HBL variability at high energies

Clues on jet structure and driving engine

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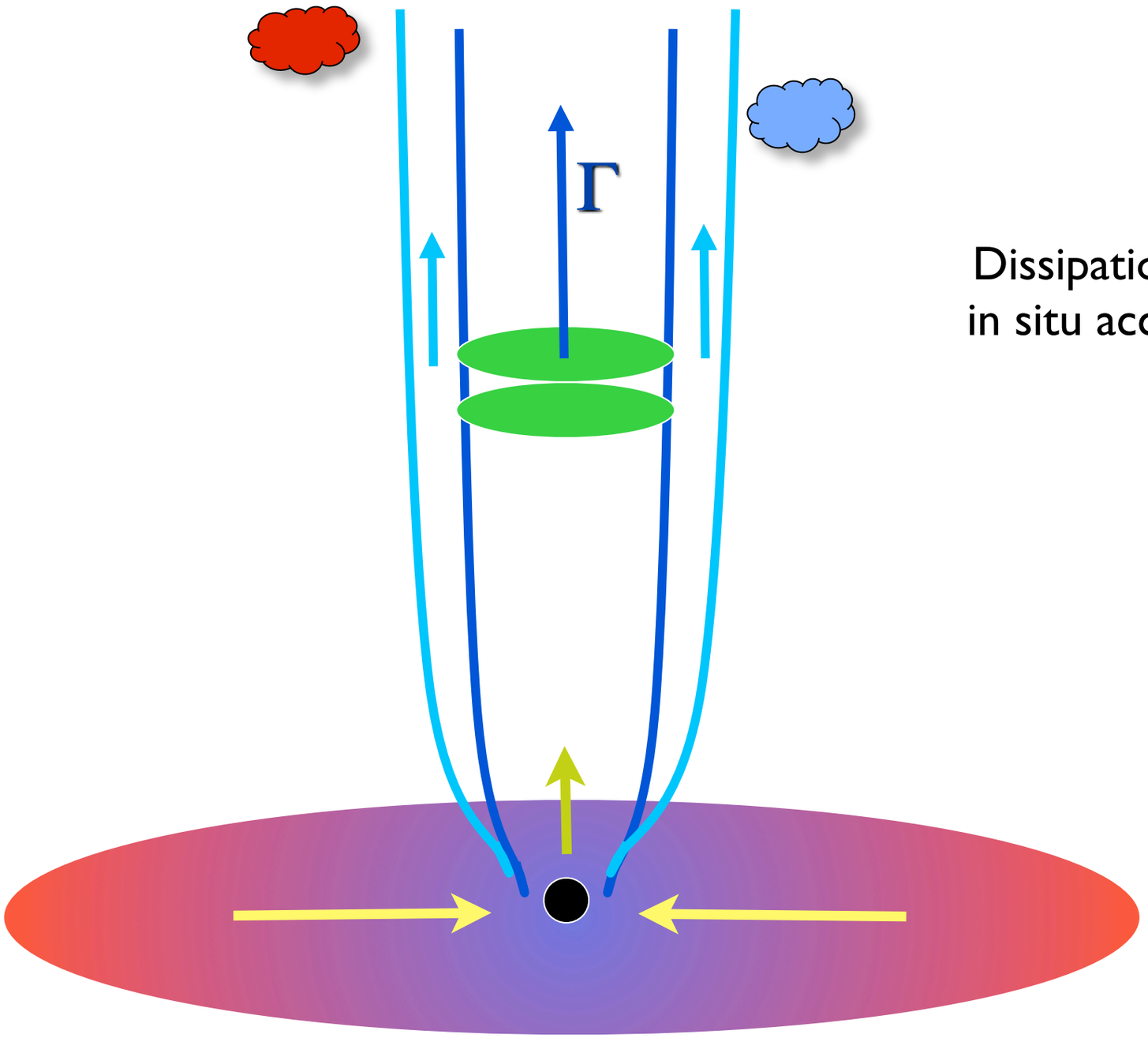
HEPL/KIPAC Stanford University

Blazars have always a combination of at least 2 types/engines of variability:



Dissipation events in the Jet:
in situ acceleration & cooling

Accretion & ejection:
modulated by Disk-BH connection

Disk & BH power the jet: variability modulated by accretion

Blazars

Acceleration & cooling in the jet : large flares and outbursts

- Disk-BH interaction
- ‘long term’ variations
- low energy electrons ($\gamma \sim 1\text{-}100$)

- sensible to jet structure
- ambient fields
- emission mechanisms
- high energy electrons
- ‘short term’ variability

X-ray binaries, RQ agns

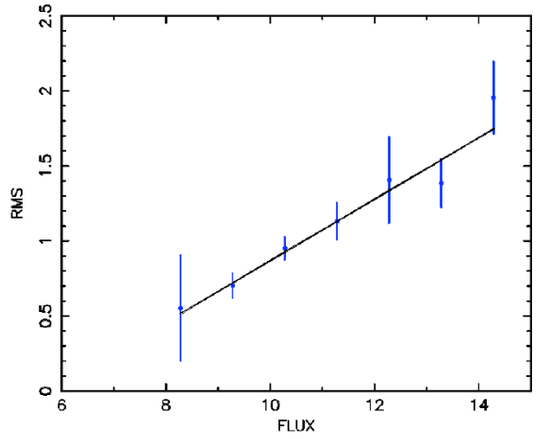
GRBs

X-ray binaries, RQ agns

Blazars

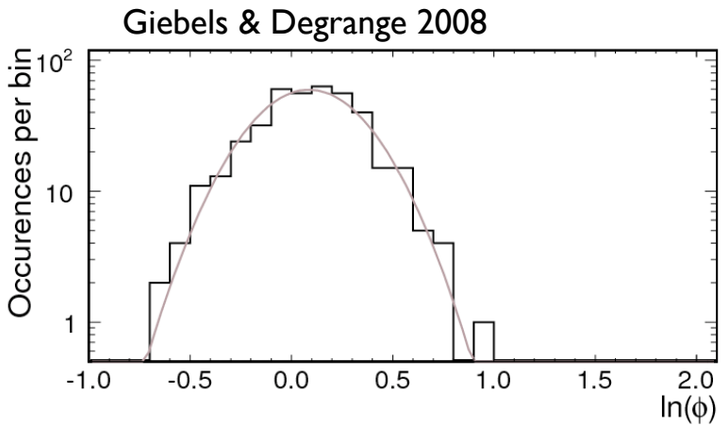
Long-term X-ray monitoring:

McHardy et al. 2008



Linear rms-flux relation
(e.g. 3C273)

Giebels & Degrange 2008

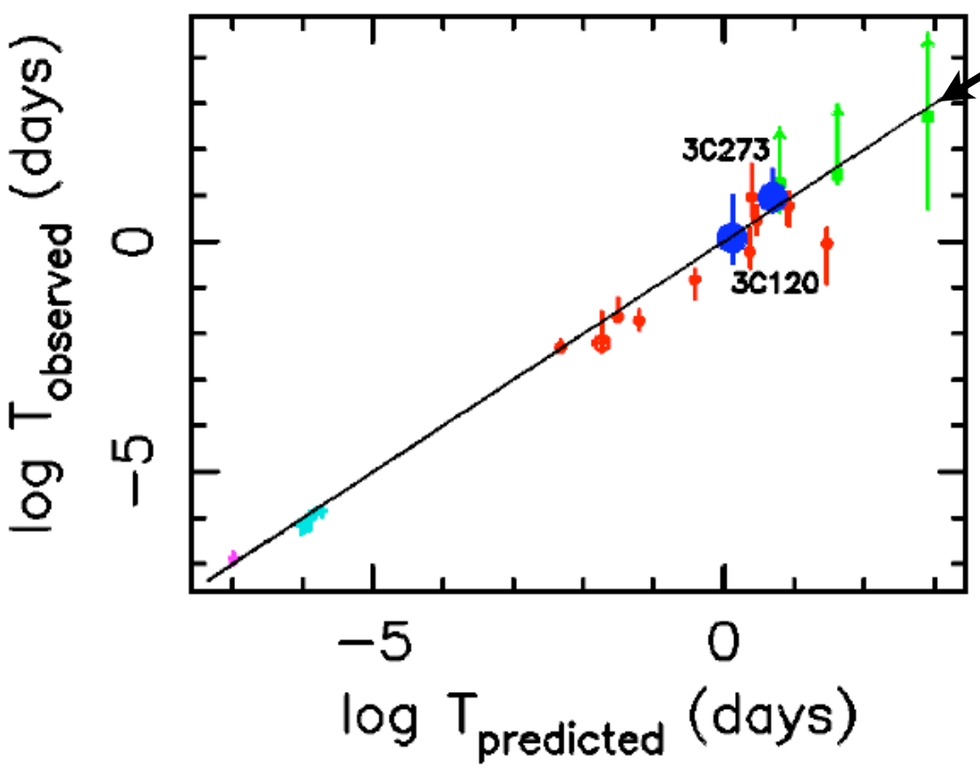


Log-normal distribution
(e.g. BL Lacertae)

X-ray binaries, RQ agns

Blazars

T= break in power density spectrum



$$T \propto M_{BH}/\dot{m}_{Edd}$$

Seyferts/Gal BH

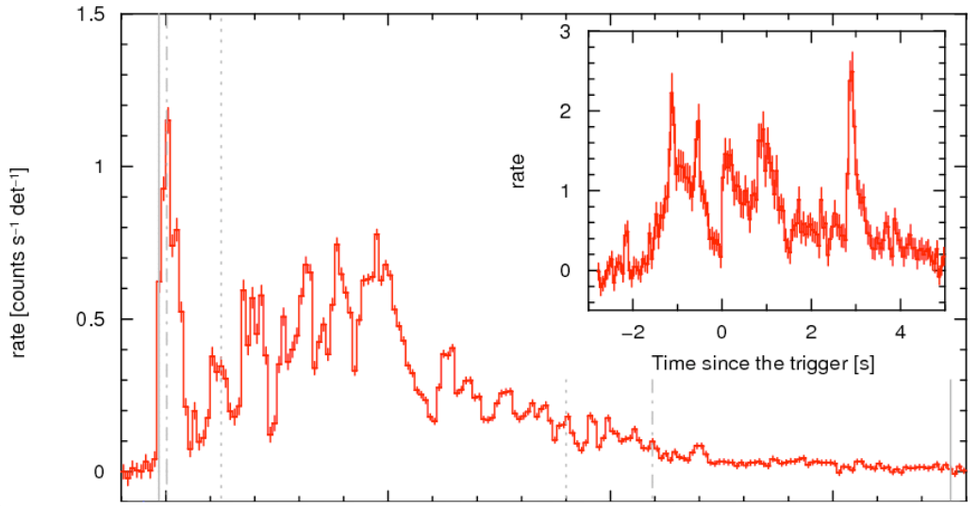
No relativistic time contractions !
Clock does not lie "in the jet"

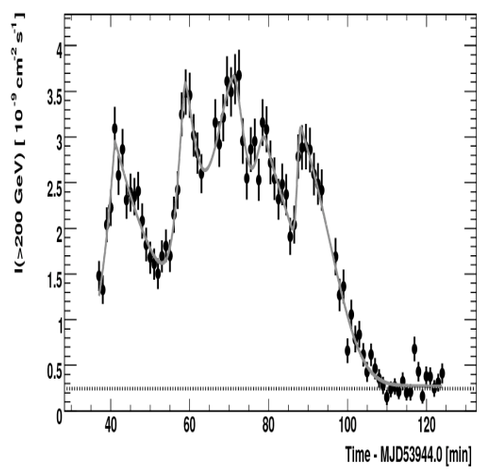
McHardy et al. 2008

Blazars

GRBs

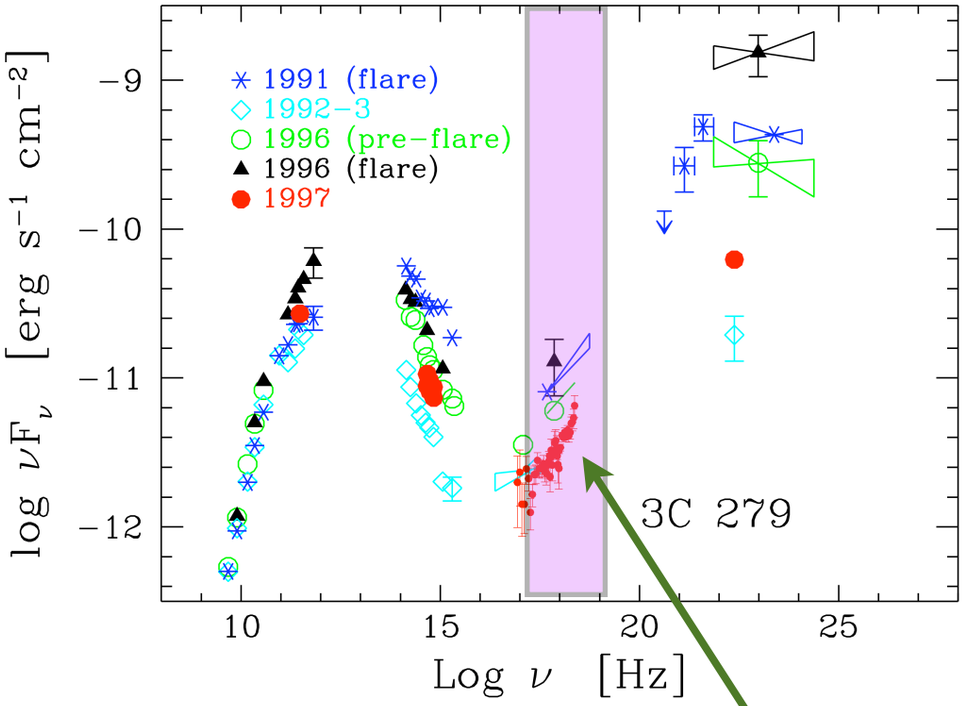
Sudden release of energy
in a compact zone



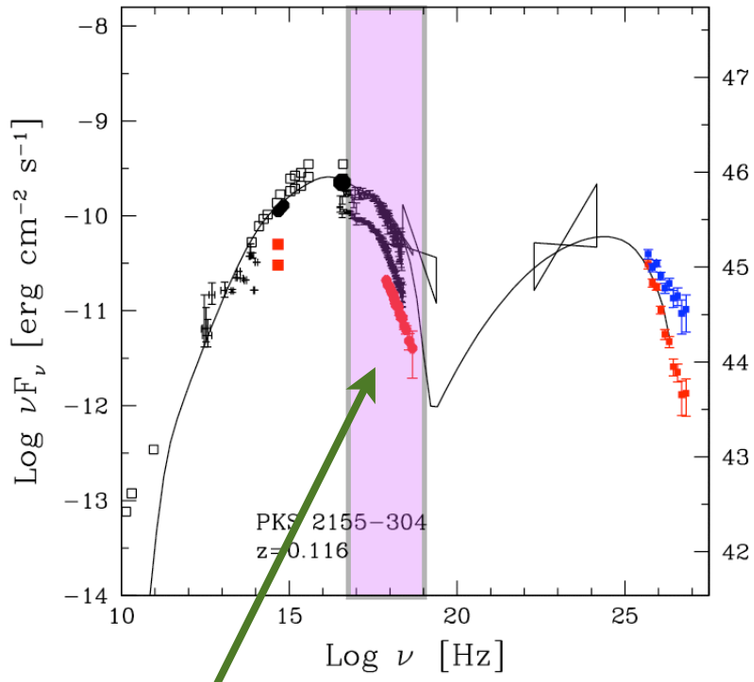


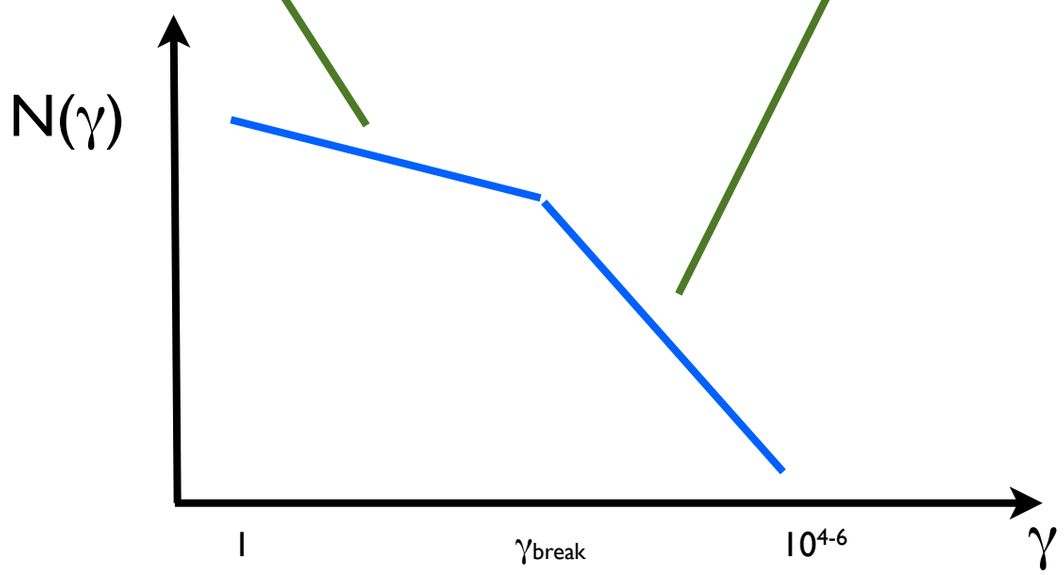
Note 2: Variability depends on the position of the observed band relative to the SED peaks

LBL/FSRQ



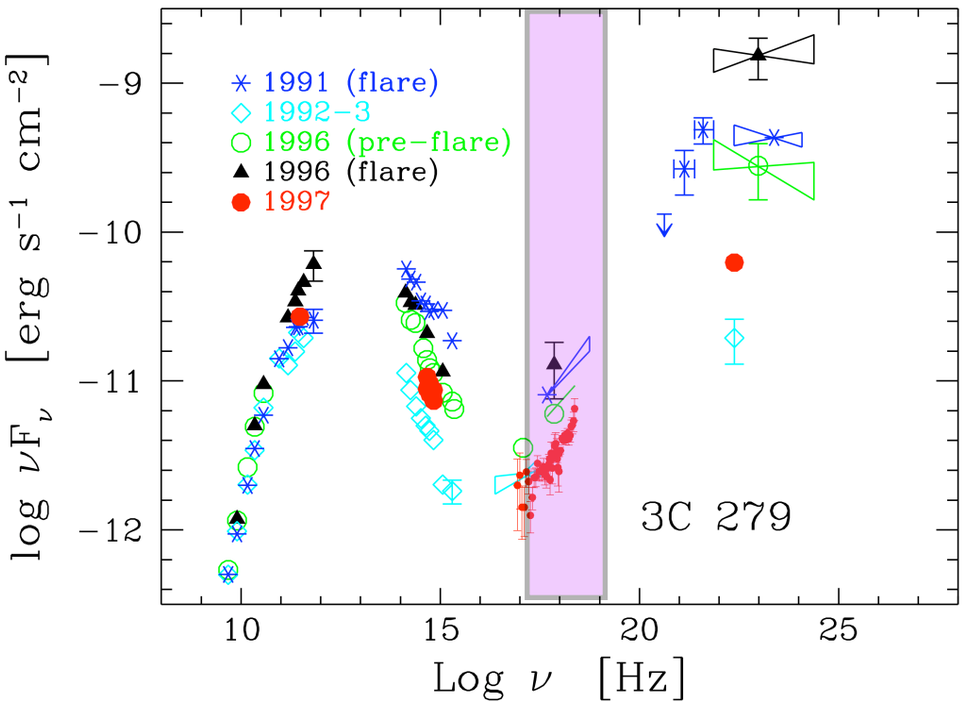
HBL



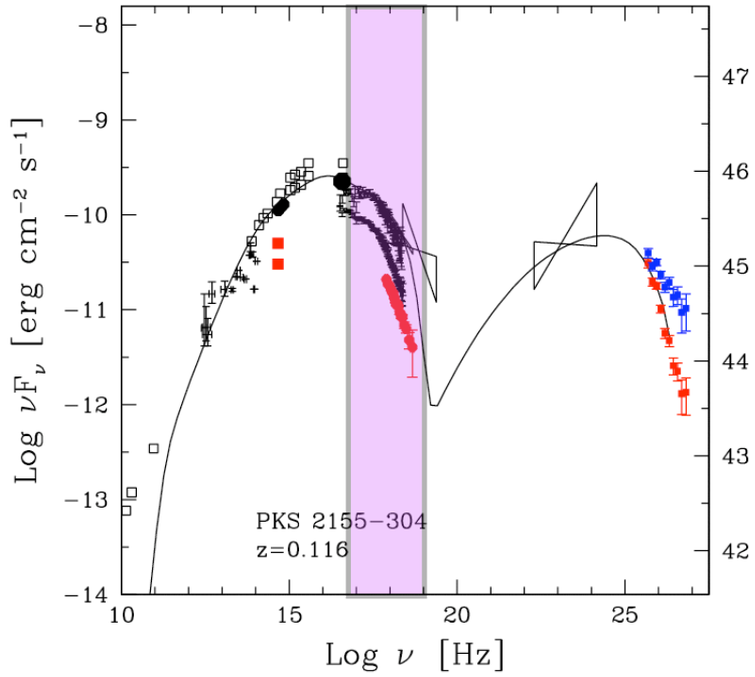


Variability depends on the position of the observed band relative to the SED peaks

LBL/FSRQ



HBL

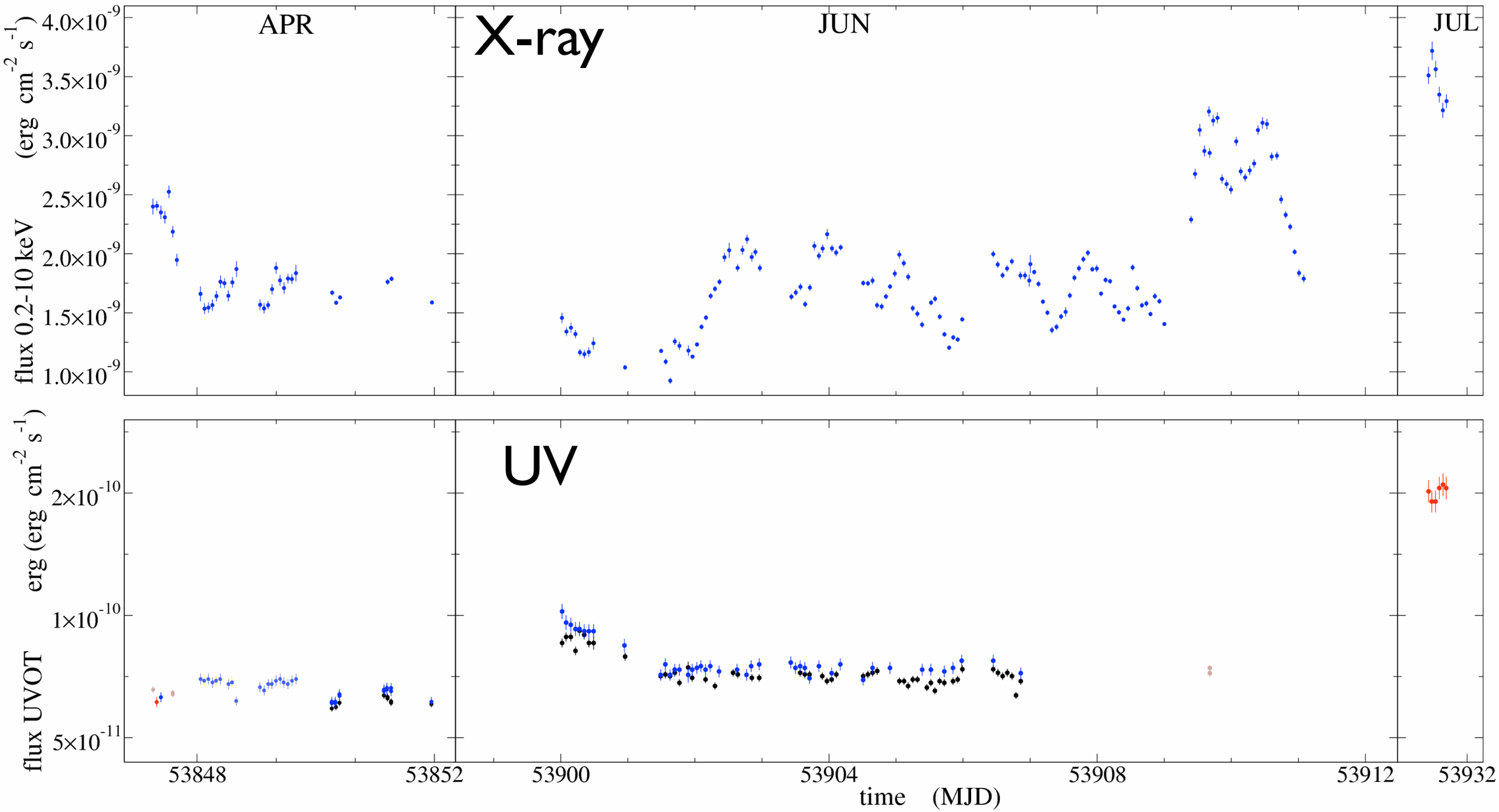


Do not compare apples with oranges...

X-ray (or Gamma-ray) variability means very different electron energies for different SED types

Behavior of the electron distribution: typically it varies much more above the 'peak'

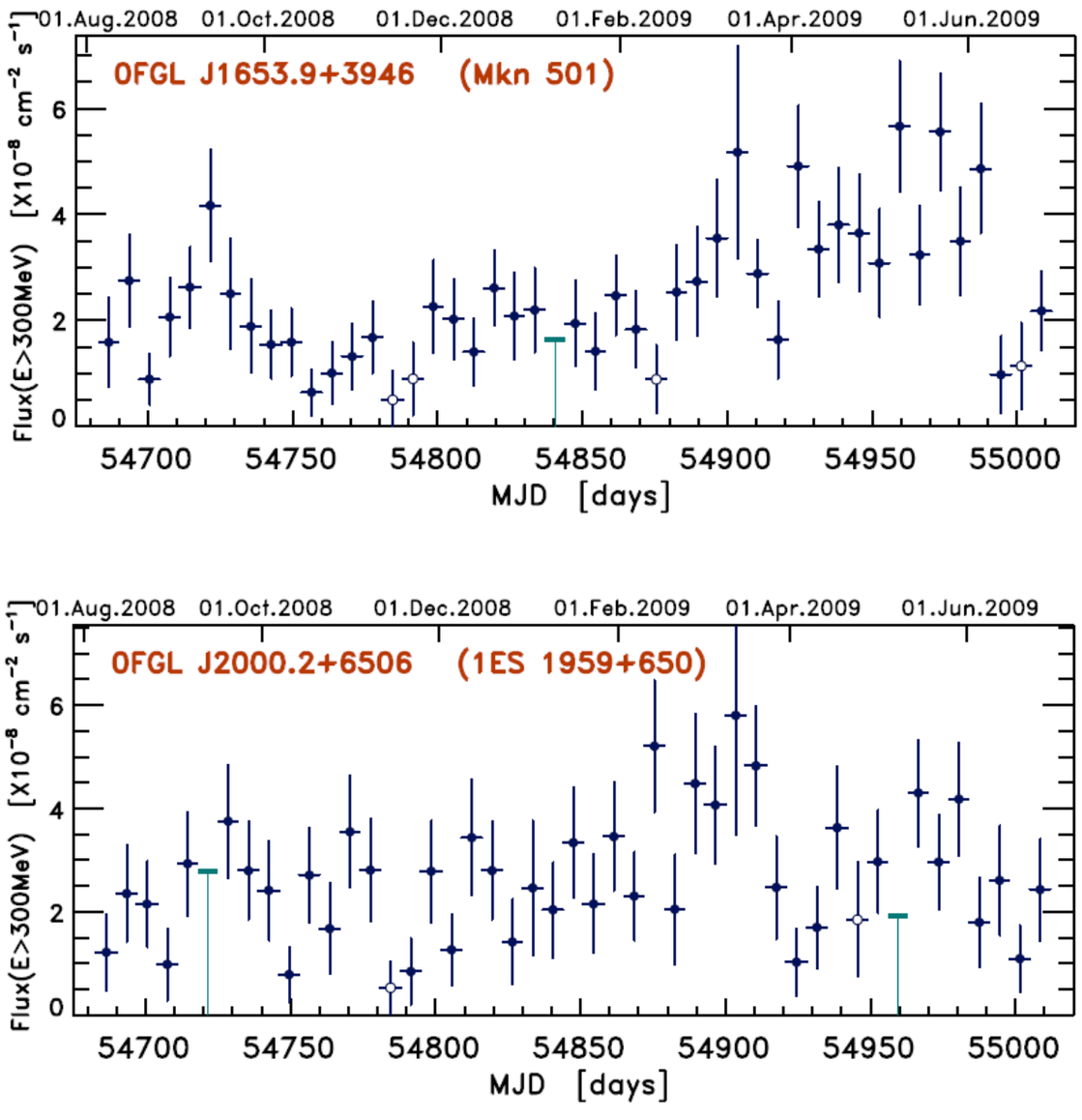
e.g. Mkn 421 in 2006

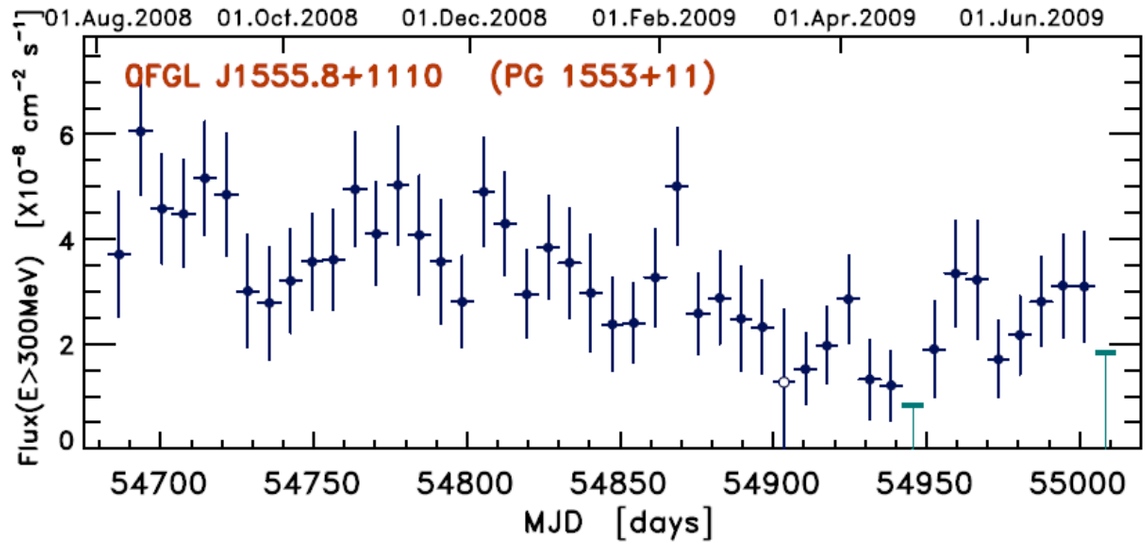


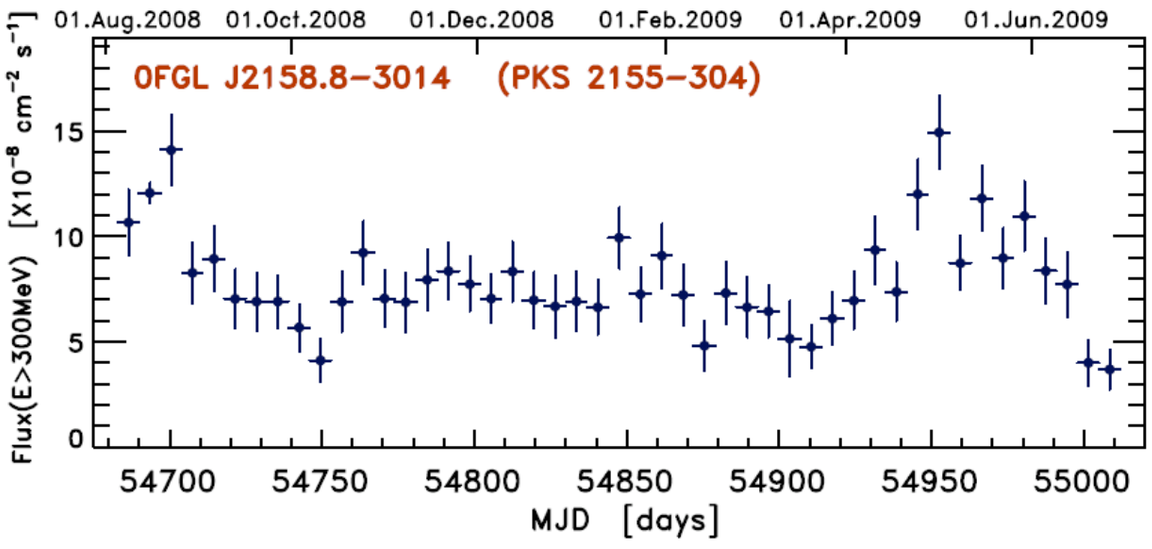
Tramacere et al 2009

Fermi band: little/no variability

(as in the optical...)



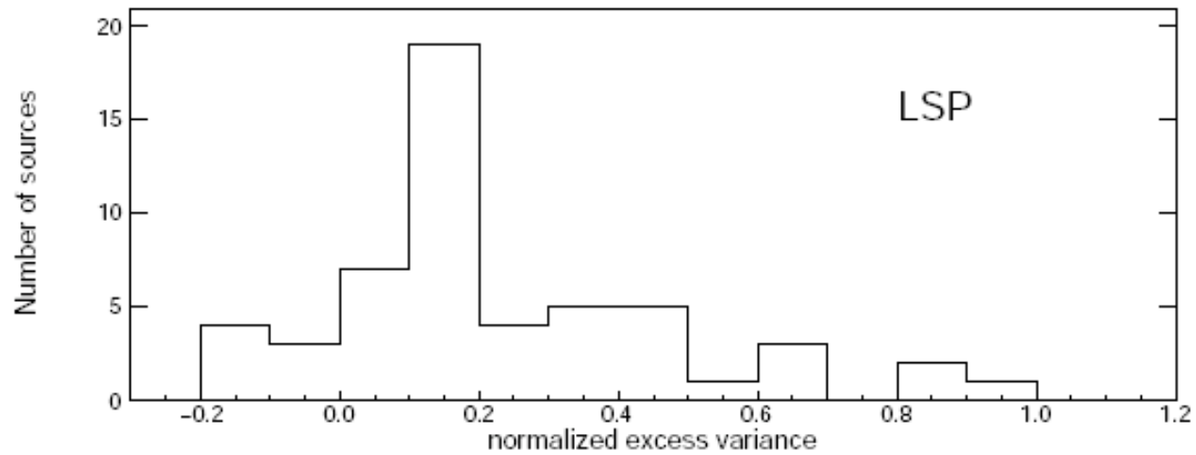




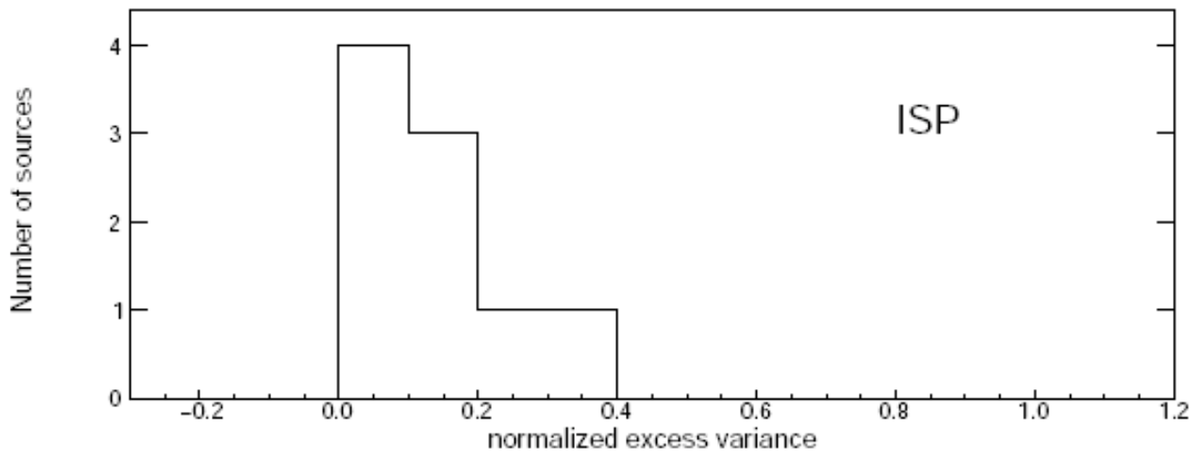
Abdo et al. 2010

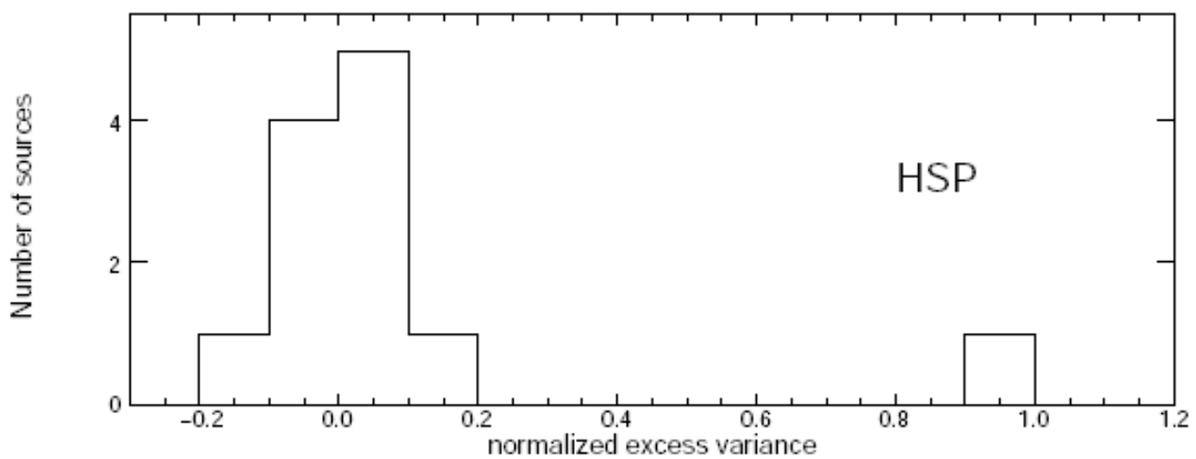
see talk by S. Ciprini, G. Tosti

Fermi band: excess variance



LBL/FSRQ





HBL

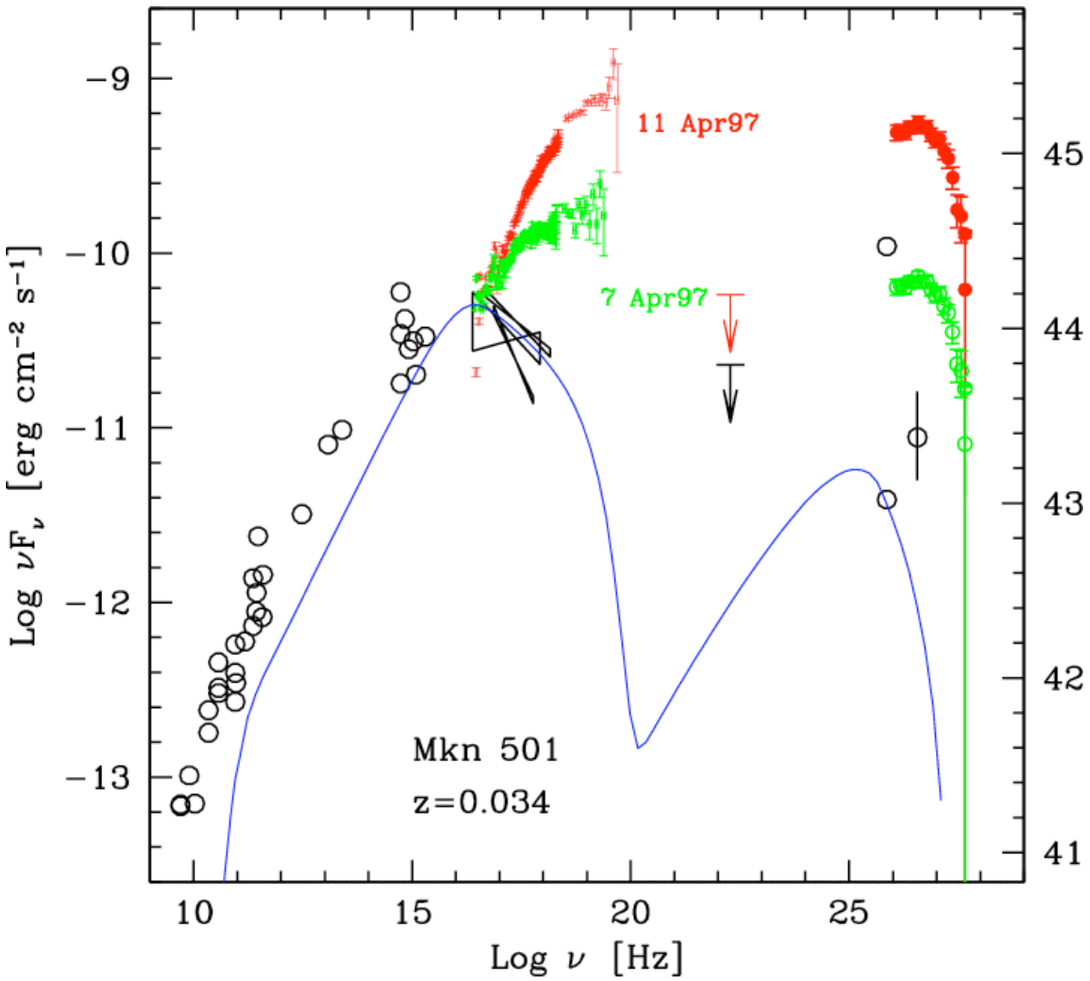
We focus now on HBLs, and the
high-energy branch of the electron distribution

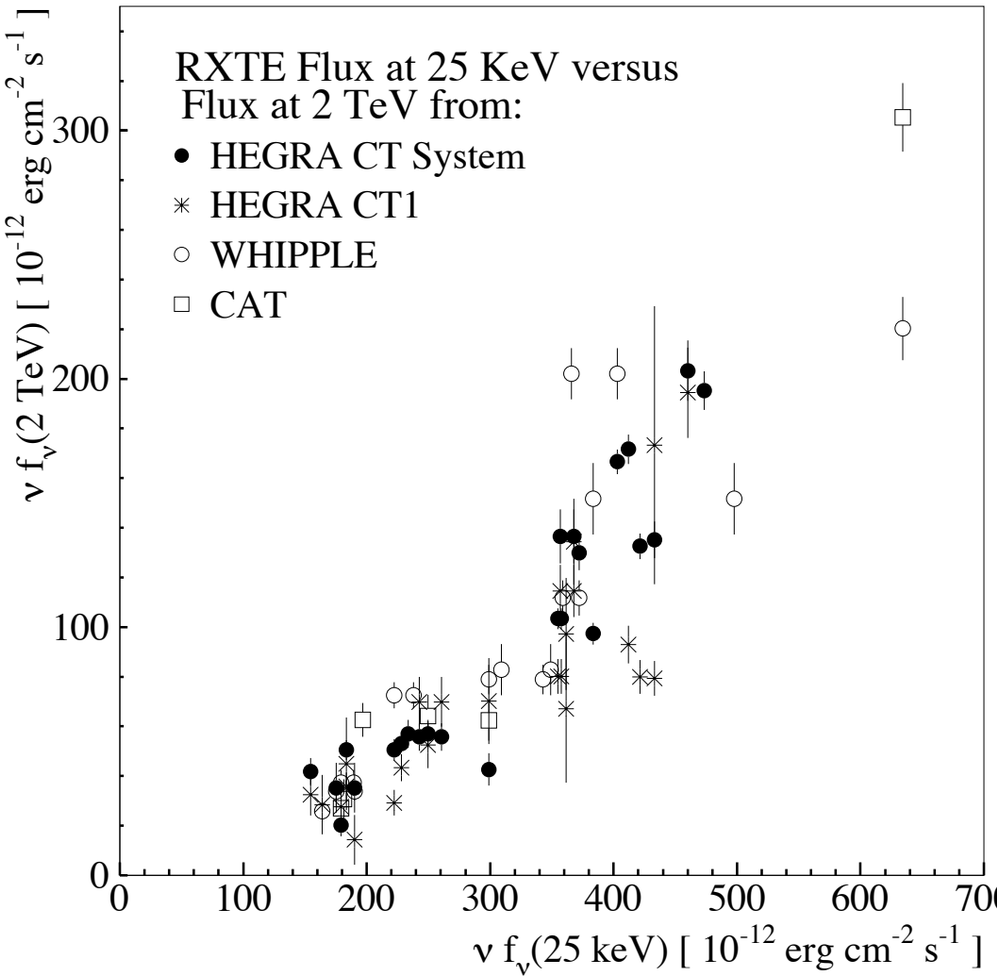
X-ray — TeV connection:
same-energy electrons emitting by Sync & IC

What have we learned so far? and recently ?

X-ray & TeV are typically highly correlated during flares

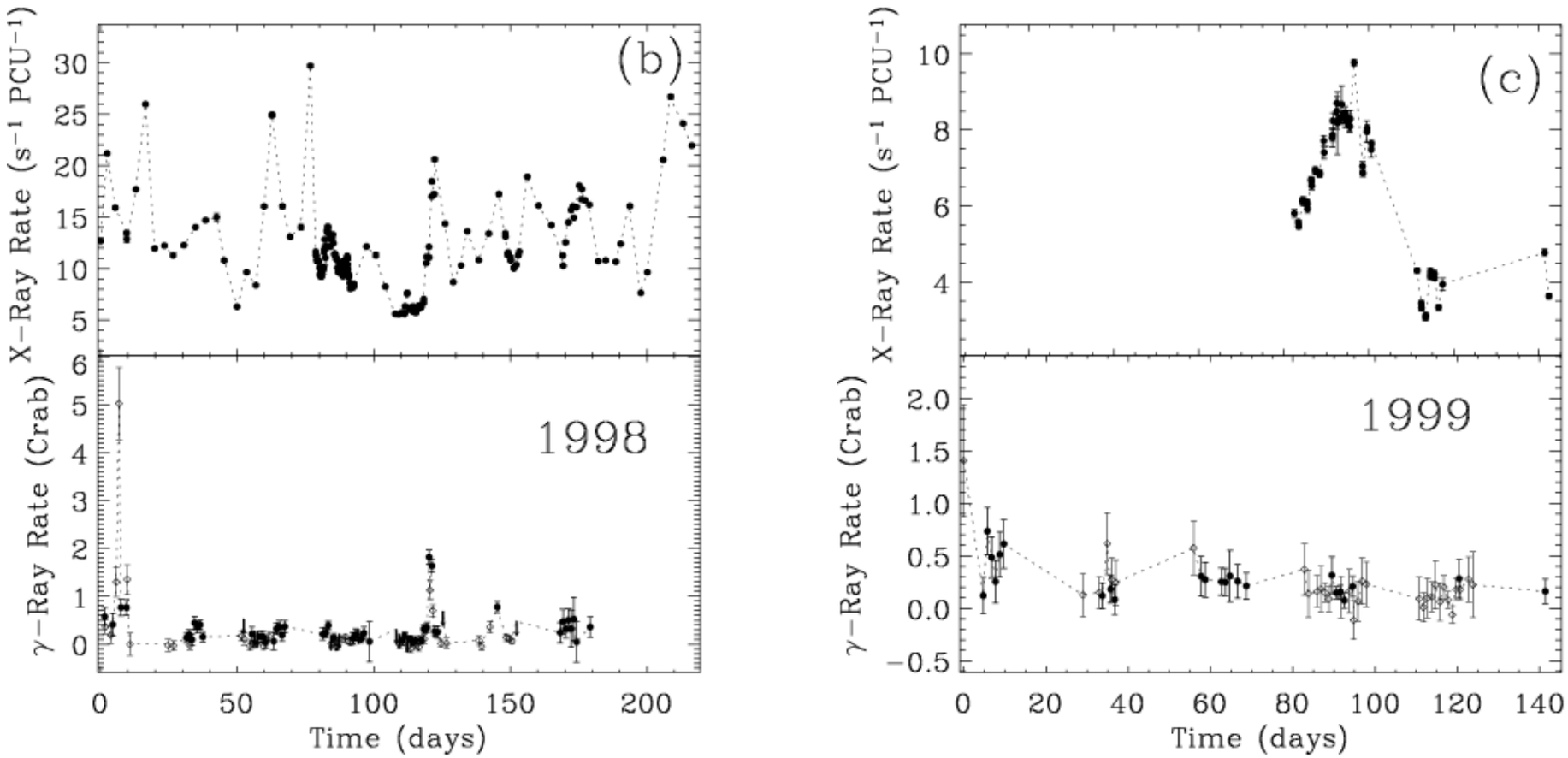
Classic cases: Mkn 501 in 1997



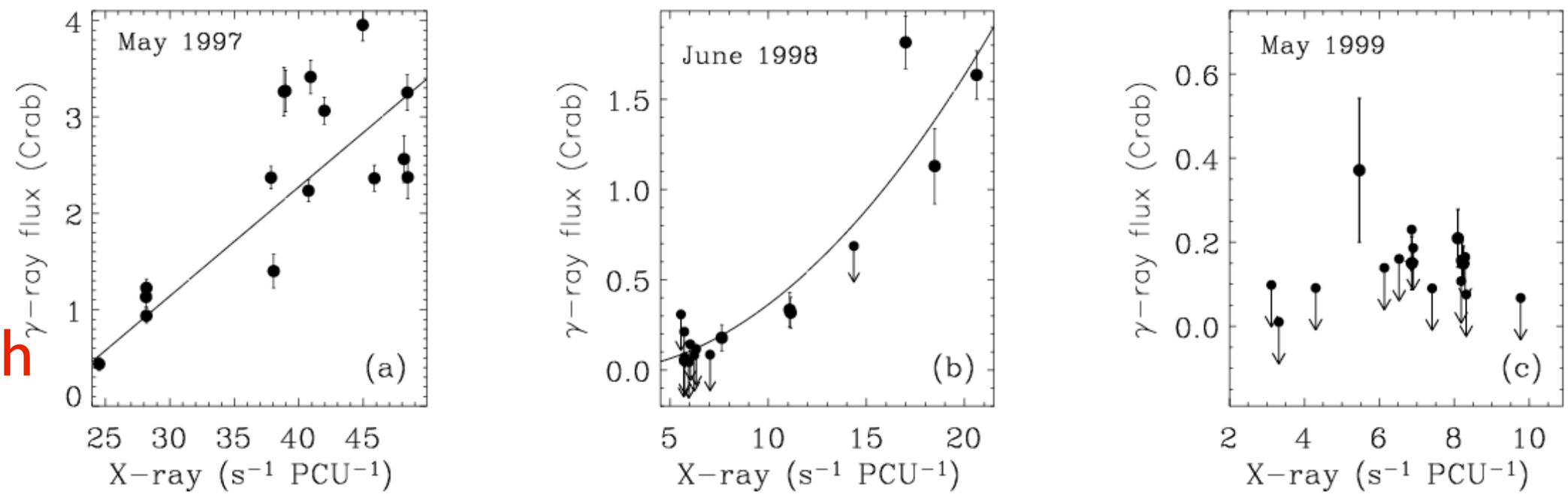


Pian et al 1998, Krawczynski et al 2002

But during the two years later...



High

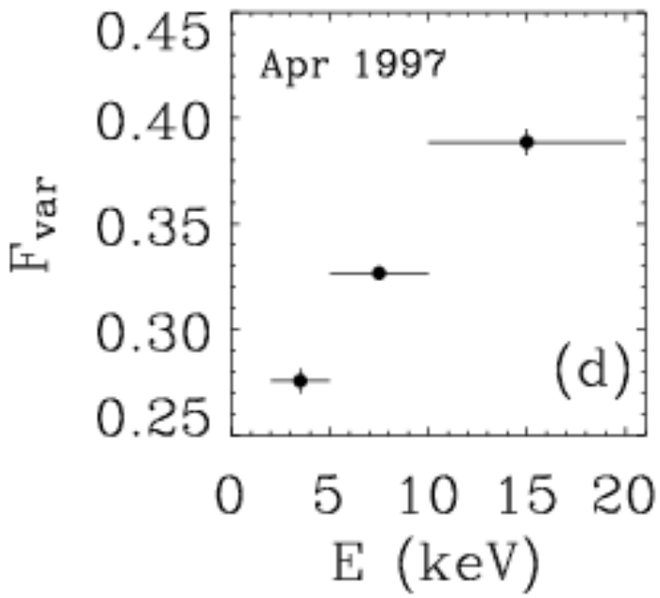


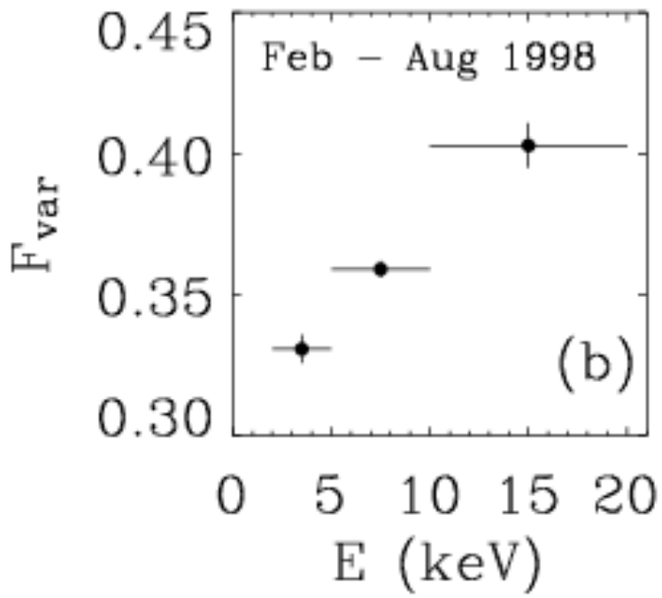
Low

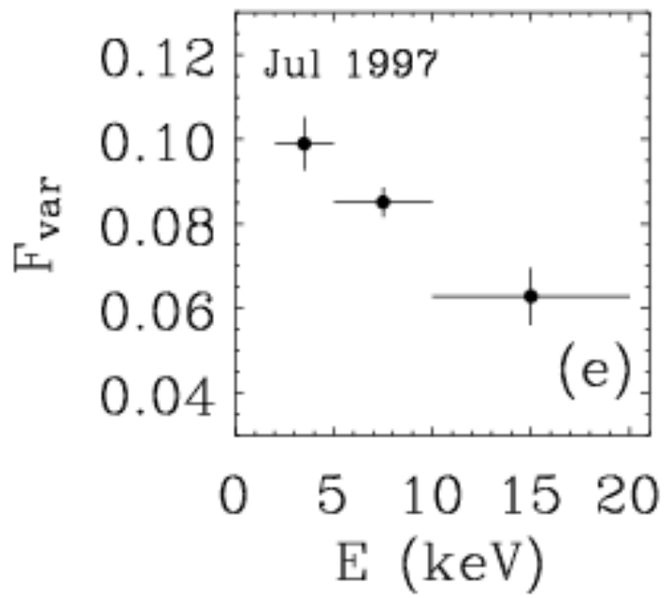
Note the flux on the axes !

Gliozzi et al. 2006

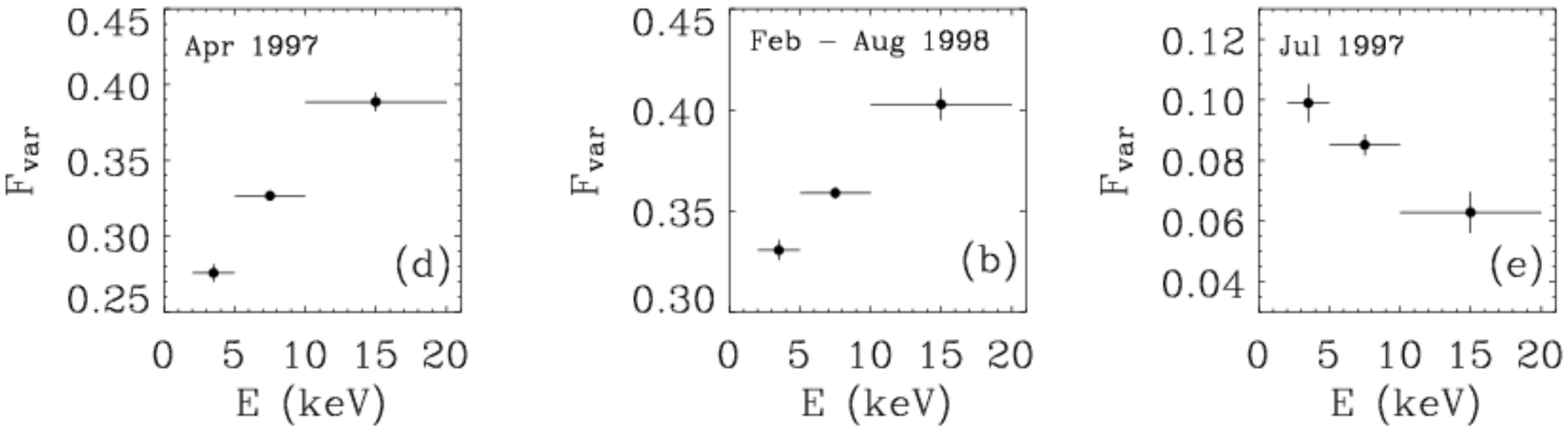
Fractional variability in X-ray:



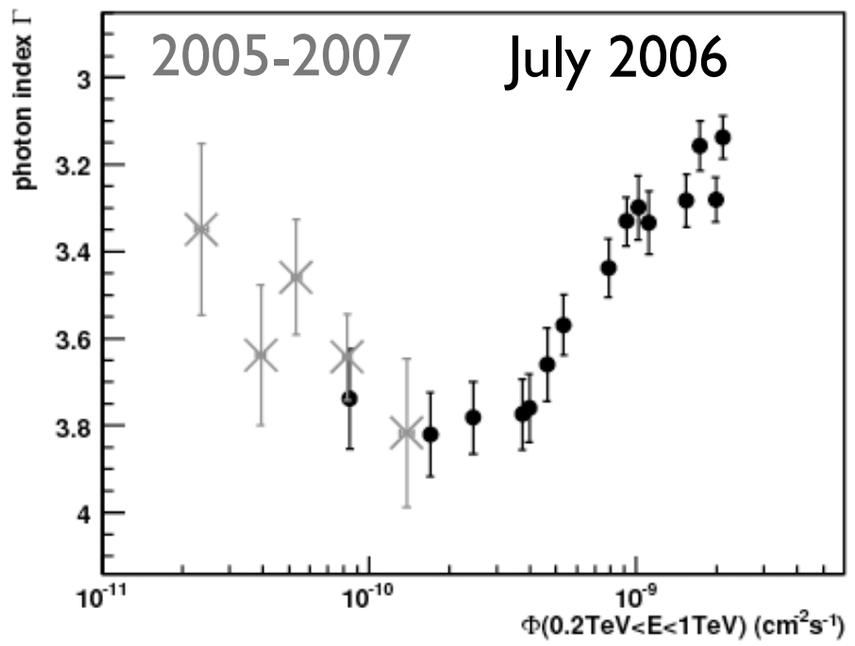




Fractional variability in X-ray:

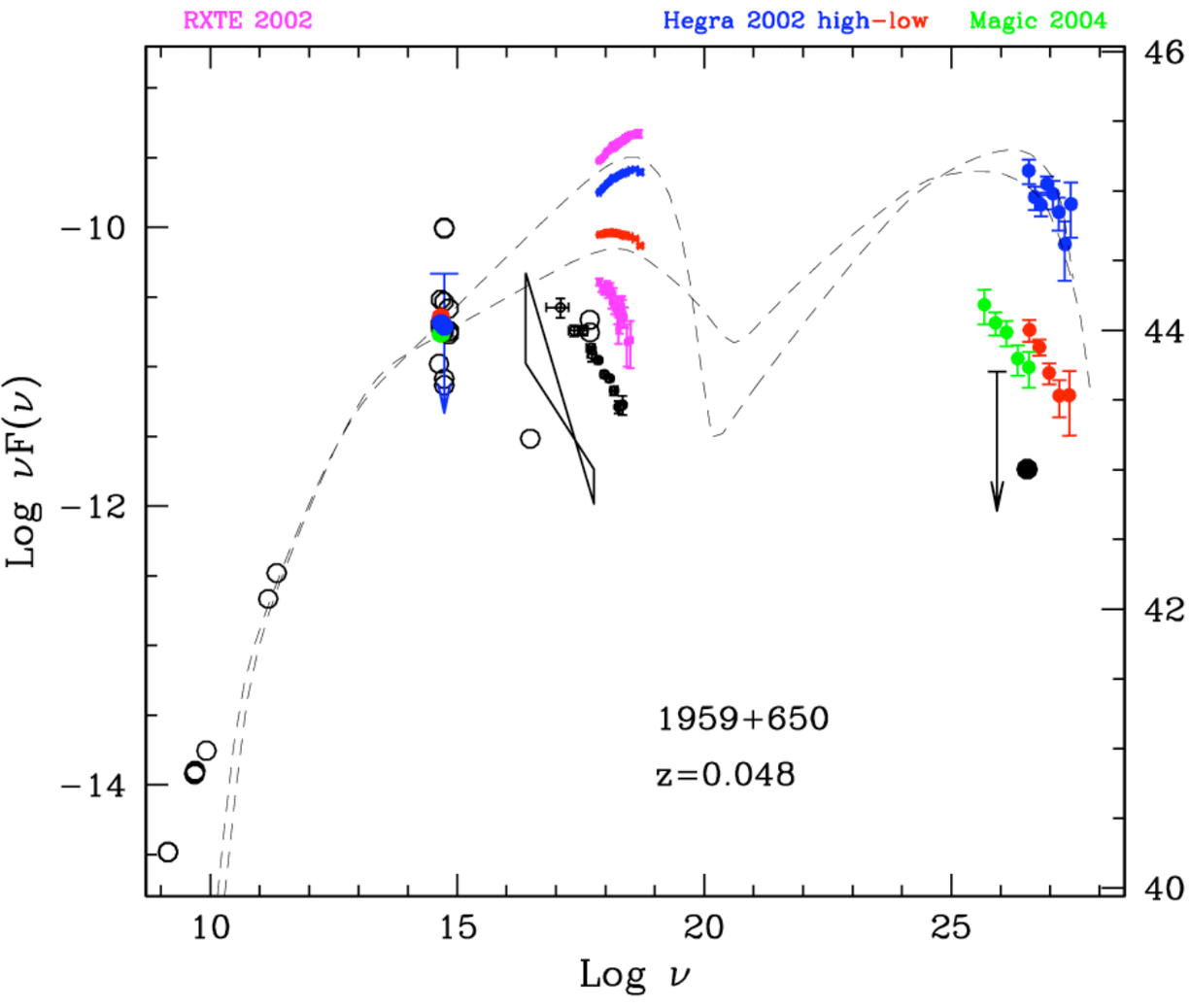


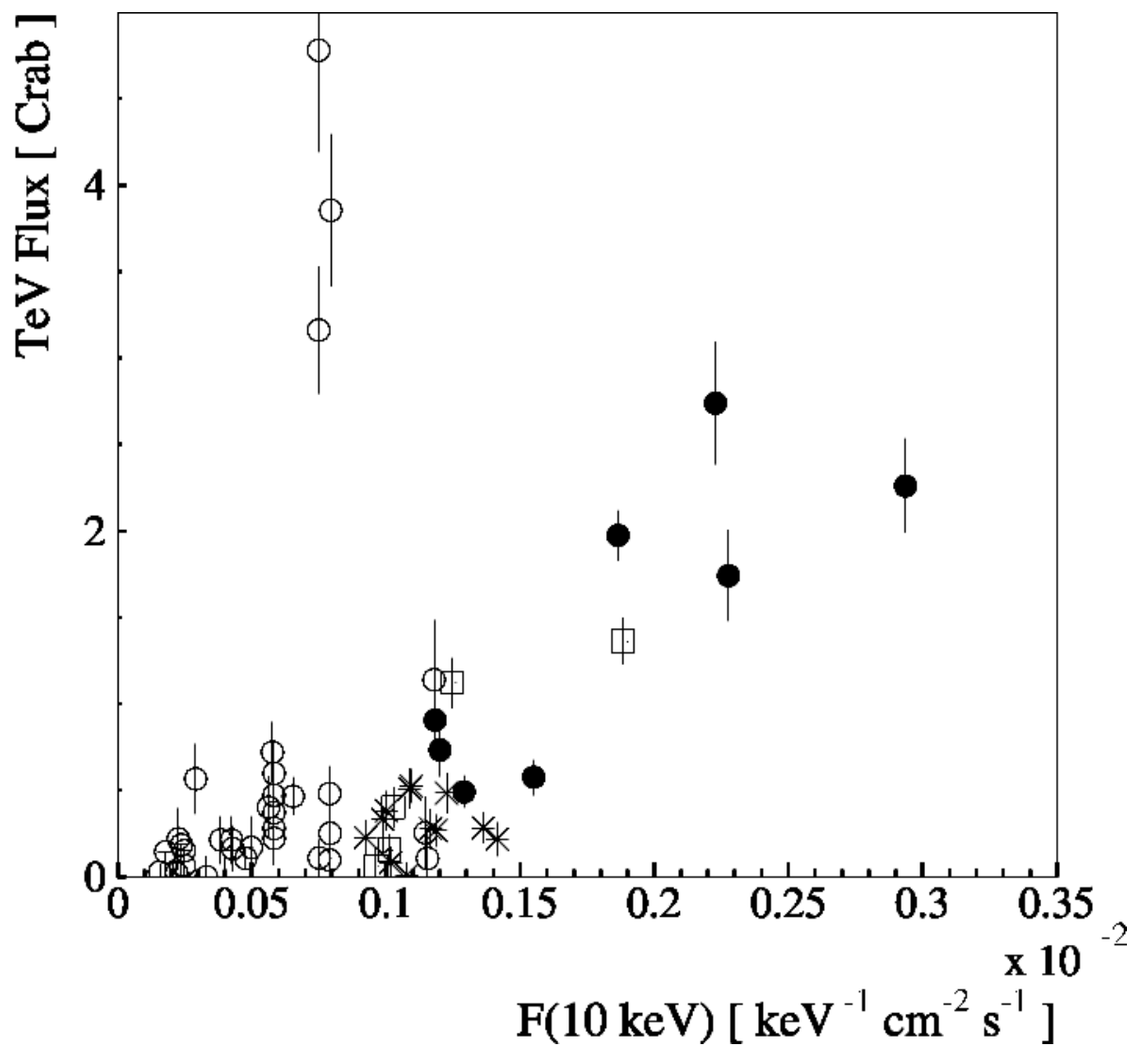
Also PKS 2155-304 at VHE shows different behaviors



Aharonian et al. 2010

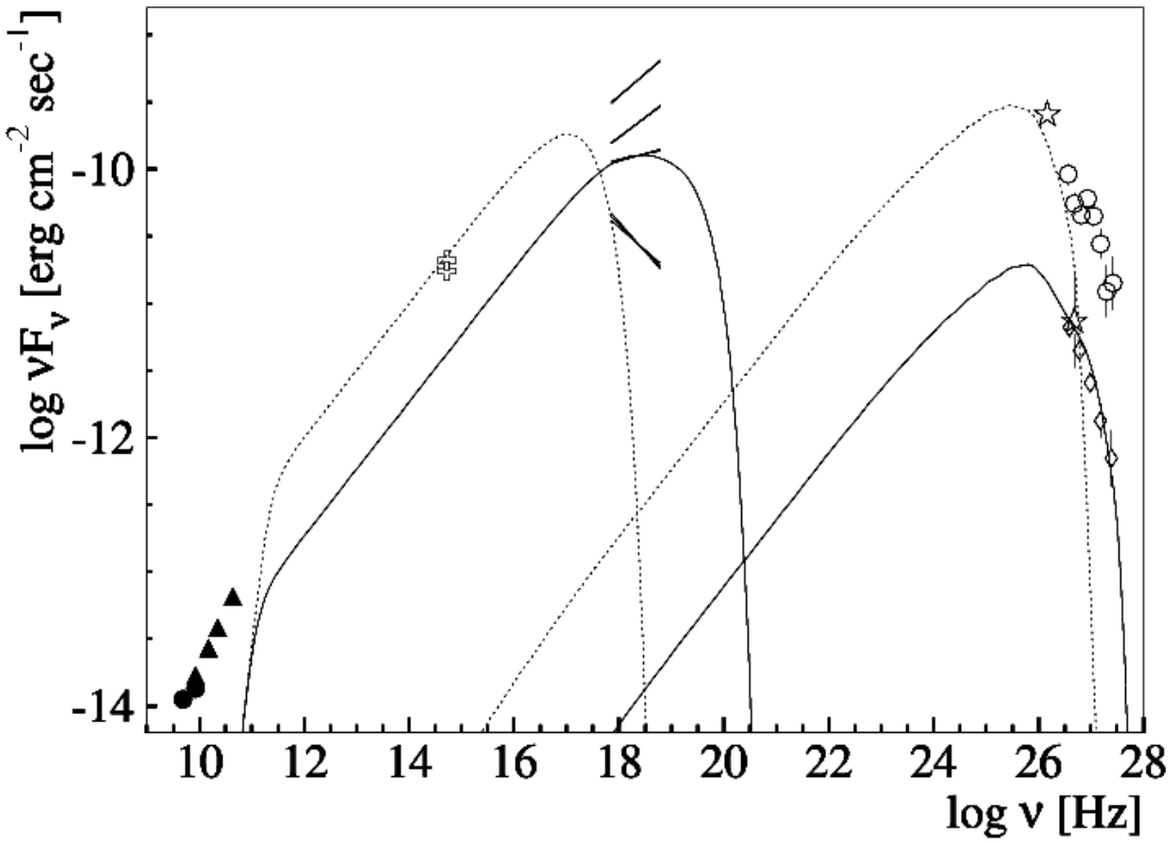
Other classic case: 1ES 1959+650 in 2002

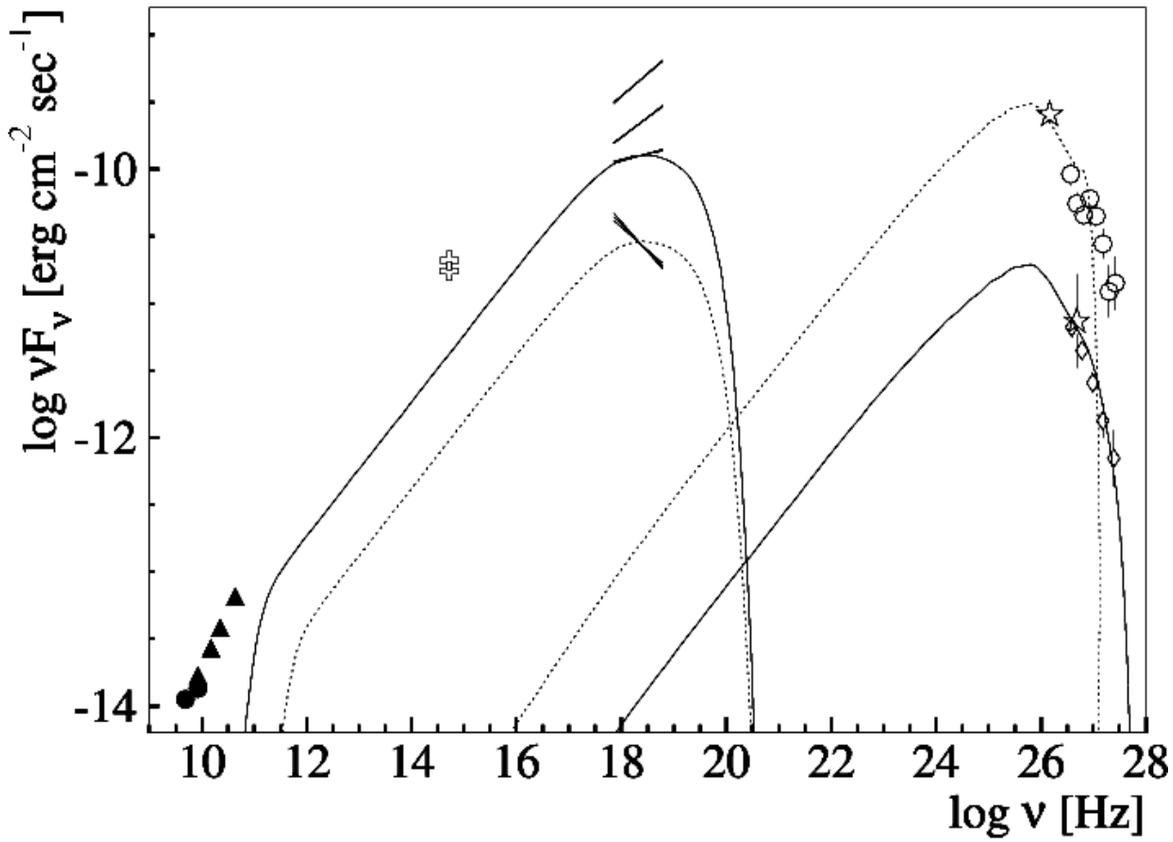




Krawczynski et al. 2004

Possible ways to obtain orphan flare





Krawczynski et al. 2004

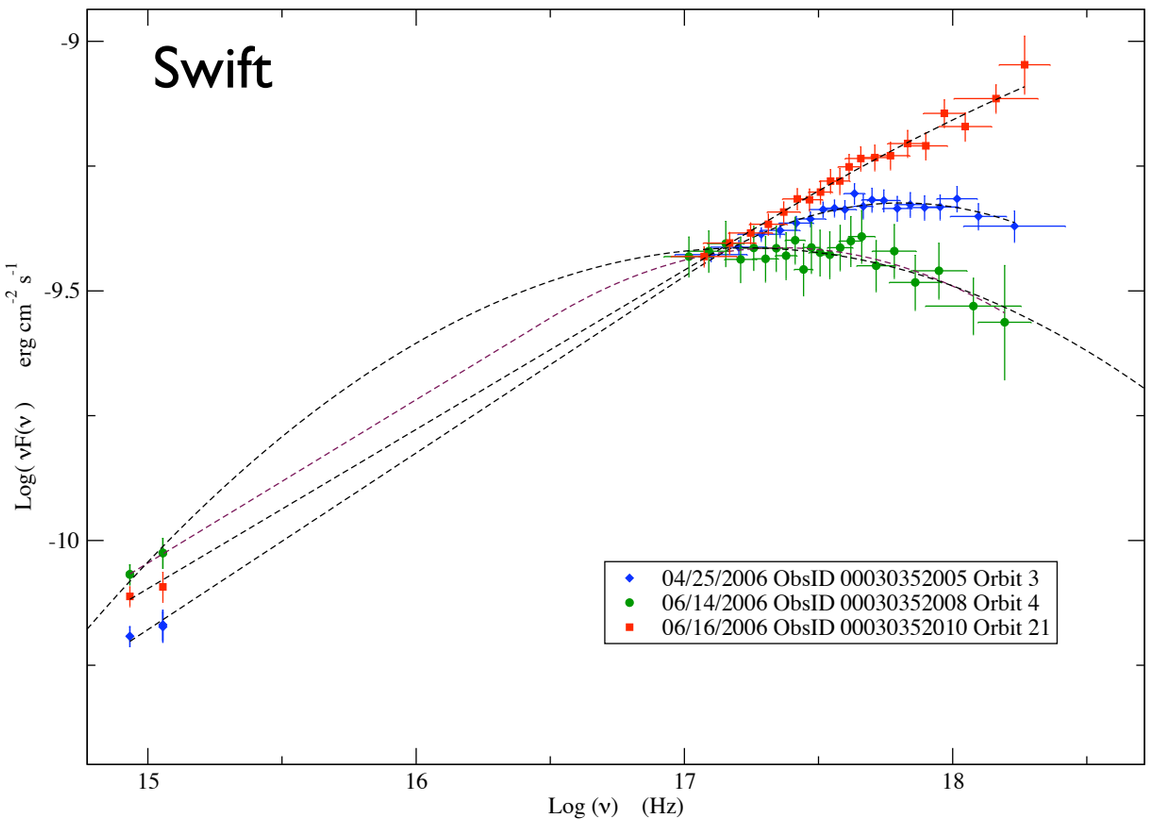
Mkn 421

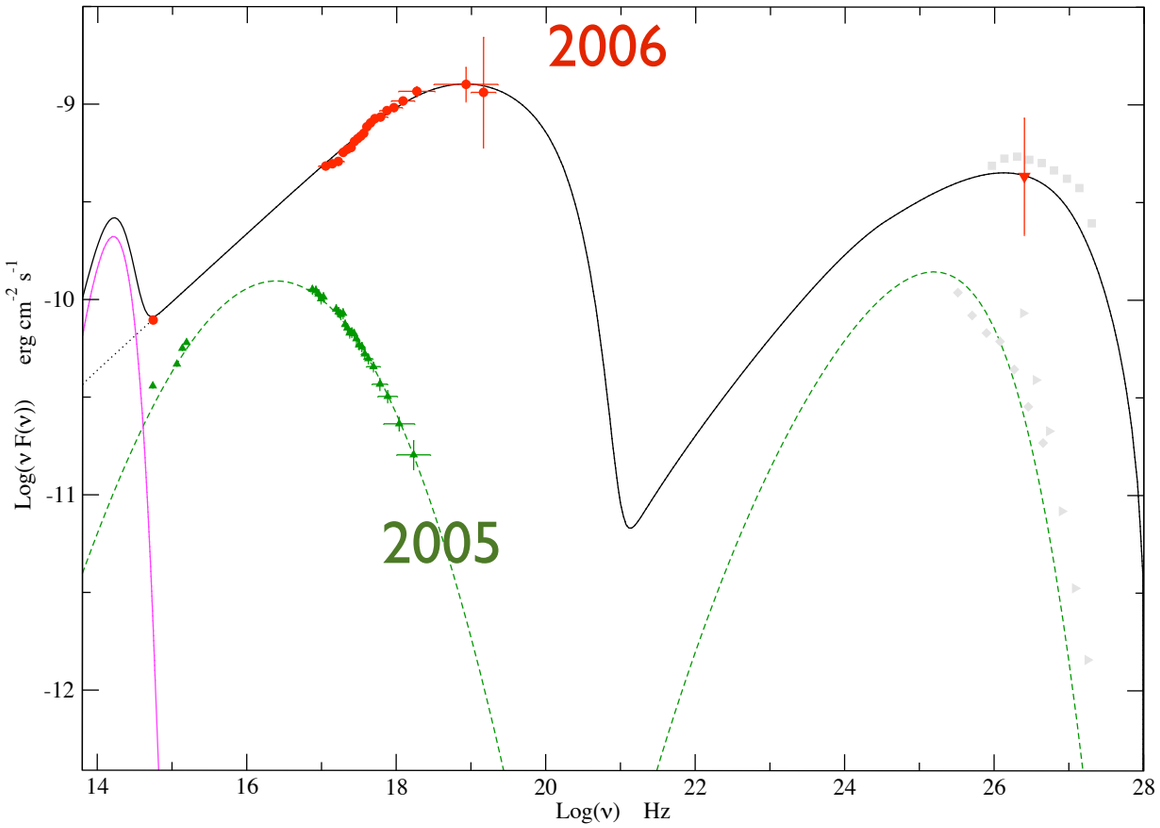
2 important active periods & mwl campaigns:

- March 2001 (dense Xray/TeV coverage, Fossati et al 2008)
- Apr-July 2006 (highest fluxes, Mkn501-style flare, Tramacere et al 2009)

Mkn 421 in 2006

Changes from log-parabola to pure power-law spectra over 4 decades in energy

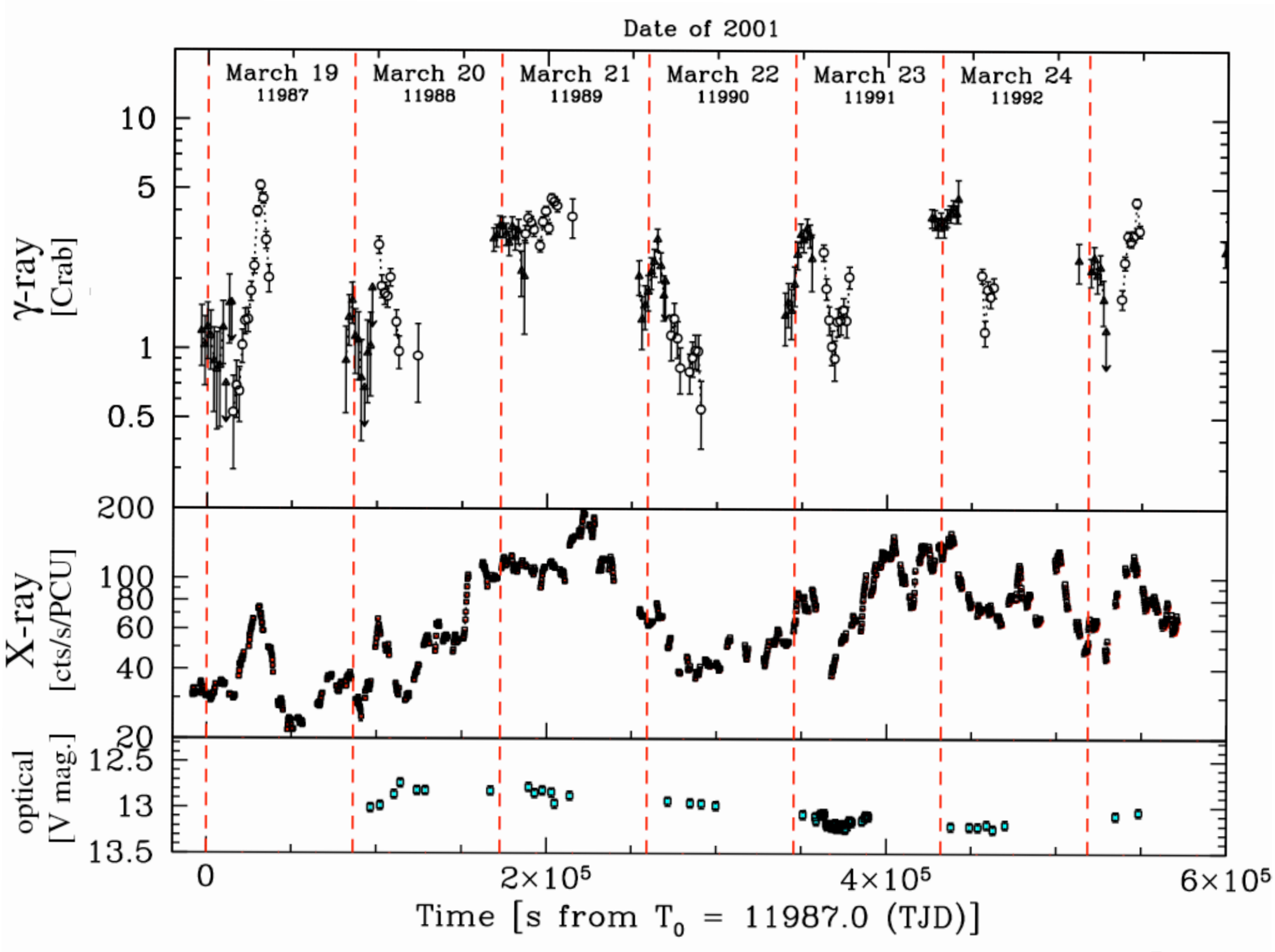




Tramacere et al. 2009

Hint of different acceleration processes at work, in low/high state

Mkn 421 in 2001



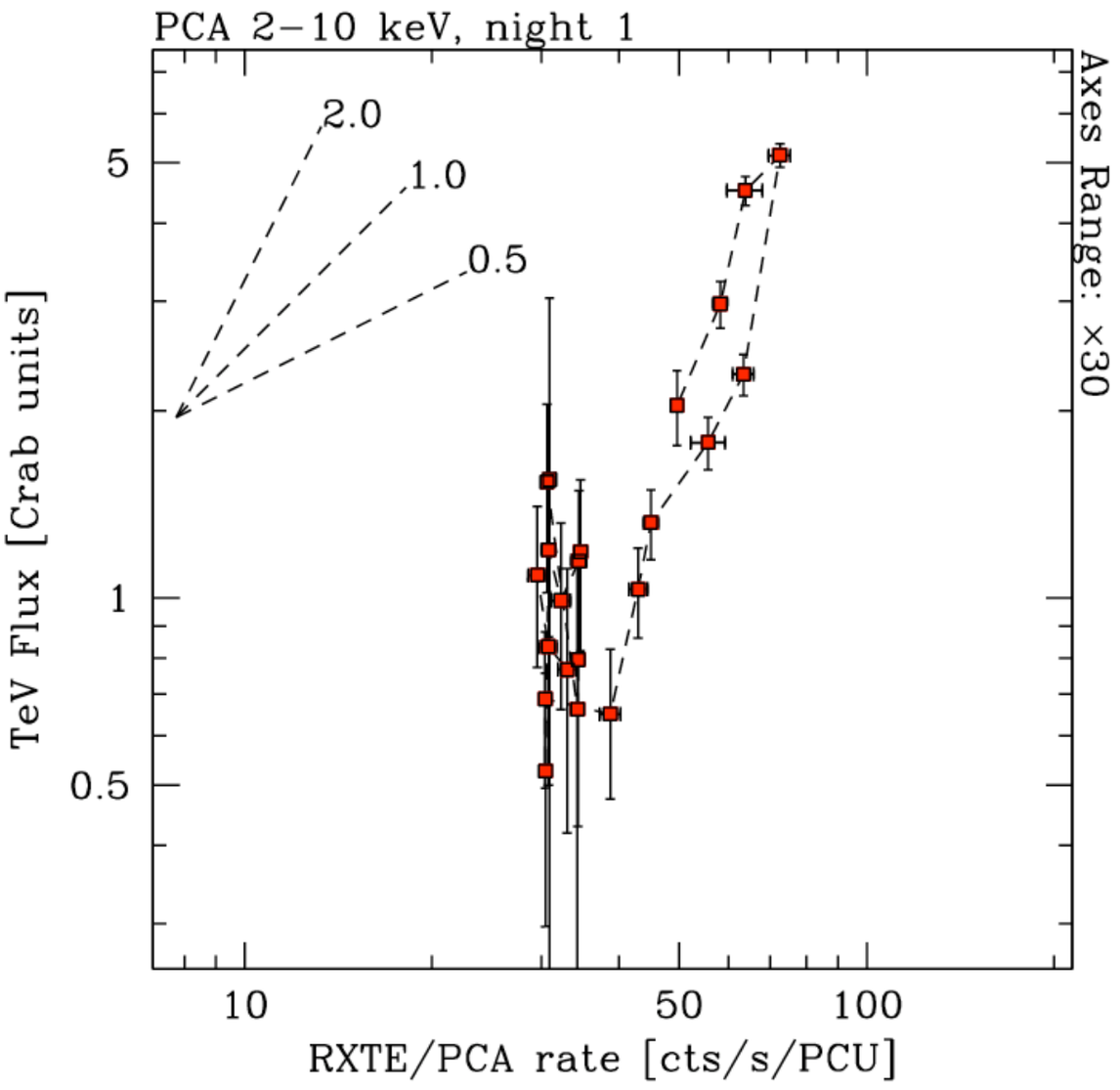
HEGRA

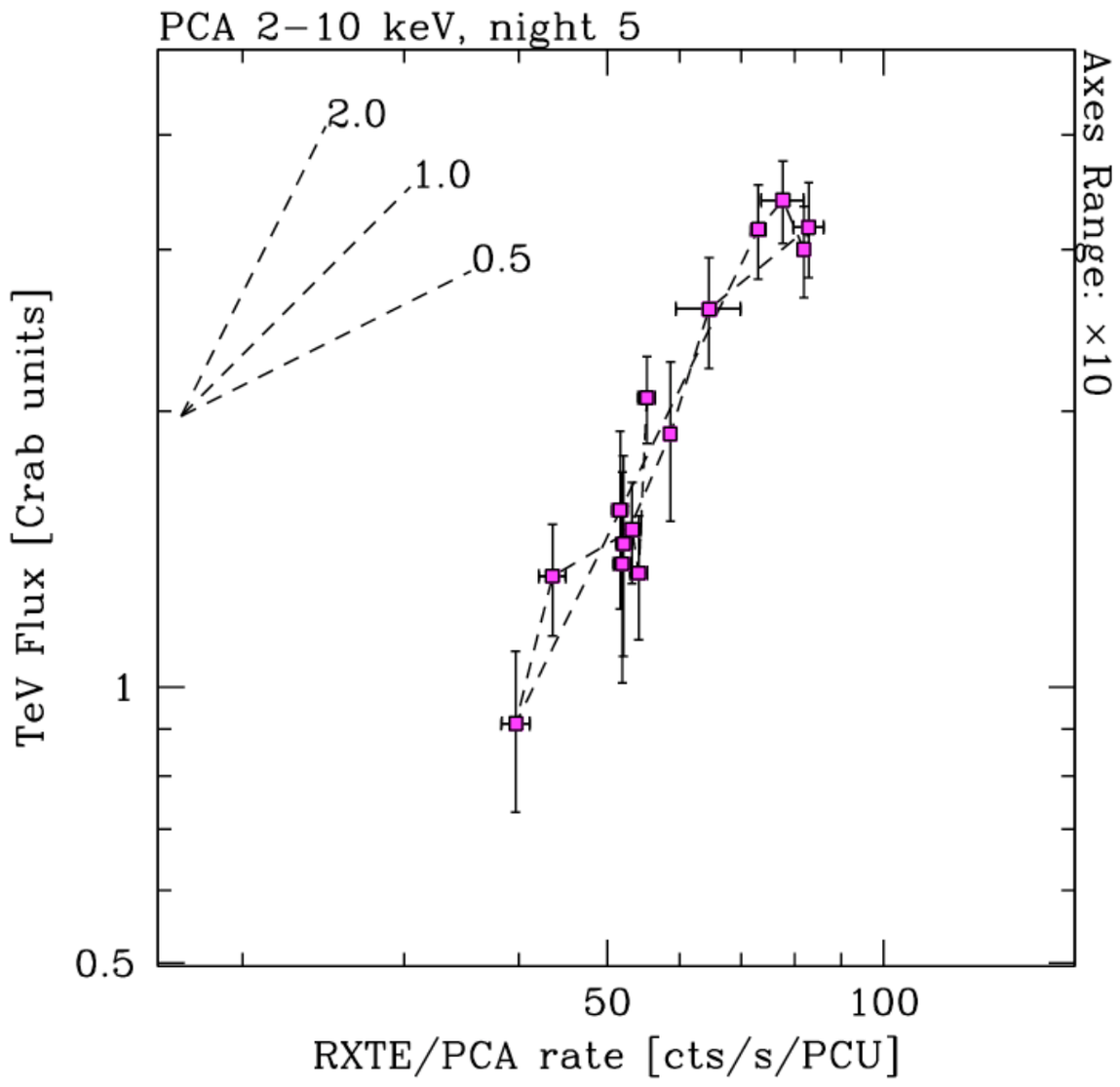
WHIPPLE

RXTE

Fossati et al 2008

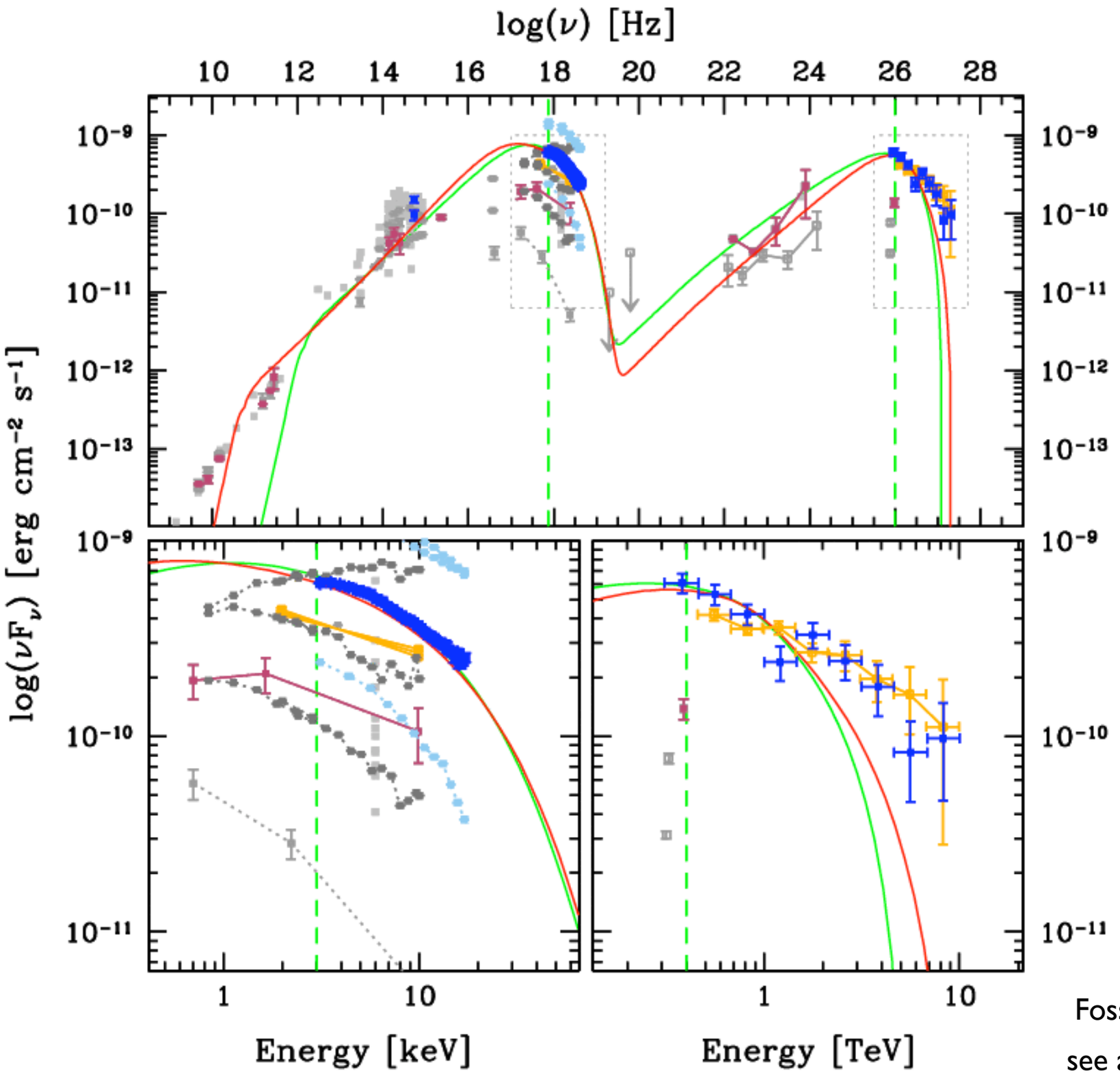
Quadratic relation also in decaying phase !





Fossati et al. 2008

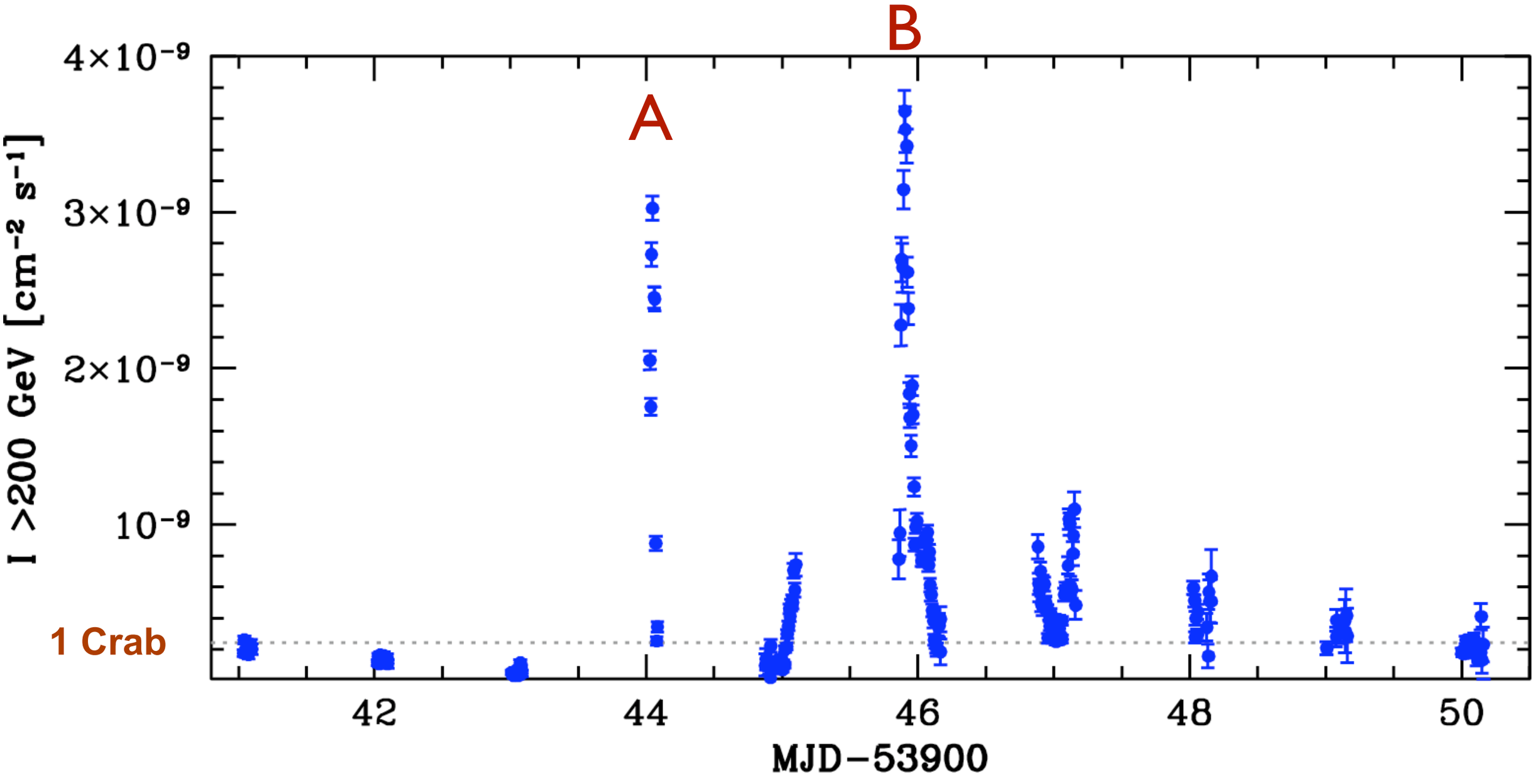
Difficult to obtain even in strict Thomson condition



Fossati et al. 2008

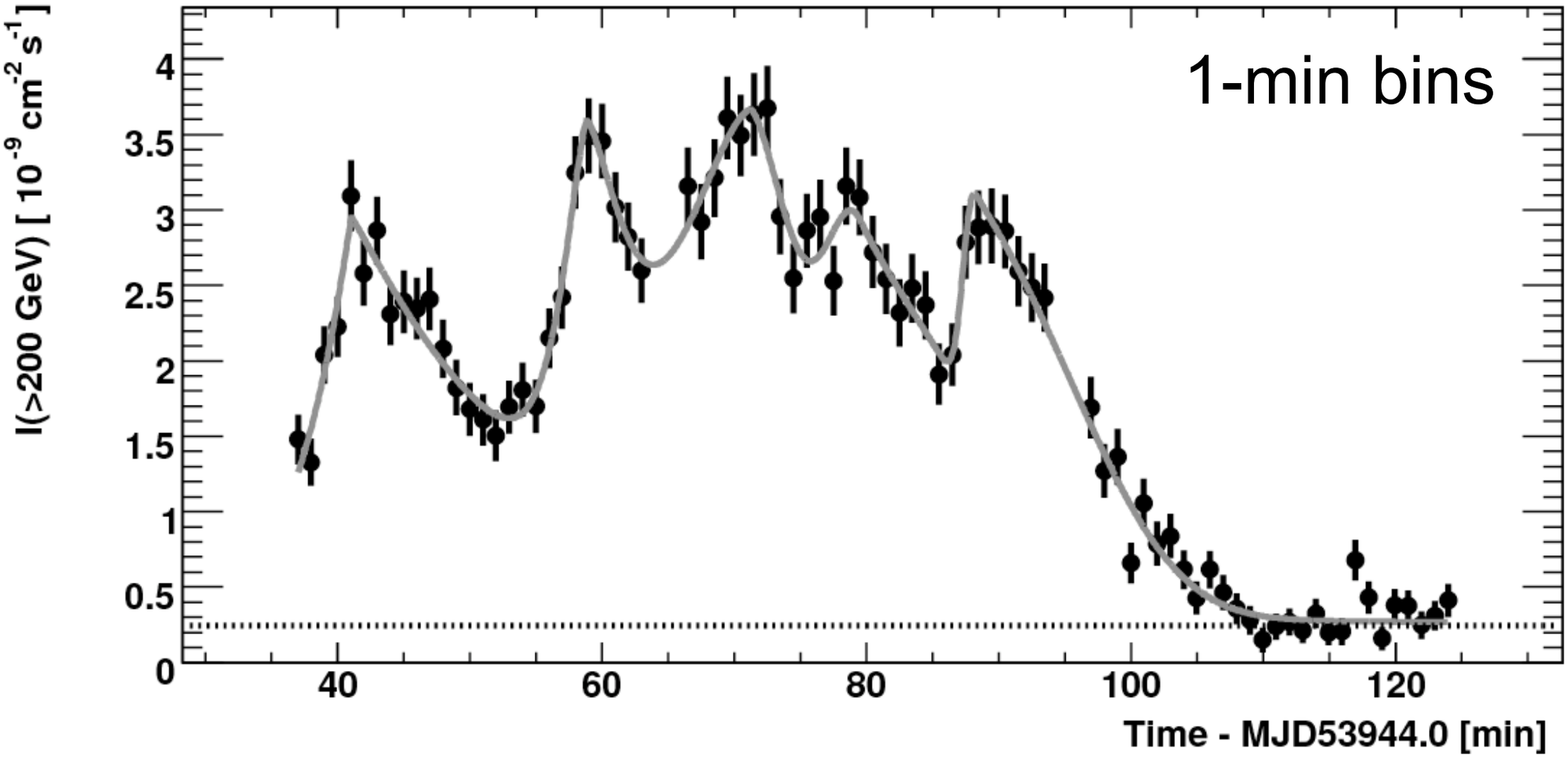
see also Katarzynski et al. 2008

Most surprising case: PKS 2155-304 in summer 2006



Ultra-fast variability ! 2x flux in ~2-3 min.
10x in less than 1 hr

A



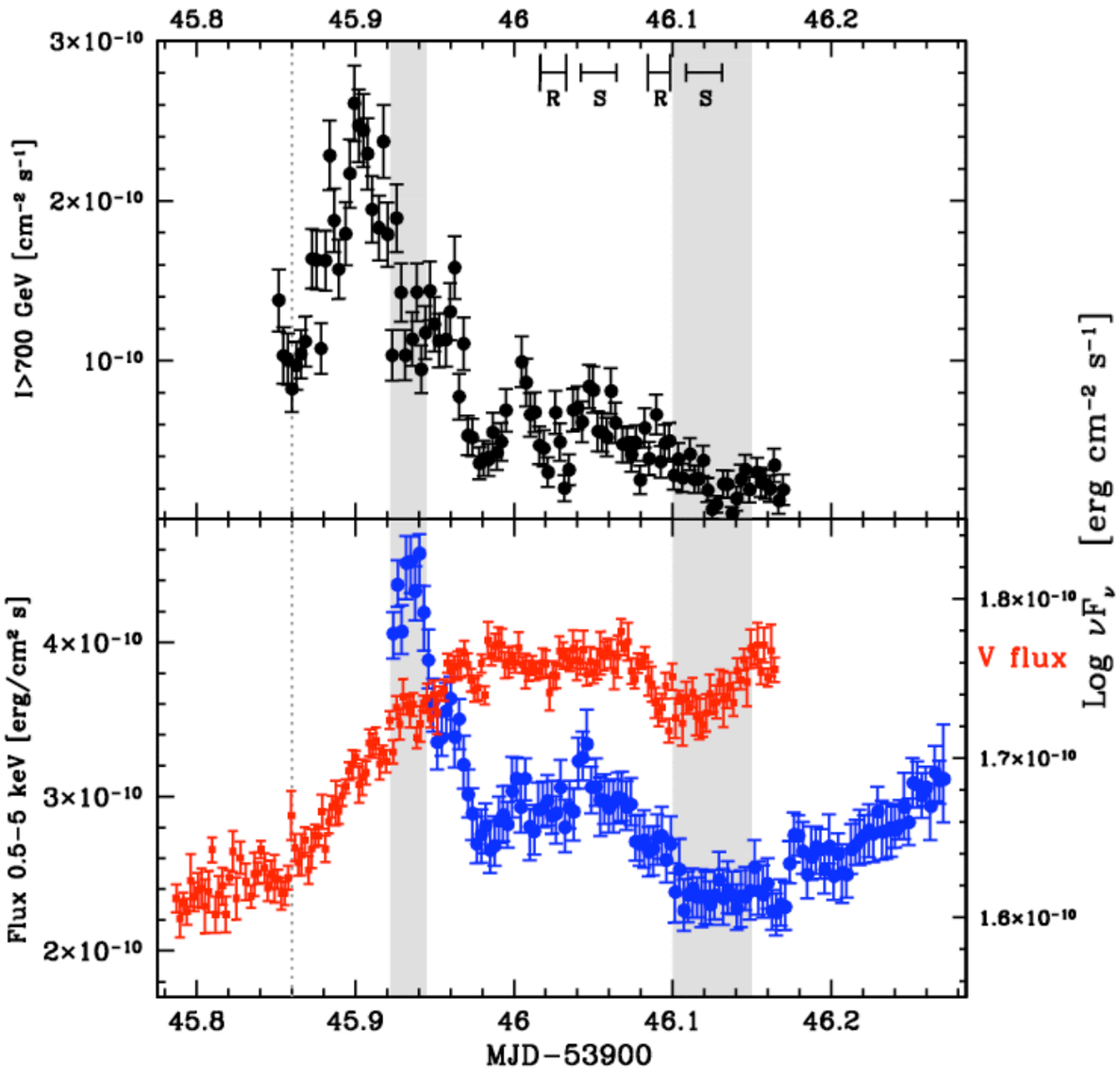
R/c 100x shorter than for its BH size ! Aharonian et al. (HESS coll) 2007

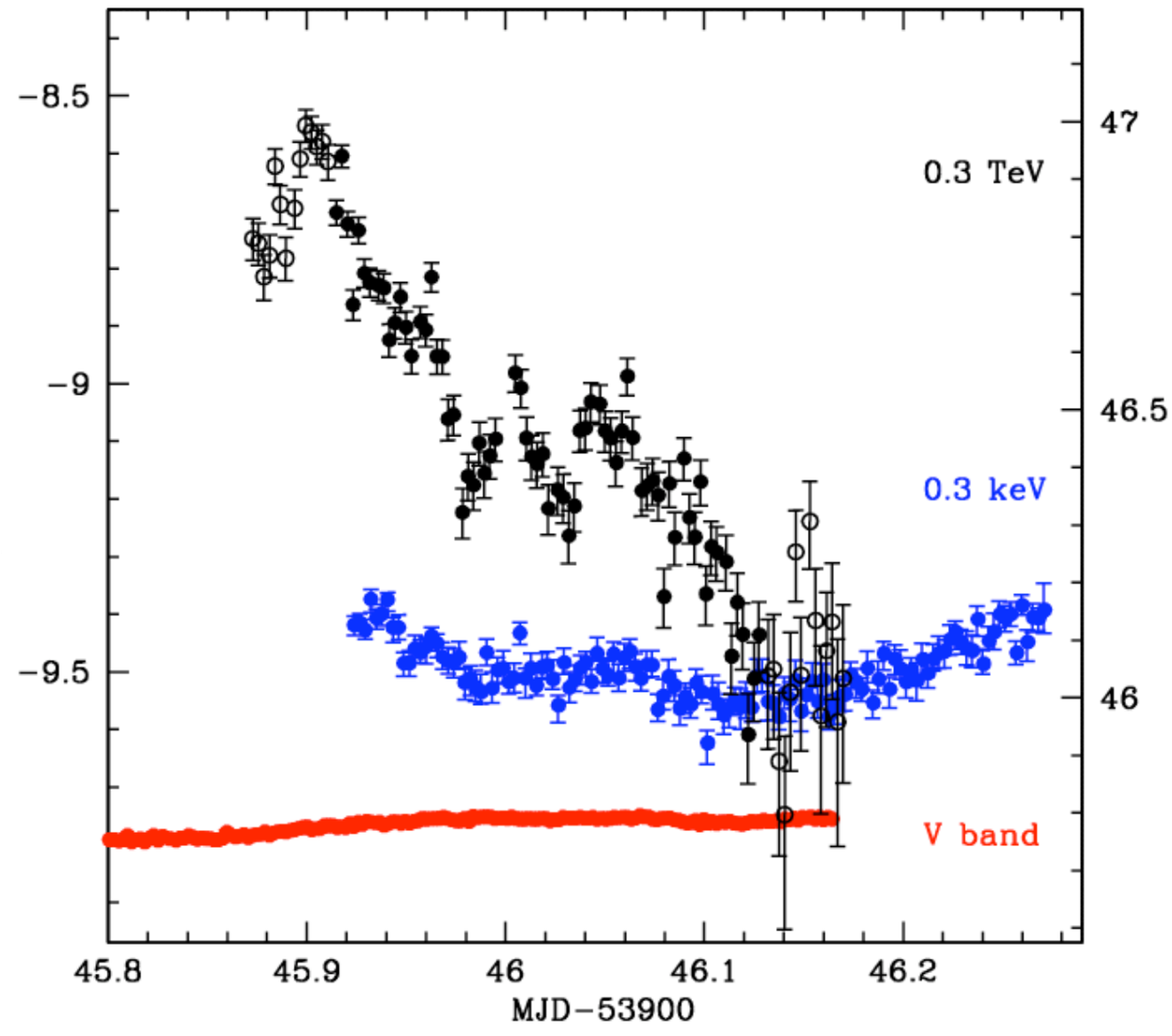
$\Gamma \geq$50-100 Needle in jet ? Jets in a jet ? magneto-centrifugal acceleration ? ...

(Ghisellini & Tavecchio 2008) (Giannios et al 2009) (Ghisellini et al 2008)

B

Full night of simultaneous HESS-Chandra-Optical observations



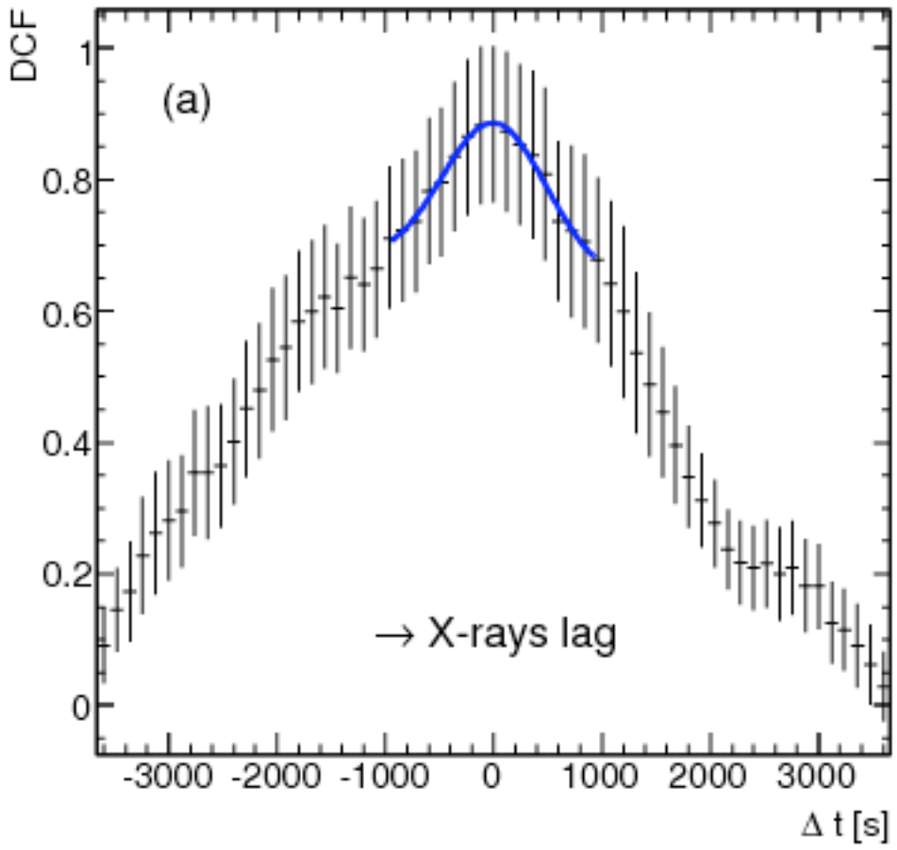


First time in HBL: high Compton Dominance !

Costamante et al. 2007, 2008
Aharonian et al. (HESS coll.) 2009

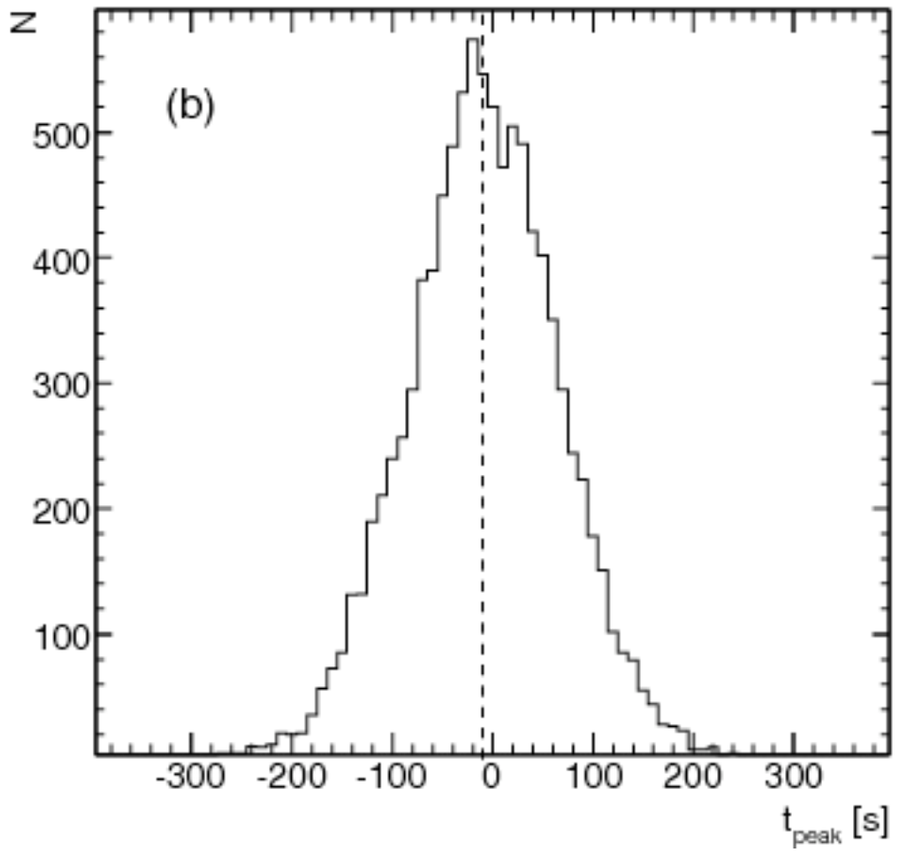
Strong and strict correlation: X-ray and TeV emissions respond to the same flaring event

DCF X-TeV



95% upper limit on lags: ~ 200s

Cross-correlation peak distribution of 10000 simulated lightcurves

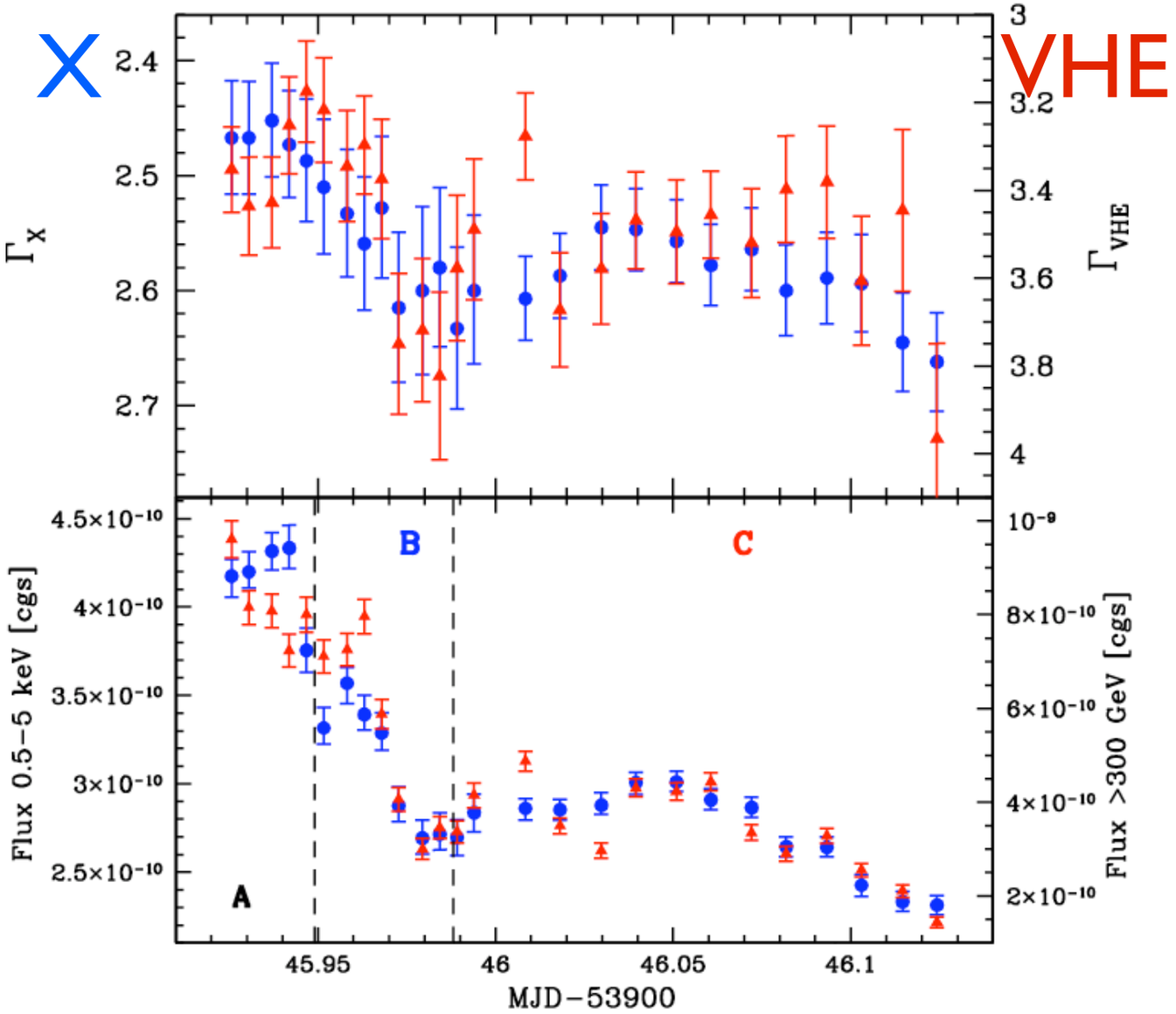


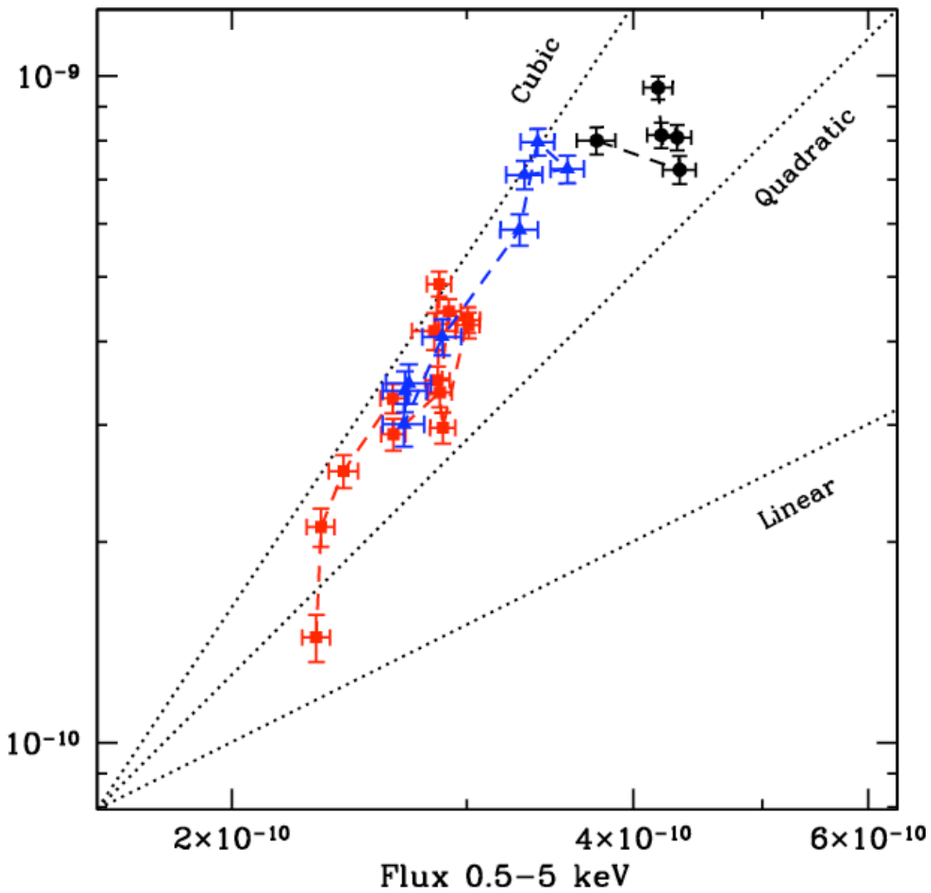
RMS = 76 s

Costamante, Buehler et al. 2007, 2008
Aharonian et al. (HESS coll.) 2009

Cubic relation X-ray / TeV flux !

Time-resolved spectroscopy
in both bands, 7-14 min bins

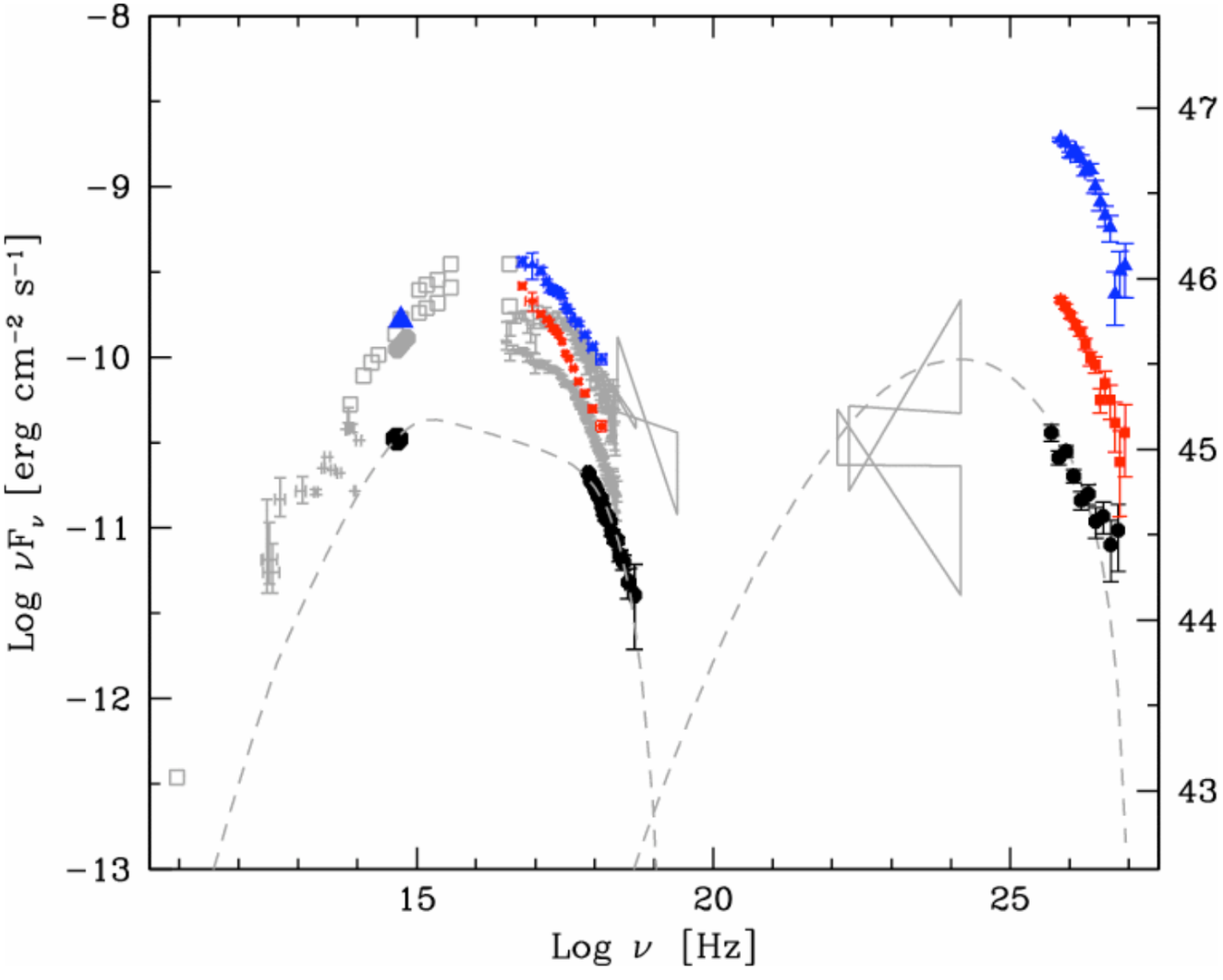




Costamante, Buehler et al. 2007, 2008
Aharonian et al. (HESS coll.) 2009

Difficult to explain with one-zone model.

Thomson alone (δ >>100) not enough to explain cubic decay

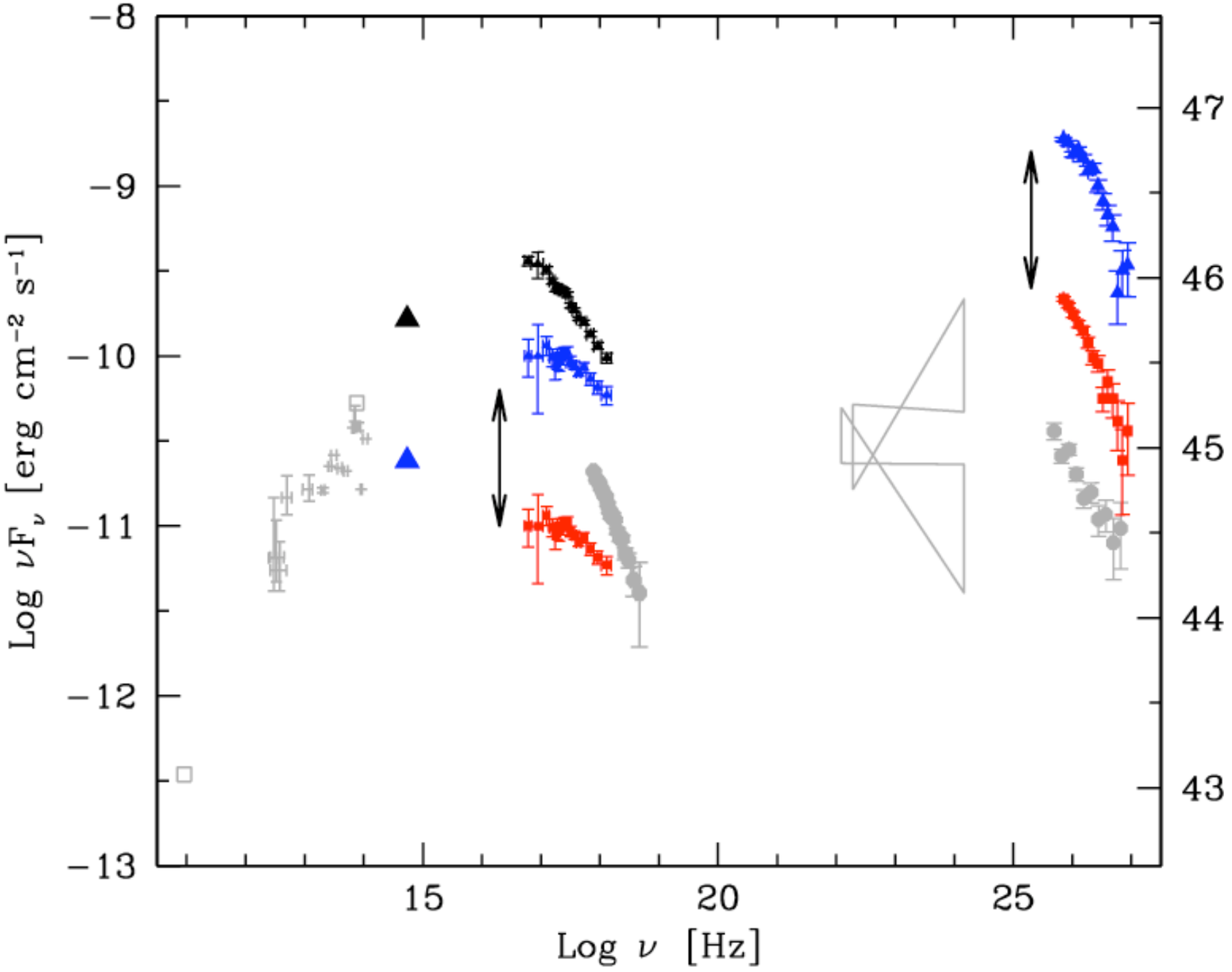


"One zone" => high energy electrons have not cooled

Adiabatic expansion: could work ! but cubic decay requires B to increase as $B \propto R^{+0.4}$ (i.e. energy density $W_B \sim R^{3.8}$), and on same timescales of X-ray/TeV variations.

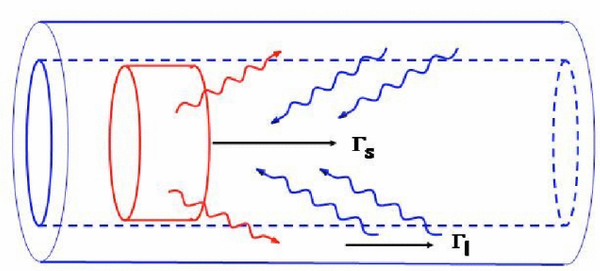
This would imply a 15% decrease in Optical synchrotron emission: not observed !

Superposition of 2 SEDs:
2 different components/zones, persistent + flaring



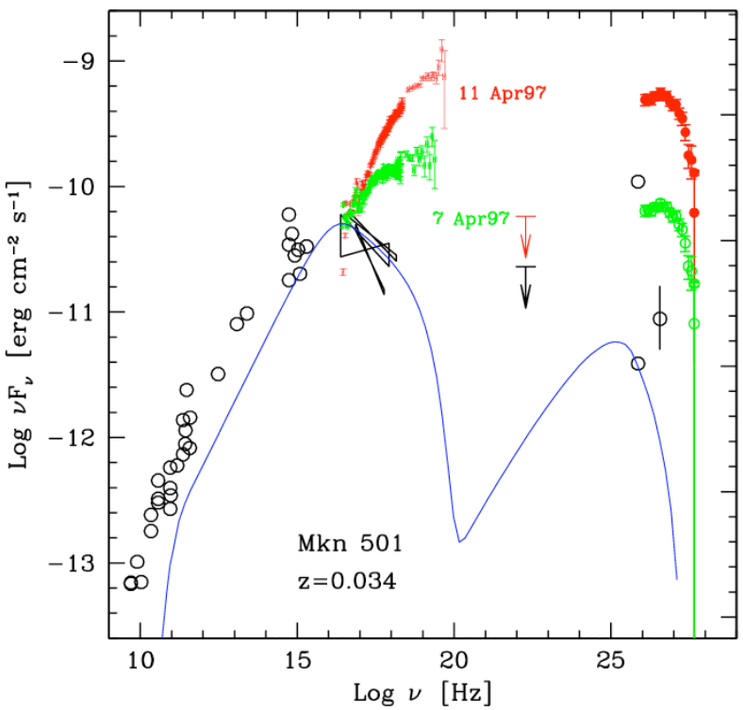
a) If $F_\gamma \propto F_x^2$
SSC ok with B ~1G
R ~3-5 10^{14} cm

b) If $F_\gamma \propto F_x$
Constantly high
Compton Dominance !
External Compton
on structured jet ?

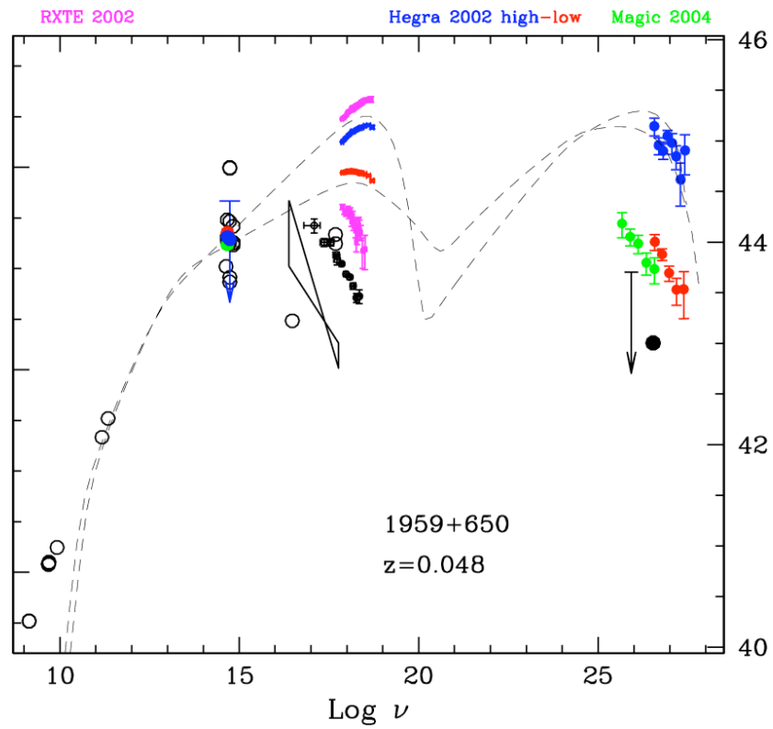


Comparison with Mkn 501, 1ES 1959: ‘same’ flare, but here it does not break through the pre-flare synchrotron SED

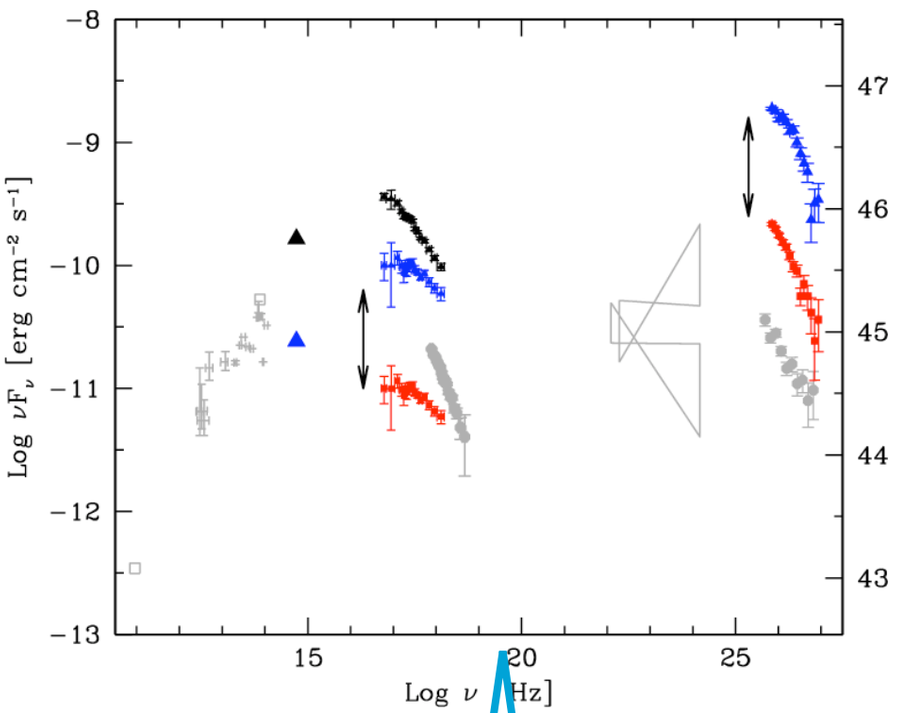
Mkn 501



1ES 1959+650



PKS 2155-304

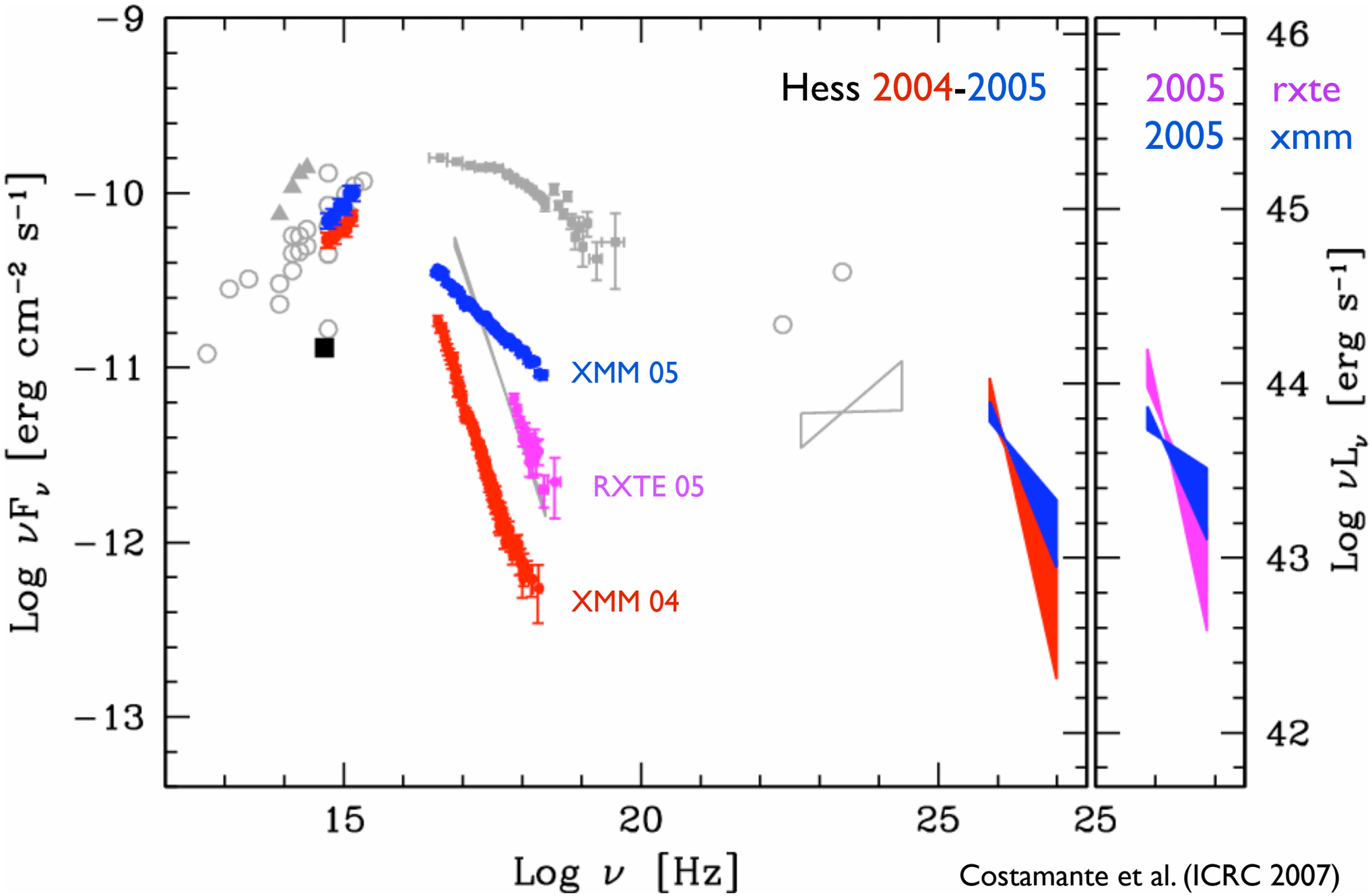


Synchrotron-dominated flares

Compton-dominated

Emerging of new components, also on long timescales: evidence in PKS 2005-489

Mwl campaigns XMM-RXTE-HESS in 2004-2005



Costamante et al. (ICRC 2007)
Aharonian et al. (HESS coll) 2009

Conclusions

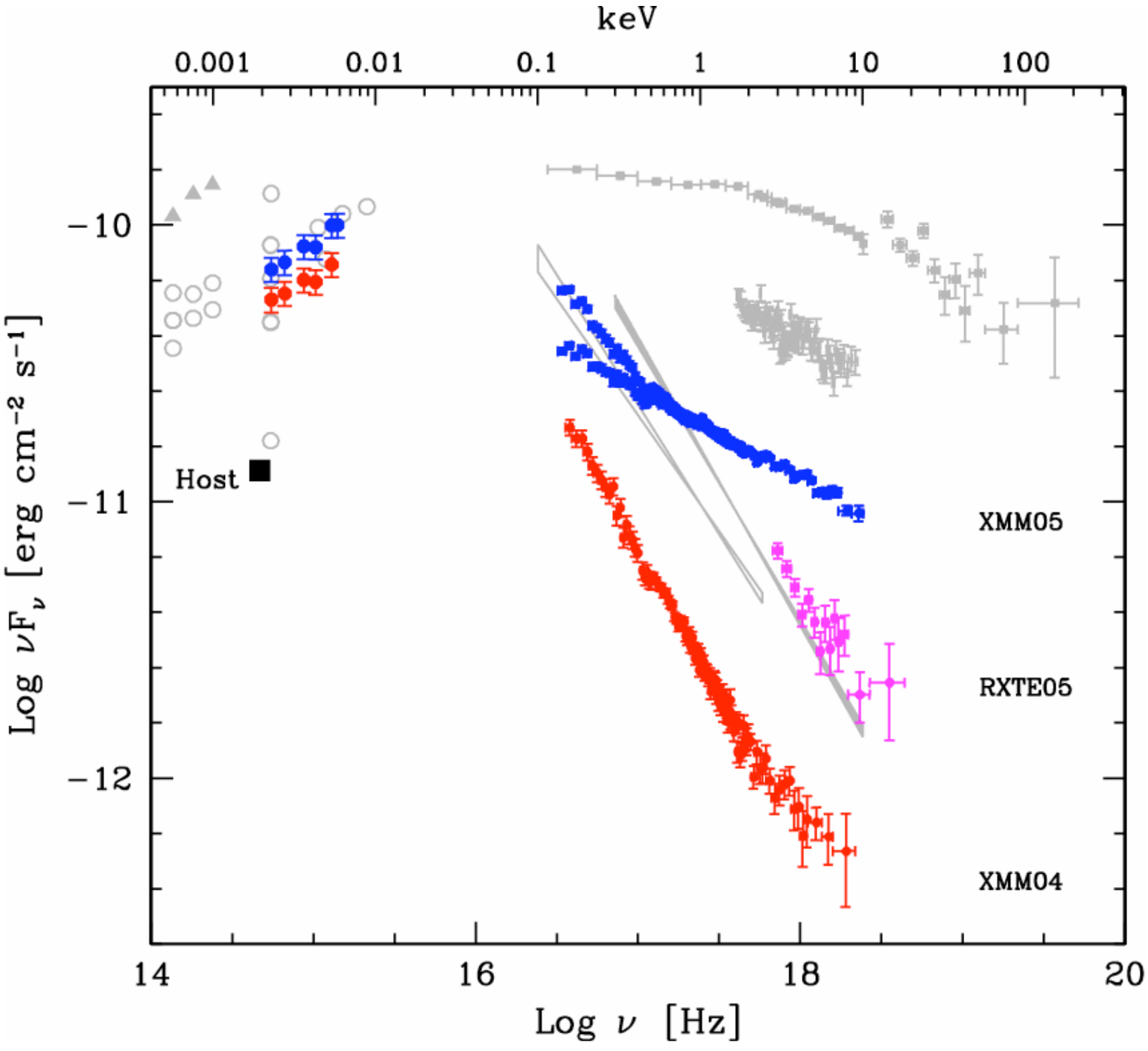
- Indications that variability clock of the jet is Disk-driven, on long timescales.

- Acceleration mechanism during low/quiescent states seems *different* from flaring events.

- Jet is structured ! Two+ zones can determine the SED even at high energies, *around and above the peak*.
  They can have or not radiative feedback between them.

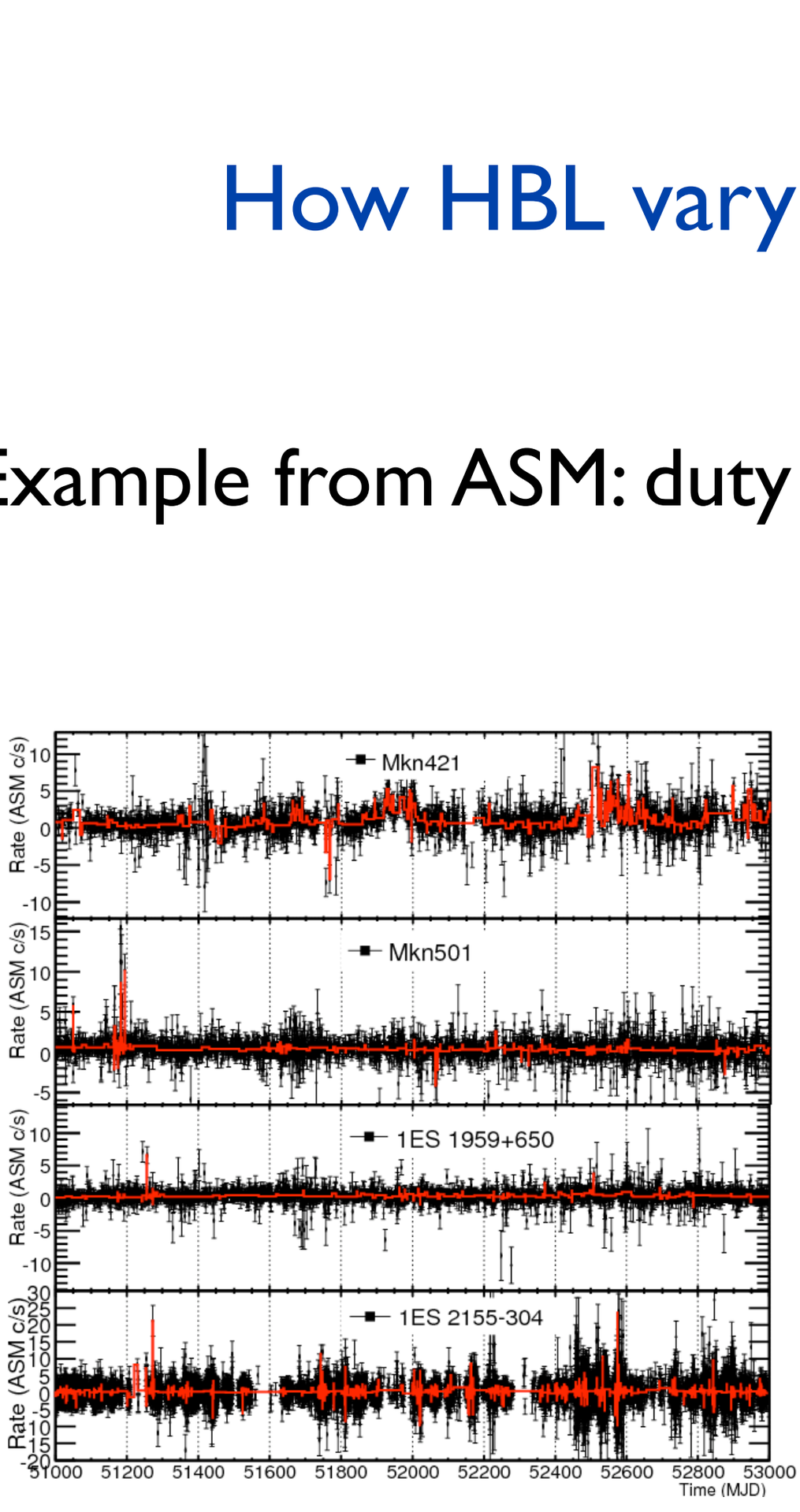
back-up slides

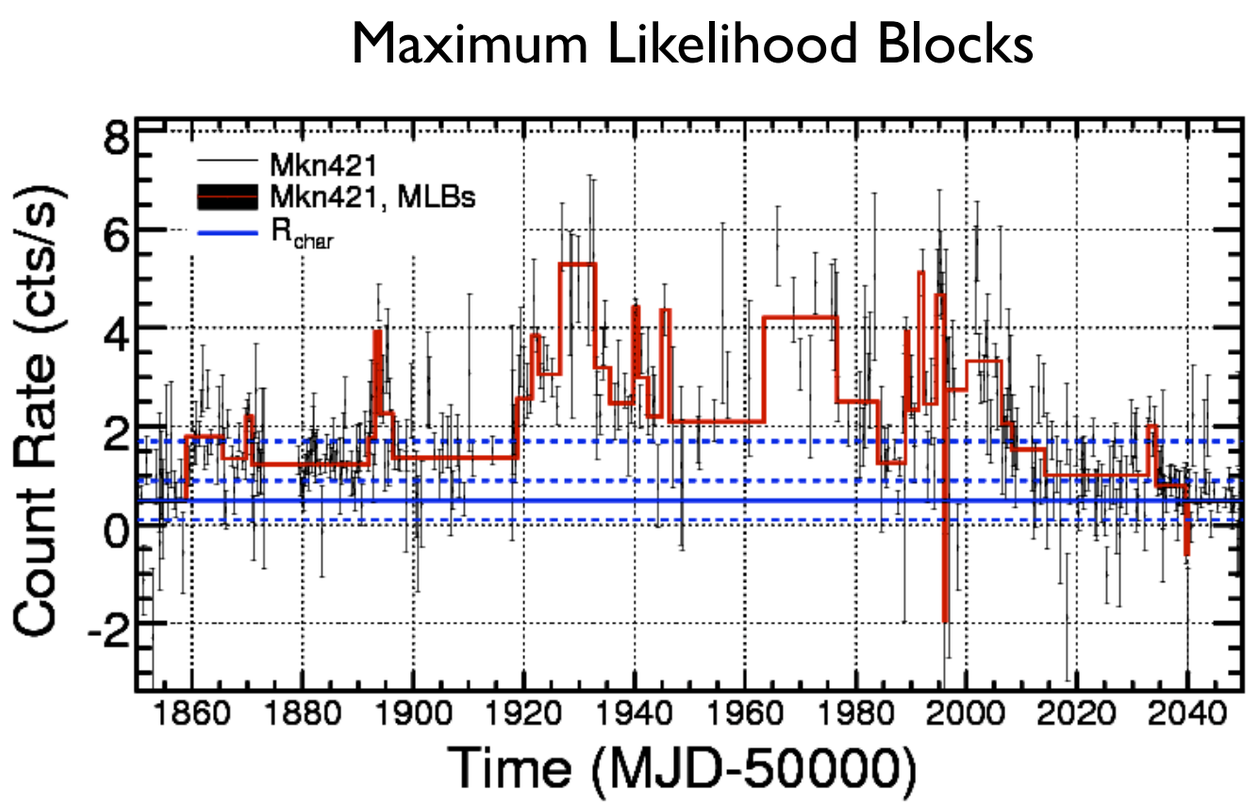
PKS 2005-489, zoom in Opt-X-ray range



How HBL vary on long timescales ?

Example from ASM: duty cycle and characteristic levels

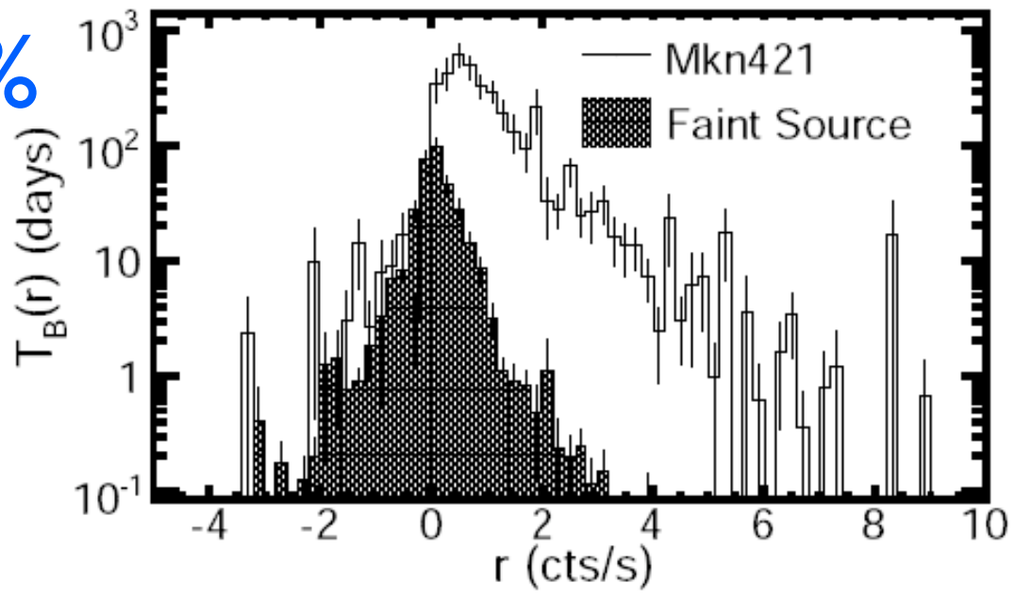




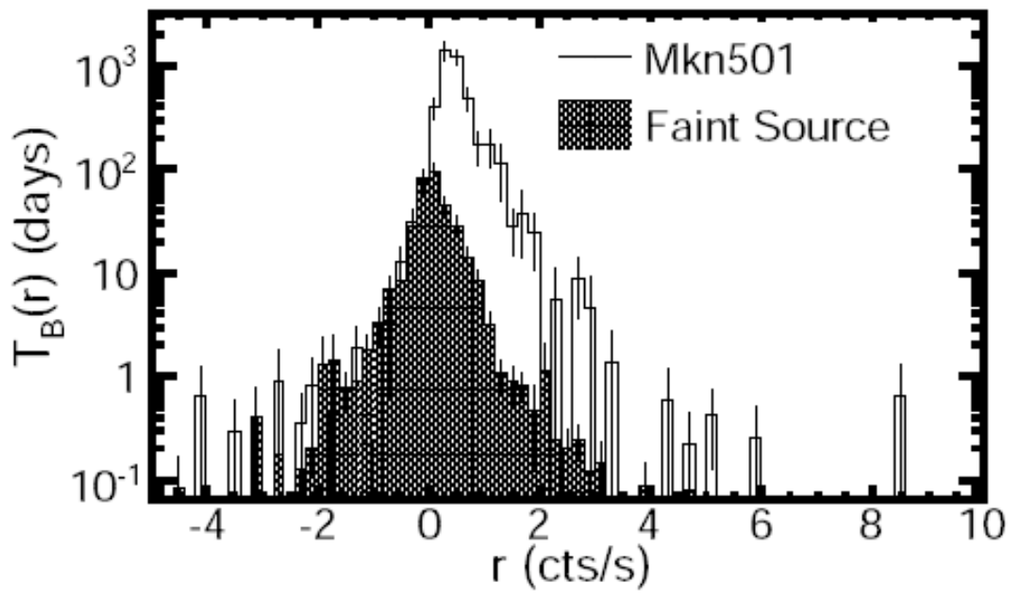
Resconi, LC et al. 2009

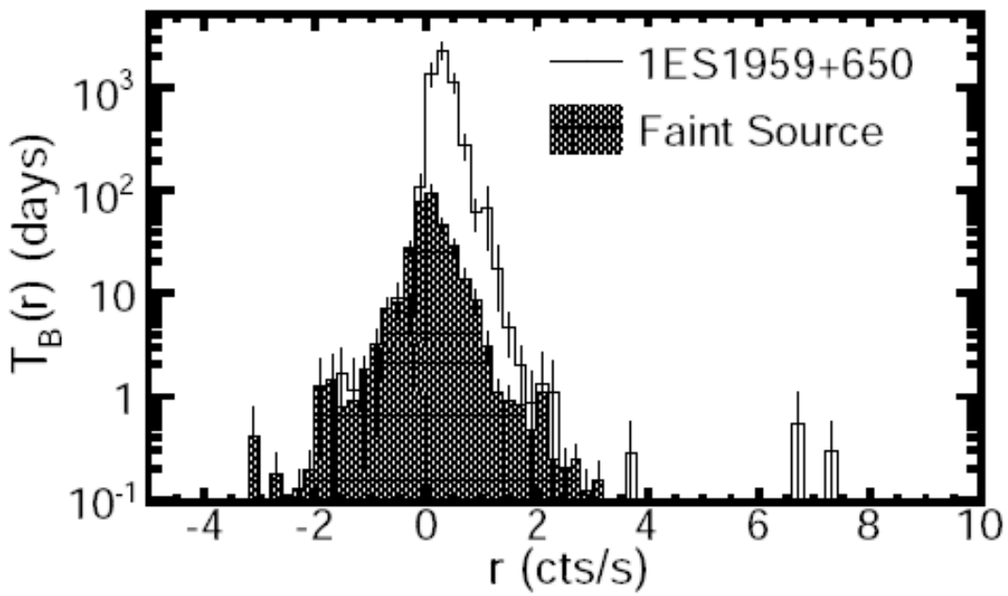
Duty cycle

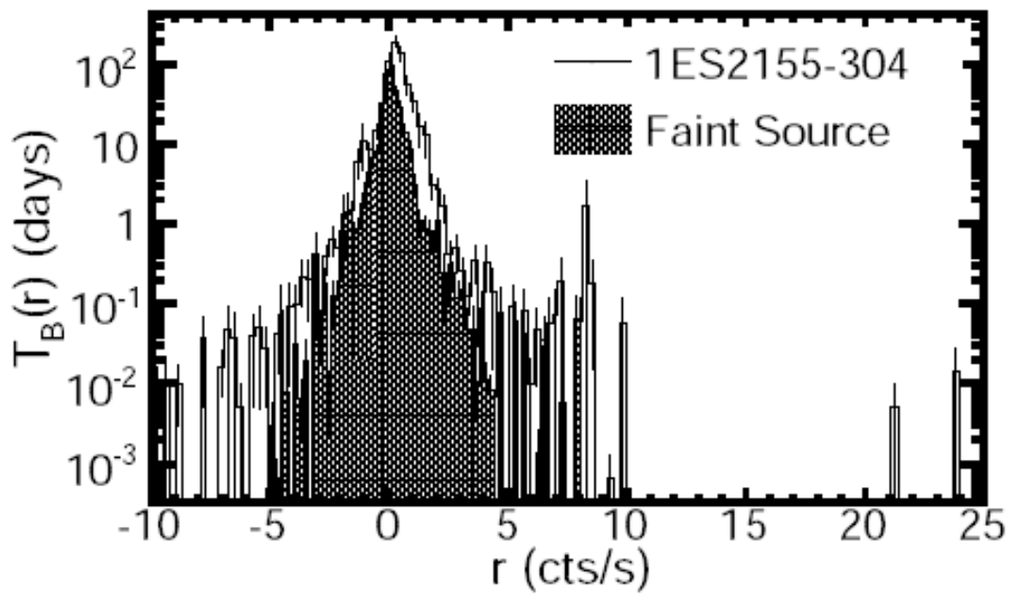
18%



10%



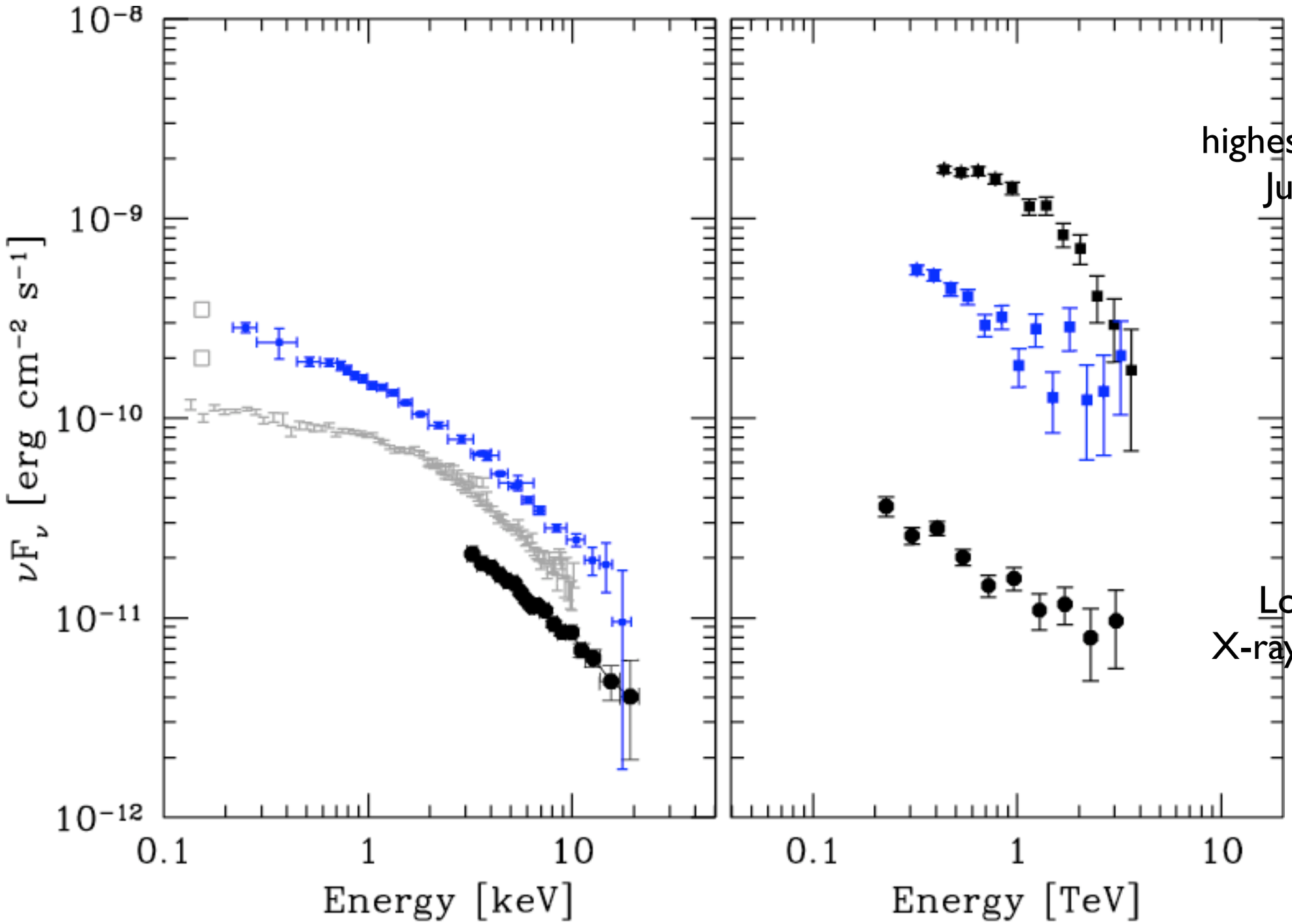




e.g.: time passed at flux 3 sigma above characteristic level

Resconi, LC et al. 2009

Chandra+RXTE, simultaneous HESS



highest TeV state,
July 2006

Low state
X-ray/TeV 2003