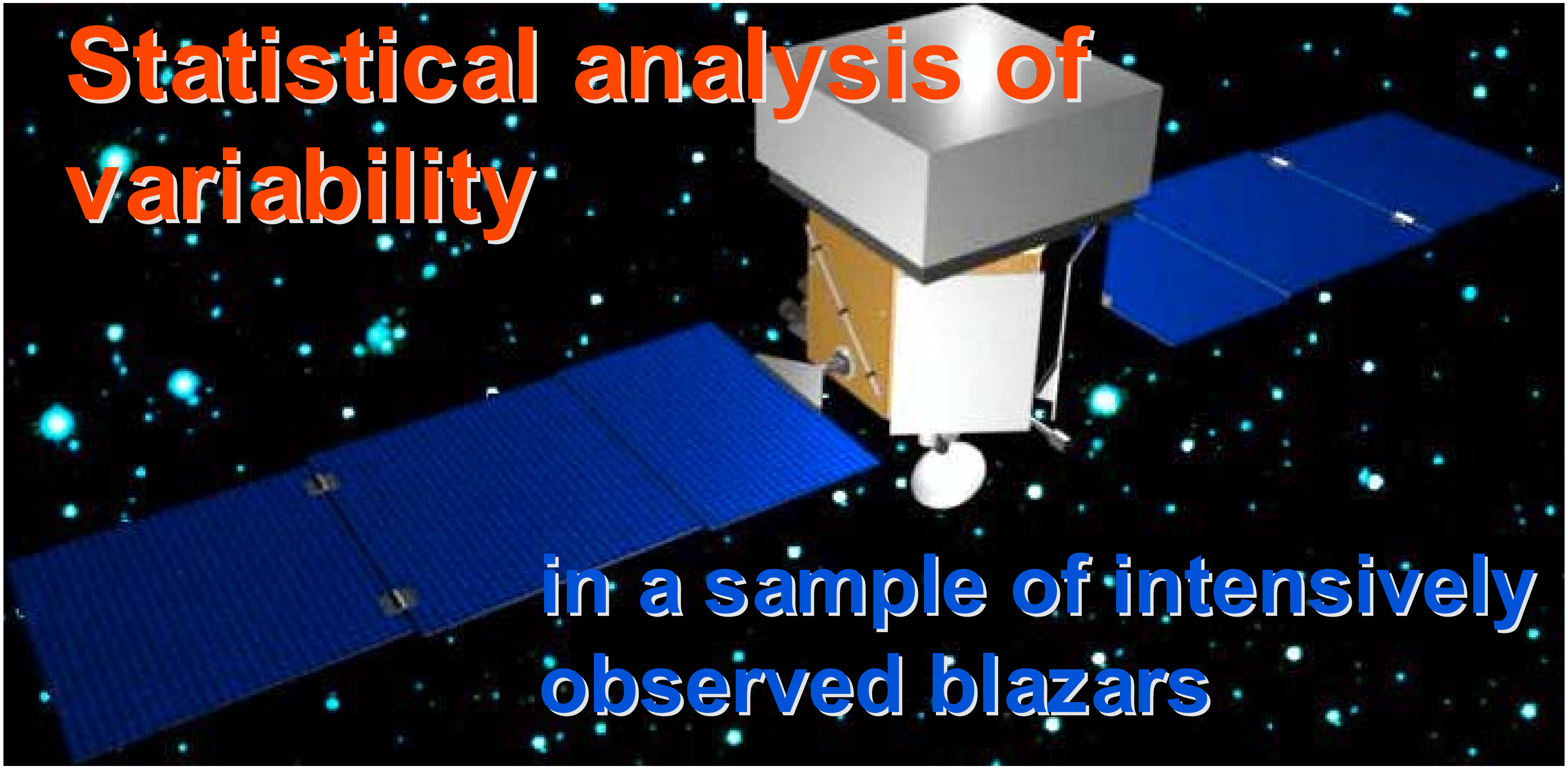
Statistical analysis of variability

in a sample of intensively observed blazars



Massimo Fiorucci
I.N.F.N. sez. Perugia. Dipartimento di Fisica, Universita` di Perugia

1) Analysis of variability in a sample of blazars observed at the Perugia Astronomical Observatory

(with S. Ciprini, N. Marchili, G. Tosti)

2) Phenomenological models of variability and simulation of blazar data that would be obtained with GLAST (with C. Cecchi, F. Marcucci, M. Pepe, G. Tosti)

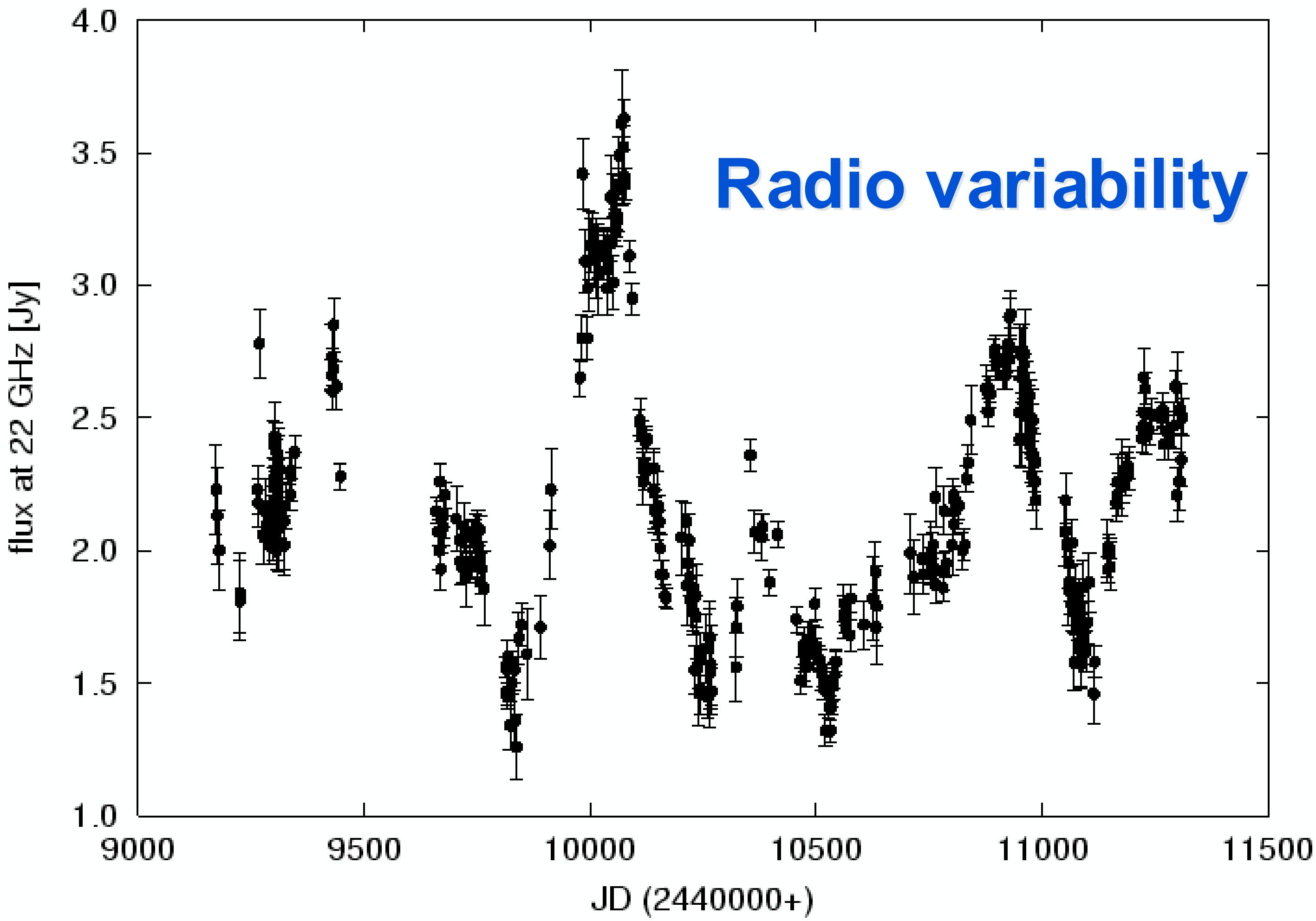
3) Analysis tools for GLAST (with P. Lubrano, G. Tosti)

- classification of variable sources
- identification of faint sources
- noise filtering

1) analysis of variability

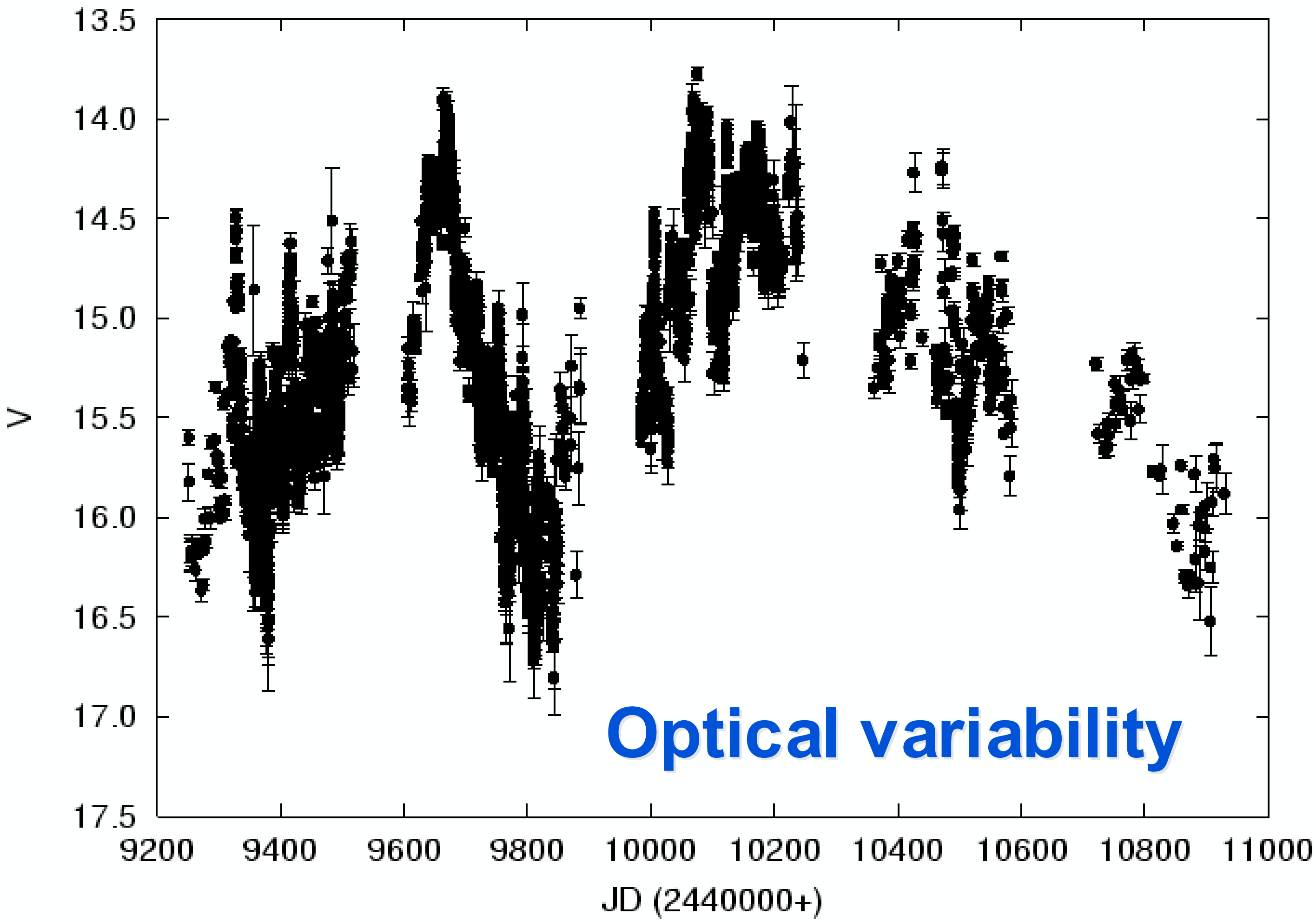
- Blazars are characterised by rapid and large variability at all frequencies
- In the last years, many efforts have been spent to understand the physical mechanisms responsible for the variable emission
- However, blazars emit signals that appear to vary chaotically with time.

1) analysis of variability



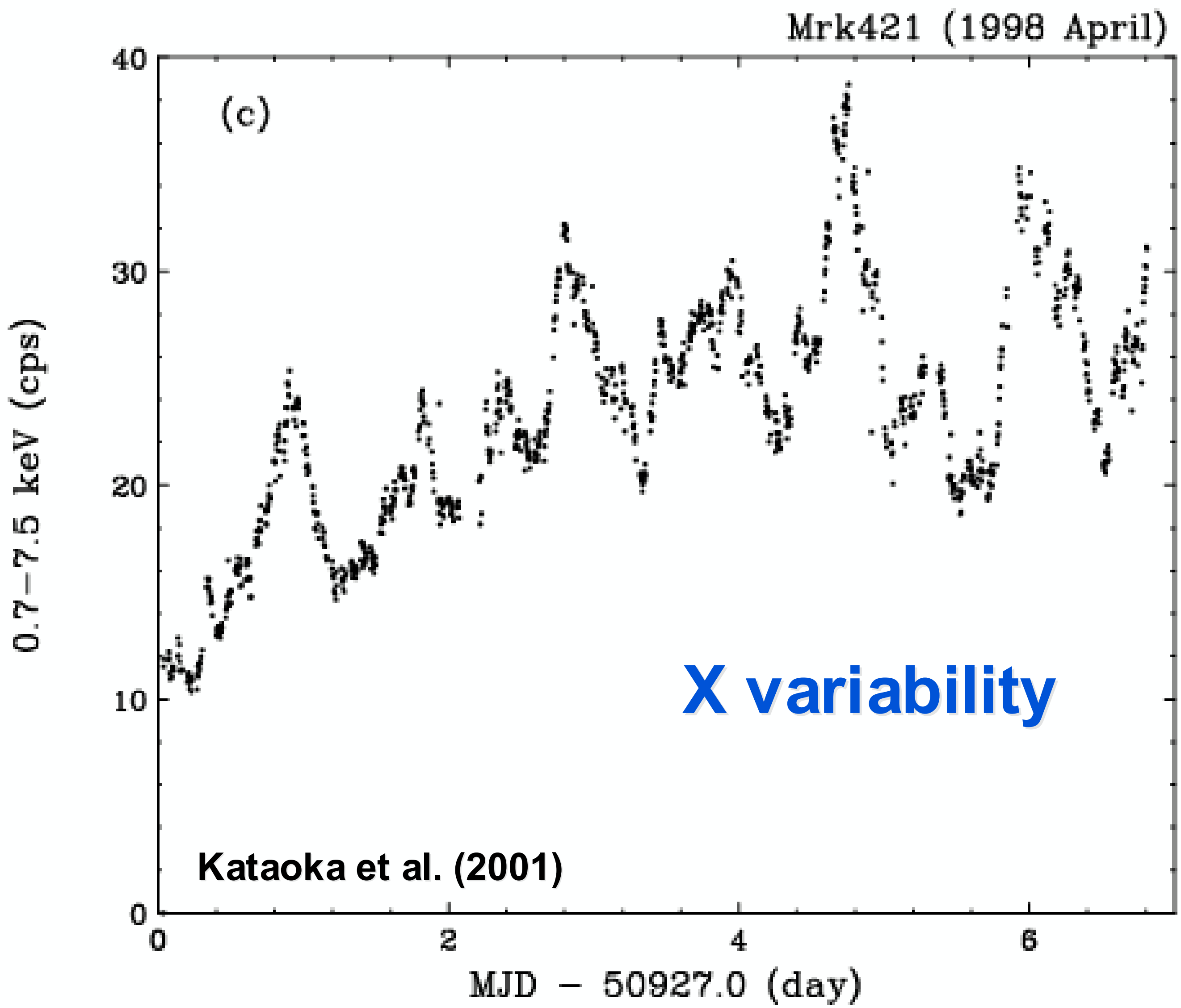
OJ94 Coll. - http://astro.utu.fi/oj94/

1) analysis of variability



OJ94 Coll. - http://astro.utu.fi/oj94/

1) analysis of variability



1) analysis of variability

This behavior is expected in two qualitatively different situations:

- In a system consisting of a large number of weakly correlated elements which appear at random and live only a short time.
- The global evolution of a system described by non-linear differential equations which shows deterministic chaos.

1) analysis of variability

Optical variability:
chaotic behaviour or correlated signal?

- The Perugia monitoring program started in 1992. We have collected more than 20000 BVRI observations and our sample forms one of the larger set of optical data available.

- We are cooperating with other international teems to improve the sampling for many blazars.

- We can use this large database to study variability with statistical techniques.

1) analysis of variability

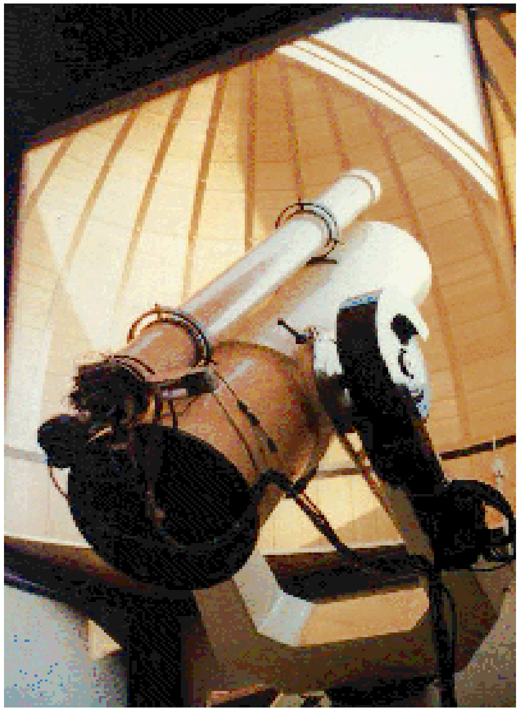
The Perugia AIT

http://wwwospg.pg.infn.it

- Diameter of the primary mirror D= 40 cm
- Focal ratio f/5
- Newtonian optical configuration
- Equatorial mount

- CCD Camera

\+ Johnson-Cousins BVRI filters

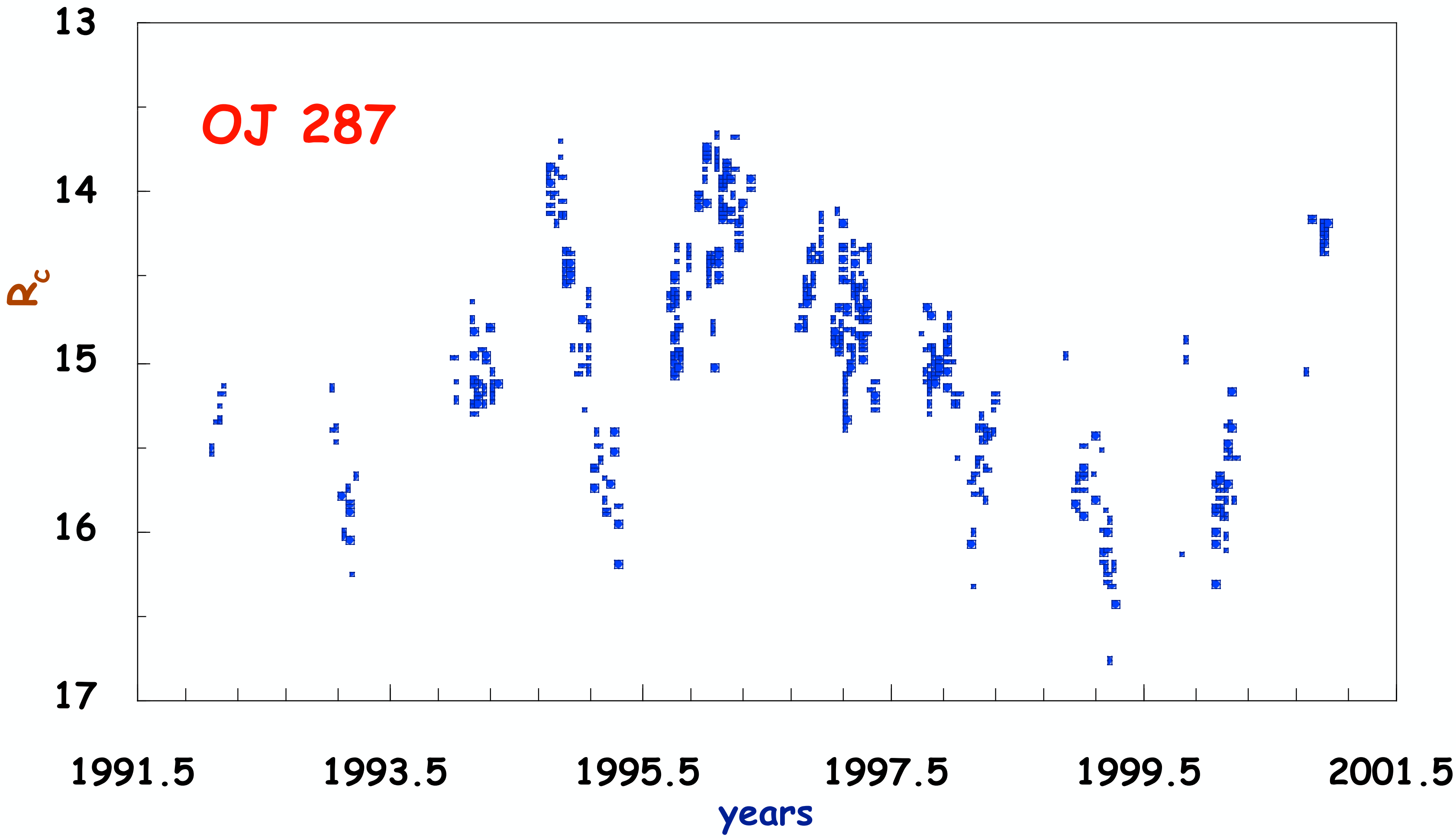


Fully automatic Data Acquisition and Reduction.

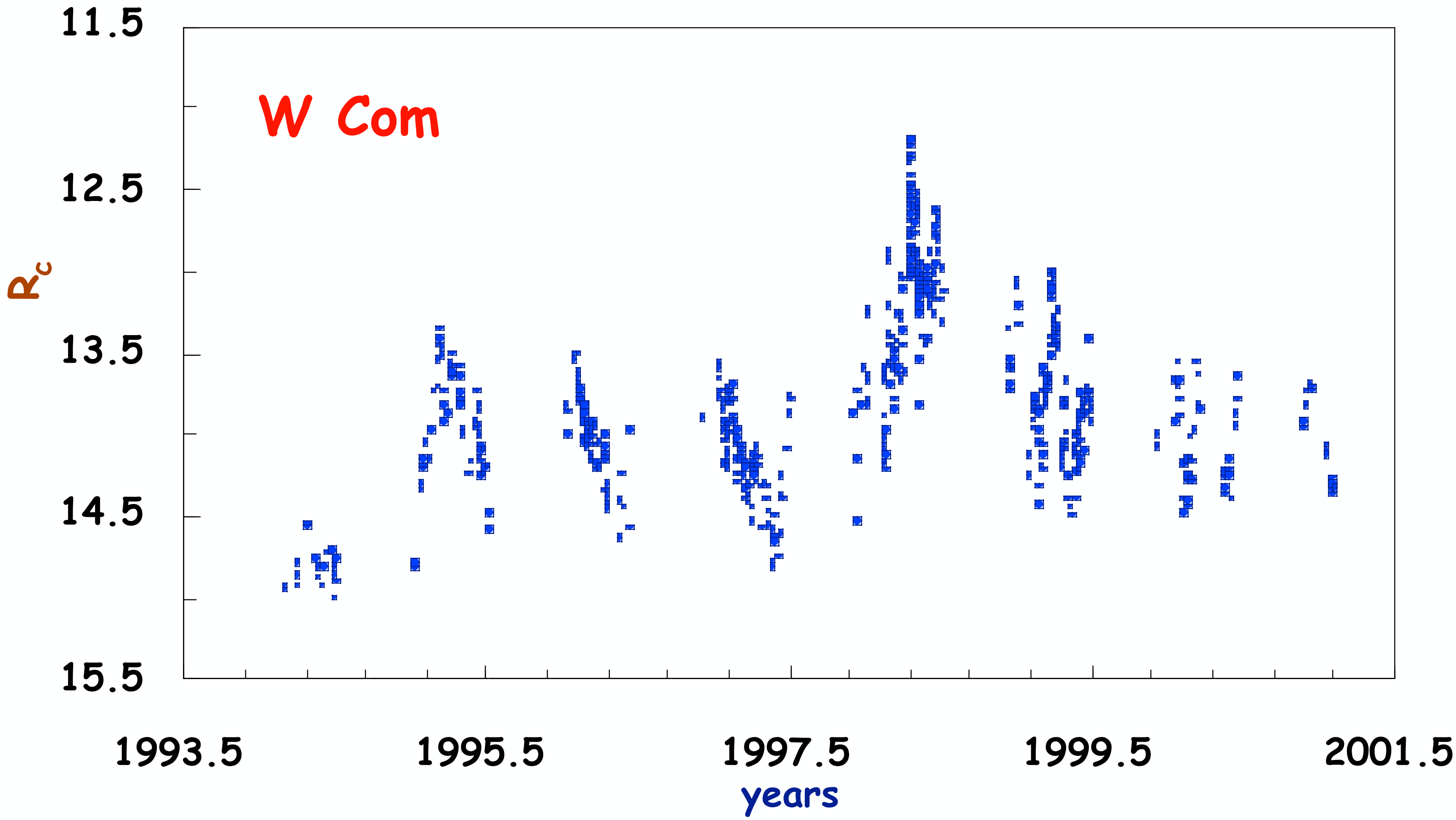
The best sampled Blazars

Common Name	AR	DEC	z	Type	Max[R]	Min[R]
S2 0109+22	01 12 05.8	+22 44 39		BL	14.82	16.2
3C 66A	02 22 39.6	+43 02 08	0.444	HPQ	13.79	14.9
AO 0235+164	02 38 38.8	+16 36 59	0.94	BL	14.98	16.9
4C 47.08	03 03 35.2	+47 16 16	0.475	BL	15.9	16.
NGC 1275	03 19 48.1	+41 30 42	0.0176	UG	13.47	13.6
1H 0323+022	03 26 14.0	+02 25 15	0.147	BL	15.73	16.5
1H 0414+009	04 16 53.8	+01 04 57	0.287	BL	16.11	16.5
PKS 0422+00	04 24 46.8	+00 36 06	0.31	BL	14.06	15.4
S5 0716+71	07 21 53.4	+71 20 36	0.3	BL	13.71	14.8
PKS 0735+17	07 38 07.4	+17 42 19	0.424	OVV	15.42	16.5
1ES 0806+524	08 09 49.1	+52 18 59	0.138	BL	15.38	15.8
PKS 0829+046	08 31 48.9	+04 29 39	0.18	BL	14.74	15.5
OJ 287	08 54 48.9	+20 06 31	0.306	OVV	14.67	16.2
S4 0954+65	09 58 47.2	+65 33 55	0.368	BL	15.43	16.4
OM 280	11 50 19.2	+24 17 54	0.2	BL	15.6	16.4
TON 605	12 17 52.1	+30 07 01	0.13	OVV	14.22	14.6
W Com	12 21 31.7	+28 13 59	0.102	BL	13.65	15
3C 273	12 29 06.7	+02 03 09	0.1583	LPQ	12.71	12.8
3C 279	12 56 11.1	-05 47 22	0.5362	HPQ	14.46	15.9
OQ 530	14 19 46.6	+54 23 15	0.151	BL	15.15	15.8
PKS 1424+240	14 27 00.4	+23 48 00		BL	14.13	14.3
MS 1458.8+2249	15 01 01.9	+22 38 06	0.235	BL	15.54	16.1
3C 345	16 42 58.8	+39 48 37	0.5928	HPQ	16.02	16.7
MRK 501	16 53 52.2	+39 45 37	0.0337	BL	13.34	13.4
H 1722+119	17 25 04.4	+11 52 16	0.018	HPQ	14.31	14.8
I Zw 187	17 28 18.6	+50 13 10	0.0554	BL	15.54	15.
3C 371	18 06 50.7	+69 49 28	0.051	OVV	14.23	14.4
1ES 1959+650	19 59 59.8	+65 08 55	0.047	BL	14.66	15.1
PKS 2032+107	20 35 22.3	+10 56 07	0.601	BL	15.01	15.3
BL Lac	22 02 43.3	+42 16 40	0.0686	BL	13.51	15.
PKS 2254+074	22 57 17.3	+07 43 12	0.19	BL	15.98	16.6
1ES 2344+514	23 47 04.8	+51 42 18	0.044	BL	14.82	15.1

1) analysis of variability



1) analysis of variability



1) analysis of variability

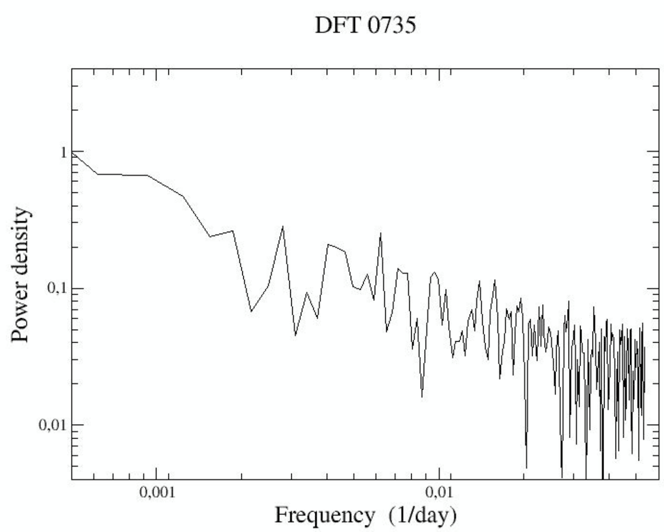
Power Spectral Density

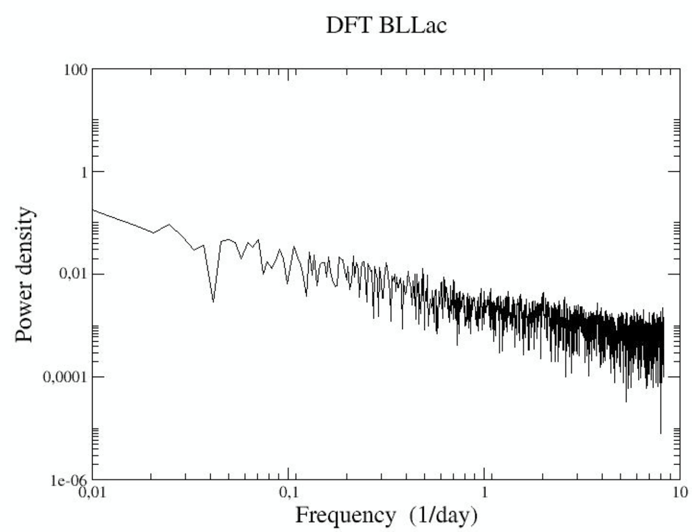
with:

Fast Fourier Transforms — Press et al. (1992)

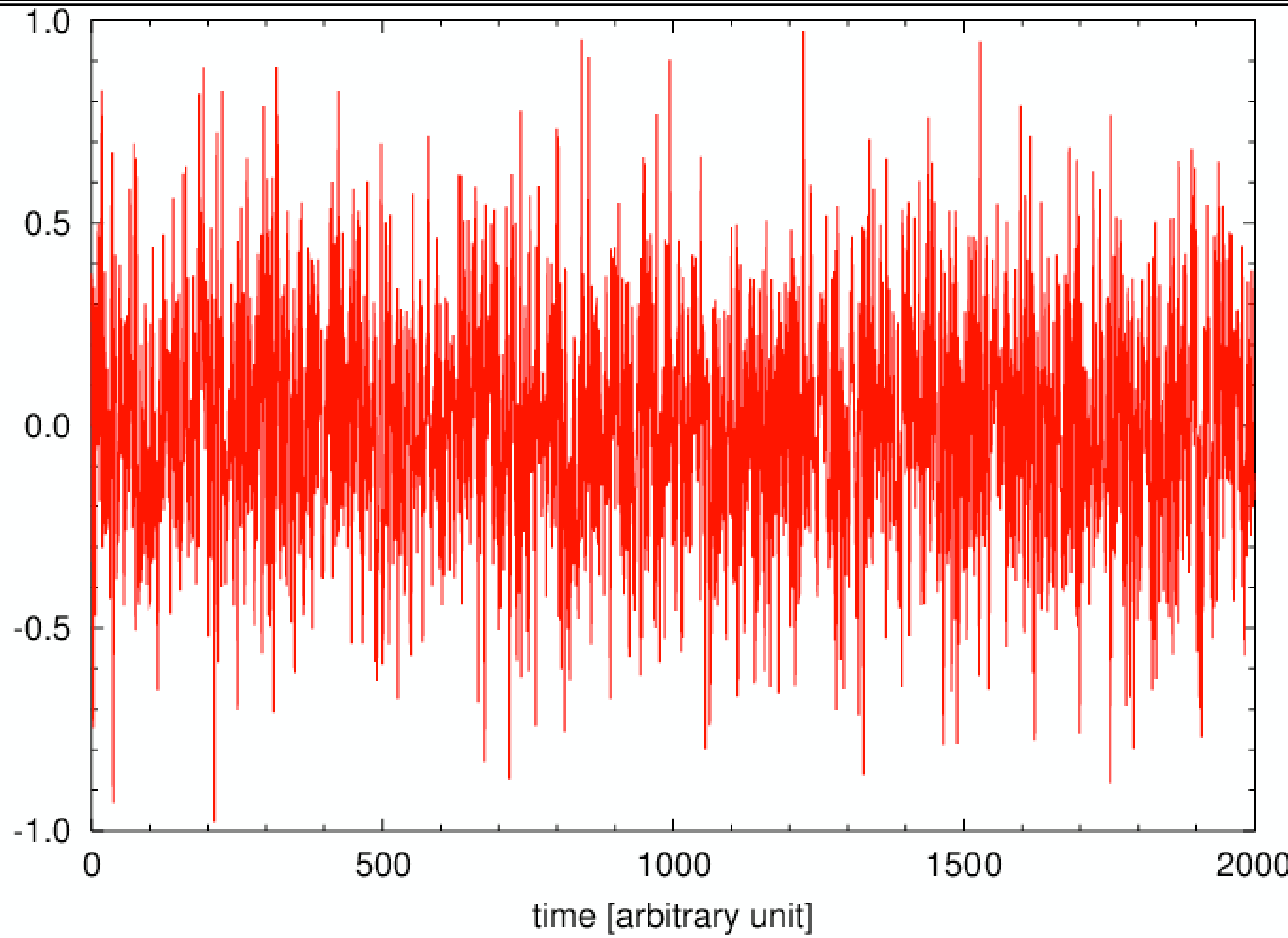
Scargle-Lomb Periodogram — Lomb (1976), Scargle (1982)

Schuster Periodogram — Marple (1987)



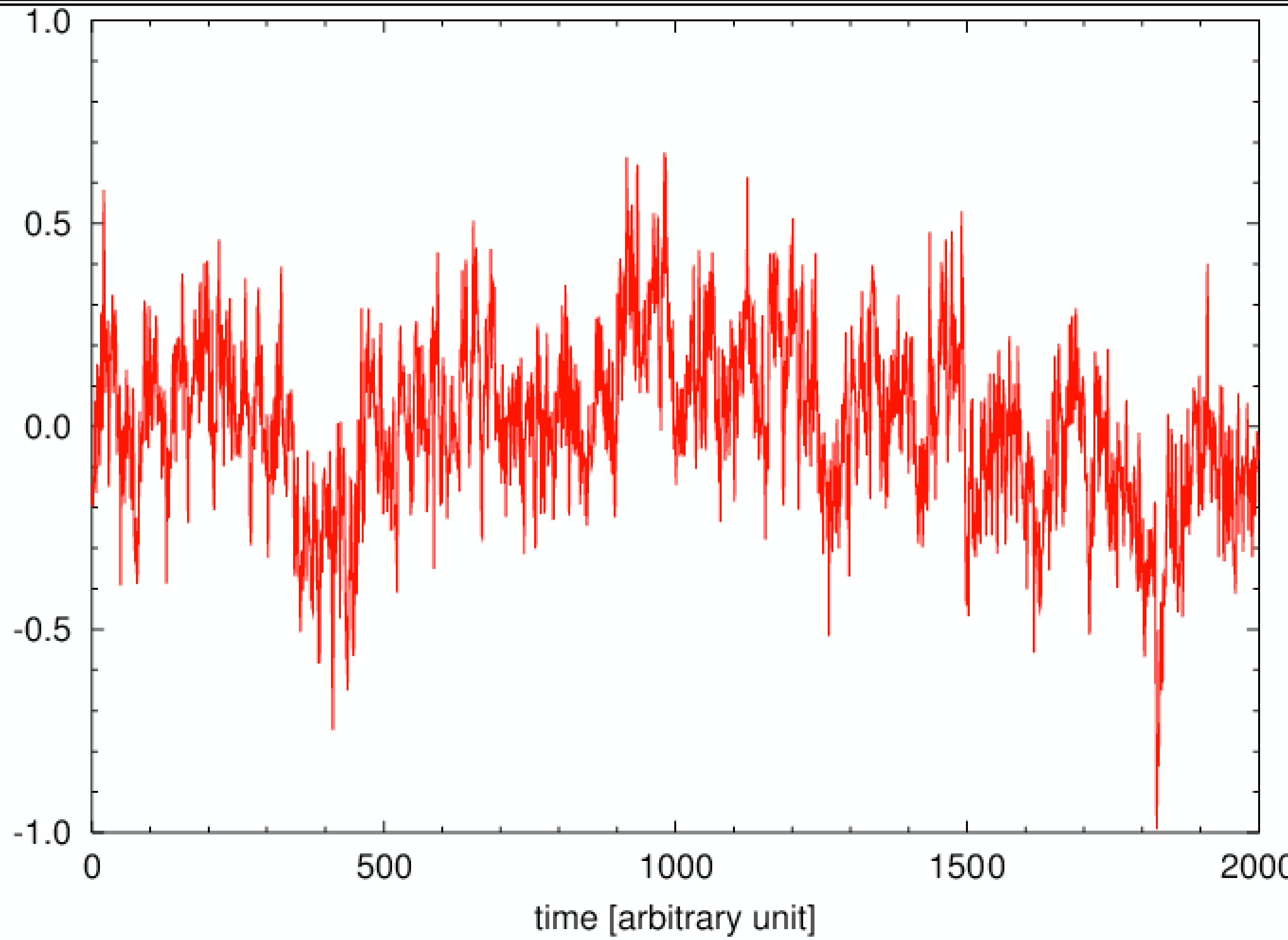


1) analysis of variability



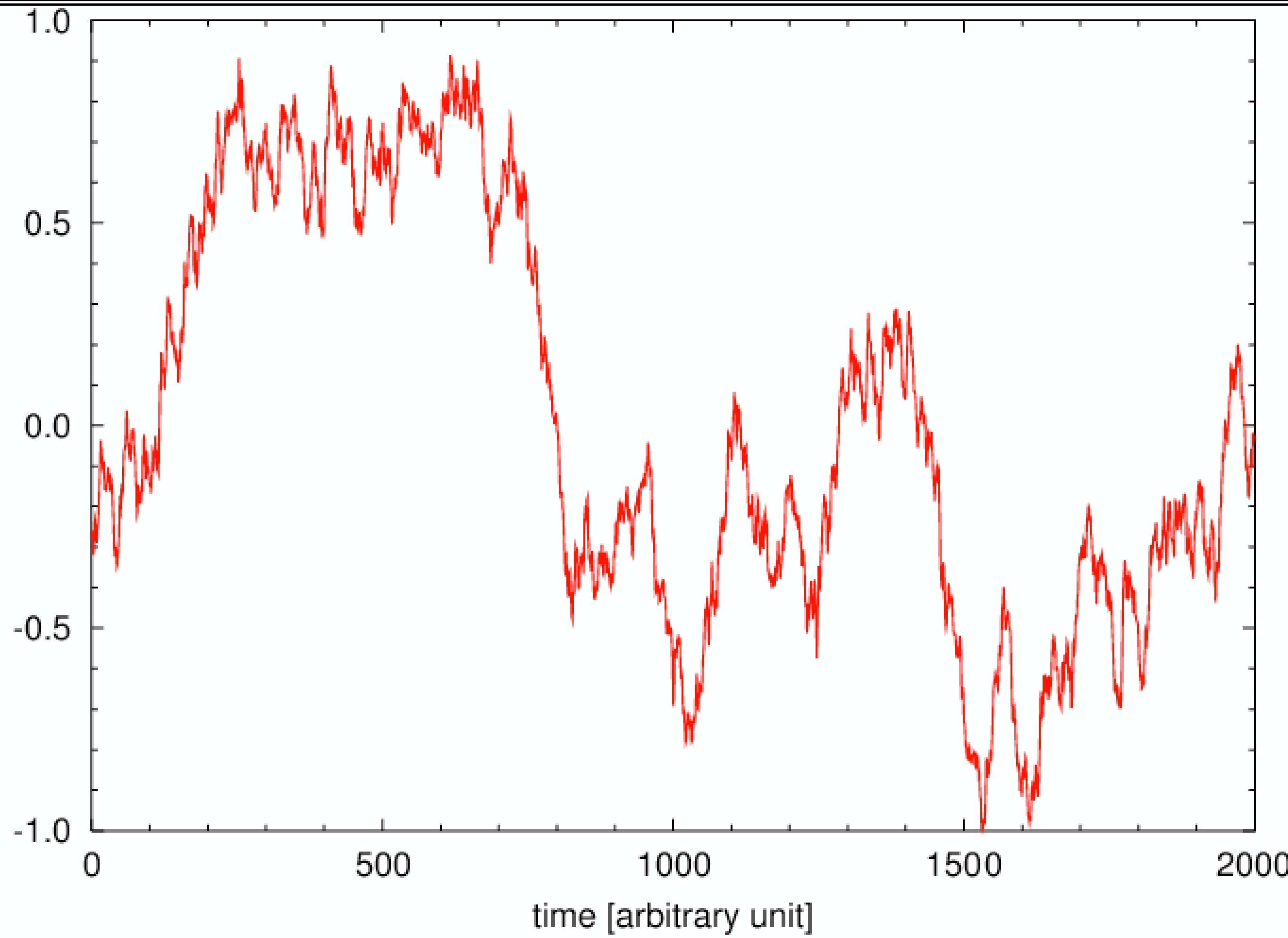
white noise

1) analysis of variability



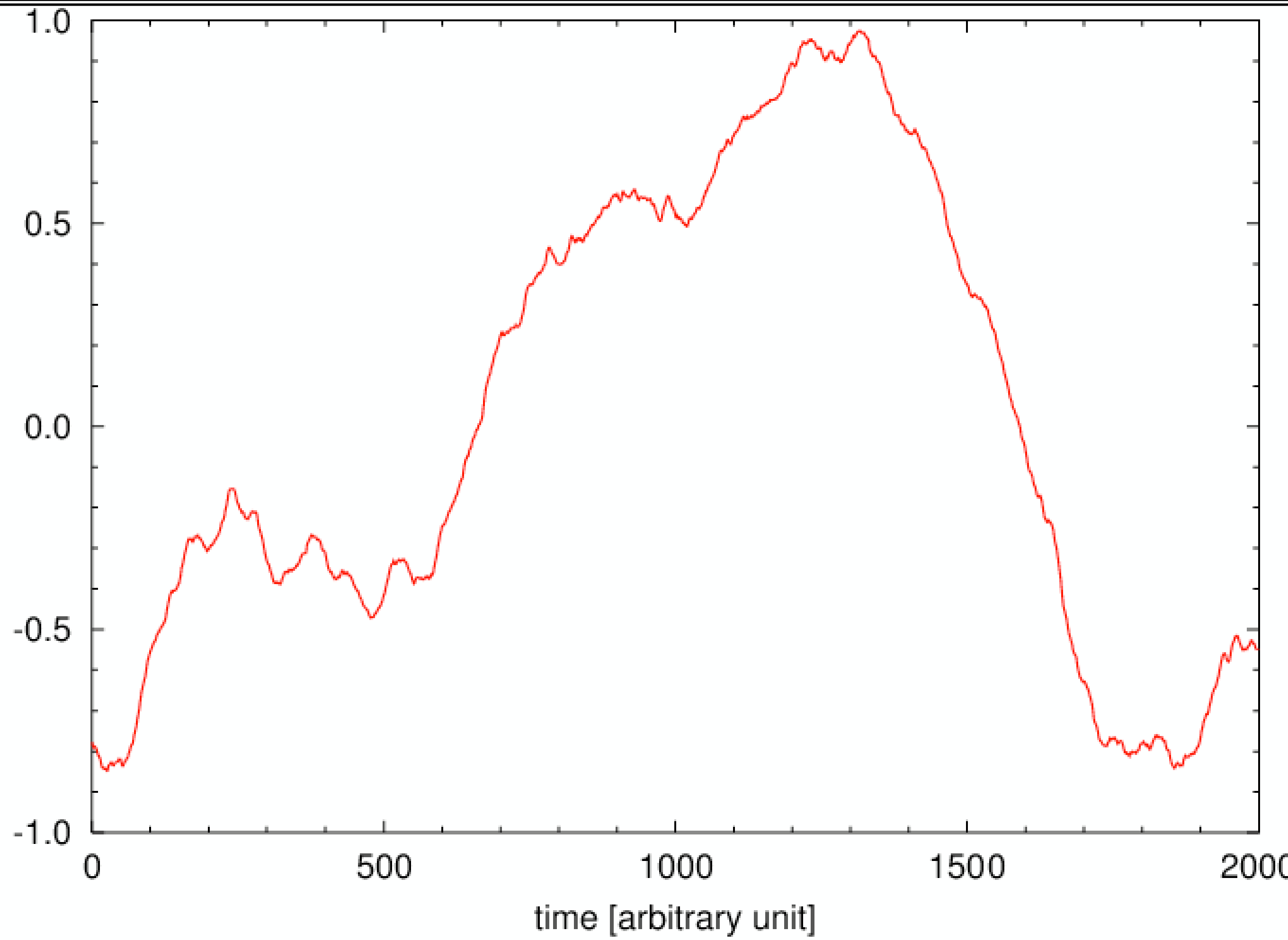
1/f noise

1) analysis of variability



$1/f^2$ noise

1) analysis of variability



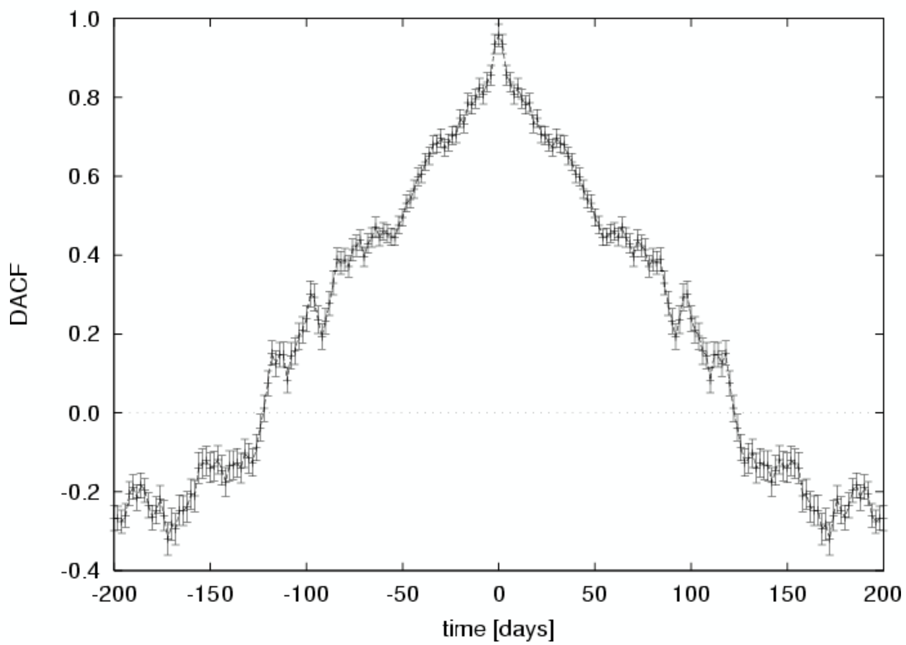
$1/f^3$ noise

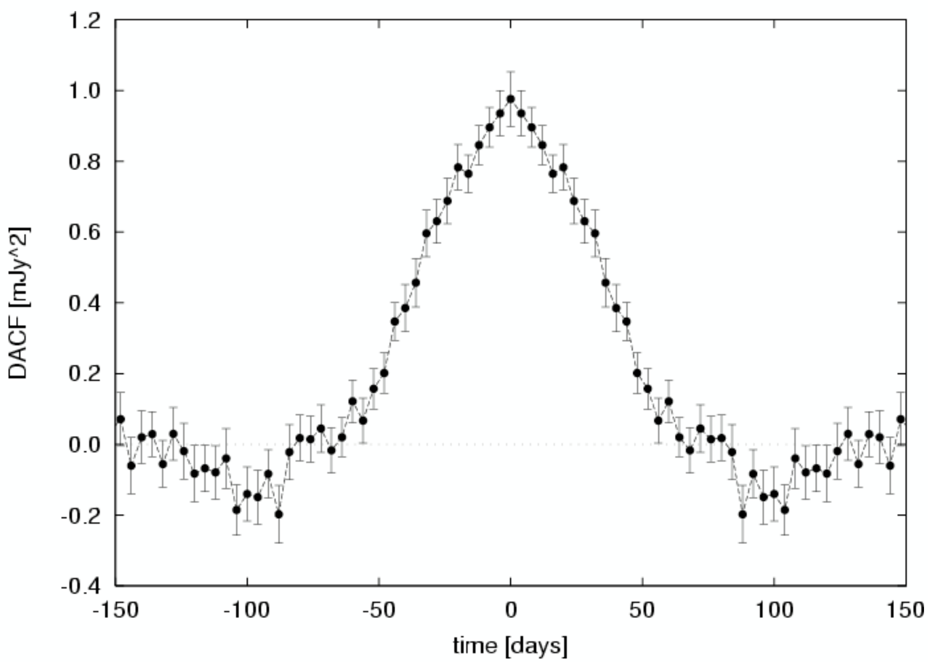
1) analysis of variability

Auto-Correlation Function

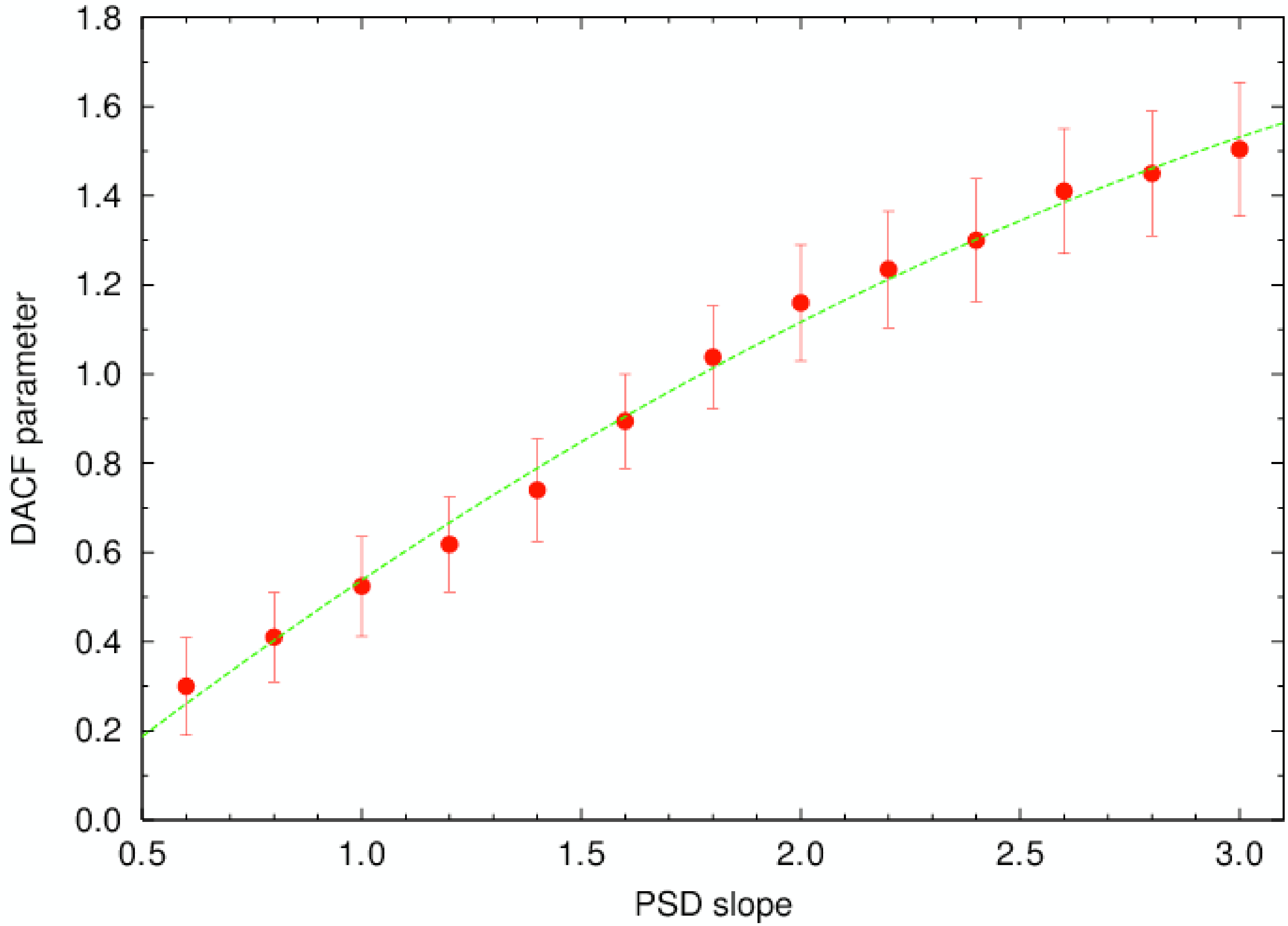
with:
Discrete ACF

Edelson & Krolik (1988)





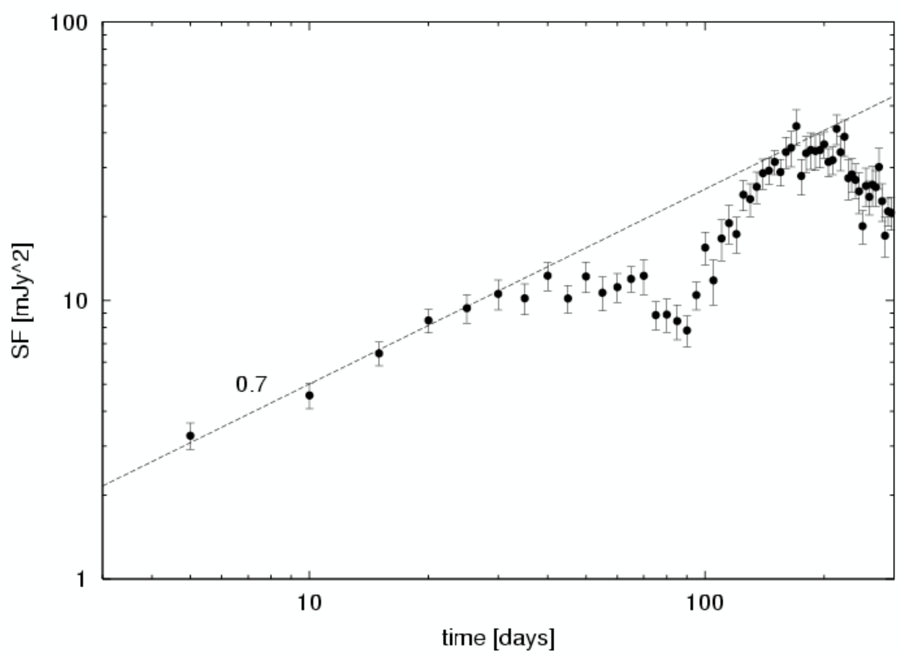
1) analysis of variability

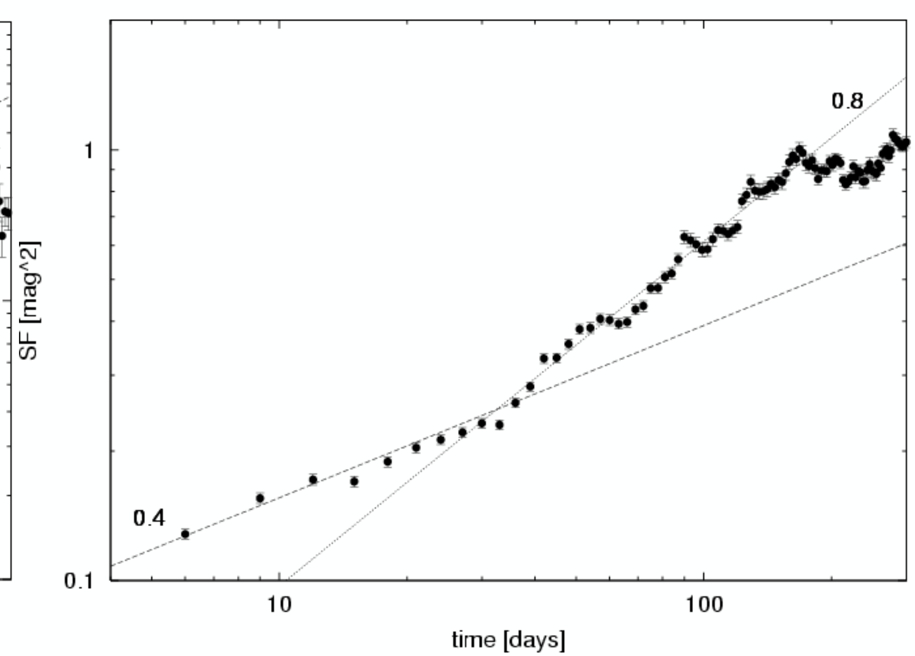


1) analysis of variability

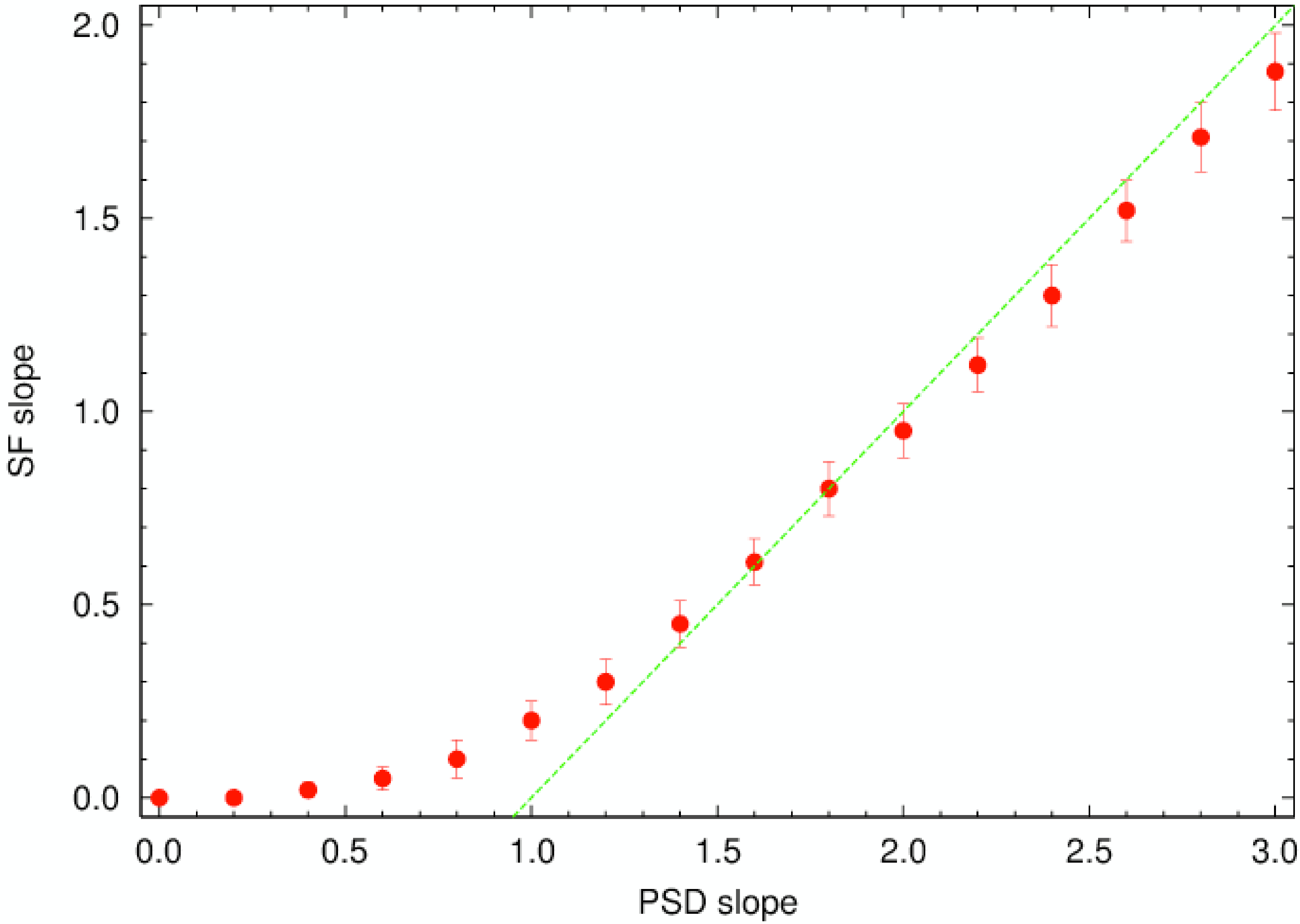
Structure Function (first order)

Simonetti et al. (1985)





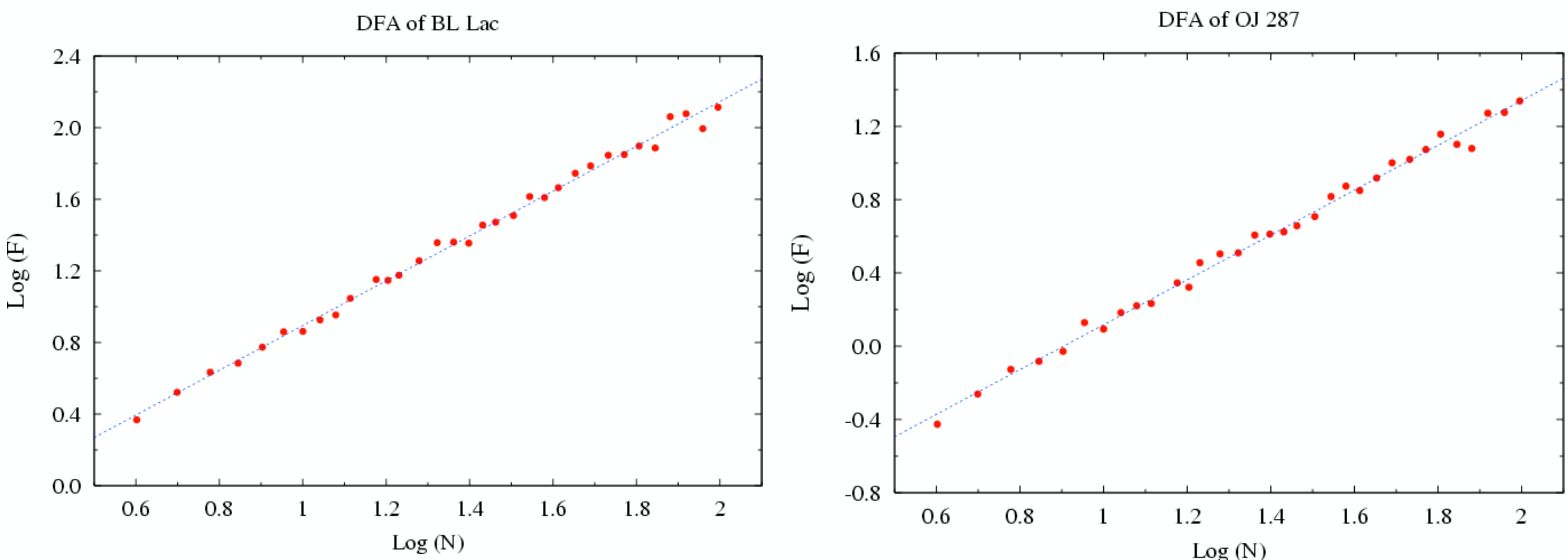
1) analysis of variability



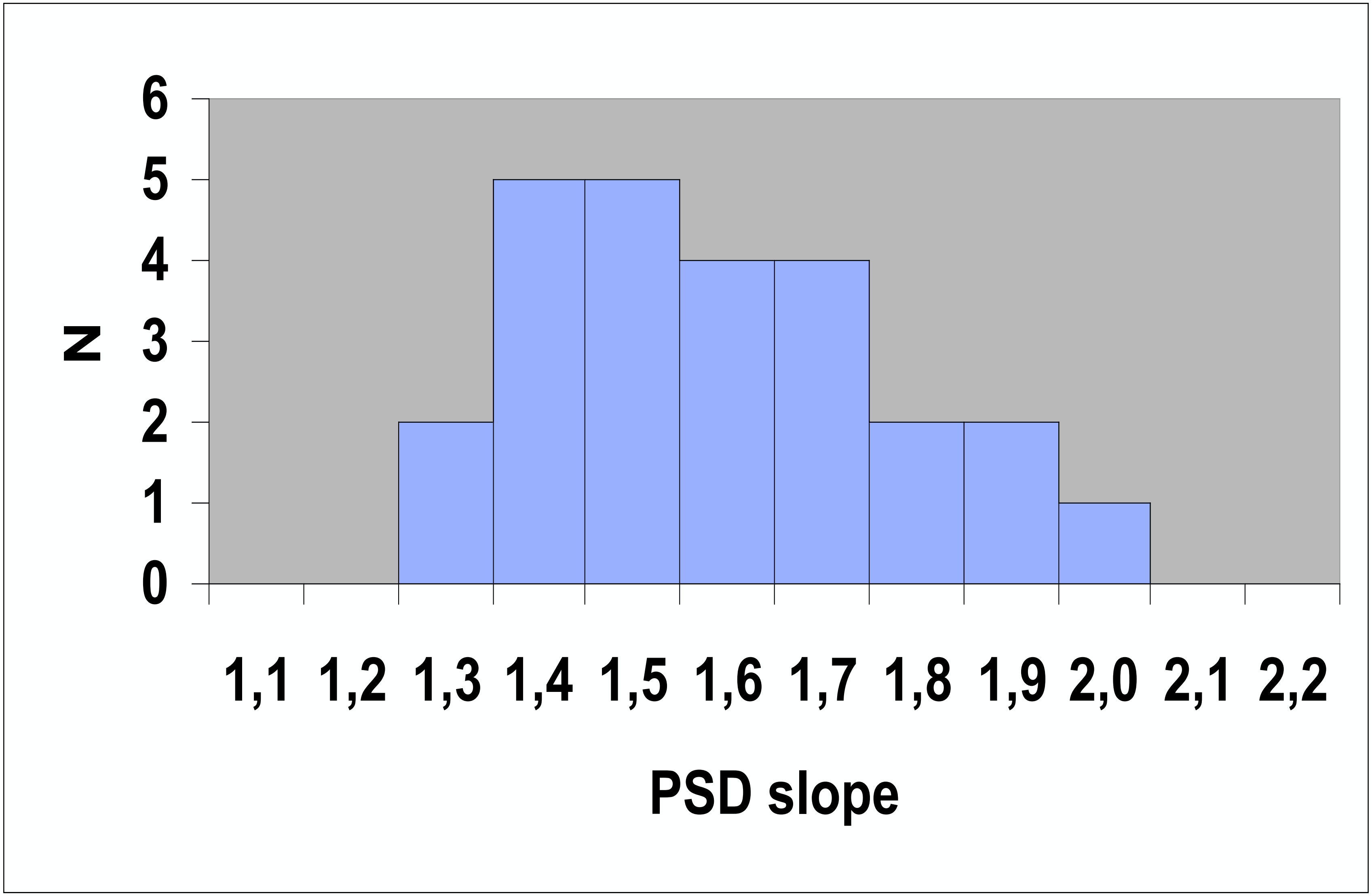
1) analysis of variability

Detrended Fluctuation Analysis

Peng et al. (1995)

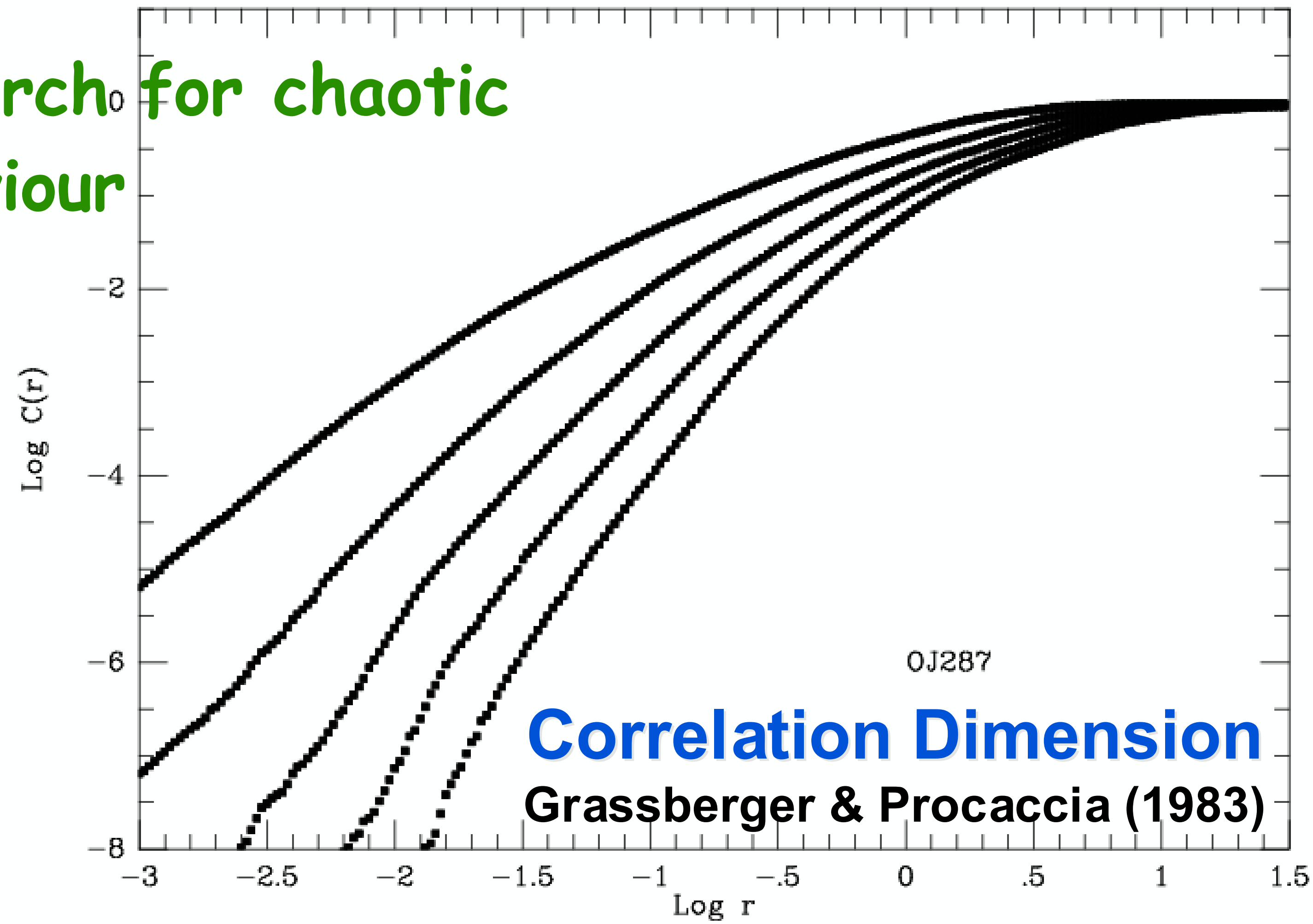


1) analysis of variability



1) analysis of variability

A search for chaotic behaviour



Correlation Dimension

Grassberger & Procaccia (1983)

1) analysis of variability

- Preliminary results show that the observed variability is truly stochastic and is not caused by deterministic chaos
- Blazar variability seems to be characterised by a power law $PSD \propto f^{-\alpha}$, with the slope within the range α = 1- 2 (shot or flicker noise)
- The system probably consist of a large number of weakly correlated elements which appear at random, live only a short time and decay

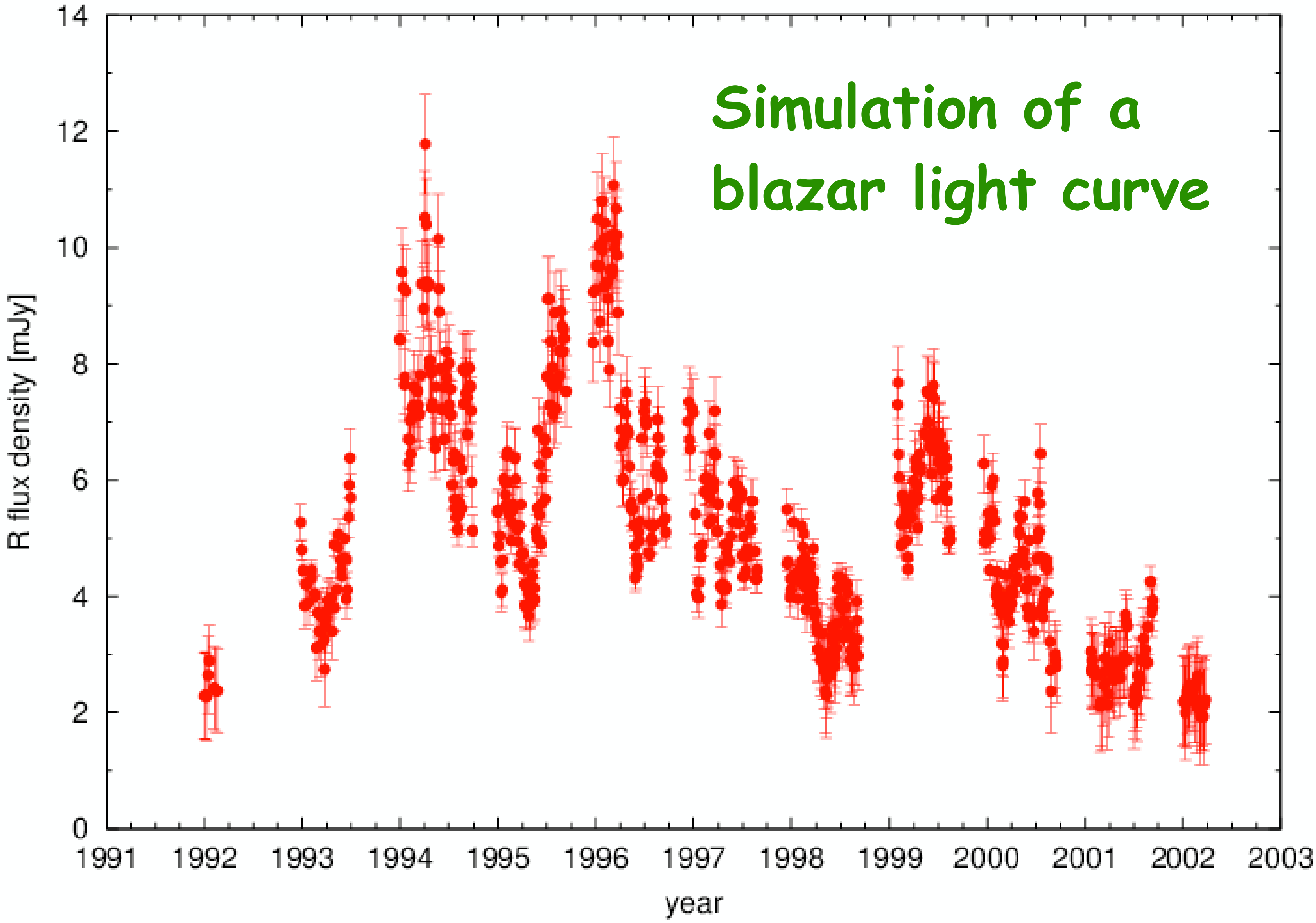
2) simulation of blazar variability

We can simulate the optical variability considering only the phenomenological behavior:

- we select the PSD spectral slope,
- the range of frequencies where the system is self-similar,
- then we opportunely compose the PSD array
- and finally we obtain a light-curve (with the Fourier Transform, for example).

- We can also decide to use a typical SED in a reasonable range of energies,
- and/or to include photon noise, other noises, irregular sampling, etc.

2) simulation of blazar variability



2) simulation of blazar variability

and GLAST ?

- **The simulation of variability can be extended towards high energy with the theoretical models.**

3) analysis tools for GLAST

- **Analysis of variability. Why?**
  - to classify variable sources (together with the Likelihood tool),
  - to search for periodic emission from a source (Pulsars)
  - to obtain a non-parametric characterization of a burst (GRBs)
  - to discriminate faint variable sources against the background noise (?)

3) analysis tools: classification

- Periodic (or quasi-periodic) sources:
  - Pulsars
  - Binary Systems (?)
- Erratic sources, with variability similar to pink (or red) noise (PSD $\propto f^{-\alpha}$):
  - GRB
  - microquasars (?)
  - Blazars and AGN

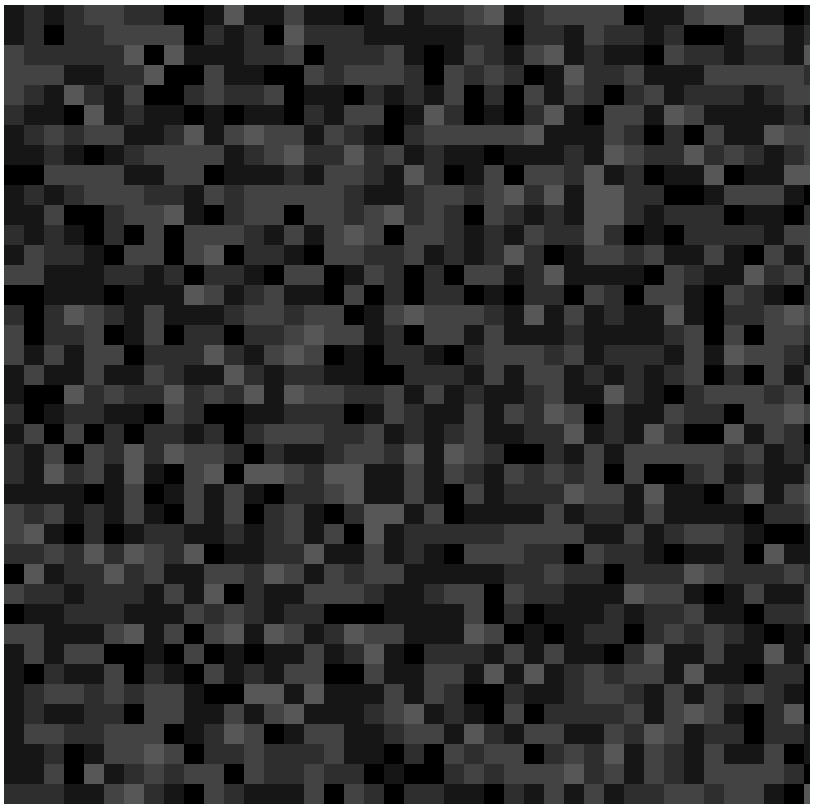
Radio: $\alpha \approx 2$ (Hufnagel & Bregman, 1992)

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

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

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

3) analysis tools: classification



Flux observed from the (i,j) position

$$F(i,j) =$$

$$\Sigma_h \Sigma_k \, PSF(i+h,j+k) \, S(i+h,j+k)$$

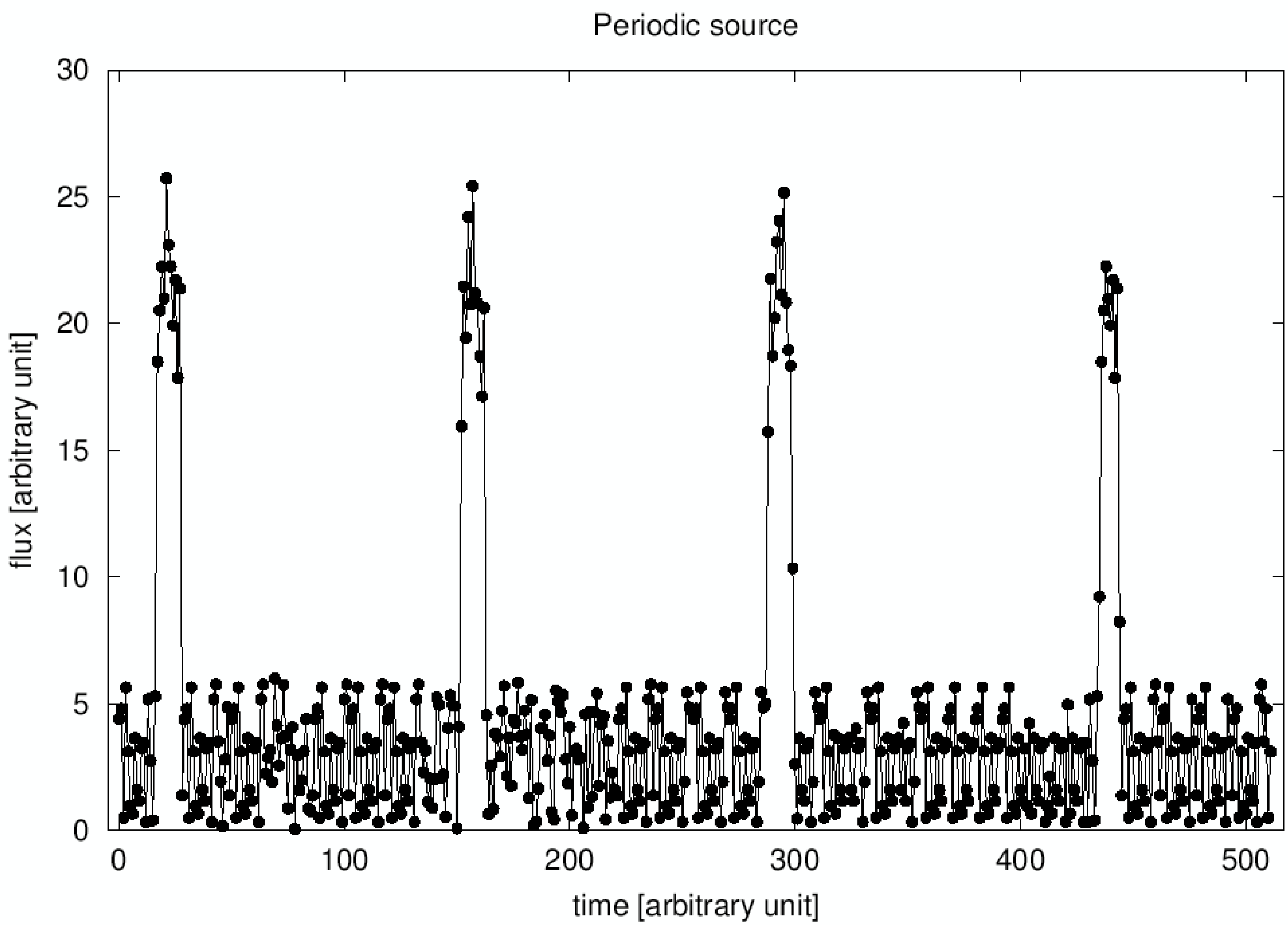
where:

PSF: Point Spread Function computed in the selected energy range and space bin (and the inclination angle during the orbit)

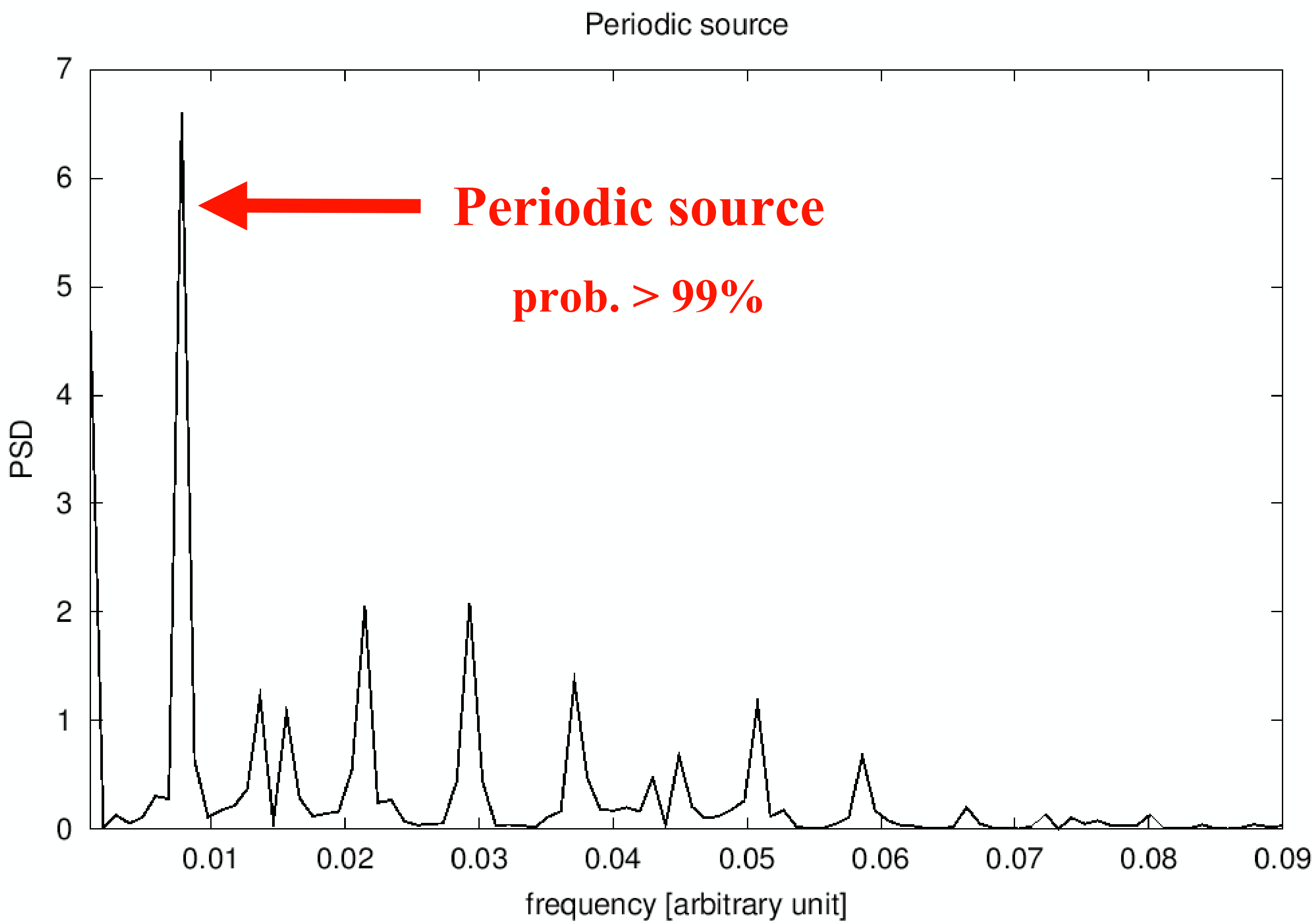
S: Gamma Ray flux observed in the selected energy range and in the selected space bin

h, k: incremental indices used to consider the adjacent pixels

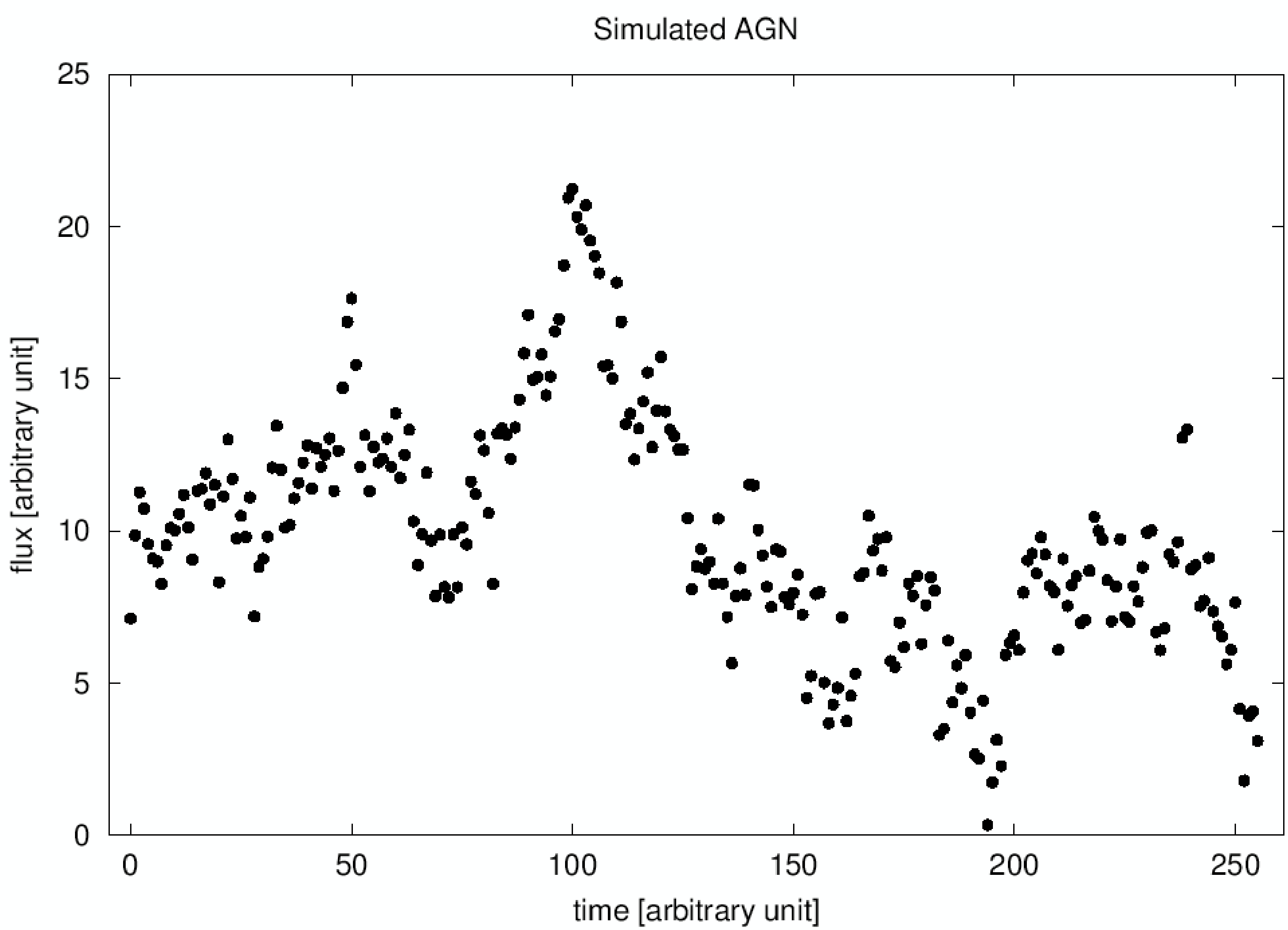
3) analysis tools: classification



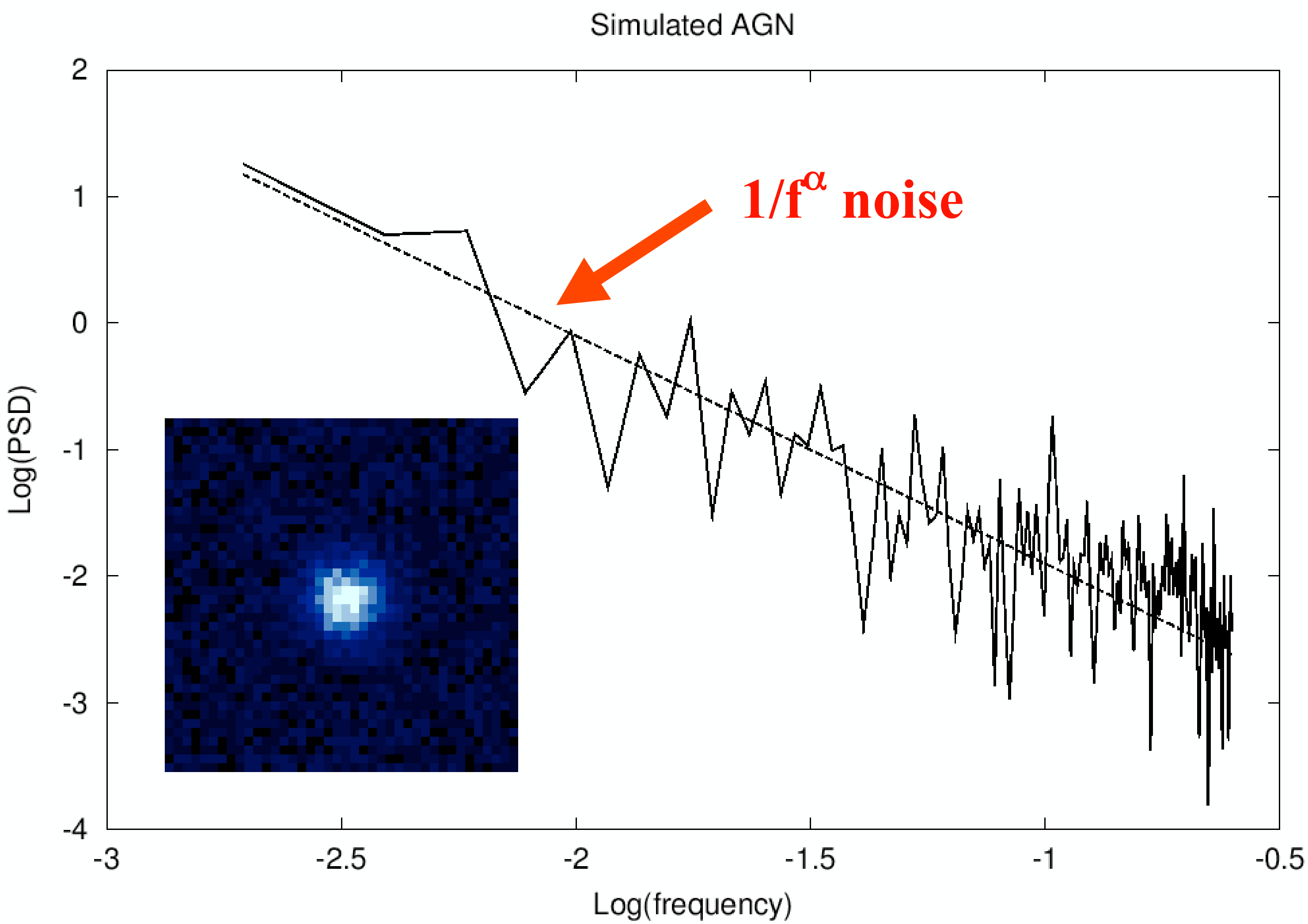
3) analysis tools: classification



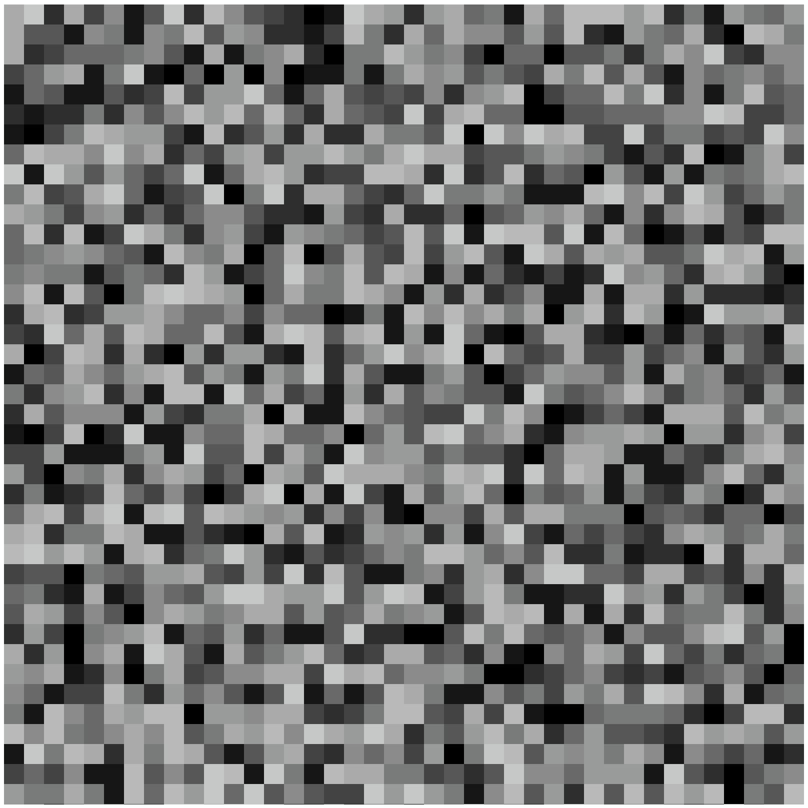
3) analysis tools: classification

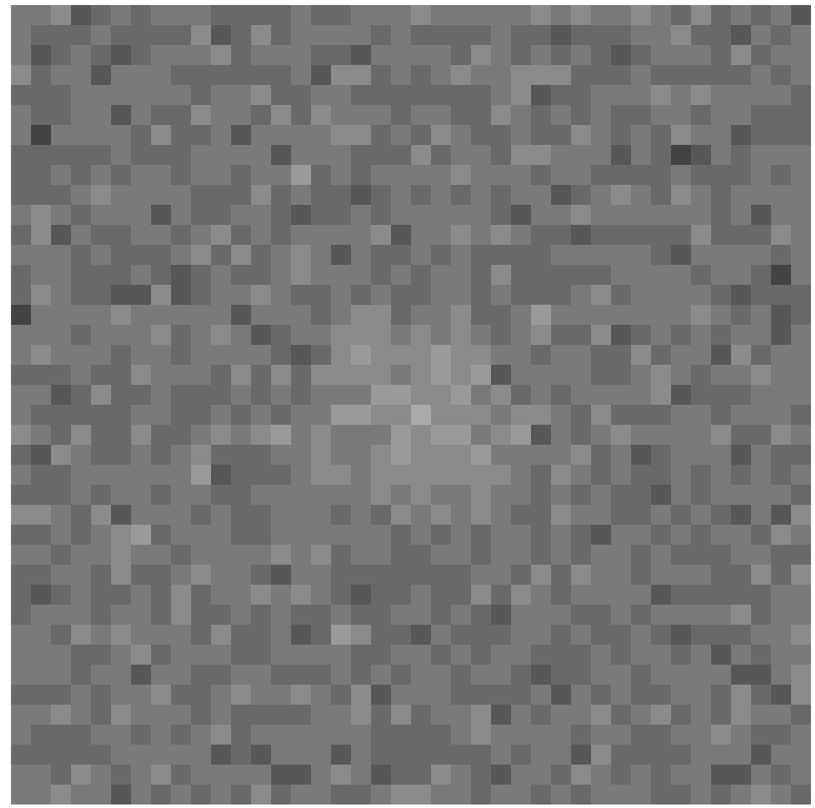


3) analysis tools: classification

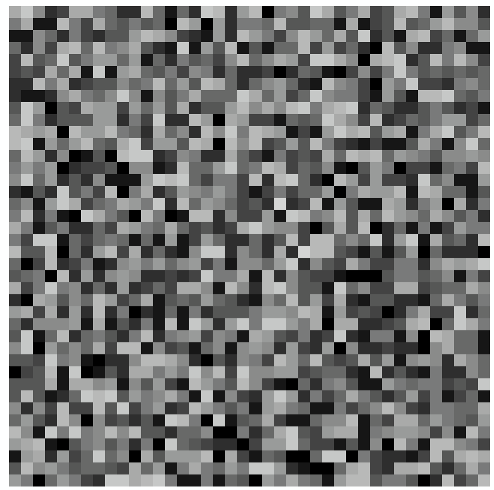


3) analysis tools: identification of faint sources





3) analysis tools: identification of faint sources

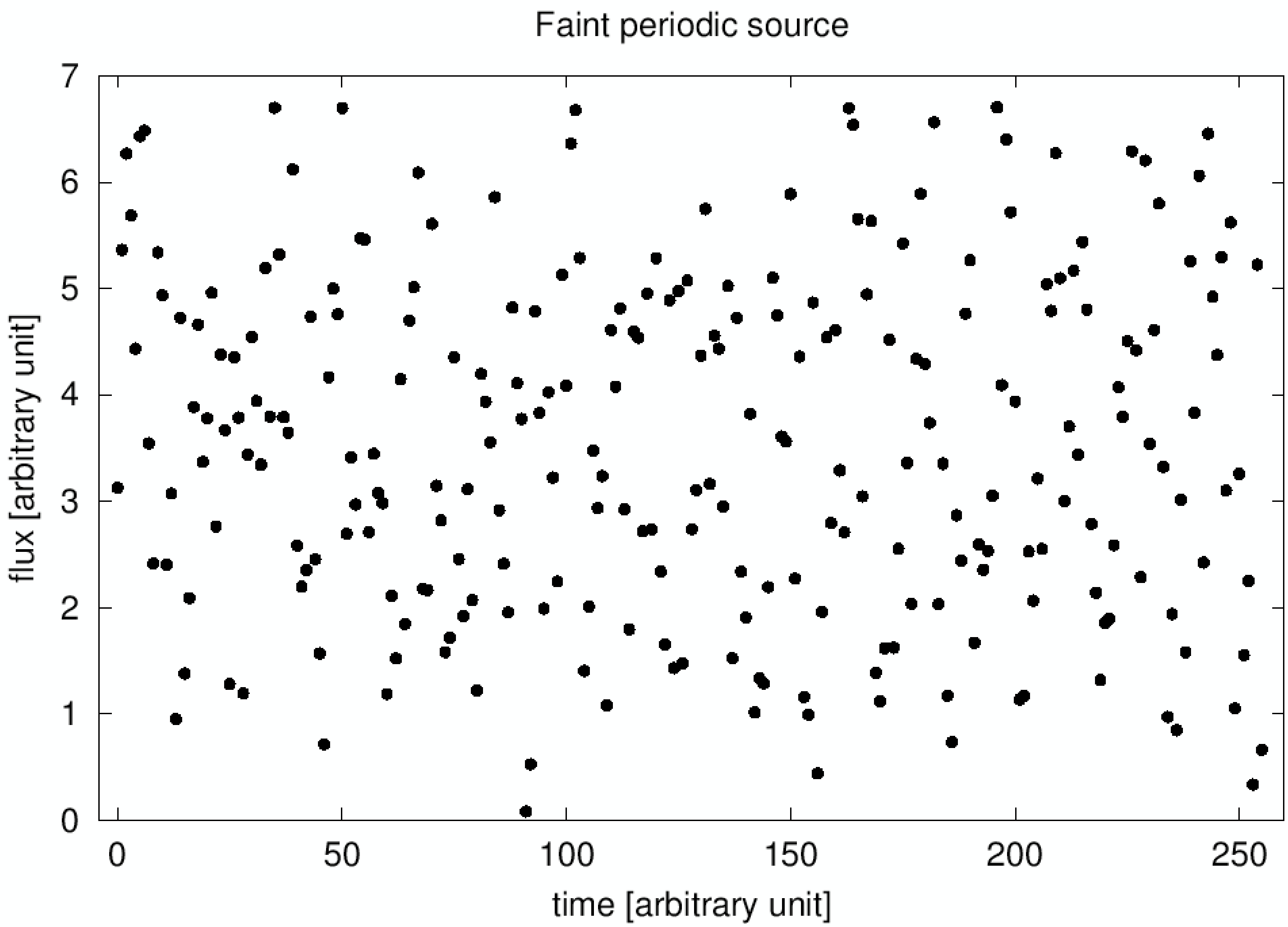


Human Eyes are able to distinguish hidden things in motion:

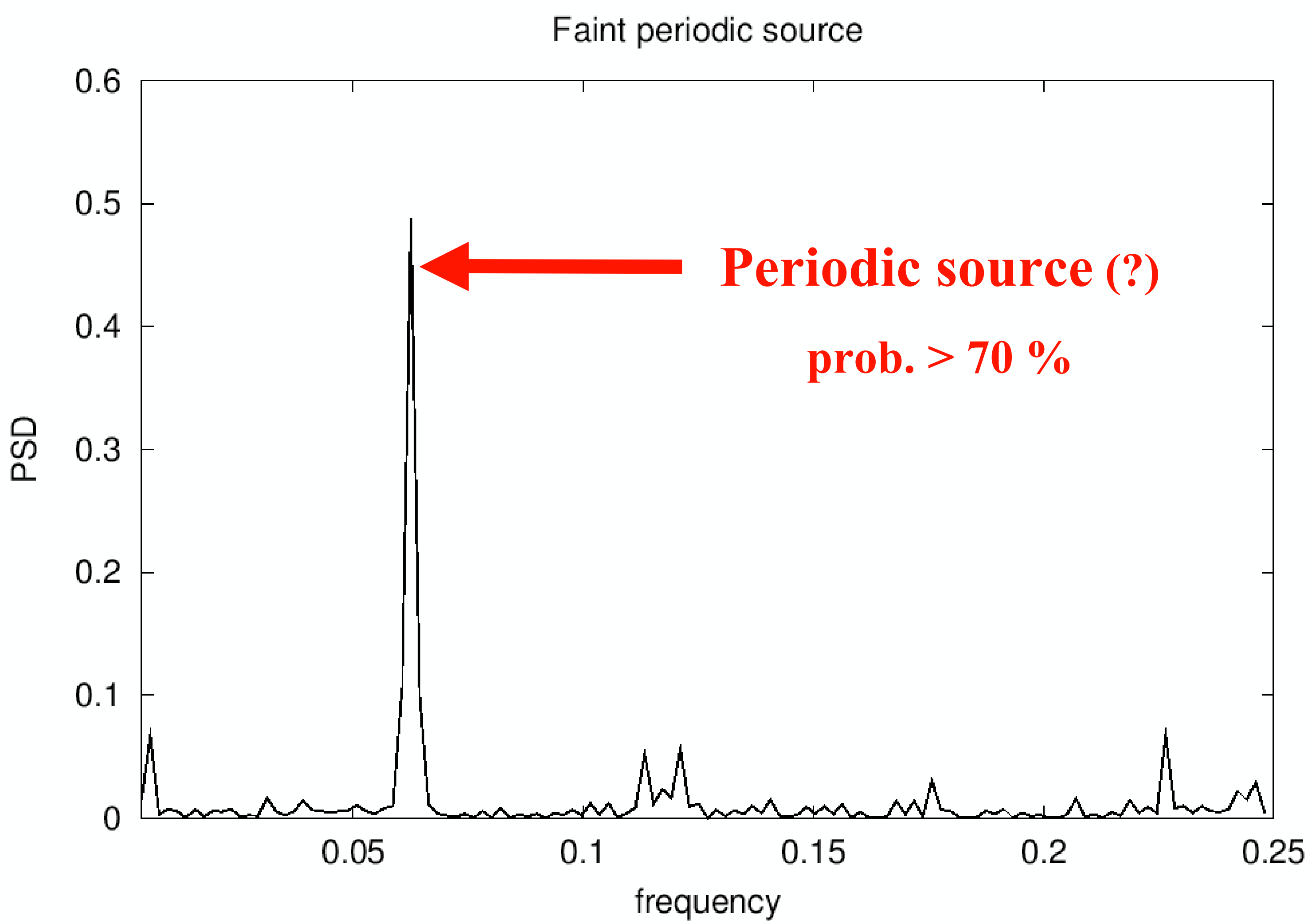
integration + spectral analysis + filtering

We'd like to reproduce this capability!

3) analysis tools: identification of faint sources

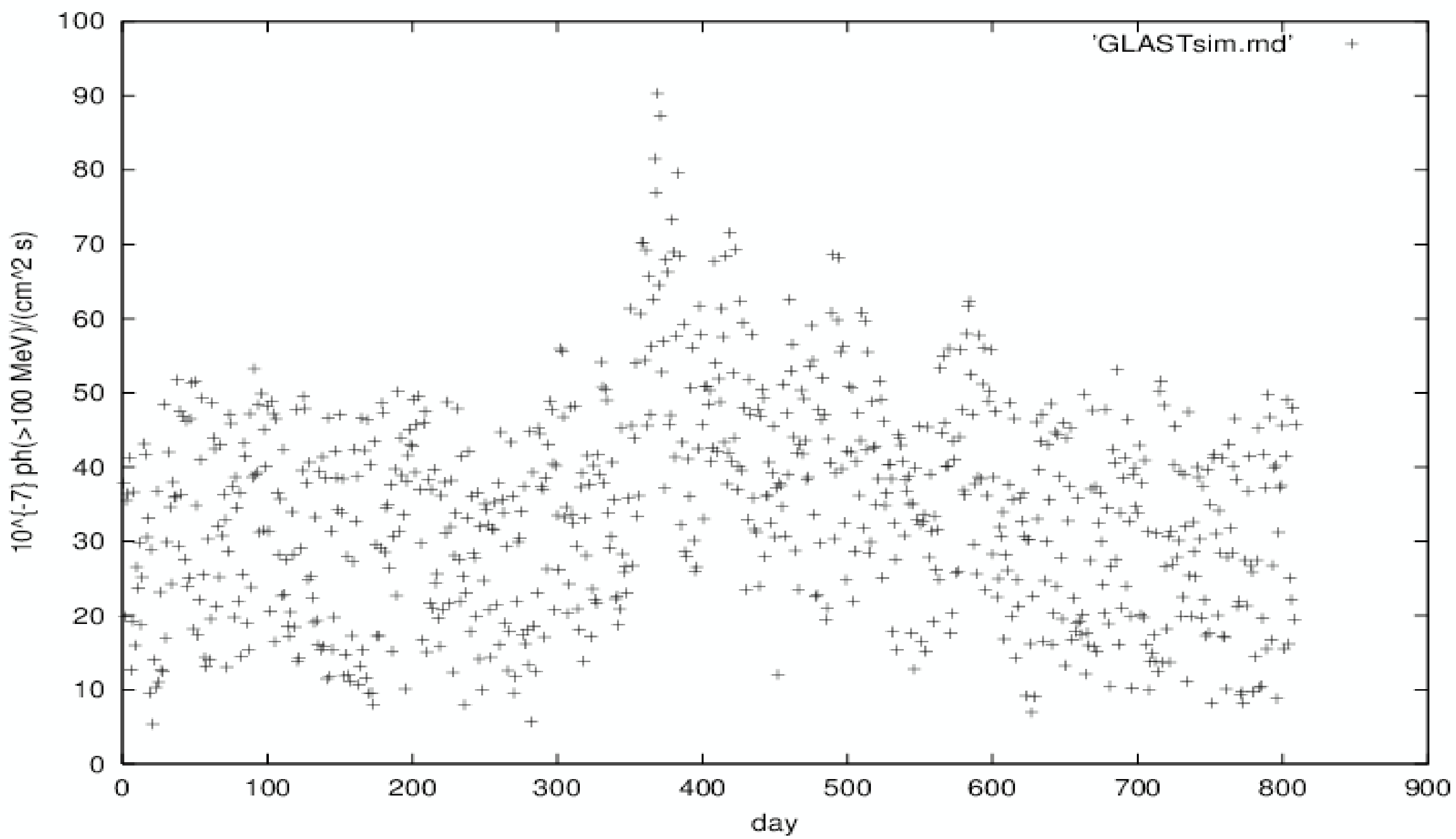


3) analysis tools: identification of faint sources

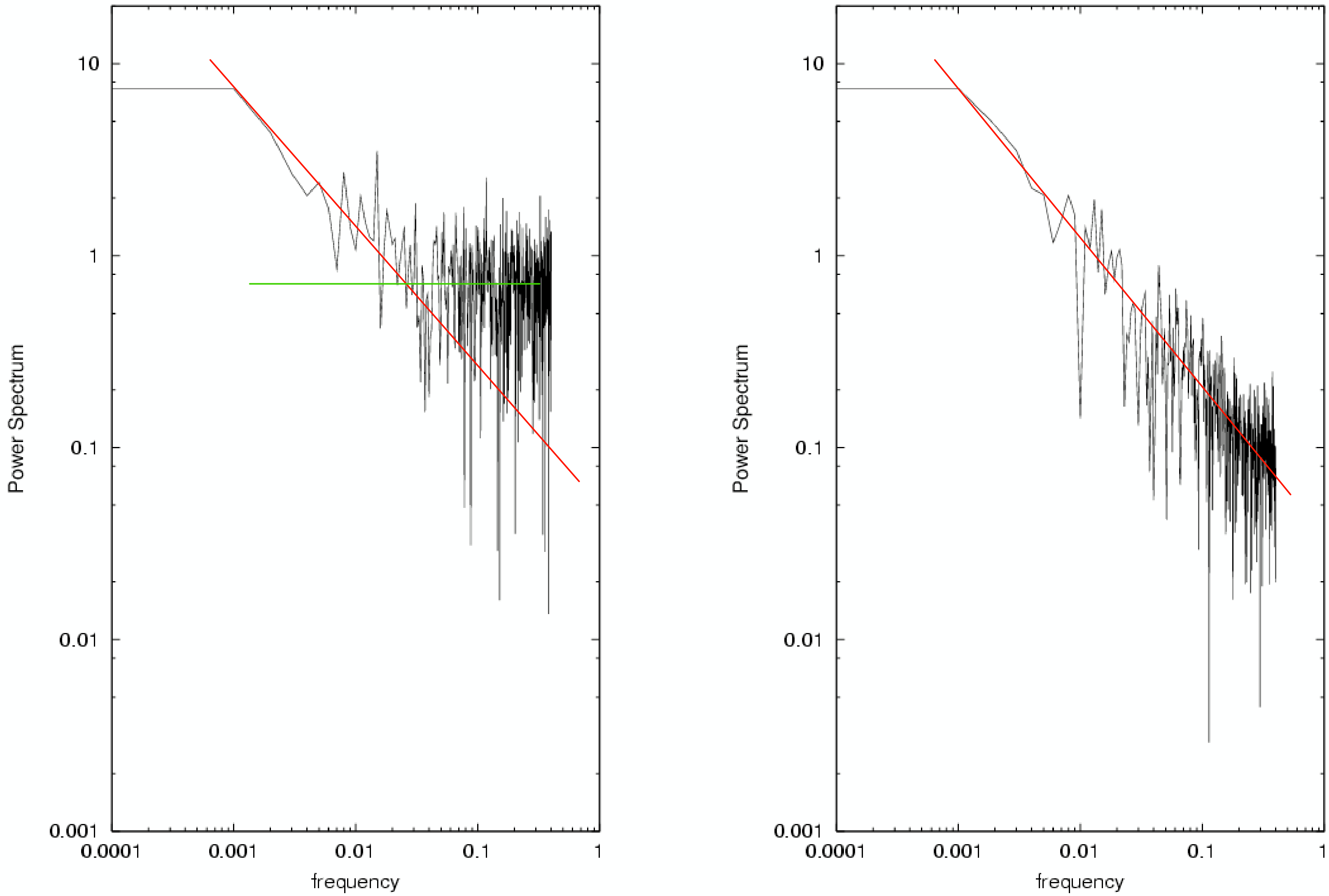


3) analysis tools: noise filtering

Simulated light curve

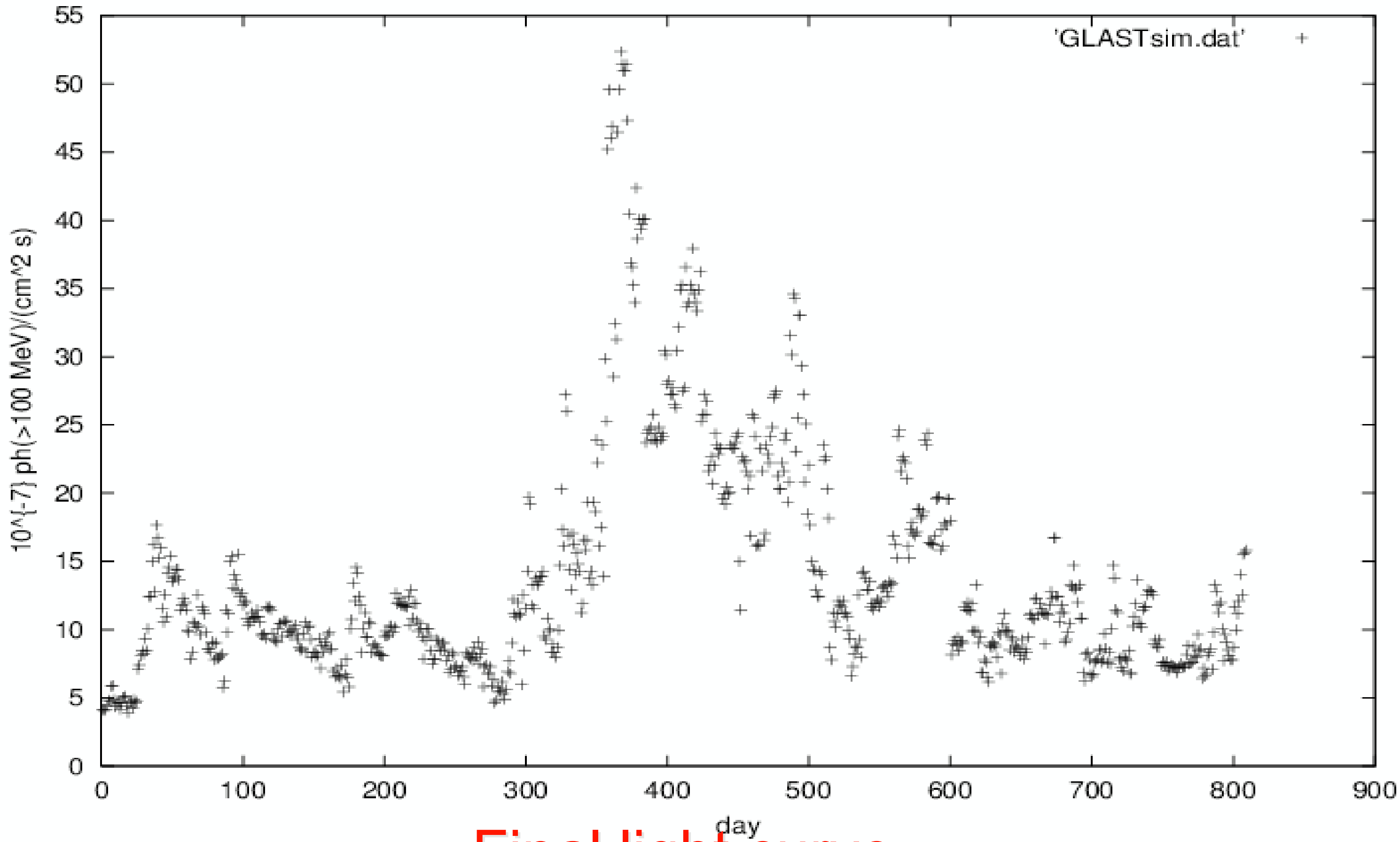


3) analysis tools: noise filtering



Variable source + background noise

3) analysis tools: noise filtering



Final light curve

Conclusions

- We must investigate all the opportunities that GLAST will offer in the time domain.
- Blazars seem to be characterized by a typical PSD and probably we can use this feature for an indirect classification.
- It is possible to simulate AGN variability starting from a phenomenological model.

- **Work in progress:**
  - to simulate “real observations” and to verify the preliminary results with MonteCarlo techniques;
  - to improve the “traditional” likelihood analysis with the inclusion of temporal analysis.

References

- Edelson R. A., Krolik J. H., 1988, ApJ 333, 646
- Fiorucci M., Tosti G., Luciani M., 1999, MSAlt 70, 223
- Grassberger P., Procaccia I., 1983, Phys Rev Lett 50, 346
- Hufnagel & Bregman, 1992, ApJ 386, 473
- Kataoka J., et al., 2001, ApJ 560, 659
- Lomb N. R., 1976, Ap. Space Sci. 39, 447
- Lawrance & Papadakis, 1993, ApJ 414, 85
- Marple S. L., 1987, "Digital Spectral Analysis", Prentice-Hall Inc.
- Peng C. K., et al., 1995, CHAOS 5, 82
- Press W. H., et al., 1992, "Numerical Recipes", Cambridge Univ. Press
- Scargle J. D., 1982, ApJ 263, 835
- Simonetti J. H., Cordes J. M., Heeschen D. S., 1985, ApJ 296, 46