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*The Role of **VLBI** in **LAT** studies of γ-ray bright AGN*

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Image:
NRAO/AUI/NSF

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VLBI arrays – “Alliance of radio antennas”

Image: H. Rottmann/MPIfR

Image: GSFC

Image: NRAO

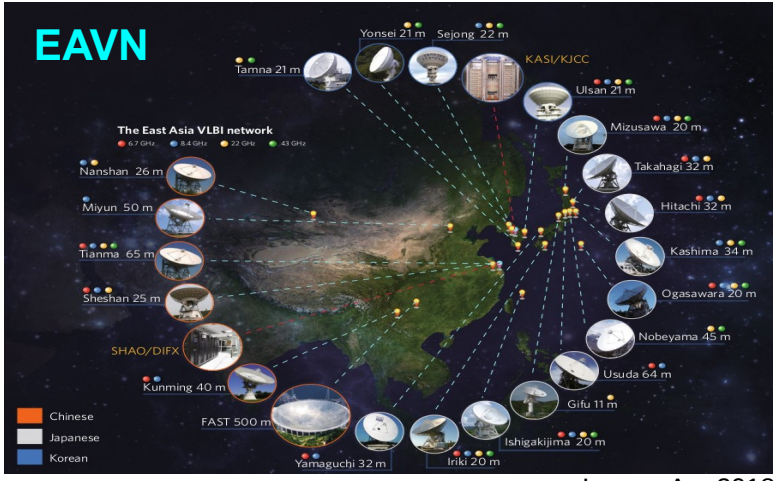


Image: An+2018

What is VLBI?

- Very Long Baseline Interferometry
- **Observational Technique**
- Pairs of radio telescopes
- The so-called “**Visibility**”
- FT – Image of the source
- “Very-Long”: longest **Baseline**!
- Angular resolution: ~**λ/*d***

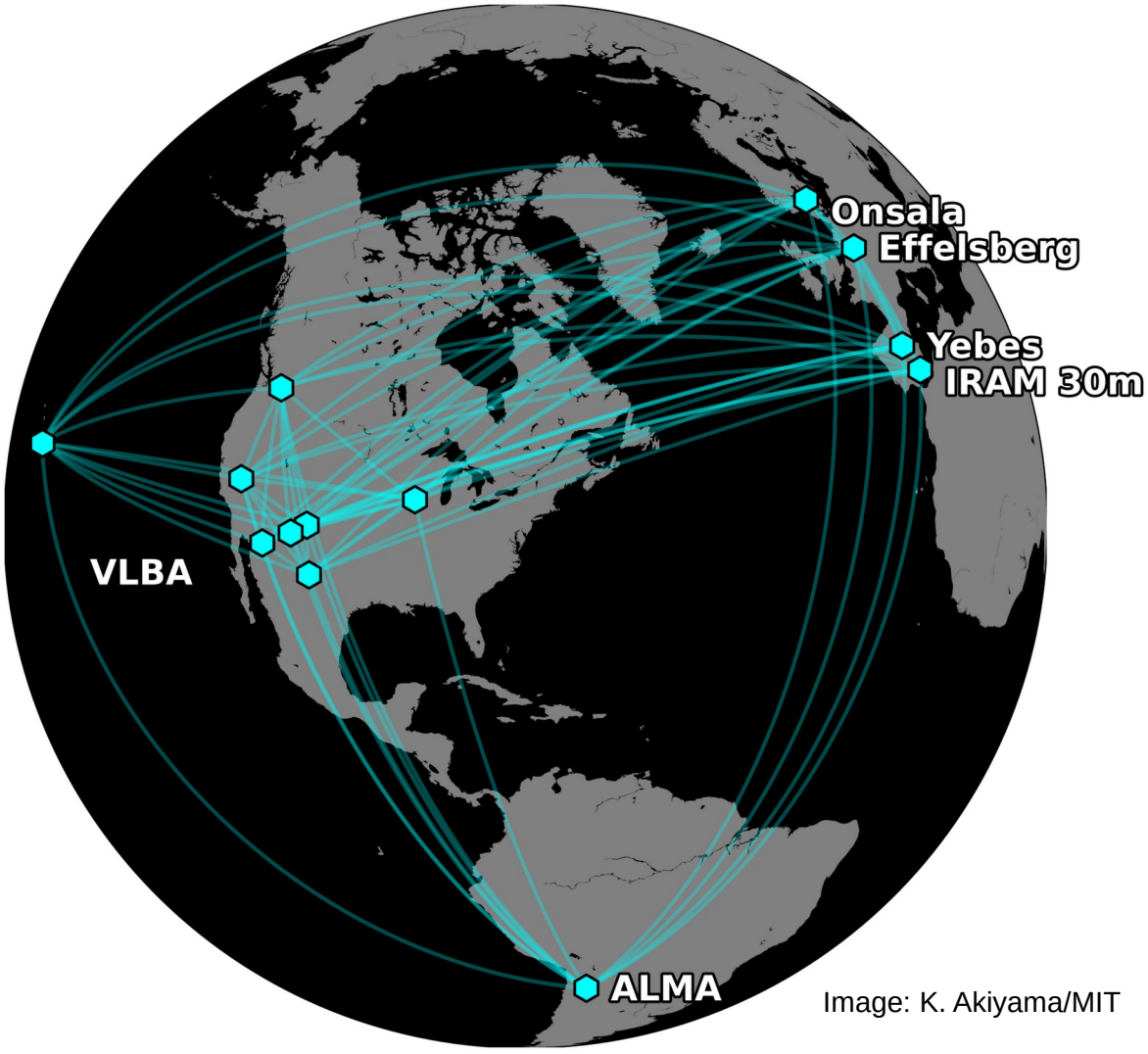
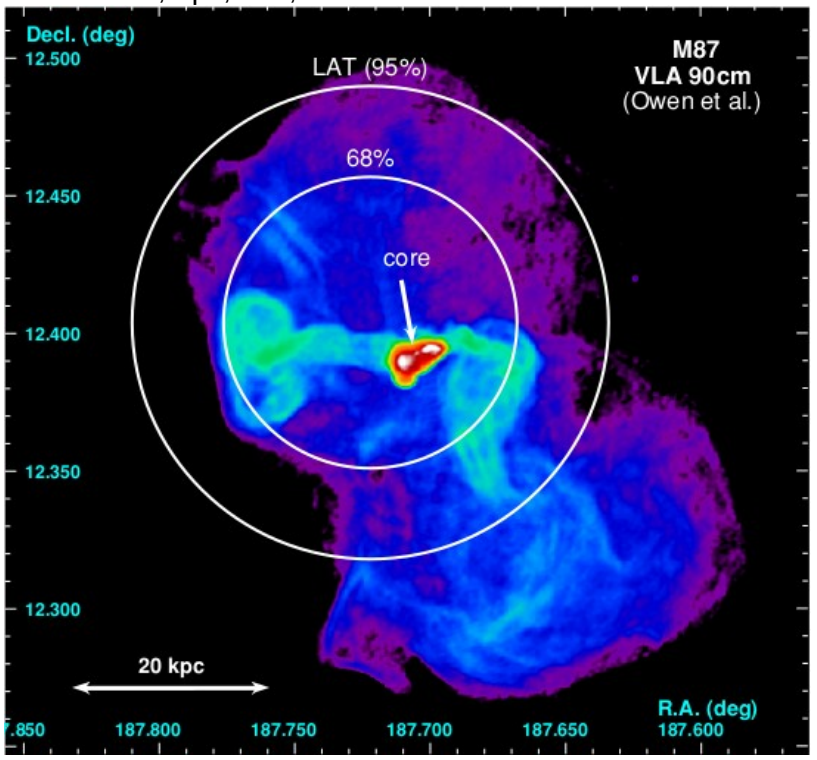


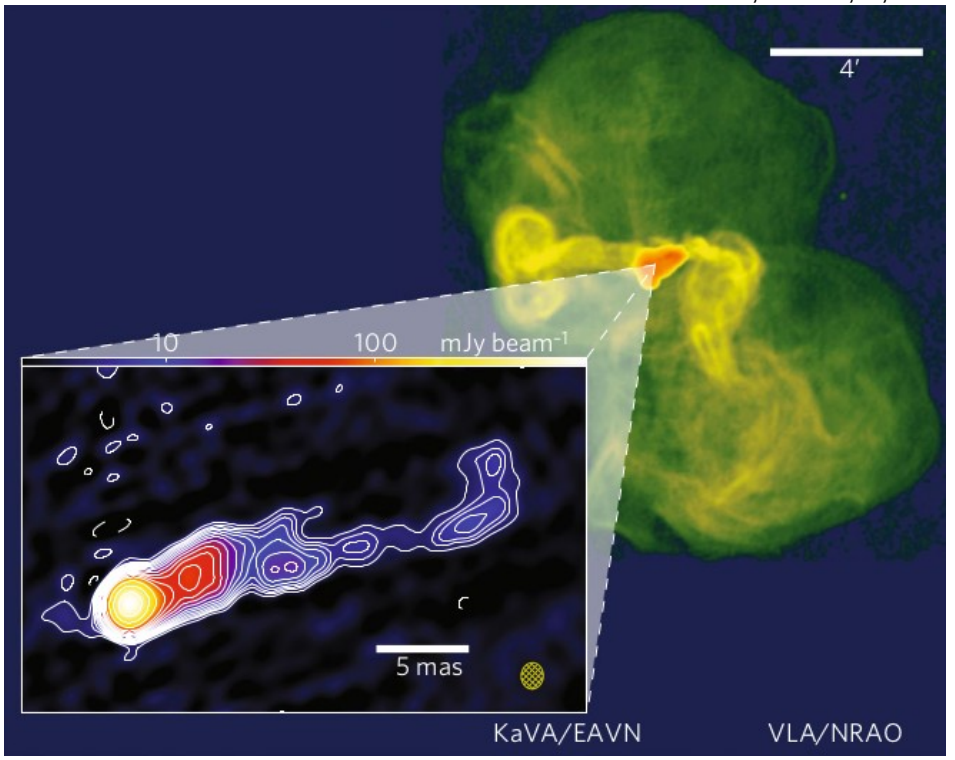
Image: K. Akiyama/MIT

Why VLBI?

Abdo+2009, ApJ, 707, 55



An+2018, NatAs, 2, 118



- *milli*-arcsecond (**mas**) scales → e.g., VLBA & EAVN
- *micro*-arcsecond (**μas**) scales → e.g., GMVA & EHT

Blazars & LAT

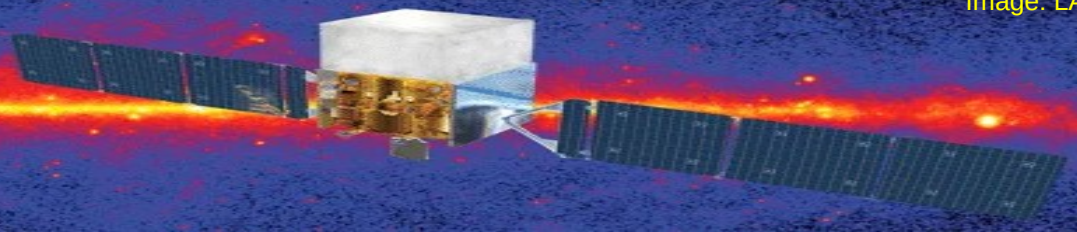


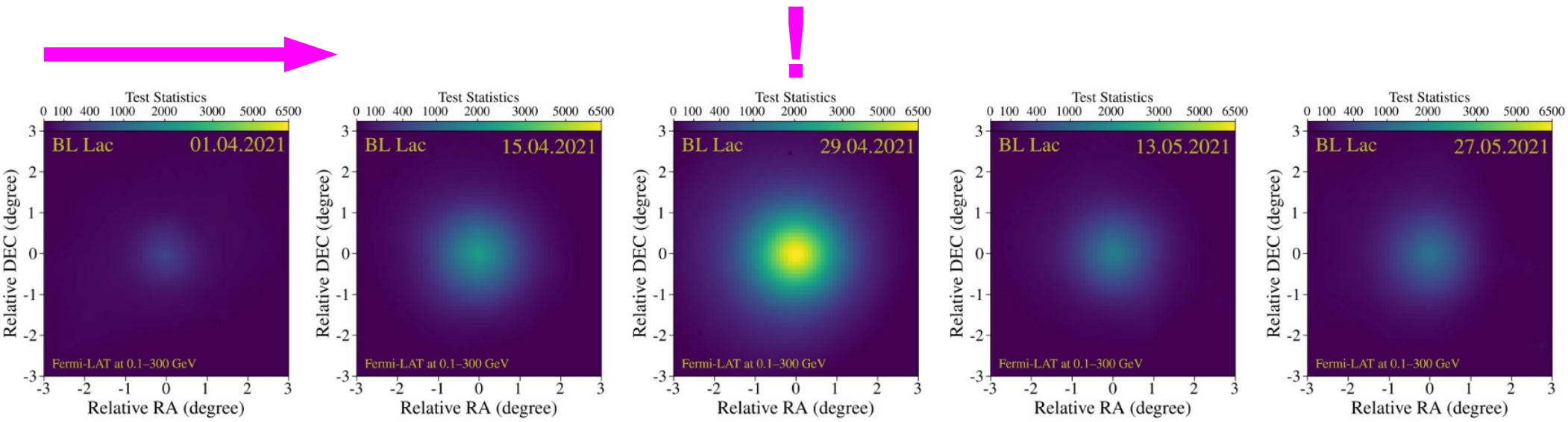
Image: LATC

- **Primary target object of the LAT**
- **Super bright & highly variable**

- Dominant source type (e.g., Ajello+2020)
- Leptonic models (e.g., Lewis+2018)
- Energy dependence (Dotson+2012)
- γ-ray absorption (Costamante+2018)
- Minute-scale events (e.g., Meyer+2019)

Image: NASA/JPL-Caltech

Beyond the LAT view



- Despite of many achievements by the LAT, yet our understanding remains limited
- To confirm *what is actually happening* in that flaring region → **'VLBI'**

Synergies with VLBI observations

- Main source in blazar SEDs → **Jet**
- γ-ray variability by the **LAT**
- Radio jet activity monitored by **VLBI**
- Jet/γ-ray physical connections?
- VLBI product → **Images** of the jets
  - *True jet structure (total intensity)*
  - *Jet kinematics*
  - *Spectral index map*
  - *Polarimetry (linearly polarized emission)*
  - *Rotation measure map*

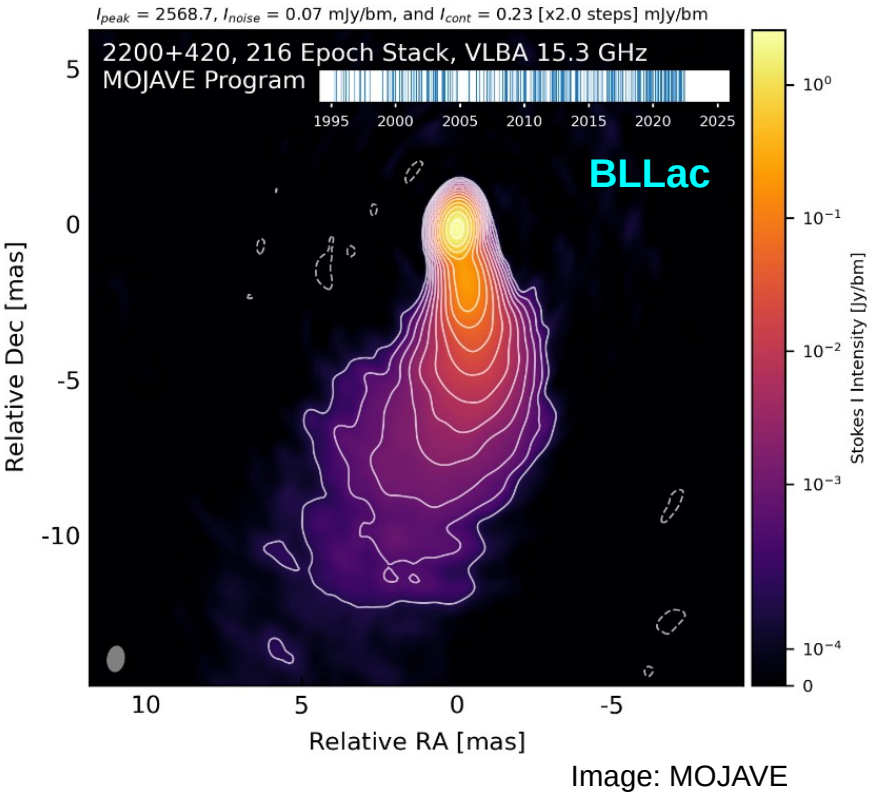
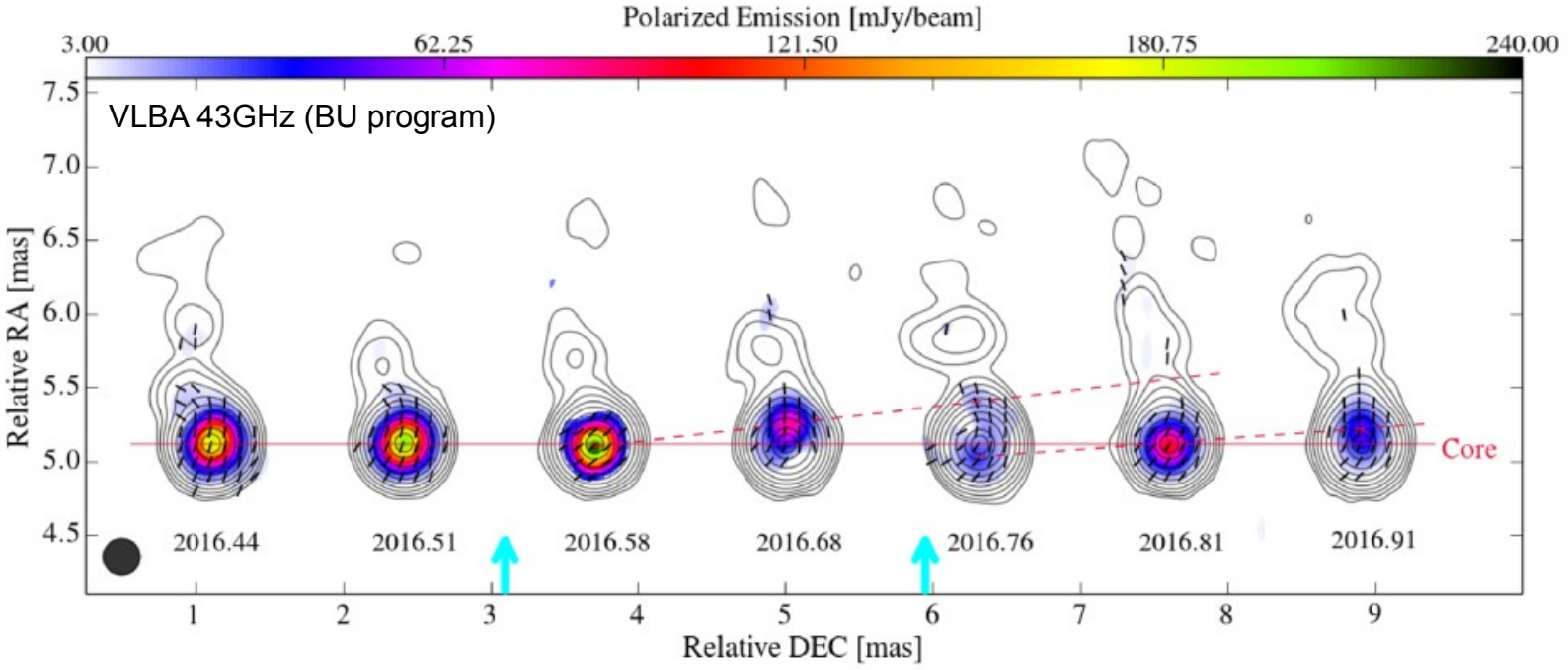


Image: MOJAVE

VLBI+LAT: Blazar OT 081

**Kim+2018, MNRAS, 480, 2324*

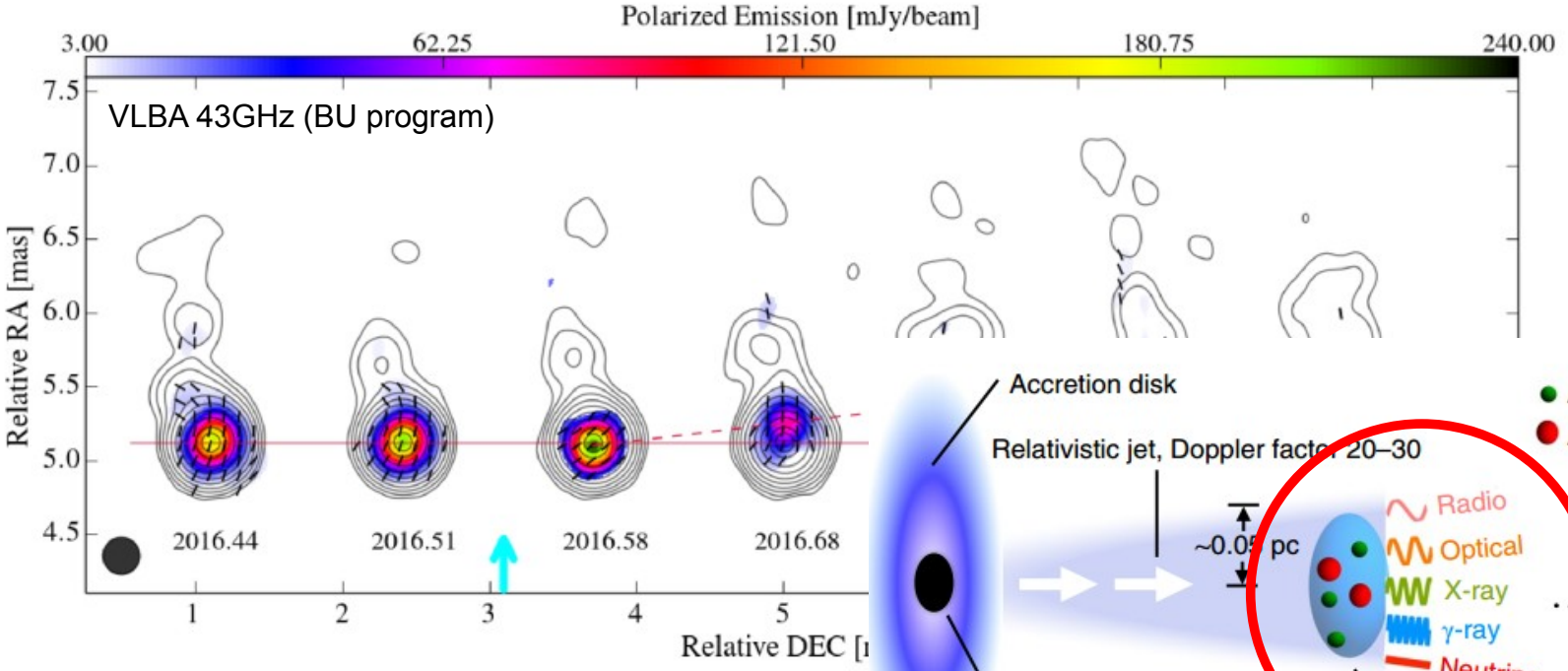


During **two γ-ray flares** (*two cyan up-arrows*),

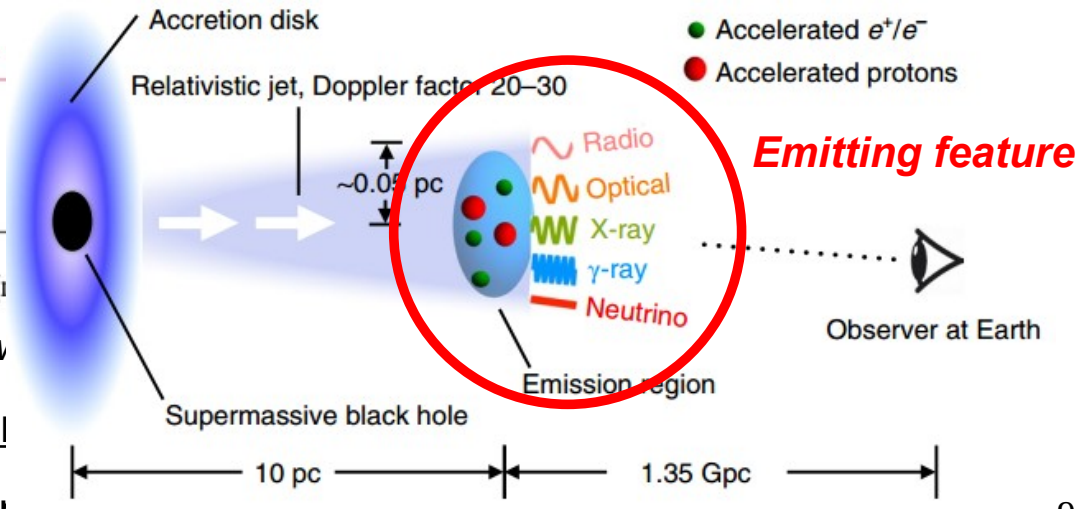
- Unresolved upstream region (i.e., **Core**) → enhanced emission/variability
- Something is ***moving***! → the emergence of an emitting feature (i.e., moving shock)

VLBI+LAT: Blazar OT 081

*Kim+2018, MNRAS, 480, 2324



Gao+2019, NatAs, 3, 88



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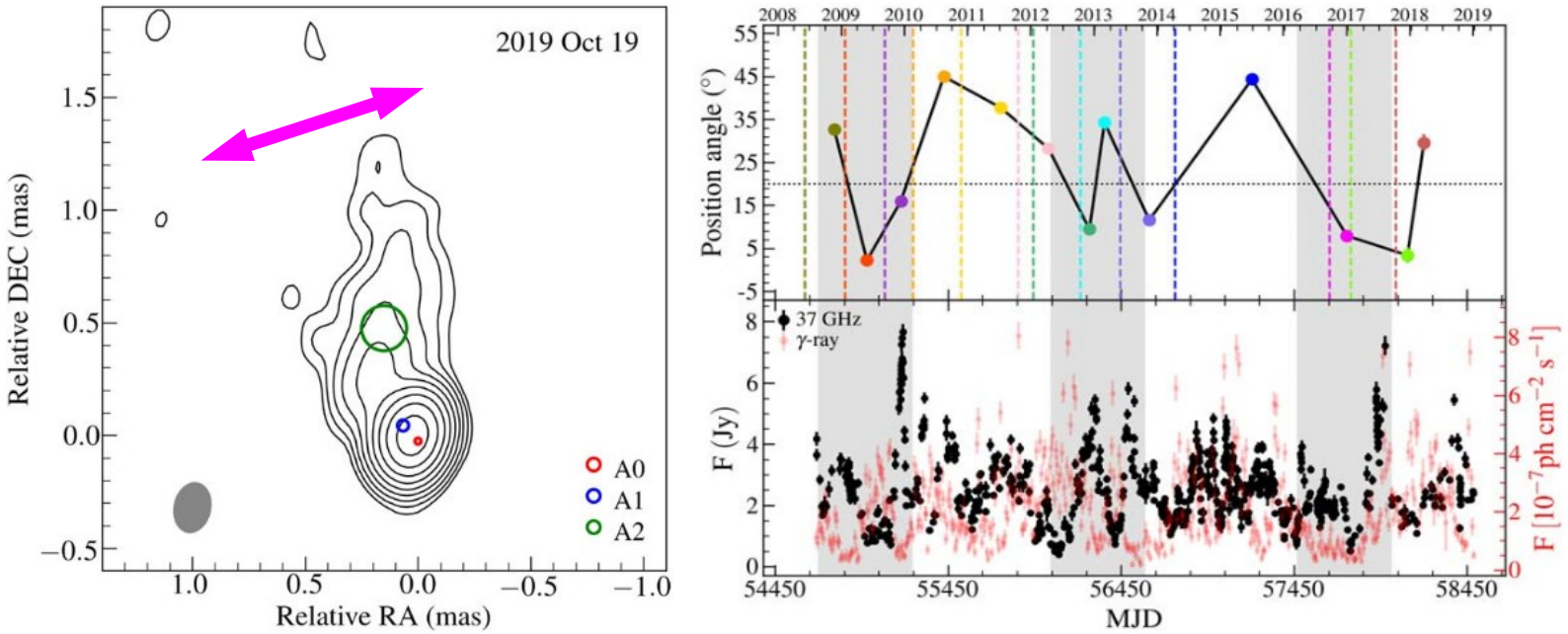
VLBI+LAT: Blazar TXS 0716+714

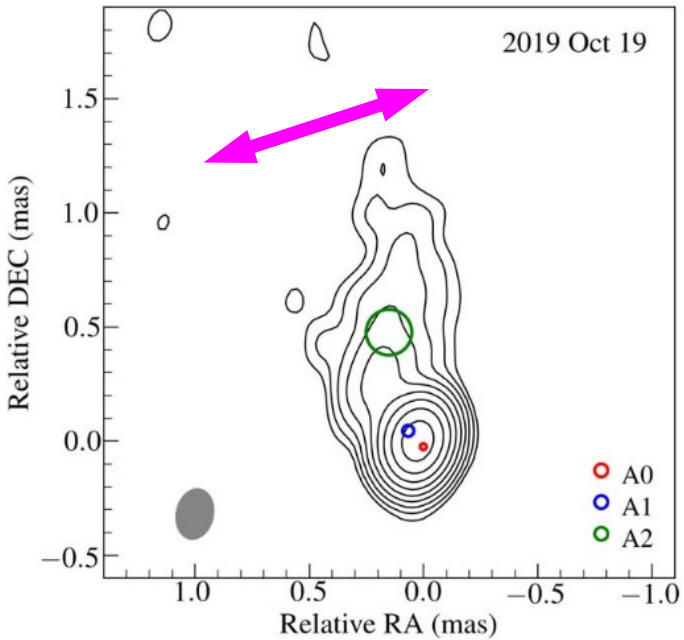
*Kim+2022, ApJ, 925, 64

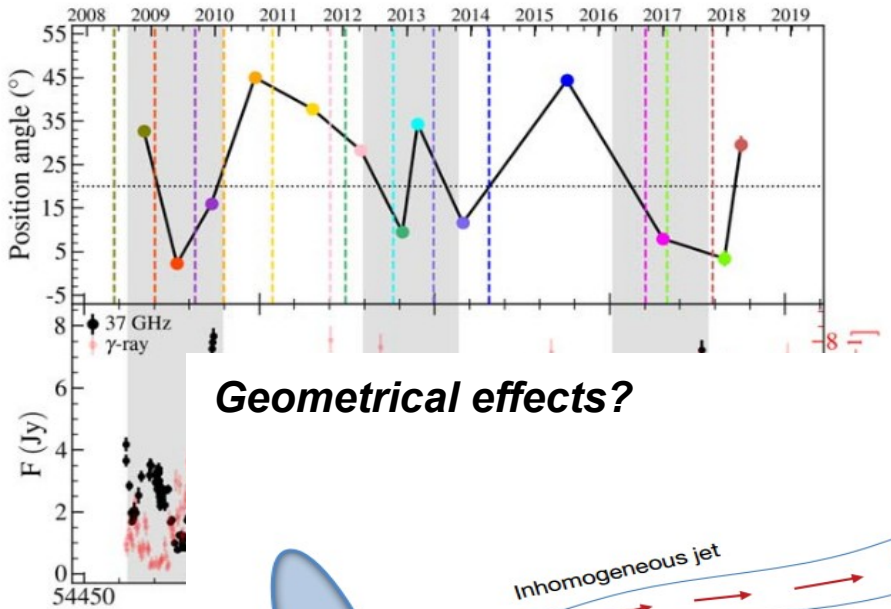


- Mean position angles of the moving features during a long-term γ-ray active state
- Significant radio–γ-ray correlations when the jet was aligned **toward the North!**

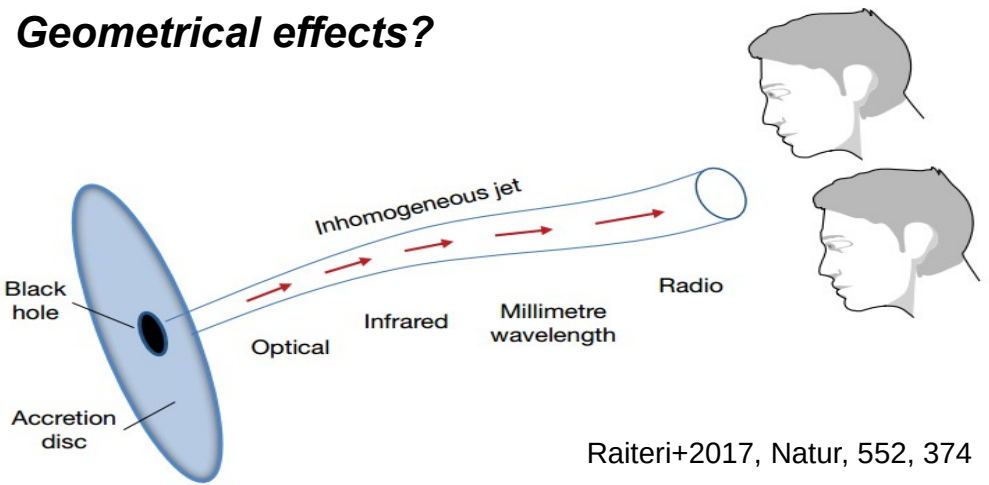
VLBI+LAT: Blazar TXS 0716+714

*Kim+2022, ApJ, 925, 64





Geometrical effects?

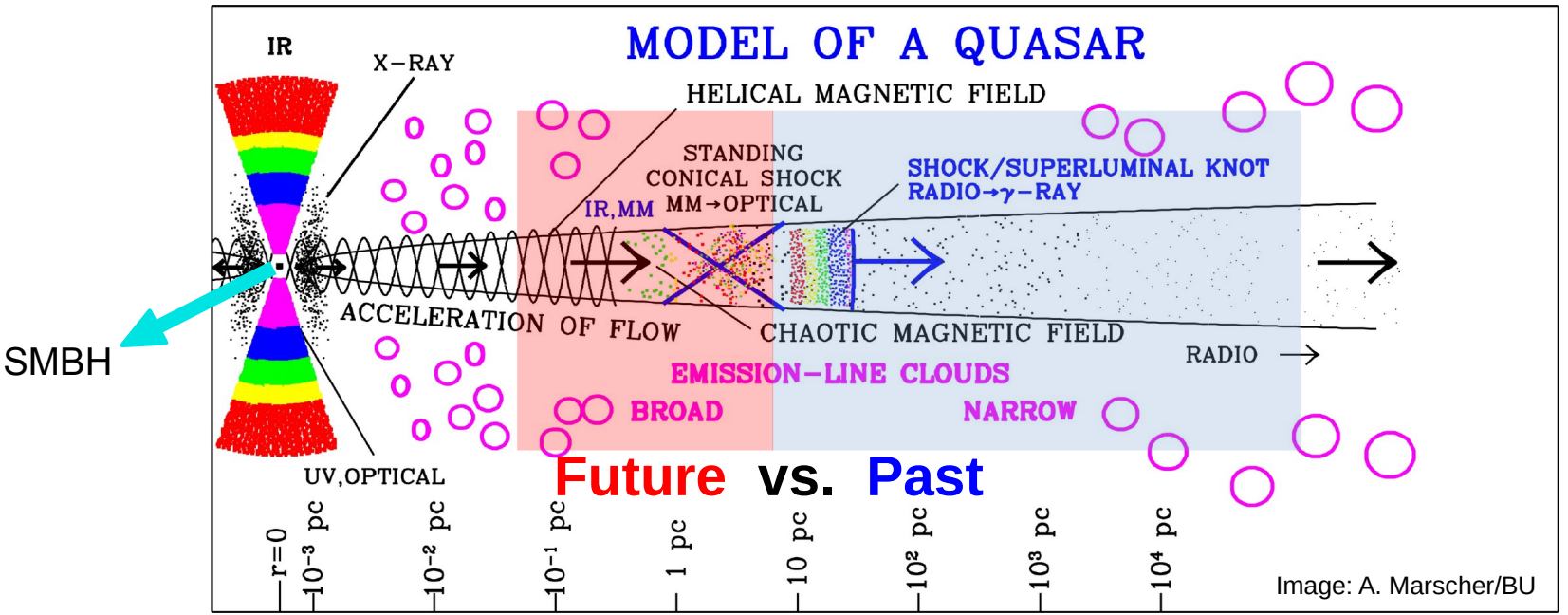


- Mean position angles of the moving fe
- Significant radio–γ-ray correlations wh

Raiteri+2017, Natur, 552, 374

VLBI still interesting?

"...it's been more than 15 yrs and they are not NEW anymore."



- **Jet downstream**: Lower frequency bands & Insufficient resolution
- **Jet upstream**: radio variability, γ-ray flares, & various Acc. processes
  - So far, NOT fully understood and rather hidden!

Remaining Questions

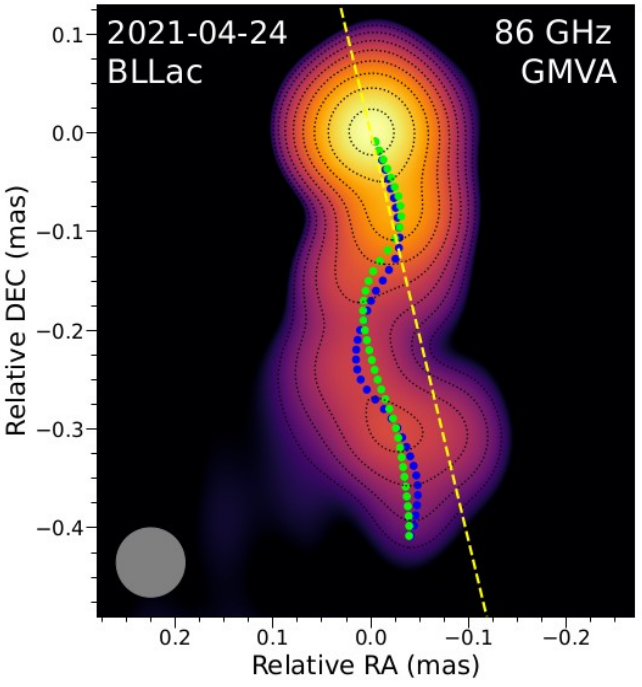
- Origin of the **orphan** γ-ray flares without multi-waveband flares (i.e., counterparts)?
- Some of the **ejections** of moving jet components without gamma-ray flares?
- Detailed **dynamics** of the gamma-ray emitting regions/knots?
- Physical **conditions/environments** of the jet upstream regions?
- Any observable **signatures** of magnetic reconnection, instabilities, turbulence, etc.?
- Is there any **relationship** between Hadronic events and VLBI-scale jet activity?

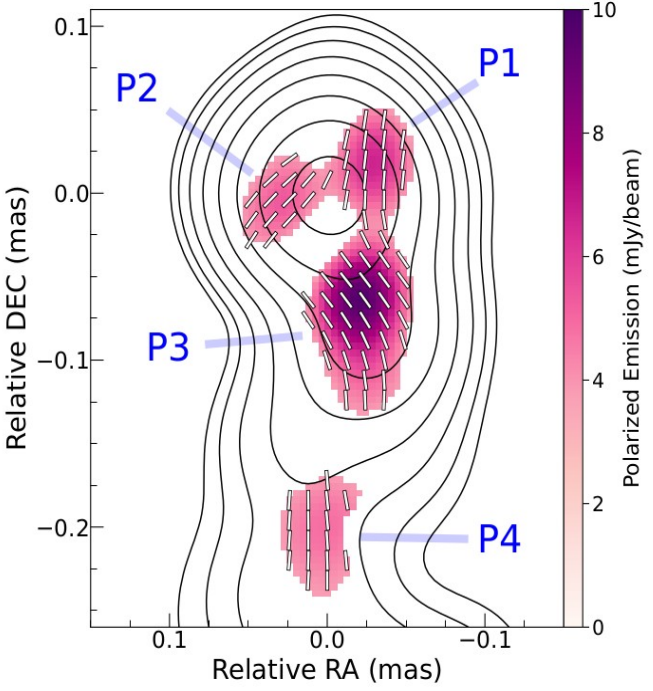
"**New VLBI era** is coming"

- Instrumentation: The upgraded **GMVA** & **EHT** (≥ 86GHz & 10–50μas)
- Techniques: Super-resolution imaging & Frequency Phase Transfer (FPT)

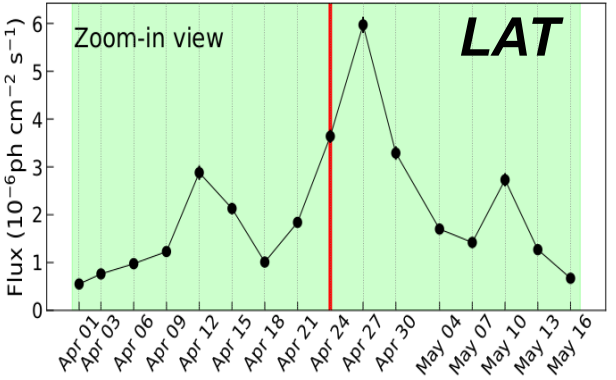
→ This could lead us to further advancement!

VLBI+LAT: Blazar BL Lacertae (BLLac)





*Kim+2023, A&A, 680, L3

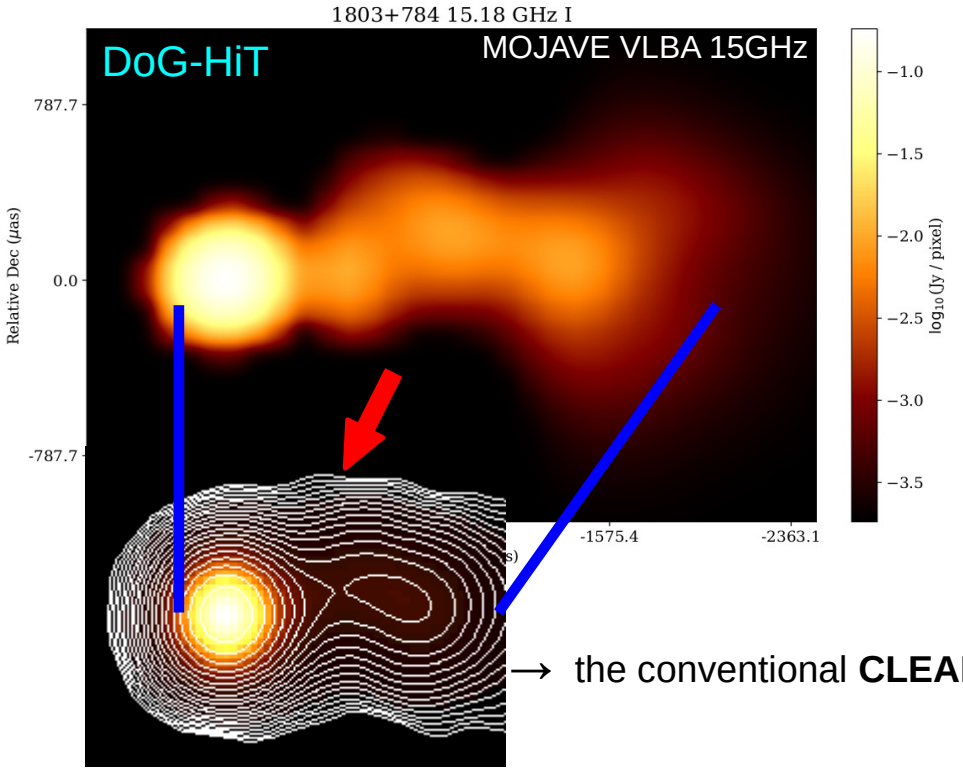


→ ~0.5–5.0pc from SMBH

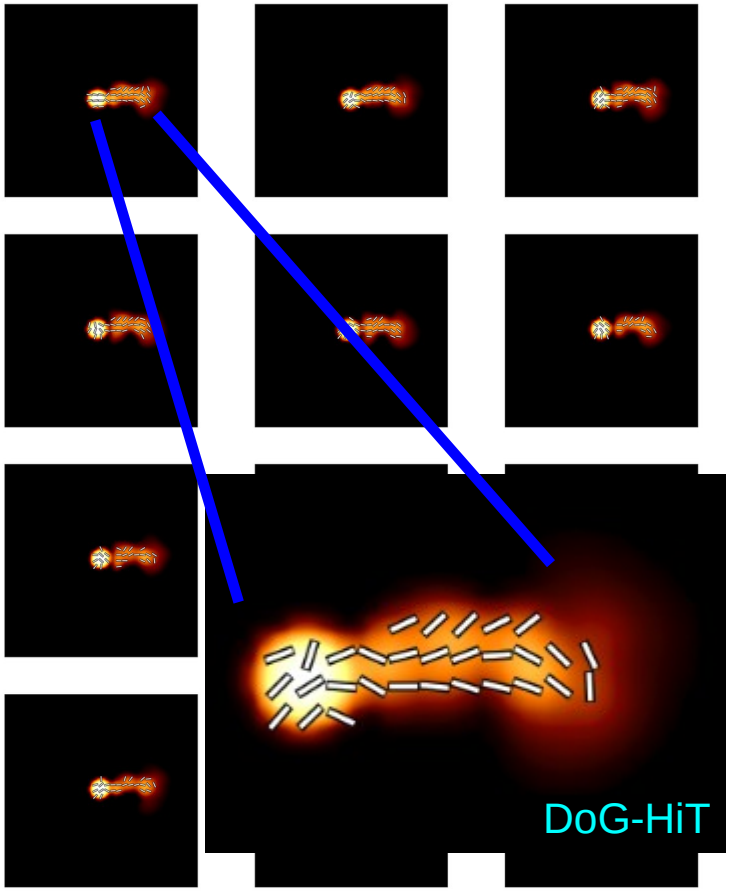
- The *upgraded* GMVA with **NOEMA** (+APEX from 2025): Img. Sensitivity → factor of 2.5
- A clear wiggling structure (not straight) & distinct polarized knots (not single knot)
- Capture of a moment of the jet just 3-days before a historically brightest γ-ray peak

VLBI+LAT: Blazar S5 1803+784

*Kim+2025, in prep.



→ the conventional **CLEAN**



Images: H. Müller/NRAO

- Advanced imaging with **DoG-HiT** (Müller & Lobanov 2022)
- <u>Resolving the source structures better than the **CLEAN**</u>
- Peculiar behavior in the core EVPAs with γ-ray flares

Access to VLBI data

1. Publicly available Archival data

- The MOJAVE monitoring program (VLBA 15GHz)
  - https://www.cv.nrao.edu/MOJAVE/allsources.html
- The BU group monitoring program (VLBA 43GHz)
  - https://www.bu.edu/blazars/BEAM-ME.html
- The NRAO archival database (GMVA/VLBA/VLA)
  - https://data.nrao.edu/portal/#/

2. Observing proposal

- The deadline for GMVA/VLBA/HSA in **Feb.** & **Aug.** every year (call for proposal)
- EHT proposals should be submitted to the ALMA cycle (**Apr.** every year).

Summary

- VLBI offers the highest resolution images of astronomical objects.

- ***The role of VLBI*** *in LAT studies of γ-ray bright AGNs* is to reveal the true nature of the source such as its resolved structures, physical properties/conditions, kinematics, and evolution.

- The new era of (sub)mm-VLBI with the instrumental/technical advancements will broaden our understanding of AGN jet physics and the origin/process of the high energy γ-ray emission in Blazar jets.

- VLBI+LAT are a great area, as there are many radio synergies with γ-ray observations.

Image: Norbert Tacken/MPIfR