# The next decade of VLBA developments

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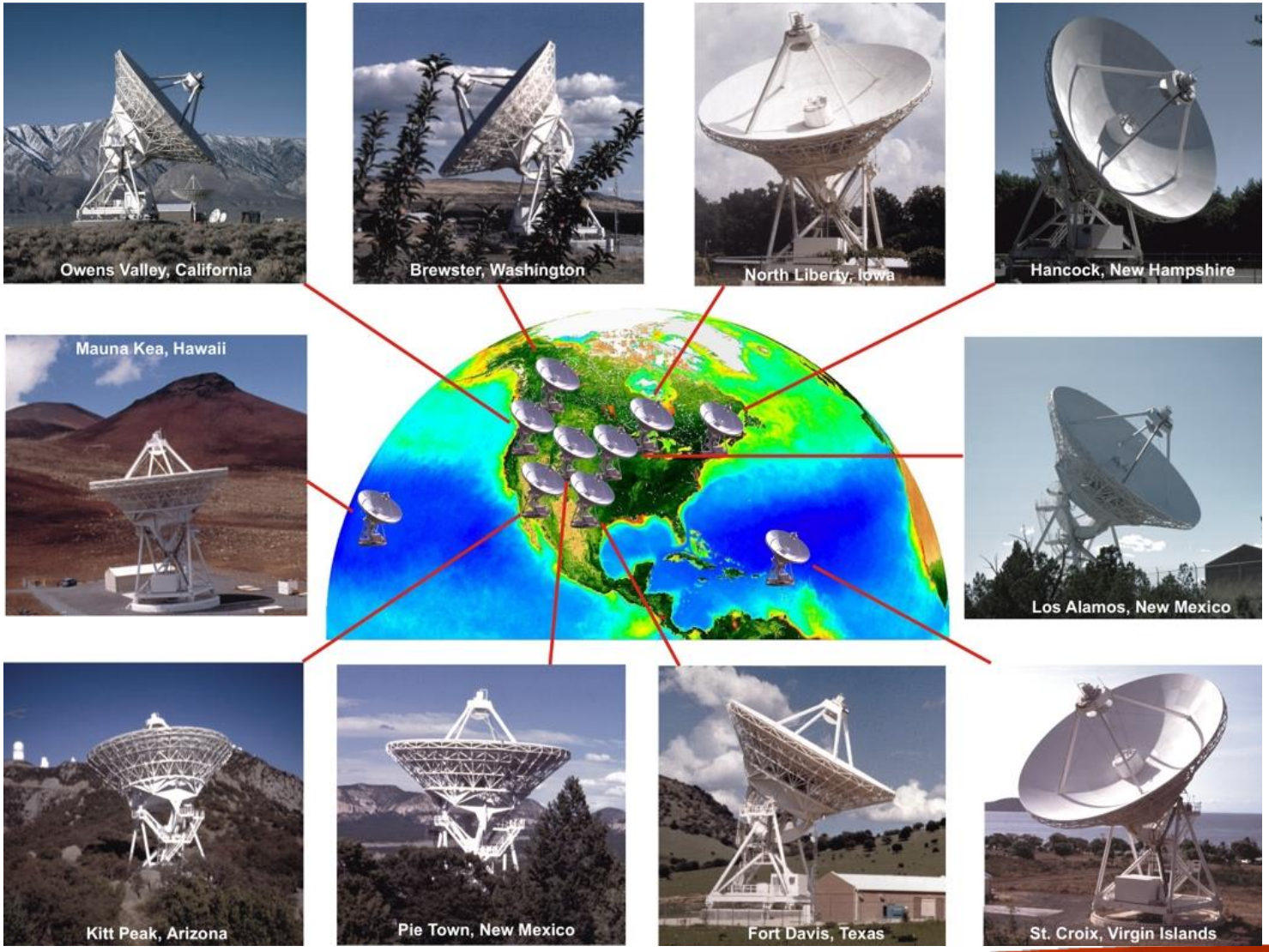
# The Very Long Baseline Array



# The Long Baseline Observatory

## A short history

- Events led to redefinition of NRAO to exclude VLBA and GBT
  - NSF recompetition for NRAO management
  - VLBA and GBT identified as targets for NSF divestment (2012)
- Since then…
  - AUI won NRAO recompetition
  - US Naval Observatory became 50% partner in operation of the VLBA; 50% of time remains for Open Sky observing
  - LBO was formed as organization that operates the VLBA
    - GBO likewise formed to operate GBT
    - AUI managing NRAO, LBO and GBO
  - Near-term future of the VLBA looks solid
    - Funding level adequate to maintain current level of operations
    - Future upgrades to the facility are being planned

# Upgrades: what does the future hold?

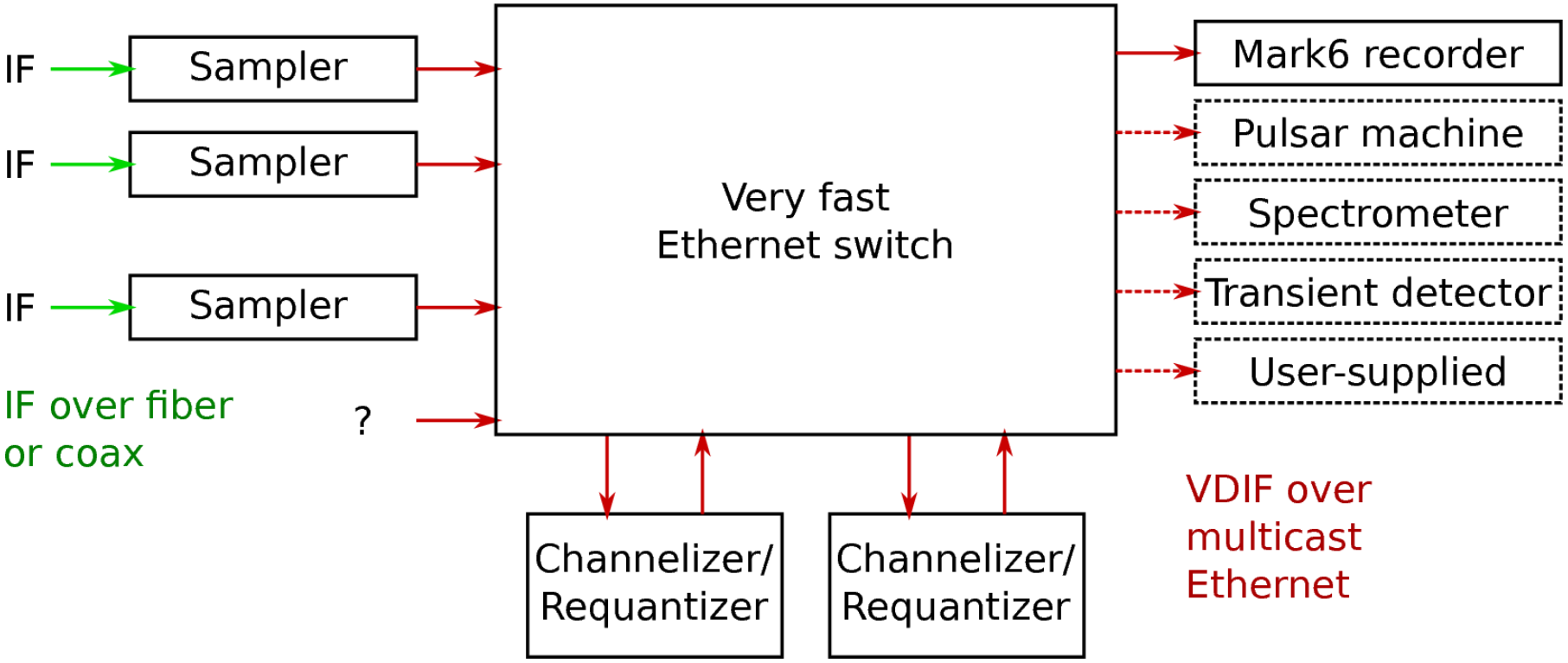
- In early part of past 10 years:
  - 4-fold increase in bandwidth
  - Improved correlator capabilities
  - New high-sensitivity C-band receiver enabling access to more spectrum
- In last 5 years:
  - No major projects (funding inhibited by divestment threat)
  - Attention spent on modernizing control system, stabilizing operations
- In next 5-10 years:
  - 8-fold increase in bandwidth?
  - New receiver?
  - Replace hard-disk recording with electronic data transfer?

# Development plan philosophy

- Upgrade elements should have well defined interfaces
  - Use of industry standard connectors and protocols
  - Compatibility with existing interfaces where possible
  - Monitor and control via EVLA "MIB" system
- Upgrades should be executable in any order
  - Some increased cost when performed in unnatural order
  - Some decreased cost possible when timed correctly
- External/university and partner involvement encouraged
- Each upgrade element to be divided into two projects:
  - Development/implementation: verify functionality at one antenna
  - Procurement/deployment: shovel ready, array-wide

# Core data path

## Possible concept under study



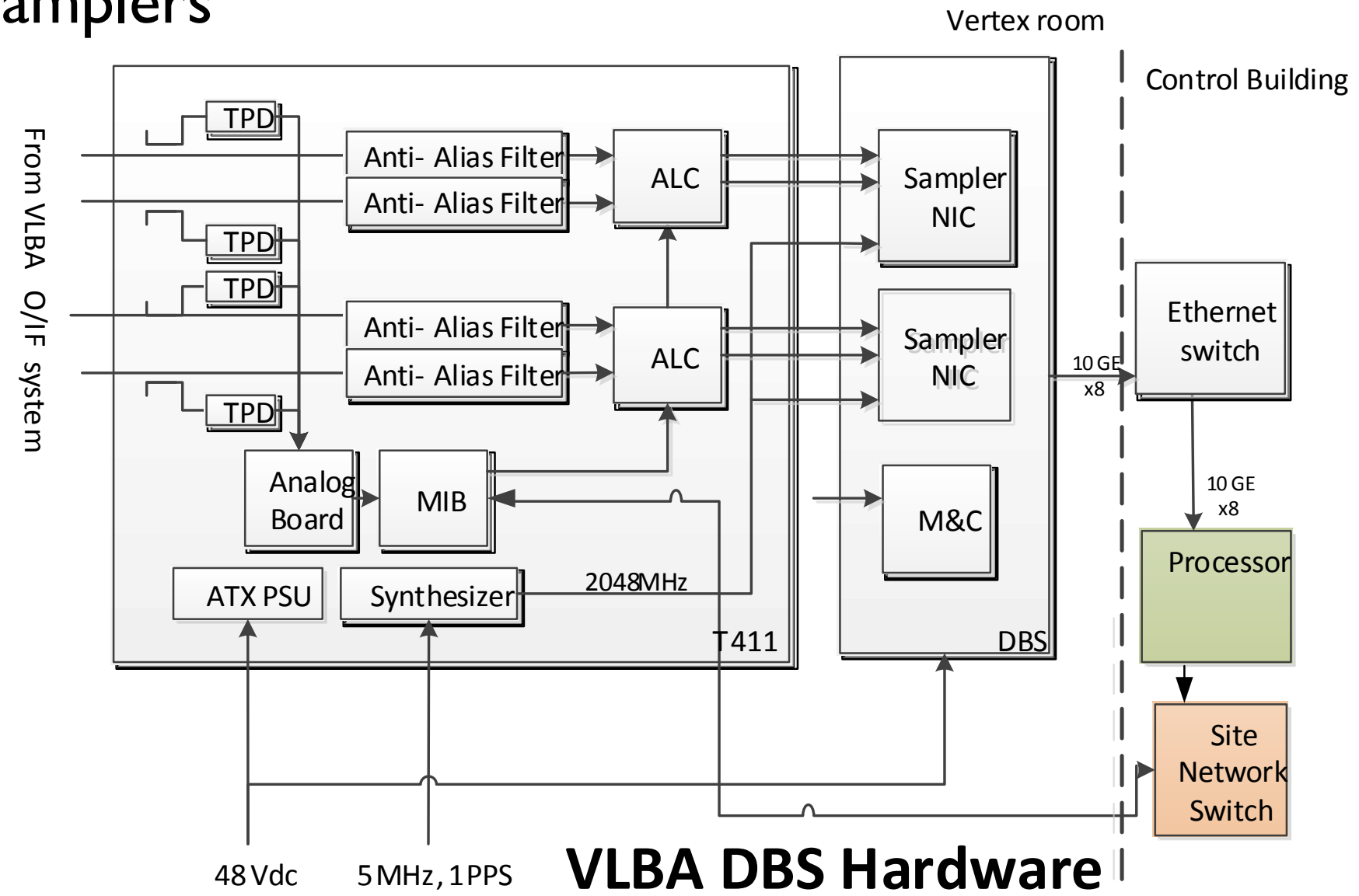
# Wideband IF system

- New synthesizers, downconverters and filters
  - NRAO-patented synthesizers will provide accurate step tuning with fine control over a full 2-12 GHz tuning range
- Produce four IF signals with 0.5, 1 or 2 GHz bandwidth
  - Two IFs per polarization
- Enable multiple polarization-pairs to attach to one receiver
  - To allow full 4 GHz bandwidth at frequencies above 4 GHz

# Samplers & channelizers

- Four 2 Gsps or 4 Gsps / 8-bit samplers
  - For operation at 2 or 4 GHz bandwidth per polarization
- FPGAs to flexibly channelize and requantize to 2, 4 or 8 bits
- Move sampler functionality to antenna vertex room
  - Reduce analog path
  - Transmit data over 10+ Gbps Ethernet on existing fibers
  - Strong RFI generator!  Effective shielding and cooling needed
- Commercially-available hardware identified as possible platform
  - Provides natural upgrade path

# Samplers



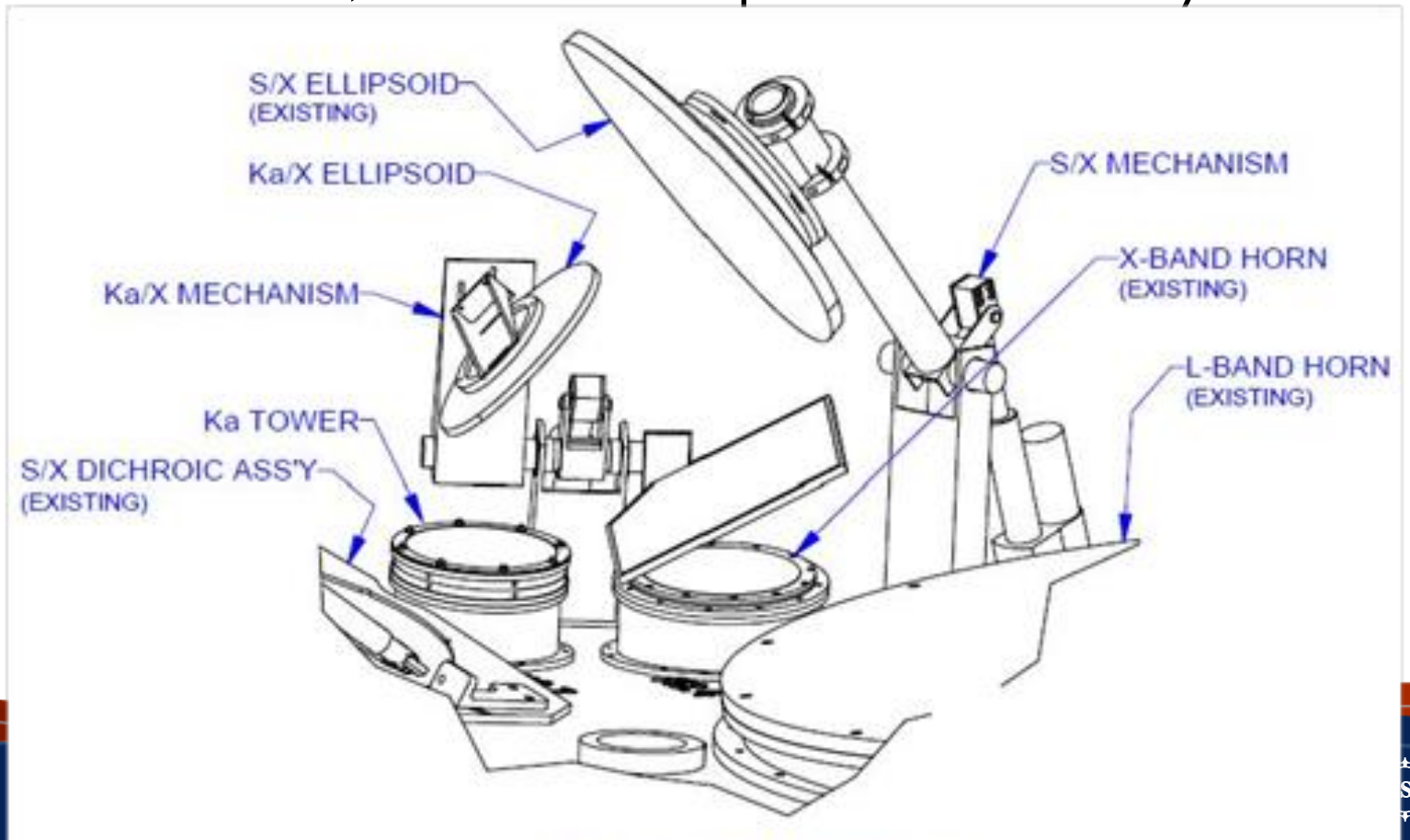

**VLBA DBS Hardware**

# Mark6 recorders

- Replace Mark5C recorders w/ Mark6
- Increase recording rate from 2-16 Gbps (immediate BW doubling)
- Provides infrastructure useful for electronic transfer VLBI
- Implementation project underway already
- Array-wide procurement awaiting funds; complete in 2019?

# Ka-band receiver w/ X-band dichroic

- Highest priority new receiver band: 26.5-40 GHz
  - Offers high angular resolution with low system temperature
  - Offers access to some spectral lines
  - With X-band, stands to be a superior astrometric system



# Some thoughts on collaboration

*Based on past experience*

- We (VLBA) would like to work with others to grow our infrastructure

- Collaboration is in radio astronomy's nature
  - VLBI not possible without it
- It is generally in our best interest, but…

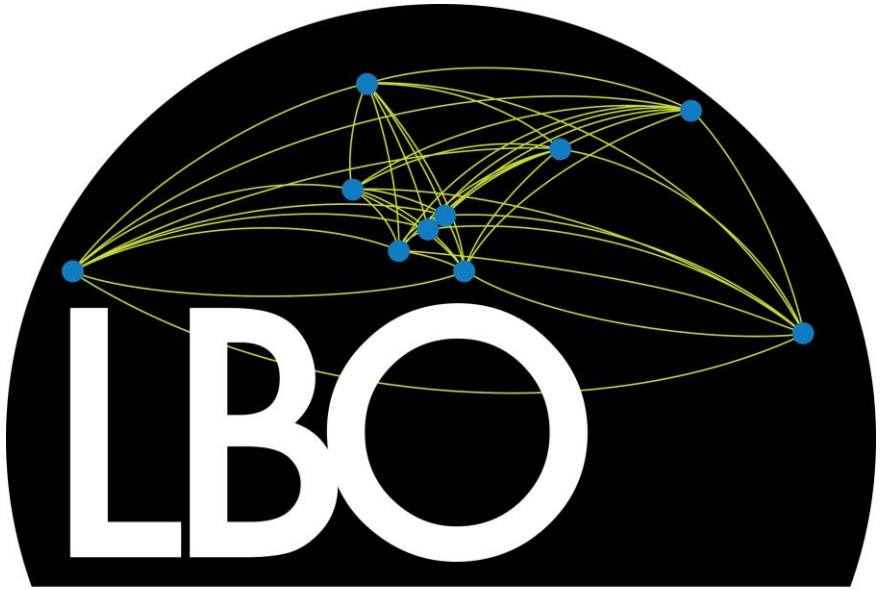
- Collaboration is difficult!
  - "Not invented here" and institutional ego can drive poor decisions
  - Trade-offs between benefit and burden need to be understood before entering joint projects
  - Beware of hidden requirements!

# Requirements mismatch

- Functional requirements tend to attract collaboration
- Other factors are sometimes overlooked:
  - Operational requirements: operational lifetime & support, reliability, level of automation, completeness of documentation
  - Physical requirements: enclosures, RFI emissions, cooling
  - Environmental requirements: temperature, vibration, tilt
  - Data security and integrity
  - Interface compatibility: connector types, M&C protocol, …
  - Development/deployment timescale
  - Certainty of funding and requirements of funding agencies

# Conclusion

- The past decade serves as indicator of what is possible over the next decade
- Increased bandwidth and increased flexibility in tuning are driving changes to the core data path
- New scientific use cases drive request for Ka-band receiver
- LBO will look to other development projects for synergy
  - E.g., ngVLA, Radionet BRAND project
  - Maybe eMERLIN and VLBA have similar requirements?
- Effective collaboration with other radio astronomy facilities is strongly desired




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.*

# The Very Long Baseline Array

## Overview

- Completed in 1993
- Ten 25m antennas on US soil from Hawaii to St. Croix, USVI
  - Baseline lengths from 236km to 8611km
- 10 receiver bands spanning 300 MHz to 96 GHz
  - Native dual circular polarization
- Data recorded on magnetic media and shipped to correlator
- VLBA correlator in Socorro, NM
  - Support for 20+ stations
  - Processes VLBA, HSA, and some global VLBI experiments

# Recent upgrades

## Correlator

- VLBA original hardware correlator replaced with DiFX software correlator (2009)
  - Increased flexibility in spectral and temporal resolution
  - Advanced pulsar processing capabilities
  - Throughput scales with computer cluster
- VLBA software correlator updated to DiFX2 advanced software correlator (2011)
  - Massive-multi-phase-center capability
    - Up to 800 arcsec-scale phase centers over 30 arcmin FoV
    - Factor of 10 cost in computing
  - Bandmatching and zooming
- Improvements continue, with new software releases every ~2 years
- *See Deller et al., 2007 and Deller et al., 2011*

# Interfaces are key!

- Use well tested and/or industry standard interfaces when possible
  - Invent new interfaces at your own risk!
- Sometimes better not to directly collaborate
  - However: competing developments can work toward common interfaces for future inter-compatibility
- Examples of enduring interfaces
  - Ethernet, VSI-S, VDIF, [vex]
- Big challenge: common "module/bin" enclosure architecture
  - VLA, VLBA, EVLA, ALMA & ngVLA all differ!
  - Rack-mount box is "lowest common denominator"
    - Poor use of space, RFI?, awkward servicability

# Recent upgrades

## Antennas

- 256 MHz bandwidth per polarization via digital back end
  - Upgraded from 64 MHz
  - Completed in 2011
- 2048 Mbps record rate via Mark5C disk recorders
  - Upgraded from 512 Mbps Mark5A
  - Large disk supply funded by NSF MRI; completed in 2011
- "Coolest C-band receivers in the known universe"
  - 4-8 GHz tuning range, upgraded from 4.5-5.1 GHz
  - Improved from EVLA receiver design
  - Dual-IF-pair capability
  - Funding provided by MPIfR; completed in 2012

# VLBA C-Band Prototype (VC#11)