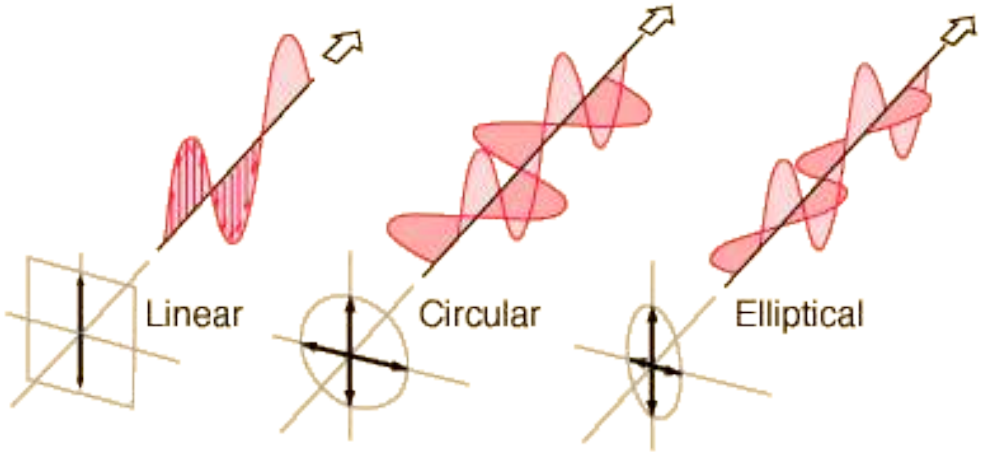
Polarimetry and Geometry of Supernovae

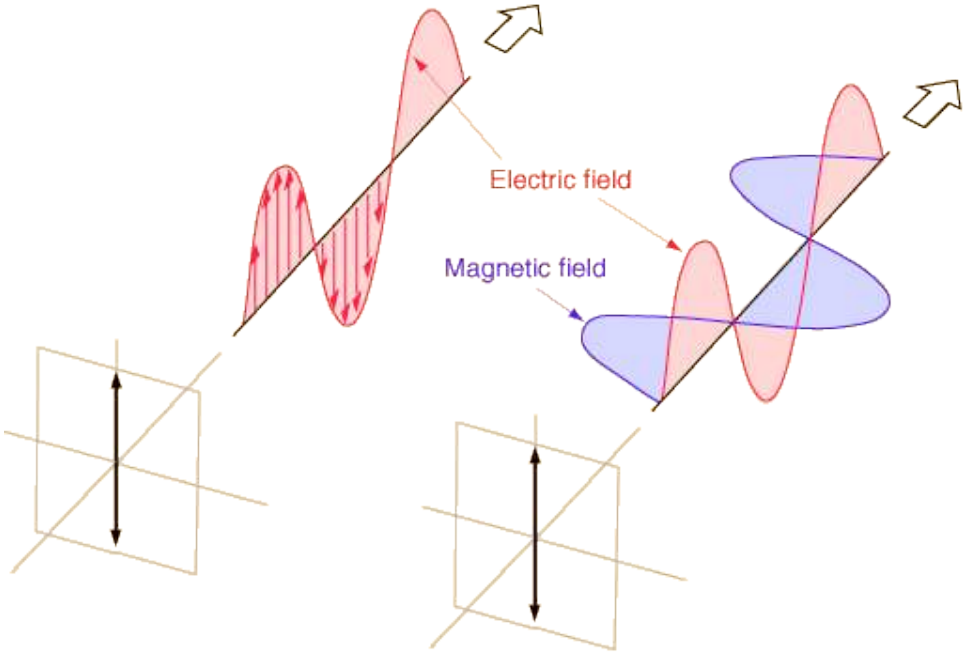
Lifan Wang

Texas A&M University

Focus Week on Messengers of Supernova Explosion
2008, 11, 19

What is Polarization?



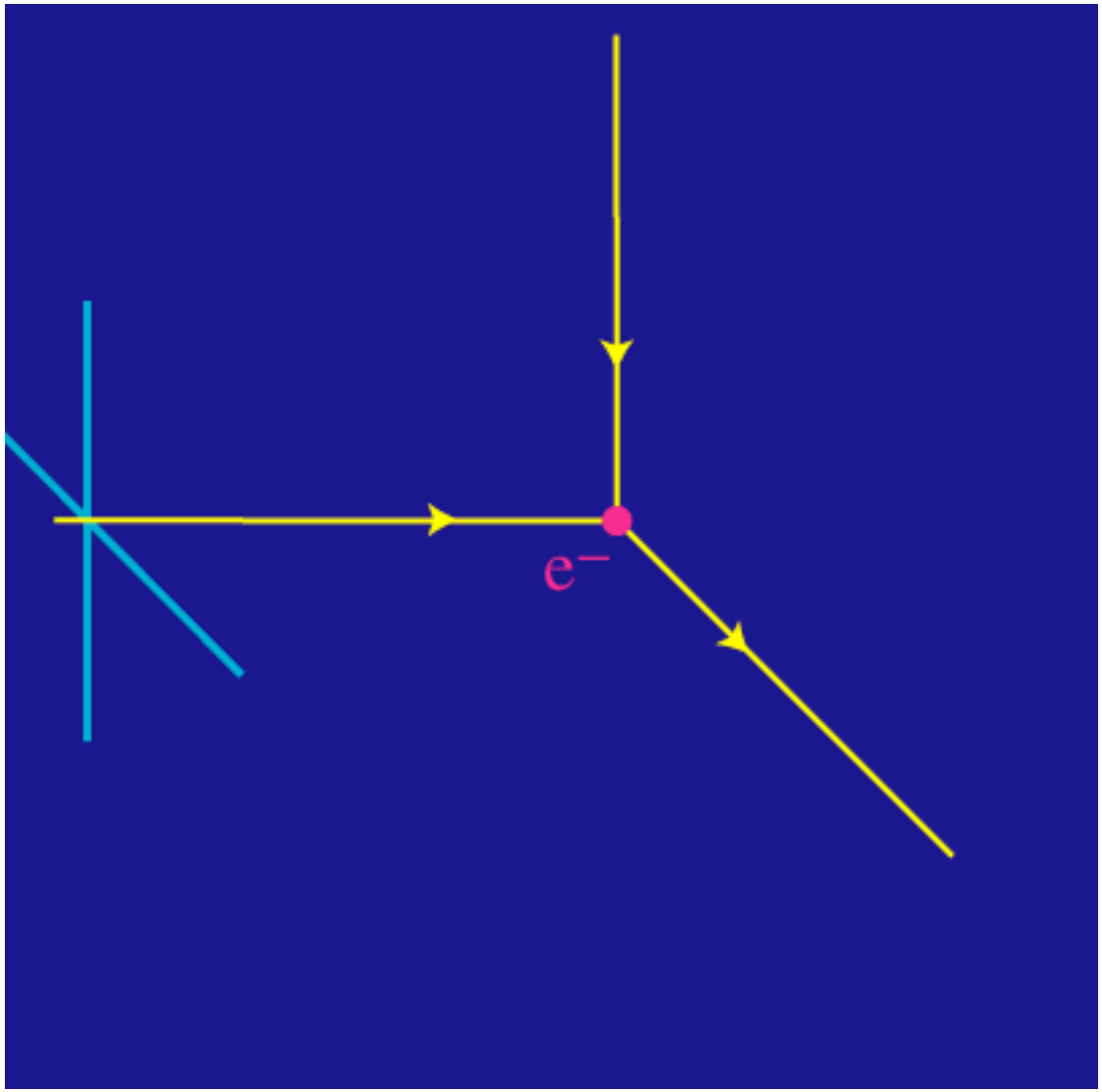


Astronomical Photometer

- Direction of Incoming Beam
- Photon Counts
- Spins?

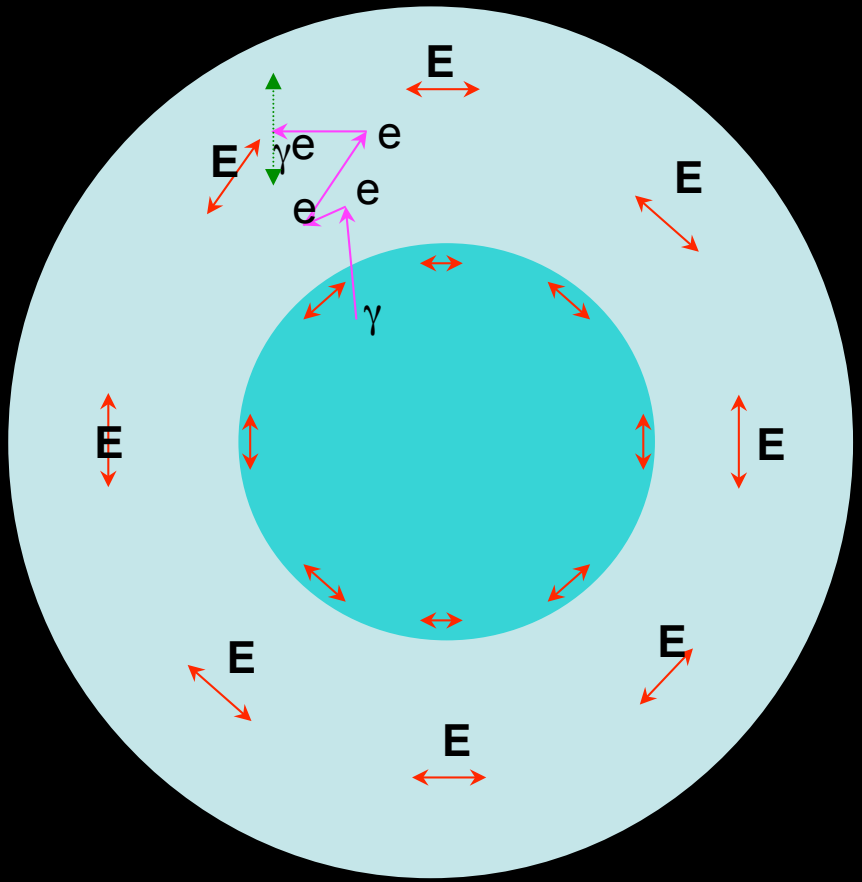
Whenever a photon is absorbed by an object, an angular momentum of either $+h/2\pi$ or $-h/2\pi$ is imparted to the object. Each photon "in transit" may be considered to possess, in addition to its phase, a certain propensity to exhibit each of the two possible states of spin when it interacts with an object, and a beam of light can be characterized by the spin propensities (polarization) and phase relations of its constituent photons.

Light Scattering



Random walk in the debris

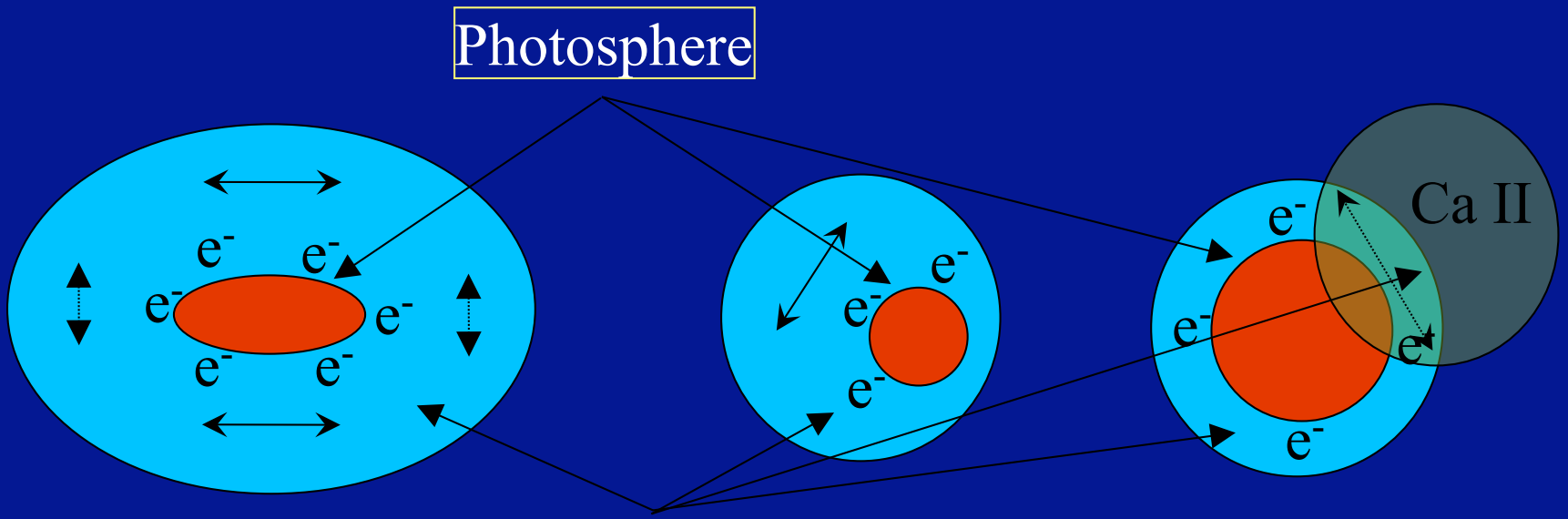
Photospheric Origin of Polarization



Polarized flux is generated by electron scattering

For spherically symmetric geometry, the integrated **polarized flux** is equal to zero

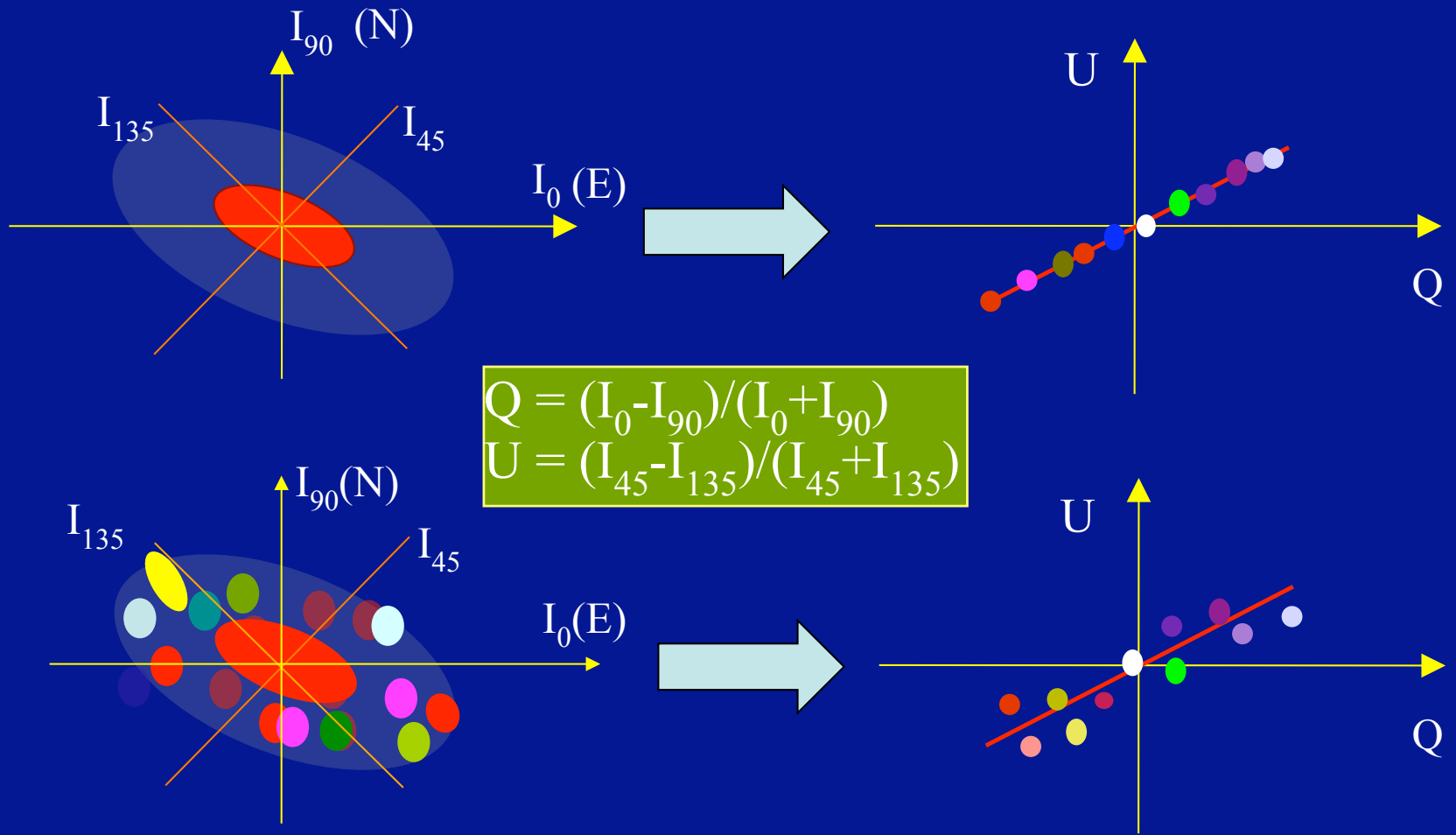
Asymmetry Creates Polarization

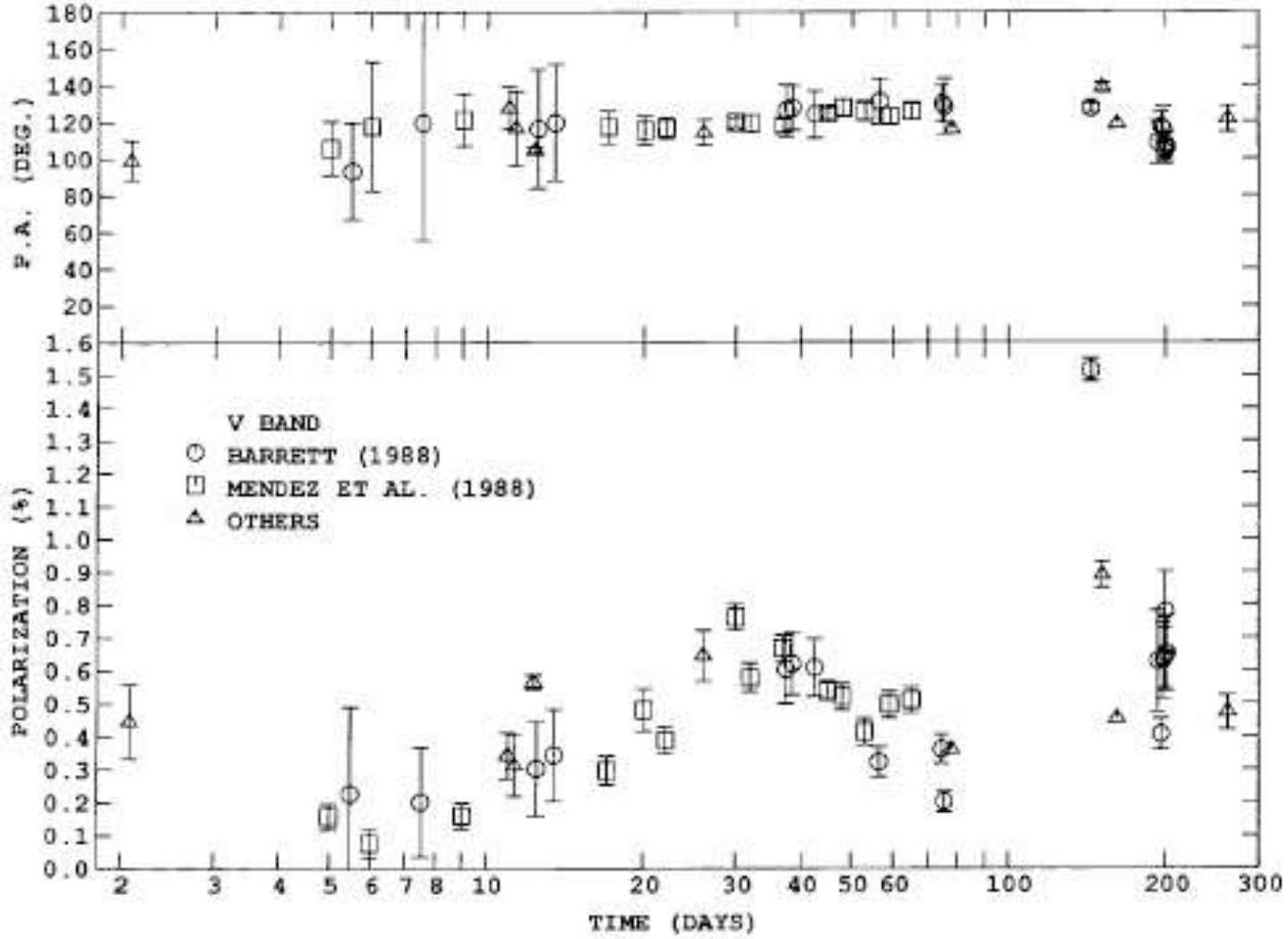


Distorted Photosphere leads to continuum/line Polarization

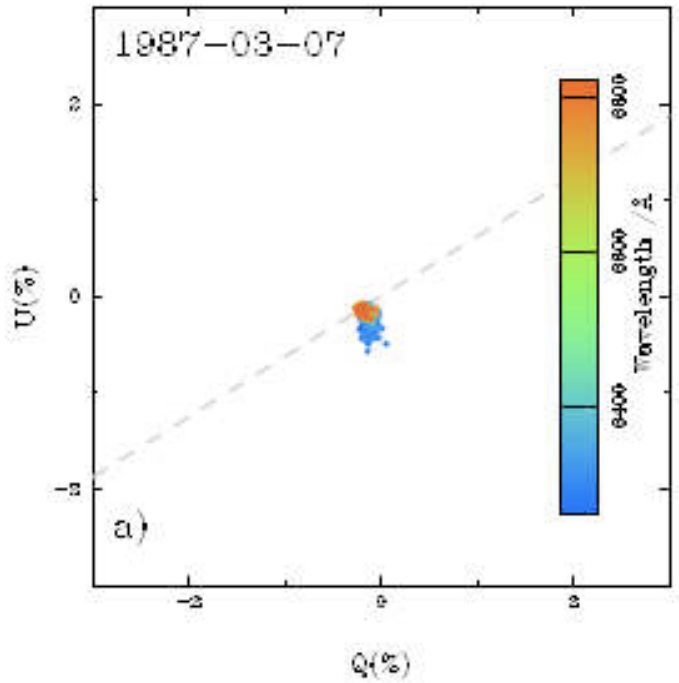
Spherical Photosphere leads to spectral line polarization only

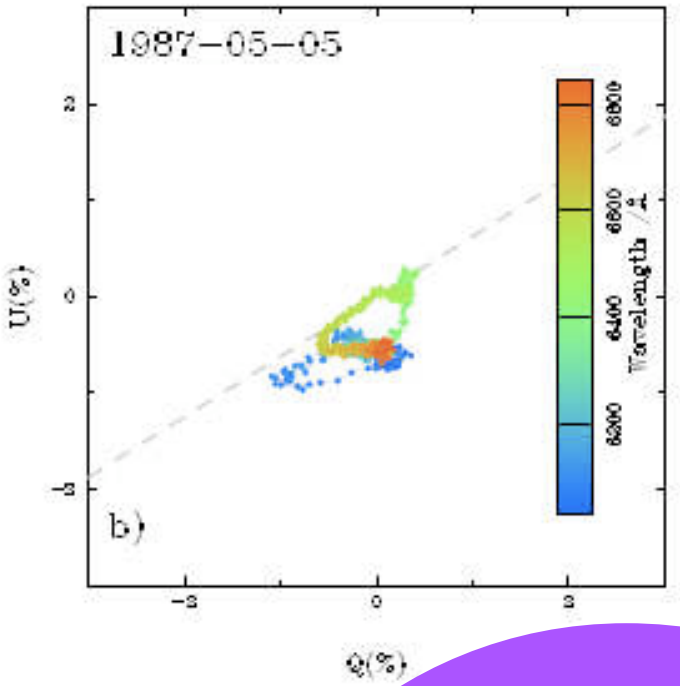
The Concept of Dominant Axis



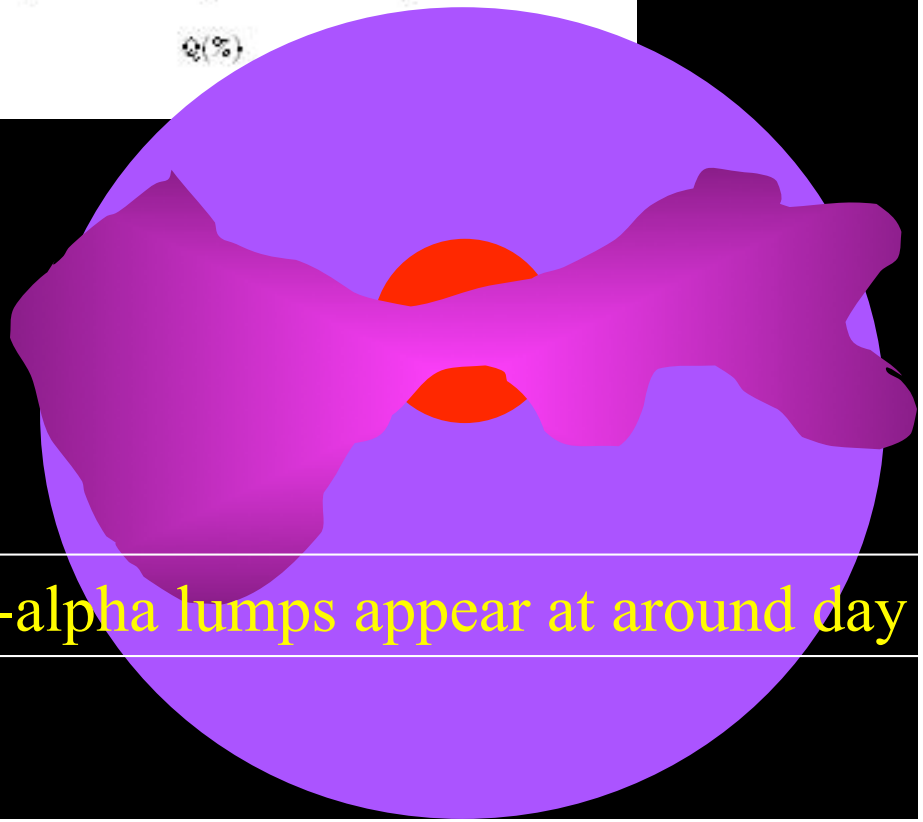


SN 1987A; Jeffery 1991

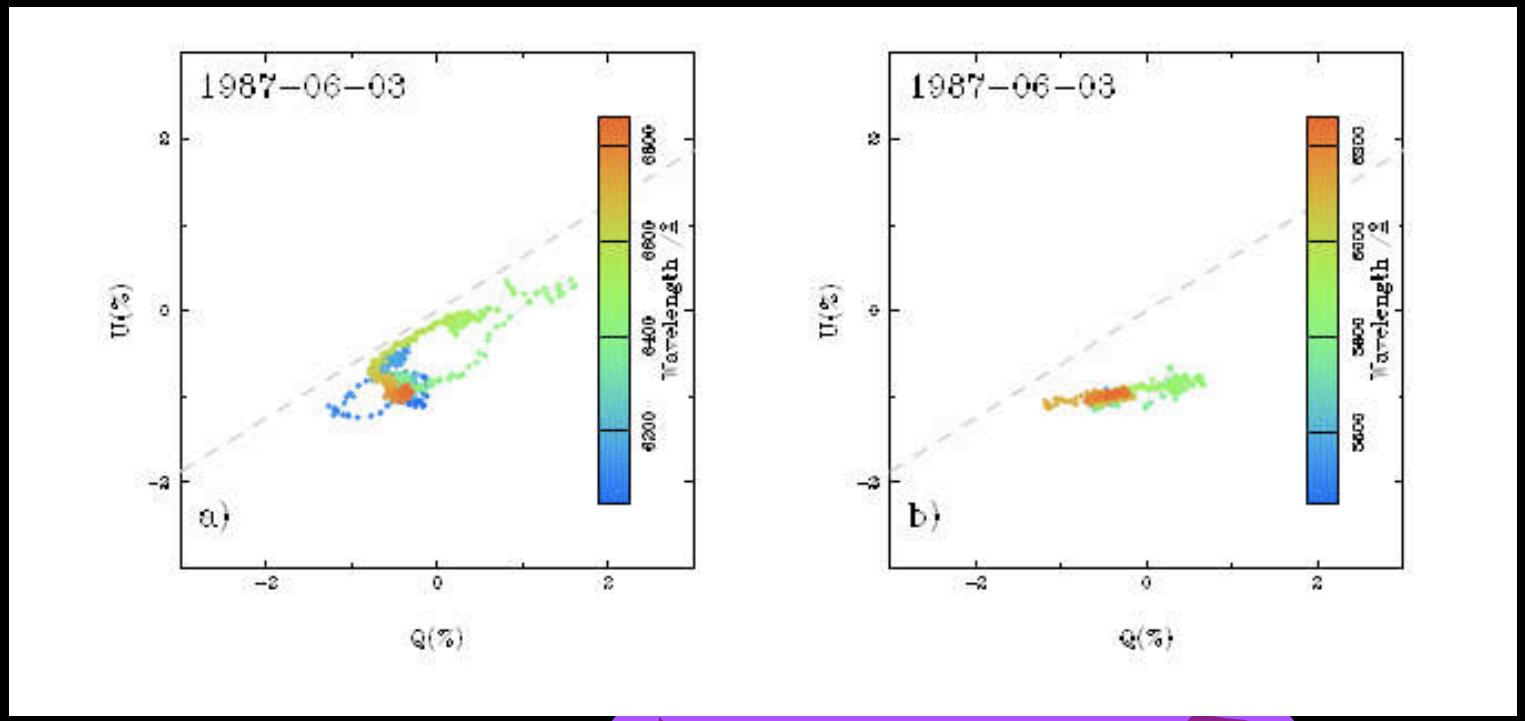


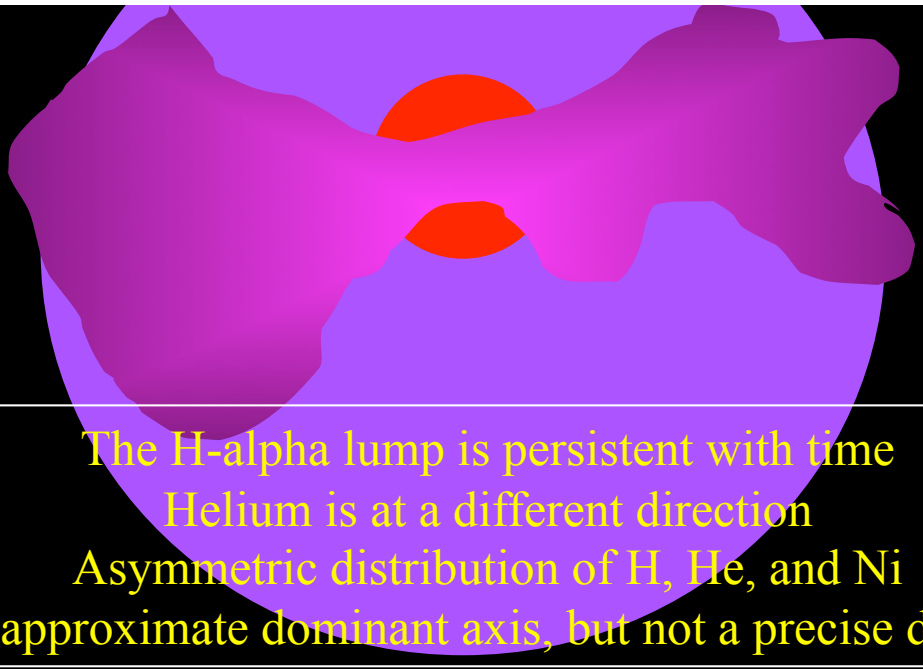


SH 1987A

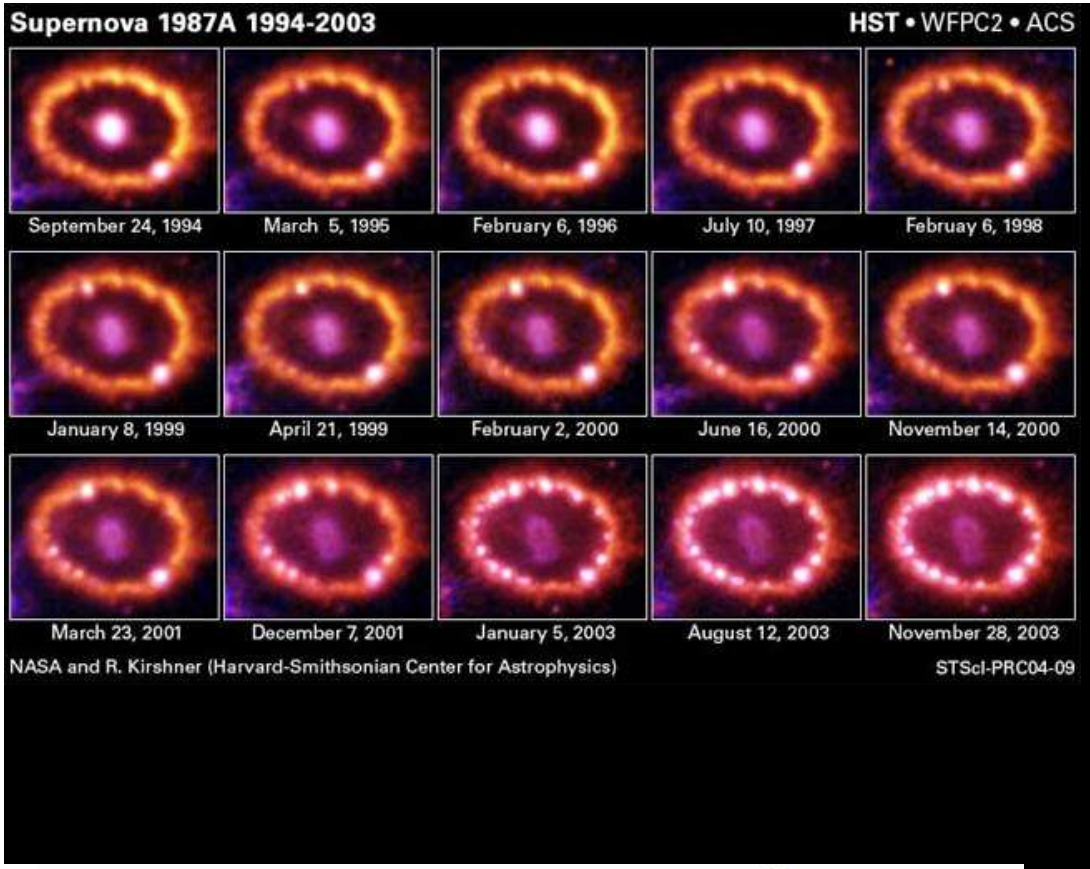


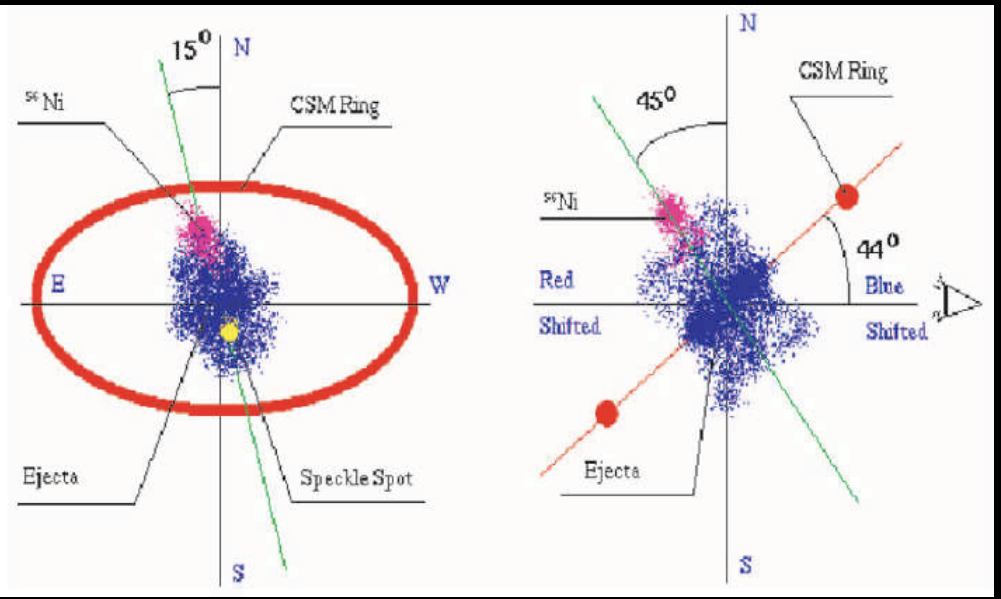
H-alpha lumps appear at around day 100

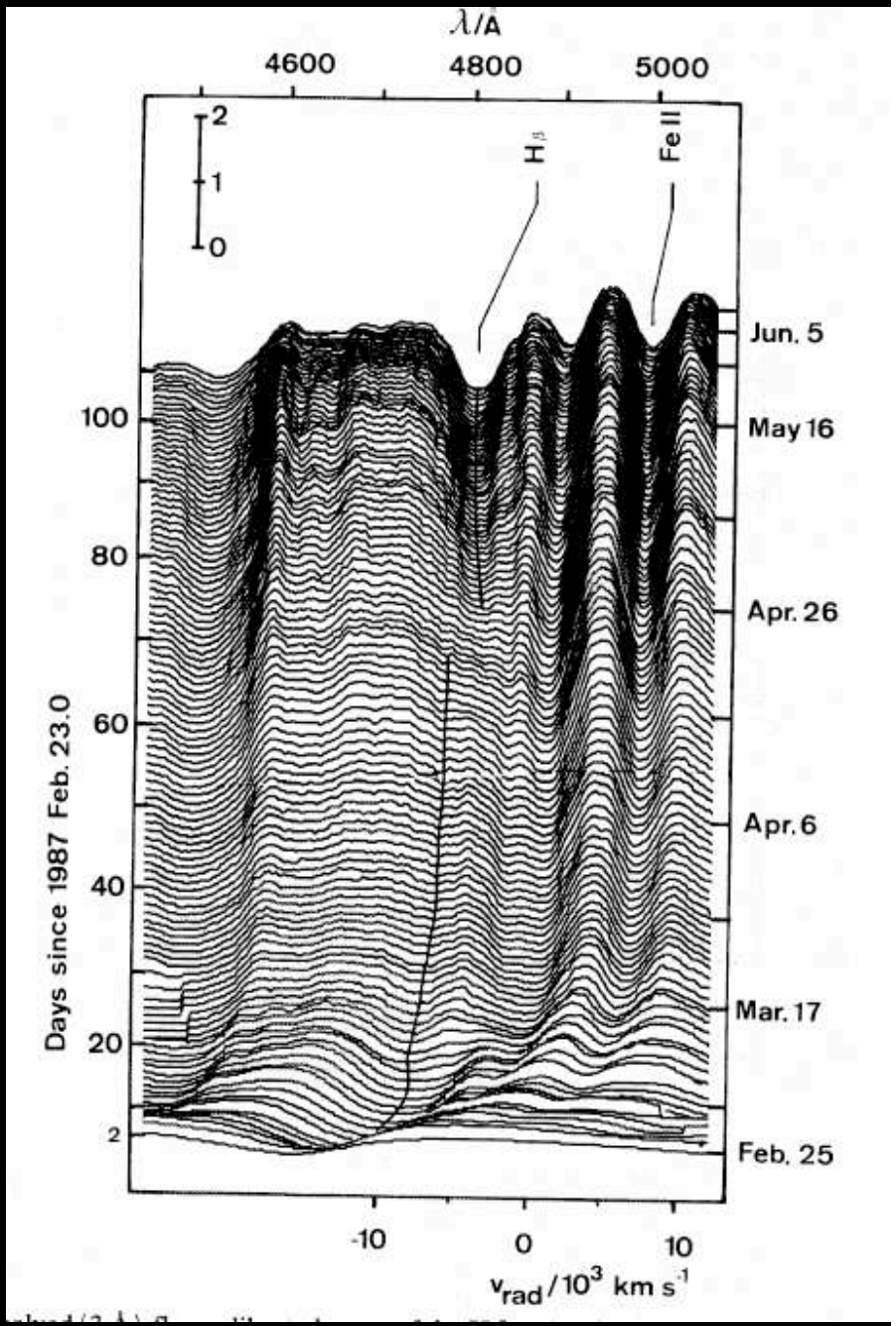




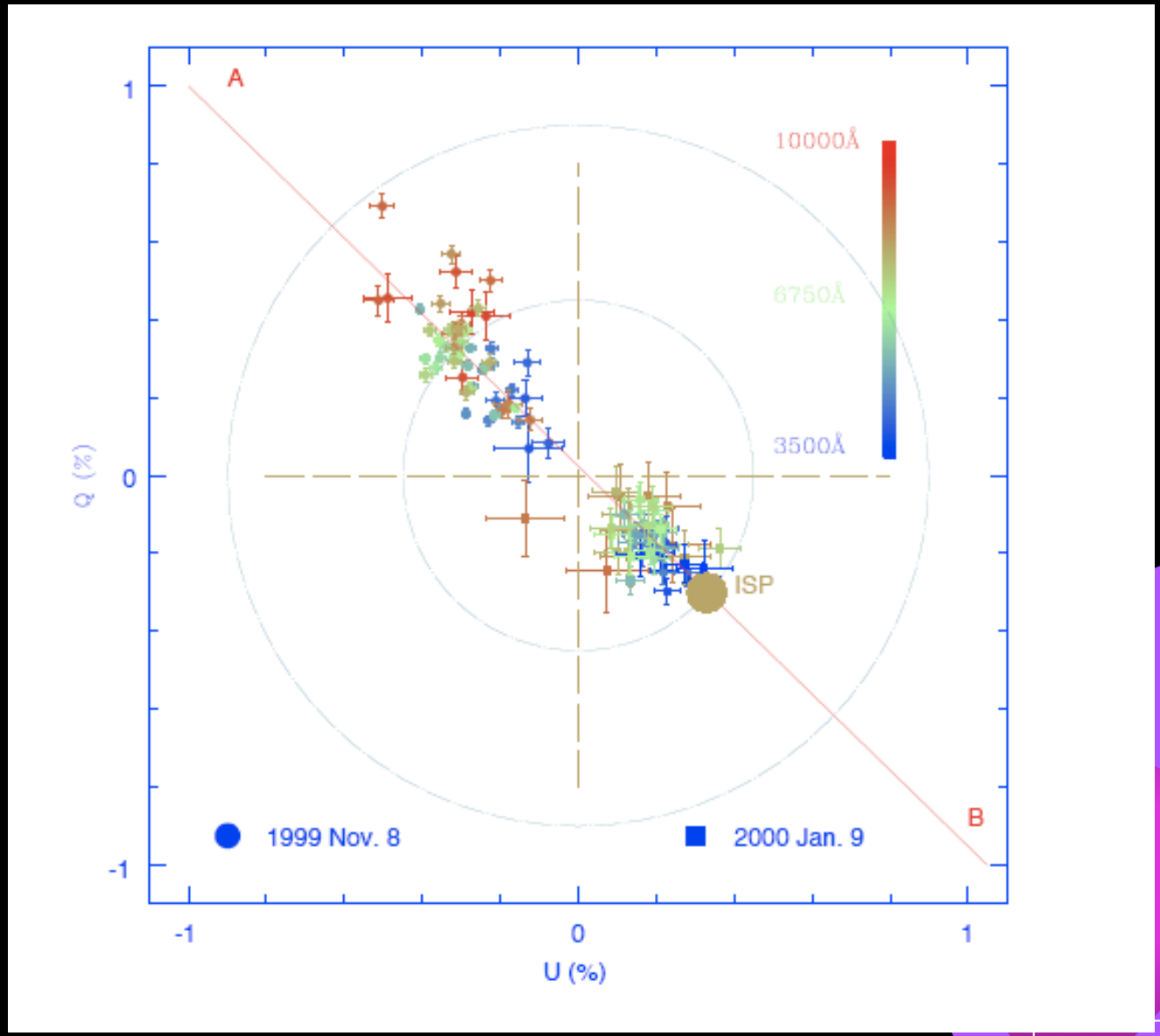
The H-alpha lump is persistent with time
Helium is at a different direction
Asymmetric distribution of H, He, and Ni
Follow an approximate dominant axis, but not a precise dominant axis

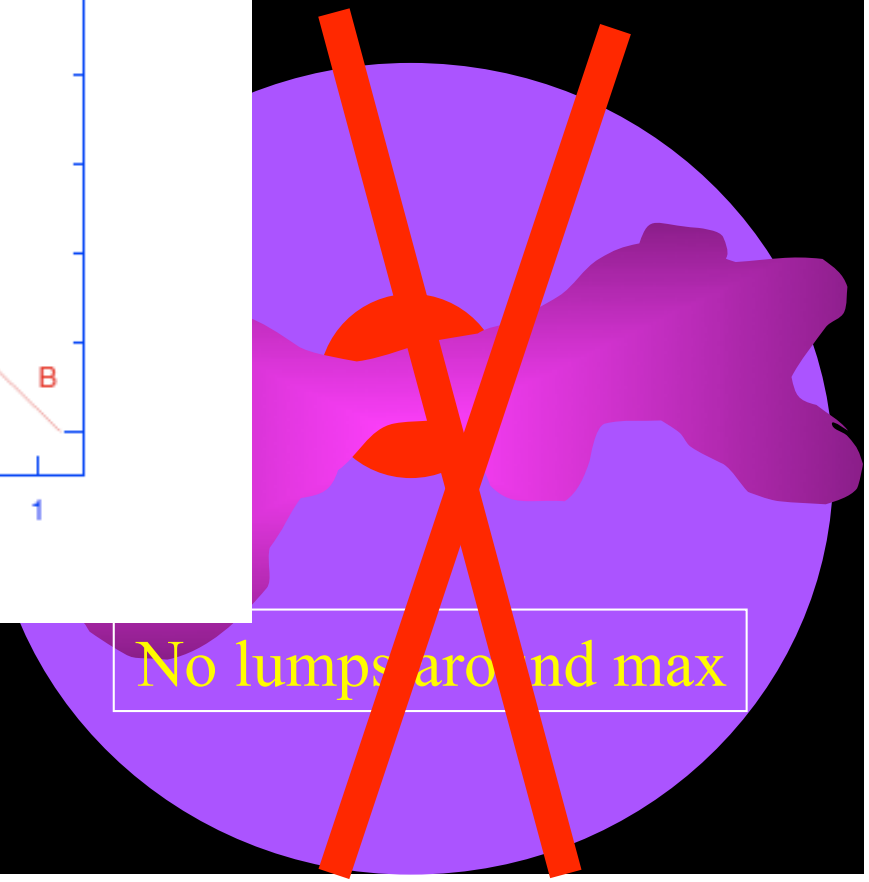






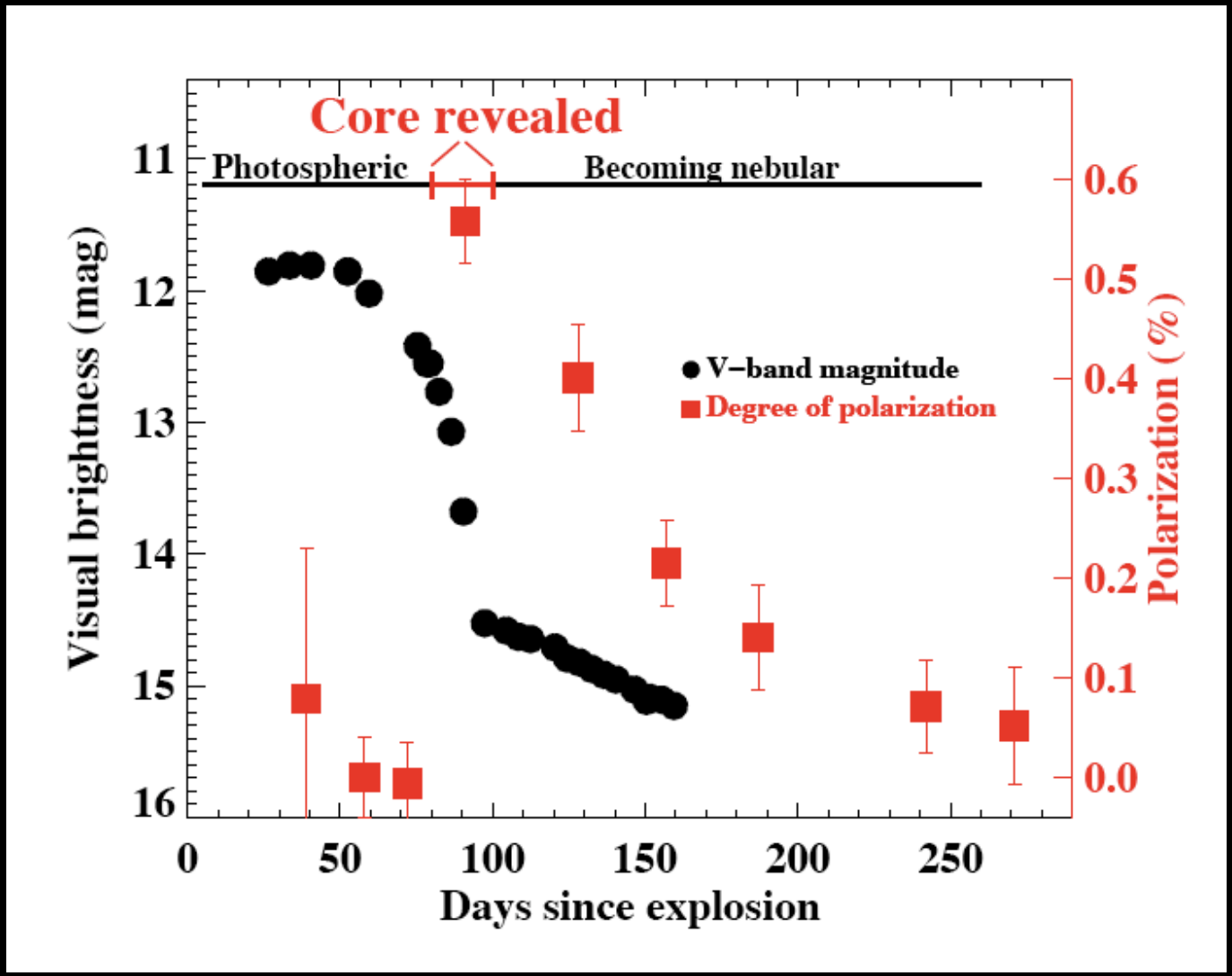
Hanuschik & Schmidt 1989


A
B
10000Å
6750Å
3500Å
ISP
1999 Nov. 8
2000 Jan. 9
Q (%)
U (%)
1
0
-1
-1
0
1


No lumps around max

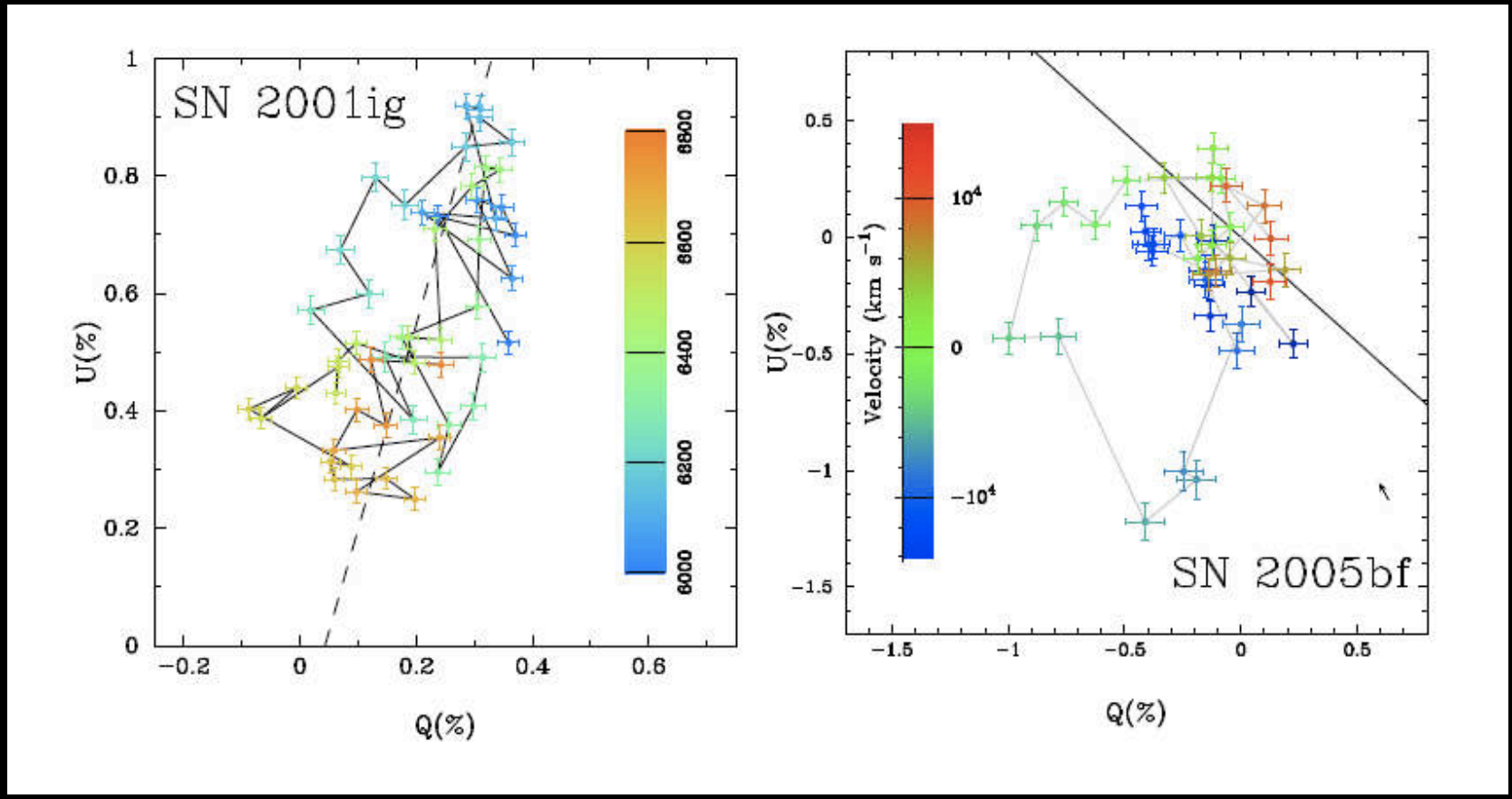
- SN 1999em

SN 2004dj

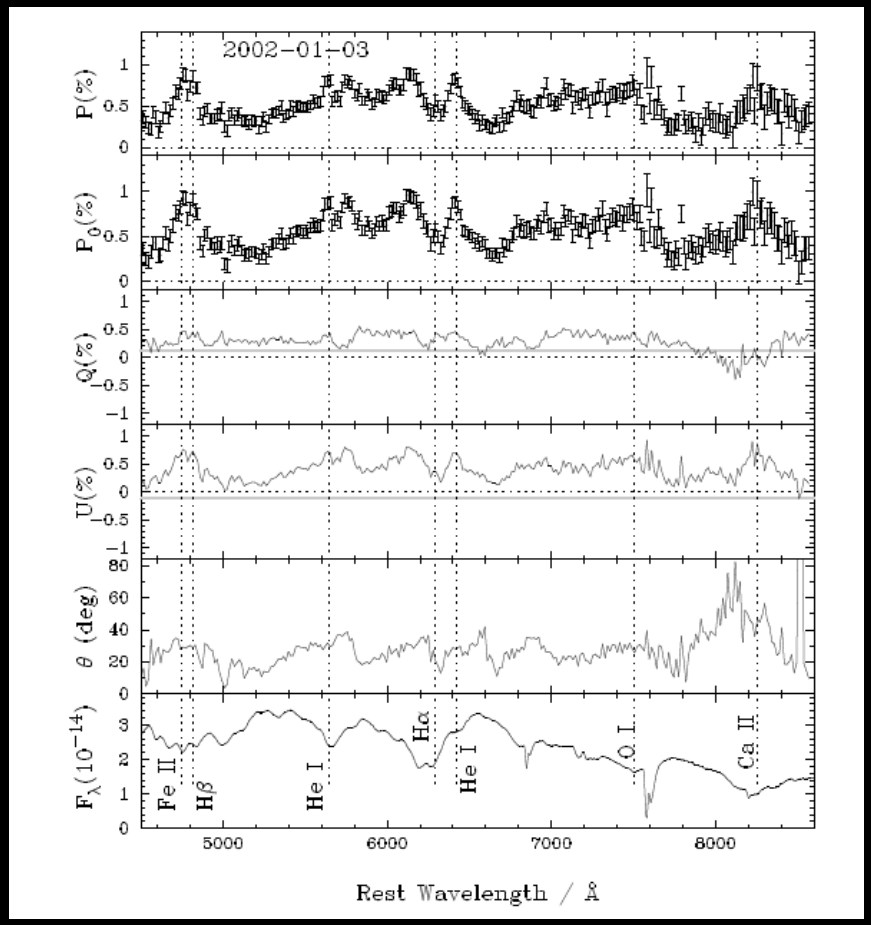


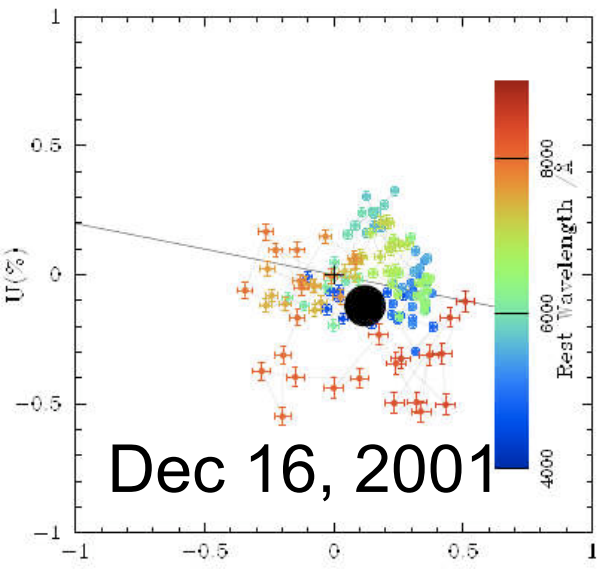
Leonard et al. 2006

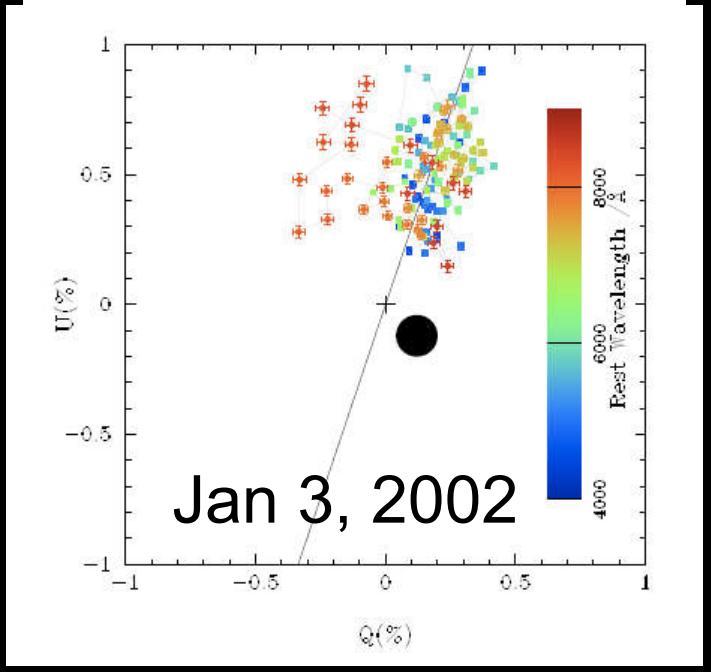
Type IIB, Ib



Maund et al. 2007

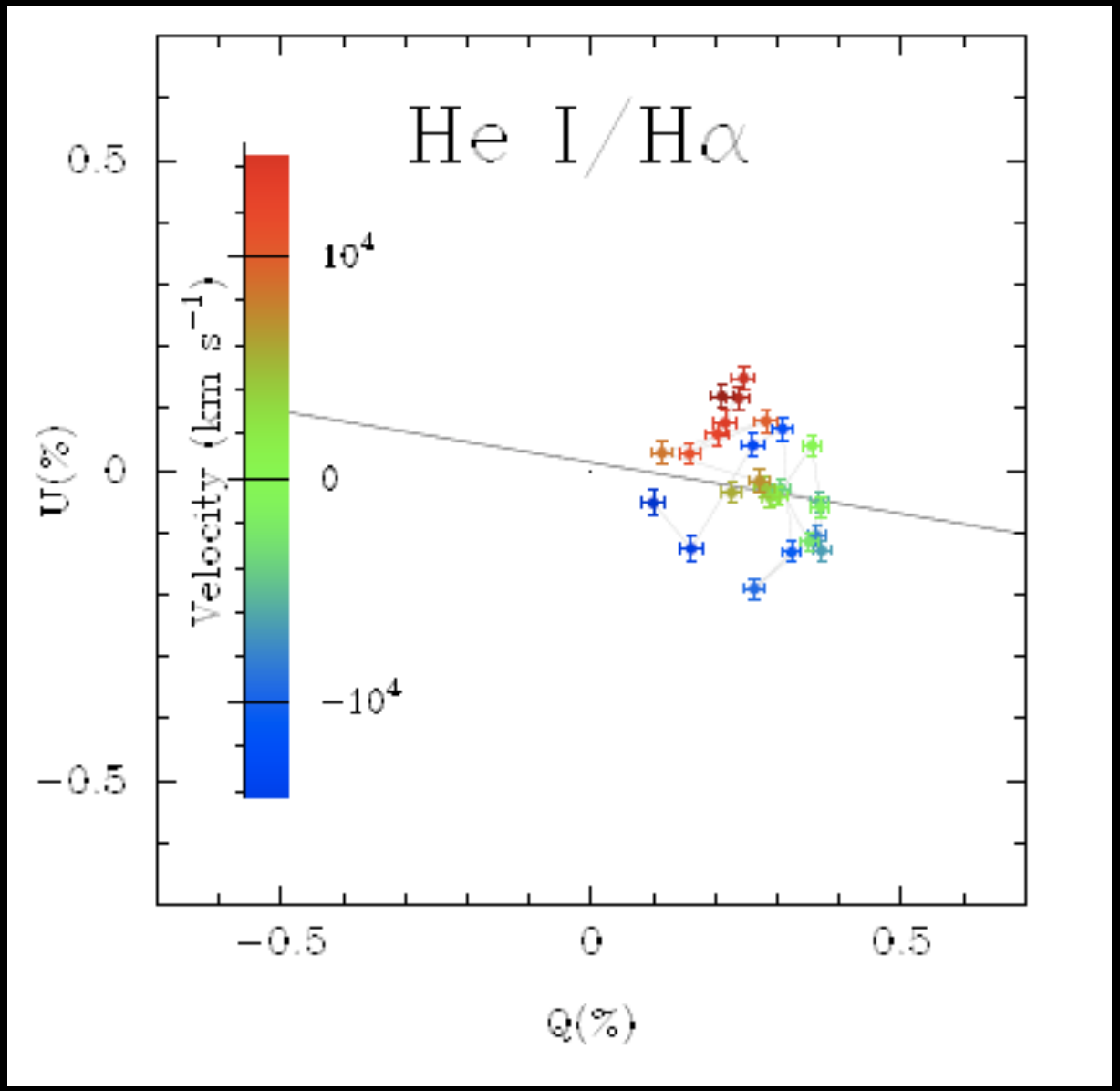






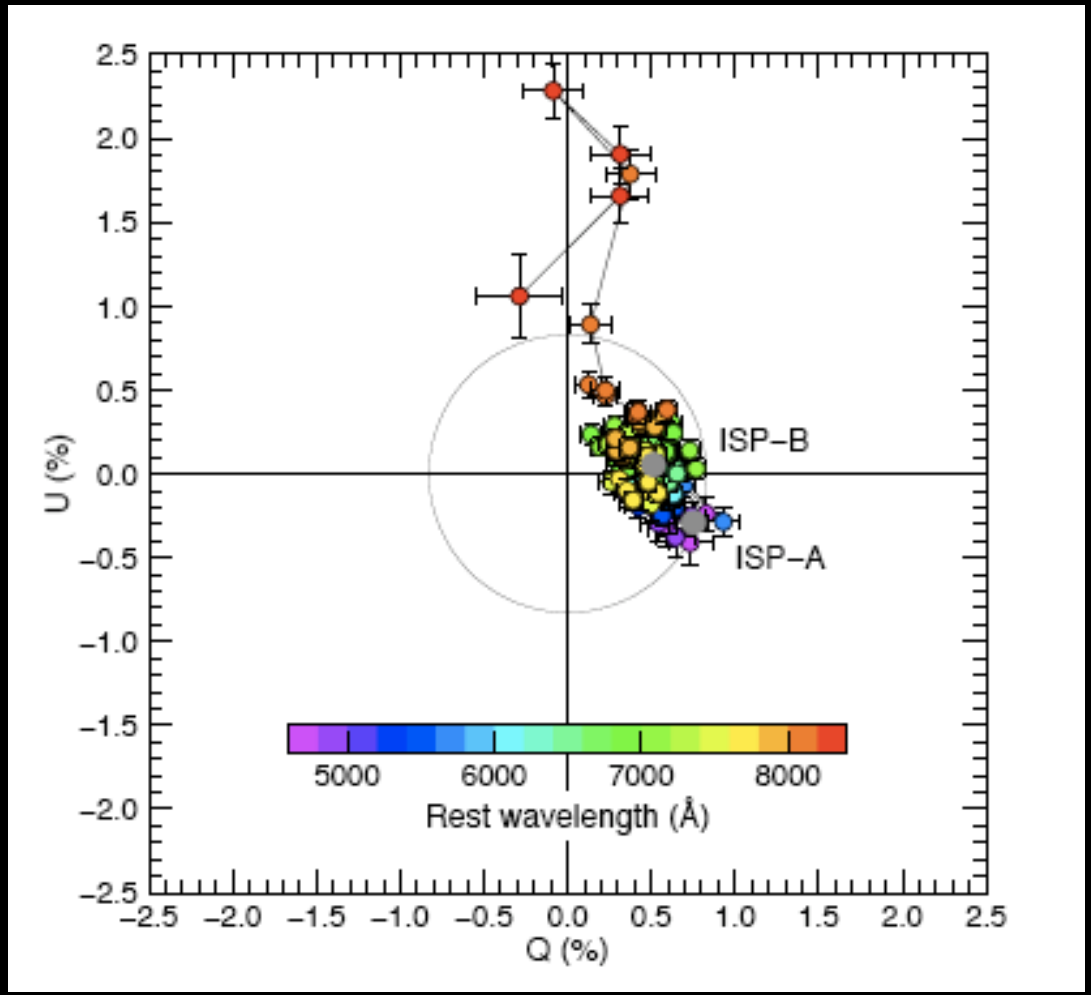
SN 2001ig

Maund et al. 2007



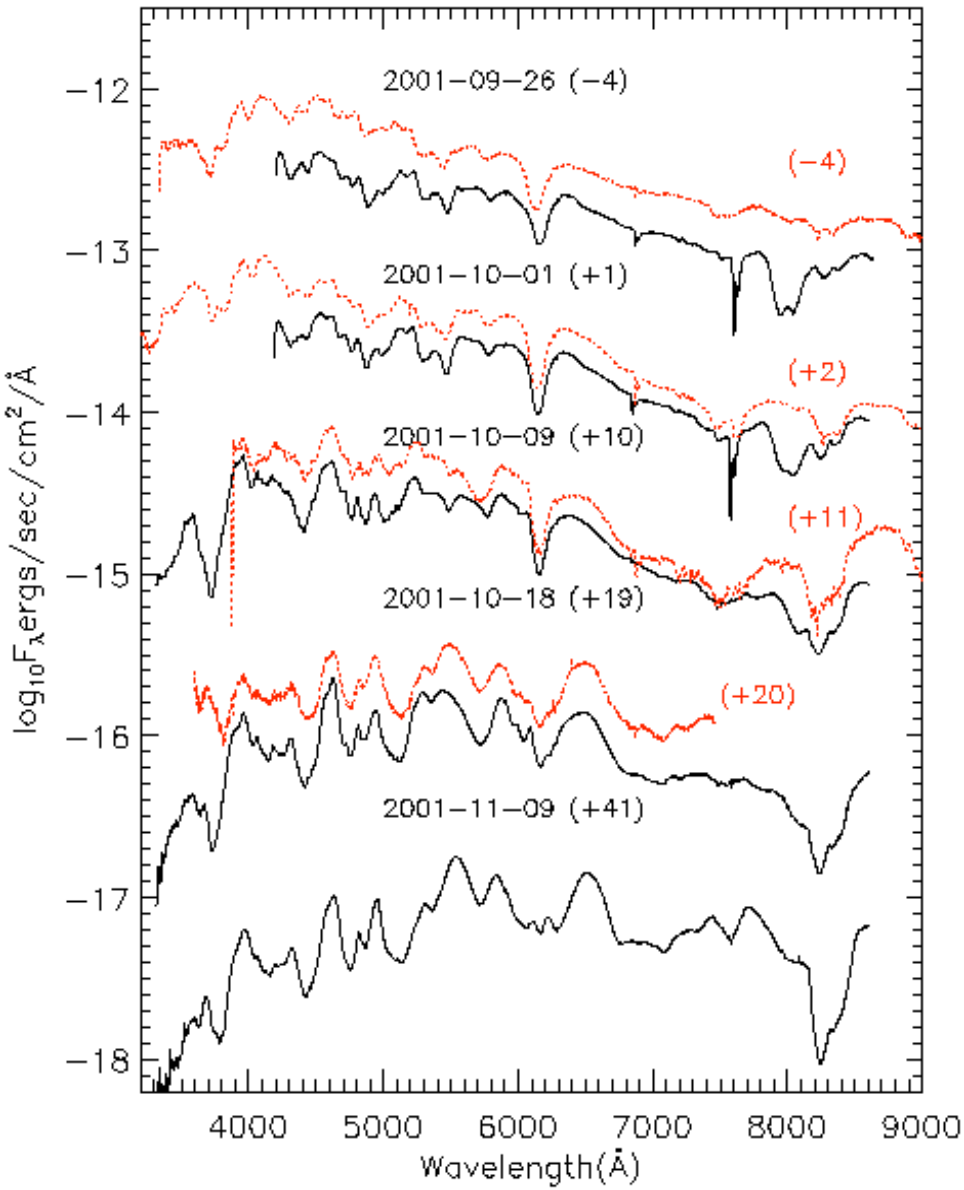
Maund et al. 2007

SNIc

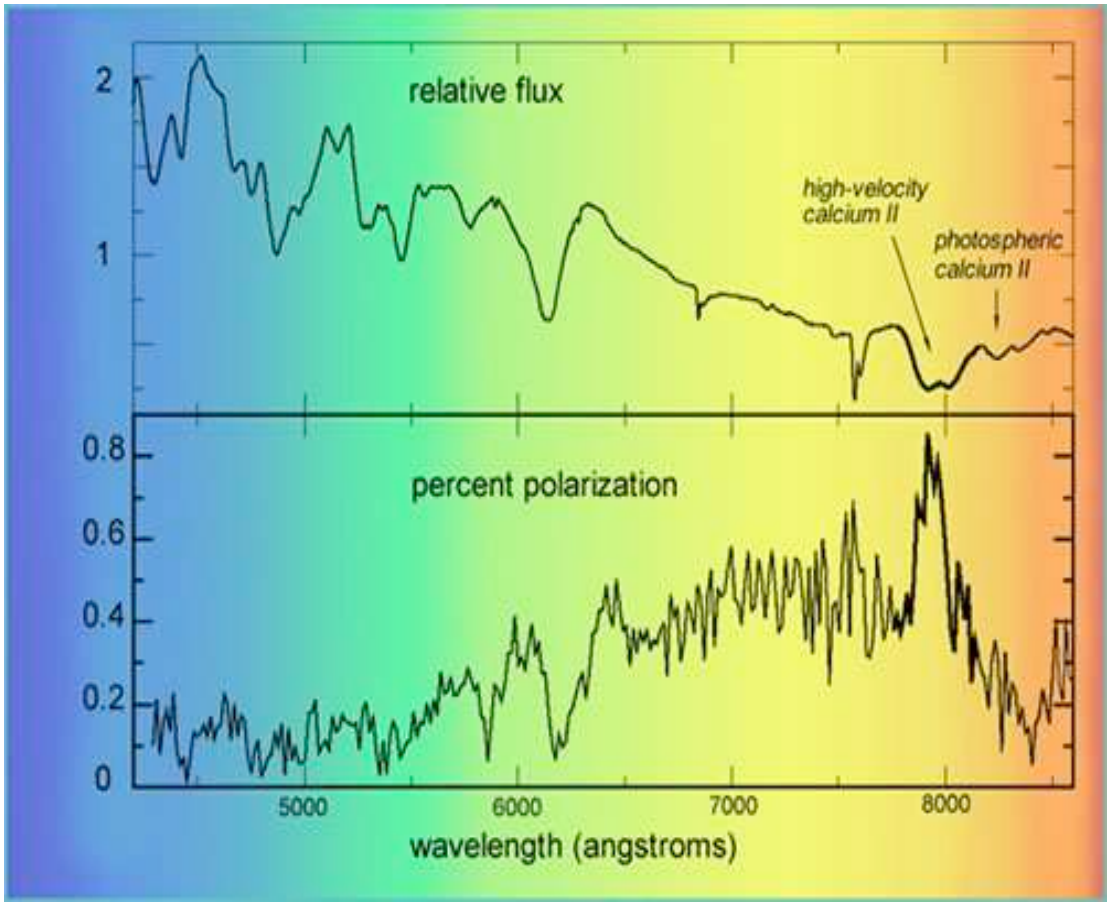


SN 2005gr; Tanaka et al. 2008

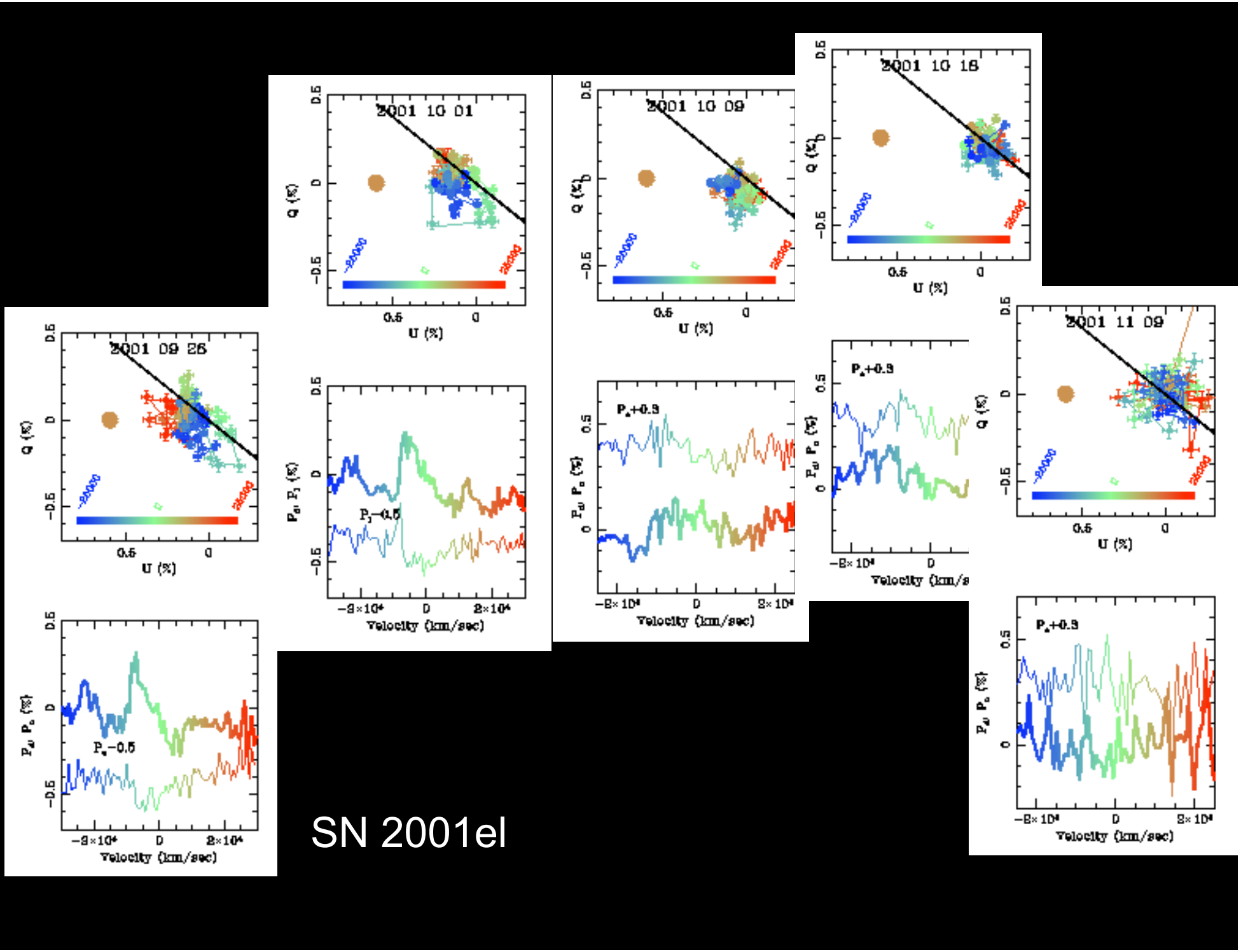
Type Ia

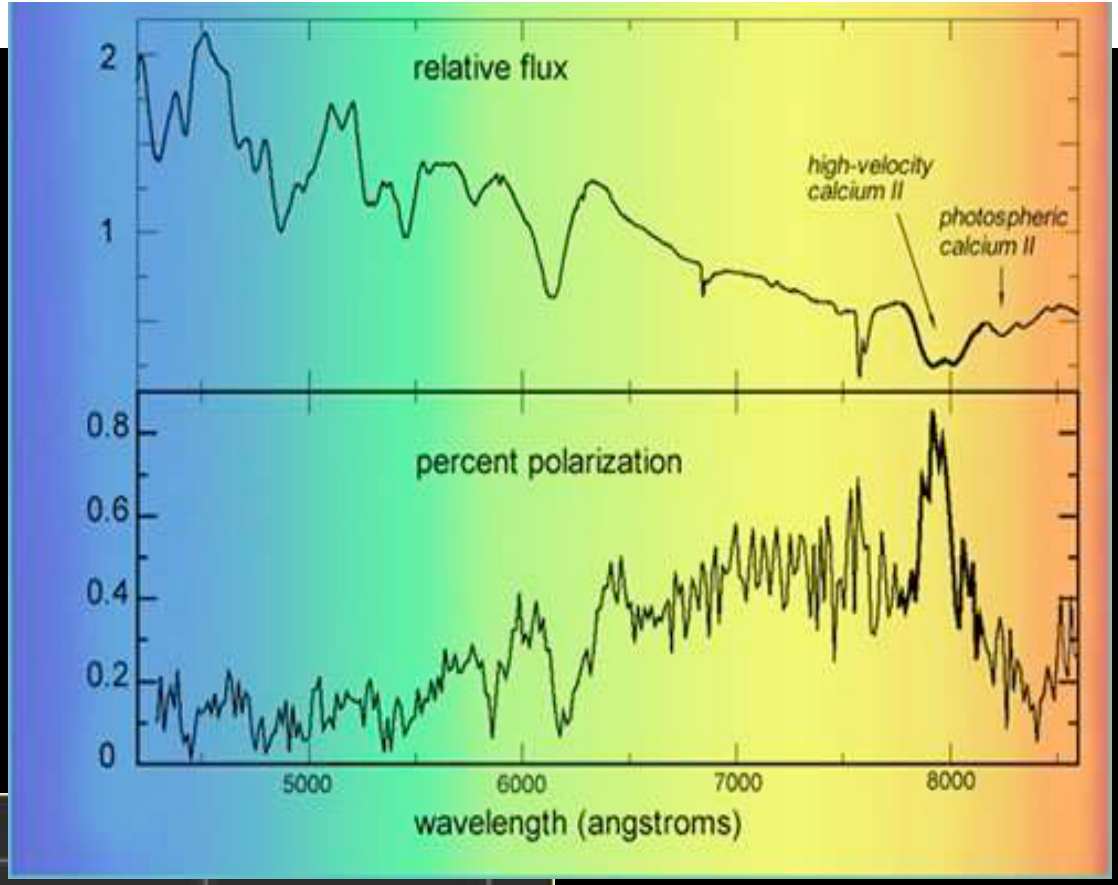

2001−09−26 (−4)
(−4)
2001−10−01 (+1)
(+2)
2001−10−09 (+10)
(+11)
2001−10−18 (+19)
(+20)
2001−11−09 (+41)
−12
−13
−14
−15
−16
−17
−18
4000
5000
6000
7000
8000
9000
Wavelength(Å)
log10Fλergs/sec/cm2/Å

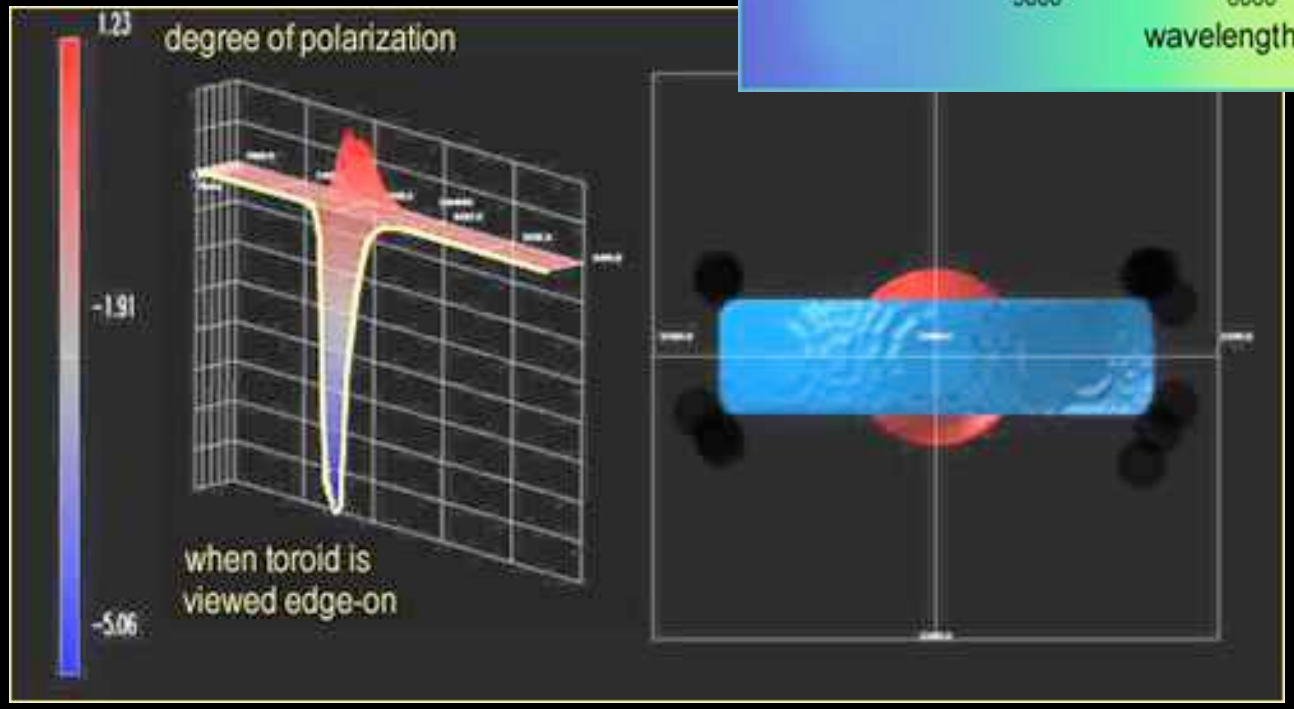
An Example



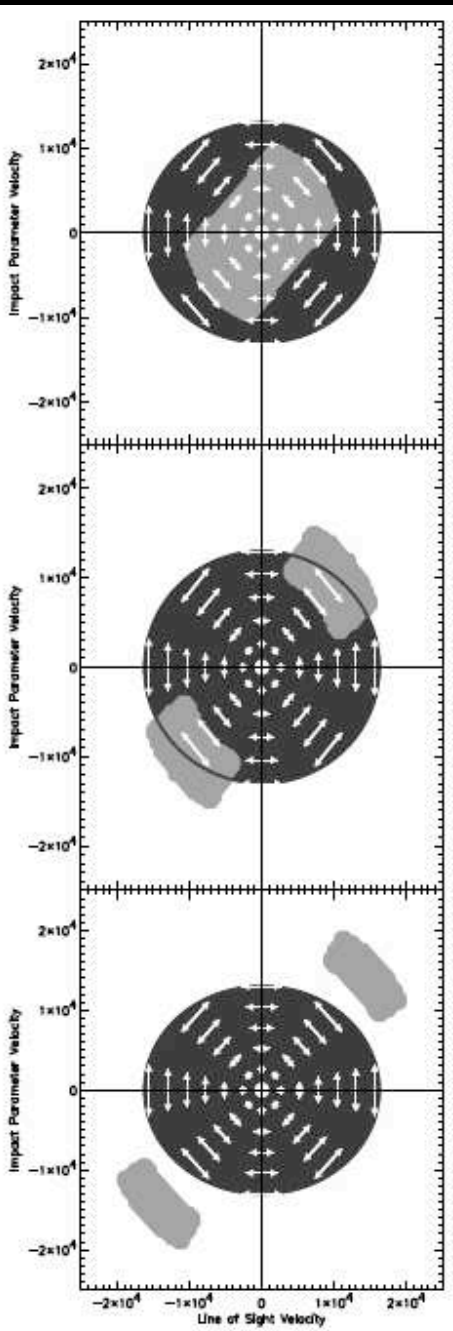
Wang et al. 2003

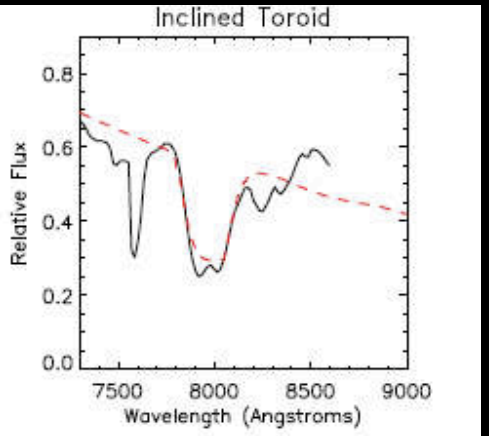

2001 09 26
2001 10 01
2001 10 09
2001 10 18
2001 11 09
Q (%)
U (%)
P_d, P_J (%)
P_J−0.5
P_d, P_a (%)
P_a−0.5
P_a+0.3
Velocity (km/sec)
SN 2001el

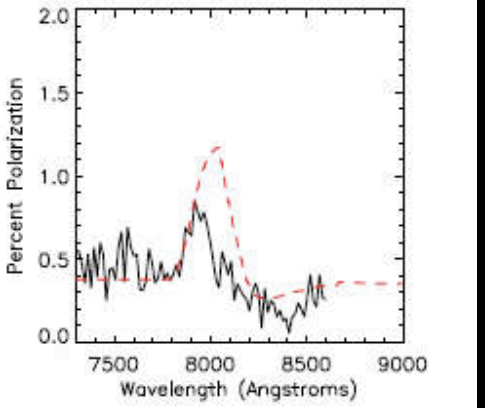


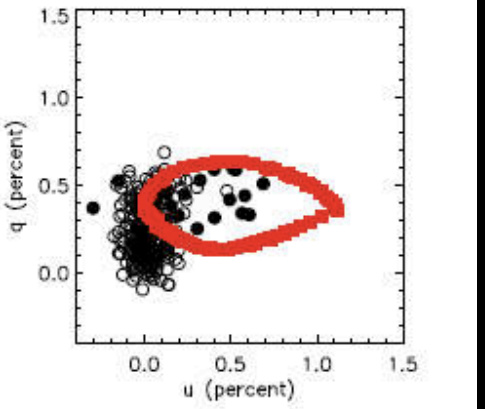


Kasen et al. 2003


Impact Parameter Velocity
2×10^4
1×10^4
0
−1×10^4
−2×10^4
Line of Sight Velocity


Inclined Toroid
Relative Flux
0.0
0.2
0.4
0.6
0.8
7500
8000
8500
9000
Wavelength (Angstroms)

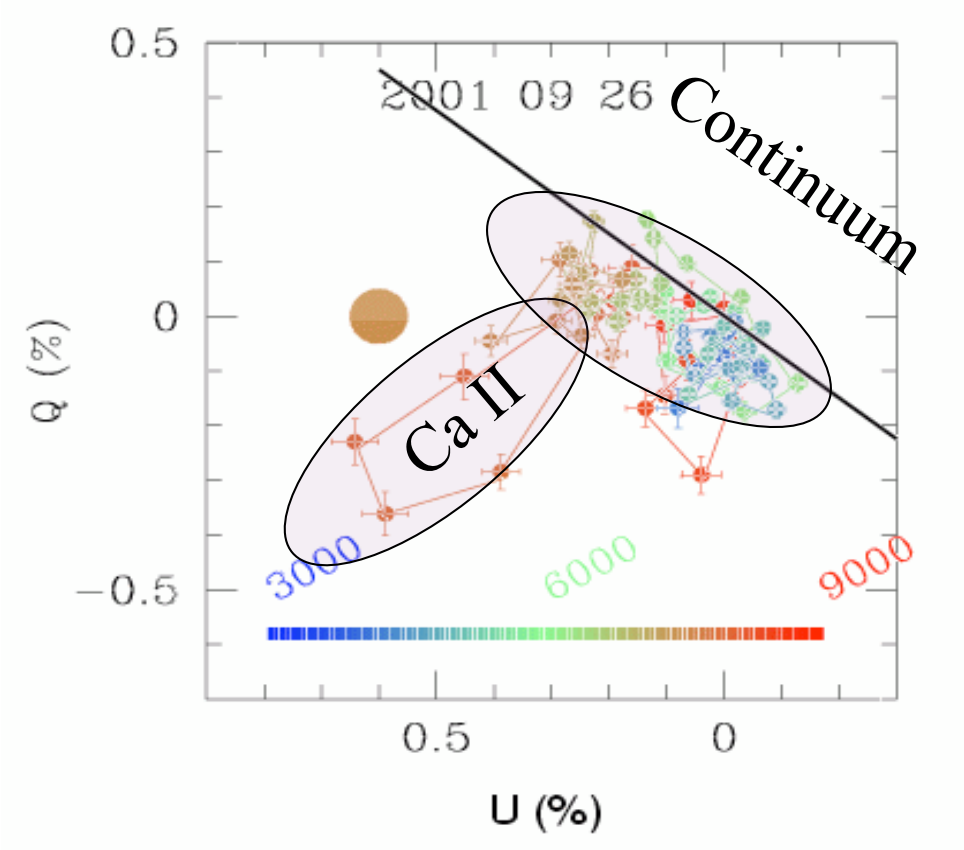

Percent Polarization
0.0
0.5
1.0
1.5
2.0
7500
8000
8500
9000
Wavelength (Angstroms)

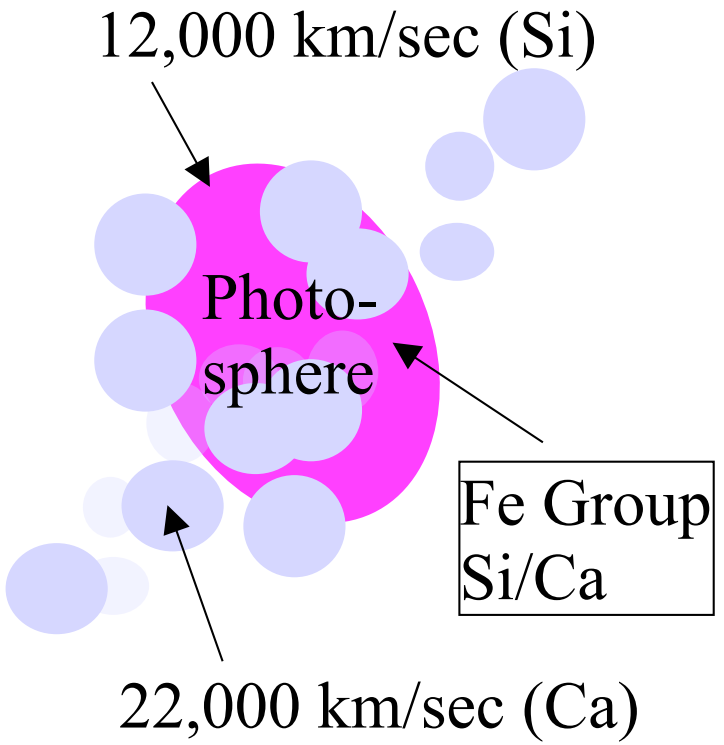

q (percent)
u (percent)
0.0
0.5
1.0
1.5

Wang et al 2003, ApJ, 591, 1110

Significant Departure from Spherical Symmetry

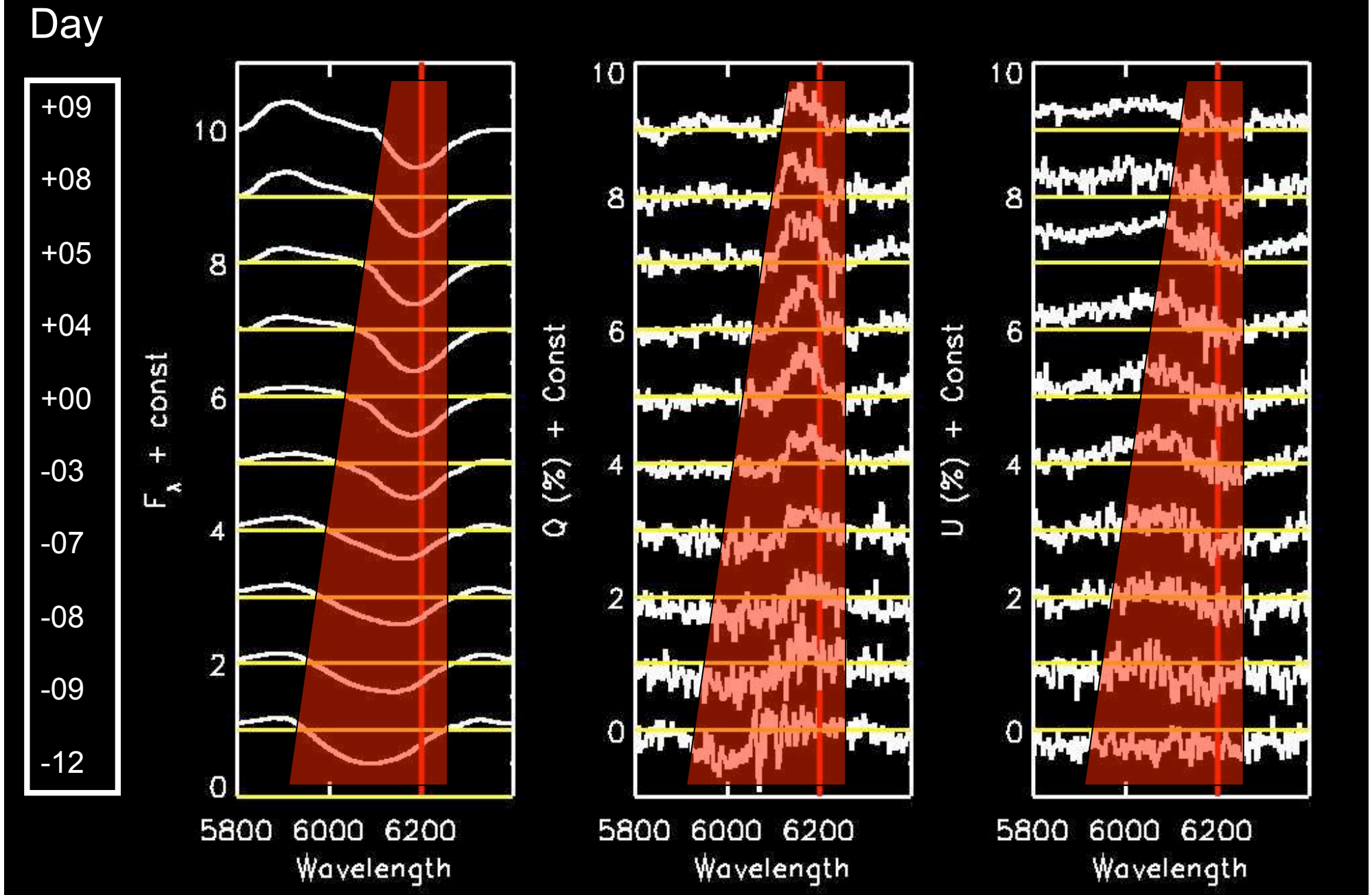
Day -4





Continuum Polarization 0.4%
Photosphere Asymmetry ~ 10%
Highly Distorted High Velocity Ca Shell

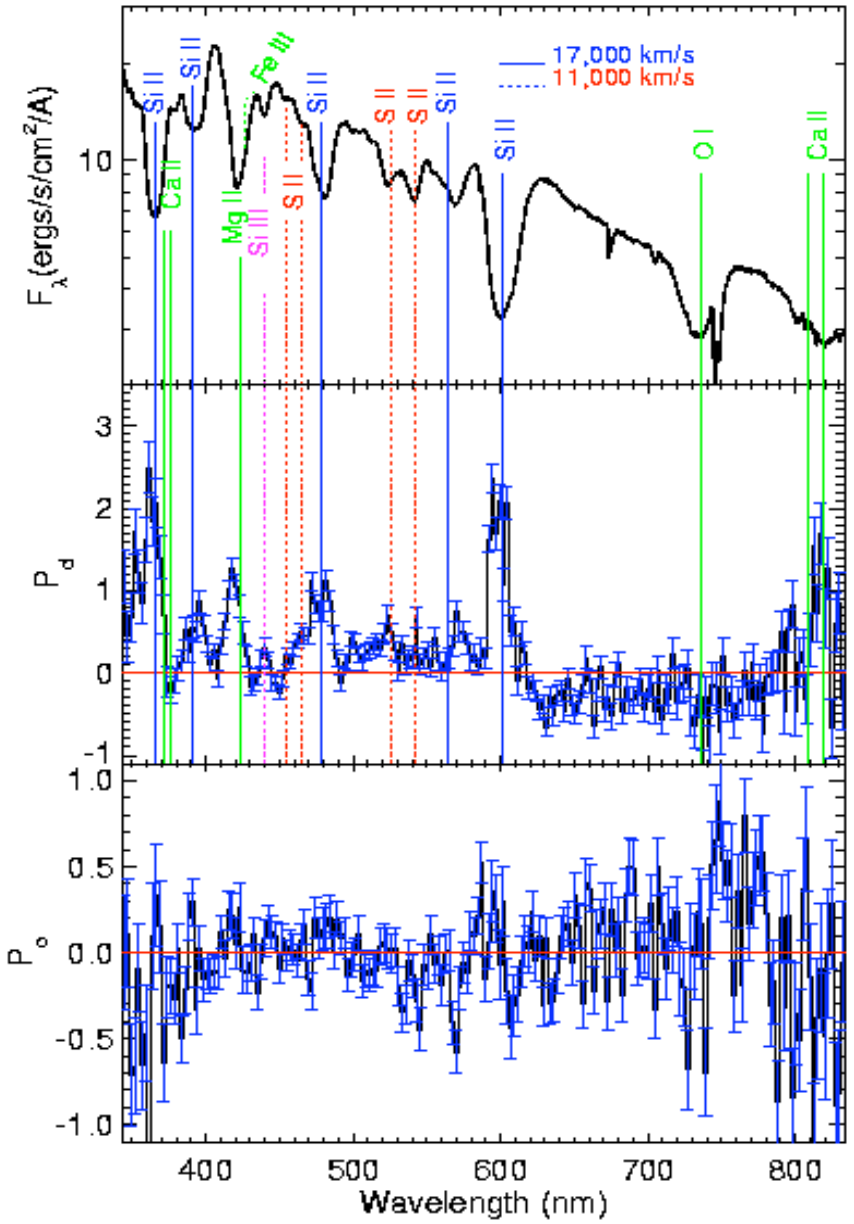
Great Time Coverage



Excellent Wavelength Coverage

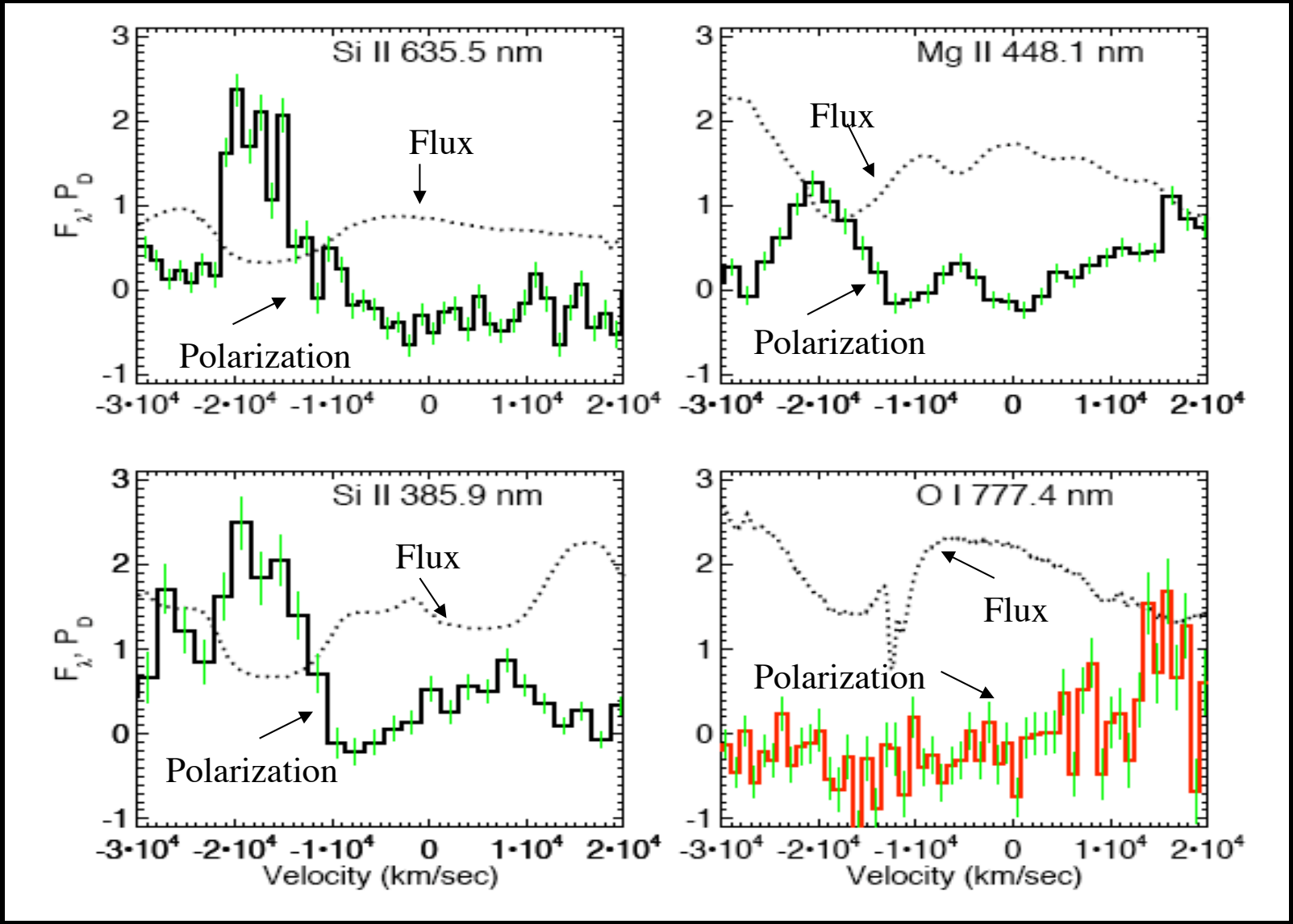
High S/N Ratio

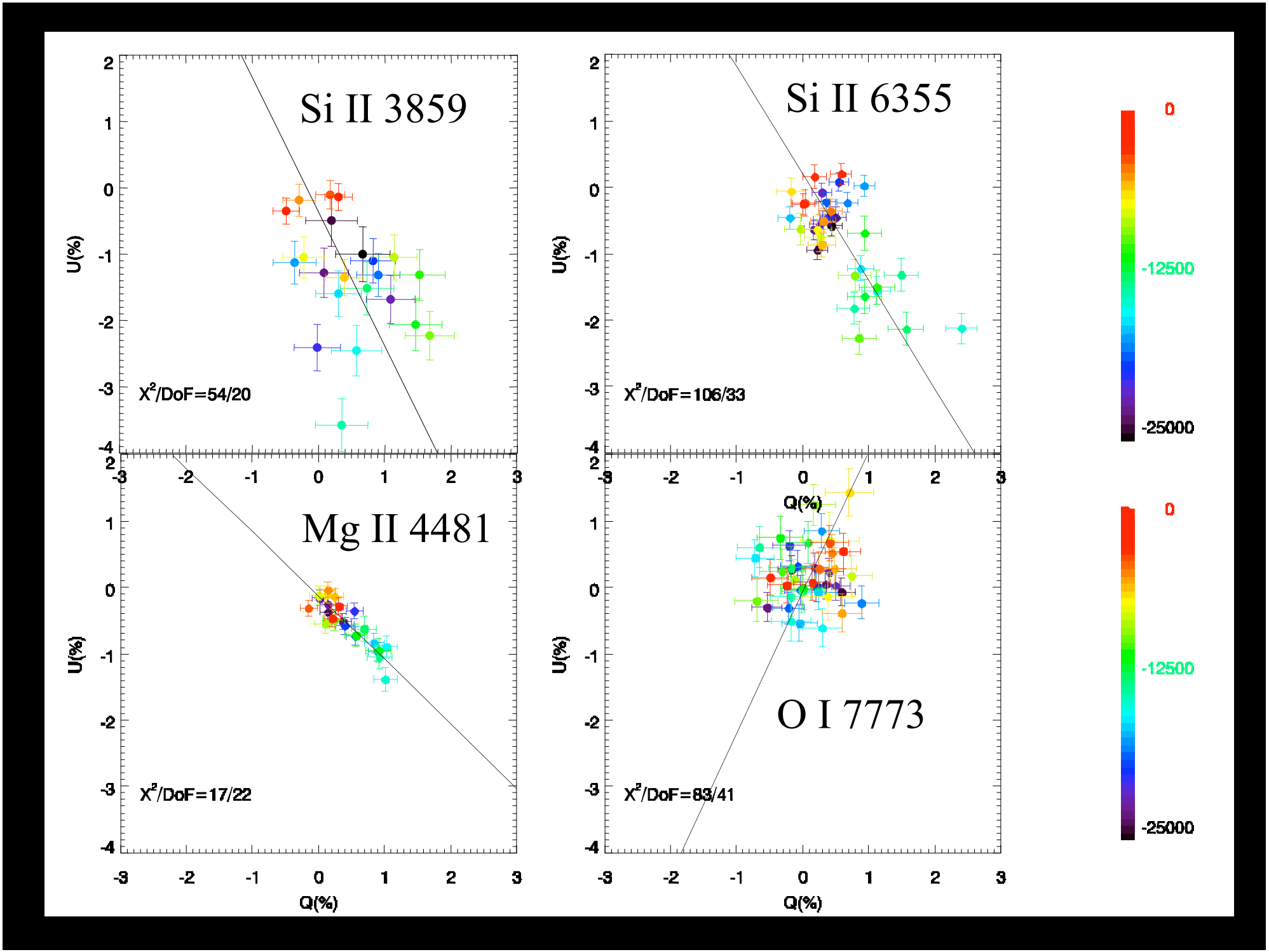
Wang et al. 2005



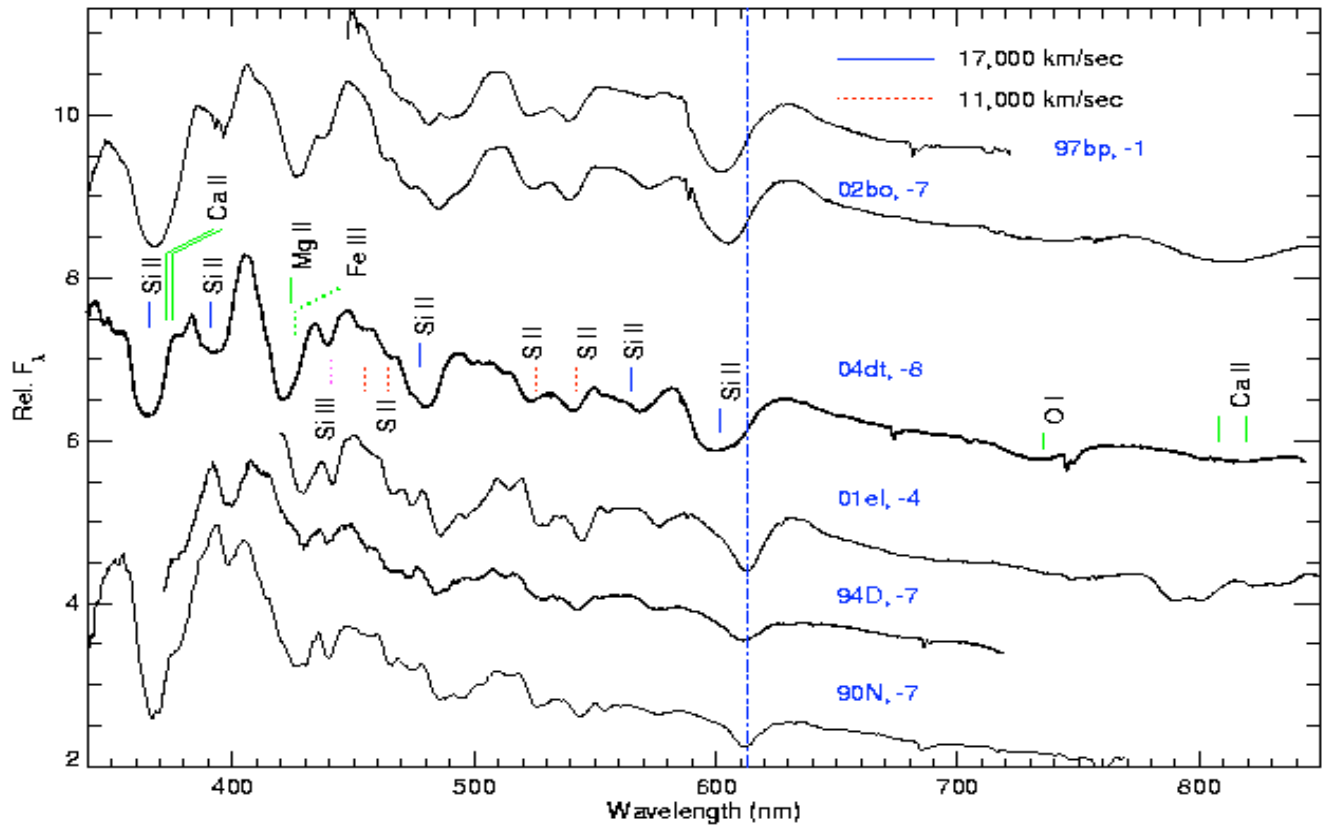
Wang et al. 2003

Line/Polarization Profiles

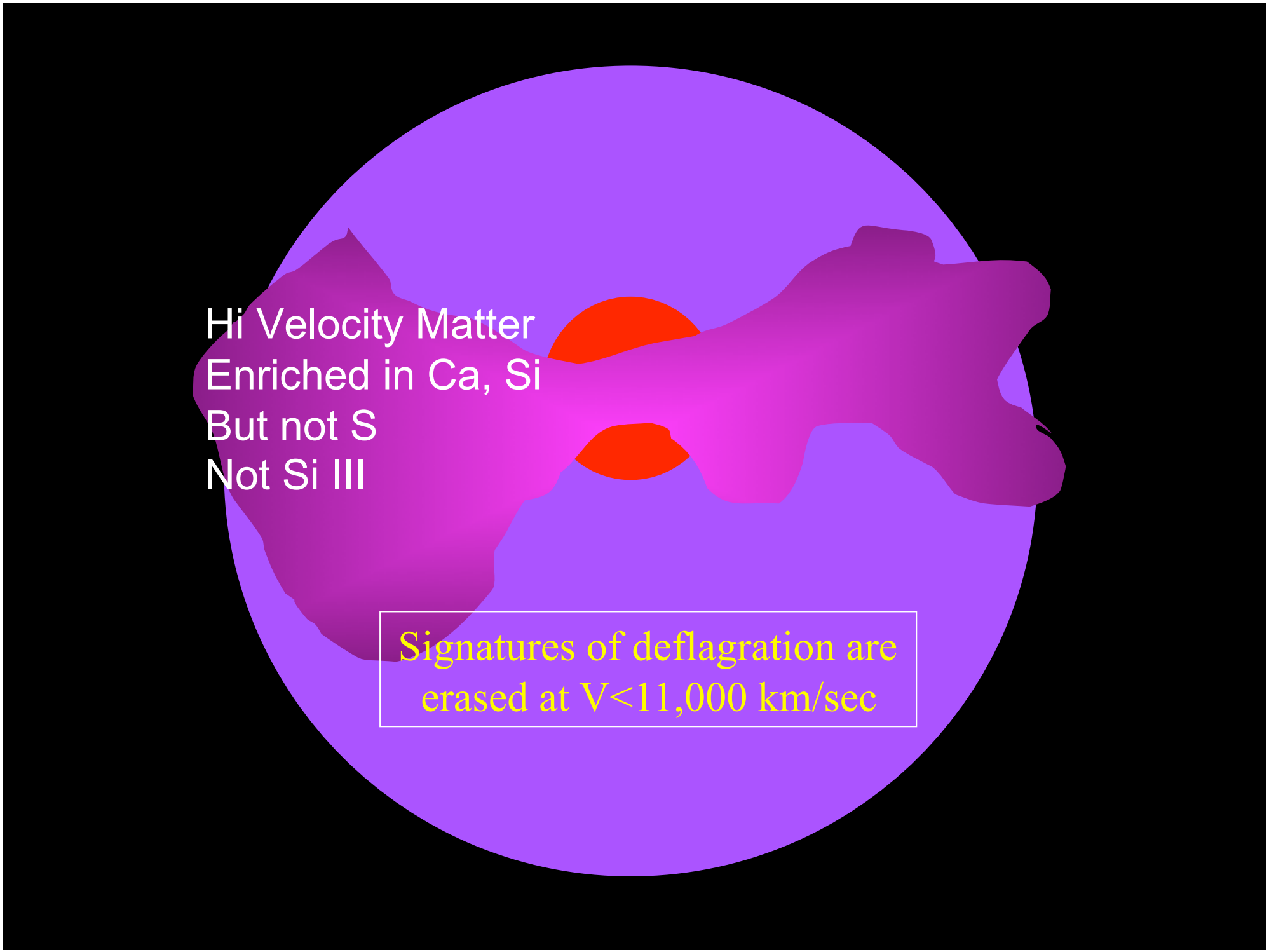


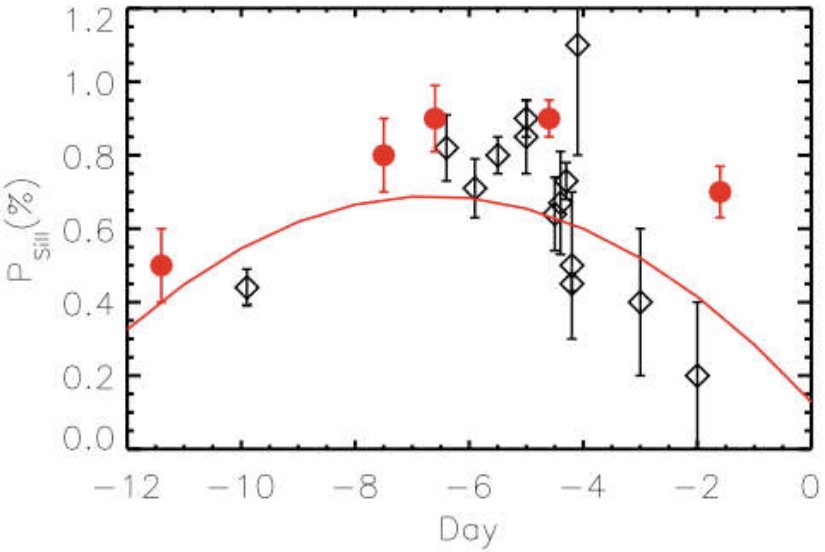

Si II 3859
X²/DoF=54/20
Si II 6355
X²/DoF=106/33
Mg II 4481
X²/DoF=17/22
O I 7773
X²/DoF=83/41
U(%)
Q(%)
0
-12500
-25000

SN 2004dt-Like



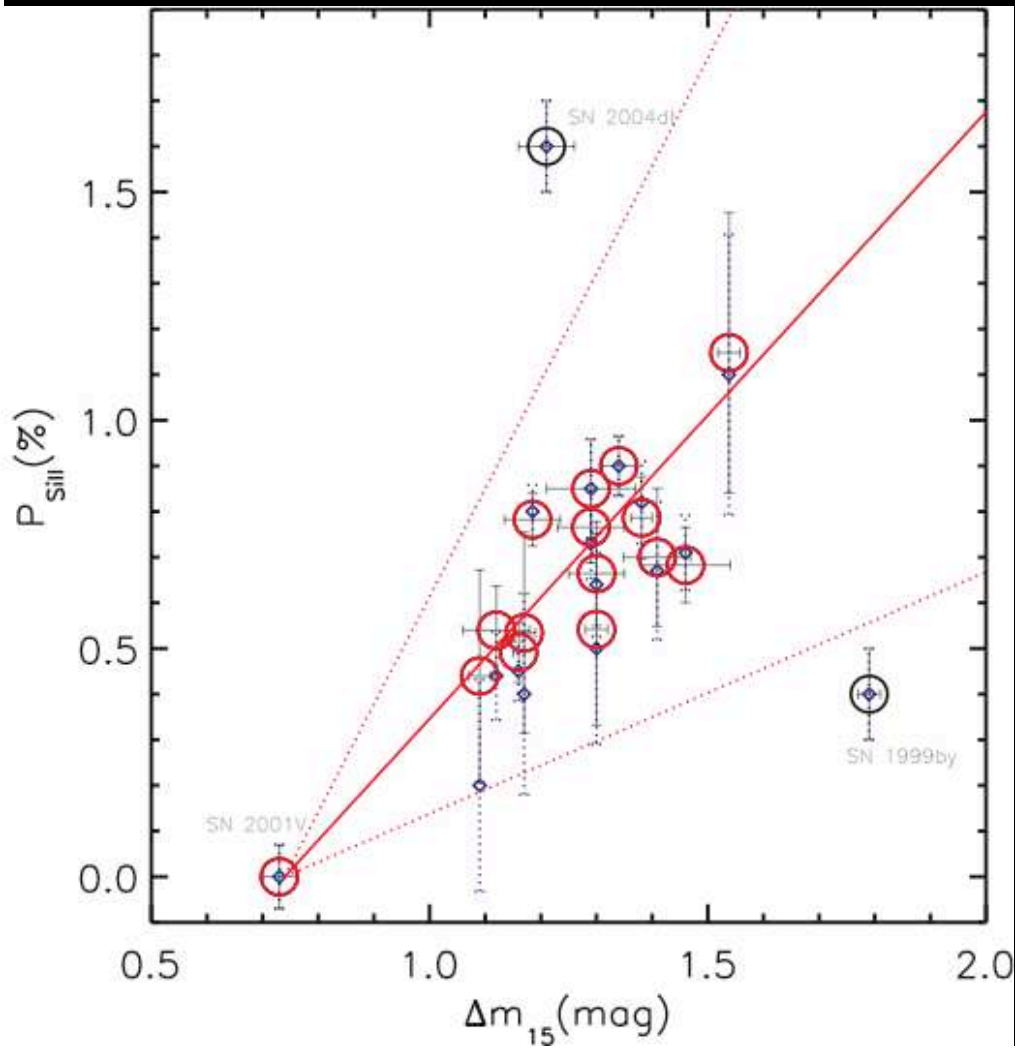
Wang et al. 2004, 2007


Hi Velocity Matter
Enriched in Ca, Si
But not S
Not Si III
Signatures of deflagration are
erased at V<11,000 km/sec

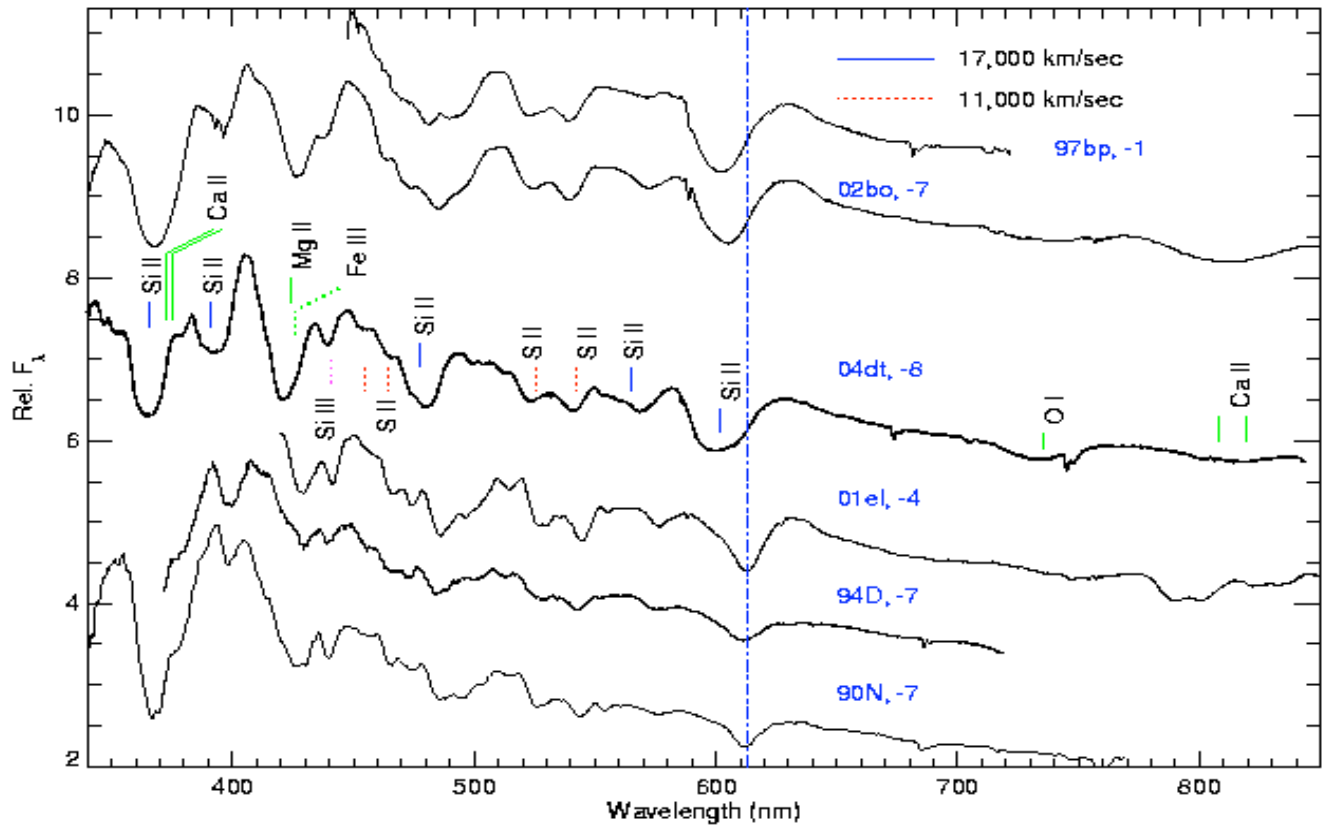


The luminosity of a SN is correlated to its geometric structure.

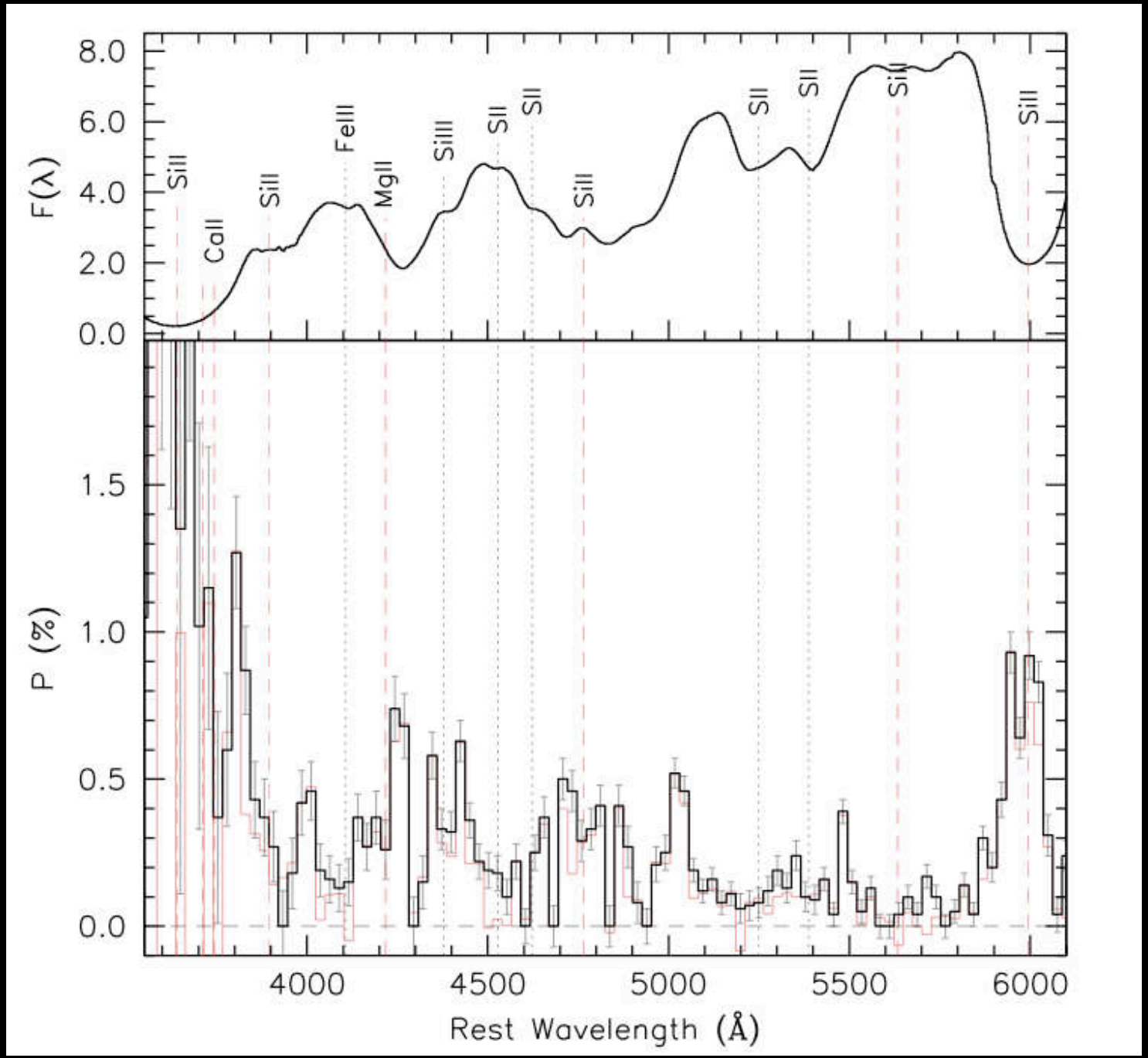
Wang et al. 2006



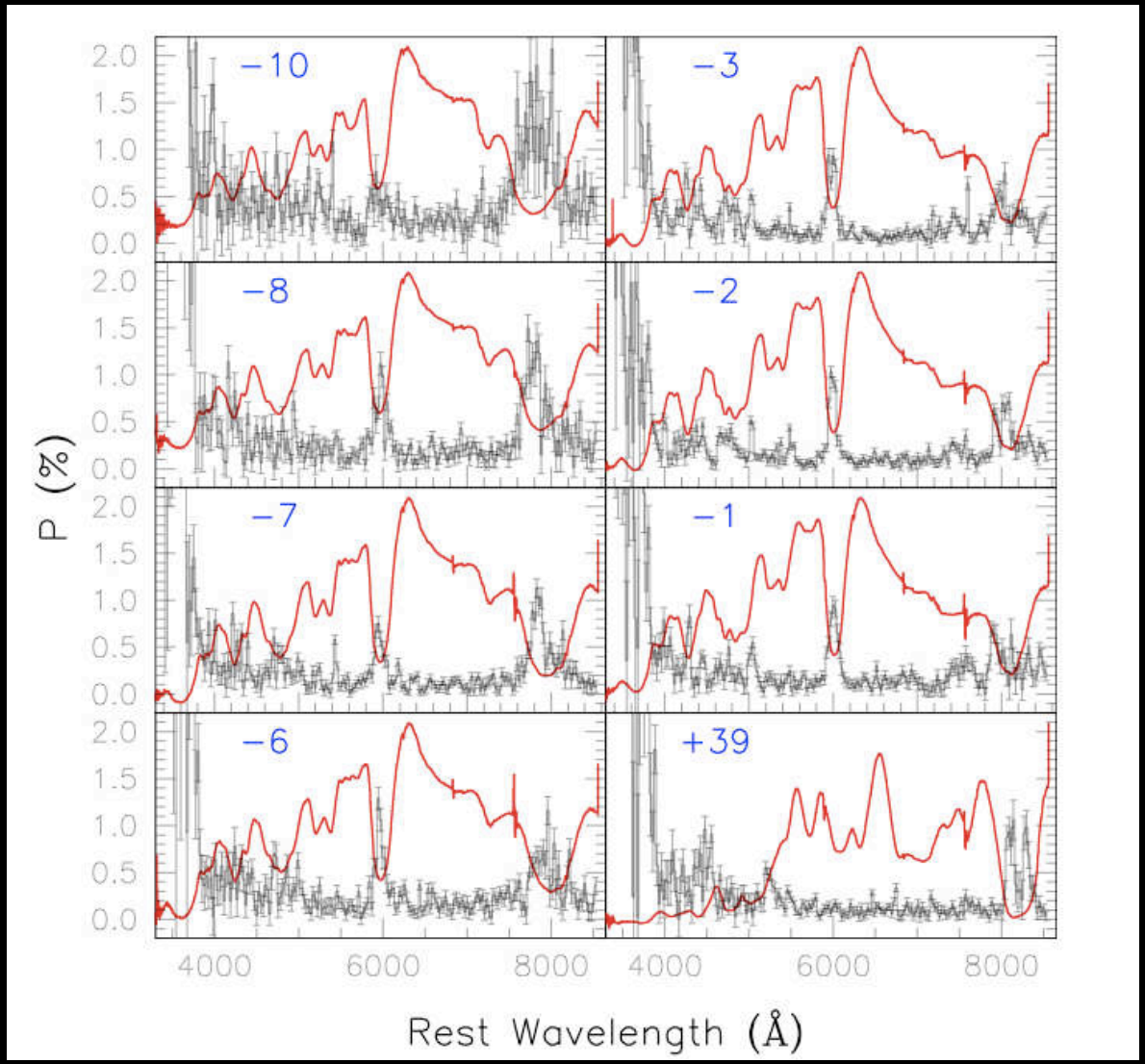
SN 2004dt-Like



Wang et al. 2004, 2007


8.0
6.0
4.0
2.0
0.0
F(λ)
SiII
CaII
SiII
FeIII
MgII
SiIII
SII
SII
SiII
SII
SII
SiII
SiII
1.5
1.0
0.5
0.0
P (%)
4000
4500
5000
5500
6000
Rest Wavelength (Å)

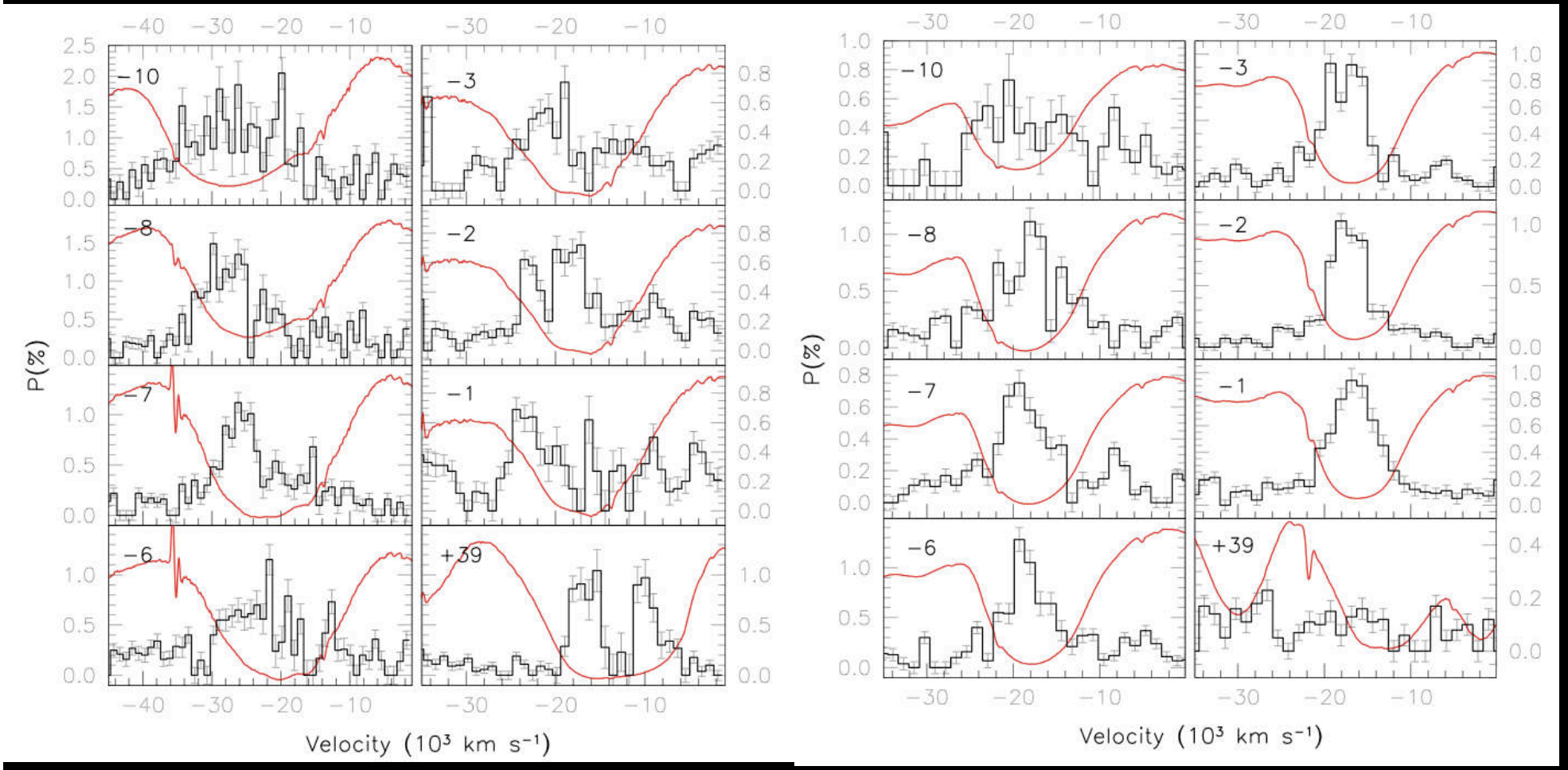
SN 2006X



Patat et al. 2008

Ca II

Si II


P(%)
−10
−3
−8
−2
−7
−1
−6
+39
Velocity (10³ km s⁻¹)
P(%)
−10
−3
−8
−2
−7
−1
−6
+39
Velocity (10³ km s⁻¹)

Summary on SN Pol

- Core-collapse
  1. High pol at late phase, low pol at early phase
  2. Some show very smooth geometry
  3. Some show persistent symmetry axis
  4. Some are rather lampy, especially IIB, Ib/c, with no trace of a clear symmetry axis

- Low pol at late phase, high pol at early phase
  1. Lumpy outside, smooth inside
  2. Processed matter at v ~ 30,000 km/sec