Sharp Polarimetric Eyes: More Trees than Forest?

(is optical polarimetry helping yet in our attempts to understand blazars?)

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Major collaborations:

- A. Marscher, S. Jorstad, V. Larionov, *et al*.

Outline:

- **Little-known "facts" about Prof. Alan Marscher**
- **Summary of the Fermi Gamma-ray Space Telescope/Steward Observatory blazar monitoring program**
- **Progress of the optical program to date**
- **Some of the contributions of polarization measurements to understanding blazars**
- **Where do we go from here (esp. *post* Fermi)?**

Fermi **Launch: June 11, 2008 @ 12:05 EDT**

The *Fermi* Mission:

- Nearly a full 8 years of *continuously* monitoring the entire sky in the 20 MeV – >300 GeV energy range with the *LAT*.
- The dominant γ-ray sources are blazars and several dozen are bright enough to measure their high-energy fluxes on daily time scales.
- Almost all of the multi-wavelength efforts on blazars have been anchored by *Fermi* during its mission (how can one pass up this opportunity?).
- The *Fermi* Guest Investigator Program concentrates on:
  - Theoretical investigations
  - Algorithm development for the analysis of Fermi data
  - *Observations at other wavelengths to complement the high-energy data.*

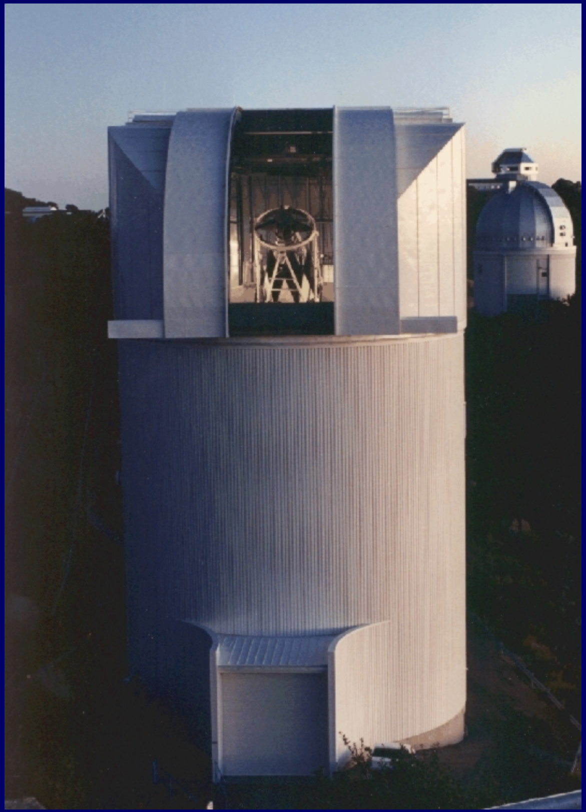
The Optical Monitoring Program at Steward Observatory:

- **To provide the *Fermi* project with a public, systematic, & accurate spectropolarimetric & spectrophotometric monitoring program that nearly *completely* characterizes the optical emission from γ-ray-bright blazars that Fermi can detect within one or a few days.**

- **Since γ-ray variability is seen on short time scales, the optical monitoring is nightly. For blazars showing significant γ-ray activity, multiple optical measurements are made during the night if possible.**

- **~Week-long observing campaigns are scheduled every month (excluding August) to keep track of the longer-term trends of the target sample. The monthly time scale is also fairly well matched to the large VLBI monitoring programs supporting *Fermi*.**

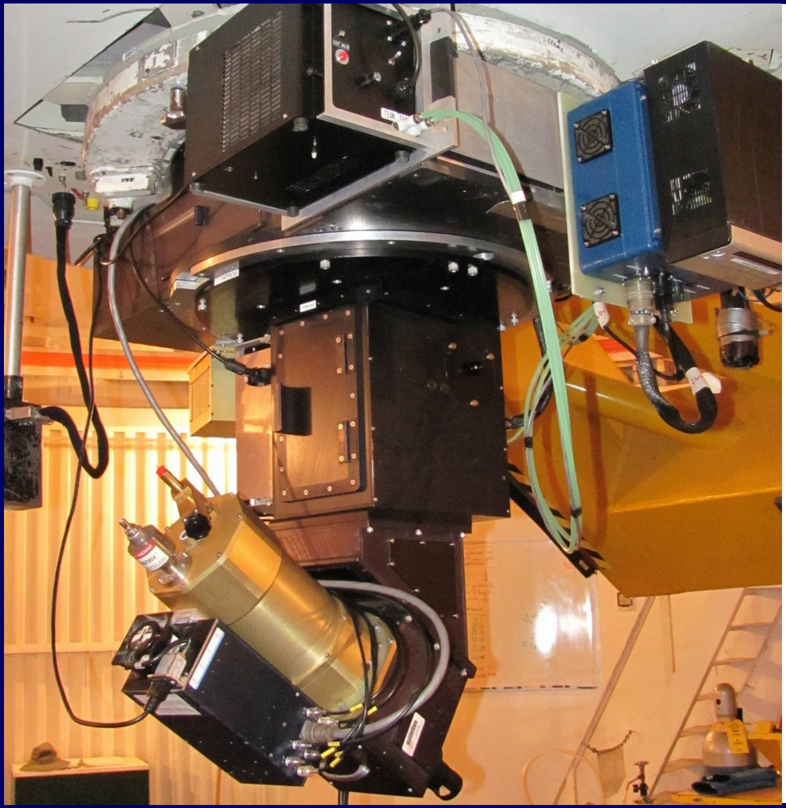
Telescopes used for the optical monitoring program:

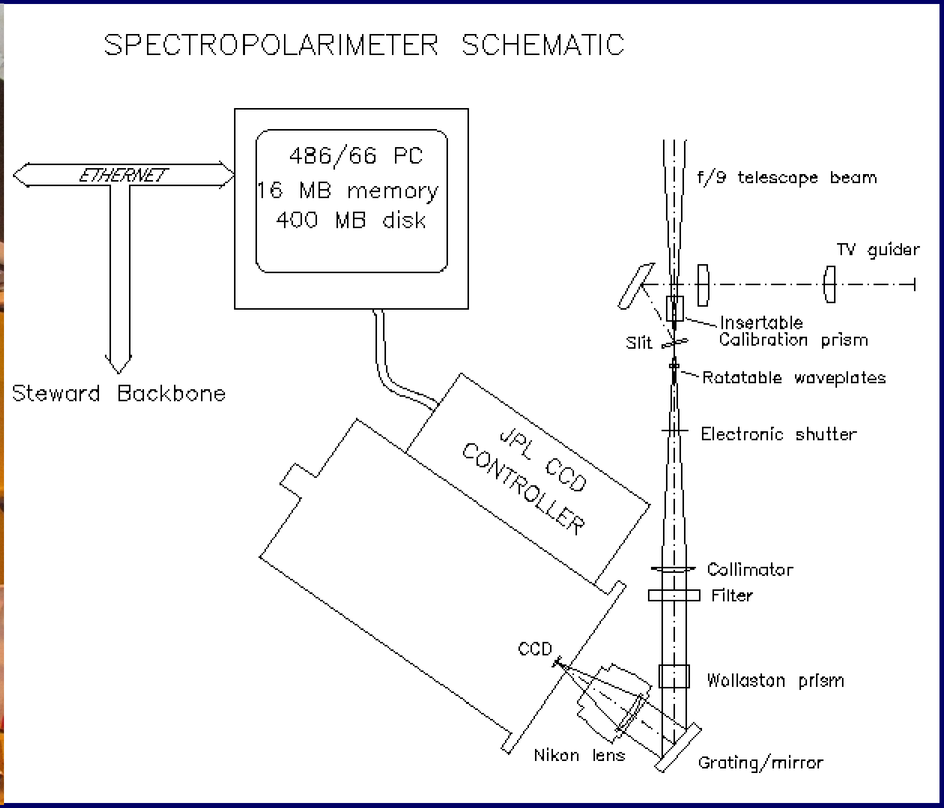


Bok 2.3m Telescope on Kitt Peak, AZ (elev.=2071m)

Kuiper 1.54m Telescope on Mt. Bigelow, AZ (elev.=2510m)

SPOL CCD Spectropolarimeter:





Dual-beam polarimetry by G. D. Schmidt and H. S. Stockman (telescope+instrument total throughput ~ 30%; very low (<0.05%) instrumental polarization; first light in 1991)

Examples of individual observations with SPOL:

Blue spectra:

• 320 s total exposure time (*R* ~ 13.0) at 1.54m Kuiper telescope; *P* = 2%

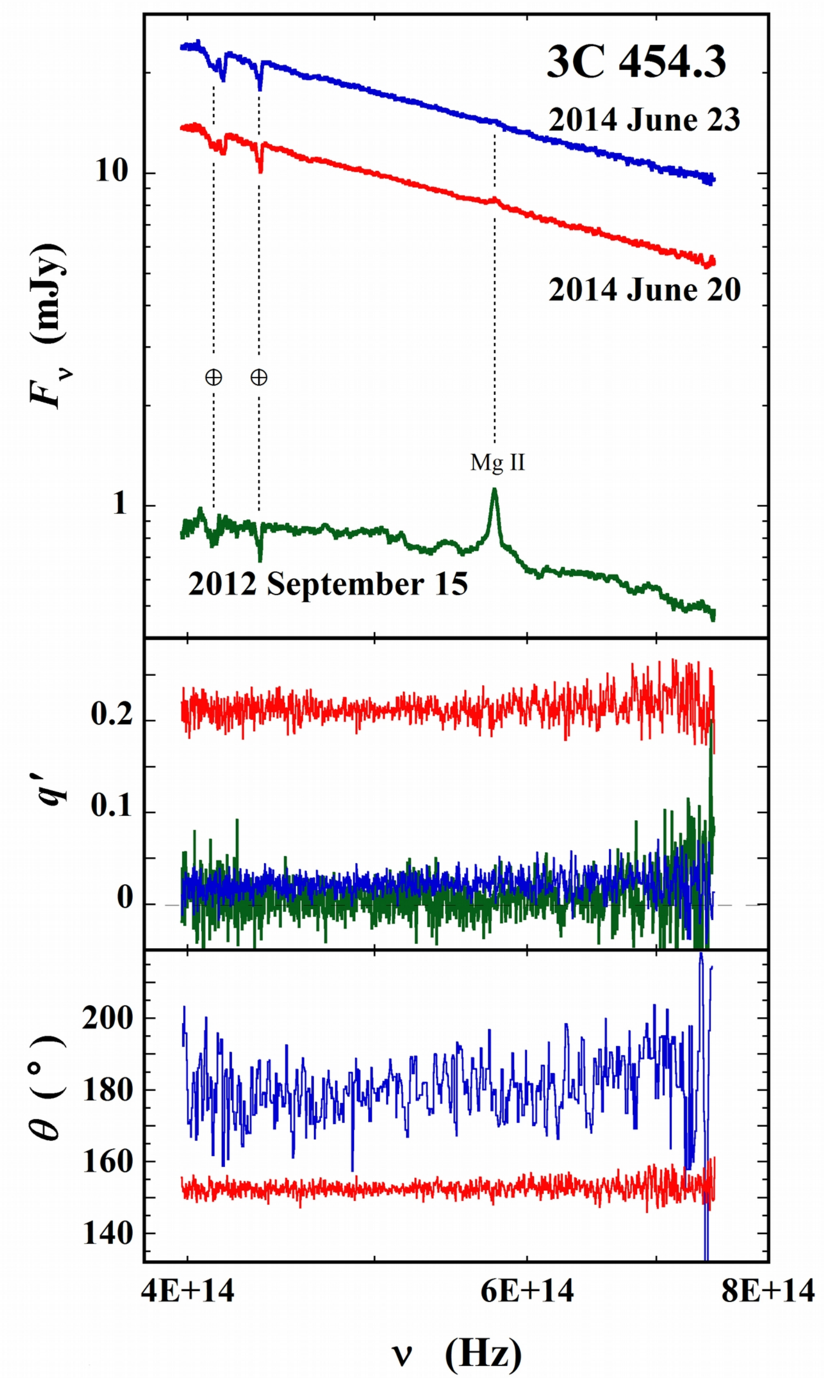
Red spectra:

• 480 s total exposure time at Kuiper telescope (*R* ~ 13.6); *P* = 21%

Green spectra:

• 1440 s total exposure time at 2.3m Bok telescope (*R* ~ 16.3); *P* ~ 0.6%

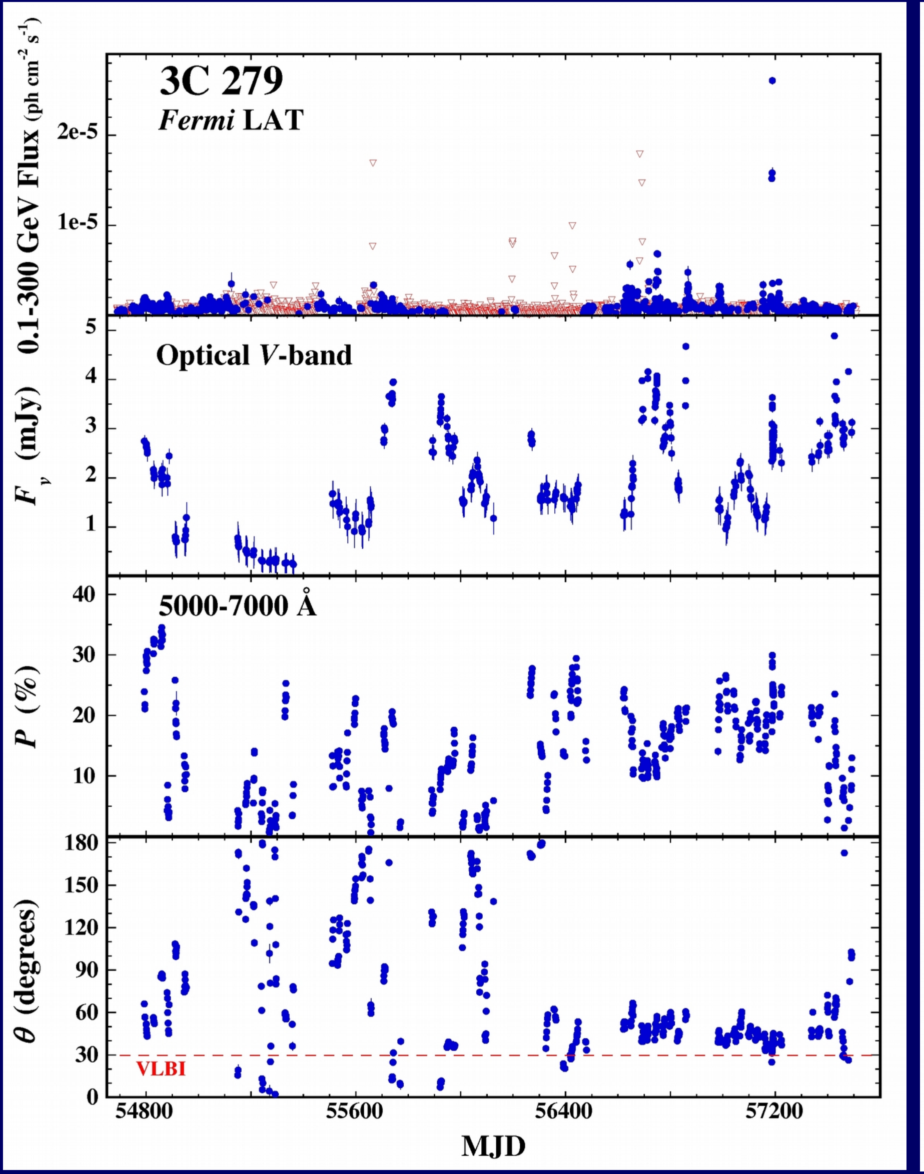
σ(*P*) < 0.1% if data binned by 2000 Å (5000-7000 Å).

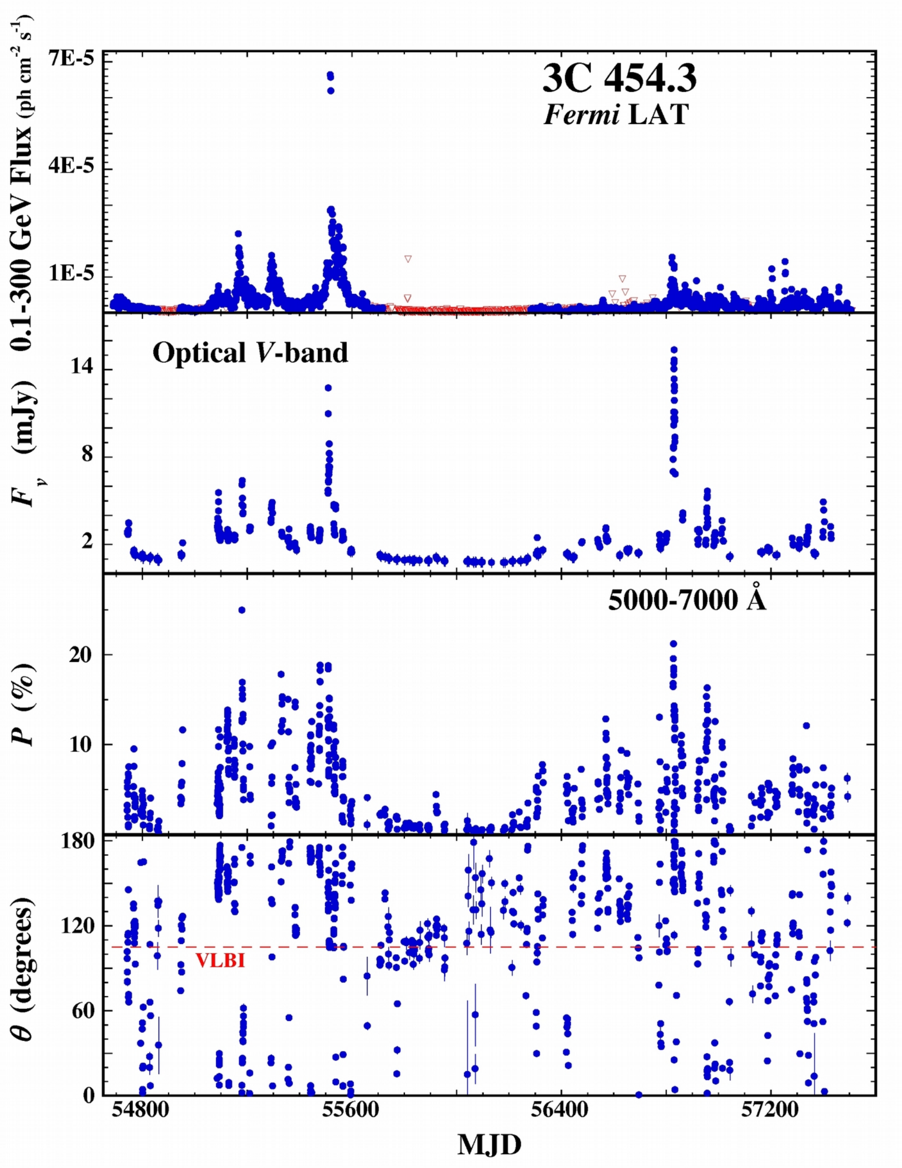


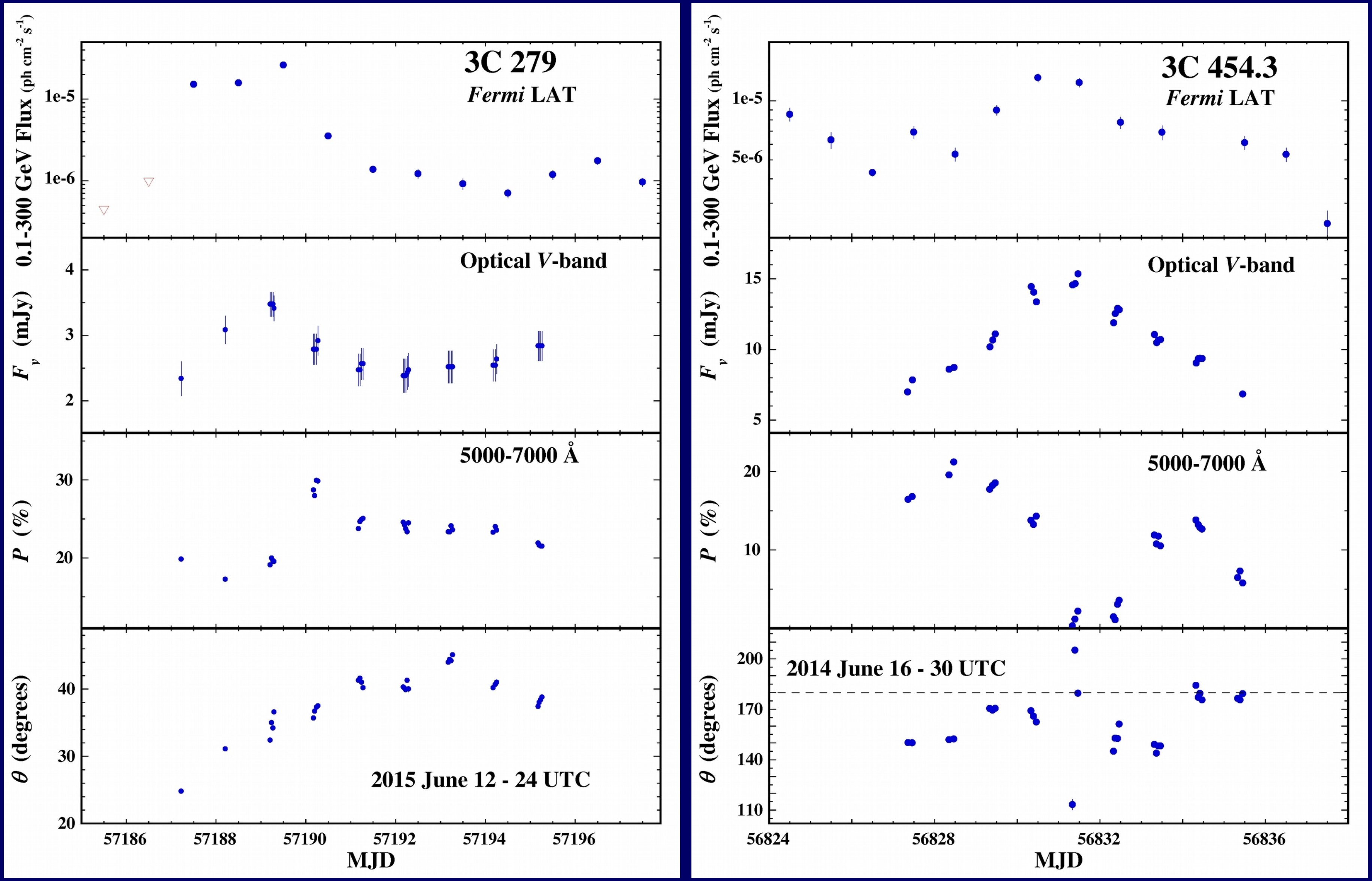
Current Status of the Program:

- 83 monthly optical campaigns completed since 2008 October
- Have obtained data on 638 nights
  - 319 nights with the Bok 2.3m Telescope
  - 307 nights with the Kuiper 1.54m Telescope
  - 12 nights with the 6.5m MMT

- Now have 9729 polarization measurements, Stokes & flux spectra
  - Spectra span 4000–7550 Å; $\lambda/\Delta\lambda \sim 350$
- 7784 differential *V* and *R*-band photometry measurements
- Data are public at http://james.as.arizona.edu/~psmith/Fermi


3C 279
Fermi LAT
0.1-300 GeV Flux (ph cm-2 s-1)
Optical V-band
Fν (mJy)
5000-7000 Å
P (%)
θ (degrees)
VLBI
MJD

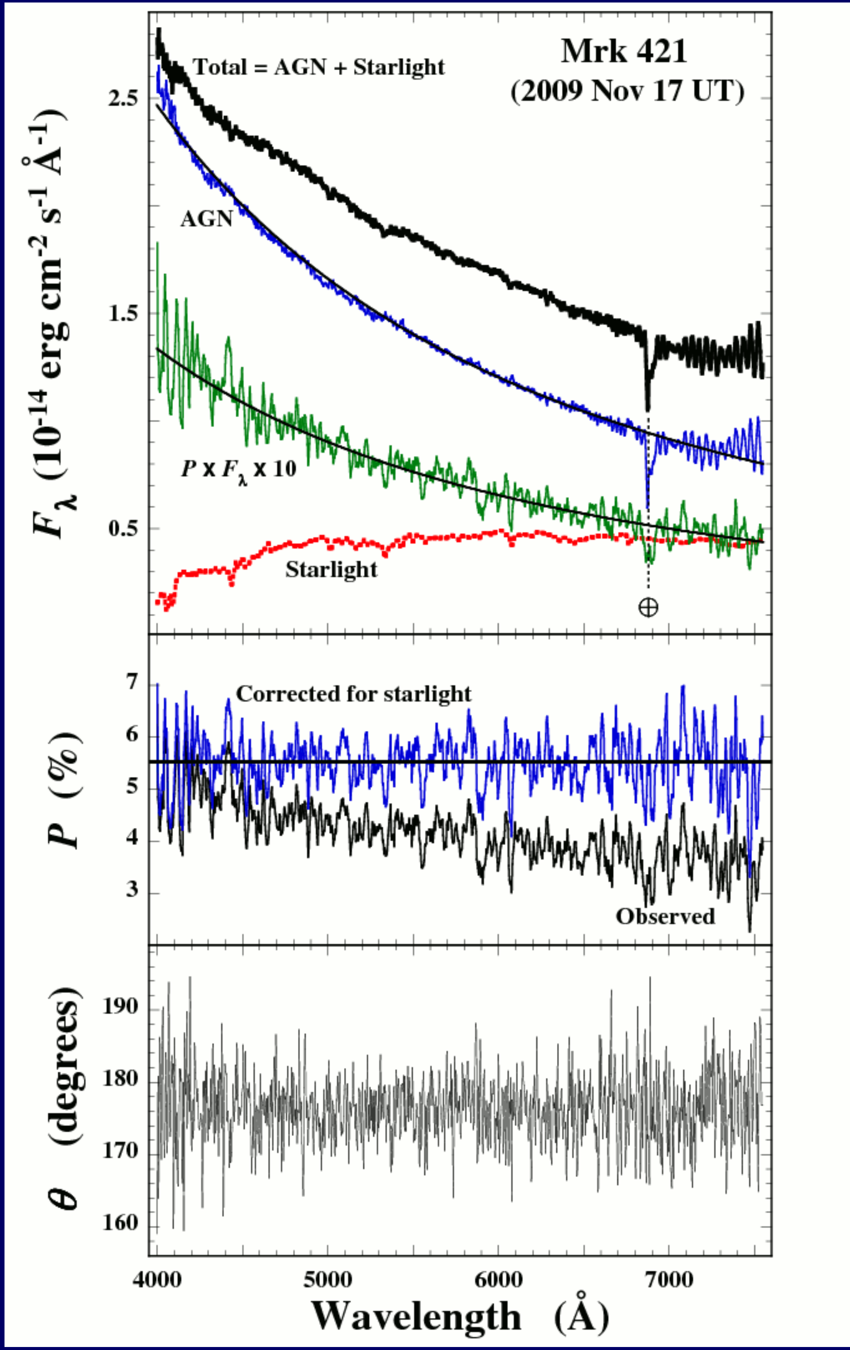

3C 454.3
Fermi LAT
0.1-300 GeV Flux (ph cm-2 s-1)
Optical V-band
Fν (mJy)
5000-7000 Å
P (%)
θ (degrees)
VLBI
MJD


3C 279
Fermi LAT
0.1-300 GeV Flux (ph cm-2 s-1)
Optical V-band
Fν (mJy)
5000-7000 Å
P (%)
θ (degrees)
2015 June 12 - 24 UTC
MJD
3C 454.3
Fermi LAT
0.1-300 GeV Flux (ph cm-2 s-1)
Optical V-band
Fν (mJy)
5000-7000 Å
P (%)
2014 June 16 - 30 UTC
θ (degrees)
MJD

A strength of the optical data set:

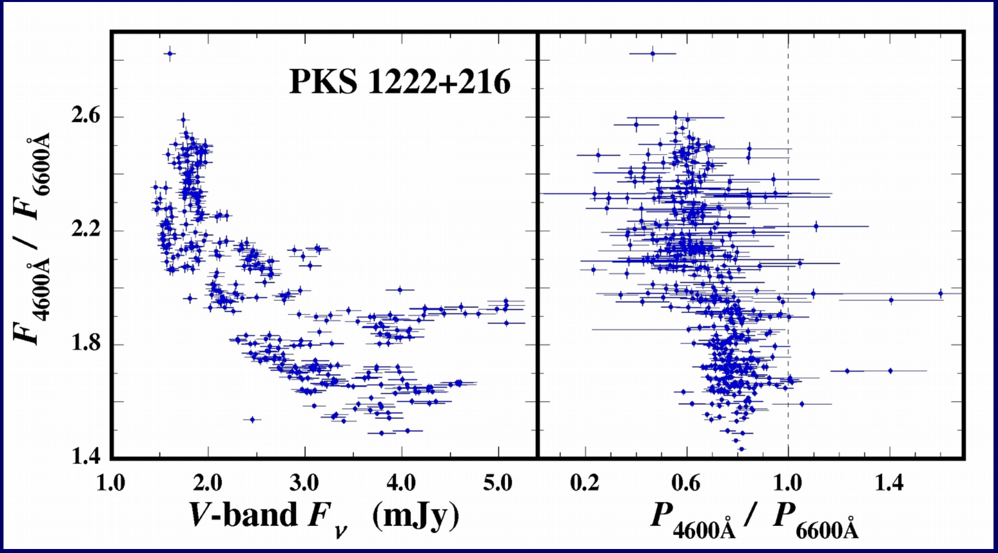
The full spectroscopic and spectropolarimetric information can be used to isolate emission sources not directly associated with the AGN jet.

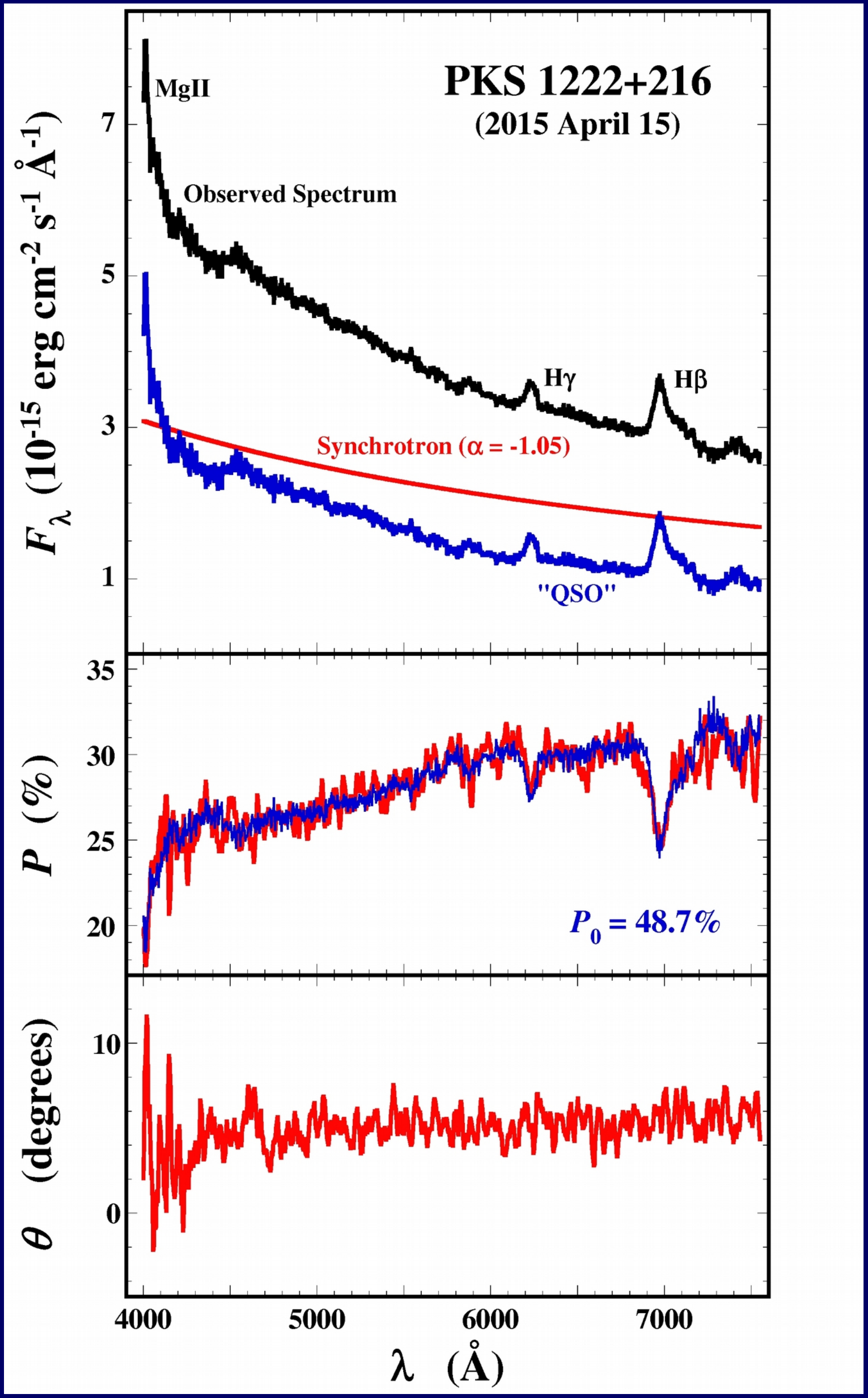
- **Example:**
  - **The amount of host galaxy starlight included in the observing aperture can be separated from the power-law continuum of the AGN *with confidence*, since $P \times F_\lambda$ is independent of any unpolarized source of flux.**



Another example: Blazars and the Big Blue Bump

- For several strong emission-line objects, spectropolarimery can help disentangle the jet emission from isotropic emission components and explain observed correlations between optical flux, color, and polarization.
- Spectra have been used to determine if the emission-line fluxes vary.

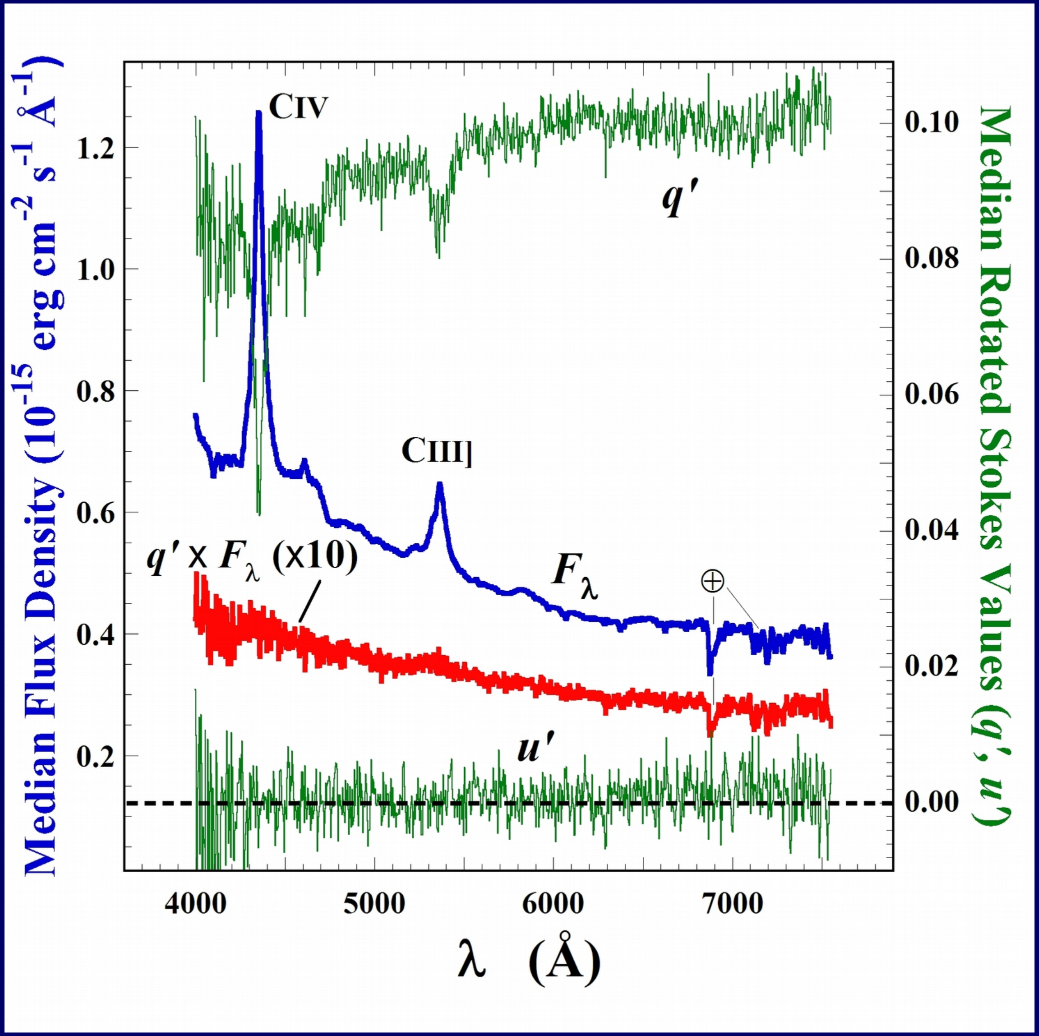




B2 1633+382 (4C 38.41; Raiteri *et al*. 2012)

- The dilution of the polarization into the UV has been traced for objects up to $z = 1.81$.

- The observations are consistent with a picture of the optical-UV emission from blazars with strong emission lines coming from a combination of polarized synchrotron light and a "normal" (unpolarized) QSO.

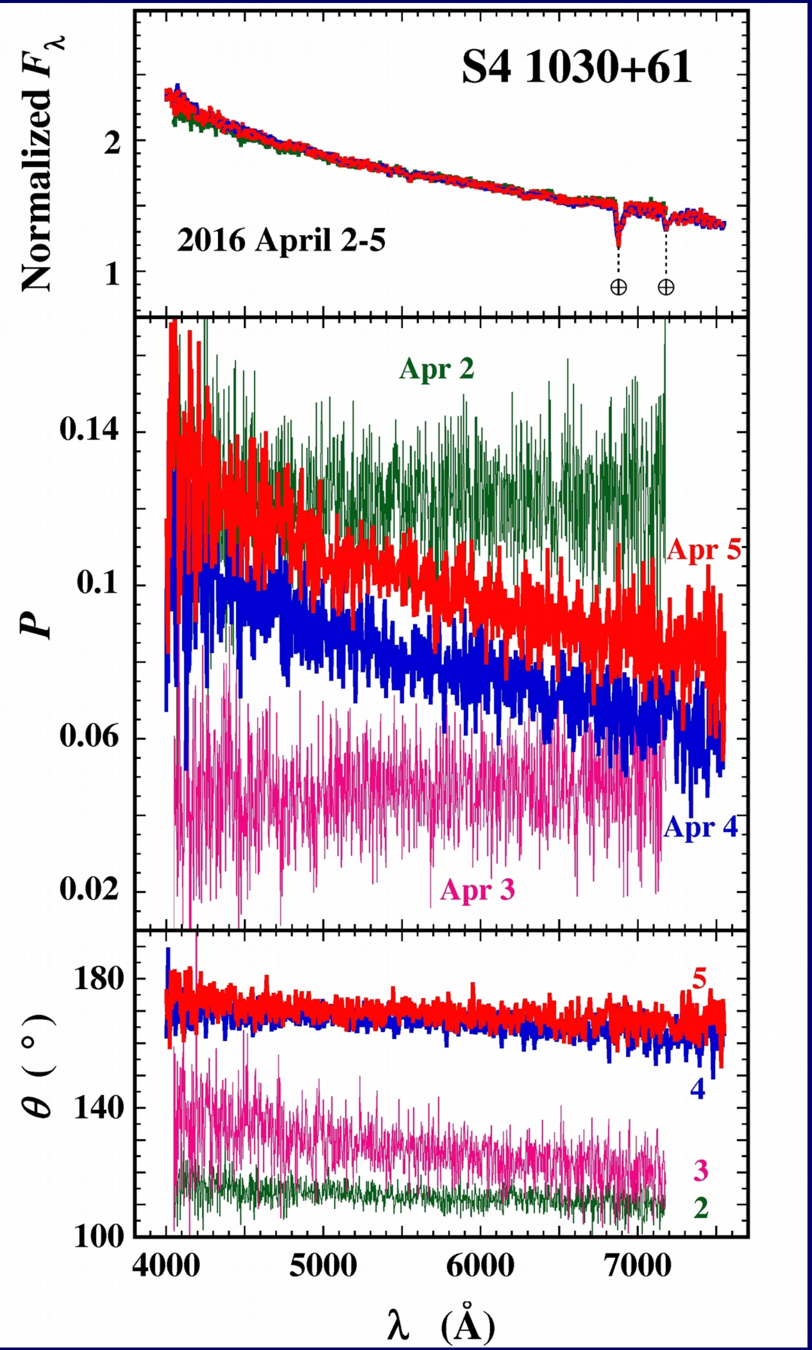


Episodes of Variable λ-dependent Polarization:

- **Although relatively rare, these events give insights into the evolution of the synchrotron emission region that the flux spectrum and its variations do not.**

- **This recent example from S4 1030+61 shows that dramatic, daily changes can occur in the polarization spectrum without any change in the shape of the non-thermal flux spectrum.**

- **We are a long way from folding this kind of information into sensible emission and structural models of blazars.** ***--more trees!***



Cautions:

- **Don't forget the bias in *P* (see, e.g., Wardle & Kronberg 1974, ApJ, 194, 249)**
- **Don't put disks into your favorite SED models of BL Lac objects if the polarization "signatures" of such components could be easily detected. *They aren't!***

Where to go from here?

- **Contemporaneous HE polarization measurements would be great.**
- **What should observationally be done after *Fermi*?**
  - **Intensive effort should continue during *Fermi* era.**
  - **All data on γ-ray-bright blazars should be made public *quickly*.**