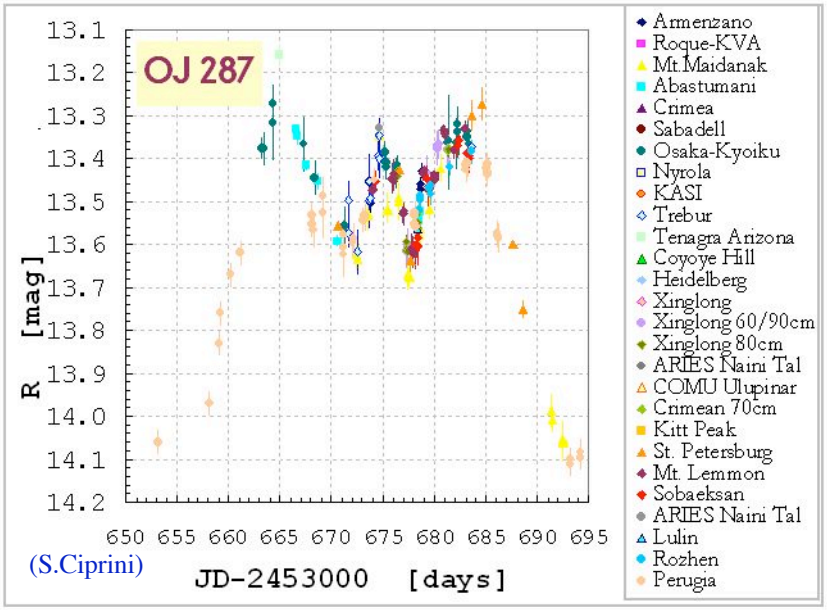
Variability of Blazars in the IR-Opt-UV energy bands: Observational Facts

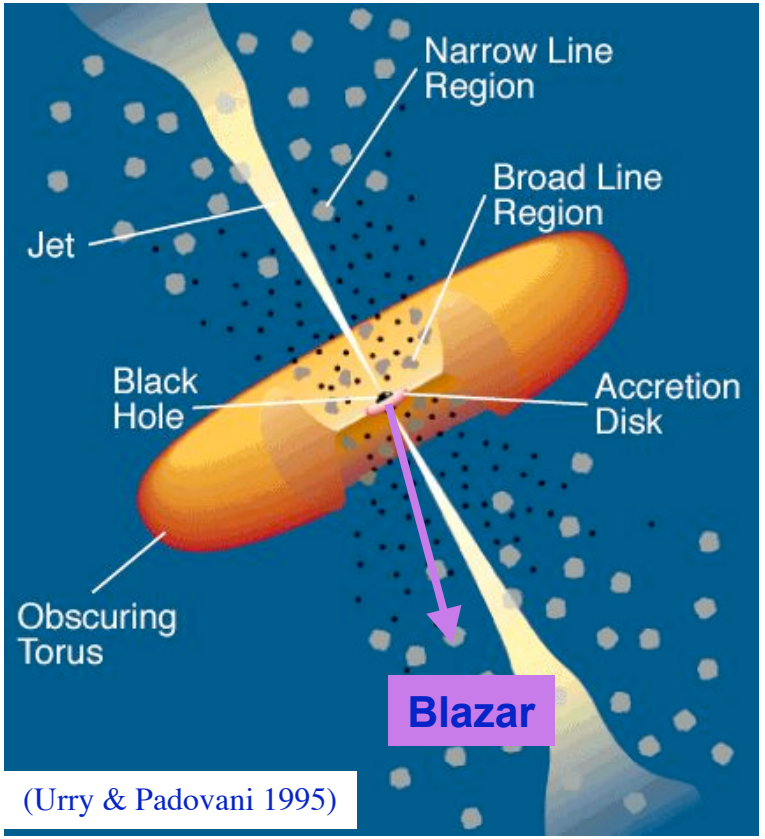


Gino Tosti

Dept. Physics & INFN Perugia

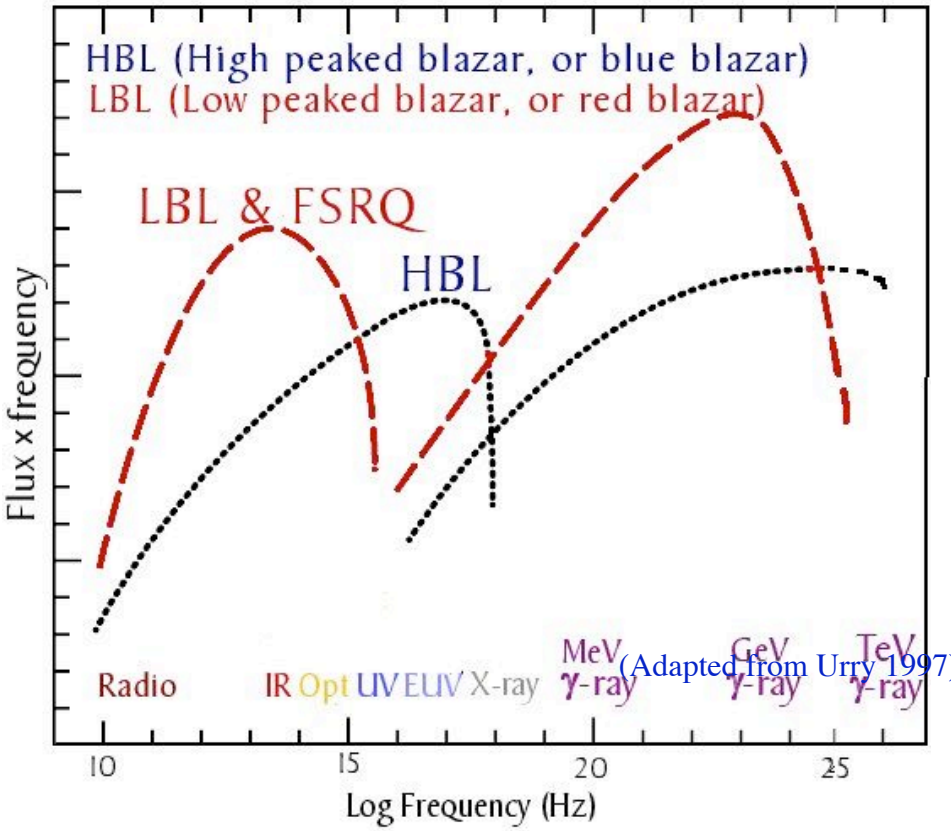
Current View

Blazars (BL Lacs and FSRQ) are radio-loud AGN with their jets practically oriented towards the observer-



(Urry & Padovani 1995)

The standard Model



(Adapted from Urry 1997)

The Spectral Energy Distribution

"Classical" definition of Blazars

FSRQ & BL Lacs share the following properties :

•variability over many timescales (from <1 day to years) and frequencies;

•high and variable optical polarization;

•flat spectrum and core dominant morphology in the radio;

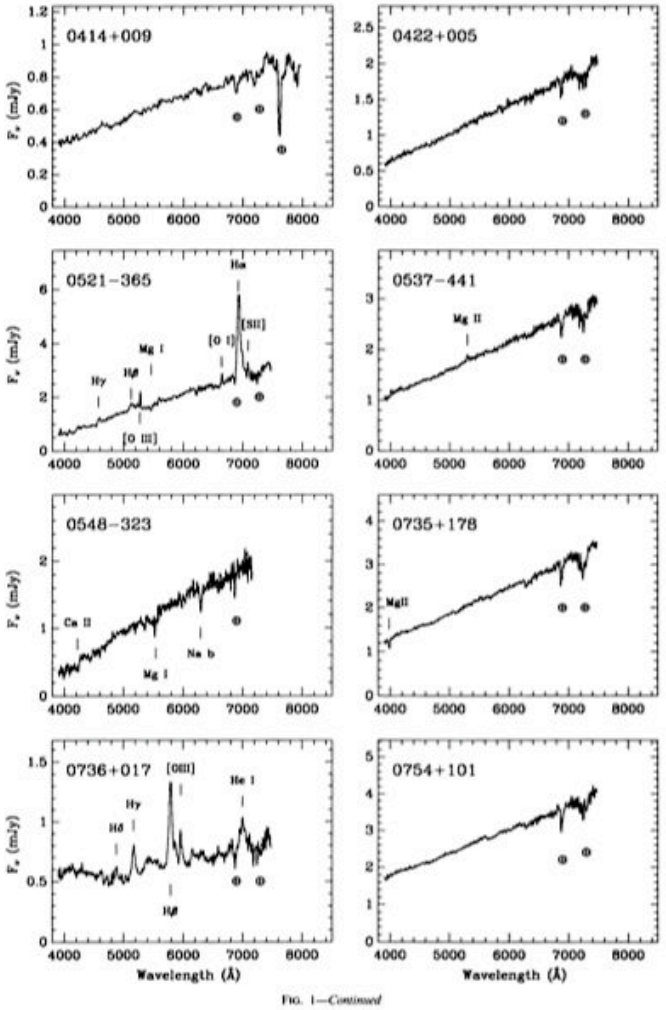
•broad band continuum extending from radio to gamma-rays.

The main difference between the two blazar classes:

- FSRQ emission lines: strong and quasarlike
- BL Lacs emission lines: weak when present

Blazar Spectroscopy

BL Lac is often not a BL Lac ob ject



Falomo et al. 1994

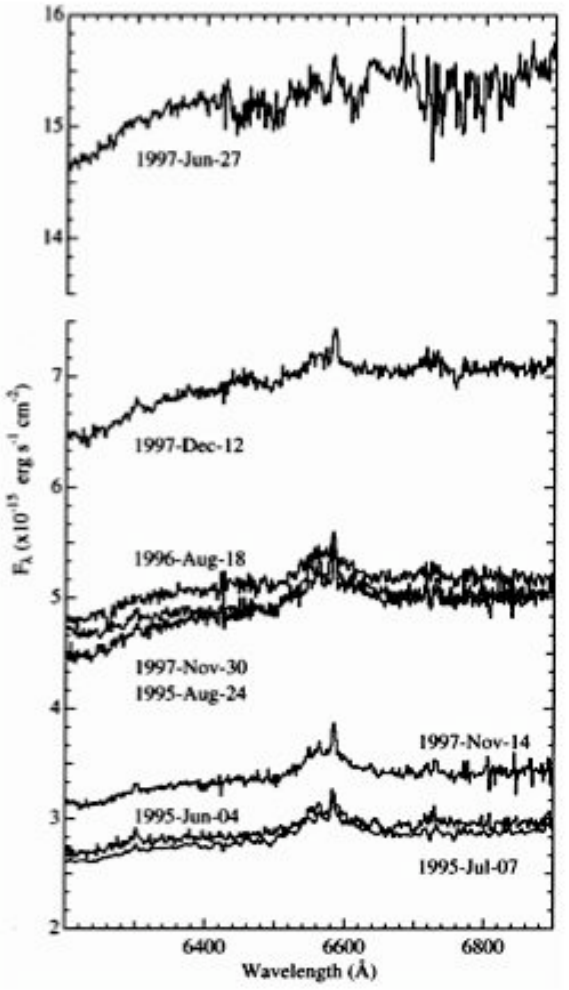
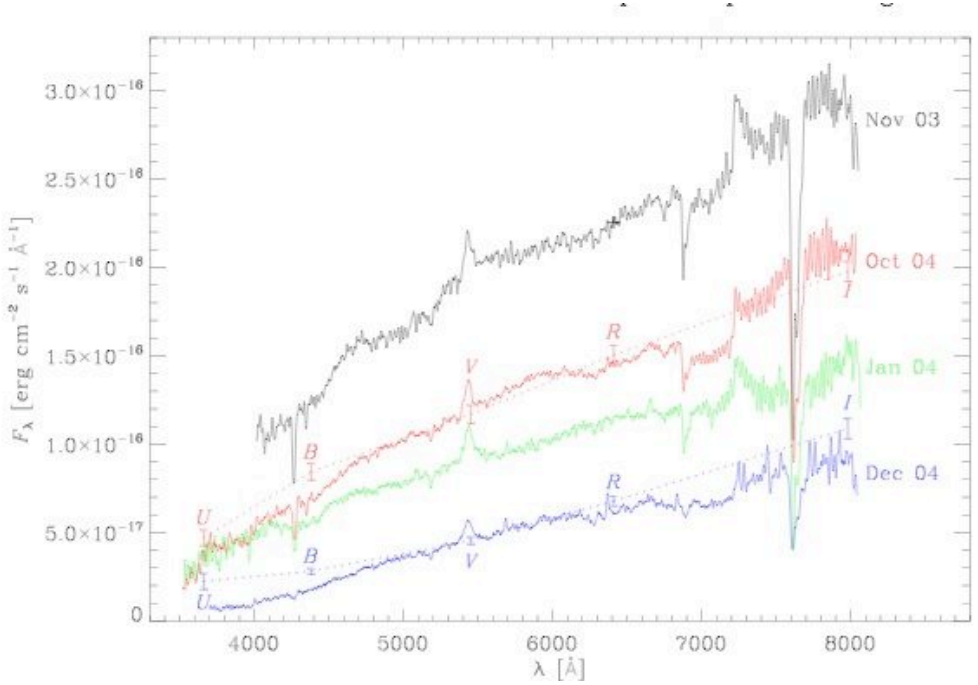


Figure 1. The observed spectra of BL Lacertae before correction for Galactic extinction and contamination by the host galaxy. Note the large change in continuum flux over the 30-month period.

(Vermeulen et al. 1995, Corbet 2000).

Spectroscopic Monitoring: AO 0235+16

Provide Important information on different components of an AGN. Only A few studies on this subjects.



The source was in a faint state, and a broad Mg II emission line was clearly detected in all spectra. The flux of the line showed an overall variation by a factor 1.9, while the continuum flux density changed by a factor 4.3.

The line Flux is independent of the optical continuum (as in BL Lac, 3C 279 and 3c273)

(Raiteri 2007)

Blazar variability studies started 40 years ago…..

- 1968 (40 years ago) - BL Lacertae is identified as the optical counterpart of the radio source VRO 42.22.01 (Schmitt, McLeod & Andrew)
- Starting of the the first long term optical monitoring program (see Smith 1996)
- Starting of the first long term radio monitoring program(see Aller et al. 1996)

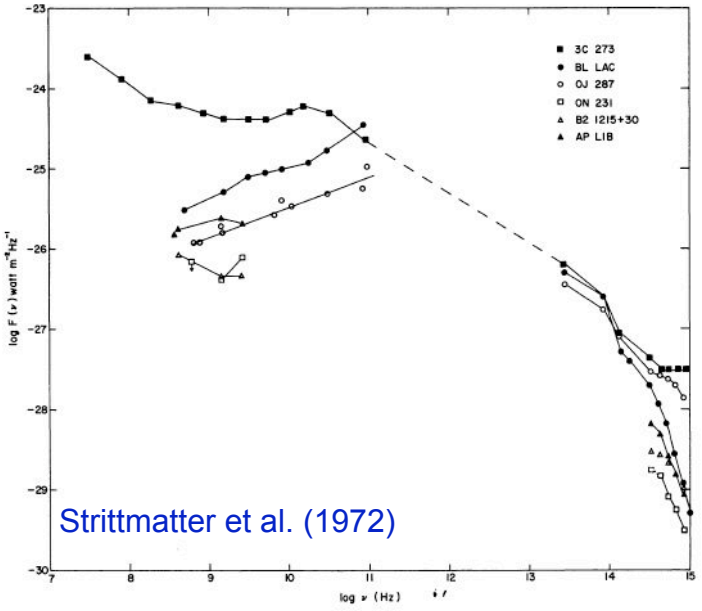
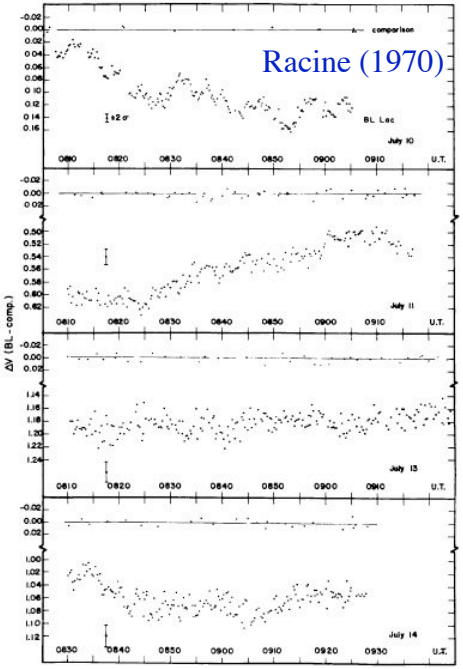


FIG. 1.—The energy distribution of the compact nonthermal sources compared with that of 3C 273



First detection of the BL Lac Microvariability

Blazar Variability

Blazars variability is observed at all wavelengths from radio through TeV gamma-rays.

Blazar variability show:

- long-term trends (timescales of several years)
- short-term outbursts (weeks to few years)
- Intranight (microvariability), intraday (IDV) variations

See e.g.: Wagner & Witzel(1995), Smith (1996),Ulrich,Maraschi & Urry (1997), Miller (2006)

Long term Monitoring program

Forward Monitoring:

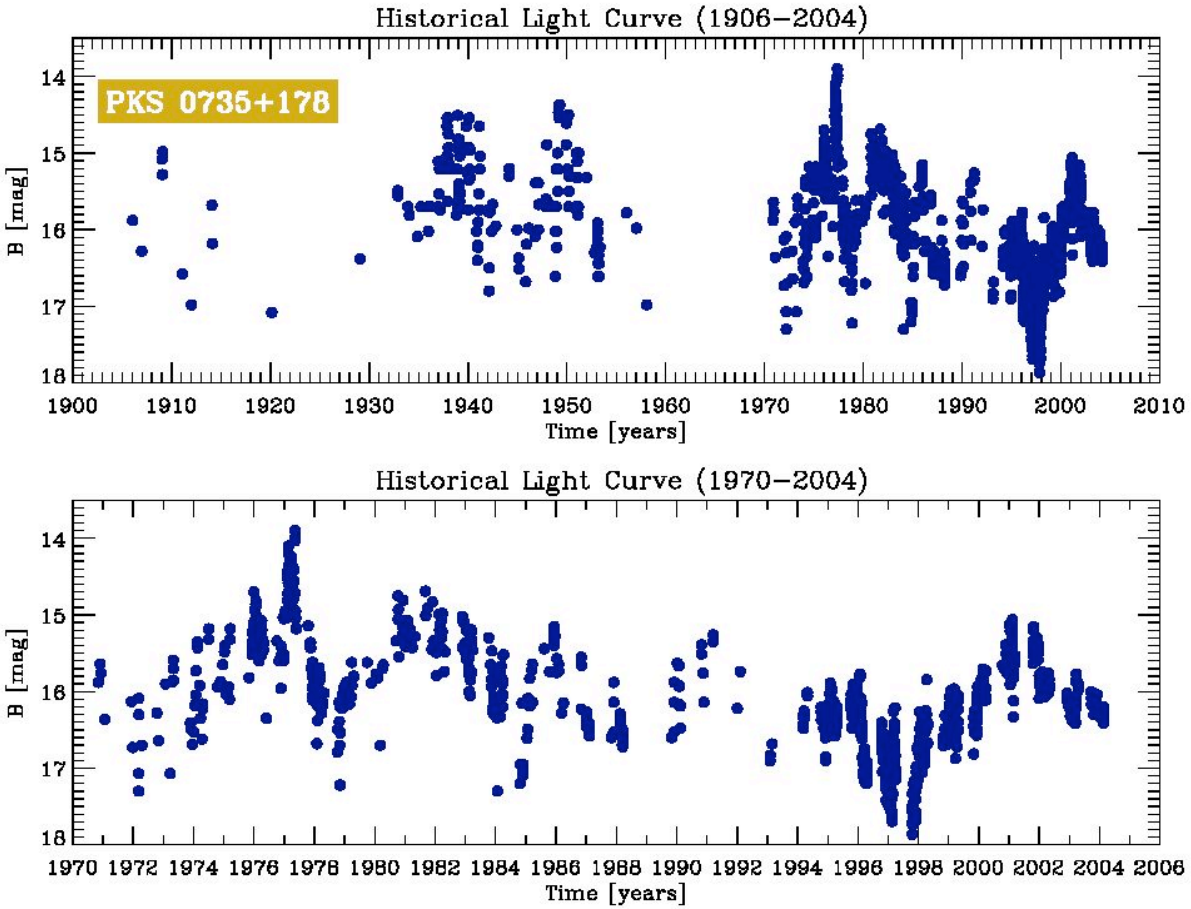
- Rosemary Hill Observatory Monitoring program started by A. Smith (e.g.,Pica et al. 1980; Webb et al. 1988; Pica et al. 1988)
- Asiago Observatory (e.g., Barbieri et al. 1979);
- Turku University Observatory (e.g., Sillanpaa et al. 1988; Sillanpaa et al. 1991)
- Hamburg Quasar Monitoring

Backward Monitoring:

- Analysis of Archival Plates (see Hudec's poster)

I apologize for omissions

Historical Light Curves



Variation timescales:
4.5, 8.5 and 11-13 yrs.

Ciprini et al 2007

Historical Light Curves

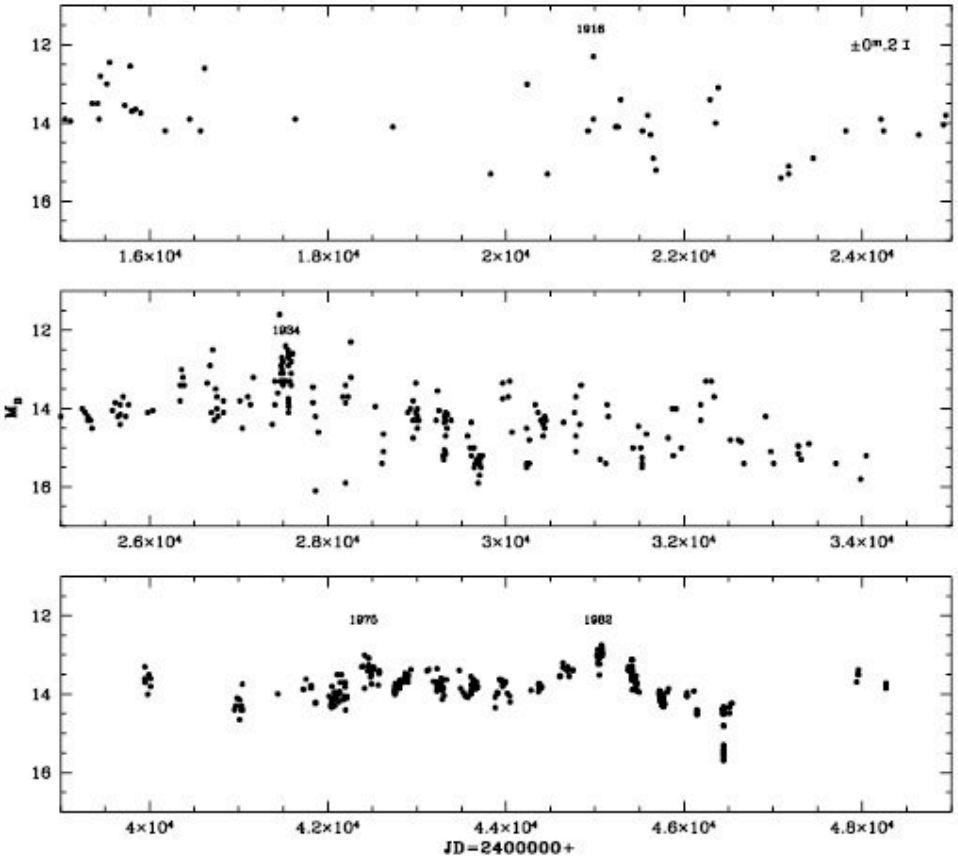


Fig. 1. a The long-term light curve of Mkn 421 from 1900 to 1991. The discontinuity of the light curve between 2435000 and 2439000 is due to lack of observations

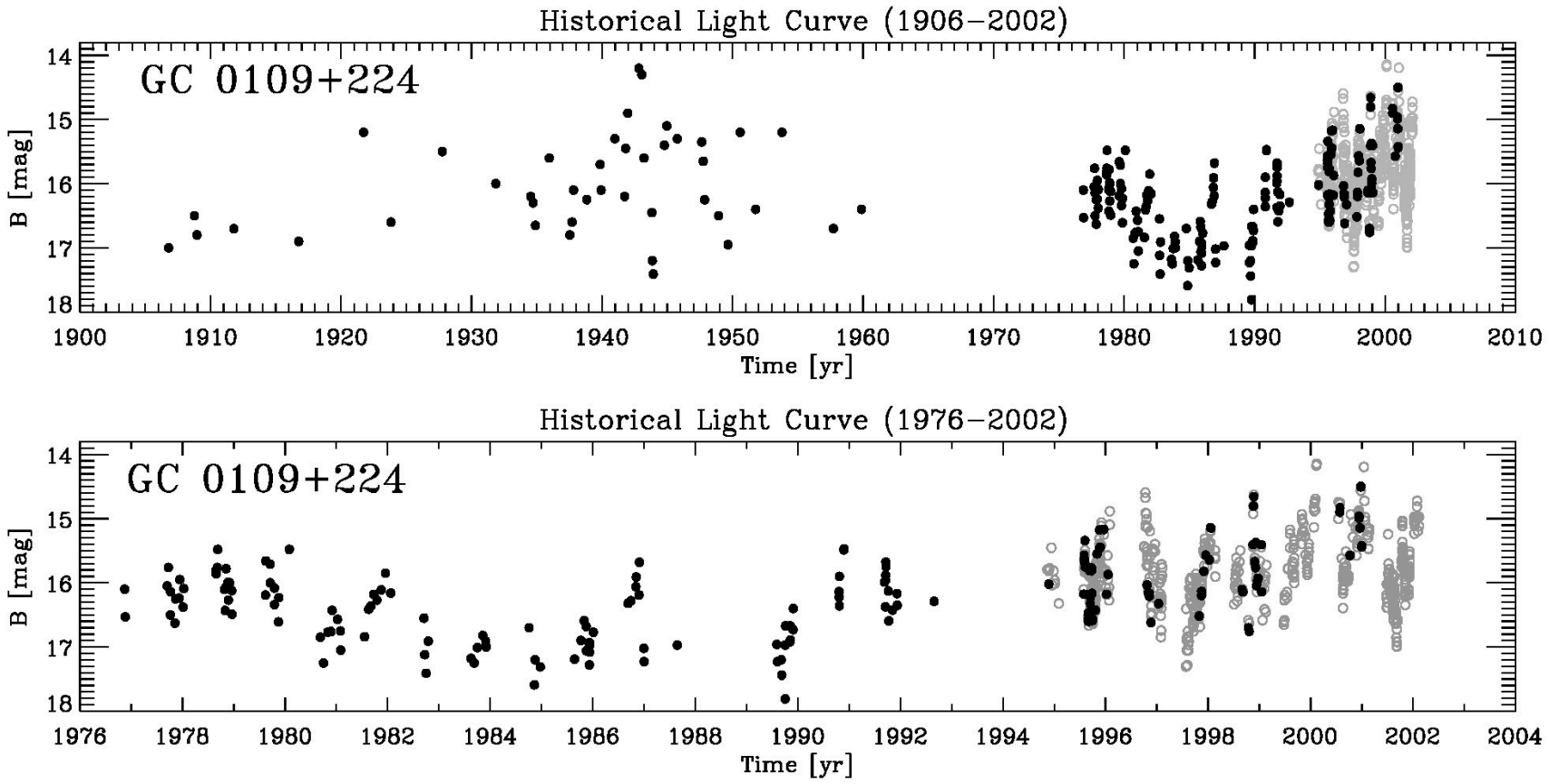
Mkn 421 - 1900-1991

Variations on time scales of hours to days.

Possible period of 23.1 ± 1.1yrs(??)

(Liu et al. 1997)

Historical Light Curves

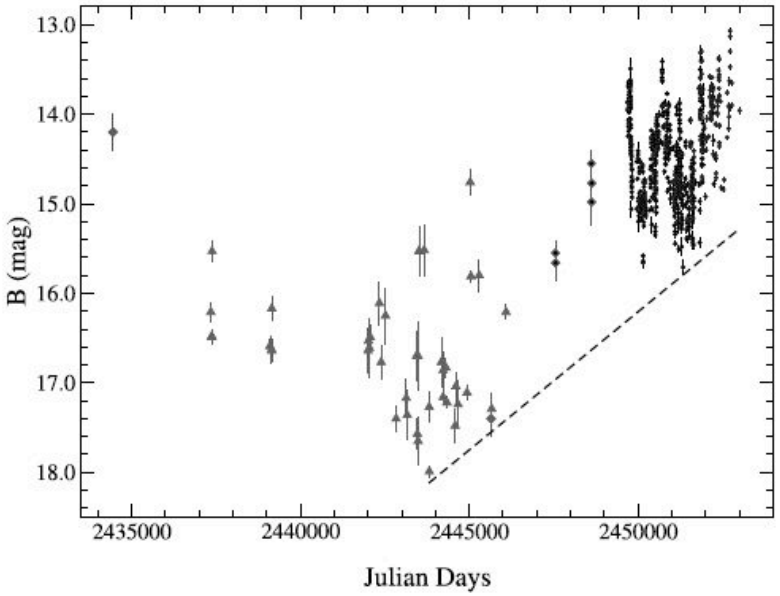


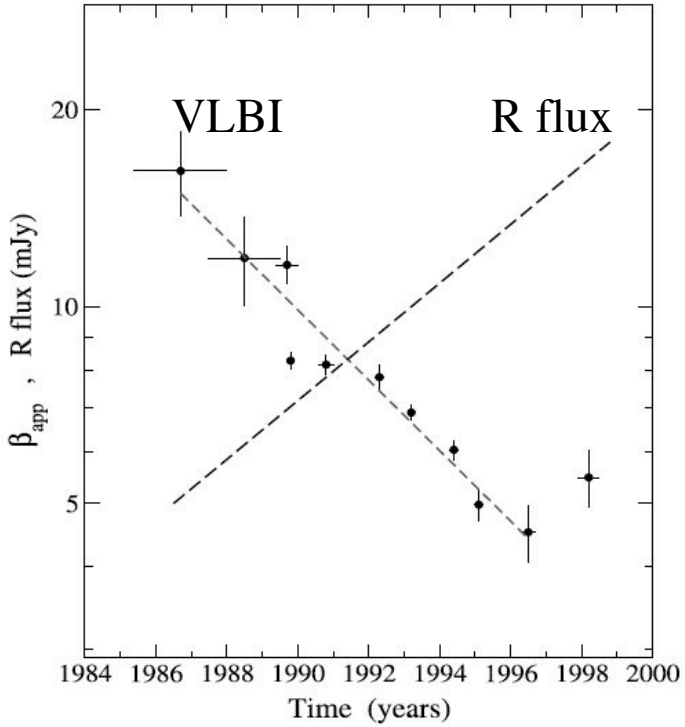
Several variability timescales are visible

Ciprini et al 2003

Historical Light Curves

Historical LC of the BL Lac object S5 0716+714, spanning the time interval from 1953 to 2003.



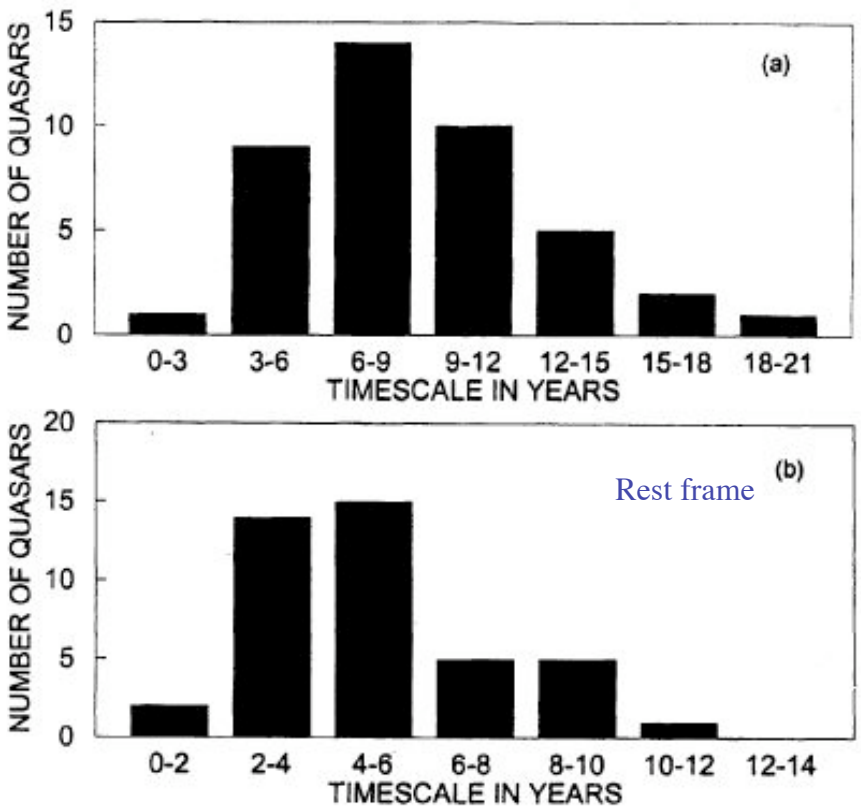


Precessing Jet ??

Nesci et al (2005)

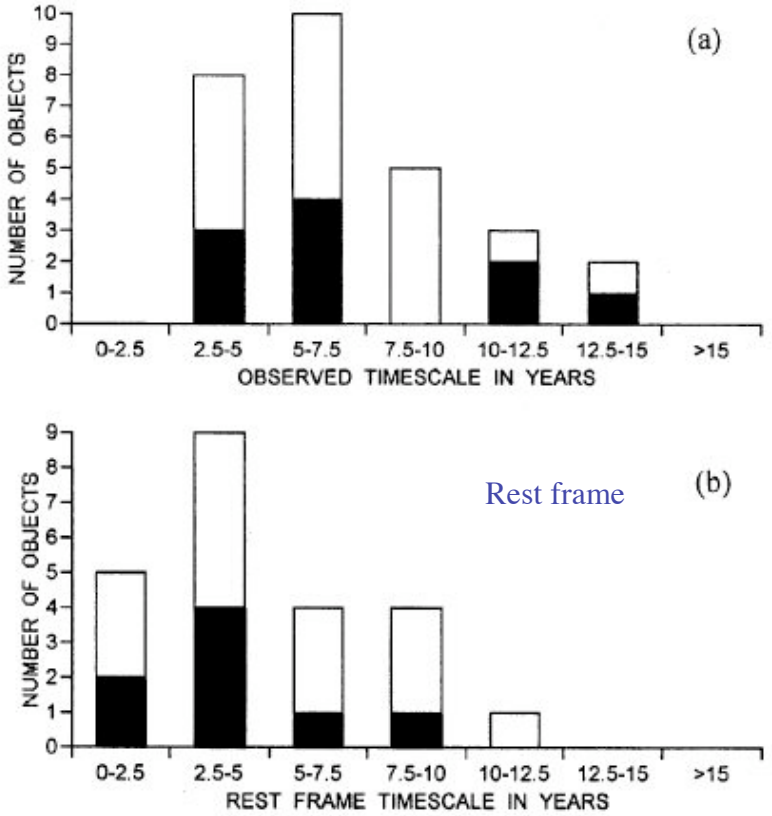
Base level variation timescales

Radio-Loud Quasar



Smith et al. (1993)

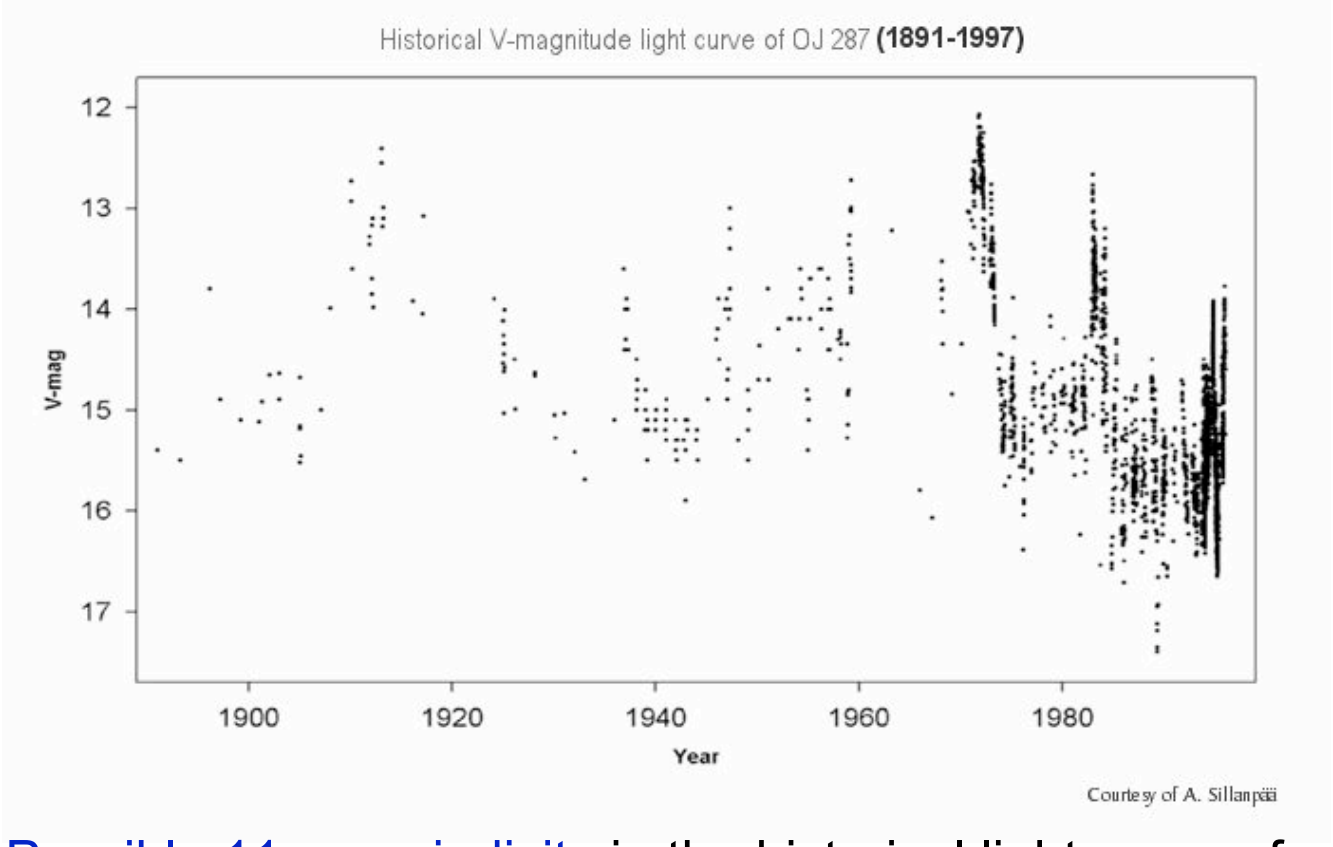
BL Lacs



Smith & Nair (1993)

Data: Rosemary Hill Observatory

Historical Light Curves: OJ 287 Periodicity



Possible 11 yr periodicity in the historical light curve of OJ 287 over a century of observations (Sillanpaa 1987).

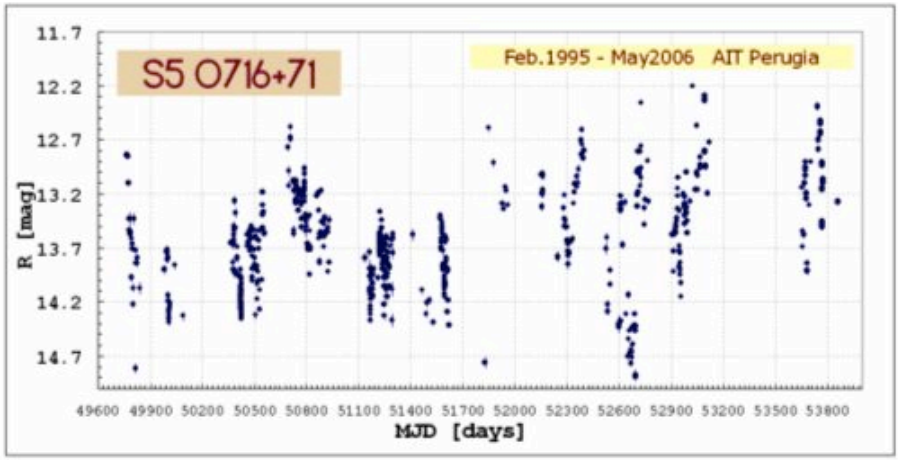
To confirm this periodicity: OJ 94 Project

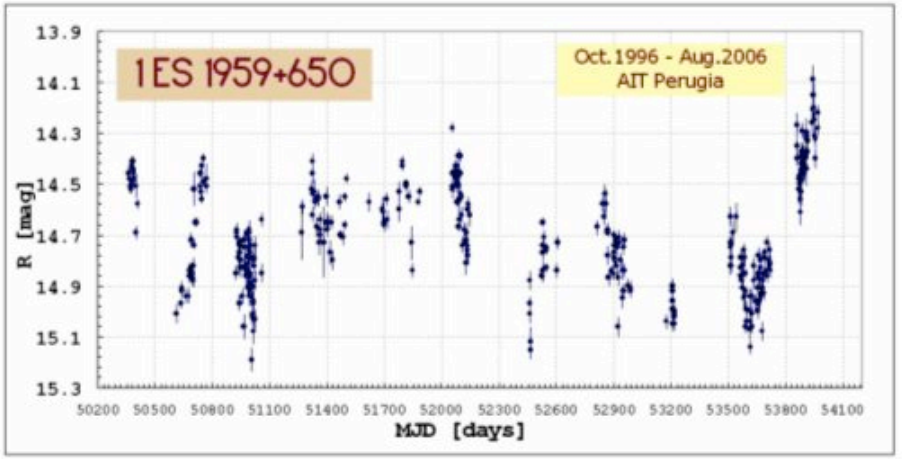
Ongoing Monitoring programs (partial list)

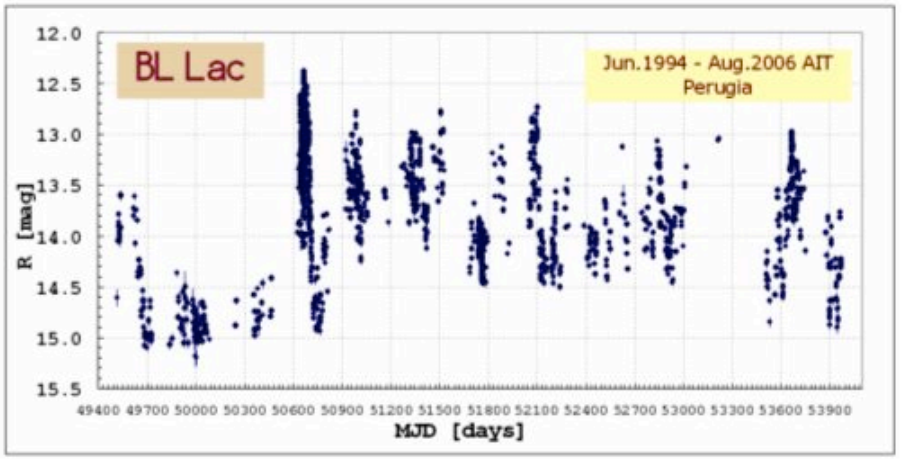
I apologize for omissions

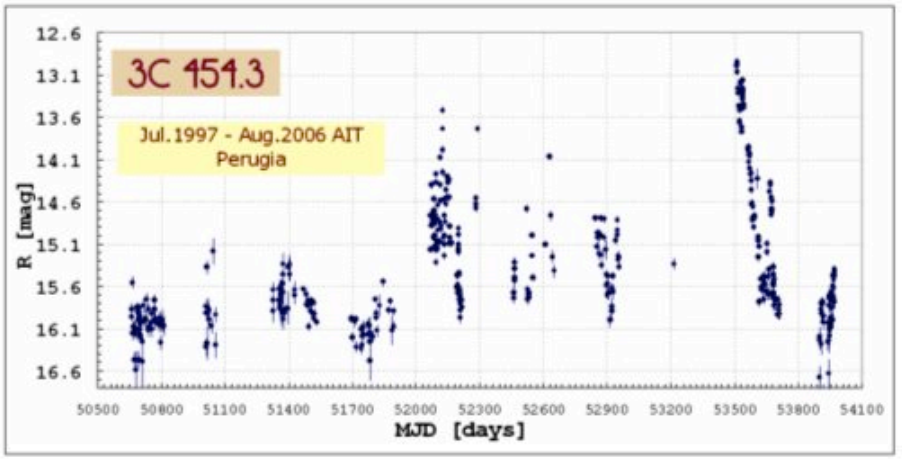
- Long Term Monitoring
  - Perugia (http://astro.fisica.unipg.it/ see Ciprini et al. poster)
  - Colgate (http://astronomy.colgate.edu/astronomy/quasaroptical.html)
  - Turin (http://www.to.astro.it/blazars/)
  - Rome (http://astro1.phys.uniroma1.it/scae.html)
  - Tuorla (http://users.utu.fi/kani/1m/index.html)
- Mid-term Campaign on selected Sources
  - OJ 287 2005-2008 Campaign (http://www.astro.utu.fi/OJ287MMVI/ see Ciprini et al. poster)
  - SMARTS Consortium
  - GASP (see Raiteri et al. poster)
  - GTN
  - REM blazar Monitoring (see Impiombato et al. poster)
  - ..
- Intensive Monitoring
  - WEBT (http://www.to.astro.it/blazars/webt/ see Raiteri et al. poster)

Perugia Blazar Monitoring



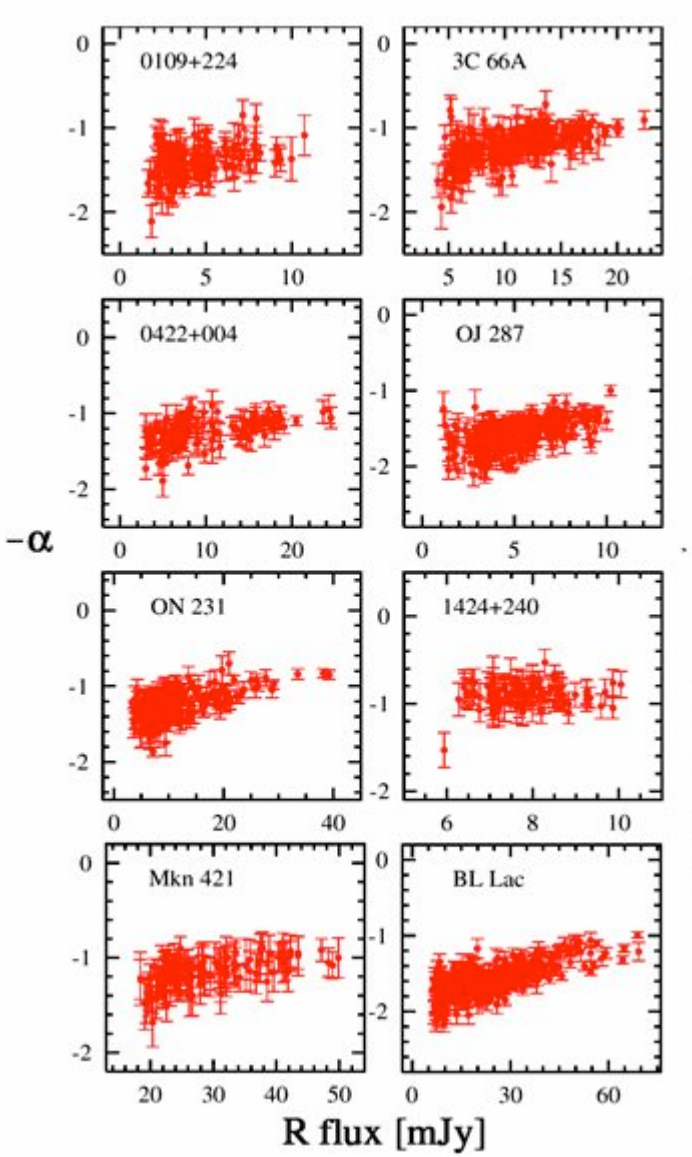


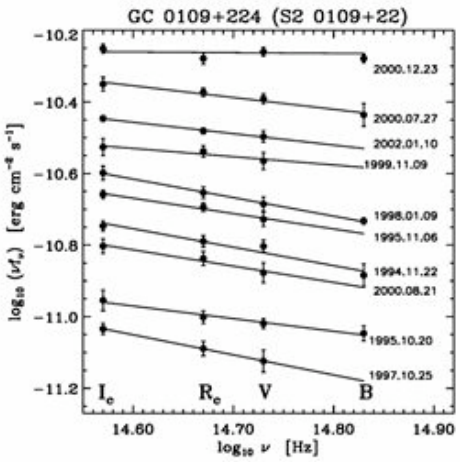


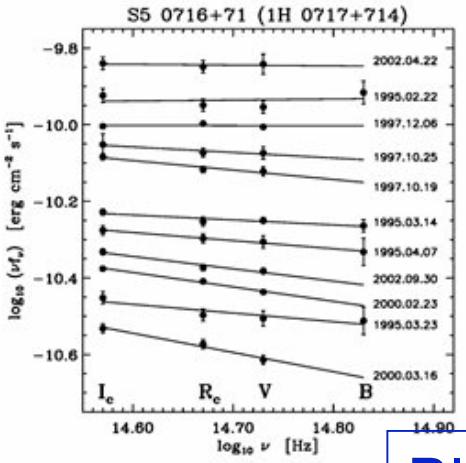


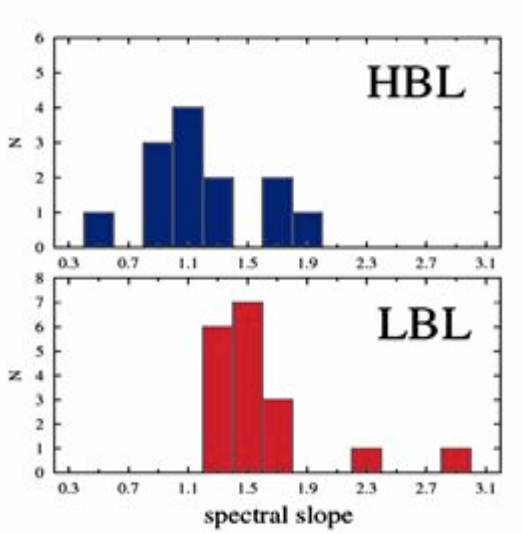
First Blazar monitoring with a Robotic telescope (see Ciprini's poster)

Perugia Blazar Monitoring: Spectral Variations





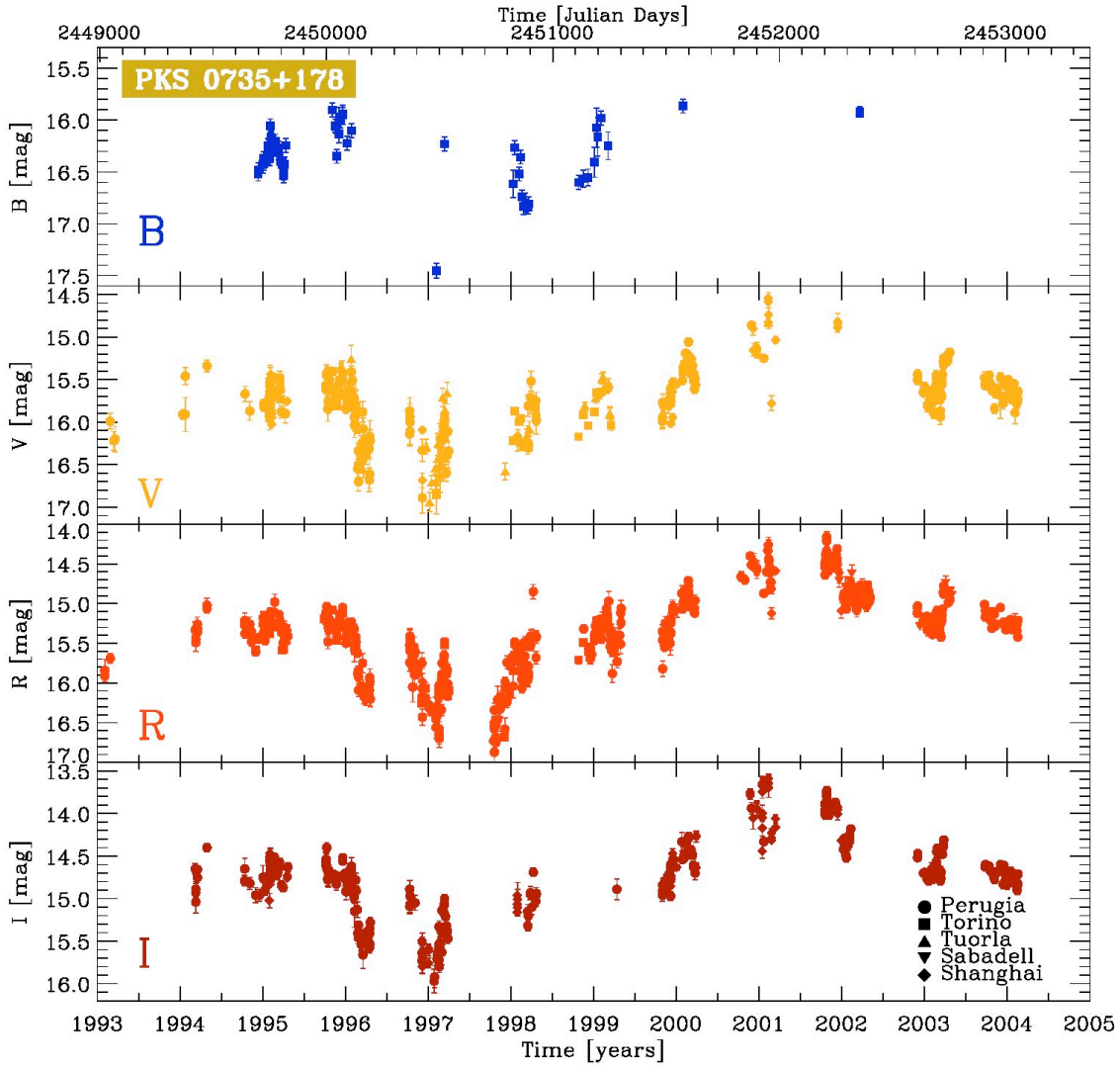


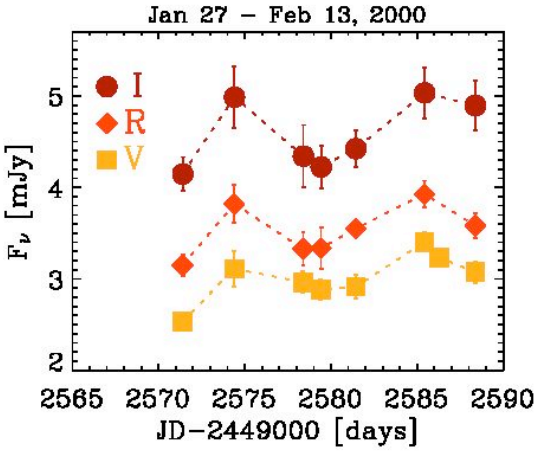


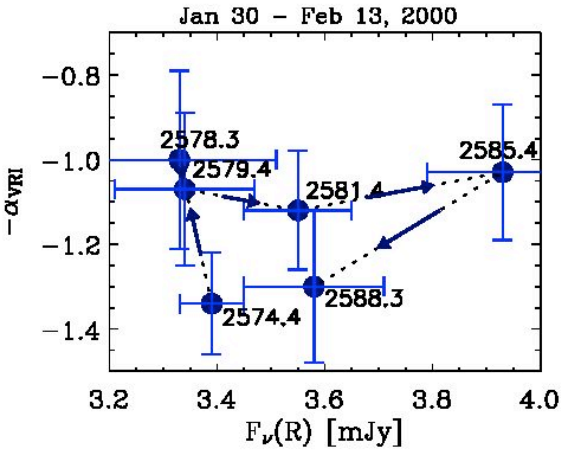
Bluer when brighter?

… any exceptions to this rule

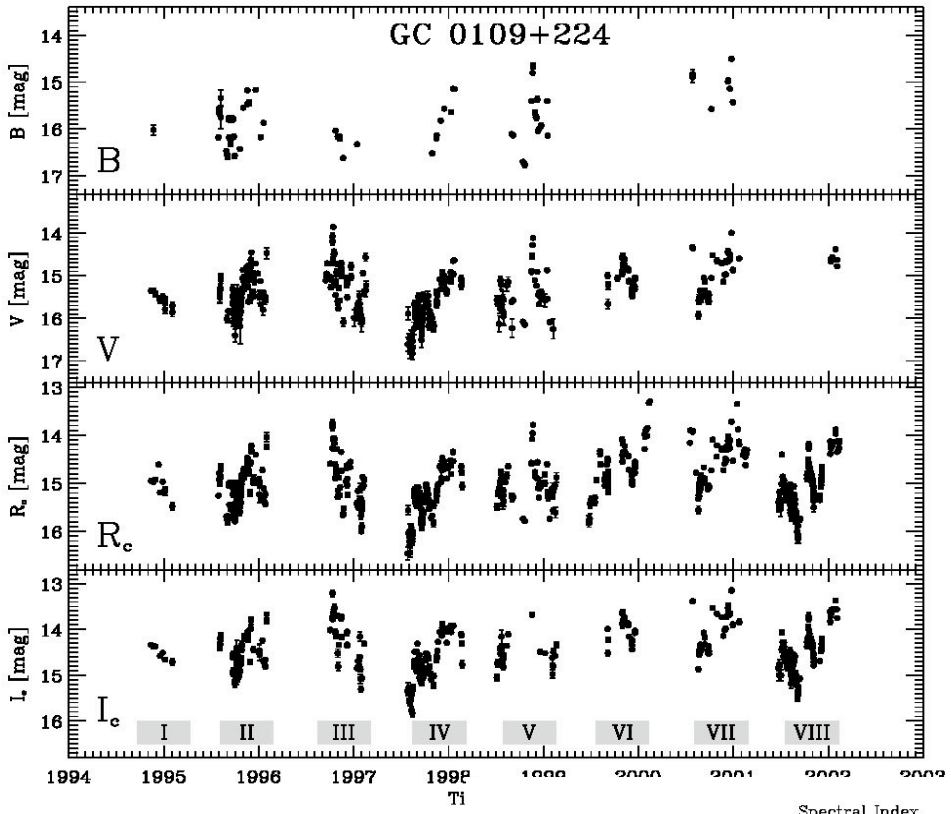
Perugia Blazar Monitoring: Spectral Loops

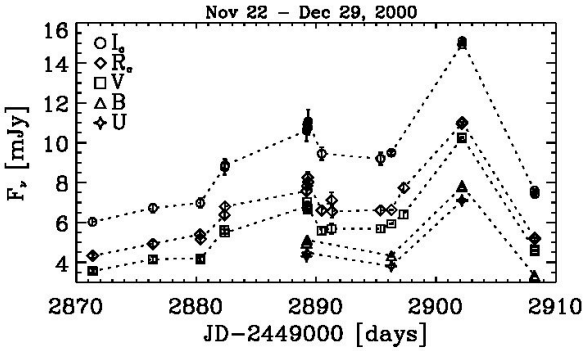


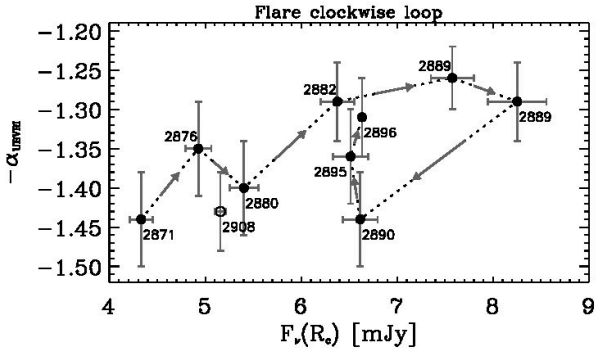


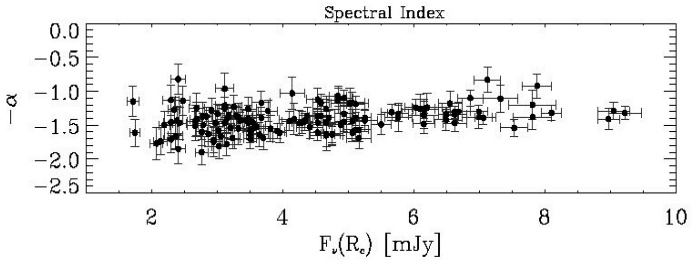


Perugia Blazar Monitoring: Spectral Loops



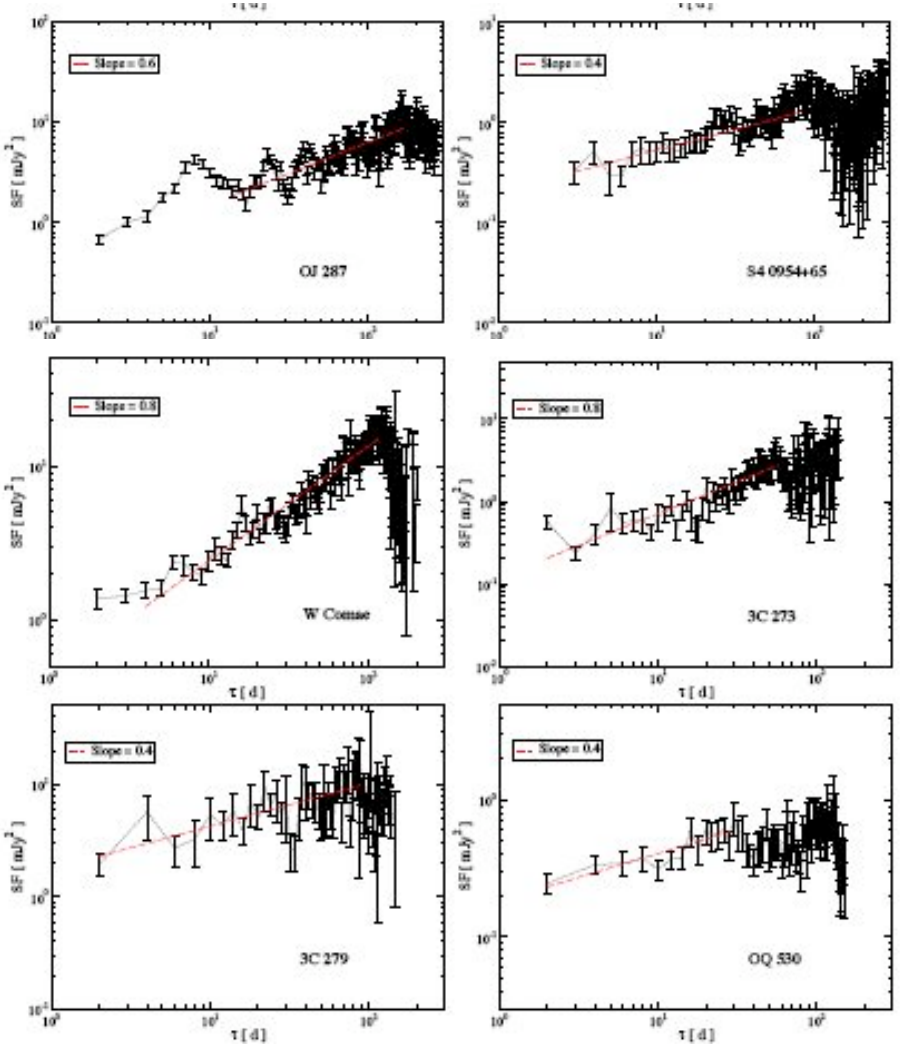


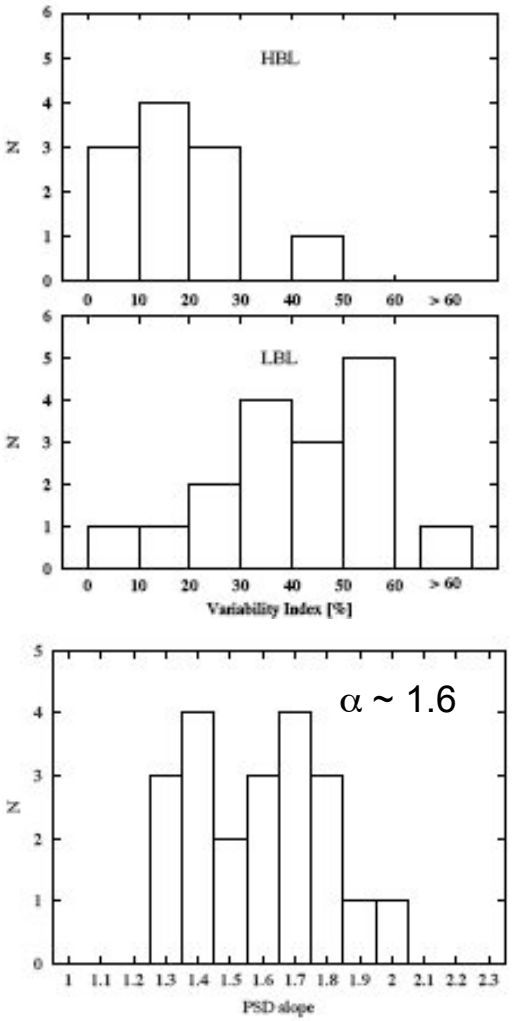




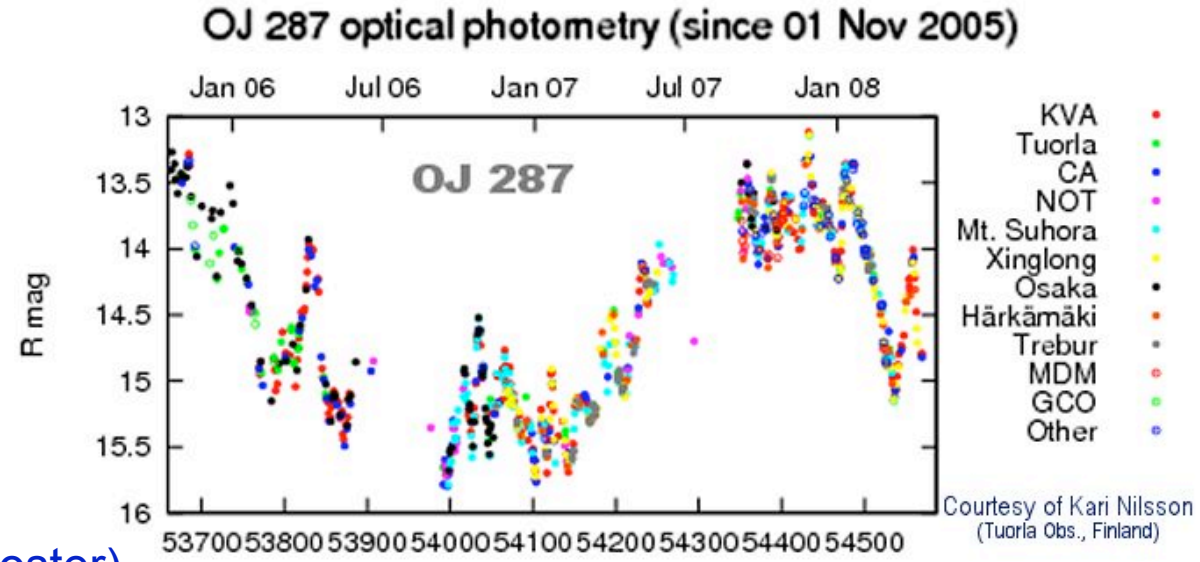
Perugia Blazar Monitoring: TSA

Variability is generally intermediate between flicker and Poissonian noise

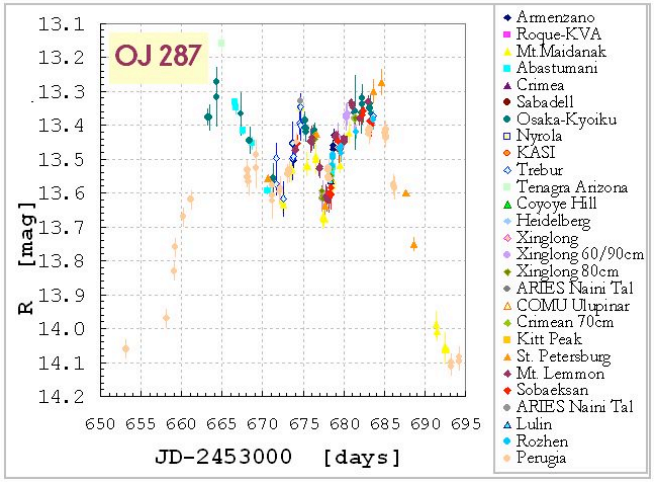


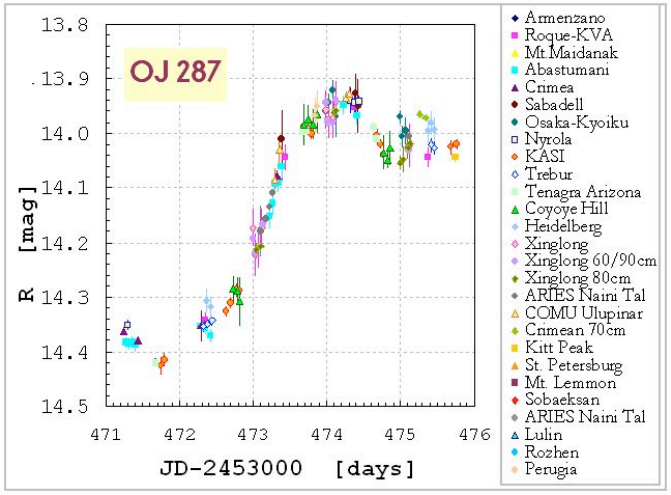


OJ 287: 2005-2008 Campaign

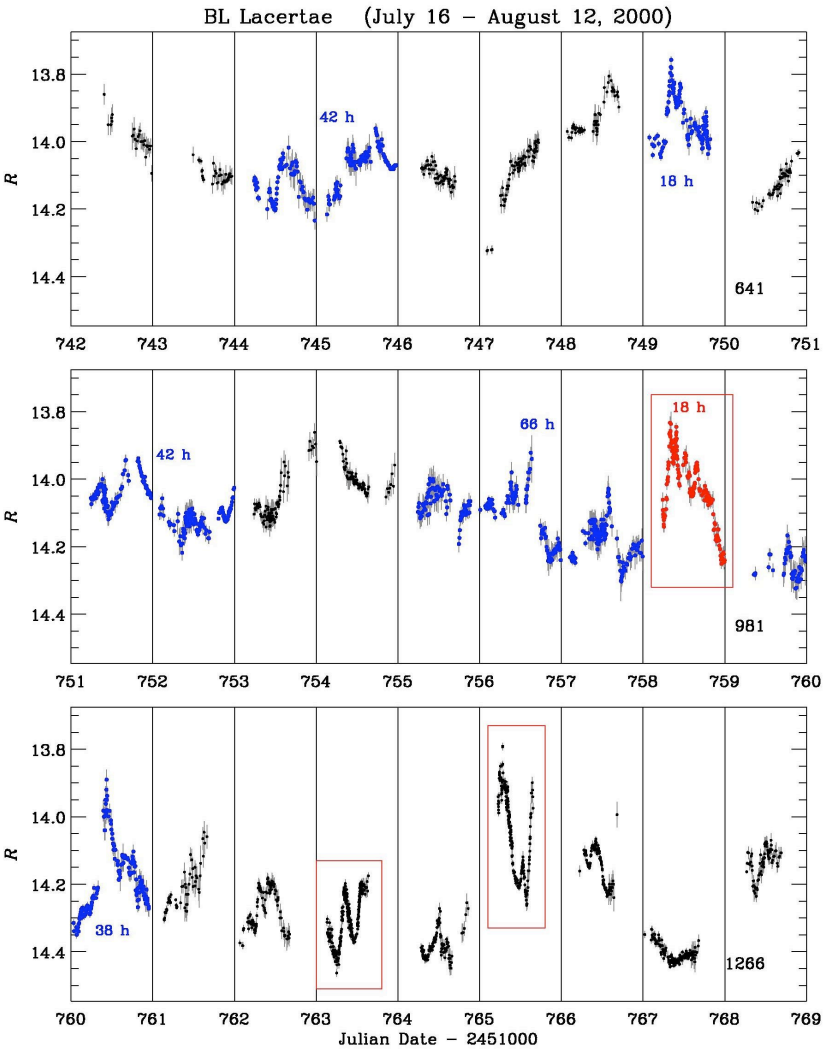


(see Ciprini's poster)





WEBT Coordinated Campaigns:BL Lac



(July 16 - August 12, 2000)

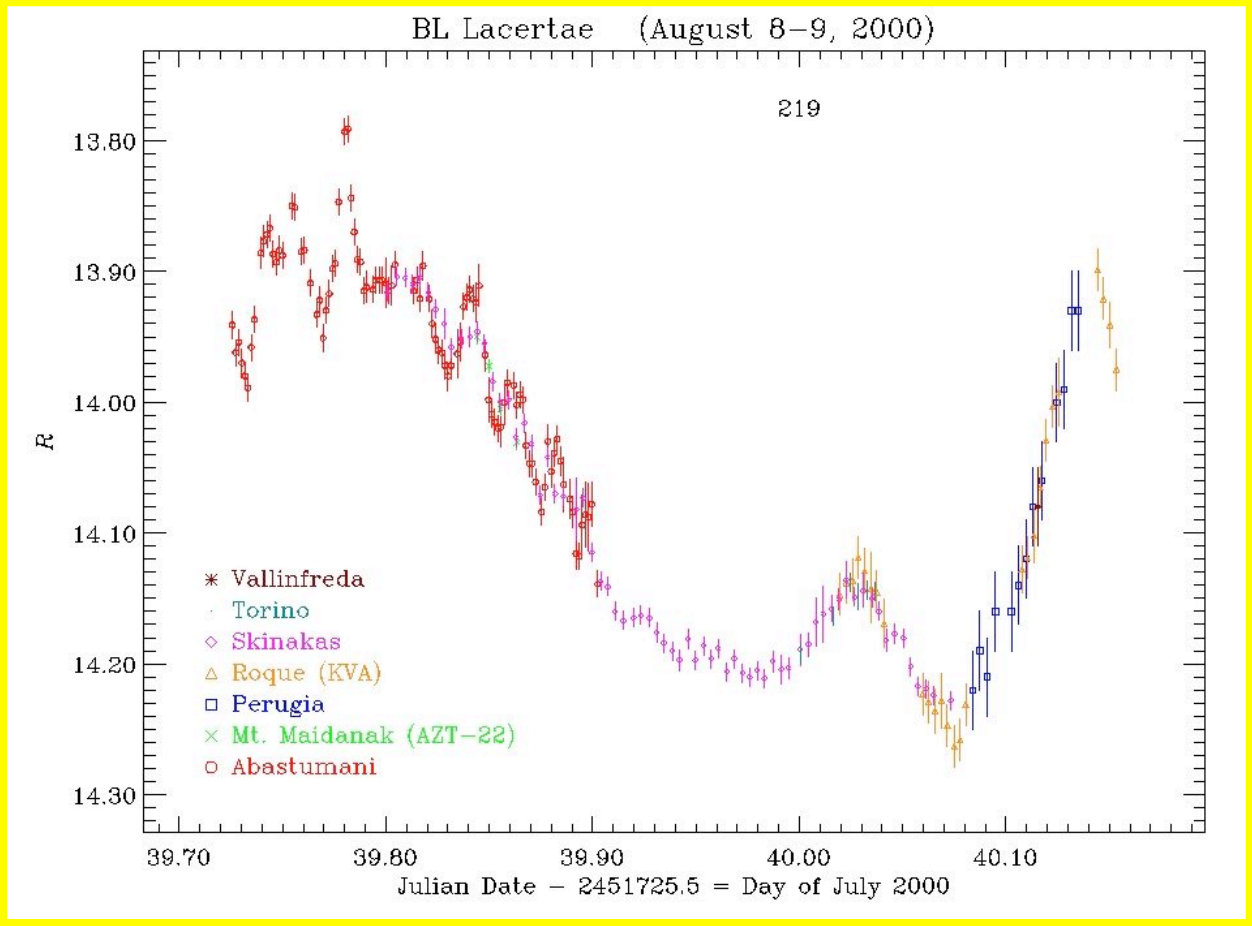
19 telescopes from Japan to Western Canada

Blue/red segments indicate the best covered periods (gaps < 4 hours)

2888 *R* final data in 27 days
107 data/day
$\Delta t(R) \sim 13$ min

Problem: paucity of observers in the Pacific area

WEBT Campaign:BL Lac 2000



7 telescopes from Uzbekistan to La Palma

219 *R* final data in 10.3 hours
$\Delta t(R) \sim 2.8$ min

0.5 mag brightness fall in ~7 h, followed by ~ 0.4 mag brightening in 1.7 h

IntraDay Variability (IDV)

- IDV was already observed in 1970s. Confirmed at end of 1980s by Miller al. (1989) (see also Carini et al. 1990)
- A complete review of the observed flux variations (across the em spectrum) of a few tenths of magnitude over the course of a day or less was given by Wagner & Witzel (1995).
- Several recent observational program have been devoted to this kind of studies (favorites also by the telescope TAC policy with respect to long term monitoring)
- Microvariability studies can help to place limits on current models of the origin of these small timescale variations and on the size of the emitting region.

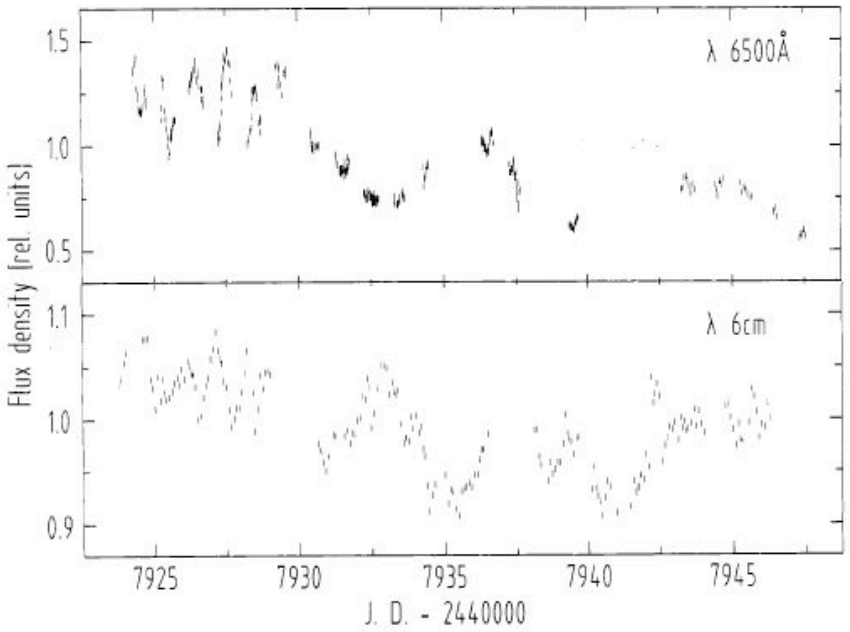


FIG. 1.—Optical (*top*) and radio (*bottom*) light curves of the BL Lacertae object 0716+714 (linear scales). In both light curves the mean flux density was set to 1, and fractional deviations from the mean are plotted on the *y*-axis.

(Quirrenbach et al. 1991)

IntraDay Variability (IDV)

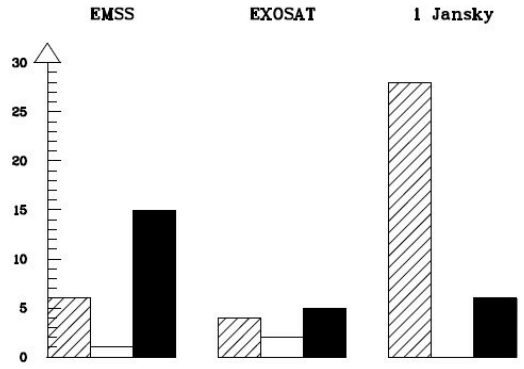
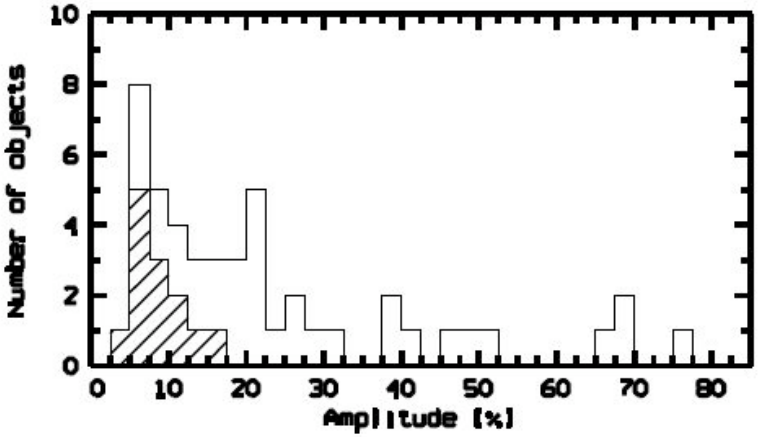


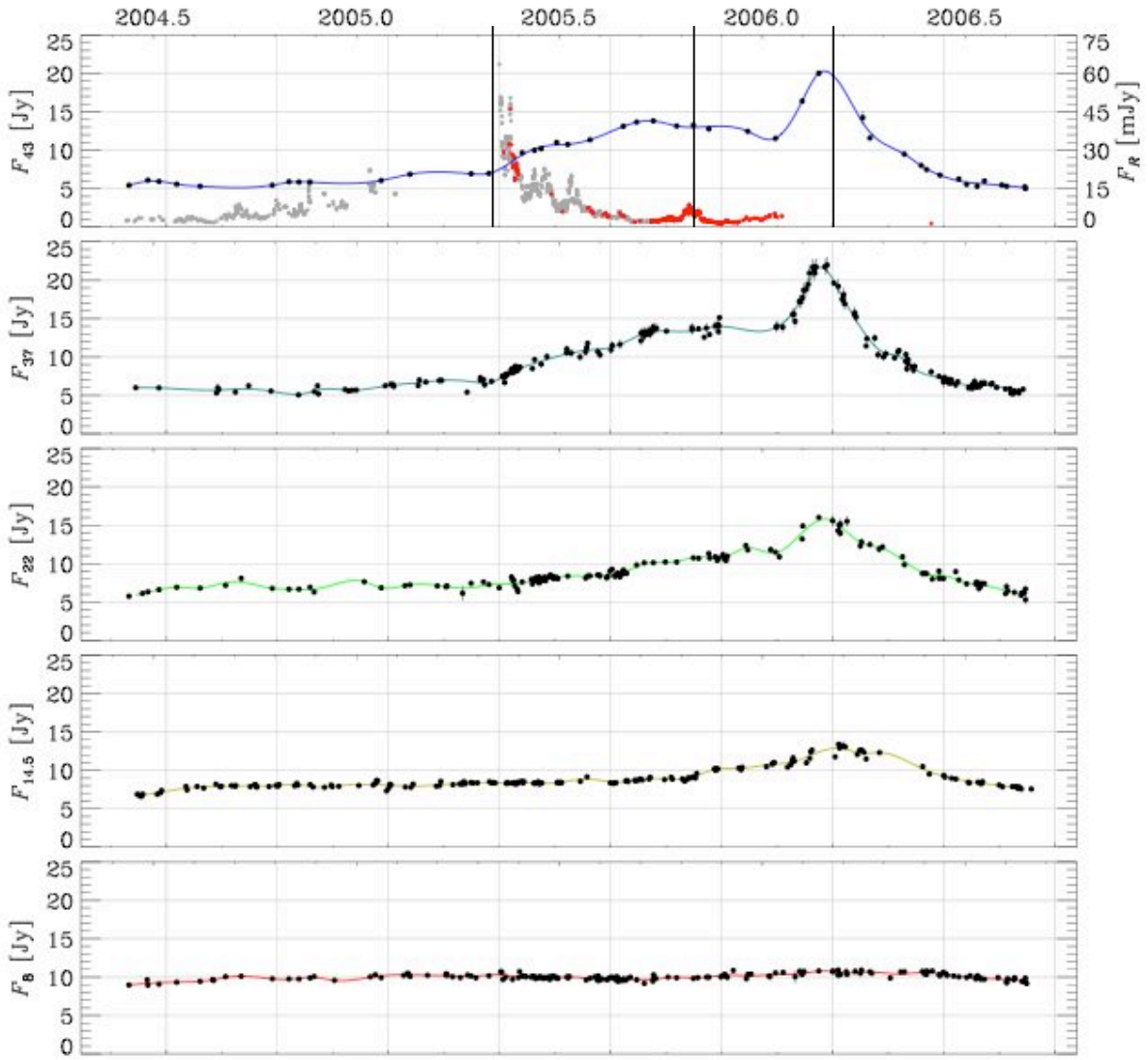
Fig. 3. Histogram showing the distribution of the sources showing IDV (shaded), the sources variable only on time-scales longer than the observing run (open) and the non-variable sources (black) among our three samples observed. Note the clear difference in the distribution between the XBL (EMSS, EXOSAT) and RBL (1 Jansky).



Heidt & Wagner 1998

- In general IDV is present at any flux level of the sources.
- Howard et al. 2004 found that the microvariability observations the objects, Mrk 421, Mrk 501, 3C 345, and BL Lacertae, were correlated with the long-term light curves, and that the presence of microvariability occurred more frequently while the flux was changing.

WEBT Coordinated Campaigns:3C 454.3



Is the 43 GHz Flare related to the optical one?

Cross-Correlation of flaring states

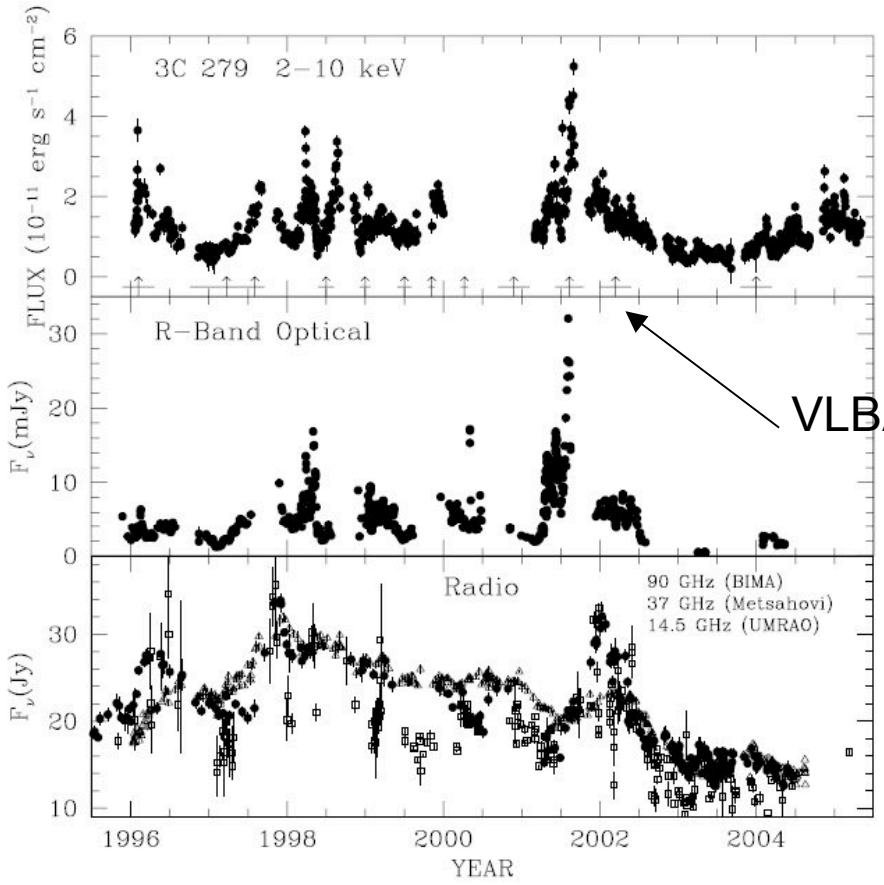


Figure 4. X-ray, optical, and radio/mm-wave light curves of 3C 279. Arrows give times of known ejections of superluminal radio knots up to 2004.3. Ejections in mid-1996 may have been missed because of gaps in the time coverage of VLBA observations. Data are from Marscher et al. (2004) and Marscher et al. (2006).

(Marscher 2006)

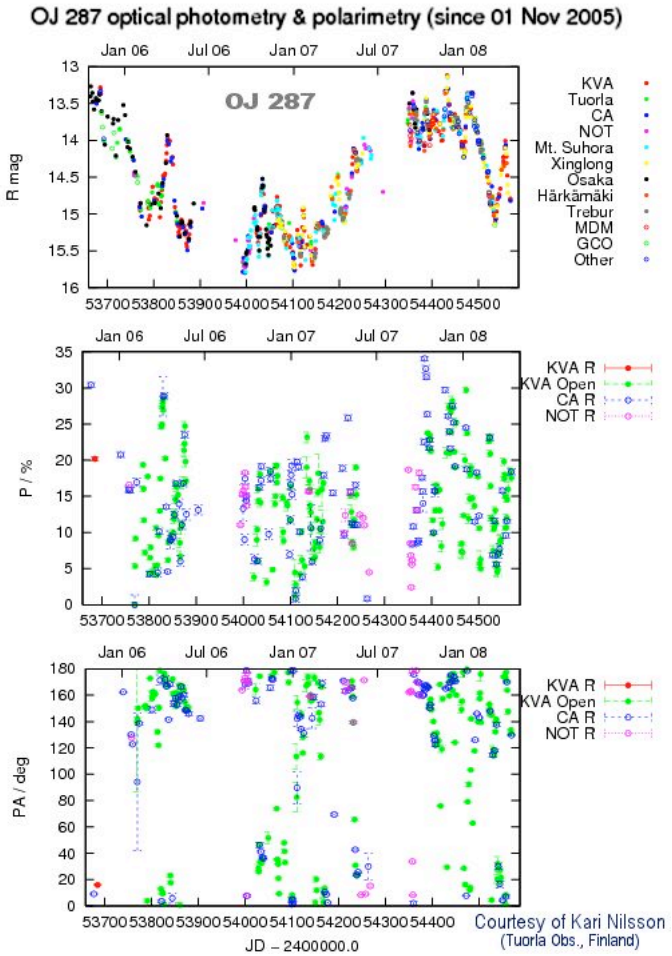
The great problem in interpreting multiwaveband light curves: **How can we associate high and low flux states at one frequency with those at another?**

Can polarization information help?

- See D'Arcangelo et al. 2007 for some recent results on PKS 0420-014
- Jorstad's talk
- Marscher's talk

Optical Polarization

- Polarization is a basic property of photons,like frequency.
- High degree (up to 30%) and variability of the optical polarization is one of the defining properties of blazars.
- However only a few polarimetric studies are available lacking a lot of information!



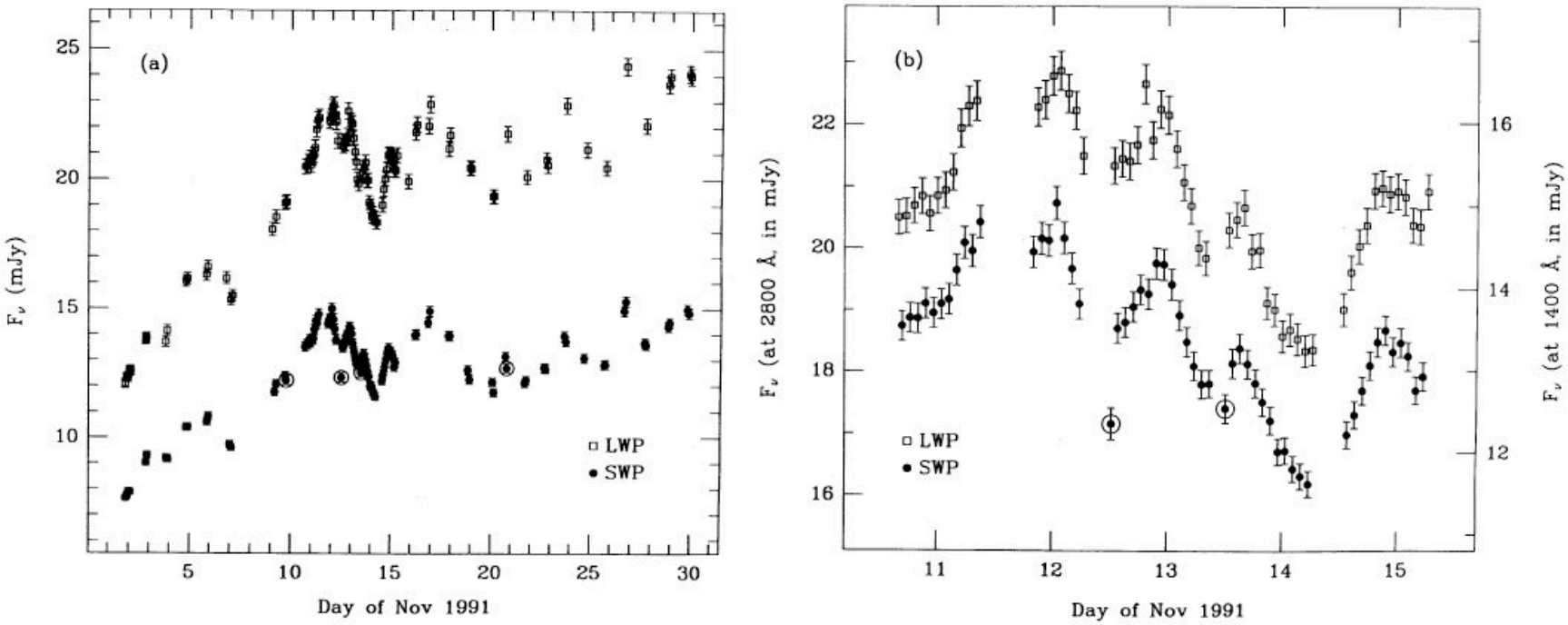
How can we increase the number of polarimetric observations of blazar?

(see e.g.. Angel & Stockman 1980, Smith 1996 for reviews)

PKS 2155 - 304: IUE Observations

Less than 20 sources have been monitored in UV (Edelson 1993)

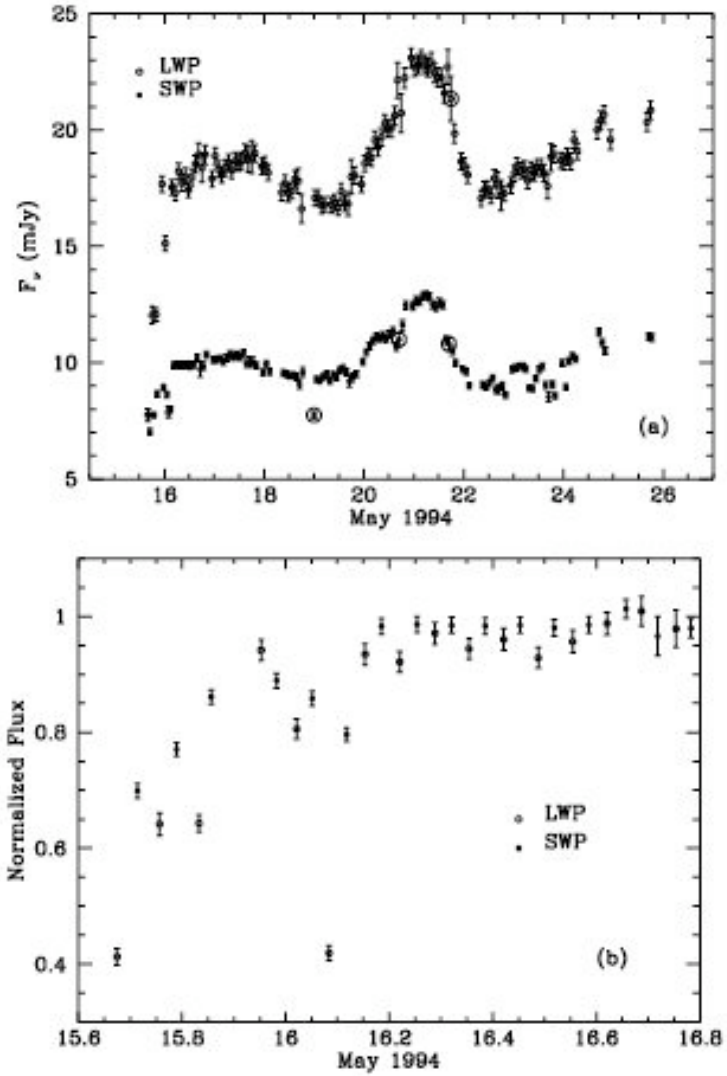
PKS 2155-304 and 3C 273have been studied in details



Urry et al. (1993)

Edelson (1992)

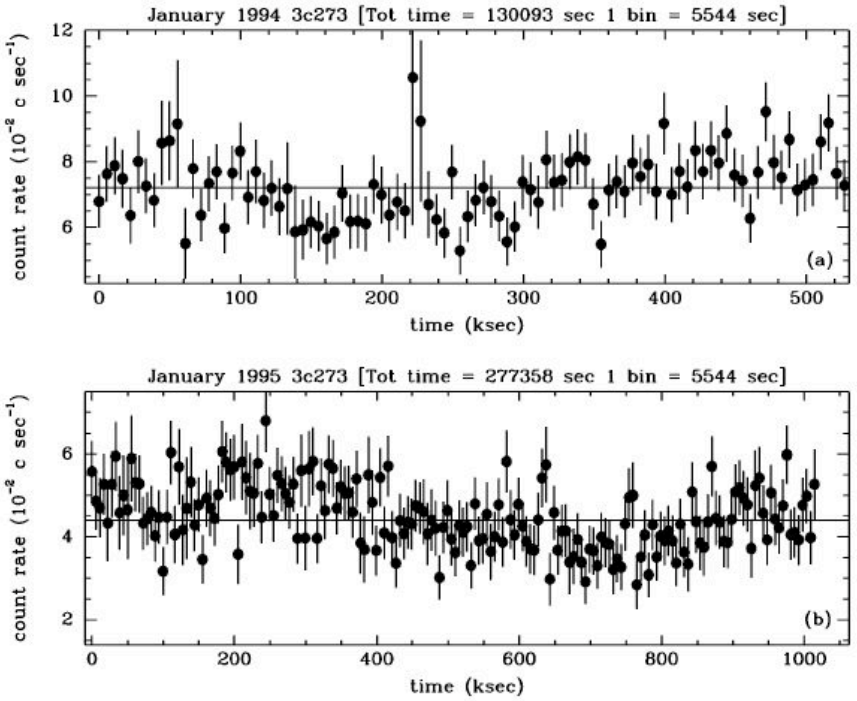
PKS 2155 - 304: IUE Observations



- **Variability is detected on timescales less than 2h**
- **more rapid variations are probably present but unresolved.**

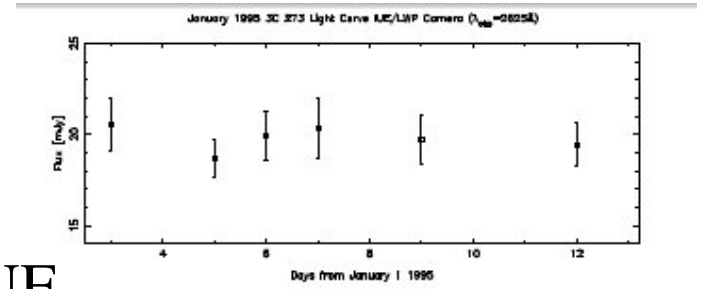
Pian et al. 1997

International Ultraviolet Explorer (IUE) and the Extreme-Ultraviolet Explorer (EUVE)

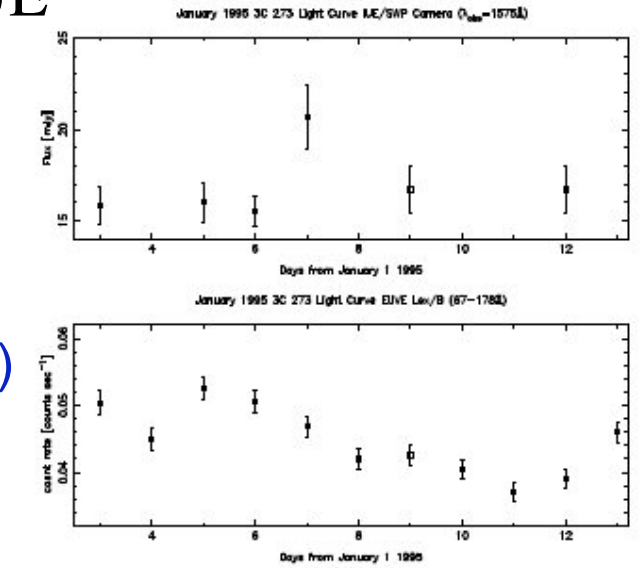


(EUVE)

IUE



(EUVE)



1994 January and 1995 January observations of 3C 273 (Ramos et al. 1997)

EUVE- Mkn 421

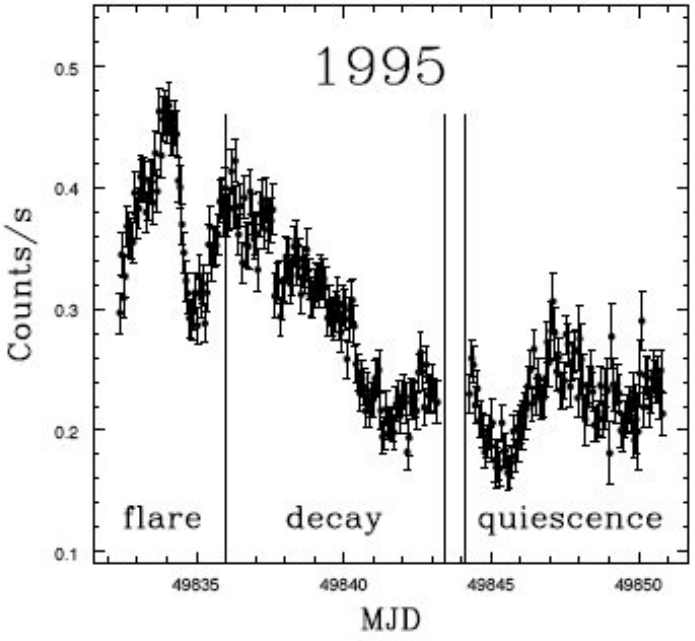


FIG. 3.—1995 April 25–May 13 Deep Survey light curve binned over one average *EUVE* orbit (~5544 s). The flare, decay, and quiescence intervals are marked.

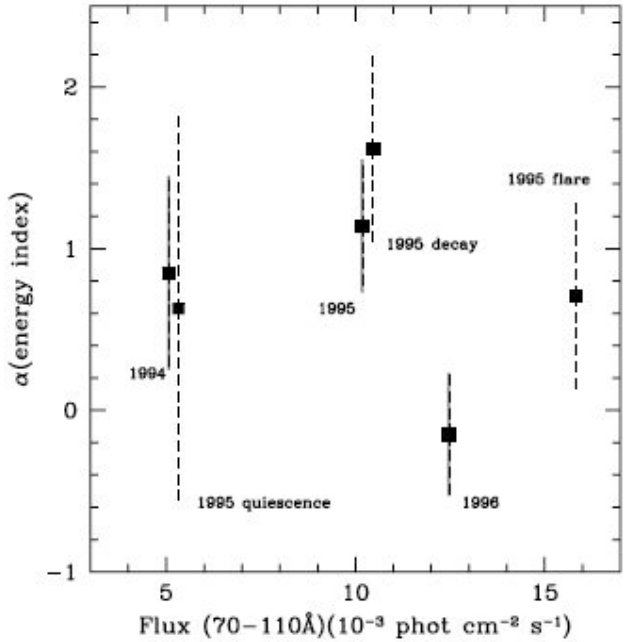


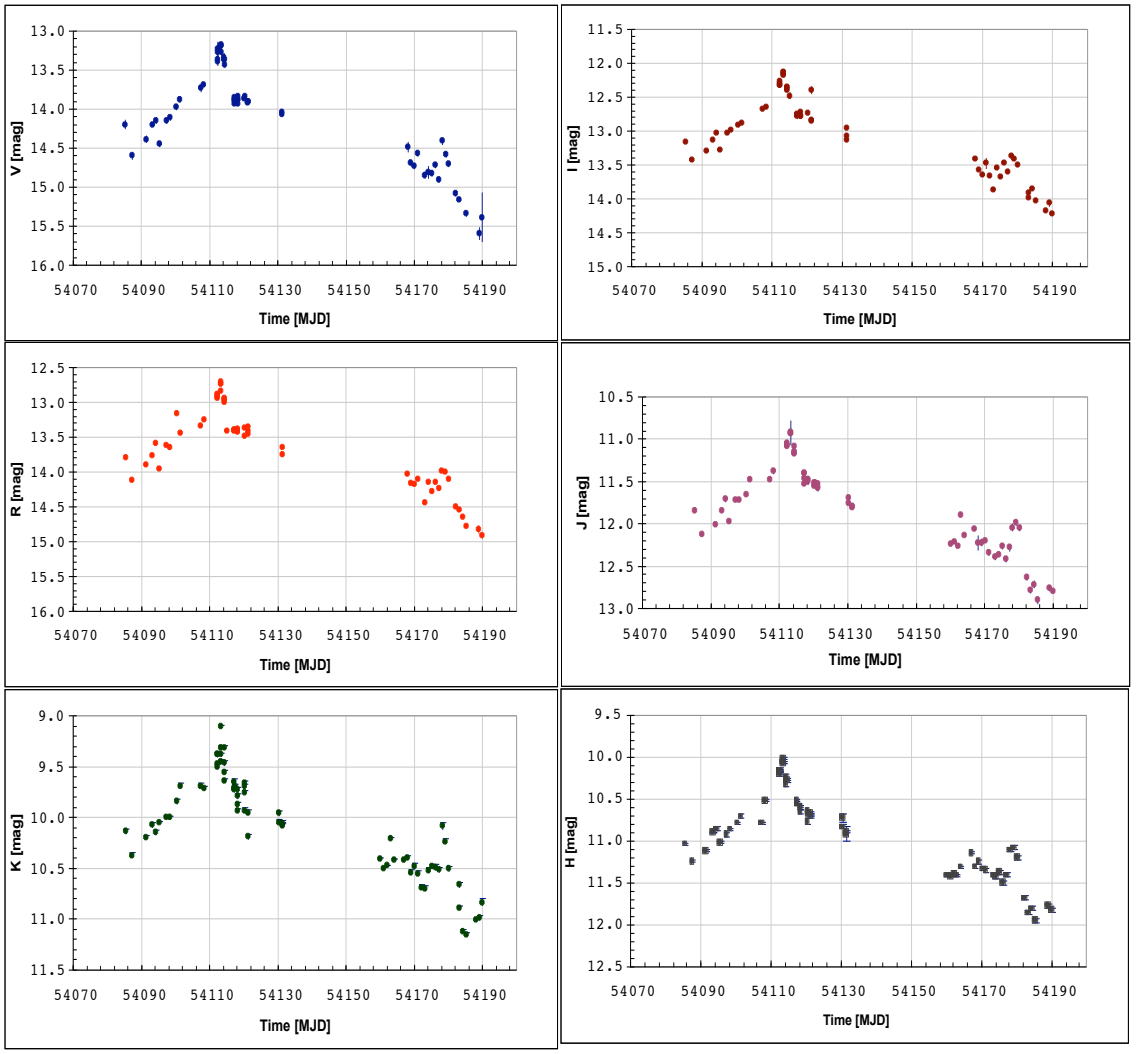
FIG. 11.—EUV source flux vs. energy index (α) for the power-law component of the power law plus Gaussian model.

- The source exhibits a flare like behavior
- The strong EUV variability is correlated with soft X-ray and TeV-energy emission

(Cagnoni & Fruscione 2001)

REM - 3C 279 during the 2007 outburst

Optical & NIR observations

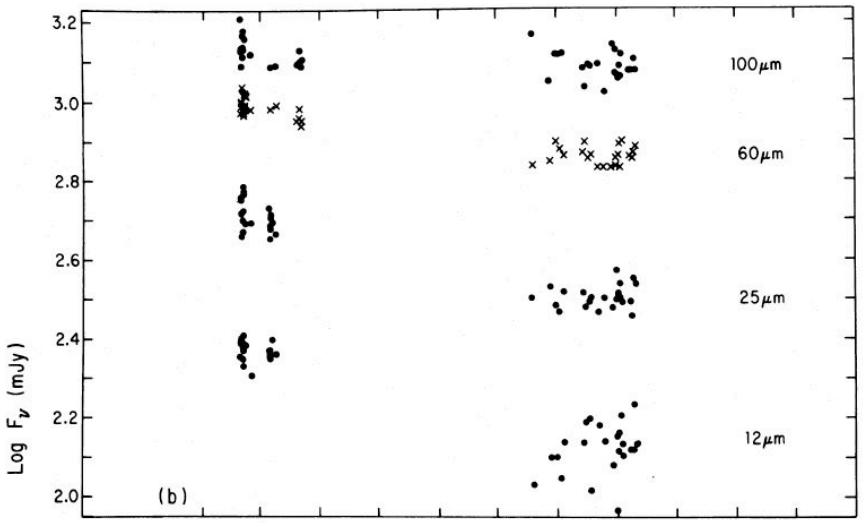


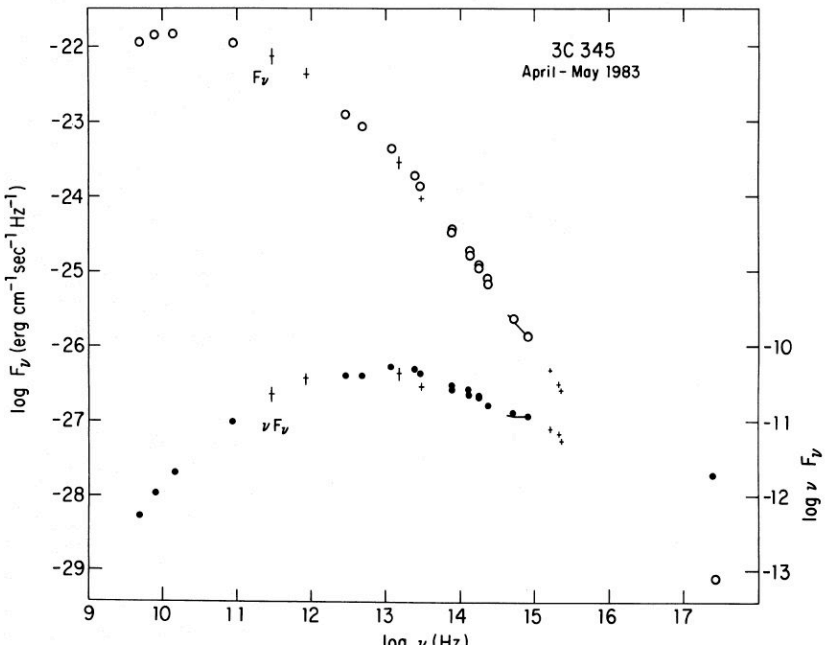
In 2005 Dolcini et al. reported a flare in PKS 2155-304 which was more prominent in the H band than in the V band

(see Impiombato et at. Poster)

Far-Infrared Variability: IRAS

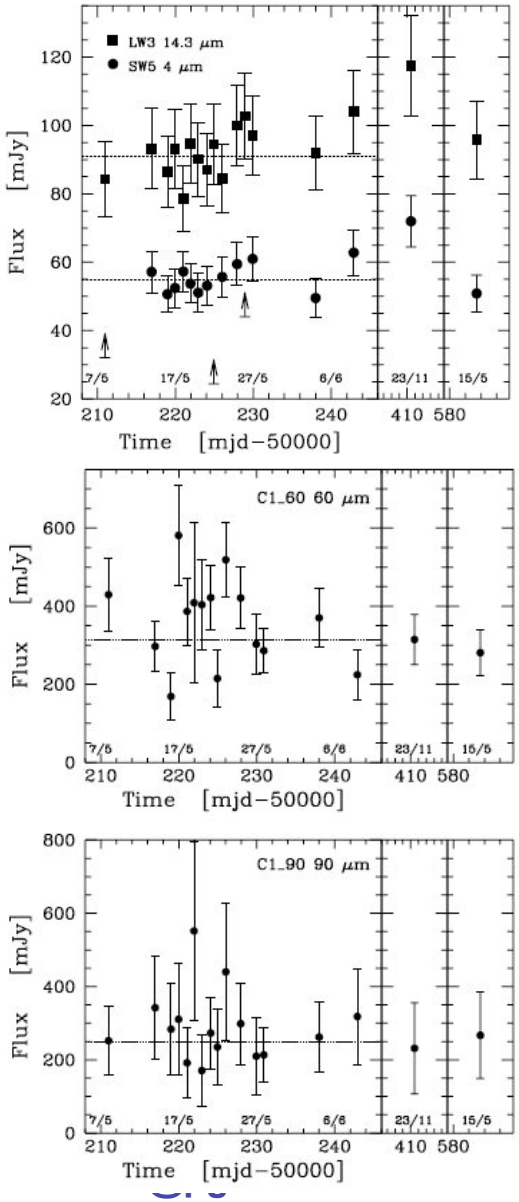
See Impey & Naugebauer (1988) for a discussion of the far infrared variability observed with IRAS)



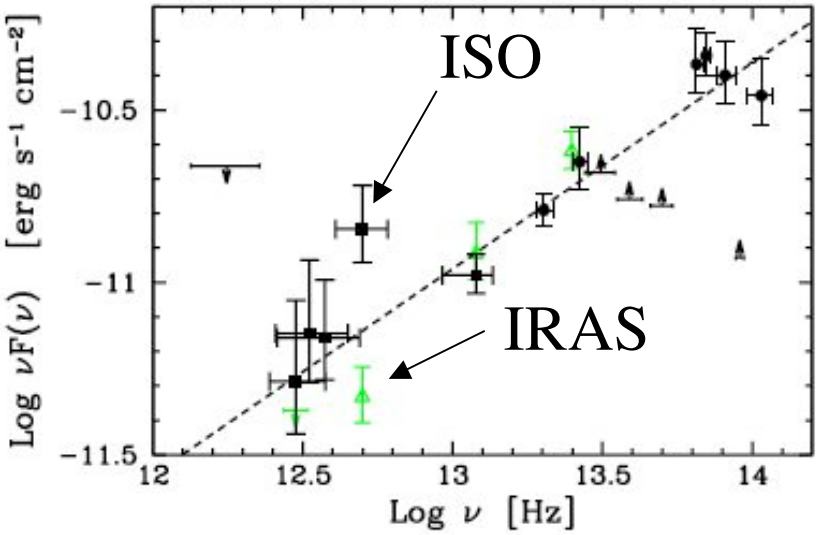


(Bregman 1986)

PKS 2155-304: ISO Observations



The infrared spectral shape of PKS 2155–304 was sampled, using 16 filters, from 2.8 to 170 mm.

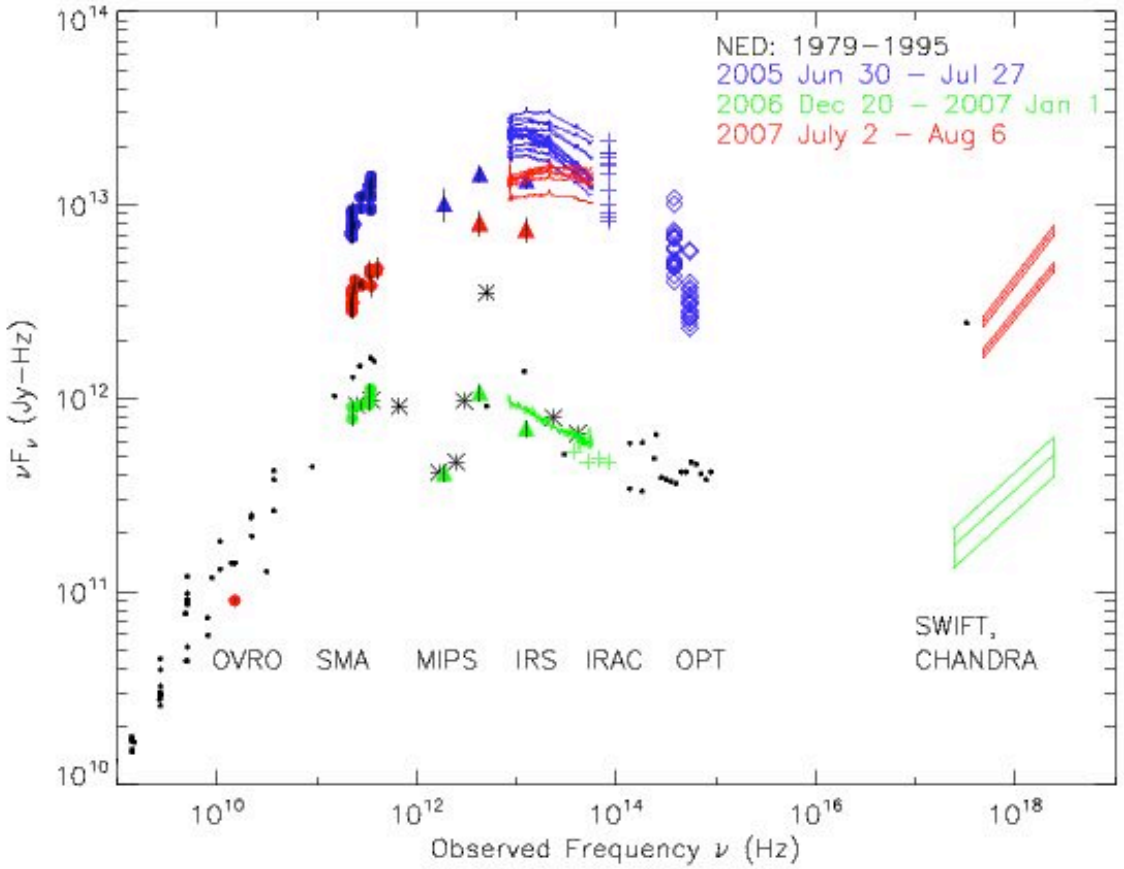


The variability of PKS 2155 – 304 in the mid– and far–infrared bands is very low (1994-1997) (Bertone (1999)

This could confirm a common behavior in blazars, for which there is a more pronounced variability at frequencies above the synchrotron peak (Ulrich et al. 1997).

Far-Infrared Variability: Spitzer

Optical data from T. Balonek (Colgate), Swift data from A. Tramacere, OVRO data from K. Grainge & A. Readhead et al., Spitzer data from A. Wehrle and P. Ogle, SMA data from M. Gurwell. NED data includes ISO data from Haas et al (*). (notice that low states observed with Spitzer and ISO are virtually identical!)



Complex and variable Structure in Far-IR!

Long term MW studies will be fundamental in next years:
Planck, Herschel, GLAST are on the ramp….

Figure will appear in Wehrle et al. 2008, in preparation.

GLAST- LAT & Blazars

- Coverage of about 20% of the sky at any instant with good sensitivity
- The entire sky will be observed every 3 hours
- Uniform exposure in survey mode
- Broad energy range (20 MeV – 300 GeV)

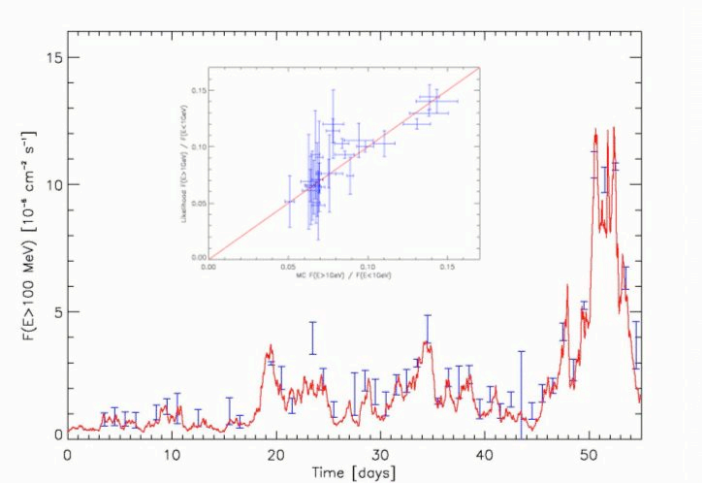
❑**Population Studies**

❑**Daily sampled LC can be easily obtained for most of the bright blazars → Variability on timescales >= 1 day can be well investigated.**

❑**Intra-day (hours) variations can be detected for the brightest gamma-ray blazars.**

❑ **Detailed spectral variation analysis and intrabands delays studies may be performed**

❑ **Multiepoch SEDs can be obtained.**



Simulation of a daily light curve as will be measured by the LAT for 3C279 . The inset displays the true F(E>1 GeV)/F(E<1 GeV) hardness ratios versus the measured ones.

MW – Planned Intensive Campaings (1-3 months)

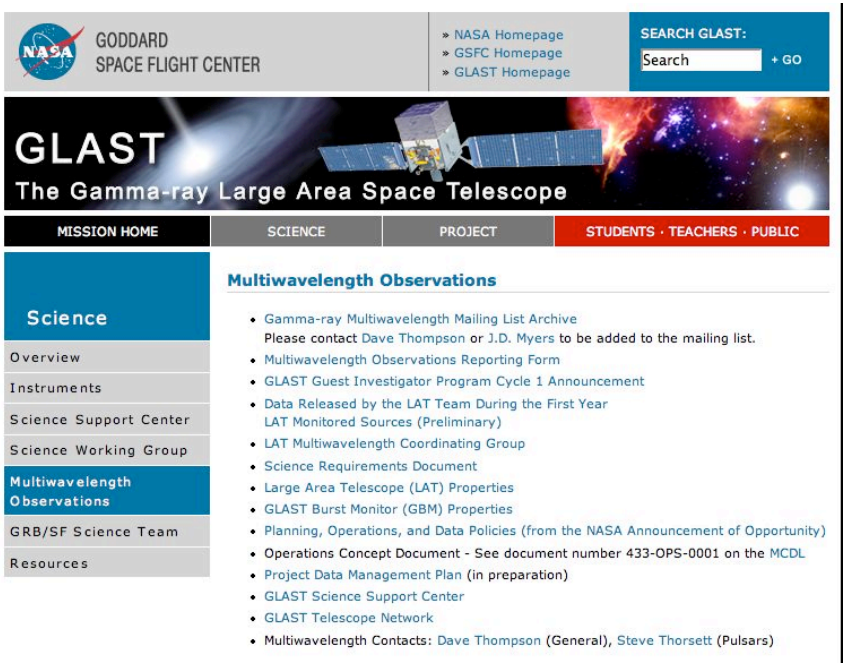
Source Name	Epoch (mm,yyyy)	Campaign Manager
PKS 0528+134	02/11,2008	B. Lott
3C 279	01,2009	G. Madejski
Mrk 501	**Ongoing**	D. Paneque
1ES 1959+650	05-10,2008	
Mrk 421	03-05,2008	
PKS 2155-304	**07- 08,2008**	**B. Giebels**
BL Lacertae	**08-09,2008**	**G. Tosti**

Other Sources of interest for MW-PIC

PKS 0735+178 , PKS 0537- 441, AO 0235+164, OJ 287, PKS 1510-08
S5 0716+714, W Com (ON 231), 3C 66A, 3C 454.3

GLAST MW Info and Coordination

- Multiwavelength observations are key to many science topics for GLAST.
- GLAST welcomes collaborative efforts from observers at all wavelengths
  - For campaigners' information and coordination, see
    - *http://glast.gsfc.nasa.gov/science/multi*
    - *https://confluence.slac.stanford.edu/display/GLAMCOG*
  - To be added to the Gamma Ray Multiwavelength Information mailing list, contact Dave Thompson:
    - *David.J.Thompson@nasa.gov*
  - For Information for Multiwavelength Observers about Working with the LAT Team see:
    - https://confluence.slac.stanford.edu/display/GLAMCOG/GLAST+LAT+Multiwavelength+Coordinating+Group

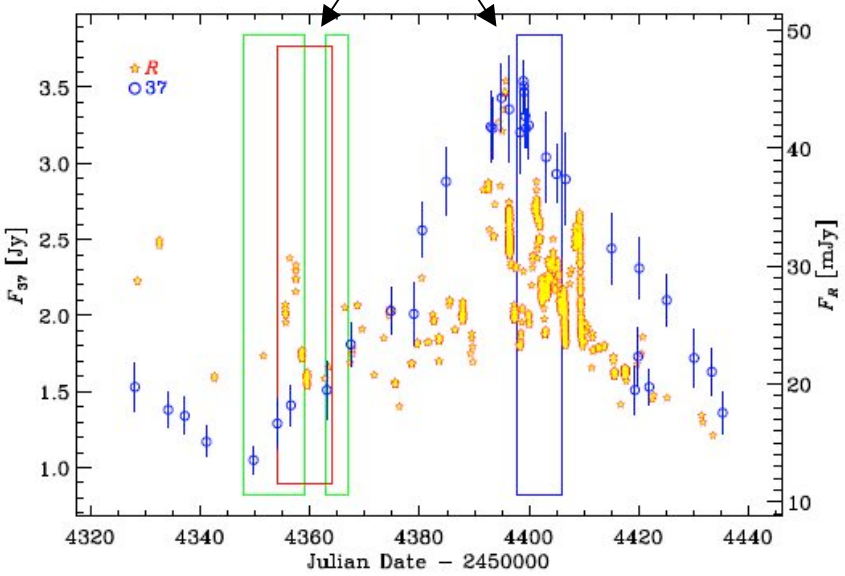


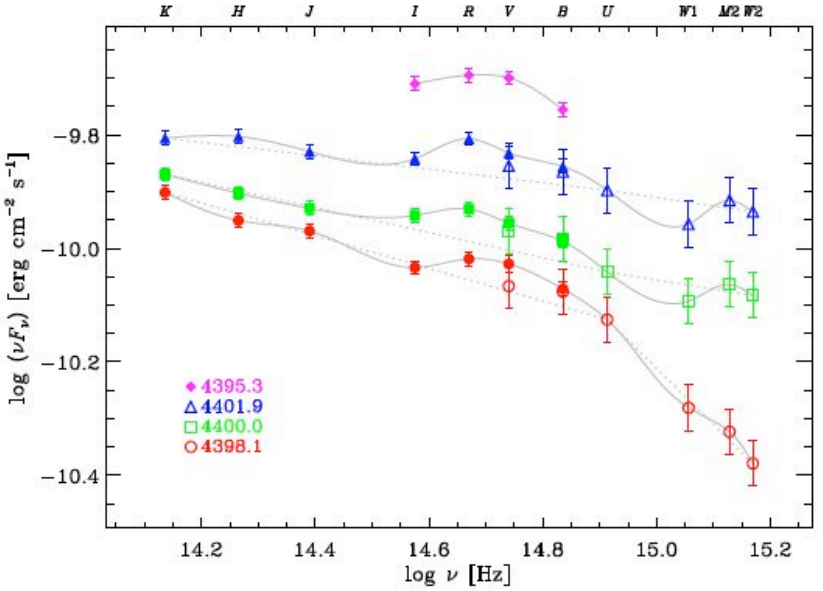
https://confluence.slac.stanford.edu/download/attachments/3169/Guidelines_Outside_Observers5.pdf

See Lucy's poster on how we can better share information and stay updated about ongoing MW campaign and observations

WEBT/GASP observations of S5 0716+71

Happy Birthday AGILE! (See Dammando's poster, Tavani's talk tomorrow)



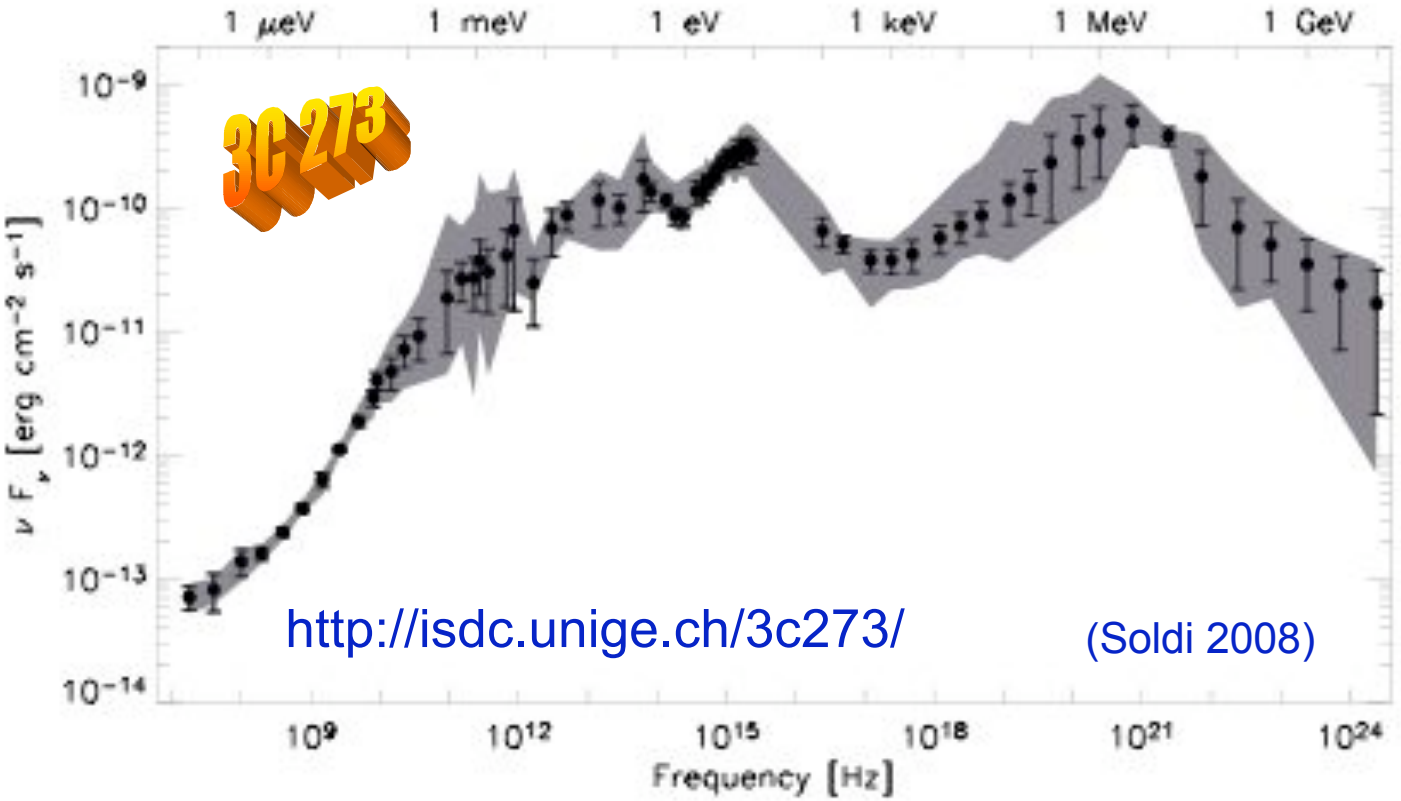


"..For the first time, a contemporaneous optical-radio outburst was followed in detail."

unexpected features: **optical excess and the UV drop-and-rise.**

(Villata et al. 2008)

The complex variability pattern of the SED of a Blazar



http://isdc.unige.ch/3c273/ (Soldi 2008)