γ-ray/X-ray flux correlations in the BL Lac Mrk 421 using HAWC data

José Andrés García-González[(1)], Magda González[(2)], Nissim Fraija[(2)]

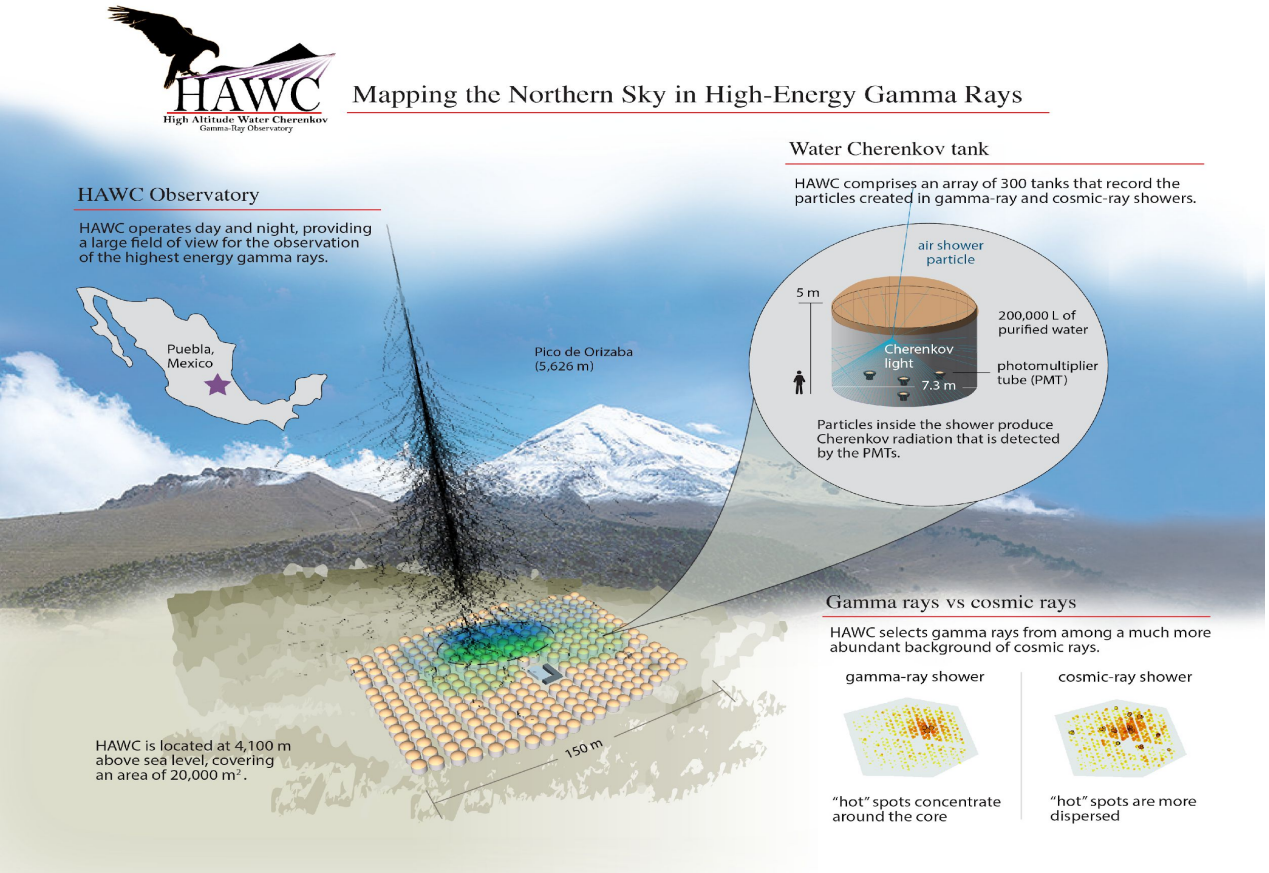
Instituto de Física, UNAM[(1)]

Instituto de Astronomía, UNAM[(2)]

Overview

- X-ray/γ-ray correlation in blazars
- Leptonic Vs Hadronic models
- Mrk 421
  - HAWC LC
- X-ray/γ-ray correlation for Mrk 421
  - data from 2014-11-26 to 2018-12-04
- Conclusions

HAWC



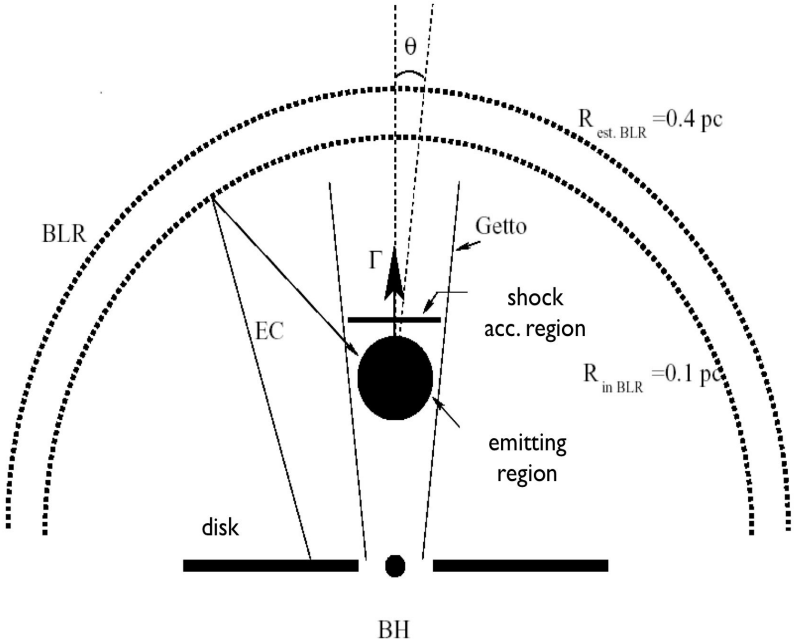
- HAWC operating since March 2015
- Sky Survey
- Instantaneous f.o.v. of 2sr
- Extended sources (>1-2˚)
- Sources of the highest energies (>10 TeV)
- Transient/variable sources
- Long term monitoring

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

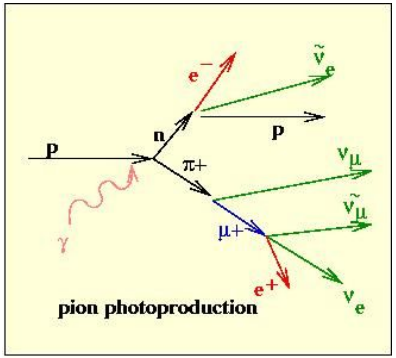
Leptonic Vs Hadronic models

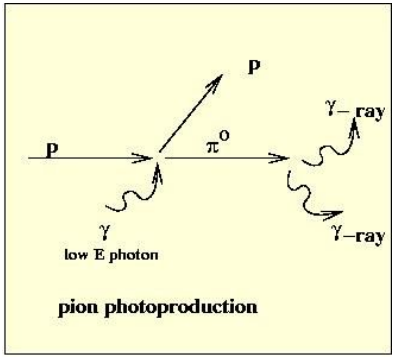
- Leptonic
  - High energy component of SED
    - Synchrotron self-compton
      - One-zone, multi-zone SSC model
    - External compton
      - Seed photons comes from accretion disk (UV) and reflects in the BLR (Sikora et al. 1994)
      - If radiation originates from a largest distance , seed photons might come from dusty torus (DT, (Sikora et al. 2002)



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





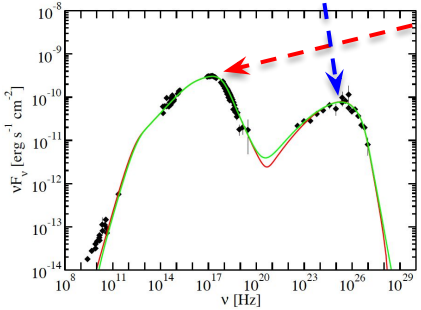
SHOPIA MC

Leptonic Vs Hadronic models

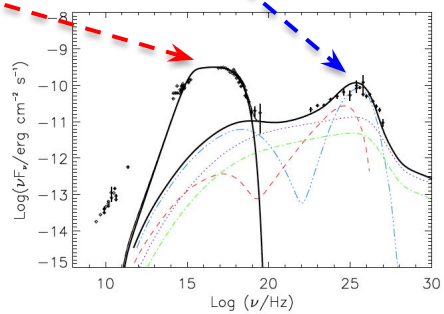
e^- Synchrotron radiation

Low-energy peak
(radio to optical/UV)

IC (SSC) model
High-energy peak



Synchrotron proton model
High-energy peak



Abdo et al. 2011

Jet power is larger for hadronic than for leptonic

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

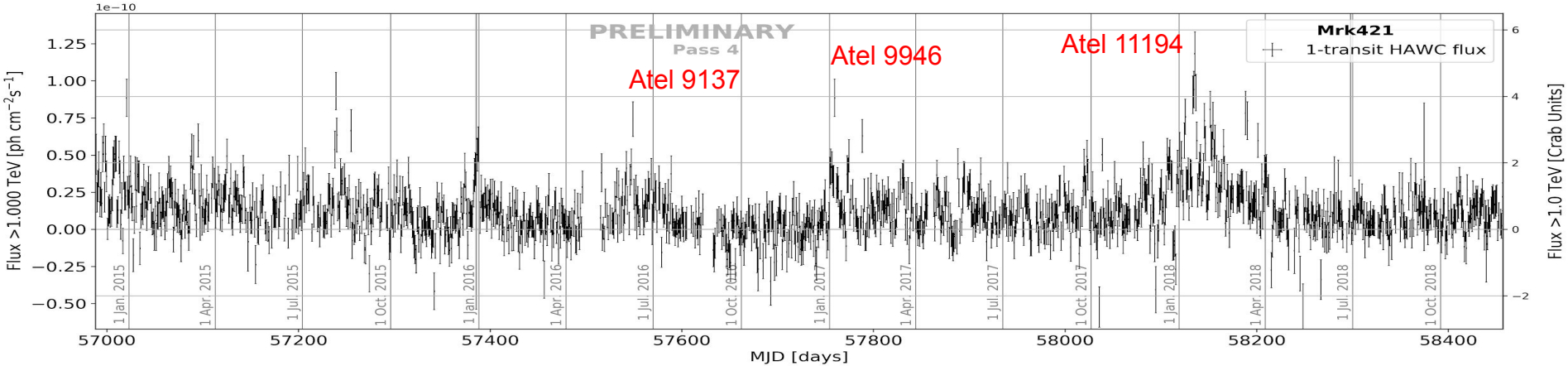
Correlation not straightforward
TeV gamma-ray and X-ray
Large magnetic field (50 Gauss)
Neutrino production

Mrk 421

- One of the closest (z = 0.03) and brightest blazars
- Emits at TeV energies
- Multiple dedicated observation campaigns
- Understanding correlation is very important
- Previous studies have shown evidence of positive correlation between X-ray and gamma-ray bands
  - (Katarzynski et al. 2003; Blazejowski et al. 2005; Revillot et al. 2006; Fossati et al. 2008; Horan et al. 2009, Acciari et al 2014; Aleksić et al. 2015, M. M. González et al 2019)
- There is evidence that supports leptonic models
  - One-zone
  - Multi-zone
- Other scenarios still being studied
  - Hadronic
  - Lepto-Hadronic

Mrk 421 LC using HAWC data

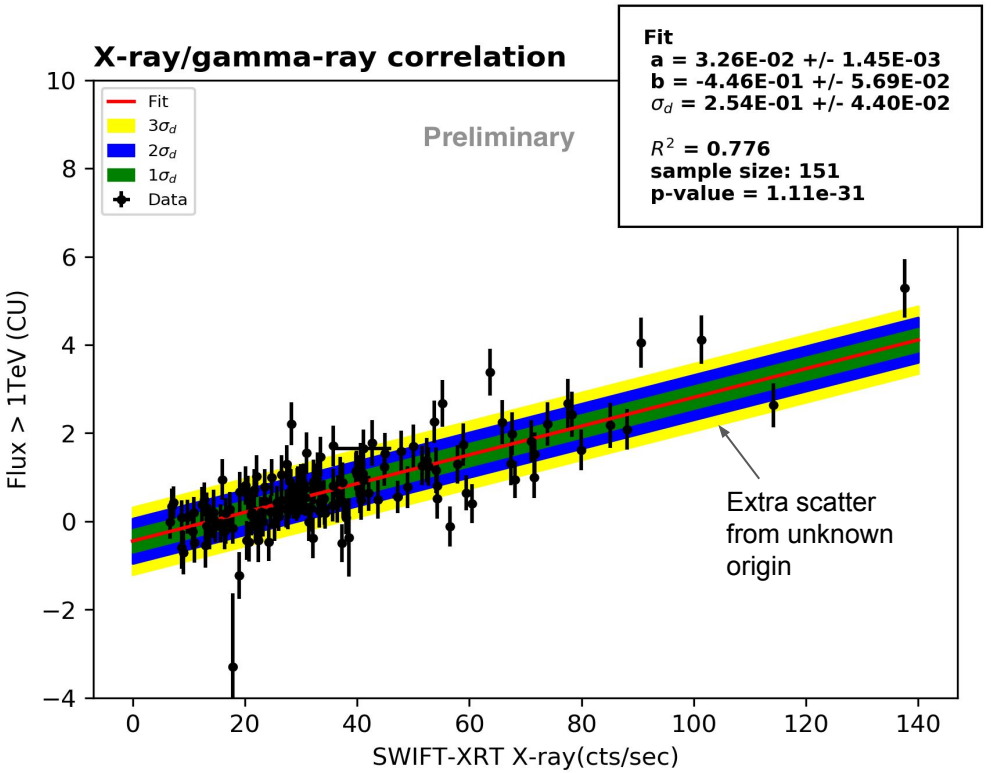
- Flux measured in 1 transit/sidereal day
  - Data from Nov, 2014 to Dec 2018
  - Including days with coverage > 50% transit
  - Source transit of ~ 6 hr will be used to average X-ray data from SWIFT-XRT



- Other works related with Mrk 421 data from HAWC
  - NU6h (Mukharbek)
  - #PS2-52 (Coutiño)

X-ray/γ-ray correlation

- X-ray averaged within HAWC transit of ~ 6hr
  - Quasi-simultaneous data
- Very strong linear correlation
  - Consistent with leptonic scenario
  - Shows linear trend
- Hadronic component has not been excluded
  - γ-ray flux uncertainty is large, hard to extract possible higher order correlation
- Interpretation of results assumes one-zone SSC model



X-ray data: **M.C. Stroh & A.D. Falcone 2013, ApJS, 207, 28**

Conclusions

- We measured a strong X-ray/γ-ray correlation for Mrk 421
  - Consistent with leptonic model
  - Consistent with linear correlation
- Higher order correlation
  - Hadronic components?
  - HAWC data has large uncertainties but we can further investigate
- Further studies
  - Bayesian Blocks
    - Variability
    - High activity states
      - Harder when brighter?