The COBRA Correlator System

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- **OVRO's COBRA Wideband Correlator**
  - 6 x 10m, 15bl, 4GHz (256 x 16MHz) bandwidth

- **SZA's Wideband Correlator**
  - 8 x 3.5m, 28bl, 8GHz (256 x 32MHz) bandwidth

- **CARMA's Multi-resolution Correlator**
  - 6 x 10m + 9 x 6m, 105bl, 4GHz IF covered by 8 independently tunable bands with 2, 8, 31, 62, 125, 250, 500MHz bandwidth options
Exploit commercial standards & technology

- FPGAs
- 6U Compact PCI Crates and CPUs
- LVDS (Ultra-SCSI) Cabling
- DSPs for 'hard' real-time control
COBRA Wideband Correlator

4GHz bandwidth, 256-channels, 16MHz resolution
(consisting of eight 500MHz bands of 32-channels)
COBRA QuadMod Noise Source

Designer: Brad Wiitala
COBRA Wideband Downconverter

Designer: Brad Wiitala
COBRA Digitizer
COBRA/SZA Crate
3C454.3 Spectra

(5min integration)
J1409 high redshift (z=2.59) quasar detection and map

Map of integrated CO emission in J140955.5+562827. The contours are multiples (-1,1,2,3,4,5) of the rms noise level, which is 0.49 Jy beam$^{-1}$ km s$^{-1}$.

Data courtesy Nick Scoville, Min Yun, and Laura Hainline.
The COBRA correlator was recently used to detect two high redshift quasars, SMM 04135+1027 (z = 2.85, detected in COBRA band w4), and J 1409+5628 (z = 2.59, detected in COBRA band w6).

In trying to detect CO emission from high redshift objects, we are trying to constrain the time when stars formed and enriched the chemical composition of the universe. Theory says that all the gas produced in the Big Bang was H and He (no heavier elements), and that any C and O we see was produced by nuclear fusion reactions in the cores of stars, formed long after the Big Bang actually occurred. However, we cannot observe individual stars in very distant galaxies to directly tell when most of the star formation in the universe happened. But, if we see CO in high-redshift galaxies, we can infer that significant star formation has occurred by the age of the universe that the galaxy's redshift represents.

Our best estimates are that the universe is about 13 billion years old, based on the current universal expansion velocities and the separations between galaxies. The quasars we have detected in CO are being observed about 1 billion years after the Big Bang. Very recently, CO emission was detected by another group in a quasar at z = 6.4, corresponding to 800 million years after the Big Bang. Thus, while our new detections in SMM 04135+1027 and J1409+5628 do not set a record in terms of look-back time, it is still amazing to see that galaxies existed so early in the history of the universe with large masses of C and O. This indicates that stellar processing must have occurred much earlier after the Big Bang than models predict. Our detections help determine how common this large degree of stellar processing was, throughout the early universe.
While most debris disks have been found around A-type stars, a debris disk around a star with the same spectral type as the Sun as recently been identified (HD 107146; Williams et al. 2003). With an age of approximately 30-100 Myr, HD 107146 provides a glimpse to the physical conditions of our Solar System at a young age when the planets are likely in the last stages of formation. The figure shows an OVRO 3mm continuum map of the HD107146 debris disk system. The debris disk is clearly detected in the continuum, but more significantly, the emission is offset from the stellar position by ~60-100 AU. Such asymmetries are often attributed to an orbiting low mass stellar, brown dwarf, or planetary companion that redistributes the debris dust.

Data courtesy; John Carpenter.
The SZA Array
The SZA Correlator

- 8 x 3.5m telescopes
- 8GHz bandwidth (1GHz to 9GHz IF)
- Block downconversion of 5 to 9GHz band to 1 to 5GHz.
- Data processed as 16 x 500MHz bands
- 4 digitizer + 3 correlator boards per band
- 500MHz band = 16-channels, $\Delta f = 32$MHz
- 8GHz band = 256-channels, $\Delta f = 32$MHz
Data transmission at 62.5MHz
Data transmission at 125MHz
The CARMA Correlator

- 6 x 10m + 9 x 6m telescopes
- 4GHz bandwidth
- 8 independently tunable bands with 2, 8, 31, 62, 125, 250, 500MHz bandwidth options
- 8 digitizer + 5 fanout + 11 correlator boards per band
# CARMA Correlator

<table>
<thead>
<tr>
<th>Bandwidth (MHz)</th>
<th>Channels (per sideband)</th>
<th>$V_{[3 \text{ mm}]}$ (km/s)</th>
<th>$V_{\text{tot}[3 \text{ mm}]}$ (km/s)</th>
<th>$V_{[1 \text{ mm}]}$ (km/s)</th>
<th>$V_{\text{tot}[1 \text{ mm}]}$ (km/s)</th>
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</table>

*Channel calculations as per FPGA place and route - Kevin Rauch.*
CARMA Downconverter
The CARMA Correlator
Correlator R&D

• Digitizer revision
  • 1GHz digitizer, 500MHz output data, 250MHz DDR clock (within FPGA capability)
  • All digitizer bits routed to the FPGA (FIR improvement, XF or FX possible)
  • FPGA upgrade - increased performance/capabilities
  • NCO/FIR-based lobe-rotation/sub-sample delays
  • Correlator revision

• Next generation system R&D
  • Review existing correlator designs
  • Exploit packet network technology
CARMA 1st Light and SZA Correlators

Digitized data fanout performed by the digitizer boards (SZA) or fanout boards (CARMA)

LVDS (Ultra-SCSI cables)
CARMA 2nd Gen Correlator

OVRO; 6 antennas, 15-baselines
SZA; 8 antennas, 28-baselines
CARMA 1st Light: 15 antennas, 105-baselines
CARMA 2nd Gen: 23 antennas, 253-baselines

Commercial Technology; eg. SONET, GbE

CARMA Array

Digitizers

Cross-bar switch-yard

Correlator

Crate with switched backplanes

high-speed digital link

high-speed digital links