Millimeter VLBI in Europe

Jet Formation in Active Galactic Nuclei

T.P.Krichbaum

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

Max-Planck-Institut für Radioastronomie

Bonn, Germany

tkrichbaum@mpifr.de

people involved:

MPIfR: T. Krichbaum (project scientist), A. Roy (project manager)
W. Alef, U. Bach, A. Bertarini, R. Güsten, D. Graham, K. Menten, D. Muders,
H. Rottmann, J. Wagner, M. Wunderlich, J.A. Zensus

IRAM: M. Bremer, S. Sanchez, M. Ruiz, C. Kramer, K. Schuster, P. Cox, et al.

OSO: M. Lindqvist, M. Pantaleev, R. Haas, H. Olofsson, et al.

INAF: G. Tuccari

ESO: G. Wieching, et al.

in collaboration with:

Haystack Obs.: S. Doeleman, V. Fish, R. Capallo, C. Ruszczyk, M. Titus, et al.

SMTO: L. Ziurys, P. Strittmatter, et al.

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)

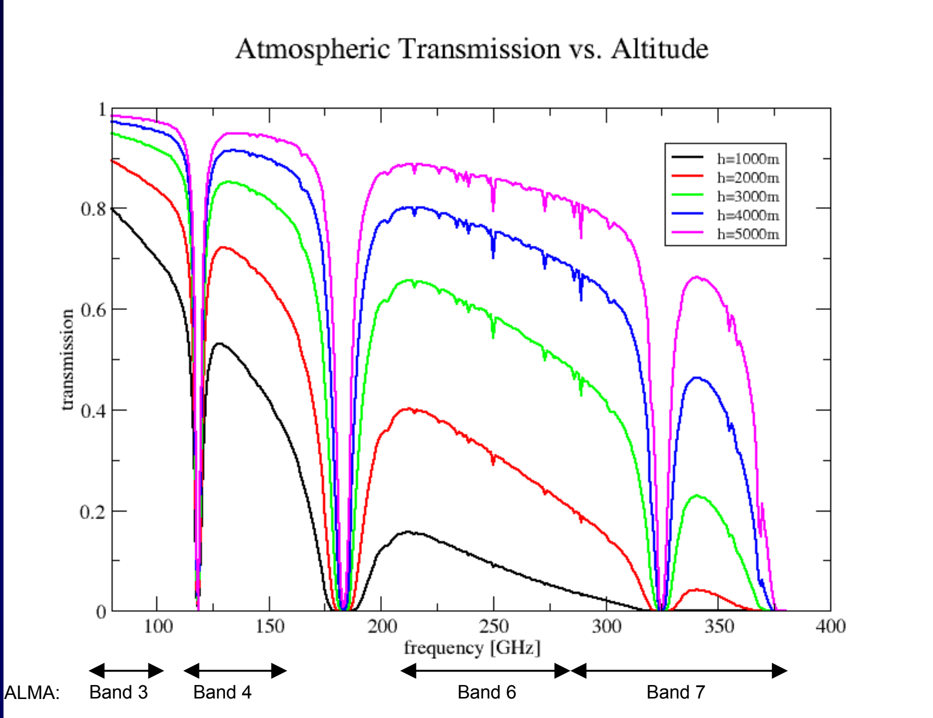
- Image regions which are (self-) absorbed and therefore not observable at longer cm-wavelength. Relate broad-band variability (radio to TeV) to jet physics (e.g. outburst – ejection relation in early stage).

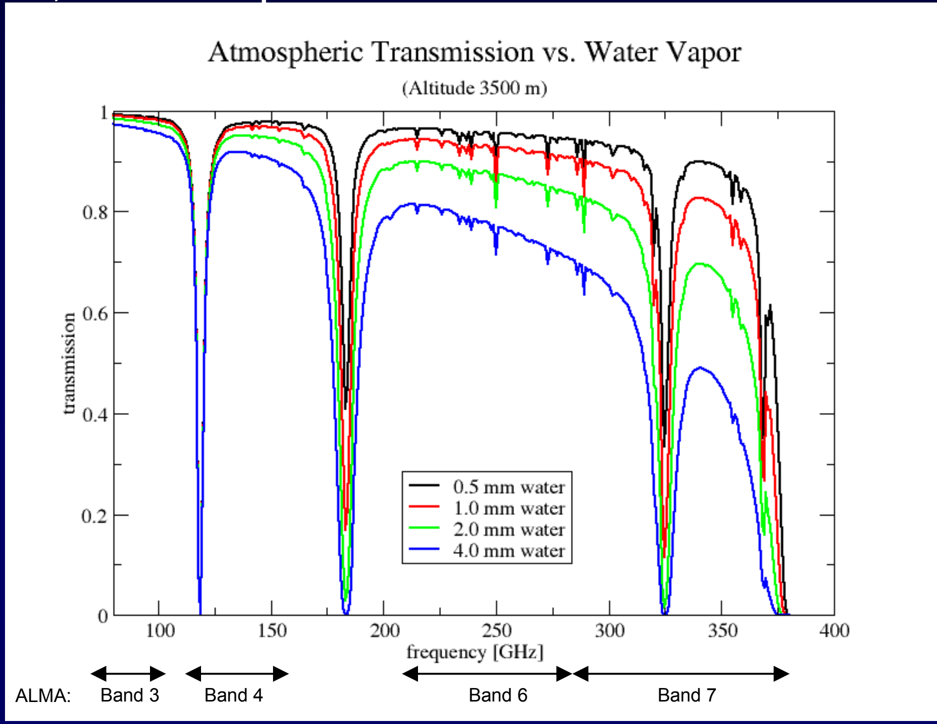
- Image the jet launching region with highest possible resolution (transverse profiles, stratification, helical motion, precession, BBHs, ...)

- 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 for sub-mm VLBI

for 1mm VLBI: H > 3000m, water vapor < 2mm





atmospheric windows allow mm-VLBI in the following bands:

- 43 GHz (SiO) AB1 regularly done at VLBA, VERA, occationally 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:

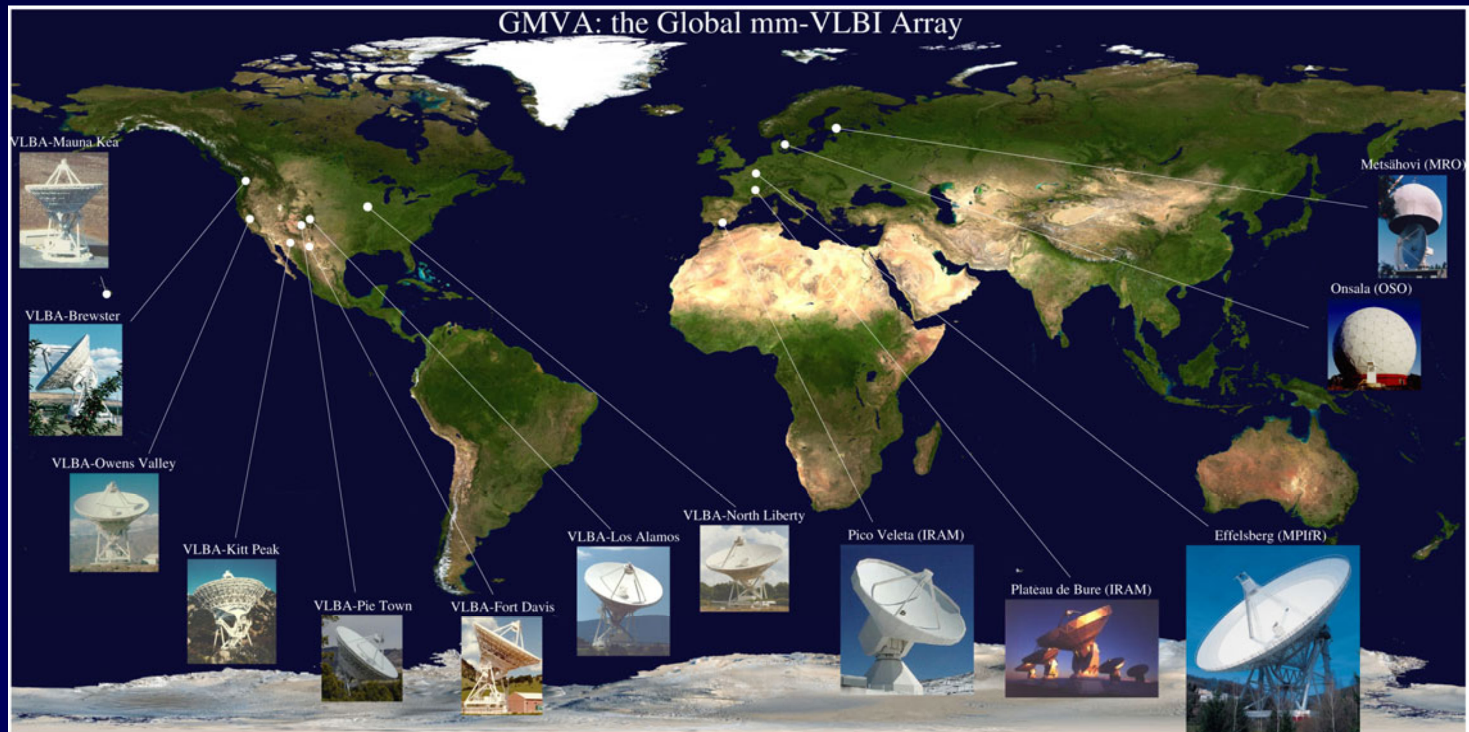
100 – 300 mJy

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:

$$T_{\rm b,s} = \frac{2\ln 2}{\pi k_{\rm B}} \frac{S_{\rm tot}\lambda^2}{d^2}(1+z)$$

Brightness temperature decreasing with frequency ?

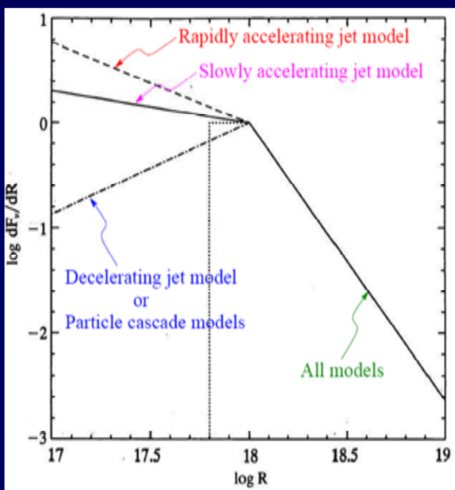
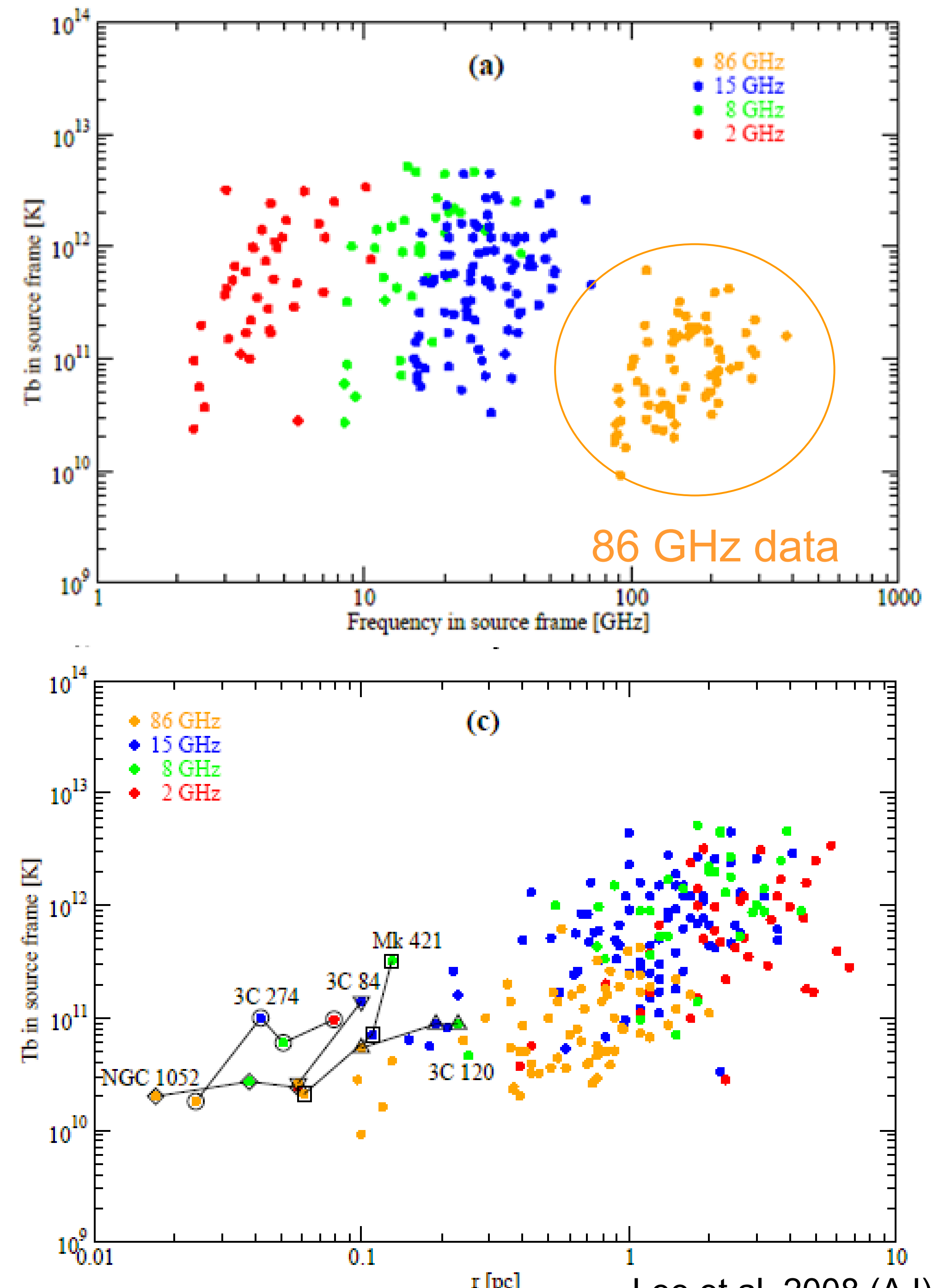


Figure adopted from

A. Marscher (1995)

Brightness temperature increasing along jet; evidence for intrinsic acceleration ?

mm-VLBI surveys of AGN can discriminate between fundamental models of jet formation

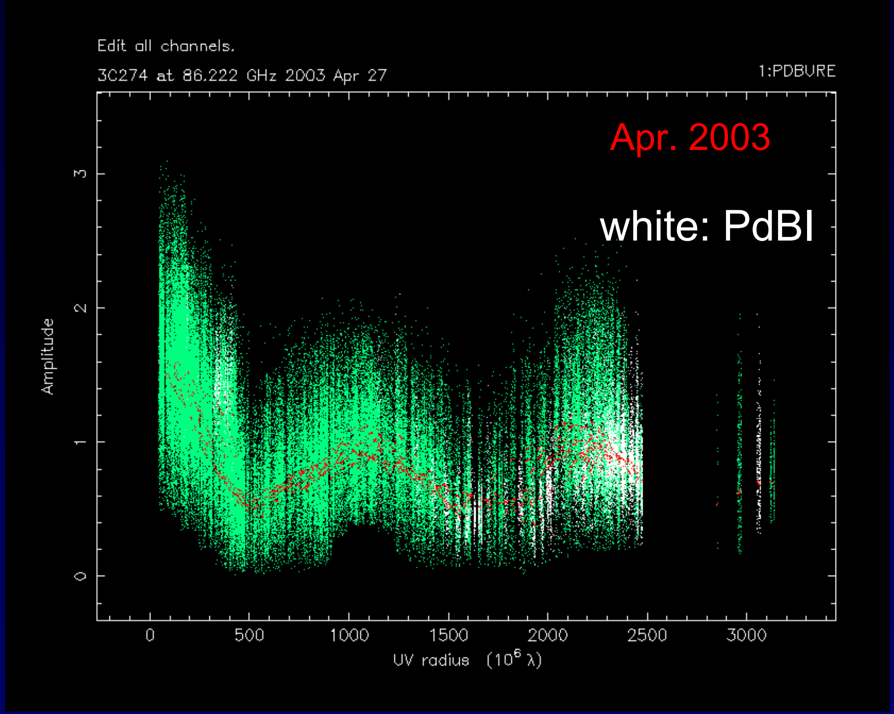


Lee et al. 2008 (AJ)

Global 3mm VLBI of M87 with the GMVA

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

Peak: approx. 1.5 Jy

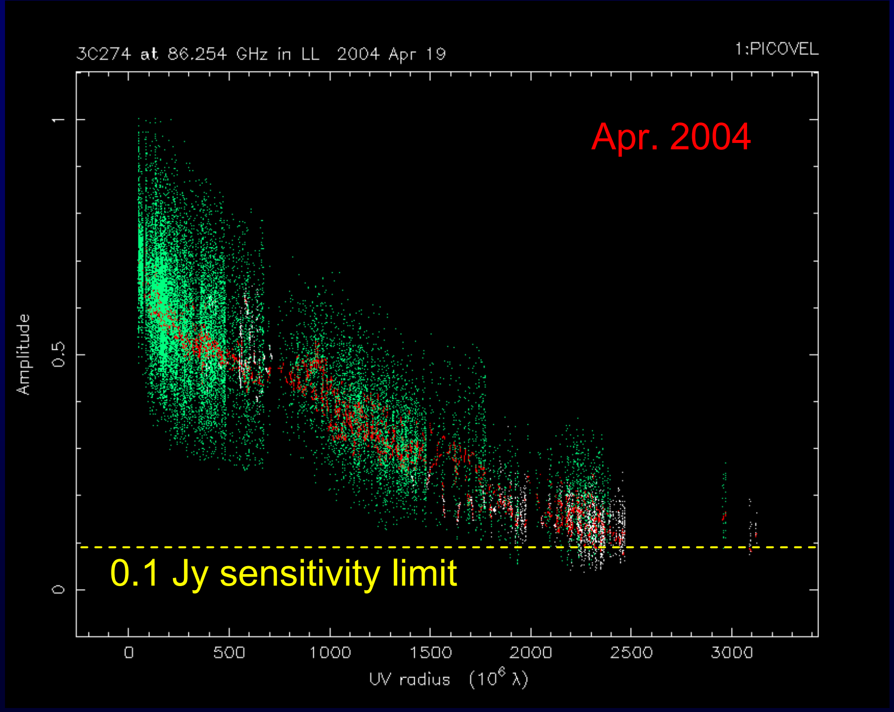


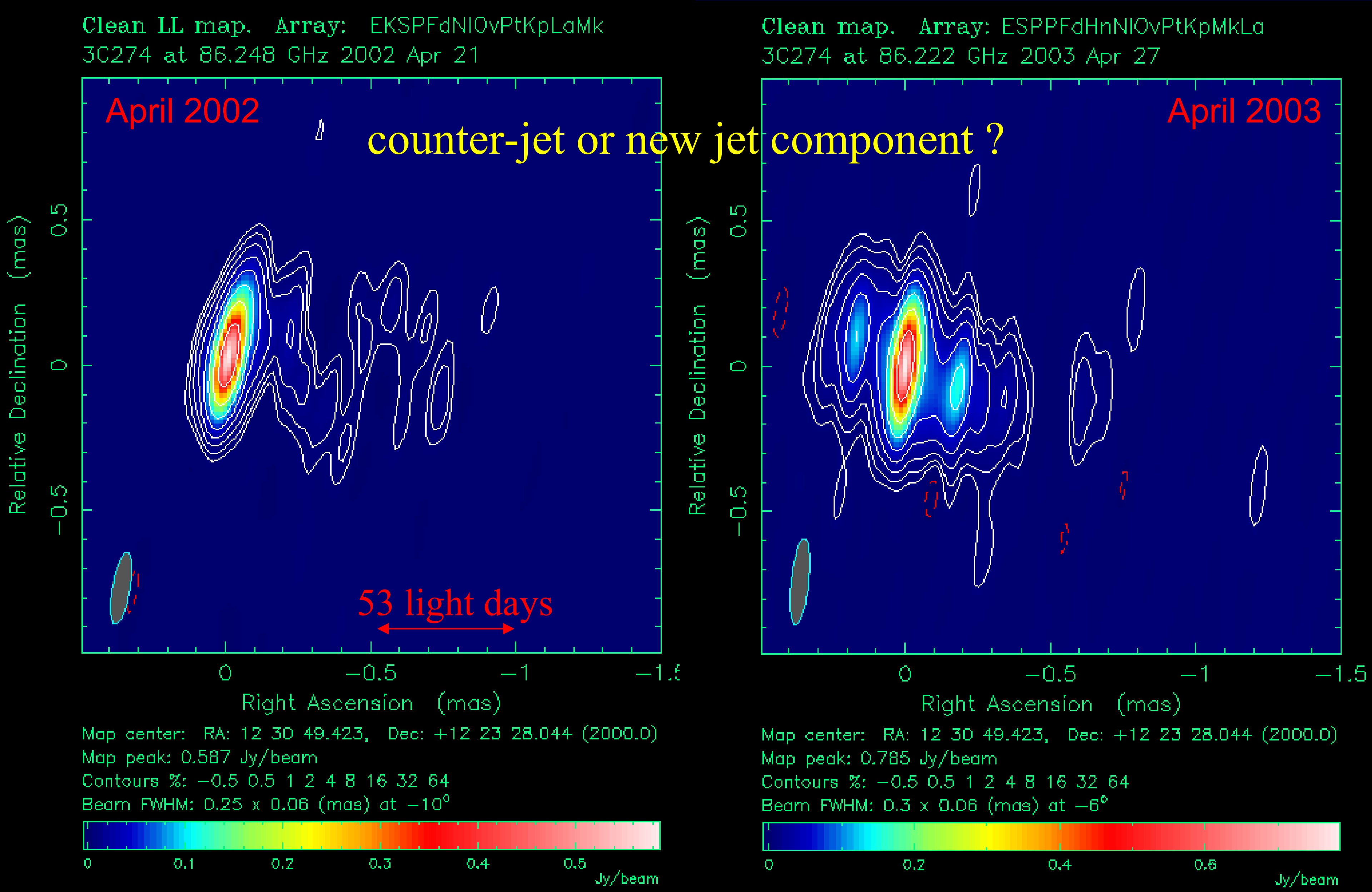
note:

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

→ need good sensitivtity (≤ 0.1 Jy)

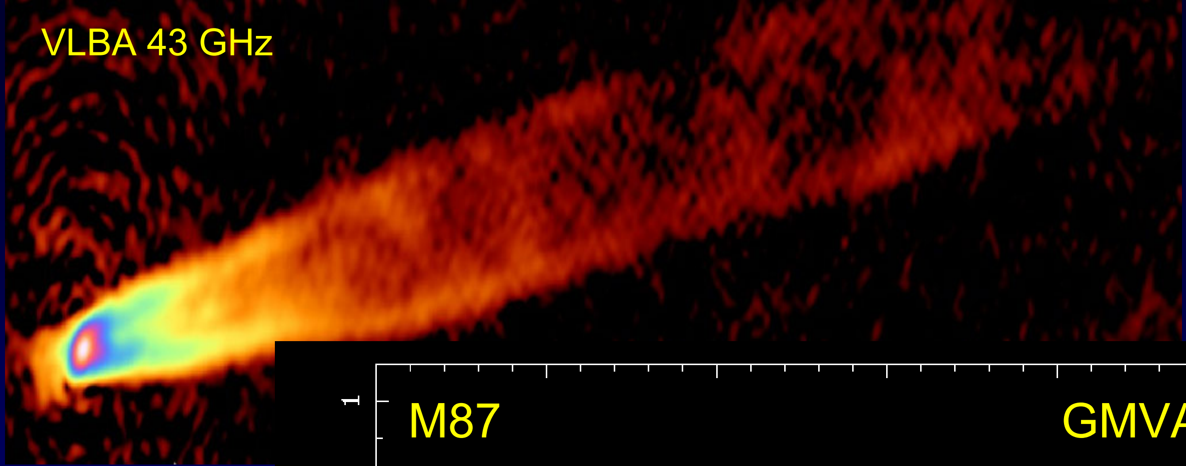
Peak: approx 0.7 Jy





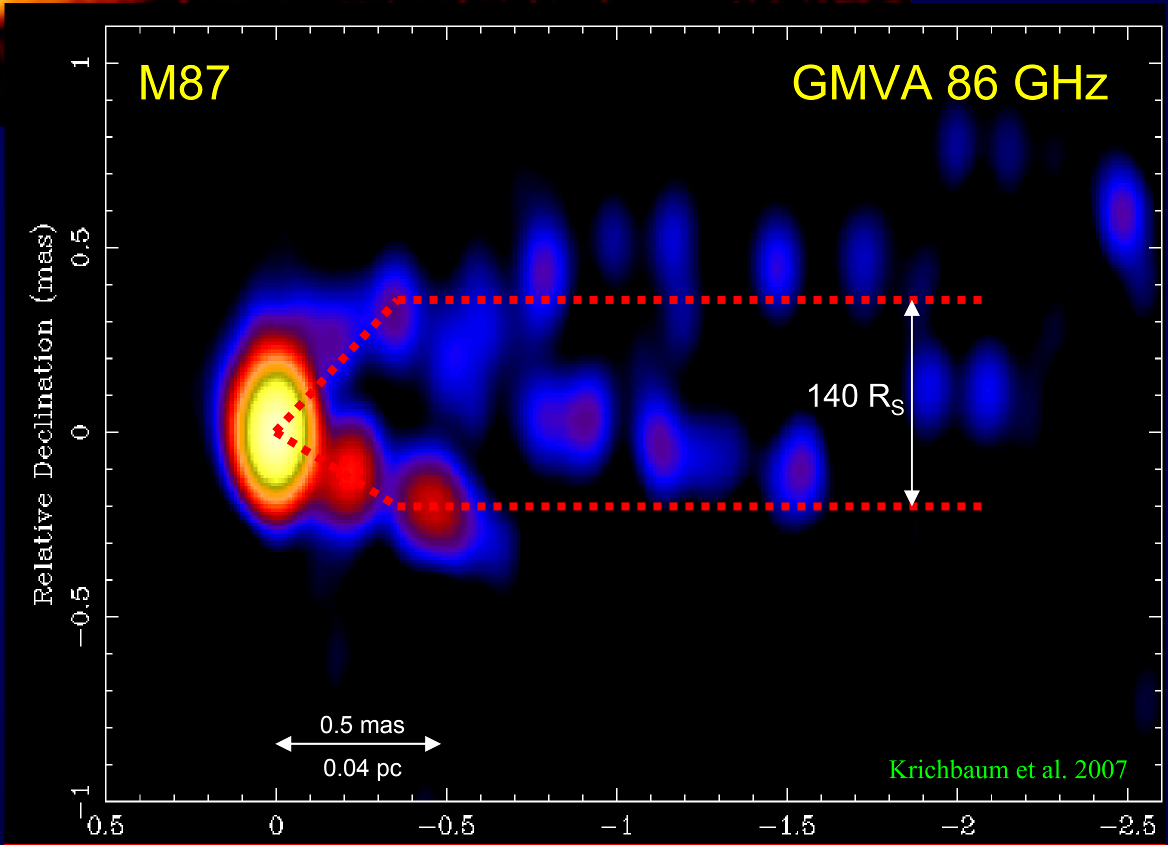
Variability in the inner jet of M87 detected : ≥ 0.2 mas/yr ↔ ≈ 18000 km/s (0.06c)

(but: 3 – 6 c seen further downstream)



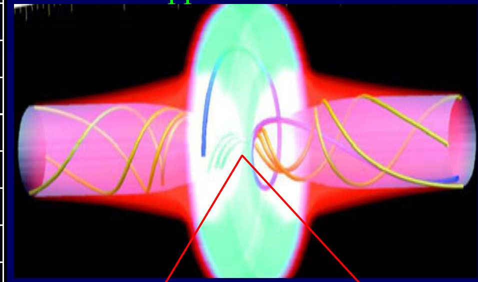
Walker et al. 2008

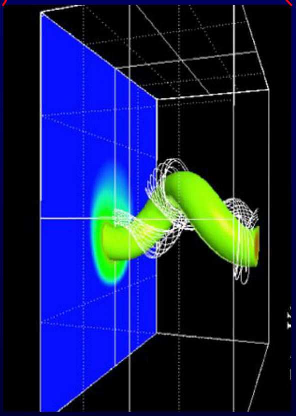
Size of jet base may be too small for magnetic sling-shot acceleration. Evidence for direct coupling to BH spin ? → a GR-MHD Dynamo ?



MHD Jet Simmulation:

Casse & Keppens 2004





Mizuno et al. 2009

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

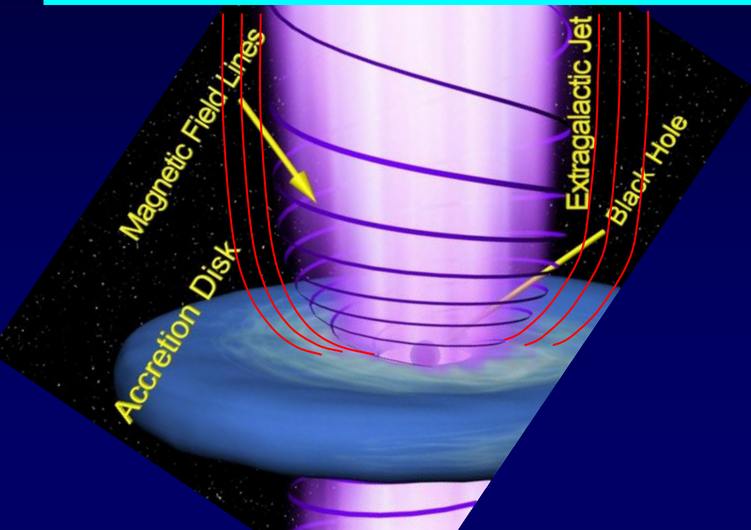
197 x 54 μas = 21 x 6 light days = <u>54 x 15</u> R_s[9]

transverse width of jet at 0.5 mas: ~140 R_s[9]

BP versus BZ mechanism

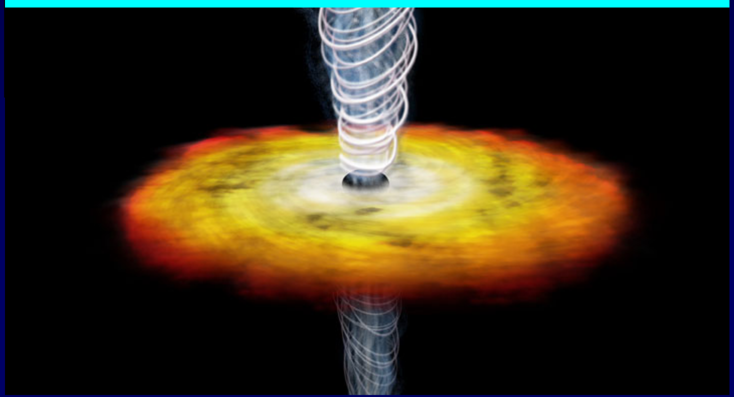
Blandford – Payne mechanism:

centrifugal acceleration in magnetized accretion disk wind



Blandford – Znajek mechanism:

electromagnetic extraction of rotational energy from Kerr BH



measure

Jet speed

Jet width

T_B

$\rightarrow$

Shape of Nozzle

Magnetic Field

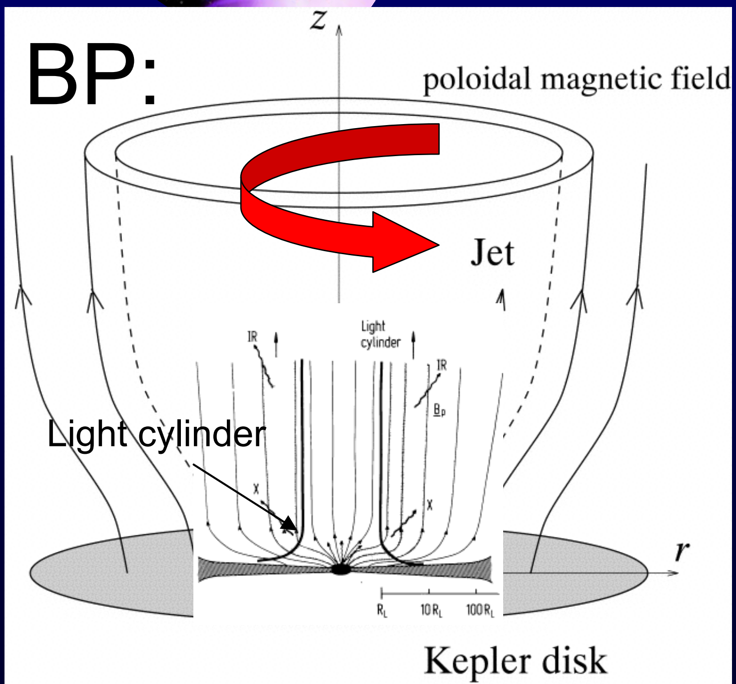
BH Spin

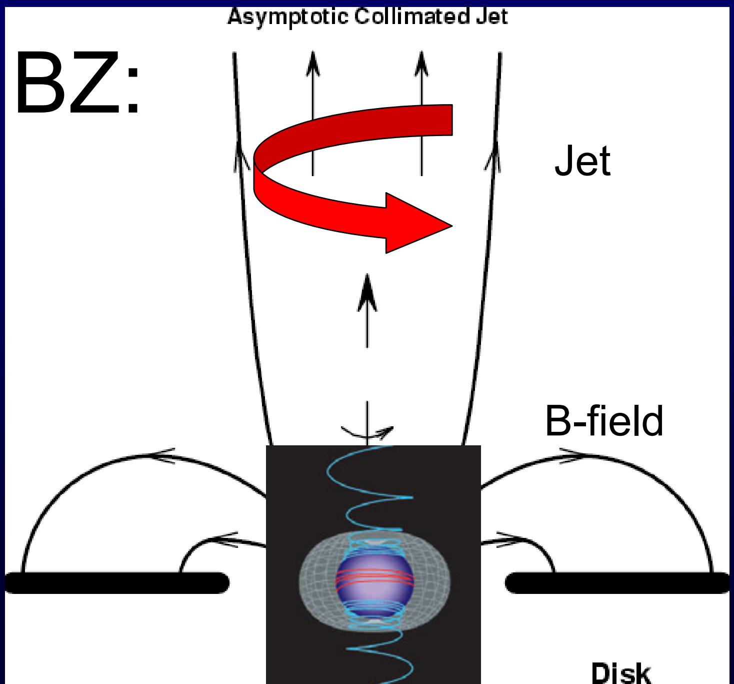
etc.

need to reach

scale of

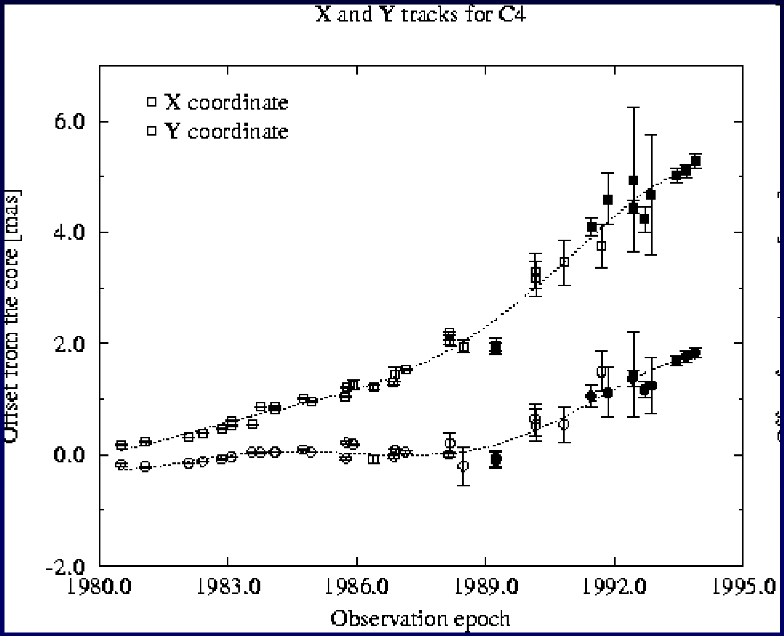
a few R_G

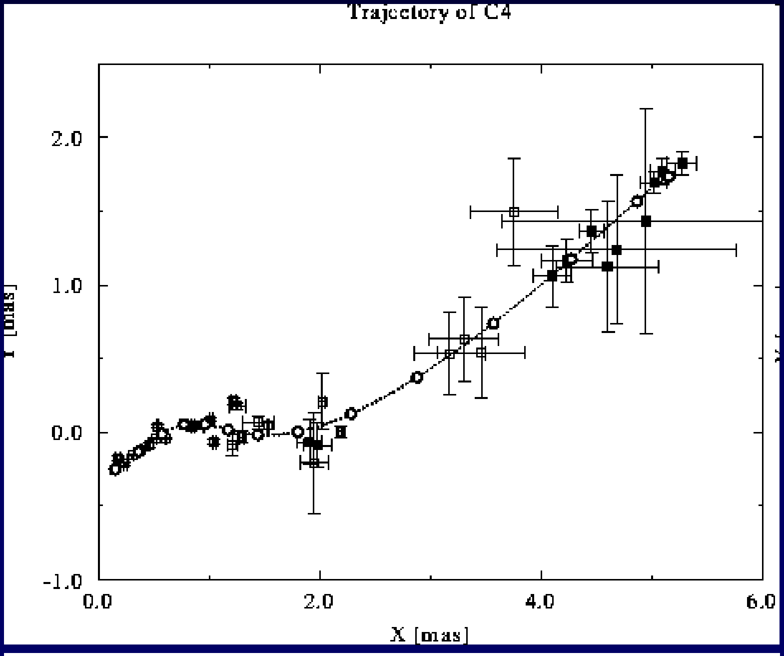


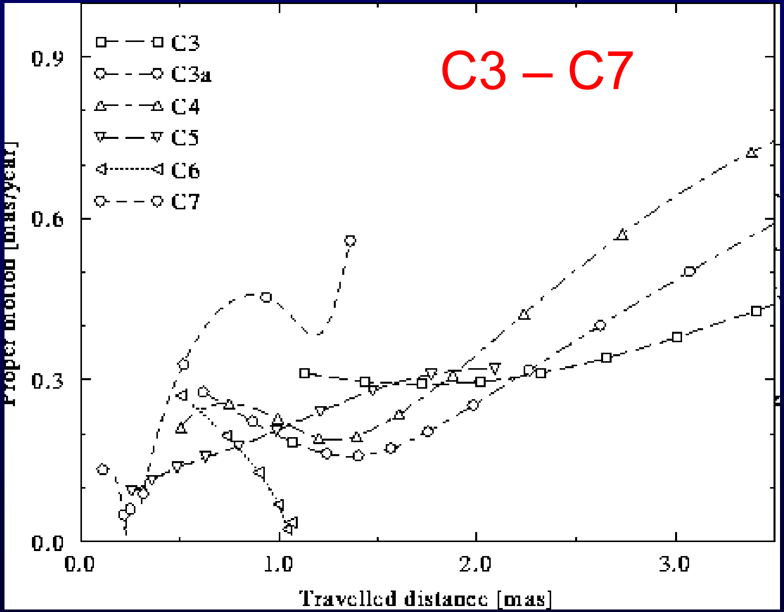


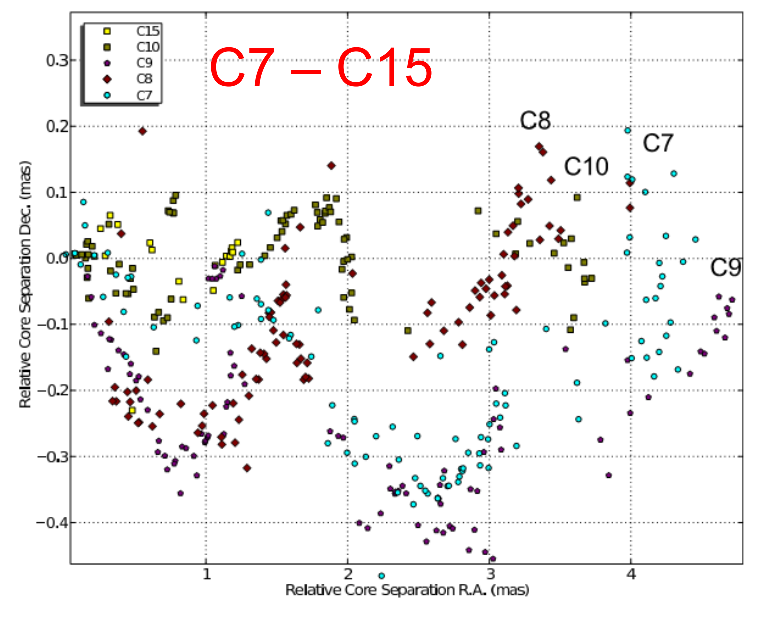
Non-ballistic (helical) motion in the jet of quasar 3C345

results from F. Schinzel, PhD Thesis 2011









Qian et al. 1991, 1992:

model of helical motion in jets

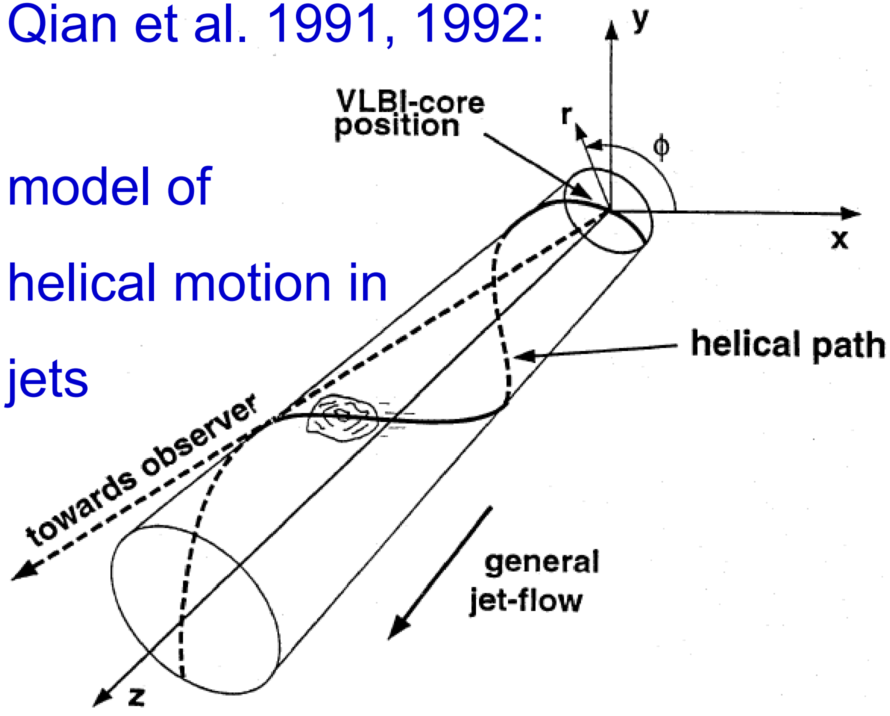


Fig. 1. Coordinate system used in the model calculations

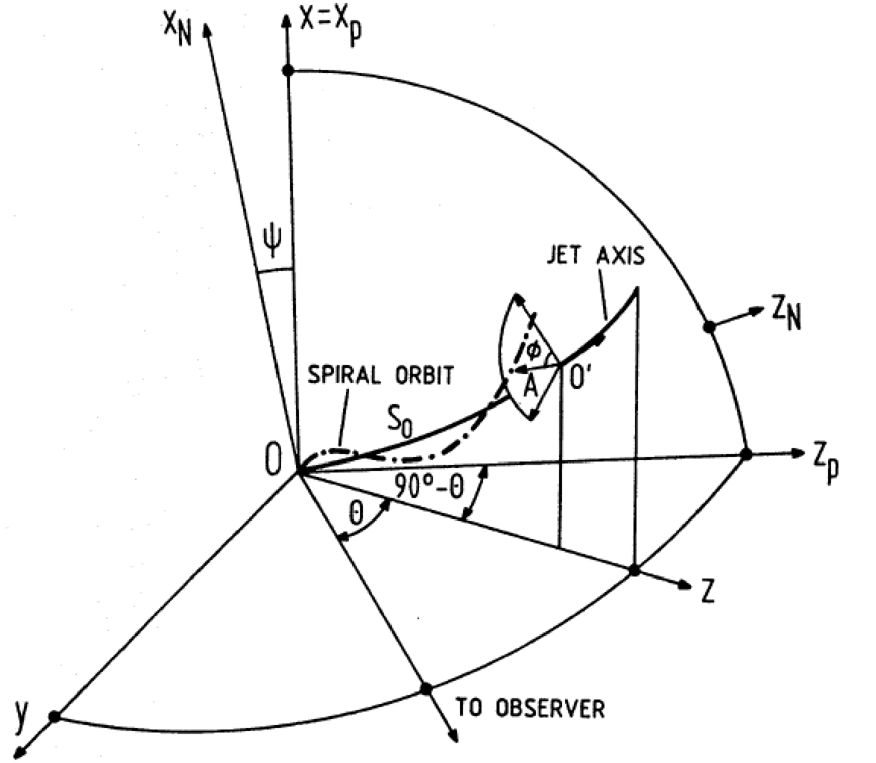
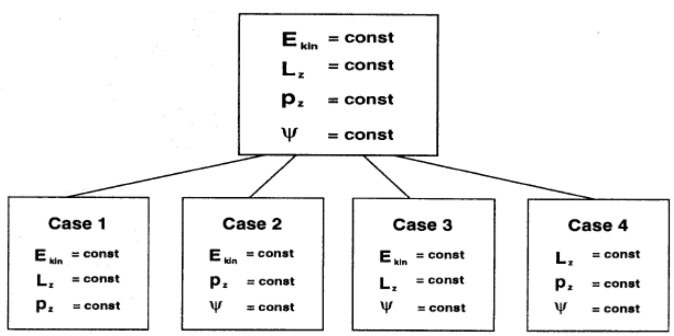


Fig. 1. Geometry and coordinate systems of the 'helical motion model' as used in Qian et al., 1992.



Steffen et al. 1995

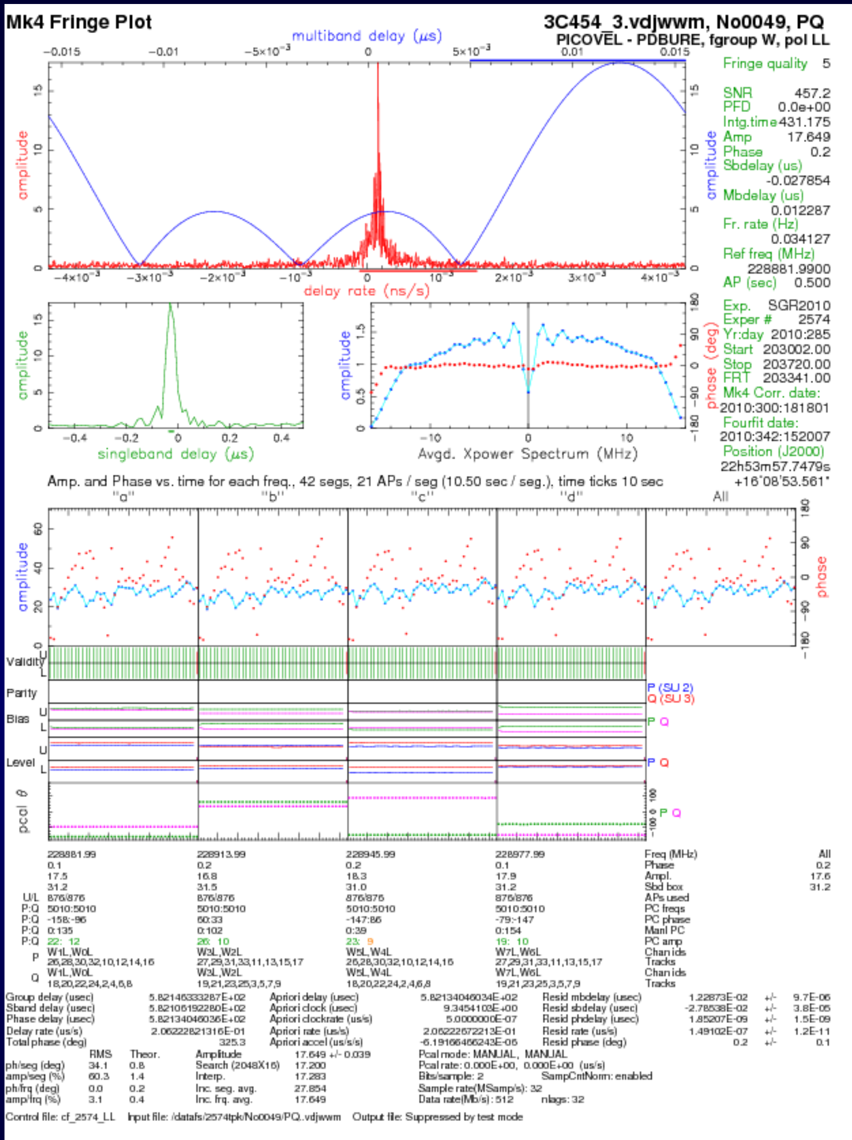
Fig. 2. Three out of four quantities are assumed to be constant during the motion of a jet component: the Lorentz factor γ, the specific angular momentum L_z and the specific momentum along the jet axis p_z, and the opening angle of the jet ψ. Three of them are needed for every specific case

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).

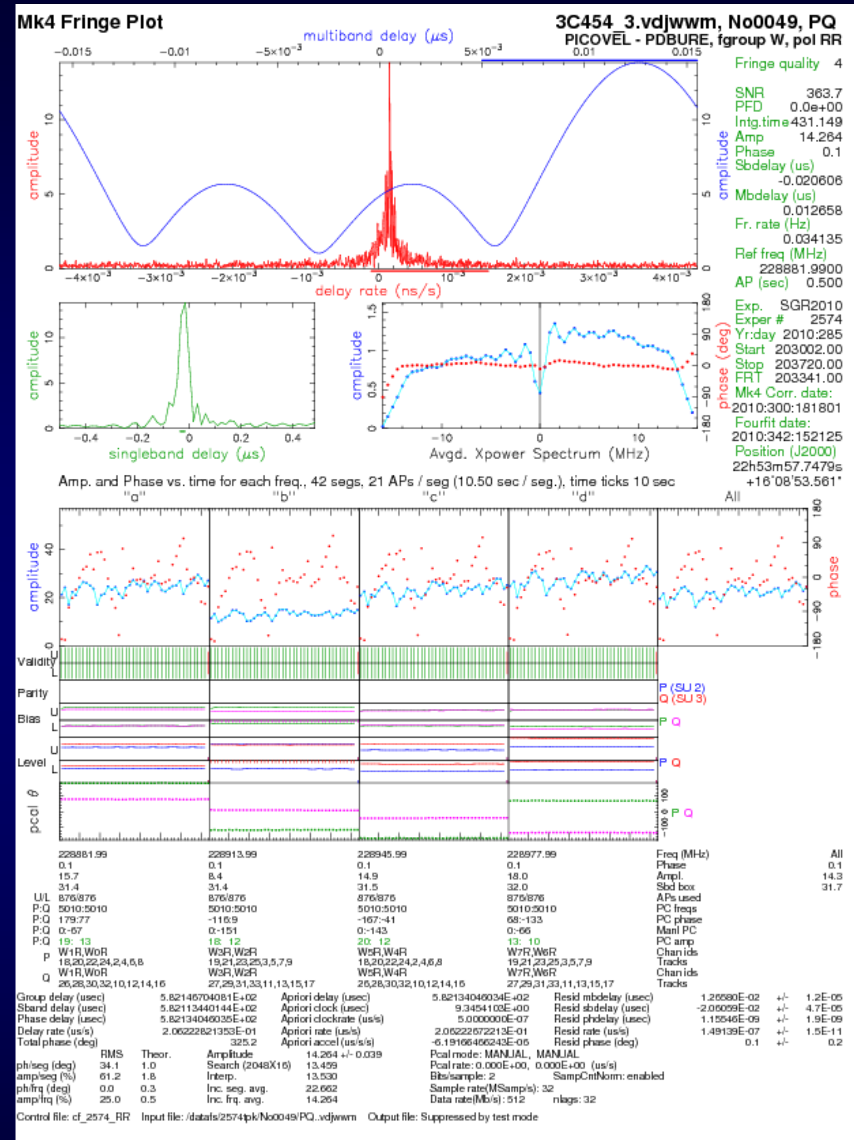
Development of mm-VLBI in Europe

- 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$_{single}$ baseline
- 1997 global 3mm VLBI, up to 10 stations, PV participates in CMVA
- 2001/2 1st 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 1st VLBI at 1.3mm (230 GHz), PV-PdBI detects 9 sources with SNR ~25,
  1st 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

Dual Polarisation Fringes 230 GHz PV – PdB, Oct. 2010 MK5A 1 Gbit/s



LCP: SNR = 457

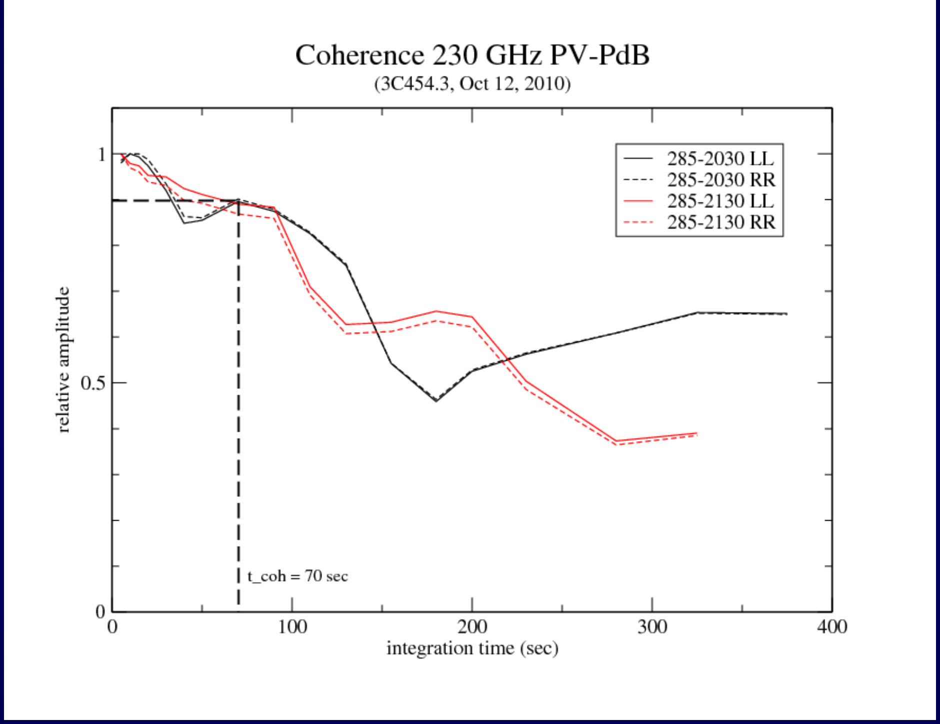


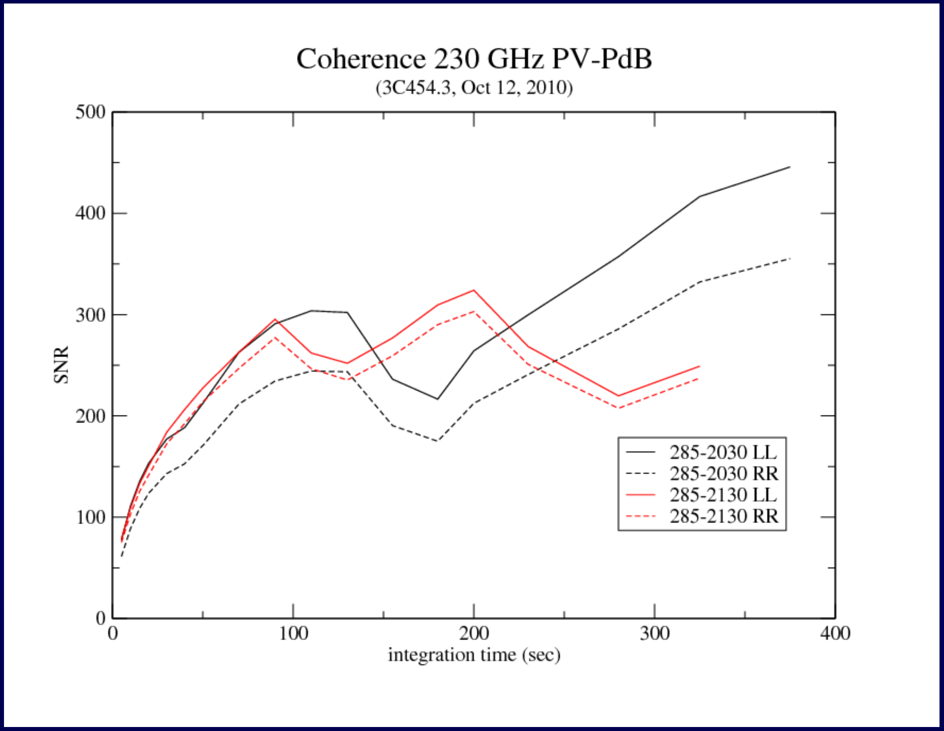
RCP: SNR = 364

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)





good VLBI-phasing efficiency of the 6 elements of the PdB interferometer

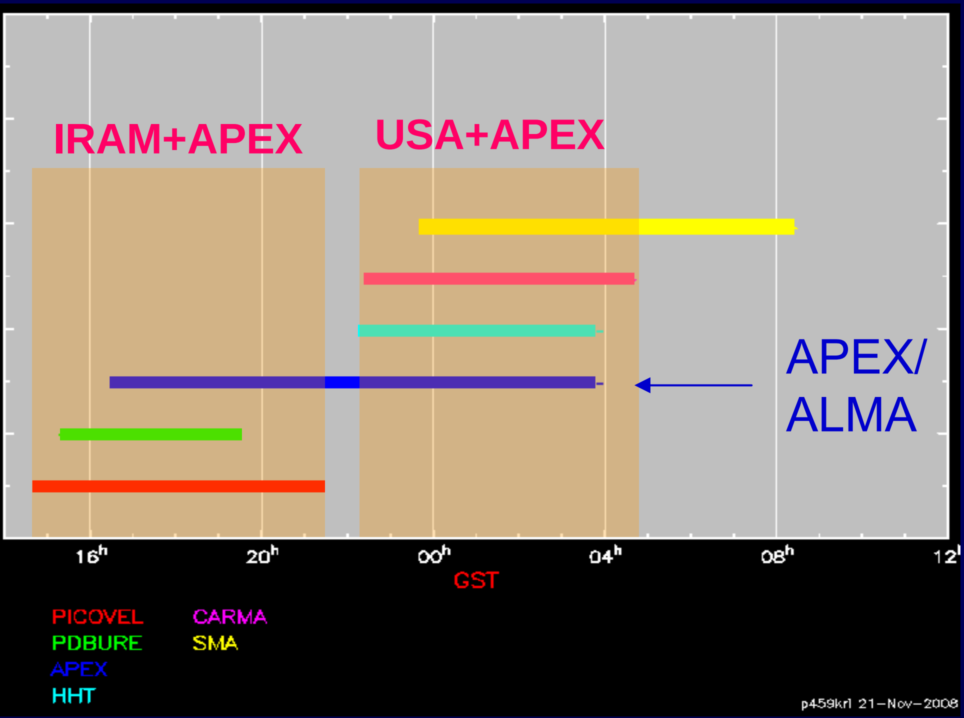
but: old correlator supports only 1 GBit/s (16 x 16 MHz, MK5A)

present WIDEX correlator does not support VLBI array phasing at all.

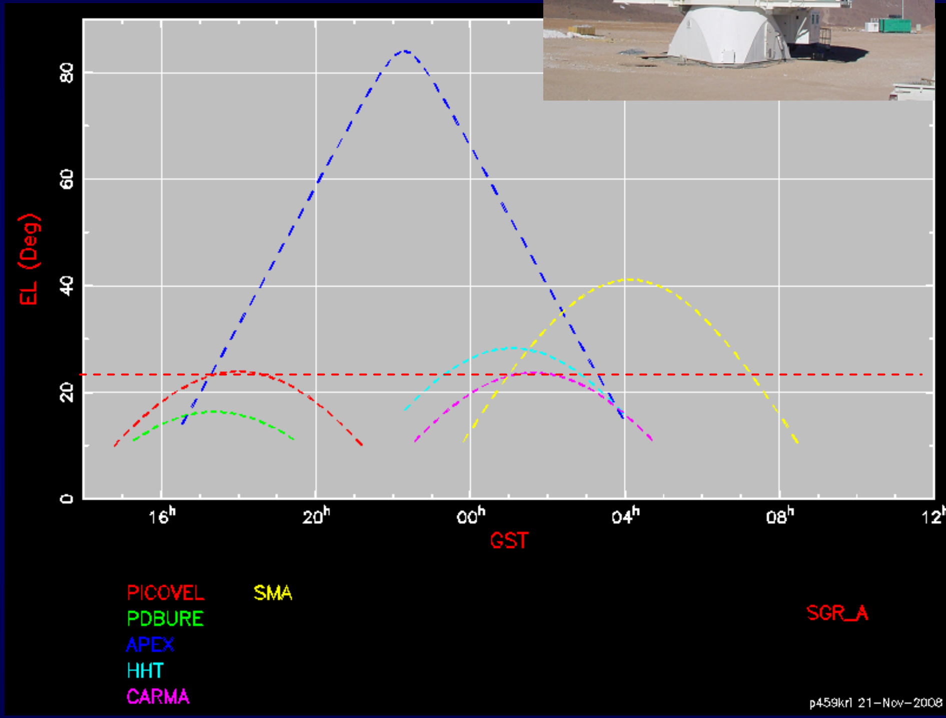
Global Millimeter VLBI with APEX

Observations of Sgr A*

ν = 230, 345 GHz



Mutual Visibility



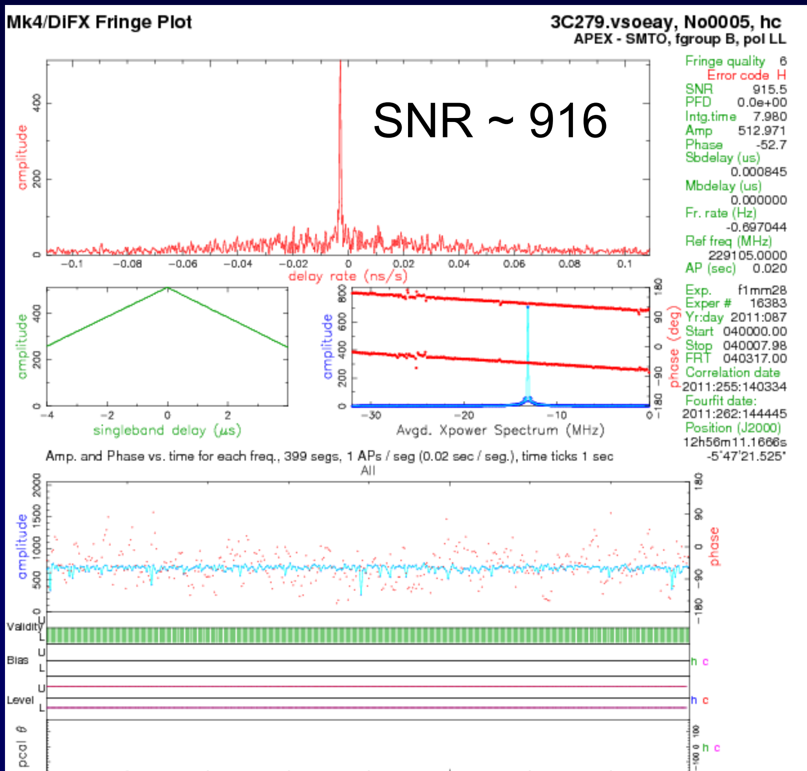
Station Elevation

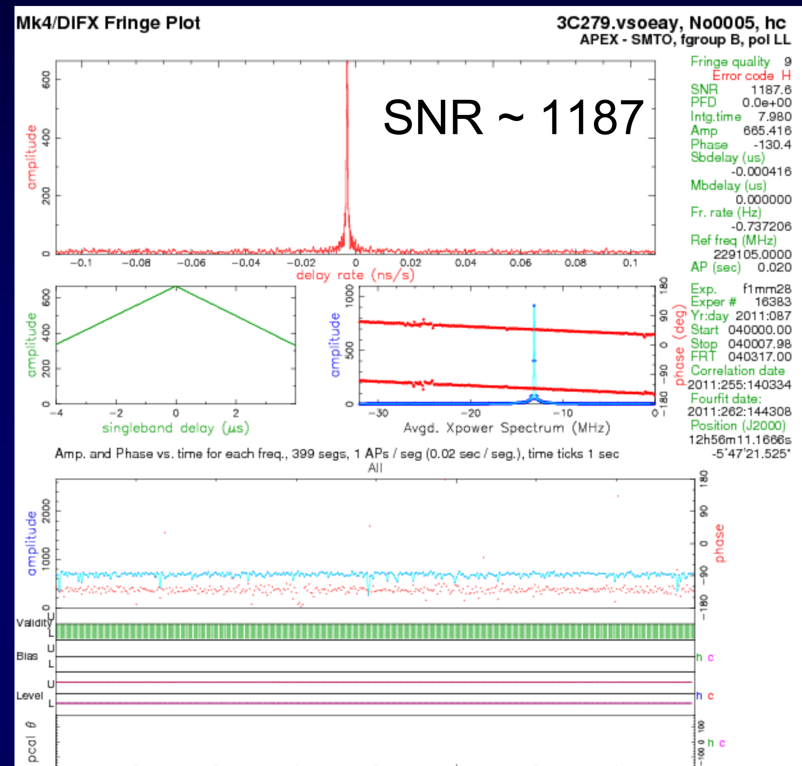
IRAM + APEX: ~5 hrs

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

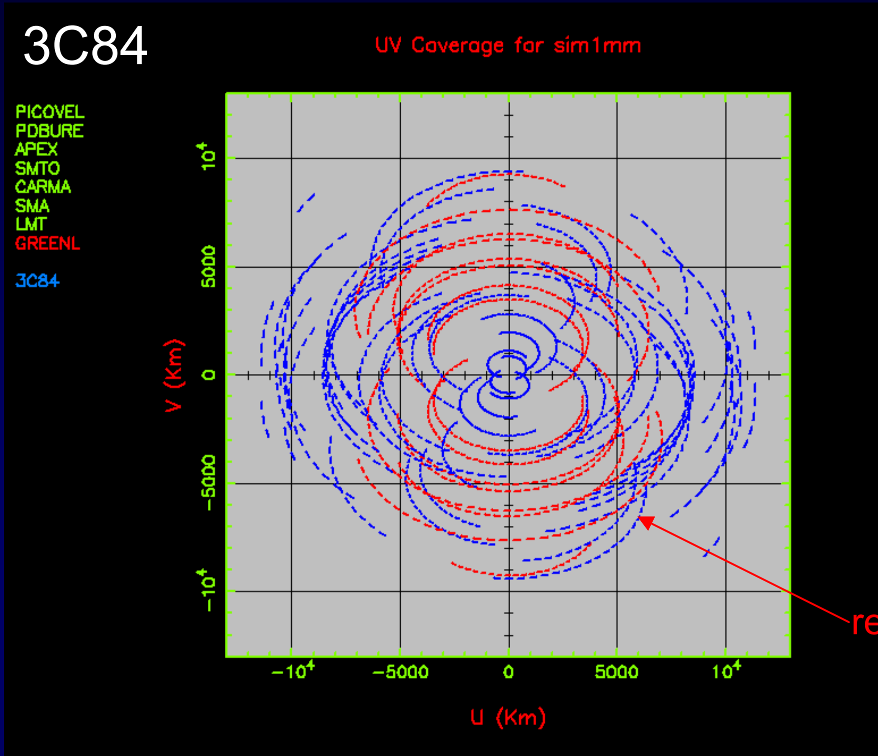
~ 30% improvement

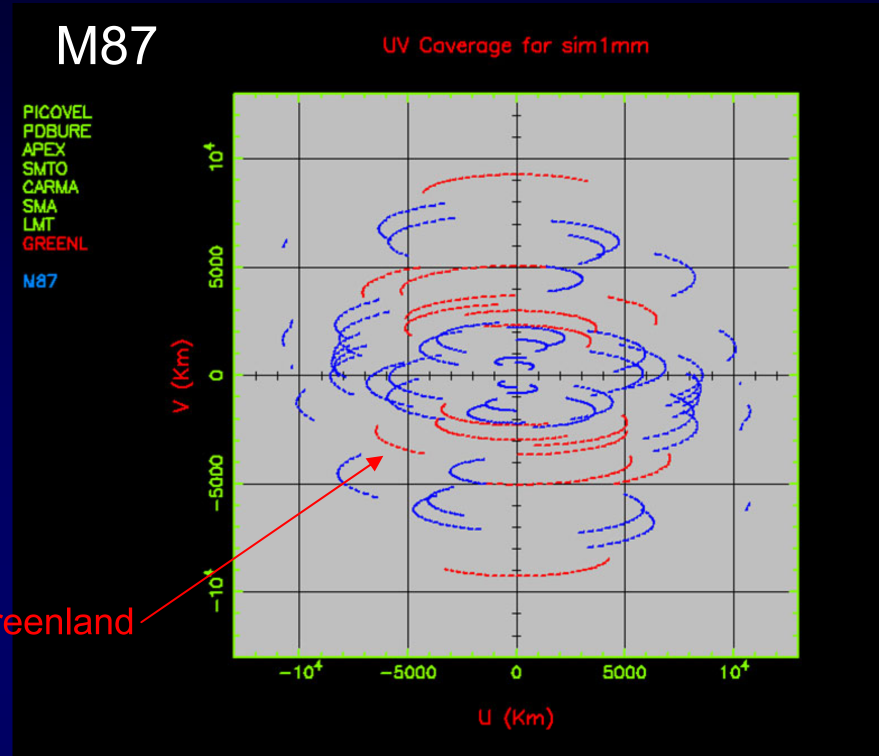
still: no fringes detected to APEX from this experiment

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

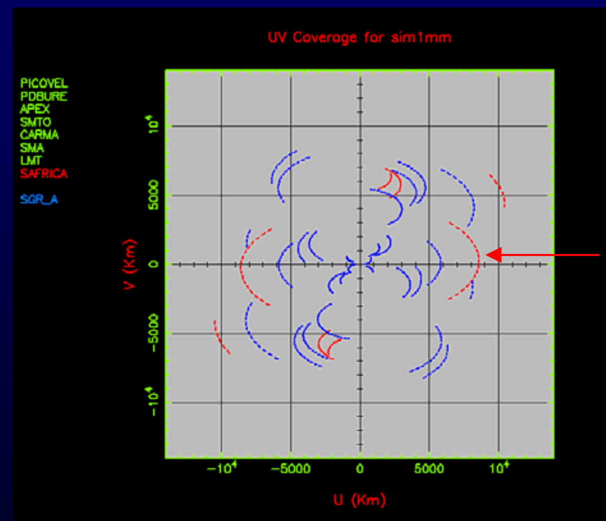
uv-coverages – Global Array with Greenland telescope





red: Greenland

A submm telescope in Greenland would improve the uv-coverage for sources with δ > -7°.



red: South Africa

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