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ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

SWINBURNE UNIVERSITY OF TECHNOLOGY

Pulsar Timing Instrumentation with SKA1

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Swinburne / CAASTRO

www.caastro.org

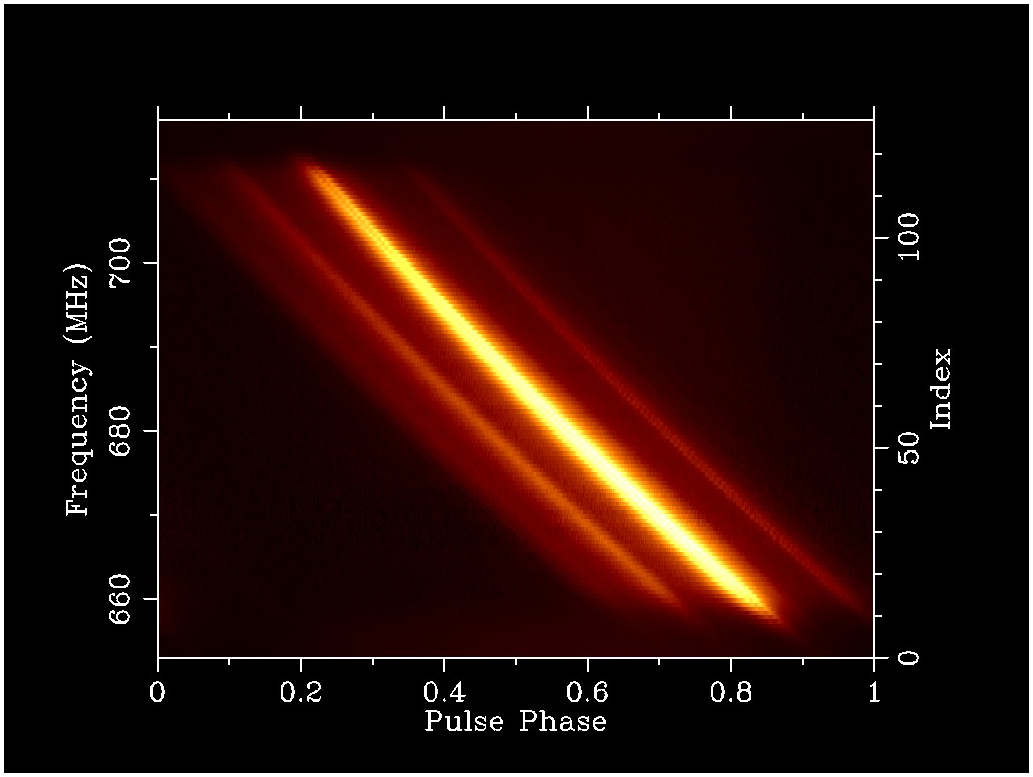
Australian Government

Australian Research Council

Swinburne; CSIRO / Swinburne; NASA / ESA

ISM Dispersion

- Due to free electrons in ISM
- Frequency dependent delay
- Highest frequencies arrive first
- Smears pulsed signal



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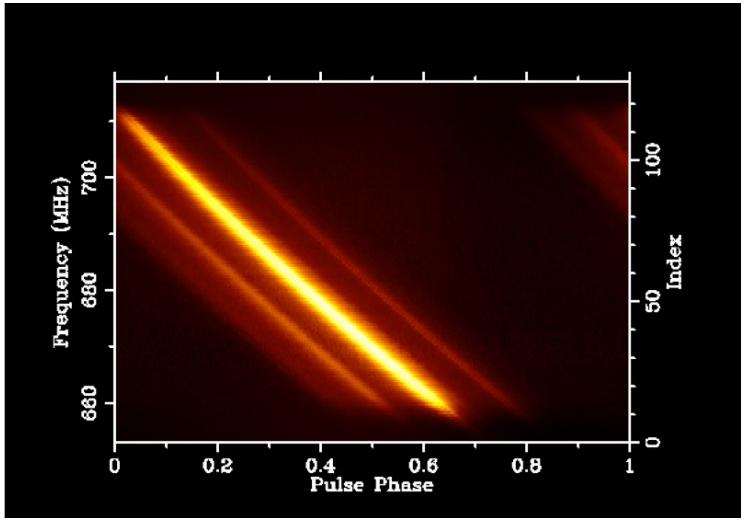
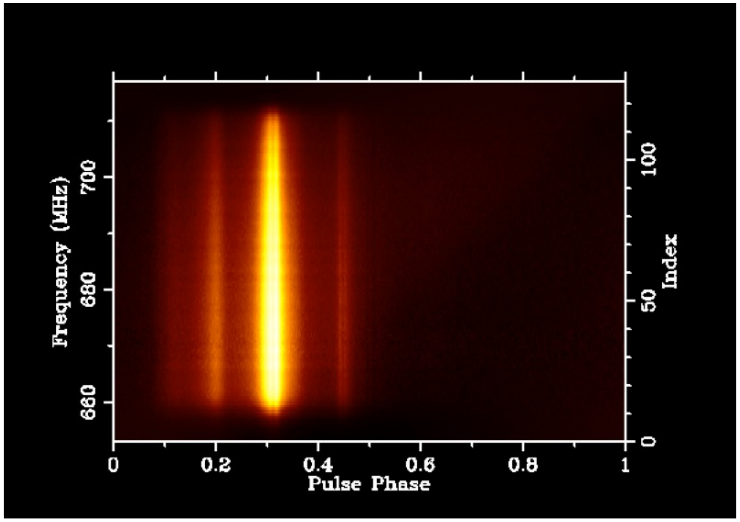
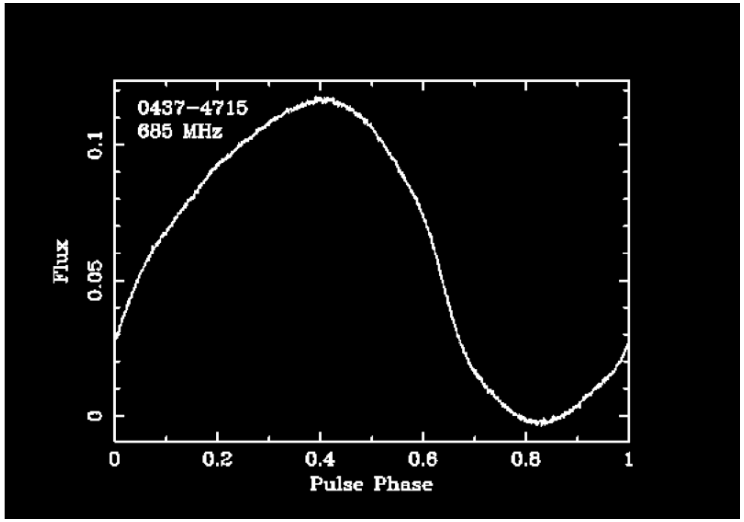
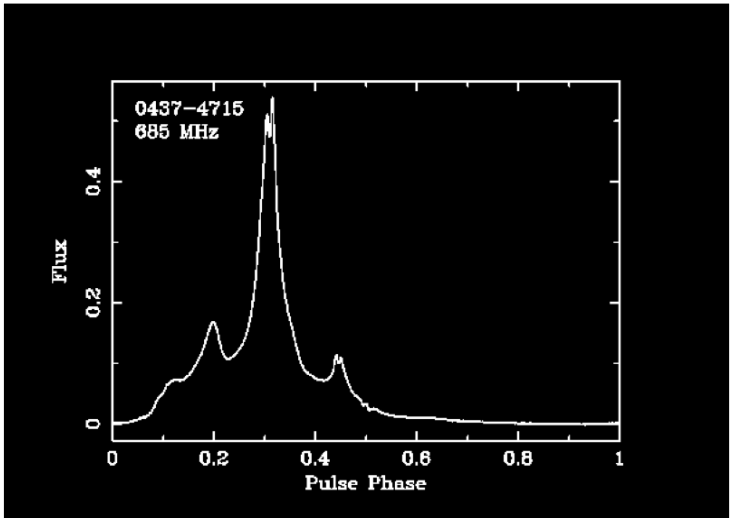
Dispersion Removal



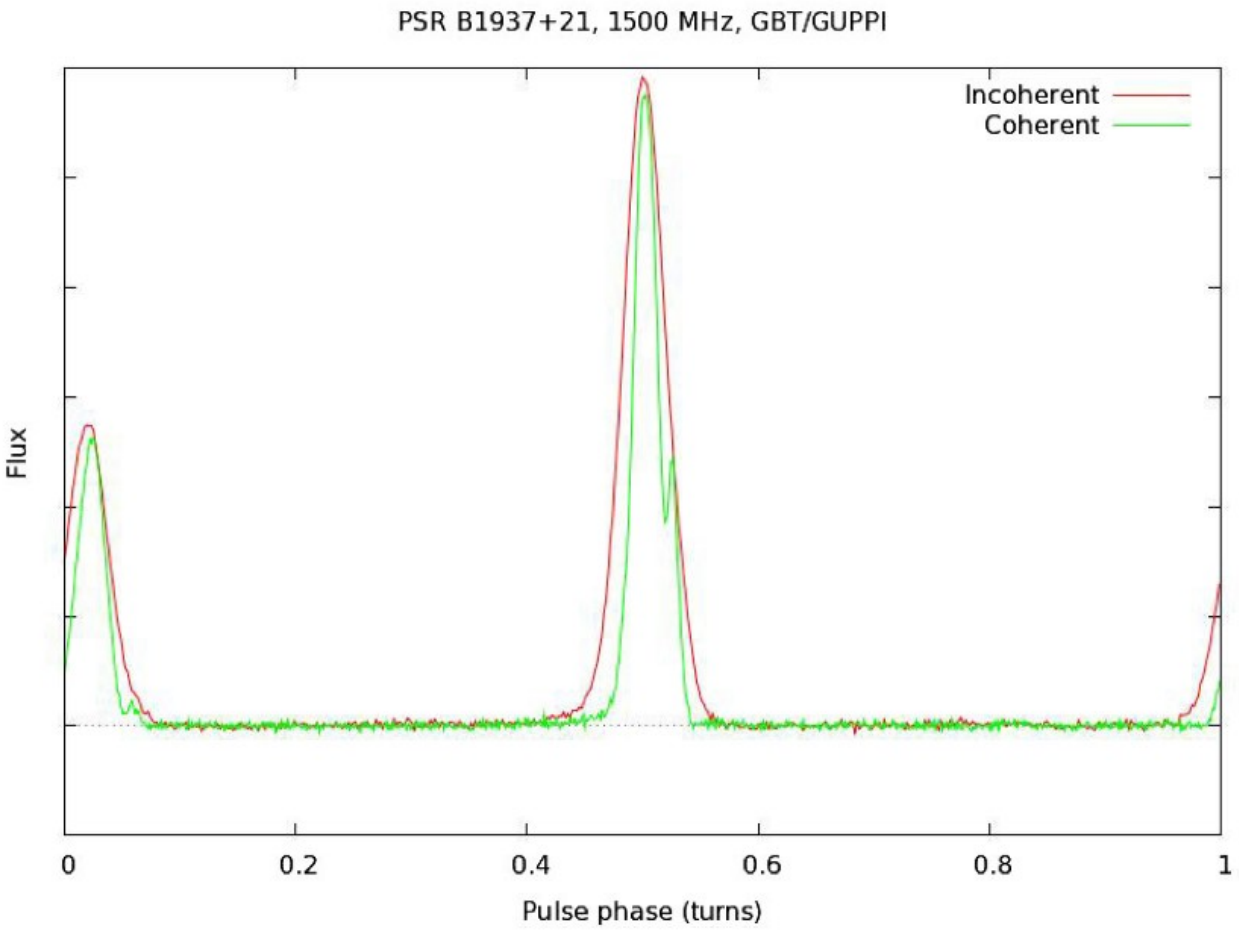






Incoherent v Coherent

- Incoherent
  - Faster
  - Residual smearing within channels
- Coherent
  - Removes all dispersive effects
  - Sharper profile features
  - Important for millisecond pulsars
  - Slower



Credit: Paul Demorest

Coherent Dedispersion

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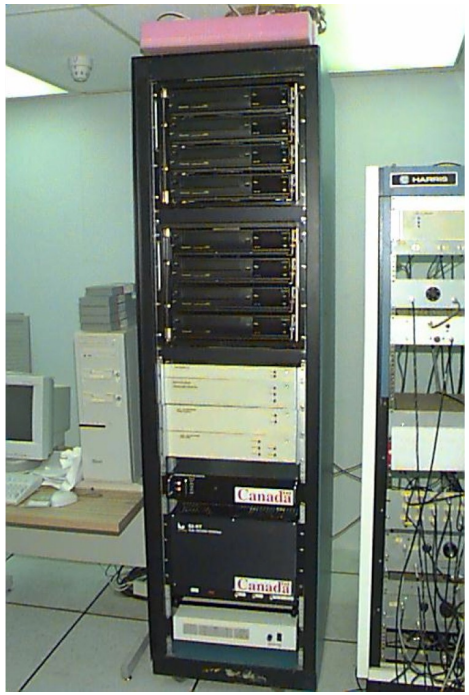
Year	Instrument	Bandwidth
1971	Sigma XDS 5	0.125
1987	Reticon	1.5
1998	S2 Recorder	16
1999	CPSR	20
2002	CPSR2	128
2007	APSR	1024
2010	CASPSR	400
2016	UWB	3500
2018	SKA1	16 x 2500



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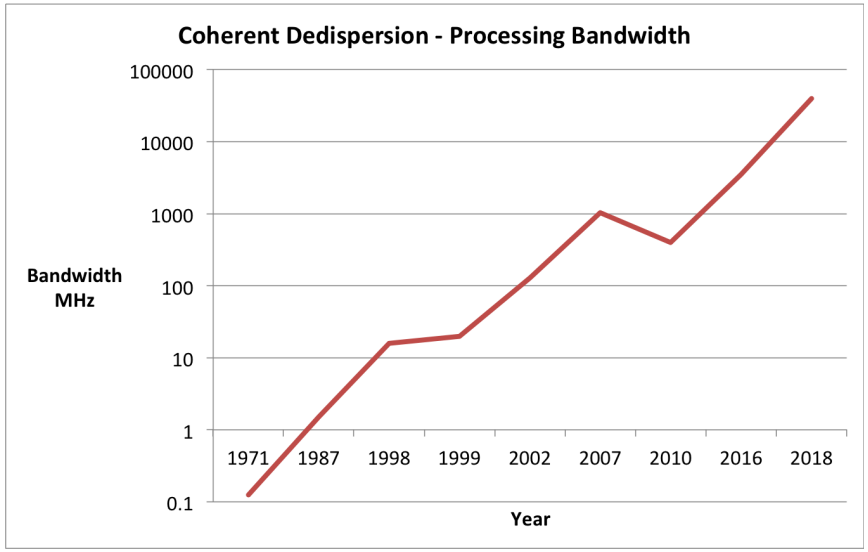
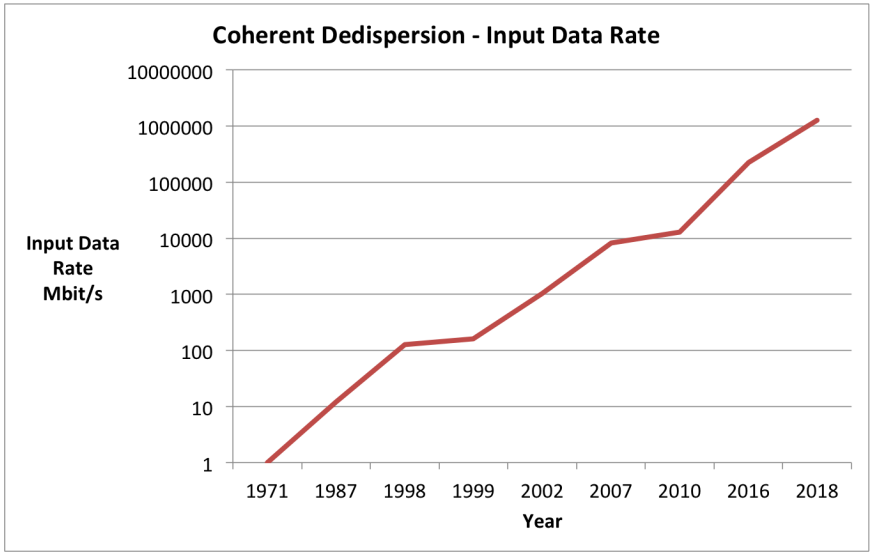
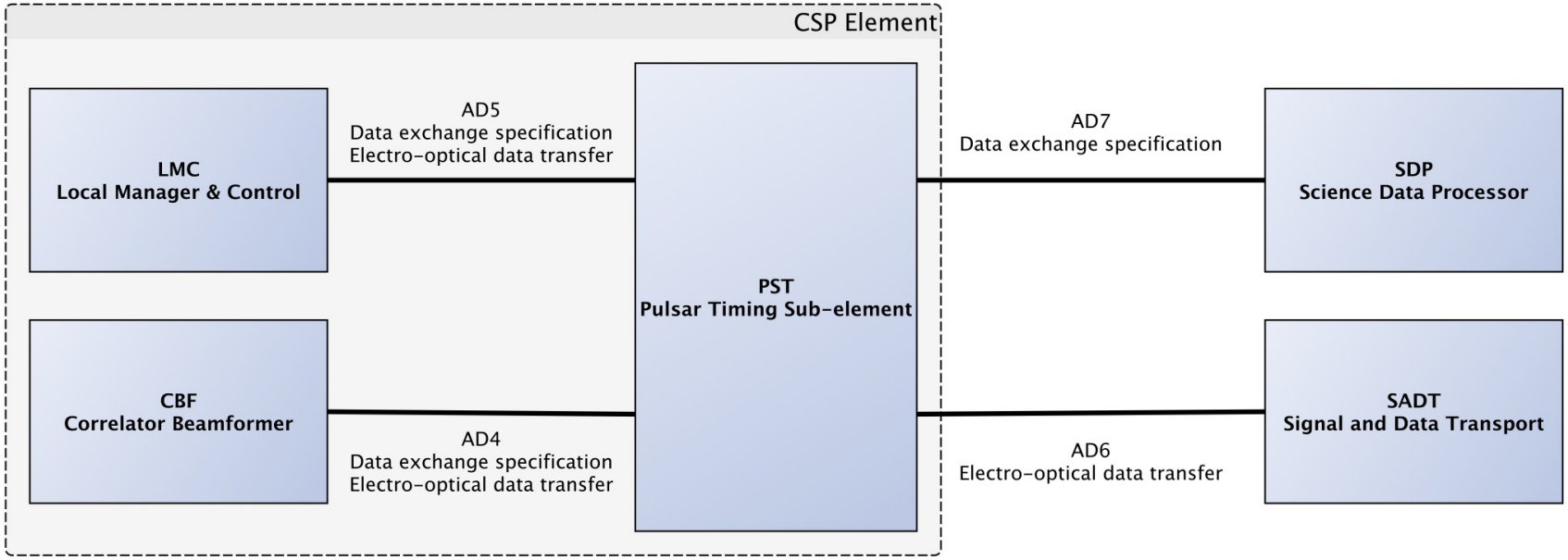




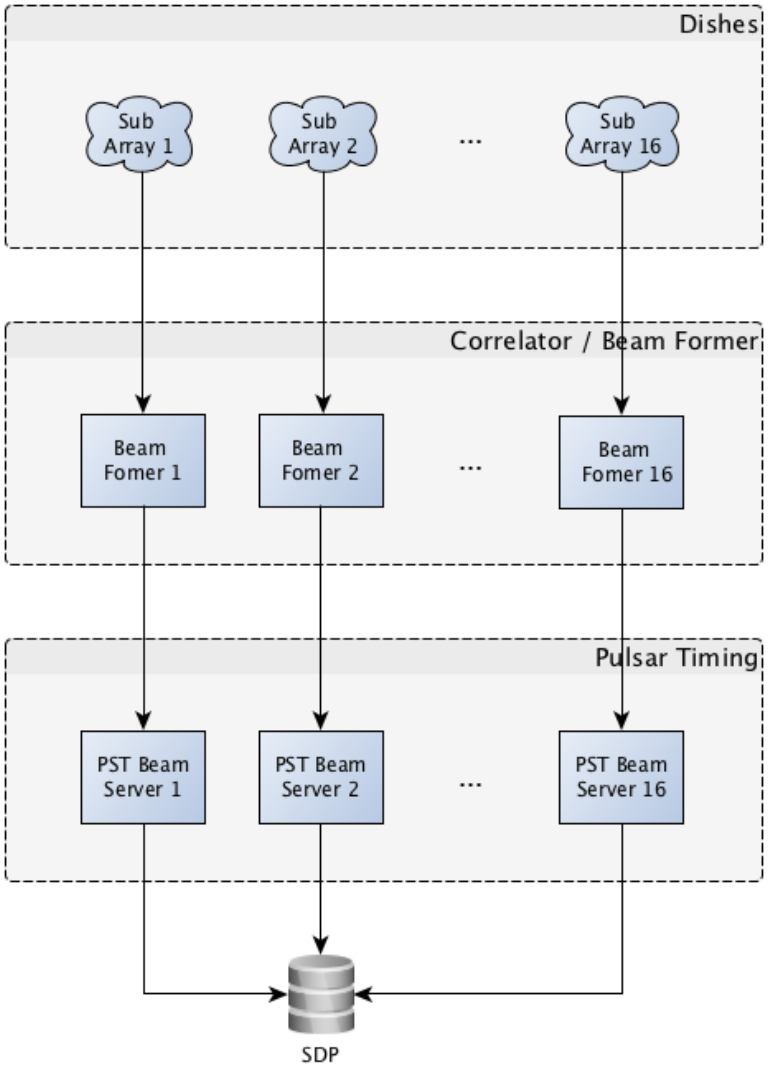
Pulsar Timing Sub-Element

- Sub-element of CSP in SKA Mid
- Receives input data streams from the Beam Former (CBF)
- Transmits folded pulsar integrations to Science Data Processor (SDP)
- Managed by Local Monitoring and Control (LMC)



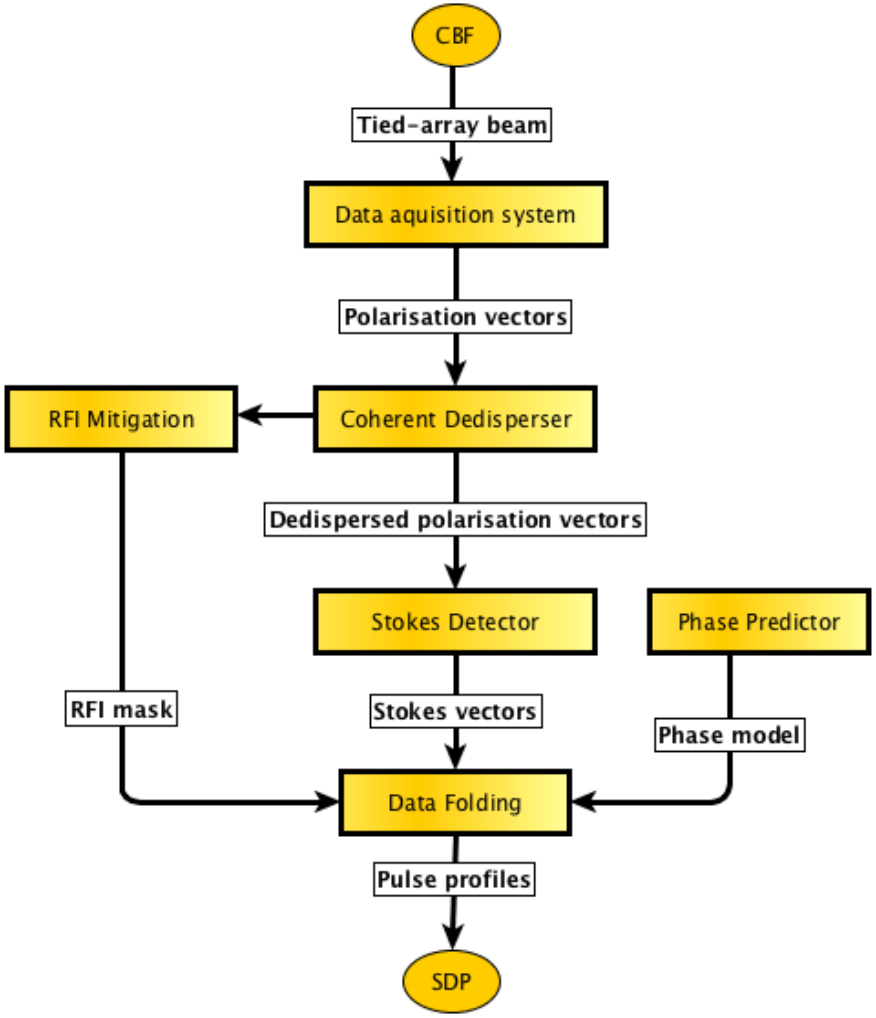
16 PST Beams

- 16 pulsars at a time
- Up to 16 sub-arrays
- 16 Beam formers
- 1 stream per PST Beam Server



Beam Server DSP

- Each PST beam server:
  - Receive tied-array beam from CBF
  - Coherent dedispersion
  - Form Stokes vectors
  - Optional RFI Mitigation
  - Fold into pulsar profile
  - Transmit to SDP ~ 1 Gb/s



Observing Parameters

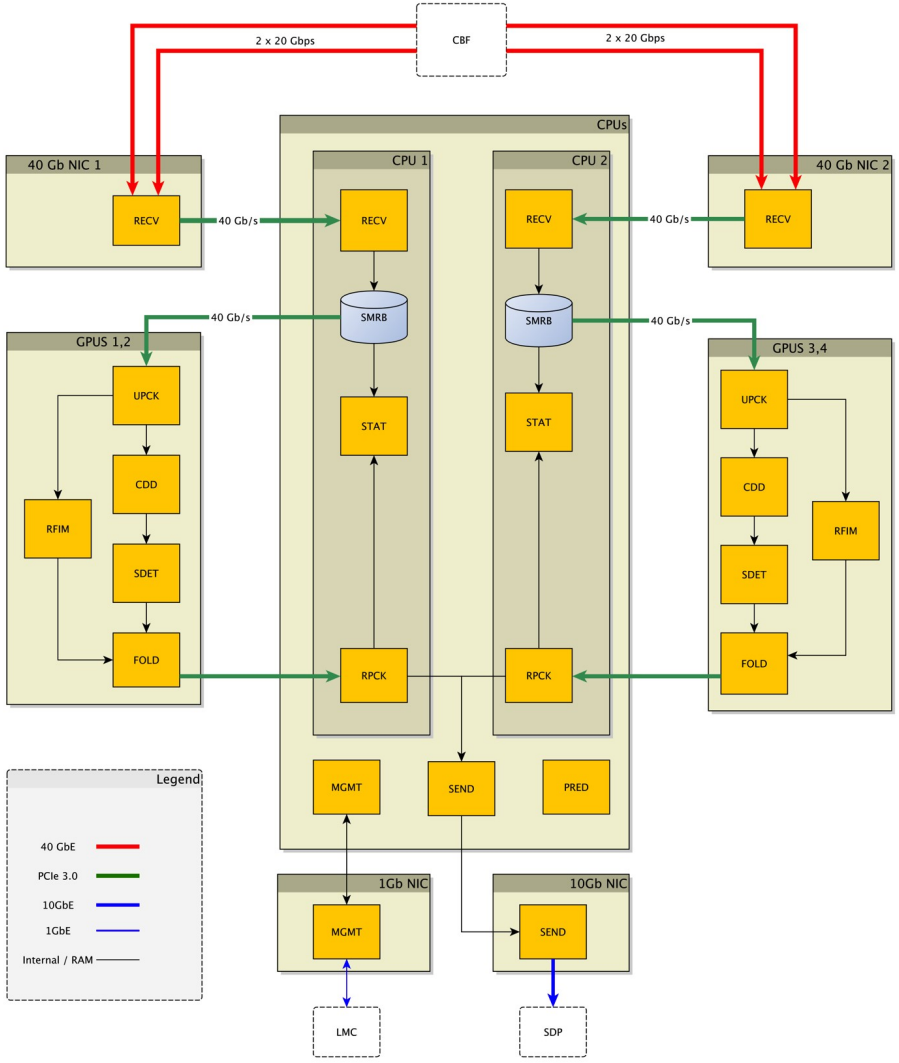
- SKA PST Bands
  - 1: 350 – 1050 MHz
  - 2: 950 – 1760 MHz
  - 5: 4600 – 13800 MHz
- Dispersion Measure (DM) up to 3000
- Resolution
  - Integration: 1s – Tobs
  - Frequency: 0.3125 – 10 MHz
  - Time: Min 0.24 μs
- Full Stokes output

Design Constraints

- Physical
  - Physical: 3 Racks
  - Power: 40 kW / rack
  - Heat: 7.5 kW / rack
- Input from beam former
  - 16 x 80 Gb/s
  - 10 MHz channels (oversampled)
- Output: PSRFITs integrations
- Technical
  - Designed for 2016 technology
  - Rigorous systems engineering process
  - Costed to 5% error

Implementation

- PST Beam Server:
  - 2 x Dual Port 40 Gb NICs
  - 2 x 8 core CPUs
  - 128 GB RAM
  - 4 x Nvidia Pascal GPUS
- Prototyping on Maxwell GPUs
- Field Testing at MeerKAT & Parkes

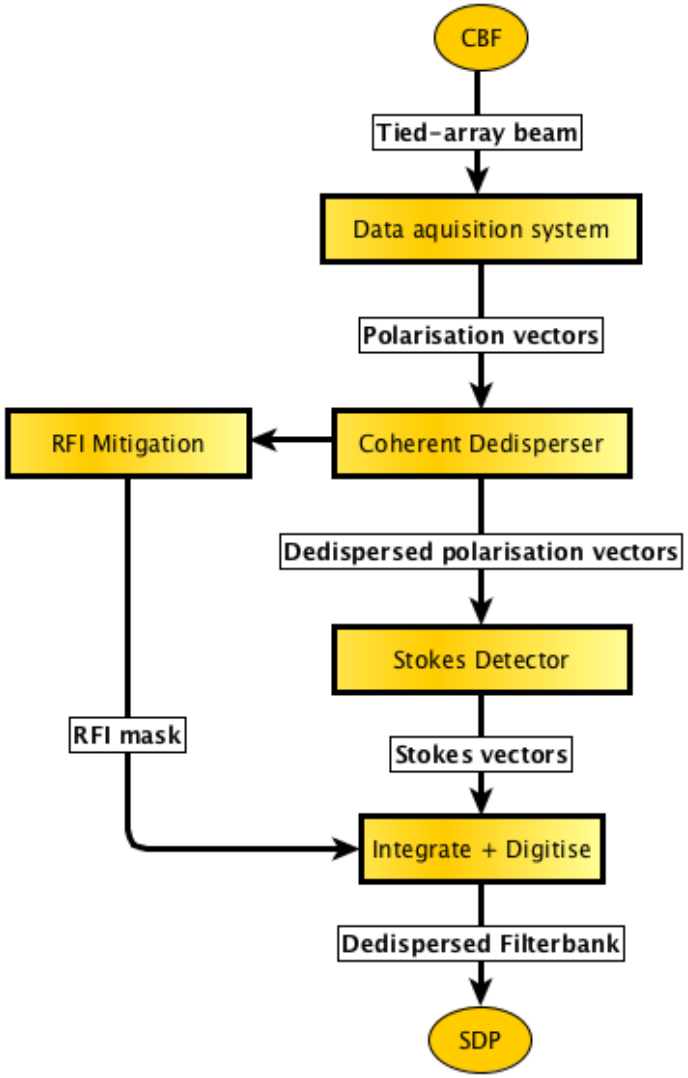


Performance Profile

- I/O: OK (NIC + PCIe)
- Memory: OK (CPU + GPU)
- Compute
  - Filterbank (FFT)
  - Freq dependent
- Limit – memory bandwidth
- NVidia Pascal Features
  - Stacked GPU RAM
  - 16-bit Floating Point
- Compute OK as well!

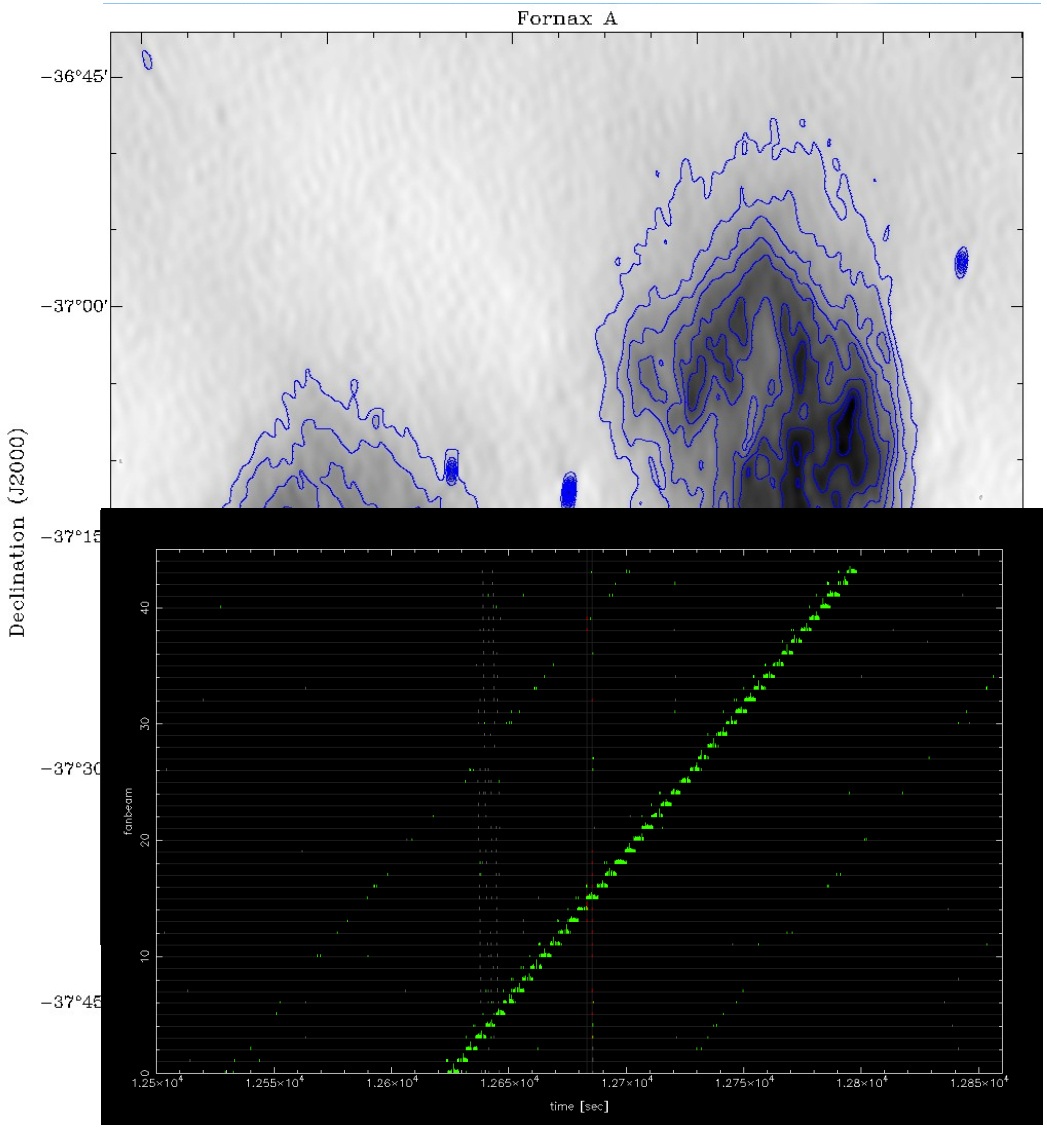
Design Features

- Low risk – proven H/W & S/W
- Commercial Of The Shelf H/W
  - Economies of scale: HPC + GPUS
  - Easier upgrade path
- Good cost estimate
- Modular Software Architecture
  - Containers and Transformations
  - Updates to algorithms
  - Accommodate unplanned capabilities
- Extensibility
  - Search mode
- Ready for SKA2



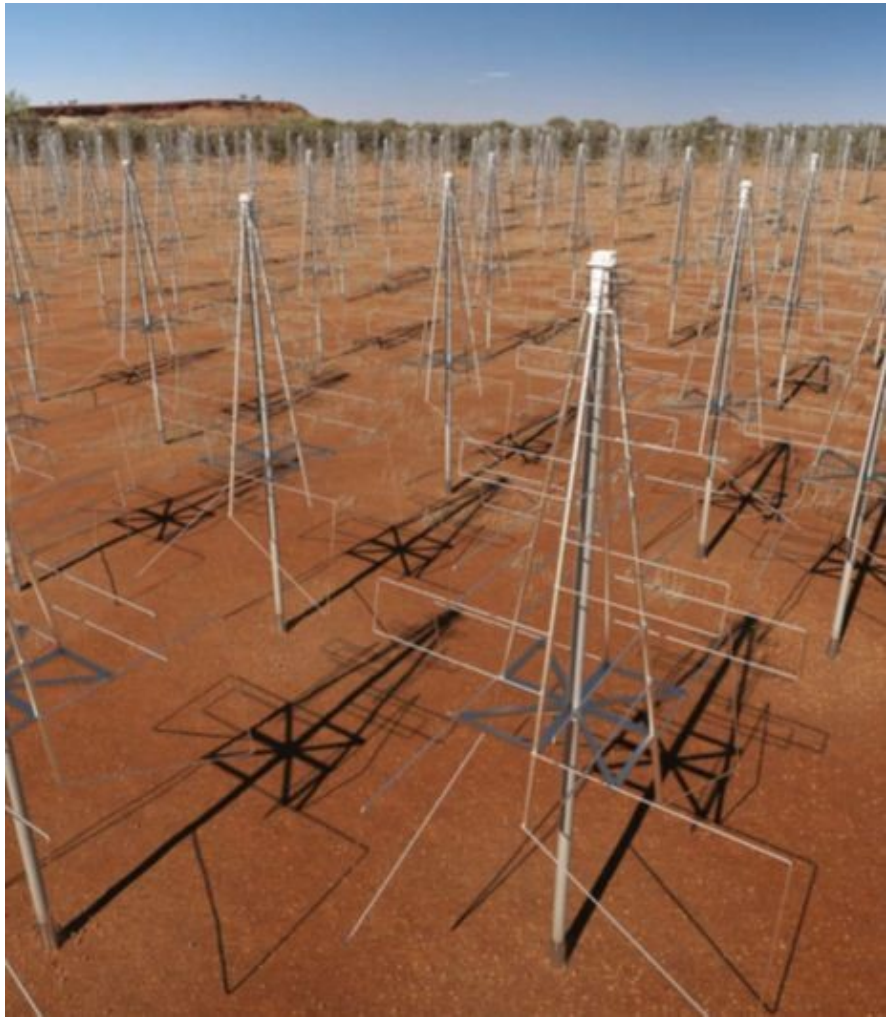
Case Study: Molonglo

- 352 Input, east/west parabolic interferometer
- New instrument: UTMOST
- FPGA frontend
- Observing Modes
  - Individual Antenna
  - Correlator
  - Beam Former
  - Beam Tiler
- Backend: HPC, GPU, 10GbE & Infiniband



Adaptability to SKA1 Low

- Scientific Motivations
  - DM Monitoring
  - Scintilation Studies
- Assume
  - Band: 50 – 350 MHz
  - Beam Former: 2048 channels
  - 6.83 μs time resolution
  - Max DM 3000
  - Identical PST hardware
- Just need the beam former



Artists Impression: Swinburne Astronomy Productions

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Summary

- PST implementation for SKA1 a safe bet
- Built on proven software & hardware architectures
- Extensible design
- Prototyped on MeerKAT and Parkes
- Deployable for SKA Low
- Transparent upgradability to SKA2