Millimetre VLBI Monitoring of AGN with sub-mas Resolution

3C 454.3 as a typical example

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In collaboration with:

- **IRAM:** M. Bremers, A. Greve, M. Grewing, *et al.*
- **Onsala:** R. Booth, J. Conway, F. Rantakyrö, *et al.*
- **Metsähovi:** P. Könönen, S. Urpo, K. Wiik, *et al.*
- **VLBA:** V. Dhawan, *et al.*

and also: S. Jorstad, A. Marscher, H. Teräsranta, H. Ungerechts, I. Agudo, M. Kadler, J.L. Gómez
Motivation

- Resolution $\sim \frac{\lambda}{D}$ → go to shorter wavelengths
- Resolve the core structure of AGN
- Penetrate the opacity barrier by observations at shorter wavelengths
- Facilitates study of jet components at their earliest stage of structural evolution
The Global 3mm VLBI campaigns

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**Sites:**
- **E** Effelsberg
- **S** Onsala
- **X** Pico Veleta
- **K** Haystack
- **Q** Quabbin
- **O** Owens Valley
- **T** Kitt Peak
- **H** Hatcreek
- **M** Metsahovi
- **P** Pietown
- **D** Sest
- **FD** Fort Davis
- **LA** Los Alamos
- **MK** Mauna Kea
- **PB** Plateau de Bure
- **NL** North Liberty
- **B** Brewster
- **HC** Hancock

**Increasing dynamic range**: ad hoc, CMVA, GMVA
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<th>Name</th>
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The Sample to be continued
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

3C 454.3

- OVV, V = $16^m$, z = 0.859
- 7.7 pc/mas
- Highly variable flux @ 3mm $\approx 2 - 15$ Jy
- Curved jet bending from P.A. $= -95^\circ$ ... $-45^\circ$
- Inner jet (< 3 mas) oriented mainly to the west
- Outer jet (> 3 mas) bends to the north
- Superluminal motion $\beta_{\text{app}} \approx 4$-$10c$ @ $r \leq 1$mas
  $\beta_{\text{app}} \approx 8c$ @ $r \leq 2$mas
  $\beta_{\text{app}} \approx 8$-$20c$ @ $r \geq 5$mas
  (Krichbaum et al., 1996; Pauliny-Toth et al., 1987 & 1998)
- Stationary component @ 0.6mas at 22GHz and 43GHz
  (Jorstad et al., 2001)

$H_0 = 71 \text{km s}^{-1} \text{Mpc}^{-1}$, $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

VLBA 43 GHz

VLBI 86 GHz

max. core size 0.5 pc

VLBA 15 GHz

VLBA 2 cm survey (http://www.cv.nrao.edu/2cmsurvey/)

VLA 1.6 GHz

Marscher priv.comm.

15 arcsec

0.5 pc
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

Component ejection at these epochs:
- 1994.01
- 1997.28
- 1999.81

(Data: Metsähovi & IRAM)
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

3C 454.3 Flux @ 22 & 37 & 90 GHz

Flux density [Jy]

22 GHz
37 GHz
90 GHz

Time [yrs]

Apr. 99 @ 86 GHz
Oct. 99 @ 86 GHz
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

3C 454.3 Maps @ 43 & 86 GHz

\[ \alpha_{\text{CORE}} = -0.15 \] (steep)
\[ \alpha_{\text{JET}} = -0.95 \] (steep)
\[ \alpha_{\text{CORE}} = 0.62 \] (inverted)
\[ \alpha_{\text{JET}} = -0.04 \] (flat)

1.13 Jy
1.55 Jy
1.74 Jy
1.40 Jy
Component Identification

![Graph showing component identification over time](image)
Flux vs. Distance

![Graph showing flux vs. distance with various lines representing different datasets labeled B, A, C1, C2, C3, C4, C5, C6, C7. The x-axis represents R [mas], the y-axis represents Flux density [Jy].]
Summary & Outlook

3mm VLBI

- μ-arcsec resolution of several AGN which show sub- and superluminal motion
- Finish the data reduction for the sample of AGN

3C 454.3

- Moving components with different velocities ($\beta_{\text{app}} \approx 4-20c$)
- At 0.6mas core distance all components brighten as they move through this region (explains previously claimed stationarity)
- Several new components appear near the core and appear correlated with flares seen in the 22-90 GHz band
- Complete the kinematic picture with further cm- and mm-VLBI monitoring.
3C 454.3 Flux @ 22 & 37 & 86 GHz

(Data: Metsähovi & IRAM)
3C 454.3 Flux @ 22 & 37 & 90 GHz

(Data: Metsähovi & IRAM)
3C 454.3 in X-rays

Red: 0.2-1.5 keV, Green: 1.5-2.5 keV, Blue: 2.5-8 keV

\[5.0'' \approx 38.5 \text{ kpc}\]

Marshall et al. 2004
3C 454.3 in X-rays

CHANDRA image

~ 0.5 Mpc

Red: 0.2-1.5 keV, Green: 1.5-2.5 keV, Blue: 2.5-8 keV
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

Epochs of 3C 454.3

Oct.96

Apr.97

Apr.99

Oct.99

May96

Nov.96

Jun.97

Apr.99

Oct.99

1 mas \( \equiv \) 7.7 pc
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

The $\mu$-arcsec view of AGN
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

6 epochs of 3C 454.3 @ 86 GHz

- Apr.93
- Jan.94
- Oct.96
- Apr.97
- Apr.99
- Oct.99

= 1 mas ≅ 7.7 pc

0.15-0.3 mas/yr

→ \( \beta_{\text{app}} \approx 3.7c-7.5c \)

Stationary component also at 86 GHz?

At least not obvious!
Millimetre VLBI Monitoring of AGN with sub-mas Resolution

Flux vs. Distance

![Graph showing flux vs. distance for different sources labeled B, A, C1, C2, C3, C4, C5, C6, C7. The x-axis represents R [mas] ranging from 0 to 2, and the y-axis represents Flux density [Jy] ranging from 0.001 to 1.0.]
Component Identification

![Graph showing component identification over time with different markers and labels. The graph includes labels for different components such as B, A, C1, C2, C3, C4, C5, C6, and C7, each with corresponding time points and mas values. The x-axis represents time in years from 1994 to 2000, and the y-axis represents R in mas.]}