Studies on the VHE γ-ray/X-ray correlation in high-synchrotron peak BL Lacs

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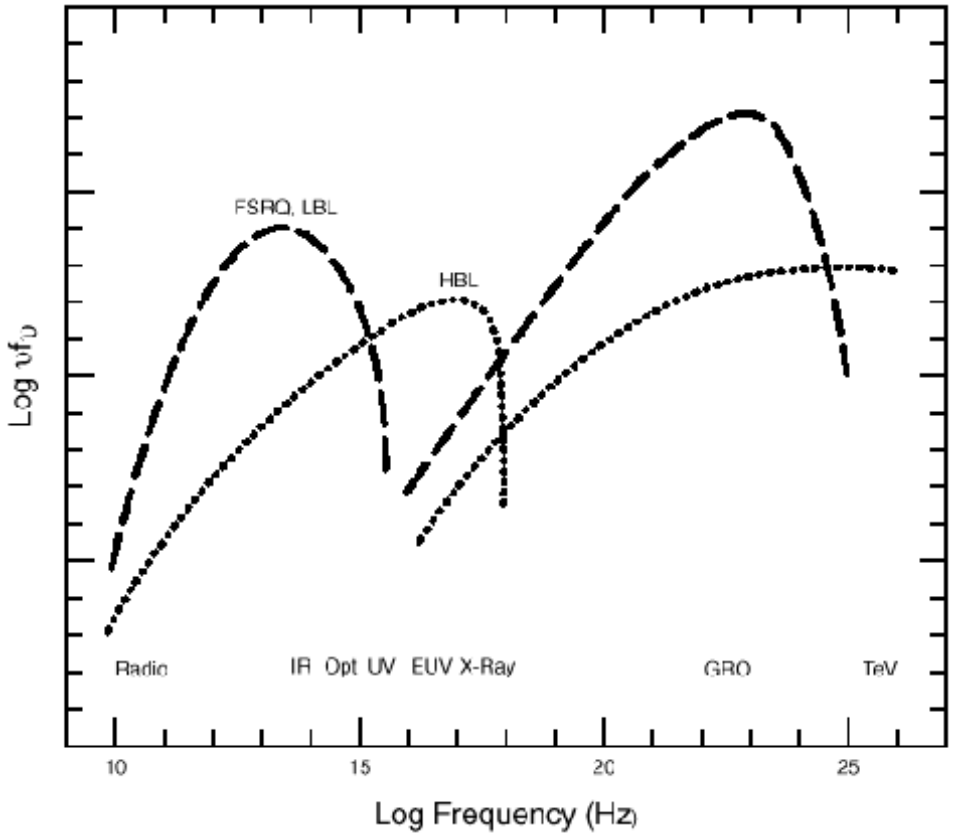
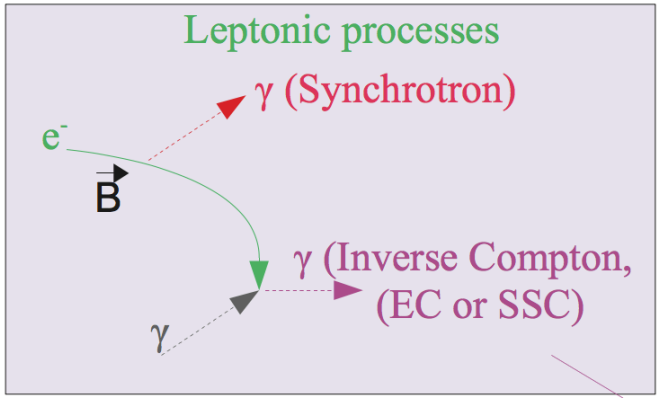
High-Synchrotron Peaked BL Lacs (HBL)⇒

- highly variable flux (short time and large amplitude)
- significant polarization
- SED dominated by non-thermal spectra
- SED peaks at X-rays and TeV gamma-rays



- Variability points to leptonic processes responsible of HE emission as SSC

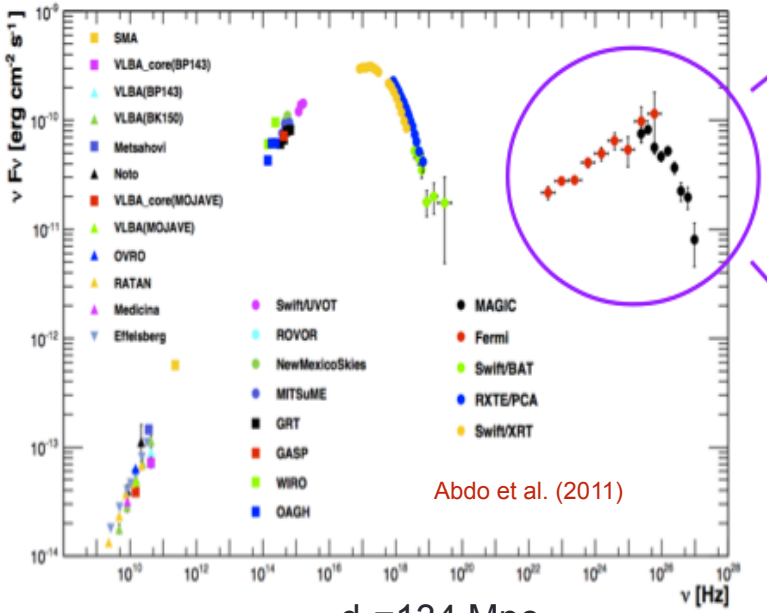
- Correlation between X and TeV is expected. Linear, quadratic ..?



- But orphan flares and evidence of hadronic processes have been observed

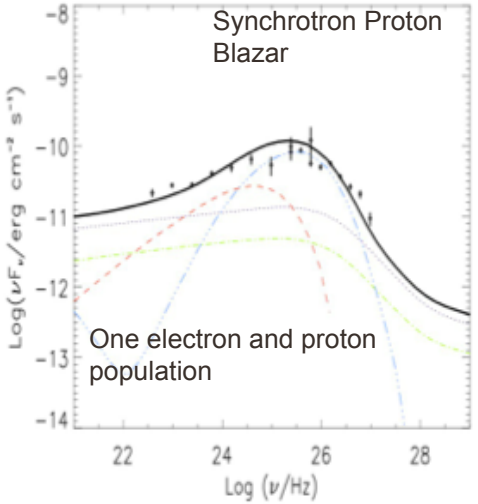
- No MW correlations

For a period of 1.5 years (August 2008 to March 2010), Mrk 421 was monitored by LAT

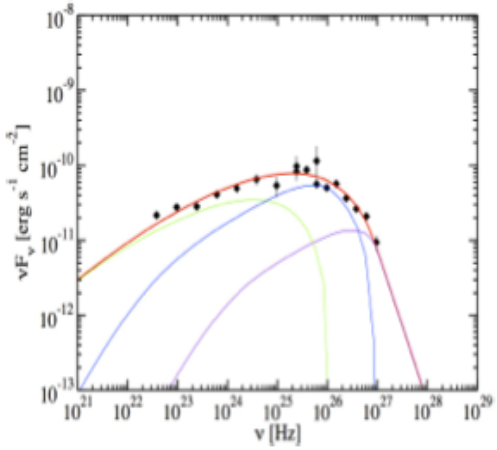


d_z=134 Mpc
z=0.031

Hadronic



SSC 3 power-law functions



After Fermi and MW observations:

- Multiple electron populations (wider HE peak)
- 2 emission zones (GeV – optical correlation)
- 3 PLs description

What can we learn from quasi-simultaneous MW correlations?

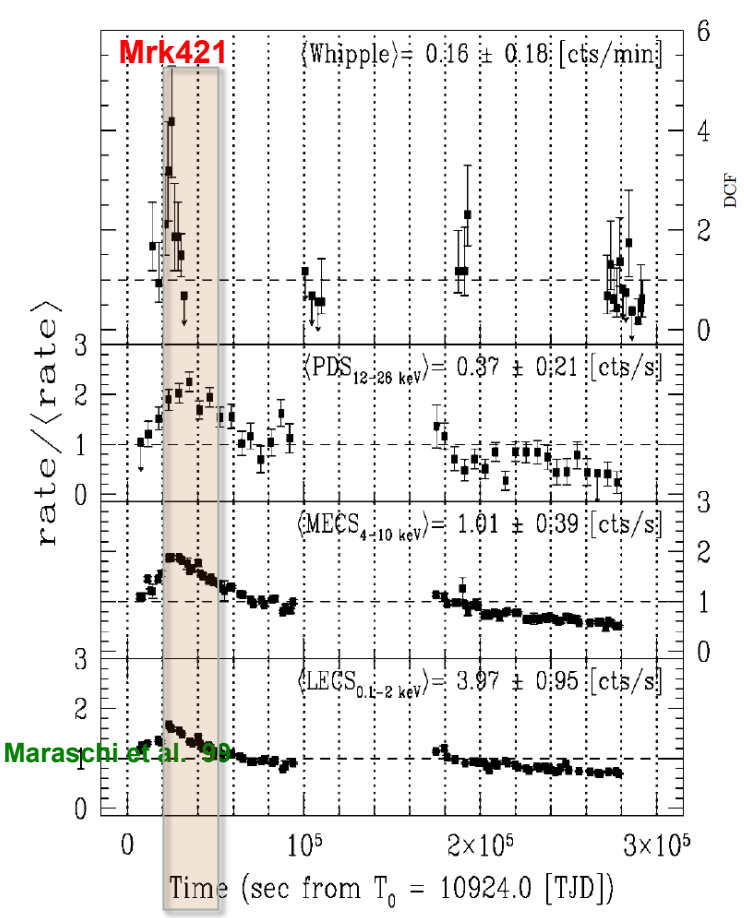
- The radiation mechanism:
  1. test the robustness of the expected correlations
  2. study the uniqueness of the correlation along the flux intensity
  3. study/search deviations from correlation as indication of new processes.
  4. study consistency of correlation along different frequencies
  5. study the SED evolution along the correlations or along blazar types (LBL<->HBL)

- Disentangle emission zones if more than one.
  1. A time integrated SED can only hint to it.
  2. Studies on the LC structure may help to disentangle contributions form each zone to the SED.

- In the SSC scenario : B and Ne

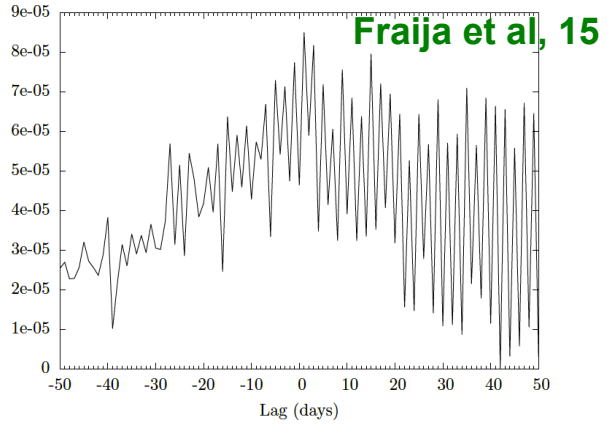
➢ Correlations

X-ray and TeV are correlated during the flare (flaring activity April/13).

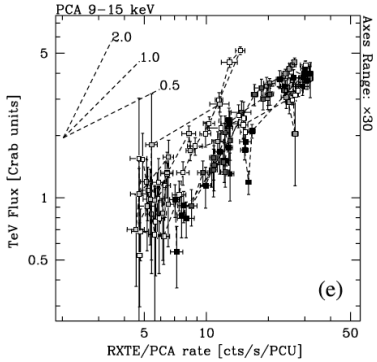


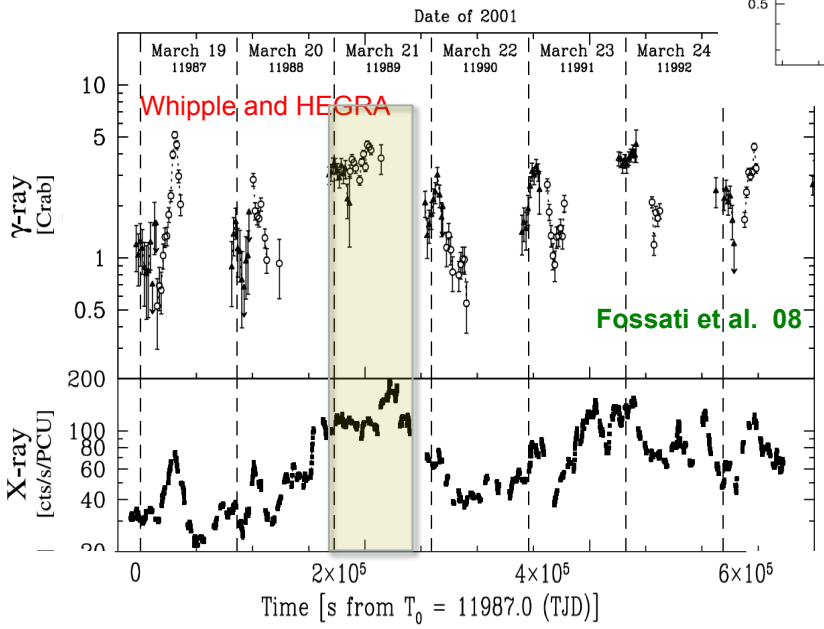
Marascchi et al. 99

X-ray and TeV are well correlated on timescale of hours (flaring activity April/98).



X-ray and TeV are highly correlated. (flaring activity 2001).

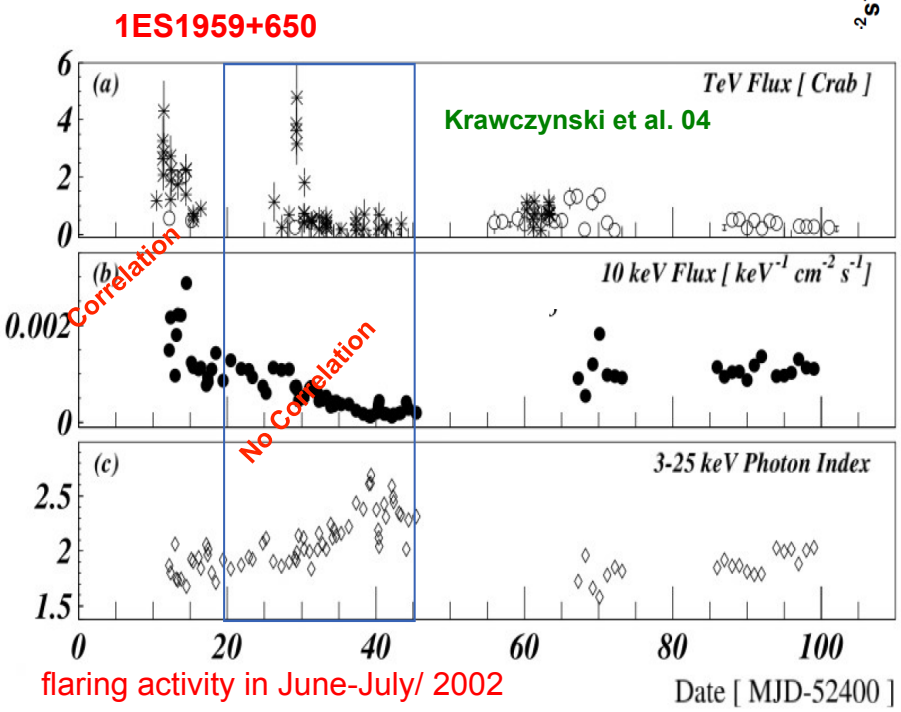


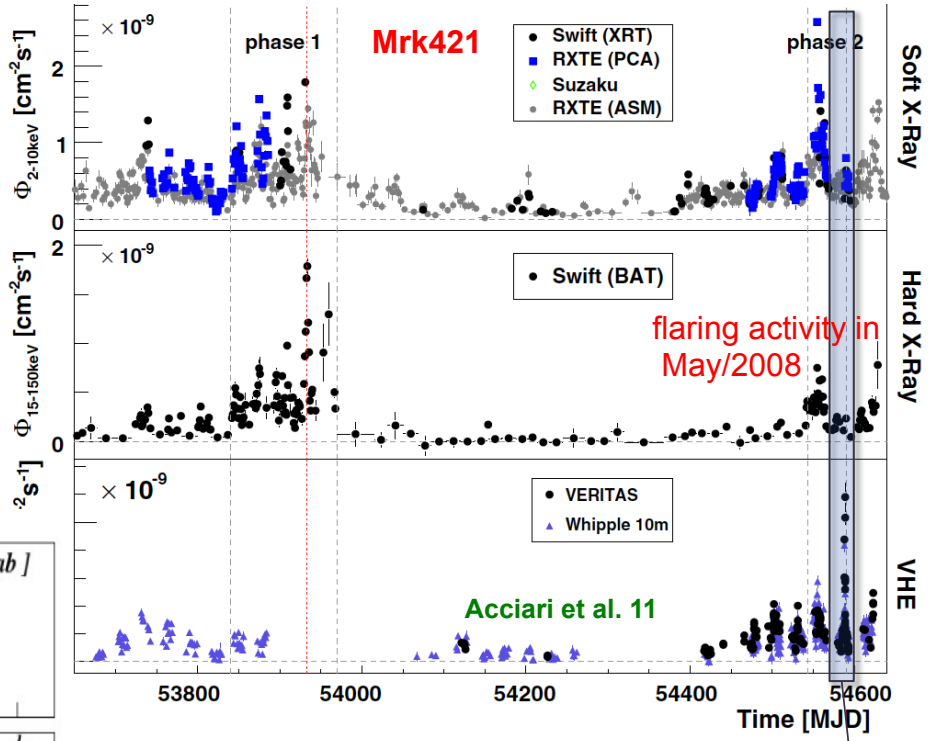


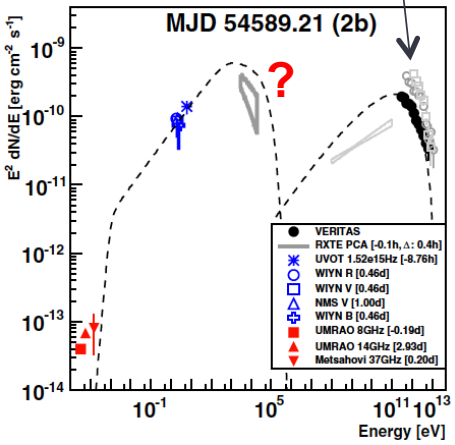
Fossati et al. 08

➢ Deviations

(Orphan Flares)





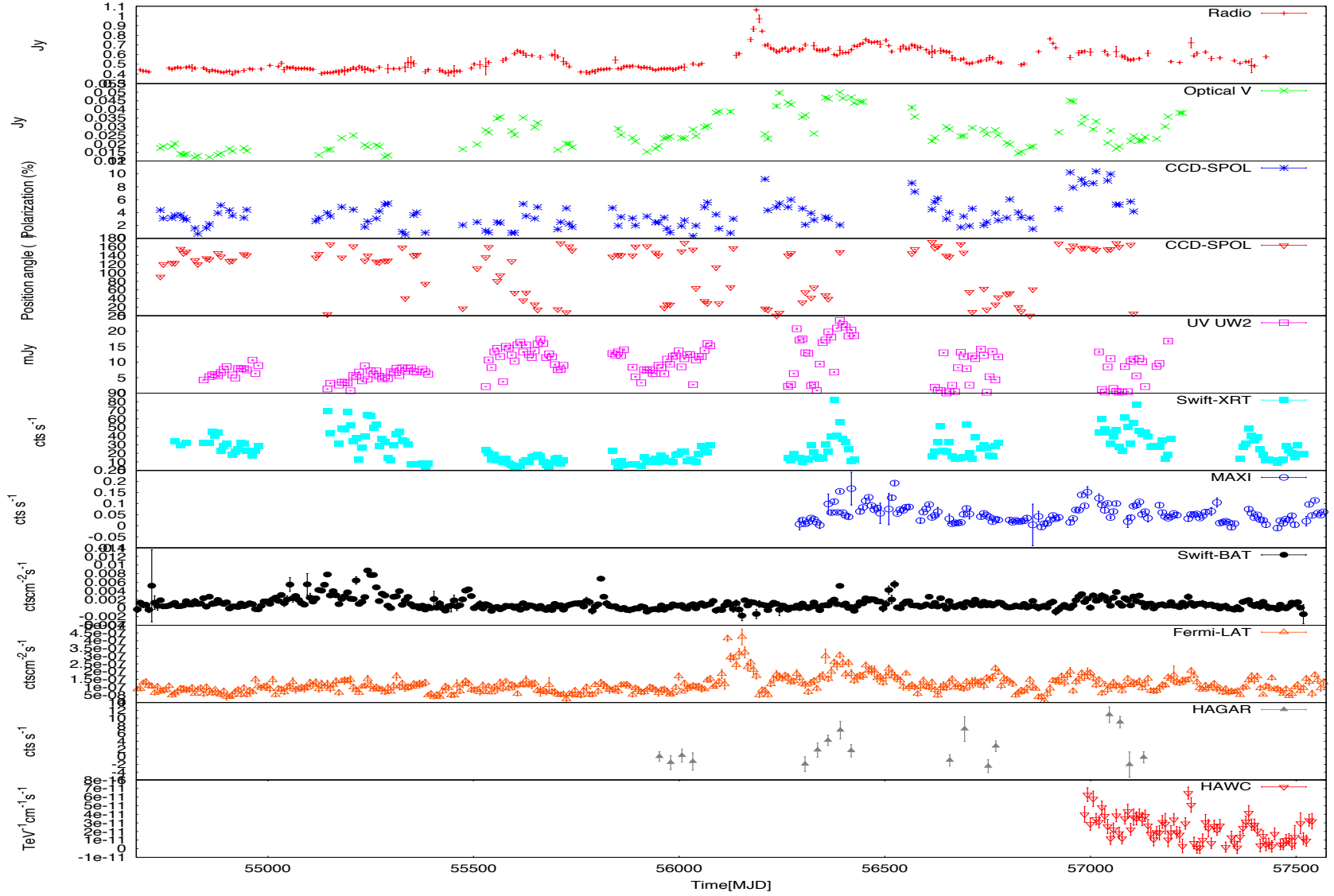


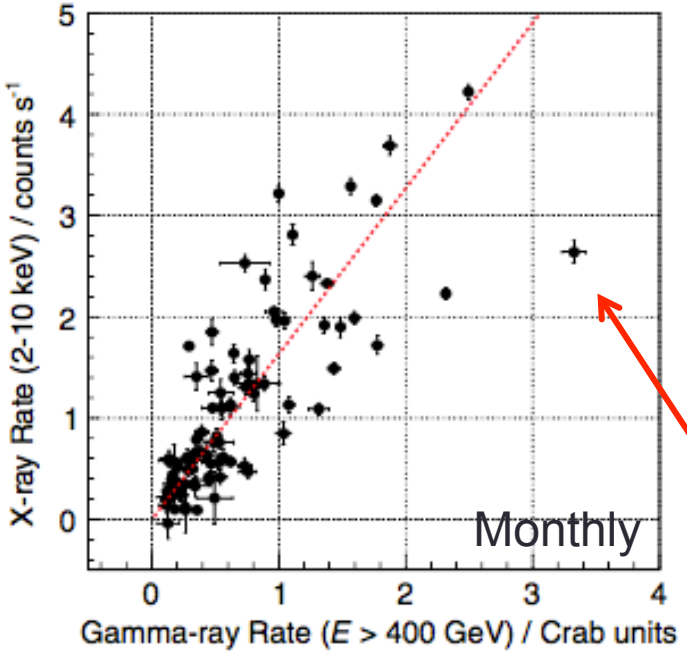
Is there a correlation between X-ray and TeV γ-ray emission ????
(hourly, daily, monthly, etc.)

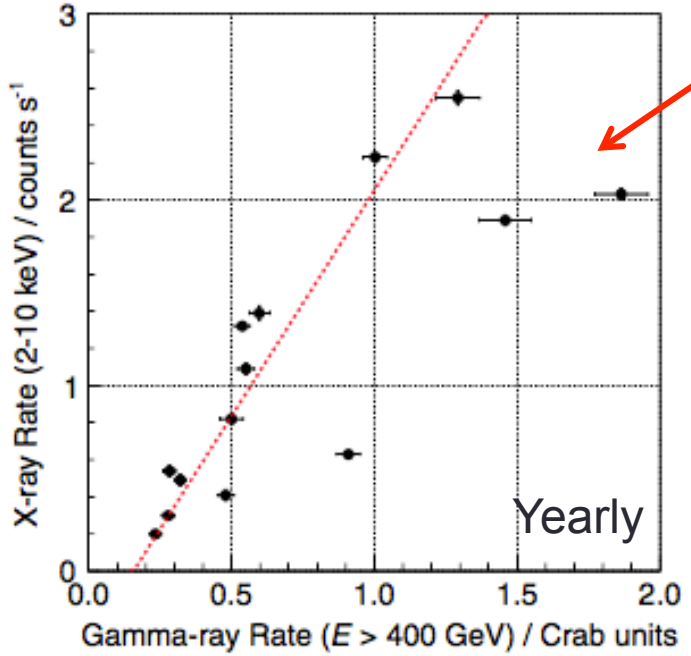
If so, what is the origin ??

How could the orphan flares be explained ???

Out of ~50 HBL, Mrk 421 is the most studied. z=0.03



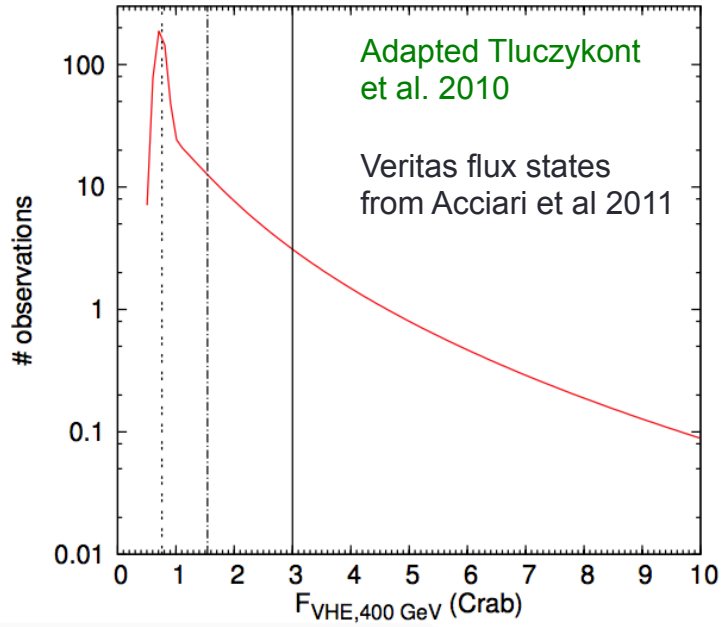




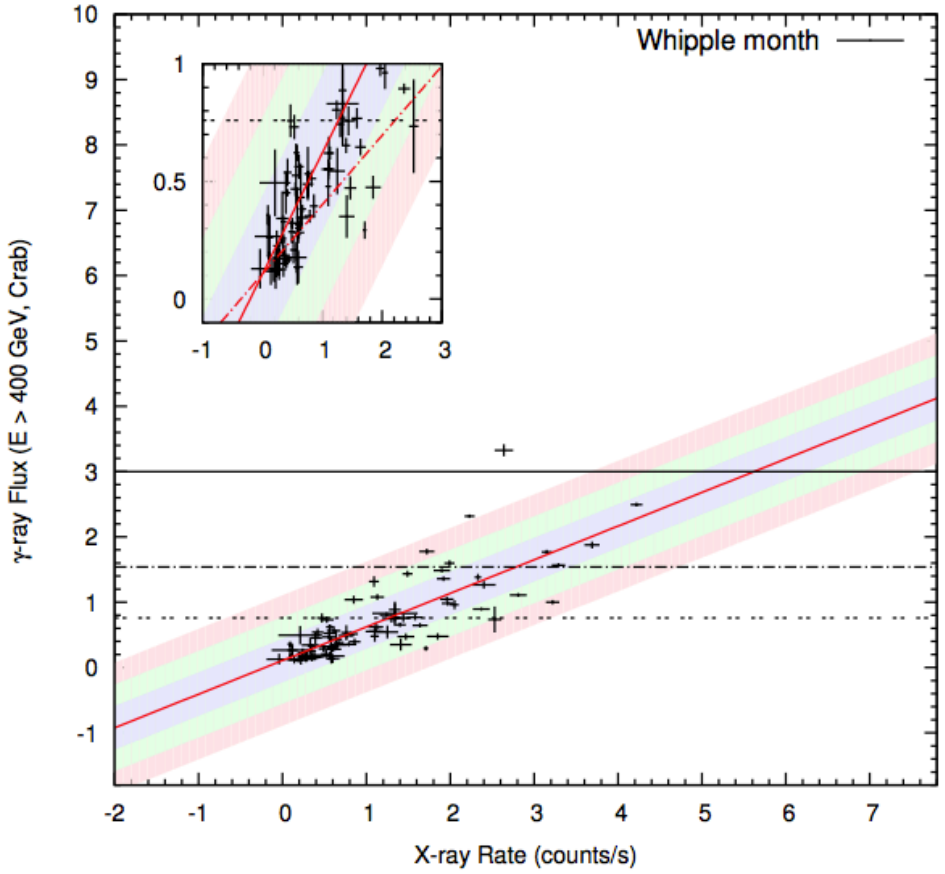
Most unbiased and comprehensive data set
14 years of Whipple-RXTE/ASM data
(Acciari et al. 14)
Whipple flux >400GeV

Best fit: linear fit
Slope = 1.63 (0.61)
R = 0.75

But, what about these?
Are they significant?



D'Agostini 2005, Maximum Likelihood Method that considers an extra scatter.



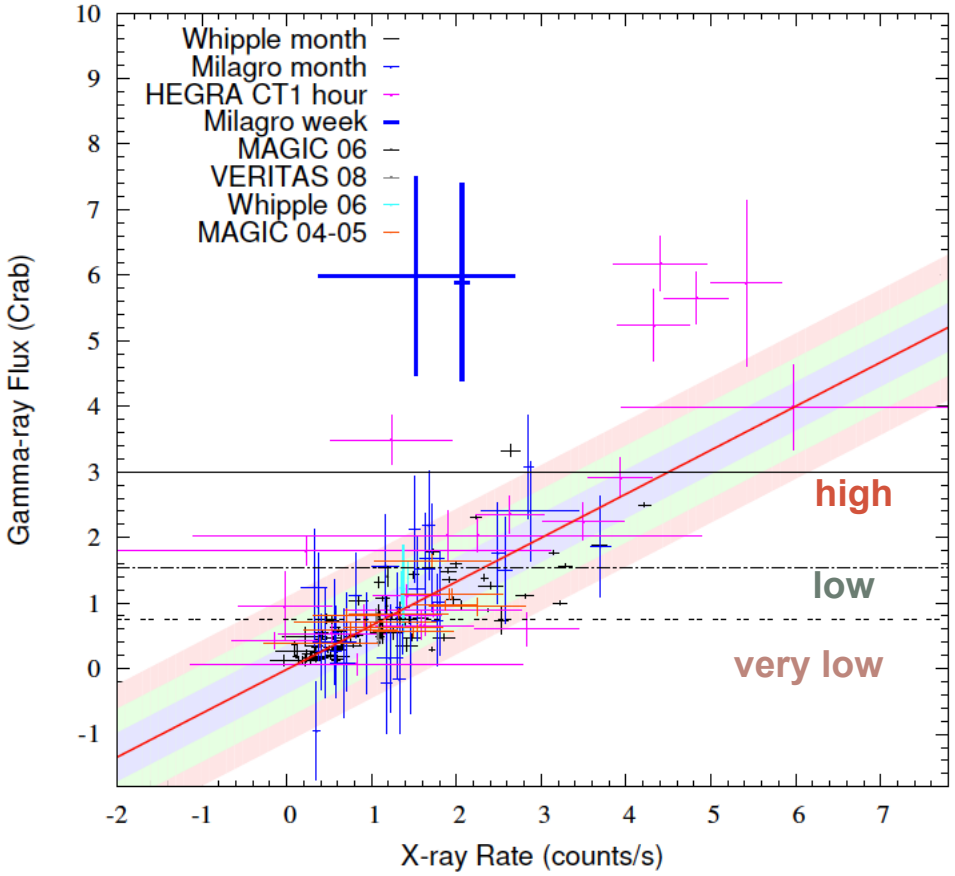
Slope 0.51 ± 0.4 (vs 0.61 Whipple)

σ = 0.33 ± 0.03

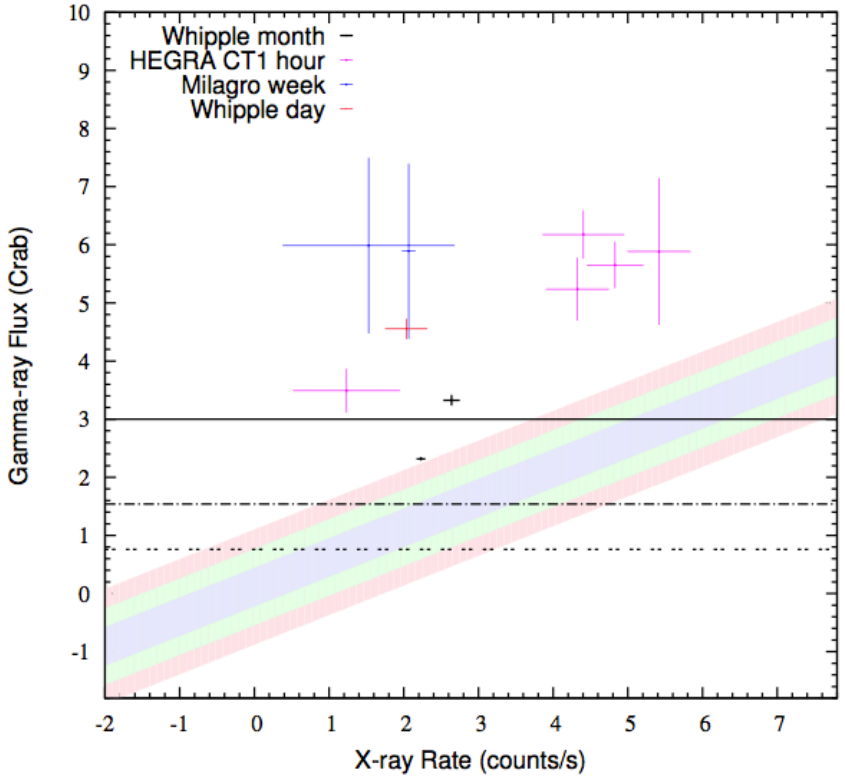
Outliers 4 & 6 σ above the best fit

Is the dispersion intrinsic to the source?

Same correlation at quiescent state?



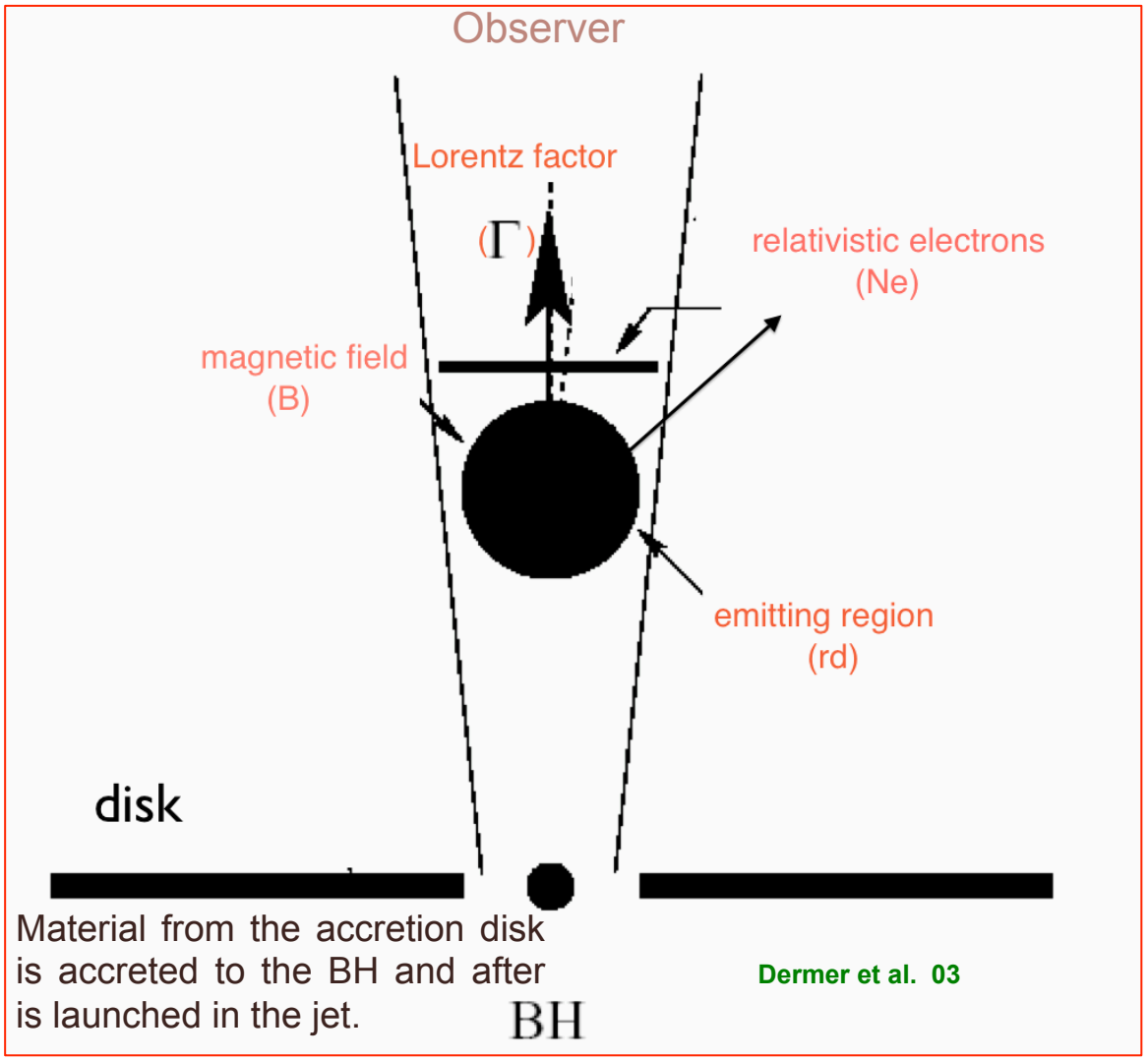
Even observations with reports of not correlation found fall within 3σ



The highest VHE γ-ray fluxes do not lie on the correlation independently on the observation period and on the instrument.

➢ Theoretical Model

Sketch of the basic model



Material from the accretion disk is accreted to the BH and after is launched in the jet.

Dermer et al. 03

We consider a spherical emitting region:

- Moving at relativistic speed with bulk Lorentz factor Γ.
- with a uniform particle densities (Ne).
- with radius (rd).
- Endowed with a magnetic field B.

Leptonic model

Just 4 parameters

(B, Γ , rd and Ne(β))

(we will use natural unities c=ħ=1 and prime quantities are in the commoving frame)

Only 3 break energies or 2 PLs

Milagro and Veritas (Low state)

Values of parameters

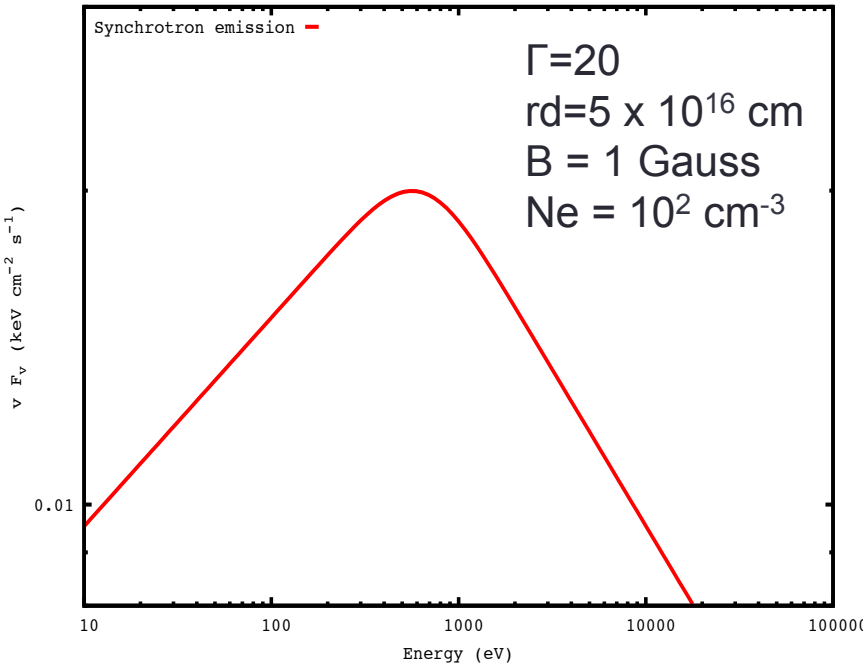
$$\beta = 2.3$$
$$r_d = 5 \times 10^{16}\,\mathrm{cm}$$
$$\Gamma = 10$$

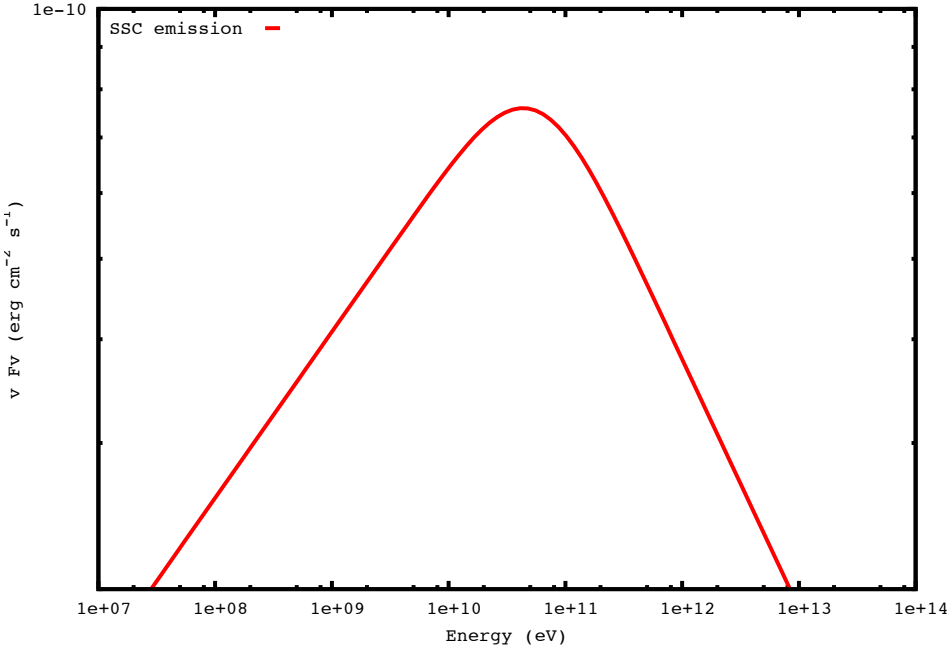
Values N_e and B are computed fitting data

Acciari et al. 2011, 2014
Abdo et al. 2014

Veritas, (Holder et al 2006) $1\,\mathrm{Crab} = 0.871 \times 10^{-10}\,\mathrm{erg/cm^2/s}$

Unities of X-ray flux were changed
(with the online WebPIMMS tool) $\mathrm{erg/cm^2/s} \rightarrow \mathrm{CPS}$





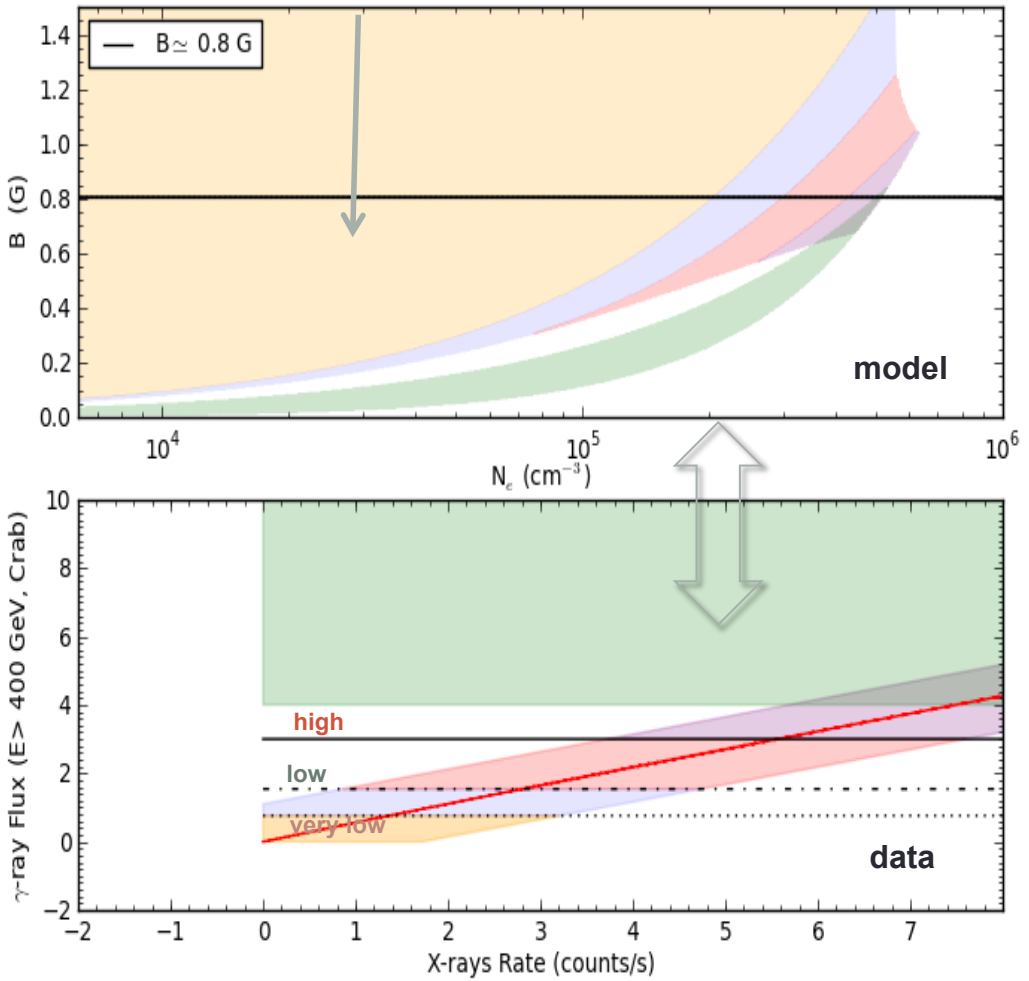
Values from fitting the SED

Magnetic field $0.01 \leq B\,(G) \leq 1.6$

Electron density $10^3 \leq N_e\,(\mathrm{cm}^{-3}) \leq 10^{5.5}$

Parameter space

Unique correlation $\mathrm{B} \simeq 0.8$ G



As further in flux we can measure the correlation as better we can determine the magnetic field.

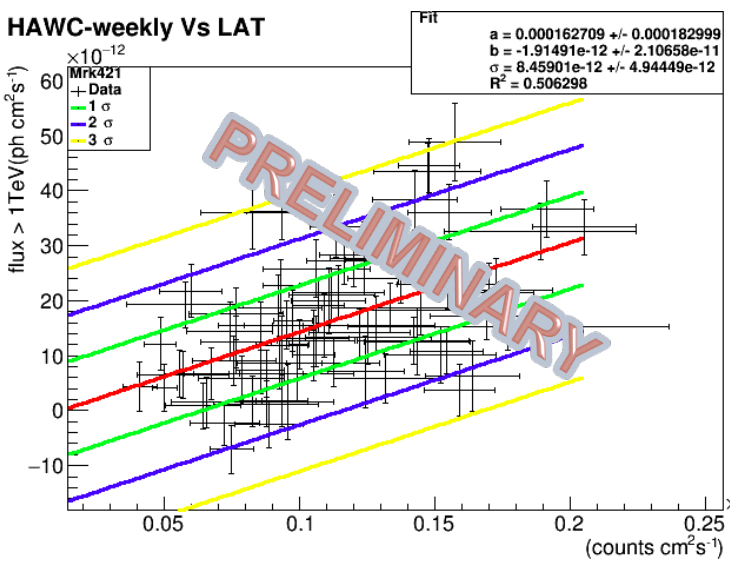
Within the one electron population SSC scenario, we can not explain the outliers without a change in B.
→ hadronic origin?

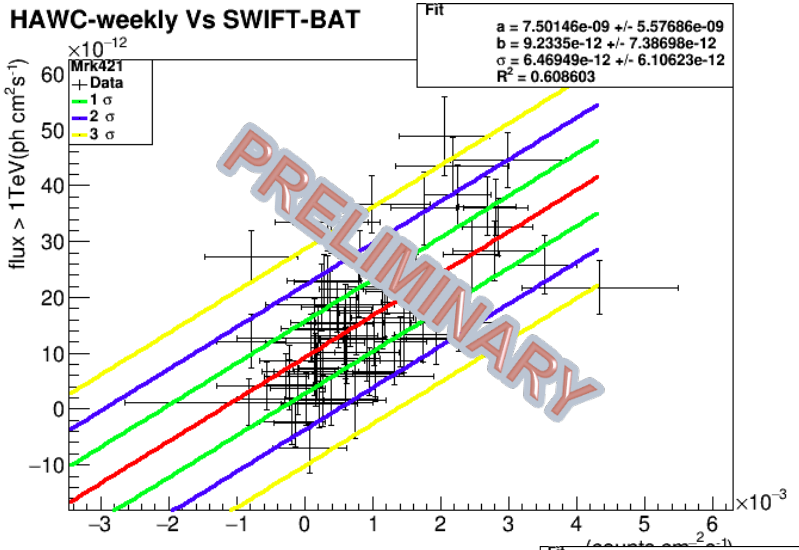
Remain questions:

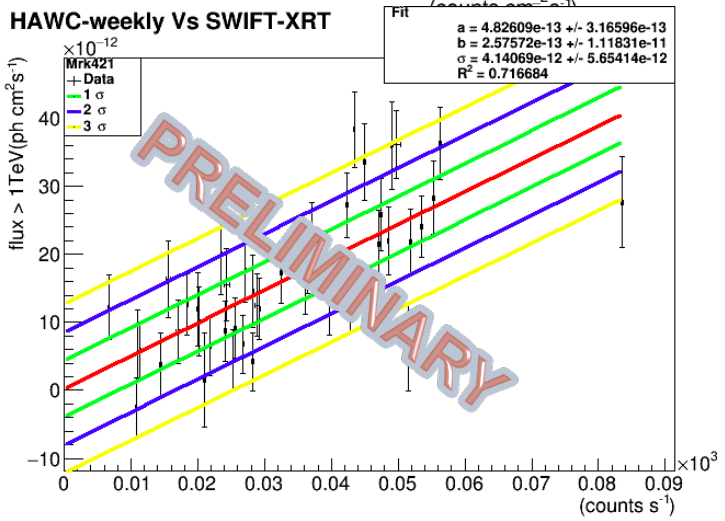
- Is σ intrinsic to the source? Flare to flare differences?
- For which time scale the correlation breaks? hrs?
- How the correlation evolves to the neighboring energies?

All is based on the Whipple data.

We need another unbiased and comprehensive data set from instruments as FACT and HAWC in TeVs.

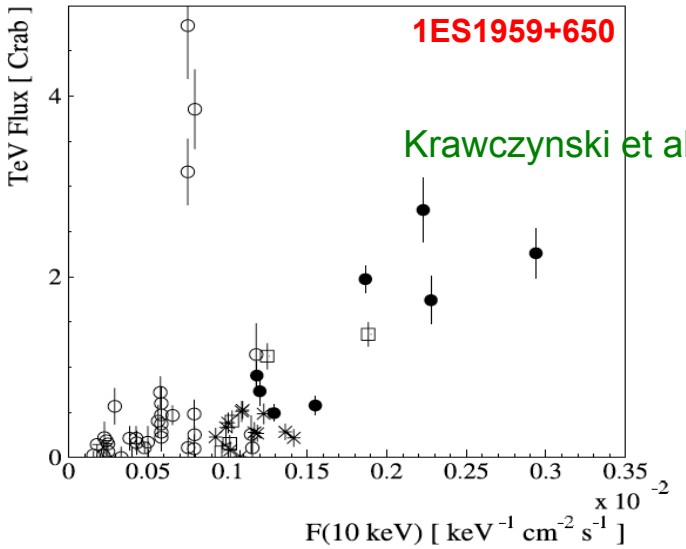




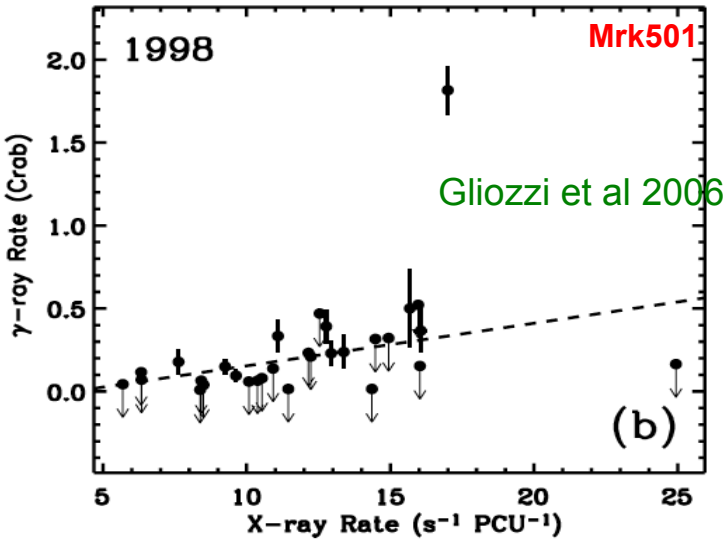


- 21 months of HAWC data, weekly average fluxes
- LC, analysis – R. Lauer´s talk
- Is the same soft X - TeV correlation?
- Are the LAT and BAT correlation consistent with the soft X-TeV correlation? If not ….
  - LAT-optical correlation – 2 region scheme

This model could be generalized to other blazars



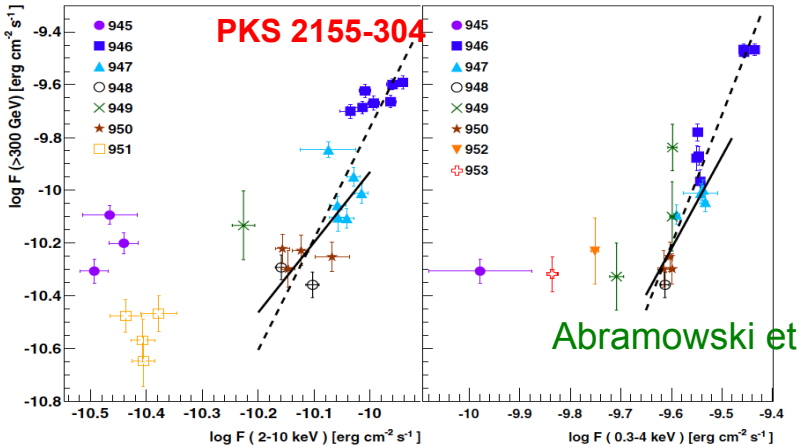
Krawczynski et al 2004



Gliozzi et al 2006

Will we be able to determine B ?

Outliers also in other HBL?



Abramowski et al 2006

➢ Conclusions

- ✓ A robust and comprehensive study of the X-TeV correlation was presented.
- ✓ A unique correlation was found, from low to high fluxes independently of instrument or time scale. Except for very high γ-ray fluxes when it breaks.
- ✓ We have developed a theoretical model that can explain the correlation between TeV γ-ray and X-ray emissions of Mrk 421
- ✓ The overall correlation can be interpreted as SSC scenario with a single value of magnetic field of $\mathrm{B} \simeq 0.8\ \mathrm{G}$ for Mrk 421.
- ✓ Other HBL show similar correlations so model should be tested. Would it be possible to estimate B for each HBL?
- ✓ More monitoring instruments are required in all frequencies.