IAU Symposium 279, 16/Mar/2012

Asymmetry in Supernovae

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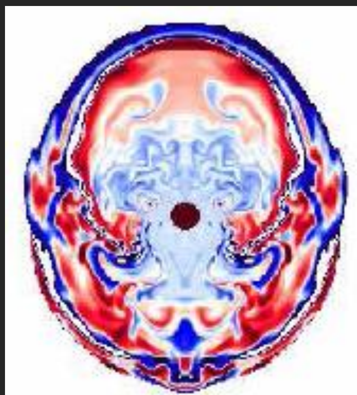
Asymmetry is common

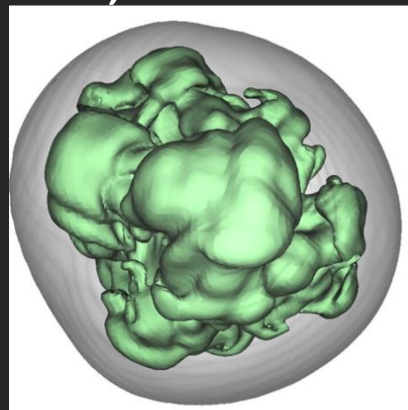
Is asymmetry common in SNe?

CC, SASI



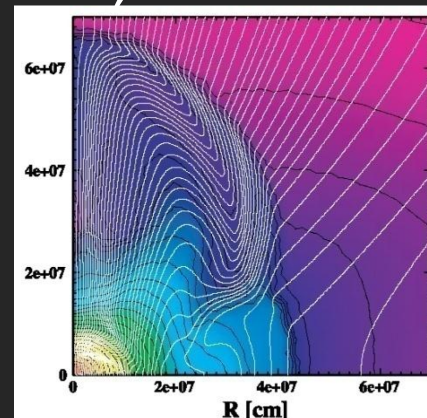
Blondin+ 05

CC, SASI



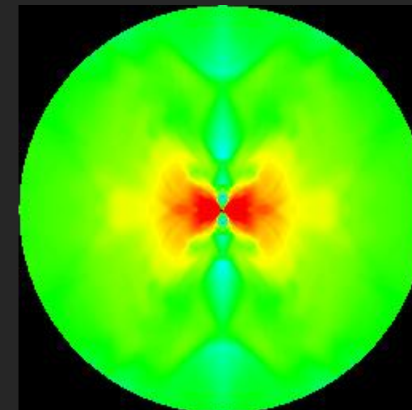
Wongwathanarat+ 10

CC, MHD

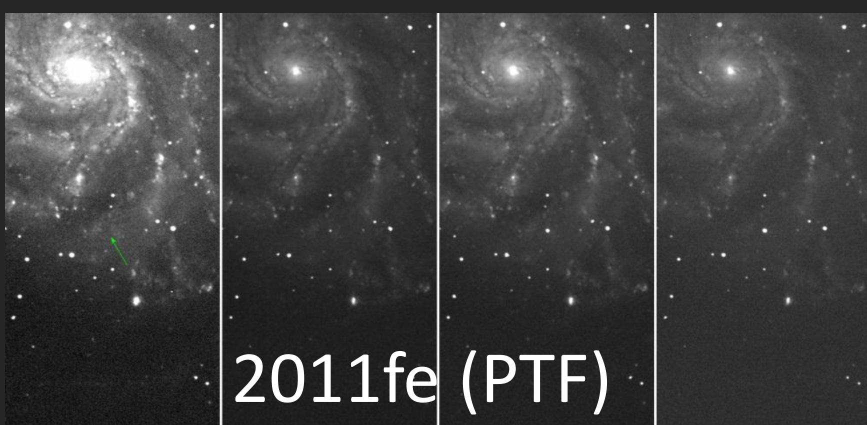


Katake+ 04

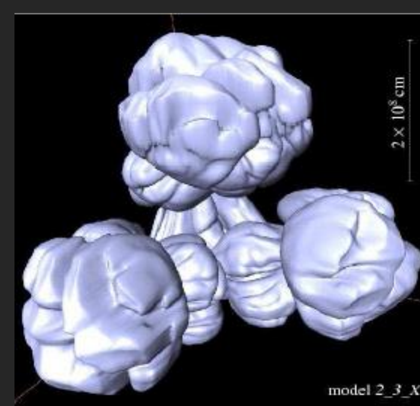
GRB, Collapser



MacFadyen+ 99

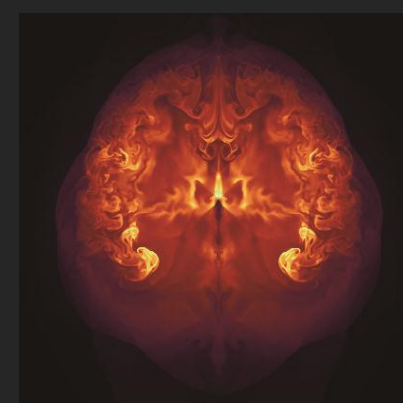


Ia, turbulence



Roepke+ 05

Ia, off-set

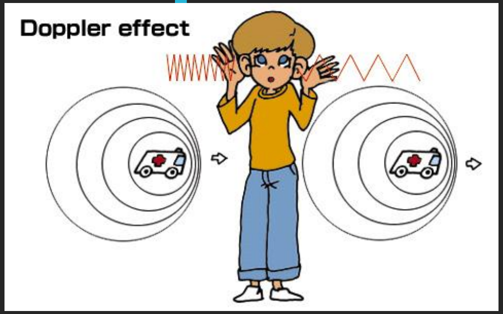


KM+ 10

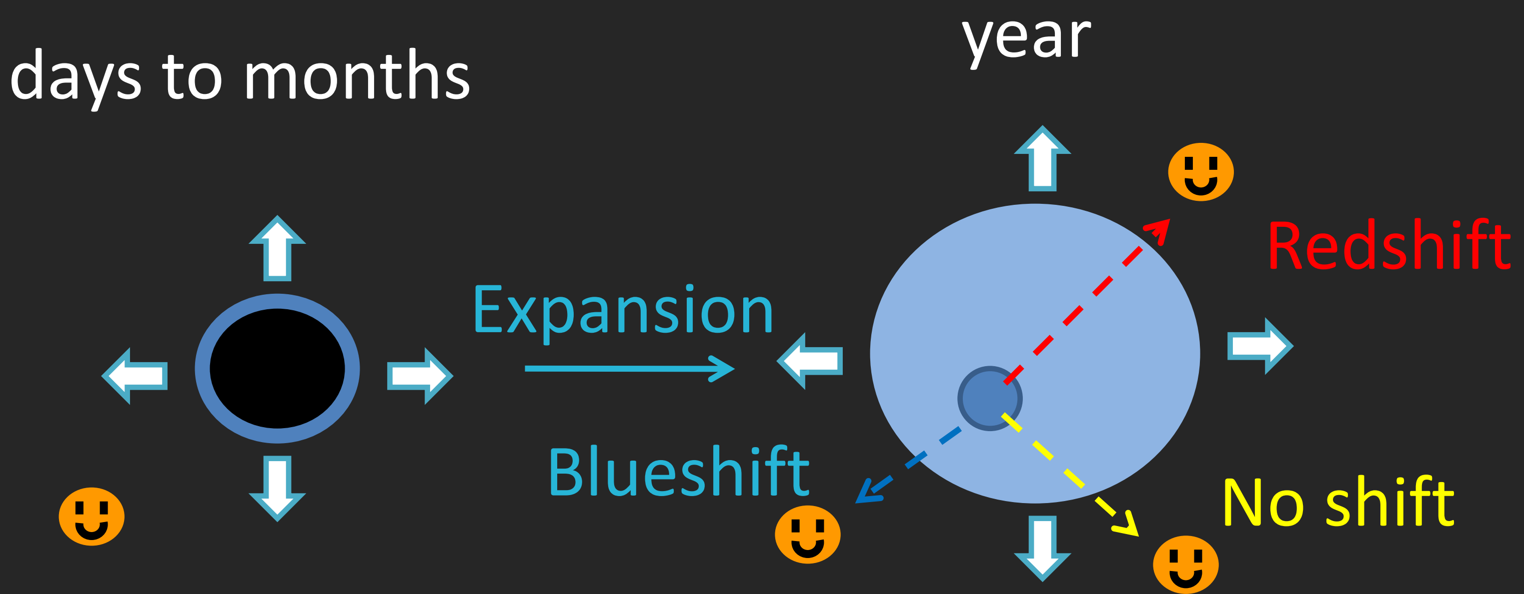
Outline

- **Geometry diagnostics** w/ late-time spectra.
- Explosion **geometry of SNe Ia**.
- Explosion **geometry of SNe Ib/c**.

Geometry Diagnostics by Late-time Spectra



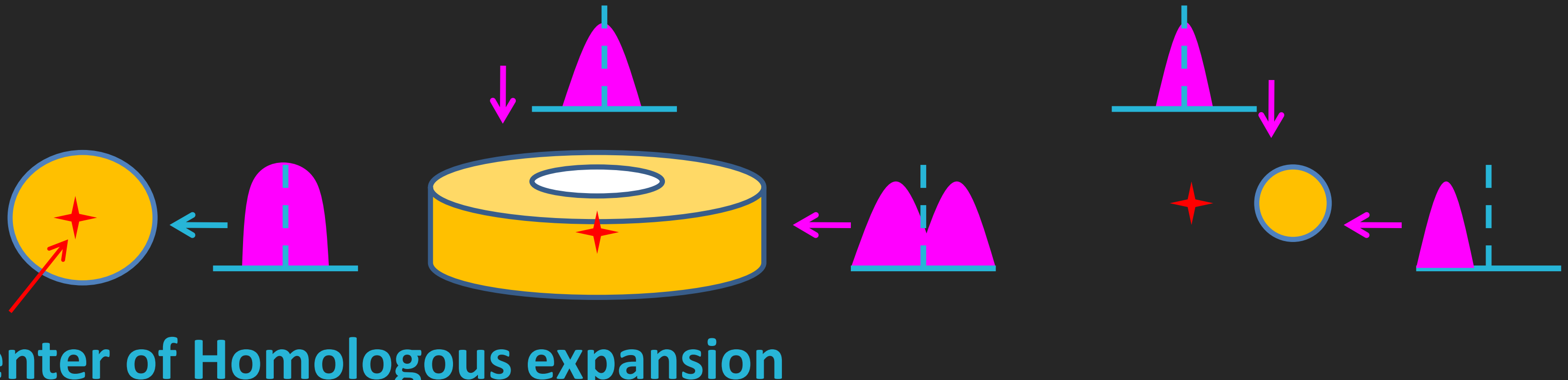
- Just simple… **Doppler shift** of homologously expanding & transparent ejecta.



Late-time, optically thin emission lines

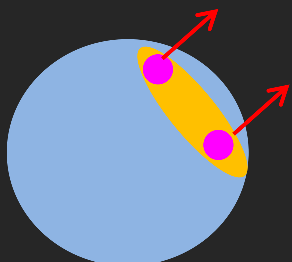
- Basic behavior **independent of model details.**

Geometry	λ @ flux max	Line profile w.r.t rest
Spherical	= Rest	Symmetric
Axi. Sym. + equ. Sym. (”bipolar”, e.g., torus)	≠ Rest (View. Dir.)	Symmetric
Axi. Sym. w/o equ. sym (e.g., one-sided)	≠ Rest (View. Dir.)	Asymmetric

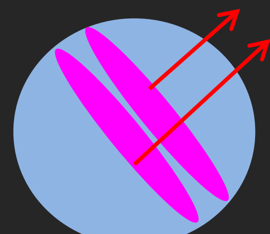


Early Polarization – Late Spectra : Difference

- **Early phase spectropolarimetry (Masaomi's Talk).**
  - **Left vs. up** in the same projection→**Non-**axisymmetry.
  - Early phase→Relatively **outer** layers.
    - **Probe the deviation from a bulk symmetry.**
- **Late-phase spectroscopy.**
  - **Near vs. far** along the line-of-sight→ **Bulk geometry**.
  - Late-phase→**Innermost** regions.
    - **Probe the typical/bulk geometry.**



Spec. Pol.

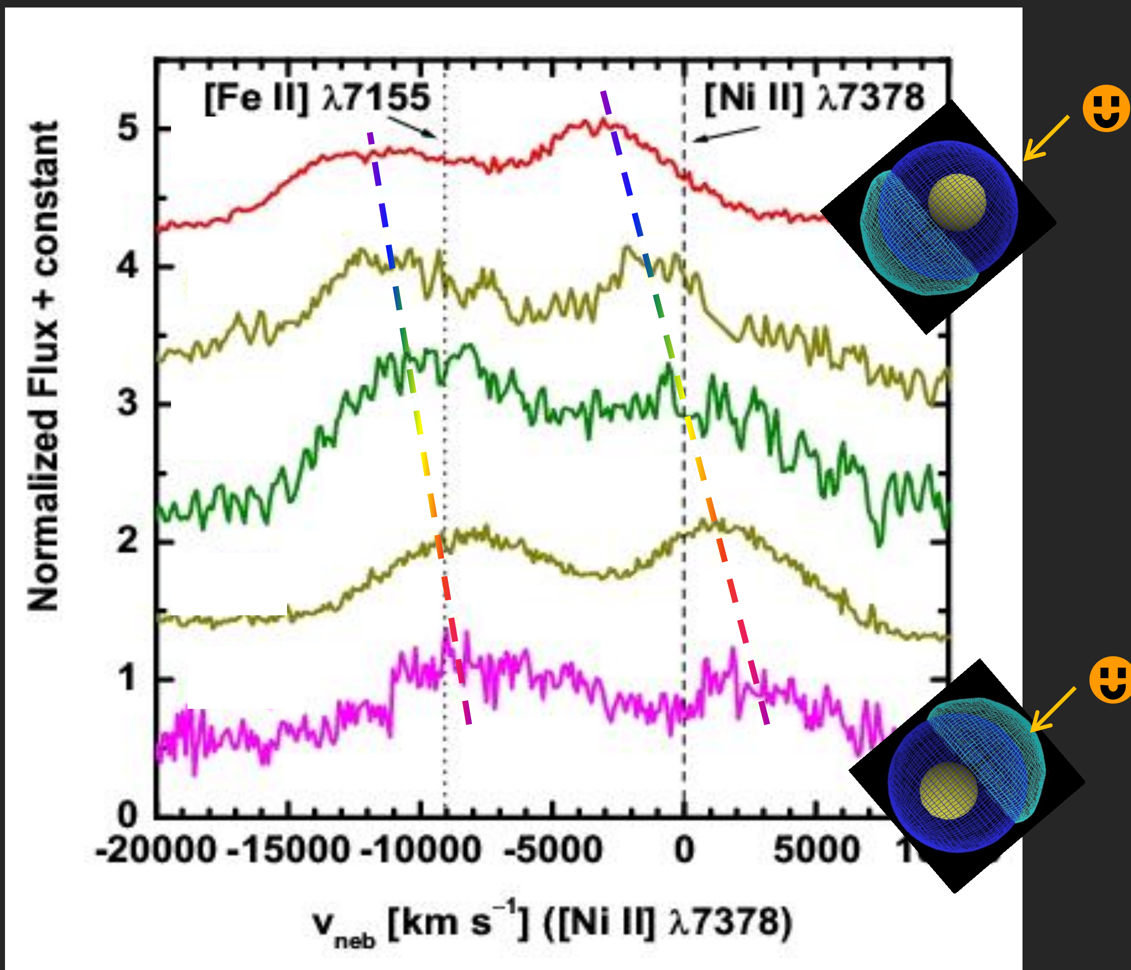


Late-time Spec.

KM, Taubenberger, Sollerman, Mazzali, Leloudas, Nomoto, Motohara, 2010, ApJ, 708, 1703

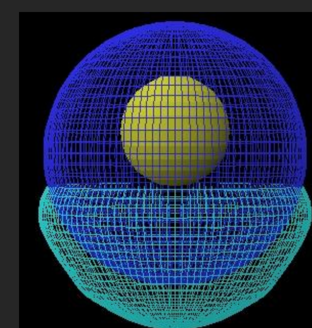
(Normal) SNe Ia

Examples of Late-time [FeII] +[NiII] (5 SNe)



Emitted by Stable Fe & Ni
(low ion + low T_{ex})

i.e., Stable Fe & Ni are **offset**

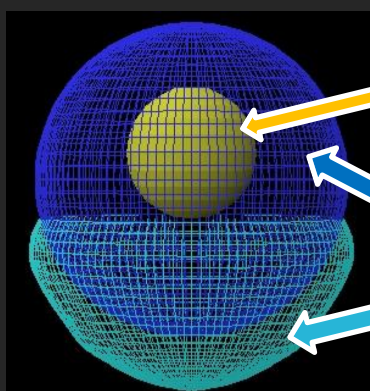


Random clumps w.r.t. the center don't do this.

(Normal) SNe Ia

Motohora+ 06, Gerardy+ 07, Leloudas+ 09
SN 2003hv, optical – IR
Black=obs, Red = model

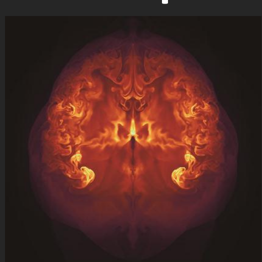
This line is emitted from
Fe from ^{56}Ni decay
(high ion + high T_{ex})



Stable Fe/Ni
(deflagration)

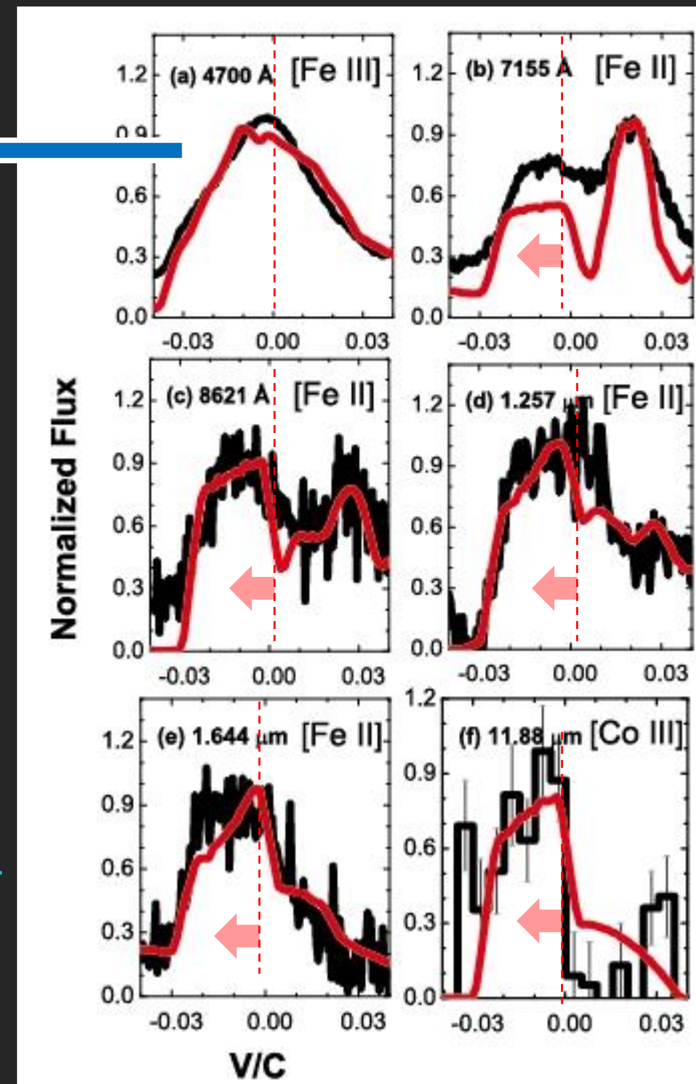
^{56}Ni (detonation)

Expected in off-set ignition



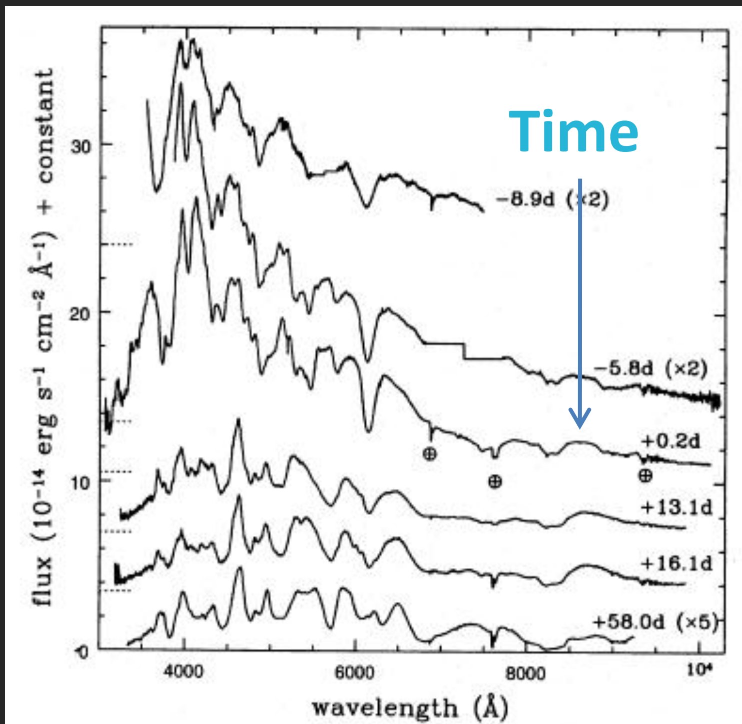
KM, Roepke, Fink+, 2010, ApJ, 712, 624
(c.f., Kasen+ 2009)

But merger may do this
as well (though tricky)

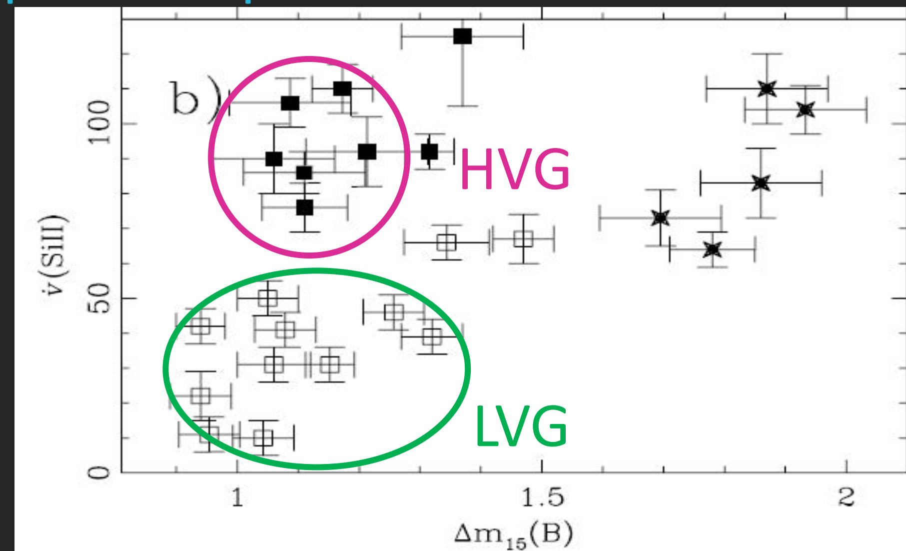


HVG/LVG = High/Low Velocity Gradient

Geometry is not only geometry?



Speed of spectral evolution



Light curve time scale ~ luminosity

Benetti+ 04, 05

- **not correlate** with the “luminosity”.
- SN Ia **diverse** as standardized candles?
  – Related to the geometry? Viewing direction?

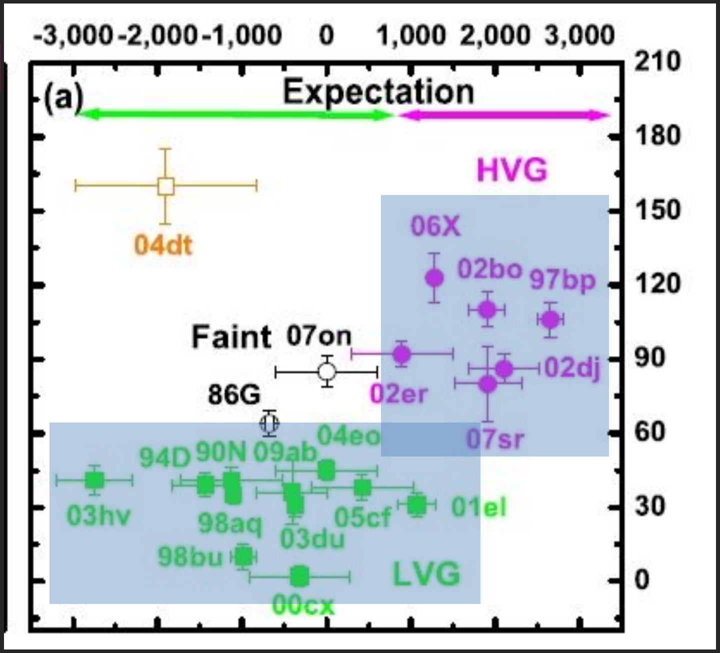
KM+, 2010, Nature, 466, 82 (w/ Folatelli, Sollerman, Nomoto, Leloudas, Tanaka, Mazzali)
KM+, 2011, MNRAS, 413, 3075 (w/ Leloudas, Sollerman, Folatelli, Mazzali)

Viewing direction as a source of diversities

Spectral Diversity

Spectral evolution

Rapid

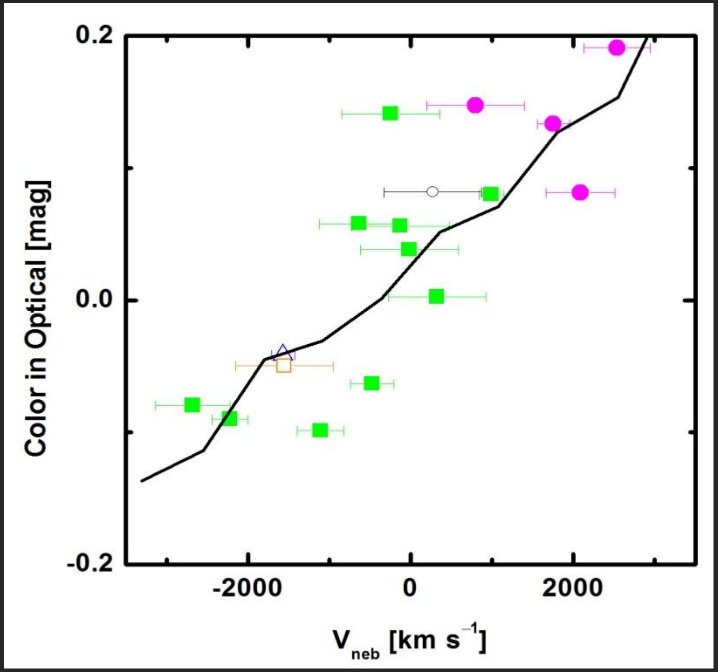


Slow

Color Diversity

Color @ maximum brightness

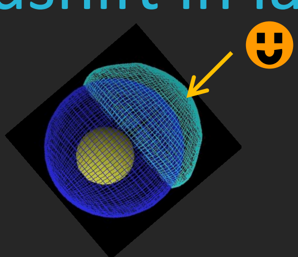
Red

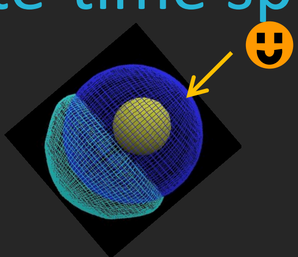


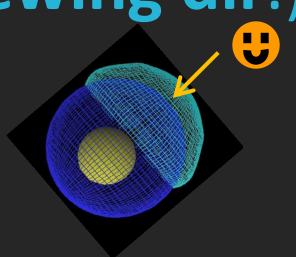
Blue

Blueshift

Redshift in late-time spec. (⇒**viewing dir.**)





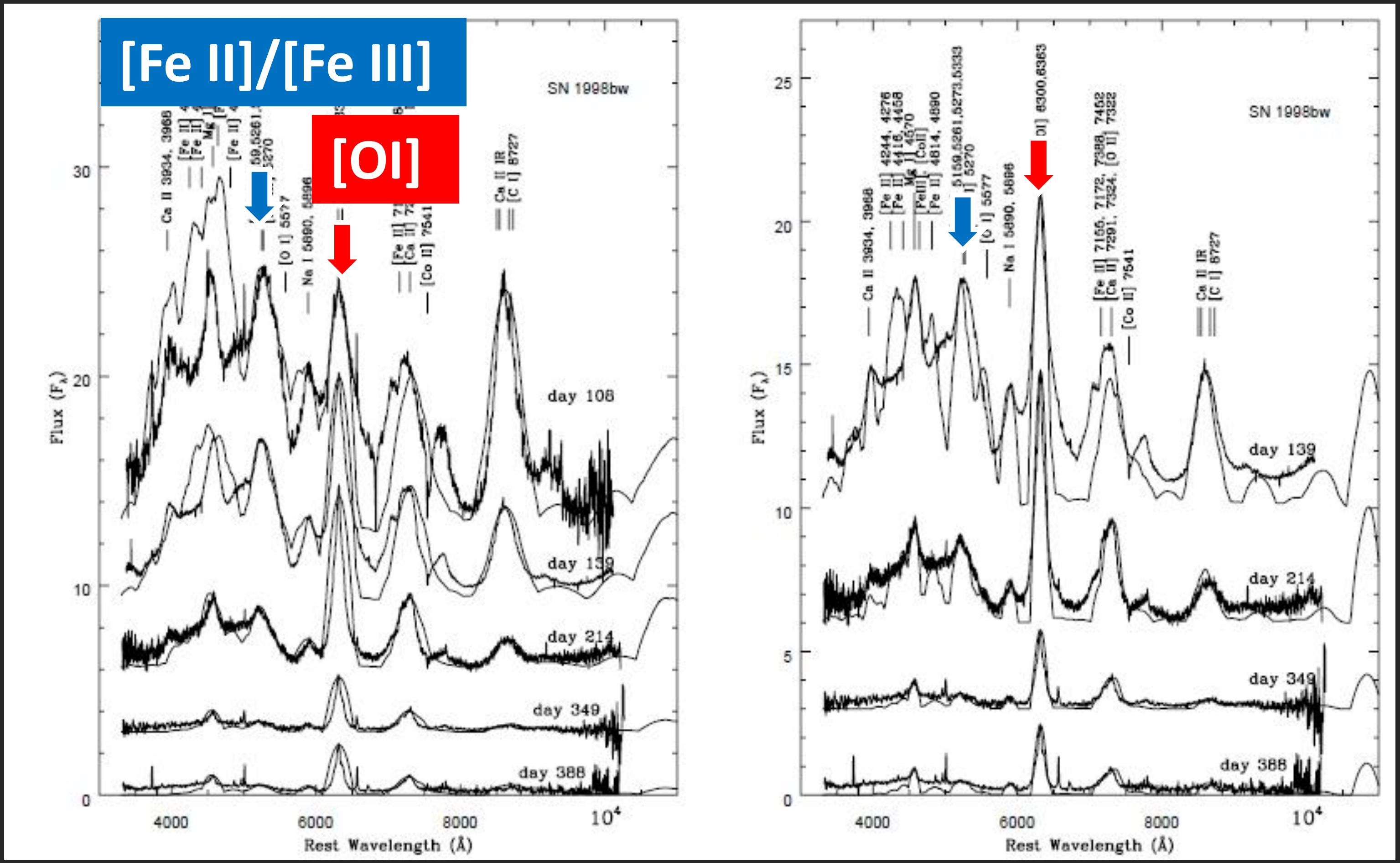


Now, SNe Ib/c

- SNe Ib/c are **best candidates** in CC SNe for the late-time Doppler shift diagnostics.
  - Enters into the nebula phase early.
  - Little transfer effect expected.
    - Maybe important in some IIb (Maurer+ 10).
    - Another phonomenological interpretation (Milisavljevic+ 10).
  - Expansion vel. high (no high res. required).
  - Connection to GRBs (various talks in this symp.).

Mazzali, Nomoto, Patat, **KM**, 2001, ApJ, 559, 1047

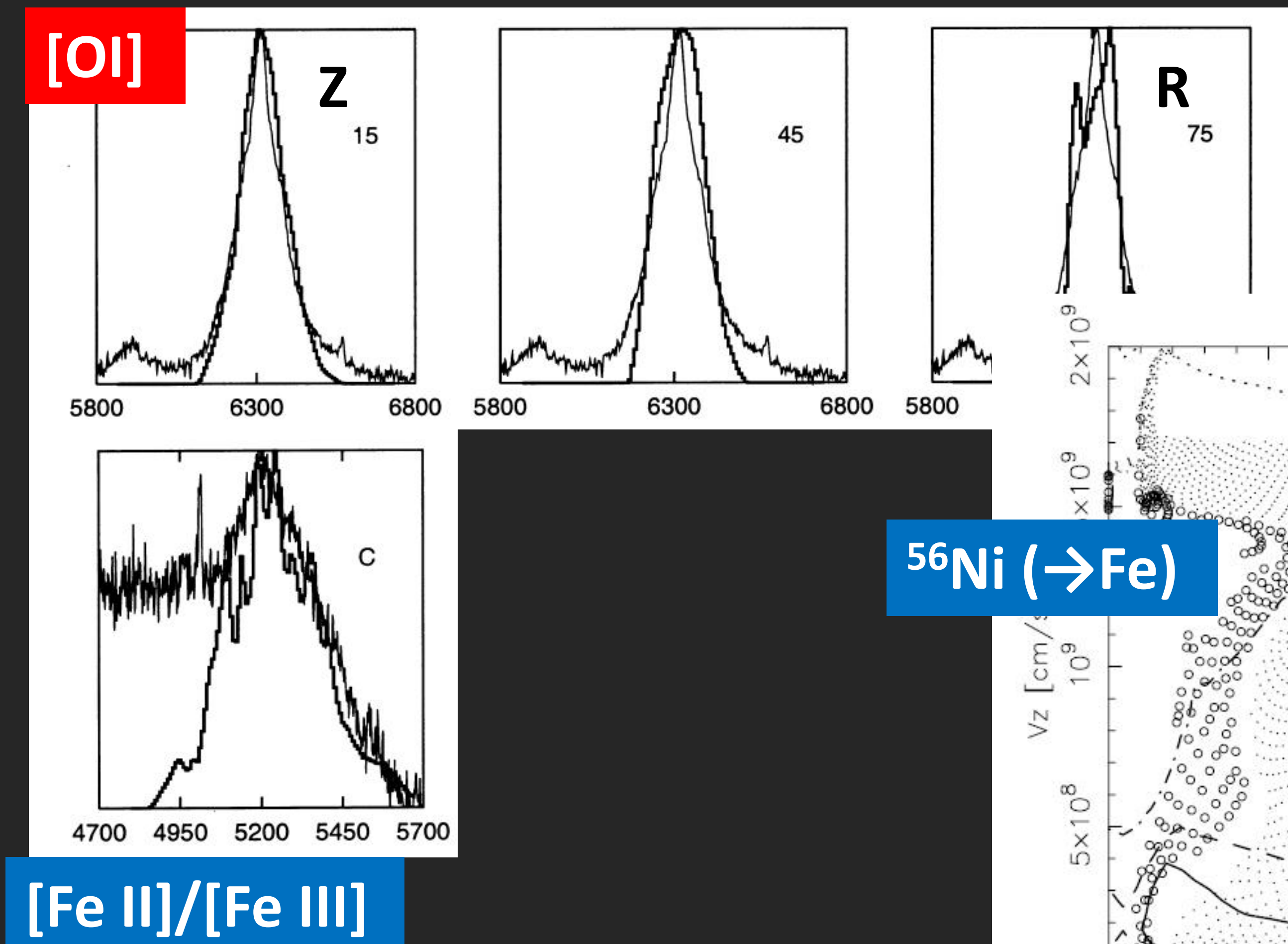
SN 1998bw (GRB980425)



- V(Fe) broader/faster than V(O). May indicate bipolar?

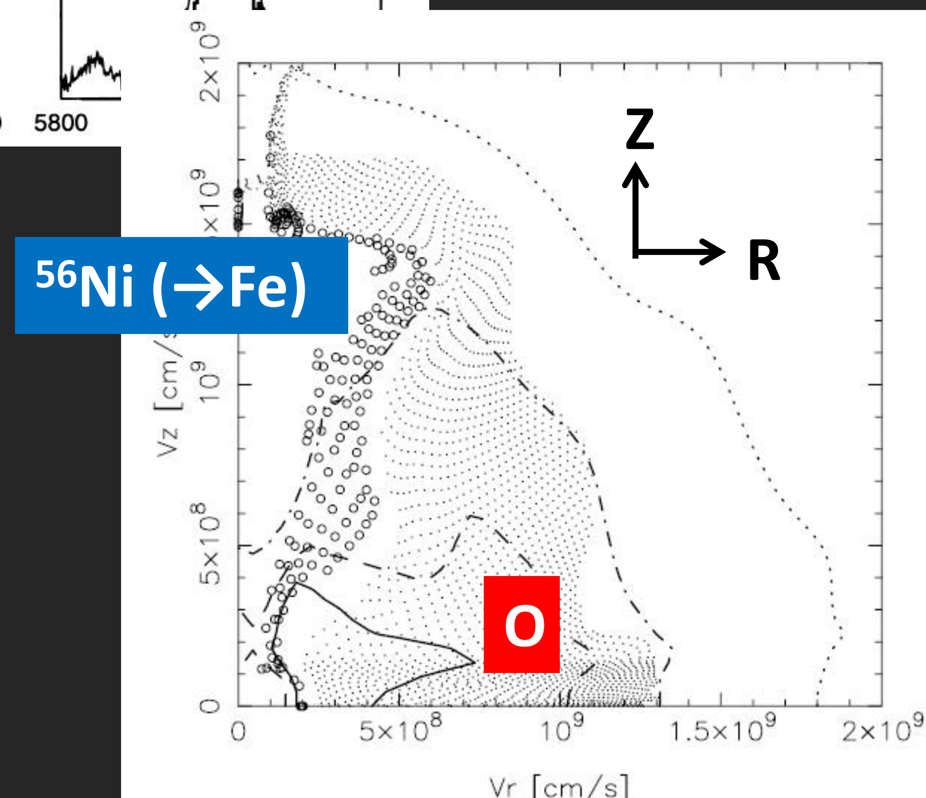
KM+, 2002, ApJ, 565, 305 (w/ Nomoto, Mazzali)
KM, Nomoto, 2003, ApJ, 598, 1163

A bipolar interpretation



Prediction:

Double-peaks from R.



V(Fe) > V(O) from Z.

Mazzali, Kawabata, **KM**+, 2005, Science, 308, 1284 (w/ Nomoto, Pian, Tominaga, Gal-Yam)

SN 2003jd – off-axis 1998bw-like?

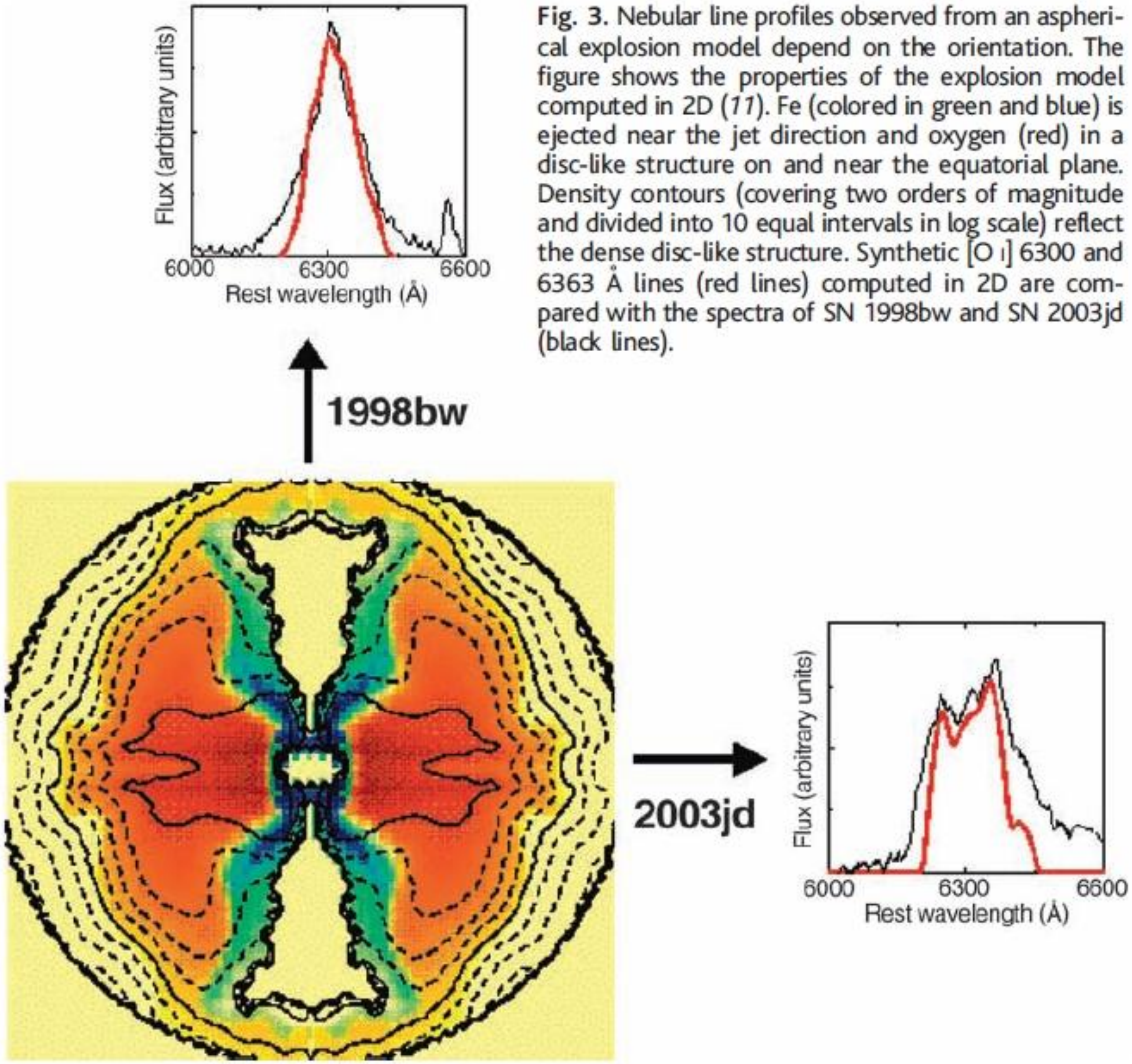


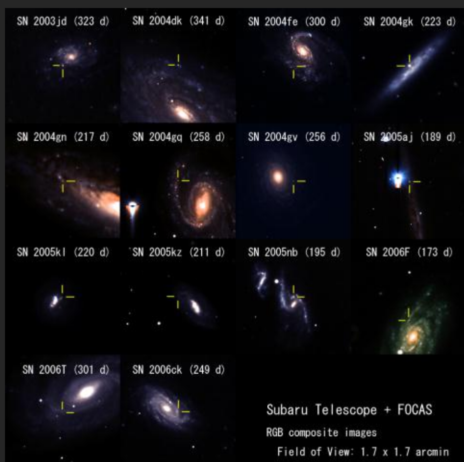
Fig. 3. Nebular line profiles observed from an aspherical explosion model depend on the orientation. The figure shows the properties of the explosion model computed in 2D (*11*). Fe (colored in green and blue) is ejected near the jet direction and oxygen (red) in a disc-like structure on and near the equatorial plane. Density contours (covering two orders of magnitude and divided into 10 equal intervals in log scale) reflect the dense disc-like structure. Synthetic [O I] 6300 and 6363 Å lines (red lines) computed in 2D are compared with the spectra of SN 1998bw and SN 2003jd (black lines).

Broad-line.

[OI] Double peak.

Late-Time Spectra of (normal) SNe b/c

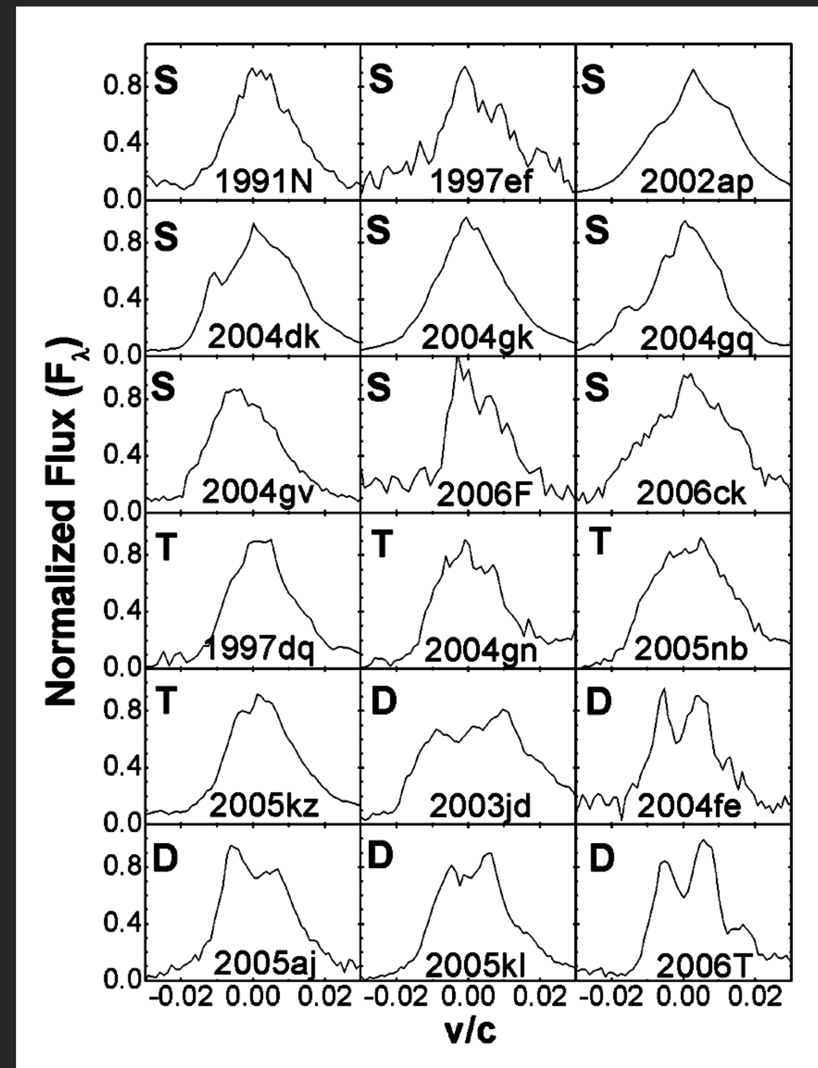
- SNe Ib/c in late phases w/ Subaru/VLT.



Single peak

+

Double peaks



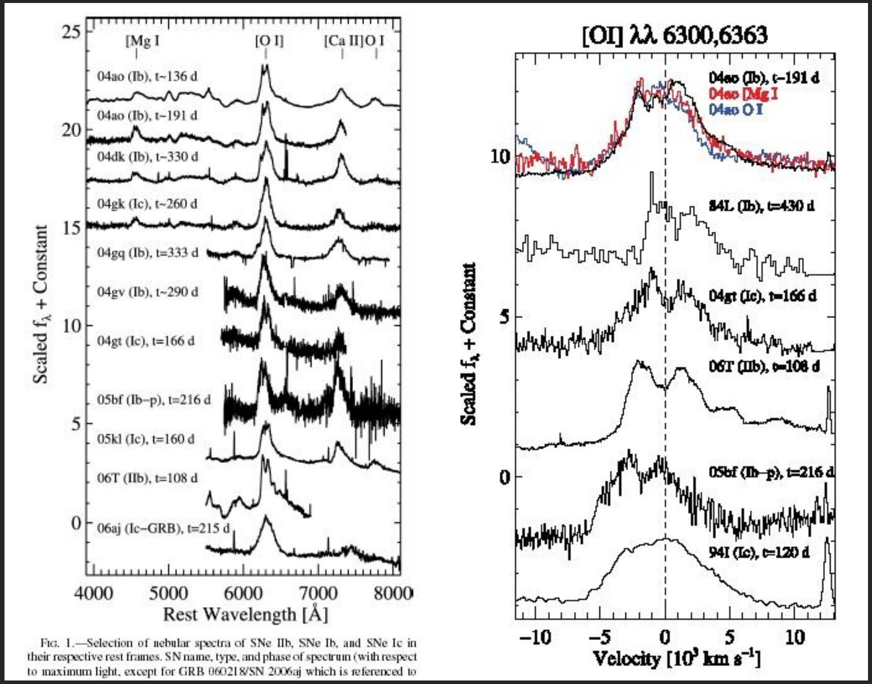
Not spherical symmetry.

Not many clumps (at most a few).

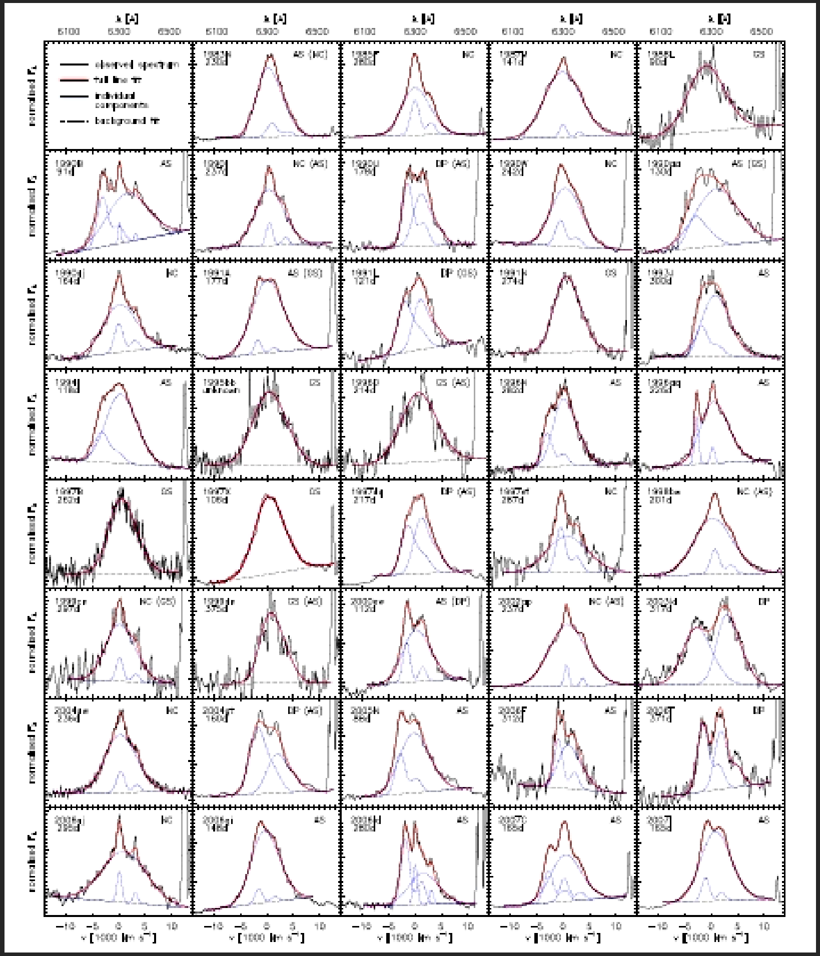
Not largely one-sided (≠ SNe Ia).

Bipolar (or torus) straightforward.

Other dataset



Modjaz+ 08



Taubenberger+ 09 (w/ **KM**)

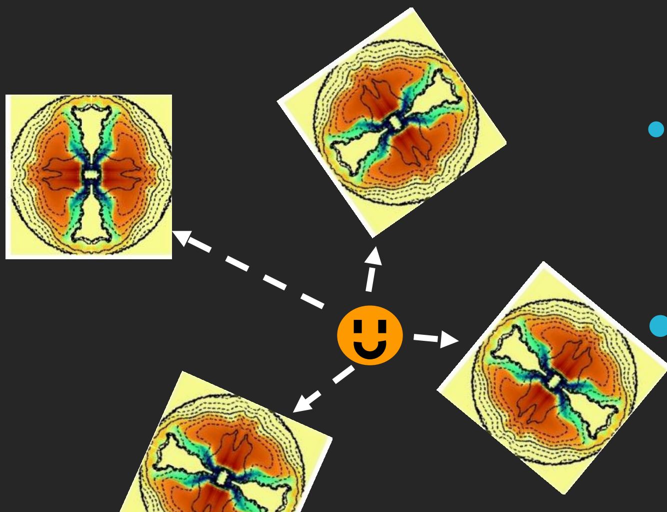
Degree of asym. in bipolar interpretation

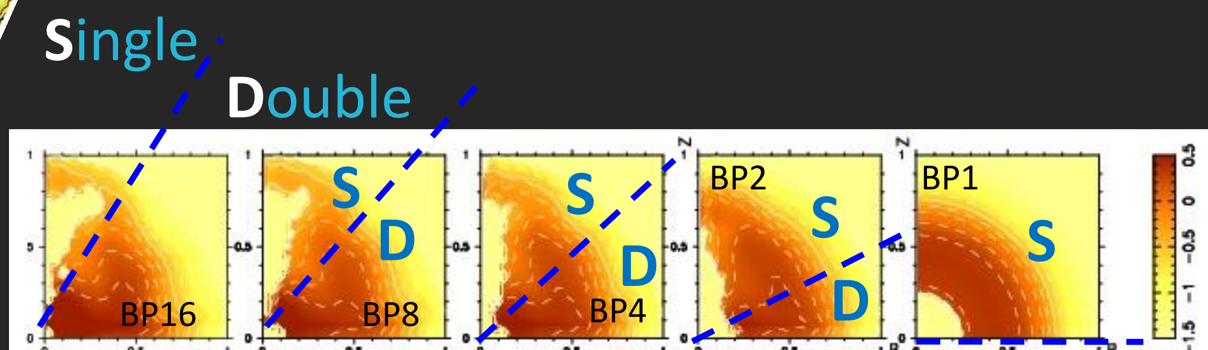
- Removing GRB-SNe→Direction random.

⬇

- **Asymmetry**

  ⇔ (double)/(single + double)

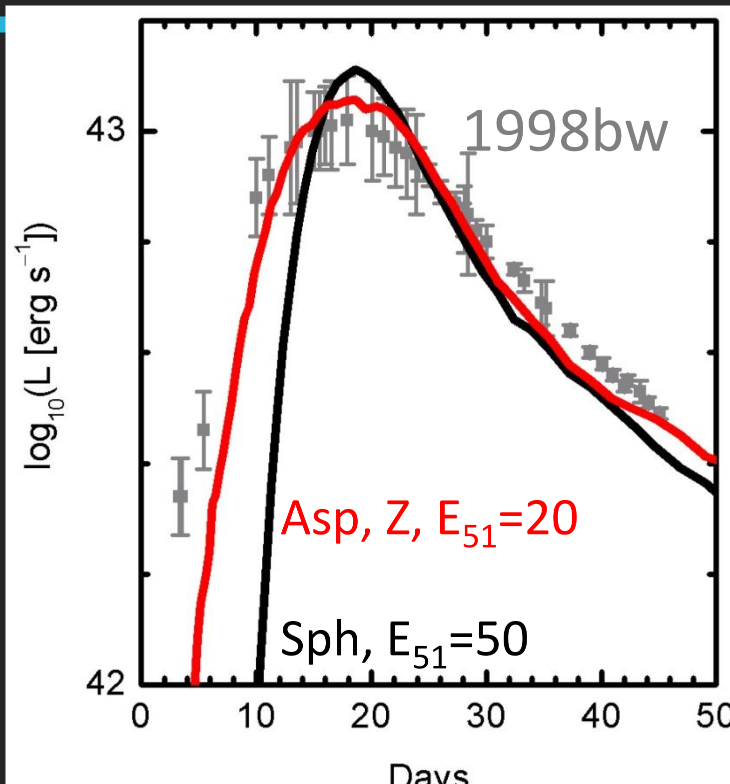




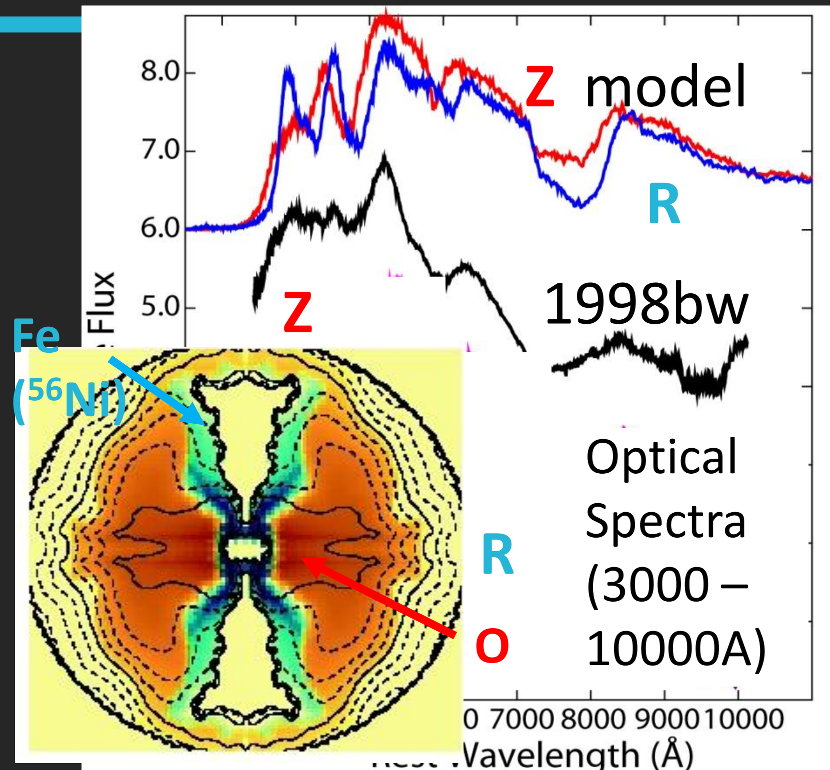
Expected D/(S+D) 0.64 0.34 0.0

Observed D/(S+D) = 0.3 ~ 0.5

Early-phase behaviors of 1998bw



KM, Mazzali, Nomoto 06, ApJ, 645, 1331

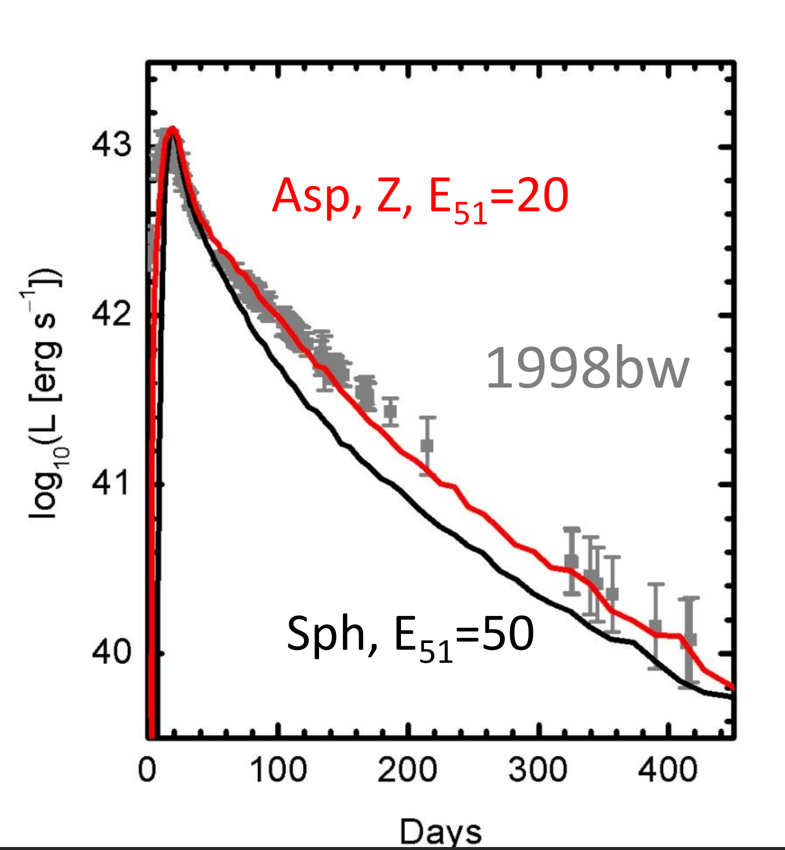


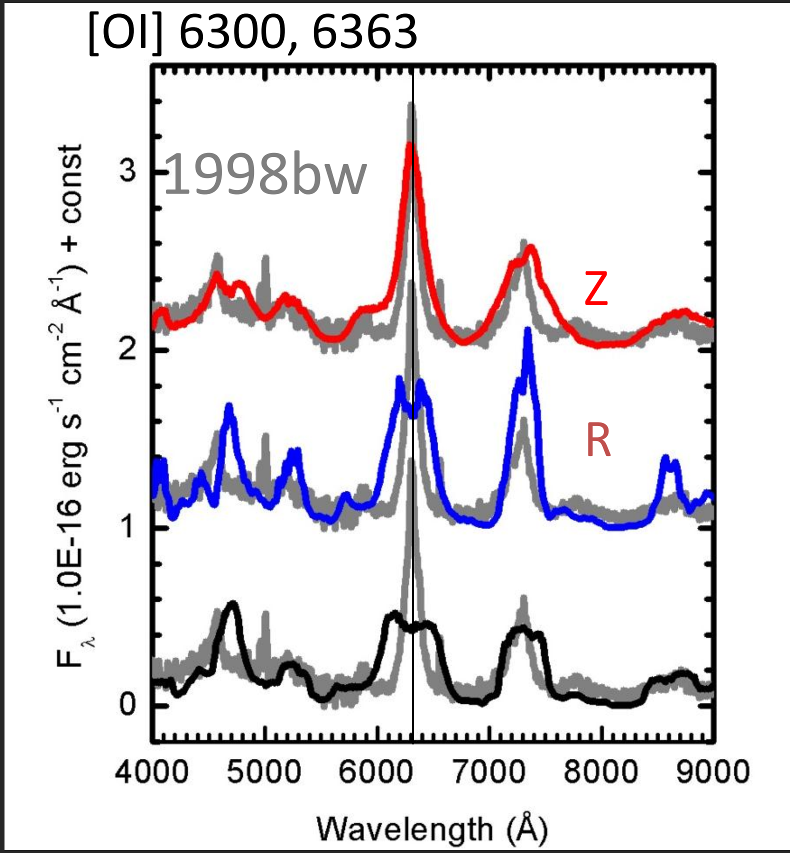
Tanaka, **KM**, Mazzali, Nomoto 07

- **The model asymmetry > “normal” SNe Ib/c.**
- **Consistent with observed properties.**

Multi-D rad. transfer (under various major simplifications).

Late-phase behaviors of 1998bw





KM, Mazzali, Nomoto 06, ApJ, 645, 1331 **KM**, Nomoto, Mazzali, Deng 06, ApJ, 640, 854

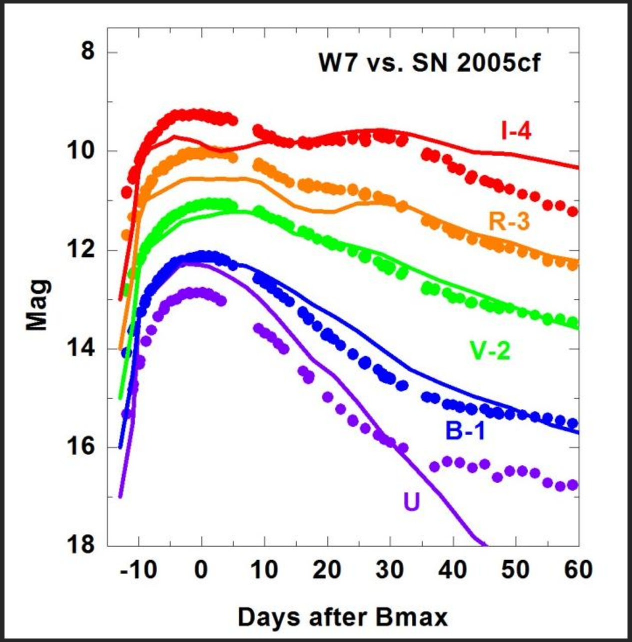
- The model asymmetry > "normal" SNe Ib/c.
- Consistent with observed properties.
- The energy reduced by a factor of a few than 1D models.

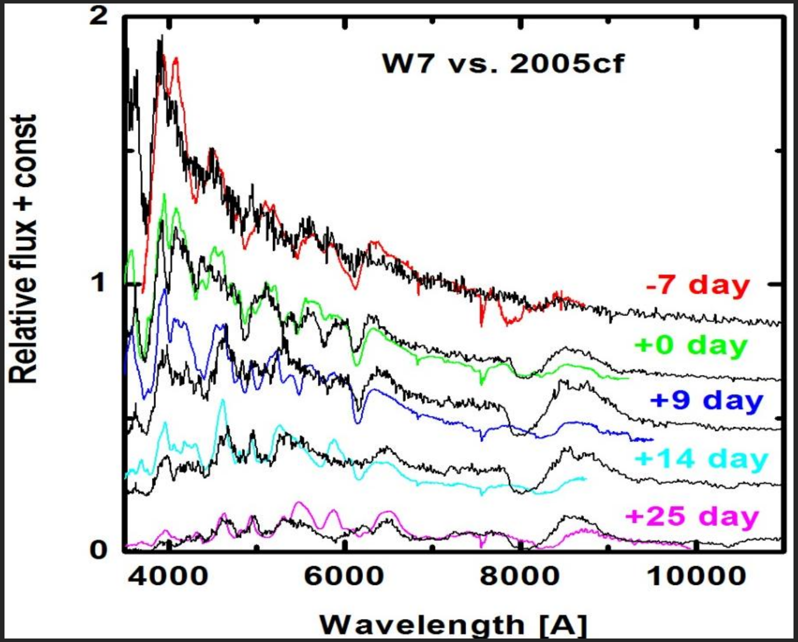
Future directions for asymmetry business

- Got more data.
  - Improving Statistic does help.
    - More specific argument for a typical geometry.
    - Typical geometry different for different populations?
- Go to other wavelengths.
  - NIR/IR helped a lot for SN Ia 2003hv.
- Provide detailed predictions for various models.
  - Realistic multi-D rad. transfer hard to tackle.

KM, in prep.

Update in Multi-D Transfer





→Works in 1-3D w/ MPI-openMP.
→Time-dependent.
→A single model input, no more input parameter.
→~ Million line transitions (LTE).
c.f., Sedona (Kasen), ATIS (Kromer)

An example: 1D, W7 (Ia)
- Works in 2D w/ reasonable comp. time.
- Investigating resources for 3D.

Conclusions

- Late-time spectra probe typical/bulk geometry.
- SNe Ia are **asymmetric.**
  - One-sided.
  - Viewing direction = Various Diversities.
- SNe Ib/c are **asymmetric.**
  - Not spherically symmetric.
  - A typical number of “clumps” at most a few.
  - No significant deviation from equ. Symmetry (so far).
    - **Bipolar** the most straightforward interpretation.
    - GRB-SN 1998bw is **more asymmetric** than norm.