Multi-epoch monitoring of TXS 0506+056 with MAGIC and MWL partners

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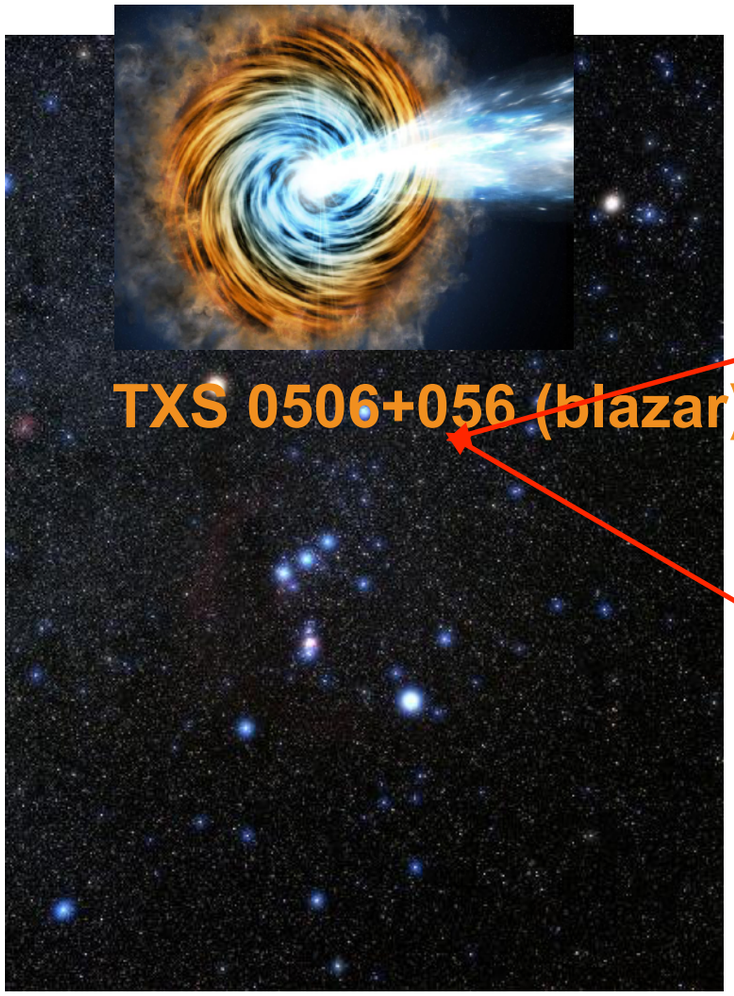
TXS 0506+056

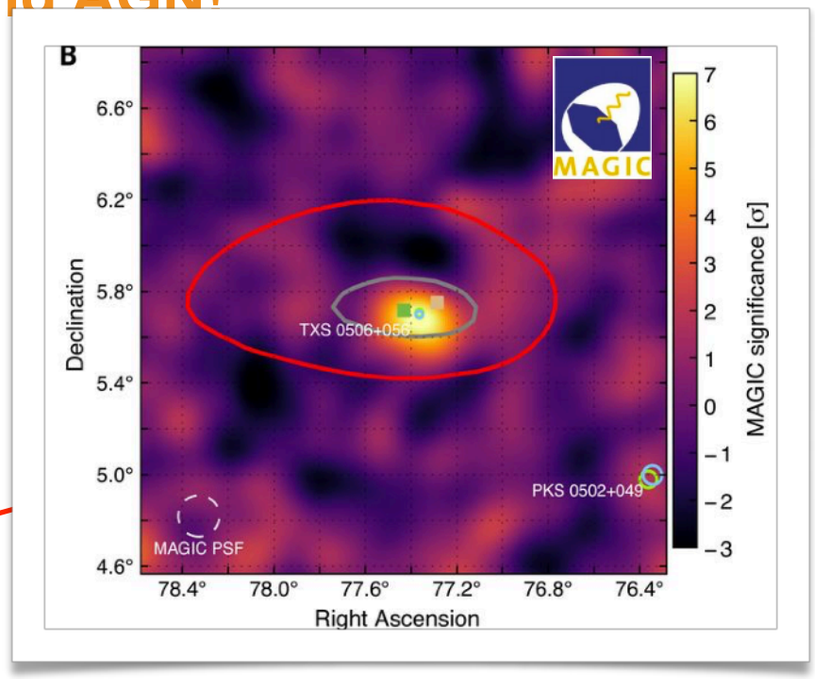
Neutrino blazar…?

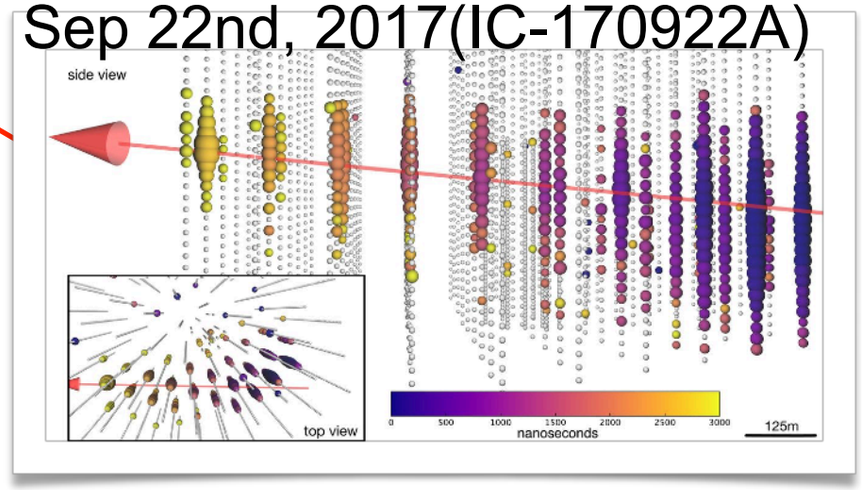
- Texas survey of radio sources, discovered in 1983
- Classified as ISP-type BL Lac object, a subclass of blazars, but recently considered as a "hidden FSRQ" (Padovani et al., 2019)
- Among the brightest 5% of blazars detected in gamma-rays by *Fermi*/LAT
- Redshift z=0.3365, ~4 billion light years (Paiano et al., 2018)
- One of the most luminous objects known up to this distance

TXS 0506+056

First evidence for a neutrino emitting AGN!







The IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. ***Science,* 361, eaat1378 (2018)**

The IceCube Collaboration, ***Science*, 361, 147 (2018)**

- ~3σ correlation of IC-170922A (~300 TeV) with the flaring gamma-ray blazar TXS 0506+056
- Looking into IC past data: excess of neutrino events, between Sep 2014 and Mar 2015, from TXS 0506+056, another ~3.5σ evidence
- Motivation for many, many theory papers… (Ansoldi et al, 2018, Gao et al., 2018, Keivani et al 2018…)

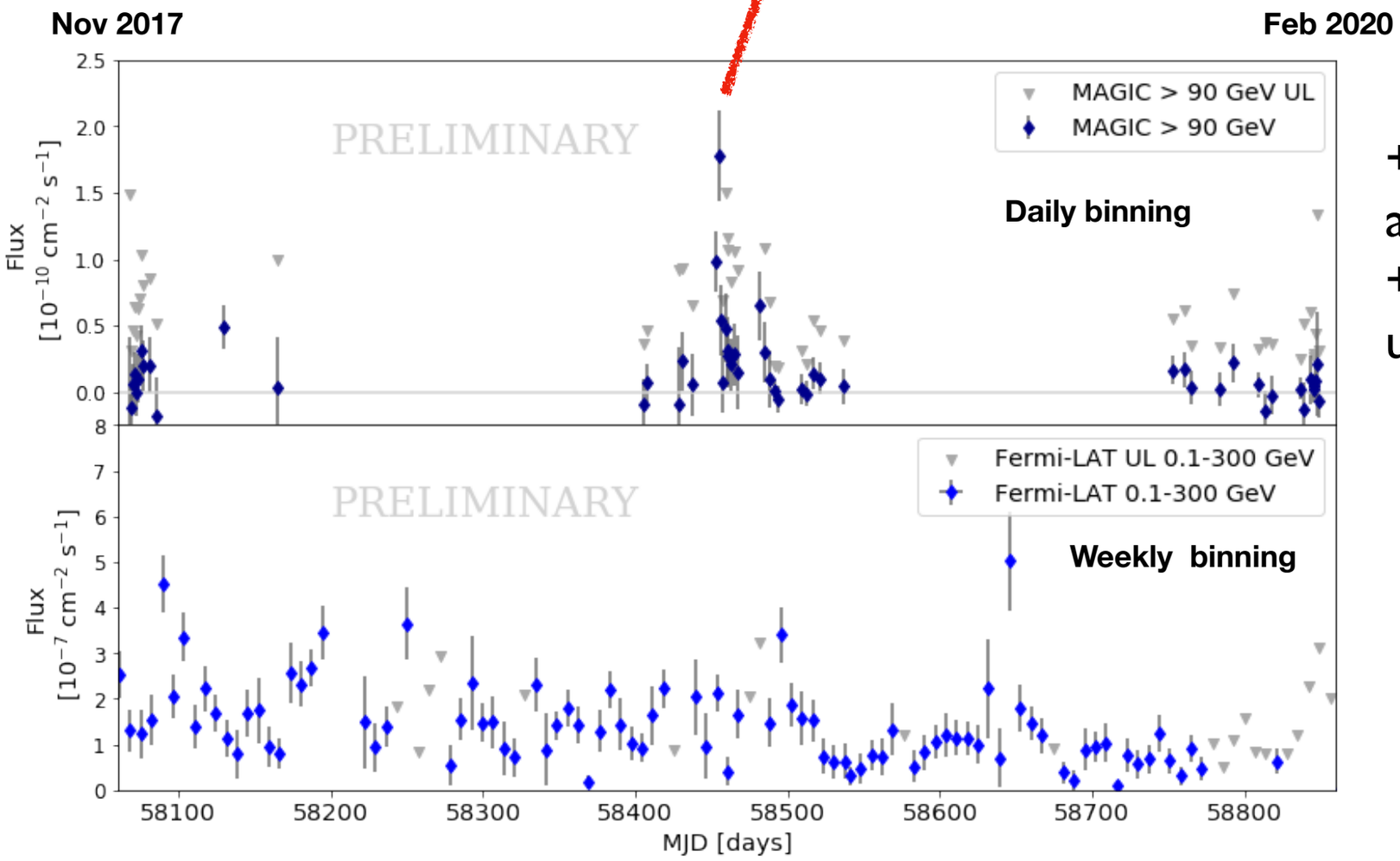
TXS 0506+056

The story continues…

- The 2017 MWL campaign following the neutrino event was the first and only detailed MWL study of the source
- Dedicated MWL monitoring program: collect a long-term data sample of TXS 0506+056
- Nov 2017 to Feb 2021: MAGIC collected ~130h
- MJD 58453 and MJD 58455: enhanced emission observed at VHE gamma-rays by MAGIC (ATel #12260), comparable to the 2017 flare; neutrino flux ULs available from ANTARES and IC
- MM SED modeling in framework of a lepto-hadronic model

TXS 0506+056

The story continues…



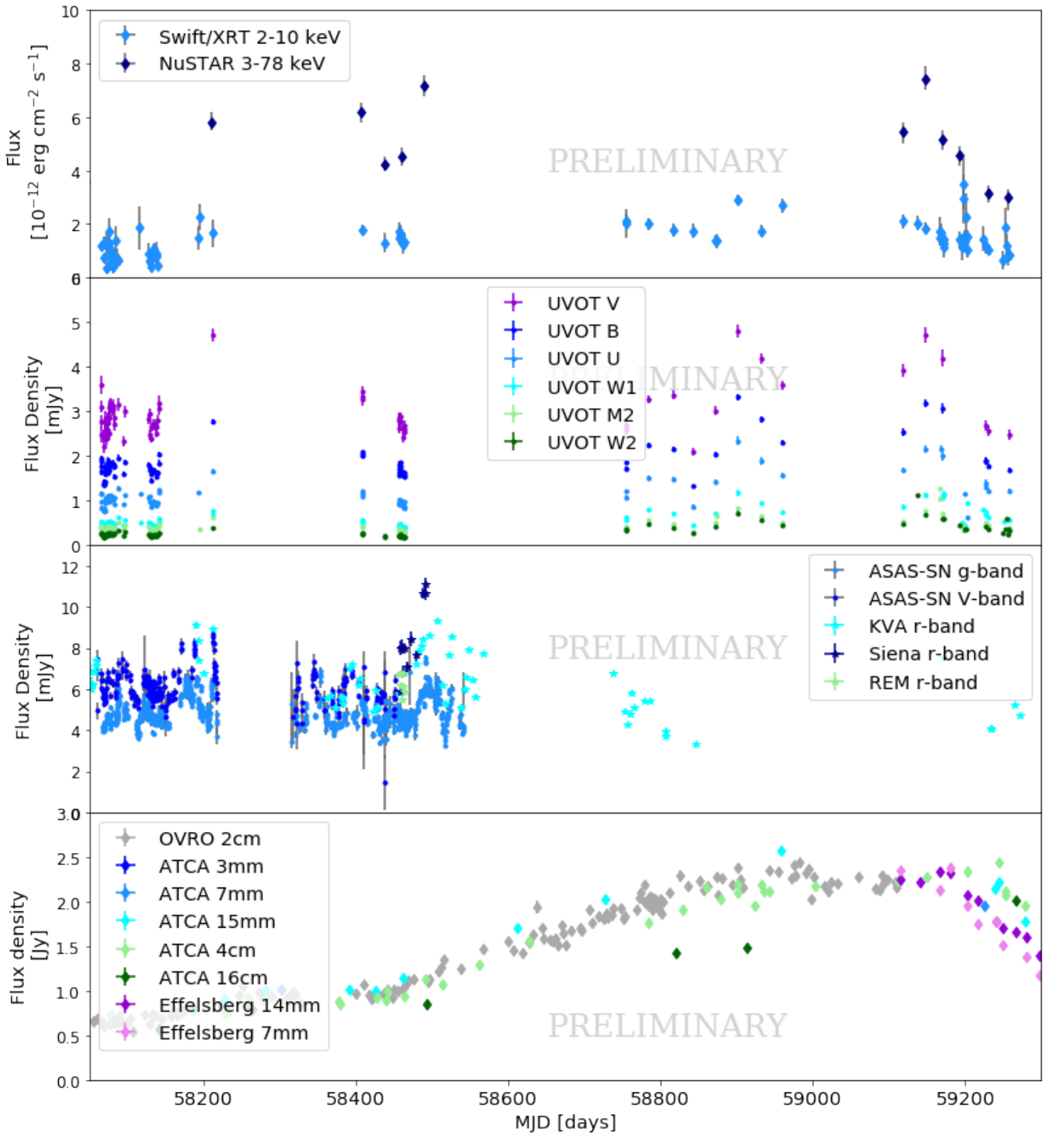
+ observations up to Feb 2021, analysis on-going
+ more data to be collected until Feb 2022

- Enhanced activity observed at VHE in two nights by MAGIC
  - 3.8-σ detection on 2018 Dec 1, Flux (E > 90 GeV) = (9.8±2.5)x10^{-11} cm^{-2}s^{-1}
  - 5.4-σ detection on 2018 Dec 3, Flux (E > 90 GeV) = (18.0±3.4)x10^{-11} cm^{-2}s^{-1}
- Low state with Flux (E > 90 GeV) < 1.0 x10^{-11} cm^{-2}s^{-1}
- Fermi-LAT observations show several short flares, differently from the long-term brightening observed in 2017

TXS 0506+056

The story continues…

Nov 2017 **Feb 2021**

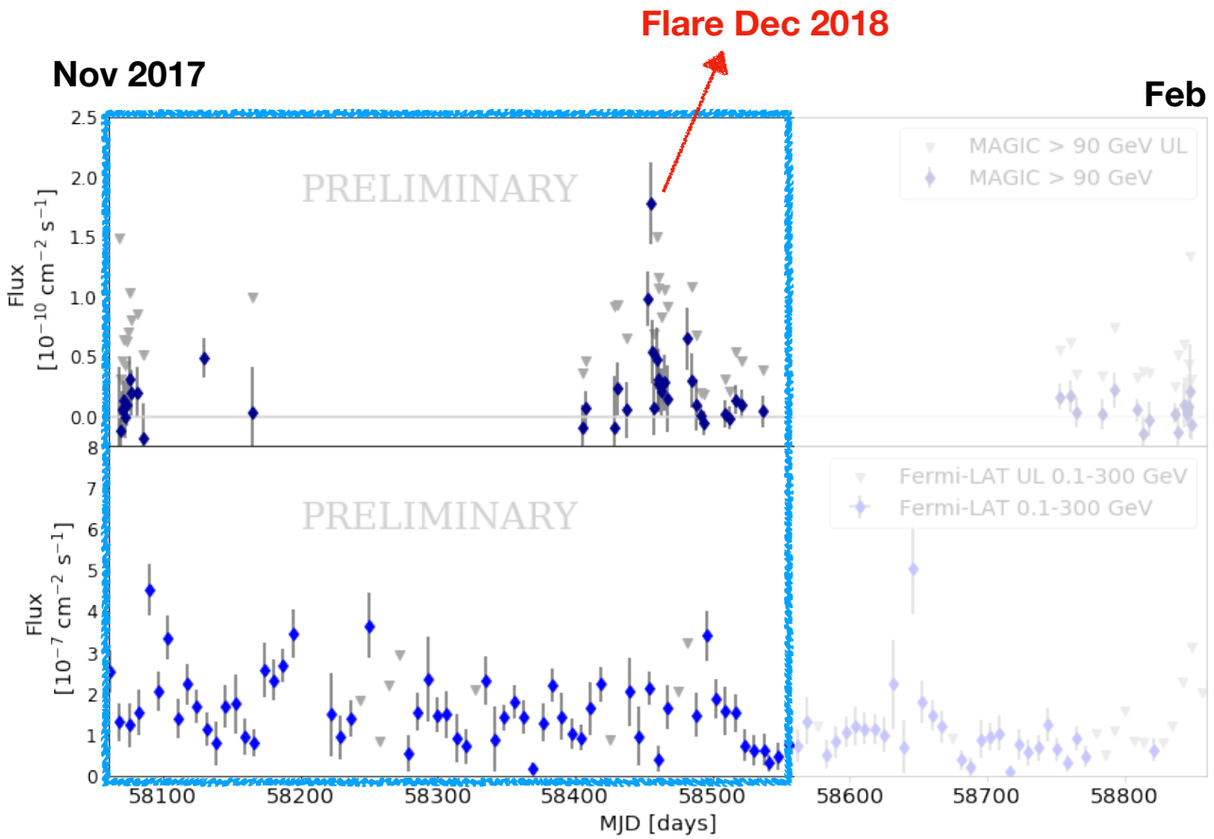


- Optical, UV and X-ray light curves show variability on a daily scale
- The X-ray flux changed by a factor of ~2-3 over the monitoring period in both the soft and hard X-ray energy ranges

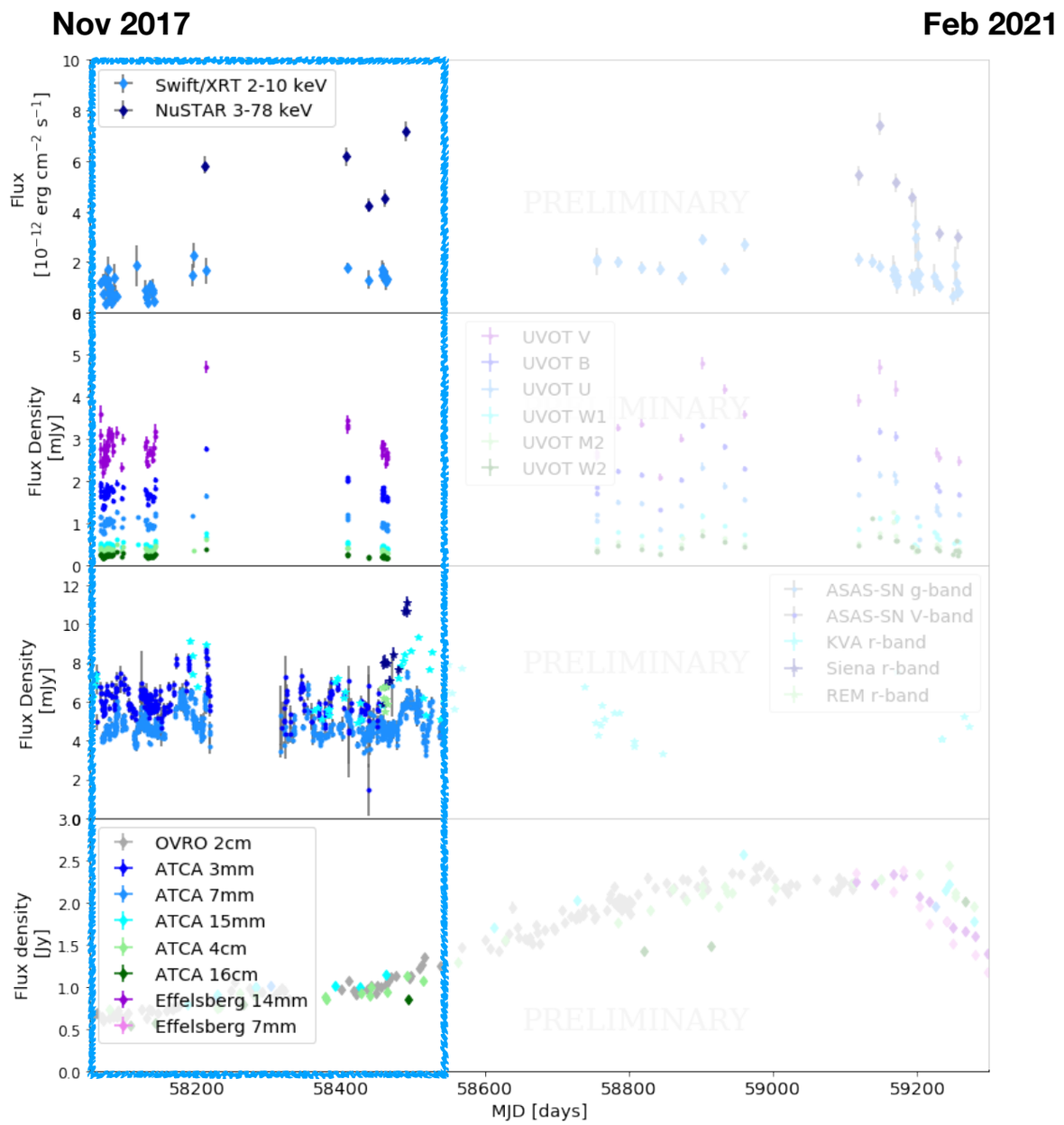
- Radio light curve shows an increasing trend with super-imposed episodes of relatively rapid variability
- Peak in the end of 2020 and then decay, which is still on-going

TXS 0506+056

Closer look at the Nov 2017 - Feb 2019 period

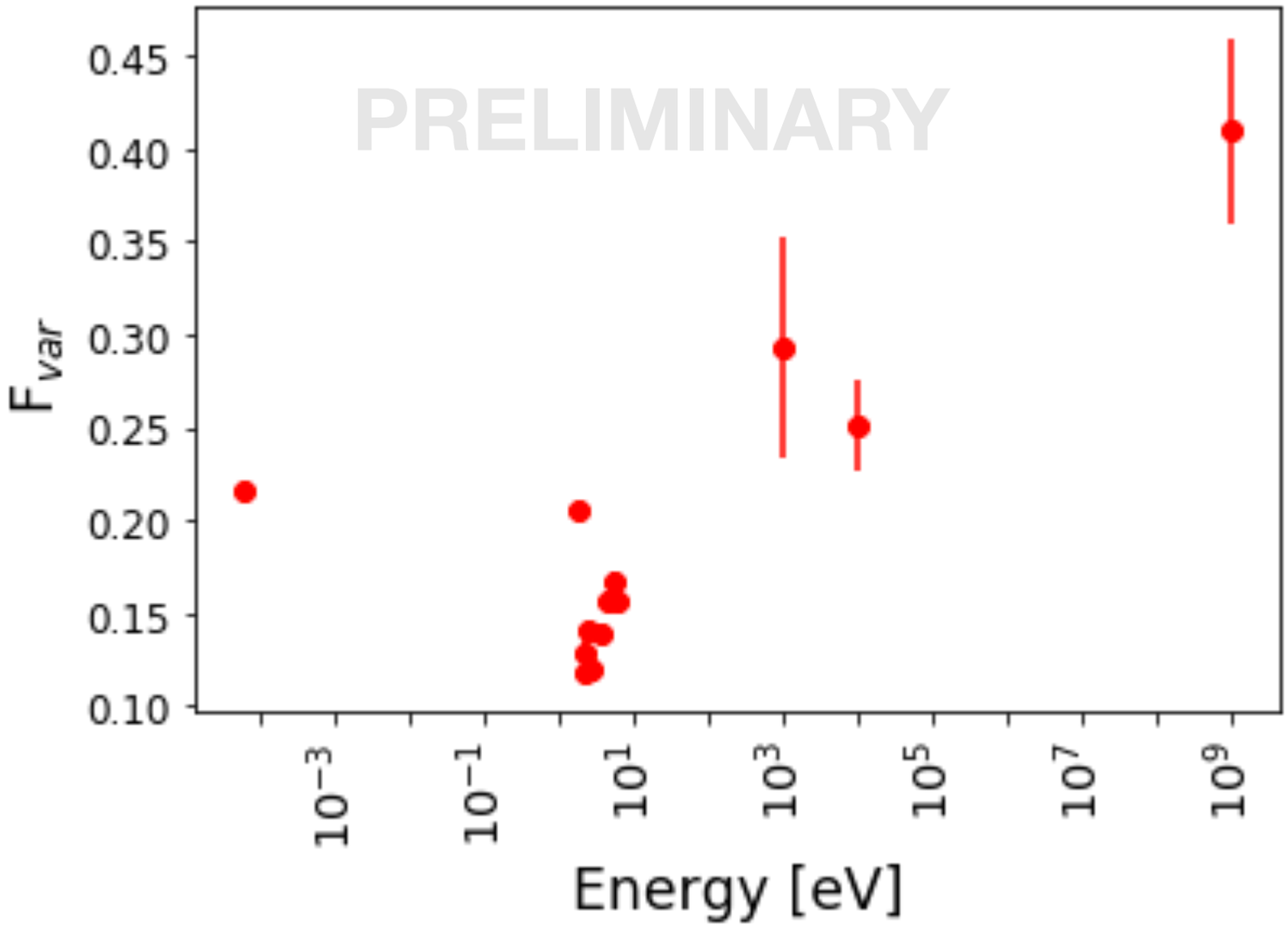


Paper coming soon!!!



TXS 0506+056

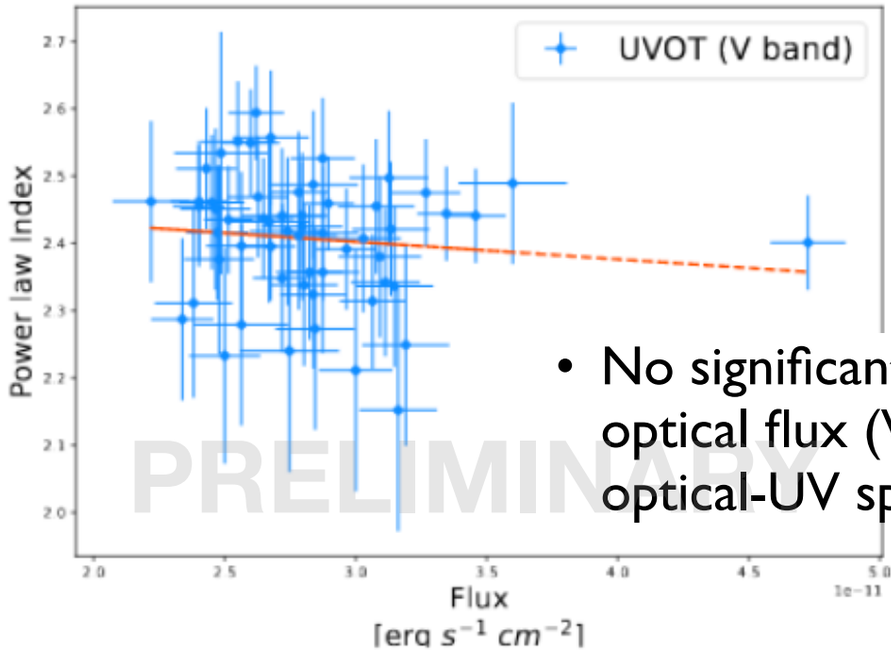
Nov 2017 - Feb 2019: fractional variability



- Fractional variability parameter F_{var} calculated according to (Vaughan et al., 2003)
- The most pronounced variability is observed in the X-ray and γ-ray bands, in particular at HE γ-rays
- The radio and optical bands display a moderate variability

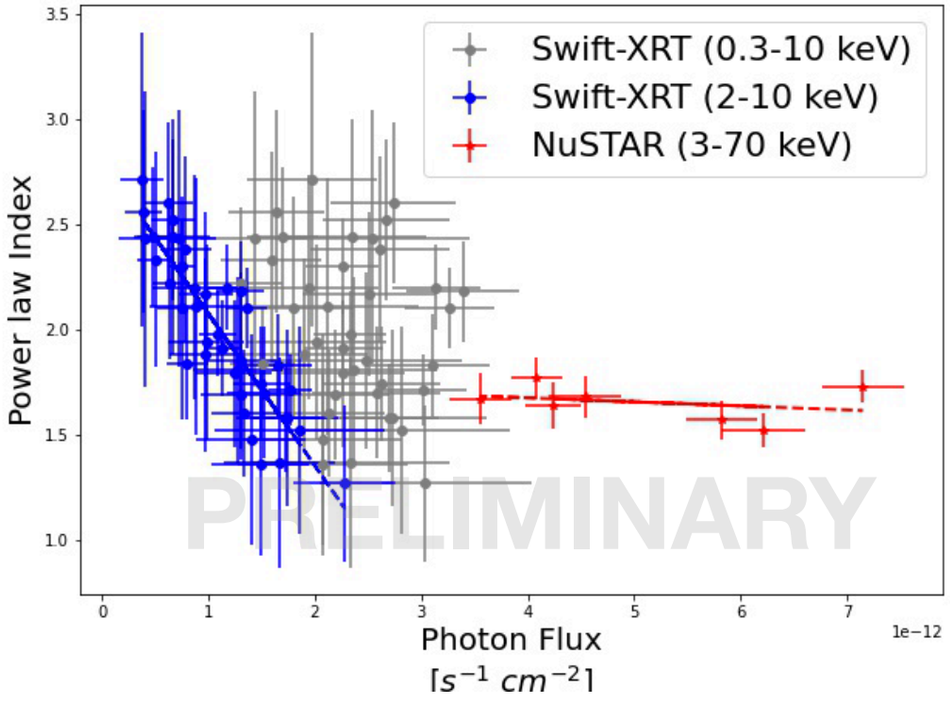
TXS 0506+056

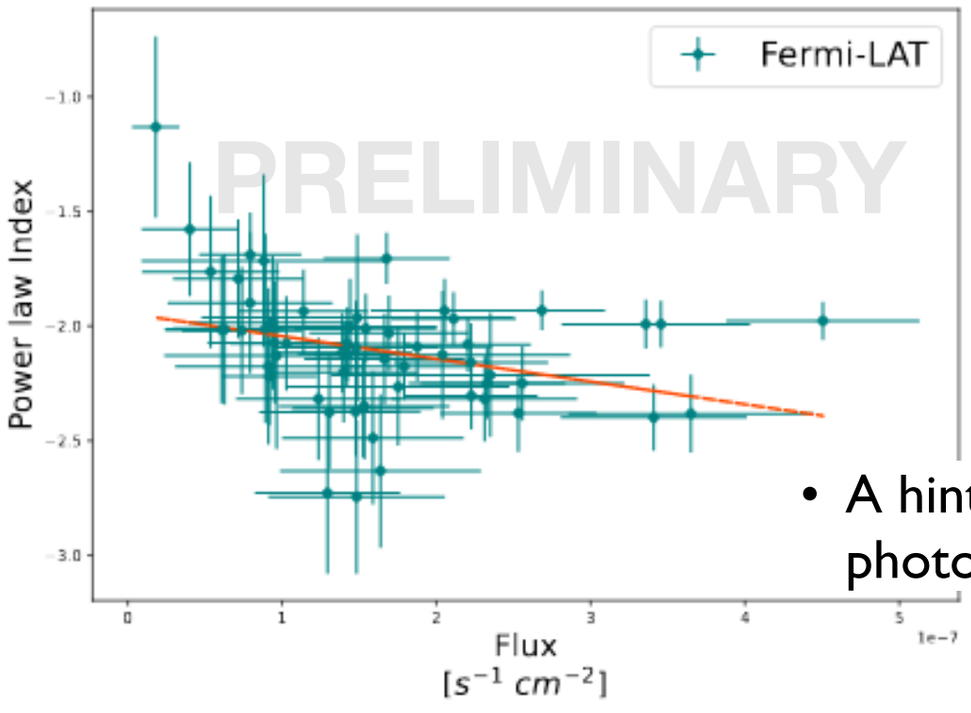
Nov 2017 - Feb 2019:
Flux vs photon index correlations



- No significant correlation between optical flux (V-band) and the optical-UV spectral index

- A strong anti-correlation between 2-10 keV flux and photon index has been observed by Swift-XRT, not confirmed if the 0.3-10 keV flux is taken into account



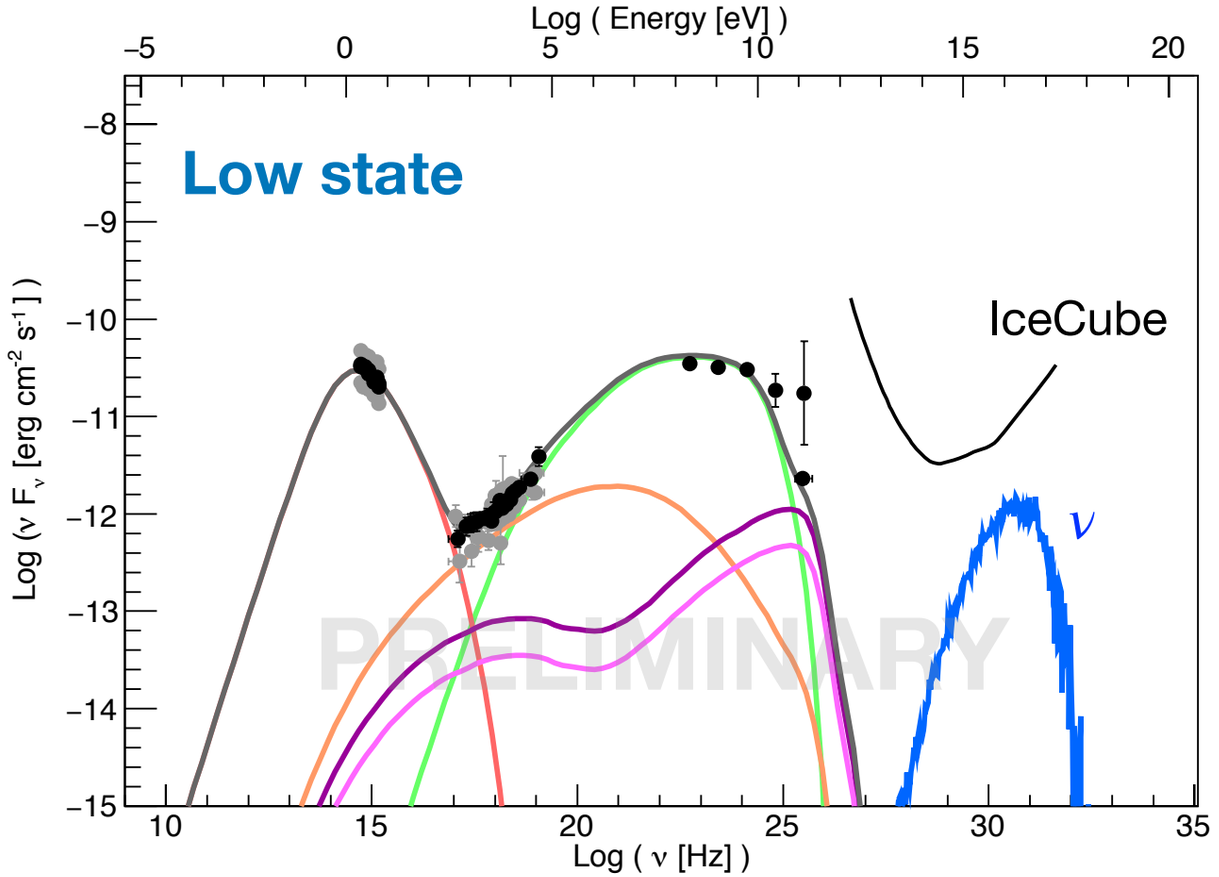


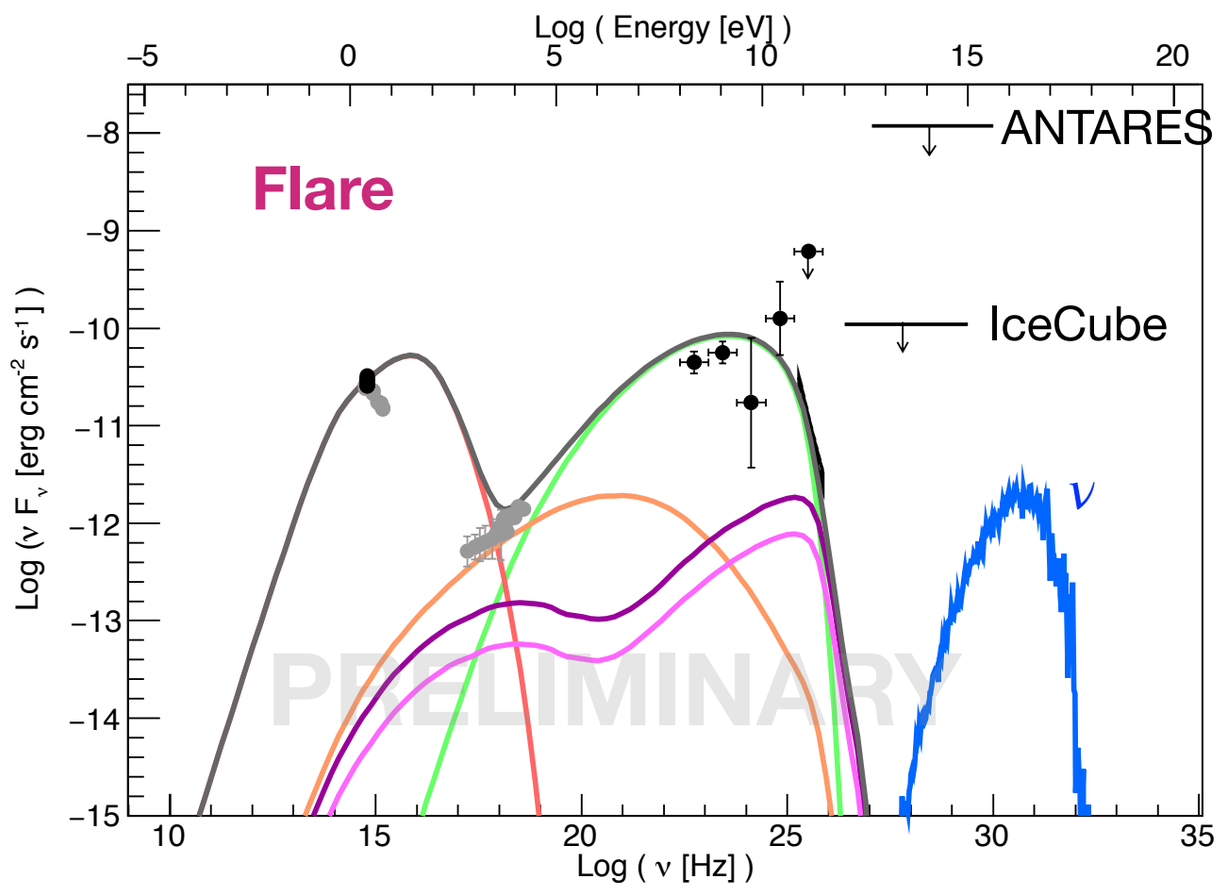
- A hint of anti-correlation between flux and photon index has been observed at HE γ-rays

TXS 0506+056

Nov 2017 - Feb 2019: SED modeling

- Model geometry: spine-layer jet, emission from spherical plasmoid in the jet (Ghisellini et al. 2005)
- Hadro-leptonic jet composition
- Dominant emission process is IC on the jet layer, sub-dominant hadronic components emerge in X-rays and VHE gamma-rays (BH, π-cascade)
- Low state: prediction for IceCube neutrino rate of 0.14 events/year, consistent with IceCube observations
- Dec 2018 flare: simultaneous obs. from MAGIC, Fermi/LAT and ASAS-SN, sync. component not fully constrained
- Dec 2018 flare: expected IceCube neutrino rate (~2 x 10^{-4} events/day) consistent with non-detection from ANTARES and IceCube





Summary

Neutrinos, blazars and all that jazz

- The neutrino event IceCube-170922A and TXS 0506+056 coincidence gave us the most compelling evidence for a neutrino emitting AGN so far
- TXS 0506+056 is one of the most luminous blazars at z~0.3, but before 2017 it was very sparsely monitored, especially in the X-ray and VHE gamma-ray bands
- Dedicated monitoring program with MAGIC and MWL partners since Nov 2017: assessing the duty cycle of blazars and particularly of TXS 0506+056 is crucial to better understand the probability of a EM-flare - neutrino coincidence
- For most of the time source not detected in VHE gamma-rays
- On Dec 1st and 3rd, 2018 a VHE gamma-ray flare observed with flux comparable to the one in 2017
- SED modeled in the frame of lepto-hadronic model revealed a sub-dominant hadronic component; expected neutrino events rates compatible with IC and ANTARES observations
- Paper describing the 2017-2019 observation campaign coming soon!

- Program on-going, guaranteed MAGIC observation up to Feb 2022 and MWL coverage up to Feb 2021
- MWL LCs show clear variability and interesting long-term trends (radio) - MWL correlation study on-going