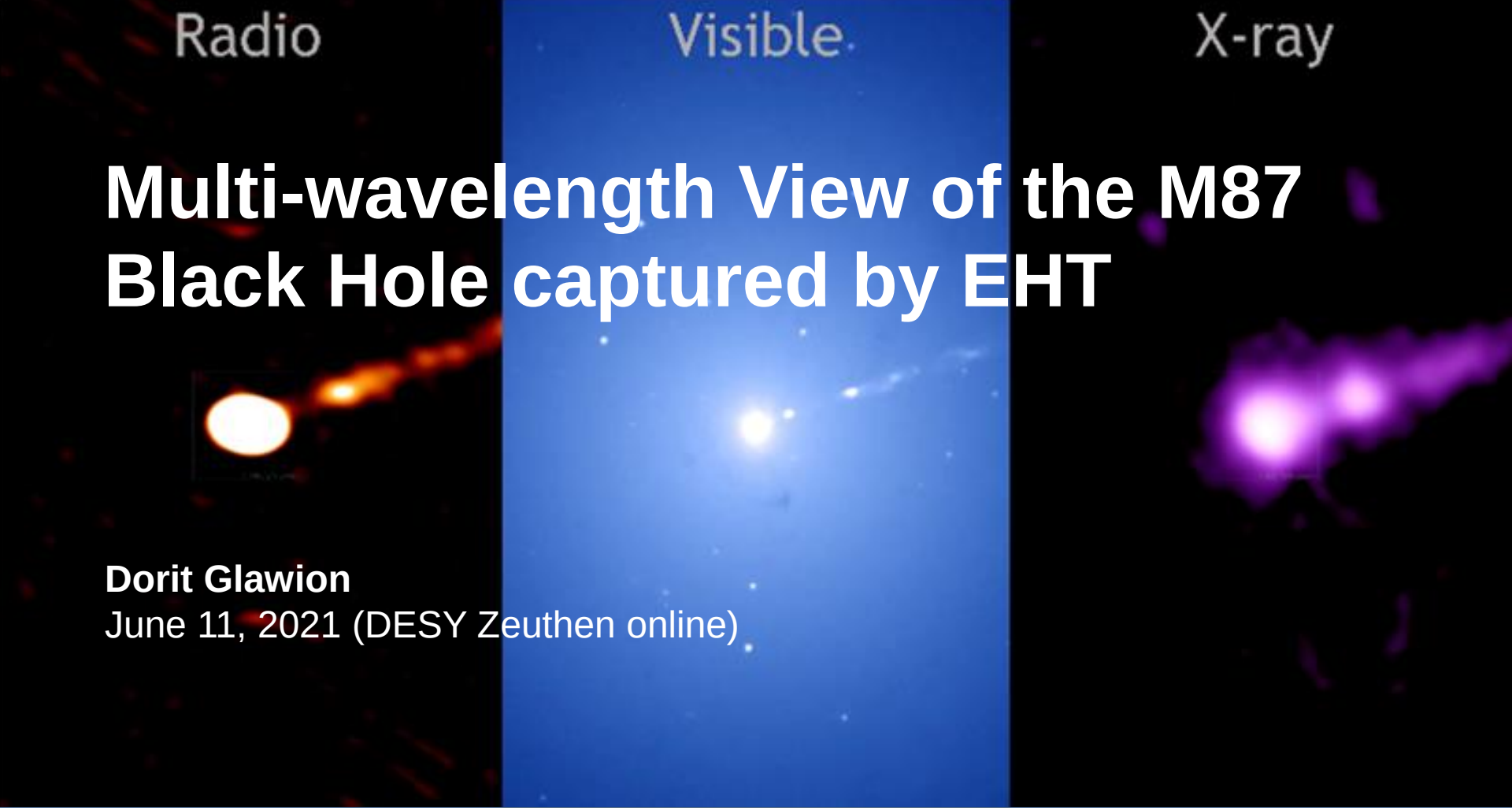

Multi-wavelength View of the M87 Black Hole captured by EHT

Dorit Glawion

June 11, 2021 (DESY Zeuthen online)

H.E.S.S.

ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Overview

M87 – the AGN
Key questions for AGN physics
EHT MWL campaign in 2017
Further campaigns

Overview

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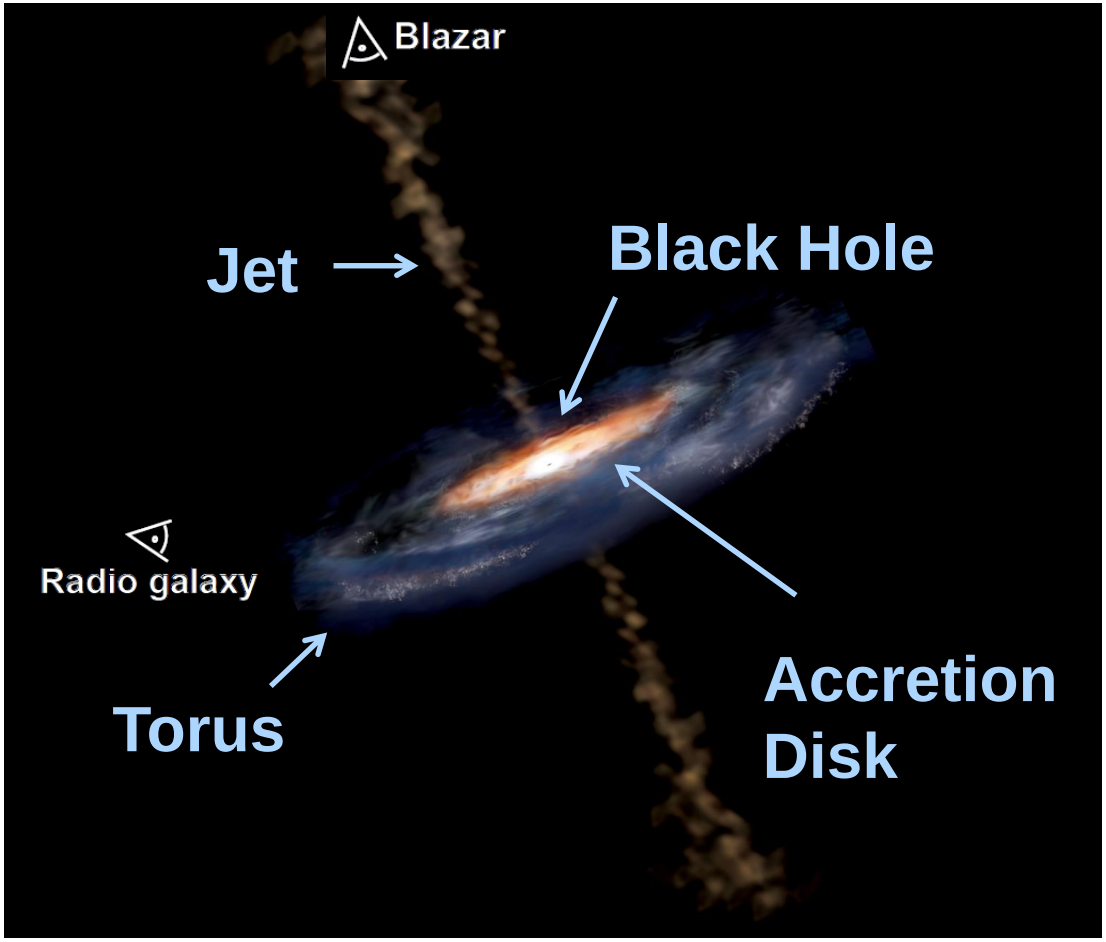
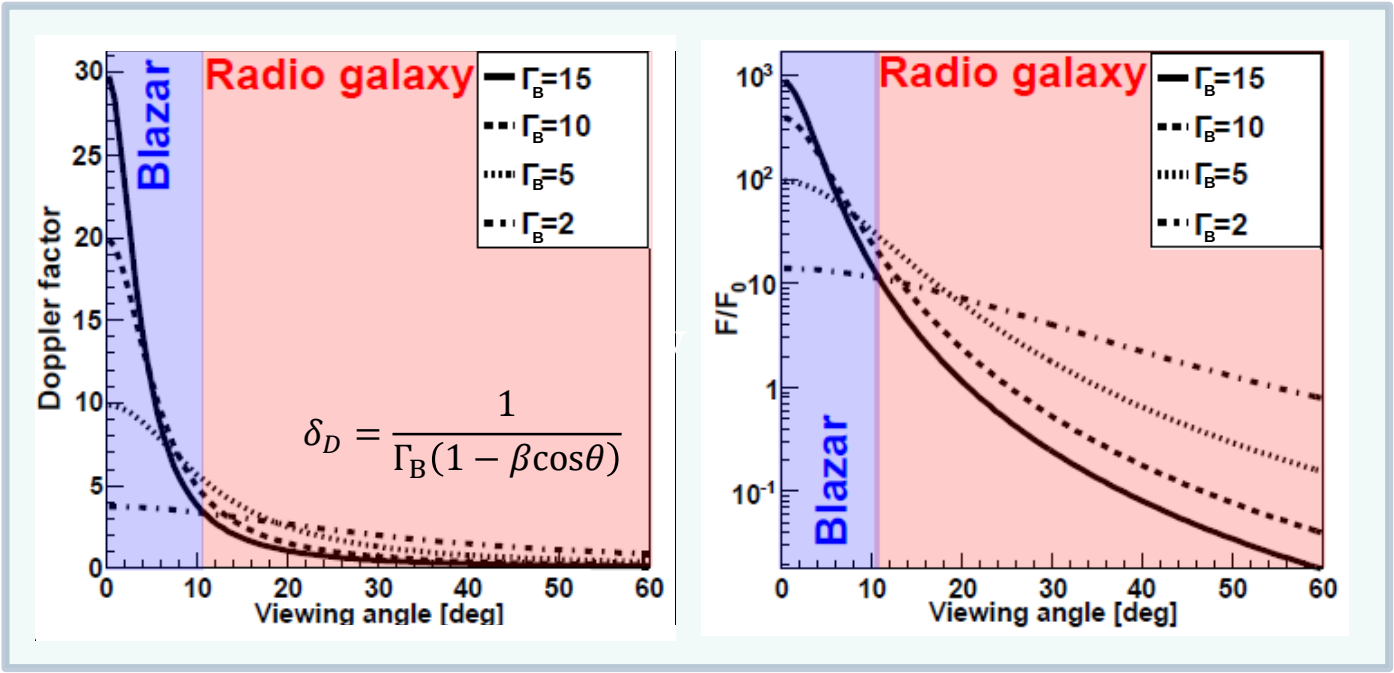
Radio Loud Active Galactic Nuclei

NASA

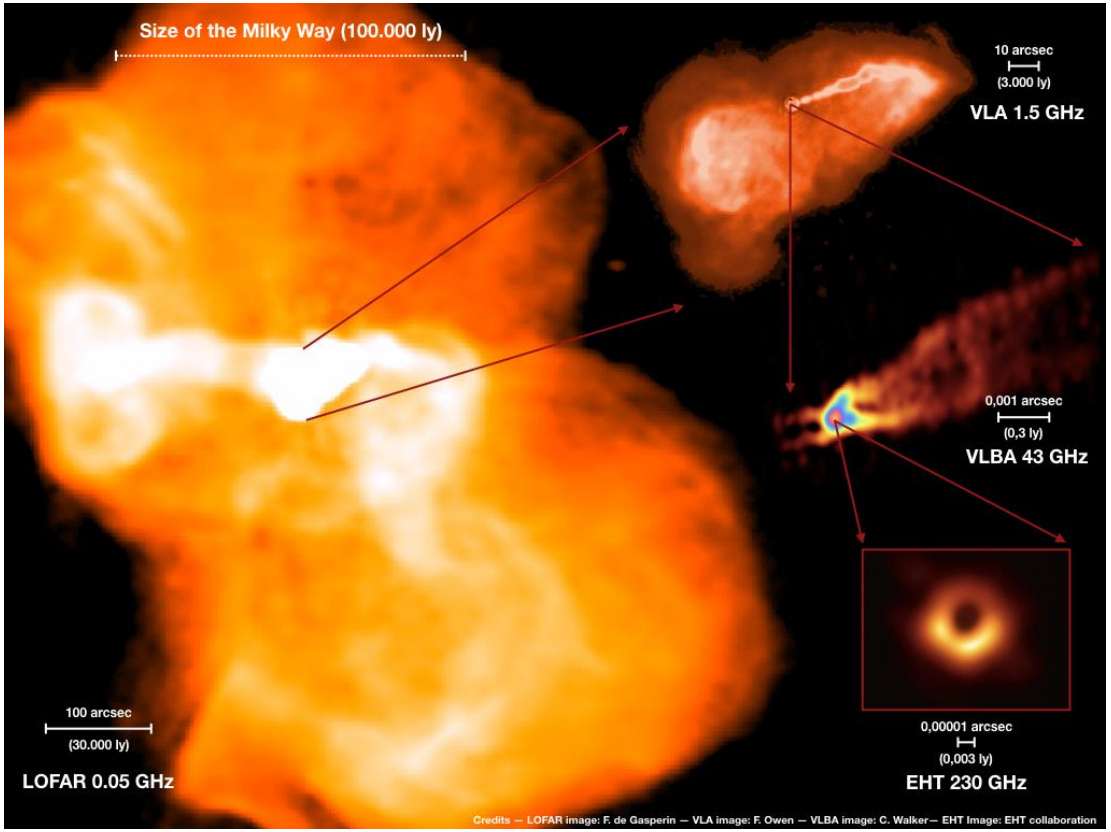


Jets Physics – Relativistic Beaming



- radiating blob along jet
- blob moves at relativistic speed
- blob radiation beamed into forward direction
- result: Lorentz boosted headlight effect

M87 – the AGN and its jet



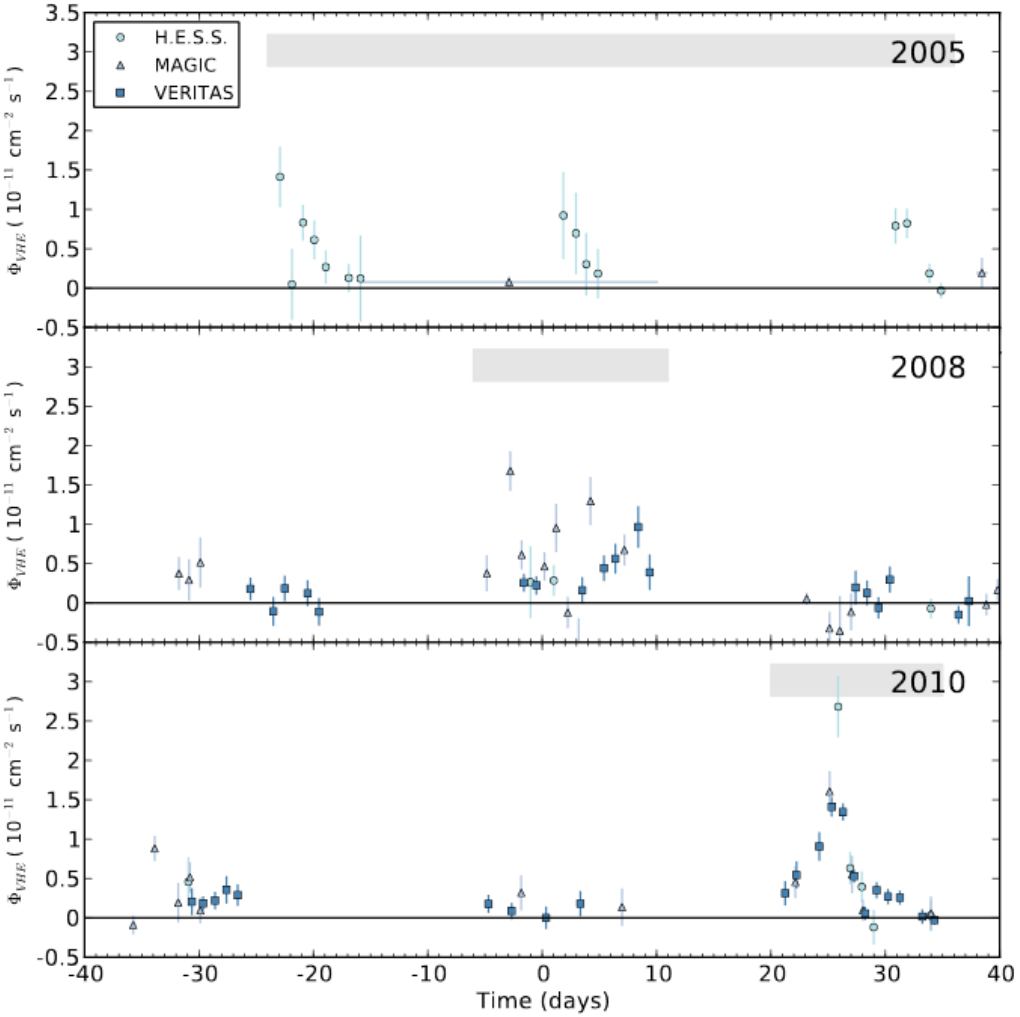
Taken from GLOW

- Known FR I radio galaxy
- Viewing angle ~20 deg (counter-jet detected, e.g. Biretta et al. 1999)
- Viewing angle $30° - 35°$ (kpc two-sided lobes, Bicknell & Begelman et al. 1996)

➢ No strong Doppler boosting

- Emission in all energy bands up to TeV energies, flux variability found
- Daily TeV flux variability previously observed with sometimes different MWL behaviour

Radio (MWL) and TeV in combination



arXiv: 1111.5341 Integral fluxes above 350 GeV

- 2005: TeV detection during X-ray and near-UV (HST) brightening of HST-1
- 2008: TeV detection during X-ray core brightening, HST-1 low flux, start of rising radio flux
- 2010: TeV flux doubling time scale about 1 day, no enhanced radio flux at 43 GHz, new radio blob appearing in HST-1, X-ray core bright

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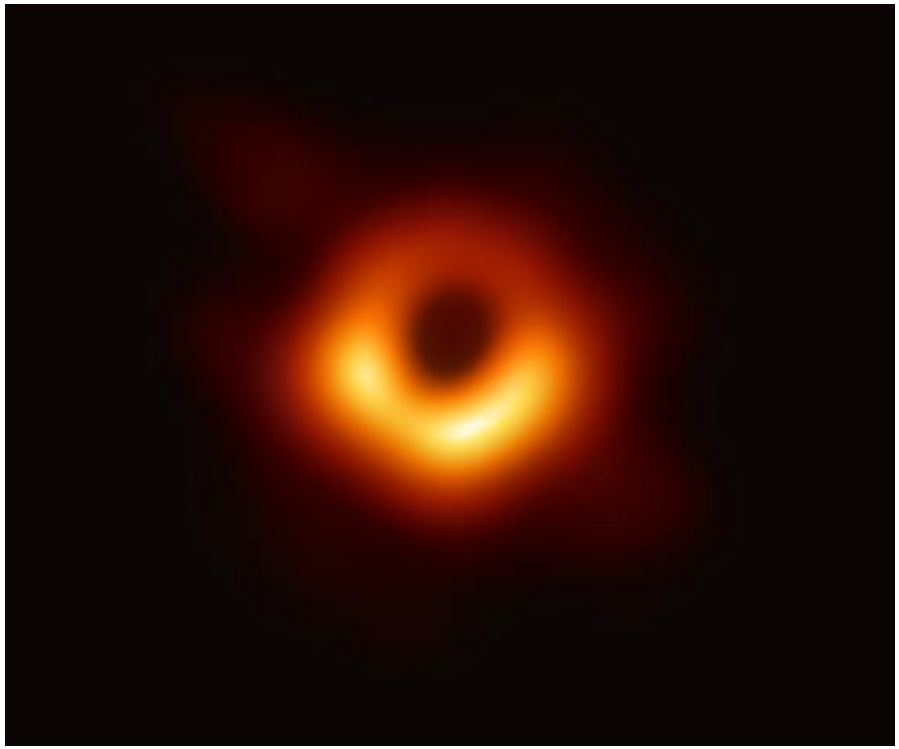
For (gamma-ray) AGN

- Unified scheme
  - Blazars (BL Lac objects) and radio galaxies (FR-I type) really the same but viewed under a different angle?
- Understanding active and quientent gamma-ray states
- Emission mechanism
  - Hadronic vs. leptonic radiation (or combination): one-zone SSC, multi-zone SSC, EC, pion-decay, sychrotorn-proton
- Acceleration mechanism for fast variability
  - Shock acceleration inside the jet
  - Jet-star/cloud interaction (based on Blandford & Znajek 1977, Bednarek & Protheroe 1997, Barkov et al. 2010/2012, …)
  - Shock acceleration on reconnection sites (mini-jets, e.g., Giannios et al. 2009/2010, Narayan & Piran 2012)
  - Gap accelation (see Levison and Rieger 2011, Hirotoni & Pu / Hirotani et al. 2016)

For (gamma-ray) AGN - observations

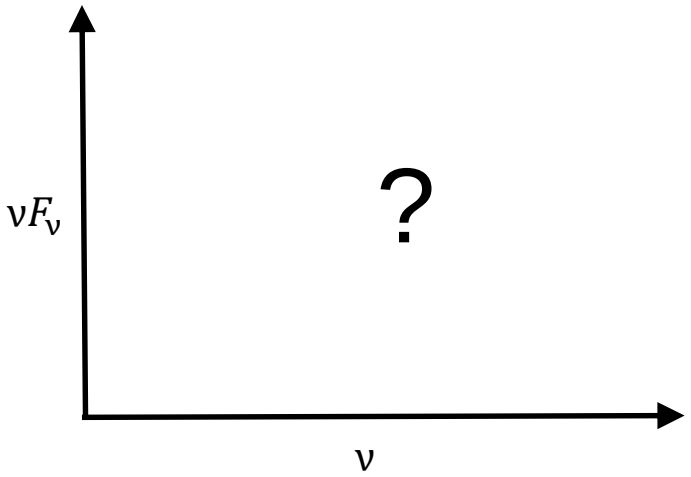
- Unified scheme
  - e.g. spectral energy distribution for BL Lac objects vs. radio galaxies/boundary objects
- Understanding active and quientent gamma-ray states -> regulare monitoring do indentify different states
- Emission mechanism -> simultenous mesaured spectral energy distribution of radio galaxies and boundardy objects, VLBI observations like EHT
- Acceleration mechanism (for fast variability)
  - Shock acceleration inside the jet -> Fast variability in light curves (monitoring)
  - Jet-star/cloud interaction -> simultanous XMM-Newton during TeV flare
  - Shock acceleration on reconnection sites -> simultaneous MWL (X-ray) observations, (EHT for magnetic field mesaurments close to BH)
  - Gap accelation -> simultaneous MWL (X-ray) observations, (EHT for magnetic field mesaurments close to BH)

Event horizon resolution and MWL approach



EHT Collaboration 2019

- Multi-band spectral energy distribution



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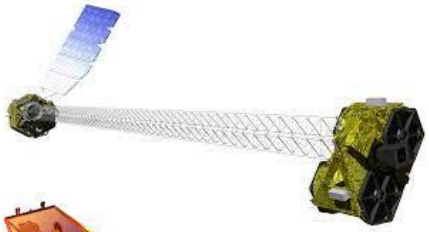
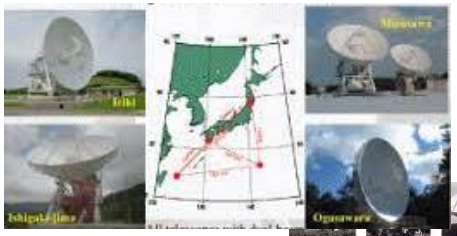
EHT Multiwavelength Team + partners

EUROPEAN VLBI NETWORK





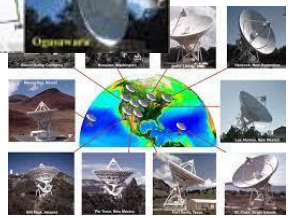


Image credits: NRAO, EVN, HSA/NRAO, M. Honma, www.kasi.re.kr, NRAO/AUI and SeaWiFS Project NASA/GSFC and ORBIMAGE, Agudo et al. 2015, Ruffnax (Crew of STS-125), NASA E/PO, Sonoma State University/Aurore Simonnet, NASA/CXC/NGST, NASA/JPL-Caltech, NASA, R. Wagner, VERITAS, Klepser, DESY, H.E.S.S. collaboration

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Svetlana Jorstad

Giacomo Principe

EUROPEAN
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Motoki Kino, M. Lucchini, Joseph Neilsen, Michael Nowak,
Sergey Savchenko, Karen Williamson, And many others…

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Daniel Mazin

Kazuhiro Hada,
Keiichi Asada

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Daryl Haggard

Dorit Glawion,
Cornelia Arcaro
Gerd Pühlhofer,
David Sanchez

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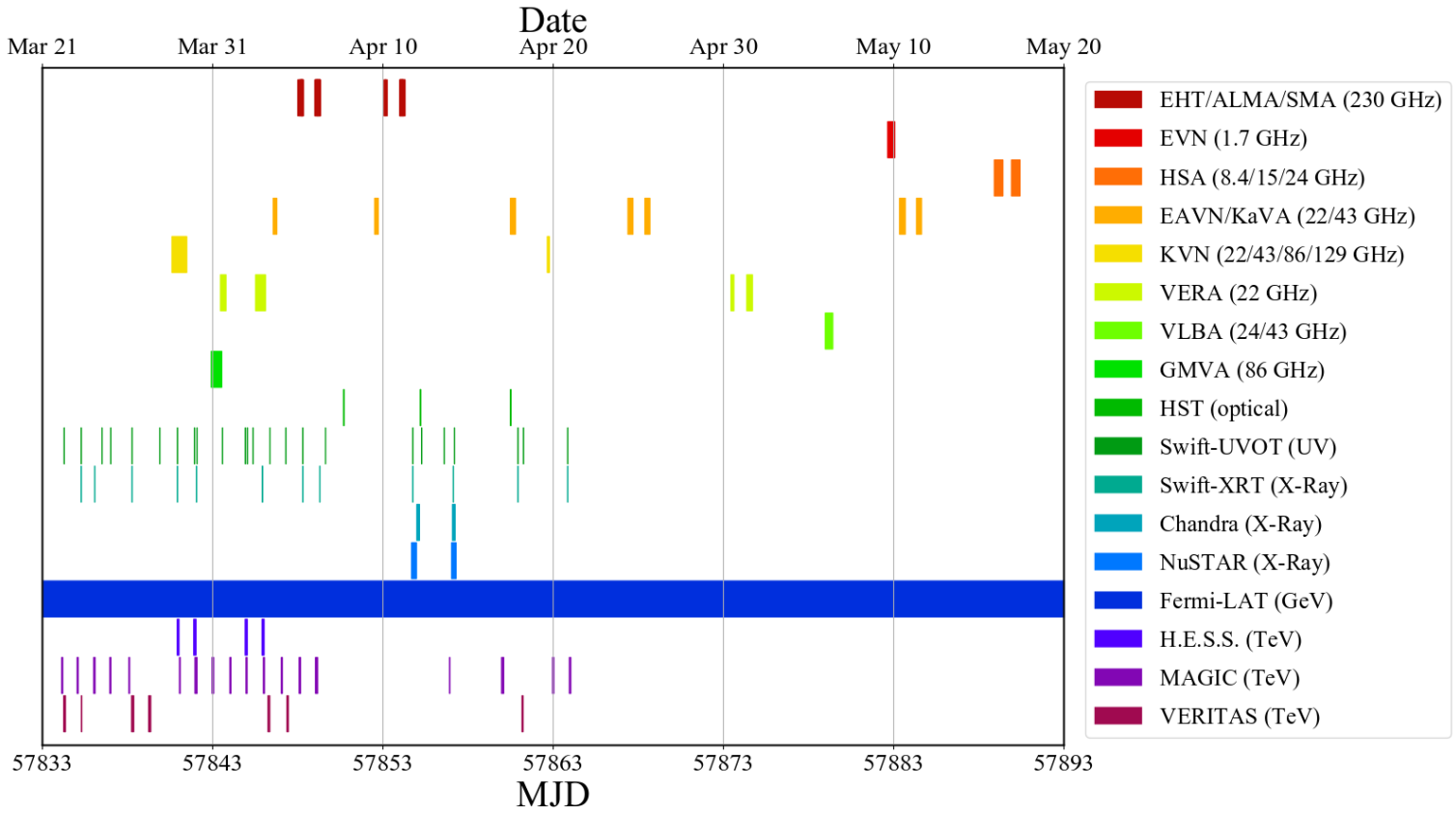
Observation during 2017 EHT campaign



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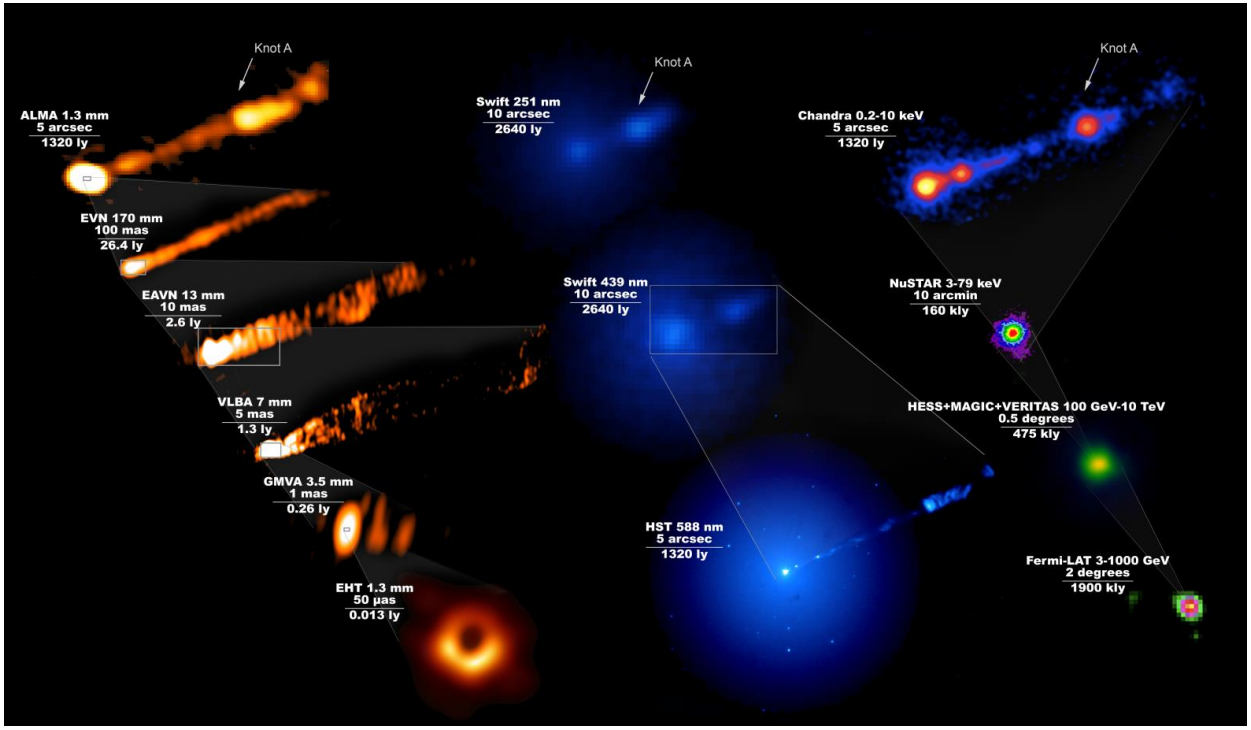
Multi-band imaging

https://youtu.be/q2u4eK-ph40



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.

Multi-band imaging

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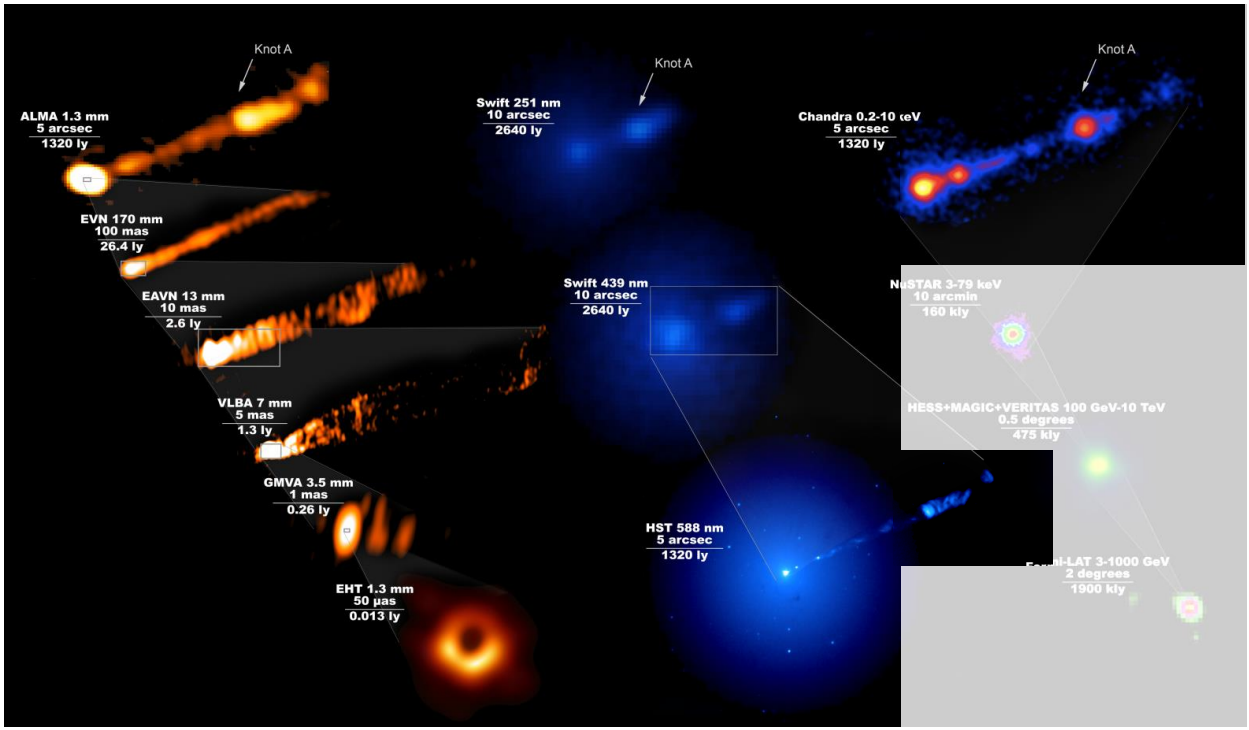
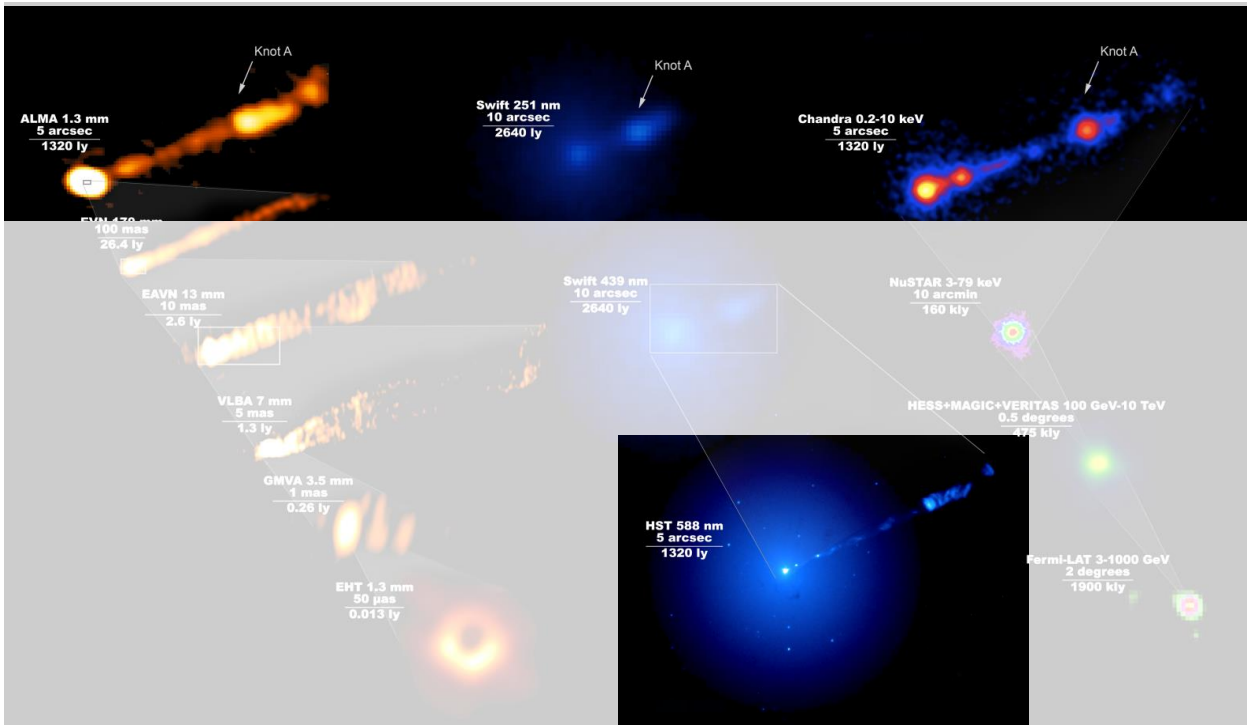


- jet is imaged/resolved at all scales from 1 kpc down to horizon scales

Multi-band imaging

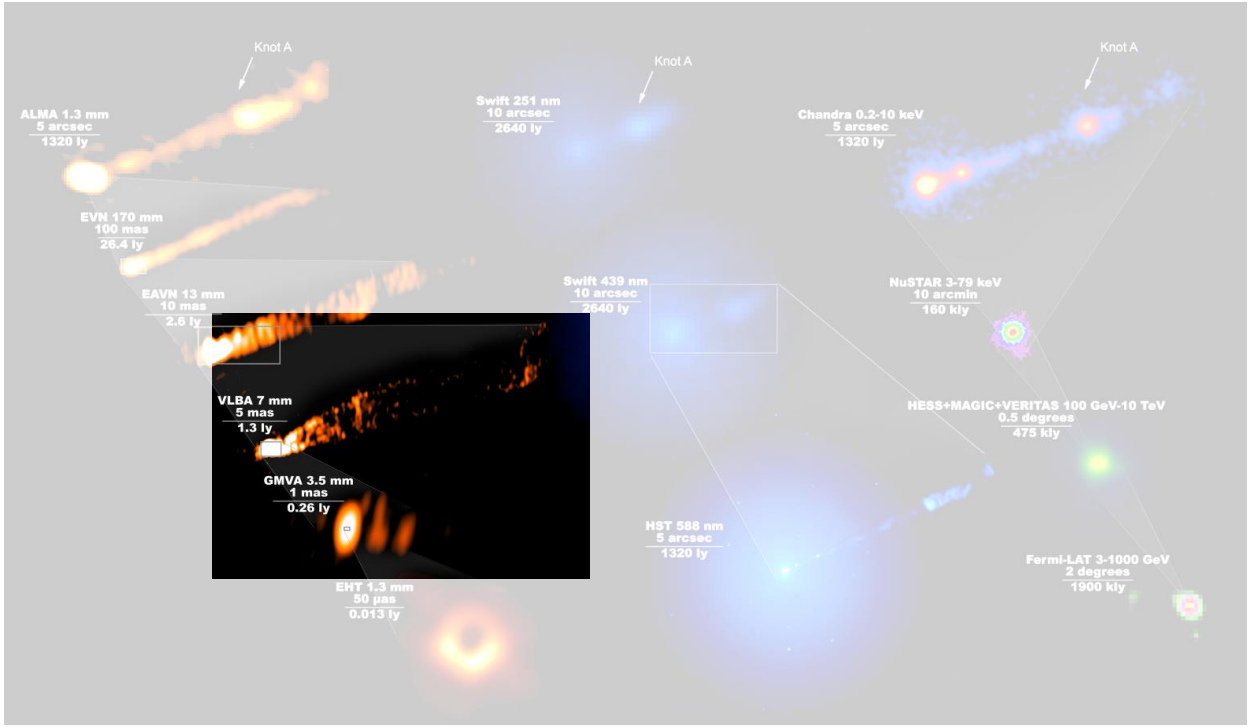
https://youtu.be/q2u4eK-ph40



- near-core knot HST-1 is well isolated from the nucleus by EVN, HST and *Chandra*

Multi-band imaging

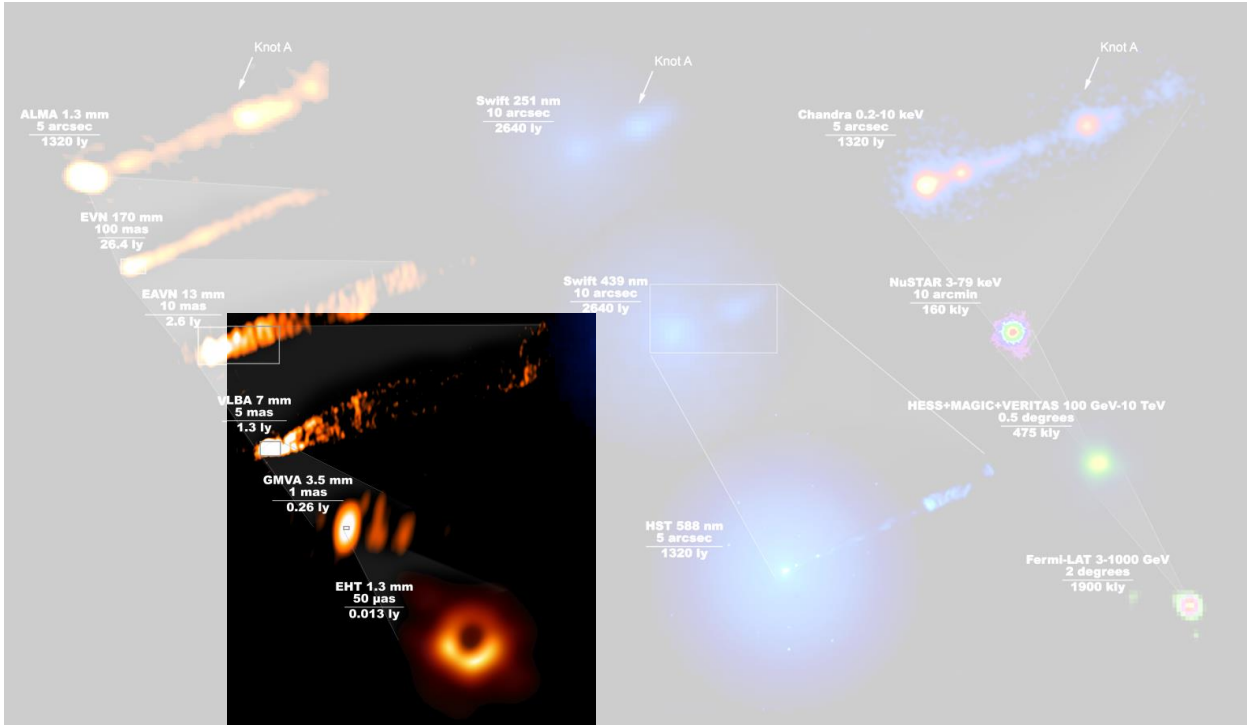
https://youtu.be/q2u4eK-ph40



- limb-brightened structure resolved (Asada & Nakamura 2012; Hada et al. 2013; Nakamura & Asada 2013; Kim et al. 2018b)

Multi-band imaging

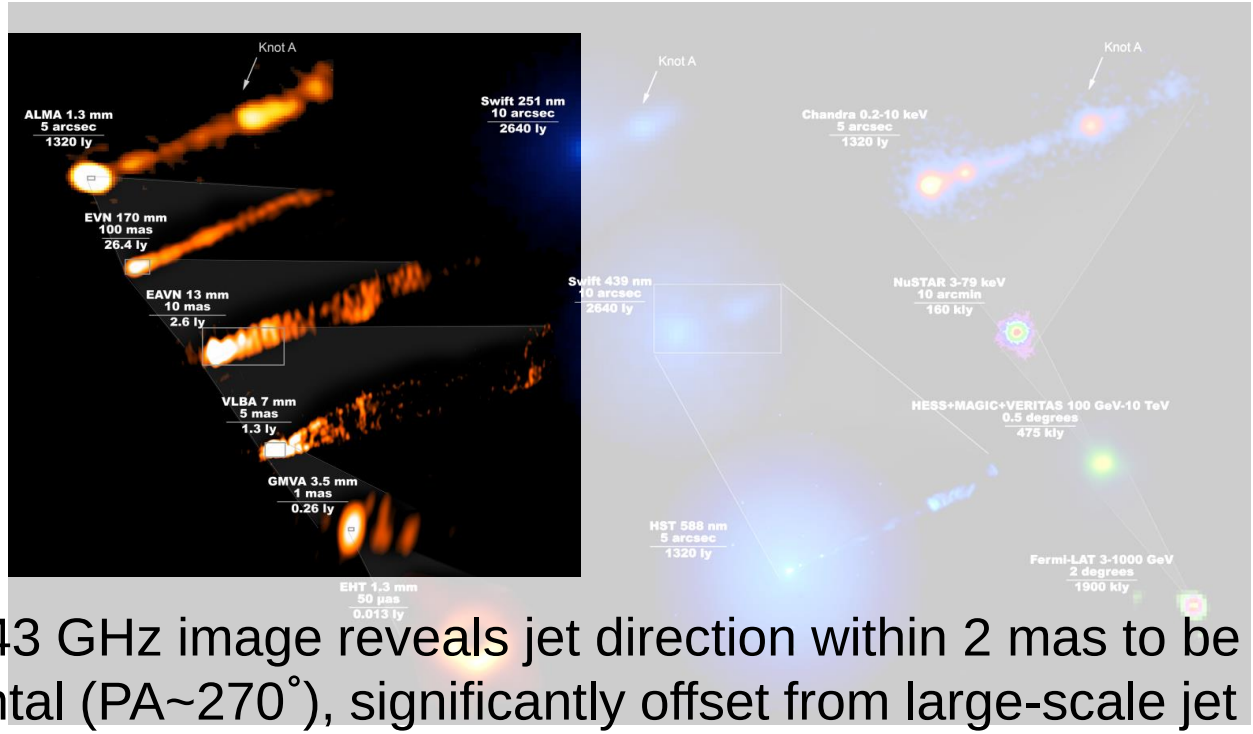
https://youtu.be/q2u4eK-ph40



- southern jet limb tends to be brighter than northern limb, similar to north-south asymmetric brightness pattern seen in EHT-2017 image

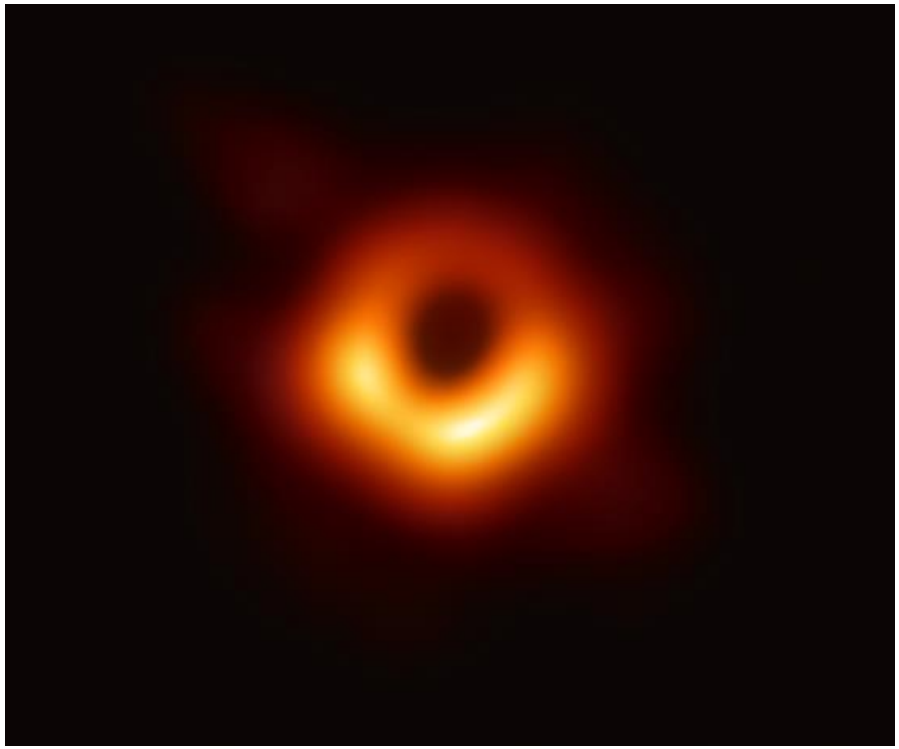
Multi-band imaging

https://youtu.be/q2u4eK-ph40



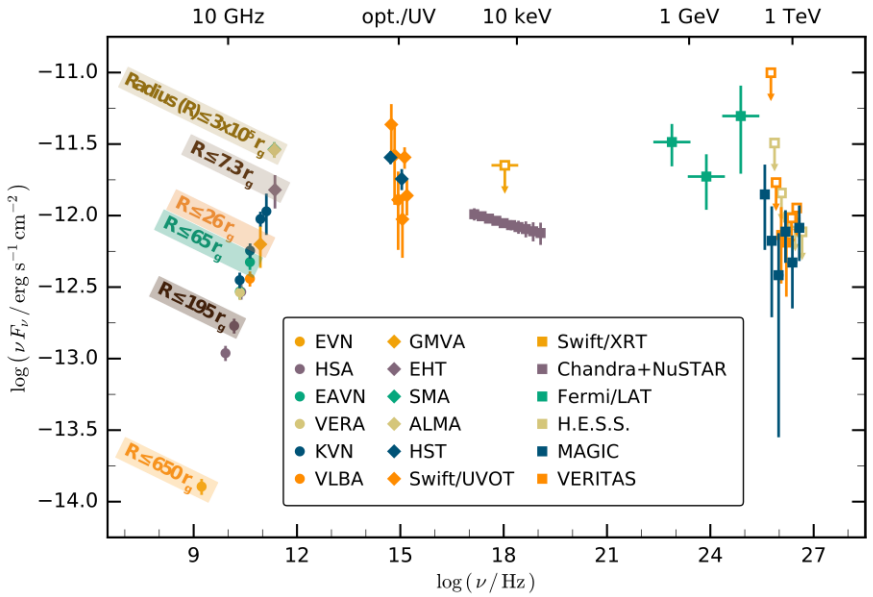
- VLBA 43 GHz image reveals jet direction within 2 mas to be close to horizontal (PA~270˚), significantly offset from large-scale jet direction (PA~290˚) consistent with GMVA 86 GHz image -> inner-jet direction seems to follow long-term periodic oscillation (Walker et al. 2018a)

Event horizon resolution and MWL approach



EHT Collaboration 2019

- Multi-band spectral energy distribution



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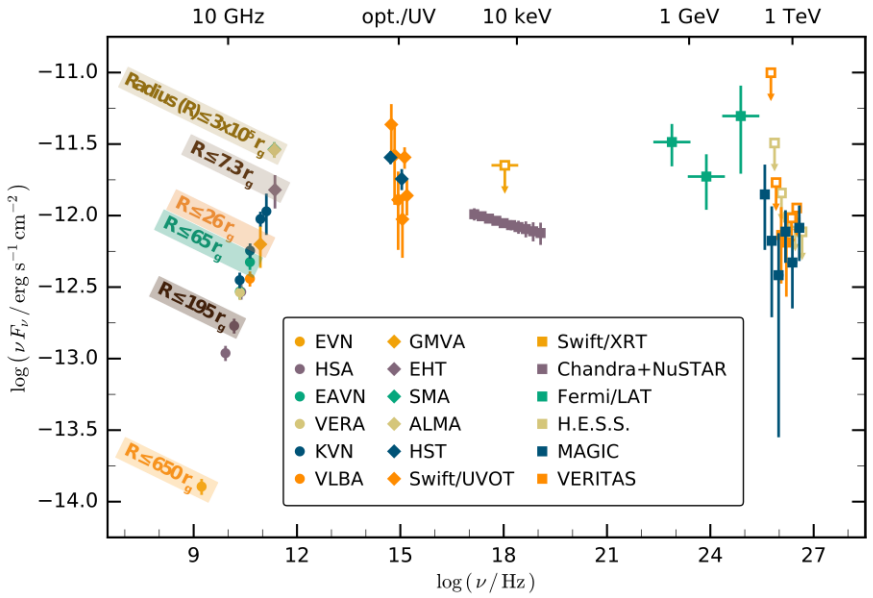
Event horizon resolution and MWL approach

- low/quiescent state and little variable
- angular scale of emission spans a factor of $\geq 10^8$: from EHT $\cong 20\mu as$, to Fermi-LAT $\cong 2°$
  - HST-1 in typical low state at radio; in optical and X-rays, HST-1 in lowest state observed so far, following decaying trend over last decade
  - HST-1 is so sub-dominant to core in higher energy bands -> total fluxes from NuSTAR, Swift, Fermi, H.E.S.S., MAGIC and VERITAS with core emission

- Multi-band spectral energy distribution



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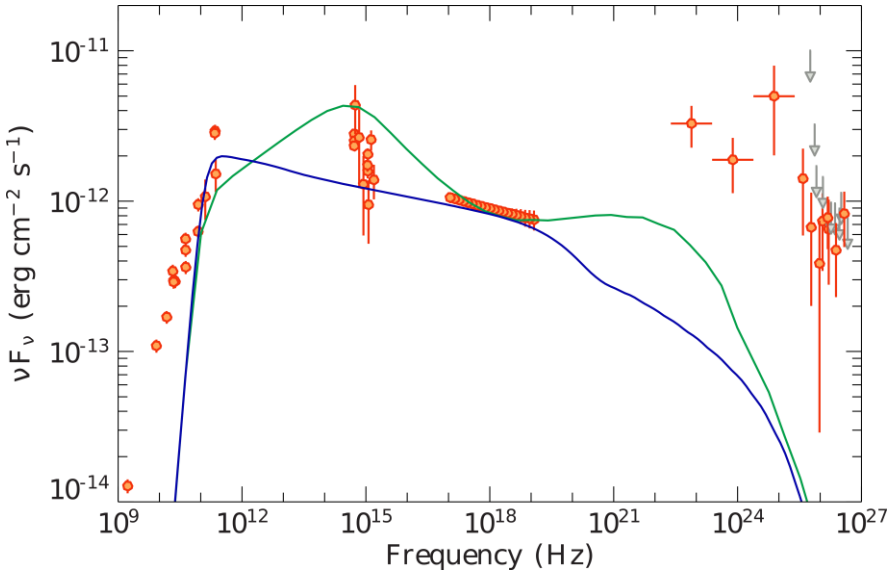
Modeling of spectal energy distribution

- 2 single-zone approaches:
  - “captures the broad properties of the SED focusing on the EHT flux and size measurement”
  - “focuses on statistical fitting of the X-rays”
- spherical geometry
- only synchrotron and synchrotron self-Compton emission
- mass to be 6.5×10^9 M_{sun}, distance of 16.8 Mpc, inclination of 17°

Modeling of spectal energy distribution

- Model 1: EHT-oriented



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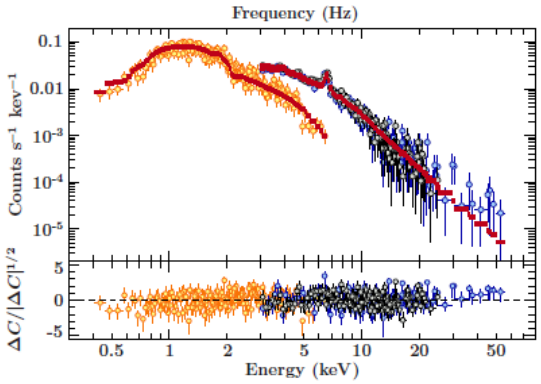
- two different non-thermal electron (and positron) distribution functions
  - 1a: includes effects of radiative cooling on initial single power-law
  - 1b: broken power-law model, without directly calculating radiative cooling
- fixed emission region to EHT ring
- $\delta = 1$, bulk motion of emission region has likely not yet reached relativistic speed
- With maximized gamma-ray flux
- Avoid over-producing UV flux density, injected power-law spectral index of non-thermal electrons to be steeper than p_1 = 2
- Not fixed: eDF normalization, B (EHT flux suggests B of ~ 5-10 G)

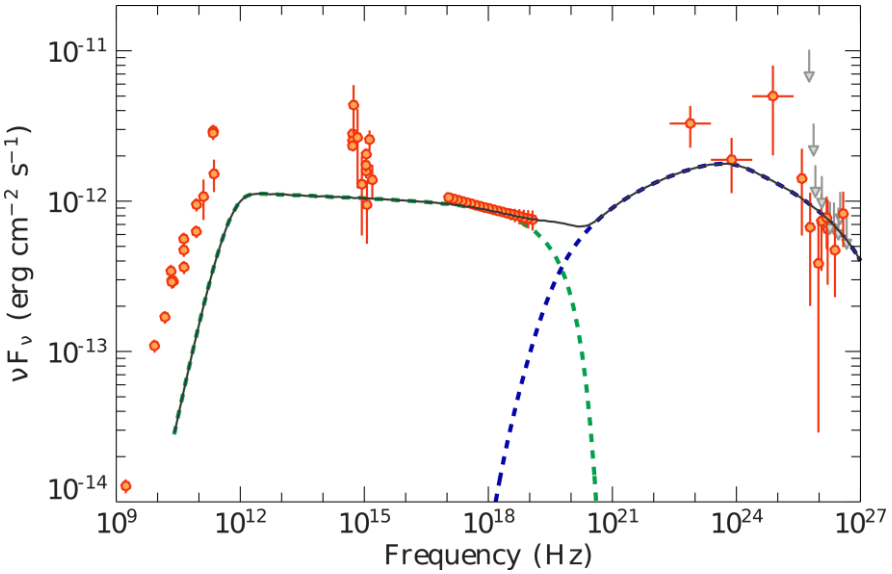
Modeling of spectal energy distribution

- „high-energy“ = X-rays
- Modelling of X-ray emission in detector space for disentangling various jet and ICM components



- Radius R moving with bulk Lorentz factor Γ_j
- Assuming $\Gamma_j = 3$, for 17° -> $\delta \approx 3.3$
- explore parameter space, evaluate model degeneracies and parameter uncertainties using Cash statistics
- Most model parameters are highly degenerate

- Model 2: High-energy oriented



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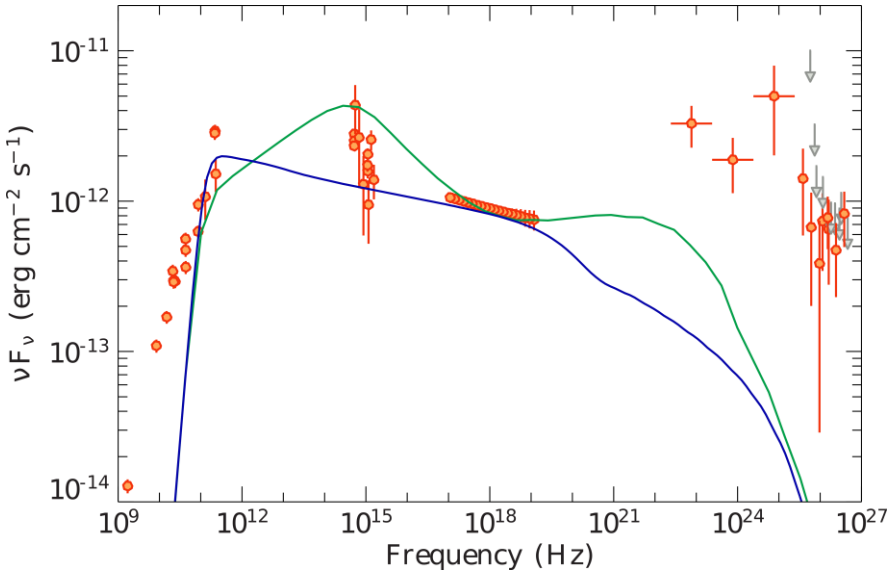
Modeling of spectal energy distribution

- Model 1: EHT-oriented



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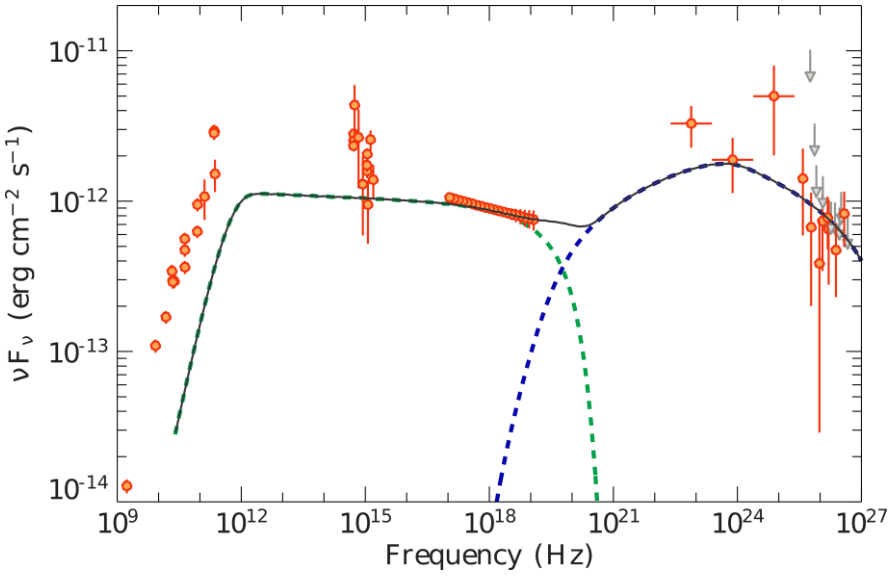
- Model 2: High-energy oriented



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Modeling of spectal energy distribution

- single-zone models cannot capture the primary features of the broadband M87 SED
- small, spherical, roughly equipartition region can explain EHT submm flux and X-ray power, but fails significantly at gamma-rays.”
- larger region, more particle-dominated well describes X-rays, but cannot explain either EHT or gamma-ray emission (GeV range)
- structured jet or additional emission component is necessary to explain VHE emission

- **moderate magnetic domination at base of M87's jets**
- more **particle dominated region** than “EHT-zone" is **responsible for the VHE emission** (this region is not in the accelerating part of jet flow, or interacting with the ICM, additional source of seed photons than jet emission alone)

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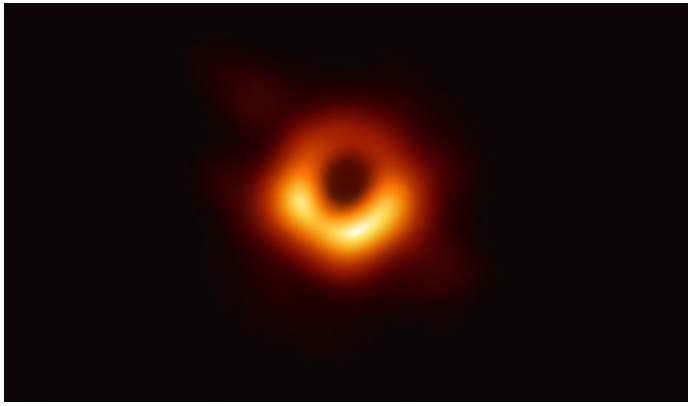
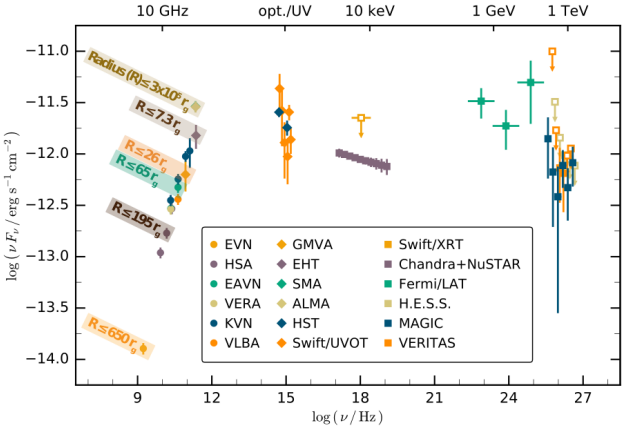
MWL approach and event horizon resolution



low gamma-ray state e.g. 2017



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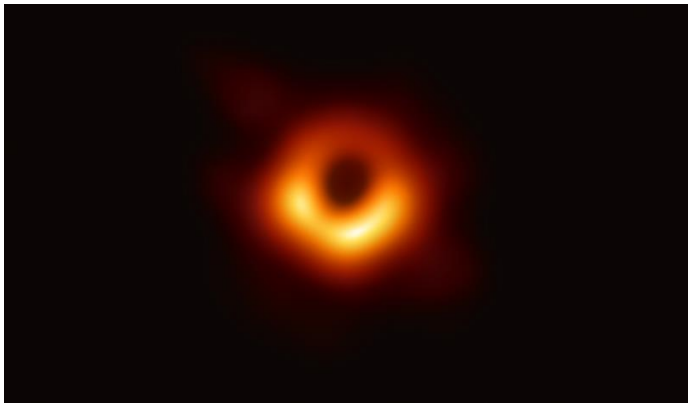
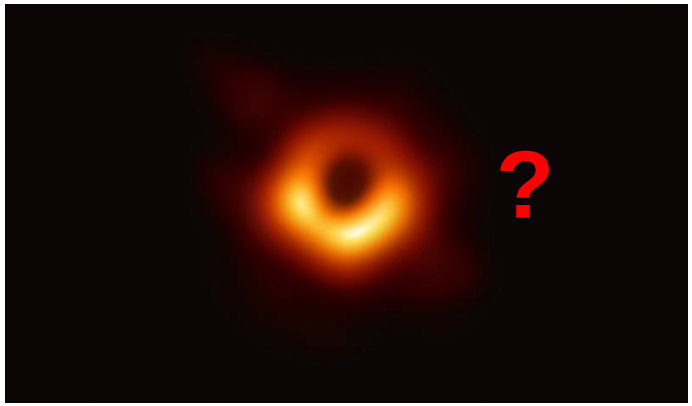
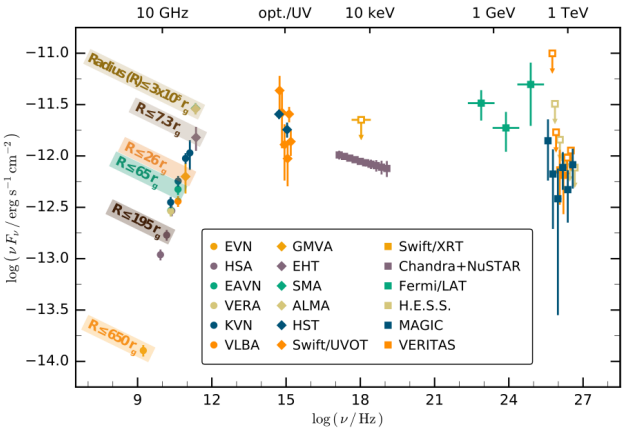




low gamma-ray state e.g. 2017 versus high gamma-ray state



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Questions?

Thanks
and stay healthy

Data? 10.25739/mhh2-cw46

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und Forschung

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