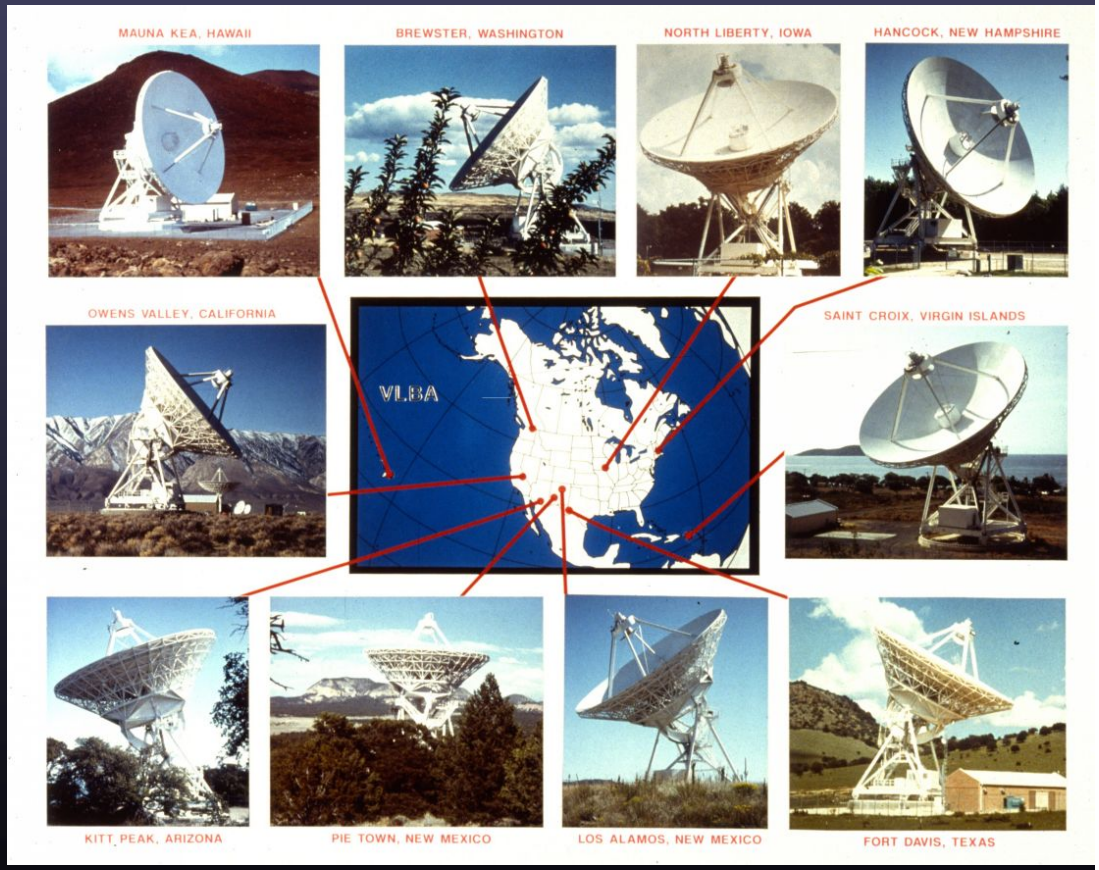
THE VLBA SENSITIVITY UPGRADE

Craig Walker, NRAO



Eleventh Synthesis Imaging Workshop

Socorro, June 10-17, 2008

CONTEXT

- The VLBA is based on 20 year old technology
- Only limited new capabilities have been added
  - Switched from tape to disk
    - Improved operations, but did not increase capability
  - Added 86 GHz: High resolution, but low performance
- Technology advances now enable a significant increase in scientific capabilities at modest cost
  - Improved signal processing with Field Programmable Gate Arrays (FPGA)
  - Wider bandwidth data recorders
  - Computers are now far more capable
  - Better low noise amplifiers at high frequencies
- Major funding, like eVLA, is not now available for VLBA

UPGRADE PROJECT GOALS

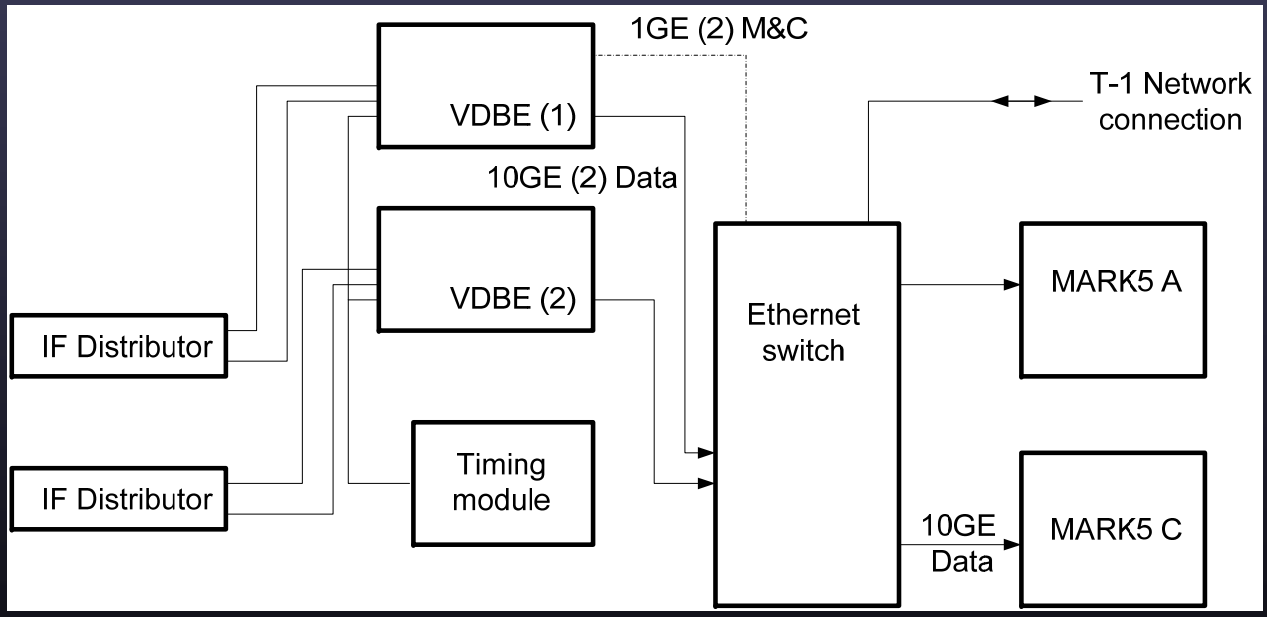
- Bandwidth increase to improve the continuum sensitivity in all bands
  - Allow observation of weaker sources - hence more sources
  - Image lower level structures in bright sources
  - Image polarized structure of weaker features
  - Allow use of closer calibrators for better phase referencing
    - In-beam calibrators more likely
    - Parallax and proper motions of more objects
      - Some of the highest impact science now being done on the VLBA
- Improve the 22 GHz receivers
  - Increase the sensitivity for both continuum and spectral line projects
  - Primary goal to help the key project to measure H_o using H_2O megamasers
- These goals are at least partially funded. Costs moderate.

TECHNICAL OVERVIEW

- Increase bandwidth to 1024 MHz (4 Gbps with 2 bit samples)
  - Current bandwidth 32 MHz sustained and 128 MHz peak
  - Sensitivity increase by factor 5.7 compared to 32 MHz
  - New digital backend (samplers, signal processing)
  - New recording system
  - New software correlator
  - All systems will be available in 2009. Sooner for the correlator
  - The major cost is disk supply. Sets time scale for sustained use (2011)
- Upgrade 22 GHz low noise amplifiers
  - Sensitivity increased by a factor of 1.6 at 22.2 GHz
  - New standard band at 23.8 GHz for more sensitivity
  - MPIfR funding - project complete

NEW VLBA SIGNAL PROCESSING

- Utilize the 500 MHz IF signals that already exist
  - No new IF/LO electronics required
- Baseband converters, samplers, and formatter to be replaced with VDBE (VLBA Digital BackEnd)
- Recording system upgrade to Mark5C (4Gbps)



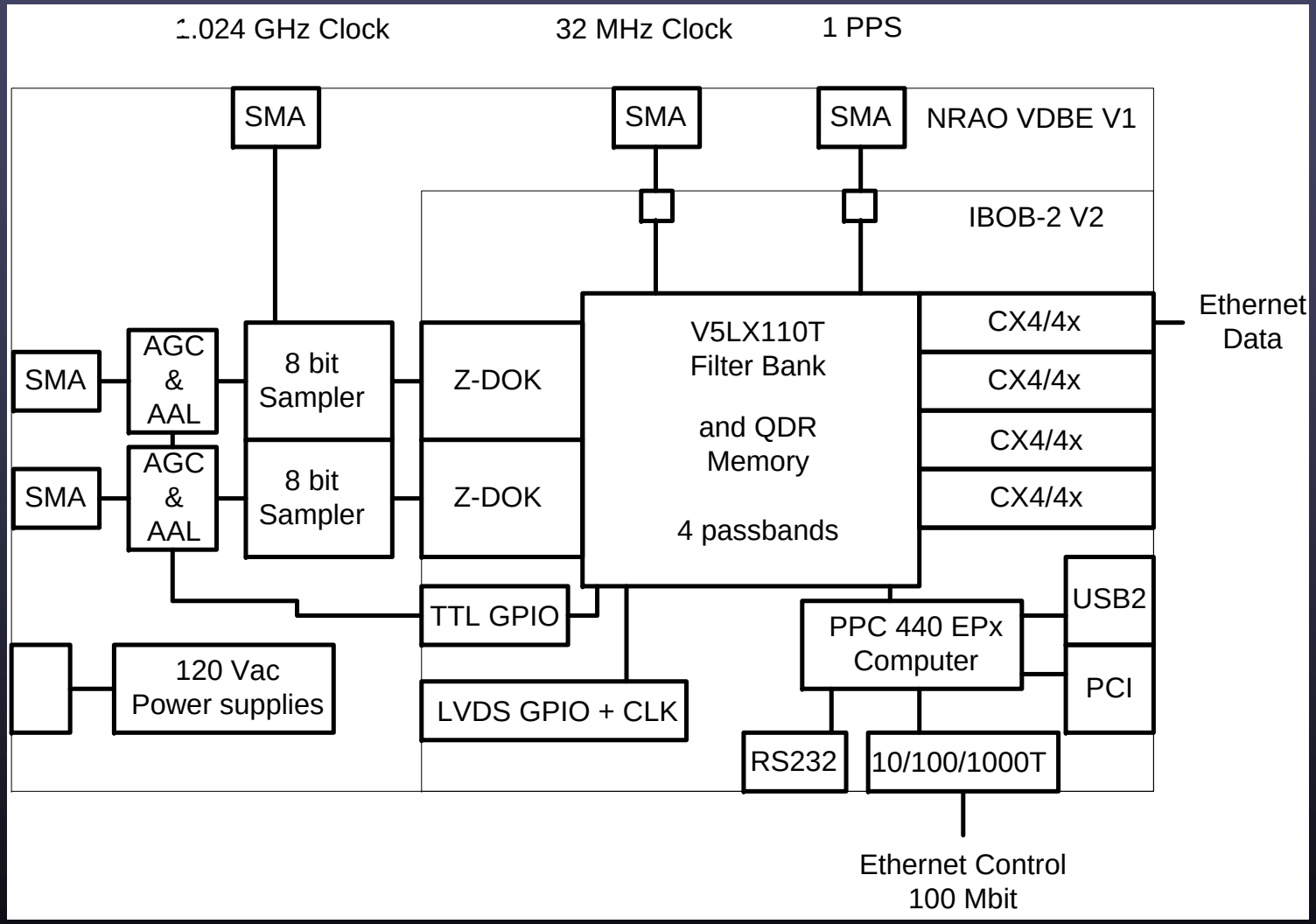
VDBE

- Samples, filters, and formats data
- Two at each VLBA site
- Each VDBE samples 2 analog IF signals of 500 MHz bandwidth (8 bit)
  - Sample clock is 1024 MHz
- Digital filters form the baseband channels and resample to 1 or 2 bits
  - Wide range of bandwidths possible
- Data formatted and reordered for one channel per Ethernet frame
- Data sent by 10GigE Ethernet to Mark5C or other media
- Can send data to the EVLA correlator (Pie Town link) by fiber
- The VDBE also obtains calibration data like Tsys and pulse cal
- VDBE project is funded and should be complete in early 2009

VDBE FILTERS

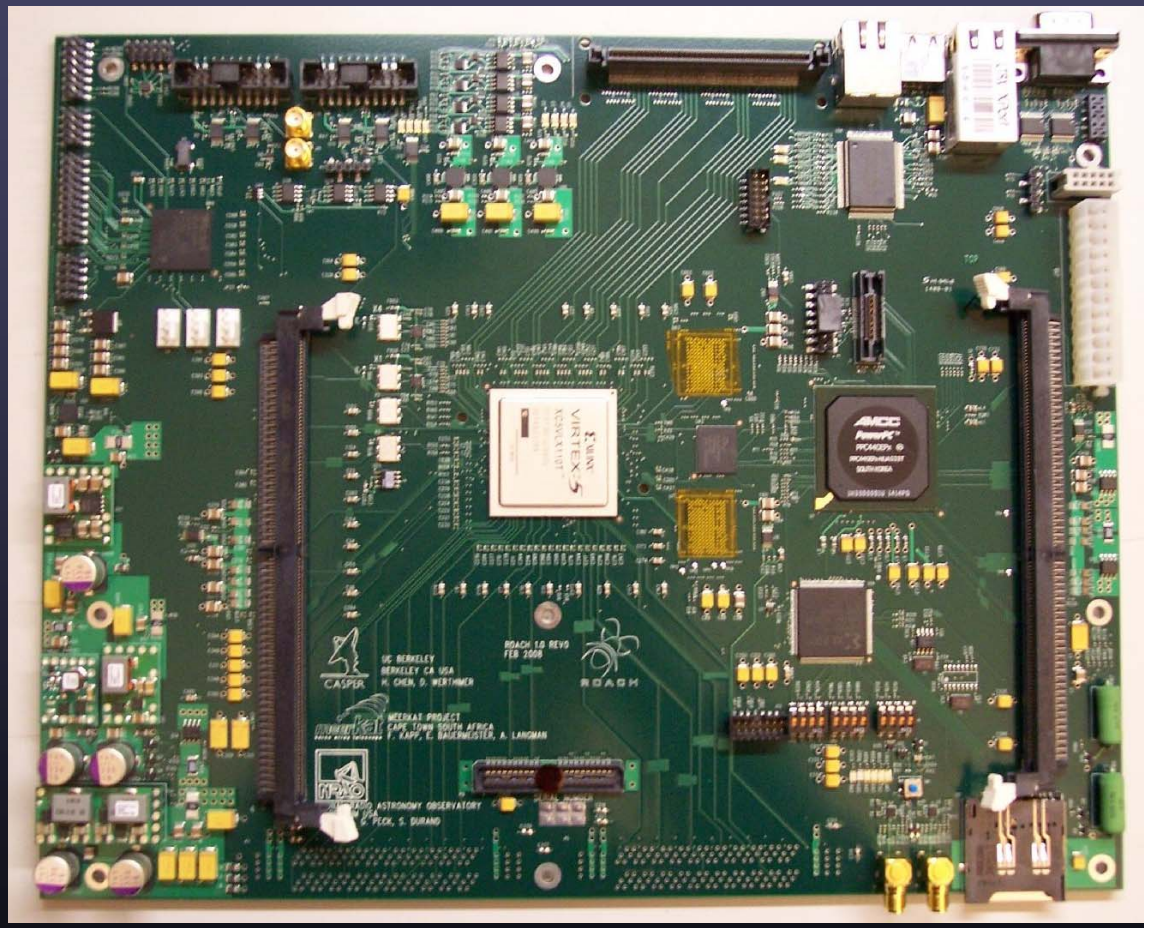
- VDBE uses CASPER Lab ROACH board
  - Contains large FPGA
- Polyphase filter option to be developed by Haystack
  - Restricted frequency settings, but good for continuum
- Digital Down Converter (DDC) option to be developed at NRAO
  - More flexible frequencies and bandwidths
  - Mainly for spectral line observations
- Both will provide very stable and well defined bandpasses
- Can switch options easily
- Could have other options for FPGA personality

VBDE BLOCK DIAGRAM



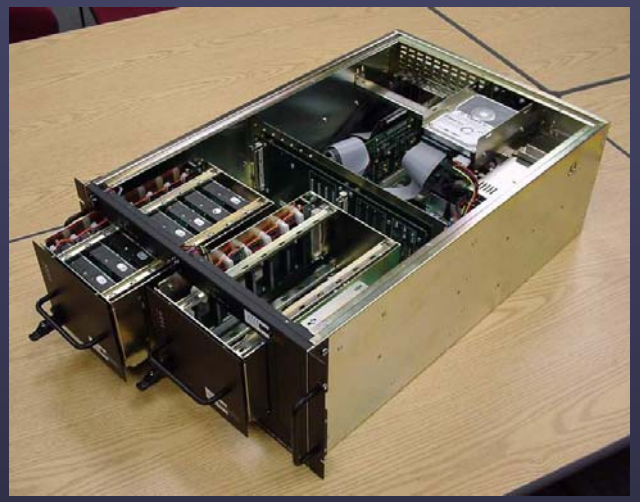
ROACH BOARD (Was iBOB2)

- UCB CASPER Lab product
  - Broadly useful for radio astronomy signal processing
- Hardware designed by NRAO, KAT, and CASPER
- Small changes needed



MARK5C RECORDING SYSTEM

- Disk based, 4 Gbps recording system
  - Developed by Conduant, Haystack, NRAO
  - Uses existing Amazon card like Mark5B+
  - Modules compatible with Mark5A/B
  - Earlier Mark5's can be upgraded
- Data input by 10GigE Ethernet
  - Only cares about packets - not specific format
  - Data files will appear as standard Linux files on playback
    - Mainly meant to be used with software correlators
  - Playback through PCI bus
  - Requires 2 modules for full bandwidth



Mark5A

MARK5C STATUS

- NRAO has issued purchase order for 3 prototypes
  - Price high to include development
- Prototype hardware delivery
  - Most of the hardware is in house being used for software correlator testing
  - The daughter board that receives 10GigE is expected soon
- Software may take until early 2009
- Deployment funds not yet identified

THE VLBA SOFTWARE CORRELATOR

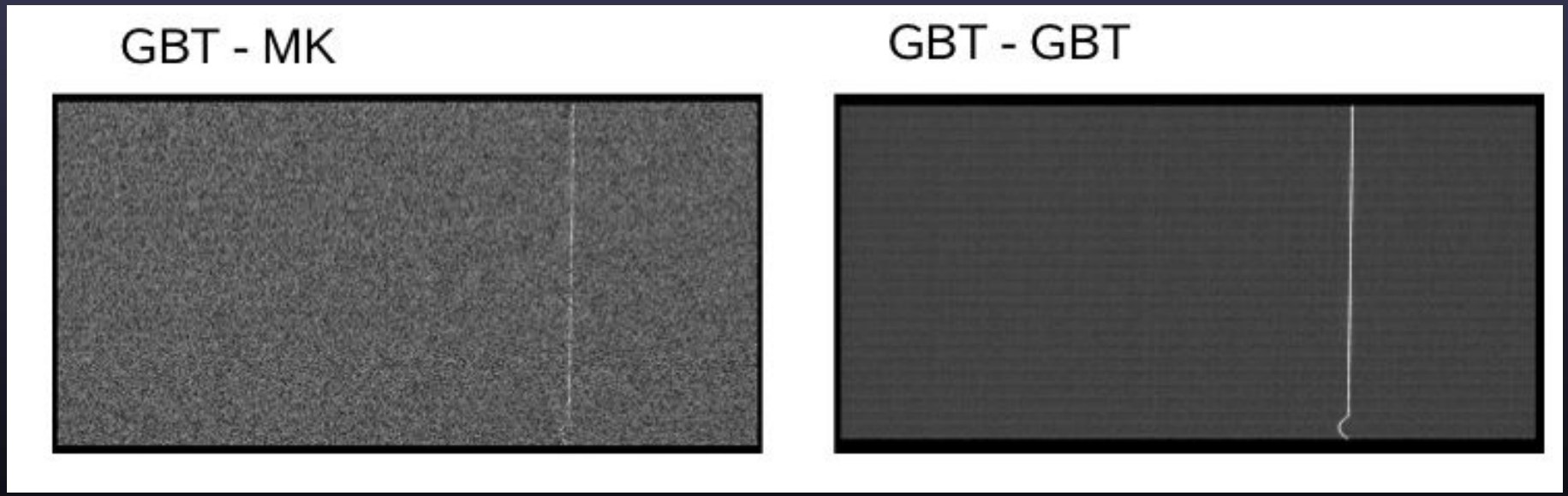
- DiFX written by Adam Deller at Swinburne
- VLBA integration by Walter Brisken
- Current cluster has 5 units each with 2 motherboards each with dual quad-core cpus (80 cores)
- Benchmark: 420 Mbps for 8 basebands, 2 bit/sample, parallel hands only, 10 stations, 256 spectral channels/baseband
- Will likely replace the hardware correlator during 2008
- To be expanded as needed
  - Will cost less than disks for any bit rate
- Under test
  - Phases agree with hardware correlator to under 1 degree in spacecraft test

SOFTWARE CORRELATOR ADVANTAGES

- Fast development
- Highly flexible
  - No fixed limits on numbers of stations, bandwidth, number of channels etc.
  - It just slows down as you ask for more
  - Relatively easy to add capabilities
- Hardware is commodity servers
  - Low cost, fast deployment, easily upgraded
  - Can purchase most after the software is finished
- Works with many types of recording media
- The correlator hardware will cost less than the disks for any sustained bit rate
- Community development (Australia, NRAO, USNO, MPIfR …)
- BUT: Still too expensive and uses too much power for larger correlators like EVLA and ALMA

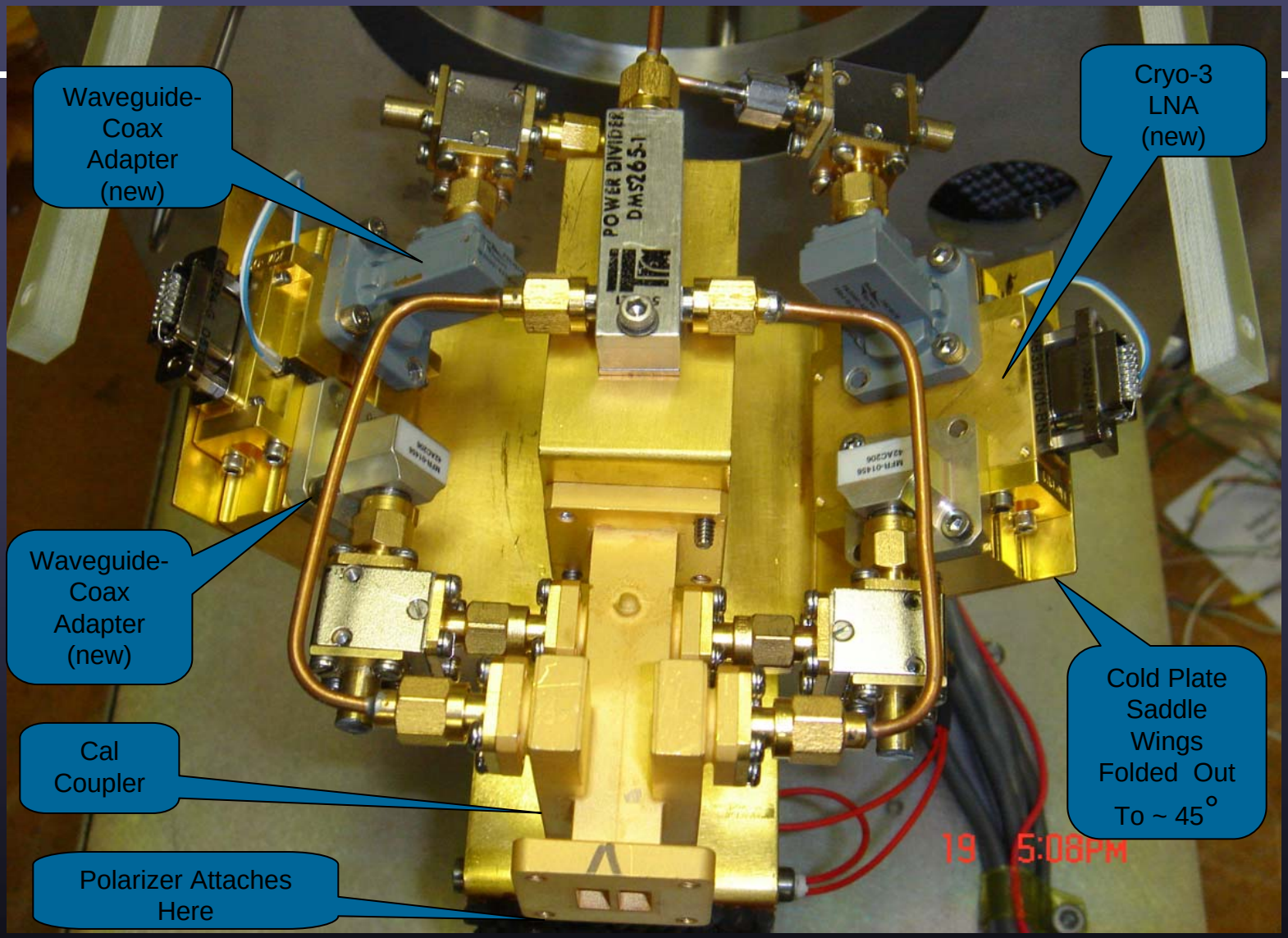
EXAMPLE SOFTWARE CORRELATOR RESULT

- Asteroid Radar
- Project of Caltech graduate student Michael Busch
- Narrow-band VLBI
  - Radar signal bandwidth = 40 Hz
  - Correlated channels (below) at 122 Hz.



22 GHz AMPLIFIER UPGRADE

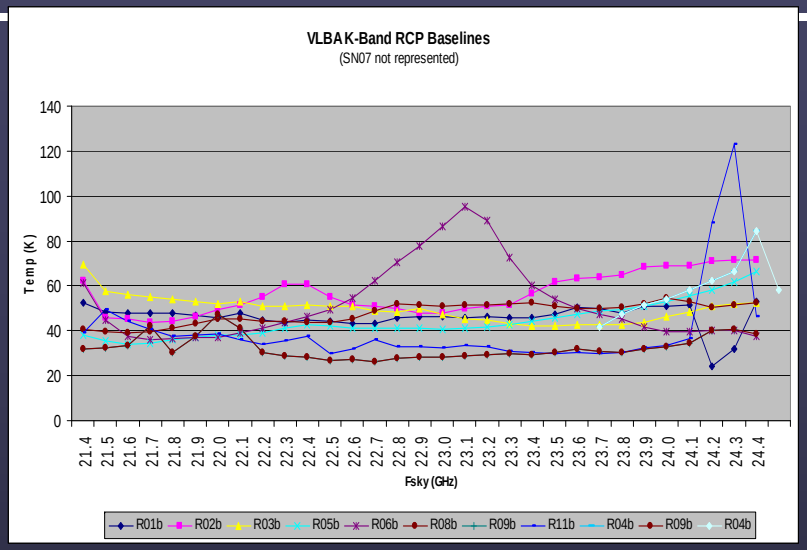
- Replaced Low Noise Amplifiers (LNA) with modern devices
  - Amplifiers from the NRAO Central Development Lab
- Other minor improvements to receivers and to subreflector focus and rotation settings
- Project finished in January 2008
- Average SEFD results for inter measurements:
  - SEFD = System Equivalent Flux Density, a good measure of sensitivity
  - Before upgrade (22.2 GHz): 815 Jy
  - After upgrade (22.2 GHz): 502 Jy
    - Sensitivity increased by factor of 1.6
  - After upgrade (23.8 GHz): 441 Jy
    - Sensitivity higher than 22 GHz before by factor of 1.8
    - Away from the center of the atmospheric water line
  - Now recommend continuum band is at 23.8 GHz
- Funded by MPIfR

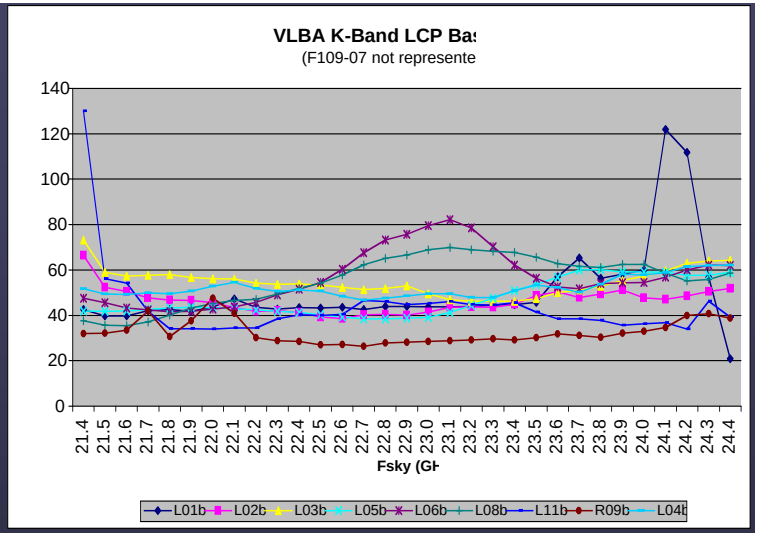

Waveguide-Coax Adapter (new)
Cryo-3 LNA (new)
Waveguide-Coax Adapter (new)
Cal Coupler
Cold Plate Saddle Wings Folded Out To ~ 45°
Polarizer Attaches Here
POWER DIVIDER
DMS265-1
19 5:08PM

BEFORE AND AFTER RECEIVER TEMPERATURES

140K —

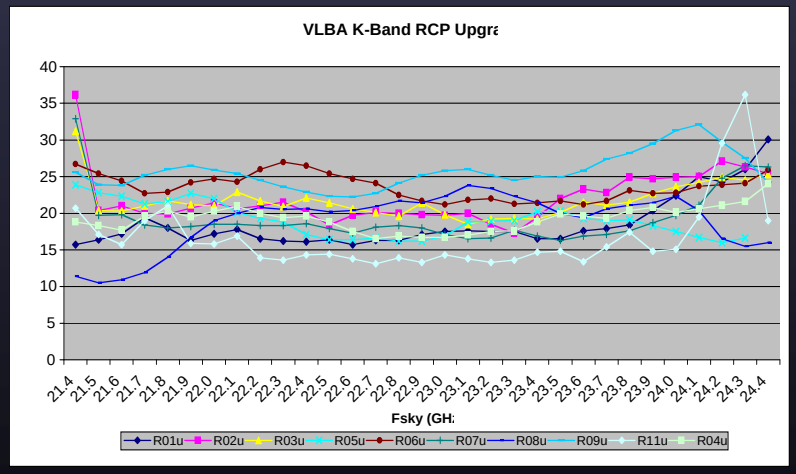
40K —

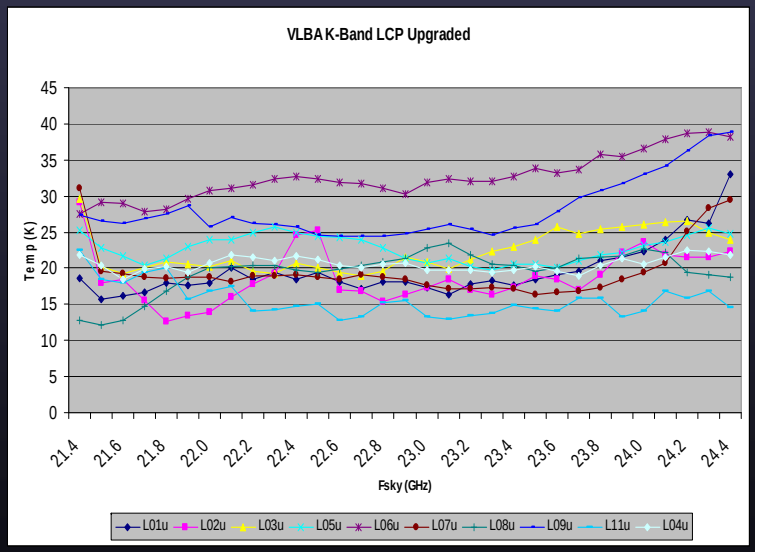




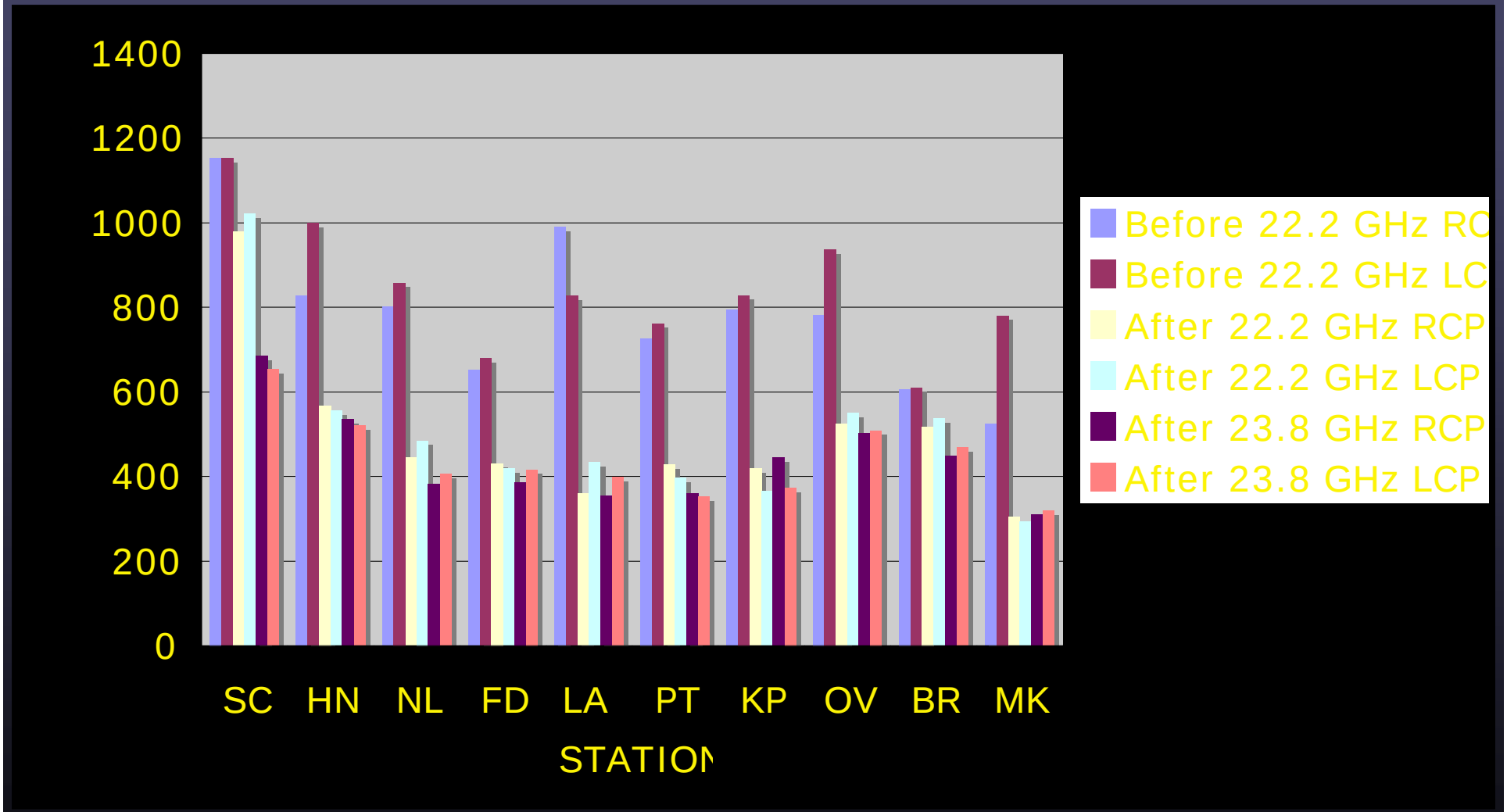
21.4 to 24.4 GHz

40K —





22 GHz UPGRADE ZENITH SEFD



LONG TERM

- Prime science goal: <5 microarcsec astrometry (10 μas routine)
- Bandwidth increase to 4 GHz (16 Gbps)
  - Requires new IF/LO system on antenna (expensive)
- Upgrade 43 GHz amplifiers
- EVLA 4-8 GHz receiver
  - New maser lines and in the sweet spot for phase referencing
- Wide band 22 GHz (18-26 GHz eVLA receiver)
- Water vapor radiometers for phase calibration
- Improve surfaces for 86 GHz
  - Especially fix Hancock surface and add receiver
- Data transfer by fiber networks (eVLBI) (required by paying customer?)
- Ka band (26-40 GHz) receiver (required by paying customer?)
- Added collecting area (SKA related?)
- All of these require funding

END OF PRESENTATION