Blazar Light Curves (LC) Simulation (...work in progress)

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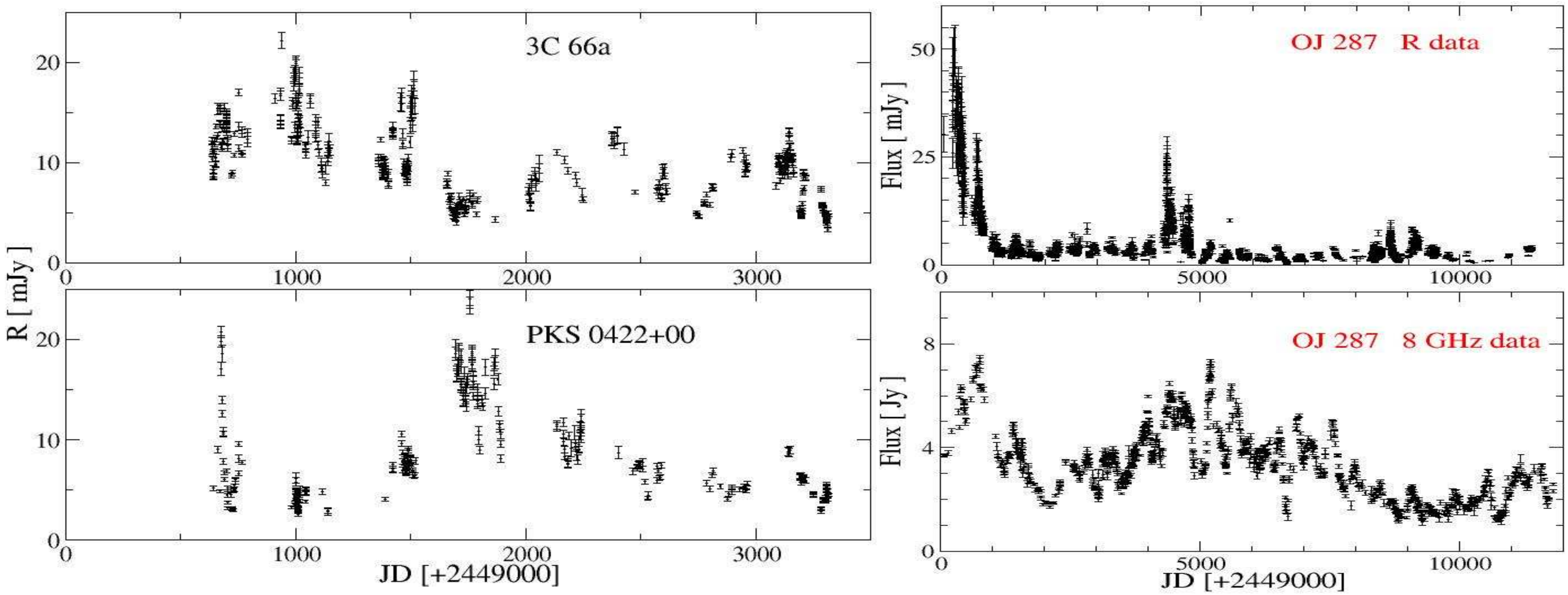
Blazar LC simulation – Introduction

Goal of this work is to provide a “realistic” appresentation of the temporal and spectral variability of Blazars, to be included in the DC2 sky simulation, in order to have a better understanding of what could be the GLAST contribution to:

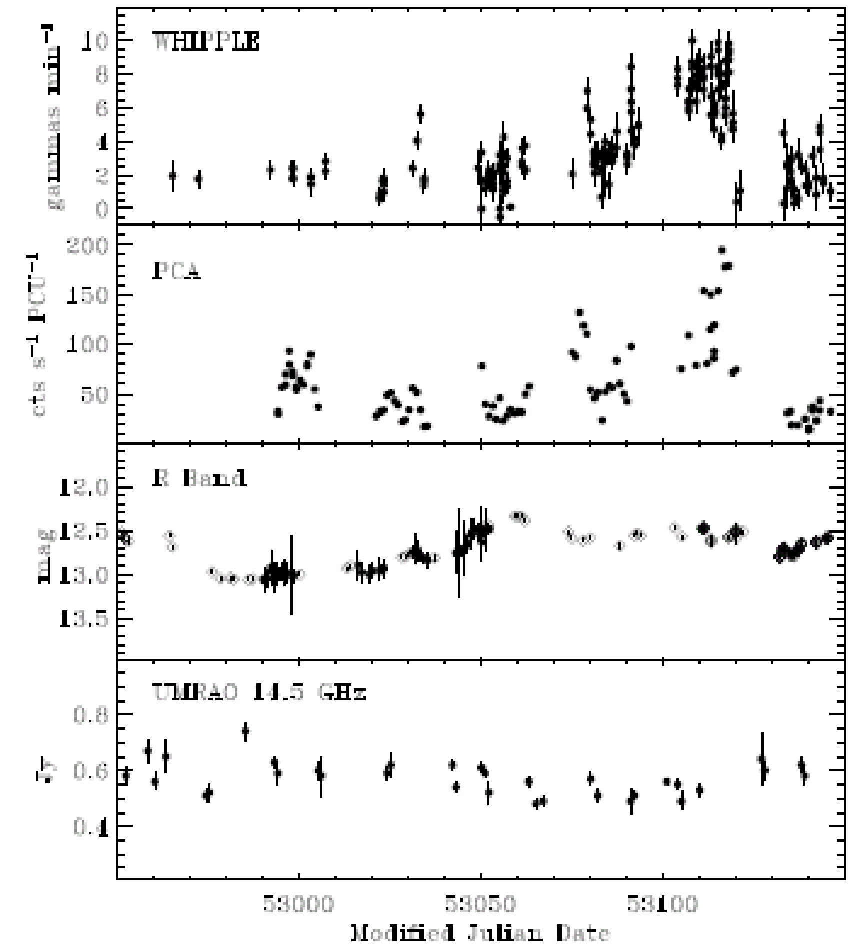
- Variability studies (single source, populations etc.)
  - Definition of good Variability indexes, Source Classification based on variability, etc
- Spectral analysis
- Emission models discrimination
  - It could be useful to have a review of all proposed models and a summary of the critical tests that can be done with GLAST
- Development of Quick-Look temporal-spectral analysis tools

Blazars LC simulation – MW observed “LC”



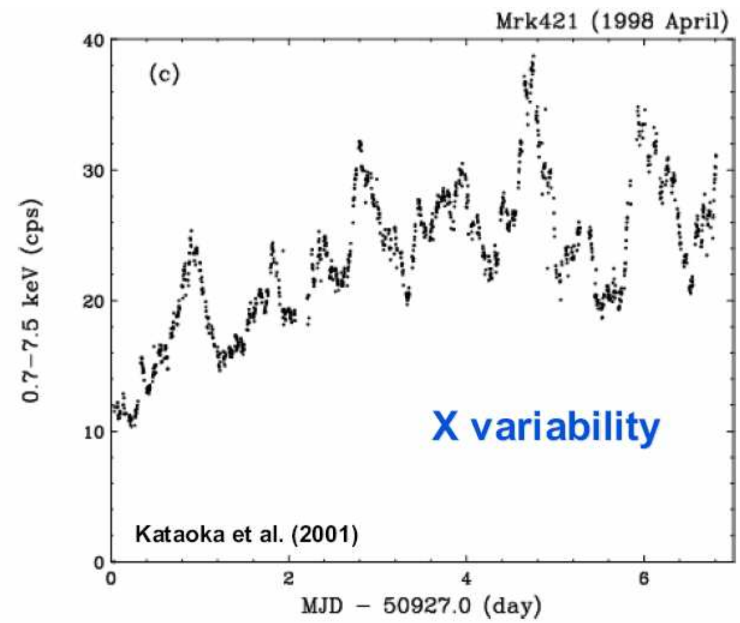
- AGN optical variability is often characterized by great outbursts spaced out by long periods of lower emission. The distribution of flux values is similar to a Poissonian.
- Radio variability presents frequent peaks and long period trends. Flux values distribution is near to a Gaussian.

Blazars LC simulation – MW observed "LC"

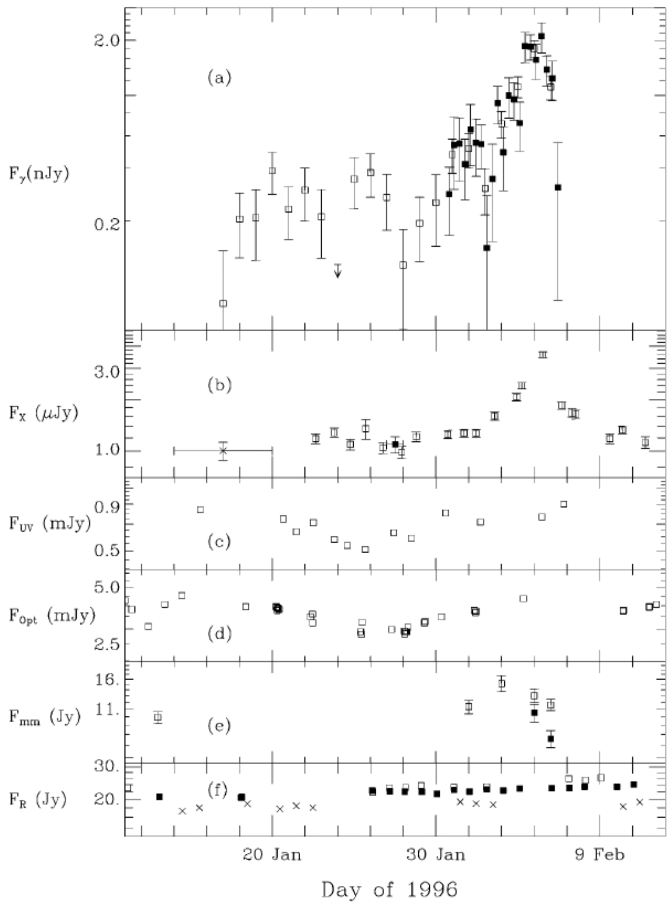


Mkn 421 2002/2003
Blazejowski et al. (2005, astro-ph/0505325)

- the LC show flares with varying amplitudes on a wide range of timescales
- some TeV flares have no counterparts at longer wavelengths,
- Possible interbands time-lags



Blazars LC simulation – MW observed “LC”



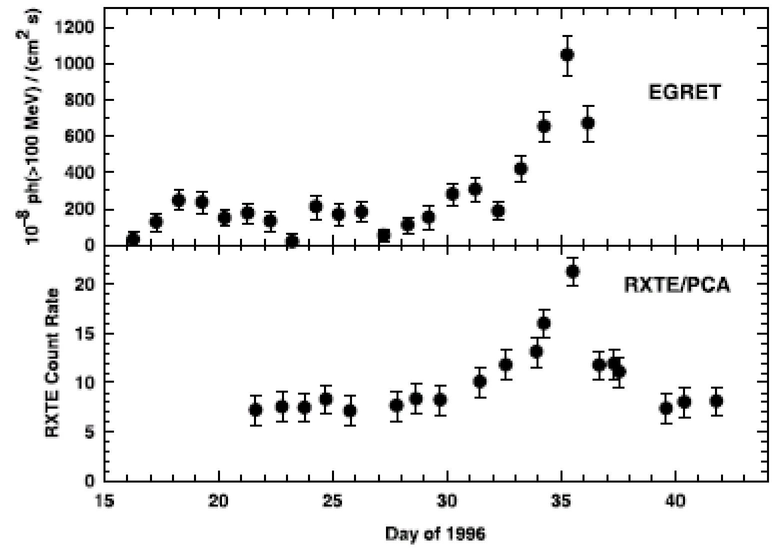


FIG. 5.—3C 279 light curves for early 1996 in γ-rays and X-rays

3C 279
Hartman et al. (2001)

3C 279
Wehrle et al. (1998)

- the LC show flares with varying amplitudes on some range of timescales
- Possible interbands time-lags

Blazars LC simulation – MW LC models

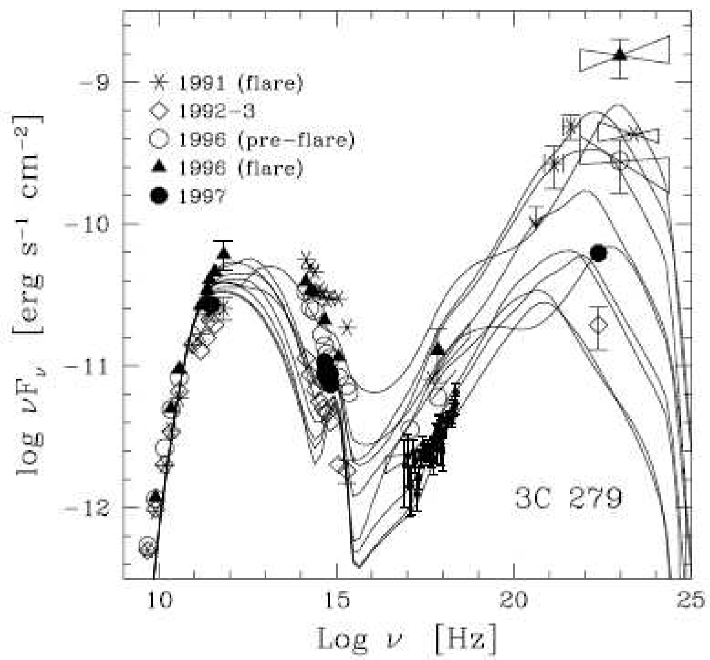


Figure 8. Example of the spectra predicted by our model compared with the SED of 3C 279 corresponding to different observational campaigns.

3C 279 – internal shock
Spada et al. (2002)

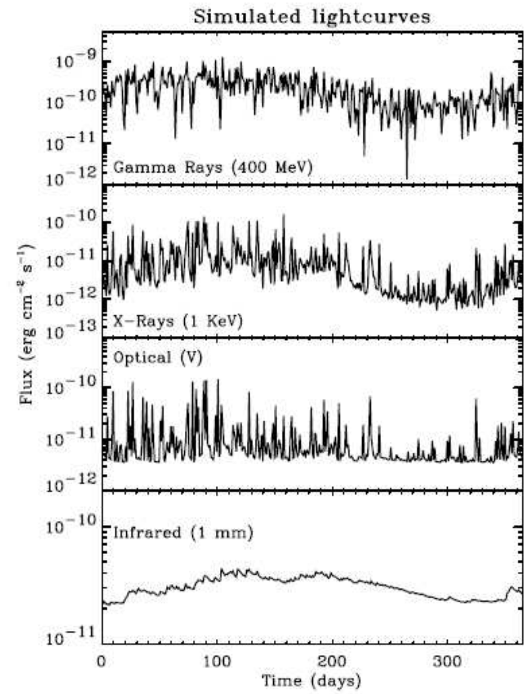


Figure 9. Light curves at different frequencies. The γ-rays, X-rays and optical light curves vary on different time-scales, with a minimum value of few hours, and the IR one varies on a time-scale of a few months.

Blazar flares can be be related to
- **internal shocks in the jet (e.g. Spada et al. 2001)**
- **ejection of relativistic plasma into the jet (e.g. Mastichiadis & Kirk 1997).**
- **magnetic reconnection events in a magnetically dominated jet (Lyutikov 2003)**
- **etc,.**

Blazars LC simulation – observed spectral evolution

"Hysteresis loops" were observed...

X-ray

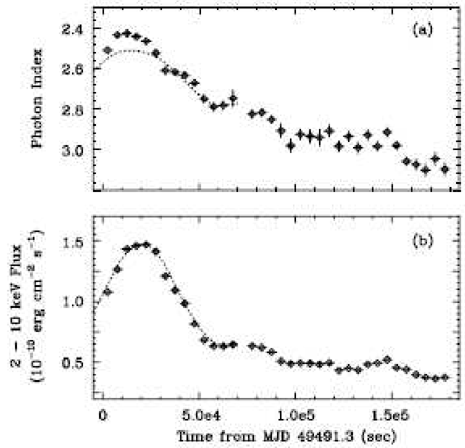


FIG. 2.—Detailed time history of PKS 2155−304 during the 1994 May campaign. Each data point corresponds to an equal 5 ks interval and all SIS/GIS data are combined for the fit. The model is a power law with free absorption. (*a*) Variation of the differential photon index in the 0.7–7.5 keV band. The dashed line is a model prediction as described in § 3. (*b*) Variation of the 2–10 keV flux in units of 10^{-10} ergs cm^{-2} s^{-1}. The dashed line shows a model prediction discussed in § 3.

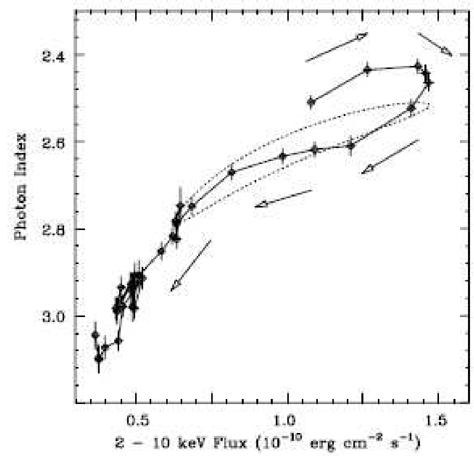
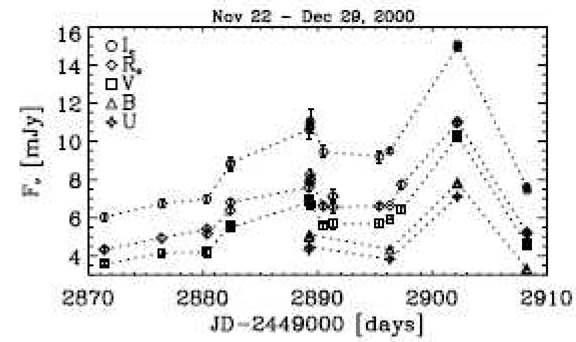


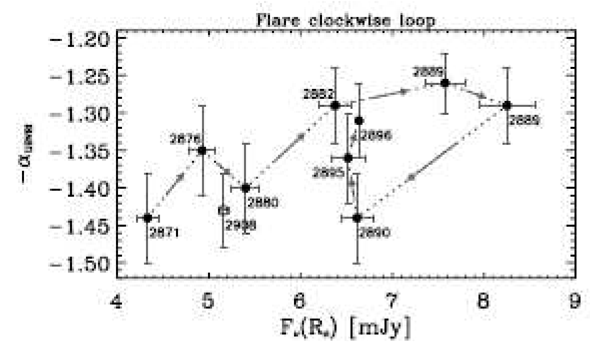
FIG. 3.—Evolution of the X-ray spectrum of PKS 2155−304 in the flux vs. photon index plane. Arrows indicate the evolution during 1994 May observation. A "clockwise loop" is clearly seen. The solid line connects the observational data, while the dashed line is the model prediction given in § 3.

PKS 2155-204

Kataoka et al. (2000)

Optical





GC 0109+224

Ciprini et al. (2003)

.............not easy to be interpreted

Blazars LC simulation – Methods

- How do we reproduce the observed temporal-spectral features?

  - Time-dependant emission models

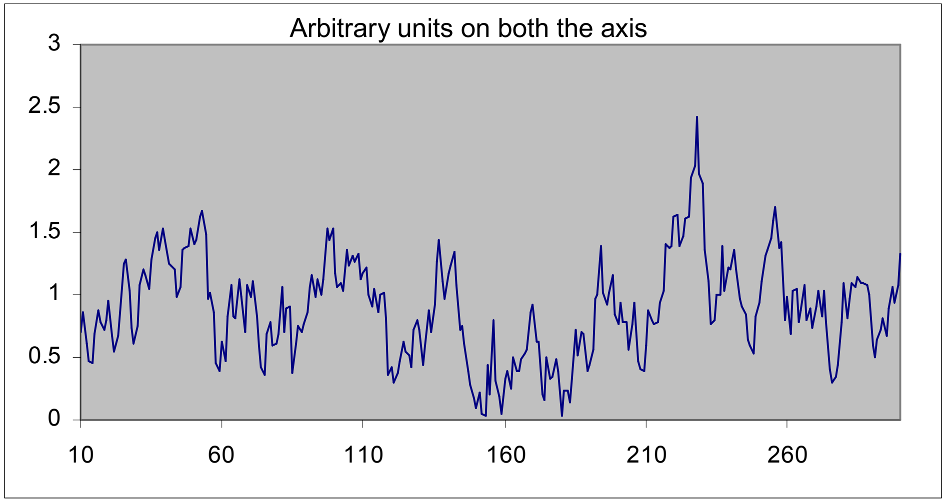
  - Phenomenological models
    - Temporal simulation
      - Simple red noise model [AR(1)]
      - PSD inversion
      - Shot noise model (..in progress)
      - Non linear models (..in progress)
    - Spectral Simulation
      - Hysteresis loops
      - Other features...

Blazar LC simulation – Simple Red noise model

``Red noise'' is often used to refer to any linear stochastic process in which power declines monotonically with increasing frequency. It can be represented by a AR(1) process:

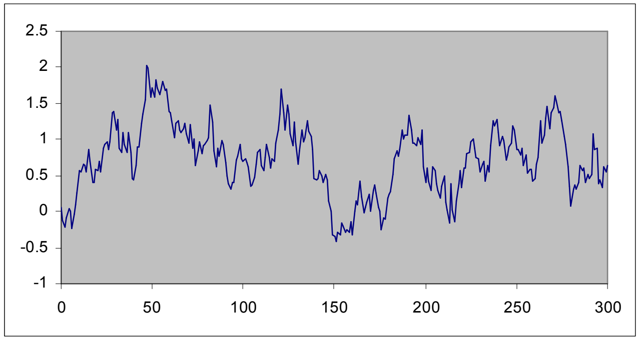
$$u_t = \gamma(u_{t-1} - u_0) + \alpha z_t + u_0$$

Where:
u_0= mean
γ,α=constants
z_t=is a gaussian-distributed white-noise process

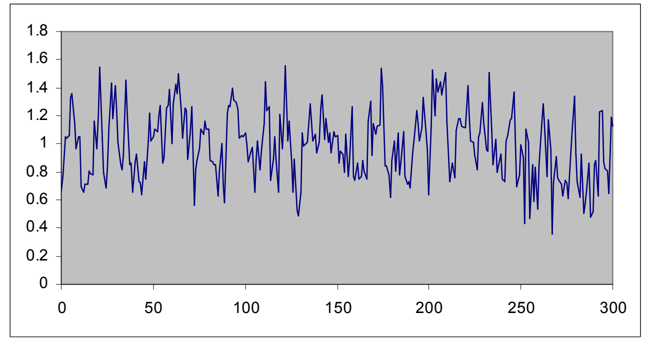


γ=0.85
α=0.2
u_0=1

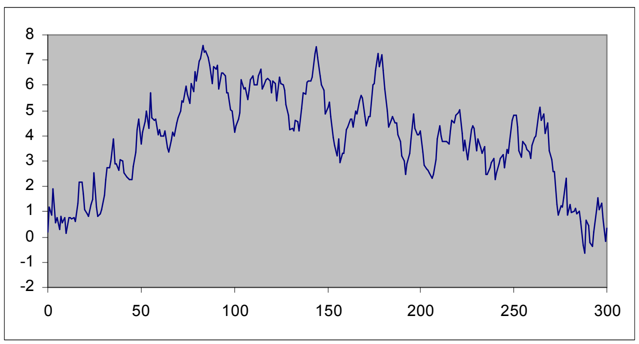
Blazar LC simulation – Simple Red noise model



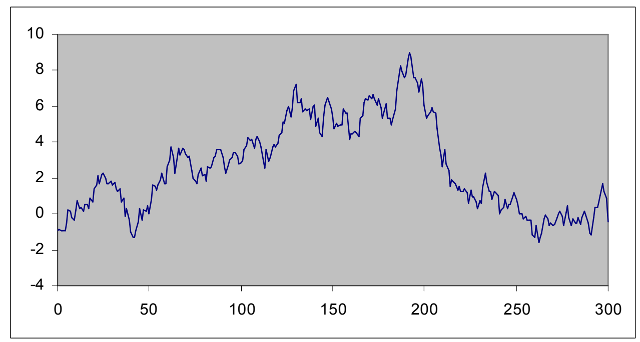
γ=0.95
α=0.2
u_0=1



γ=0.5
α=0.2
u_0=1



γ=0.99
α=0.5
u_0=1



γ=0.99
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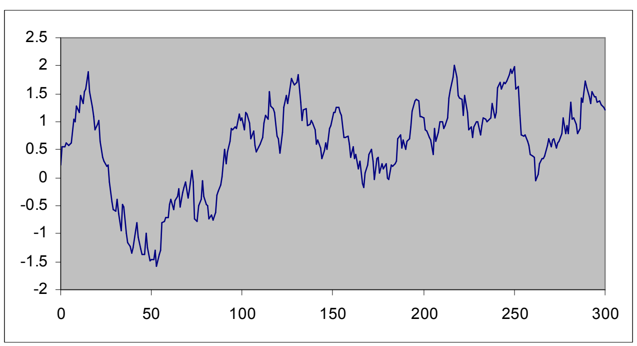
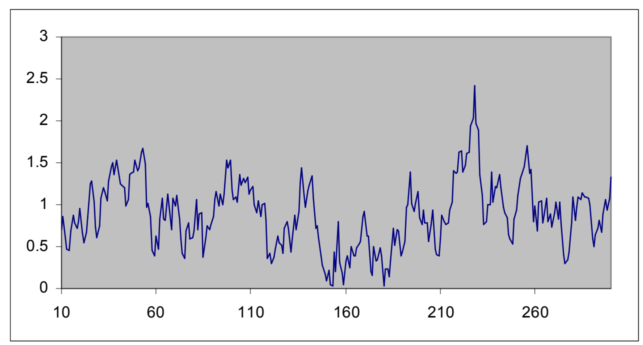


γ=0.99
α=0.2
u_0=1



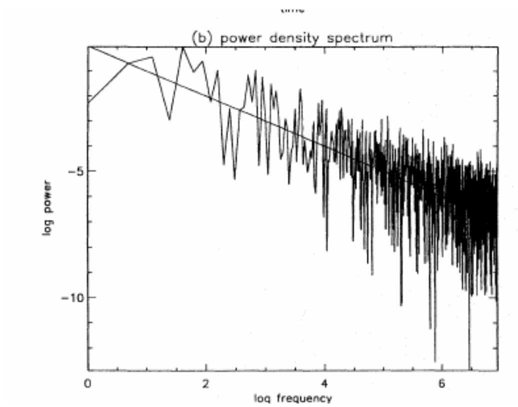
γ=0.85
α=0.2
u_0=1

Arbitrary units on both the axis

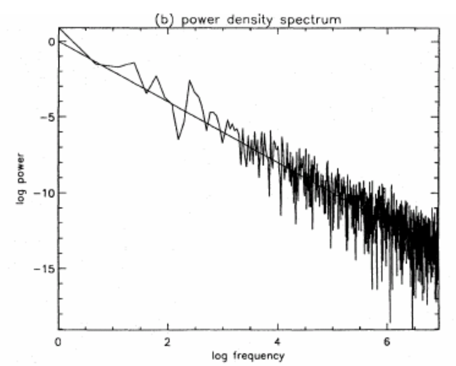
Blazars LC simulation – PSD inversion

Spectral analysis of LC is an important tool because it allows the variance of a time series to be separated into contributions associated with different time scales. It thus helps to understand better the physical processes, which generate the variability recorded in a time series.

Light curves of blazars appear to behave randomly at all the frequencies, from the radio to the high energy rays. They are usually characterized by some kind of noise that produces a power-law power spectrum (PSD)



$$PSD(f) \propto f^{-\alpha}$$



– **Blazars and AGN**

Radio: $\alpha \approx 2$ (Hufnagel & Bregman, 1992)

Optical: $\alpha \approx$ 1-2 (Fiorucci et al., 1999)

X: $\alpha \approx$ 1 - 2 (Lawrance & Papadakis, 1993)

$\alpha \approx$ 2 - 3 blazars (Kataoka et al., 2001)

.......red noise

Blazars LC simulation – PSD inversion

We simulate light curves using the metod of Timmer & Konig (1995), which is superior to the Done (1992) method (superposition of sine waves with random phases) in that the power spectral amplitude is drawn from a χ^2 distribution as should be the case for a noise process. With this method it is posssible to generate LC starting from any PSD.

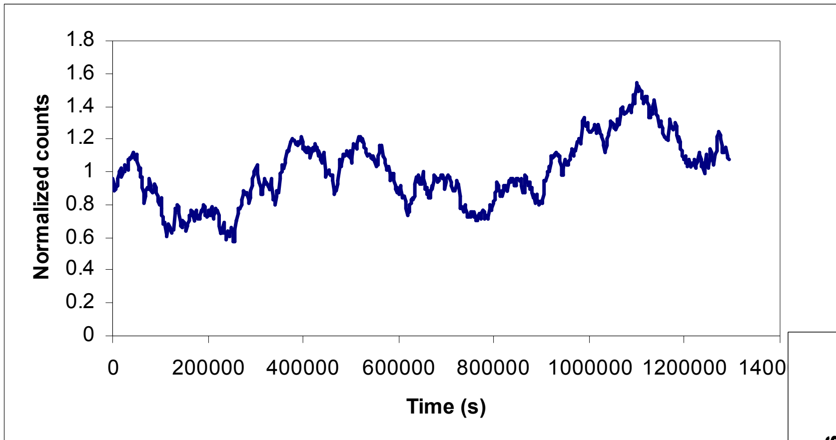
First we specify a PSD model to be used for LC generation.
We can use:

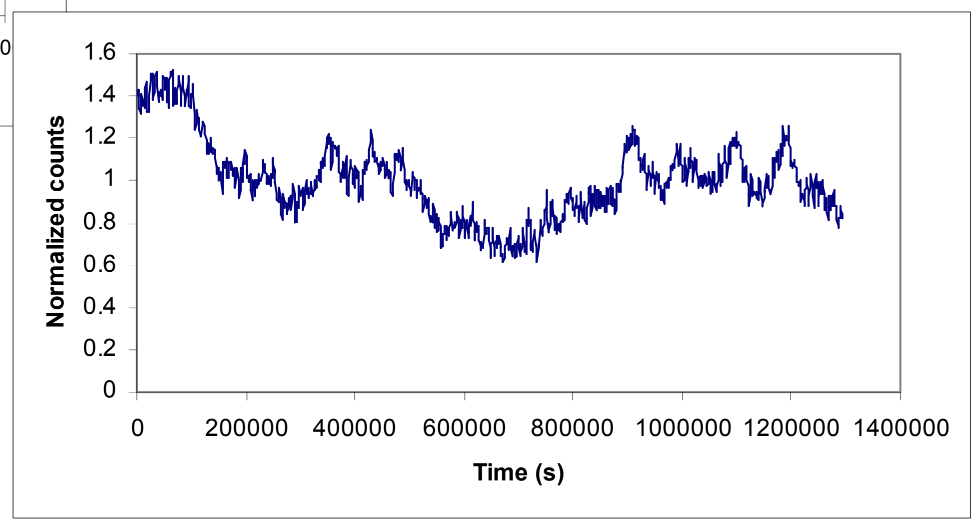
- **Simple Power-Law**
- **Broken Power-Law**
- **Letho (1989, shot noise)**

.......Other forms are possible.

Blazars LC simulation – PSD inversion

The LC were obtained with a simple PL having α = 1.95 and an oversampling factor of 8, to take into account that any observed segment of LC includes components having much lower frequencies (red-noise leakage).



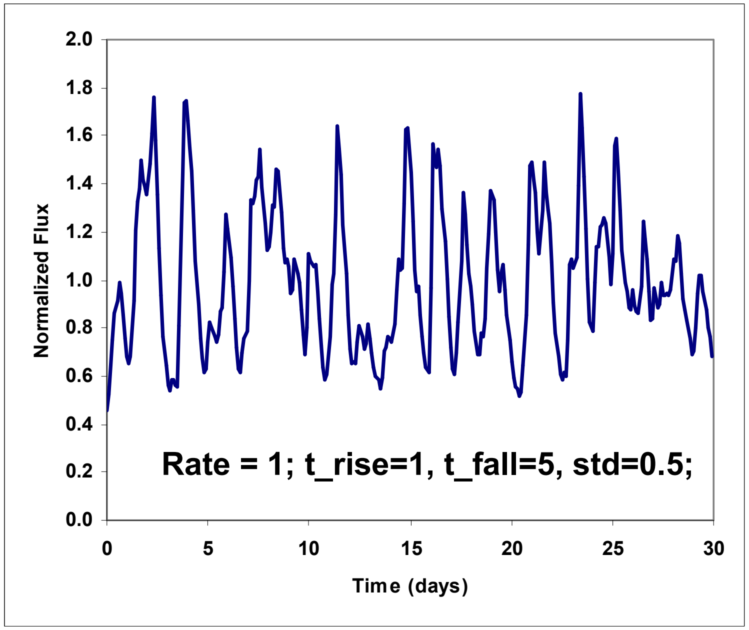


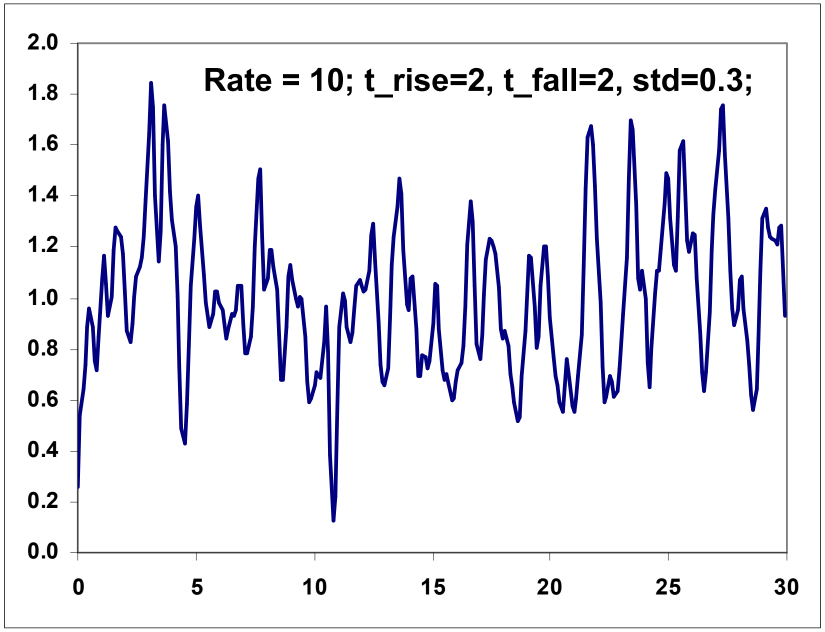
INPUT parameters:

- PSD(f) indexes
- Variance of the output LC
- Duration
- Sampling interval
- oversamplig

Blazars LC simulation – Shot noise model

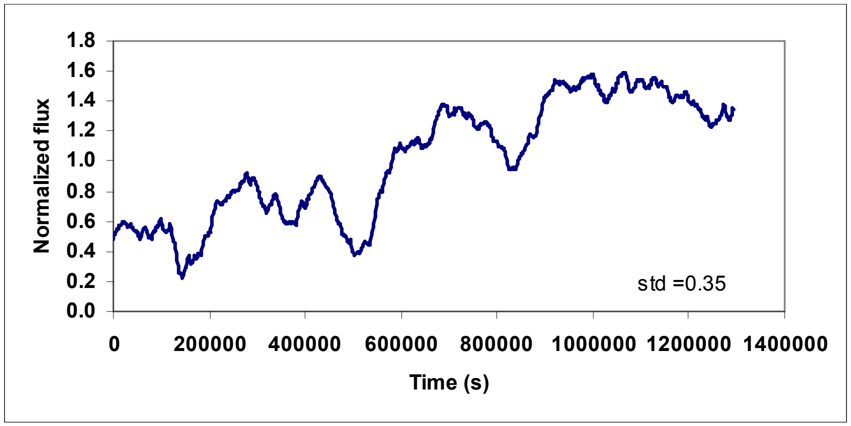
The LC were obtained using the method described by Terrel & Olsen (1972). The value of the flux in each time point is the superposition of a number of pulses having a poissonian distribution. The input parameters are: pulse rate, pulse lengths and pulse shape, variance. The pulse shape used here is that adopted by Norris et al. (1996) to fit GRB LC. The amplitude of each pulse was drawn from an exponential distribution.
Other pulse models are possible.



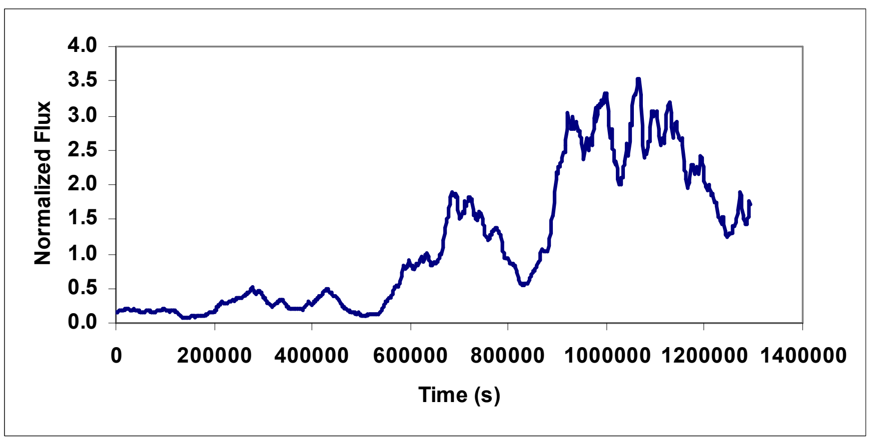


Blazars LC simulation – Non Linear LC

The LC were obtained with α = 2.5 and an oversampling factor of 8, to take into account that any observed segment of LC includes components having much lower frequencies (red-noise leakage).



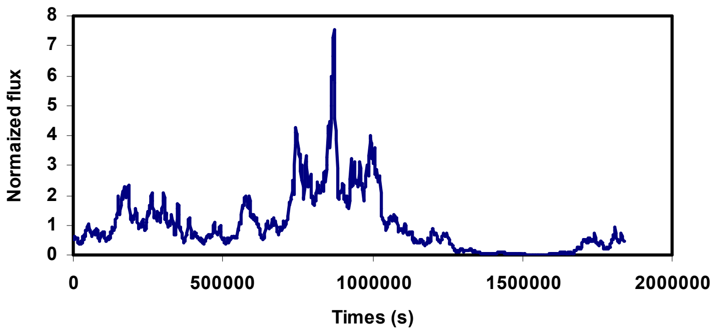
Original PSD Inverted LC
(gaussian distribution of the flux)

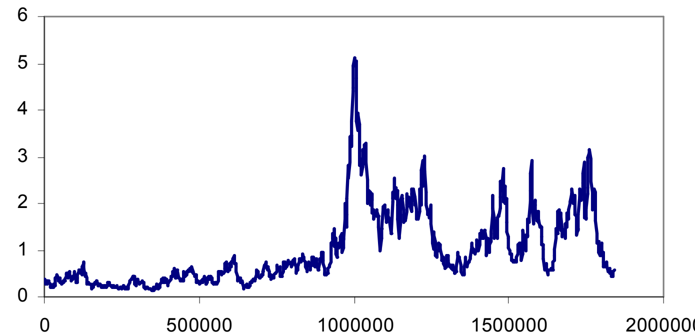


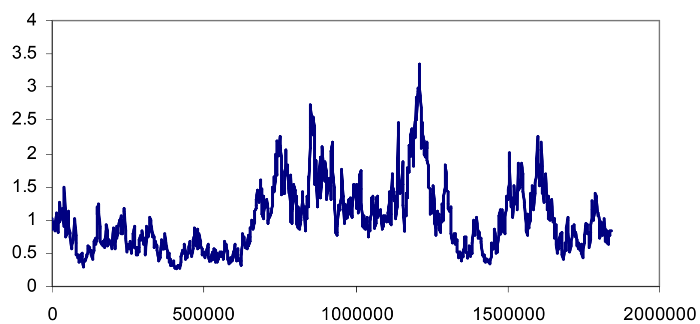
Non linearity is introduced by a Exponential transformation of the LC (Uttley et al. 2005)

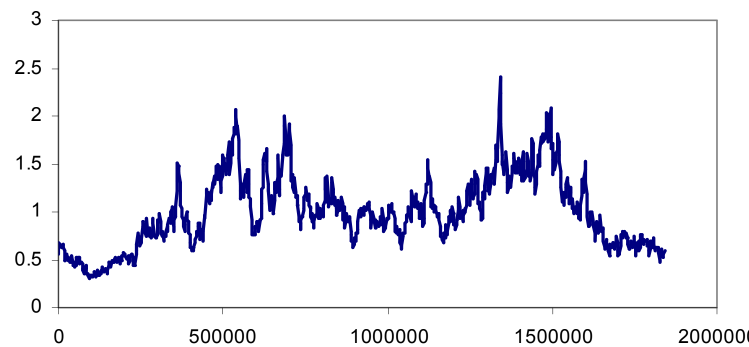
Blazars LC simulation – Non Linear LC

The original LC were obtained with α =1.6-2.0 and an oversampling factor of 8, and large stds, and then an exponential transformation was applied









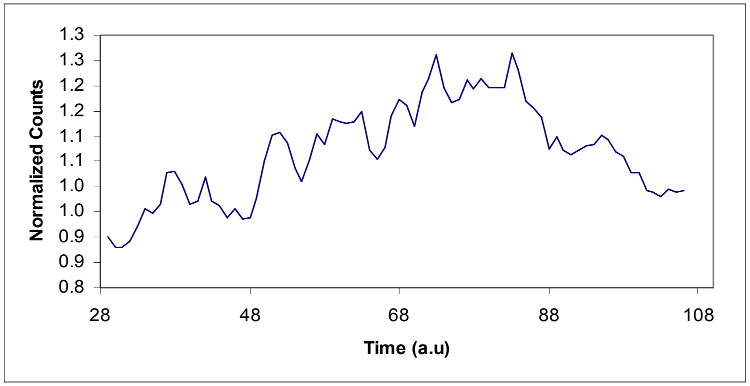
Blazars LC simulation – Spectral variation

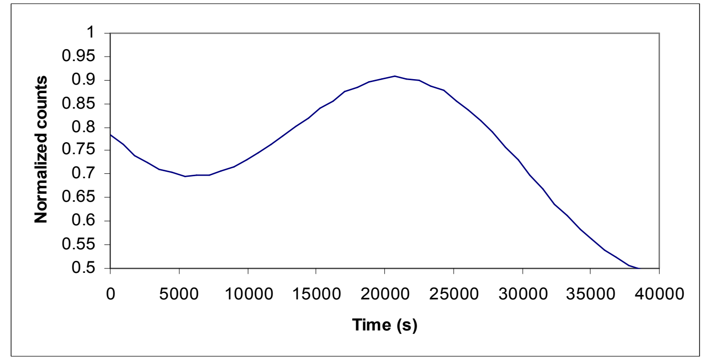
The LC can be obtained with several energy distributions:

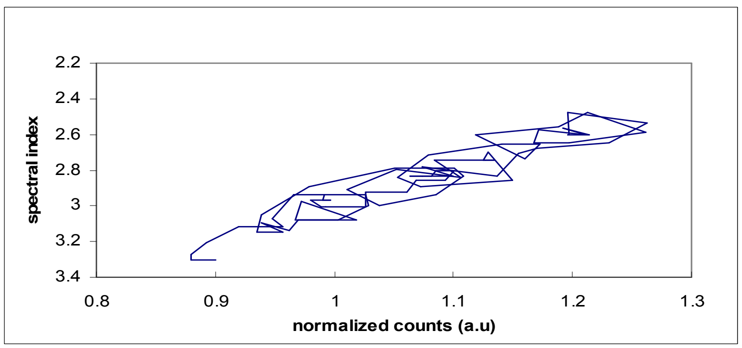
- Power Law
- Broken Power Law
- Continous broken power Law
- Log-parabola

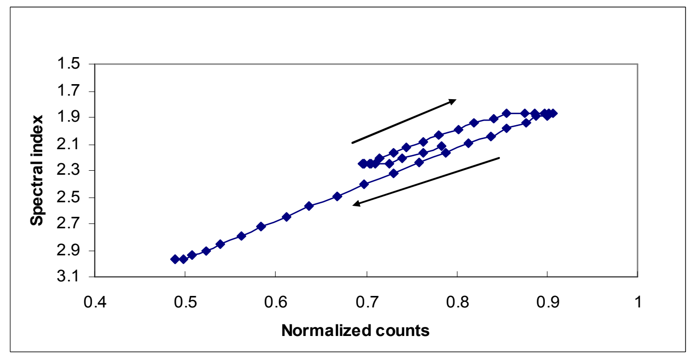
Blazars LC simulation – Spectral variation

Broken Power Law model









Parameters:

index_1;   the initial value is extracted from a Gaussian distribution having mean =2. and std=0.2

index_2;   the initial value is : index_2= index_1+rand(0.5,1.5)

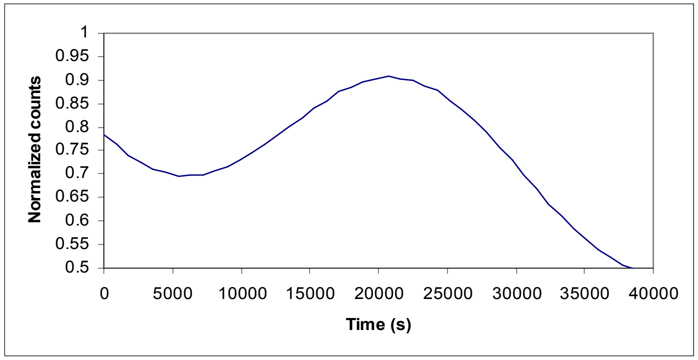
Ebreak (MeV): rand (200-1000)

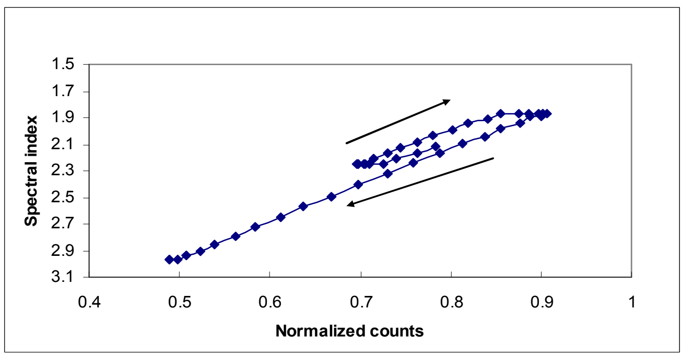
The rate of change of the ph index correlates with the fractional variation of the flux.

We can play with the parameters to simulate all the possible spectral variations of a source during a flare.

Blazars LC simulation – Spectral variation

Broken Power Law model





Simulation

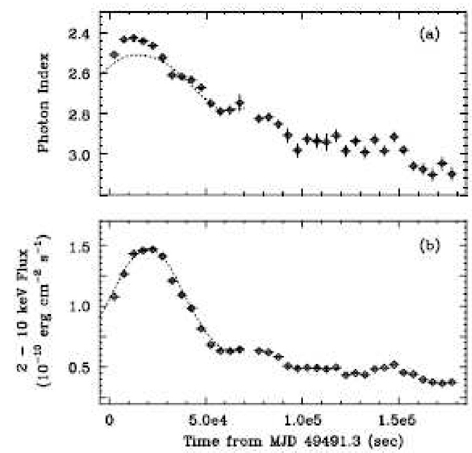


FIG. 2.—Detailed time history of PKS 2155 – 304 during the 1994 May campaign. Each data point corresponds to an equal 5 ks interval and all SIS/GIS data are combined for the fit. The model is a power law with free absorption. (*a*) Variation of the differential photon index in the 0.7–7.5 keV band. The dashed line is a model prediction as described in § 3. (*b*) Variation of the 2–10 keV flux in units of 10^{-10} ergs cm^{-2} s^{-1}. The dashed line shows a model prediction discussed in § 3.

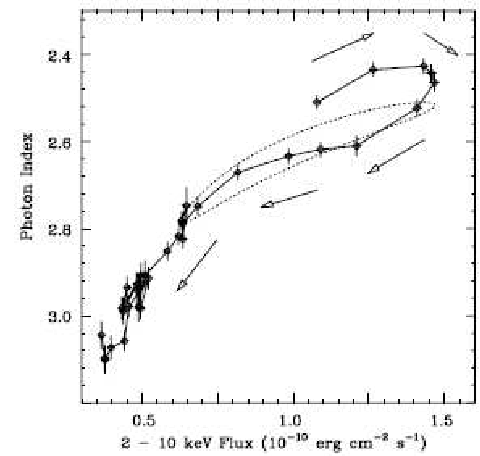


FIG. 3.—Evolution of the X-ray spectrum of PKS 2155 – 304 in the flux vs. photon index plane. Arrows indicate the evolution during 1994 May observation. A "clockwise loop" is clearly seen. The solid line connects the observational data, while the dashed line is the model prediction given in § 3.

PKS 2155-204

Kataoka et al. (2000)

Future Work....

- Test and clean the code (as it is) to have a first version in the CVS (Julie's suggestion)

- Include intraband Time-Lags, Epeak shift etc. In the simulation (is this useful?)

- Do you want use physical models to generate LC? (e.g. A simple internal shock model)

- All your comments & suggestions are welcome

- Using LC to generate LAT simulated output to start to develop time-analysis tools