



MAGIC in the multi-messenger Universe: latest news from the neutrino blazar TXS 0506+056

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Multimessenger and neutrino astrophysics

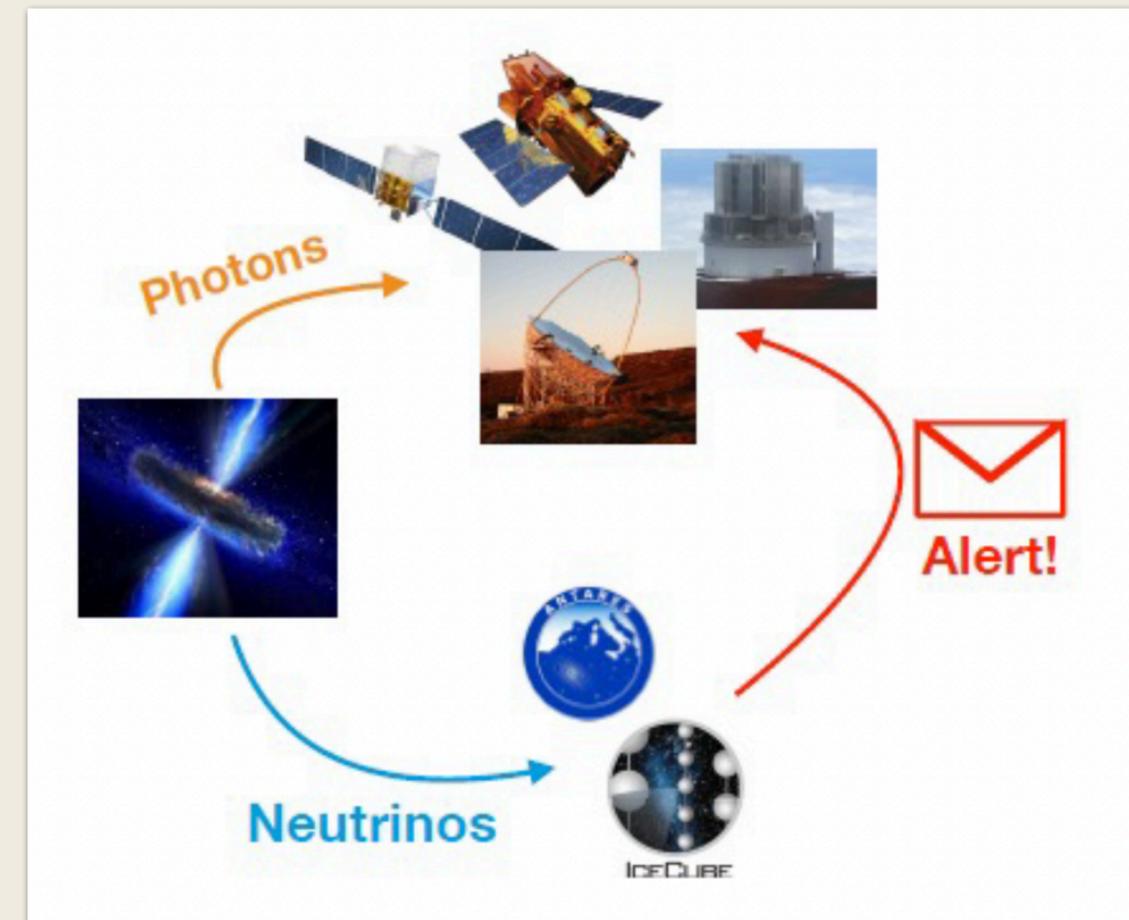
- Cosmic-rays, photons and neutrinos from same sources
- All-sky astrophysical neutrino flux suggests extragalactic origin
- AGNs among promising candidate neutrino emitters
- Emission processes and precise composition of blazar jets are still unknown
 - ▶ Leptonic and hadronic emission schemes
 - ▶ Neutrino production possible only with hadronic interactions

Important to find neutrino sources:

- Spatial and temporal correlations between neutrinos and photons can trace the origin of cosmic-rays

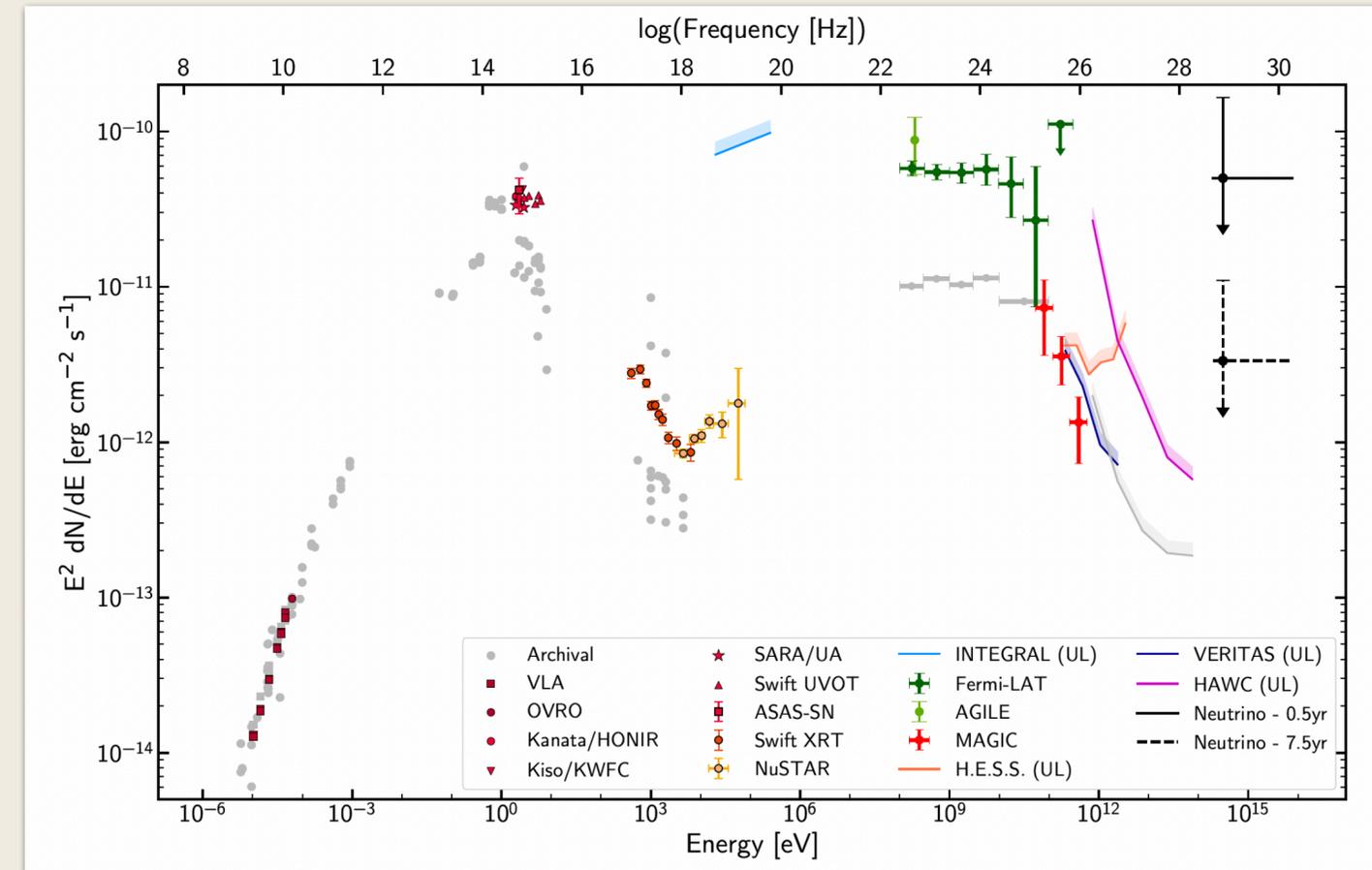
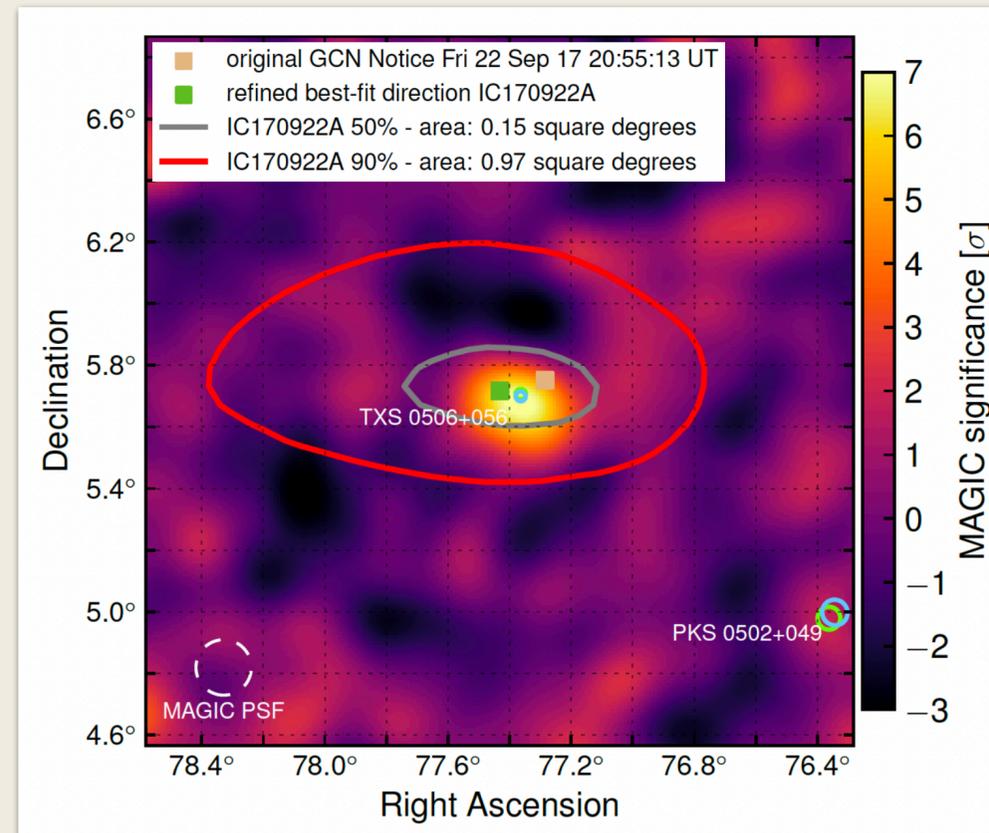
Multimessenger and neutrino astrophysics

- ❖ Contribution from different instruments needed:
 - Neutrino telescopes: alert emission
 - Telescopes for EM radiation: alert response
- ❖ Alerts from IceCube to MAGIC:
 - Neutrino clusters, $E > 100$ GeV
 - Single high energy tracks, $E > 60$ TeV



TXS 0506+056

First evidence of the electromagnetic counterpart of a neutrino source



Most significant association (3σ) of a high-energy (~290 TeV) neutrino with an astrophysical source

First multimessenger SED!

TXS 0506+056

- Blazar source
- Poorly studied object before neutrino event
- Information only from survey instruments, like *Fermi/LAT* and OVRO
- Redshift $z=0.336$ (Paiano et al., 2018)
- Among the brightest 5% of blazars detected in HE γ -rays
- One of the most luminous objects known up to this distance



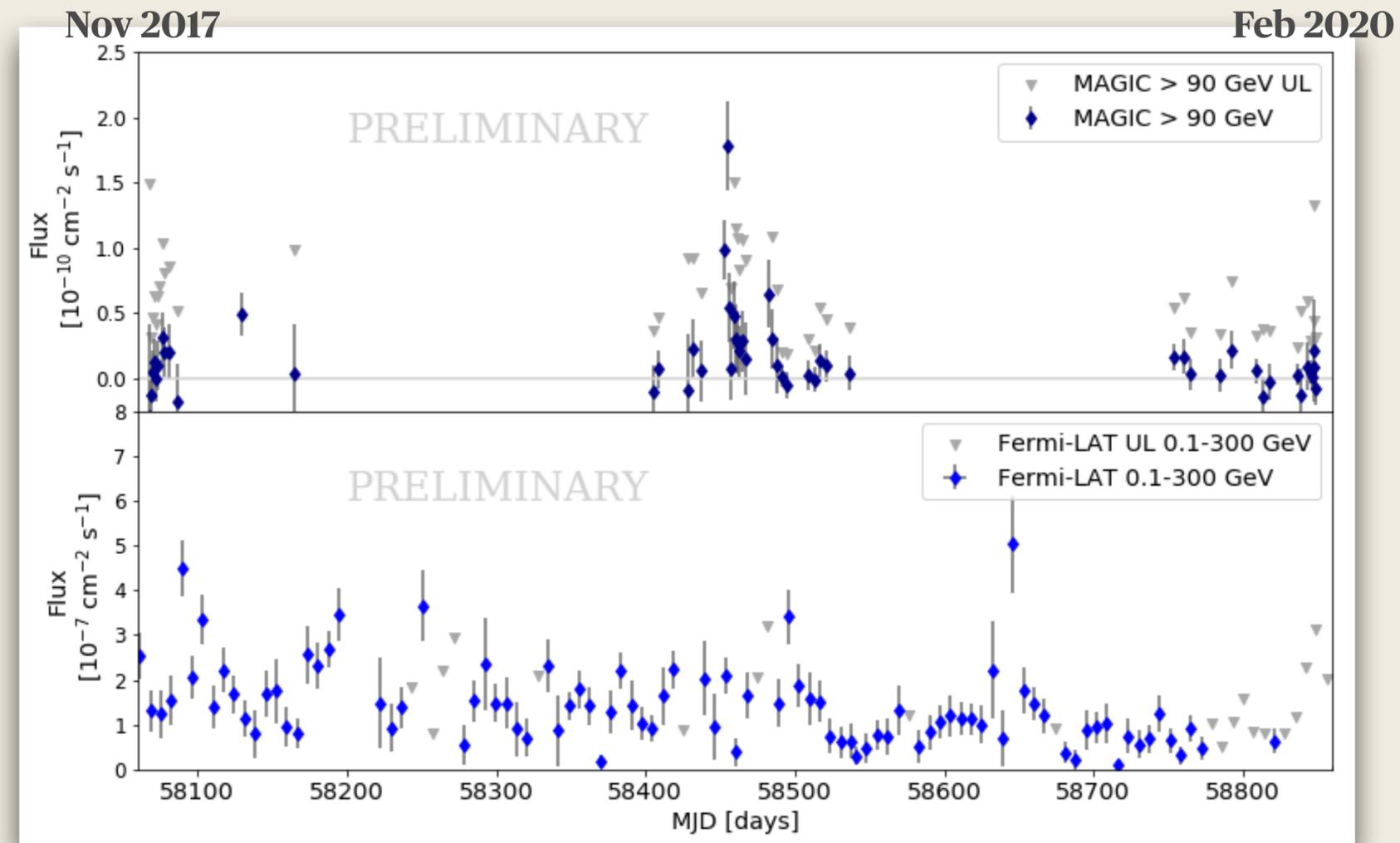
TXS 0506+056

Multi-year and multi-wavelength monitoring

- MWL campaign after neutrino event:
 - ▶ First and unique detailed study of the source collecting long-term data
 - ▶ Covering from radio band to VHE γ -rays
- MAGIC observations from Nov 2017 to Feb 2021
 - ▶ ~120 hours of good quality data
- MM SED model created in the frame of lepto-hadronic emission
- Program on-going, guaranteed MAGIC observation up to Feb 2022

HE and VHE light curve

- Low state of activity during most of monitored period
- Flaring activity in MAGIC band consistent with 2017 flare
- MAGIC data up to Feb 2021, analysis ongoing
- Several short flares detected by *Fermi/LAT*, differently from the long-term brightening observed in 2017



MWL light curve

X-rays:

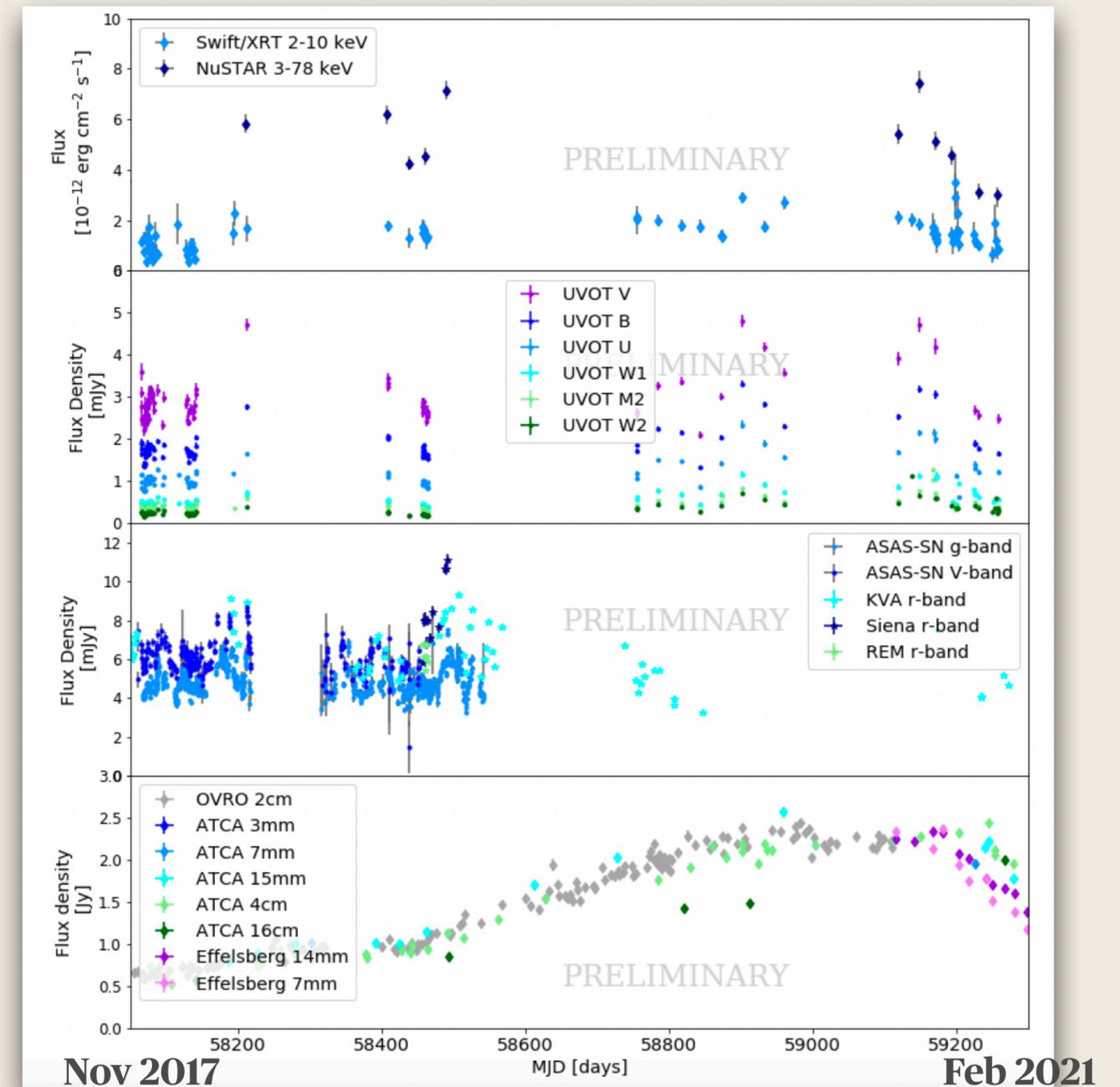
- Flux changed by a factor of ~ 2 in both hard X-rays (NuSTAR) and soft X-rays (Swift/XRT)
- Decay trend in 2020-2021

Optical and UV:

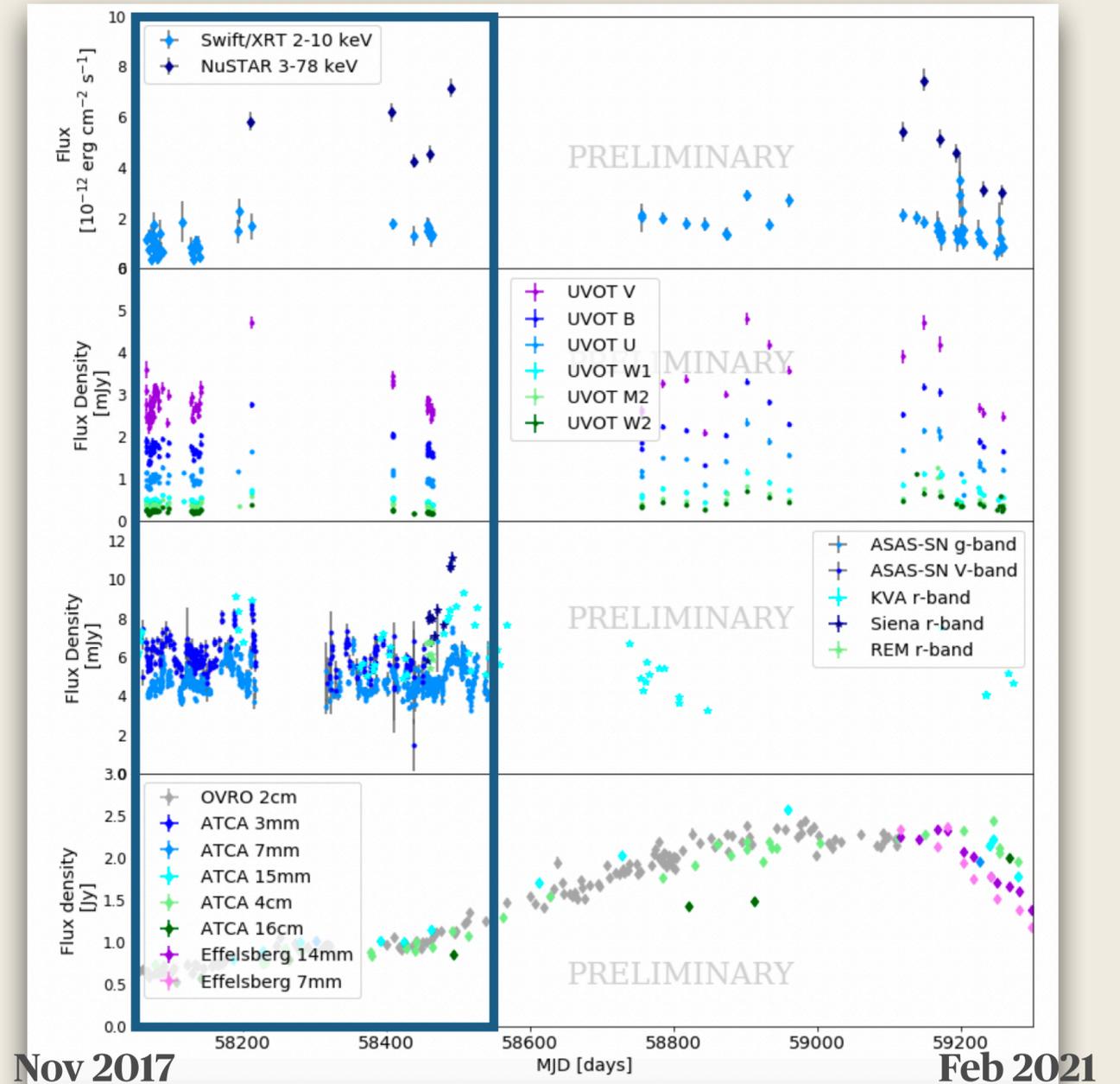
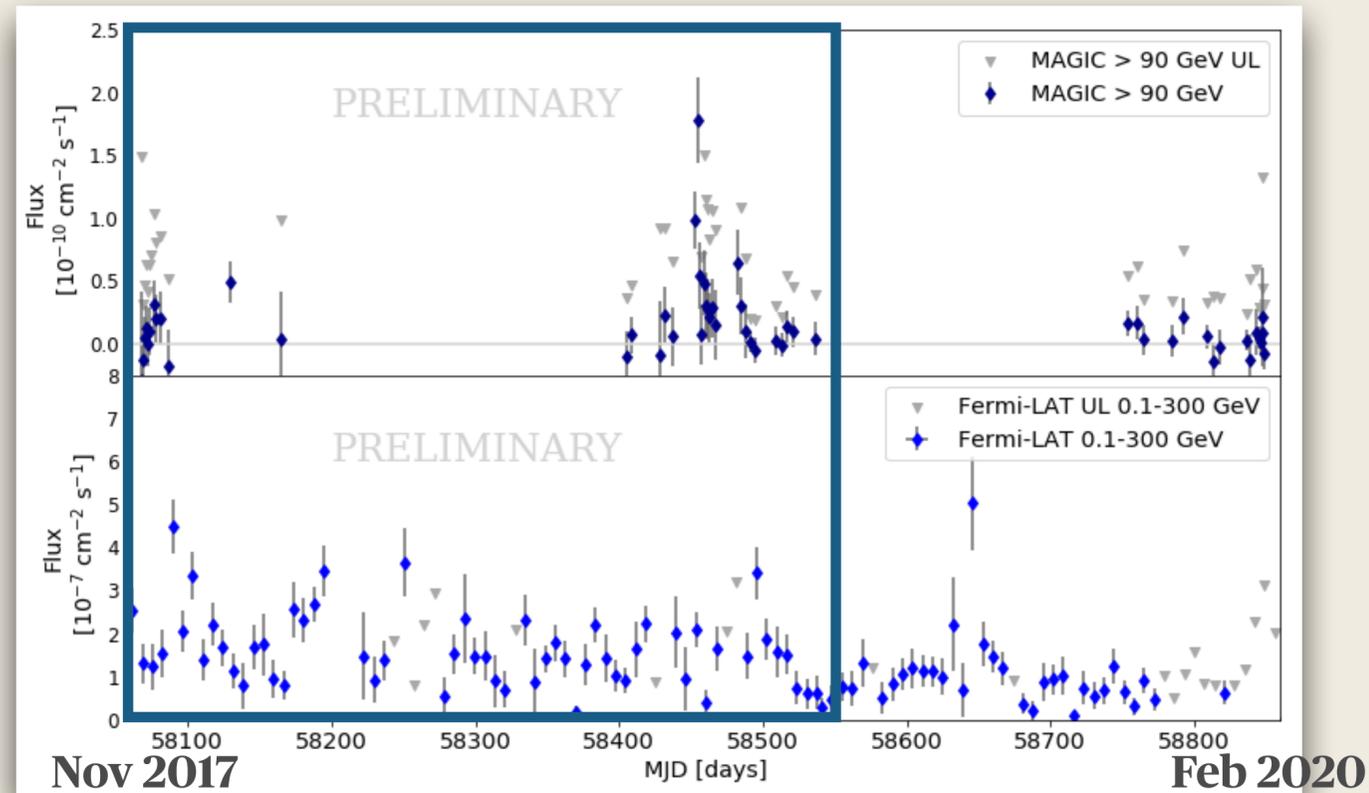
- Moderate variability on a daily time-scale

Radio:

- Increasing trend from Nov 2017 to late 2020
- Long term brightening uncorrelated to other wavebands
- Steep decay from late 2020



Concentrating on Nov 2017 - Feb 2019

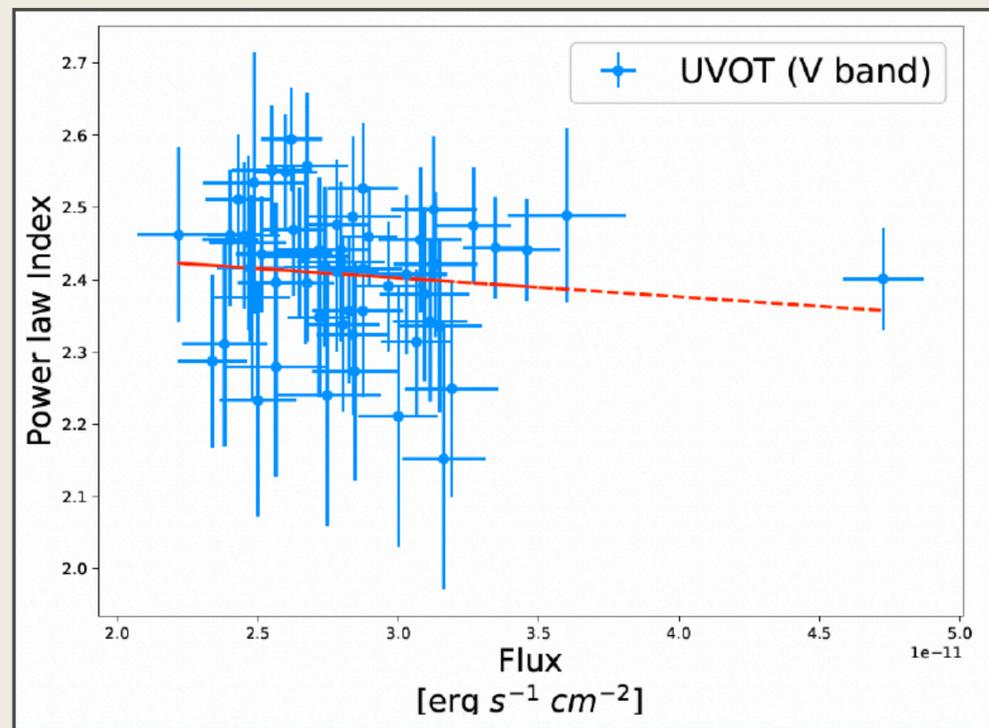


- MAGIC analysis up to Feb 2021 on-going
- MWL correlation studies from Feb 2019 to Feb 2021 in prep

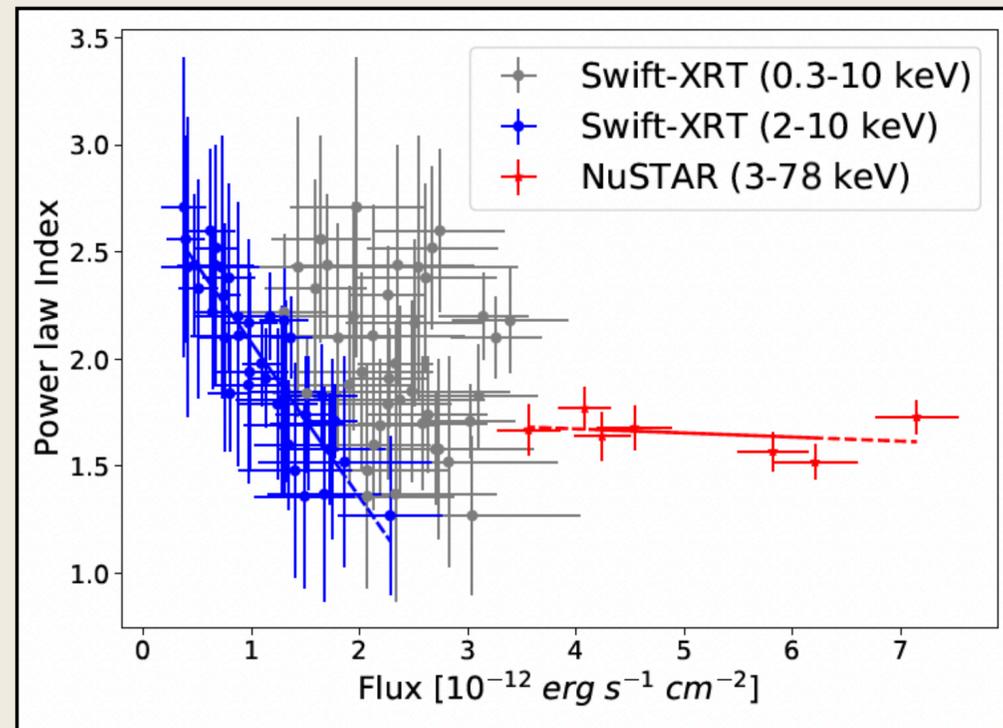
Paper on 2017 - 2019 observations coming soon!

Spectral variability in 2017 - 2019

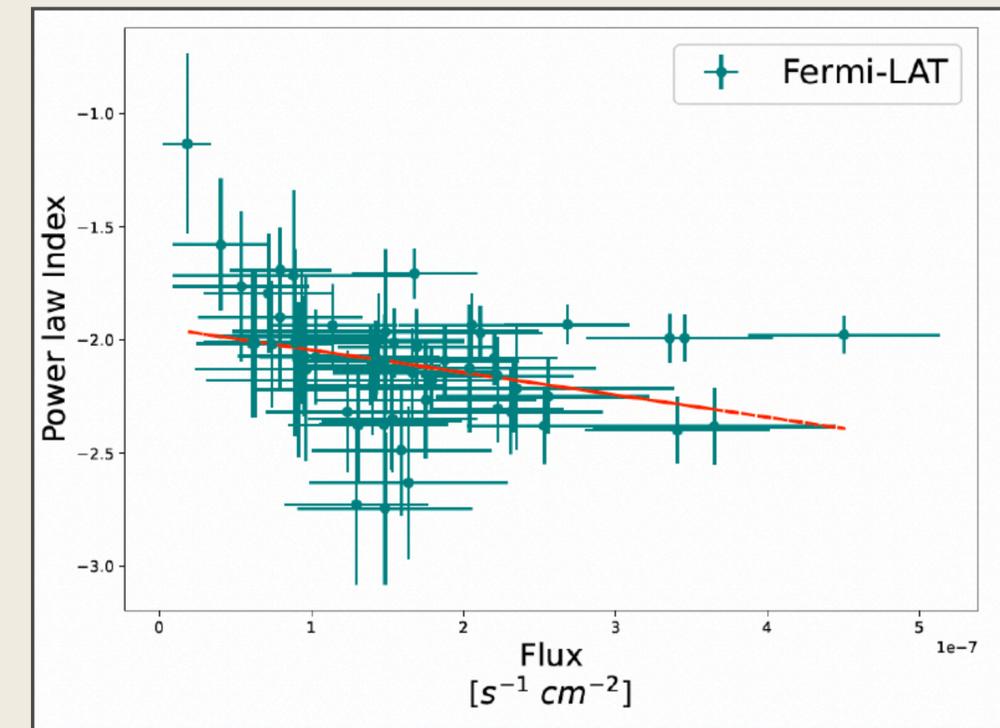
Flux - index correlation



Swift/UVOT: No significant correlation between optical flux and spectral index



Swift/XRT: Strong anti-correlation between flux and index in 2-10 keV
NuSTAR: no spectral variability observed



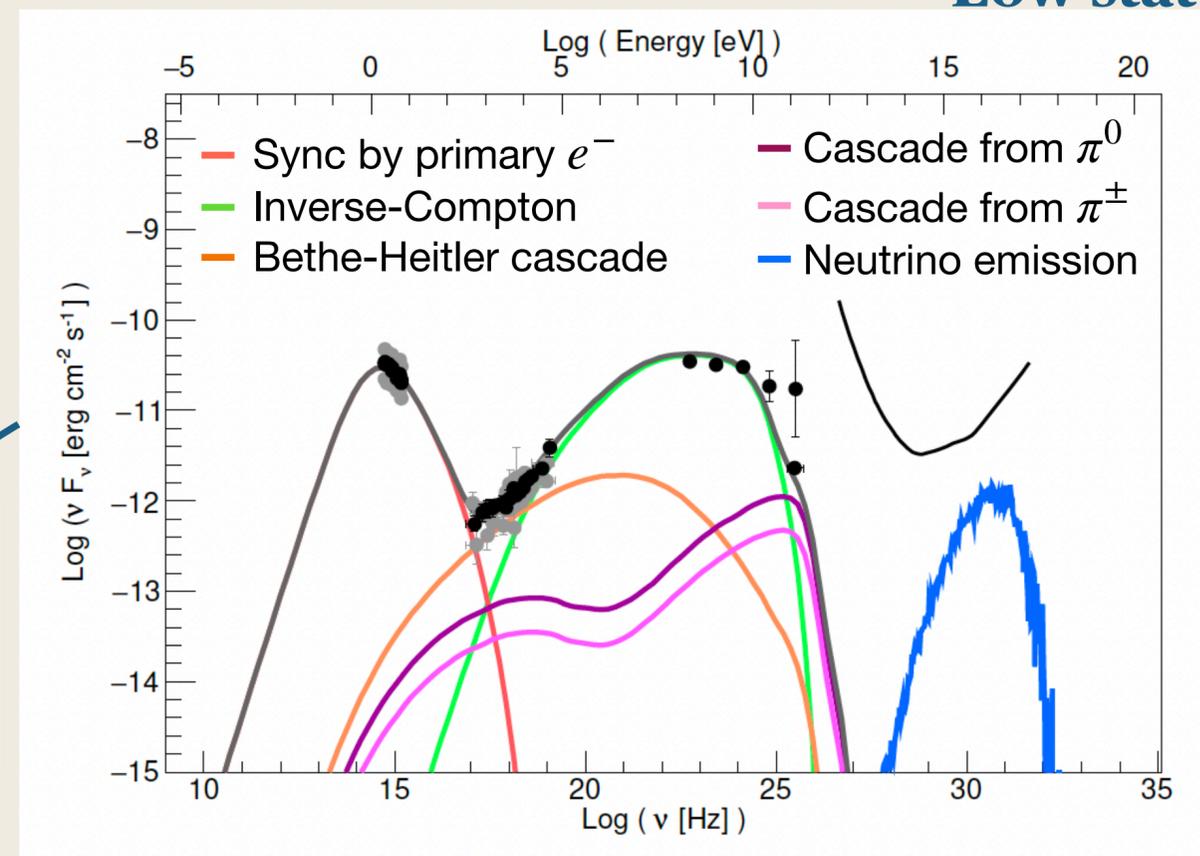
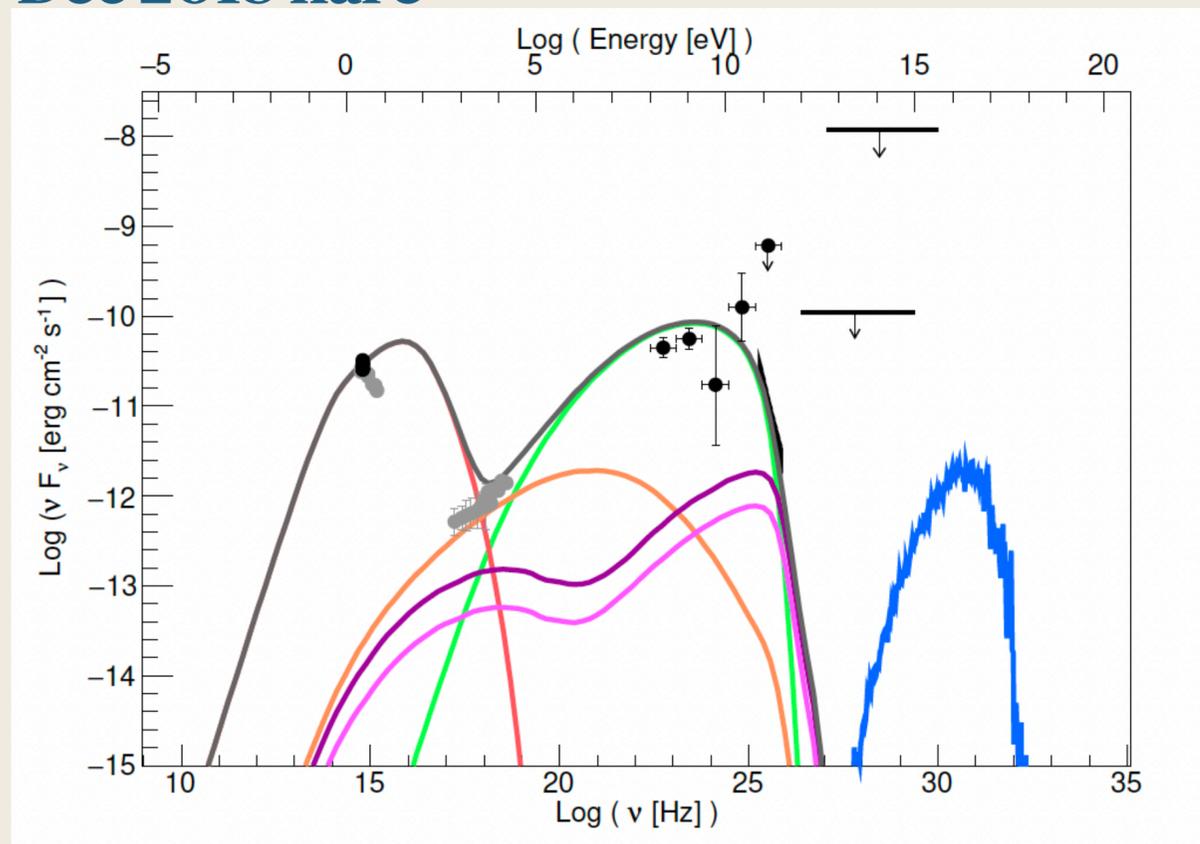
Fermi/LAT: Hint of correlation in the GeV band

SED modeling in 2017 - 2019

Low state

- Lepto-hadronic jet composition
- SSC as dominant emission process
- hadronic components emerge in X-rays and VHE γ -rays (Bethe-Heitler and π -decay cascade)

Dec 2018 flare



Prediction neutrino rate compatible with IceCube observations

Simultaneous obs. from MAGIC, *Fermi*/LAT and ASAS-SN
 Sync component poorly constrained
 Expected IceCube neutrino rate consistent with non-detection from IceCube

Summary and future works

- TXS 0506+056 is the astrophysical source with the highest significance for the association with a high-energy neutrino up to now
- Long-term observations needed to shed light on emission mechanisms
- Detected two flares in VHE consistent with 2017 one
- Spectral variability in soft X-rays, no spectral variability in hard X-rays
 - ▶ transition between different radiation mechanisms in keV band suggested
- Lepto-hadronic model with dominant leptonic component and sub-dominant hadronic emission, predicted neutrino rate consistent with IceCube obs.
- Future obs needed, program on-going:
 - ▶ MAGIC observations guaranteed until Feb 2022, data analysis up to Feb 2021 on-going
 - ▶ Paper on 2017 - 2019 observation campaign coming soon!
 - ▶ MWL Correlation studies in prep

Thank you for your attention!