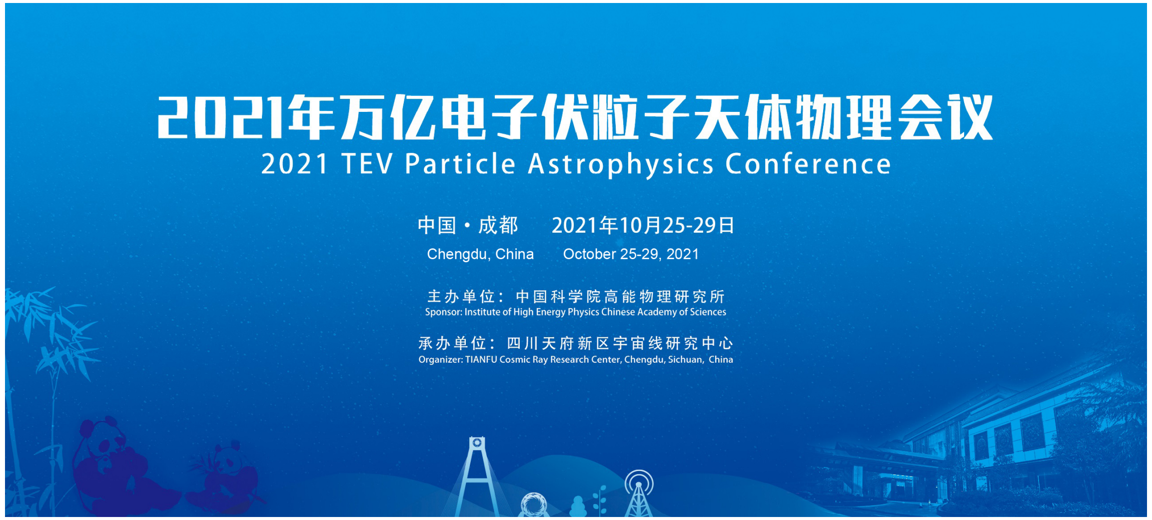

The discovery in very-high-energy gamma rays of Blazar TXS1515-273 by MAGIC and extreme MAGIC results

Serena Loporchio – INFN Bari

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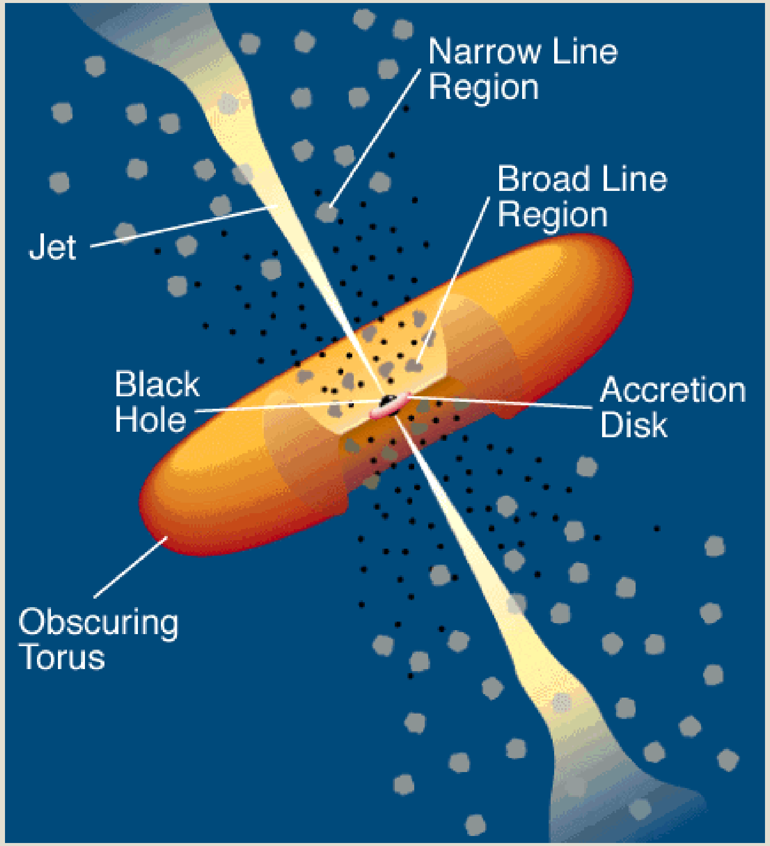
Blazars

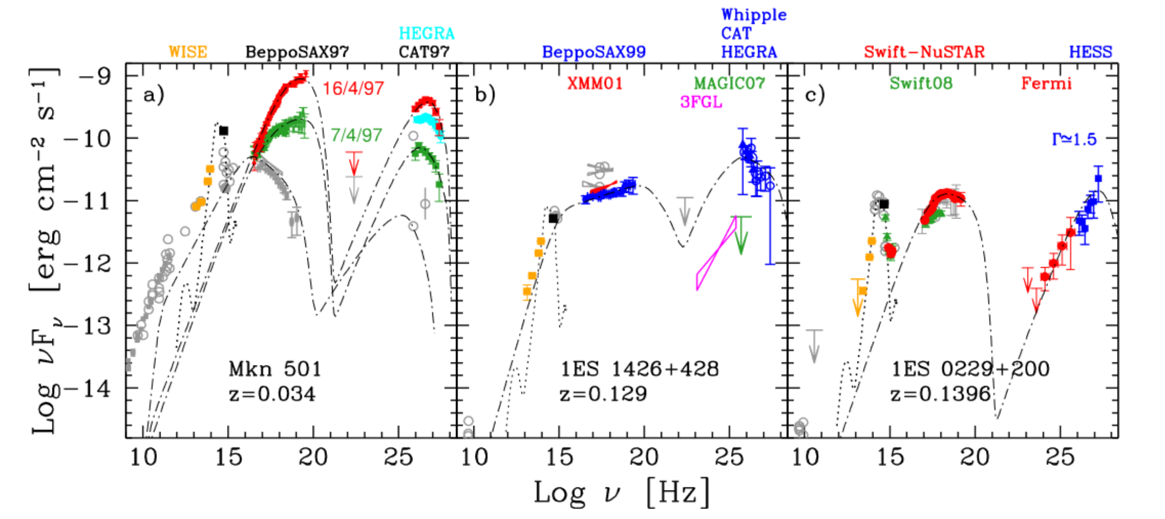


- Radio loud AGN closely aligned towards the observer
- The jets emission hides the thermal emission from the rest of the AGN component
- Non-thermal emission in all e.m. spectrum, variability
- SED with two bump continuum and possible evidence of broad emission lines (FSRQ or BL Lacs)
  - BL Lacs: classified as LSP, ISP and HSP according to the location of the synchrotron peak (<10^{14} Hz, IR, 10^{14} Hz – 10^{15} Hz, OPTICAL, >10^{15} Hz, UV/X-rays)

Extreme high-frequency-peaked BL Lac objects (EHBLs)

- High synchrotron peak frequency exceeding soft X-rays band: $\nu_s > 10^{17}$ Hz
- Heterogeneous population:
  - Extreme during flares → both peaks shifting
  - Steady hard synchrotron spectrum but no hard-TeV
  - Hard TeV spectrum

Biteau et al., *Nat Astron* **4,** 124–131 (2020)



- Lack of unbiased surveys @ TeV
- Unique population of EHBL?
- Leptonic/leptohadronic scenario?
- Tests of γ-ray propagation: probes for EBL, IGMF and fundamental physics

The MAGIC telescopes

- 2 Cherenkov telescopes located at La Palma, Canary Island (2200 m a.s.l.)
- 17 m parabolic aluminum reflectors
- PMT-based camera of ~ 1000 pixels
- From 20 GeV up to 100 TeV
- 3.5-degree FoV

MAGIC EHBLs

V. A. Acciari *et al* 2020 *ApJS* **247** 16

Source	z	N_H $\times 10^{21}$ (cm^{-2})	$\log(\nu_{peak})$ (Hz)
TXS 0210+515	0.049[a]	1.440	17.3
TXS 0637−128	0.136[b]	2.990	17.4
BZB J0809+3455	0.082[c]	0.432	16.6
RBS 0723	0.198[c]	0.317	17.8
1ES 0927+500	0.187[c]	0.138	17.5
RBS 0921	0.236[c]	0.382	17.9
1ES 1426+428	0.129[c]	0.113	18.1
1ES 2037+521	0.053[a]	4.360	N.A.
RGB J2042+244	0.104[d]	1.010	17.5
RGB J2313+147	0.163[e]	0.514	17.7

- Extend hard-TeV EHBLs population
- 10 potential EHBLs selected:
  - Hard X-ray index < 2
  - HE properties from Fermi-LAT
  - High X-ray-to-radio flux ratio
  - MWL luminosity correlation
  - Low redshift
- Among the potential EHBLs:
  - 3 new TeV emitters: TXS 0210+515, RBS 0723, 1ES 2037+521
  - 1 already known: 1ES 1426+428
  - 1 hint of signal: RGB J2042+244

MAGIC EHBL catalog
10.3847/1538-4365/ab5b98

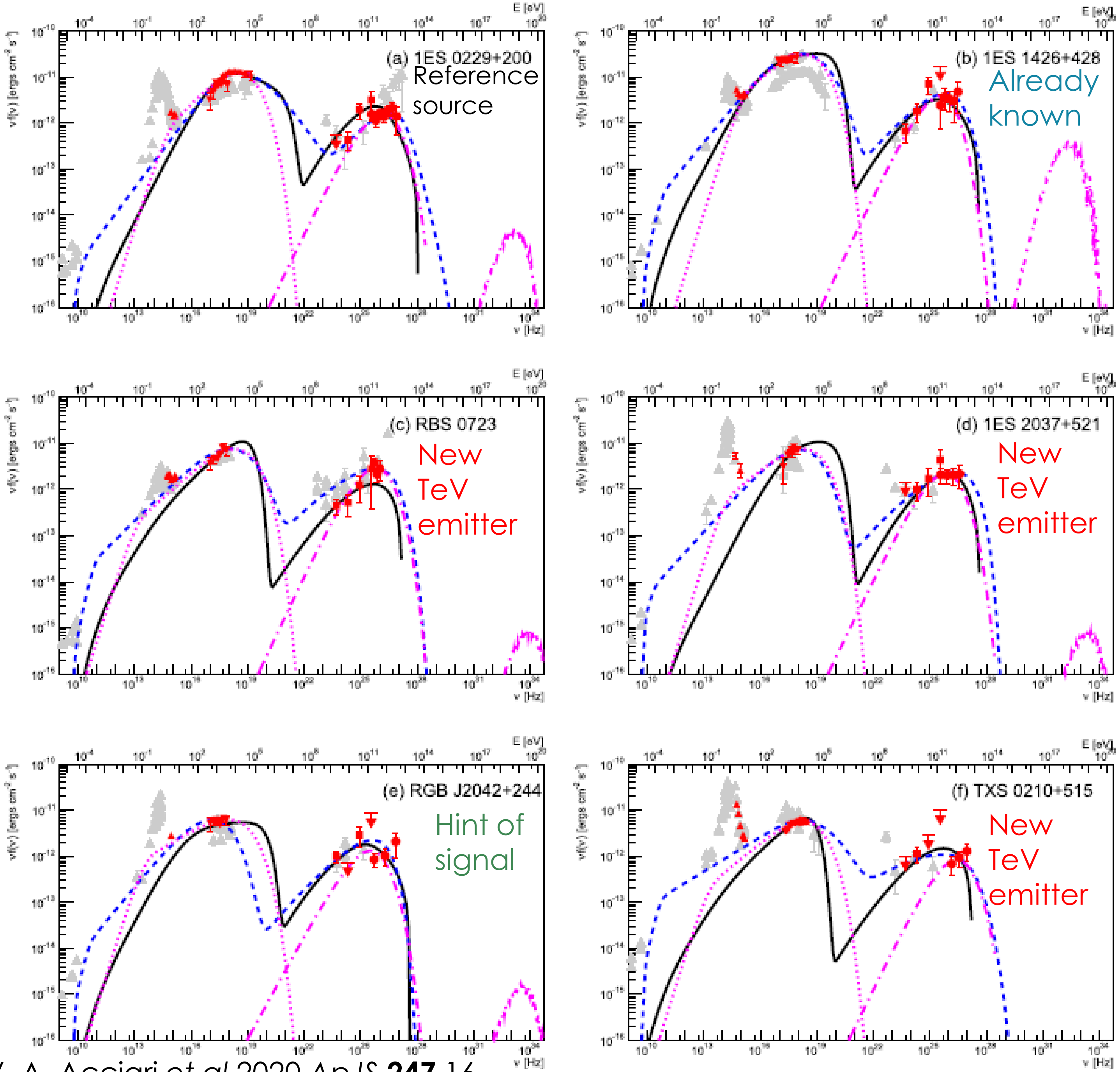
Emission interpretation

Blue: one-zone leptonic model

Black: spine-layer leptonic model

Pink: proton-synchrotron model

In SSC and PS models we are far from equipartition



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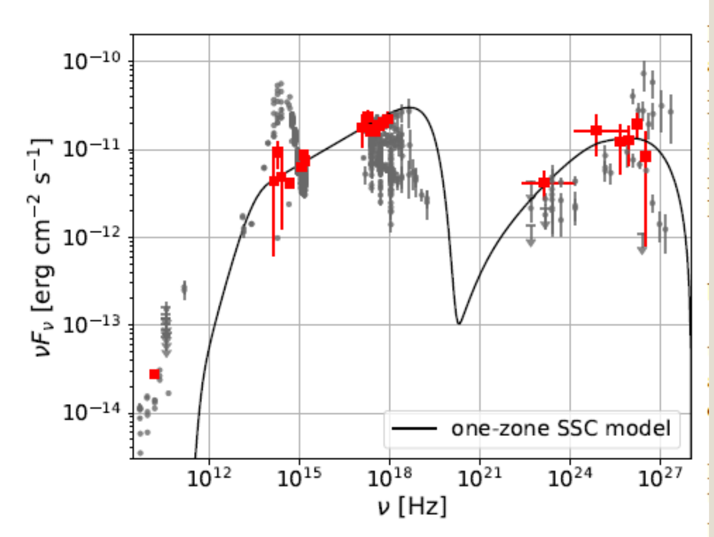
The intermittent 1ES 2344+514

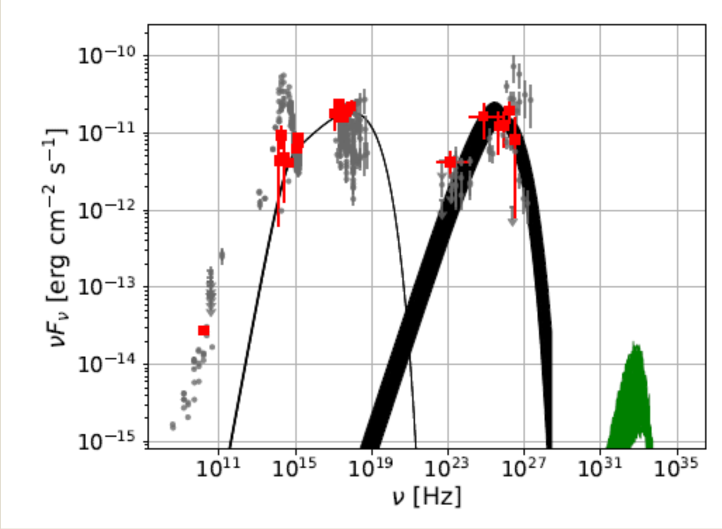
- Detected at VHE in 1995 during intense flare
- Variability in the X-rays in 1996: shift of synch peak → first EHBL
- Many MWL campaign during low activity
- Flare during 2016 → FACT triggered MWL campaign

V. A. Acciari *et al* 2020 *MNRAS* **496** 3



leptonic (right) and proton-synchrotron (left)

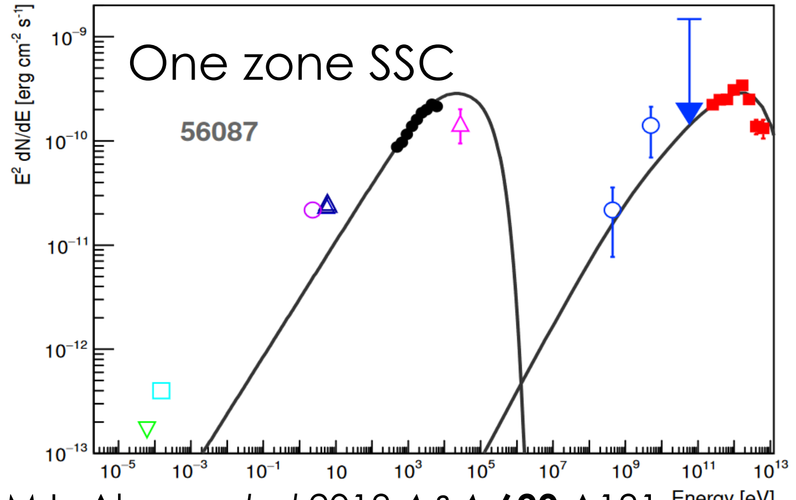
in both scenarios: far from equipartition of energy



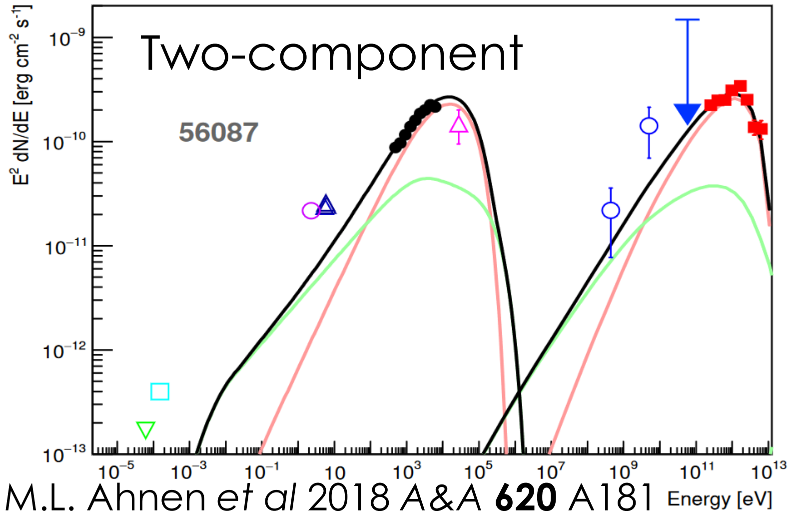
V. A. Acciari *et al* 2020 *MNRAS* **496** 3

Mrk 501: EHBL during 2012

- Flaring activity in June 2012 → peaks of the SED above 5 keV and 0.5 TeV
- Hard X-ray and VHE spectra during the campaign
- Extreme behavior may not be a permanent characteristic of blazar, but a state changing over time



M.L. Ahnen *et al* 2018 A&A **620** A181



M.L. Ahnen *et al* 2018 A&A **620** A181

Detection of sub-TeV gamma-ray emission from the flaring blazar TXS 1515-273 with the MAGIC telescopes

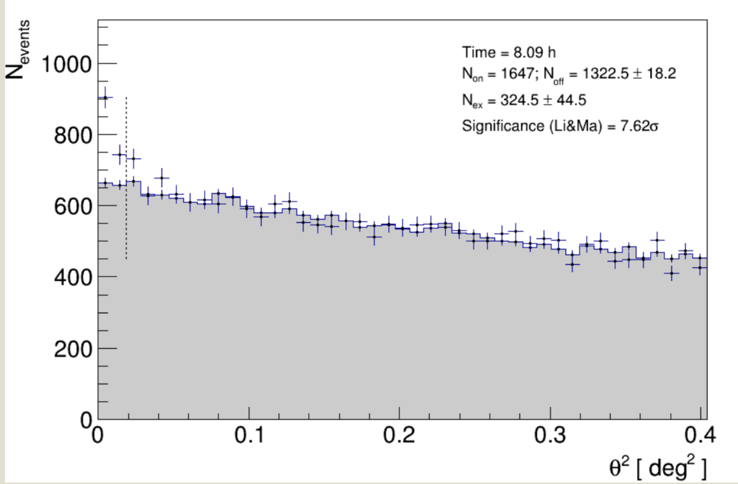
ATel #12538; *Razmik Mirzoyan (Max-Planck-Institute for Physics, Munich), on behalf of the MAGIC collaboration*
on 28 Feb 2019; 22:14 UT

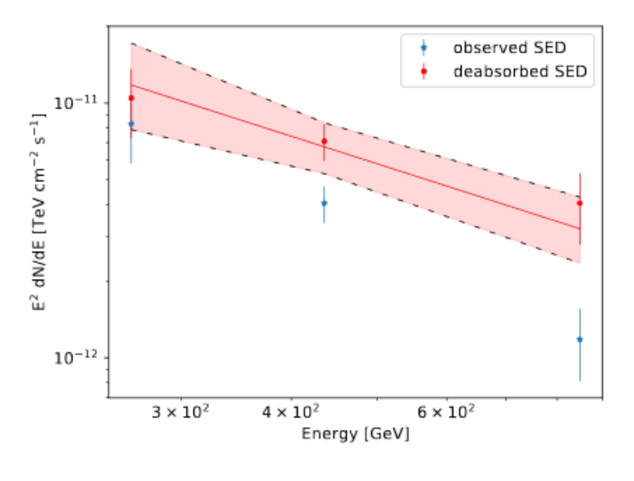
The TXS 1515 – 273 case

- Present in 2FGL and 3FGL as blazar candidate of uncertain type (BCU)
- Classified as BL Lac object in 4FGL
  - Photon index ~ 2 → EHBL candidate?
- Flaring activity reported by Fermi-LAT in the HE gamma-ray band (ATel 12532) in February 2019
- Quasi simultaneous observations in different energy bands – from optical to VHE gamma-ray
  - Excellent X-ray coverage (XMM-Newton, NuSTAR, Swift-XRT)
- First detection at VHE with MAGIC telescopes (ATel 12538)
- VLBA observations as part of MOJAVE program in June 2019

VHE detection & spectrum

- 6 nights between Feb 27 and Mar 05 → 8.1 hours
- Observations under moderate moonlight
- High zenith distance (55°-60°)
- 7.6 sigma detection
- Data from all nights combined → Spectral index = -3.11 ± 0.32
- Normalization = (1.76 ± 0.28) 10^{-11} TeV^{-1} cm^{-2} s^{-1}
- Norm energy = 546 GeV
- Corrected for EBL absorption Domìnguez et. al (2011) model
- Soft spectrum → HE bump likely to be peaking at GeV energies





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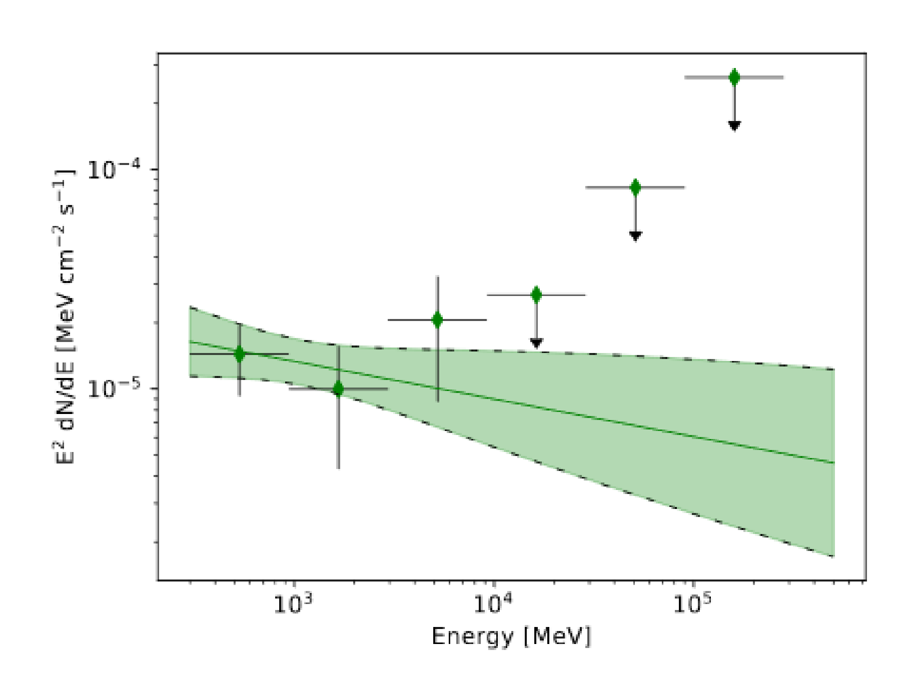
HE spectrum

- LAT data selected in 300 MeV – 500 GeV energy range between Feb. 27 and Mar. 04 for smoother connection to VHE data
- LC computed in daily bins
- Γ: 2.16 ± 0.28
- N_0 = (20.48 ± 7.18) $\times 10^{-13}$ MeV^{-1} cm^{-2} s^{-1}
- $f_{E>300\ MeV}$ = (4.46 ± 1.34) $\times 10^{-8}$ cm^{-2} s^{-1}



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MWL lightcurve

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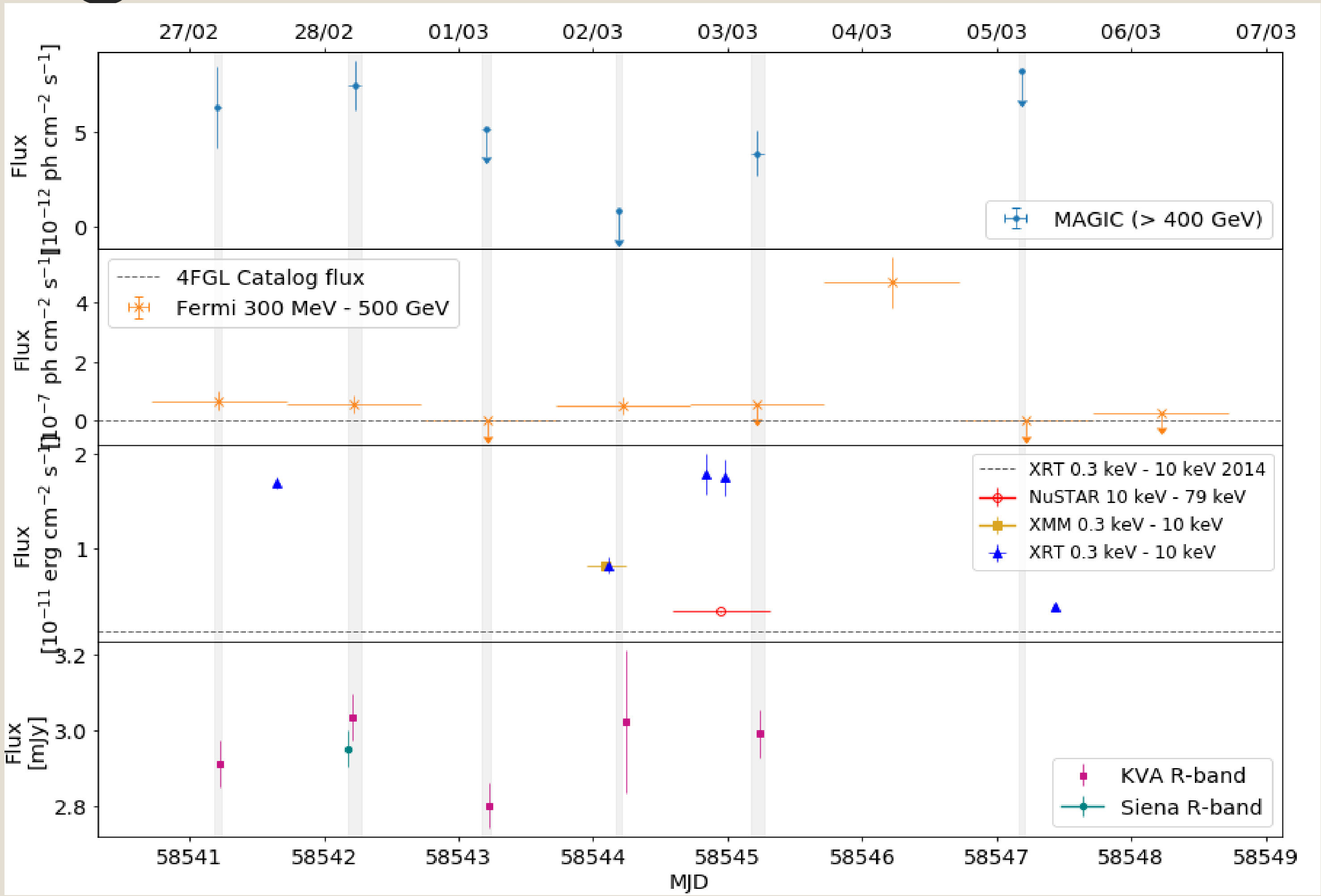

MWL lightcurve

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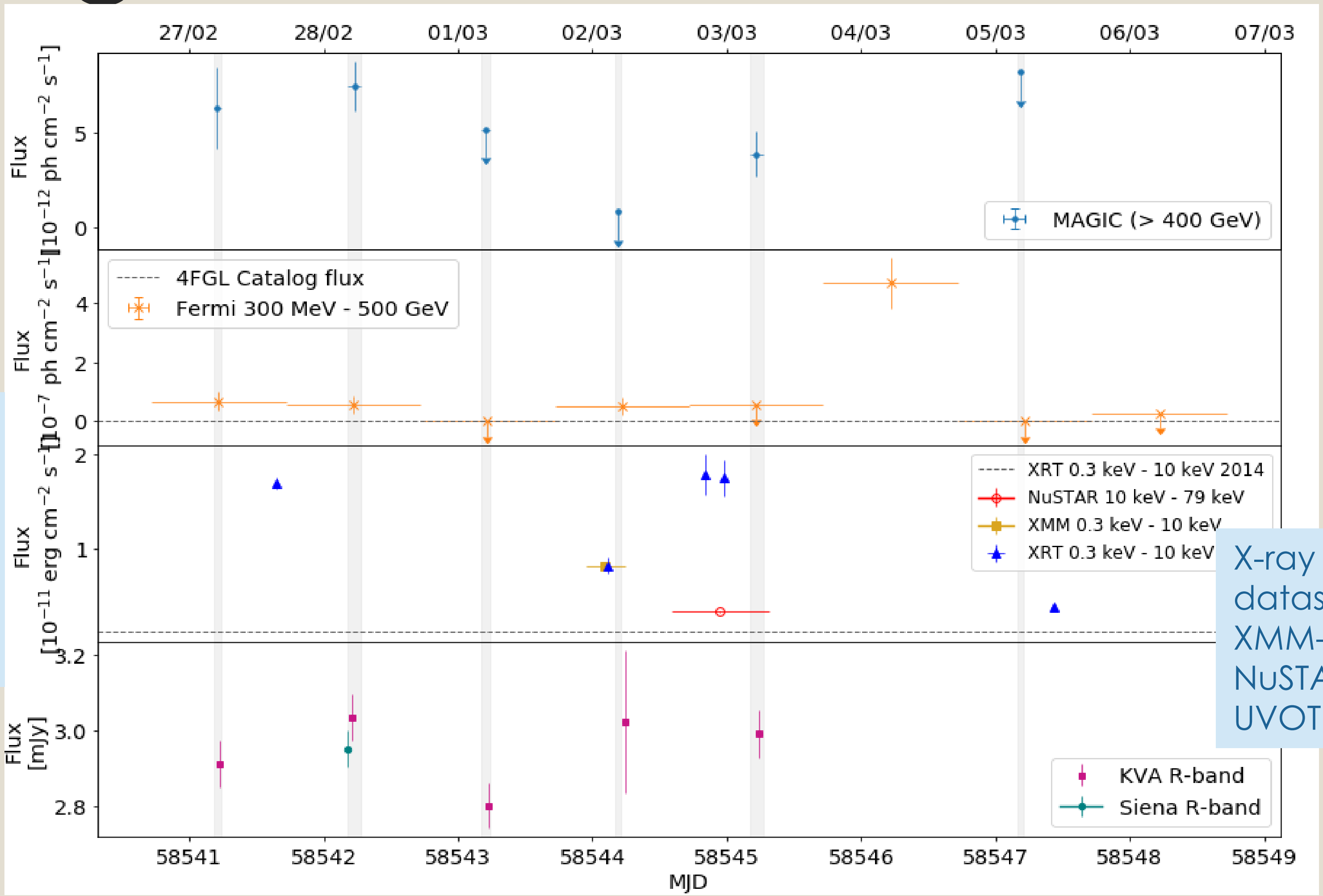


HIGH STATE in all energy bands

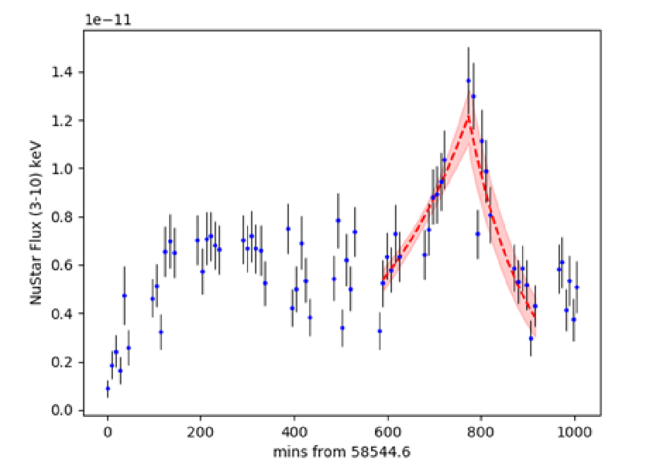
Non-simulteneous X-ray observations with rapid variability observed

X-ray data split in two datasets:
XMM-Newton & XMM-OM
NuSTAR + Swift-XRT & Swift-UVOT

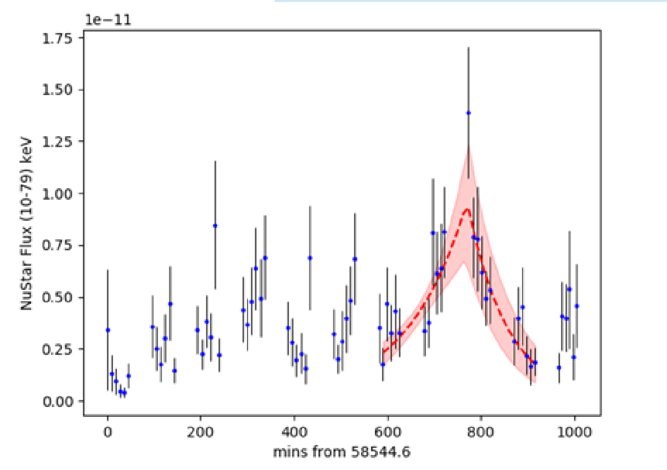
X-ray variability

- Exponential function to fit the flare on MJD 58544 – 58545
- The fit was performed in both the soft and the hard X-ray spectra of the two instruments
- Hour scale variability found in both the X-ray datasets
- Variability timescale shorter in the high energy band → cooling regime

NuSTAR soft band



NuSTAR hard band



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Constraints on the emission region

- Shortest time scale variability used to constrain the size of the emission region

$$R \leq \frac{ct_{\text{var}}\delta}{(1+z)}$$

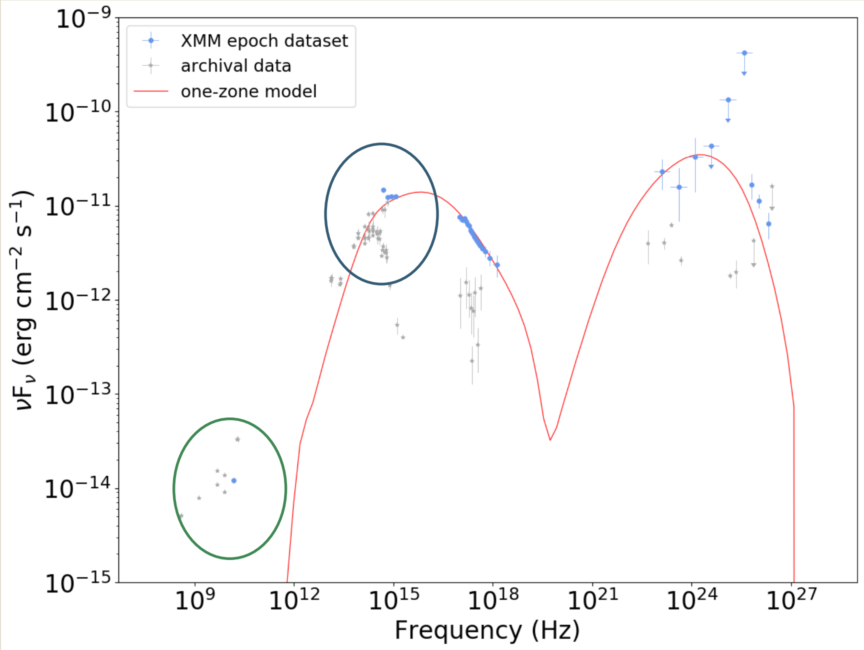
- Time lag of observations is not statistically significant → B doesn't vary between epochs
- The decay time is used to constrain the intensity of the magnetic field (Zhang et al. 2002, ApJ 572 762)

$$B = 210 \times \left(\frac{1+z}{E_l \times \delta}\right)^{1/3} \left[\frac{1-(E_l/E_h)^{1/2}}{\tau_{\text{soft}}}\right]^{2/3} \quad \text{G}$$

$$\tau_{\text{soft}} = t_{\text{decay,XMM}} - t_{\text{decay,NuSTAR}}$$

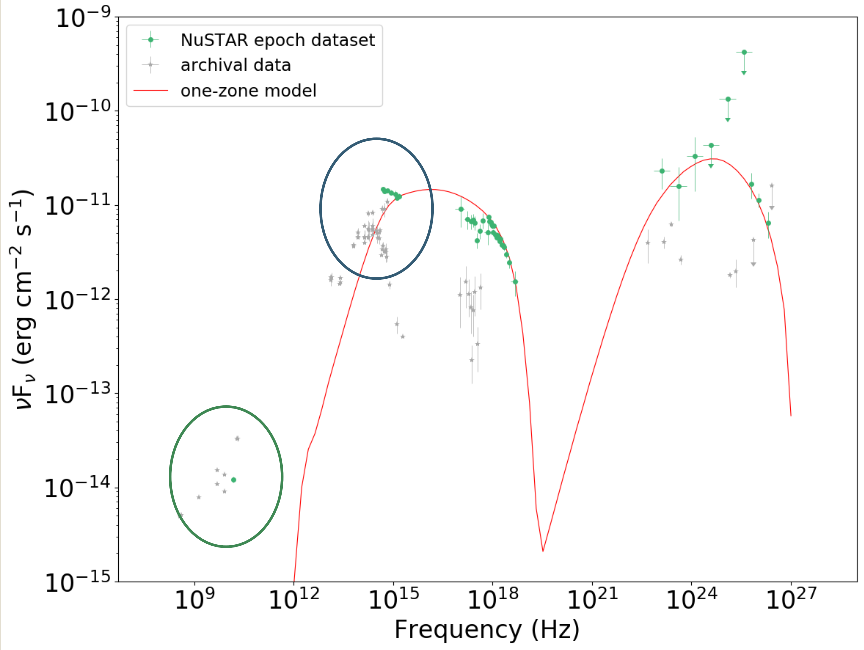
- Upper limits on R and estimated B were used for the SED modeling

SED modeling with SSC



Not very good agreement with optical data

Far from equipartition $U_B/U_E \sim 10^{-3}$



VLBA radio data not reproduced (expected due to synchrotron self absorption)

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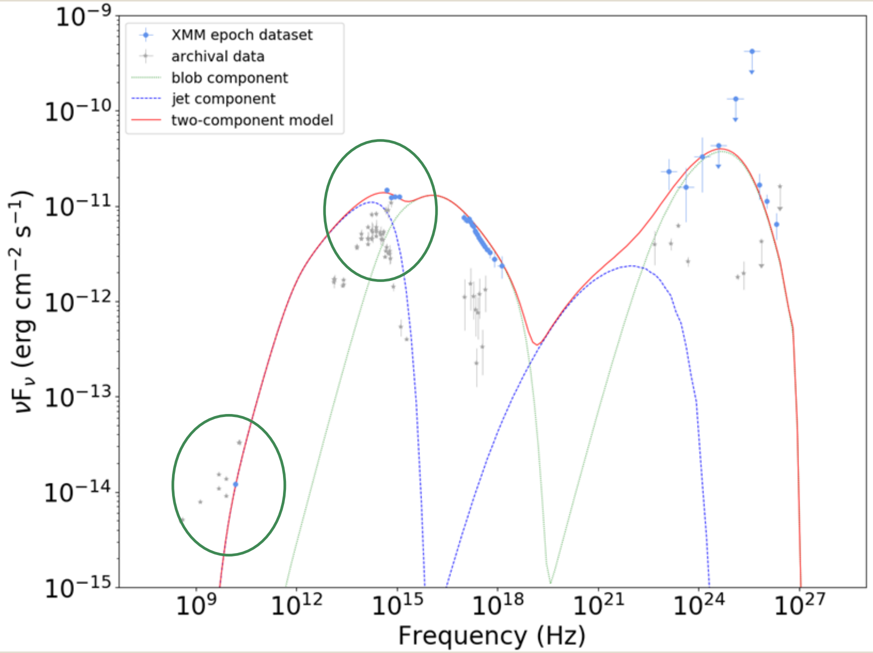
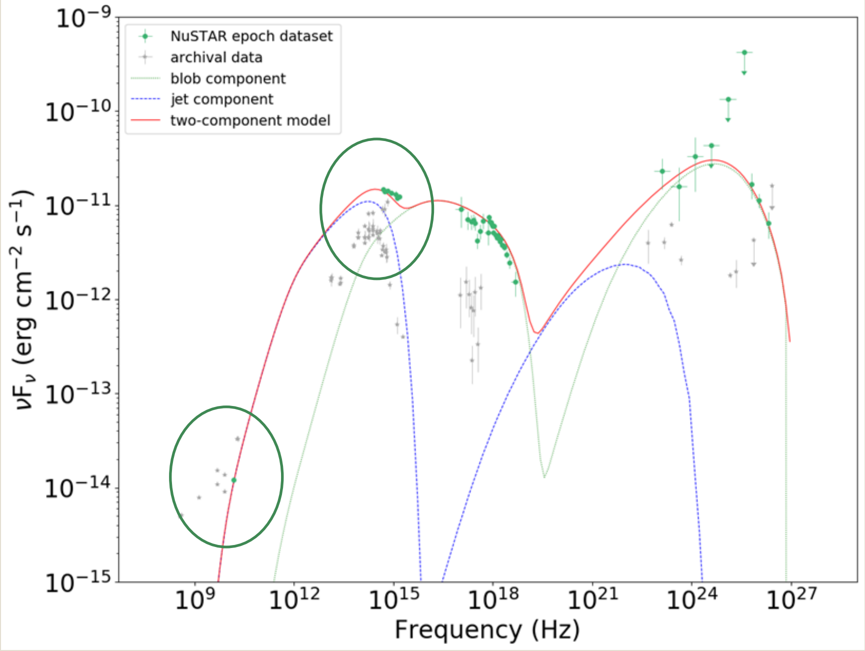
Two-component model



The evolution of the SED suggests that a new injection of e^- starts to dominate the emission



Jet component close to equipartition $U_B/U_E \sim 1$

Radio and optical data reproduced

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Why do we need two components?

- Many MWL campaign on BL Lacs → Growing evidence that the SSC model is too simple
  - Radio emission is synchrotron self absorbed → emission originates in a different region
  - Parameters always far from equipartition (see Tavecchio et al. 2016 MNRAS 456:3)
- Two interacting emission regions: small "blob" & larger "jet"
  - The blob dominates from X-ray to VHE
  - The jet models the radio and extends up to the optical band → lower energy part of the blob is constrained to lower flux levels → narrow energy range for electrons in the blob
  - If the two regions are co-spatial, additional seed photons for IC are provided
- Changes in the SED may be produced by the blob exiting from the emission region & a new one entering

Source classification

- Synchrotron peak fitted with a logparabola function
- Log of peak frequency for the 3 datasets:
  - 2014 Swift observations 13.46 ± 2.53
  - XMM: 15.28 ± 0.06
  - NuSTAR + Swift: 15.56 ± 0.11

→ Clear shift between epochs

HSP during flare, not extreme

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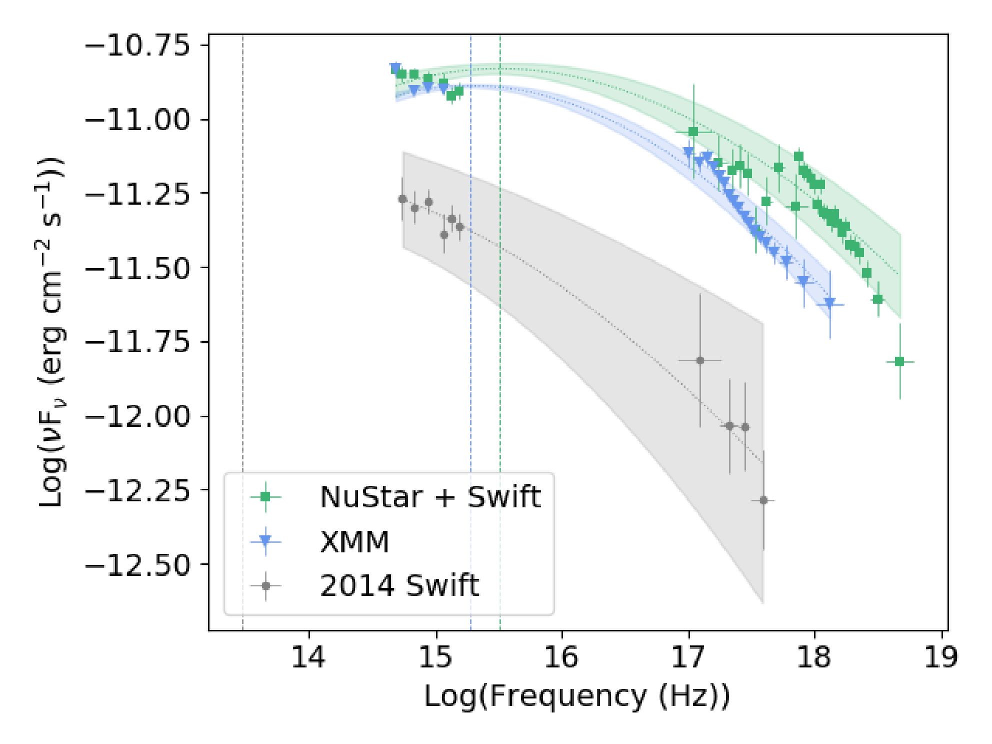

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Conclusions and discussions

- Several new hard-TeV blazars detected + Monitoring of known EHBLs
- TXS 1515-273: not extreme, only HSP during the flare
- In all cases SED modeled with SSC and/or two-component/hadronic models
- SSC generally good, but…
- In two-component model: important contribution to radio emission from the jet component
- Closer to equipartition with the two-component model
- Observational constraints + modelling of SEDs with two-component → good agreement for ISP and HSP in low and flaring state (Acciari et al. 2020 A&A 640, A132) and EHBLs (V. A. Acciari et al 2020 ApJS 247 16)
- Deep exposures of hard-TeV blazars currently on-going

THANK YOU!

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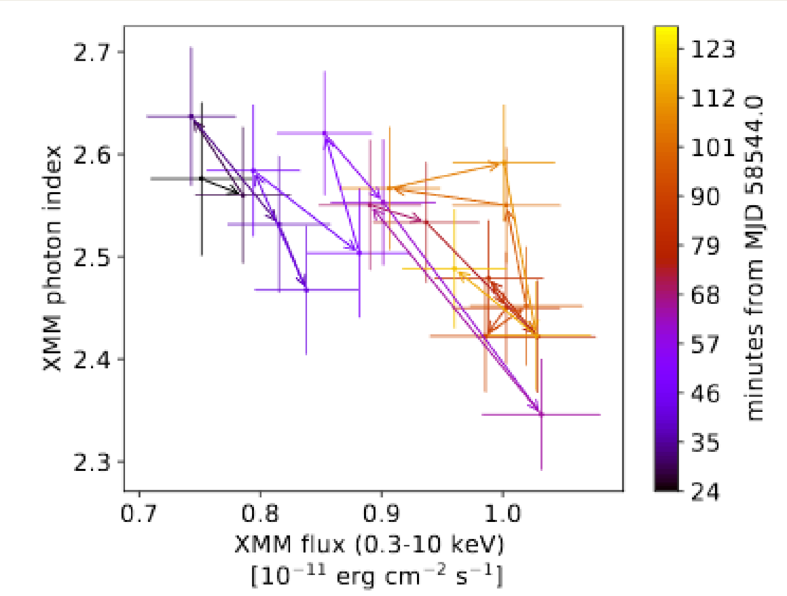
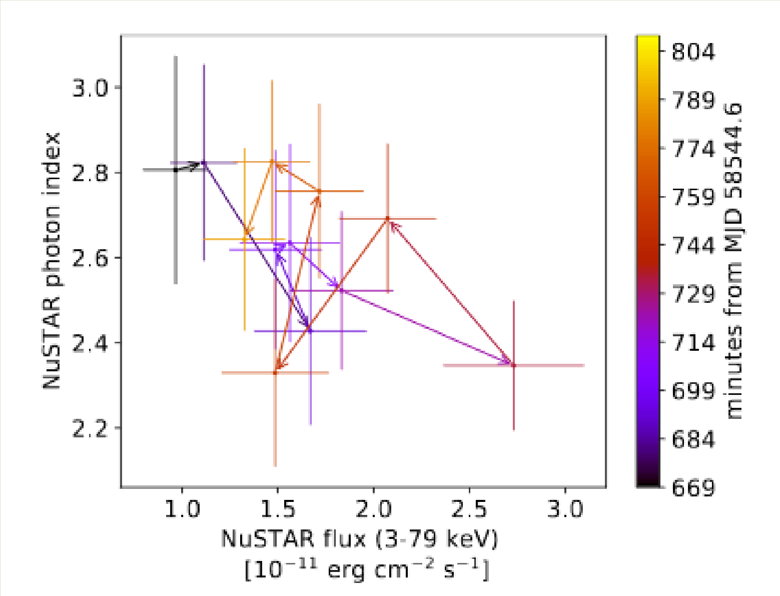
Spectral evolution

- Dependence of photon index vs flux in the full energy range of XMM and NuSTAR
- More complicated behavior than spectral hardening considering full observations
- Harder-when-brighter trend when focusing on most prominent flare time slots





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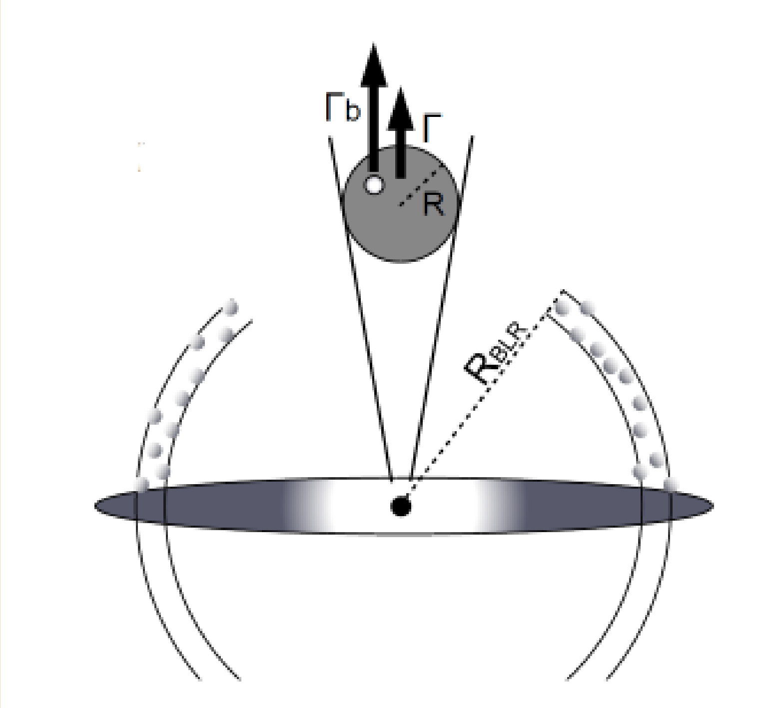
Two-component model

- Each region is filled with electron populations distributed as broken power-law
- B is assumed to be the same in the two co-spatial regions
- XMM and NuSTAR epochs very close in time → The jet (larger region) is assumed not to change from one to the other

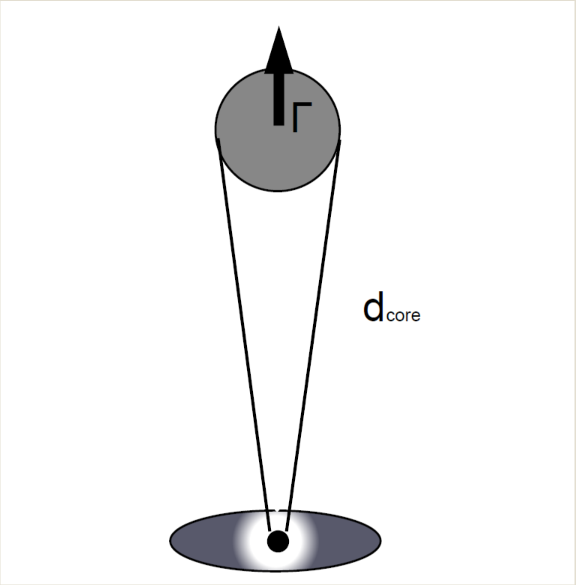


SED modeling

- Spherical blob of radius R in magnetic field B
- Electrons distributed as broken power-law

$$N(\gamma) = \begin{cases} K\gamma^{-n_1} & \text{if } \gamma < \gamma_b \\ K\gamma_b^{n_2-n_1}\gamma^{-n_2} & \text{if } \gamma > \gamma_b, \end{cases}$$

- Synchrotron self-Compton
  - Simplest case
  - Electrons accelerated in magnetic field produce synchrotron radiation
  - Inverse Compton of the synchrotron photons on the same electron population

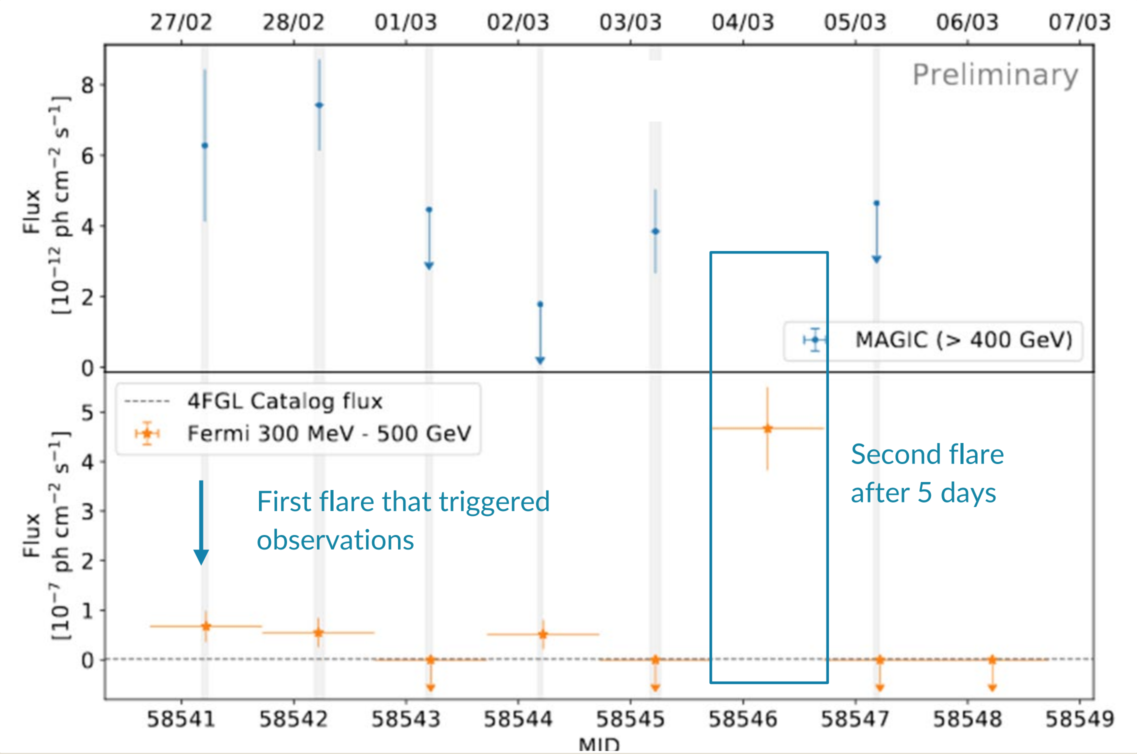


Two-component model: constraints

- 2 x parameters w.r.t. one-zone → can be constrained:
  see V.A. Acciari et al., A&A 640, A132 (2020)
  - Size and Doppler factor of the jet region from VLBI speed and variability
  - UL of the blob size from X-ray/VHE variability
  - B of the two components from cooling timescales or VLBI measurements

Fermi-LAT & MAGIC LC

- Second flare in the Fermi-LAT LC on MJD 58546
- Decided to consider Fermi data up to (and including) MJD 58545
- Smoother connection between HE and VHE



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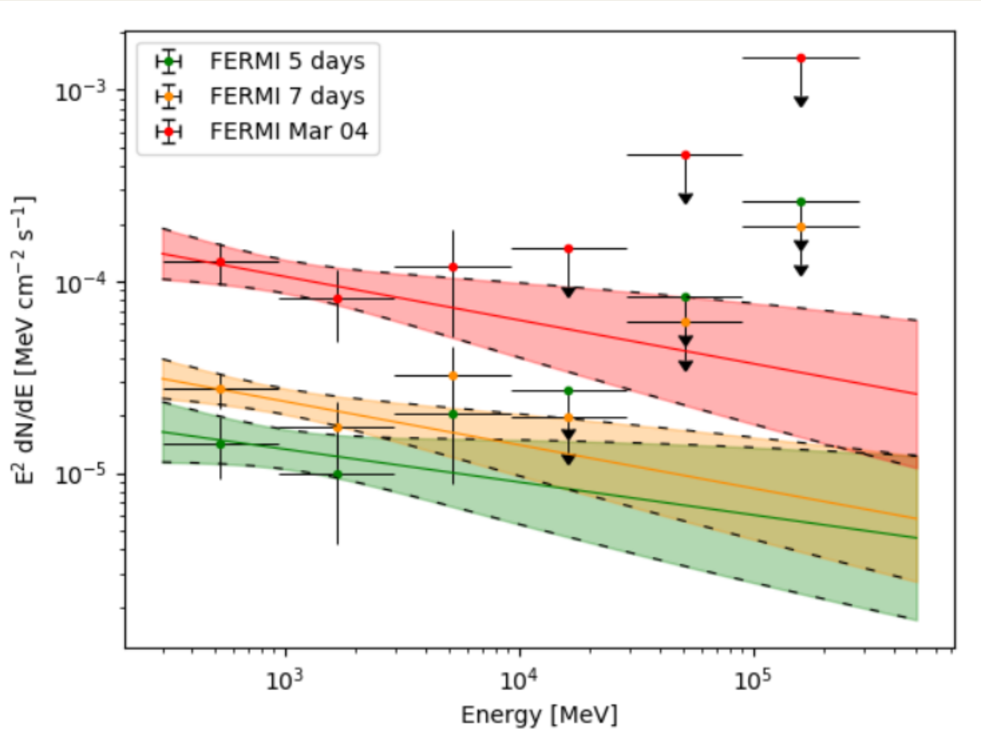
Fermi-LAT flare analysis

7 days (February 27 – March 05)
TS: 115.94
index: 2.23 ± 0.18
$N_0 = (35.21 \pm 8.22)\ 10^{-13}\ \mathrm{MeV^{-1}\ cm^{-2}\ s^{-1}}$
$f_{E>300\ \mathrm{MeV}} = (8.31 \pm 1.52)\ 10^{-8}\ \mathrm{cm^{-2}\ s^{-1}}$
5 days (February 27 – March 03)
TS: 43.40
index: 2.16 ± 0.28
$N_0 = (20.48 \pm 7.18)\ 10^{-13}\ \mathrm{MeV^{-1}\ cm^{-2}\ s^{-1}}$
$f_{E>300\ \mathrm{MeV}} = (4.46 \pm 1.34)\ 10^{-8}\ \mathrm{cm^{-2}\ s^{-1}}$
1 day (March 04)
TS: 99.00
index: 2.23 ± 0.23
$N_0 = (161 \pm 47)\ 10^{-13}\ \mathrm{MeV^{-1}\ cm^{-2}\ s^{-1}}$
$f_{E>300\ \mathrm{MeV}} = (3.79 \pm 0.92)\ 10^{-7}\ \mathrm{cm^{-2}\ s^{-1}}$

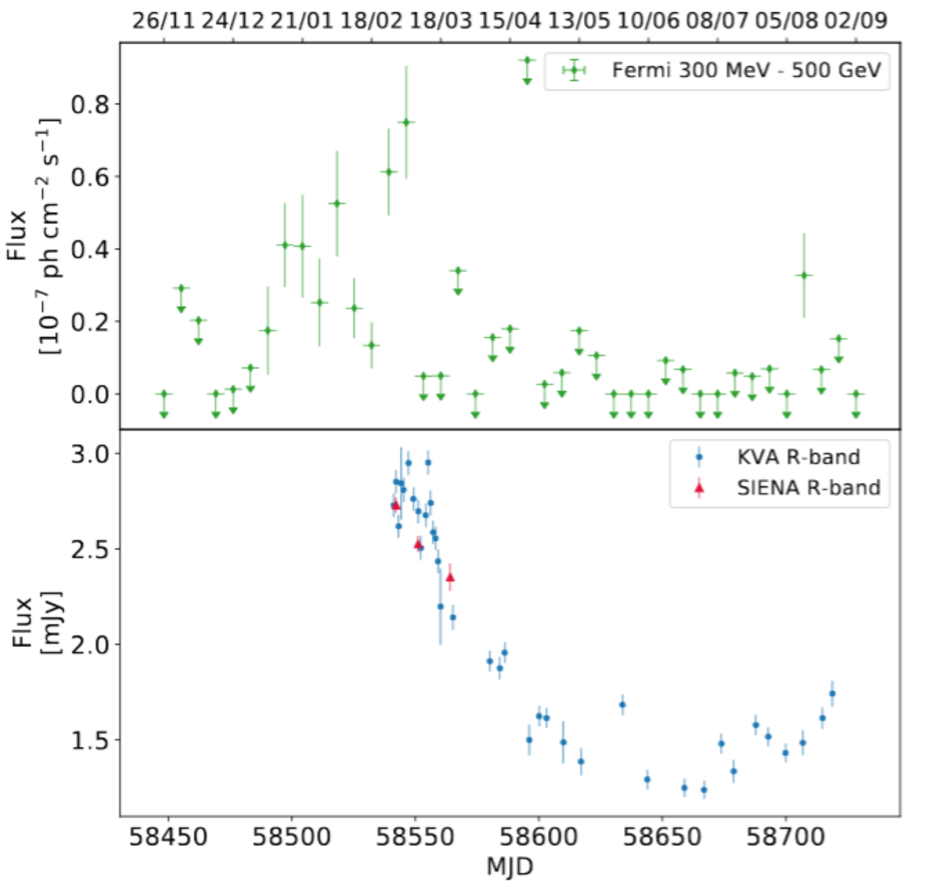
V. A. Acciari *et al* 2020 *MNRAS* **507** 1



Long term LCs in optical and HE

HE: Fermi-LAT data from Nov 2018 to Aug 2019 show the flux level increased and then dropped

Optical: KVA observations were performed for several months after the flaring activity (up to August). The flux level dropped after the flare



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Hadronic model?

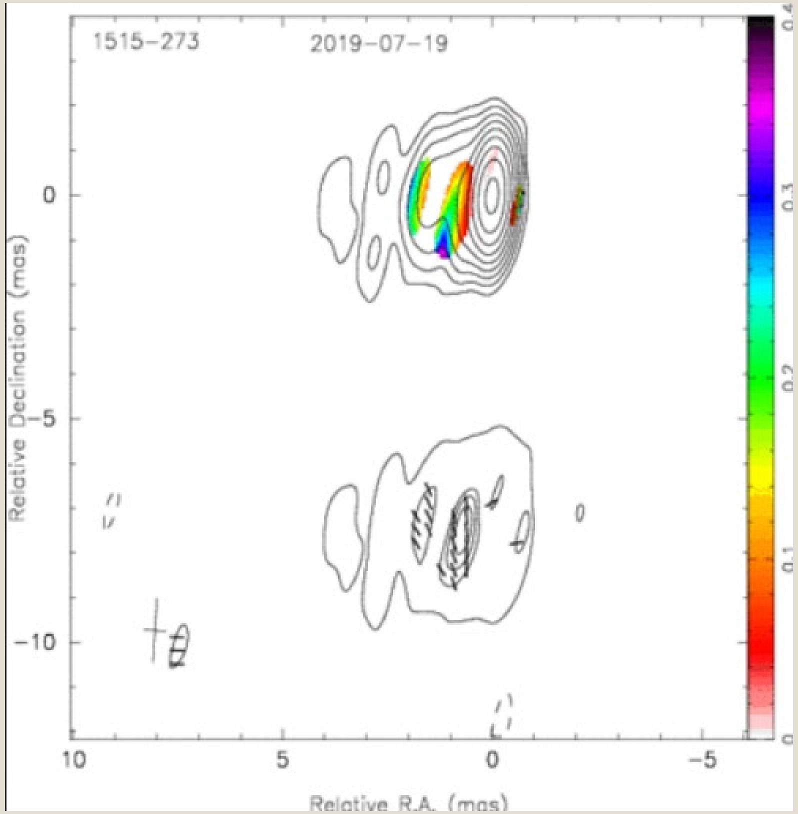
- VHE emission from blazars can be explained with hadronic and lepto-hadronic models
- Indication of a link between neutrino and EM emission from TXS 0506+056
  - Lepto-hadronic scenario: e and p accelerated in the jet, synchrotron from p leads to neutrinos
- HOWEVER
  - TXS 1515-273 seems a typical HSP in flaring state
  - No neutrino detected from its direction (also in the past)

→ only leptonic models have been investigated

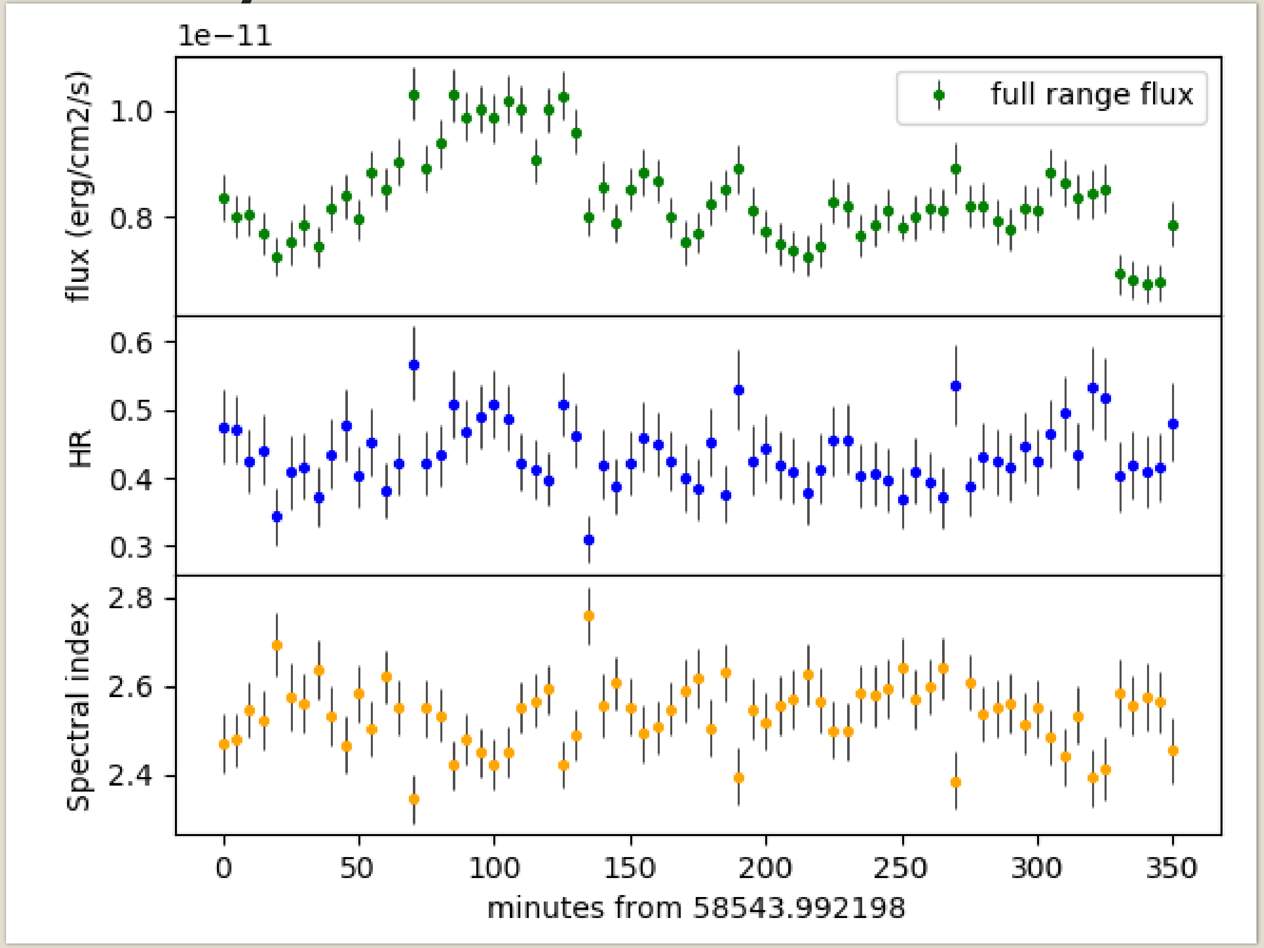
MOJAVE results

- Dedicated analysis
- 6 epochs between 2017 and 2019, closest were June and July 2019
- Polarized flux increased from 2017 to 2019
- Hint of increased core flux in the last period
- Very spare sampling makes it difficult to connect it to the flaring event

V. A. Acciari *et al* 2020 *MNRAS* **507** 1



XMM analysis



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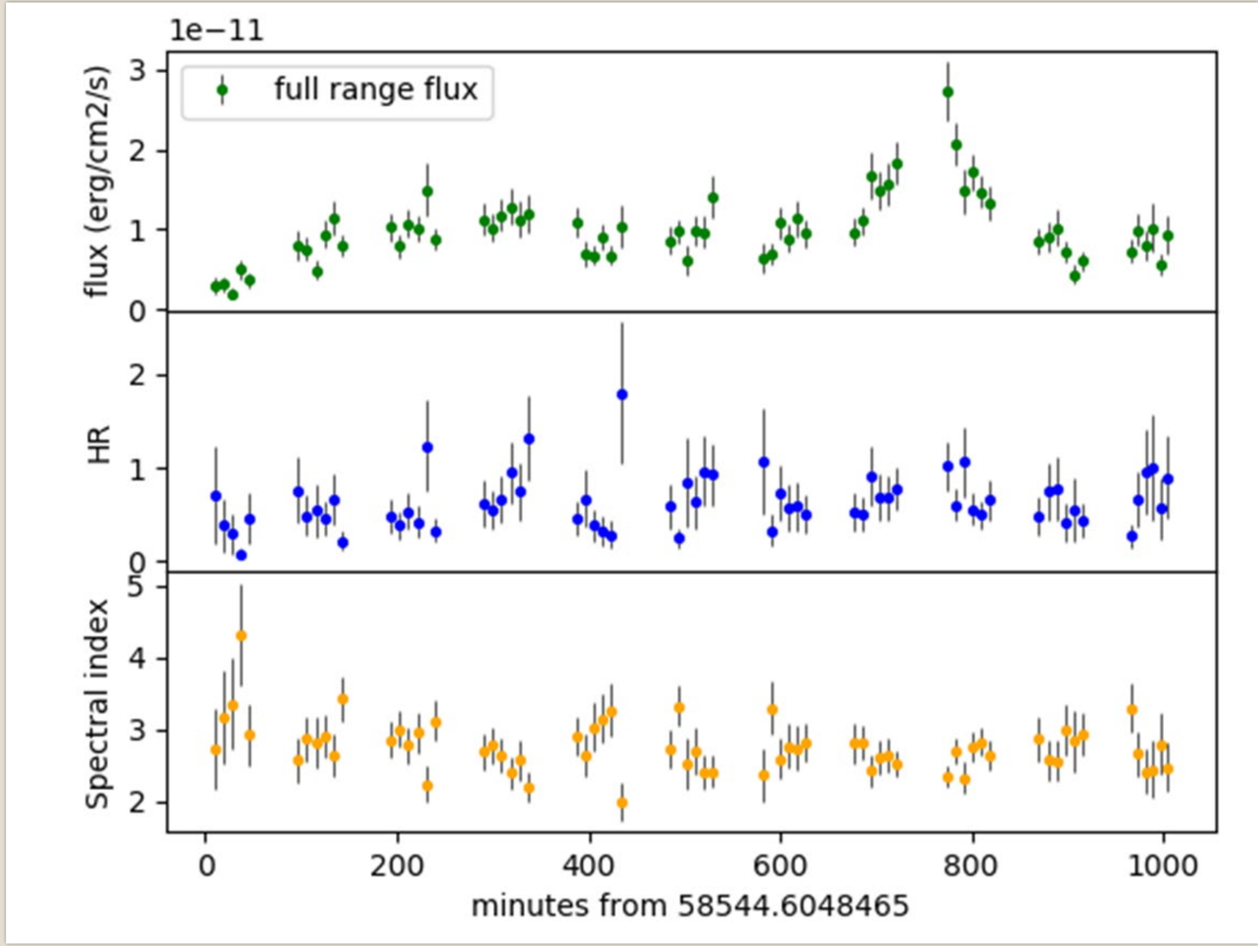
NuSTAR analysis



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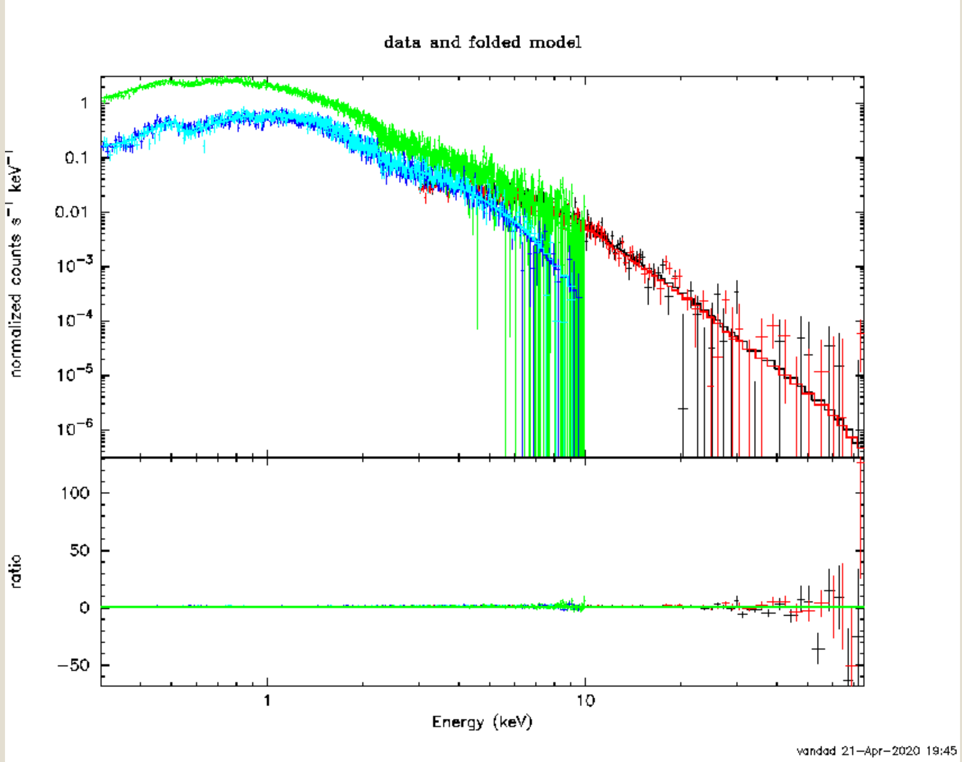
X-ray spectrum

- Joint fit: n_H = 1.679 10^{21} cm^2 calculated from XMM data, then frozen
- 5 models tested
- Broken PL was the best with:
  - $n_1 = 2.53 \pm 6.05e\text{-}3$
  - $E_b = 8.42 \pm 0.70$ keV
  - $n_2 = 3.04 \pm 0.12$



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LAT data analysis setup

- Data selection:
  - Energy range: 300 MeV – 500 GeV
  - Time range: Feb. 26 2019 – Mar. 05 2019
  - Event class: SOURCE
  - Filters: DATA_QUAL > 1 && LAT_CONFIG == 1
- Binning: 8 bins per dec, 0.08°, ROI: 12°
- Energy dispersion: -1
- Models:
  - catalog: gll_psc_v18
  - galdiff: gll_iem_v07
  - isodiff: iso_P8R3_SOURCE_V2_v1
- IRFS: P8R3_SOURCE_V2

- Fermitools version 1.2.1
- Fermipy version 0.18.0