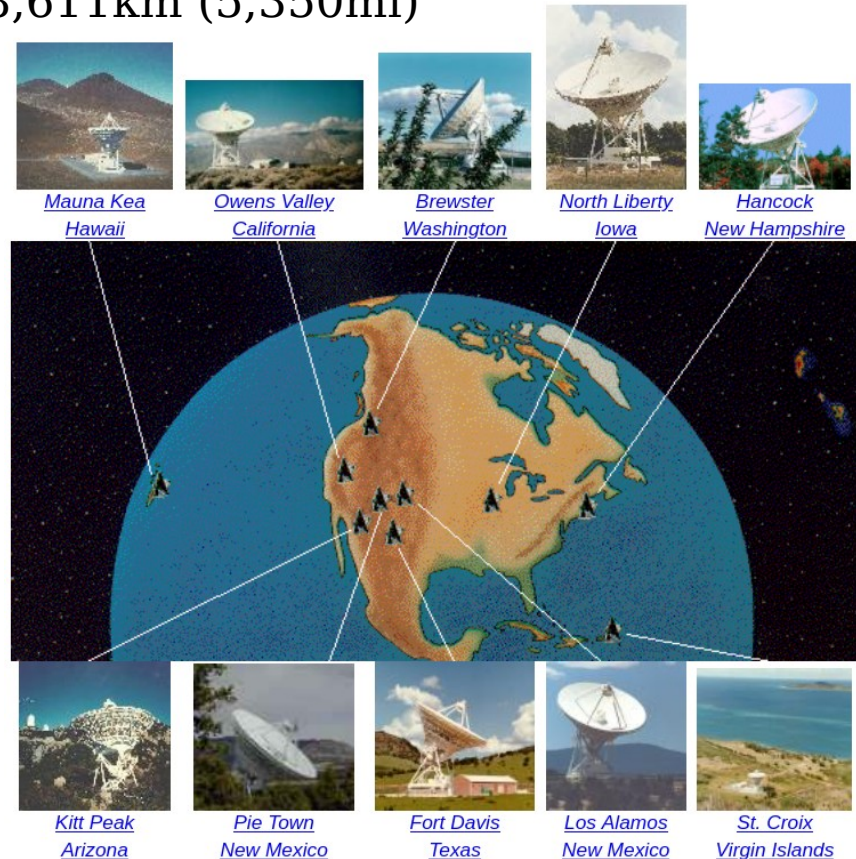# Very Long Baseline Array

Anna D. Kapinska (NRAO)

VLBA Interferometer

VLBA antennas are spread across USA with the longest baseline between Hawai'i and St Croix locations.

→ 10 antennas, with longest baseline 8,611km (5,350mi)
→ each location has one antenna
→ no configurations as such, but free
   selection of dishes

→ frequency coverage
   0.3 GHz – 96 GHz (90cm – 3mm)
→ resolution 0.17 – 22 mas

Mauna Kea
Hawaii

Owens Valley
California

Brewster
Washington

North Liberty
Iowa

Hancock
New Hampshire

Kitt Peak
Arizona

Pie Town
New Mexico

Fort Davis
Texas

Los Alamos
New Mexico

St. Croix
Virgin Islands

VLBA Interferometer

Realtime Photos for All Sites

St. Croix

Hancock

North Liberty

Fort Davis

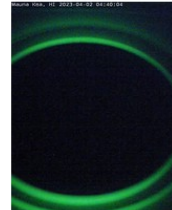Los Alamos (not realtime)

Pie Town

Kitt Peak

Owens Valley

Brewster

Mauna Kea

VLBA data correlator: located in Socorro, NM
→ data from each antenna are digitalised locally, recorded and physically sent to Socorro
→ data correlation to the specifications of PI
→ supporting multiple phase centres, and correlations "per mode"

VLBA Frequency Bands

https://science.nrao.edu/facilities/vlba/docs/manuals/oss/bands-perf

[1] Receiver Band Designation (*)	[2] Nominal Frequency Range [GHz]	[3] Typical Zenith SEFD [Jy]	[4] Center Frequency for SEFD [GHz]	[5] Typical Peak Gain [K Jy^{-1}]	[6] Baseline Sensitivity $\Delta S^{512,1m}$ [mJy]	[7] Image Sensitivity $\Delta I_m^{4096,8h}$ [μJy beam^{-1}]
90 cm (a)	0.312 - 0.342	2742	0.326	0.077	111	(i) 266
50 cm (a,b)	0.596 - 0.626	2744	0.611	0.078	443	(j) 753
21 cm (c)	1.35 - 1.75	289	1.438	0.110	2.9	(k) 10
18 cm (c)	1.35 - 1.75	314	1.658	0.112	3.2	(k) 11
13 cm	2.2 - 2.4	347	2.269	0.087	3.5	(k) 12
13 cm (d)	2.2 - 2.4	359	2.269	0.085	3.6	(k) 12
6 cm (e)	3.9 - 7.9	210	4.993	0.119	2.1	5
7 ghz (e)	3.9 - 7.9	278	6.660	0.103	2.8	7
4 cm	8.0 - 8.8	327	8.419	0.118	3.3	8
4 cm (d)	8.0 - 8.8	439	8.419	0.105	4.4	11
2 cm	12.0 - 15.4	543	15.363	0.111	5.5	13
1 cm (f)	21.7 - 24.1	640	22.236	0.110	6.5	16
24 ghz (f)	21.7 - 24.1	534	23.801	0.118	5.4	13
7 mm	41.0 - 45.0	1181	43.124	0.090	12	29
3 mm (g)	80.0 - 90.0	4236	86.2	0.033	(h) 60	(l) 184

Single receiver

13/4-cm (S/X) dichroic system

C-band simultaneous tunings anywhere in 4-8GHz band

C-band → best sensitivity

VLBA Resolution & Data rates

Milli-acrsecond resolution

Observing band [cm]: 90 50 21 18 13   6   4   2   1   0.7 0.3
θ_{HPBW} [mas]:   22 12 5.0 4.3 3.2 1.4 0.85 0.47 0.32 0.17 0.12

22 mas in P band   120 µs at 3mm

Data rates: up to 4Gbps

→ in principle allows for broadband (frequency) observing

→ but full polarisation products will reduce the bandwidth (and max number of correlator passes)

→ some bands allow only 32 Mbps – 2Gbps (the lowest ones)

VLBA Specialised Modes

Ultra-high Spectral Resolution Observing
→ transition rest frequency, approximate velocity, and velocity width for the line target must be known in order to set the observing frequency and bandwidth correctly
→ must not use pulse cal generators
→ minimum spectral resolution: 1 Hz
→ maximum of 4096 points per channel, for routine DiFX processing
→ support of "spectral zooming" (selection of a subset of correlated spectral points from any or all data channels)
→ some documentation: https://science.nrao.edu/facilities/vlba/docs/manuals/oss/spec-tech/line

Pulsar Observations
→ all special processing required for pulsar observations is supported within the DiFX correlator
→ available gating and binning options: binary and matched-filter gating, pulsar binning
→ Pulsar modes incur a minimum correlation-time penalty of about 50%

https://science.nrao.edu/facilities/vlba/docs/manuals/oss

CDE Haystack – April 2023

VLBA Backend

RDBE – Roach Digital BackEnd

<div style="border:1px solid">Current system</div>

→ two data systems:

    – PFB = Polyphase FilterBank

        → gives better amplitude calibration, should be used if <10% accuracy needed

        → up to 16 fixed-bandwidth 32 MHz data channels (IFs) within single RDBE

        → maximum data rates 2Gbps

    – DDC = Digital DownConverter

        → generally use as default, especially for spectroscopy

        → allows 4Gbps data rates (Mark6)

        → either 1, 2, 4 or 8 data channels (IFs) in range 1 – 128 MHz in binary steps

VLBA Backend

RDBE – Roach Digital BackEnd

Current system

→ two data systems:
– PFB = Polyphase FilterBank
– DDC = Digital DownConverter

Upgrade ongoing: **VNDA – VLBA New Digital Architecture**

→ to replace aging RDBE system (will be backward compatible
→ will allow for larger bandwidths
→ will support 2, 4, 8 bit sampling (maybe even 12 bit)
→ will provide timing stability
→ support for non-VLBI use (pulsars, spectroscopy, transients)
→ easier maintenance, better RFI avoidance and tolerance, better compatibility with other VLBI systems

Extended VLBA: Y1/Y27, HSA, GMVA, etc

VLBA + VLA/Y1
→ can use a single VLA antenna (Y1) with standard VLBA
→ offers shortest baseline on VLA – VLBA/PT station: ~50km

HSA (High Sensitivity Array)
→ VLBA, VLA/Y27, GBT, Effelsberg combined into a single interferometer
→ can use any combination of the stations
→ note that GBT time is very limited, Effelsberg support 5GHz and above

GMVA (Global 3mm VLBI Array)
→ combines: 8 VLBA stations (HN and SAC excluded), GBT, Effelsberg, Pico Veleta, Onsala, Metsaehovi, Yebes, and Korean VLBI Network (KVN)
→ phased ALMA can be requested
→ European part of the GMVA coordinated by MPIfR, Germany

EVN (European VLBI Network) and Global cm VLBI
→ a VLBI network of stations operated by an international consortium of institutes: https://www.evlbi.org/
→ VLBA can be requested for observations

https://science.nrao.edu/facilities/vlba/docs/manuals/oss/vlba-plus
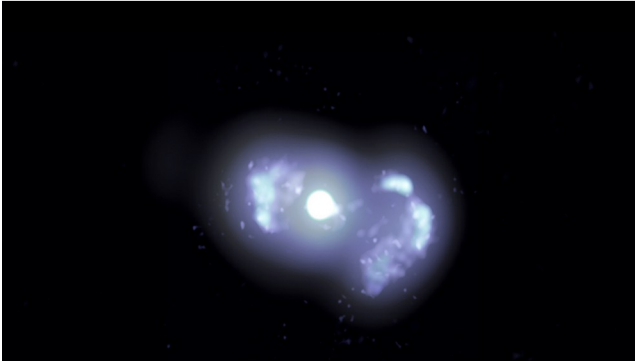
VLBA Science

VLBA is best suited to:

- non-thermal continuum emission (including polarisation) from AGN, pulsars and other compact galactic and extragalactic objects

- Maser emission lines, such as OH (1.7 GHz, 6 GHz), CH3OH (6.7 GHz, 12.2 GHz), H2O (22 GHz), SiO (43 GHz, 86 GHz), and others

- parallax and proper motion studies at accuracies of ~10mas

- absolute astrometry with accuracy of ~200 µas to expand International Celestial Reference Frame

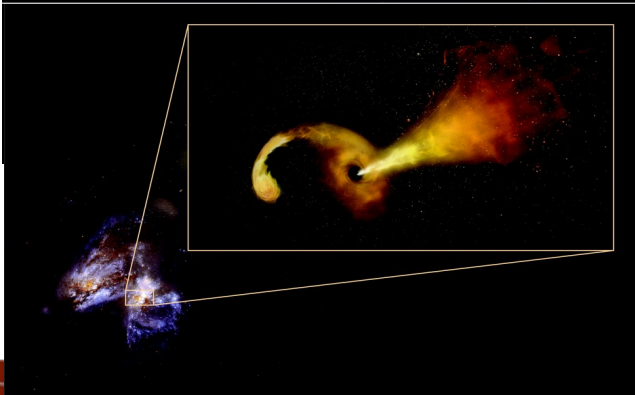- can also support multi-phase center surveys (wide field)
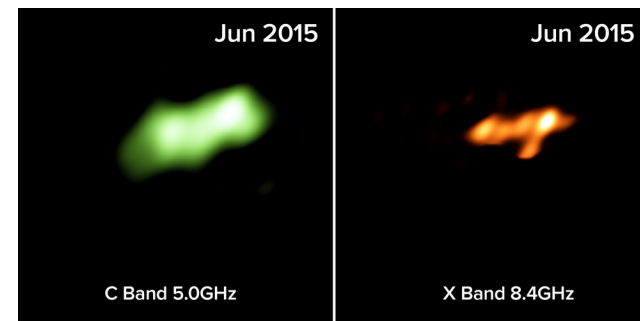
VLBA Science
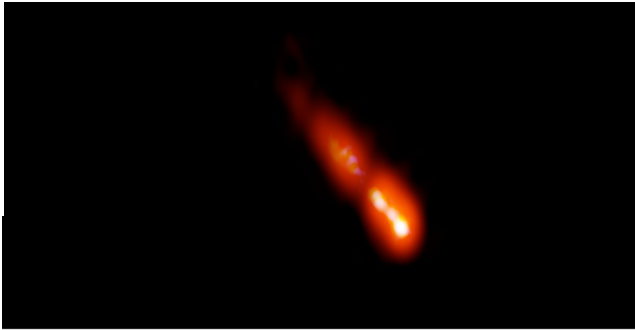
Resolving High-z blazar jets, PSO J0309+27
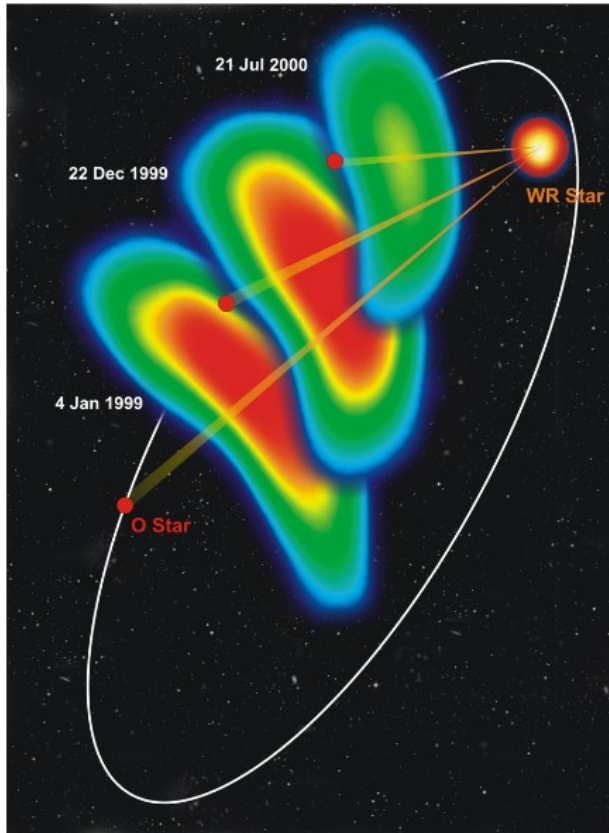Credit: B.Saxon, Spignola+

Multi-frequency VLBA image (2.2–22 GHz)
of jets and shocks in galaxy TXS 0128+554
Credit: S.Dagnello, Lister+

Tidal Disruption Event
in Arp299
Credit: S.Dagnello,
Matilla, Perez-Torres+

Jun 2015   Jun 2015

C Band 5.0GHz   X Band 8.4GHz

VLBA Science

21 Jul 2000

22 Dec 1999

WR Star

4 Jan 1999

O Star

BeSSeL

Bar and Spiral Structure Legacy Survey, a VLBA Key Science Project

WR140: imaging the evolution of the colliding wind region in Wolf-Rayet & O binary star system. Separation between stars: ~5-15 mas = 9-27 AU (Dougherty et al. 2010)
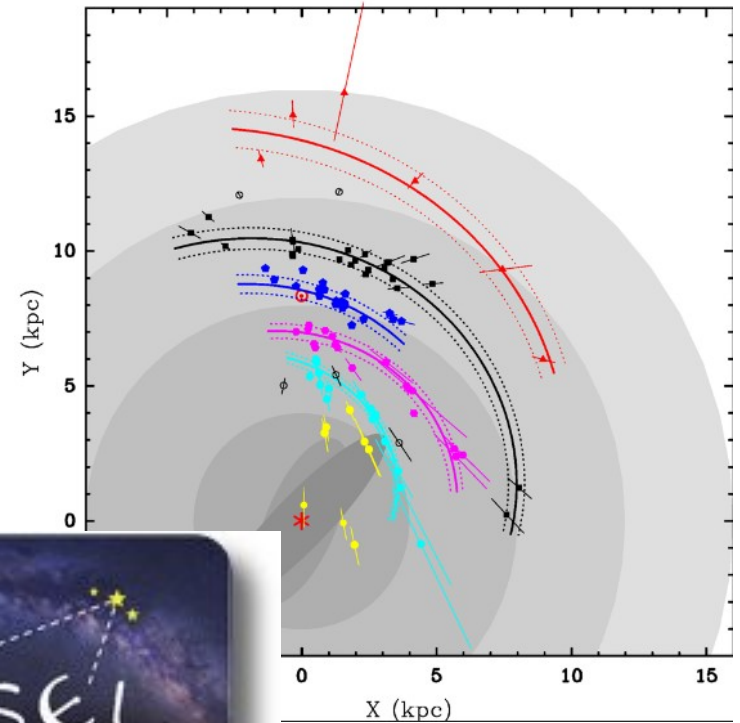
High precision relative astrometry → BeSSeL project measures distances to star forming regions through methanol masers (Reid et al) determining the structure of the spiral arms of the Galaxy.

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