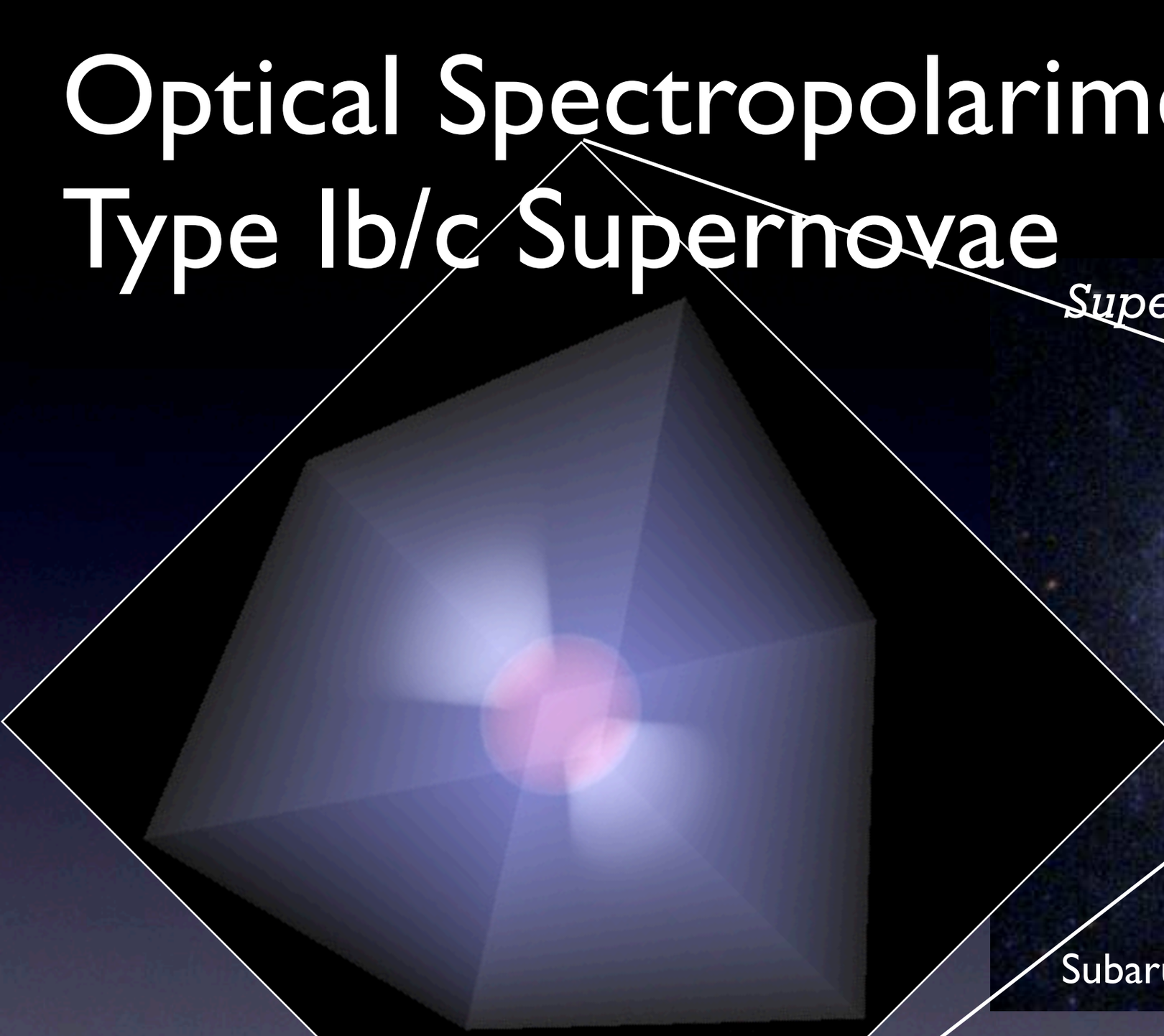
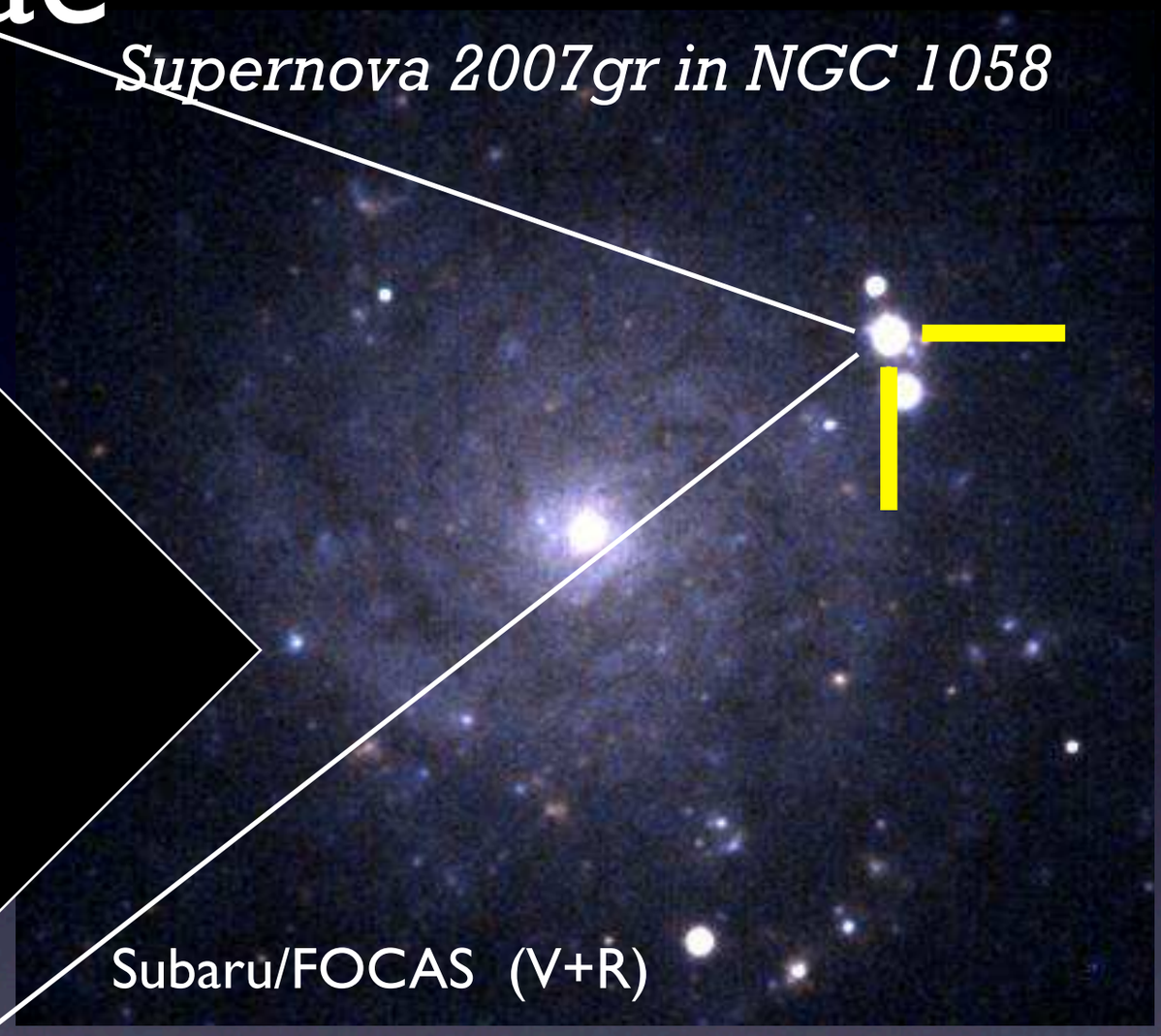
Optical Spectropolarimetry of Type Ib/c Supernovae





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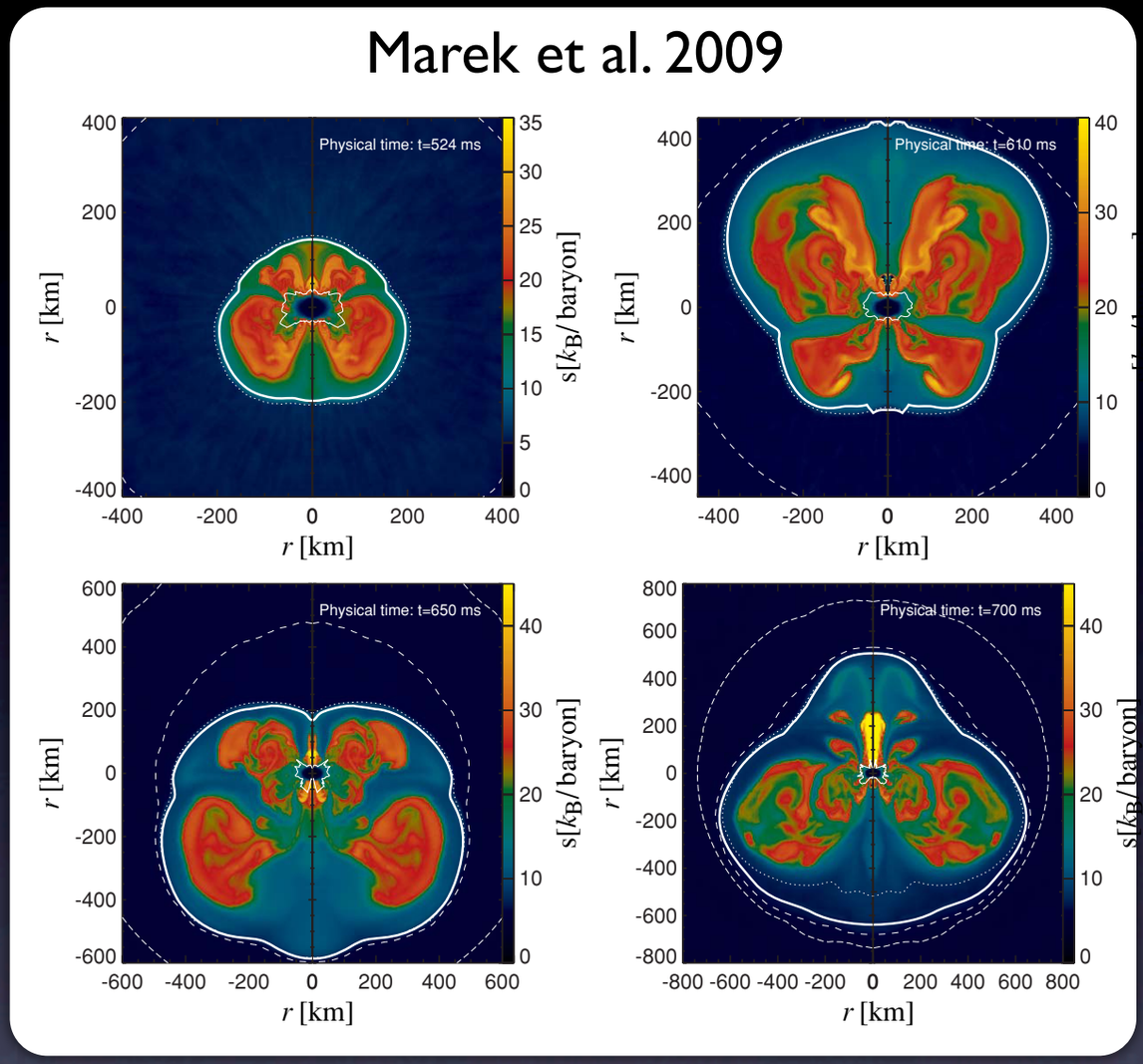
Explosion Geometry of SNe

- ***A key to the successful core-collapse SNe***
  - SASI
  - Convection + neutrino
  - Rotation + magnetic field
  - ...
- A diagnostic of binary companion (Kasen et al. 2004 for SNe Ia)

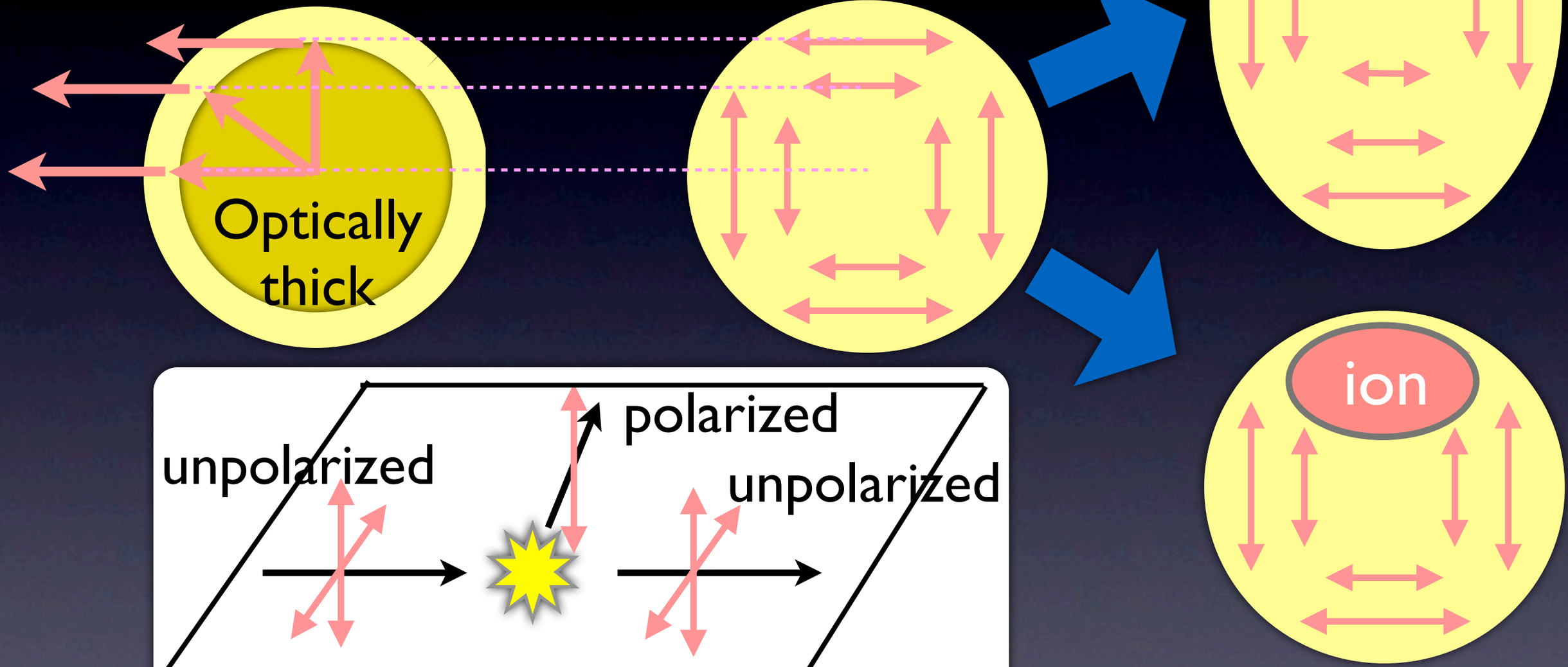


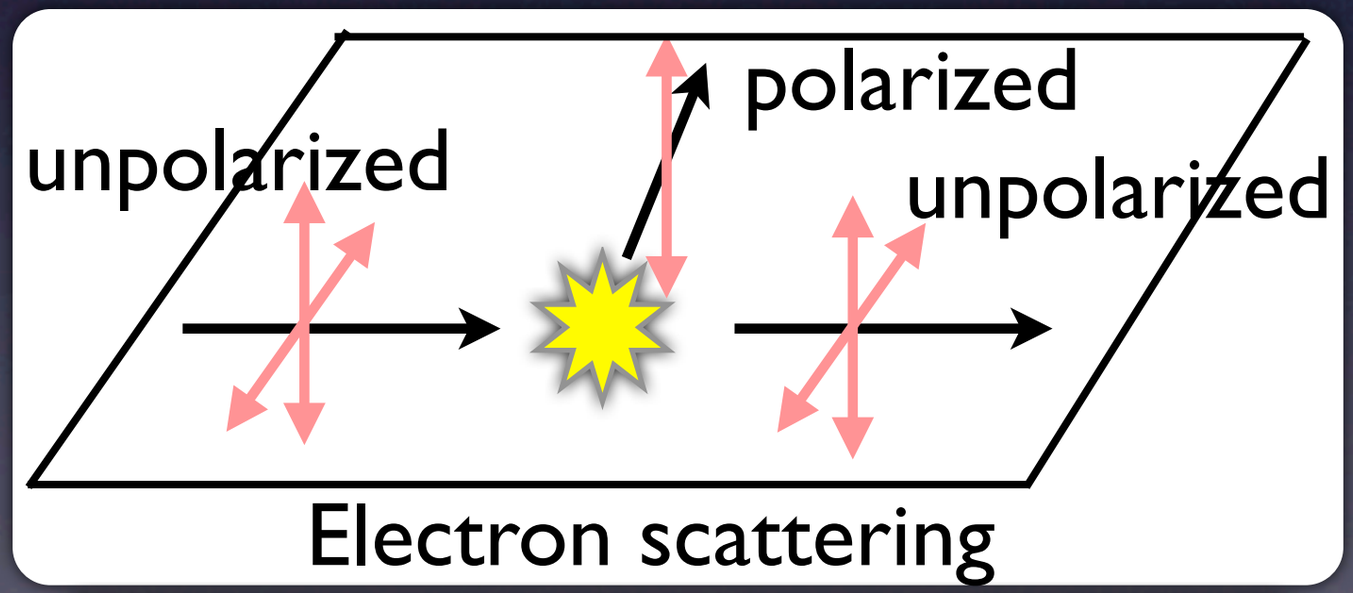
QUESTIONS;
Q1. Are core-collapse SNe really non-spherical?
Q2. If non-spherical, what geometry?

Power of Polarization

From the side

On the sky





The unique method to explore the "shape" of extragalactic SNe

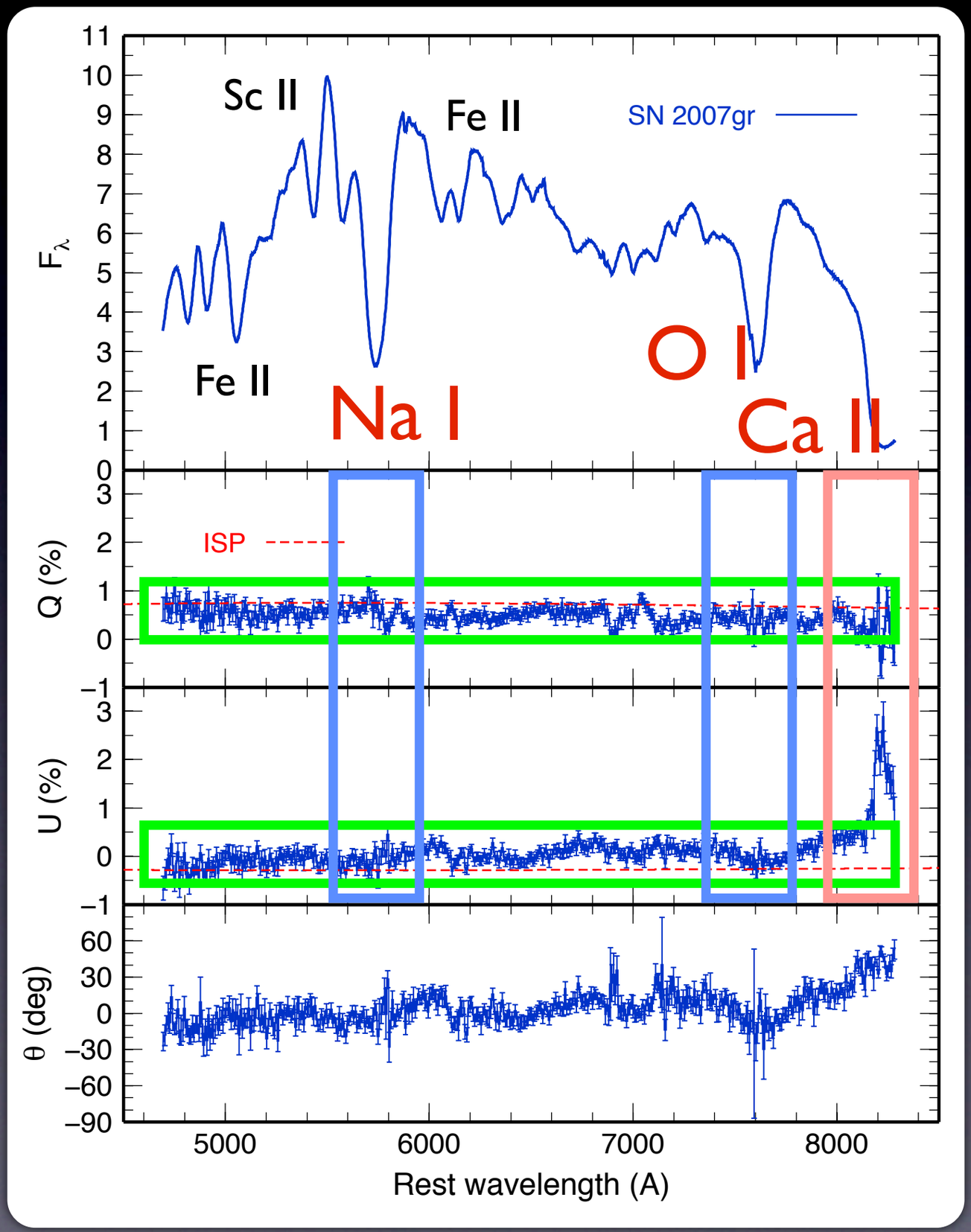
Shapiro & Thutherland 1982
Hoeflich 1991
Wang & Wheeler 2008

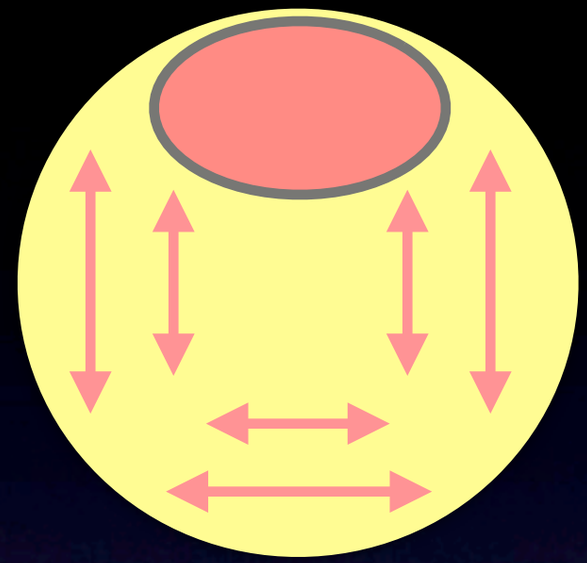
Strategy for SN Spectropolarimetry

- Spectropolarimetry = "Photon-hungry"
  - V <~ 17 mag with 8-10m telescopes (ΔP ~ 0.1%)

- ToO observations with Subaru (PI: MT)
- Follow-up observations with 1-2m telescopes (led by M. Yamanaka et al.)
- Target: Type Ib/c SNe
  - C+O core exposed
  - but very small samples so far (Wang & Wheeler 2008); SNe 2002ap (Ic, Kawabata+, Leonard+, Wang+), 2003gf (Ic, Leonard+), 2005bf (Ib peculiar, Maund+, Tanaka+), 2006aj (Ic broad, Maund+), 2008D (Ib, Maund+)

Polarization Spectrum of SN Ic 2007gr



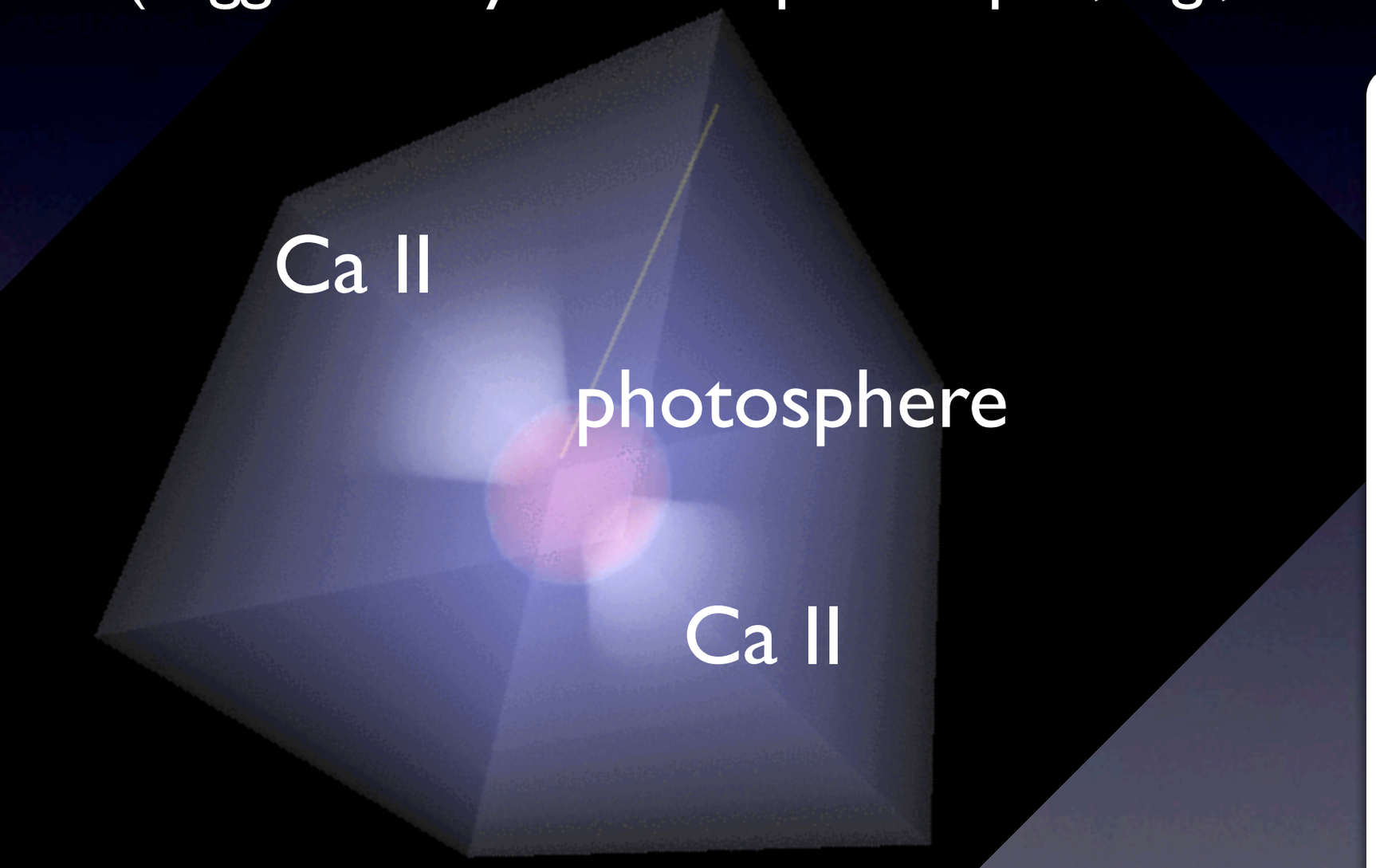


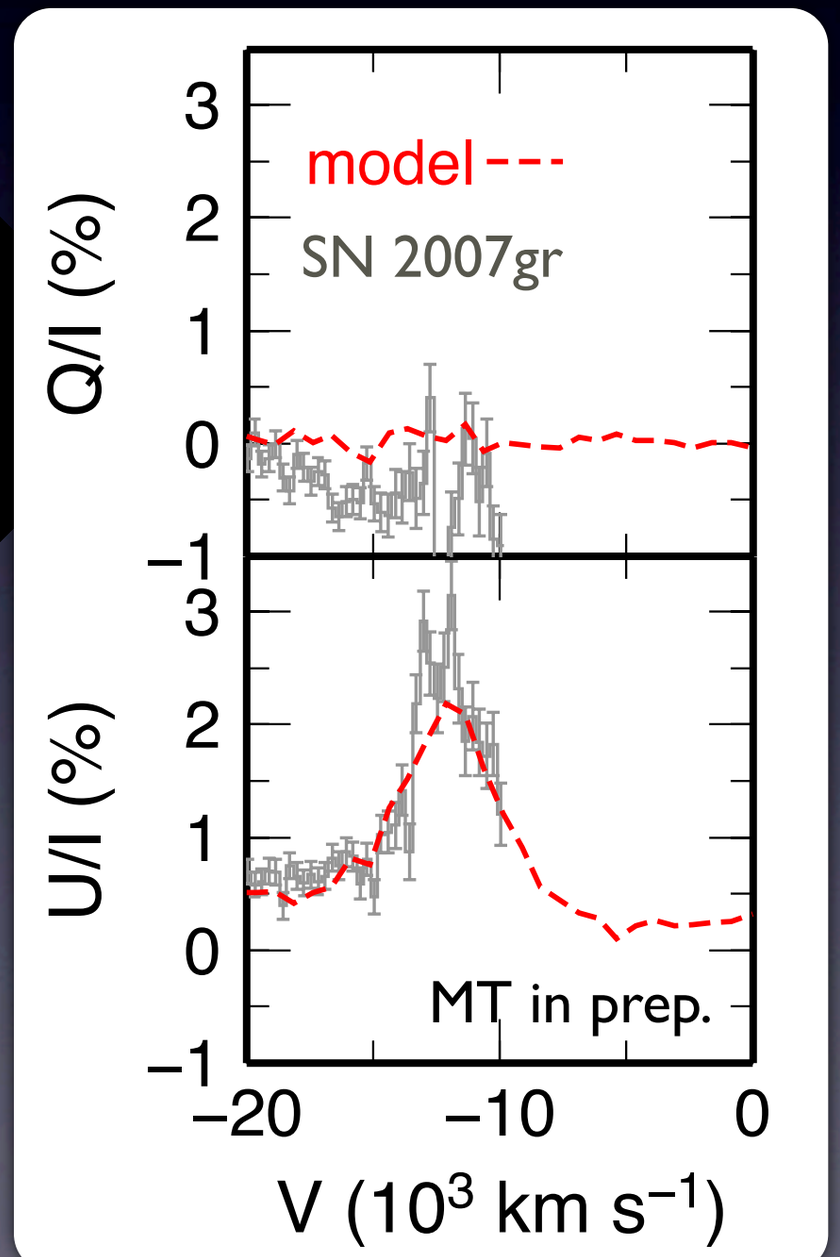
- Large polarization at Ca
- But no polarization at O/Na
  => different distribution between Ca and O/Na
- Continuum (interstellar polarization?)

MT et al. 2008, ApJ, 689, 1191

3D Monte-Carlo Polarization Transfer

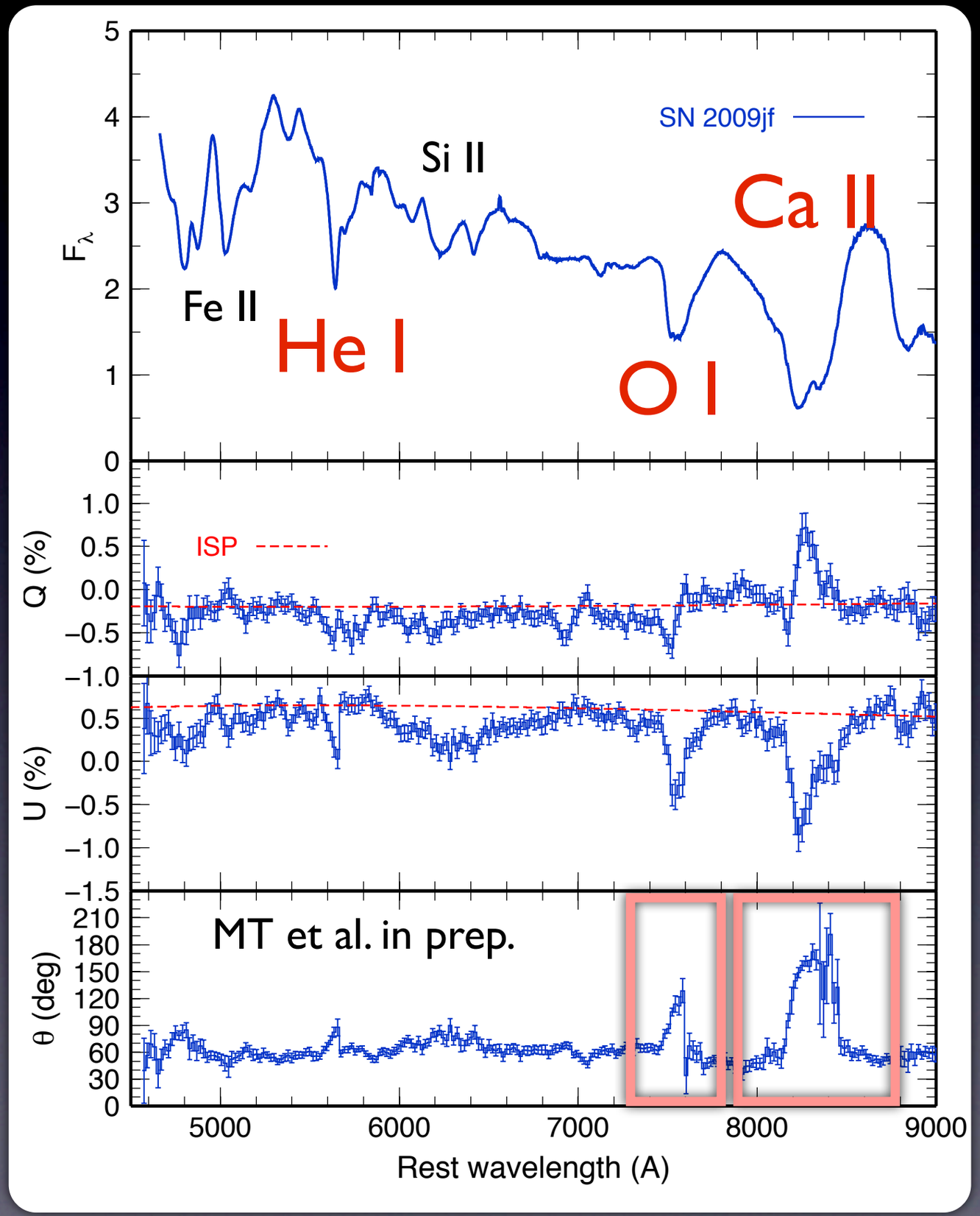
Bipolar explosion model
(suggested by nebular phase spec, e.g., Maeda+08)



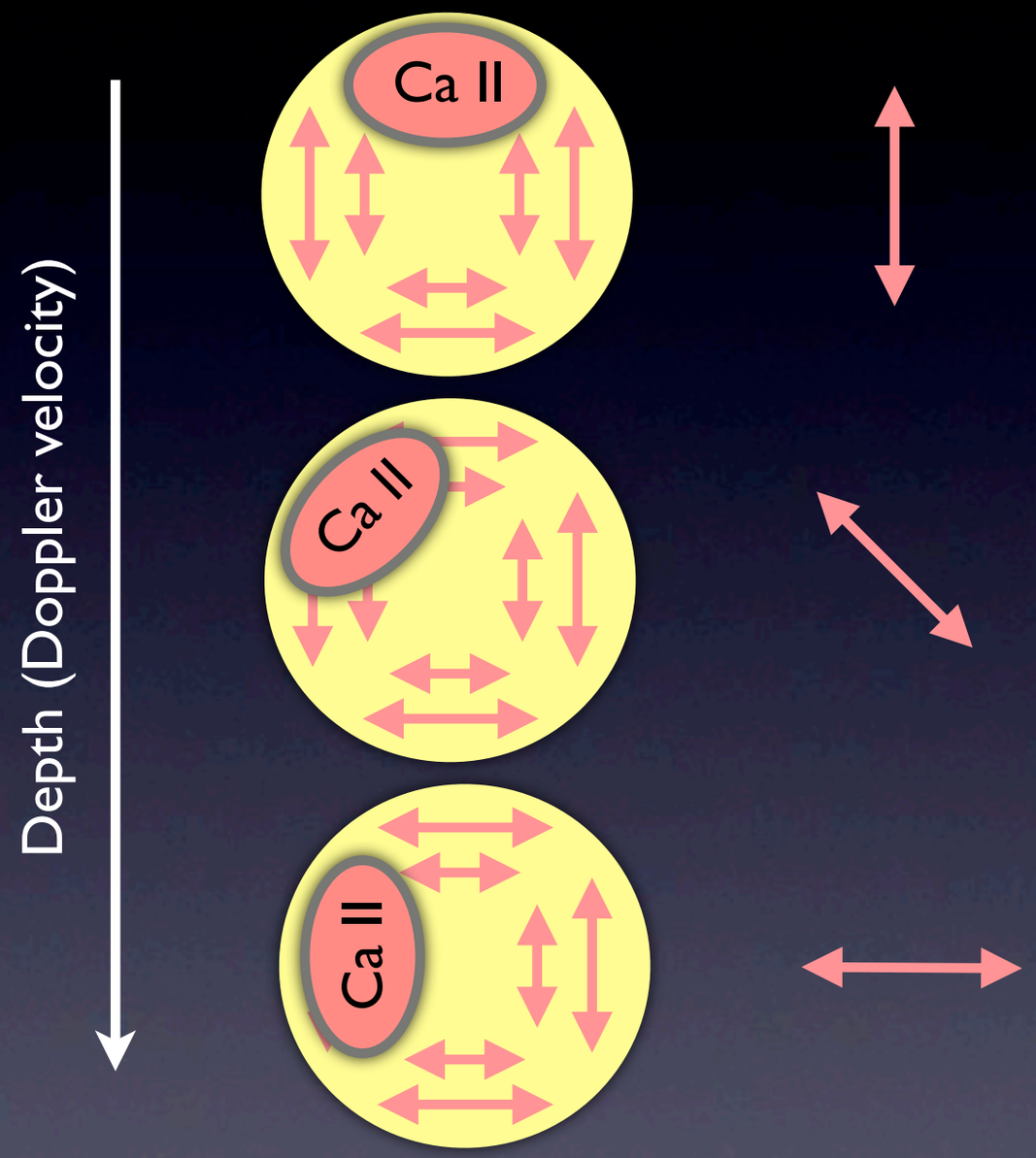


Bipolar geometry is successful (though not unique)

Polarization Spectrum of SN Ib 2009jf



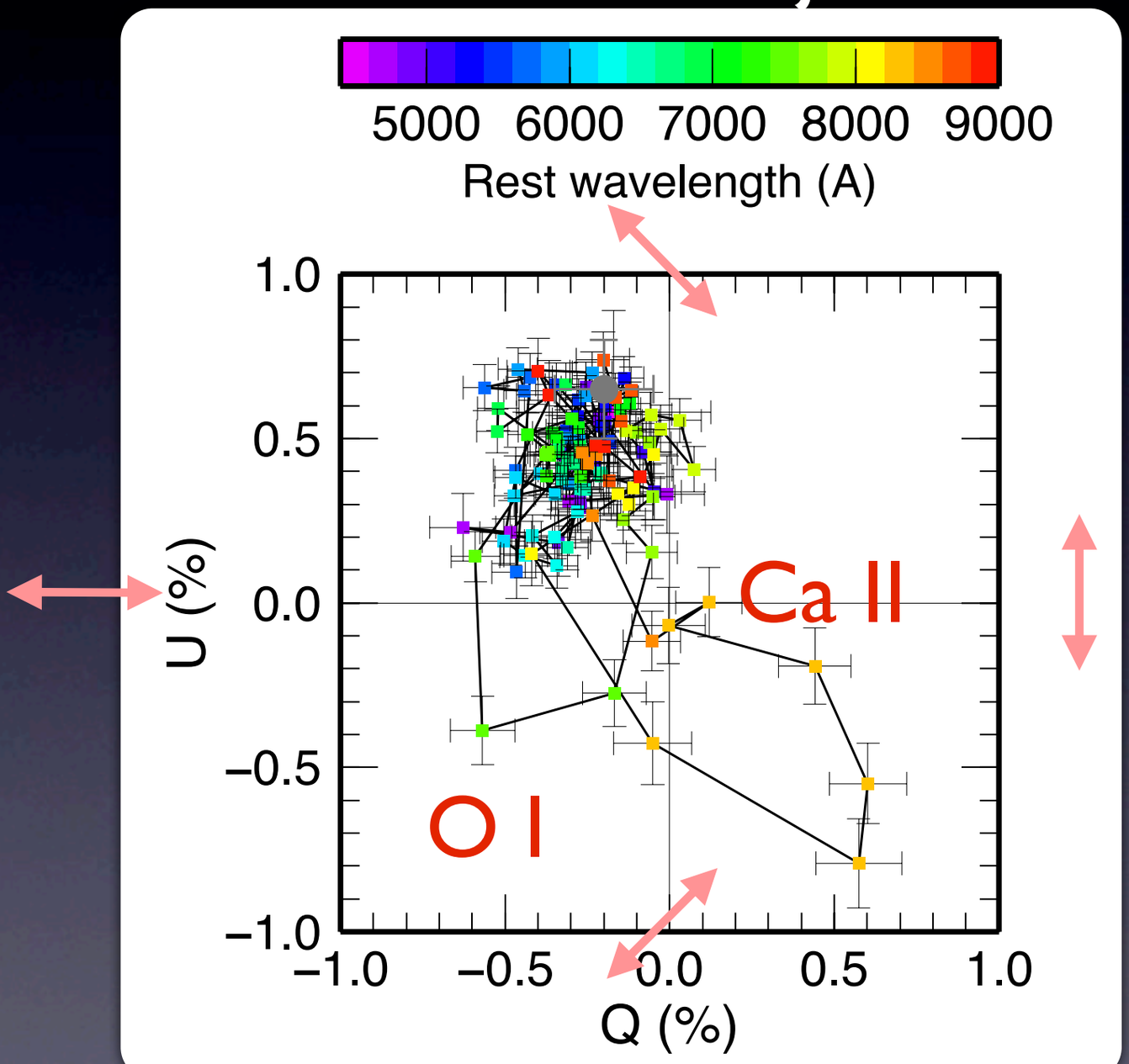
- Rotation of the position angle



No "defined" symmetric axis in the element distribution

Polarization Data in Q-U Plane

SN 2009jf



Q = ↕ -- ↔

U = ↘↙ -- ↗↖

- "loop" in Q-U plane (Common in SNe Ia)
- Cannot be explained by 2D geometry
- Ca II and O I do not share the distribution

e.g., Kawabata+02, Wang+03, Maund+07, 09

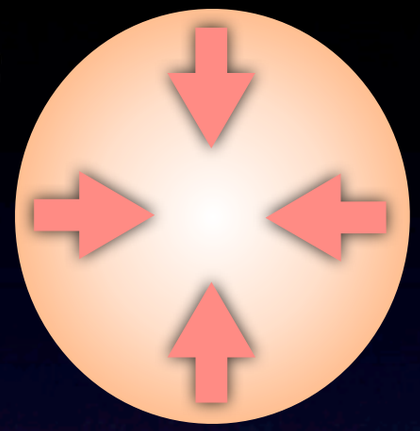
Polarization Properties of Type Ib/c SNe

Object	Type	Epoch	Quality	3D	Ref.
SN 2002ap	Ic broad	-6, -2, +1, +2, +3, +5, +26, +27, +29	Good	YES	Kawabata+02, Leonard +02, Wang+03
SN 2003gf	Ic	+5	?	?	Leonard+05
SN 2005bf	Ib	-6, +8	Good	YES	Maund+07, MT+09
SN 2006aj	Ic broad	9.6 (from XRF)	Marginal	x	Maund+07
SN 2007gr	Ic	+21	Good	x (edge of spec.)	MT+08
SN 2008D	Ib	+3, +18	Good	YES	Maund+09
SN 2009jf	Ib	~25 (from disc.)	Good	YES	MT+ in prep.
SN 2009mi	Ic	+20	Good	YES	MT+ in prep.

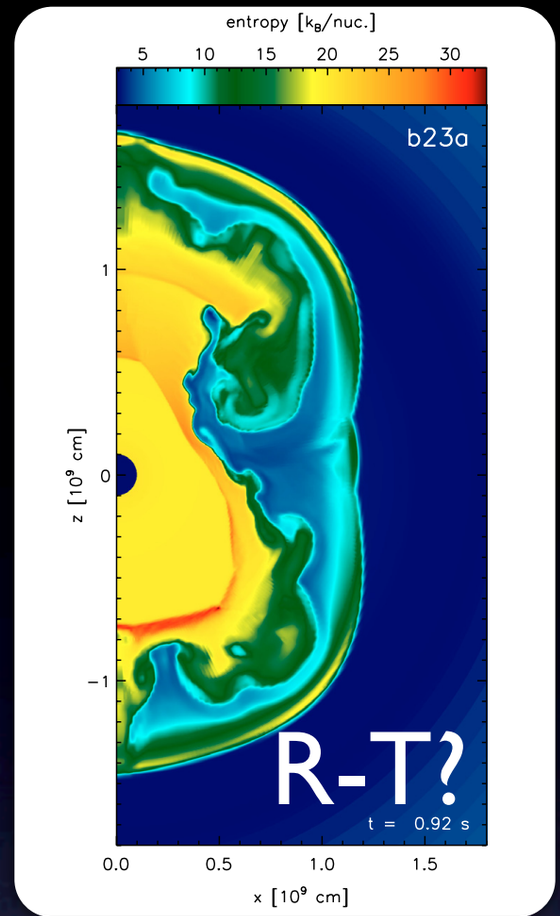
3D Geometry is Common!!

Spherical or axisymmetric collapse

?



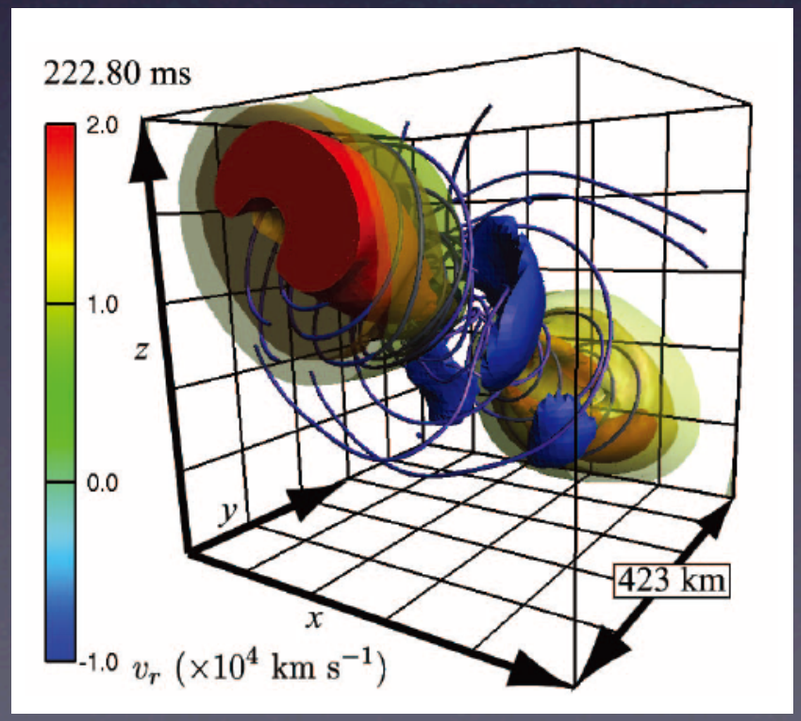
3D explosion



Kifonidis et al. 2006

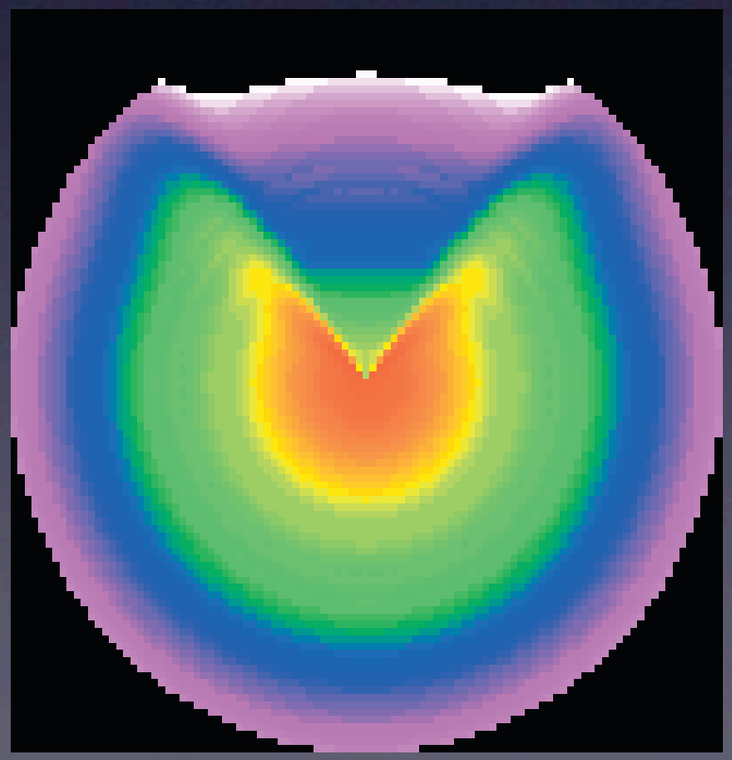
Two-axes?

(e.g., rotation, magnetic)



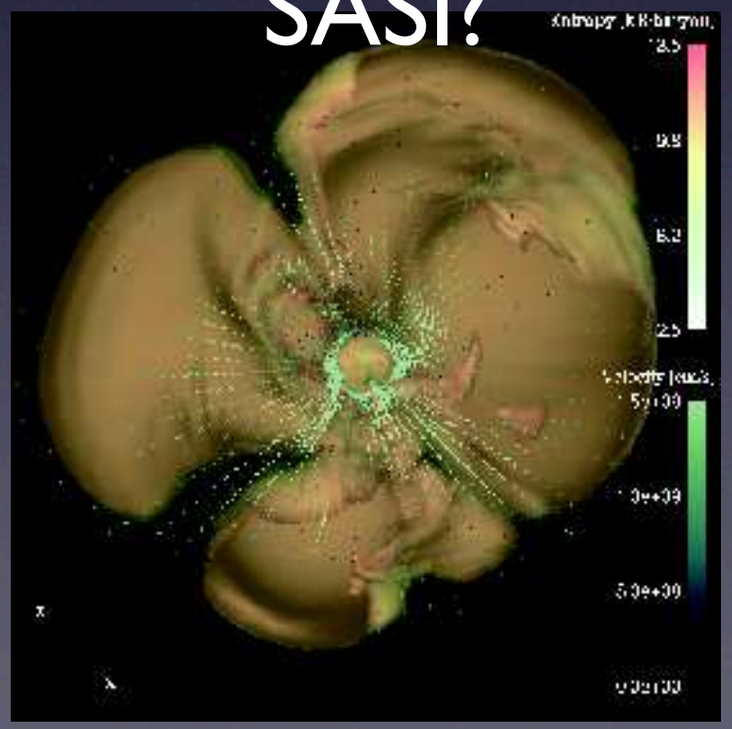
Mikami et al. 2008

Binary interaction?



Kasen et al. 2004 for SNe Ia

SASI?



Iwakami et al. 2008

Summary

- ***Spectropolarimetry of Type Ib/c SNe with Subaru***
- ***A1. <u>Core-collapse SNe are not spherical</u>***
  (c.f. late-phase spectroscopy)
- ***A2. <u>what geometry?</u>***
  - Axisymmetric, bipolar geometry (+disk) can explain only a part of observational properties
  - Loop in Q-U plane is commonly seen in Type Ib/c SNe
    => 3D explosion is common
  - ***<u>What is the origin?</u>*** -- two-axes? clumpy? binary?
    Accumulating high-quality data
    (3 Type Ib/c SNe from 2007, 6 ToO triggers with Subaru)
    + Analysis with the 3D transfer code