

EHT-MWL campaigns on AGNi involving γ -ray observatories (with the participation of the H.E.S.S. Collaboration)

Anna Luashvili

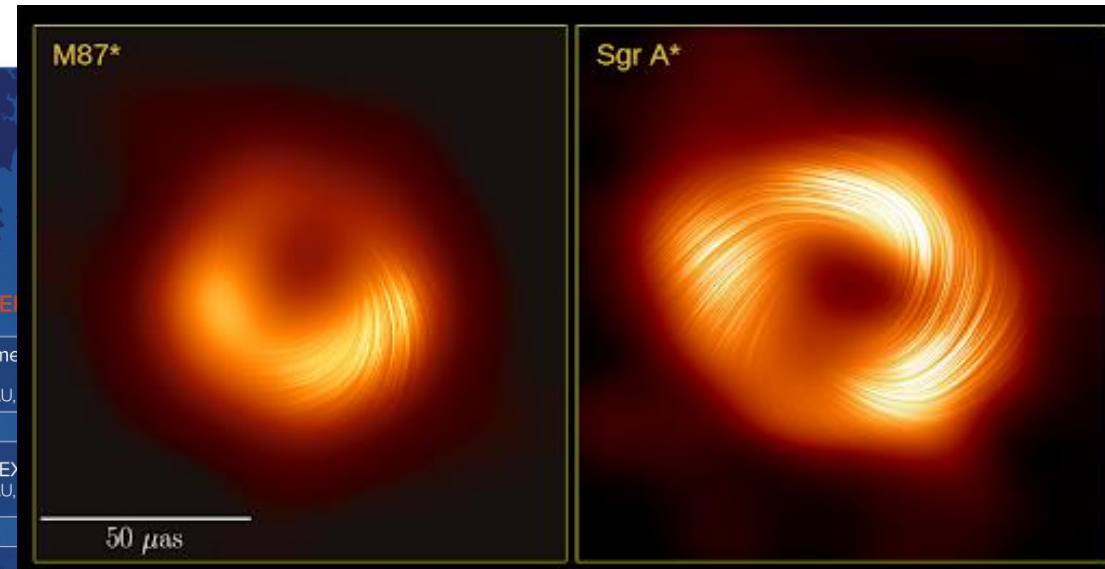


Event Horizon Telescope (EHT)

A Global Network of Radio Telescopes



Credit: NRAO



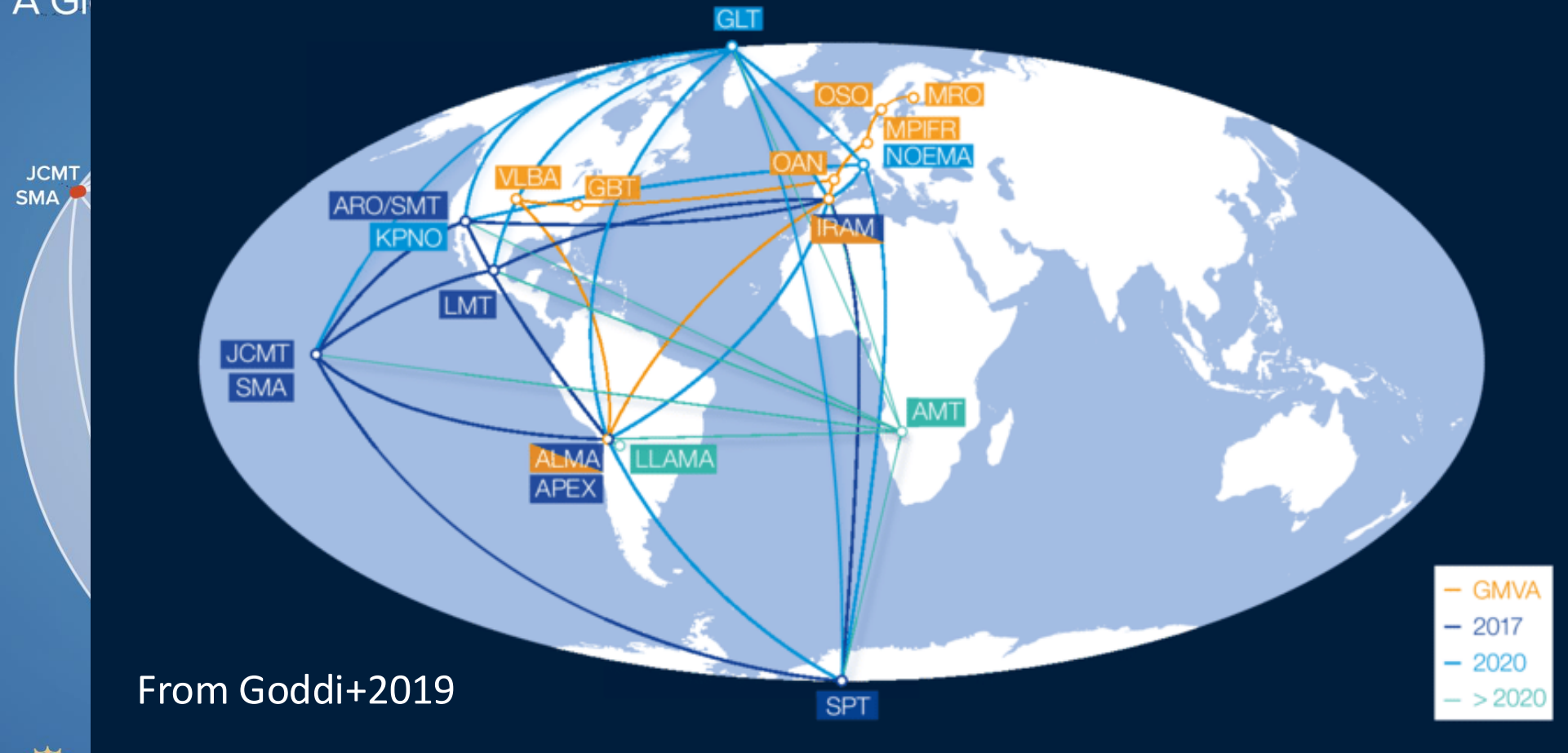
Credit: EHT Collaboration

M87* and Sgr A*: only two targets resolved at event horizon scales.

+ very high resolution images of innermost jet regions of other sources (e.g. [Röder et al. 2025](#))

Event Horizon Telescope (EHT)

A GI



M87*

Sgr A*

oration

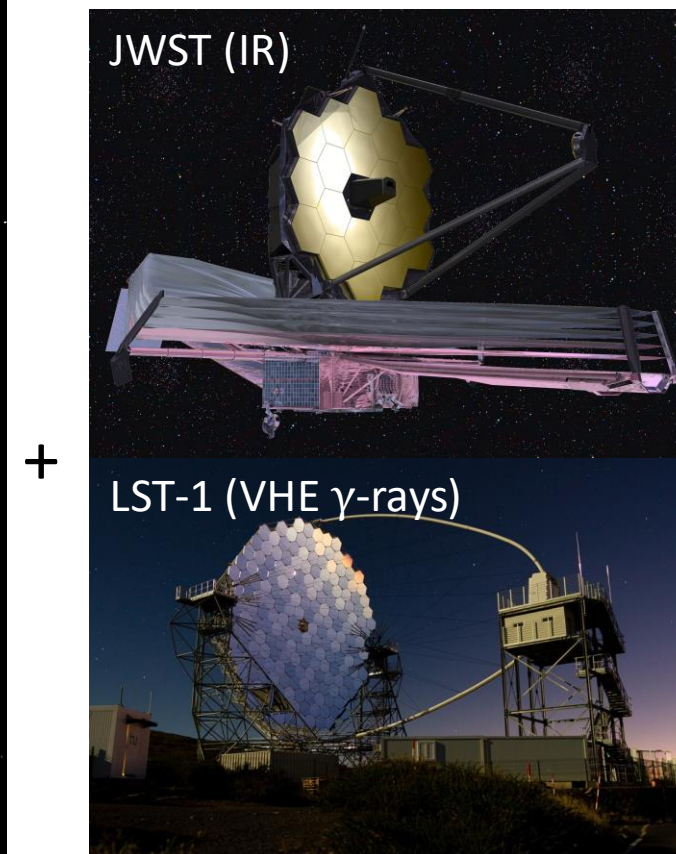
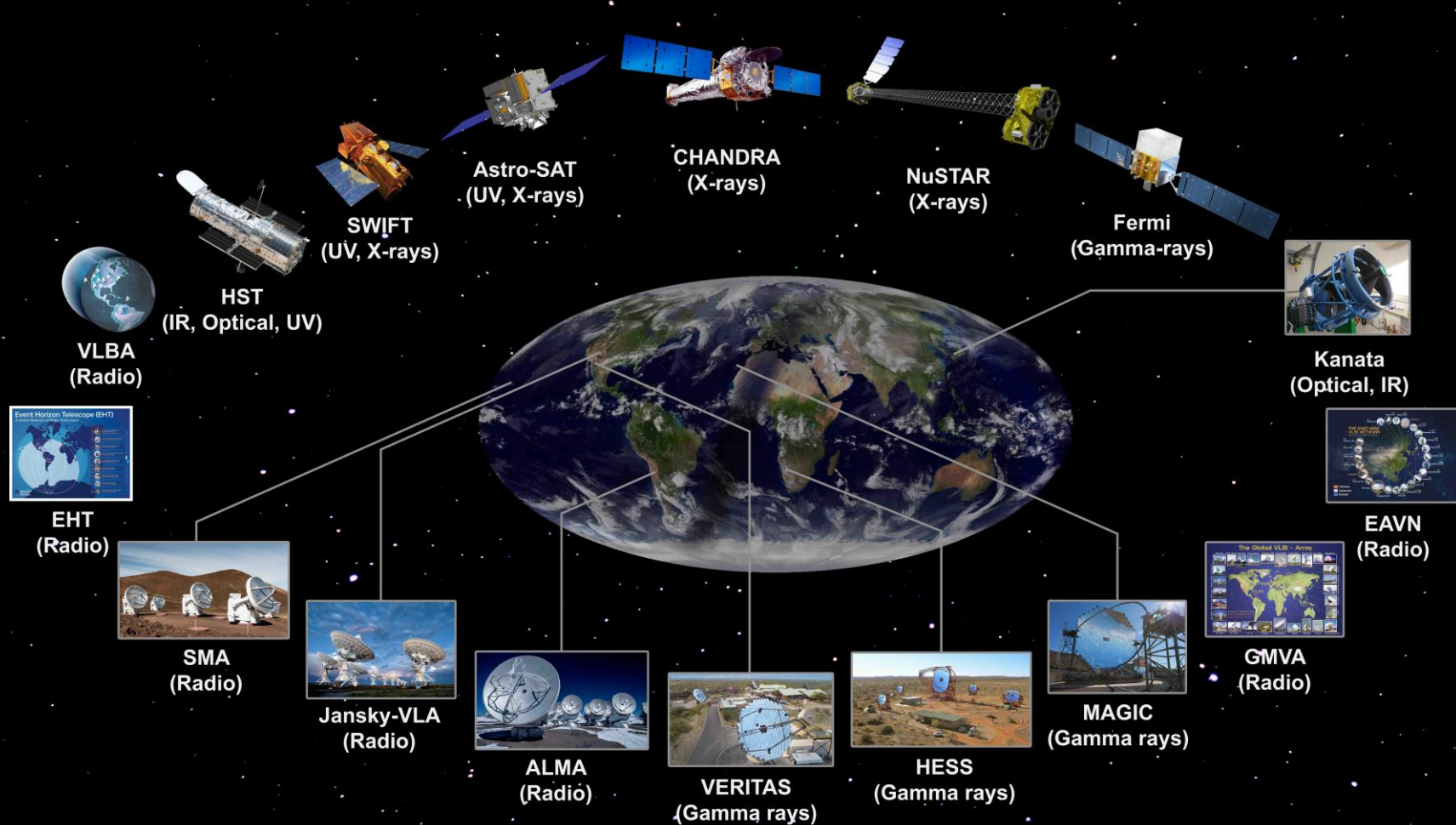
: only two targets
t horizon scales.

ation images of
ions of other sources
(2025)



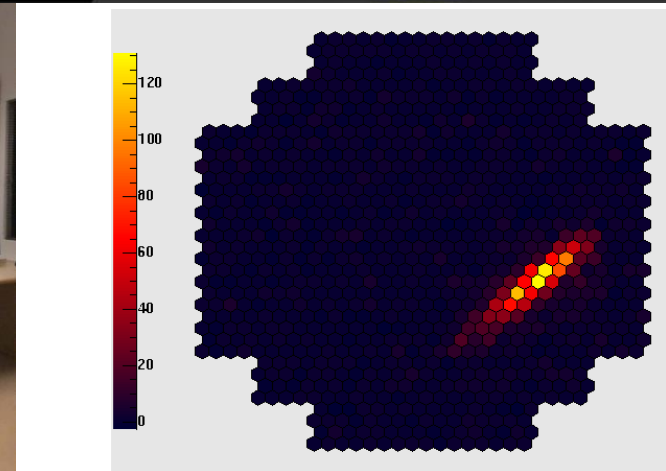
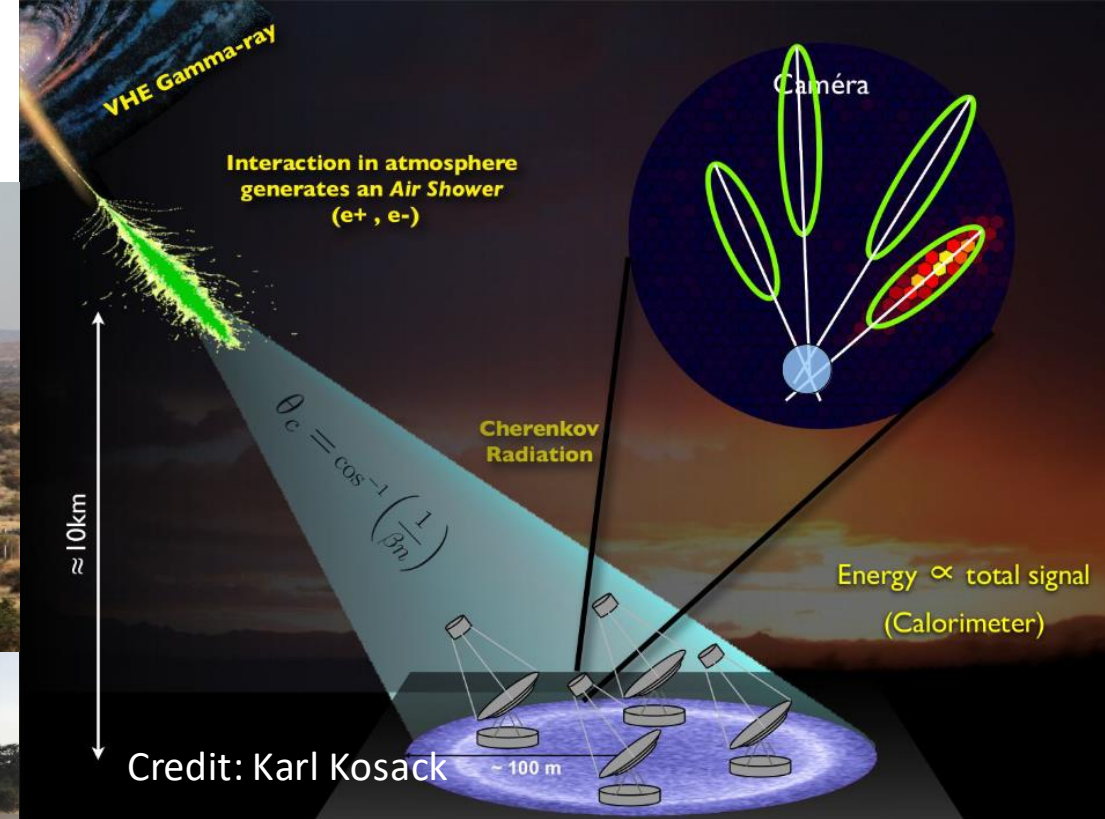
Credit: NRAO

M87* MULTIWAVELENGTH CAMPAIGN 2018

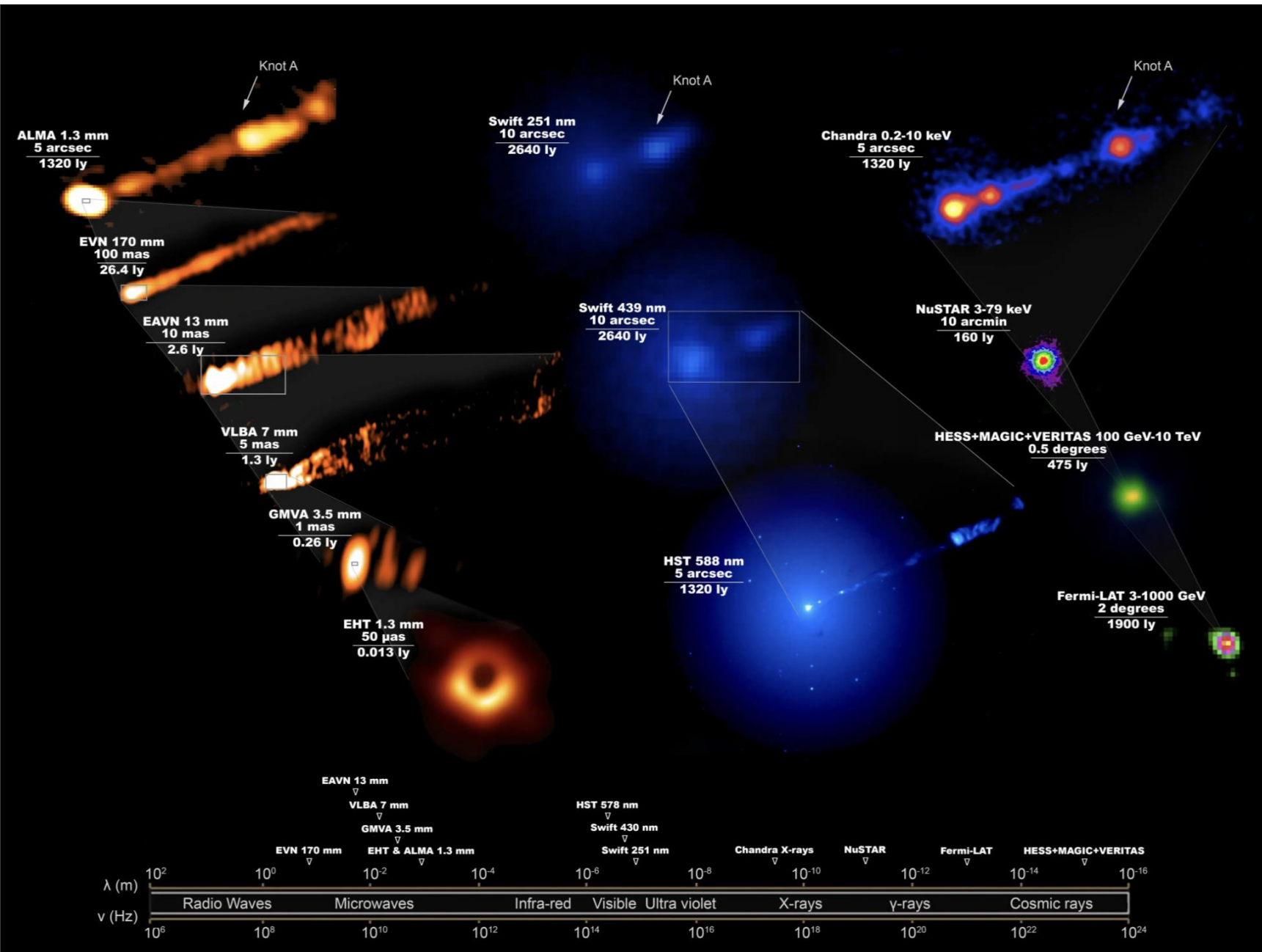


Credits: EHT Collaboration, Fermi-LAT Collaboration, H.E.S.S. Collaboration, MAGIC Collaboration, VERITAS Collaboration, EAVN Collaboration, NASA/JWST, O. Ballester/LST-CTAO

High Energy Stereoscopic System (H.E.S.S.)

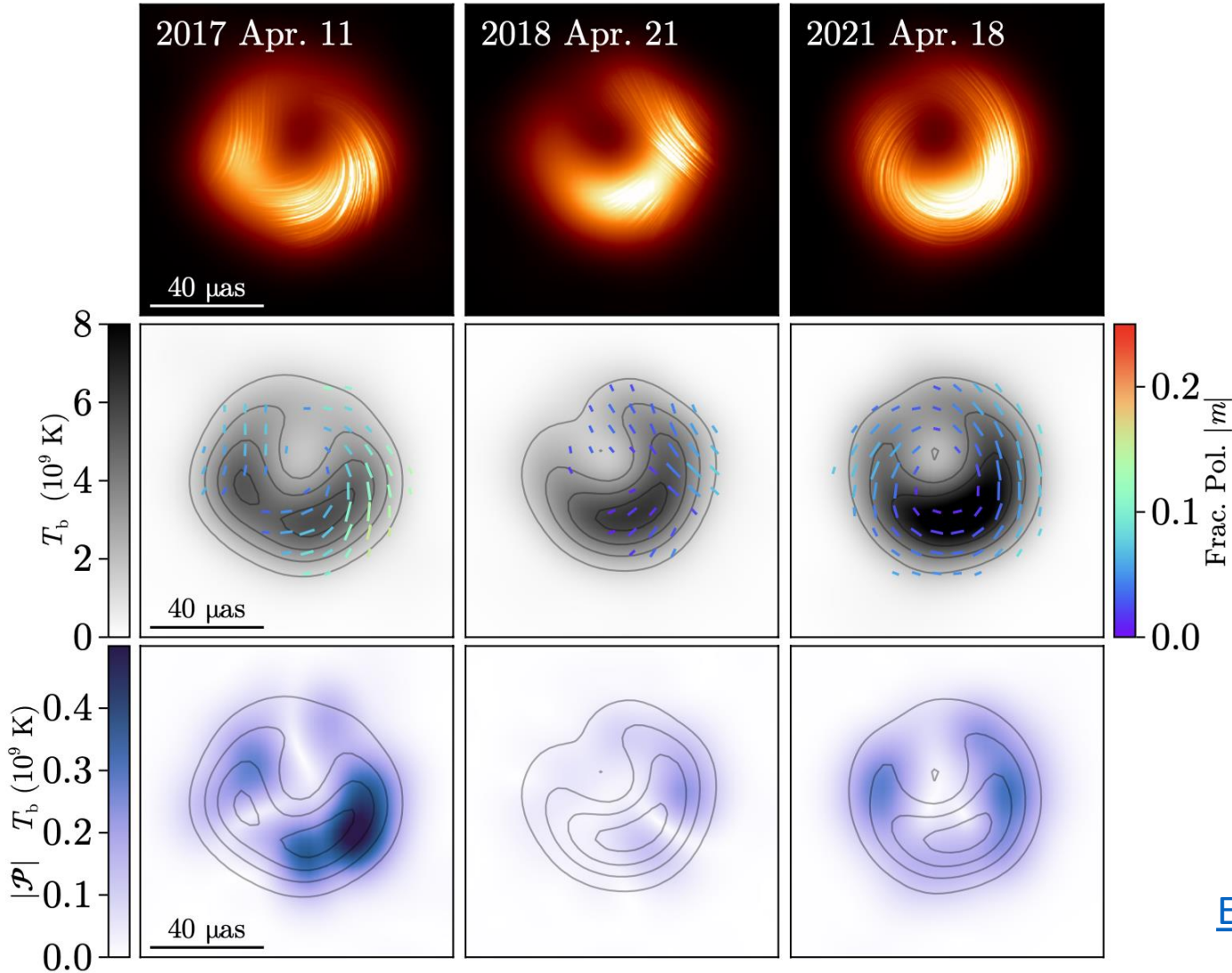


M87 – complex jet structure



Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S. collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba.

M87* multi-year variability



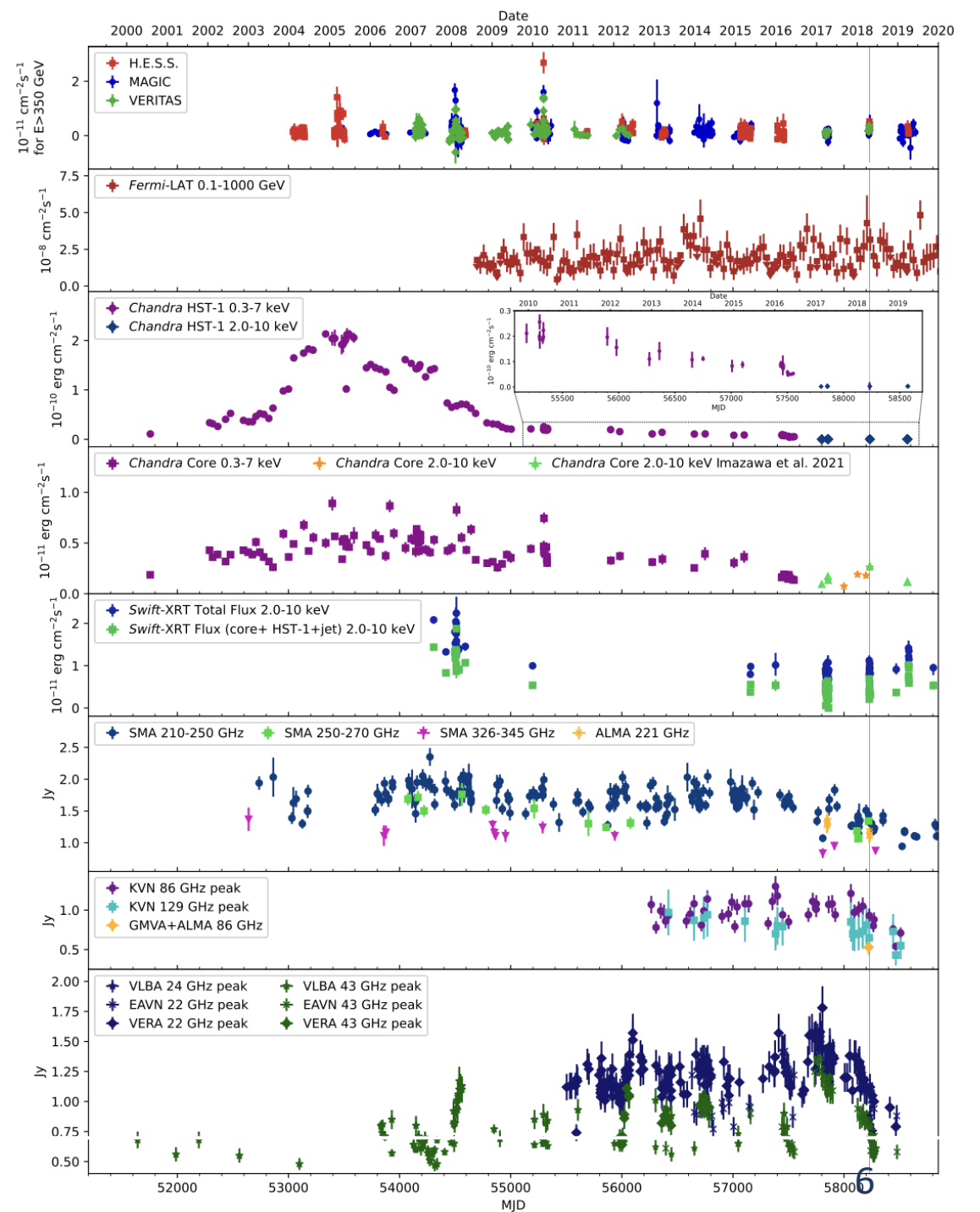
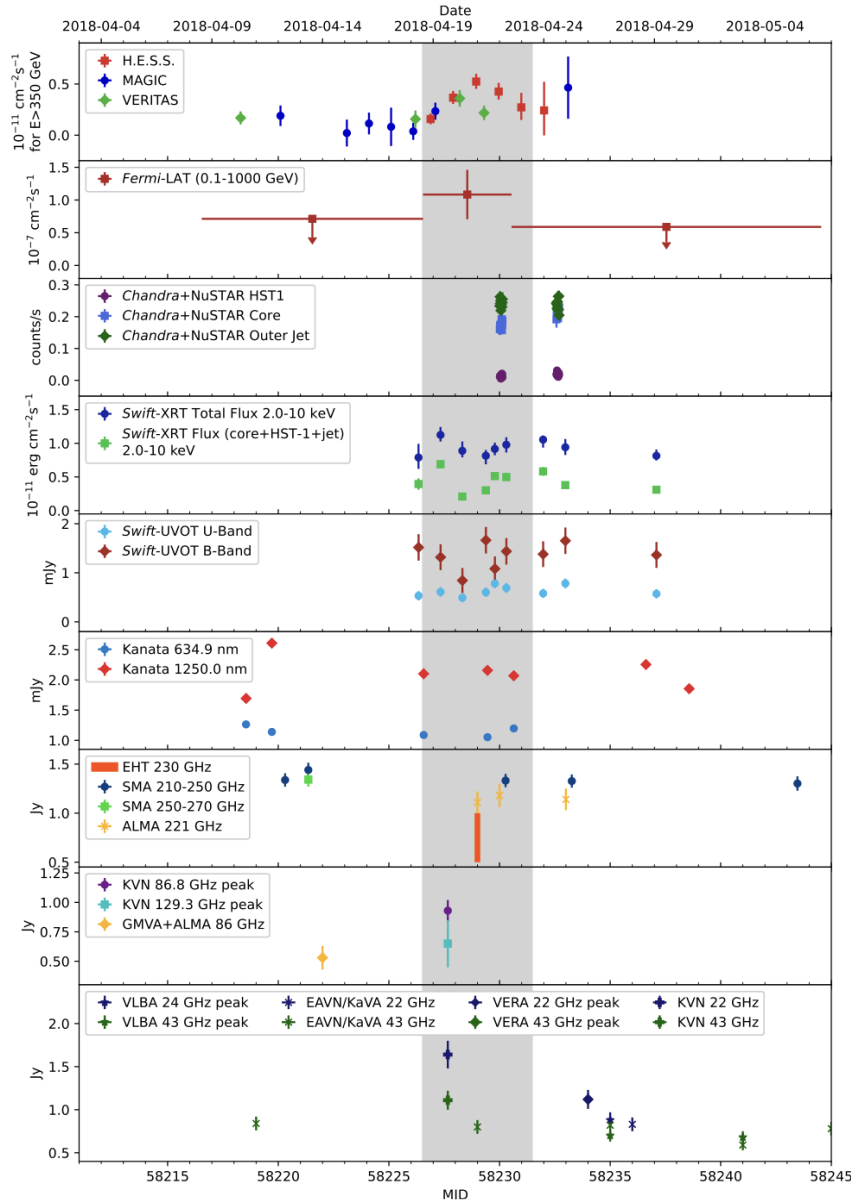
- Improved resolution in 2021, with KPT and NOEMA joining the EHT network.
- Persistent diameter of the bright asymmetric ring (43.9 ± 0.6) μas , but significant variability of its properties across the years.
- Total intensity and linear polarization vary, as expected for a stochastic accretion regime.
- Similar EHT images for very different γ -ray states of the source
- Fast and year-to-year variability studies made possible with the EHT network.

[Event Horizon Telescope Collaboration \(2025\)](#)

M87 – complex MWL variability

[EHT MWL Science WG \(2021\)](#) – low state (2017)

[EHT MWL Science WG \(2024\)](#) – high state (2018)



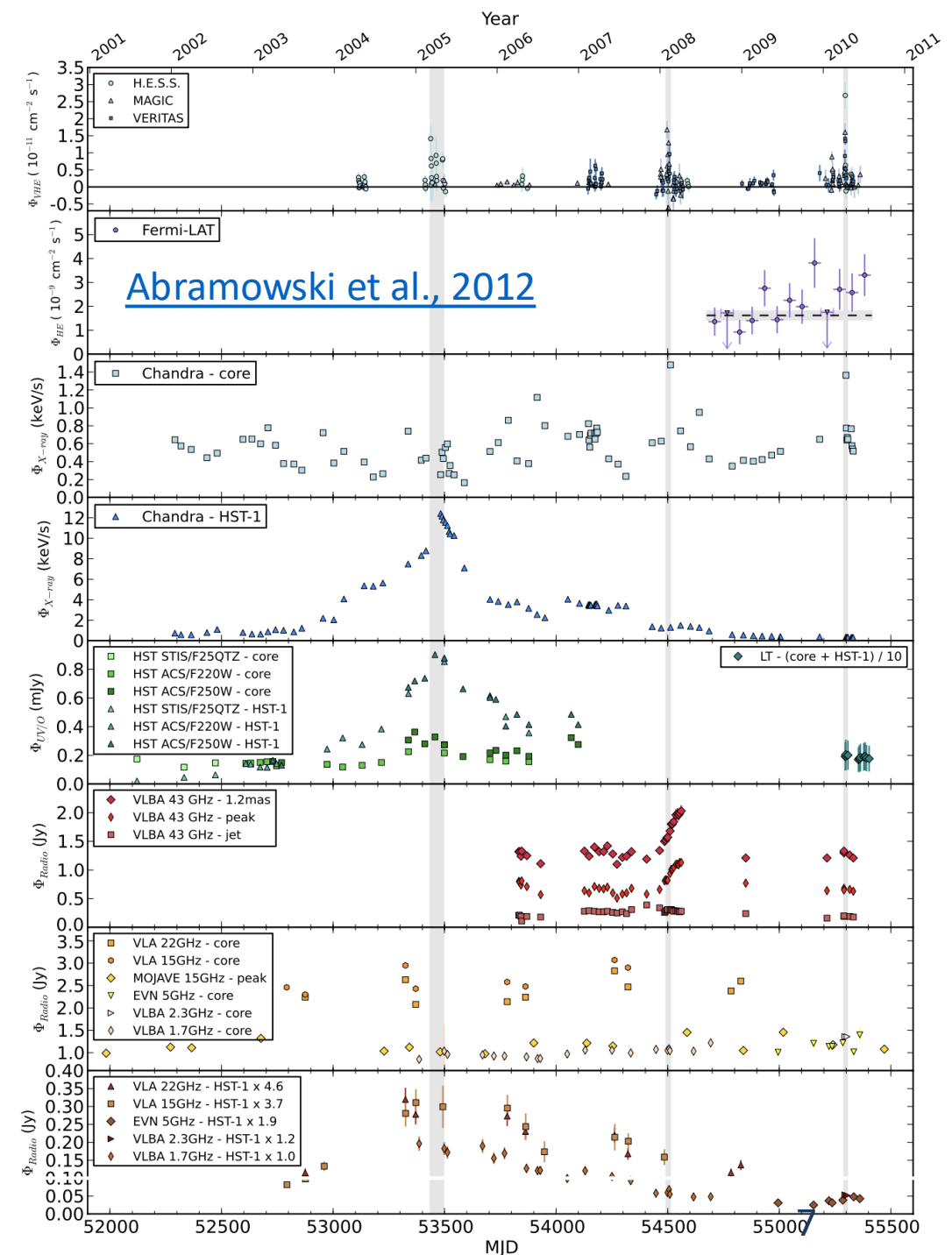
What are we (still) trying to understand?

Various VHE behaviors – different physical origin? MWL links?

- VLBA activity seen in fast 2008 and 2010 flares -> new components emerging from the jet base are probably associated with the TeV activity. Magnetic reconnection?
- Later reported long-lasting high VHE state (weekly timescales, e.g. [Beilicke+2012](#)) without inner structure changes @ 1.3 mm but emergence of a new component at longer wavelengths suggesting VHE γ -rays come from few tens to hundreds of R_S ?
- Historically low in 2017, and while the radio and mm core fluxes were consistent between 2017 and 2018, VHE γ -ray variability on daily timescales and an increase in the X-ray flux was found in 2018.

Single zone leptonic scenario cannot explain simultaneously EHT mm-band emission and VHE constraints.

-> Stratified jet model needed.

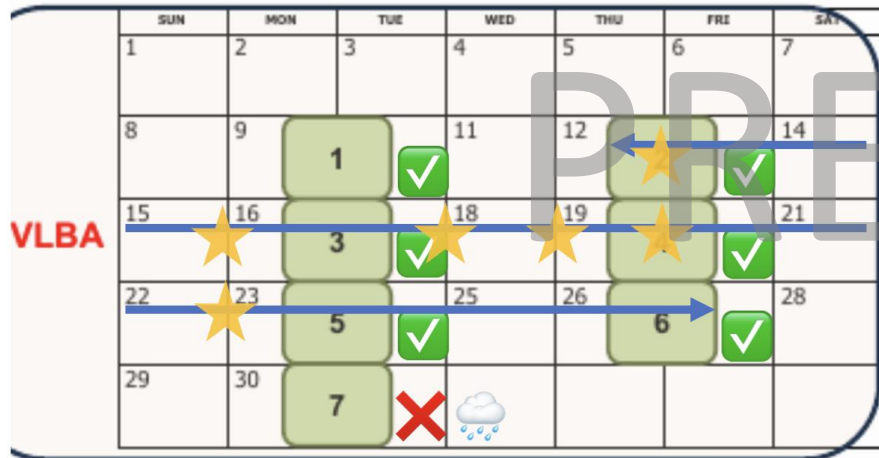


M 87 movie campaign – VHE coverage with H.E.S.S.

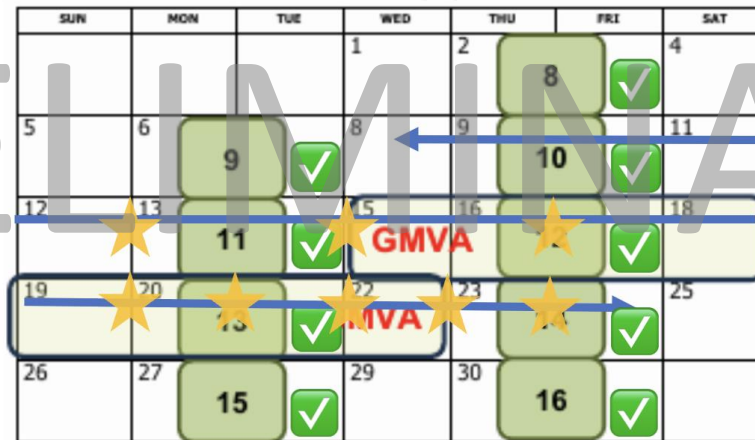
High cadence EHT and MWL observations during 2 – 3 months, instead of 1 – 2 weeks.

Cross-correlate VHE/multi-band variability with structural changes in the horizon scales.

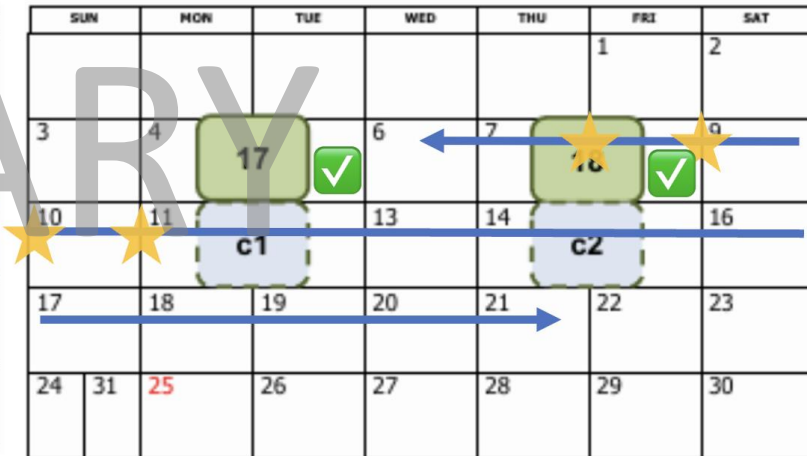
March



April



May



✓ : Confirmed EHT session

✗ : Cancelled EHT session

M87 visible for H.E.S.S. at least 1h with max ZA = 50°

★ : H.E.S.S. observed M87

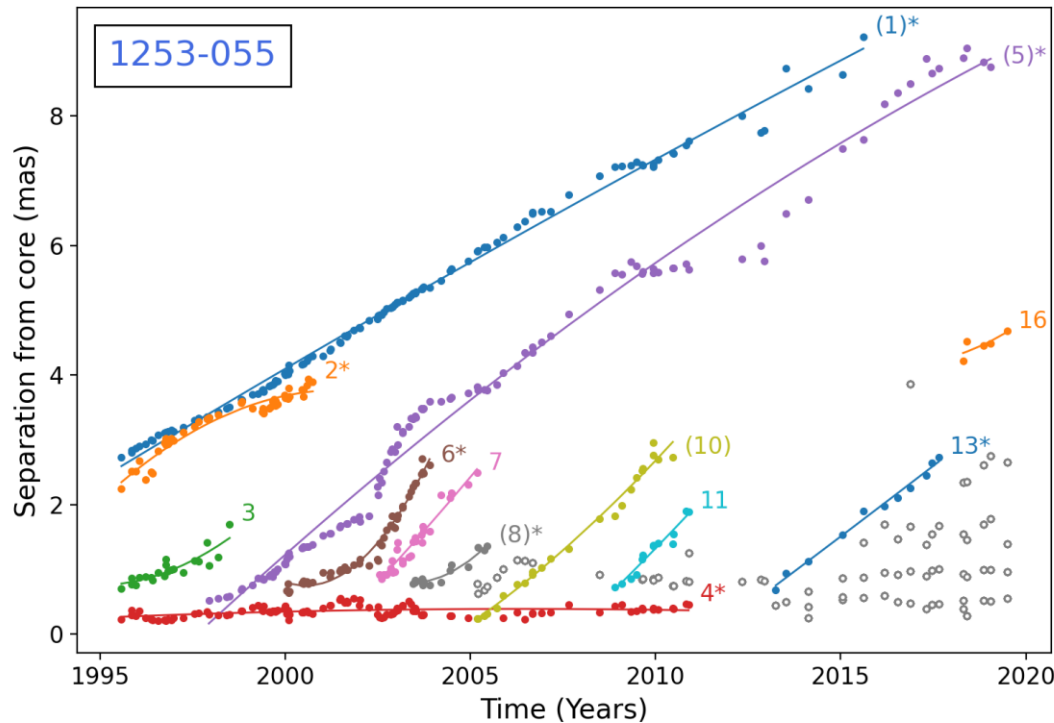
18 sessions of 3hrs/session, 2/week

3C 279 – intriguing blazar

- **Primary EHT calibrator for Sgr A* and M87 observations, for which we accumulated several years of data.**
- 3C 279 ($z = 0.536$): 1st FSRQ to be detected at HE and VHE γ -ray energies (≥ 100 GeV) ([Hartman et al., 1999](#), [MAGIC Collaboration \(2008\)](#)).
- 2014 & 2015 observations (HE triggers) lead to a significant detection in 2015 only, but no variability was observed ([H.E.S.S. Collaboration \(2019\)](#)).
- One of the most studied blazars, but not well understood.
Chaotic MWL behaviour, appearance of orphan flares, that standard one zone models tend to fail to reproduce ([Abdo et al., 2010](#), [Hayashida et al., 2015](#)).
Dramatic optical polarization changes ([Abdo et al., 2010](#)).
- Record HE γ -ray outburst ($\sim 3.5 \times 10^{-5} \text{ cm}^{-2}\text{s}^{-1}$) in June 2015, with doubling times ~ 5 min ([Ackermann et al. 2016](#)), implying a very compact zone a few hundred R_S only from the BH + min-scale variability in [Shukla & Mannheim \(2020\)](#).

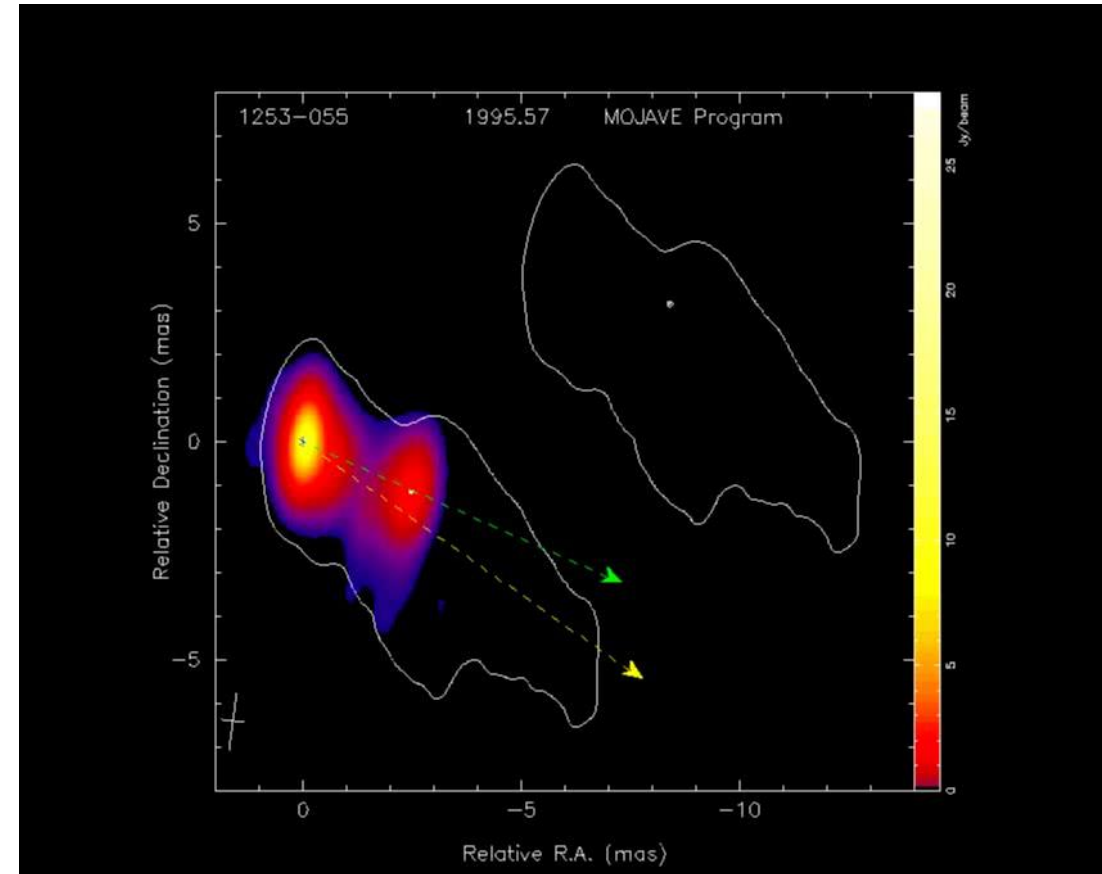
3C 279 – intriguing blazar

Characterised by several radio components moving at relativistic speeds, whose relation, if any, with the observed high energy emission remains unclear.



MOJAVE program

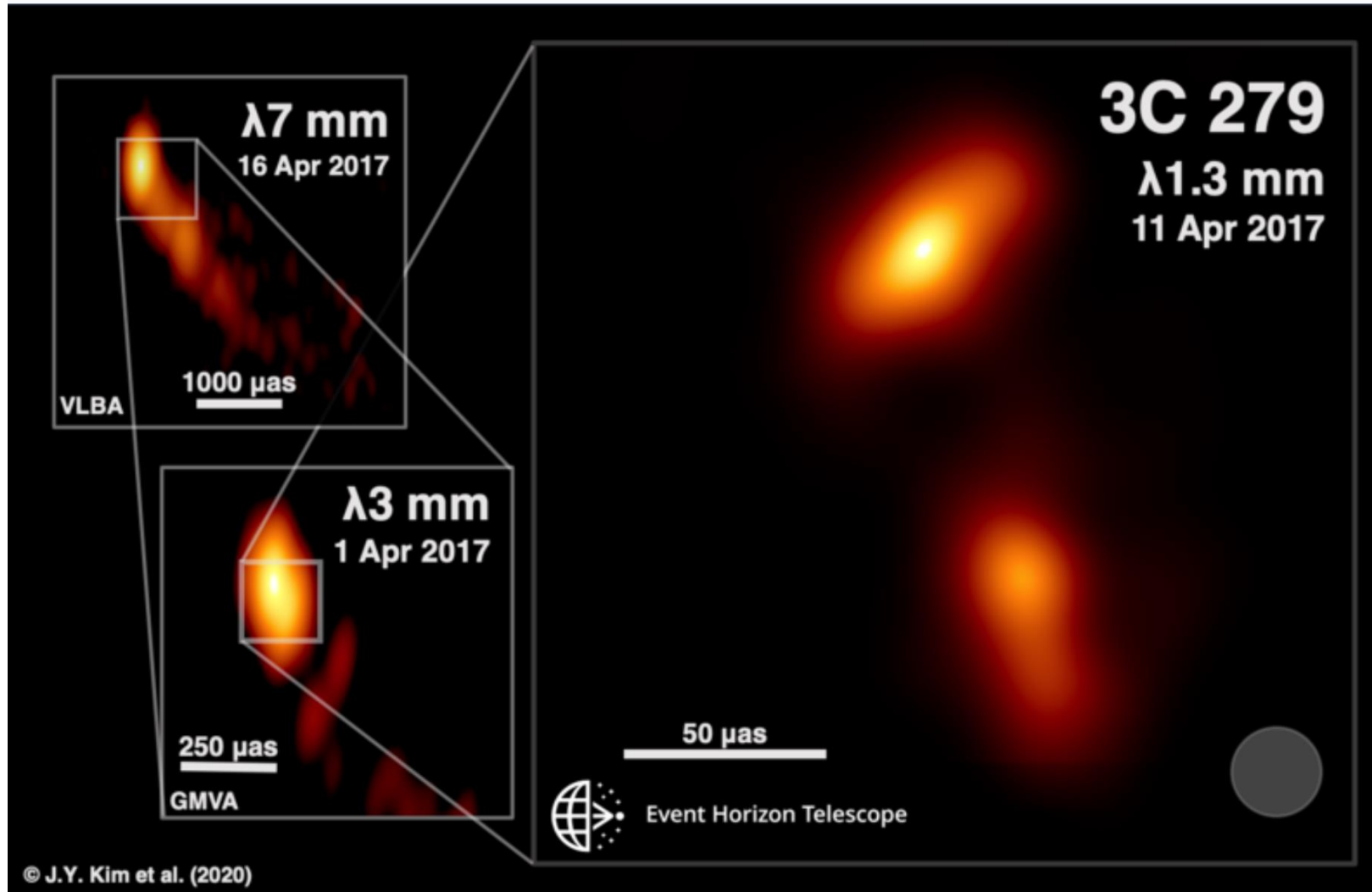
Lister et al., 2019 & 2021



MOJAVE program

Homan et al. 2003

3C 279 2017 EHT observations



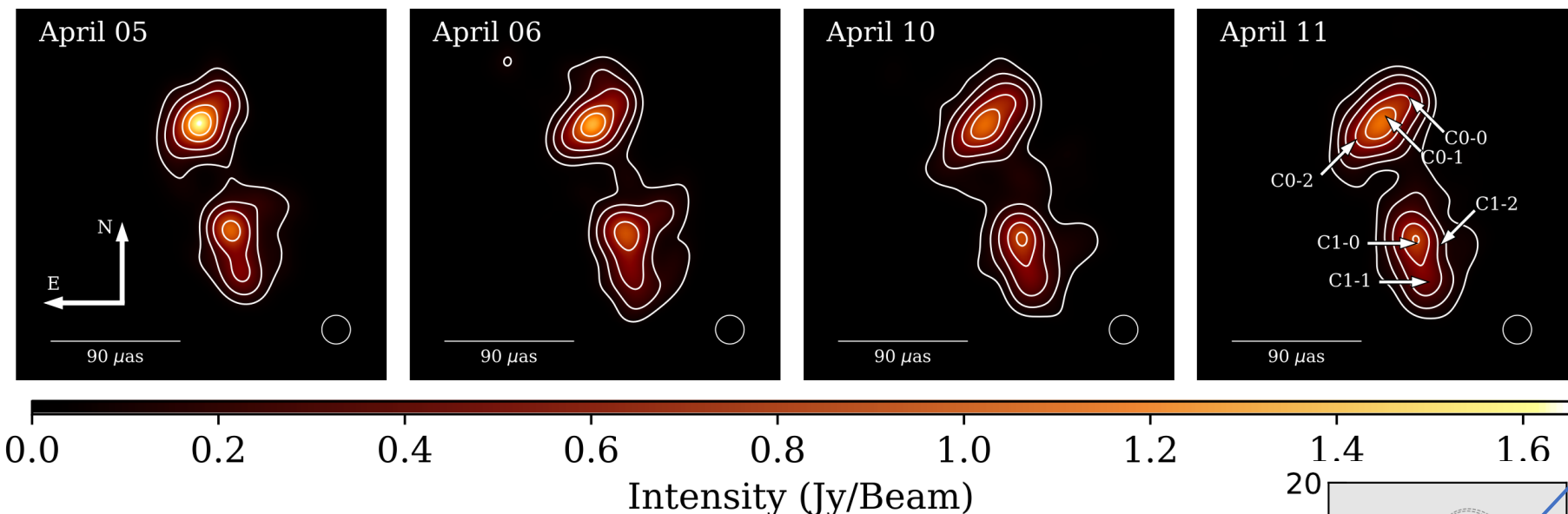
[Kim et al., 2020](#)

20 μ as resolution @ $z = 0.536$
 $\sim \mathbf{0.13\ pc} \sim 1700\ R_S$ for
 $M_{BH} = 8 \times 10^8\ M_{\odot}$.

**Innermost jet regions, where
rapidly variable γ -ray emission
is thought to be produced.**

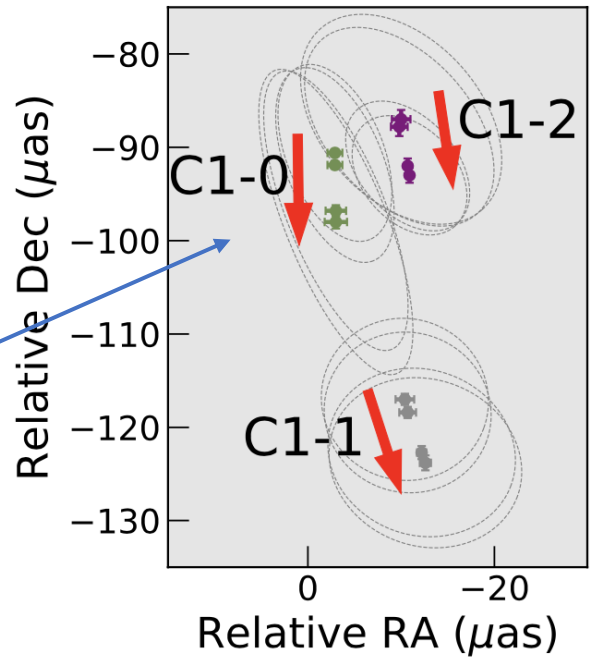
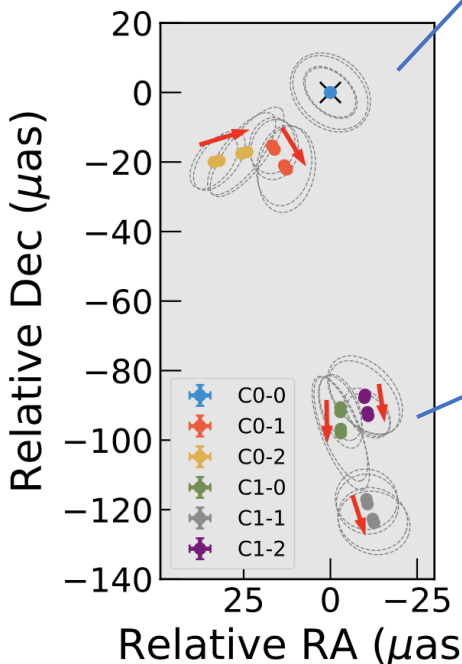
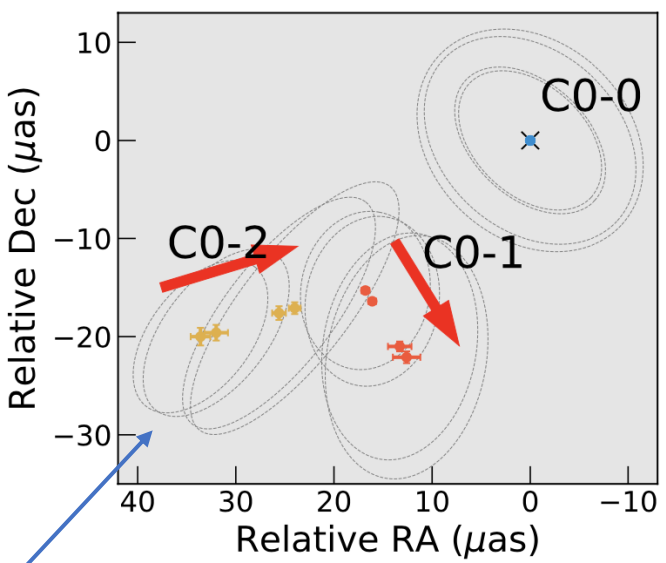
3C 279 2017 EHT observations

[Kim et al., 2020](#)

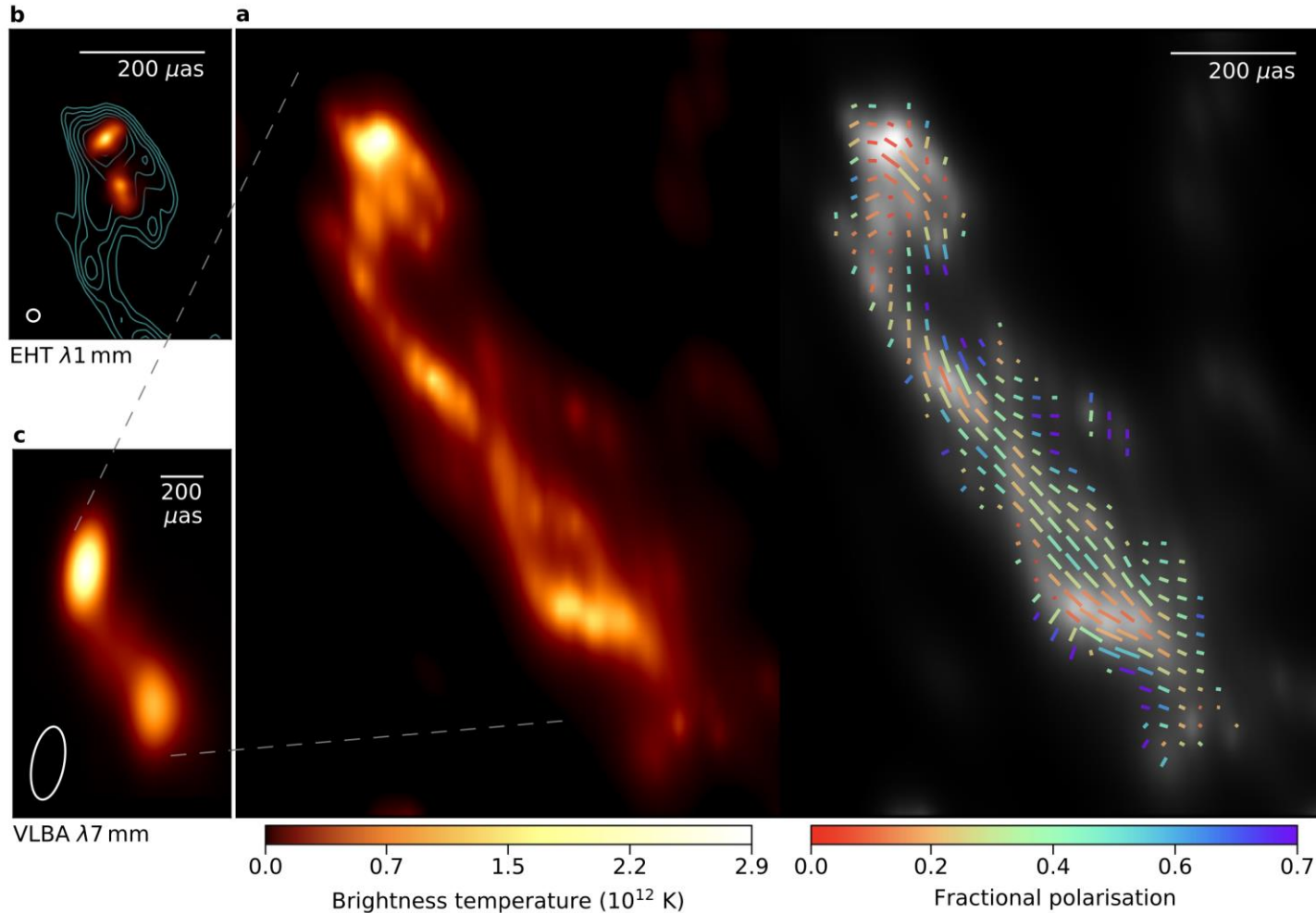


Multicomponent morphology of the inner jet, with two perpendicular components moving at apparent speeds $\sim 15c$ and $20c$, sign of “*traveling shocks or instabilities in a bent, possibly rotating jet.*”

ID	β_{app} (c)	θ ($^\circ$)	Γ	δ
Curved jet case ^(a)				
C0-1	16^{+3}_{-2}	≤ 1.5	≥ 20	≥ 32
C0-2	20 ± 1	≤ 2.9	≥ 20	≥ 20
C1-0/1/2	$(13-15) \pm 2$	$\geq 6-8$	≥ 20	$\leq 5-7$
Straight jet case ^(b)				
C1-0/1/2	$(13-15) \pm 2$	2	16-17	24-25



RadioAstron observations of 3C 279



- Space VLBI mission RadioAstron, a 10m Space Radio Telescope +23 ground based telescopes; Projected baseline distance of up to 8 Earth diameters, probing a large range of spatial frequencies perpendicular to the jet propagation axis.
- 10 March 2014 observations @ 22 GHz (1.3 cm) with a resolution power of ~27 μas, similar to that of the EHT network @ 230 GHz.
- Filamentary structure suggesting instabilities in a kinetically dominated jet.

[Fuentes et al., \(2023\)](#)

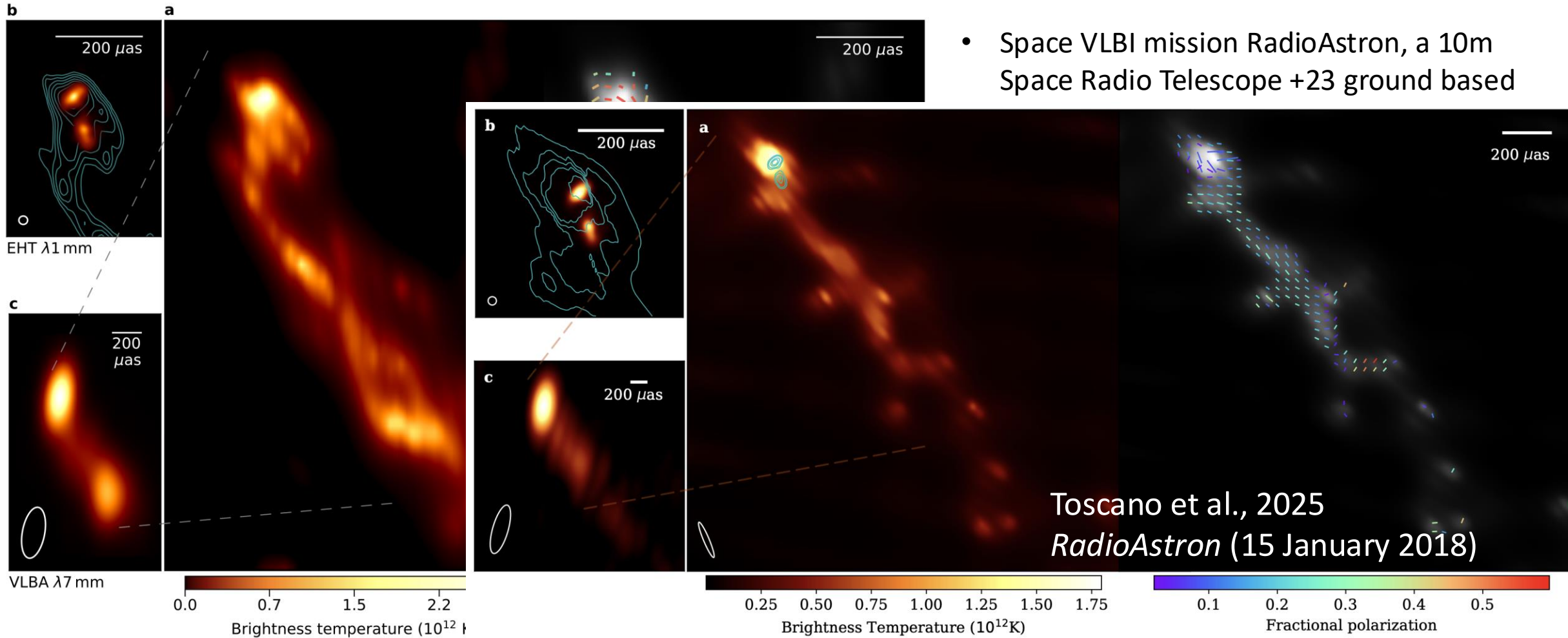
a) Total intensity and linearly polarized RadioAstron image maps @ 1.3 cm.

EVPA in ticks where the length and colour are proportional to the level of linearly polarized intensity and fractional polarization, respectively.

b) The 1:1 scale 1.3 mm EHT image obtained in April 2017, with *RadioAstron* contours

c) The 7 mm VLBA-BU-BLAZAR program image, obtained on the 25 February 2014 with RadioAstron

RadioAstron observations of 3C 279



a) Total intensity and linearly polarized RadioAstron image maps @ 1.3 cm.

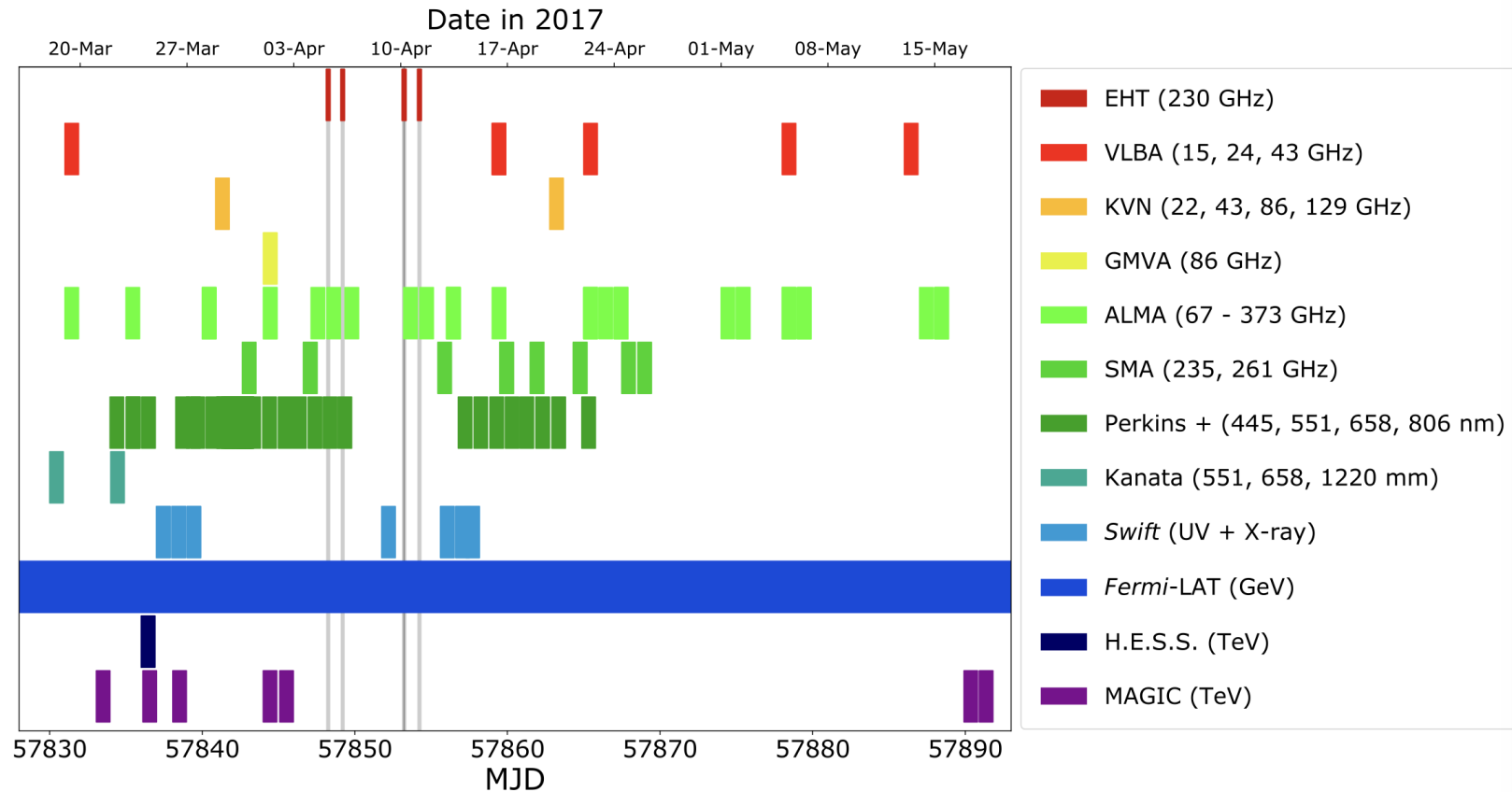
EVPA in ticks where the length and colour are proportional to the level of linearly polarized intensity and fractional polarization, respectively.

b) The 1:1 scale 1.3 mm EHT image obtained in April 2017, with *RadioAstron* contours

c) The 7 mm VLBA-BU-BLAZAR program image, obtained on the 25 February 2014 with RadioAstron

3C 279 2017 EHT-MWL campaign

First extensive MWL campaign for 3C 279!

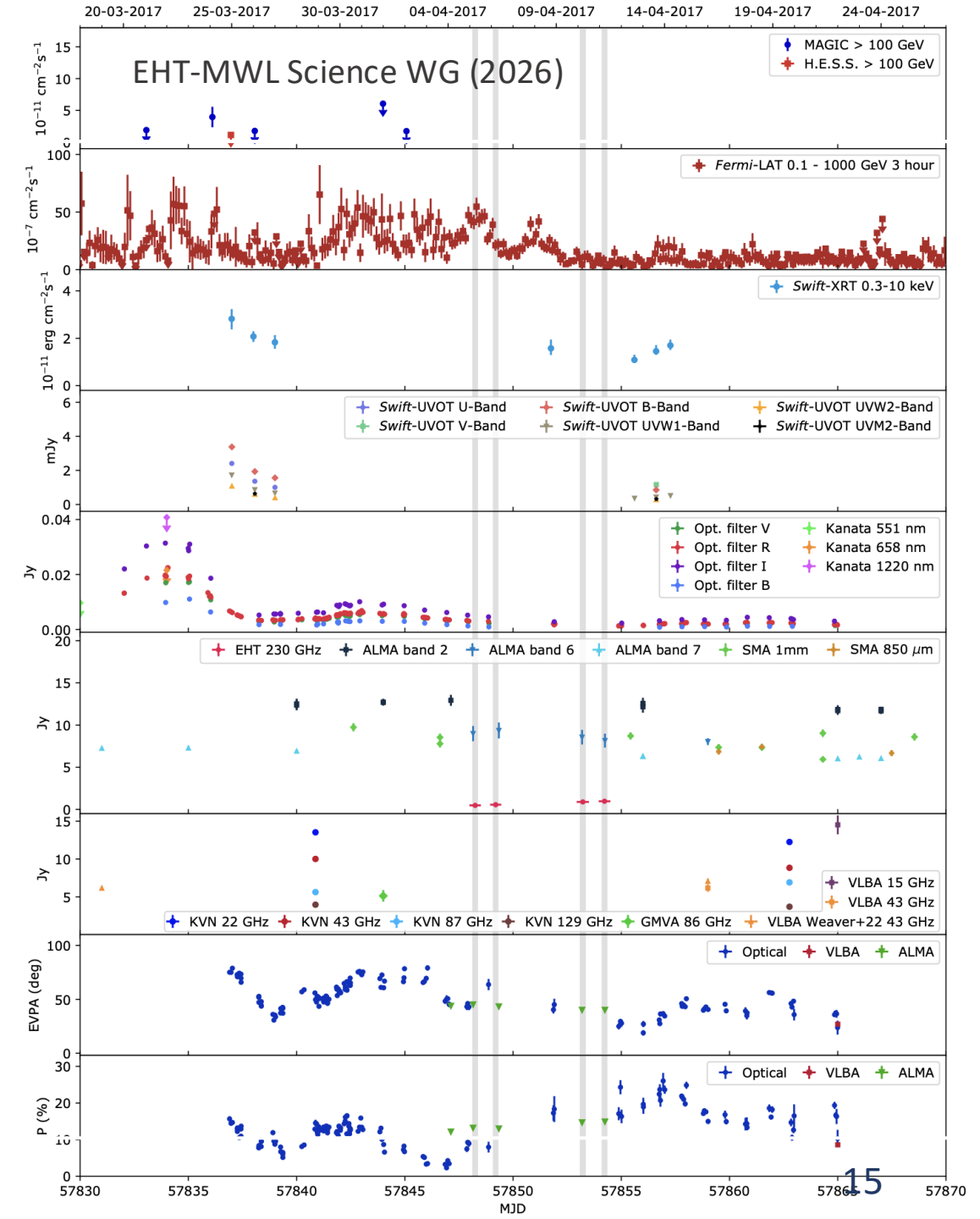


EHT-MWL Science WG (2026)

None of the EHT sessions have strictly simultaneous VHE γ -ray and X-ray coverage.

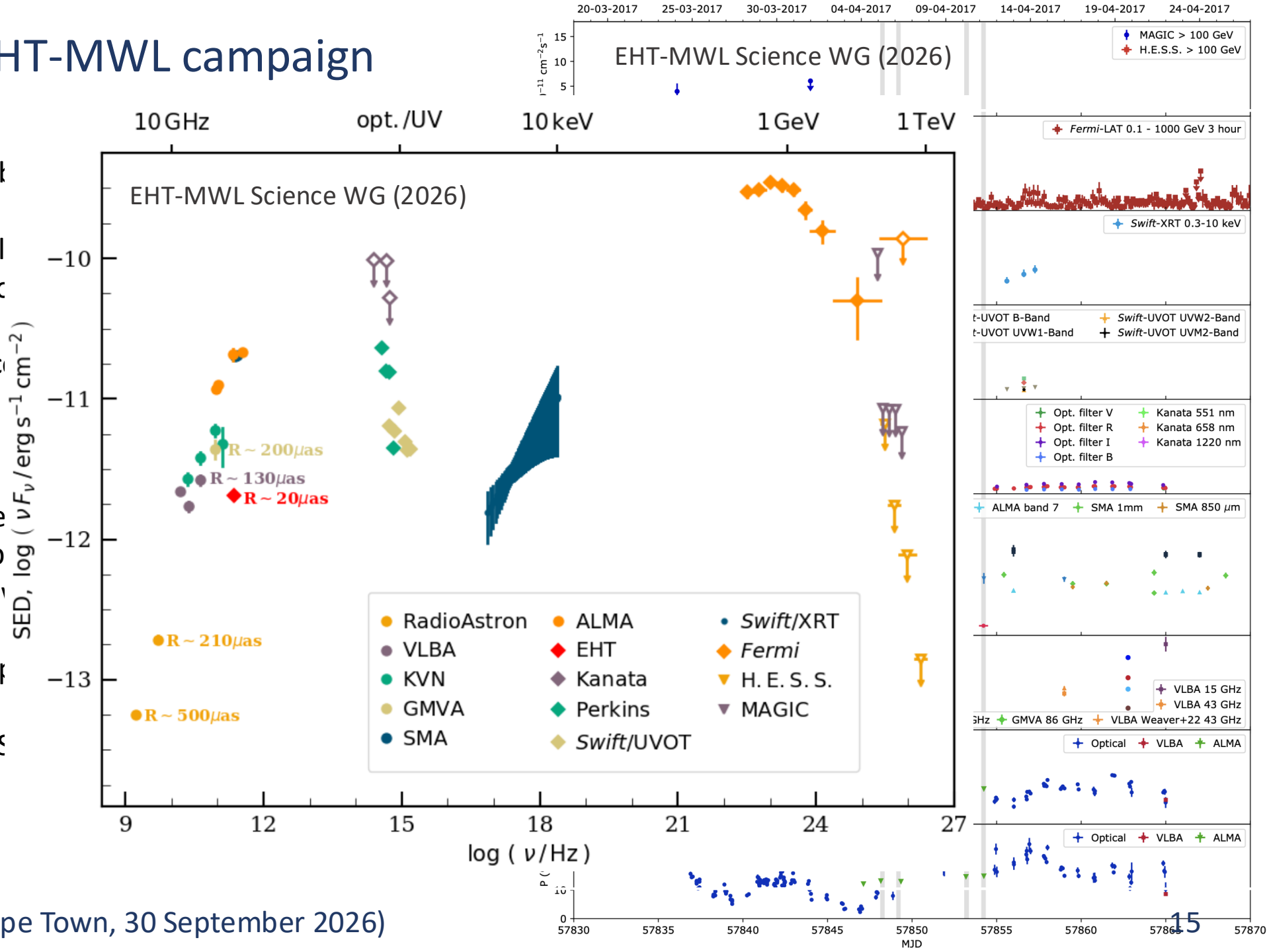
3C 279 2017 EHT-MWL campaign

- H.E.S.S. & MAGIC observations resulted in upper limits.
- Record optical flux level reached ~21-22 March 2017, accompanied by moderate HE γ -ray activity.
- Four EHT sessions covered the peak and decay of a *Fermi*-LAT flare and a quiescent HE γ -ray state of the source.
- Flux doubling in the C0-0 component between 5-6 and 10-11 April 2017 observations (~0.5 Jy to ~0.95 Jy). C0-1 flux dimmers, while C0-2 brightens.
- Strongly variable optical PD and PA.
- Epoch selected for SED modelling: 10 April 2017.



3C 279 2017 EHT-MWL campaign

- H.E.S.S. & MAGIC observations
- Record optical flux level accompanied by major outburst
- Four EHT sessions captured the onset of the *Fermi*-LAT flare and the subsequent decay of the source.
- Flux doubling in the 10-11 April 2017 observation followed by CO-1 flux dimmers, indicating a complex emission structure.
- Strongly variable optical emission
- Epoch selected for VLBA observations

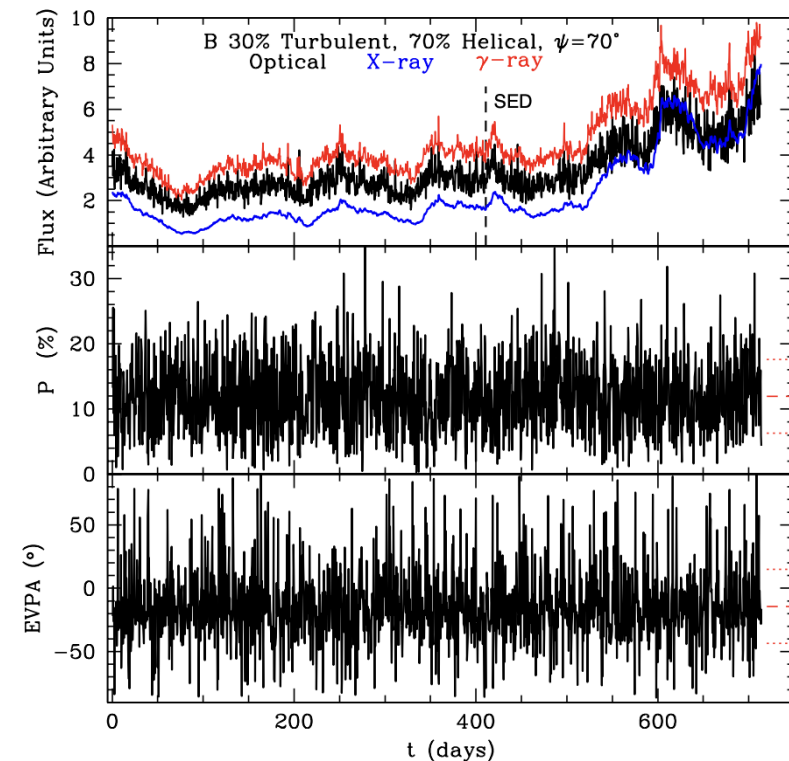
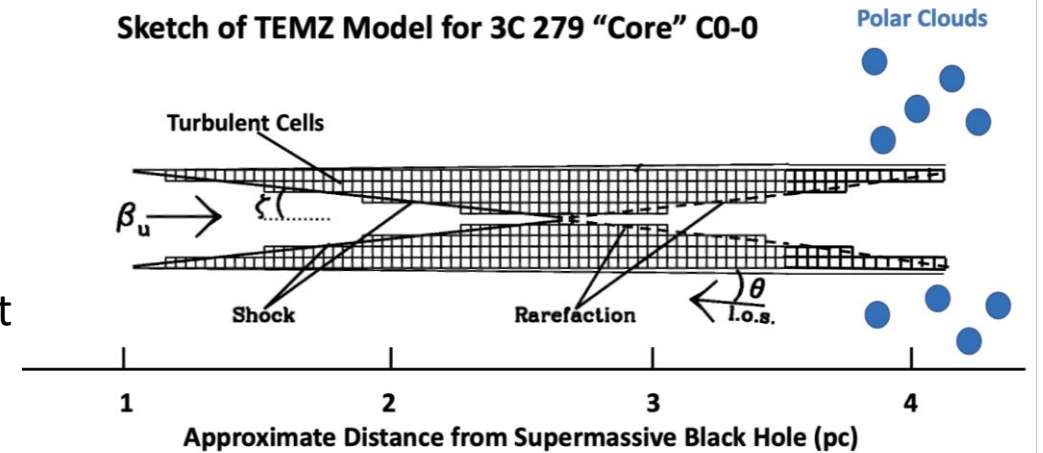
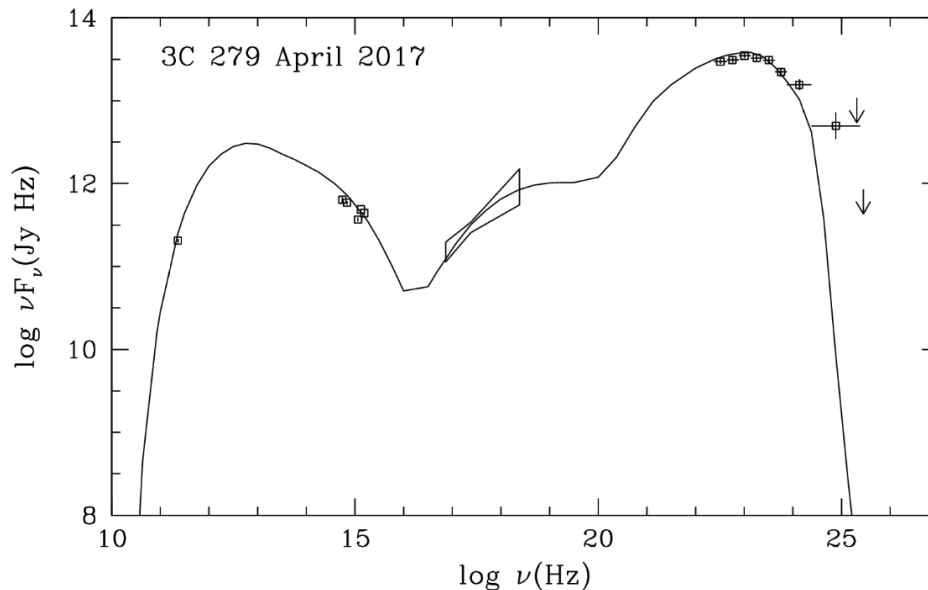


3C 279 2017 MWL dataset - modelling

Goal: reproduce multi-band flux variability and PD & PA fluctuations.

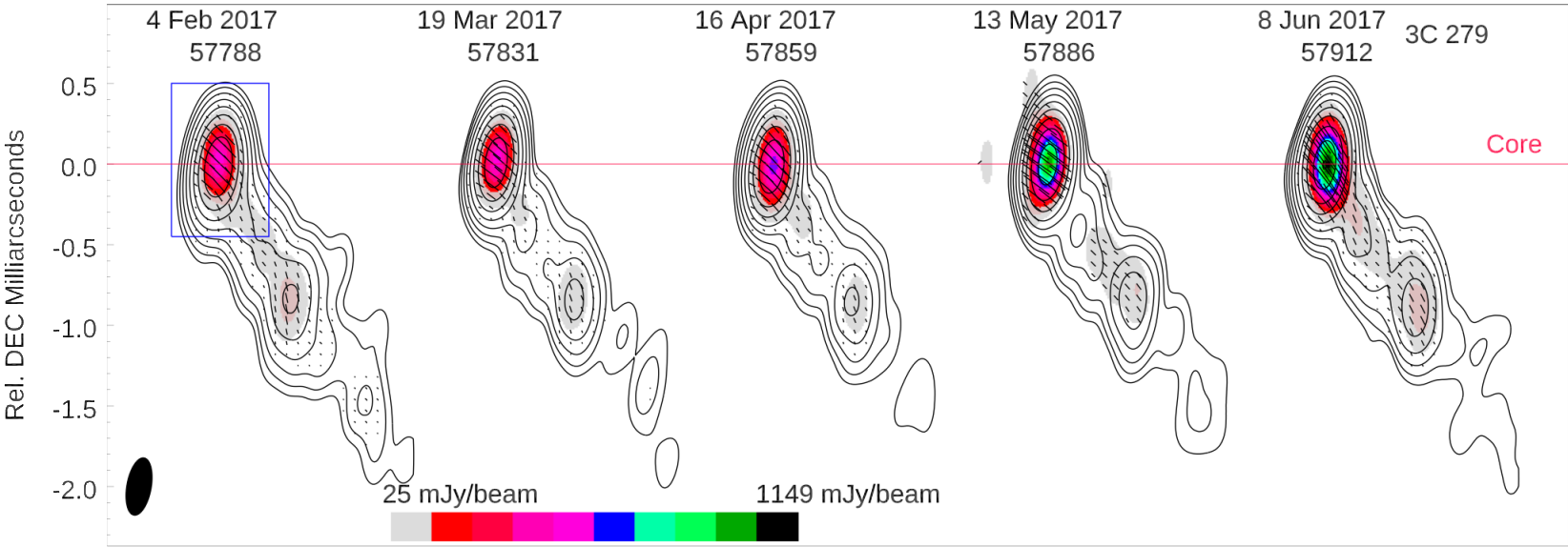
- **Turbulent Extreme Multi-zone (TEMZ) model** ([Marscher 2014](#)) applied to C0-0, interpreted as a standing conical shock located at 1pc from the SMBH.

Turbulent plasma cells pass through a stationary conical cone, where they get compressed and can give rise to fast γ -ray flares.



Alternative scenarios

- Shock-in-jet scenario



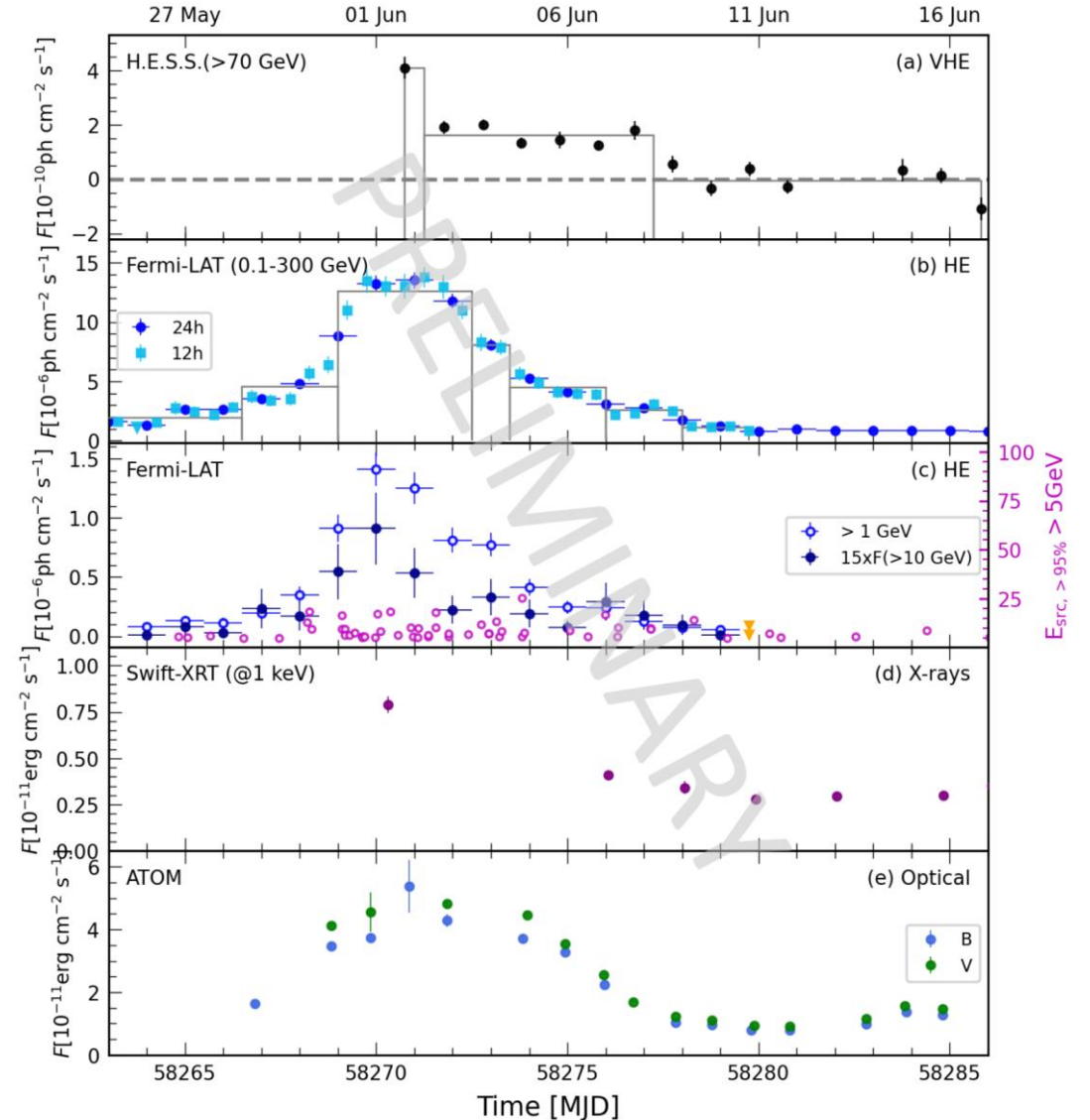
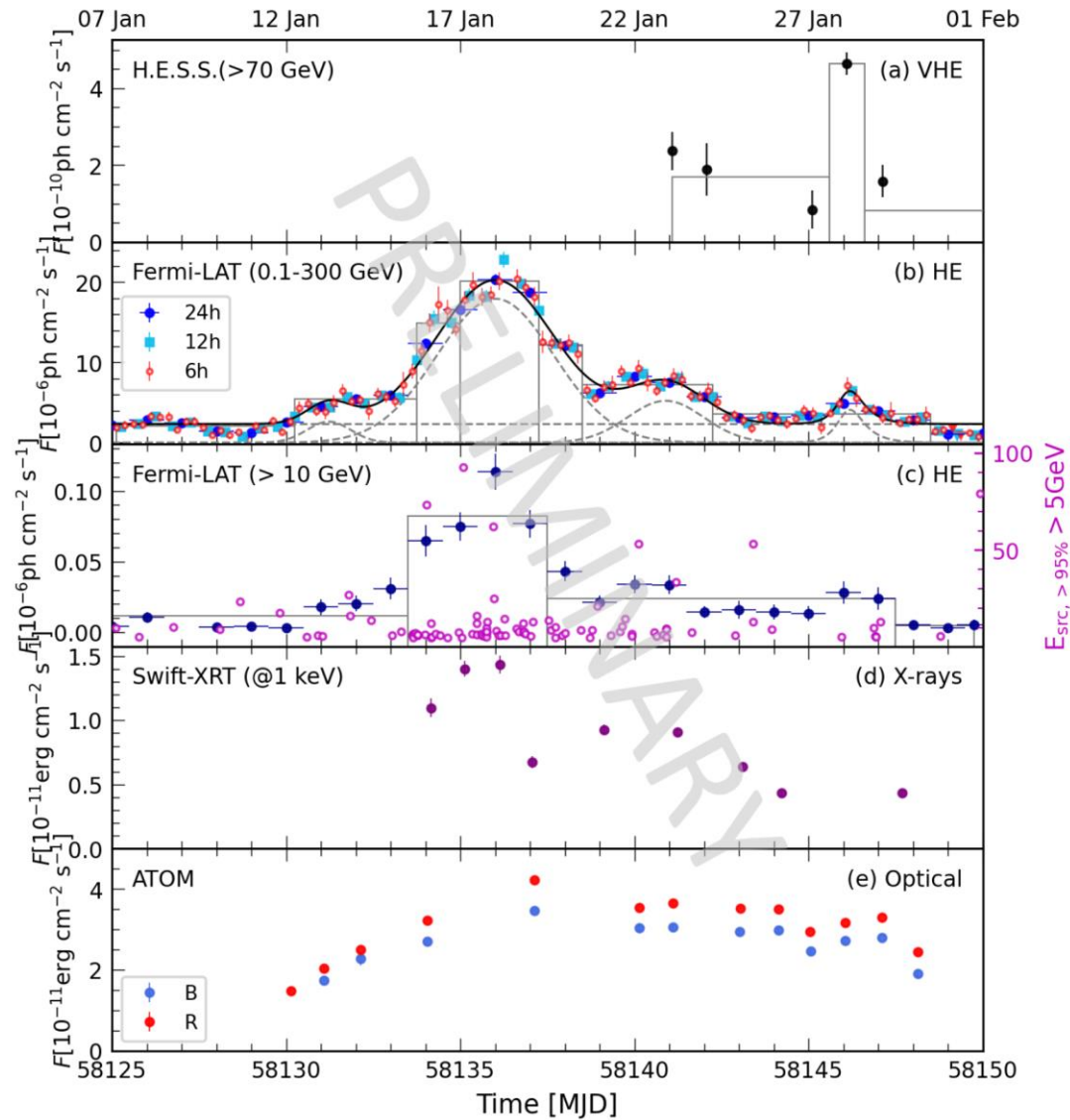
VLBA observations @ 43 GHz
with a monthly cadence

Ejection of a superluminal plasma knot on 2 April 2017
(± 12 days) with apparent speed of $(25 \pm 2)c$
-> Triggered an increase in the total and polarized flux.

Date	Date	MJD	S_{int} , Jy	P_{int} , %	$\chi_{\text{int}}^{\circ}$	S_{core} , Jy	P_{core} , %	$\chi_{\text{core}}^{\circ}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4 Feb	57788	11.77±0.59	9.7±1.0	35±6	8.66±0.44	8.7±0.9	40±6	
19 Mar	57831	7.70±0.39	10.7±1.1	42±6	6.14±0.31	10.1±1.0	47±6	
16 Apr	57859	8.47±0.43	11.1±1.1	40±5	7.05±0.36	10.4±1.1	43±5	
13 May	57886	12.69±0.64	11.5±1.2	50±6	11.03±0.55	11.0±1.2	50±7	
8 Jun	57912	14.76±0.74	13.1±1.3	35±6	12.87±0.65	11.3±1.1	34±6	

- Magnetic reconnection (see 2018 behavior)...

3C 279 very active in 2018 (January & June)

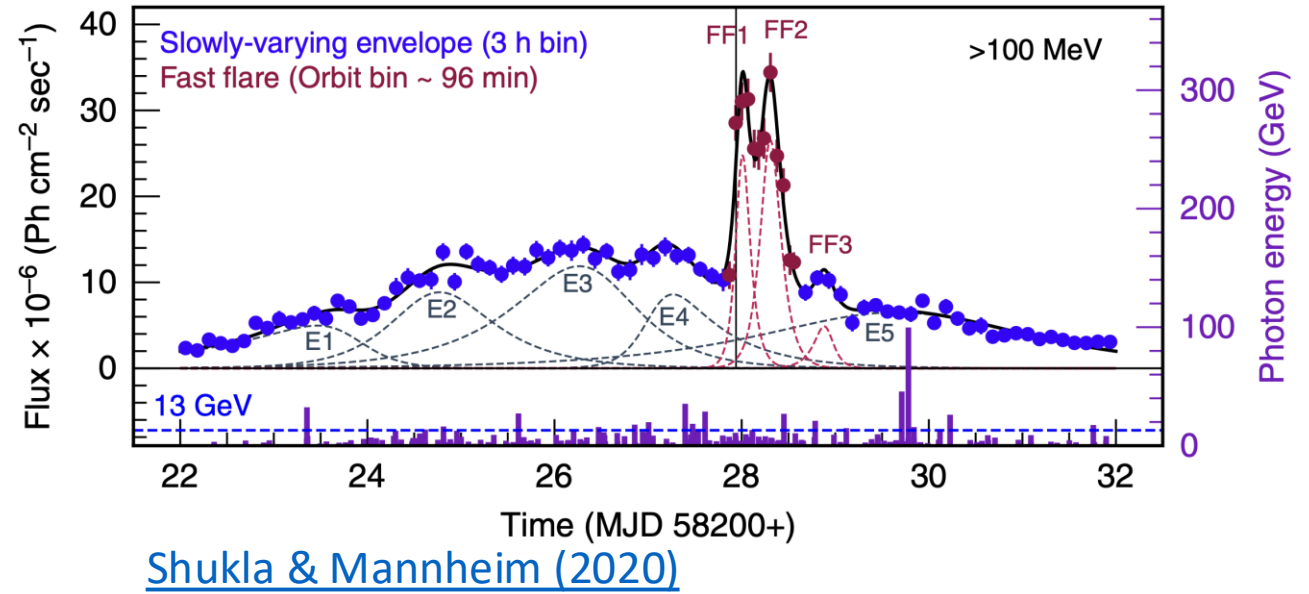


[Luashvili et al. \(2026\)](#)

3C 279 during 2018 EHT-MWL campaign

- **Major flare detected by *Fermi*-LAT in April 2018**, with “peak-in-peak” structure and minimal flux doubling time ~ 8 min.

Reconnection-driven mini-jets model ([Giannios \(2013\)](#)) favored and shock-in-jet scenario rejected.

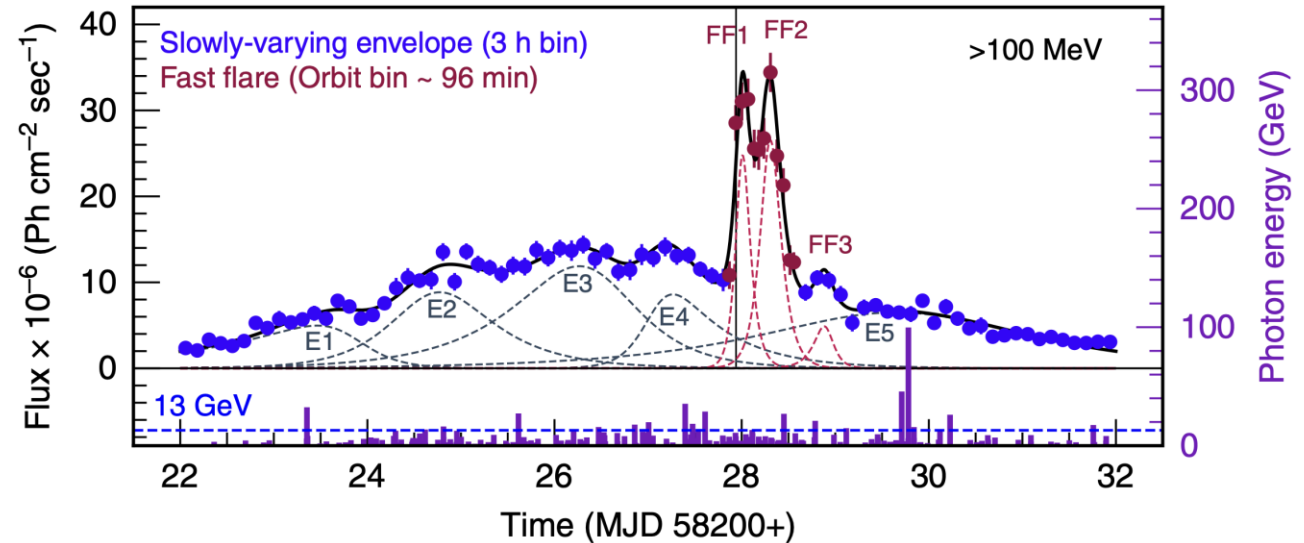


3C 279 during 2018 EHT-MWL campaign

- **Major flare detected by *Fermi*-LAT in April 2018**, with “peak-in-peak” structure and minimal flux doubling time ~ 8 min.

Reconnection-driven mini-jets model ([Giannios \(2013\)](#)) favored and shock-in-jet scenario rejected.

- MAGIC detected a **VHE γ -ray flare on 17-18 April 2018** (similar to the 2015 flux level and 2 – 3 times fainter than the H.E.S.S.-detected January and June 2018 peaks, > 100 GeV).



[Shukla & Mannheim \(2020\)](#)

MAGIC detection of increased activity from FSRQ 3C 279 at very-high-energy gamma rays

ATel #11545; **Razmik Mirzoyan** (Max-Planck-Institute for Physics, Munich), on behalf of the **MAGIC collaboration**

on **18 Apr 2018; 18:40 UT**

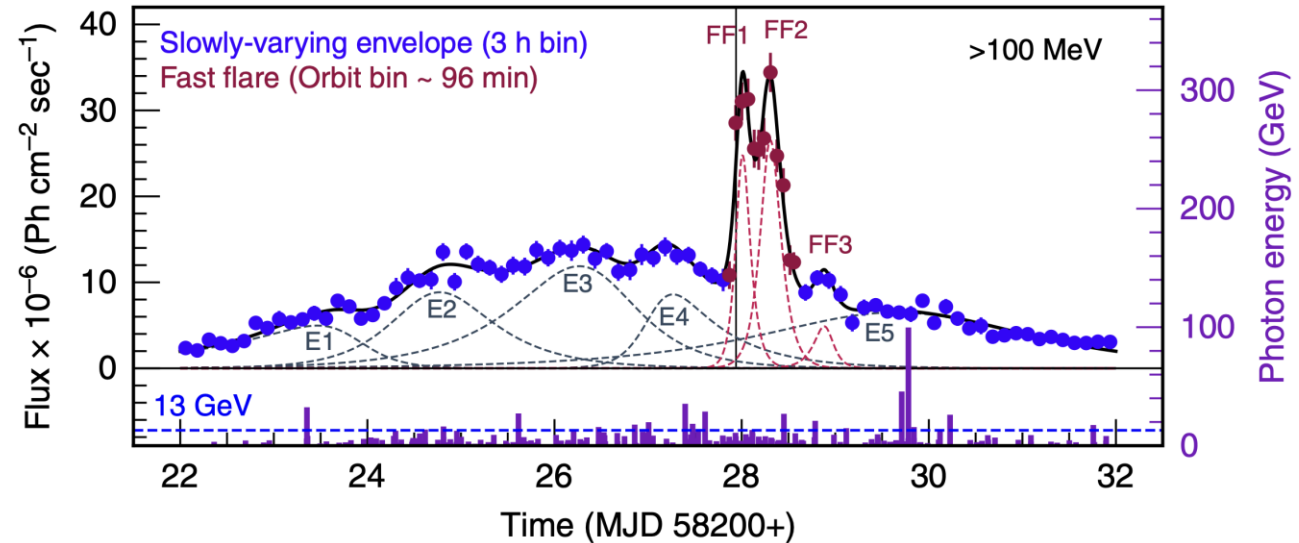
Credential Certification: Adrian Biland (biland@phys.ethz.ch)

3C 279 during 2018 EHT-MWL campaign

- **Major flare detected by *Fermi*-LAT in April 2018**, with “peak-in-peak” structure and minimal flux doubling time ~ 8 min.

Reconnection-driven mini-jets model ([Giannios \(2013\)](#)) favored and shock-in-jet scenario rejected.

- MAGIC detected a **VHE γ -ray flare on 17-18 April 2018** (similar to the 2015 flux level and 2 – 3 times fainter than the H.E.S.S.-detected January and June 2018 peaks, > 100 GeV).
- Unfortunately, no H.E.S.S. observations (colliding with M87 2018 campaign).
- **EHT observations: 21 - 25 April 2018** ([Principe et al. 2025](#)), only a few days after the major HE and bright VHE γ -ray outbursts.
Looking forward to the EHT results (analysis ongoing)!



[Shukla & Mannheim \(2020\)](#)

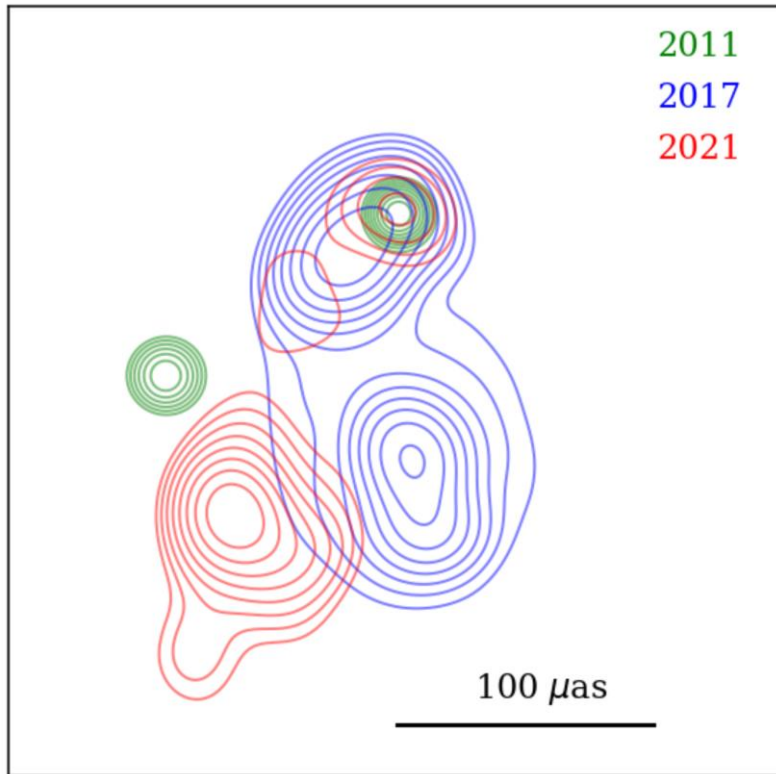
MAGIC detection of increased activity from FSRQ 3C 279 at very-high-energy gamma rays

ATel #11545; *Razmik Mirzoyan (Max-Planck-Institute for Physics, Munich), on behalf of the MAGIC collaboration*

on 18 Apr 2018; 18:40 UT

Credential Certification: Adrian Biland (biland@phys.ethz.ch)

3C 279 in April 2021

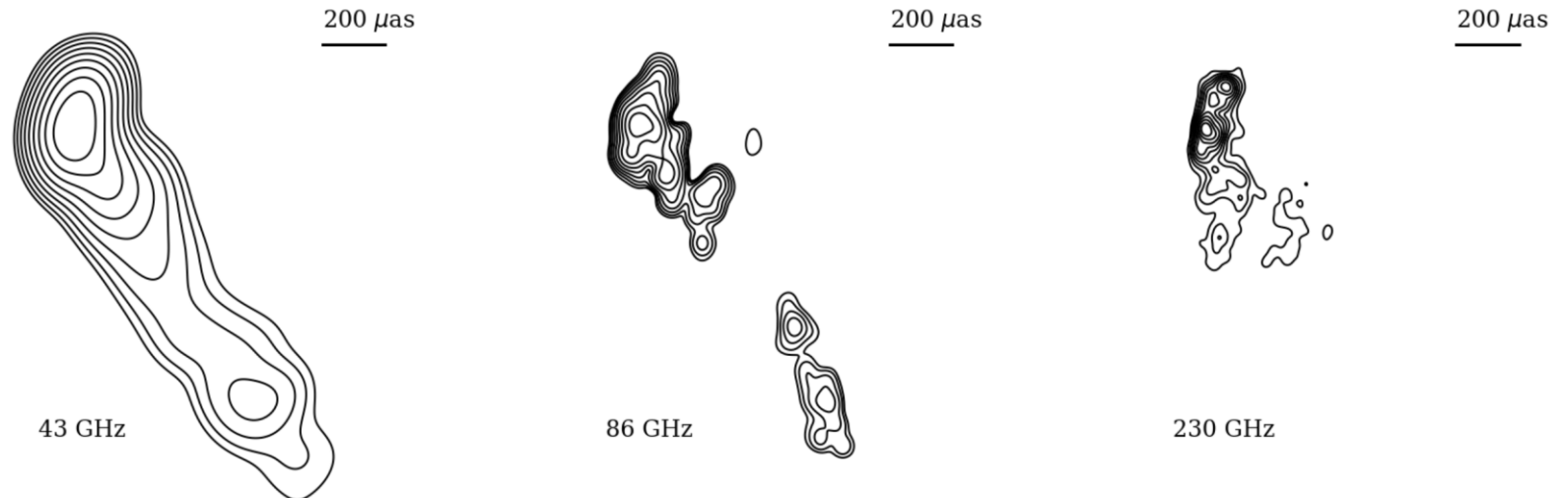


[Müller et al. 2026](#)

2021 EHT observations of 3C 279 just published (with the largest EHT configuration published to date)!

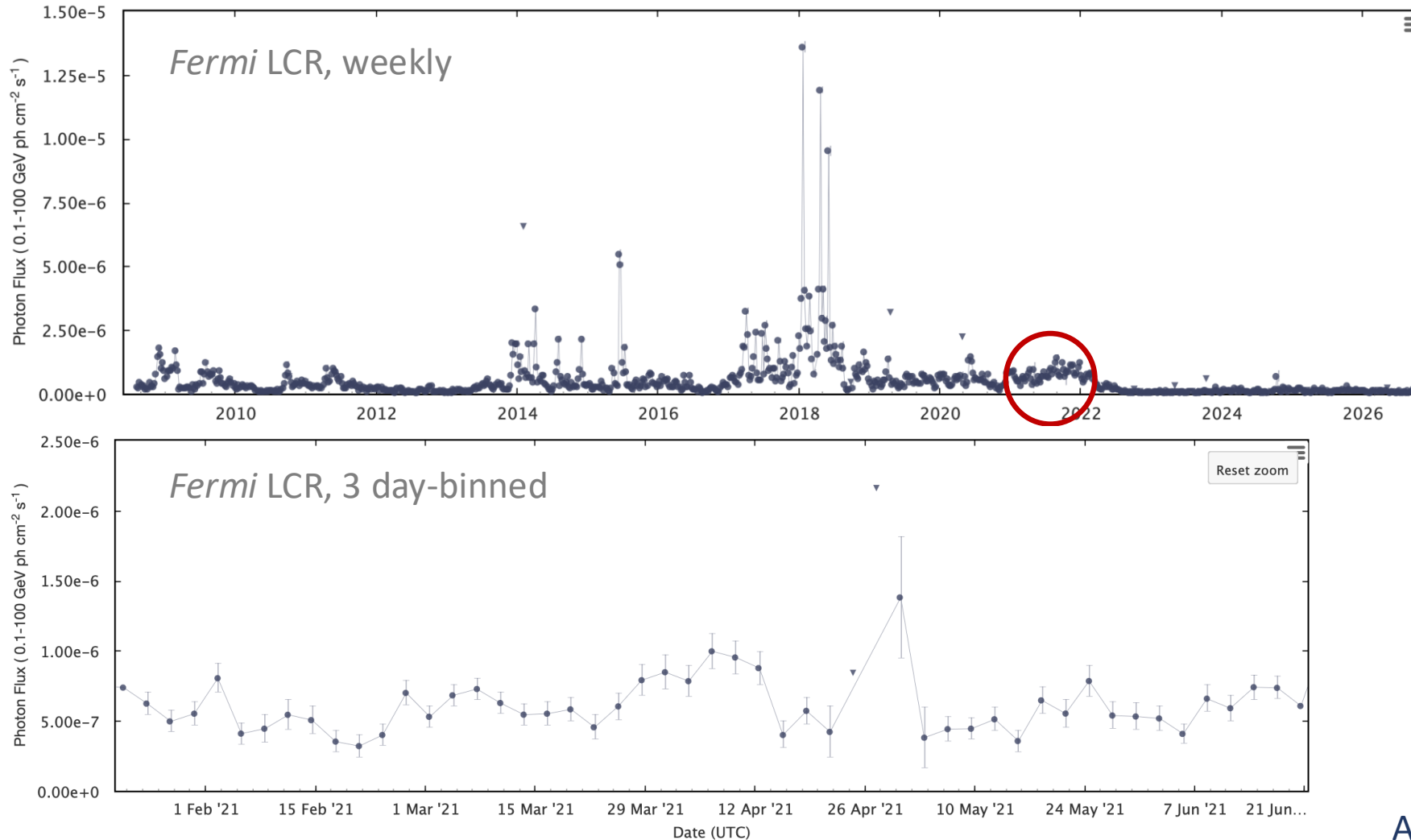
Compact features $\sim$ orthogonal to the large-scale jet axis, consistent with earlier EHT results from 2017.

- $\Gamma \geq 10$ within the inner $\sim 5000 R_G$ from the kinematic origin – acceleration occurs near the core.
- The 1st downstream structure much brighter than the core (master recollimation shock).
- Very small ϑ values and jet bending towards the observer on sub-pc scales (can be caused by the jet – ISM interactions, instabilities, magnetic reconnection near the horizon, precession induced by a binary system).



3C 279 in April 2021

- 3C 279 seems in a **low γ -ray flux state during the EHT-MWL campaign in April 2021.**
- Cannot comment on the VHE observations yet (stay tuned).

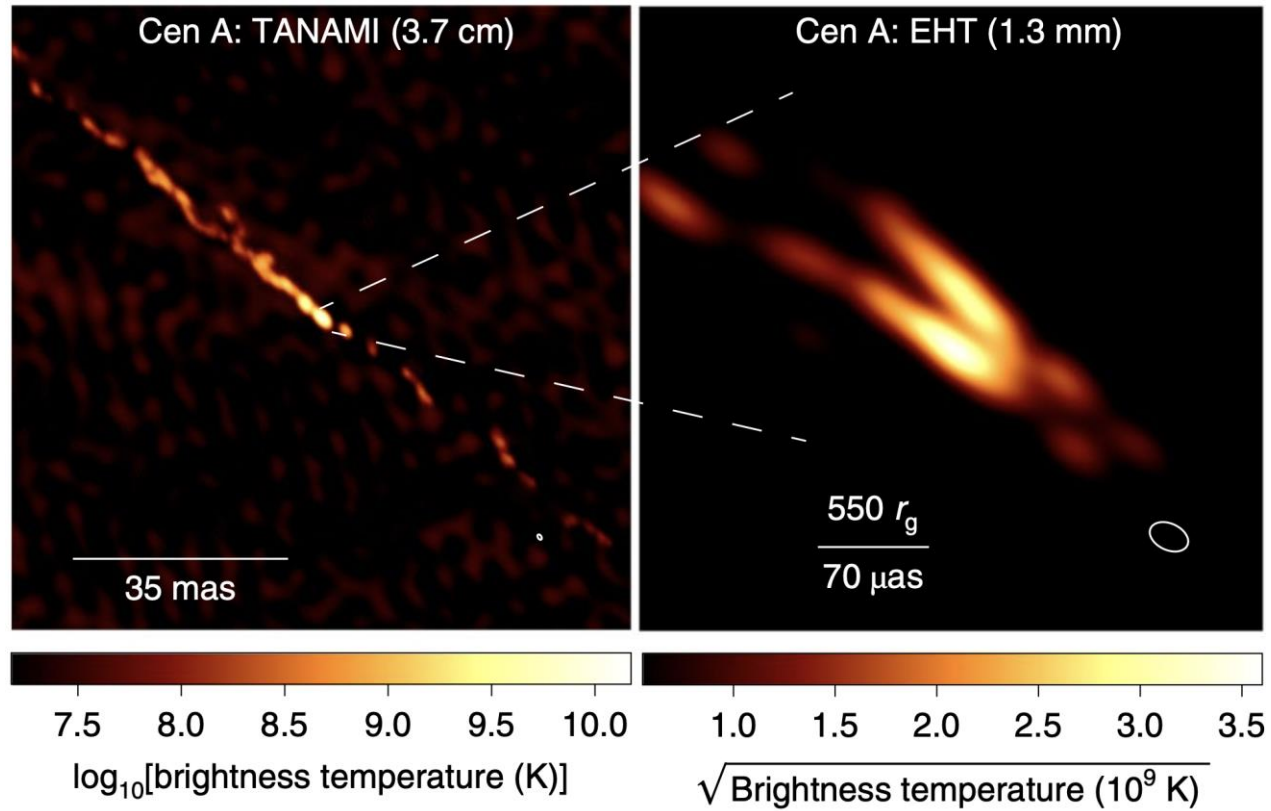


- Optical flares reported, but in January 2021 ([ATel#14310](#), [ATel#14353](#)).
- Flare in polarized flux, with biggest EVPA jump ($\sim 90^\circ$) of ALMA history, reported in February 2021 ([ATel#14385](#)).

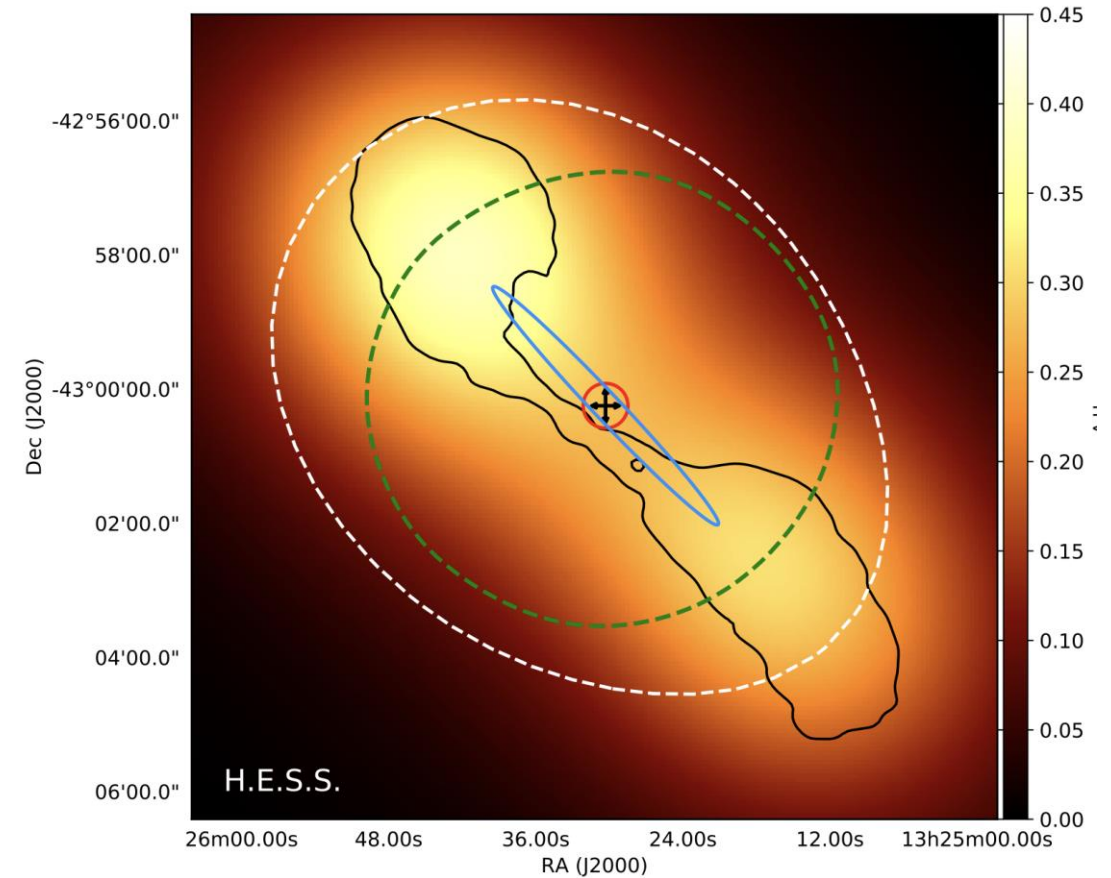
Interesting dataset to explore for a new EHT-MWL project!

What's next?

Cen A



[Janssen et al., 2021](#)

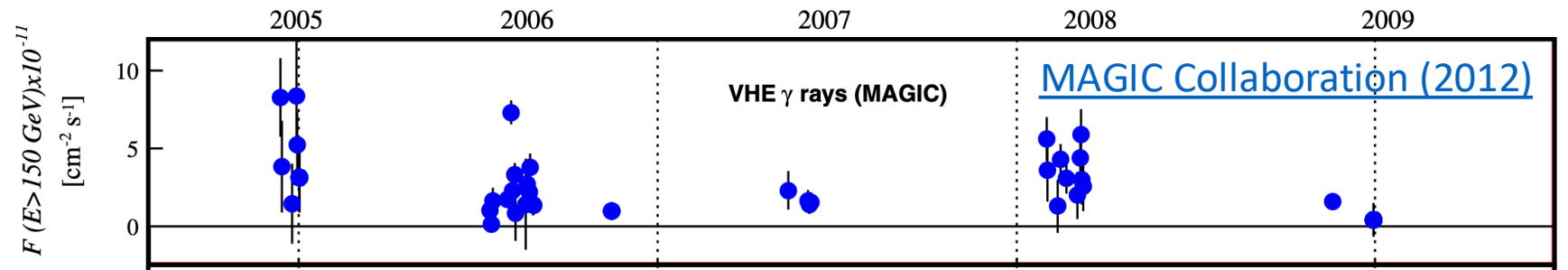
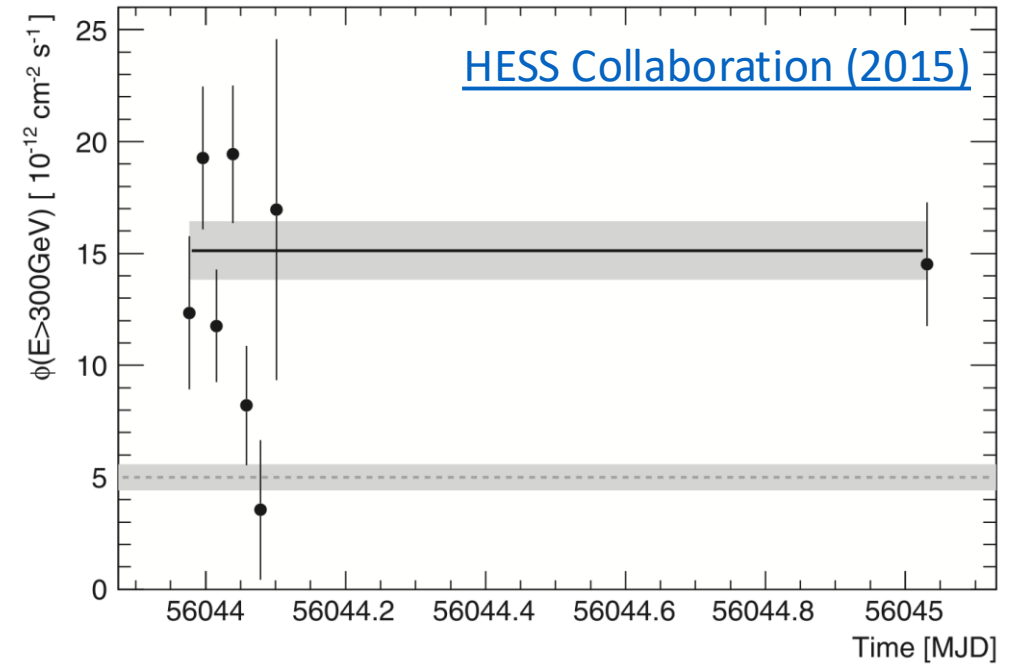


[H.E.S.S. Collaboration \(2020\)](#)

What's next?

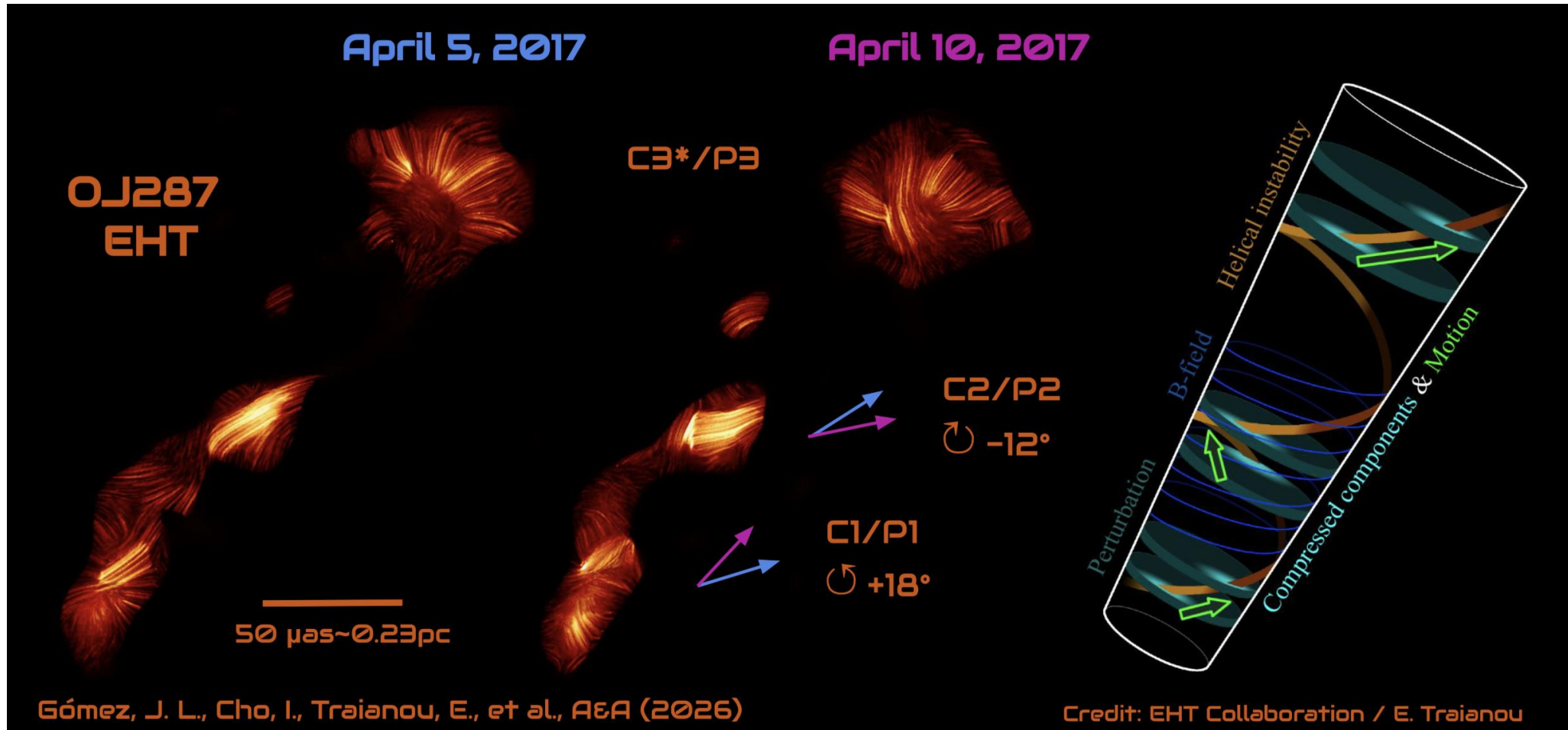
PG 1553+113

- HBL blazar ($z \sim 0.43$), known for MWL variability and strong VHE flares
 - SMBH binary system $\leftrightarrow$ long-term quasi-periodic variability
 - 2012 VHE flare [HESS Collaboration \(2015\)](#)
 - *Fermi*-LAT LC: ~ 2.2 yr periodicity ($>4\sigma$) ([Penil+2020](#)), probably closely correlated with lower energy emission ([Ackermann+2015](#)).
 - One of the EHT targets
- + also observed by other IACTs.



What's next?

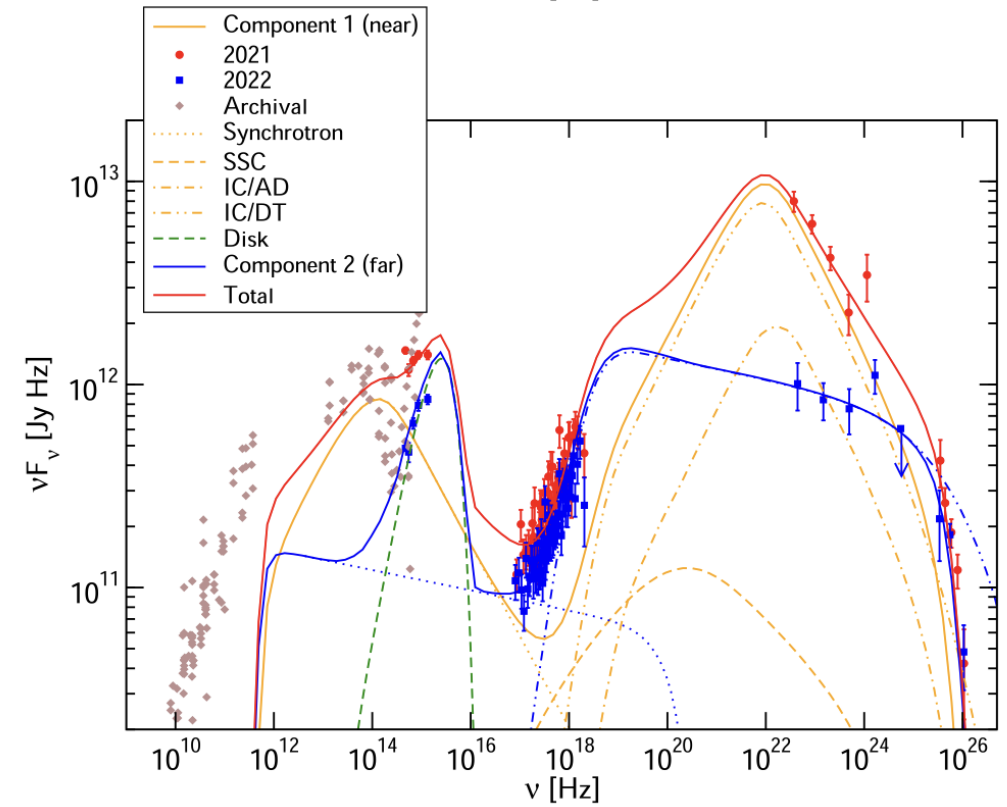
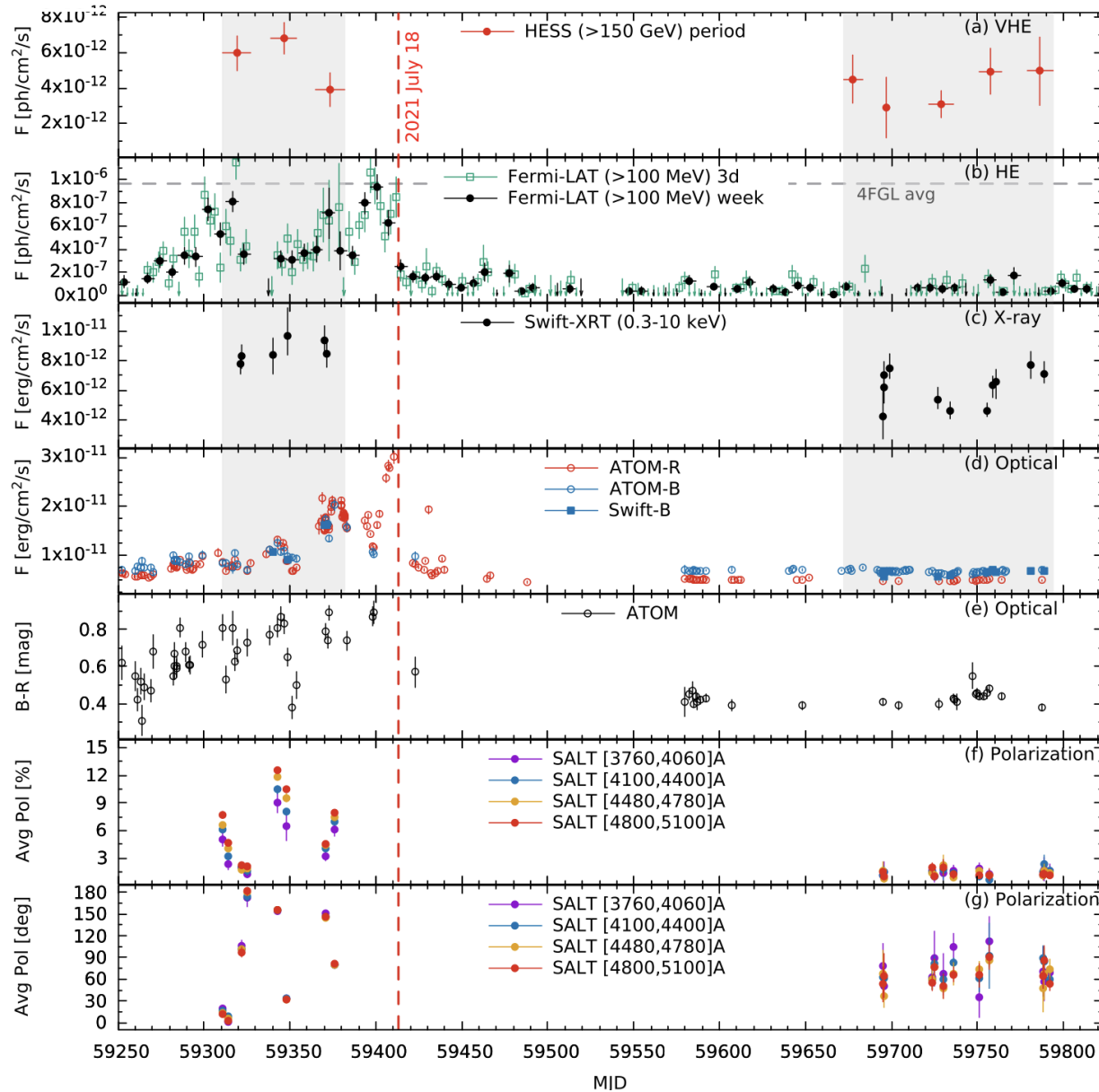
PG 1553+113 – similar to OJ 278?



[Gomez+2026](#)

What's next?

PKS 1510-089



[H.E.S.S. Collaboration \(2023\)](#)

Can EHT resolve any of those zones (overlap in 2022)?

Conclusions / Outlook

- Three exceptionally dense EHT-MWL campaigns with the involvement of H.E.S.S. published: quiescence (2017) and high state M87 (2018), 3C 279 campaign (2017).
More to come... Moving towards multi-year projects and movie campaign(s)!

Conclusions / Outlook

- Three exceptionally dense EHT-MWL campaigns with the involvement of H.E.S.S. published: quiescence (2017) and high state M87 (2018), 3C 279 campaign (2017).
More to come... Moving towards multi-year projects and movie campaign(s)!
- Need to be watching during low and flaring states as well (before and beyond CTAO-South)...
- Extensive data sets from EHT-MWL campaigns become available to the community.
 - Test a variety of models incorporating both EHT & high-energy constraints (not straightforward even for quiescent states).

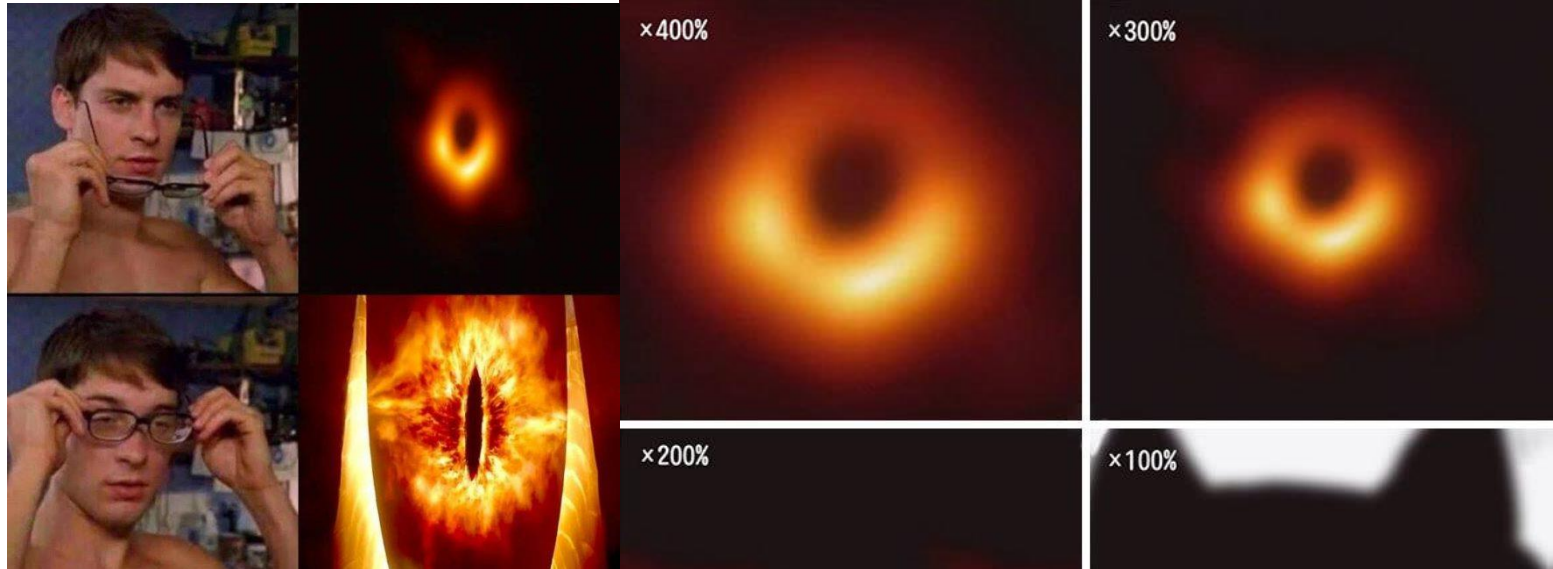
Conclusions / Outlook

- Three exceptionally dense EHT-MWL campaigns with the involvement of H.E.S.S. published: quiescence (2017) and high state M87 (2018), 3C 279 campaign (2017).
More to come... Moving towards multi-year projects and movie campaign(s)!
- Need to be watching during low and flaring states as well (before and beyond CTAO-South)...
- Extensive data sets from EHT-MWL campaigns become available to the community.
 - Test a variety of models incorporating both EHT & high-energy constraints (not straightforward even for quiescent states).
- H.E.S.S. has a major role in Sgr A* observations, one of the primary EHT targets.

Conclusions / Outlook

- Three exceptionally dense EHT-MWL campaigns with the involvement of H.E.S.S. published: quiescence (2017) and high state M87 (2018), 3C 279 campaign (2017).
More to come... Moving towards multi-year projects and movie campaign(s)!
- Need to be watching during low and flaring states as well (before and beyond CTAO-South (hopefully))...
- Extensive data sets from EHT-MWL campaigns become available to the community.
 - Test a variety of models incorporating both EHT & high-energy constraints (not straightforward even for quiescent states).
- H.E.S.S. has a major role in Sgr A* observations, one of the primary EHT targets.
- Exciting times for EHT-MWL activities!
Expanding EHT network, VHE – high-frequency radio monitoring, growing number of EHT-targets (population studies?)...

Thank you!



Finally remembered what that black hole photo reminds me of

