The Very Long Baseline Array

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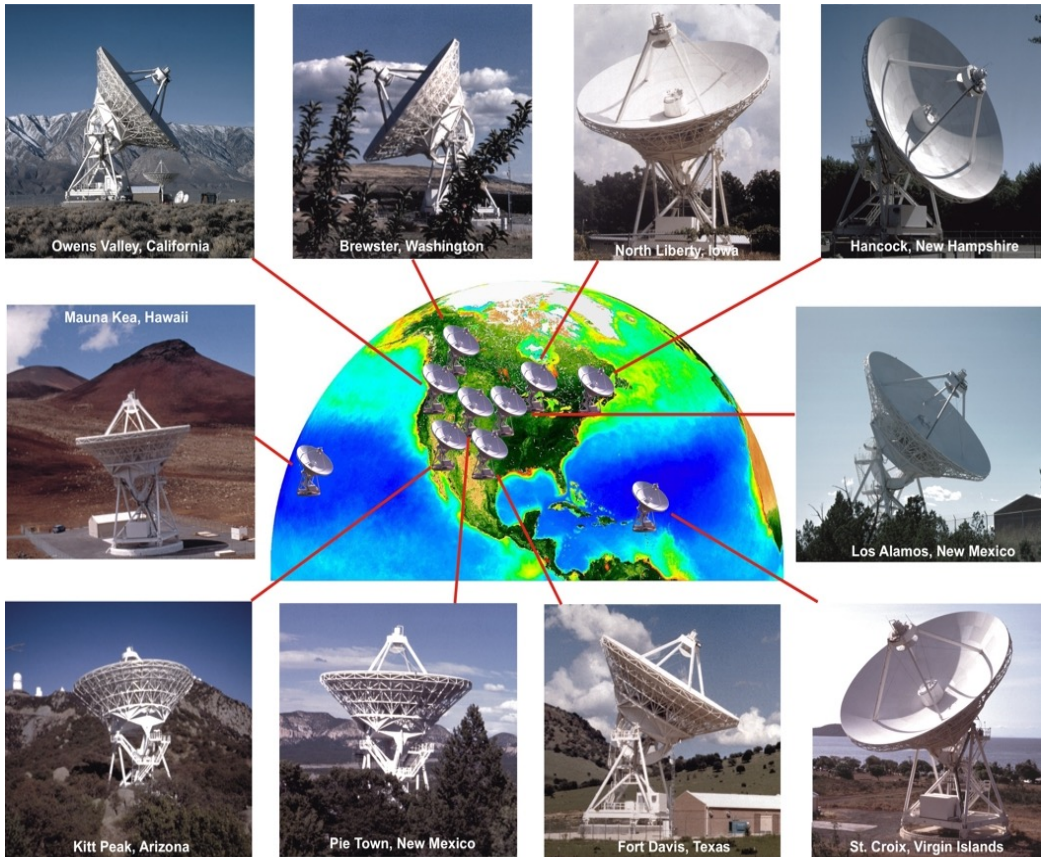
LBO LONG BASELINE OBSERVATORY

NSF

Associated Universities, Inc.

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



Instrument Overview II

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

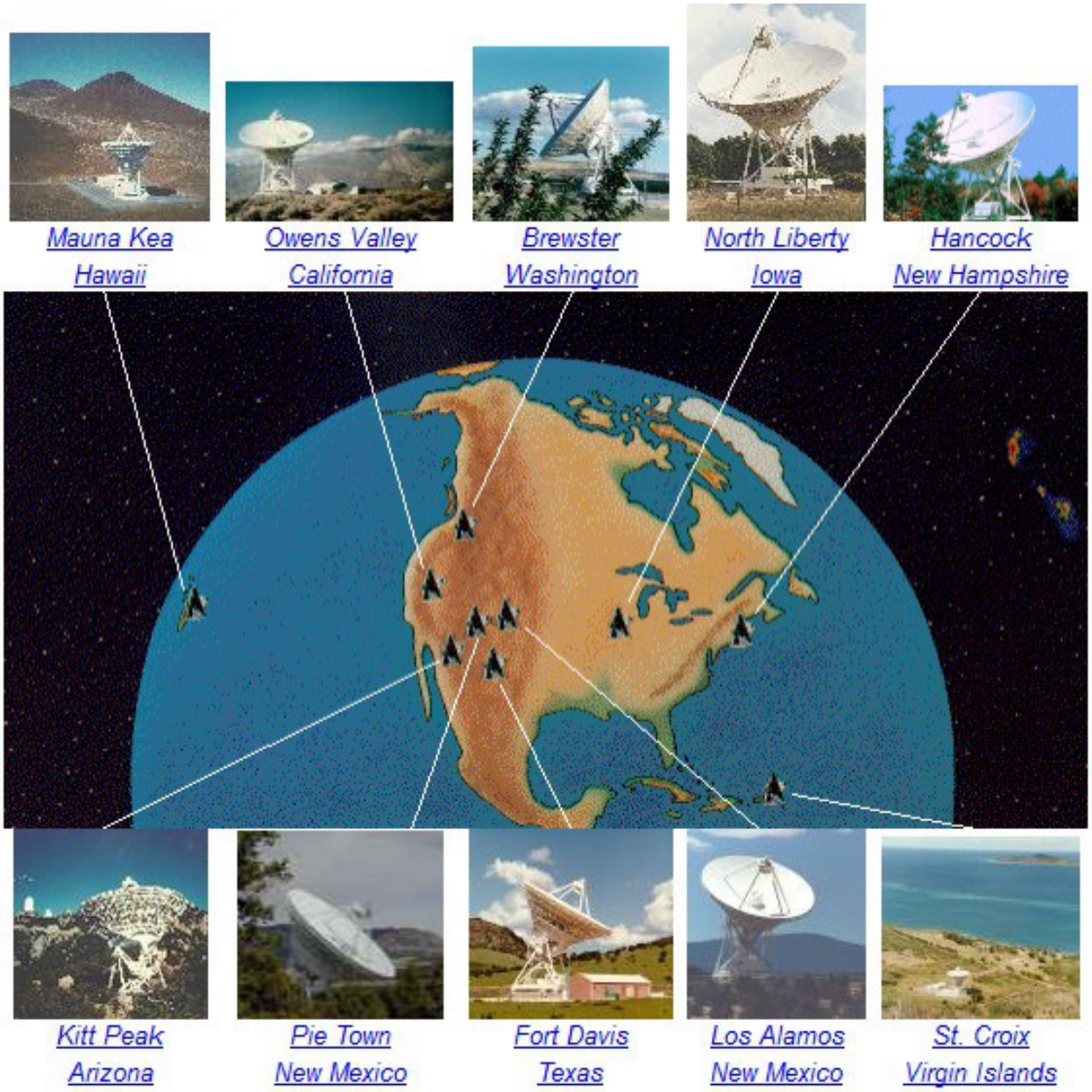
- In 10 frequency bands
- Current highest bandwidth 256MHz (dual polarization)
- Wide instantaneous spanned bandwidth:
  - S/X mode: simultaneous 2.4 GHz and 8.4 GHz observing
  - C-band receiver: simultaneous tunings anywhere in 4-8 GHz band

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†

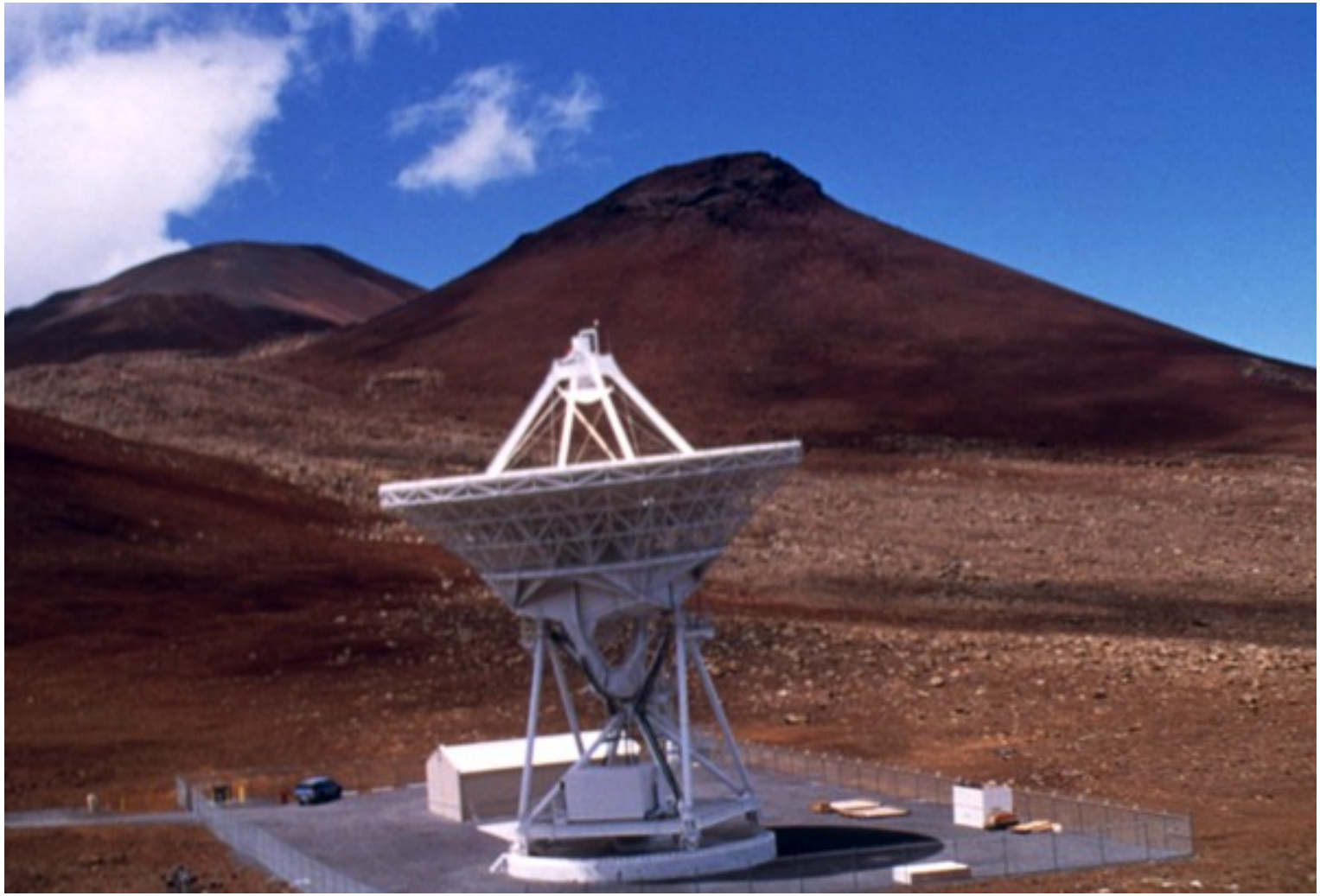
Instrument Overview III

- The RDBE (Roach Digital Back End) has two observing systems: the PFB and the DDC
- The PFB is limited to 8 X 32MHz dual pol channels (or subbands in VLA terminology, or IF in AIPS terminology).
  - or 16 X 32 MHz single polarization
  - this gives you 2Gbps, the highest data rate
  - is completely inflexible although the placement in the sideband is more flexible than the BBC
  - Generally recommended for continuum observations
- The DDC is (assuming dual pol) either 2 or 4 channels (subbands) range downward from 128MHz to 1MHz in binary steps.
  - again maximum of 256MHz dual pol (2Gbps)
  - Where BBCs are put in baseband is much more limited, there are 2 "cross-over points" which cannot be crossed
  - Generally used for spectral line because of the possibility of wider subbands

Locations of VLBA antennas

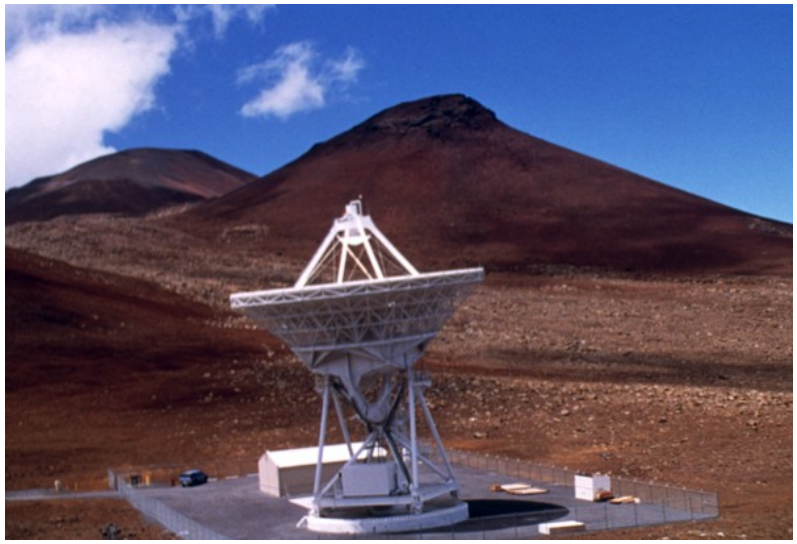


Mauna Kea VLBA site



Science applications of VLBA and VLBI

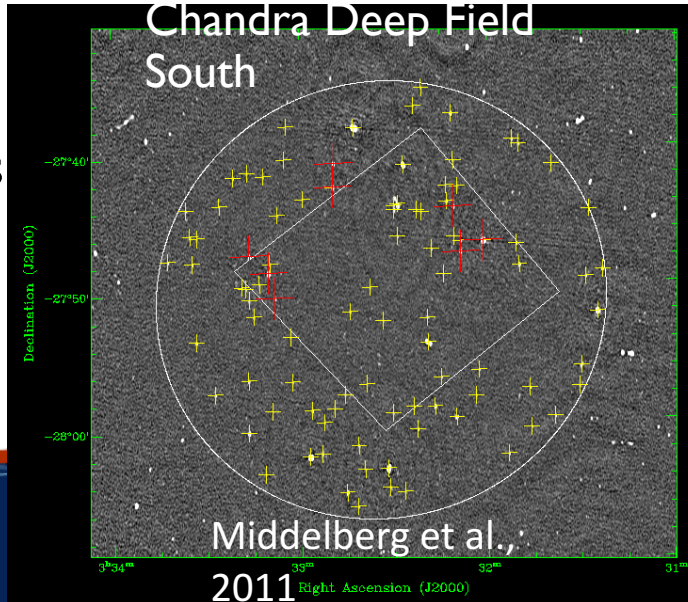
- VLBI provides a tool to study mas-level structure in radio sources. For example:
  - Active Galactic Nuclei (AGN)
  - Pulsars
  - Masers
  - Supernova/Supernova Remnants
  - Magnetically active stars
  - X-ray binaries
  - Nova



- 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

- 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
  - spectral resolution up to132096 channels
  - Used in some asteroid radar observing



Middelberg et al., 2011

Resident Shared Risk Observing

As for the VLA you can propose for RSRO time which gives you access to new modes while requiring help commissioning those modes. One week of residence is required for every 20 hours of VLBA time.

Some possible RSRO projects:

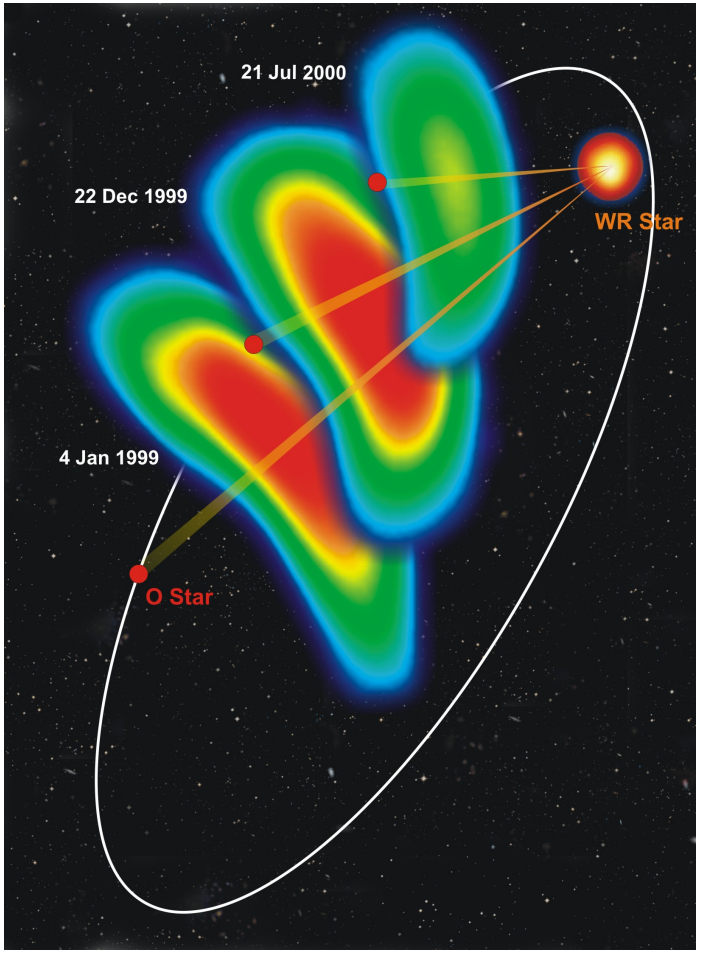
- VLA single dish VLBI
- DDC-4 capability at Arecibo
- Rapid response capability
- 3mm VLBI with the LMT
- Mixed phased-VLA VLBI recording and VLA observing modes.

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

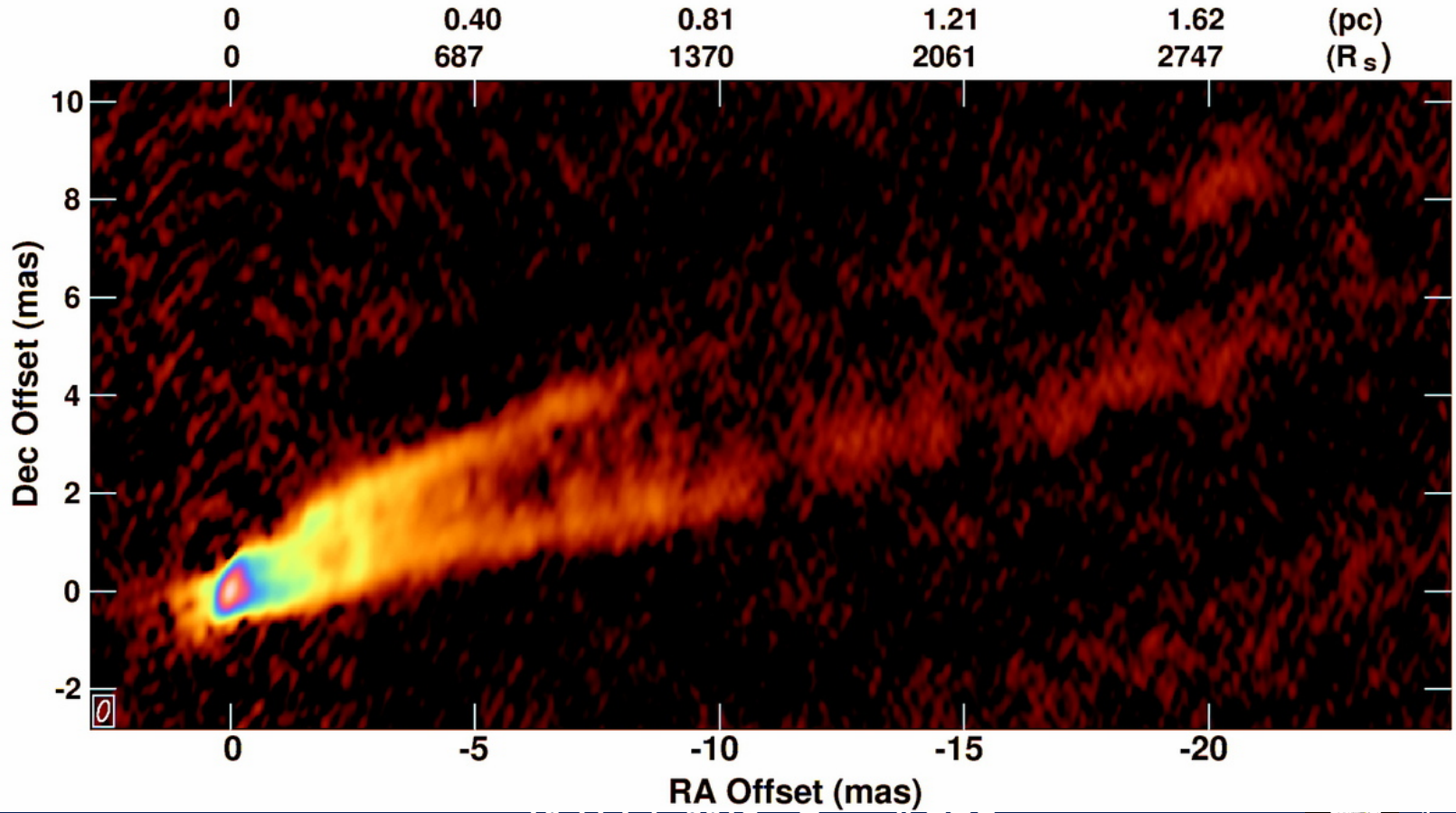
Example: WR140, imaging the evolution of the colliding wind region in Wolf-Rayet + O binary star system. Separation between stars between ~5-15 mas or 9-27 AU (Dougherty et al. 2010).



Strengths of the VLBA

High dynamic range imaging at milliarcsecond resolution

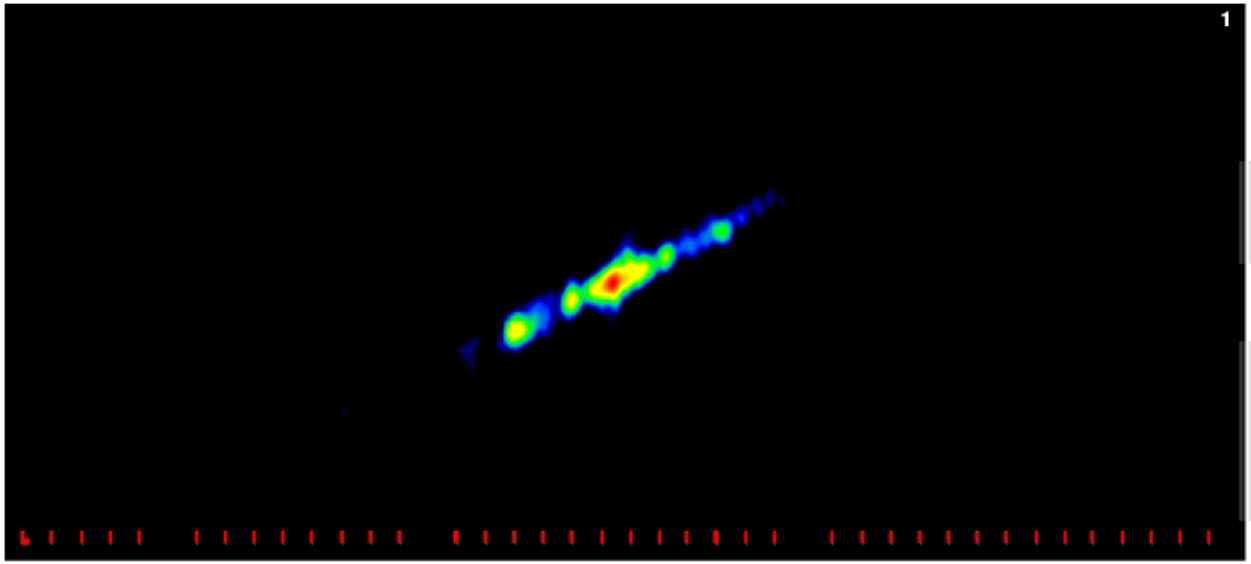
- M87 Jet at 43 GHz (R.C. Walker)
- Challenging: structure changes over time, high contrast



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 etal)

Strengths of the VLBA

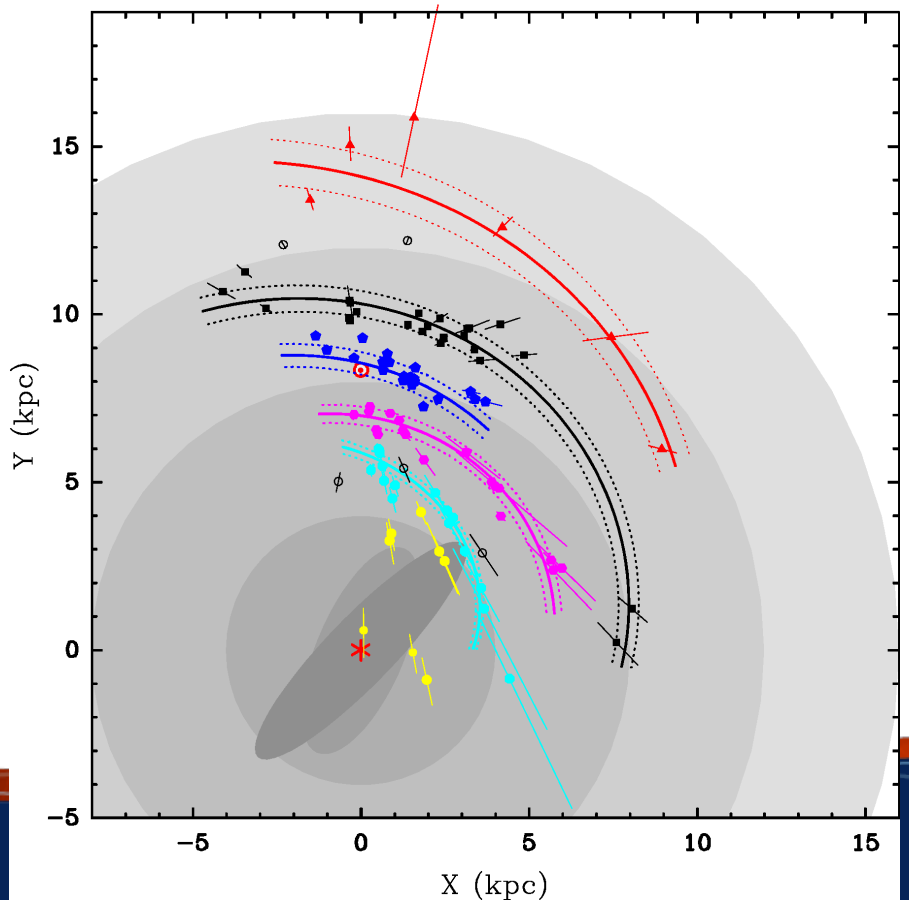
High precision relative astrometry

- Astrometry of target object relative to 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

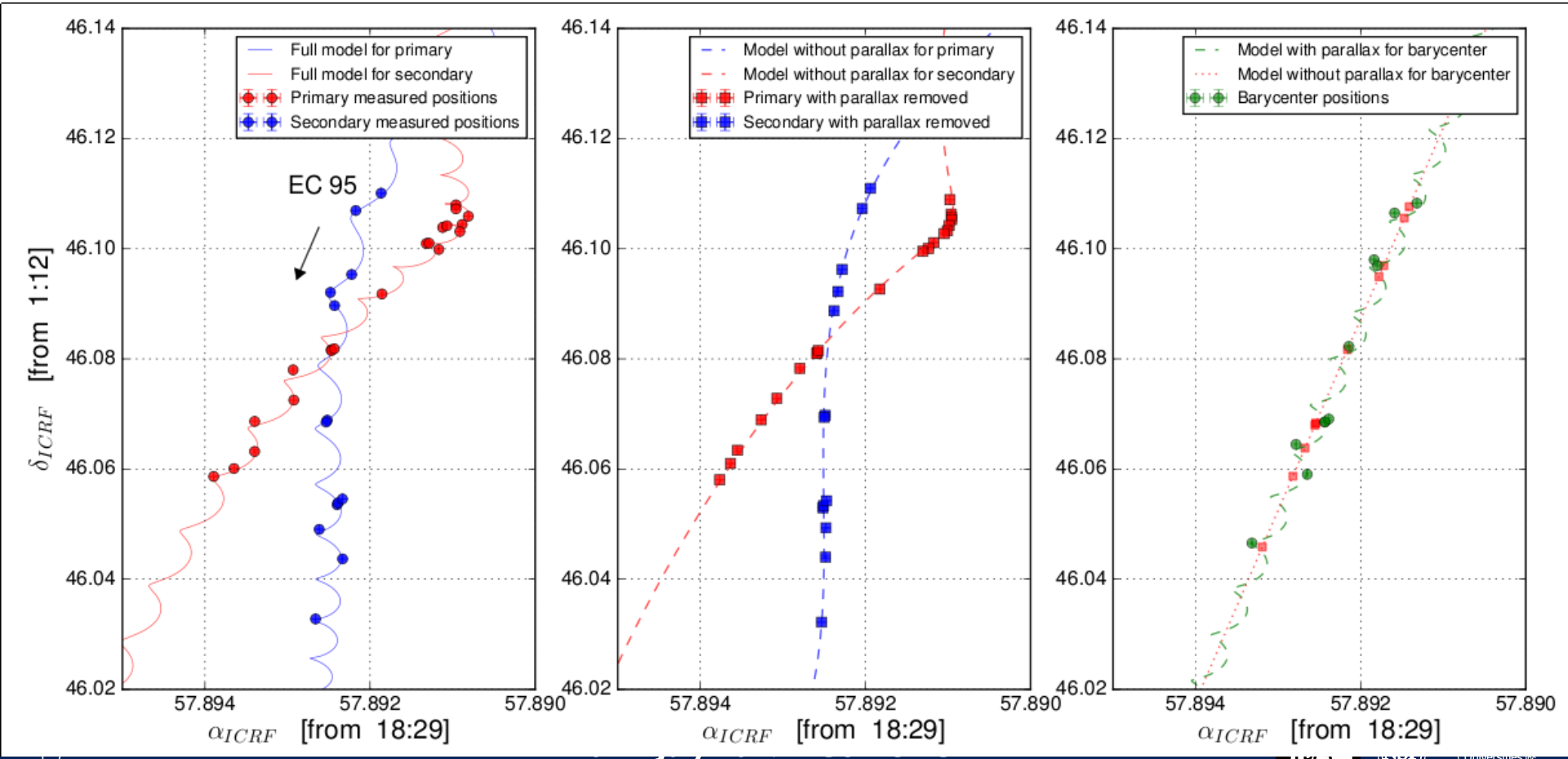
- BeSSeL project measures distances to star forming regions through methanol masers (Reid et al.), determining the structure of the spiral arms of the Galaxy.



Strengths of the VLBA

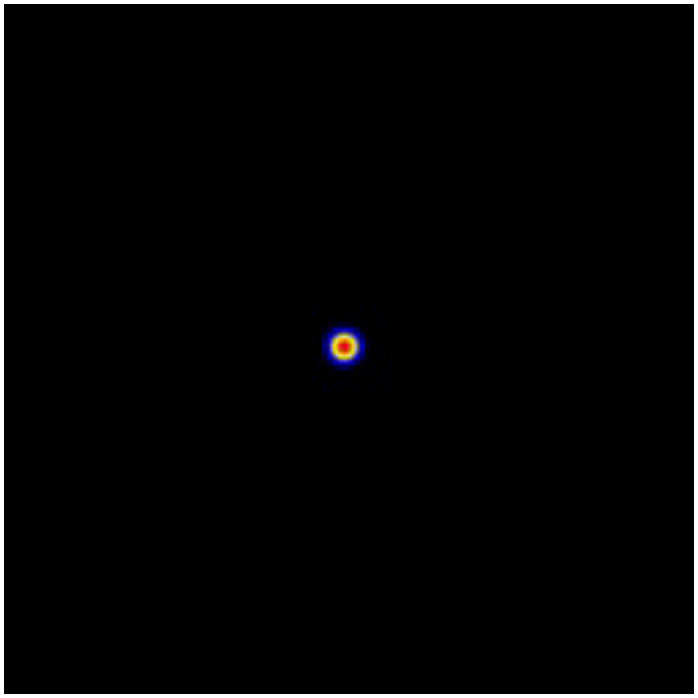
High precision relative astrometry

- Gobelins: continuum stellar astrometry for distance and multiple-system dynamics (Ortiz-Leon et al.)



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 VLBI Millimeter 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.

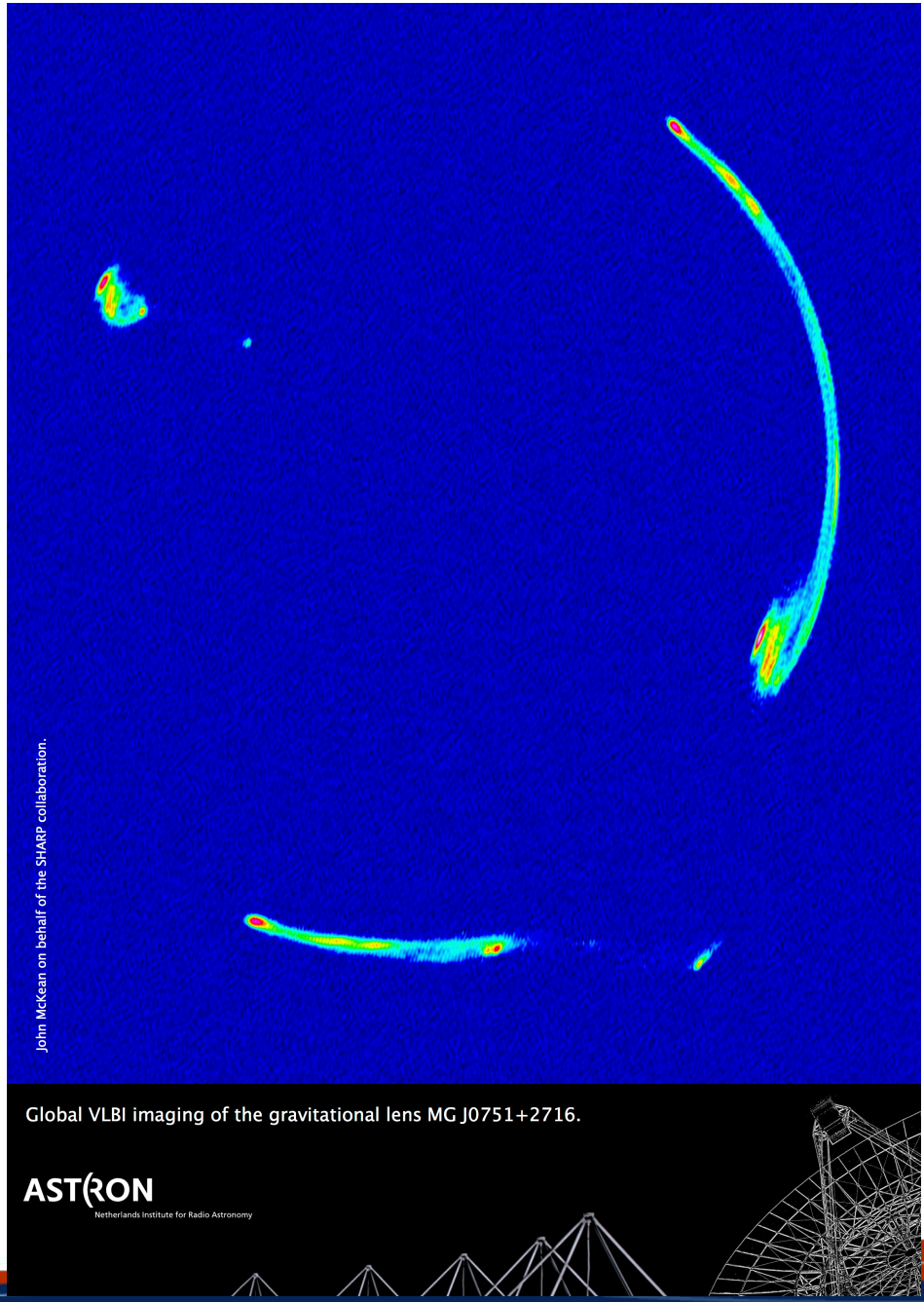


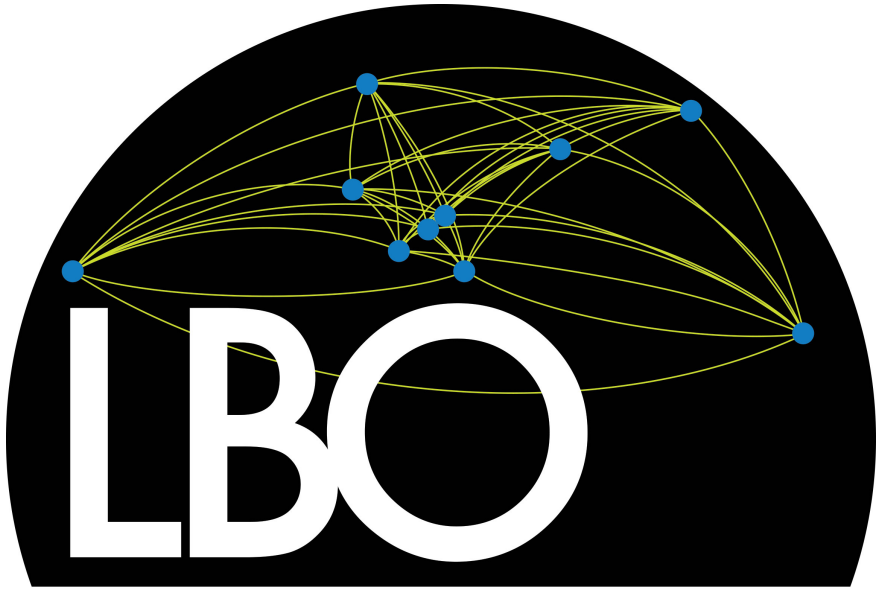
Example: SN1993J imaged over 10 years with VLBA+DSN+EVN (Bietenholz etal.)

Extended arrays

Example: Gravitational lens with VLBA+GBT+EVN (McKean)

Radio galaxy lensed by a galaxy at a redshift of 3.2





LONG BASELINE OBSERVATORY

www.lbo.us

The Long Baseline Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Future of the VLBA

- VLBA is open for business as usual. About half our observing time is available for Open Skies
- The medium to long term [5-10 year] financial stability of the 10-element VLBA is now relatively firm.
- Instead of worrying about operations funding, VLBA is now focusing attention on a significant upgrade path. As plans develop, we will start involving the community in discussions and hopefully also in the development effort.
- High Sensitivity Array observations are still available, however two of our partner observatories (GBT and Arecibo) are undergoing restructuring which may reduce the time available on them. LBO will do its best to inform proposers about this availability.
- VLBA's future is looking pretty good.