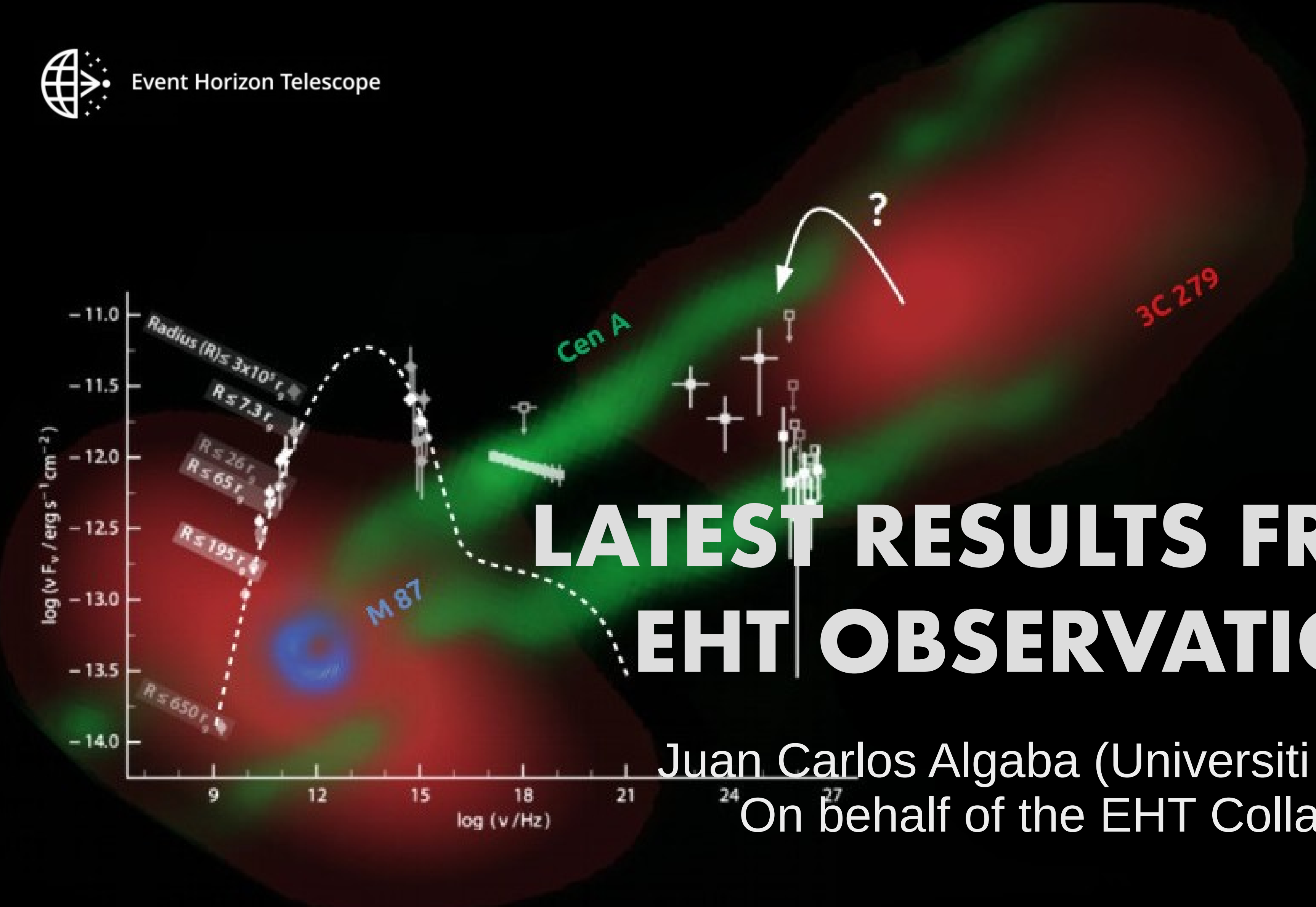
Event Horizon Telescope



LATEST RESULTS FROM EHT OBSERVATIONS

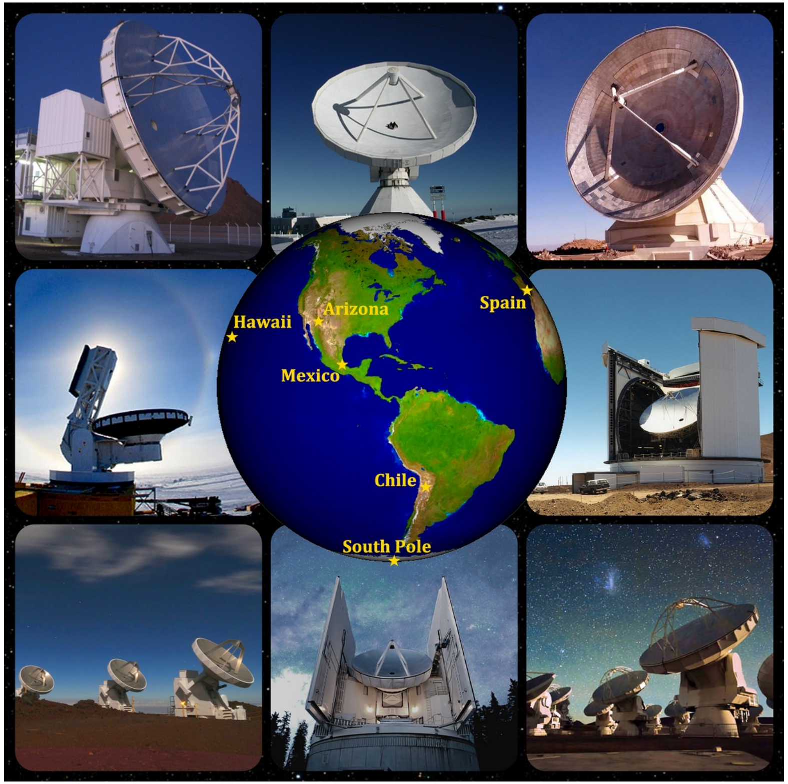
Juan Carlos Algaba (Universiti Malaya)
On behalf of the EHT Collaboration

Contents

- The First Image of a Black Hole
- Polarization
- Multiwavelength
- Non-Horizon Science
- The Future

The First Image of a Black Hole

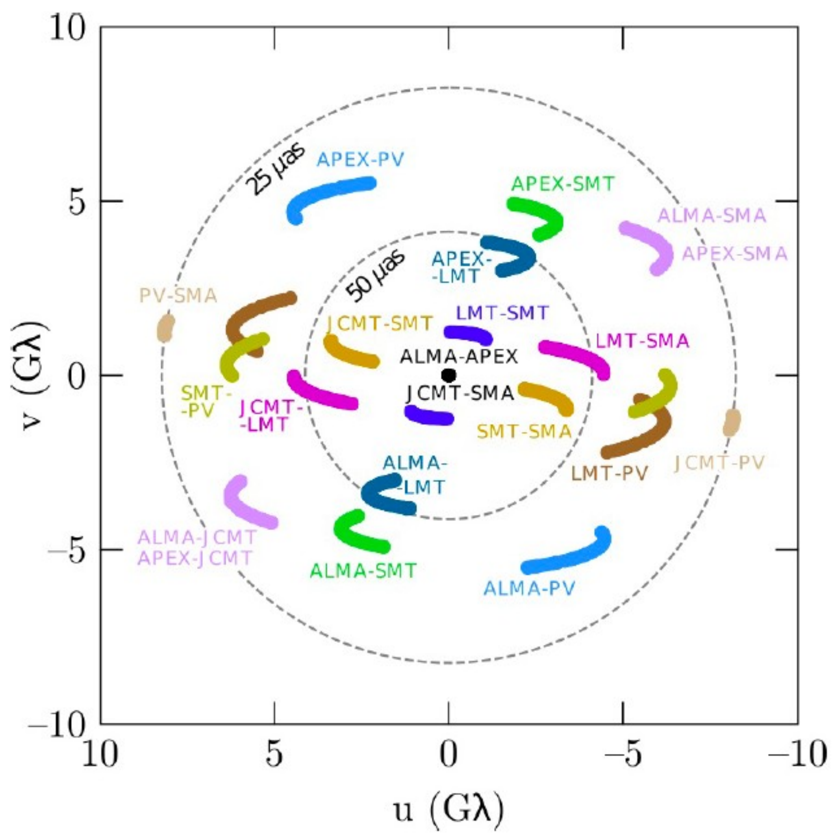
- The Event Horizon Telescope
- Array with 8 different facilities (2017)
  - Atacama Large Millimeter Array (ALMA), Chile
  - ALMA Pathfinder Experiment (APEX), Chile
  - James Clerk Maxwell Telescope (JCMT), Hawaii
  - Large Millimeter Telescope (LMT), Mexico
  - IRAM 30-meter Telescope, Spain
  - South Pole Telescope (SPT), South Pole
  - Submillimeter Array (SMA), Hawaii
  - Submillimeter Telescope (SMT), Arizona
- Wavelength: 1.3 mm
- Baseline: 160 m – 10700 km
- Resolution: 25 μas



M. Johnson/SAO

The First Image of a Black Hole

- UV Coverage of M87
  - Fourier Transform of the 2D location of antennas as seen from the sky
  - As Earth rotates during the observation, those spatial frequencies form tracks in the Fourier plane (aperture synthesis)
- Good coverage maximizes imaging potential
  - JCMT giving shortest/longest baselines
- Scales large enough to reach horizon scale features confirmed



The First Image of a Black Hole

- April 10th, 2019: First image of a black hole shadow
  - M87*
- Kick-off for test of GR under strong conditions
- Interesting Facts:
  - Diameter: ~ 42 µas ~ 2.5 RSchw
    - Almost perfectly circular
  - Brightness Asymmetry
    - Direction of rotation
  - High brightness temperature
    - Synchrotron radiation

The First Polarized Image of a Black Hole

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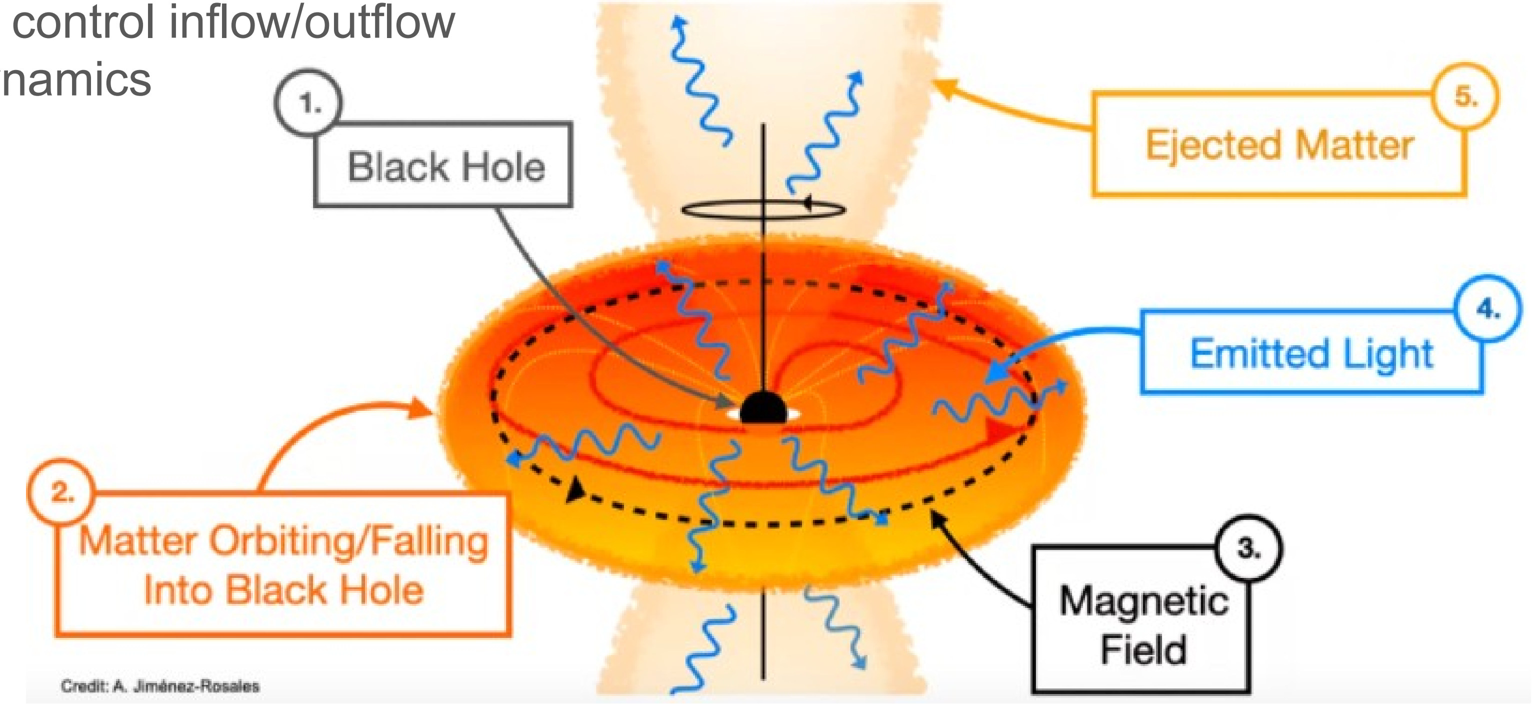
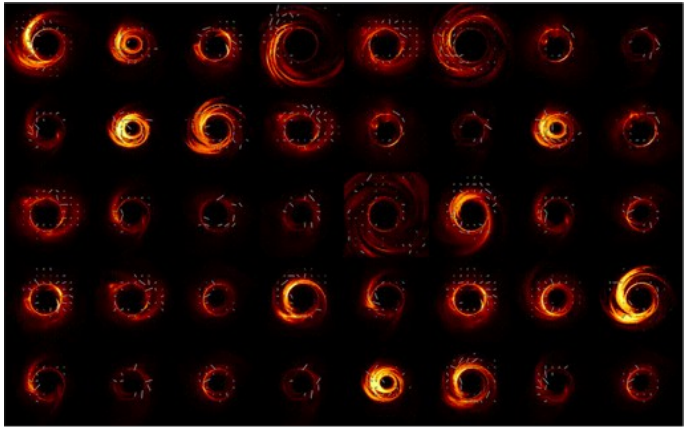
The First Polarized Image of a Black Hole

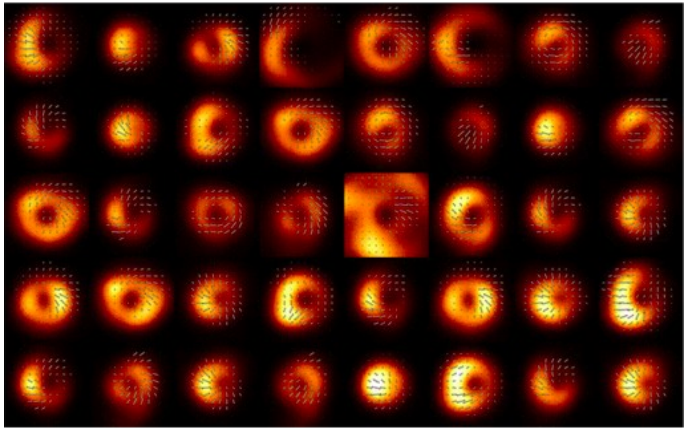
- For M87, the SMBH is the central engine for an extragalactic jet
  - Interplay of many different pieces
- Magnetic forces control inflow/outflow
- Jet formation/dynamics
  - GRMHDs
  - MAD/SANE



The First Polarized Image of a Black Hole

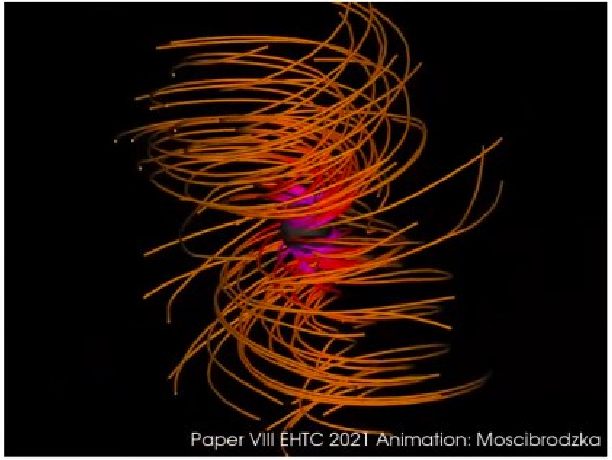
- Model Simulations
  - 2 models: SANEs and MADs
  - 200 snapshots via GRMHD simulation
  - 3 angles of inclination: 12º / 17º / 22º ($a^* < 0$) or 158º / 163º / 168º ($a^* \geq 0$)
  - Ion temperature vs electron temperature ratio
    - 6 values for upper limit: 1, 10, 20, 40, 80, 160
    - 2 values for lower limit: 1, 10
  - 5 spin speeds: a^* = -0.9375, -0.5, 0, 0.5, 0.9375
- 2×200×3×6×2×5 = 72000 Models!



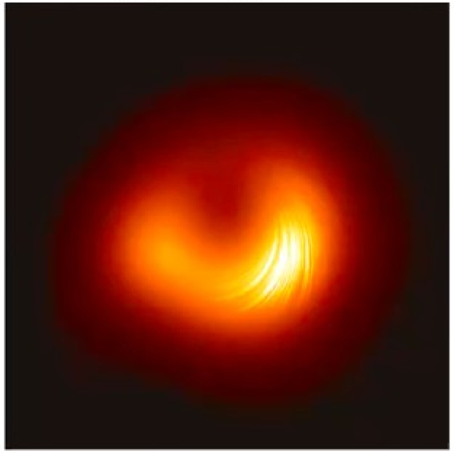


The First Polarized Image of a Black Hole

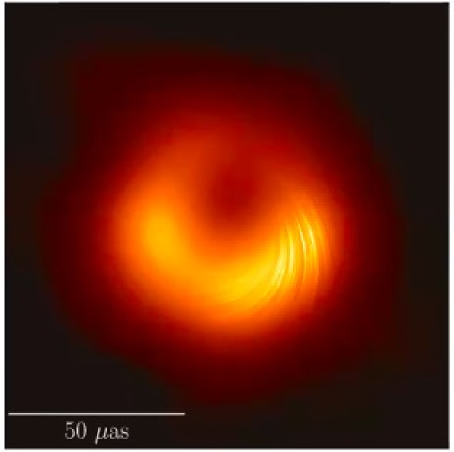
MODEL OF MAGNETIC FIELDS
NEAR M87 BLACK HOLE



MODEL IMAGE



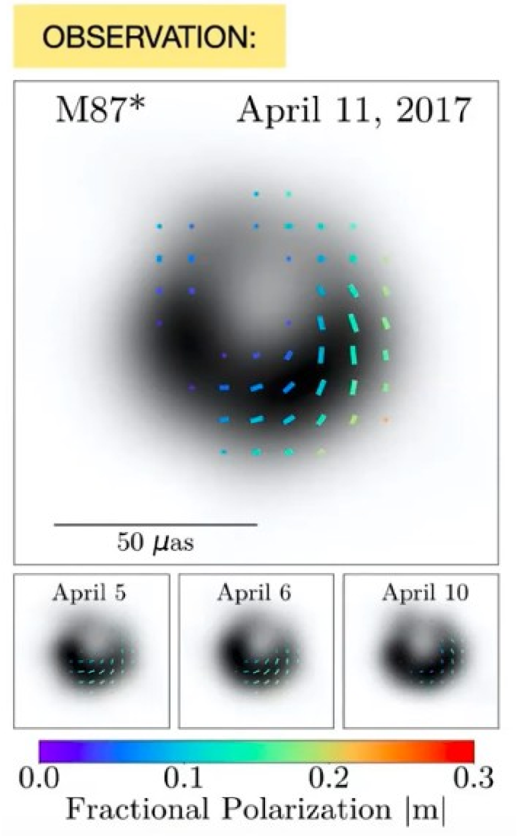
OBSERVED IMAGE

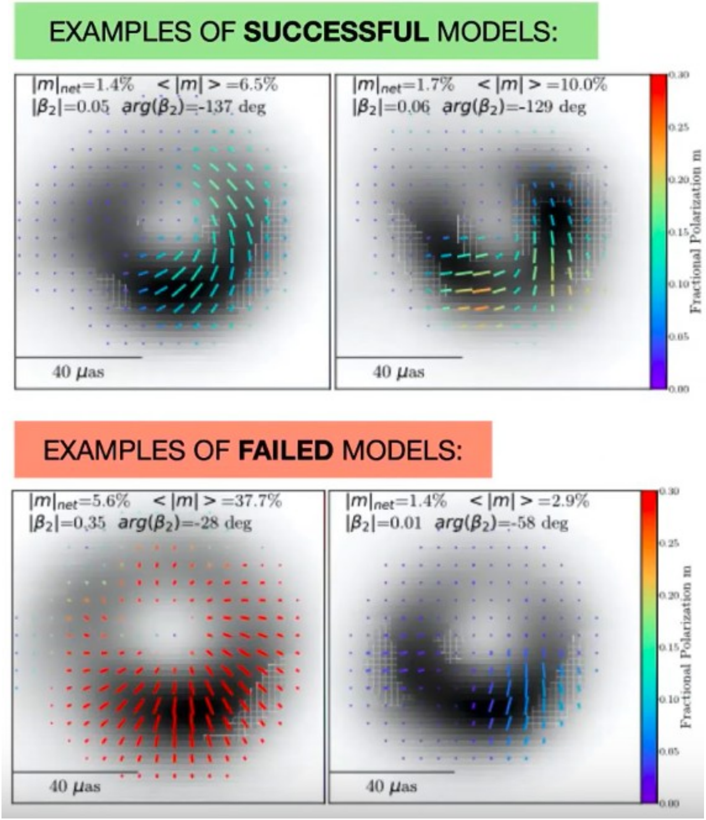


Model of emission & transport of electromagnetic wave (light)

Comparison algorithm

The First Polarized Image of a Black Hole

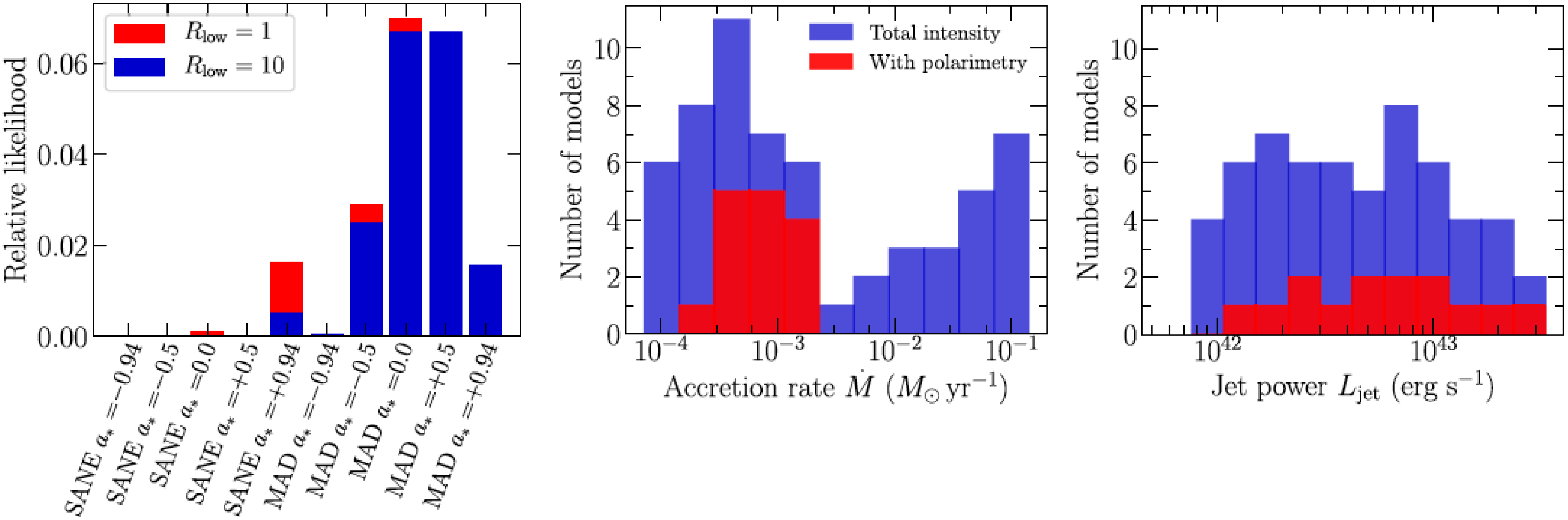




- Fractional Polarization (length & color of ticks)
- Average Polarization
- Azimuthal "wrapping" pattern of polarization

The First Polarized Image of a Black Hole

- Additional constrains on the model describing the physical conditions and environment around M87 SMBH



Multi-wavelength View of M87

- M87 2017 Multi-wavelength Campaign
  - Provide quasi-simultaneous MWL data for the 2017 EHT campaign
  - Resource for the community
- Up to 17 decades in frequency
  - Radio
    - VLBA, EVN, KVN, EAVN, VERA, GMVA, SMA, ALMA, EHT
  - IR-Optical-UV
    - Swift-UVOT, HST
  - X-rays
    - Swift-XRT, Chandra, NuSTAR
  - Gamma rays
    - Fermi-LAT, MAGIC, VERITAS, H.E.S.S

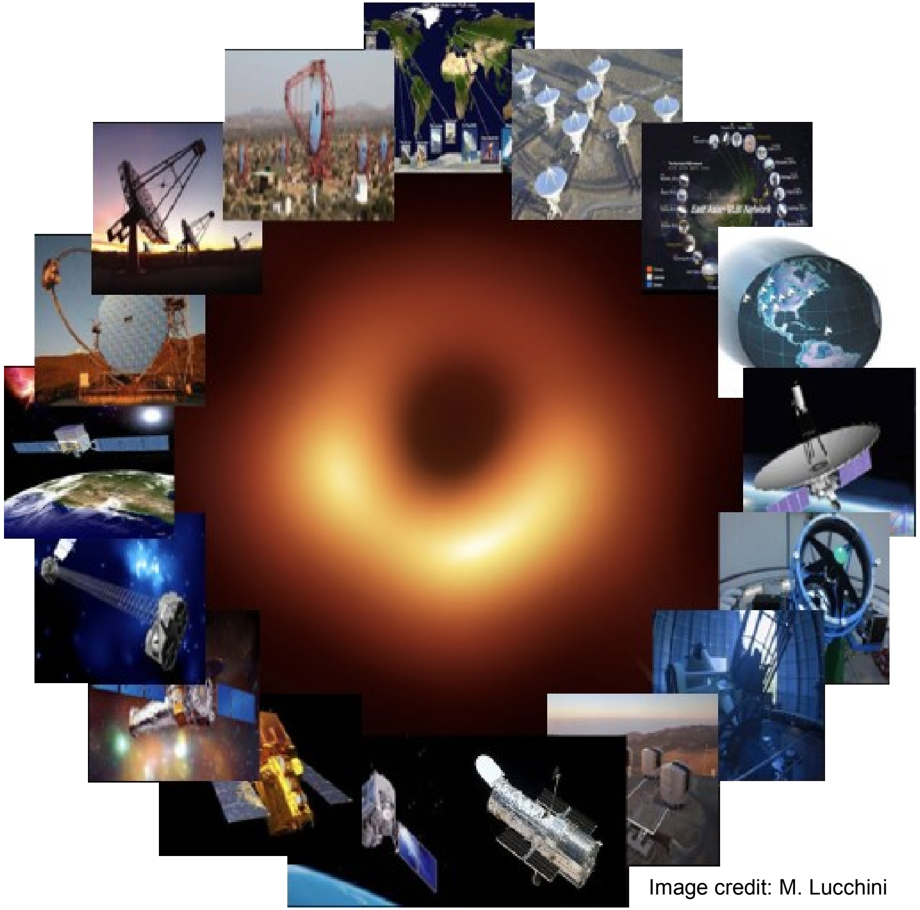


Image credit: M. Lucchini

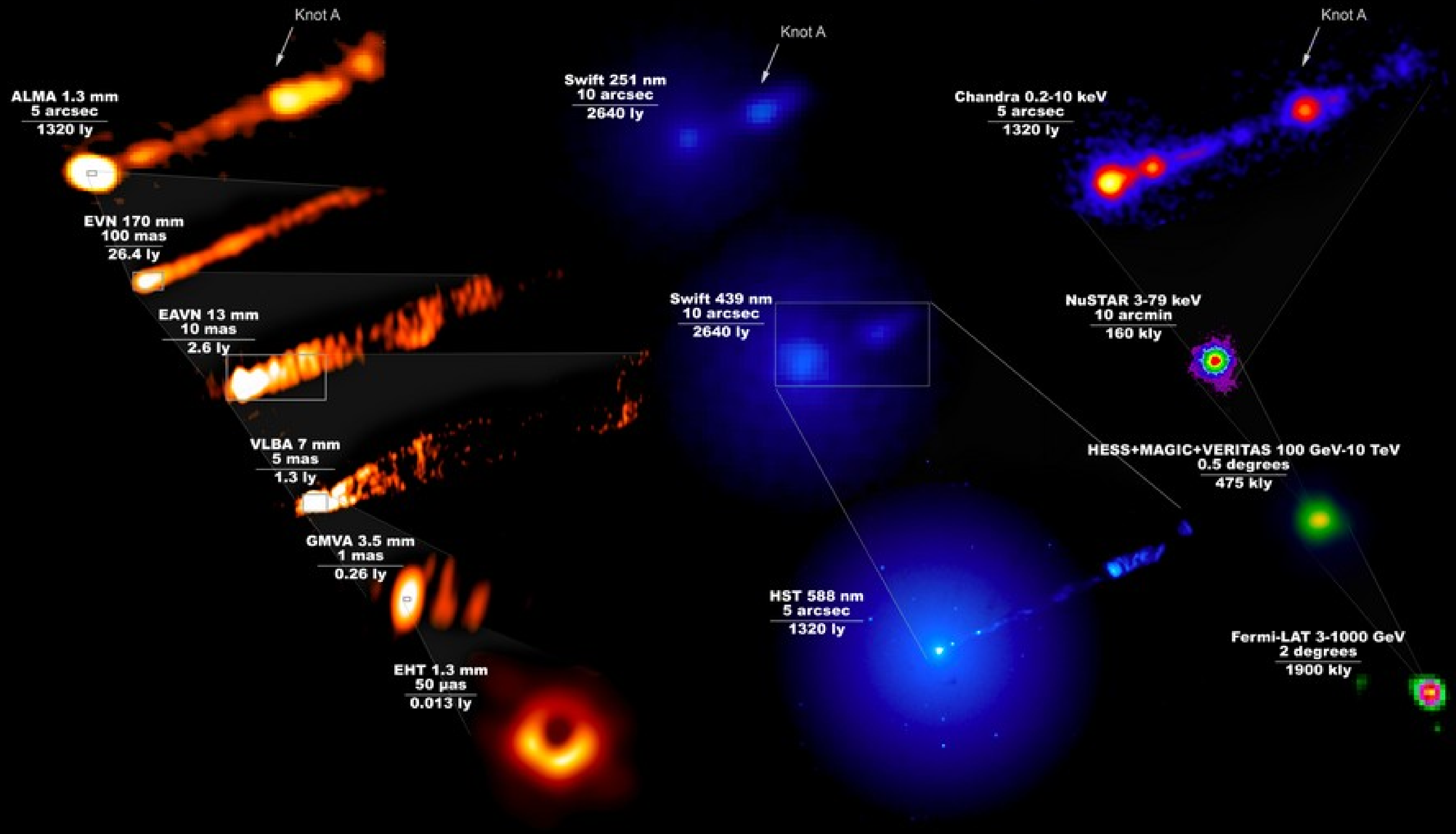
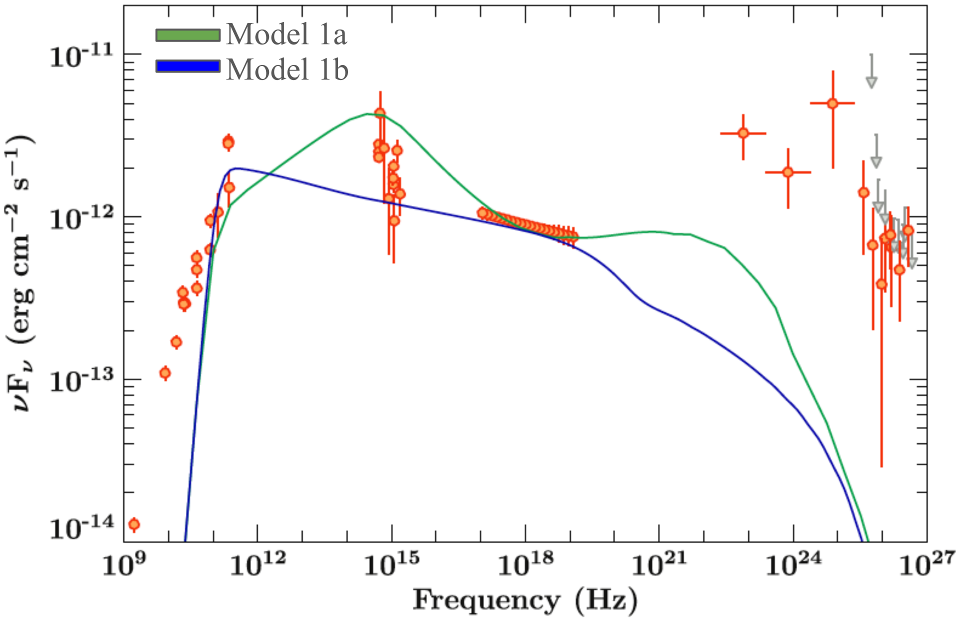


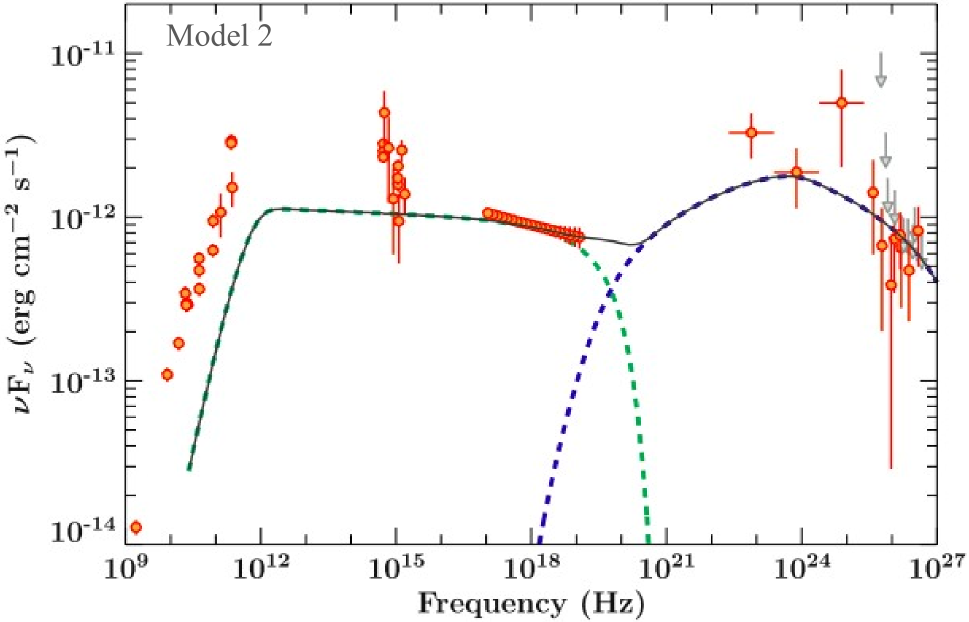
Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; 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-wavelength View of M87

- The study of the SED can provide us with useful information.
  - Physical properties that we can understand with the help of the models
    - Non-thermal electron (and positron) distribution
    - Size, speed, and magnetic fields of the emitting region
    - Injection of electrons into the emitting region
    - Magnetic vs particle energy density dominance
- Starting strategy: simpler single model-zone approach
  - Model 1: Focusing on the launch point of the jet
    - Maximizes contribution from compact regions
    - With/without radiative cooling (1a, 1b)
  - Model 2: Focusing on the large scales
    - Statistical fitting on X-rays

Multi-wavelength View of M87

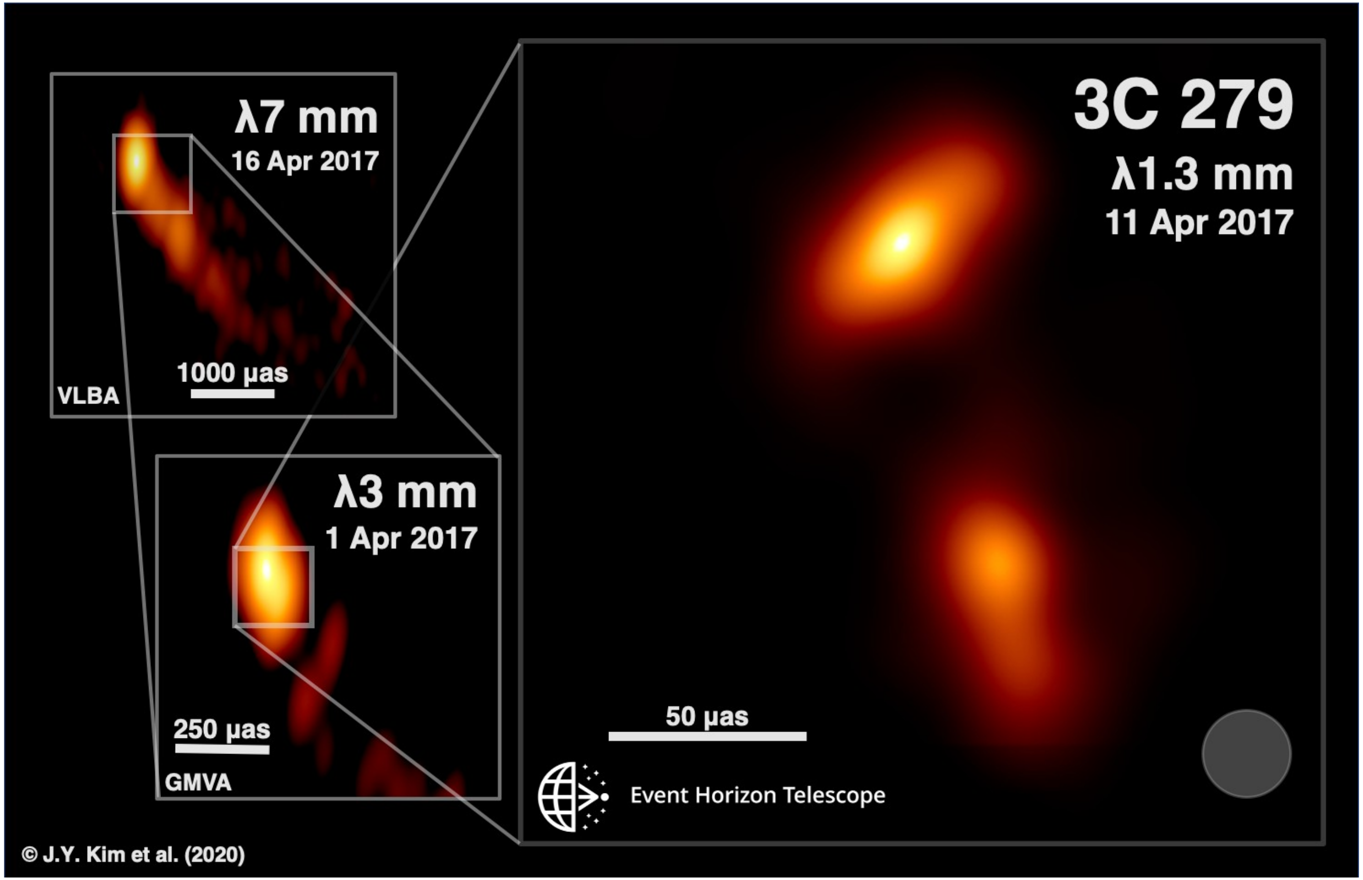




- A single model is not enough to explain all the properties of M87
- Unrealistic fitted parameters (e.g., deviation from equipartition)
- A structured jet is necessary to understand the observational properties

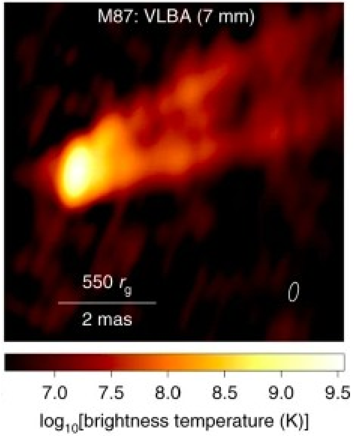
Non-Horizon Science

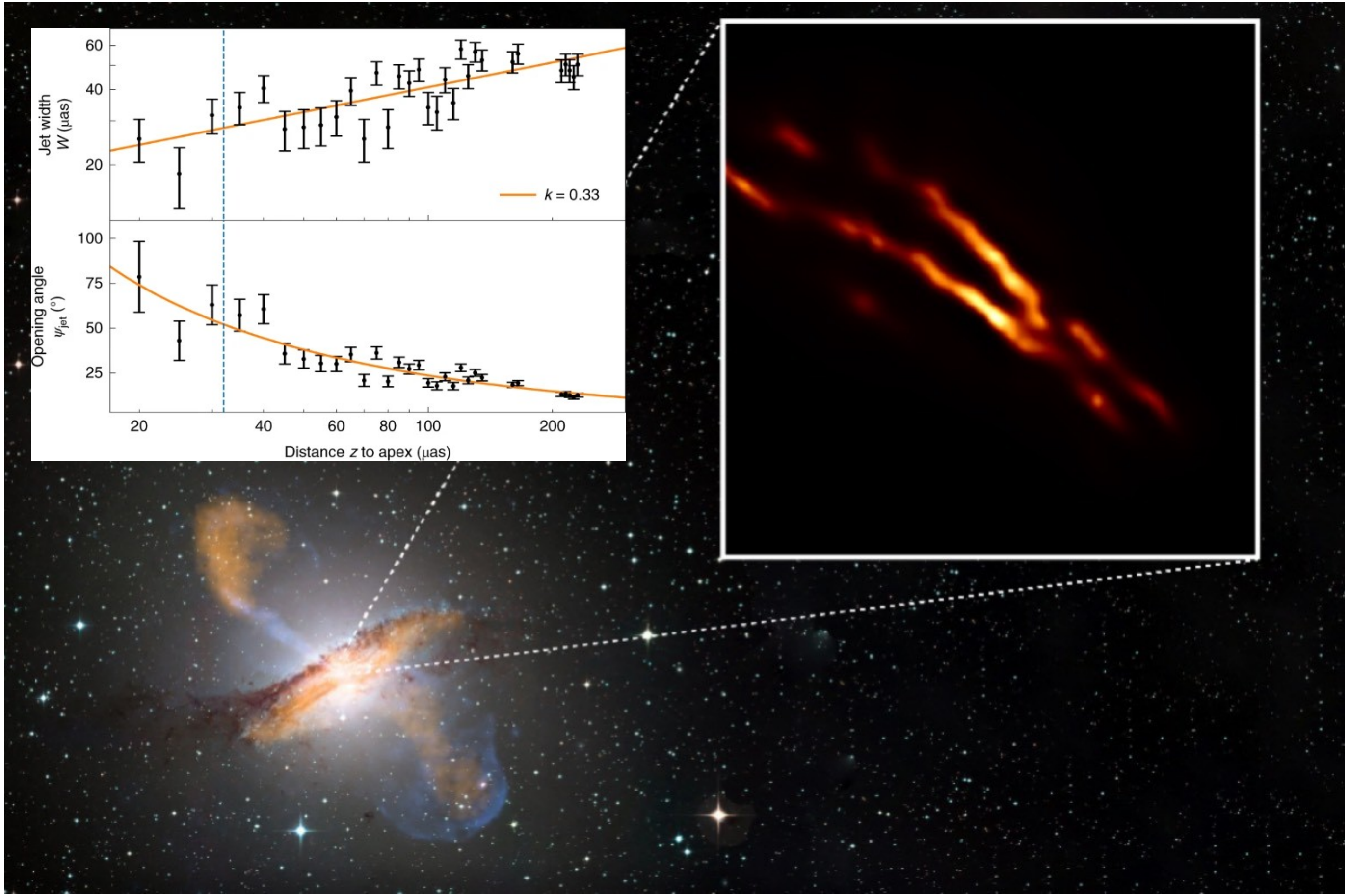
- 3C 279
- Core perpendicular to jet direction
  - Resolved jet base?
  - Bend jet?
- Non radial component speeds comparable with large-scale kinematics



Non-Horizon Science

- Centaurus A
- 16x resolution: sub-day structures
- Asymmetric jet
- Collimation profile
- Universality?





...and more!

- Dynamical Studies of M87
  - Turbulence and structure of the accretion flow (Wielgus+2020, Satapathy+2022,...)
  - Jet precession
- Tests for General Relativity (Psaltis+2020)
- Constraints on black hole charges (Kocherlakota+2021)

The Future

- More about M87*
- Sgr A*
- More non-horizon sources

- ngEHT