The role of ALMA in the WSU era: Variability of Active Galactic Nuclei, Jets, and Black Holes

Boris Georgiev

On behalf of the Event Horizon Telescope Collaboration

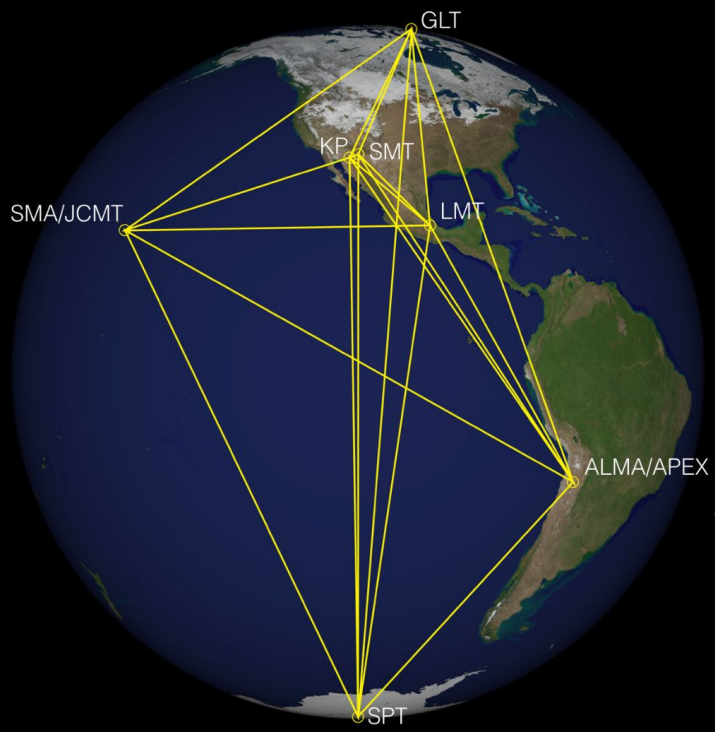
AAS 247 Winter Meeting

Phoenix, Arizona

VLBI with ALMA

Event Horizon Telescope

Band 6/7
Resolution ~10 microarcseconds



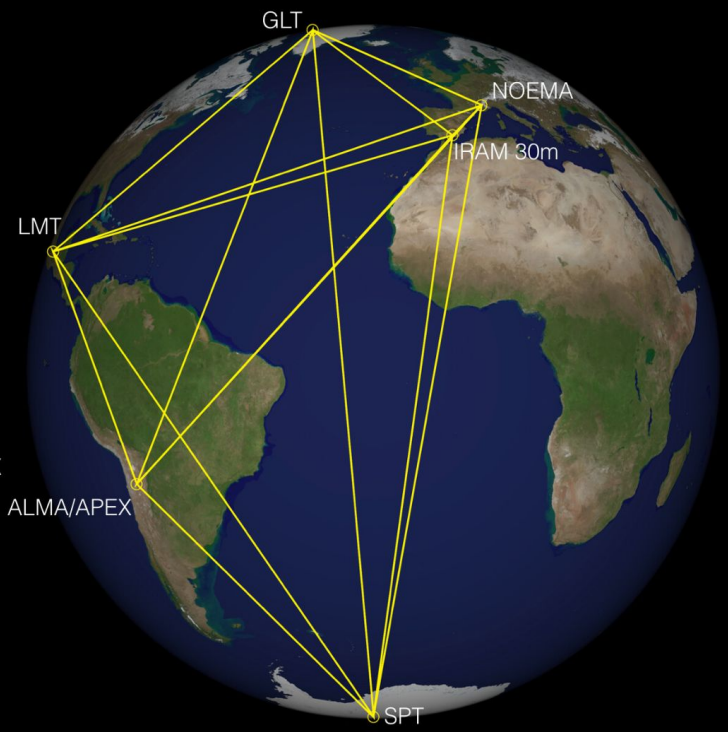


Image credit: Dan Marrone

VLBI with ALMA

Band 3
Resolution ~30 microarcseconds

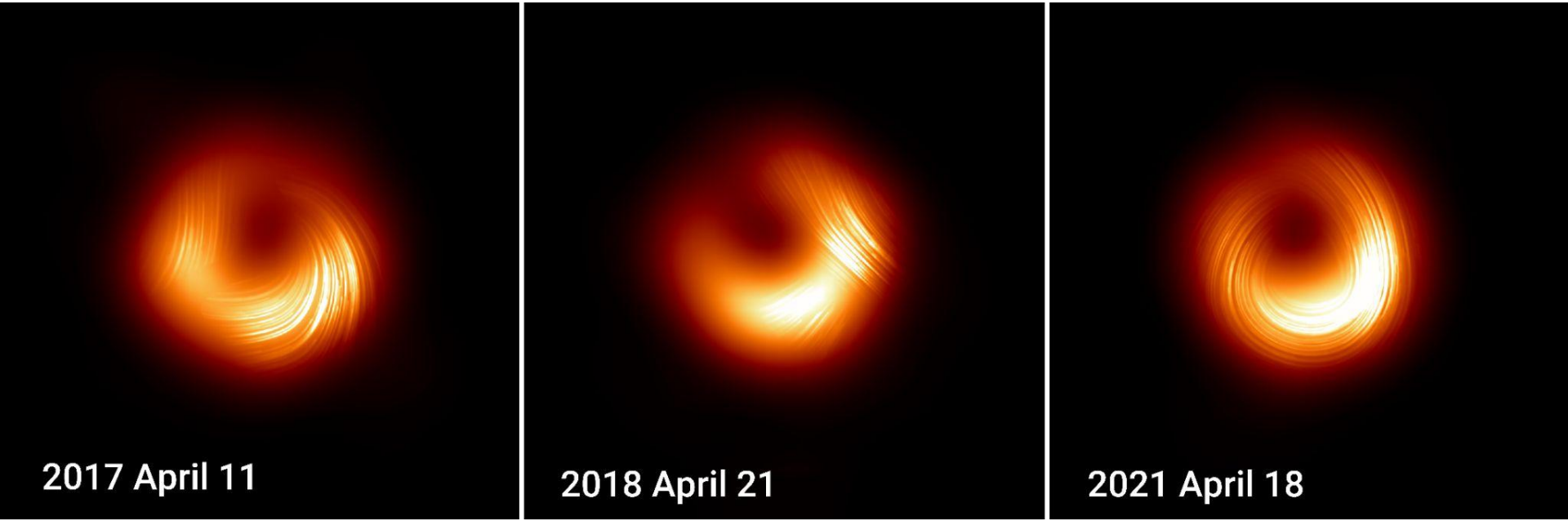
Image credit: Helge Rottmann

Yearly Variability - Event Horizon Scales

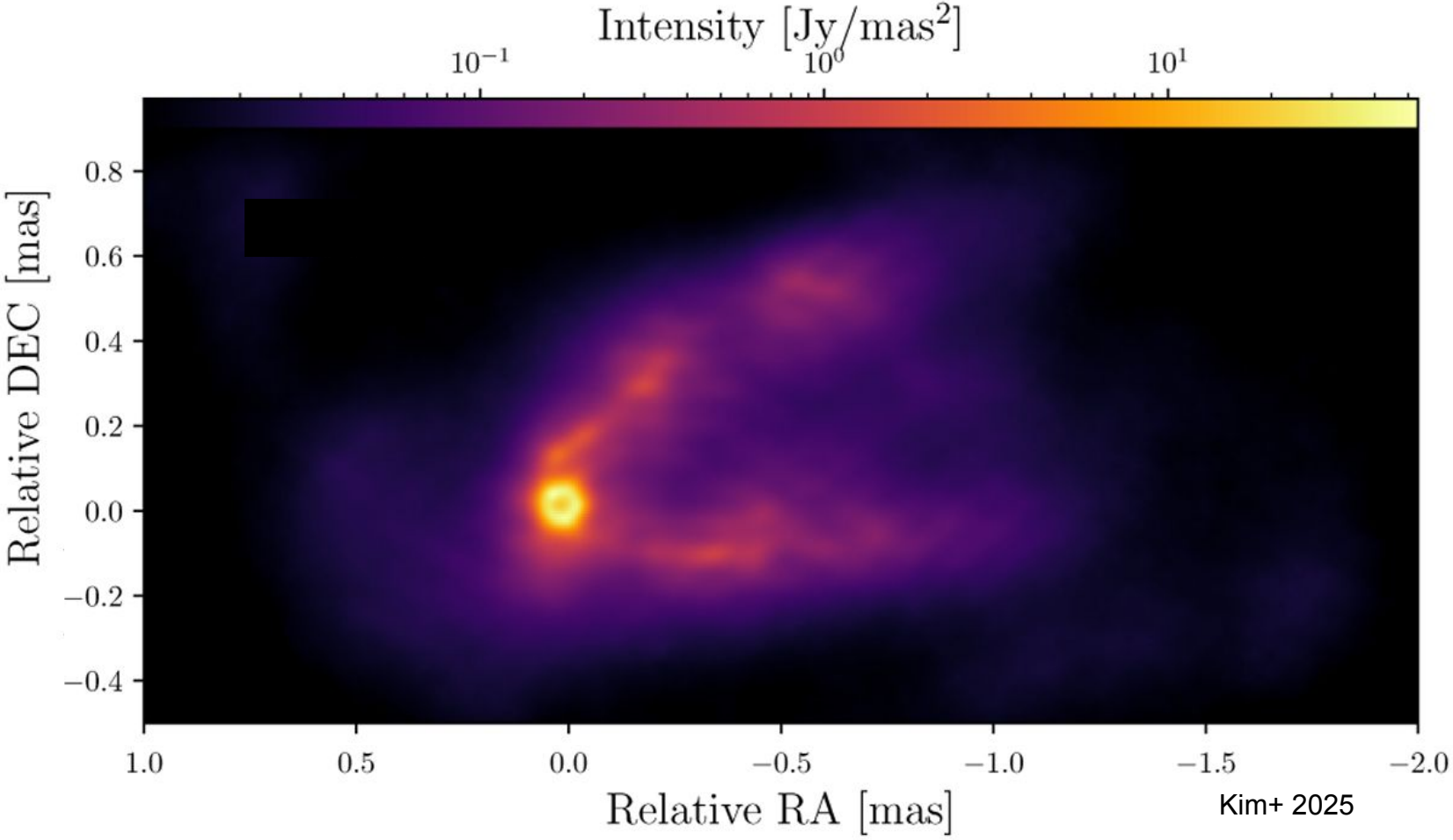
Polarization changes amount and helicity (evolving magnetic field structure)

Ring brightness structure changes (turbulence)

Size does not change (gravity)

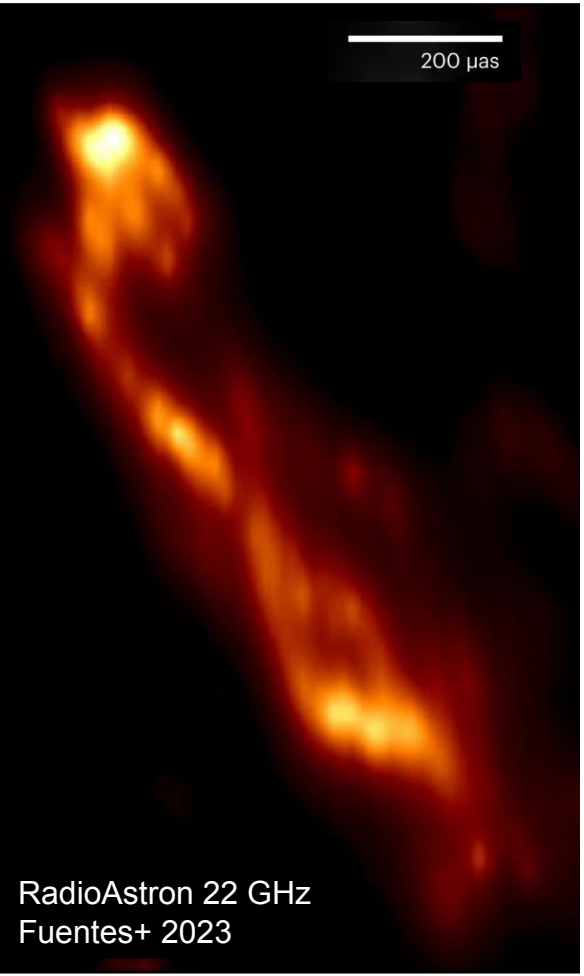


GMVA+ALMA Band 3 view of M87*



Kim+ 2025

3C 279: Blazar with a complex jet



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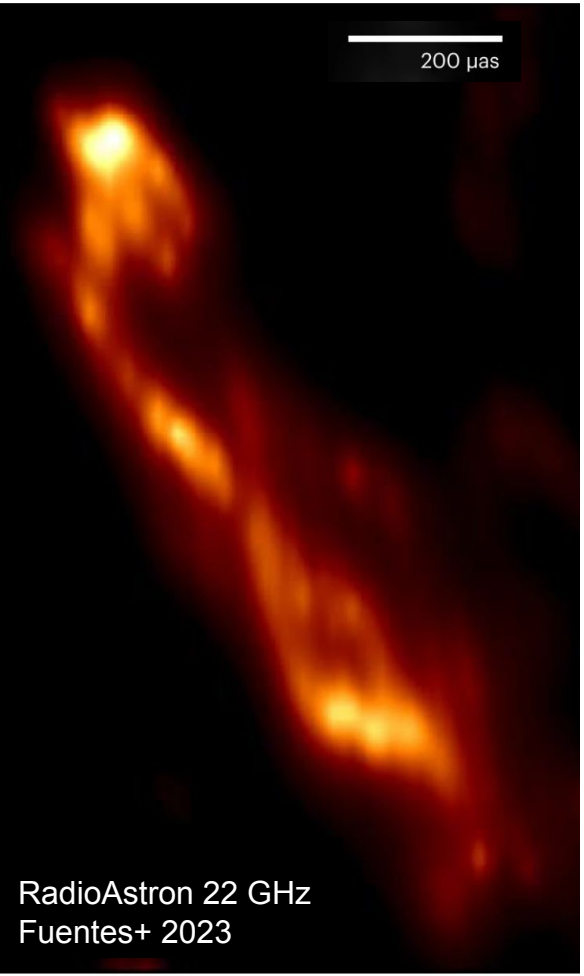
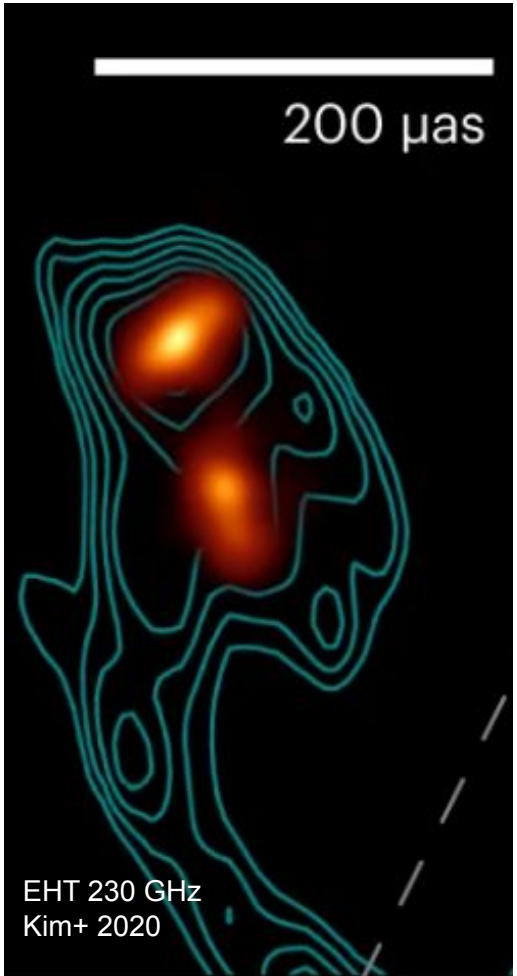
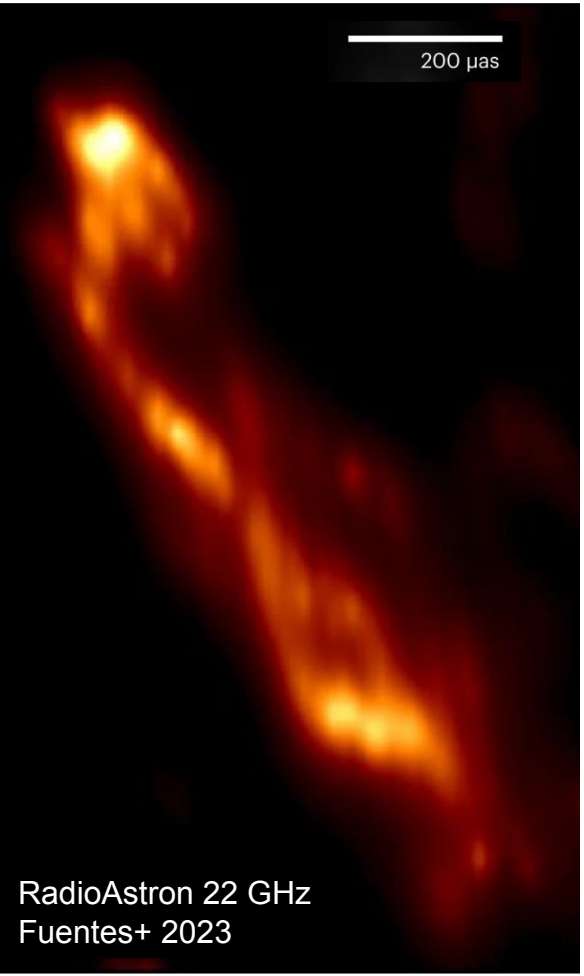
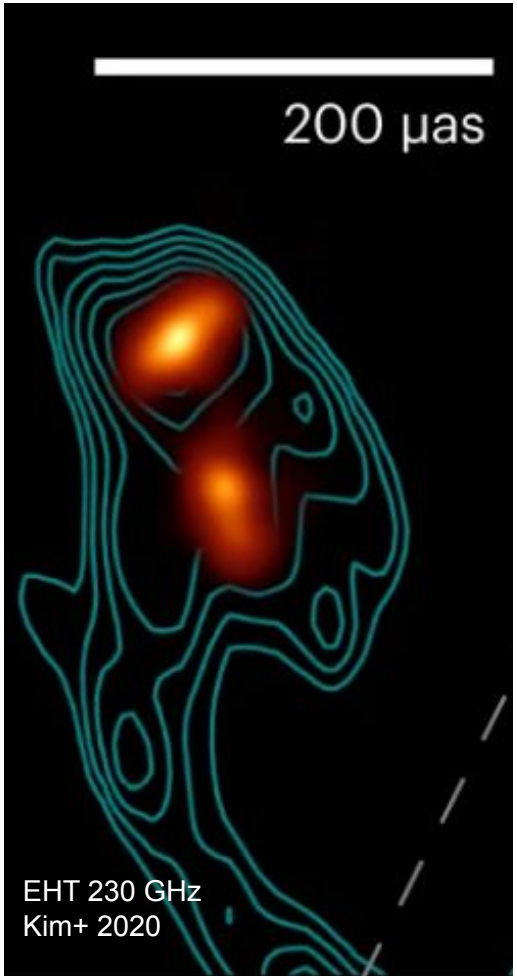
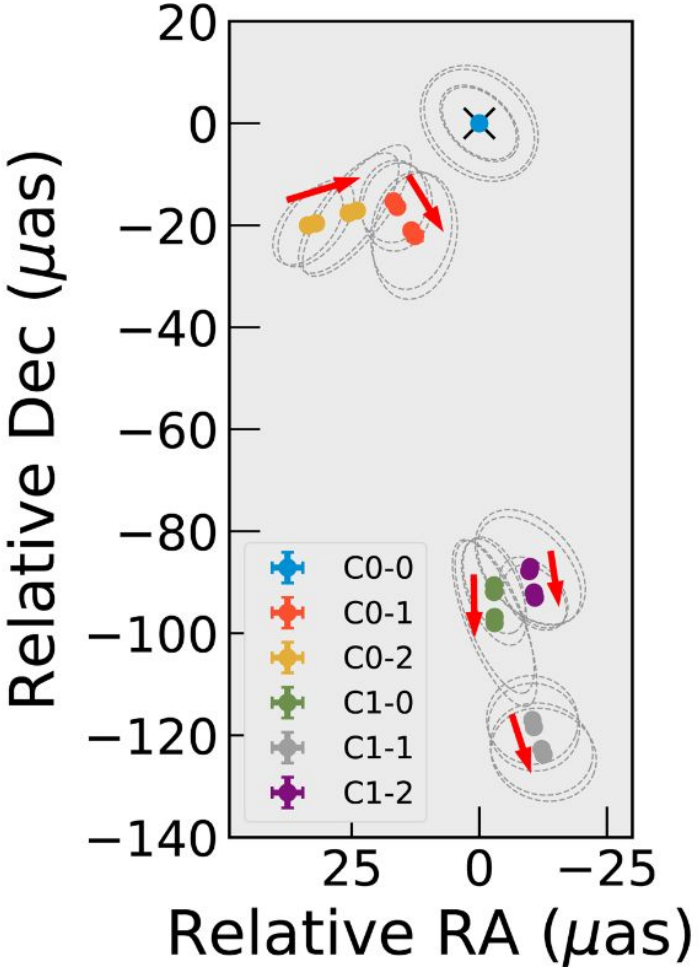




3C 279: Blazar with a complex jet







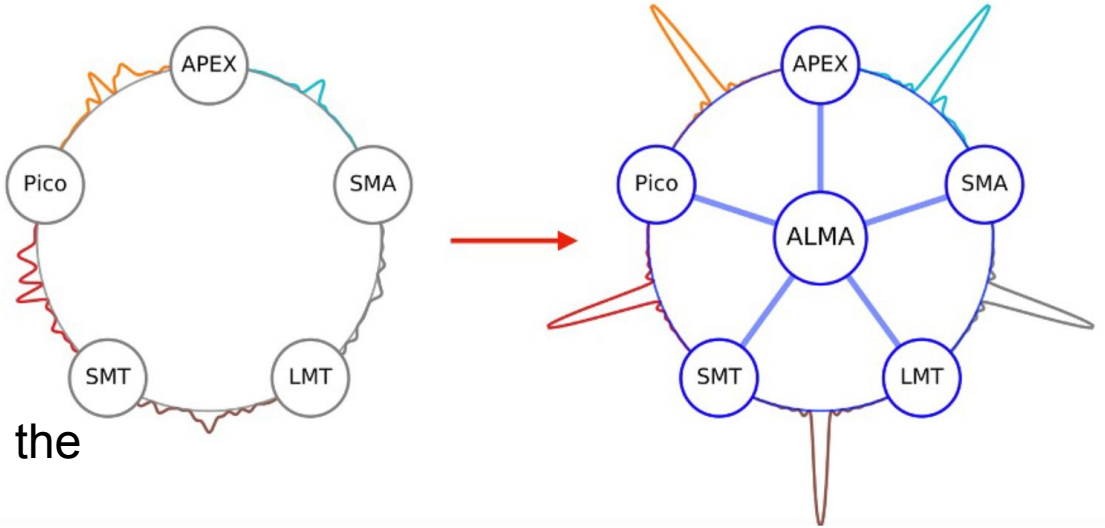
Wideband Sensitivity Upgrade

Increase in continuum sensitivity:

- Larger Bandwidth
- Improved Receivers
- Digital Improvements

At least 1.5 times boost

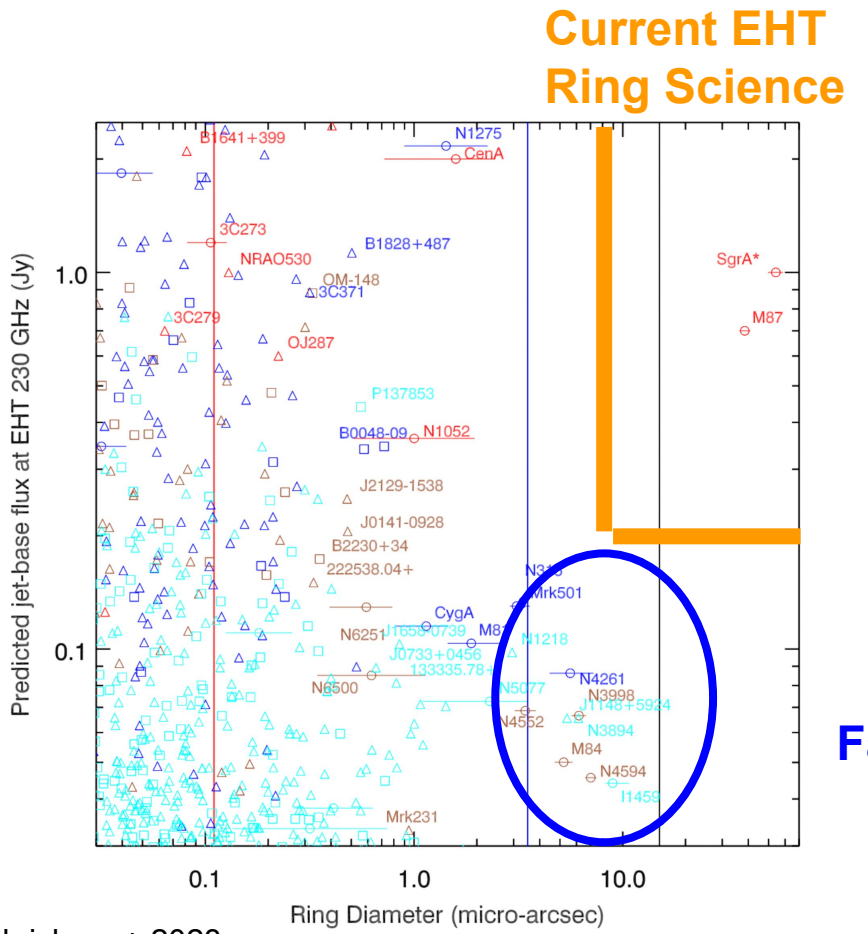
Phase-steering to ALMA improves the whole array



Increased Bandwidth:

- Spectral Index
- Faraday Rotation Measure

Demographics



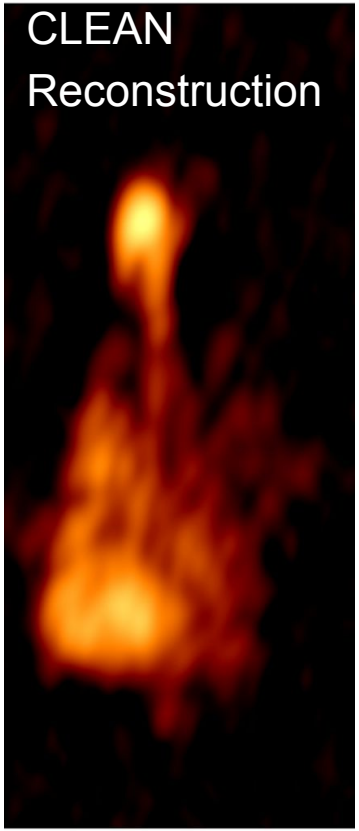
Sensitivity improvements allow for detections in fainter sources

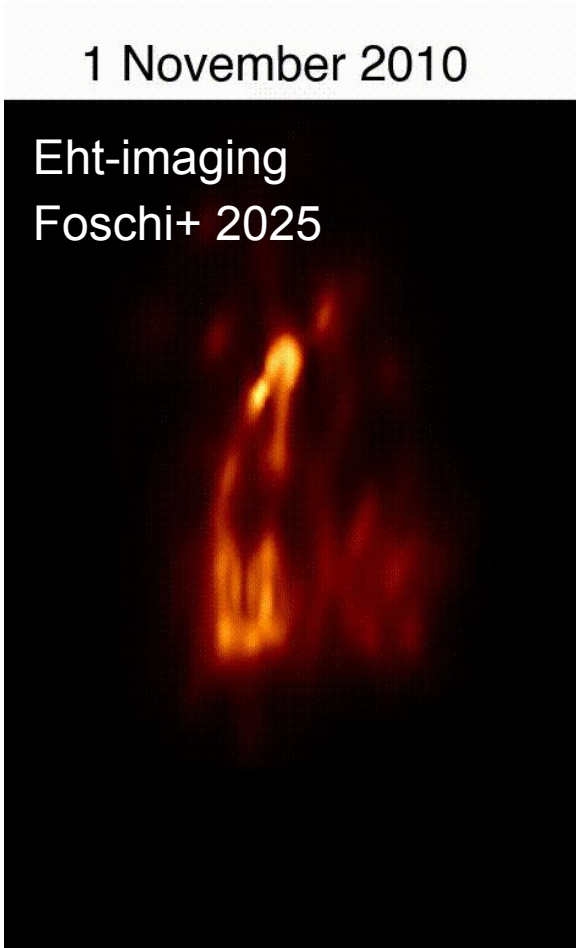
ALMA can passively/actively phase on more sources

Faint Targets

Ramakrishnan+ 2023

Advances in Reconstruction Algorithms





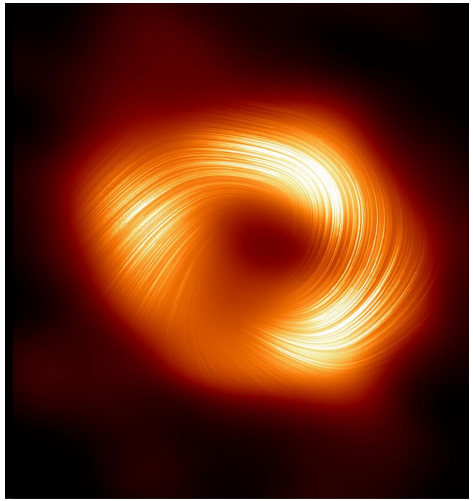
Sophisticated imaging assumptions allow for super-resolution

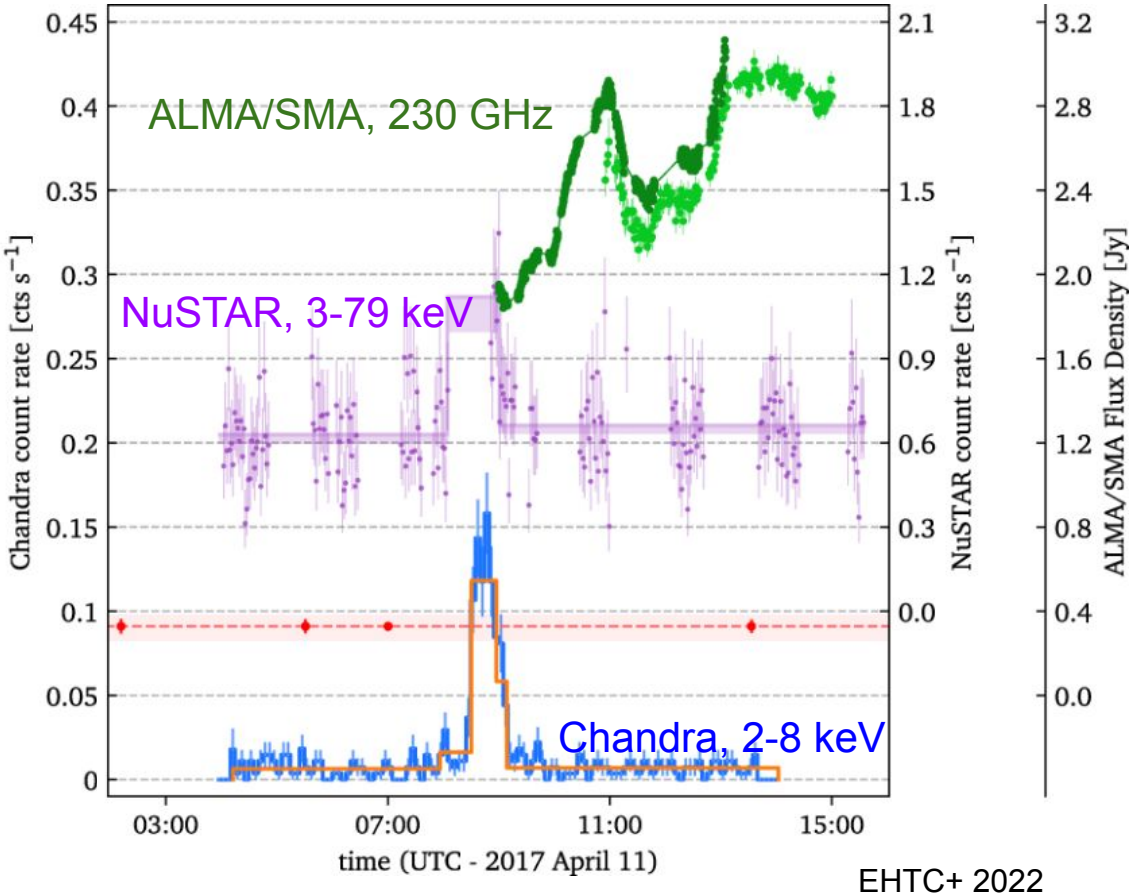
Movie-techniques can connect with archival data

Jet morphology and variability is very complex

Daily X-ray Flares in SgrA*

- Magnetic reconnection
- GRAVITY hot spots?
- Come from very compact region near the black hole
- Tenuous connection to infrared flares



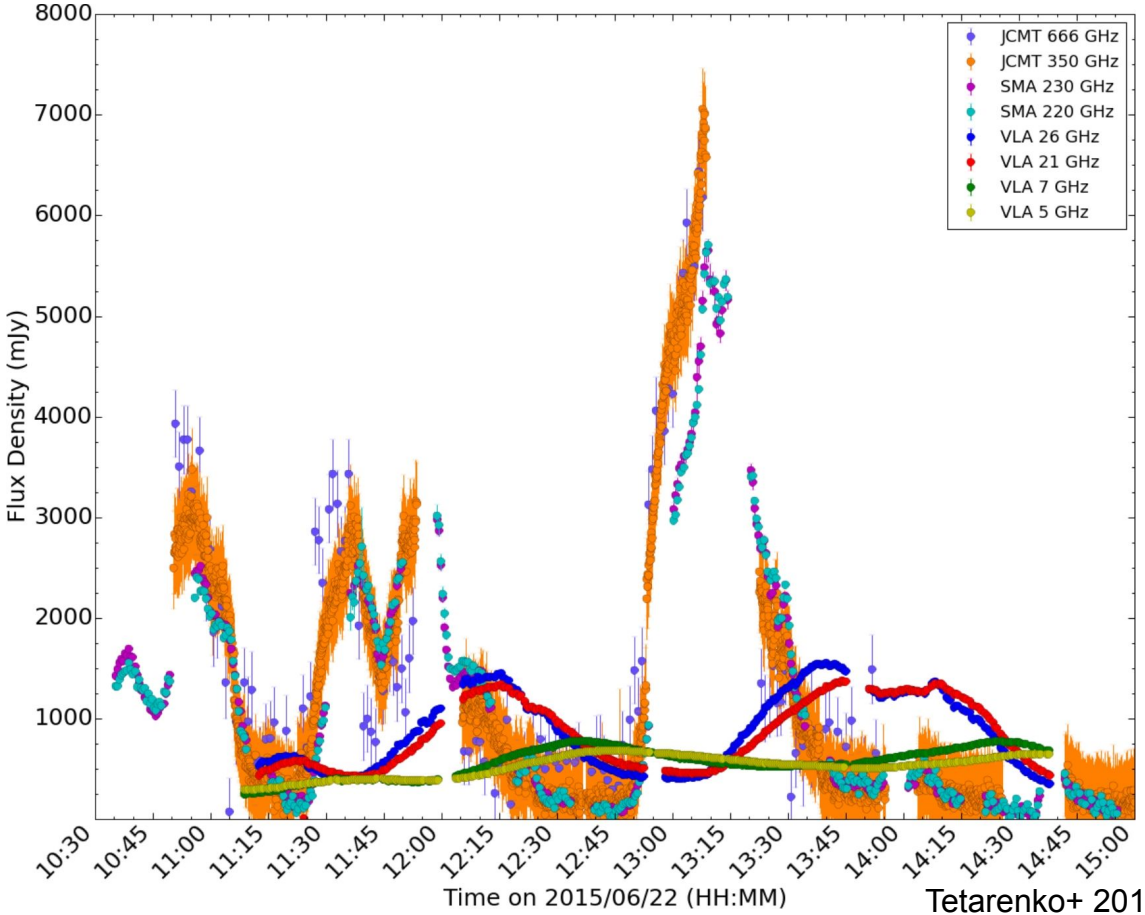


EHTC+ 2022

Flexibility of sub-arraying with ALMA

Single-dish observing mode

- Source monitoring
- X-ray Binary Transients



Tetarenko+ 2017

Flexibility of sub-arraying with ALMA

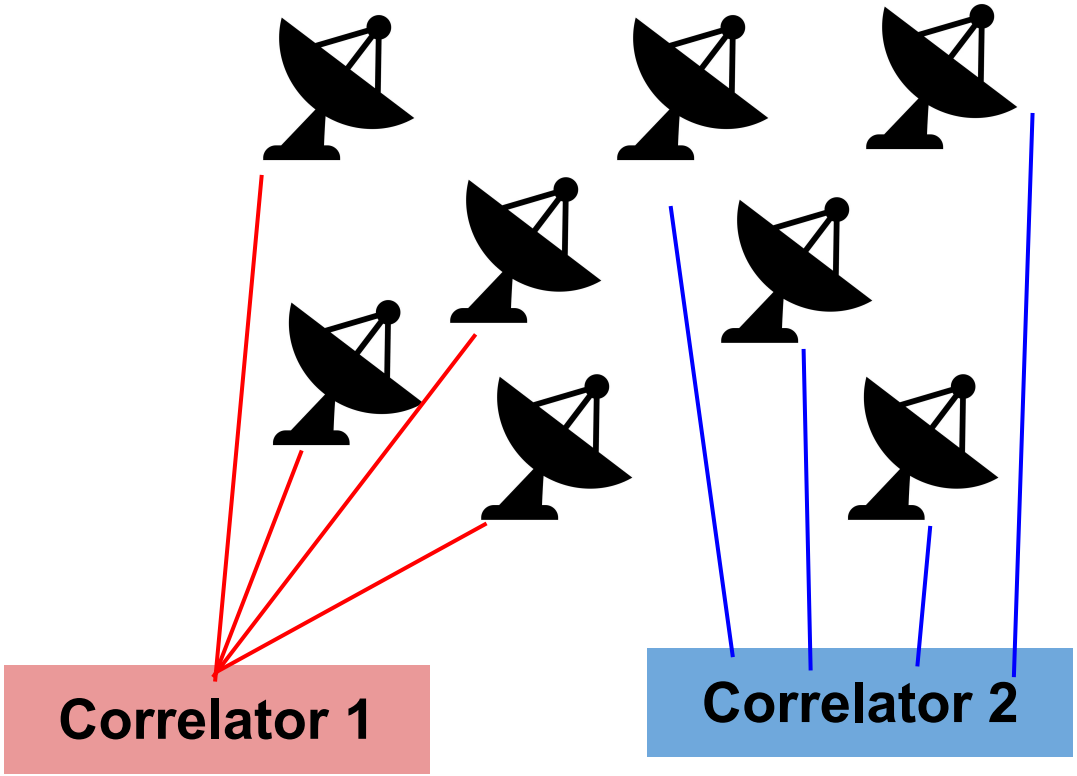
Single-dish observing mode

- Source monitoring
- X-ray Binary Transients

Second correlator allows sub-arraying

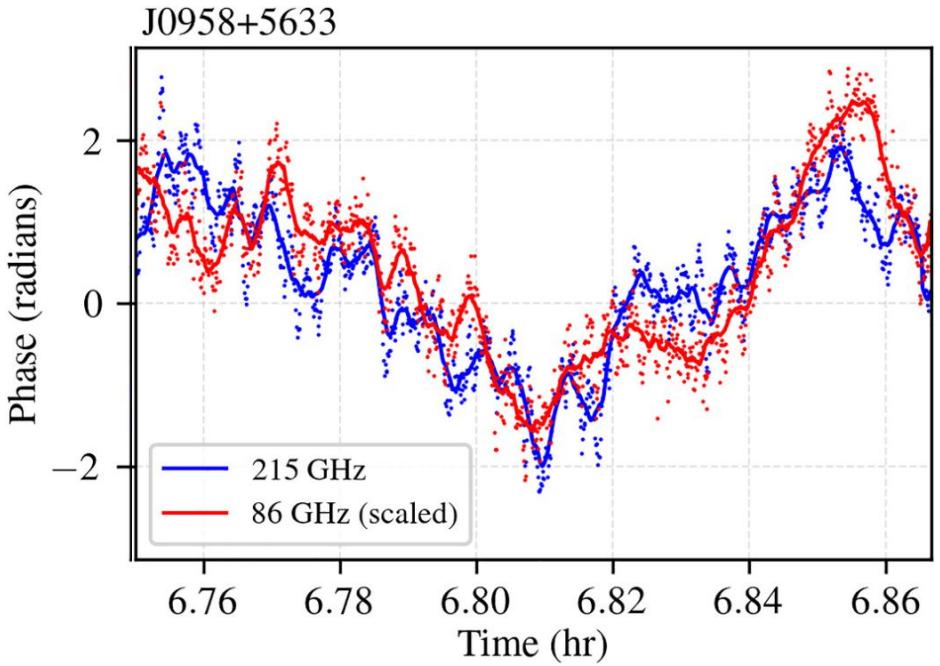
- Simultaneous multi-band
- Necessary for Frequency Phase Transfer

Enabled by the WSU

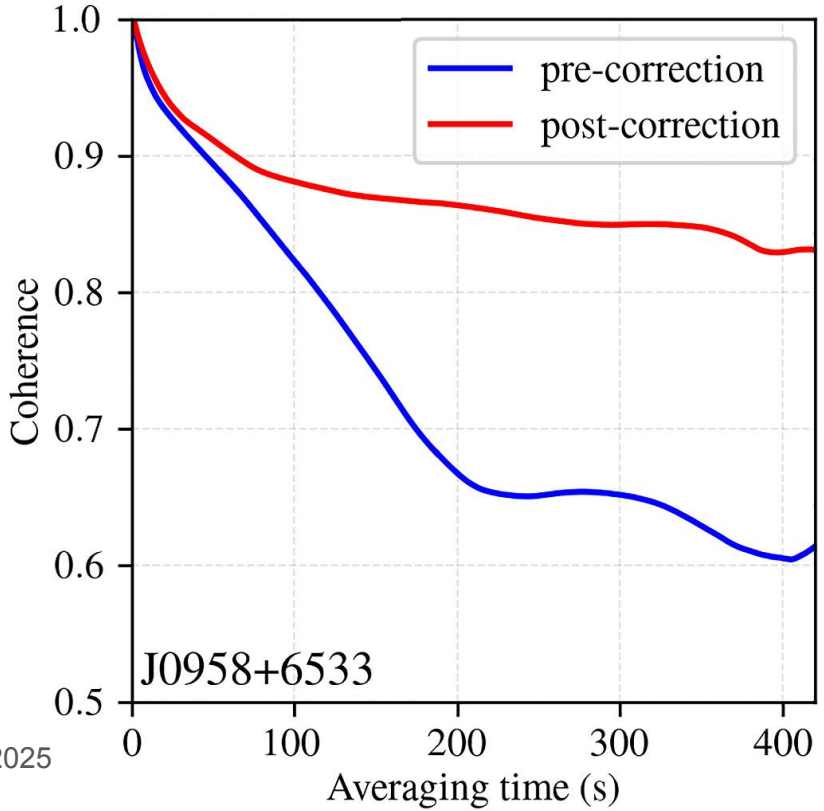


Frequency phase transfer

- Transfer the atmospheric phase from low (slowly-varying) to high (quickly-varying) frequency
- Requires simultaneous observations at multiple frequencies



Issaoun+ 2025

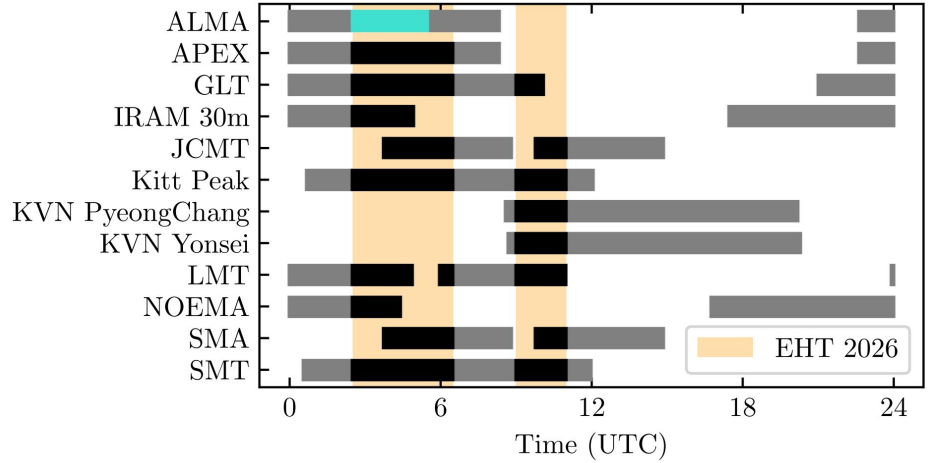


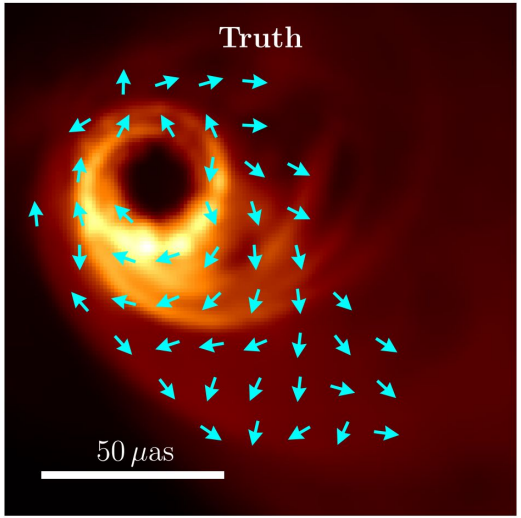
Black Hole Movies

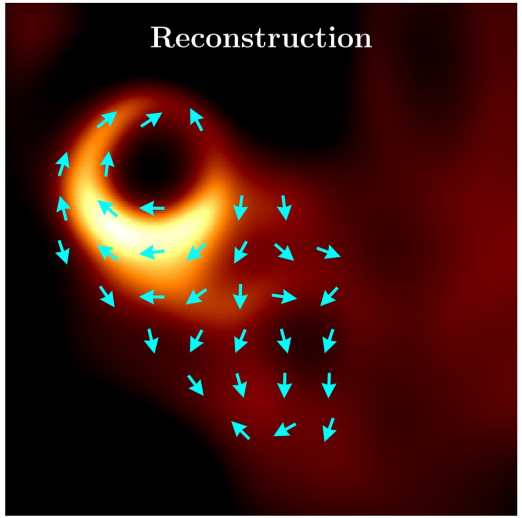
Short track twice a week for 2 months

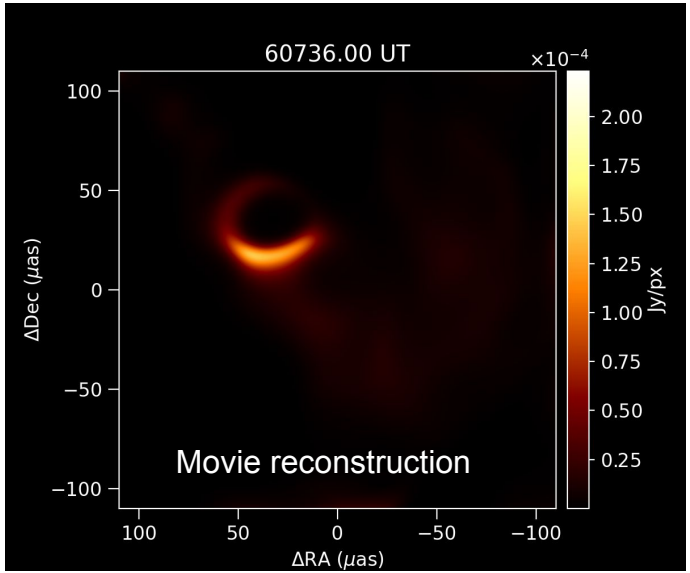
Expected motion ~2 μas/day

March/April 2026









Summary

Science Results:

- General relativity tests over 3 orders of magnitude
- Complex transverse jet motions and structure
- Structural variability on event-horizon scales
- Standard GRMHD simulations are insufficient
- Improvements in imaging techniques
- Pulsar searches

Future:

- X-ray binaries and flare origin
- Spectral Line VLBI
- Closing in on jet launching region and mechanism
- Black Hole Movies

2 key ways the WSU impacts VLBI observations

Improvements in Sensitivity

- Phasing on fainter sources and calibrators
- More sources and demographics
- More details in diffuse jets
- Increased bandwidth matches other observatories

Flexibility

- Single-dish observations for transients
- Simultaneous multi-band observations
- Frequency phase transfer
- Requires further developments after WSU

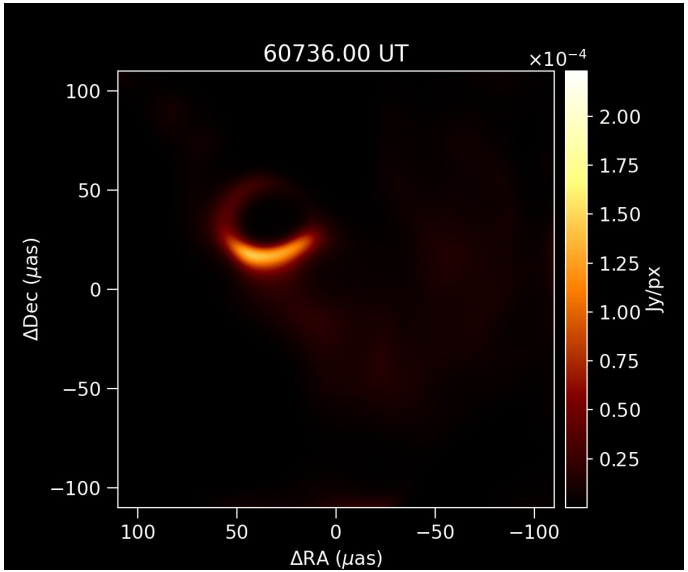
Extra Slides

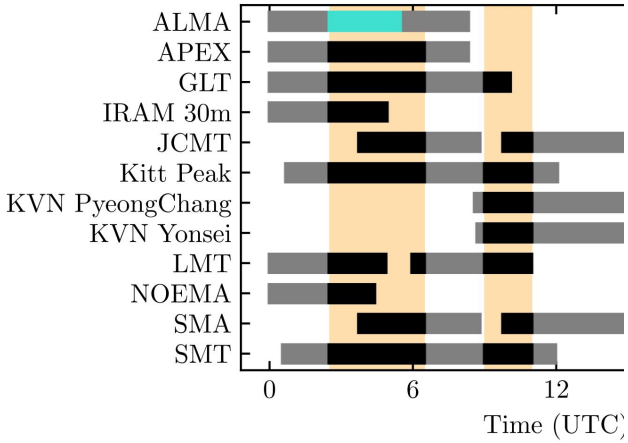
Black Hole Movies

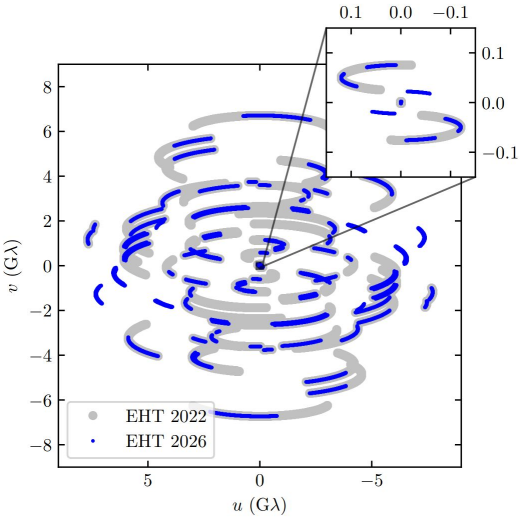
Short track twice a week for 2 months

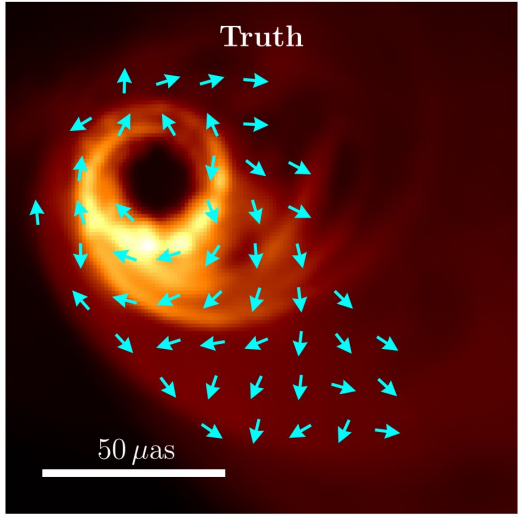
Expected motion ~ 2uas/day

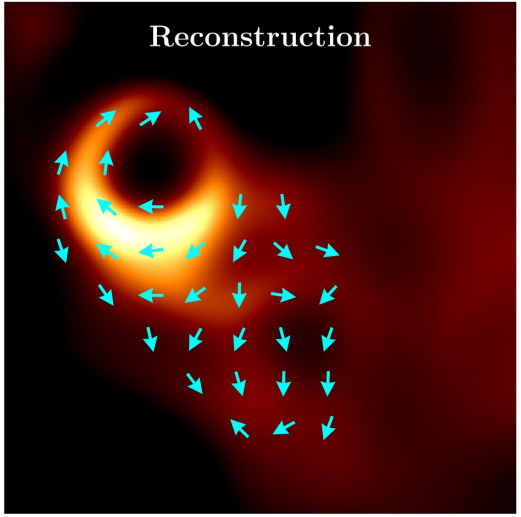
March/April 2026



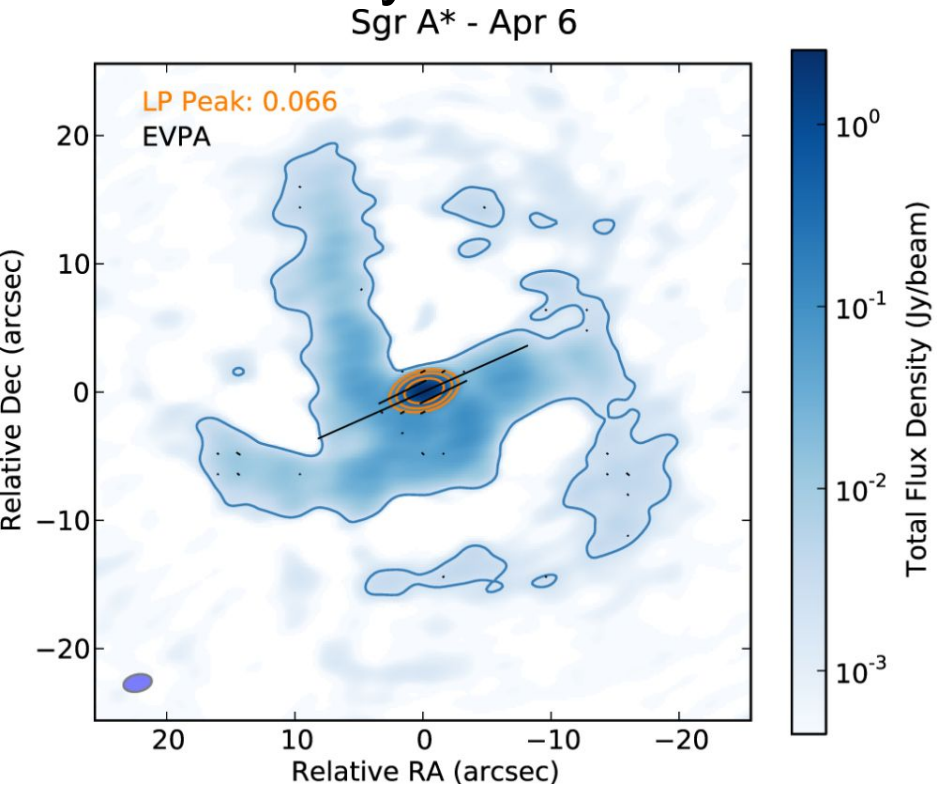


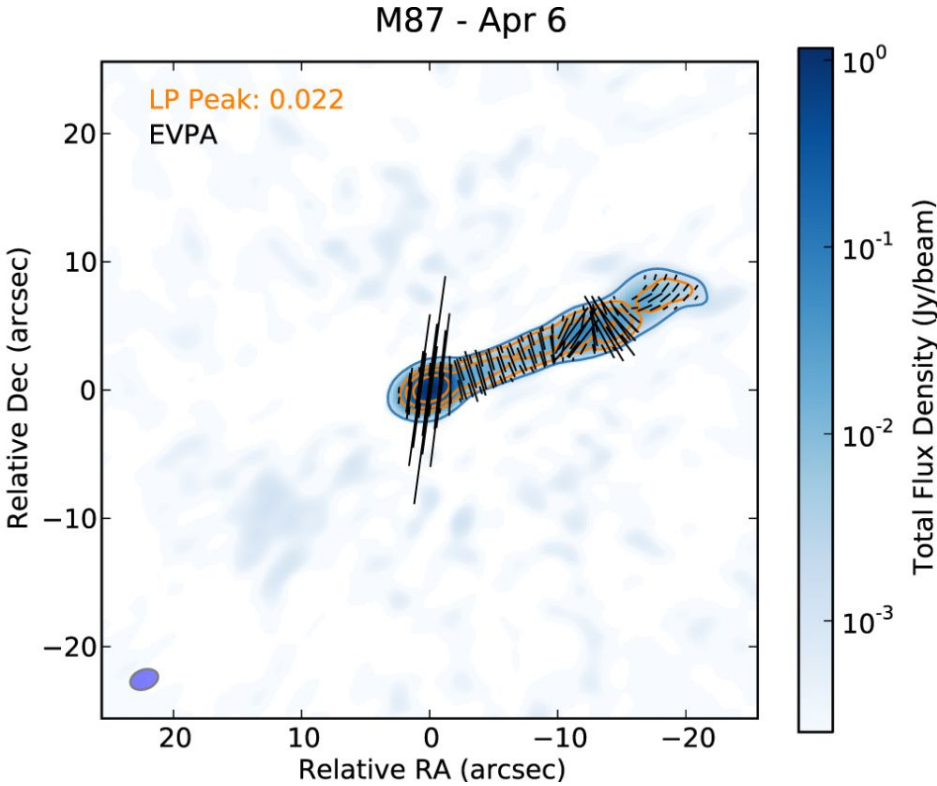






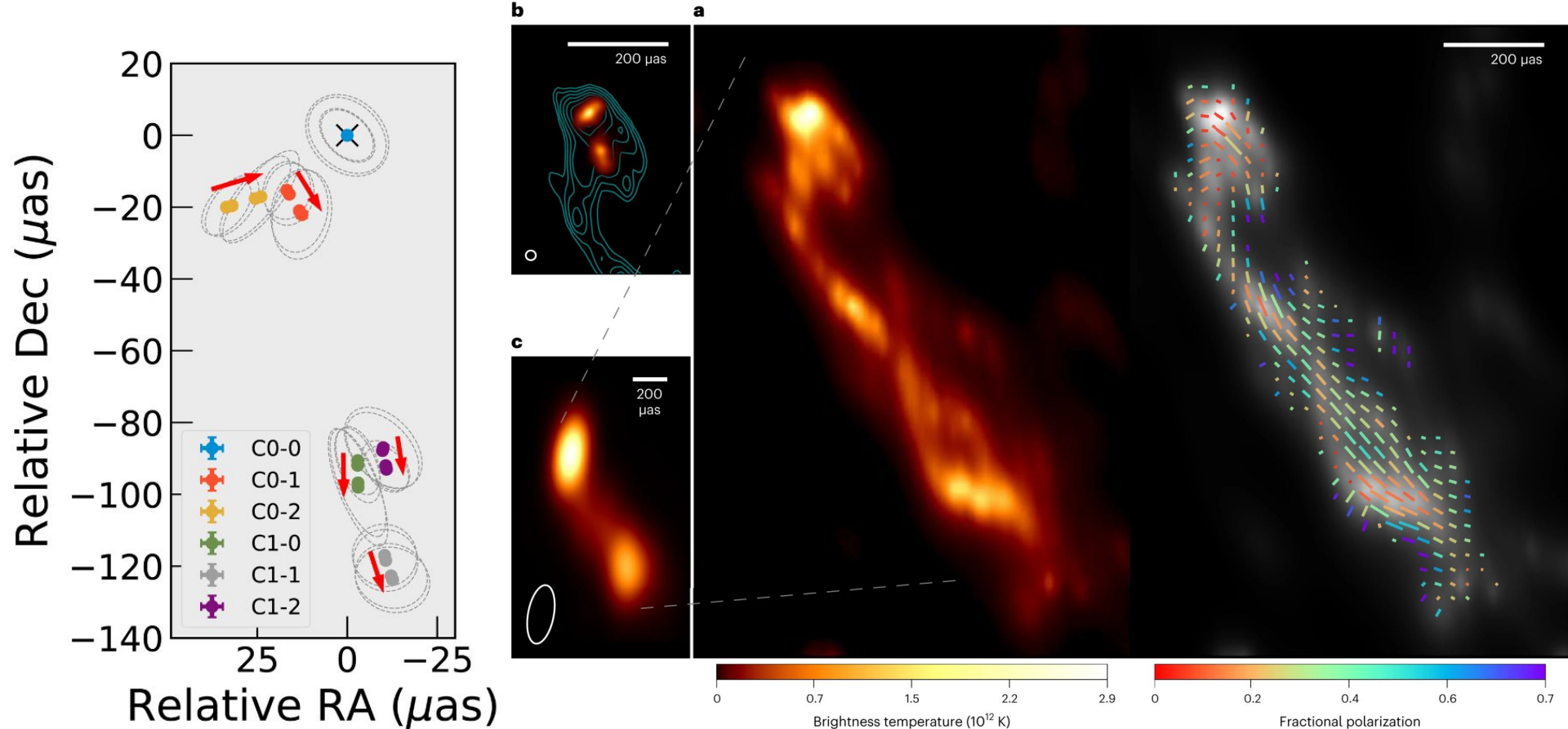
ALMA-only observations





AGN+ polarized cores

3C 279: Blazar with a complex jet



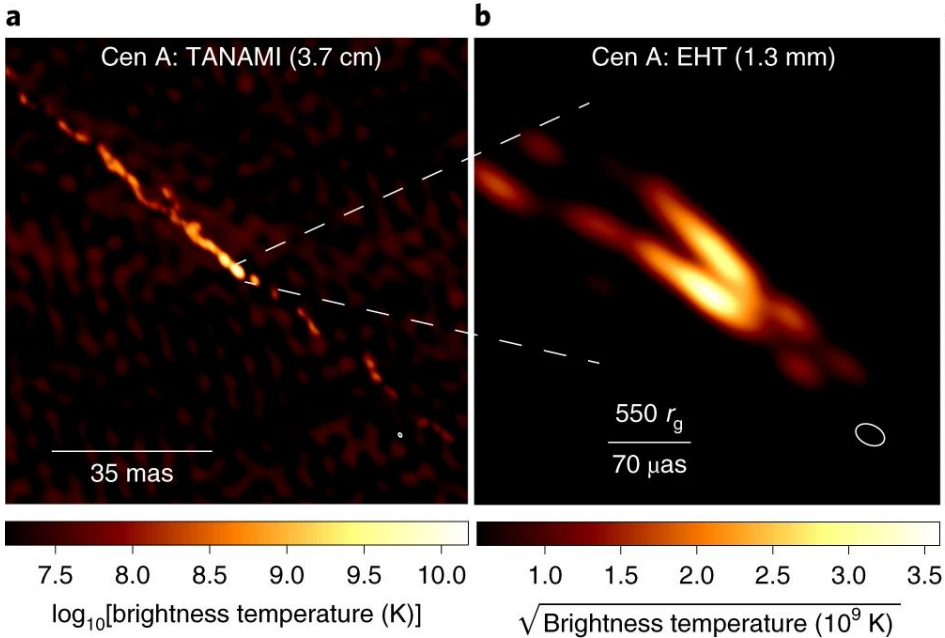
Other science

Pulsar searcher in the galactic center

Spectral Line VLBI

GMVA observations of Xray Binaries

Many more AGN/blazars



Results and Future

General Relativity tests over 3 orders of magnitude

Jet launching is directly next to the black hole

Complex transverse jet motions

Structural variability on event-horizon scales

Preference for Magnetically Arrested Disks

What is the origin of relativistic jets in SMBHs?

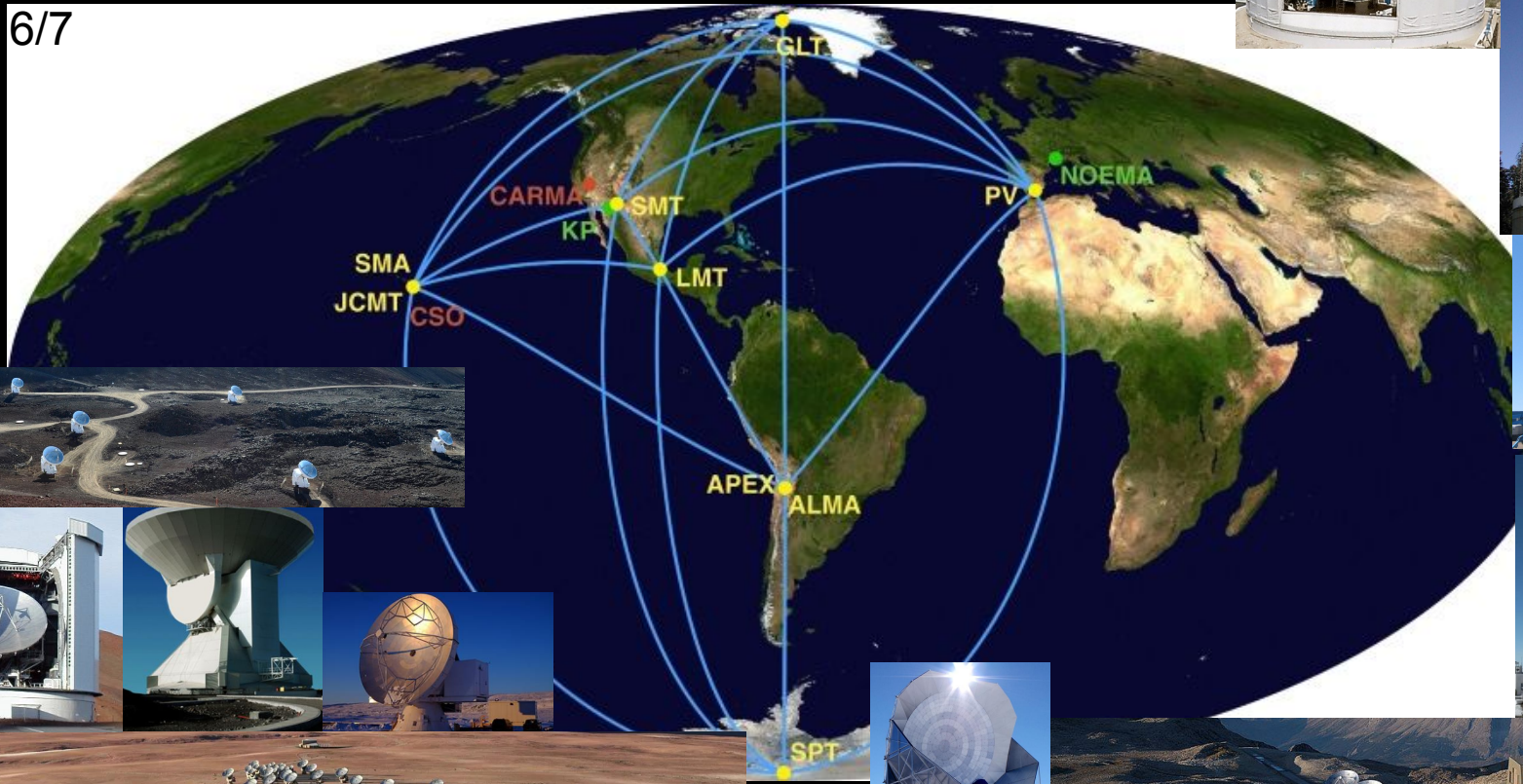
What causes flaring near SMBHs?

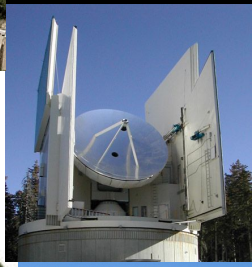
Do SMBHs have strong magnetospheres that extract spin energy?

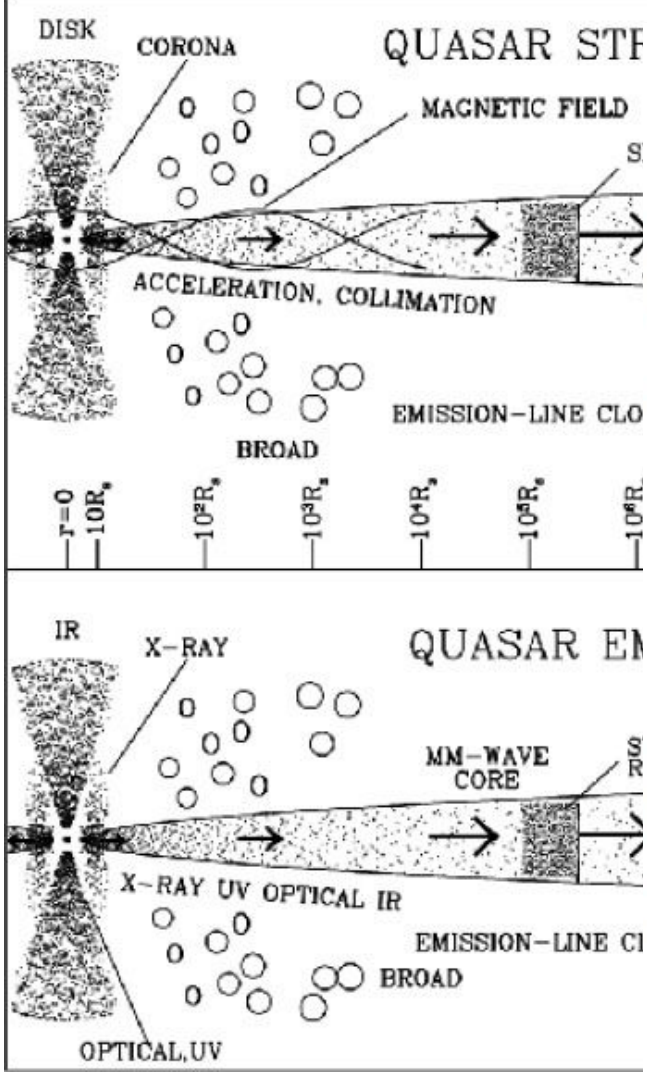
What are the space-time properties of the massive compact objects in galactic nuclei?

Event Horizon Telescope

6/7







radio-loud (RL) AGN

radio-quiet (RQ) AGN