High frequency VLBI imaging of OVV 1633+382

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Introduction: pc-scale AGN jet

- pc-scale jet physics: missing link between AGN jet and feedback
  - “We suggest that radio, maintenance-mode feedback is responsible for keeping hot gas hot in individual giant ellipticals and in clusters of galaxies. The microphysics of this process is not well understood. Can radio jet energy be confined within individual galaxies and can it be thermalized?” (Kormendy & Ho 2013 Review)
Introduction: pc-scale AGN jet

• Needs for VLBI (Very Long Baseline interferometry) observation
  – Very high angular resolutions can be synthesized (e.g. @43GHz, ~ 0.17mas has using the largest VLBI on the Earth)
  – High radio frequencies allow us to probe detailed structures of the inner region of the AGN jet
Target of this study: OVV 1633+382

- **OVV 1633+382**
  - FR II with small line-of-sight angle: blazar
  - Very powerful radio luminosity
  - High z: 1.813
  - High accretion rate
  - Feedback is active (‘quasar’ mode)?

- **c.f. M87**
  - FR I
  - Low z: 0.004238 (17Mpc)
  - Relatively low accretion rate
  - Modest feedback (‘maintanence’ mode)?
Target of this study: OVV 1633+382

- Near 2002, a major flare occurred in mm wavelength
  - A dense and bright outflow is expected after the flare
- Larger flux at higher frequency
  - Flare occurred inner part of the jet

[Graph showing flux monitoring at Metahevi with epochs from 1980 to 2005 and frequencies from 8GHz to 90GHz]
Observation

• Very Large Baseline Array (VLBA) + Effelsberg 100m radio telescope

• 12 epochs between 2002 – 2005
  – VLBA + EB for 9 epochs
  → Investigate the evolution of the jet properties

• 3 frequencies: 22, 43, 86 GHz
  → Probe jet structure in different scales and probe spectral index

• Full polarization observations
  → Probe magnetic field properties
Data reduction and imaging

• Data reduction and imaging tools
  : AIPS (Astronomical Image Processing System), difmap

• Current progress of data reduction: all 43 GHz data and 5 epochs of 22GHz data have been processed (polarization not calibrated yet)

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Result 1:
Total intensity maps

- One-sided jet, overall extends ~30pc
- The component located ~ 3mas from the core is stationary
- Inner jet (< 1.5mas): grows with time, consists of 2-3 components
Result 2 : Flux variation

- Significant flux variation: characteristic of blazar

<table>
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<tr>
<th>Frequency</th>
<th>Average [Jy]</th>
<th>Stddev. [Jy]</th>
<th>Stddev. average [%]</th>
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<tbody>
<tr>
<td>43GHz</td>
<td>3.70</td>
<td>0.96</td>
<td>25.8</td>
</tr>
<tr>
<td>22GHz</td>
<td>4.66</td>
<td>0.81</td>
<td>17.4</td>
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- The total flux variation strongly correlates with the core flux variation
Result 3 : Model-fitting

- ‘modelfit’ task inside the difmap package
- Independent components that are found by 2D Gaussian fitting
- Distance from the core, position angle, size, and the flux can be measured from each Gaussian component

<table>
<thead>
<tr>
<th>component</th>
<th>C5</th>
<th>C4</th>
<th>C3</th>
<th>C2</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>distance [mas]</td>
<td>0.31±0.0</td>
<td>0.71±0.01</td>
<td>1.35±0.08</td>
<td>2.0±0.1</td>
<td>3.13±0.07</td>
</tr>
<tr>
<td>position angle [°]</td>
<td>-78.36±0.46</td>
<td>-66.36±0.97</td>
<td>80.82±3.47</td>
<td>-90.31±2.81</td>
<td>-90.86±1.29</td>
</tr>
<tr>
<td>width [mas]</td>
<td>0.27±0.01</td>
<td>0.38±0.02</td>
<td>0.6±0.16</td>
<td>0.79±0.2</td>
<td>0.65±0.14</td>
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<tr>
<td>flux [mJy]</td>
<td>75.6±69.2</td>
<td>82.5±21.0</td>
<td>27.9±9.2</td>
<td>63.6±16.8</td>
<td>77.1±17.8</td>
</tr>
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Discussion 1: Superluminal motion and jet orientation

- **Outer components (C1, C2)**: almost stationary during the epochs
- **Inner components (C4, C5, C7)**: superluminal motion (up to ~ 32c)
Discussion 1: Superluminal motion and jet orientation

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<tr>
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<th>apparent velocity $\beta_{app} (= v/c)$</th>
<th>maximum viewing angle $\theta_{max}$ [$^\circ$]</th>
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<tr>
<td></td>
<td>22GHz</td>
<td>43GHz</td>
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<tr>
<td>C1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.43 (0.28)</td>
<td>1.16 (2.6)</td>
</tr>
<tr>
<td>C2</td>
<td>-1.2 (2.96)</td>
<td>-2.99 (9.42)</td>
</tr>
<tr>
<td>C4</td>
<td>26.25 (0.75)</td>
<td>19.54 (4.27)</td>
</tr>
<tr>
<td>C5</td>
<td>10.33 (3.3)</td>
<td>14.77 (5.25)</td>
</tr>
<tr>
<td>C7</td>
<td>-</td>
<td>31.9 (0.0)</td>
</tr>
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- Maximum viewing angle: $3.6 \sim 11^\circ$
- The jet is slightly offset from the observer’s line-of-sight

\[ \beta = \frac{v}{c} \quad \beta_{app} \sim 32c \]

\[ \theta_{max} : 3.6 - 11^\circ \]
Discussion 2: Which one is moving. Component? or Jet core?

Vertical motion of the component?
Discussion 2: Which one is moving. Component? or Jet core?

- Possible scenarios
  1. Motion of the component
     - Interaction with external medium?
  2. Motion of the jet core (reference position)
     - Accretion disk precession?
     - Binary blackhole?
     - Perturbation by something else (e.g. Kelvin Helmholtz instability)?

![Diagram of possible scenarios](image)
Future works

• Further test the robustness of the results from the model-fit and compare the results of different frequencies and epochs
  – Study detailed motion of outer(~3mas) and inner(<1.5mas) components

• 22 - 43GHz Spectral index properties
  – Amount of synchrotron self-absorption (electron density)
  – Compare synchrotron ages along the jet

• Polarization properties: magnetic field structure
  – Rotation measure → magnetic field strength along line of sight
  – Degree of polarization → amount of depolarization
  – Polarization angle → magnetic field direction
Spectral index maps: Preliminary result

$\Delta R.A = 0.02\text{mas}, \ \Delta Dec. = -0.035\text{mas}$

- Model fitting result is not unique.
  $\rightarrow$ Combine additional way of image alignment (2D correlation method)
New major flare – KaVA proposal

flare @ mm wavelength ~2002

flare @ mm wavelength ~2013

KaVA proposal:
22GHz and 43GHz
2 epochs

Credit: Terasranta, H.

http://www3.mpifr-bonn.mpg.de/div/vlbi/fgamma/results.html