Long-term Variability of PKS 1510-089 in VHE γ-rays and Faint AGN sources

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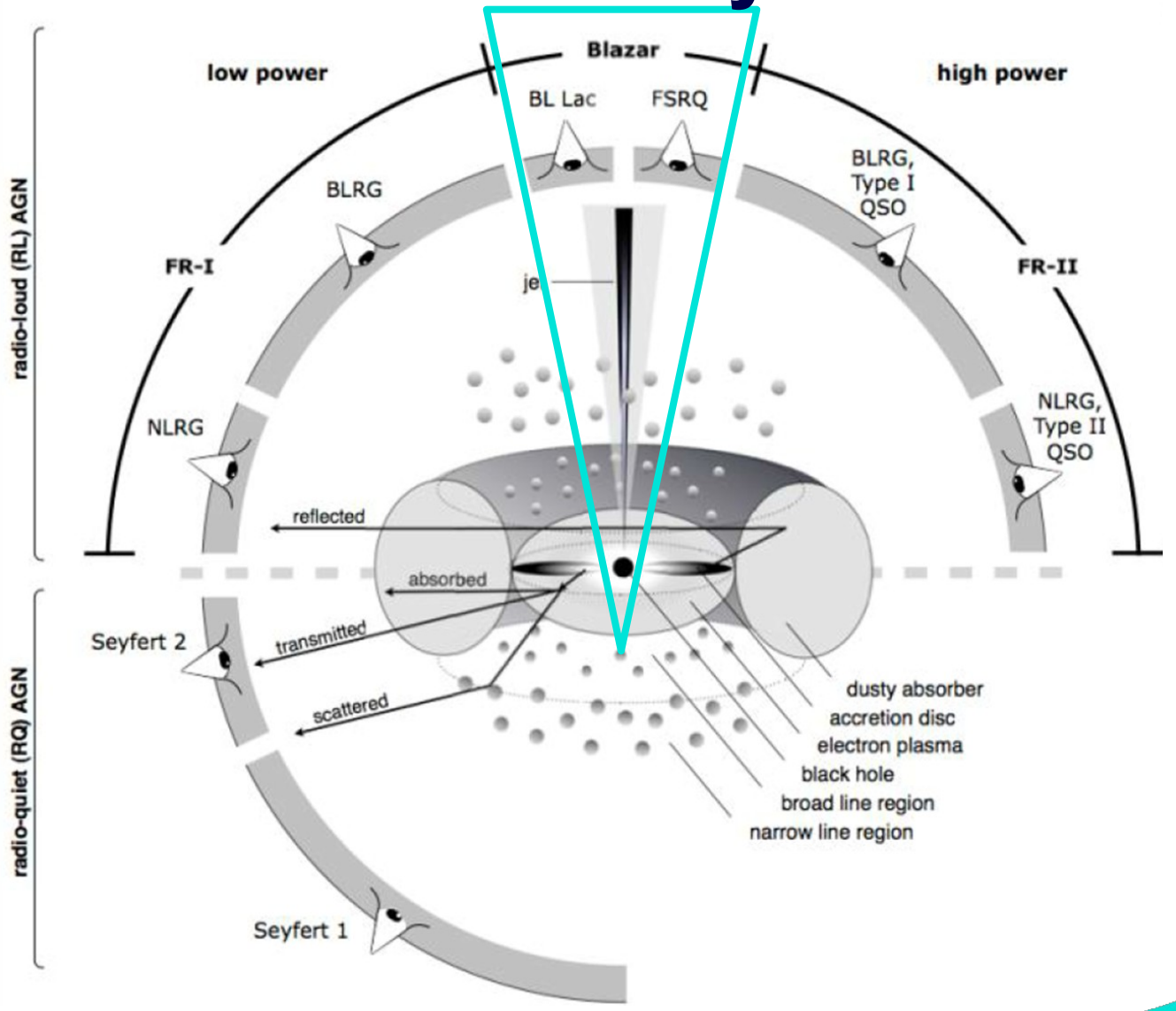
Active Galactic Nuclei: A very brief introduction

Radio Loud AGNs:

- Radio Galaxies
  - Narrow line(NLRG)
  - Broad line(BLRG)
- Blazars
  - BL Laceratae
  - **Flat Spectrum Radio Quasar(FSRQ)**

Radio Quiet Quasars

- Seyfert Galaxies
  - Type 1
  - Type 2



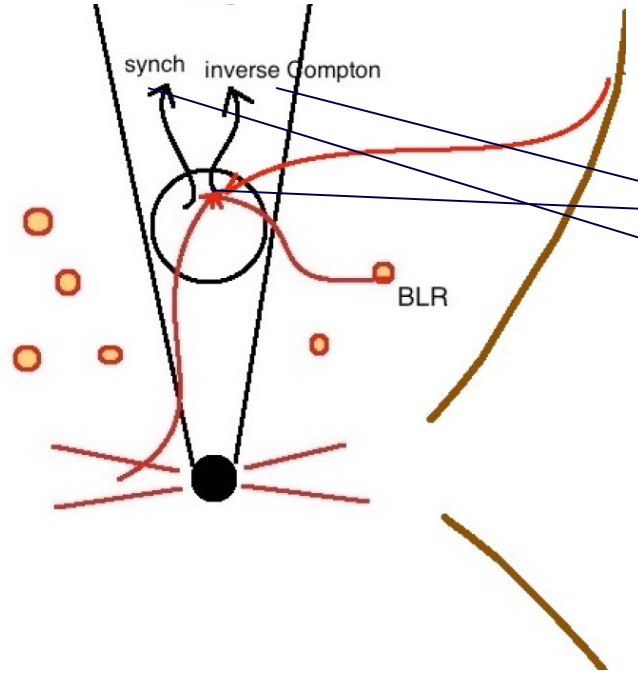
High powered jet with Broad Line region

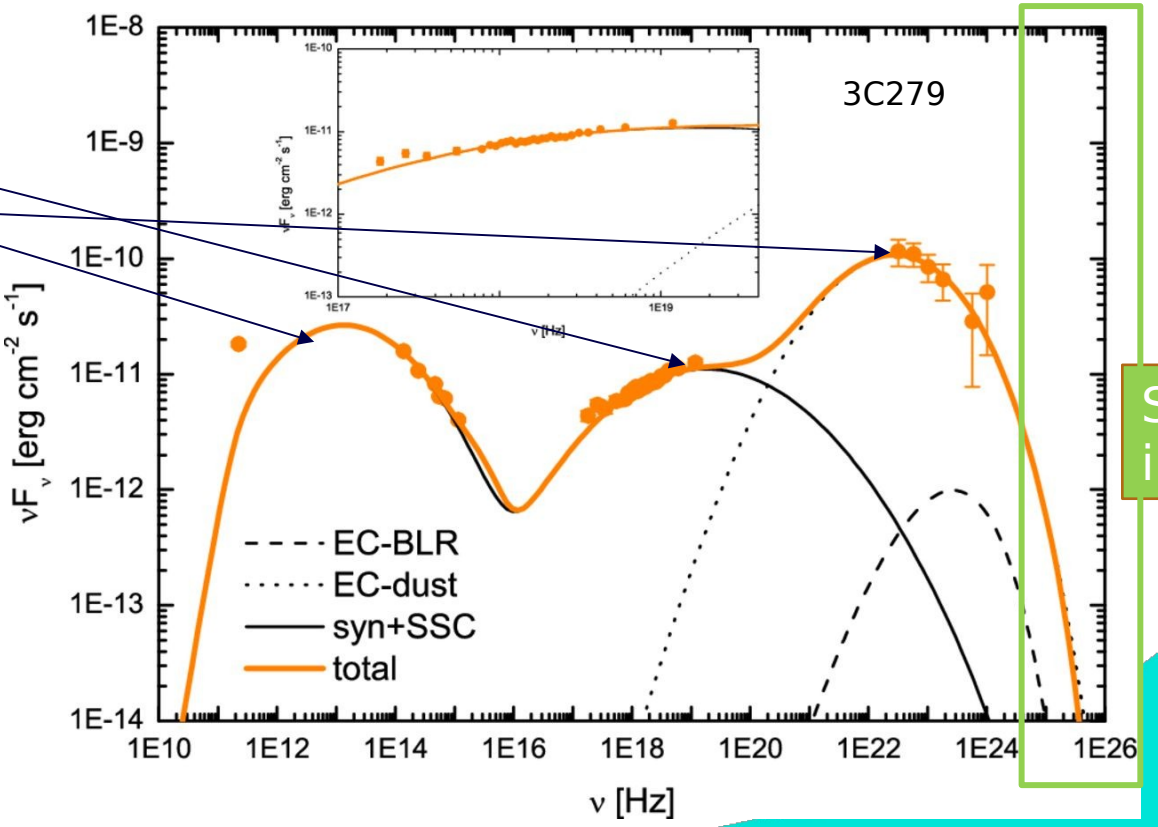
Schrader, C. & Beckmann, V. 2012, Active Galactic Nuclei (John Wiley and Sons, Inc.)

FSRQ

In the 1-zone leptonic scenario, one sees two bumps corresponding to **synchrotron emission** and **self comptonization.**

May also have an **External Inverse Compton component**.





Steep decline in VHE

http://galaxy.astro.uni.torun.pl/~kat/mfe501.html

Variability Studies

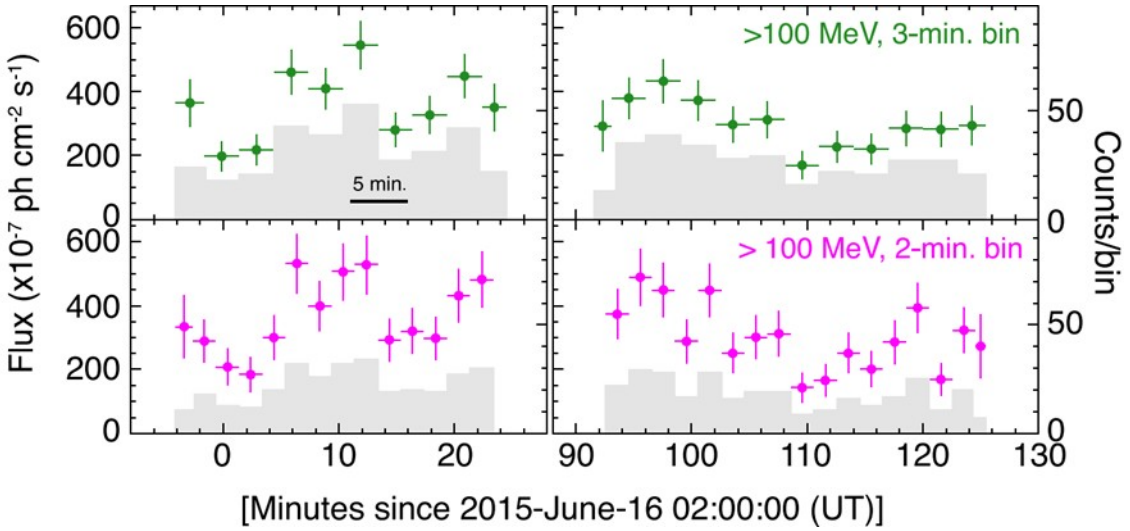
Flux Variability:

$t_{var} \propto R$: faster variability -> smaller emission region

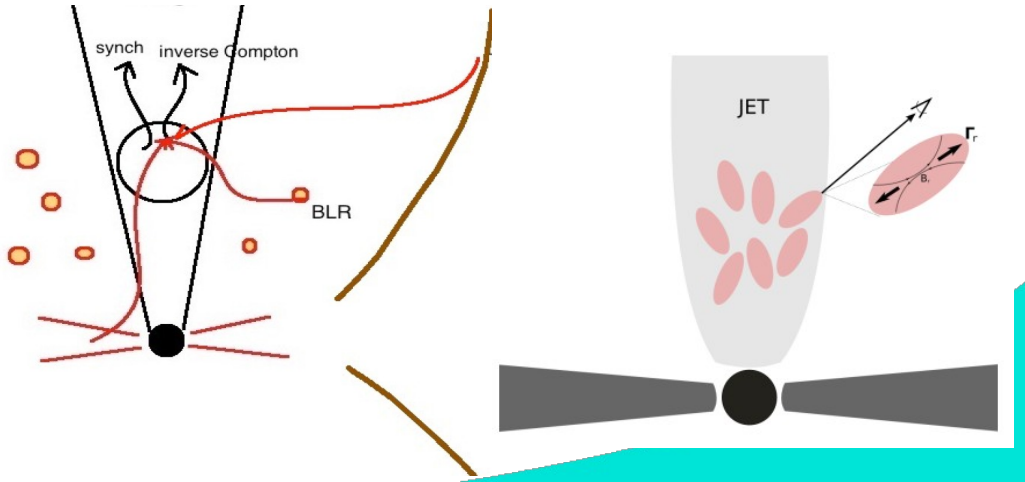
- Long term variability -> inherent low states?

Spectral Variability:

- Different Mechanisims?
- Harder when brighter



Ackermann et al., ApJ(2016)



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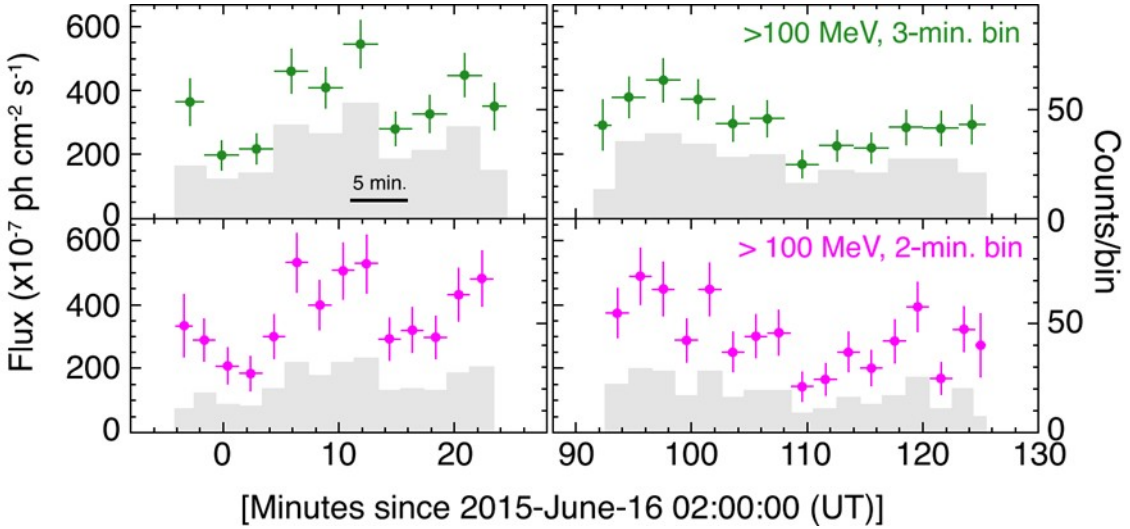

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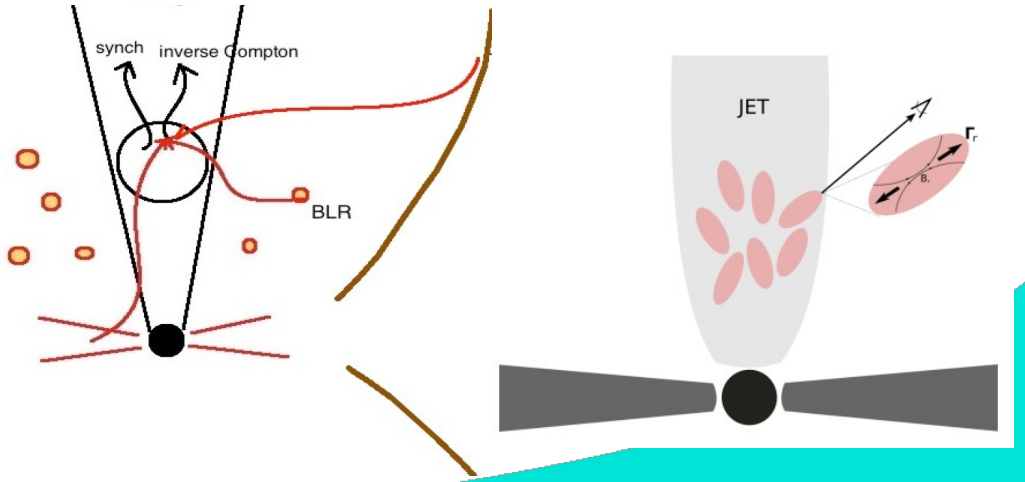


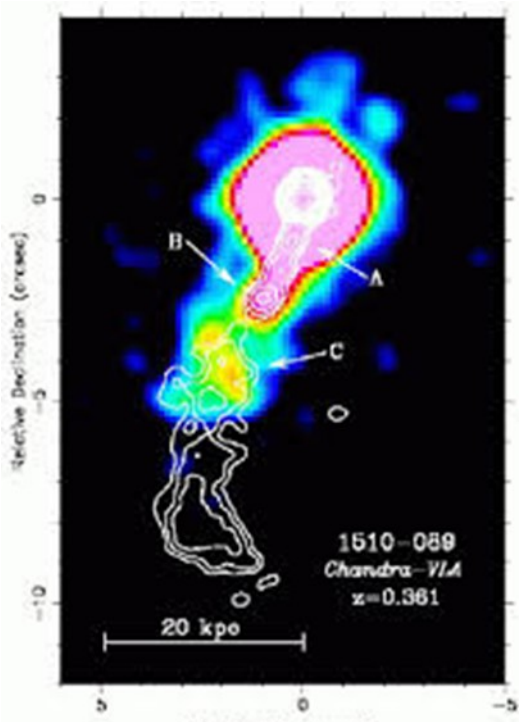
PKS 1510-089

Detected and shows variability at Radio, Near-IR, optical, UV, X-ray, and γ-ray

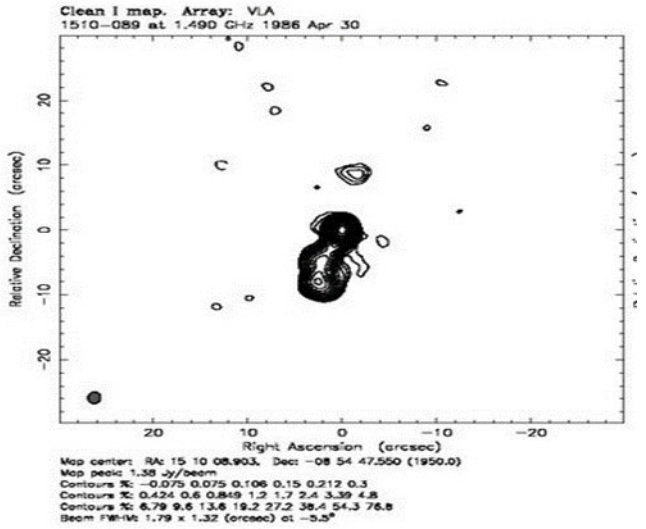
Redshift z = 0.36

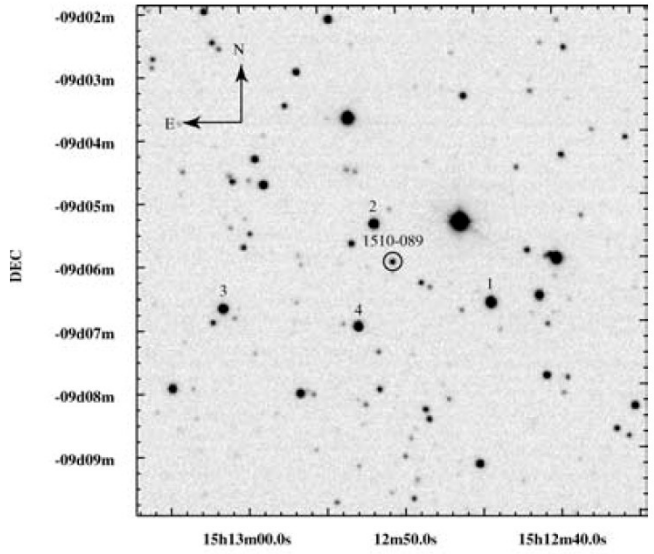
Optical Mag = ~16-17

Flat Spectrum Radio Quasar observed in low state by MAGIC(2018)



http://labx.iasfbo.inaf.it/2014/resources/PKS1510.pdf





Lister et al., 2018, ApJS, 232, 12

High Energy Spectroscopic System: H.E.S.S.

HESS-I (up to 2012)

- 4 telescopes: Ø 12 m,107 m^2
- Energy threshold :100 GeV
- FOV: 5°
- Angular resolution: <0.1°

HESS-II (2012-present)

- 4 telescopes: Ø 12 m,107 m^2
- Added telescope: Ø 28 m, 600 m^2
- Energy threshold: 30 GeV
- FOV: 3.5°
- Angular resolution: 0.4 ° -0.1°

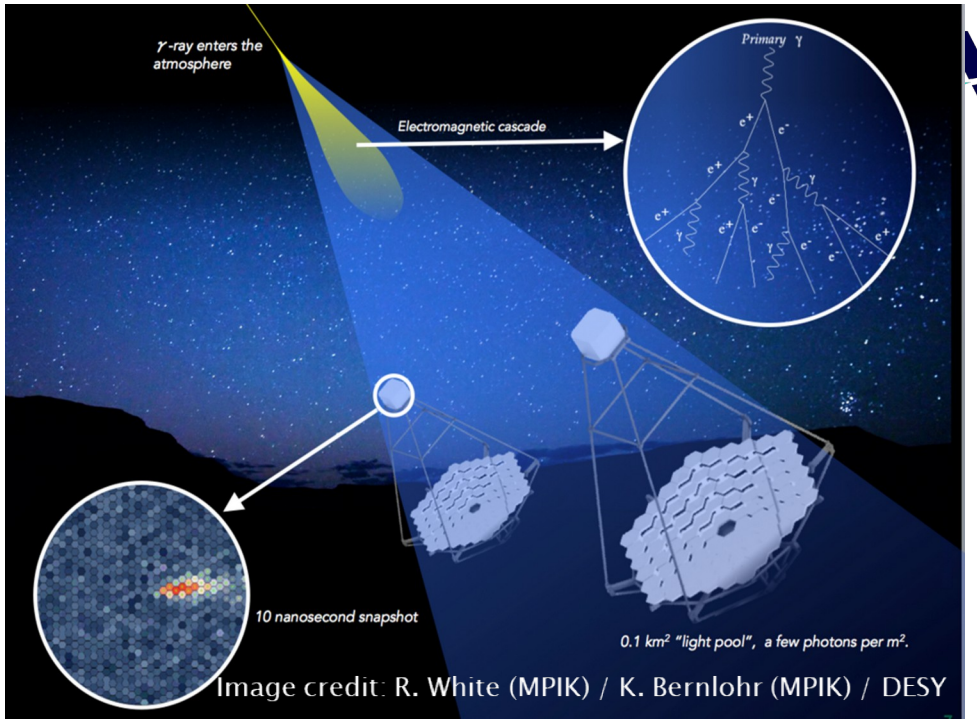
Shower Reconstruction

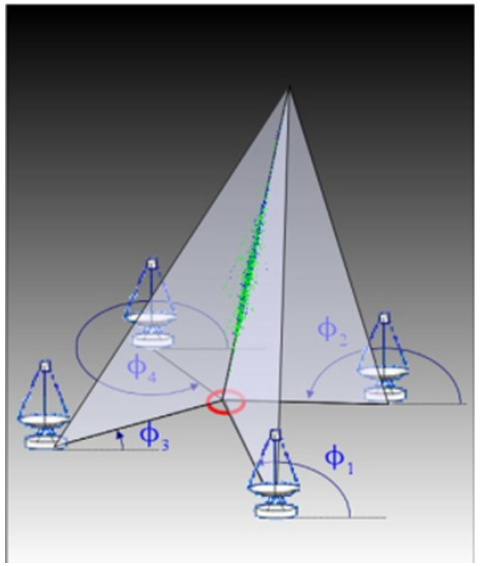
Directional stereoscopic reconstruction via images from multiple cameras

Image templates are generated using MC simulations for a given set of parameters and then the average is saved.

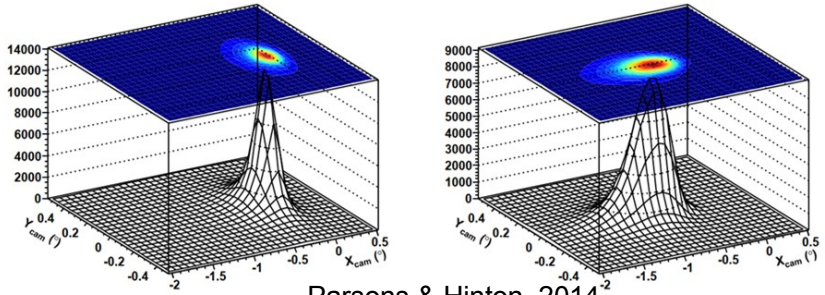
Likelihood fit to the image template per pixel

Event likelihood goodness minimized in a fit over shower maximum, primary energy, direction, impact point.

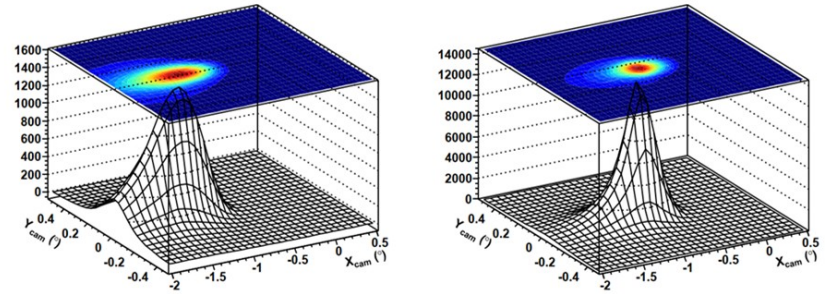




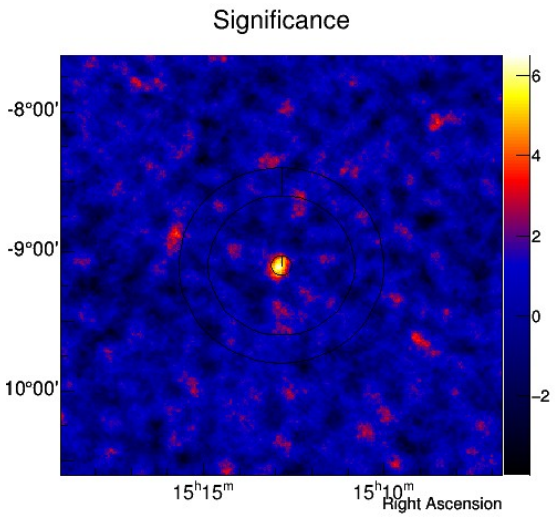
deNaurois+ 2015 C.R. Phys. 16 610



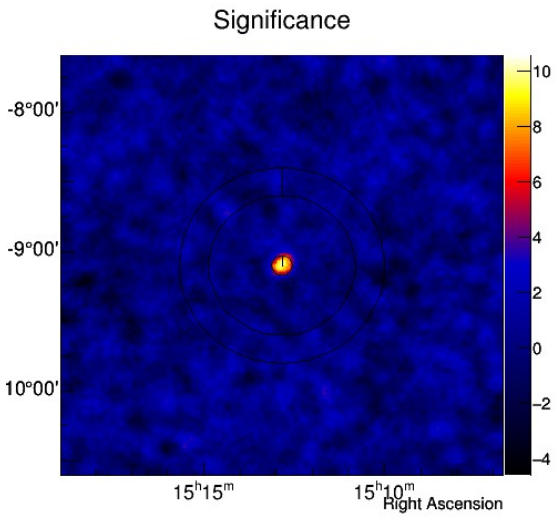
Parsons & Hinton, 2014



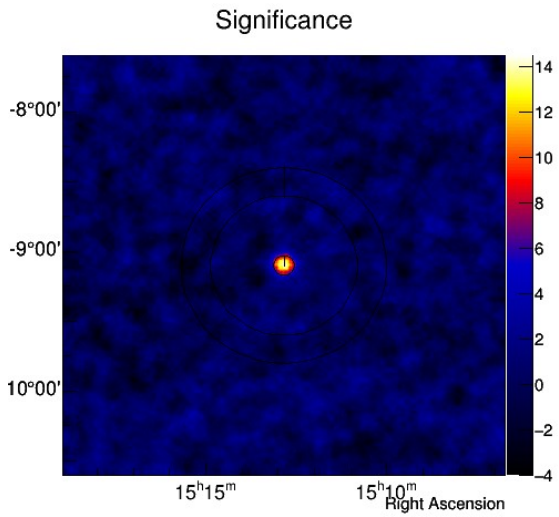
PKS 1510-089 in VHE gamma rays



HESS-I



HESS-II



HESS-IU

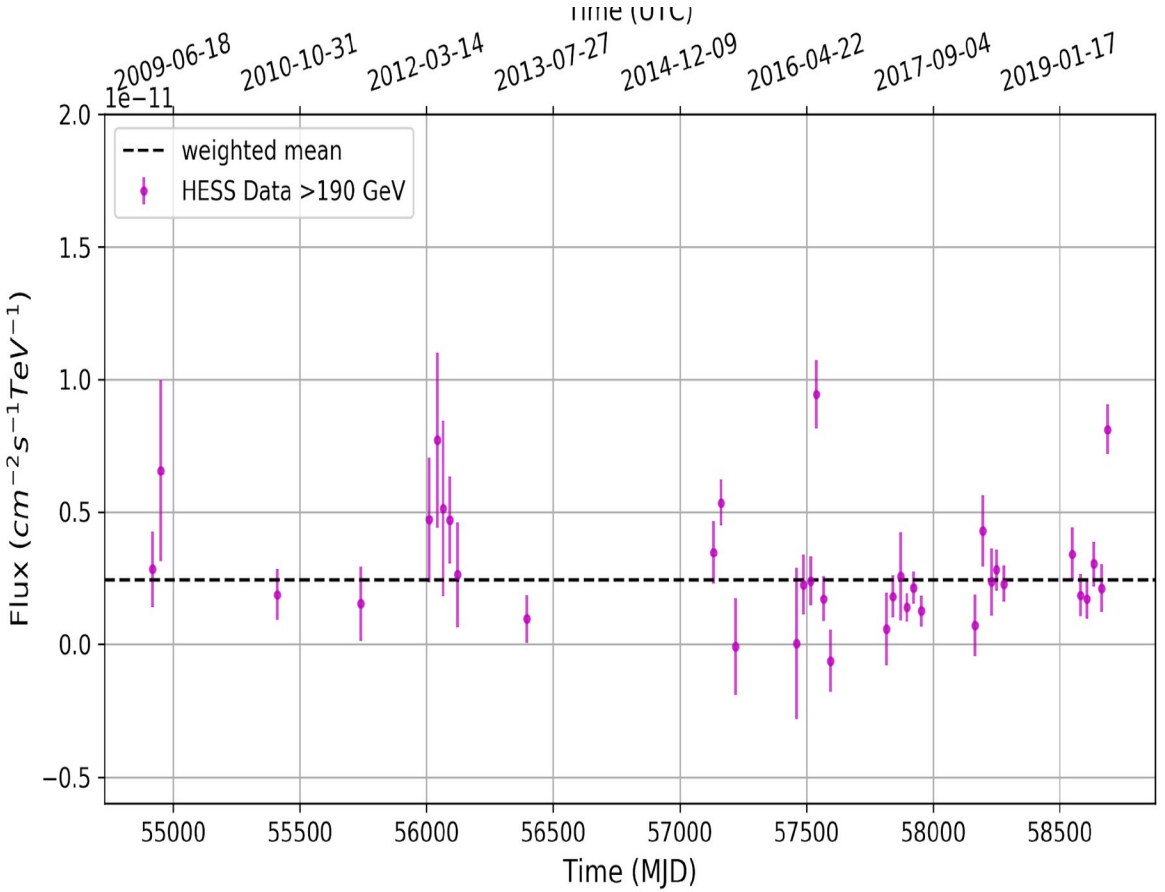
Dataset	Runs	date start $dd/mm/yyyy$	date stop $dd/mm/yyyy$	Livetime hr	N_{On}	N_{Off}	Alpha	Significance σ
HESS - I	81	22/03/2009	18/07/2012	34	370	12010	0.021	6.56
HESS - II	225	06/04/2013	27/06/2016	94.4	877	27358	0.021	11.11
HESS - IU	324	25/02/2017	30/07/2019	142.1	2875	99017	0.021	15.84

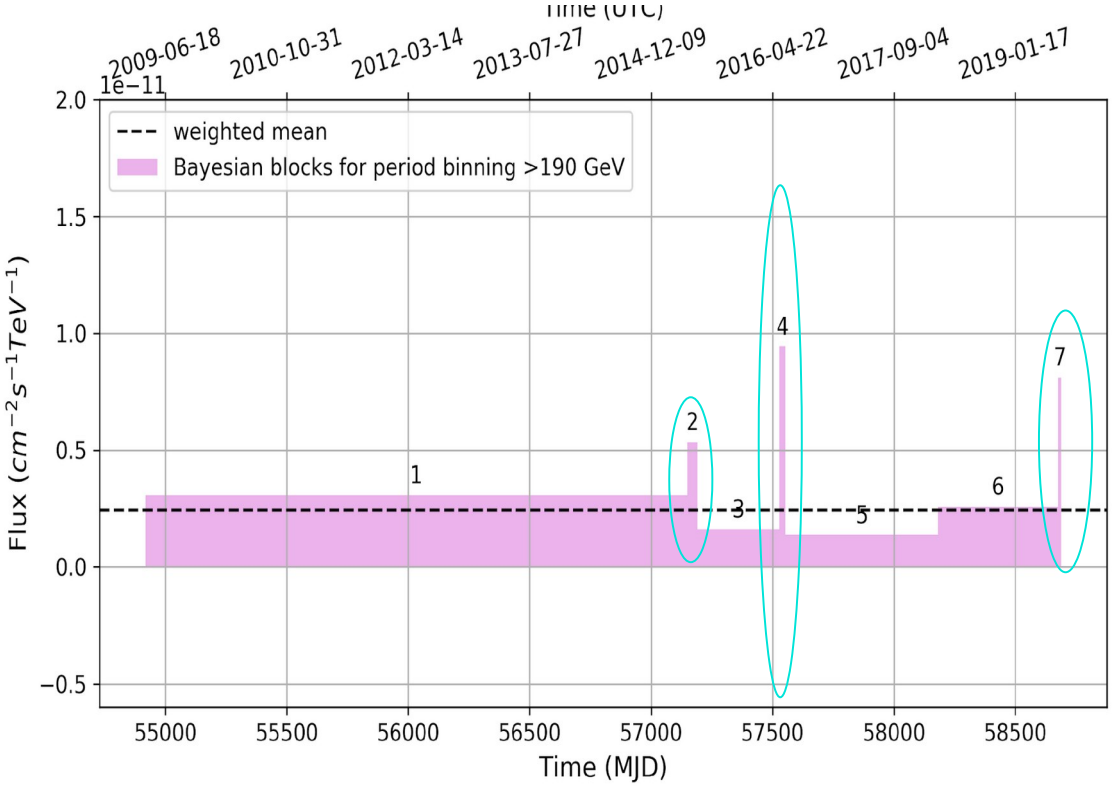
Light-curve (monthly) 2009-2019

Spectral index = 4.2

Fux mean= (2.44 +/- 0.16) x 10^{-12} cm^{-2} s^{-1} TeV^{-1}

X^2/v = 2.3 , constant flux fit excluded by 4σ





MAGIC 2015

HESS 2017, 2021

HESS *atel 2019

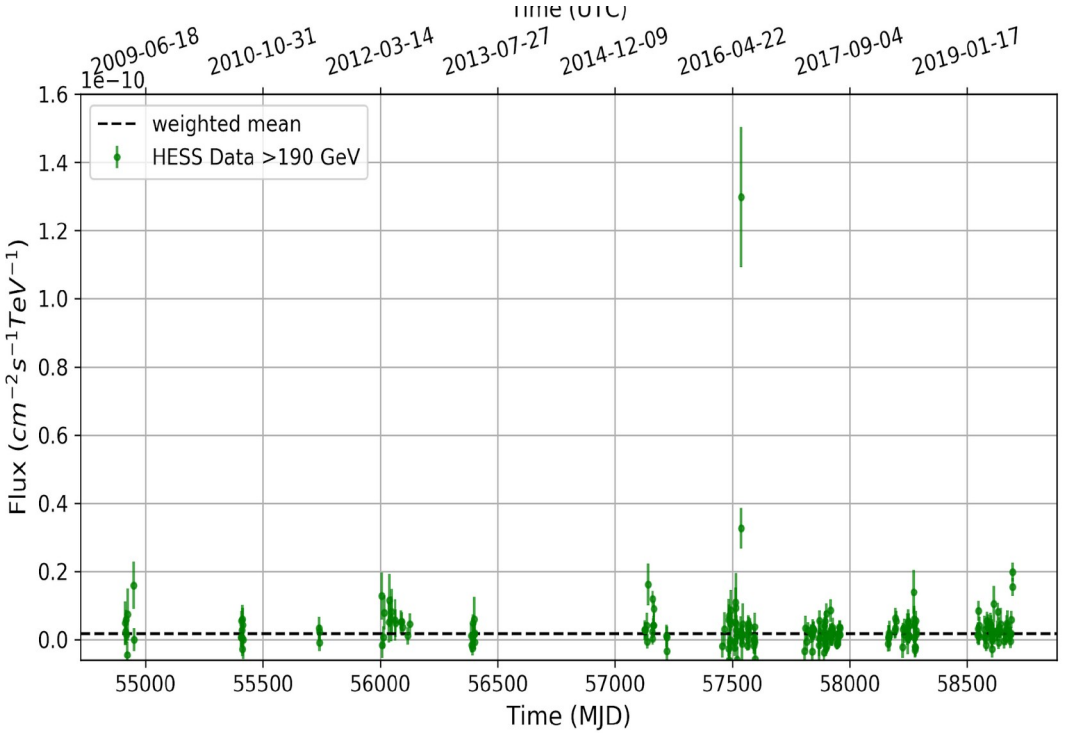
Light-curve(Night)

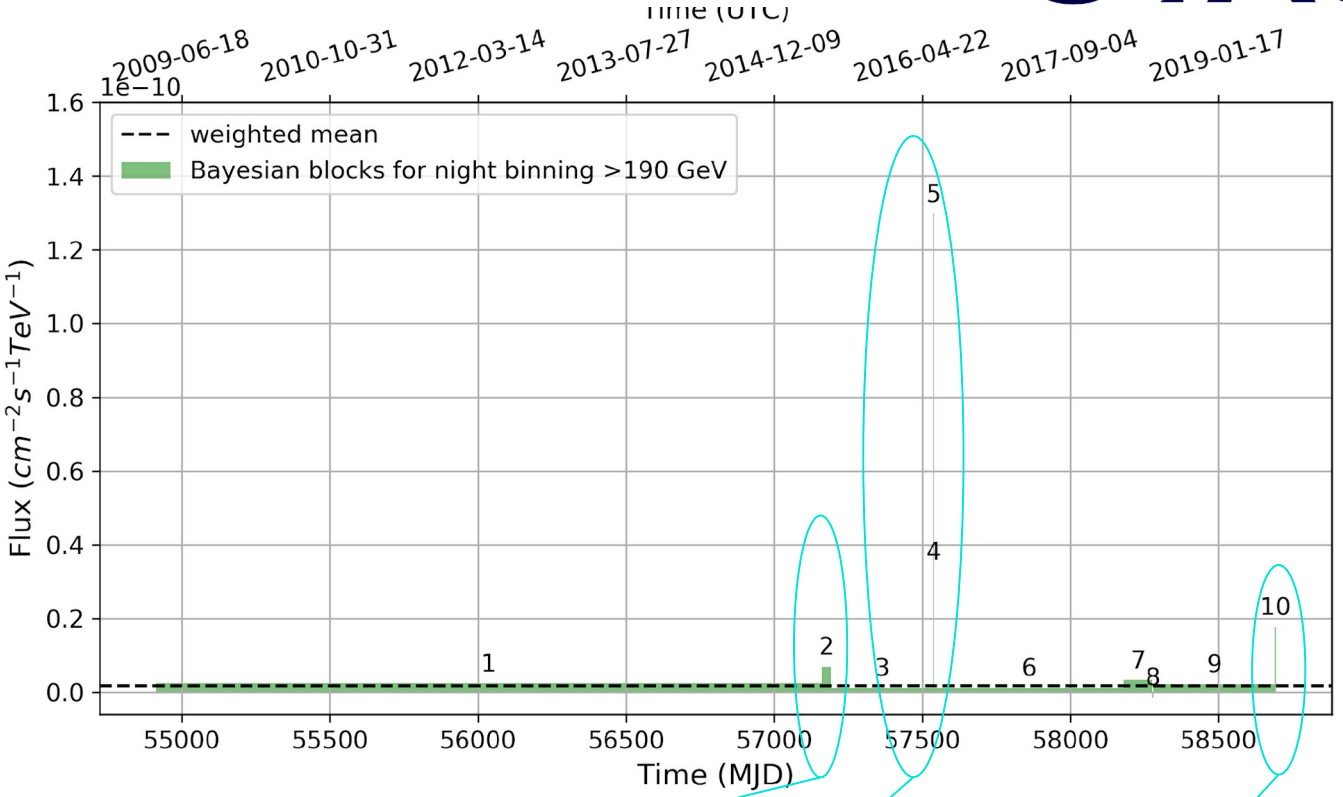
Spectral index = 4.2

Weighted mean = (1.78 +/- 0.16) x 10^{-12} cm^{-2} s^{-1} TeV^{-1}

X^2/v = 1.58,constant flux fit excluded by 6σ

Fractional variability = 1.8 +/- 0.1





MAGIC 2015

HESS 2017, 2021

HESS *atel 2019

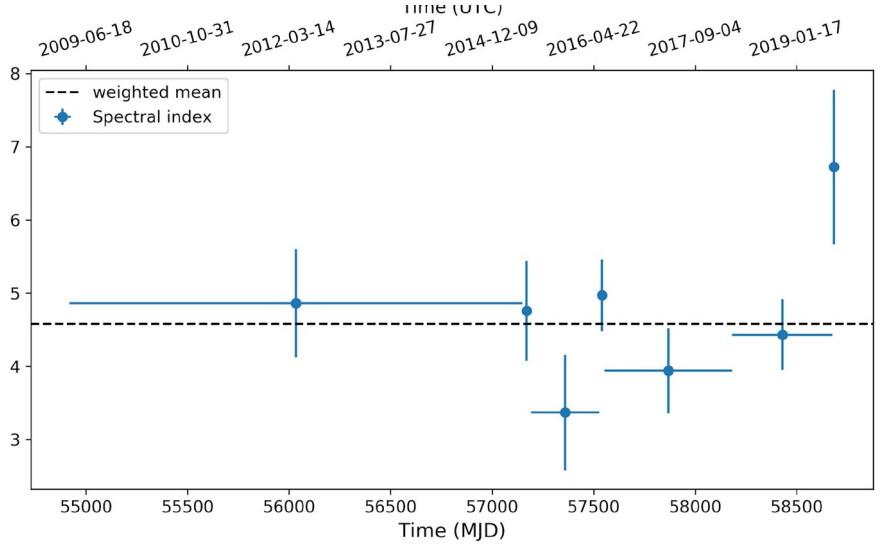
Spectral analysis

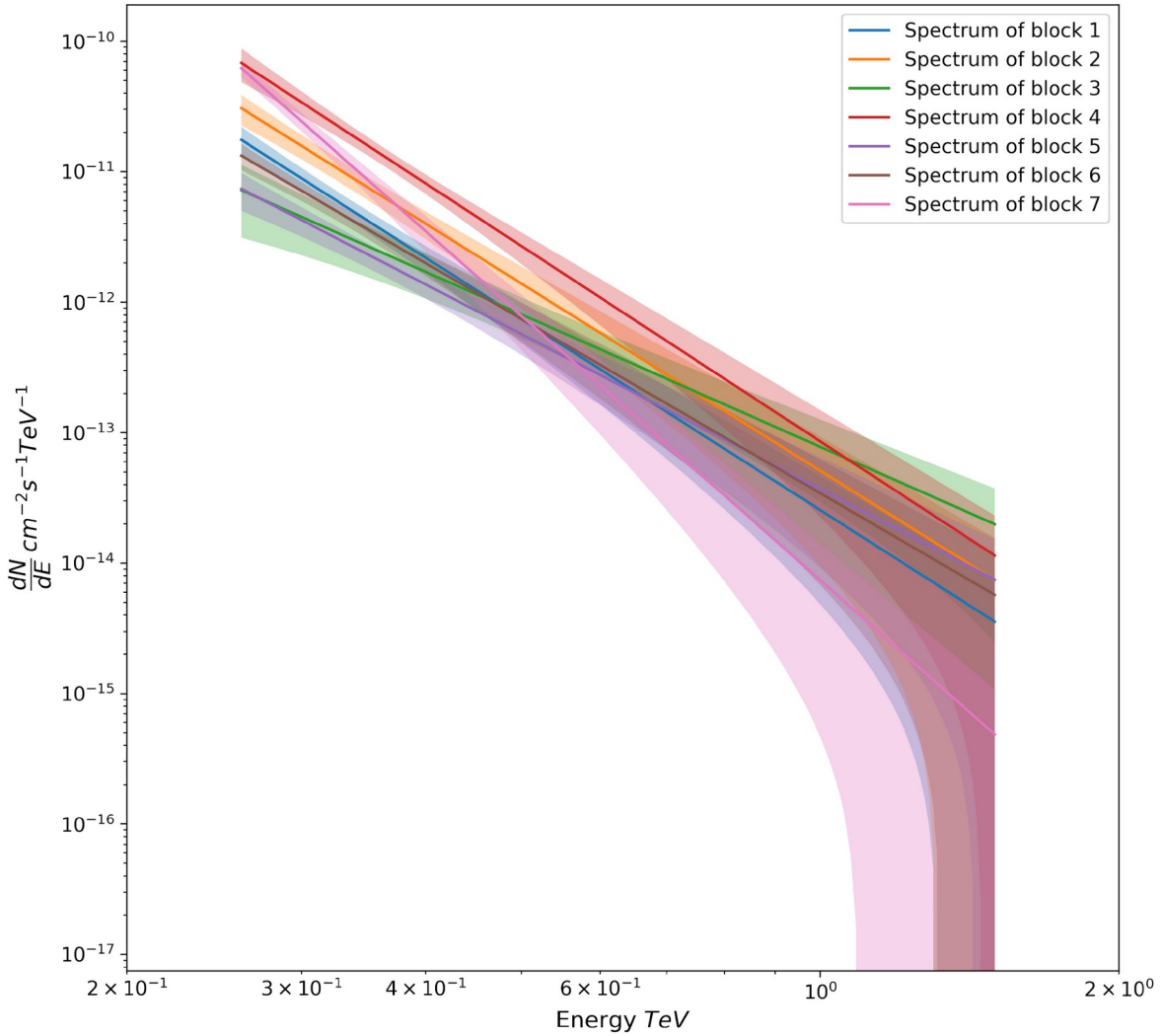
Spectrum for 0.26 TeV- 1.5 TeV

Spectral index = 4.58±0.24

$X^2/v = 0.75$

No Spectral variability





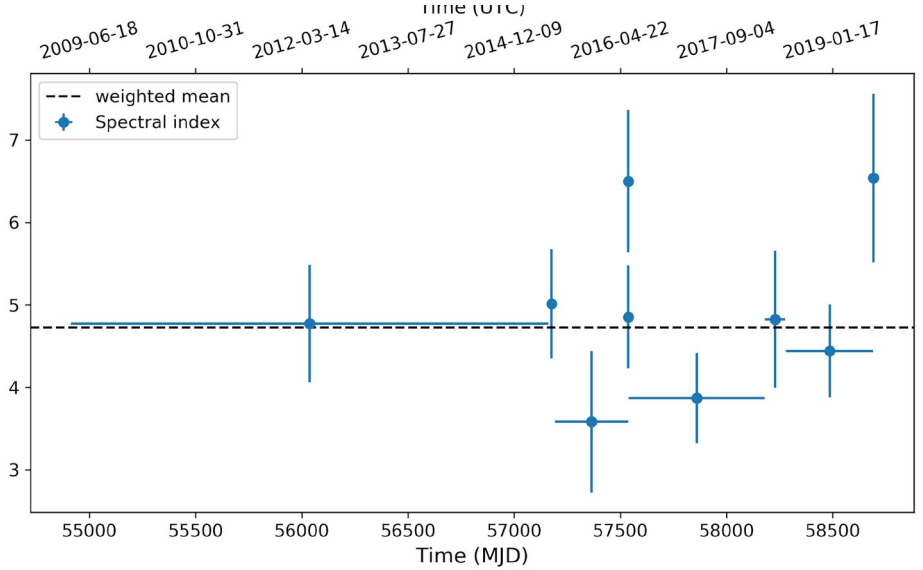
Spectral analysis

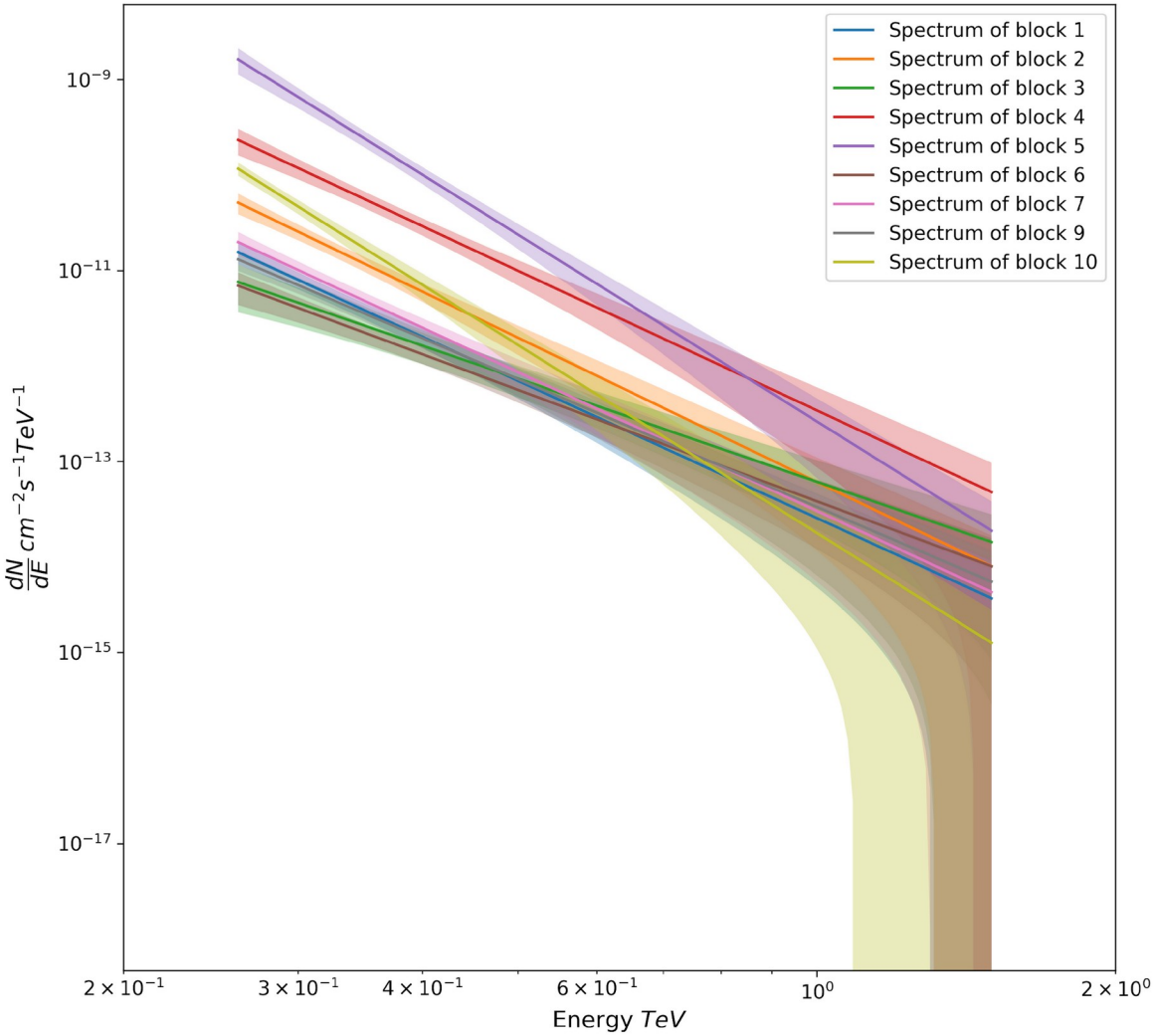
Spectrum for 0.26 TeV- 1.5 TeV

index = (4.73+/- 0.23)

$X^2/v = 1.12$

No Spectral variability





Summary and Outlook (1st part)

Analysed H.E.S.S. data from 2009-2019

Flux Variability: Monthly: 7 flux states , Nightly: 10 flux states

Low flux state ~ $(1.70 \pm 0.23) \times 10^{-12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

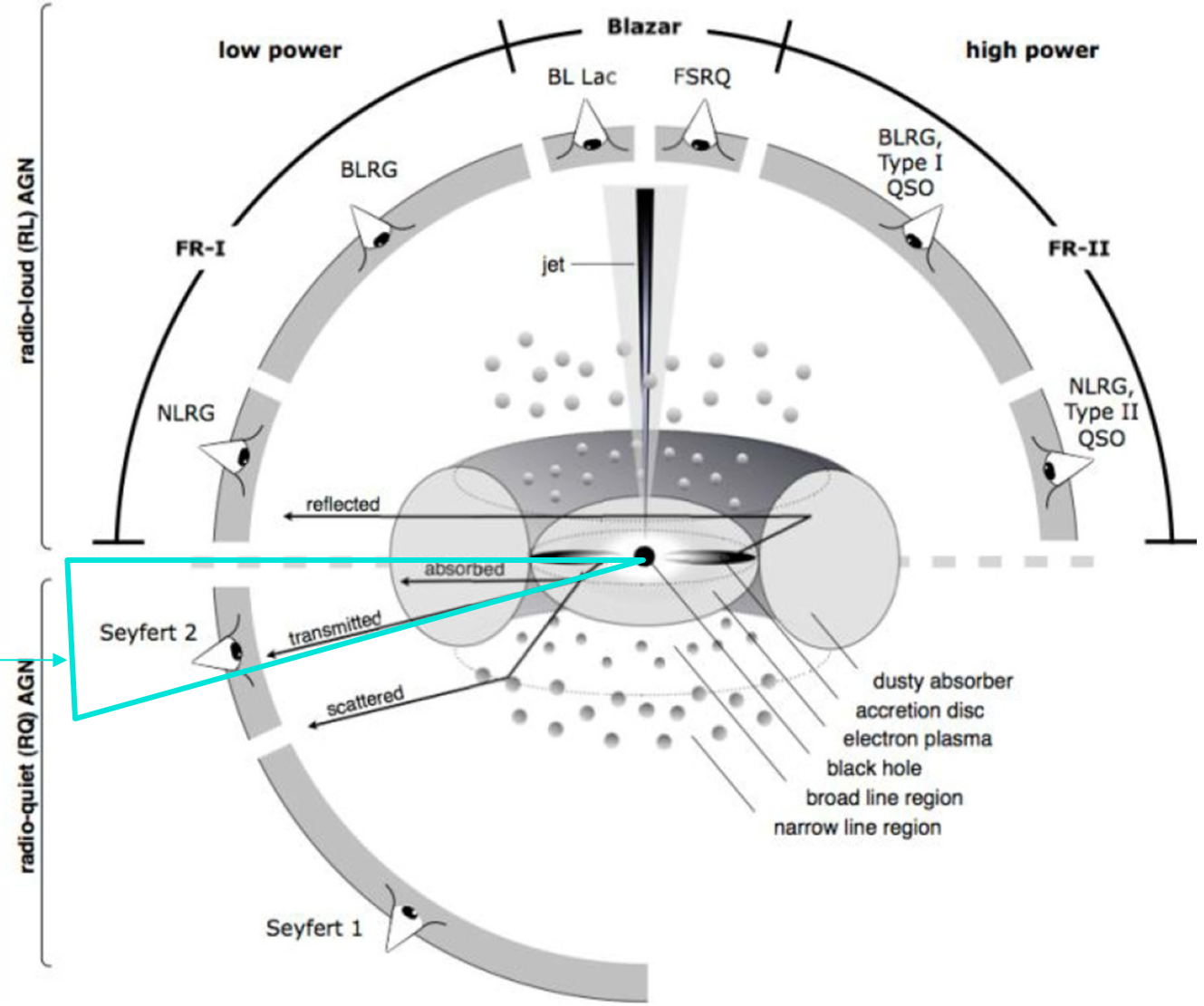
No spectral variability found within the time blocks associated with the nightly or period-wise binned data

Contemporaneous multiwavelength data studies will help shed more light on the emission regions and Compton processes in the jet of PKS 1510-089

The FUTURE : Multimessenger Synergies

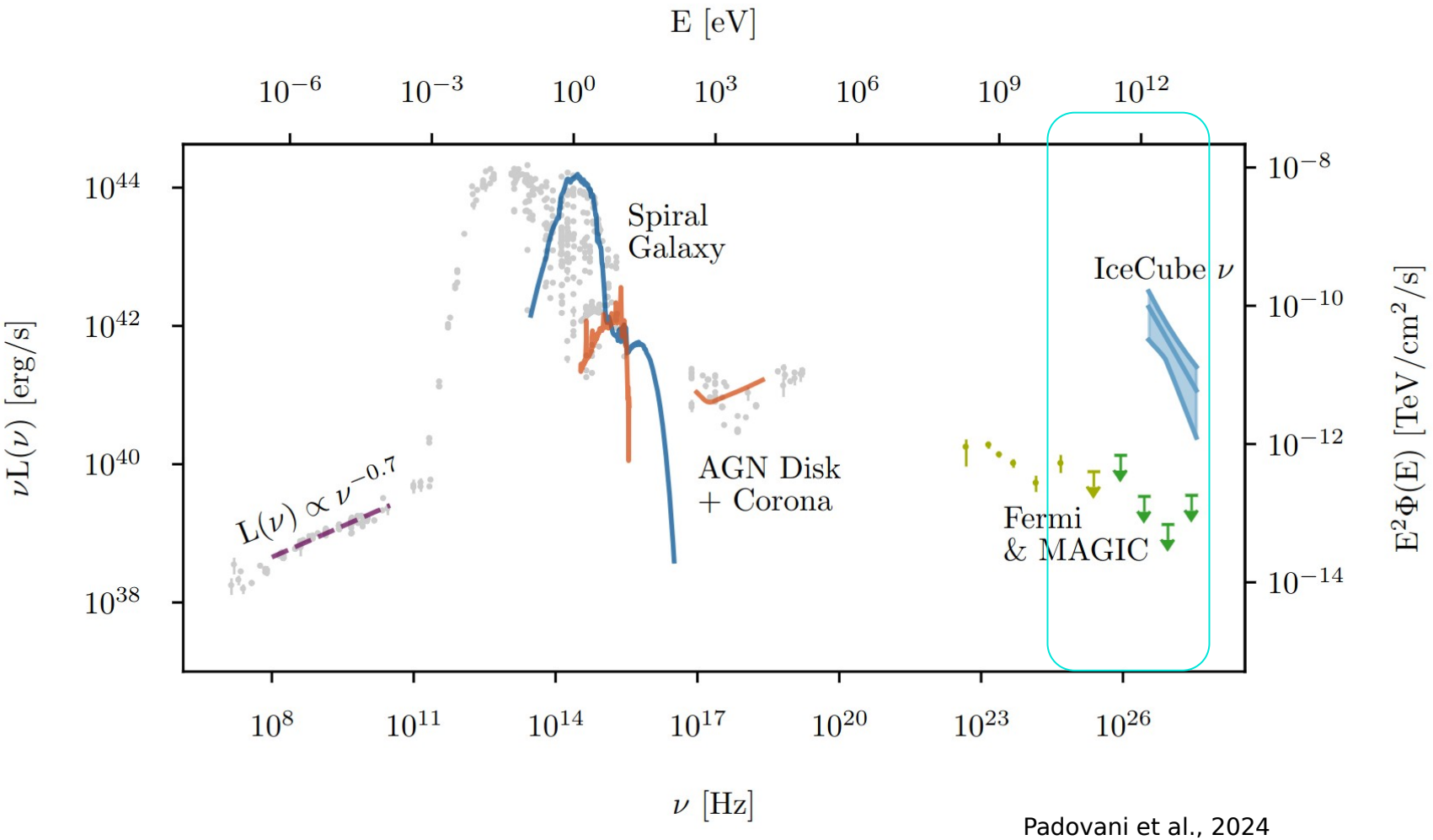
Possible IceCube neutrino sources :
TXS 0506

Possible IceCube neutrino sources :
NGC 1068



Schrader, C. & Beckmann, V. 2012, Active Galactic Nuclei (John Wiley and Sons, Inc.)

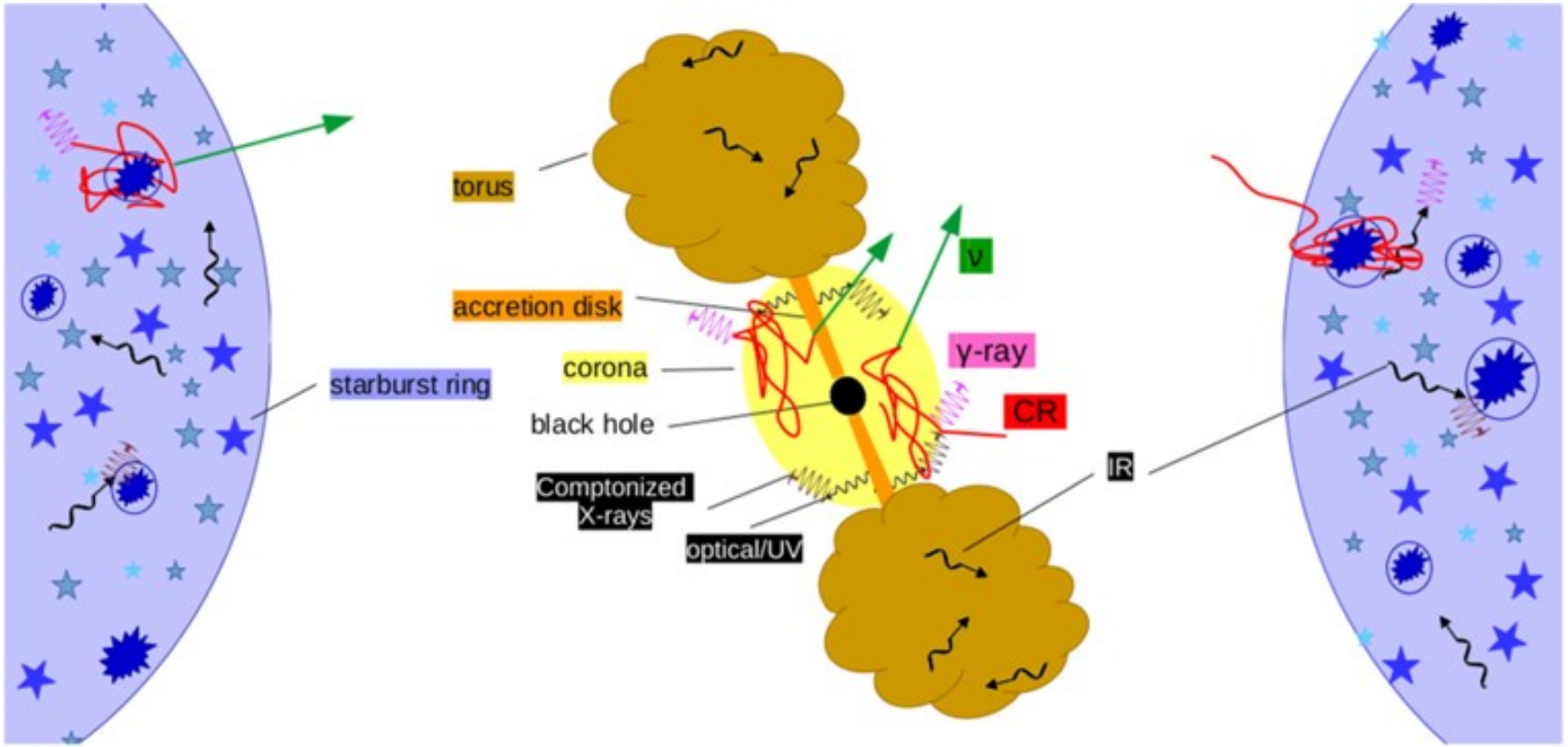
Multimessenger Spectral Energy Distribution



Padovani et al., 2024

Neutrinos produced at a site opaque to VHE gamma rays

Seyferts and composites

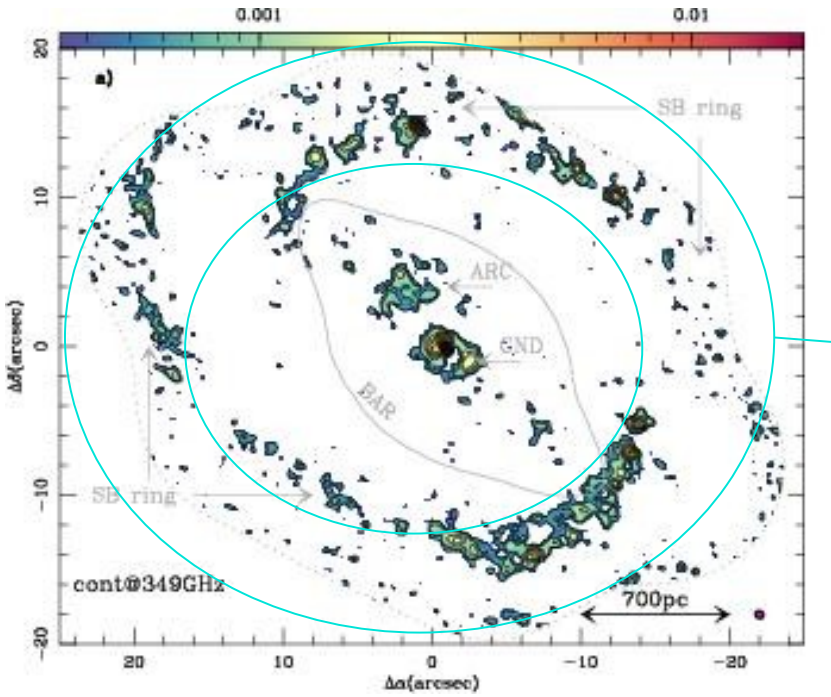


Eichmann et al., 2022

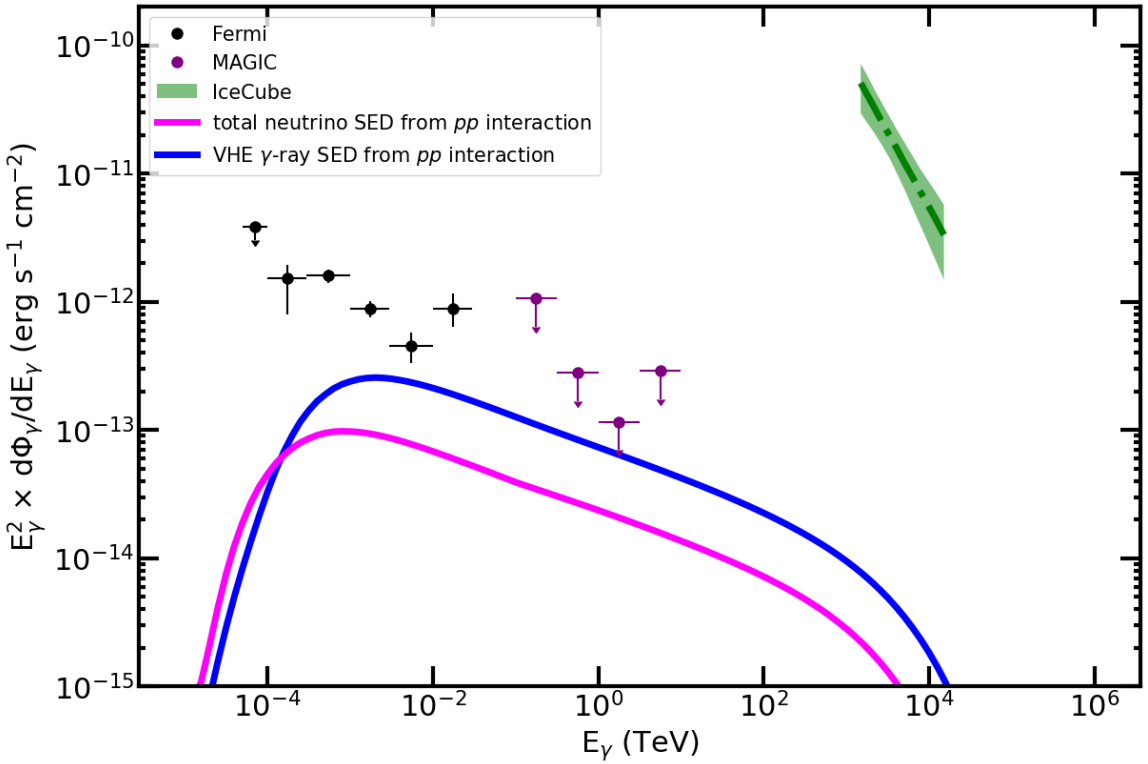
Possible sites of gamma ray and neutrino production:

Star Forming regions: high rates of star formation -> high SN rate
AGN driven winds: Wide angle winds with sub-relativistic speeds
AGN corona: Hot plasma ~ $10^{8\text{-}9}$ K

A preliminary starburst model



Garcia-Burillo et al., 2014



SB model : E. Peretti 2019
SB geometry: Garcia-Burillo 2014

Can not reproduce the neutrino spectrum