



X-ray/gamma-ray Correlation in Blazars

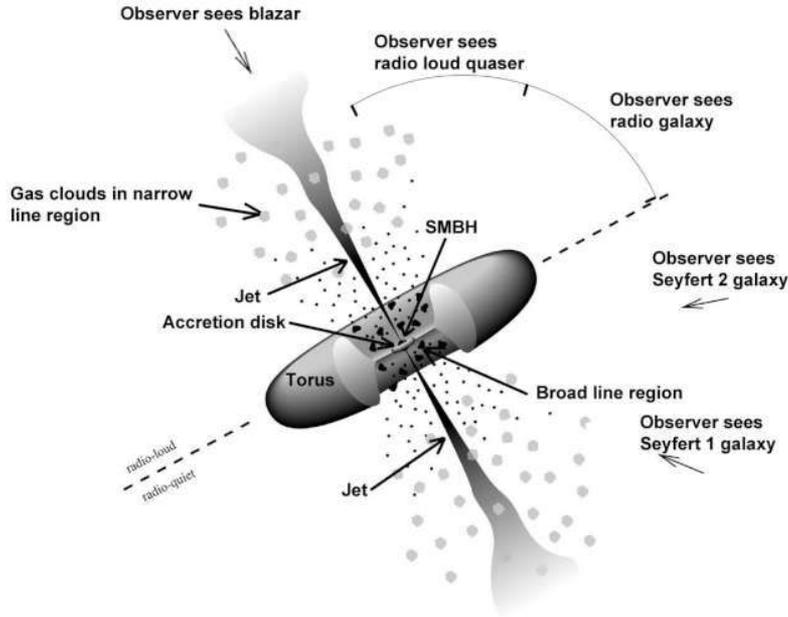
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Overview

- Introduction
- X-ray/gamma-ray emission in blazars
- Leptonic Vs Hadronic models
- X-ray/gamma-ray correlation in blazars
- Mrk421 as an example
- Conclusions and perspectives

Introduction



Credit: Fermi and NASA: <https://fermi.gsfc.nasa.gov/science/eteu/agn/>

- In the unified model Blazars are active galaxies that have pairs of relativistic jets that flow in opposite directions aligned to our line of sight
- Their spectral energy distributions (SEDs) are characterized by beamed jet emission and take the form of two broad components, one at low energies, peaking in the radio through optical, and one at high energies, peaking in the γ -rays.

Introduction

- Synchrotron emission in AGN jets
 - When a charged particle is accelerated in a magnetic field

Total luminosity

$$L = 4Z^4e^4B^2E^2/9c^7m^4.$$

Radiation observed in laboratory frame with an opening angle

$$\varphi \approx \gamma^{-1}$$

Introduction

- Synchrotron emission in AGN jets
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Total luminosity

$$L = 4Z^4 e^4 B^2 E^2 / 9c^7 m^4.$$

Process more efficient
for e^-/e^+ than for p

Radiation observed in laboratory frame with an opening angle

$$\varphi \approx \gamma^{-1}$$

Introduction

- The total emissivity is:

$$\epsilon(\nu) = \int_{E_1}^{E_2} L(E, \nu) n(E) dE$$

$$n(E)dE = kE^{-p}dE,$$

$$\alpha_R = \frac{p-1}{2}$$

Electron distribution

$$\epsilon(\nu) \propto \nu^{-\alpha_R}$$

X-ray & gamma-ray emission in blazars

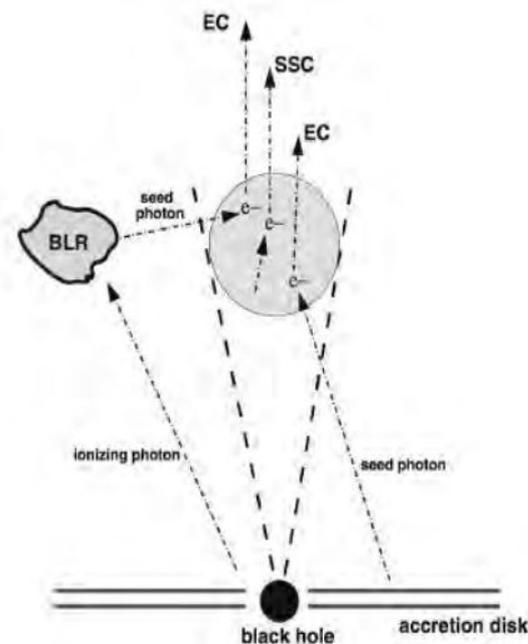
- Electron Synchrotron emission is believed to be responsible of X-ray emission from blazars.
 - Low synchrotron peaked blazars
 - Intermediate synchrotron peaked blazars
 - High synchrotron peaked blazars

X-ray & gamma-ray emission in blazars

- For gamma-ray emission we have inverse compton:
 - Energy is transferred to the photon $\gamma_e \gg 1$
 - This scatters up the photon to higher energies.
 - The scattering can be made by e^-/e^+ and p
- Synchrotron self-compton
 - The seeds photons of the inverse compton scattering come from the synchrotron emission
 - These photons are up-scattered to higher energies by the same population of electrons which has produced them.

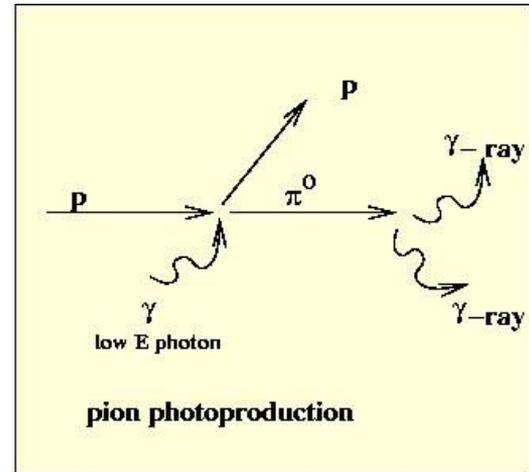
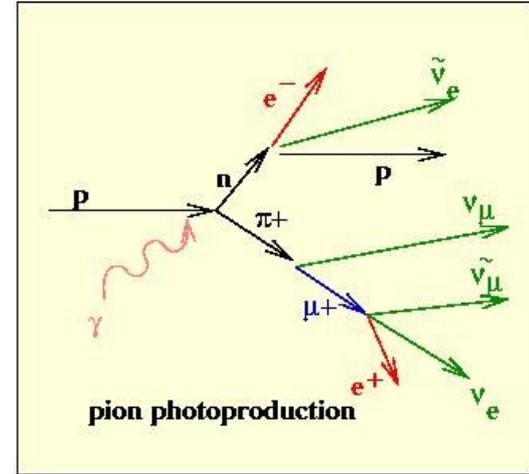
Leptonic Vs Hadronic models

- Leptonic
 - High energy component of SED
 - Synchrotron self-compton
 - One-zone, multi-zone SSC model
 - External compton
 - Seed photon comes from accretion disk, BLR



Leptonic Vs Hadronic models

- Hadronic
 - High energy component of SED
 - Synchrotron proton blazar (SPB)
 - synchrotron radiation of relativistic protons and muons
 - Photo-meson production with subsequent synchrotron-pair cascading

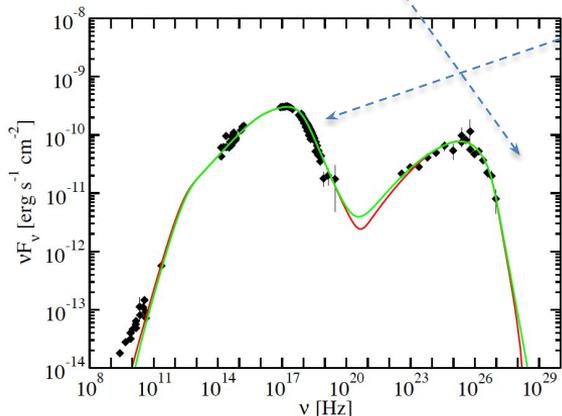


Leptonic Vs Hadronic models

e^- Synchrotron radiation

Inverse Compton (SSC) model

High-energy peak
(X-rays to gamma-rays)



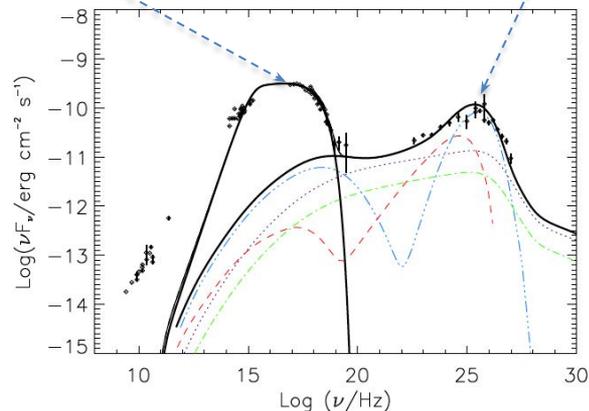
Low-energy peak
(radio to optical/UV)

Abdo et al. 2011

Jet power is
larger for
hadronic
than leptonic

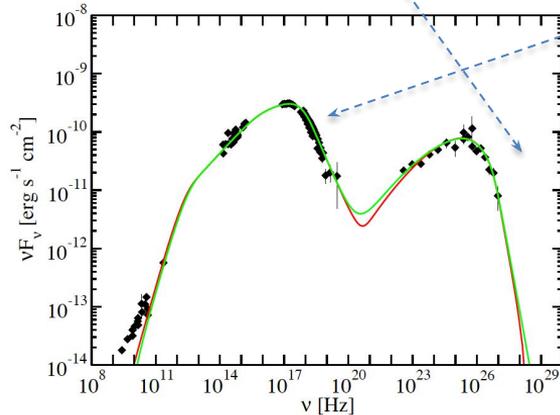
Synchrotron proton model

High-energy peak
(X-rays to gamma-rays)



Leptonic Vs Hadronic models

Inverse Compton (SSC) model
High-energy peak
(X-rays to gamma-rays)



Correlation:

- TeV gamma-rays and X-rays
- Small magnetic field (< 100 mGauss)
- Fast Variability
- No neutrino production

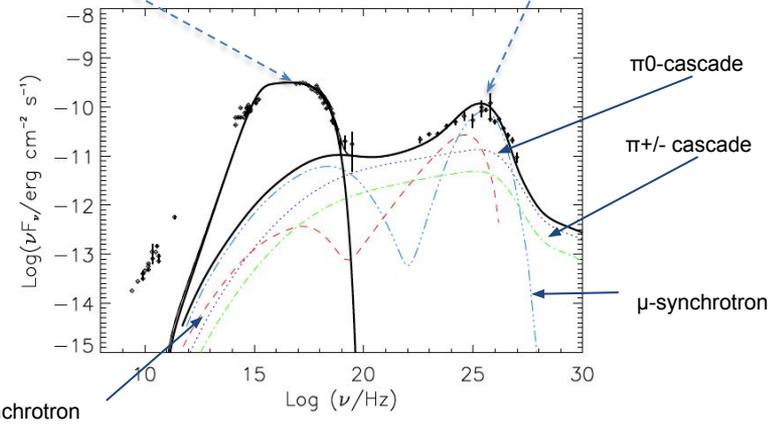
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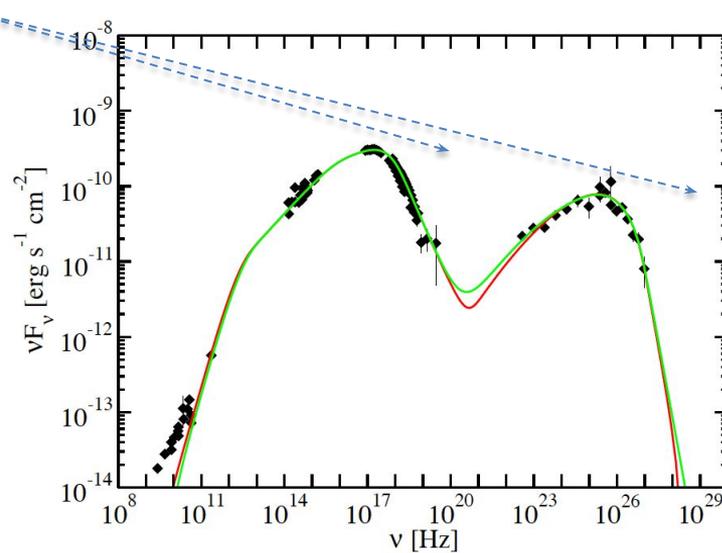
No correlation:

- TeV gamma-ray and X-ray
- Large magnetic field (50 Gauss)
- Large (Ne) Variability
- Neutrino production

X-ray/gamma-ray correlation in blazars

Inverse Compton (SSC) model High-energy peak (X-rays to gamma-rays)

- Correlation is expected between the two peaks of the SED
 - Linear?
 - Quadratic?
 - Higher orders?

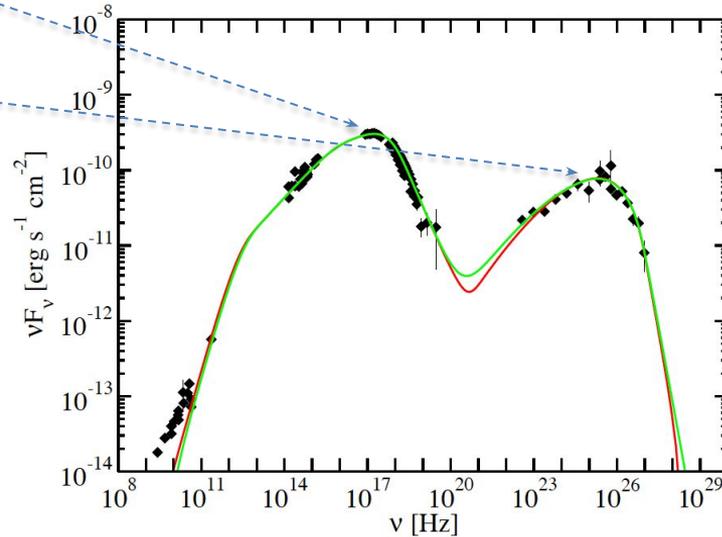


X-ray/gamma-ray correlation in blazars

Inverse Compton (SSC) model High-energy peak (X-rays to gamma-rays)

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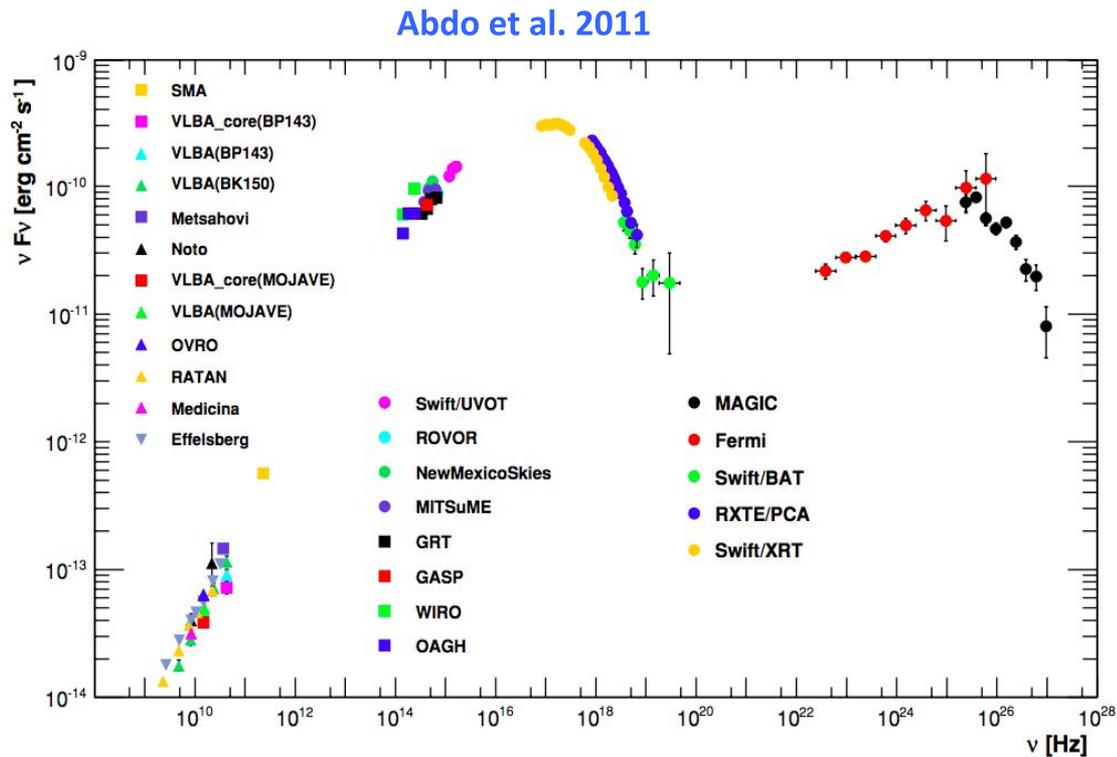
- Linear?
- Quadratic?
- Higher orders?



- Correlation studies can shine some light in this matter
- Unbiased monitoring very useful for correlation (FACT, HAWC)

Mrk 421

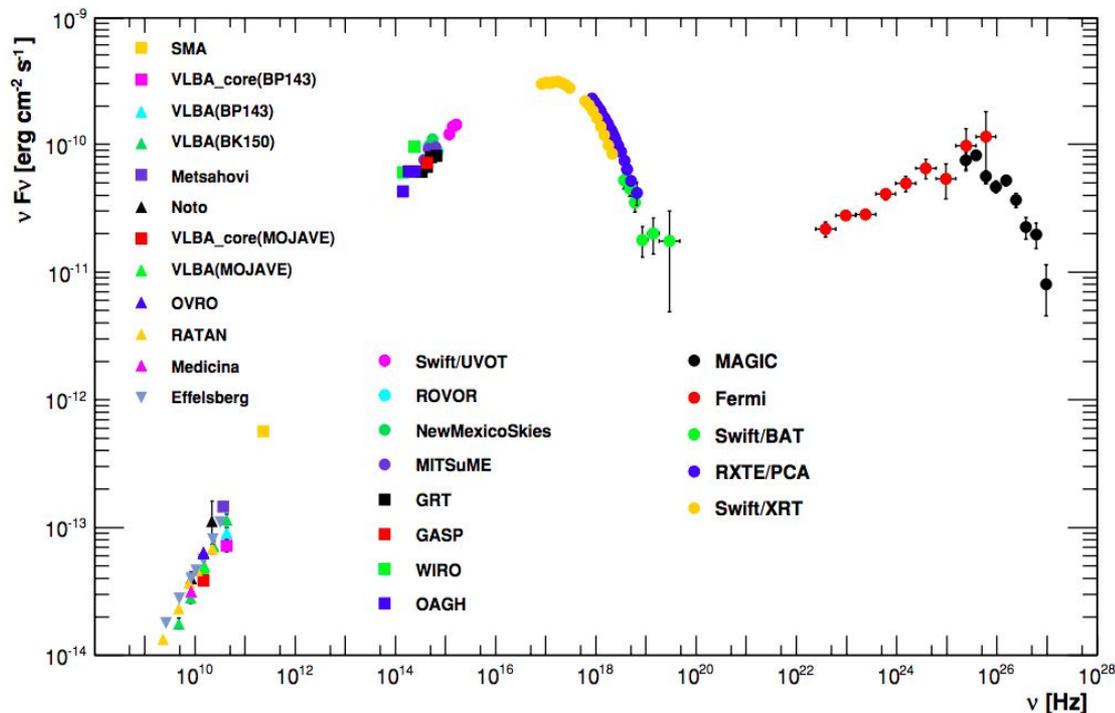
- One of the closest and brightest blazars
- Emits at TeV energies
- Multiple dedicated observation campaigns
- Understanding correlation very important
 - (Katarzynski et al. 2003; Blazejowski et al. 2005; Revillot et al. 2006; Fossati et al. 2008; Horan et al. 2009; Aleksić et al. 2015)



Mrk 421

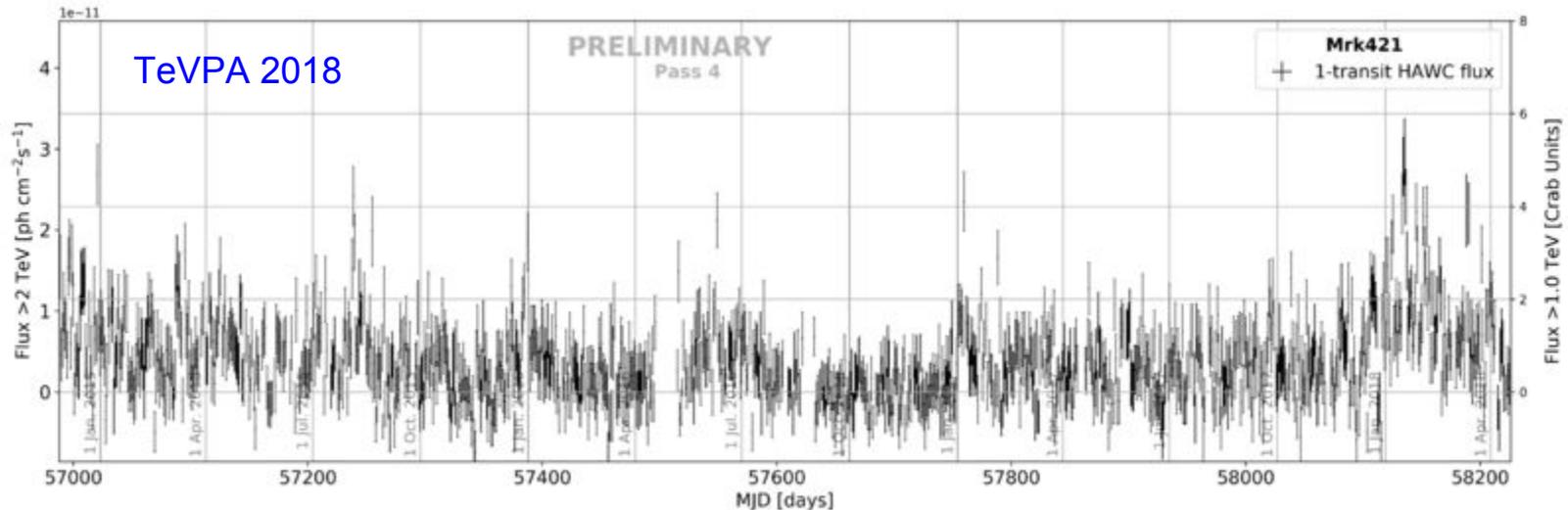
- Previous studies have shown evidence of positive correlation between X-ray and gamma-ray bands
 - Although there is not a final conclusion yet
 - Linear?, higher orders?
- There is evidence that supports leptonic models
 - One-zone
 - Multi-zone
- Hadronic scenarios still being studied

Abdo et al. 2011



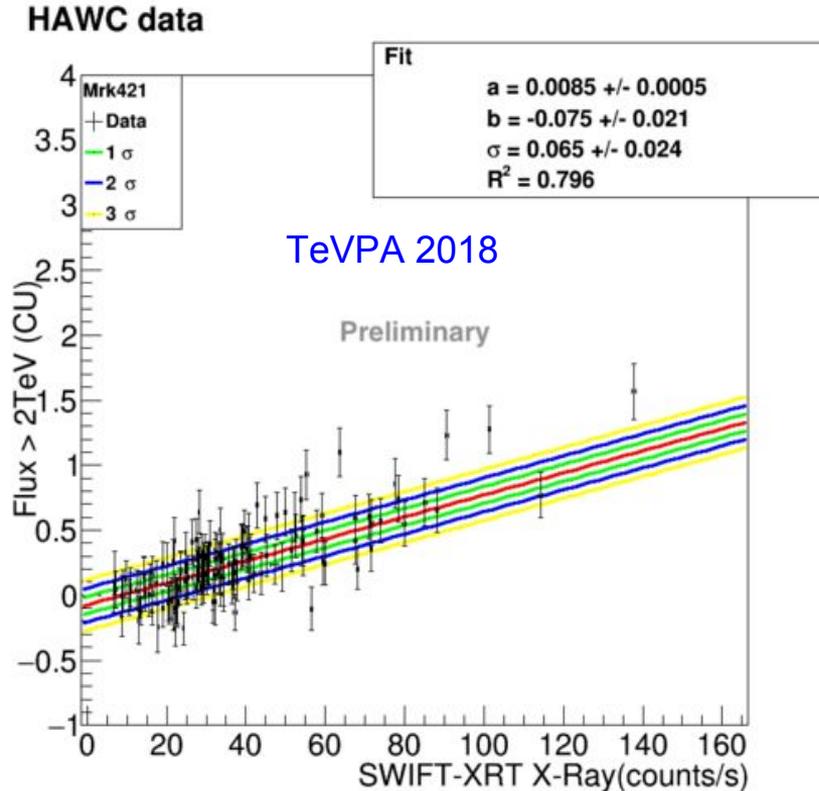
Mrk 421

- HAWC have been continuously monitoring Mrk 421 for more than 3 years
 - Unbiased monitoring



Mrk 421

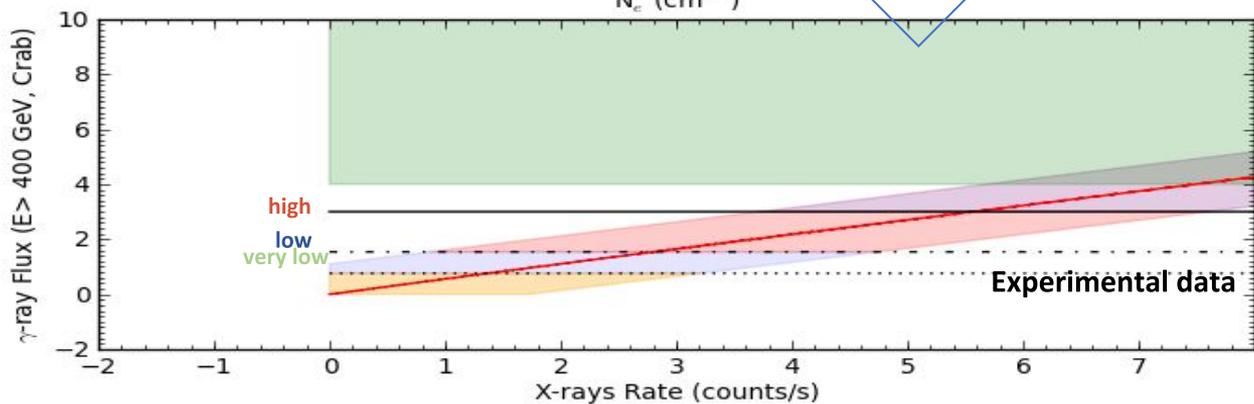
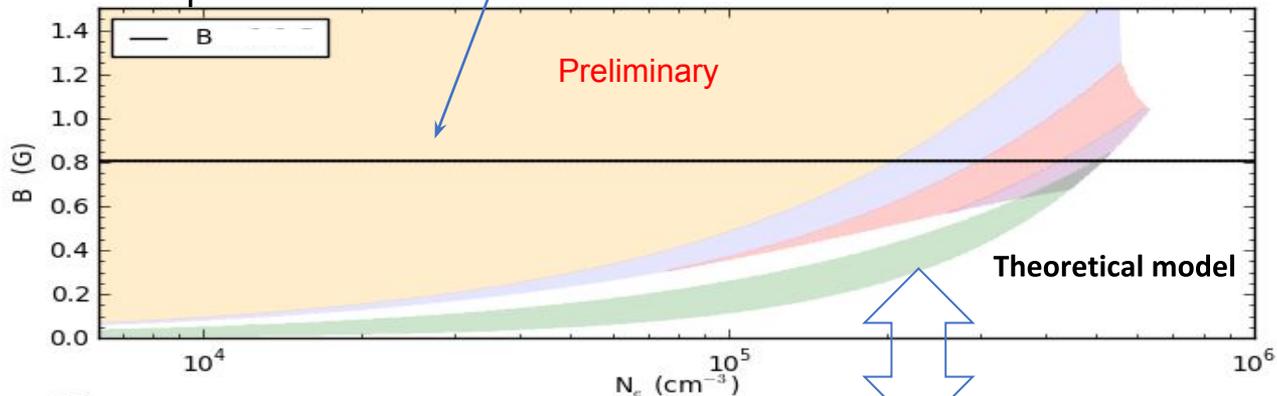
- Very strong linear correlation
 - Favors leptonic scenario
 - Shows linear trend
- Hadronic component has not been excluded
- Interpretation of results assumes one-zone SSC model
- See talk by M.M. Gonzalez on Friday



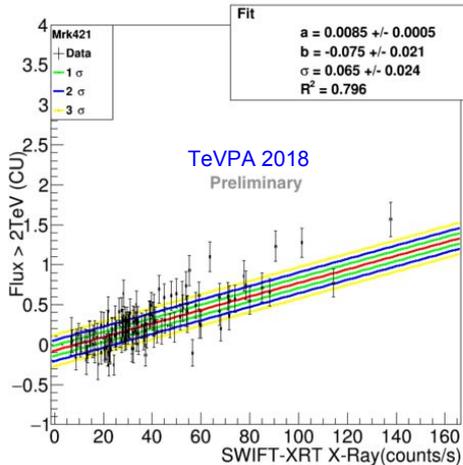
Mrk 421

Assuming one-zone SSC model

Unique correlation



HAWC data



Fit
 $a = 0.0085 \pm 0.0005$
 $b = -0.075 \pm 0.021$
 $\sigma = 0.065 \pm 0.024$
 $R^2 = 0.796$

see Nissim's talk on Wednesday

Conclusions and perspectives

- The modeling of the SED for blazars using leptonic or hadronic models is still an open question
 - Several Multi-frequency campaigns have been performed without conclusive results so far
 - Correlation studies can help to better constrain the aforementioned models
- Mrk421 is a very important source of information
 - Close and bright
 - High variability
 - Focus of several multi-frequency campaigns
- Unbiased monitoring
 - HAWC, FACT (see M.M. Gonzalez talk on Friday and J.A. García-González talk on Wednesday)
- So far there is evidence in favor of a leptonic model
 - One-zone SSC
 - Multi-zone SSC
- Linear correlation trend
 - Higher orders not completely studied/ruled-out
 - Hadronic components in gamma-rays not completely excluded in VHE emission