The Supernova Spectropolarimetry Project: Probing the Evolution of Asymmetries in Supernovae

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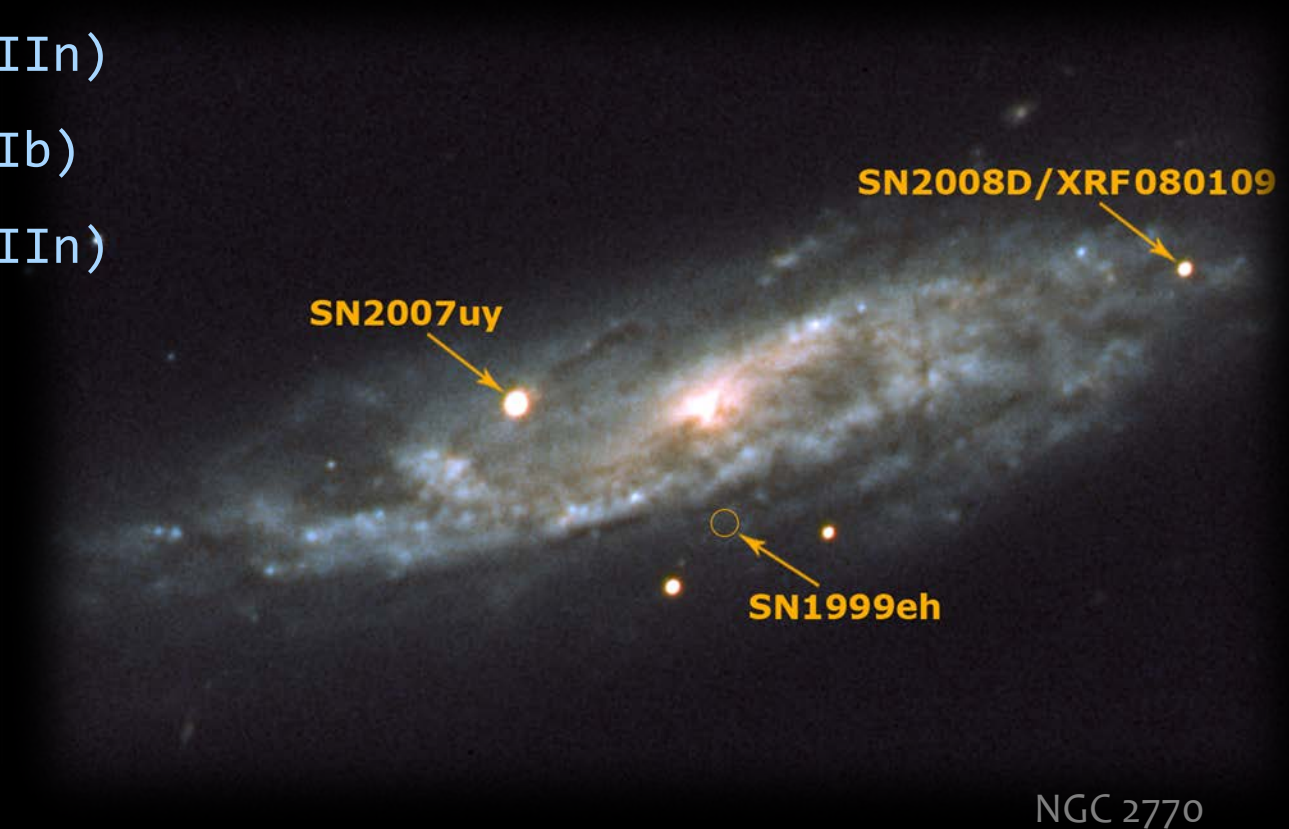
NSF AST-1210599

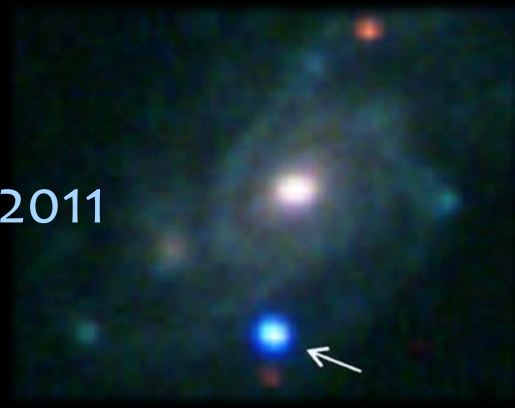
SN 1994D

Outline

- Polarimetry and ELTs
- Overview of supernova polarization
- The SNSPOL project
- Recent observational results
  - ✶ SN 2009ip (IIn)
  - ✶ SN 2012au (Ib)
  - ✶ SN 2010jl (IIn)
- Future prospects



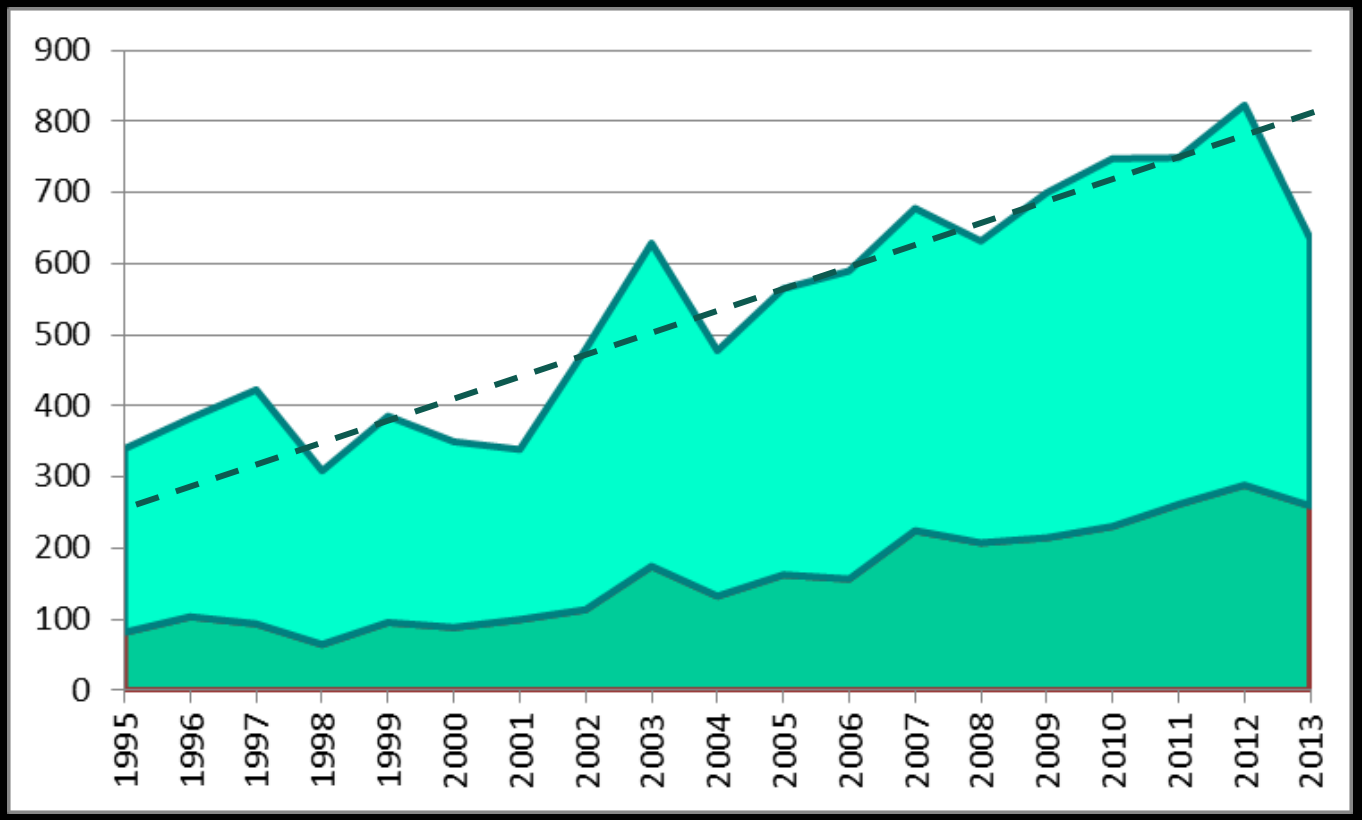
SN 2013cu



Is there a demand for ELT polarimetry?

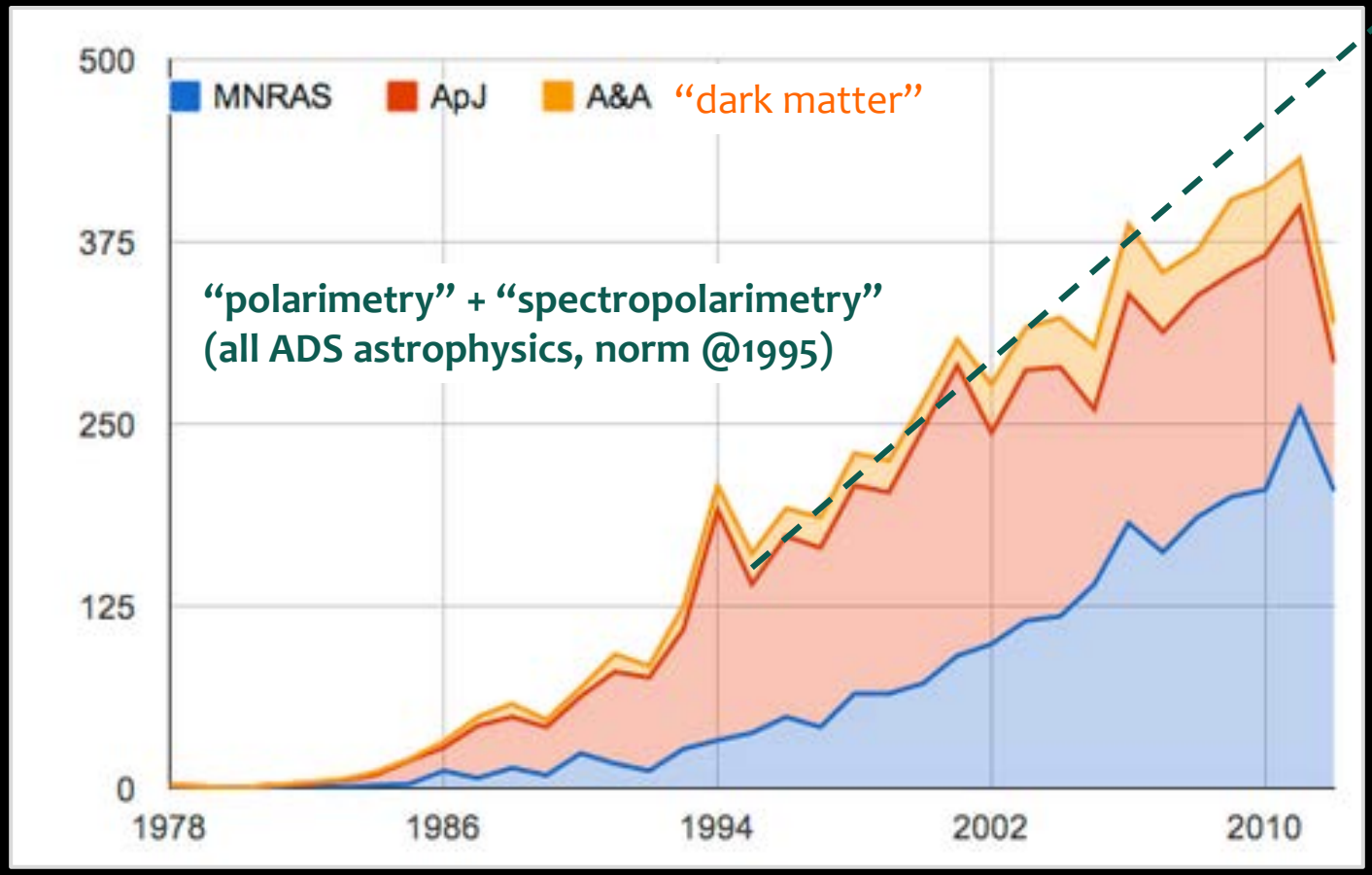
- It was identified as a community priority at the 2011 *Stellar Polarimetry* meeting (90 attendees; Hoffman+ 2012)
- Astro2010 decadal survey: 5 white papers on polarimetry with 22 unique authors
- Recent exciting spectropolarimetric variability results in a variety of areas

Is there a demand for ELT polarimetry?



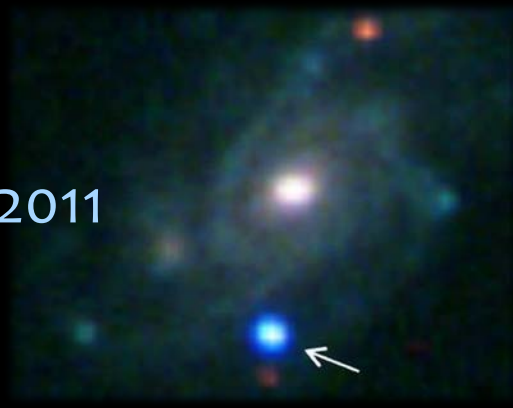
First-order check: Cumulative ADS abstracts including "spectropolarimetry" or "polarimetry" variants, + by-eye trend

Is there a demand for ELT polarimetry?



Simpson, orbitingfrog.com

SN 2013cu



Is there a demand for ELT polarimetry?

- It was identified as a community priority at the 2011 *Stellar Polarimetry* meeting (90 attendees; Hoffman+ 2012)

- Astro2010 decadal survey: 5 white papers on polarimetry with 22 unique authors

- Recent exciting spectropolarimetric variability results in a variety of areas:

stellar magnetic fields
colliding-wind binaries
YSO's and TTS's
AGN tori and jets
supernovae

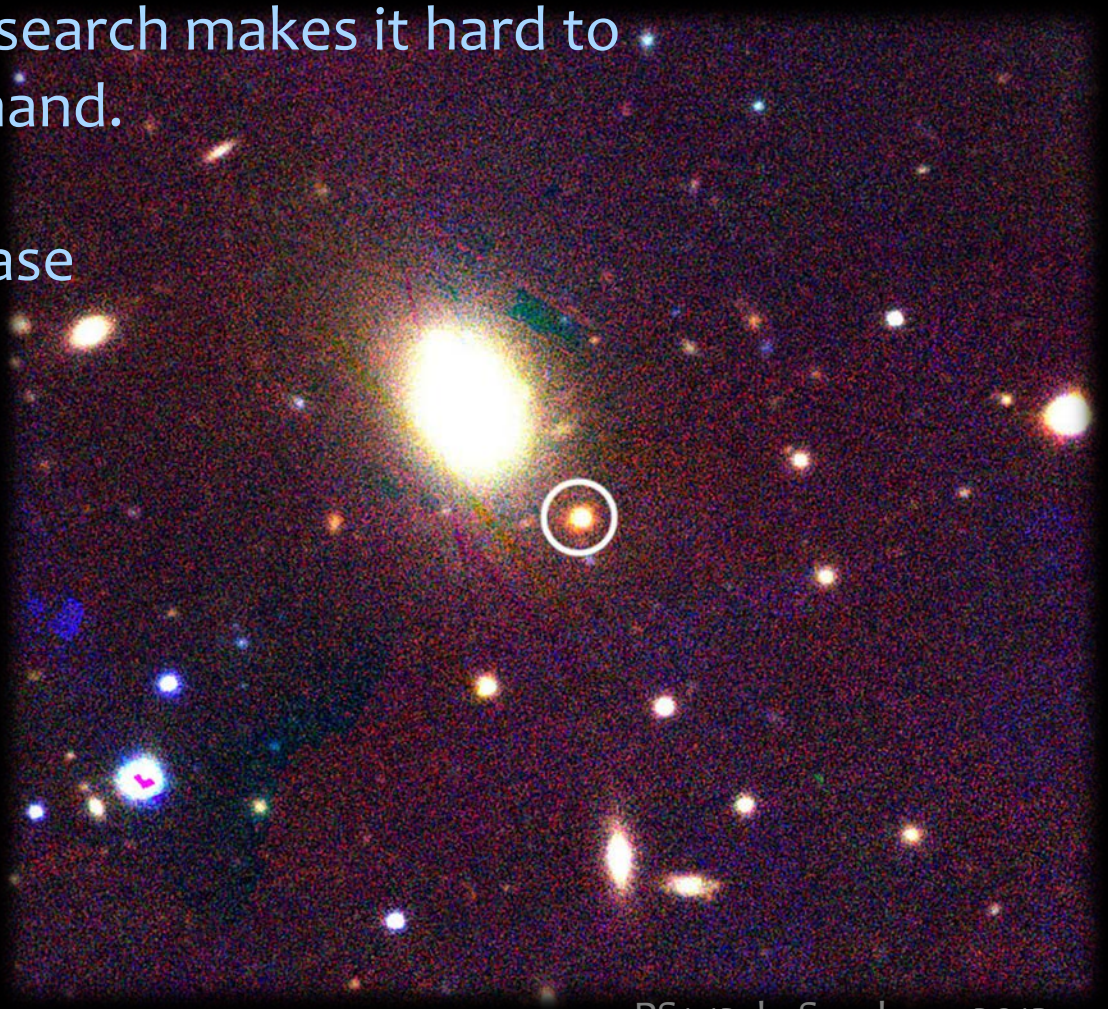
interstellar dust (MW+others)
Wolf-Rayet winds
binary-disk systems
solar studies
exoplanets (upcoming!)…

Is there a demand for ELT polarimetry?

Diversity of polarimetric research makes it hard to demonstrate a unified demand.

But a compelling science case for ELT polarimetry could "float all boats."

… supernova polarization!



PS1-12sk; Sanders+ 2013

Supernova polarization is big news!

SCIENCE NEWS
THE WEEKLY NEWSMAGAZINE OF SCIENCE
JULY 8, 2006 PAGES 17-32 VOL. 170, NO. 2

asbestos among us
cancer, development link
wild, warming west
light smoking, less quitting

www.sciencenews.org

a polarized view

SHAPING UP THE UNIVERSE

ASTRONOMY GETS POLARIZED

New angles on exploding stars and the cosmos' first light

BY RON COWEN

Astronomers usually count themselves lucky if a telescope collects enough light to image a distant star or galaxy. But some researchers are getting pickier. No longer content with the average light wave, they don the astronomical equivalent of polarizing sunglasses to eschew all but the tiny fraction of light waves that are polarized.

Groups of light waves are called polarized when their electric fields oscillate in just one direction instead of in random patterns. The phenomenon occurs when light scatters off a clump of charged particles, such as electrons. The intensity and distribution of the polarized light therefore provide information about the environment from which the light has emanated.

But with the meager number of aligned photons coming from most sky objects, "polarization studies used to be the stepchild of astronomy," notes theorist Adam Burrows of the University of Arizona in Tucson. However, high-powered telescopes put in use over the past decade can collect even small amounts of polarized light.

Polarization is giving new insight into the death throes of stars, some of the most spectacular fireworks in the universe. These explosions, known as supernovas, have a profound influence on the cosmos. They supply the heavens with most of the elements heavier than helium and hurl shock waves that can trigger the birth of new generations of stars.

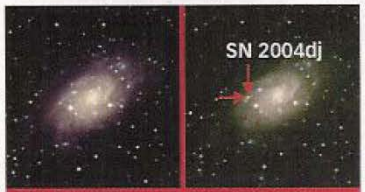
Yet researchers don't know the full story of how stars blow up. The bright light radiated by the outermost layers of blast debris obscures the inner parts of a supernova. But as the outer debris layers thin and become more transparent, polarization studies can detect new details of the supernova mechanism.

Probing an era well before the first supernova explosions, astronomers have begun measuring the polarization of the first light in the universe—the radiation left over from the Big Bang. These measurements are describing the earliest moments of the cosmos as well as pinpointing the time when the first stars began to glow.

BEHIND THE LENS To understand how a polarizing filter, or spectropolarimeter, works, picture a star like Betelgeuse that's bright enough to be seen with the naked eye. Consider what will happen when Betelgeuse goes supernova, as astronomers expect it to do within the next million years.

To make a crude estimate of light's polarization from such a nearby explosion, a pair of polarized sunglasses would be sufficient, says Doug Leonard of San Diego State University. A person would just have to look at the burst through the sunglass lens while slowly rotating it 180°. The lens orientation at which the exploded star appeared brightest and the intensity of light there would provide the same sort of information that astronomers obtain from a spectropolarimeter.

If the Betelgeuse supernova appeared equally bright no matter the angle of the sunglass lens, then it would be radiating the same amount of light at all angles, as a perfectly round ball of gas does. But if the light from the Betelgeuse supernova appeared brighter at certain angles, then it must be asymmetric, perhaps egg-shaped. The greater the polarization, the more out of round the supernova would be.



SCENE CHANGE — A galaxy before (left) and after (right) the violent demise of a star in an explosion known as supernova 2004dj.

Sunglasses work by preventing half the polarized light—the glare from the ocean, for example, from passing through the lenses. But a modern spectropolarimeter preserves all the light, incorporating a beam splitter so that both a polarized beam and the beams at right angles to it are recorded simultaneously.

"One does not see deeper into an object using polarimetry," says Leonard, "but rather, astronomers are better able to interpret the light coming from an astronomical source by knowing its polarization state."

Because even the largest telescopes can't discern the shapes of the explosions, astronomers turn to polarization to find subtle indications of geometry.

Astronomers divide supernovas into two general types. The most common, known as core-collapse supernovas, are the catastrophic deaths of massive, bloated stars. The cores of these heavyweights implode under their own weight, creating either a neutron star or a black hole and blasting their outer layers into space.

The less-massive supernovas, which are called type Ia, explode in a different manner. Astronomers' current view is that an elderly, shriveled star, called a white dwarf, siphons mass from a companion star until the dwarf reaches a critical mass about 1.4 times as great as that of our sun. The weight of the infalling material triggers a thermonuclear explosion on the dwarf's surface, demolishing the star.

Astronomers are using polarization to examine both types of supernovas. The work has already revealed a surprise. Although core-collapse supernovas arise from symmetrical objects and type Ia explosions come from naturally asymmetric configurations, the core-collapse supernovas appear to be more misshapen.

K. SAWICZKY, LEONARD

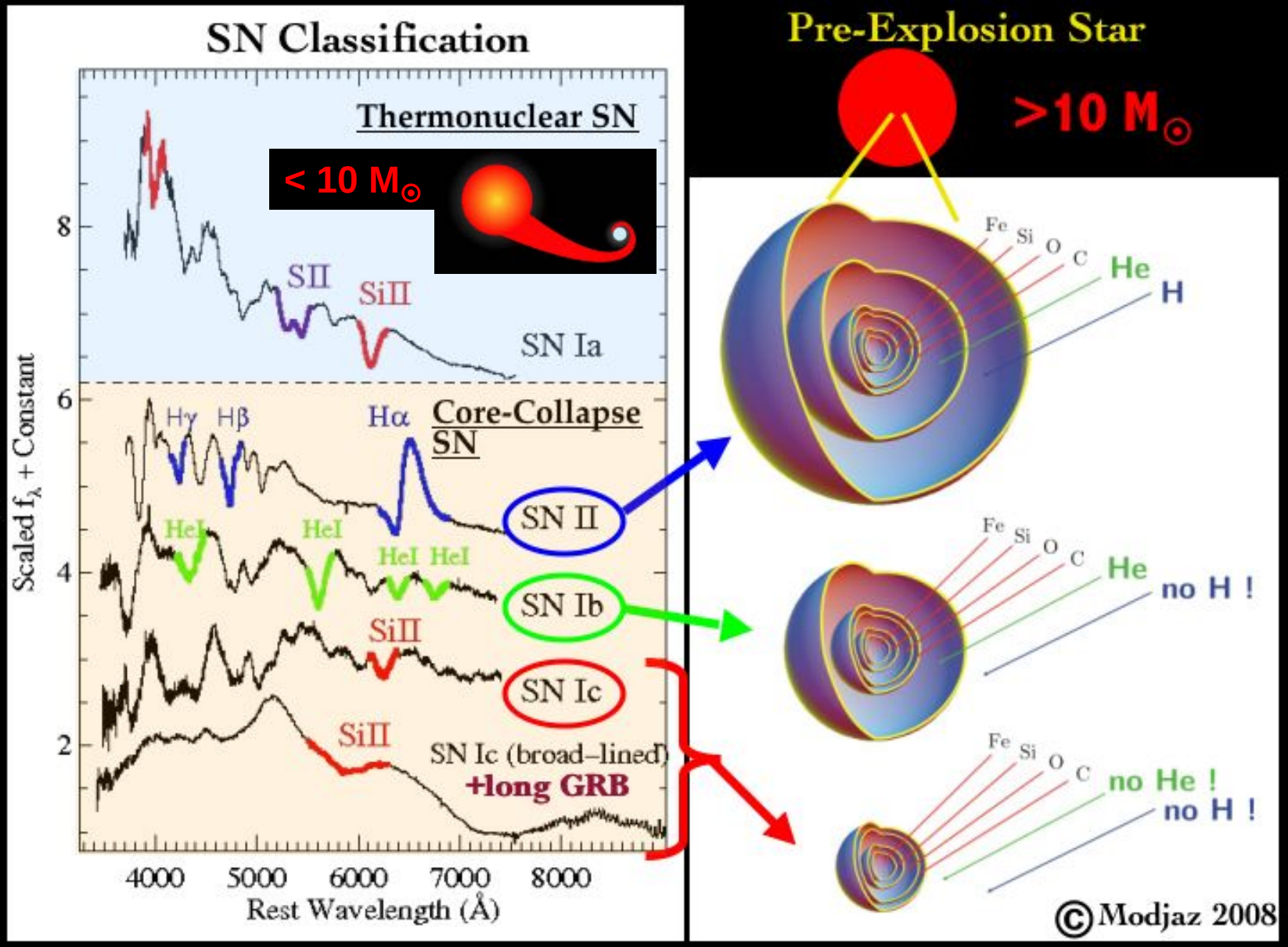
Why do we care about supernova polarization?

(Linear) polarization results from asphericity, so…

- It yields insight into collapse/explosion mechanisms (GRBs…).
- It tells us about the stellar winds and circumstellar material of progenitor stars.
- It helps us probe stellar evolution in faraway galaxies.
- It has potential implications for the use of some supernovae as cosmological probes.

SN 2008aq

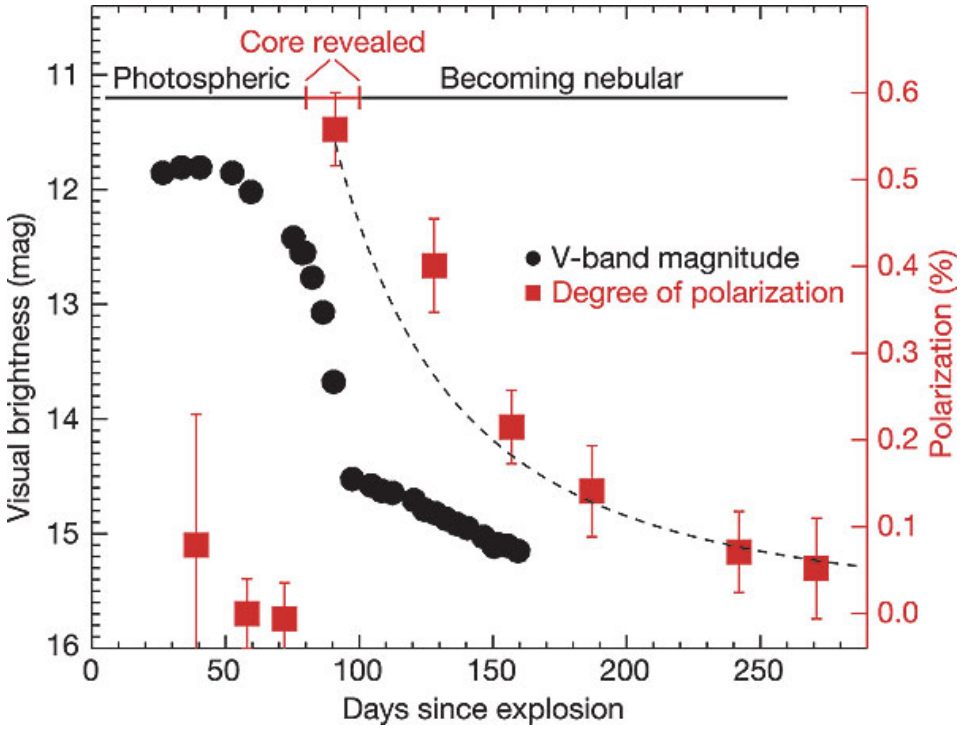
All types of supernovae can be polarized!



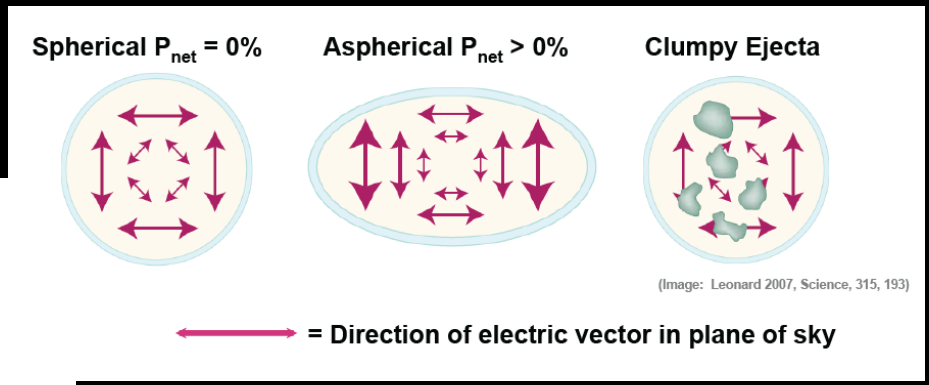
Overview

Broadband polarization measurements indicate ejecta asphericity.

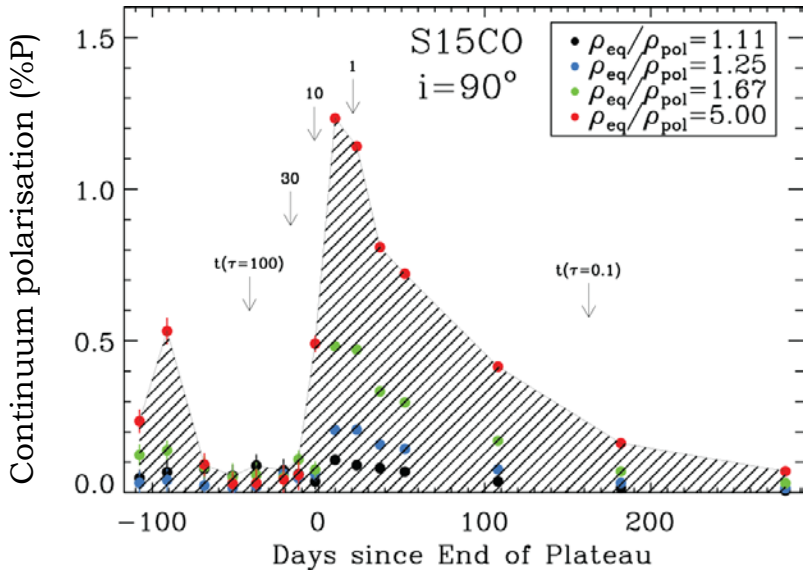
SN 2004dj (II-P)



Leonard+ 2006



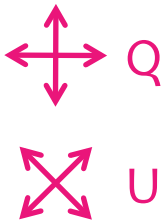
Leonard+ 2007

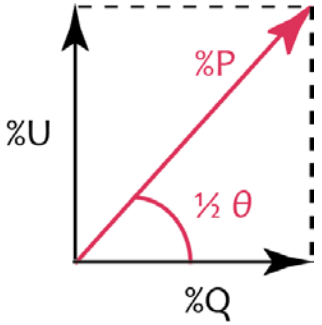


Dessart & Hillier 2011

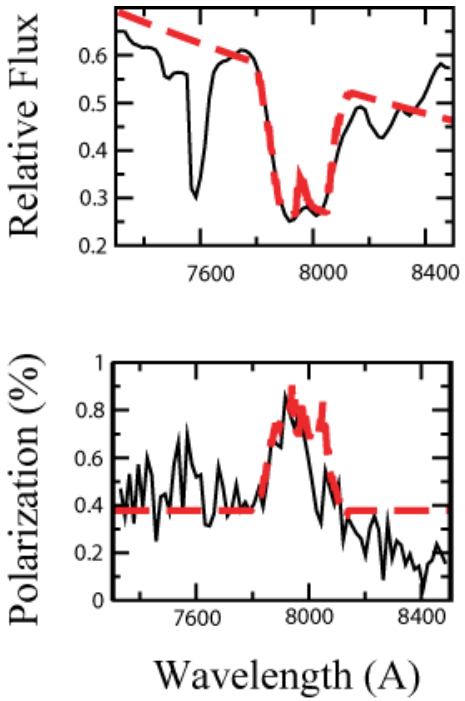
Overview

Polarization across spectral lines probes distribution of elements in the ejecta and surroundings.





SN 2001el (Ia)



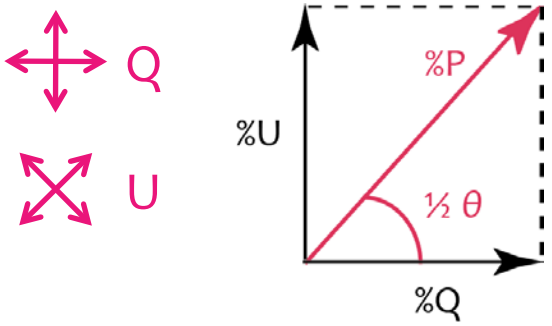
SN2001el

clumped shell model

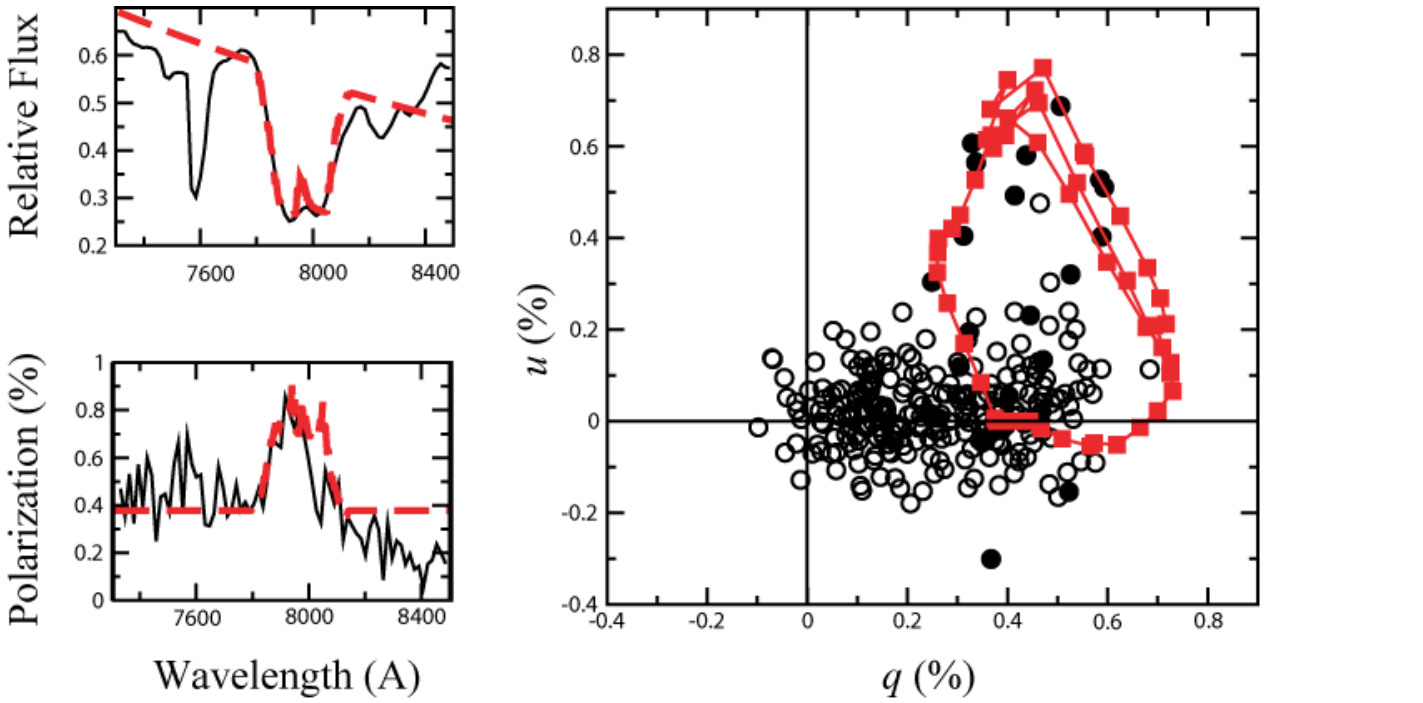
Kasen+ 2003

Overview

Polarization across spectral lines probes distribution of elements in the ejecta and surroundings.



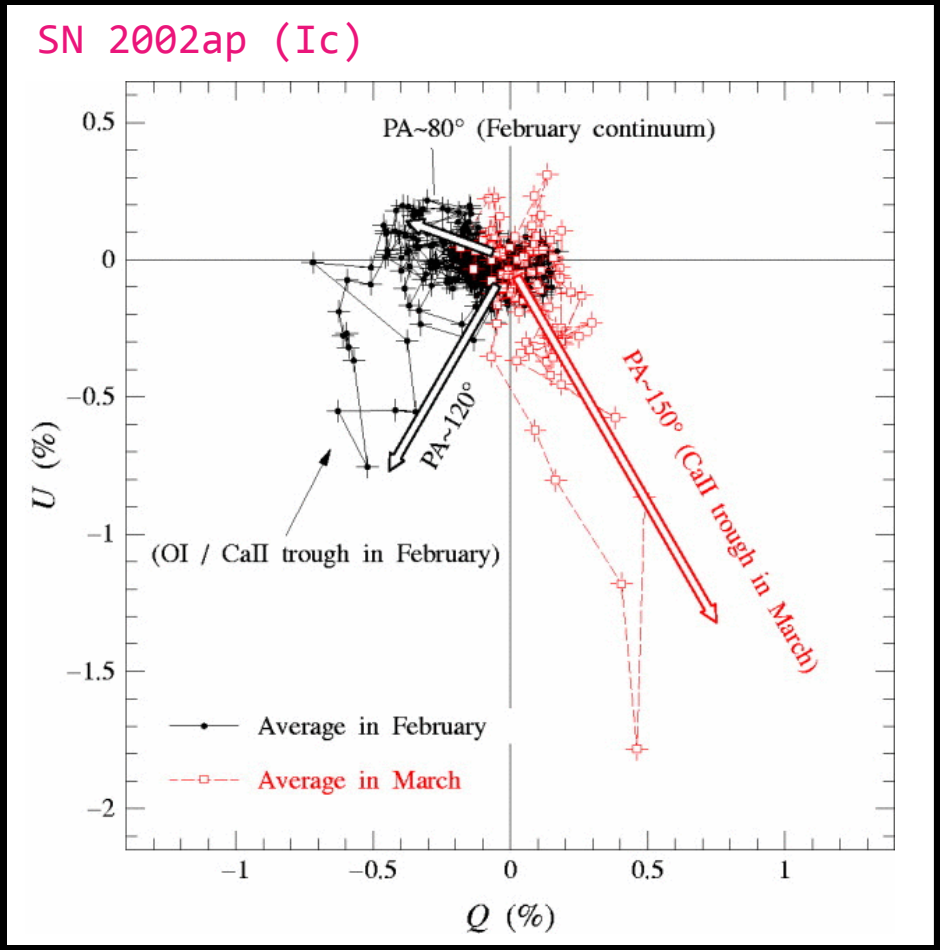
SN 2001el (Ia)



Kasen+ 2003

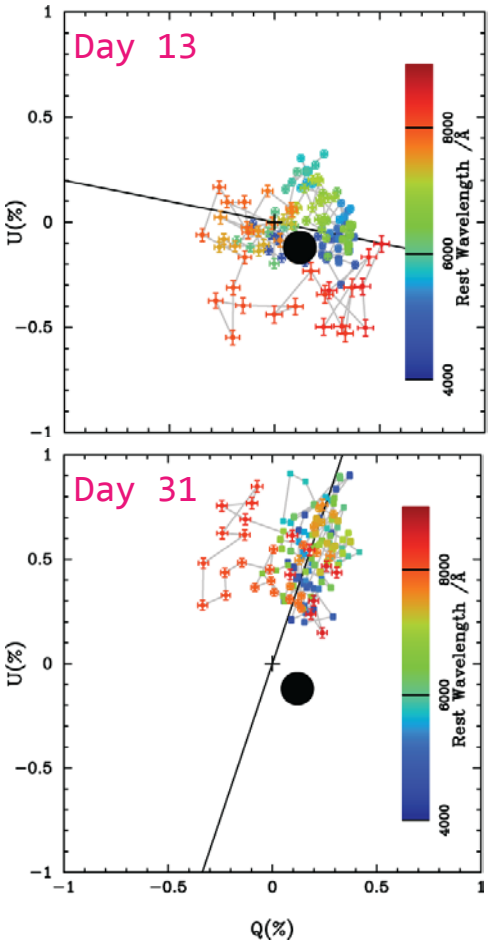
New frontier: time-domain spectropolarimetry!

SN 2002ap (Ic)



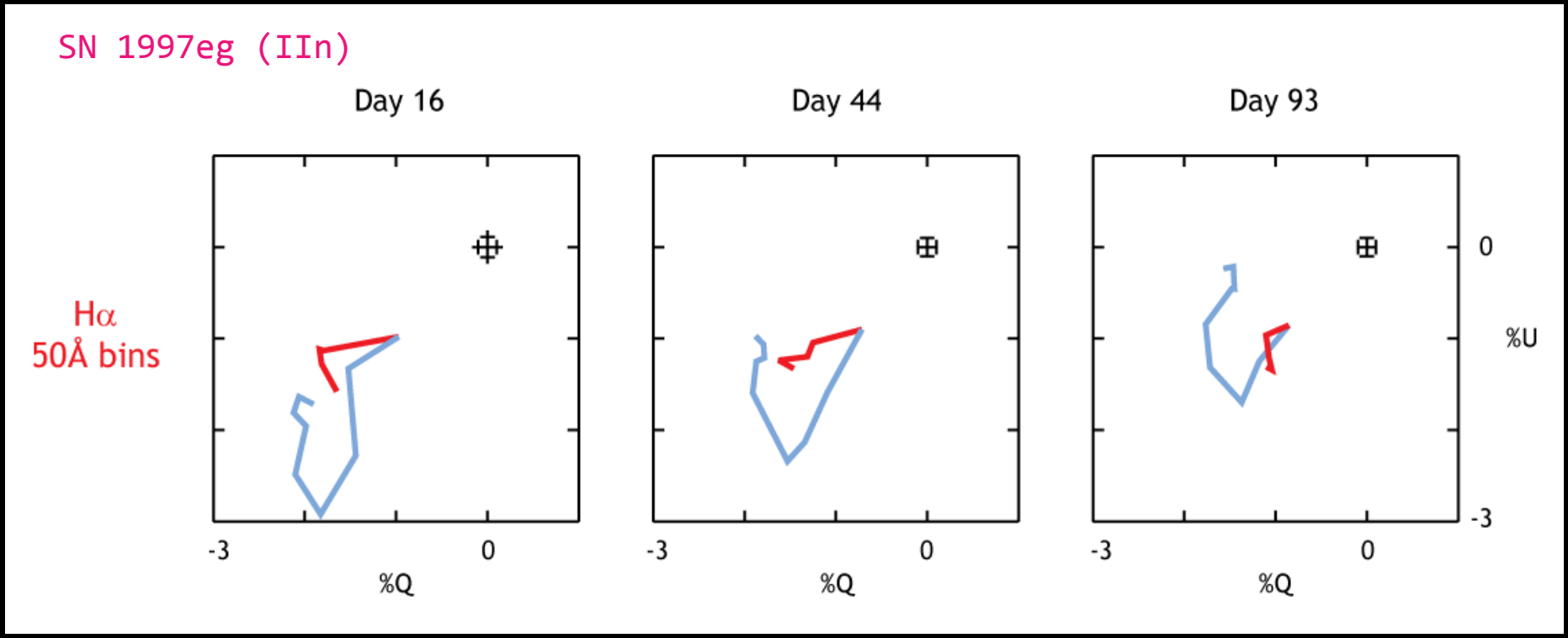
Kawabata+ 2002

SN 2001ig (IIb)



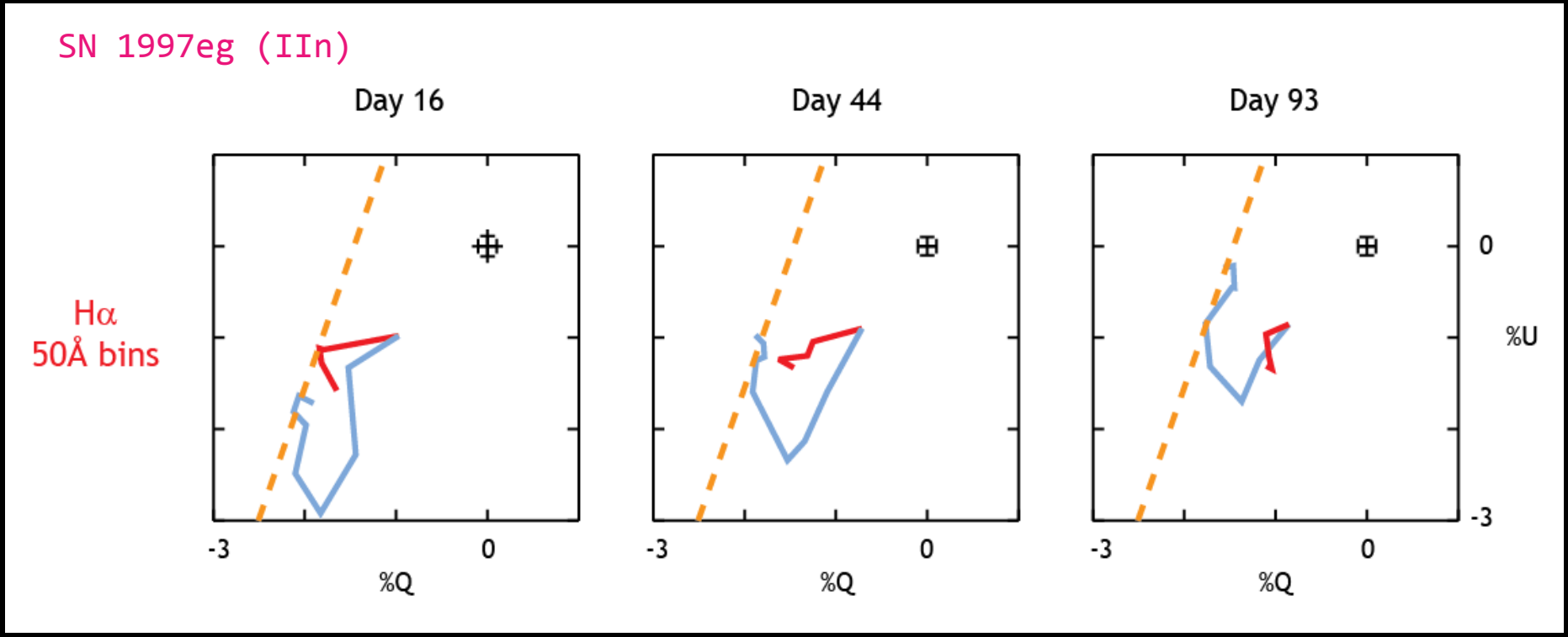
Maund+ 2007

New frontier: time-domain spectropolarimetry!



Hoffman+ 2008

New frontier: time-domain spectropolarimetry!



Hoffman+ 2008

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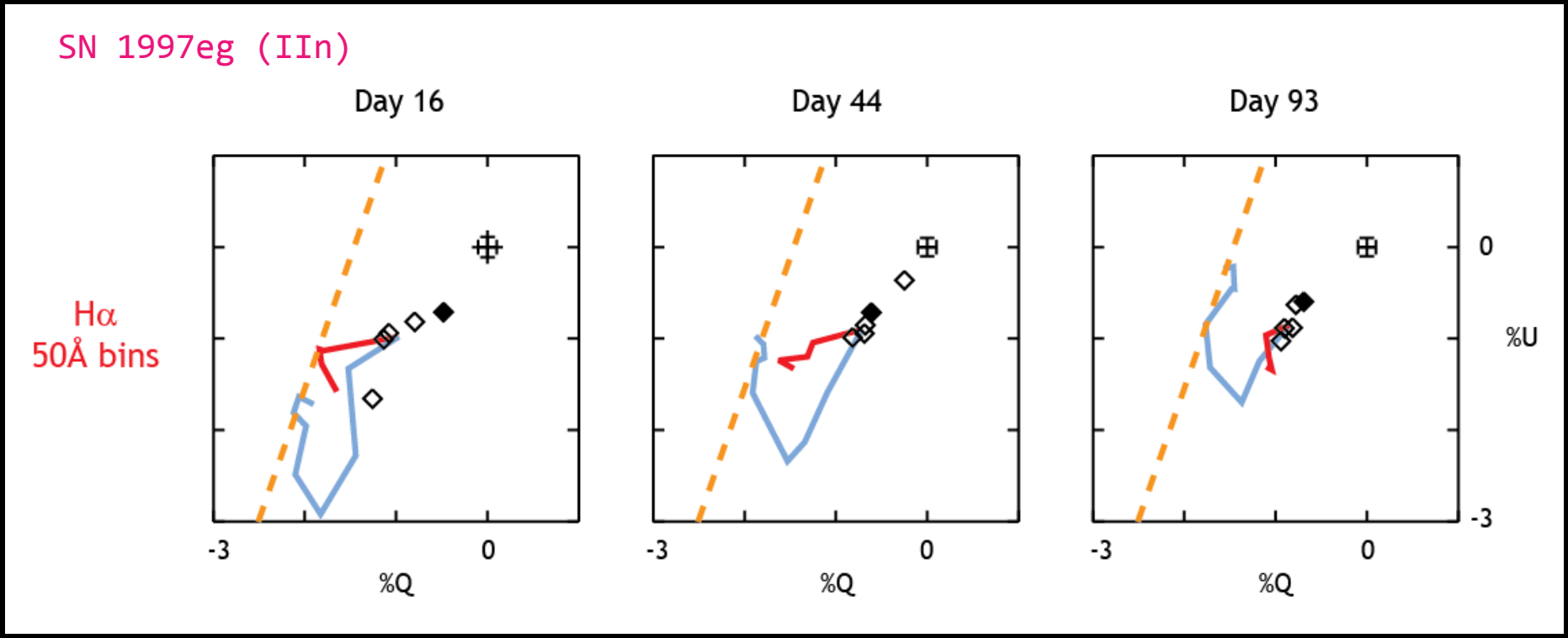
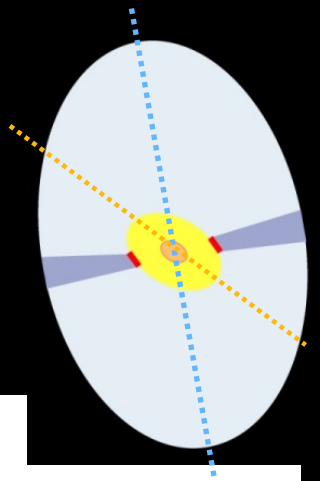


Hoffman+ 2008

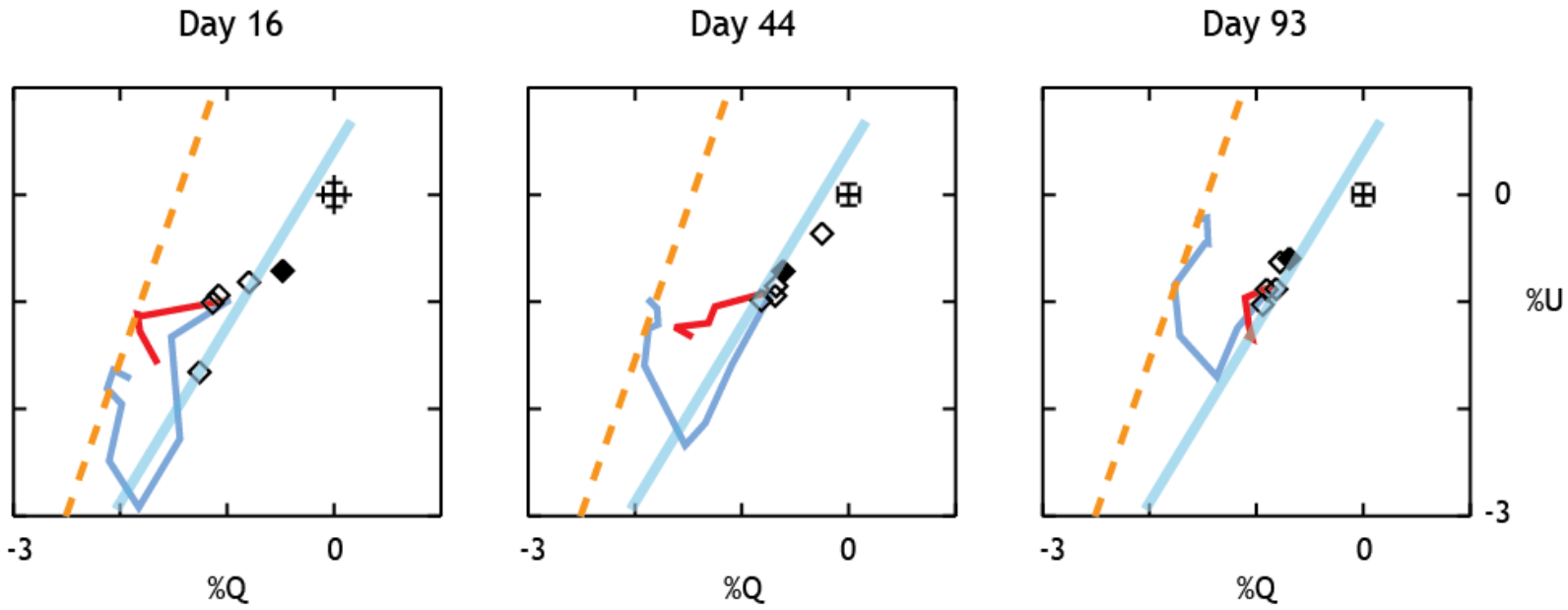
Overview

New frontier: time-domain spectropolarimetry!
Reveals details inaccessible by other methods.



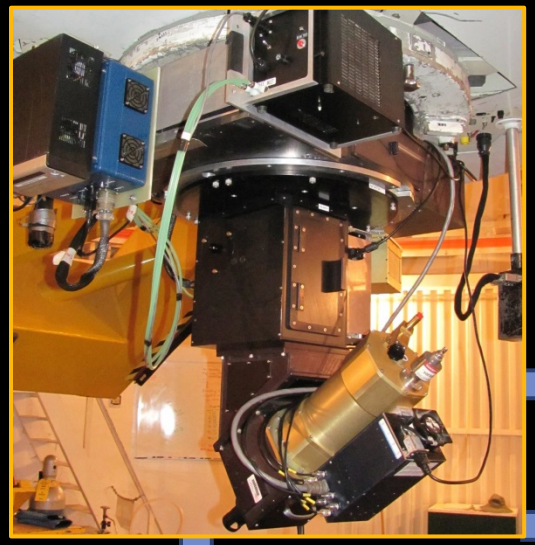
SN 1997eg (IIn)

Hα
50Å bins



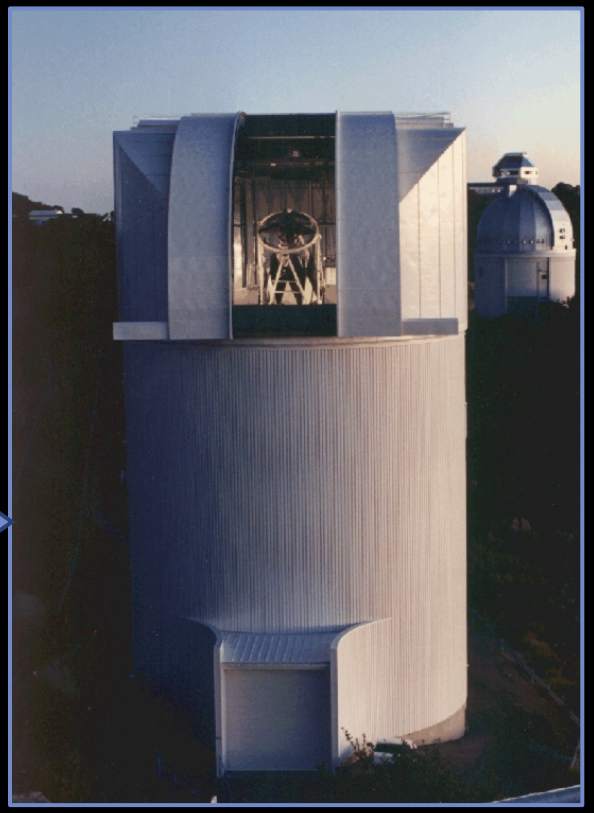
Hoffman+ 2008

The SNSPOL project

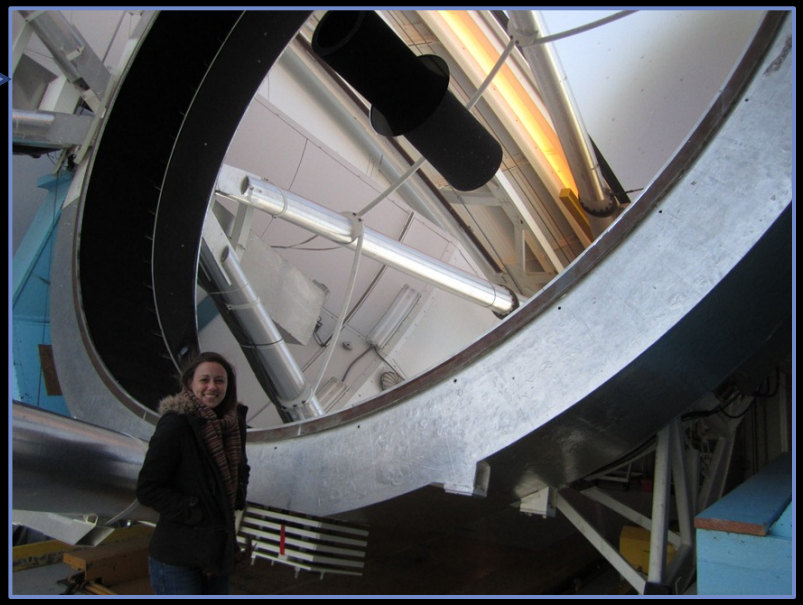


SPOL

61” Kuiper, Mt. Bigelow

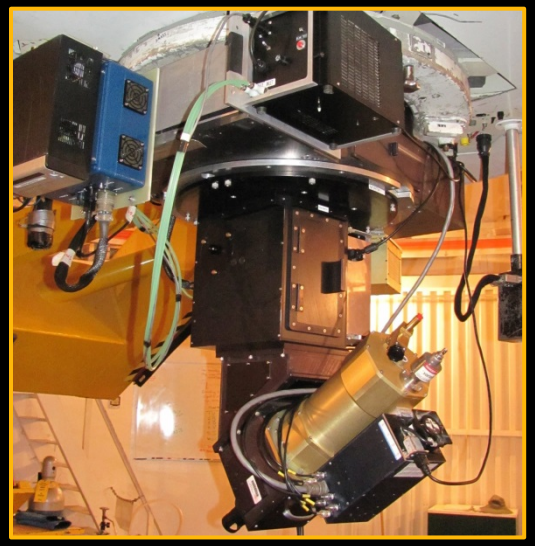


2.3-m Bok, Kitt Peak



6.5-m MMT, Mt. Hopkins (with DU grad student Leah Huk)

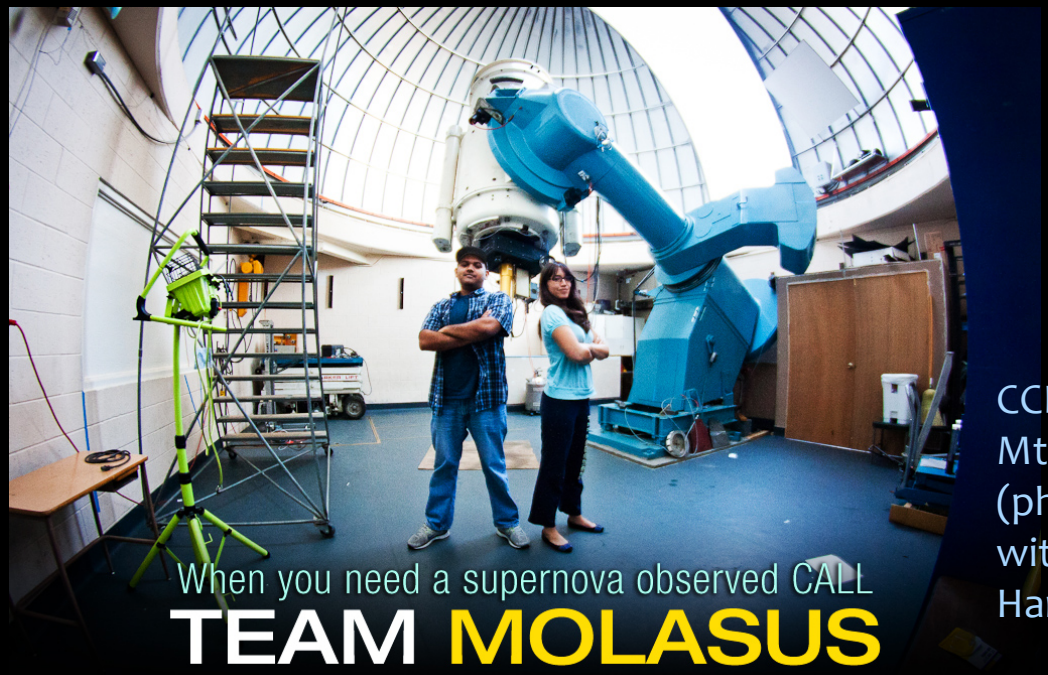
The SNSPOL project



SPOL

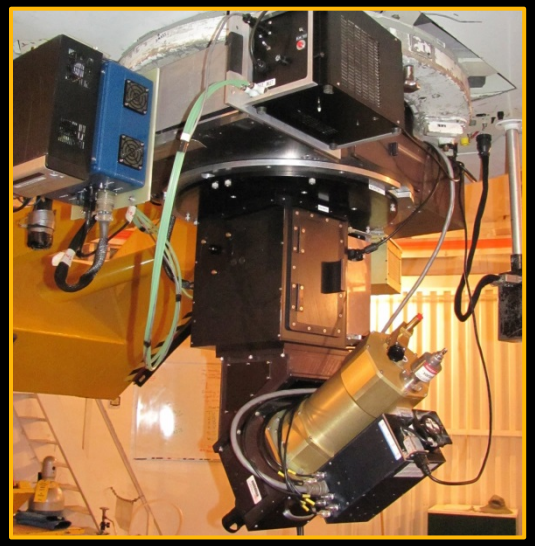
… plus supporting observations from

HPOL, 1-m telescope
Ritter Observatory
(ISP measurements; with
Toledo postdoc Jimmy Davidson)



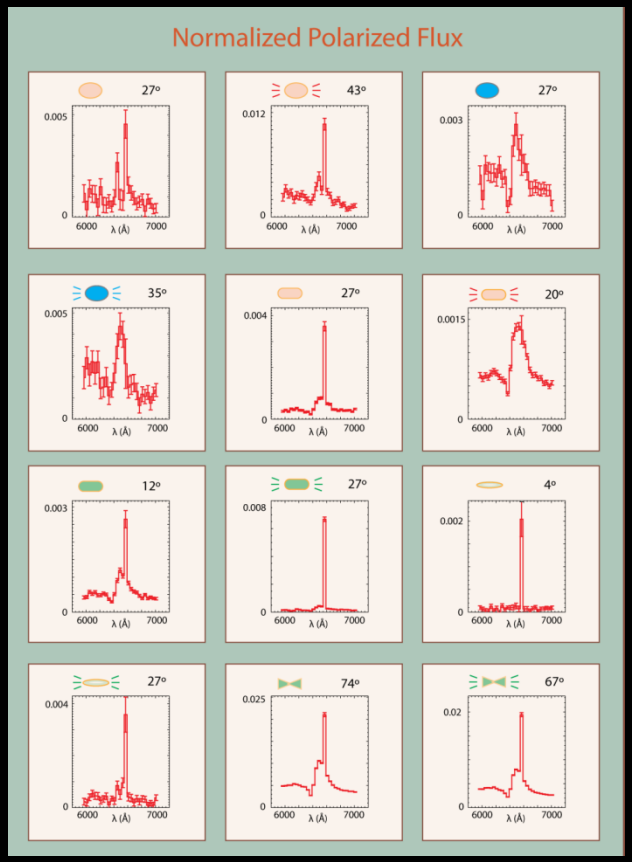
CCD447 camera, 40” telescope
Mt. Laguna Observatory
(photometric monitoring;
with SDSU grad students
Harish Khandrika and Alisa Rachubo)

The SNSPOL project

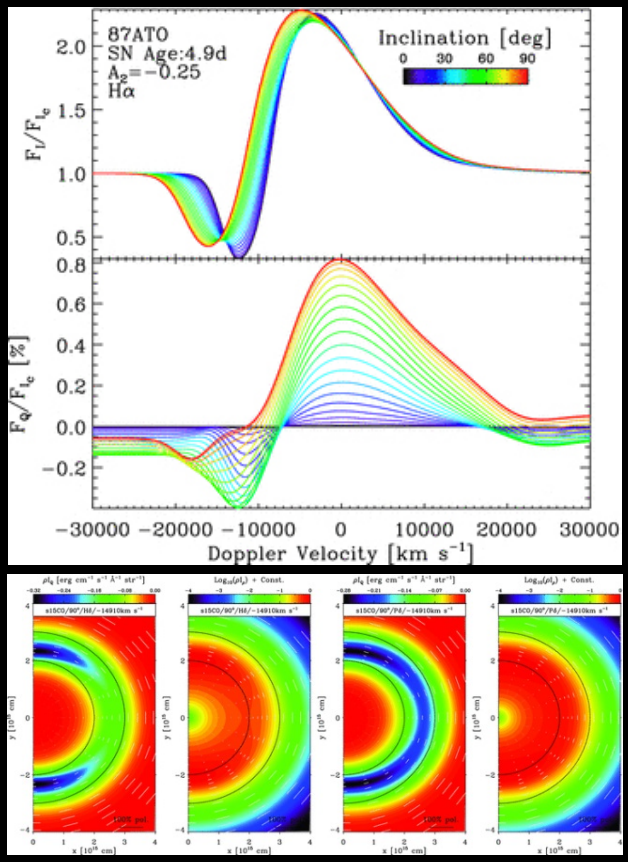


SPOL

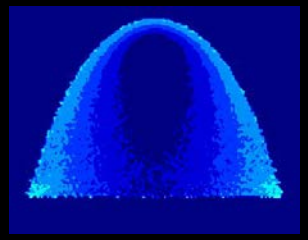
… plus theoretical modeling.



Hoffman+ 2008, 2009



Dessart & Hillier 2011



with DU grad student
Manisha Shrestha

The SNSPOL project

50+ supernovae of all types observed so far, most at multiple epochs.

Ia
SN 2011 fe (16)
SN 2012cg (11)
SN 2012ht (3)
SN 2013fw (1)
SN 2014ao (4)
SN 2014J (7)

Ib
SN 2012 au (19)
iPTF13bvn (3)

Ic
PTF12gzk (5)
SN 2012ej (8)
SN 2012fh (16)
SN 2013ff (7)
SN 2013ge (8)
SN 2014as (2)
SN 2014ad (7)
SN 2014L (10)

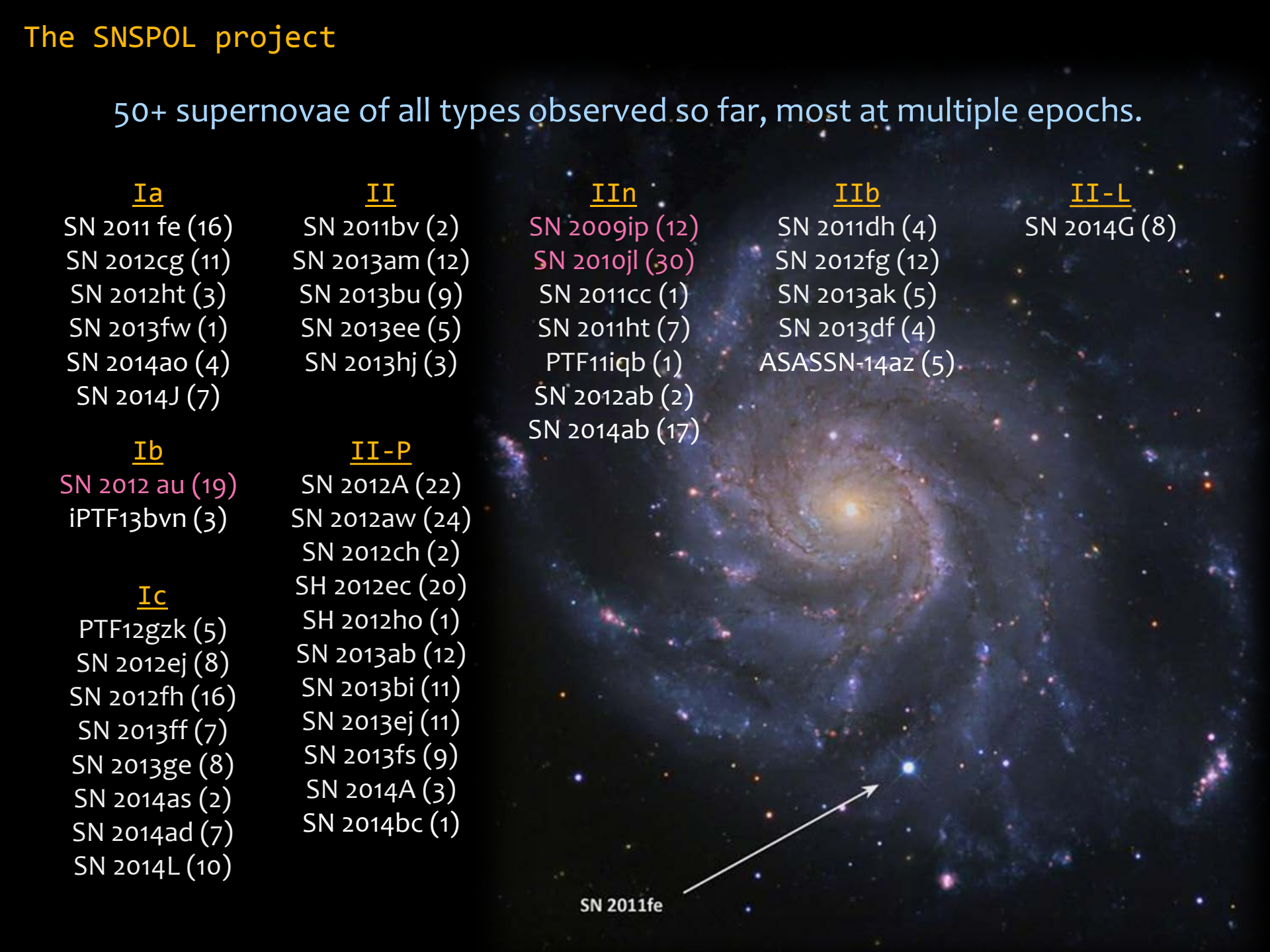
II
SN 2011bv (2)
SN 2013am (12)
SN 2013bu (9)
SN 2013ee (5)
SN 2013hj (3)

II-P
SN 2012A (22)
SN 2012aw (24)
SN 2012ch (2)
SH 2012ec (20)
SH 2012ho (1)
SN 2013ab (12)
SN 2013bi (11)
SN 2013ej (11)
SN 2013fs (9)
SN 2014A (3)
SN 2014bc (1)

IIn
SN 2009ip (12)
SN 2010jl (30)
SN 2011cc (1)
SN 2011ht (7)
PTF11iqb (1)
SN 2012ab (2)
SN 2014ab (17)

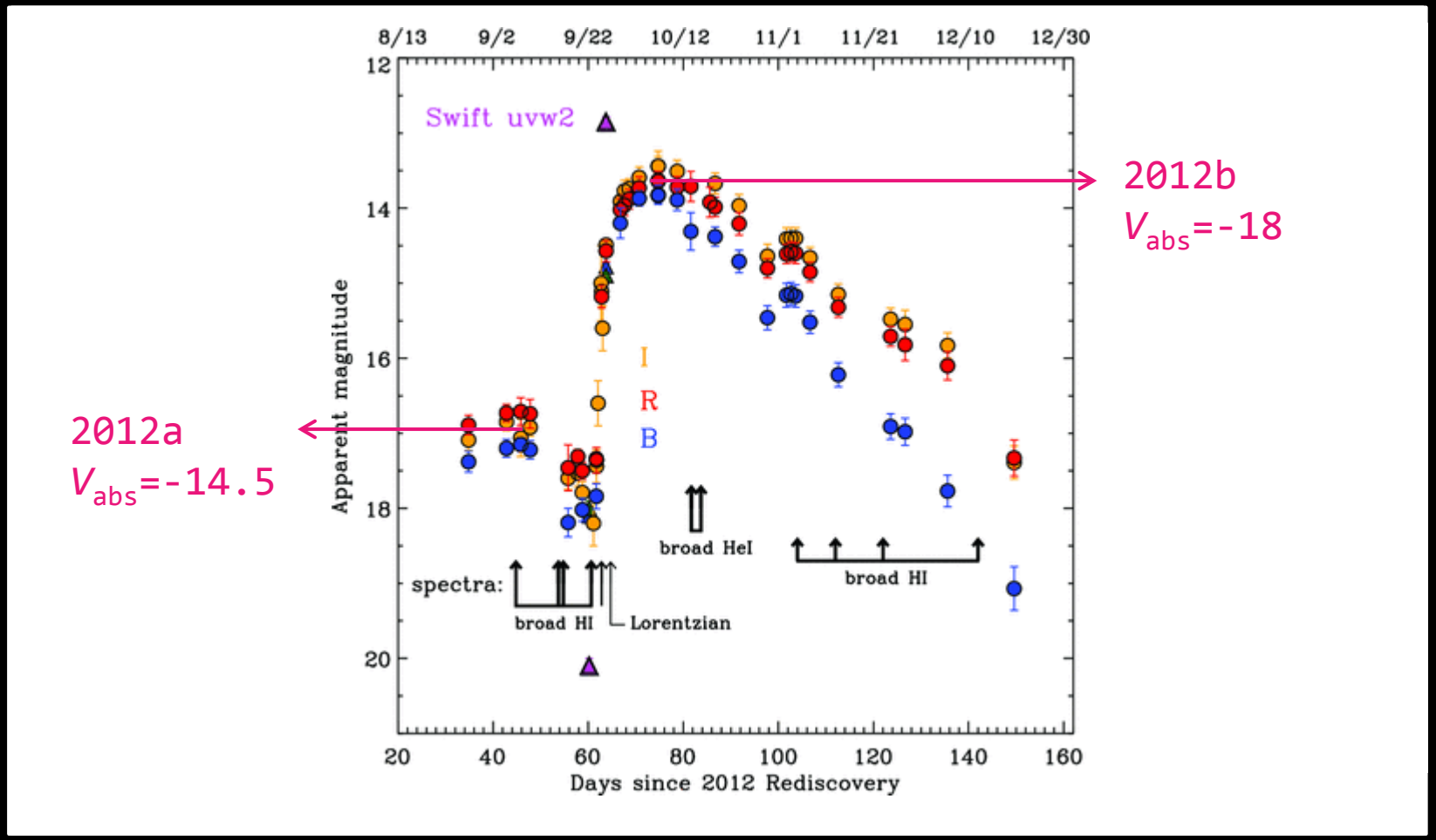
IIb
SN 2011dh (4)
SN 2012fg (12)
SN 2013ak (5)
SN 2013df (4)
ASASSN-14az (5)

II-L
SN 2014G (8)



SN 2009ip (LBV/IIn)

Mauerhan+ 2013



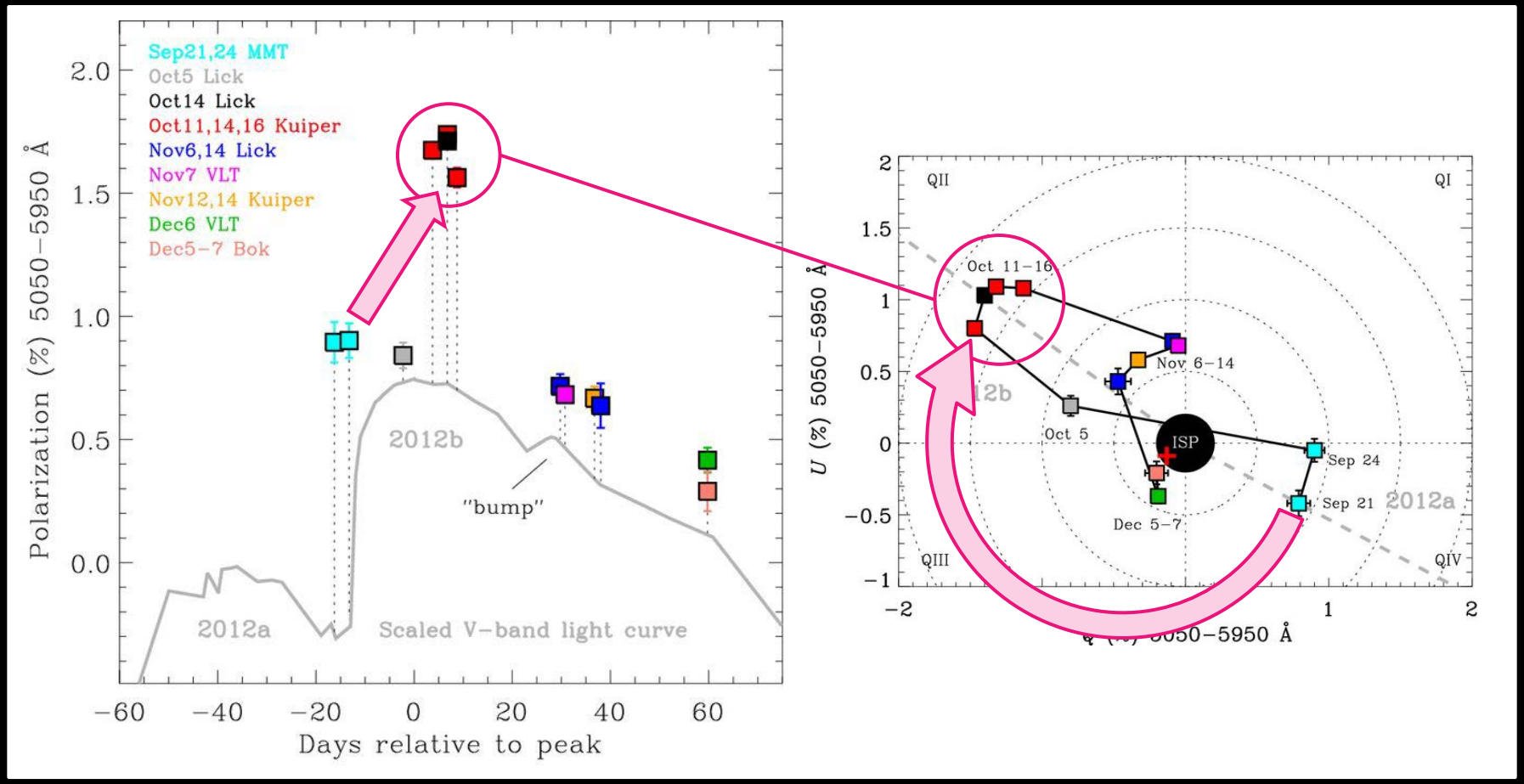
2012b
V_{abs}=-18

2012a
V_{abs}=-14.5

Multiple maxima over several years suggest pre-explosion LBV eruptions.
What caused the 2012a maximum?

SN 2009ip (LBV/IIn)

Mauerhan+ 2014

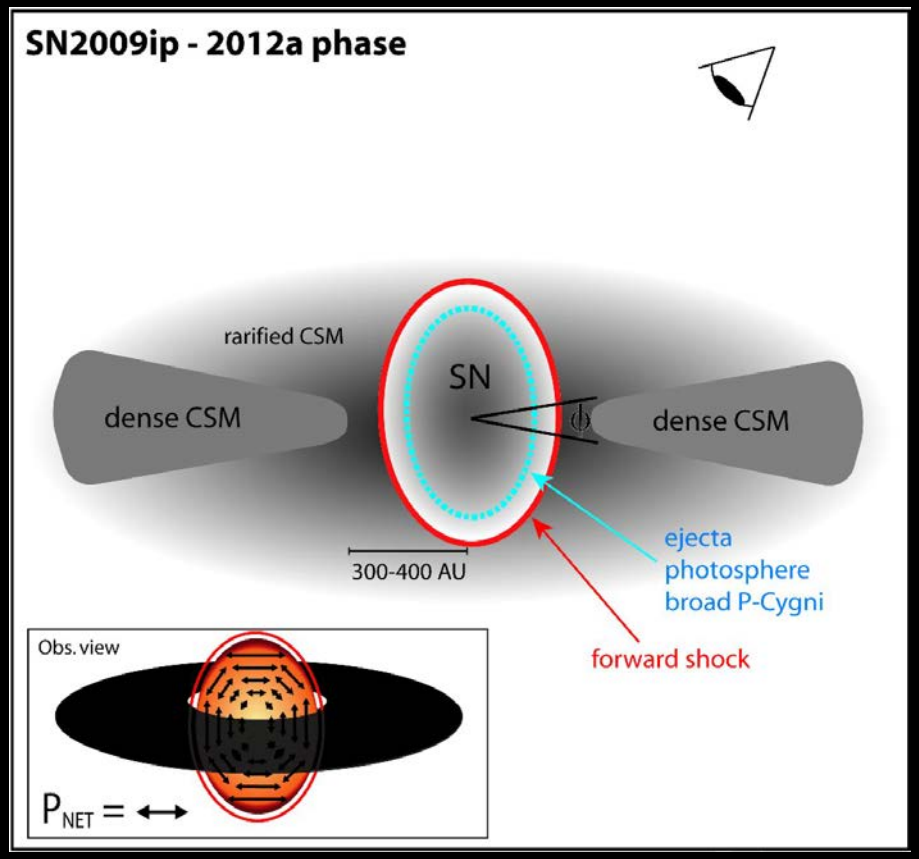


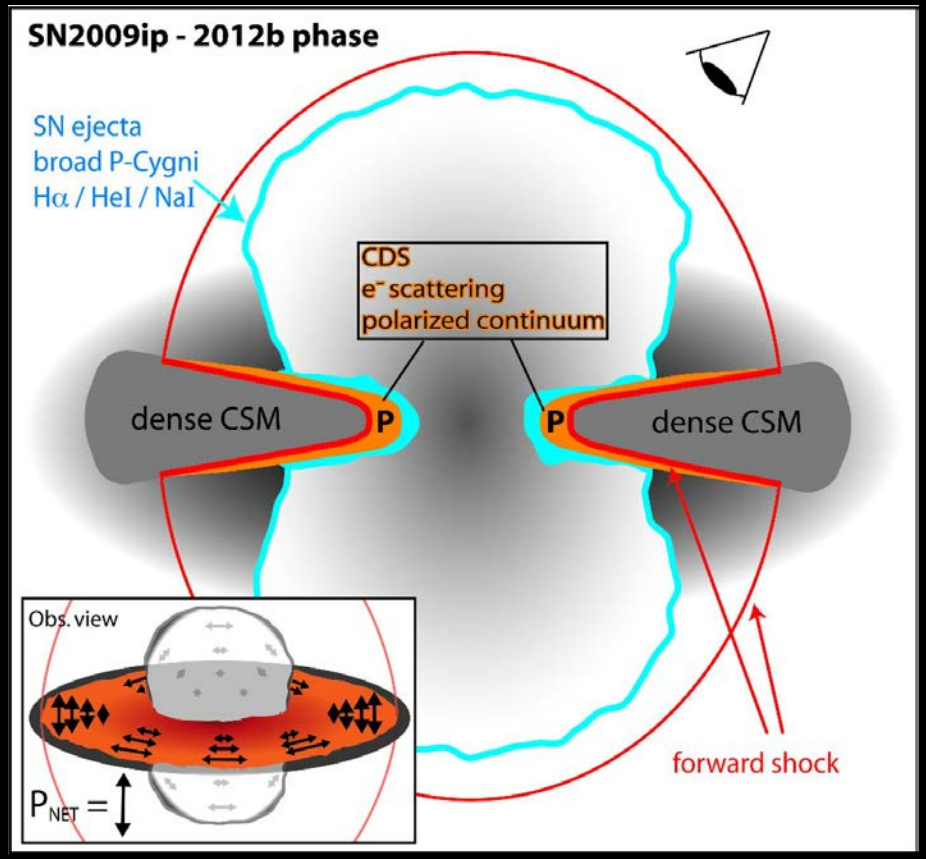
The 2 maxima were associated with distinct, orthogonal scattering regions. This suggests the 2 peaks are not due to successive shell ejections!

High %P at 2012b is typical of SNe IIn with CSM interaction.

SN 2009ip (LBV/IIn)

Mauerhan+ 2014

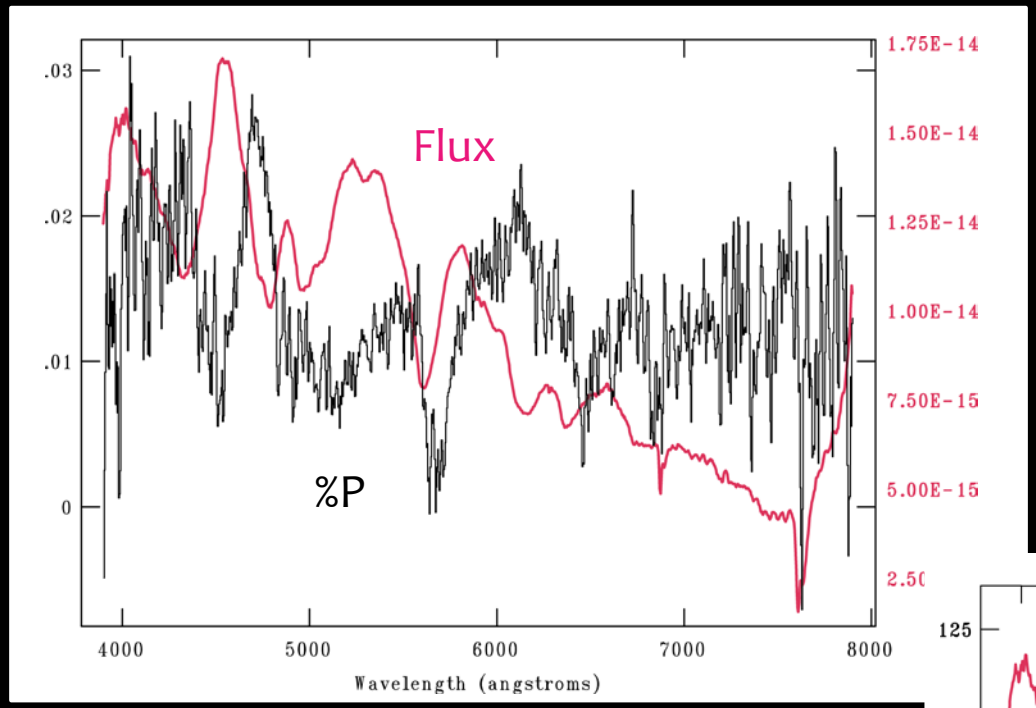




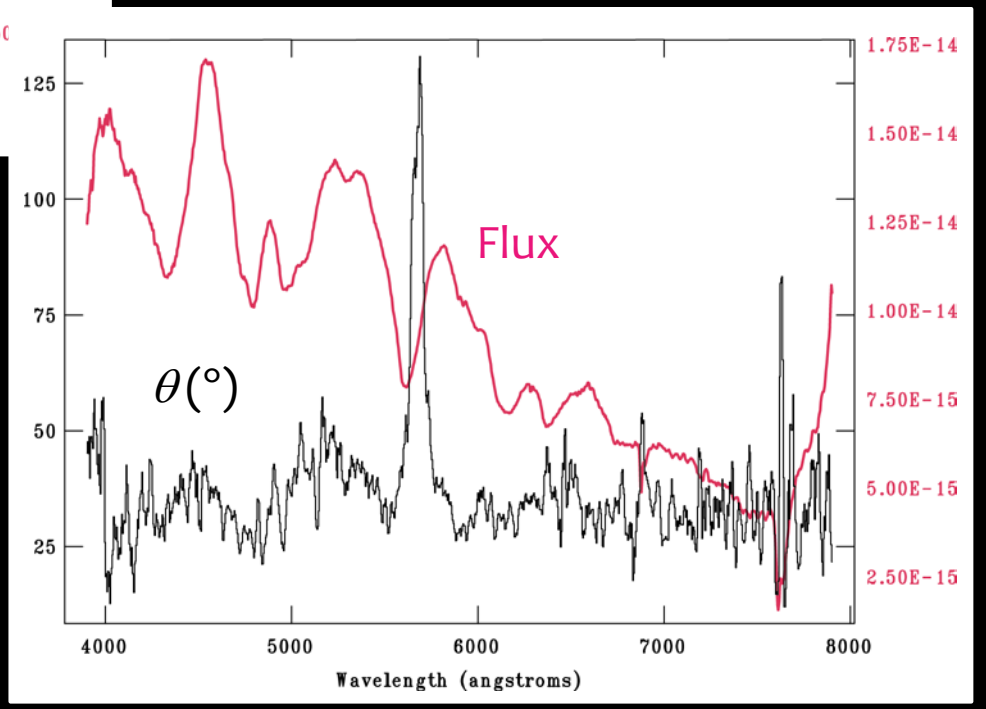
2012a peak: typical CCSN flux peak, polarization arises from ejecta asphericity (+ possible CSM obscuration).

2012b peak: flux AND polarization maxima arise from strong interaction with equatorial CSM orthogonal to the ejecta's axis.

SN 2012au (Ib)

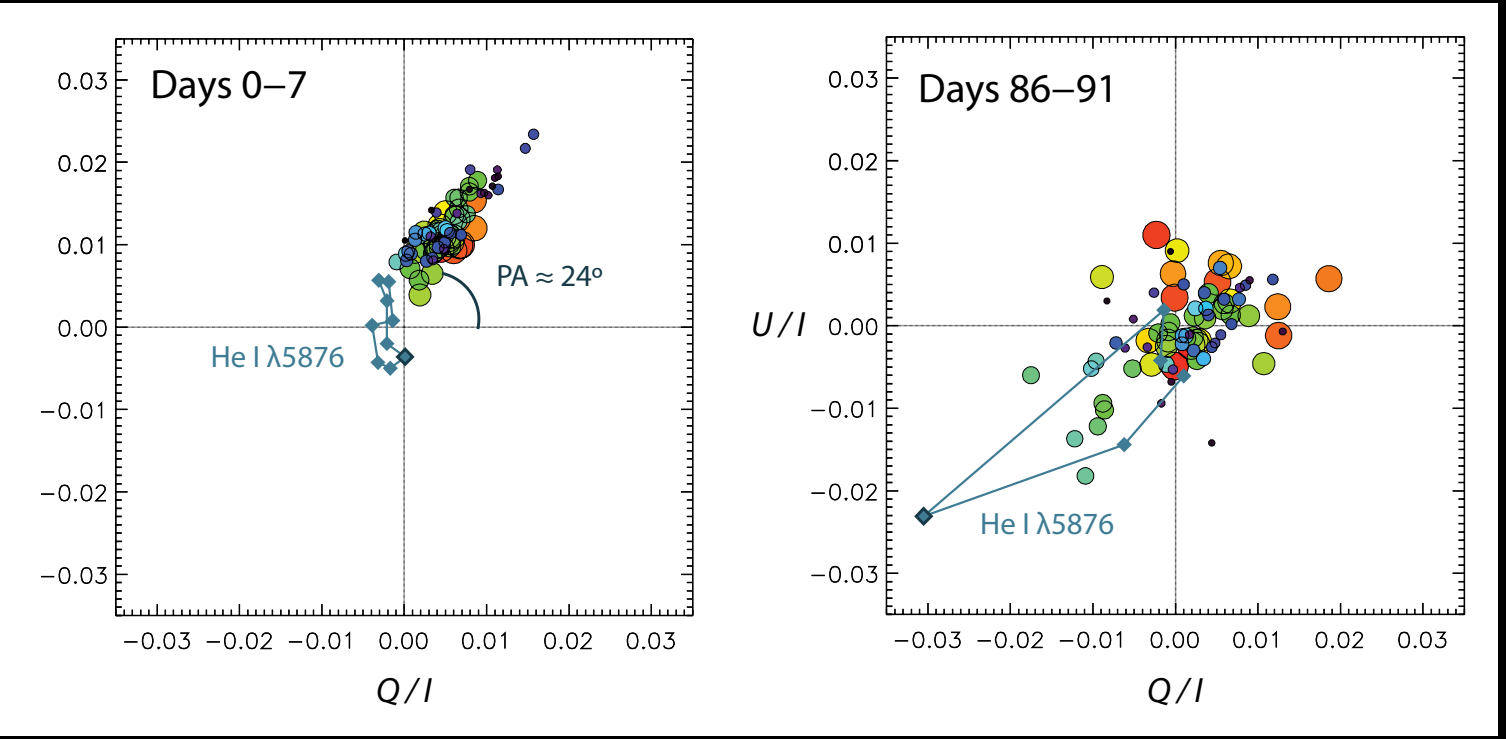


He I λ5876 shows strong, time-variable polarization, supporting previous hypotheses of an asymmetric explosion.

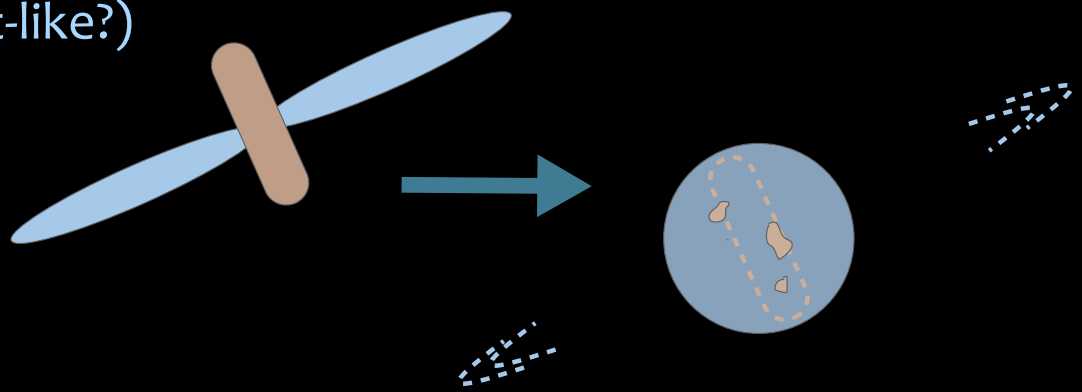


SN 2012au (Ib)

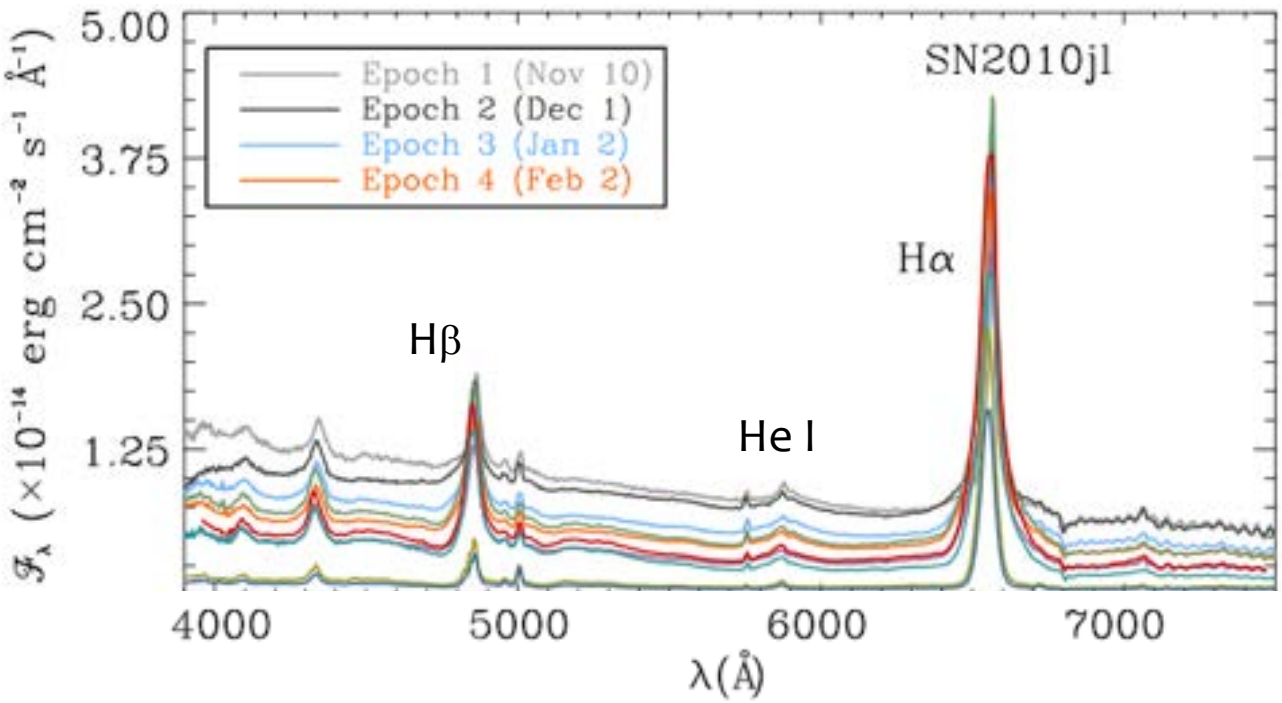
Hoffman+ 2014



Ejecta went from elongated (jet-like?) to ~spherical in first 90 days. Prominent He I line may trace an equatorial structure.

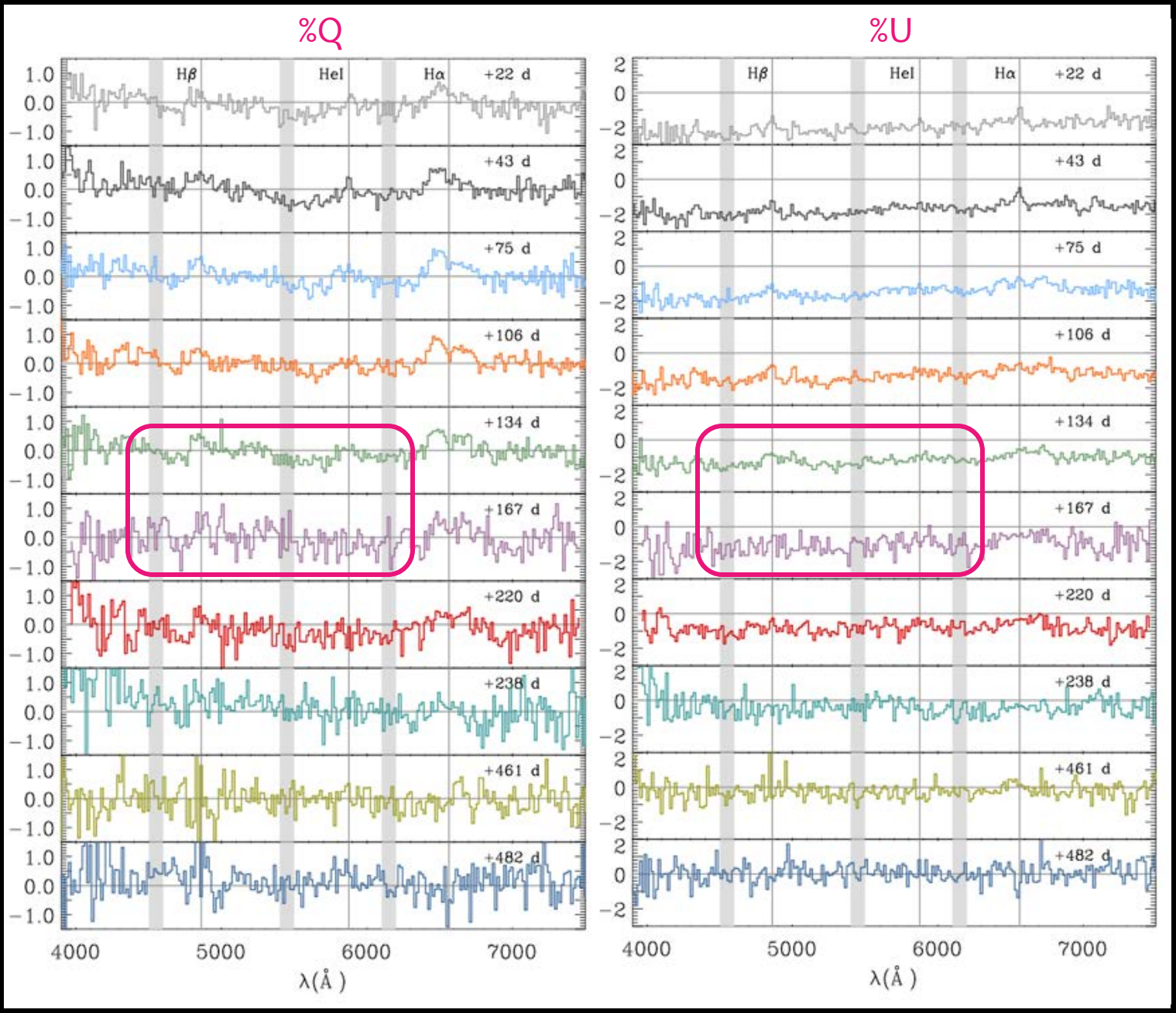


SN 2010jl (IIn)



H, He lines show different polarization behavior, allowing us to probe ejecta, CSM composition, illumination pattern.

SN 2010jl (IIn)



H, He lines show different polarization behavior, allowing us to probe ejecta, CSM composition, illumination pattern.

Where are we now?

- Community has realized the importance of spectropolarimetry in SN studies. SNSPOL is building a large database of these observations over time.

- SNSPOL data are yielding insights into the time-variable asymmetries of explosions, ejecta composition, and CSM.

- Photometric monitoring and ISP measurements give a complete picture of each SN observed.

SN 2002bo, Benetti+ 2004

What's next for polarized SNe?

SN 2004dj

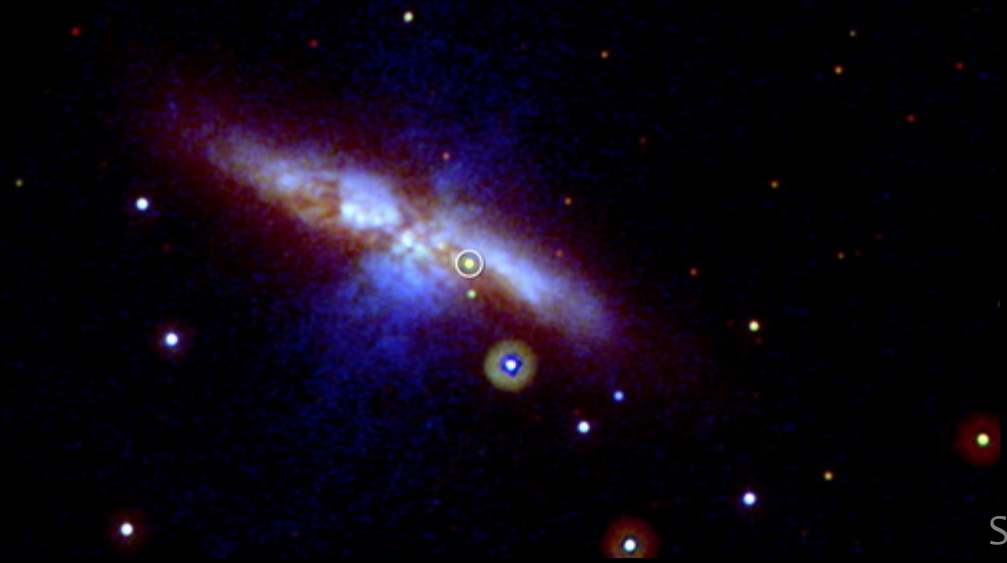
- Ongoing observations ⇒ better statistics: more SNe in each class, greater wavelength and time coverage
- Modeling of objects, object classes
- Classification: illuminate relationships between classes
- Late stellar evolution: identify SN/GRB progenitors. "Flash" spectropolarimetry?

ELT polarimetry will revolutionize all this!

Final thought:

Polarization represents an independent, unique dimension of information in the light we detect from astrophysical objects.

If we don't measure it, we are not taking full advantage of the light we work so hard to collect and analyze.



SN 2014J

New Views of Stellar Explosions: The Supernova Spectropolarimetry Project

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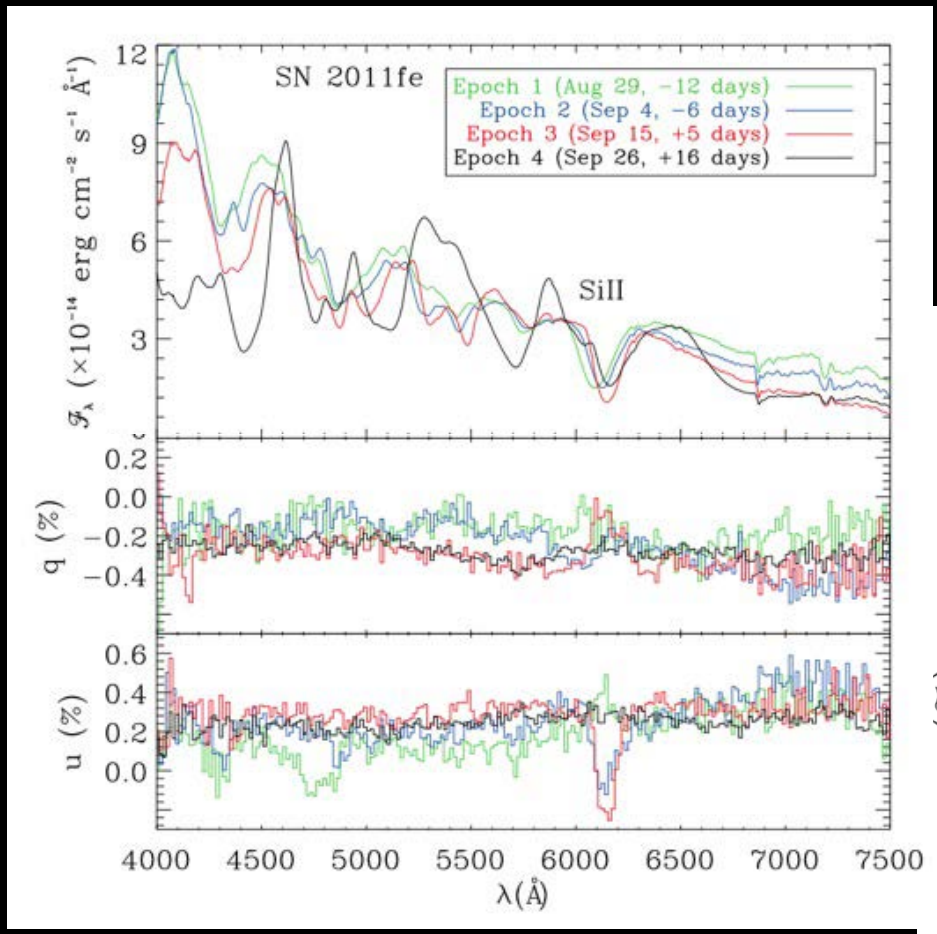
NSF AST-1210599

SN 1994D

SN 2011fe (Ia)



Dramatic changes across Si II line suggest clumpy ejecta or changes in illumination.