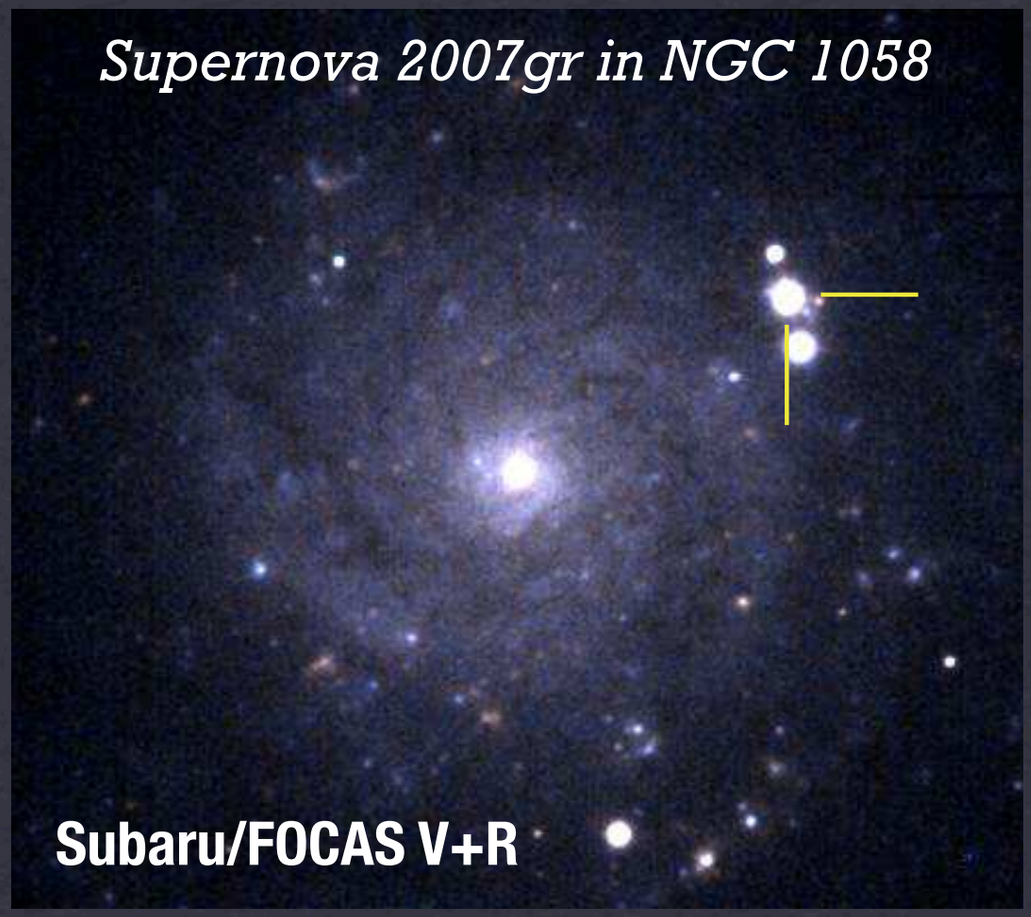
Explosion Geometry of Supernovae Revealed by Spectropolarimetry with Subaru/FOCAS

MT, Kawabata, Maeda, et al. 2008, ApJ, 689, 1191
MT, Kawabata, Maeda, et al. 2009, ApJ, 699, 1119
MT, Kawabata, Yamanaka, et al. 2009, submitted to ApJ (arXiv:0908.2057)



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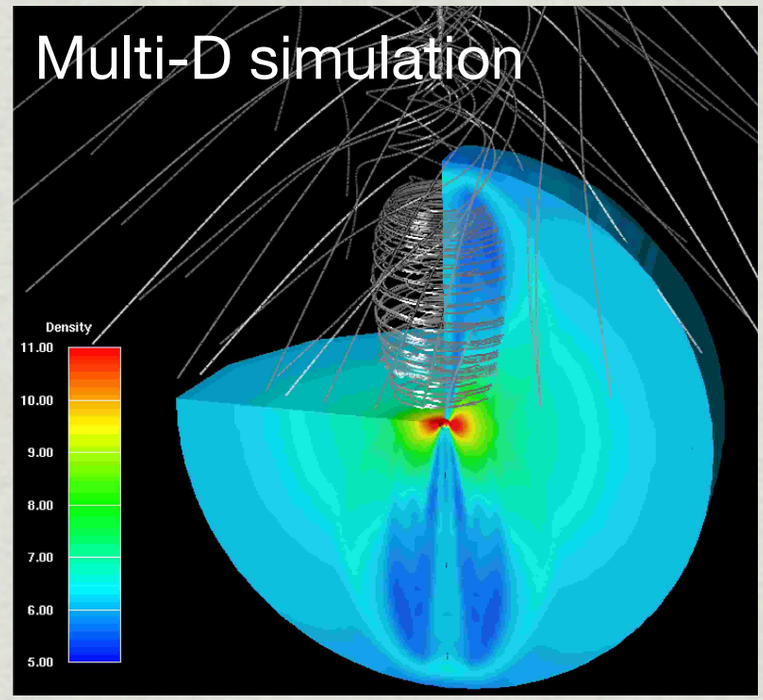
with great help by the Subaru staff/observers

How Massive Stars End Their Life?

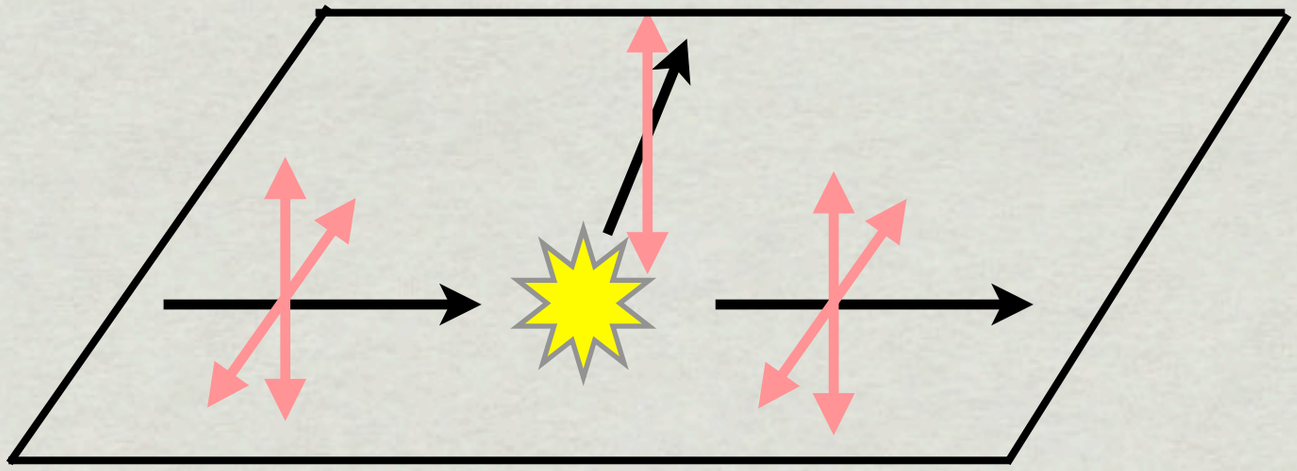
- ***Supernova!***
  - But, how?
    core-collapse --> bounce --> ??
    Longstanding mystery (> 50 yrs)
  - Recent numerical simulations
    - Explosion would not succeed in 1-dimensional simulations
      (e.g., Rampp+00; Sumiyoshi+05)
  - ***"The Last Hope"*** = non-spherical explosion
    (e.g., rotation, magnetic field, instabilities)



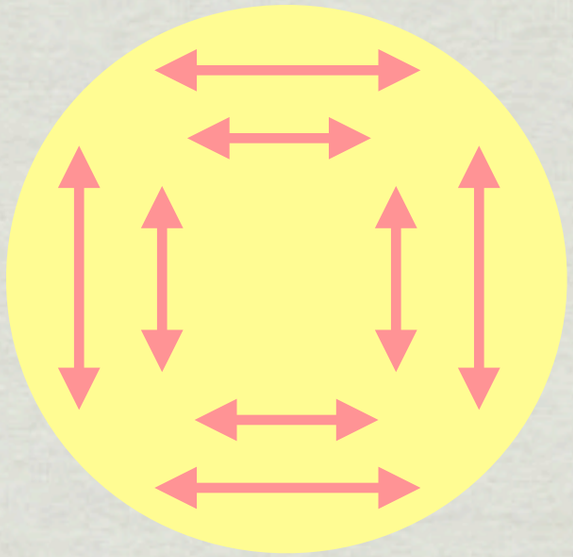
Harikae et al. 2009

Are SNe Really Non-Spherical?
--> Extracting Explosion Geometry of SNe from Observations

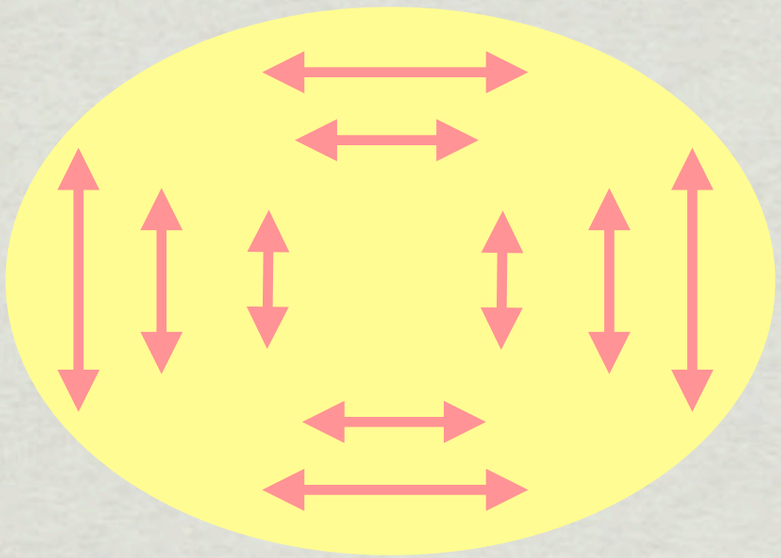
Power of Polarization



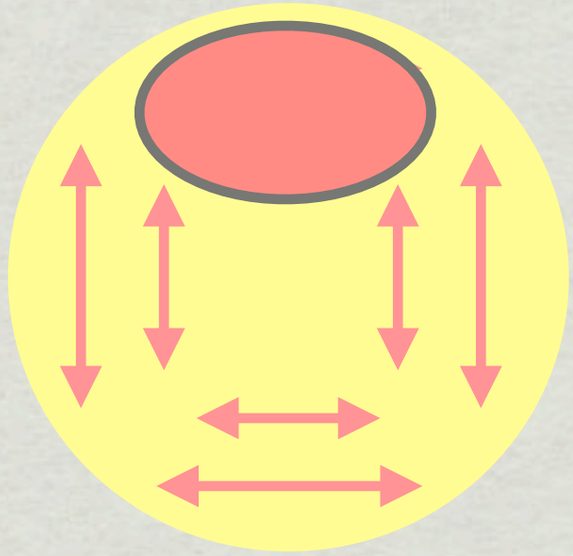
Electron scattering



Zero polarization



Non-zero polarization



Non-zero polarization
(at line)

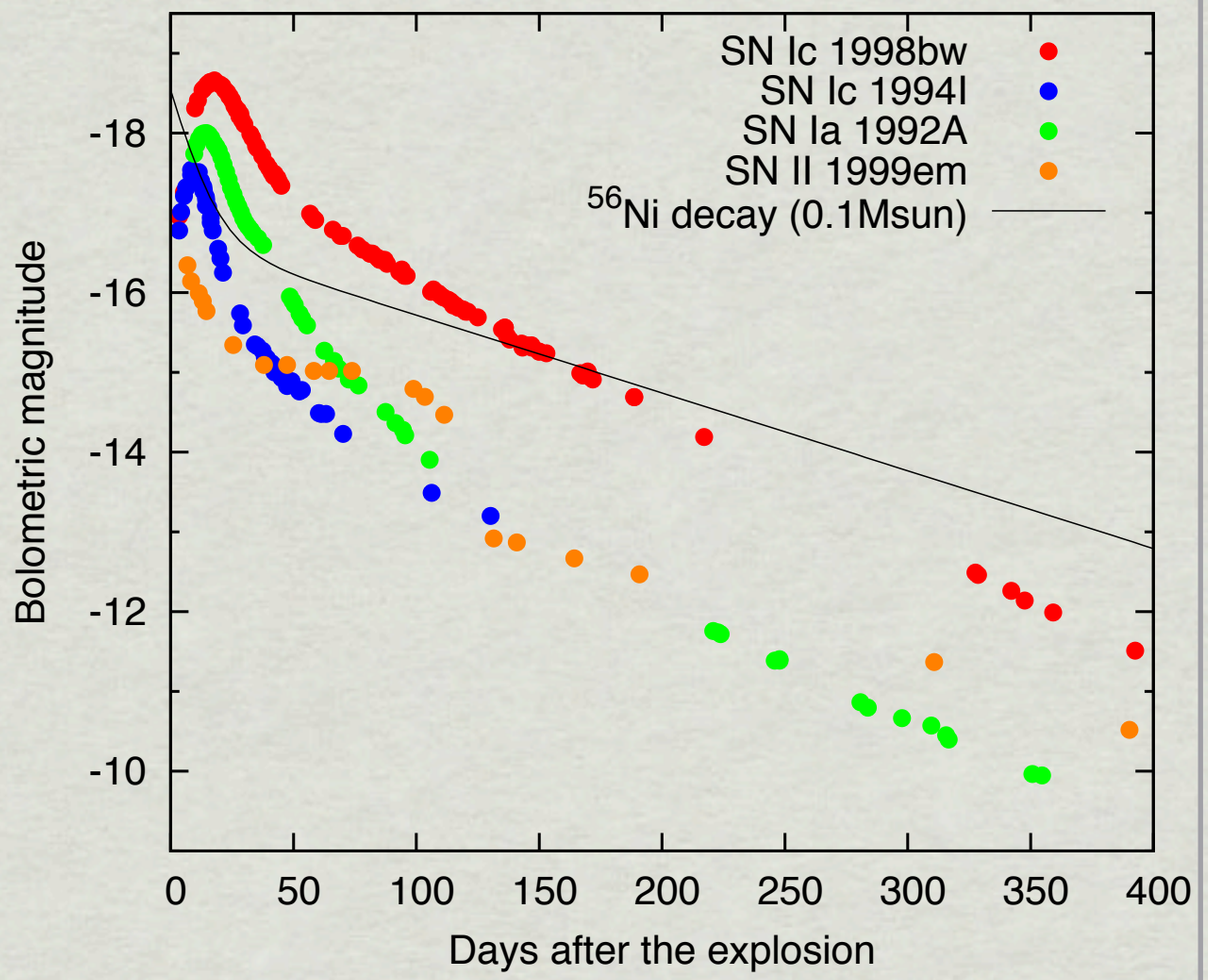
The unique method to explore the "shape" of extragalactic (point source) SNe

Strategy for SN Spectropolarimetry

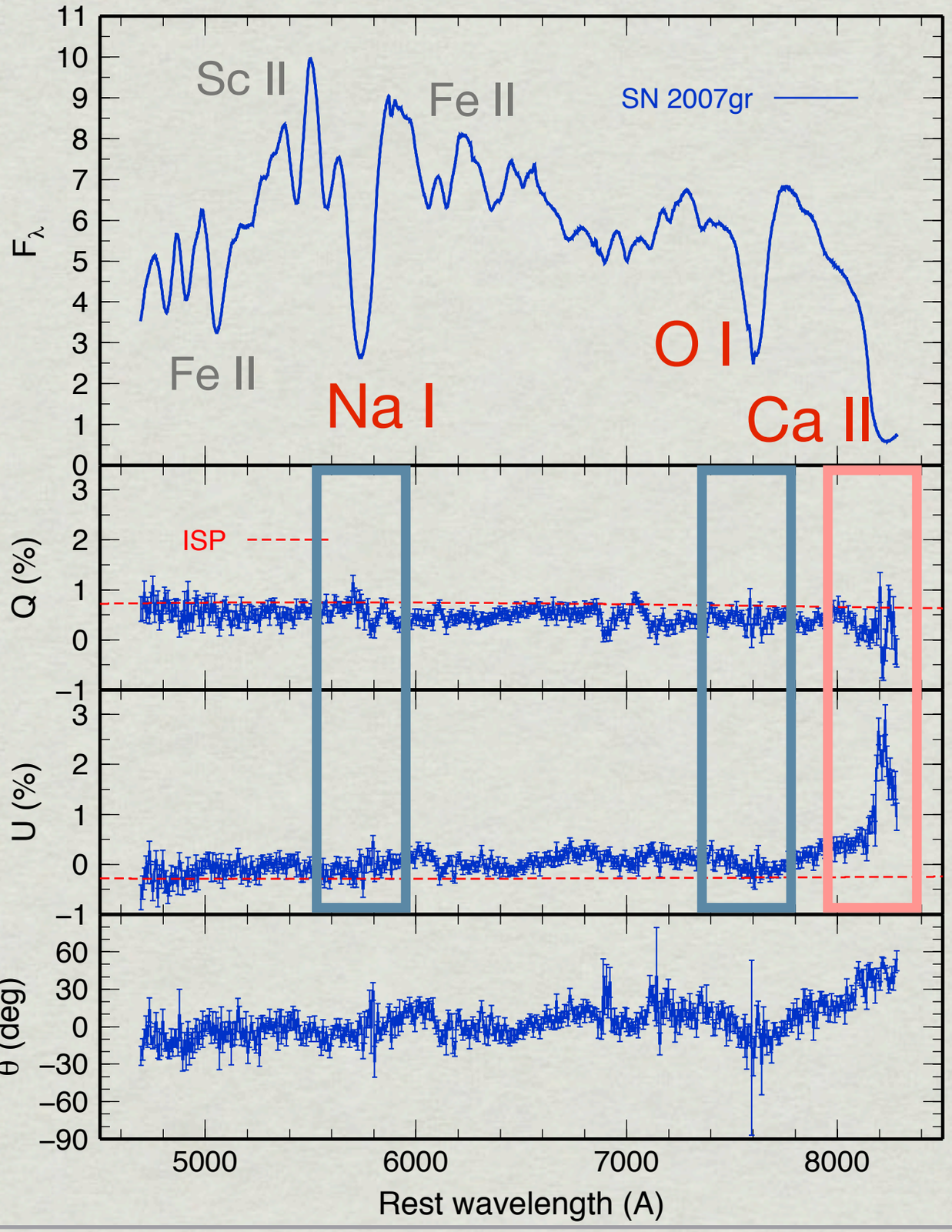
- Spectropolarimetry = “Photon-hungry” technique
  - Wavelength resolution (R~600), polarization accuracy (0.1%)
- SN = transient
  - Fading rate ~1-2mag/50 days

Time-critical Observation

- ***Need for ToO***
  < 30 days after the discovery
- Very small samples so far



Polarization Spectrum of SN 2007gr



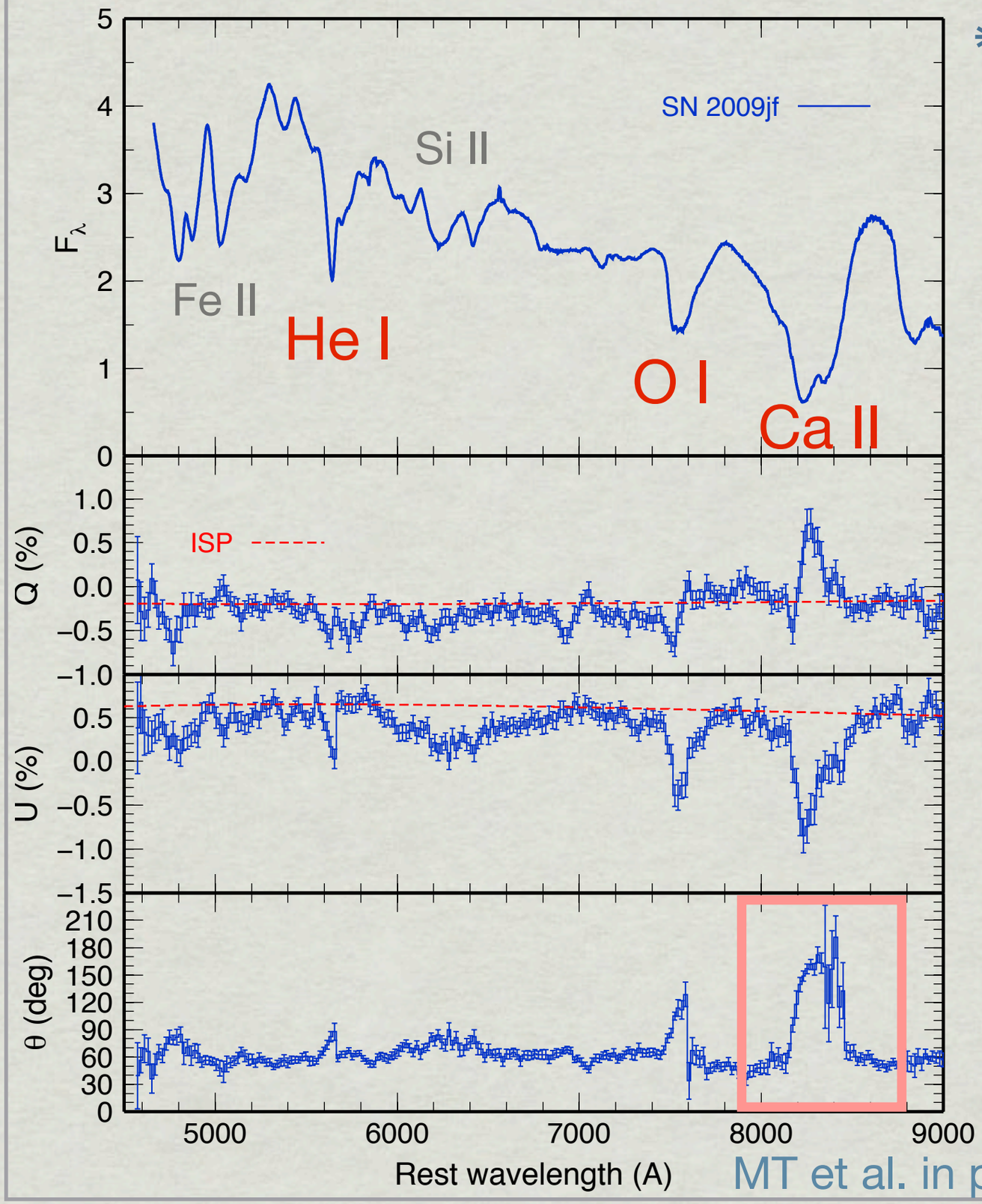
Q = ↕ -- ↔

U = ⤡ -- ⤢

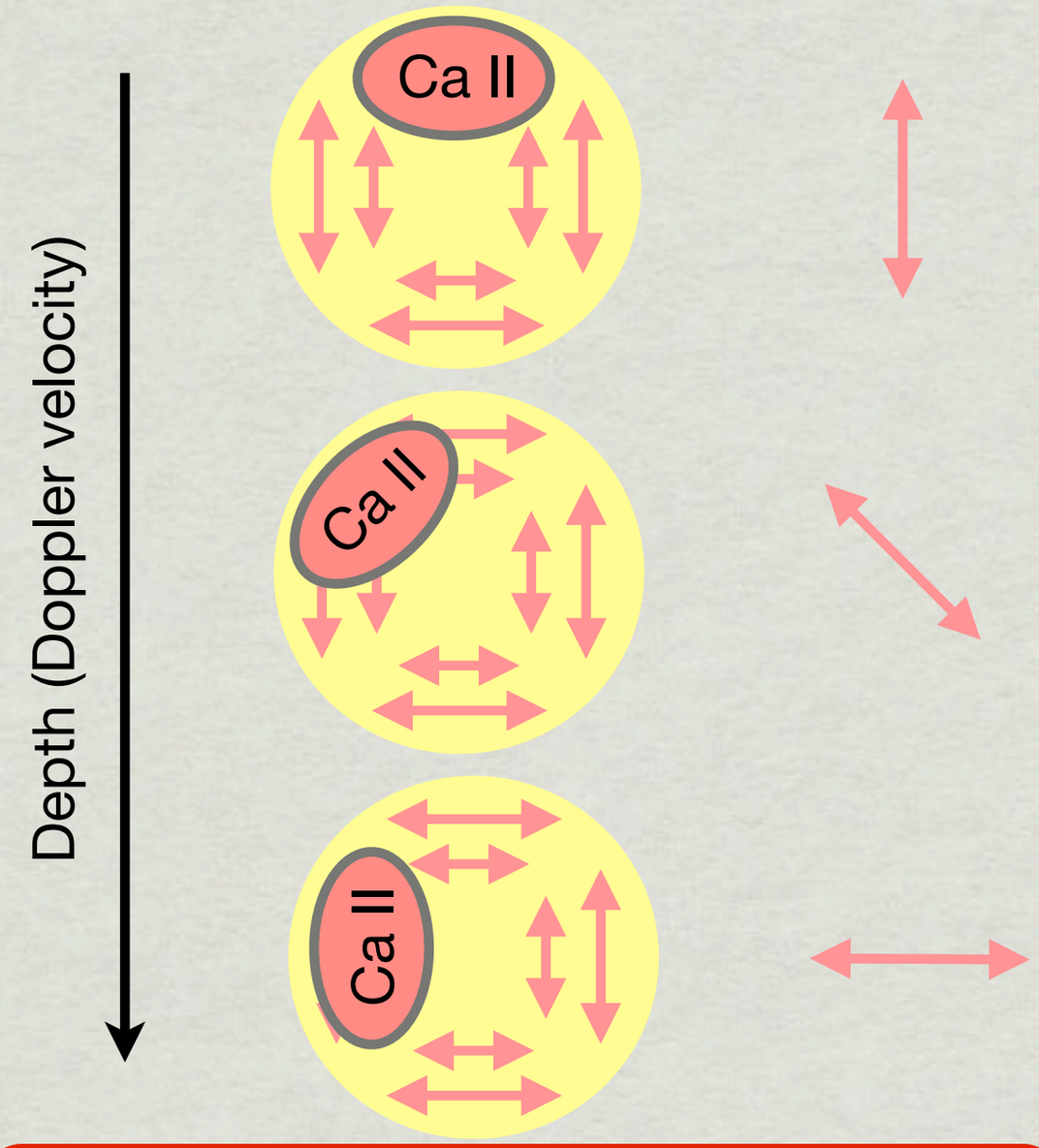
- Large polarization at Ca = ***Explosion is not spherically symmetric!***
- No polarization at O/Na = different distribution between Ca and O/Na

MT et al. 2008, ApJ, 689, 1191

Polarization Spectrum of SN 2009jf



- Rotation of the position angle



No "defined" symmetric axis in the element distribution

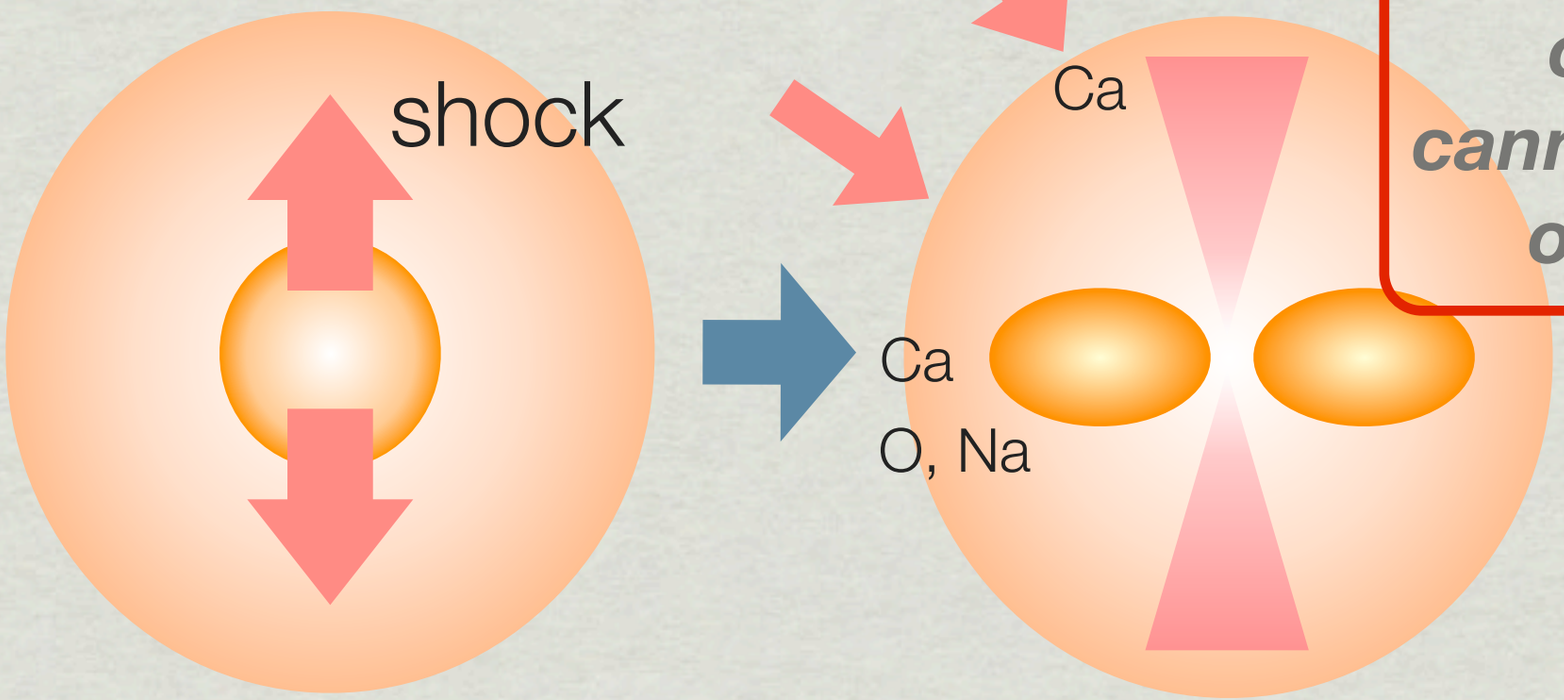
MT et al. in preparation

Element Distribution in Supernovae

- ***No SN shows completely zero polarization***
  - O I and Na I: Sometimes polarized
    (Pre-exist in the massive stars)
  - Ca II: Almost always polarized
    (Synthesized by the explosion + pre-exist)

→ ***Unified scenario?***

Example:
bipolar explosion



NOTE: Two-dimensional (axisymmetric) geometry is often assumed, but cannot explain the rotation of the position angle

Current Status and Future Prospects

- Subaru ToO program for SN spectropolarimetry
  (PI: MT, Co-I: K. Kawabata, T. Hattori, M. Yamanaka, K. Maeda, et al.)
  S09A (1 night ToO), S09B (2 nights ToO), S10A (2 nights ToO) --> 2 SNe so far
  - Doubling the number of high-quality samples in 2-3 yrs with Subaru
    --> ***Seeking a unified scenario*** (c.f. AGN) with >10 samples
  - +Quantitative study with 3D radiative transfer simulations
- Prospects for TMT spectropolarimetry (+ AO)
  - Distribution of ***all the elements in the SN spectrum***
    --> especially Fe
    (if <0.1% “relative” accuracy is achieved)
  - Explosion geometry of ***GRB***
    (gamma-ray burst) ***-associated SN***

Summary: How Massive Stars End Their Life?

- **Spectropolarimetry of SNe**
  - The unique method to extract the geometry
  - ***No SN shows completely zero polarization***
  - Line polarization --> Element distribution
    --> ***seeking a (simple) unified scenario***
  - But, two dimensional geometry is not perfect
- **Future prospects**
  - With higher polarization accuracy
    --> ***Complete study of element distributions***
  - With more photons --> ***Geometry of gamma-ray bursts***