The Optical Properties of PKS 1222+216 During the *Fermi* Mission

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Summary:

The optical properties of the z = 0.435 quasar PKS1222+216 (4C+21.35) are summarized since the discovery by Fermi/LAT of increased γ-ray activity in this source[1]. Unlike several other γ-ray-bright blazars, there appears to be little connection between optical and γ-ray activity. Spectropolarimetry shows this object to be a composite system with optical emission from both a polarized, variable synchrotron power-law and unpolarized light from a blue continuum source (+broad emission-line region) contributing to the observed spectrum.

Optical and γ-ray Variability:

Since the announcement by the Fermi project on 2009 Apr 17[1] of increased γ-ray emission from PKS 1222+216, it has been intensively monitored as part of the Steward Observatory program[2] supporting Fermi using the 2.3m Bok and 1.54m Kuiper telescopes and the SPOL Spectropolarimeter.

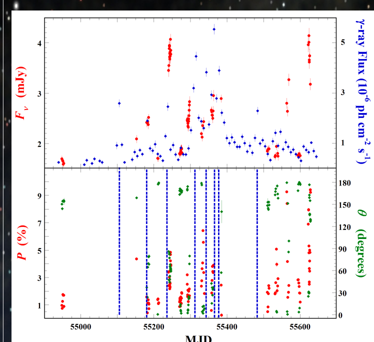

Figure 1. *Top panel*: The γ-ray (blue) and optical (red; from 2009 Apr 27 – 2011 Mar 8) flux variations of PKS 1222+216. Weekly LAT averages are shown for the γ-ray light curve. *Bottom panel*: Optical polarization variations, with the degree of polarization, P, shown in red and the polarization position angle, θ, in green. The dotted vertical lines denote the occurrence of eight distinct γ-ray outbursts. The major optical outburst during 2011 Mar (MJD ~ 55625) has no apparent γ-ray analog.

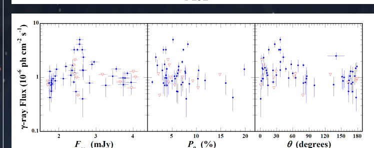

Figure 2. Simultaneous γ-ray and optical measurements. No clear trend is observed between γ-ray flux and either optical flux or polarization. Upper limits for single-day LAT fluxes are shown as red triangles.

In both spectral regimes, the variability of PKS 1222+216 is characterized by numerous short-duration flares. For instance, the 0.1-300 GeV light curve shows at least 8 outbursts, each lasting just a few days at most. Similarly, large daily fluctuations in both the optical flux and polarization are observed. Interestingly, the optical and γ-ray activity do *not* show a direct correspondence, unlike several other well-studied blazars where the site(s) of γ-ray production can be directly tied to those producing the bulk of the optical and radio flux[3][4][5]. In fact, a very recent optical outburst in 2011 March has apparently occurred without any corresponding γ-ray activity. The majority of measurements show θ to be within 30° of north, more-or-less aligned with both the PAs of the VLBI jet[6][7] and the polarized flux of the millimeter core[7].

Emission Lines:

The optical spectrum of the object exhibits strong, broad MgII and Balmer emission lines. Narrow-line emission is weak relative to the broad lines in this quasar.

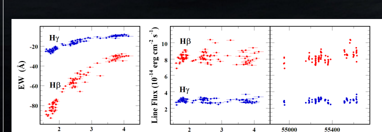

Figure 3. Measurements of the equivalent width (EW) and flux of the Hβ and Hγ emission lines. The line fluxes stay relatively constant with time and continuum brightness over the ~2-yr period. As a result, the EWs are closely tied to variations of the optical continuum.

As expected, the emission from the broad-line region does not vary in the extremely short time scales observed for the continuum and was stable over nearly 2 years.

Optical Continuum and Polarization:

A strong correlation is found between optical brightness and color. As PKS 1222+216 brightens, the continuum becomes redder. In addition, the polarization is almost always observed to decrease toward the blue regardless of the level of polarization observed (P_{obs}<1-10%). The polarized flux spectrum ($P \times F_\nu$) is well represented by a power-law with α ~ -1.3, where α = (d log F_ν)/(d log ν).

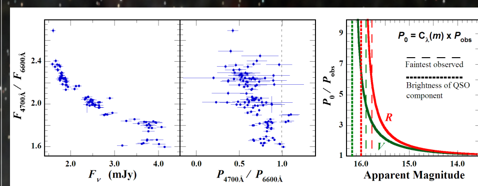

Figure 4. *Left panel*: The flux density ratio between 4700Å and 6600Å plotted against the *V*-band brightness. The object becomes redder as it brightens. *Center Panel*: The same quantity plotted against the ratio of polarization at the same wavelengths. As the object fades, the polarization decreases more strongly to the blue. *Right Panel*: The correction to the observed broad-band polarization as a function of apparent magnitude, assuming a constant source of light that dilutes the polarized flux (P_0×F) from a power-law continuum.

The polarization properties and the correlation between brightness and optical color lead directly to a picture that has the optical emission coming from two sources: (1) a variable, polarized synchrotron continuum that is produced by the relativistic jet, and (2) a much more stable (at least on the time scale of a year or more), unpolarized source with a spectrum similar to an optically-selected QSO.

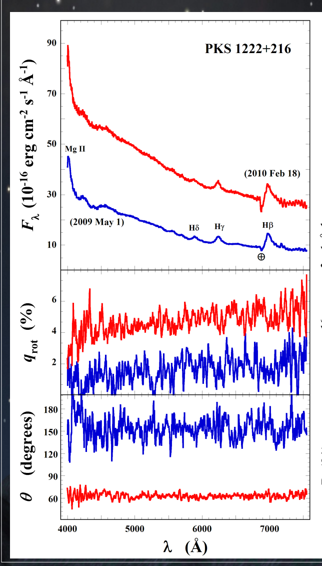

Figure 5. Spectropolarimetry when the blazar was bright (red) and faint (blue). *Top panel*: The spectrum with major emission lines identified. The atmospheric O_2 feature in the blue wing of Hβ is also marked. *Middle panel*: The q Stokes parameter rotated so that u averages to 0 over the spectrum. Notice the decrease in polarization to the blue. *Bottom panel*: The spectrum of θ, which is generally observed to be constant with wavelength, as expected if the polarized emission is dominated by a single component.

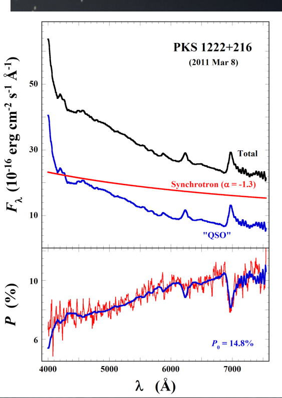

Figure 6. PKS 1222+216 on 2011 Mar 8. *Top panel*: The optical spectrum is modeled with a polarized (P_0 = 14.8%), power-law synchrotron spectrum and an unpolarized continuum+broad emission-line spectrum similar to a typical optically-selected QSO. *Bottom panel*: The effect of the dilution of the nonthermal polarized flux by the bluer QSO component. The model is shown by the blue curve and the observed data indicated in red. Such a picture explains both the decrease in P toward shorter wavelengths and the observed correlation between optical color and flux.

Summary and Conclusions:

PKS 1222+216 is an important object for continued intensive study across the entire electromagnetic spectrum. Although direct connections can be made between the optical and radio emission owing to the rough alignment of the polarization position angles and the PA of the inner VLBI jet, there are significant differences between the behavior of this quasar relative to other γ-ray-bright blazars at optical and GeV energies. In particular, major optical or γ-ray events can occur with no obvious corresponding activity in the other energy regime. The importance of PKS 1222+216 to the questions of the how and where high-energy photons are produced in blazars is underlined by the recent discovery of TeV emission from this source[8]. Continued optical spectropolarimetry enables not only efficient monitoring of the high-energy tail of the primary relativistic electrons and the magnetic field within the jet, but also the "normal QSO" emission, which provides valuable information on the accretion processes that presumably give rise to the jet.

•Fully reduced optical spectropolarimetry and photometry of PKS 1222+216 and ~40 other blazars are available at: http://james.as.arizona.edu/~psmith/Fermi.

•The Steward Observatory blazar monitoring program supporting the Fermi Gamma-ray Space Telescope is funded by Fermi GI grants NNX09AW56G and NNX09AU10G.

See the accompanying sheet for the list of references cited in this poster.