PASEO Meeting

July 15-16, 2010 – Socorro, NM

WIDAR Correlator

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

NRAO

Overview

- The role of the WIDAR correlator
- How WIDAR works: a 5-minute primer
- Commissioning WIDAR
- WIDAR for the observers
- Current status & schedule

- Conclusions:
  - WIDAR promises a **lot** of capabilities
  - WIDAR hardware is (almost) all here, and works well
  - Software development on-going (capabilities & robustness), with a very aggressive, science-driven schedule
  - Standard (OSRO) observing is going well
  - Wideband (RSRO) science has just begun – a few teething issues
  - No obvious roadblocks to future RSRO capabilities

The role of WIDAR: bandwidth

	VLA	EVLA (WIDAR)
Architecture	XF	FXF
Quantization	3-level	16/256-level
# antennas	27	32
Max. bandwidth	0.2 GHz	**16 GHz**
# subband pairs	1 - 2	1 – 64
# channels (total)	2-512	16,384 – 4,194,304
Max./min. δν	50 MHz / 381 Hz	2 MHz / 0.12 Hz
dt_{min}	1.7 sec	0.01 sec
Max. data rate	3.3×10^3 vis/sec	7.5×10^6 vis/sec ($1600\text{-}16000 \times 10^6$ vis/sec)
Extras	Phasing	Phasing Pulsar phase bins Burst mode Auto-correlation

The role of WIDAR: spectroscopy

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The role of WIDAR: flexibility

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Extras	Phasing	**Phasing** **Pulsar phase bins** **Burst mode** **Auto-correlation**

The role of WIDAR: data rates

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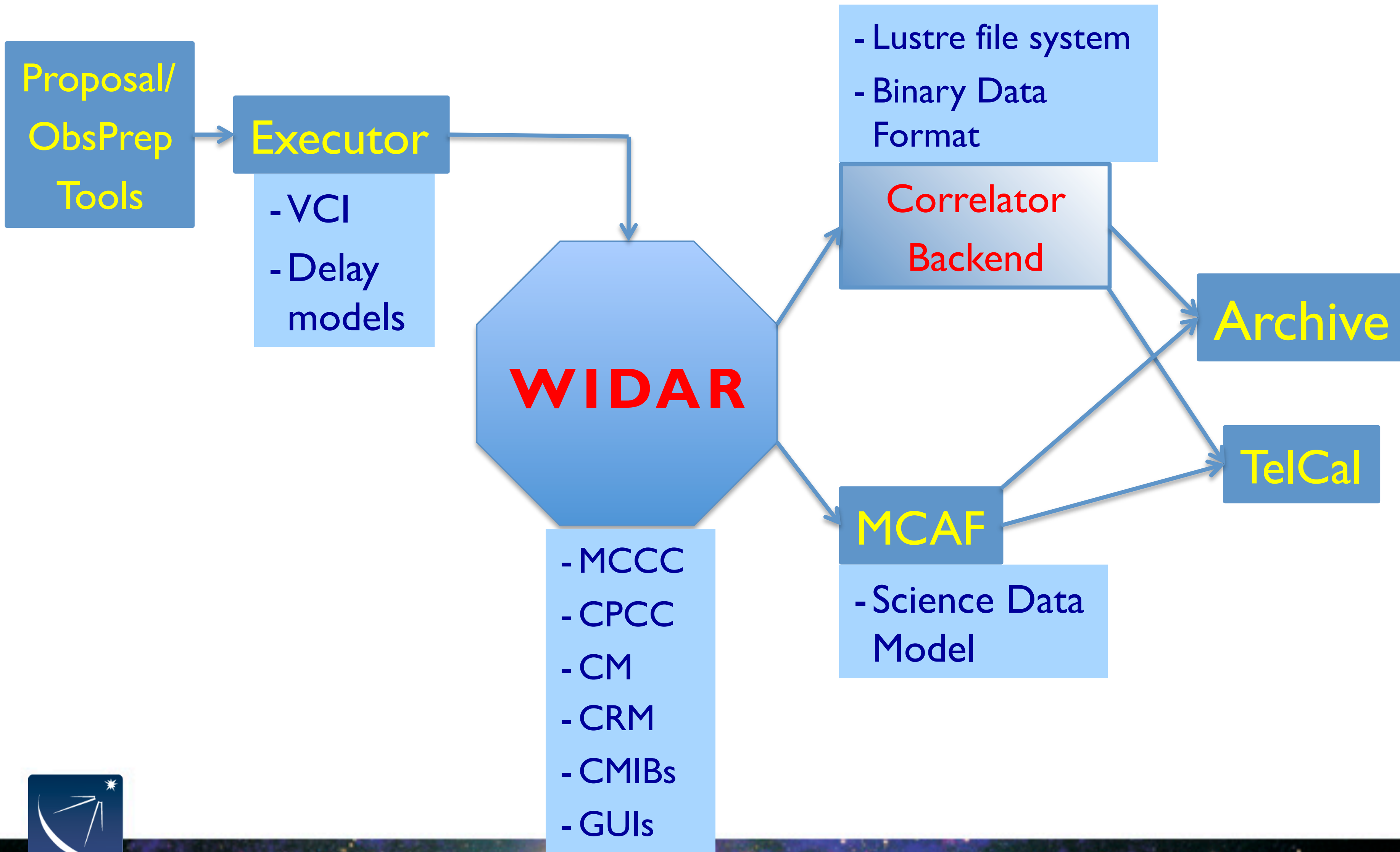
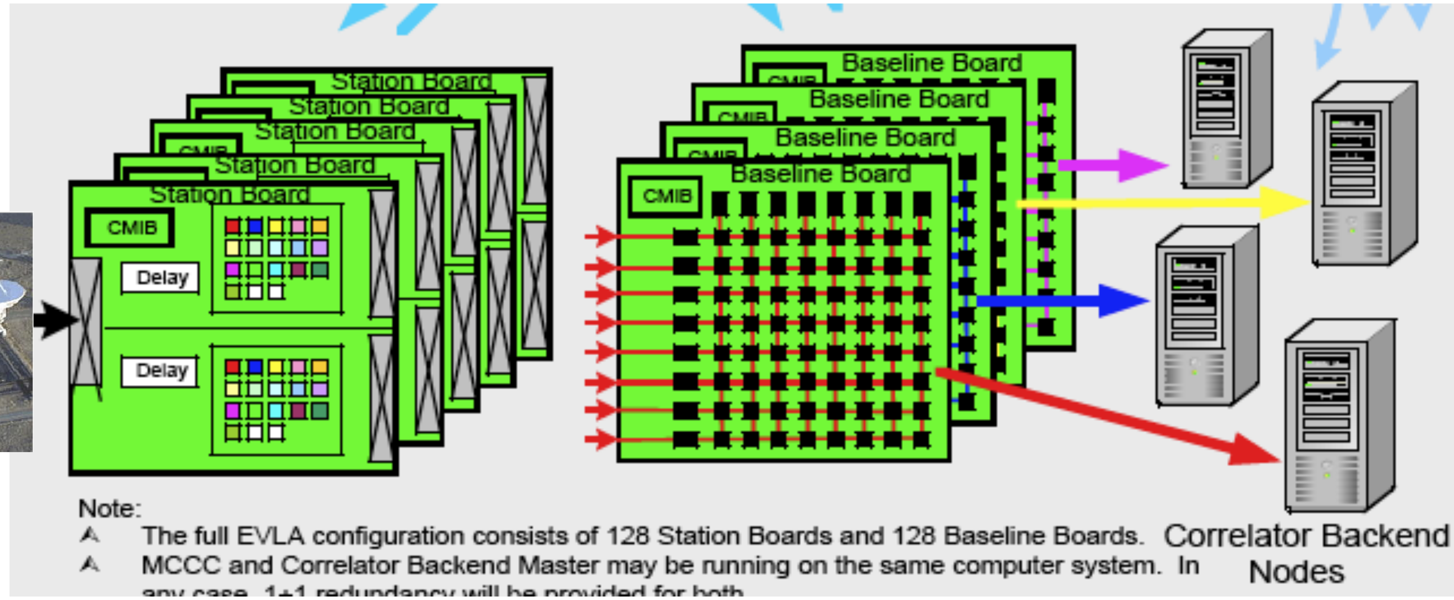
WIDAR: at the heart of the EVLA



WIDAR architecture



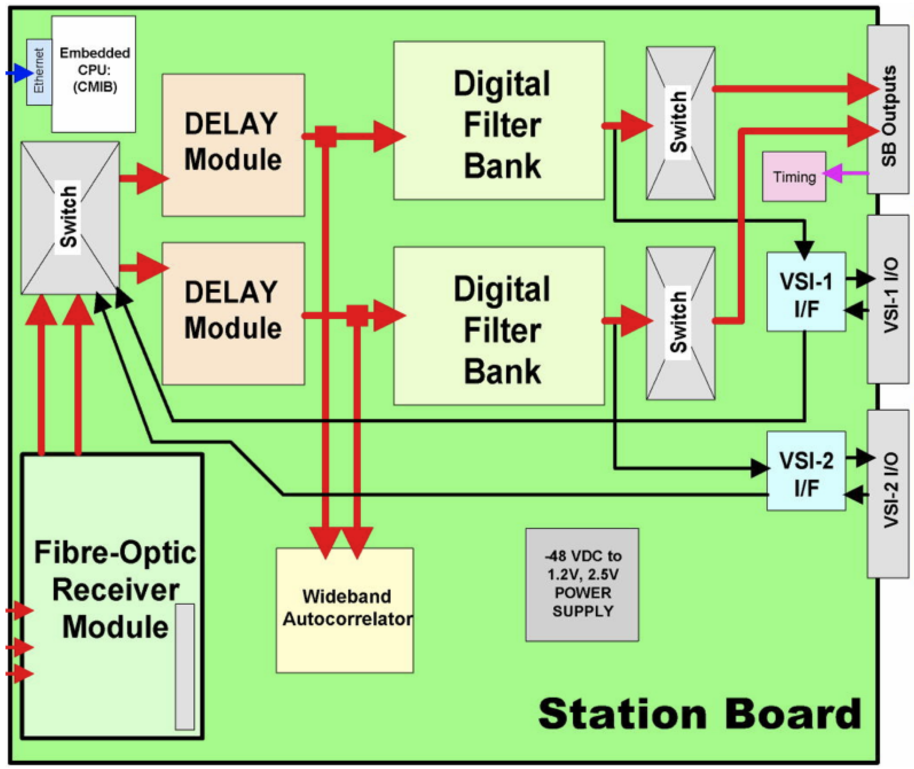
16 GHz/ant split into 4 x 2 GHz/pol'n (Baseband pairs)

Station Boards: split into 64x128 MHz/pol'n (Sub-band pairs)

Baseline Boards: cross-multiply signals from antennas

CBE: Fourier transform, process, & write to disk

Station Board



- 3 fibers go into each StB
  - **2 x 2 GHz @ 3 bits/sample**

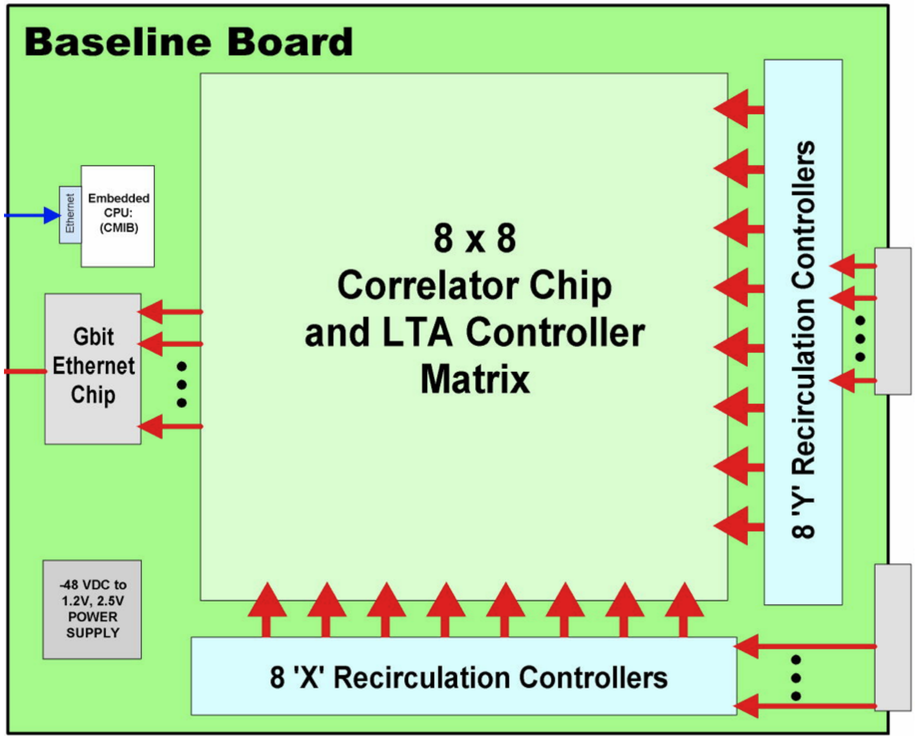
    OR
  - **1 x 1 GHz @ 8 bits/sample**
  - **4 StB/antenna**
- Coarse digital delay tracking
- Dual 18-FPGA filter banks (4-stage, 512-taps, optional DSSB mixer in Stage 2)
  - **Completely independent**
- Switched power, state counts

➔ 16 x (31 kHz-128 MHz) output subband pairs

Crossbar board

- Takes data grouped **by antenna**, and switches to grouping **by subband** (pair) to allow cross-correlation
- Can flexibly route subband pairs to Baseline Boards
  - Allows observer to choose spectral resolution separately for each subband pair

Baseline Board



- Input: one subband pair (31 kHz-128 MHz) from all (<=32) antennas
- Two "RXP" (re-timing, X-bar, phasing) FPGAs receive & distribute, and phase the array
- Recirc FPGAs perform recirculation (more channels for narrow bandwidths), phase generation, formatting to daisy-chained rows/columns
- Correlator chip array: 8x8 set of correlator chips, each with 16 CCCs
- 2048 complex-lag (4-bit multiply, 3-level phase rotation, dual 23-bit accum) CCC dumps to LTA

Correlator Backend, TelCal, & Archive

- Baseline Boards each have 1 GigE (1 Gbps), upgradeable to 10 Gbps
- Lag frames are routed to **Correlator Backend** (CBE) cluster of Linux boxes
- CBE collects the lag frames, processes them (Fourier transform etc.), and writes out in ALMA+EVLA Binary Data Format
  - Parallel writes using Lustre file system for speed (75 MB/s)
- TelCal and the Science Data Archive both snag data from the Lustre temporary storage (cbe-store) as needed

Staged hardware delivery & testing

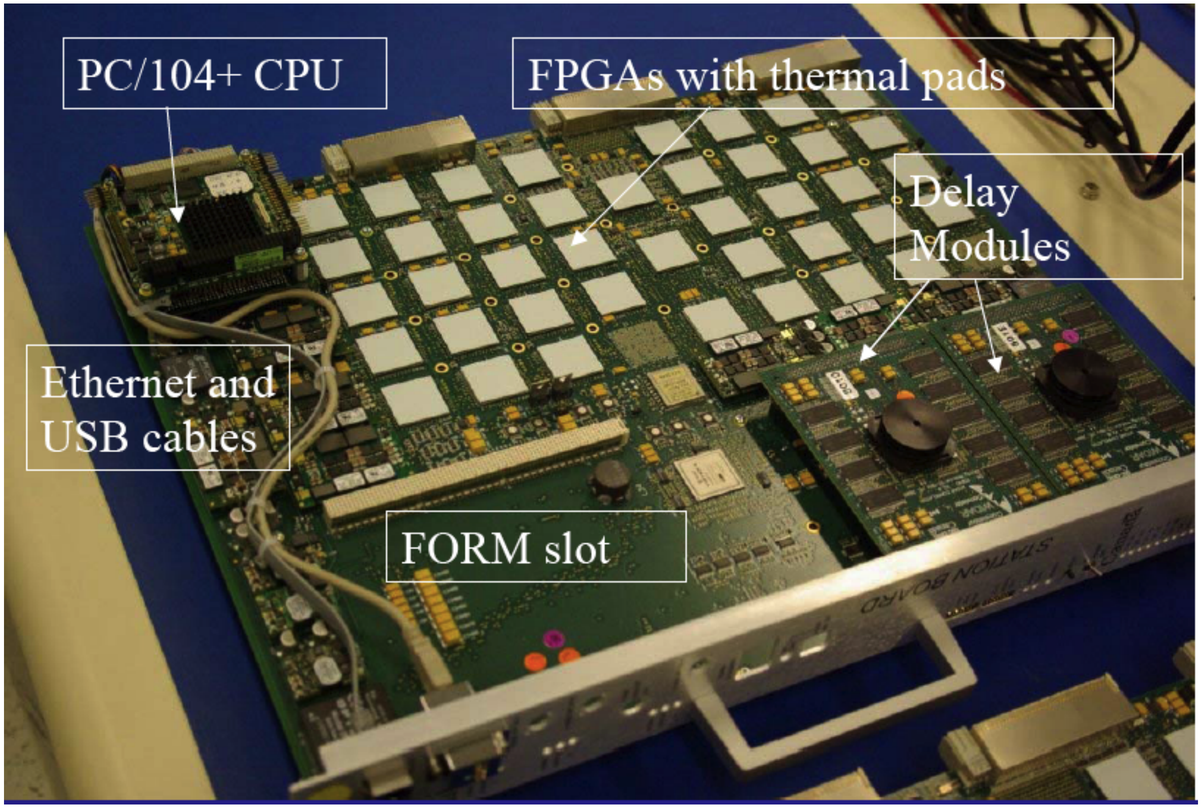
- Prototype Correlator June-December 2008
  - 4 antennas, RCP only, 8-bit samplers: 4 StB
  - 1 BIB, manual chip-level setups: 1 GHz
  - aimed at hardware tests leading to final production orders

- WIDAR-0 March 2009-January 2010
  - First subset of final correlator hardware
  - 12 antennas, full pol'n, 8-bit samplers: 24 StB
  - 20 BIBs, manual setup shifting to Configuration Mapper: 10 sb pairs
  - aimed at systems integration, robustness, & preparation for OSRO

- WIDAR March 2010-December 2012

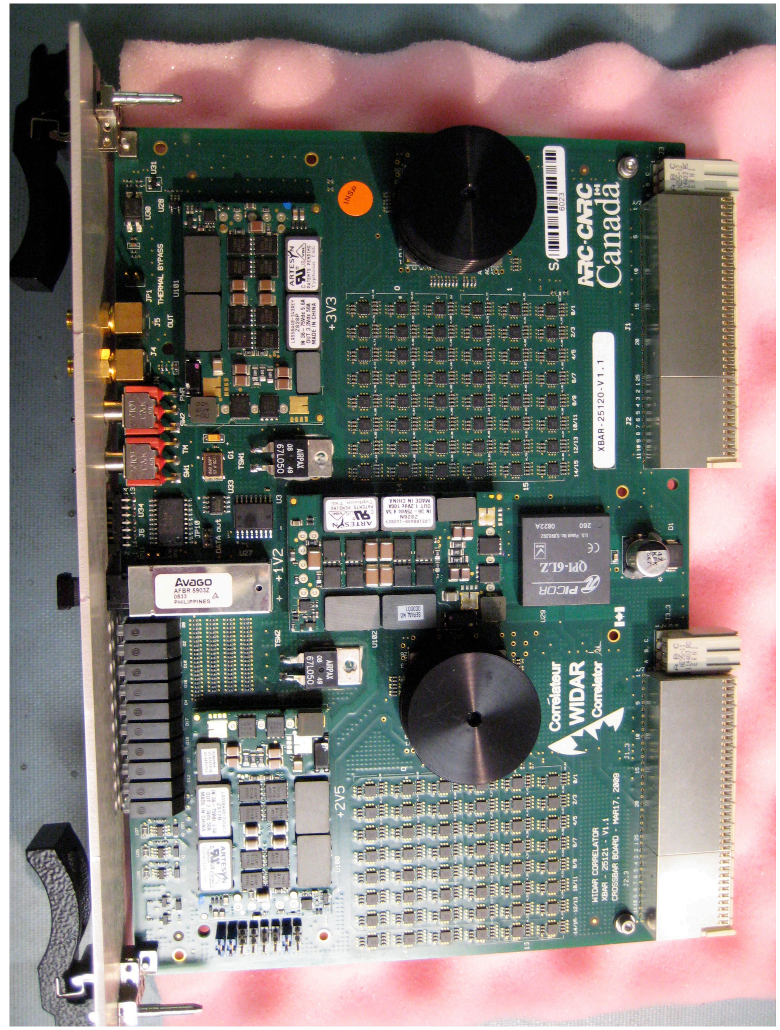
Hardware status: Station Boards

- 128 Station Boards (4/ant x 32 ant) + 6 spares
- All delivered & installed
- 27 x 4 in constant use since March 2010



Hardware status: Crossbar Boards

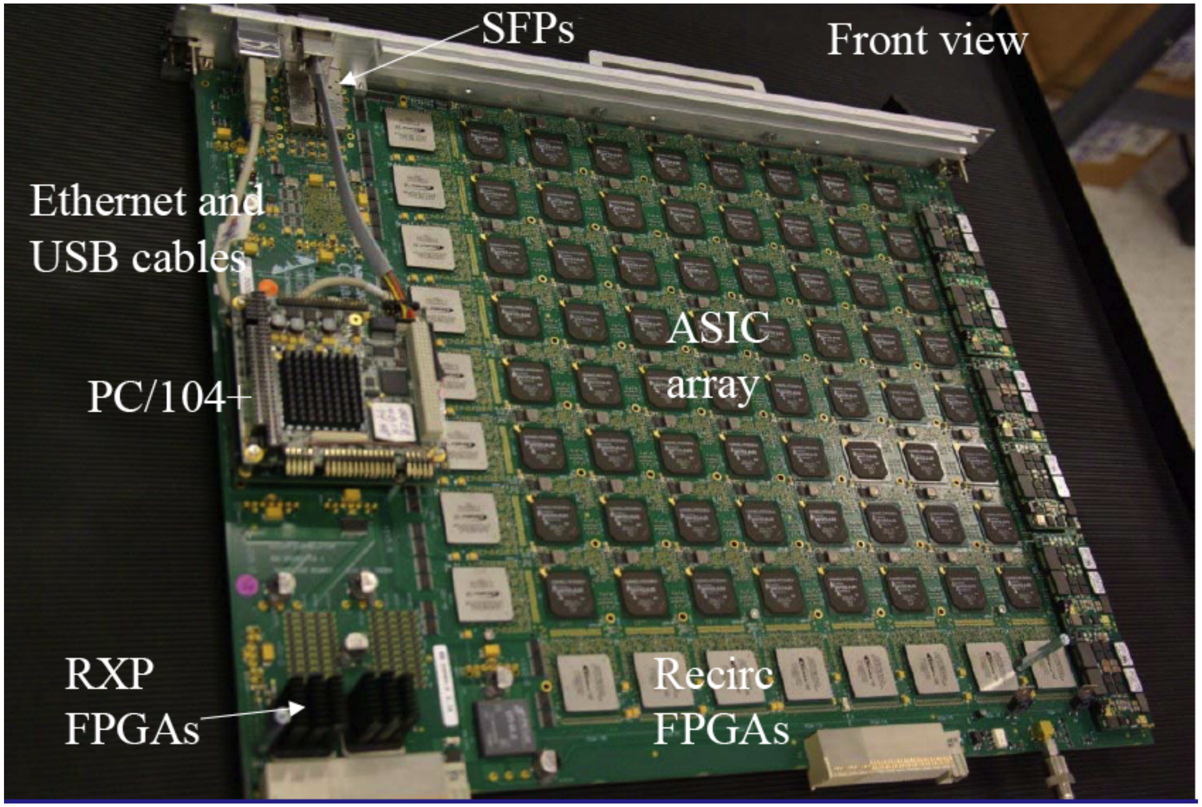
- 64 Crossbar Boards + 12 spares
- All delivered & installed
- 56 in constant use since March 2010



Hardware status: Baseline Boards

- 128 Baseline Boards + 12 spares
- All but 44 delivered & installed
- Remainder due by September 2010

- 4 in constant use (OSRO)
- 32 used for current (2 GHz/pol'n) RSRO



Commissioning WIDAR

- Very complex instrument
  - hardware: boards, chips (25000), cabling (30 miles!), connections, timing
  - firmware: 11 major FPGA personalities (6 StB, 4 BIB, 1 XBB)
  - internal software: CMIBs, Configuration Mapper, Correlator Resource Monitor, Monitor & Control Computer for the Correlator, Correlator Power Control Computer, Correlator Backend
  - external hardware: Fiber Optic Receiver Module, TIMECODE & clock, Mark 5 units, …
  - external software: Proposal & ObsPrep Tools, Executor, Metadata Capture & Formatter (MCAF), TelCal, Science Data Archive, Monitor and Parameters Data Bases

Commissioning WIDAR

- Requires careful planning and staged development
- Driven by:
  - scientific priorities: SAGE (e.g., wide bandwidths)
  - hardware commissioning: 3-bit samplers
  - practicality: finite staff, complex interconnected system
- KISS (Keep It Simple, Stupid!) principle
  - capability before flexibility: aim at maximum science for minimum software/documentation effort
  - make it easy to use!
  - test & commission well-defined (and we hope well-chosen), small subsets of a vast parameter space
- Simple default correlator modes which allow a lot of astronomy (SAGE)
  - OSRO= VLA++; RSRO= gradual growth of complexity & capability
- Priorities= bandwidth, subbands, spectral resolution, flexibility

Status of standard observing: OSRO

- Two basic "VLA++" modes:
  - OSRO-1: 2 subband pairs @ 64 channels/pol'n product * 4 pp
  - OSRO-2: 1 subband pair @ 256 channels/pol'n product * 2 pp
- Allow any subband bandwidth (128 MHz → 31.25 kHz)
- 1 sec dumps
- 102 Station Boards, 4 Baseline Boards
- Tuning performed by antenna LO system → subband pairs completely independent
- Data rate ~1.7 MB/s → 60 GB/10 hours

- First scientific observations 2mar10
- Observed all high-priority low-frequency projects
- Working through last few high-frequency projects
  - challenges= referenced pointing, band changes, weather

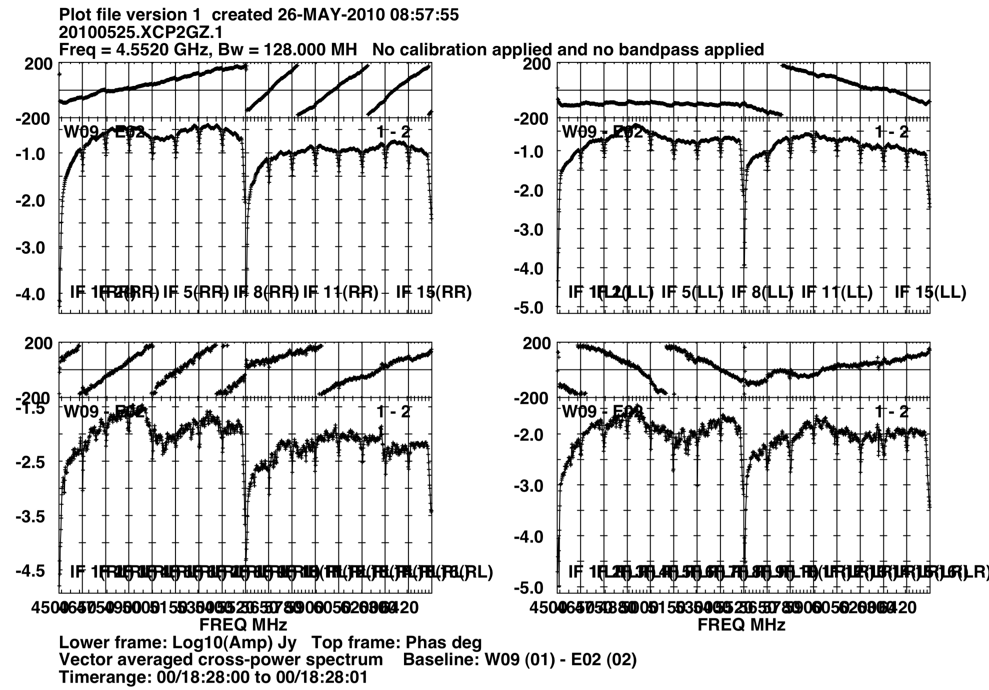
Status of resident observing: RSRO

- 16 subband pairs, all identical
- Each 256 channels spread over 1-4 pol'n products
- 8-bit samplers → max 2 GHz/pol'n
- Subtle restrictions on tuning etc.
- 1 sec dumps
- Max 14 MB/s → 480 GB/10 hours

- Most approved proposals are wideband for sensitivity
- A couple are more fun: e.g., 16 simultaneous spectral lines spread over several GHz
- First true science data taken 3jul10
- Low-frequency single-band data are excellent
- High-frequency observations limited by ref.ptg., band change, weather issues

Results: one baseline

- 2 x 1 GHz baseband pairs
- = 16 x 128 MHz subband pairs
- 64 ch/pp/sb → 4096 x 2 MHz channels
- *One baseline, one dump!*



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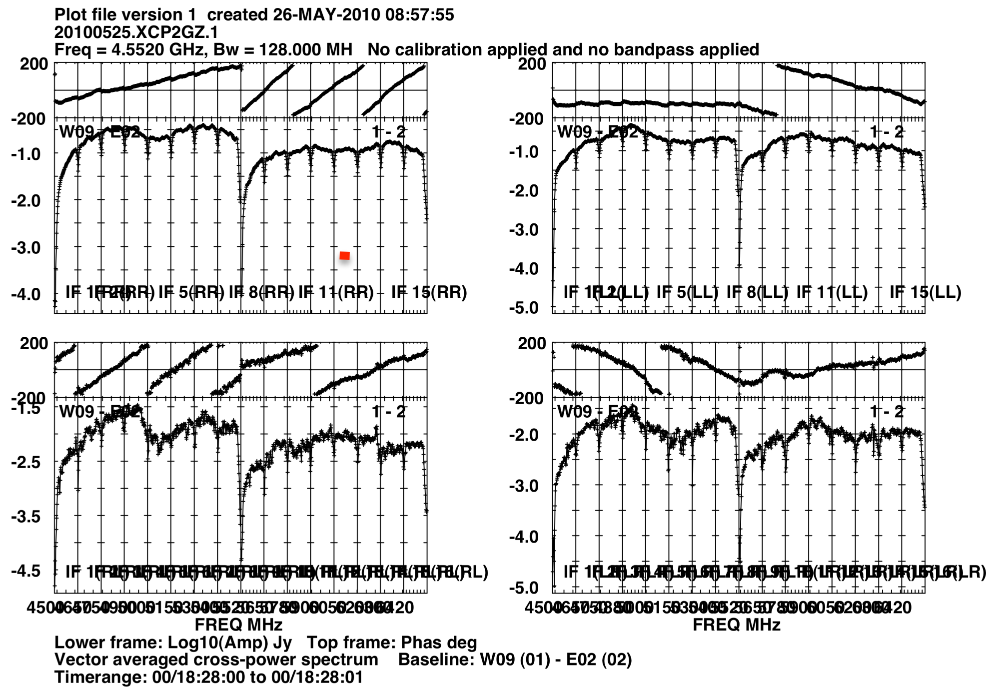
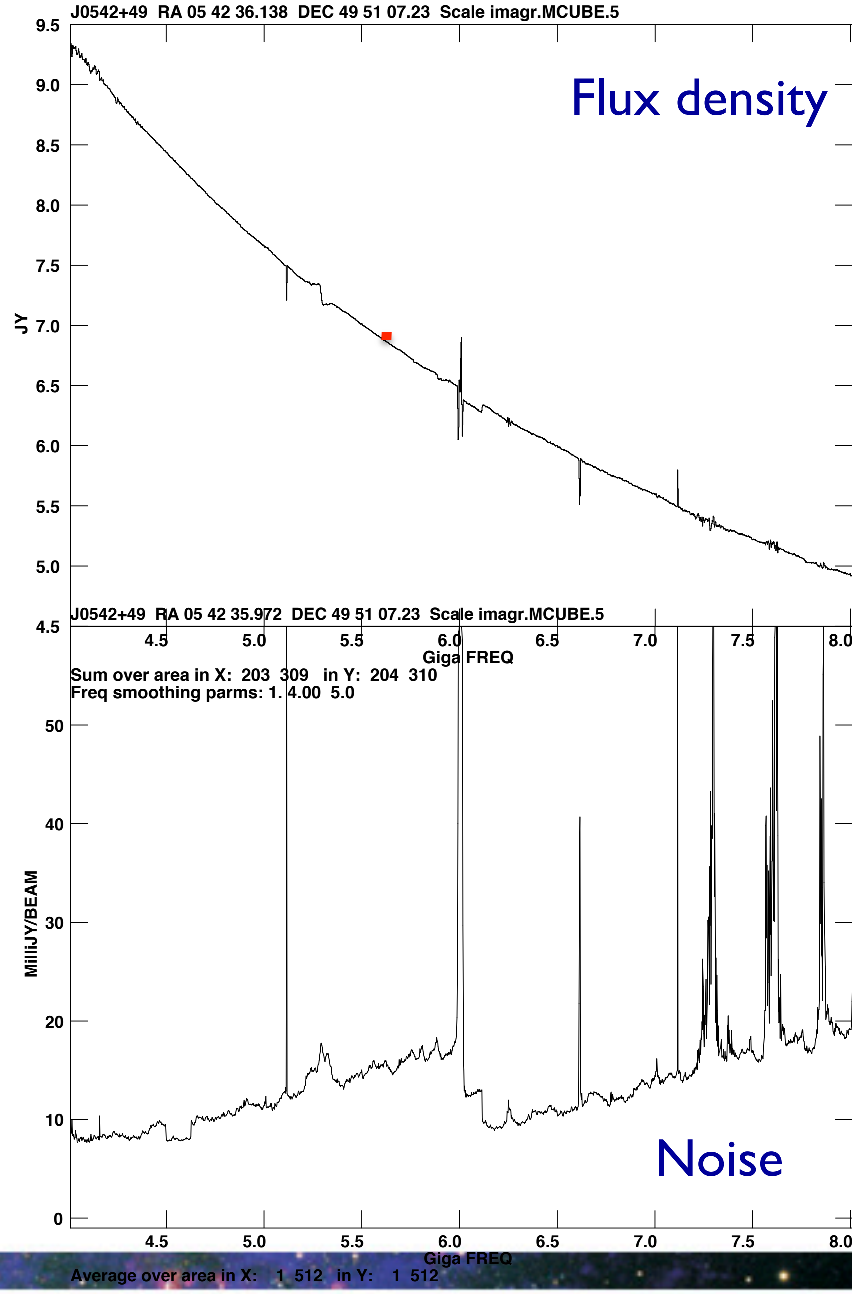


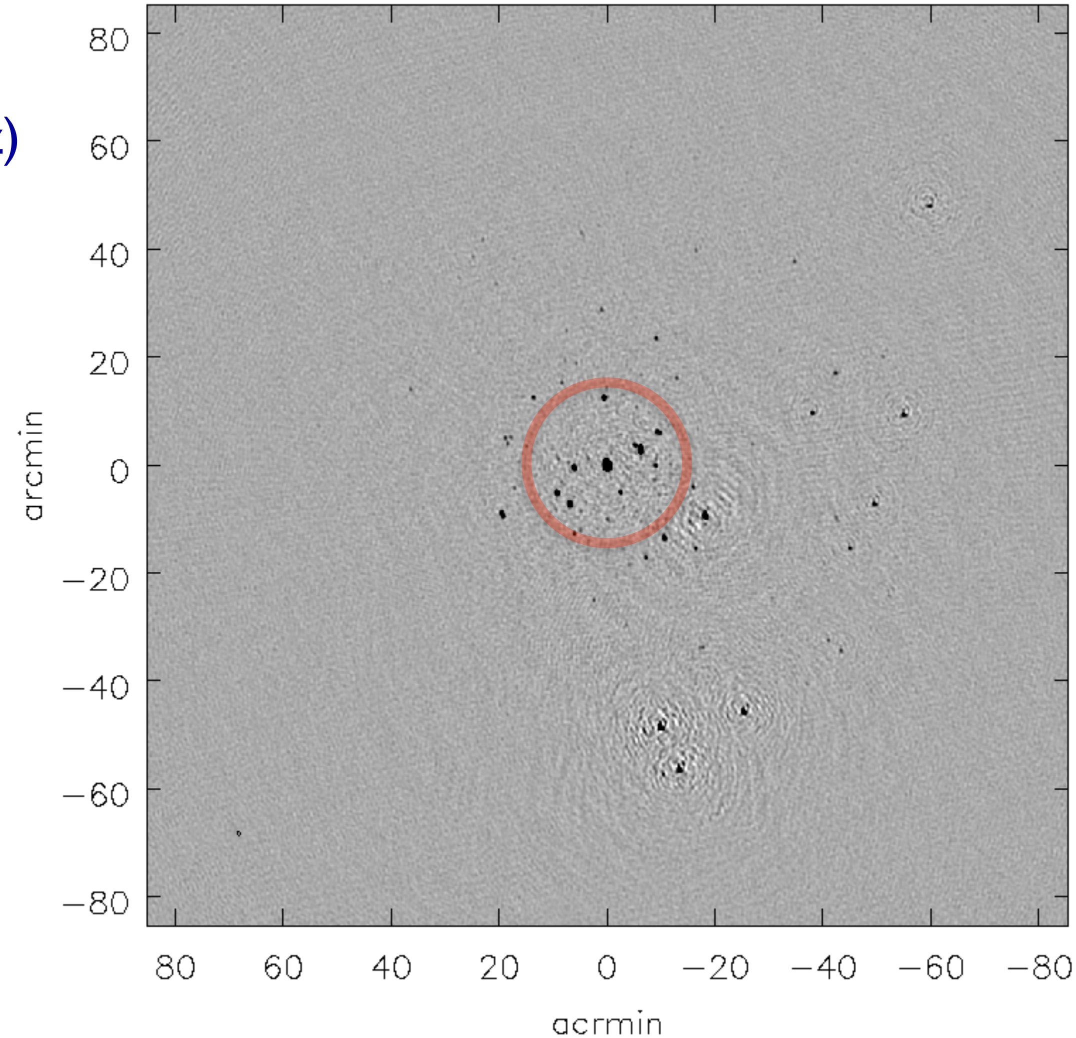
Results: spectrum

- 3C147
- Two tunings covers **all** of C band (4-8 GHz)
- 2:1 bandwidth ratio
- Lots to think about!



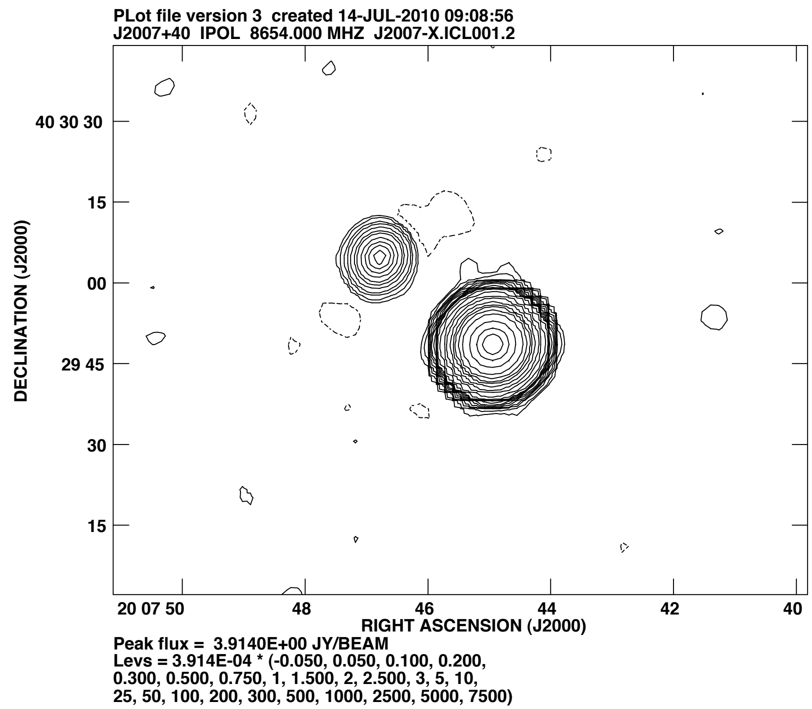
Results: high dynamic range

- 3C147 for 6 hours
- One subband pair (128 MHz) at 1436 MHz
- 800,000:1 dynamic range
- Encouraging – but extended sources (e.g., Cygnus) are harder!



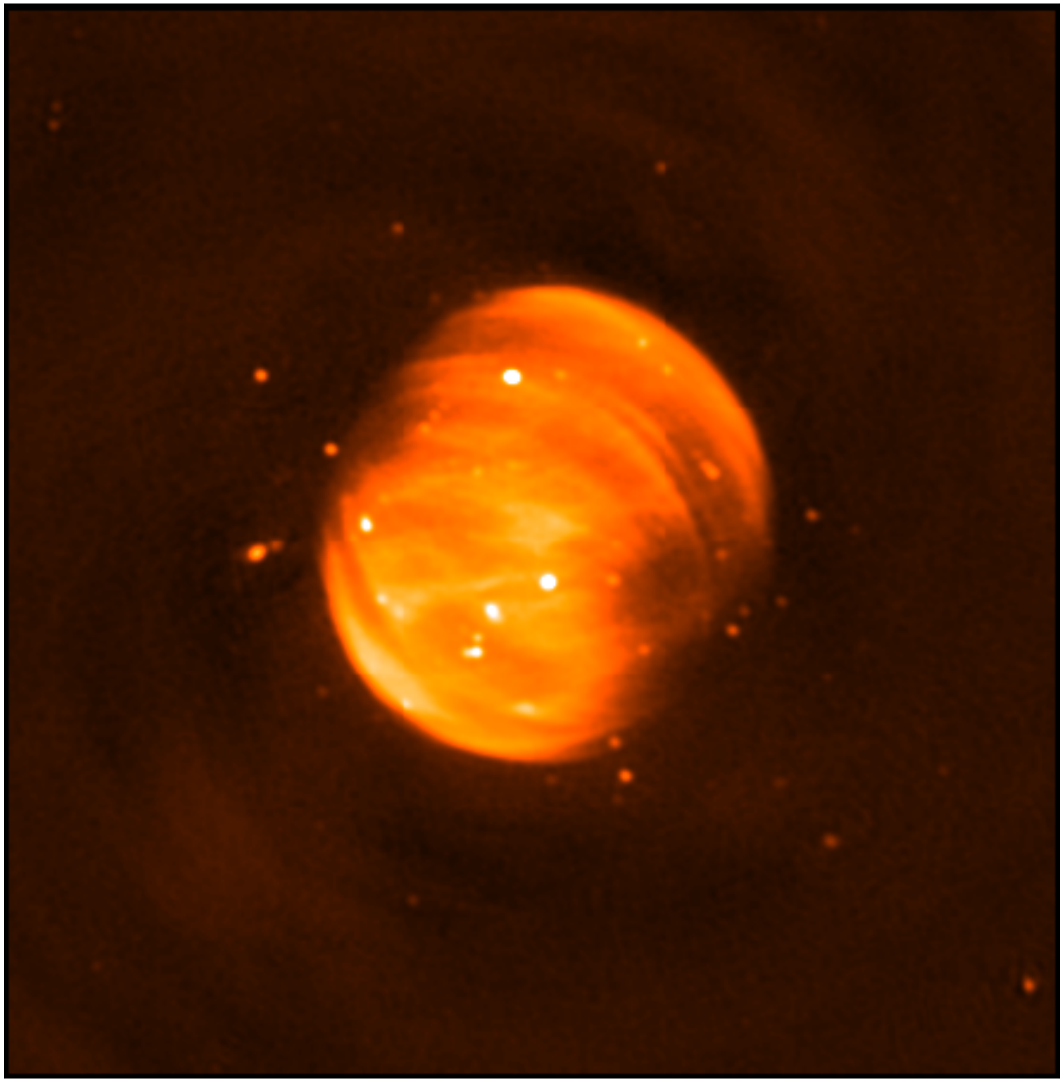
Results: high dynamic range

- X-band 8.400-8.912 GHz
- No heroic measures – regular self-cal
- 525,000:1 w/o BLCAL
- 545,000:1 with BLCAL
    - time-independent
    - closure errors ~few e-4
    - consistent with D terms
- Uniform noise across the image – because there are no background sources
- NA-weighting lumps – CygA?
- Rms noise=7.2 microJy/beam
    - vs. expected ~7 microJy/bm



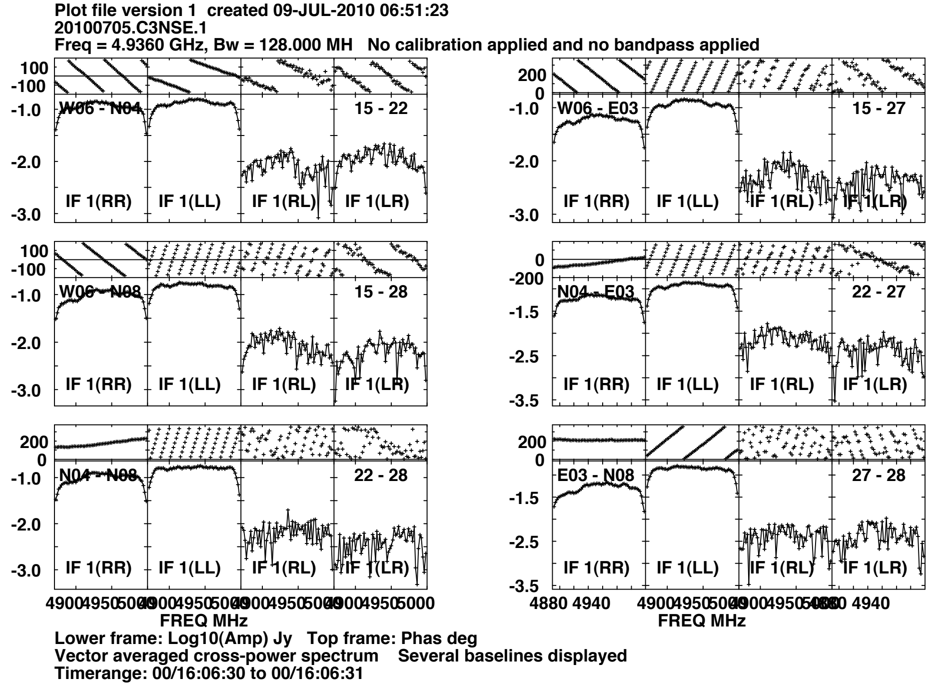
Results: extended source

- SNR G93.6+6.9 for 4-5 hours
- Two subband pairs (2 x 128 MHz) at 1458/1826 MHz
- Again, an encouraging first step



Results: 3-bit samplers

- Four antennas, 1 pair of samplers
  - →2 GHz/pol'n (R+L)
- 1 subband (128 MHz) on 3C147
- Closures are nice and boring
- Last major hardware design in the EVLA
  - Just beginning scientific testing



Growing capabilities

Date	Array cfg.	Max BW/ pol'n	# subband pairs	Channels/ sbp @ 4pp	Max. data rate	Flexibility
2010/T1	D	**2 GHz**	**16**	64	15 MB/s	-sb identical - sb indep tunable with restrictions - trade pp/ channels
2010/T2	C	2 GHz	**>16**	64	**75 MB/s**	- Trade sb/ channels
2010/T3	B	2 GHz	**64**	64	75 MB/s	
2011/T1	A	2 GHz	64	**<= 16384**	75 MB/s	-Recirculation - sb tuning more flexible
2011/T2	D	2 GHz	64	<=16384	75 MB/s	-Sb indep tuned - diff. BW/Nchan/ sb
2011/T3	C	**8 GHz**	64	<=16384	75 MB/s	

Other bits

- 7-bit correlation
- Fast (burst) dumps
- **Phased array**
- Pulsar phase bins
- **Planets**
- **On-the-fly mosaicking**

Conclusions

- Most hardware is here & working well
  - not all aspects are fully tested
- Most major correlator software components are working, but many extensions are needed for both capability & robustness
- Very aggressive, science-driven schedule
- OSRO (standard observing) is fairly routine
- RSRO (simple wideband) at low frequencies is working nicely
- Software & firmware robustness issues
- Data are excellent
  - correlator problems are obvious (no data, or no fringes) & easy to flag

- Currently there are no obvious WIDAR-related roadblocks to the advertised (RSRO) deadlines – but there is a **lot** to do!