

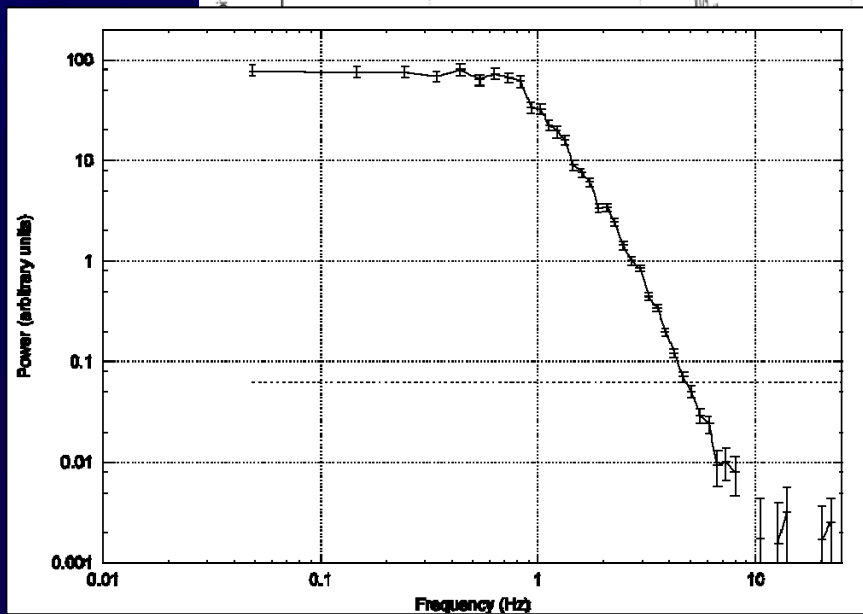
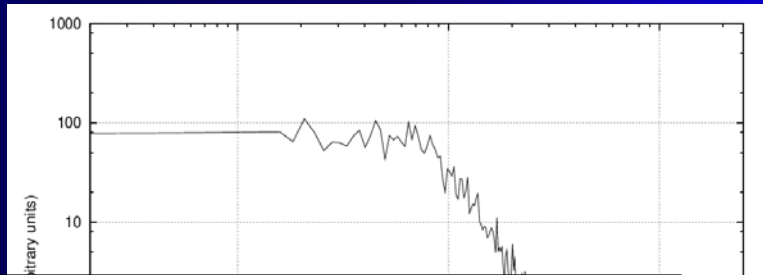
Beamforming for IPS and Pulsar Observations

Divya Oberoi
MIT Haystack Observatory

Function, Inputs and Outputs

- Function - combine the voltage signal from each of the 512 tiles to form up to 16 independent tied array beams for each polarisation
- Inputs
 - Time series of Nyquist sampled voltage spectra for each polarisation from each of the 512 tiles
 - Instrumental gain solutions
 - Ionospheric phase solutions
- Outputs
 - 16 time series of power detected data for each polarisation for IPS observations (IPS beams) OR
 - 16 time series of voltage data for each polarisation for Pulsar observations (Pulsar beams) OR
 - maybe a mix of IPS and pulsar beams

Single station IPS – measurable and model parameters



- The power spectrum of intensity fluctuations
- Model parameters
 - Velocity – V_{\perp}
 - Strength of scattering – C_n^2 ($\propto \delta n_e^2$)
 - Spectral index of n_e fluctuations - α
 - Inner scale - q_i
 - Axial ratio – **AR**
 - Source size - θ_0
 - Freq. of observation - ν

Science specifications

- IPS

- Required

- 16 dual polarisation beams
 - Time resolution – 10 ms
 - Frequency resolution – 500 kHz

**0.2 M samples/sec
(16 dual pol beams)**

- Desired

- Non contiguous spectral coverage
 - Frequency resolution – 100 kHz

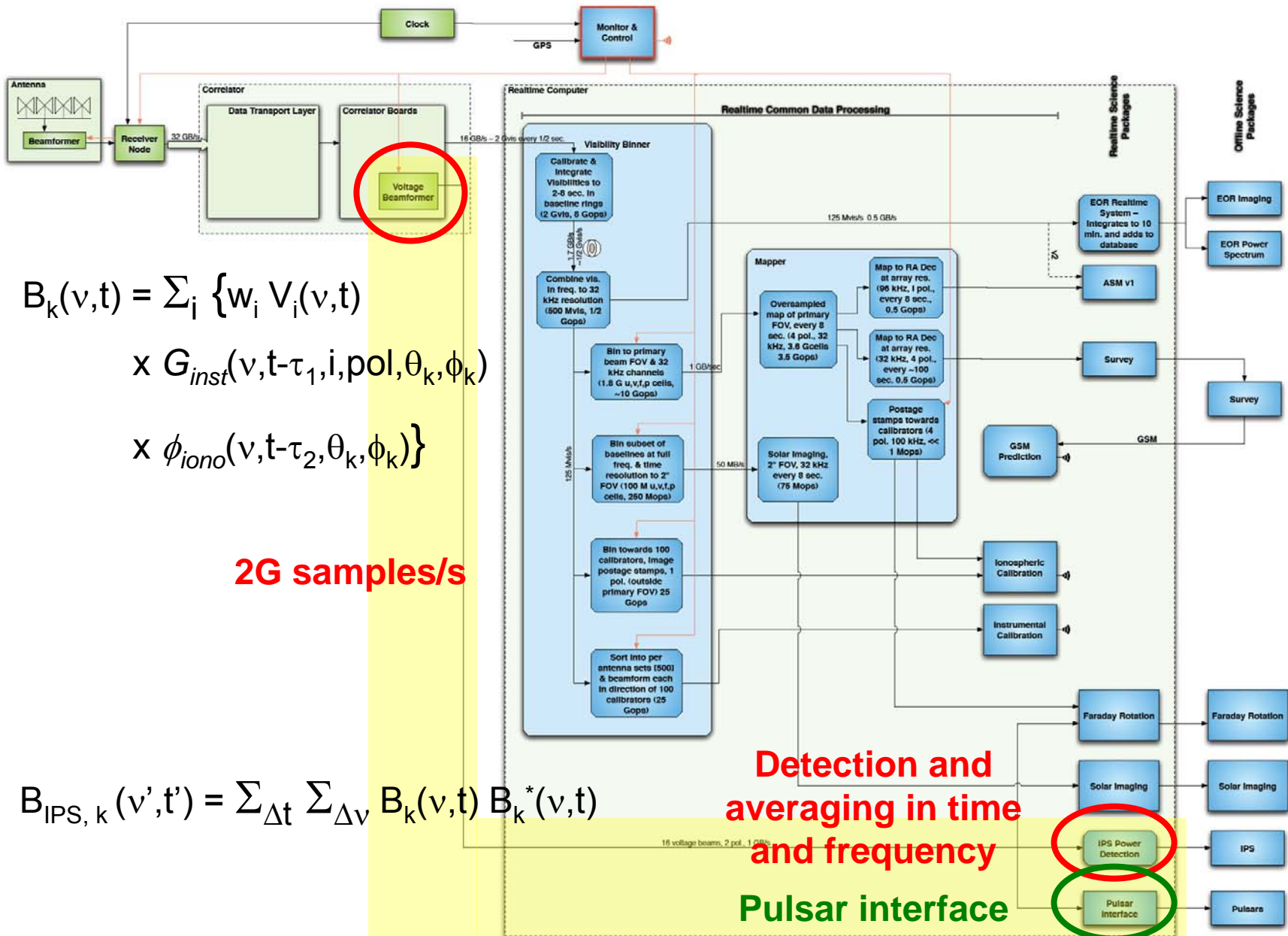
- Pulsars

128 M samples/sec/beam

- Desired

- At least 1 tied array voltage beam for each polarisation
 - Few chunks, each few MHz wide distributed over 80-300 MHz

MWA-LFD Dataflow Diagram



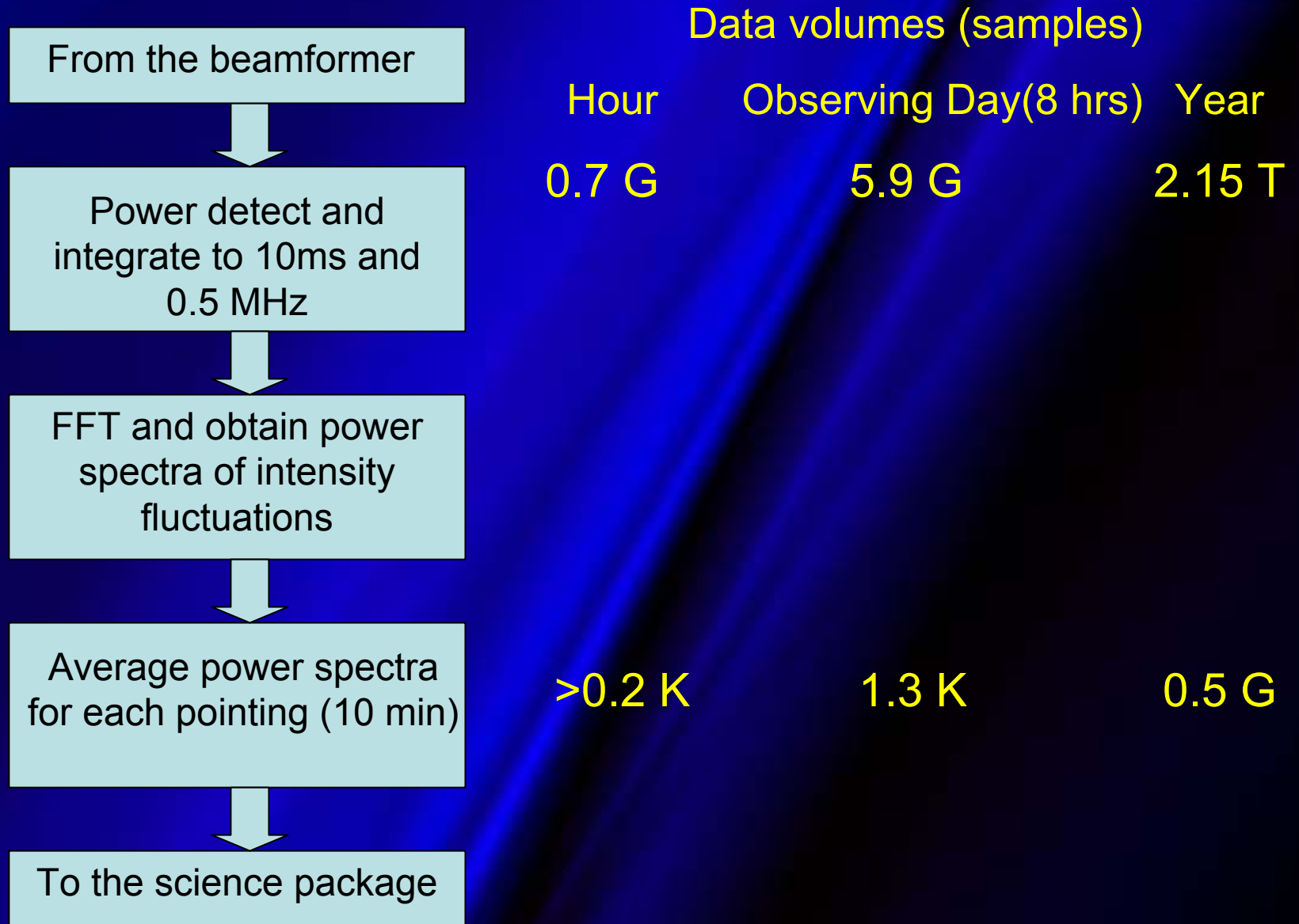
$$B_k(v,t) = \sum_i \{w_i V_i(v,t) \times G_{inst}(v,t-\tau_1,i,pol,\theta_k,\phi_k) \times \phi_{iono}(v,t-\tau_2,\theta_k,\phi_k)\}$$

2G samples/s

$$B_{IPS,k}(v',t') = \sum_{\Delta t} \sum_{\Delta v} B_k(v,t) B_k^*(v,t)$$

Detection and averaging in time and frequency
Pulsar interface

IPS system



Design status

- Beamformer
 - Intimately tied to correlator architecture
 - Level of maturity – low
- IPS system
 - Level of maturity – conceptual
 - Complexity – low
- Pulsar system
 - Level of maturity – low
 - Complexity - low

Key features

- Multi-beaming capability
 - 16 dual polarisation beams which can be pointed independently anywhere above the horizon
- Originally motivated by IPS - useful for (non imaging) high time/frequency resolution observations
- Pulsars
 - ‘Bring-your-own-pulsar-machine’
 - Observation specific analysis (e.g. known pulsars, targeted/blind survey, etc.)
 - Tangible collaborator contribution

Challenges / Risks / Issues

- Technical (Beamformer)
 - Problem of distributing the beamformer within the correlator such that it has access to all the signals it needs without adversely effecting the correlator architecture
 - Getting the instrumental and ionospheric calibration information at the right place at the right time
 - Ionospheric calibration – stale by 16 sec / predicted via a model
- Cost
 - Data transport into the real time computer (2G sample/s)

Skills needed

- Beamforming (Correlator work-package)
 - Hardware - FPGA based digital engineering
 - Bitcode – FPGA programming
- IPS work-package
 - Realtime software experience
 - Knowledge of radio astronomy techniques (IPS)
- Pulsar work-package
 - Realtime software experience

Dependencies on other sub-systems

- Forms a part of the *correlator* sub-system
- Depends on *visibility binner* and *mapper* for instrumental and ionospheric calibration solutions
- Interacts with M&C
- Feeds the IPS science package & the Pulsar Machine

Interface definitions

- Being a part of the correlator system, does not require any independent input interface
- IPS – TBD - output might be a time series of spectra which will be archived in a database along with suitable metadata
 - A software interface to allow the science software to query and access this database
- Pulsars – TBD - a somewhat flexible interface to pipe the data to a custom Pulsar machine

IPS Source density

- Cambridge IPS survey (81.5 MHz)
 - Purvis et al., 1987, MNRAS, 229, 589-619
 - 1789 sources (Dec range -10° to 83° , 58% of sky)
 - Sensitivity – 5 Jy total flux, ~ 0.3 Jy scintillating flux at 90° elongation
 - Source size $0.2''$ – $2''$
- Puschino IPS survey (102 MHz)
 - Artyukh and Tyul'bashev, 1996, Astronomy Reports, 42, 601
 - 414 sources in 0.144 sr (1 source/1.14 deg²)
 - Sensitivity – 0.1 Jy
 - 50% of sources $< 3''$
- Ooty Radio Telescope (327 MHz)
 - Manoharan, 2006, Solar Physics, 235, 345-368
 - Observe ~ 700 sources per day
 - Sensitivity – 0.04 Jy (1 sec, 4 MHz)

IPS Survey parameters

- Cambridge Survey (81.5 MHz)
 - 4096 full-wave dipoles
 - Beam – 26.8' x 165' Sec(z)
 - Bandwidth – 10.7 MHz
- Puschino Survey (102 MHz)
 - Physical collecting area – 70,000 m²
 - Beam – 49' x 26' Sec(z)
 - Bandwidth – 160 kHz
- Ooty Radio Telescope (327 MHz)
 - Effective collecting area – ~8,000 m²
 - Beam – 105' x 3.5' Sec(δ)
 - Bandwidth – 4 MHz