# Microvariability of bright blazars – probes from optical polarization and color variability

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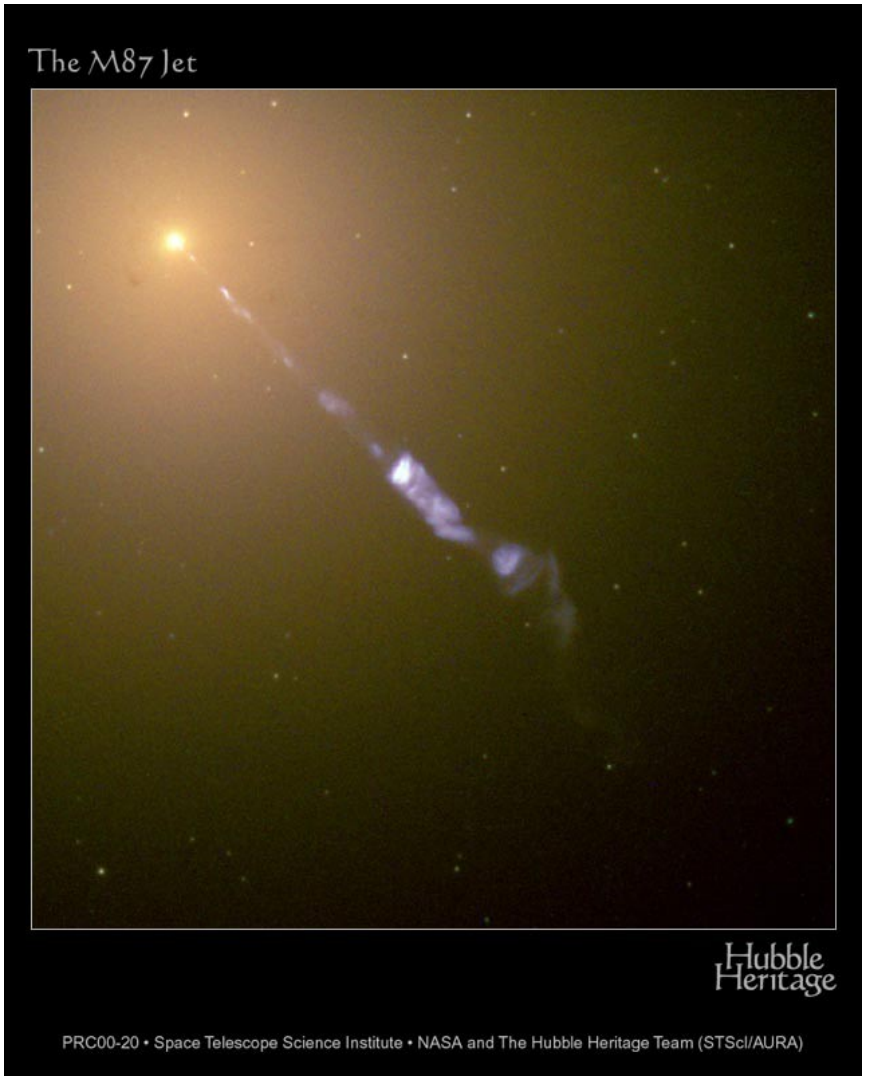
# AGNs in Universe




"Twinkle, twinkle, quasi-star
Biggest puzzle from afar
How unlike the other ones
Brighter than a billion suns
(…)"

– George Gamow (May 1964)

Mrk 421

**Blazars**:

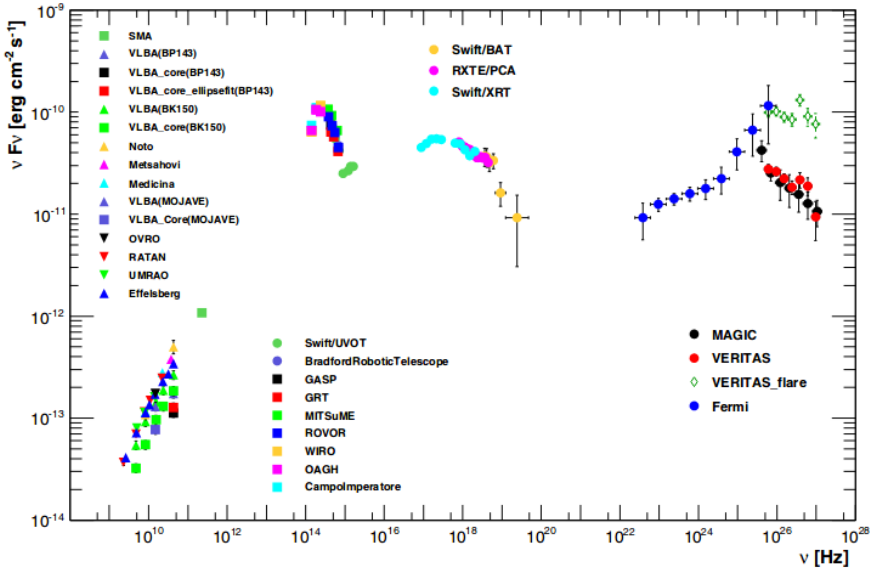
→ jet viewing angle $\lesssim 5^{o}$

→ luminosities up to $10^{48}$ erg/s

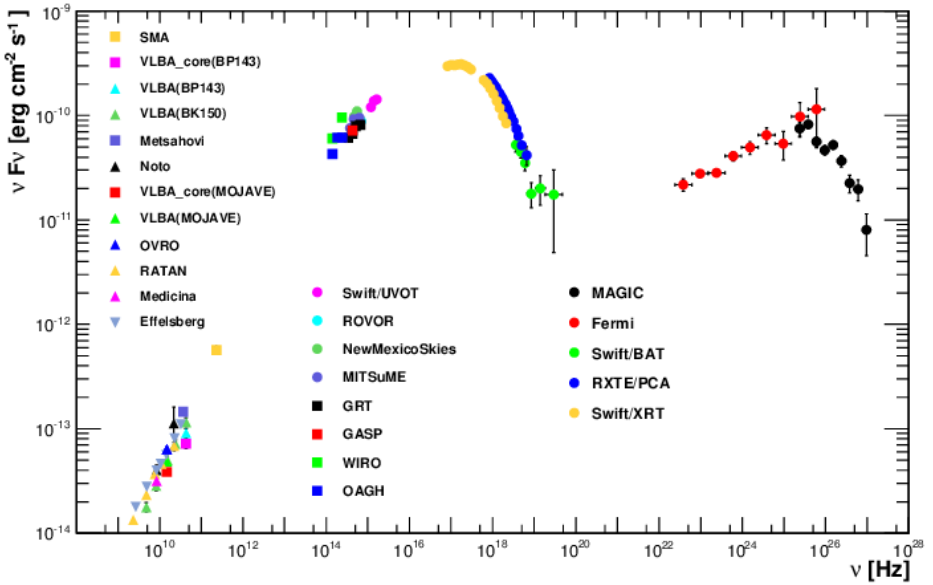
→ highly variable in whole e-m spectrum

# Spectral Energy Distribution

## Mrk 501




## Mrk 421



# Motivation:

- Innermost parts of the jet with light crossing timescales $GM/c^3$ ~ 15 minutes for $10^8$ $M_\odot$ BH
- Intra-night flux changes are challenging

$$\Delta T_{obs} = (1+z)\, \Delta T_{rest} / \delta \qquad (\delta \text{ - Doppler boosting factor})$$

- Invokes large Doopler boosing factors $\delta$ ~ 50–100
- From radio measurements, Doppler boosting factors are of the order of 10–15
- Highly efficient particle acceleration is needed

To probe the plasma conditions in detail:

- Studies of a sample of blazars in flux, color and polarization at optical frequency
- A systematic study for a sample of optically bright (< 16 mag) blazars
- Simultaneous color and polarization monitoring
- Involving few observatories/telescopes fitted with CCD and polarimeter

# Data acquisition and analysis

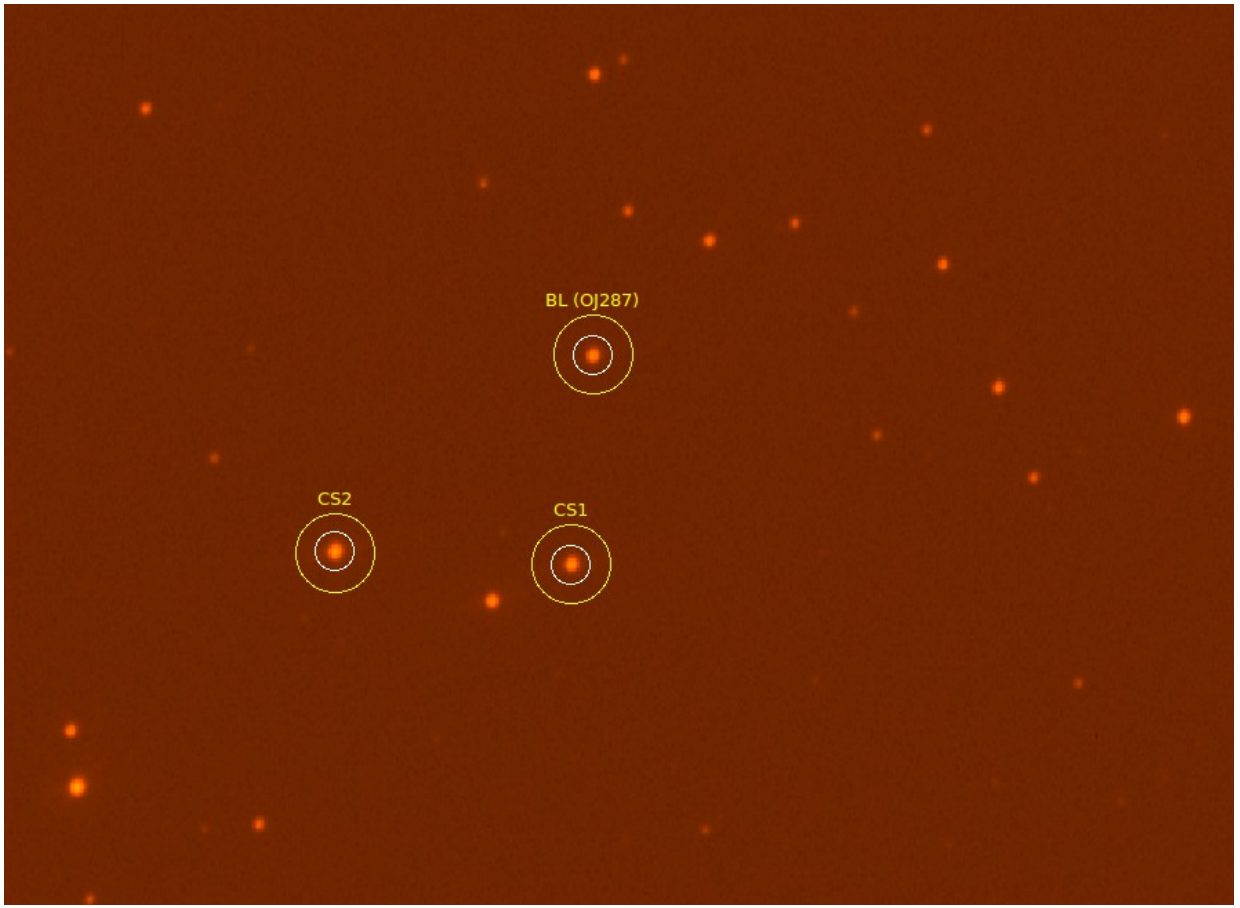
- Optical flux monitoring:
  - **50cm Cassegrain** (**OA-UJ, Poland**)
  - **ST-104cm** and **DOT** (**India**),
  - **IST-60cm** (**Turkey**)

- Optical polarization monitoring: **1.5m KANATA** (**Japan**), **40cm** (**St. Petersburg**) and **70cm** in **Crimea**

- Flux measurements in few filters (**B,V, R,** and **I**) and polarization measurements in **R-band** for a continuous duration of ~4 hr.

- Data analysis for the total intensity measurements (IRAF)
  → Differential photometry

# CCD image of blazar OJ 287



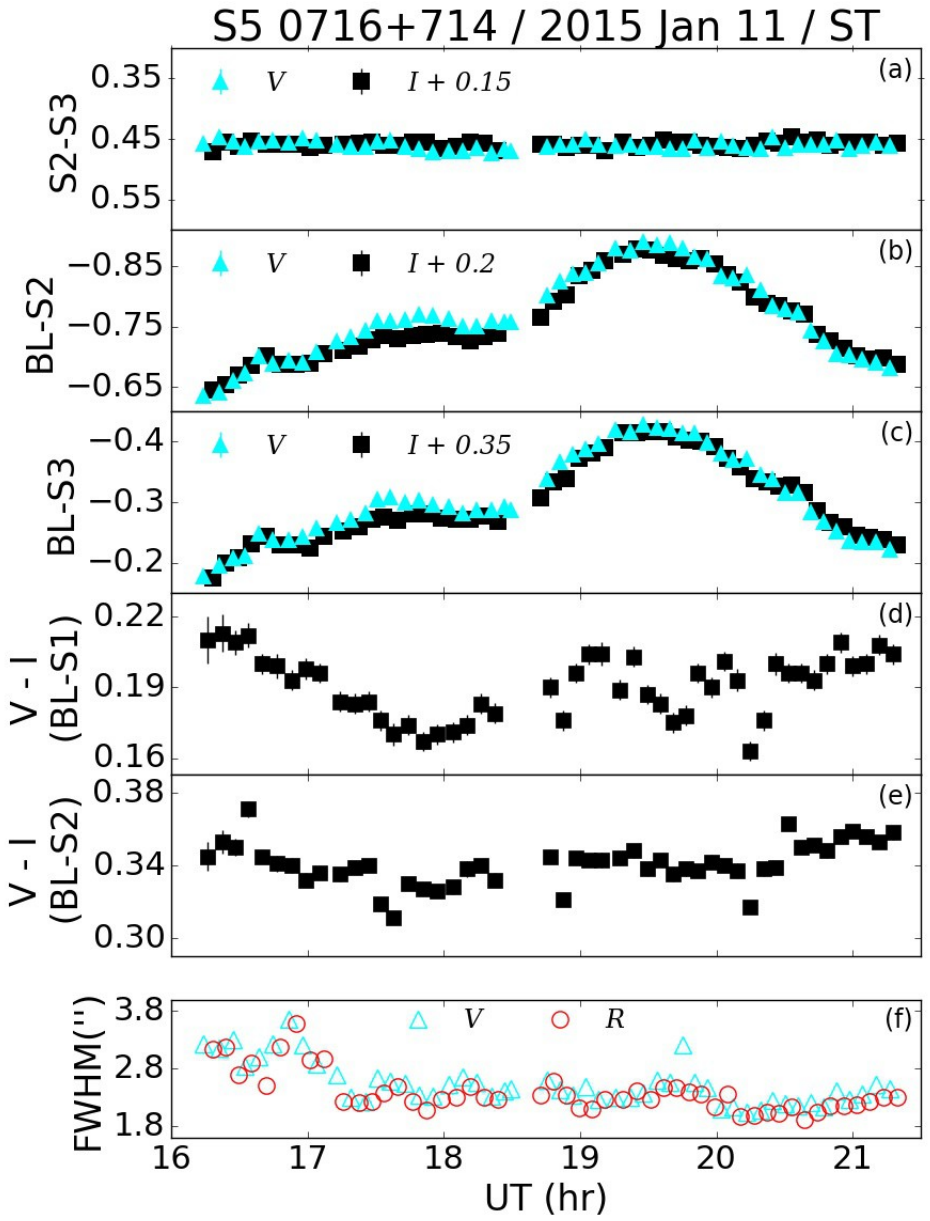

Differential Photometry

– brightness of blazar measured against one comparison star

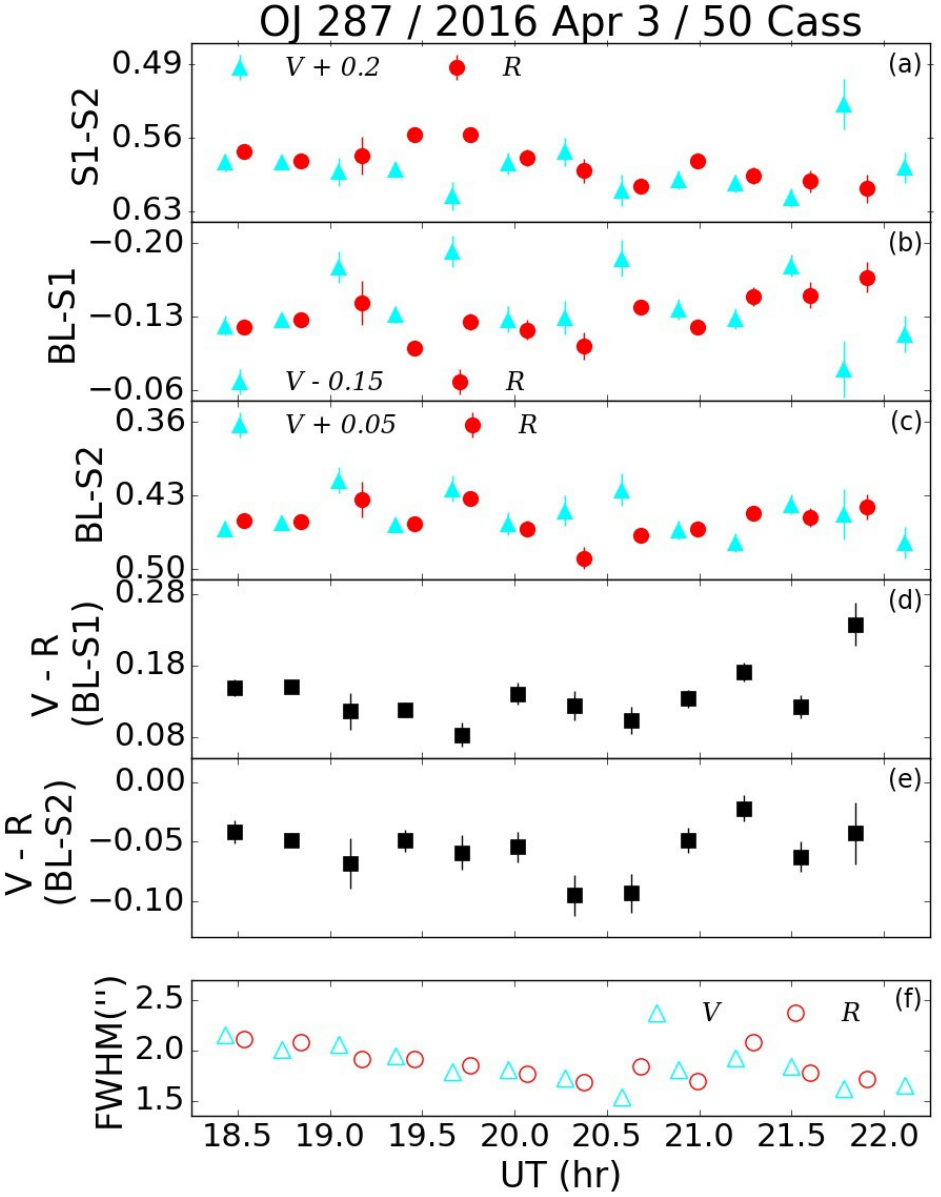
– check star (to ensure the comparison star is not varying itself)

——> differential light curves (DLCs)

# DLCs examples




(Variable)




(Non-variable)

| Object Name | Date of observation | Telescope used (1) | Filter used | Dur. (h) (2) | $N_p$ (3) | $\sigma$ (mag) (4) | $\psi$ (mag) (5) | $F_{CS1}$, $F_{CS2}$, (Status*) (6) | $F_{CS1-CS2}$ (Status) (7) | Final status (8) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0109+224 | 2015 Nov 14 | IST60 | B | 5.92 | 30 | 0.0278 | 0.115 | 2.01, 7.74 (PV, V) | 1.82 (N) | PV |
| | | | V | 5.74 | 28 | 0.0165 | 0.097 | 1.81, 5.21 (N, V) | 1.83 (N) | PV |
| | | | R | 5.74 | 25 | 0.0186 | 0.101 | 3.79, 7.33 (V, V) | 2.67 (V) | N |
| 3C 66A | 2015 Oct 19 | IST60 | B | 6.11 | 34 | 0.0113 | 0.083 | 2.30, 0.91 (V,N) | 0.72 (N) | PV |
| | | | V | 6.11 | 34 | 0.0080 | 0.074 | 2.49, 1.46 (V,N) | 0.74 (N) | PV |
| | | | R | 6.11 | 35 | 0.0104 | 0.065 | 1.68, 1.45 (N,N) | 1.38 (N) | N |
| | 2015 Nov 15 | IST60 | B | 5.69 | 37 | 0.0159 | 0.045 | 0.72, 1.06 (N,N) | 1.25 (N) | N |
| | | | V | 5.69 | 36 | 0.0082 | 0.073 | 1.42, 0.74 (N,N) | 0.67 (N) | N |
| | | | R | 5.08 | 32 | 0.0073 | 0.036 | 0.88, 0.61 (N,N) | 0.73 (N) | N |
| S5 0716+714 | 2015 Jan 11 | ST | V | 5.03 | 50 | 0.00656 | 0.254 | 147.38, 212.65 (V,V) | 1.20 (N) | V |
| | | | I | 5.02 | 49 | 0.0048 | 0.233 | 271.87, 326.90 (V,V) | 0.97 (N) | V |
| | 2015 Jan 13 | ST | V | 1.29 | 10 | 0.0067 | 0.020 | 1.27, 3.33 (N,PV) | 1.19 (N) | N |
| | | | I | 1.16 | 11 | 0.00608 | 0.055 | 10.31, 17.19 (V,V) | 1.13 (N) | V |
| | 2015 Jan 15 | ST | V | 2.35 | 27 | 0.00707 | 0.090 | 10.42, 20.40 (V,V) | 1.52 (N) | V |
| | | | I | 2.46 | 27 | 0.0044 | 0.040 | 6.88, 7.72 (V,V) | 0.98 (N) | V |
| | 2015 Feb 9 | ST | V | 5.18 | 55 | 0.0054 | 0.073 | 5.91, 3.90 (V,V) | 1.46 (N) | V |
| | | | I | 5.54 | 62 | 0.0080 | 0.039 | 5.97, 6.82 (V,V) | 1.37 (N) | V |
| OJ 287 | 2014 Feb 20 | DOT | V | 6.26 | 17 | 0.0027 | 0.073 | 89.66, 84.64 (V,V) | 1.54 (N) | V |
| | | | I | 6.48 | 17 | 0.00228 | 0.066 | 89.90, 72.33 (V,V) | 0.93 (N) | V |
| | 2015 Feb 12 | ST | V | 4.52 | 27 | 0.00835 | 0.067 | 3.53, 3.61 (V,V) | 1.17 (N) | V |
| | | | I | 5.86 | 35 | 0.00556 | 0.019 | 0.96, 1.43 (N,N) | 1.05 (N) | N |
| | 2016 Jan 13 | IST60 | B | 3.01 | 16 | 0.0202 | 0.080 | 2.71, 1.94 (PV,N) | 1.68 (N) | N |
| | | | V | 3.01 | 22 | 0.0074 | 0.052 | 1.20, 1.59 (N,N) | 0.39 (N) | N |
| | | | R | 2.90 | 22 | 0.0111 | 0.046 | 0.90, 1.97 (N,N) | 0.72 (N) | N |
| | 2016 Feb 6 | 50CAS | V | 6.21 | 25 | 0.0191 | 0.205 | 3.53, 3.01 (V,V) | 1.25 (N) | V |
| | | | R | 6.21 | 26 | 0.01938 | 0.150 | 2.63, 3.02 (V,V) | 1.20 (N) | V |
| | 2016 Mar 7 | IST60 | B | 5.97 | 33 | 0.0119 | 0.087 | 5.37, 7.33 (V,V) | 0.85 (N) | V |
| | | | V | 5.80 | 27 | 0.0072 | 0.066 | 5.77, 10.99 (V,V) | 0.72 (N) | V |
| | | | R | 5.80 | 29 | 0.0126 | 0.097 | 4.09, 10.47 (V,V) | 1.06 (N) | V |
| | 2016 Apr 2 | 50CAS | B | 5.69 | 32 | 0.01879 | 0.119 | 3.75, 6.03 (V,V) | 1.34 (N) | V |
| | | | V | 5.54 | 31 | 0.01057 | 0.106 | 5.00, 7.21 (V,V) | 0.86 (N) | V |
| | | | R | 5.56 | 30 | 0.0145 | 0.091 | 3.74, 6.66 (V,V) | 1.40 (N) | V |
| | 2016 Apr 3 | 50CAS | V | 3.67 | 13 | 0.0229 | 0.101 | 2.20, 0.99 (N,N) | 1.40 (N) | N |
| | | | R | 3.37 | 12 | 0.0171 | 0.062 | 1.46, 1.36 (N,N) | 1.37 (N) | N |
| | 2016 Apr 4 | 50CAS | V | 3.84 | 27 | 0.01637 | 0.093 | 1.79, 1.77 (N,N) | 0.88 (N) | N |

... .... .... 

**7 blazars, 20 nights in total**

# Statistical test for variability

**F-test** (deDiego 2010, Goyal et al., 2013): $F_\nu^\alpha = \frac{V_{\rm obs}}{V_{\rm exp}} = \frac{V_{t-s}}{\langle \eta^2 \sigma_{t-s}^2 \rangle}$

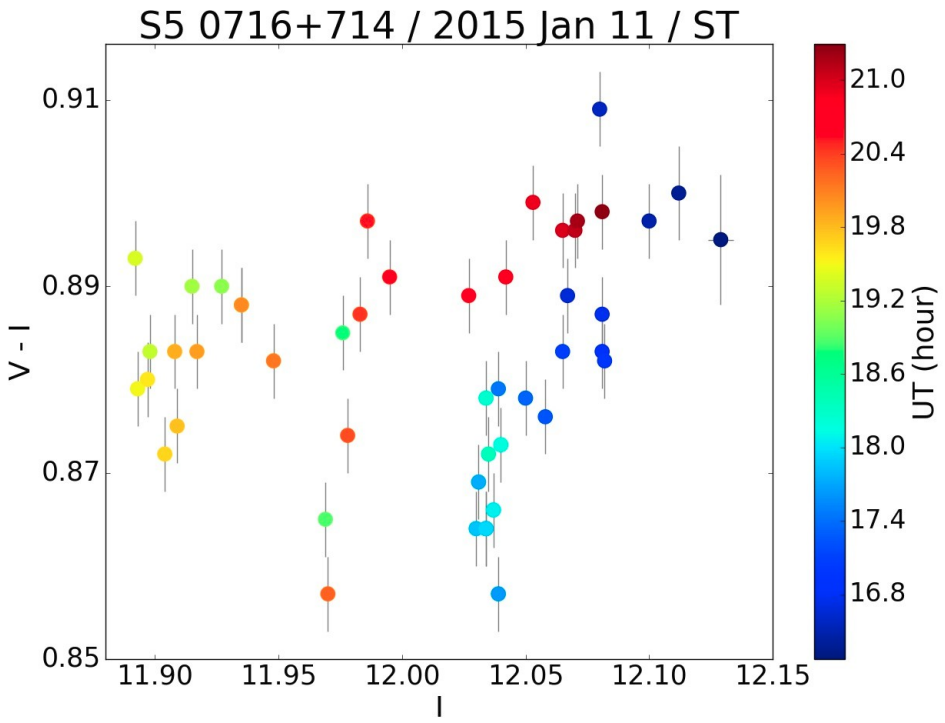
**Number of false-positives** (type 1 error)

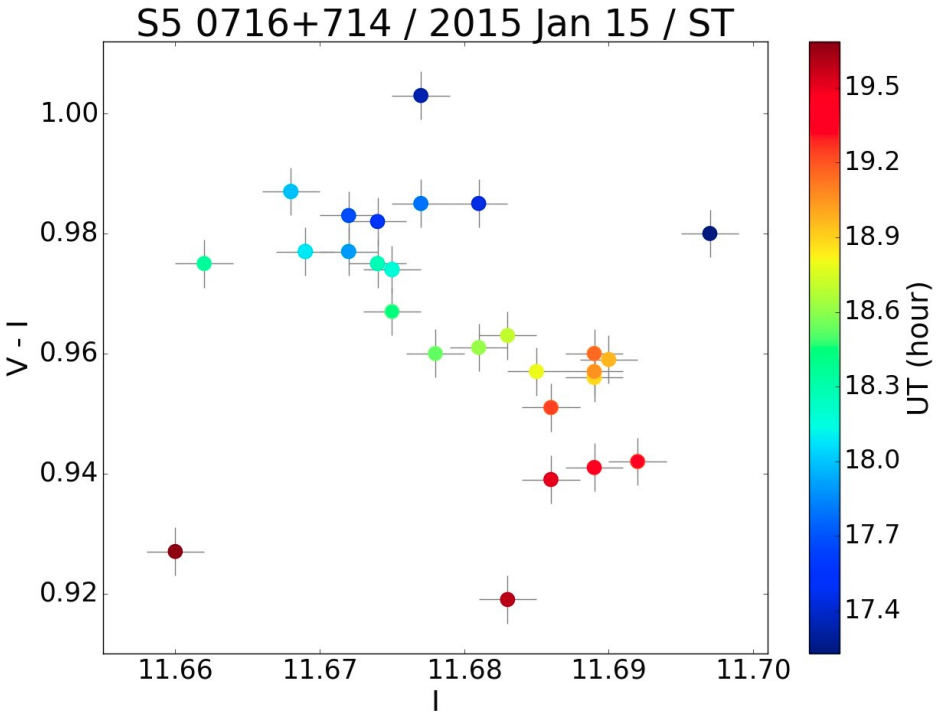
The significance level assess the expected number of false positives Detections. For our sample of 20 observations we can expect ~0.2 and ~1 light curves to be variable (with α=0.01 and 0.05, respectively)

**in agreement with our results**

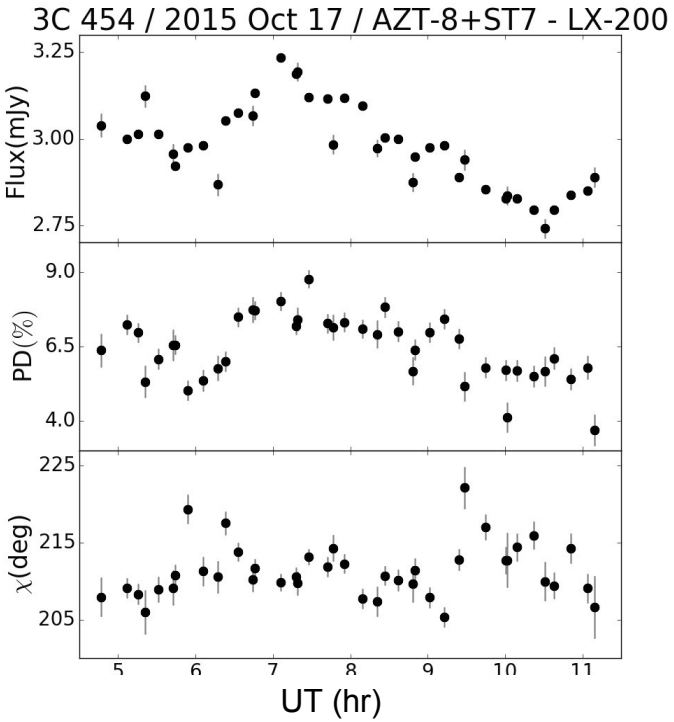
**Duty Cycle of microvariabilty**:

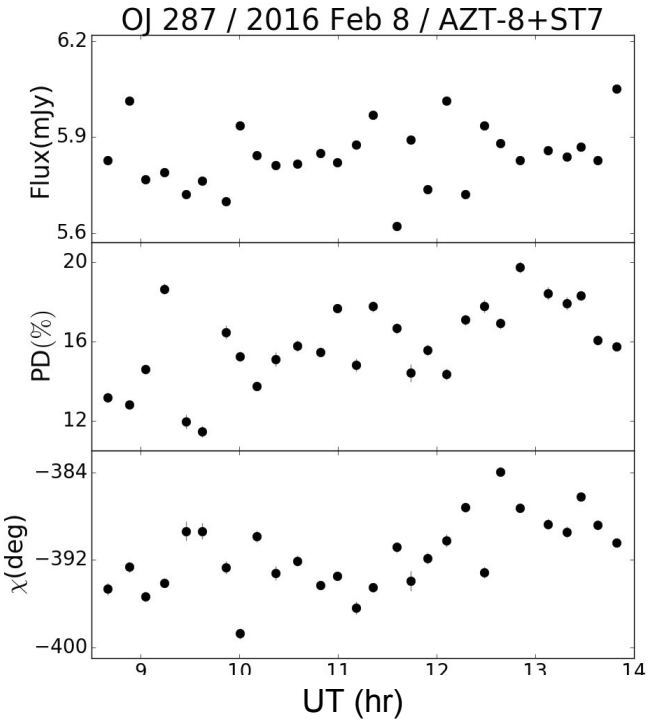
# Color vs. flux variability – clues to particle acceleration

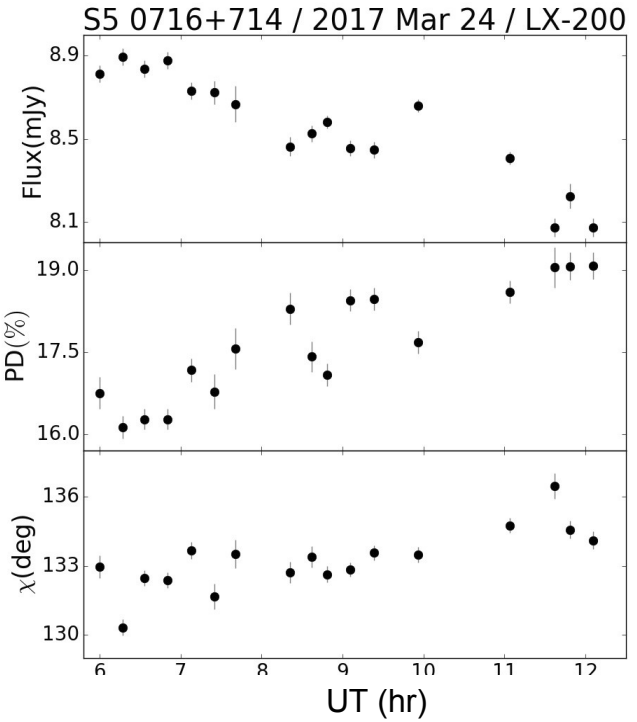


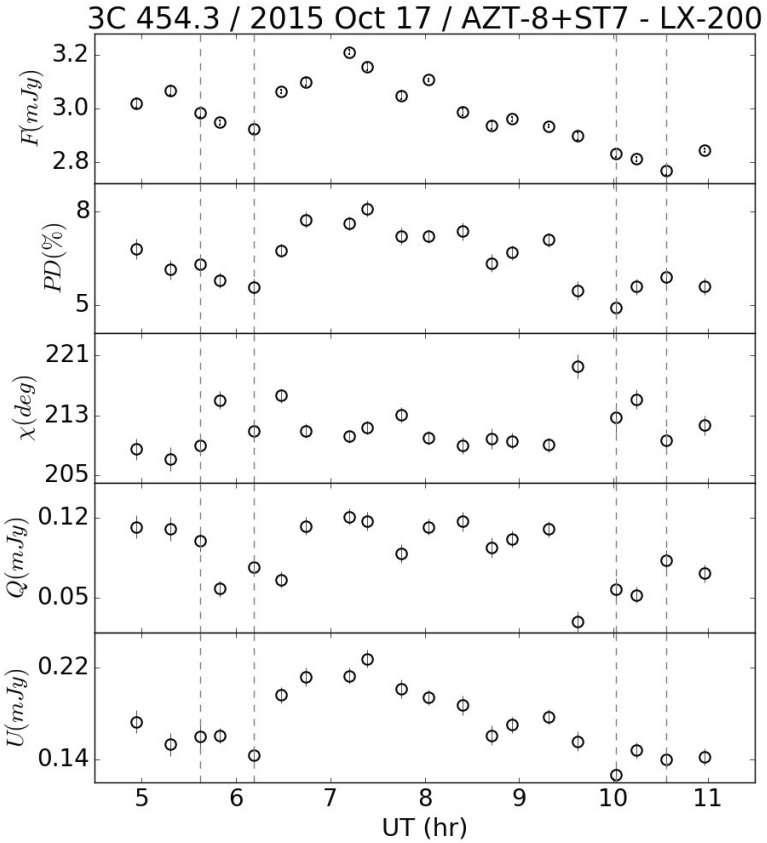
# Polarization microvariability light curves

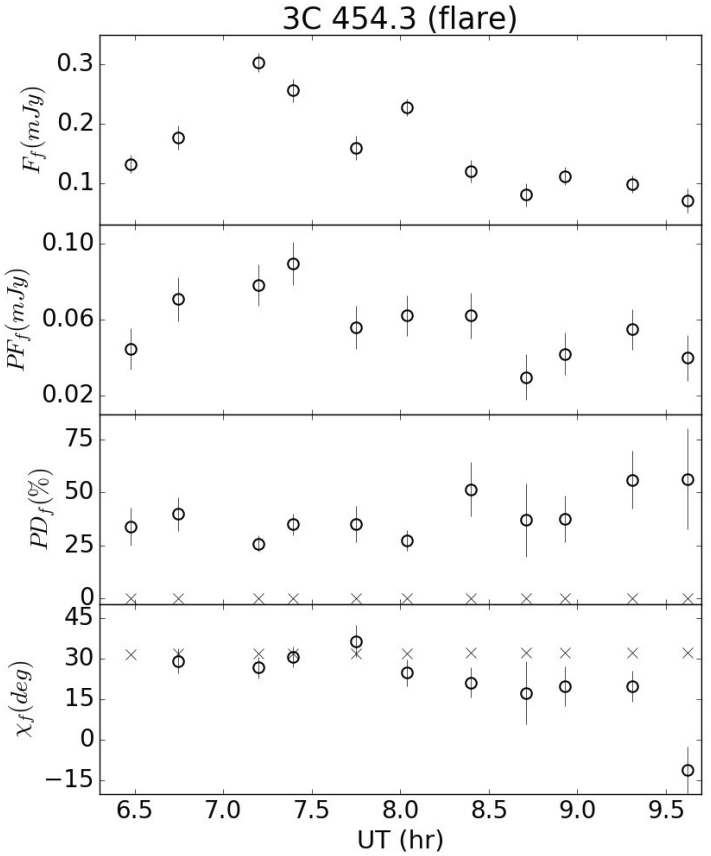


# Flare analysis

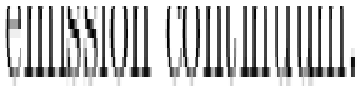



$F_{total} = F_{base} + F_{flare}$

$Q_{total} = Q_{base} + Q_{flare}$

$U_{total} = U_{base} + U_{flare}$



# Results and Summary

- Microvariability DC is ~45% (checks with previous results)
- Blazars show achromatic flux variability on hourly timescales. The color microvariability DC ~ 25%
- Significant changes are noted in PD and EXPA on hourly timescales.
- From the flare analysis, the flare has a PD ~40% as against the total PD ~8% → the emission region has highly uniform B-field (similar to Bhatta et al. 2015).
- The analysed microflare shows an exponential rise and decay with a sharp peak in between → indicates a small volume filling factor for the production of highest energy electrons and short radiative

Thank you for your attention