

# Probing the Three Dimensional Nature of Supernovae; Results from the Supernova Spectropolarimetry Project (SNSPOL)\*

\*Supernovae Are Not Spherical Cows

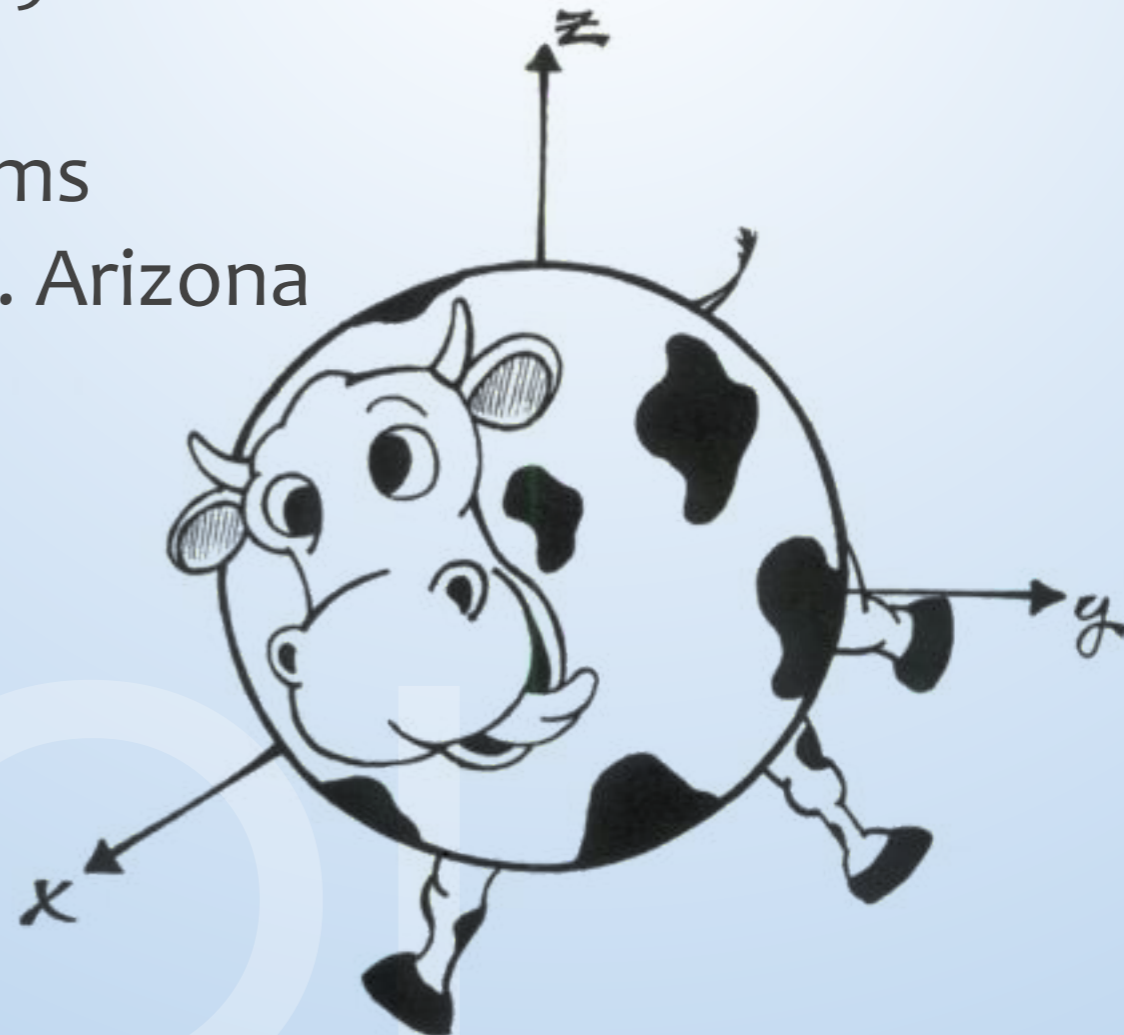
NSF AST-1210599

G. Grant Williams

MMT Observatory/U. Arizona

June 3, 2015

≠



SN 1987A

NASA/ESA/Challis & Kirshner



N. Smith



P. Smith



P. Milne



C. Bilinski



U. Arizona

L. Dessart

Lagrange, CNRS



+ many more

Leah Huk  
U. Denver



J. Hoffman  
U. Denver

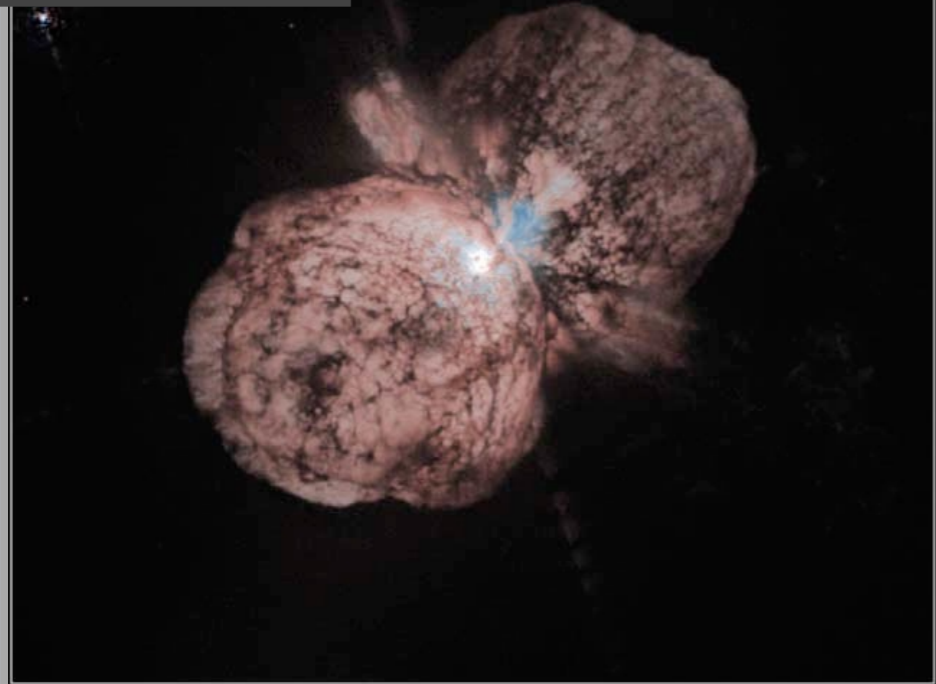


D. Leonard  
SDSU



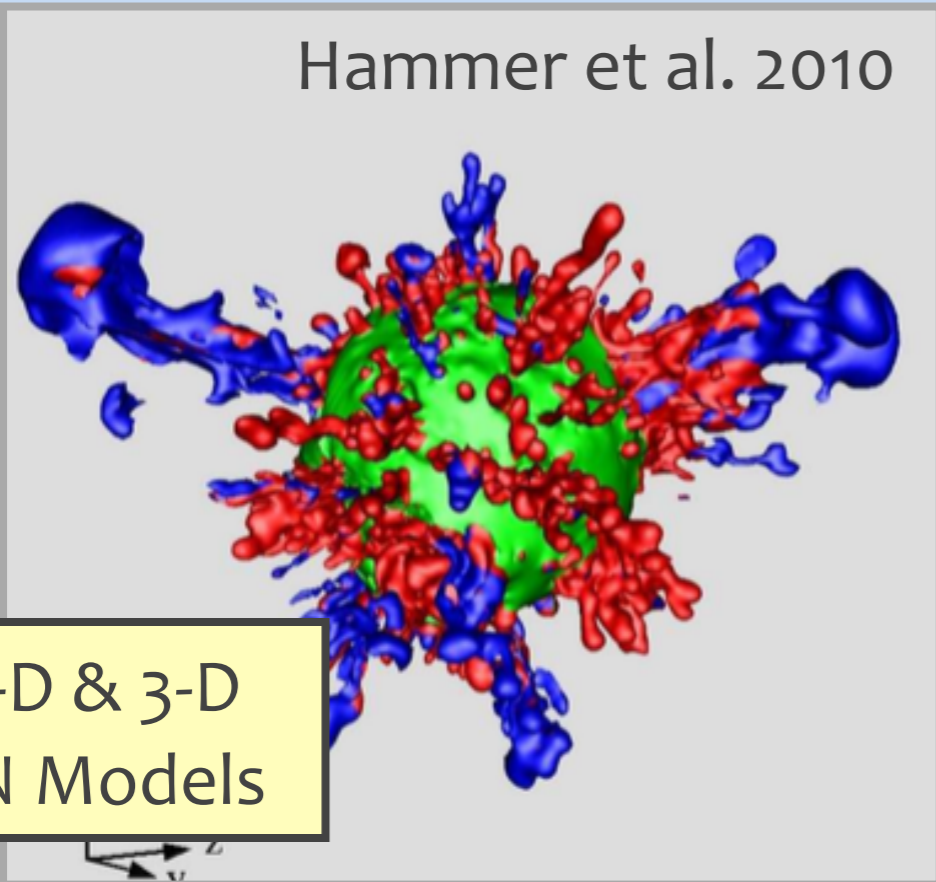
SNPDL

Eta Carinae  
SN Progenitor



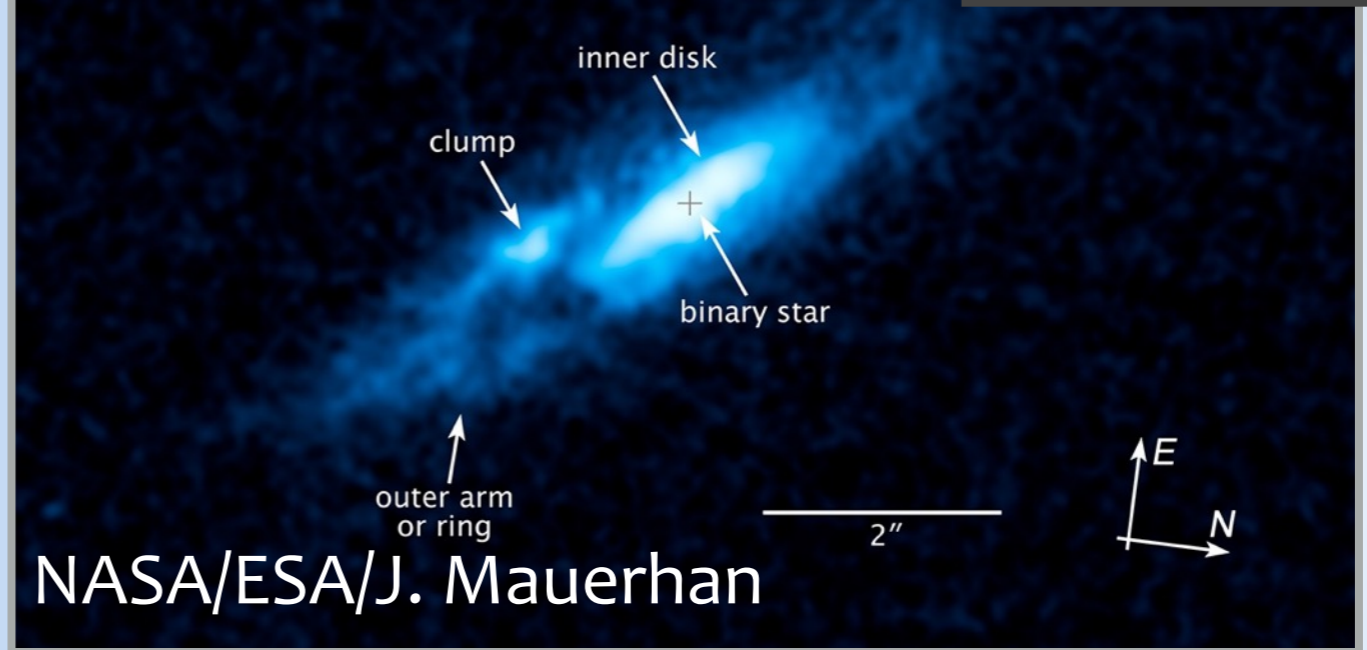
Eta Carinae HST · WFPC2  
PRC96-23a · ST ScI OPO · June 10, 1996  
J. Morse (U. CO), K. Davidson, (U. MN), NASA

2-D & 3-D  
SN Models



NaSt1 (Wolf-Rayet 122)  
HST WFC3/UVIS F658N-F645N

NaSt1 (Nasty1)  
WR Binary

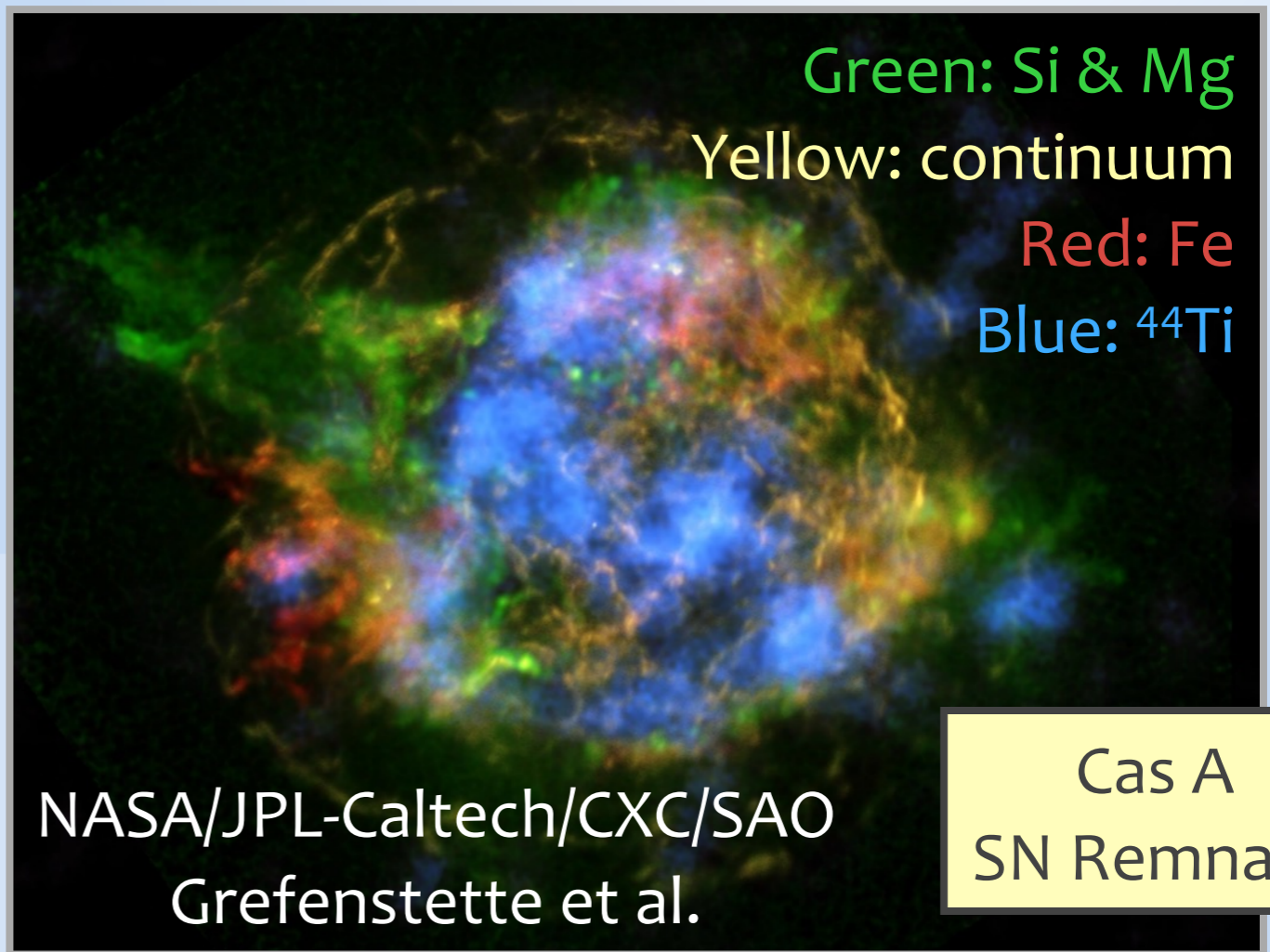


NASA/ESA/J. Mauerhan

Green: Si & Mg  
Yellow: continuum  
Red: Fe  
Blue: <sup>44</sup>Ti

NASA/JPL-Caltech/CXC/SAO  
Grefenstette et al.

Cas A  
SN Remnant





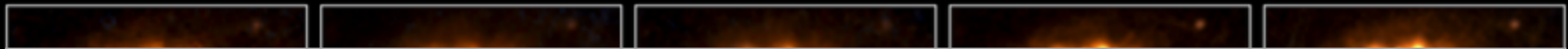
Sep, 1994

Mar, 1995

Feb, 1996

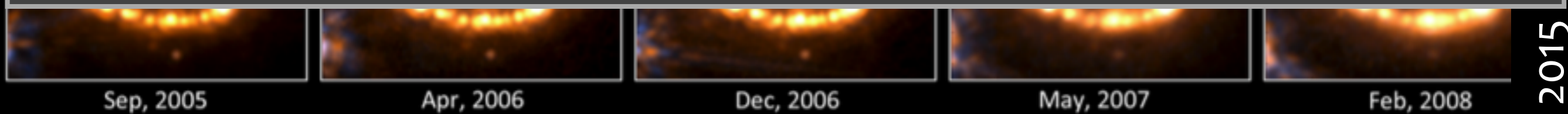
Jul, 1997

Feb, 1998



Polarimetry allows us to probe scales in a supernova that cannot be imaged from earth or space.

Spectropolarimetry enhances the power of this technique by allowing us to probe the geometry of specific ionic species.



Sep, 2005

Apr, 2006

Dec, 2006

May, 2007

Feb, 2008



Apr, 2009

Dec, 2009

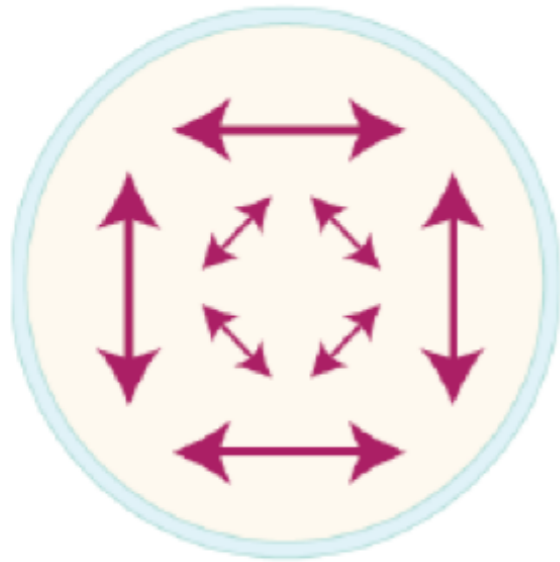
Jan, 2011

Feb, 2013

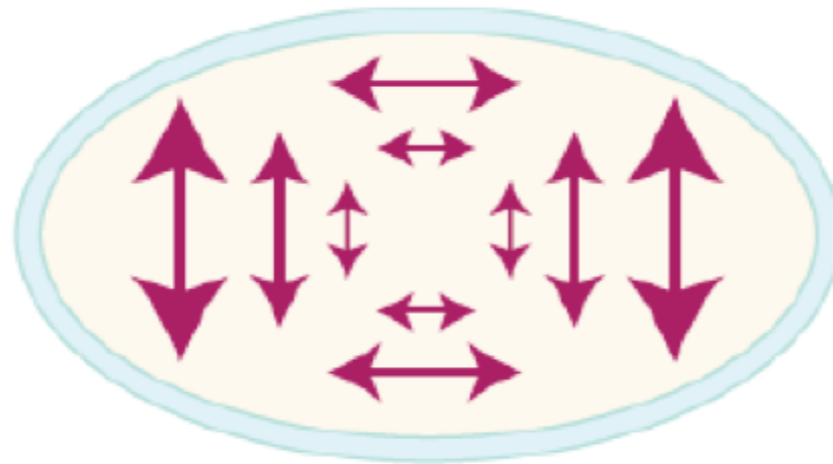
Jun, 2014

# Electron Scattering → Polarizing Mechanism

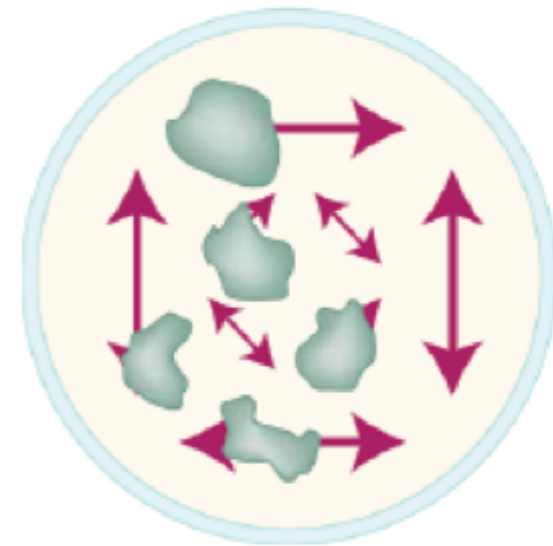
**Spherical  $P_{\text{net}} = 0\%$**



**Aspherical  $P_{\text{net}} > 0\%$**



**Clumpy Ejecta**



(Image: Leonard 2007, Science, 315,

 = Direction of electric vector in plane of sky

Wang & Wheeler ARAA 2008

# of published SN polarization observations = 94

one epoch = 55\*

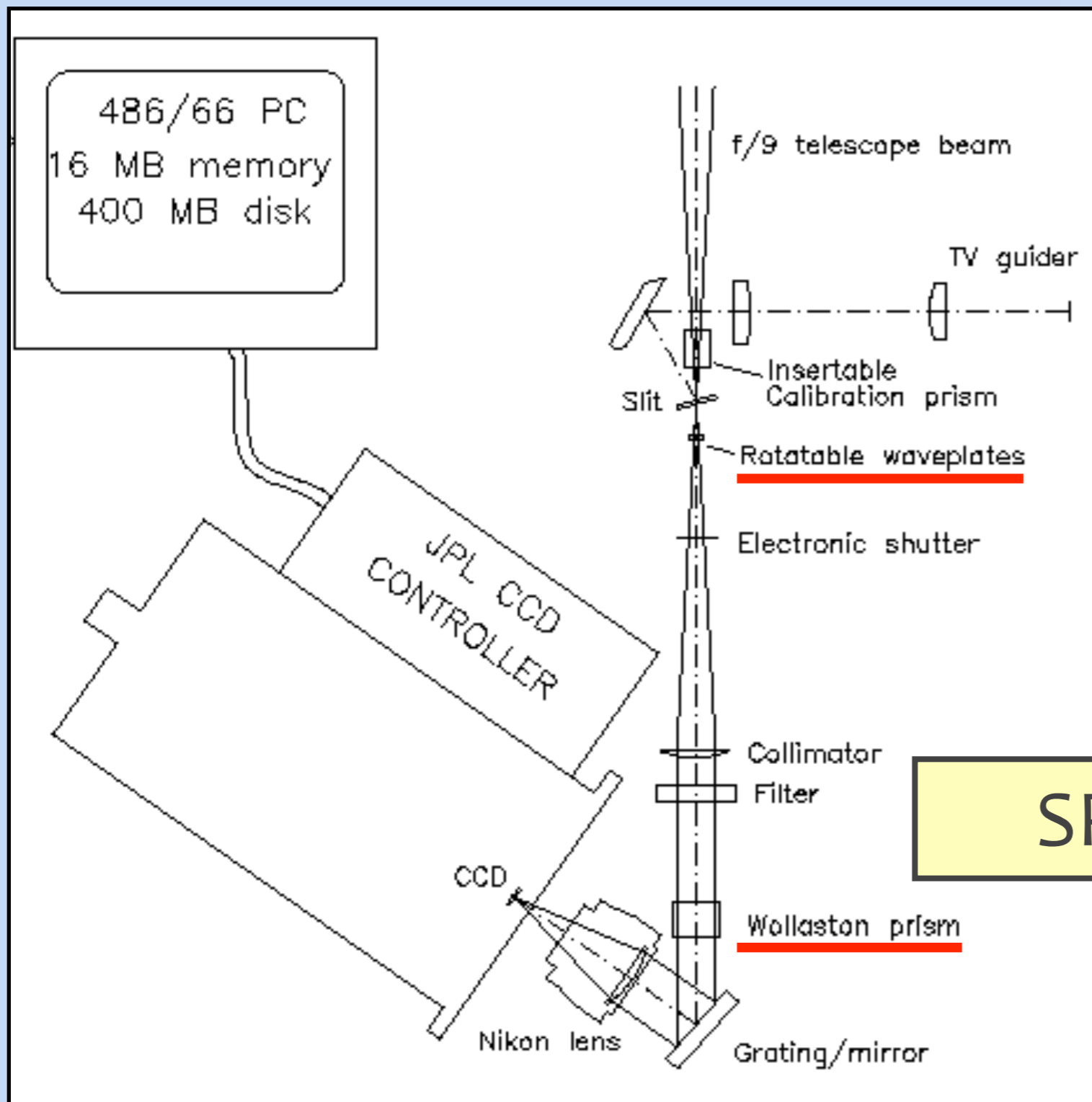
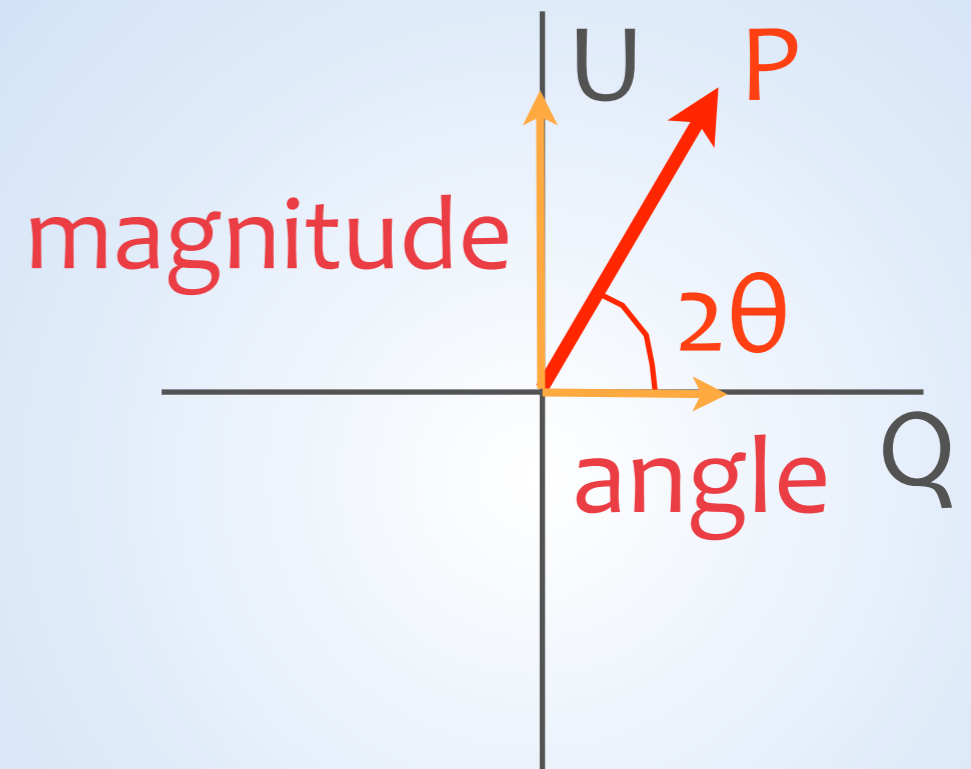
two epochs = 19

three or more = 20

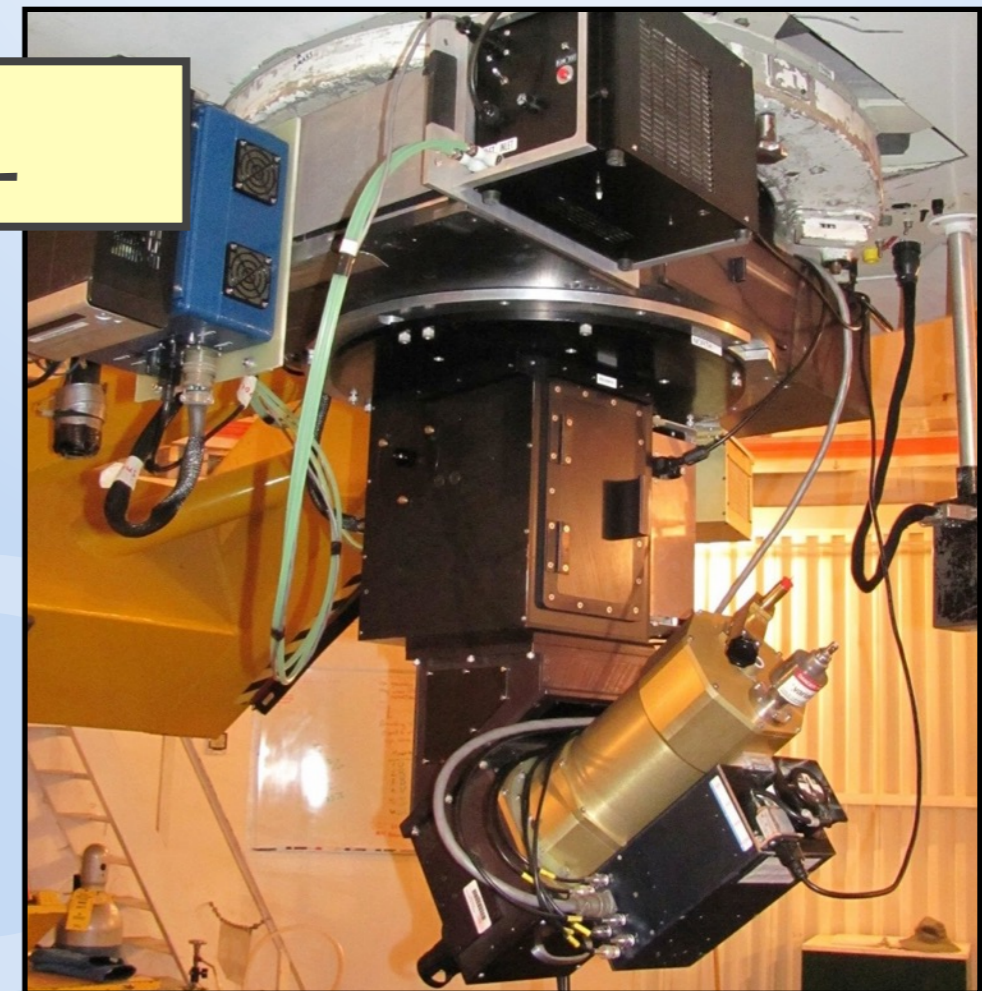
\*Interstellar Polarization (ISP) vs. Intrinsic SN Polarization

SN SPOL

# Linear Stokes Parameters



SPOL



## Linear Polarization

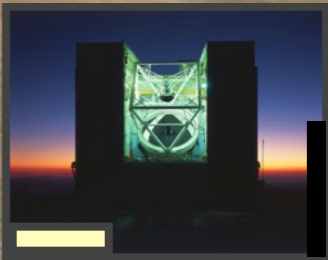
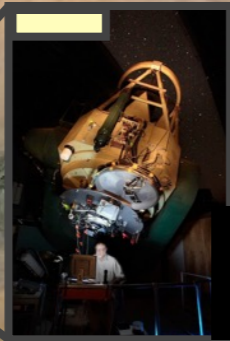
$$P = (Q^2 + U^2)^{1/2}$$

$$\theta = 1/2 \arctan (U/Q)$$





Tucson



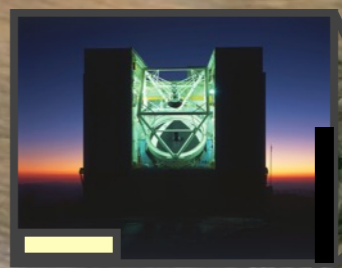
# 61" Kuiper



Image Credit: T. & J. Polakis



Tucson

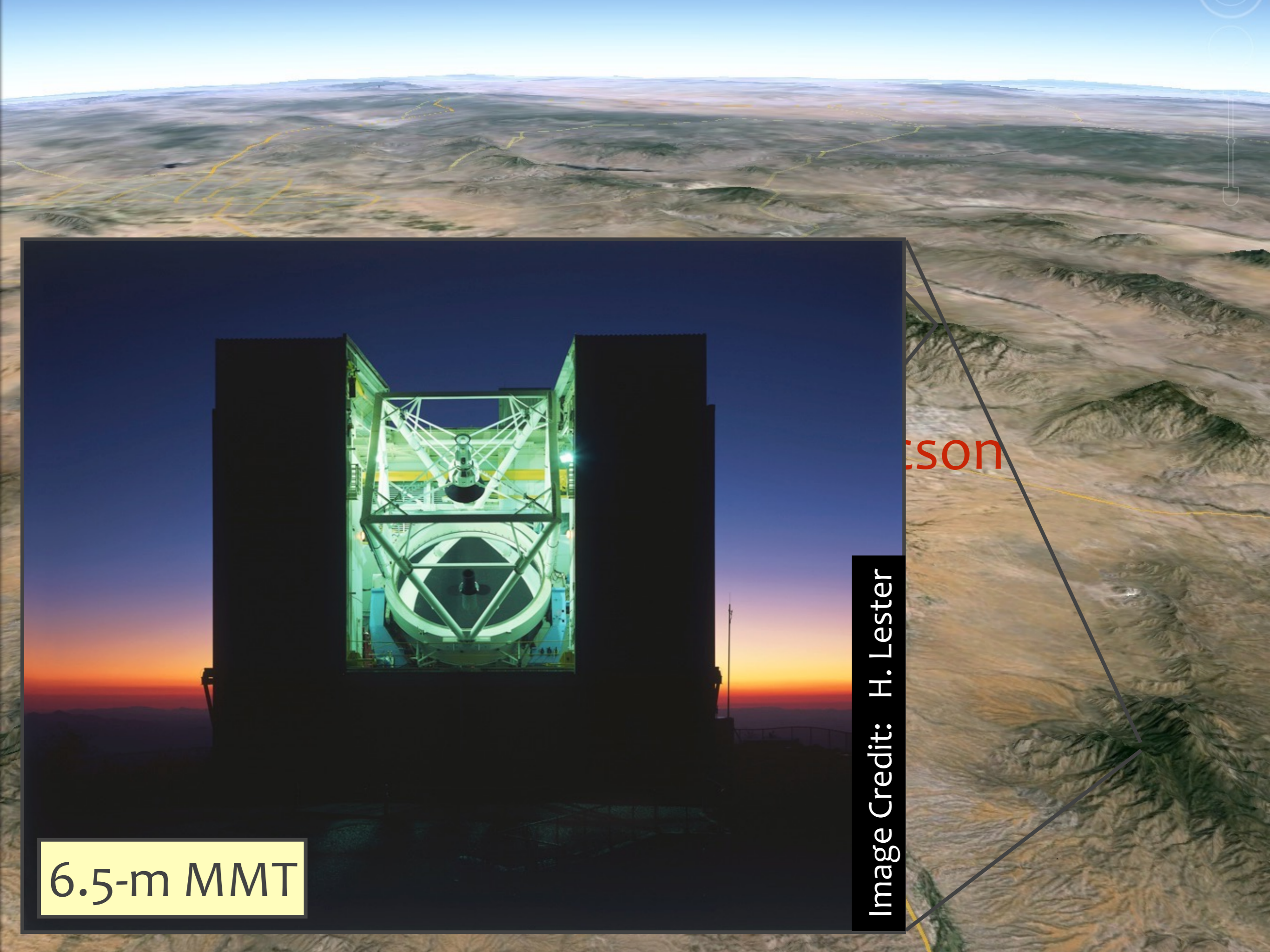




90" Bok



Image Credit: D. Harvey



6.5-m MMT

Image Credit: H. Lester

son

# The Supernova Spectropolarimetry Project (SNSPOL)

## GOAL:

To complete a long-term comprehensive **multi-epoch** spectropolarimetry survey of all types of supernovae.

## OBJECTIVE:

To improve our understanding of the predominance and characteristics of asymmetries in the different types of supernovae.

Queue observing as part of a larger specpol program guarantees that SN data **every month**.

# 59 SNe, 44 multiple-epoch

## Ia (6/8)

SN 2011fe (8)  
SN 2012cg (2)  
SN 2012ht (2)  
SN 2013fw (hv, 1)  
SN 2014J (5)  
SN 2014ao (2)  
ASASSN-14lp (6)  
ASASSN-15hy (1)

## Ib (2/3)

SN 2011au (6)  
iPTF13bvn (1)  
M12045 (7)

## Ic (7/8)

PTF12gzk (pec, 2)  
SN 2012ej (4)  
SN 2012fh (6)  
SN 2013ff (3)  
SN 2013ge (2)  
SN 2014L (4)  
SN 2014ad (4)  
SN 2014as (BL,1)

## II (5/7)

SN 2011bv (1)  
SN 2013am (4)  
SN 2013bu (3)  
SN 2013ee (2)  
SN 2013hj (2)  
SN 2014ce (1)  
ASASSN-14kg (2)

## IIP (10/15)

SN 2012A (5)  
SN 2012aw (7)  
SN 2012ch (1)  
SN 2012ec (8)  
SN 2012ho (1)  
SN 2013ab (5)  
SN 2013bi (4)  
**SN 2013ej (5)**  
SN 2013fs (4)  
SN 2014A (2)  
SN 2014bc (1)  
SN 2014cx (6)  
SN 2014cy (2)  
J17492 (1)  
J10491 (1)

## III (1/1)

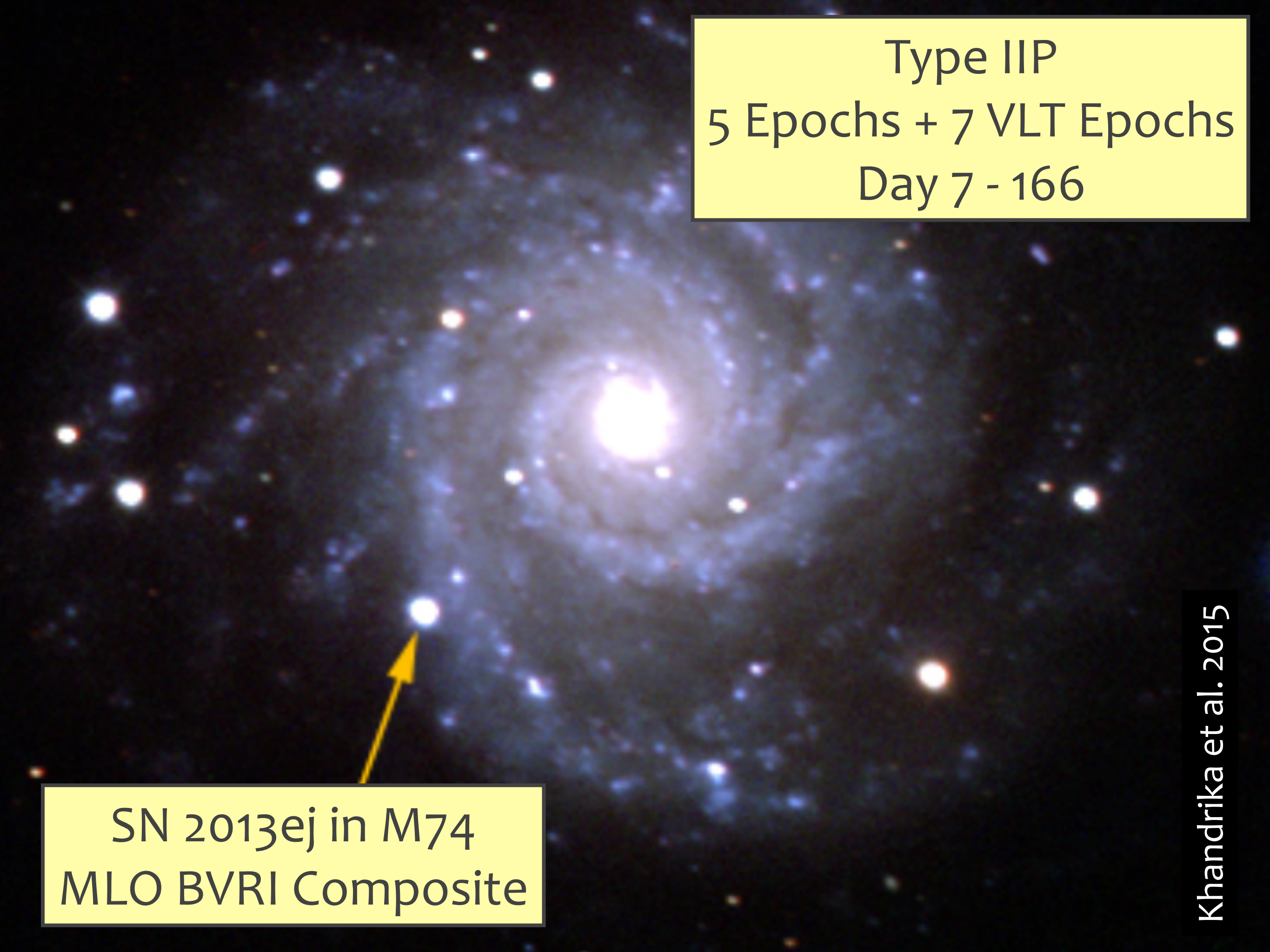
SN 2014G (4)

## IIb (5/5)

SN 2011dh (2)  
SN 2012fg (3)  
SN 2013ak (2)  
SN 2013 df (2)  
ASASSN-14az (4)

## IIIn (8/12)

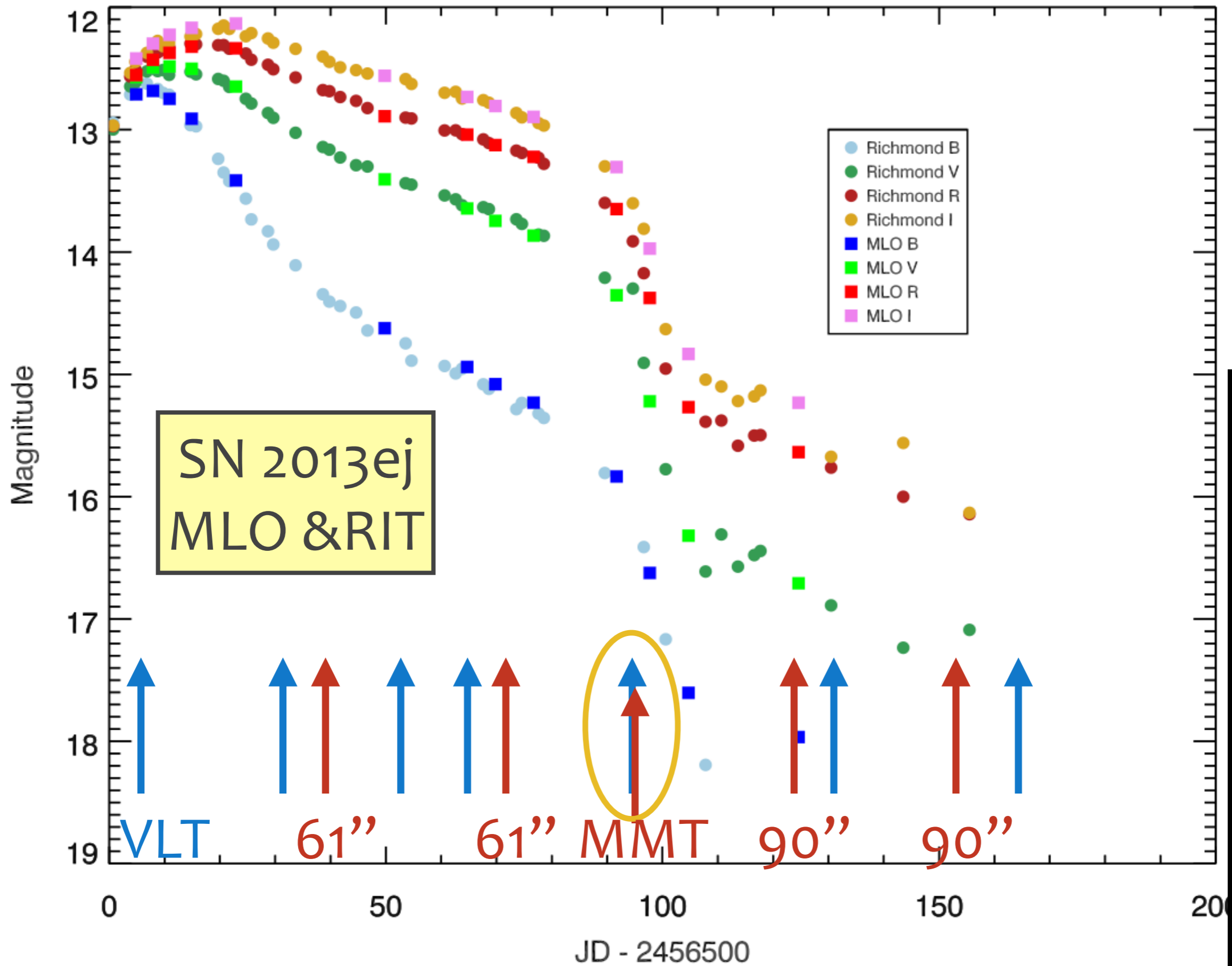
**SN 2010jl (11)**  
SN 2011cc (1)  
SN 2011ht (2)  
SN 2012ab (2)  
PTF11iqb (1)  
**SN 2009ip (4)**  
SN 2014ab (5)  
ASASSN-14il (3)  
J07285 (2)  
M04421 (1)  
J13522 (3)  
J090934 (1)



Type IIP  
5 Epochs + 7 VLT Epochs  
Day 7 - 166

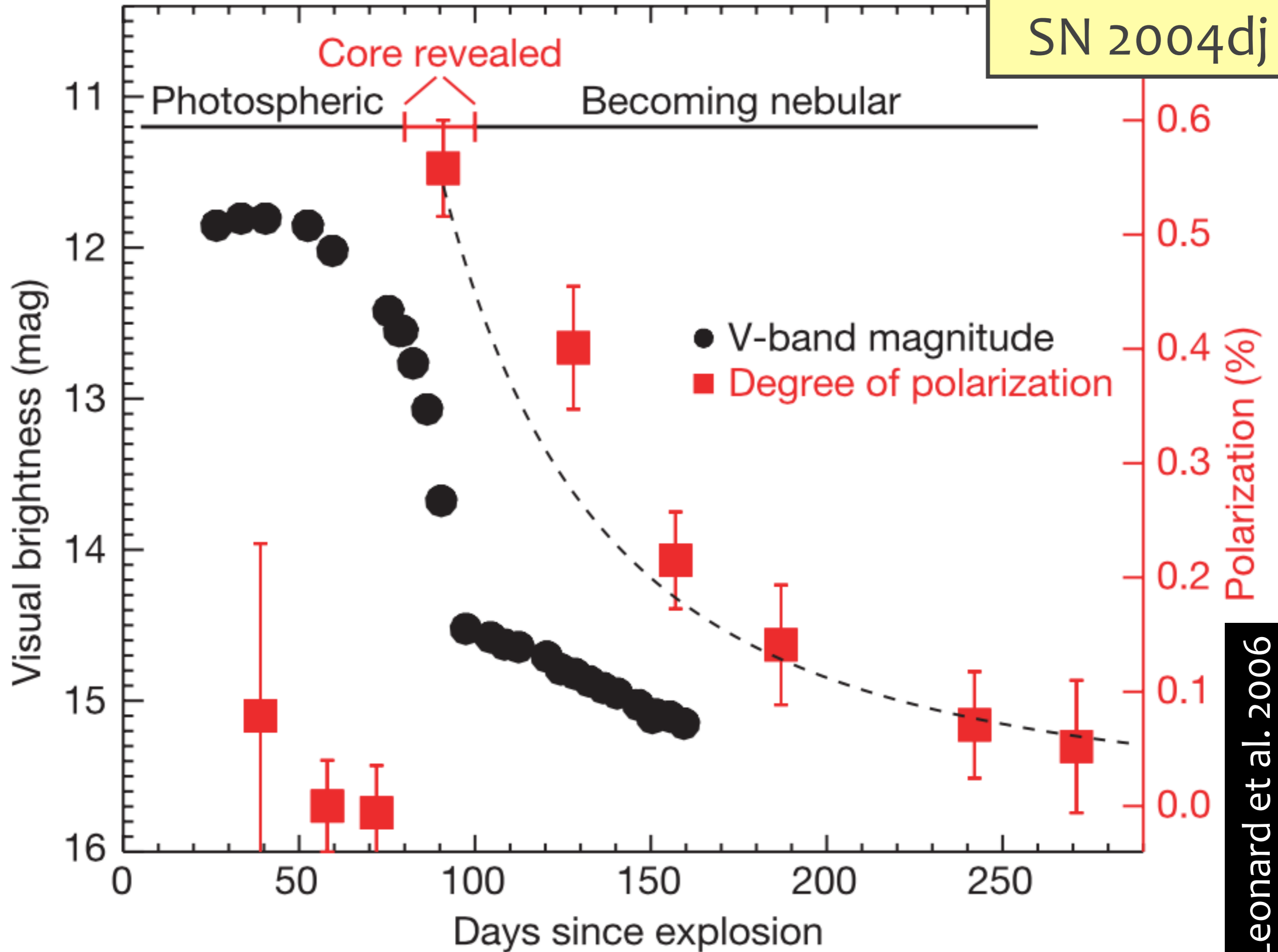
SN 2013ej in M74  
MLO BVRI Composite

# SN2013ej - Richmond (2014) vs MLO



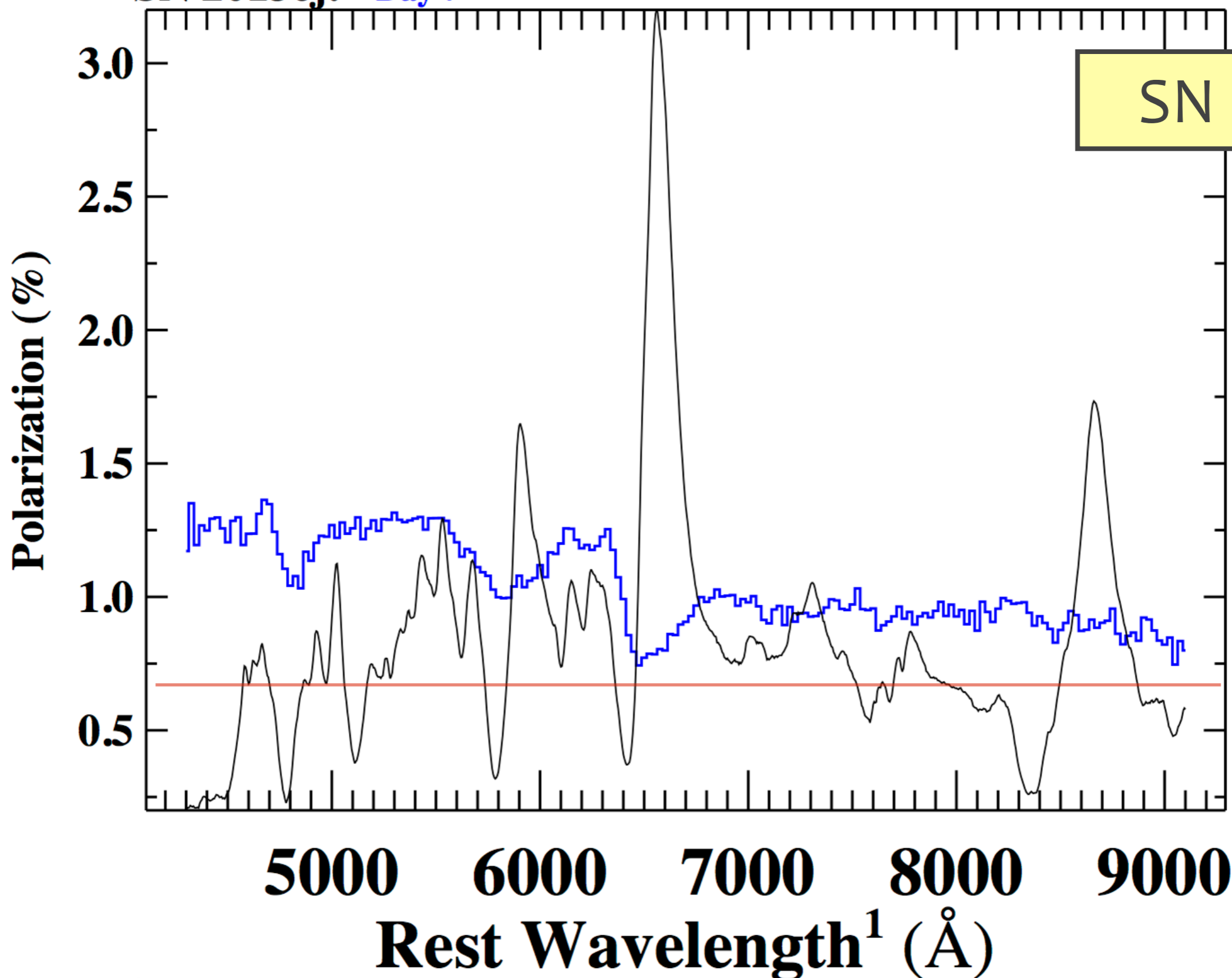


# SN 2004dj



SN 2013ej: Day 7

SN 2013ej

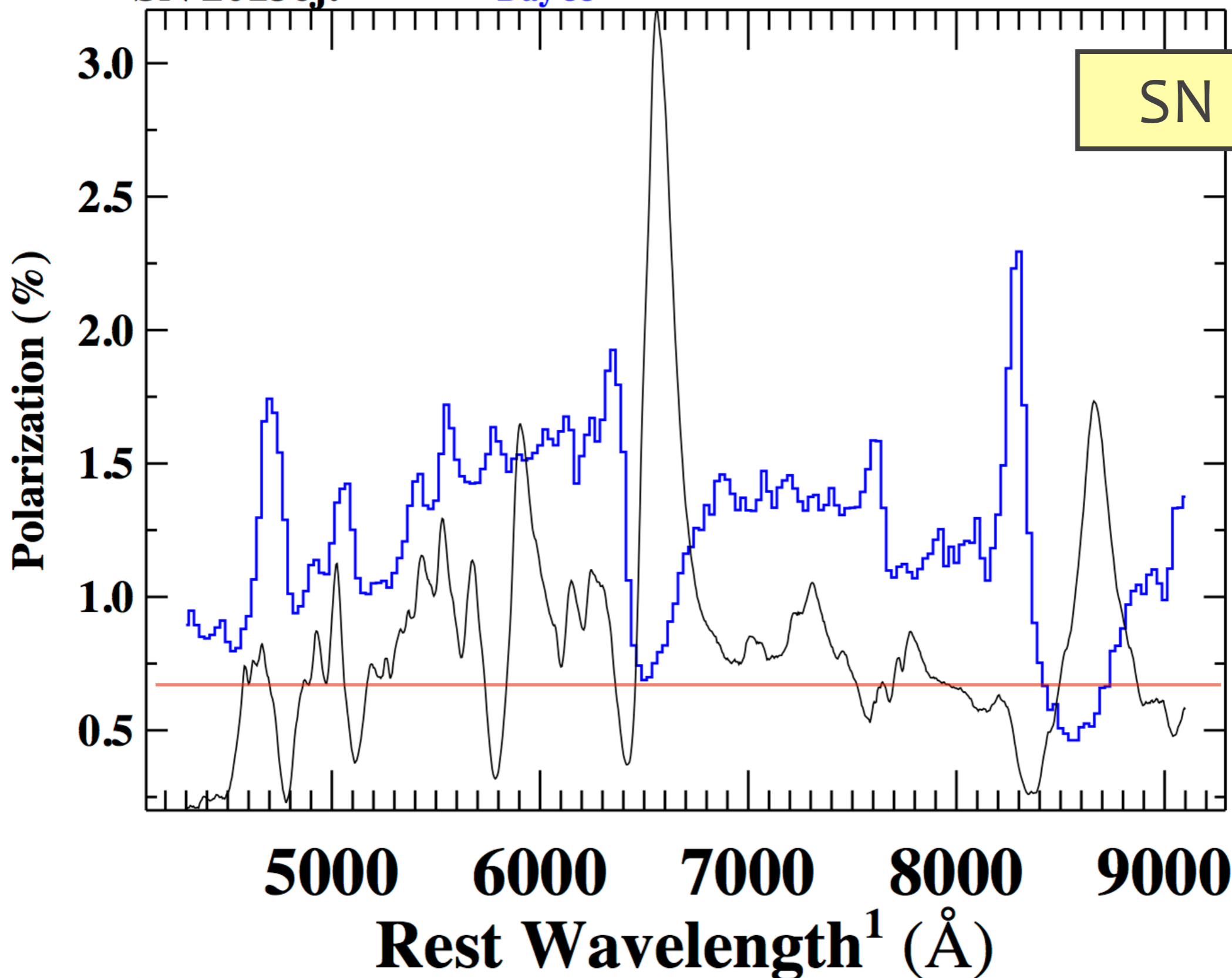


<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.

SN 2013ej:

Day 33

SN 2013ej

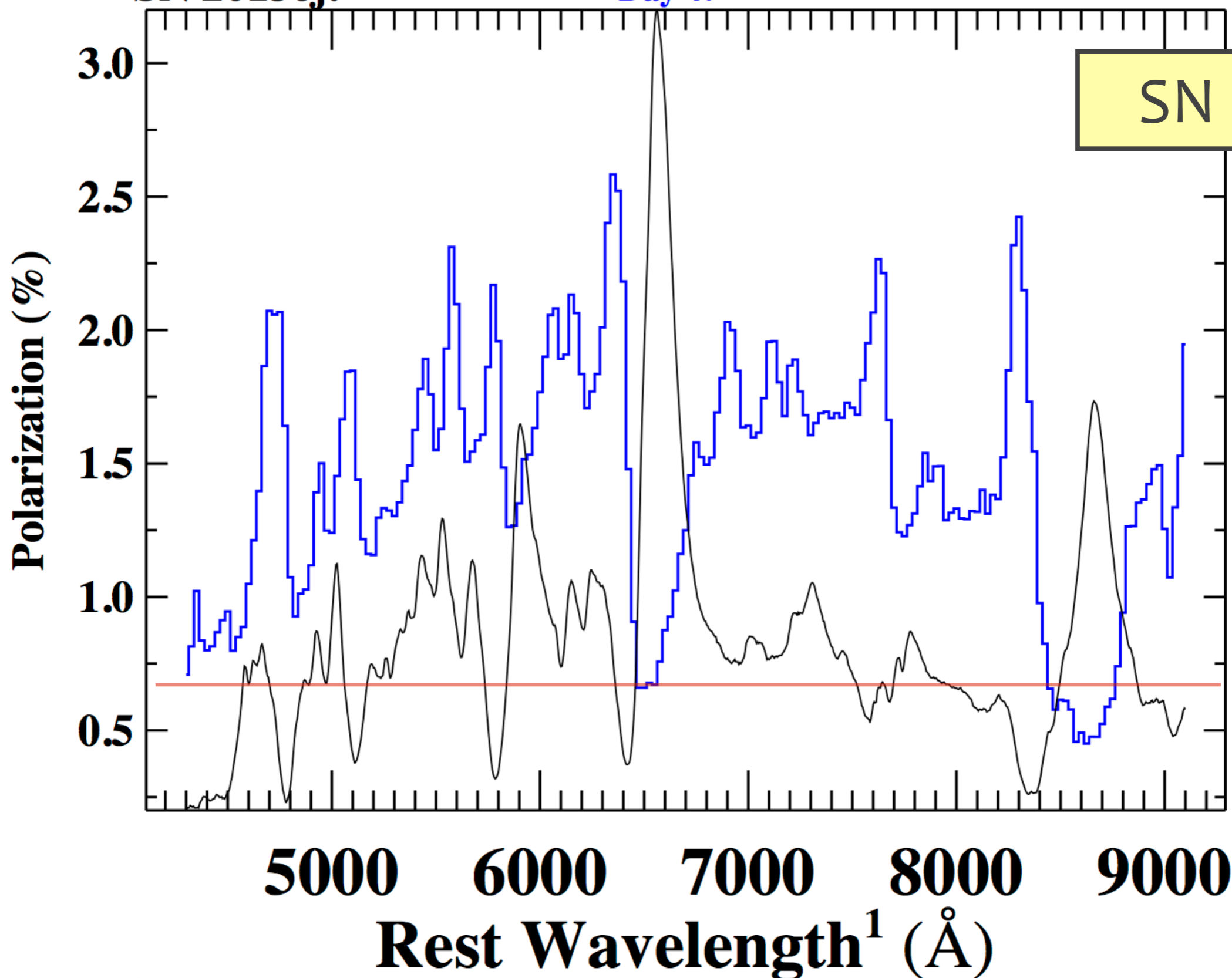


<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.

SN 2013ej:

Day 47

SN 2013ej

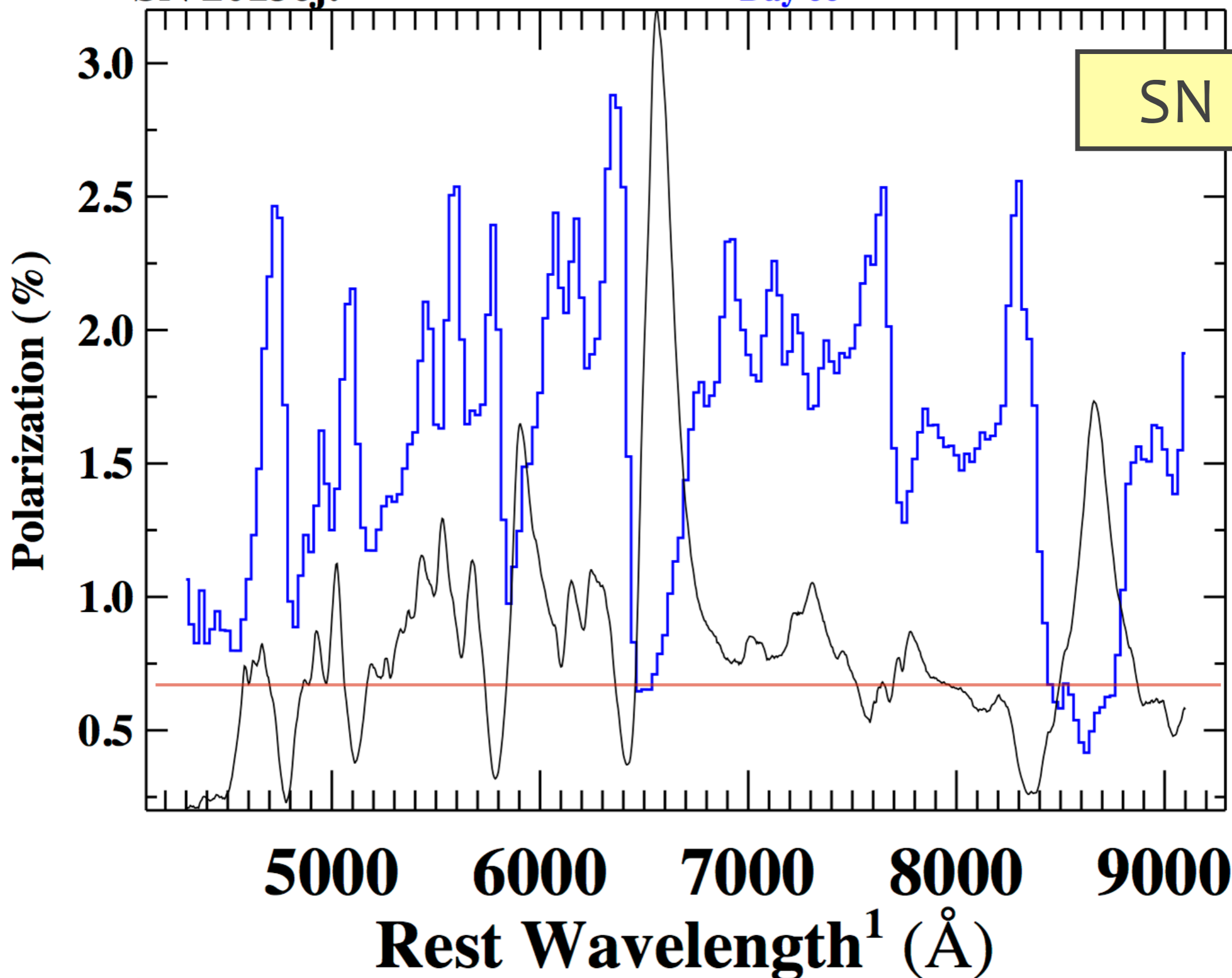


<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.

SN 2013ej:

Day 66

SN 2013ej

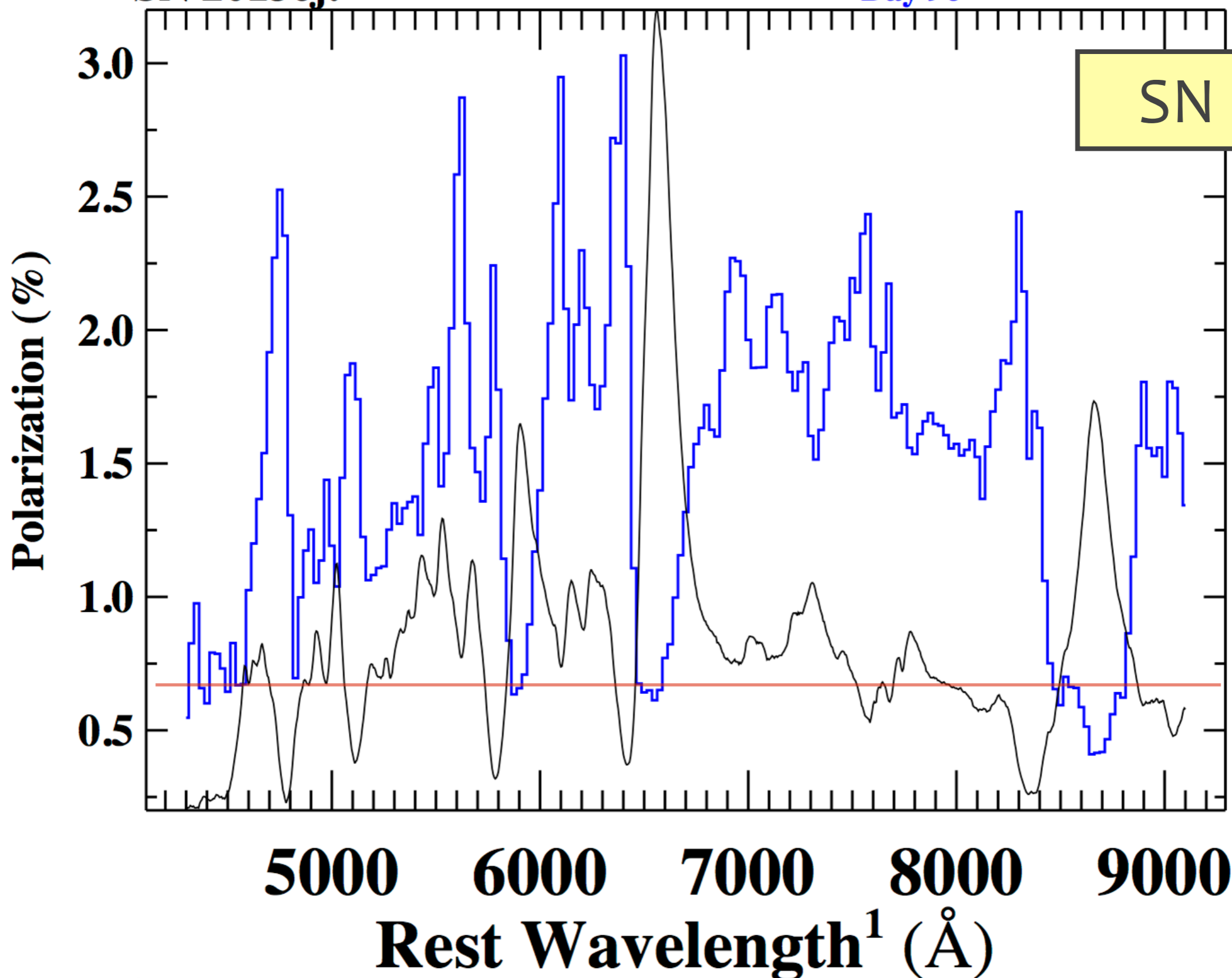


<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.

SN 2013ej:

Day 96

SN 2013ej

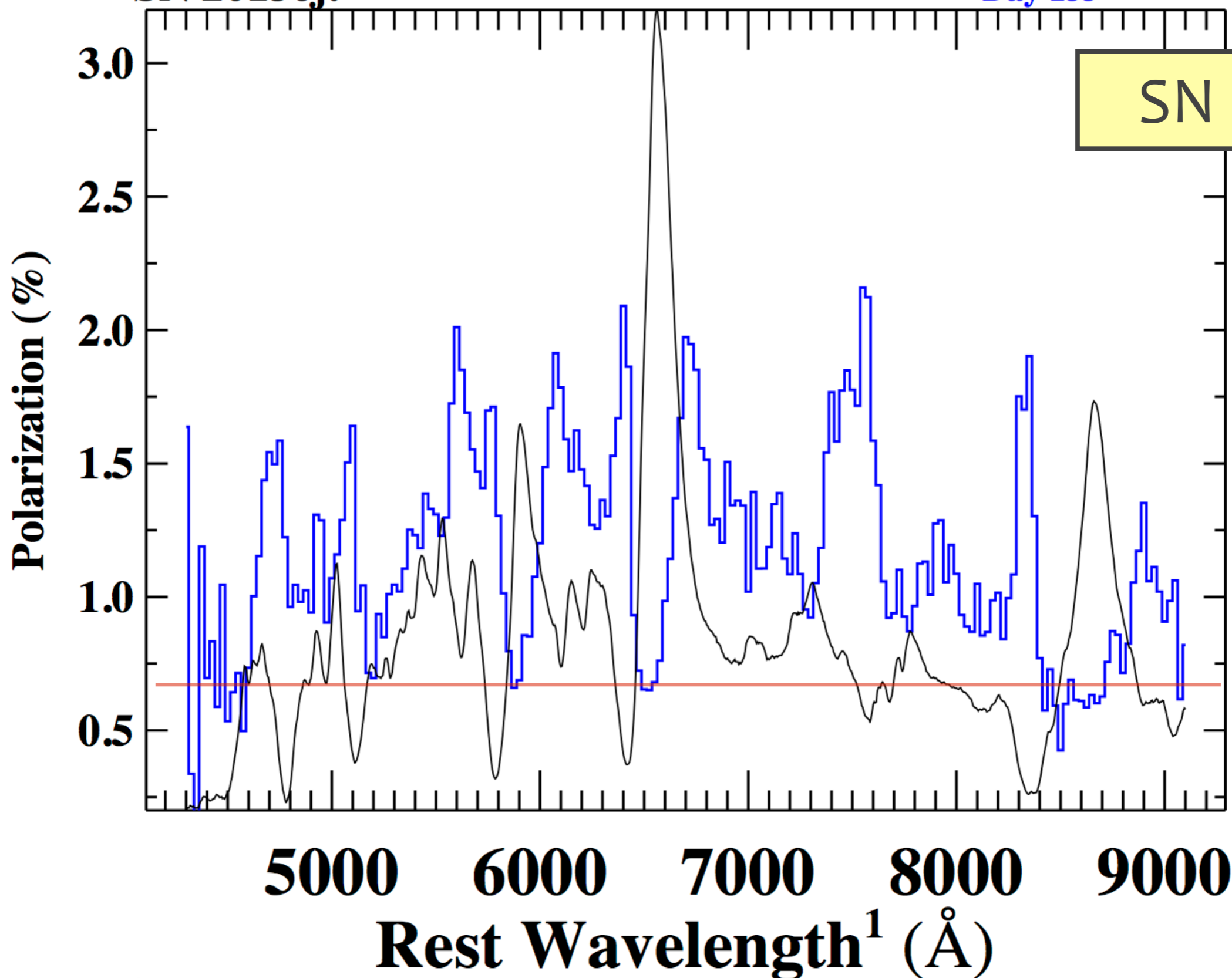


<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.

SN 2013ej:

Day 133

SN 2013ej

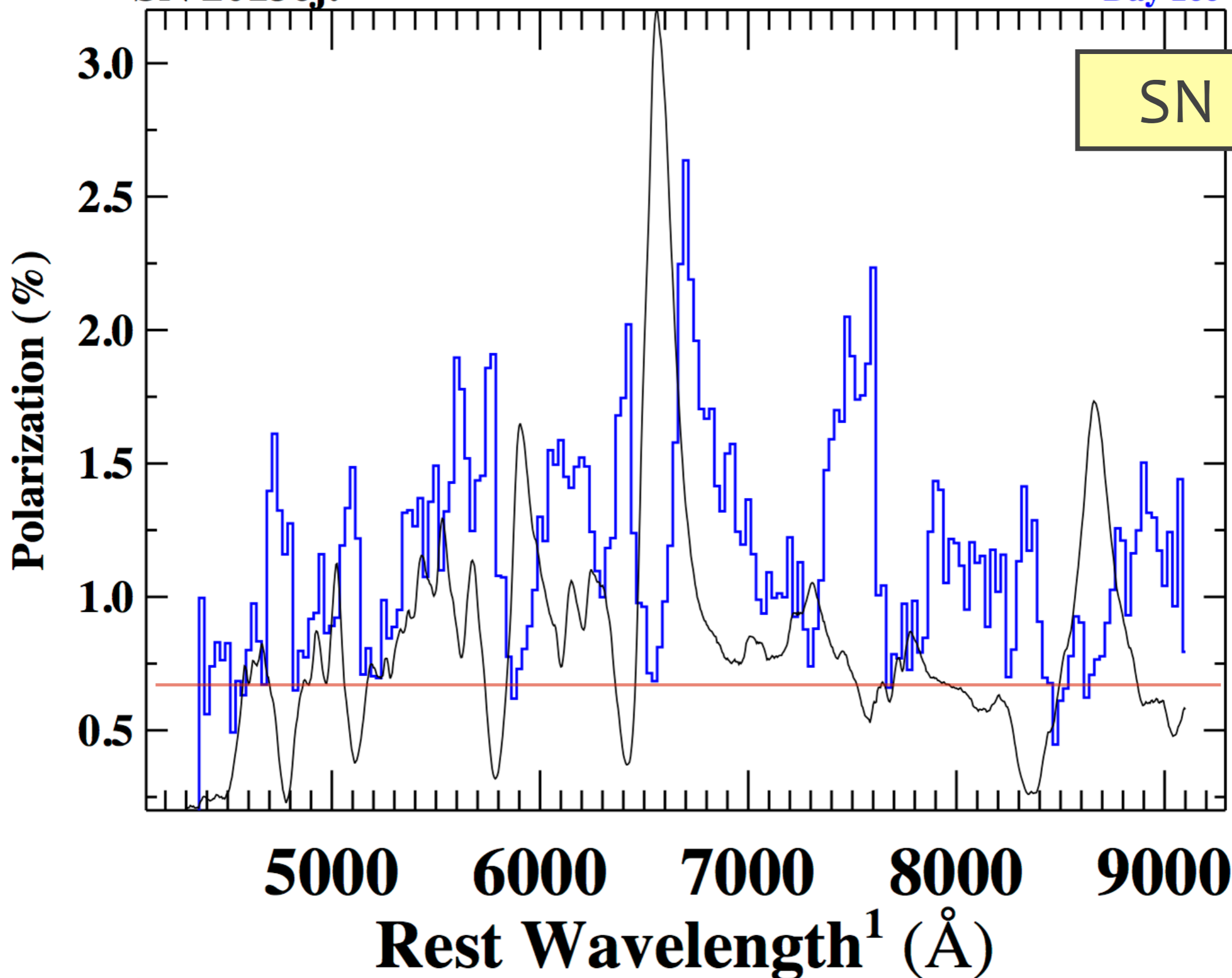


<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.

SN 2013ej:

Day 166

SN 2013ej



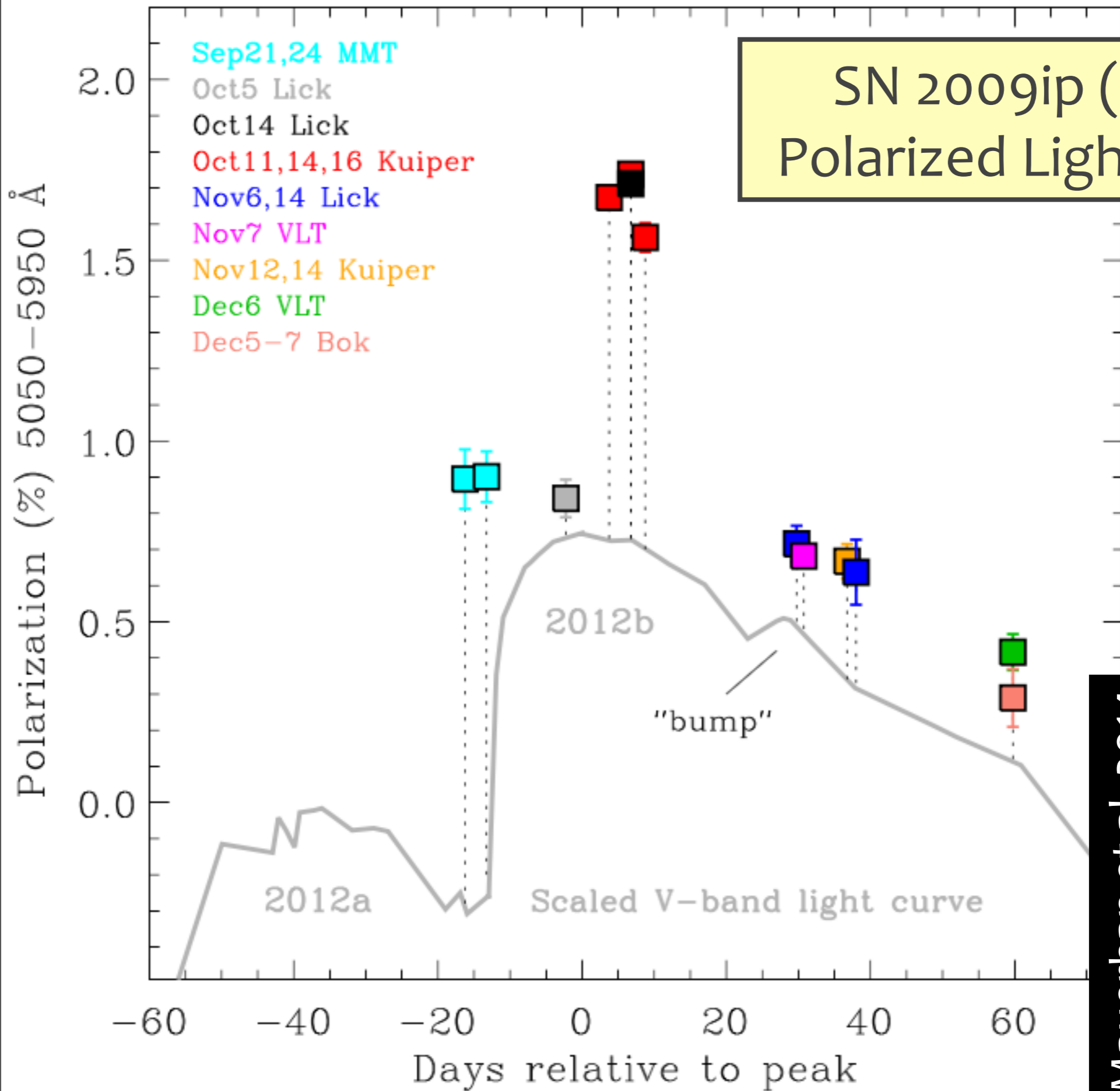
<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum from Day 96 is overplotted for feature comparison.



SN 2009ip  
Type IIIn  
4 Epochs + 5 Lick/VLT

20"  
↔

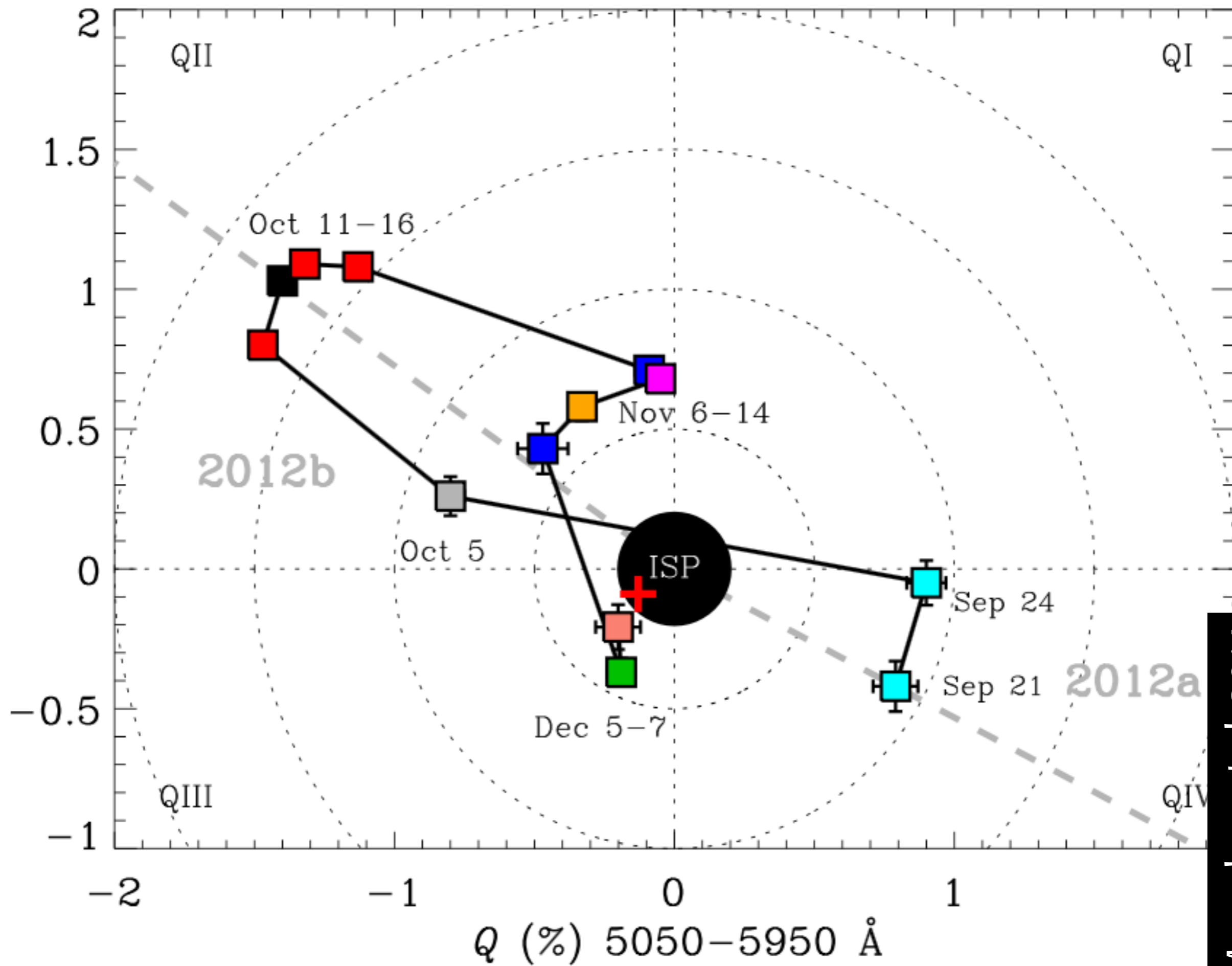
# SN 2009ip (2012) Polarized Light Curve



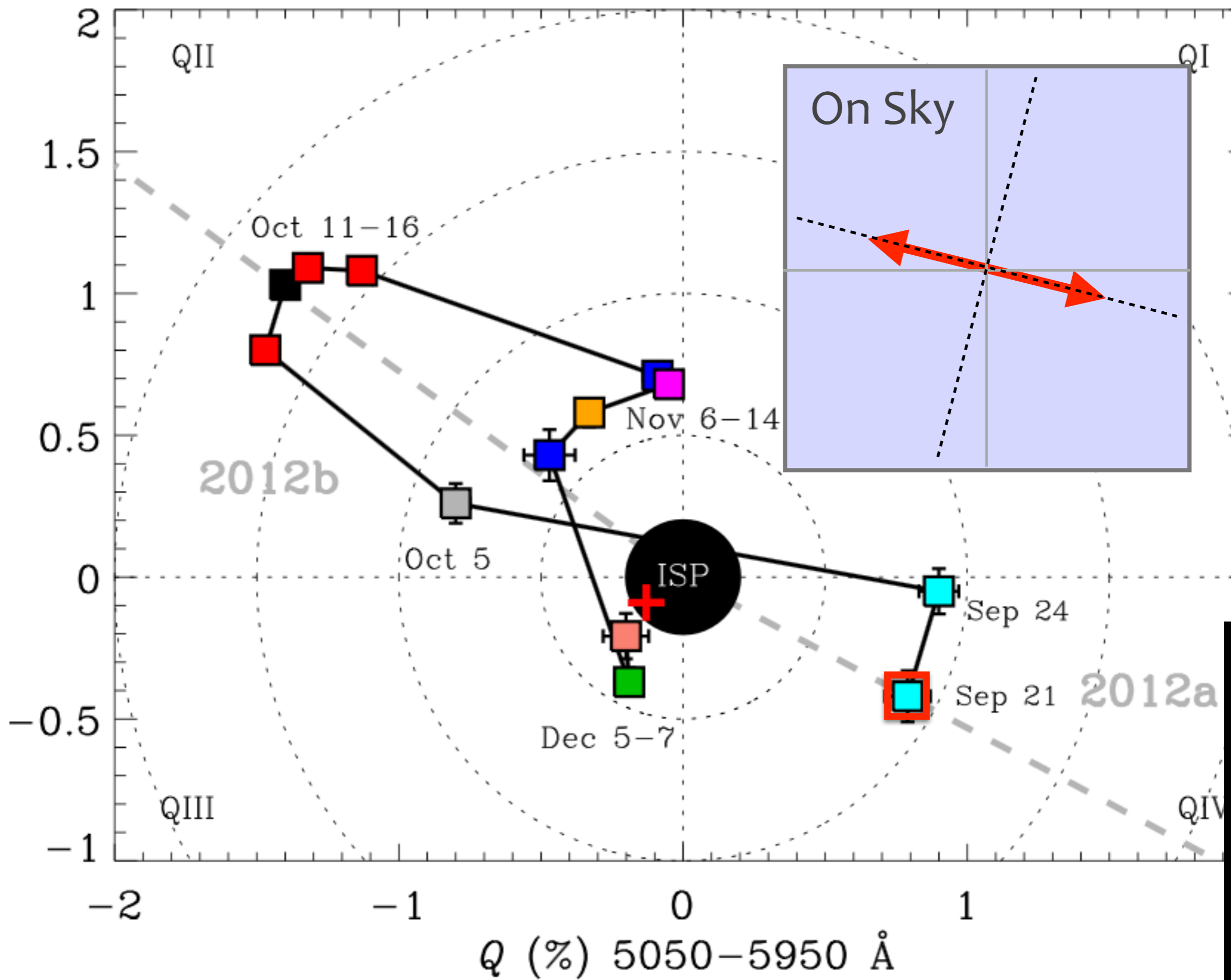
Mauerhan et al. 2014



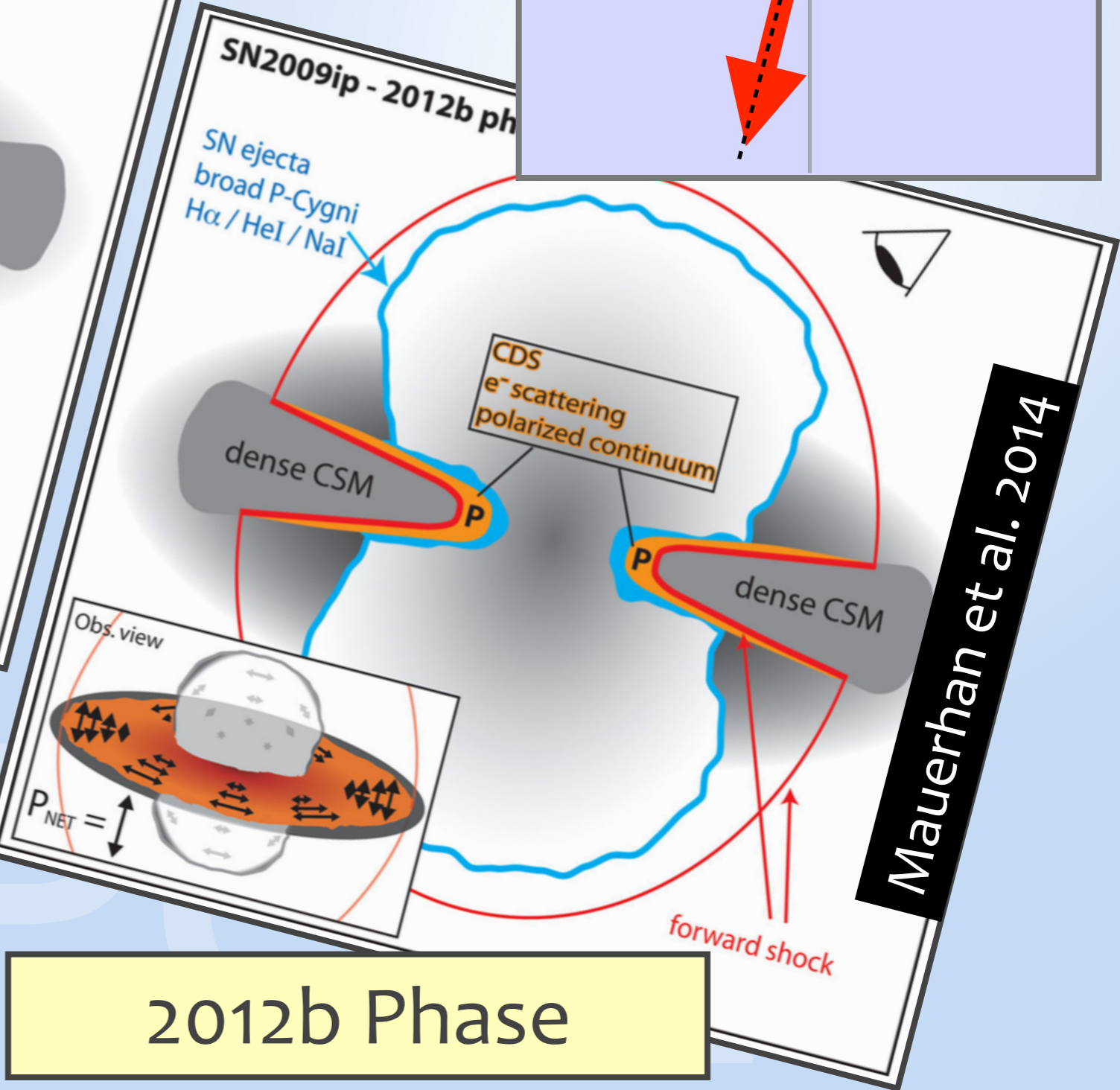
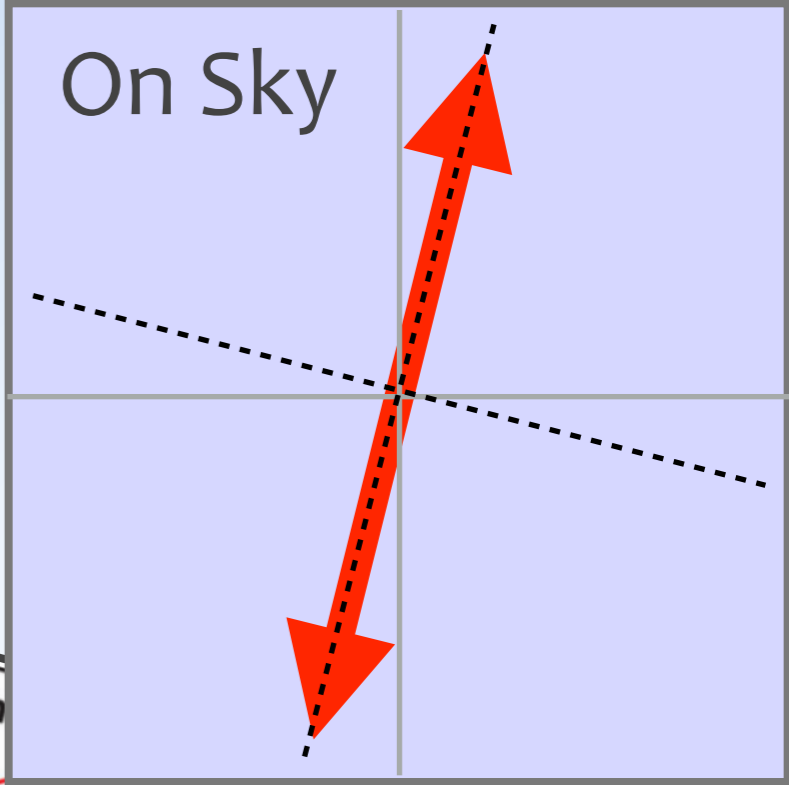
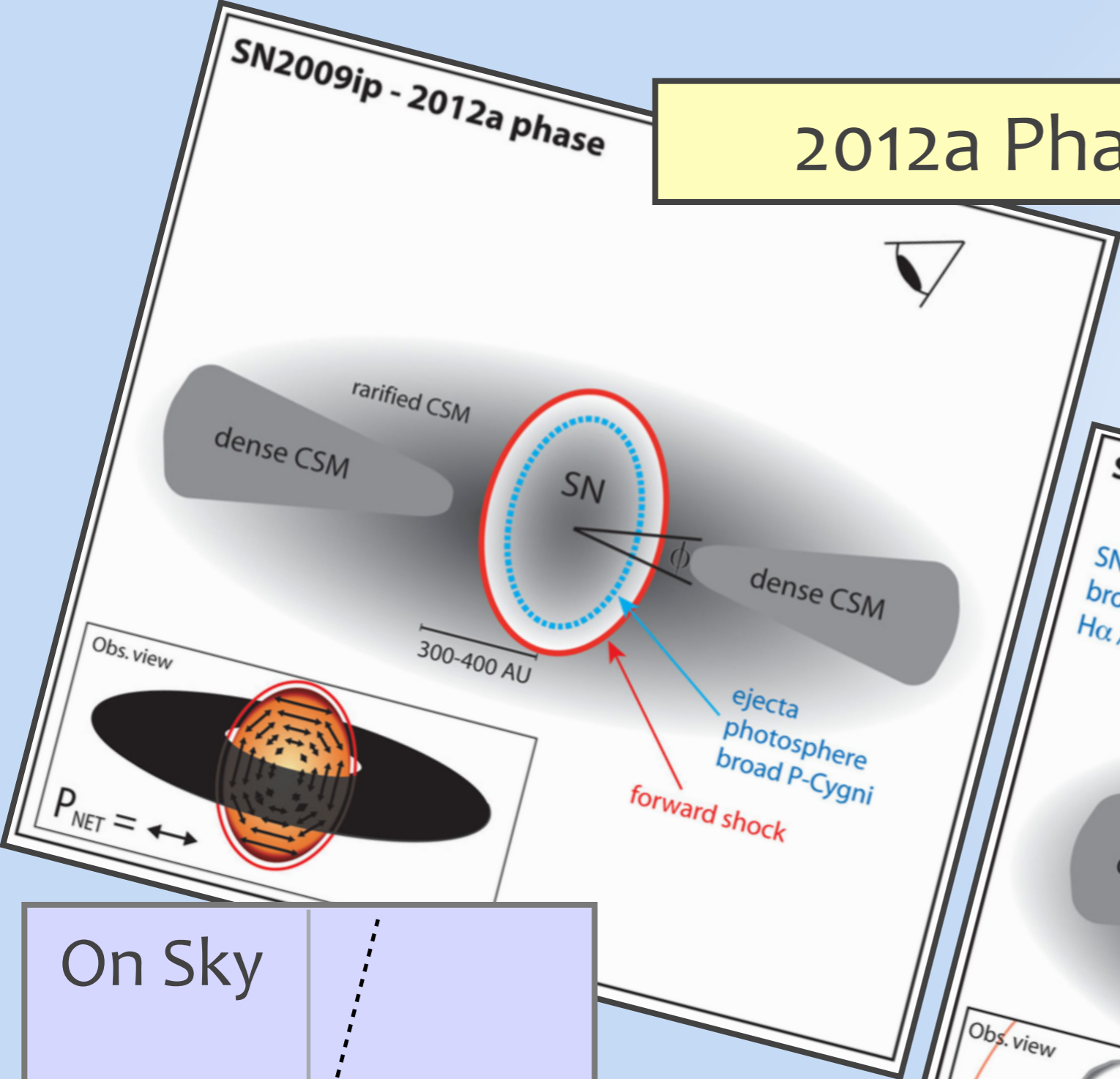
$U$  (%) 5050–5950 Å



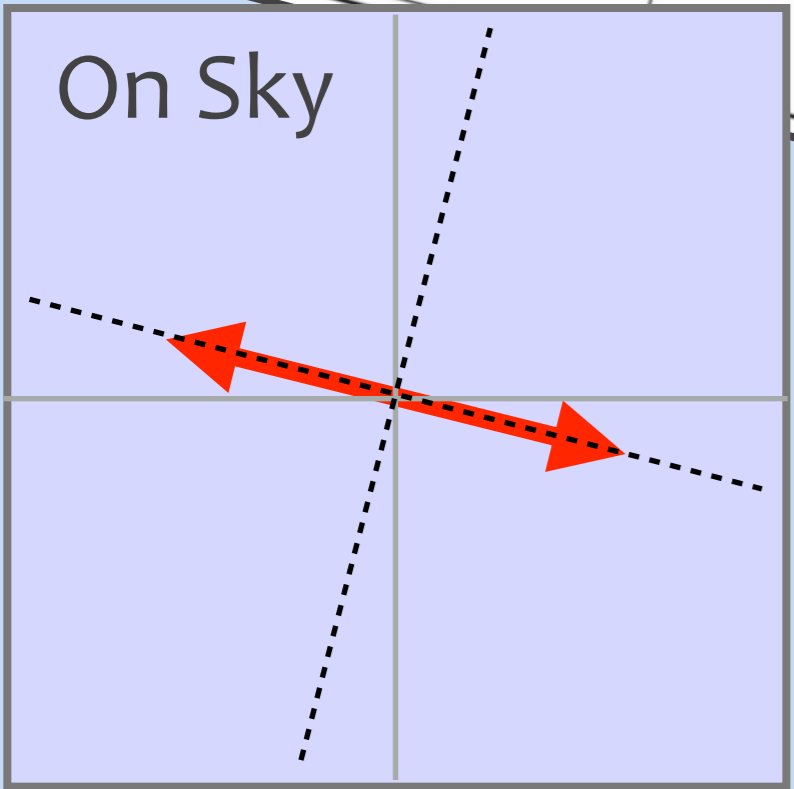
$U$  (%) 5050–5950 Å




# 2012a Phase



# 2012b Phase



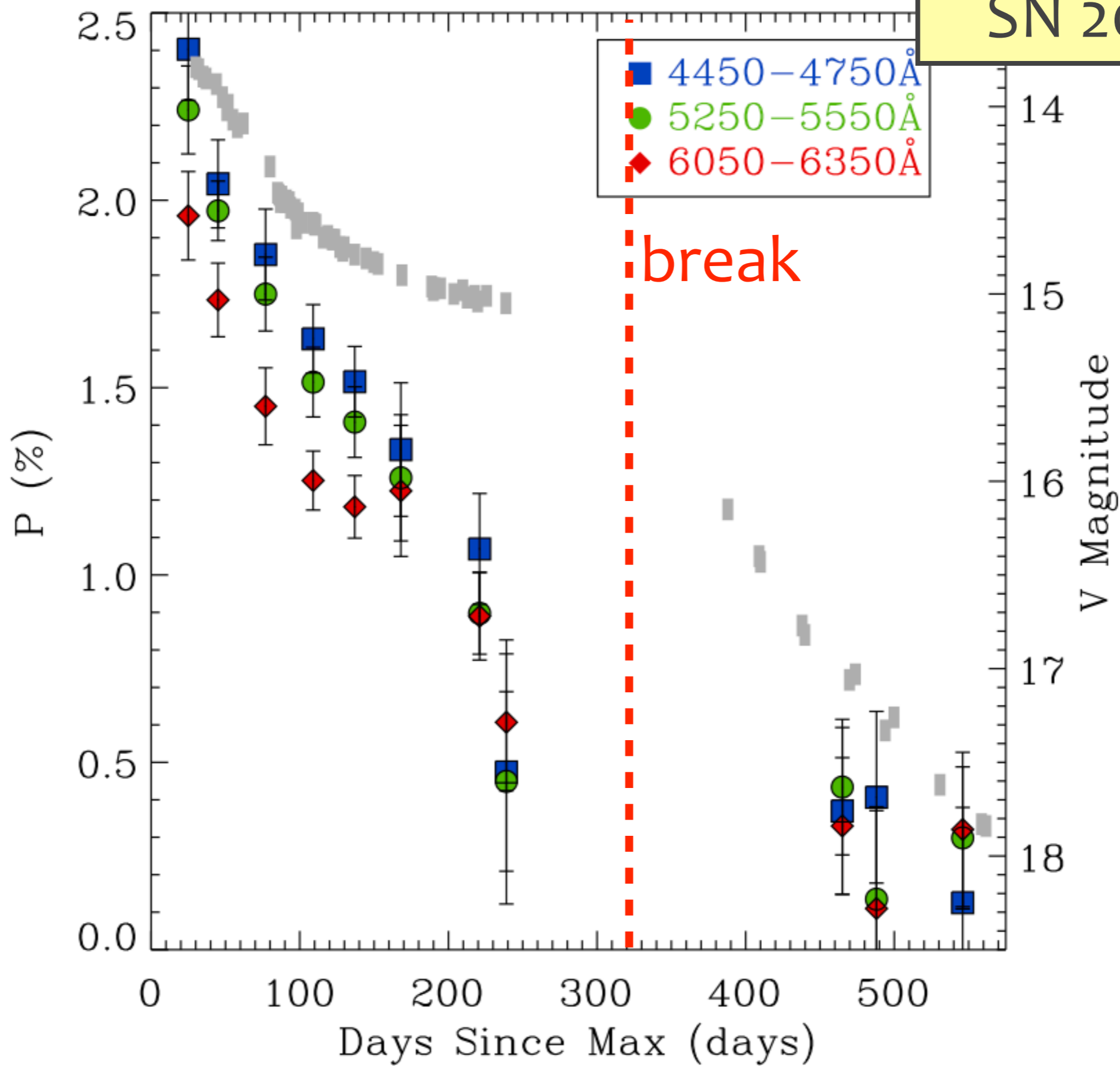
Mauerhan et al. 2014



SN 2010jl  
Type IIIn  
11 Epochs  
Day 25 - 546

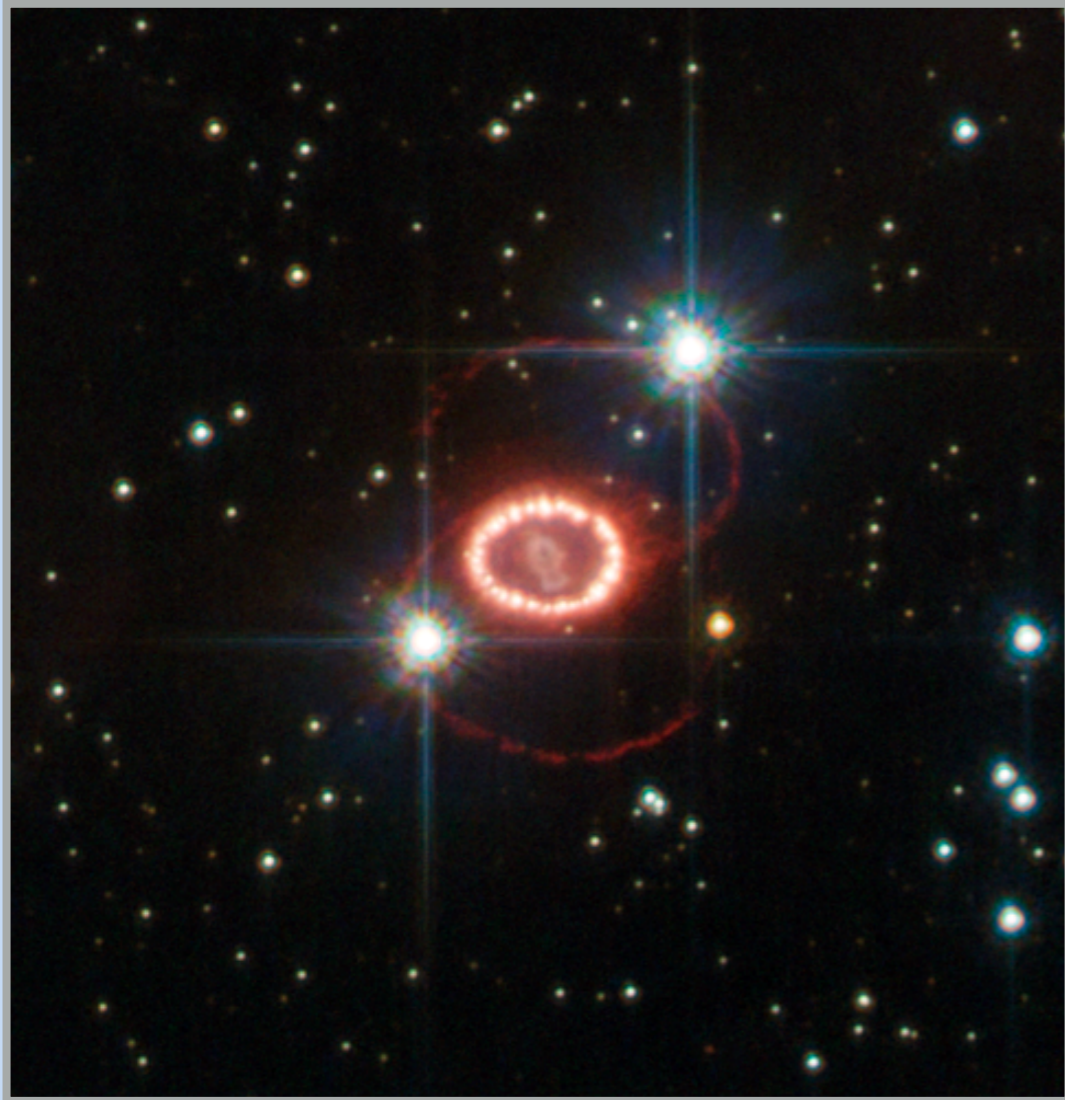
NASA/CXC/Royal Military College of  
Canada/P.Chandra et al

# SN 2010jl

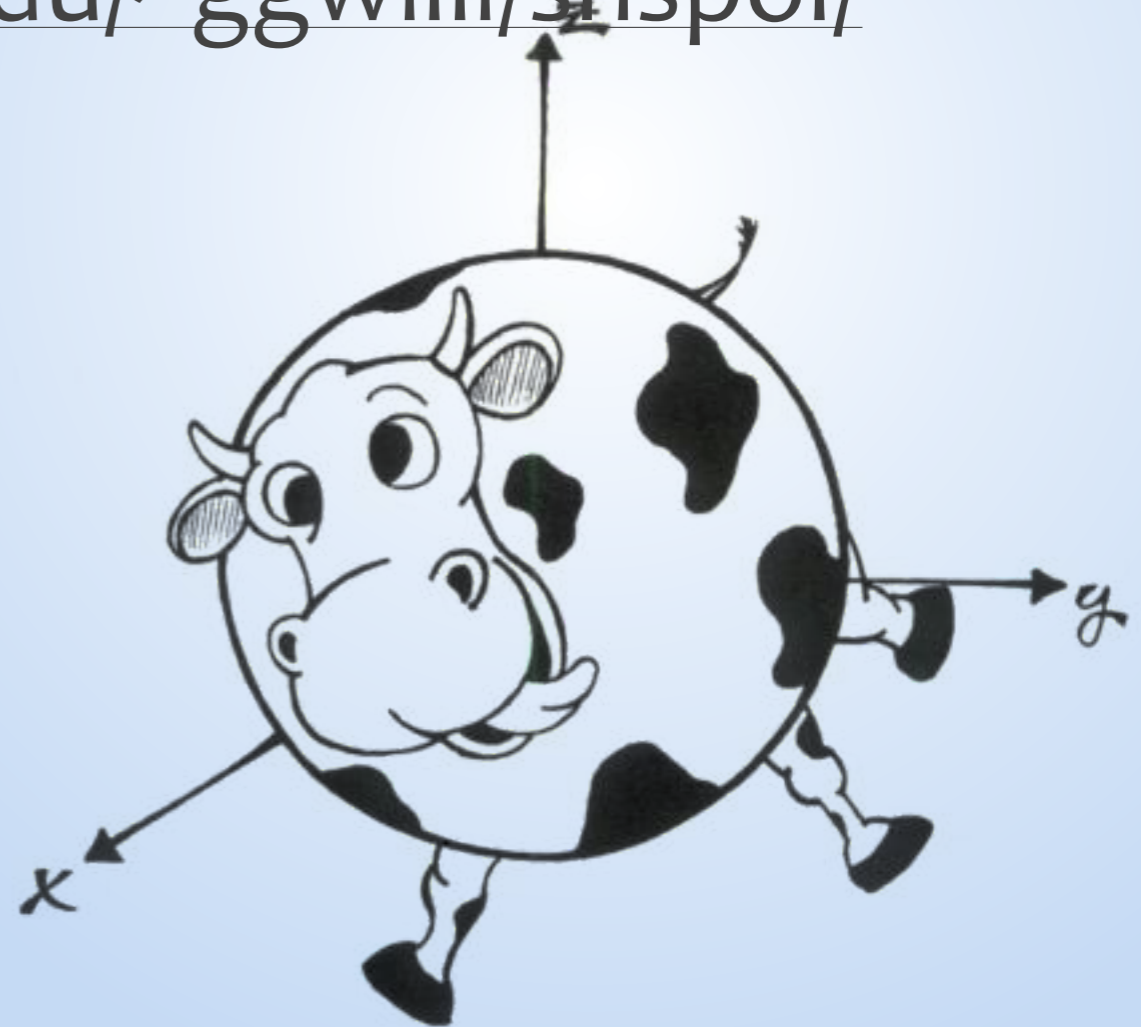


SNSPOL: Multi-epoch spectropolarimetry is a powerful tool for studying the shapes of supernovae.

<http://grb.mmta.arizona.edu/~ggwilli/snspol/>

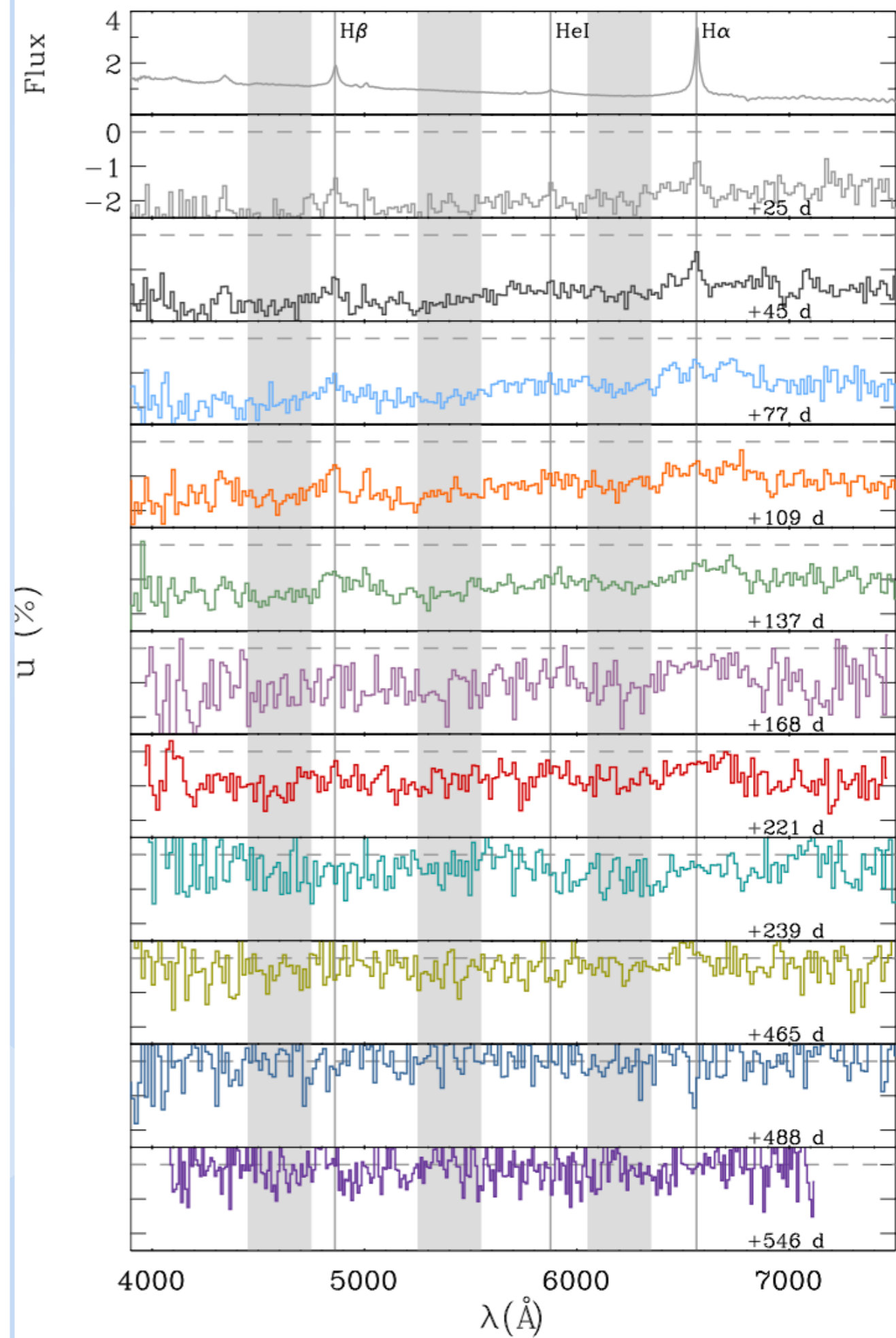
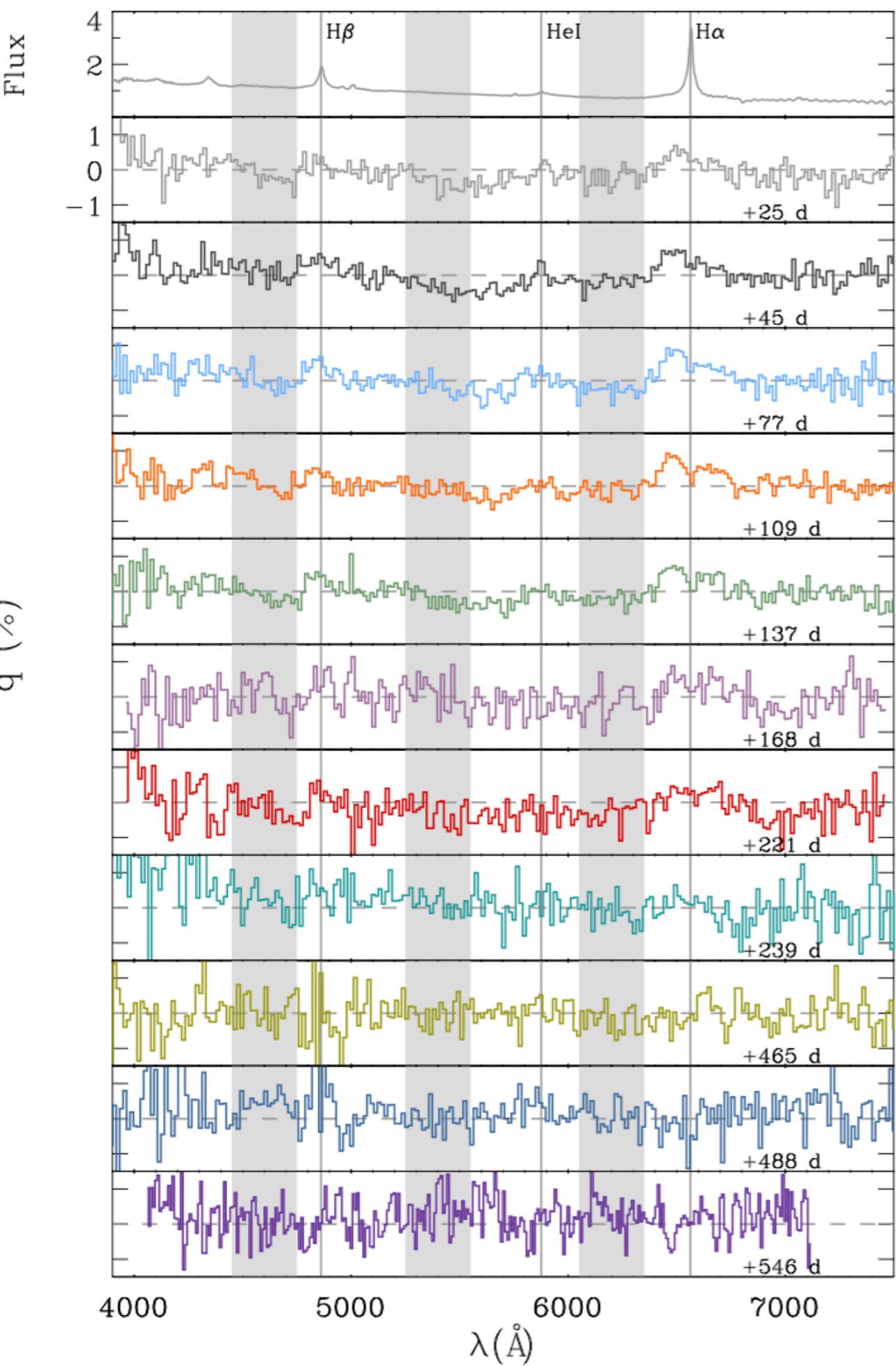


$\neq$

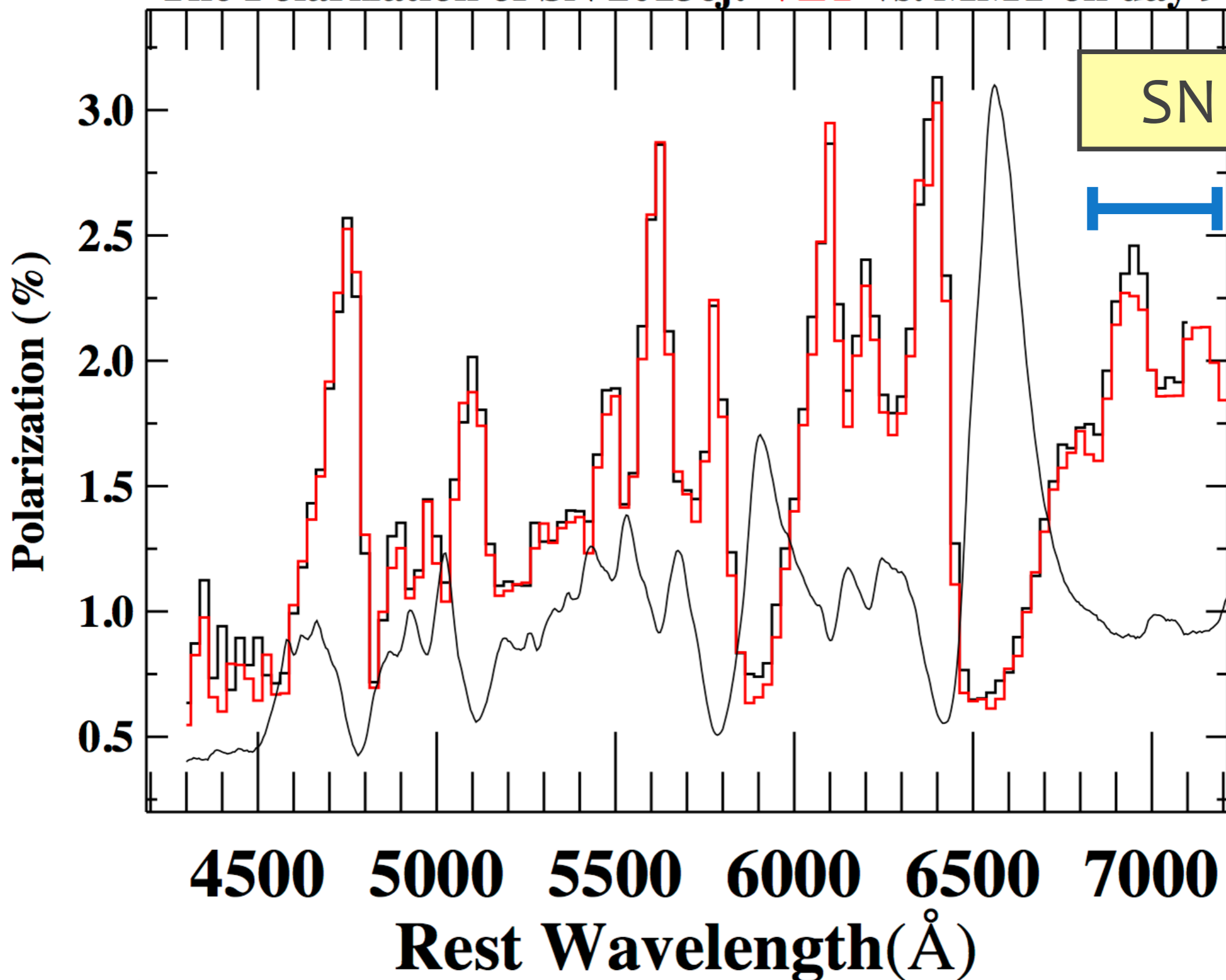


Thank You!





# The Polarization of SN 2013ej: **VLT** vs. MMT on day 96



<sup>1</sup>A redshift of 657 km/s has been removed. The flux spectrum is overplotted for feature comparison.

SN 2011dh

FLWO/KeplerCam

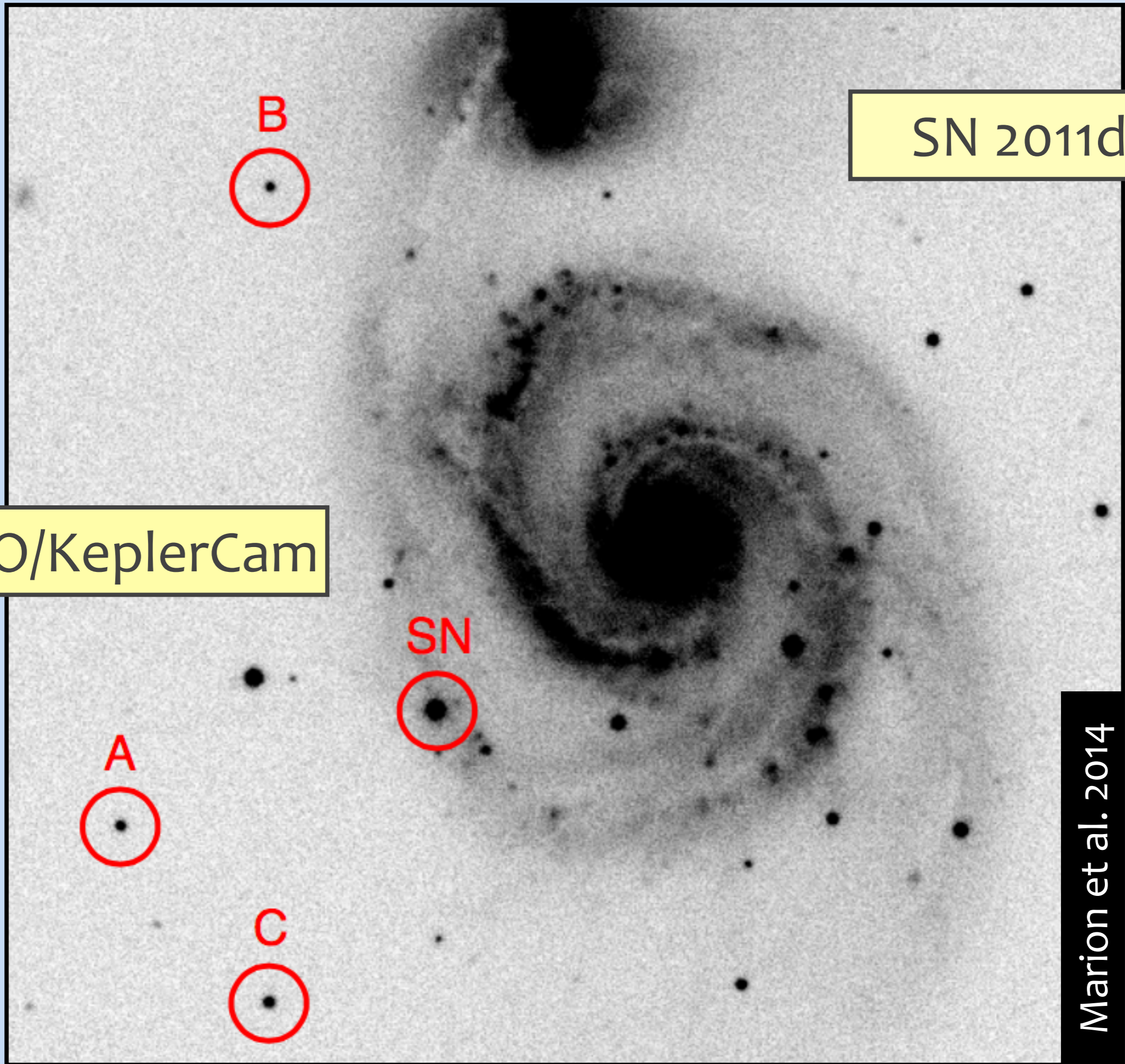
A

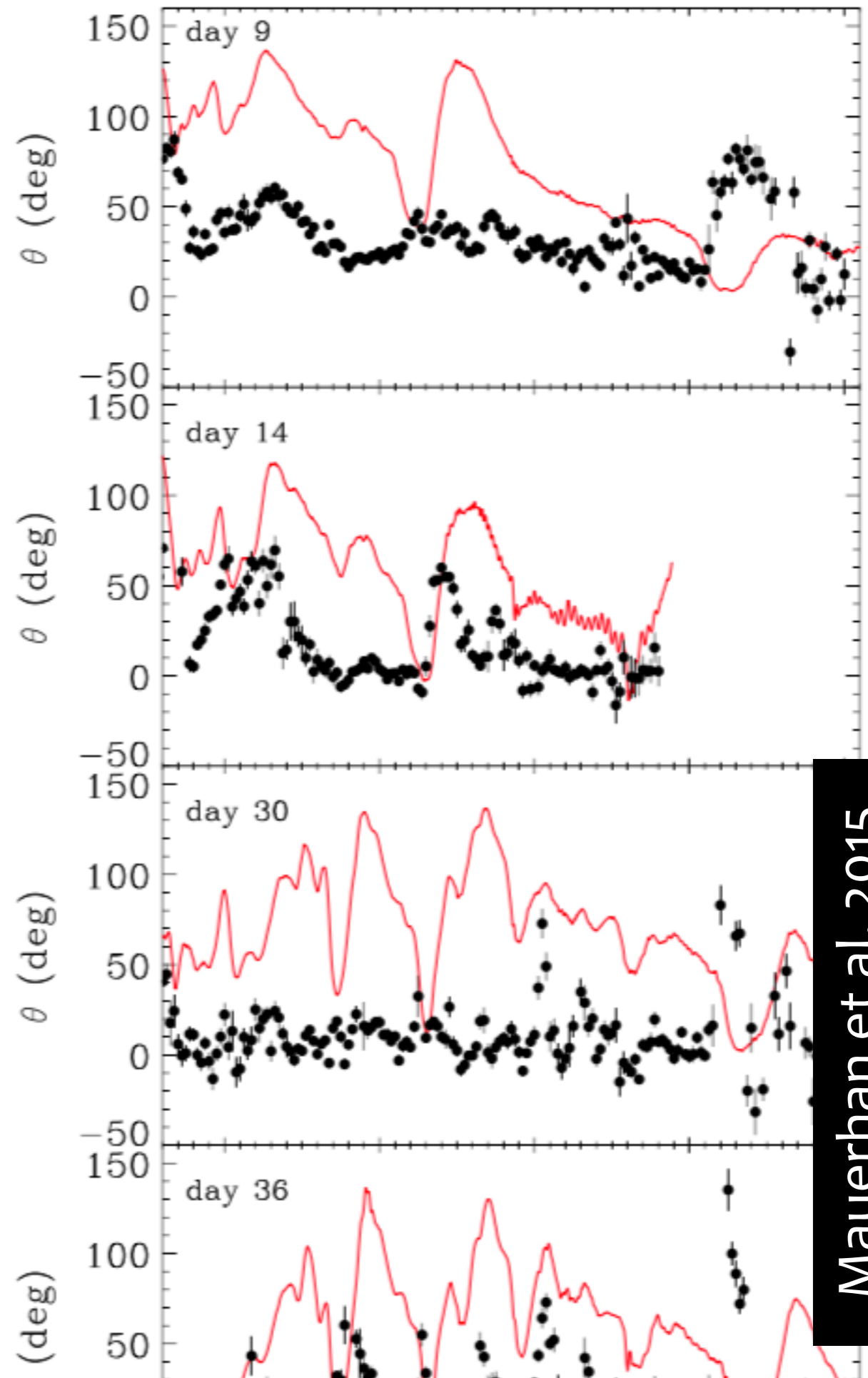
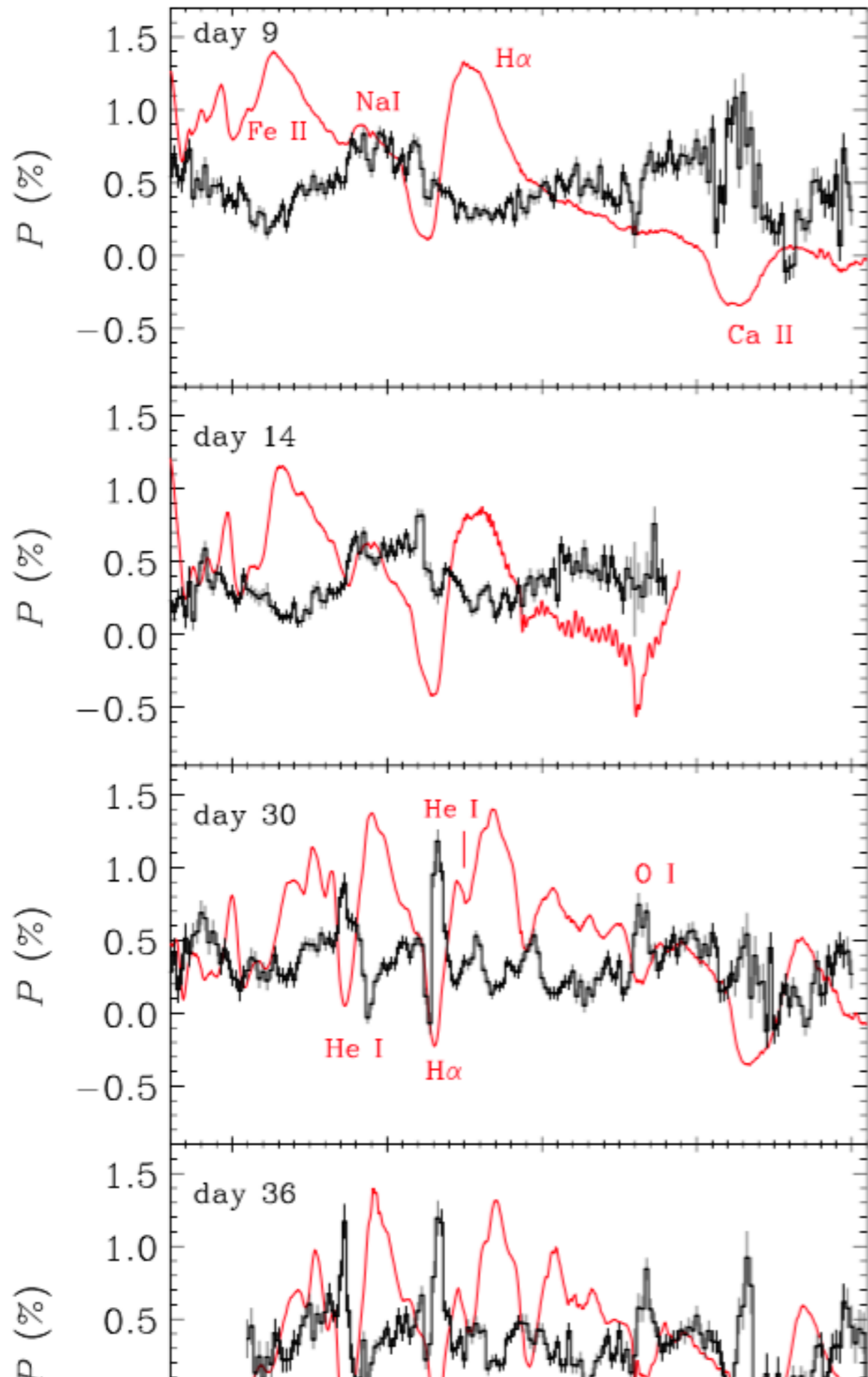
C

B

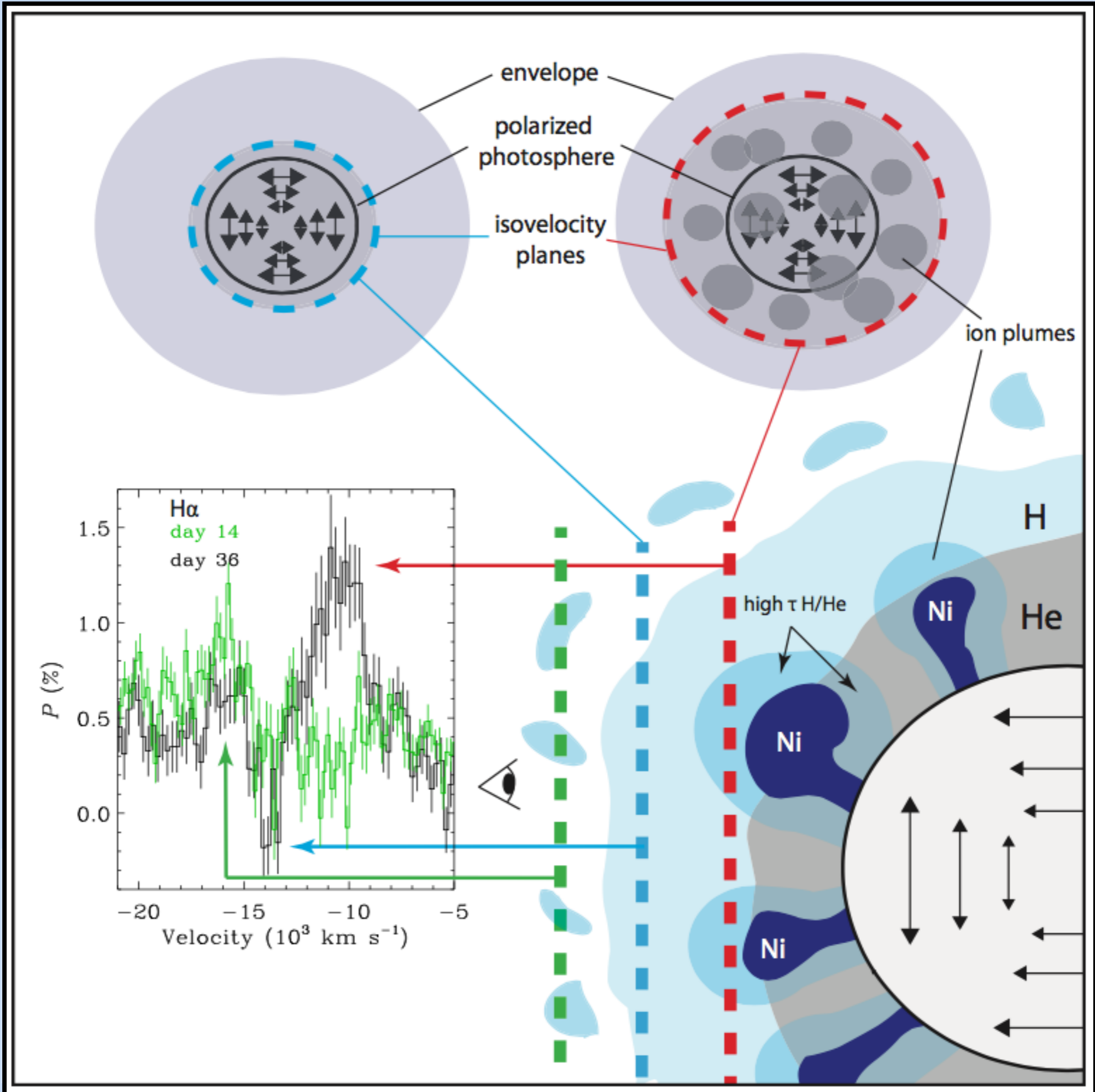
SN

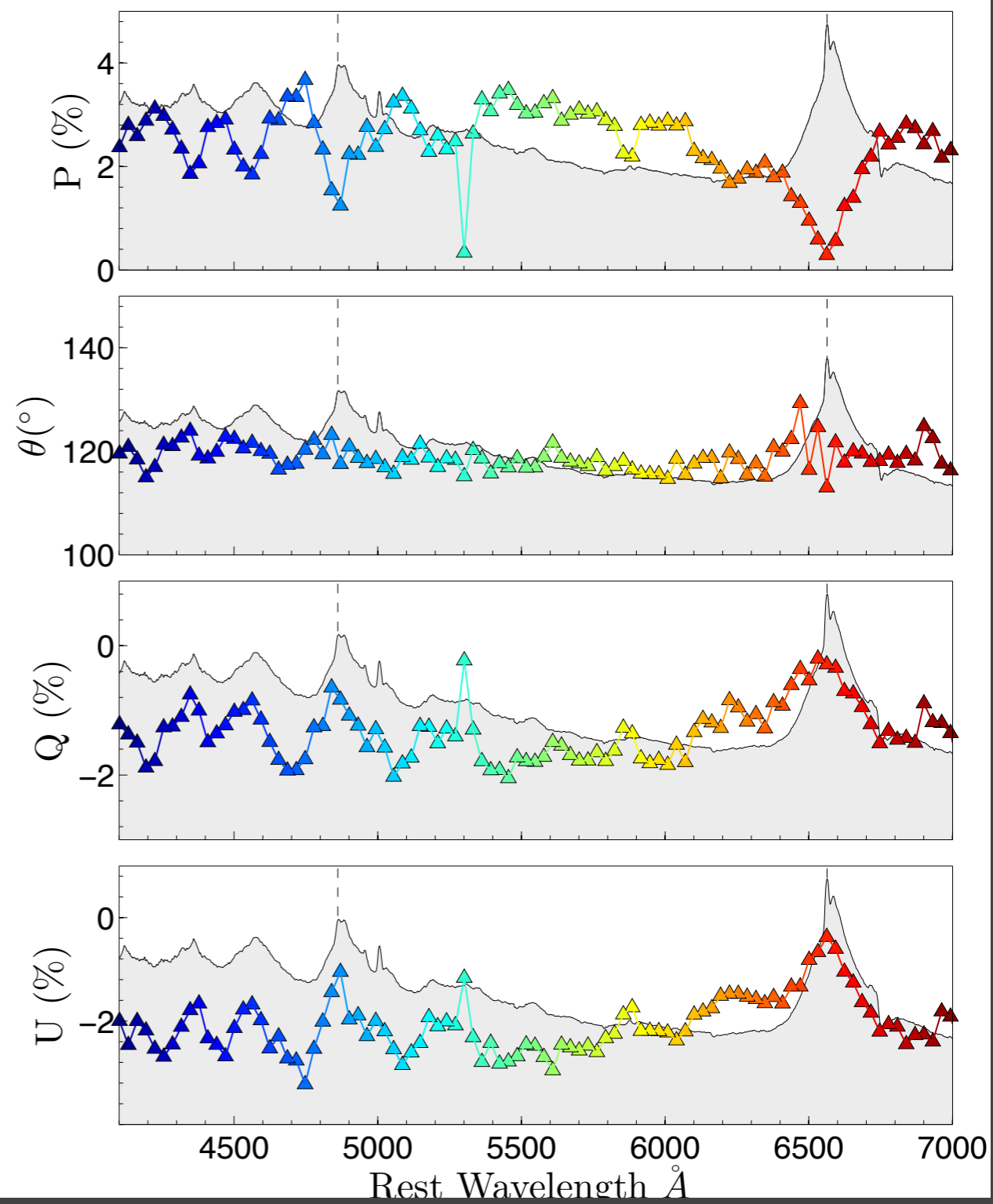
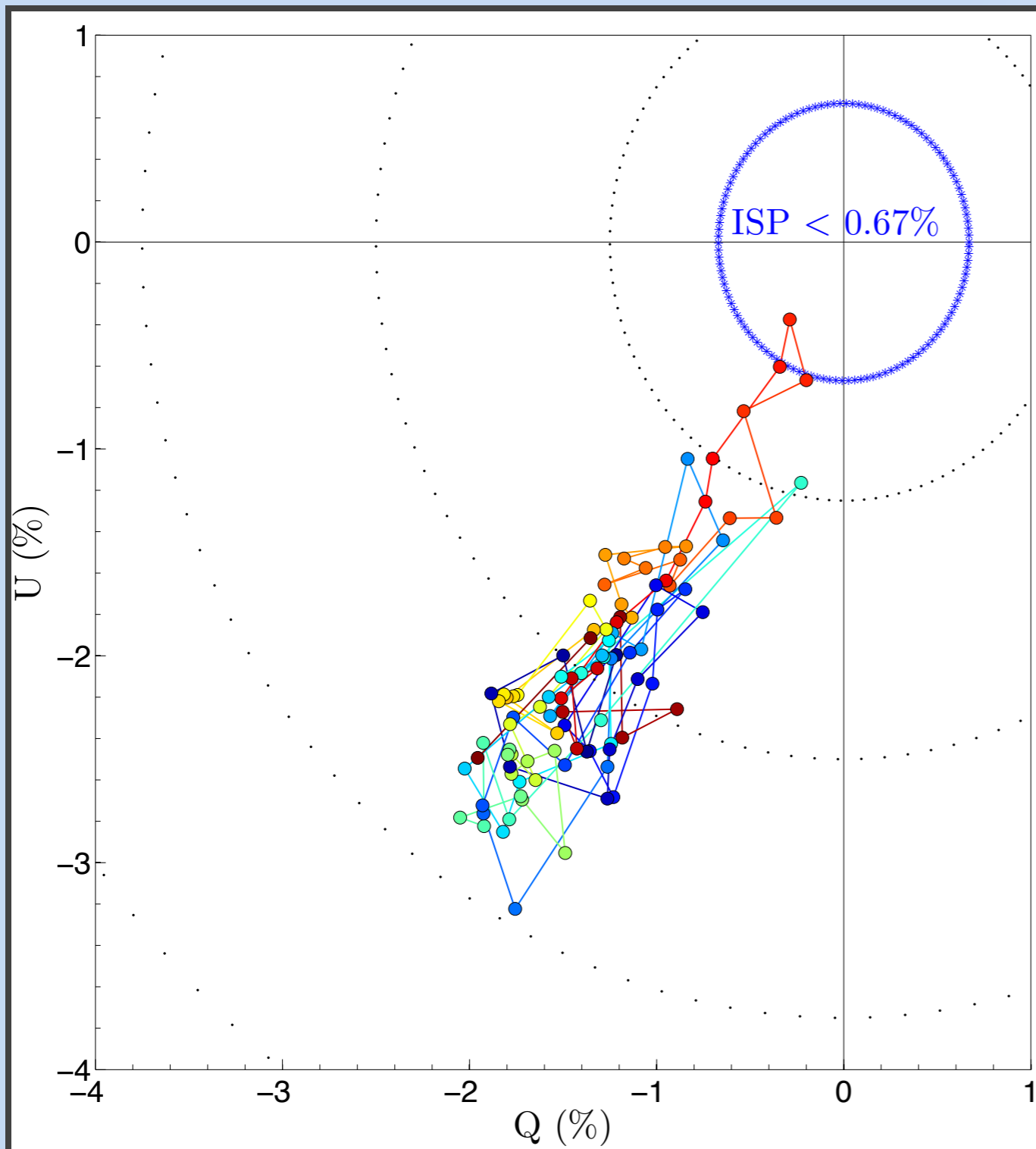
Marion et al. 2014

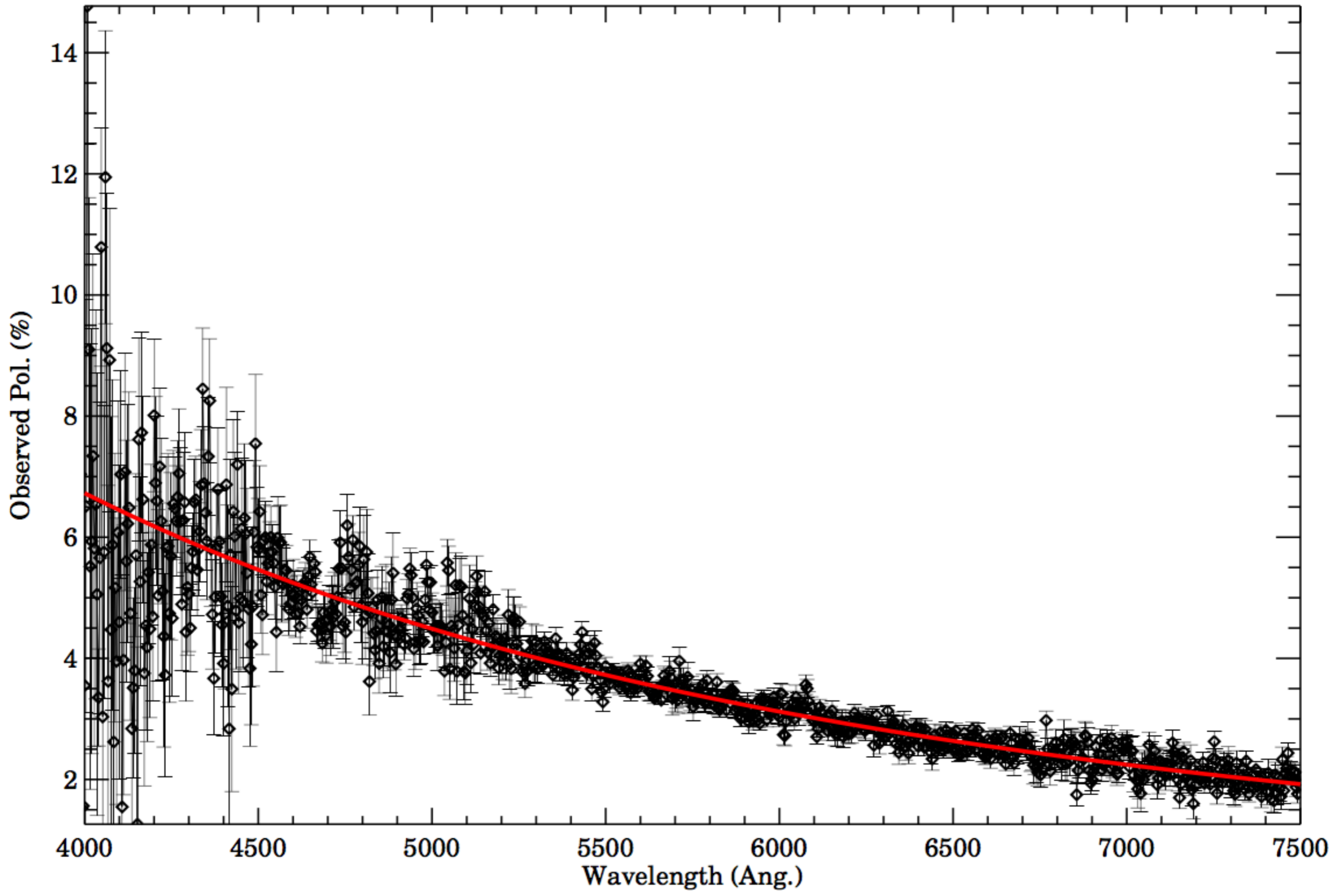


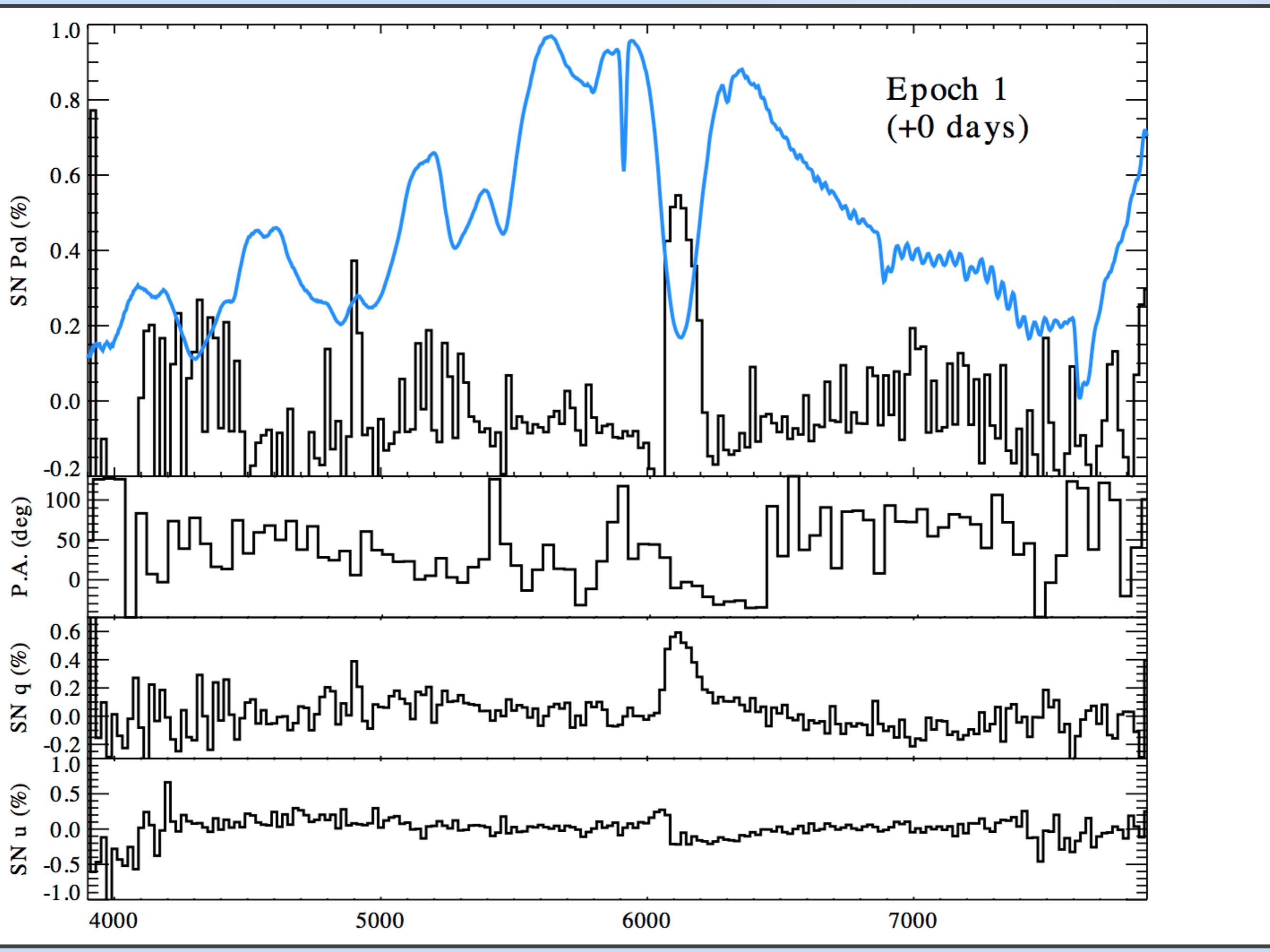


Mauerhan et al. 2015

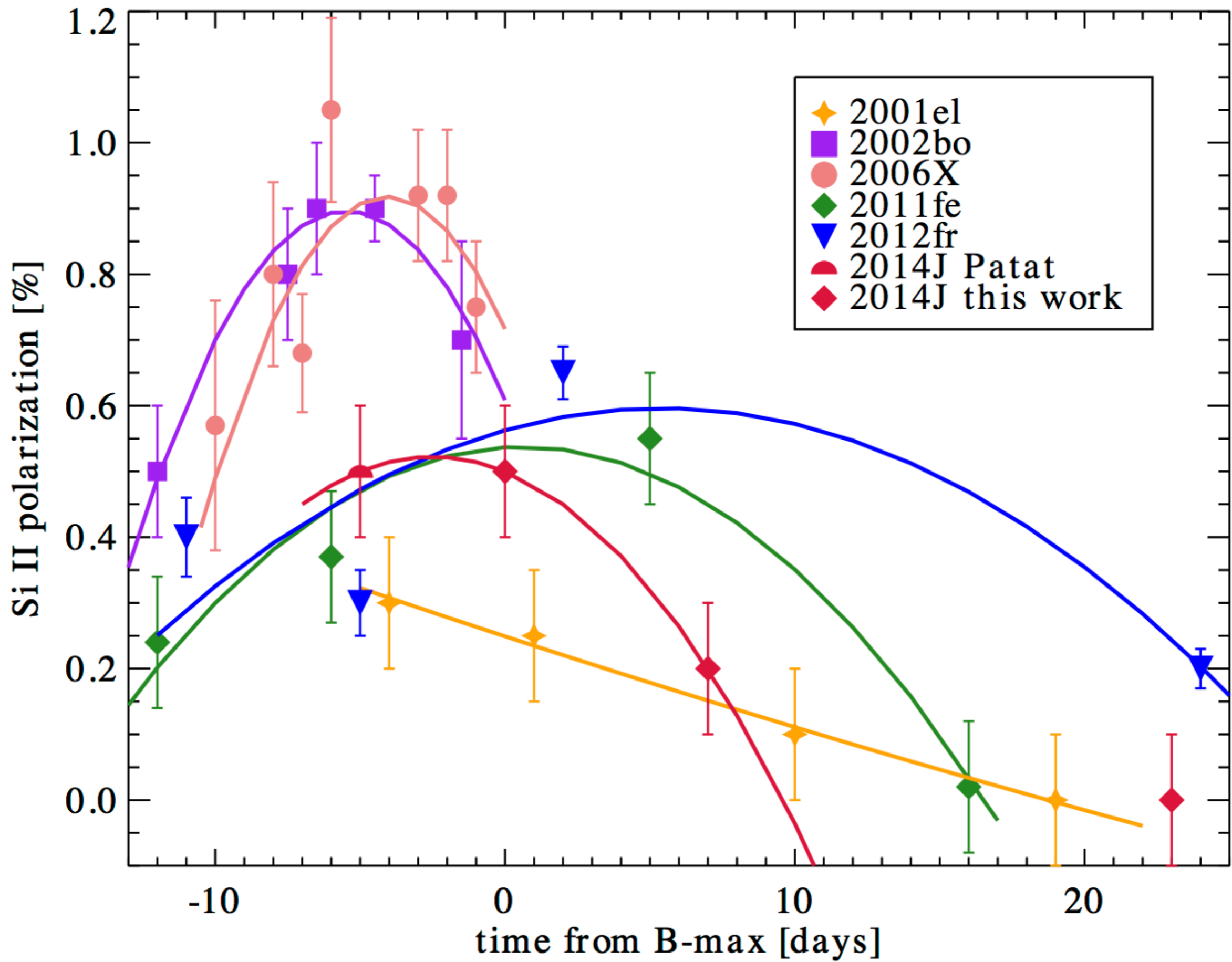


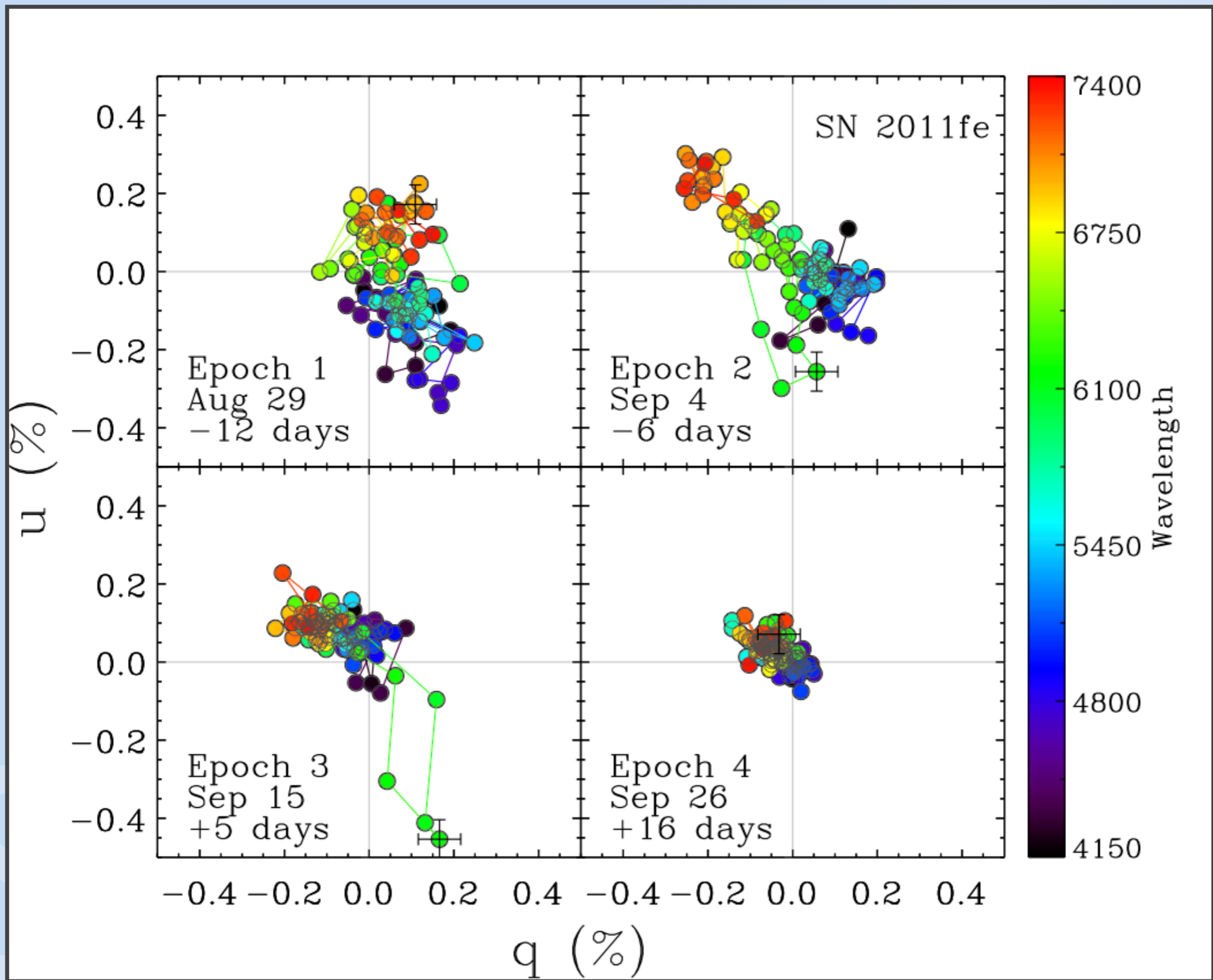


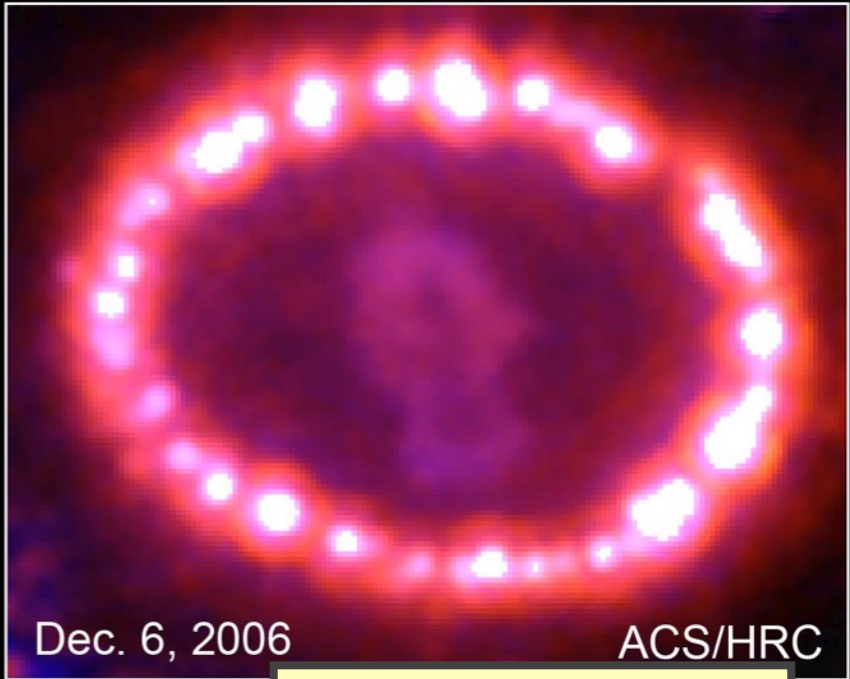
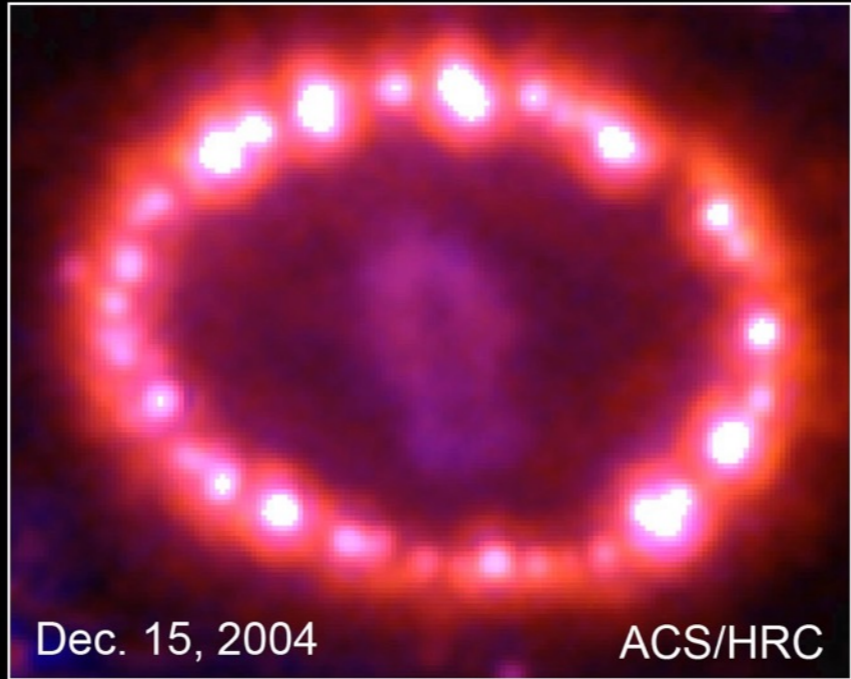
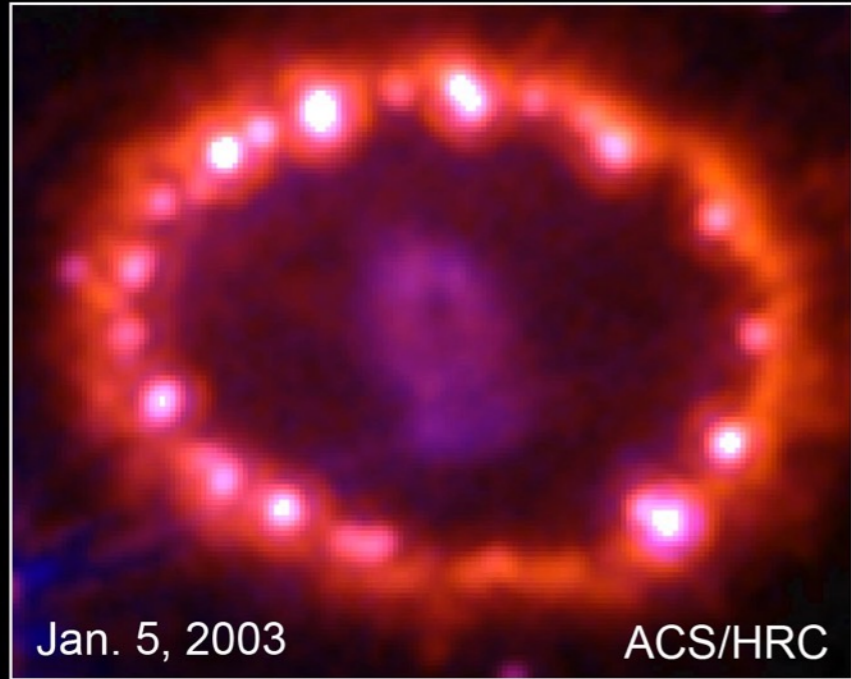
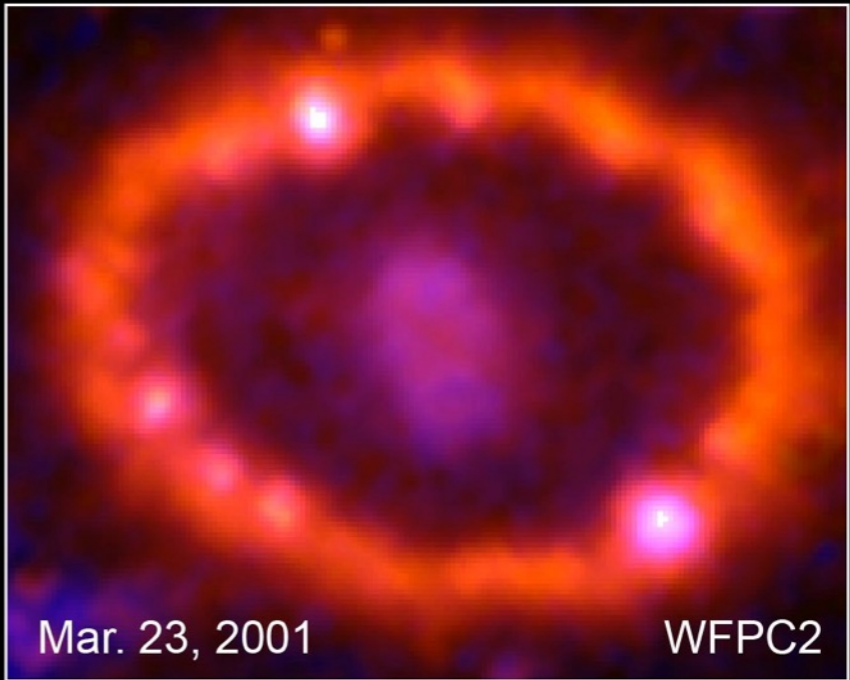
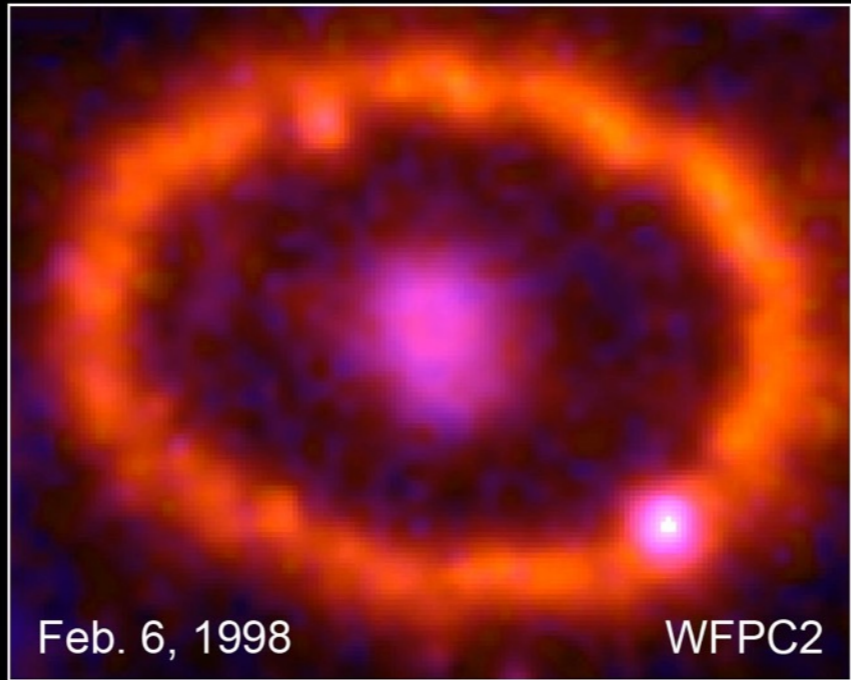
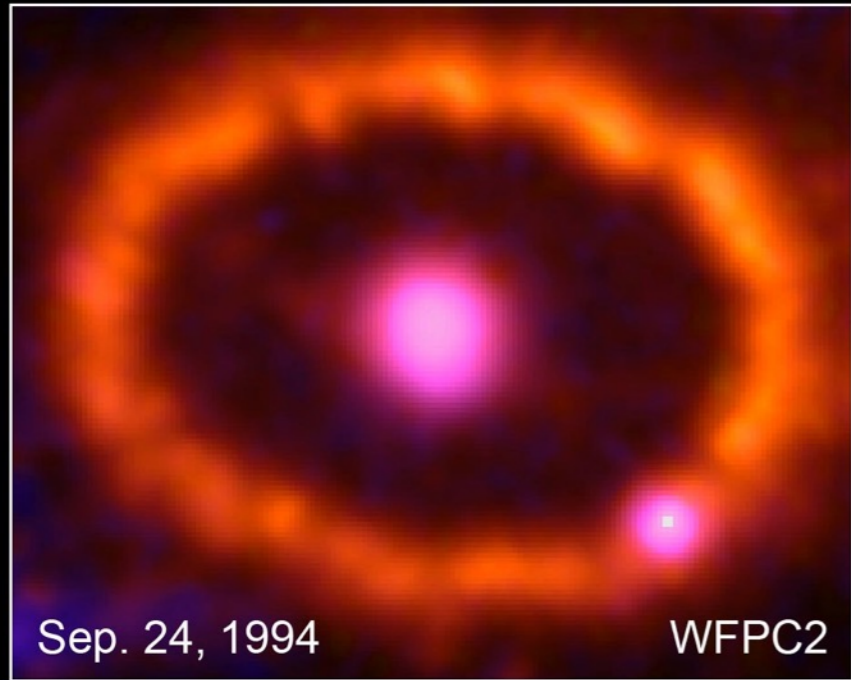












**Supernova 1987A • 1994-2006**  
*Hubble Space Telescope • WFPC2 • ACS*

~20 Years After  
Explosion