Millimeter VLBI in Europe

Jet Formation in Active Galactic Nuclei

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(on behalf of the European mm/sub-mm VLBI team)

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What does VLBI at short millimeter wavelengths offer?

- Study compact galactic and extragalactic radio sources with an angular resolution of a few ten micro-arcseconds (size, structure, kinematics, polarization).

- Image regions which are (self-) absorbed and therefore not observable at longer cm-wavelength. Relate broad-band variability (radio to TeV) to jet physics (e.g. outburst – ejection relation in early stage).

- Image the jet launching region with highest possible resolution (transverse profiles, stratification, helical motion, precession, BBHs, ...).

- For nearest Black Holes a chance to map immediate vicinity of a SMBH (Sgr A*, M87, etc.) with a spatial resolution of 2-100 gravitational radii (accretion disk, orbital motion, jet-launching, General Relativity effects: space-time curvature, frame dragging + BH spin, GRMHD).
Atmospheric windows allow mm-VLBI in the following bands:

- **43 GHz (SiO)** AB1 regularly done at VLBA, VERA, occasionally also global
- **86 GHz (SiO)** AB3 regular global observing (GMVA, VLBA-only)
- **129/150 GHz** AB4 pilot studies, fringes detected for continuum & spectral lines
- **215/230 GHz** AB6 first results, SgrA* + some AGN for up to 8500 km baselines
- **345 GHz** AB7 planned
The Global Millimeter VLBI Array (GMVA)

Imaging with ~40 μas resolution at 86 GHz

Baseline Sensitivity

in Europe:
30 – 300 mJy

in US:
100 – 300 mJy

transatlantic:
50 – 300 mJy

Array:
1 – 3 mJy / hr

(assume 7σ, 100sec, 512 Mbps)

http://www.mpifr-bonn.mpg.de/div/vlbi/globalmm

- Europe: Effelsberg (100m), Pico Veleta (30m), Plateau de Bure (35m), Onsala (20m), Metsähovi (14m), planned: Yebes (40m), GBT (100m), ALMA

- USA: 8 x VLBA (25m)

Proposal deadlines: February 1st, August 1st
A 3mm VLBI survey of 127 AGN:

\[ T_b = \frac{2 \ln 2}{\pi k_B} \frac{S_{\text{tot}} \lambda^2}{d^2} (1 + z) \]

Brightness temperature decreasing with frequency?

Brightness temperature increasing along jet; evidence for intrinsic acceleration?

mm-VLBI surveys of AGN can discriminate between fundamental models of jet formation.
Global 3mm VLBI of M87 with the GMVA

Structural variability in M87 on < 50 μas scales (15 R_s)

Peak: approx. 1.5 Jy

note:

at mm/sub-mm wavelength AGN generally become weaker and jets are partially resolve

→ need good sensitivity (≤ 0.1 Jy)

Peak: approx 0.7 Jy
Variability in the inner jet of M87 detected: $\geq 0.2 \text{ mas/yr} \leftrightarrow \approx 18000 \text{ km/s (0.06c)}$

(but: $3 - 6 \text{ c}$ seen further downstream)
Size of jet base may be too small for magnetic sling-shot acceleration. Evidence for direct coupling to BH spin? → a GR-MHD Dynamo?

Limit of the size of the jet base (uniform weighting):

\[197 \times 54 \text{ \mu as} = 21 \times 6 \text{ light days} = \frac{54 \times 15}{9} R_s\]

Transverse width of jet at 0.5 mas: \(~140 R_s\)
BP versus BZ mechanism

Blandford – Payne mechanism:
centrifugal acceleration in magnetized accretion disk wind

Blandford – Znajek mechanism:
electromagnetic extraction of rotational energy from Kerr BH

Jet speed
Jet width
\( T_B \)

Shape of Nozzle

Magnetic Field
BH Spin
etc.

need to reach scale of a few \( R_G \)
Non-ballistic (helical) motion in the jet of quasar 3C345

results from F. Schinzel, PhD Thesis 2011

C3 – C7

C7 – C15
Qian et al. 1991, 1992: model of helical motion in jets

Need highest angular resolution to trace helical trajectories back to origin. Need mm-VLBI to discriminate between jet fluid instabilities (KH or MHD) and/or geometrical causes (precession, BBH or orbiting nozzle).

Steffen et al. 1995

Fig. 1. Coordinate system used in the model calculations

Fig. 1. Geometry and coordinate systems of the 'helical motion model' as used in Qian et al., 1992.

Fig. 2. Three out of four quantities are assumed to be constant during the motion of a jet component: the Lorentz factor \( \gamma \), the specific angular momentum \( L_z \), and the specific momentum along the jet axis \( p_z \), and the opening angle of the jet \( \psi \). Three of them are needed for every specific case.
Development of mm-VLBI in Europe

- 1991  first VLBI with Pico Veleta at 7mm (43 GHz)
- 1992  3mm (86 GHz) VLBI pilot studies in small arrays
- 1993/95 1.4mm (215 GHz) VLBI pilot studies on PV-PdB\textsubscript{single} baseline
- 1997  global 3mm VLBI, up to 10 stations, PV participates in CMVA
- 2001/2 1\textsuperscript{st} VLBI at 147 GHz on PV-Metsa baseline, first transatl. fringes PV-HHT
- 2002.8 phasing of PdB becomes possible
- 2003  GMVA established, PdBI joins global 3mm VLBI (N=13, 5 x Eur + 8 x VLBA)
- 2003.3 1\textsuperscript{st} VLBI at 1.3mm (230 GHz), PV-PdBI detects 9 sources with SNR ~25, 1\textsuperscript{st} transat. fringes PV-HHT (2 sources, SNR = 6-7)
- 2005  switch to MK5A disk recording, improved GMVA performance, dual pol.
- 2007/8 PdBI receiver upgrade, better phase stability due to new H-Maser and LO
- 2007  VLBI at 230 GHz, 4 Gbit/s, SgrA* detected on US-Hawaii basel., NOF@PV
- 2009  new EMIR receiver at PV, at 86 GHz SNR 3840 on 3C273 (PV-PdBI)
- 2010  VLBI at 1.3mm (230 GHz) at 1 Gbit/s (PV – PdBI, SNR ~ 460)
- 2011/12 combine APEX + IRAM + US, DBBC/DBE + MK5C bandwidth upgrade
The sensitivity of both IRAM telescopes (PV & PdBI) for VLBI at ~230 GHz is excellent.
Phase coherence at 230 GHz in October 2010
PV - PdB (phased)

Coherence 230 GHz PV-PdB
(3C454.3, Oct 12, 2010)

Coherence 230 GHz PV-PdB
(3C454.3, Oct 12, 2010)

good VLBI-phasing efficiency of the 6 elements of the PdB interferometer
but: old correlator supports only 1 GBit/s (16 x 16 MHz, MK5A)
present WIDEX correlator does not support VLBI array phasing at all.
Global Millimeter VLBI with APEX

Observations of Sgr A*

ν = 230, 345 GHz

Mutual Visibility

IRAM + APEX: ~5 hrs
USA + APEX: ~6 hrs

APEX/ALMA connect the European with the US VLBI subarray
Applying phase correction using the phasecal

Detection of phasecal tone in fourfit

SNR ~ 916

After phase correction using phasecal tone: SNR ~ 1187

~ 30% improvement

Still: no fringes detected to APEX from this experiment
Research Plan

• Image Sgr A* with highest possible angular resolution (IRAM-APEX-USA), study for the first time the silhouette around a super-massive Black Hole

• Study the origin of the jet in M87 and how the jet is launched, make polarimetric VLBI images, perform variability studies.

• Study jet acceleration & confinement in nearby Radio Galaxies, where possible determine size of obscuring nuclear torus/disk (for two-sided jets like Cyg A)

• Study distant AGN at their blue shifted sub-mm restframe frequency ((1+z)-correction), determine size and brightness temperature as function of redshift, determine ratio of thermal to non-thermal emission as function of cosmological distance and AGN classification (1.3mm VLBI pilot survey)

• MPIfR/OSO/IRAM continue to work towards mm-VLBI with APEX, solve remaining technical issues, perform further VLBI tests, do global VLBI at 230 and 345 GHz
A submm telescope in Greenland would improve the uv-coverage for sources with $\delta > -7^\circ$.

For SgrA* a location in South Africa or Namibia would be also very good!