Pulsar and fast transient capabilities with the SKA telescopes

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Pulsar observing modes

PSS
- Perform real-time pulsar search and real-time fast transient search
- Transient search will be commensal and can run during all observing modes
- Pulsar search will be set up as an all-sky survey, performed with set survey parameters over a long time period (few years)
- Current suggested parameters and requirements include
  - All-sky survey with SKA-Mid focusing on the Galactic plane and SKA-Low covering higher Galactic latitudes
  - ~10-minute pointings
  - 6000 DM steps up to DM=3000 pc/cm^3
  - 8 Mpoint FFT
  - 85 frequency domain acceleration filters up to +/- 500 m/s^2

PST
- Real-time pulsar timing with coherent dedispersion
- Dynamic spectrum mode will enable deep "search-mode" observations with optional coherent dedipsersion, for e.g. searches of globular clusters or the Galactic center
- Flow through mode for storing raw beamformed data

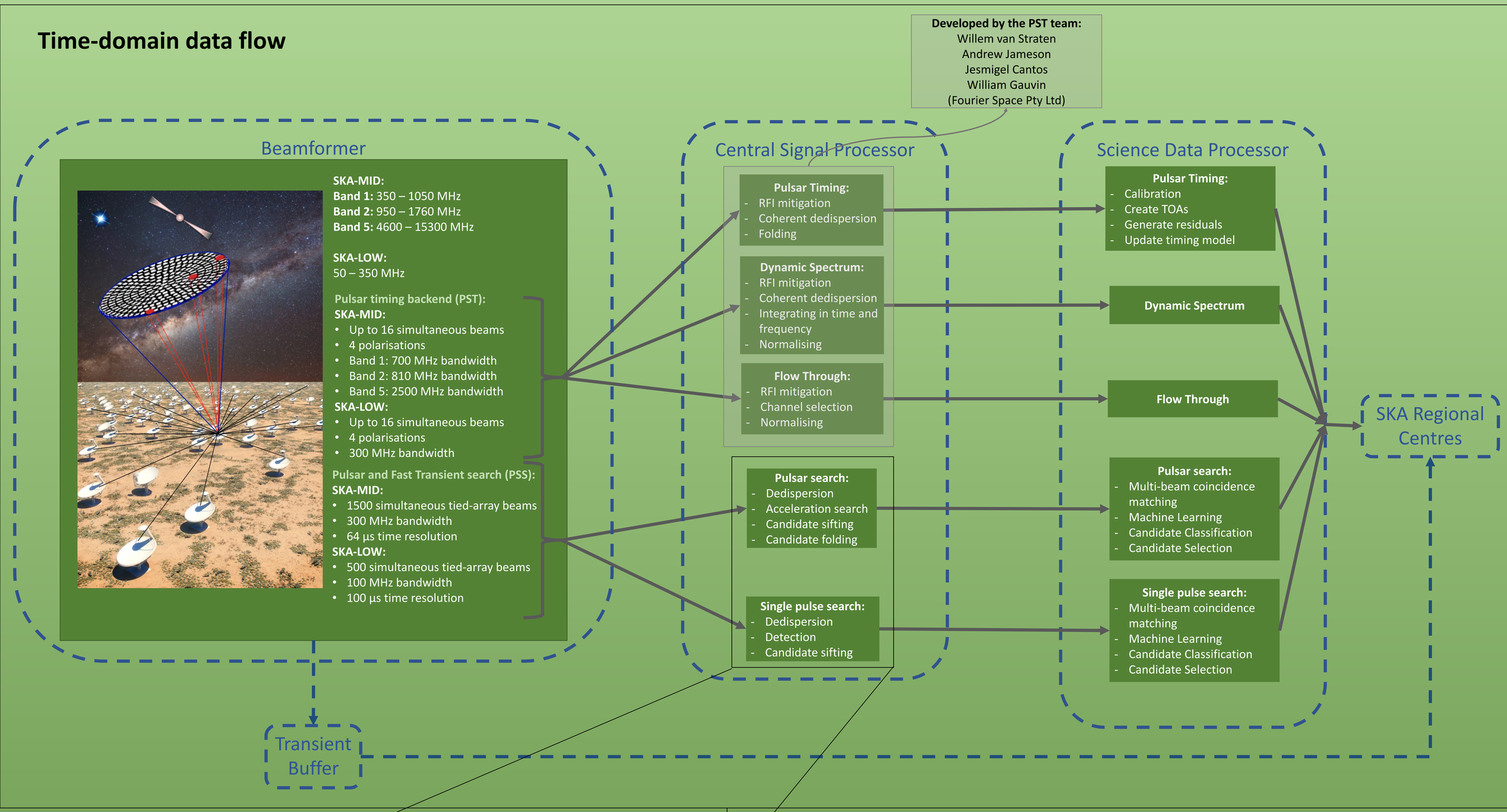
Summary

Time-domain data collection will be running at both SKA-MID and SKA-LOW. Pulsar and Fast Transient Search (PSS) and Pulsar Timing (PST) will receive data from the beamformer, and each carry out the main, compute-intensive, processing steps in dedicated compute clusters in the Central Signal Processor (CSP). All data will then undergo post-processing at the Science Data Processor (SPD) before data products are sent to the Science Regional Centres (SRCs), where astronomers will be able to access the data.
The PSS team are developing the PSS pipeline at CSP, as well as all post-processing pipelines for time-domain data in the SDP. Here we show the time-domain data flow through the telescope backends, the current plans for time-domain processing, the PSS processing pipelines and current development work, as well as a prediction on how many pulsars the SKA telescopes will be able to discover.

Challenges in the data processing development

- High data rates
  - PSS: 1500 x 244 MB/s in and 1500 x (1.5 GB + 13 MB/s) out for MID
  - PSS: 500 x 244 MB/s in and 500 x (1.5 GB + 13 MB/s) out for LOW
  - PST: Up to 16 x 9 GB/s in for MID and 16 x 1 GB/s in for LOW. Up to 4 Gb/s/beam out for both telescopes.
- Processing pipelines have to be run in real time
- Complex algorithms with high computational load
- An all-sky survey should preferably be done without changing the system throughout
- RFI mitigation will be crucial not to overload the systems, in particular for fast transients
- Power consumption is an important consideration when developing large systems.

Time-domain data flow



PSS pipeline developments

Single Pulse Pipeline and Dedispersion
It is crucial that the Single Pulse Search pipeline runs in real time for all beams. We are currently implementing a version that dedisperses the data and searches for single pulses using AVX intrinsics on a CPU, to investigate its performance as compared to a GPU version, which is currently running on lower resolution data at MeerKAT.

Acceleration search
The acceleration search step of the pipeline is very compute intensive and will require of the order 10 PetaOps. We are implementing a Fourier Domain Acceleration Search technique to search for pulsars in binary systems. We have successfully written this on an Arria 10 FPGA card, and we are currently porting the design to the new Intel Agilex card for increased performance.

Candidate folding
Pulsar candidates will be folded at the best pulse period, dispersion measure and acceleration as found by the acceleration searching code. Our goal is to fold 1000 pulsar candidates per observing beam, which means that the folding code has to be extremely efficient. We are currently writing folding code to run on a CPU, which we are hopeful will be provide higher performance than our previous GPU prototype code.

Pulsar population predictions

To estimate the numbers of pulsars expected to be discovered with the SKA telescopes, we have run simulations with the PSRPOP.py software (Bates et al., 2014). The input parameters to the model are listed in the table. To maximise the number of pulsar discoveries, we considered separate surveys for SKA-LOW and SKA-MID to focus on different regions of the sky, with the MID telescope concentrating on the Galactic plane and the LOW telescope covering higher Galactic latitudes. Some overlap between the surveys is included for calibration purposes, but also because simulations show that the two telescopes find different sets of pulsars in this region (between 5°≤ |b| ≤ 10°).

Here we label the currently funded SKA telescope SKA1 and a hypothetical full square kilometre instrument SKA2. The results from the two surveys at the different telescopes are listed below.

Survey	Ordinary pulsars	Millisecond pulsars
SKA1-MID	3500	700
SKA1-LOW	6500	600
Combined SKA1	9000	1200
SKA2-MID	5000	1000
SKA2-LOW	24500	4500
Combined SKA2	27000	5000

Parameter	SKA1-LOW	SKA1-MID	SKA2-LOW	SKA2-MID
Centre frequency (MHz)	200	1400	200	1400
Bandwidth (MHz)	100	300	100	300
Antenna gain (K/Jy)	26.85	3.92	107.35	39.2
System temperature (K)	56	20	56	20
Integration time (s)	600	600	600	600
Galactic latitude	$5° \leq \lvert b \rvert \leq 90°$	$\lvert b \rvert \leq 10°$	$5° \leq \lvert b \rvert \leq 90°$	$\lvert b \rvert \leq 10°$
Declination	$-90° \leq \delta \leq 30°$	$-90° \leq \delta \leq 45°$	$-90° \leq \delta \leq 30°$	$-90° \leq \delta \leq 45°$

Simulation results using Psrpoppy:
https://github.com/samb8s/PsrPopPy
Bates et al. (2014)