The Future of Very Long Baseline Interferometry and AGN surveys at milliarcsecond resolution
Greg Taylor
NRAO/KIPAC
GLAST Lunch talk, 2004 October 21

• Frequencies ranging from 330 MHz to 86 GHz
• Angular resolution to 100 microarcseconds at highest frequency

Very Long Baseline Array (VLBA)
Dedicated in 1993
10 antennas recording to tape
Correlator in Socorro, NM
Combiable with Global Arrays

If the source emission is unchanging, there is no need to collect all of the incoming rays at one time. One could imagine sequentially combining pairs of signals. If we break the aperture into N sub-apertures, there will be N(N−1)/2 pairs to combine. This approach is the basis of aperture synthesis.
The Stationary, Monochromatic Interferometer

A small (but finite) frequency width, and no motion.
Consider radiation from a small solid angle $d\Omega$, from direction $s$.

$$V = V_s \cos(t - \omega t_s)$$

$$R_n = \frac{V_s[V_c \cos(\omega t_s) + \cos(\omega t - \omega t_s)]}{2}$$

u,v coverage for 1543+517 in VIPS

single frequency

u,v coverage for 1543+517 in VIPS

four frequencies

Mapping the Future of VLBI Science in the U.S.

http://www.nrao.edu/VLBIfuture

VLBI Future Committee:
Shep Doeleman (Haystack Obs.)
Dave Hough (Trinity College)
Shri Kulkarni (Caltech)
Colin Lonsdale (Haystack Obs.) co-chair
Alan Marscher (Boston Univ.)
Chris O'Dea (STScI)
Greg Taylor (NRAO) co-chair
David Wilner (Harvard-Smithsonian CfA)
Joan Wrobel (NRAO)

Future Science Prospects

Imaging Massive Black Holes
Gravitational Lenses – Where is the Dark Matter?
Supernova Factories and nascent AGNs
Launching AGN Jets
Kinematics of the Local Group
Magnetism in Stars
Binary Black Holes
Imaging Cosmic Explosions from GRBs and SNe
Future Science Prospects

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June 20, 2003
+83 days
Peak ~ 3 mJy
Size 0.172 +/- 0.043 mas
0.5 +/- 0.1 pc
average velocity = 3c

VLBA+Y27+GBT+EB+AR+WB = 0.11 km^2

Resolving the Afterglow
4th Epoch – May 19, t +51 days
VLBA+EB+GBT+Y27
Beam is 0.67 x 0.24 mas
Jet component at 0.28 +/- 0.05 mas
Not consistent with standard model prediction of 0.12 mas expansion
average expansion velocity of ~19c

Recommendations
Hardware
• Implement Mark 5 disk-based recording
• Increase VLBI participation of GBT and Arecibo
• Upgrade the 22-86 GHz performance of the VLBA
• Investigate connections with EVLA and future facilities
• Support VLBI at mm wavelengths on new facilities

Recommendations
Software
• Dedicate new resources in order to:
  • Improve ease-of-use
  • Provide new capabilities
  • Coordinate with activities in the U.S., Europe, and abroad

Recommendations
Astronomical Community
• Support graduate students at U.S. Universities
• Investigate financial support for time awarded on VLBI networks
• Send Greg on sabbatical to SLAC/Stanford
Previous AGN surveys at mas resolution

- Pearson-Readhead (PR - 1988): 5 GHz, 35 sources
- Caltech-Jodrell Bank (CJ1 - 1995): 1.7 and 5 GHz, 65 sources
- Second Caltech-Jodrell Bank (CJ2 - 1994): 5 GHz, 192 sources
- CJ Flat spectrum (CJF – 1996): 5 GHz, 293 sources
- VLBA 2cm survey (2000): 15 GHz, 152 sources
- VSOP pre-launch survey (1998): 5 GHz, 374 sources
- USNO geodetic survey (2004): 2.2 and 8GHz, 452 sources

Polarization: partial observations at a single frequency for PR and CJF
Multi-epoch: PR, CJ, VLBA 2cm, USNO

CJF Survey

- Caltech-Jodrell Bank flat-spectrum survey
- 293 extragalactic radio sources
- Parent samples include: PR (81, 88), CJ1 (95), CJ2 (94) surveys
- Criteria: $S_{4850} \geq 350$ mJy
  - $a_{4850} \geq 0.5$
  - $d_{1950} \geq 35^\circ$
  - $|b| \geq 10^\circ$

CJF Polarimetry

- Characteristics, Classifications & Completeness
  - 182 CJF sources imaged with the VLBA on 1998 February, 1999 November and 2000 December
  - ~300 hours of observation over 15 days
  - Optical classifications by Henstock, Vermeulen & Taylor, 1995 give:
    - 113 Quasars
    - 36 Galaxies
    - 11 BL Lacs
    - 22 ‘others’
  - Redshift completeness: 151/182

Defining the Source Characteristics

- Morphologies based on total intensity give:
  - 37 naked cores, 137 core-jets and 8 compact symmetric objects
- Define jet angle ($\theta$) using closest component to core
- Define jet length as distance to farthest component (irrespective of jet bend)
- Measure: $I_{\text{tot}}, P_{\text{tot}}, I_{\text{core}}, P_{\text{core}}$ (peak flux at core position in Jy beam$^{-1}$)
  - $m_{\text{core}}, m_{\text{jet}}$ average $m_{\text{core}} \cdot m_{\text{jet}}$
Defining the Source Characteristics

Discussion

- K-S test says $m_{jet}$ for BL Lacs is drawn from different parent distribution than Qs or Gs.

jet axis – Jet EVPA

- All consistent with flat distribution, no preferred orientation

jet axis – Core EVPA

- K-S test says 2% chance that $|\theta - \chi_{core}|$ is flat or randomly distributed
- Faraday rotation may conceal correlation

VLBA Imaging Polarimetry Survey (VIPS)

Parent Sample: CLASS
1000 sources: S > 50 mJy, dec > 20, |b|>10 at 5 & 15 GHz
Will require 1500 hours on the VLBA (63 days) @ 128 Mbps
or 750 hours @ 256 Mbps
Identifications and redshifts from SLOAN
Goals:
- Characterize GLAST sources
- Understand polarization properties of AGN classes
- Study AGN environments via Faraday rotation
- Find new Compact Symmetric Objects
- Find (possibly) the first milli-lenses

VIPS Pilot Project

4 x 12 hours with the VLBA on Mar 13, 14, Jun 28, Aug 18
24 target sources at 5 and 15 GHz
16 GB of data
All data reduced by new pipeline procedures
Spectral Indices detected in 9/24 sources (38%)
Faraday Rotation

\[ \psi = \psi_0 + \text{RM} \lambda^2 \]

\[ \text{RM} = 812 \, \text{rad m}^{-2} \]

Zavala & Taylor (2002)

Summary

Exciting time for VLBI:
- Major scientific results being made possible by new technologies
- Increased synergy with other wavelengths

Good time for a big AGN survey:
- GLAST
- The Gamma-ray Large Area Space Telescope