Catching a glimpse of the radio light from the earliest AGN jets

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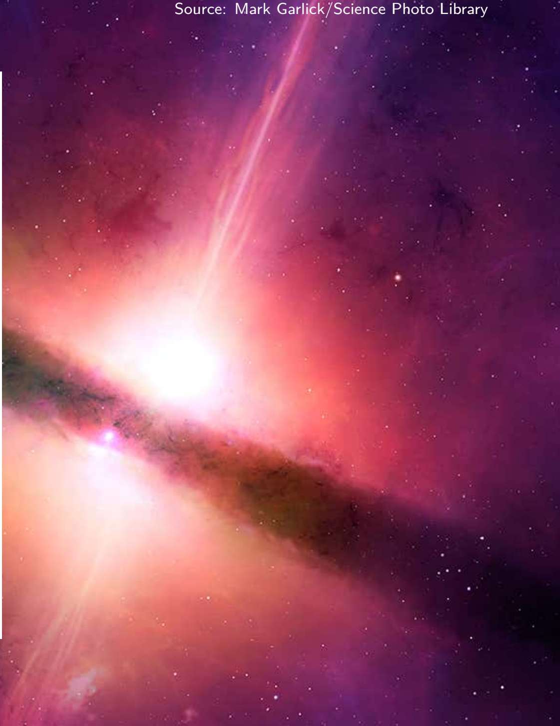
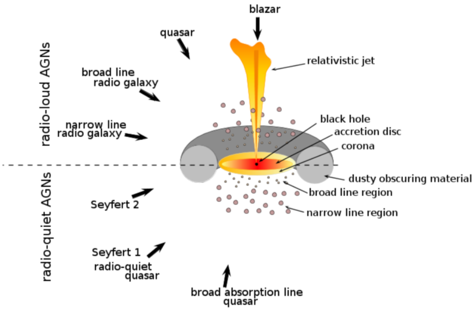
KONKOLY SEMINAR



Source: Mark Garlick/Science Photo Library

Active galactic nuclei – AGNs

- compact regions
- SMBH accretion
- luminous through the entire EM regime
- radio jets (synchrotron emission)
- classfication: radio emission and inclination



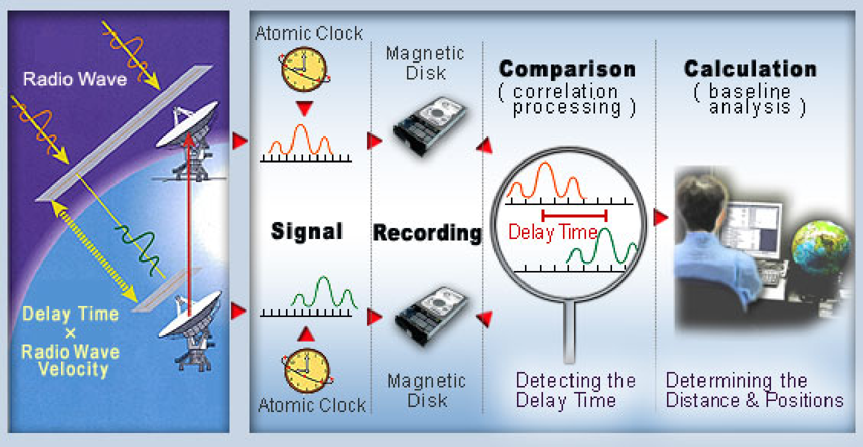
(Perger 2020, doi: 10.15476/ELTE.2020.161)

AGNs at high redshifts

Open questions:

- ‘too many blazars’ problem
- relationship between AGNs and SF
- formation of the first SMBHs
- cosmological evolution of AGNs
- AGN activity cycle

Very long baseline interferometry (VLBI)

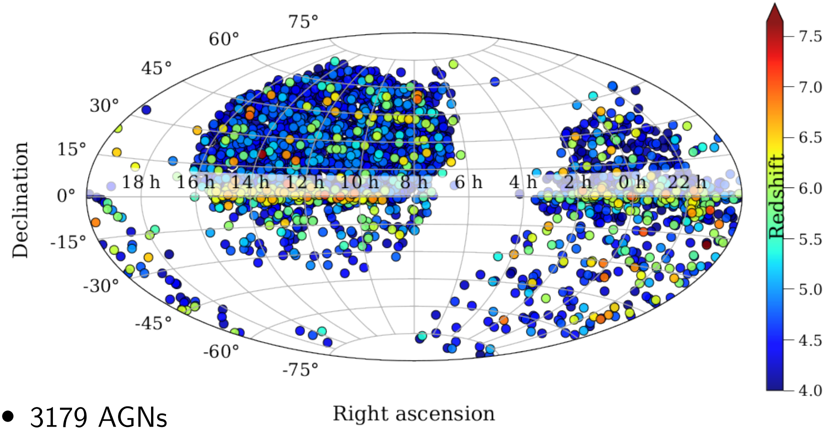


source:spacegeodesy.go.jp

- spatial resolution better than mas
- VLBI array – baselines $\sim$ Earth diameter
- space-VLBI (RadioAstron; future: THEZA)
- correlation of data
- fringe-fitting, amplitude and phase calibration in AIPS or CASA
- amplitude and phase self-calibration, imaging, and model fitting (circular/elliptical Gaussian) with DIFMAP

Catalogue of $z \geq 4$ AGNs

(Perger 2020, doi: 10.15476/ELTE.2020.161)



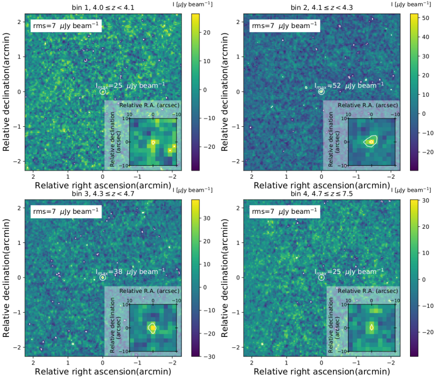
- 3179 AGNs
  - FIRST, NVSS, and/or VLASS detection: 222 (70 VLBI)
  - not detected (FIRST coverage): 2442
  - outside FIRST/NVSS coverage: 460

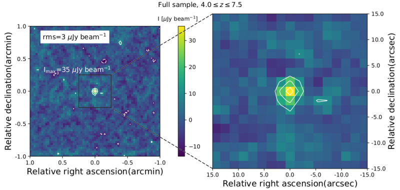
Revealing sub-mJy radio emission by image stacking

- Faint Images of the Radio Sky at Twenty-Centimeters (FIRST) survey
- low-power AGNs: not well-known $\rightarrow$ stacking
- image noise decreases, ‘real’ radio emission is revealed
- 2229 AGN in FIRST coverage but no detection
- mean and median stacking
- what is the origin?

Median

(Perger et al. 2019)





SNR (4,7,5,4,11)

Flux densities

- 2D circular Gaussian model
- unresolved point source
- 52 μJy (after correction)

- bit higher than low-z jets
- radio-AGN in the sample!

- point source: central pixels
- co-added images: 77 mJy
- assumption: all same characteristic power

- spectral indices: $-0.5 \geq \alpha \geq -1$
- 1.4 GHz radio power: $2.9 - 6.8 \times 10^{24}$ W Hz^{-1}

What is the origin of the radio emission?

AGN activity

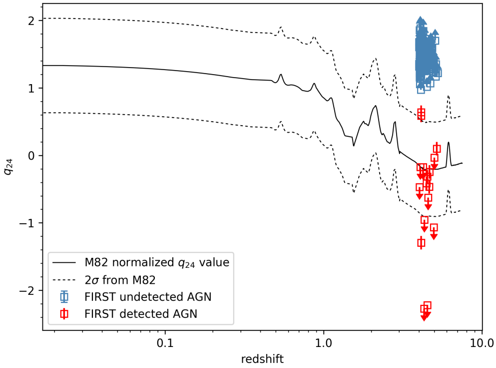
- synchrotron emission by radio jets
- moderately radio-loud AGN
- most luminous AGN: 10^{24} W Hz^{-1} to 10^{26} W Hz^{-1}
- however: upper limits!

host galaxy SF

- SF dominance is below $100~\mu$Jy
- radio-to-SFR $400 - 4200$ M$_{\odot}$ yr^{-1}
- high-z quasar hosts with 1000 M$_{\odot}$ yr^{-1}

Origin of radio emission – MIR analisis

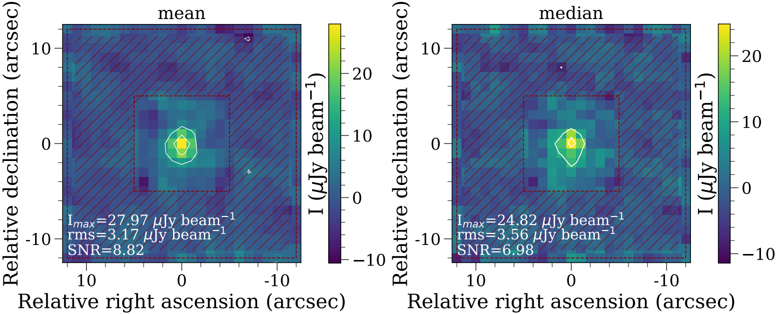
(Perger 2020, doi: 10.15476/ELTE.2020.161)



- MIR flux densities from $P_{1.4\mathrm{GHz}}$: $S_{24\mu\mathrm{m}} = 30 - 50$ mJy
- WISE: detection at 124 positions; $2 - 11$ mJy
- radio excess in the stacked sample $\rightarrow$ AGN contamination

Stacking of VLASS 3 GHz images – preliminary results

- better resolution and thermal sensitivity
- ~ 900 additonal radio non-detected AGN in my catalogue with available maps
- 2nd epoch VLASS observations soon concluded



Study of individual AGNs

J2134–0419

- $z = 4.334$
- compact: FIRST/NVSS
- VLA A observations and two epochs of EVN observations available
- X-ray study by Sbarrato et al. 2015

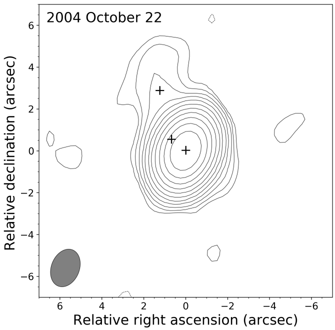
J0909+0354

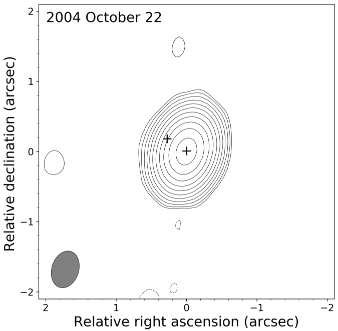
- $z = 3.29$
- compact: FIRST/NVSS
- VLA A: double
- *Chandra*: triple!
- available global VLBI
- new EVN observations planned

J2134–0419

Large-scale radio structure – VLA A configuration

(Perger et al., 2018)





1.4 GHz

- three components
- 311.5 ± 6.8 mJy.
- jet visible up to ∼35 kpc

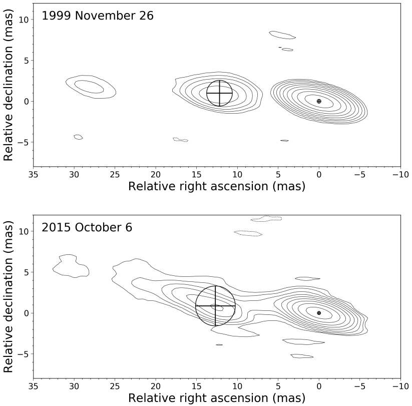
4.8 GHz

- two components
- 224.8 ± 6.2 mJy
- jet ‘resolved’

J2134–0419

Parsec-scale radio structure – EVN observations

(Perger et al., 2018)



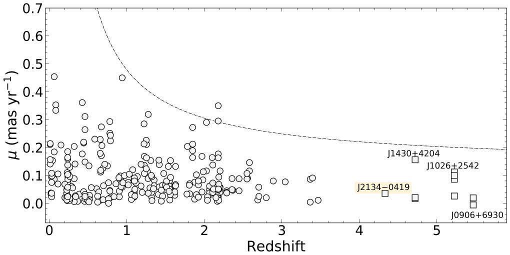
- $S_{1999,\text{total}}$ =136.1±5.9 mJy
- $S_{2015,\text{total}}$ =185.5±12.0 mJy
- $\sim 30\%$ core variability
- jet bending $\sim 60^{\circ}$ pc→kpc
- component proper motion:

  μ =0.035±0.023 mas yr^{-1}

  β_a =(4.1±2.7) c

Physical parameters

J2134–0419



- brightness temperature:

  $T_{b,1999} = (1.5 \pm 0.2) \times 10^{11}$ K

  $T_{b,2015} = (2.5 \pm 0.4) \times 10^{11}$ K

- Doppler factor:

  $3 \leq \delta_{1999} \leq 5$

  $5 \leq \delta_{2015} \leq 8.3$

- bulk Lorentz factor:

  $4.3 \leq \Gamma_{1999} \leq 4.5$

  $4.3 \leq \Gamma_{2015} \leq 5.2$

- viewing angle:

  $11.4^{\circ} \leq \theta_{1999} \leq 18.3^{\circ}$

  $5.5^{\circ} \leq \theta_{2015} \leq 11.4^{\circ}$

J2134–0419

Summary

- flux density variability
- helical jet (60° bending)
- high brightness temperatures
- superluminal motion
- marginally lower bulk Lorentz factor than from SED
- marginally higher viewing angles

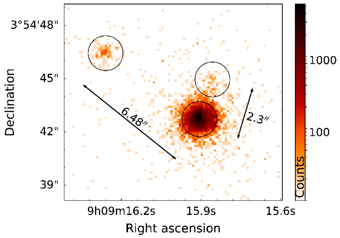
J2134–0419 is a blazar. The jet component proper motion is $\mu =$0.035$\pm$0.023 mas yr^{-1}, and is in agreement with the prediction of cosmological models.

J0909+0354

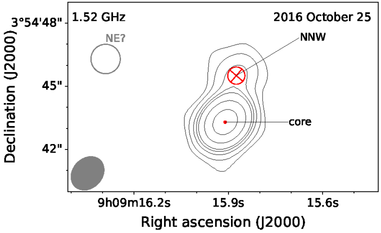
Large-scale structure – X-ray and radio

F_{C}=1.76e–12 erg cm^{-2} s^{-1}

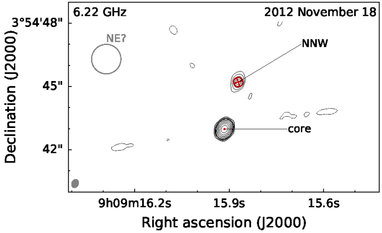
F_{NE}=4.5e–15 erg cm^{-2}s^{-1} F_{NE}=2.3e–14 erg cm^{-2} s^{-1}



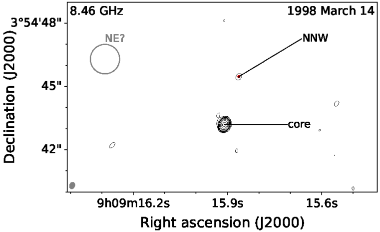
S_{L}=153.1±14.4 mJy (133.1±13.8 mJy)



S_{C}=198.9±12.6 mJy (193.6±12.5 mJy)



S_{X}=211.1±13.3 mJy (208.3±13.3 mJy)

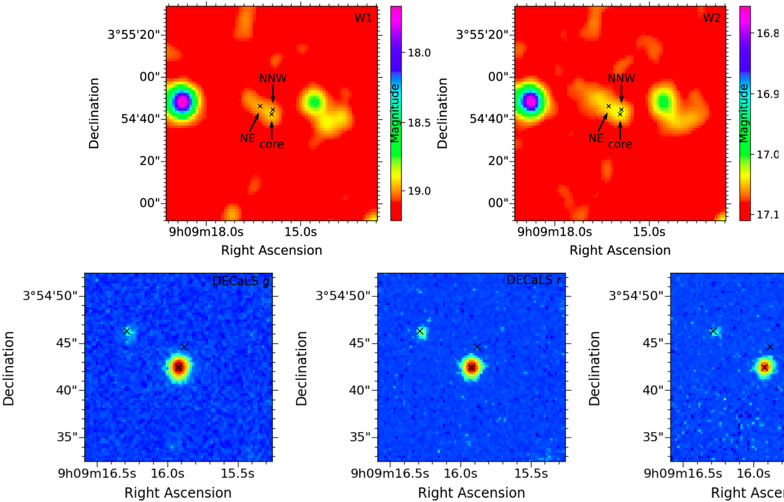


(Perger et al., 2021)

J0909+0354

Large-scale structure – MIR and optical

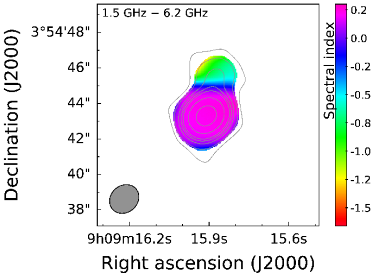
(Perger et al., 2021)

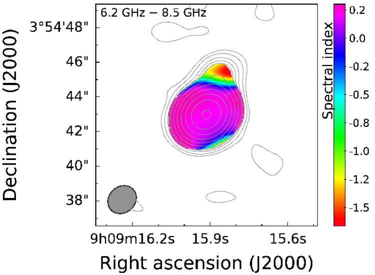


Legacy Surveys / D. Lang (Perimeter Institute)

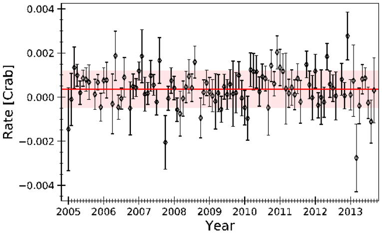
Spectral properties

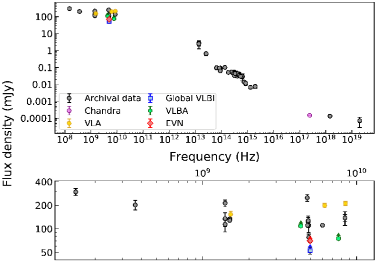
J0909+0354





$\alpha_{\text{NNW}} = -1.08 \pm 0.17$ $\alpha_{\text{core}} = 0.19 \pm 0.01$ $\alpha_{150\text{ MHz}}^{8.5\text{ GHz}} = -0.13 \pm 0.06$





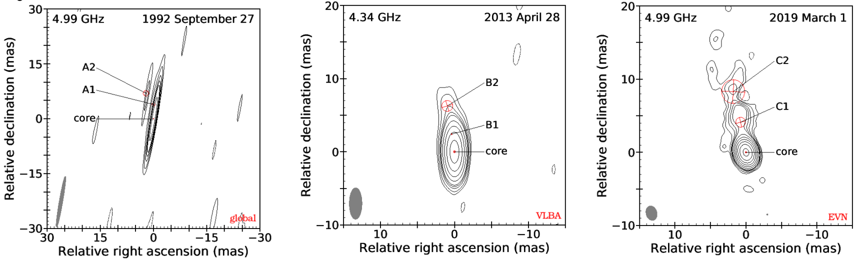
(Perger et al., 2021)

J0909+0354

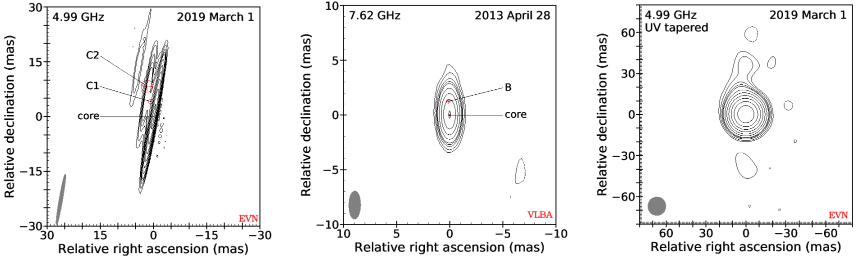
Parsec-scale structure

$S_{V4.3}$=108.9±7.2 mJy (102.2±6.7 mJy)

S_{gl}= 52.2±5.2 mJy (35.9±4.6 mJy) $S_{V7.6}$=75.1±5.4 mJy (67.4± 4.8 mJy) S_{EVN}=70.2±3.6 mJy (65.3±3.6 mJy)



(Perger et al., 2021)



Summary

J0909+0354

Detections

- core: radio MIR optical X-ray
- NNW: radio MIR X-ray
- NE: MIR optical X-ray

Spectral properties

- flat core, outward steepening
- variability in radio and X-ray

Structure

- ~250 pc jet towards NNW (at ~ 17 kpc)
- $\sim 30^{\circ}$ bending pc→kpc
- X-ray at kpc: core–NNW jet, core–NE no jet
- possible connection: MIR

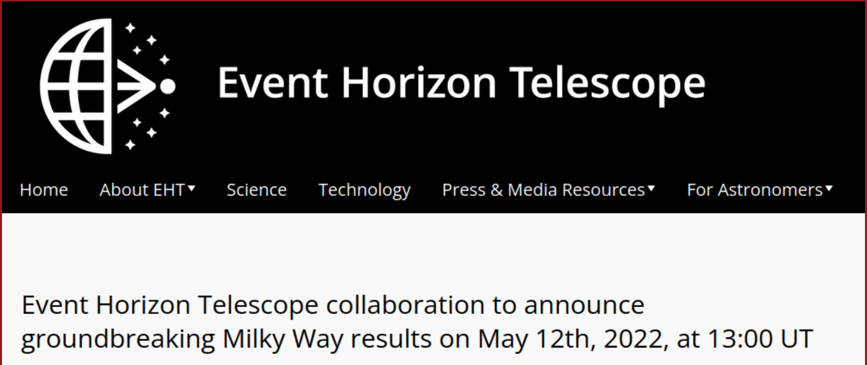
J0909+0354 is a blazar. NNW is a hotspot, NE is not a jet component, but might be in physical connection with the system.

Source: ESO/M. Kornmesser

Collaborators:

S. Frey, K. É. Gabányi, M. Krezinger, L. V. Tóth, T. An, S. Britzen, H-M. Cao, D. Cseh, J. Dennett-Thorpe, L. I. Gurvits, I. Hook, X. Hong, Z. Paragi, S. Pintér, R. Schilizzi, D. Schwartz, J. Yang, Y. Zhang

Stay tuned for new EHT results at 15^{00} CET



Vajon mit láthatott a különleges, világméretű rádióteleszkóp-hálózat, az Eseményhorizont Távcső? (Facebook live)

Press Conference at ESO on new Milky Way results from the EHT team, followed by a public Q&A event (Youtube)