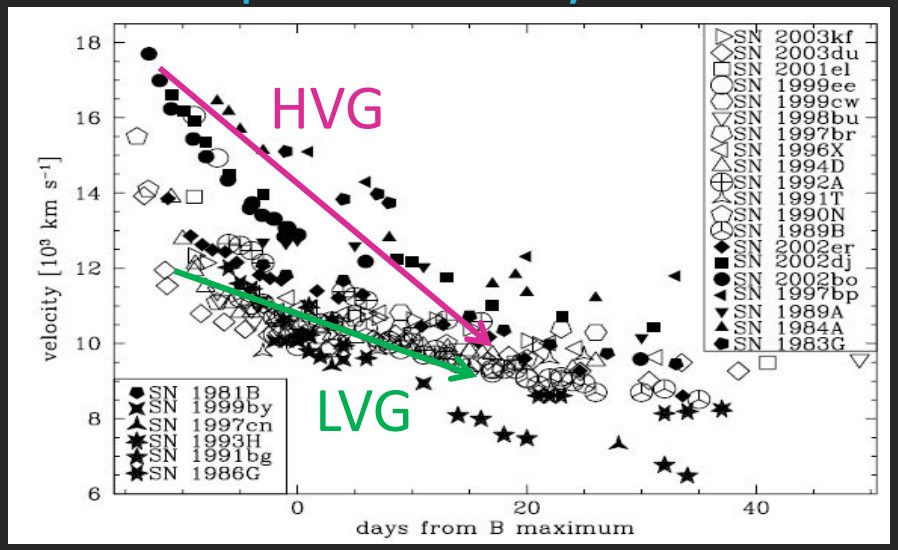
- Two categories in lines.
  - No shift.
  - blue-shift.
    - The shift behavior

ALL just as expected.



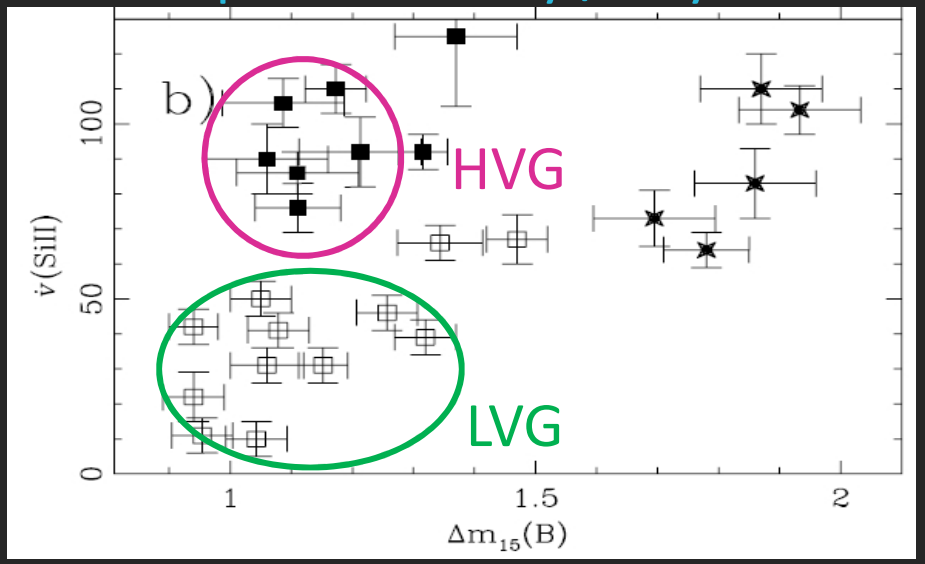
More? Spectral evolution diversity

Si II absorption velocity



Days

Si II absorption velocity / day



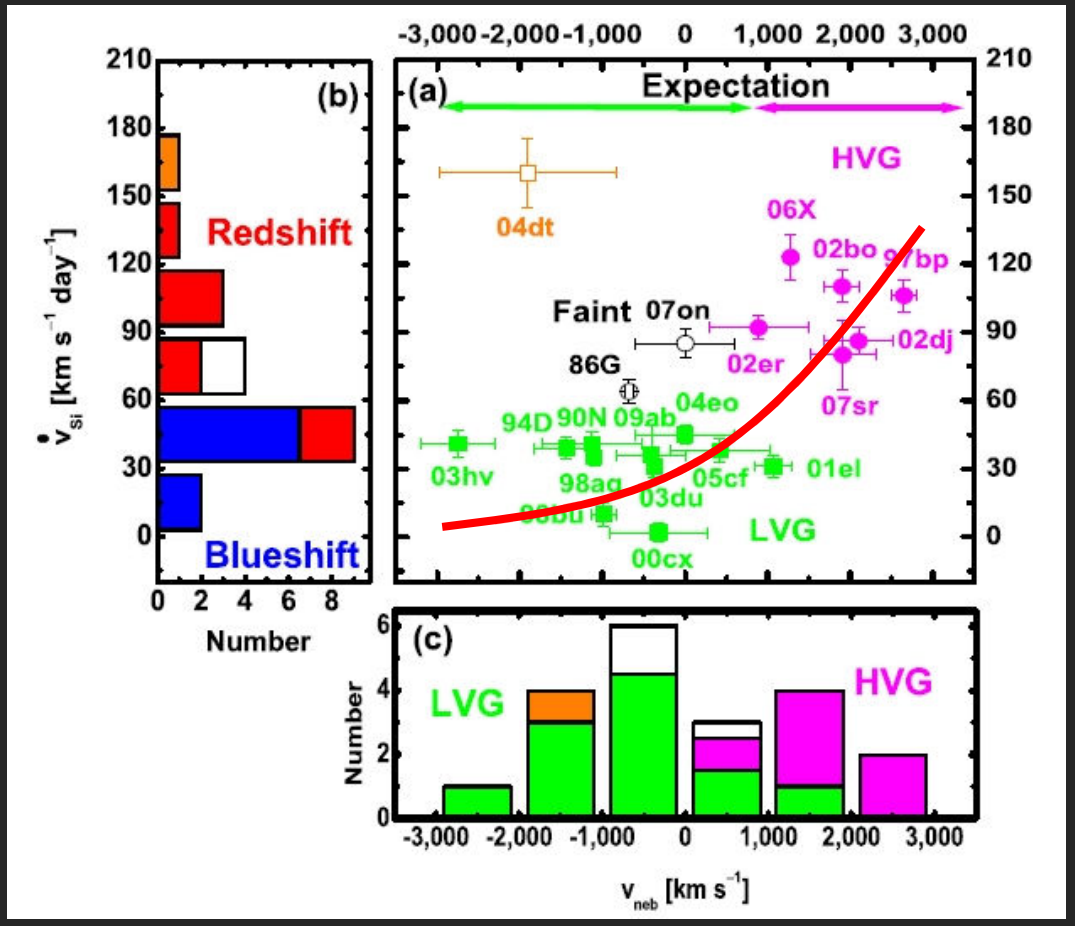
Decline Rate = Luminosity indicator

- Spectral evolution does **not correlate** with the "luminosity".
  - First noticed by Branch+88, but no one has provided an answer about its origin (for > 20 years!).
  - The no-correlation noticed by Benetti+05, raising a challenge to the concept of "SNe Ia = uniform class = good standard candles"

KM, Benetti, Stritzinger+, 2010, Nature, 466, 82-85 (**today!**, arXiv 1006.5888)

Just a viewing angle!

Velocity gradient



- Prob. for chance coincidence = **0.06%**

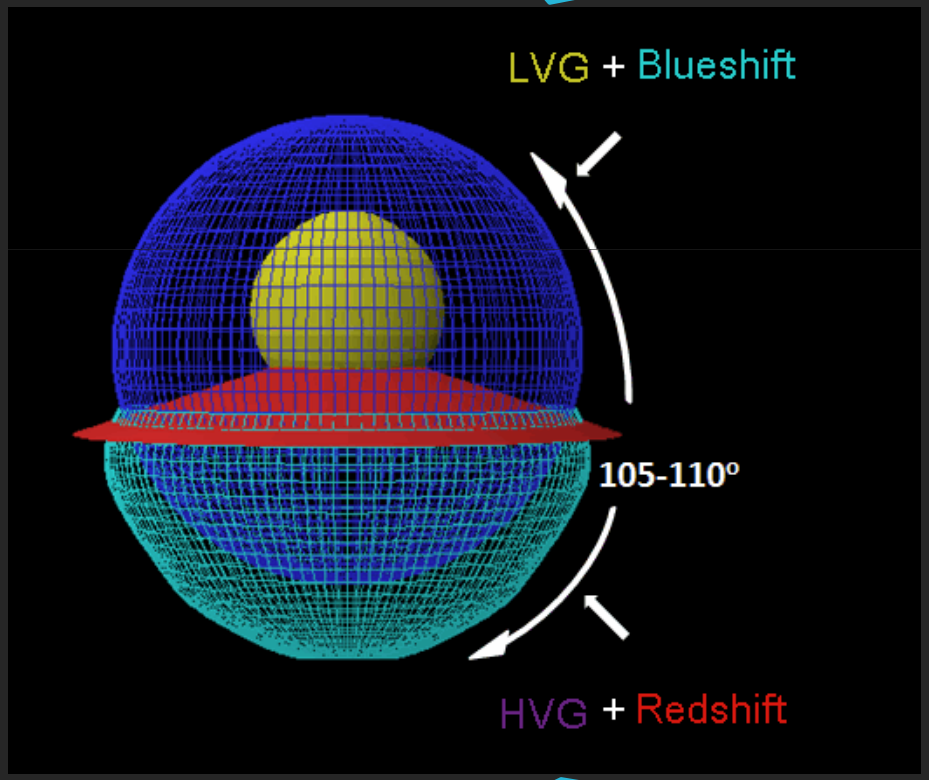
HVG all viewed at the direction **OPPOSITE** to the deflagration ash.

Wavelength Shift of [Fe II]7155+[Ni II] 7378 = **viewing angle**

KM, Benetti, Stritzinger+, 2010, Nature, 466, 82-85 (**today!**, arXiv 1006.5888)

"typical" SN Ia configuration

Distribution of wavelength shift



- Two **independent** information points to the **same** config.

Number ratios HVG/LVG

Conclusions… Toward a unified picture

Asymmetry

- Is a **generic** feature.
  - Theoretically not unexpected.
  - Late-time spectra have provided the **first evidence**.
    - Strong support for the "one-sided" nature.
  - **Solves the "diversity"** in SNe Ia.
    - The spectral evolution **no more a concern** in cosmology.
      - Even if the "diversity" would introduce scatter in the luminosity calibration**, it is just "random", not systematic.**
  - More coming soon out of the idea… Stay tuned!