Multi-wavelength view on M87 during the 2018 EHT campaign including a gamma-ray flaring episode

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EHT coll. et al. 2019

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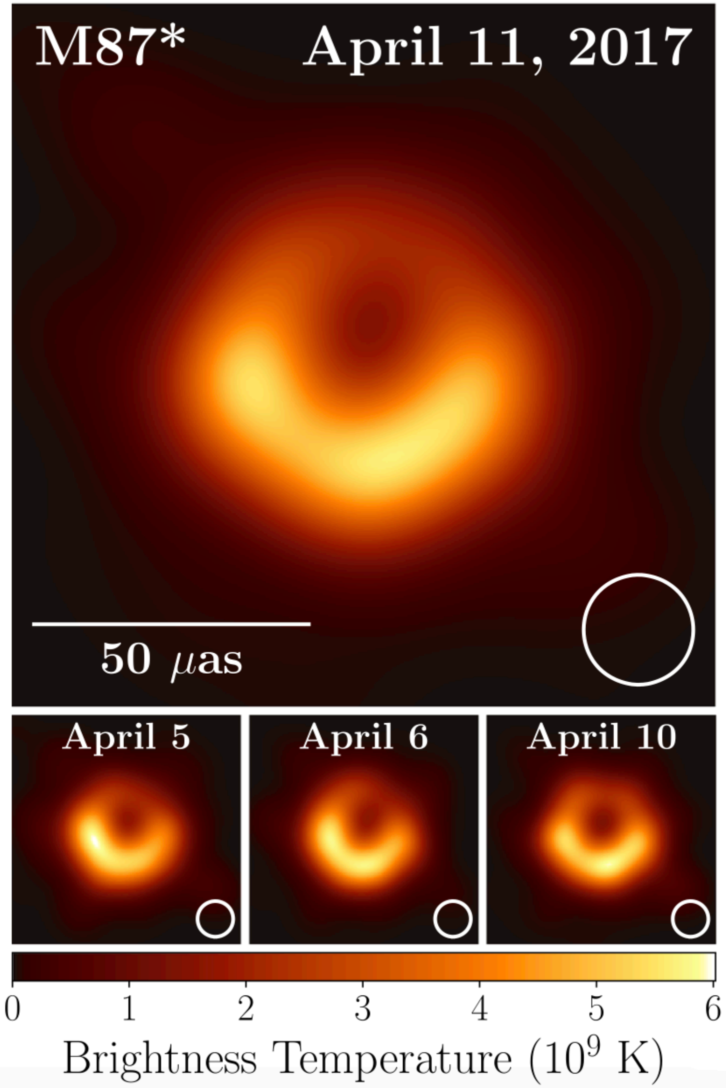

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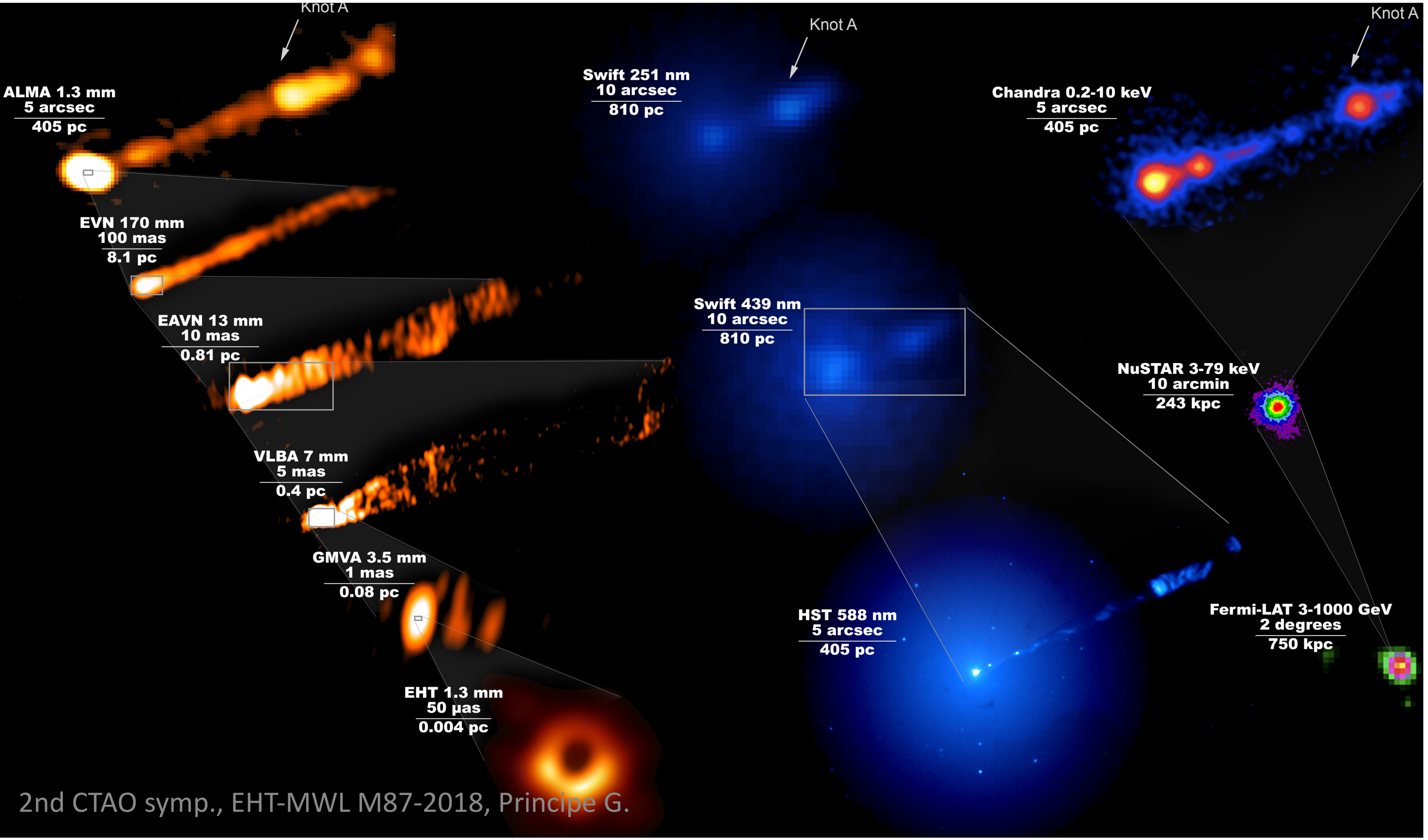
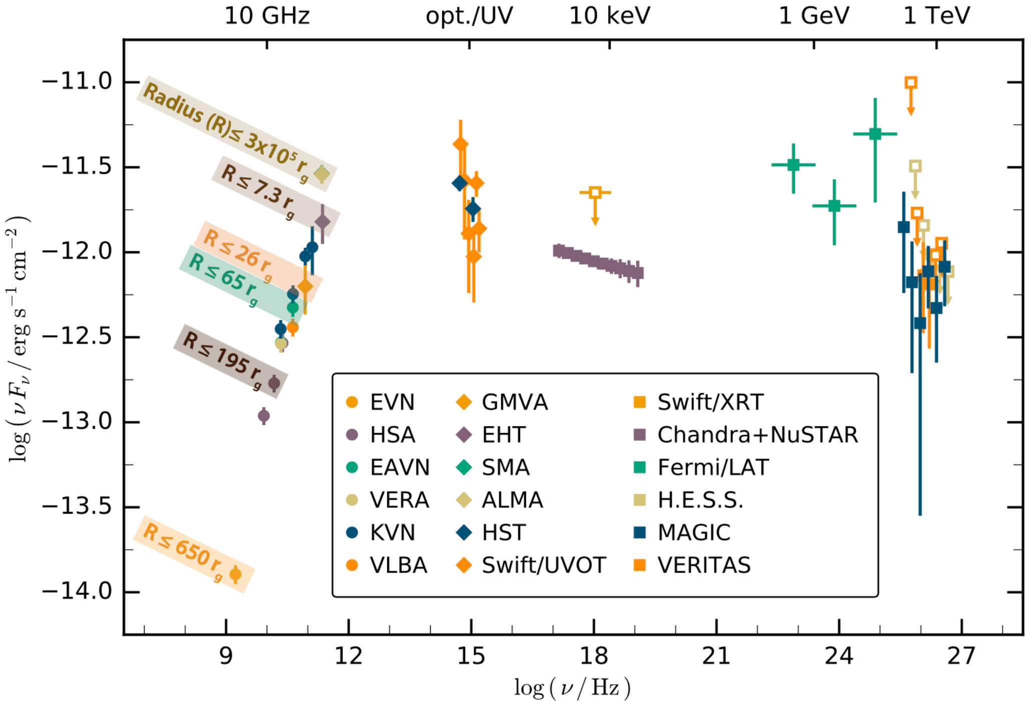
Recap M87-2017 results

1. M87 core was in a relatively low state, as seen at all frequencies/energies (HST-1 knot subdominant)
2. M87's SED cannot be modeled by a single zone
3. Not yet clear where the VHE γ-rays originate, we can rule out that they coincide with the EHT region for leptonic processes.

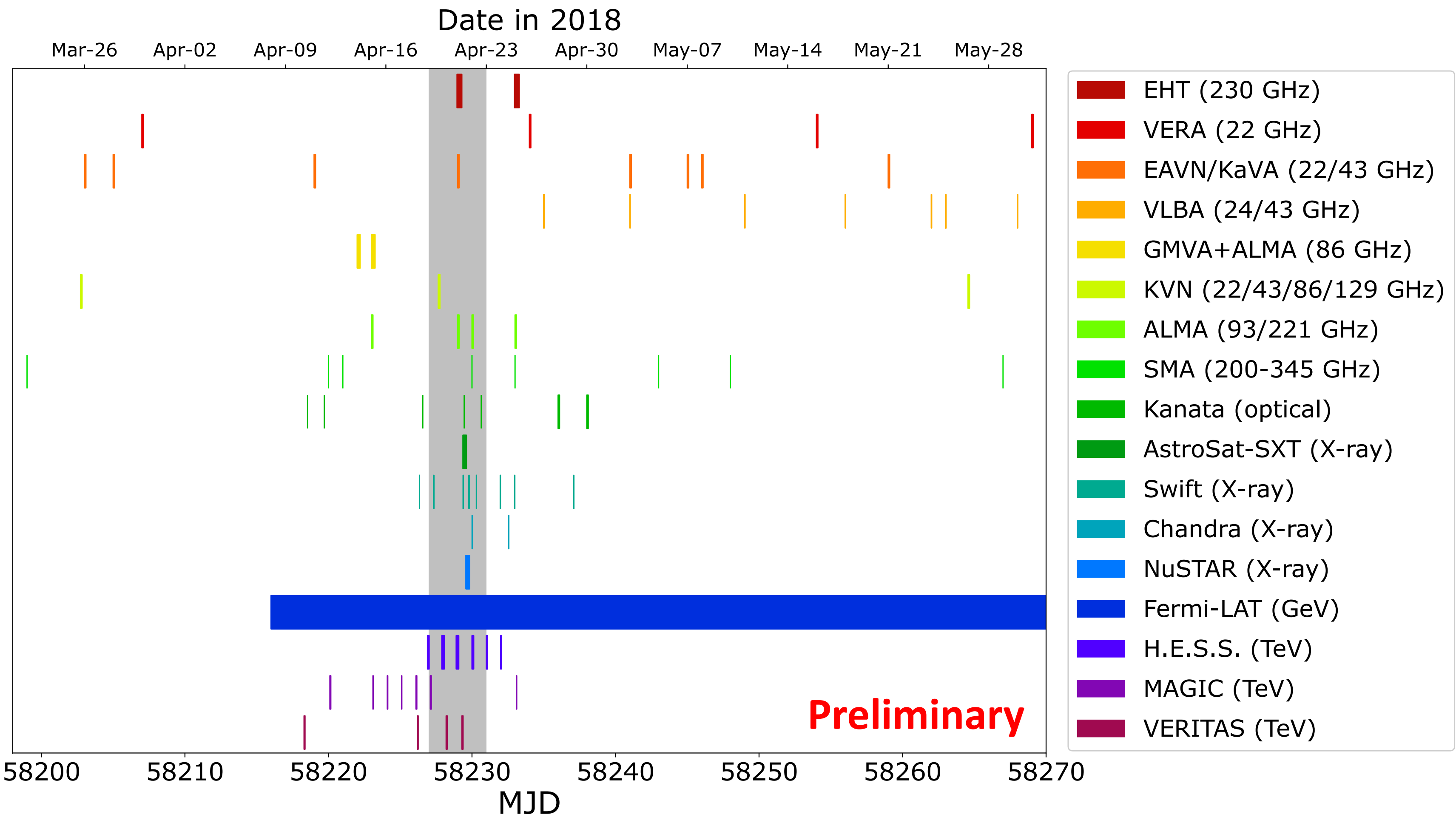




EHT MWL Science Working Group, et al. 2021

Summary instrument coverage: 2018 EHT-MWL observations

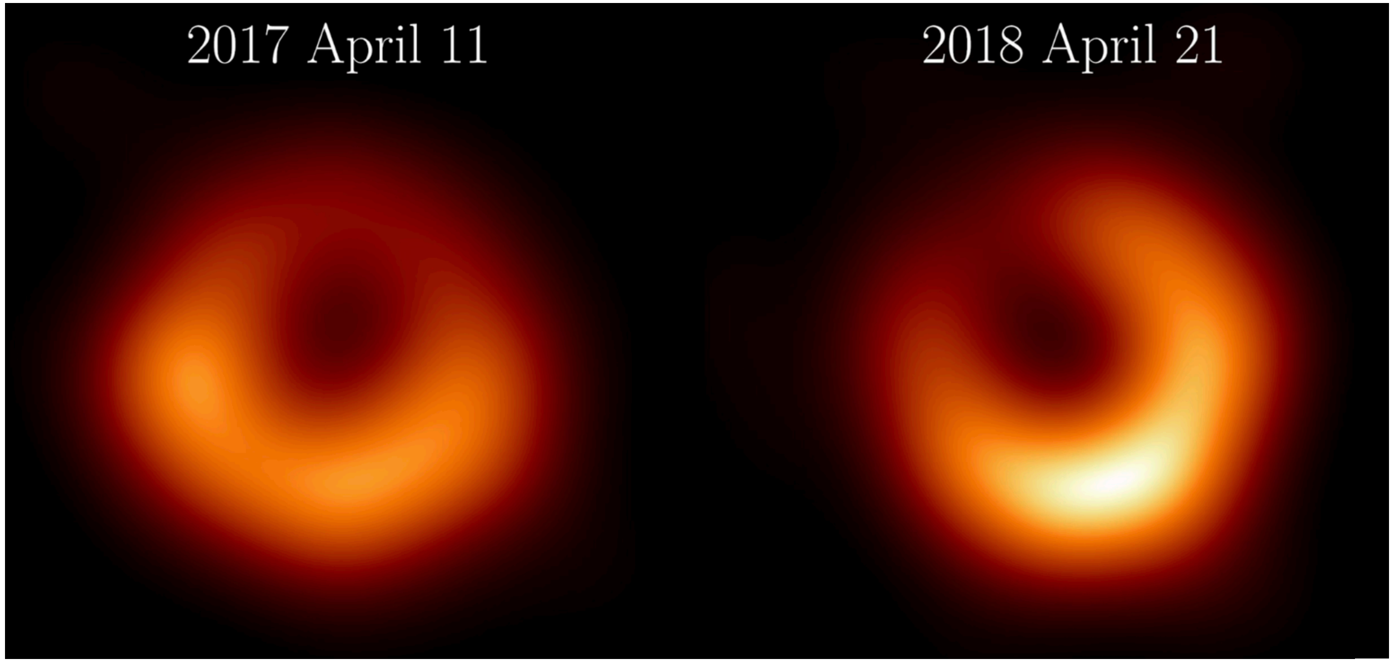
Freq./En.	Observatory
22 GHz	VERA
24, 43 GHz	VLBA
22,43 GHz	EAVN
43 GHz	Global VLBI
86 GHz	GMVA+ALMA
87, 129	KVN
93, 221 GHz	ALMA only
200-345 GHz	SMA
230 GHz	**EHT**
Optical-NIR	Kanata telescope
UV	AstroSat-UV, Swift-UVOT
X-ray - KeV	Chandra,NuSTAR, Swift-XRT, AstroSAT-SXT
0.1-1000 GeV	Fermi-LAT
0.1-10 TeV	H.E.S.S., MAGIC, VERITAS



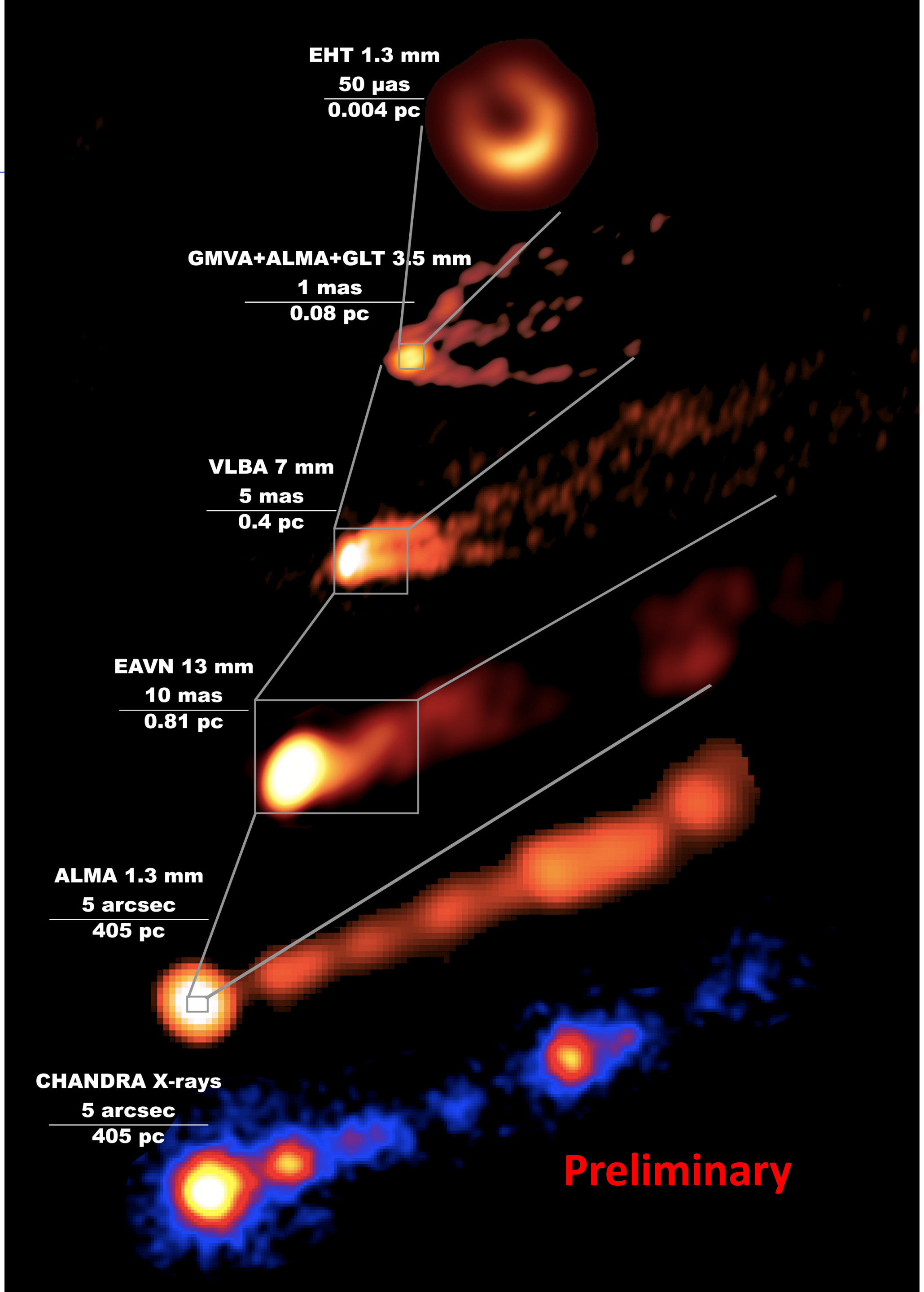
MWL image

During 2018 EHT-MWL observational campaign the M87 jet is imaged at all scales from ~1 kpc down to a few Schwarzschild radii.

EHT results: persistent event horizon, change in micro-arcsec scale ring assymetry position



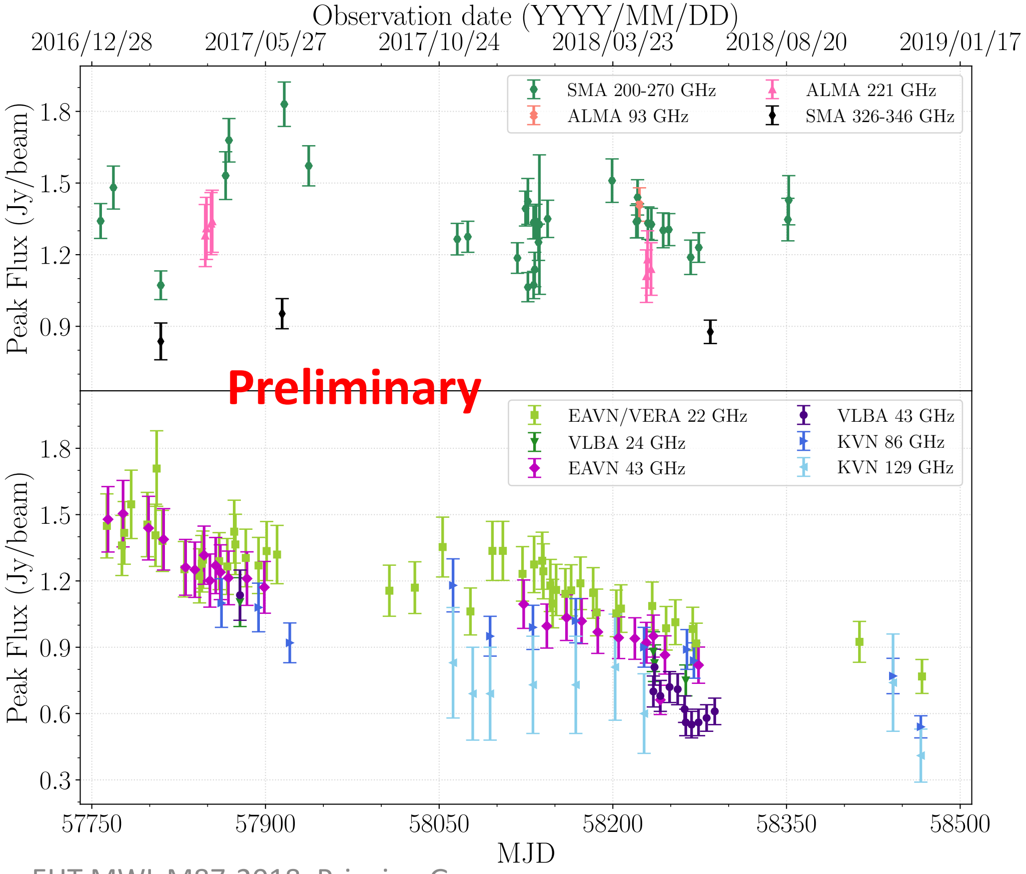
EHT coll. et al. 2019 EHT coll. et al., 2024

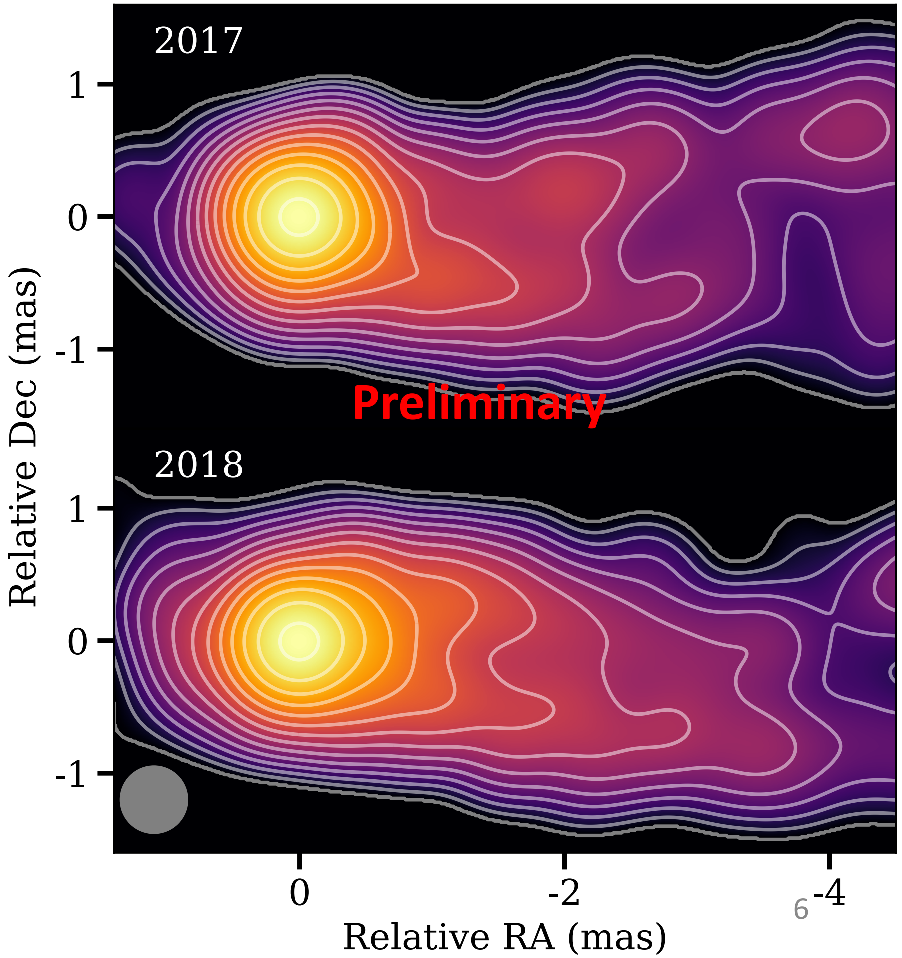


M87-2018 MWL status

Radio

- radio emission was comparable or even lower w.r.t. 2017 one at both cm and mm wavelengths
- similarly to EHT 2018 results (which reveals a significant shift of the PA of the brightness asymmetry of the ring), **we observed a change in jet position angle** (VLBA) indicating the presence of year-scale structural evolution transverse to the jet (for more information see Cui et al., 2023)

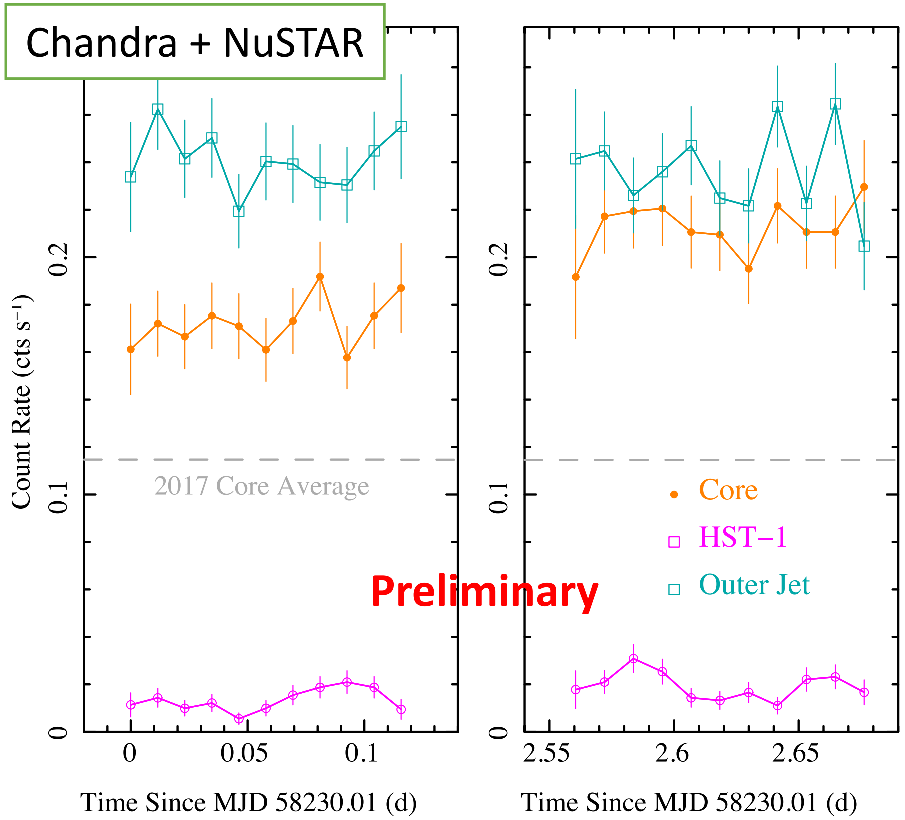


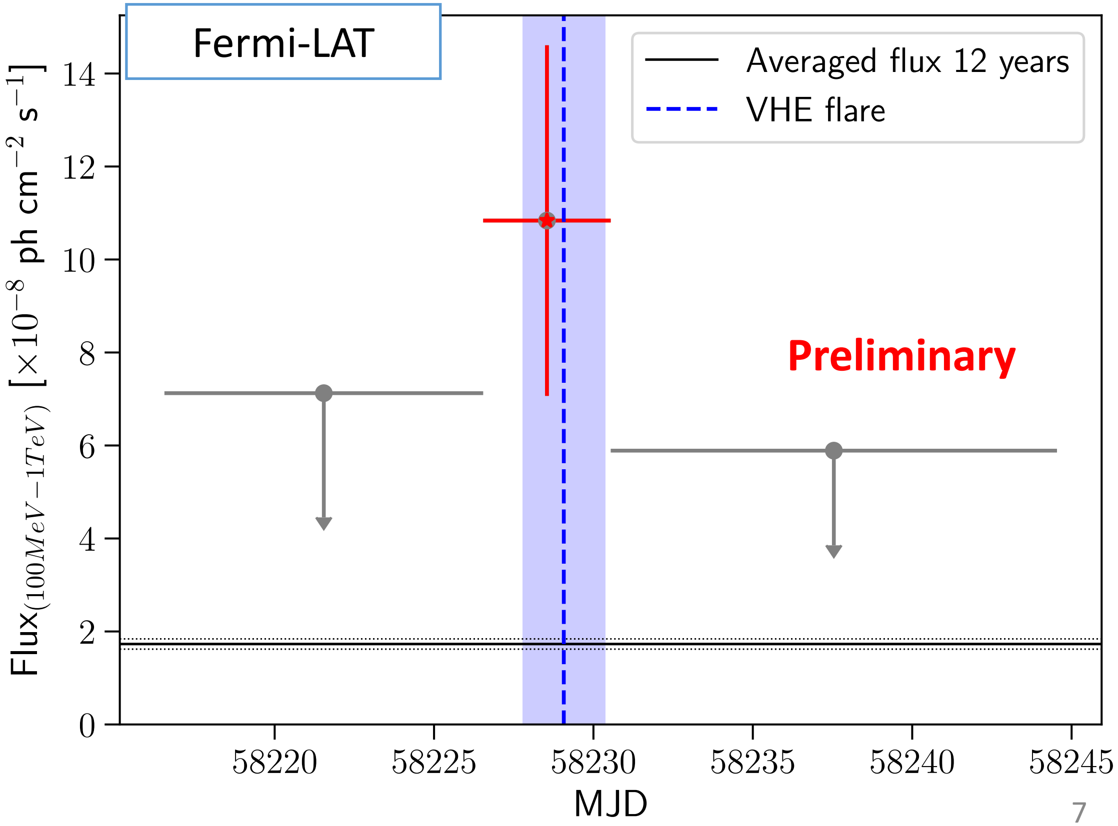


M87-2018 MWL status

X-ray & HE gamma-ray

- a **flux increase** (a factor 2) was observed in the X-ray band (**Chandra+NuSTAR**) w.r.t. 2017 observations
  > due to the lack of time constraint there is no clear evidence for its connection to the VHE flare
- HST1 was clearly subdominant in the X-ray, while core and outer jet had a similar emission
- corresponding to the VHE gamma-ray flare (next slide) **a flux enhancement (about 8x the average flux)** was seen also by **Fermi-LAT** at energies above 100 MeV

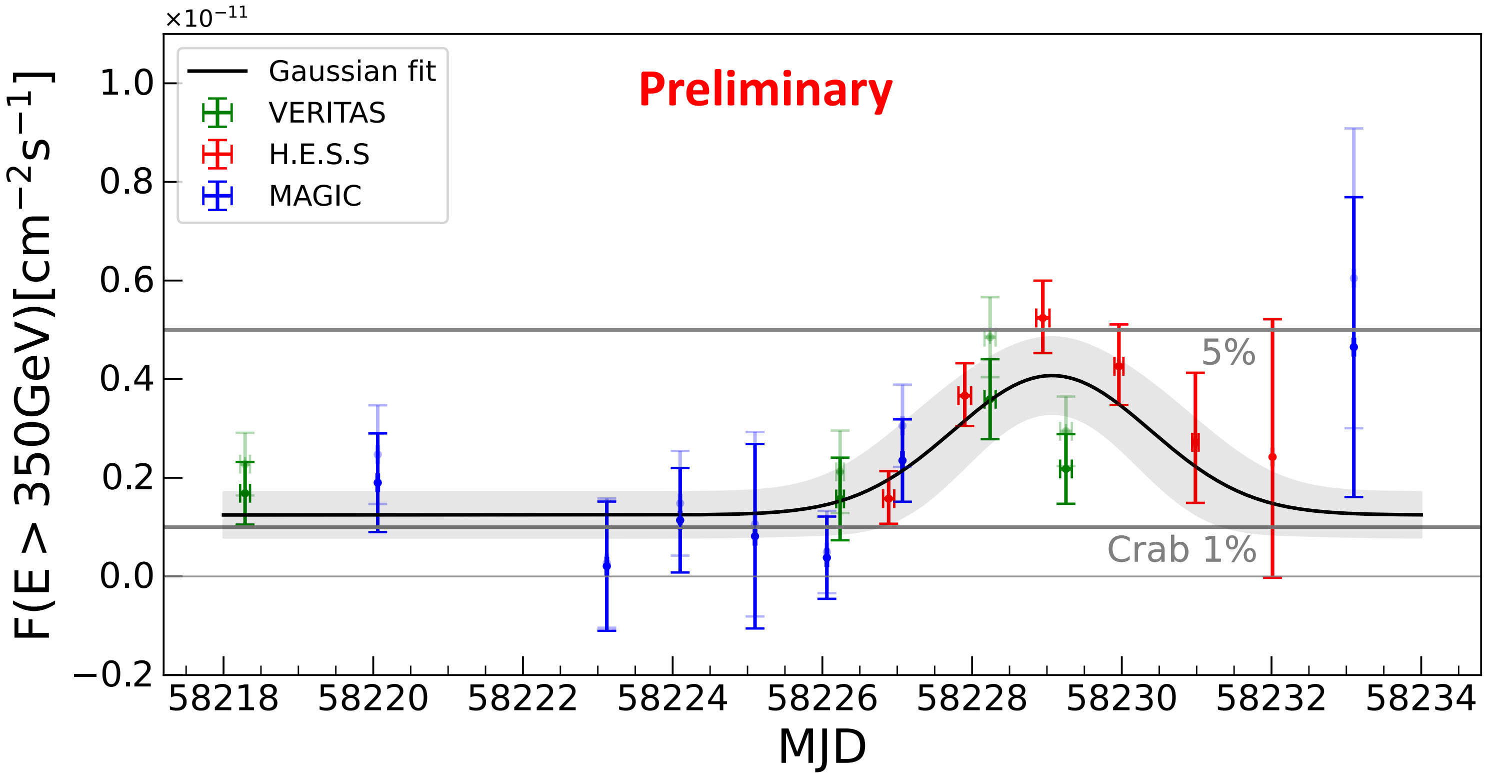


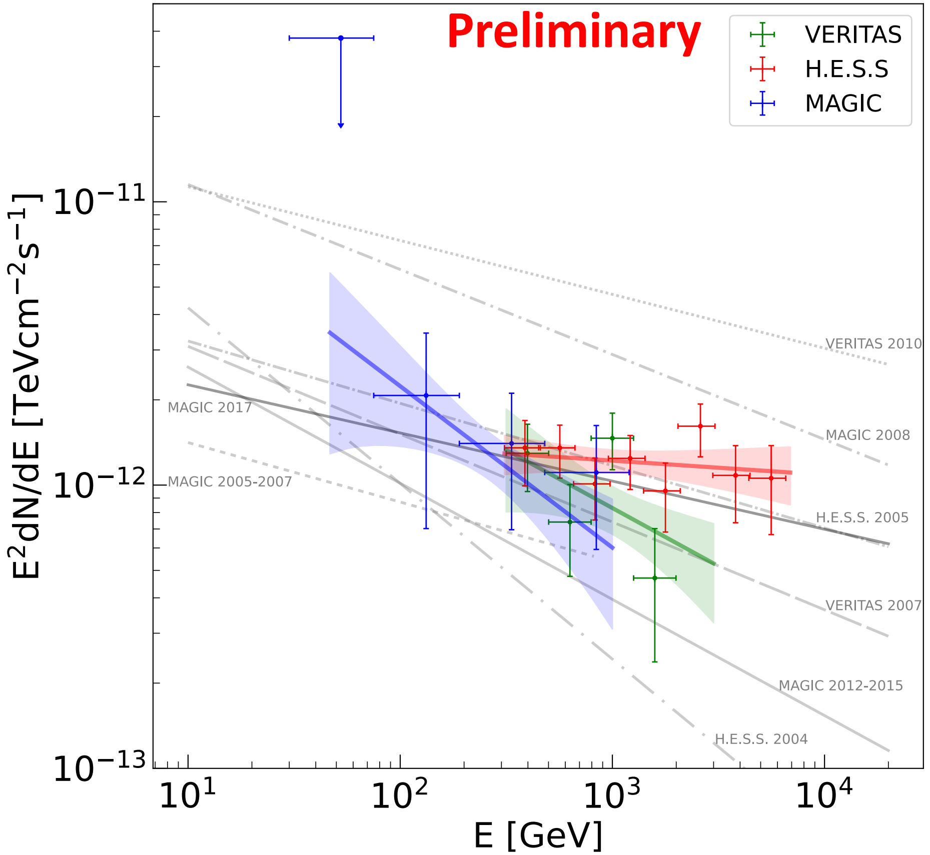


M87-2018 MWL status

VHE gamma-ray

- During the 2018 observational campaign **we detected a short VHE (E>100 GeV) gamma-ray flaring episode** (the first since 2010)
- Hint for a spectral hardening was observed during the flare (observed by H.E.S.S.)





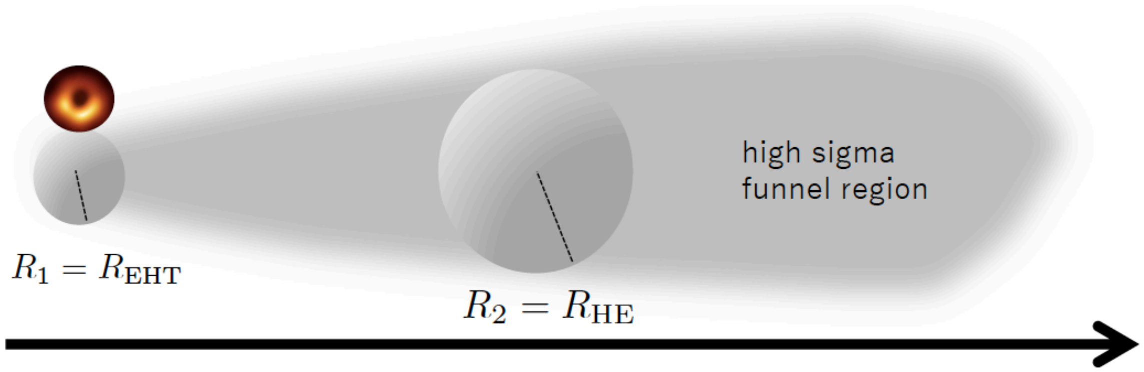
Semi-transparent points obtained scaling the original data with the fudge factors derived from the best Gaussian fit.

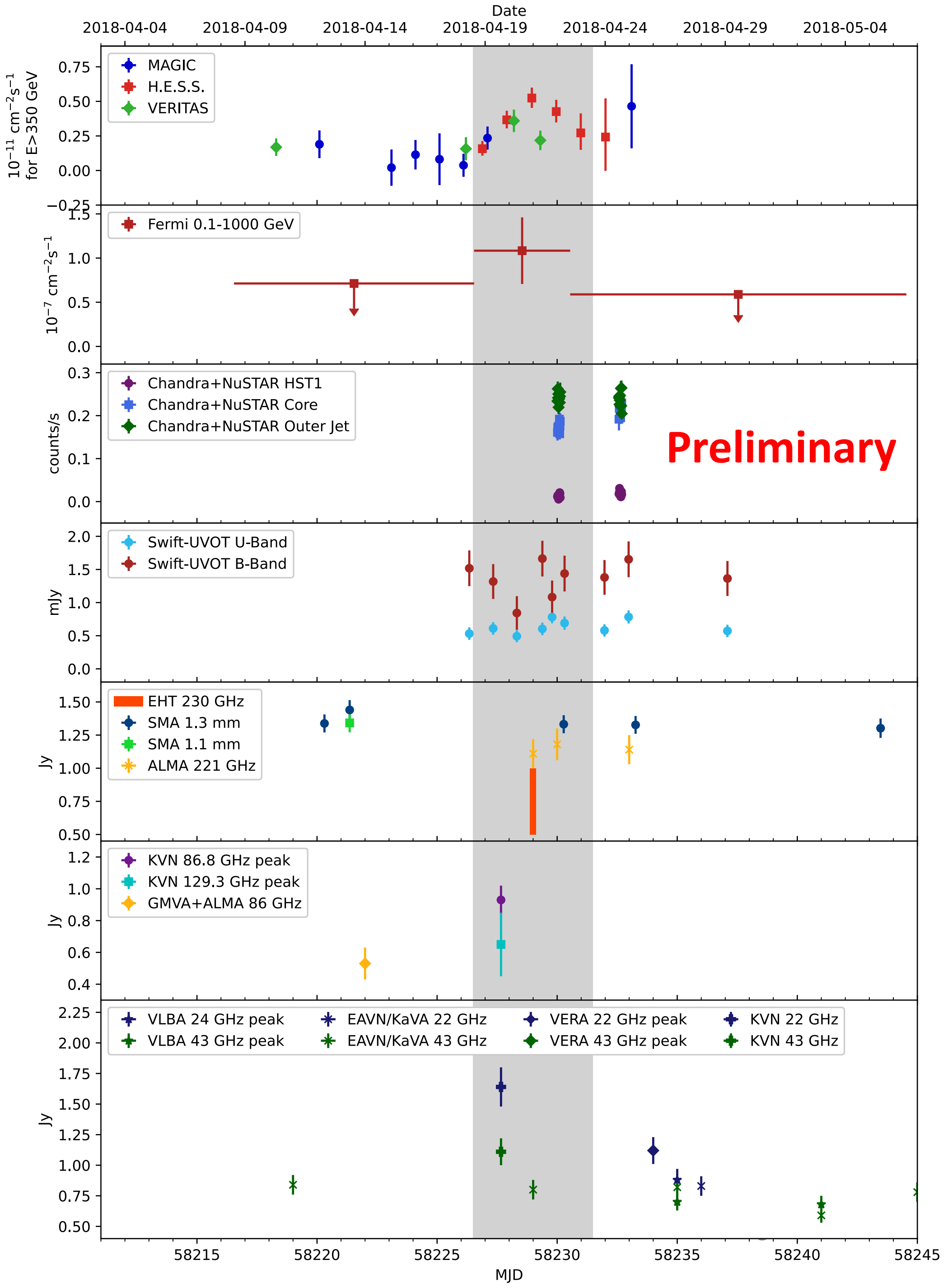
MWL lightcurve

We compare the 2018 M87 status and the observed gamma-ray flaring episode with historical MWL observations.
During the 2018 observational campaign **we detected a short VHE (E>100 GeV) gamma-ray flaring episode** (the first since 2010).

The observed variability time scale indicates that the characteristic size of the VHE gamma-ray emitting region (**R_{VHE} ~2 R_{EHT} ,** for a Doppler factor = 1)

$$R_{\rm HE} \lesssim 8 r_g \delta \left(\frac{\Delta t}{3\ \rm days} \right)$$

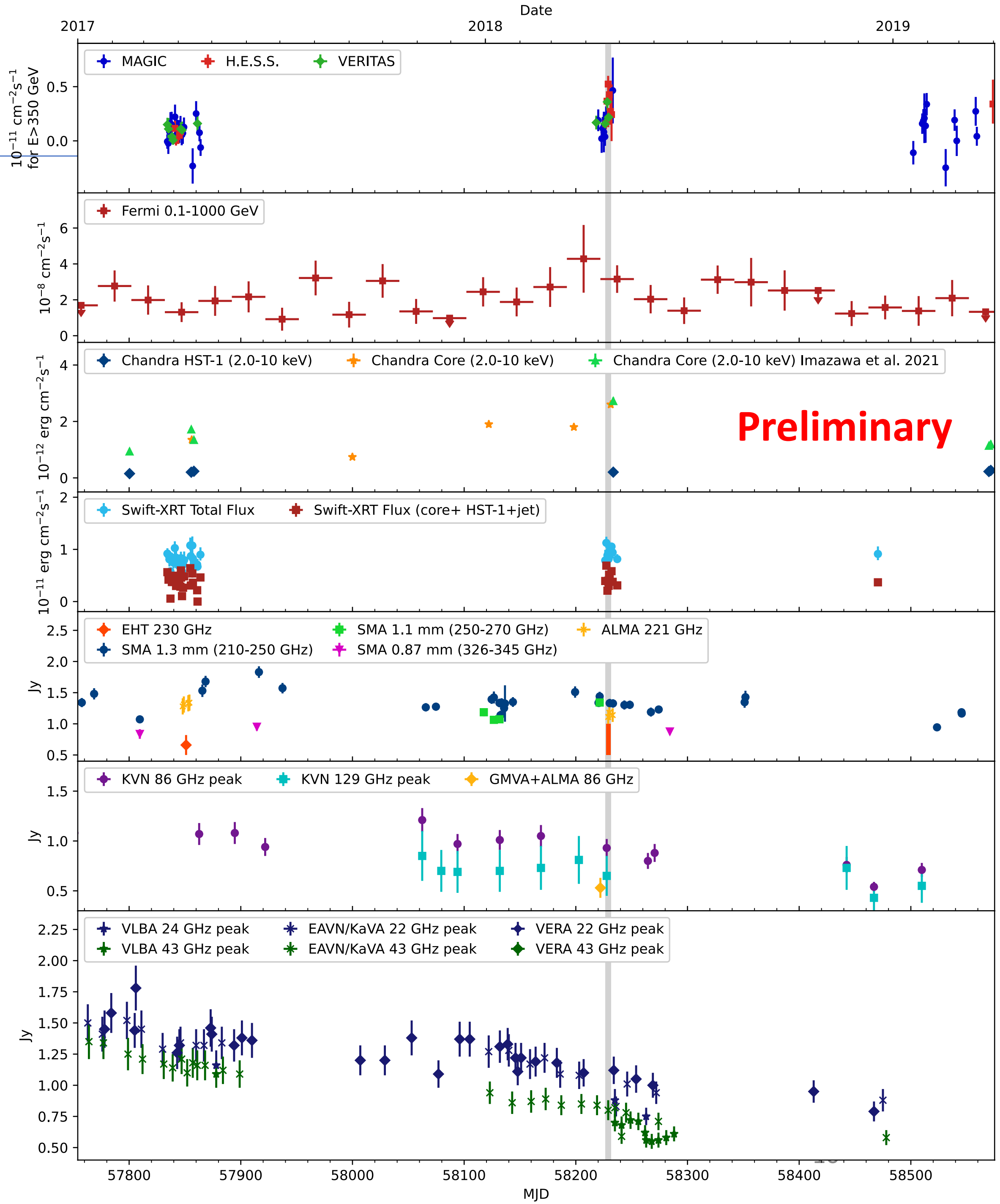




MWL lightcurve

We compare the 2018 M87 status and the observed gamma-ray flaring episode with historical MWL observations on:

- short time scales (April 2018)
- **mid time scales (2017-2019)**
- long time scales (2000-2022)



MWL lightcurve

We compare the 2018 M87 status and the observed gamma-ray flaring episode with historical MWL observations on:

- short time scales (April 2018)
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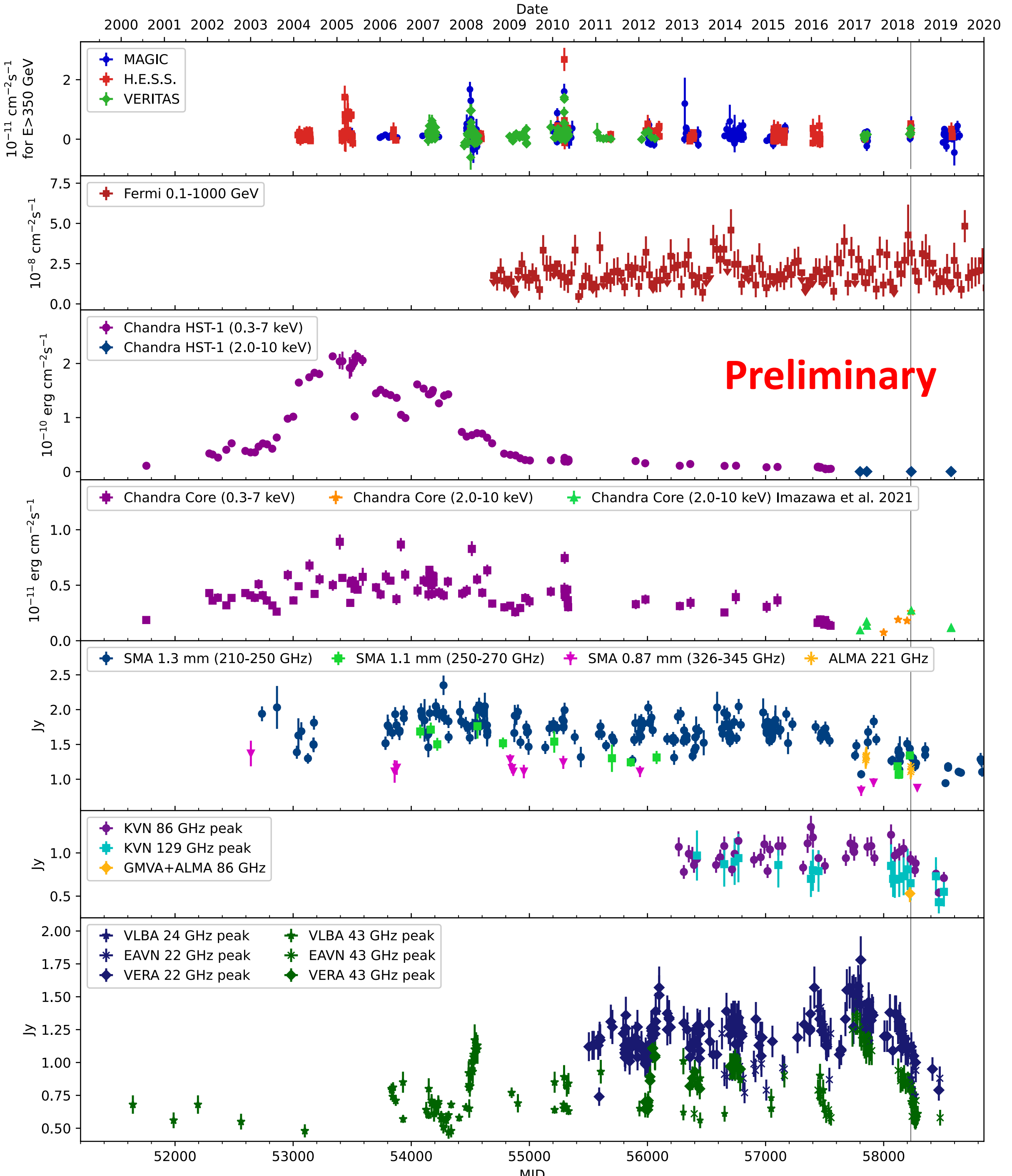
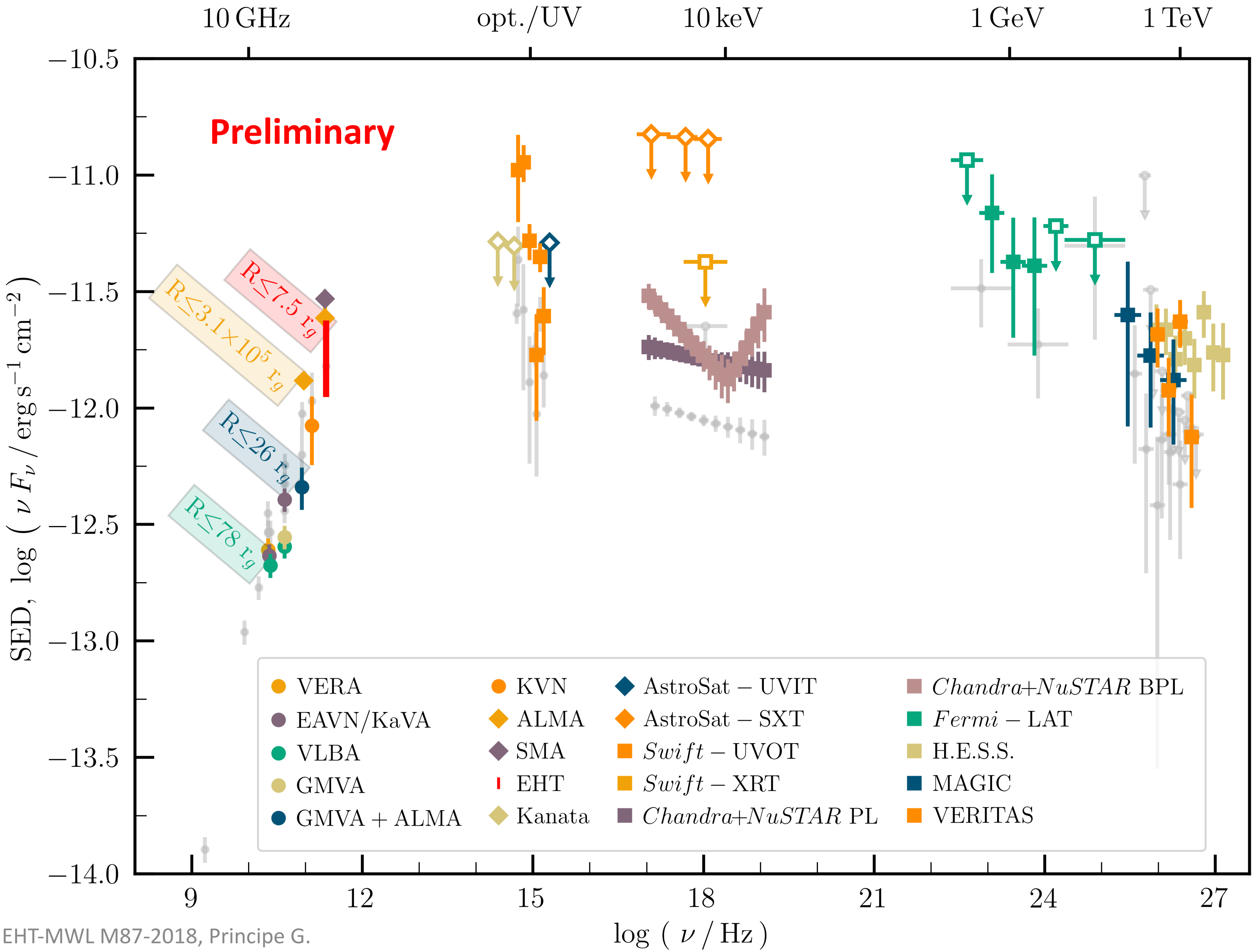


M87-2018 MWL SED



2017 SED plotted in grey for a comparison

Chandra+NuSTAR BPL derived with a stacked analysis of 14 NuSTAR observations (*Sheridan et al., in preparation*)

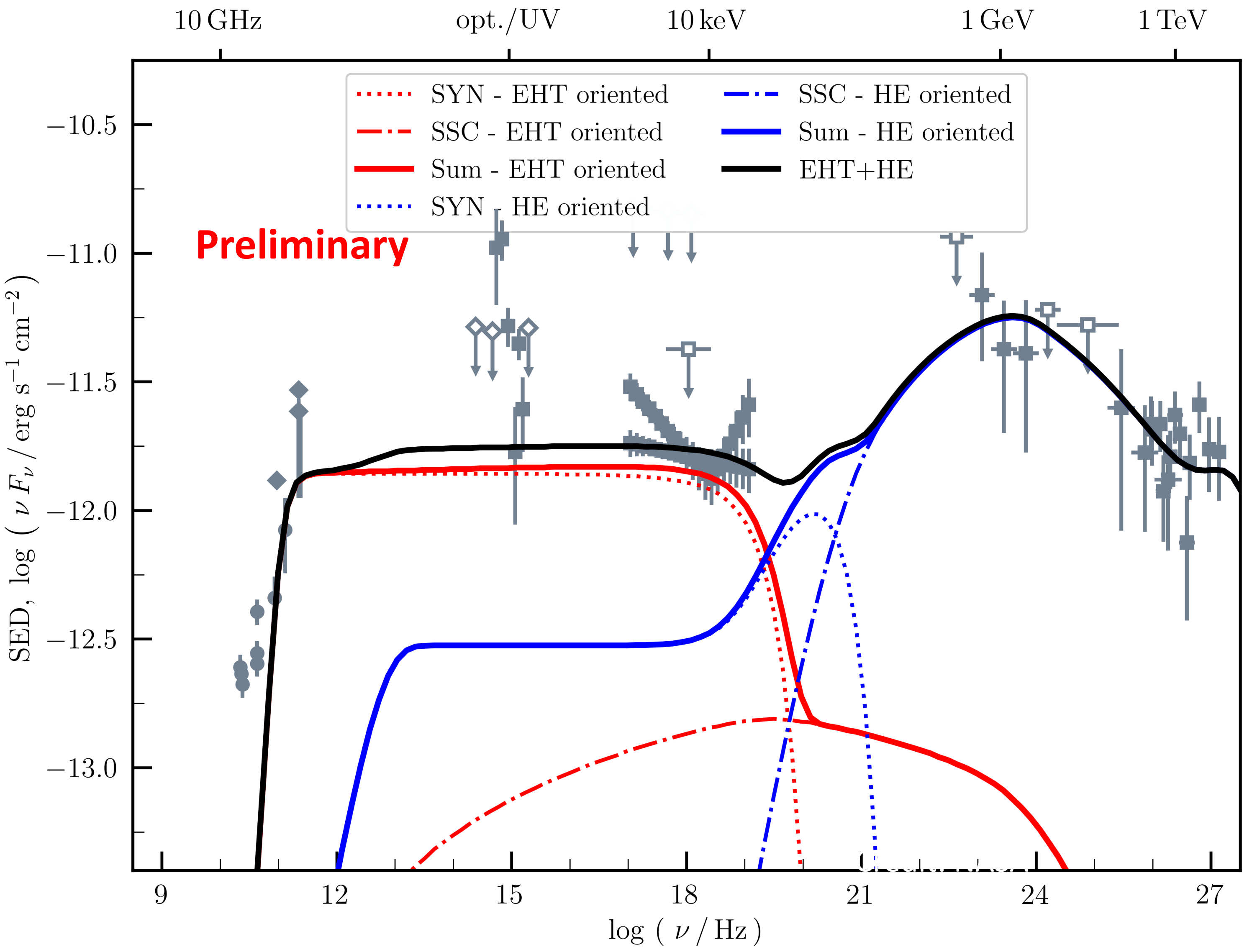
SED Model A

Two single-zone models

Model	A (EHT) [5]	A (HE)
δ	1	1.82
$R\ [r_g]$ [1 2]	5.0	10.0
$n'_e\ [\mathrm{cm}^{-3}]$ [3]	2.0×10^6	1.7×10^1
B' [G]	5.3	2.3×10^{-2}
γ_{min}	1	5×10^3
γ_{br}	–	7×10^6
$\gamma_{max}/10^6$	1.0	50
p_1	3.0	3.0
p_2	–	2.0
U_e/U_B [4]	2.9	6.7×10^3

A broken power-law was used to explain the observed hardening of the VHE spectrum.

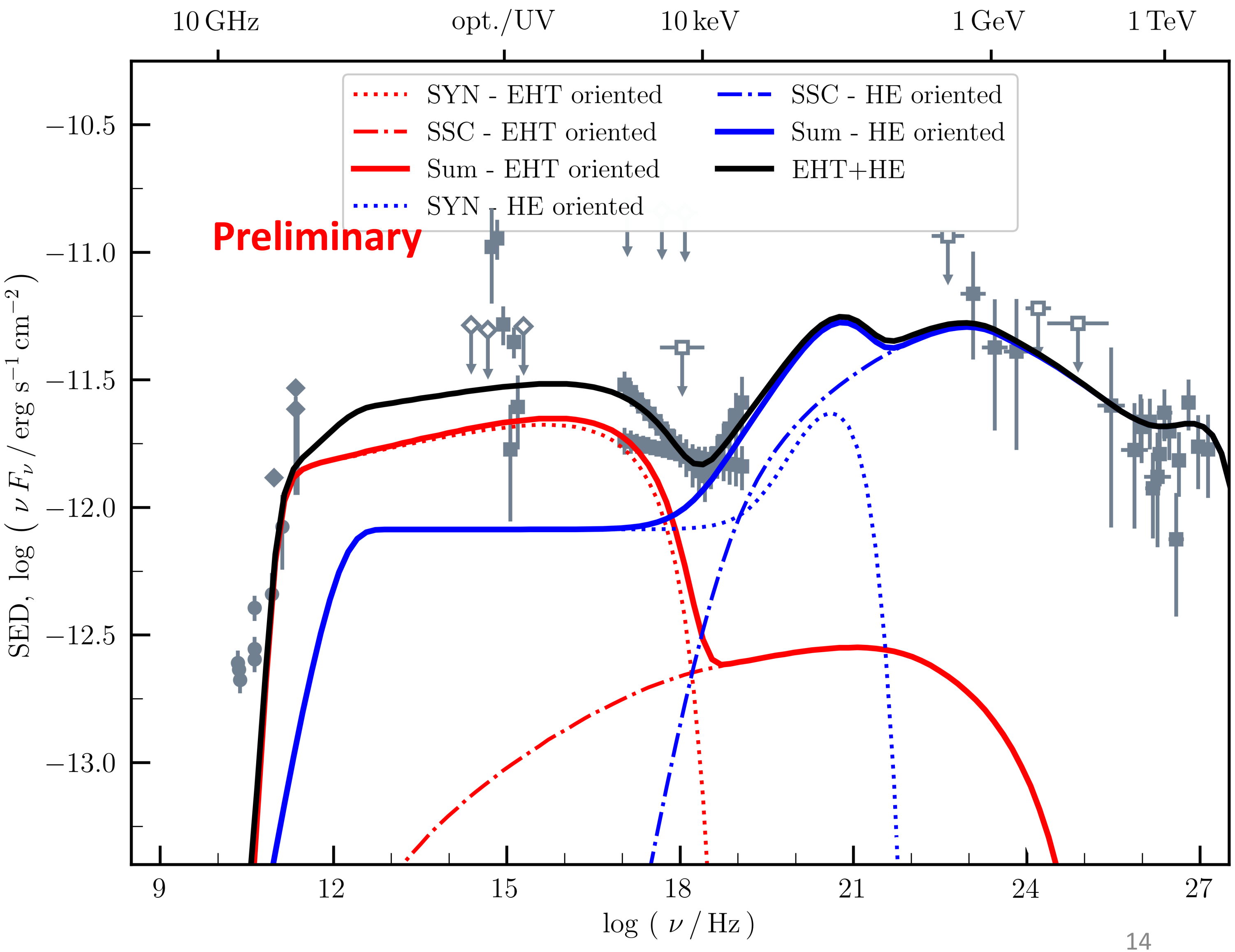
The hard electron spectrum approximates the effect of inefficient cooling in the Klein-Nishina regime.



SED Model A BPL

Two single-zone models

Model	A (EHT/BPL)	A (HE/BPL)
δ	1	1.82
$R\ [r_g]$ [1 2]	5.0	10.0
$n'_e\ [\mathrm{cm}^{-3}]$ [3]	1.8×10^6	6.6×10^1
B' [G]	4.6	8.0×10^{-2}
$\gamma_{\rm min}$	1	1.2×10^3
$\gamma_{\rm br}$	–	7×10^6
$\gamma_{\rm max}/10^6$	0.19	45
p_1	2.9	3.0
p_2	–	2.0
U_e/U_B [4]	3.6	5.2×10^2



M87 take away message

Main results:

- We detected the first VHE γ-ray flare from M87 since 2010 and identify strong indication of spectral hardening during the outburst
- A likely longer-term core flux enhancement was observed in the X-ray band by Chandra
- While radio and mm core fluxes are compatible with the emission seen in April 2017, VLBA observations present a clear change (on annual basis) of the jet-position angle similar to the micro-arcsec scale ring assymetry position seen by EHT
- Although the presence of the flaring episodes allowed us to constrain the size of the VHE γ-ray emitting region in the SED modelling, its location is still uncertain.

Outlook

- Our results show the value of continued multi-wavelength monitoring together with precision imaging
- The gamma-ray flare itself presents a challenge to simpler modelling approaches, emphasising the need for more detailed, structured models.

Paper will be submitted soon!

Thanks for your attention

Backup slides

SED Model B

Three single-zone models

Model	B (EHT)	B (HE)	B (VHE-flare)
δ	1	1.82	2.55
$R\ [r_g]$ [1 2]	5.0	10.0	20.0
$n'_e\ [\mathrm{cm}^{-3}]$ [3]	4.0×10^5	1.6×10^3	1.5×10^1
B' [G]	10	2.5×10^{-2}	4.0×10^{-3}
γ_{min}	1	30	10^3
γ_{br}	4×10^2	3×10^5	–
$\gamma_{max}/10^6$	10	100	60
p_1	2.8	2.1	2.5
p_2	4.5	3.15	–
U_e/U_B [4]	0.18	7.6×10^3	5.8×10^4

An additional component, with a fast moving blob, is used to explain the hard VHE spectrum.

The obtained extremely-weakly magnetized plasma might be generated via magnetic reconnection.