Radio Galaxies with the Event Horizon Telescope

Elisabetta Liuzzo
INAF-Istituto di Radioastronomia - Bologna/ Italian node of the European ALMA Regional Centre (ARC)

Bologna, 1 marzo 2023

Event Horizon Telescope

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ALMA
EUROPEAN ARC
ALMA Regional Centre || Italian

The EHT Italian members

Mariafelicia De Laurentis

- Deputy Project Scientist
- Theories of gravitatioon
- Leader SgrA* paper VI

Ciriaco Goddi

- Osservazioni
- Calibration & Errors
- Segretario EHT (fino 2020)

Rocco Lico

- Imaging
- Co-lead parameter survey & gains team
- ICT Officer & Segretario EHT

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INFN Istituto Nazionale di Fisica Nucleare

Università degli Studi di Napoli Federico II

Università degli Studi di Cagliari

Elisabetta Liuzzo

- EHT Board guest
- Calibration & Errors

Nicola Marchili

- 2° author Official Sgr A* paper
- Variability

Kazi Rygl

- Publication commettee
- Calibration and Errors

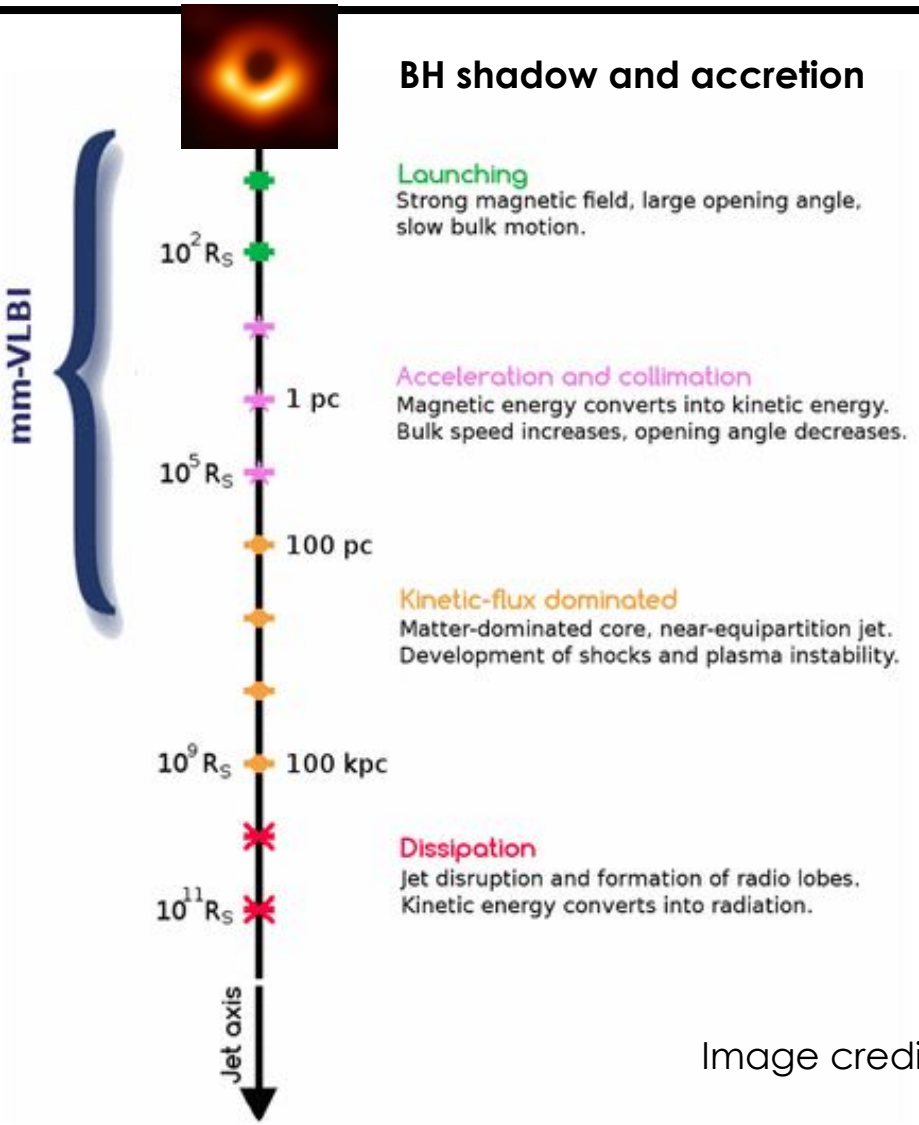
Giacomo Principe

- EHT AGN WG
- EHT Multiwavelength Science WG

Marcello Giroletti

- EHT Multiwavelength Science WG

EHT AGN scales



Schwarzschild radius

$$R_S = \frac{2GM}{c^2}$$

Image credit: Boccardi+ 2017

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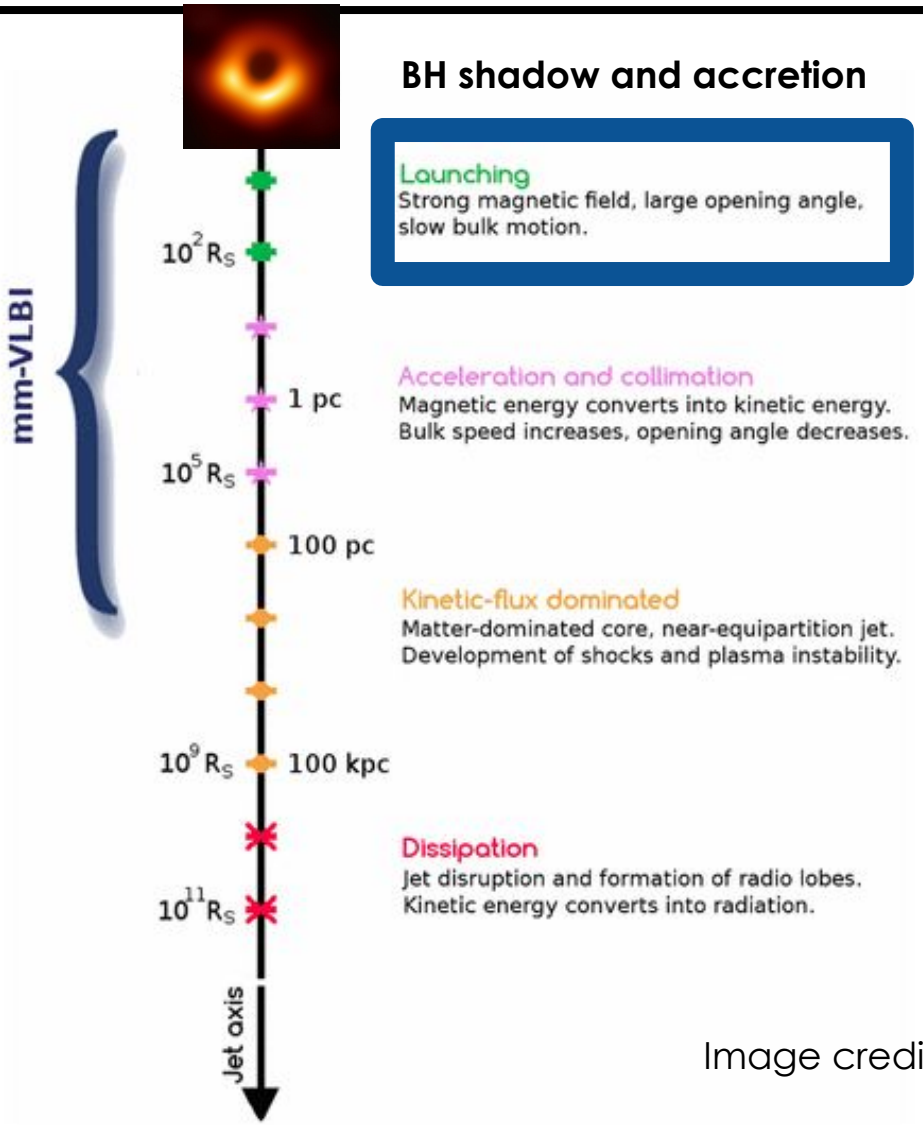
EHT AGN scales



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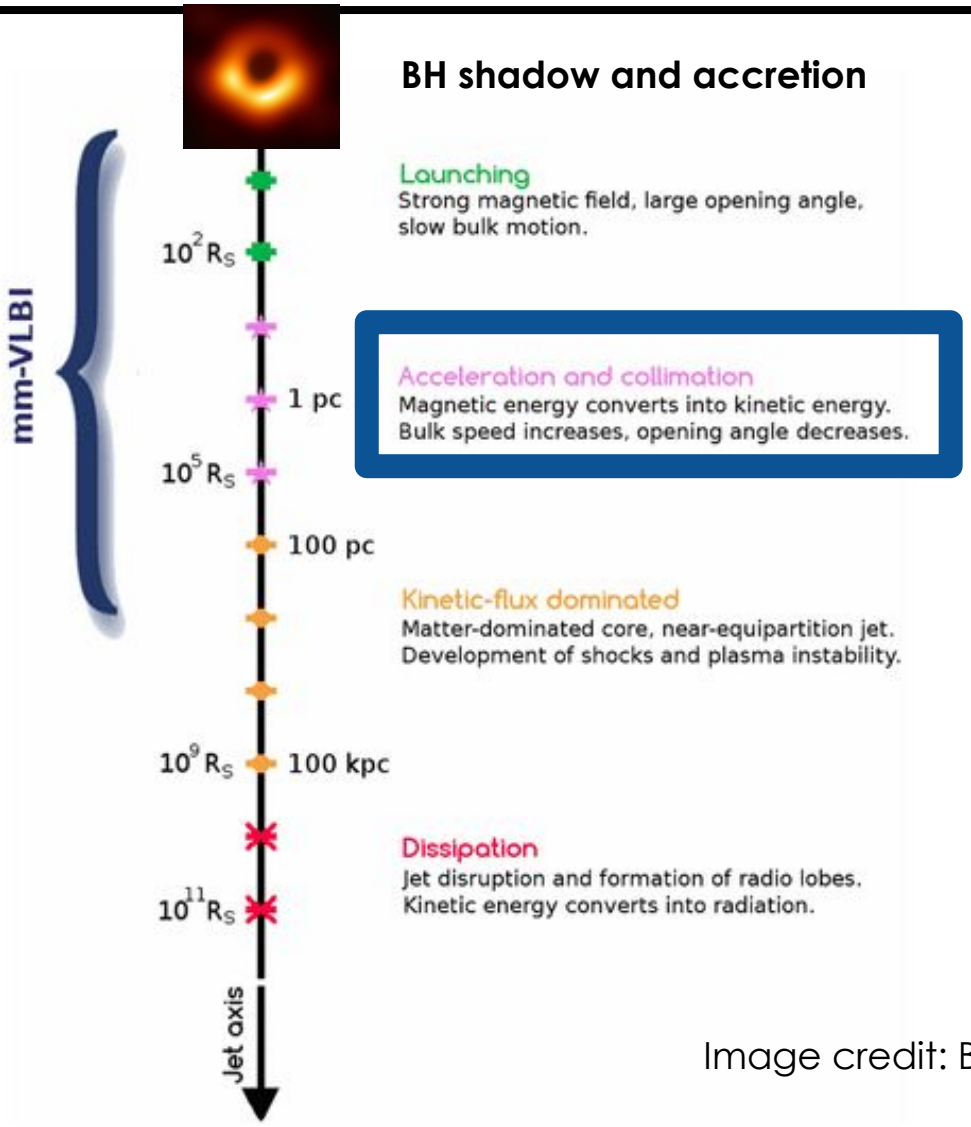

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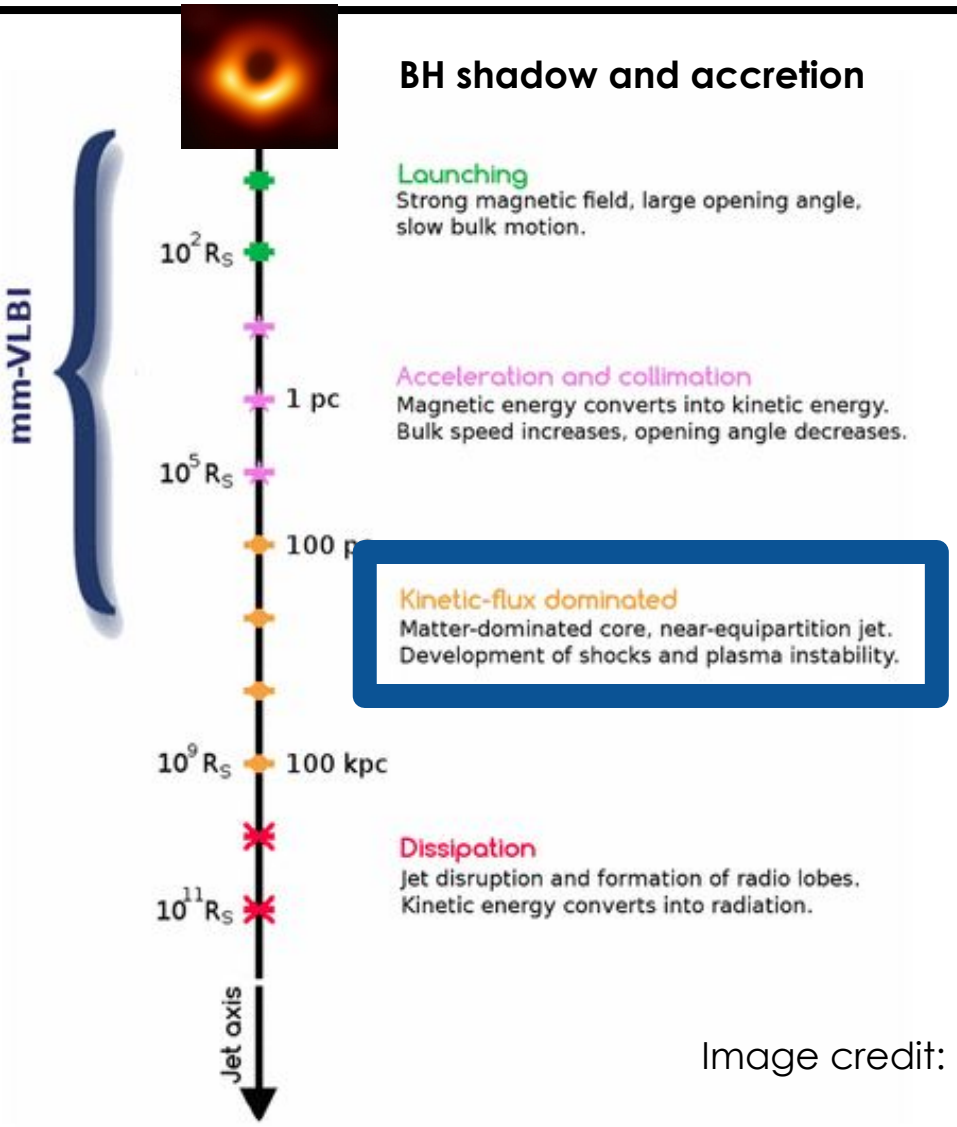

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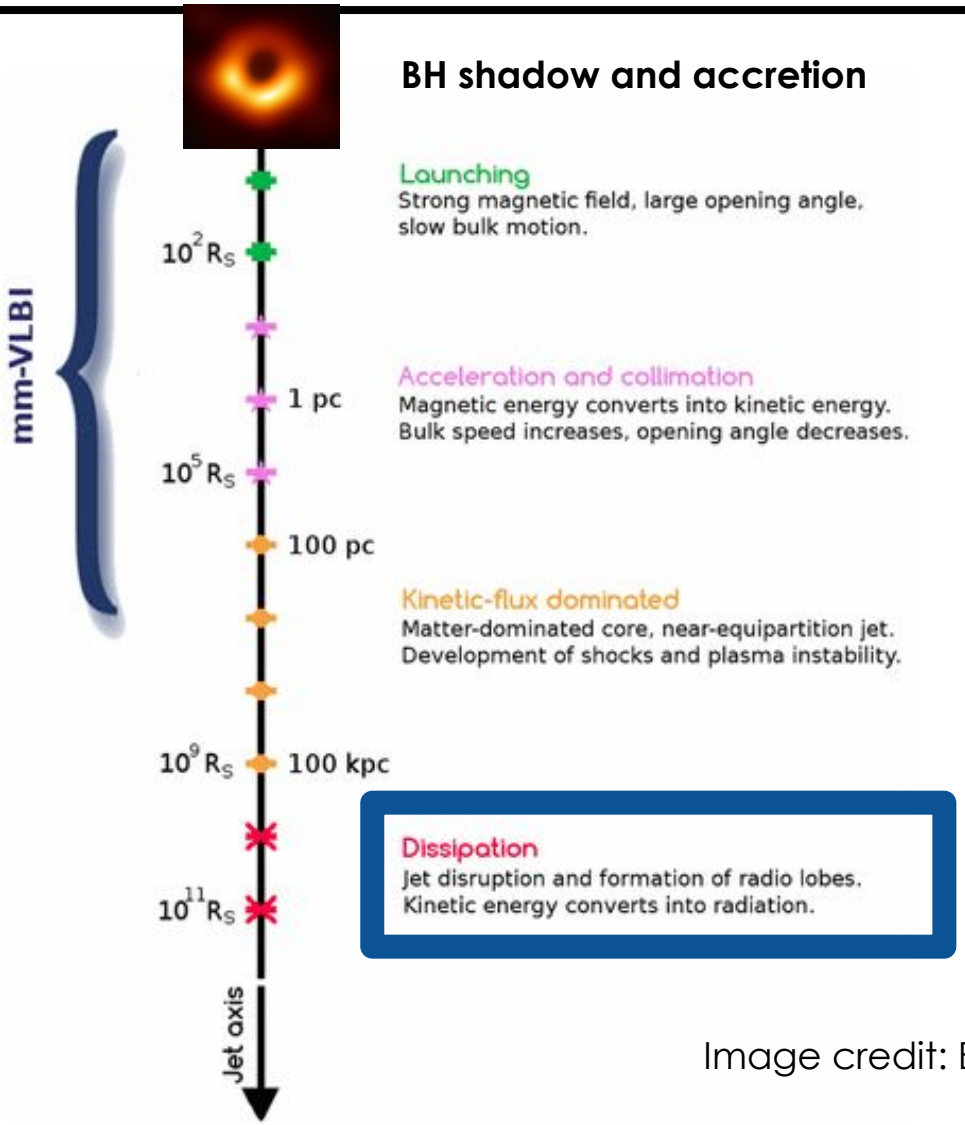

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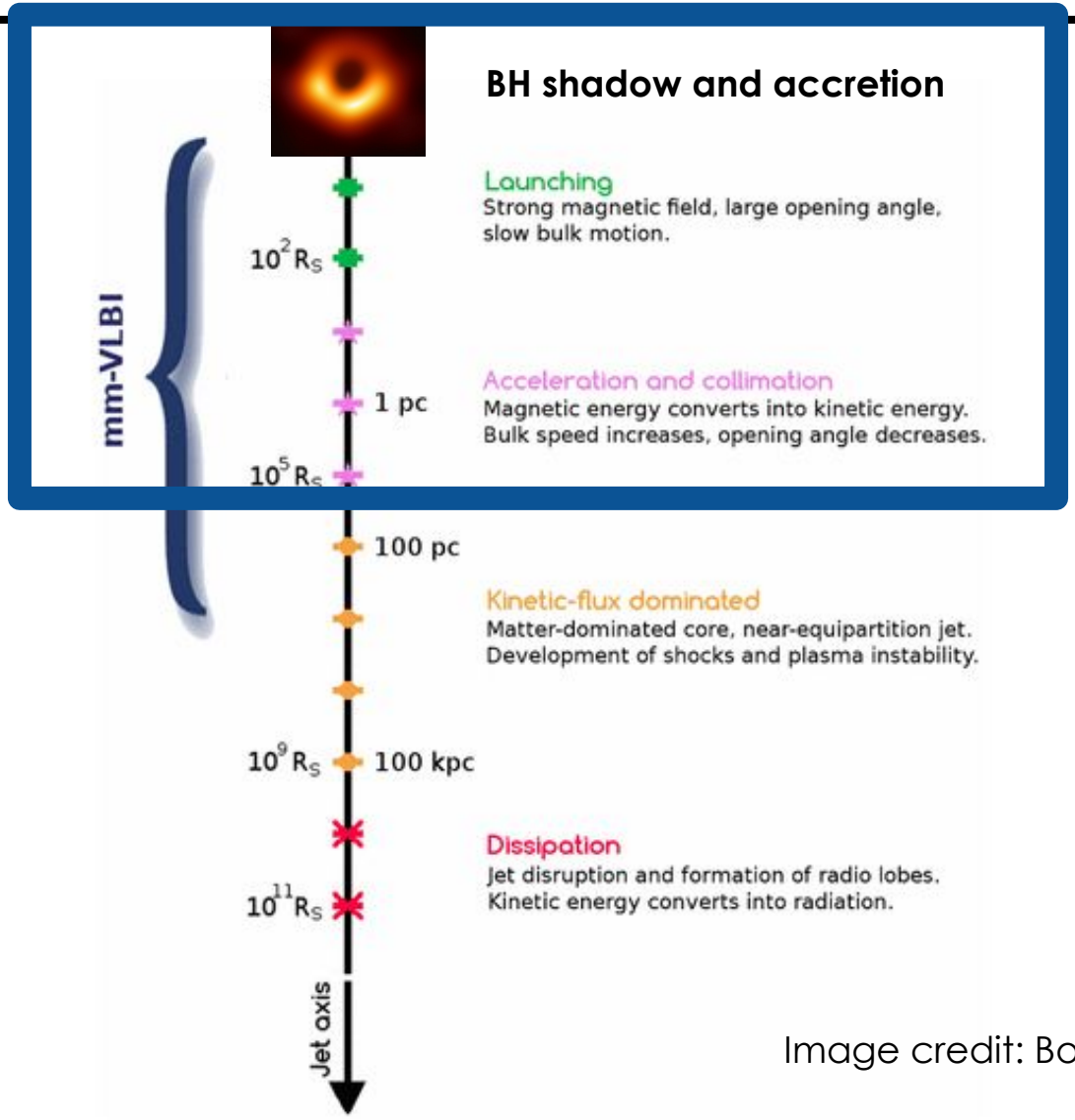

Schwarzschild radius

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Image credit: Boccardi+ 2017

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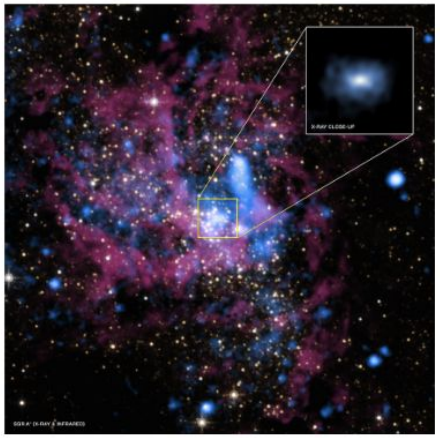
Results on BH shadow (~4.5R_s)

Different kinds of beasts

Sgr A*



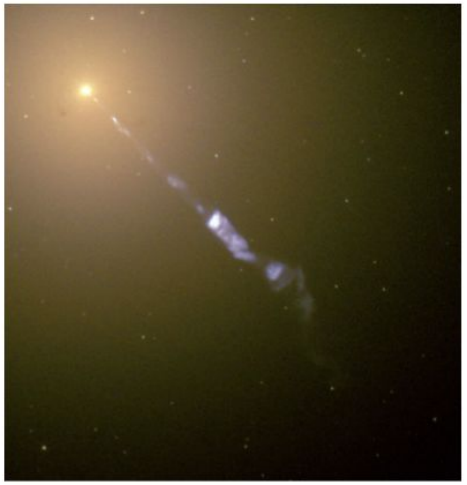
LLAGN
25000 light years,
M_{BH} ~4.3x10^6 $M_\odot$

variability= mins
No jet, *i*??
Accretion rate
~ 10^{-8} $M_\odot$ /y

LLAGN
55 millions light years,
M_{BH} ~6.5x10^9 $M_\odot$

variability=days
Jet, *i*=20 deg
Accretion rate
~ 10^{-3} $M_\odot$ /y

M87*



10^6 Msun 10^7 Msun 10^8 Msun 10^9 Msun

EHTC+
2019a,2022a

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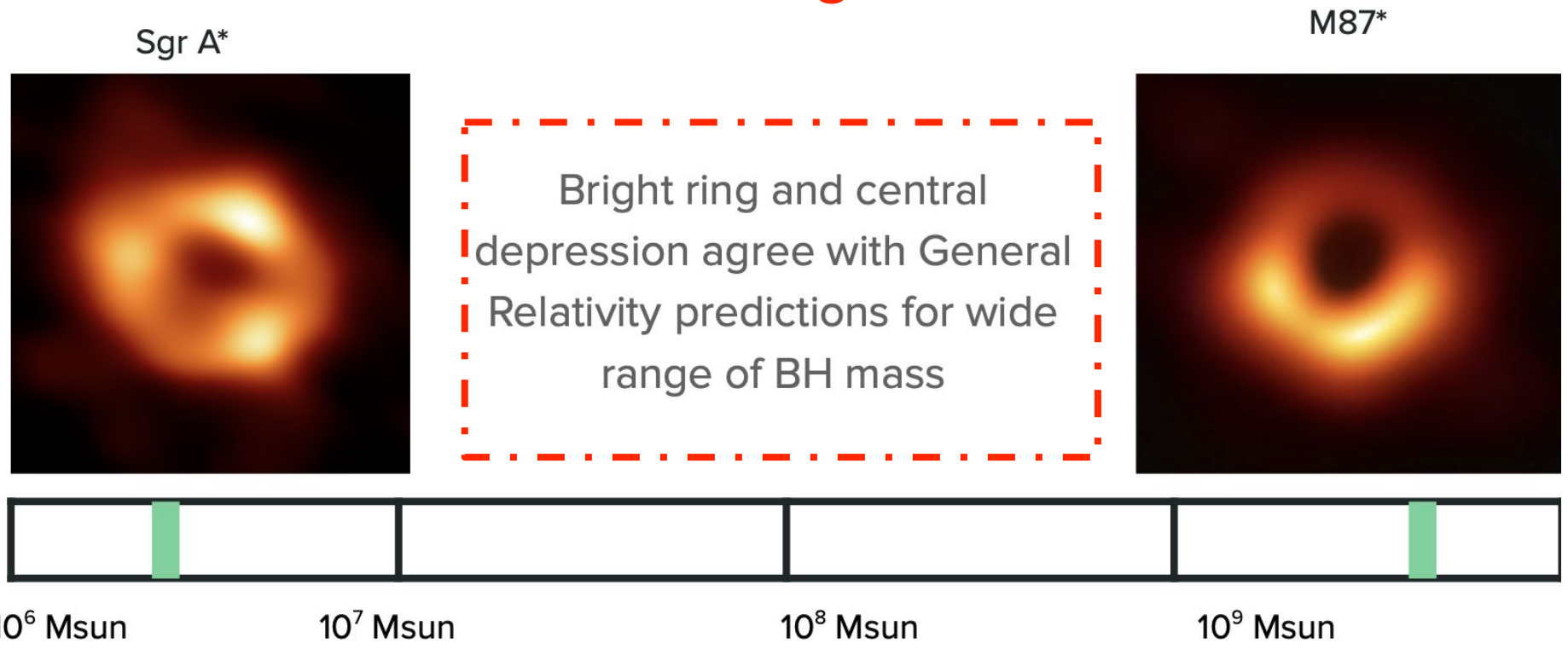
Results on BH shadow (~4.5R_s)

… but similar ring structure



=> Gravitationally-lensed size ~40-50 micro-arcseconds

EHTC+ 2019a,2022a

Results on BH accretion:

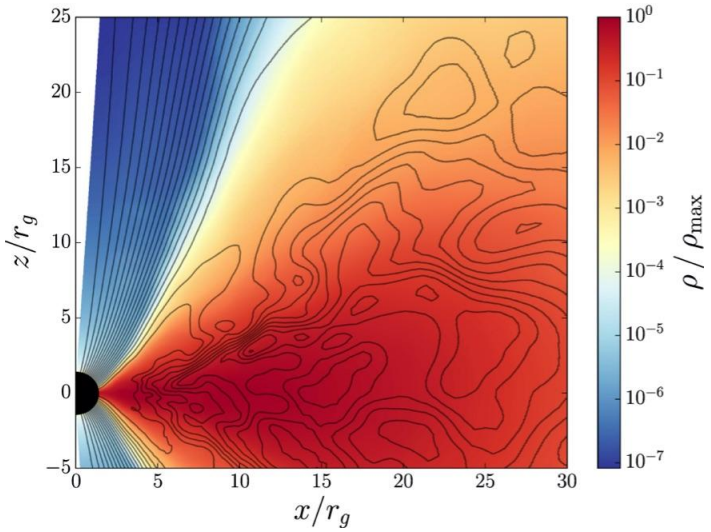
Standard and normal evolution (SANE):

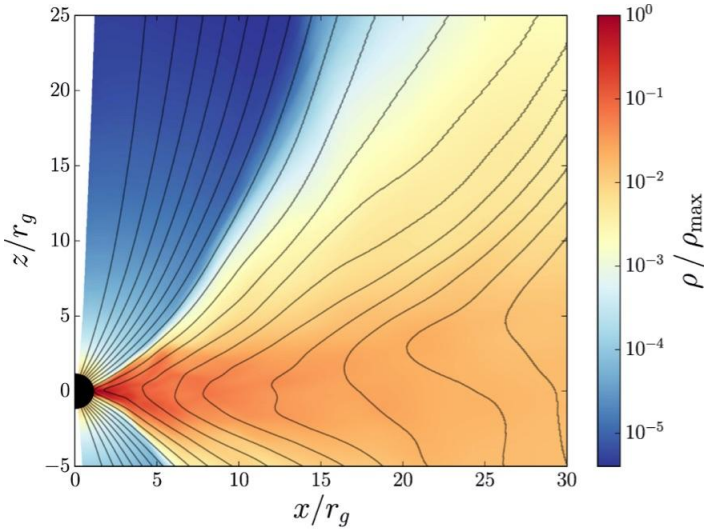
Φ low and turbolent

GRMHD Simulations

Magnetically arrested disk (MAD):

Φ high and coherent





Φ is magnetic flux

$\mathbf{a_*}$ = BH spin (=Jc/GM^2)

$\mathbf{R_{high}}$ ~T_{Ion}/T_{e-}
(if >> jet is dominant)

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Mizuno 2022 review

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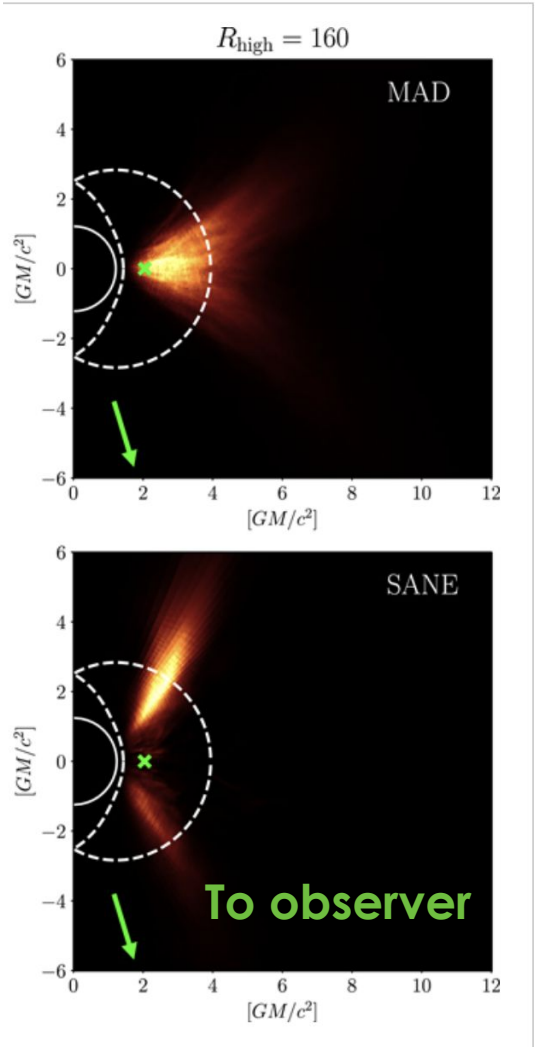
Results on BH accretion

Where do mm photons originate?



MAD

($a_* = 0.96$)

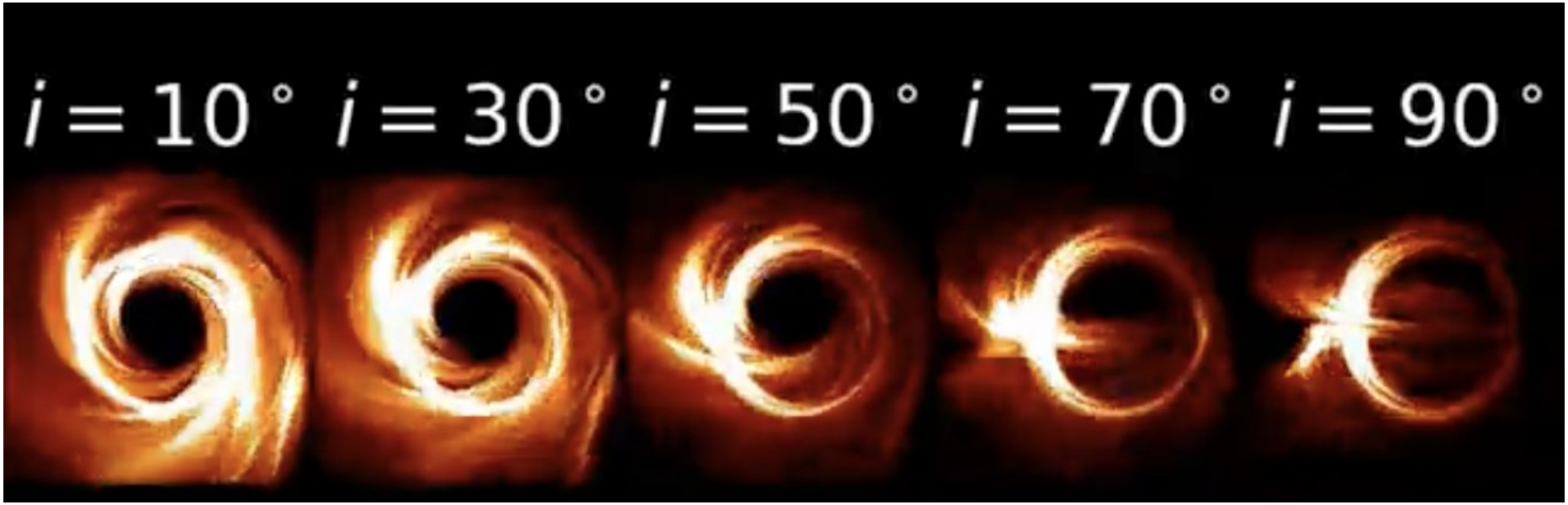
SANE

EHT images
+
Multiband validation criteria
→
MAD models are preferred

EHTC M 87 Paper V, 2019
EHTC SgrA* Paper V, 2022

Results on SGR A* accretion

I is the observer inclination vs the disk's spin. EHTC Sgr A* Paper V, 2022



MAD models with

i < 30 deg

a = 0.5, 0.94

Agreement with GRAVITY results

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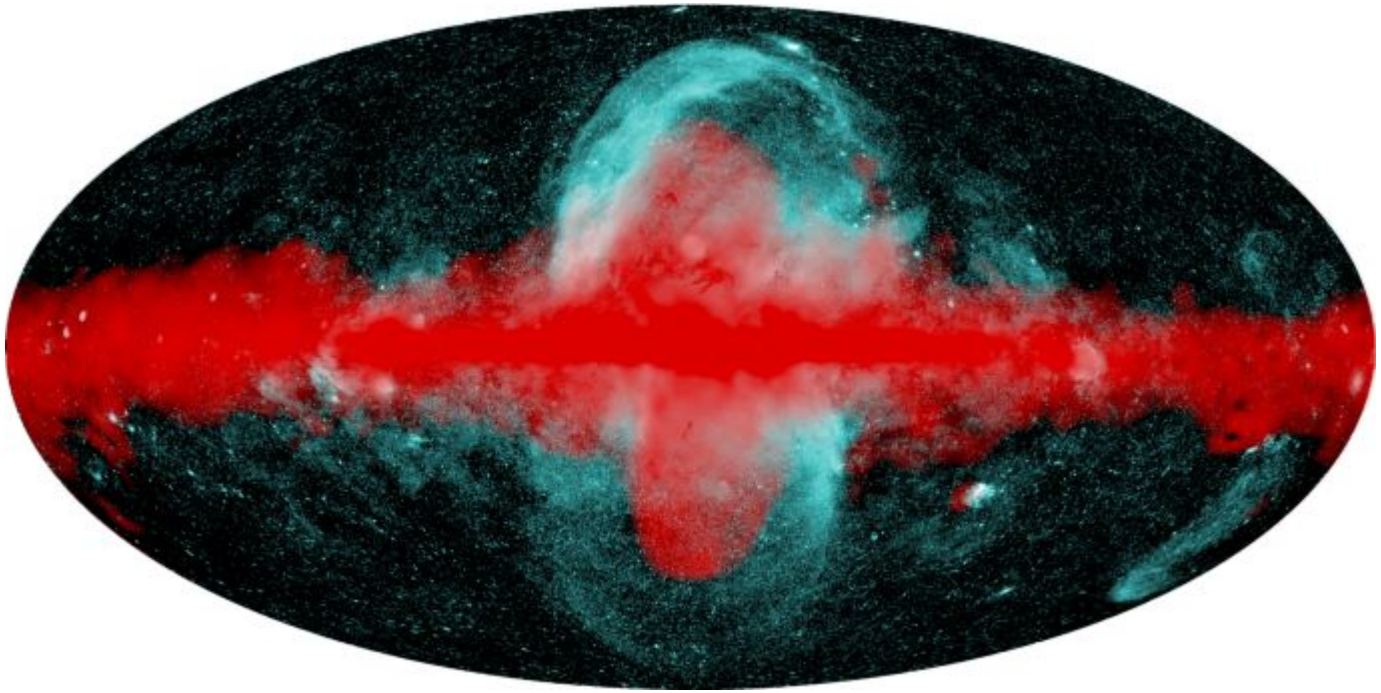
Results on SGR A* accretion

Relation with the large scale Bubbles?



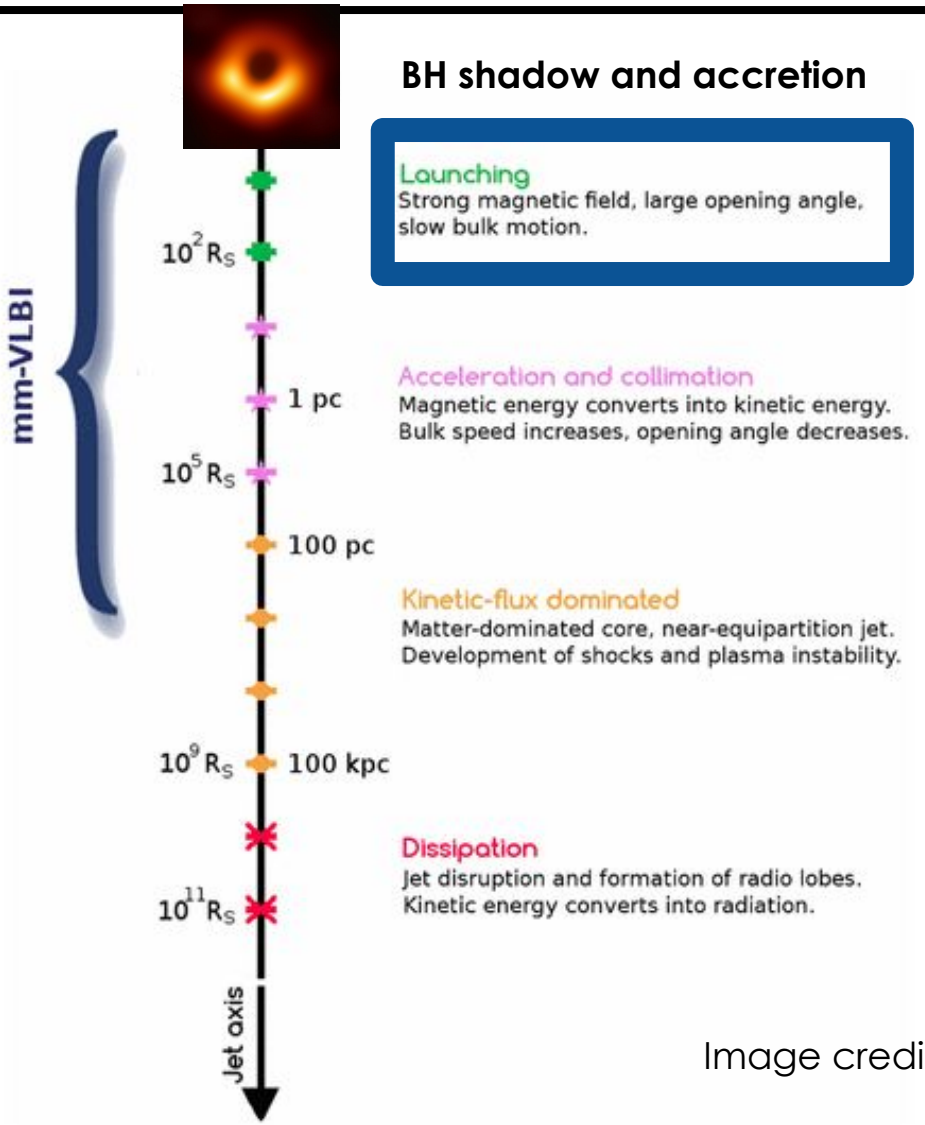
Fermi

Ackermann+ 2014

eRosita

Predhel+ 2021

EHT AGN scales: launching region



Schwarzschild radius

$$R_S = \frac{2GM}{c^2}$$

Image credit: Boccardi+ 2017

Results on AGN jet launching region

- **BH launched jet:** Blandford & Znajek (1977)
- **Disk launched jet**: Blandford & Payne (1982)
- **Combination**

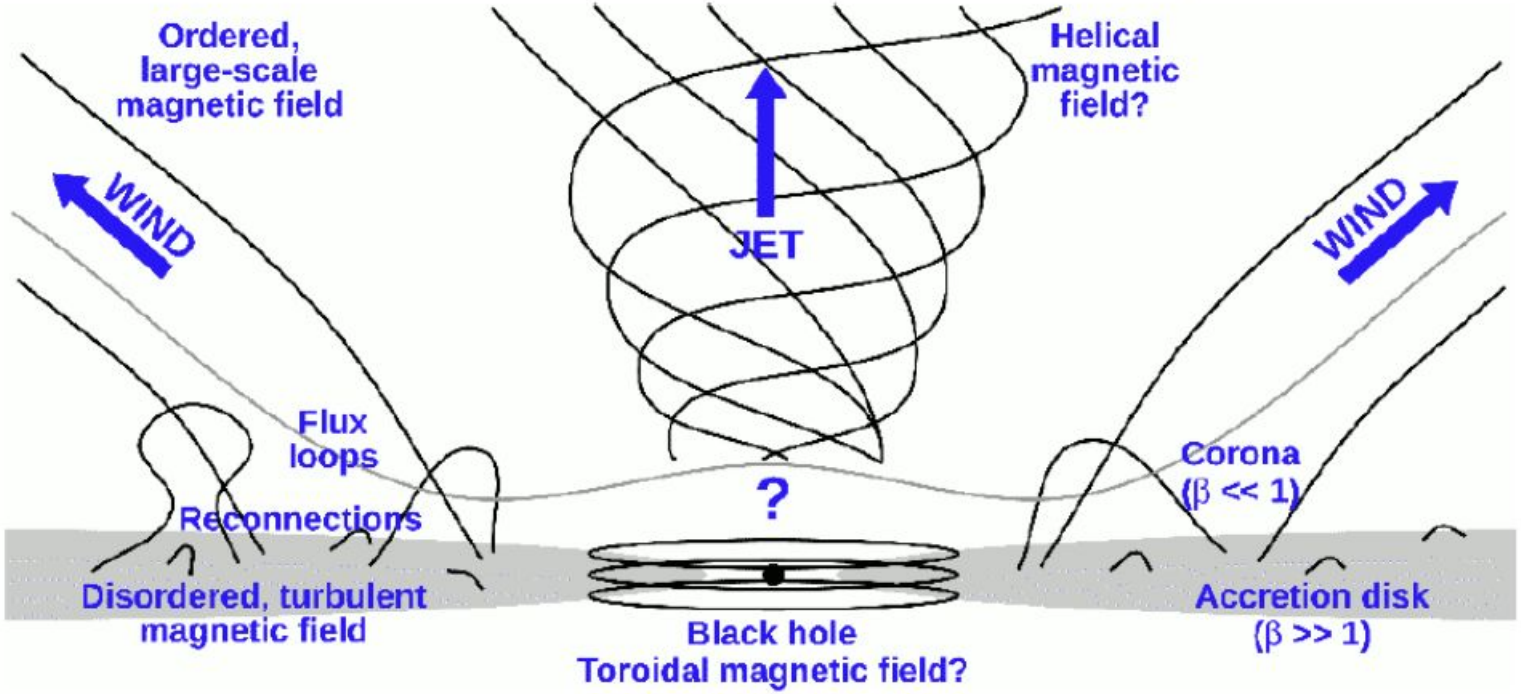


Image credit: Dobbie+ 2009

Results on AGN jet launching region

- **BH launched jet:** Blandford & Znajek (1977)
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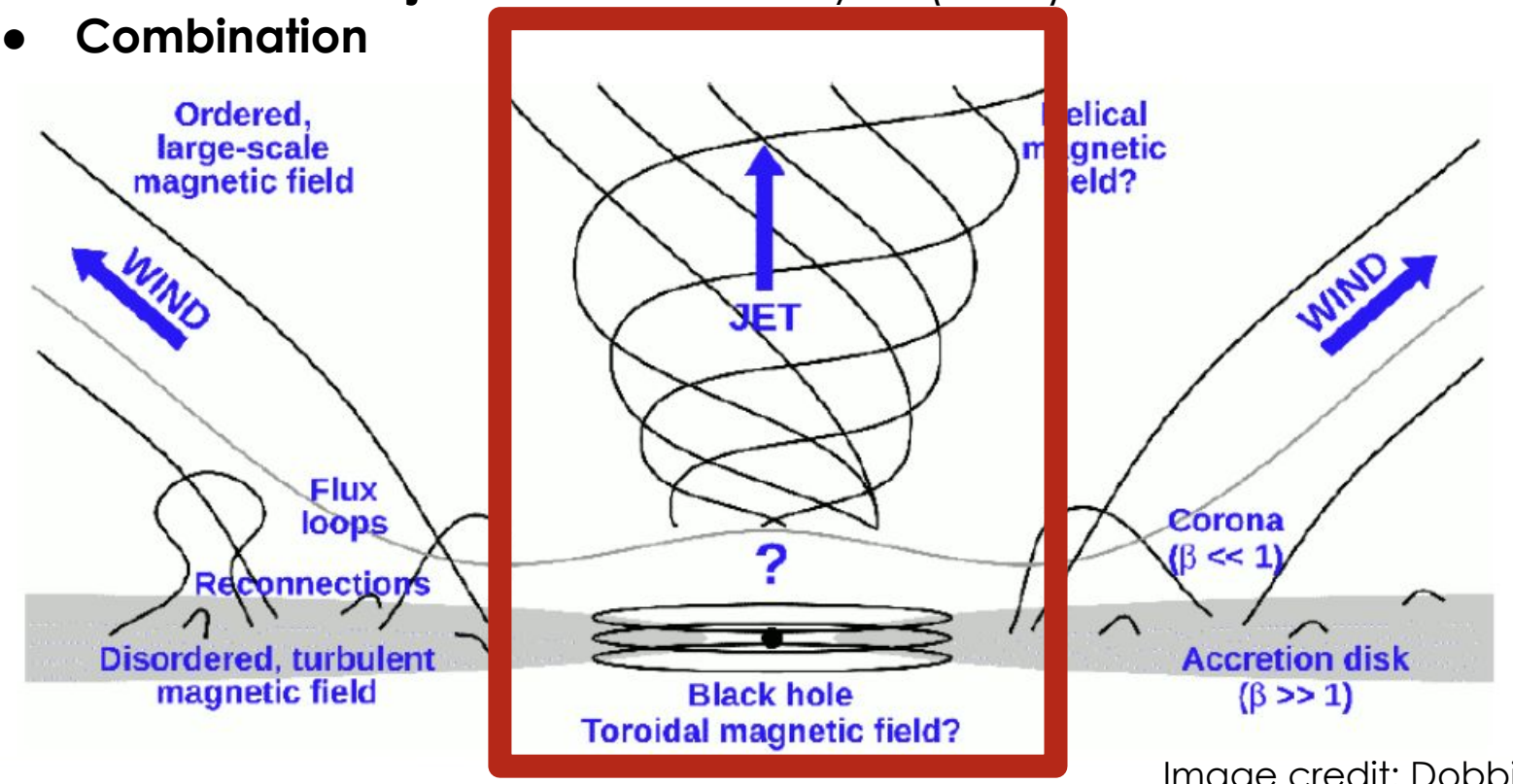
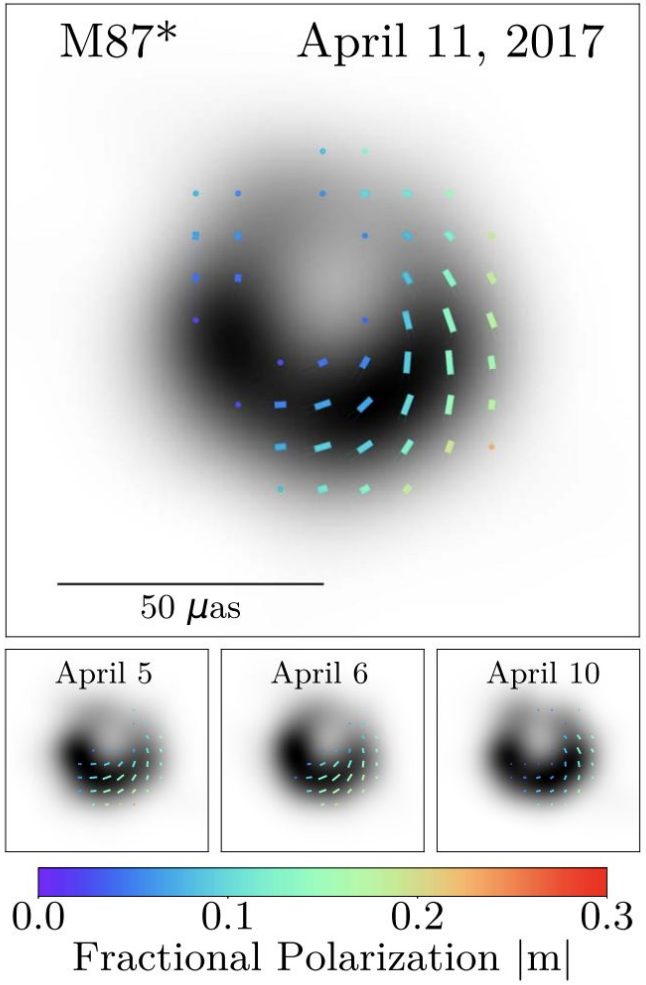


Image credit: Dobbie+ 2009

M87 EHT data in agreement with BZ jet (from multiband constraints)

Results on BH magnetic field (~4.5 R_s)



M87 BH Polarization

EHT collaboration: M87 Paper VII, VIII 2021

Important constraints on the Magnetic field structure and plasma properties!!

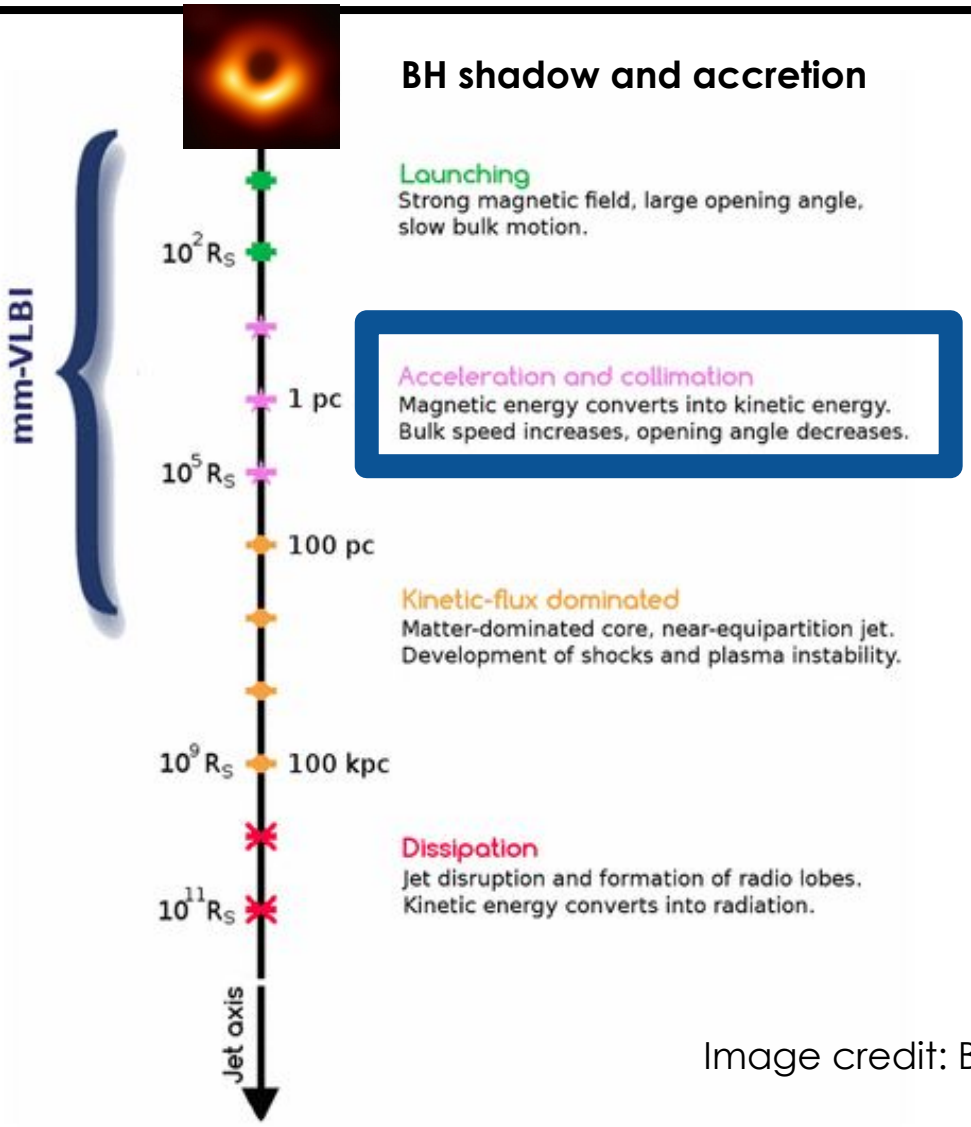
Poloidal magnetic field and MAD models

Low fractional linear polarization

Depolarization due to Faraday rotation internal to the emission region

- Electron density: $n_e \sim 10^{4\text{-}7}$ cm^{-3}
- Magnetic field strength: B ~ (1–30) G
- Electron temperature: $T_e = (1\text{–}12) \times 10^{10}$ K

EHT AGN scales: acceleration and collimation



Schwarzschild radius

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Image credit: Boccardi+ 2017

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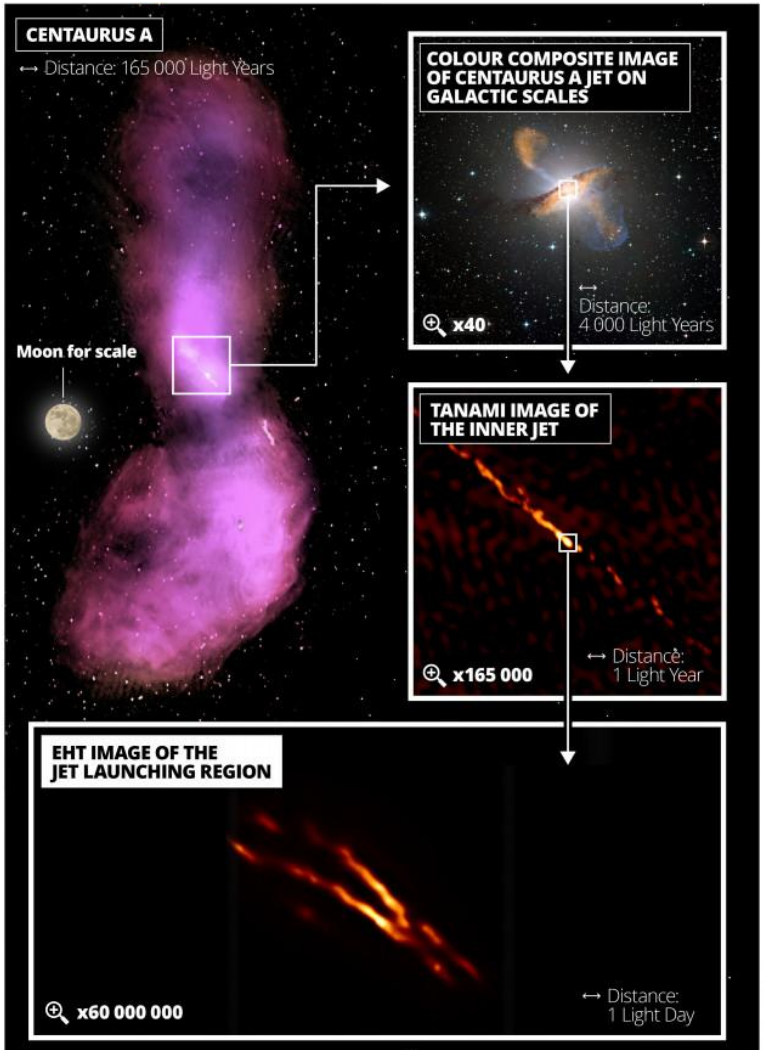
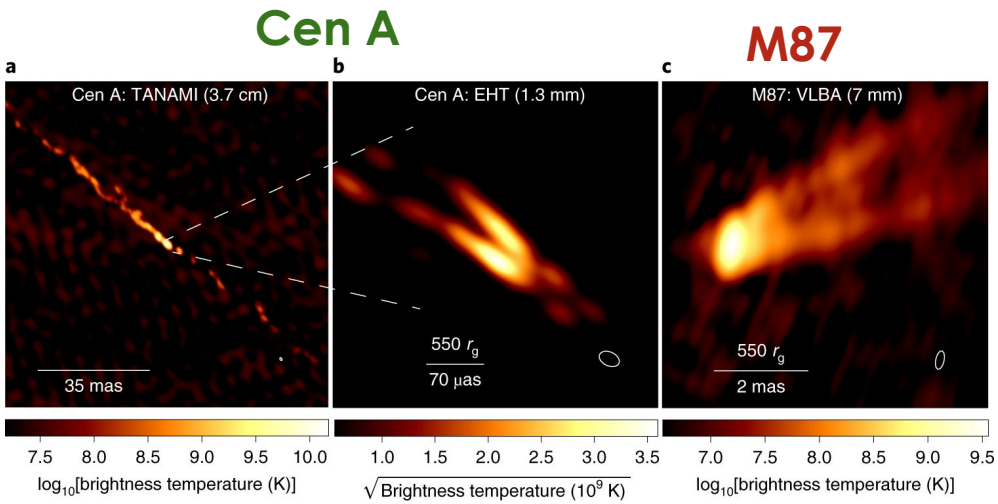
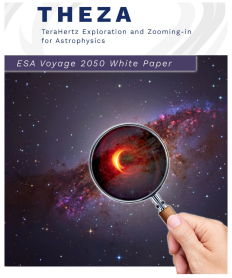
Results on jets: Cen A (~100R_s)



Janssen et al. 2021



Edge brightening structure
→ dominant jet sheath emission in LLAGN?
e.g. also M87, 3C84 (Giovannini et al. 2018)
→ GRMHD modeling will be required



BH shadow at THz
→ submm space VLBI

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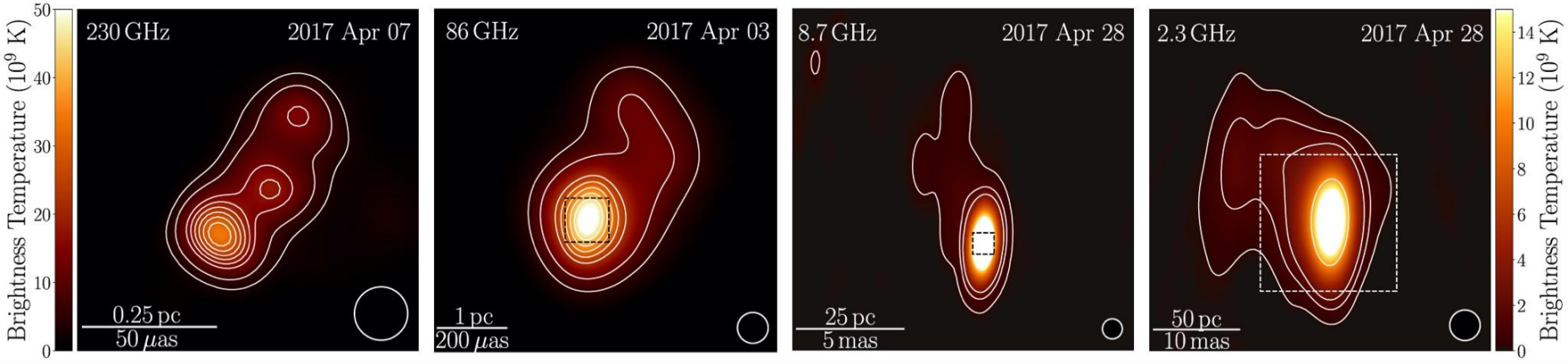
Results on jets: J1924-2914 (~1000 R_s)

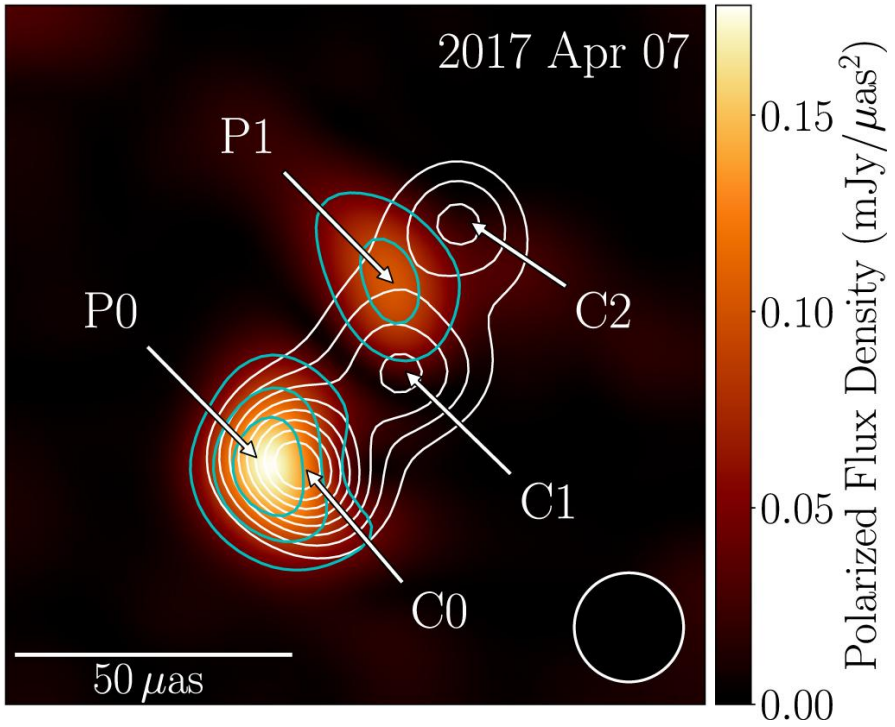
Issaoun et al. 2022



- **Very good EHT blazar calibrator for Sgr A*** → little variability on time scale of several days
- **3 compact component in NW direction**
- From multiband data, **helical jet** with a gradual clockwise rotation of the jet projected position angle of about 90° between 2.3 and 230 GHz

Results on jets: J1924-2914 (~1000 R_s)

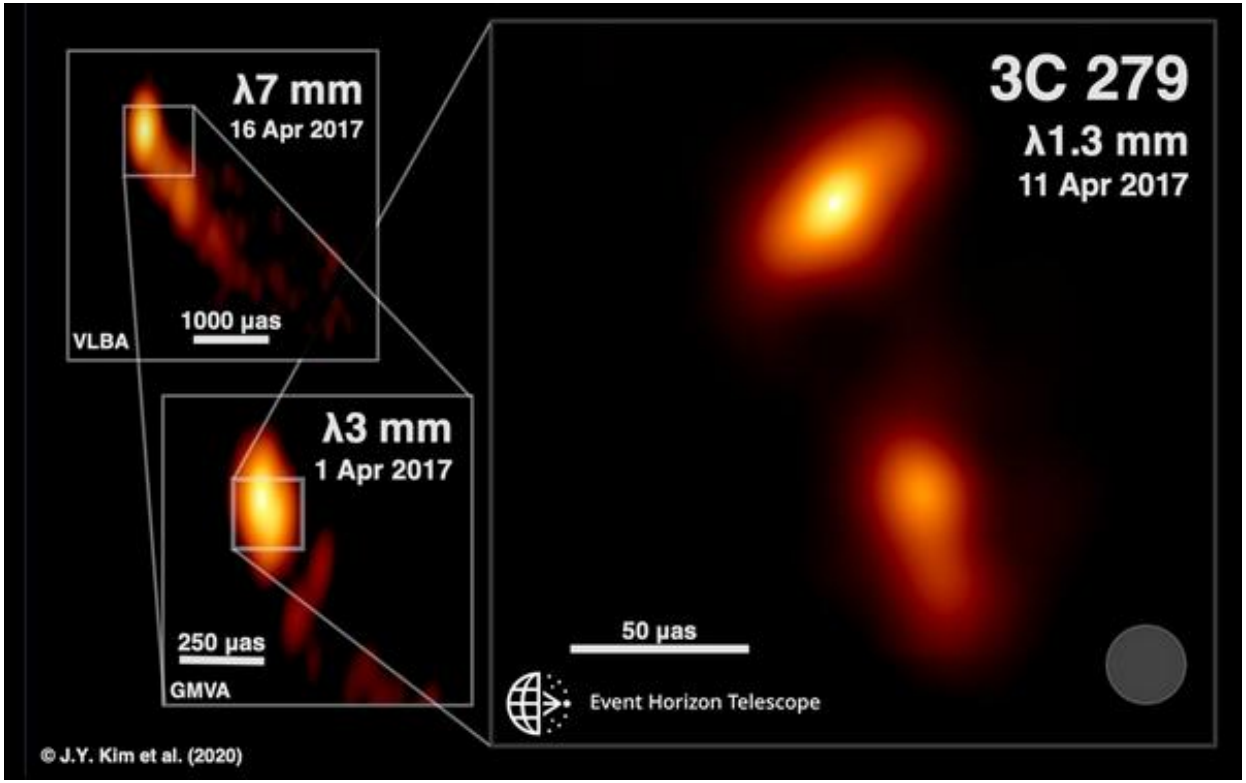
Issaoun et al. 2022



- **Linearly polarized features separated by the total intensity ones** → substructure within the shock
- **Toroidal magnetic field in the core** → helical B excluded or absence of time variability of PA
- **Fermi source**→ excellent to study high-energy emission vs jet morphology and kinematics at millimeter wavelengths.

Results on jets: 3C 279 (~1700 R_s)

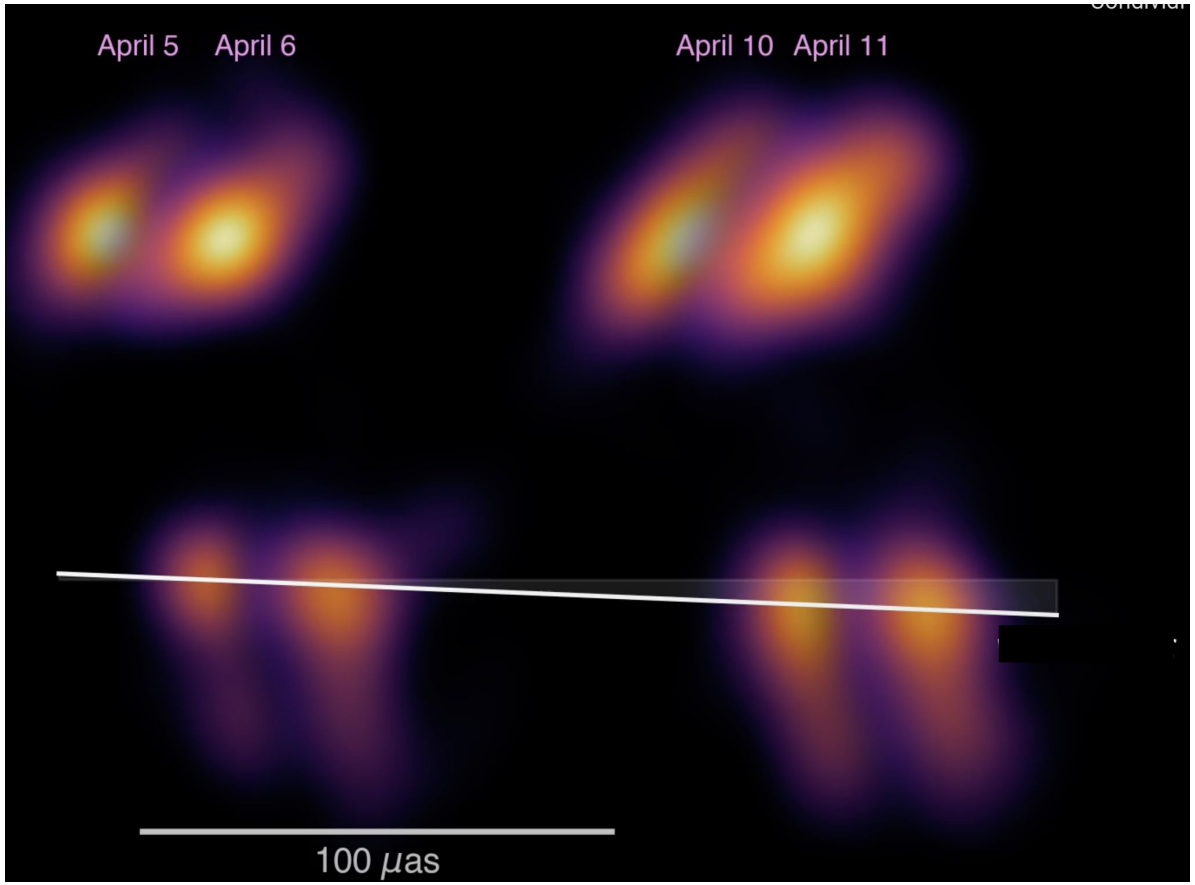
Kim et al. 2020



- **Peculiar jet structures** → the core is the northern cc → **Bending jet?**
- **gamma-rays activity during EHT observations** → analysis of multiband data close in time

Results on jets: 3C 279 (~1700 R_s)

Kim et al. 2020

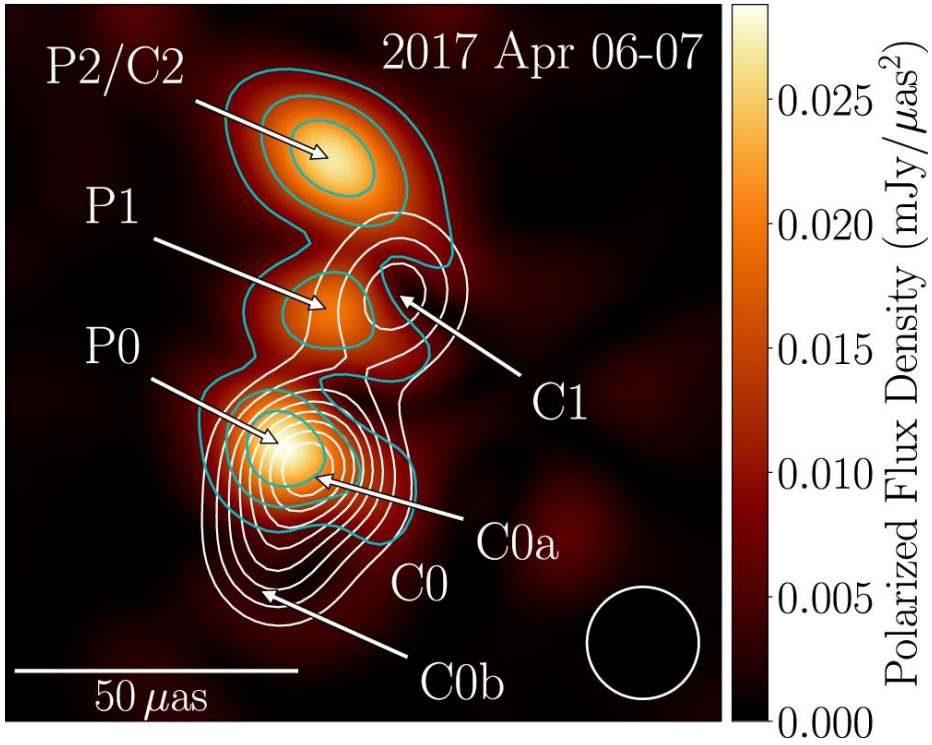


- **Rapid flux variability and proper motion** 1.1 −1.7 μas day^{-1}

→ **shocks or instabilities in a bent, possibly rotating jet**

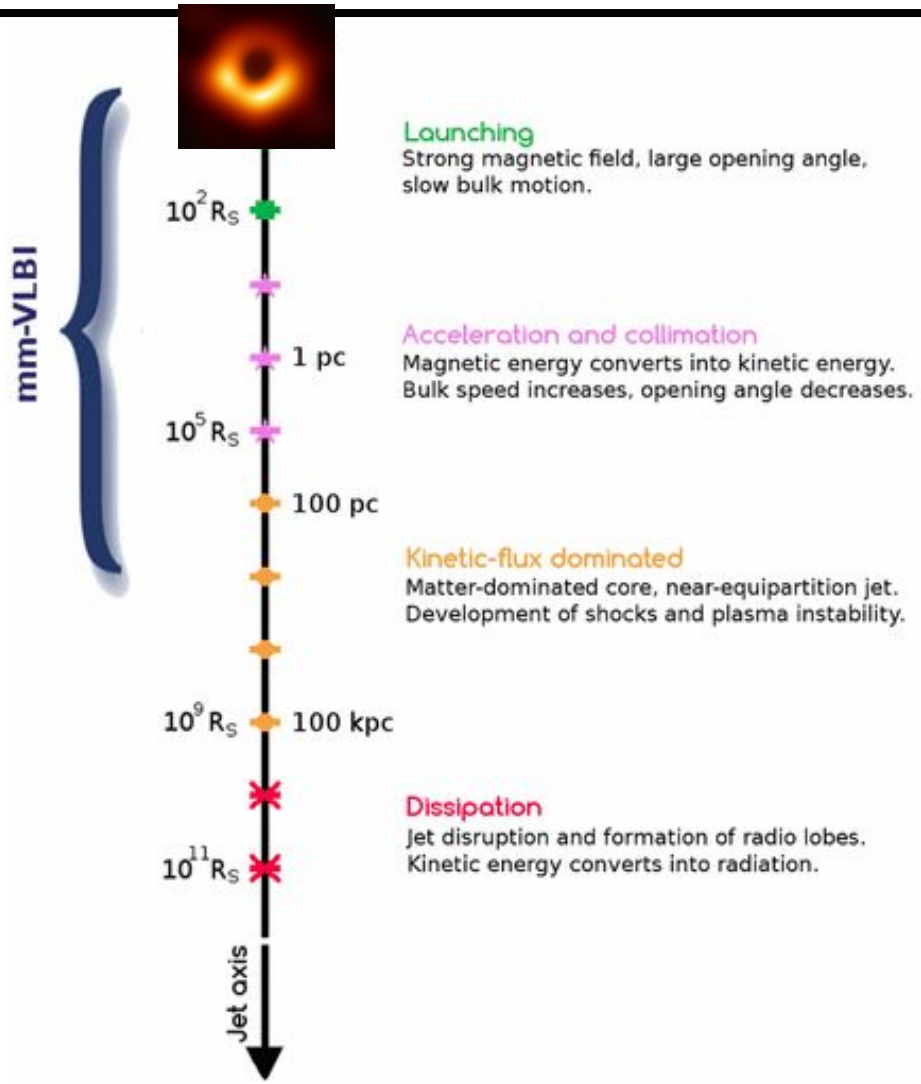
Results on jets: NRAO 530 (~4000 R_s)

Jorstad et al.2023



- **Gamma-ray flat spectrum radio quasar at z=0.902** → Most distant EHT imaged object
- **Wiggling jet** → PA changes at lower freq for jet precession or flow instabilities
- **Helical magnetic field** → change in EVPA along the jet
- **Shift of polarized emission** → different ordering of B or strong interaction with surrounding?

Summary



- BH physics → evidence of **rotating BH**
- Accretion → **MAD models are preferred**
- Launching jet → **BZ models are preferred**
- **Magnetic field** → when the transition between toroidal/poloidal/helical ?
- Along the jet → **edge brightning structures + bending + helical jet + knots** interesting for high-energy sources

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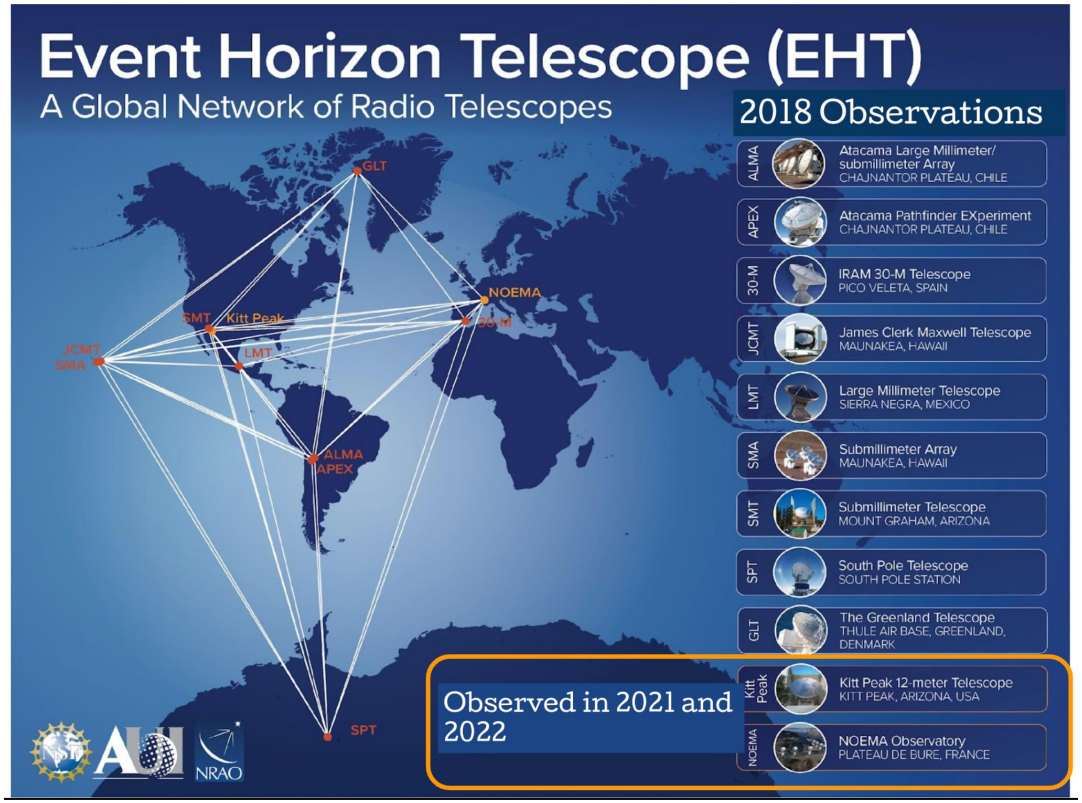
EHT is in evolution



2017 - Only EHT 2017 published data!!

- VLBI at 1.3 mm
- 8 antennas
- Typical angular resolution of 25 μas
- Continuum and polarization

2018

- 2017 + GLT

2019-2020

- No observations

2021-2022- 2023

- 2018 + NOEMA + Kitt Peak 12m tel

The future is also higher frequencies and space VLBI observations!

The future is also more EHT + multi-band data

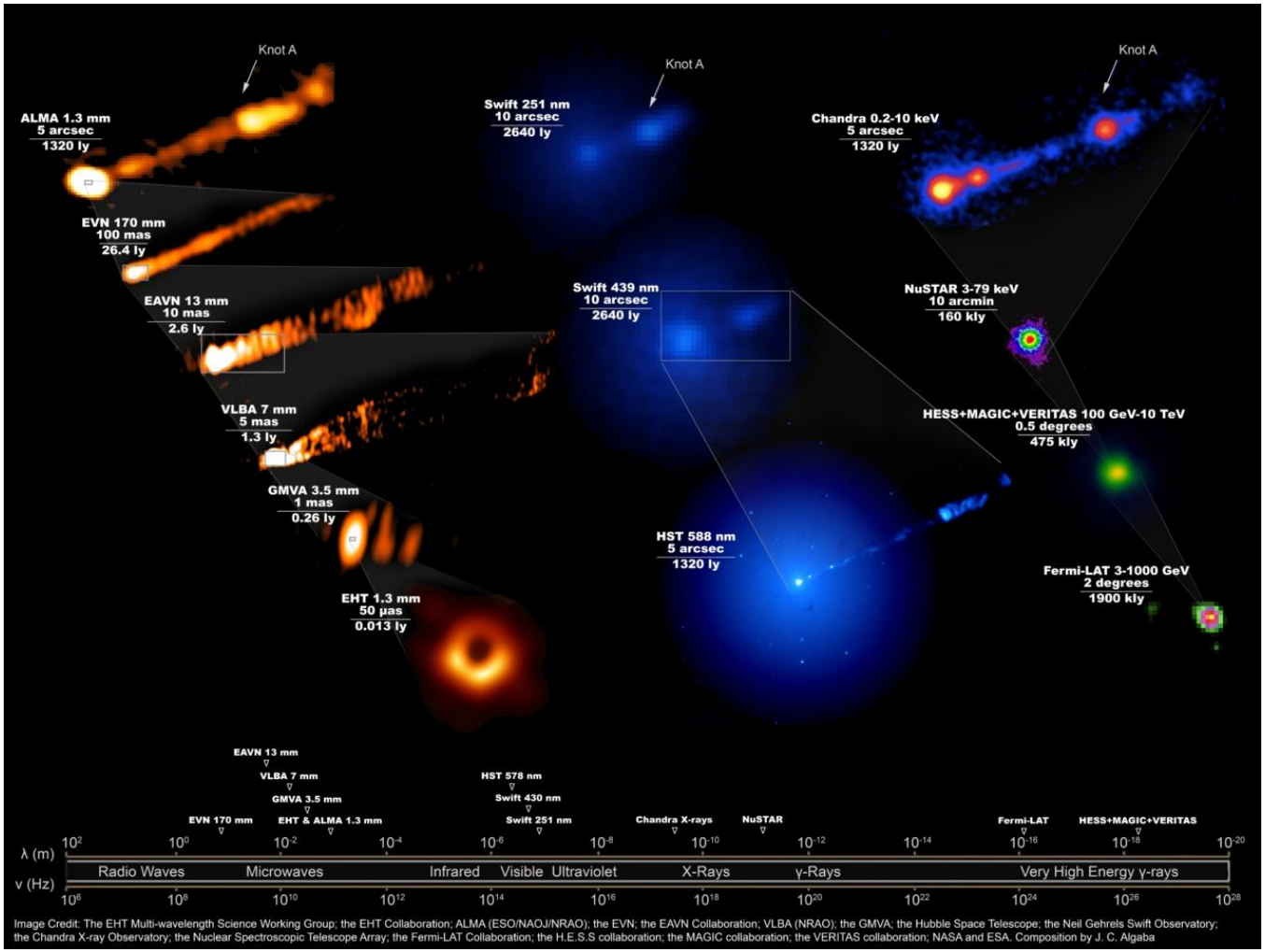


Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array;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

Thank you!!

Event Horizon Telescope

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Bologna, 1 March 2023

Backup slides