The Very Long Baseline Array

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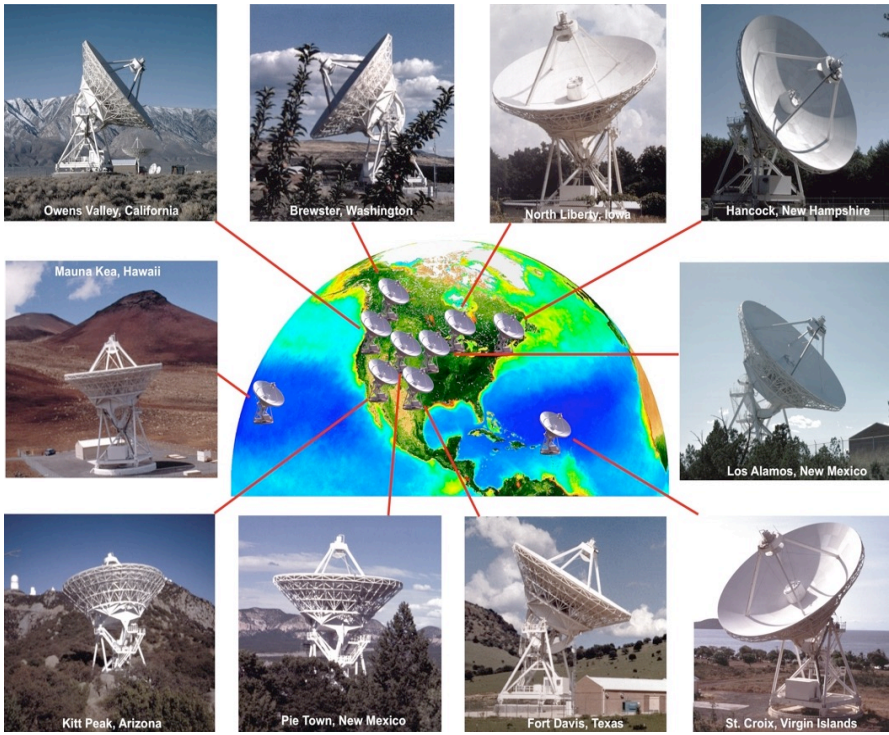
NRAO NSF AUI

Credit

- Large parts of this talk were written by:
- Amy Mioduszewski
- Emmanuel Momjian
- Many others!

Instrument Overview

- A 10 element interferometer radio telescope
  - Identical 25m diameter antennas
  - Array dedicated to Very Long Baseline Interferometry (VLBI)
- Antenna sites in US territory from Mauna Kea Hawaii to St. Croix, US Virgin Islands
  - Baseline lengths between 236 km and 8611 km
- Software Correlator (DiFX) in Socorro, NM



Instrument Overview II

Frequency coverage from 330 MHz (90 cm) to 90 GHz (3mm)

- In 10 frequency bands
- Current standard bandwidth 256 MHz (dual polarization)
  - Being updated to 512 MHz
- Wide instantaneous spanned bandwidth:
  - S/X mode: simultaneous 2.4 GHz and 8.4 GHz observing
  - C-band receiver: simultaneous tunings anywhere in 4-8 GHz band

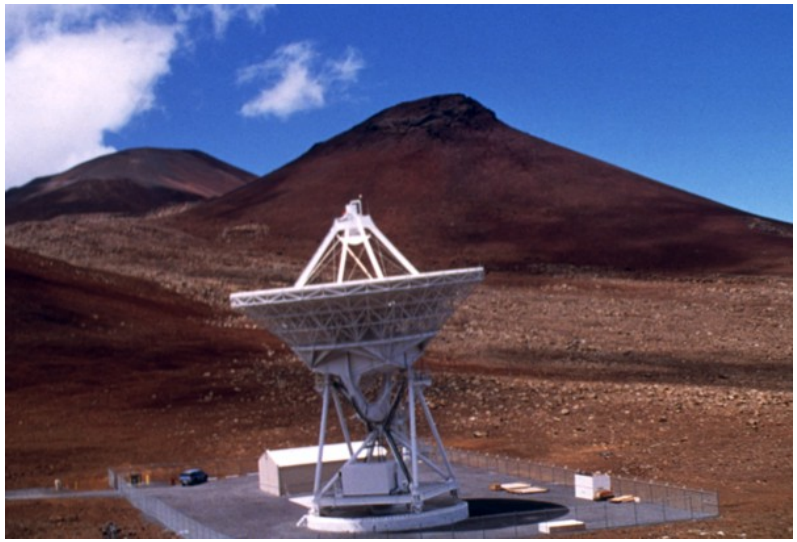
λ(cm)	ν(GHz)	σ(μJy/beam) in 8 hrs at 2Gbps
90 cm	0.312 - 0.342	266*
50 cm	0.596 - 0.626	681*
21 cm	1.35 - 1.75	10-12
13 cm	2.15 - 2.35	12
6 cm	3.9 - 7.9	6-9
4 cm	8.0 - 8.8	11-15
2 cm	12.0 - 15.4	18
1 cm	21.7 - 24.1	18-22
7 mm	41.0 - 45.0	40
3 mm	80.0 - 90.0	180†

Instrument Overview III

- The RDBE (ROACH Digital Back End) has two systems: the PFB and the DDC
- The PFB has
  - 8 X 32MHz dual pol channels (or subbands in VLA terminology, or IF in AIPS terminology), or 16 X 32 MHz single polarization.
  - these result in 2Gbps recording, the current highest data rate.
  - generally recommended for continuum observations.
- The DDC is (assuming dual pol)
  - either 2 or 4 data channels (subbands) range downward from 128MHz to 1MHz in binary steps.
  - again (current) maximum of 256MHz dual pol (2Gbps)
  - generally used for spectral line.
- Starting in Semester 2020A: Mark6 - 4 Gbps recording (general observing) using two RDBE's per station.

Science applications of VLBA and VLBI

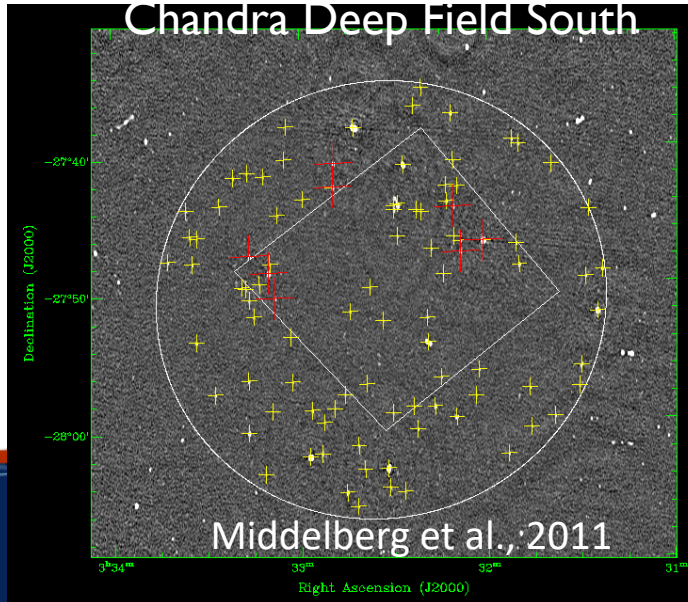
- VLBI provides a tool to study mas-level structure in radio sources.
  - Active Galactic Nuclei (AGN)
  - Pulsars
  - Masers
  - Supernova/Supernova Remnants
  - Magnetically active stars
  - X-ray binaries
  - Nova



- A VLBI detection instantly identifies a compact non-thermal source
  - Synchrotron/cyclotron radiation (electrons in a magnetic field)
  - Maser emission (stimulated emission)
  - Thermal lines seen in absorption against non-thermal background

Special correlator capabilities (DiFX)

- Pulsar gate
  - Synchronous correlator gate to improve signal to noise ratio of repeating signals, such as pulsars
- Multi-phase-center capability
  - Can simultaneously correlate at 100s of points in the antenna primary beam
  - Especially effective w/ VLBA due to identical antennas
- Ultra-high spectral resolution
  - Using "zoom" modes, can achieve 1 Hz
  - Up to132096 channels if justified.
  - Used in some asteroid radar observing



(Resident) Shared Risk Observing (R)SRO

Some possible SRO projects:

- VLA (Y1) single dish VLBI

Some possible RSRSO projects:

- DDC-4 capability at Arecibo
- Rapid response capability
- 3mm VLBI with the LMT
- Multi tone pulsecal

No longer shared risk for 2020A:

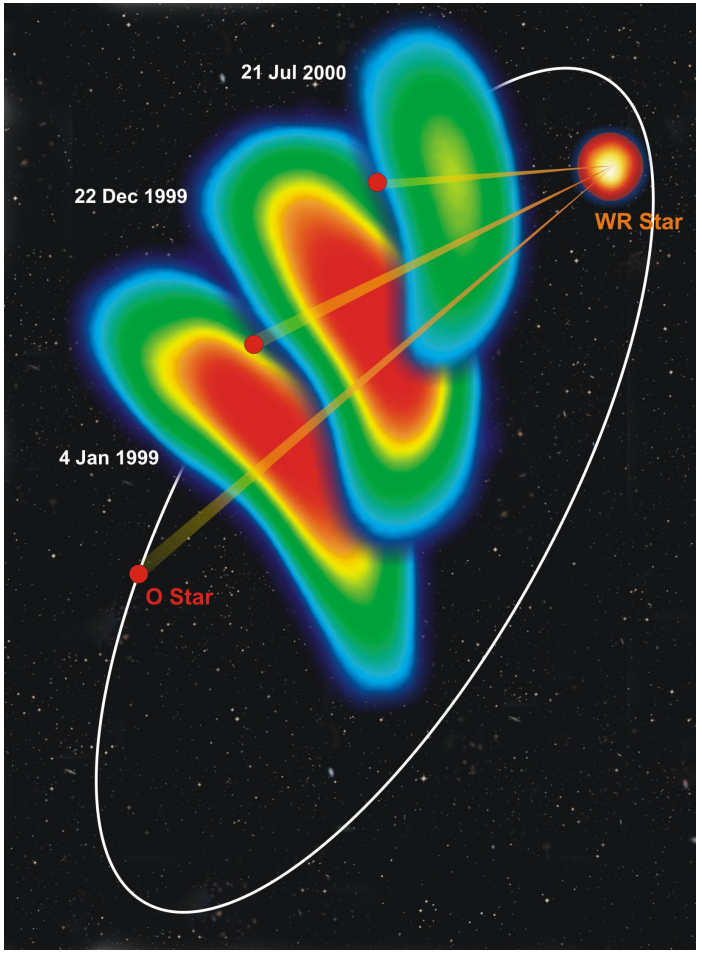
- 4 Gbps observing (512 MHz bandwidth)

Strengths of the VLBA

High dynamic range imaging at milliarcsecond resolution

- Locations of 10 antennas carefully chosen for optimal "UV coverage"
- Imaging resolution in different observing bands:
  - L-band (~1.6 GHz / 20 cm): 5 mas
  - X-band (~8 GHz / 4 cm): 0.85 mas
  - Q-band (~50 GHz / 7mm): 0.17 mas
- E.g. for ~1mas resolution
  - 1 AU at 1 Kpc
  - Few-10 stellar radii at 100pc

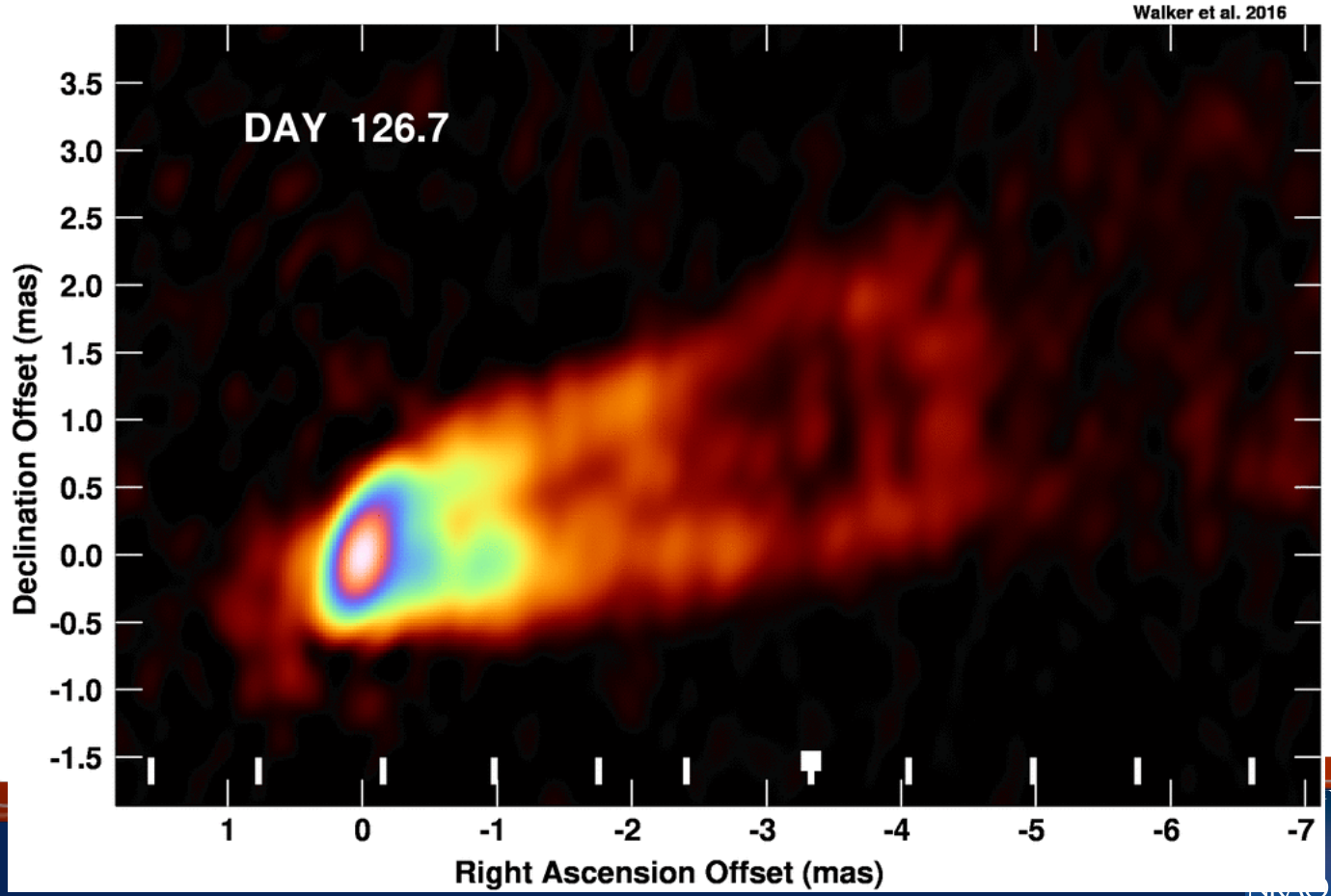
Example: WR140, imaging the evolution of the colliding wind region in Wolf-Rayet + O binary star system. Separation between stars between ~5-15 mas or 9-27 AU (Dougherty et al. 2010).



Strengths of the VLBA

High dynamic range imaging at milliarcsecond resolution

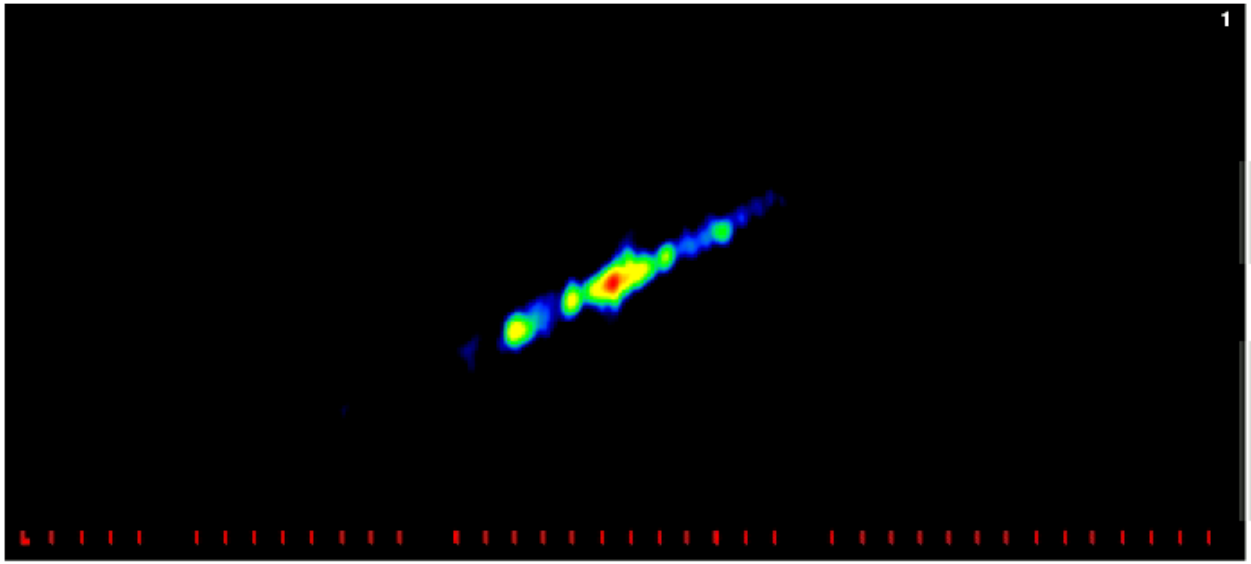
- M87 Jet at 43 GHz (R.C. Walker)
- Challenging: structure changes over time, high contrast



Strengths of the VLBA

Time-dependent phenomena

- VLBA available 24 hours per day, all year
- Can probe phenomena ranging from hours to years in duration
- VLBI sources tend to be variable in brightness, structure, and polarization
- Perfect instrument for wide range of science within graduate student's thesis timescale!



Example: Daily observations of X-ray binary SS433 over 40 days. (Mioduszewski et al)

Strengths of the VLBA

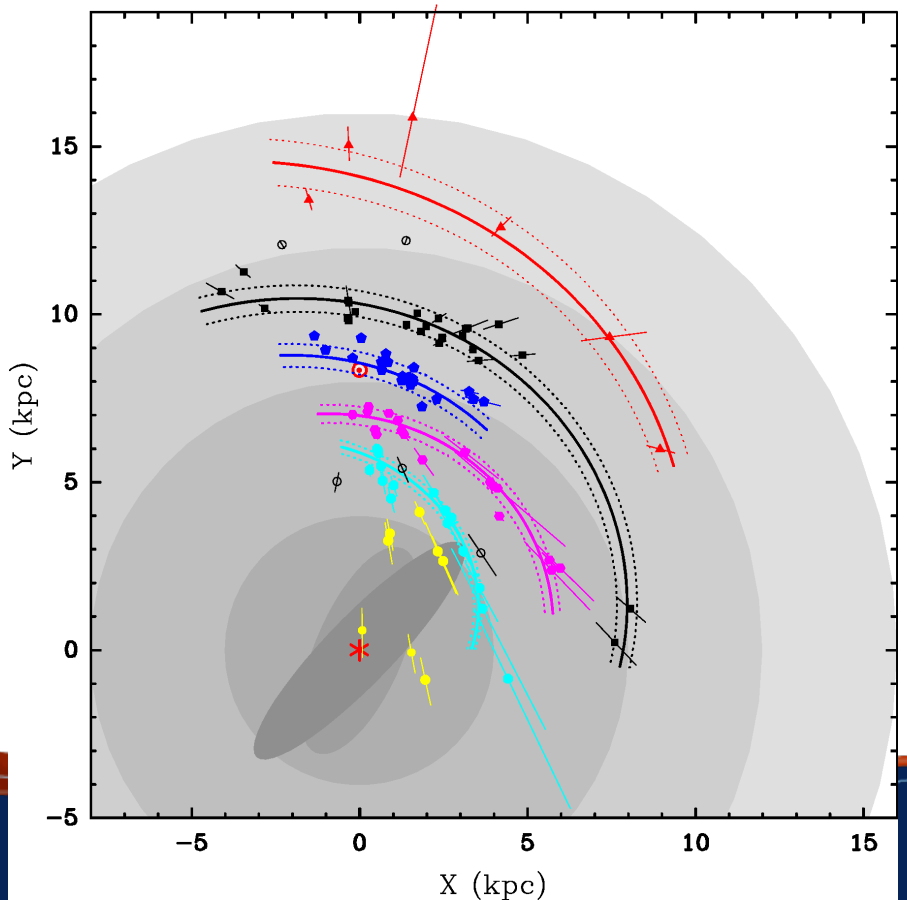
High precision relative astrometry

- Astrometry of a target object relative to a background quasar
  - Usually tied to ICRF to 0.25 mas
- Routinely repeatable at 0.1 mas precision
- Best astrometry to date better than 0.01 mas
- Can be performed on continuum or spectral line sources
  - E.g., pulsars, stars, masers

Strengths of the VLBA

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.



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

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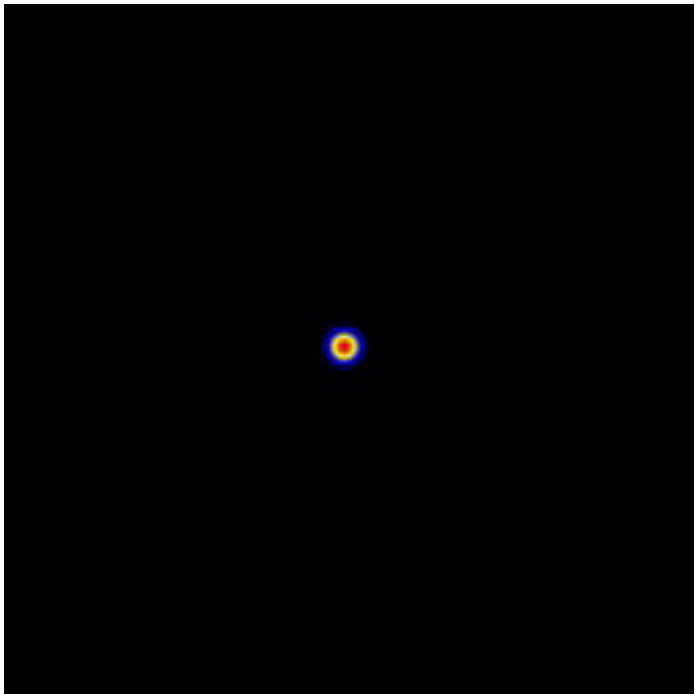
Extended arrays

- VLBA uses data formats and setups compatible with other VLBI antennas
- Routinely involved in High Sensitivity Array (HSA) with Arecibo, phased VLA, Green Bank Telescope and Effelsberg
  - Increases sensitivity by an order of magnitude
- Participates with European VLBI Network in the "Global VLBI Array"
- Joins the Global mm VLBI Array (GMVA) for 86-90 GHz (3mm) observations twice per year. Now with ALMA!
- Participates in global array of geodetic antennas for reference frame measurements.



Example: SN1993J imaged over 10 years with VLBA+DSN+EVN (Bietenholz etal.)

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