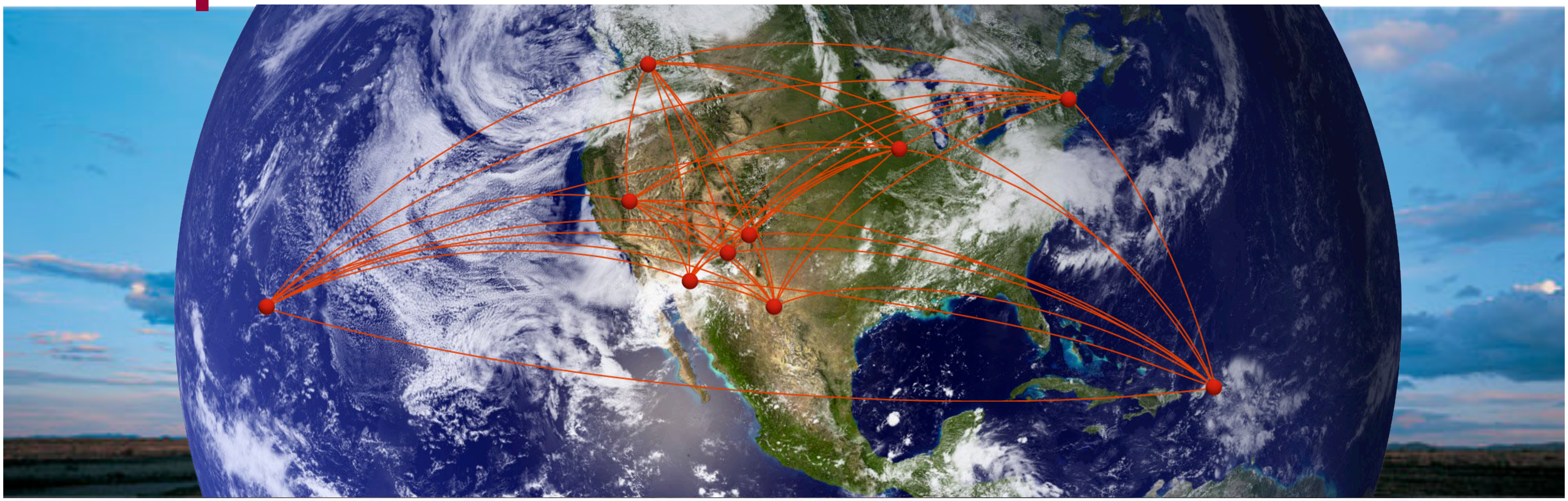
The Very Long Baseline Array: Capabilities

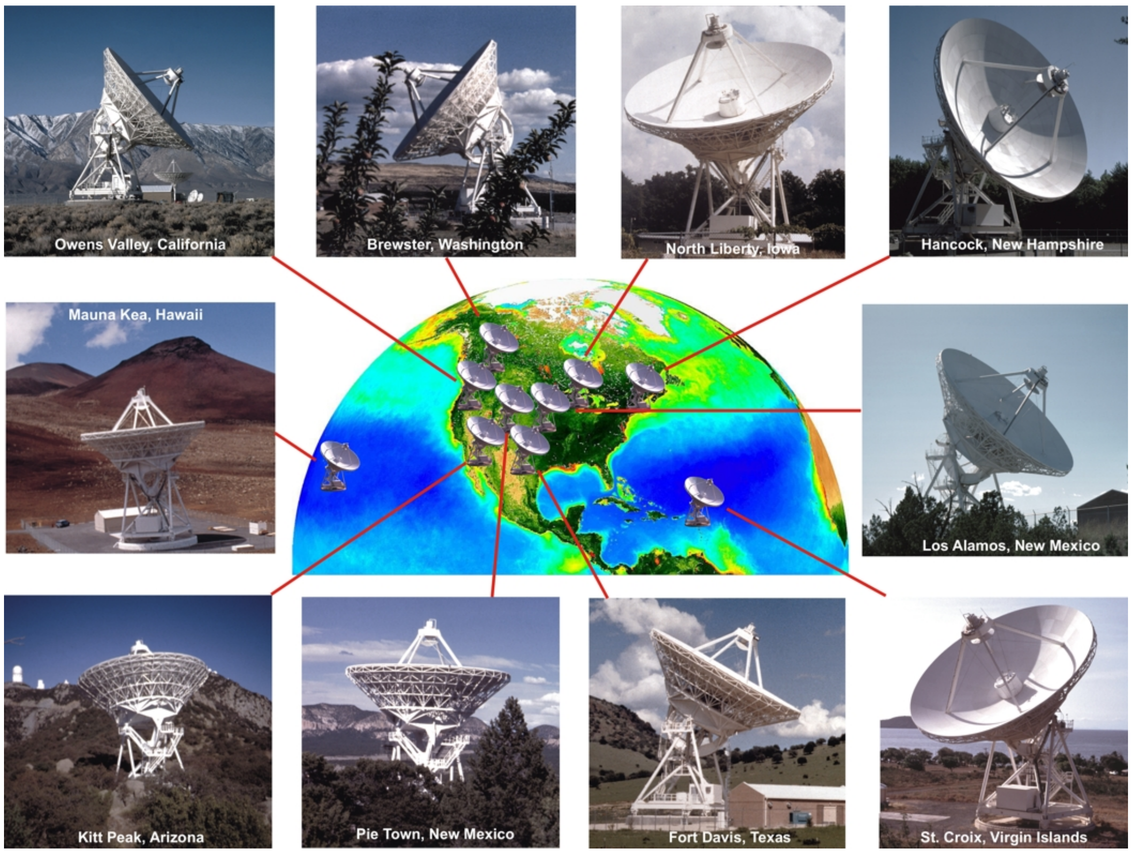


Amy Mioduszewski
Array Science Center

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

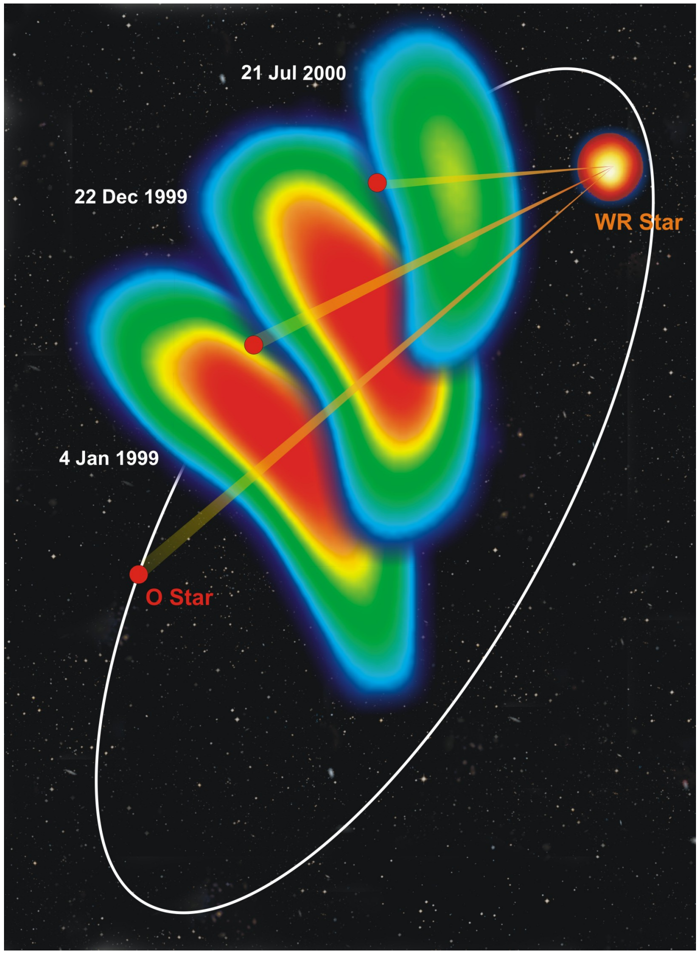
Basics

- 10 x 25 meter antennas.
- Spread from Mauna Kea, Hawaii to St. Croix, Virgin Islands.
- Baseline lengths range from 200 to 8600 km.
- Sensitive to compact structures with brightness temperatures above10^5 K.
- Correlated on a software correaltor, DiFX.



What can the VLBA do?

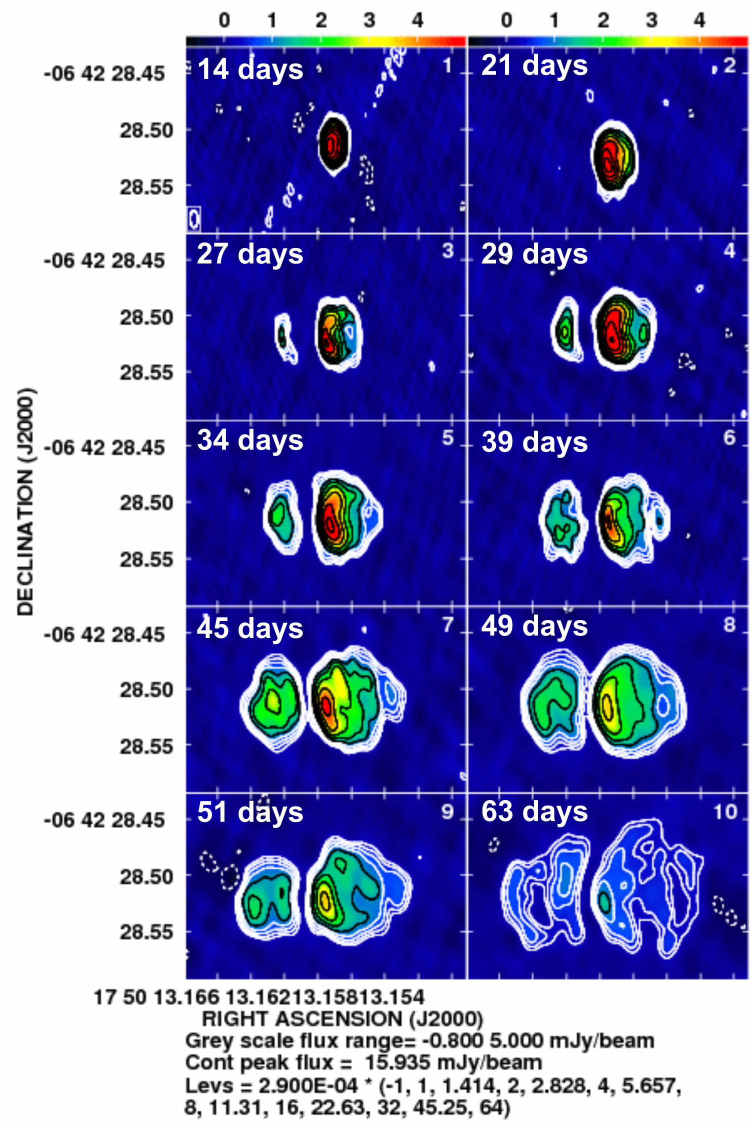
- Resolution
  - 80μas to 25 mas
    - In the galaxy (100pc-10kpc): 1 mas resolution is 0.1-10 AUs (even less than a stellar radius for nearby stars)
    - For nearby extragalactic (1-1000Mpc): 1 mas resolution is 1000 AU-5pc
  - E.g., WR140, colliding wind region in Wolf-Rayet binary star system



Dougherty et al. 2005

What can the VLBA do?

- Monitoring/fast response
  - Dedicated array
  - Targets of Opportunity
  - Watching objects evolve
    - E.g. 1.6 GHz observations recurrent nova RS Ophiuchi (Rupen et al. 2007)



What can the VLBA do?

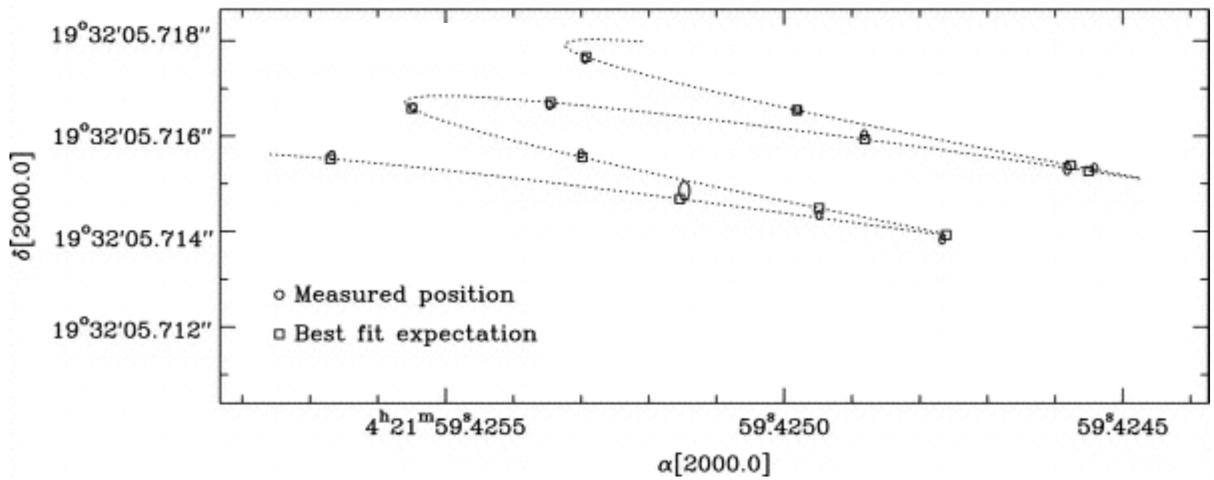
Geodesy

- Earth Rotation and Orientation, tectonic plate motions
- E.g. Daily UT1-UTC observations
  - US Naval Observatory is contributing to VLBA operations in exchange for daily ~1 hour observations using 2 VLBA antennas: Mauna Kea and Pie Town
  - High speed network links have been installed at these two sites
    - MK and PT to Washington D.C. at ~250 Mbps
  - Daily ~1 hour observations to begin soon
    - When the US Government establishes a budget…
  - VLBA science to face potential interruptions
    - Users have been contacted with tips to reduce impact on observing

What can the VLBA do?

Astrometry

- Highly precise positions
  - 100μas precision easily obtained
  - 20μas precision with effort
- Fundamental reference frame
- Parallax, proper motions… (e.g., TTauSb Loinard et al. 2007)

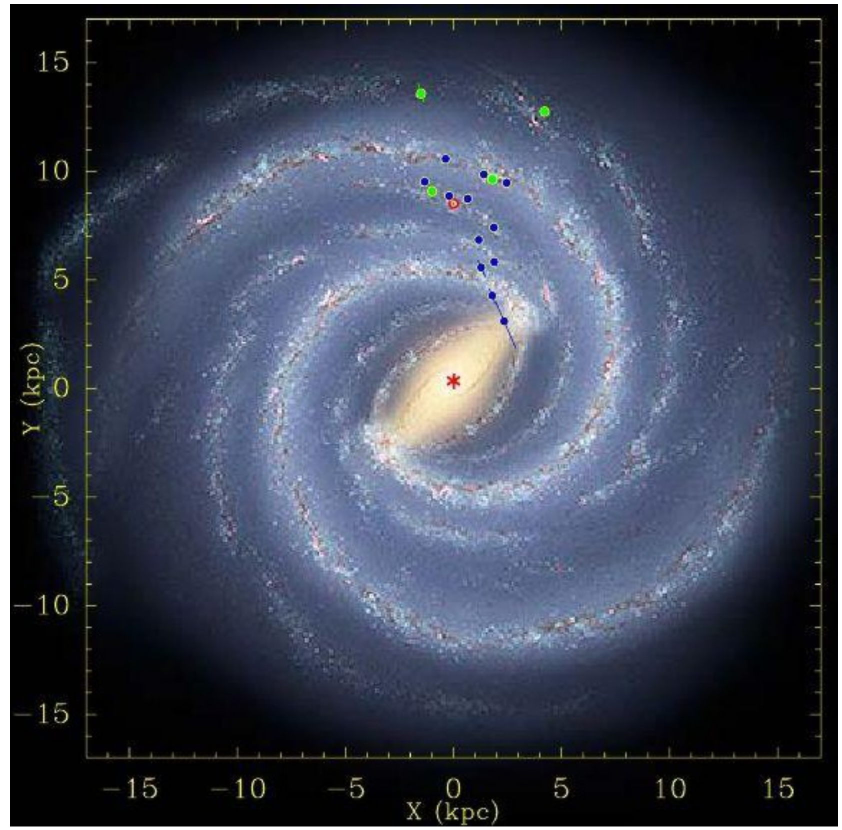


π=6.83 ± 0.03mas d = 147.6 ± 0.6 – 0.4% precision

Bar and spiral structure legacy survey (BeSSeL)

Reid et al.

- Goal: determine structure and kinematics of the Milky Way Galaxy
- Perform astrometry on masers in star forming regions
  - Water masers at 22 GHz
  - Methanol at 11 and (soon) 6.7 GHz
- Early results have improved measurements of the distance to the Galactic Center and rotational velocity
  - $R_0 = 8.4 \pm 0.6$ kpc
  - $\Theta_0 = 254 \pm 16$ km/s



Frequency bands and sensitivity

λ(cm)	ν(GHz)	σ(μJy/beam) in 4 hrs at 2Gbps
90 cm	0.312 - 0.342	277*
50 cm	0.596 - 0.626	782*
21 cm	1.35 - 1.75	13-14
13 cm	2.15 - 2.35	14
6 cm	4.6 - 5.1	13
6 cm (upgrade)	4.1 - 7.9	8
4 cm	8.0 - 8.8	13
2 cm	12.0 - 15.4	24
1 cm	21.7 - 24.1	18-22
7 mm	41.0 - 45.0	66
3 mm	80.0 - 90.0	316†

- New maximum bandwidth 256 MHz with two polarizations (2Gbps)
- More later about:
  - Increasing sensitivity by adding more/ larger telescopes to the array
  - Sensitivity upgrade
  - C-band upgrade

* Narrower bandwidths

† 8 stations

High Sensitivity Array (HSA)

- Adding the Green Bank Telescope (GBT), Arecibo (AR), Effelsberg (EB) and/or the phased VLA with the VLBA can increase the sensitivity by an order of magnitude
  - The VLBA + any two of these telescopes is considered an HSA experiment
- All these telescopes have a smaller field of view than the VLBA and may not have all the frequencies available at the VLBA.
- Phased VLA under development and can be proposed for in the 2012 August 1 deadline.

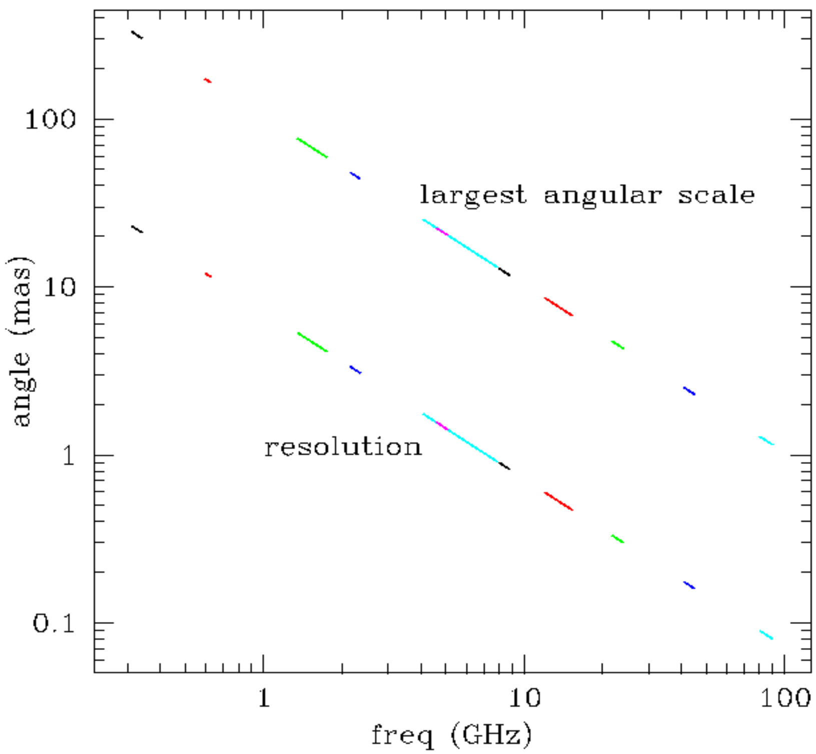



Global VLBI

- Add telescopes from the European VLBI Network (EVN) to the VLBA.
- The EVN has many large sensitive telescopes adding them increases the sensitivity as well as improving *uv* coverage (e.g. EVN has many more short baselines so can be more sensitive to larger structures.)

Resolution and Largest Angular scale

- Depending on frequency the resolution of the VLBA is anything from 0.08 to 25 mas
- The largest angular scale determines the largest structure the telescope is sensitive to.



Sensitivity Upgrade

- There are many parts to the sensitivity upgrade, some have already been implemented:
  - DiFX correlator: allows several new capabilities (more later)
  - Wider bandwidths: for a total of 256 MHz, dual polarization. This gives a total bit rate of 2 Gbps, and enables twice the sensitivity of the old VLBA.
    - 256 MHz bandwidth must be justified in proposal
    - 64 MHz bandwidths are standard
- Some in the process of being implemented:
  - C-band upgrade: replace the VLBA's 6 cm receivers
    - To expand the tuning range to 4.1 - 7.9 GHz. Which will enable observations of the 6.7 GHz transition of methanol.
    - To increase sensitivity: noise will go down by ~35%
    - New receivers installed on 7.5 antennas. Complete mid-August.

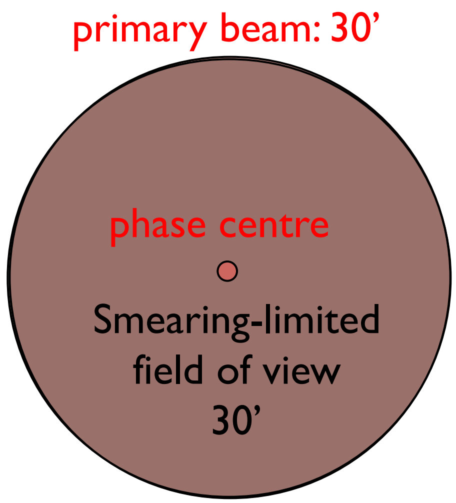
NRAO

DiFX Correlator Capabilities I: Spectral Resolution

- DiFX is a software correlator in Socorro, NM
- Supports up to 4096 channels per sub-band routinely
- Up to 32,768 channels if required and adequately justified
- Spectral zooming – can do higher spectral resolution in one or more sub-bands. Useful for:
  - Masers with in-beam continuum calibrators: wide bands used for maximum sensitivity on calibrator while at the same time high spectral resolution on maser lines.
  - Masers with multiple transitions: wide bands are used to cover a large number of widely separated maser transitions, spectral zooming allows the empty portions of high-resolution spectrum to be discarded

DiFX Correlator Capabilities II: Wide Field Imaging

- DiFX enables wide field imaging due to high spectral and time resolution.
- This ability has been widely used since the introduction of DiFX
- However, full-beam VLBA imaging is still a logistical impracticality,



Time resolution:
20 ms

Freq. resolution:
4 kHz

Calculations for 1.6 GHz, total smearing = 10%

DiFX Correlator Capabilities III: Multi-Field Imaging

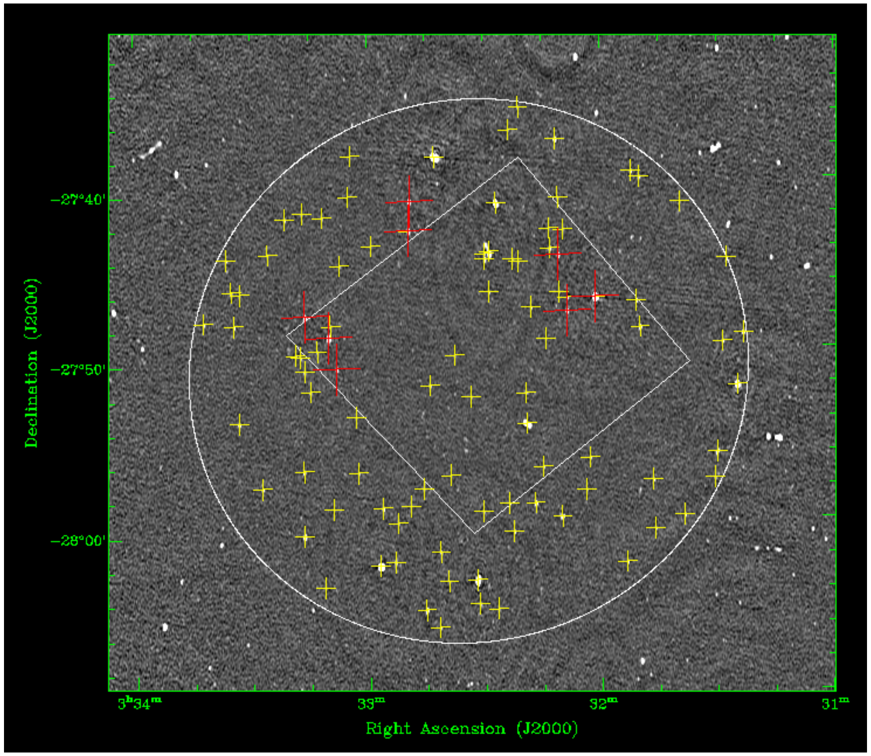
- The sky is almost entirely empty at VLBI resolution
  - "full beam" imaging not needed; rather, many small "fields" (phase centers)
- In previous correlators, multiple fields required multiple correlator passes (usually at same or twice the rate of observation time)
  - Impractical for more than a few fields.

DiFX Correlator Capabilities III: Multi-Field Imaging

- Using *uv* shifts inside the correlator
  - DiFX allows many phase centers in one correlator pass
  - The overhead is ~2.5 and is only weakly dependent on the number of phase centers
- For reasonable spectral and time resolution requirements, **200 phase centers require only 20% more correlator time than 2 phase centers**.

DiFX Correlator Capabilities III: Multi-Field Imaging

- This enables new science:
  - mJy-sensitivity secondary calibrator searches within a beam
  - Efficient VLBI surveys of mJy and sub-mJy objects are feasible. E.g. Middelberg et al. (2011) already published VLBA results on Chandra Deep Field South



From Middelberg et al., 2011

Commissioning Opportunities

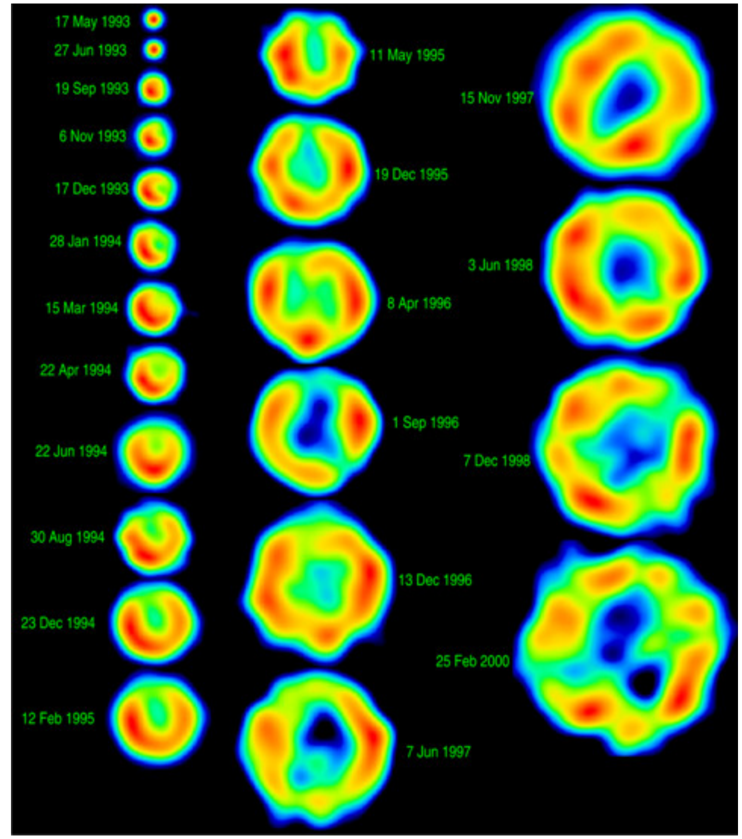
Resident Shared Risk Observations – early access to new capabilities in exchange for a period of residency in Socorro to help commission those capabilities.

- For example, phased-array VLBI on the JVLA
  - We are offering the very simple phased-VLA for next year but there are many things that still need to be commissioned (multiple subarrays, phase transfer from one bandwidth to another…).

Important Links

- NRAO Help Desk
  https://help.nrao.edu
- VLBA Observational Status Summary
  http://www.vlba.nrao.edu/astro/obstatus/current/
- EVN Sensitivity Calculator
  http://www.evlbi.org/cgi-bin/EVNcalc
- Proposal Submission Tool
  my.nrao.edu
- SCHED – observation preparation software
  http://www.aoc.nrao.edu/software/sched/index.html
- AIPS – data reduction software
  http://www.aips.nrao.edu/index.shtml

SN1993J in M81



10 mas

36,000 AU

Bartel et al. 2000