FACT – 10 Years Operation

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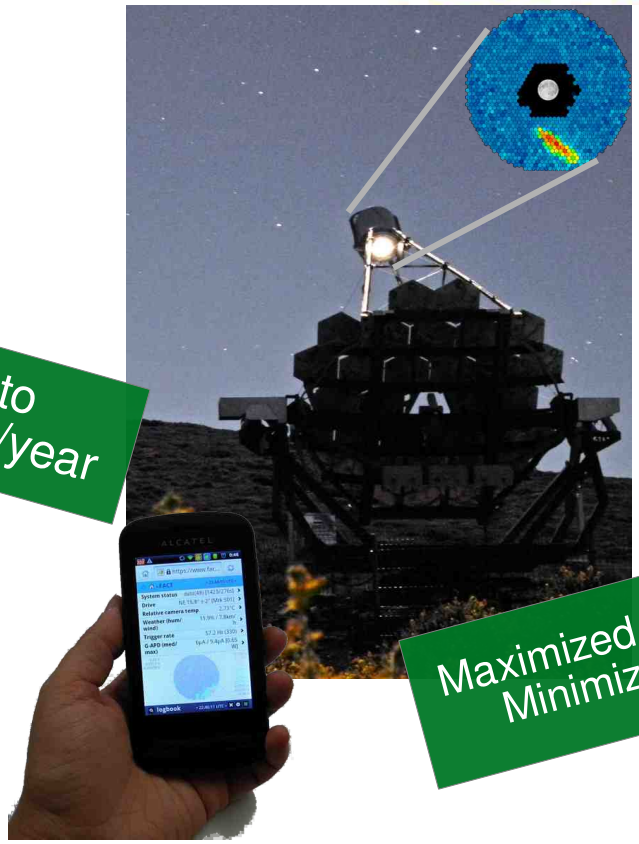
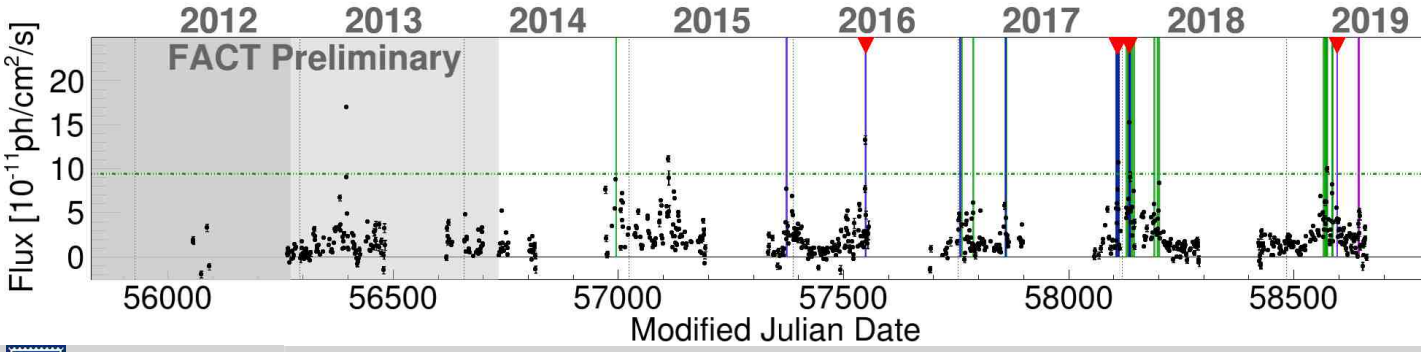
FACT – 10 Years Operation

Main Take-Aways

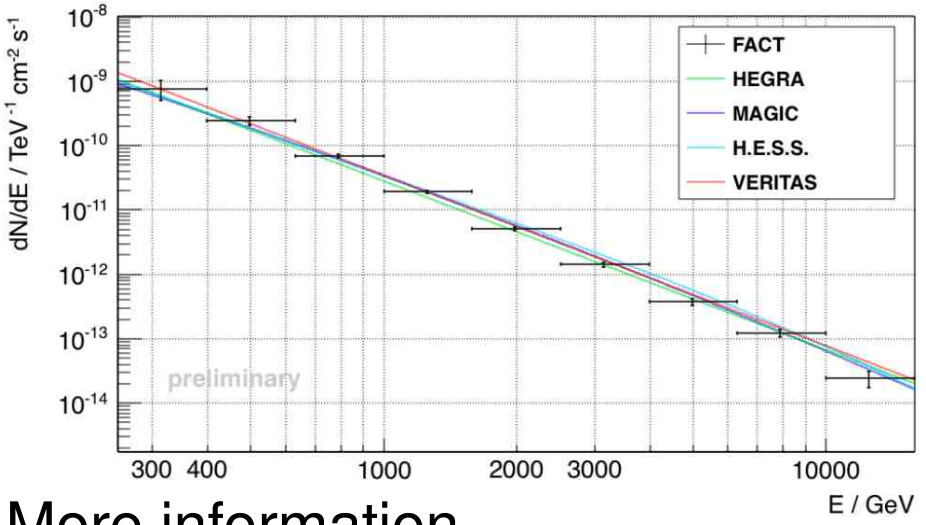
- Major Goals:
  - Establish SiPMs in Cherenkov Astronomy ✓
  - Robotic Operation ✓
  - Unbiased Monitoring of Blazars ✓
- Unprecedented data sample
  - 10 years of monitoring
  - Unbiased, densly-sampled light curves
    → Systematic variability studies
    → Unbiased multi-wavelength studies
  - Target-of-Opportunity (ToO) observations
  - Low-latency quick-look analysis
    → Flare alerts
    → Multi-wavelength (MWL) studies





First G-APD Cherenkov Telescope

- Operational since Oct 2011
- 9.5 m² mirror area
- Camera: Silicon based photosensors (SiPM), 4.5° FoV, 1440 pixels à 0.11°
- Imaging Air-Cherenkov Technique
- Energy range: > 300 GeV

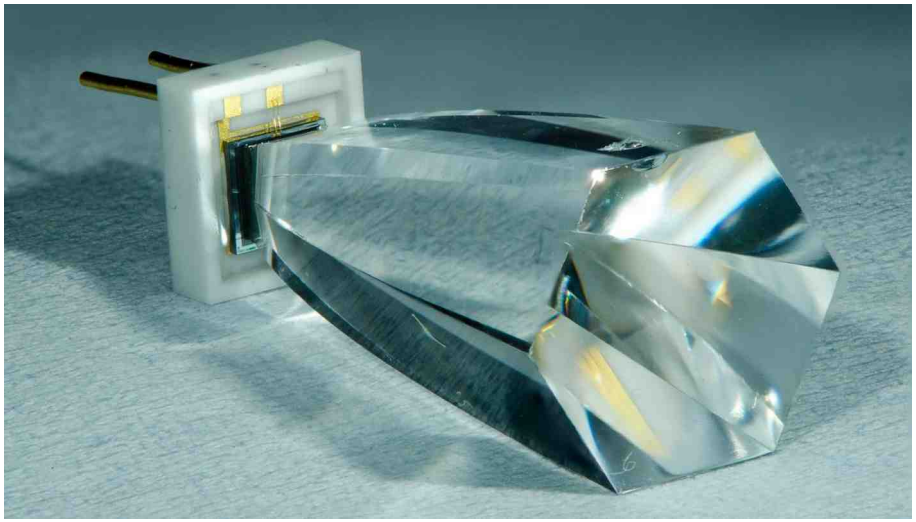


F. Temme et al. (FACT Collaboration), ICRC 2015

- More information

H Anderhub et al 2013 JINST 8 P06008
A Biland et al 2014 JINST 9 P10012

SiPM Camera



- 2008: SiPMs become commercially available

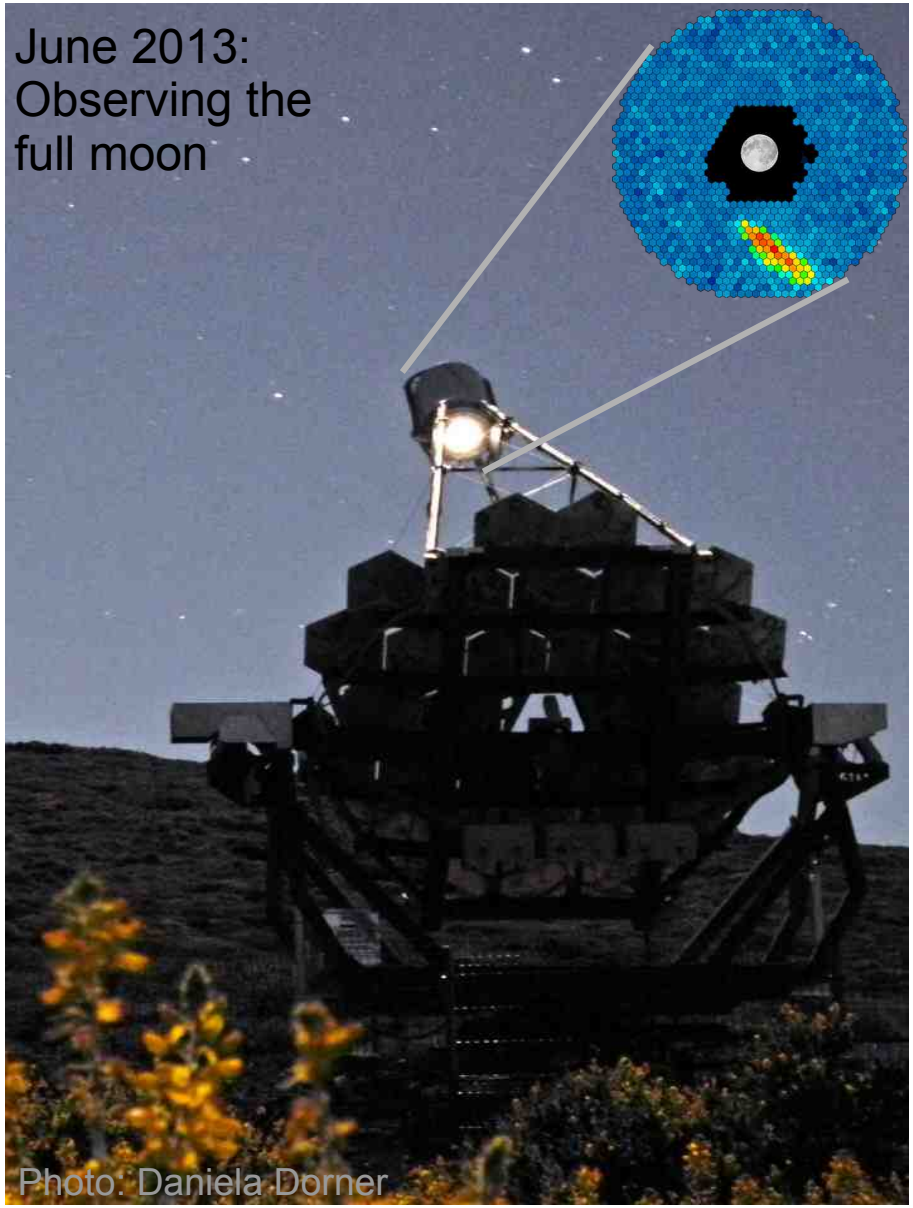
  big doubts they are ready for IACTs

  → start of FACT collaboration to explore feasibility of SiPM in IACTs
- 2009: first self-triggered prototype

  module of 36 pixels
  (proc. ICRC 2009 Lodz)
- Development of SiPM camera
- Oct 2011: FACT operation starts

  goal: identify SiPM problems in real IACT operation
- …
- 2023: still looking for first SiPM problem to show up...

FACT – Ideal Monitoring Telescope



- Gain of SiPMs: no degradation when exposed to bright light
  → **Observations during strong moon light possible**
- SiPMs robust and stable
  → Stable telescope performance
  → Robotic operation
  https://www.fact-project.org/smartfact
  → High data taking efficiency

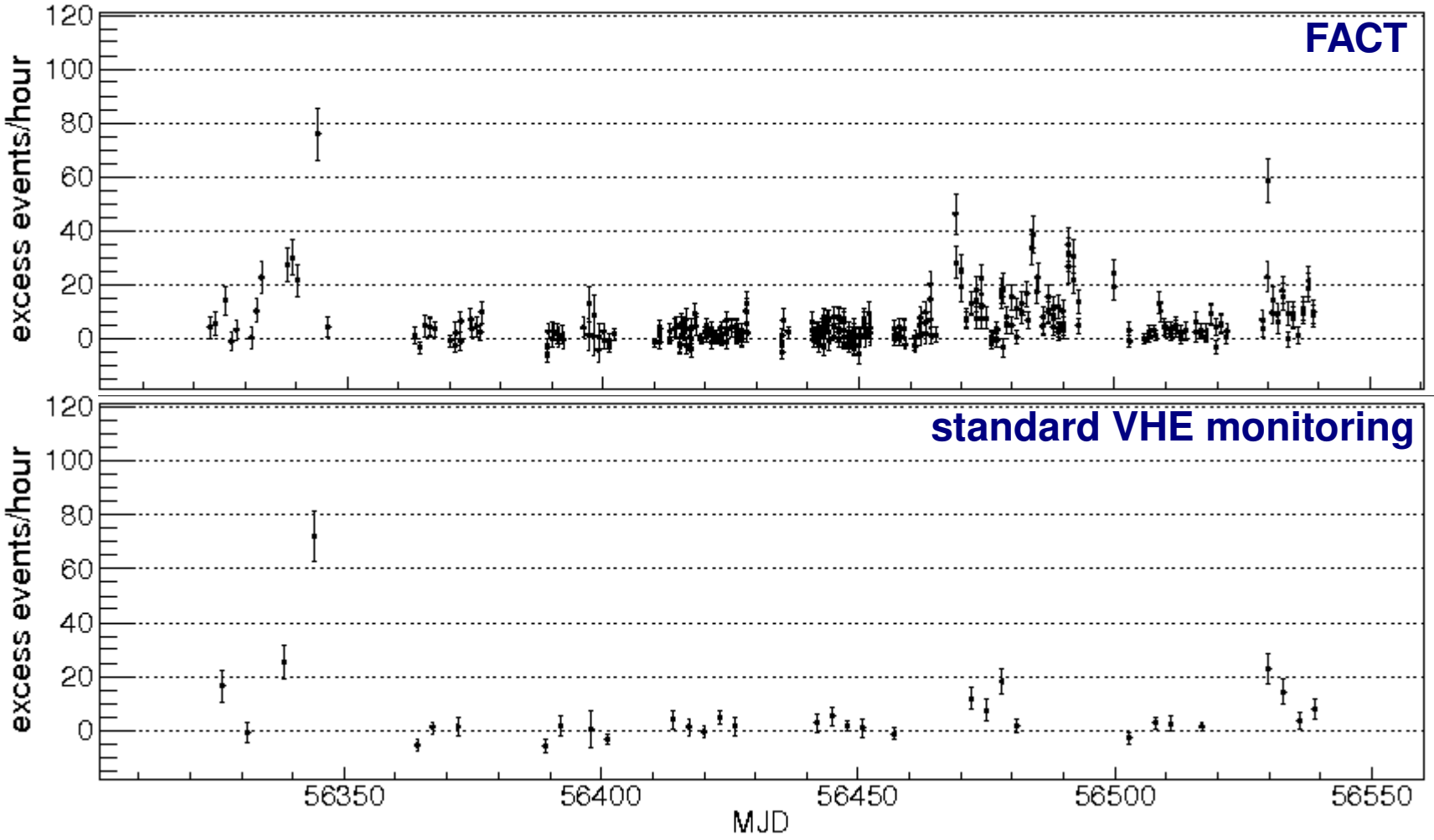
- **More complete data sample**
  → Maximized duty cycle
  → Minimized gaps
  → Denser light curve

Up to 2400 h/year

- FACT Observation Strategy
  → **Unbiased Monitoring**

Unbiased Monitoring

Mrk 501 (2013) 1-hour-binning



All data ~410h

Moon < 65%
1h every
~3rd night
→ ~32h

Dorner et al. (FACT Collaboration), Proceedings of 34th ICRC

Unbiased Monitoring

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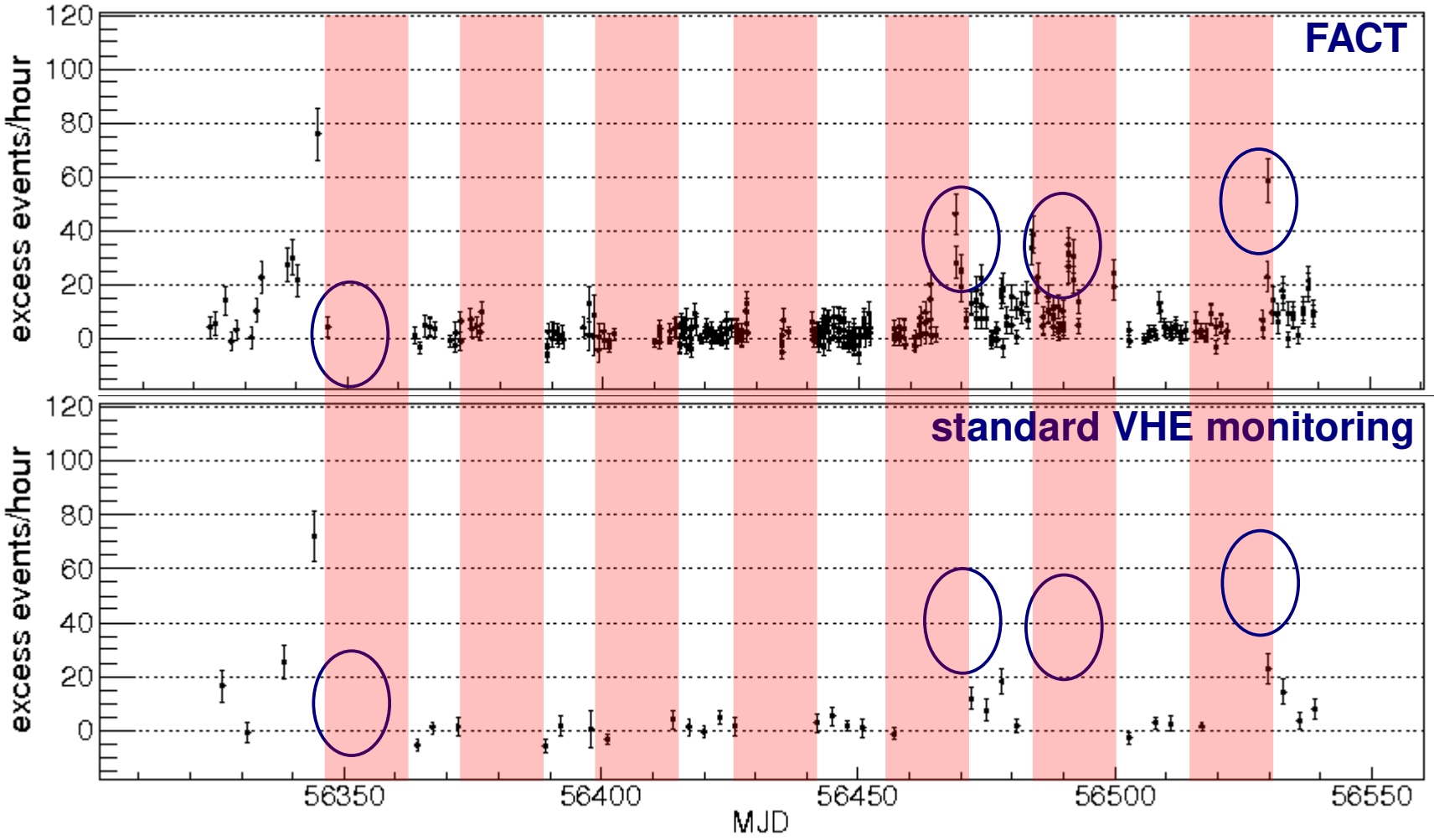

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Unbiased Monitoring

FACT monitoring strategy
→ Unbiased observation

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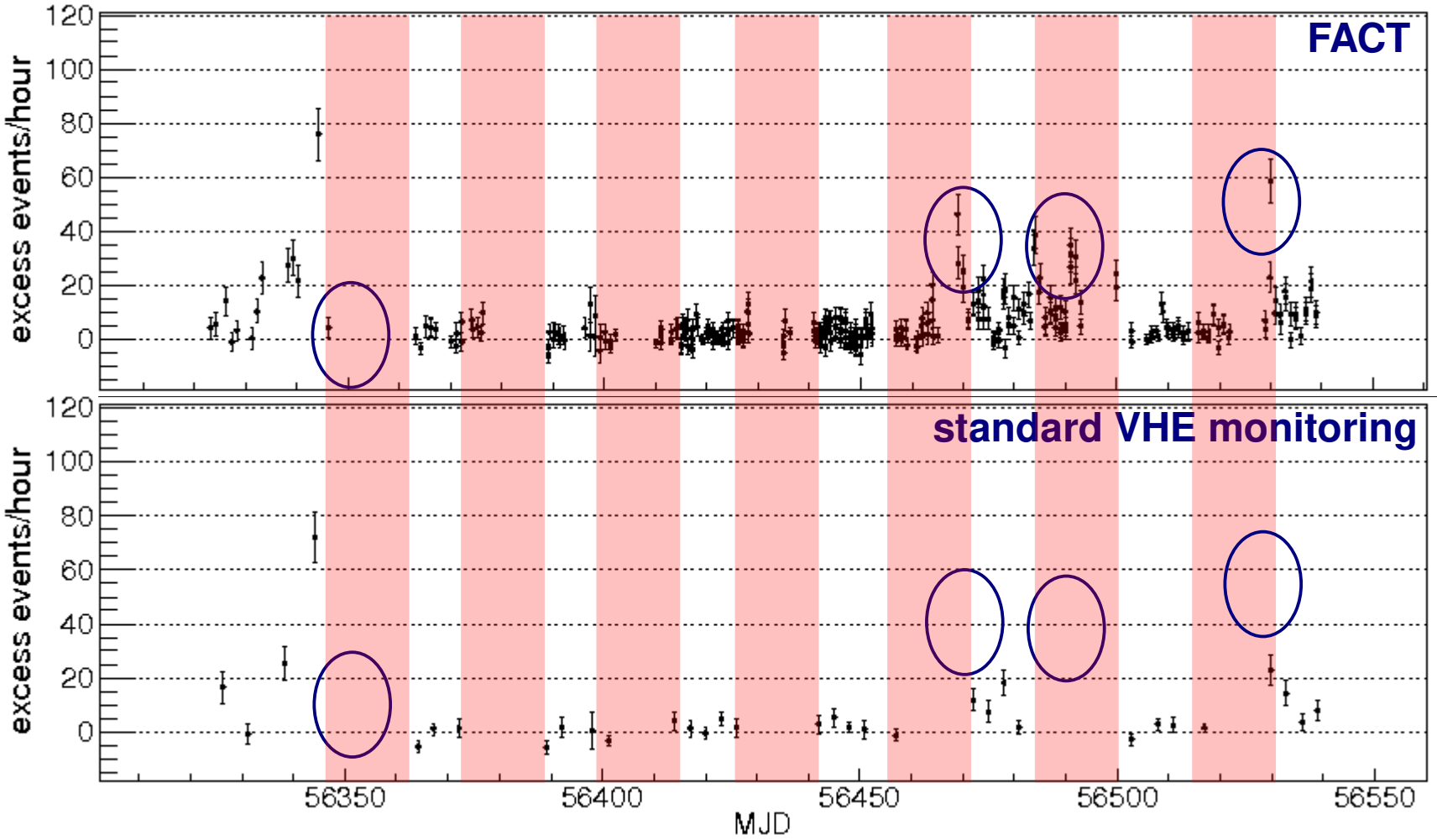

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Standard VHE: Follow-up of flares → bias toward high fluxes

Observations

- Total amount of **physics data** in 10 years:
  > 14'900 hours
- Open data policy
  - Crab raw data sample
  - Quick-look analysis results
  - Schedule public
  - FACT as instrument for teaching & student projects

Source	Time[h]
Mrk 501	2993.84
Mrk 421	3196.49
1ES 1959+650	2230.76
Crab	2386.43
1ES 2344+51.4	1975.72
1H0323+342	1179.28
PKS 0736+01	151.43
V404 Cyg	71.46
TeV J2032+4130	64.79
1ES 1218+304	35.21
IC 310	42.59
IceCubeEHE20171106b	15.64
H 1426+428	13.25
PG 1553+113	14.13
PKS 2155-304	10.55
TOMAS2345736	11.46
TOMAS2445523	9.72
2FHL J0326.0-1644	11.61
M87	9.98
AMON20160218	4.33

Source Sample

- Bright TeV blazars
- Crab Nebula as standard candle at VHE
- Multi-wavelength campaign on various VHE sources
- Follow-up of multi-wavelength and multi-messenger alerts

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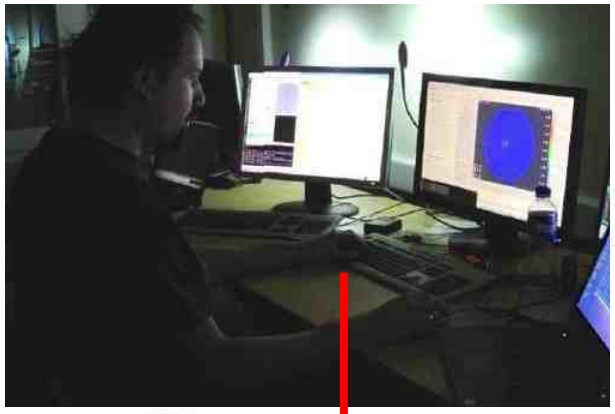
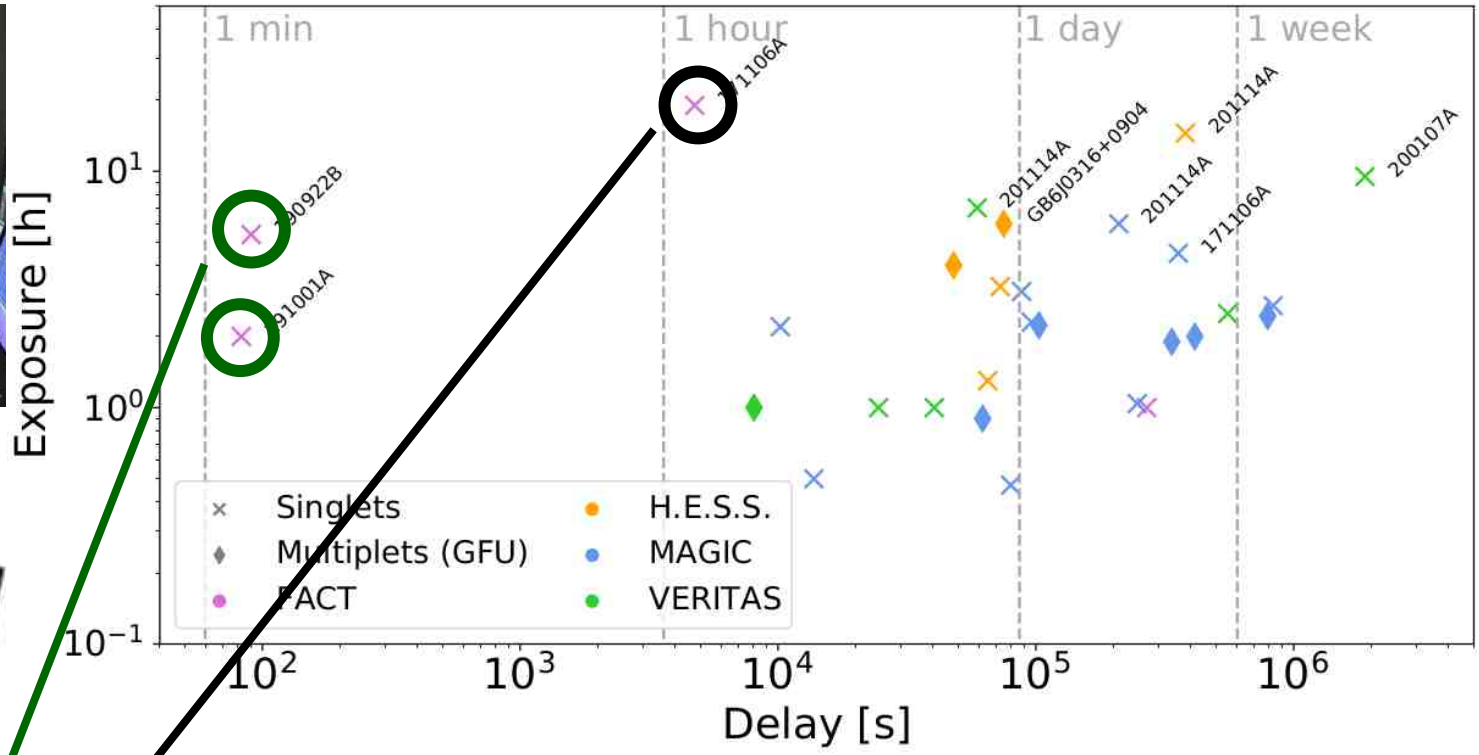
Core monitoring sample

Follow-up of Neutrino Alerts



paper in preparation



2011: start of operation

2012: remote operation without data-taking crew onsite

2017: automatic operation with manual scheduling of follow-up observations

2019: automatic scheduling activated for follow-up observations

2020: no operation (problem in DAQ electronics, repair delayed due to SARS-CoV-2)

June 2021: back to operation, waiting for alerts

Sep 2021: volcano...

MWL and ToO Activities

- Multi-Messenger: AMON Network
- Multi-Wavelength (MWL) Projects: [joint with]
  - Mrk 501 Jun 2012 [MAGIC, MWL]
  - Mrk 501 Jun 2014 [H.E.S.S.]
  - Mrk 501 Jul 2014 [MAGIC, MWL]
  - Mrk 421 2015/2016 [MAGIC, MWL]
  - 1ES 1959+650 2015-19 [MAGIC, MWL]
  - Mrk 421 Dec 2015 [X-ray ToO]
  - 1ES 2344+51.4 [MAGIC, MWL]
  - Mrk 421 Jan 2018 [MAGIC, HAWC]
  - Mrk 421 Jan 2019 [AstroSAT, WEBT]
  - Mrk 421 Jun 2019 [X-ray ToO]

11 Atels

- MWL Observations triggered by FACT

101 alerts since March 2014

- Target-of-Opportunity (ToO) campaigns with X-ray satellites
  - 2013: *XMM-Newton / Swift*

Successful ToO Dec 2015

  - 2015/6: *INTEGRAL / Swift*

Successful ToO June 2019

  - 2019-21: *INTEGRAL*, *Swift* and *XMM-Newton*

MoU & MWL partners

Swift-XRT

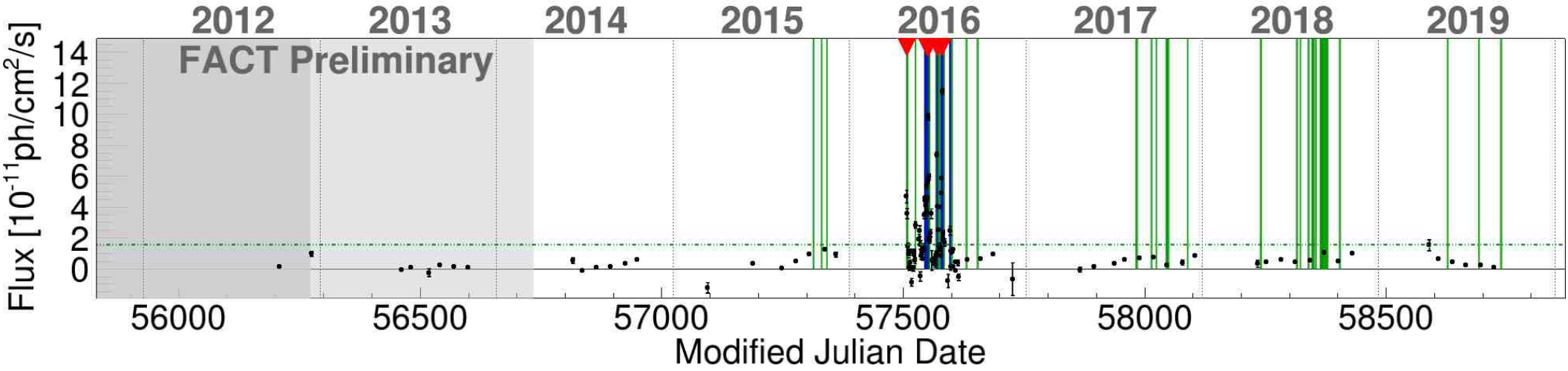
INTEGRAL

XMM-Newton

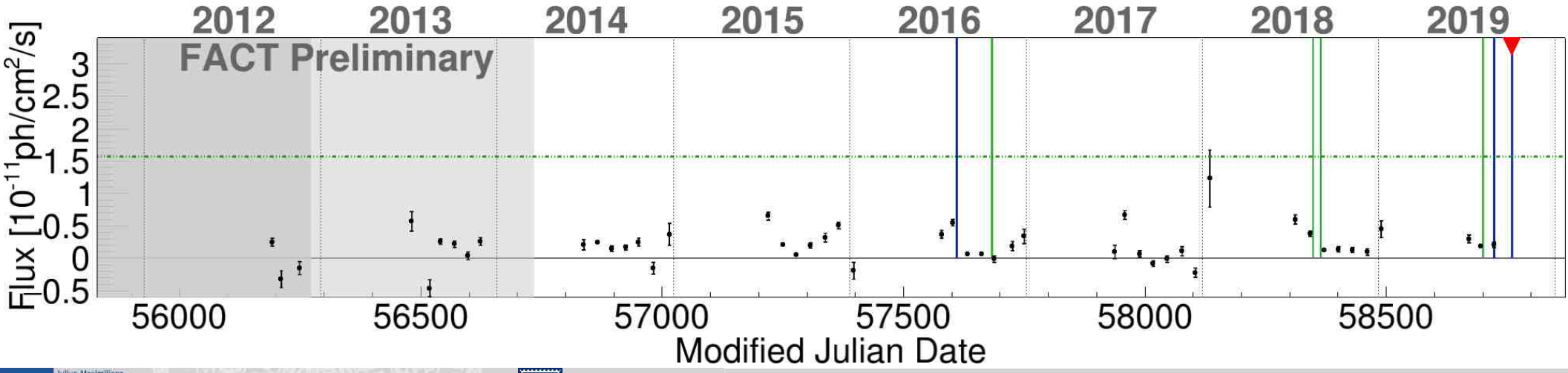
ATels

Long-Term Monitoring

1ES 1959+650



1ES 2344+51.4



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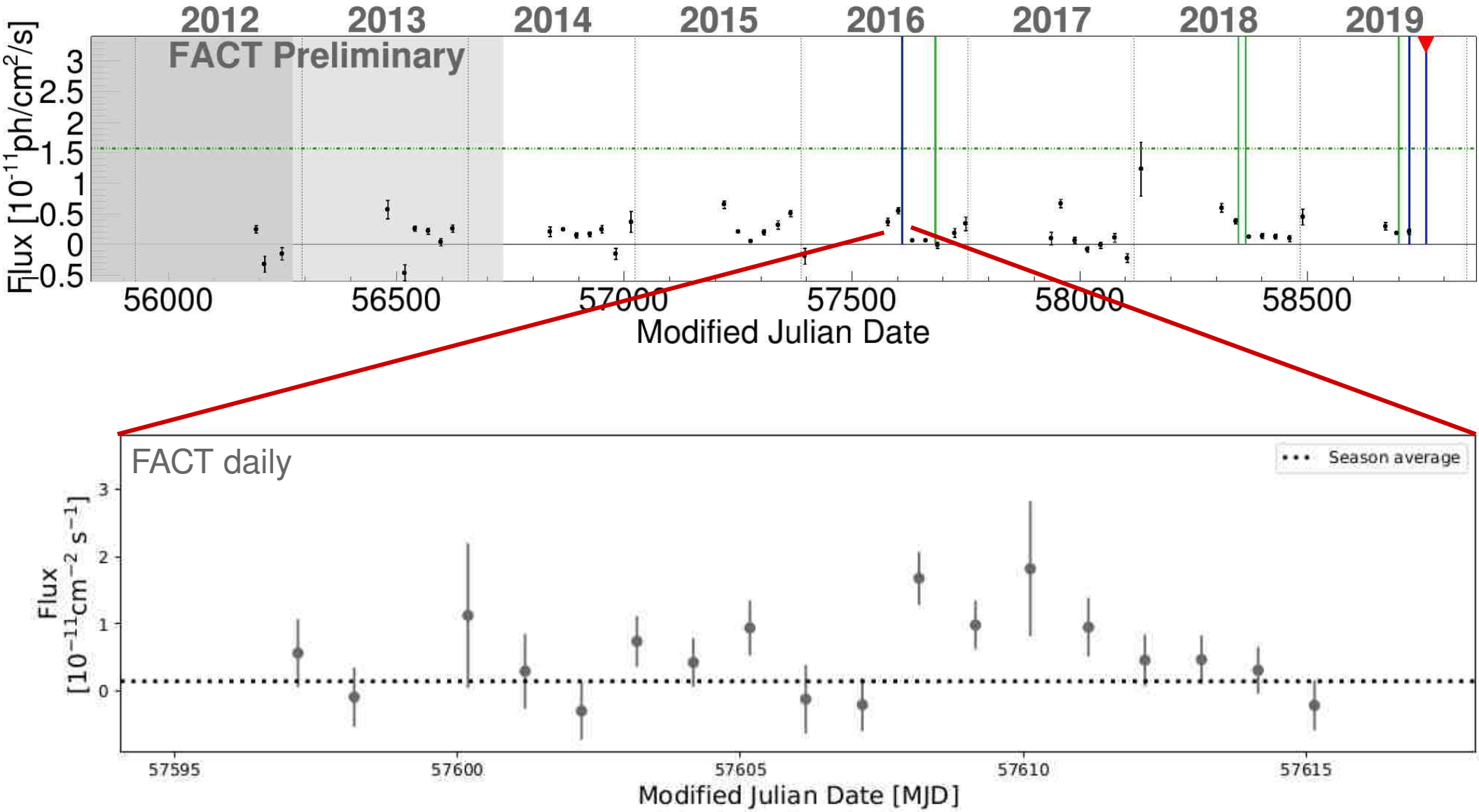
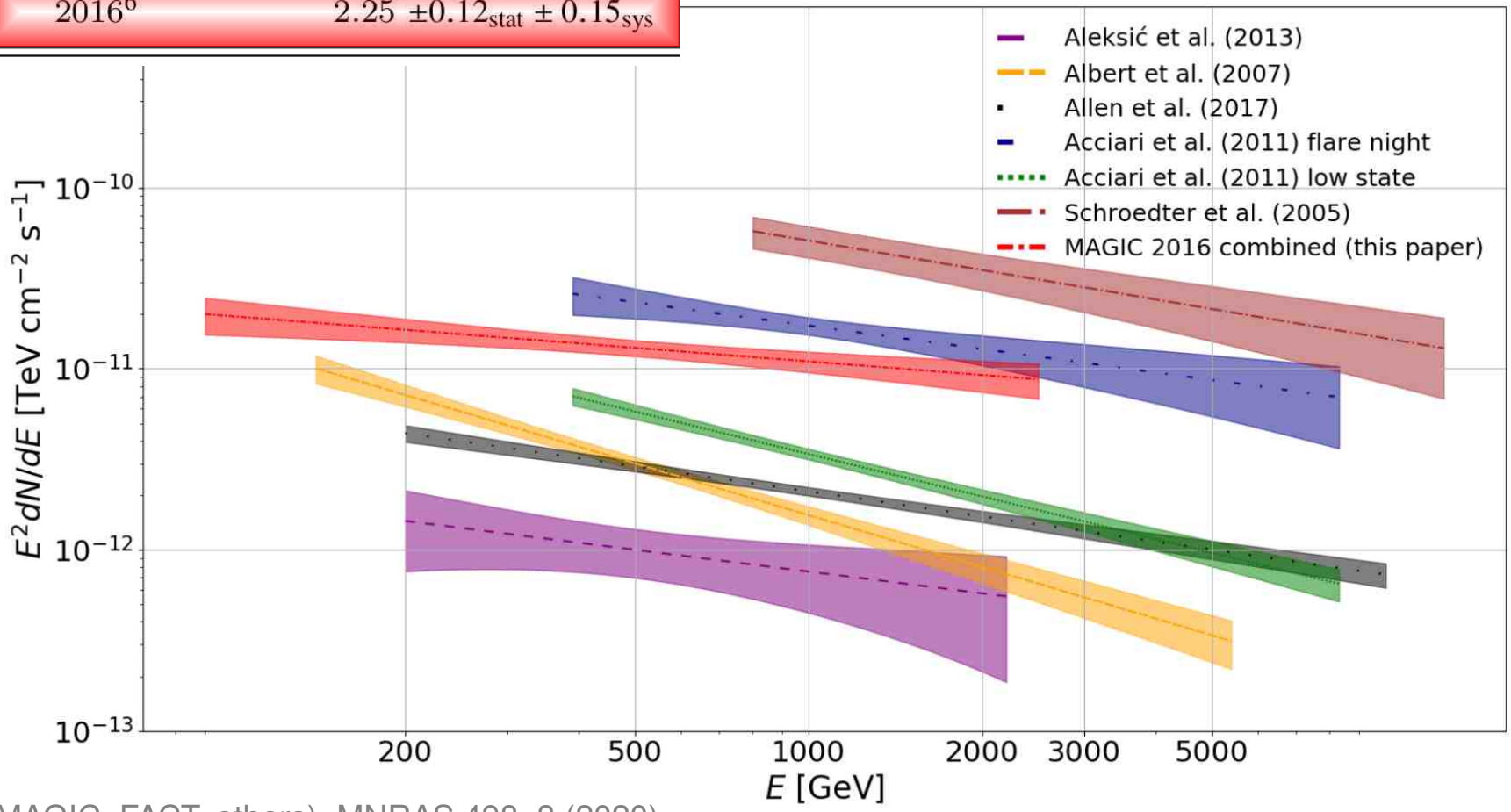


V. A. Acciari et al. (MAGIC, FACT, others), MNRAS 498, 3 (2020)

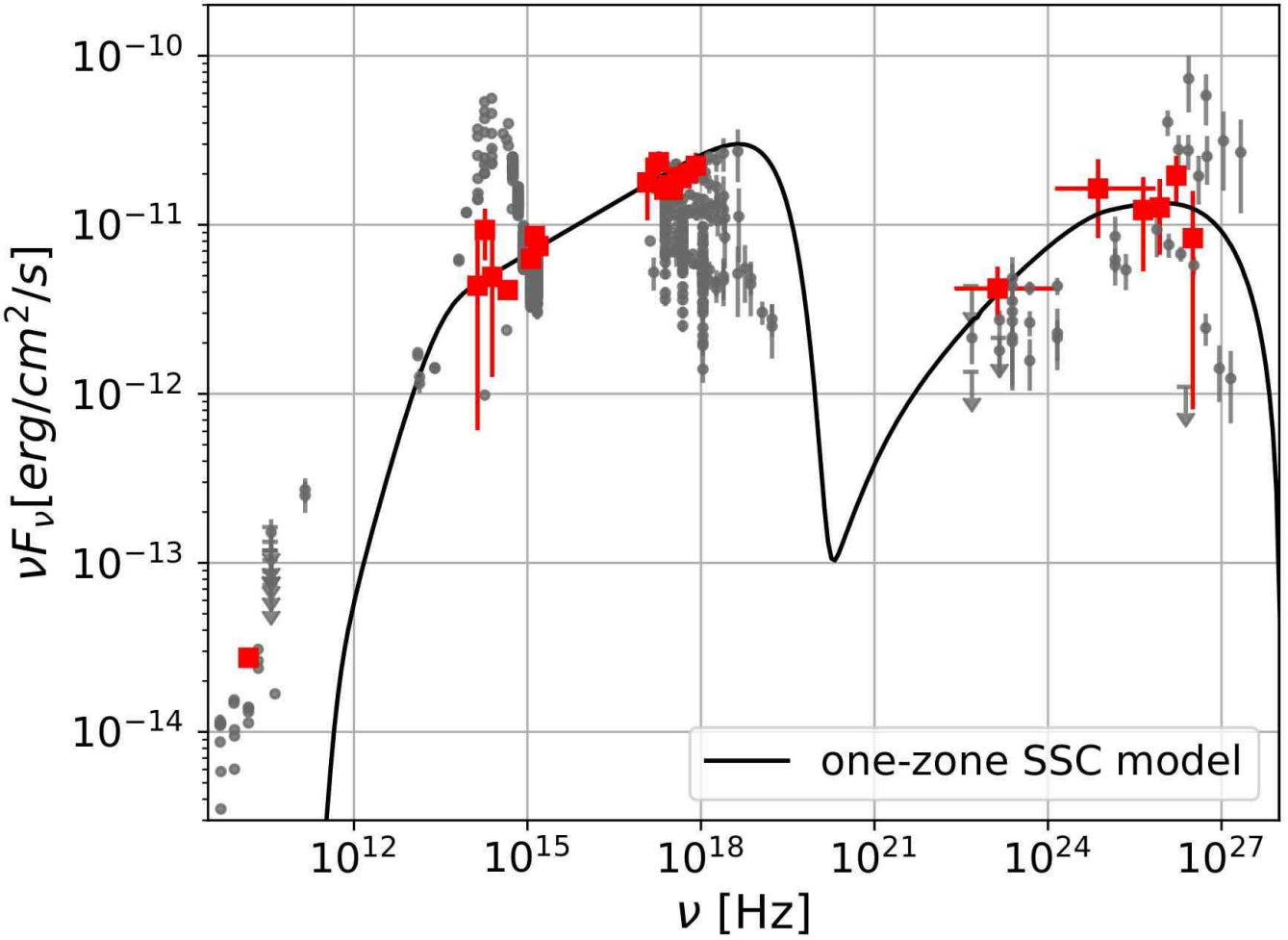
1ES 2344+51.4

	Epoch[b]	Γ (observed spectrum)
Whipple	1995[1]	$2.54 \pm 0.17_{\mathrm{stat}} \pm 0.07_{\mathrm{sys}}$
MAGIC	2007[2]	$2.95 \pm 0.12_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$
VERITAS	2007–2008[3] (low state)	$2.78 \pm 0.09_{\mathrm{stat}} \pm 0.15_{\mathrm{sys}}$
	2007–2008[3] (flare)	$2.43 \pm 0.22_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$
MAGIC	2008[4]	$2.4 \pm 0.4_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$
VERITAS	2007-2015[5]	$2.46 \pm 0.06_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$
MAGIC	2016[6]	$2.25 \pm 0.12_{\mathrm{stat}} \pm 0.15_{\mathrm{sys}}$



V. A. Acciari et al. (MAGIC, FACT, others), MNRAS 498, 3 (2020)

1ES 2344+51.4 an Intermittent Extreme Blazar



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MoU & MWL partners

Swift-XRT

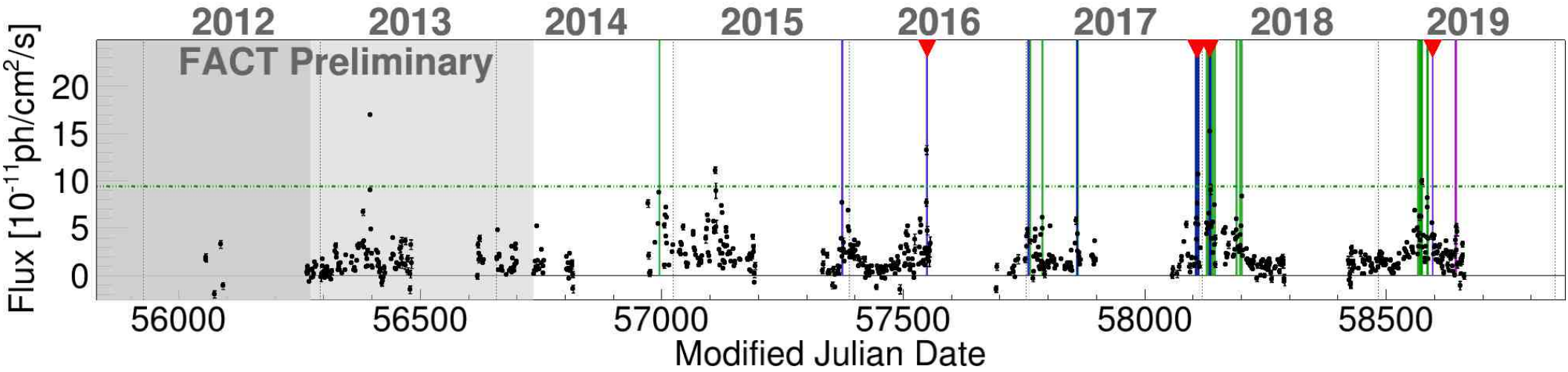
INTEGRAL

XMM-Newton

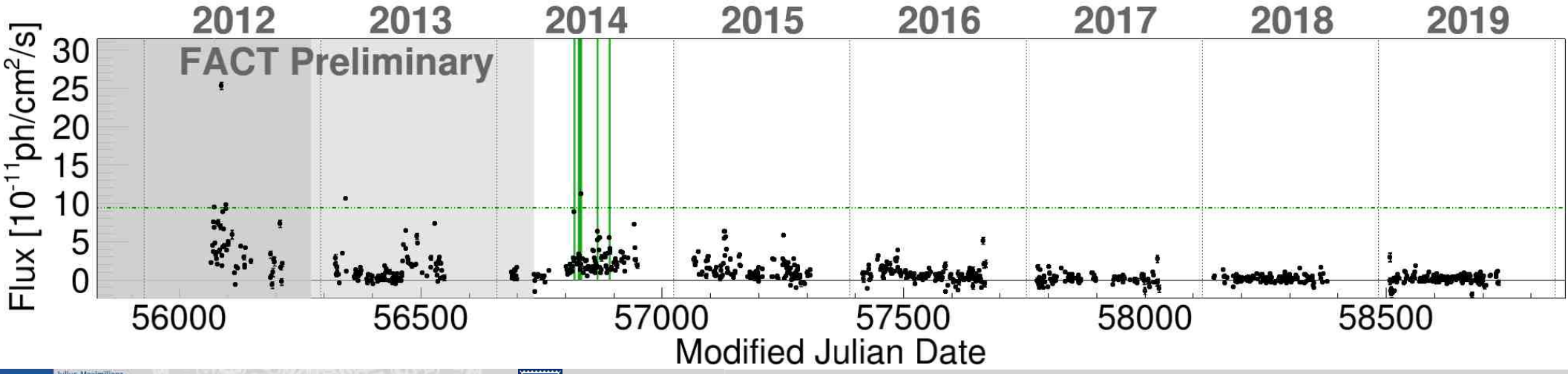
ATels

Long-Term Monitoring

Mrk 421

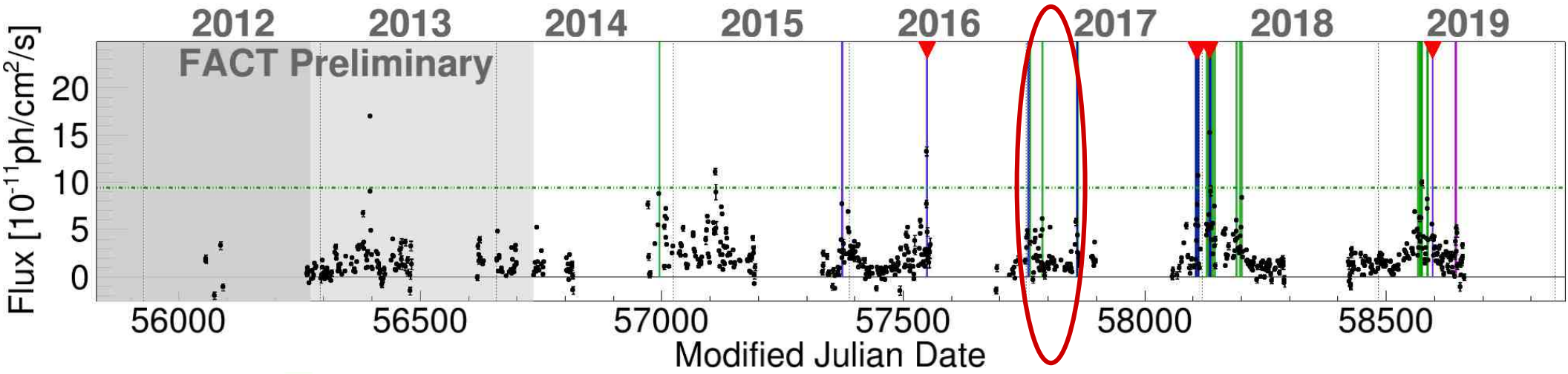


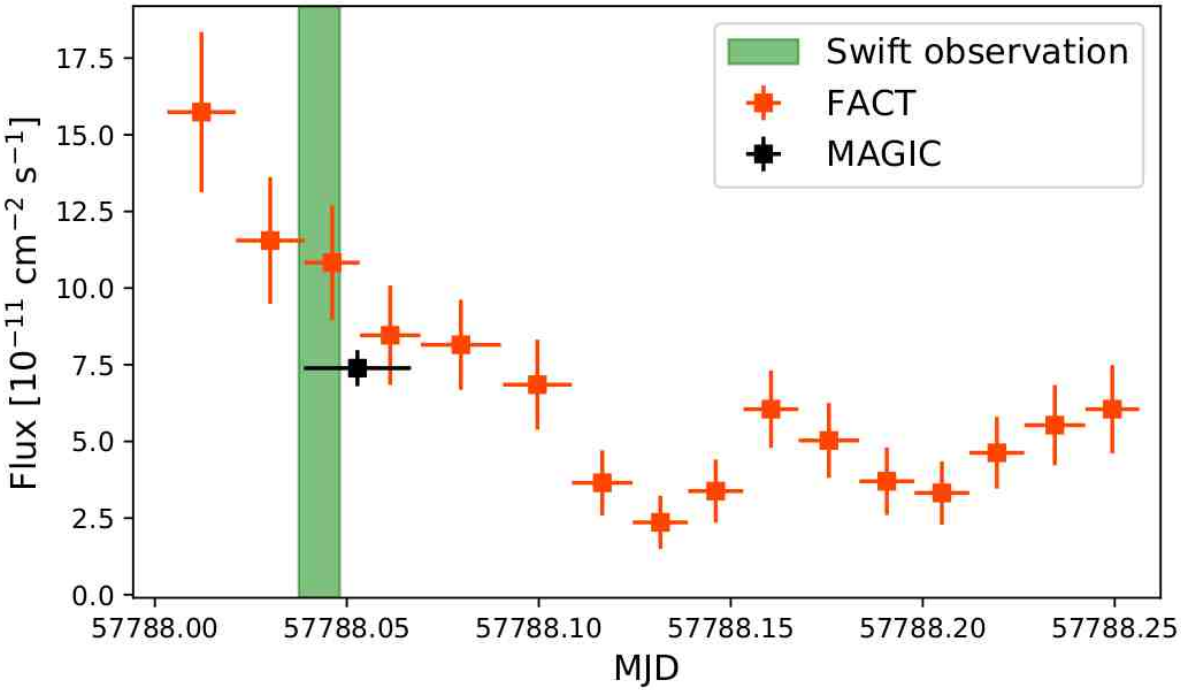
Mrk 501



Multi-Wavelength Campaigns

Mrk 421



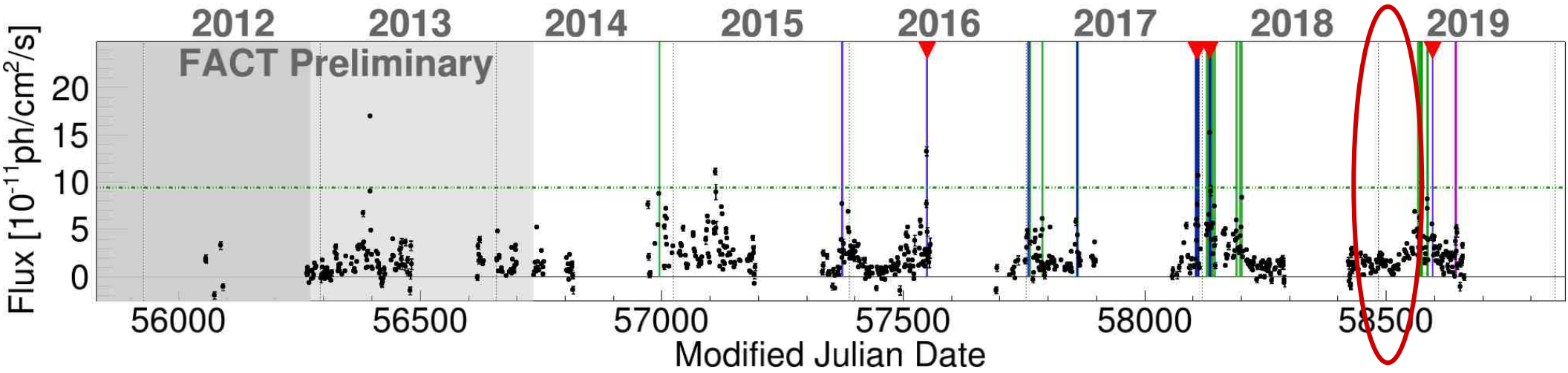


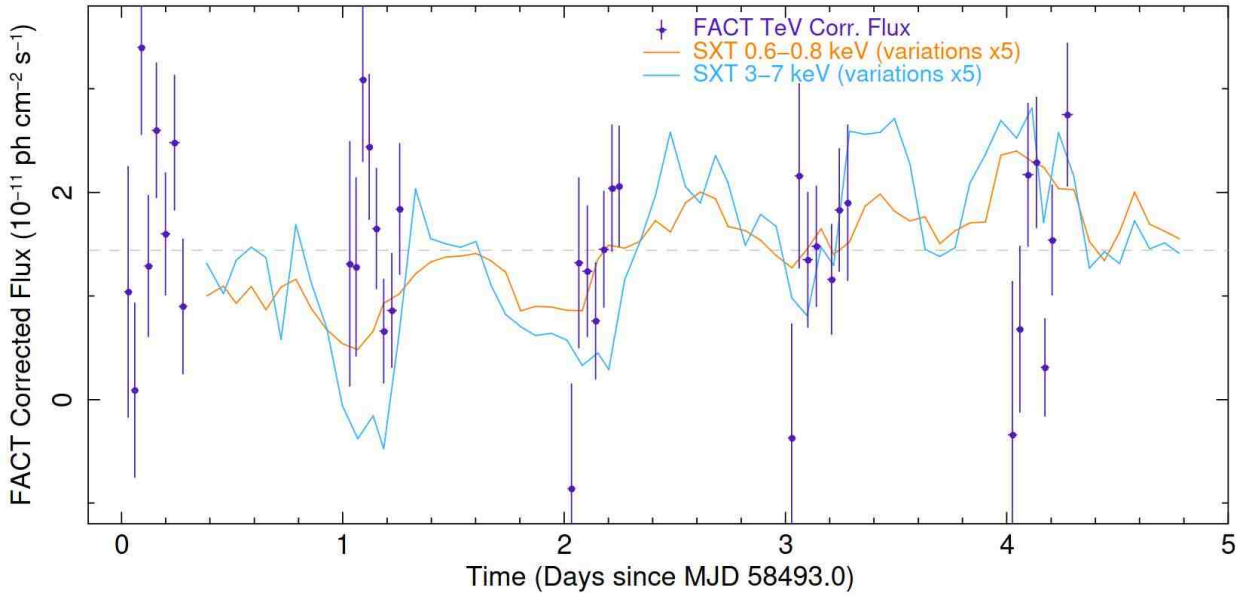
MWL campaign:
- NuStar observations
- outburst in Feb 2017

MAGIC Collab. et al. A&A, 655, 89

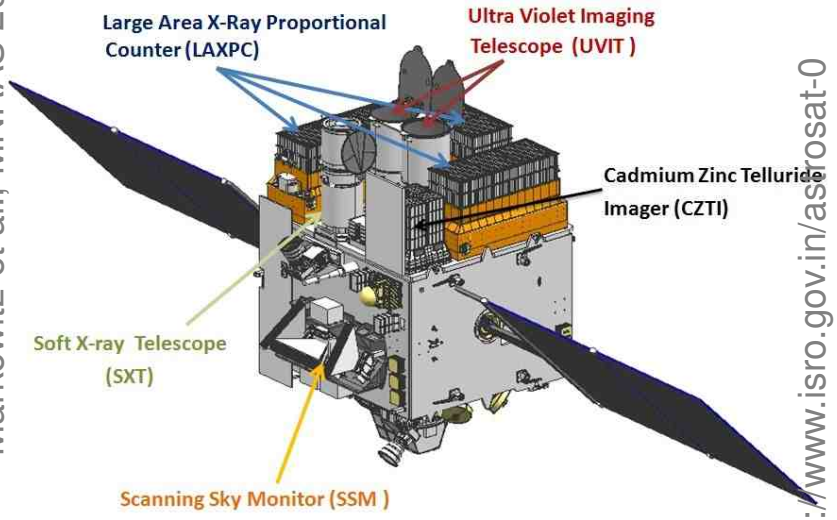
Multi-Wavelength Campaigns

Mrk 421





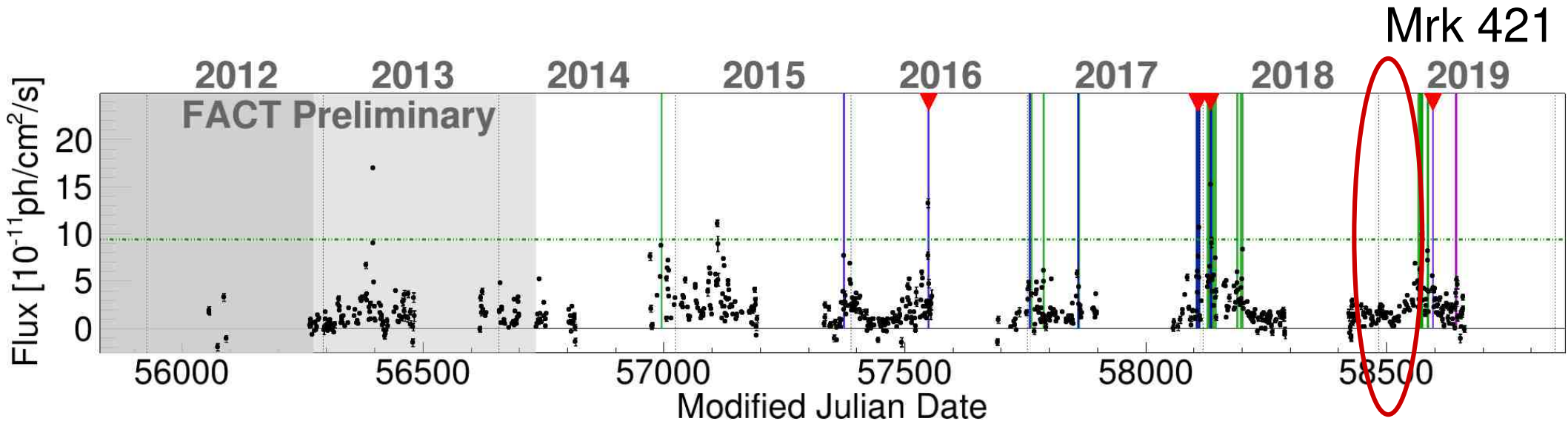
Markowitz et al., MNRAS 2022

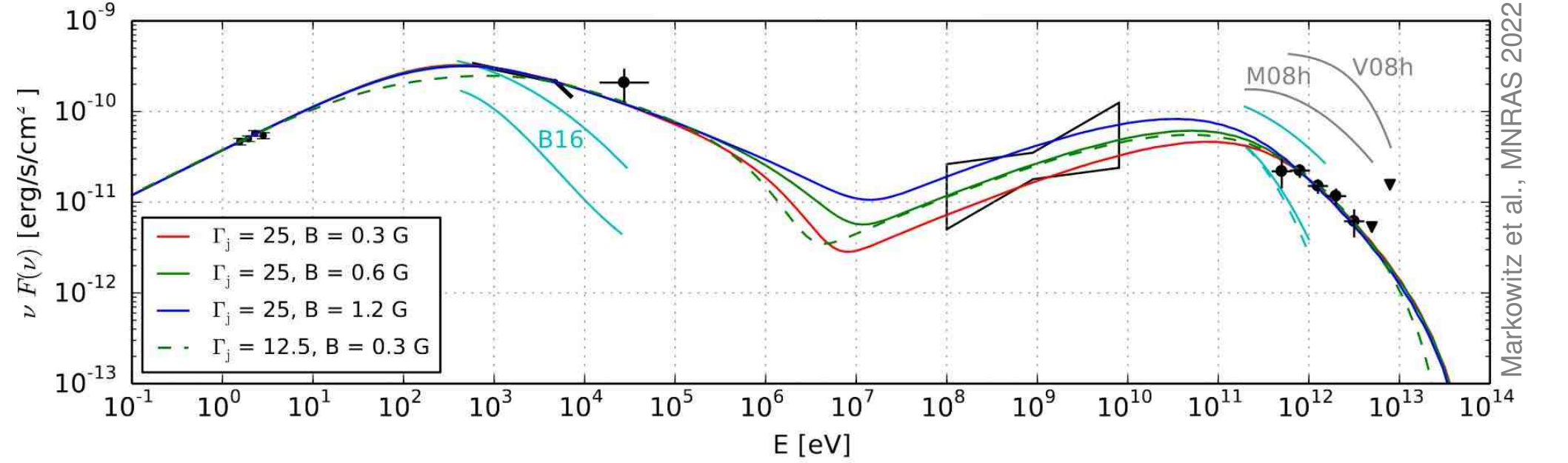


https://www.isro.gov.in/astrosat-0

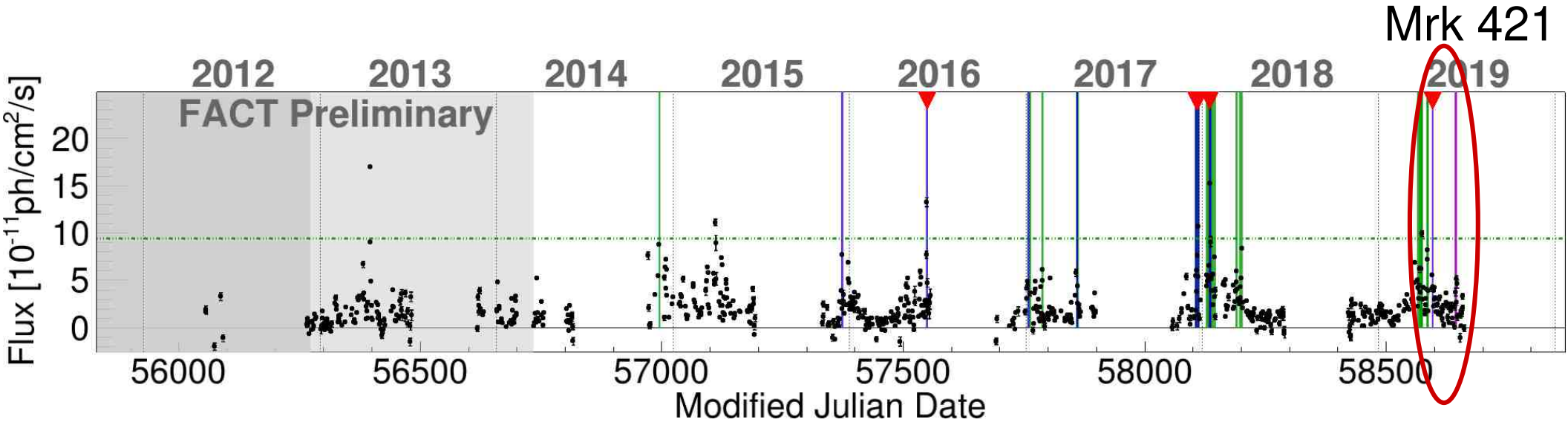
Joint campaign with AstroSAT and WEBT: Jan 2019

Multi-Wavelength Campaigns

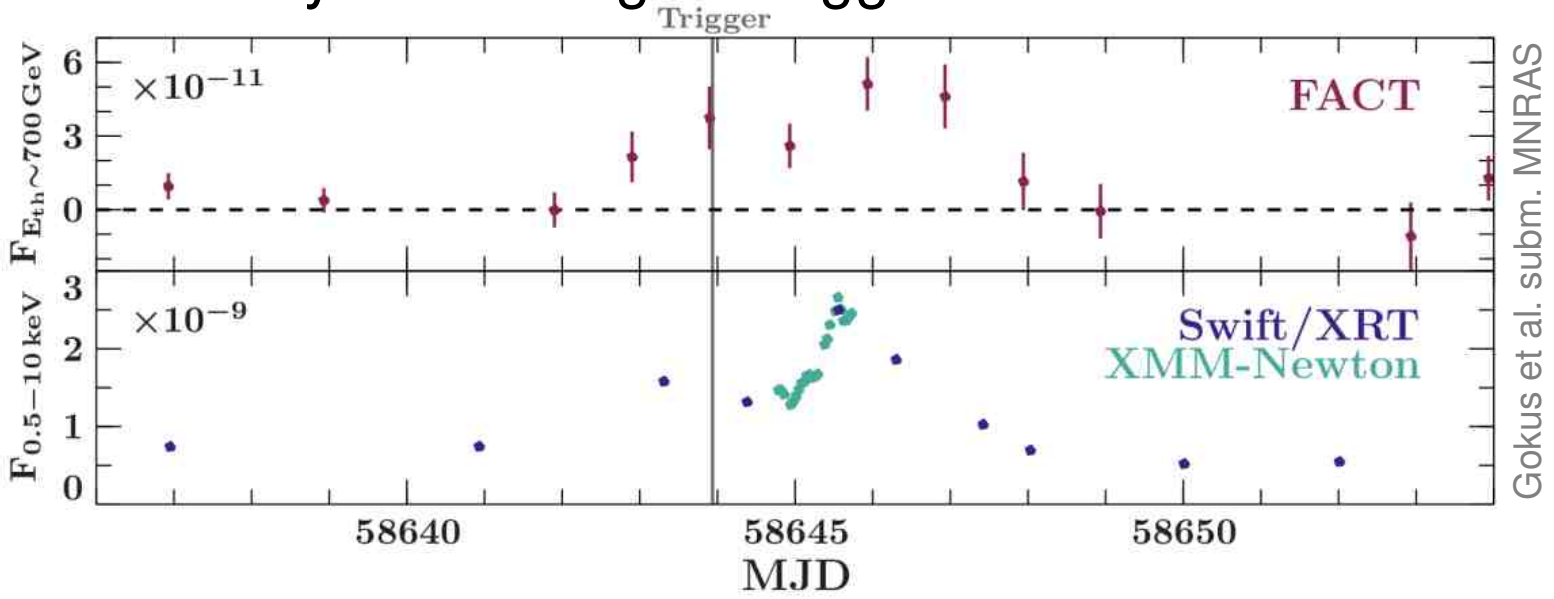




Triggers from Long-Term Monitoring



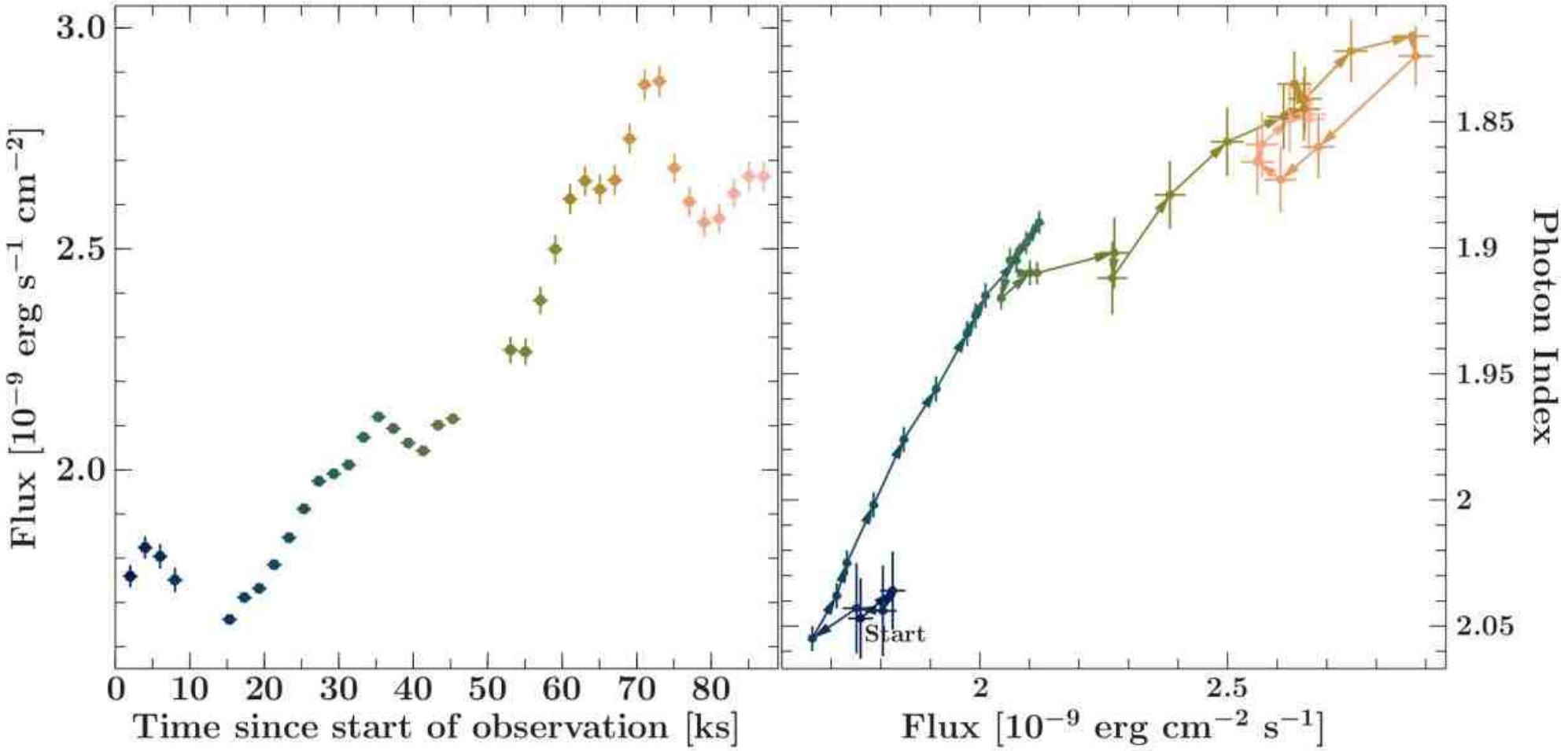
TeV + X-ray monitoring → Trigger to *XMM-Newton* and *INTEGRAL*



Gokus et al. subm. MNRAS

Mrk 421 Flare in 2019

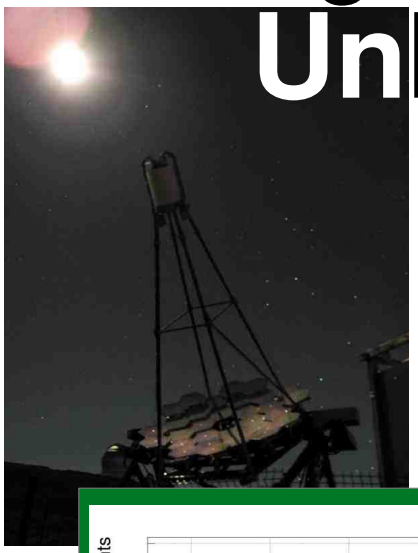
Analysis of XMM-Newton data in sections of 2 ks
→ harder-when-brighter trend
Brightest phase of flare: Clockwise rotation, i.e. soft lag
→ cooling time scales dominate underlying physics processes

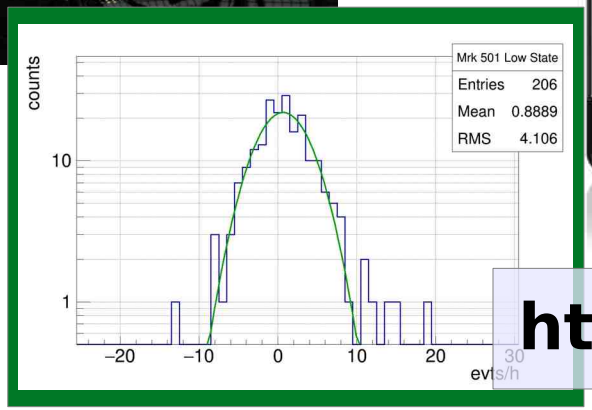


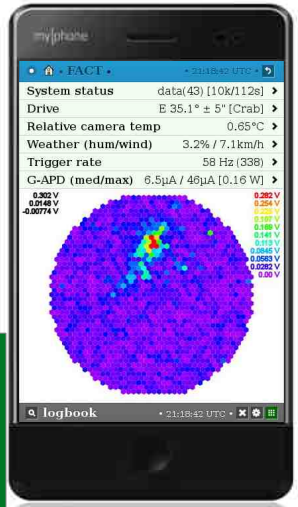
Gokus et al. submitted to MNRAS

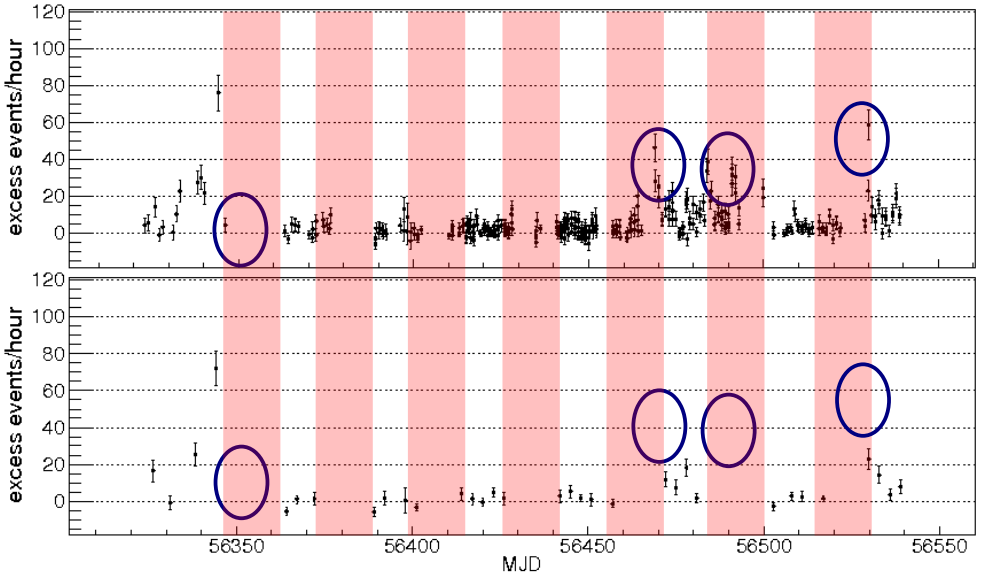
Long-term Studies @TeV Energies

Unbiased Monitoring & ToO

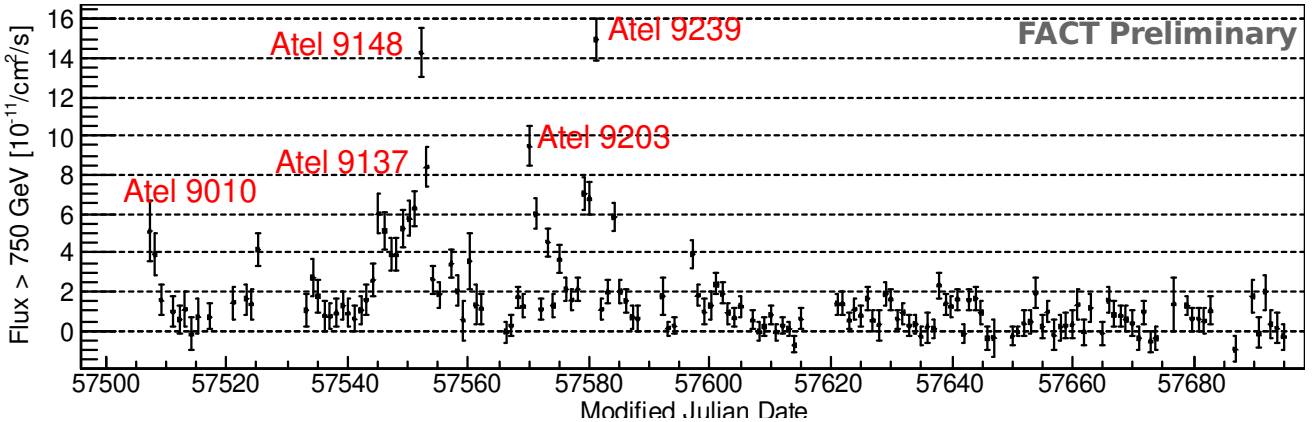


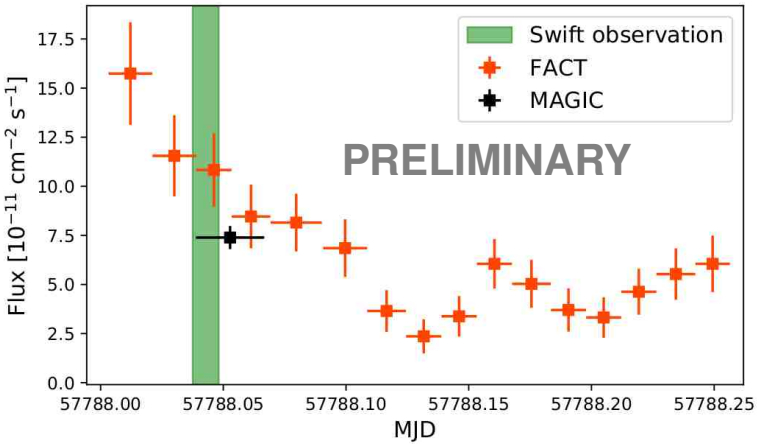






http://www.fact-project.org/monitoring





Thank you for your attention!