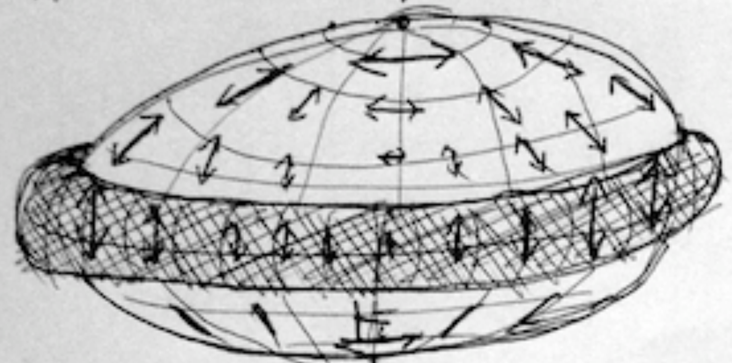
Spectropolarimetry and Asphericity of Supernovae

N&O P@@

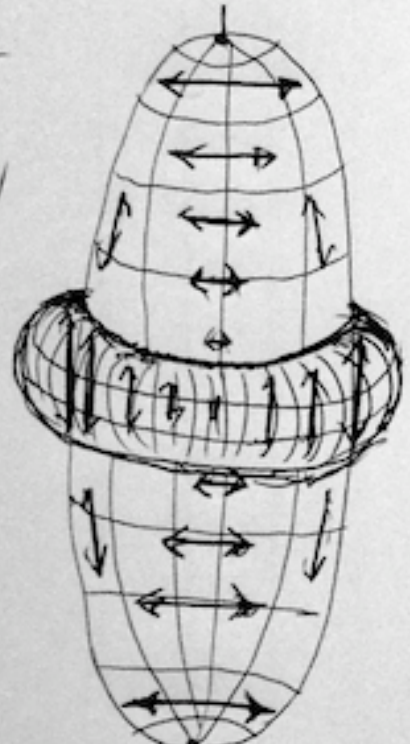
European Southern Observatory

OBLATE:
+ TORUS

- continuum: ↕
- lines: ↔



INCOMPLETE CANCELLATION OF SCATTERING INDUCED POLARIZATION BY THOMSON SCATTERING



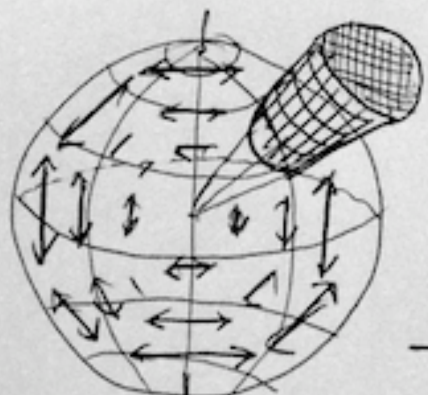
PROLATE
+ TORUS

- continuum: ↕↔
- lines: ↔

⇨ they share the same symmetry axis.

Dear Mando,

one of the reasons you may not understand them, is that you make assumptions that may be wrong. For instance, they are <u>not</u> spherically symmetric. It goes without saying that they present interesting deviations from axial-symmetry.



← HV CaII

CONTINUUM : P = Ø

LINES : rotation

→ PRODUCE A TOY MODEL (POSSIBLY 3D/MC)

Any photon is polarized, but...

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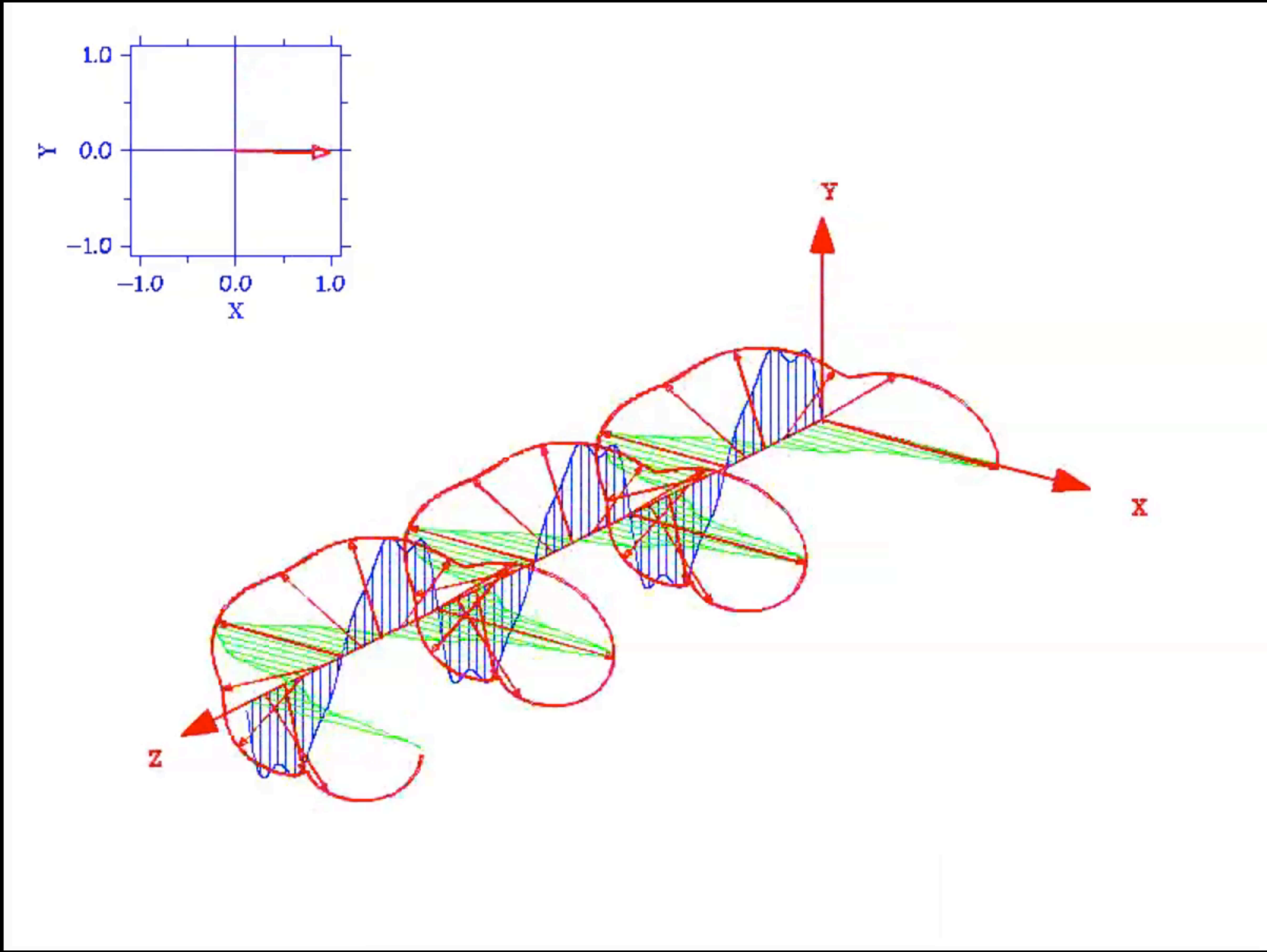
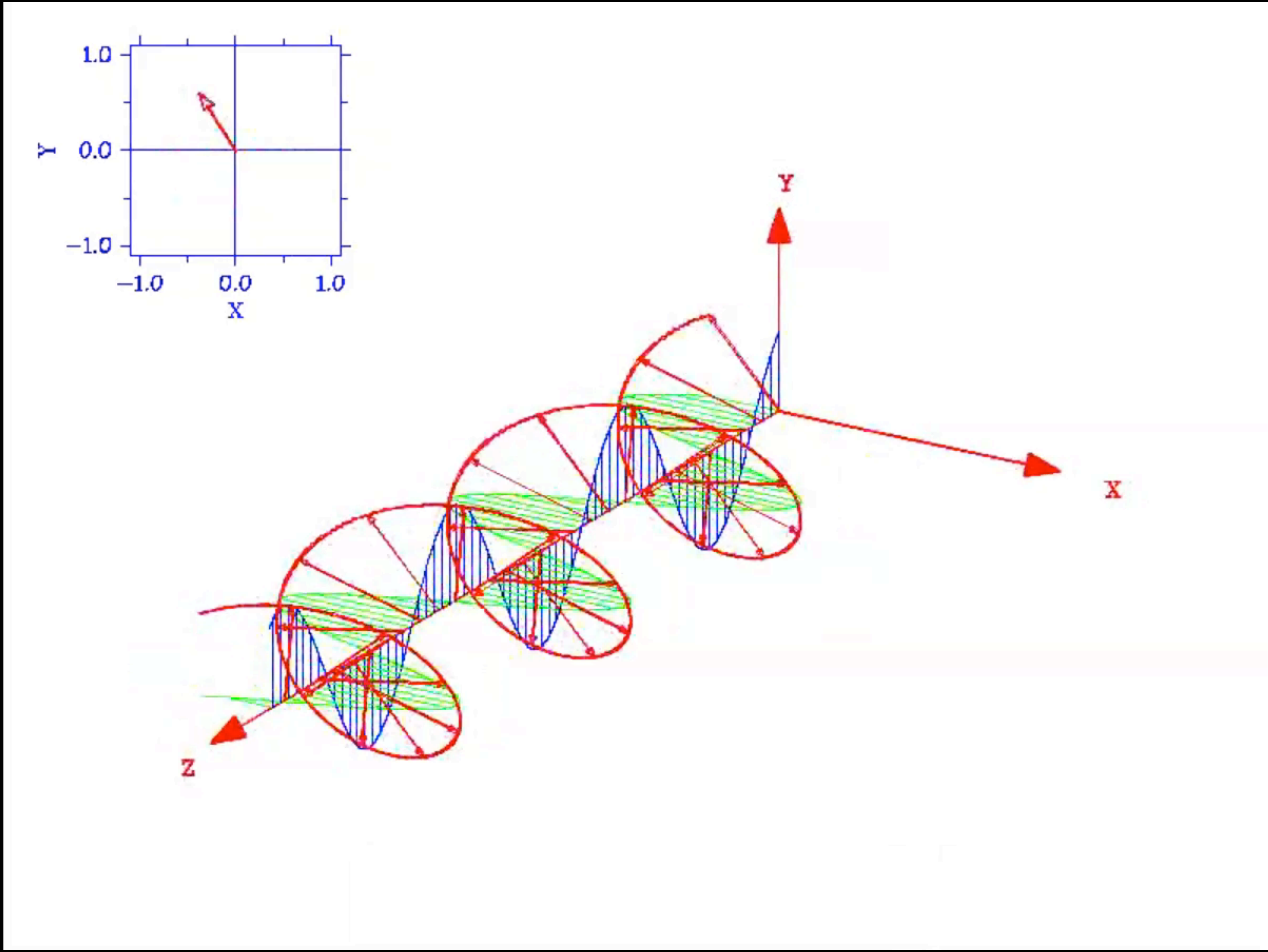
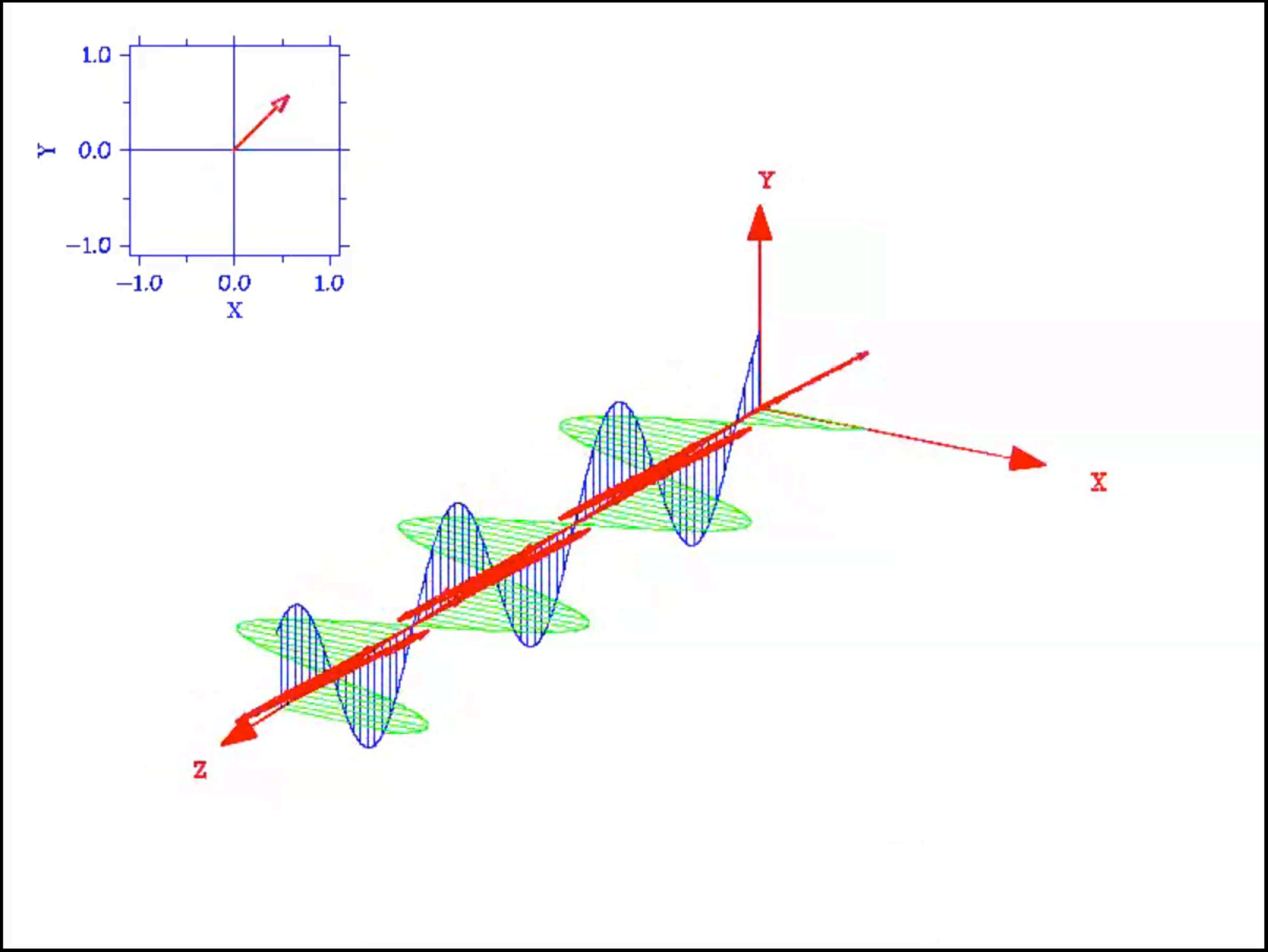


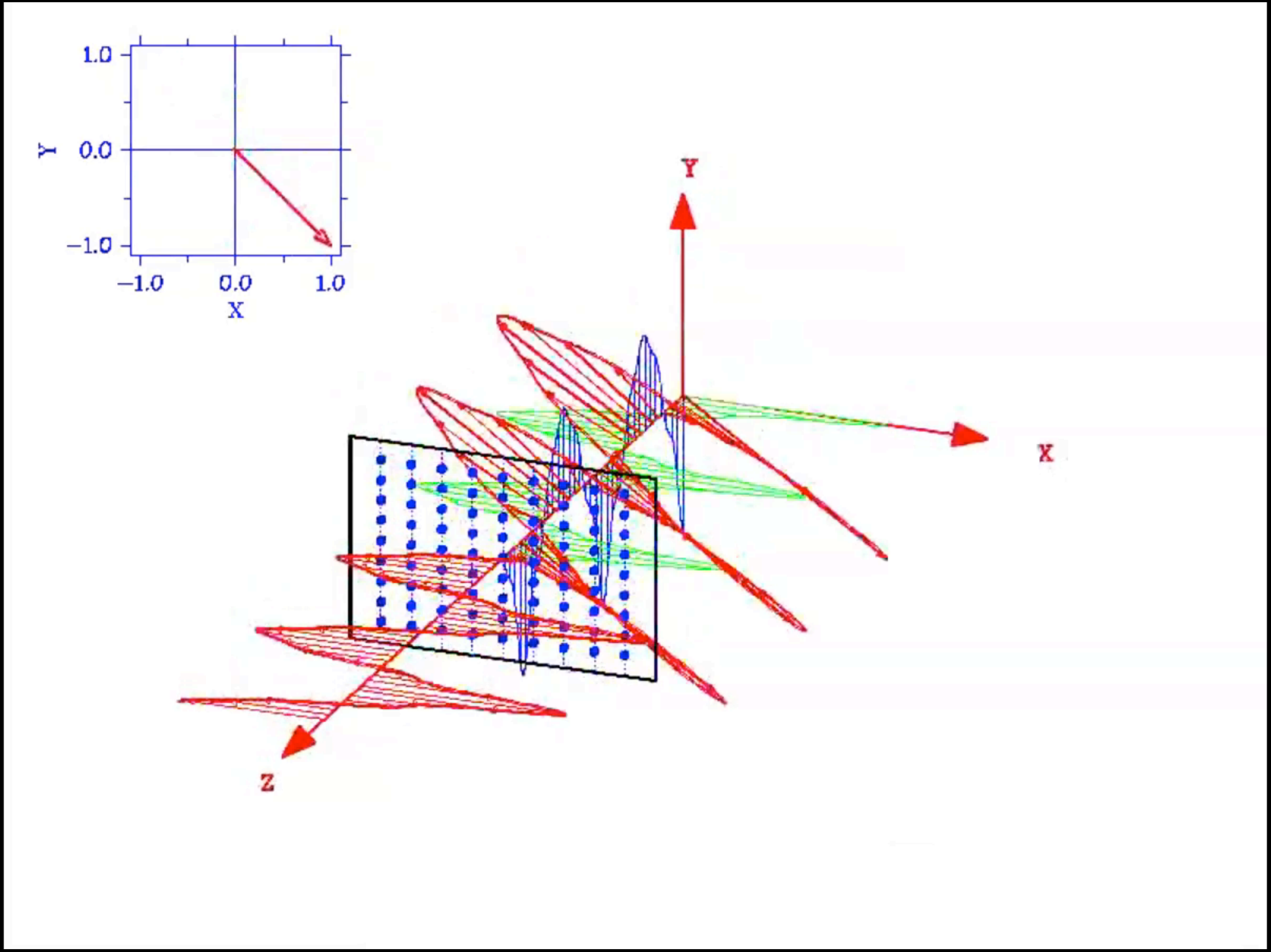
Circular polarization



Linear polarization



Selecting planes with an analyzer



A Brief History of SN Polarimetry/I

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- First robust detections: 1987A (Cropper+88; Jeffery +91) and 1993J (Trammel+93; Doroshenko+95; Tran +97).

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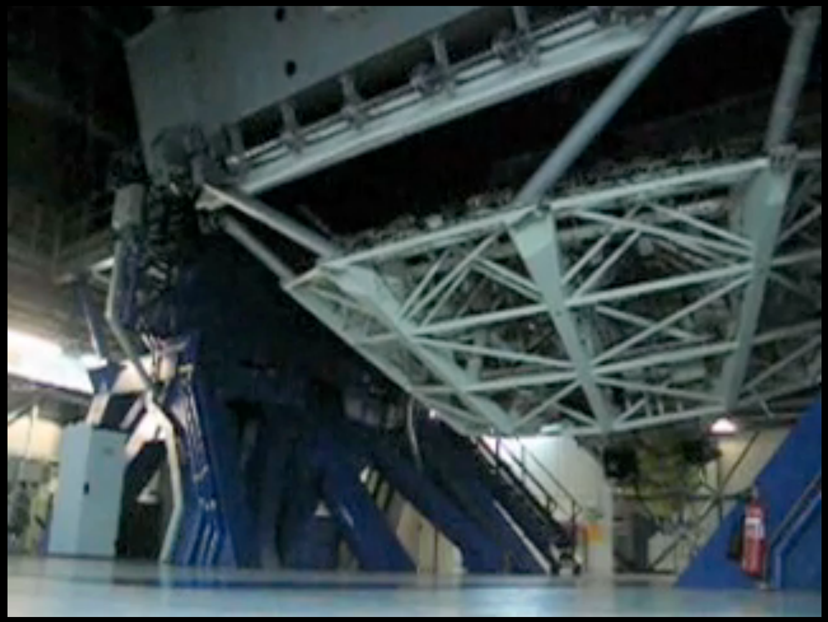
- For more, see Wang & Wheeler (2008; WW08)

What's wrong with Specpol?



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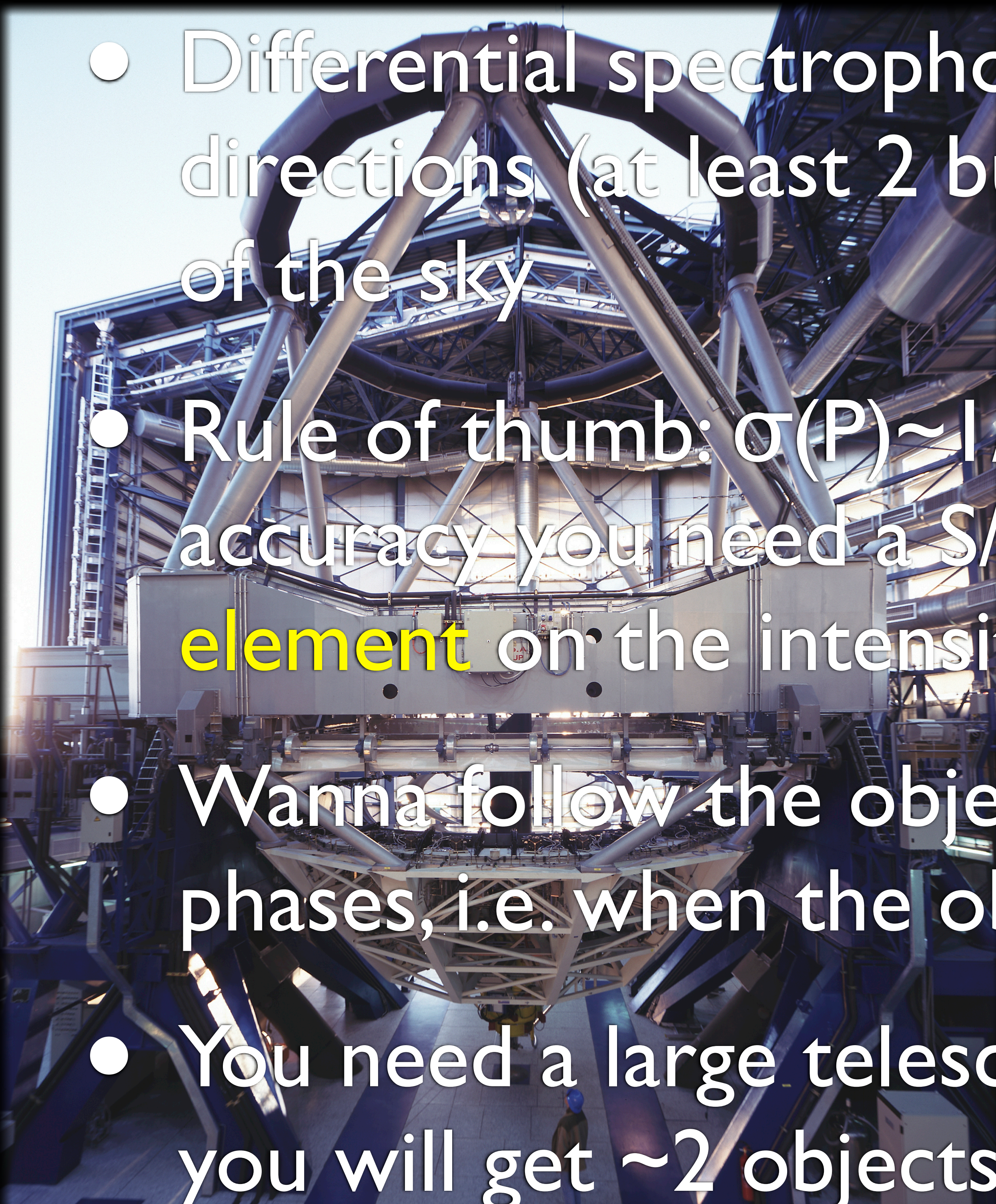

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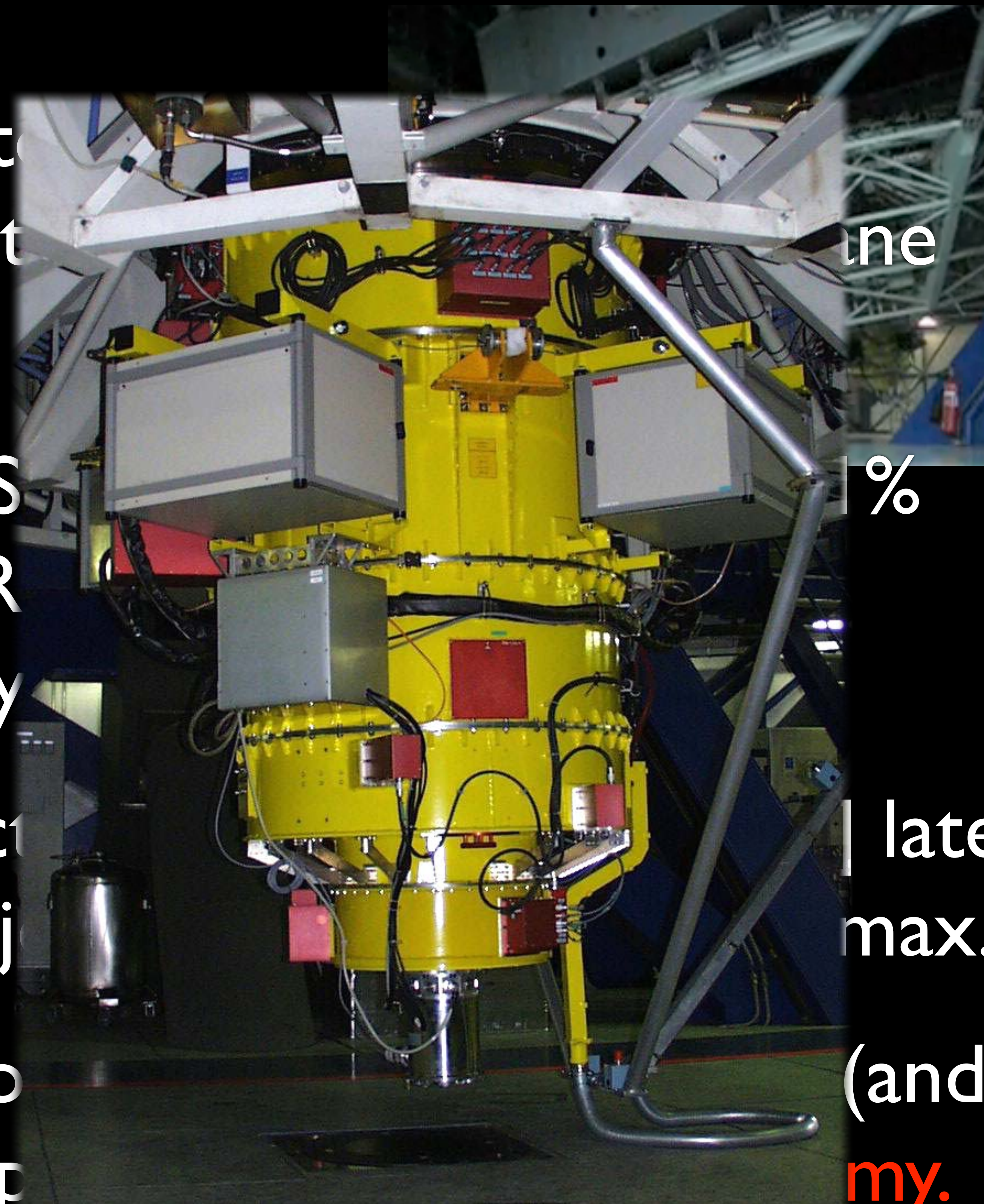

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but, on the positive side, ...

“Spectropolarimetry is a straightforward, powerful diagnostic tool for supernova explosions. Contrary to conventional perceptions that the interpretation of polarimetry data is complicated and heavily model dependent, many important insights on the geometric structure of supernovae ejecta can be derived from diagnostic analyses that do not rely on detailed modeling"

(Wang+ 2006, on SN2004dt)

A SN Polarization Primer/I

Acquiring polarization by Thomson scattering on e^-

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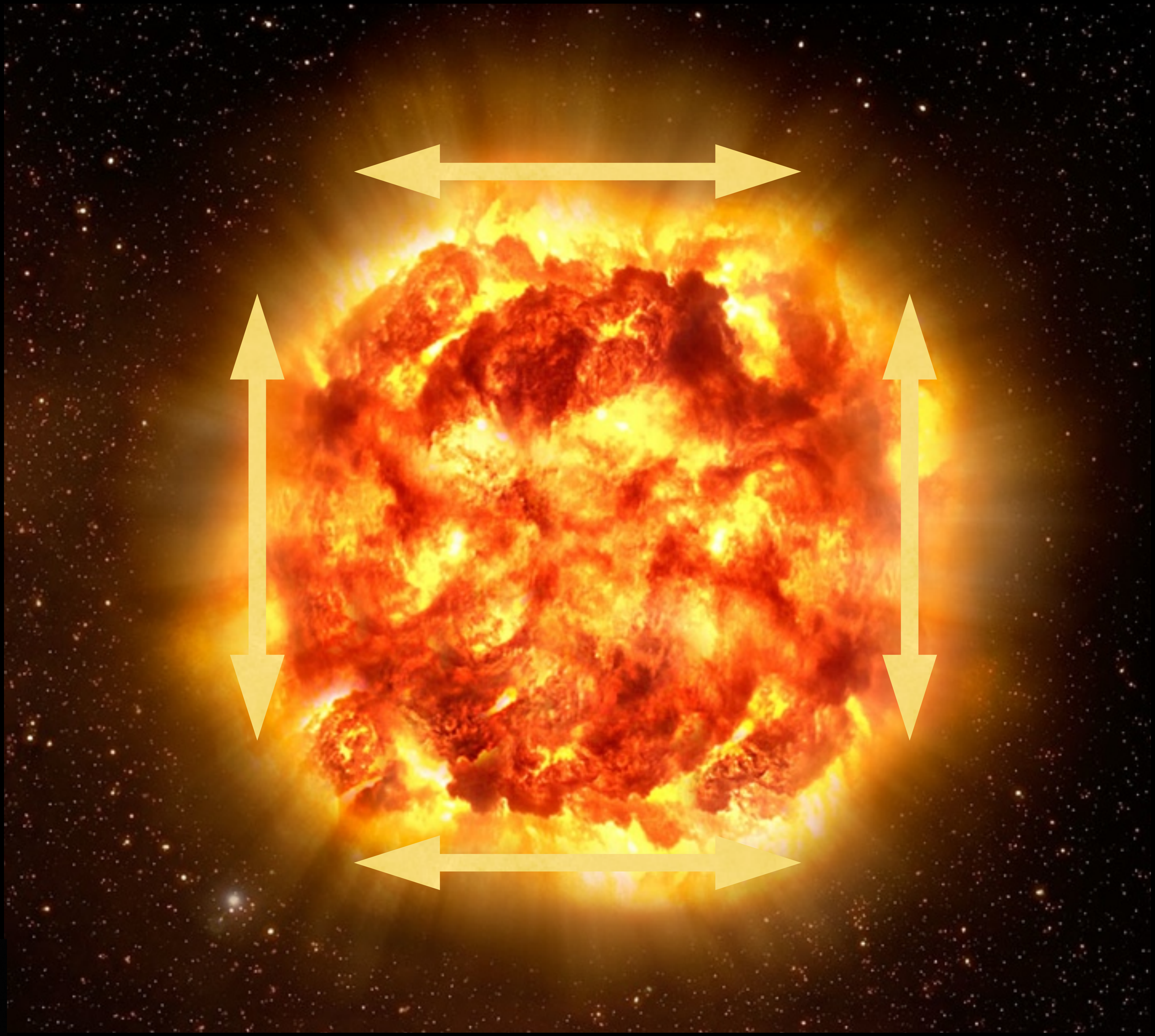

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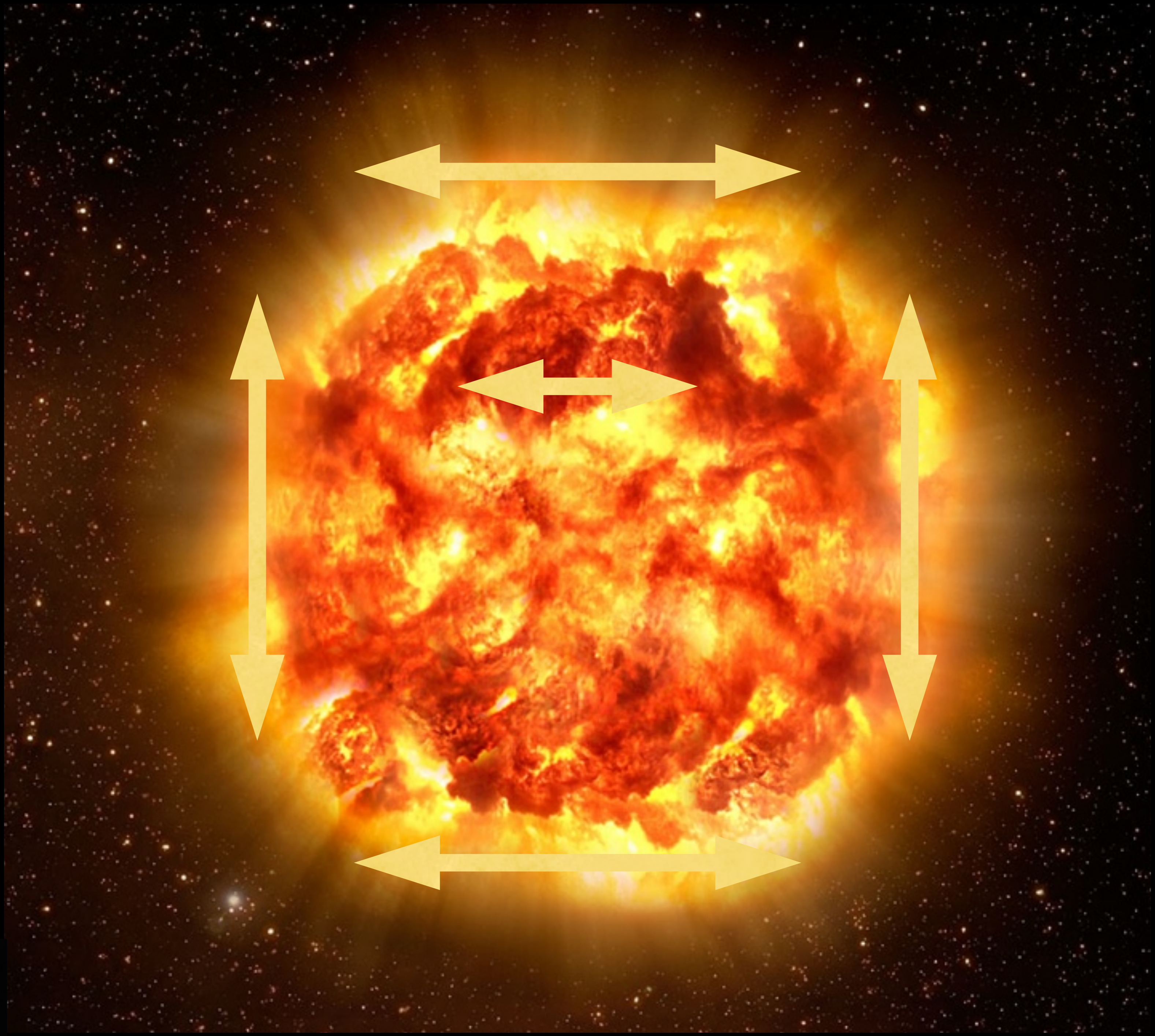

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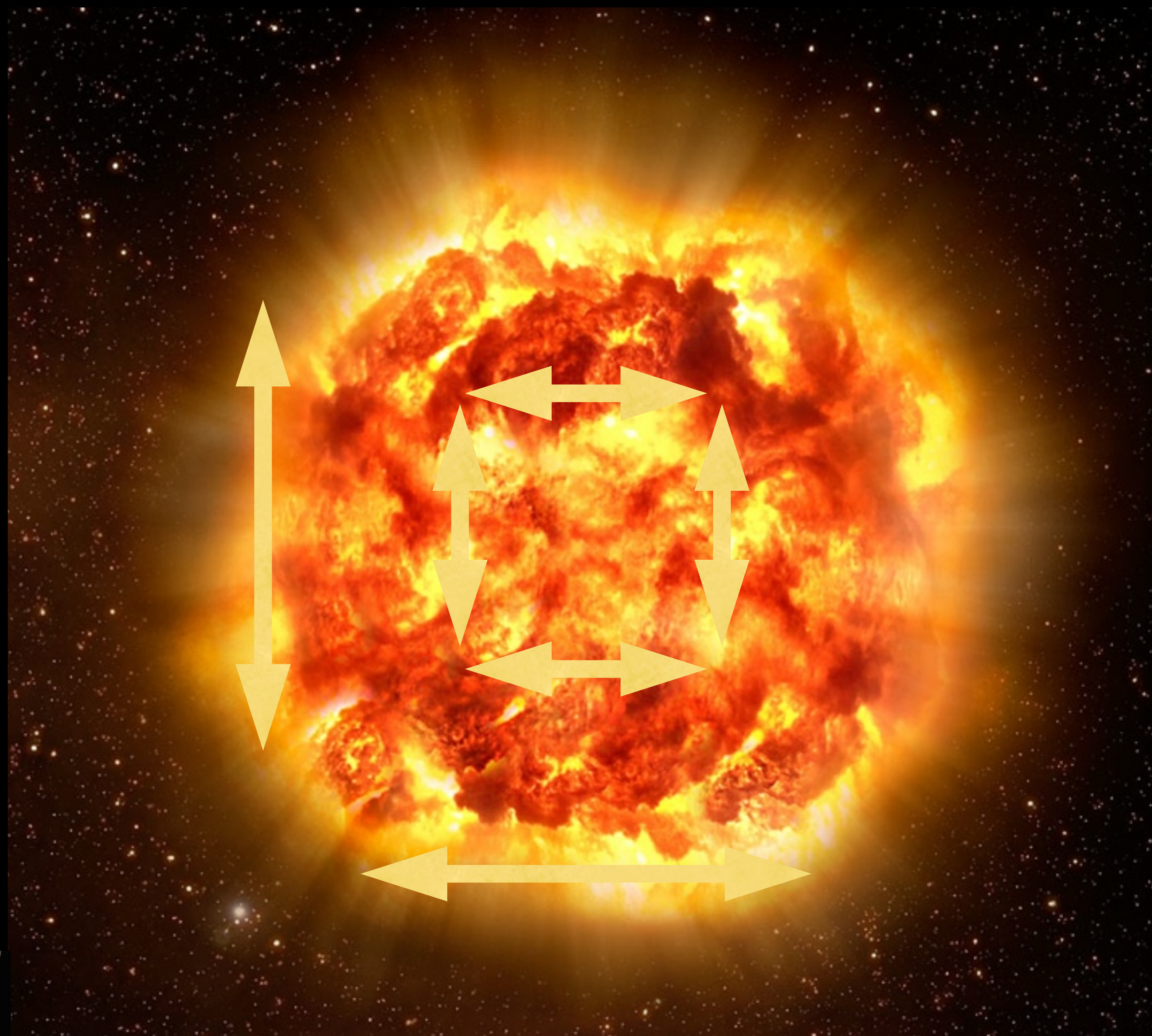

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A SN Polarization Primer/II

Incomplete cancellation by overall asymmetry

A SN Polarization Primer/II

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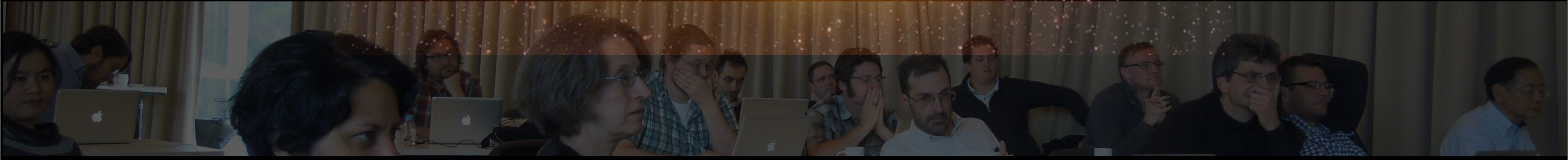
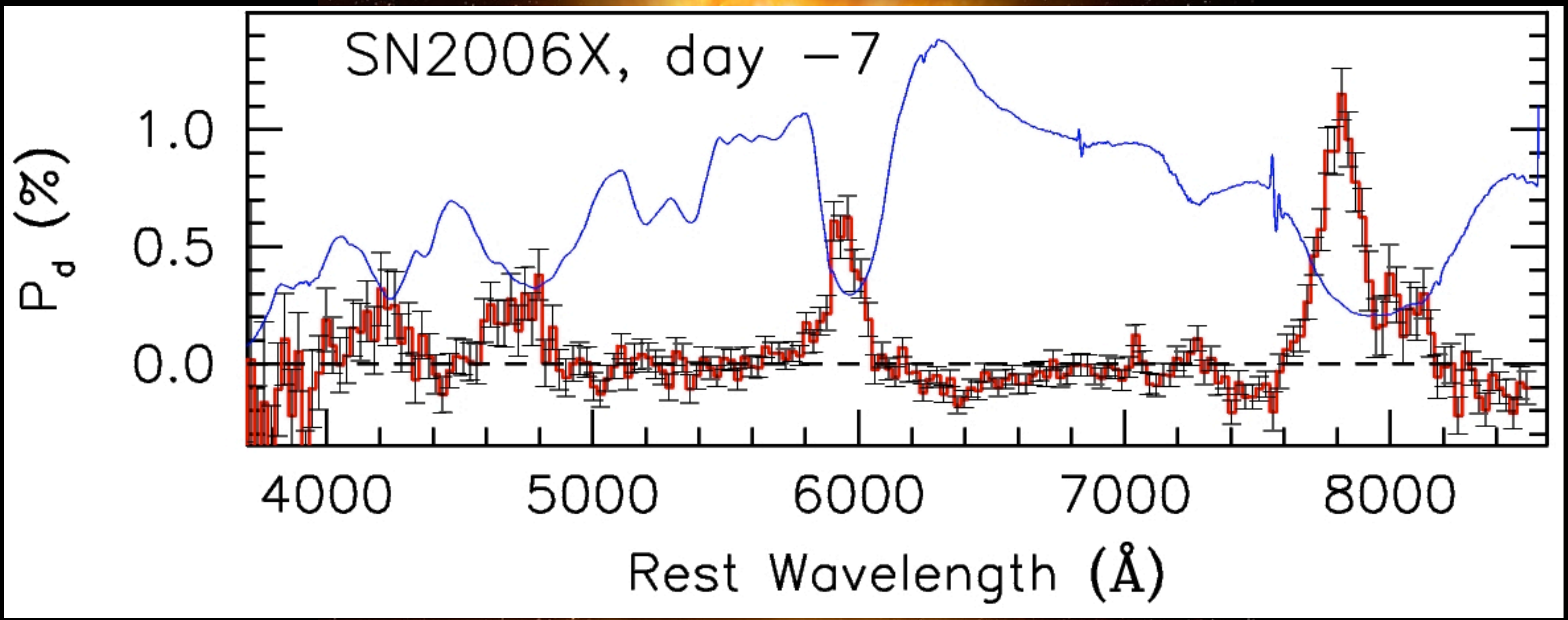
A SN Polarization Primer/III

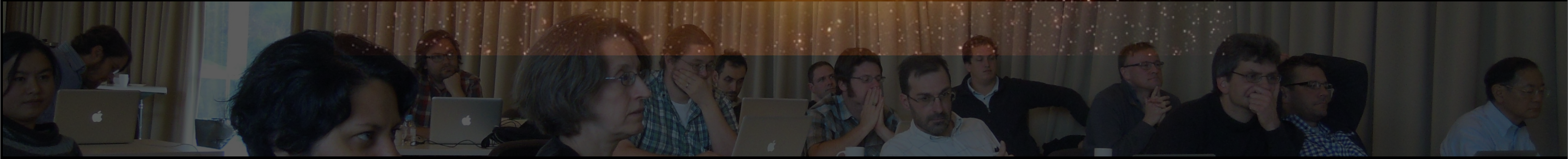
Incomplete cancellation by chemical asymmetry



A SN Polarization Primer/III

Incomplete cancellation by chemical asymmetry





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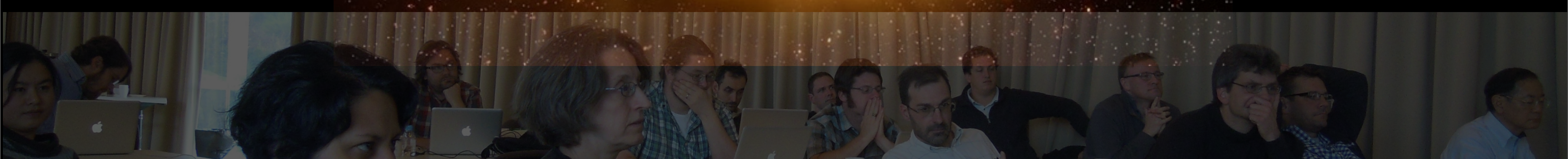
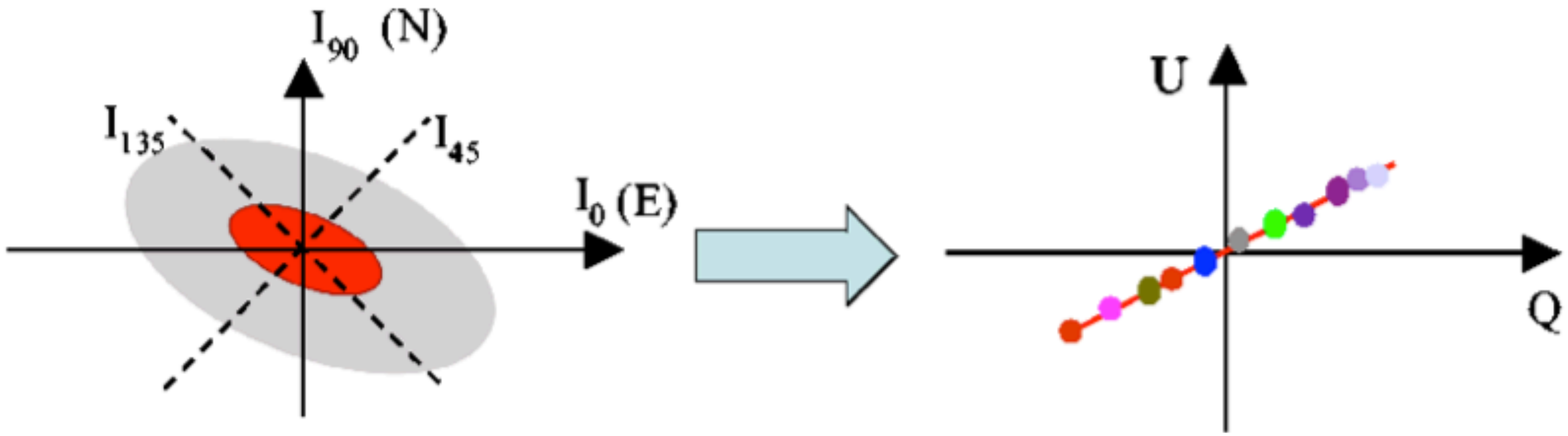
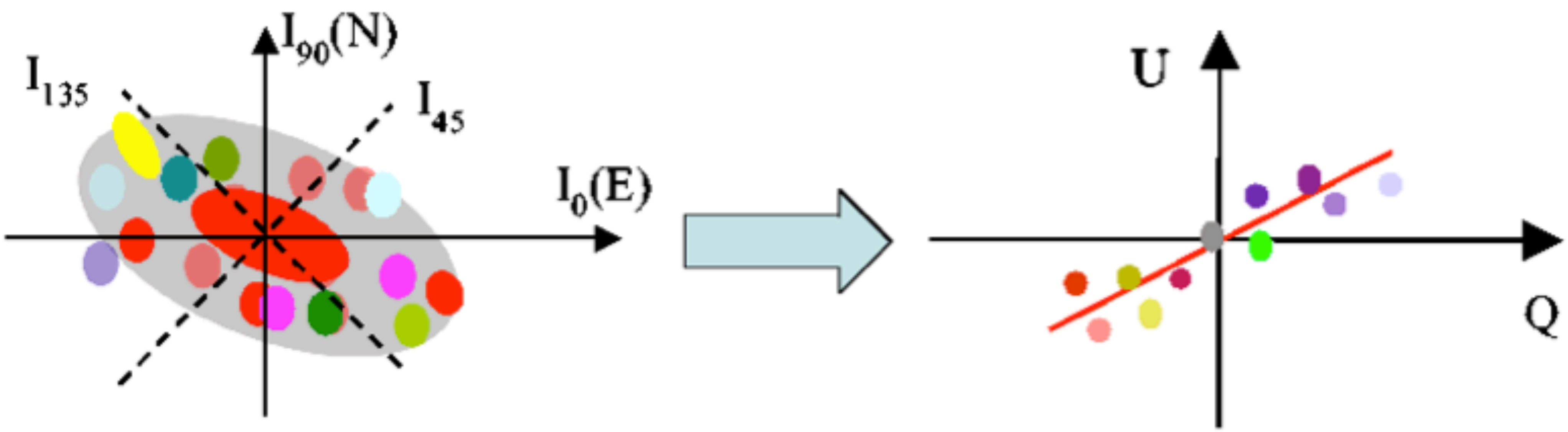


Introducing the Q-U plane

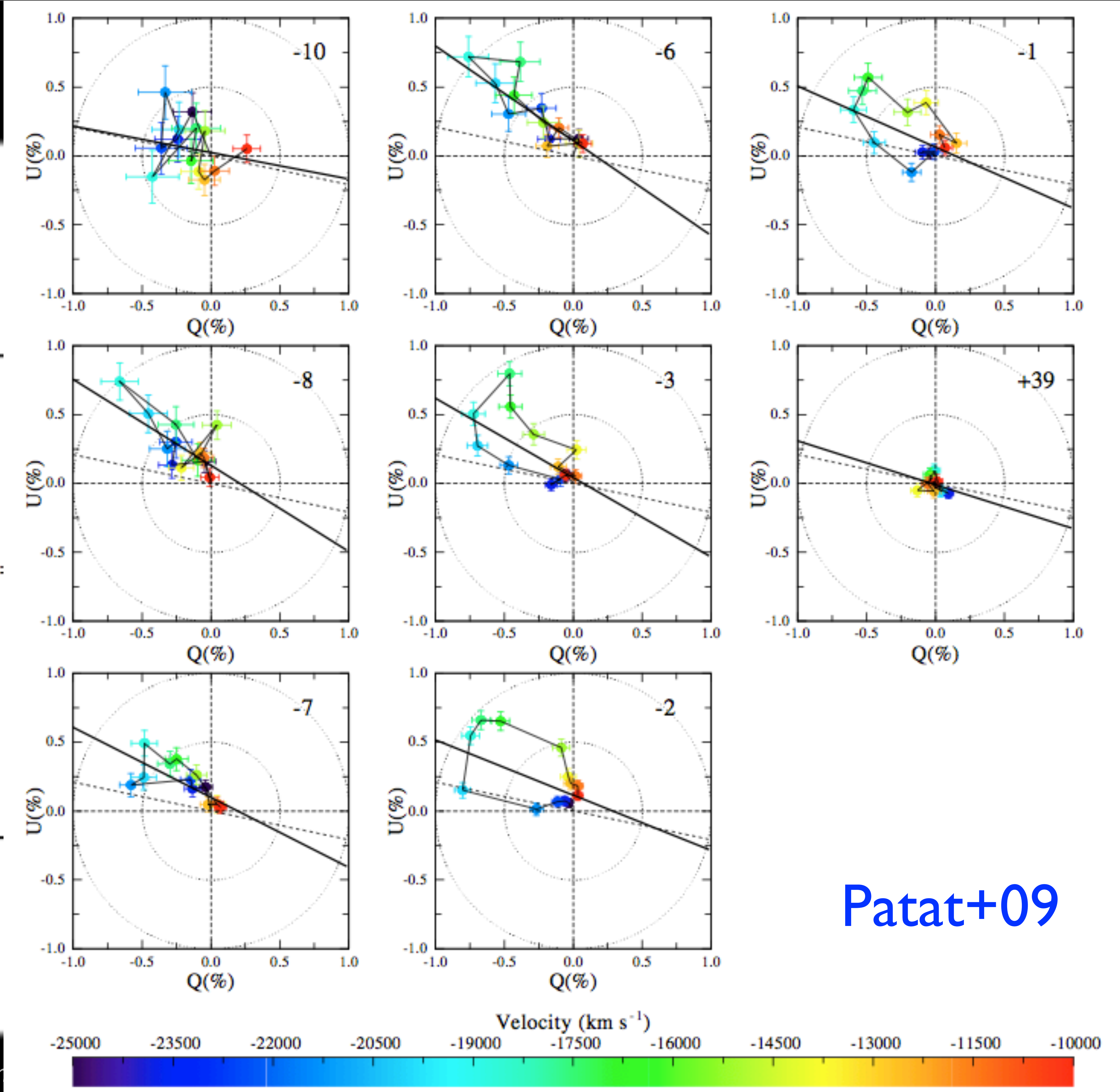


$$P = \frac{\sqrt{\hat{Q}^2 + \hat{U}^2}}{I} = \sqrt{Q^2 + U^2},$$

$$\theta = \frac{1}{2}\arctan\frac{\hat{U}}{\hat{Q}},$$



WW08


-10
-6
-1
-8
-3
+39
-7
-2
Q(%)
U(%)
Velocity (km s⁻¹)
-25000
-23500
-22000
-20500
-19000
-17500
-16000
-14500
-13000
-11500
-10000

Patat+09

'08

P

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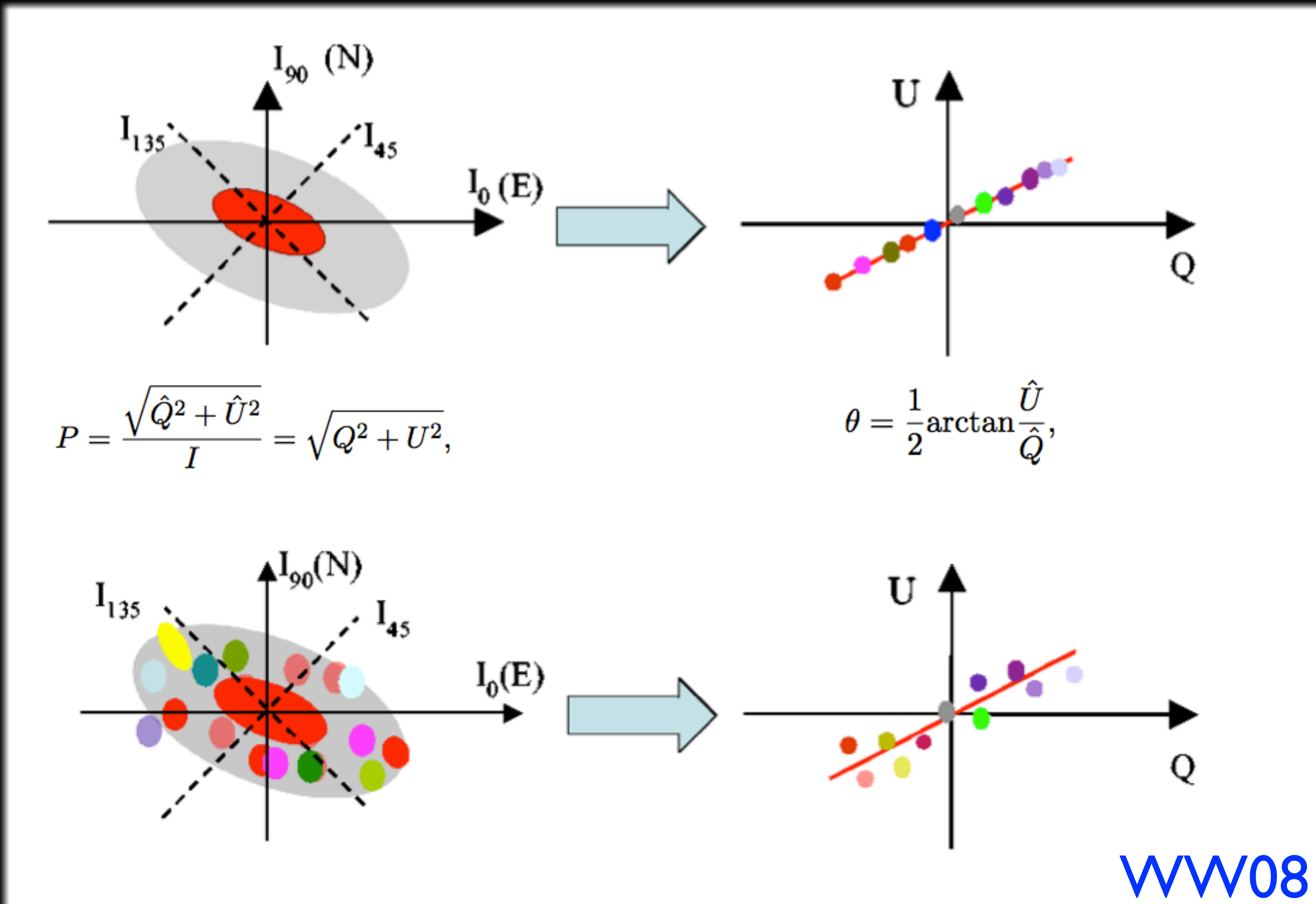

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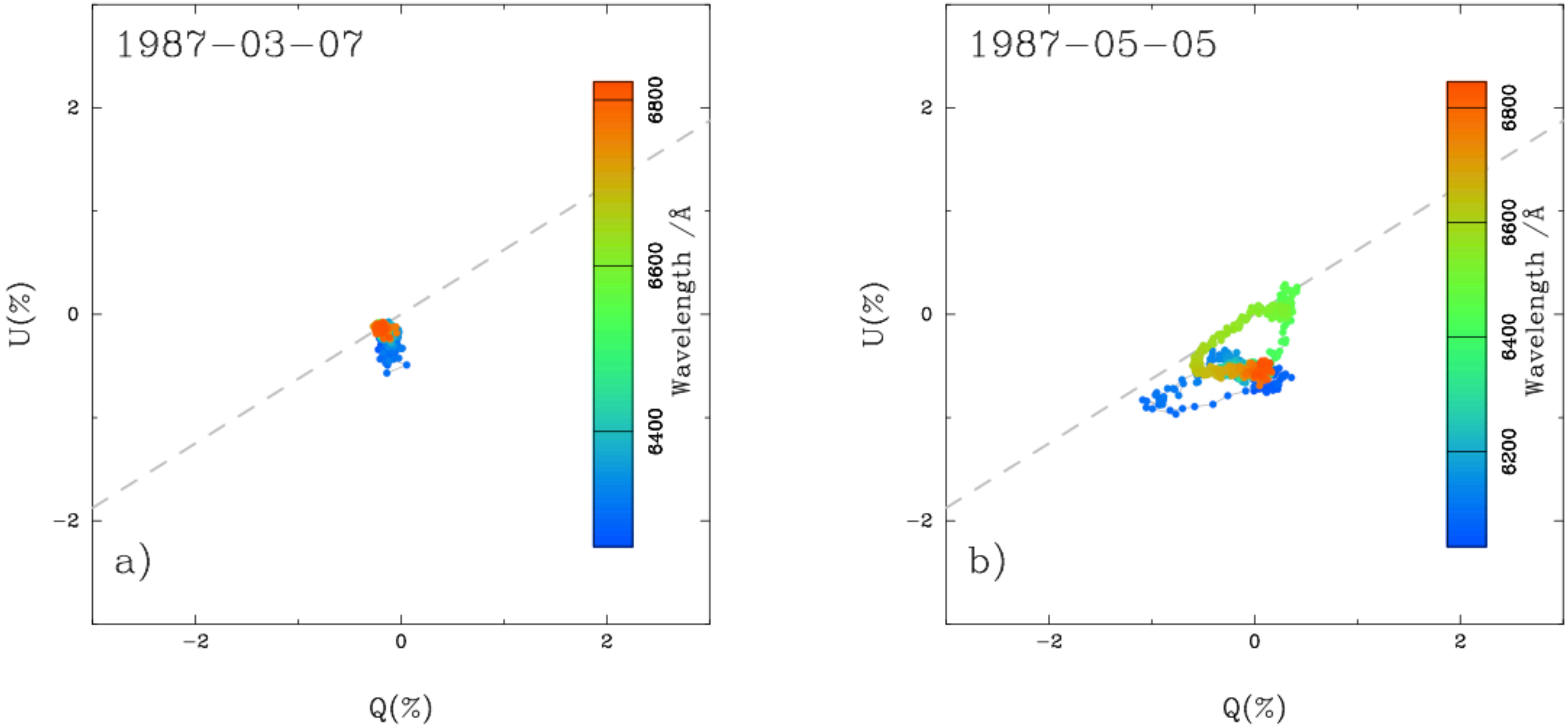
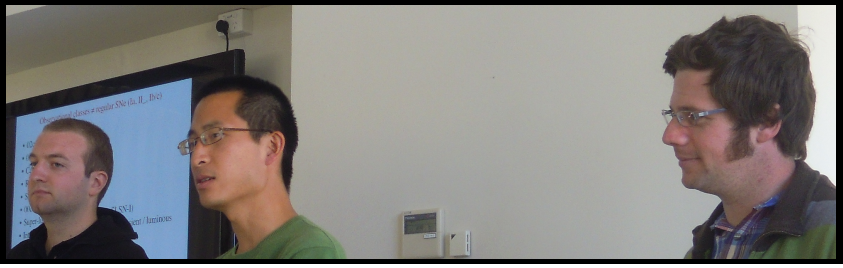
- The overall structure of SN 1987A was remarkably axially symmetric from deep inside the oxygen rich zone out to the hydrogen envelope.
- Persistent polarization position angle of the dominant axis across a broad wavelength range; lack of significant evolution of the polarization position angle indicate the photosphere at early and late epochs shares the same geometric structure.

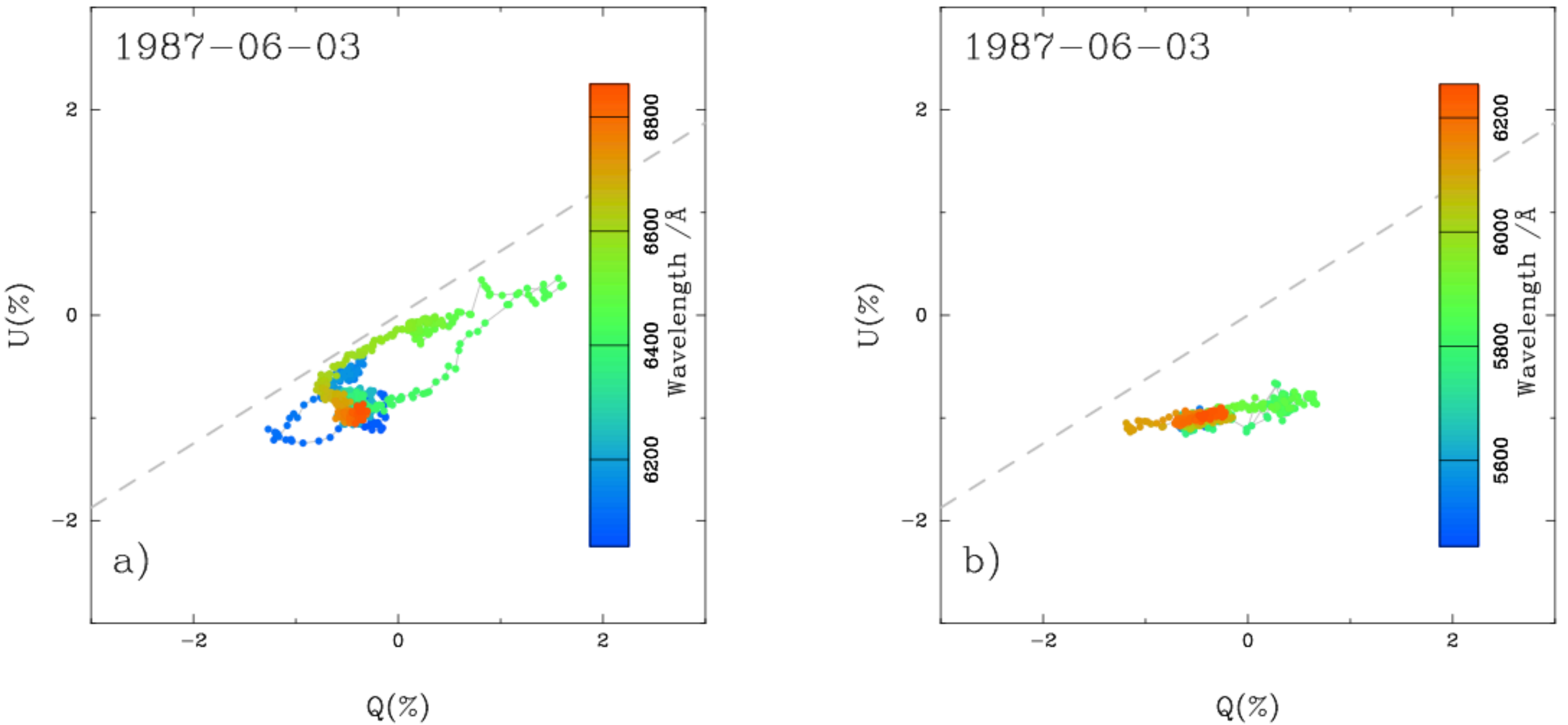
SN1987A/2



The likely cause for departure from spherical symmetry is the non-spherical distribution of the source of ionization in the form of a “lump” of radioactive nickel and cobalt (Chugai 1992). Aligned with the “mystery spot” (Meikle 1987; Dotani 1987). Dominant axis 15 deg off w.r.t. CS rings (Wang+02).

SN1987A/2





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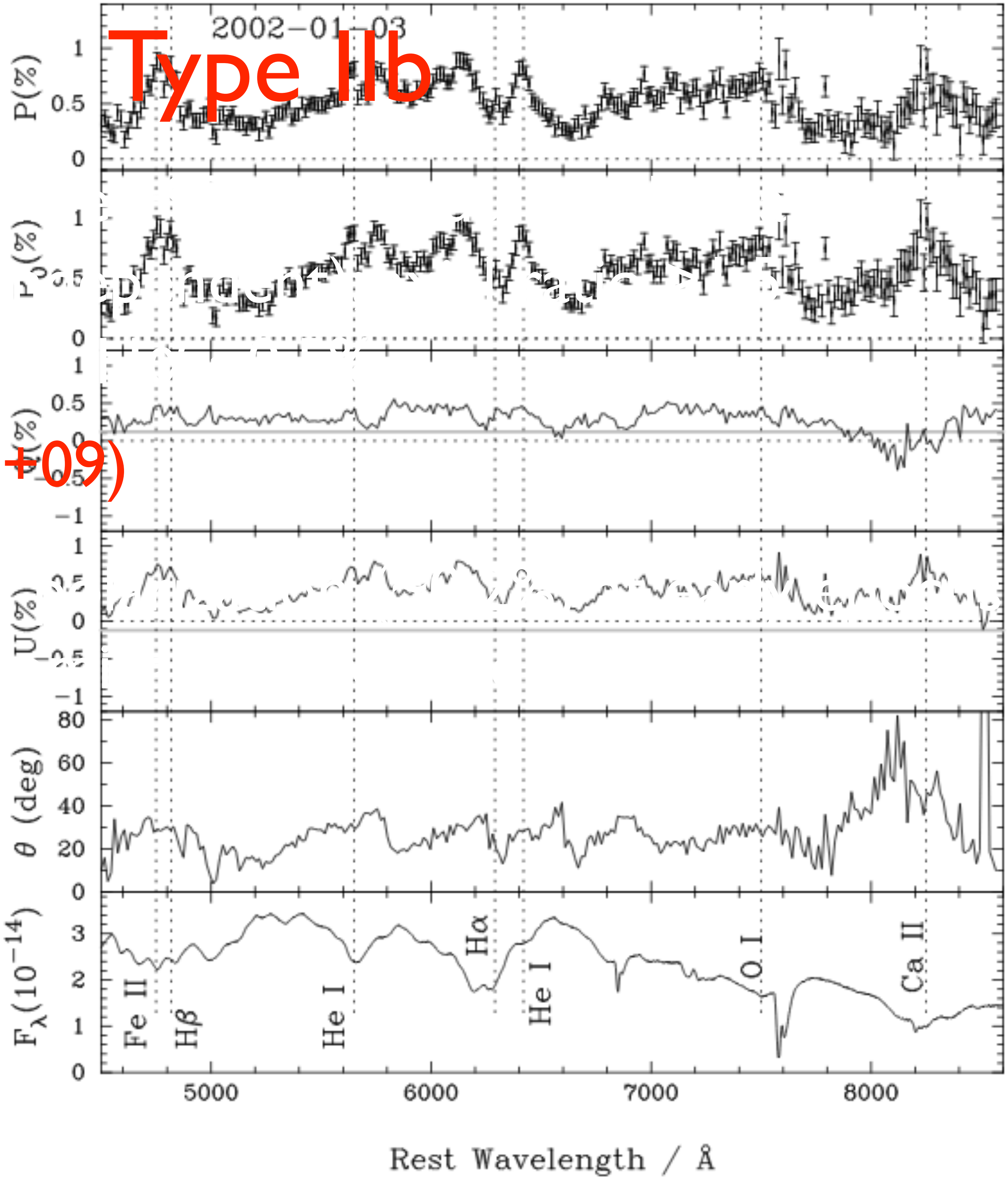

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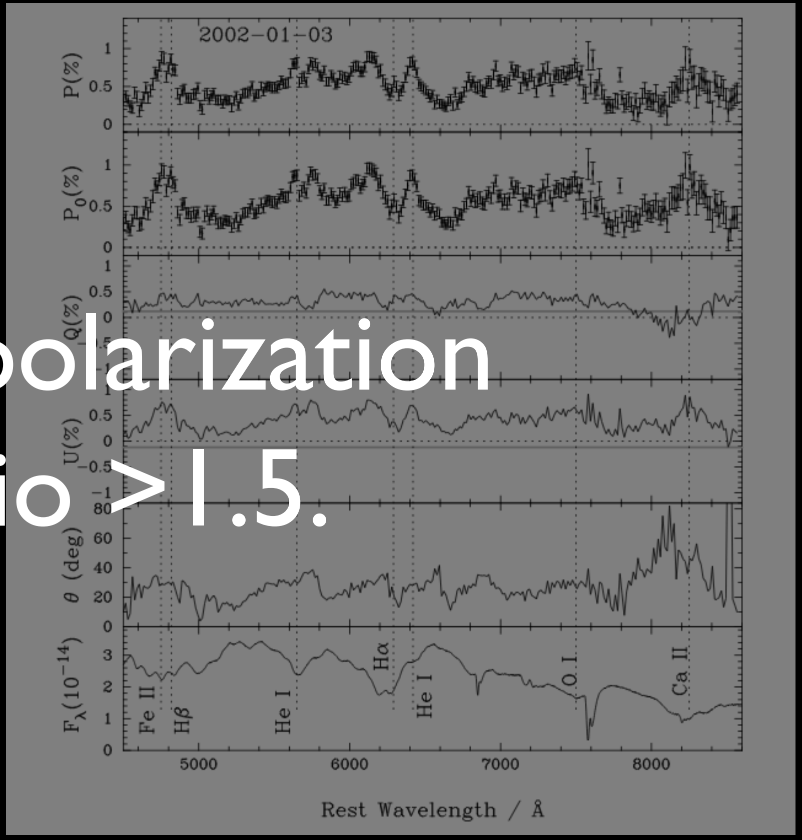

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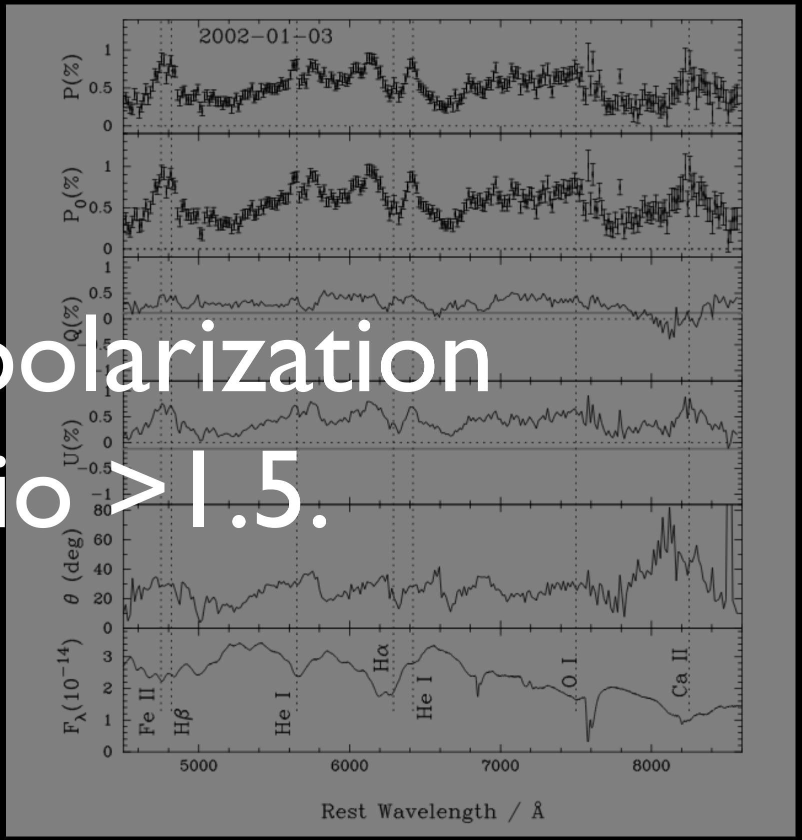

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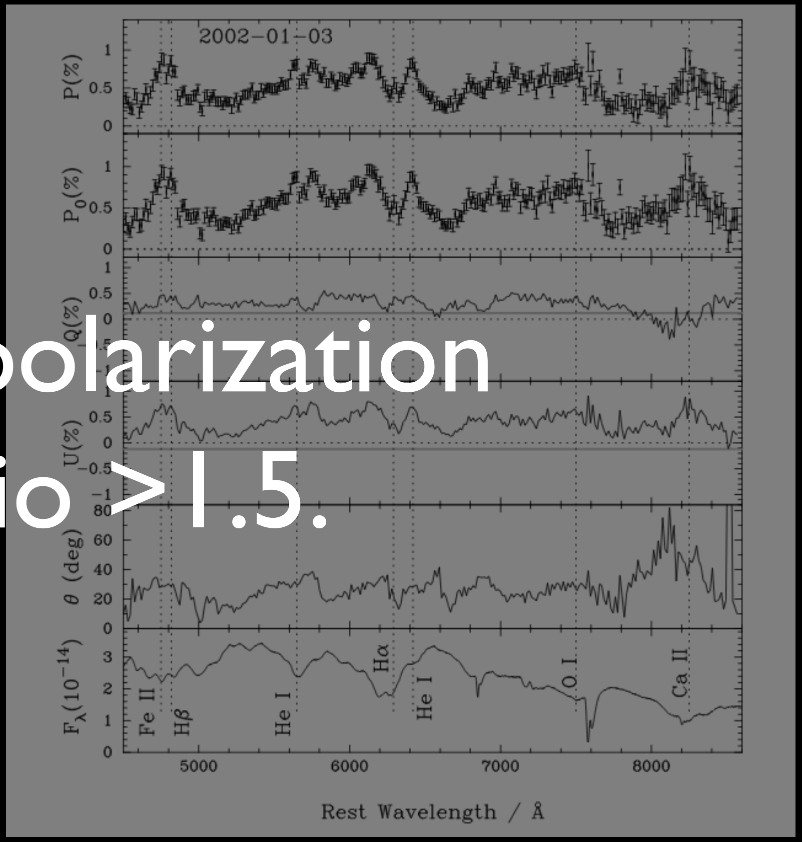

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- He asymmetries (HeI5876, 6678: ~0.8%).

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- Differences in 1993J, 1996cb, 2001ig tell us that IIb are not geometrically homogeneous.

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- Indications of jet-like explosions
- A likely cause of the early polarization is an asymmetric distribution of radioactive elements that distorts the ionization and excitation structure even though the density structure remains essentially spherically symmetric (Chugai, 1992; Hoeflich+01)

Type IIn

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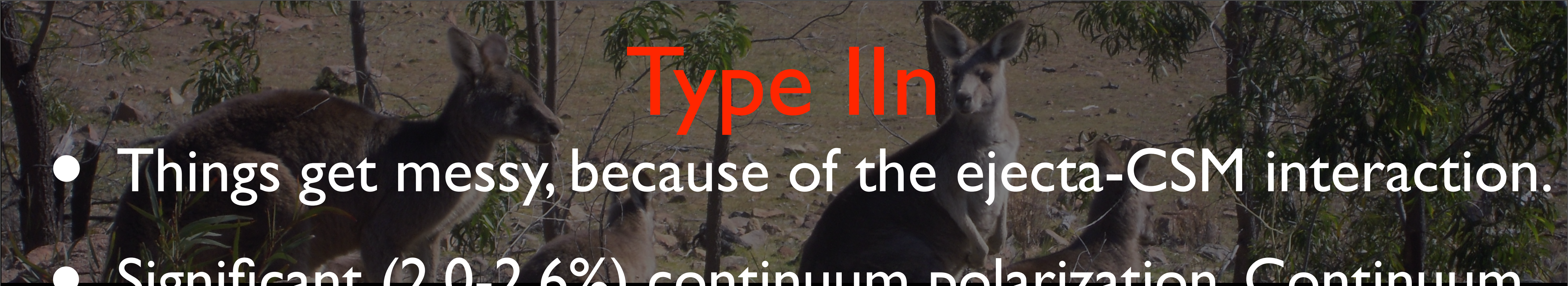
- Things get messy, because of the ejecta-CSM interaction.



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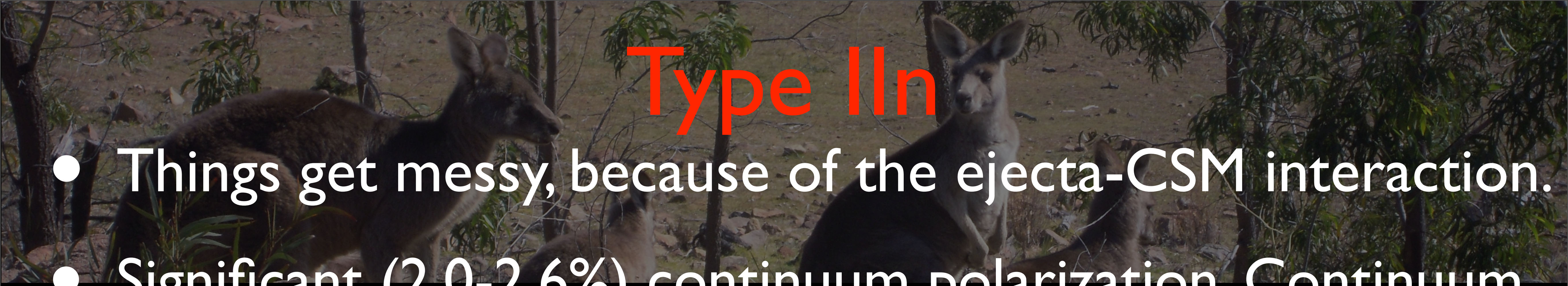

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- significant depolarization @ Hαβγ, HeI

Type IIn (2010jl)

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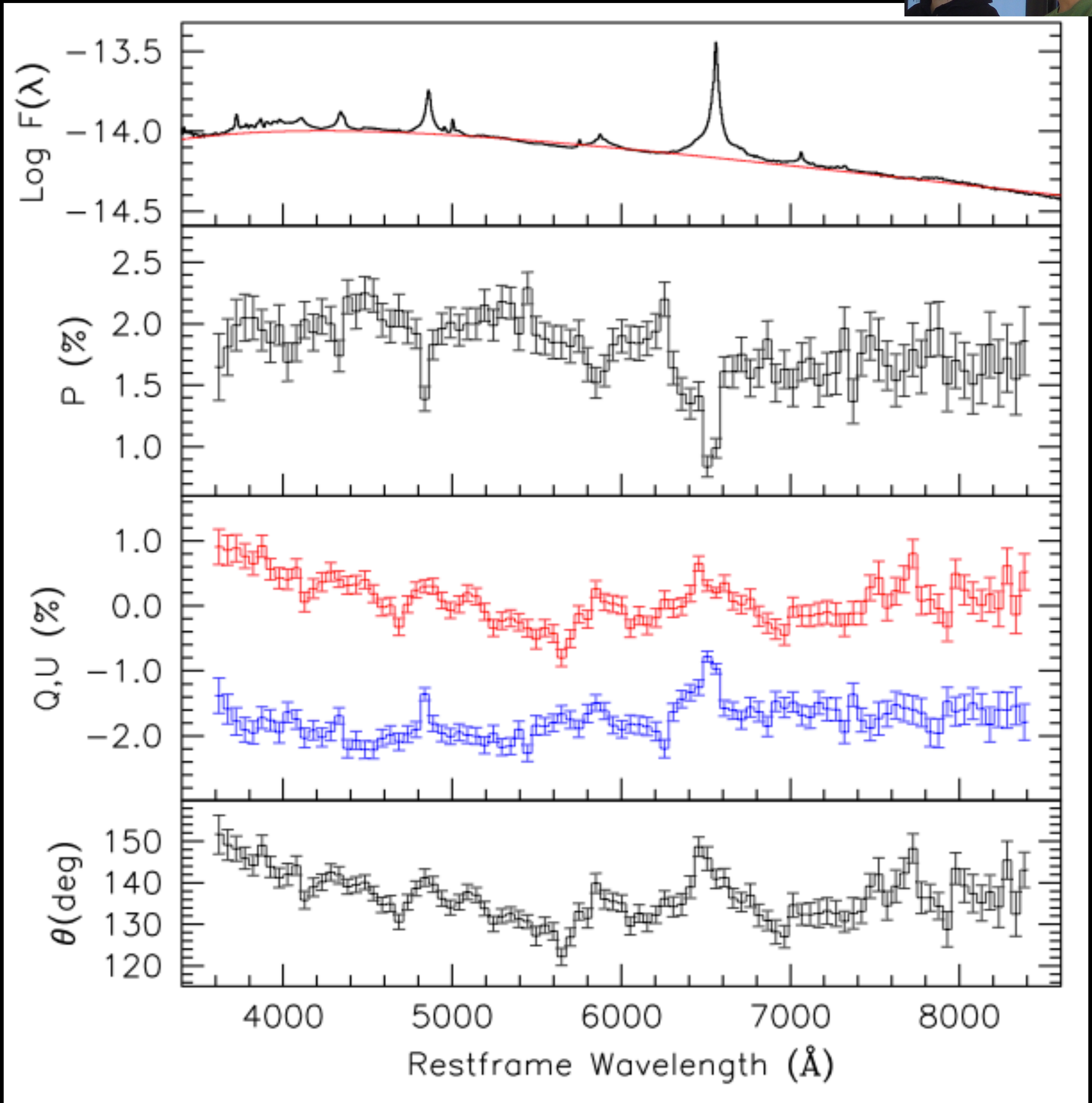
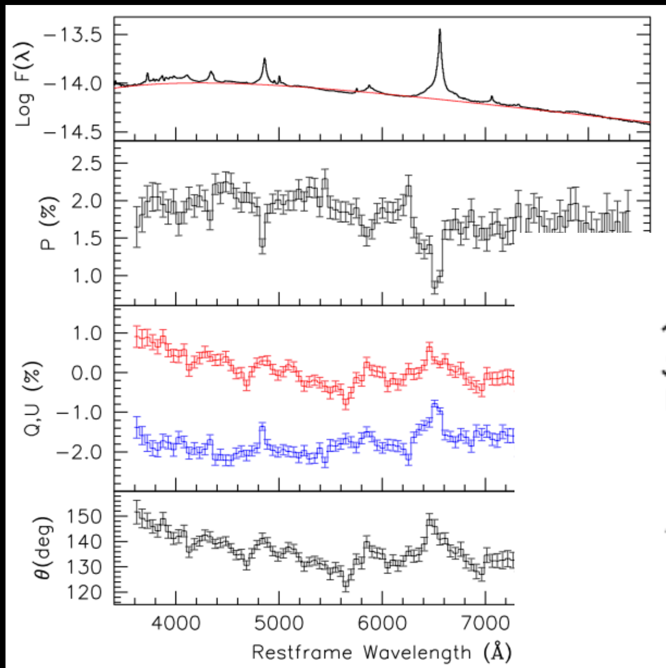
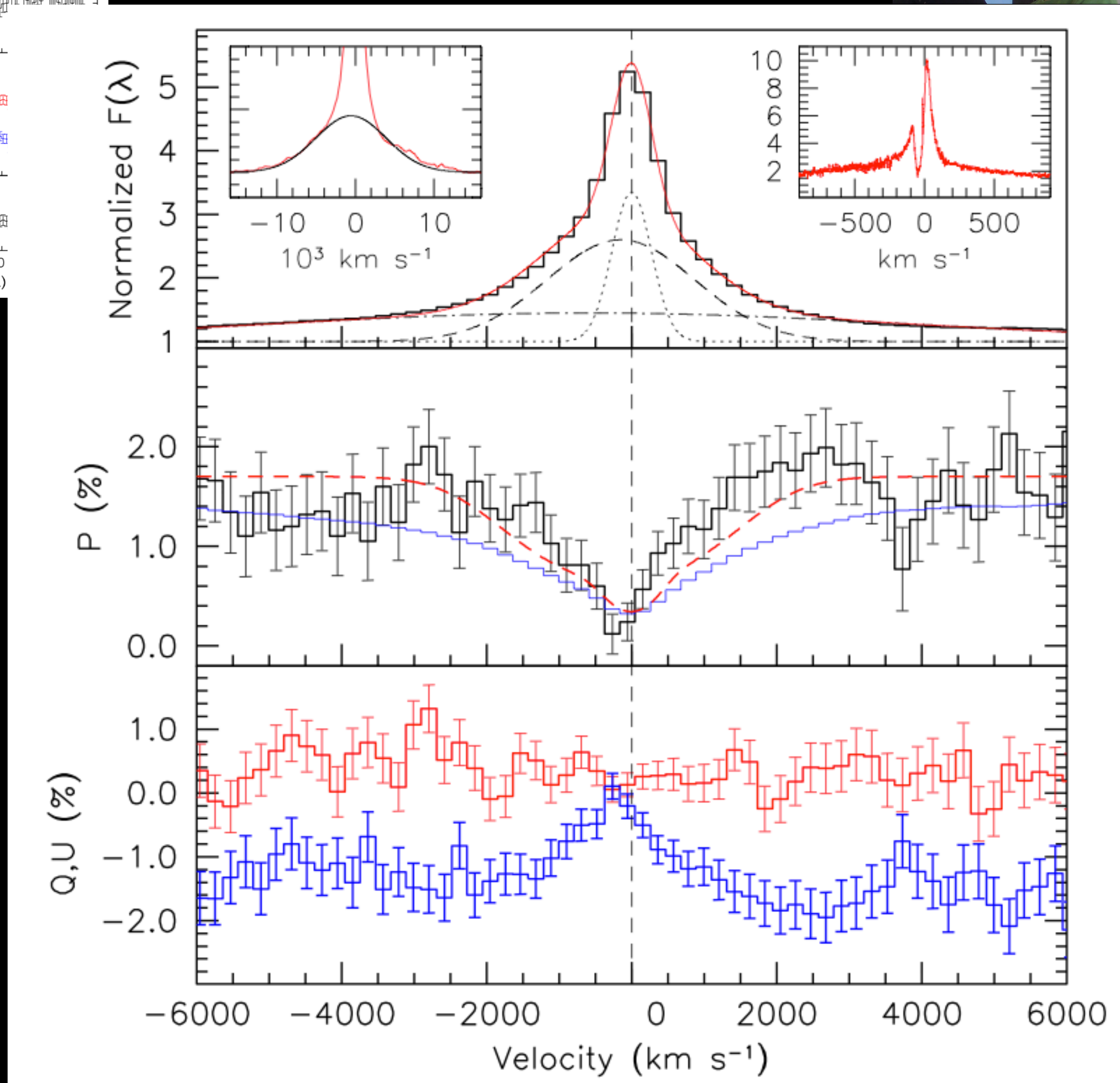
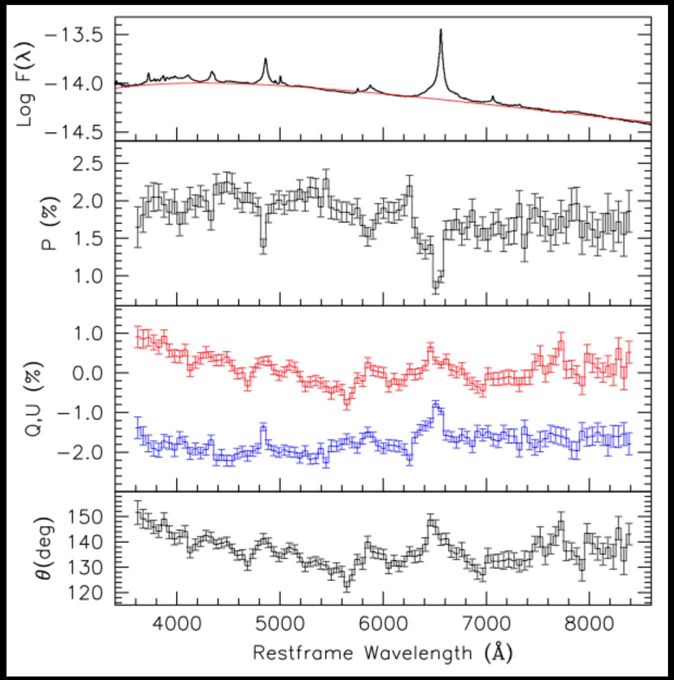


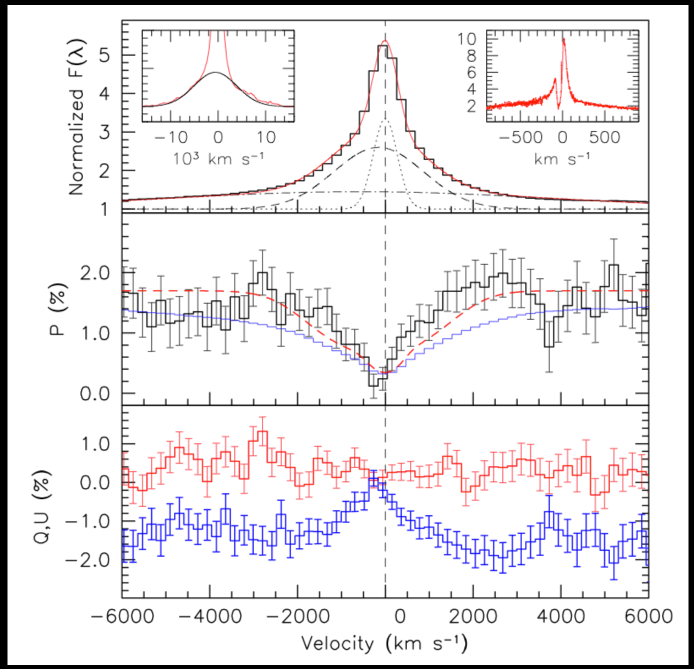
Type IIn (2010jl)



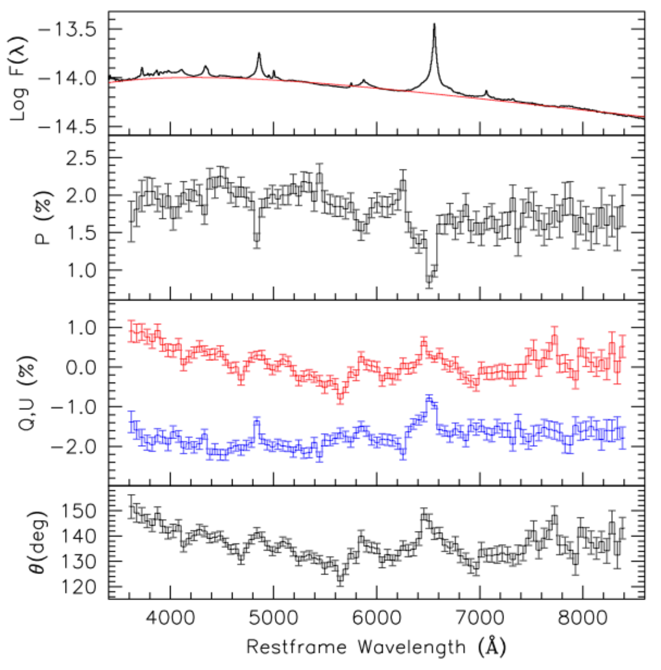


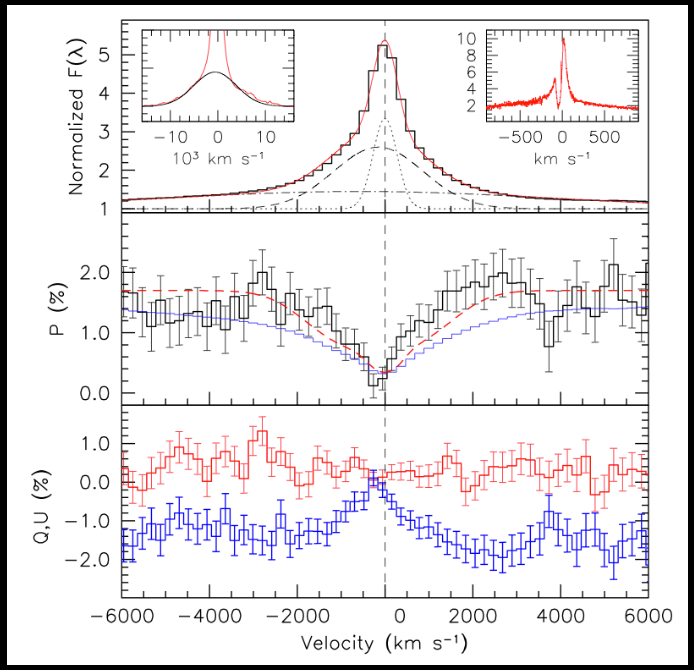
Type IIn (2010jl)



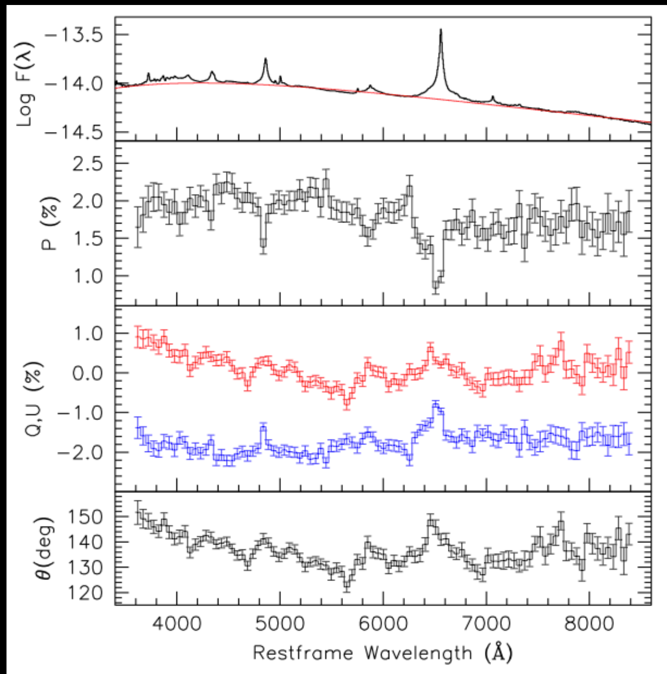


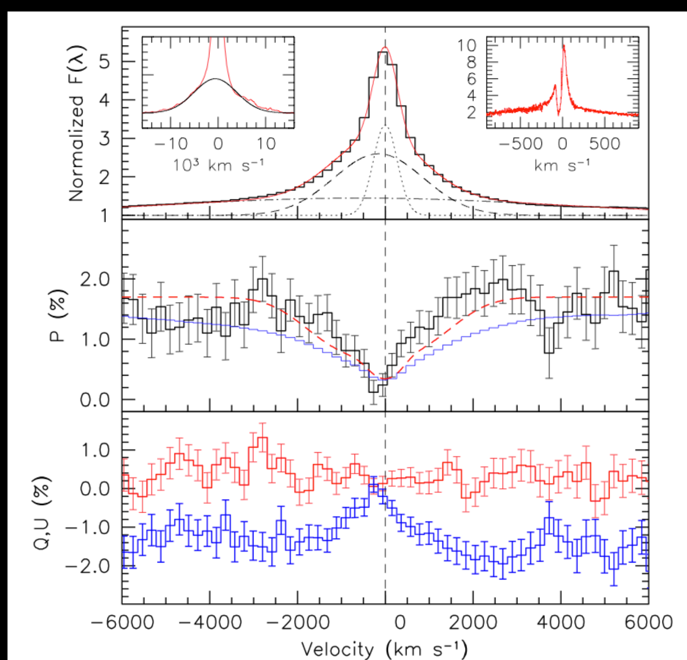
Type IIn (2010jl)





- Narrow and intermediate components must arise well above the electron scattering photosphere
- The broad component (FWHM=10,000 km/s) is not depolarized (see Chugai 2001). Obscuration of blue side (see Shivvers' talk)
- Complete depolarization of Hα (+dP/dλ~0) suggests small amounts of dust in the CSM (!). UV/shock dust destruction?
- The geometries of the broad-line region and the photosphere are different





Type IIn (2010jl)

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must arise well above the electr
scattering photosphere
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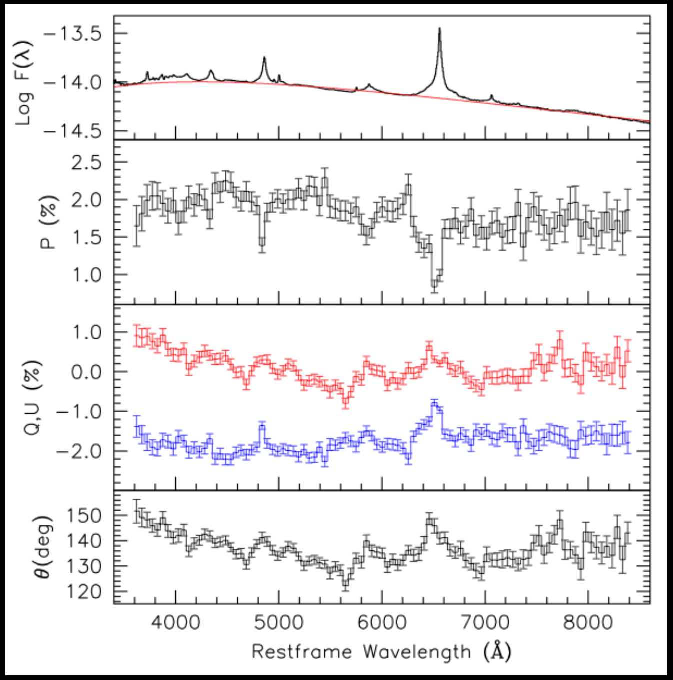
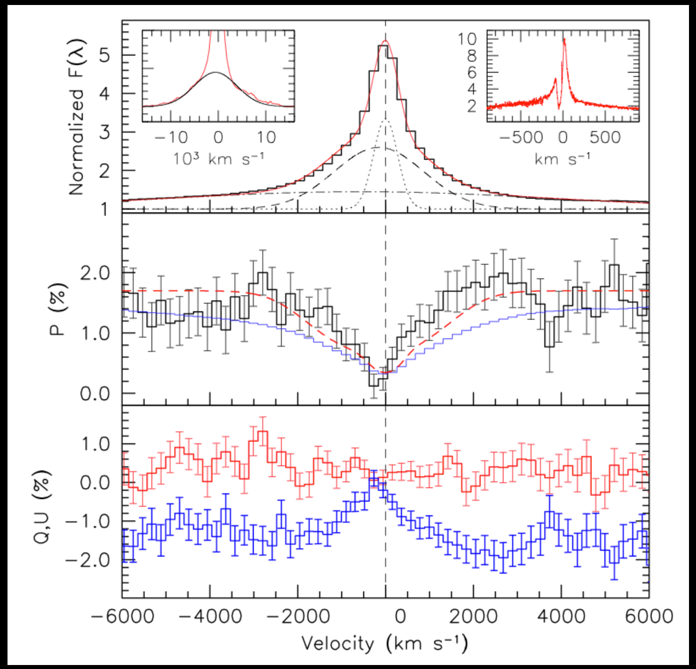
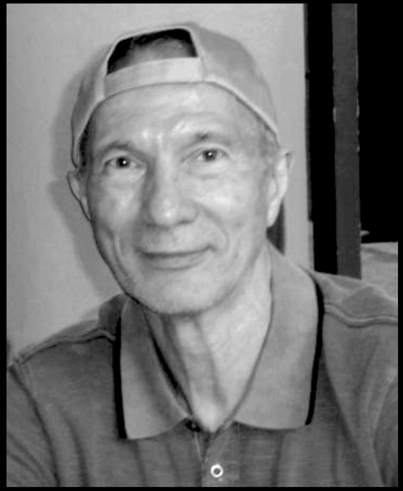
Type IIn (2010jl)







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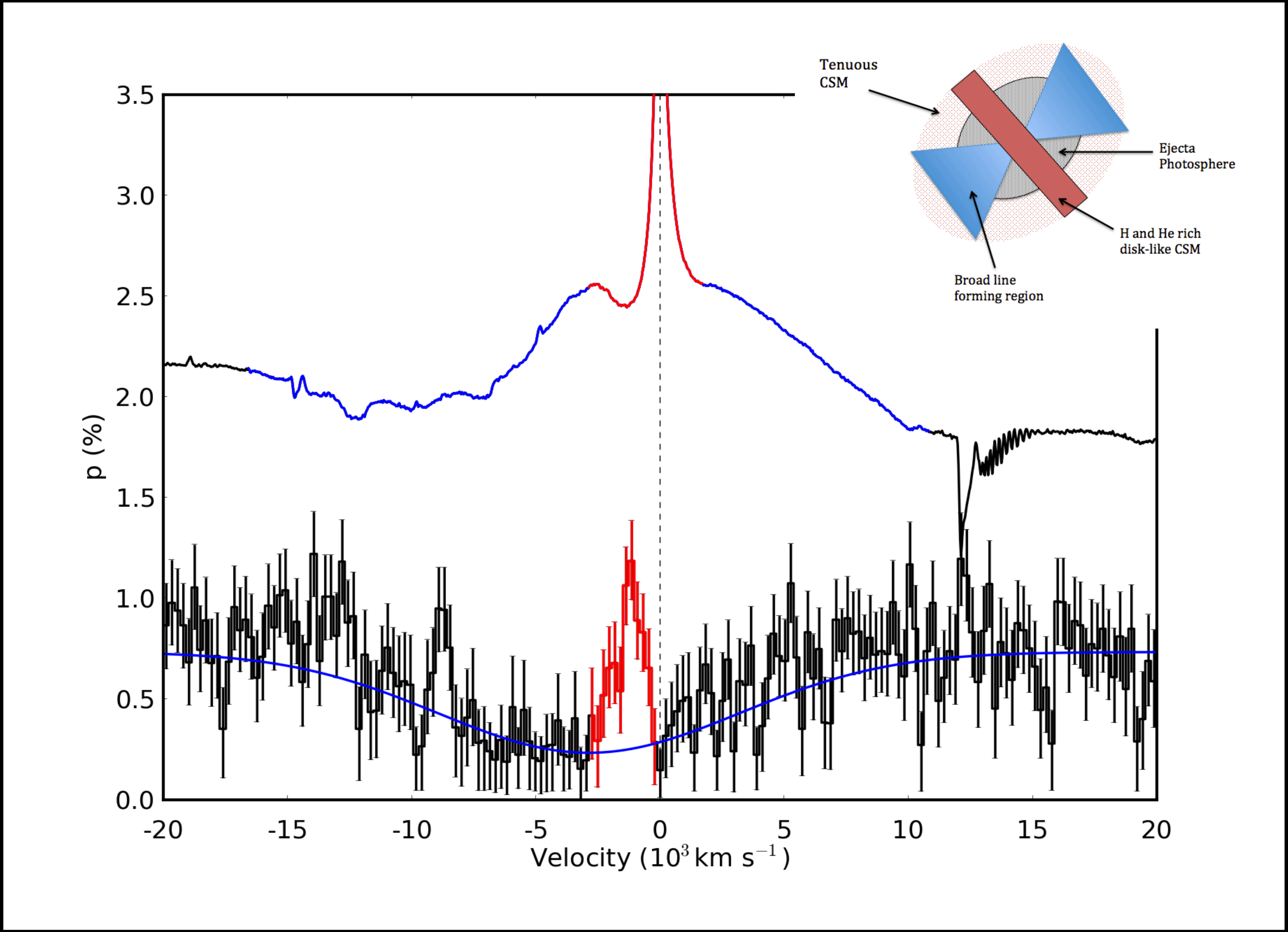
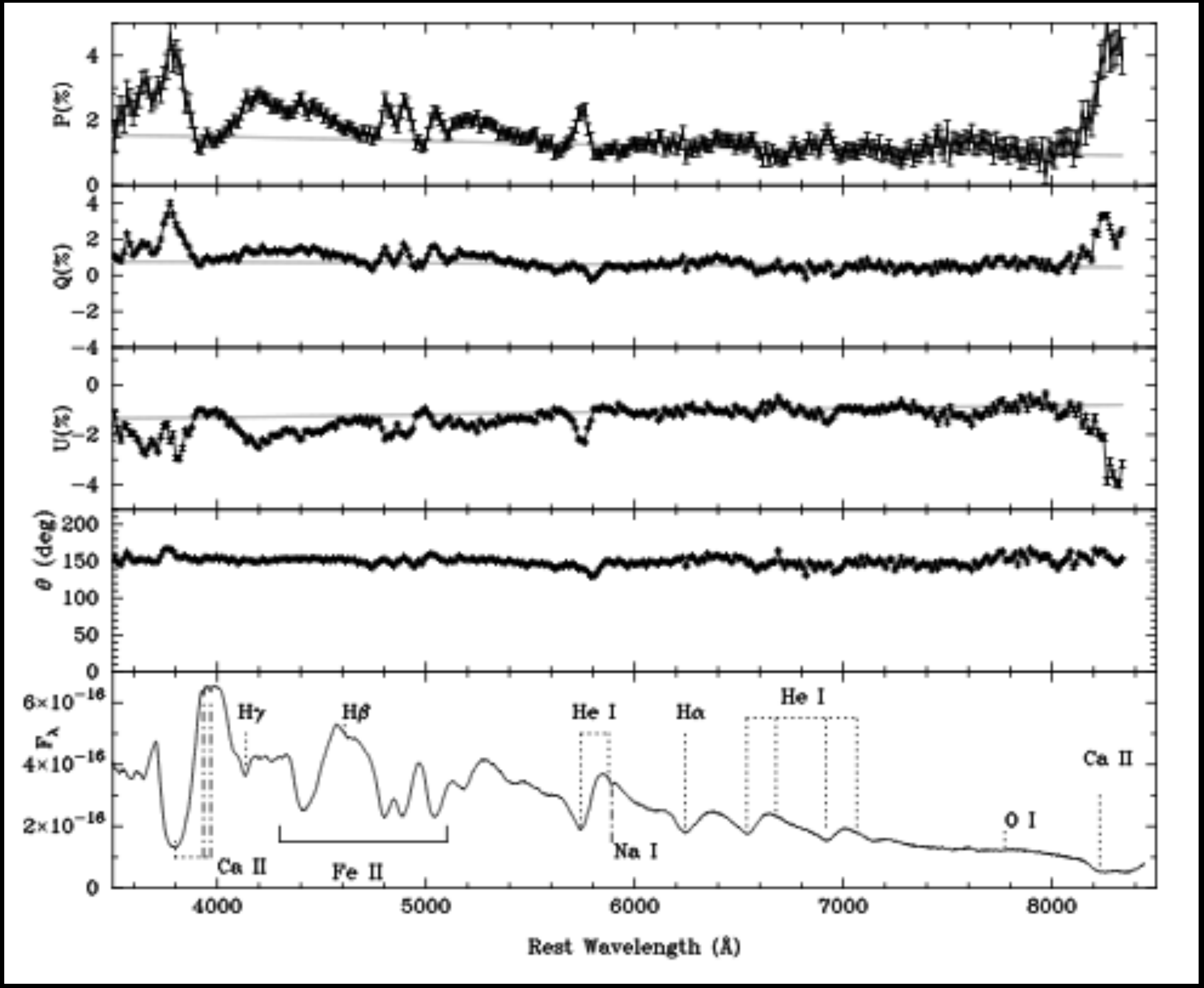
SN2009ip


Tenuous CSM
Ejecta Photosphere
H and He rich disk-like CSM
Broad line forming region
p (%)
Velocity (10^3 km s^{-1})
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-20
-15
-10
-5
0
5
10
15
20

Type Ib and Ic (some B-L)

Type Ib and Ic (some B-L)



2005bf Maund+07

Type Ib and Ic (some B-L)

Type Ib and Ic (some B-L)

- 1997X(Wang+01); 1998bw (Patat+01); 2002ap (Wang+02; Leonard+02;Kawabata+02); 2003dh (Kawabata+03); 2005bf (Maund+07;Tanaka+09); 2006aj (Maund+07; Mazzali+07); 2007gr (Tanaka +08); 2008D (Maund+09)

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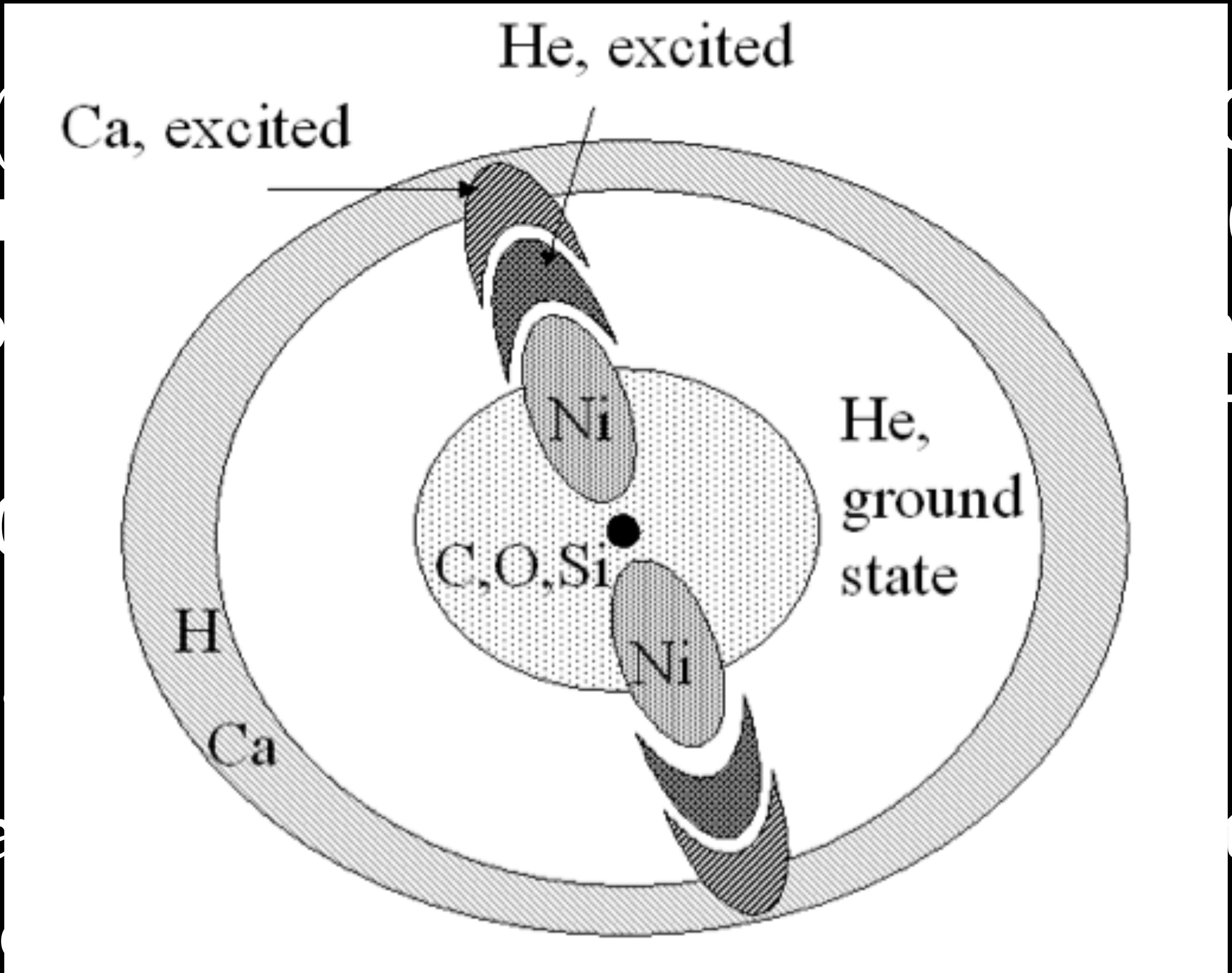
- There are variations, but all cases suggest the existence of a jet, possibly "stalled" within the core, or tilted-jet (tilted-jet paradigm).

Type Ib and Ic (some B-L)



- 1997X(02ap (Wang+ 03dh (Kawab +09); 2006aj Tanaka +08); 20
- Global
- There a the existen the core, or tilted-jet (tilted-jet paradigm).

Type Ib and Ic (some B-L)

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- Global asymmetries 10%-20%.
- There are variations, but all cases suggest the existence of a jet, possibly "stalled" within the core, or tilted-jet (tilted-jet paradigm).

Core-Collapse Summary

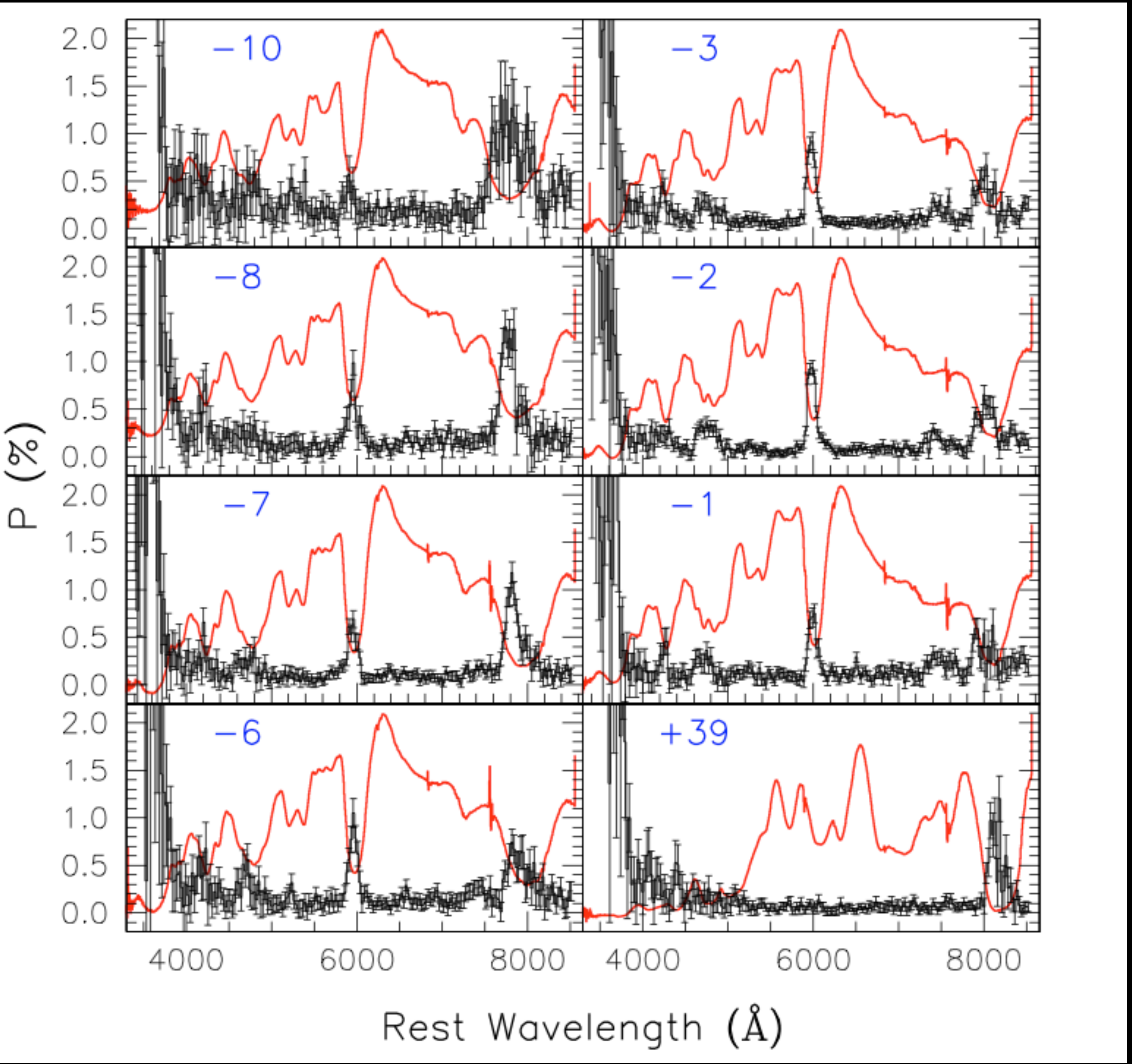
- They are all polarized and hence substantially asymmetric. This is a general property of core-collapse, not the peculiarity of single events. While each individual supernova has its own properties, basic themes emerge.

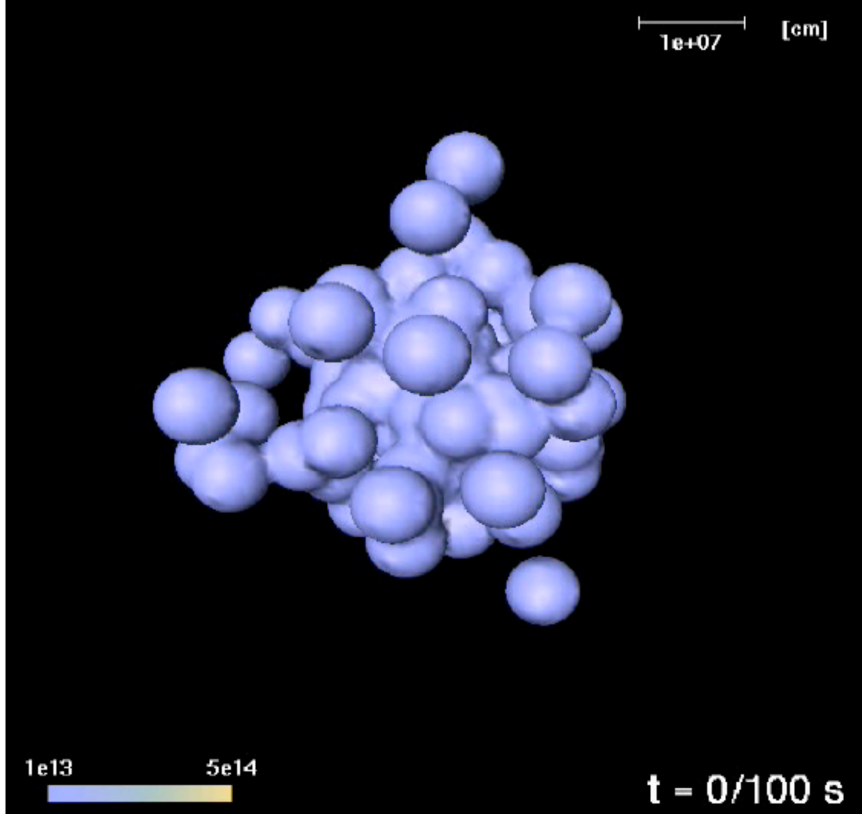
- The fundamental cause of the asymmetry is deep in the ejecta. It is a generic property of core collapse. The asymmetry is characterized by a dominant polarization angle. The most straightforward explanation is a jet.

- Atop this basic structure there are significant, composition-dependent structures that signal generic, large-scale departures from axial symmetry.

- Any physical model of core-collapse must address these facts.

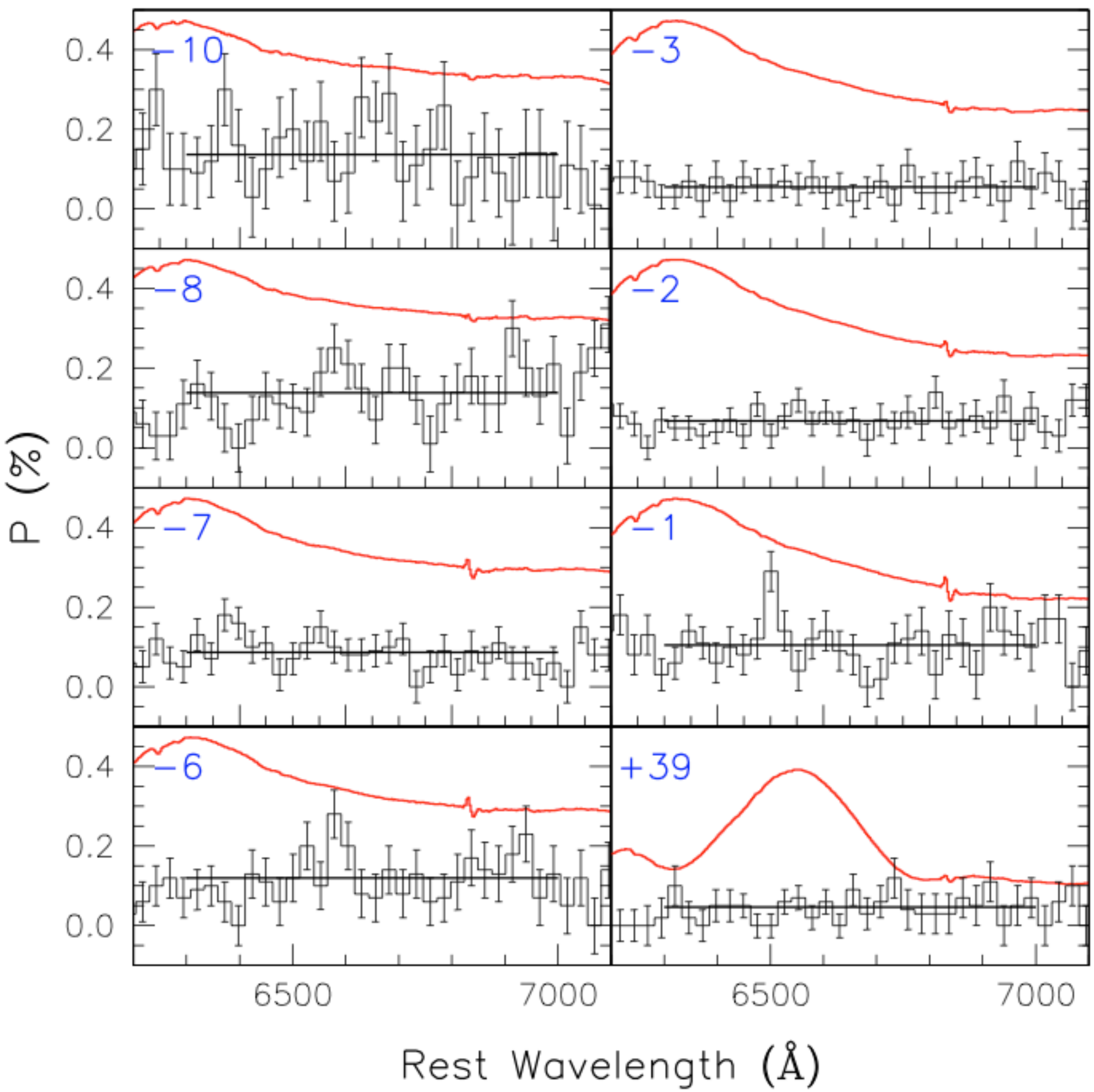
Type Ia/1

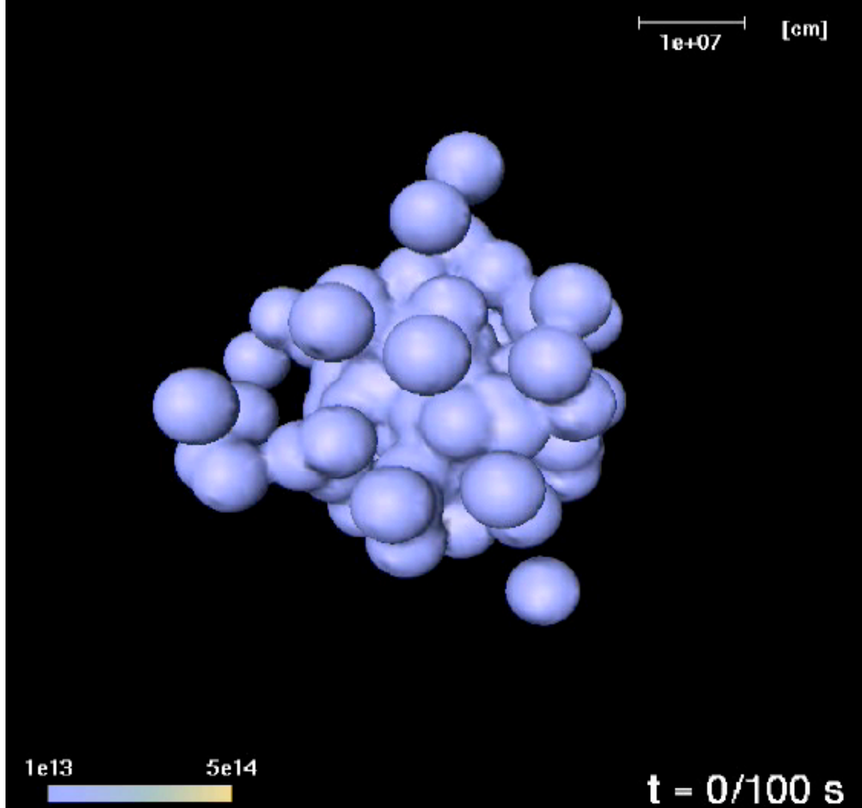




Courtesy of F. Roepke

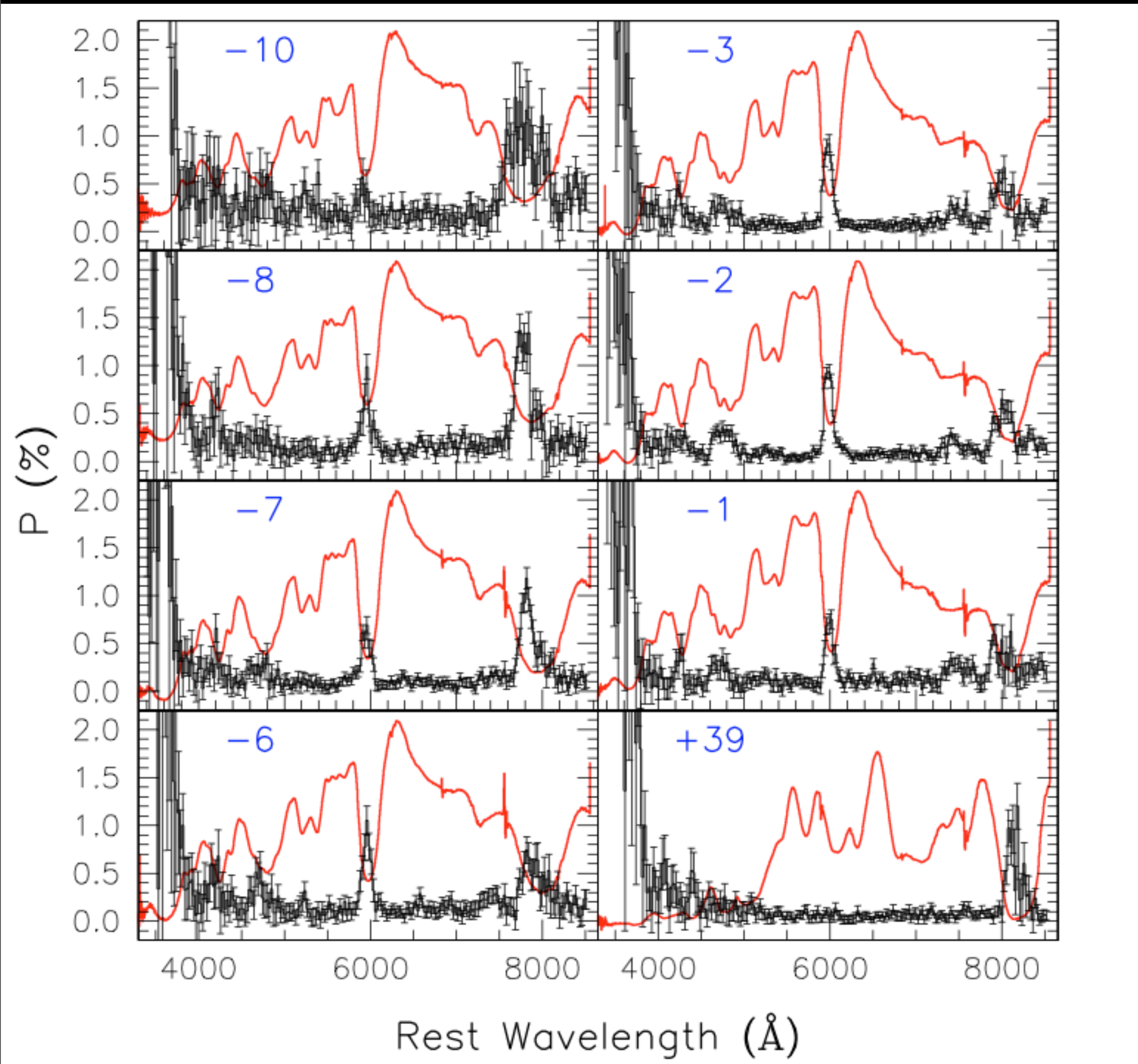
Type Ia/1



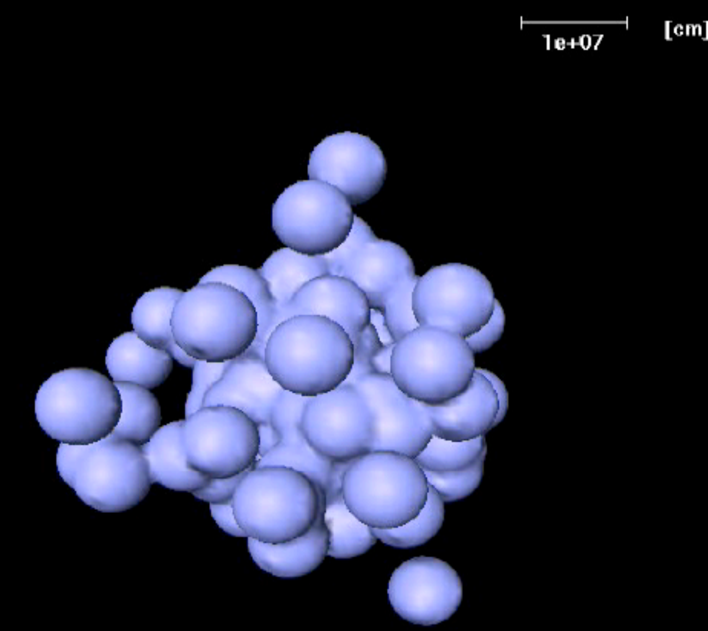


Courtesy of F. Roepke

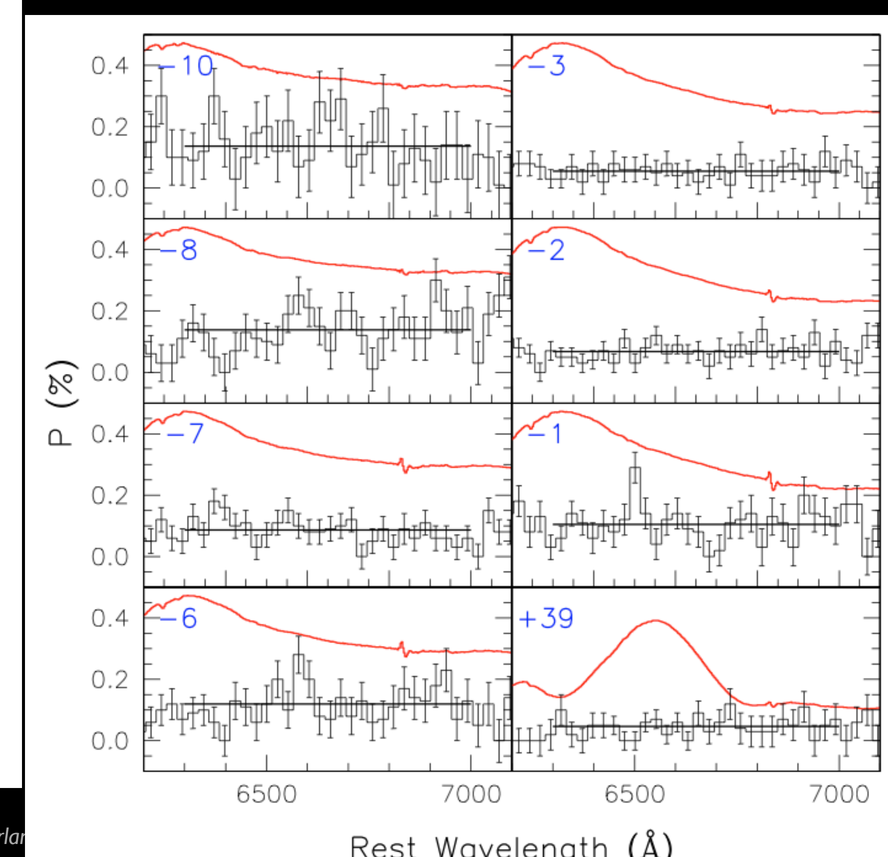
Type Ia/1



−10
−3
−8
−2
−7
−1
−6
+39
P (%)
2.0
1.5
1.0
0.5
0.0
4000
6000
8000
Rest Wavelength (Å)

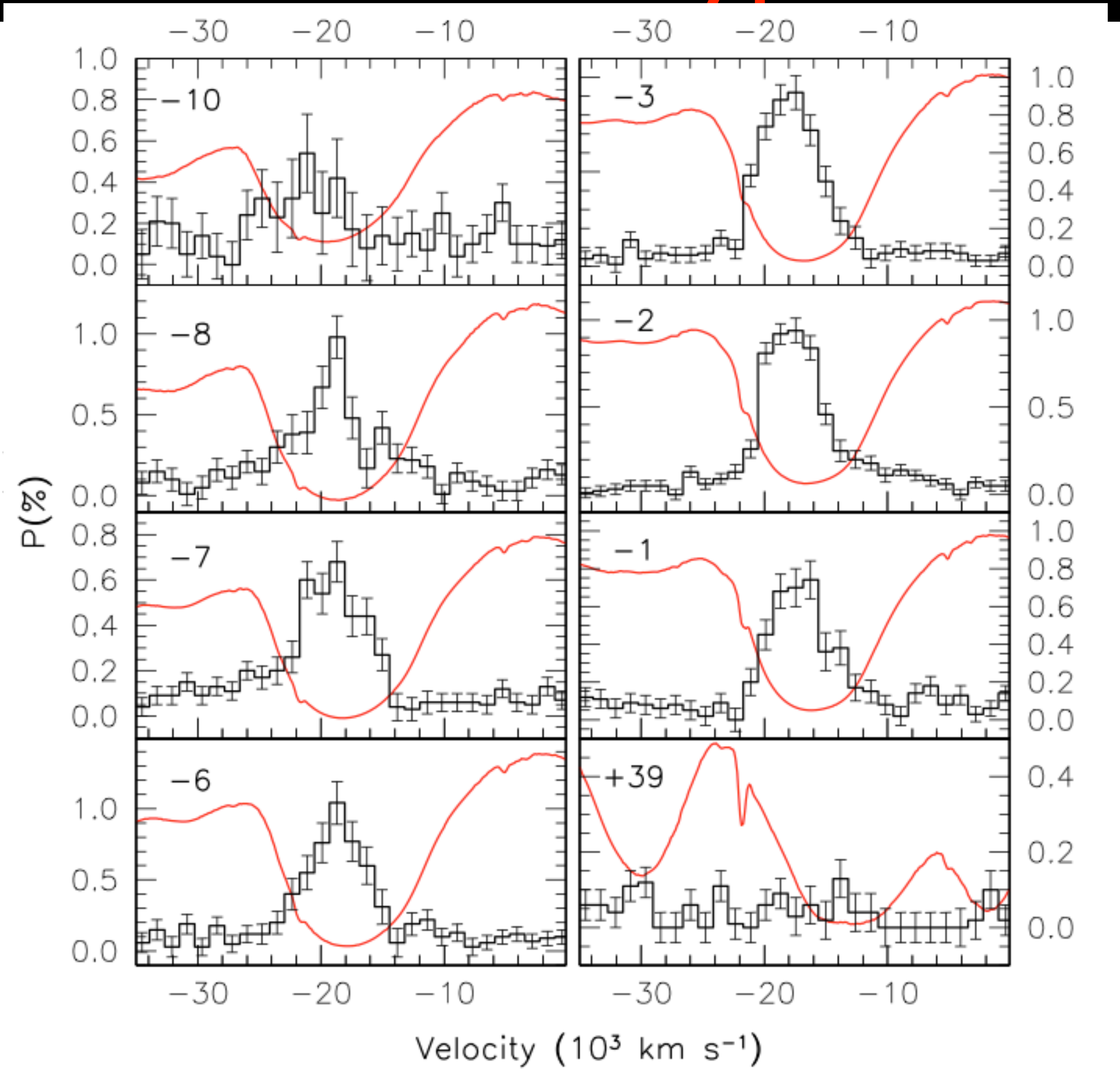


1e+07
[cm]

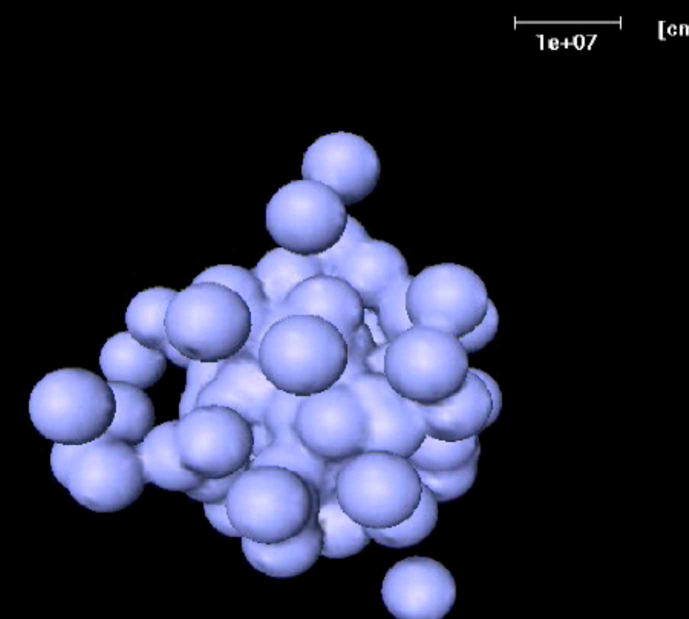


−10
−3
−8
−2
−7
−1
−6
+39
P (%)
0.4
0.2
0.0
6500
7000
Rest Wavelength (Å)

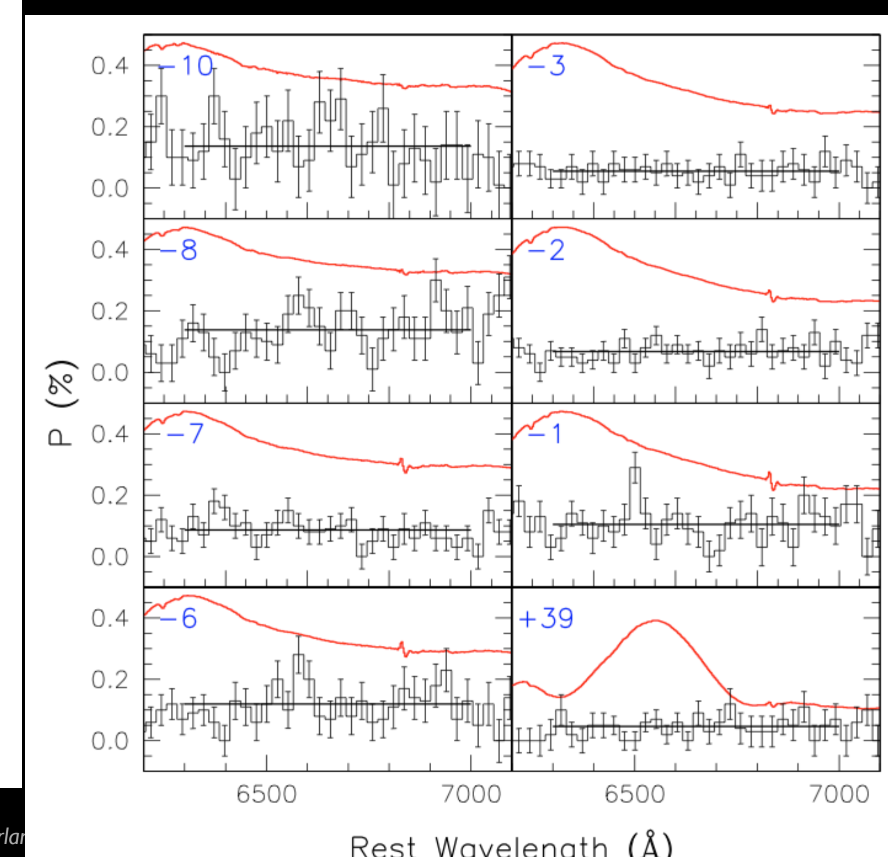
Type Ia/1



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

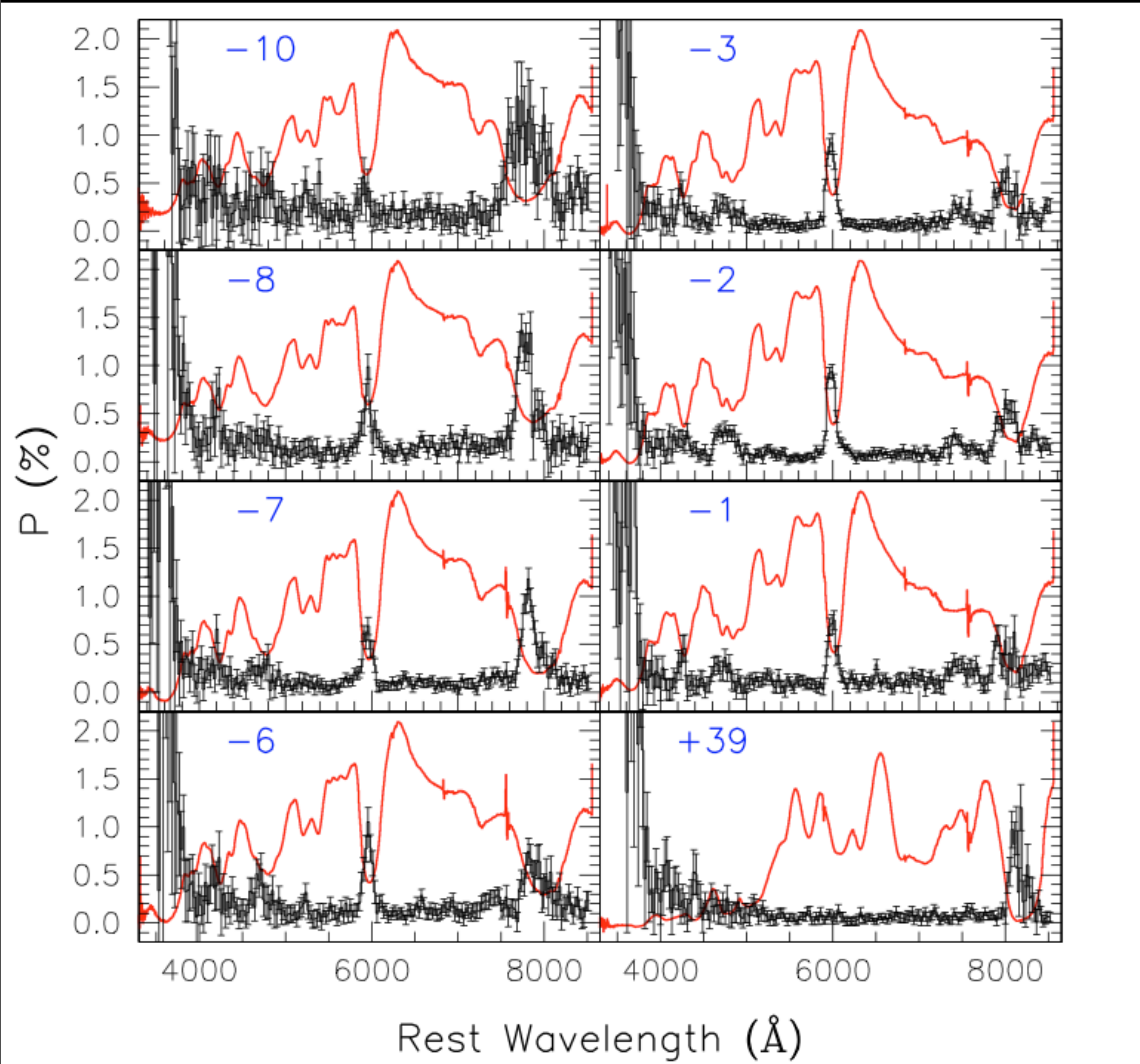


1e+07
[cm]

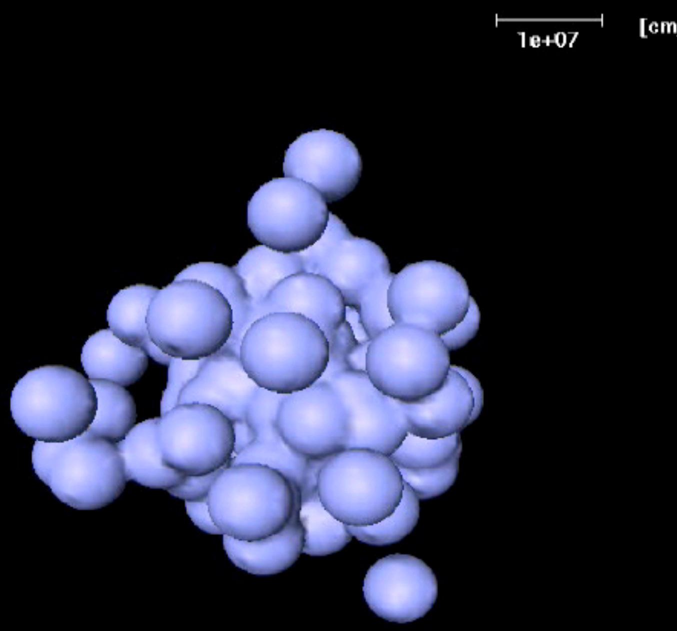


−10
−3
−8
−2
−7
−1
−6
+39
P (%)
Rest Wavelength (Å)

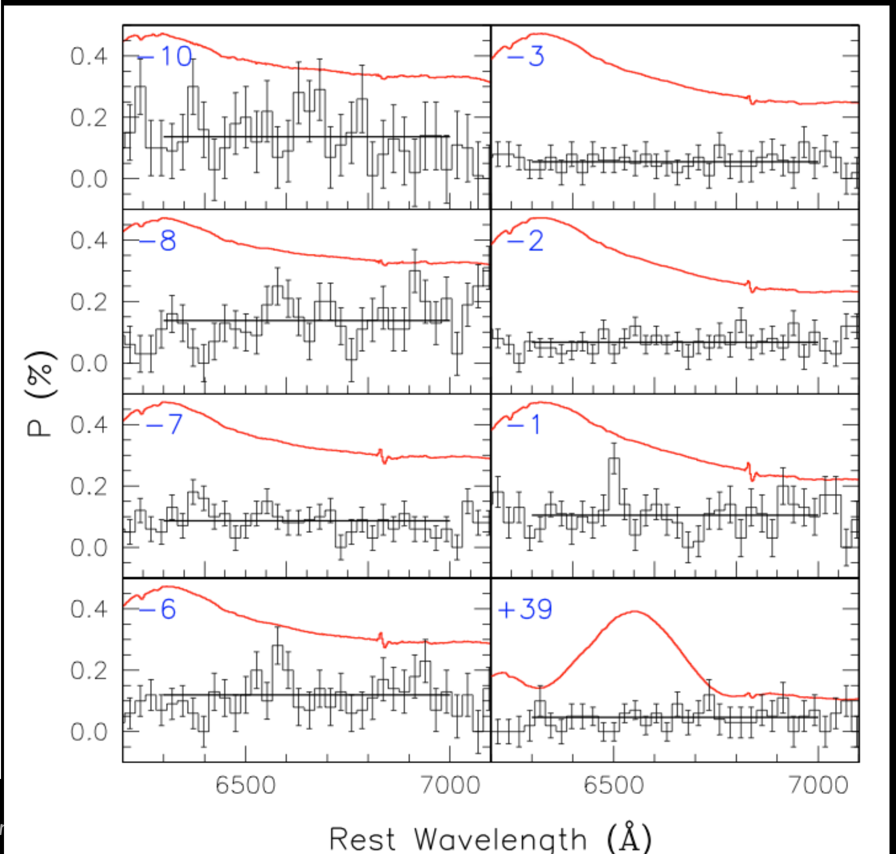
Type Ia/1



−10
−3
−8
−2
−7
−1
−6
+39
2.0
1.5
1.0
0.5
0.0
P (%)
4000
6000
8000
Rest Wavelength (Å)

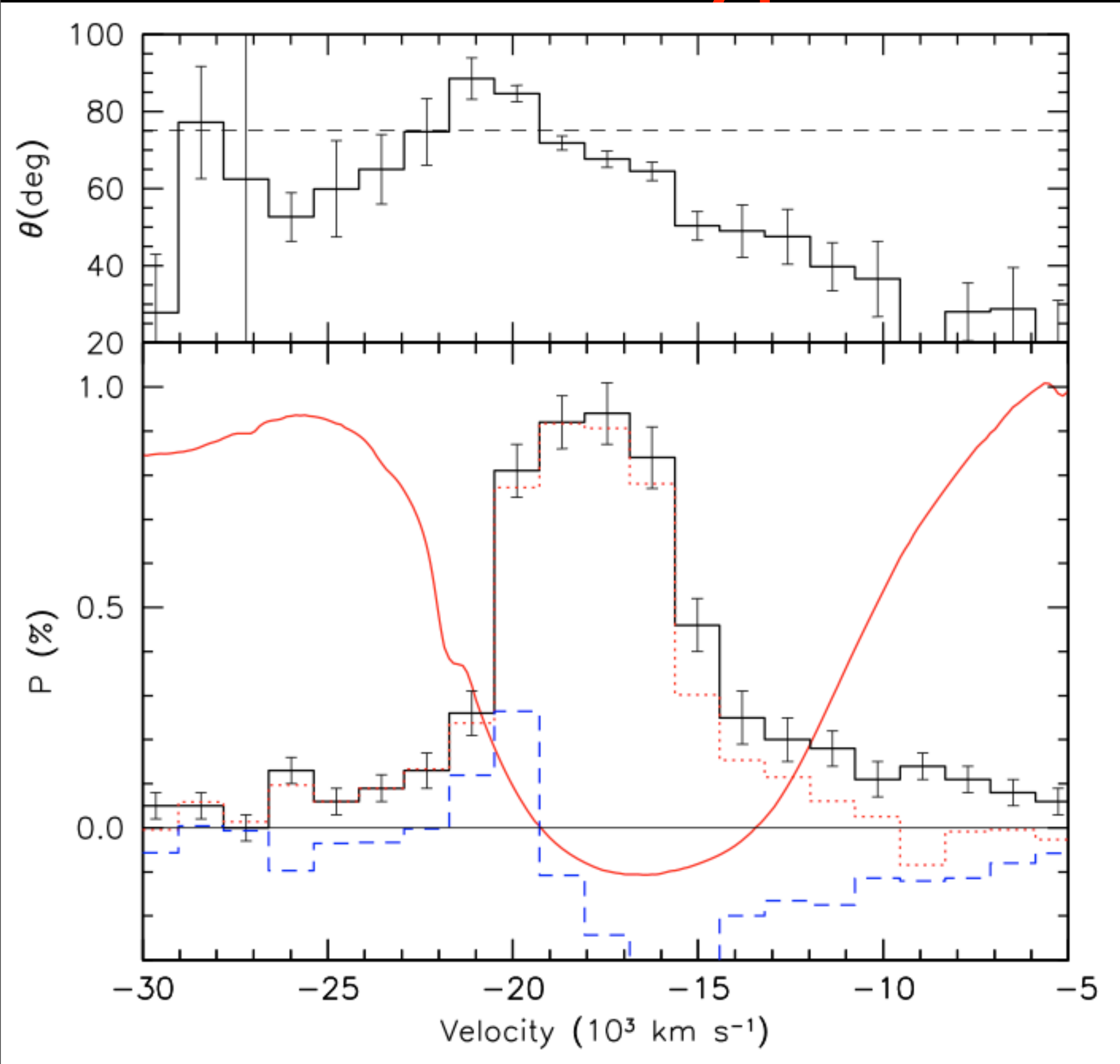


1e+07
[cm]

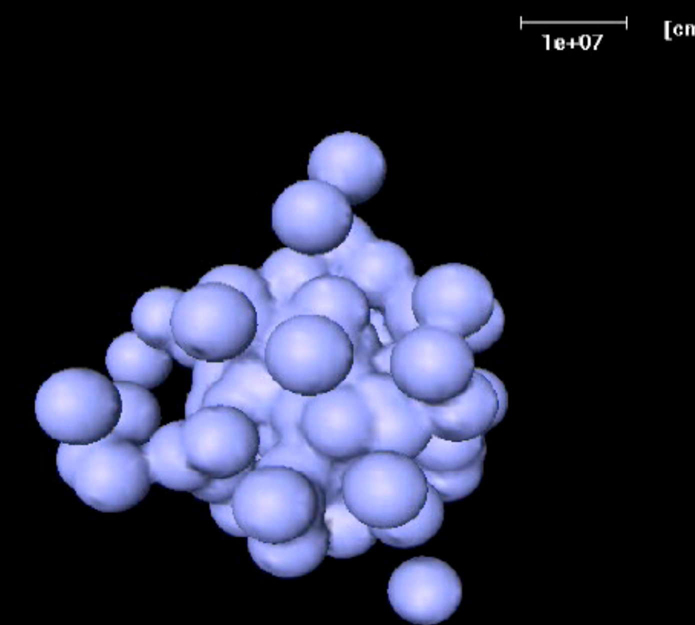


−10
−3
−8
−2
−7
−1
−6
+39
0.4
0.2
0.0
P (%)
6500
7000
Rest Wavelength (Å)

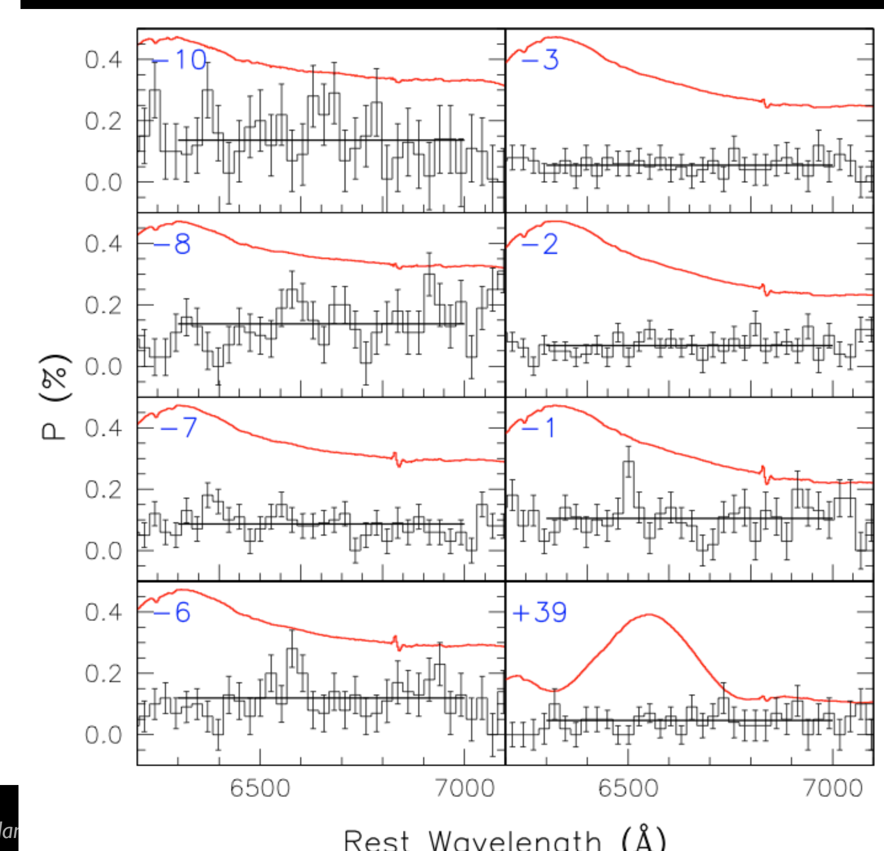
Type Ia/1



θ(deg)
100
80
60
40
20
P (%)
1.0
0.5
0.0
−30
−25
−20
−15
−10
−5
Velocity (10³ km s⁻¹)

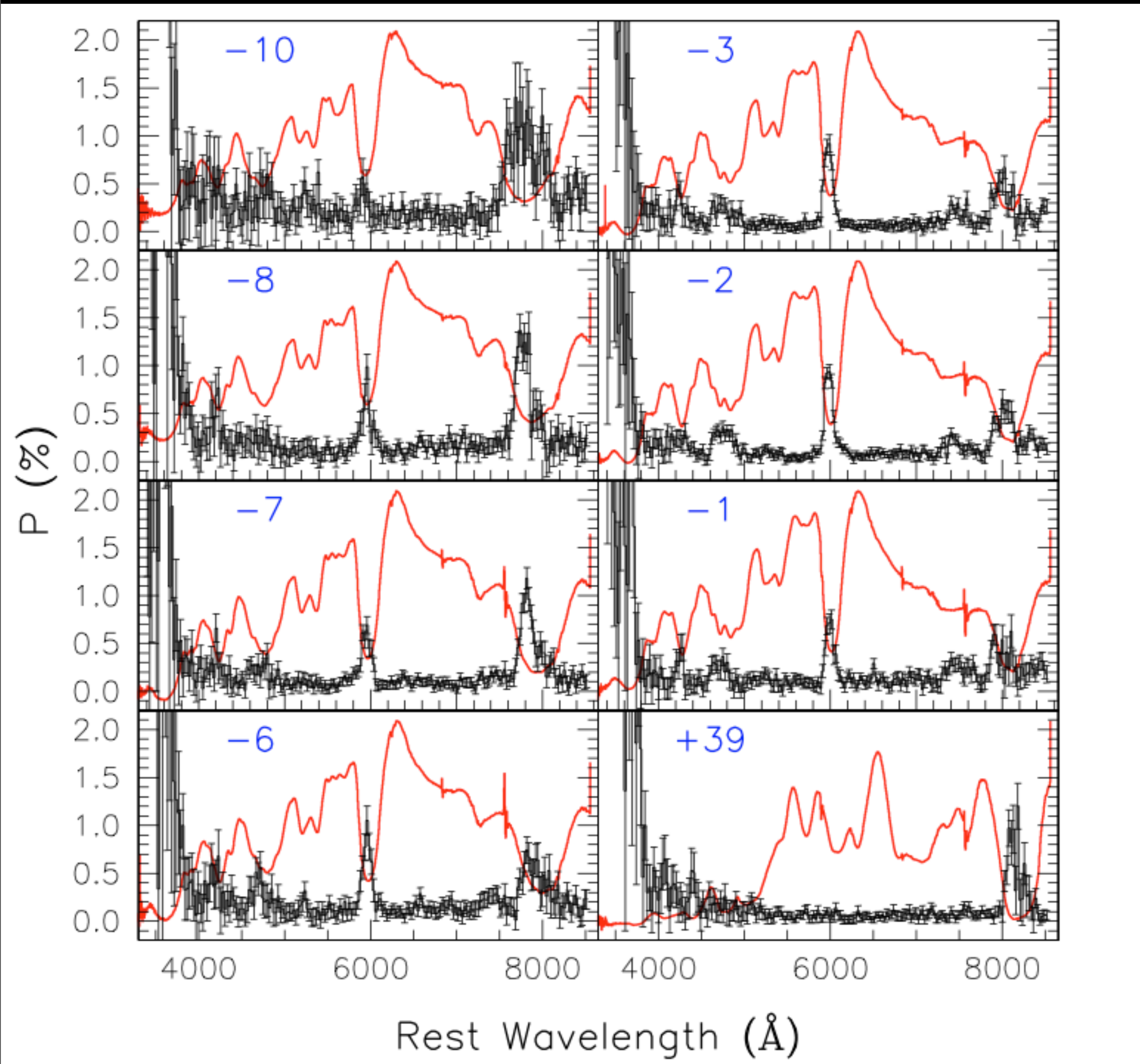


1e+07
[cm]

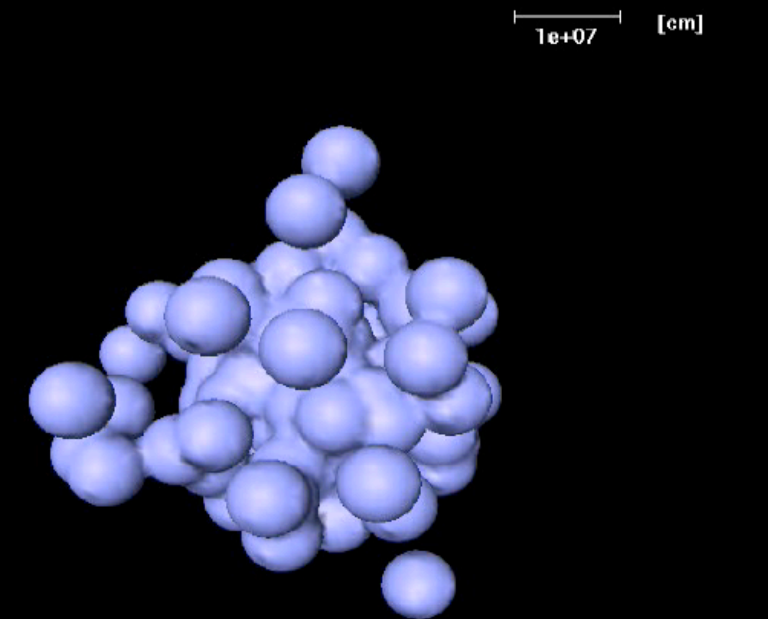


−10
−3
−8
−2
−7
−1
−6
+39
P (%)
0.4
0.2
0.0
6500
7000
Rest Wavelength (Å)

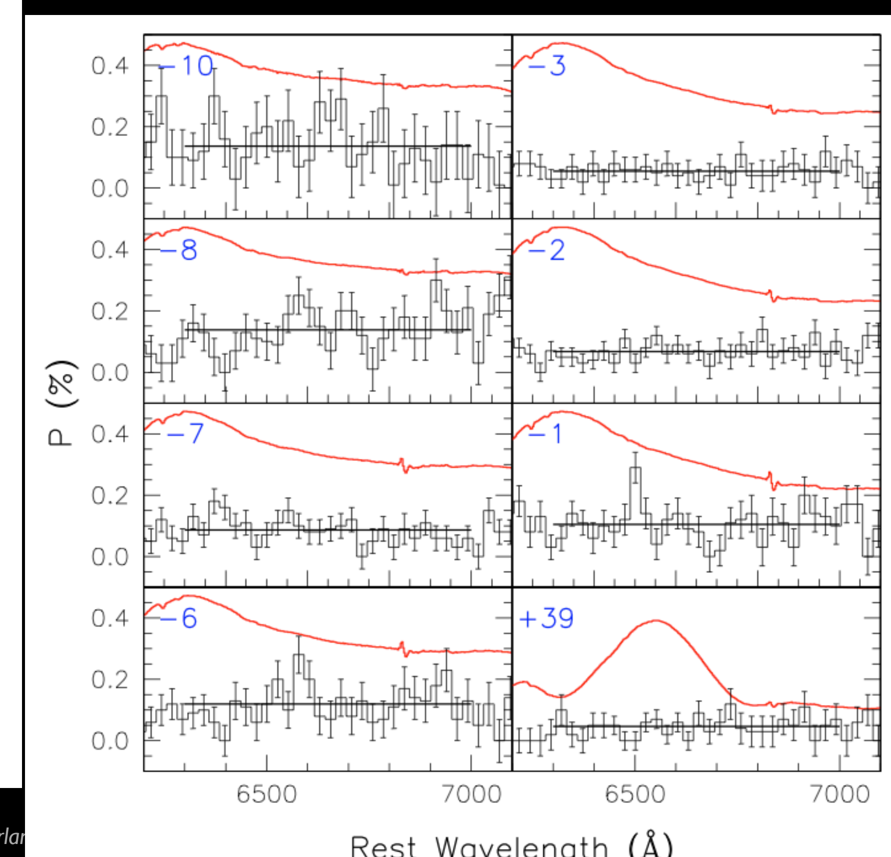
Type Ia/1



−10
−3
−8
−2
−7
−1
−6
+39
2.0
1.5
1.0
0.5
0.0
P (%)
4000
6000
8000
Rest Wavelength (Å)

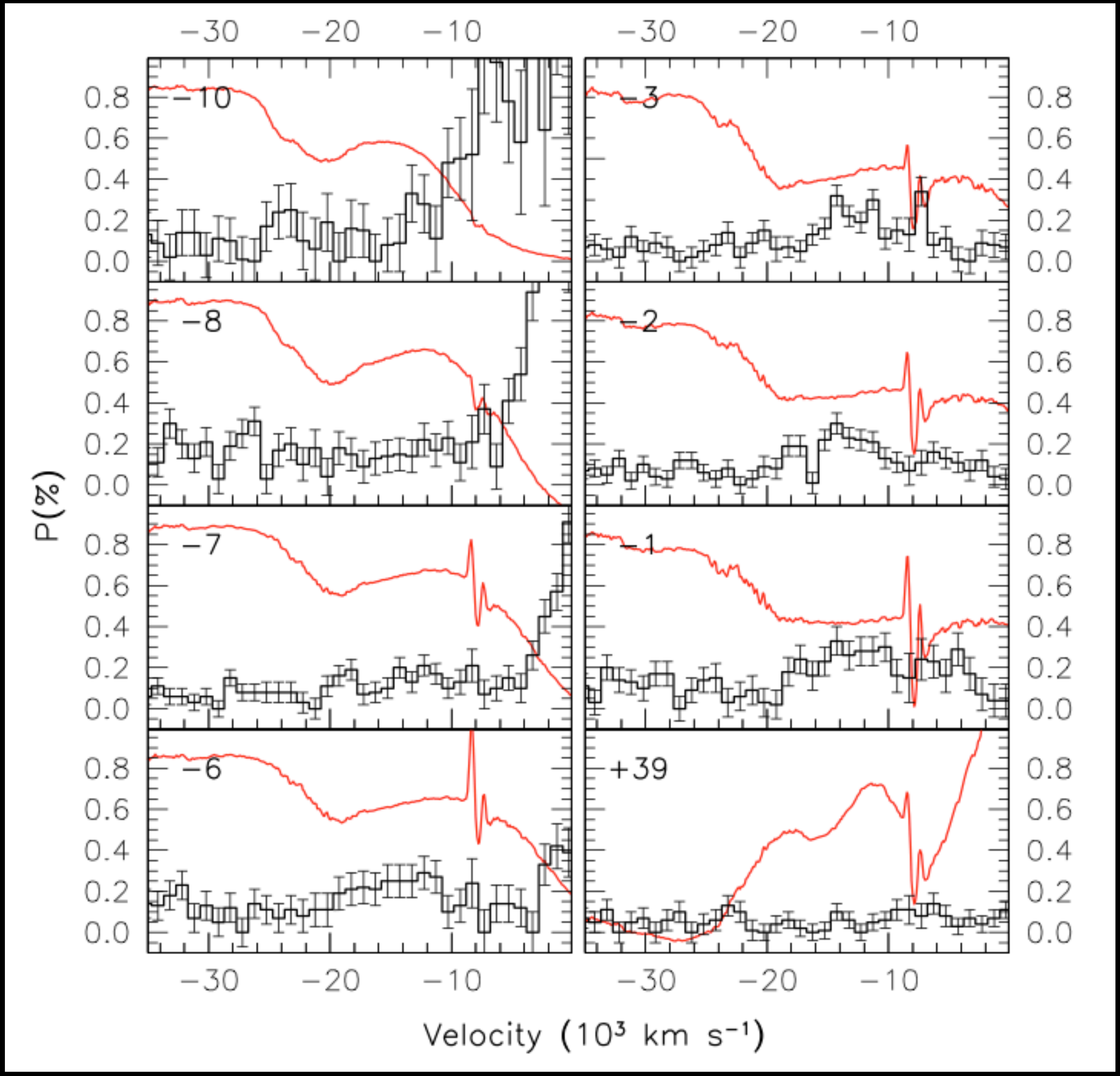


1e+07
[cm]

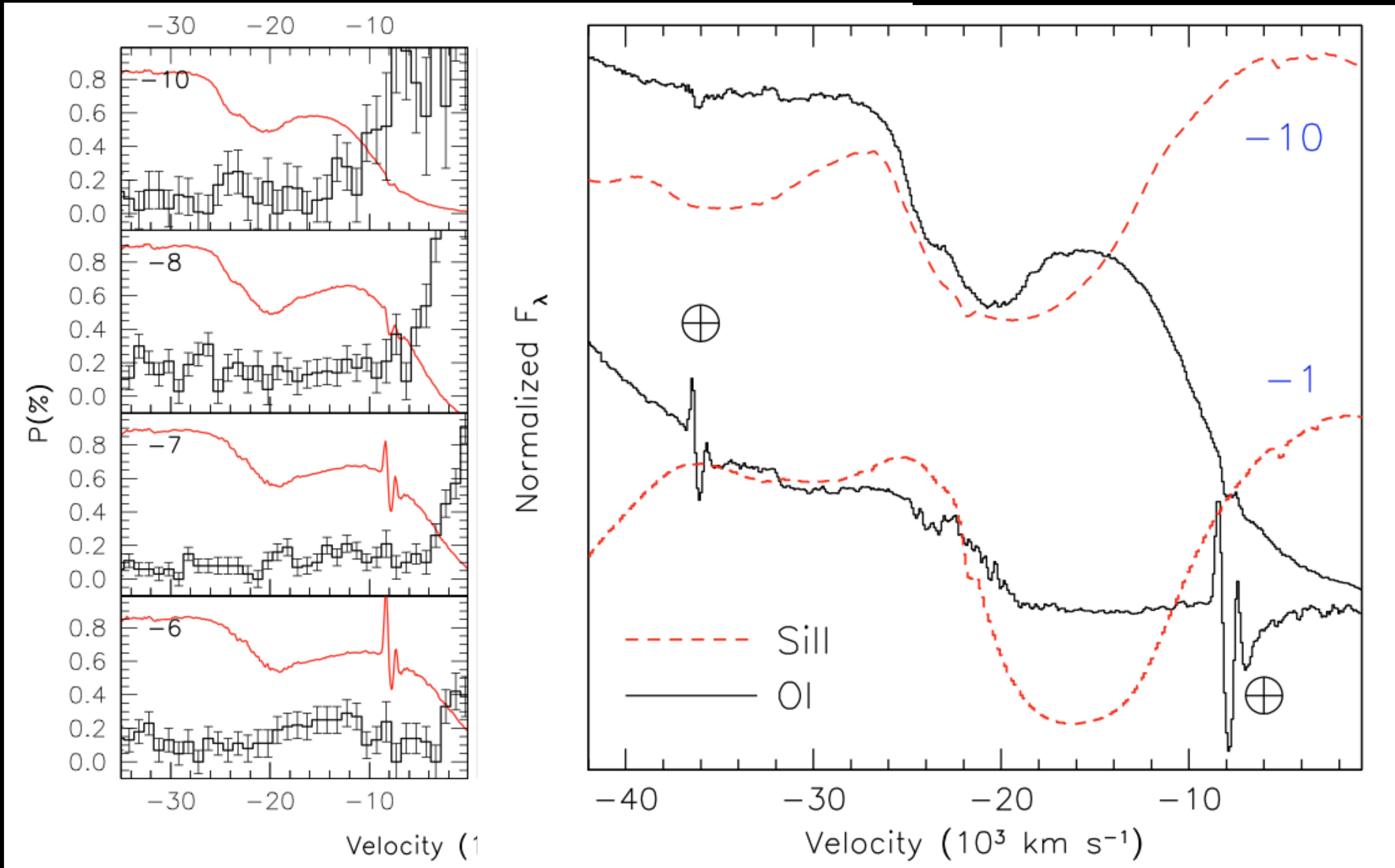


−10
−3
−8
−2
−7
−1
−6
+39
0.4
0.2
0.0
P (%)
6500
7000
Rest Wavelength (Å)

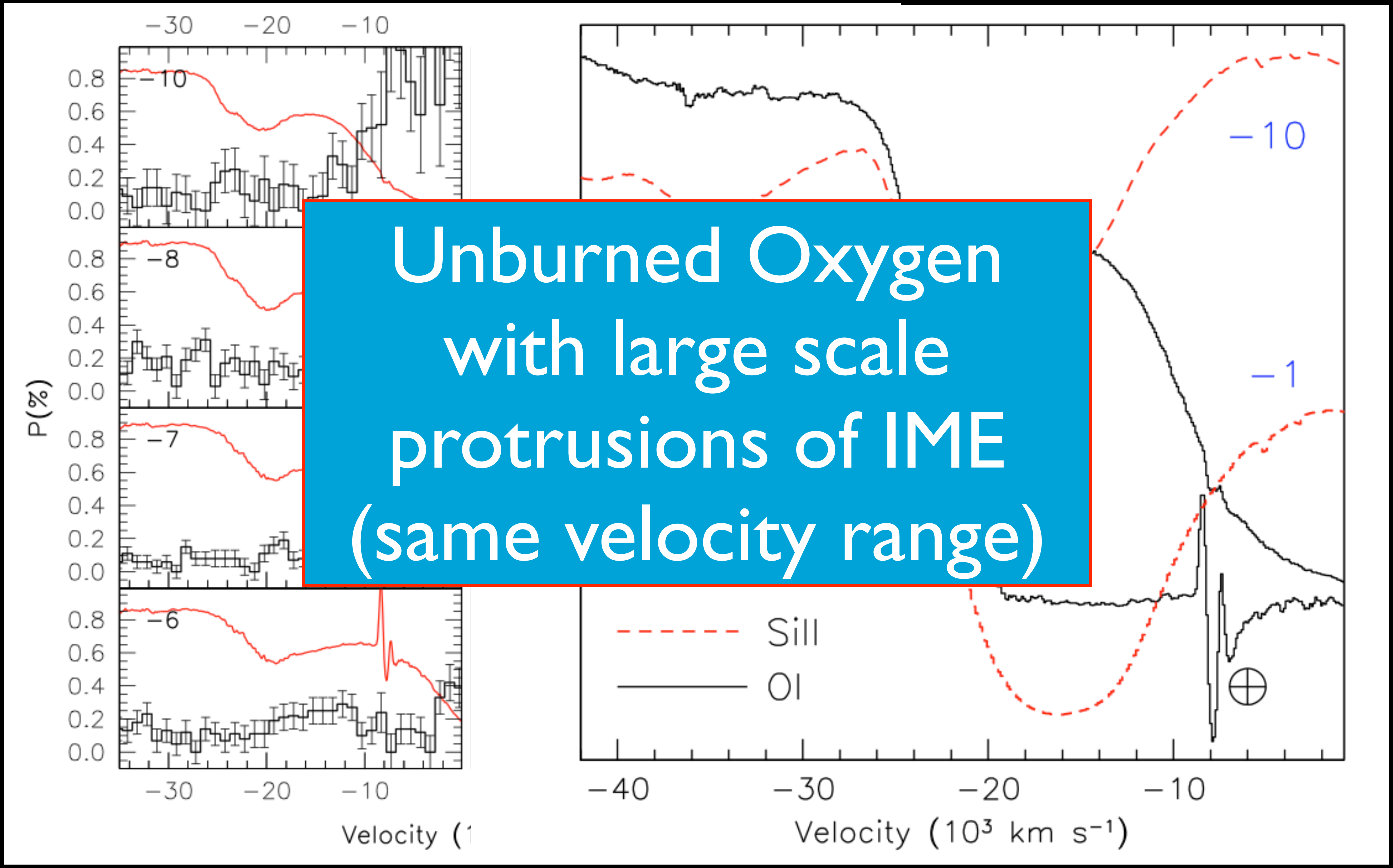
Type Ia - Oxygen (7774)



Type Ia - Oxygen (7774)



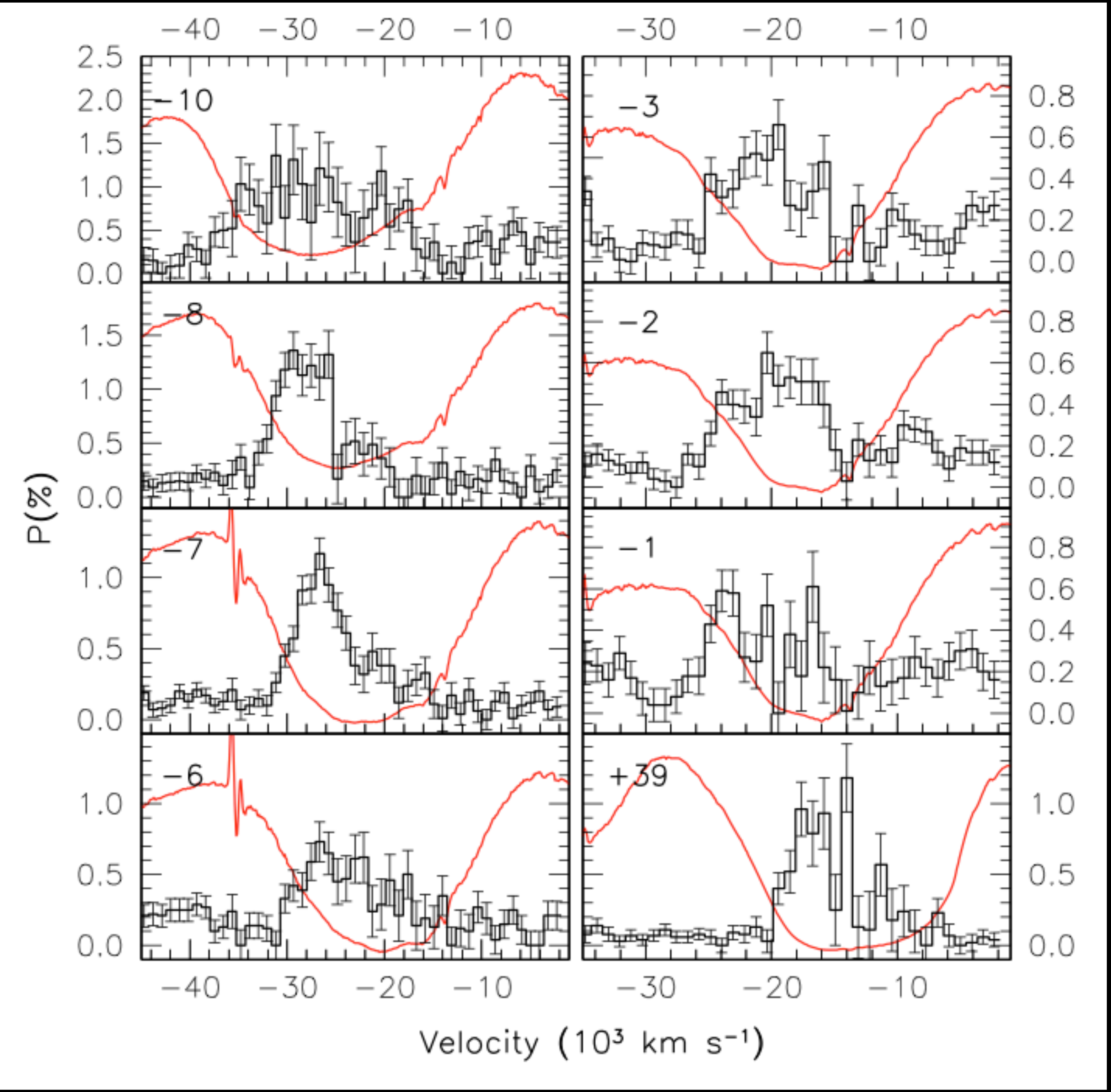
Type Ia - Oxygen (7774)



Unburned Oxygen with large scale protrusions of IME (same velocity range)

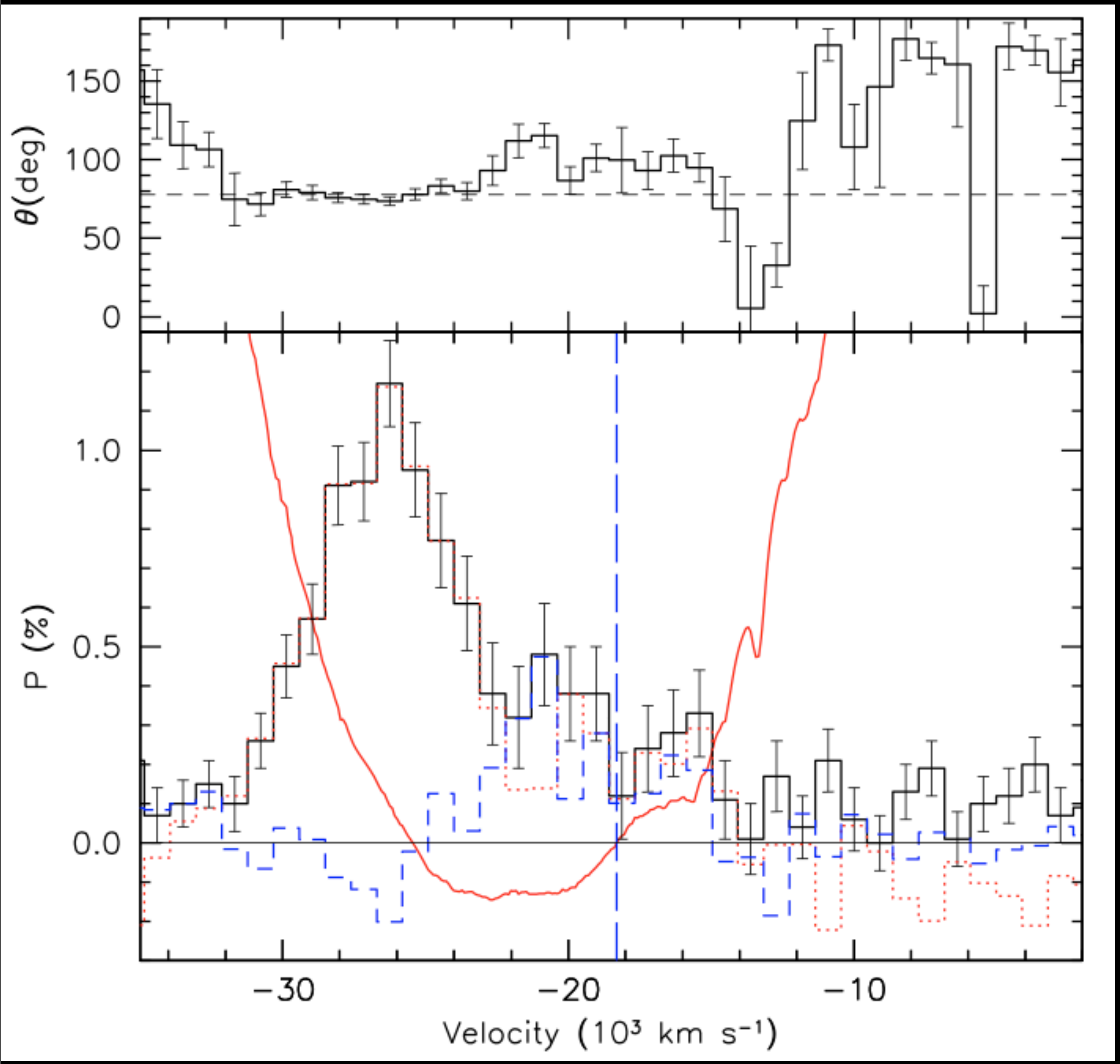
Type Ia - CaII and HVF

Patat+09



Type Ia - CaII and HVF

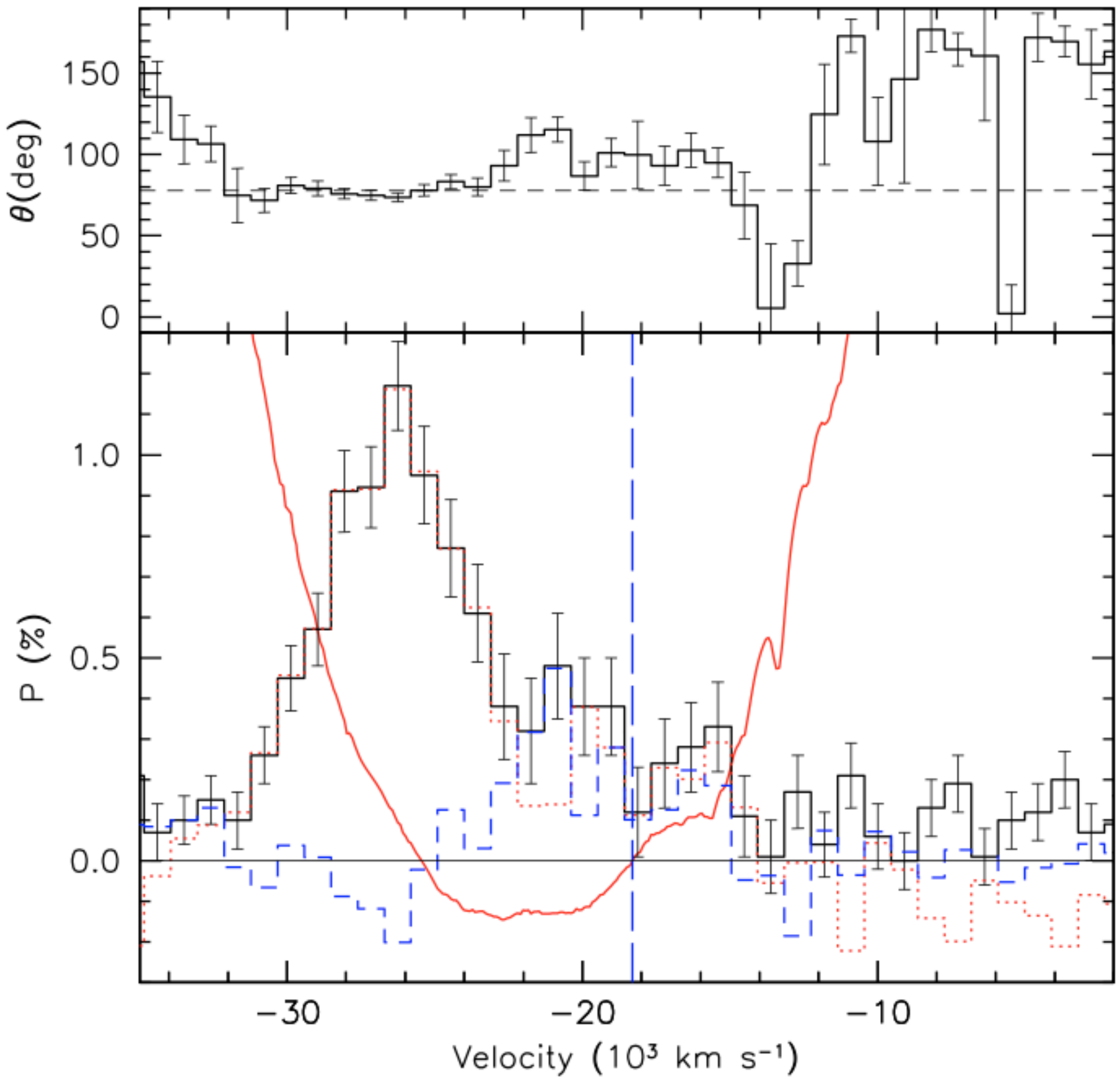
Patat+09

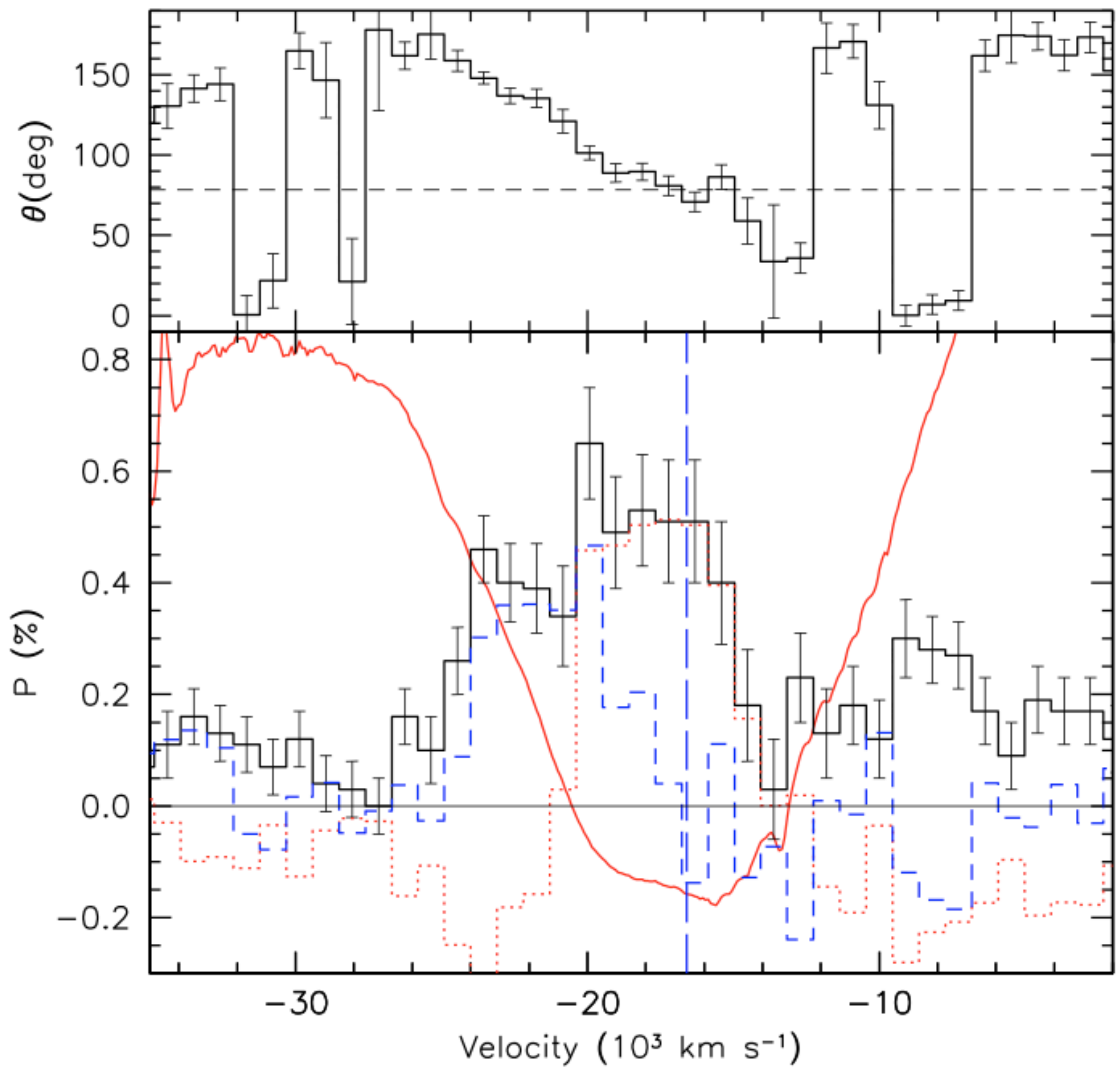


Day -7

Type Ia - CaII and HVF

Patat+09

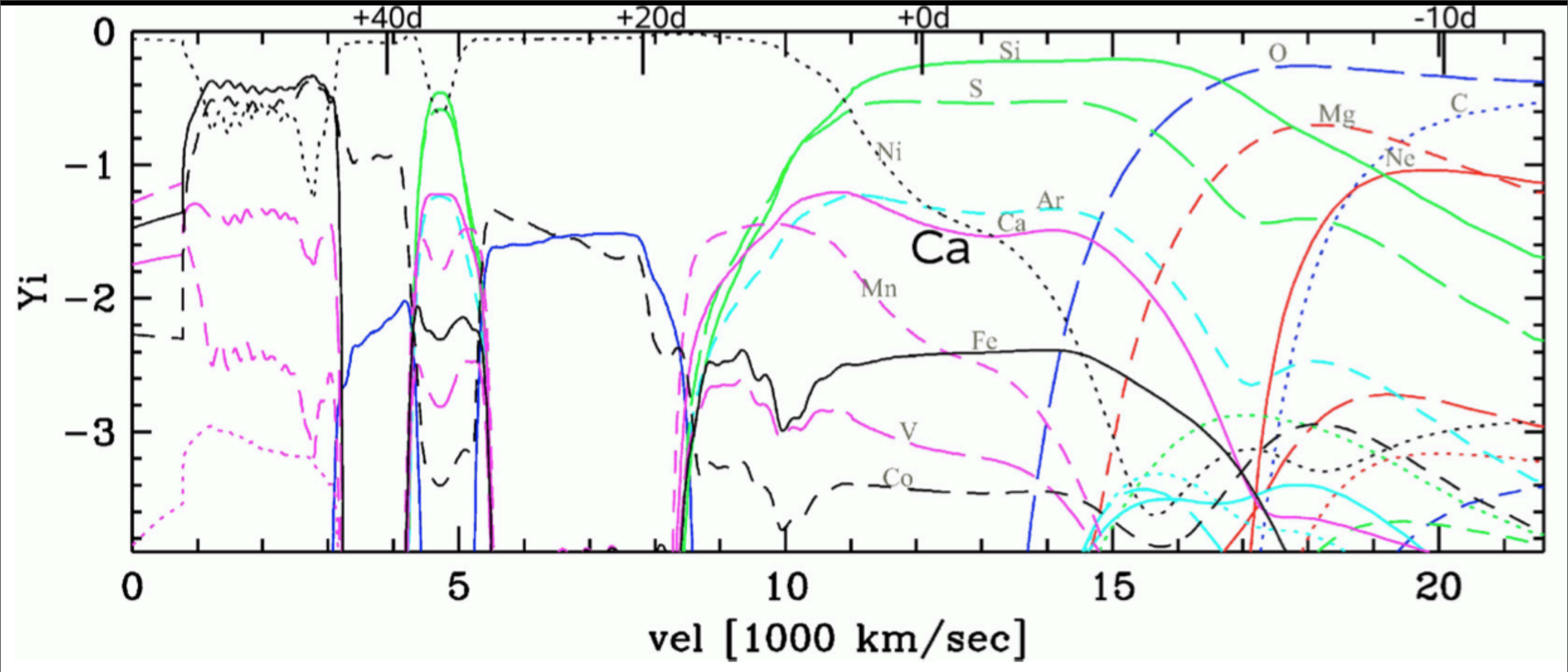


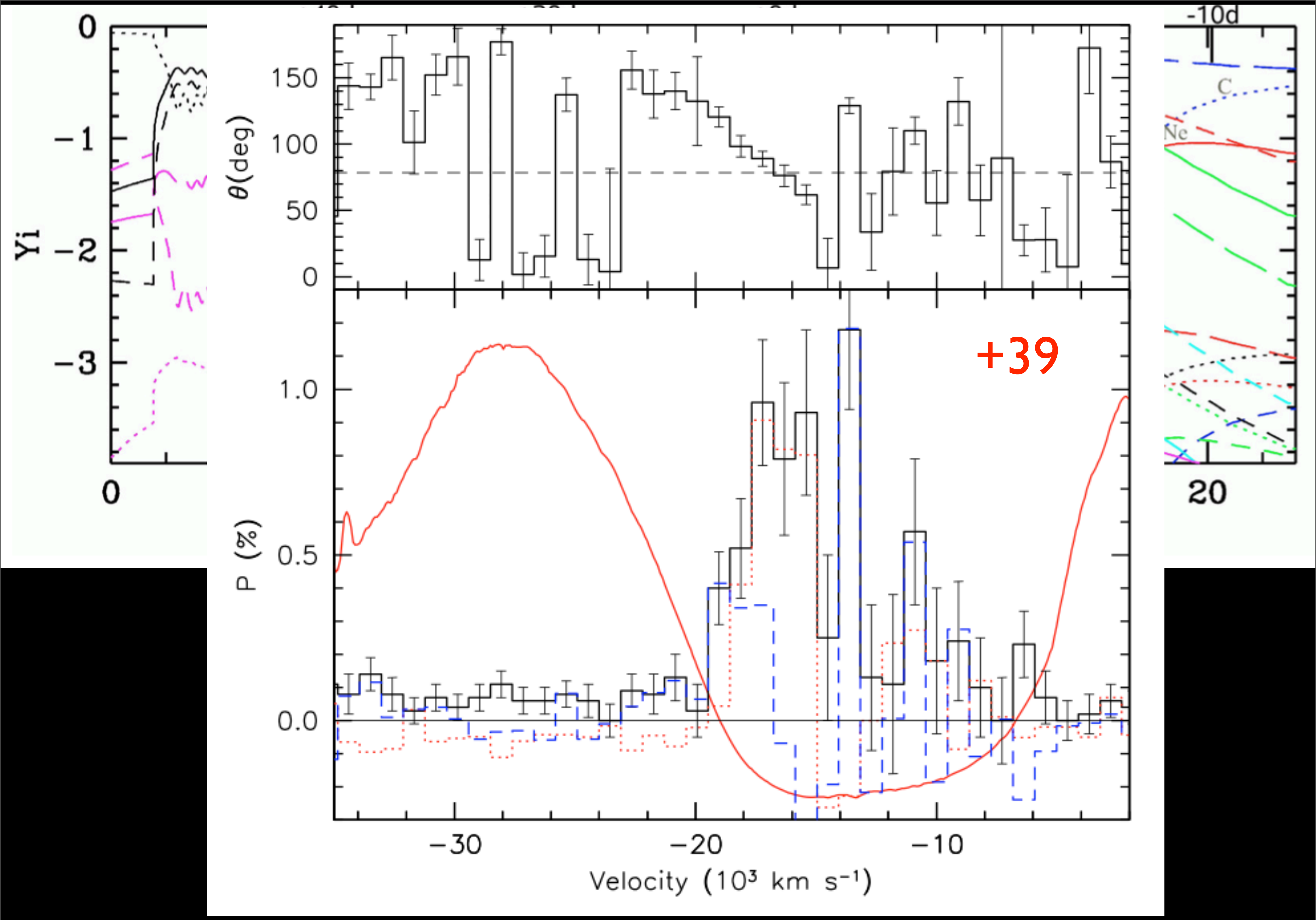


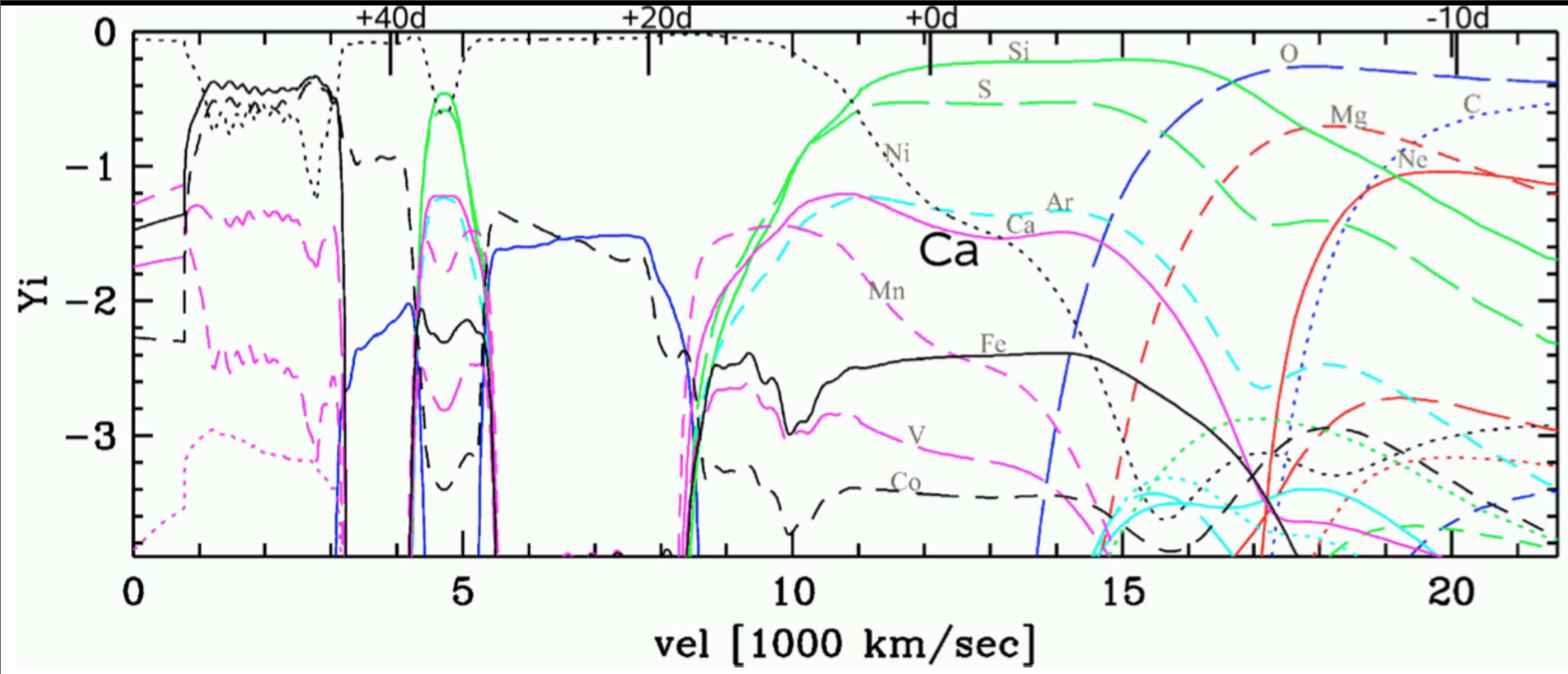
Day -7

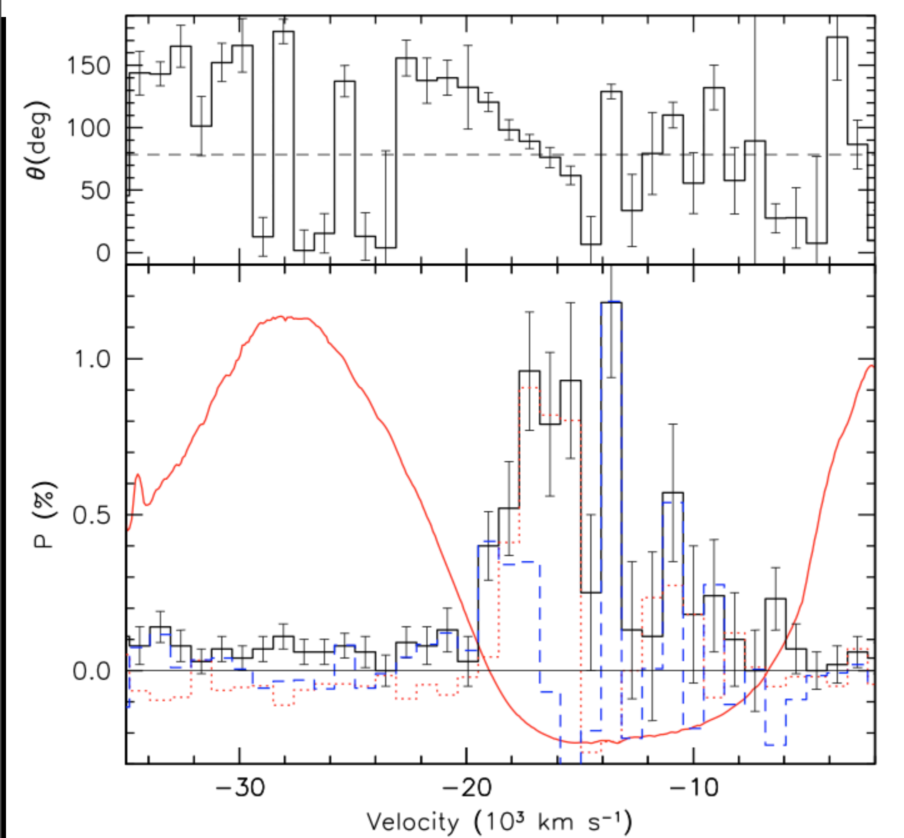
Day -2

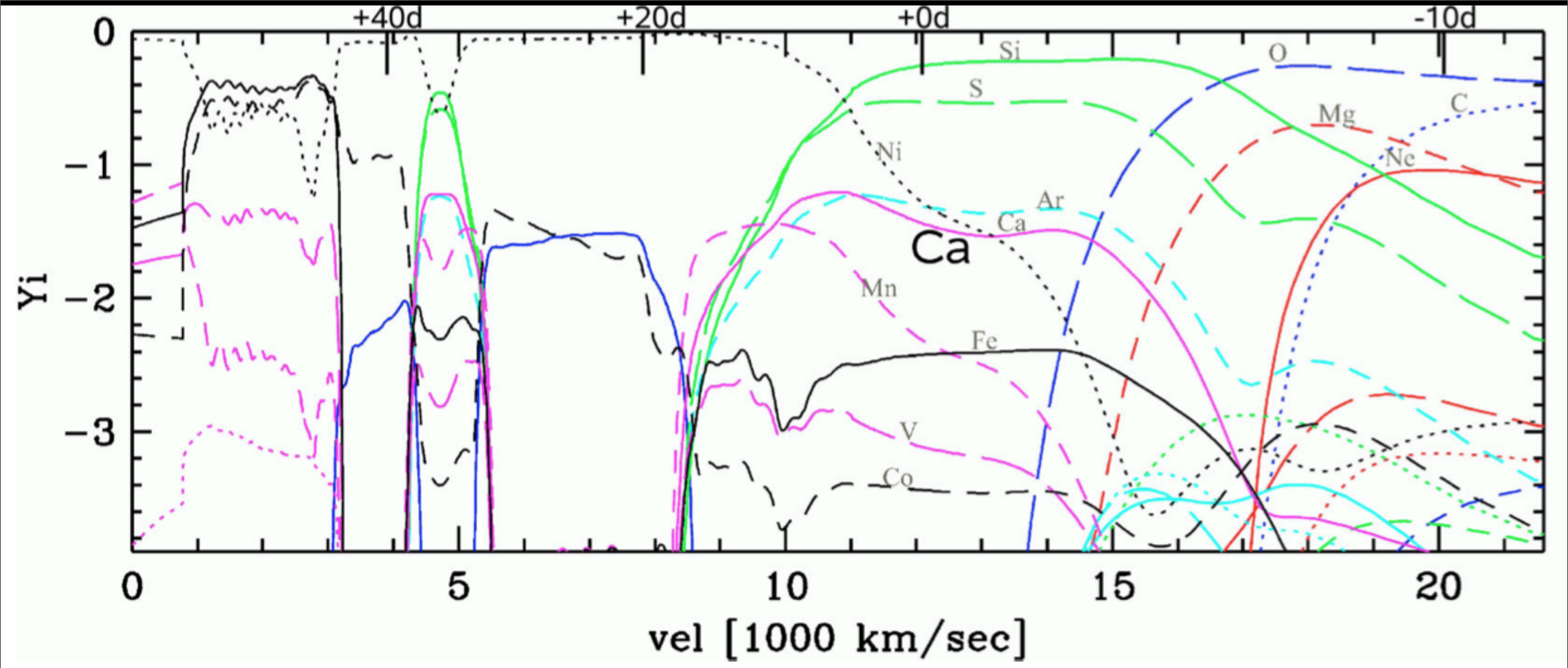
See J. Silverman's poster on HVF

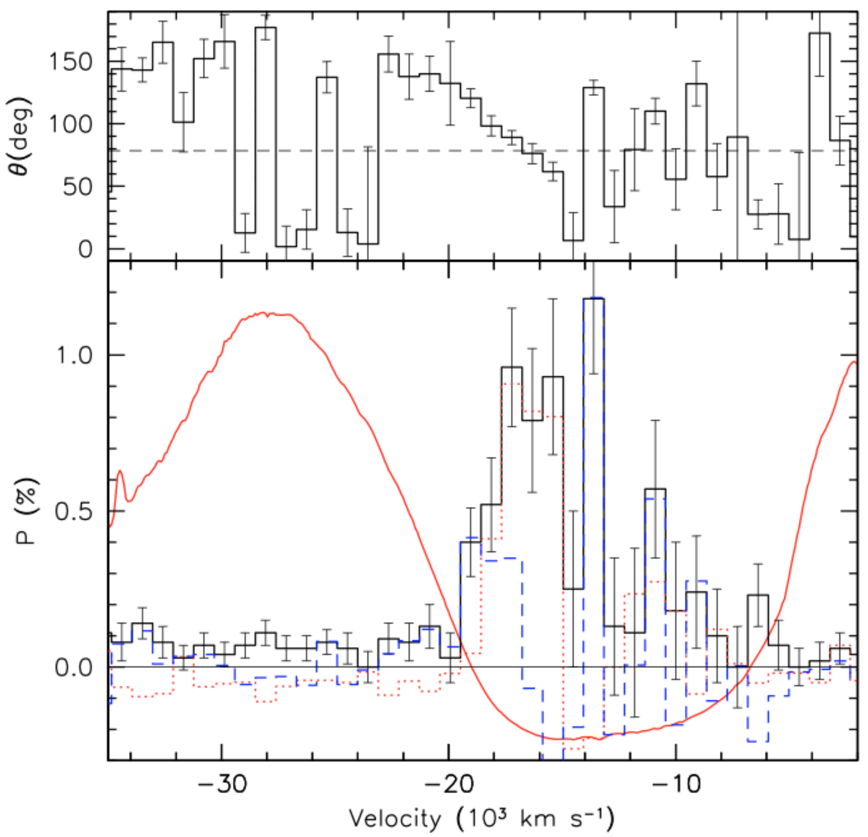

+40d
+20d
+0d
-10d
0
-1
-2
-3
Yi
0
5
10
15
20
vel [1000 km/sec]
Si
S
O
Mg
C
Ni
Ne
Ar
Ca
Ca
Mn
Fe
V
Co


θ(deg)
150
100
50
0
P (%)
1.0
0.5
0.0
−30
−20
−10
Velocity (10³ km s⁻¹)
+39
Yi
0
−1
−2
−3
0
-10d
C
Ne
20


+40d
+20d
+0d
-10d
Yi
0
−1
−2
−3
Si
S
O
Mg
C
Ne
Ni
Ar
Ca
Ca
Mn
Fe
V
Co
0
5
10
15
20
vel [1000 km/sec]


θ(deg)
150
100
50
0
P (%)
1.0
0.5
0.0
−30
−20
−10
Velocity (10³ km s⁻¹)

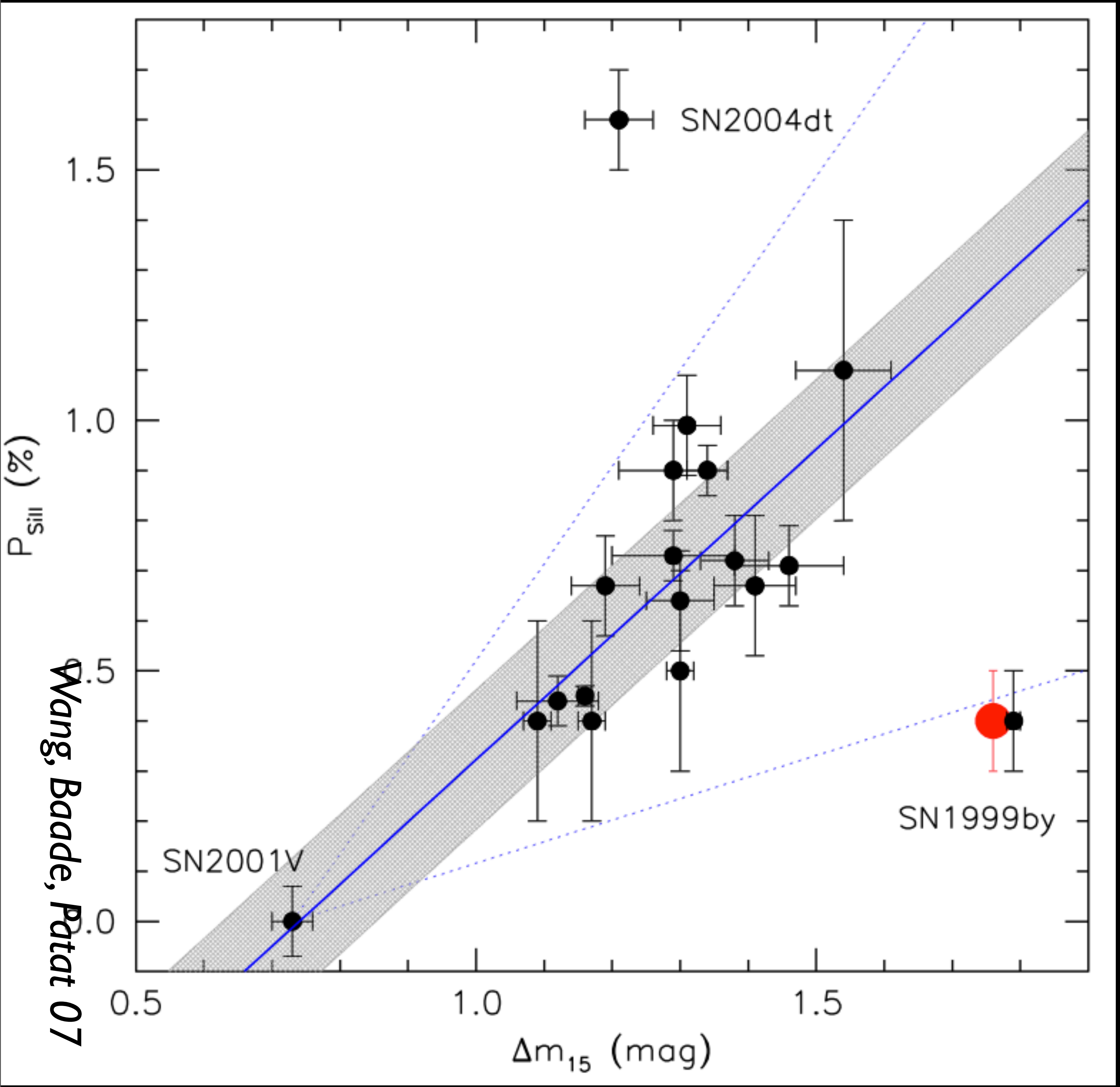




SN2007sr (Zelaya+12); SN2012fr (Maund+13) show the same behavior (re-polarization at late phases). This seems related to the presence of HVF. In 2012fr LVF and HVF are orthogonal, and both have axial symmetry.

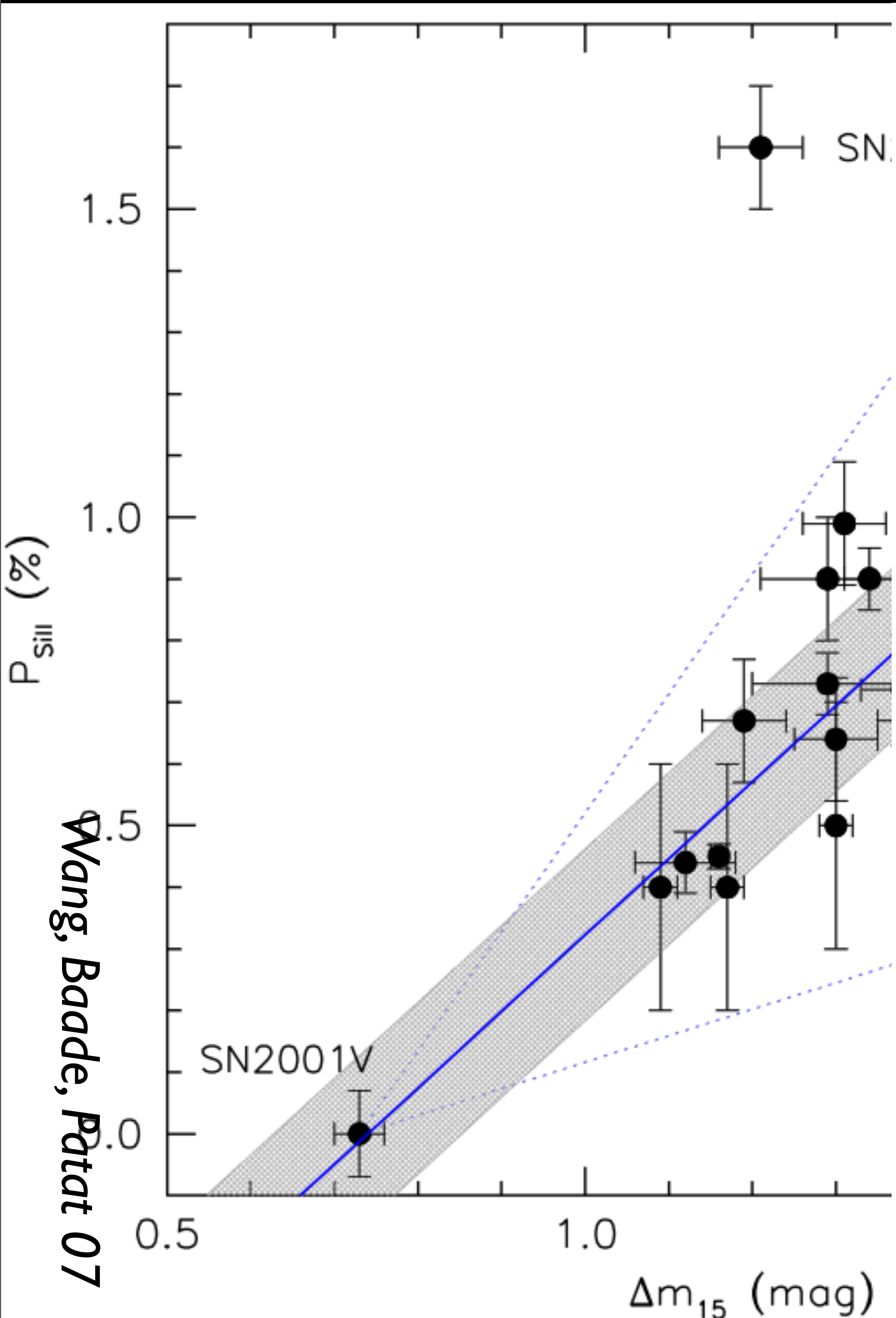
The P(SiII)-Δm_{15}-V_{dot} relation

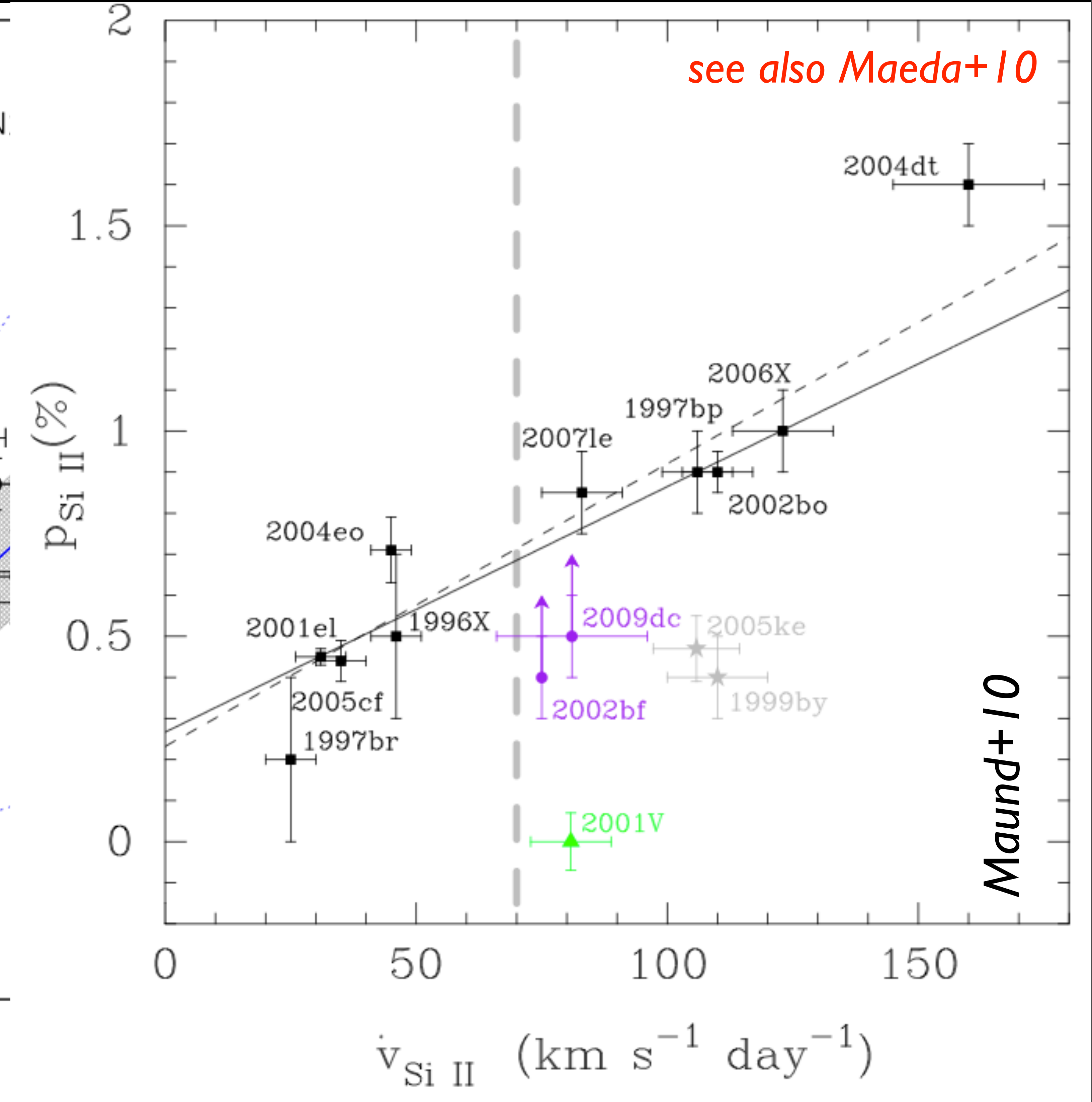
The P(SiII)-Δm_{15}-V_{dot} relation



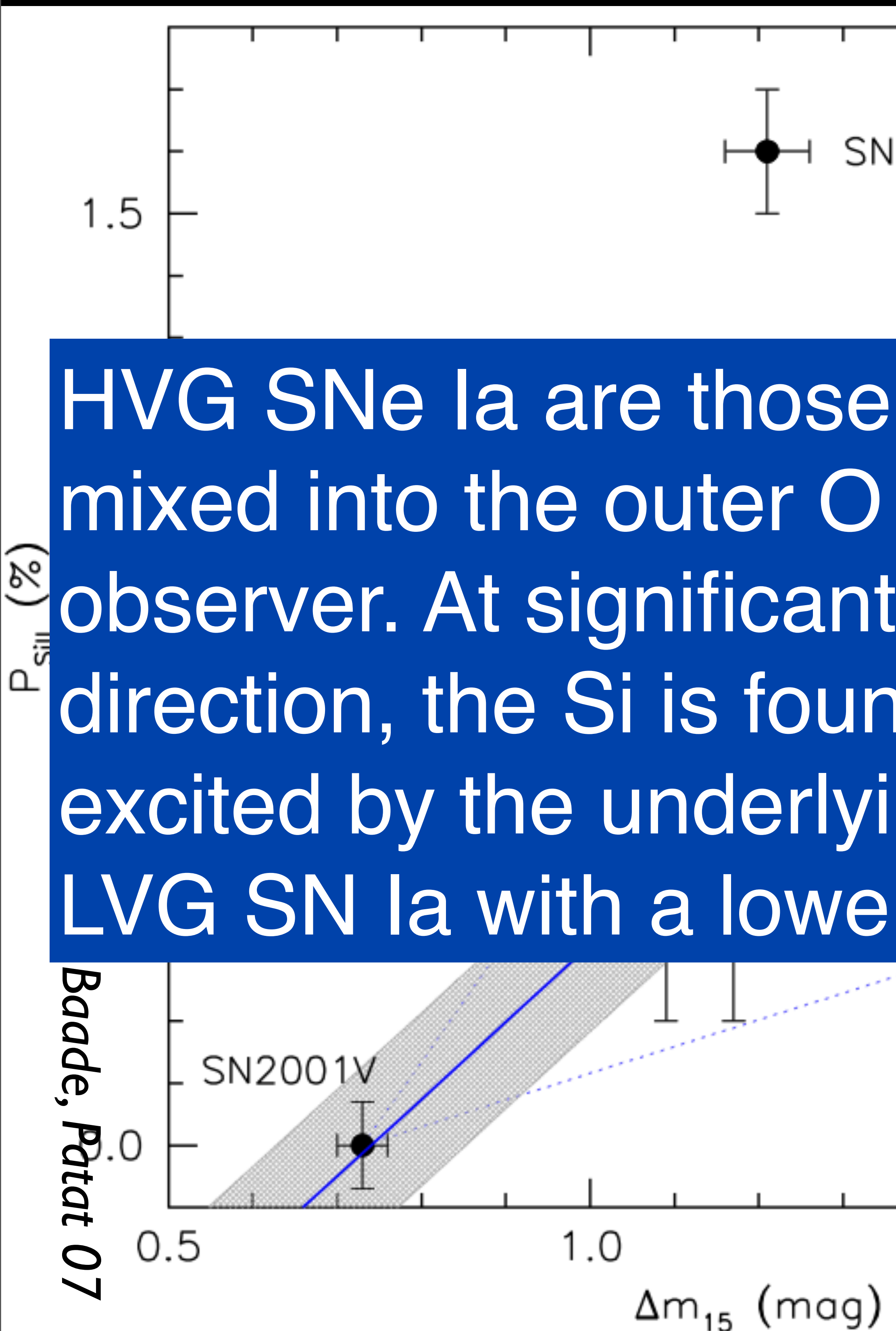
Wang, Baade, Patat 07

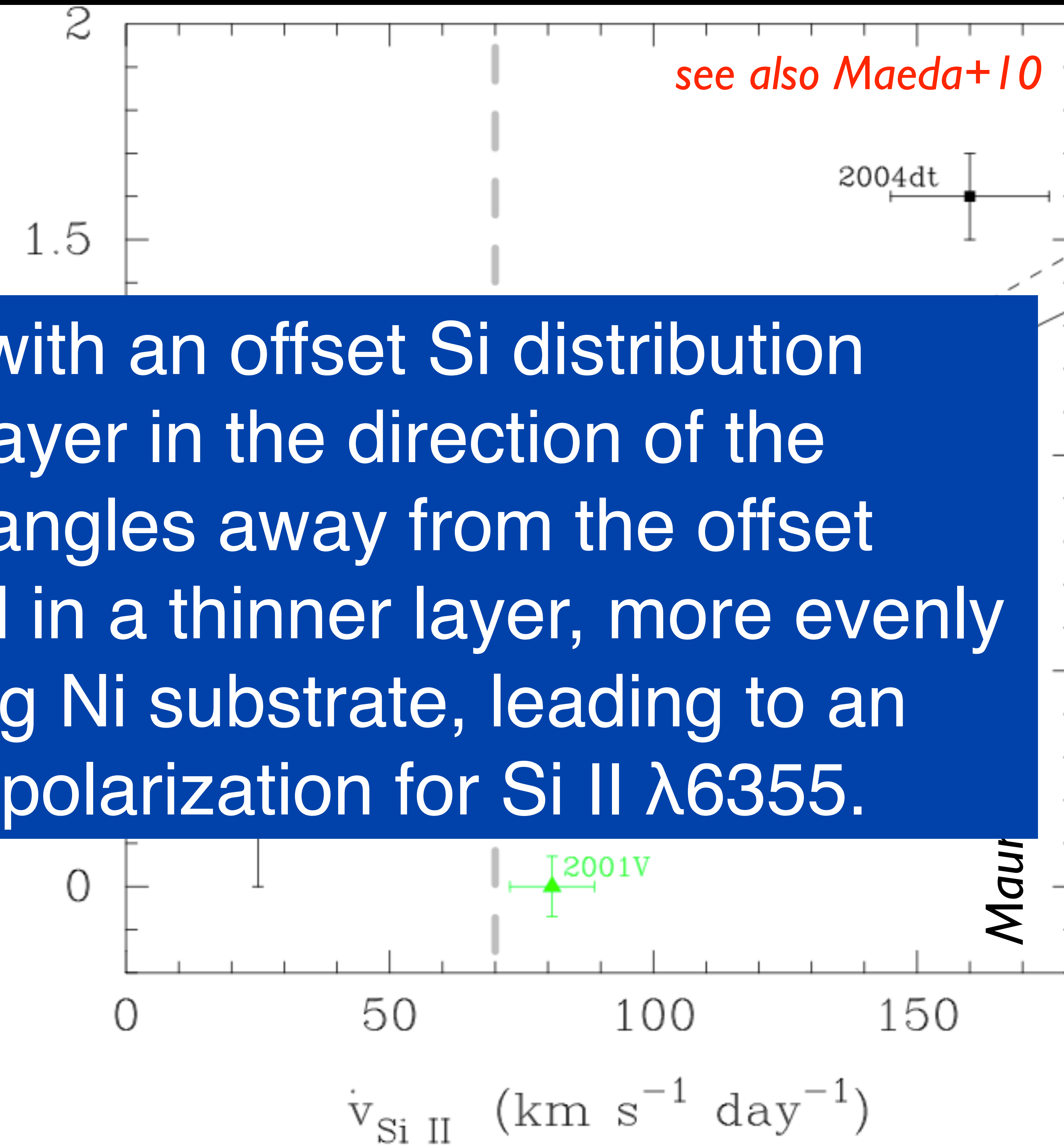
The P(SiII)-Δm_{15}-V_{dot} relation





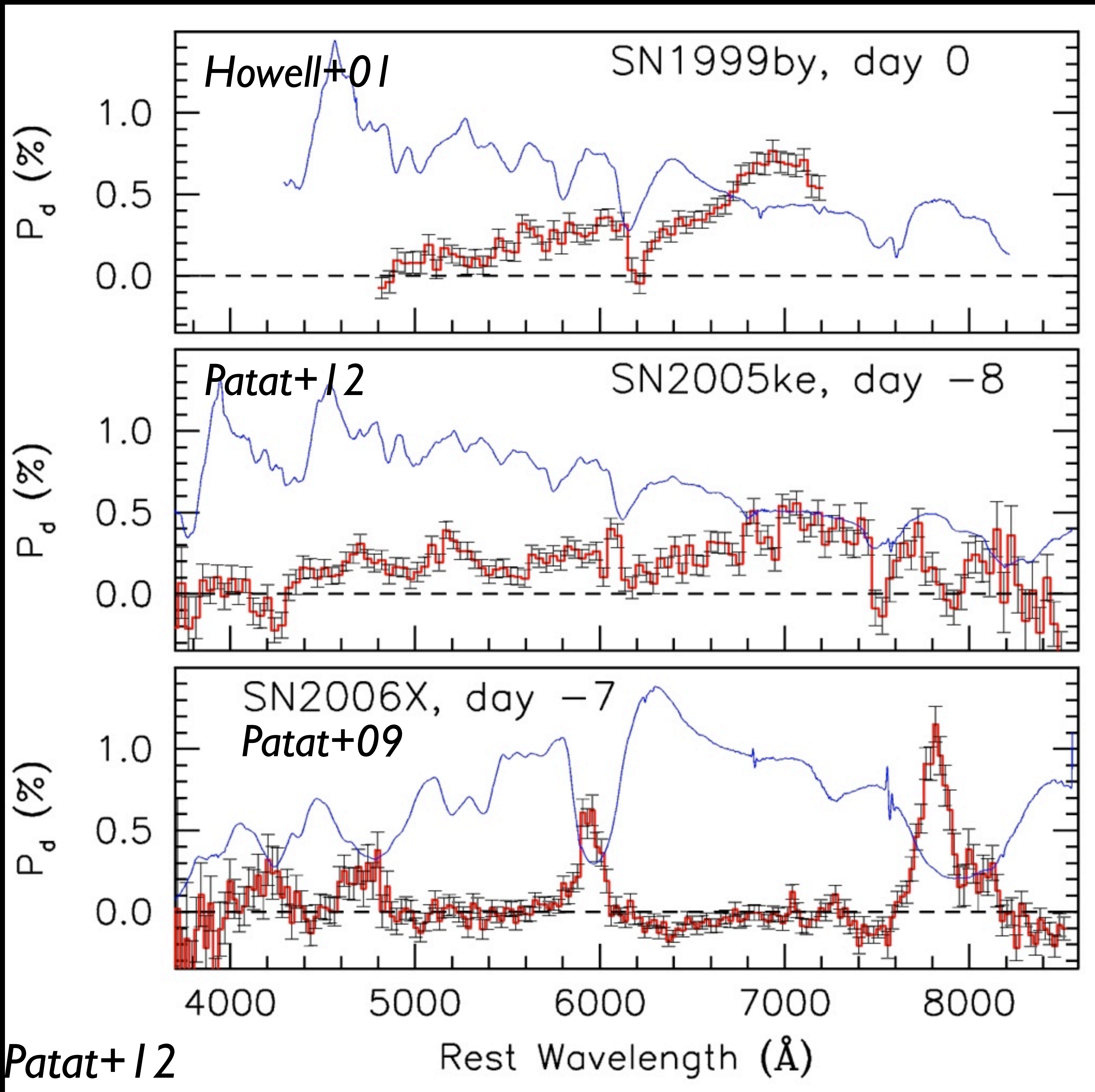
The P(SiII)-Δm_{15}-V_{dot} relation





HVG SNe Ia are those with an offset Si distribution mixed into the outer O layer in the direction of the observer. At significant angles away from the offset direction, the Si is found in a thinner layer, more evenly excited by the underlying Ni substrate, leading to an LVG SN Ia with a lower polarization for Si II λ6355.

Type Ia/Subluminous



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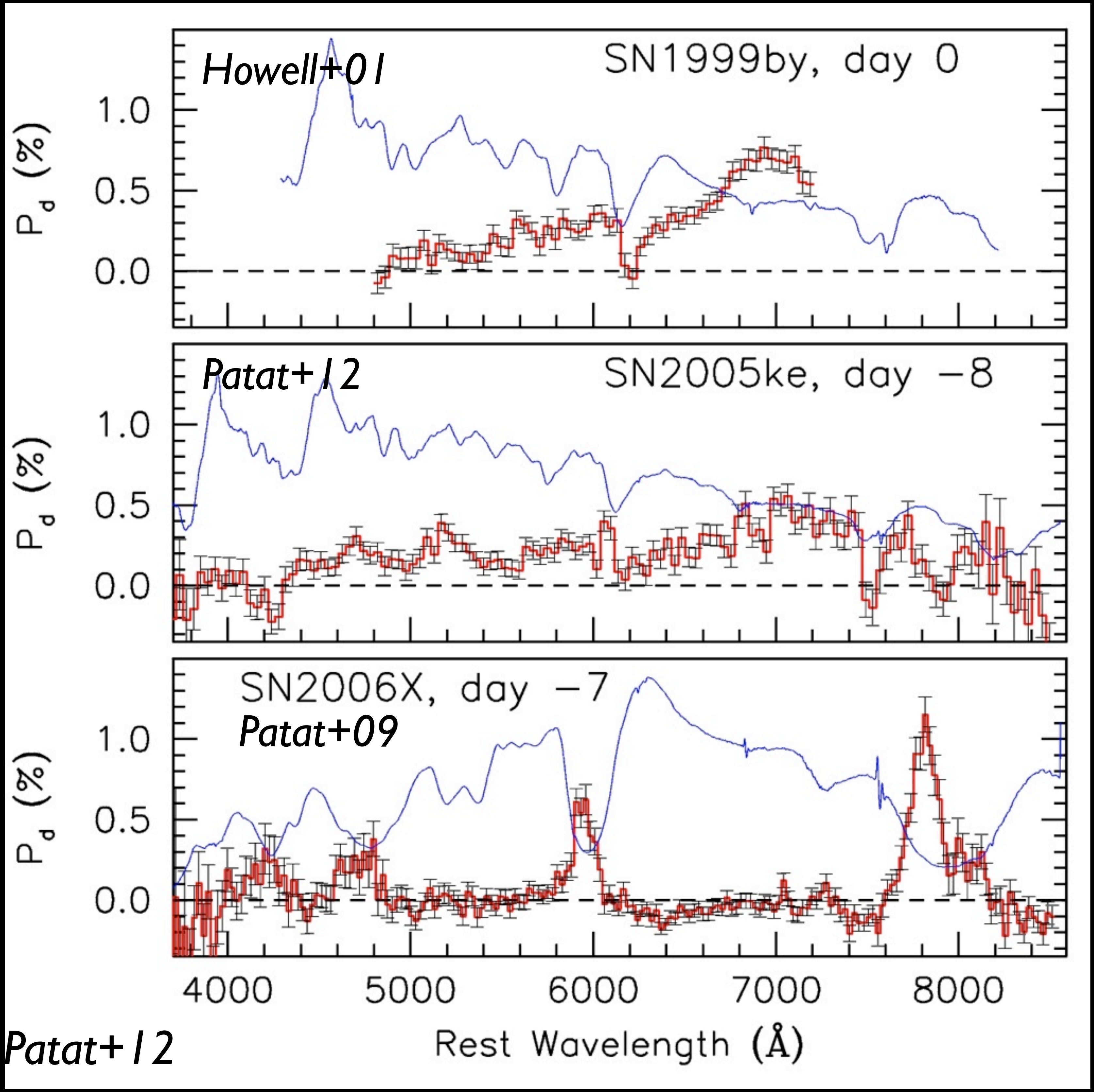

Patat+12

Continuum polarization, weak line polarization

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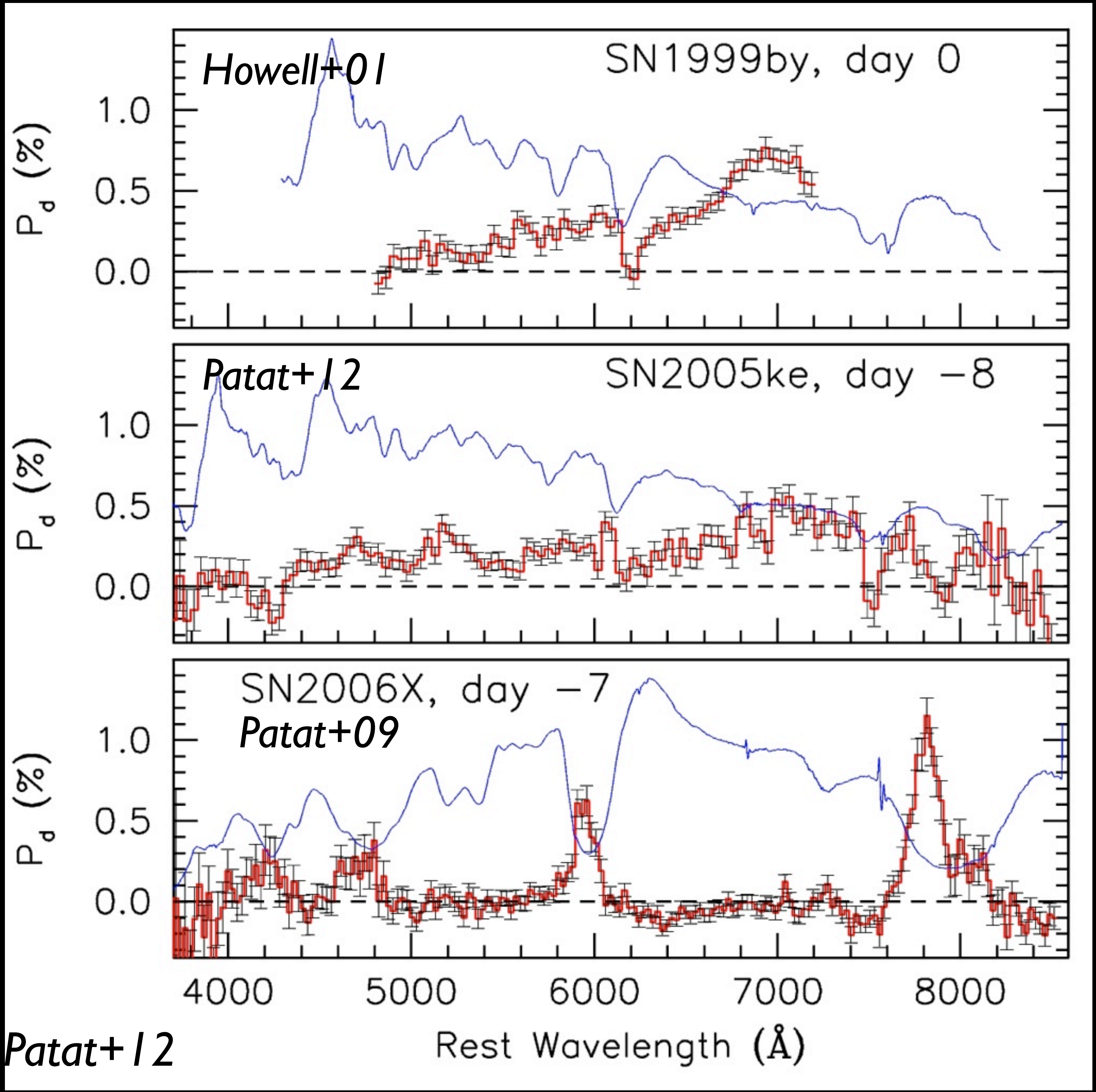

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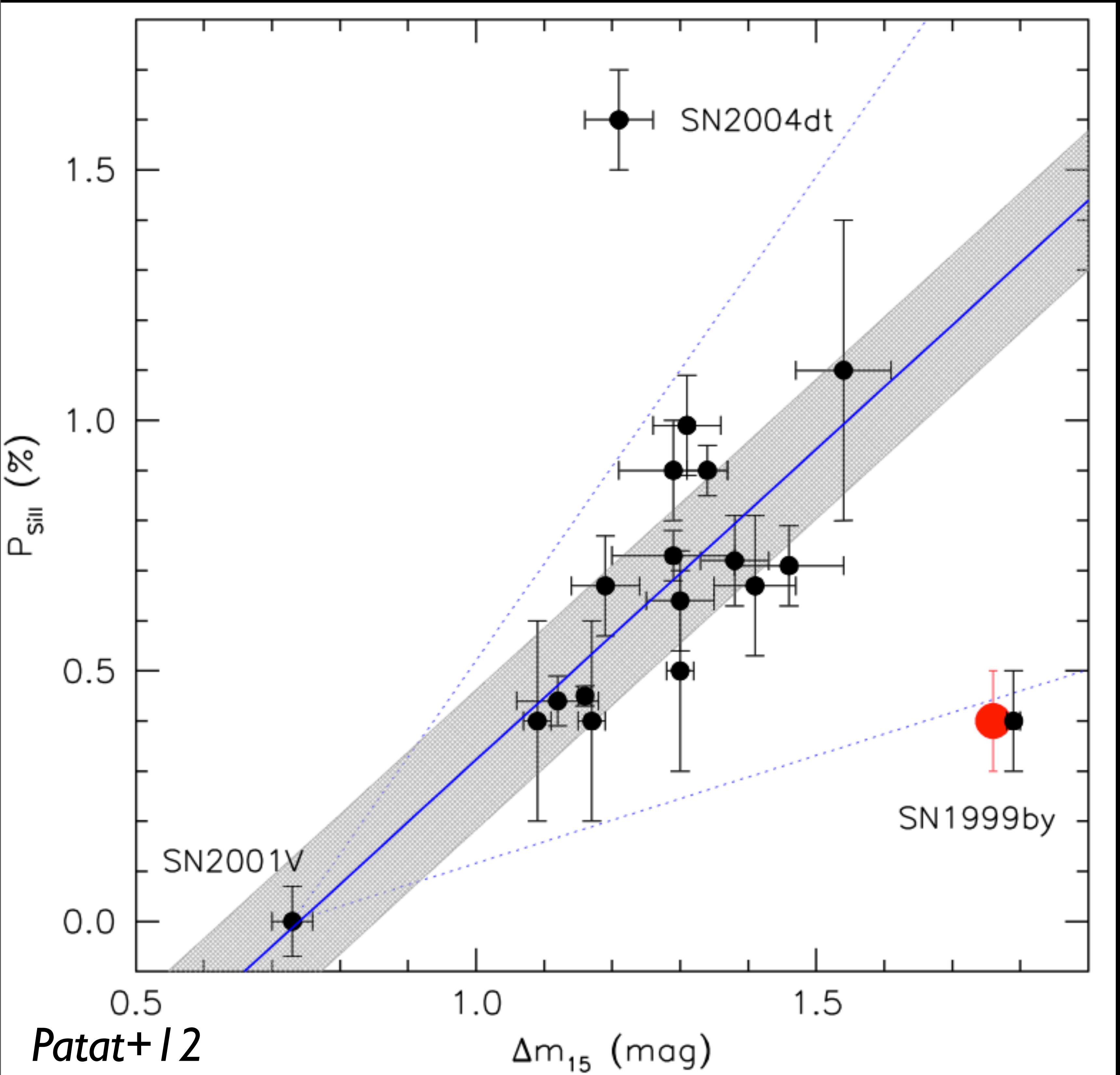

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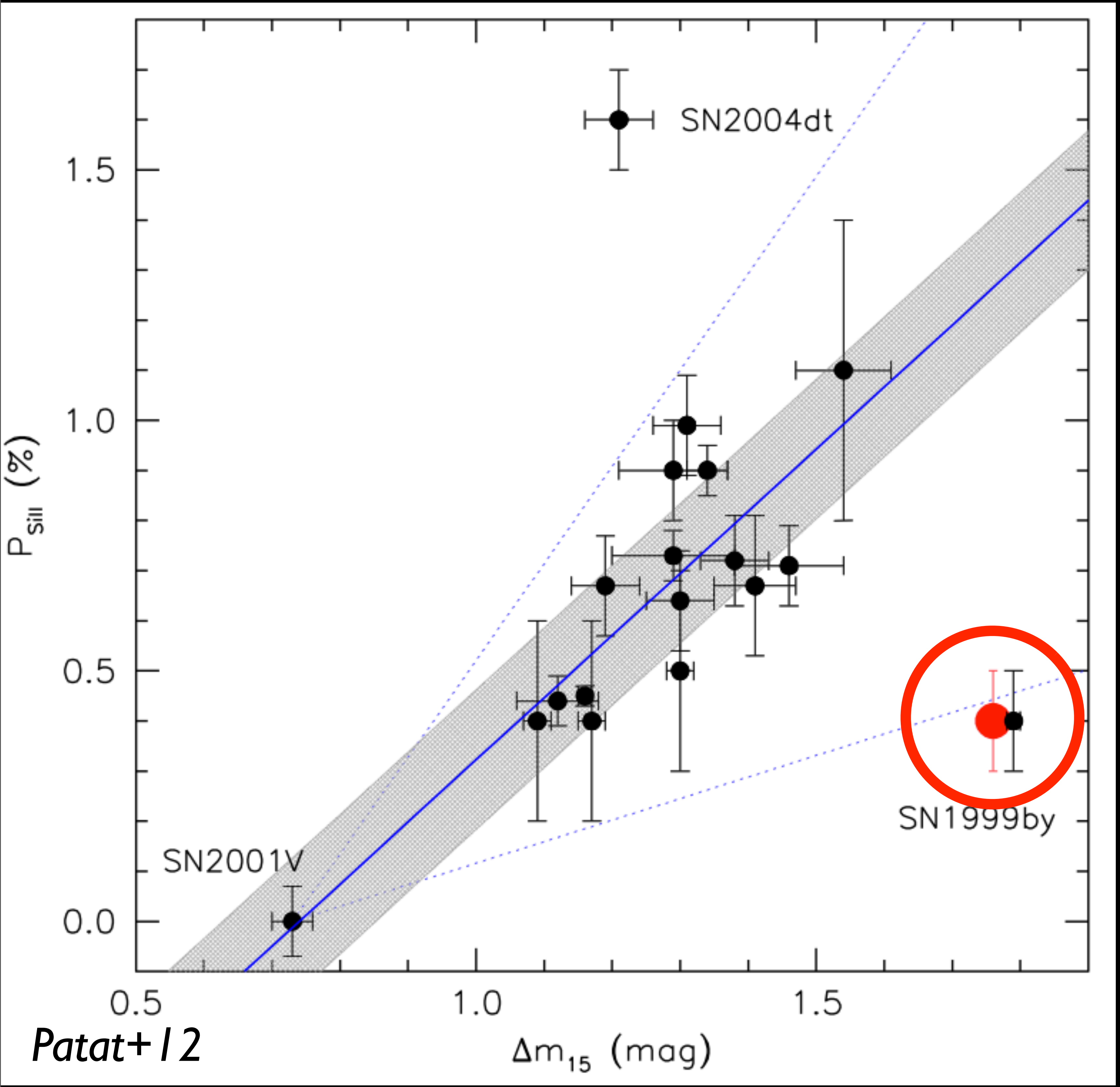

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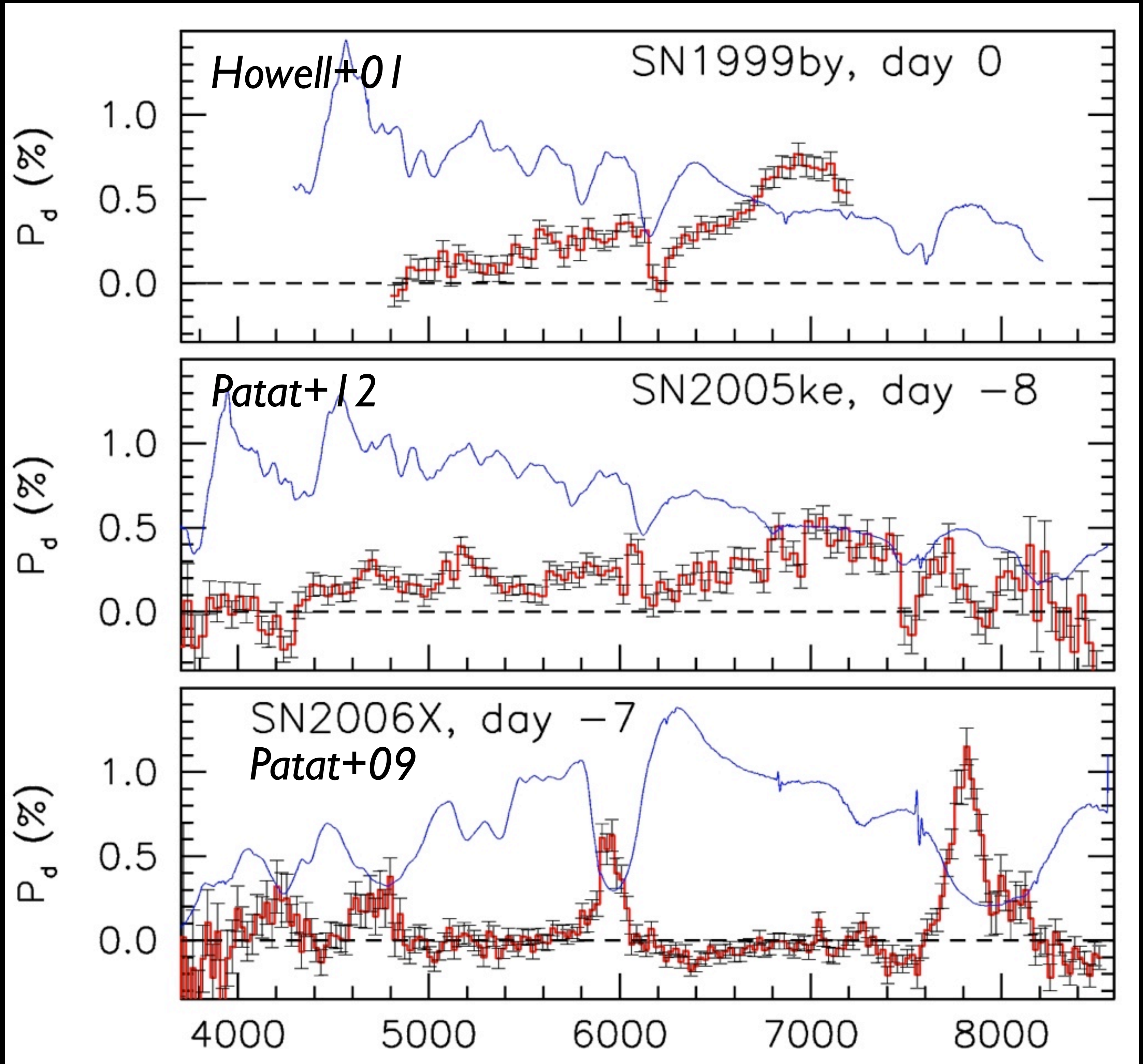

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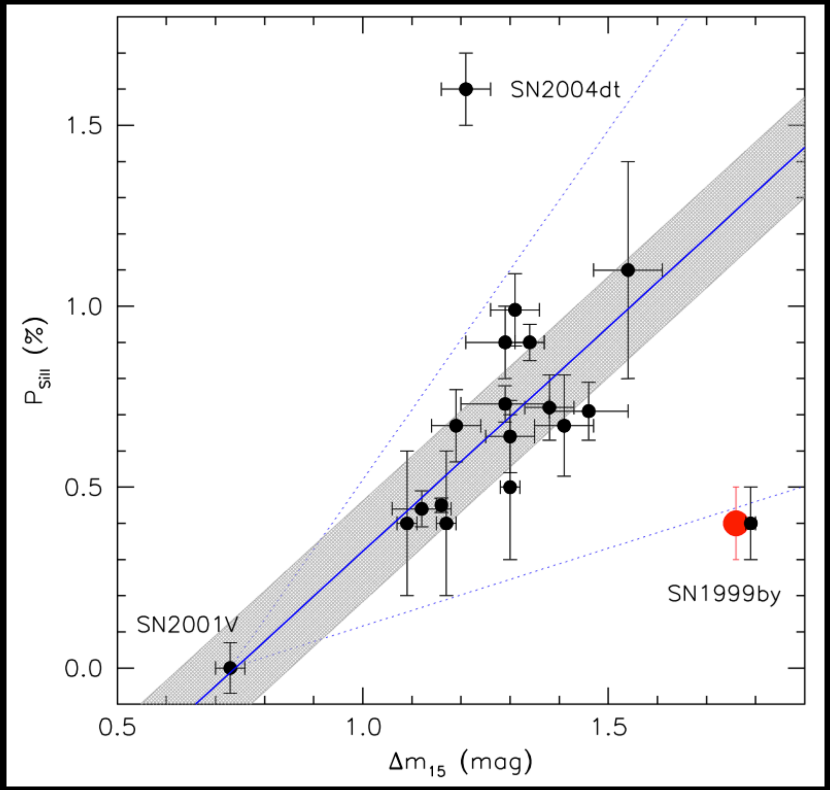

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courtesy of F. Roepke

The differences w.r.t. normal Ia are caused by low photospheric temperatures, in combination with layers of unburned C and more massive products of explosive C and O burning

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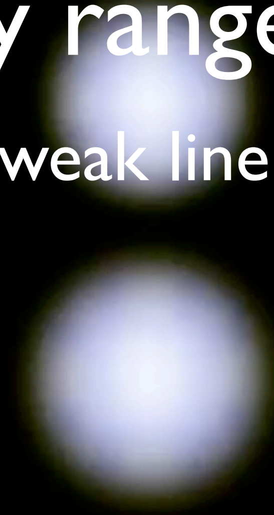

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- In the two sub-lum events, the lines of IMEs form far from chemical boundaries, and over a large velocity range. This causes a blocking of the entire photosphere (weak line polarization).
- The overall asphericity characterizing sub-lum Ia may be produced either by a fast WD rotation, or by a double-degenerate merger.

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A digression into a dusty territory

Things to remember

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- line polarization: chemical asymmetries (selective photosphere line-blocking). Can exceed a few %.

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ISP : Polarization = Reddening:Spectrophotometry

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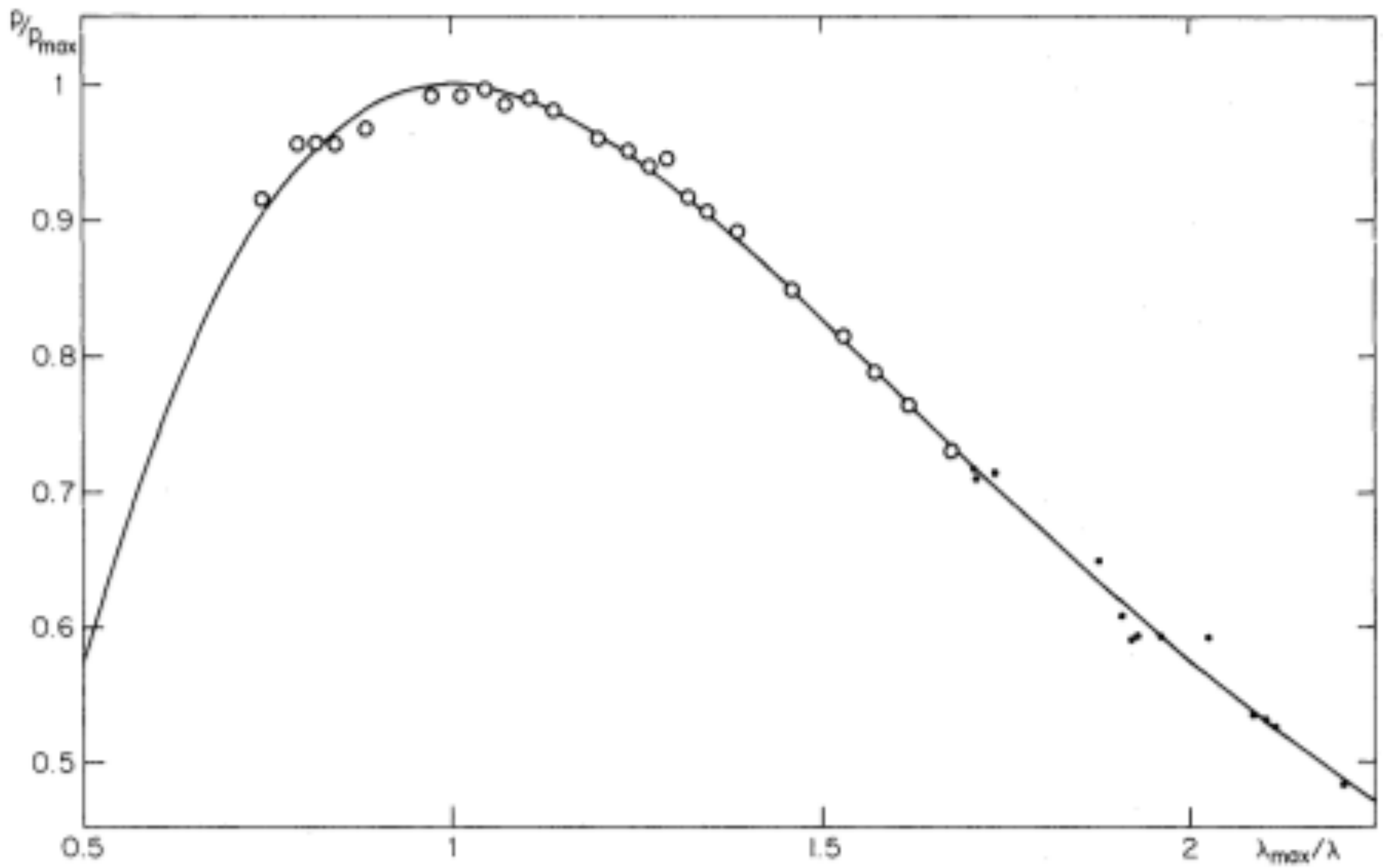
What do we know about ISP?

WAVELENGTH DEPENDENCE OF INTERSTELLAR POLARIZATION AND RATIO OF TOTAL TO SELECTIVE EXTINCTION

K. SERKOWSKI, D. S. MATHEWSON, AND V. L. FORD
Mount Stromlo and Siding Spring Observatories, Research School of Physical Sciences, Australian National University
Received 1974 July 30

SERKOWSKI, MATHEWSON, AND FORD



$$P(\lambda) = P_{\max} \exp\left(-K \ln^2 \frac{\lambda_{\max}}{\lambda}\right)$$

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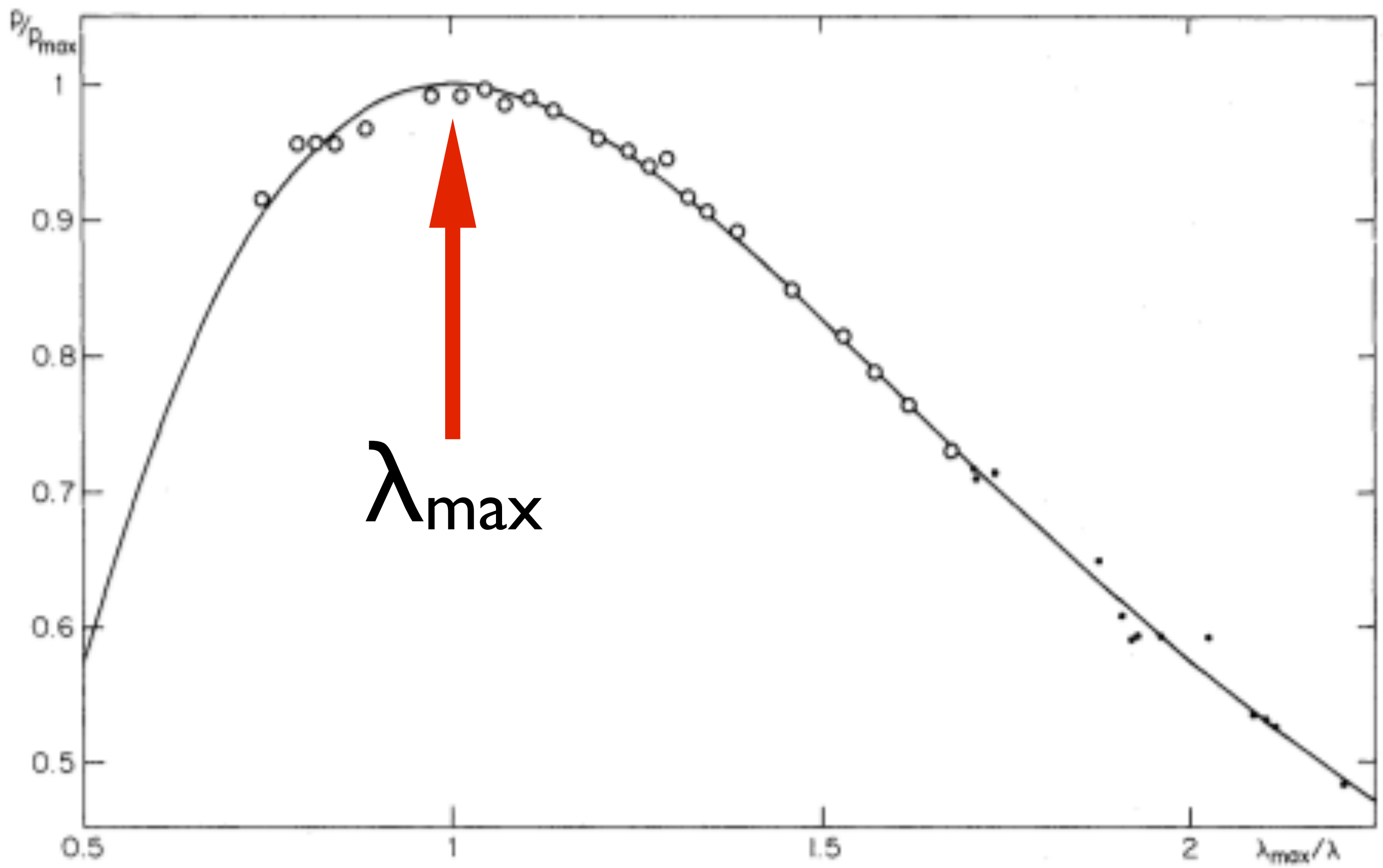

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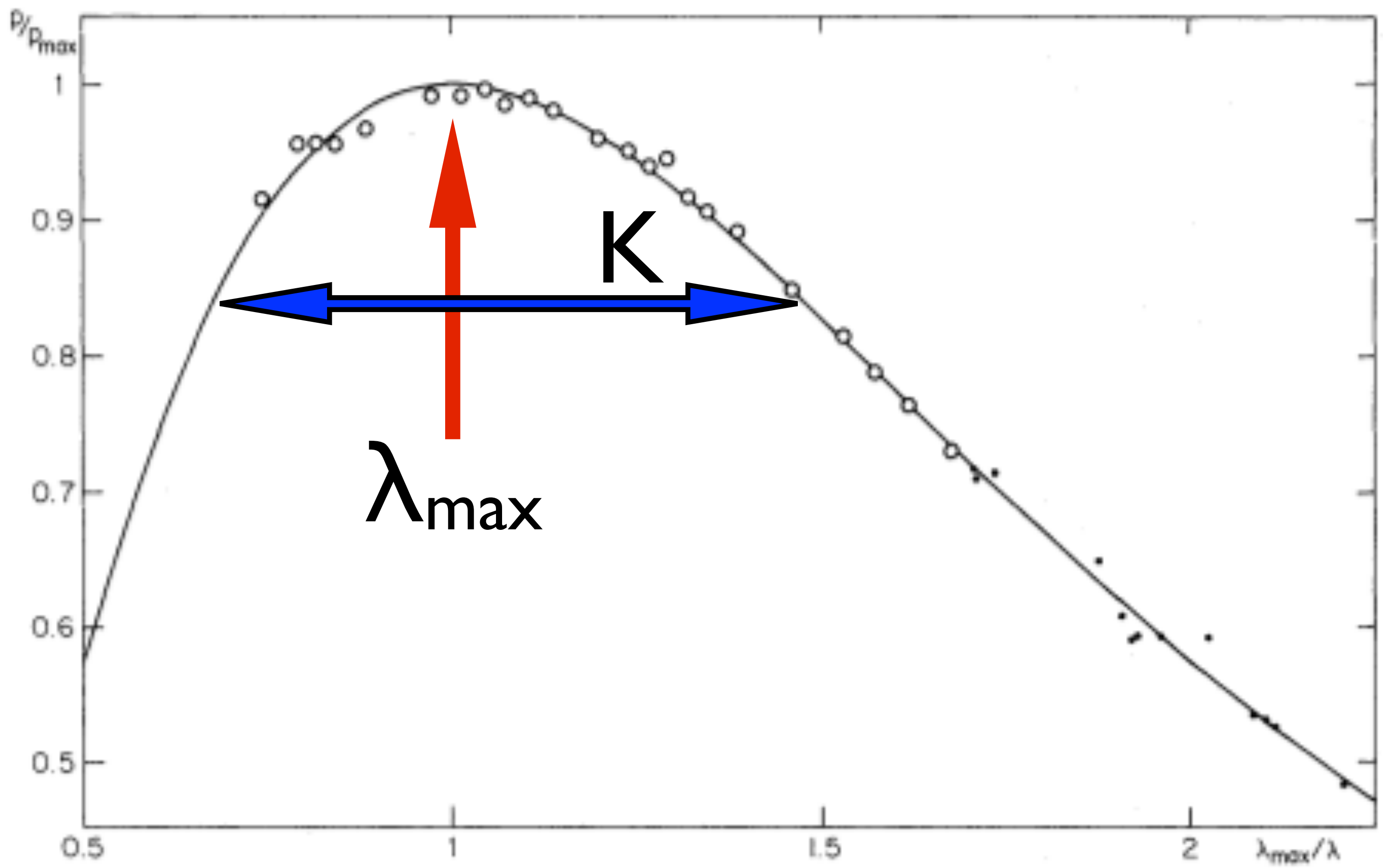

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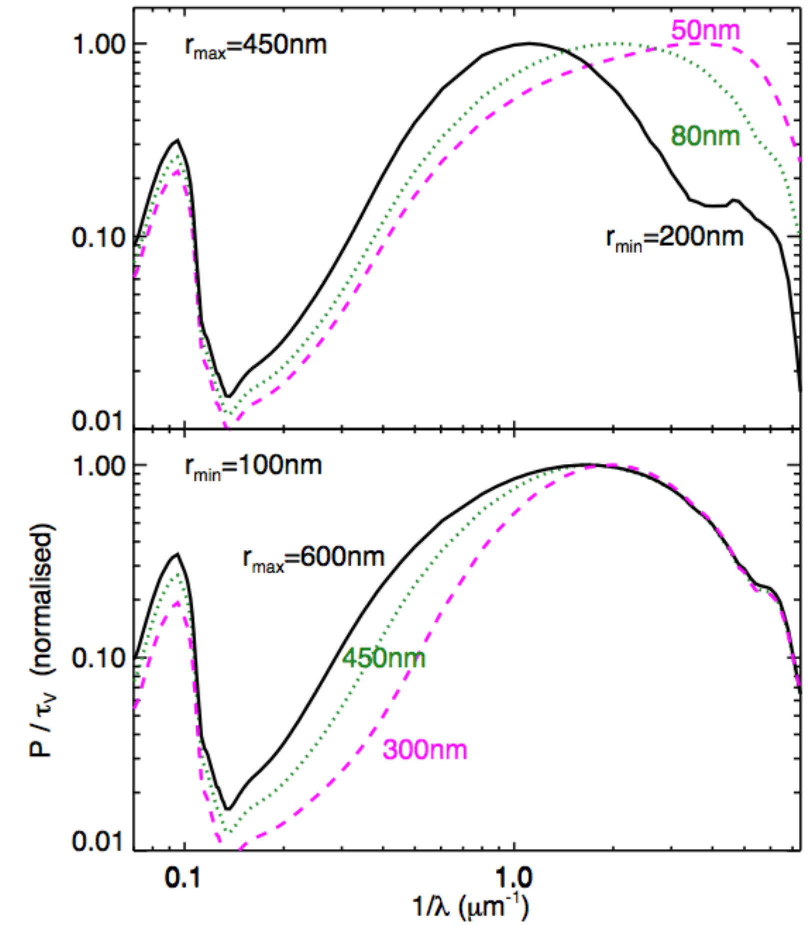
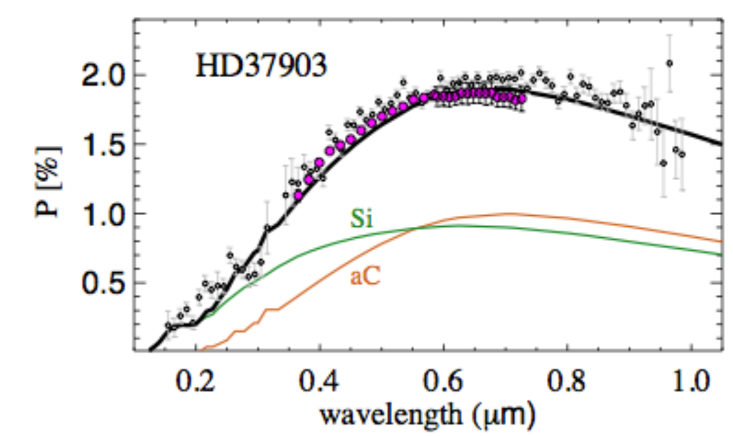
•We are starting to have a physical explanation for the *empirical* Serkowski law (in terms of dust composition and grain size distribution).

•It seems to be a well defined law in the MW, similarly to the Reddening Law. There are no reasons to believe it is not *universal (on average...)*.

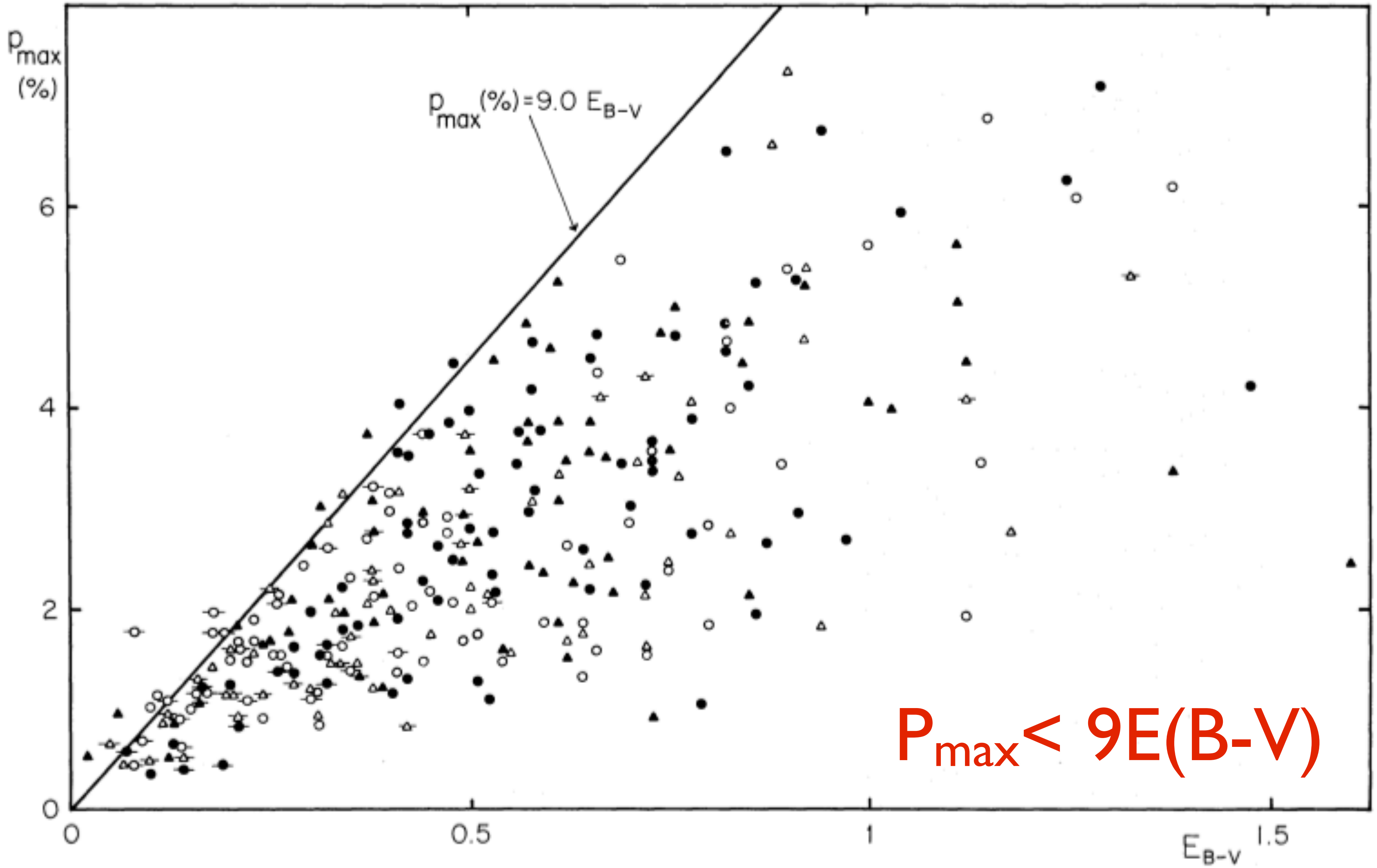


Siebenmorgen+13



$$R_V = (5.6 \pm 0.3)\lambda_{max}$$

P_{max} vs. E(B-V)

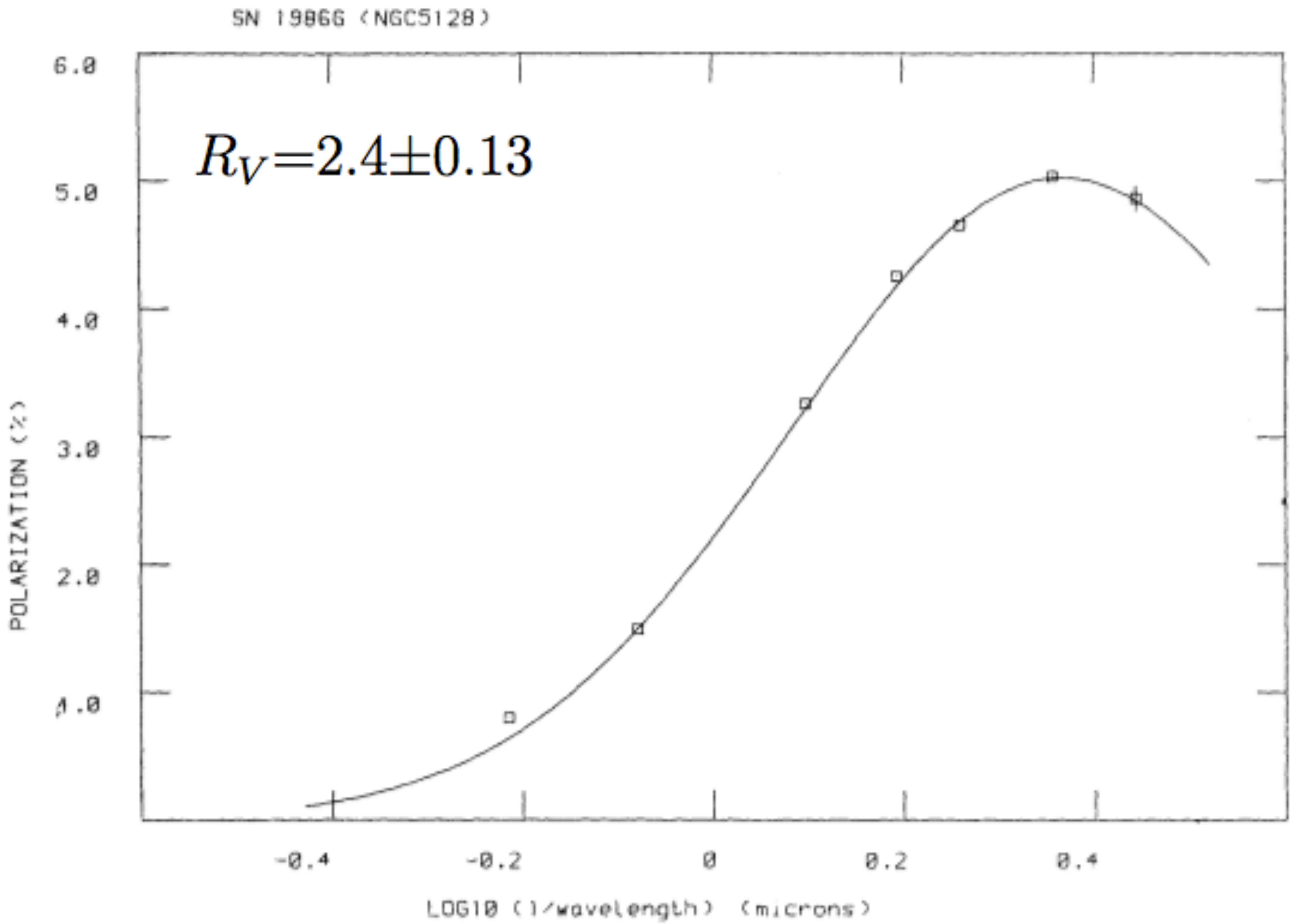


P_{max}< 9E(B-V)

Linear polarization induced by dychroism on aligned dust grains

Can we do it outside of the MW?

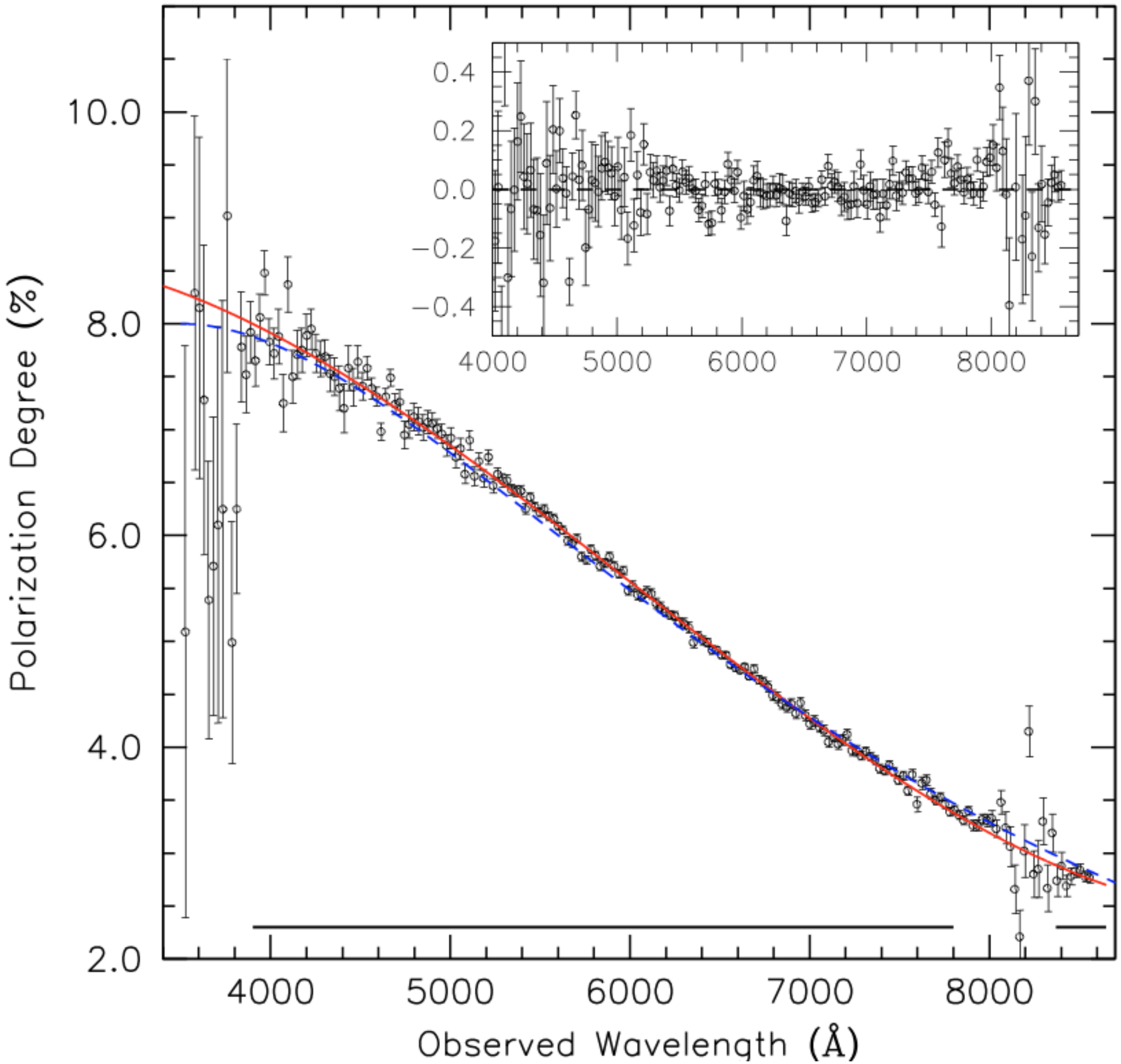
SN1986G in Cen-A *Interstellar polarization in NGC 5128*

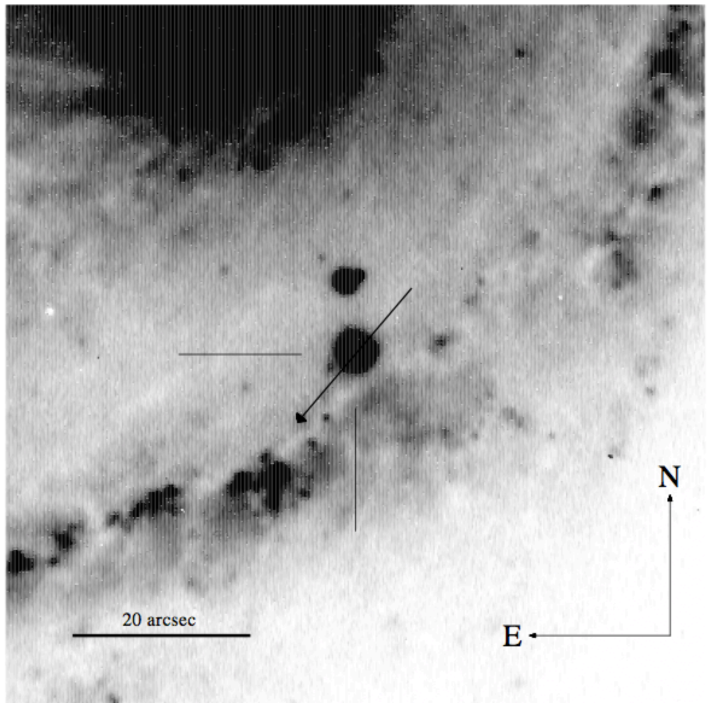


R_V =2.6±0.2 (Phillips et al. [2013])

Hough et al. 1987

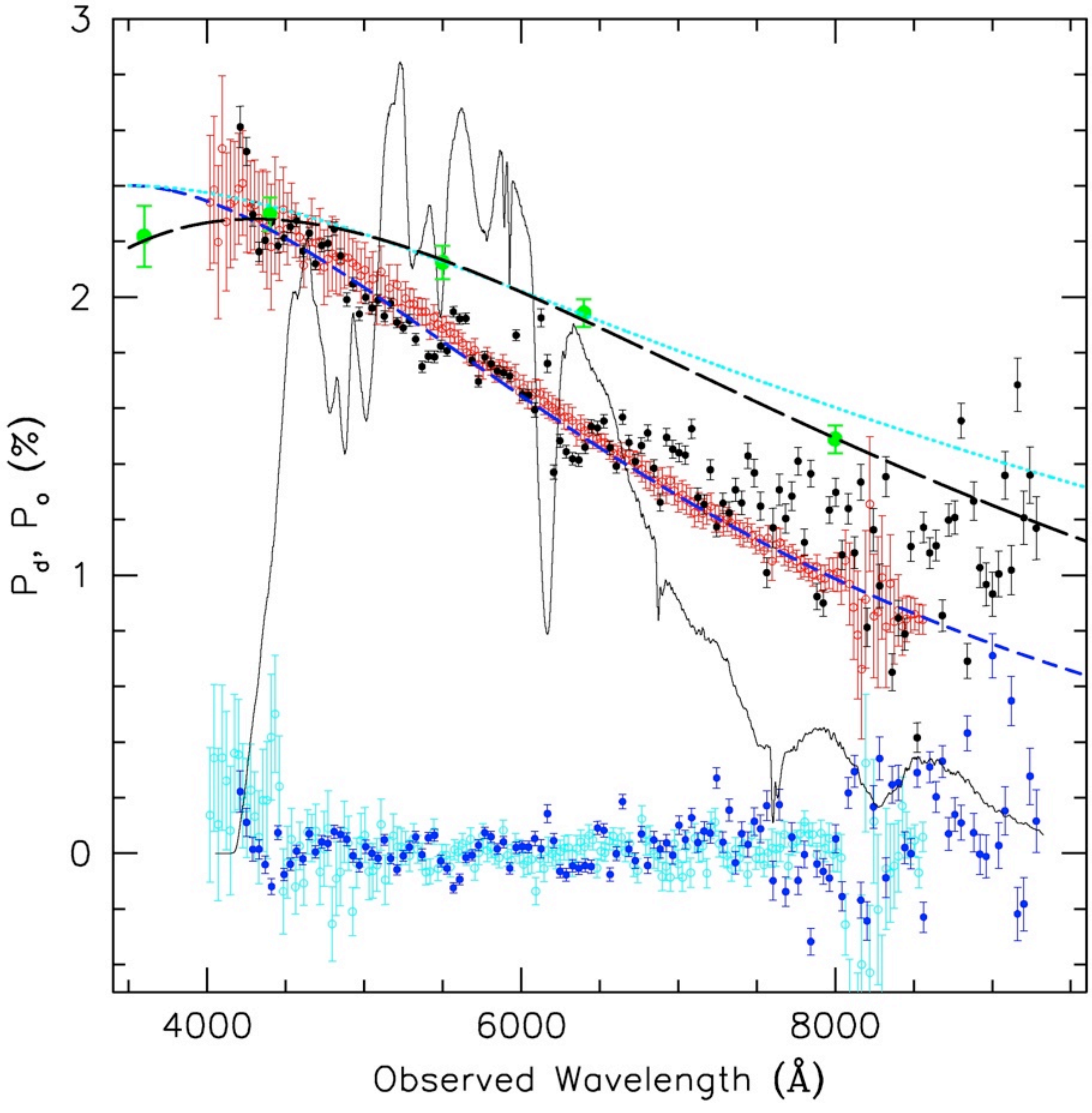
Rv= 1.48±0.06 (Wang et al. [2008a]), $1.31^{+0.08}_{-0.10}$ (Phillips et al. [2013]).

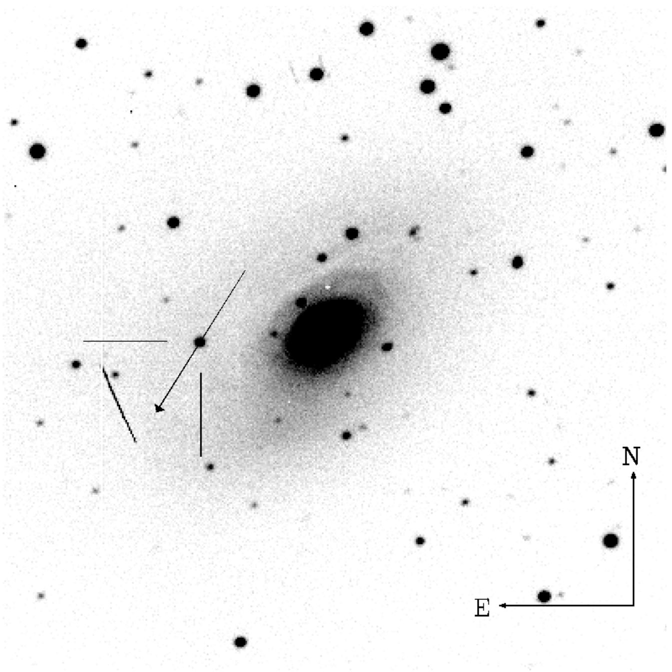




SN2006X

Serkowski (and Whittet) where are you?

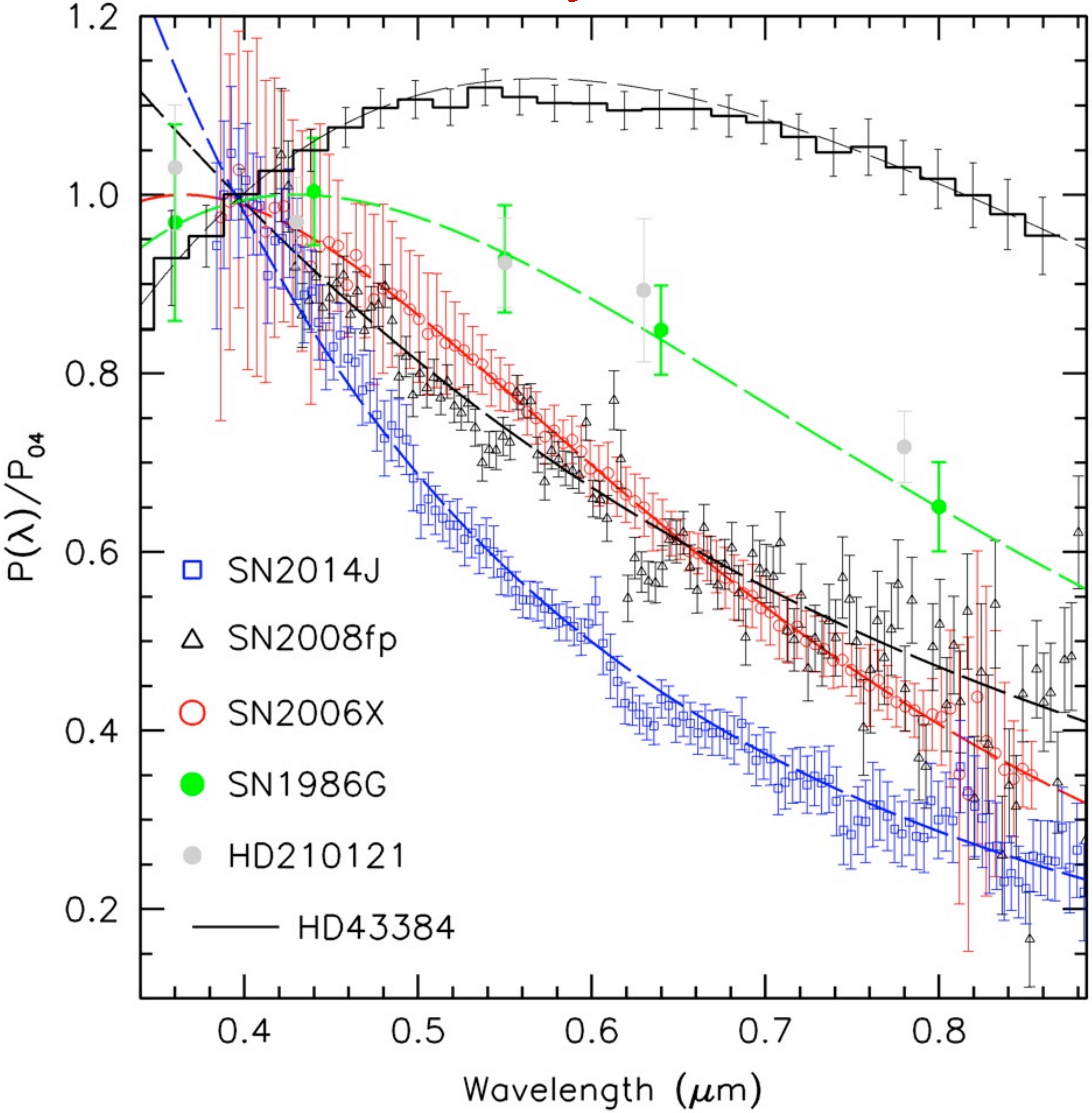




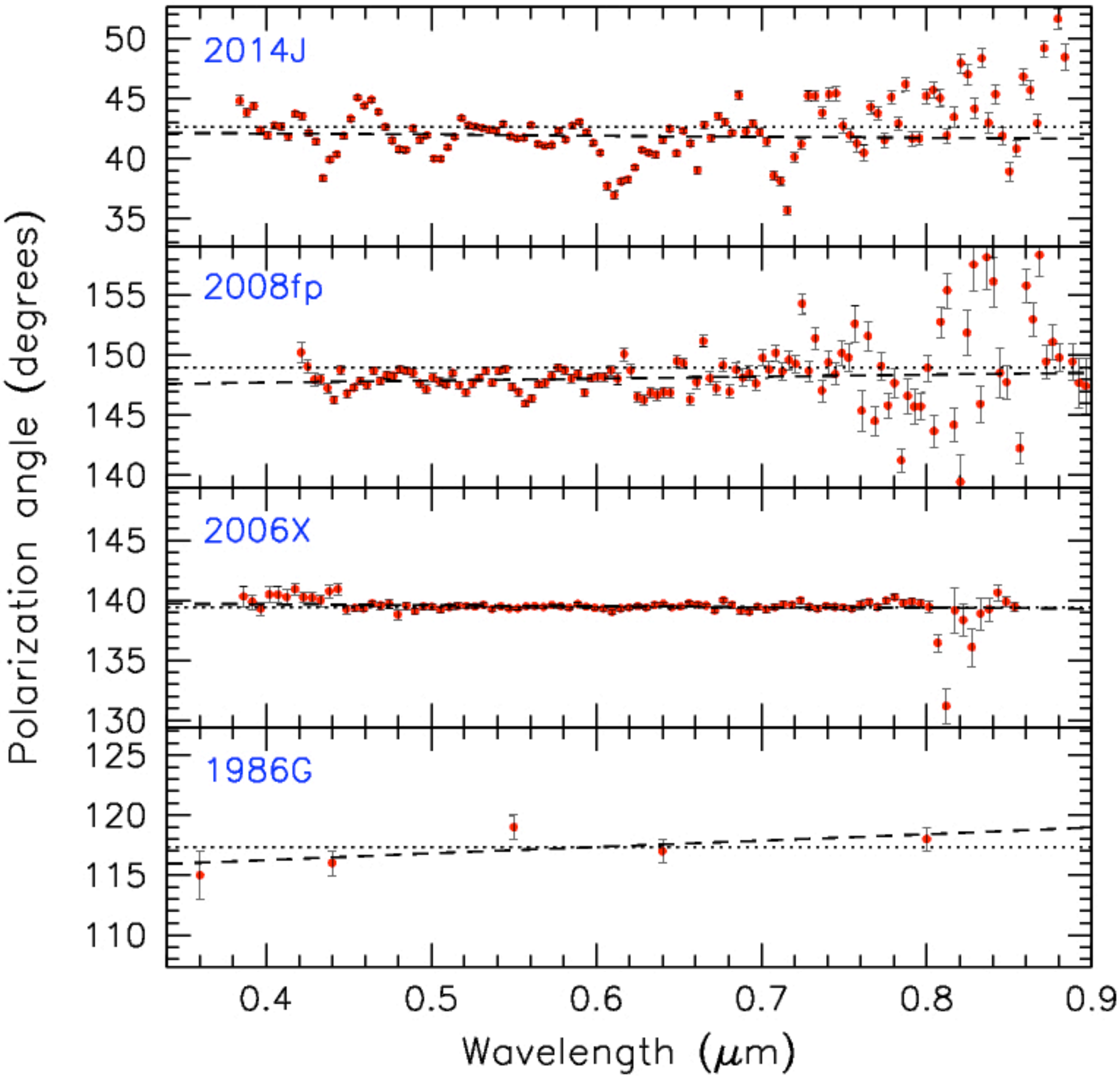
SN2008fp

Cox & Patat, 2014

SN2014J & Co

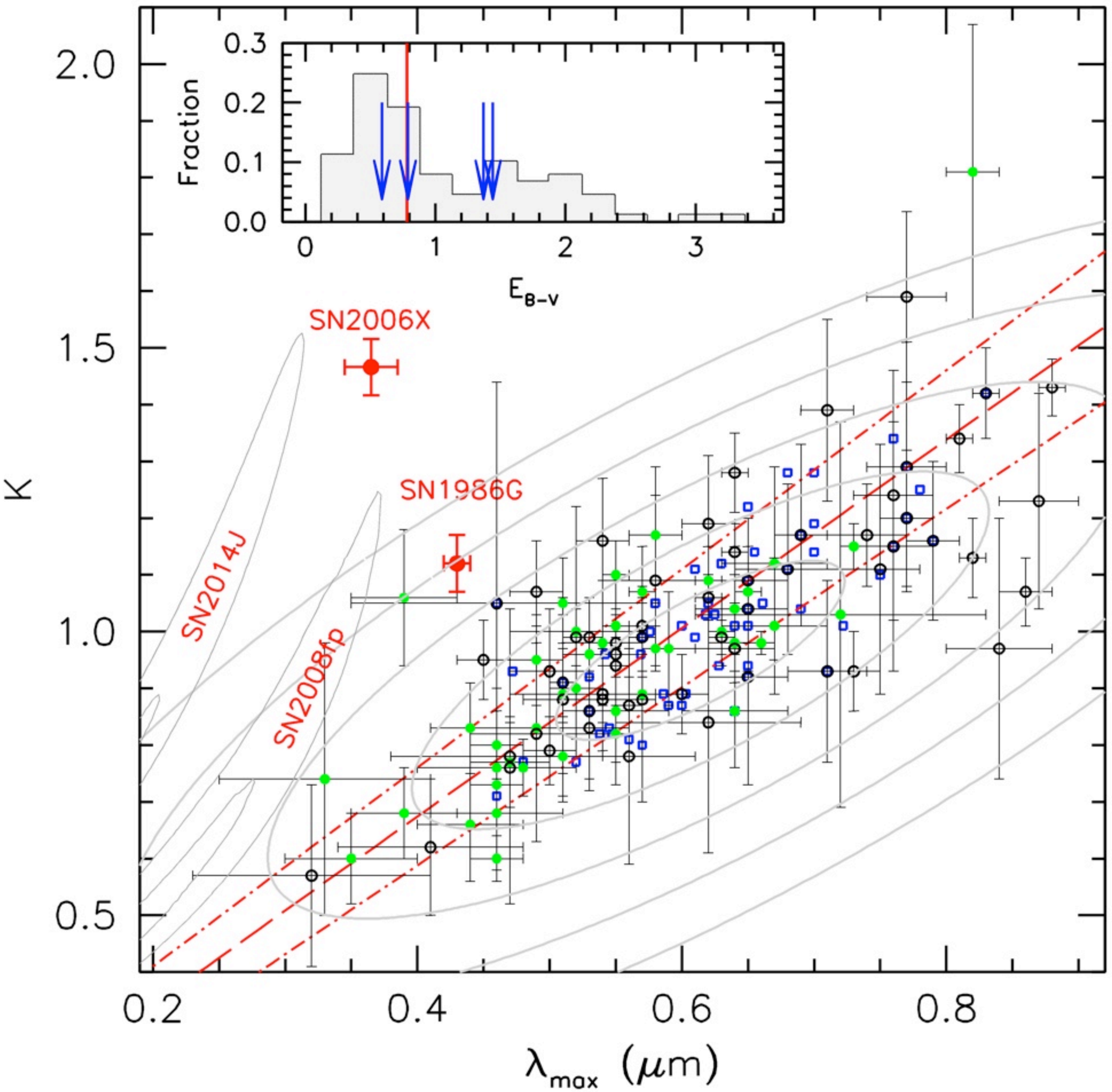


Patat+ 2014



2014J
2008fp
2006X
1986G
Polarization angle (degrees)
Wavelength (μm)

How exceptional is this?



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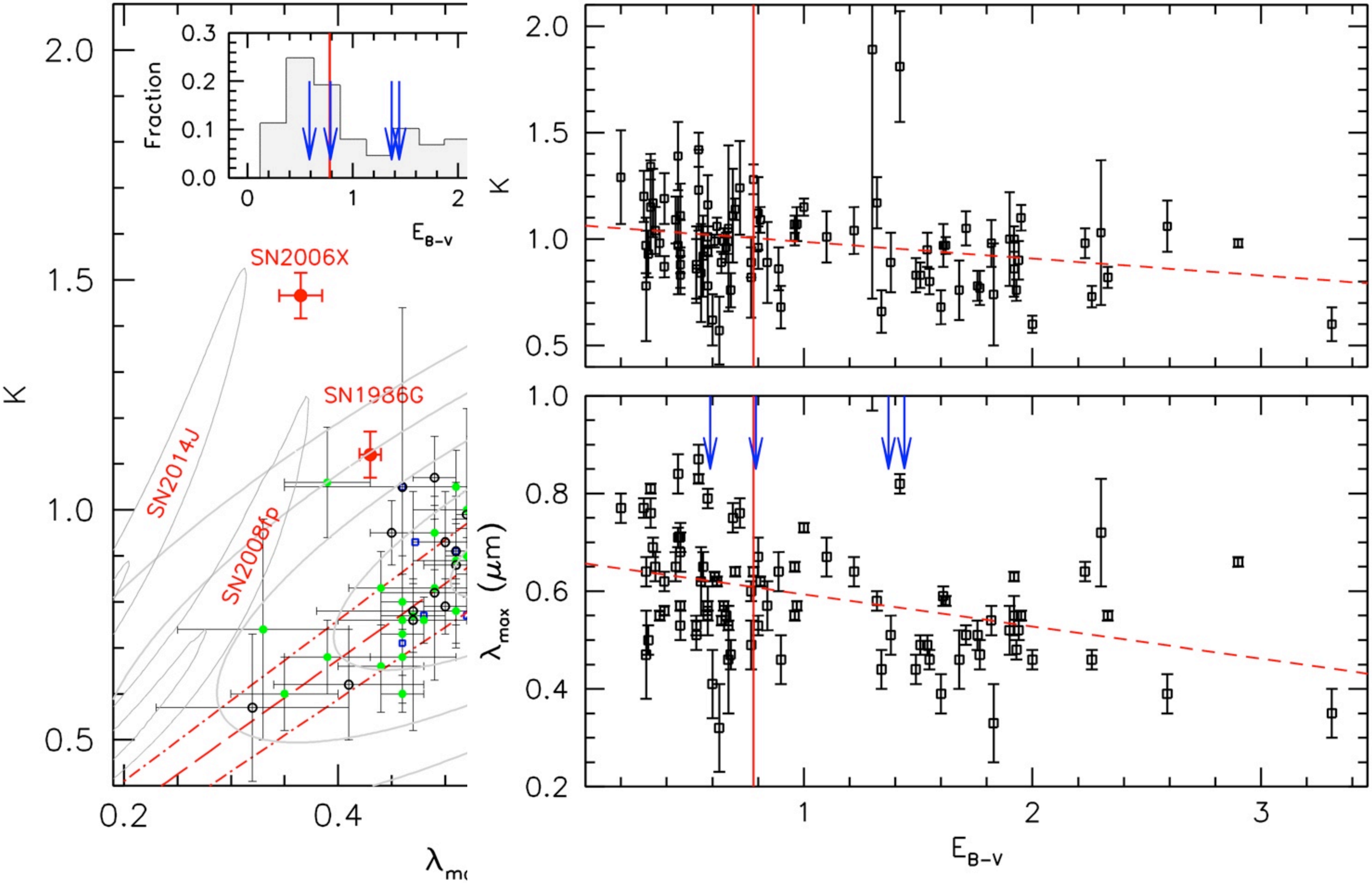
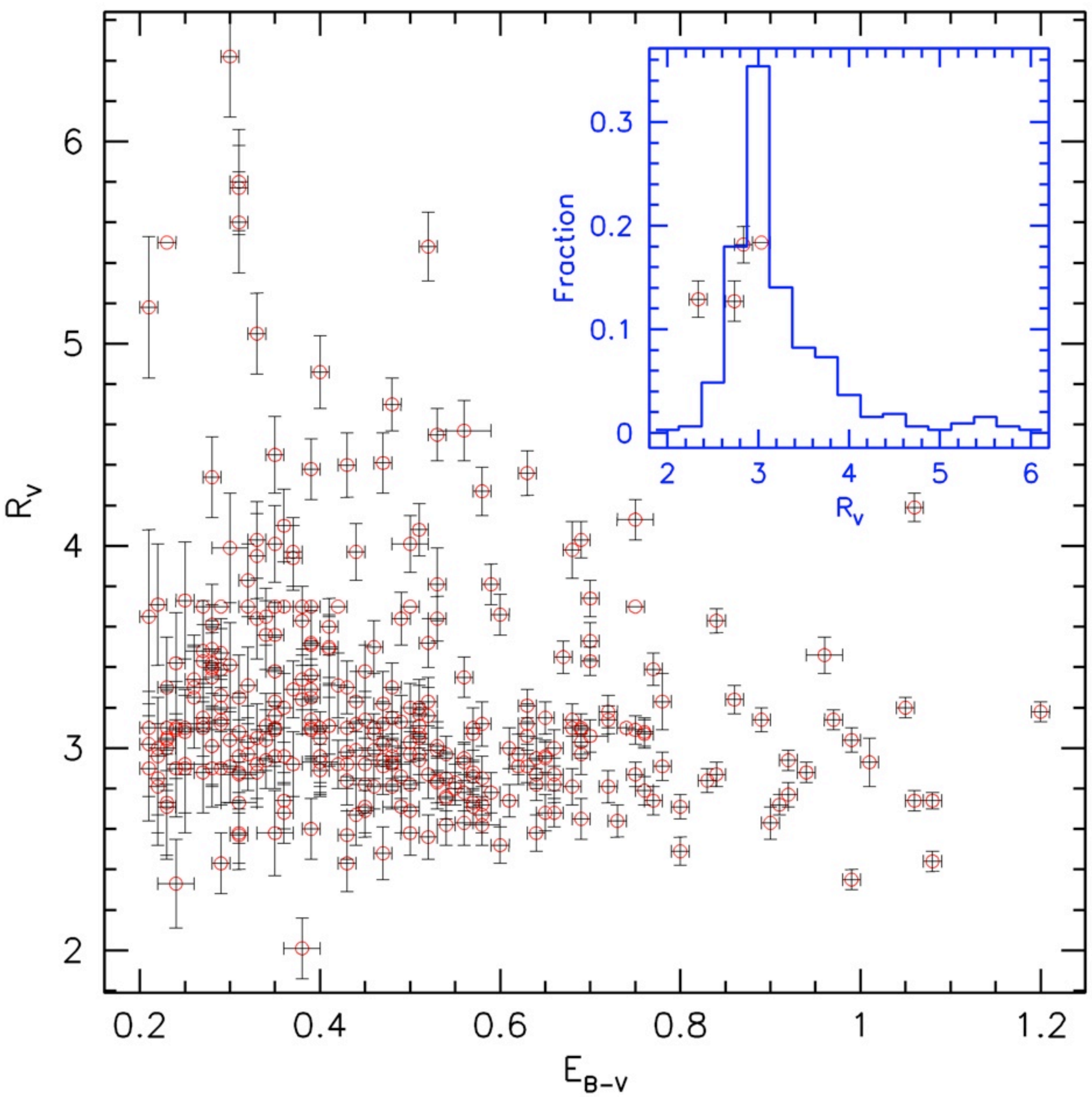
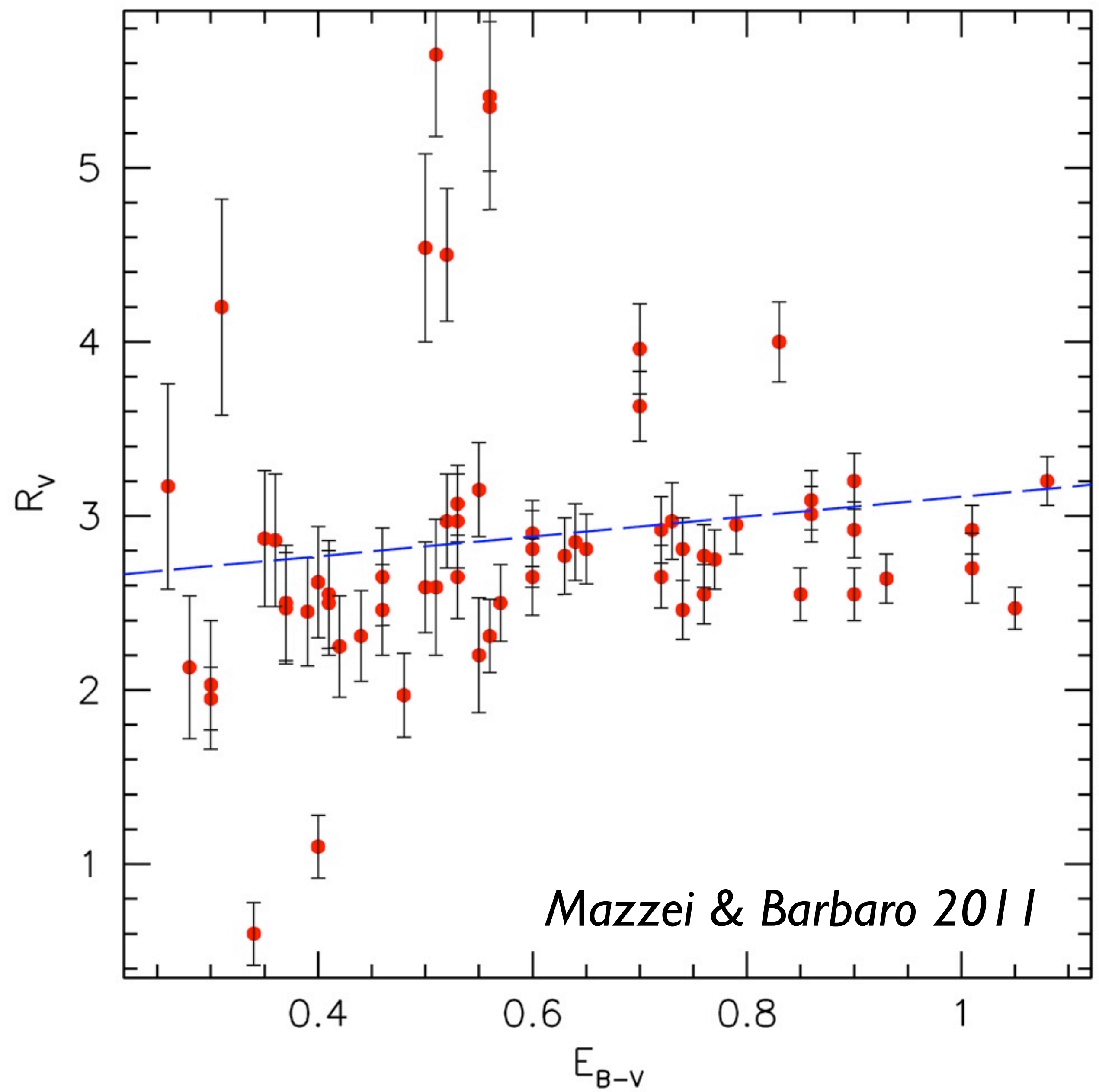


Small R_V ?

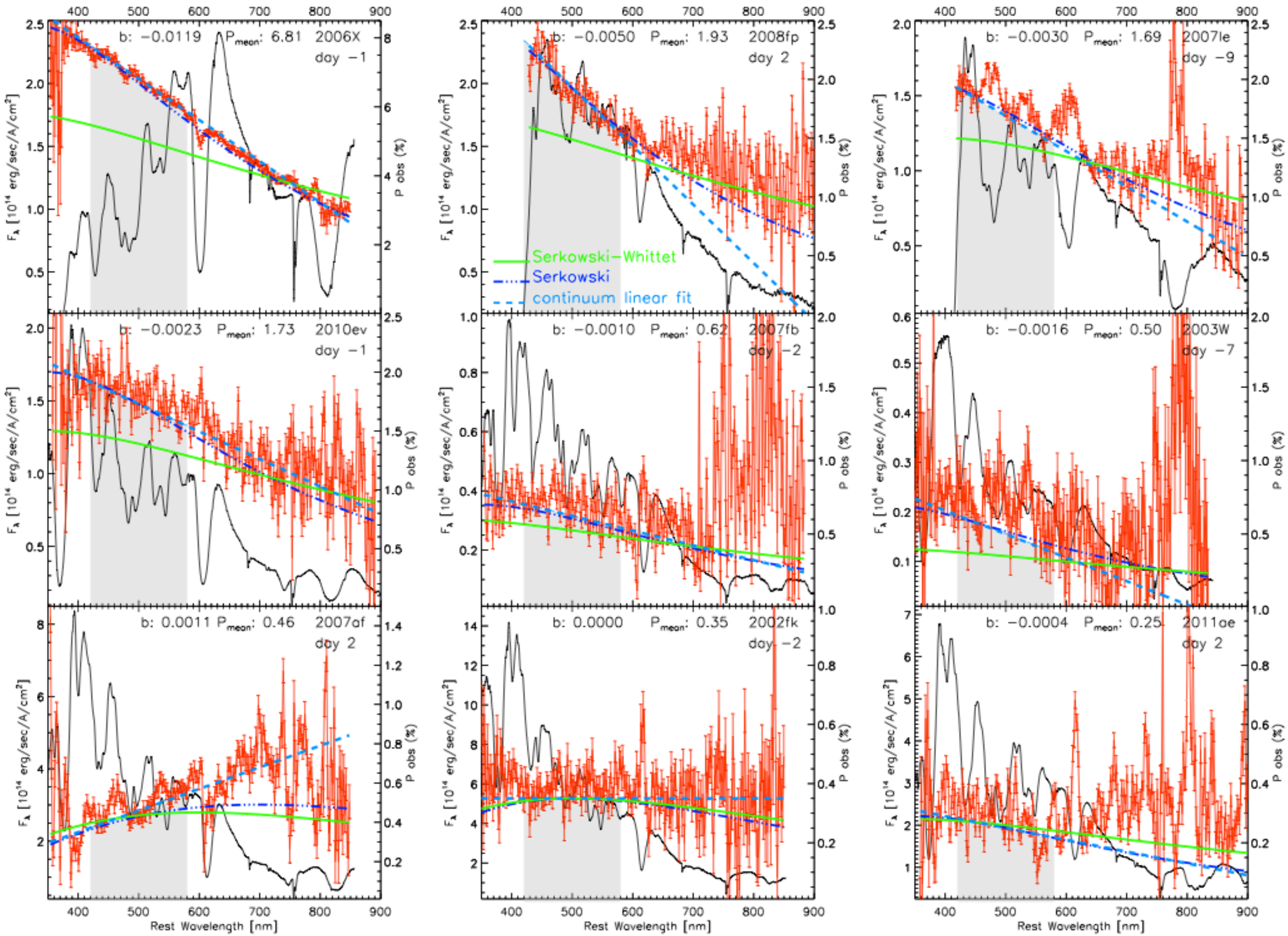
Fitzpatrick & Massa, 2007



anomalous l.o.s. in the MW



no preference for low R_V values at high E_{B-V}



Zelaya et al. 2015, in preparation

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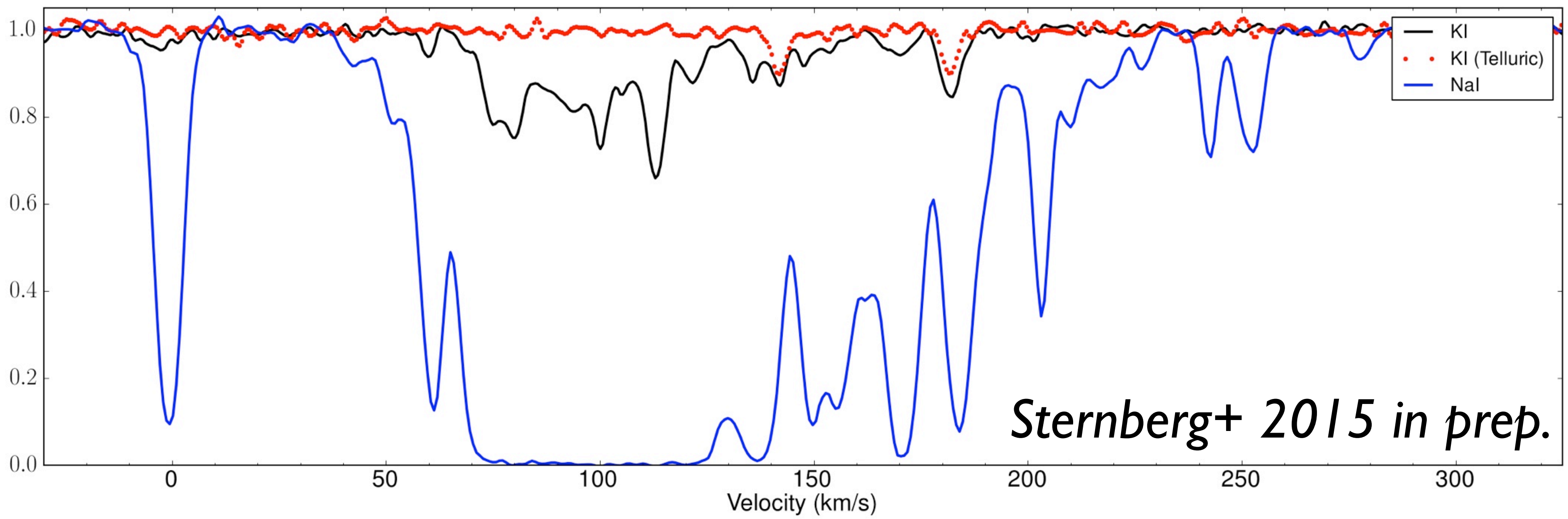
The case of 2014J

see Patat+14
Kawabata+14
Foley+14
Brown+14
Amanullah+ 14

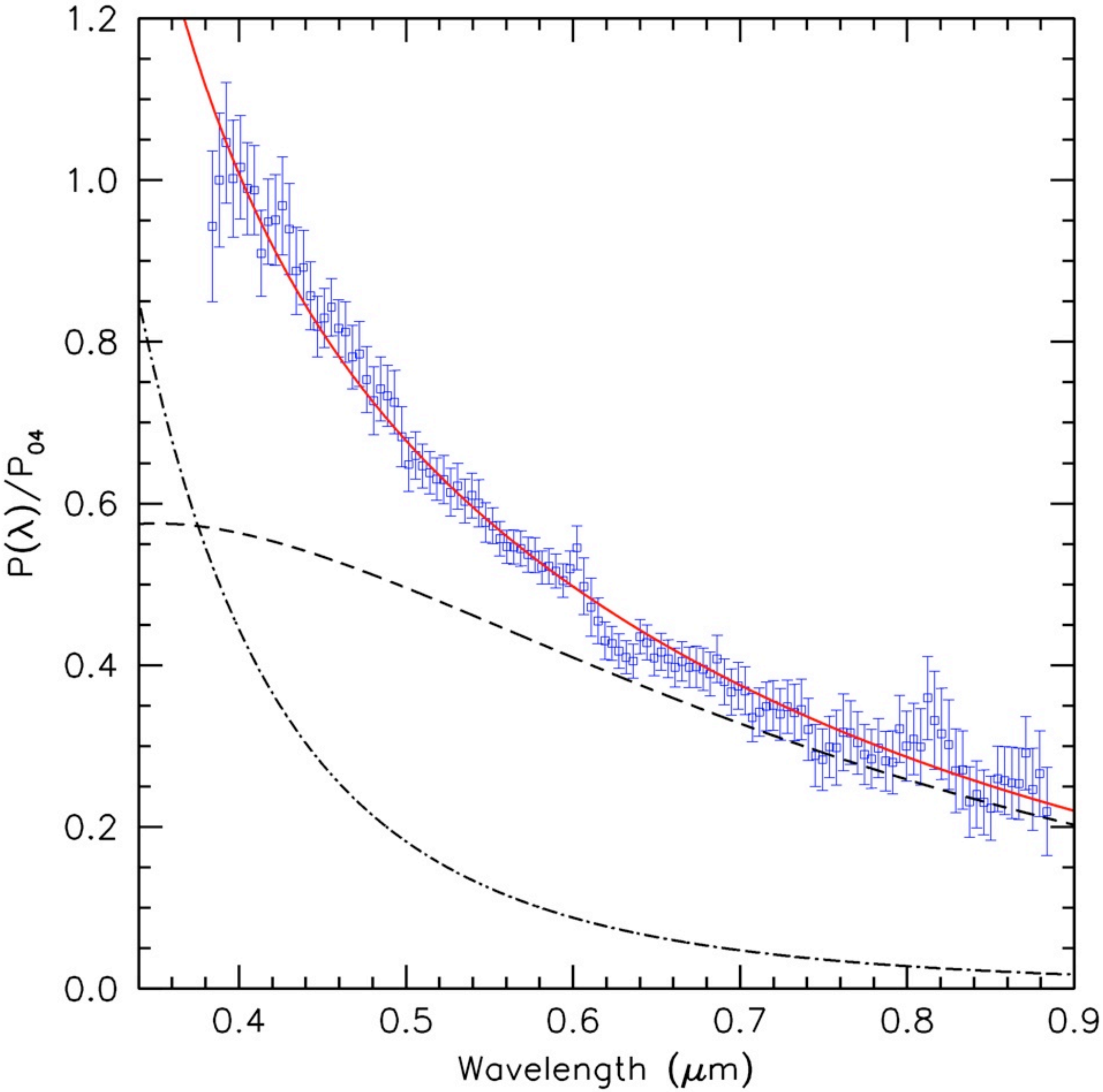


The line of sight is probing a number of clouds within the disk of M82

It is very reasonable to think that the bulk of reddening (and polarization) is of IS nature

[See the LE detection by Crotts 14]

Scattering by CS dust in 2014J?



Phillips et al. 2014
Burns et al. 2014 (in preparation)

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(Maguire+ 2013)

Specpol data of 2006X, 2008fp, 2014J go in the same direction (but it is “just” 3 events...)

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The question remains as to why this dust seems to be [systematically] different from the typical MW mixture.

Open Questions

- Is the "weird" dust local? Many things seem to speak against this, but...
- Are the dust properties rather related to the host galaxy and its evolutionary stage (dust composition and size distribution are not static)?

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We may be able to disentangle the two contributions via HST polarimetry at late epochs. HST proposal accepted (PI: L. Wang). Observations ongoing!


Thanks!


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