Discovery of TXS 1515-273 at VHE gamma rays and modelling of its Spectral Energy Distribution

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On behalf of the Fermi-LAT and MAGIC collaborations

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TXS 1515 – 273

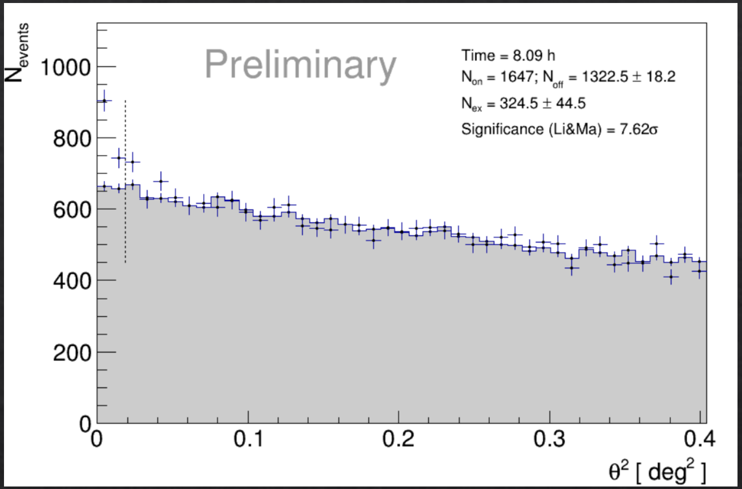
- Present in 2FGL and 3FGL as blazar candidate of uncertain type (BCU)
- Classified as BL Lac object in 4FGL
  - Photon index ~ 2 → EHBL candidate?
    - Search for new VHE gamma-ray emitter
- z = 0.1285 (Goldoni et al. 2020 A&A 650 A106, Becerra González et al. 2020 MNRAS 504:4)
- Flaring activity reported 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

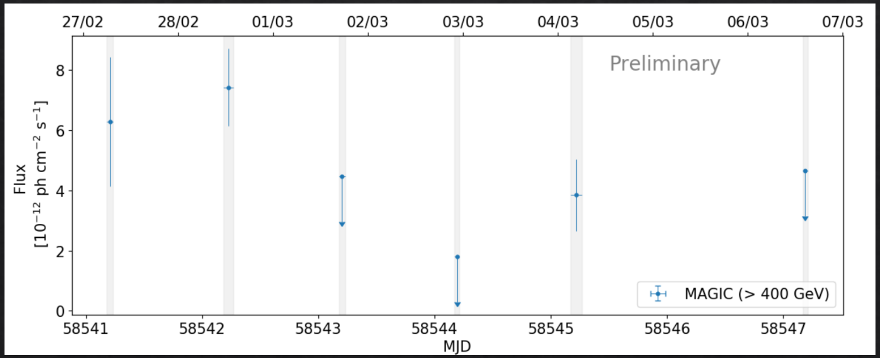
Detection of sub-TeV gamma-ray emission from the flaring blazar TXS 1515-273 with the MAGIC telescopes

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

VHE detection

- 6 nights between Feb 27 and Mar 05
- 8.1 hours
- Observations under moderate moonlight
- High zenith distance (55°-60°)
- 7.6 sigma detection





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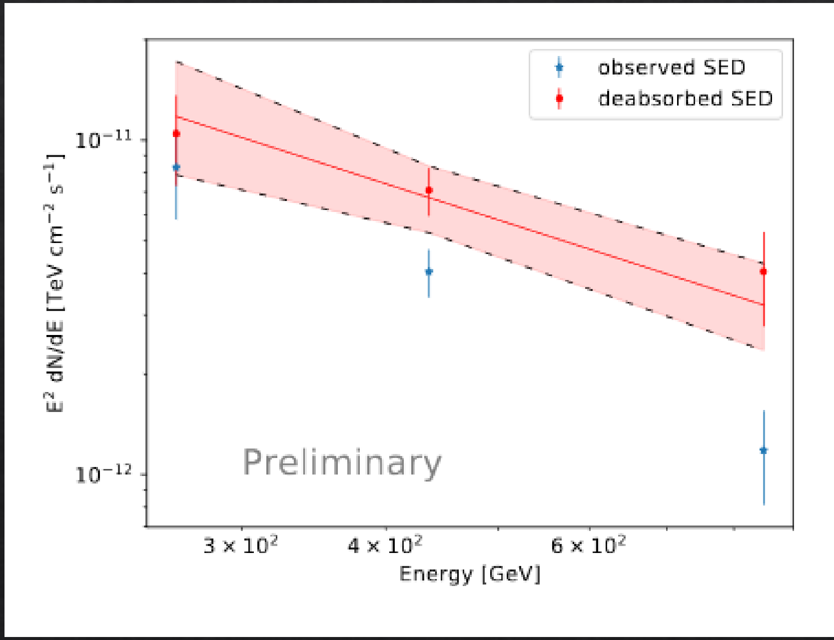
VHE spectrum

- 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 frequencies

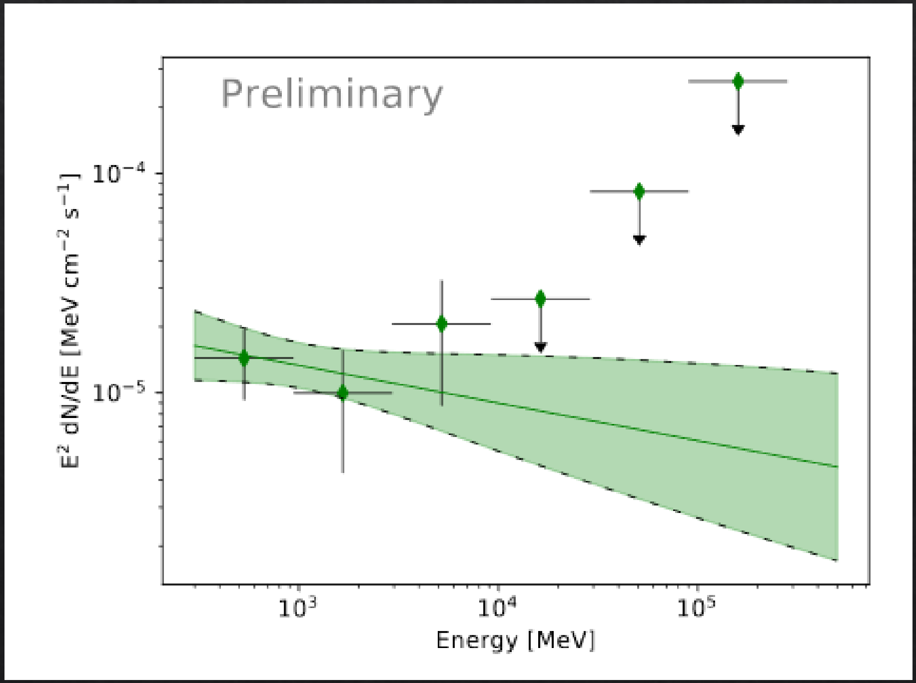


LAT setup

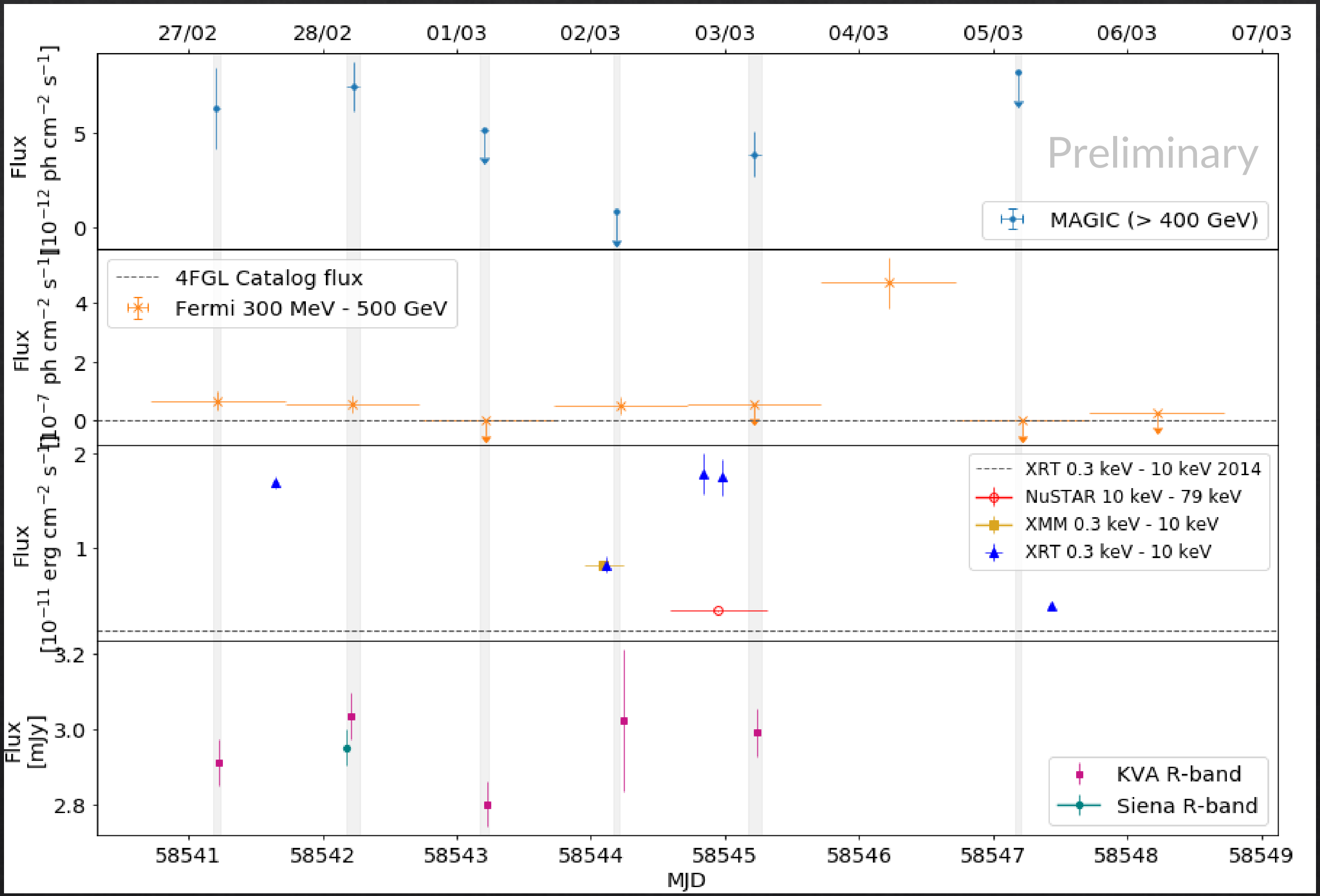
- Data selected in 300 MeV – 500 GeV energy range between Feb. 27 and Mar. 05
- Sources with TS > 10 within 5° of TXS 1515-273 set free in the fit (‘norm’ parameter)
- Sources with TS < 4 not taken into account
- Sources with 4 < TS < 10 fixed to 4FGL values
- TXS 1515-273, galactic and isotropic diffuse models set free
- LC computed in daily bins

HE spectrum

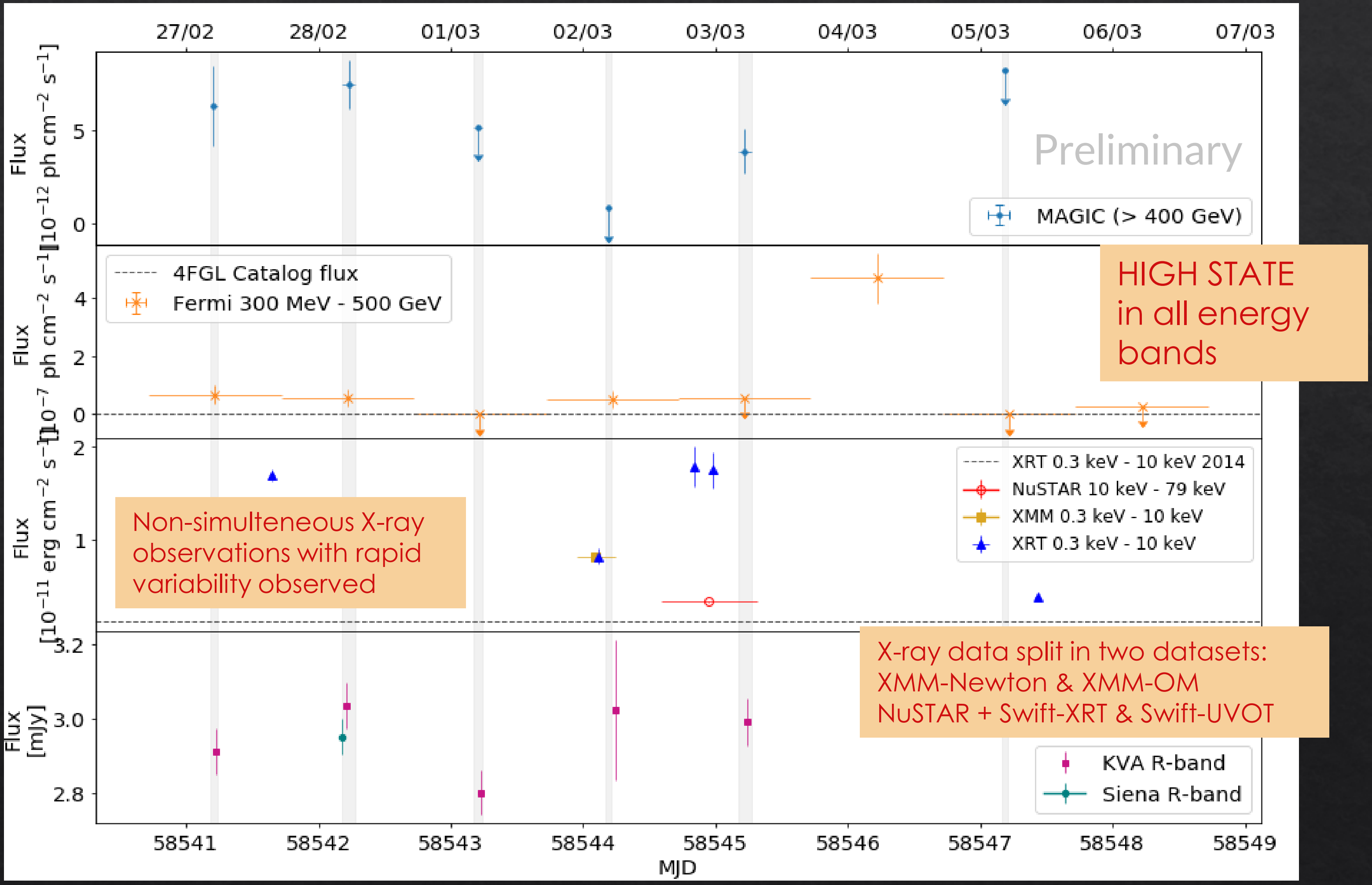
- Evaluated between Feb 27 and Mar 04 to have a smoother connection to VHE data
- Γ: 2.16 ± 0.28
- $N_0 = (20.48 \pm 7.18) \times 10^{-13}\ \mathrm{MeV^{-1}\ cm^{-2}\ s^{-1}}$
- $f_{E>300\ \mathrm{MeV}} = (4.46 \pm 1.34) \times 10^{-8}\ \mathrm{cm^{-2}\ s^{-1}}$



MWL lightcurve



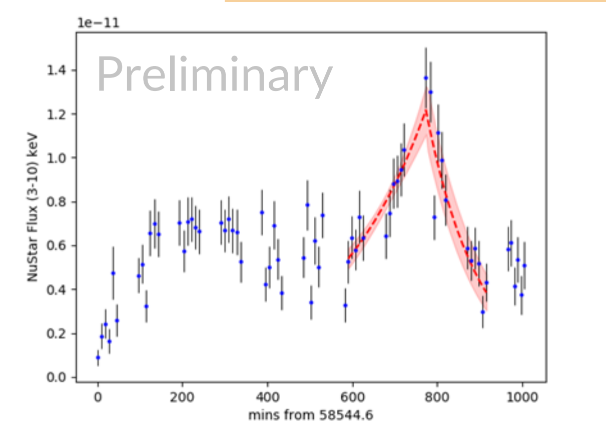
MWL lightcurve



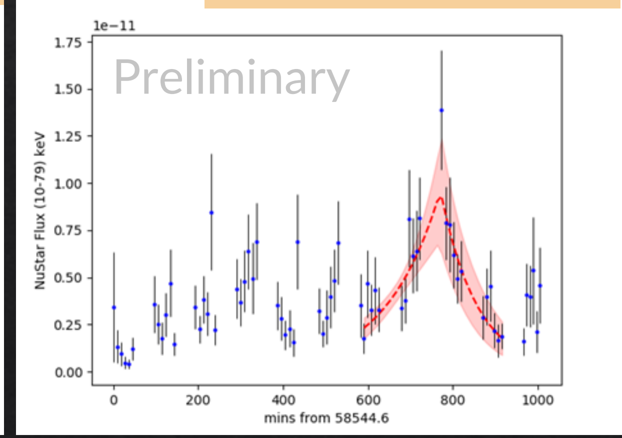
X-ray variability

- 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



Constraints on the emission region

- Shortest time scale variability used to constrain the size of the emission region $R \leq \frac{c t_{\mathrm{var}} \delta}{(1+z)}$
- 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)

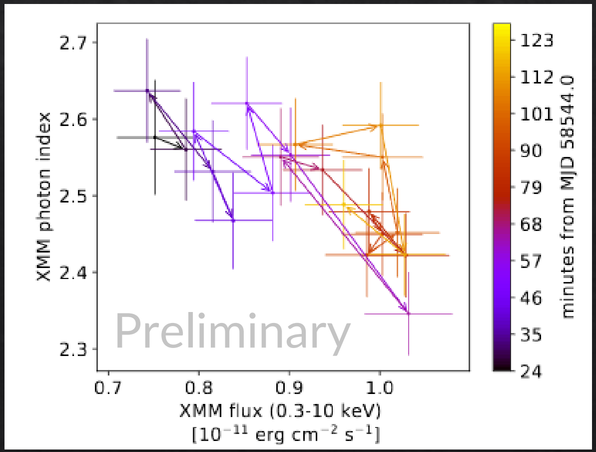
$$B = 210 \times \left(\frac{1+z}{E_l \times \delta}\right)^{1/3} \left[\frac{1-(E_l/E_h)^{1/2}}{\tau_{\mathrm{soft}}}\right]^{2/3} \quad \mathrm{G}$$

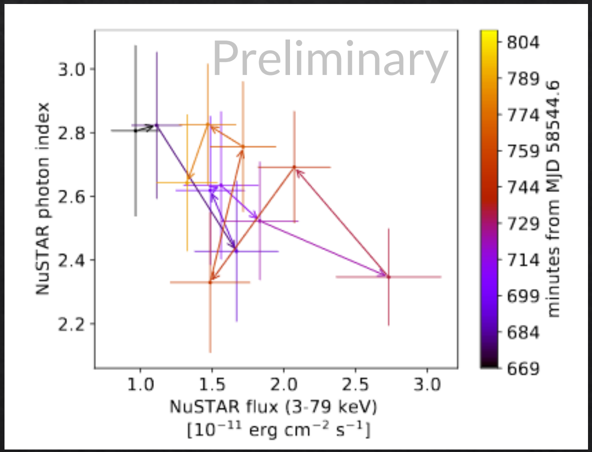
$$\tau_{\mathrm{soft}} = t_{\mathrm{decay,XMM}} - t_{\mathrm{decay,NuSTAR}}$$

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

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

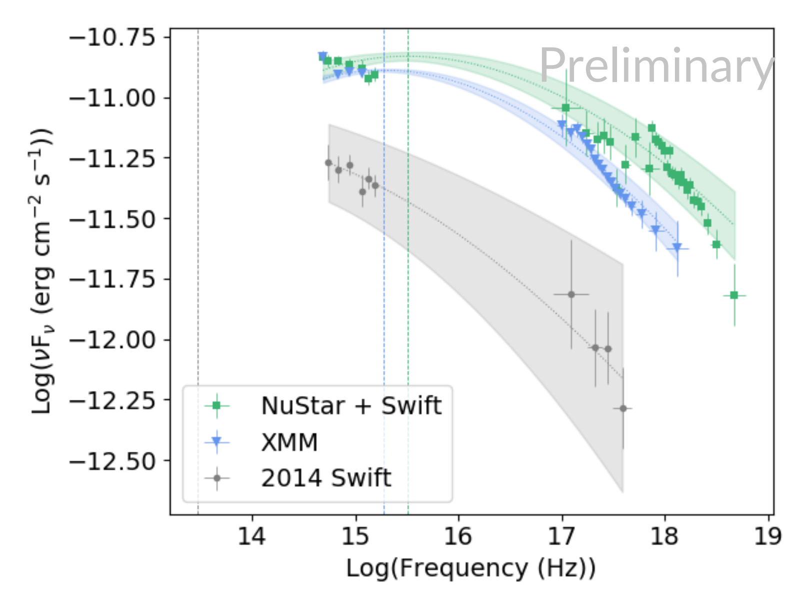




Source classification

- 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

No conclusion for 2014 data

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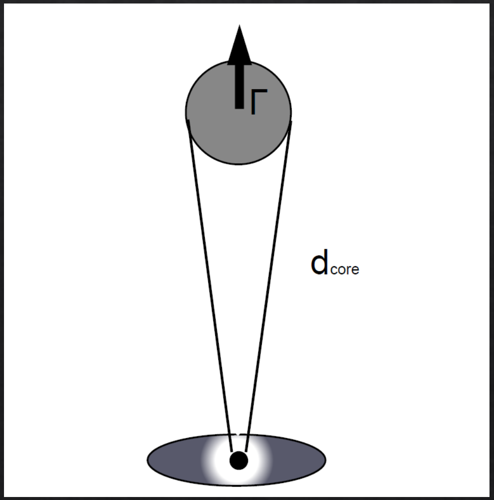
SED modeling

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

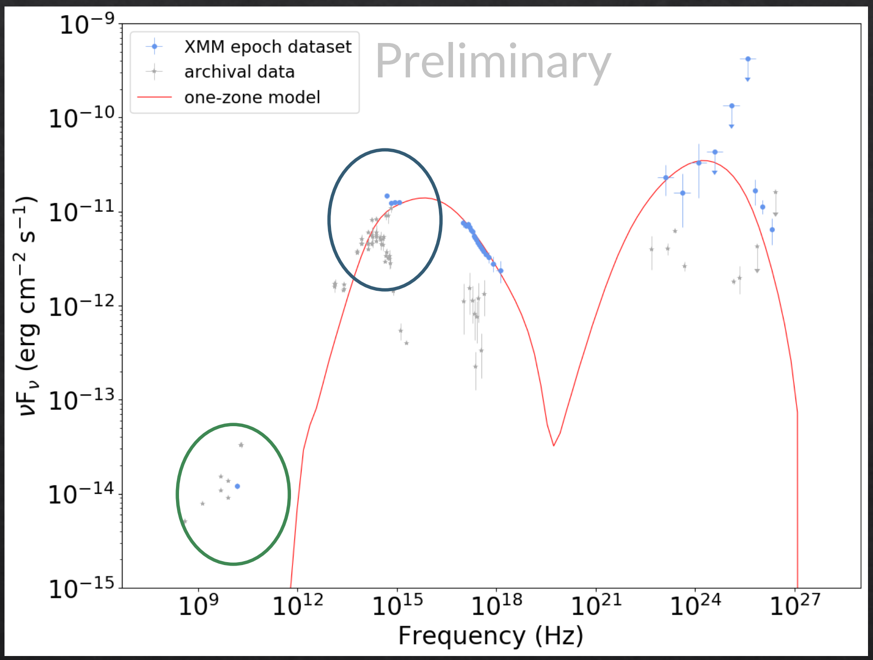
$$N(\gamma) = \begin{cases} K\gamma^{-n_1} & \text{if } \gamma < \gamma_b \\ K\gamma_b^{n_2-n_1}\gamma^{-n_2} & \text{if } \gamma > \gamma_b, \end{cases}$$

- Synchrotron self-Compton



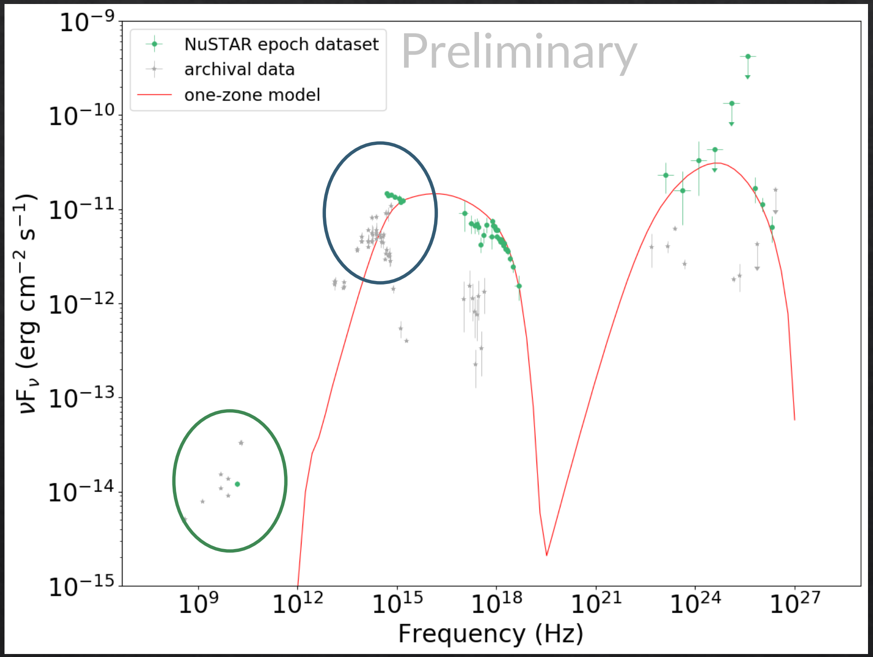
- Simplest case
- Electrons accelerated in magnetic field produce synchrotron radiation
- Inverse Compton of the synchrotron photons on the same electron population

SED modeling with SSC



Not very good agreement with optical data

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



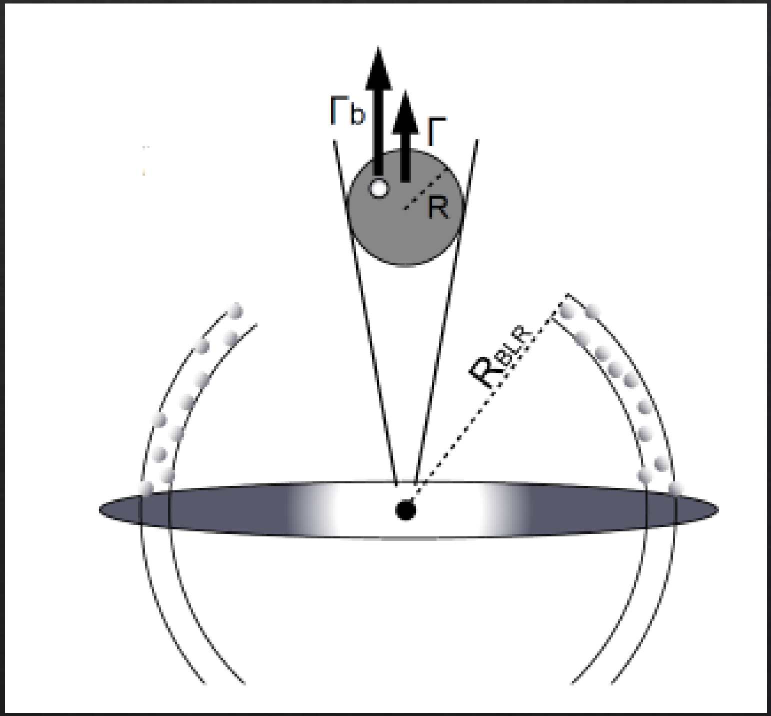
VLBA radio data not reproduced (expected due to synchrotron self absorption)

Why do we need two components?

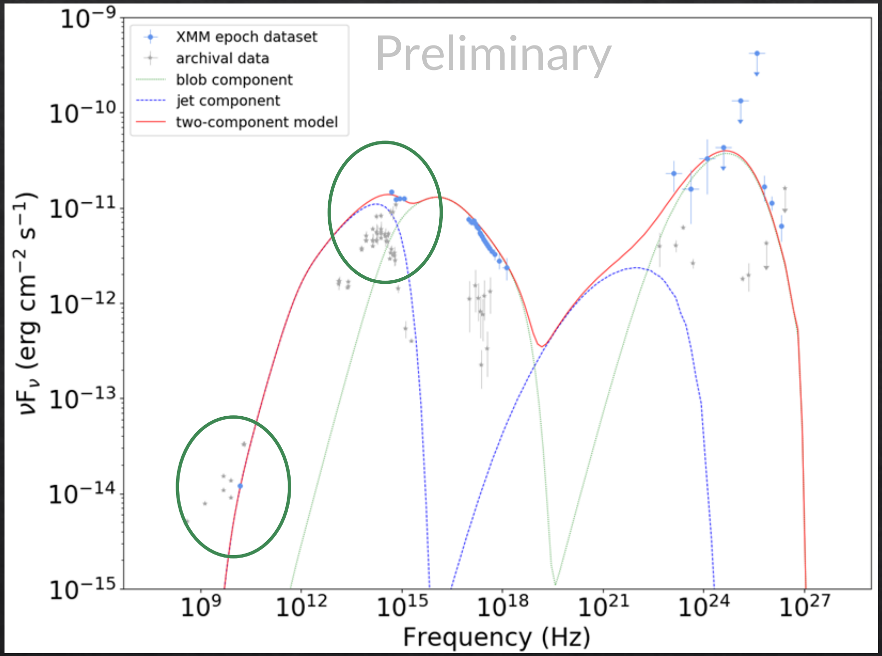
- Many MWL campaign on BL Lacs → Growing evidence that the SSC model is too simple
  - Radio emission is synchrotron self absorbed → emission originates in a different region
  - Parameters always far from equipartition (see Tavecchio et al. 2016 MNRAS 456:3)
- Two interacting emission regions: small "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
- Solution closer to equipartition can be found
- Observational constraints + modelling of SEDs with two-component → good agreement for ISP and HSP in low and flaring state (see Acciari et al. 2020 A&A 640, A132)

Two-component model

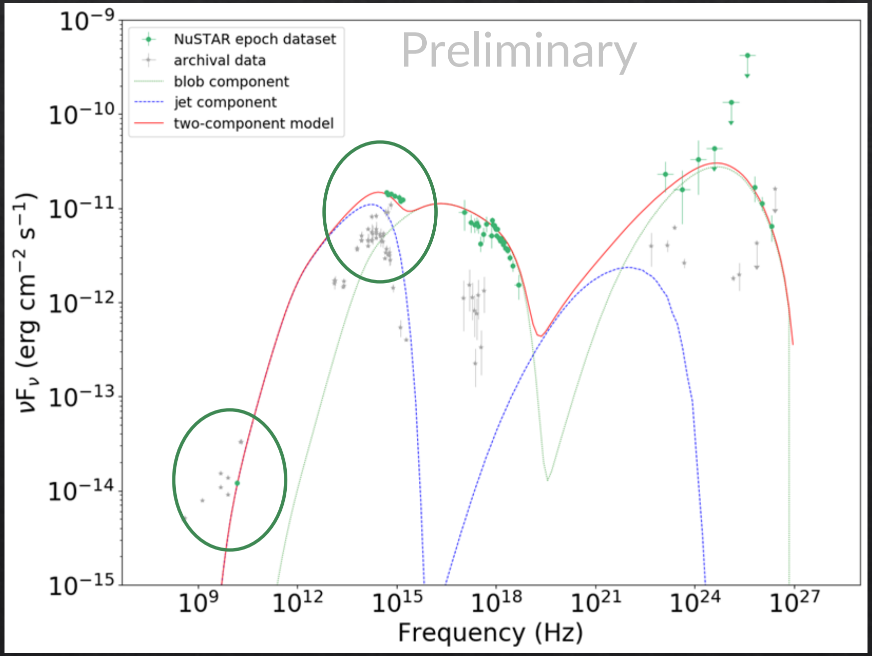
- Each region is filled with electron populations distributed as broken power-law
- B is assumed to be the same in the two co-spatial regions
- XMM and NuSTAR epochs very close in time →
  The jet is assumed not to change from one to the other



SED modeling with two-component model



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



Radio and optical data reproduced

Conclusions and discussions

- Flaring state in all energy bands
- First detection at VHE gamma rays with MAGIC
- Short time scale variability in the X-rays
- Source classified as HSP (not EHBL) during flare with shift of the synchrotron peak frequency to higher energies in a timescale of less than a day
- SED modeled with one-zone and two-component models
- The evolution of the SED between epochs suggests that a new injection of e^- starts to dominate the emission
- Good agreement with data with the two-component model
  - Important contribution to radio emission from the jet
  - Jet in equipartition

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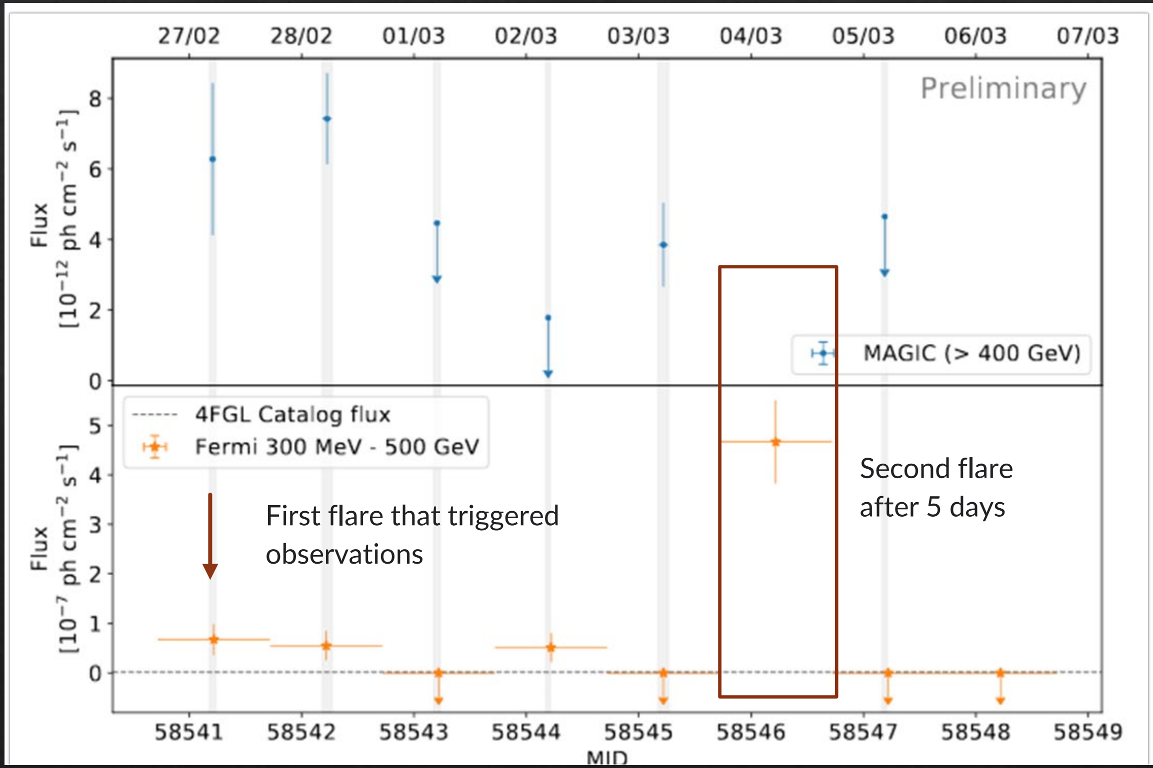
THANK YOU!

Two-component model: constraints

- 2 x parameters w.r.t. one-zone → can be constrained: see 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



Fermi-LAT flare analysis

7 days (February 27 – March 05)

TS: 115.94

index: 2.23 ± 0.18

$N_0 = (35.21 \pm 8.22)\ 10^{-13}\ MeV^{-1}\ cm^{-2}\ s^{-1}$

$f_{E>300\ MeV} = (8.31 \pm 1.52)\ 10^{-8}\ cm^{-2}\ s^{-1}$

5 days (February 27 – March 03)

TS: 43.40

index: 2.16 ± 0.28

$N_0 = (20.48 \pm 7.18)\ 10^{-13}\ MeV^{-1}\ cm^{-2}\ s^{-1}$

$f_{E>300\ MeV} = (4.46 \pm 1.34)\ 10^{-8}\ cm^{-2}\ s^{-1}$

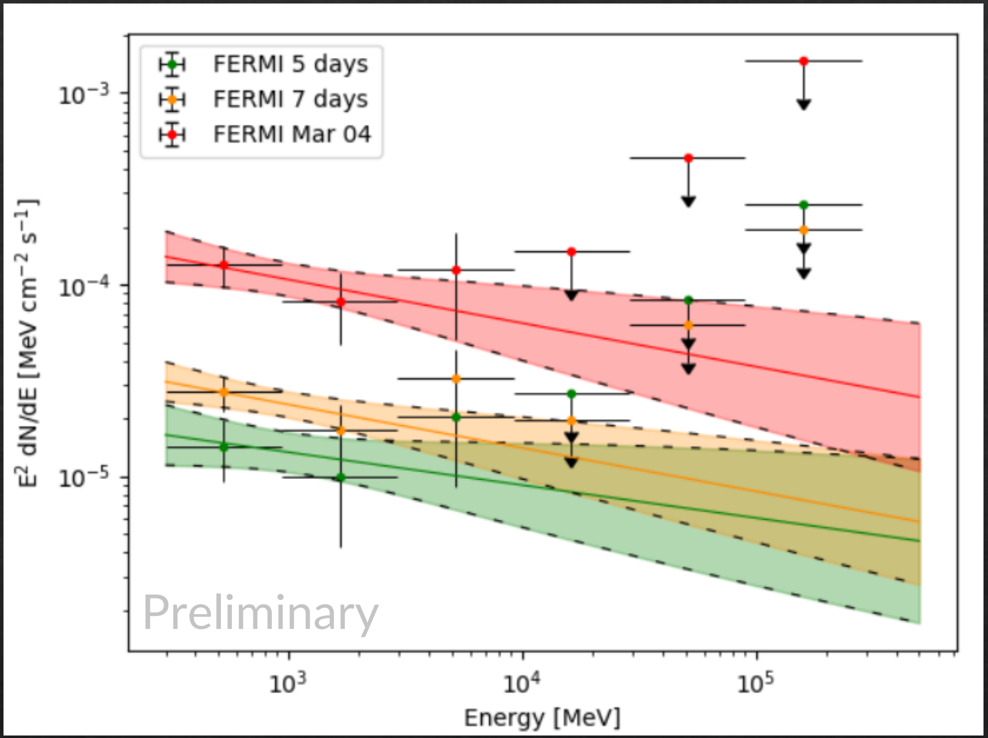
1 day (March 04)

TS: 99.00

index: 2.23 ± 0.23

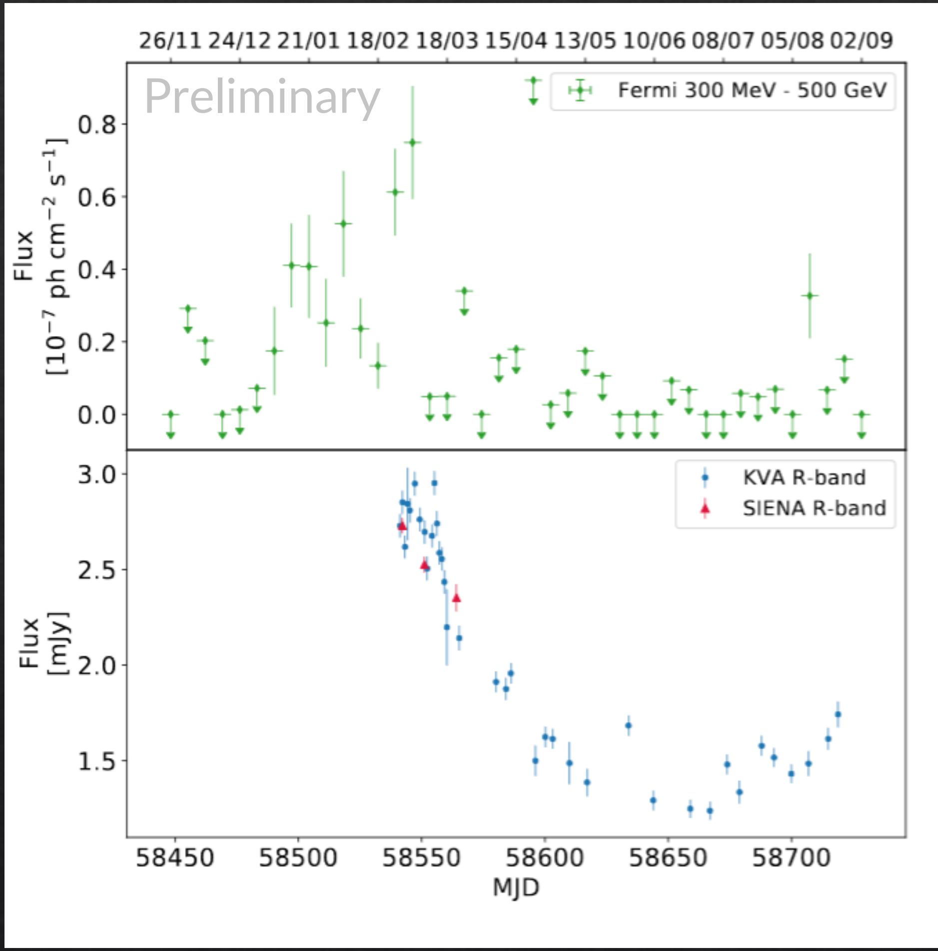
$N_0 = (161 \pm 47)\ 10^{-13}\ MeV^{-1}\ cm^{-2}\ s^{-1}$

$f_{E>300\ MeV} = (3.79 \pm 0.92)\ 10^{-7}\ cm^{-2}\ s^{-1}$

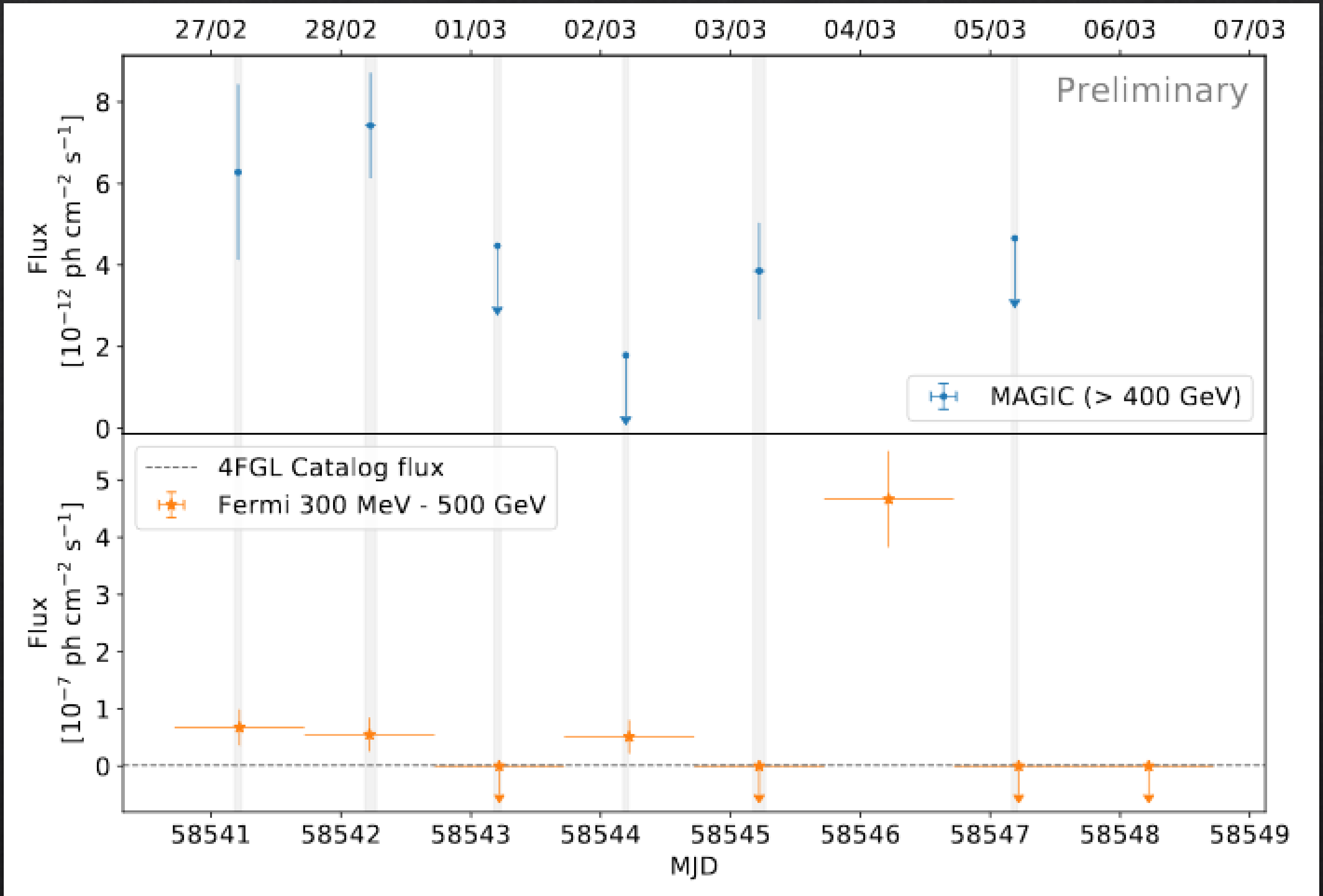


Long term LCs in optical and HE

- 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 (up to August). The flux level dropped after the flare



VHE & HE light curve



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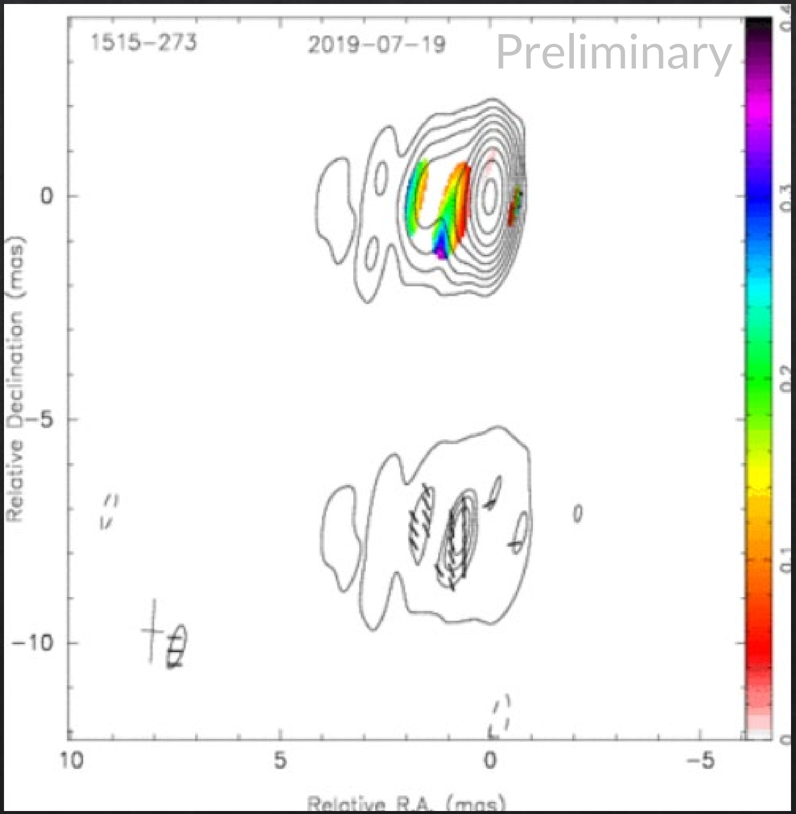
Hadronic model?

- 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)

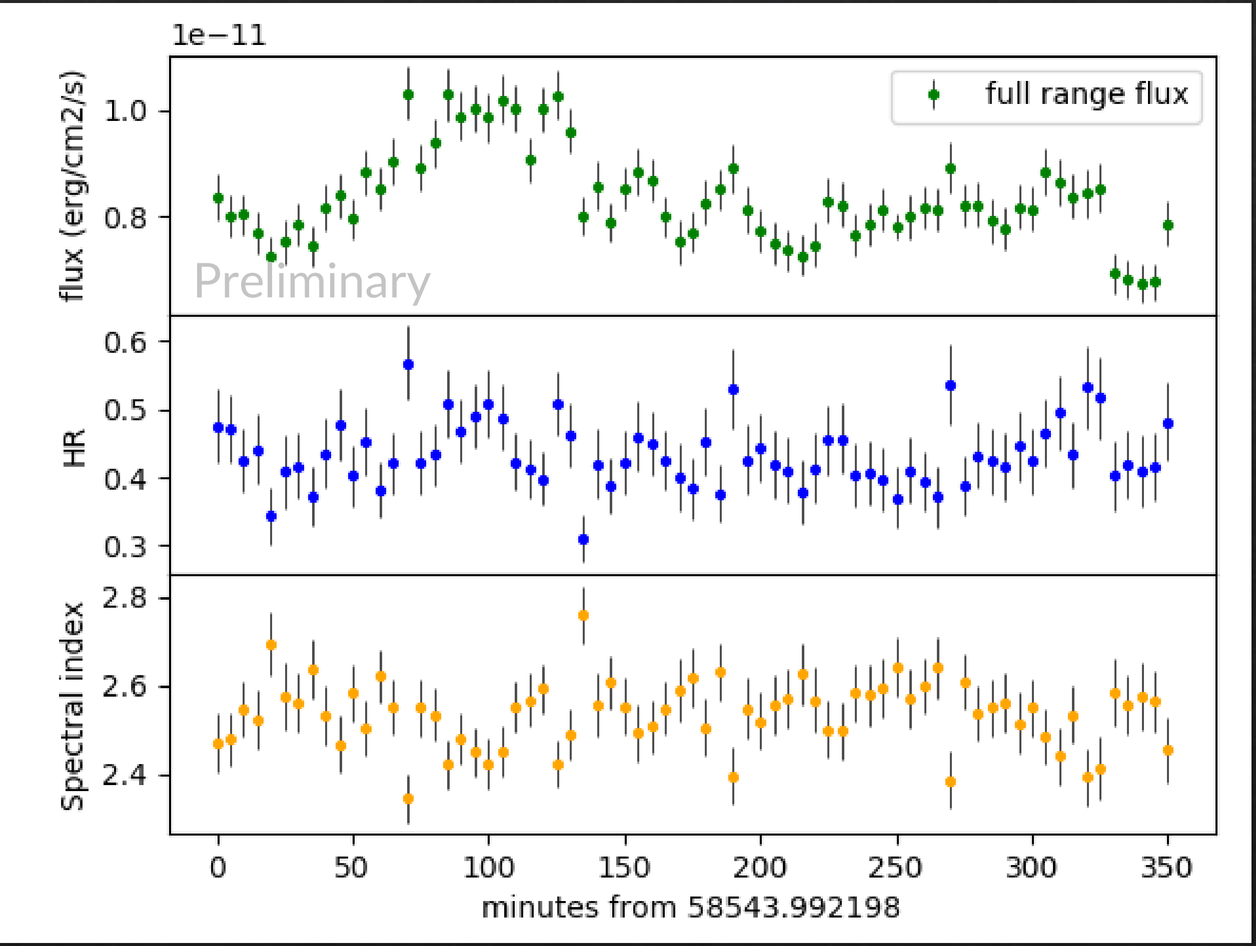
→ only leptonic models have been investigated

MOJAVE results

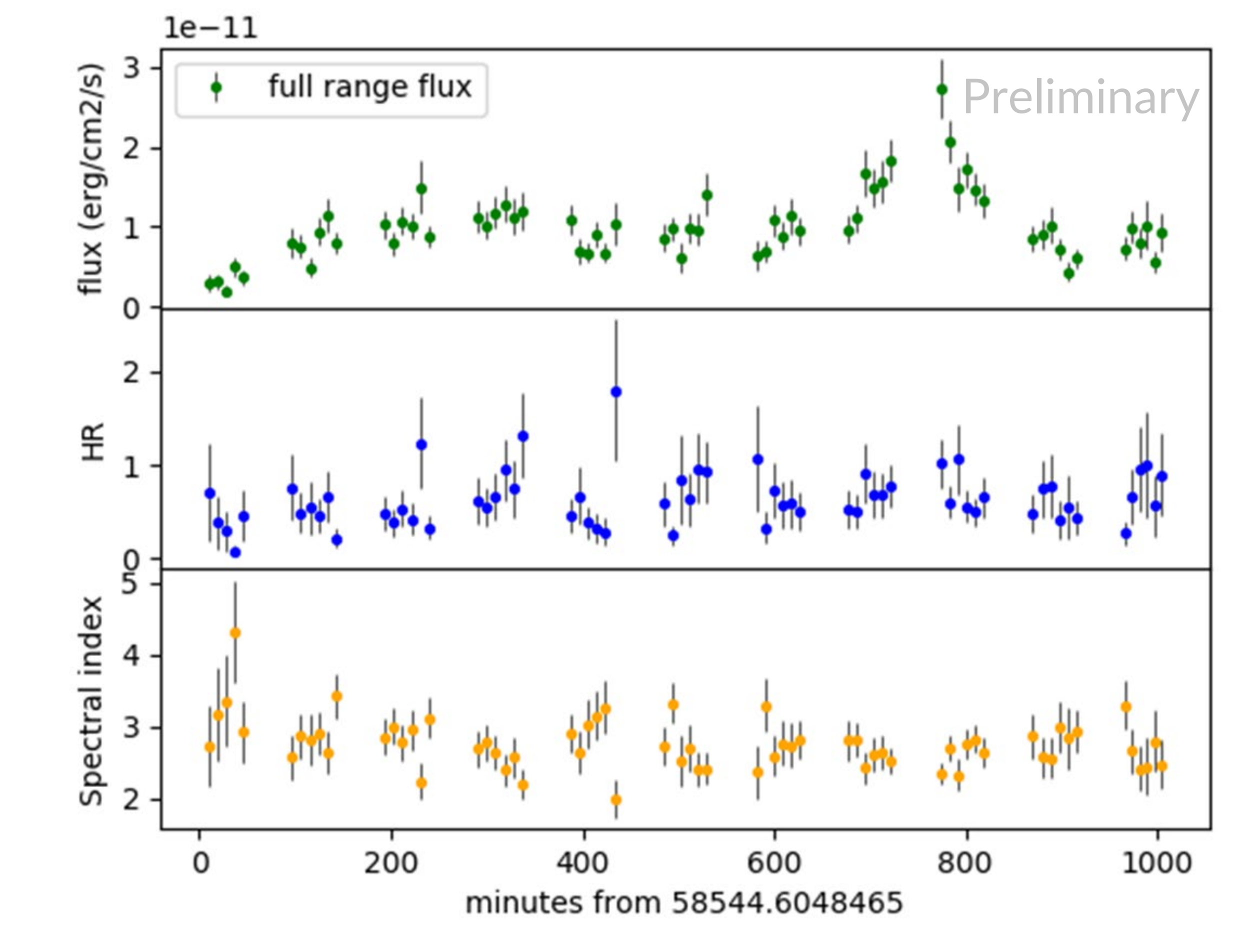
- Dedicated analysis
- 6 epochs between 2017 and 2019, closest were June and July 2019
- Polarized flux increased from 2017 to 2019
- Hint of increased core flux in the last period
- Very spare sampling makes it difficult to connect it to the flaring event



XMM analysis

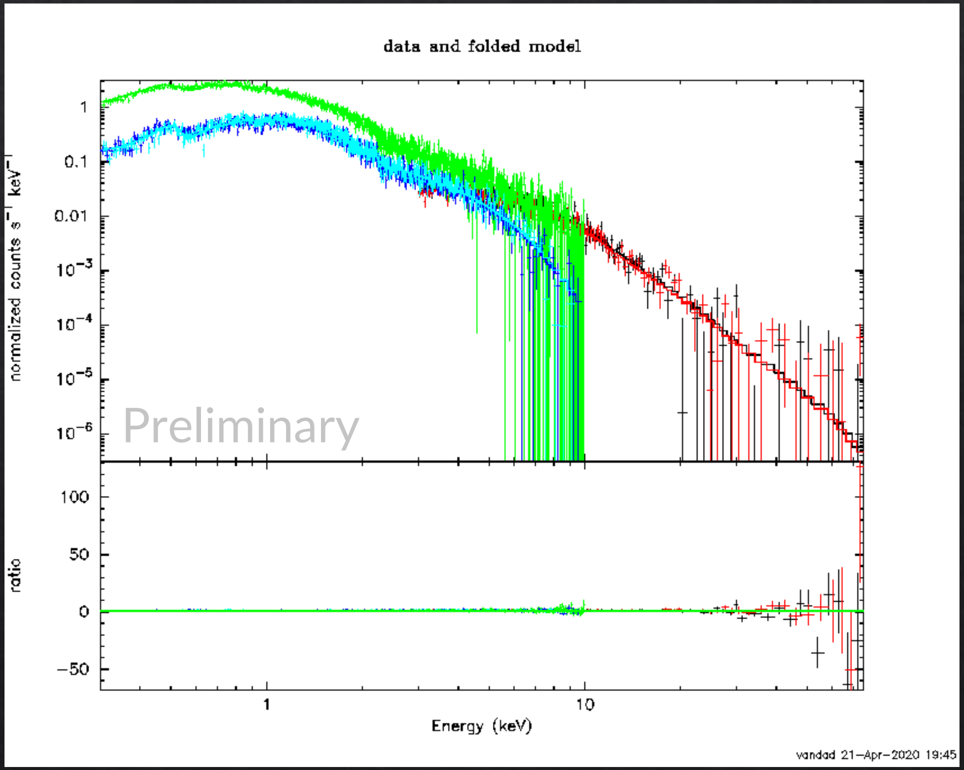


NuSTAR analysis



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
  - $n_2 = 3.04 \pm 0.12$



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

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