MAGIC

Major Atmospheric Gamma Imaging Cerenkov Telescopes

3-year low-state at very high energies of the blazar 1ES1959+650: the broadband SED analysis

Cristina Nanci

and Cosimo Nigro, Cornelia Arcaro, Elisa Prandini, Daniela Dorner, Roberta Zanin, Axel Arbet-Engels, Mireia Nievas Rosillo, Filippo D'Ammando, Ettore Bronzini, Shunsuke Sakurai on behalf of the MAGIC Collaboration
with the contribution of the OVRO Collaboration and TELAMON Collaboration

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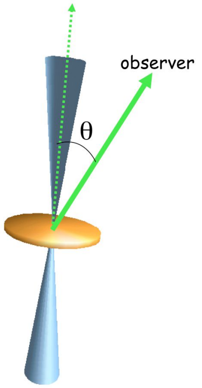
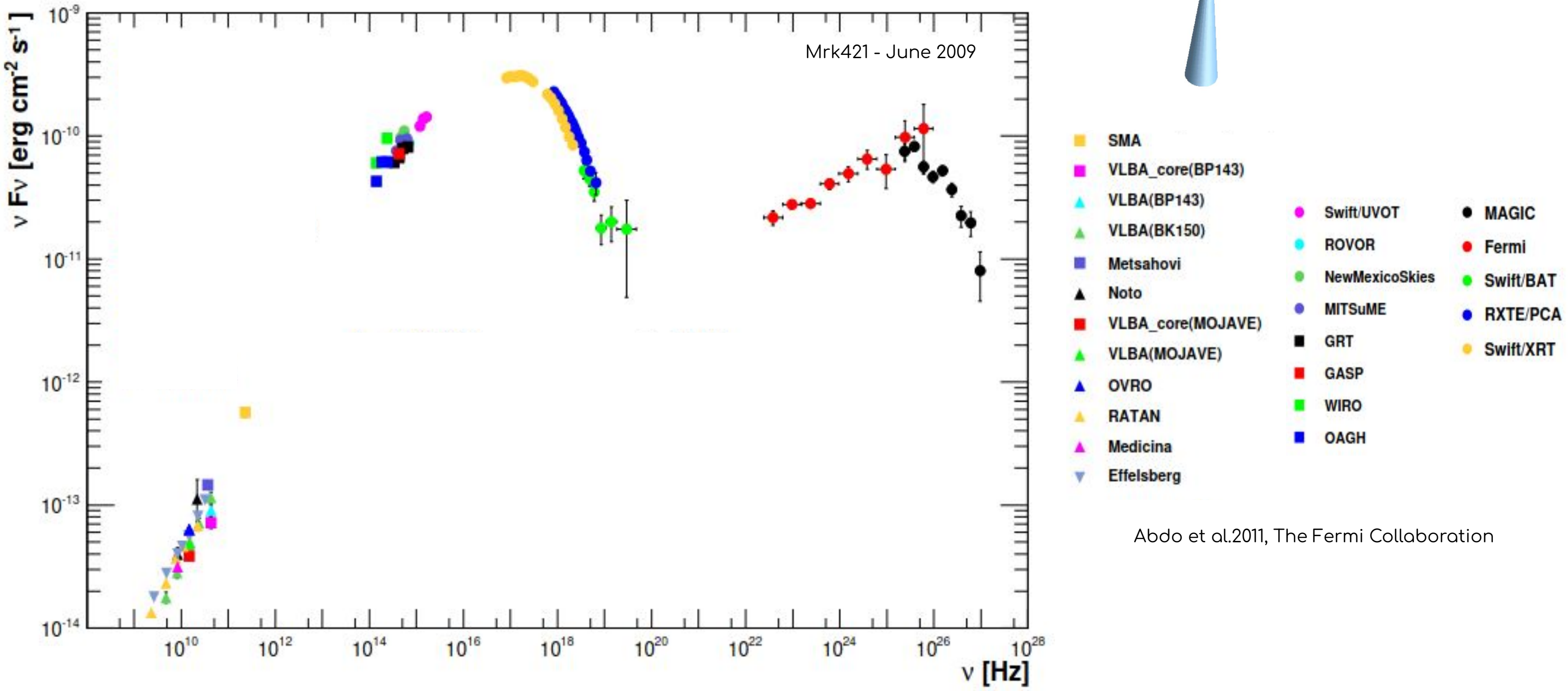
INAF ISTITUTO NAZIONALE DI ASTROFISICA

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

Blazars' emission mechanisms

- AGN with jet aligned to the line of sight
- Broadband emission from radio to gamma rays **up to Very High Energies (VHE, E > 100 GeV)**





Abdo et al.2011, The Fermi Collaboration

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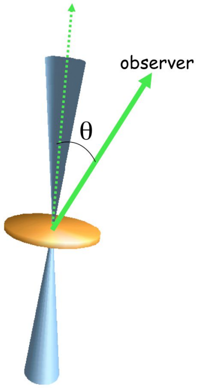

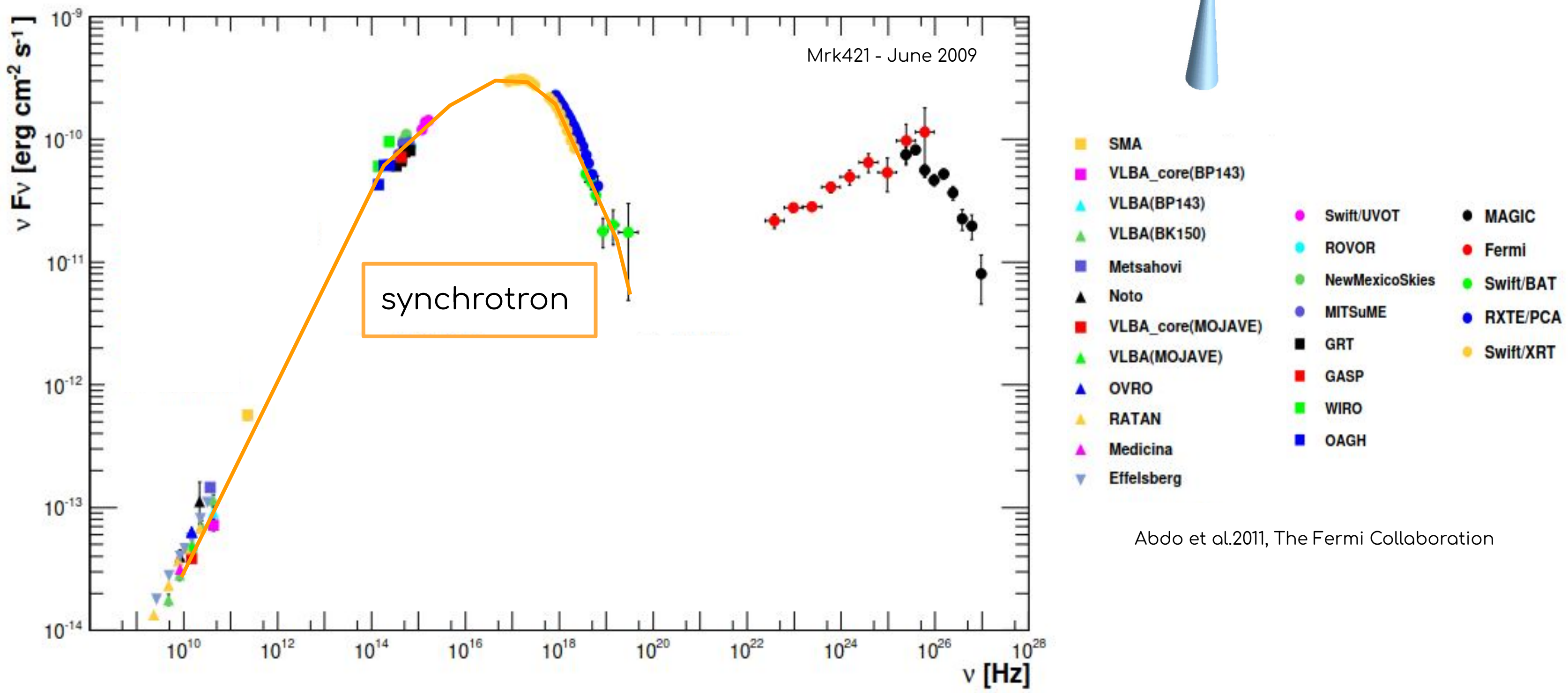

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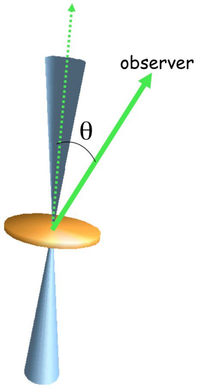
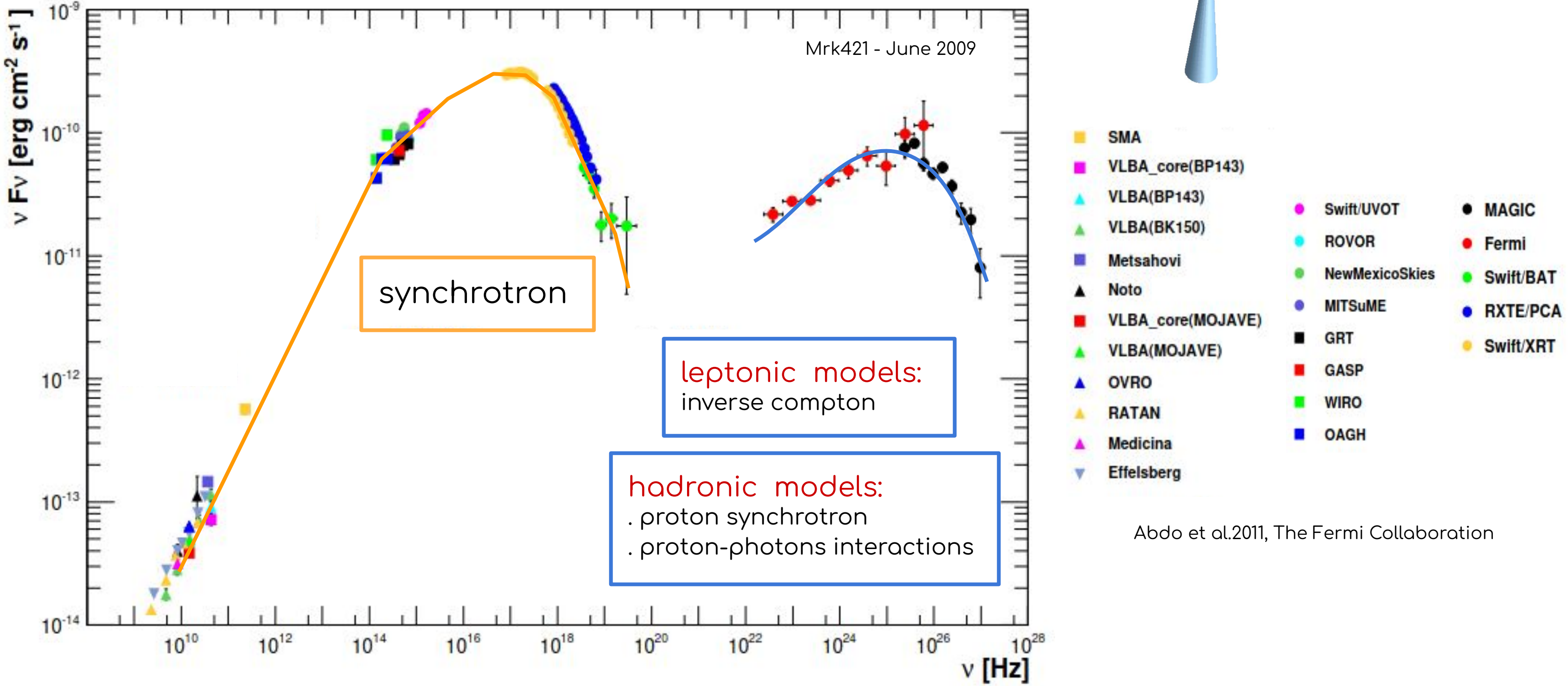
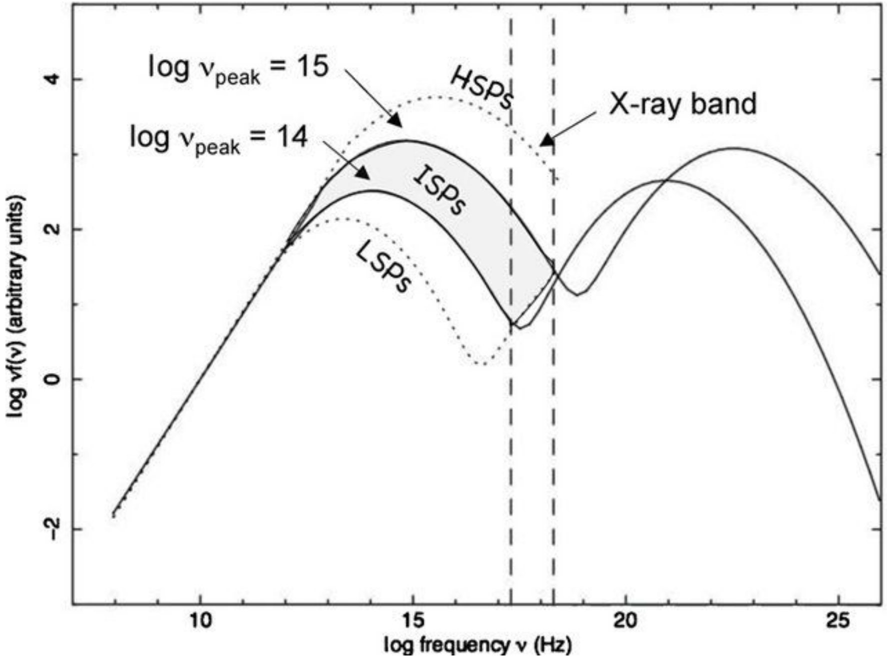




Abdo et al.2011, The Fermi Collaboration

Blazars’ classification

- **Classification based on synchrotron position (in BL Lacs):**
  - extreme high energy-peaked → **EHBL**, $\nu_{peak} > 10^{17}$ Hz
  - high-energy peaked BL → **HBL**, 10^{15} Hz $< \nu_{peak} < 10^{17}$ Hz
  - intermediate-energy peaked → **IBL**, 10^{14} Hz $< \nu_{peak} < 10^{15}$ Hz
  - low-energy peaked BL → **LBL**, $\nu_{peak} < 10^{14}$ Hz



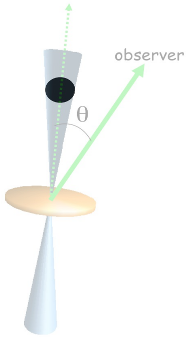
Emission mechanisms investigation

Broadband spectral energy distribution (SED) modelling

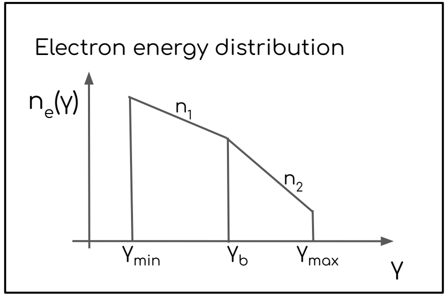
One-zone model:

The emission is coming from a blob filled:

- with homogeneous magnetic field
- with particles following a particle distribution



The blob is moving towards the observer with bulk Lorentz factor and bulk Doppler factor $\delta = 1 / \Gamma(1 - \beta \cos\theta)$



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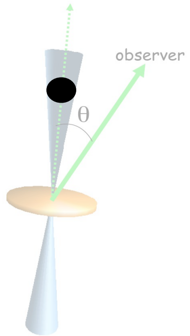

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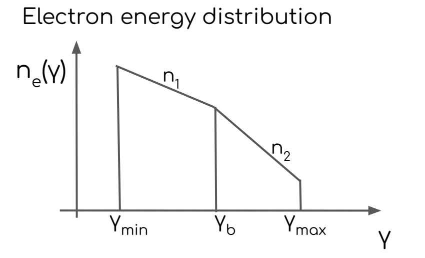


Two-zone model:

The emission is coming from two regions:

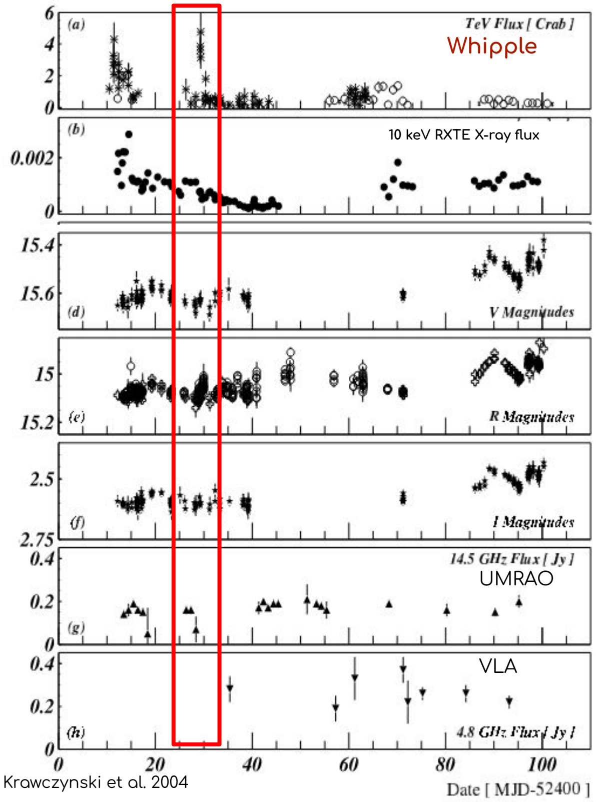
- looking for correlations between bands and different variability time scale in different bands

→ emission coming from different regions

The BL Lac 1ES1959+650

z = 0.047 (Schachter et al. 1993) at Ra: 19h59m59.85s, Dec:+65d8'54.65"

Orphan VHE gamma-ray flare in **2002**
+ hint of AMANDA neutrino detection



Krawczynski et al. 2004

MWL lc from June to August 2002

Orphan flare detection challenges the standard SSC model

↓

Alternative models:

- Multiple-zone SSC Models
- External Compton Models
- Magnetic Field Aligned along Jet Axis
- **Hadronic Models → AMANDA neutrino detection**

Halzen & Hooper 2005

The BL Lac 1ES1959+650

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Orphan VHE gamma-ray flare in **2002**
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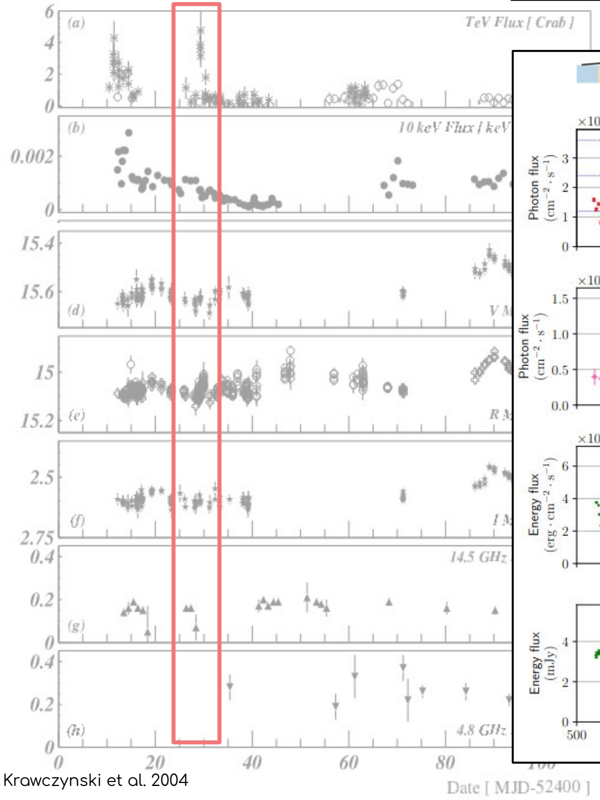
Detected by MAGIC in **2004**
MAGIC Collaboration 2006

Extreme VHE outburst in **2016**

5 years MWL monitoring



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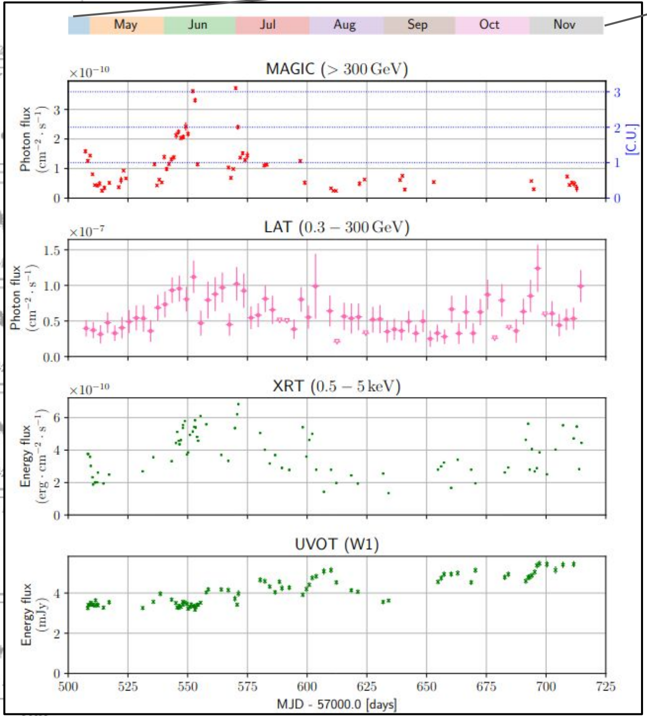
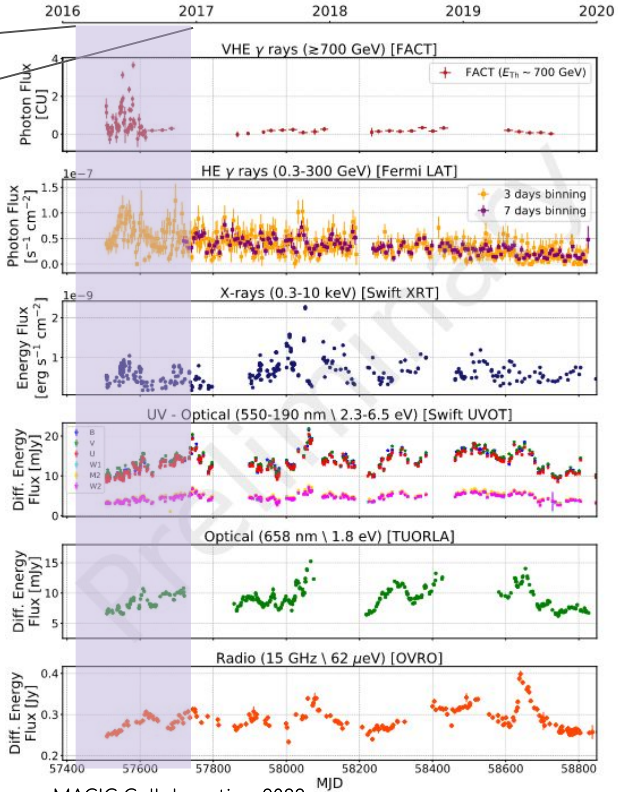


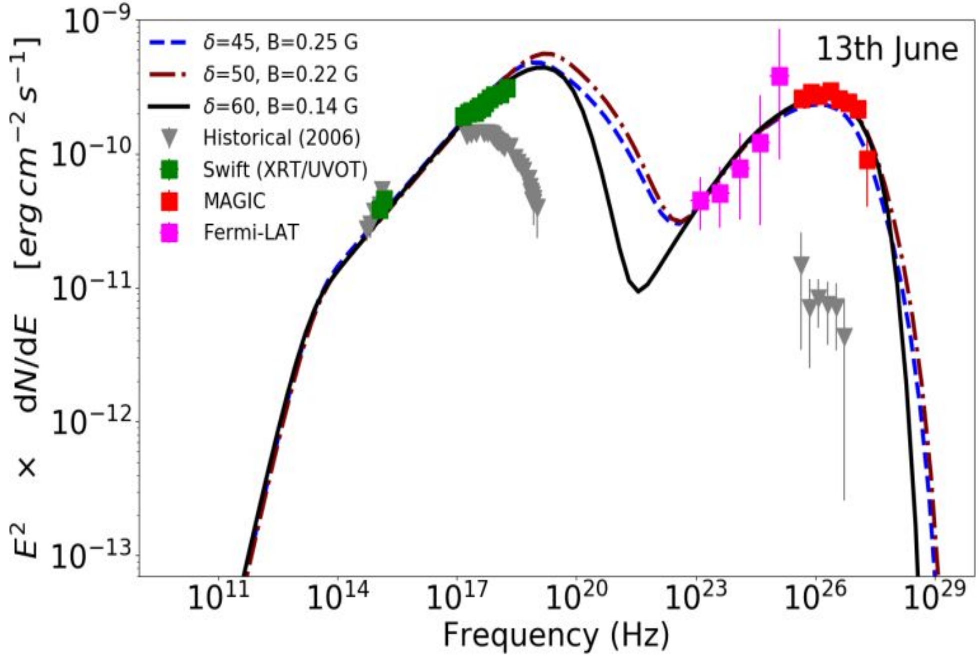
MAGIC Collaboration 2020



MAGIC Collaboration 2022

2016 flare SED analysis

1. leptonic scenario:
   one-zone SSC model



The parameters of the model are compatible with an EHBL-like behaviour

EHBL-like behaviour seen in **Mrk501** and **1ES 2344+514** (ICRC2023)

MAGIC Collaboration 2020

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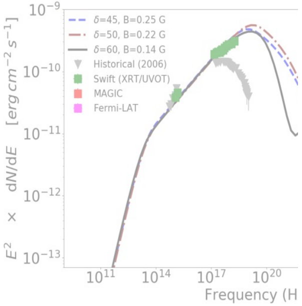
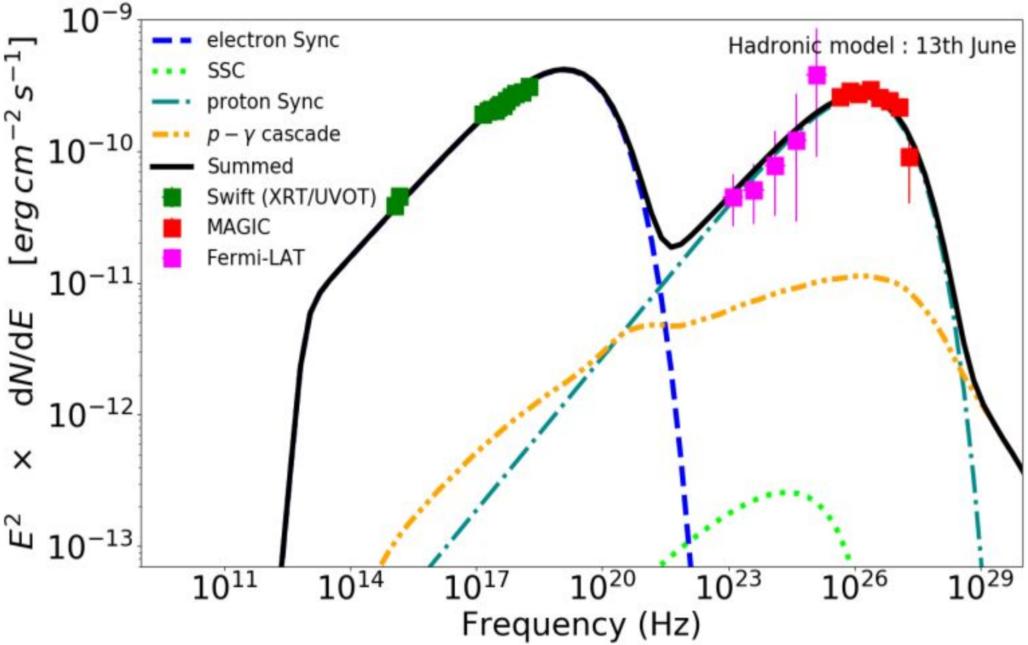


2. hadronic scenario: proton-synchrotron



extreme values of magnetic field strength required (~100 G)

MAGIC Collaboration 2020

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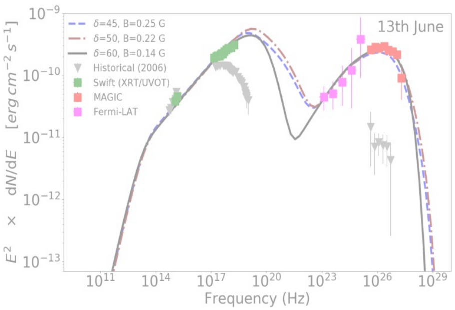

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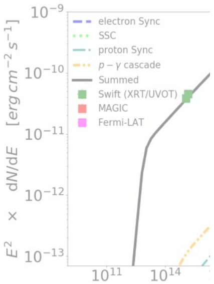
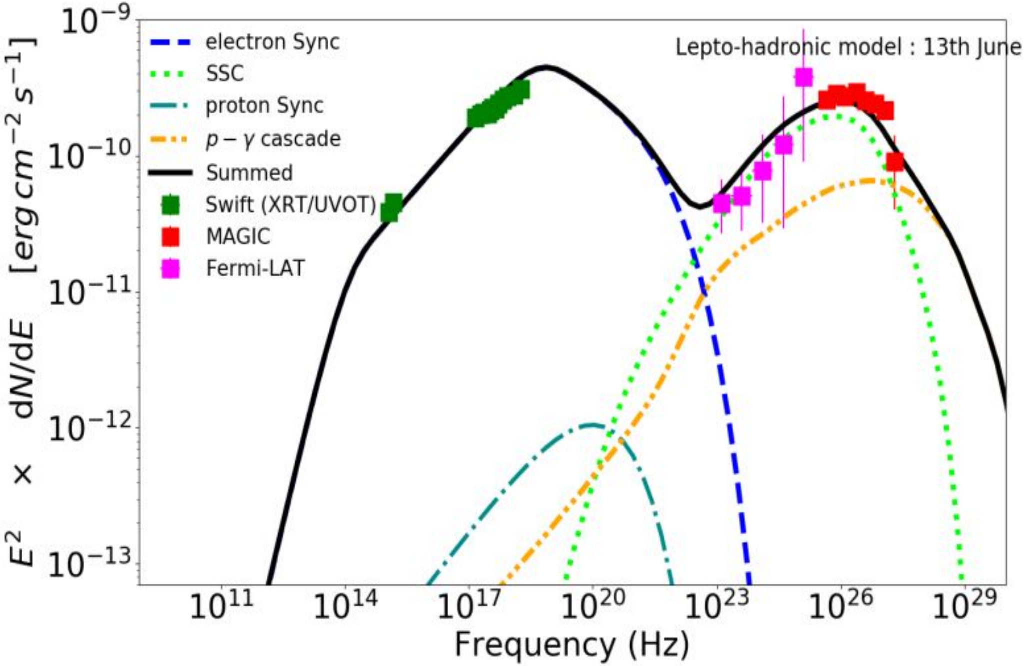


extreme values of jet power (above Eddington luminosity of the source) required

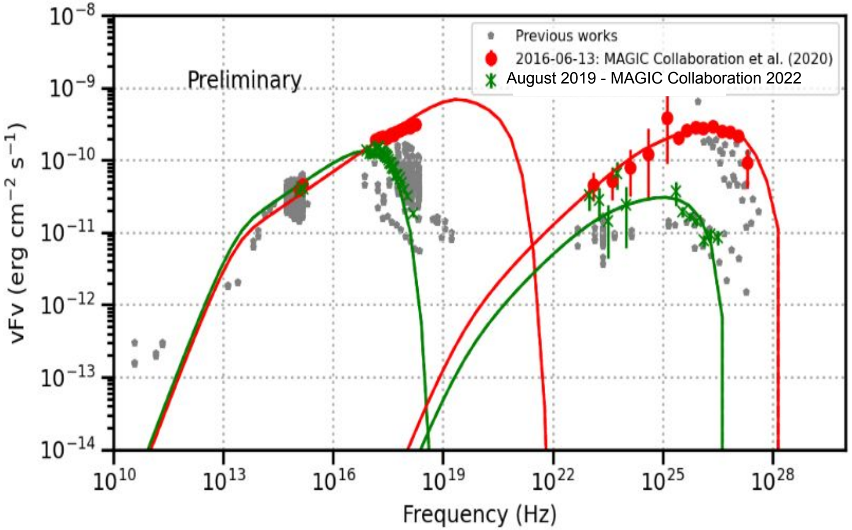
3. lepto-hadronic scenario



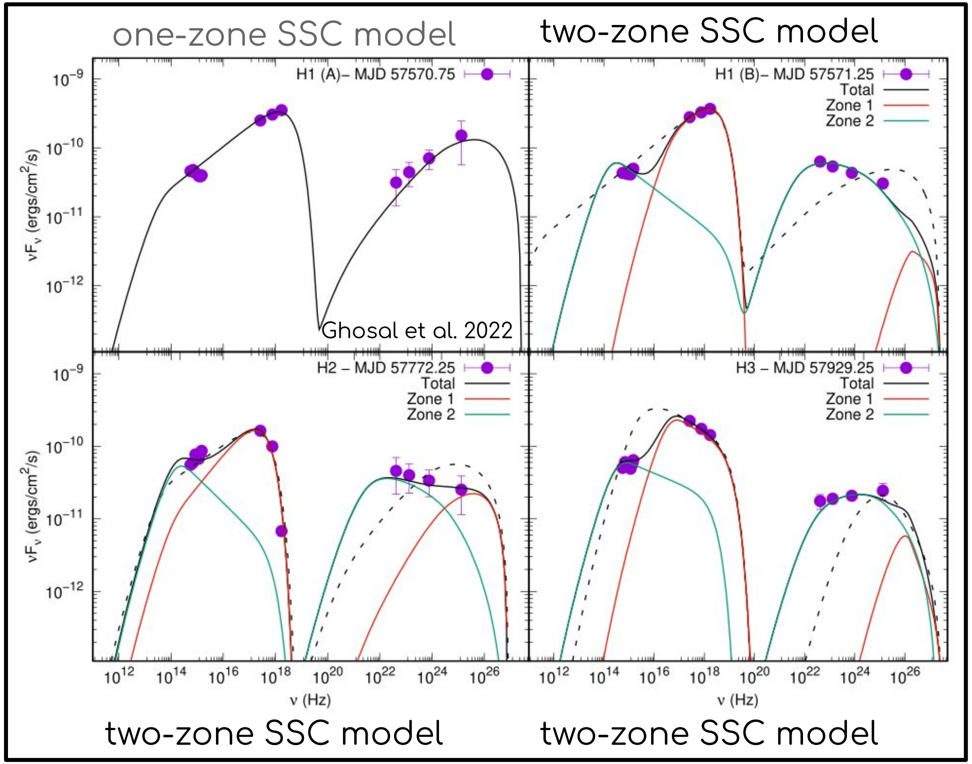
MAGIC Collaboration 2020

Other SED analysis: a few recent results

one-zone SSC model for
2019 quiescent state

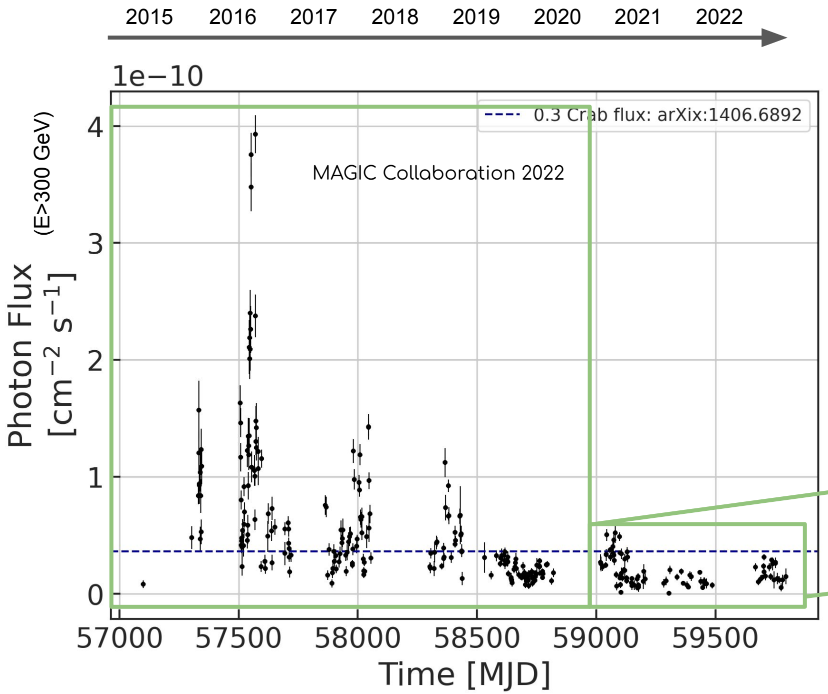


2016 - 2017 MWL data (TACTIC at VHE)

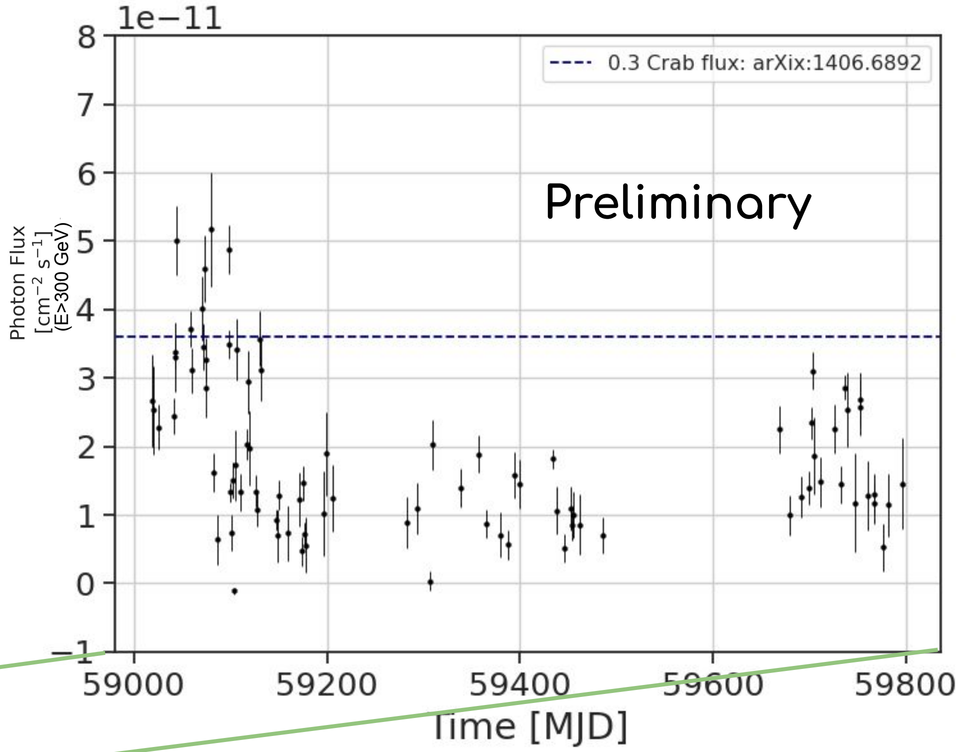


The 2020-2022 MAGIC data

Observing period from 2020 to 2022
~ 100 hours of MAGIC observation

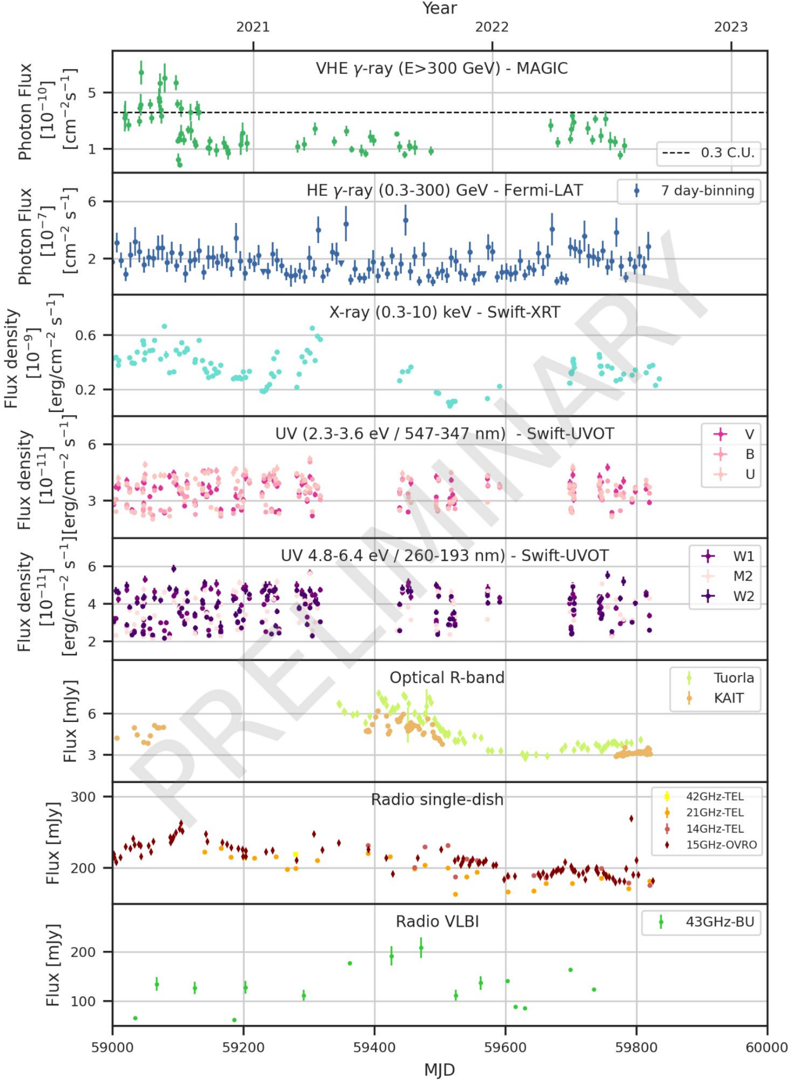


moon + dark MAGIC data



The 2020-2022 MWL data

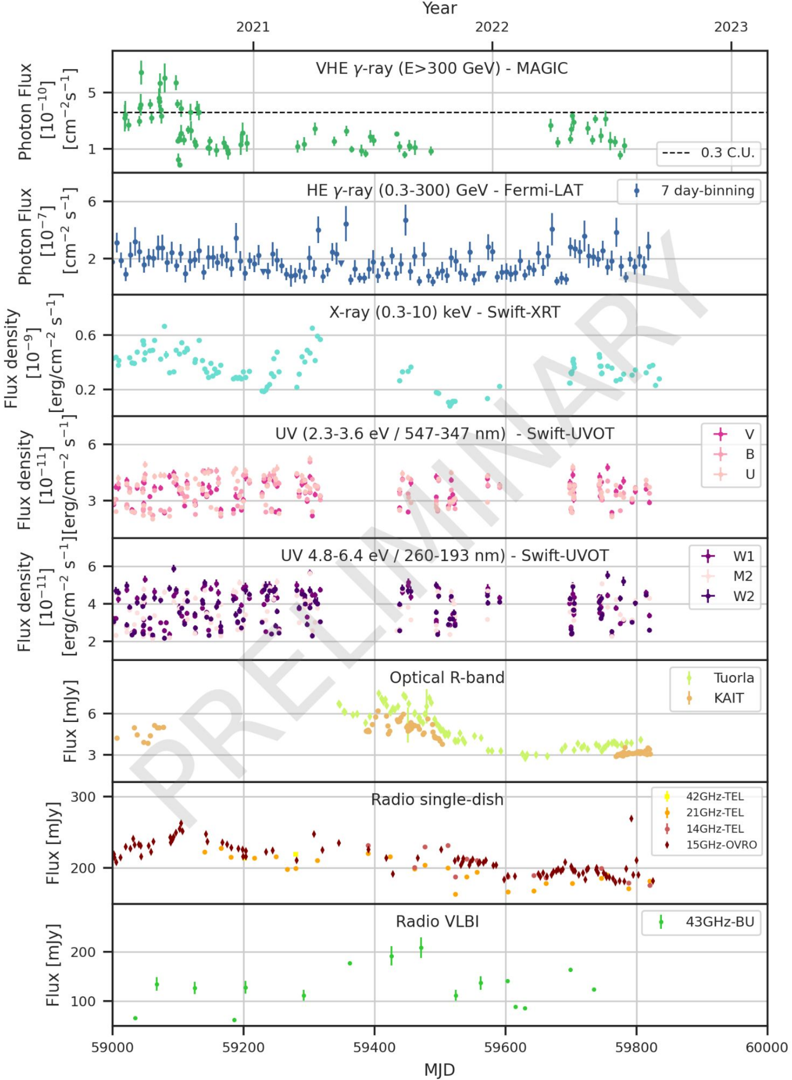
- **Gamma-ray**: Fermi-LAT
- **X-ray**: Swift XRT
- **UV**: Swift UVOT
- **Optical:** Tuorla and KAIT
- **Radio single-dish:** OVRO and TELAMON
-
- **Radio VLBI**: BO-VLBA



Preliminary

The 2020-2022 MWL data

- **High variability in X-rays** confirmed by other works e.g. Wani et al. 2023
- **No major outburst in the 2020-2022 data**
- **SSC approach are being tested** to model the MWL



Preliminary

Summary

What we know:

- Orphan flares at VHE (2002 and 2012)
- Candidate neutrino source?
- Occasionally EHBL-like behaviour
- One-zone SSC model works but it is not the end of the story
- High variability in X-rays, often lack of intraband correlations (e.g., Li et al. 2022)

What we aim to understand:

- Which process powers the low state 1ES 1959+650 emission and what is different from the flaring state?
- Which are the parameters that drive the 1ES 1959+650 emission mechanism during the low state?

MAGIC Collaboration paper on 2020-2022 monitoring results is in preparation

Interested in proposing observations with MAGIC ?

Next MAGIC observing call (Cycle-19) will come very soon.
It will be posted here: https://magic.mpp.mpg.de/public/magicop/
(Deadline for submitting proposals in the end of October or beginning of November)

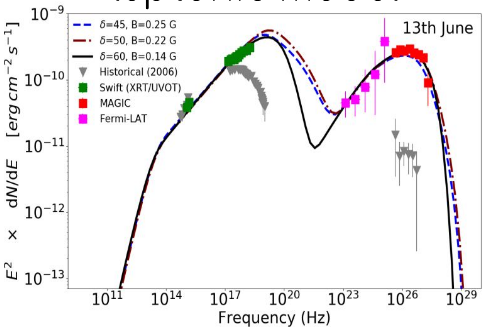
Thank you!


Backup

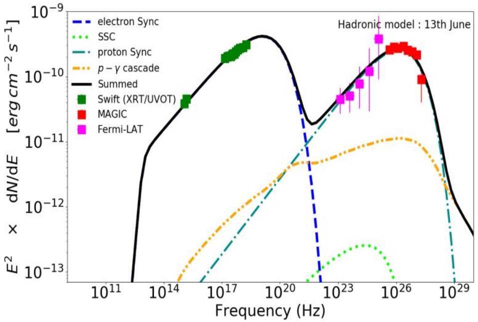
The BL Lac 1ES1959+650: SED analysis

MAGIC Collaboration 2020

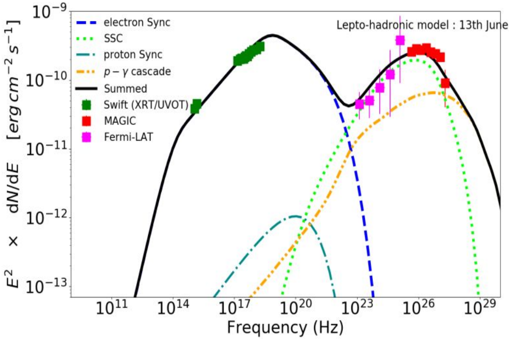
leptonic model



hadronic model



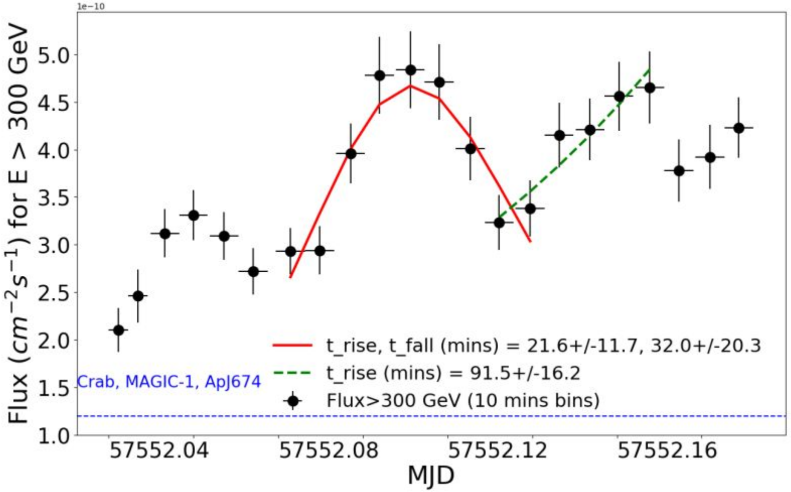
lepto-hadronic model

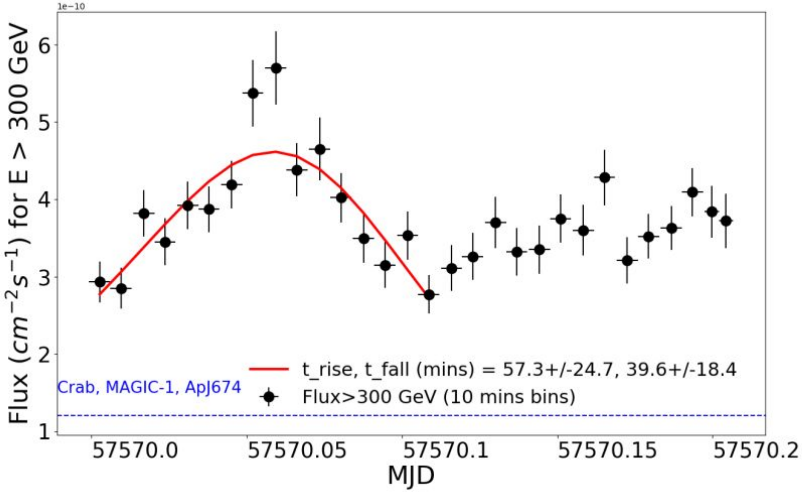


- Doppler factor
- magnetic field
- emission region size
- slope 1 of the powerlow (electron distribution)
- slope 2 of the powerlow (electron distribution)
- minimum electrons Lorentz factor
- maximum electrons Lorentz factor
- break Lorentz factor
- proton spectral index
- maximum exponential cutoff Lorentz factor
- minimum exponential cutoff Lorentz factor
- total jet power

	13th June		
Parameters	SSC	Hadronic	Lepto-hadronic
δ	40–60	25	45
B (G)	0.10–0.25	150	0.6
R (cm)	7×10^{14}–10^{15}	2.1×10^{14}	4×10^{14}
n_1	2.2–2.3	2.3	2.3
n_2	3.2–3.3	...	3.3
$\gamma_{e,\min}$	7×10^2	5	8×10^2
$\gamma_{e,\max}$	10^6–7×10^6	5×10^4	7×10^6
$\gamma_{e,\mathrm{brk}}$	4×10^5–10^6	...	2×10^5
n_p	...	2.23	2.2
$\gamma_{p,\min}$	...	1	1
$\gamma_{p,\max}$	...	7×10^9	6×10^7
L_j (erg s^{-1})	10^{43}–5×10^{43}	1.5×10^{46}	8×10^{48}

The BL Lac 1ES1959+650: 2016– flare variability analysis

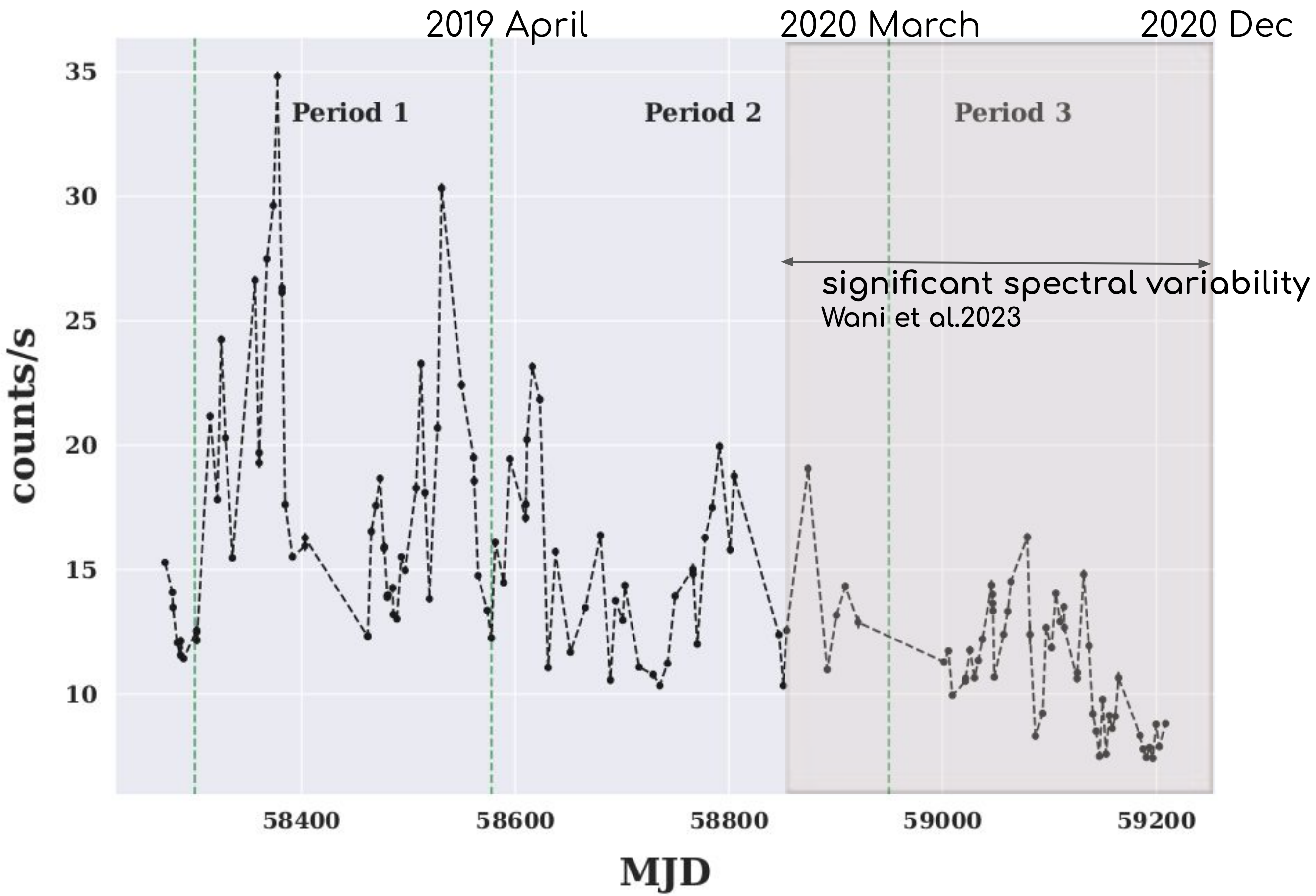




Fast intranight variability constraints size of extremely compact emitting region

$$R \leq \frac{c\,\Delta t\,\delta}{1+z}$$

X-ray variability



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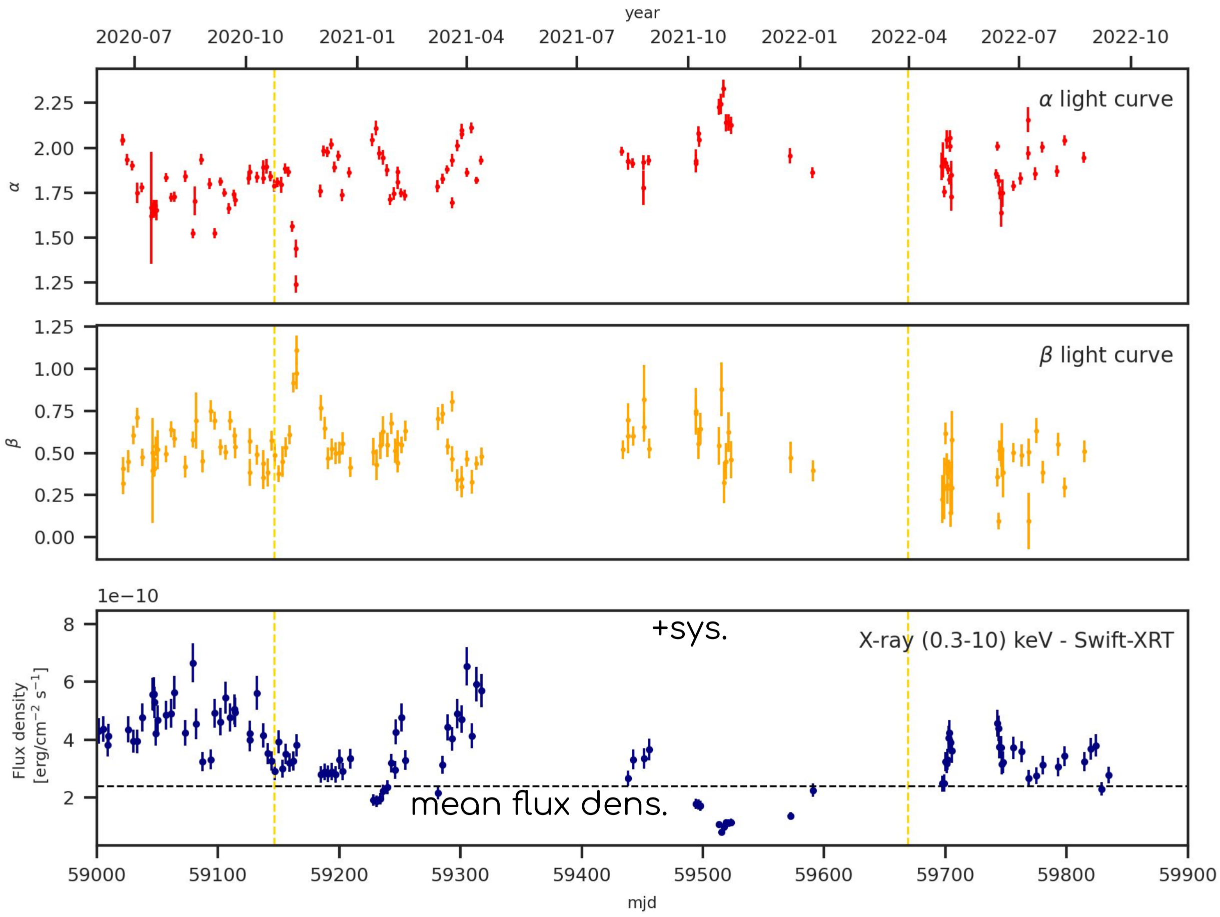
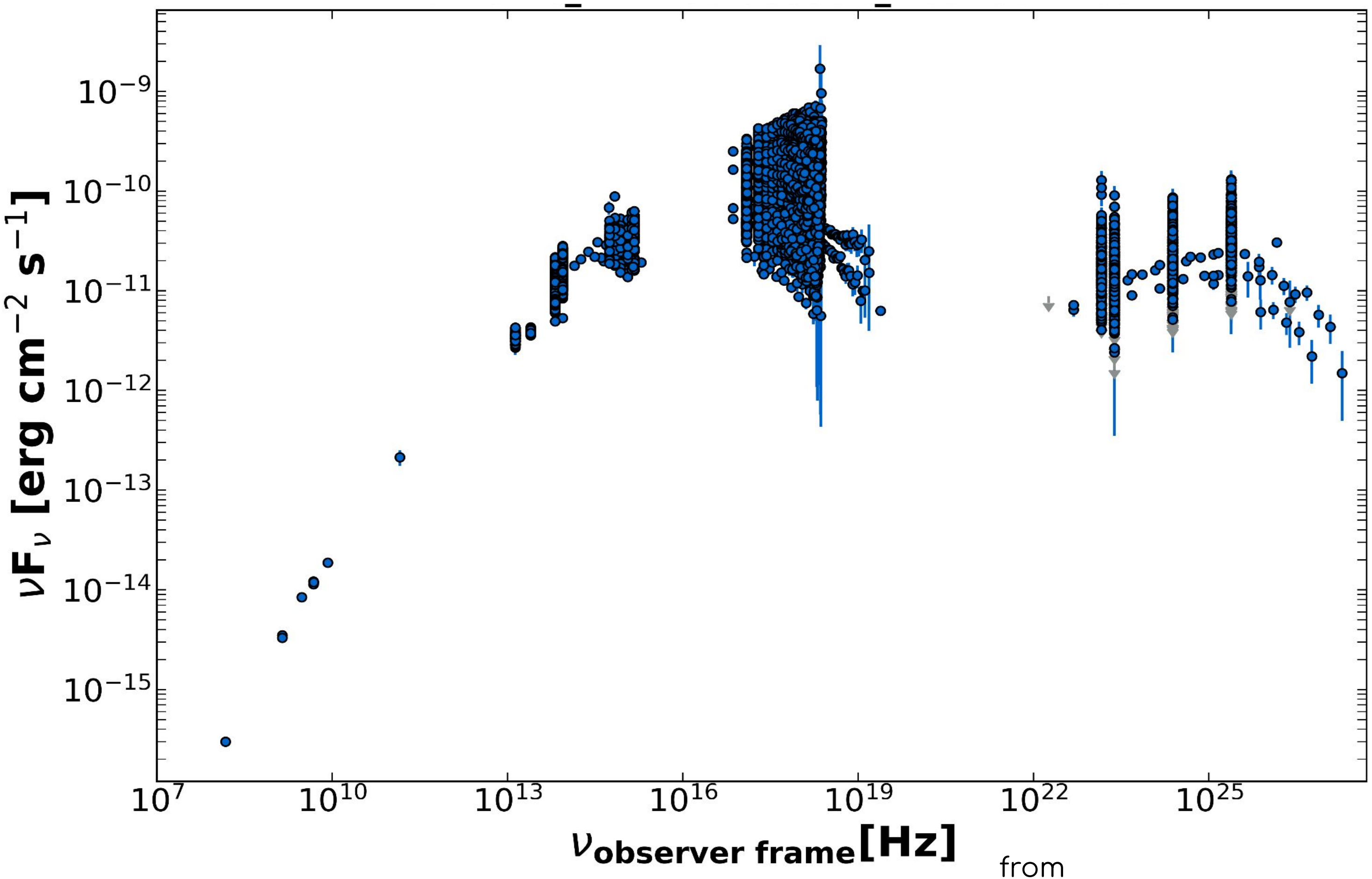
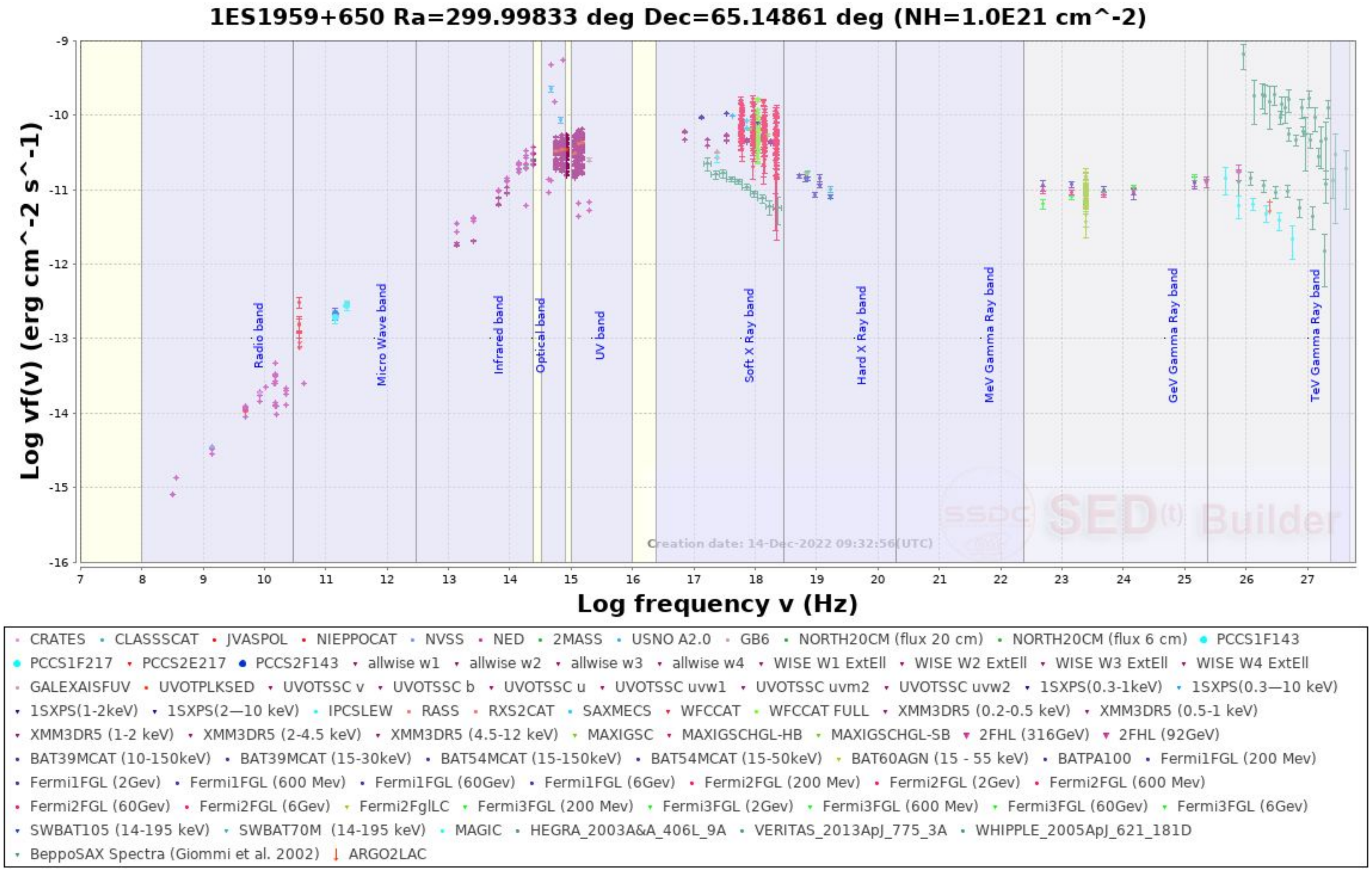


$$\frac{dN}{dE} = f_0 \times \left(\frac{E}{200\,\mathrm{GeV}}\right)^{-\alpha-\beta\log(E/200\,\mathrm{GeV})}$$



from https://firmamento.hosting.nyu.edu/home


1ES1959+650 Ra=299.99833 deg Dec=65.14861 deg (NH=1.0E21 cm^-2)
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
Radio band
Micro Wave band
Infrared band
Optical band
UV band
Soft X Ray band
Hard X Ray band
MeV Gamma Ray band
GeV Gamma Ray band
TeV Gamma Ray band
Creation date: 14-Dec-2022 09:32:56(UTC)
SSDC SED(t) Builder
CRATES CLASSSCAT JVASPOL NIEPPOCAT NVSS NED 2MASS USNO A2.0 GB6 NORTH20CM (flux 20 cm) NORTH20CM (flux 6 cm) PCCS1F143
PCCS1F217 PCCS2E217 PCCS2F143 allwise w1 allwise w2 allwise w3 allwise w4 WISE W1 ExtEll WISE W2 ExtEll WISE W3 ExtEll WISE W4 ExtEll
GALEXAISFUV UVOTPLKSED UVOTSSC v UVOTSSC b UVOTSSC u UVOTSSC uvw1 UVOTSSC uvm2 UVOTSSC uvw2 1SXPS(0.3-1keV) 1SXPS(0.3—10 keV)
1SXPS(1-2keV) 1SXPS(2—10 keV) IPCSLEW RASS RXS2CAT SAXMECS WFCCAT WFCCAT FULL XMM3DR5 (0.2-0.5 keV) XMM3DR5 (0.5-1 keV)
XMM3DR5 (1-2 keV) XMM3DR5 (2-4.5 keV) XMM3DR5 (4.5-12 keV) MAXIGSC MAXIGSCHGL-HB MAXIGSCHGL-SB 2FHL (316GeV) 2FHL (92GeV)
BAT39MCAT (10-150keV) BAT39MCAT (15-30keV) BAT54MCAT (15-150keV) BAT54MCAT (15-50keV) BAT60AGN (15 - 55 keV) BATPA100 Fermi1FGL (200 Mev)
Fermi1FGL (2Gev) Fermi1FGL (600 Mev) Fermi1FGL (60Gev) Fermi1FGL (6Gev) Fermi2FGL (200 Mev) Fermi2FGL (2Gev) Fermi2FGL (600 Mev)
Fermi2FGL (60Gev) Fermi2FGL (6Gev) Fermi2FglLC Fermi3FGL (200 Mev) Fermi3FGL (2Gev) Fermi3FGL (600 Mev) Fermi3FGL (60Gev) Fermi3FGL (6Gev)
SWBAT105 (14-195 keV) SWBAT70M (14-195 keV) MAGIC HEGRA_2003A&A_406L_9A VERITAS_2013ApJ_775_3A WHIPPLE_2005ApJ_621_181D
BeppoSAX Spectra (Giommi et al. 2002) ARGO2LAC