Modeling the non-flaring VHE emission from M87 as detected by the HAWC gamma ray observatory

Fernando Ureña-Mena [1]
Alberto Carramiñana [1]
Anna Lia Longinotti [2]
Daniel Rosa-González [1]
for the HAWC Collaboration

[1] Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE)

[2] Instituto de Astronomía, Universidad Nacional Autónoma de México (IA-UNAM)

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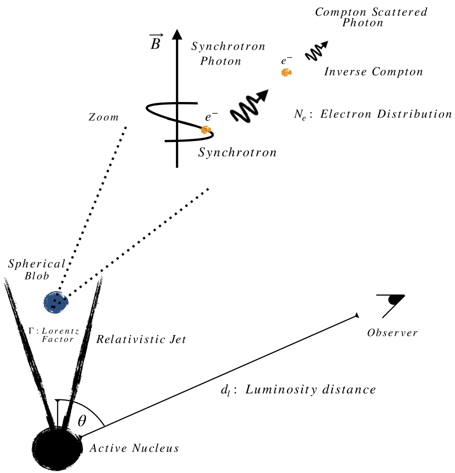
Contents

Outline

- M87 is a supergiant elliptical galaxy with an active nucleus (AGN), which is a well-established MeV, GeV and TeV gamma-ray source.
- The High Altitude Water Cherenkov (HAWC) gamma-ray observatory marginally detected this source at $E > 0.5$ TeV (Albert et al.,2021).
- The physical mechanism that produces this emission is not known, but it is commonly accepted that an one-zone synchrotron self Compton (SSC) scenario is not enough to explain this emission.
- This is supported by the evidence of a spectral turnover at energies of ~ 10 GeV (Ait Benkhali et al., 2018)
- We constructed a broadband spectral energy distribution (SED) of M87 using archive data. A lepto-hadronic model, which combines an SSC model presented by Finke et al., 2008 and photo-hadronic model presented by Sahu, 2019, was fitted to the SED.
- We obtained the best fit values for the model parameters.

Emission model: leptonic emission

- The model that we use postulates an electron population contained in a spherical region in the inner jet.
- The one-zone SSC (Finke et al., 2008) scenario explains the SED range from radio to X-rays as synchrotron emission produced by electrons moving in the magnetic field. A second energy component, from X-rays to gamma rays, is produced when electrons Compton scatter synchrotron photons.



SSC scenario: Fitting parameters

- The electron spectral distribution is given by:

$$N_e(\gamma') \propto \begin{cases} \gamma'^{-p_1} \text{ for } \gamma' < \gamma'_c \\ \gamma'^{-p_2} \text{ for } \gamma' > \gamma'_c \end{cases} , \quad (1)$$

from which we have three fitting parameters:

- p_1: low energy electron spectral index
- p_2; high energy electron spectral index
- γ'_c: break Lorentz factor

Other two model parameters are:

- B, the mean intensity of the randomly oriented magnetic field
- D, the Doppler factor of the emission zone.

Emission model: Photo-hadronic component

This scenario (Sahu, 2019) postulates that gamma-ray emission is produced in particle cascades generated by interaction between SSC photons and accelerated protons

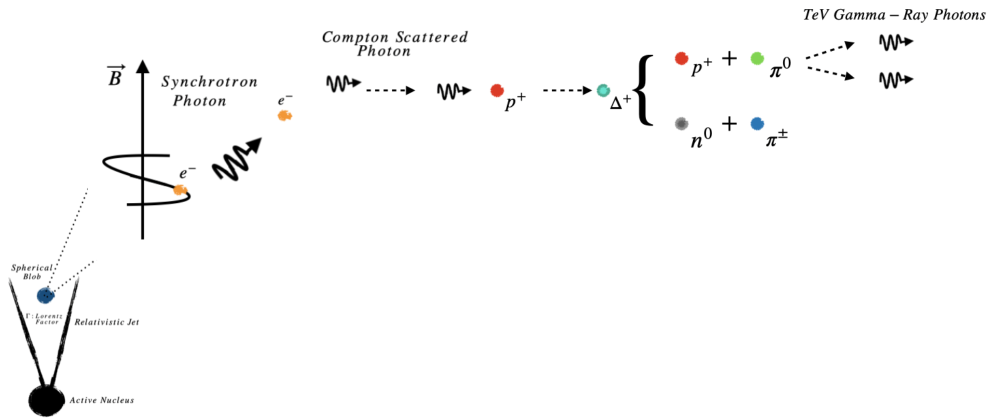


Photo-hadronic component: Fitting parameters

The proton spectral distribution is given by:

$$N_p(\gamma'_p) \propto \gamma'^{-\alpha}_p, \tag{2}$$

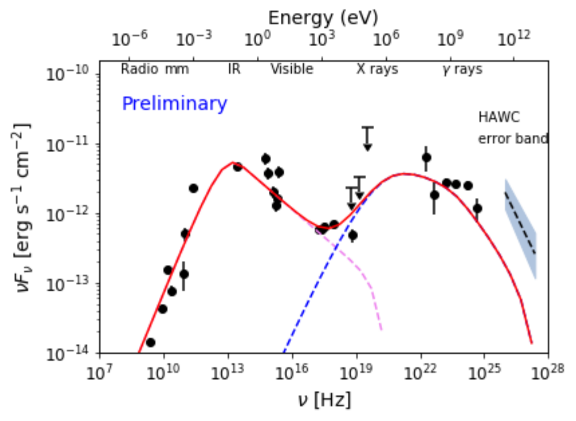
The fitting parameters are:

- the proton spectral index α
- a normalization constant $A_{p\gamma}$

Methodology

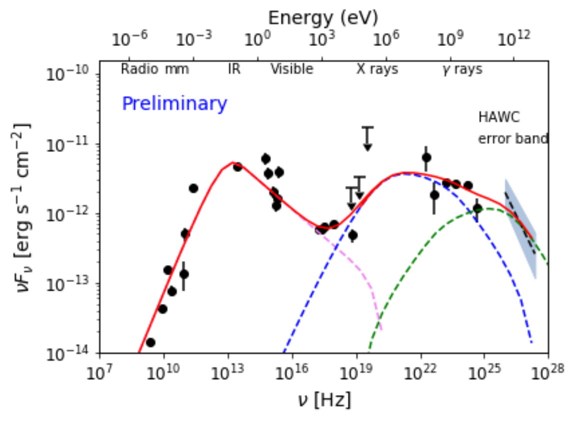
- The methodology consisted of developing a Python code to fit the emission model to the SED.
- The one-zone SSC model was fitted to the data between radio and MeV-GeV gamma rays.
- Then, the photo-hadronic component was added to fit the VHE emission.
- The best fit values of the model parameters were obtained with chi-square minimization and errors were estimated with Monte Carlo simulations.

Results: SSC fit (Preliminary)



SED of M87 with the best fit SSC model (Preliminary).

Results: lepto-hadronic fit (Preliminary)



SED of M87 with the photo-hadronic model fit for data from HAWC (Preliminary).

Best fit values for the fitting parameters

Parameter		Value
Magnetic Field intensity (mG)	B	46 ± 3
Doppler Factor	D	4.3 ± 0.2
Electron spectral parameters		
Broken PL index	p_1	$1.52^{+0.02}_{-0.01}$
Broken PL index	p_2	3.53 ± 0.02
Break Lorentz factor	γ'_c	3800^{+70}_{-50}
Photo-hadronic Component		
Proton spectral index	α	3.0 ± 0.2
Normalization	$\log(A_\gamma)$	-0.5 ± 0.2
χ^2_ν(d.o.f)		25.8 (22)

Best fit values for the model parameters with estimated errors

Summary and Conclusions

- M87 is a giant RDG that emits in gamma rays up to TeV bands
- The physical mechanism that produces the VHE emission has yet to be determined.
- In this work we fit a lepto-hadronic model to a SED which includes HAWC data.
- We conclude that this scenario could explain the M87 VHE emission,including some spectral features like a possible turnover at ~ 10 GeV