Recent observations of Active Galactic Nuclei with H.E.S.S.

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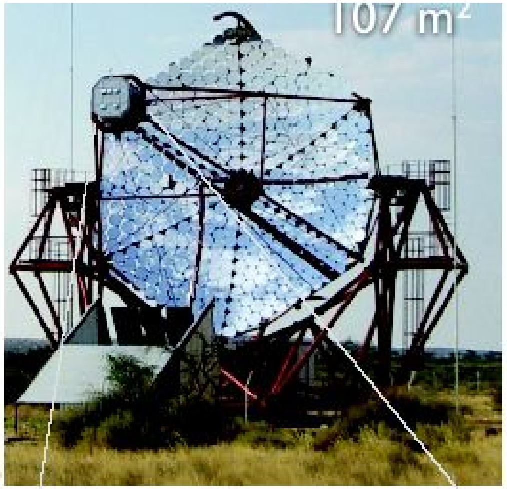
The H.E.S.S. array of Cherenkov Telescopes



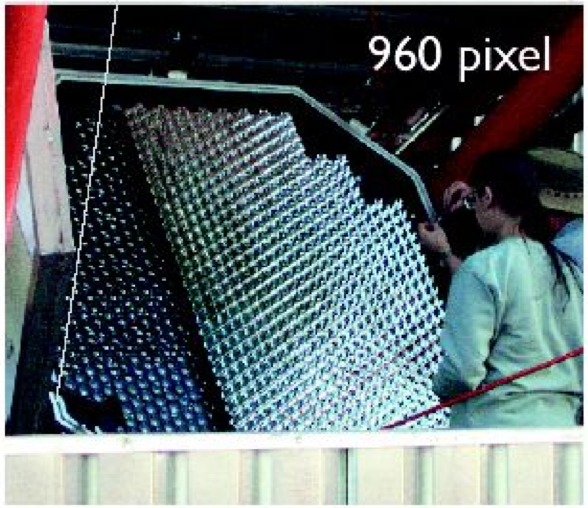
- 4 Cherenkov telescopes array located in Namibia
stereoscopic observation mode

- 107 m^2 mirror area per telescope

- Photomultiplier camera:
960 PMTs, ~5 deg field of view

- Energy range: 100 GeV up to several 10 TeV
dE/E ~ 15%

- Angular resolution: ~0.1 deg per event

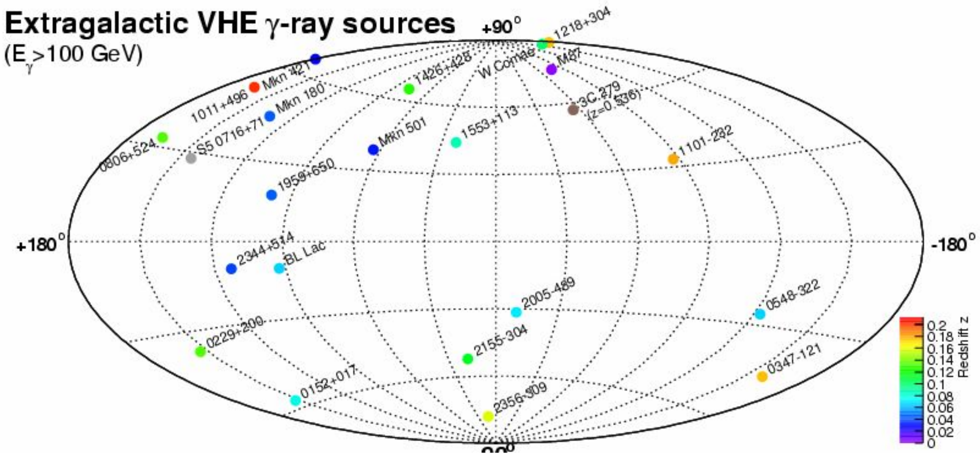


Details in W. Hofmann's talk
in this conference

22 VHE extragalactic sources (I)

Object	Redshift	Type	1st Detection	EGRET
M 87	0.004	FR I	HEGRA*	N
Mkn 421	0.030	HBL	Whipple*	Y
Mkn 501	0.034	HBL	Whipple*	Y
1ES 2344+514	0.044	HBL	Whipple*	N
Mkn 180	0.046	HBL	MAGIC	N
1ES 1959+650	0.047	HBL	7-Tel. Array*	N
BL Lac	0.069	LBL	MAGIC	Y
PKS 0548-322	0.069	HBL	H.E.S.S.	N
PKS 2005-489	0.071	HBL	H.E.S.S.	N
RGB J0152+017	0.080	HBL	H.E.S.S.*	N
W Comae	0.102	IBL	VERITAS	Y
PKS 2155-304	0.116	HBL	Mark VI*	Y
H 1426+428	0.129	HBL	Whipple*	N
1ES 0806+524	0.138	HBL	VERITAS	N
1ES 0229+200	0.139	HBL	H.E.S.S.	N
H 2356-309	0.165	HBL	H.E.S.S.	N
1ES 1218+304	0.182	HBL	MAGIC*	N
1ES 1101-232	0.186	HBL	H.E.S.S.	N
1ES 0347-121	0.188	HBL	H.E.S.S.	N
1ES 1011+496	0.212	HBL	MAGIC	N
PG 1553+113	>0.25	HBL	H.E.S.S.*	N
3C 279	0.536	FSRQ	MAGIC	Y

* = detected by ≥2 observatories



Most recent HESS detection:

Aharonian et al. A&A 481 (2008) L103

- RGB J0152+017 (2% Crab)

6,6σ in 15 h (in 2 months) - 173 γ

- Spectral index Γ= 2.95 ±0.36 (0.3- 2 TeV)
- Typical SED well described by SSC model
- No significant variability

22 VHE extragalactic sources (II)

- The 3rd generation of Cherenkov Telescopes has greatly increased the sensitivity allowing 22 extragalactic detections
- Most of these source are faint (few % of the Crab)
- Monitoring some of them permits to detect flaring episodes (monitoring strategies are not so easy in VHE domain)

Historically:

- for ~ 1/4 of TeV emitters, no variability has been detected
- few present weak variability (monthly, daily scales)
- only for H1426+428, 1ES 1959+650, Mkn 501, Mkn 421 and PKS 2155-304 detected flares of smaller time scales

PKS 2155-304 observed by HESS in 2006 with an unprecedented statistics permits to have access to AGN temporal and spectral variability.

Outline

- PKS 2155-304 in active state
  - Observation in 2006 (exceptional flaring episodes)
    - spectral and flux variability
  - Multi-wavelength observations with CHANDRA satellite
    - correlation X-γ ray flux
- Temporal variability study: is the variability due to a stationary gaussian process?
- Conclusions

PKS 2155-304 observations

PKS 2155-304 (z=0.116)

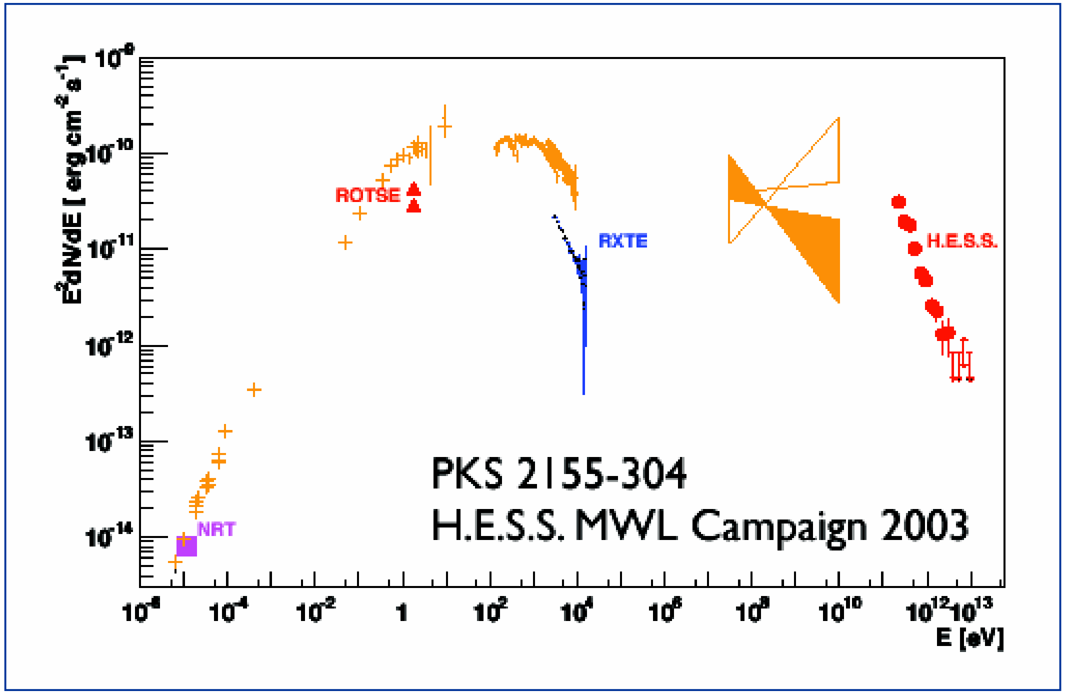
- High-frequency peaked BL-Lac object (HBL) – the first seen by HESS

- Discovered in TeV in 1999 (Mark 6) / Confirmed by H.E.S.S.
Chadwick et al. (1999), Aharonian et al. , A&A, 430, 865 (2004)

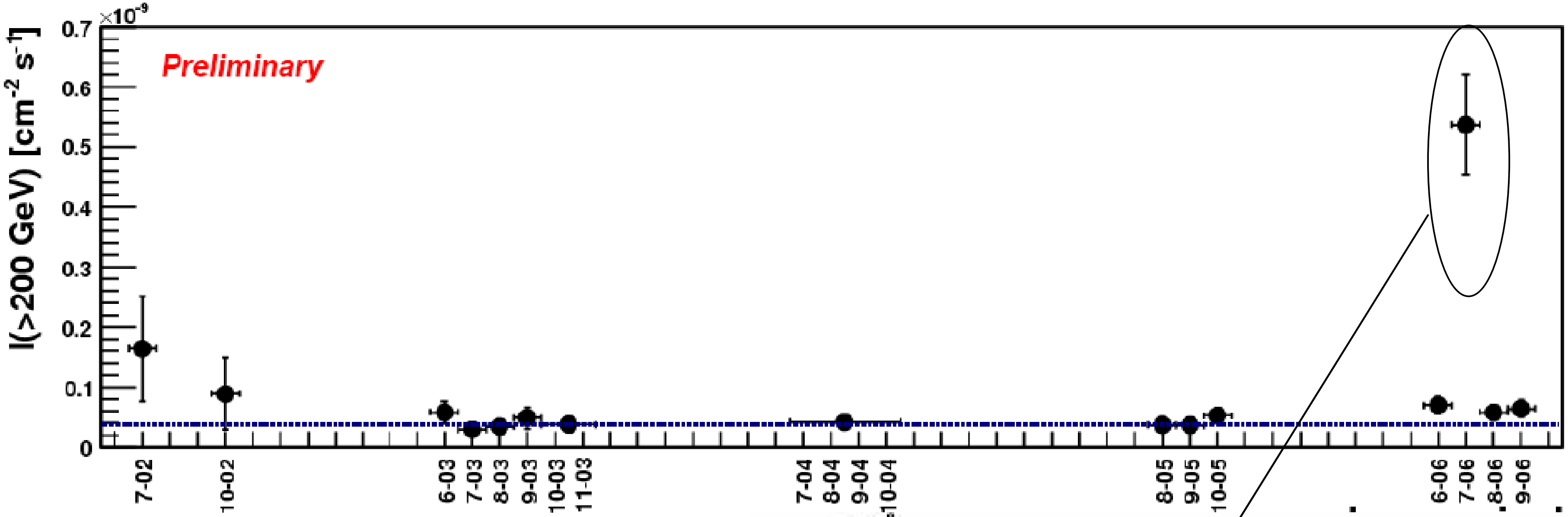
- Extensive multi wavelength studies in 2003 and 2004
Simultaneous radio, optical ,x-ray & TeV observations
Aharonian et al. 2005, A&A, 442, 895 (2005),

- Source always detected in TeV!
"quiescent state" (0.08-0.15 Crab)

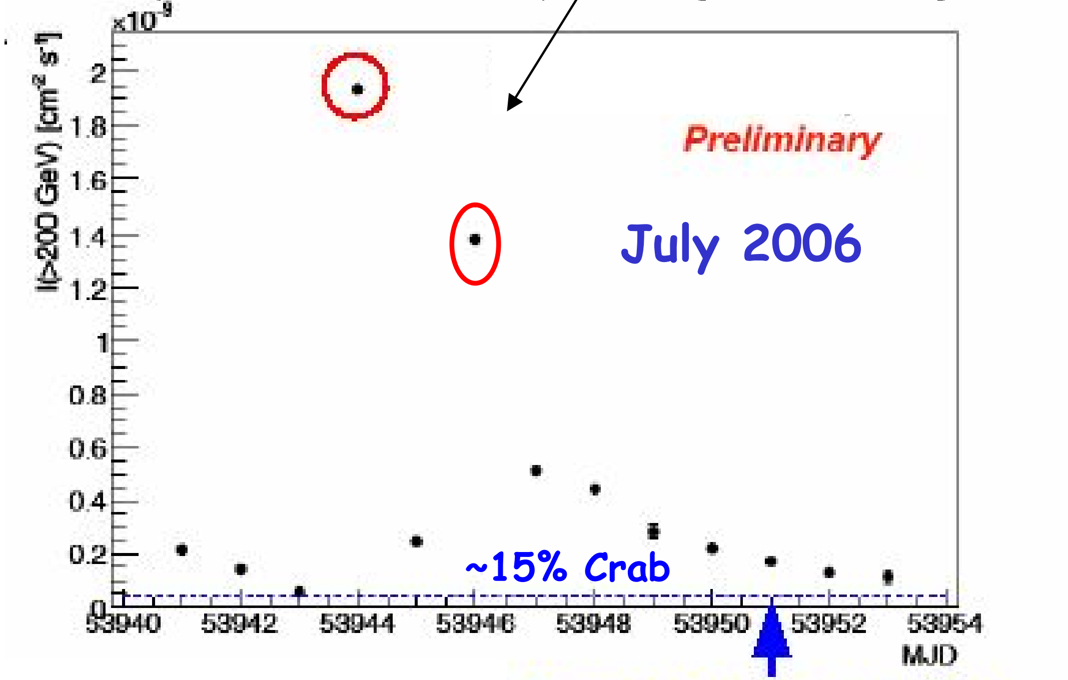
- Significant nightly HESS detection systematic



PKS 2155-304 (HESS campaign in 5 yrs)



- Monitored by HESS from 2002 to 2006 (~200 h)
- Quiescent flux at $\Phi(E>200GeV) \sim (4 \pm 0.4) \times 10^{-11}\ cm^{-2}\ s^{-1}$
- July 2006: 2 flaring nights!!!



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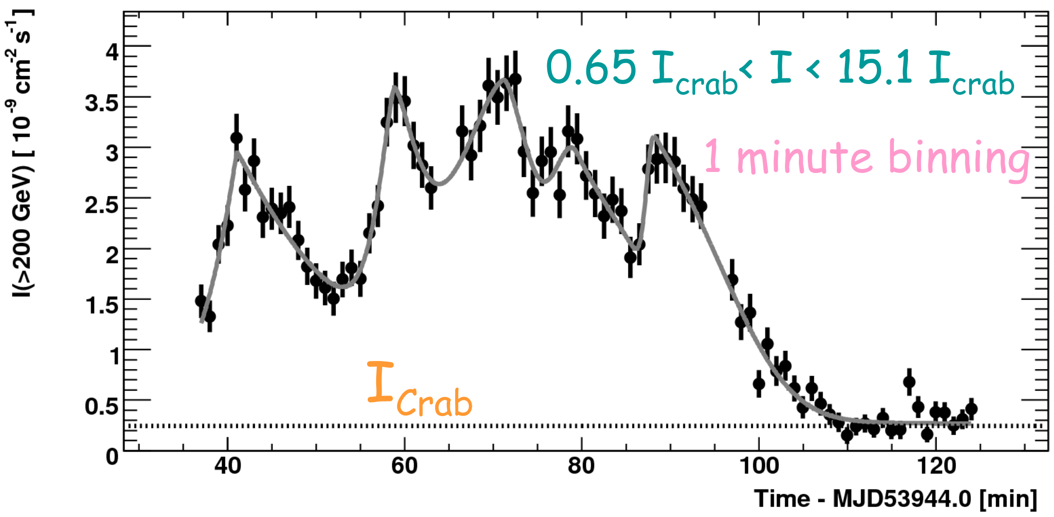
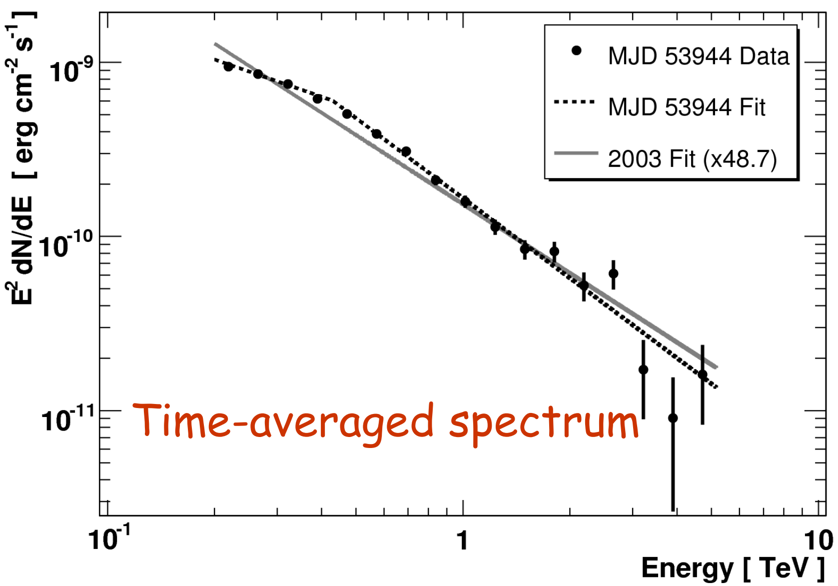
PKS 2155-304: 1st flaring night

Astrophys. Journal Lett. 664 (2007) L71-L74



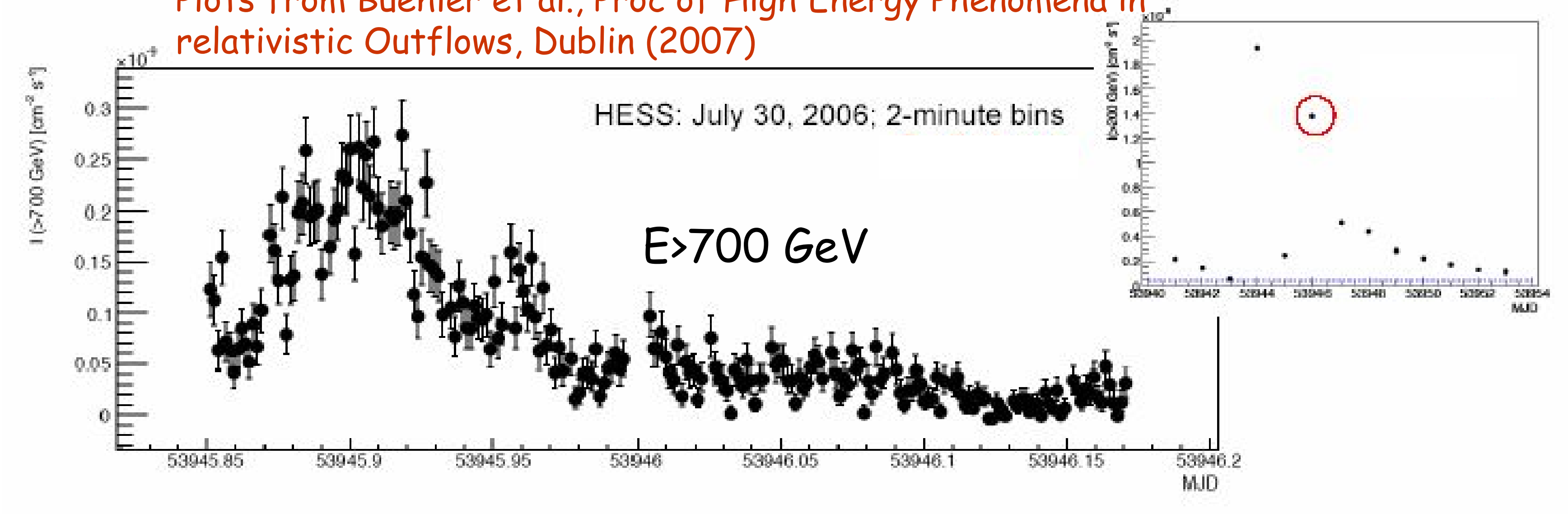


- July 28, 2006 (MJD 53944)
- 1.32h live time
- 5 peaks
- fastest rise time 174 ± 28 s
- One of the fastest VHE-flux variability (also Mkn 501 seen by MAGIC)
- Causality arguments imply a limit on the size of the emission region $R \leq c\, t_{var}\, \delta/(1+z) \Rightarrow$
  δ >60-120 R/R_S for 1-2$\times 10^9$ $M_\odot$ SMBH
- Despite 50 $\times$ higher flux $\Delta\Gamma$ < 0.2

No evidence of significant spectral variability!

PKS 2155-304: 2nd flaring night

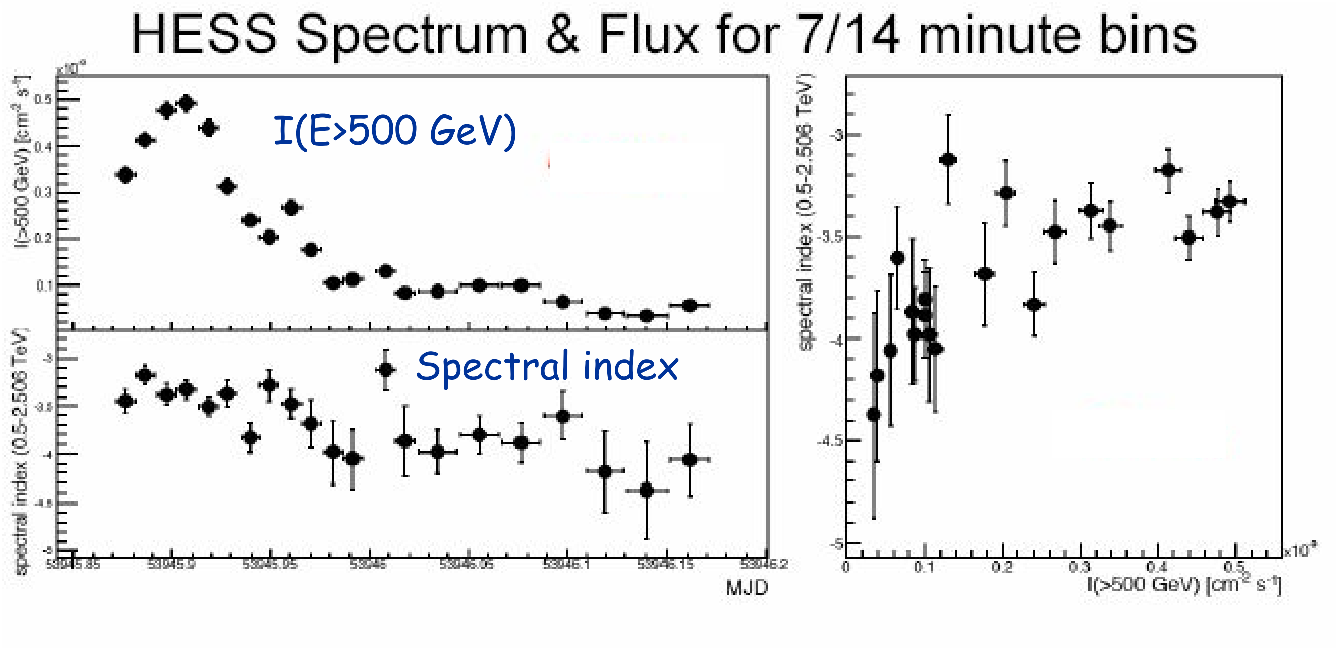
Plots from Buehler et al., Proc of High Energy Phenomena in relativistic Outflows, Dublin (2007)



- Almost full night coverage (~6.6h)
- Maximum peak

  ~ 7 I_{crab}
- Evidence of a slight spectral variability

  $\Delta\Gamma$ ~ 0.5



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HESS & Chandra simultaneous observations

- **Simultaneous observation July 30, 2006**

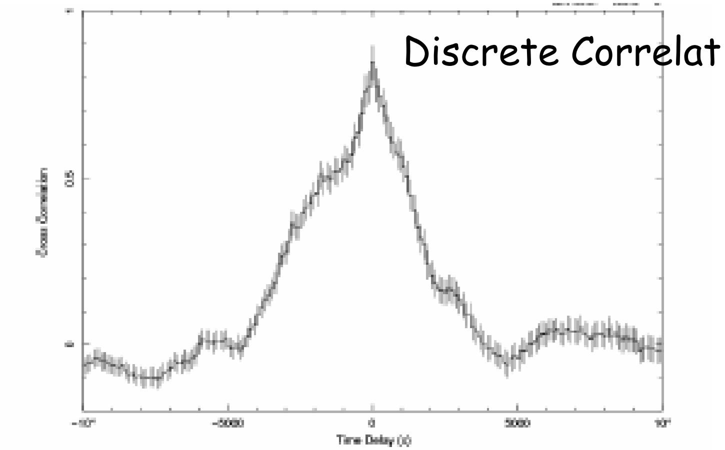
-H.E.S.S. : Φ(E> 200 GeV)

- Chandra satellite:

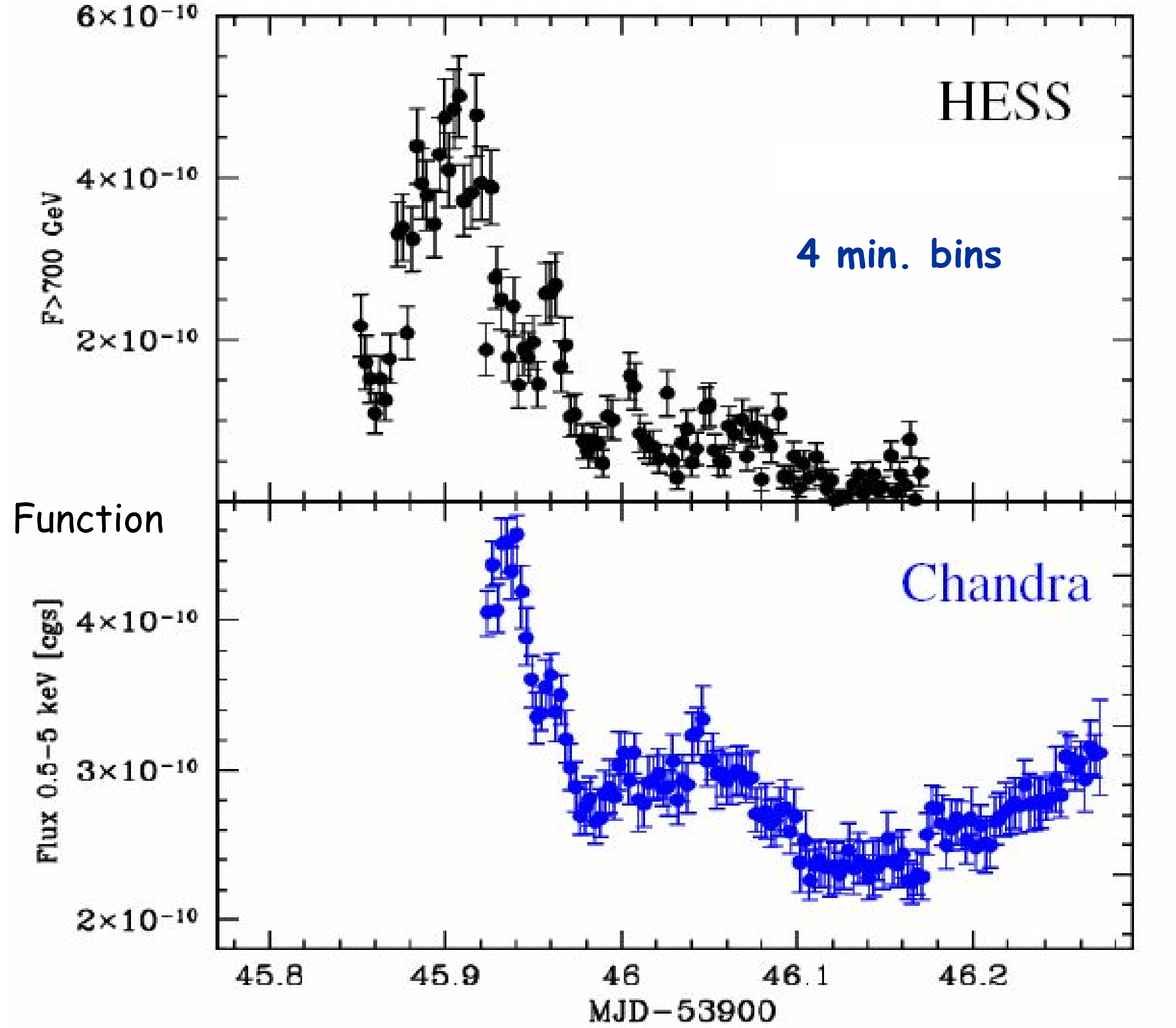
Φ(0.5 <E< 5 KeV)

- **Correlation**

Discrete Correlation Function



Plots from Costamante et al., Proc of High Energy Phenomena in relativistic Outflows, Dublin (2007)

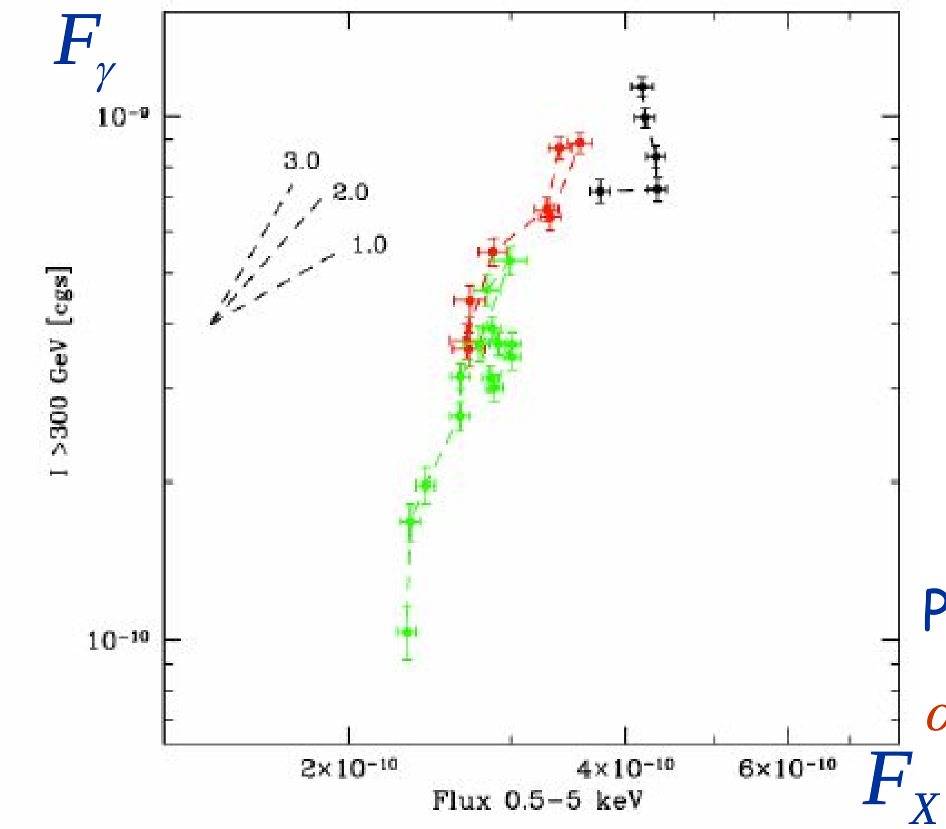


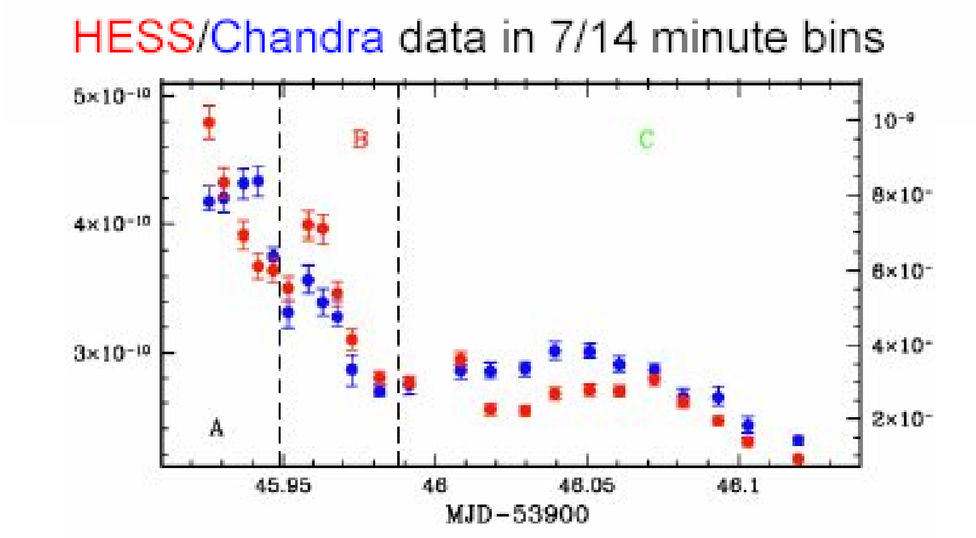
-strong correlation : 0.82 ± 0.18

- no lag evidence

HESS – CHANDRA correlations

Plots from Costamante et al., Proc of High Energy Phenomena in relativistic Outflows, Dublin (2007)





Power law relation $F_\gamma \propto F_X^\alpha$

α = 2.7±0.3 in the decaying phase

- Strong correlation: same population responsible of the emissions in the two energy ranges ->standard scenario (SSC)
- Modeling the ~cubic correlation (difficult in SSC scenario)

Temporal variability of PKS 2155-304

Quantifying the variability (1)

➢Empirical variables estimated on the LC

depending on the binning ΔT and on the duration of the observation T

- Flux variance $$S^2 = \frac{1}{N-1}\sum_{i=1}^{N}\left(\phi_i - \bar{\phi}\right)^2$$
- Excess rms $$\sigma_{xs} = \sqrt{S^2 - \overline{\sigma_{err}^2}}$$ where $$\overline{\sigma_{err}^2} = \frac{1}{N}\sum_{i=1}^{N}\sigma_{err,i}^2$$ error meas. contrib.
- Fractional variability $$F_{\mathrm{var}} = \frac{\sigma_{xs}}{\bar{\phi}}$$
- Doubling time $$\min(T_2^{ij}) \quad \textit{or} \quad \text{average 5 smallest } (T_2^{ij})$$

where $$T_2^{ij} = \left|\frac{T_i - T_j}{\phi_i - \phi_j}\right| \cdot \frac{\phi_i + \phi_j}{2}$$

Doubling Times

$$T_2 = \min(T_2^{ij}) \quad or \quad \tilde{T}_2 = \langle 5smallest(T_2^{ij}) \rangle \quad where \quad T_2^{ij} = \left| \frac{T_i - T_j}{\phi_i - \phi_j} \right| \cdot \frac{\phi_i + \phi_j}{2}$$

MJD 53944	T_2(min)	$\tilde{T}_2$(min)
ΔT=1 min	1.28 ± 0.38	2.84 ± 1.0
ΔT=2 min	2.63 ± 0.54	4.53 ± 1.59

MJD 53946	T_2(min)	$\tilde{T}_2$(min)
1 min	1.38 ± 0.37	2.33 ± 0.97
2 min	3.49 ± 1.0	6.22 ± 2.22

Strongly depending on the sampling ΔT !!

- T_2 is a lower limit for the fastest variability (limited by the resolution of the instrument)
- And what about the ultimate causality "time scale"?

Important to address this question because the fastest variability is a direct access to the emission region

Quantifying the variability (2)

➢Power Spectral Density (PSD)

an intrinsic property of the source state

The flaring period of PKS 2155-304 allowed to make the first estimate of a PSD in VHE domain
in the 1st flaring night:

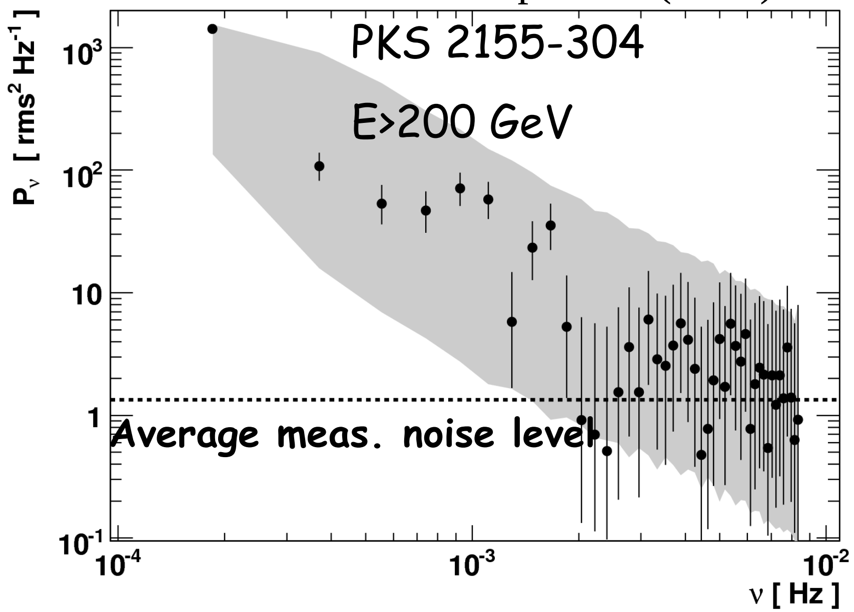
-power law Fourier Spectrum of index -2 similar in X-rays ->red noise process

- accessibility 10 ^{4}- 10 ^{2}Hz

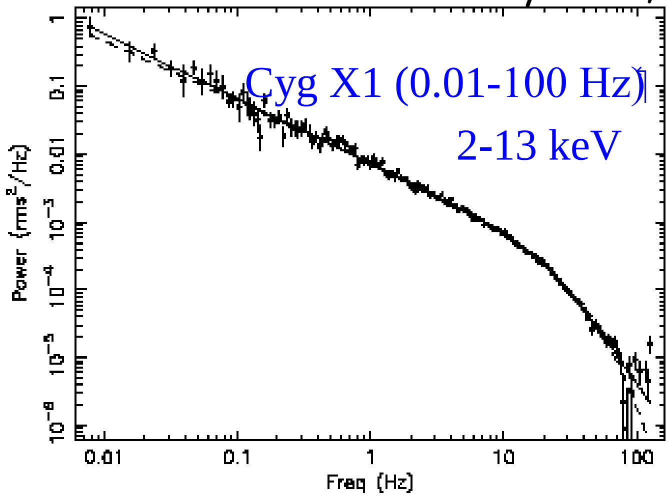
In X-rays the variability of Seyfert, Binaries and (recently also) of AGN is described as a noise process characterizing the PSD

⇒Studies modeling the PSD with simulations

Aharonian et al. ApJ 664 (2007) L71



Ian Mc Hardy et al., 2004



What about the variability of PKS 2155-304

Is the variability of PKS 2155-304 in the flaring period described by a Stationary Gaussian Process?

What is the gaussian variable?

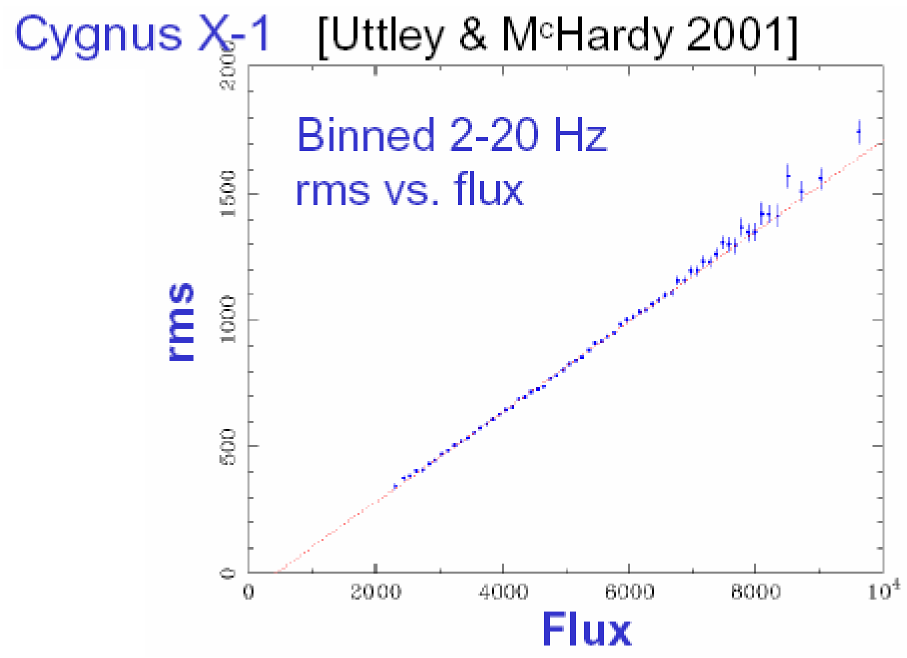
- Flux Φ-> additive process

Average flux completely independent of its variance (or rms)

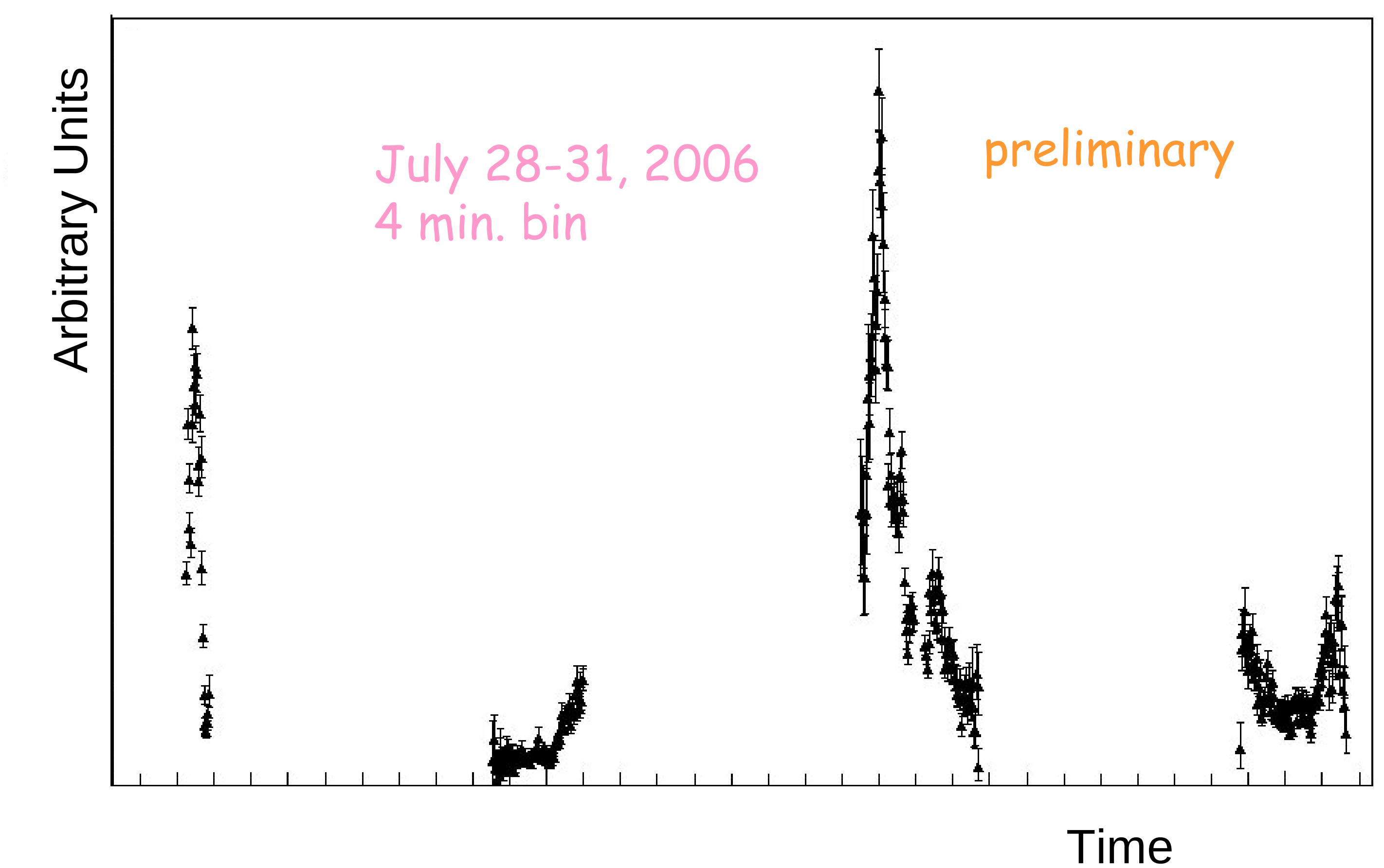
-ln(Φ)-> multiplicative process

Expected strong correlation between average flux and rms

➢Many cases of such correlation for Seyferts, X-ray binaries (P. Uttley et al., MNRAS 359 (2005) 345) .. also for few AGN



Normal or log-normal?

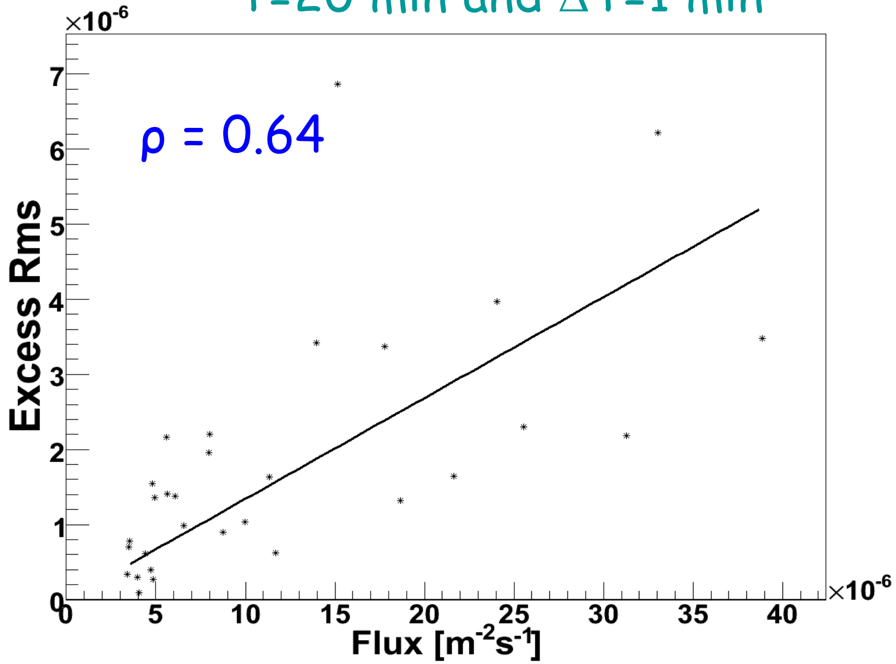


Check the excess rms-flux correlation in 2 cases for PKS 2155-304:

- T=20 min and ΔT=1 min
- T=80 min and ΔT=4 min

Excess rms-flux correlation

T=20 min and ΔT=1 min

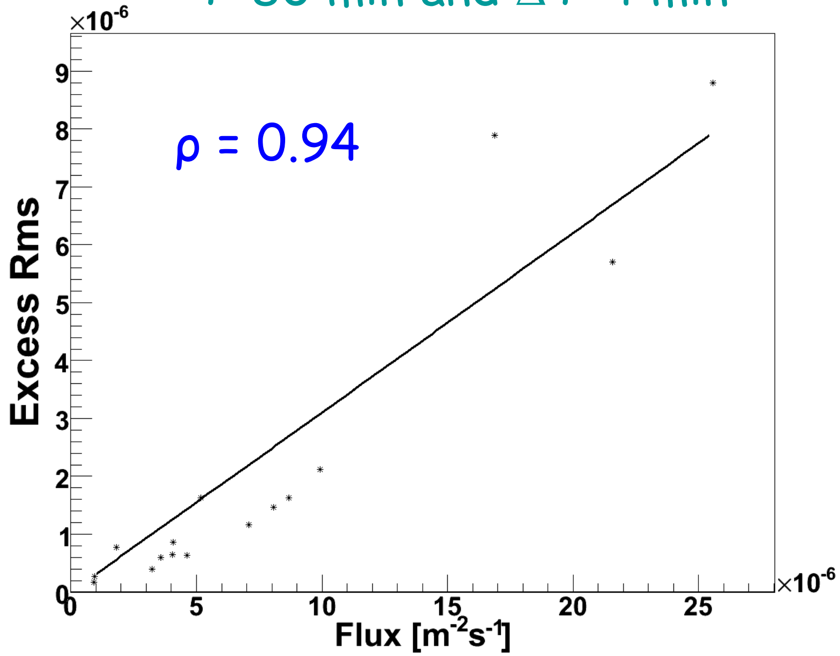


Correlation ⇒ 0.36 < ρ < 0.81
at 95% confidence interval

Negligible measurement errors on the correlation factor

Gaussian process excluded
at 4 sigma level

T=80 min and ΔT=4 min



Correlation ⇒ 0.84 < ρ < 0.98

Gaussian process excluded
at 7 sigma level

→ Well described as log-normal process

Charaterizing with a log-normal process

➢Parametric estimation of the PSD in the assumption of a log-normal process

$$\frac{dP(\ln\Phi)}{d\nu} = K_{\ell}\left(\frac{\nu_{ref}}{\nu}\right)^{\alpha}$$

-PSD depending on 2 parameters α and K_{ℓ}

-the reference frequency is chosen conventionally: $\nu_{ref} = 10\ ^{4}$Hz

➢Used simulations of realistic time series defined by PSD corresponding to different values of the 2 parameters

➢Compared data with simulation for 3 observables : excess rms-flux correlation, structure functions and doubling time.

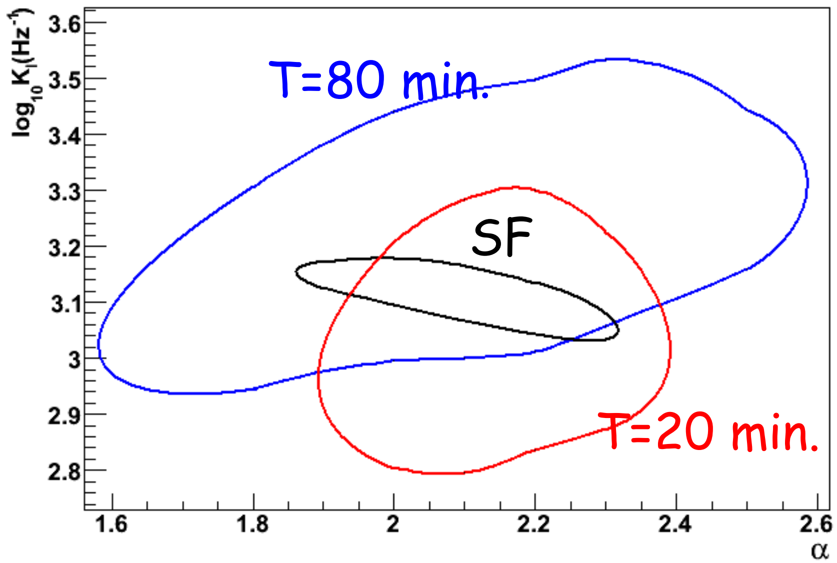
➢Parameters α and K_{ℓ} constraint using maximum likelihood fit with experimental distributions

Self consistent determination of the parameters

- Excess rms-flux : same correlation as in the experimental cases
  - •T=20 min and ΔT=1 min
  - •T=80 min and ΔT=4 min
- Structure Function (SF)

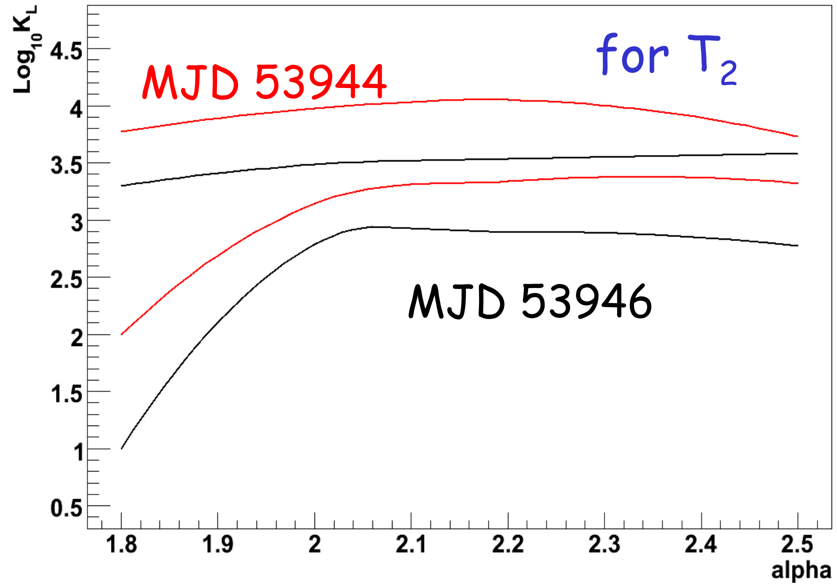
$$SF(\tau) = \left\langle \left[\Phi(t) - \Phi(t+\tau) \right]^2 \right\rangle$$

- Doubling Time



Determined 95% confidence intervals for the parameters (α,K_ℓ)

✓SF better determin α and K_ℓ
✓rms discriminate between gaussian or log-normal process
✓T_2 not sensitive to α



-PSD compatible with that of a red noise (α=2.0±0.2)

-the power K_ℓ at 10 ^{4}Hz is Log(K_ℓ/Hz ^{1})=3.1±0.2

Conclusions (1)

➢ Monitoring PKS2155-304 has allowed to

- detect an active state in July 2006 followed by the detection of two extraordinary flares
    - fastest time variability
    - spectral variability
- make multi-wavelength observation with the CHANDRA satellite in the second flaring night
    - strong correlation
    - no lag
    - more than quadratic correlation between X and γ-rays

Conclusions (2)

- First evidence in the VHE domain of a strong correlation between excess rms and flux for PKS 2155-304

- Variability of this source can be accounted for a log-normal stationary process. ⇒ Multiplicative process originating its variability

- Parametric determination of the PSD.

  Consistent determination of the parameters with three methods

  Compatibility with a red noise process between 10^{4} and 10^{2} Hz

Open points:

-Where the variability originates in AGN? And how is this related to the emission? Models should be consistent to the observed correlation between excess-rms and flux.

- Ultimate causality time scale : if there is no cutoff in the PSD at high frequencies, future CherenkovTelescopes (CTA) should be able to lower the limit in the measured doubling times.