

Very Long Baseline Interferometry (VLBI) – Techniques and Applications

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Overview

- The technique – how is it similar, how is it different to connected element interferometry;
- VLBI instrumentation;
- VLBI science
 - Black hole masses - NGC 4258/Circinus;
 - Low redshift AGN - M87/Centaurus A;
 - Wide field imaging;
 - Astrometry/low mass stellar companions;
 - "superluminal" motion – 3C1.20;
 - Microquasars – GRO J1655-40.

The Technique

- Elements are not connected
 - Electronics are locked using station clocks;
 - Data are recorded on tape for post-observation processing
- Elements can therefore be placed, in principle, anywhere, including in space;
- Resolution between an Earth-based antenna and a space antenna in a 20,000 km orbit at 5 GHz is approximately 0.25 mas – Earth baseline, 15 GHz;
- VLBI is thus very sensitive to errors in the geometric model used by the correlator
 - Source and station positions (these change with time);
 - Vastly different weather conditions at each Element

Table 22-1. Terms of a VLBI Geometric Model ^a

Item	Approx max Magnitude ^b	Time scale
Zero order geometry	6000 km	1 day
Nutation	~ 20"	< 18.6 yr
Precession	~ 0.5 arcmin/yr	years
Annual aberration	20"	1 year
Retarded baseline	20 m	1 day
Gravitational delay	4 mas @ 90° from sun	1 year
Tectonic motion	10 cm/yr	years
Solid Earth Tide	50 cm	12 hr
Pole Tide	2 cm	~1 yr
Ocean Loading	2 cm	12 hr
Atmospheric Loading	2 cm	weeks
Post-glacial Rebound	several mm/yr	years
Polar motion	0.5"	~ 1.2 years
UT1 (Earth rotation)	Random at several mas	Various
Ionosphere	~ 2 m at 2 GHz	seconds to years
Dry Troposphere	2.3 m at zenith	hours to days
Wet Troposphere	0 – 30 cm at zenith	seconds to seasonal
Antenna structure	<10 m. 1cm thermal	—
Parallactic angle	0.5 turn	hours
Station clocks	few microsec	hours
Source structure	5 cm	years

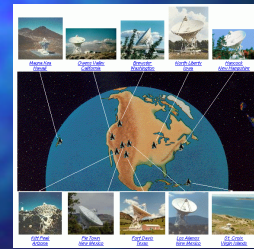
^aAdapted from Sovers, Fenselow, & Jacobs 1998
^bFor an 8000 km baseline, 1 mas ↔ 3.9 cm. ↔ 130ps

The Technique (cont)

- A time-variable delay error in the geometric model used by the correlator causes slopes of phase with frequency and time;
- Several schemes (some closely related to self-calibration) have been developed to determine these errors directly from the data;
- Modern (last ten years) correlators have access to geometric models that are good to a few cm at worst at all stations and GPS for time-keeping – the atmosphere becomes the limiting factor for determination of the astronomical phase – similar to connected element arrays like the ATCA.

VLBI Instrumentation

- Very Long Baseline Array (VLBA), a dedicated 10 station array within US territory, operated by NRAO;
- Correlator in Socorro;
- Open proposal system;
- 25 m antennas;
- 8,600 km baseline;
- 330 MHz to 43 GHz;



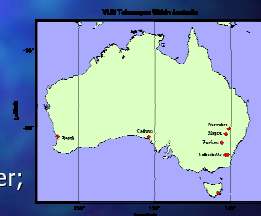
Instrumentation (Cont)

- European VLBI Network (EVN), a consortium of observatories and institutes in Eurasia – 18 stations;
- JIVE, VLBA, Bonn;
- Open proposals;
- 9,169 km baseline;
- Various antennas;
- 3 week blocks;
- 3 times per year;
- 330 MHz – 43 GHz.



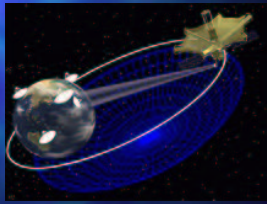
Instrumentation (cont)

- Australian VLBI National Facility, 6 - 9 stations in Australia and South Africa;
- Marsfield correlator;
- Open proposals;
- 9,853 km baseline;
- Various antennas;
- 843 MHz – 22 GHz;
- 1 week per AT semester;

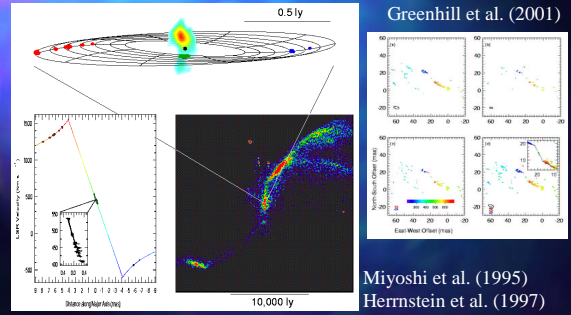


Instrumentation (cont)

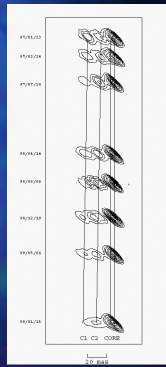
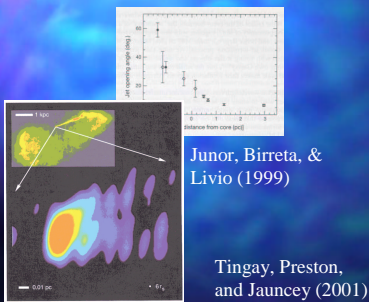
- VLBI Space Observatory Programme (VSOP) – has been operated since 1997, supported by ground networks;
- 20,000 km orbit;
- 30,000 km baseline;
- 1.6 and 5 GHz;
- RadioAstron;
- ARISE;
- VSOP2.



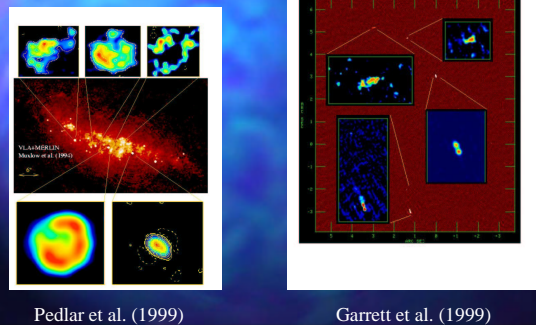
Black Hole Masses – NGC 4258 and Circinus



Low redshift AGN – M87 and Centaurus A

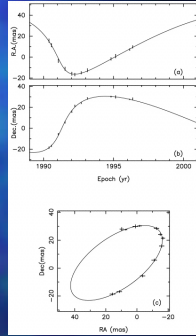


Widefield imaging



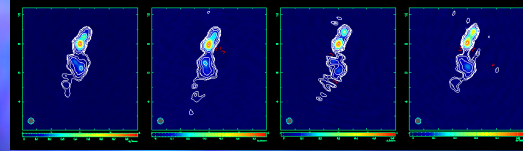
Astrometry/low mass stellar companions

- AB Doradus, binary stellar system and weak radio source;
- Australian VLBI array at 8.4 GHz;
- Phase referenced observations of the radio source;
- Measured accurate RA and Dec as a function of time;
- After parallax and proper motion are subtracted, left with the orbital signature due to a 0.08 – 0.11 solar mass companion.



Guirado et al. (1999)

Space VLBI



Murphy et al. (2000)

- 1928+738, suggested helical jet due to binary black hole;
- VLBA+HALCA VSOP observations at 5 GHz give approximately 0.25 mas angular resolution;
- Apparent component speeds $>10c$, variations in the structure of components in the jet;

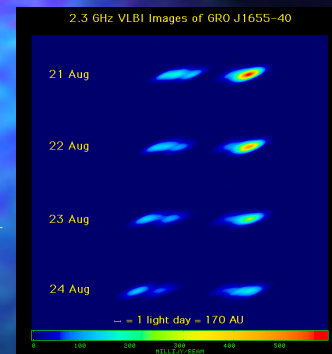
Superluminal motion – 3C120

VLBA 22 GHz Observations of 3C120

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<i>Cristina García-Miró</i>	<i>IAA (Spain)</i>

Microquasars

- 3.2 kpc distant;
- Binary system of star (1.7 – 3.3 solar masses) and black hole (4 – 7 solar masses);
- VLBI shows 65 mas/day – largest transverse apparent motion for an extra-solar system object, 1.1c - 1.9c;
- True speed 0.92c and inclined 85 degrees to our line of sight.



Tingay et al. (1995)