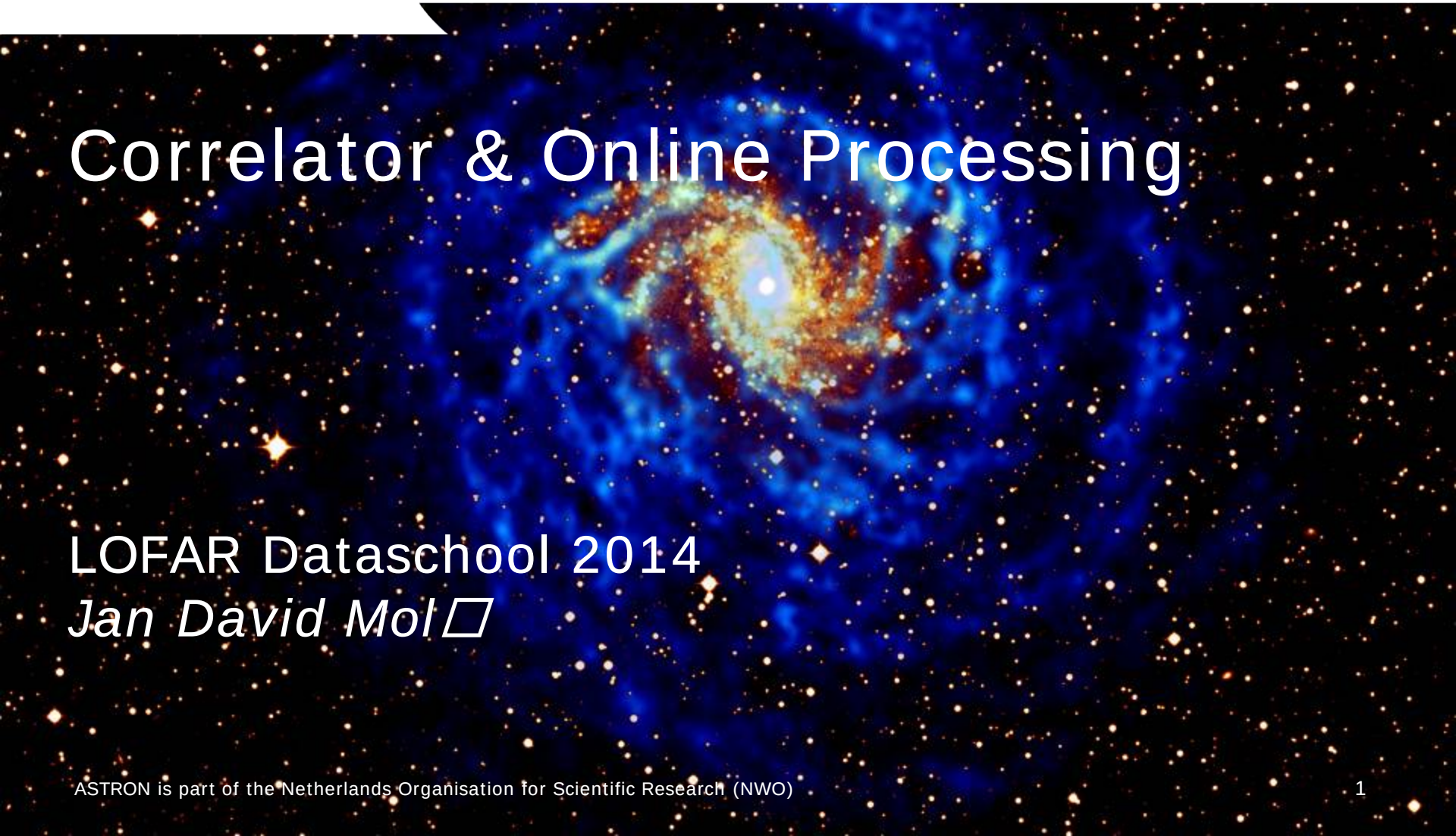
ASTRON

Netherlands Institute for Radio Astronomy



Correlator & Online Processing

LOFAR Dataschool 2014

Jan David Mol

Outline

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- Online Processing
- Data Collection
- Correlator Pipeline
- Beamformer Pipeline

Online Processing

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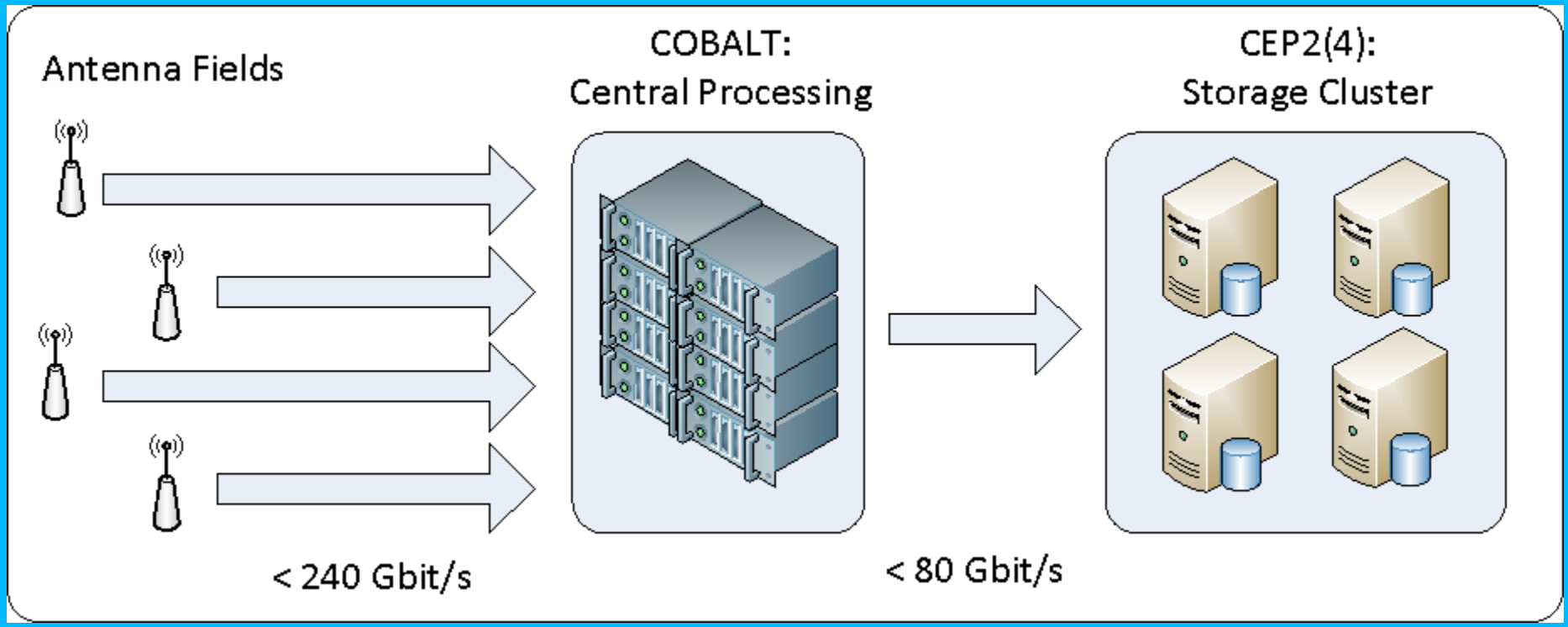

COBALT

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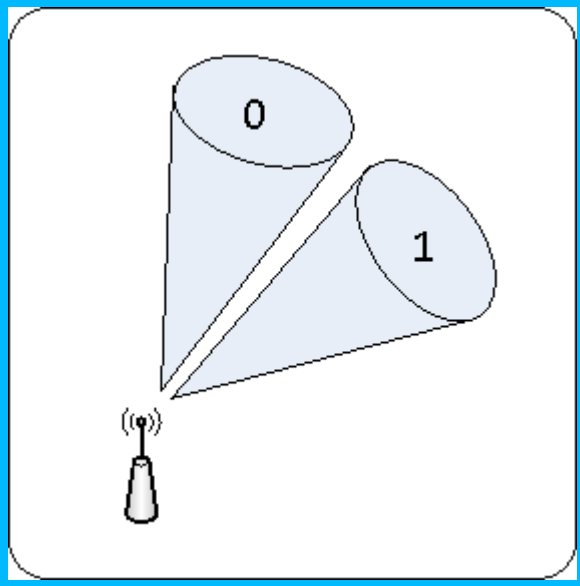
Per-subband Processing

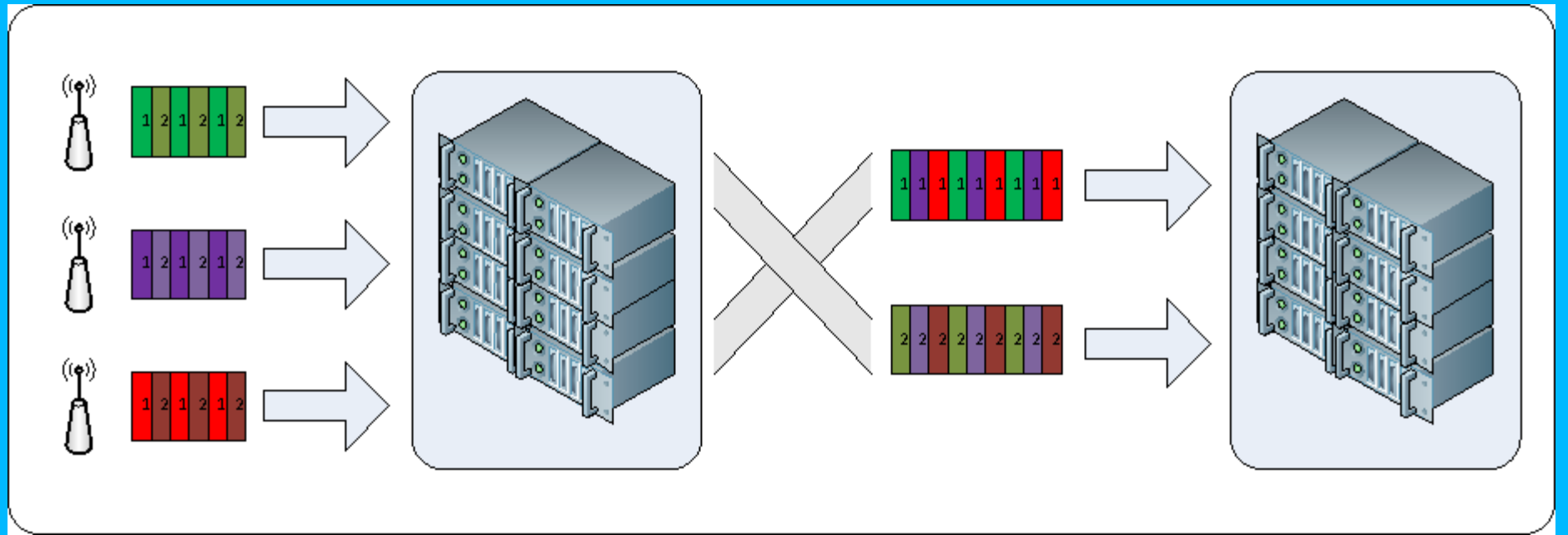
Sub-array Pointing (SAP)	Pointing	Subbands
0	Cygnus A	[1…244]
1	Cassiopeia A	[101…344]



Subband Index	Pointing	Subband
#0	Cygnus A	1
#1	Cygnus A	2
…	…	…
#243	Cygnus A	244
#244	Cassiopeia A	101
…	…	…
#487	Cassiopeia A	344

Collect data per subband

- Data arrives in *packets:* 122 subbands x 16 samples x (X,Y)
  - Lost data = 0+0i
- Incoming data is *transposed*
  - From: per antenna field (all subbands)
  - To: per subband (all antenna fields)



COBALT Processing

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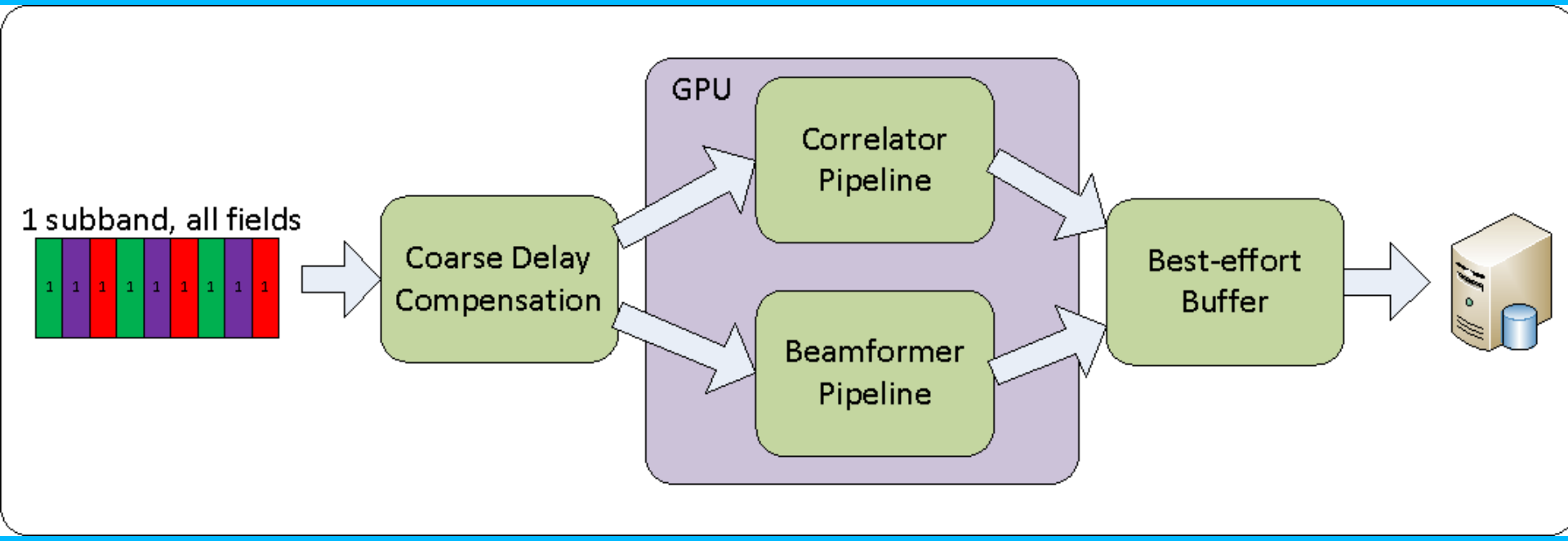
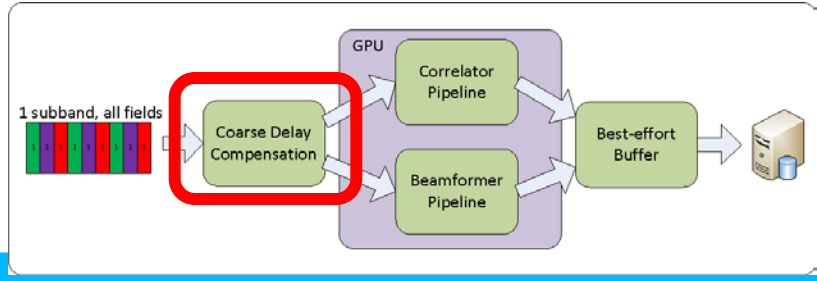
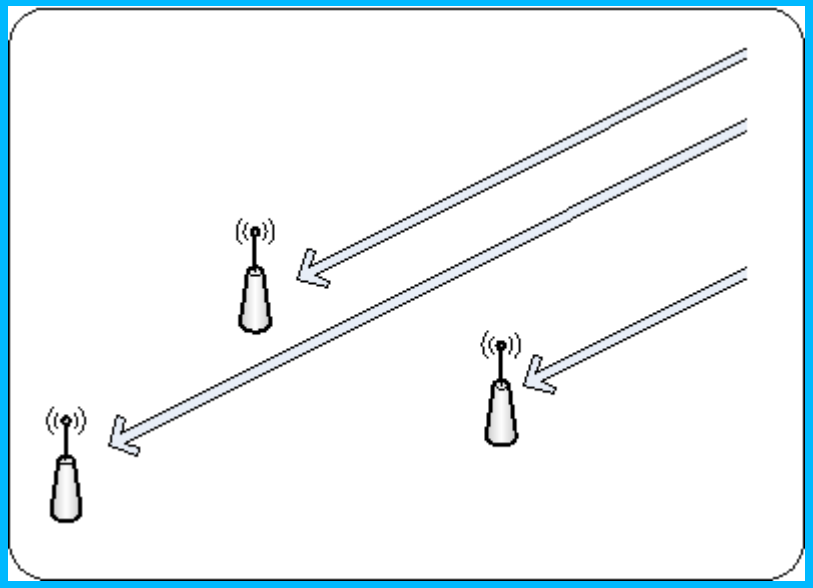


Delay Compensation





- Signal arrival differs per field
  - Align signals
- Coarse @CPU:
  - Shift samples
  - Error ≤ ½ sample = 2.56μs
- Fine @GPU:
  - Phase rotation
  - Frequency dependent (resolution 3 kHz)

NVIDIA Tesla K10

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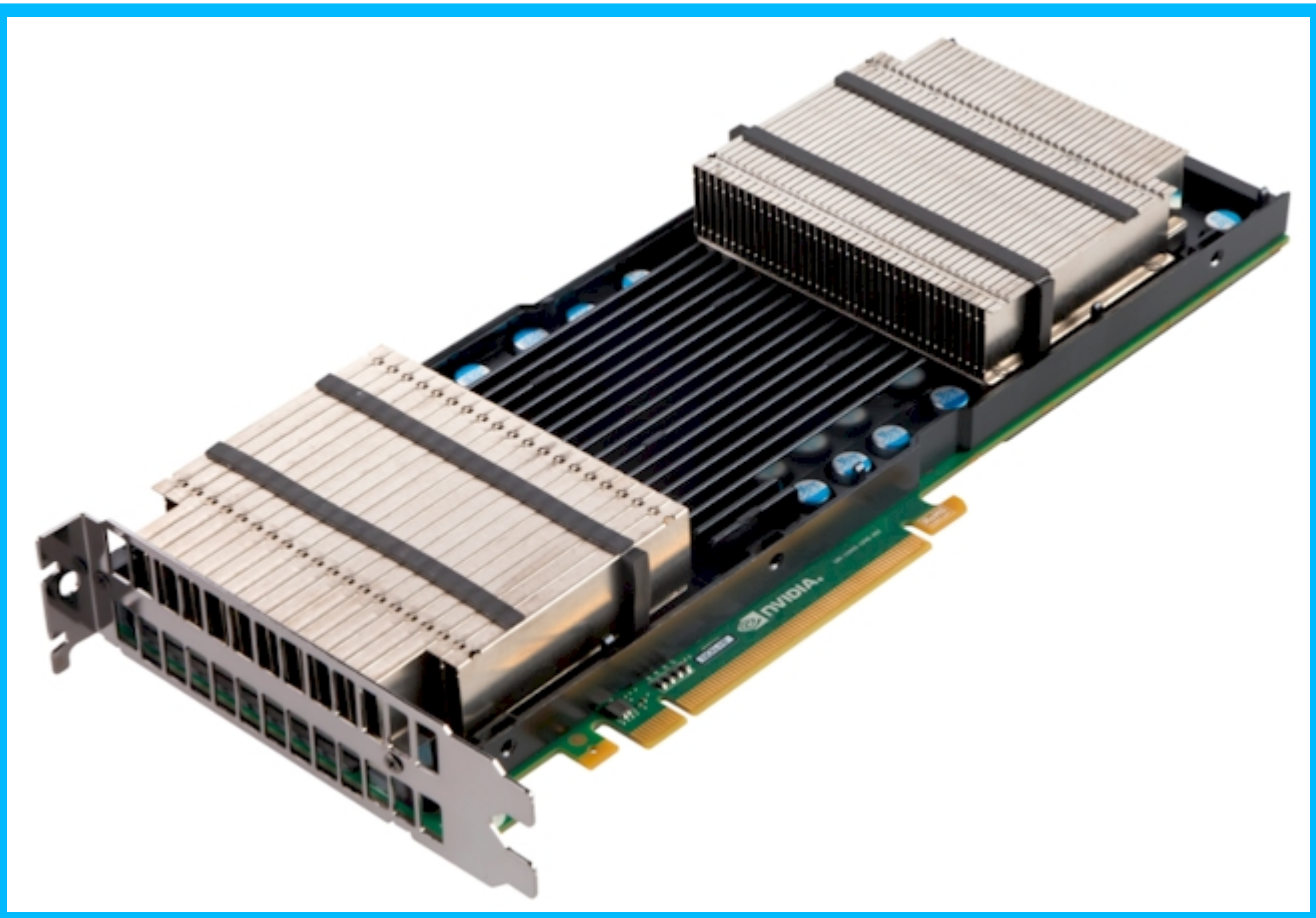
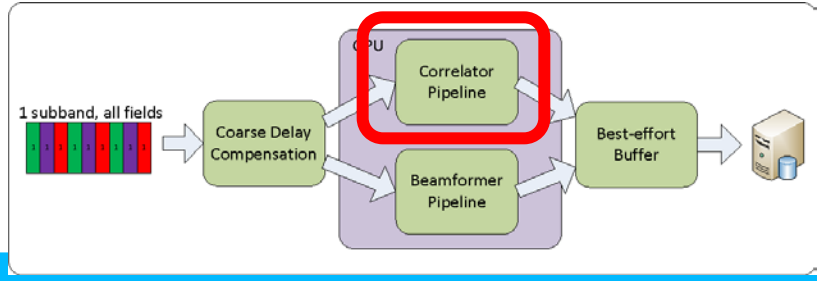


Correlator Pipeline – Goal

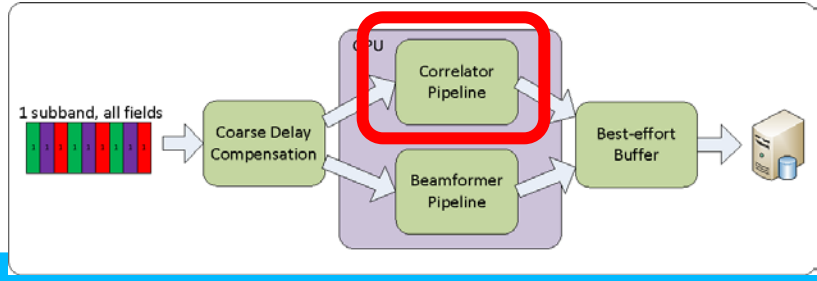


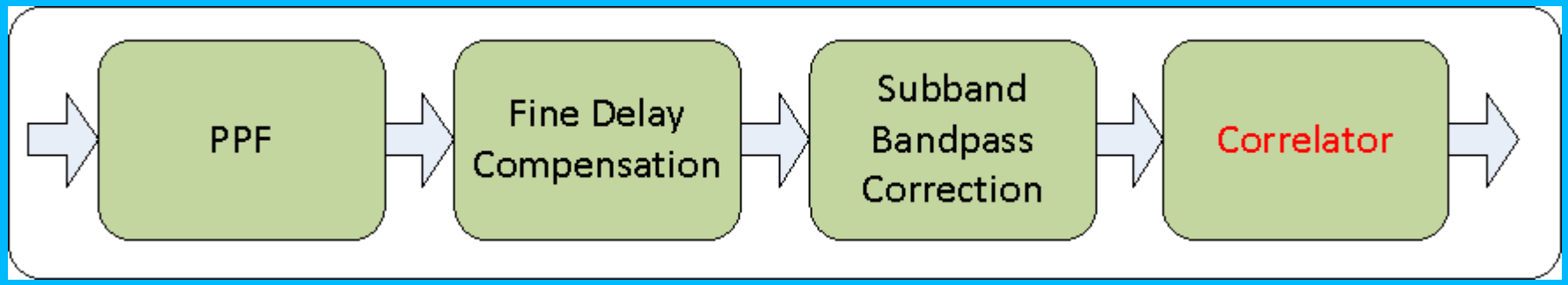
- We *cross correlate* the signals across all *baselines*.
  - *Baseline = pair of antenna fields.*
- For each baseline, we compute:

$$\begin{bmatrix} \langle X_1 X_2^* \rangle & \langle X_1 Y_2^* \rangle \\ \langle Y_1 X_2^* \rangle & \langle Y_1 Y_2^* \rangle \end{bmatrix}$$

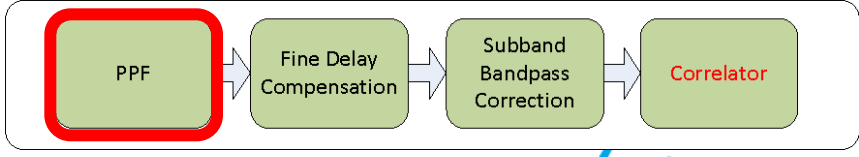
- Parameters:
  - Integration time (typically 1 s)
  - Frequency resolution (typically 3 kHz)

Correlator Pipeline – Layout





PPF



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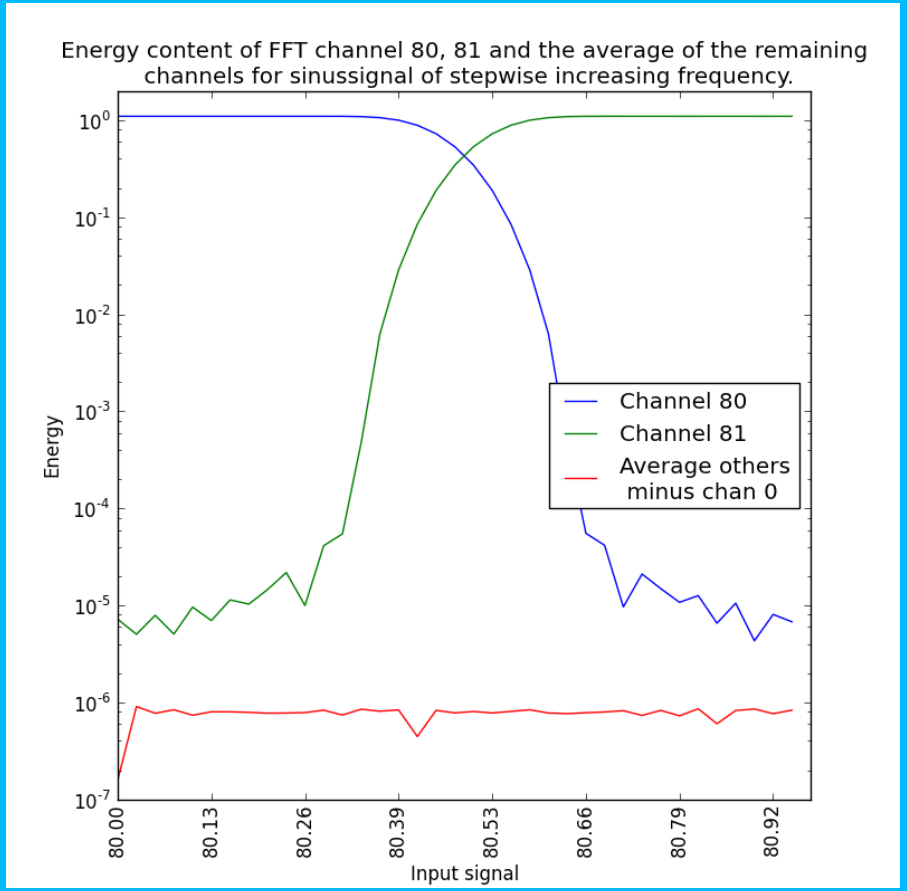
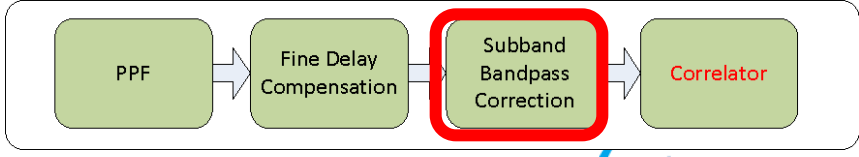
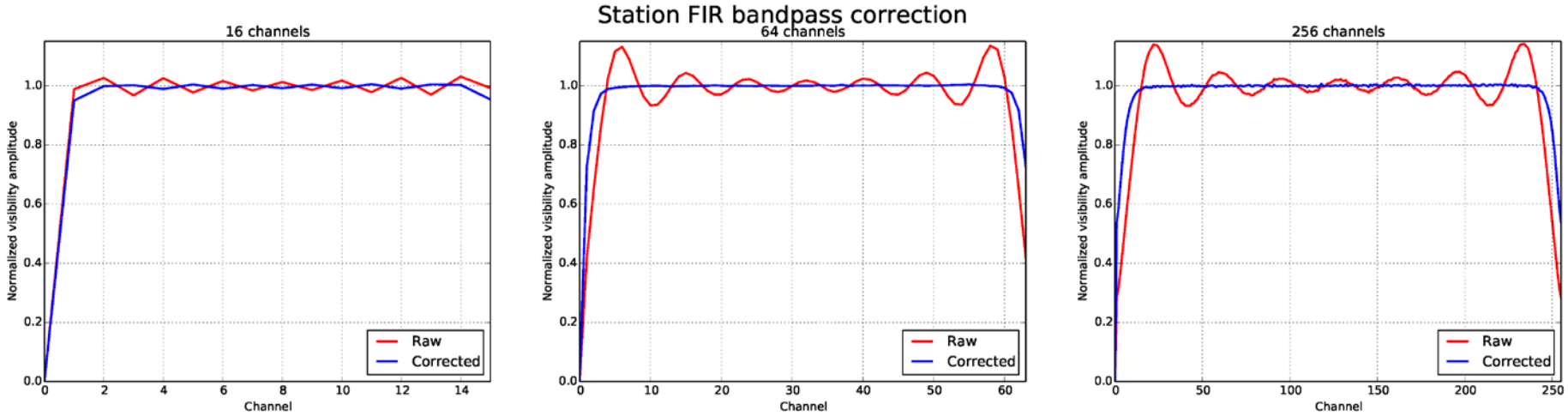
- *Subband* = 195 kHz wide.
- A Polyphase Filter (PPF) separates *channels*
- Example:
  - 64-pt PPF produces 3 kHz channels
- Channel 0 is always lost.
  - COBALT flags.



Subband bandpass correction



ASTRON



- First, last few channels have low amplitude.
  - Our post-processing flags first, last $\frac{1}{32}^{th}$.

Correlator – Storage Format

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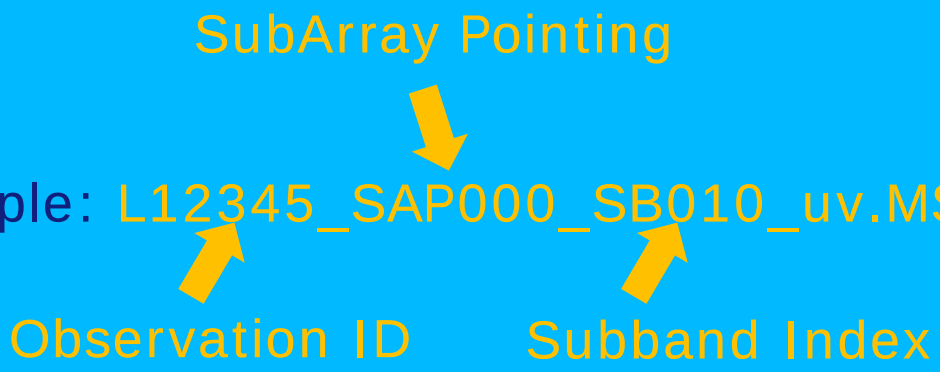
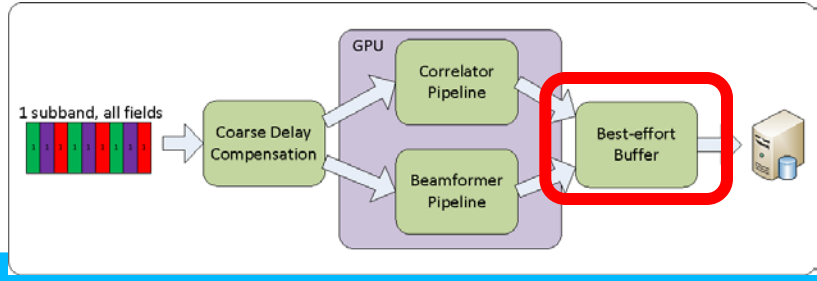
- Format: Measurement Sets

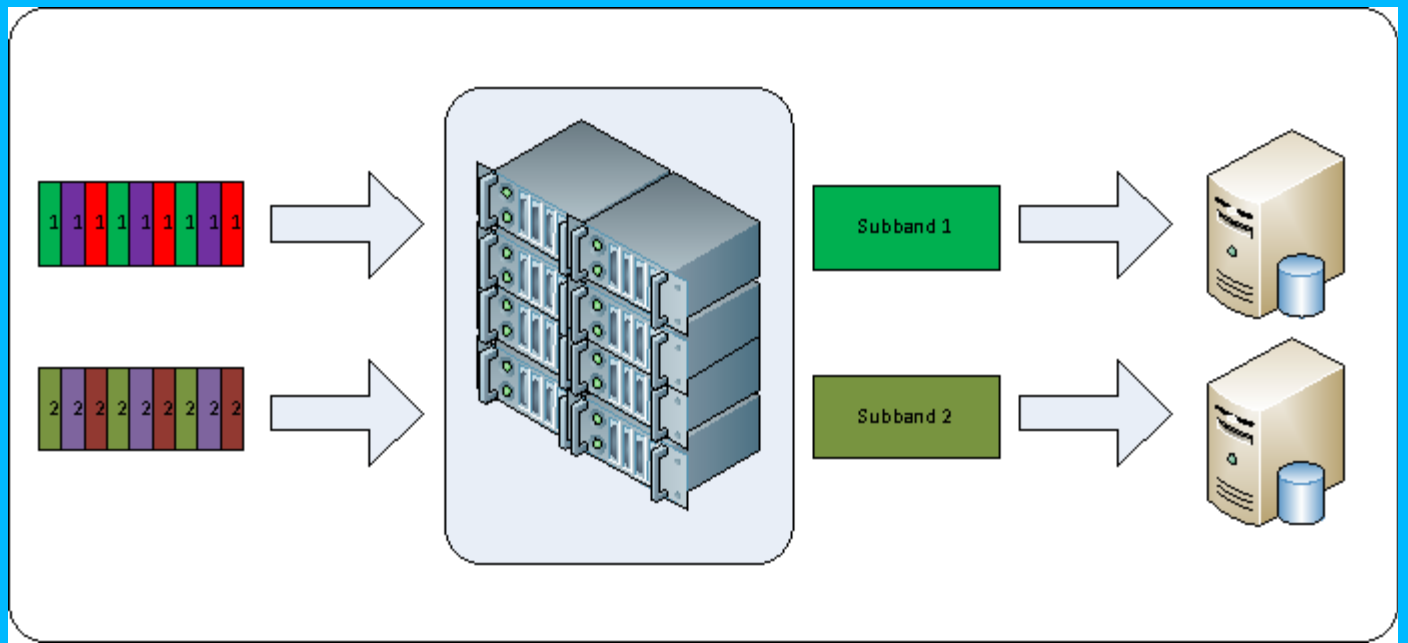


- Includes:
  - Obs specification, subband details
  - Participated hardware (broken antenna info)
  - Sample weights

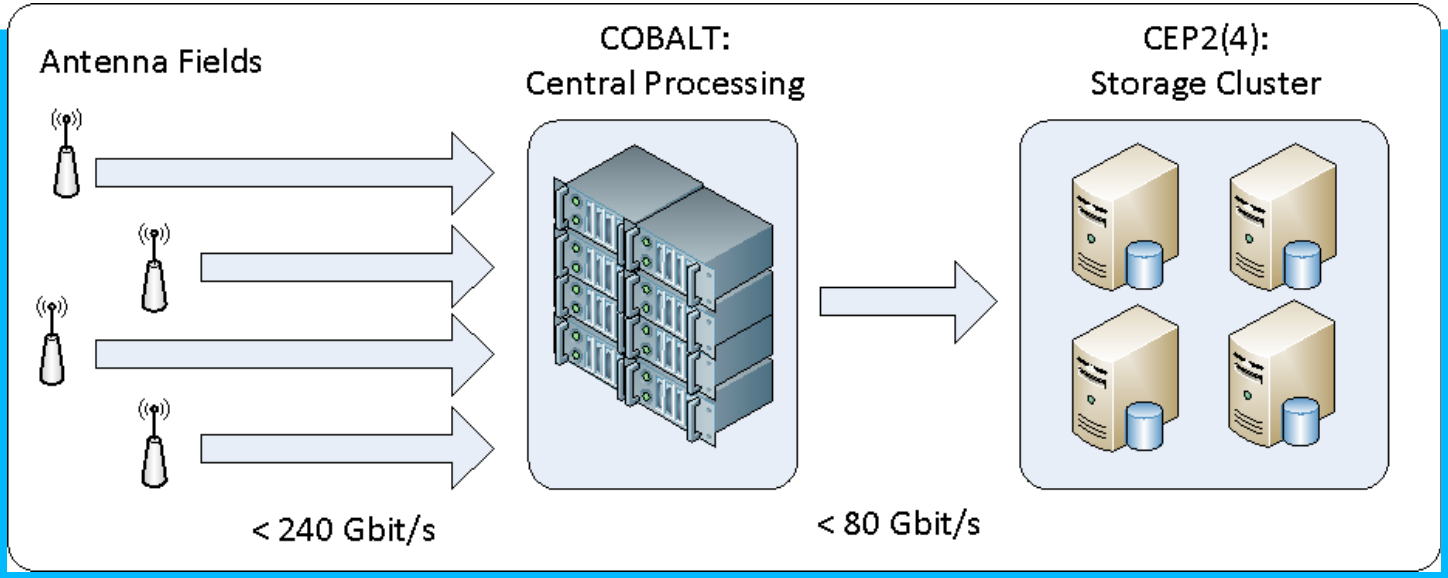
Correlator – Writing to Disk



- 1 file = 1 subband
- 488 subbands max, but only ~100 storage nodes
- Distribution round-robin (scattered):
  - Node 0 holds SB000, SB099, SB199, etc.
  - Node down = scattered loss.

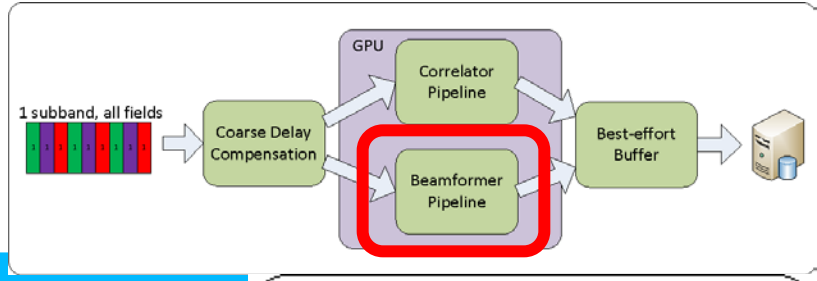


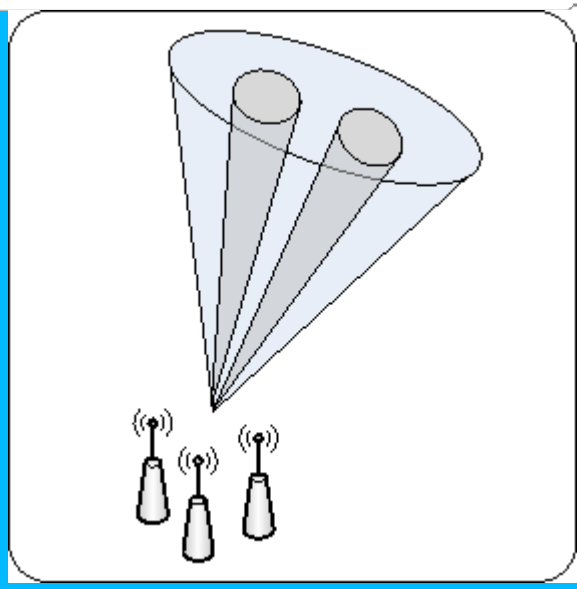
Correlator - Data loss



Loss type	Unit of loss	Effect in MS
Field data stream		
- Incidental loss	1 field x 16 sampl x 122 sb	Weight <1
- Field down	1 field	Weight 0, Visibilities 0+0i
Storage node		
- Jitter	1 integration x 1 subband	Weight 0, Visibilities 0+0i
- Node down	1-5 subbands	Loss of 1-5 subbands

Beamformer Pipeline - Goal





- *Beamforming* is increasing sensitivity by accumulating signal.
- Coherent Tied-Array Beams (TABs):

$$CohTAB(t) = Stokes\left(\sum_{f \in fields} w(f,t) \cdot f(t)\right)$$

  - Weight = refocus within antenna field FoV
- Incoherent Tied-Array Beam (TAB):

$$IncohTAB(t) = \sum_{f \in fields} Stokes(f(t))$$

  - FoV = antenna field FoV

BF - Stokes

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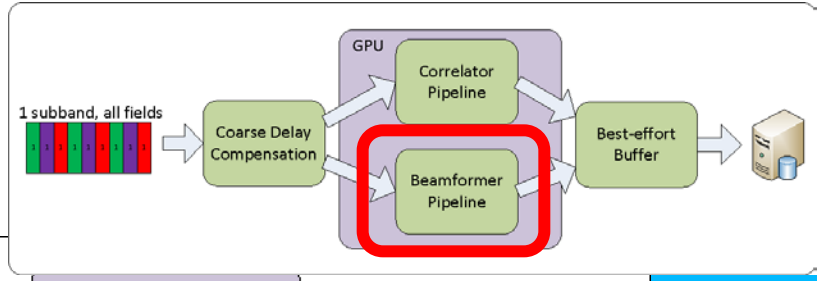
- Stokes parameters:

$$I = |X|^2 + |Y|^2 \quad \leftarrow \text{amplitude}$$
$$Q = |X|^2 - |Y|^2$$
$$U = 2Re(XY^*)$$
$$V = 2Im(XY^*) \quad \} \text{ phase aspects}$$

- COBALT can output:
  - Stokes I
  - Stokes I, Q, U, V
  - Complex Voltages (X, Y)
- Further parameters:
  - Temporal integration

Beamformer Pipeline (BF)



64-pt FFT

Fine Delay Compensation

Subband Bandpass Correction

Coherent Beamformer

64-pt iFFT

PPF

Stokes + Integration

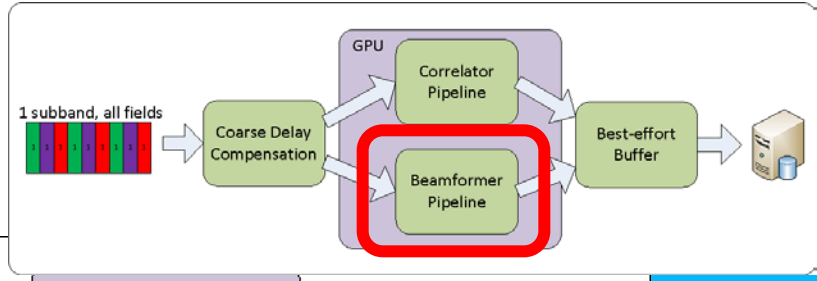
Incoherent Beamformer

64-pt iFFT

PPF

Stokes + Integration

BF - Work at 3 kHz resolution



64-pt FFT

Fine Delay Compensation

Subband Bandpass Correction

Coherent Beamformer

64-pt iFFT

64-pt iFFT

PPF

PPF

Stokes + Integration

Stokes + Integration

Incoherent Beamformer

BF - Subband Bandpass Correction

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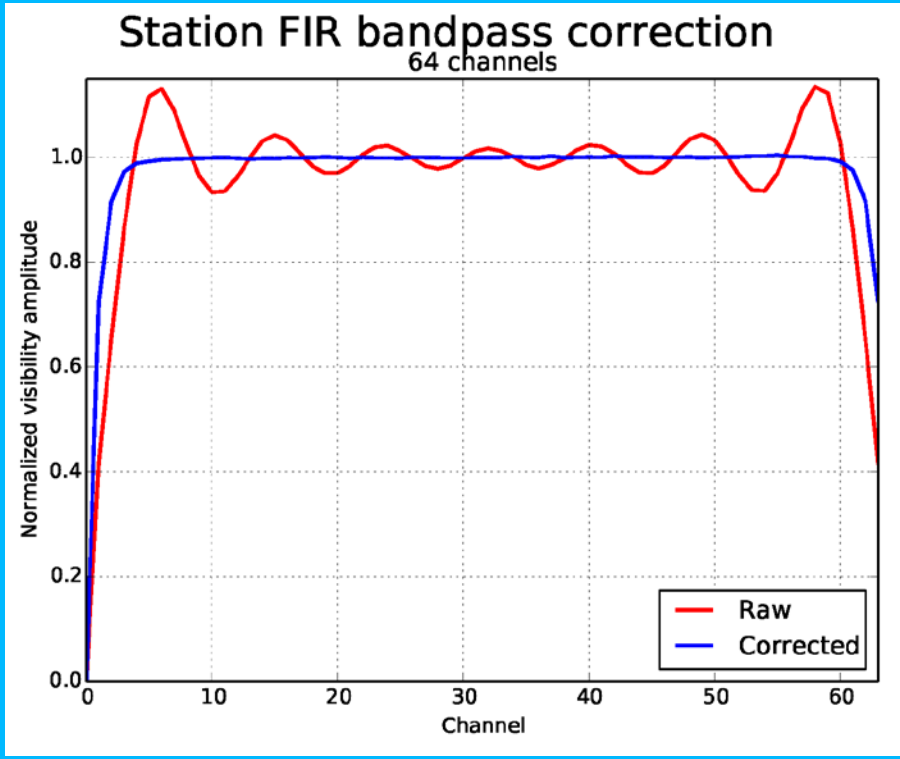
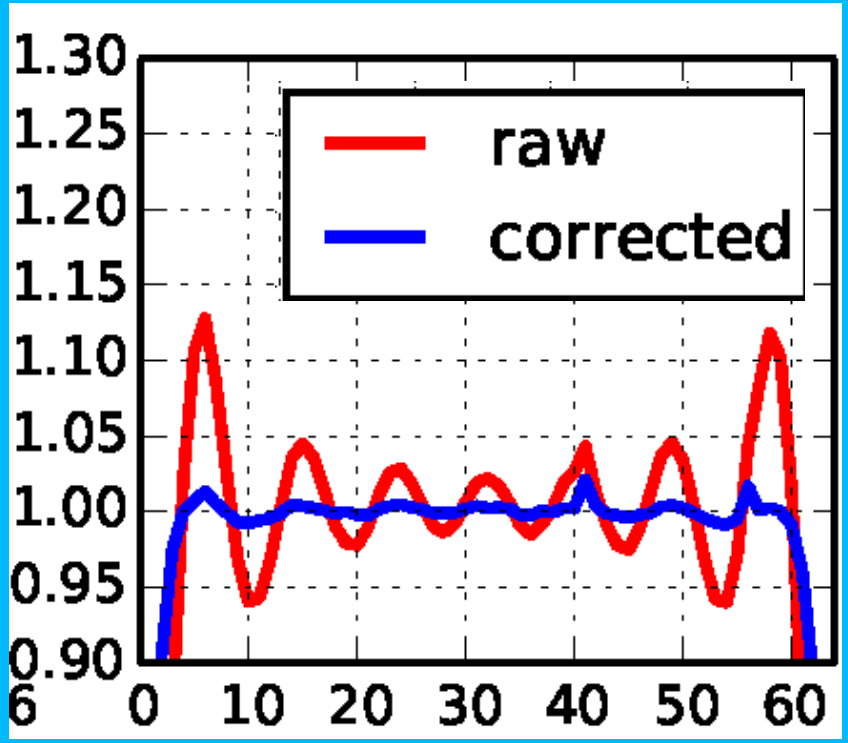
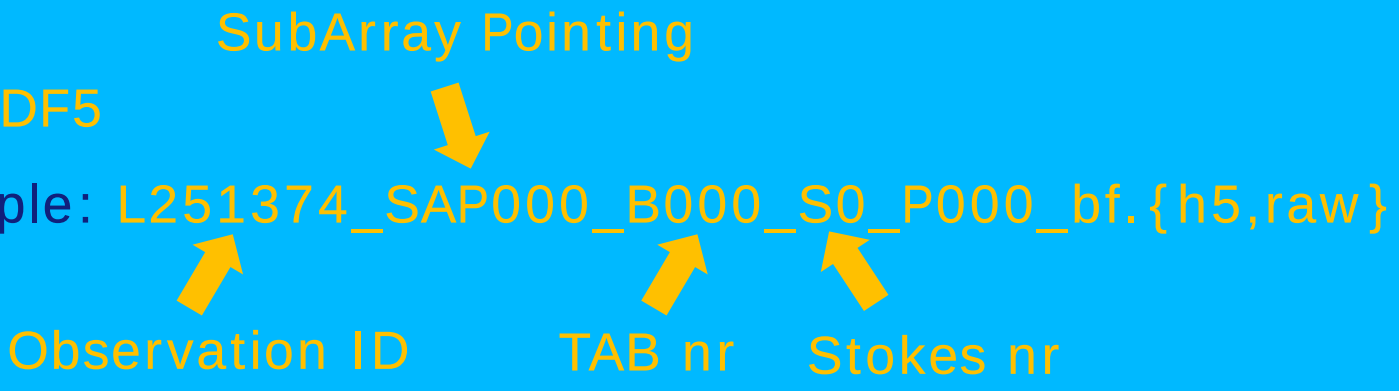
64-pt PPF (Correlator)



64-pt FFT (Beamformer)



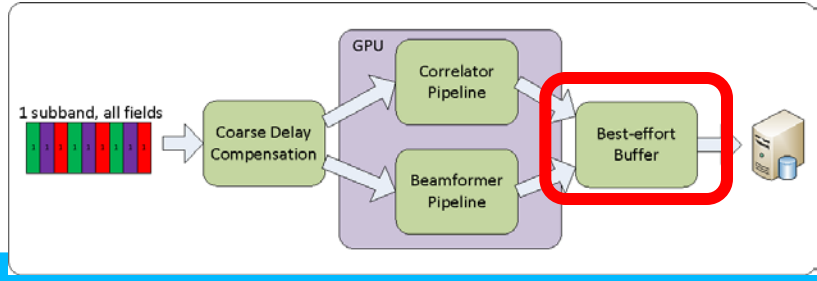
BF – Storage Format



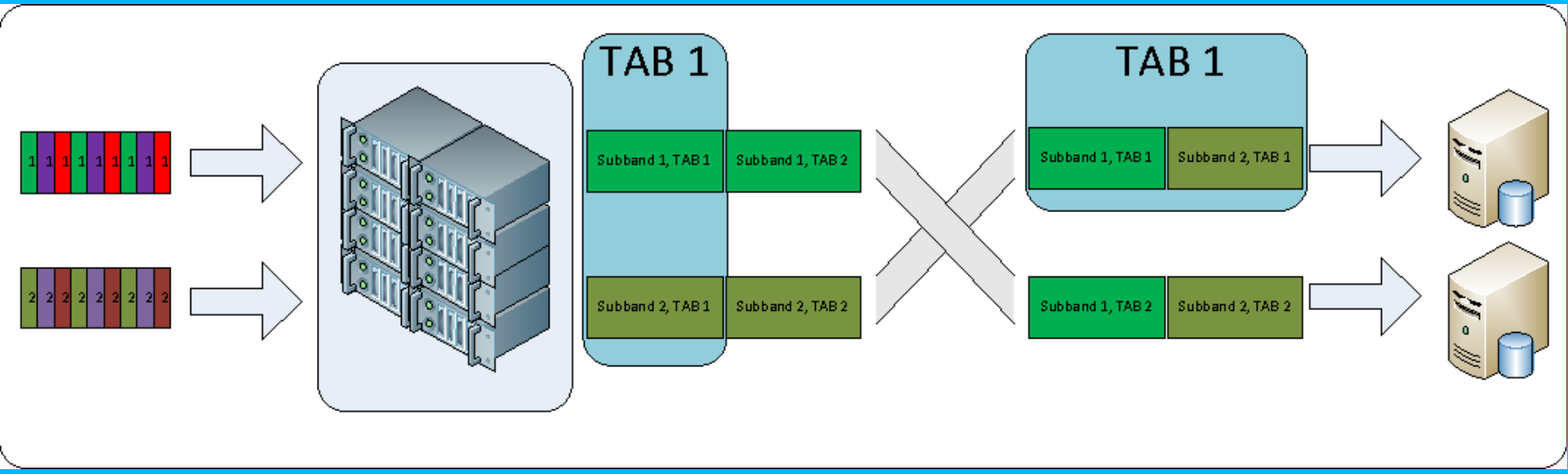
- Format: HDF5
  - Example: L251374_SAP000_B000_S0_P000_bf.{h5,raw}
- Includes:
  - Obs specification, TAB details

http://www.hdfgroup.org

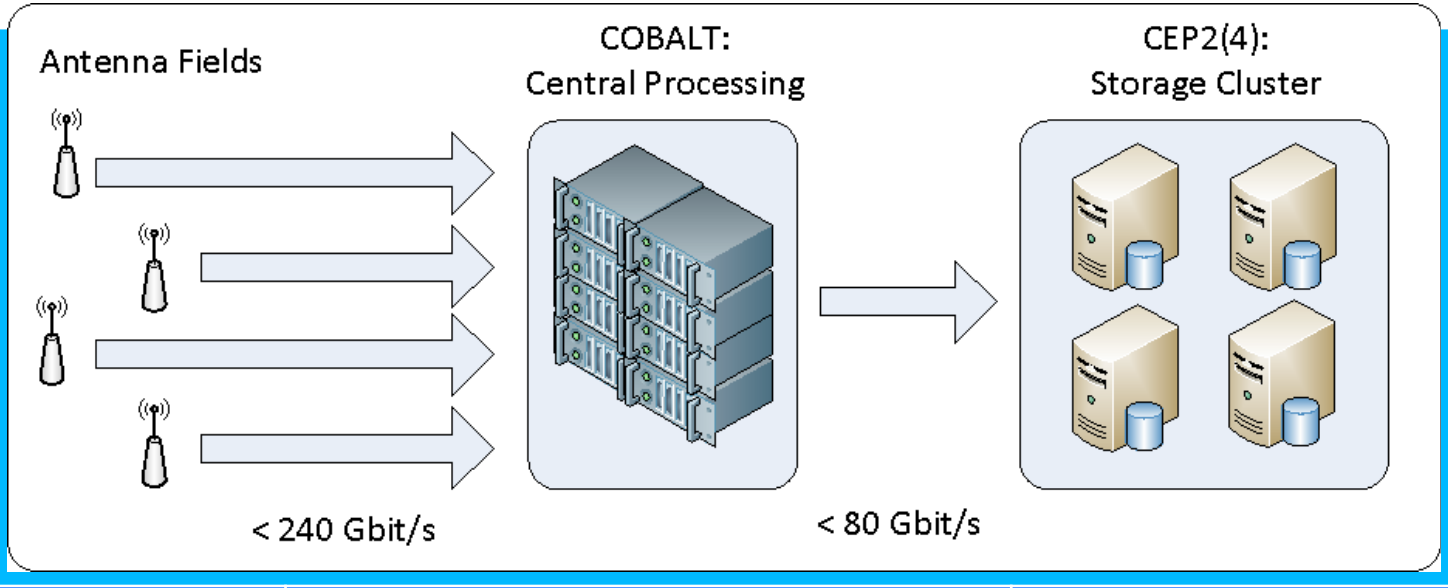
BF – Writing to Disk



- 1 file = 1 TAB (Stokes), all subbands
- Outgoing data is *transposed*
  - From: per subband (all TABs)
  - To: per TAB (all subbands)



BF - Data loss



Loss type	Unit of loss	Effect in TAB
Field data stream		
- Incidental loss	1 field x 16 sampl x 122 sb	Lower amplitude
- Field down	1 field	Lower amplitude
Storage node		
- Jitter	1 s x 1 subband	Amplitude = 0
- Node down	1-3 Stokes	Loss of 1-3 Stokes

Questions?